Probable Maximum Precipitation Study for North Carolina
Final Report

Prepared for:

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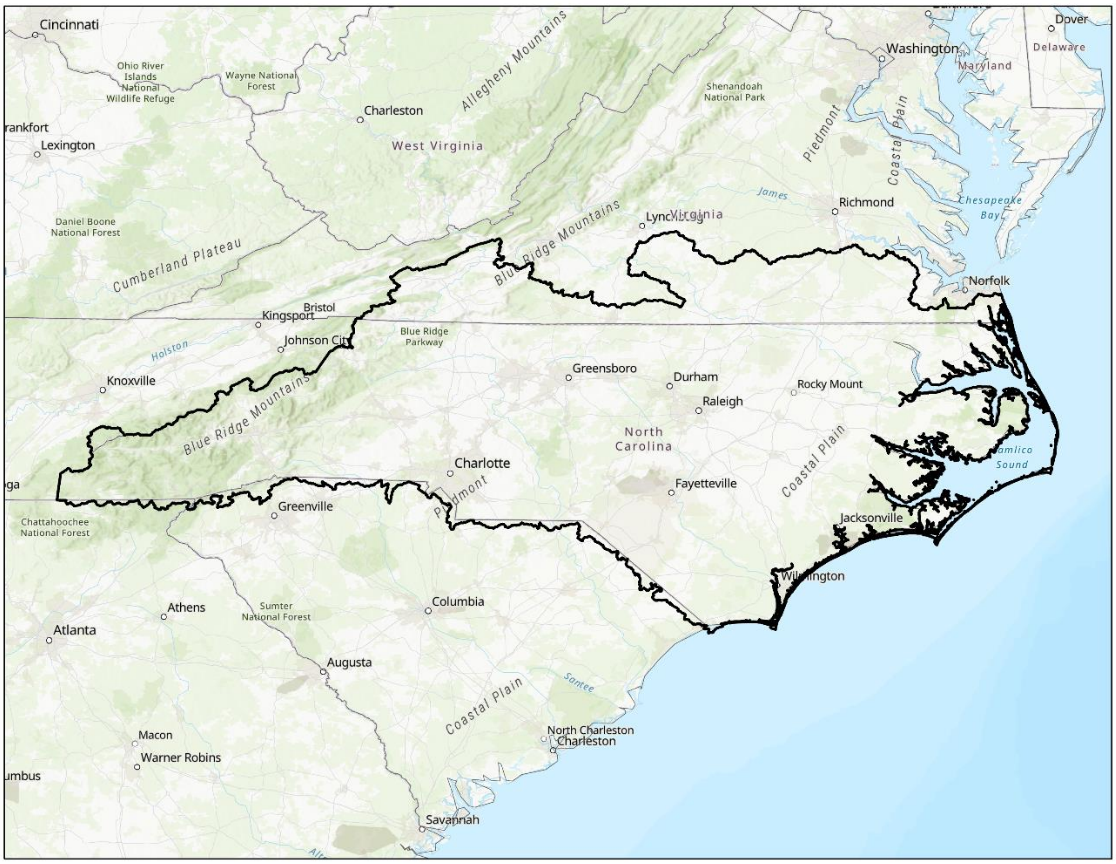

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Bill Kappel, President/Chief Meteorologist, Applied Weather Associates

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Executive Summary

This study produced gridded Probable Maximum Precipitation (PMP) values for the project domain covering the entire state of North Carolina and immediate surrounding regions adjacent to the state that also provide runoff into drainage basins within North Carolina. The PMP grid domain uses a spatial resolution of approximately 2.3-square miles (0.025 x 0.025 decimal degrees). This spatial resolution assists in capturing the variations in topography, climate and storm types across the state. Storm types considered for PMP development were the local storm, general storm, and tropical storm. A large set of storm data was analyzed for use in developing the PMP depths with numerous storm events for each storm type relevant for PMP evaluated for every region within the overall study domain. The storm data were also used to develop North Carolina specific temporal patterns. These replace the HMR 52 alternating block method and the Bureau of Reclamation critically stacked pattern. Most important, these represent actual patterns which have occurred during PMP type rainfall events that were used for PMP development. Therefore, they represent physically possible patterns which could occur during the PMP design storm event. These were developed by storm type and region in order to represent the variances that occur across the study domain.

In addition to the PMP development, annual exceedance probabilities for the 6- and 24-hour durations were developed over the entire PMP domain with North Carolina specific Area Reduction Factors and included in the Geographic Information System (GIS) tool. This information provides the recurrence interval of the PMP depths and inputs which can be used for risk informed decision making and many other types of analyses. For application of the Annual Exceedance Probability (AEP) depths for rainfall-runoff modeling, the same temporal patterns developed for the PMP are recommended for recurrence intervals of 100-year or rarer. For more frequent recurrence intervals (50-yr, 25-yr, 10yr, etc.), applying National Oceanic and Atmospheric Administration (NOAA) Altas 14 (or similar documents that replace NOAA Atlas 14) temporal patterns are recommended.

Finally, climate change projections were evaluated specifically to understand how extreme precipitation may change over the study domain both in magnitude and frequency. The climate change projections demonstrated that the most likely outcome regarding precipitation over the region going forward is that the PMP envelope will not change, but there is a tendency for an increase in mean annual and seasonal precipitation, but the individual extreme events will stay within the range of uncertainty included in the PMP process.

During the course of this study, the National Academy of Science released its recommendations regarding PMP development[1]. These findings recommend the use of probabilistic evaluations in addition to the deterministic storm-based approach. They also recommend accounting for climate change. As noted, this study develops deterministic PMP depths, then calculates probabilities out to 10^{-10}, which provides the average recurrence interval of the PMP depths and evaluated climate change projections related to PMP and extreme rainfall.

These updated PMP depths supersede those provided in Hydrometeorological Reports (HMRs), including HMRs 33, 51, 52, and 56. Results of this analysis reflect the most current practices used

[1] https://www.nationalacademies.org/our-work/modernizing-probable-maximum-precipitation-estimation

for defining PMP, including comprehensive storm analyses procedures, extensive use of GIS, explicit quantification of topography and coastal effects, updated maximum dew point and sea surface temperature climatologies for storm adjustments, and improved understanding of weather and climate related to extreme rainfall in the region.

The approach used in this study followed the same philosophy used in the numerous site-specific, statewide, and regional PMP studies that AWA has completed, including regions adjacent to the state and regions encompassing portions of this domain. AWA utilized the storm-based approach which follows the same general procedures used by the National Weather Service (NWS) in the development of the HMRs and the World Meteorological Organization (WMO) Manual on Estimation of PMP (2009). The storm-based approach identified extreme rainfall events that have occurred in regions considered transpositionable to any location within the overall study domain. These are storms that had meteorological and topographical characteristics similar to extreme rainfall storms that could occur over any location within the project domain and were deemed to be PMP-type storm events. Detailed discussions of the storms considered took place with North Carolina Dam Safety Program personnel, the Technical Advisory Committee, and other study participants. This resulted in the list of storms used for PMP development. Each storm was analyzed in detail to produce the required outputs for PMP development.

All data, PMP assumptions, and PMP development methods used in this study have been extensively reviewed and accepted as part of PMP studies in the region and again as part of this study. North Carolina Dam Safety Program personnel provided significant input and review to ensure data and outputs were specifically relevant to their dam safety requirements. Finally, North Carolina Department of Environmental Quality and several private engineering firms completed extensive testing and provided valuable feedback and hydrologic analyses of the outputs and recommendations.

Although this study produced deterministic PMP depths, it must be recognized that there is some subjectivity associated with the PMP development procedures. Examples of decisions where scientific judgment was involved include determining which storms are used for PMP, determination of storm adjustment factors, and storm transposition limits. For areas where uncertainties in data were recognized, conservative assumptions were applied unless sufficient data existed to make a more informed decision. All data and information supporting decisions in the PMP development process have been documented so that results can be checked and verified.

A total of 91 individual storm centers were included for PMP development. This includes 33 tropical storm rainfall centers, 27 general storm rainfall centers, and 28 local storm rainfall centers. Finally, three storm centers exhibited characteristics of more than one storm type, with one utilized for PMP development as both a local and general storm and two utilized for PMP development as both a general and tropical storm.

Each storm center used for PMP development was analyzed using AWA's Storm Precipitation Analysis System (SPAS), which produced several standard products including hourly gridded rainfall depths, depth-area-duration values, storm center mass curves, and total storm isohyetal patterns. Radar outputs from the NWS Next Generation Weather Radar (NEXRAD) were used in storm analyses when available (generally for storms which occurred after the mid-1990's). This added significant detail regarding spatial patterns and temporal accumulation of rainfall.

Standard PMP methods were applied for in-place maximization adjustments (e.g., HMR 51 Section 2.3) in combination with improved techniques and updated datasets to increase accuracy and reliability of the storm adjustments, while adhering to the basic approach used in the HMRs. Updated precipitation frequency analyses data available from the NOAA Atlas 14 were used for this study. These were used to calculate the Geographic Transposition Factors (GTFs) for each storm and were important for spatial distribution of PMP depths. The GTF procedure provided explicit evaluations of the effects of terrain on rainfall and differences in precipitation processes throughout the region and between each storm location and the regions where each storm was utilized. This procedure, through its correlation process, provided quantifiable and reproducible analyses of the differences in precipitation processes between each location including the effects of terrain and coastal convergence processes on rainfall. Results of these factors (in-place maximization and geographic transposition) were applied for each storm at each grid point for each of the area sizes and durations used in this study to define the PMP depths for this study.

Maximization factors were computed for each of the analyzed storm events using updated dew point and sea surface temperature (SST) climatologies representing the maximum moisture equivalent to the 100-year recurrence interval for dew points or +2 sigma for SST that could have been associated with each rainfall event. Note, most of the storms used in this study have been applied in previous PMP studies and therefore the maximization factors have been derived and reviewed. However, these were re-checked and updated dew point and SST climatologies were applied. The maximization process utilizes the average 6-, 12-, and 24-hour 100-year return frequency dew point values and the SST climatology utilizes the +2 sigma values. The most appropriate duration consistent with the duration of the storm rainfall was used for maximization, thereby evaluating storm events by storm type. Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model output, which represents model reanalysis fields of air flow in the atmosphere, and NWS synoptic weather maps were used as guidance in identifying the storm representative moisture source regions for each of the storms.

To store, analyze, and produce results from the large datasets developed in the study, the PMP calculation information was stored and analyzed in individual Excel spreadsheets and in a GIS database. This combination of Excel and GIS was used to query, calculate, and derive PMP depths for each grid point for each duration for each storm type. The database and the GIS tool allowed PMP to be calculated at any area size and/or duration available in the underlying SPAS data from a point location anywhere within the region to the overall region domain.

When compared to previous PMP depths provided in HMR 51 the updated values from this study resulted in a wide range of reductions at most area sizes and durations, with some regions resulting in increases when compared to HMR 51. PMP depths are highest near the coast and along the initial ridges of the Appalachians. These regions have exhibited past extreme rainfall accumulations that are the result of both moisture availability, coastal convergence, and topographic enhancement. Minimum values are seen in areas inland from the coast but before reaching significant topography.

The contributing watersheds to the majority of dams in North Carolina are relatively small in area size, with many of the dams having contributing drainage areas less than 10-square miles. Therefore, a significant amount of emphasis was placed on developing PMP and temporal patterns most relevant for smaller area sizes and quick response basins. This included extensive analysis of short duration, high intensity rainfall accumulation patterns and development of PMP depths for area sizes and durations that are important for these types of basins. Providing PMP depths down to area sizes at 1/3rd-square miles and temporal accumulation patterns at 5-minute increments was a significant improvement for dam safety evaluations in North Carolina over what was previously available in the HMRs.

Comparing the PMP depths against HMR 51 PMP across the entire domain, a 12% reduction at 6-hour 10-square miles and a 24% reduction at 24-hour 10-square miles was noted. For the longer durations, larger area sizes, statewide reductions were 24% at 24-hours for 200-square miles, and 25% at 72-hours for 200-square miles. Figures E.1-E.4 provide the average percent difference (negative is a reduction) from HMR 51 across the study region for 6-hour 10-square miles, 24-hour 10-square miles, 24-hour 200-square miles, and 72-hours 200-square miles. Tables E.1 and E.2 provide the transposition zone average difference from HMR 51 for 6-hours and 24-hours at 10-square miles and 24-hours and 72-hours at 200 square miles.

6-Hour 10 mi² PMP - Percent Difference from HMR 51
North Carolina PMP Analysis

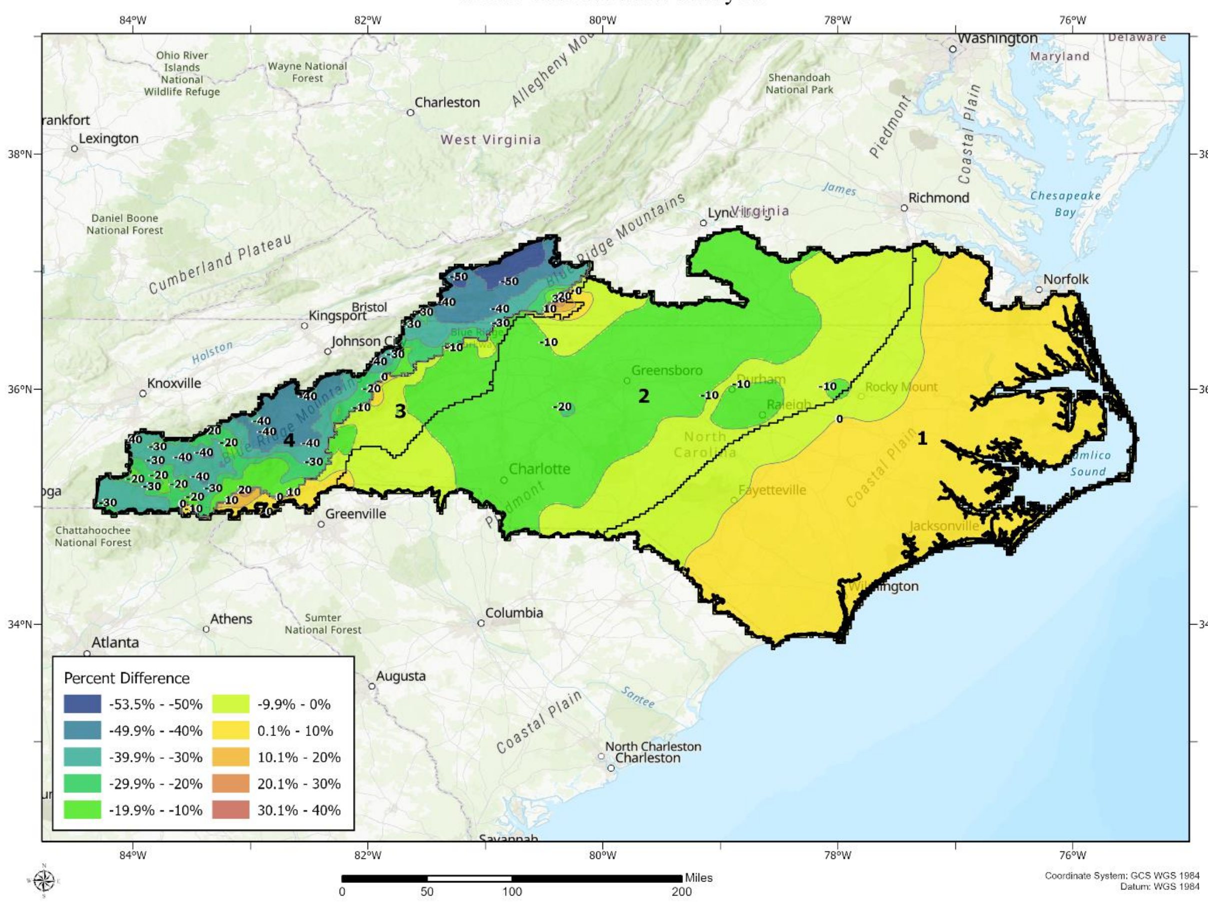


Figure E.1 PMP percent difference from HMR 51 PMP at 6-hour 10-square miles comparing the largest PMP depths regardless of storm type.

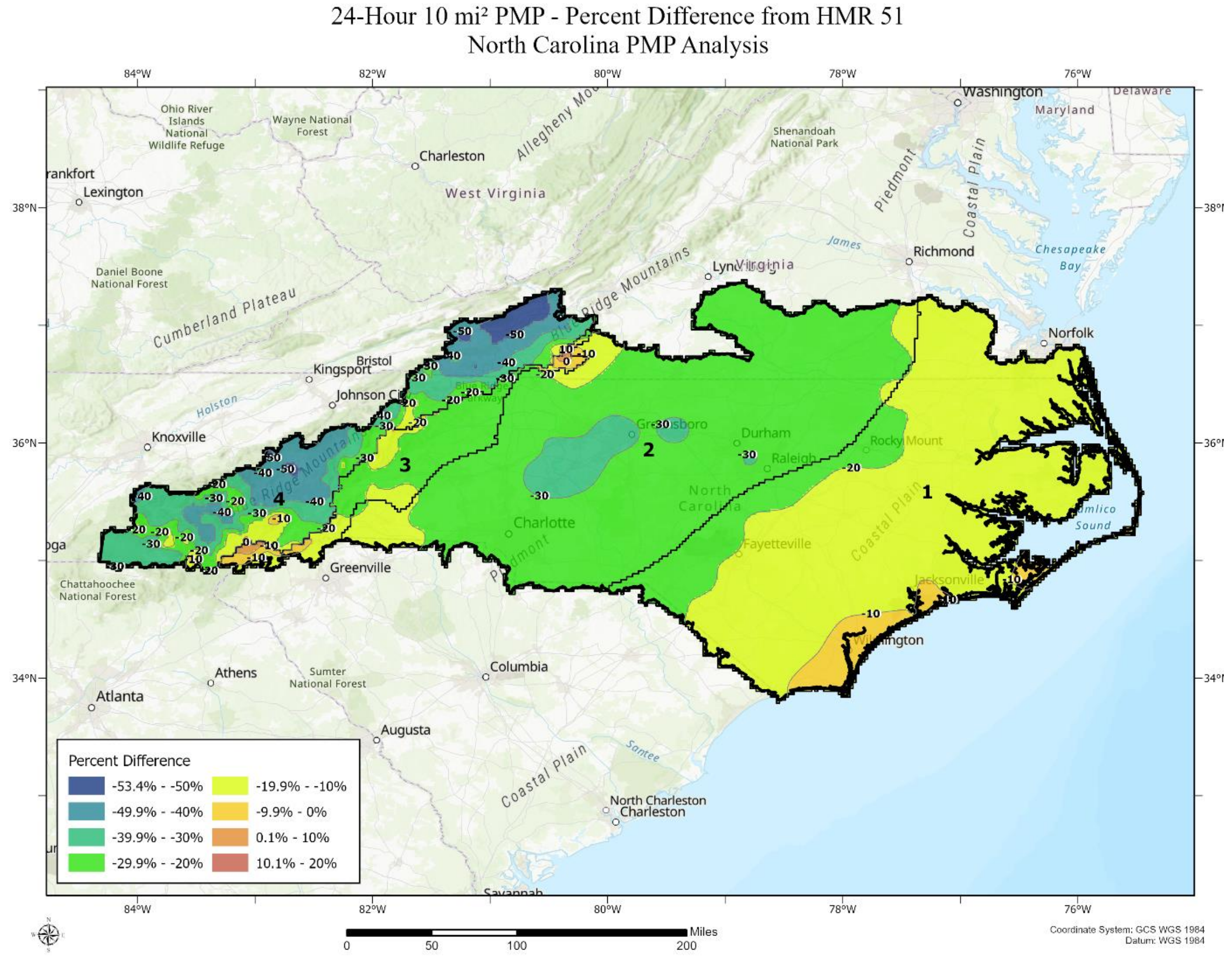


Figure E.2 PMP percent difference from HMR 51 PMP at 24-hour 10-square miles comparing the largest PMP depths regardless of storm type.

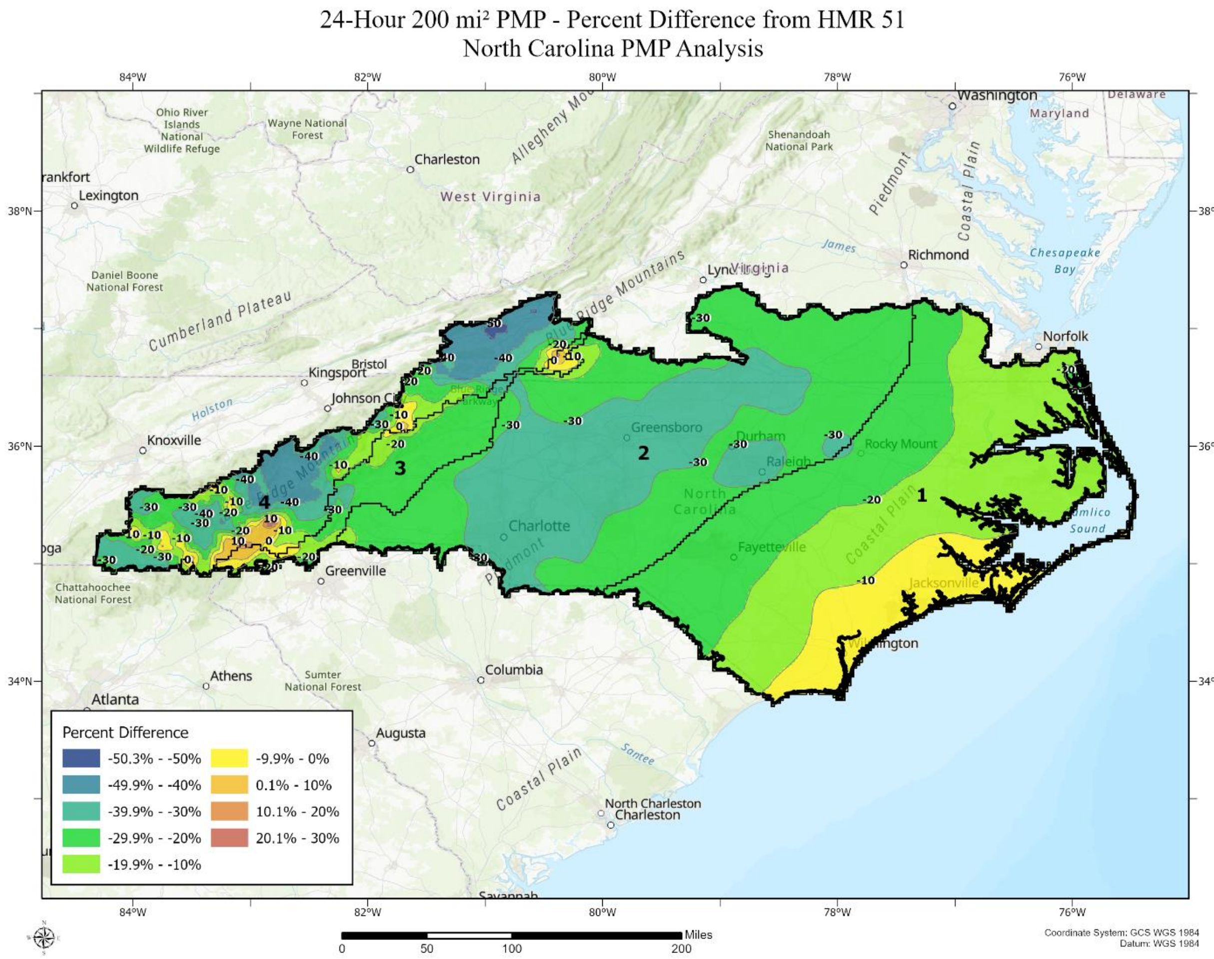


Figure E.3 PMP percent difference from HMR 51 PMP at 24-hour 200-square miles comparing the largest PMP depths regardless of storm type.

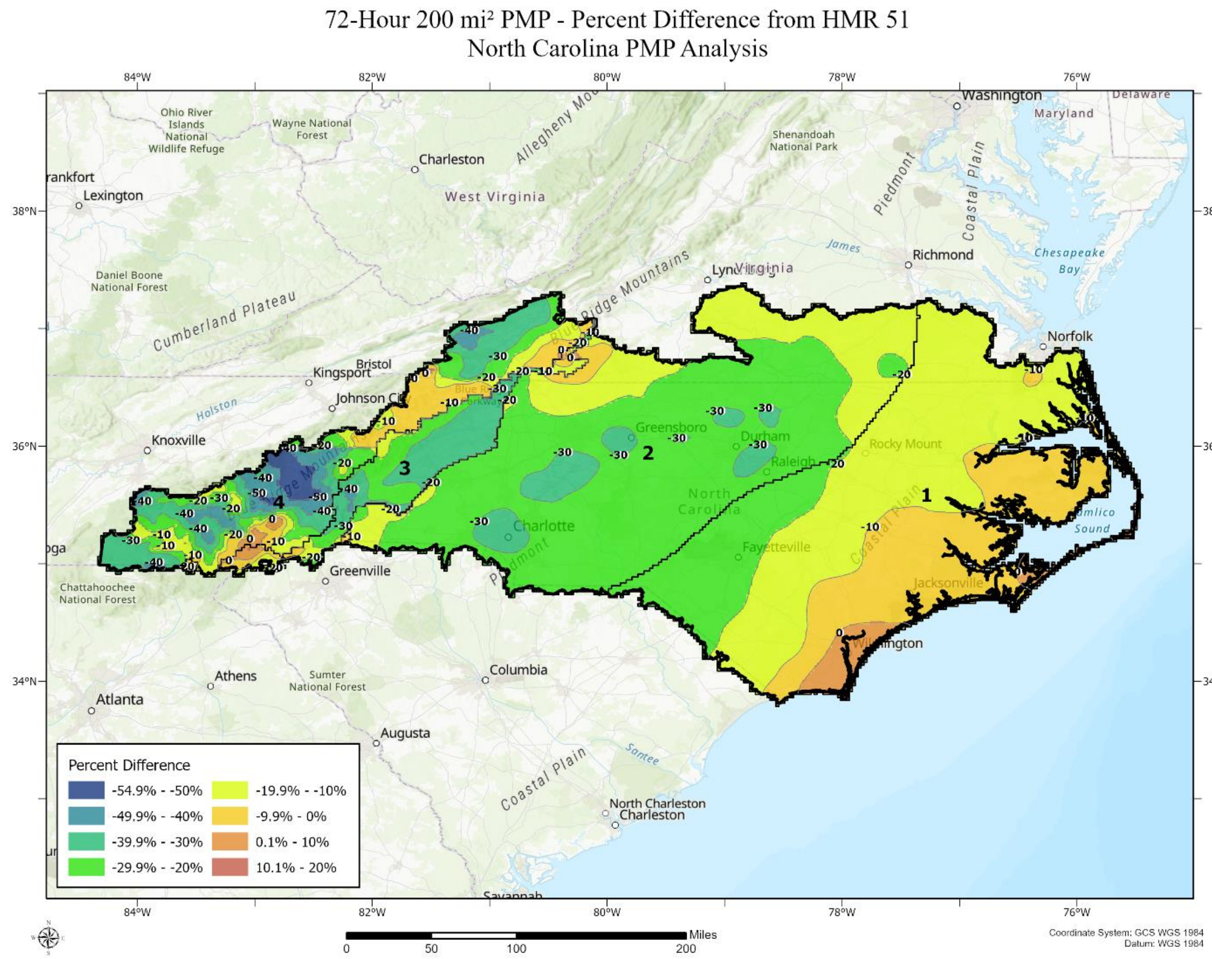


Figure E.4 PMP percent difference from HMR 51 PMP at 72-hour 200-square miles comparing the largest PMP depths regardless of storm type.

Table E.1 PMP percent difference from HMR 51 PMP at 6-hour and 24-hour 10- square miles by transposition zone.

10 Square Miles						
ZONE	6-Hour Average PMP	6-Hour HMR 51	Percent Difference from HMR 51	24-Hour Average PMP	24-Hour HMR 51	Percent Difference from HMR 51
1 - Coastal Plain	30.67	29.82	2.9%	35.11	41.60	-15.6%
2 - Piedmont	26.27	29.41	-10.7%	29.52	39.59	-25.4%
3 - Blue Ridge East	28.01	29.46	-5.0%	31.50	38.99	-19.2%
4 - Blue Ridge West	19.24	29.38	-34.6%	24.81	38.64	-35.9%

Table E.2 PMP percent difference from HMR 51 PMP at 24-hour and 72-hour 200- square miles by transposition zone.

200 Square Miles						
ZONE	24-Hour Average PMP	24-Hour HMR 51	Percent Difference from HMR 51	72-Hour Average PMP	72-Hour HMR 51	Percent Difference from HMR 51
1 - Coastal Plain	26.79	31.93	-16.3%	34.12	38.59	-11.7%
2 - Piedmont	21.19	29.98	-29.3%	27.17	35.92	-24.3%
3 - Blue Ridge East	22.81	29.20	-21.9%	26.05	35.29	-26.3%
4 - Blue Ridge West	20.38	28.83	-29.5%	25.58	34.93	-26.7%

Glossary

Adiabat: Curve of thermodynamic change taking place without addition or subtraction of heat. On an adiabatic chart or pseudo-adiabatic diagram, a line showing pressure and temperature changes undergone by air rising or condensation of its water vapor; a line, thus, of constant potential temperature.

Adiabatic: Referring to the process described by adiabat.

Advection: The process of transfer (of an air mass property) by virtue of motion. In particular cases, advection may be confined to either the horizontal or vertical components of the motion. However, the term is often used to signify horizontal transfer only.

Air mass: Extensive body of air approximating horizontal homogeneity, identified as to source region and subsequent modifications.

Barrier: A mountain range that partially blocks the flow of warm humid air from a source of moisture to the basin under study.

Basin centroid: The point at the exact center of the drainage basin as determined through geographical information systems calculations using the basin outline.

Basin shape: The physical outline of the basin as determined from topographic maps, field survey, or GIS.

Cold front: Front where relatively colder air displaces warmer air.

Convective rain: Rainfall caused by the vertical motion of an ascending mass of air that is warmer than the environment and typically forms a cumulonimbus cloud. The horizontal dimension of such a mass of air is generally of the order of 12 miles or less. Convective rain is typically of greater intensity than either of the other two main classes of rainfall (cyclonic and orographic) and is often accompanied by thunder. The term is more particularly used for those cases in which the precipitation covers a large area as a result of the agglomeration of cumulonimbus masses.

Convergence: Horizontal shrinking and vertical stretching of a volume of air, accompanied by net inflow horizontally and internal upward motion.

Cooperative station: A weather observation site where an unpaid observer maintains a climatological station for the National Weather Service.

Correlation coefficient: The average change in the dependent variable, the orographically transposed rainfall (P_o), for a 1-unit change in the independent variable, the in-place rainfall (P_i).

Cyclone: A distribution of atmospheric pressure in which there is a low central pressure relative to the surroundings. On large-scale weather charts, cyclones are characterized by a system of closed constant pressure lines (isobars), generally approximately circular or oval in form, enclosing a central low-pressure area. Cyclonic circulation is counterclockwise in the northern hemisphere and clockwise in the southern. (That is, the sense of rotation about the local vertical is the same as that of the earth's rotation).

Depth-Area curve: Curve showing, for a given duration, the relation of maximum average depth to size of area within a storm or storms.

Depth-Area-Duration: The precipitation values derived from Depth-Area and Depth-Duration curves at each time and area size increment analyzed for a PMP evaluation.

Depth-Area-Duration curve: A curve showing the relation between an averaged areal rainfall depth and the area over which it occurs, for a specified time interval, during a specific rainfall event.

Depth-Area-Duration values: The combination of depth-area and duration-depth relations. Also called depth-duration-area.

Depth-Duration curve: Curve showing, for a given area size, the relation of maximum average depth of precipitation to duration periods within a storm or storms.

Dew point: The temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content for saturation to occur.

Envelopment: A process for selecting the largest value from any set of data. In estimating PMP, the maximum and transposed rainfall data are plotted on graph paper, and a smooth curve is drawn through the largest values.

Explicit transposition: The movement of the rainfall amounts associated with a storm within boundaries of a region throughout which a storm may be transposed with only relatively minor modifications of the observed storm rainfall amounts. The area within the transposition limits has similar, but not identical, climatic and topographic characteristics throughout.

First-order NWS station: A weather station that is either automated or staffed by employees of the National Weather Service and records observations on a continuous basis.

Front: The interface or transition zone between two air masses of different parameters. The parameters describing the air masses are temperature and dew point.

General storm: A storm event that produces precipitation over areas in excess of 500-square miles, has a duration longer than 6 hours, and is associated with a major synoptic weather feature.

Geographic Transposition Factor (GTF): A factor representing the comparison of precipitation frequency relationships between two locations which is used to quantify how rainfall is affected by physical processes related to location and terrain. It is assumed the precipitation frequency data are a combination of what rainfall would have accumulated without topographic affects and what accumulated because of the topography, both at the location and upwind of the location being analyzed.

Hydrologic Unit: A hydrologic unit is a drainage area delineated to nest in a multi-level, hierarchical drainage system. Its boundaries are defined by hydrographic and topographic criteria that delineate an area of land upstream from a specific point on a river, stream or similar surface waters. A hydrologic unit can accept surface water directly from upstream drainage areas, and indirectly from associated surface areas such as remnant, non-contributing, and diversions to form a drainage area with single or multiple outlet points. Hydrologic units are only synonymous with classic watersheds when their boundaries include all the source area contributing surface water to a single defined outlet point.

HYSPLIT: Hybrid Single-Particle Lagrangian Integrated Trajectory. A complete system for computing parcel trajectories to complex dispersion and deposition simulations using either puff or particle approaches. Gridded meteorological data, on one of three conformal (Polar, Lambert, or Mercator latitude-longitude grid) map projections, are required at regular time intervals. Calculations may be performed sequentially or concurrently on multiple meteorological grids, usually specified from fine to coarse resolution.

Implicit transpositioning: The process of applying regional, areal, or durational smoothing to eliminate discontinuities resulting from the application of explicit transposition limits for various storms.

Isohyets: Lines of equal value of precipitation for a given time interval.

Isohyetal pattern: The pattern formed by the isohyets of an individual storm.

Isohyetal orientation: The term used to define the orientation of precipitation patterns of major storms when approximated by elliptical patterns of best fit. It is also the orientation (direction from north) of the major axis through the elliptical PMP storm pattern.

Jet Stream: A strong, narrow current concentrated along a quasi-horizontal axis (with respect to the earth's surface) in the upper troposphere or in the lower stratosphere, characterized by strong vertical and lateral wind shears. Along this axis it features at least one velocity maximum (jet streak). Typical jet streams are thousands of kilometers long, hundreds of kilometers wide, and several kilometers deep. Vertical wind shears are on the order of 10 to 20 mph per mile of altitude and lateral winds shears are on the order of 10 mph per 100 miles of horizontal distance.

Local storm: A storm event that occurs over a small area in a short time period. Precipitation rarely exceeds 6 hours in duration and the area covered by precipitation is less than 500 square miles. Frequently, local storms will last only 1 or 2 hours and precipitation will occur over areas of up to 200 square miles. Precipitation from local storms will be isolated from general-storm rainfall. Often these storms are thunderstorms.

Low Level Jet stream: A band of strong winds at an atmospheric level well below the high troposphere as contrasted with the jet streams of the upper troposphere.

Mass curve: Curve of cumulative values of precipitation through time.

Mesoscale Convective Complex: For the purposes of this study, a heavy rain-producing storm with horizontal scales of 10 to 1000 kilometers (6 to 625 miles) which includes significant, heavy convective precipitation over short periods of time (hours) during some part of its lifetime.

Mesoscale Convective System: A complex of thunderstorms which becomes organized on a scale larger than the individual thunderstorms, and normally persists for several hours or more. MCSs may be round or linear in shape, and include systems such as tropical cyclones, squall lines, and MCCs (among others). MCS often is used to describe a cluster of thunderstorms that does not satisfy the size, shape, or duration criteria of an MCC.

Mid-latitude frontal system: An assemblage of fronts as they appear on a synoptic chart north of the tropics and south of the polar latitudes. This term is used for a continuous front and its characteristics along its entire extent, its variations of intensity, and any frontal cyclones along it.

Moisture maximization: The process of adjusting observed precipitation amounts upward based upon the hypothesis of increased moisture inflow to the storm.

Observational day: The 24-hour time period between daily observation times for two consecutive days at cooperative stations, e.g., 6:00PM to 6:00PM.

One-hundred year rainfall event: The point rainfall amount that has a one-percent probability of occurrence in any year. Also referred to as the rainfall amount that has a 1 percent chance of occurring in any single year.

Polar front: A semi-permanent, semi-continuous front that separates tropical air masses from polar air masses.

Precipitable water: The total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels in the atmosphere; commonly expressed in terms of the height to which the liquid water would stand if the vapor were completely condensed and collected in a vessel of the same unit cross-section. The total precipitable water in the atmosphere at a location is that contained in a column or unit cross-section extending from the earth's surface all the way to the "top" of the atmosphere. The 30,000-foot level (approximately 300mb) is considered the top of the atmosphere in this study.

Persisting dew point: The dew point value at a station that has been equaled or exceeded throughout a period. Common durations of 12 or 24 hours are used, though other durations may be used at times.

Probable Maximum Flood: The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.

Probable Maximum Precipitation: Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographic location at a certain time of the year.

Pseudo-adiabat: Line on thermodynamic diagram showing the pressure and temperature changes undergone by saturated air rising in the atmosphere, without ice-crystal formation and without exchange of heat with its environment, other than that involved in removal of any liquid water formed by condensation.

Rainshadow: The region, on the lee side of a mountain or mountain range, where the precipitation is noticeably less than on the windward side.

Saturation: Upper limit of water-vapor content in a given space; solely a function of temperature.

Shortwave: Also referred to as a shortwave trough, is an embedded kink in the trough / ridge pattern. This is the opposite of longwaves, which are responsible for synoptic scale systems, although shortwaves may be contained within or found ahead of longwaves and range from the mesoscale to the synoptic scale.

Spatial distribution: The geographic distribution of precipitation over a drainage according to an idealized storm pattern of the PMP for the storm area.

Storm transposition: The hypothetical transfer, or relocation of storms, from the location where they occurred to other areas where they could occur. The transfer and the mathematical adjustment of storm rainfall amounts from the storm site to another location is termed "explicit transposition." The areal, durational, and regional smoothing done to obtain comprehensive individual drainage estimates and generalized PMP studies is termed "implicit transposition" (WMO, 1986).

Synoptic: Showing the distribution of meteorological elements over an area at a given time, e.g., a synoptic chart. Use in this report also means a weather system that is large enough to be a major feature on large-scale maps (e.g., of the continental U.S.).

Temporal distribution: The time order in which incremental PMP amounts are arranged within a PMP storm.

Tropical storm: A cyclone of tropical origin that derives its energy from the ocean surface.

Total storm area and total storm duration: The largest area size and longest duration for which depth-area-duration data are available in the records of a major storm rainfall.

Transposition limits: The outer boundaries of the region surrounding an actual storm location that has similar, but not identical, climatic and topographic characteristics throughout. The storm can be transpositioned within the transposition limits with only relatively minor modifications to the observed storm rainfall amounts.

Undercutting: The process of placing an envelopment curve somewhat lower than the highest rainfall amounts on depth-area and depth-duration plots.

Warm front: Front where relatively warmer air replaces colder air.

List of Acronyms

AEP: Annual exceedance probability

AMS: Annual maximum series

ARF: Areal Reduction Factor

ARI: Average Recurrence Interval

AWA: Applied Weather Associates

CDF: Cumulative Distribution Function

DA: Depth-Area

DAD: Depth-Area-Duration

dd: decimal degrees

DND: Drop number distribution

DSD: Drop size distribution

EPRI: Electric Power Research Institute

F: Fahrenheit

FERC: Federal Energy Regulatory Commission

GCM: Global Circulation Models

GCS: Geographical coordinate system

GIS: Geographic Information System

GRASS: Geographic Resource Analysis Support System

GTF: Geographic Transposition Factor

HMR: Hydrometeorological Report

HRRR: High-Resolution Rapid Refresh Model

HYSPLIT: Hybrid Single-Particle Lagrangian Integrated Trajectory Model

IDW: Inverse distance weighting

IPCC: Intergovernmental Panel on Climate Change

IPMF: In-place Maximization Factor

LLJ: Low-level Jet

MADIS: NCEP Meteorological Assimilation Data Ingest System

MAM: Mean Annual Max

mb: millibar

MCC: Mesoscale Convective Complex

MCS: Mesoscale Convective System

MDE: North Carolina Department of the Environment

MTF: Moisture Transposition Factor

NCAR: National Center for Atmospheric Research

NCDC: National Climatic Data Center

NCEI: National Centers for Environmental Information

NCEP: National Centers for Environmental Prediction

NEXRAD: Next Generation Radar

NOAA: National Oceanic and Atmospheric Administration

NC DEQ: North Carolina Department of Environment Quality

NRC: Nuclear Regulatory Commission

NRCS: Natural Resources Conservation Service

NWS: National Weather Service

PMF: Probable Maximum Flood

PMP: Probable Maximum Precipitation

POR: Period of Record

PRISM: Parameter-elevation Relationships on Independent Slopes

PW: Precipitable Water

QA/QC: Quality Assurance/Quality Control

RAWS: Remote Automated Weather Stations

RCM: Regional Circulation Models

RH: Relative Humidity

RMSE: Root Mean Square Error

SMC: Spatially Based Mass Curve

SPAS: Storm Precipitation and Analysis System

SPP: Significant Precipitation Period

SSM: Storm Separation Method

SSPs: Shared Socioeconomic Pathways

SST: Sea Surface Temperatures

TAF: Total Adjustment Factor

TAR: Total Adjusted Rainfall

TVA: Tennessee Valley Authority

USACE: US Army Corps of Engineers

USACE EM: USACE Engineering Manual

USBR: Bureau of Reclamation

USGS: United States Geological Survey

WGS: World Geodetic System

WMO: World Meteorological Organization

1. Overall Study Development Overview

This study provides Probable Maximum Precipitation (PMP) depths for all drainage basins within North Carolina, including regions adjacent to the state that also provide runoff into drainage basins within North Carolina (Figure 1.1). In addition to the deterministic PMP, annual exceedance probabilities (AEP) were derived for the 6-hour and 24-hour durations over the same grid as the PMP. These produced probabilities estimates that extend to 10^{-10} and provide valuable information related to the probability of the deterministic PMP and many other risk-based processes. Finally, climate change assessments using regional downscaled outputs for CMIP6 projections were evaluated. Specific emphasis was placed on how these projections related to extreme rainfall at various frequencies and durations including PMP.

PMP is a deterministic estimate of the theoretical maximum depth of precipitation that can occur over a specified area, at a given time of the year. Parameters to estimate PMP were developed following the storm-based approach as discussed in the Hydrometeorological Reports (HMRs) and subsequently refined in the numerous site-specific, statewide, and regional PMP studies completed since the early 1990's. PMP depths are used in the computation of the Probable Maximum Flood (PMF). PMP depths provided in this study can be used in place of previous design values including those from HMR 51 (Schreiner and Riedel, 1978) and HMR 52 (Hansen et al., 1982).

Methods used to derive PMP for this study included consideration of numerous extreme rainfall events that have been appropriately adjusted to each grid point and represent each PMP-storm type that can occur in the study domain, local, general, and tropical. Although no specific date restrictions are applied to the PMP depths, each storm type has preferred times of the year when they are most likely to occur. The local storm type PMP are most likely to occur from April through October, while tropical storm PMP would occur from June through November, and general storm PMP from August through May.

The process of combining maximized storm events by storm type into a hypothetical PMP design storm resulted in a reliable PMP estimation by combining a combination of meteorological factors in a physically possible manner that represent the most extreme rainfall possible. The combination of storm data and storm adjustments provided adequate data from which to derive reasonable PMP depths for use in PMF development and hydrologic evaluations.

During this calculation process, air masses that provide moisture to both the historic storm and the idealized PMP storm were assumed to be saturated through the entire depth of the atmosphere and contain the maximum moisture possible based on the surface dew point or sea surface temperatures (SST) value used to represent the storm environment. The calculation of the saturated atmospheric profile used moist pseudo-adiabatic temperature profiles for both the historic storm and the PMP storm. This method assumed that a sufficient period of record was available to identify rainfall observations over a large region. Further, within that region at least a few storms have been observed which attained or came close to attaining the maximum storm efficiency possible for converting atmospheric moisture to rainfall. The PMP development process assumes that if additional atmospheric moisture had been available, an individual extreme storm would have maintained the same storm efficiency for converting atmospheric moisture to precipitation and hence more precipitation would result. Therefore, the ratio of the maximized precipitation amounts to the actual precipitation amounts would be the same as the ratio of the precipitable water (calculated from the dew point or SST) observed versus the climatological maximum amount in the atmosphere associated with each storm.

Current understanding of meteorology does not support an explicit evaluation of storm efficiency for use in PMP evaluation. To compensate for this, the period of record includes the entire historic record of rainfall data (nearly 150 years for this study), along with an extended geographic region from which to choose storms. By including a long period of record and the large geographic region, it is assumed that one or more of these storms represented storm dynamics that approached the maximum efficiency for rainfall production. Therefore, the assumption is the PMP development process and resulting calculations represent PMP for any given location within the study domain. In essence, the process is trading time for space to capture the PMP process.

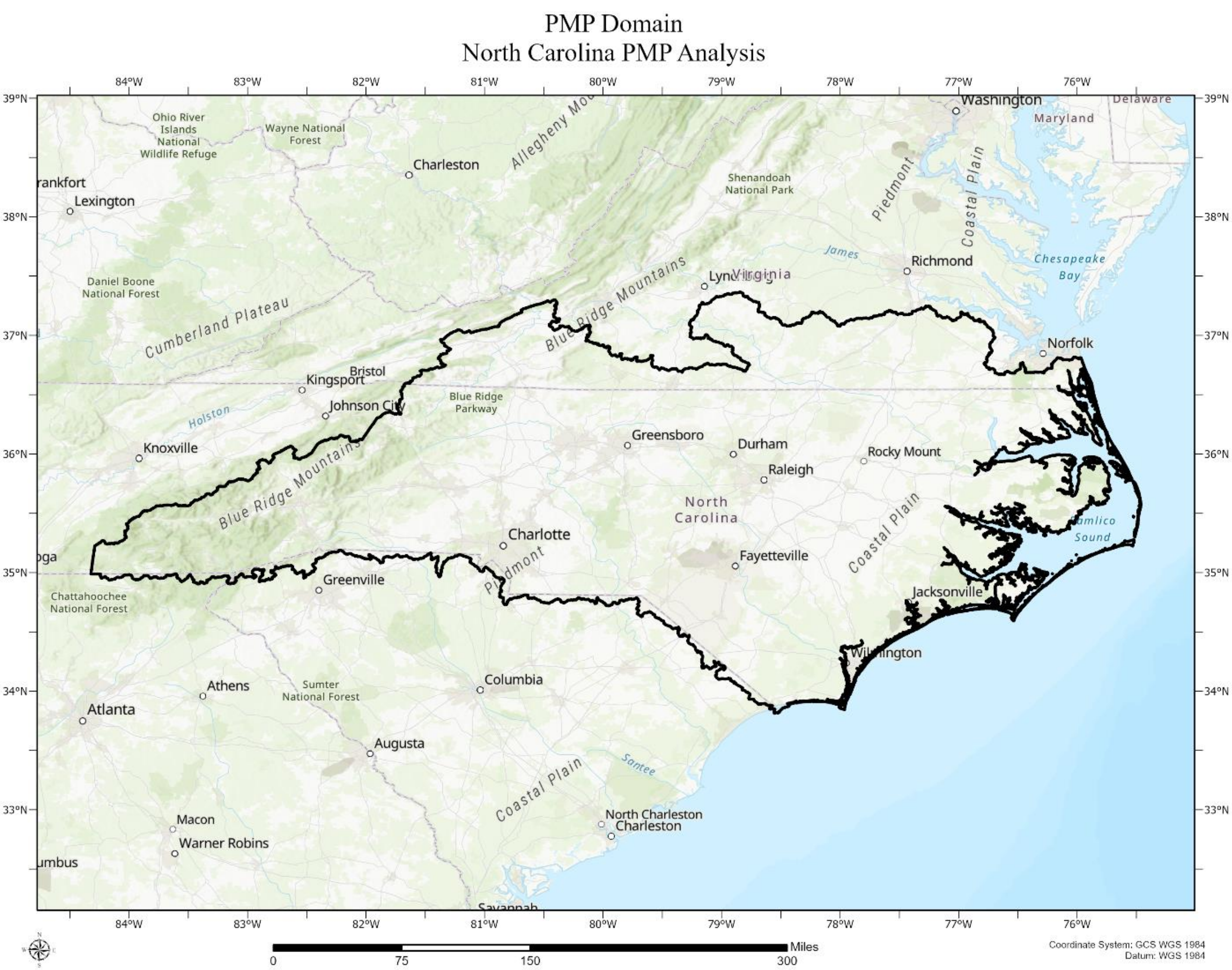


Figure 1.1: Probable Maximum Precipitation study domain utilized for North Carolina

1.1 Probable Maximum Precipitation Background

Definitions of PMP are found in most of the HMRs issued by the National Weather Service (NWS). The definition used in the most recently published HMR is "theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year" (HMR 59, p. 5) (Corrigan et al., 1999). Since the early 1940s, several government agencies have developed methods to calculate PMP for various regions of the United States. The NWS (formerly the U.S. Weather Bureau), the U.S. Army Corps of Engineers (USACE), and the U.S. Bureau of Reclamation (USBR) have been the primary federal agencies involved in this activity. PMP values presented in their reports are used to calculate the PMF, which in turn, is often used for the design of critical infrastructure and high hazard hydraulic facilities. It is important to remember that the methods used to derive PMP and the hydrological procedures that use the PMP outputs need to adhere to the requirement of being “physically possible.” In other words, various levels of conservatism and/or extreme aspects of storms that could not physically co-occur in a PMP storm environment should not be used to produce combinations of storm characteristics that are not physically consistent in determining PMP outputs or for the hydrologic applications of those outputs.

The generalized PMP studies currently in use in the contiguous United States include HMRs 49 (1977) and 50 (1981) for the Colorado River and Great Basin drainage; HMRs 51 (1978), 52 (1982), and 53 (1980) for the U.S. east of the 105th meridian; HMR 55A (1988) for the area between the Continental Divide and the 103rd meridian; HMR 57 (1994) for the Columbia River and Pacific Coast Drainages; and HMRs 58 (1998) and 59 (1999) for California (Figure 1.2). In addition to these HMRs, numerous Technical Papers and Reports deal with specific subjects concerning precipitation (e.g., Technical Paper 1, 1946; Technical Paper 16, 1952; NOAA Tech. Report NWS 25, 1980; and NOAA Tech. Memorandum NWS HYDRO 40, 1984). Topics in these papers include maximum observed rainfall amounts for various return periods and specific storm studies. Climatological atlases (e.g., Technical Paper No. 40, 1961; NOAA Atlas 2, 1973; and NOAA Atlas 14, 2004-current) are available for use in determining precipitation return periods.

Several site-specific, statewide, and regional studies (e.g., Tomlinson et al., 2002-2013; Kappel et al., 2013-2025) augment generalized PMP reports for specific basins or regions included in the areas addressed by the HMRs. Recent site-specific PMP projects completed within the North Carolina domain and immediately surrounding regions have updated the storm database and many of the procedures used to estimate PMP depths in the HMRs (e.g. Kappel et al., 2020; Kappel et al., 2023). This study continued that process by applying the most current understanding of meteorology related to extreme rainfall events and updating the storm database through May of 2025. PMP results from this study provide values that replace those derived from the various HMRs in the region.

During the course of this study, the National Academy of Science released its recommendations regarding PMP development (National Academy of Sciences, 2024). These findings recommend the use of probabilistic evaluations in addition to the deterministic storm-based approach. They also recommend accounting for climate change. For the long term (10 years and beyond), they recommend the use of numerical weather prediction models as another option to derive PMP depths. As part of the North Carolina statewide PMP development, AWA applied the recommendations by including probabilistic evaluations and climate change projections.

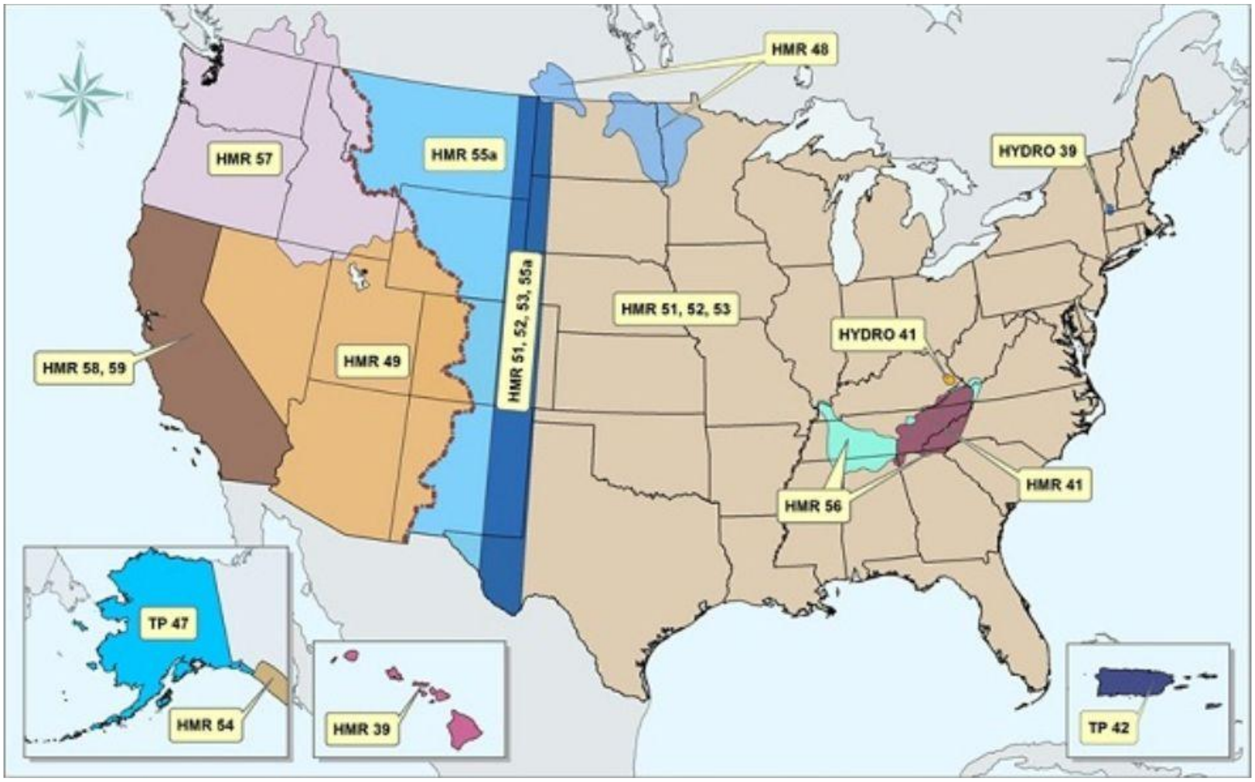


Figure 1.2: Hydrometeorological Report coverages across the United States, from https://www.weather.gov/owp/hdsc_pmp

North Carolina is included within the domain covered by HRM 41 (Schwartz, 1965), HMR 51, and HMR 52. HMR 51 is the most relevant HMR for this study, covering the entire study region, while HMR 41 was developed for the Tennessee Valley Authority (TVA) and covers the area west of the Appalachian Mountains. HMR 52 provides background information and hydrologic implementation guidelines for the storm data developed in HMR 51. These HMRs cover diverse meteorological and topographical regions. HMR 51 provides generalized estimates of PMP depths for a large, climatologically diverse area and recognizes that studies addressing PMP over specific regions can incorporate more site-specific considerations and provide improved PMP estimates.

North Carolina contains many diverse climatological and physiographic regions (Figure 1.3) where climate and terrain vary, sometimes over short distances. Because of the distinctive climate regions and variations in topography, the development of PMP depths must account for the complexity of the meteorology and terrain throughout the state. Although the HMRs provided relevant data at the time they were published, the understanding of meteorology, including the effects of coastal convergence and terrain on rainfall (orographic effects) have advanced significantly in the subsequent years.

Limitations associated with the HMRs have been explicitly addressed as part of this study. These include updating the storm database from the limited number of analyzed storms utilized in HMR 51 (no storms that have occurred since the early 1970s are included), evaluating of orographic effects, utilizing consistent data and procedures throughout the region, improving documentation describing the PMP development process, and updating procedures and outputs for PMP development and PMF application. This project incorporated the latest methods, technology, and data to address these complexities. Each of these were addressed and updated where data and current understanding of meteorology allowed.

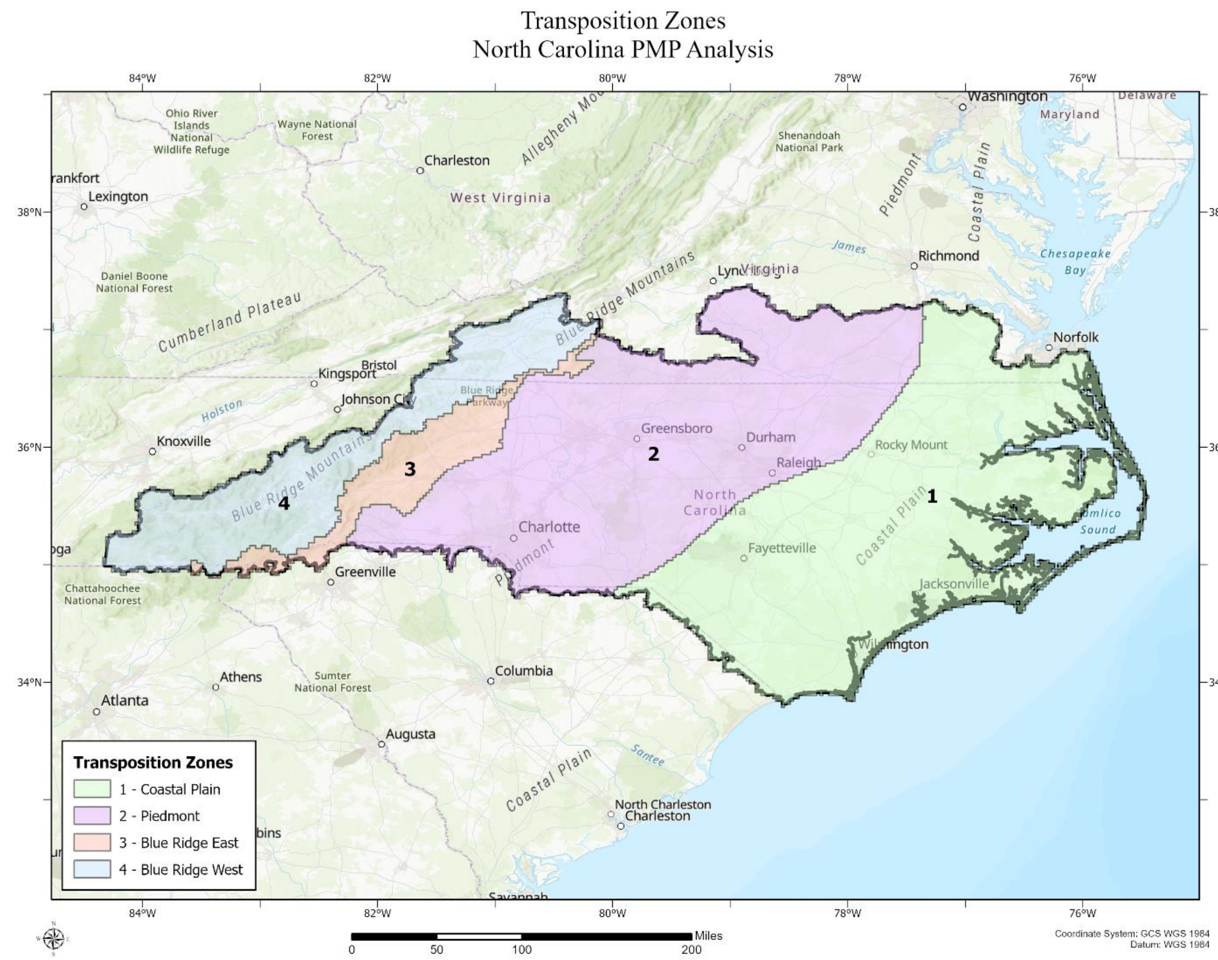


Figure 1.3: North Carolina PMP project domain and transposition zones utilized in this study. The overall project domain extends beyond the state boundaries in some areas to ensure all drainage areas are included.

Previous site-specific, statewide, and regional PMP projects completed by AWA provide examples of PMP studies that explicitly consider characteristics of historic extreme storms over meteorologically and topographically similar regions surrounding the area being studied. Most important for this study include the Virginia statewide PMP (2015), the Pennsylvania statewide PMP (2019), the New Jersey statewide PMP (2023), and the Maryland statewide PMP (2024). The procedures incorporate the most up-to-date sets, techniques, and applications to derive PMP. All AWA PMP studies have received extensive review, and the results have been used in computing the PMF for various watersheds. This study follows similar procedures employed in those studies while making improvements where advancements in storm data, PMP calculation processes, and storm transposition procedures have become available.

Several PMP studies have been completed by AWA within the region covered by HMR 51 and within North Carolina itself, which are directly relevant to this study (Figure 1.4). Each of these studies provided PMP depths which updated those from HMR 51. These are examples of PMP studies that explicitly consider the meteorology and topography of the study location along with characteristics of historic extreme storms over climatically similar regions. Information, experience, and data from these PMP studies were applied in this study. These included use of previously analyzed storm events using the Storm Precipitation and Analysis System (SPAS) program, previously derived storm lists, previously derived in-place storm maximization factors, climatologies, and explicit understanding of the meteorology of the region.

In addition, comparisons to these previous studies provided sensitivity and context with the results of this study. These regional, statewide, and site-specific PMP studies received extensive review and were accepted by the appropriate state dam safety regulatory agencies. In addition, AWA site-specific studies have been accepted by the Federal Energy Regulatory Commission (FERC), the Nuclear Regulatory commission (NRC), and the Natural Resources Conservation Service (NRCS). This study followed the same procedures used in those studies to determine PMP depths. These procedures, together with the SPAS rainfall analyses (Hultstrand and Kappel, 2017; Hultstrand et al., 2024), were used to compute PMP following standard storm-based procedures outlined in HMR 51.

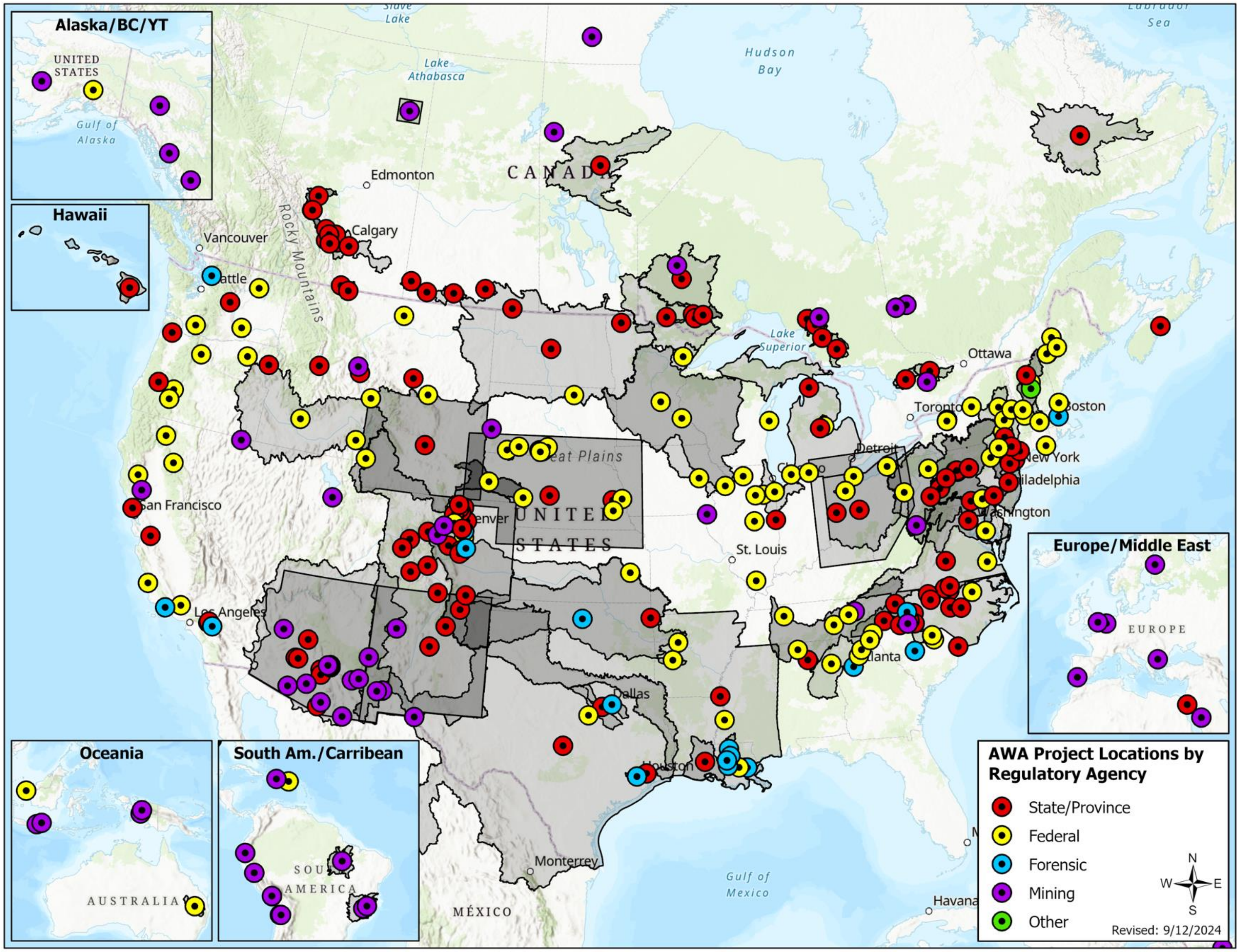


Figure 1.4: Locations of AWA PMP studies as of September 2024

1.2 Objective of This Study

This study determines estimates of PMP depths, AEP probabilities, and climate change assessments for use in computing the PMF and other hydrologic analyses for various watersheds in the state and within the overall project domain. The most reliable methods and data available were used and updates to methods and data used in HMRs were applied where appropriate. Information is included in this report and the study database so that calculations can be checked, and depths can be reproduced and updated in the future.

1.3 Overall Project Domain

The project domain was defined to cover all of North Carolina as well as watersheds that extended beyond state boundaries for which North Carolina Dam Safety (NC DEQ) has responsibility for regulation. This study allows for gridded PMP values and AEP depths to be determined for each grid cell within the project domain. The project domain is shown in Figure 1.1. Discussions with NC DEQ, FERC, NRCS, Technical Advisory Committee members, and private consultants involved in the study helped refine the analysis region beyond state boundaries to fully incorporate all potential sites that may affect North Carolina.

1.4 PMP and AEP Analysis Grid Setup

A uniform grid covering the project domain provides a spatial framework for the analysis. The PMP grid resolution for this study was 0.025 x 0.025 decimal degrees (dd), or 90 arc-seconds, using the Geographic Coordinate System (GCS) spatial reference with the World Geodetic System of 1984 (WGS 84) datum. This resulted in 26,439 grid cells with centroids within the domain. Each grid cell represents an approximate area of 2.3-square miles. The grid network placement is essentially arbitrary. However, the placement was oriented in such a way that the grid cell centroids are centered over whole number coordinate pairs and then spaced evenly every 0.025 dd. For example, there is a grid cell centered over 34°N and 78°W with the adjacent grid point to the west at 34°N and 78.025°W. The PMP analysis grid over the Lake Lure Basin is shown in Figure 1.5.

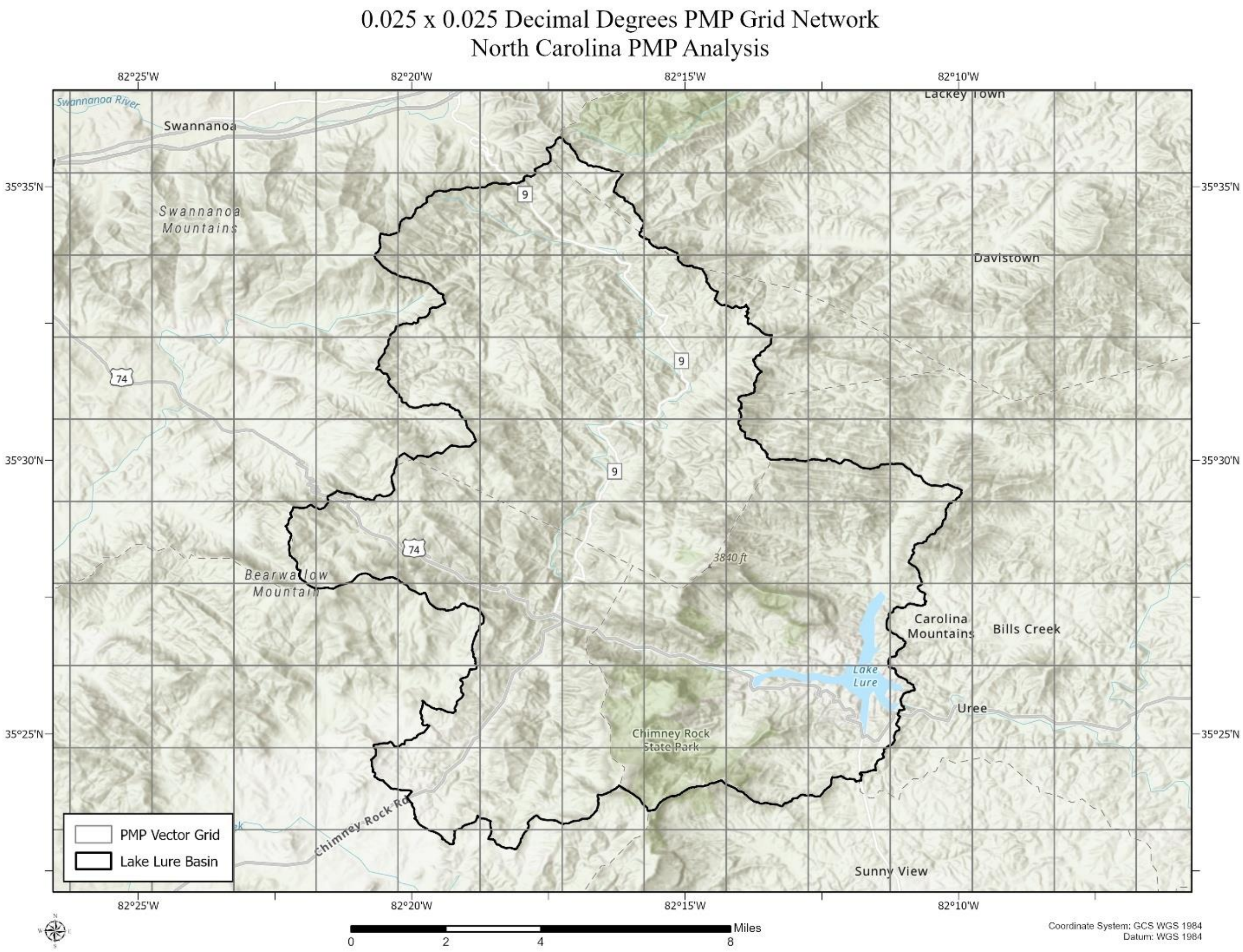


Figure 1.5: Example PMP analysis grid placement over the Lake Lure Basin

2. PMP Development Methodology

The storm-based approach used in this study is consistent with many of the procedures that were used in the development of the HMRs and as described in the World Meteorological Organization PMP documents (WMO, 2009), with updated procedures implemented where appropriate. Methodologies reflecting the current standard of practice were applied in this study considering the unique meteorological and topographical interactions within the region as well as the updated scientific data and procedures available. Figure 2.1 provides the general steps used in deterministic PMP development utilizing the storm-based approach.

This study identified major storms that occurred within the region and areas where those storms were considered transpositionable within the study region. Each of the PMP storm types capable of producing PMP-level rainfall were identified and investigated. The PMP storm types included local storms, general storms, and tropical storms. The "short list" of storms was extensively reviewed, quality controlled, and accepted as representative of all storms that could potentially affect PMP depths at any location or area size within the overall study domain. This short list of storms was utilized to derive the PMP depths for all locations. The influence of terrain and coastal interaction on extreme rainfall are addressed as they specifically affect precipitation patterns spatially, temporally, and in magnitude.

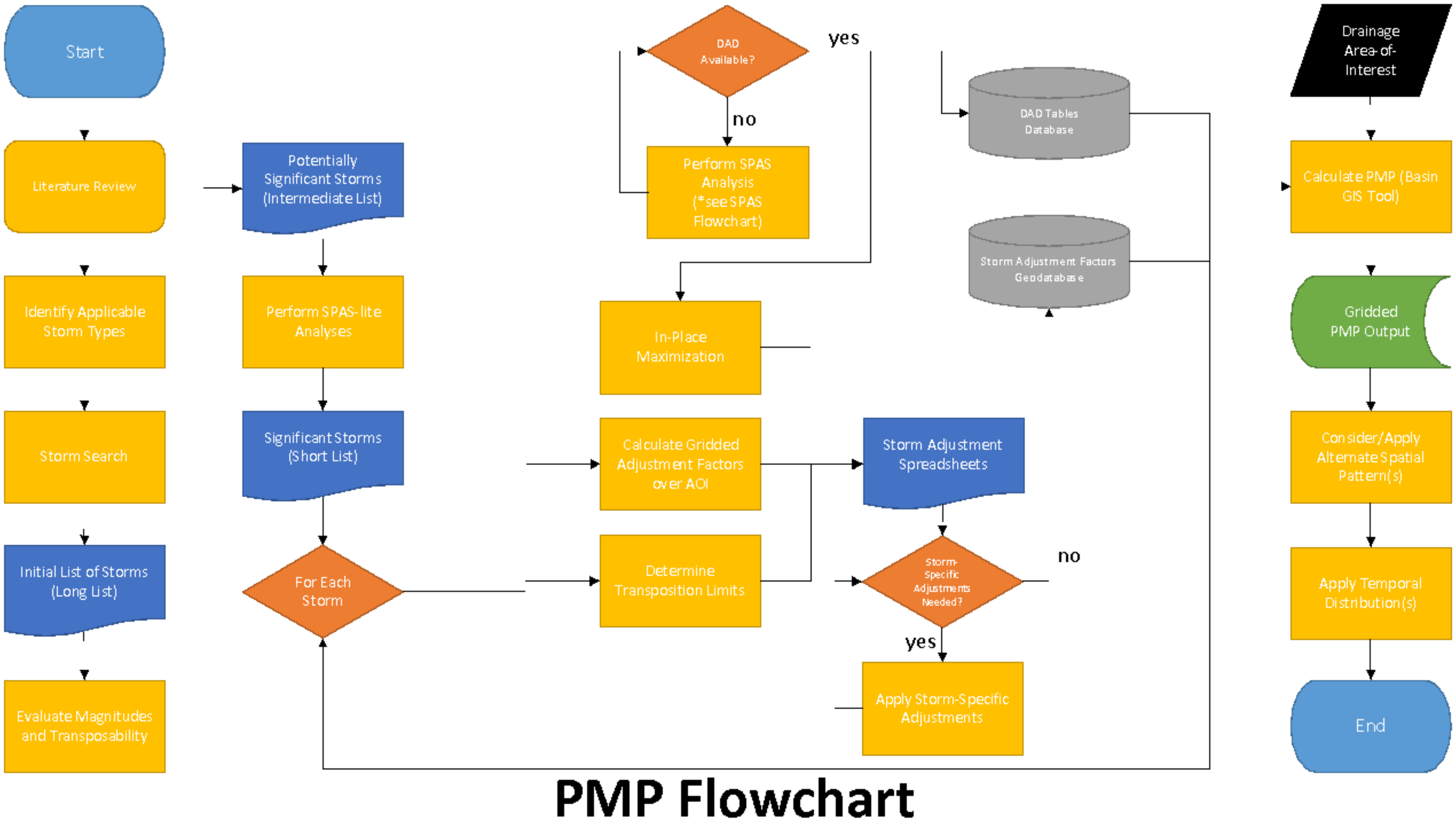


Figure 2.1: Probable Maximum Precipitation calculation steps

The moisture content of each of the short list storms was maximized to provide worst-case rainfall accumulation for each storm at the location where it occurred (in-place storm location). Storms were then transpositioned to regions with similar meteorological and topographical characteristics. Locations where each storm was transpositioned were determined using meteorological judgment, comparison of adjustment factors, comparisons of PMP depths, comparison against previous transposition limits from HMRs and AWA, discussions with the Technical Advisory Committee, study participants, and comparisons against precipitation frequency climatologies. Adjustments were applied to each storm as it was transpositioned to each grid point to calculate the amount of rainfall each storm would have produced at each grid point versus what it produced at the original location. These adjustments were combined to produce the total adjustment factor (TAF) for each storm for each grid point.

The TAF is applied to the observed precipitation values at the area size of interest for each analysis. SPAS is used to analyze the rainfall associated with each storm used for PMP development. SPAS has been used to analyze more than 950 extreme rainfall events since 2002. SPAS analyses are used in PMP development as well as other meteorological applications. SPAS has been extensively peer reviewed and accepted as appropriate for use in analyzing precipitation accumulation by numerous independent review boards and as part of the Nuclear Regulatory Commission (NRC) software certification process (e.g., Kappel et al., 2015 and Hultstrand and Kappel, 2017). Appendix E provides a detailed description of the SPAS program. The TAF is a product of the In-Place Maximization Factor (IPMF) and the Geographic Transposition Factor (GTF).

The governing equation used for computation of the Total Adjusted Rainfall (TAR), for each storm for each grid cell for each duration, is given in Equation 1.

$$TAR_{xhr} = P_{xhr} \times IPMF \times GTF \qquad \text{(Equation 1)}$$

where:

TAR_{xhr} is the Total Adjusted Rainfall value at the x-hour (x-hr) duration for the specific grid cell at each duration at the target location;

P_{xhr} is the x-hour precipitation observed at the historic in-place storm location (source location) for the basin-area size;

In-Place Maximization Factor (*IPMF)* is the adjustment factor representing the maximum amount of atmospheric moisture that could have been available to the storm for rainfall production;

Geographic Transposition Factor (GTF) is the adjustment factor accounting for precipitation frequency relationships between two locations. This is used to quantify all processes that affect rainfall, including terrain, location, and seasonality.

Note, the largest of these values at each duration becomes PMP at each grid point. The data and calculations are run at the area size and duration(s) specified through user input. The PMP output depths are then provided for durations required for Probable Maximum Flood (PMF) analysis at a given location by storm type and provided as a basin average. These data have a spatial pattern and temporal pattern associated with them for hydrologic modeling implementation. The spatial and temporal patterns are based on climatological patterns (spatial) and a synthesis of historic storm accumulation patterns (temporal) used in this study.

3. Weather and Climate of the Region

Warm ocean temperatures associated with the Gulf Stream in the Atlantic Ocean and the Gulf of America provide ample moisture to the atmosphere for storm development and precipitation production. When this moisture is drawn into storm systems and advected into the study domain, significant precipitation events can occur. This can be enhanced by topographic interactions and coastal convergence processes (Figure 3.1). The change in elevation and distance from the Atlantic Ocean and/or Gulf of America helps to create a variety of climate patterns. These interactions influence the moisture available for precipitation production over the region as well as the spatial rainfall pattern of individual storms (Gelber, 1992; Thaler, 1996).

The latitude of the study domain places the region in the path of both the polar and sub-tropical jet streams, allowing fronts and areas of low pressure to traverse the region on a consistent basis throughout the year. Storms originating in the Great Plains, Gulf of America, and Atlantic Ocean can produce significant precipitation over different parts of the overall domain. In general, precipitation is evenly distributed throughout the year, although each storm type exhibits preferred seasonality.

For the majority of the study region east of the Appalachian crest, the main low-level moisture source region is the Atlantic Ocean and specifically the warm water associated with the Gulf Stream Current (Figure 3.2). For the region of North Carolina west of the Appalachian crest, significant low-level moisture is also contributed by the Gulf of America moving in from the southwest through the west to the northwest. High levels of atmospheric moisture can be entrained from both sources as storm systems move through and continue to develop in the region. Depending on the atmospheric steering currents, the moisture and/or storm can move onshore and over eastern sections of North Carolina. This will often result in heavy rainfall, which can then be further enhanced as it encounters the first major ridgelines and elevated terrain.

During the tropical season, which extends from June through November in the Atlantic Ocean and Gulf of America, tropical systems (Tropical Depressions, Tropical Storms, and Hurricanes) can move directly into the region or along the coastline and produce heavy rainfall. The moist air moving inland from the Gulf Stream and Gulf of America will provide significant low-level moisture that feeds into developing thunderstorms, most common from late spring through early fall. This can then be enhanced by a front, areas of low pressure, and/or interactions with topography.

Because of the movement and strength of the upper-level winds in the region, storm patterns generally do not stay fixed over the region for long periods. Therefore, the synoptic patterns which produce high levels of atmospheric moisture in the region are generally transient and limit the magnitude of precipitation at any one location. However, PMP-type rainfall occurs during situations where the storm movement is blocked or slowed and allowed to concentrate heavy rainfall for extended durations over the same region. In addition, topography plays a role in the initiation of storms in the region, the magnitude of the rainfall, and the spatial distribution of the rainfall. Higher elevations generally act to enhance rainfall production and therefore exhibit higher rainfall values. Conversely, sheltered valleys and regions in general downwind locations exhibit lower rainfall values. This effect of topography and distance from the coast is seen in the PMP spatial patterns across the regions, with the highest amounts near the coast and along the Appalachian crest and lower amounts to the east of the Appalachian crest inland from the coastal region.

In simple terms, precipitation is a product of two processes, rising air motion (lift) and moisture. The lift required to convert atmospheric moisture into precipitation is generated in several ways in and around the region. Synoptic storm dynamics are very effective in converting atmospheric moisture into precipitation. This type of storm environment is most often associated with fronts (boundaries between two different air masses) and areas of low pressure. Fronts can be a focusing mechanism providing upward motion in the atmosphere resulting in heavy precipitation production. In some instances, the pattern can become blocked causing these fronts to stall or move very slowly across the region. This pattern allows heavy rainfall to continue for several days in the same general area, causing widespread flooding.

Another mechanism which creates lift in the region is heating of the lower atmosphere by solar radiation, conduction, and convection. This creates warmer air below colder air resulting in atmospheric instability and leads to rising motions called convection. In unique circumstances, the instability and moisture levels in the atmosphere can reach very high levels and can potentially stay over the same region for an extended period of time. This can lead to intense thunderstorms and very heavy precipitation.

Another common mechanism for heavy precipitation is associated with tropical systems which affect the region every few years during the summer and fall seasons. The lift associated with such storms is a combination of convective process and lift provided by the topography and coastal convergence.

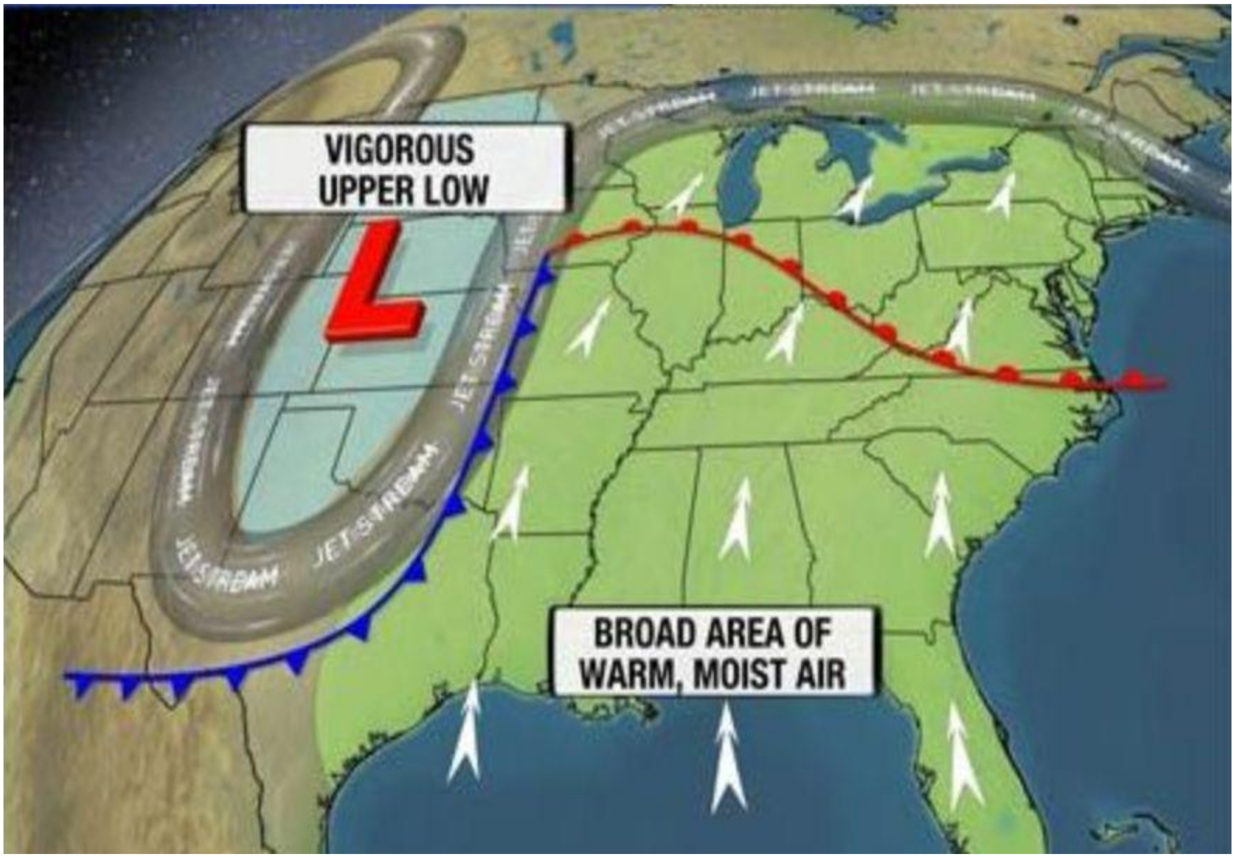


Figure 3.1: Synoptic weather features associated with moisture moving into the region from the Gulf of America and Atlantic Ocean into the region

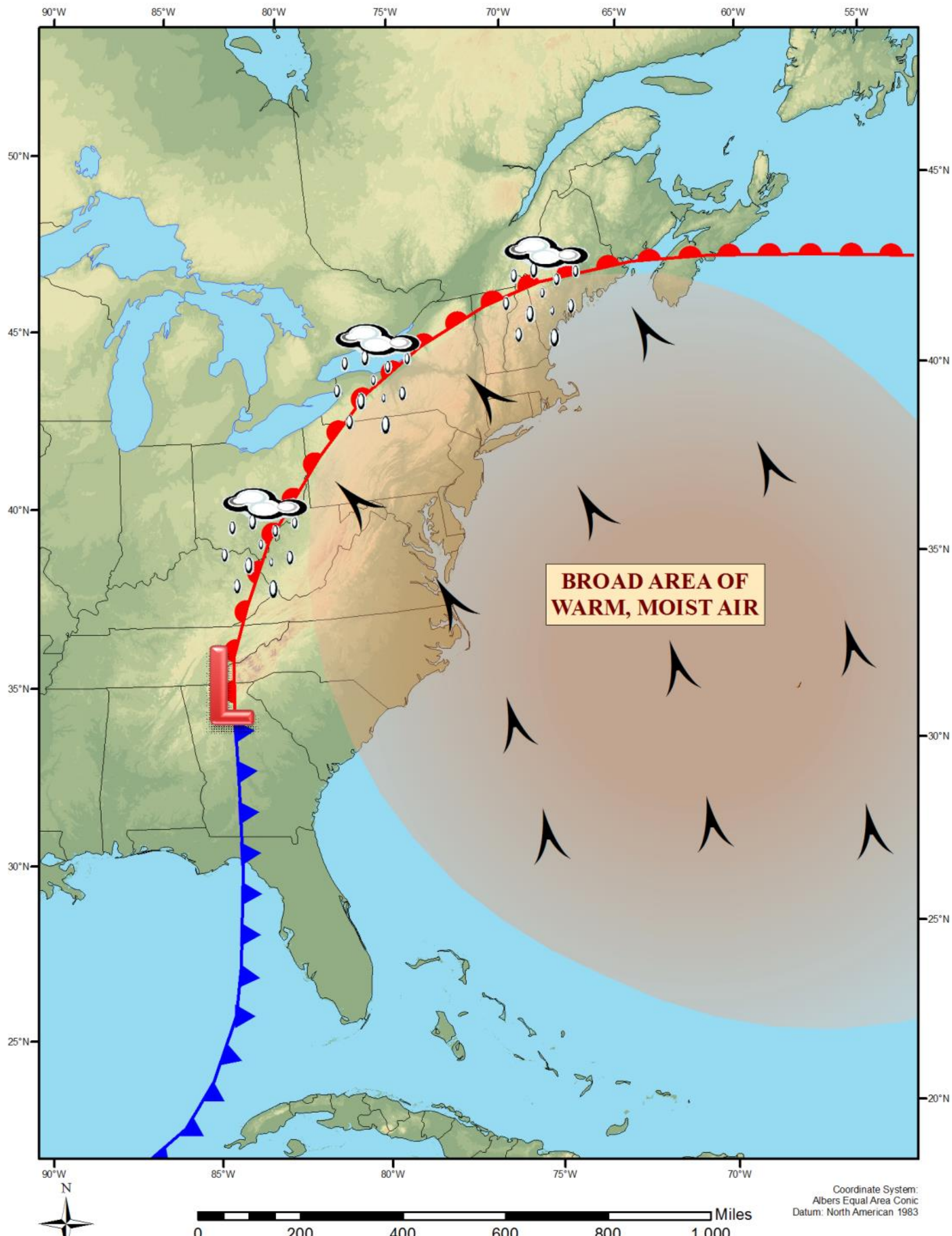


Figure 3.2: Locations of surface features associated with moisture advection from the Atlantic Ocean

3.1 Climatological Characteristics Affecting PMP Storm Types

Weather patterns in the region are characterized by three main types:

1. Areas of low pressure moving through the region from the west through the southwest or redeveloping along the lee slopes of the Appalachians or over the warm water of the Gulf of America and Gulf Stream (general storms);
2. Direct tropical system or remnant tropical moisture either from the Atlantic Ocean or Gulf of America (tropical storms); and
3. Isolated thunderstorms/Mesoscale Convective Systems (local storms).

General storms which produce PMP-type rainfall are most frequent in the spring and fall. Tropical systems occur from June through November. Local storms which can produce PMP-type rainfall are most active from late spring through early fall, with an increase in activity during the summer (Smith et al., 1996; Smith et al., 2011). General storms associated with frontal systems do occur often in the winter season; however, these sometimes produce snow instead of rain, are associated with lower levels of moisture, and move through relatively quickly. These factors all limit the amount of total precipitation that can occur in the study region.

The unique temporal patterns associated with each of these storm types were explicitly investigated and applied to PMP outputs. Numerous discussions and testing of PMP outputs were completed by NC DEQ and other study participants. This was an important aspect of this study, as it allowed for direct application of the PMP depths for hydrologic testing and evaluation. This ensured that the PMP depths and outputs were thoroughly tested and evaluated from a hydrologic application perspective and are appropriate for use in deriving the PMF.

The classification of storm types, and hence PMP development by storm type used in this study, is similar to descriptions provided in several HMRs (e.g., HMR 55A Section 1.5). Storms were classified by rainfall accumulation characteristics, while trying to adhere to previously used classifications. In addition, the storm classifications were cross-referenced with the storm typing completed as part of several other AWA PMP studies in the region (e.g., Kappel et al., 2015a; Kappel et al., 2015b; Kappel et al., 2019; Kappel et al., 2023; Kappel et al., 2024) to ensure consistency with adjacent studies.

Local storms were defined using the following guidance:

- The main rainfall accumulation period occurred over 6-hours or less
- Previously classified as a local storm by the USACE, in the HMRs, or adjacent studies
- Not associated with overall synoptic patterns leading to rainfall across large regions
- Exhibited high intensity accumulations over short periods (i.e., 1-hour or less)
- Occurred during the appropriate season, spring through fall

General storms were defined using the following guidance:

- The main rainfall accumulation period lasted for 24 hours or longer

- Occurred with a synoptic environment associated with a low-pressure system, frontal interaction, and/or regional precipitation coverage
- Was previously classified as a general storm by the USACE, in the HMRs, or adjacent studies
- Exhibited lower rainfall accumulation intensities compared to local storms

Tropical storms were defined using the following guidance:

- The rainfall was a direct result of a tropical system, either landfalling or directly offshore and a warm core circulation
- Was previously classified as a tropical storm by the USACE, in the HMRs, or adjacent studies
- Occurred during the appropriate season, June through November

It should be noted that some of the storms exhibit characteristics of more than one storm type and therefore have been included for PMP development as more than one type. These are classified as hybrid storms.

3.1.1 Local Storms

Localized thunderstorms and MCSs can produce extreme amounts of precipitation for short durations and over small area sizes, generally 6 hours or less over area sizes of 500 square miles or less. During any given hour, the heaviest rainfall only covers small areas, generally less than 100 square miles. This is the result of sustained low-level moisture availability combined with atmospheric stability parameters required to create sustained lift through deep layers of the atmosphere. Because these ideal combined factors do not stay over the same location for sustained periods and cover small areas at a given time, limitations are applied to the local storm PMP for hydrologic application. Limitations are based on the DAD values from local storms used for PMP development in this study. For each of these local storms, the rainfall depths decrease rapidly after the 100-square mile area size, demonstrating that the ideal combination of moisture and stability are not maintained above this area size. Therefore, it is recommended that the local storm PMP only be applied to any individual basin of 100-square miles or less. This is consistent with other studies and reflects the PMP rainfall environment associated with local storms in North Carolina.

Many of the storms previously analyzed by the USACE and NWS Hydrometeorological Branch, in support of pre-1979 PMP research, have features that indicate they were most likely Mesoscale Convective Complexes (MCCs) or MCSs. However, this nomenclature had not yet been introduced into the scientific literature, nor were the events fully understood. It is important to note that an MCC is a subset of the broader MCS category of mesoscale atmospheric phenomena. Another example of an MCS is the derecho, an organized line of thunderstorms that are notable for strong winds and resultant significant straight-line wind damage. On rare occasions derechos will move through the region generally from west to east and produce significant straight line wind damage and brief heavy rainfall.

For the study domain east of the Appalachian crest the MCC storm type is not common. Instead, these storms take on a different form, which includes interaction with a front or remnant tropical moisture (Letkewicz and Parker, 2010). This is because there is a lack of low-level jet

(LLJ) east of the Appalachians. However, the MCS storm type is very important for determining PMP values for small area sizes and short durations.

Separate from MCC and MCS storm types, individual thunderstorms can be isolated from the overall general synoptic weather patterns and fueled by localized moisture sources. The local storm type in the region has a distinct seasonality, occurring during the warm season when the combination of moisture and atmospheric instability is at its greatest, most common from spring through fall. This is the time of the year when convective characteristics and moisture within the atmosphere are adequate to produce lift and instability needed for thunderstorm development and heavy rainfall.

Local storm PMP depths derived in this report are valid from spring through fall when no snowpack would co-occur and can be associated with various synoptic conditions. Local storm PMP depths should not be applied with snowpack on the ground as that would not allow the atmospheric instability and moisture levels to occur in combination that would produce convective initiation and PMP level local storm rainfall. Examples of the local storm type include Jewell, MD July 1897, Ewan, NJ September 1940, Smethport, PA July 1942, Rapidan, VA June 1995, and Sparta, NJ August 2000.

3.1.2 General Storms

General storms occur in association with frontal systems and along boundaries between sharply contrasting air masses. Precipitation associated with frontal systems is enhanced when the movement of weather patterns slow or stagnates, allowing moisture and instability to affect the same general region for several days. In addition, when there is a larger than normal thermal contrast between air masses in combination with higher than normal moisture, PMP-level precipitation can occur. The processes can be enhanced by the effects of topography, with heavier precipitation occurring along and immediately upwind of upslope regions. Intense regions of heavy rain can also occur along a front as a smaller scale disturbance moving along the frontal boundary, called a shortwave, creating a region of enhanced lift and instability. These shortwaves are not strong enough to move the overall large-scale pattern but instead add to the storm dynamics and energy available for producing precipitation.

This type of storm will usually not produce the highest rainfall rates over short durations, but instead results in flooding situations as moderate rain continues to fall over the same region for an extended period of time. This storm is not expected to control PMP depths for any basins less than 100-square miles. Therefore, it is recommended that the general storm PMP only be applied to any individual basin larger than 10-square miles.

The seasonality of general storms varies, but the general storm PMP depths produced in this study are assumed to be a rainfall only event where melting snow would not contribute significantly to runoff. Although they can occur at almost any time of the year, they are most likely to produce flooding rainfall during spring and fall. Strong frontal systems do affect many parts of the region in winter. However, most of the precipitation occurs in the form of snow or moves through too quickly to produce PMP level rainfall.

3.1.3 Tropical Storms

Tropical systems directly impact the study region on a relatively frequent basis. When these systems move slowly over the area, large amounts of rainfall can be produced both in convective bursts and over longer durations. These types of storms require warm water and proper atmospheric conditions to be in place over the Gulf of America and Atlantic Ocean, and therefore only form from June through November, with August and September being the most common period of tropical storm activity in this region. Significant research is available on past tropical systems affecting the study region including strike probability for a given location per year (e.g., Keim et al., 2007).

3.1.4 Hybrid Storms

Hybrid storms include characteristics of more than one storm type. In this study, three storms were considered hybrid events. One storm was classified as both a local and general storm (Liberty, KY May 1984 SPAS 1376) and two storms were classified as general and tropical storms (Big Meadows, VA, October 1942 SPAS 1340 and Montgomery Dam, PA September 2004 SPAS 1275). These were applied as each storm type for PMP development to ensure inclusion for overall PMP development.

4. Topographic Effects on Precipitation

Terrain plays a significant role in precipitation development, magnitudes, and accumulation spatial patterns. The terrain within the region both enhances and depresses precipitation depending on whether the terrain is forcing the air to rise (upslope effect) or descend (downslope effect). To account for the effect of precipitation by terrain features (called orographic effects) evaluations were performed using precipitation frequency climatologies and investigations into past storm spatial accumulation patterns across the region. NOAA Atlas 14 precipitation frequency climatologies (Bonin et al., 2004; Perica et al., 2013a; Perica et al., 2013b) were used in this analysis. These climatologies were used to derive the GTF and the spatial distribution of the PMP. This approach is similar to the use of the NOAA Atlas 2 100-year 24-hour precipitation frequency climatologies used in HMRs 55A (Sections 6.3 and 6.4, Hansen et al., 1988), HMR 57 (Section 8.1, Hansen et al., 1994), and HMR 59 (Sections 6.6.1 and 6.6.2, Corrigan et al., 1999) as part of the Storm Separation Method (SSM) to quantify orographic effects in topographically significant regions.

The terrain within the study domain analyzed varies from sea level to elevated terrain in the western region within the Appalachian Mountains (Figure 4.1). When incoming air is forced to rise as it encounters elevated terrain, release of conditional instability can occur more effectively and enhance the conversion of moisture in the air to precipitation. These interactions must be considered in the PMP determination procedures including storm adjustment processes and determination of transposition limits.

The quantification of terrain effects was completed by evaluating rainfall depths at the 100-year recurrence interval using the 6-hour duration for local storms and the 24-hour duration for tropical and general storms at both the source (storm center) and target (grid point) location. This comparison produced a ratio that quantified the differences of precipitation processes, including terrain, between the two locations. The assumption is that the precipitation frequency data represent all aspects that have produced precipitation at a given location over time, including the effect of terrain. Therefore, if two locations are compared within regions of similar meteorological and topographical characteristics, the resulting difference of the precipitation frequency climatology should reflect the difference of all precipitation processes between the two locations, including topography, access to moisture, coastal convergence, seasonality, etc.

This relationship between precipitation frequency climatology and terrain is also recognized in the WMO PMP Manual (WMO, 1986 pg. 54) and by the Australian Bureau of Meteorology (Section 3.1.2.3 of Minty et al., 1996). Although the terrain effects at a particular location may vary from storm to storm, the overall effect (or lack thereof) is inherently included in the climatology of precipitation that occurred at that location, assuming that the climatology is based on storms of the same type. In WMO 2009 Section 3.1.4 it is stated "since precipitation-frequency values represent equal probability, they can also be used as an indicator of the effects of topography over limited regions. If storm frequency, moisture availability, and other precipitation-producing factors do not vary, or vary only slightly, over an orographic region, differences in precipitation-frequency values should be directly related to variations in orographic effects." Therefore, by applying appropriate transposition limits, analyzing by storm type, and utilizing the duration for storm typing, it is assumed the storms being compared using the precipitation frequency data are of similar moisture availability and other precipitation-producing factors.

This assumption was evaluated and determined to be acceptable during the development of PMP in the adjacent statewide studies in Virginia, Pennsylvania, New Jersey, and Maryland statewide studies and again evaluated in this study. Various sensitivity analyses and discussions with NC DEQ, the Technical Advisory Committee, and others involved in this study took place to determine how terrain influenced storm patterns and storm transposition limits.

These analyses and discussions included testing of PMP depths from a spatial perspective, comparing the difference of using the single grid at the storm center location versus an area size of several grids around the storm center, and comparing resulting PMP depths against 100-year recurrence interval depths. In previous PMP studies, additional sensitivities and evaluations were completed through numerical modeling applications which included removing/adding topography (Volume IV of the Colorado-New Mexico Regional Extreme Precipitation Study, Kappel et al., 2018).

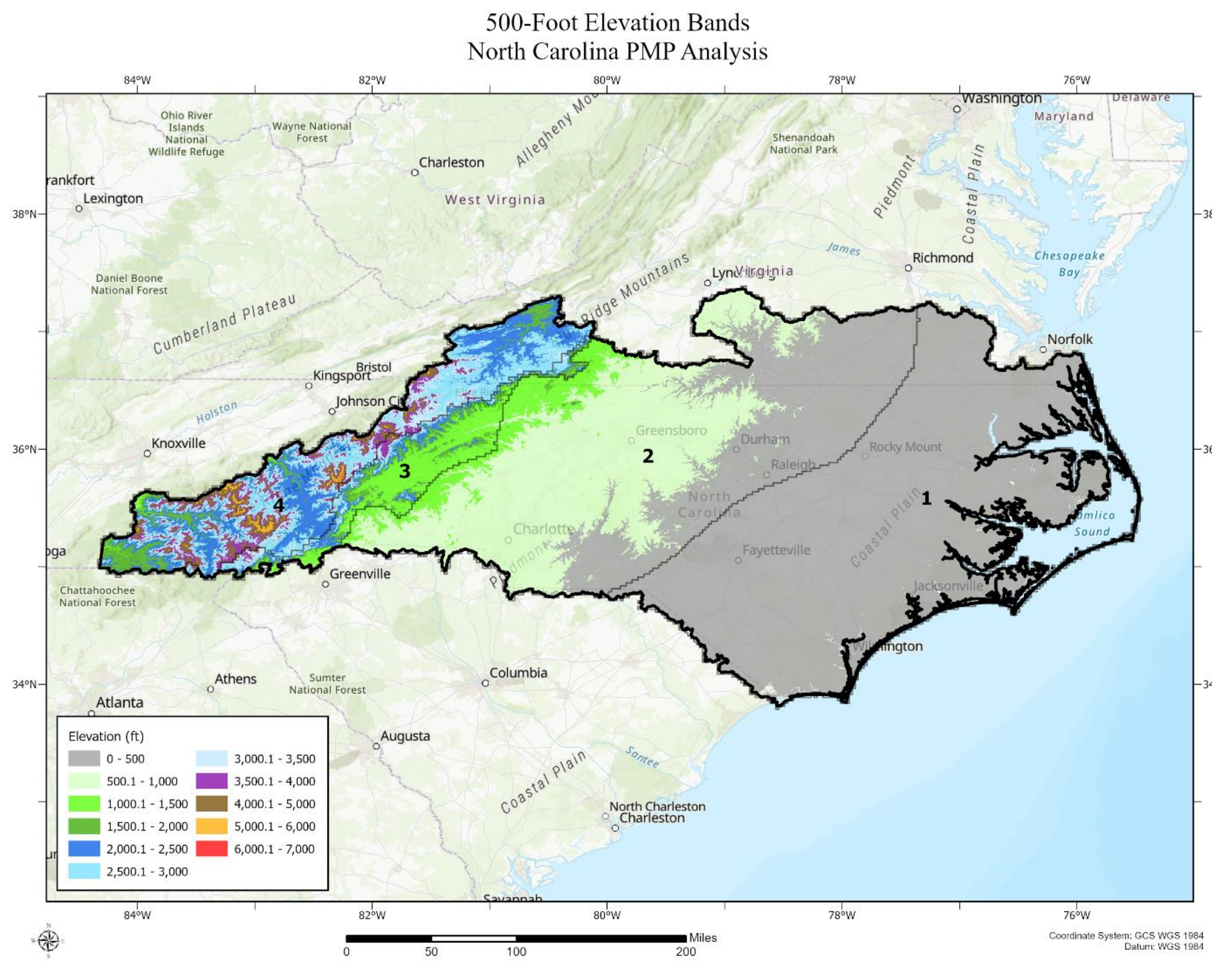


Figure 4.1: Elevation bands at 500-foot intervals over the region analyzed

5. Data Description and Sources

Detailed evaluations of potential storms to use for PMP development were conducted as part of this study. This included investigating the storm lists from previous relevant studies in the region (e.g., statewide studies in Ohio, Virginia, Pennsylvania, New Jersey, and Maryland as well as the regional PMP study for the Tennessee Valley Authority, and several site-specific studies within the region). The storm list was augmented by an updated storm search which included inputs on potential additional storms that were important for North Carolina. This was focused on the Piedmont region between the coast and Appalachians. This resulted in the identification of the Fayetteville September 2016 local storm event. During the study, the near world record rainfall near Rockport, WV in July 1889 was also analyzed based on additional information that became available. Finally, two extreme events occurred during September of 2024, Hurricane Helene and tropical cyclone 8. These storms were fully analyzed with SPAS using data from the following sources and included in PMP development:

1. Storm data and meteorological information from various Hydrometeorological Reports (e.g., 1, 33, 41, 51, and 52) each of which can be downloaded from the Hydrometeorological Design Studies Center website at https://www.weather.gov/owp/hdsc_pmp
2. Cooperative Summary of the Day / TD3200. These data are published by the National Centers for Environmental Information (NCEI), previously the National Climatic Data Center (NCDC). These are stored on AWA's database server and can be obtained directly from the NCEI.
3. Hourly Weather Observations published by NCEI, U.S. Environmental Protection Agency, and Forecast Systems Laboratory (now National Severe Storms Laboratory). These are stored on AWA's database server and can be obtained directly from NCEI.
4. NCEI Recovery Disk. These are stored on AWA's database server and can be obtained directly from the NCEI.
5. U.S. Army Corps of Engineers Storm Studies (USACE, 1973).
6. United States Geological Survey (USGS) Flood Reports.
7. Other data published by NWS offices. These can be accessed from the National Weather Service homepage at http://www.weather.gov/.
8. Data from supplemental sources, such as Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS), Weather Underground, Forecast Systems Laboratories, RAWS, and various Google searches.
9. Previous and ongoing PMP and storm analysis work (Tomlinson et al., 2008-2013; Kappel et al., 2013-2024).
10. Peer reviewed journals (e.g., Smith et al., 1996; Keim, 1998; Pontrelli et al., 1999; Konrad, 2001; Robinson et al., 2001; Hicks et al., 2005; Keim et al., 2007; Smith et al., 2010; Smith et al., 2011; Keim et al., 2018; Brown et al., 2020: Brown et al., 2024).

5.1 Use of Dew Point Temperatures for Storm Maximizations

HMR and WMO procedures for storm maximization use a representative storm dew point as the parameter to represent available moisture to a given storm. Prior to the mid-1980s, maps of maximum 12-hour persisting dew point values from the *Climatic Atlas of the United States*

(EDS, 1968) were the source for maximum dew point values. This study used the 100-year return frequency dew point climatology, which is periodically updated by AWA. Storm precipitation amounts were maximized using the ratio of precipitable water for the maximum dew point to precipitable water for the storm representative dew point, assuming a vertically saturated atmosphere through 30,000 feet. The precipitable water values associated with each storm representative value were taken from the WMO Manual for PMP Annex 1 (1986).

The use of the 100-year recurrence interval dew point climatology in the maximization process is appropriate because it provides a sufficiently rare occurrence of moisture level when combined with the maximum storm efficiency to produce a combination of rainfall producing mechanisms that could physically occur. Research has shown that the assumption of combining the maximum storm efficiency with the maximum dew point value results in the most conservative combination of storm parameters and hence the most conservative PMP depths when considering all the possibilities of PMP development (Ben Alaya et al., 2018).

An envelope of maximum dew point values is no longer used because in many cases the maximum observed dew point values do not represent a meteorological environment that would produce rainfall, but instead often represent a local extreme moisture value that can be the result of local evapotranspiration and other factors not associated with a storm environment and fully saturated atmosphere. Also, data availability increased significantly since the publication of the maximum dew point climatologies used in HMR 51. Hourly dew point observations became standard at all first-order NWS weather stations starting in 1948. This has allowed for a sufficient period of record of hourly data to exist from which to develop the climatologies out to the 100-year recurrence interval. These data were not available in sufficient quantity and period of record during the development of HMR 51.

Maximum dew point climatologies are used to determine the maximum atmospheric moisture that could have been available. Prior to the mid-1980s, maps of maximum dew point values from the *Climatic Atlas of the United States* (EDS, 1968) were the source for maximum dew point values. For the region covered by HMR 49, HMR 50 (Hansen and Schwartz, 1981) provided updated dew point climatologies. HMR 55A contained updated maximum dew point values for a portion of the United States from the Continental Divide eastward into the Central Plains. HMR 57 updated the 12-hour persisting dew points values and added a 3-hour persisting dew point climatology. The regional PMP study for Michigan and Wisconsin produced dew point frequency maps representing the 50-year recurrence interval. The choice to use a recurrence interval and average duration was first determined to be the best representation of the intent of the process during the Electric Power Research Institute (EPRI) Michigan/Wisconsin region PMP study (Section 2-1 and 7, Tomlinson, 1993). That study included original authors of HMR 51 on the review board.

The EPRI study was conducted using an at-site method of analysis with L-moment statistics. The review committee for that study included representatives from NWS, FERC, Bureau of Reclamation, and others. They agreed that the 50-year recurrence interval values were appropriate for use in PMP calculations. For the Nebraska statewide study (Tomlinson et al., 2008), the review committee and FERC Board of Consultants agreed that the 100-year recurrence interval dew point climatology maps were appropriate because their use added a layer of conservatism over the 50-year return period. This has subsequently been utilized in all PMP studies completed by AWA. This study is again using the 100-year recurrence interval climatology constructed using dew point data updated through 2018 (Figure 5.1).

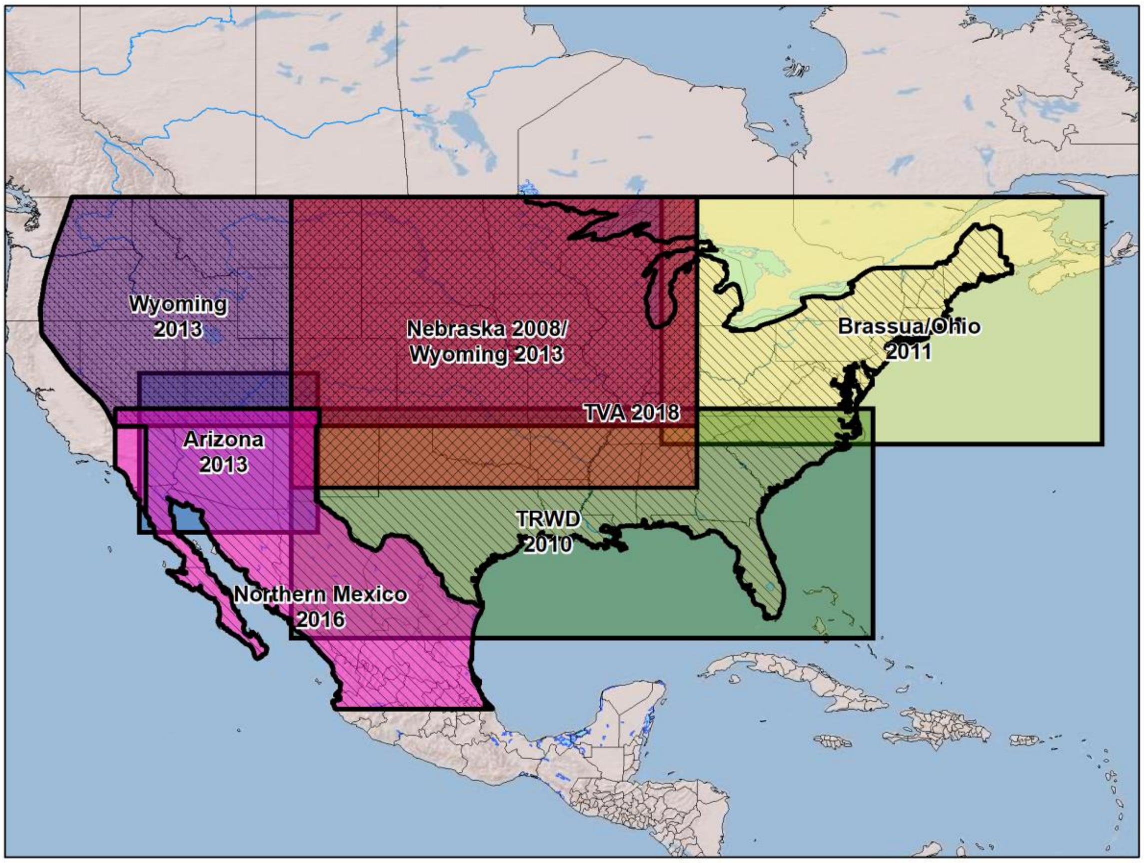


Figure 5.1: Maximum dew point climatology development regions and dates

5.2 Use of Sea Surface Temperatures for Storm Maximizations

Dew point observations for use in storm maximizations are not available over ocean regions. Therefore, when the source region of atmospheric moisture advecting into a rainfall event originates from over the ocean, a substitute for dew points observations is required. The NWS adopted a procedure for using SSTs as surrogates for dew point data (U.S. Navy Marine Climate Atlas, 1981). The value used as the maximum SST in the PMP calculations is determined using the SSTs two standard deviations warmer (+2 sigma) than the mean SST (Worley et al., 2005; Kent et al., 2007; and Reynolds et al., 2007). This provides a value for the maximum SST that has a probability of occurrence of about 0.025 (i.e., about the 40-year recurrence interval value). Use of the mean plus 2-sigma SSTs is consistent with the NWS procedure used in HMRs 57 and 59 (e.g., HMR 57 Section 4.3). These discussions note that SSTs change slowly in time and space when compared to surface-based dew points. In addition, AWA has completed evaluations of the difference between +2 and +3 sigma SSTs in the Atlantic Ocean and Gulf of America. These showed only small differences, less than a 0.5°F. This is well within the rounding error and uncertainty involved in developing the storm representative values. Therefore, we continue to utilize the +2 sigma for consistency with use in the HMRs and all past AWA studies where SSTs are utilized for storm maximizations.

HYSPLIT model output provides detailed analyses for determining the upwind trajectories of atmospheric moisture that was advected into the storm systems. Using these trajectories as general guidance, the moisture source locations can be investigated. This is especially helpful over ocean regions where surface data are lacking to help with guidance in determining the moisture source region for a given storm. The procedures followed are similar to the approach used in HMR 59. However, by utilizing the HYSPLIT model trajectories, much of the subjectivity is eliminated. Further, details of each evaluation can be explicitly provided, and the results are reproducible.

Use of SSTs for in-place maximization and storm transpositioning follow a similar procedure to that used with land-based surface dew points. Use of the HYSPLIT model provides a significant improvement in determining the inflow wind vectors compared to older methods of extrapolating coastal wind observations and estimating moisture advection from synoptic features over the ocean. This more objective procedure is especially useful for situations where a long distance is involved to reach warmer ocean regions.

Timing is not as critical for inflow wind vectors extending over the oceans since SSTs change very slowly with time compared to dew point values over land. What is important is the changing wind direction, especially for situations where there is curvature in the wind fields. Any changes in wind curvature and variations in timing are inherently captured in the HYSPLIT model re-analysis fields, thereby eliminating another subjective parameter.

The start time of HYSPLIT is determined using the rainfall mass curves from the region of maximum rainfall associated with a given storm event. The location of the storm representative SST was determined by identifying the location where the SSTs are generally changing less than 1-2°F in an approximate 1° x 1° latitude and/or longitude distance following the inflow vector upwind. This is used to identify the homogeneous (or nearly homogeneous) region of SSTs associated with the atmospheric moisture source for the storm being analyzed. The value from the SST daily analysis for that location is used for the storm representative SST. The storm representative SST becomes a surrogate for the storm representative dew point in the maximization procedure.

The value for the maximum SST was determined using the mean +2 sigma (two standard deviations warmer than the mean) SST for that location. SSTs were substituted for dew points in this study for several storms where the inflow vector originated over the Atlantic Ocean or Gulf of America. The data presented in Appendix F show the moisture source region for each storm and whether dew points or SSTs were used in the maximization calculations. For storm maximization, the value for the maximum SST is determined using the mean +2 sigma SST for that location for a date two weeks before or after the storm date (whichever represents the climatologically warmer SST period). Storm representative SSTs and the mean +2 sigma SSTs are used in the same manner as storm representative dew points and maximum dew point climatology values in the maximization and transpositioning procedure.

6. Data Quality Assurance and Quality Control

During the development of the deterministic PMP depths, quality assurance (QA) and quality control (QC) measures were in-place to ensure data used were free from errors and processes followed acceptable scientific procedures. QA/QC procedures were in-place internally from AWA and externally from NC DEQ, Technical Advisory Committee, and other study participants.

Numerous QA/QC checks are part of the SPAS algorithms and are included in each SPAS analysis. These include gauge quality control, gauge mass curve checks, statistical checks, gauge location checks, co-located gauge checks, rainfall intensity checks, observed versus modeled rainfall checks and ZR relationship checks (if radar data are available). These data QA/QC measures help ensure accurate precipitation reports, ensure proper data analysis and compilation of values by duration and area size, and consistent output of SPAS results. For additional information on SPAS, the data inputs, modeled outputs, and QA/QC measures, see Appendix E. For the storm adjustment process, internal QA/QC included validation that all IPMF were 1.00 or greater, that the MTF was set to 1.00, that upper (1.50) and lower (0.50) limits of the GTF were applied, and that any unique GTF limits were appropriate.

Maps of gridded GTF values were produced to cover the PMP analysis domain (Appendix B). These maps serve as a tool to spatially visualize and evaluate adjustment factors. Spot checks were performed at various positions across the domain and calculations were completed via Excel file equations to verify adjustment factor calculations are consistent. Internal consistency checks were applied to compare the storm data used for PMP development against previous PMP studies including Virginia (Kappel et al., 2015), Pennsylvania (Kappel et al., 2019), New Jersey (Kappel et al., 2023), Maryland (Kappel et al., 2024) and numerous site-specific studies in the region (Kappel et al., 2014-2022). Comparisons against HMR 51 PMP depths and other data such as NOAA Atlas 14 precipitation depths, and world record rainfall depths were completed.

Maps of each PMP version (see Appendix I for the Version Log notes) were plotted at standard area sizes and durations to ensure proper spatial continuity of PMP depths. Updates were applied to ensure reasonable gradients and depths based on overall meteorological and topographical interactions. The PMP tool utilized in this study employs very few calculations, however, the script utilizes Python’s ‘try’ and ‘except’ statements to address input that may be unsuitable or incorrect.

AWA and the NC DEQ completed external QA/QC on several important aspects of the PMP development. Each explicitly evaluated storms used for PMP development, the transposition limits of important storms, the storm representative values for each storm, and applied the hydrology to derive the PMF for sample basins across the region.

7. Storm Selection for PMP Calculations

7.1 Storm List Development Process

The initial search began with identifying storms that had been used in other PMP studies in the region covered by the storm search domain (Figure 7.1). These storm lists were combined to produce an initial list of storms for this study. As mentioned in Section 5, previous lists analyzed included the Ohio PMP study (2013), the Virginia PMP study (2015), the Tennessee Valley Authority regional PMP study (2015), the Pennsylvania statewide PMP study (2019), the New Jersey PMP study (2023), the Maryland PMP statewide study (2024) and the numerous site-specific PMP studies in the region (see Figure 7.2). The storm search included storms extending from the early 1800's through the course of this study.

These previous storms lists were updated with data through the course of this study and from other reference sources such as HMRs, USGS, USACE, USBR, state climate center reports, and NWS reports. In addition, discussions with NC DEQ and other project participants were reviewed to identify dates with large rainfall amounts for locations within the storm search domain. As noted in Section 5, four new storms were included in this study; Rockport, WV July 1889 (SPAS 1944); Fayetteville, NC September 2016 (SPAS 1952); tropical cyclone 8 September 2024 (SPAS 1981), and Hurricane Helene September 2024 (SPAS 1984).

Storms from each of these sources were evaluated to see if they occurred within the initial storm search domain shown in Figure 7.1 and were previously important for PMP development. Next, each storm was analyzed to determine whether it was included on the short list for any of the previous studies, whether it was used in the relevant HMRs, and/or whether it produced an extreme flood event. Storms included on the initial storm list all exceeded the 100-year return frequency value for specified durations at the station location.

Each storm was then classified by storm type (e.g., local, general, tropical) based on their accumulating characteristics and seasonality as discussed in Section 2. Storm types were discussed with the review board to ensure concurrence and cross-referenced with previous storm typing to ensure consistency. The storms were then grouped by storm type, storm location, and duration for further analysis to define the final short list of storms used for PMP development. These storms were plotted and mapped using GIS to better evaluate the spatial coverage of the events throughout the region by storm type to ensure adequate coverage for PMP development.

The recommended storm list was presented to NC DEQ, the Technical Advisory Committee, and other study participants for discussion and evaluation. The recommended short list of storms was based on the above evaluations and experience with past studies and relevance for this project. The recommended short storm list was discussed in detail during review meetings and subsequently through the end of the project as various iterations of the PMP were developed and new storms were added. A few storms were removed from final consideration because of transposition limits and others were classified as hybrid events when they exhibit rainfall accumulation characteristics of more than one storm type. Iterations of how each storm was used can be found in the PMP Version Log provided in Appendix I.

Figure 7.1: Initial storm search domain used for initial storm identification

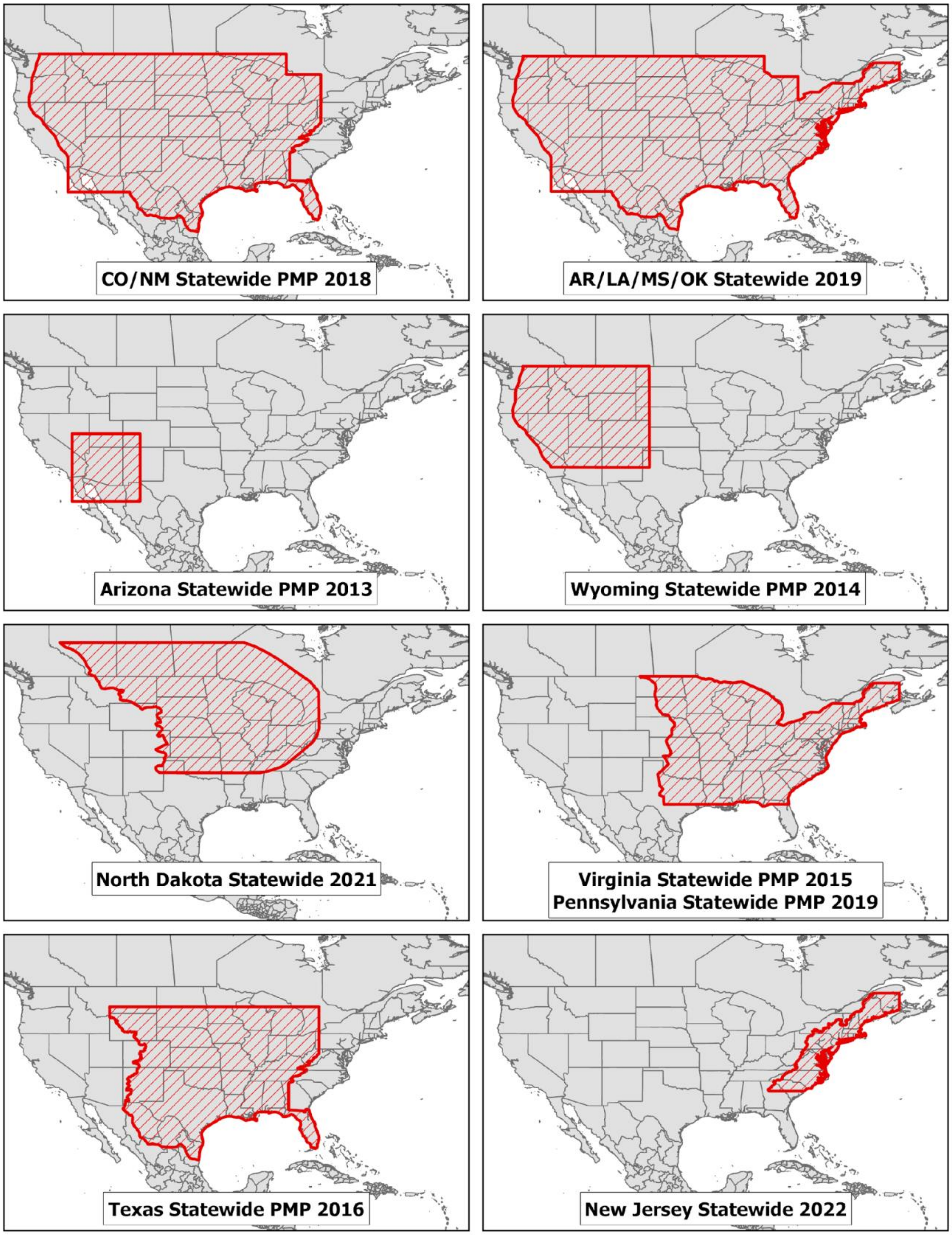


Figure 7.2: Previous AWA Statewide PMP studies storm search domains

From the initial storm list, the storms to be used for PMP development were identified and moved to the recommended short storm list. Each storm was investigated using both published and unpublished references described above and AWA PMP studies to determine its significance in the rainfall and flood history of surrounding regions. These included evaluations and comparisons of the storms, discussions of each storm's effects in the location of occurrence, discussion of storms in regions that were underrepresented, discussion of storms importance for PMF development in previous design analyses, and other meteorological and hydrological relevant topics.

Consideration was given to each storm's transpositionability within the overall domain and each storm's relative magnitude compared to other similar storms on the list and whether another storm of similar storm type was significantly larger. In this case, what is considered is whether after all adjustments are applied a given storm would still be smaller than other storms used. To determine this, several evaluations were completed. These included how a given storm was used in previous PMP studies, comparison of the precipitation values at area sizes relevant to the basin, and comparison of precipitation values conservative increases to the observed values.

7.2 Final PMP Storm List Development

The final storm list used to derive PMP depths for this study considered each of the discussions in the previous sections in detail. Each storm on the final short storm list exhibited characteristics that were determined to be possible over some portion of the overall study domain. The storms that made it through these final evaluations were placed on the PMP storm list (Table 7.1 and Figure 7.3). Figure 7.4, Figure 7.5, and Figure 7.6 provide the short list storms by storm type with a callout providing the storm name and date that can be cross-referenced with the information provided in Table 7.1. Each of these storms were fully analyzed in previous PMP studies or as part of this study using the SPAS process (Appendix E). Note, Sparta, NJ SPAS 1674 is an updated analysis of SPAS 1017 used in the Pennsylvania and Virginia statewide studies. Similarly, Wellsboro, PA SPAS 1339 has been updated to include three DAD zones versus the single DAD zone used in the previous studies.

The PMP storm list contains 91 unique SPAS storm Depth-Area-Duration (DAD) zones, far more storms than were ultimately controlling of the PMP depths. This is one of the steps that helps to ensure no storms were omitted which could have affected PMP depths after all adjustment factors were applied. The conservative development of the PMP storm list is completed because the final magnitude of the rainfall accumulation associated with a given storm is not known until all the total adjustment factors have been calculated and applied. In other words, a storm with large point rainfall values may have a relatively small total adjustment factor, while a storm with a relatively smaller but significant rainfall value may end up with a large total adjustment factor. The combination of these calculations may provide a total adjusted rainfall value for the smaller rainfall event that is greater than the larger rainfall event after all adjustments are applied.

Table 7.1: Storm list used for PMP developments

SPAS ID	Storm Name	State	Lat	Lon	Year	Month	Day	Max Rainfall	TYPE
SPAS_1047_1	TAMAQUA	PA	41.68	-75.38	2006	6	26	12.26	General
SPAS_1195_2	PADDY MOUNTAIN	WV	39.02	-78.56	1936	3	16	8.32	General
SPAS_1208_1	WARNER PARK	TN	36.06	-86.91	2010	5	1	19.71	General
SPAS_1218_1	DOUGLASVILLE	GA	33.87	-84.76	2009	9	19	25.37	General
SPAS_1218_2	LA FAYETTE	GA	34.77	-85.26	2009	9	19	19.61	General
SPAS_1219_1	BIG FORK	AR	35.87	-92.12	1982	12	1	15.92	General
SPAS_1242_1	ALLEY SPRING	MO	37.12	-91.45	2008	3	17	15.10	General
SPAS_1244_1	LOUISVILLE	KY	38.10	-85.67	1997	2	28	13.51	General
SPAS_1278_1	MADISONVILLE	KY	37.35	-87.50	1964	3	8	11.67	General
SPAS_1298_1	HARRISBURG	PA	39.99	-76.50	2011	9	4	18.32	General
SPAS_1305_1	ELBA	AL	31.36	-86.12	1929	3	12	29.73	General
SPAS_1311_1	MCKENZIE	TN	36.44	-87.91	1937	1	17	19.86	General
SPAS_1312A_1	ROSMAN	NC	37.74	-81.60	1964	9	26	9.22	General
SPAS_1312A_2	ROSMAN	NC	35.15	-82.80	1964	9	26	17.86	General
SPAS_1339_1	WELLSBORO (DAD 1)	PA	41.70	-77.23	1889	5	30	10.11	General
SPAS_1339_2	WELLSBORO (DAD 2)	PA	40.90	-78.60	1889	5	30	8.99	General
SPAS_1339_3	WELLSBORO (DAD 3)	PA	40.40	-76.93	1889	5	30	9.19	General
SPAS_1346_1	BLUE RIDGE DIVIDE	NC	35.04	-83.08	1940	8	28	14.09	General
SPAS_1350_1	NEW BERN	NC	35.18	-77.22	2010	9	27	23.44	General
SPAS_1357_1	BURNSVILLE	TN	34.84	-88.40	1973	3	14	12.15	General
SPAS_1362_2	ROBBINSVILLE	VA	35.32	-83.69	1977	4	2	9.21	General
SPAS_1380_1	BURTON DAM	GA	34.80	-83.70	1967	8	21	18.42	General
SPAS_1514_1	VADE MECUM	NC	36.31	-80.28	1908	8	23	18.00	General
SPAS_1533_1	MONTEBELLO	VA	37.81	-79.16	1985	11	1	22.56	General
SPAS_1564_1	MOUNT PLEASANT	SC	32.90	-79.77	2015	10	1	27.97	General
SPAS_1680_1	WEST SHOKAN	NY	42.00	-74.40	1955	10	14	20.27	General
SPAS_1804_1	HALIFAX	VT	42.75	-72.76	2005	10	7	15.53	General
SPAS_1376_1	LIBERTY	KY	37.26	-84.97	1984	5	7	9.62	Hybrid (G/L)
SPAS_1275_2	MONTEGOMERY DAM	PA	40.61	-76.47	2004	9	18	8.80	Hybrid (G/T)
SPAS_1340_1	BIG MEADOWS	VA	38.55	-78.40	1942	10	12	19.77	Hybrid (G/T)
SPAS_1040_1	TABERNACLE	NJ	39.88	-74.69	2004	7	13	15.63	Local
SPAS_1049_1	DELAWARE COUNTY	NY	42.01	-74.90	2007	6	19	11.69	Local
SPAS_1209_1	WOOSTER	OH	40.91	-81.97	1969	7	4	14.95	Local
SPAS_1226_1	COLLEGE HILL	OH	40.09	-81.65	1963	6	3	19.39	Local
SPAS_1343_1	JOHNSON CITY	TN	36.30	-82.06	1924	6	13	16.14	Local
SPAS_1344_1	SIMPSON	KY	38.10	-83.30	1939	7	4	20.82	Local
SPAS_1362_1	COEBURN	VA	37.28	-81.80	1977	4	2	15.66	Local
SPAS_1402_1	LITTLE BARREN	TN	36.36	-83.72	1965	7	24	11.00	Local
SPAS_1402_2	ROSEDALE	TN	36.18	-84.23	1965	7	24	13.32	Local
SPAS_1406_1	RAPIDAN	VA	38.42	-78.34	1995	6	27	28.39	Local
SPAS_1415_1	ISLIP	NY	40.81	-73.07	2014	8	13	14.23	Local
SPAS_1489_1	JEWELL	MD	38.73	-76.57	1897	7	26	15.88	Local
SPAS_1534_1	EWAN	NJ	39.69	-75.18	1940	9	1	24.30	Local
SPAS_1536_1	GLENVILLE	WV	38.90	-80.77	1943	8	4	15.04	Local
SPAS_1546_1	LITTLE RIVER	VA	38.86	-79.19	1949	6	17	15.13	Local
SPAS_1548_1	REDBANK	PA	41.26	-79.16	1996	7	19	9.42	Local
SPAS_1550_1	JOHNSTOWN	PA	40.40	-78.95	1977	7	18	12.64	Local
SPAS_1674_1	SPARTA	NJ	41.03	-74.64	2000	8	11	16.70	Local
SPAS_1681_1	SMETHPORT (DAD 1)	PA	41.84	-78.27	1942	7	17	35.30	Local
SPAS_1681_2	SMETHPORT (DAD 2)	PA	41.72	-78.08	1942	7	17	26.67	Local
SPAS_1681_3	SMETHPORT (DAD 3)	PA	41.97	-78.19	1942	7	17	23.93	Local
SPAS_1681_4	SMETHPORT (DAD 4)	PA	41.91	-77.90	1942	7	17	32.76	Local
SPAS_1681_5	SMETHPORT (DAD 5)	PA	42.36	-77.95	1942	7	17	25.33	Local
SPAS_1681_6	SMETHPORT (DAD 6)	PA	41.60	-78.57	1942	7	17	20.41	Local
SPAS_1700_1	ELLICOTT CITY	MD	39.27	-76.76	2018	5	27	14.22	Local
SPAS_1927_1	FORT LAUDERDALE	FL	26.08	-80.13	2023	4	12	26.88	Local
SPAS_1944_1	ROCKPORT	WV	39.06	-81.54	1889	7	18	21.07	Local
SPAS_1952_1	FAYETTEVILLE	NC	34.95	-79.15	2016	9	28	14.26	Local
SPAS_1224_1	MAPLECREST	NY	42.30	-74.16	2011	8	27	22.91	Tropical
SPAS_1243_1	WESTFIELD	MA	42.20	-72.82	1955	8	17	18.93	Tropical
SPAS_1275_1	MONTGOMERY DAM	PA	40.65	-80.39	2004	9	18	8.79	Tropical
SPAS_1276_1	WELLSVILLE	NY	42.04	-78.07	1972	6	18	18.78	Tropical
SPAS_1276_2	ZERBE	PA	40.54	-76.62	1972	6	18	18.79	Tropical
SPAS_1299_1	ALTA PASS	NC	35.88	-81.87	1916	7	13	24.90	Tropical
SPAS_1299_2	KINGSTREE	SC	33.66	-79.83	1916	7	13	16.79	Tropical
SPAS_1312B_2	ROSMAN	NC	35.14	-82.84	1964	10	3	17.53	Tropical
SPAS_1317_1	AMERICUS	GA	32.10	-84.23	1994	7	4	28.09	Tropical
SPAS_1342_1	MT MITCHELL	NC	36.29	-81.48	1940	8	11	20.27	Tropical
SPAS_1373_1	ANTREVILLE	SC	34.86	-82.23	1995	8	26	19.99	Tropical
SPAS_1490_1	EASTON	MD	38.86	-76.07	1935	9	4	17.00	Tropical
SPAS_1491_1	TYRO	VA	37.81	-79.00	1969	8	19	27.23	Tropical
SPAS_1515_1	ST. GEORGE	GA	30.52	-82.02	1911	8	28	19.12	Tropical
SPAS_1516_1	GLENVILLE	GA	31.95	-81.89	1929	9	23	21.20	Tropical
SPAS_1516_2	GLENVILLE	GA	34.82	-84.15	1929	9	23	20.88	Tropical
SPAS_1517_2	MONCURE	NC	35.60	-79.07	1929	9	29	11.55	Tropical
SPAS_1517_3	SETTLE	NC	35.95	-80.70	1929	9	29	9.97	Tropical
SPAS_1518_1	ROCKINGHAM	NC	34.95	-79.73	1945	9	13	14.97	Tropical
SPAS_1526_1	RIDGEWAY	SC	34.34	-81.01	2006	6	10	9.32	Tropical
SPAS_1535_1	EDENTON	NC	35.86	-76.50	2003	9	17	7.96	Tropical
SPAS_1535_2	UPPER SHERANDO	VA	37.91	-79.03	2003	9	17	20.22	Tropical
SPAS_1551_1	RICHMOND	VA	37.71	-77.38	2004	8	30	14.38	Tropical
SPAS_1552_1	SOUTHPORT	NC	34.01	-78.00	1999	9	14	24.30	Tropical
SPAS_1552_2	YORKTOWN	VA	37.28	-76.56	1999	9	14	19.22	Tropical
SPAS_1552_3	POMPTON LAKE	NJ	41.00	-74.29	1999	9	15	14.62	Tropical
SPAS_1552_4	CAIRO	NY	42.30	-74.01	1999	9	15	11.71	Tropical
SPAS_1669_1	EVERGREEN	NC	34.46	-78.87	2016	10	6	19.12	Tropical
SPAS_1679_1	SLIDE MOUNTAIN	NY	42.02	-74.40	1955	8	11	15.20	Tropical
SPAS_1720_1	WRIGHTSVILLE BEACH	NC	34.24	-77.77	2018	9	14	43.92	Tropical
SPAS_1891_1	DOWNINGTON	PA	39.98	-75.67	2021	8	31	10.29	Tropical
SPAS_1981_1	KURE BEACH	NC	33.78	-77.74	2024	9	12	32.41	Tropical
SPAS_1984_1	BUSICK (Helene)	NC	35.77	-82.18	2024	9	24	32.76	Tropical

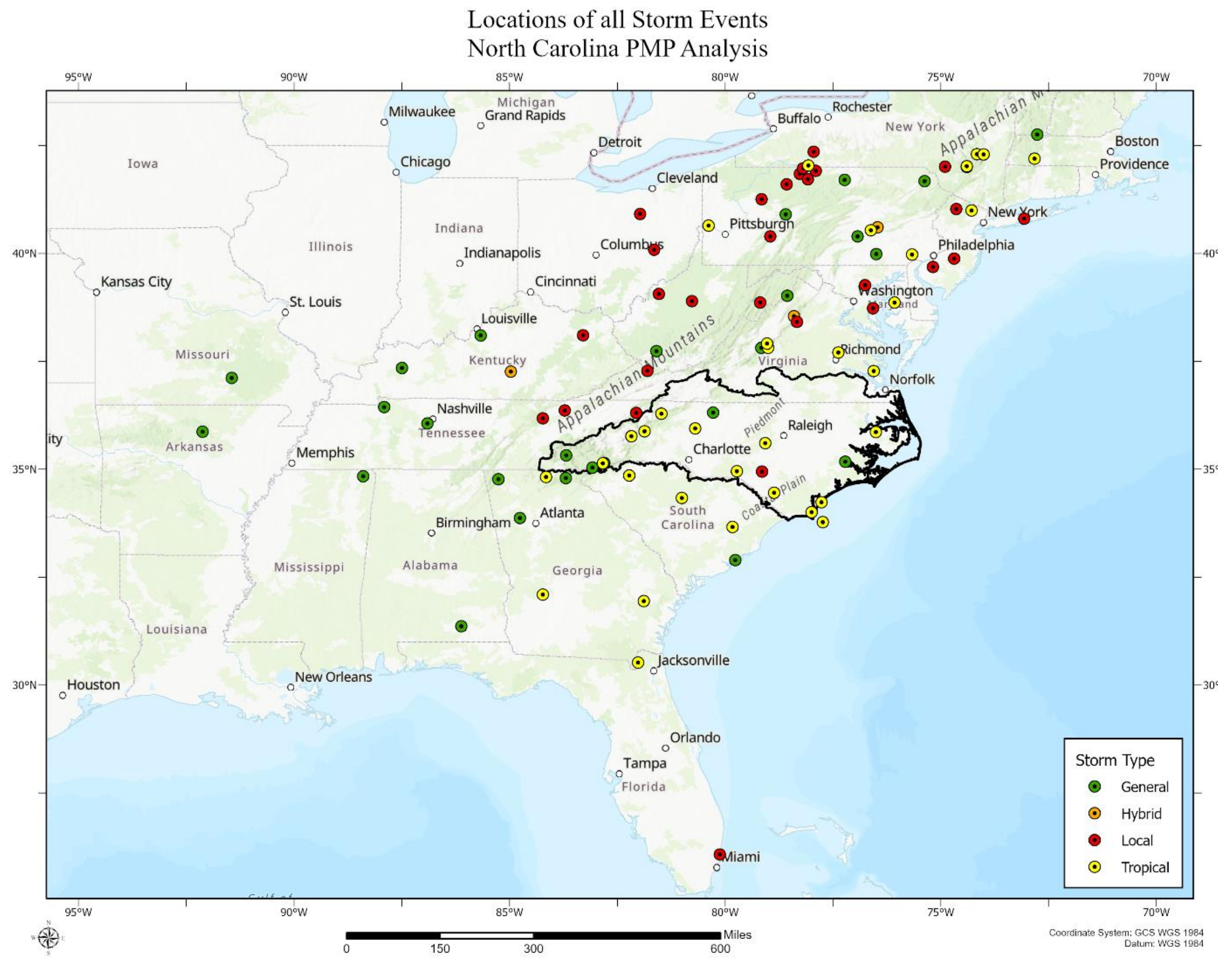


Figure 7.3: Storm list locations, all storms used for PMP development

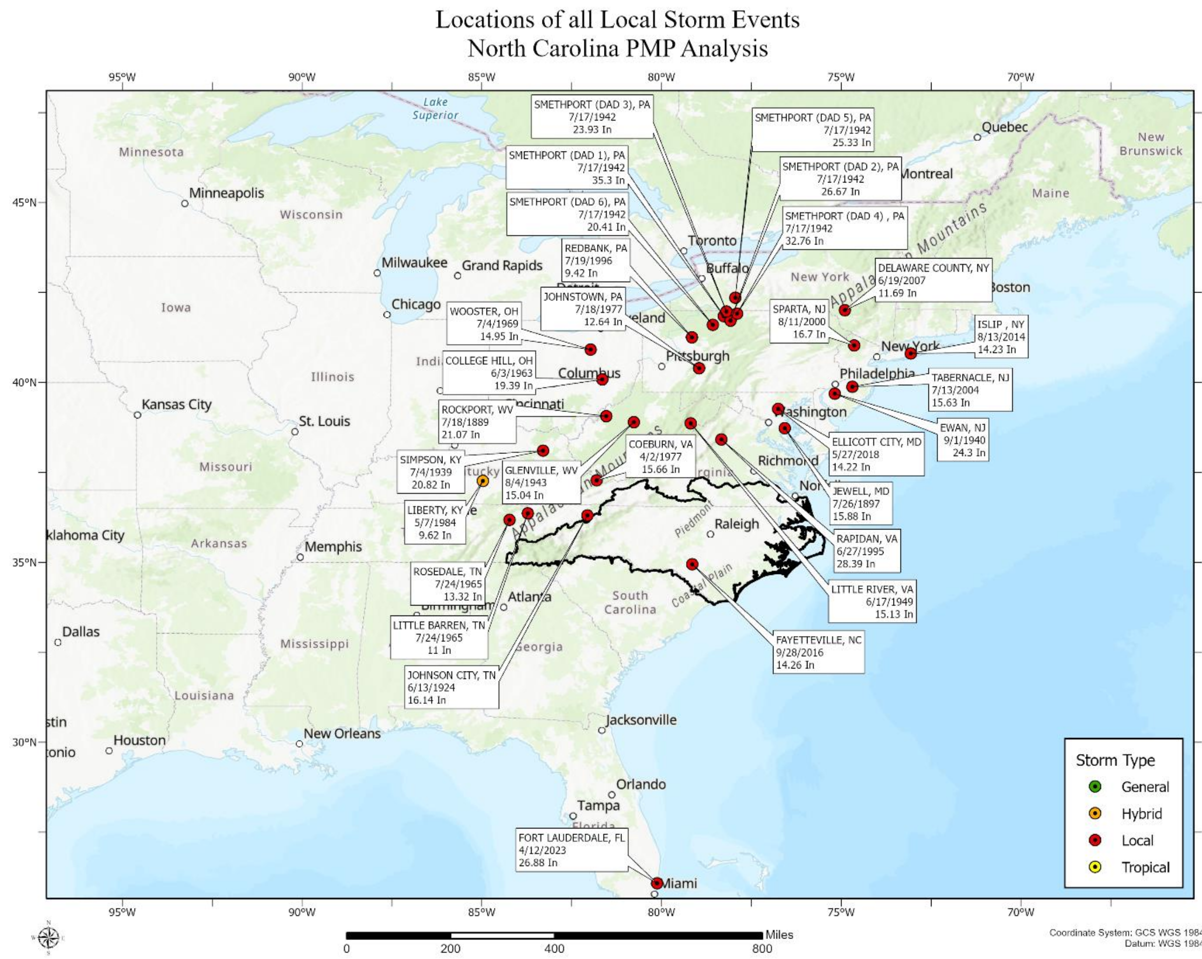


Figure 7.4: Location of local storms on the PMP storm list

Locations of all General Storm Events
North Carolina PMP Analysis

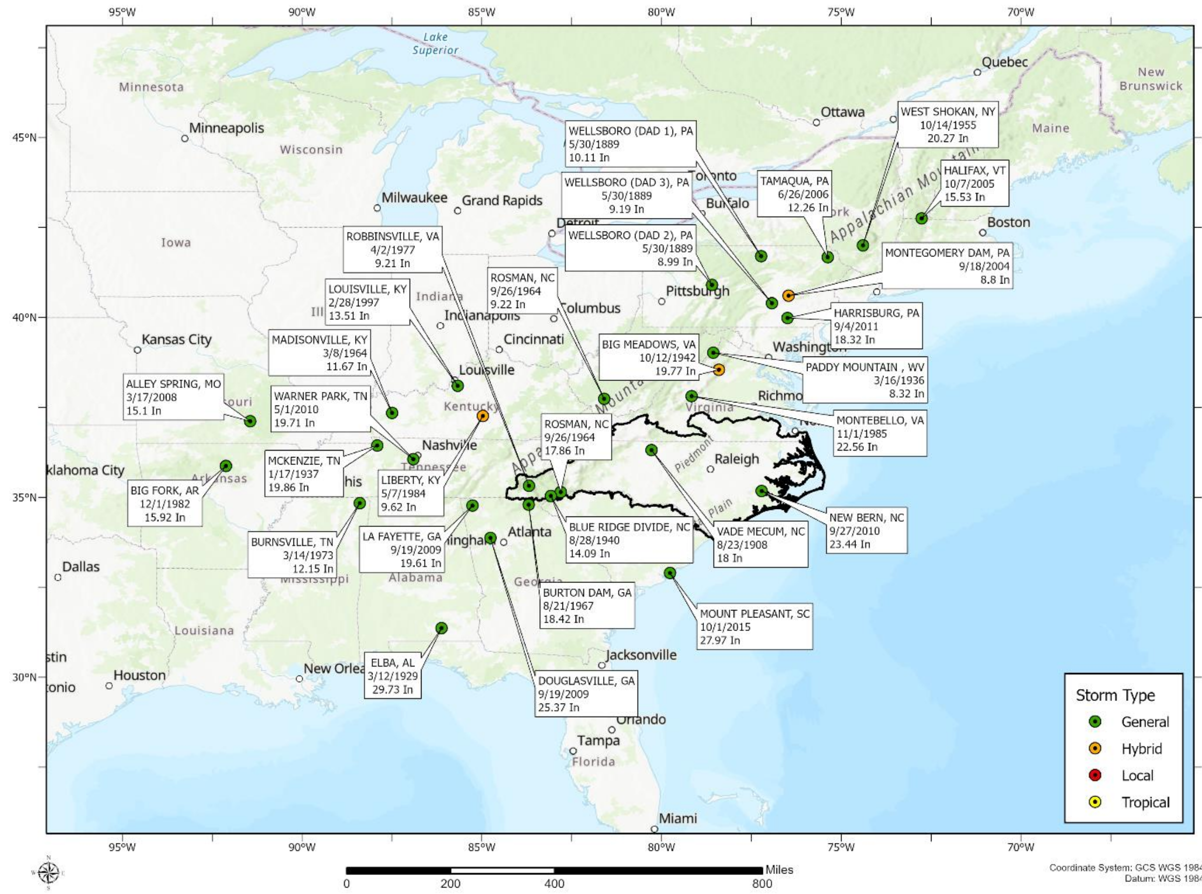


Figure 7.5: Location of general storms on the PMP storm list

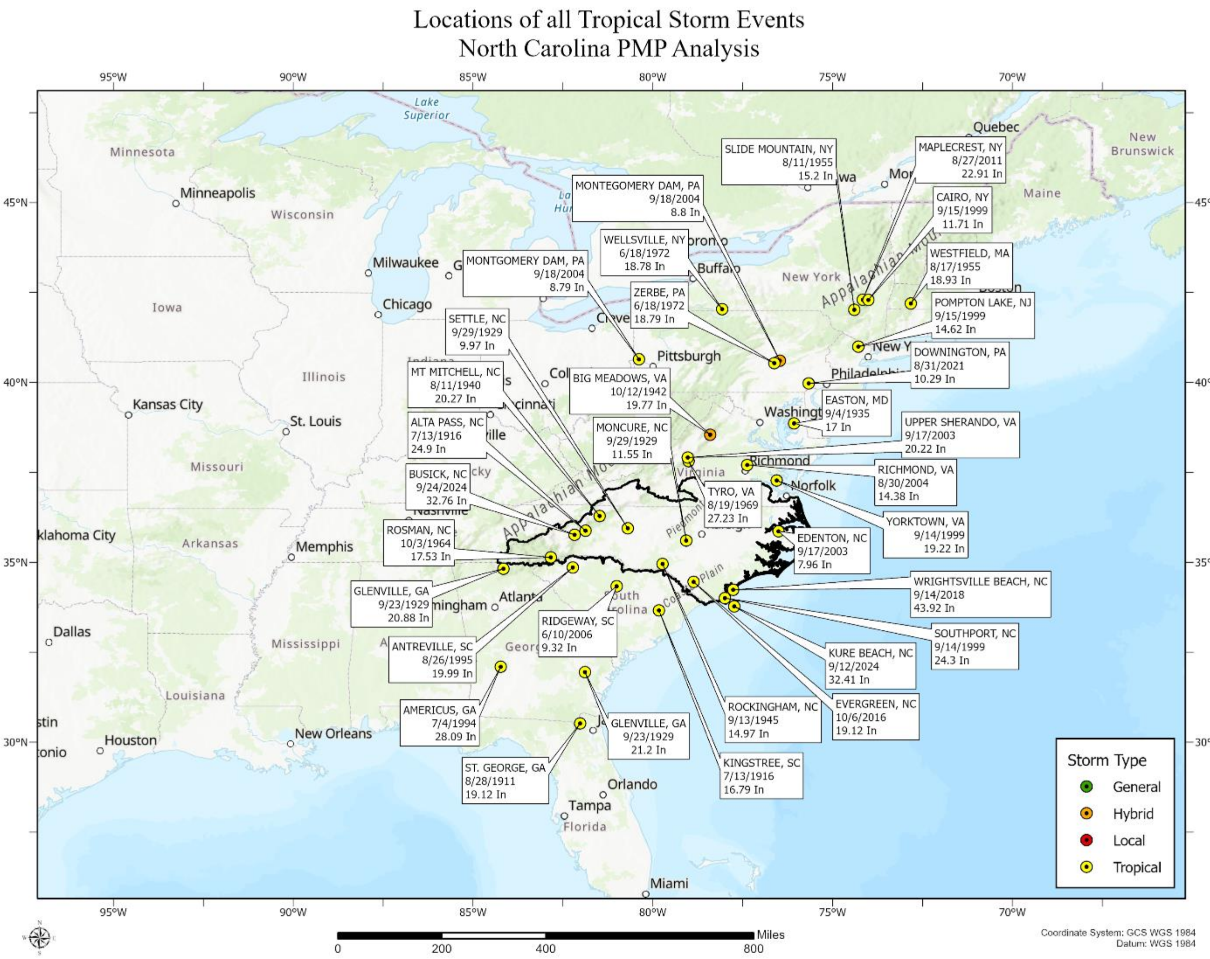


Figure 7.6: Location of tropical storms on the PMP storm list

8. SPAS Analysis Process

For all storms identified as part of this study, DAD data and hourly rainfall accumulation gridded outputs are required for PMP development. These outputs are required for GTF calculations and to calculate PMP depths. SPAS was used to compute DADs for all the storms used in this study. Results of all SPAS analyses used in the study are provided in Appendix F. This Appendix includes the standard output files associates with each SPAS analysis, including the following:

- SPAS analysis notes and description
- Total storm isohyetal
- DAD table and graph
- Storm center mass curve (hourly and incremental accumulation)

There are two main steps in the SPAS DAD analysis: 1) The creation of high-resolution hourly rainfall grids and 2) the computation of Depth-Area (DA) rainfall amounts for various durations, i.e., how the depth of the analyzed rainfall varies with area sizes being analyzed. The reliability of the results from step 2) depends on the accuracy of step 1). Historically, the process has been very labor intensive. SPAS utilizes GIS concepts to create spatially oriented and accurate results in an efficient manner (step 1). Furthermore, the availability of NEXRAD (NEXt generation RADar) data allows SPAS to better account for the spatial and temporal variability of storm precipitation for events occurring since the early 1990s. Prior to NEXRAD, the NWS developed and used a method based on Weather Bureau Technical Paper No. 1 (1946). Because this process has been the standard for many years and holds merit, the DAD analysis process developed for this study attempts to follow the NWS procedure as much as possible. By adopting this approach, some level of consistency between the newly analyzed storms and the hundreds of storms already analyzed by the USACE, USBR, and/or NWS can be achieved. Appendix E provides a detailed description of the SPAS program with the following sections providing a high-level overview of the main SPAS processes.

8.1 SPAS Data Collection

The areal extent of a storm’s rainfall is evaluated using existing maps and documents along with plots of total storm rainfall. Based on the storm’s spatial domain (longitude-latitude box), hourly and daily rain gauge data are extracted from the database for the specified area, dates, and times. To account for the temporal variability in observation times at daily stations, the extracted hourly data must capture the entire observational period of all extracted daily stations. For example, if a station takes daily observations at 8:00 AM local time, then the hourly data needs to be complete from 8:00 AM local time the day prior. As long as the hourly data are sufficient to capture all of the daily station observations, the hourly variability in the daily observations can be properly addressed.

The daily database is comprised of data from NCDC TD-3206 (pre-1948) and TD-3200 (generally 1948 through present). The hourly database is comprised of data from NCDC TD-3240 and NOAA's Meteorological Assimilation Data Ingest System (MADIS). The daily supplemental database is largely comprised of data from “bucket surveys,” local rain gauge networks (e.g., USGS, CoCoRaHS, etc.) and daily gauges with accumulated data.

8.2 SPAS Mass Curve Development

The most complete rainfall observational dataset available is compiled for each storm. To obtain temporal resolution to the nearest hour in the final DAD results, it is necessary to distribute the daily precipitation observations (at daily stations) into hourly bins. In the past, the NWS had accomplished this process by anchoring each of the daily stations to a single hourly station for timing. However, this may introduce biases and may not correctly represent hourly precipitation at locations between hourly observation stations. A preferred approach is to anchor the daily station to some set of nearest hourly stations. This is accomplished using a spatially based approach called the spatially based mass curve (SMC) process (see Appendix E).

8.3 Hourly and Sub-Hourly Precipitation Maps

At this point, SPAS can either operate in its standard mode or in NEXRAD-mode to create high resolution hourly or sub-hourly (for NEXRAD storms) grids. In practice, both modes are run when NEXRAD data are available so that a comparison can be made between the methods. Regardless of the mode, the resulting grids serve as the basis for the DAD computations.

8.4 Standard SPAS Mode Using a Basemap Only

The standard SPAS mode requires a full listing of all the observed hourly rainfall values, as well as the newly created estimated hourly data from daily and daily supplemental stations. This is done by creating an hourly file that contains the newly created hourly mass curve precipitation data (from the daily and supplemental stations) and the “true” hourly mass curve precipitation. If not using a base map, the individual hourly precipitation values are simply plotted and interpolated to a raster with an inverse distance weighting (IDW) interpolation routine in GIS.

8.5 SPAS-NEXRAD Mode

Radar has been in use by meteorologists since the 1960s to estimate rainfall depth. In general, most current radar-derived rainfall techniques rely on an assumed relationship between radar reflectivity and rainfall rate. This relationship is described by the Equation 2 below:

$$Z = aR^b \qquad \text{Equation 2}$$

where Z is the radar reflectivity, measured in units of dBZ, R is the rainfall rate, a is the “multiplicative coefficient” and b is the “power coefficient”. Both a and b are related to the drop size distribution (DSD) and the drop number distribution (DND) within a cloud (Martner et al., 2005).

The NWS uses this relationship to estimate rainfall using their network of Doppler radars (NEXRAD) located across the United States.

A standard default Z-R algorithm of $Z = 300R^{1.4}$ has been the primary algorithm used throughout the country and has proven to produce highly variable results. The variability in the results of Z vs. R is a direct result of differing DSD and DND, and differing air mass characteristics across the United States (Dickens, 2003). The DSD and DND are determined by a complex interaction of microphysical processes in a cloud. They fluctuate hourly, daily, seasonally, regionally, and even within the same cloud (see Appendix E for a more detailed description).

Using the technique described above, also discussed in Appendix E, NEXRAD rainfall depth and temporal distribution estimates are determined for the area in question.

8.6 Depth-Area-Duration Program

The DAD extension of SPAS runs from within a Geographic Resource Analysis Support System (GRASS) GIS environment and utilizes many of the built-in functions for calculation of area sizes and average rainfall depths. The following is the general outline of the procedure:

1. Given a duration (e.g., x-hours) and cumulative precipitation, sum up the appropriate hourly or sub-hourly precipitation grids to obtain an x-hour total precipitation grid starting with the first x-hour moving window.
2. Determine x-hour precipitation total and its associated areal coverage. Store these values. Repeat for various lower rainfall thresholds. Store the average rainfall depths and area sizes.
3. The result is a table of depth of precipitation and associated area sizes for each x-hour window location. Summarize the results by moving through each of the area sizes and choosing the maximum precipitation amount. A log-linear plot of these values provides the depth-area curve for the x-hour duration.
4. Based on the log-linear plot of the rainfall depth-area curve for the x-hour duration, determine rainfall amounts for the standard area sizes for the final DAD table. Store these values as the rainfall amounts for the standard sizes for the x-duration period. Determine if the x-hour duration period is the longest duration period being analyzed. If it is not, analyze the next longest duration period and return to step 1.
5. Construct the final DAD table with the stored rainfall values for each standard area for each duration period.

8.7 Comparison of SPAS DAD Output Versus Previous DAD Results

The SPAS process and algorithms have been thoroughly reviewed as part of many AWA PMP studies. The SPAS program was reviewed as part of the NRC software verification and validation program to ensure that its use in developing data for use in NRC regulated studies was acceptable (Hultstrand and Kappel, 2017). The result of the NRC review showed that the SPAS program performed exactly as described and produced expected results.

As part of this study, comparisons were made of the SPAS DAD tables and previously published DAD tables developed by the USACE and/or NWS. AWA discussed these comparisons for important storms where previous DADs were available that covered the same domain as the SPAS analysis. Table 8.1 provides an example comparison of a SPAS 1566 DAD from the analysis of the Paterson, NJ storm versus the USACE GL 4-9 DAD previously developed. As expected, the differences between SPAS DAD depths and previously published depths varied by area size and duration. The differences were a result of one or more of the following:

- SPAS utilizes a more accurate basemap to spatially distribute rainfall between known observation locations. The use of a climatological basemap reflects how rainfall has occurred over a given region at a given time of the year and therefore how an individual storm pattern would be expected to look over the location being analyzed. Previous DAD analyses completed by the NWS and USACE often utilized simple IDW or Thiessen polygon methods that did not reflect climatological characteristics as accurately. In some cases, the NWS and USACE utilized precipitation frequency climatologies to inform spatial patterns. However, these relied on NOAA Atlas 2 (Miller et al., 1973) patterns and data that are not as accurate as current data from PRISM (Daly et al., 1994 and Daly et al., 1997) and NOAA Atlas 14.
- In some cases, updated sources of data uncovered during the data mining process were incorporated into SPAS that were not utilized in the original analysis. SPAS utilizes sophisticated algorithms to distribute rainfall temporally and spatially. In contrast, the isohyetal maps developed previously were hand drawn. Therefore, they reflected the best guess of the analyst of each storm, which could vary between each analyst's interpretations. Also, only a select few stations were used for timing, which limited the variation of temporal accumulation patterns throughout the overall domain being analyzed. SPAS uses the power of all the rainfall observations that have passed QA/QC measures to inform patterns over the entire domain. These temporal and spatial fits are evaluated and updated on an hourly basis for the entire duration.

Table 8.1: Comparison of SPAS 1566 DAD versus the USACE GL 4-9 DAD, both representing the Paterson New Jersey October 1903 storm event

Percent Difference ((SPAS 1566 - GL 4-9)/GL 4-9) MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)									
areasqmi	6-hr	12-hr	18-hr	24-hr	36-hr	48-hr	72-hr	96-hr	Total
10	-2%	5%	1%	1%	5%	4%	6%	2%	2%
100	-4%	9%	4%	3%	8%	7%	5%	5%	5%
200	-5%	5%	4%	2%	5%	4%	3%	2%	4%
500	-5%	0%	4%	1%	4%	4%	1%	1%	2%
1,000	-1%	1%	4%	0%	3%	2%	1%	1%	2%
2,000	1%	0%	5%	-2%	0%	-1%	-3%	1%	2%
5,000	3%	-6%	-1%	-10%	1%	-2%	-2%	1%	2%
10,000	10%	-1%	-3%	-6%	1%	-1%	3%	2%	3%
20,000	11%	0%	-2%	-10%	4%	0%	3%	2%	4%

9. Storm Adjustments

9.1 In-Place Maximization Process

Maximization was accomplished by increasing surface dew points (or SST when the storm representative location is over the ocean) to a climatological maximum and calculating the enhanced rainfall amounts that could potentially be produced if the climatological maximum moisture had been available during the observed storm period. Additionally, the climatological maximum dew point/SST for a date 15 days towards the warm season is selected with higher amounts of moisture from the date that the storm occurred. This procedure assumes that the storm could have occurred with the same storm dynamics two weeks towards the time in the year when maximum dew points occur.

This assumption follows HMR guidance and is consistent with procedures used to develop PMP depths in all the current HMR documents (e.g., HMR 51 Section 2.3), the WMO Manual for PMP (WMO, 2009), as well as in all prior AWA PMP studies. The storm data in Appendix F provides the individual analysis maps used for each storm adjustment process including the HYSPLIT model output, the surface dew point/SST observations, the storm center location, the storm representative location, and the IPMF for each storm.

Each storm used for PMP development was thoroughly evaluated in adjacent studies and again during this study to confirm the reasonableness of the storm representative value and location used. As part of this process, AWA provided and discussed all the information used to derive the storm representative value for review, including the following:

- Hourly surface dew point observations
- Daily SST observations
- HYSPLIT model output
- Storm adjustment spreadsheets
- Storm adjustments maps with data plotted

These data allowed for an independent review of each storm. Results of this analysis demonstrated that the values AWA utilized to adjust each storm were reasonable for PMP development.

For storm maximization, average dew point or daily SST values for the appropriate duration that are most representative of the actual rainfall accumulation period for an individual storm (e.g., 6-, 12-, or 24-hour) are used to determine the storm representative value. This value (either dew point or SST) is then maximized using the appropriate climatological value representing the 100-year return interval or +2 sigma SST at the same location moved two weeks towards the season of higher climatological maximum values.

The HYSPLIT model (Draxler and Rolph, 2013; Stein et al., 2015; and Rolph et al., 2017) provides detailed and reproducible analyses for assisting in the determination of the upwind trajectories of atmospheric moisture that was advected into the storm systems. Using these model trajectories, along with an analysis of the general synoptic weather patterns and available surface dew point temperature data/daily SST data, the moisture source region for candidate storms is determined. The procedure is followed to determine the storm representative location and is similar to the approach used in the HMRs. However, by utilizing the HYSPLIT model, much of the subjectivity found in the HMR analysis process was corrected. Further, details of each evaluation can be explicitly provided, and the HYSPLIT trajectory results based on the input parameters defined are reproducible. Available HYSPLIT model results are provided as part of Appendix F.

The IPMF process results in a ratio of observed moisture compared to climatological maximum moisture. Therefore, this value is always 1 or greater. The intent of the process is to produce a hypothetical storm event that represents the upper limit of rainfall that the storm could have produced if the ideal combination of moisture and maximum storm efficiency (atmospheric processes that convert moisture to precipitation) had occurred during the storm. This assumes that the storm efficiency processes remain constant as more moisture is added to the storm environment. Therefore, an upper limit of 1.50 (50%) is applied to the IPMF with the assumption that increases beyond this amount would change the storm efficiency processes, and the storm would no longer be the same storm as observed from an efficiency perspective.

This upper limit is a standard application applied in the HMRs (e.g., HMR 51 Section 3.2.2). During this study the 1.50 upper limit was applied against two storms, Jewell, MD July 1897 (SPAS 1489) and Sparta, NJ August 2000 (SPAS 1674). Note, this upper limit was investigated further during the Colorado-New Mexico REPS study using the Dynamical Modeling Task and the HRRR model interface (Alexander et al., 2015). This explicitly demonstrated that storm efficiency changes as more moisture is added, well before the 50% moisture increase level for the storms investigated (Mahoney, 2016). Therefore, the use of 1.50 as an upper limit is a conservative application.

9.2 Storm Representative Determination Process

For storm maximization using dew point observations, average dew point values for the duration most consistent with the actual rainfall accumulation period for an individual storm (i.e., 3-, 6-, 12-, or 24-hour) were used to determine the storm representative dew point. To determine which time frame was most appropriate, the total rainfall amount was analyzed. The duration closest to when approximately 90% of the rainfall had accumulated was used to determine the duration used, i.e., 6-hour, 12-hour, or 24-hour.

The storm representative dew point was investigated for each of the storm events analyzed in previous studies and re-evaluated in this study. Once the general upwind location was determined, the hourly surface observations were analyzed for all available stations within the vicinity of the inflow vector. From these data, the appropriate durational dew point value was averaged for each station (6-, 12-, or 24-hour depending on the storm's rainfall accumulation). These values were then adjusted to 1,000mb (approximately sea level) and the appropriate storm representative dew point and location were derived. The line connecting this point with the storm center location (point of maximum rainfall accumulation) is termed the moisture inflow vector. The information used and values derived for each storm’s moisture inflow vector are included in Appendix F.

HYSPLIT was used during the analysis of each of the rainfall events included on the short storm list when available (1948-present). Use of a trajectory model provides increased confidence in determining moisture inflow vectors and storm representative dew points. The HYSPLIT trajectories have been used to analyze moisture inflow vectors in other PMP studies completed by AWA over the past several years. During these analyses, the model trajectory results were verified, and the utility explicitly evaluated (e.g., Tomlinson et al., 2006-2012; Kappel et al., 2013-2024).

In determining the moisture inflow trajectories, the HYSPLIT was used to compute the trajectory of the atmospheric moisture inflow associated with the storm's rainfall production, both location and altitude, for various levels in the atmosphere. The HYSPLIT model was run for trajectories at several levels of the lower atmosphere to capture the moisture source for each storm event. These included 700mb (approximately 10,000 feet), 850mb (approximately 5,000 feet), and storm center location surface elevation.

For most of the analyses, a combination of all three levels was determined to be most appropriate for use in evaluation of the upwind moisture source location. It is important to note that the resulting HYSPLIT trajectories are only used as a general guide to evaluate the moisture source for storms in both space and time. The final determination of the storm representative dew point and its location was made following the standard procedures used by AWA in previous PMP studies (e.g., Tomlinson, 1993; Tomlinson et al., 2006-2013; Kappel et al., 2013-2022) and as outlined in the HMRs (e.g., HMR 51 Section 2.3) and WMO Manual for PMP (Section 2.2). HYSPLIT trajectories are run backwards in time for a 72-hour period starting at the storm center location. This is done to determine where the moisture originated from that eventually ended up within the storm system and produced the observed precipitation. AWA then evaluated the trajectories in relation to the general synoptic weather patterns, likely moisture source regions, storm type(s), and consistency between each level of the atmosphere. In addition, for trajectories that utilize SST as the storm representative location, it is also valuable to see where one or more of the levels reaches the surface at some point during the analysis period. Finally, dew point (or SST) values are then plotted in the large general region around and along the trajectories for analysis.

The process to determine the storm representative values involves deriving the average dew point (or SST) values at all stations with dew point (or SST) data in a large region along the HYSPLIT inflow vectors. Values representing the average 6-, 12-, and 24-hour dew points or daily SST are analyzed in Excel spreadsheets. The appropriate duration representing the storm being analyzed is determined and data are plotted for evaluation of the storm representative dew point (or SST). This evaluation includes an analysis of the timing of the observed dew point (or SST) values to ensure they occurred in a source region where they would be advected into the storm environment at the time of the rainfall period. Several locations are investigated to find values that are of generally similar magnitude (within a degree or two Fahrenheit). Once these representative locations are identified, an average of the values to the nearest half degree is determined and a location in the center of the stations is identified. This becomes the storm representative dew point (or SST) value, and the location provides the inflow vector (direction and distance) connecting that location to the storm center location.

This follows the approach used in HMR 51 Section 2, HMR 55A Section 5, and HMR 57 Section 4, with improvements provided using HYSPLIT and updated maximum dew point and SST climatologies. Appendix F of this report contains each of the HYSPLIT trajectories analyzed as part of this study for each storm (when used). Figure 9.1 is an example map used to determine the storm representative dew point for the Tamaqua, PA June 2006, SPAS 1047 storm event.

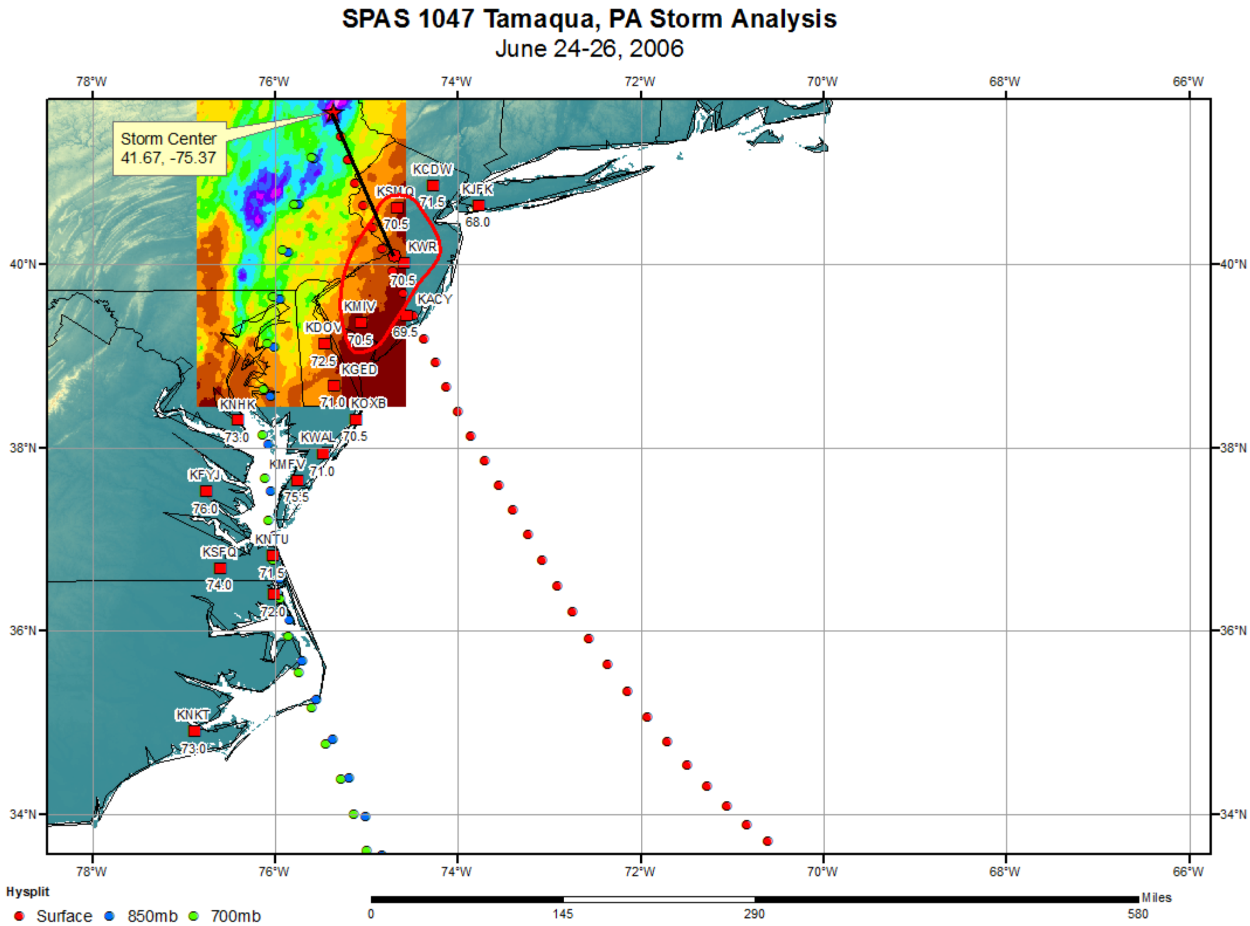


Figure 9.1: Dew point values used to determine the storm representative dew point for Tamaqua, PA June 2006, SPAS 1047 storm event

The value for the maximum SST was determined using the mean +2 sigma (two standard deviations warmer than the mean) SST for that location. SSTs were substituted for dew points in this study for many storms where the inflow vector originated over the Atlantic Ocean or Gulf of America. Data presented in Appendix F show the moisture source region for each storm and whether dew points or SSTs were used in the maximization calculations. For storm maximization, the value for the maximum SST was determined using the mean +2 sigma SST for that location for a date two weeks before or after the storm date (which ever represents the climatologically warmer SST period). Storm representative SSTs and the mean +2 sigma SSTs were used in the same manner as storm representative dew points and maximum dew point climatology representing the 15th of the month values in the maximization and transpositioning procedure. Figure 9.2 is an example of a daily SST map used to determine the storm representative SST for the SPAS 1276 Hurricane Agnes June 1972 storm event.

In this example, the first decision was whether surface dew points were available to derive the storm representative dew point. However, this was not possible for this storm because there was rainfall to the coast, thereby contaminating the dew point readings along the inflow pathway to the Atlantic. Next, SSTs were investigated to determine regions of homogenous temperatures in a region that was appropriate in time and space according to the HYSPLIT trajectories. Several regions were possibilities in this case.

Next, the track of the Hurricane and its relation to moisture advection into the storm center was considered. This better matched the surface (red dots) HYSPLIT trajectory. Finally, sensitivity calculations were performed using several couplets of storm representative SST values versus the +2 sigma climatological maximum values to ensure the range of maximizations was within a reasonable range (i.e., greater than 1.00). After the investigations were completed, the storm representative location of 36.0°N and 67.0°W was chosen. This was an average of several of the SST values within the red circled area of Figure 9.2 on June 18 and June 19, 1972.

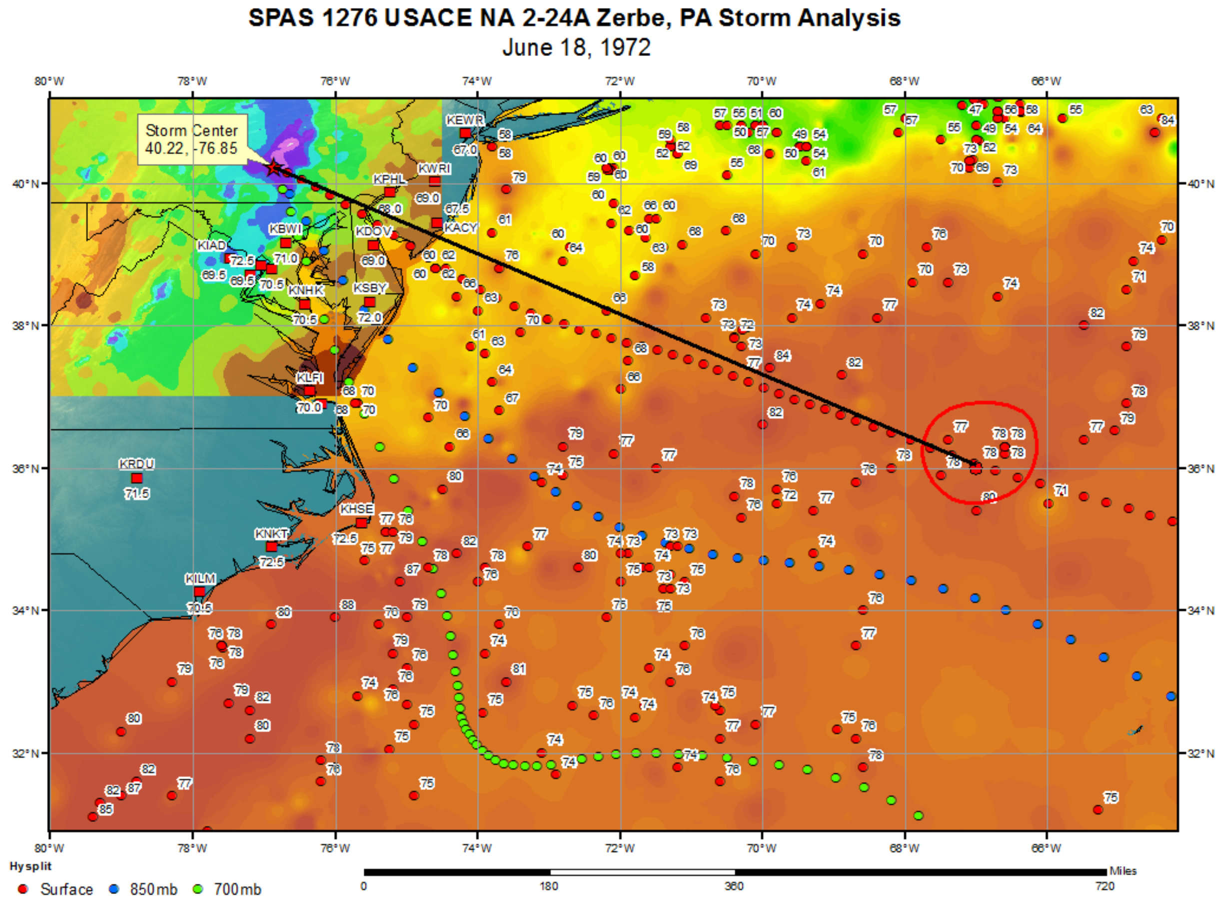


Figure 9.2: Daily SST observations used to determine the storm representative SST value for the SPAS 1276, June 1972 storm event

9.3 In-Place Maximization Factor Calculation

Storm maximization is quantified by the IPMF using Equation 3.

$$IPMF = \frac{W_{p,max}}{W_{p,rep}} \qquad \text{Equation 3}$$

where,

$W_{p,max}$ = precipitable water for maximum dew point (in.)

$W_{p,rep}$ = precipitable water for representative dew point (in.)

The available precipitable water, Wp, is calculated by determining the precipitable water depth present in the atmospheric column (from sea level to 30,000 feet) and subtracting the precipitable water depth that would not be present in the atmospheric column between sea-level and the surface elevation at the storm location using Equation 4.

$$W_p = W_{p,30,000'} - W_{p,elev} \qquad \text{Equation 4}$$

where,

W_p	=	precipitable water above the storm location (in.)
$W_{p,30,000'}$	=	precipitable water, sea level to 30,000′ elevation (in.)
$W_{p,elev}$	=	precipitable water, sea level to storm surface elevation (in.)

9.4 Transposition Zones Utilized in PMP Development

PMP-type storm events in regions of similar meteorological and topographic settings surrounding a location are a very important part of the historical evidence on which a PMP estimate is based. Since most locations have a limited period of record for rainfall data, the number of extreme storms that have been observed over a location is limited. Historic storms that have been observed within similar meteorological and topographic regions are analyzed and adjusted to provide information describing the storm rainfall as if that storm had occurred over the location being studied.

Transfer of a storm from where it occurred to a location that is meteorologically and topographically similar is called transposition. The underlying assumption is that storms transposed to the location could have occurred under similar meteorological and topographical conditions. To properly relocate such storms, it is necessary to address issues of similarity as they relate to meteorological conditions, moisture availability, and topography. In this study, adjustment factors used in transpositioning of a storm are quantified by using the GTF.

The regional transposition zones developed for this study were based on the meteorological and topographical characteristics across the PMP study domain along with considerations of moisture source region characteristics, storm types, and seasonality. Initial delineations were developed utilizing information from the National Centers for Environmental Information (formally the National Climatic Data Center) climate regions, USGS physiographic regions, NOAA Atlas 14 precipitation frequency climatologies, and transposition regions used in adjacent/overlapping PMP studies were evaluated in this process. Results of these analyses were discussed with the review board and NC DEQ to develop final transposition zones.

Figure 9.3 shows the transposition zones utilized in this study. Note, that the zones were used as general guidance and for initial evaluations. Many storms were ultimately allowed to move between zones and/or were restricted within a given zone for final PMP development.

Transposition zones 1 and 2 represent the coastal and Piedmont region where there is direct access to moisture from the Atlantic Ocean and no significant topography. These regions are often affected by tropical systems. Transposition zones 3 and 4 represent the transition from the coastal lowlands to the Appalachians and include the ridge and valley region of North Carolina. These regions are orographically influenced regions where rainfall is both enhanced on upwind locations and decreased on downwind locations. In addition, precipitation generally decreases at locations further inland as these are farthest from the low-level moisture source to the east while at the same time low-level moisture is blocked by the Appalachians to the west.

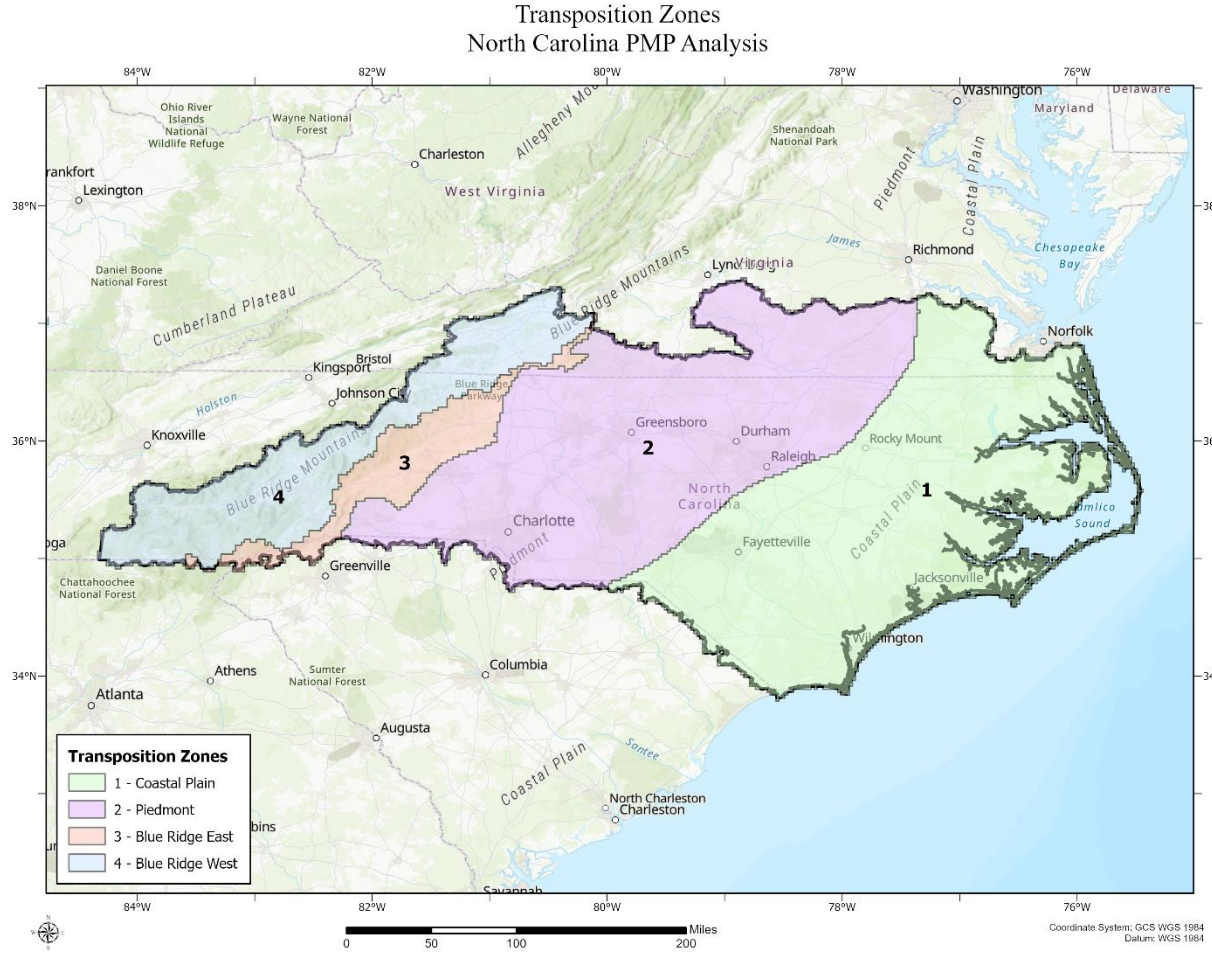


Figure 9.3: Transposition zones utilized for the North Carolina PMP study

Initial transposition limits were assigned with the understanding that additional refinements would take place as the data were run through the PMP evaluation process. Numerous sensitivity runs were performed using the PMP database to investigate the results based on the initial transposition limits. Several storms were re-evaluated based on the results that showed inconsistencies and/or unreasonable values, either too high or too low. Examples of inconsistencies and unreasonable values include areas where gradients of PMP depths between adjacent grid points were significantly different and not specifically related to a similar meteorological or topographical change. When these occur because of excessive GTF values or because a storm was likely moved beyond reasonable transposition limits, adjustments are applied.

Although somewhat subjective, decisions to adjust the transposition limits for a storm were based on the understanding of the meteorology which resulted in the storm event, similarity of topography between the two locations, access to moisture source, seasonality of occurrence by storm type, and comparison to other similar storm events. Appendix I provides a description of the iterations and adjustments that were applied during each PMP version to arrive at the final values via the PMP Version Log.

For all storms, the IPMF does not change during this process. The GTF changes as a storm is moved from its original location to a new location. The spatial variations in the GTF were useful in making decisions on transposition limits for many storms. As described previously, values larger than 1.50 for a storm's maximization factor exceed limits that would no longer produce the same storm as the originally observed event. In these situations, changing a storm by this amount is likely also changing the original storm characteristics so that it can no longer be considered the same storm at the new location. The same concept applies to the GTF. GTF values greater than 1.50 indicate that transposition limits have most likely been exceeded. In addition, a lower limit of 0.50 was applied for the same reason, but this inherently affects a much more limited set of storms and regions. Therefore, storms were re-evaluated for transpositionability in regions which results in a GTF greater than 1.50.

The transposition process is one of the most important aspects of PMP development. This step also contains subjectivity as the processes utilized to define transposition limits are difficult to quantify and based on meteorological judgment. General guidelines are provided in the HMRs (e.g., HMR 51 Section 2.4.1 and HMR 55A Section 8.2). AWA utilized these guidelines as well as updated procedures and datasets developed during the many PMP studies completed in the region since the HMRs were published. General AWA guidelines included:

- Investigation of previous NWS transposition limit maps
- Experience and understanding of extreme rainfall processes in the study region and how those factors vary by location, storm type, and season
- Understanding of topographical interactions and how those affect storms by location, storm type, and season
- Previously applied transposition limits from adjacent statewide PMP studies
- Limiting transposition to east or west of the Appalachian crest
- Use of GTF values as sensitivity
- Spatial continuity of PMP depths
- Comparisons against NOAA Atlas 14 precipitation frequency climatology
- Discussions with the Technical Advisory Committee, NC DEQ, and others involved in the study

An important aspect of this study was the involvement of the Technical Advisory Committee and NC DEQ in evaluating and reviewing individual storm transposition limits of controlling storms. They had initial input in helping to define the overall transposition zones used in the study shown in Figure 9.3. Once initial transposition limits were applied to each storm, the resulting GTF values were reviewed during the review meetings. These were most focused on the controlling storms.

The PMP Version Log provided in Appendix I provides the numerous iterations of PMP development and the various transposition limit adjustments that were applied to storms during the PMP development process. In some cases, storms originally considered for a given location were removed after evaluation and in other cases transposition limits were adjusted within a given transposition zone. The red hatch area on the GTF maps contained in Appendix B indicate the final transposition limits applied to each storm.

9.5 Geographic Transposition Factor

The GTF process is used to capture all processes that result in precipitation reaching the ground at one location versus another location, including the effects of terrain. The GTF is a mathematical representation of the ratio of the precipitation frequency climatology at one location versus another location. The precipitation frequency climatology is derived from observed precipitation events which produced amounts used to identify the Annual Maximum Series (AMS) at a given station. An upper limit of 1.50 and a lower limit of 0.50 were applied to the GTF as described in Section 9.4. This was done to ensure the storm being adjusted was not exceeding reasonable limits when moving a storm from one location to another. The intent was to ensure the original storm characteristics could occur at the new location in a manner as the original location and therefore that would violate the PMP process assumptions related to storm transposition.

GTF values were calculated utilizing NOAA Atlas 14 precipitation frequency data at the 100-year recurrence interval, volumes 2 and 10 (Bonnin et al., 2006 and Perica et al., 2015). These data were used to ensure consistency in the climatological datasets and to ensure required coverage for all storm locations within the overall storm search domain. The storms used in NOAA Atlas 14 represent observed precipitation events that resulted in an AMS accumulation. Therefore, they represent all precipitation producing processes that occurred during a given storm event. In HMR terms, the resulting observed precipitation represents both the convergence-only component and any orographic component. The NOAA Atlas 14 gridded precipitation frequency climatology was produced using gridded mean annual maxima (MAM) grids that were developed with the PRISM (Daly et al., 1994). PRISM utilizes geographic information such as elevation, slope, aspect, distance from coast, and terrain weighting for weighting station data at each grid location. As noted, use of the precipitation frequency climatology grids should be reflective of all precipitation producing processes. Further, the use of the gridded precipitation climatology at the 100-year recurrence interval represents an optimal combination of factors, including representing extreme precipitation events equivalent to the level of rainfall utilized in AWA's storm selection process, and providing the most robust statistics given the period of record used in the development of the precipitation frequency climatologies.

Therefore, the GTF represents the difference in topographic effects between two locations, but also represents the difference in all precipitation processes between two locations. This is one reason it is very important to apply appropriate transposition limits to each storm during the PMP development process.

Effects of terrain and coastal convergence on precipitation production is well known. However, there are many orographic processes and interactions that are not well understood or quantified. Therefore, observed data (precipitation accumulations represented in the precipitation frequency data) are used as a proxy, where it is assumed that the observed precipitation represents all the precipitation processes associated with a storm event. This follows guidance provided by the WMO 2009, Section 3.1.4 and discussed in Section 4 of this document. Observed precipitation at a given location represents a combination of all factors that produced the precipitation, including what would have occurred without any terrain influence and what actually occurred because of the terrain influence. Judgement is inherent when determining transposition limits because the process of quantifying similar regions of meteorology and topography is highly subjective. As part of the GTF process, the following assumptions are applied:

- NOAA Atlas 14 precipitation frequency climatologies represent all precipitation producing factors that have occurred at a location. This is based on the fact that the data are derived from AMS values at individual stations that were the result of an actual storm event. That actual storm event included both the amount of precipitation that would have occurred without topography and the amount of precipitation that occurred because of topography (if any).
- If it is accepted that the precipitation frequency climatology is representative of all precipitation producing processes for a given location, then comparing the precipitation frequency climatology at one point to another will produce a ratio that shows how much more or less efficient the precipitation producing processes are between the two locations. This ratio is called the GTF.
- If there is no orographic influence at either location being compared or between the two locations, then the differences should be a function of (1) storm precipitation producing processes in the absence of topography (thermodynamic and dynamic), (2) how much more or less moisture is available from a climatological perspective, and/or (3) elevation differences at the location.

9.6 Geographic Transposition Factor Calculation

The GTF is calculated by taking the ratio of transposed 100-year rainfall to the in-place 100-year rainfall.

$$GTF = \frac{R_t}{R_s} \qquad \text{Equation 5}$$

where,

R_t = climatological 100-year rainfall depth at the target location

R_s = climatological 100-year rainfall depth at the source storm center

The in-place climatological precipitation (R_s) was determined at the grid point located at the SPAS-analyzed total storm maximum rainfall center location. The corresponding transposed climatological precipitation (R_t) was taken at each grid point in the study region. The 100-year precipitation was used for each transposed location and for the in-place location for storm centers. For this region, the 6-hour precipitation frequency climatologies were used for the local storm type. Conversely, the 24-hour precipitation frequency climatologies are used for the general and tropical storm types based on accumulation characteristics associated with each storm type.

9.7 Total Adjustment Factor Calculation

The TAF is a product of the IPMF and GTF, which represent the combination of increased moisture and differences in precipitation processes of a given storm from where it occurred versus the transpositioned location.

$$TAF_{xhr} = P_{xhr} \times IPMF \times GTF \qquad \text{(from Equation 1)}$$

The TAF, along with the other storm adjustment factors, is exported and stored within the storm's adjustment factor feature class to be accessed by the GIS PMP tool as described in the following section. These are also stored within an Excel file unique to each storm, via the TAF spreadsheet.

10. Development of PMP Values

10.1 PMP Calculation Process

To calculate PMP, the TAF for each storm must be applied to the storm's SPAS analyzed DAD value for the area size and duration of interest to yield a total adjusted rainfall value. The storm's total adjusted rainfall value is then compared with the adjusted rainfall values of every storm in the database transposable to the target grid point. The largest adjusted rainfall depth becomes the PMP for that point at a given duration. This process must be repeated for each of the grid cells intersecting the input drainage basin for each applicable duration and storm type. The gridded PMP is averaged over the drainage basin of interest to derive a basin average. The depths are then temporally distributed by storm type.

A GIS-based PMP calculation tool was developed to automate the PMP calculation process. The PMP tool is a Python scripted tool that runs from a Toolbox in the ArcGIS desktop environment. The tool accepts a basin polygon feature or features as input and provides gridded, basin average, and temporally distributed PMP depths as output. These PMP output elements can be used with hydrologic runoff modeling simulations for PMF calculations. Full documentation of the PMP tool usage and structure is found in Appendix G. The PMP tool provides depths representing an areal average for the drainage basin area size, grid points, or other combinations of grid points or sub basins. This area can be overwritten with a specific user-defined area-size within the tool dialogue. The PMP tool can be used to calculate PMP depths for the following durations.

Local Storm PMP Durations:
1-, 2-, 3-, 4-, 5-, 6-, 12-, and 24-hour

General/Tropical Storm PMP Durations:
1-, 2-, 3-, 4-, 5-, 6-, 12-, 24-, 48-, and 72-hour

10.1.1 Sample Calculations

The following sections provide sample calculations for the storm adjustment factors for the Rapidan, VA June 1995 (SPAS 1406) local storm event when transposed to randomly chosen grid point at 35.35°N, 82.25°W (grid point ID #8525). Table 10.1 highlights the adjustment factors in the Storm Adjustment Factor feature class table for the storm at this target grid point location. The target location is about 300 miles southwest of the storm location at an elevation of 1,211 feet in the southwestern part of the PMP domain in transposition zone 3 (Figure 10.1).

Table 10.1: Sample transposition of Rapidan, VA 1995 (SPAS 1406) to grid point #8525

ID	STORM	LON	LAT	ZONE	ELEV	IPMF	MTF	GTF	TAF	TRANS
8525	1406_1	-82.25	35.35	3	1,211	1.09	1	1.09	1.19	1

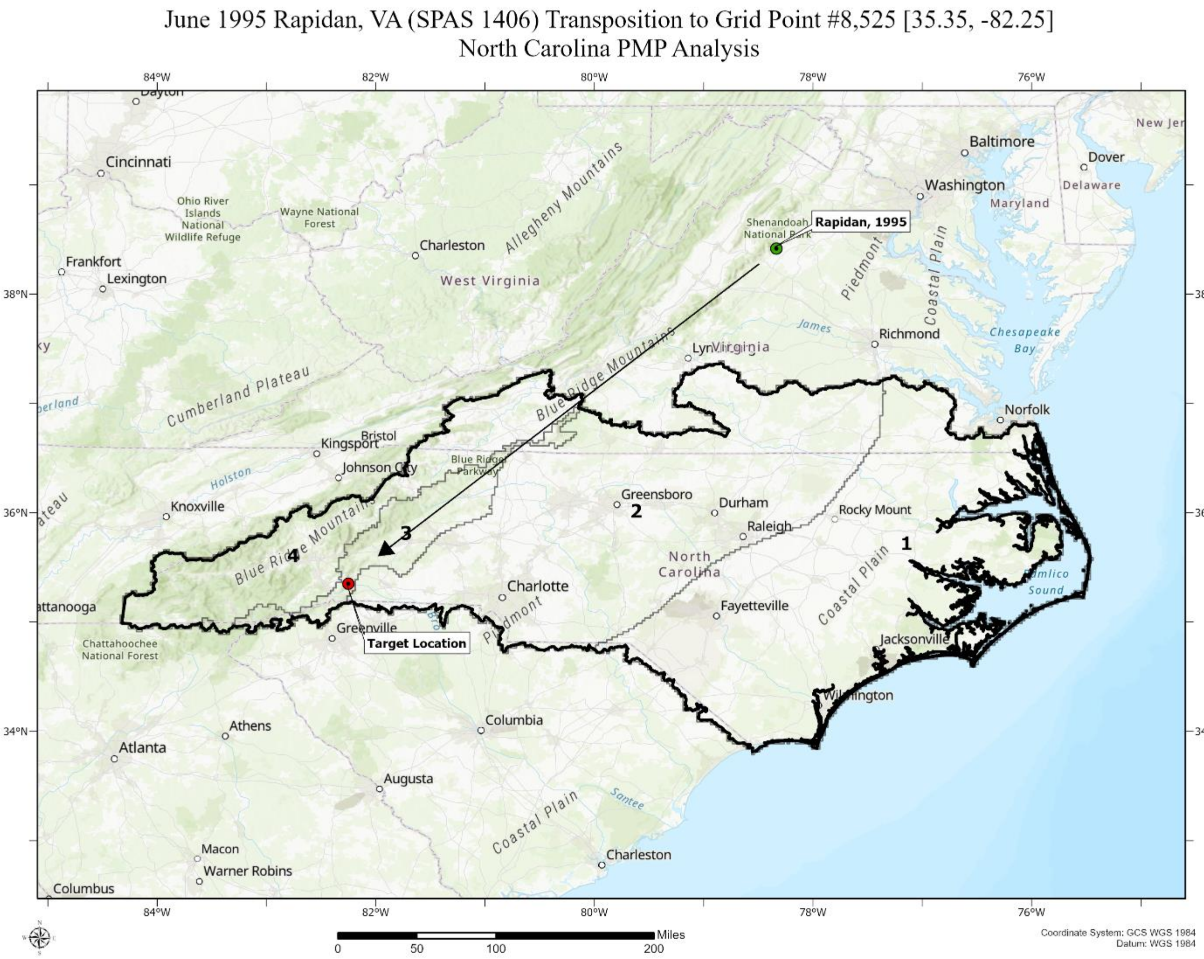


Figure 10.1: Sample transposition of Rapidan, VA 1995 (SPAS 1406) to grid point #8525

10.1.2 Sample Precipitable Water Calculation

Using the storm representative sea surface temperature (SST) and storm center elevation as input, the precipitable water lookup table returns the depth, in inches, used in Equation 4. The storm representative SST temperature is 82°F at the storm representative SST location 350 miles southeast of the storm center (see Appendix F for the detailed storm maximization and analysis information). The storm center elevation is approximated at 1,300 feet at the storm center location of 38.415°N, 78.335°W. The storm representative available moisture ($W_{p,\ rep}$) is calculated using Equation 4:

$$W_{p,rep} = W(@82°)_{p,30{,}000'} - W(@82°)_{p,1{,}300'}$$

or,

$$W_{p,rep} = 3.95'' - 0.39''$$

$$W_{p,rep} = 3.56''$$

The late June storm was adjusted 15 days toward the warm season to a temporal transposition date of July 10th. A weighted average of the June and July +2 sigma sea surface temperatures was used for the July 10th temporal transposition date. The June +2 sigma SST at the storm representative SST location is 81.85°F and the July is 84.24°F. The two monthly temperatures are averaged (weighted toward July 10th) and rounded to the nearest ½ degree to a climatological maximum SST temperature of 84°F. The in-place climatological maximum available moisture ($W_{p,\,max}$) is calculated.

$$W_{p,max} = W(@84°)_{p,30{,}000'} - W(@84°)_{p,1{,}300'}$$

$$W_{p,max} = 4.3'' - 0.42''$$

$$W_{p,max} = 3.88''$$

10.1.3 Sample IPMF Calculation

In-place storm maximization is applied for each storm event using the methodology described in Section 9.1. Storm maximization is quantified by the IPMF using Equation 3:

$$IPMF = \frac{W_{p,max}}{W_{p,rep}}$$

$$IPMF = \frac{3.88''}{3.56''}$$

$$IPMF = 1.09$$

10.1.4 Sample GTF Calculation

The ratio of the 100-year 6-hour climatological precipitation depth at the target grid point #8525 location to the Rapidan, 1995 storm center was evaluated to determine the storm's GTF at the target location. The 6-hour rainfall depth (R_t) of 5.87" was extracted at the grid point #8525 location from the 100-year 6-hour NOAA Atlas 14 precipitation frequency climatology.

$$R_t = 5.87''$$

Similarly, the 6-hour rainfall depth (R_s) of 5.39" was extracted at the storm center location from the 100-year 6-hour NOAA Atlas 14 precipitation frequency climatology.

$$R_s = 5.39''$$

Equation 5 provides the climatological precipitation ratio to determine the GTF.

$$GTF = \frac{R_t}{R_s}$$

$$GTF = \frac{5.87"}{5.39"}$$

$$GTF = 1.09"$$

The GTF at grid #8525 is 1.09, or a 9% rainfall increase from the storm center location due to the orographic effects captured within the precipitation climatology. The GTF is then considered to be a temporal constant for the spatial transposition between that specific source/target grid point pair, for that storm only, and can be applied to the other durations for that storm.

10.1.5 Sample TAF Calculation

$$TAF = IPMF \times GTF \text{ (from Equation 1)}$$

$$TAF = 1.09 \times 1.09$$

$$TAF = 1.19$$

The TAF for Rapidan, VA 1995 when moved to the grid point at 35.35°N, -82.25°W, representing storm maximization and transposition, is 1.19. This is an overall increase of 19% from the original SPAS analyzed in-place rainfall. This increase accounts for differences in moisture availability, orographic enhancement, and other precipitation processes that are different between the original location and the grid location being analyzed. The results of these calculations for each storm for each grid are then evaluated to validate the calculation and that the results represent realistic differences in meteorological, climatological, and topographical characteristics.

The TAF can then be applied to the DAD value for a given area size and duration to calculate the total adjusted rainfall. If the total adjusted rainfall is greater than the depth for all other transposable storms, it becomes the PMP depth at that grid point for that duration.

11. PMP Tool Outputs

The PMP tool provides basin-specific PMP based for the area-size of the basin. For each storm type analyzed, the tool provides output in ESRI file geodatabase raster format. The output also includes a basin average PMP table. If the sub-basin average option was checked, the tool provides averages for each sub-basin. The depths are calculated for the area-size of the basin, so no further areal reduction should be applied. The tool also provides a point feature class containing PMP depths and controlling storms listed by SPAS ID. There are also temporally distributed accumulated rainfall tables for each temporal pattern that can be applied to the basin.

Spatial patterns of PMP follow the precipitation frequency climatologies patterns. However, other spatial patterns are possible. In general, for basins less than 500-square miles, alternative spatial patterns do not affect the PMF elevation. For basins larger than 500-square miles or where significant terrain influences rainfall accumulation patterns, alternative spatial patterns may produce high water surface elevations and therefore should be investigated. These can be derived from observed storm patterns that have occurred over the basin or from patterns of storms in the region that are moved over the basin. PMP depths can then be redistributed over a given basin so that the final basin average PMP depths are the same, but the spatial pattern is representative of observed storm patterns.

Finally, a basin average PMP depth-duration chart in the .png image format is also included in the output folder. An example depth-duration chart is shown in Figure 11.1. Detailed output information is included in the PMP tool documentation in Appendix G.

Gridded PMP depths were calculated for the entire study region at various index area-sizes for several durations as a visualization aid. Numerous iterations of the maps were produced during the study. These were evaluated to determine areas that needed adjustments or further evaluation. Changes were made to individual storms so that the final spatial pattern of PMP represented reasonable depths and meteorically support spatial patterns. The maps in Appendix A illustrate the depths for 1-, 10-, and 100-square mile area sizes for local storm PMP for 1-, 6-, and 24-hour durations and 10-, 100-, and 1,000-square mile area sizes for general and tropical storm PMP at 6-, 24-, and 72-hour durations.

Note, concurrent rainfall outside of a given basin is not part of the PMP tool outputs. If this information is needed, AWA recommends applying the 100-year areal reduced rainfall representing the concurrent region or applying the ratios provided in HRM 52 (e.g. Figure 13 and 17 of that report). If a more accurate analysis is needed, AWA should be contacted to develop site-specific information from the storm data used in this study.

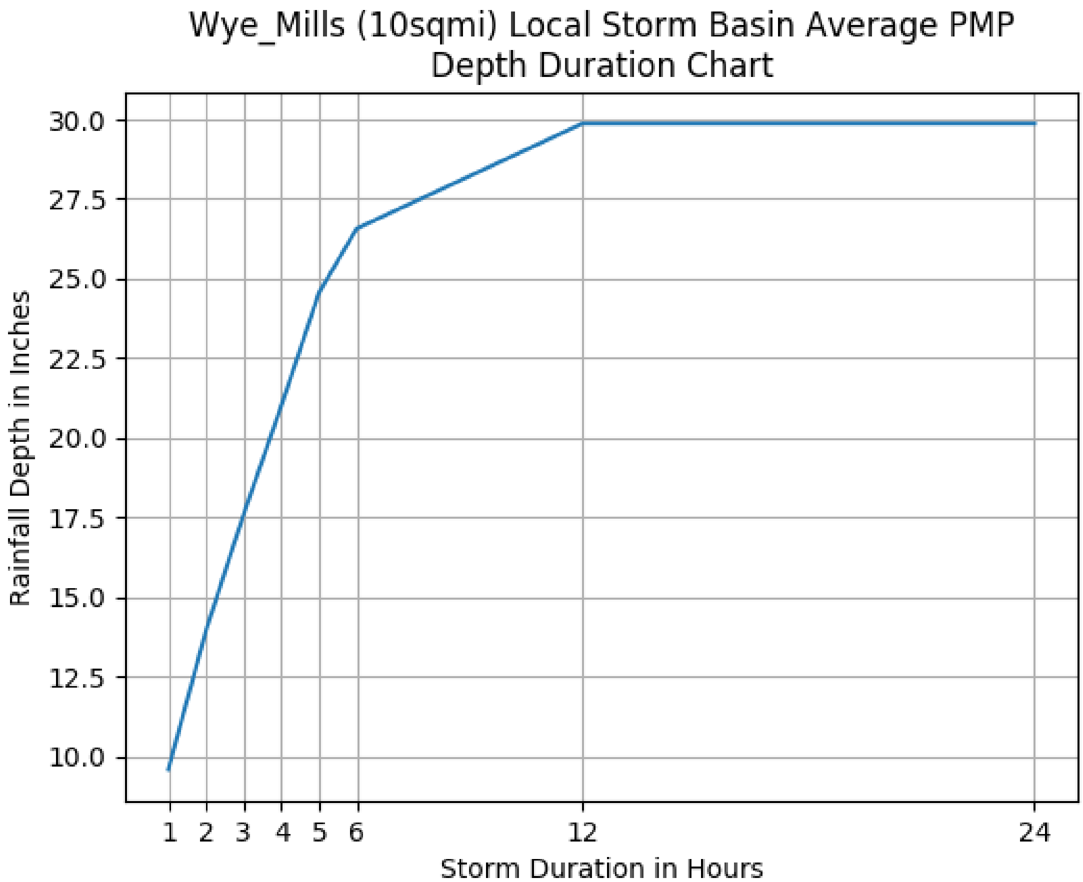


Figure 11.1: Sample PMP depth-area chart image provided in output folder

12. Development of Temporal Distributions for Use in Runoff Modeling

Site-specific temporal patterns were developed which reflect the rainfall accumulation characteristics of the storm used for PMP in this basin. These temporal patterns were investigated and developed as part of adjacent studies, including the Virginia, Pennsylvania, New Jersey, and Maryland statewide studies and re-evaluated as part of this study. Storm temporal patterns were developed by storm type (local, general, and tropical), application of controlling storm patterns, and through frequency analysis following Huff curve methods applied in NOAA Atlas 14 (e.g., Bonnin et al., 2006 and Perica et al., 2019). These are to be used in place of the HMR 52 (Hansen et al., 1982) alternating block pattern and/or the critically stacked pattern (Cudworth, 1989) as they represent temporal patterns that occur in PMP-type storms which are possible over North Carolina.

In terms of storm types, local storms are characterized by short duration (6-hours or less) and small area size high intensity rainfall accumulations. They are often not associated with large scale weather patterns and can be influenced by local moisture sources. General storms produce precipitation over longer durations (greater than 6-hours) and cover larger areas with comparatively lower intensity rainfall accumulations. General storms are produced by large scale synoptic patterns generally associated with areas of low pressure and frontal systems. These are most common during the fall, winter, and spring seasons. Tropical storms rely on warm water from the Gulf of America and the Gulf Stream in the Atlantic just off the East Coast along with supporting synoptic and upper-level weather patterns which occur from June through November. When these storms move slowly over a region, large amounts of rainfall can be produced both in convective bursts and over longer durations. Some storms exhibit characteristics of both the local and general storm or local and tropical rainfall accumulation patterns. For PMP analysis in this study, these are termed hybrid storms and are evaluated for PMP as more than one storm type.

The result of these methods produces several possible temporal patterns that were applied to the PMP depths. These included the 10^{th} percentile, 90^{th} percentile, synthetic, and controlling storms distributions. The development of each of these patterns are detailed below.

These outputs were provided for detailed testing and evaluation as part of the adjacent study and applied to numerous example basins for testing. This provided confirmation that the final set of temporal patterns applied to the PMP tool represented PMP storm patterns by storm type for this study. In the final PMP tool, all temporal patterns evaluated in this study are available for use as needed. Appendix G provides more details on the application of the temporal patterns within the PMP GIS tool including the error check process for final application.

12.1 Temporal Curve Development Methodology

Hourly gridded rainfall data were used for all SPAS analyzed storms. The maximum rain accumulations were based on rainfall at the storm center. The rainfall mass curve at the storm center was used for the temporal calculations. The steps used to derive the synthetic curves are described below.

12.1.1 Standardized Timing Distribution by Storm Type

The Significant Precipitation Period (SPP) for each storm was selected by excluding relatively small rainfall accumulations at the beginning and end of the rainfall duration. Accumulated rainfall (R) amounts during the SPP were used in the analysis for the hourly storm rainfall. The total rainfall during the SPP was used to normalize the hourly rainfall amounts. The time scale (T_S) was computed to describe the time duration when half of the rainfall accumulated (R). The procedures used to calculate these parameters are listed below.

12.1.2 Temporal Analysis Parameters Evaluated

SPP - Significant Precipitation Period when the majority of the rainfall occurred
R - Accumulated rainfall at the storm center during the SPP
R_n - Normalized R
T - Time when R occurred
T_s – Time when 50% accumulation occurs, value is set to zero. Negative time values precede the time to 50% rainfall, and positive values follow
T50 - Time when $R_n = 0.5$

12.1.3 Procedures used to Calculate Parameters

Below are the steps utilized to investigate the rainfall accumulation patterns from each storm used in the PMP development. Each of these were applied to the SPAS analyzed mass curves by storm type.

1. Determine the SPP. Inspect each storm's rainfall data for "inconsequential" rainfall at either the beginning and/or the end of the records. Remove these "tails" from calculations. Generally, AWA used a criterion of less than 0.1 inches/hour intensity to eliminate non-intense periods. No internal rainfall data were deleted.
2. Recalculate the accumulated rainfall records for R. This yields the SPP.
3. Plot the SPAS rainfall and R mass curves and inspect for reasonableness.
4. Normalize the R record by dividing all values by the total R to produce R_n for each hour, R_n ranges from 0.0 to 1.0.
5. Determine T50 using the time when $R_n = 0.5$.
6. Calculate T_s by subtracting T50 from each value of T. Negative time values precede the time to 50% rainfall, and positive values follow.
7. Determine maximum 24-hour and maximum 6-hour precipitation, convert accumulations into a ratio of the cumulative rainfall to the total accumulated rainfall for that duration.
8. Visually inspect resulting data to determine a best fit of the curves. This includes both the intensity (steepness) of accumulation and whether most of the accumulations are exhibiting a front, middle, or back loaded accumulation.

Graphs were prepared of a) R vs T, b) R_n vs T, c) R_n vs T_s, and d) maximum point precipitation for General (24-hour), Local (6-hour), and Tropical (24-hour) storm events. Evaluations of the resulting rainfall accumulation curves individually and in relation to each other were completed by visually inspecting the data. From these investigations, a rainfall accumulation pattern that represented a significant majority of the patterns with a steep intensity was utilized as the synthetic pattern. This process is subjective. The objective is to produce a synthetic pattern that captures the majority of the worst-case runoff scenarios for most basins and represents a physically possible temporal accumulation pattern. However, it is not possible for a single synthetic curve to capture all of the worst-case runoff scenarios for all basins.

12.1.4 Examples of Temporal Pattern Analyses from Adjacent Studies

Following the procedures and description from the previous section, results are presented as three graphs. The graphs are a) R vs T, b) R_n vs T, and c) R_n vs T_s for local, general, tropical, and hybrid storm types. Figure 12.1 to Figure 12.12 show these graphs for SPAS storm events east of the Appalachian Mountains which are relevant to this study.

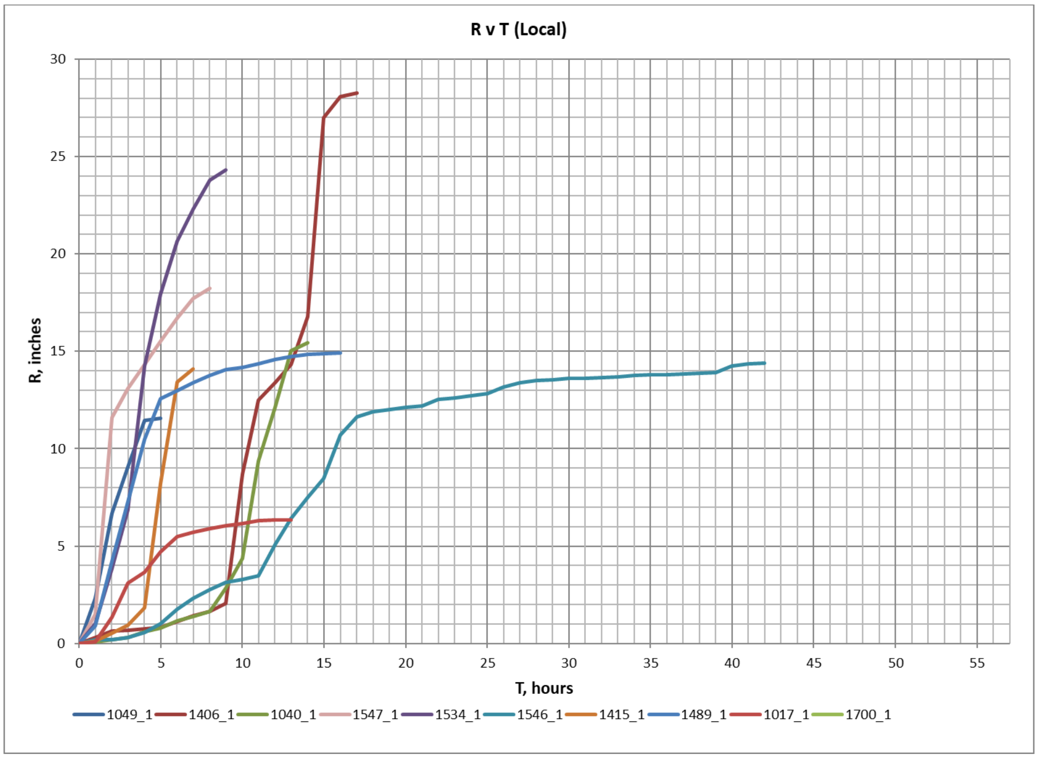


Figure 12.1: SPAS Rainfall (R) versus time (T) for local type storm east of the Appalachians

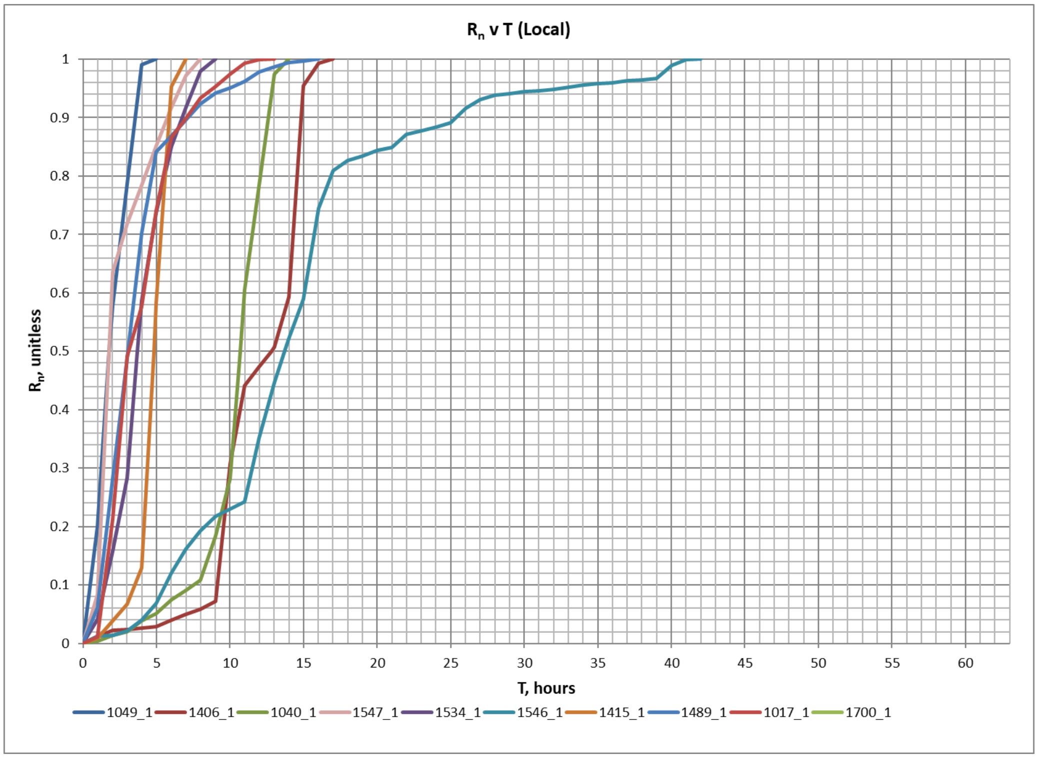


Figure 12.2: Normalized R (Rn) versus time (T) for local type storm east of the Appalachians

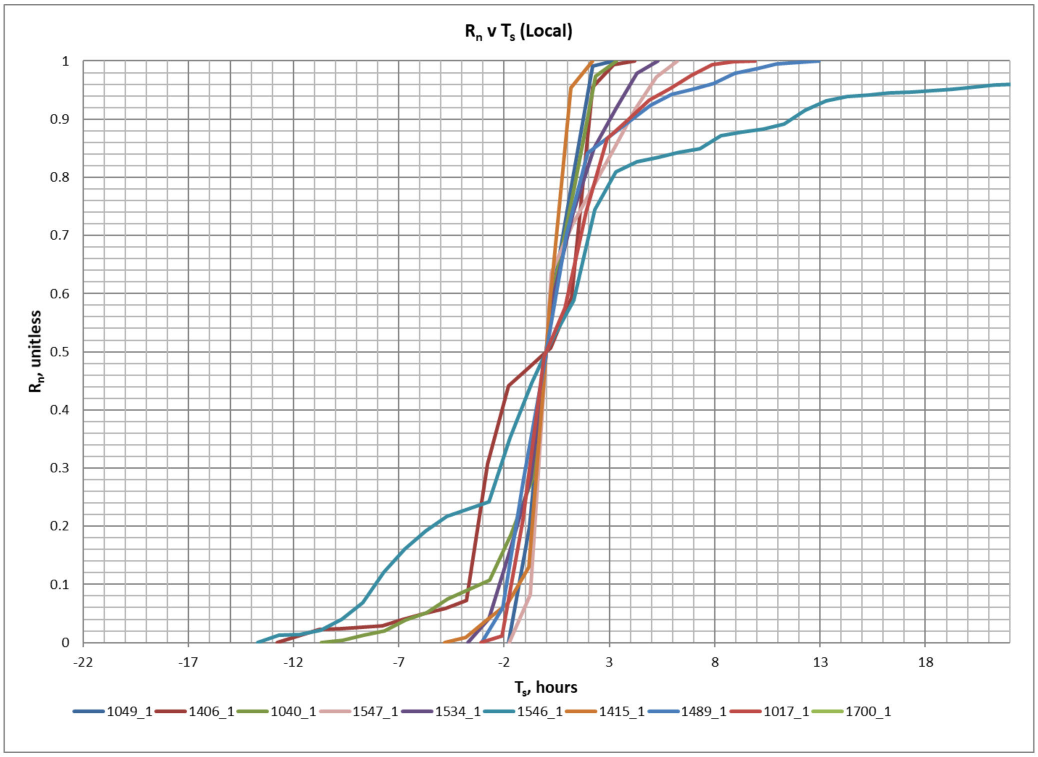


Figure 12.3: Normalized R (Rn) versus shifted time (Ts) for local type storm east of the Appalachians

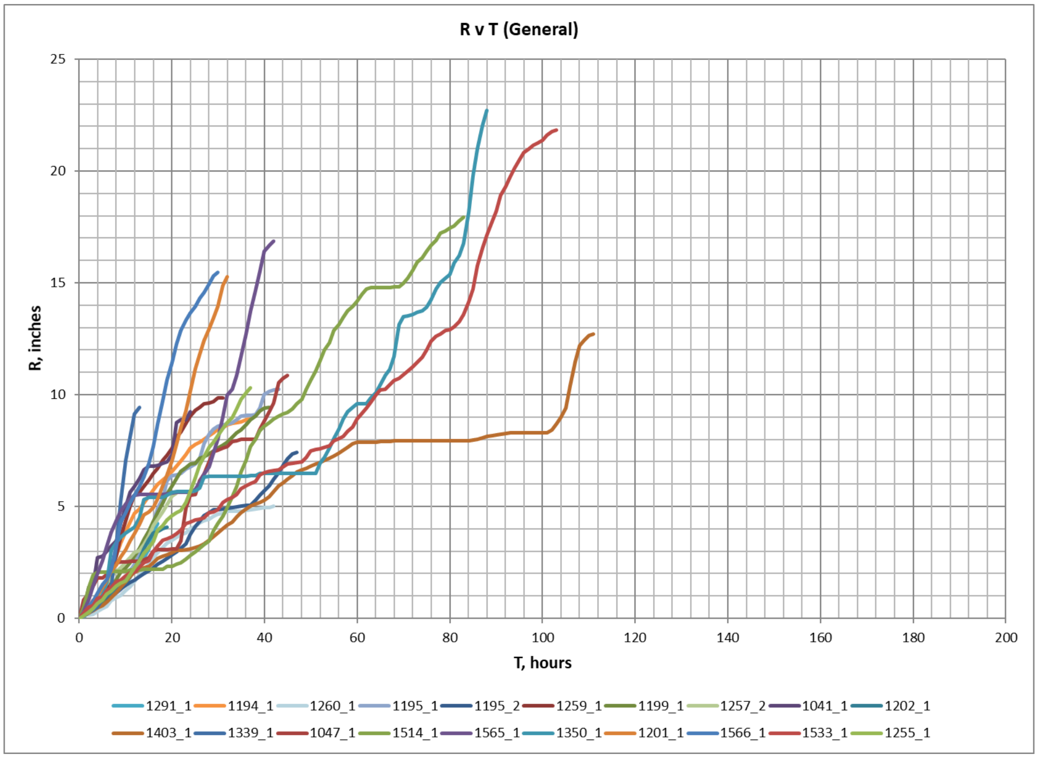


Figure 12.4: SPAS Rainfall (R) versus time (T) for general type storm east of the Appalachians

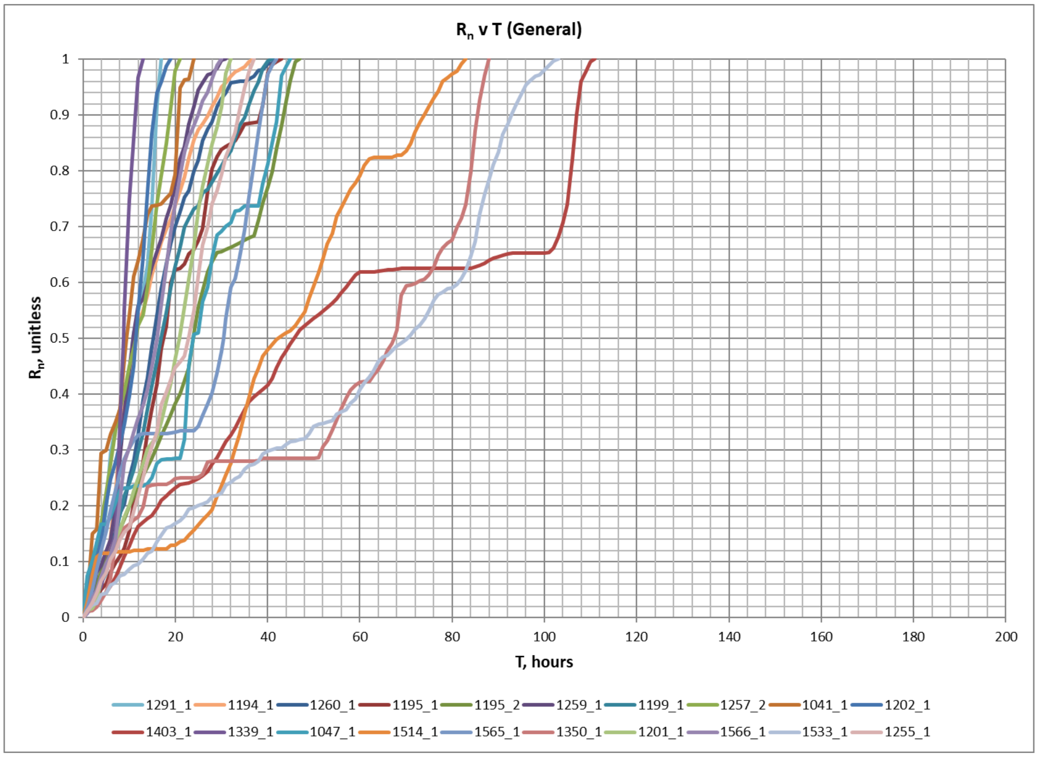


Figure 12.5: Normalized R (Rn) versus time (T) for general type storm east of the Appalachians

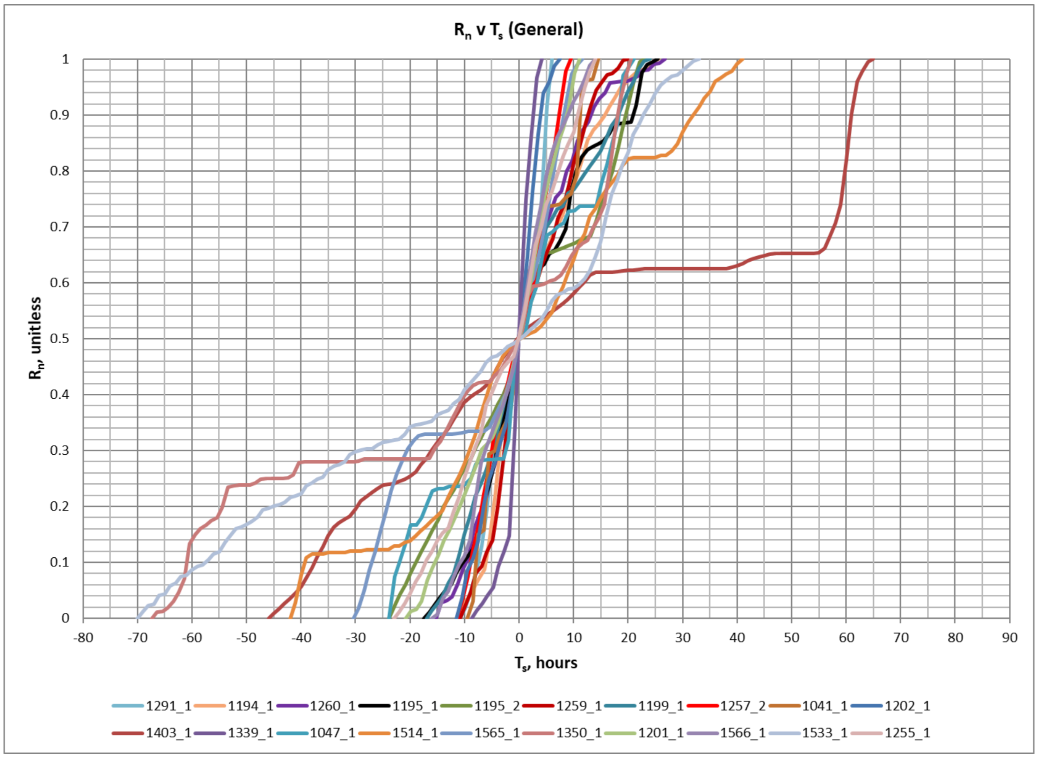


Figure 12.6: Normalized R (Rn) versus shifted time (Ts) for general type storm east of the Appalachians

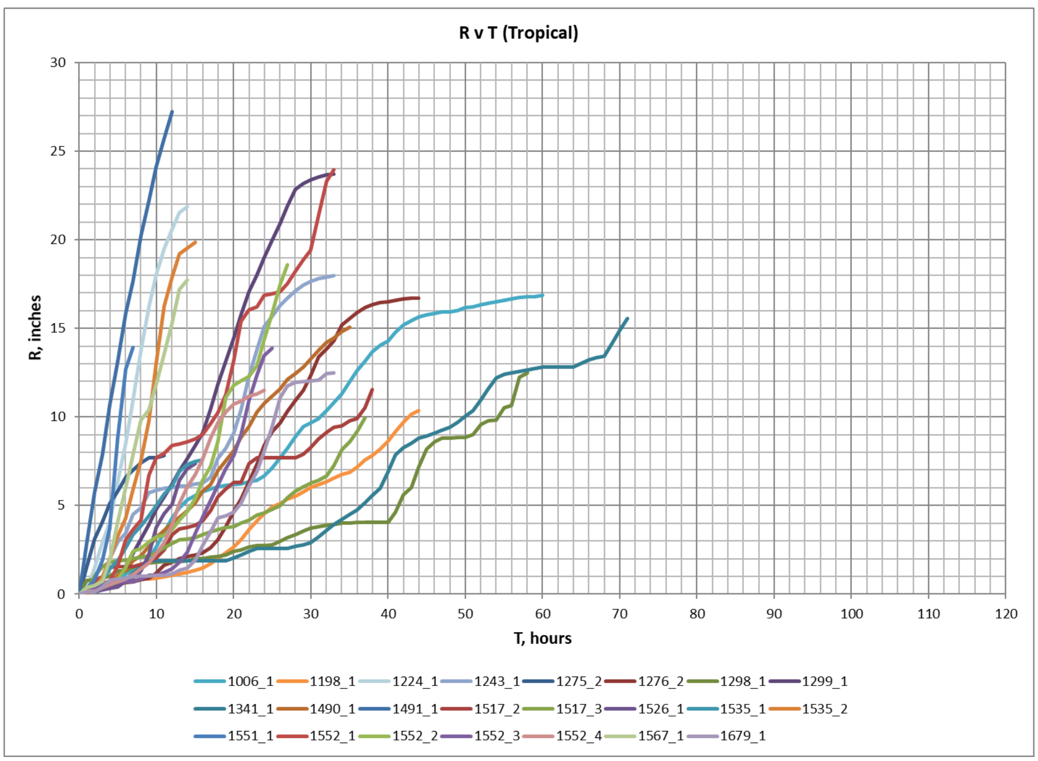


Figure 12.7: SPAS Rainfall (R) versus time (T) for tropical type storm east of the Appalachians

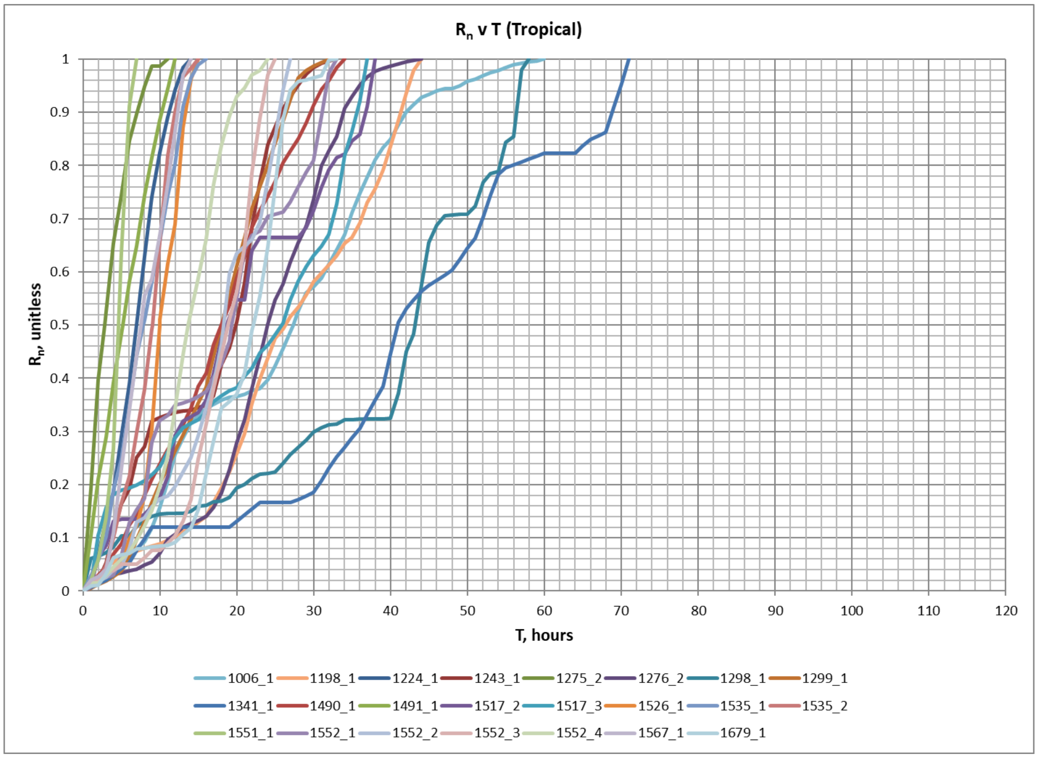


Figure 12.8: Normalized R (Rn) versus time (T) for tropical type storm east of the Appalachians

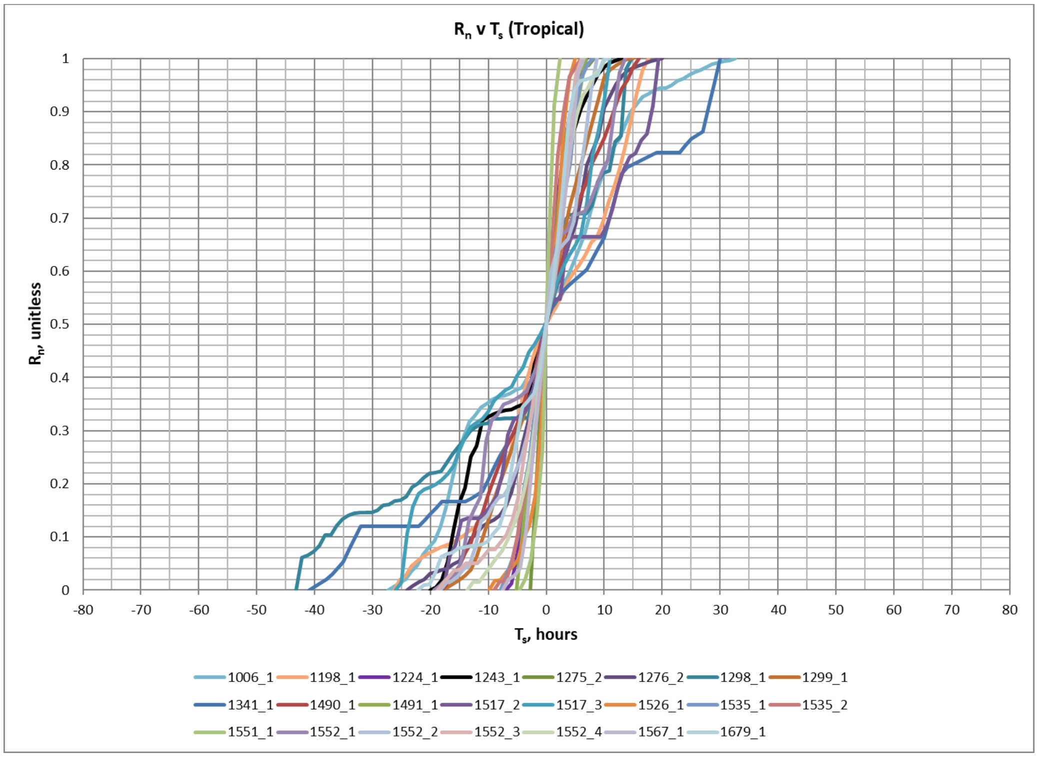


Figure 12.9: Normalized R (Rn) versus shifted time (Ts) for tropical type storm east of the Appalachians

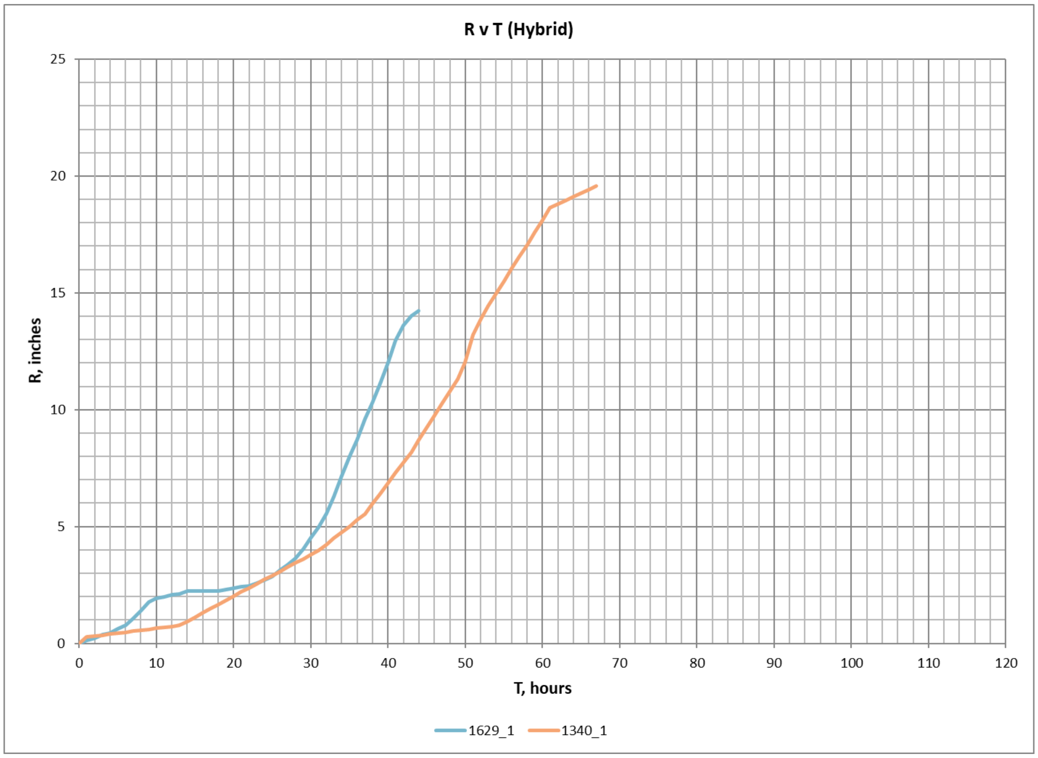


Figure 12.10: SPAS Rainfall (R) versus time (T) for hybrid type storm east of the Appalachians

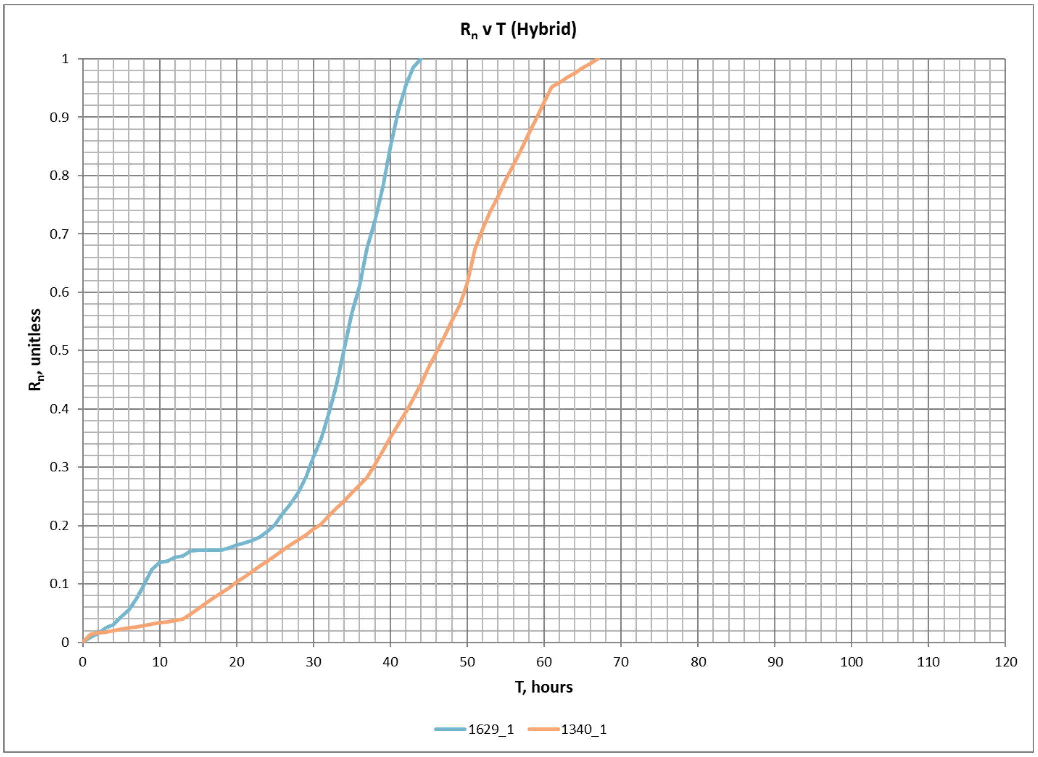


Figure 12.11: Normalized R (Rn) versus time (T) for hybrid type storm east of the Appalachians

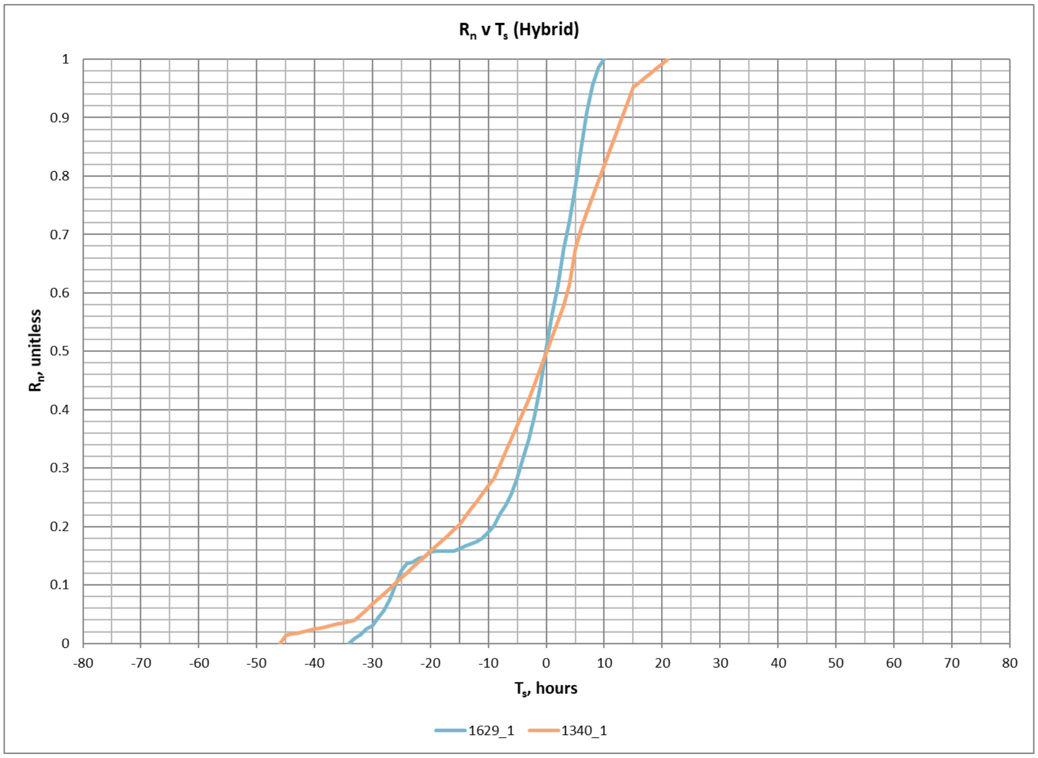


Figure 12.12: Normalized R (Rn) versus shifted time (Ts) for hybrid type storm east of the Appalachians

12.2 Huff Curve Methodology

Huff curves provide a method of characterizing storm mass curves. They are a probabilistic representation of accumulated storm depths for corresponding accumulated storm durations expressed in dimensionless form. The development of Huff curves is described in detail in Huff (1967) and Bonta (2003), a summary of the steps is listed below.

For each SPAS storm center mass curve, the core cumulative precipitation amounts (R, noted in above section) were identified, the core cumulative rainfall were non-dimensionalized and converted into percentages of the total precipitation amount at one hour time steps. The non-dimensionalized duration values were interpolated and extracted at 0.02 increments from 0 to 1. Storms were grouped by storm type: local, general, tropical, and hybrid. The uniform incremental storm data (by duration and location) were combined, and probabilities of occurrence were estimated at each 0.02 increment. Probabilities were estimated at 0.1 increments. The raw recommended curves (90^{th} and 10^{th}) were smoothed using a non-linear regression. Smoothing of the raw curves is performed to account for statistical noise in the analysis (Huff, 1967; Bonta, 2003).

The curves generated in this study can be generically described as:

- 90^{th} curve - the 90th curve indicates that 10% of the corresponding SPAS storms had distributions that fell above and to the left of the 90^{th} curve (front-loaded)
- 50^{th} curve - the 50th curve indicates that 50% of the corresponding SPAS storms had distributions that fell above and below the 50^{th} curve (mid-loaded)

- 10^{th} curve - the 10th curve indicates that 10% of the corresponding SPAS storms had distributions that fell below and to the right of the 10^{th} curve (back-loaded)

The raw data results are presented below (Figures 12.13-12.16); the final curves selected for use were smoothed using non-linear regression and data were provided at 5-minute (local storms) and 15-minute (general, hybrid, tropical) time steps from the non-linear regression equation (data were extracted from the non-linear equation). Some of the Huff curves result in accumulated precipitation at time zero, this is a result of front-loaded storms that generate a significant portion of their precipitation in the first hour, the analysis that was performed on hourly data, and the interpolation method that did not force the curve to zero. The final set of Huff curves were set to zero at time zero. The NRCS Type II curve (also known as the SCS curve) is considered a standard temporal pattern for design purposes in many regions of the country; see Section 12.7 for additional description (NRCS, 2005). The Type II curve is added to figures in its native state for comparison (Type II).

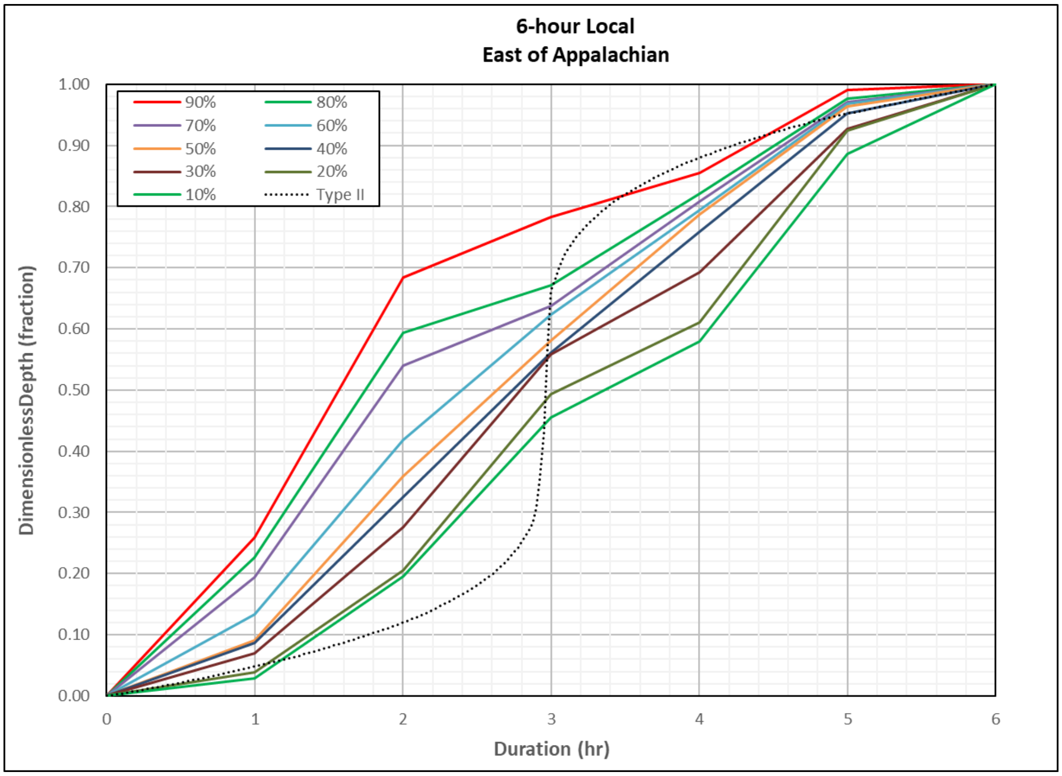


Figure 12.13: Raw Huff temporal curves for 6-hour local type storm east of the Appalachians

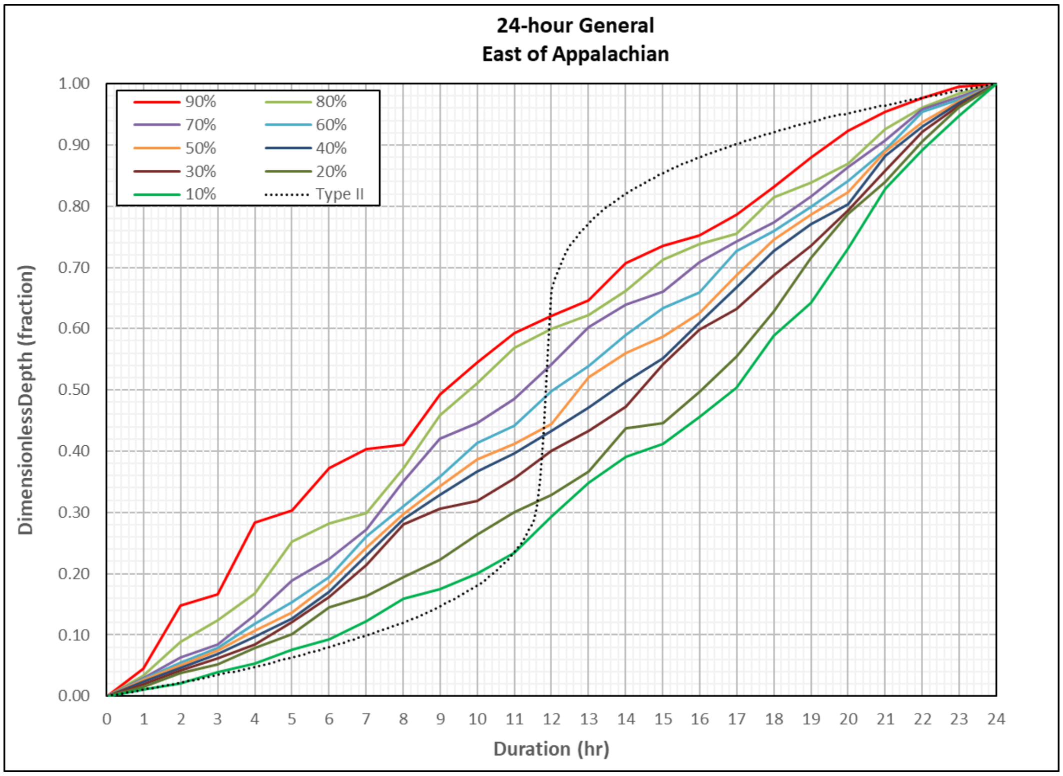


Figure 12.14: Raw Huff temporal curves for 24-hour general type storm east of the Appalachians

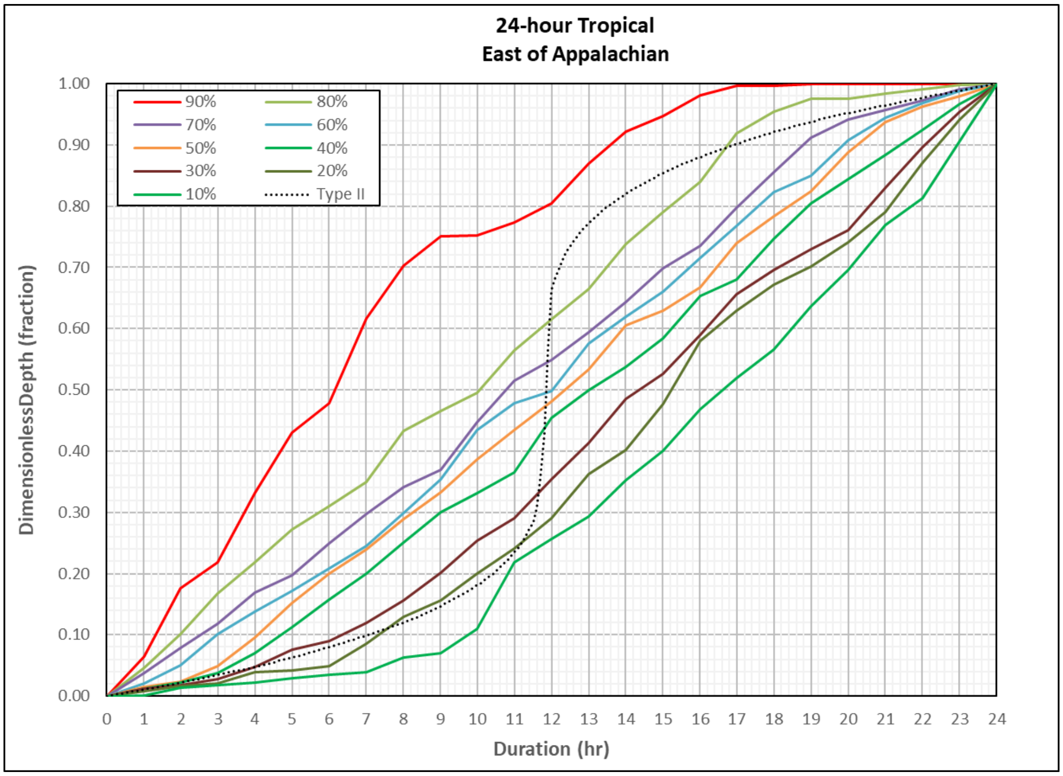


Figure 12.15: Raw Huff temporal curves for 24-hour tropical type storm east of the Appalachians

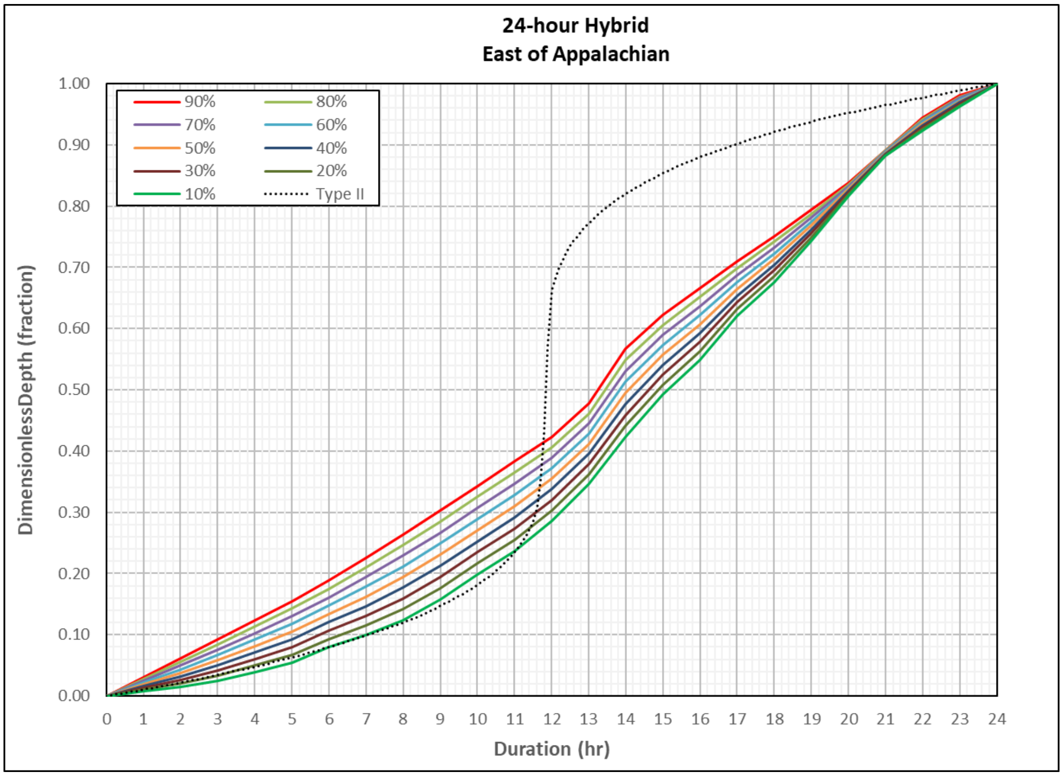


Figure 12.16: Raw Huff temporal curves for 24-hour hybrid type storm east of the Appalachians

12.3 Sub-hourly Timing and 2-hour Local Storm Timing

AWA evaluated the 5-minute incremental rainfall accumulations patterns for thirty-six storms from the PMP type that had been analyzed with SPAS-NEXRAD to identify events that could be used to derive site-specific sub hourly accumulation guidance. This SPAS-NEXRAD 5-minute data were used to derive ratios of the greatest 15-, 30-, and 45-minute accumulations during the greatest 1-hour rainfall accumulation. Data from 36 local storm events allowed a specific evaluation of the sub-hourly rainfall patterns to be considered for the PMP study region.

HMR 55A provided recommended temporal patterns to be applied to the North Carolina PMP to estimate sub-hourly timing. It is important to note that the 15-minute incremental accumulation ratios derived for the local PMP storm in HMR 55A is based on very limited (almost none) sub-hourly data. HMR 55A made reference to the limited amount of available data and suggested using HMR 49 information instead (HMR 55A Section 12.7).

Table 12.1 displays the results of this analysis. The largest difference between HMR 55A and this study occurs during the greatest 15-minute increment, where HMR 55A provides a value of 68% (see HMR 55A Table 12.4), while the actual storm data have an average of 38% and a maximum of 64%. HMR55A is used for comparison because that is the only HMR where an evaluation of sub hourly rainfall was completed.

AWA completed additional sensitivity analysis by comparing the sub hourly ratio data to similar data developed during the Arizona statewide PMP study (Kappel et al., 2013) and the Colorado-New Mexico statewide study (Kappel et al., 2018). The results from the Arizona and Colorado-New Mexico statewide PMP analyses and the EM 1-hour percentages are provided in Table 12.1 for comparison with the results. The 2-hour local storm temporal pattern was developed to account for local storms that are less than 2-hours. The 2-hour local storm temporal pattern utilized the stacked 5-min sub-hourly ratio data for the first hour and the second hour was evenly distributed. For example, if a storm event had 8-inches in the first hour and 1-inch in the second hour for a total storm of 9-inches, the accumulation pattern is shown in Figure 12.17.

Table 12.1: Sub-hourly ratio data from HMR 55A and evaluated again during the Pennsylvania study

Duration (hr)	Duration (min)	HMR 55A Table 12.4	MD PMP Local Storms	EM	CO/NM	AZ
0.083	5	-	16%	21%	15%	-
0.167	10	-	28%	38%	28%	-
0.25	15	68%	38%	46%	39%	34%
0.50	30	86%	64%	67%	65%	61%
0.75	45	94%	83%	85%	84%	82%
1.00	60	100%	100%	100%	100%	100%

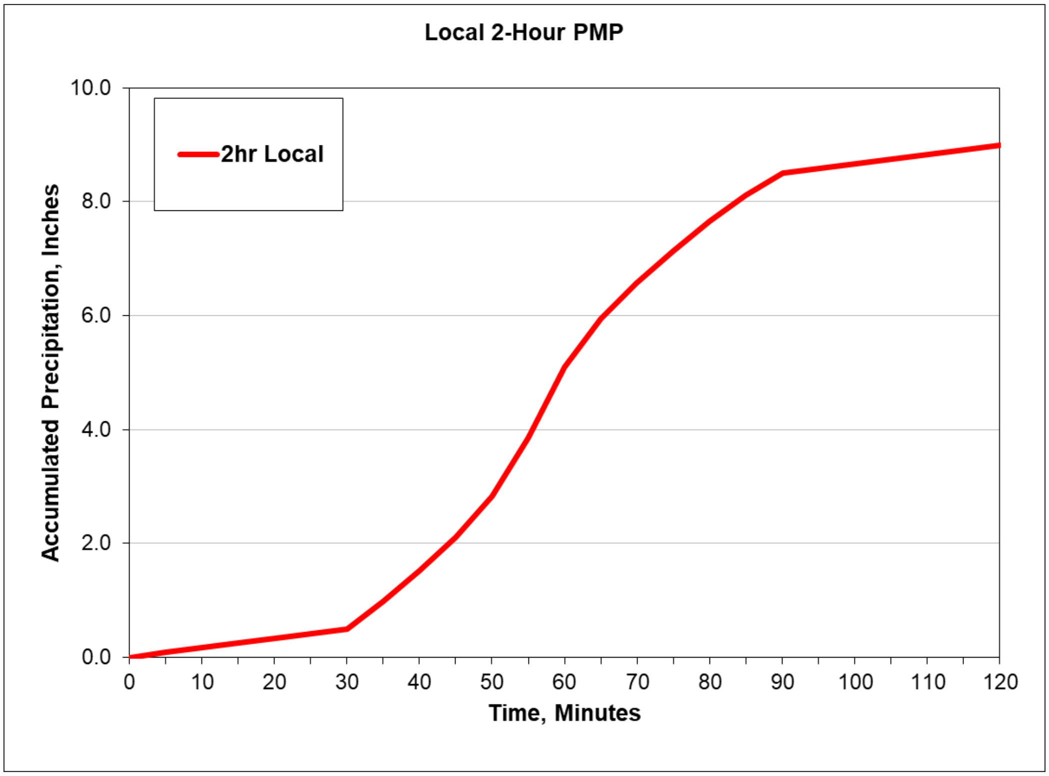


Figure 12.17: Hypothetical 2-hour local storm distribution

12.4 Application of Temporal Patterns

Each of the temporal patterns were derived through visual inspection, meteorological analyses, and comparisons with similar work. Analysis was completed after separating each event by storm type (e.g., general, local, tropical, hybrid). The temporal patterns reflect the meteorological conditions that produce each storm type. These represent observed extreme rainfall accumulation characteristics. It is assumed that similar patterns would occur during a PMP event. Therefore, it is recommended that the PMP temporal patterns included in the tool be used as they represent North Carolina specific temporal patterns derived from extreme rainfall events used in this study.

In the PMP tool, there are a number of temporal patterns that can be applied. It is recommended that only patterns which “pass” the interim PMP depth test be used for a given basin per storm type. In some cases, most of the patterns will “exceed” the one or more interim PMP depths leaving a limited to no temporal patterns to apply. In this situation, if the “exceed” amount is within 5% of the PMP depth then it is acceptable to use that pattern.

In addition, for basins larger than 100-square miles, the local storm PMP may not be required. In those situations, the alternating block pattern can be applied to confirm that storm type does not control PMP as this pattern represents the worst-case temporal pattern and therefore if it does not control, no additional local storm PMP runs would be required. Similarly, for basins less than 10-square miles, the tropical and general storm types are unlikely to control the PMP depths and the same test using the alternating block (critically stacked) pattern can be run to confirm those storm types are not required.

13. PMP Depth Sensitivities and Comparisons

In the process of deriving PMP depths, various assumptions and meteorological judgments were made within the framework of state-of-the-practice processes. These parameters and derived values are standard to the PMP development process; however, it is of interest to assess the sensitivity of PMP values to assumptions that were made and to the variability of input parameter values.

PMP depths and intermediate data produced for this study were rigorously evaluated throughout the process. ArcGIS was used as a visual and numerical evaluation tool to assess gridded values to ensure they fell within acceptable ranges and met test criteria. Several iterations of maps were produced as visual aids to help identify potential issues with calculations, transposition limits, DAD values, or storm adjustment values. The maps also helped to define storm characteristics and transposition limits, as discussed previously. Over the entire PMP analysis domain, different storms control PMP values at different locations for a given duration and area size.

In some instances, a discontinuity of PMP depths between adjacent grid point locations resulted. This occurs as a result of the binary transposition limits applied to the controlling storms, with no allowance for gradients of transpositionability. Therefore, different storms are affecting adjacent grids and may result in a shift in values over a short distance. In reality, there would be some transition for a given storm, but the process and definition of transpositionability does not allow for this. It is important to note that these discontinuities make little difference in the overall basin average PMP depths when applied for hydrologic analysis purposes for most basins. The discontinuities are only seen when analyzing data at the highest resolution (e.g., individual grid points). The non-meteorological discontinuities were addressed by adjusting transposition limits.

13.1 Comparison of PMP Depths Against HMR 51

This study employs a variety of improved methods when compared to previous HMR studies. These methods include:

- A far more robust storm analysis system with a higher temporal and spatial resolution
- Improved dew point/SST and precipitation climatologies that provide an increased ability to maximize and transpose storms
- Gridded PMP calculations which result in higher spatial and temporal resolutions
- A greatly expanded storm record

Unfortunately, working papers and notes from the HMRs are not available in most cases. Therefore, direct PMP comparisons between the HMRs and the values from this study are somewhat limited. Furthermore, due to the generalization of the regionally based HMR studies, comparisons to the detailed gridded PMP of this study can vary greatly over short distances. However, comparisons were made for sensitivity purposes where data allowed. The PMP values in this study resulted in a wide range of both reductions and increases as compared to the HMRs.

Gridded index PMP depths were available for HMR 51 allowing a direct gridded comparison with the depths produced for this study. A gridded percent change was calculated for the area-sizes and durations common with the HMR index PMP maps. The maximum PMP depth from the general storm, tropical storm, or local storm types were used for the HMR 51 comparisons to account for differences in storm typing between this study and HMR 51. Table 13.1 shows the PMP depth comparisons made to HMR 51 by comparing the 10 square mile 6- and 24-hour PMP for each transposition zone.

Table 13.1: Average gridded percent change from HMR 51 to 10sqmi PMP depths

10 Square Miles						
ZONE	6-Hour Average PMP	6-Hour HMR 51	Percent Difference from HMR 51	24-Hour Average PMP	24-Hour HMR 51	Percent Difference from HMR 51
1 - Coastal Plain	30.67	29.82	2.9%	35.11	41.60	-15.6%
2 - Piedmont	26.27	29.41	-10.7%	29.52	39.59	-25.4%
3 - Blue Ridge East	28.01	29.46	-5.0%	31.50	38.99	-19.2%
4 - Blue Ridge West	19.24	29.38	-34.6%	24.81	38.64	-35.9%

13.2 Comparison of PMP Depths with Precipitation Frequency

The ratio of the PMP to 100-year return period precipitation amounts is generally expected to range between two and four, with values as low as 1.7 and as high as 5.5 for regions east of 117°W found in HMR 57 and HMR 59 (Hansen et al., 1994; Corrigan et al., 1999). Further, as stated in HMR 59 "…*the comparison indicates that larger ratios are in lower elevations where short-duration, convective precipitation dominates, and smaller ratios in higher elevations where general storm, long duration precipitation is prevalent*" (Corrigan et al., 1999, p. 207).

For this study, the maximum 24-hour 1-square mile PMP was compared directly to the 100-year 24-hour values on a grid-by-grid basis for the entire analysis domain using GIS. The comparison was presented as a ratio of PMP to 100-year rainfall and was determined for each grid point. Figures 13.1-13.2 illustrate the PMP to 100-year rainfall ratios for 6-hour and 24-hour PMP, respectively. The PMP to 100-year return period rainfall ratios vary from 3.5 to 8, after combining all storm types (local, general, and tropical). The values are in reasonable proportion expected for the study area, are similar to adjacent studies, and demonstrate the PMP values are at appropriately rare levels.

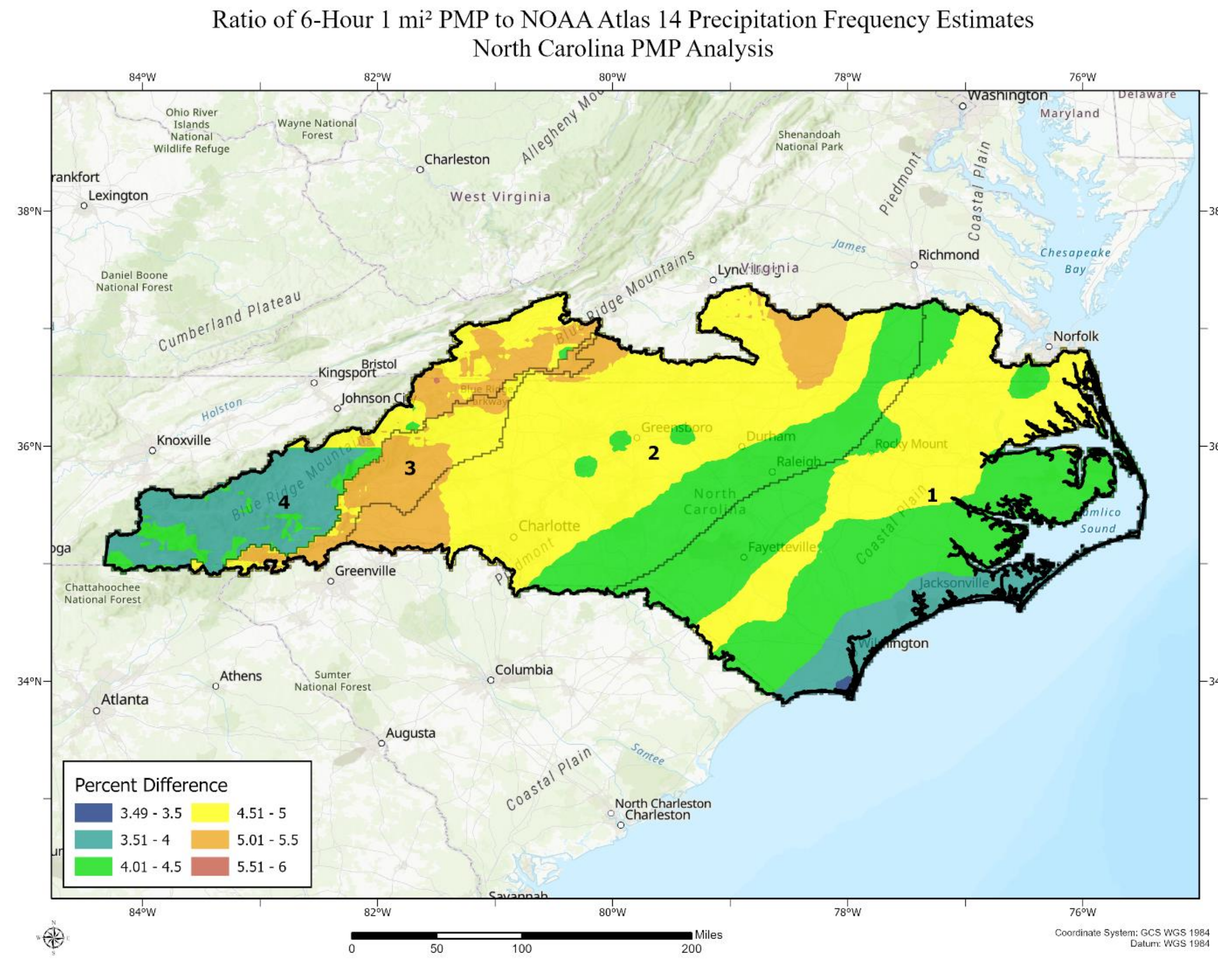


Figure 13.1: Ratio of 6-hour 1-square mile PMP to 100-year precipitation

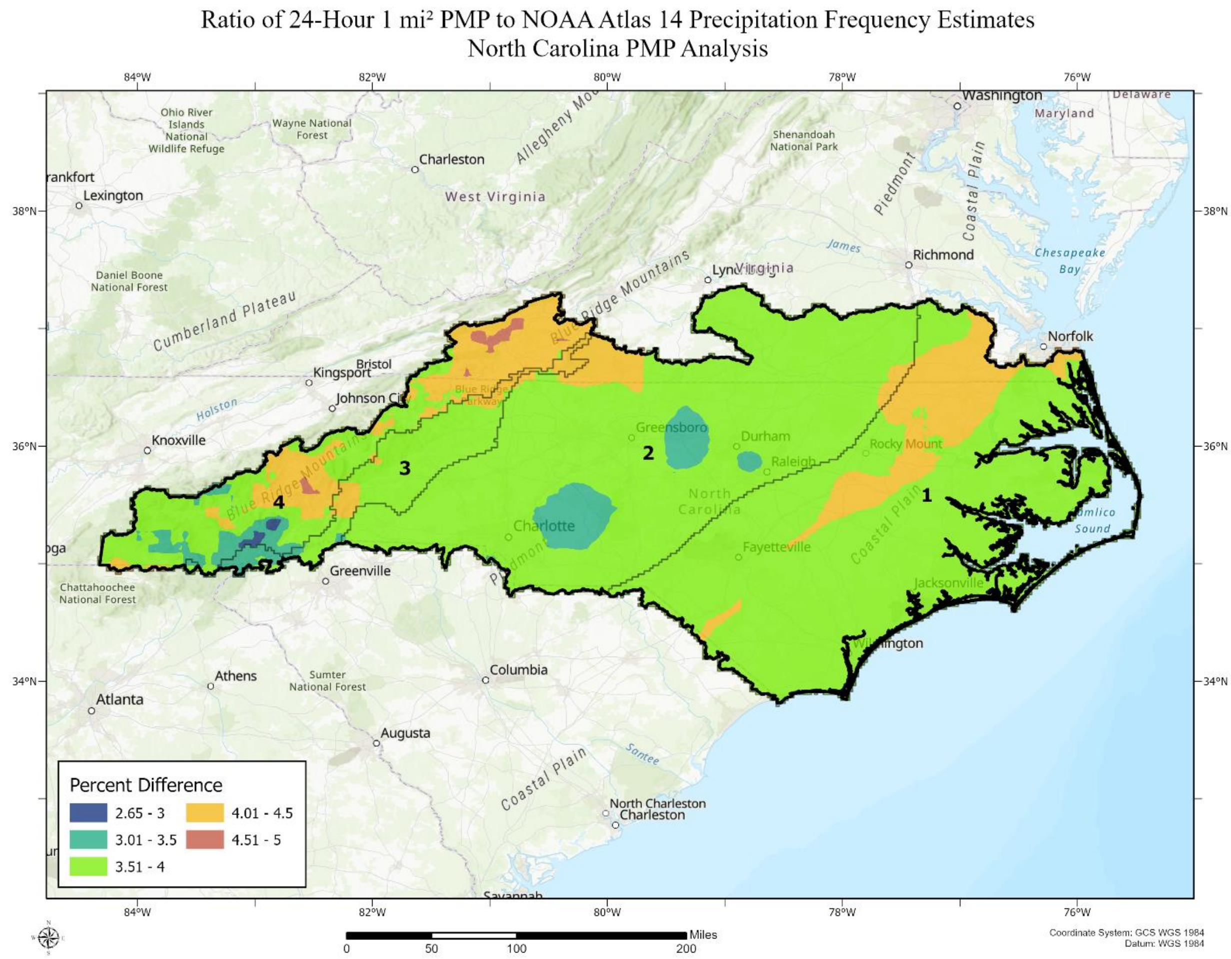


Figure 13.2: Ratio of 24-hour 1-square mile PMP to 100-year precipitation

13.3 Comparison of PMP Against Virginia and Pennsylvania Studies

Some areas of the North Carolina Statewide study domain overlap the statewide study for Virginia (2015). Differences were expected due to updated datasets and procedures since the completion of that study, but direct comparisons were made for all 3 storm types where overlap occurred for reference. Figures 13.3 through 13.5 show the percent difference from the previous PMP versions by storm type at relevant area sizes. A negative value indicates a decrease from the previous study and a positive value an increase. In areas where there is overlap, the North Carolina PMP values represent the most current at the time of this publication and should be used by North Carolina Dam Safety in areas of overlap. The main reasons for the differences between the studies include the following:

- Updated dew point climatology datasets used for storm maximizations where the climatological dew points have increased slightly in some storm maximizations
- Updated storm transposition limits were applied representing updated information specifically related to the North Carolina study domain
- Additional storms were used in the North Carolina study that were not used in the Virginia study because they occurred subsequent to that study

- The Virginia Study used a moisture transposition factor (MTF) in the total adjustment factor (TAF) calculations, which is not used in this study
- The Virginia study used a trendline along a series of return frequencies to calculate the GTF, where the GTF currently applied the 100-year recurrence interval

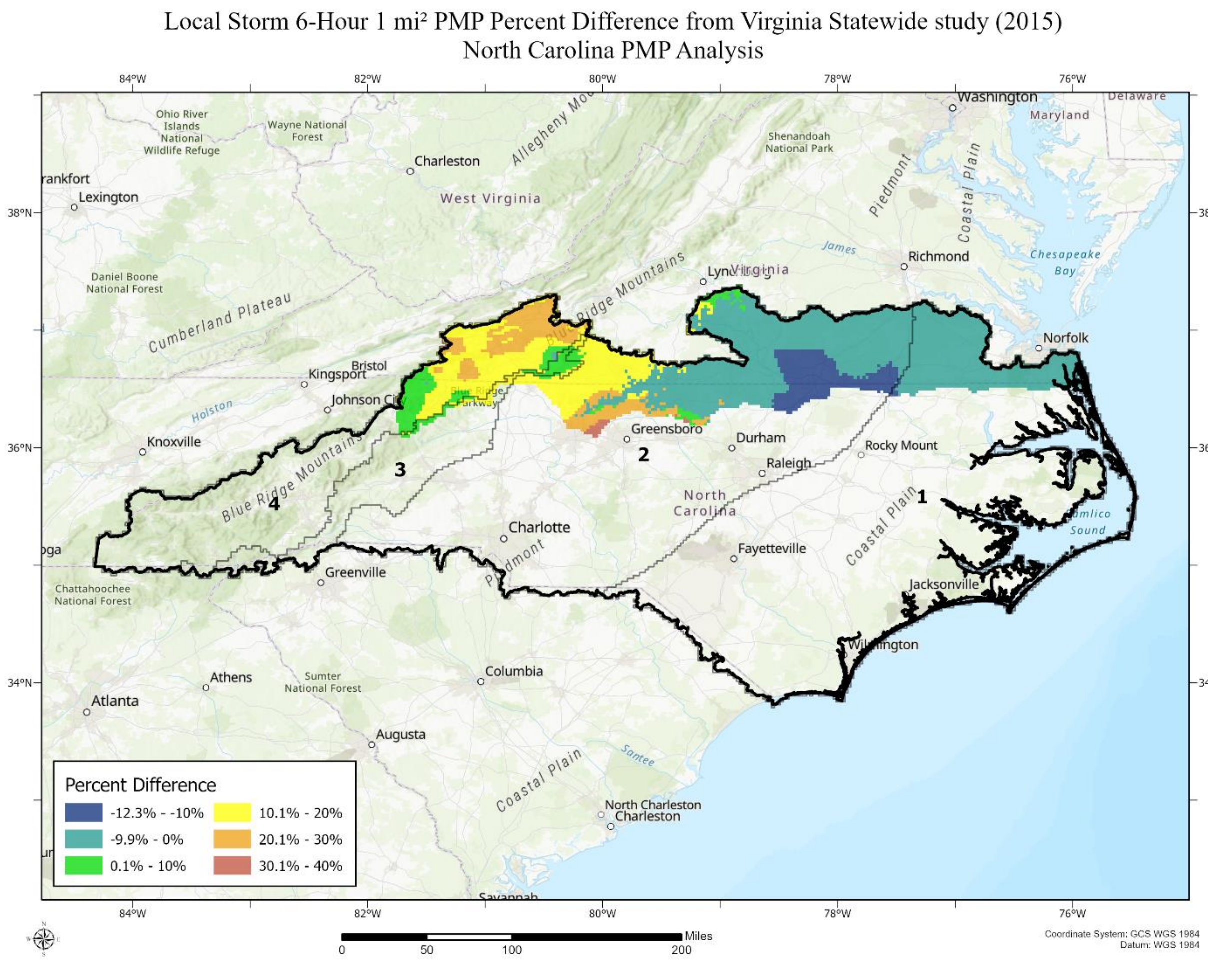


Figure 13.3: Percent difference for Local storm 6 hour 1 square mile PMP from Virginia Study

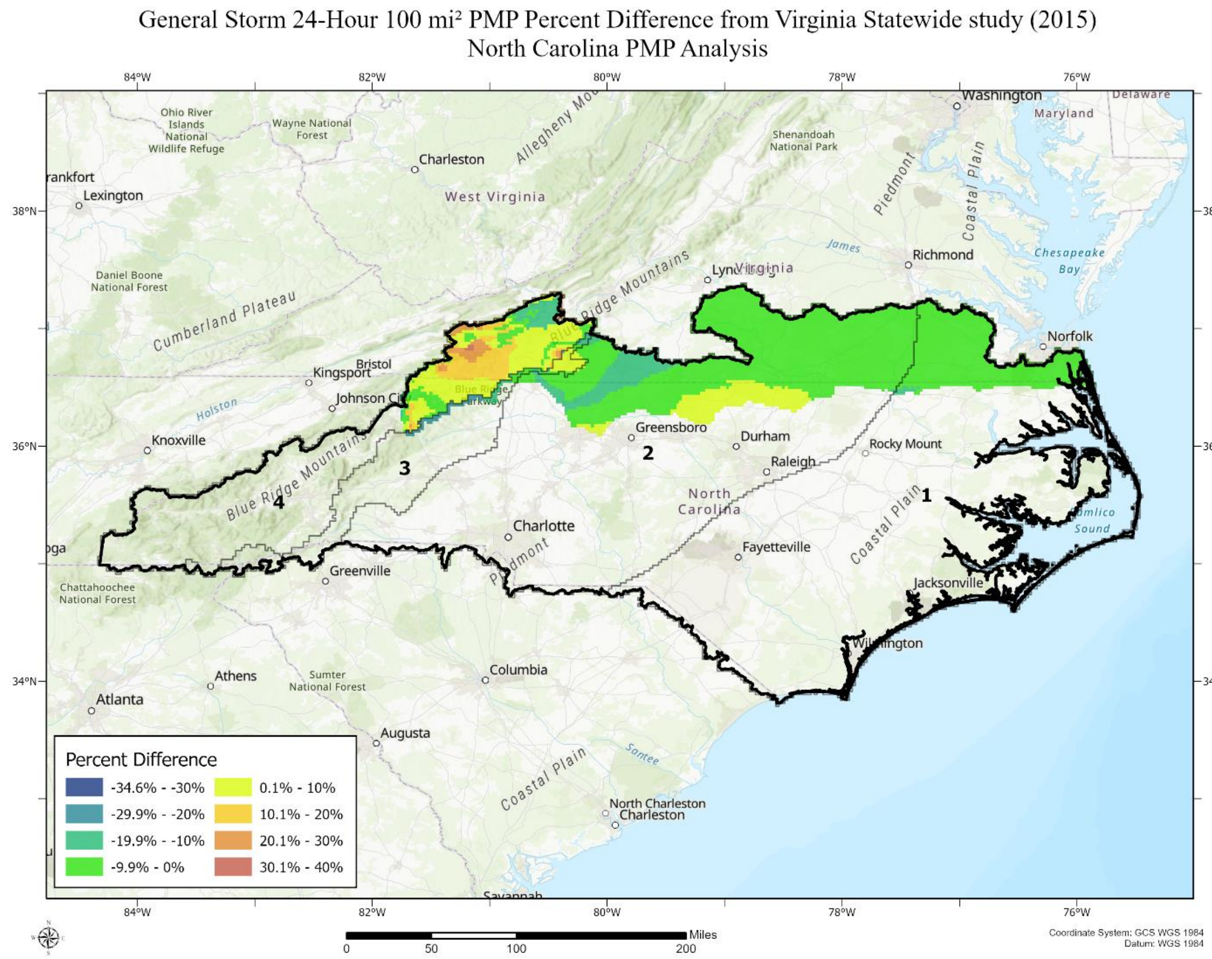


Figure 13.4: Percent difference for General storm 24 hour 100 square mile PMP from Virginia Study

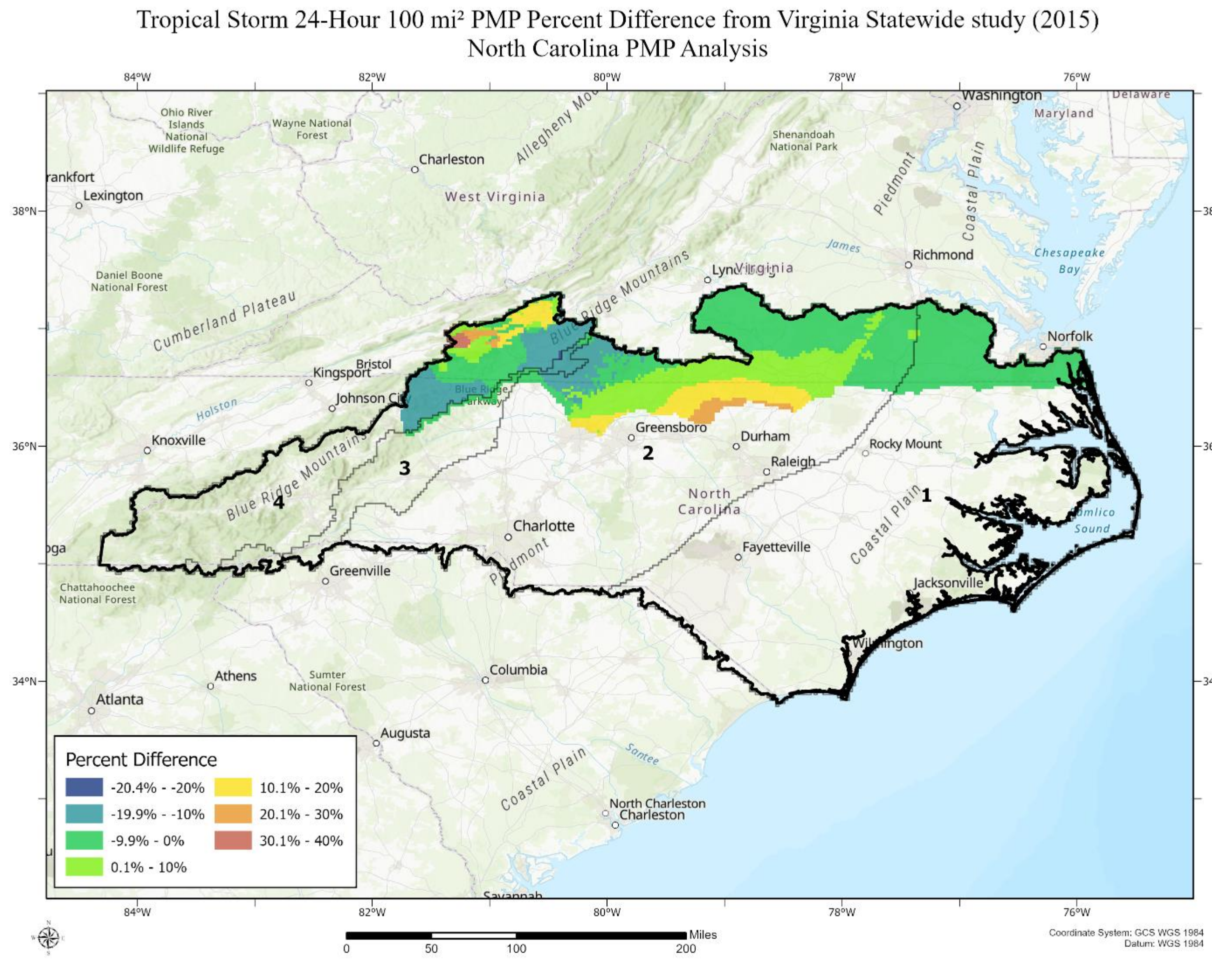


Figure 13.5: Percent difference for Tropical storm 24 hour 100 square mile PMP from Virginia Study

14. Annual Exceedance Probability Analysis of PMP Depths

Precipitation-frequency relationships were analyzed by AWA to derive the Annual Exceedance Probability (AEP) for the 6-hour and 24-hour PMP throughout the state. A regional L-moment analysis based on methods described in Hosking and Wallis (1997) and utilizing the R-statistical software packages lmom and lmomRFA developed by Hosking (Hosking 2015a, and Hosking 2015b) conducted.

14.1 Regional Frequency Analysis

A regional frequency analysis approach utilizes L-moment statistics instead of product moment statistics, which decreases the uncertainty of rainfall frequency estimates for more rare events and dampens the influence of outlier precipitation amounts from extreme storms (Hosking and Wallis, 1997). The basis of a regional frequency analysis is that data from sites within a homogeneous region can be pooled to improve the reliability of the magnitude-frequency estimates for all sites. A homogeneous region may be a geographic area delineated by meteorological climatologies or may be a collection of sites having similar characteristics pertinent to the phenomenon being investigated. The data and methods used are listed in the following sub-sections.

14.2 Precipitation Data and Annual Maximum Series Data

A search to identify individual stations in the region was conducted using precipitation data sources from official NWS stations, Remote Automated Weather Stations (RAWS), and USGS stations. Each station's period of record (POR) was evaluated to determine which stations were appropriate for use in the final regional analysis.

The term "annual maximum" refers to a single 6-hour and 24-hour precipitation maximum being selected for each precipitation gauge for each year of record. Several procedures were required for assembly of the precipitation annual maximum series (AMS) dataset. Figure 14.1 shows the extent of the study area and the stations used in the analysis after the completion of these procedures and all subsequent quality checks. Regional L-moment statistics (Hosking and Wallis, 1997) were computed for the annual maximum data for stations used in the analysis. A total of 184 hourly stations were used in the analysis with an equivalent period of record of 3,765-years. A total of 630 daily stations were used in the analysis with an equivalent period of record of 38,878-years.

- **Hourly Data Extraction** – Precipitation data from hourly gauges were applicable to the 6-hour and 24-hour duration. Precipitation annual maxima for hourly gauges were identified for each year. In the case of the 6-hour and 24-hour durations, a 6-hour and 24-hour window was examined and precipitation for the given 6-hour and 24-hour period were considered as a candidate annual maximum.

- **Daily Data Extraction** – Precipitation data from daily gauges were applicable to the 24-hour duration. Precipitation annual maxima for daily gauges were identified for each year. In the case of the 24-hour duration, each 1-day window was examined and precipitation for the given 1-day period was considered as a candidate annual maximum.

- **Identification of Duplicate Gauges** – “Duplicate” gauge is the term given to the situation where two or more gauges are either co-located at a given site or closely located and have overlapping years of record. Closely located gauges were considered to be gauges within about 5 miles of each other and within about a hundred feet of elevation. The AMS of candidate pairs were scrutinized for having duplicate data before determining which gauge to be excluded as a duplicate. Generally, the longer record was retained for analysis as appropriate. Duplicate gauges were marked and not considered in regional frequency analysis to avoid double-counting.

- **Observational Period Adjustments** – Precipitation annual maxima for continuous durations are desired for regional precipitation-frequency analysis. This can be visualized as having continuous precipitation measurements and sliding a window of time for the desired duration through the continuous data to determine the precipitation maximum for the climatic year. However, daily precipitation is reported on fixed time intervals and not on a continuous basis. For example, at a daily gauge where measurements are taken each day at 7 AM, it is easy to imagine situations where part of a continuous 24-hour precipitation event is reported on day 1 (the first calendar day) and the remainder on day 2 (the second calendar day) during a 24-hour period that overlaps midnight. In this example, the maximum 1-day measurement underestimates the continuous 24-hour measurement, 3-day versus 72-hour measurements suffer the same issue, but with less underestimation, and 5-day versus 120-hour measurements suffer the same issue, also with less underestimation. Standard practice is to use an Observational Period Adjustment (Weiss, 1964; Young and McEnroe, 2003)) to adjust the sample statistics for the mean and standard deviation from fixed interval measurements to be representative of continuous measurements. For these adjustments a value of 1.13 (Young and McEnroe, 2003) was applied to the 1-day observational period and a value of 1.01 was applied to the 6-hour observational period, these adjustments are similar to other frequency studies (Hershfield, 1961; Young and McEnroe, 2003; Bonin et al., 2011). The observational period adjustment was applied to sample at-site mean values for precipitation gauges and durations (Hosking and Wallis, 1997). No adjustments are needed for dimensionless sample L-Moment ratio statistics for L-Cv, L-Skewness and L-Kurtosis.

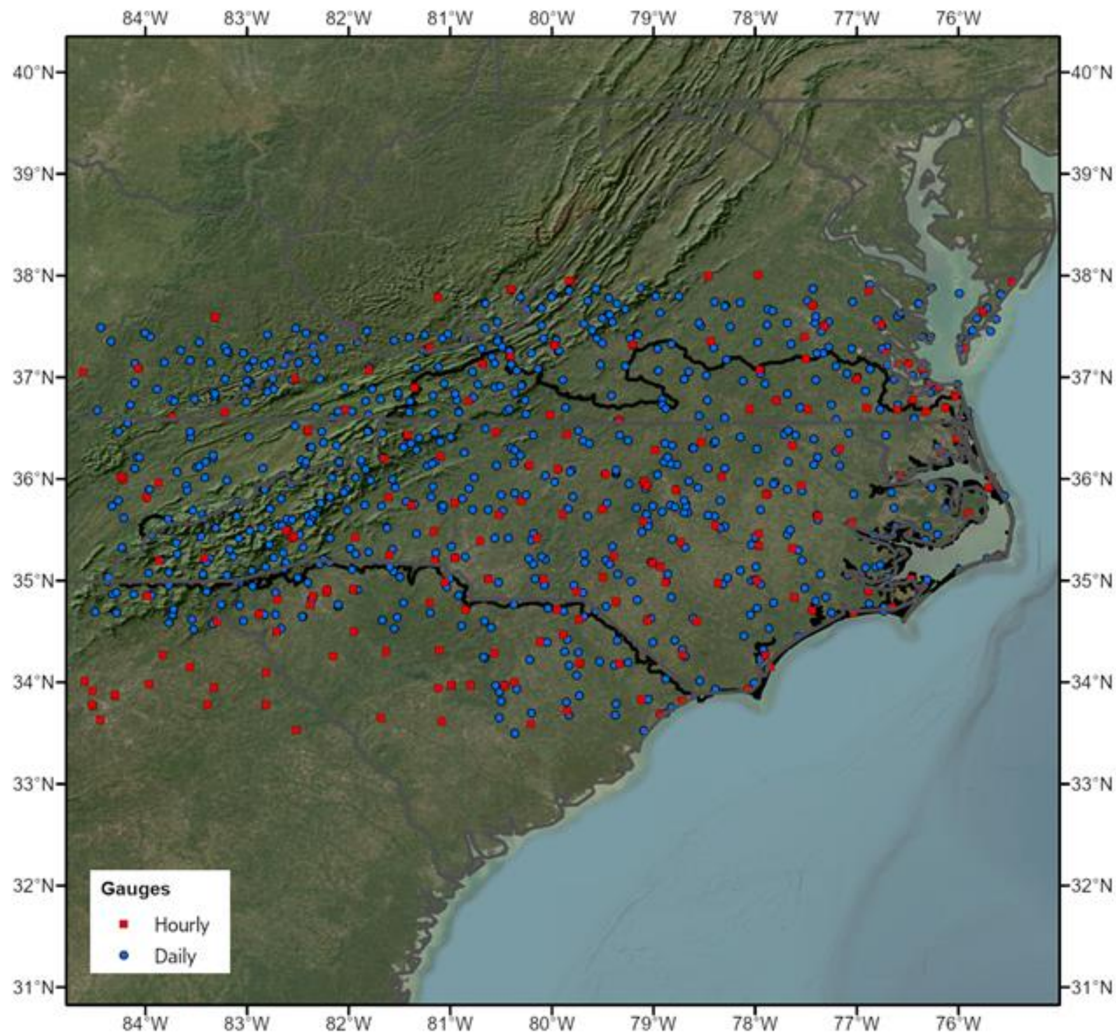


Figure 14.1: Locations of stations used for regional frequency analysis, red plus symbols are hourly stations and light blue circles are daily stations

14.3 Regional L-moments

Key steps in the regional precipitation-frequency analysis included: i) extraction and quality control (QC) of annual maximum data, ii) calculation of an areal reduction factor used to relate point precipitation to areal/basin precipitation, iii) determination of homogeneous regions, iv) calculation of goodness-of-fit measurements, v) calculation of regional frequency curves, vi) estimation of the at-site mean (scaling factor) at any location in a region, and vii) derivation of uncertainly bounds.

The definition of a homogeneous region is the condition that all sites can be described by one probability distribution having common distribution parameters after the site data are rescaled by their at-site mean (Hosking and Wallis, 1997; Schaefer et al., 2006). The at-site mean is calculated as the mean value of the AMS data. All sites within a homogeneous region have a common regional magnitude-frequency curve, termed as a regional growth curve, that becomes site-specific after scaling by the at-site mean of the data. Quantile estimates at a given site, *i*, are estimated by:

$$Q_i(F) = u_i q(F) \qquad \text{Equation 6}$$

where $Q_i(F)$ is the at-site inverse Cumulative Distribution Function (CDF), u_i is the index flood, taken as the estimate of the at-site mean, and $q(F)$ is the regional growth curve, or regional inverse CDF. This method is often called an index-flood approach to regional frequency analyses (Hosking and Wallis, 1997). Regional L-moment statistics (Hosking and Wallis, 1997) were computed for the annual maximum data for stations in the basin of interest using R-statistical software packages lmom and lmomRFA developed by Hosking (Hosking, 2015a, and Hosking, 2015b). Figure 14.2 provides a graphical example of a regional growth curve that would be scaled to the at-site mean annual maximum (MAM) value (Equation 6).

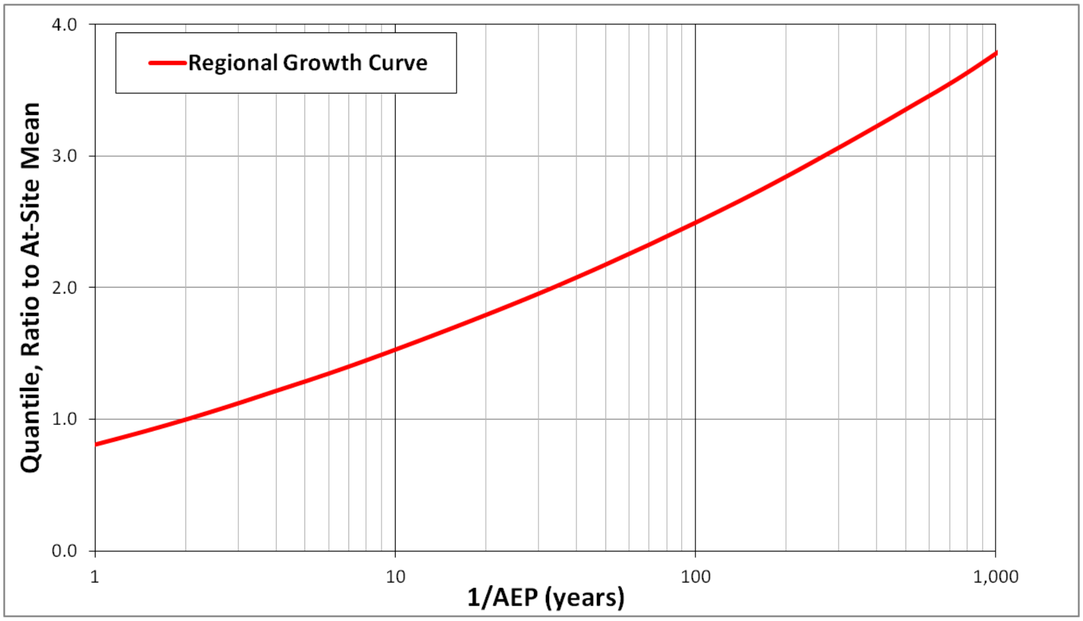


Figure 14.2: Example of regional growth curve

14.4 Areal Reduction Factor: Point to Areal Precipitation

AWA calculated storm centered areal reduction factors (ARFs) using a storm centered depth-area approach based on gridded hourly rainfall data from SPAS. The storm centered ARF does not have a fixed area in which rain falls but changes dynamically with each storm event (NOAA Atlas 2, 1973; Guo, 2012). Instead of the representative point being an average, the representative point is the center of the storm, defined as the point of maximum rainfall. Storm centered ARFs are calculated as the ratio of areal storm rainfall enclosed between isohyets equal to or greater than the isohyet value to the maximum point rainfall at the storm center. A storm centered ARF is calculated as:

$$ARF_{center} = \frac{\overline{R}_i}{R_{center}} \qquad \text{Equation 7}$$

where $\underline{R_i}$ is the areal storm rainfall enclosed between isohyets equal to or greater than the isohyets, and R_{center} is the maximum point rainfall at the storm center.

The SPAS DAD program was used to derive 6-hour and 24-hour depth-area values based on a set of SPAS storms analyzed and used as part of the PMP development. The point maximum (1-mi^2) 6-hour and 24-hour rainfall (within each SPAS DAD zone) was selected as the storm center. The maximum 6-hour and 24-hour rainfall depth for standard area sizes (1-, 10-, 25-, 50-, 100-, 150-, 200-, 250-, 300-, 350-, 400-, 450-, 500-, 700-, 1000-, 2000-, and 5000-mi^2) were calculated. The point maximum and maximum areal averages depths were used to calculate each event's specific ARFs. The ARFs for the basins were determined by linear interpolation using the two bounding area sizes. A three-parameter log-logistic function with an upper limit of 1 was used to estimate the average, maximum, and minimum ARF by area size following:

$$ARF_x = c + \frac{1-c}{1+exp\,(b(LN(x)-LN(e)))} \qquad \text{Equation 8}$$

where *x* is area size, and *c*, *b*, and *e* are fitting coefficients. The maximum, average, and minimum ARF curves, based on each event from the short list, are shown in Figures 14.3 through Figure 14.6. For this study, the average storm event ARF were applied for the point to basin area conversion of the 6-hour and 24-hour precipitation data. Several test basins within the North Carolina PMP domain were selected, some of the basins' relatively small area size produced very little difference from the point values to the areal values shown in Table 14.1. This was expected but the use of the site-specific ARF information provides a more accurate representation of the AEP across the region.

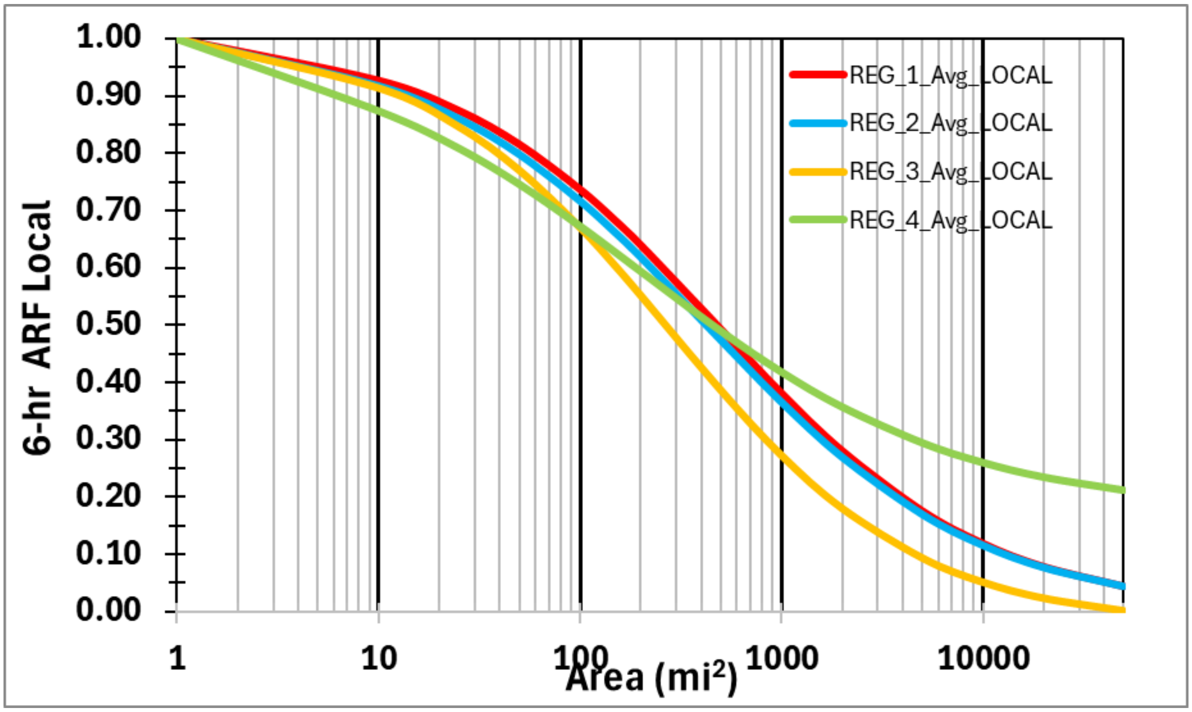


Figure 14.3: North Carolina 6-hour ARF values for each transposition region

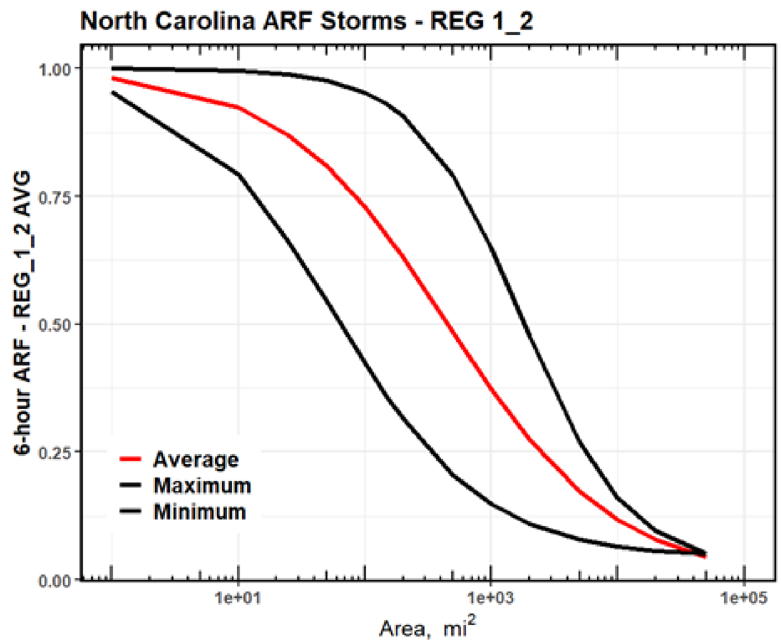


Figure 14.4: North Carolina 6-hour ARF values for transposition region 1 and 2

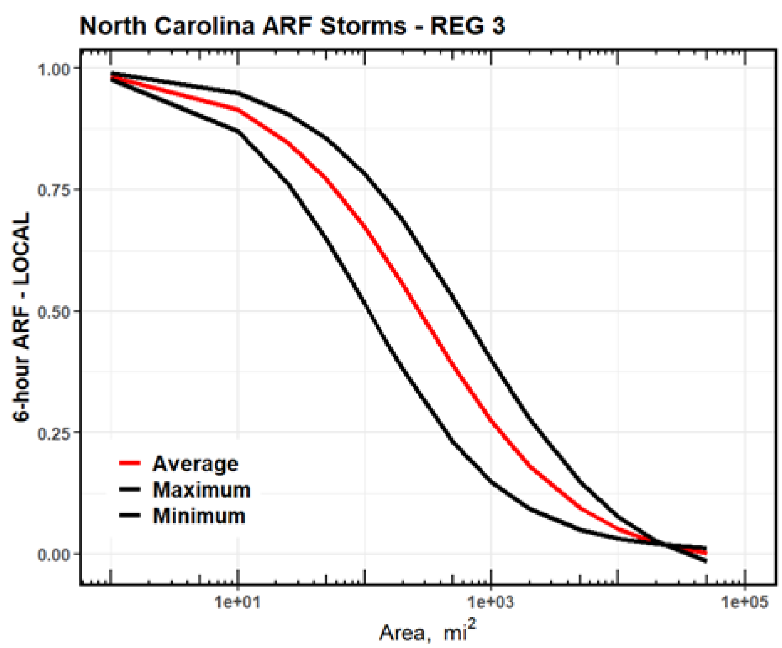


Figure 14.5: North Carolina 6-hour ARF values for transposition region 3

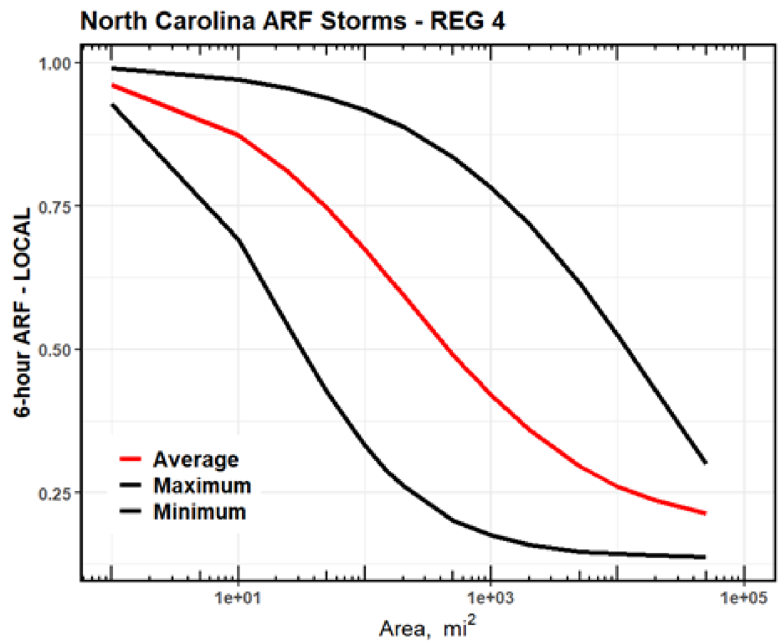


Figure 14.6: North Carolina 6-hour ARF values for transposition region 4

Table 14.1: Basin specific ARF values used to convert point precipitation to areal precipitation

Test Basin	Transposition Zone	Area (sqmi)	6hr Storm ARF	24hr Storm ARF
CUMBE_052_ArranLakesWestDam	Zone 1	2.4	0.969	0.987
WAYNE_013_Bass_Lake_Dam	Zone 1	5.0	0.950	0.981
CABAR_002_Lake_Fisher_Dam	Zone 2	18.9	0.889	0.963
PERSO_013_Roxboro_Afterbay_Dam	Zone 2	203.1	0.628	0.880
RUTHE_003_Lake_Lure	Zone 3	94.4	0.681	0.917
BUNCO_088_Lake_Julian_DA	Zone 4	4.8	0.912	0.982
MACON024_WataugaVistaDam	Zone 4	0.6	0.971	0.994

14.5 Homogenous Regions

The regional analysis approach is based on the concept that at-site data can be pooled within regions that are "homogeneous." In this context, homogeneous is taken to mean that probability distributions and their resultant frequency curves for at-site data are identical, except for a site-specific scaling factor, at all sites in a region. The at-site station mean MAM value is commonly used as the scaling factor in regional analyses. It was initially assumed that one homogeneous region was represented by all stations within close proximity to the basin location. This assumption is reasonable and justifiable to make for a small local region prior to performing heterogeneity measures. For the cluster analysis, regions based on 1, 2, 3, and 4 clustered regions, were performed to test and to identify the set of regions to group. An example of the 6-hour and 24-hour cluster analysis is shown in Figure 14.7 and Figure 14.8. The final 6-hour and 24-hour cluster analysis regions used are shown in Figure 14.9 and Figure 14.10.

Heterogeneity measures were computed for the annual maximum data for stations within the region. Hosking and Wallis (1997) developed heterogeneity measures to help indicate the level of heterogeneity or homogeneity in the L-moment ratios for a group of stations representing a sub-region. The statistics H1 and H2 denote the relative variability of observed L-Cv and L-Skewness respectively for stations within a sub-region. The H1 and H2 measures compare the observed variability to that which is expected from a large sample drawn from a homogeneous region based on the Kappa distribution. The 24-hour duration passed the homogeneity criteria (H1<3) while the 6-hour duration barely exceeded the homogeneity criteria (H1<3) but was still deemed homogeneous (Hosking and Wallis, 1997). Although Hosking and Wallis (1997) recommend homogenous regions screening of the H1 statistic to be less than three, numerous studies have claimed homogenous regions with H1 values to be larger than three. For example, England et al., (2014) deemed one basin in New Mexico to be homogeneous with an H1 value of 7.73. The heterogeneity tests and three parameter distributions that are statistically significant for the region are shown in Table 14.2.

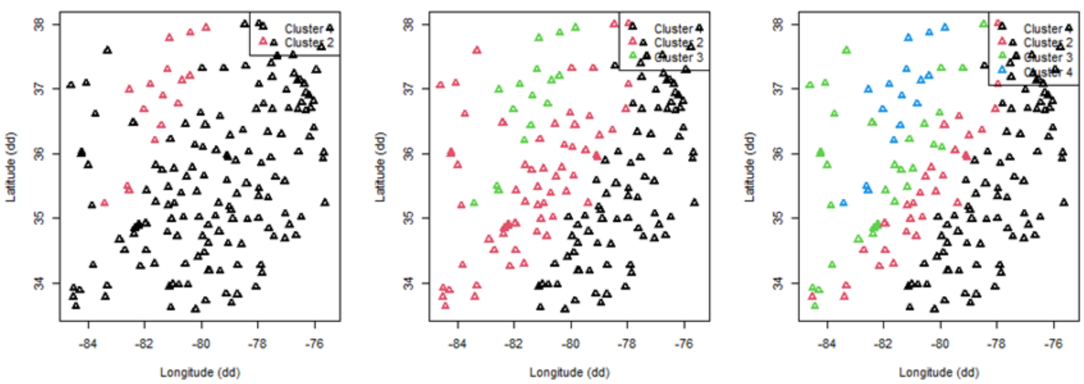


Figure 14.7: 6-hour cluster analysis investigated in the region

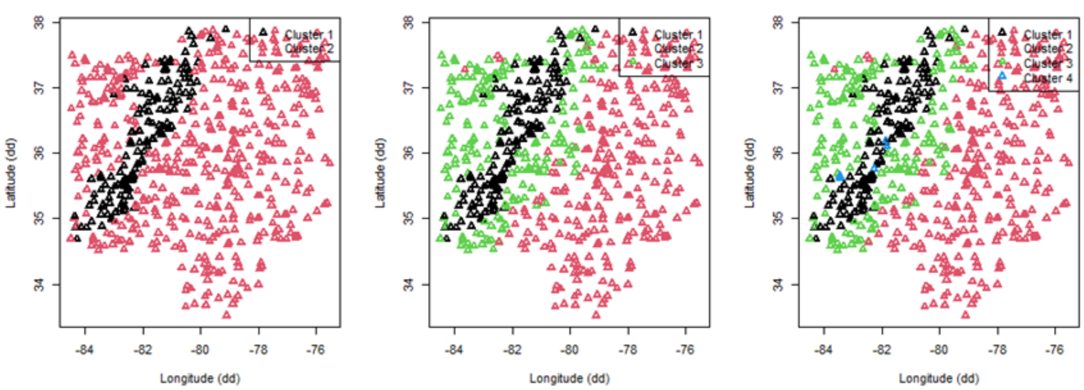


Figure 14.8: 24-hour cluster analysis investigated in the region

Table 14.2: Heterogeneity statistics for the region

Duration	H1	H2	Distribution
6-hour			
Region 1	2.12	2.93	GEV
Region 2	3.05	3.16	GEV, GNO
Region 3	3.06	3.21	GEV,GNO, PE3
24-hour			
Region 1	2.75	0.59	GEV, GNO
Region 2	1.52	1.61	GEV, GNO, PE3
Region 3	2.94	0.08	GEV, GNO

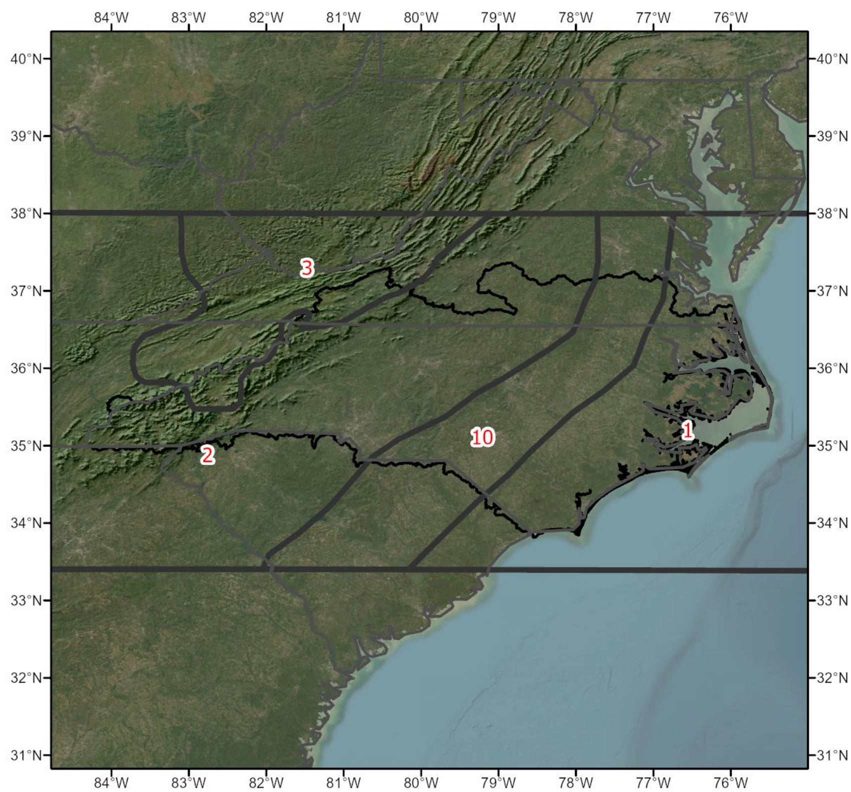


Figure 14.9: Final 6-hour cluster analysis regions

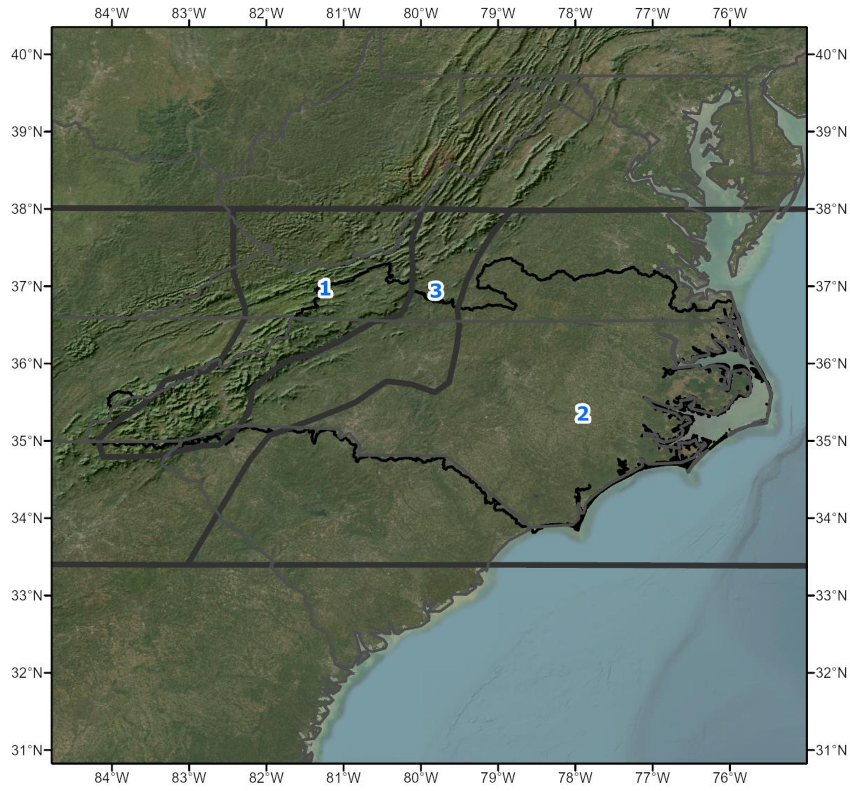


Figure 14.10: Final 24-hour cluster analysis regions

14.6 Discordancy Test

Even among homogeneous regions, some stations may be considered grossly inconsistent from the region as a whole. Such stations are identified using a test, which resulted in a discordancy measure. The discordancy measure provided an important indicator of stations that should be moved to a different region and/or contained data errors in their AMS. However, by nature of the L-moment approach, an erroneous individual annual maximum at this early stage in the analysis will have a limited negative impact on the results. For the final set of stations utilized in this study, all passed the discordancy tests (D<3) (Hosking and Wallis, 1997).

14.7 Identification of Probability Distribution

Regional L-moment statistics were computed for annual maximum data for each site at the homogenous region discussed above. Goodness of fit measures were evaluated for five candidate distributions: generalized logistic (GLO), generalized extreme value (GEV), generalized normal (GNO), Pearson type III (PE3), and generalized Pareto (GPA). An L-Moment Ratio Diagram was prepared based on L-Skewness and L-Kurtosis pairs for the collection of stations in each homogenous region for each duration (Figure 14.11 and Figure 14.12). The regional weighted-average L-Skewness and L-Kurtosis pairing were found to be very near the GEV and GLO distributions.

The GEV distribution was selected over the GNO for frequency estimates because: i) the GEV distribution was ranked statistically higher, ii) NOAA Atlas 14 precipitation frequency studies in the region use this distribution, iii) the GEV was identified in goodness-of-fit measures and used for frequency estimates in nearby AWA studies, and iv) using the same distribution among frequency studies ensures a direct comparison to more rare values of the frequency curve (Kappel et al., 2018; Kappel et al., 2023). The GEV is a general mathematical form that incorporates Gumbel's Extreme Value (EV) type I, II, and III distributions for maxima. The parameters of the GEV distribution are the ξ (location), α (scale), and k (shape). The Gumbel EV type I distribution is obtained when $k = 0$. For $k > 0$, the distribution has finite upper bound at $\xi + \alpha / k$ and corresponds to the EV type III distribution for maxima that are bounded above. For $k < 0$, this corresponds to the Gumbel EV type II distribution.

Regional growth curves were created for the homogenous region based on a GEV distribution and quantiles for eighteen return periods (1, 2, 5, 10, 25, 50, 100, 200, 500, 1,000, 5,000, 10,000, 100,000, 1,000,000, 10,000,000, 100,000,000, 1,000,000,000, and 10,000,000,000 years) were calculated for the 6-hour and 24-hour durations.

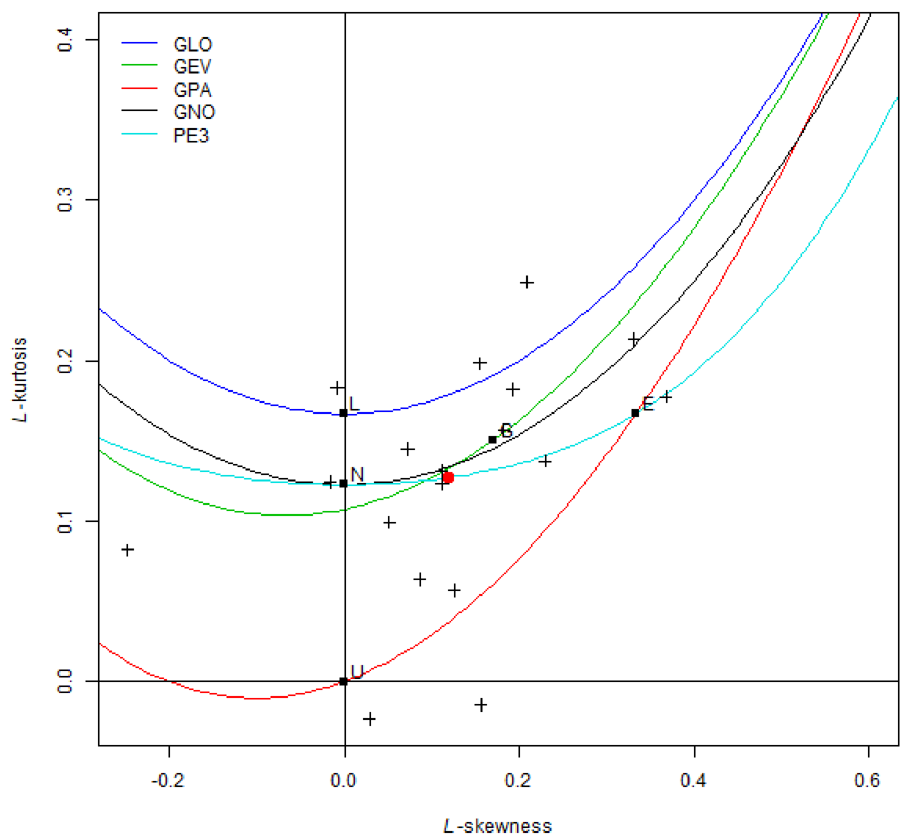


Figure 14.11: 6-hour L-moment ratio diagram for Region 3 stations used in the regional analysis

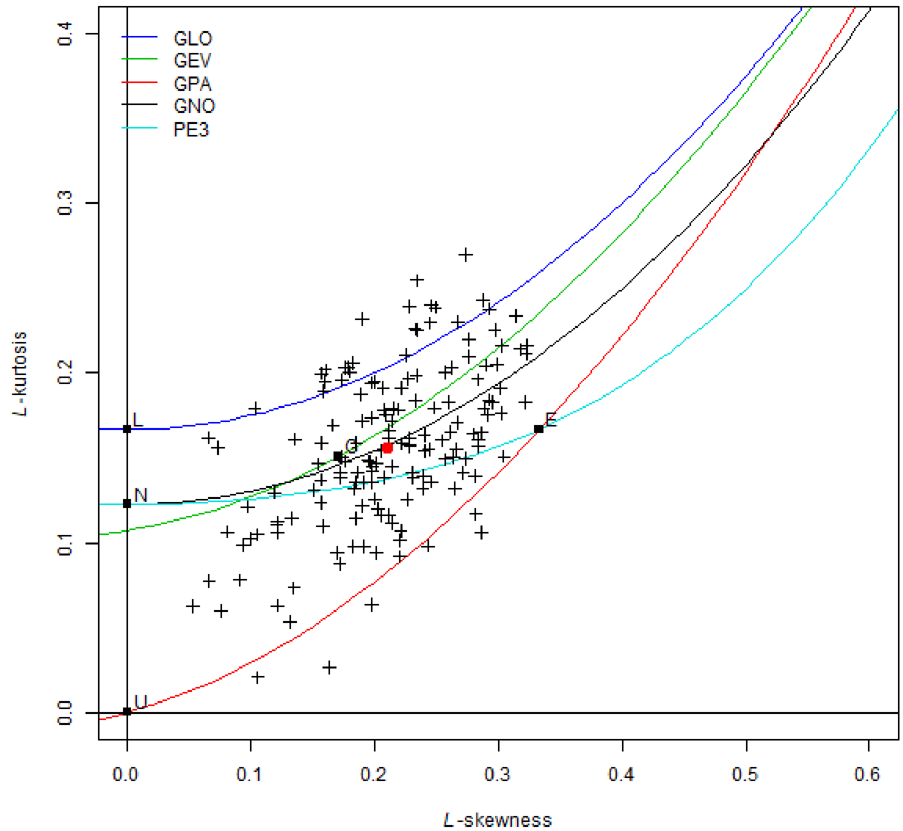


Figure 14.12: 24-hour L-moment ratio diagram for Region 3 stations used in the regional analysis

14.8 Derivation of Uncertainty Bounds

The uncertainty analysis for deriving the frequency curve and uncertainty bounds were conducted as follows. The frequency distributions at the site were randomly permuted, and data were simulated from the selected frequency distribution. The procedure is described in Hosking and Wallis (1997) and Hosking (2015b), except that the permutation of frequency distributions is a later modification, intended to give more realistic sets of simulated data (Hosking, 2015b). From each permutation, the sample mean values and estimates of the quantiles of the regional growth curve for non-exceedance probabilities are saved. From the simulated values, for each quantile specified the relative root mean square error (relative RMSE) is computed as in Hosking and Wallis (1997). The error bounds are sample quantiles of the ratio of the estimated regional growth curve to the true at-site growth curve or of the ratio of the estimated to the true quantiles at individual sites (Hosking, 2015b).

14.9 Spatial Mapping of At-Site Scaling Factor

The at-site mean or MAM L-moment statistics were spatially mapped for development of frequency grids. Typically, explanatory variables and associated predictor equations are used to map at-site MAM using existing continuous gridded variables. Explanatory variables considered included climatic and location indices such as PRISM mean annual precipitation (Daly et al., 1997). Spatial mapping of at-site MAM involved a three-step process:

1. Determine a predictor equation that describes the regional behavior of the at-site means across the study area.
2. Compute a best-estimate of the at-site mean at a given station using a weighted average of the regionally-predicted at-site mean (step 1 above) and the sample at-site MAM.
3. Adjust the resulting at-site means to account for spatial coherence of the error residuals (observed-predicted values) in a given locality.

At-site MAM have been well-predicted by climate indicators such as PRISM precipitation. Review of the behavior of at-site means like this allowed for the development of regression relationships for the prediction of at-site means for spatial mapping. Best estimates of the at-site MAMs at the stations were obtained using an Empirical Bayes Approach (Kuczera, 1982) as a weighted average of the values predicted from the regression relationship and the sample value of the station at-site MAM (Step 2 above). Greater weight was given to the sample value of the at-site mean as the record length at a station increased. Residuals were defined as the difference between the weighted-average at-site mean and the regression-predicted at-site mean. Adjustments were then made to the predicted estimates of the at-site means to account for coherence in the spatial distribution of residuals, where the residuals in some geographic areas were not random, but rather systematically over-estimated or under-estimated the at-site mean relative to the regression prediction (Step 3 above); this was done by interpolating standardized residuals and summing the residual grid with the at-site mean grid developed in Step 1.

The estimated at-site MAMs for the study area are compared to the unadjusted observed values. A reduction in the predictive error for the estimated at-site MAMs and better statistical fit were found (e.g. 24-hour initial MAM $r^2 = 0.7301$; final MAM $r^2 = 0.9609$). This is a result of accounting for both regional information (regional predictive equation), local information (station at-site mean) and accounting for the spatial coherence of residuals. The final (mapped) values of the at-site MAM are judged to be the best-estimates achievable from the collection of regional and at-site information. Figure 14.13 and Figure 14.14 depict the final mapped MAM values of the 6-hour and 24-hour at-site MAM.

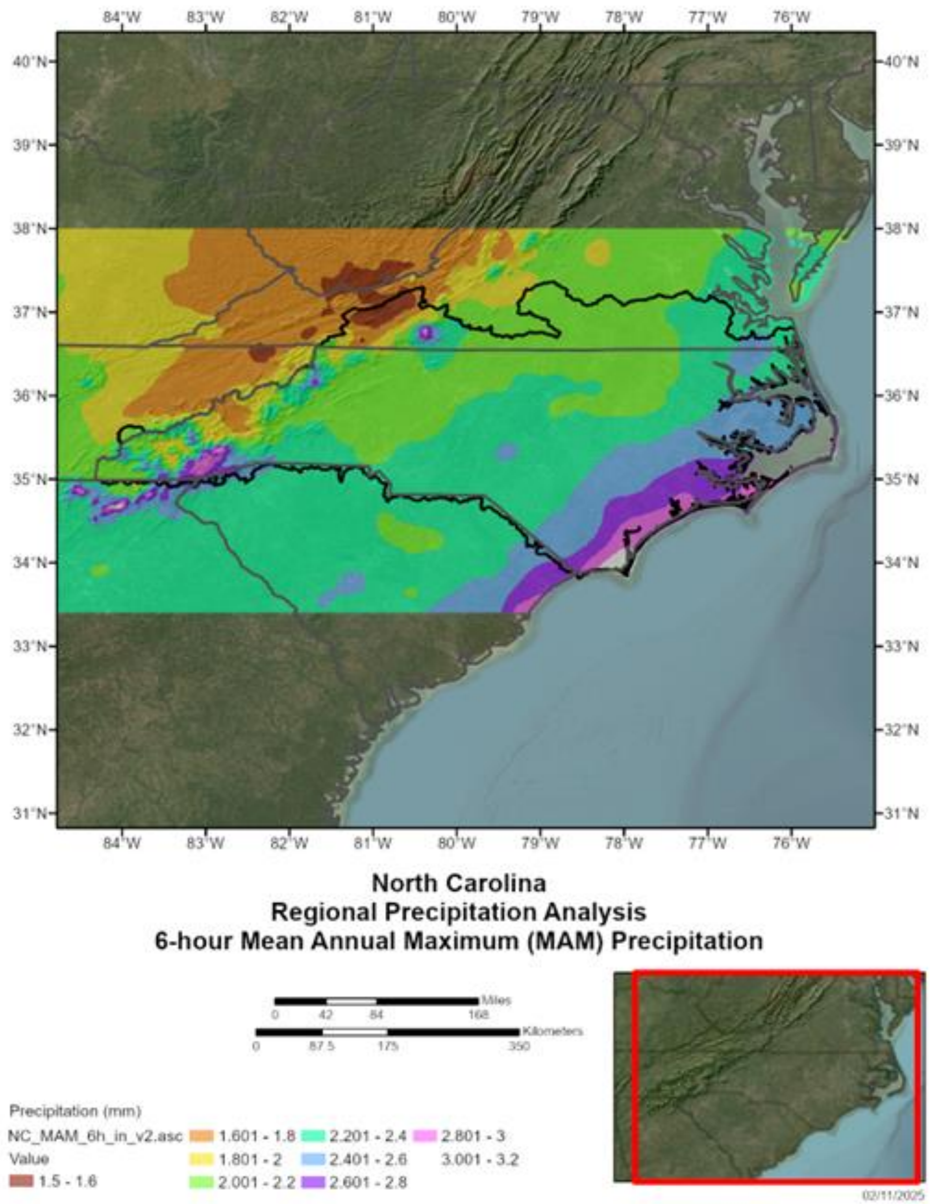


Figure 14.13: Spatially mapped at-site MAM values for 6-hour duration

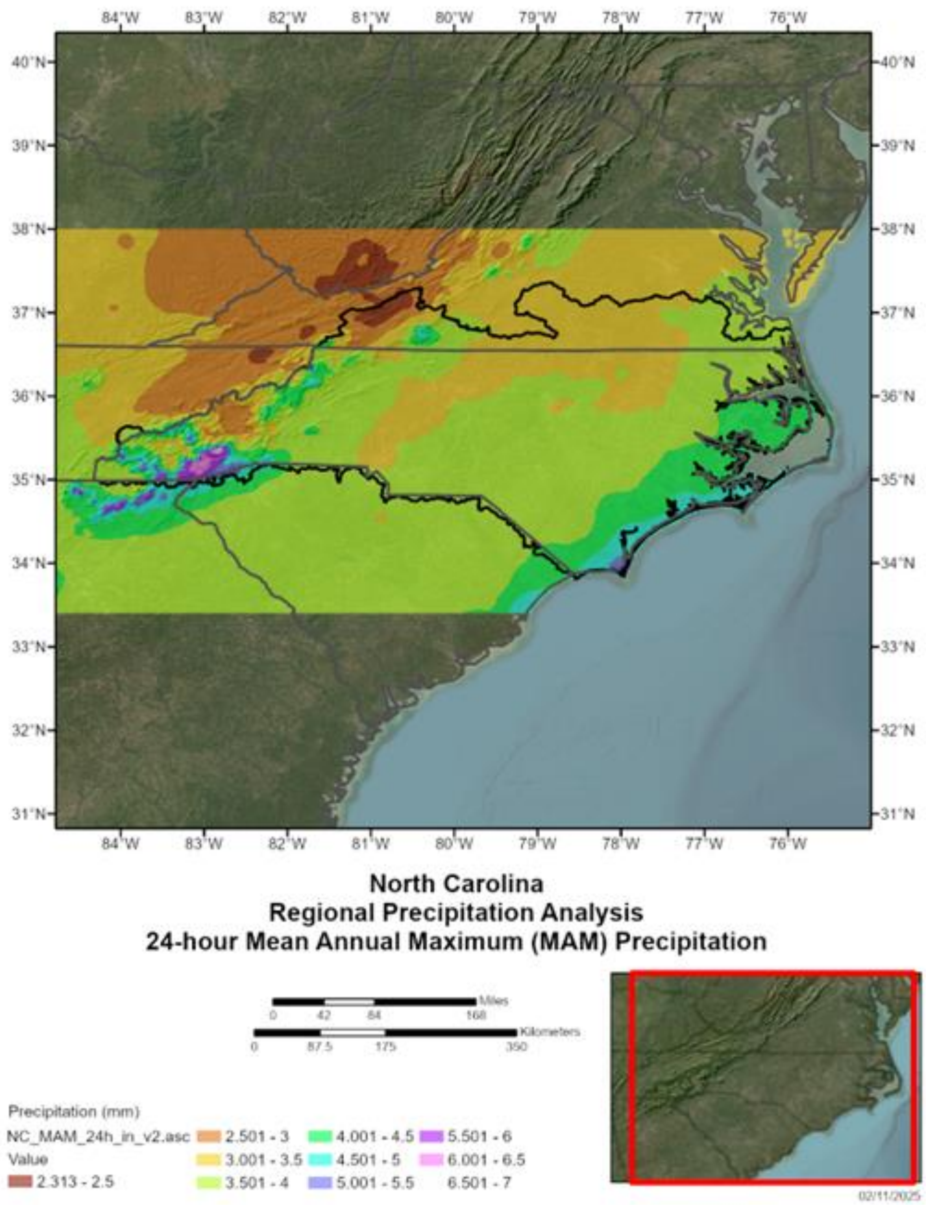


Figure 14.14: Spatially mapped at-site MAM values for 24-hour duration with the test basins shown

14.10 Gridded Precipitation Frequency Estimates

The gridded datasets for the at-site MAM statistics described in the above sections were then used to scale the GEV distribution regional curve for each duration (Equation 6) on a grid-cell by grid-cell basis. This allowed spatial mapping of precipitation-frequency estimates for selected recurrence intervals for the durations of 6-hour and 24-hour. Eighteen average recurrence interval (ARI) grids per duration were prepared from this information for point precipitation maxima for 1, 2, 5, 10, 25, 50, 100, 200, 500, 1,000, 5,000, 10,000, 100,000, 1,000,000, 10,000,000, 100,000,000, 1,000,000,000, and 10,000,000,000 years. The final 6-hour 100-year ARI and 24-hour 100-year ARI are shown in Figure 14.15 and Figure 14.16. Point frequency grids were converted to basin average precipitation using the site-specific ARF discussed above.

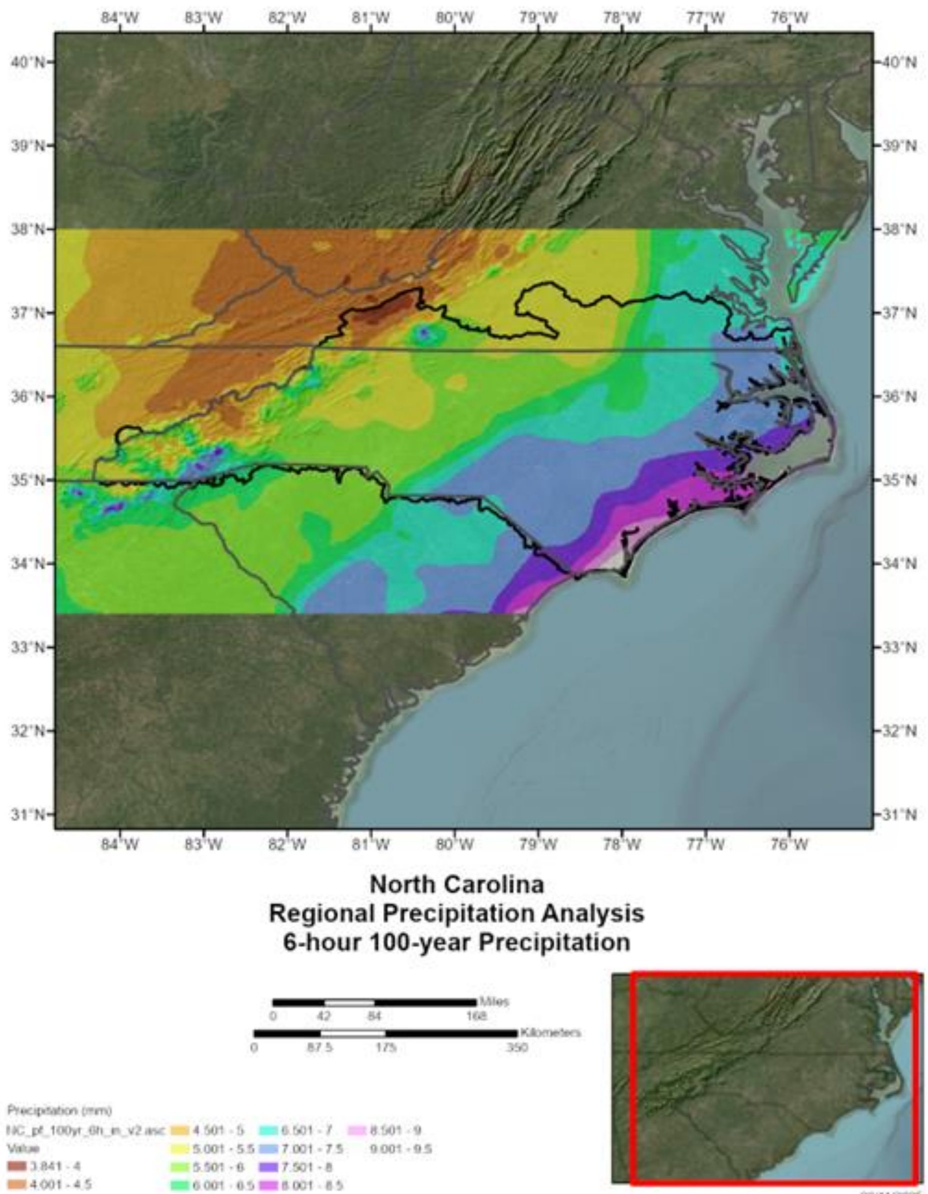


Figure 14.15: Spatially mapped 6-hour 100-year precipitation

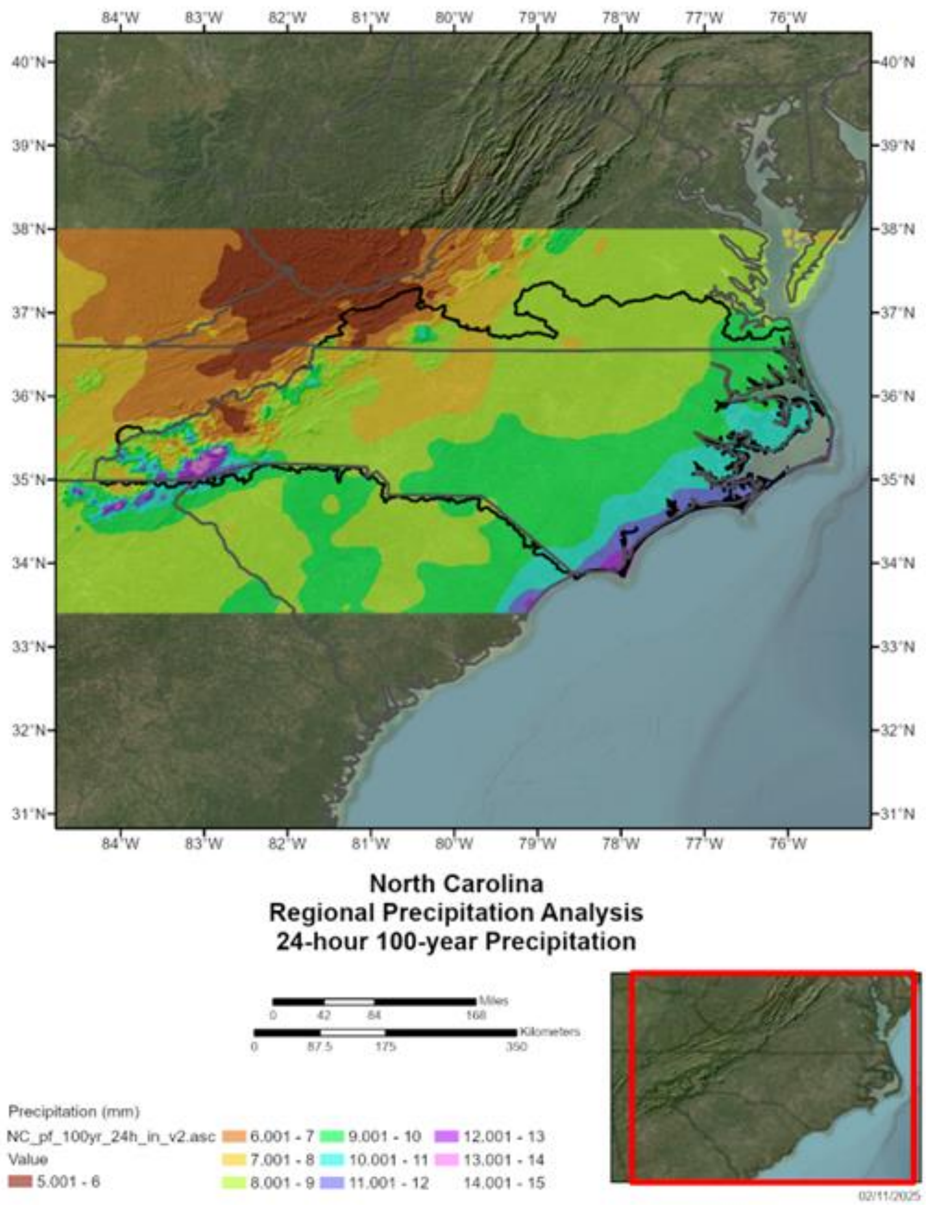


Figure 14.16: Spatially mapped 24-hour 100-year precipitation

14.11 Annual Exceedance Probability Table

Annual Exceedance Probability grids for the 6-hour and 24-hour were used to extract the 1-sq mi AEPs and the seven test basin's average AEPs, the point frequency estimates converted to a basin average precipitation based on ARF, and then estimating the average AEP from all grids within the defined basin (Table 14.3 and Figure 14.17). The 6-hour and 24-hour basin average AEP values for the test basins are provided in Table 14.4 through Table 14.10 and illustrated in Figure 14.18 through Figure 14.24. The test basins 6-hour PMP have AEP estimates of 10^{-8} while the 24-hour PMP have AEP estimates of 10^{-8} (Table 14.11). For temporal pattern guidance, the information developed for this study as discussed in Section 12 should be applied. Additional details are provided in Appendix K.

Table 14.3: Test basins used to evaluate the 6-hour and 24-hour AEP of PMP

Test Basin	Transposition Zone	Area (sqmi)	6hr Storm ARF	24hr Storm ARF
CUMBE_052_ArranLakesWestDam	Zone 1	2.4	0.969	0.987
WAYNE_013_Bass_Lake_Dam	Zone 1	5.0	0.950	0.981
CABAR_002_Lake_Fisher_Dam	Zone 2	18.9	0.889	0.963
PERSO_013_Roxboro_Afterbay_Dam	Zone 2	203.1	0.628	0.880
RUTHE_003_Lake_Lure	Zone 3	94.4	0.681	0.917
BUNCO_088_Lake_Julian_DA	Zone 4	4.8	0.912	0.982
MACON024_WataugaVistaDam	Zone 4	0.6	0.971	0.994

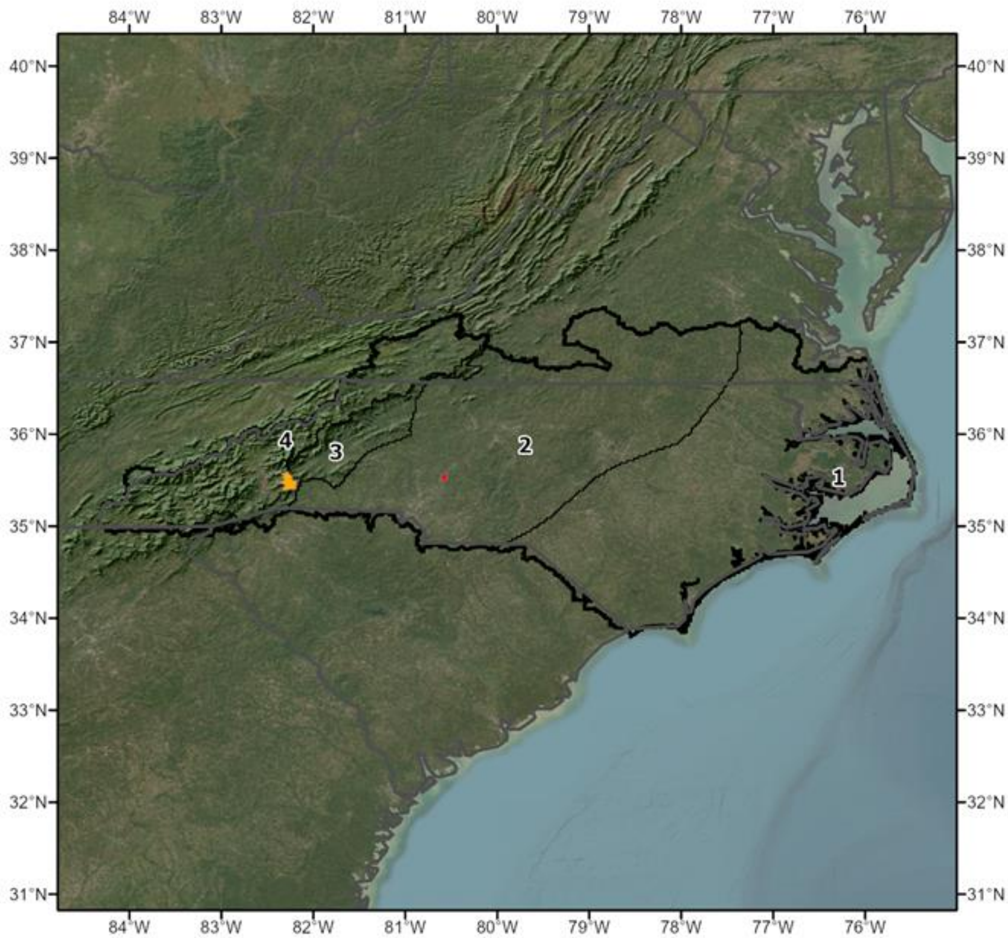


Figure 14.17: Spatial location of the test basins used to evaluate the 6-hour and 24-hour AEP of PMP

Table 14.4: Arran Lakes West Basin AEP for 6-hour and 24-hour PMP

Arran Lakes West Dam (2.4 mi^2)		6-hour			24-hour		
ARI	**AEP**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**
1	9.9^{-1}	***0.5***	0.4	0.6	***1.7***	1.5	1.9
2	5.0^{-1}	***2.0***	1.8	2.2	***3.4***	3.0	3.7
5	2.0^{-1}	***3.1***	2.8	3.4	***4.6***	4.2	5.1
10	1.0^{-1}	***3.9***	3.5	4.3	***5.5***	5.0	6.1
25	4.0^{-2}	***5.0***	4.5	5.5	***6.8***	6.1	7.5
50	2.0^{-2}	***5.9***	5.3	6.5	***7.9***	7.0	8.8
100	1.0^{-2}	***6.9***	6.1	7.7	***9.2***	8.1	10.2
200	5.0^{-3}	***8.0***	6.9	9.0	***10.5***	9.1	11.8
500	2.0^{-3}	***9.6***	8.2	10.9	***12.5***	10.7	14.2
1,000	1.0^{-3}	***10.9***	9.2	12.5	***14.2***	12.0	16.3
5,000	2.0^{-4}	***14.4***	11.8	16.8	***19.0***	15.5	22.1
10,000	1.0^{-4}	***16.2***	13.0	19.2	***21.4***	17.2	25.3
100,000	1.0^{-5}	***23.2***	17.7	29.3	***31.4***	24.0	39.6
1,000,000	1.0^{-6}	***32.6***	23.5	43.8	***45.6***	32.9	61.2
10,000,000	1.0^{-7}	***45.0***	30.7	64.6	***65.5***	44.6	93.9
100,000,000	1.0^{-8}	***61.6***	39.4	94.8	***93.5***	59.9	143.9
1,000,000,000	1.0^{-9}	***83.6***	50.2	138.6	***133.0***	79.8	220.3
10,000,000,000	1.0^{-10}	***112.9***	63.5	201.7	***188.5***	106.0	336.7

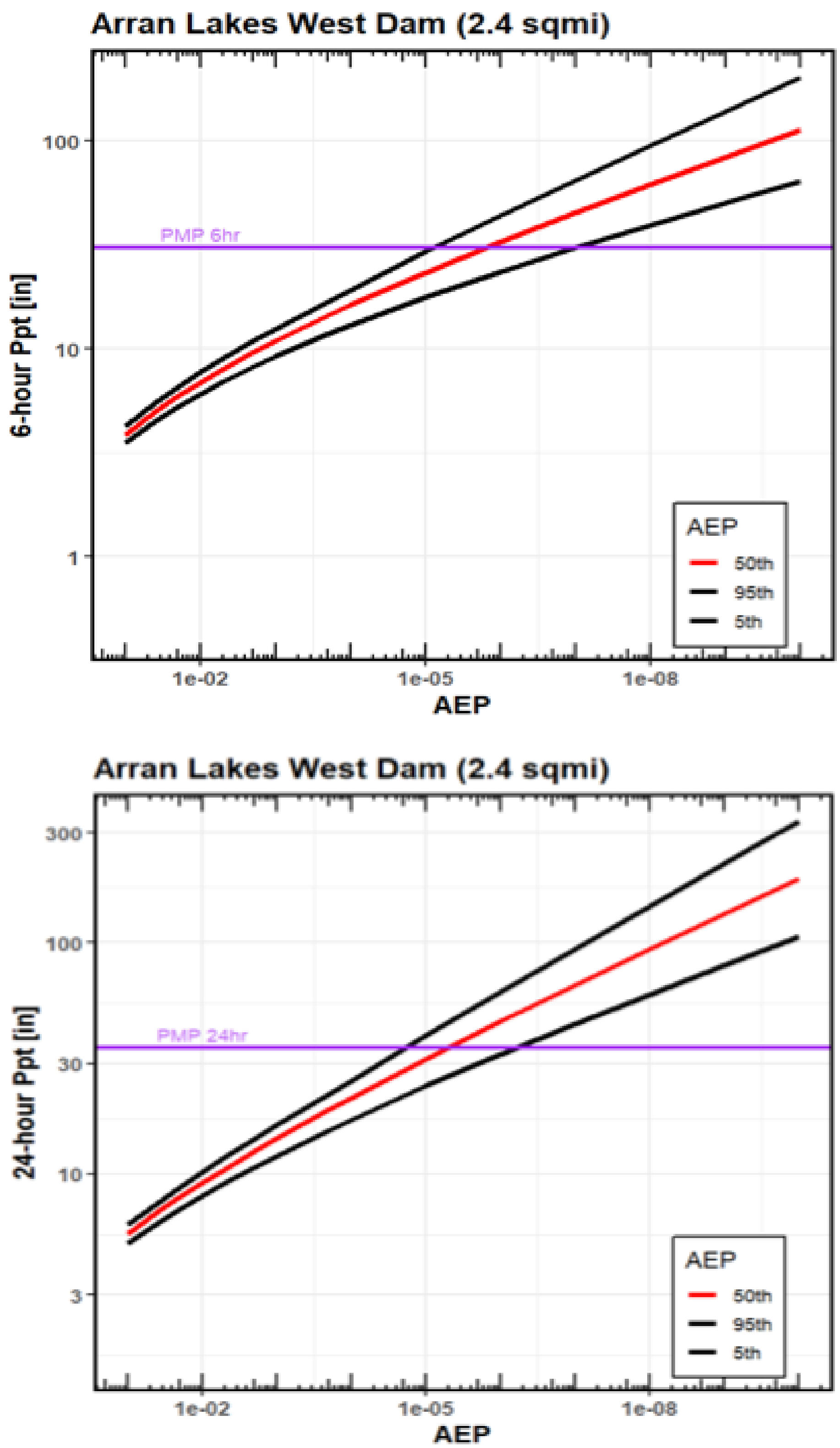


Figure 14.18: Arran Lakes West Basin regional L-moment frequency curve (red line) and uncertainty bounds (black line) with basin average PMP (purple line) for the 6- and 24-hour durations

Table 14.5: Bass Lake Basin AEP for 6-hour and 24-hour PMP

Bass Lake Dam (5.0 mi^2)		6-hour			24-hour		
ARI	**AEP**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**
1	9.9^{-1}	***0.5***	0.4	0.5	***1.7***	1.5	1.9
2	5.0^{-1}	***2.0***	1.8	2.2	***3.4***	3.0	3.7
5	2.0^{-1}	***3.1***	2.8	3.4	***4.6***	4.2	5.1
10	1.0^{-1}	***3.9***	3.5	4.3	***5.5***	5.0	6.1
25	4.0^{-2}	***5.0***	4.5	5.4	***6.8***	6.1	7.5
50	2.0^{-2}	***5.9***	5.2	6.5	***7.9***	7.1	8.8
100	1.0^{-2}	***6.8***	6.0	7.6	***9.2***	8.1	10.2
200	5.0^{-3}	***7.8***	6.8	8.8	***10.5***	9.1	11.8
500	2.0^{-3}	***9.3***	8.0	10.6	***12.5***	10.7	14.2
1,000	1.0^{-3}	***10.5***	8.9	12.1	***14.2***	12.0	16.3
5,000	2.0^{-4}	***13.7***	11.2	16.0	***19.0***	15.5	22.1
10,000	1.0^{-4}	***15.3***	12.3	18.1	***21.4***	17.2	25.3
100,000	1.0^{-5}	***21.4***	16.4	27.0	***31.4***	24.0	39.6
1,000,000	1.0^{-6}	***29.3***	21.2	39.4	***45.6***	32.9	61.3
10,000,000	1.0^{-7}	***39.4***	26.8	56.5	***65.5***	44.6	93.9
100,000,000	1.0^{-8}	***52.4***	33.6	80.7	***93.5***	59.9	144.0
1,000,000,000	1.0^{-9}	***69.2***	41.5	114.6	***133.0***	79.9	220.4
10,000,000,000	1.0^{-10}	***90.6***	51.0	161.9	***188.6***	106.1	336.8

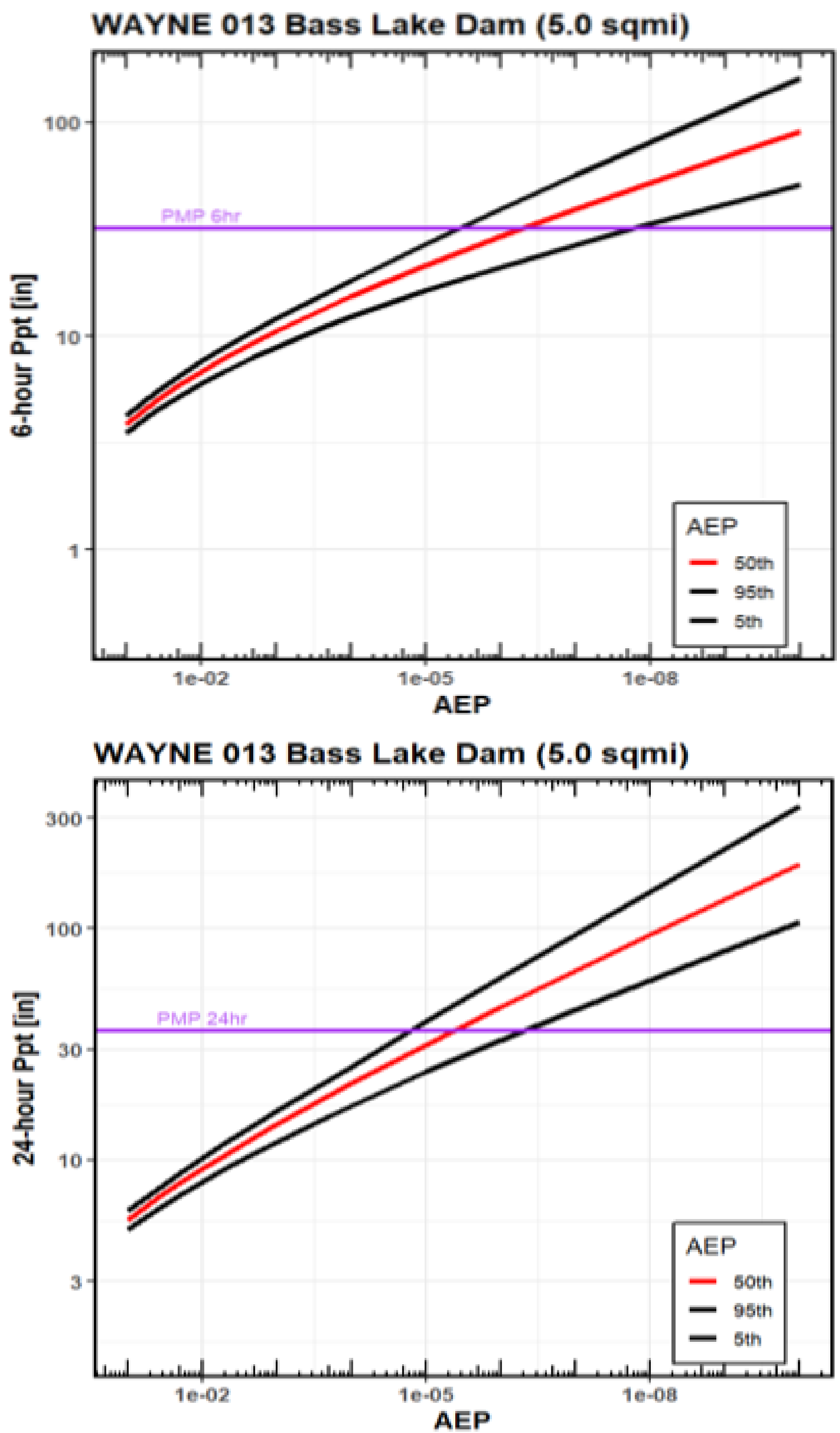


Figure 14.19: Bass Lake Basin regional L-moment frequency curve (red line) and uncertainty bounds (black line) with basin average PMP (purple line) for the 6- and 24-hour durations

Table 14.6: Lake Fisher Basin AEP for 6-hour and 24-hour PMP

Lake Fisher Dam (18.9 mi^2)		6-hour			24-hour		
ARI	AEP	50%	5%	95%	50%	5%	95%
1	9.9^{-1}	***0.7***	0.6	0.8	***1.6***	1.4	1.7
2	5.0^{-1}	***1.7***	1.6	1.9	***3.0***	2.7	3.3
5	2.0^{-1}	***2.5***	2.3	2.7	***4.1***	3.7	4.5
10	1.0^{-1}	***3.0***	2.7	3.3	***4.9***	4.5	5.4
25	4.0^{-2}	***3.7***	3.4	4.1	***6.1***	5.4	6.6
50	2.0^{-2}	***4.3***	3.8	4.8	***7.0***	6.2	7.8
100	1.0^{-2}	***5.0***	4.4	5.5	***8.1***	7.1	9.0
200	5.0^{-3}	***5.6***	4.9	6.3	***9.3***	8.0	10.4
500	2.0^{-3}	***6.6***	5.6	7.5	***11.0***	9.4	12.5
1,000	1.0^{-3}	***7.4***	6.2	8.5	***12.5***	10.5	14.3
5,000	2.0^{-4}	***9.4***	7.7	11.0	***16.5***	13.4	19.2
10,000	1.0^{-4}	***10.4***	8.4	12.4	***18.5***	14.9	21.9
100,000	1.0^{-5}	***14.3***	10.9	18.0	***26.9***	20.5	33.9
1,000,000	1.0^{-6}	***19.1***	13.8	25.7	***38.5***	27.8	51.8
10,000,000	1.0^{-7}	***25.2***	17.2	36.2	***54.7***	37.2	78.5
100,000,000	1.0^{-8}	***32.9***	21.1	50.6	***77.2***	49.4	118.8
1,000,000,000	1.0^{-9}	***42.6***	25.6	70.6	***108.3***	65.1	179.5
10,000,000,000	1.0^{-10}	***54.8***	30.8	97.8	***151.6***	85.3	270.8

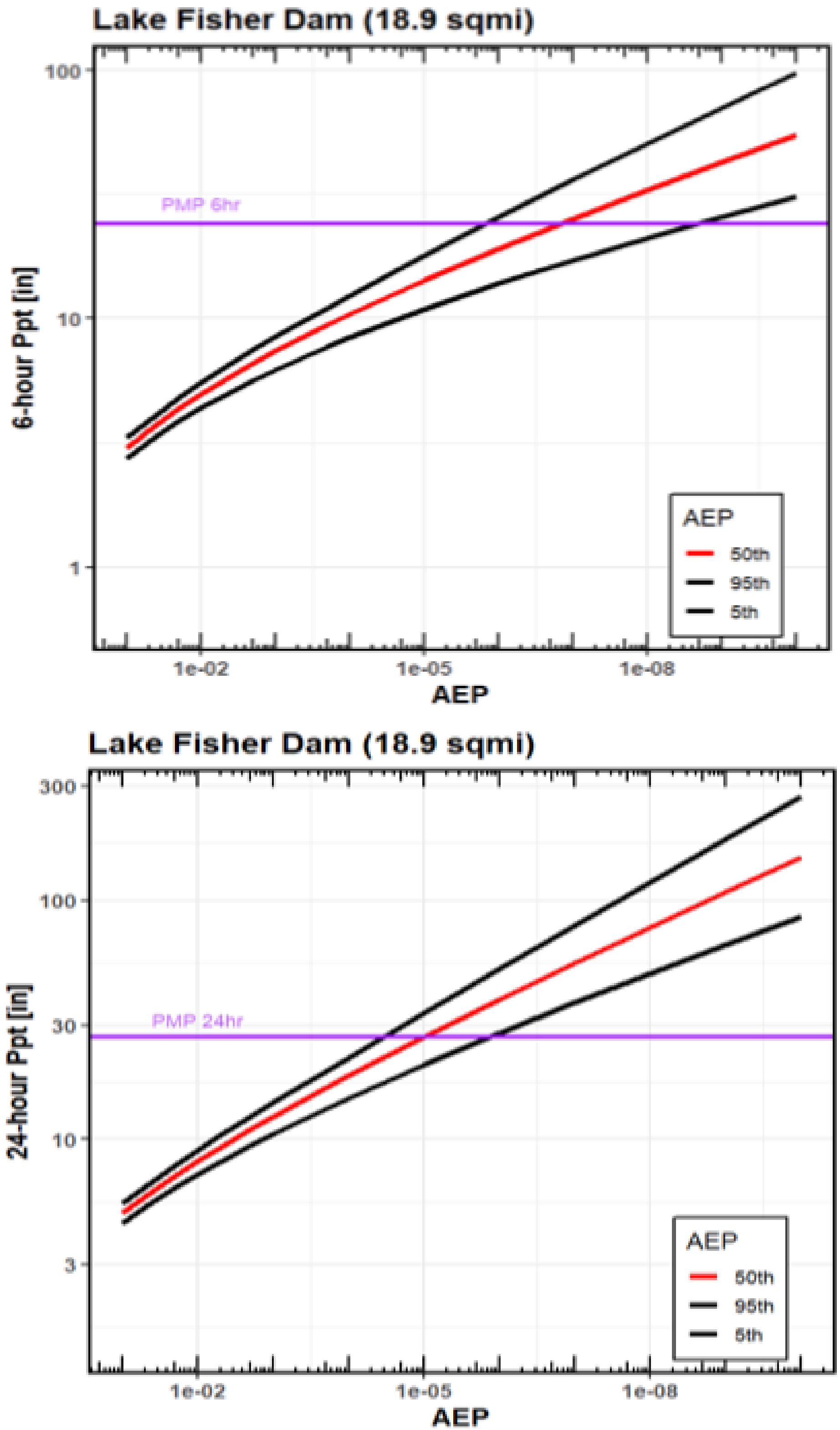


Figure 14.20: Lake Fisher Basin regional L-moment frequency curve (red line) and uncertainty bounds (black line) with basin average PMP (purple line) for the 6- and 24-hour durations

Table 14.7: Roxboro Afterbay Basin AEP for 6-hour and 24-hour PMP

Roxboro Afterbay Dam (203.1 mi^2)		6-hour			24-hour		
ARI	**AEP**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**
1	9.9^{-1}	***0.5***	0.4	0.5	***1.4***	1.2	1.6
2	5.0^{-1}	***1.2***	1.1	1.4	***2.8***	2.5	3.1
5	2.0^{-1}	***1.8***	1.6	1.9	***3.8***	3.4	4.1
10	1.0^{-1}	***2.1***	1.9	2.4	***4.5***	4.1	5.0
25	4.0^{-2}	***2.7***	2.4	2.9	***5.6***	5.0	6.1
50	2.0^{-2}	***3.1***	2.7	3.4	***6.5***	5.8	7.2
100	1.0^{-2}	***3.5***	3.1	3.9	***7.5***	6.6	8.4
200	5.0^{-3}	***4.0***	3.5	4.5	***8.6***	7.5	9.7
500	2.0^{-3}	***4.7***	4.0	5.3	***10.3***	8.8	11.7
1,000	1.0^{-3}	***5.3***	4.4	6.0	***11.7***	9.9	13.4
5,000	2.0^{-4}	***6.7***	5.5	7.8	***15.6***	12.7	18.1
10,000	1.0^{-4}	***7.4***	6.0	8.8	***17.5***	14.1	20.8
100,000	1.0^{-5}	***10.2***	7.8	12.8	***25.8***	19.7	32.5
1,000,000	1.0^{-6}	***13.6***	9.8	18.3	***37.4***	27.0	50.3
10,000,000	1.0^{-7}	***17.9***	12.2	25.7	***53.7***	36.6	77.1
100,000,000	1.0^{-8}	***23.4***	15.0	36.0	***76.7***	49.1	118.1
1,000,000,000	1.0^{-9}	***30.3***	18.2	50.2	***109.1***	65.5	180.8
10,000,000,000	1.0^{-10}	***38.9***	21.9	69.6	***154.7***	87.0	276.3

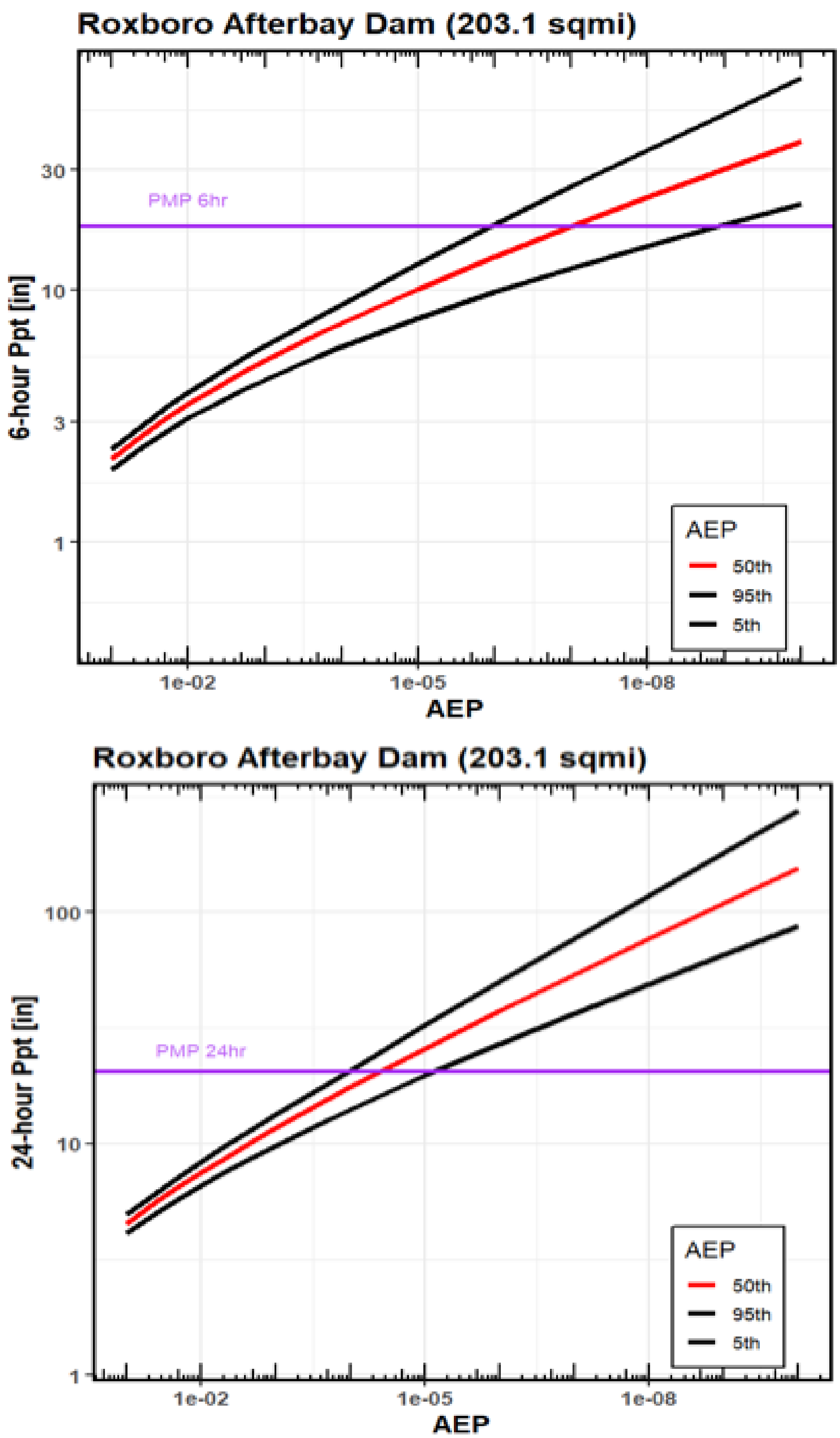


Figure 14.21: Roxboro Afterbay Basin regional L-moment frequency curve (red line) and uncertainty bounds (black line) with basin average PMP (purple line) for the 6- and 24-hour durations

Table 14.8: Lake Lure Basin AEP for 6-hour and 24-hour PMP

RUTHE 003 Lake Lure (94.4 mi^2)		6-hour			24-hour		
ARI	**AEP**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**
1	9.9^{-1}	***0.5***	0.4	0.6	***1.6***	1.4	1.8
2	5.0^{-1}	***1.3***	1.2	1.5	***3.1***	2.8	3.4
5	2.0^{-1}	***1.9***	1.7	2.1	***4.0***	3.7	4.4
10	1.0^{-1}	***2.3***	2.1	2.5	***4.7***	4.3	5.2
25	4.0^{-2}	***2.9***	2.6	3.1	***5.6***	5.1	6.2
50	2.0^{-2}	***3.3***	2.9	3.6	***6.4***	5.7	7.1
100	1.0^{-2}	***3.8***	3.3	4.2	***7.2***	6.3	8.0
200	5.0^{-3}	***4.3***	3.7	4.8	***8.0***	6.9	9.0
500	2.0^{-3}	***5.0***	4.2	5.6	***9.2***	7.8	10.4
1,000	1.0^{-3}	***5.5***	4.7	6.3	***10.1***	8.5	11.6
5,000	2.0^{-4}	***7.0***	5.7	8.2	***12.6***	10.3	14.6
10,000	1.0^{-4}	***7.7***	6.2	9.1	***13.7***	11.0	16.3
100,000	1.0^{-5}	***10.4***	7.9	13.1	***18.1***	13.9	22.9
1,000,000	1.0^{-6}	***13.6***	9.8	18.3	***23.5***	17.0	31.6
10,000,000	1.0^{-7}	***17.7***	12.0	25.3	***30.1***	20.5	43.2
100,000,000	1.0^{-8}	***22.6***	14.5	34.8	***38.1***	24.4	58.7
1,000,000,000	1.0^{-9}	***28.7***	17.2	47.5	***47.9***	28.8	79.4
10,000,000,000	1.0^{-10}	***36.1***	20.3	64.5	***59.8***	33.7	106.9

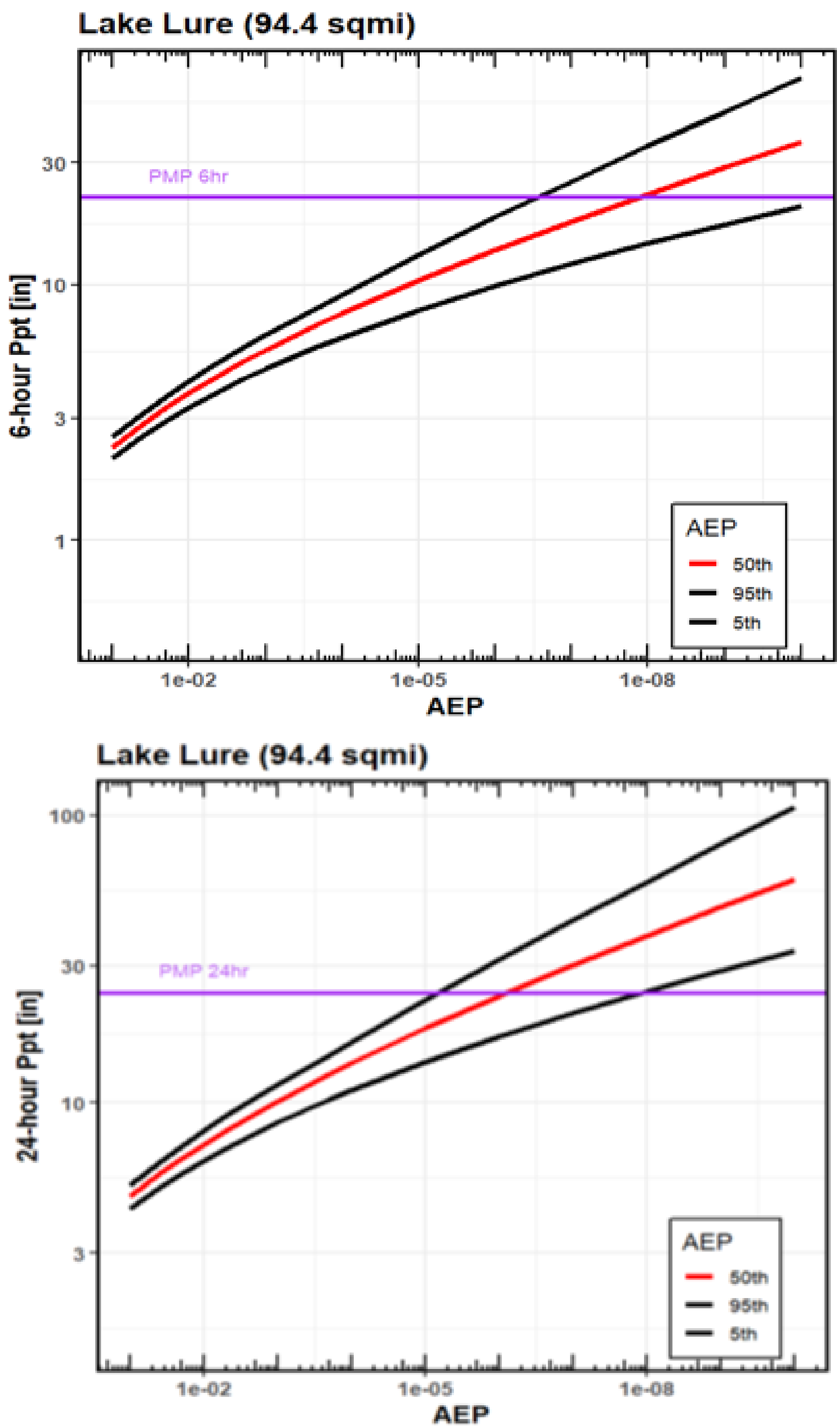


Figure 14.22: Lake Lure Basin regional L-moment frequency curve (red line) and uncertainty bounds (black line) with basin average PMP (purple line) for the 6- and 24-hour durations

Table 14.9: Lake Julian Basin AEP for 6-hour and 24-hour PMP

BUNCO 088 Lake Julian DA (4.8 mi^2)		6-hour			24-hour		
ARI	**AEP**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**
1	9.9^{-1}	***0.5***	0.5	0.6	***1.7***	1.5	1.9
2	5.0^{-1}	***1.7***	1.5	1.9	***3.1***	2.8	3.5
5	2.0^{-1}	***2.4***	2.2	2.7	***4.1***	3.7	4.5
10	1.0^{-1}	***3.0***	2.7	3.3	***4.8***	4.4	5.3
25	4.0^{-2}	***3.7***	3.3	4.0	***5.7***	5.1	6.3
50	2.0^{-2}	***4.2***	3.7	4.6	***6.5***	5.8	7.2
100	1.0^{-2}	***4.8***	4.2	5.3	***7.3***	6.4	8.1
200	5.0^{-3}	***5.4***	4.6	6.0	***8.1***	7.0	9.1
500	2.0^{-3}	***6.2***	5.3	7.0	***9.2***	7.9	10.5
1,000	1.0^{-3}	***6.8***	5.7	7.8	***10.2***	8.6	11.7
5,000	2.0^{-4}	***8.4***	6.9	9.8	***12.6***	10.3	14.6
10,000	1.0^{-4}	***9.1***	7.4	10.8	***13.7***	11.0	16.2
100,000	1.0^{-5}	***11.8***	9.0	14.9	***17.9***	13.7	22.6
1,000,000	1.0^{-6}	***14.9***	10.8	20.1	***23.1***	16.6	31.0
10,000,000	1.0^{-7}	***18.5***	12.6	26.5	***29.2***	19.9	41.9
100,000,000	1.0^{-8}	***22.6***	14.4	34.7	***36.6***	23.4	56.4
1,000,000,000	1.0^{-9}	***27.3***	16.4	45.2	***45.6***	27.4	75.5
10,000,000,000	1.0^{-10}	***32.6***	18.4	58.3	***56.3***	31.7	100.6

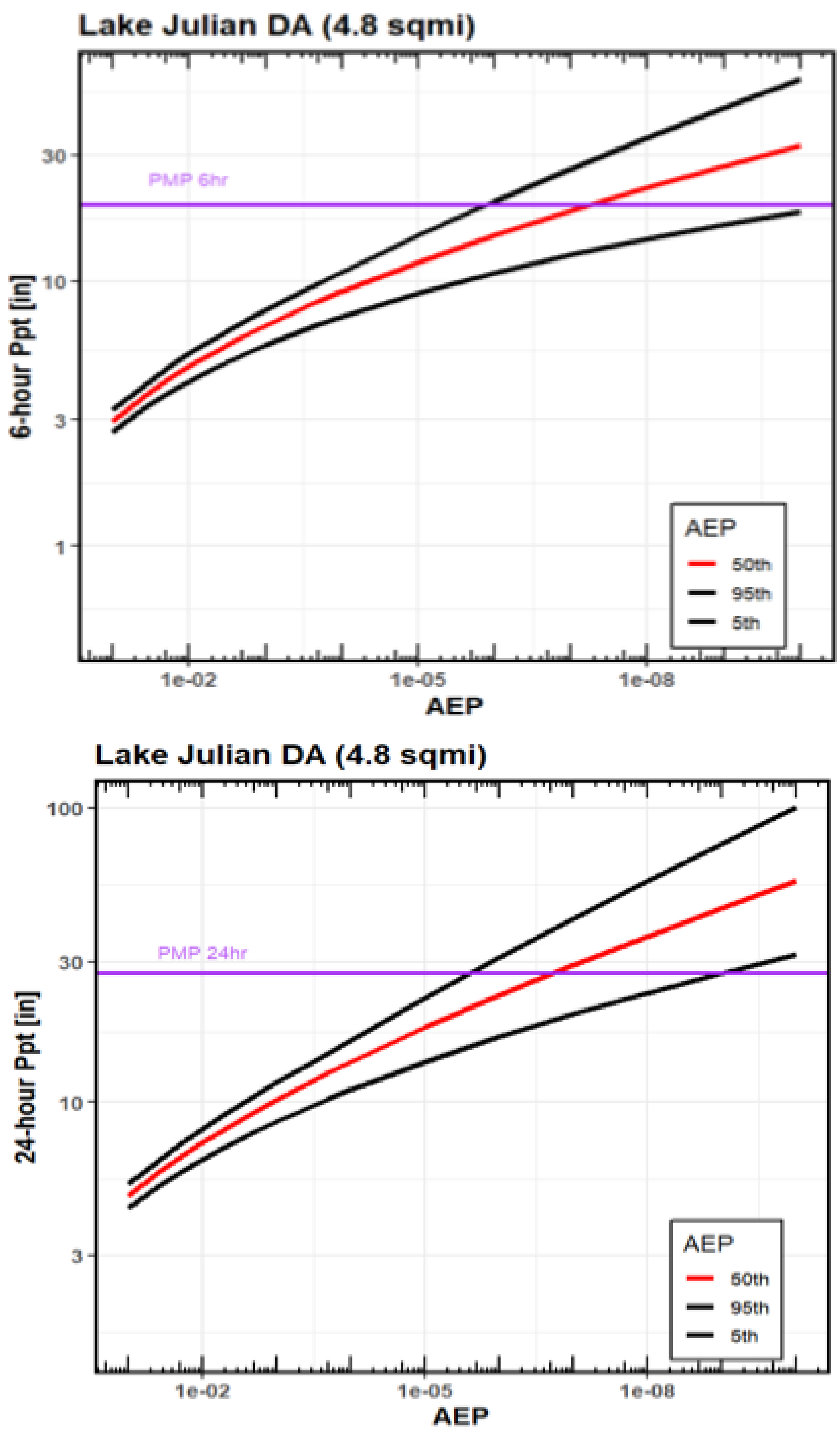


Figure 14.23: Lake Julian Basin regional L-moment frequency curve (red line) and uncertainty bounds (black line) with basin average PMP (purple line) for the 6- and 24-hour durations

Table 14.10: Watauga Vista Basin AEP for 6-hour and 24-hour PMP

Watauga Vista Dam (0.6 mi^2)		6-hour			24-hour		
ARI	**AEP**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**
1	9.9^{-1}	***0.7***	0.6	0.8	***2.0***	1.7	2.2
2	5.0^{-1}	***1.9***	1.7	2.1	***3.7***	3.3	4.1
5	2.0^{-1}	***2.7***	2.4	2.9	***4.8***	4.4	5.3
10	1.0^{-1}	***3.2***	2.9	3.6	***5.7***	5.1	6.2
25	4.0^{-2}	***4.0***	3.6	4.4	***6.8***	6.1	7.4
50	2.0^{-2}	***4.7***	4.1	5.2	***7.7***	6.8	8.5
100	1.0^{-2}	***5.4***	4.7	6.0	***8.6***	7.5	9.6
200	5.0^{-3}	***6.1***	5.3	6.8	***9.6***	8.3	10.7
500	2.0^{-3}	***7.1***	6.1	8.1	***10.9***	9.3	12.4
1,000	1.0^{-3}	***8.0***	6.7	9.1	***12.0***	10.1	13.8
5,000	2.0^{-4}	***10.2***	8.3	11.8	***14.9***	12.1	17.3
10,000	1.0^{-4}	***11.2***	9.0	13.3	***16.2***	13.0	19.2
100,000	1.0^{-5}	***15.4***	11.7	19.4	***21.2***	16.2	26.7
1,000,000	1.0^{-6}	***20.6***	14.9	27.7	***27.2***	19.7	36.6
10,000,000	1.0^{-7}	***27.2***	18.5	39.0	***34.5***	23.5	49.5
100,000,000	1.0^{-8}	***35.4***	22.7	54.6	***43.3***	27.7	66.6
1,000,000,000	1.0^{-9}	***45.9***	27.5	76.0	***53.8***	32.3	89.2
10,000,000,000	1.0^{-10}	***59.0***	33.2	105.4	***66.6***	37.4	118.9

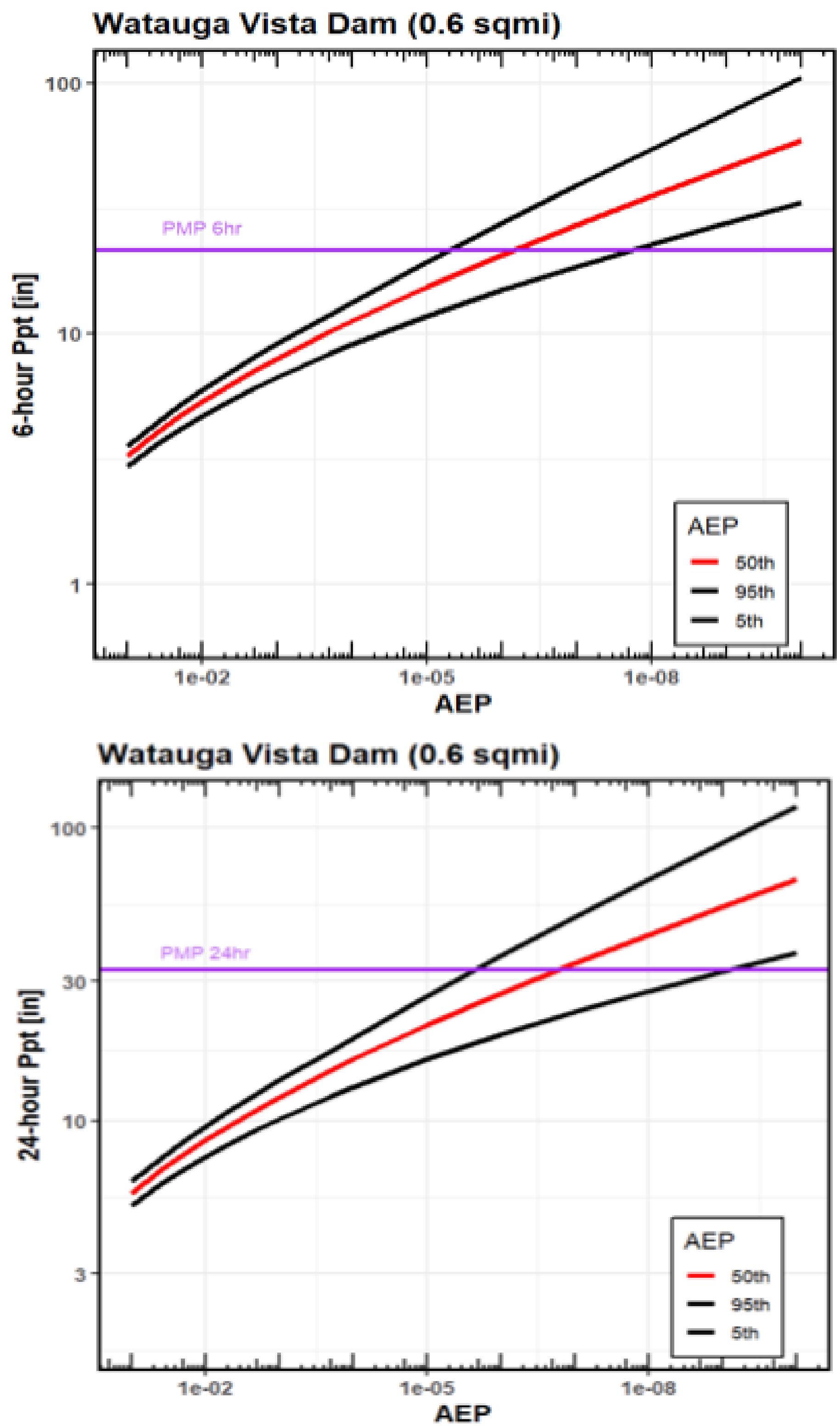


Figure 14.24: Watauga Vista Basin regional L-moment frequency curve (red line) and uncertainty bounds (black line) with basin average PMP (purple line) for the 6- and 24-hour durations

Table 14.11: Summary of the test basins AEP of PMP for 6-hour and 24-hour durations. The 50% values represent our best estimate, the 5% and 95% values represent the upper and lower confidence bounds based on Monte-Carlo simulation.

	Arran Lakes West Dam (2.4 mi2)					
	PMP v1 (in)	AEP	ARI	50%	5%	95%
6hr	30.7	$1.22x10^{-6}$	816,519	10^{-6}	10^{-8}	10^{-6}
24hr	35.0	$3.07x10^{-6}$	325,791	10^{-6}	10^{-7}	10^{-5}
	Bass Lake Dam (5.0 mi2)					
	PMP v1 (in)	**AEP**	**ARI**	**50%**	**5%**	**95%**
6hr	32.0	$2.93x10^{-7}$	3,412,649	10^{-7}	10^{-8}	10^{-6}
24hr	36.3	$2.44x10^{-6}$	409,448	10^{-6}	10^{-7}	10^{-5}
	Lake Fisher Dam (18.9 mi2)					
	PMP v1 (in)	**AEP**	**ARI**	**50%**	**5%**	**95%**
6hr	24.1	$1.20x10^{-7}$	8,347,428	10^{-7}	10^{-9}	10^{-6}
24hr	26.7	$1.02x10^{-5}$	98,434	10^{-5}	10^{-6}	10^{-5}
	Roxboro Afterbay Dam (203.1 mi2)					
	PMP v1 (in)	**AEP**	**ARI**	**50%**	**5%**	**95%**
6hr	18.0	$9.60x10^{-8}$	10,420,355	10^{-8}	10^{-9}	10^{-6}
24hr	20.5	$2.36x10^{-5}$	42,365	10^{-5}	10^{-6}	10^{-5}
	RUTHE 003 Lake Lure (94.4 mi2)					
	PMP v1 (in)	**AEP**	**ARI**	**50%**	**5%**	**95%**
6hr	21.9	$1.14x10^{-8}$	87,511,955	10^{-8}	10^{-10}	10^{-7}
24hr	24.1	$5.61x10^{-7}$	1,783,249	10^{-7}	10^{-8}	10^{-6}
	BUNCO 088 Lake Julian DA (4.8 mi2)					
	PMP v1 (in)	**AEP**	**ARI**	**50%**	**5%**	**95%**
6hr	19.5	$3.17x10^{-8}$	31,495,554	10^{-8}	10^{-10}	10^{-6}
24hr	27.4	$1.35x10^{-7}$	7,390,113	10^{-7}	10^{-10}	10^{-6}
	Watauga Vista Dam (0.6 mi2)					
	PMP v1 (in)	**AEP**	**ARI**	**50%**	**5%**	**95%**
6hr	21.6	$4.23x10^{-7}$	2,364,790	10^{-7}	10^{-8}	10^{-6}
24hr	32.7	$1.29x10^{-7}$	7,746,709	10^{-7}	10^{-10}	10^{-6}

14.12 Comparison to NOAA PF Estimates

This analysis follows methods similar to those used in NOAA Atlas 14 Vol. 2 (Bonin et al., 2006). NOAA Atlas 14 was based on regional L-moments and goodness-of-fit measures, akin to the North Carolina analysis. The updated North Carolina frequency analysis incorporates a significantly larger dataset, including an additional 24 years of observations (2000–2024). The AWA study utilized 184 hourly stations and 630 daily stations, with approximate station record lengths of 3,765 and 36,878 years of data, respectively. In comparison, NOAA Atlas 14 used 51 hourly stations and 196 daily stations within North Carolina, with approximate station record lengths of 2,260 and 13,258 years.

The updated North Carolina analysis applied cluster analysis methods to develop homogeneous regions, ensuring that stations with similar precipitation characteristics were grouped together based on spatial and statistical patterns. This approach enhances regional frequency analysis by reducing variability within each cluster and improving the robustness of estimated precipitation frequency values. In contrast, NOAA Atlas 14 utilized the star methodology, which relies on predefined regional boundaries and statistical homogeneity tests without explicitly clustering stations based on shared precipitation behavior. The cluster analysis method used in this study allows for a more data-driven and flexible regionalization process, adapting to localized precipitation trends and station density variations, ultimately leading to more precise and representative frequency estimates.

To illustrate differences between the AWA and NOAA analyses, we conducted a spatial comparison of precipitation estimates for the 100-year return period at both 6-hour and 24-hour durations (Figure 14.25). This comparison highlights regional variations in estimated precipitation magnitudes, with the most significant differences observed in the Piedmont region of North Carolina.

In this region, the AWA analysis indicates a substantial increase in precipitation magnitudes compared to NOAA Atlas 14. These differences are primarily attributed to the incorporation of a significantly larger and more recent dataset, improved statistical methodologies, and refined regionalization techniques. The inclusion of 24 additional years of data (2000–2024) captures more extreme precipitation events that were not represented in NOAA Atlas 14, leading to higher frequency estimates. Furthermore, the use of cluster analysis for regionalization, rather than the star methodology, allows for more precise grouping of stations with similar precipitation characteristics, reducing statistical bias and improving the accuracy of precipitation frequency estimates.

The spatial variability observed in the updated analysis suggests that previous estimates in the Piedmont region may have underestimated extreme precipitation events. This has important implications for hydrologic modeling, infrastructure design, and flood risk assessments, particularly as climate trends continue to evolve.

Regarding the NOAA Atlas 15 precipitation frequency update, the general methodology will be similar to this analysis. However, instead of L-moment statistics, it will rely on maximum likelihood estimation (MLE). Direct comparisons to NOAA Atlas 15 remain challenging, as its overall methodology is still under evaluation (Perica et al., 2024). Additionally, NOAA Atlas 15 is designed to cover the entire contiguous United States (CONUS), whereas this study focuses on region- and site-specific analyses, necessitating different methodological approaches.

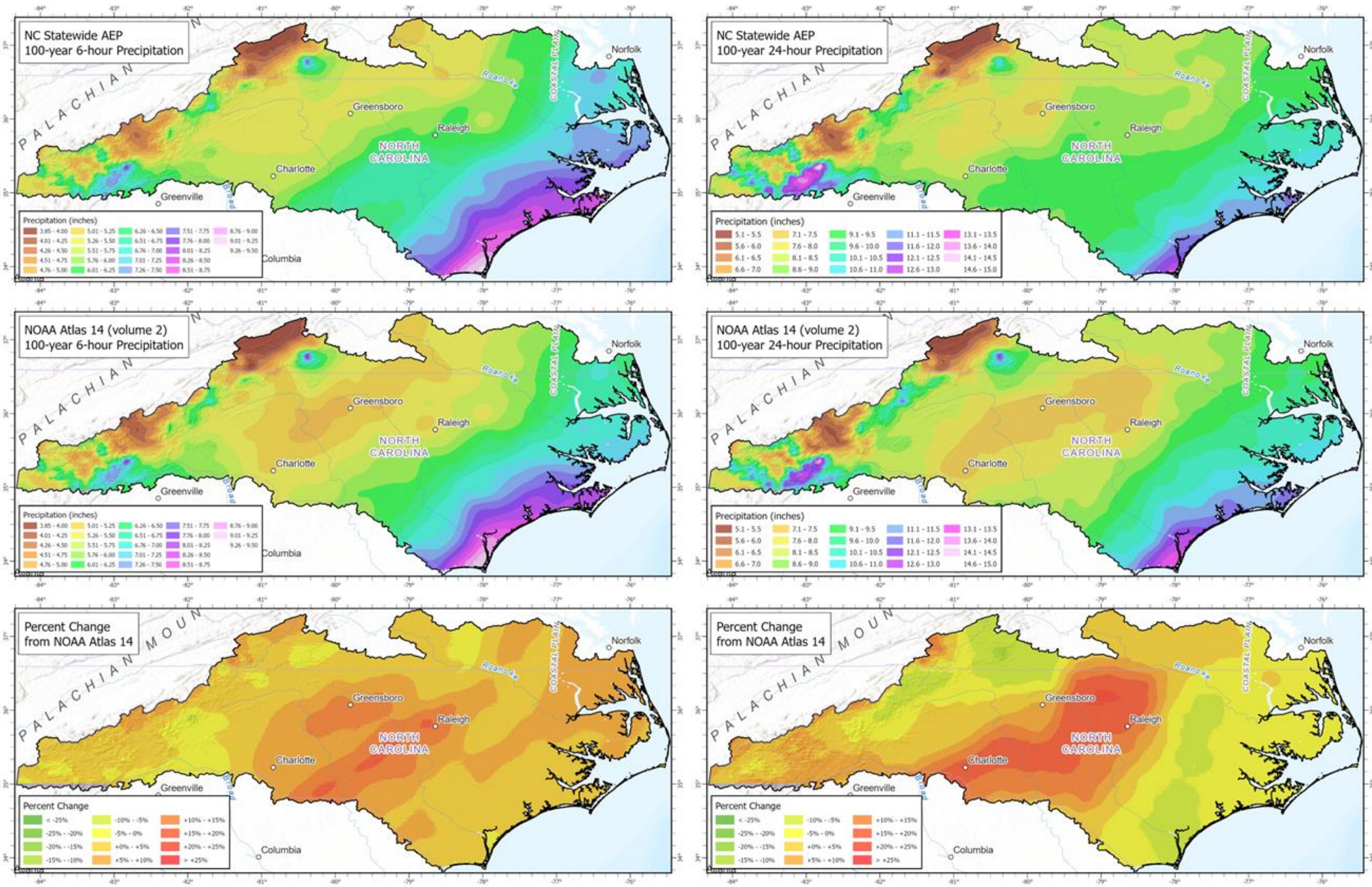


Figure 14.25: Spatial comparison of precipitation estimates for the 100-year return period at 6-hour (left column) and 24-hour (right column) durations. Top row displays the updated North Carolina 100-year precipitation estimates, the middle row shows the NOAA Atlas 14 100-year estimates, and the bottom row illustrates the difference between the two datasets, highlighting regional variations in estimated precipitation magnitudes.

15. Climate Change Projections Related to PMP

Climate is changing, always has been changing, and always will change as long as the energy received from the sun across the Earth's surface is out of balance. Accounting for future changes in climate is important to reduce risk and to test the resiliency of critical infrastructure against potential future changes (Kunkel et al., 2013a; Kunkel et al., 2013b; Kunkel and Champion, 2019). Unfortunately, quantification of the amount and rate of change at any given location for any specific meteorological parameter in the future is not explicitly known and instead has to be modeled based on our incomplete understanding of the Earth climate system and its response to many variables including greenhouse gas emissions and concentrations.

To address the uncertainties and unknowns and to provide projections that can be tested, model projections that utilize our current understanding of the Earth climate system are developed. The climate projections are based on a physical understanding of various atmospheric parameters and how those affect weather and climate through time and space. However, because our quantification of these parameters is incomplete (and at times inaccurate) and because our understanding of the various interactions and feedbacks is limited, the projections represent possible outcomes (Kappel et al., 2020). None of which can be considered truth.

To overcome these significant limitations, numerous iterations and slight changes in the input parameters are performed so that a suite of ensembles are produced that represent a wide range of potential outcomes. From this output, inferences can be made, with more confidence given when ensemble outcomes converge on a common projection (Mahoney et al., 2013; Ohara et al., 2017). Another layer of uncertainty within the climate change projection process relates to the assumption applied for future emissions scenarios and how those may affect the climate system. Future emissions scenarios have two major areas of uncertainty. First, the assumption that any given emission scenario will occur following a specific path through time is unknown as there are many internal and external factors that can influence the amount of emissions produced through time. Second, the understanding and quantification of how the Earth's climate will respond to any given greenhouse gas emission is limited. Both uncertainties introduce errors into the outcomes of climate projections. Finally, Global Circulation Models (GCMs) are computationally intensive and are therefore run at low resolution both in time and space. In general, the resolution of the GCMs is inadequate to capture the spatial variations. To overcome this, projections from GCMs are downscaled using a statistical process into regional downscaled model projections. The regionally downscaled models are what were utilized for this climate change analysis.

Given all the limitations and uncertainties noted above, it is still useful to evaluate Regional Circulation Models (RCMs) to understand the range of potential outcomes that could occur through time over the basin. To complete this process, AWA investigated Coupled Model Intercomparison Project Phase 6 (CMIP6) output that were newly available over the course of this study.

15.1 Overview of Global Climate Change Models

GCMs produce realizations of the Earth's climate on a generally coarse scale of around 1000 km by 1000 km. Because the scale is so coarse, a single GCM grid may cover vastly differing landscapes (e.g., from very mountainous to flat coastal plains) that have greatly varying potential for floods, droughts, or other extreme events.

15.1.1 Regional Downscaled Climate Change Models

RCMs and Empirical Statistical Downscaling applied over limited areas are done at a much finer resolution. These are therefore able to capture the spatial and temporal variations related to a site-specific region. These downscaling methods are driven by GCMs, where the RCM is nested within the overall GCM and utilizes the GCM to set the initial boundary conditions. The initial boundary conditions are then downscaled using either statistical methodology or the RCM based on a meteorological model interface. The RCM process can provide projections of future climate conditions on a much smaller scale (e.g., 25km by 25km), which supports more detailed site-specific information and allows for adaptation assessment. Examples of different climate model resolutions across the region are shown in Figure 15.1.

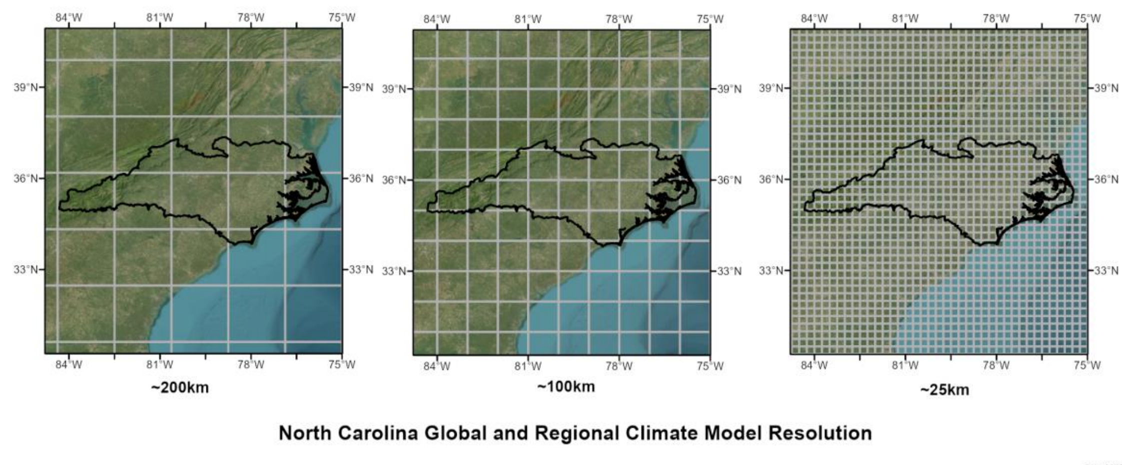


Figure 15.1: Example of global and regional climate model resolutions across the region

15.2 Climate Change Projections Analysis Methods

The Intergovernmental Panel on Climate Change's (IPCC) sixth assessment report (AR6) contains Shared Socioeconomic Pathways (SSP)s. SSPs are scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emissions scenarios with different climate policies. The SSPs are based on five narratives describing broad socioeconomic trends that could shape future society. These are intended to span the range of plausible futures. These include a world of sustainability-focused growth and equality (SSP1); a "middle of the road" world where trends broadly follow their historical patterns (SSP2); a fragmented world of "resurgent nationalism" (SSP3); a world of ever-increasing inequality (SSP4); and a world of rapid and unconstrained growth in economic output and energy use (SSP5) (IPCC, 2021). The SSPs investigated; SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP85; are labeled after a possible range of greenhouse gas emissions scenarios with different climate policies through the year 2100 (Figure 15.2) (IPCC, 2021). SSP4-8.5 represents the 95-

percentile of all possible ranges of greenhouse gas emissions forcing scenarios through in the year 2100. The IPCC AR6 report does not estimate the likelihoods of the climate scenarios (Masson-Delmotte et al., 2021) but Hausfather and Peters (2020) concluded that SSP5-8.5 was highly unlikely, SSP3-7.0 was unlikely, and SSP2-4.5 was likely. In this assessment, AWA evaluated the projections associated with SSP2-4.5 and SSP5-8.5. These two SSPs were evaluated to be consistent with AWA climate change assessments that utilize the likely scenario and the highly unlikely scenario to bracket various outcomes. In addition, both SSPs provide the parameters needed for the assessments completed by AWA.

The NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) dataset is comprised of thirty-five global downscaled climate scenarios derived from the GCM runs conducted under the Coupled Model Intercomparison Project Phase 6 (CMIP6) and across all of the four "Tier 1" greenhouse gas emissions scenarios. The CMIP6 GCM runs were developed in support of the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6) (Thrasher et al., 2021; Thrasher et al., 2022). The purpose of this dataset is to provide a set of global, high resolution, bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients and the effects of local topography on climate conditions.

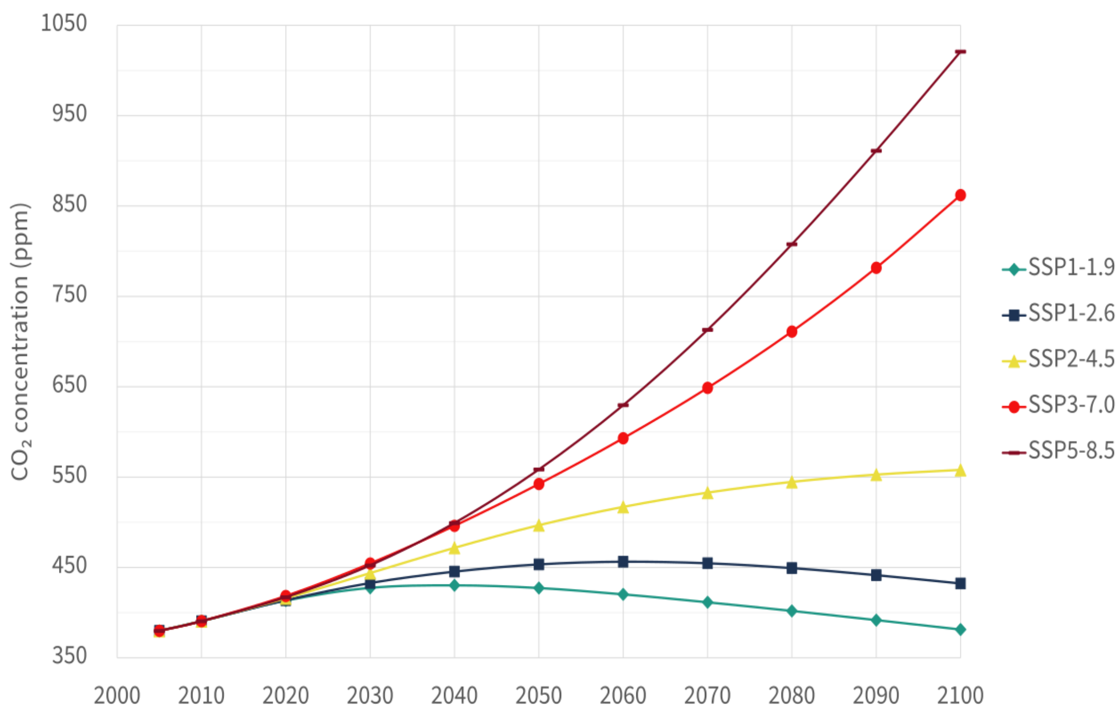


Figure 15.2: Shared Socioeconomic Pathways (SSP) trajectories. Reproduced from IPCC (2021).

The key climate model parameters used in this analysis were precipitation (Ppt), air temperature (Ta), and dew point temperature (Td). The parameters of relative humidity (RH) and Ta were used to derive the estimates of Td. The NEX-GDDP-CMIP6 dataset consists of thirty-five models, of these thirty-five models twenty-six models had the parameters and projections needed for the North Carolina climate change analysis (Table 15.1). An example of the modeled climate projection parameters of Ppt, Ta, and Td are shown in Figure 15.3 and

Figure 15.4 and the grid resolution covering the four climate analysis regions is shown in Figure 15.5.

Table 15.1: Subset of twenty-six CMIP6 models and projections of RH, Ppt, and Td utilized

		Relative Humidity (hurs)			*Precipitation (pr)*			*Temperature (tas)*		
Model #	**MODEL NAME**	**HISTORICAL**	**SSP45**	**SSP85**	**HISTORICAL**	**SSP45**	**SSP85**	**HISTORICAL**	**SSP45**	**SSP85**
1	ACCESS-CM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
2	ACCESS-ESM1-5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
4	CanESM5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
5	CESM2-WACCM	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
6	CESM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
7	CMCC-CM2-SR5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
8	CMCC-ESM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
9	CNRM-CM6-1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
10	CNRM-ESM2-1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
11	EC-Earth3-Veg-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
12	EC-Earth3	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
13	FGOALS-g3	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
14	GFDL-CM4_gr1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
15	GFDL-CM4_gr2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
16	GFDL-ESM4	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
17	GISS-E2-1-G	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
21	INM-CM4-8	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
22	INM-CM5-0	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
23	IPSL-CM6A-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
26	MIROC-ES2L	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
27	MIROC6	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
28	MPI-ESM1-2-HR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
29	MPI-ESM1-2-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
30	MRI-ESM2-0	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
33	NorESM2-MM	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
34	TaiESM1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100

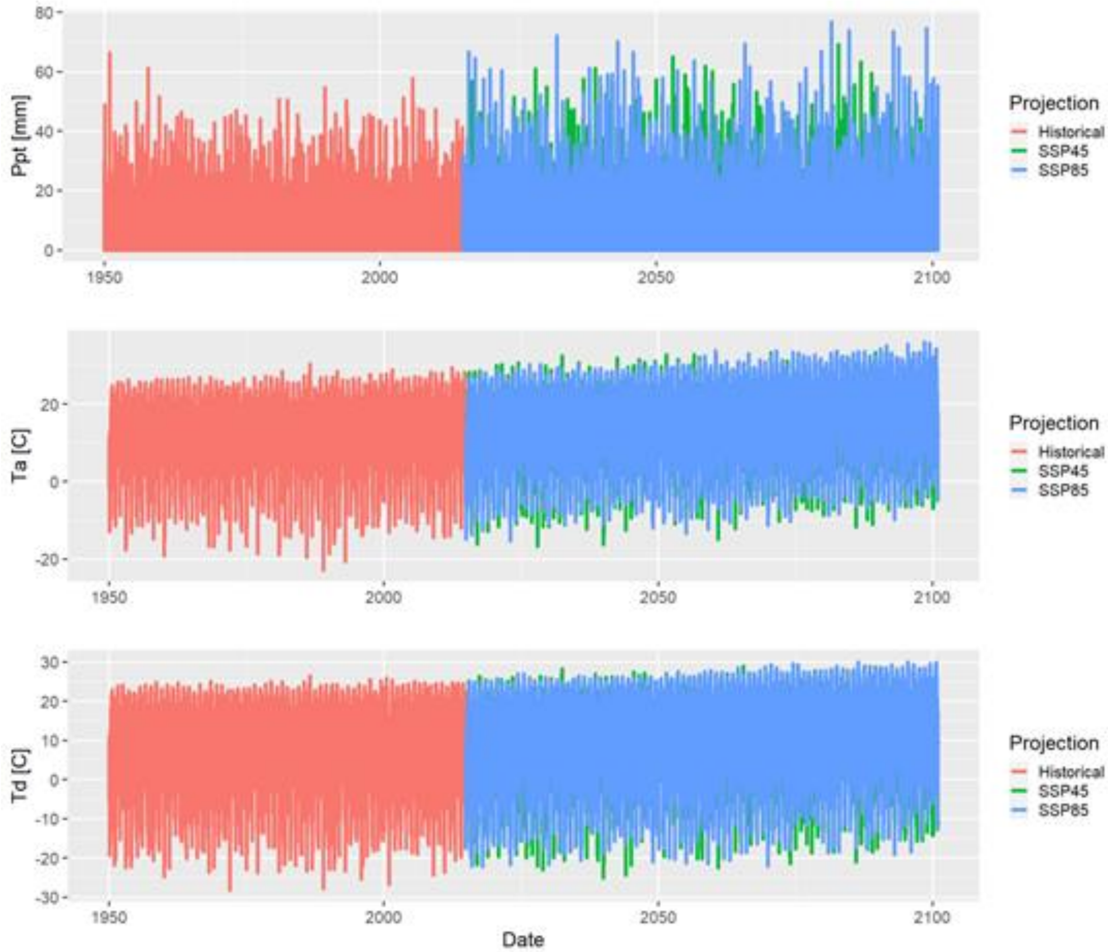


Figure 15.3: Climate projection parameters of Ppt, Ta, and Td from Model 1 Region 1(ACCESS-CM2)

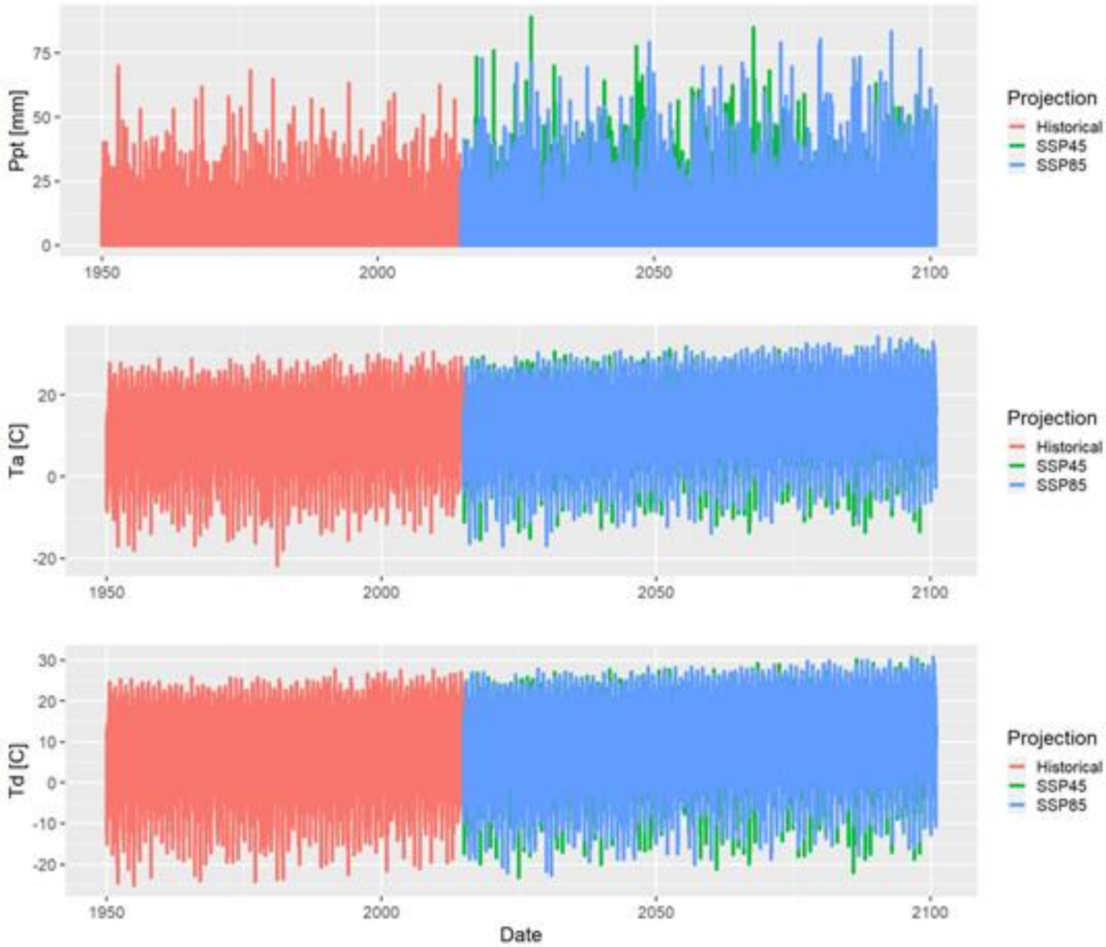


Figure 15.4: Climate projection parameters of Ppt, Ta, and Td from Model 8 Region 1 (CMCC-ESM2)

Figure 15.5: CMIP6 climate model grid resolution across the region. The four regions used for the climate change analysis.

15.2.1 Trend Analysis

Mann-Kendall trend analysis (Mann, 1945; Hipel and McLeod, 2005) was performed on twenty-six climate model projections using the three scenarios (historic, SSP2-4.5, SSP5-8.5) for durations of 1-day, 3-day, and annual. Figure 15.6 shows an example of the results for Model 1 Region 1 trend analysis for the historic, SSP2-4.5, and SSP4-8.5 projections.

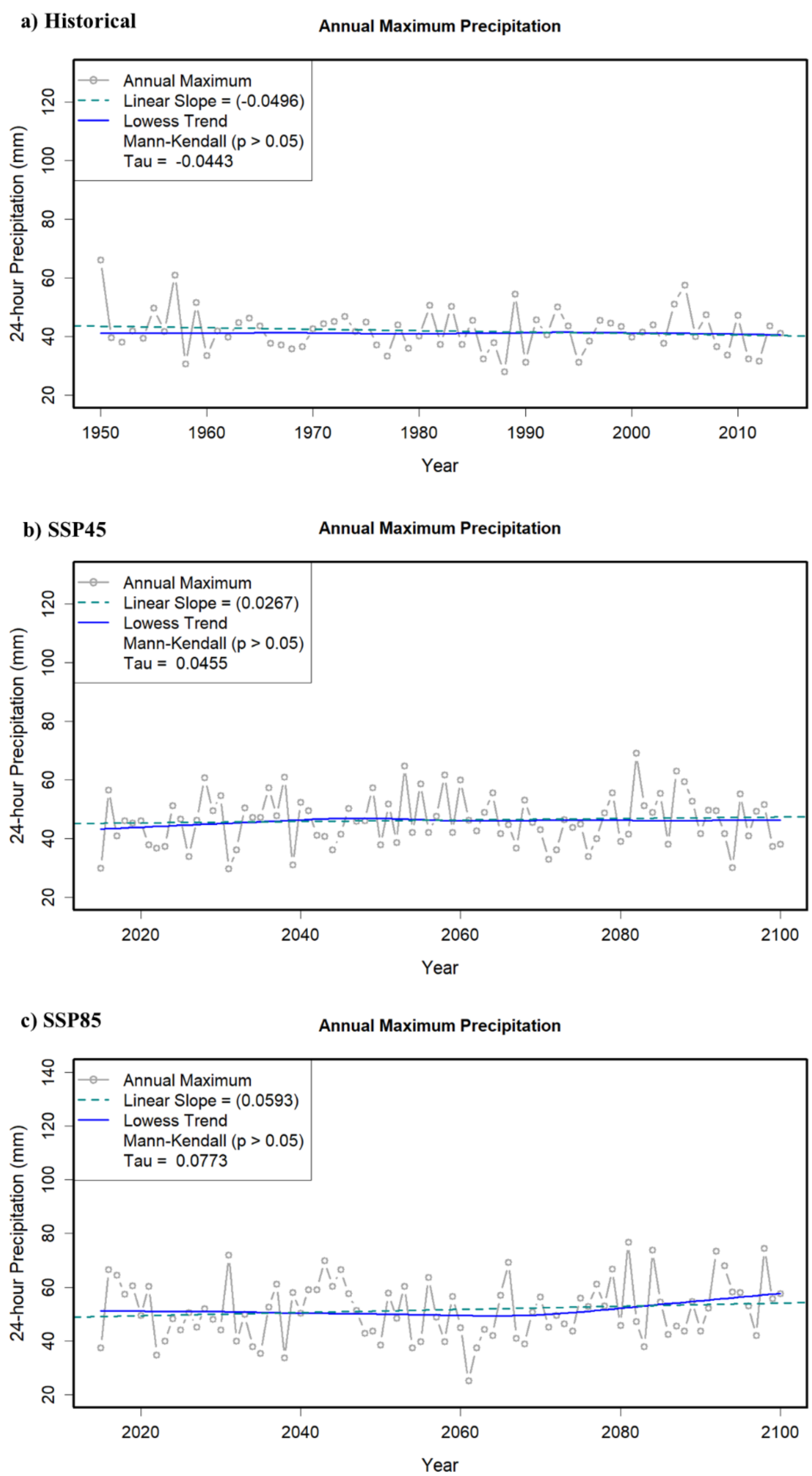


Figure 15.6: Example results for 1-day trend analysis from Model 1 Region 1 (ACCESS-CM2): a) no trend for historical period, b) no trend for SSP45 scenario, and c) no trend for SSP85 scenario. Blue line is Lowess trend line, dashed line is a linear trend, and Mann-Kendall p-value shown in lower legend.

15.2.2 Precipitation Frequency Analysis

The precipitation frequency analysis method utilized L-moment statistics instead of product moment statistics, which decrease the uncertainty of rainfall frequency estimates for more rare events and dampen the influence of outlier precipitation amounts from extreme storms (Hosking and Wallis, 1997). Methods to account for non-stationarity in projections were not addressed so the projections were applied assuming stationarity. For the precipitation frequency analysis, AWA utilized the daily climate model projections to perform frequency analysis on the 1-day, 3-day, and annual durations.

AWA identified, extracted, and quality controlled maximum precipitation projections from the NEX-GDDP-CMIP6 dataset for twenty-six CMIP6 models and three projection scenarios. The Annual Maximum Series (AMS) were then subjected to the frequency analysis methods (Hosking and Wallis, 1997). L-moment statistics were computed for annual maximum data for each projection and duration. Goodness of fit measures were evaluated for five candidate distributions: generalized logistic (GLO), generalized extreme value (GEV), generalized normal (GNO), Pearson type III (PE3), and generalized Pareto (GPA). An L-Moment Ratio Diagram was prepared based on L-Skewness and L-Kurtosis pairs for each duration. The weighted-average L-Skewness and L-Kurtosis pairing were found to be near the GEV distribution for all projections.

The GEV distribution was selected because: i) This is the most common distribution used for precipitation frequency studies (e.g., NOAA Atlas 14, Perica, 2015), ii) the GEV was identified on the 1-day, 3-day, and annual goodness-of-fit measures, and iii) using the same distribution ensures a more direct comparison to more rare values of the frequency curve.

In order to account for seasonality of events (winter vs summer) the 1-day and 3-day annual maximum were also extracted for the summer season (May - October) and for the winter season (November – April). The summer and winter AMS data were used to perform L-moment frequency analysis methods as described above. Comparisons of percent change were made among model projections for 10-year through 1,000-year recurrence intervals, beyond this the uncertainty in probability distributions estimates is large. Figure 15.7 shows an example of the results for Model 1 Region 1 1-day precipitation frequency analysis for all seasons, the summer season, and the winter season for the historic, SSP2-4.5, and SSP4-8.5 projections.

*** 1-Day Precipitation

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	51.6	59.2	62.0	67.7	69.9	-	-	-	-	-	
SSP45	58.0	65.7	68.3	73.1	74.8	12%	11%	10%	8%	7%	**10%**
SSP85	66.4	76.5	80.0	86.7	89.1	29%	29%	29%	28%	27%	**28%**

*** 1-Day Summer

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	33.8	47.1	54.1	74.1	84.6	-	-	-	-	-	
SSP45	39.5	56.9	65.9	91.6	105.2	17%	21%	22%	24%	24%	**22%**
SSP85	38.1	50.8	56.8	72.0	79.2	13%	8%	5%	-3%	-6%	**3%**

*** 1-Day Winter

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	51.3	59.1	62.1	68.2	70.5	-	-	-	-	-	
SSP45	57.7	66.2	69.2	74.8	76.8	13%	12%	11%	10%	9%	**11%**
SSP85	66.2	76.9	80.7	88.1	90.7	29%	30%	30%	29%	29%	**29%**

Figure 15.7: Example results for 1-day precipitation frequency analysis for climate projection from Model 1 Region 1 (ACCESS-CM2)

15.3 Uncertainty

Measurement (observed data), modeling (physical representation of observed data), and simulation (application of physical and empirical relationships to estimate meteorological parameters) of many meteorologic components can be highly uncertain, the main reason being the fundamental dynamics of many processes cannot be measured and modeled accurately Kampf et al., 2020). Most meteorologic processes are not observed in detail, consequently accurate mathematical representation of the variables spatial and temporal processes, model initial boundary layer conditions, and physical processes, cannot be represented accurately. Mantovan and Tondini (2006) have identified sources of water balance uncertainties as: (i) data uncertainty, (ii) model parameter uncertainty, (iii) model structure uncertainty, and (iv) natural uncertainty.

15.3.1 Data Uncertainty

The performance of models is mainly affected by data uncertainty. This uncertainty arises from errors in the observed data, particularly data used for model calibration. The errors may be linked to the quality of the data which depends on the type and conditions of measuring instruments as well as data handling and processing. Precipitation and streamflow are usually the major sources of input and output data that are used to calibrate and evaluate model uncertainty with the spatial and temporal precipitation uncertainty being large.

15.3.2 Model Parameter Uncertainty

Model parameter uncertainty is also known as model specification uncertainty. This relates to the inability to converge to a single best parameter set using available data, which leads to parameter identifiability problems (Beven, 2001; Wagener et al., 2004). The parameters are optimized so that the model results are as good as possible (Beven, 2001; Scharffenberg et al., 2018).

Uncertainty then depends on how parameters are optimized (peak flow, volume, residuals) and results are applied (Scharffenberg et al., 2018; Pokorny et al., 2021).

15.3.3 Model Structure Uncertainty

Model structure uncertainty is introduced through simplifications and/or inadequacies in the representation of physical processes in a given model. It also originates from inappropriate assumptions within the modelling procedure, inappropriate mathematical description of these processes (Beven, 2001), and the scale at which processes are represented in the model (Heuvelink, 1998; Blöschl, 1999; Koren et al., 1999). However, no matter how exact the model is calibrated, there always exists discrepancy between model outcome and observed data (Chiang et al., 2007; Beven, 2006).

15.3.4 Natural Uncertainty

Natural uncertainty arises due to the randomness of natural processes (Beven, 2001). This uncertainty can be linked to data uncertainty, whereby the quality and type of data plays a significant role in determining the amount of uncertainty. For example, the spatial and temporal randomness of rainfall can somewhat be represented explicitly when using good rain gauge networks and radar rainfall data (Segond, 2006). In addition, scaling issues, spatial representativity and interpolation methods are typically represented within natural uncertainty (Heuvelink, 1998; Blöschl, 1999).

For this study, the meaning of "within uncertainty" is considered to be within +/-20 percent and was based on several factors. This range is based on AWA's extensive professional experience evaluating each of these factors below and how they relate to the PMP calculations:

- Multiple sources of uncertainty and varying ranges of uncertainty inherent in the PMP development process and inputs
  - Gauge/Observed Precipitation
    - Point measurement 5 to 15% percent for long-term series, and as high as 75% for individual storm events
  - Frequency Analysis
    - NOAA Atlas 14 Volume 1 24-hour 100-year error bounds are approximately +/-18% (Bonin et al., 2011)
  - Climate Projections
    - Projection uncertainty for individual regional model methods can be quite large: 20 to >50% (Lehner et al., 2020)
  - Selection of the storm representative value used in the In-place Maximization Factor calculations
    - Range between 5 and 30%, with an average around 20%

15.4 Results of Analysis

The results of modeled trends and estimated precipitation frequencies have a large variability that can be attributed to the uncertainty inherent with GCMs and RCMs projections. The different climate models used for the example regions represent a significant component of future climate uncertainty in climate models. This uncertainty is represented by the range of climate futures indicated by the Coupled Model Intercomparison Project 6 (CMIP6) ensemble of projections (McSweeney and Jones, 2016; Masson-Delmotte et al., 2021).

The median of the twenty-six models shows an increase in mean annual temperature and mean annual precipitation (Figure 15.8). Temperature, in regard to daily maximum (frequency based) and monthly averages show an increase by 2100 for both the SSP2-4.5 and SSP4-8.5 projections (Figure 15.9 and Figure 15.10). Numeric values representing the change in temperature are shown in Table 15.2 and Table 15.3.

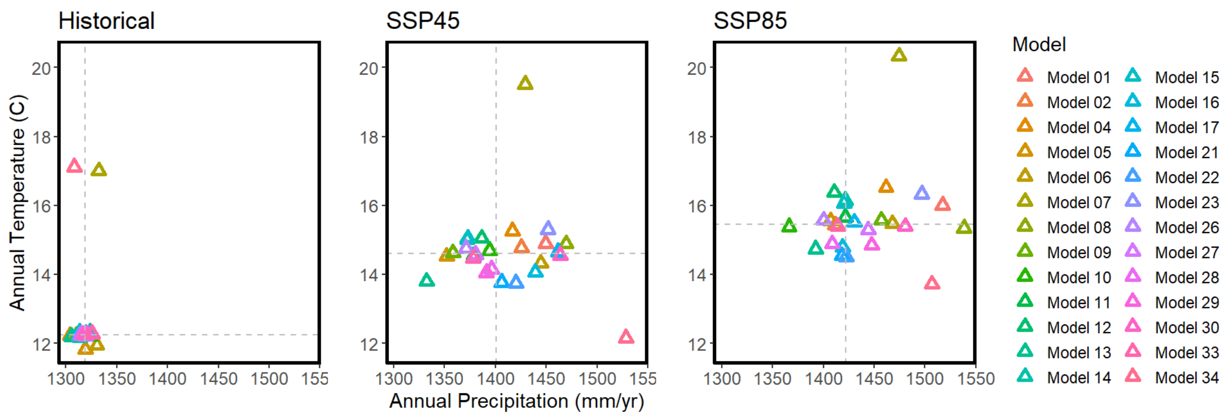


Figure 15.8: Comparison of mean annual temperature and mean annual precipitation for the three climate projection periods in Region 1

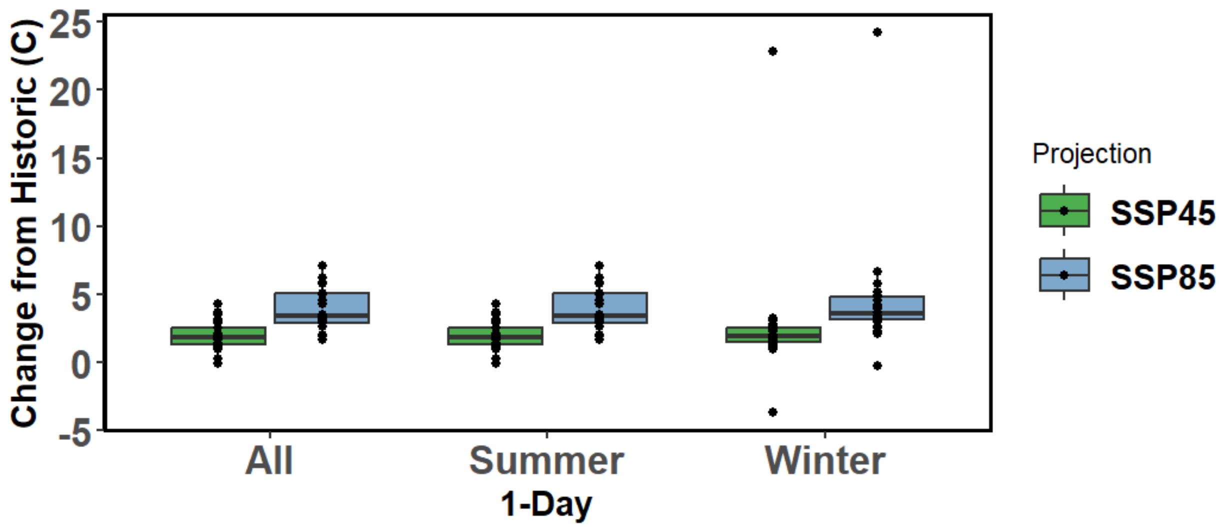


Figure 15.9: Change in daily average maximum temperatures from historic (1950-2014) climate conditions in Region 1. Results are based on annual maximum frequency analysis.

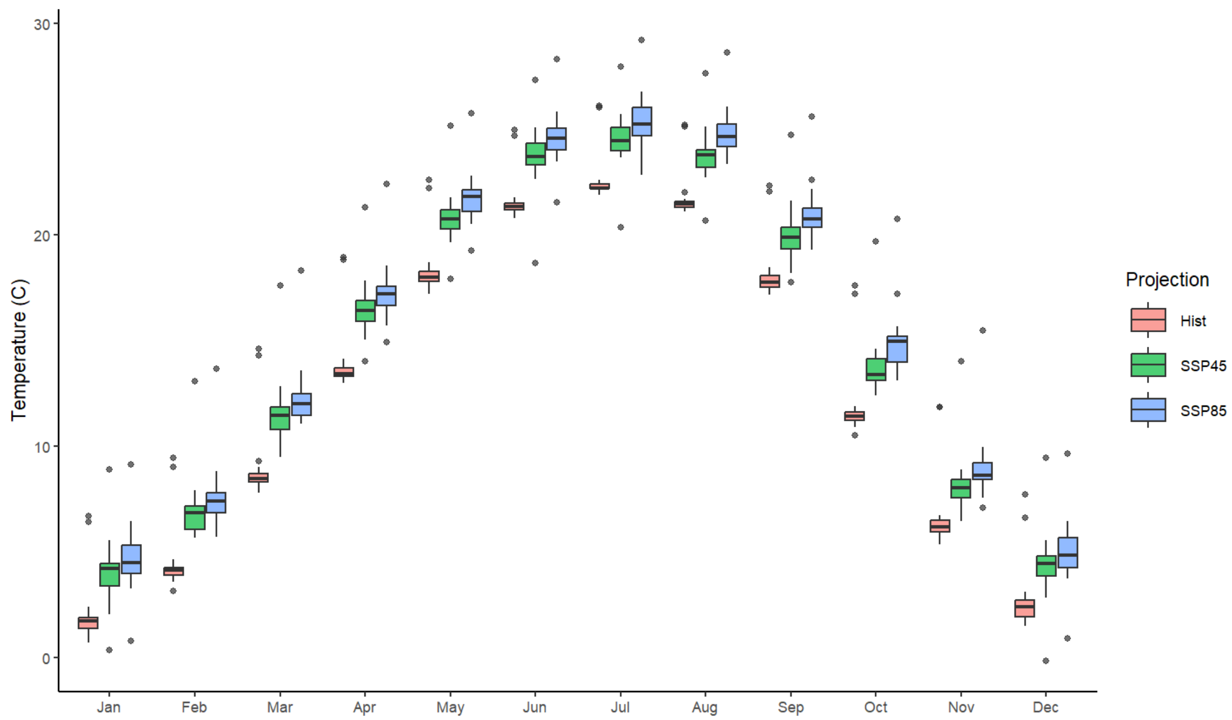


Figure 15.10: Monthly temperature normal compared for historical period (1950-2014) to climate change temperature normal period (2015-2100) for Region 1. Results are based on daily normal calculations.

Precipitation frequency analysis results are summarized below for 1-day, 3-day, and annual durations split into all seasons, the summer season, and the winter season. Results indicate a large range of change with the largest change occurring in the summer season for 1-

day and 3-day durations (Figure 15.11). Numeric values representing the change in precipitation are shown in Table 15.2.

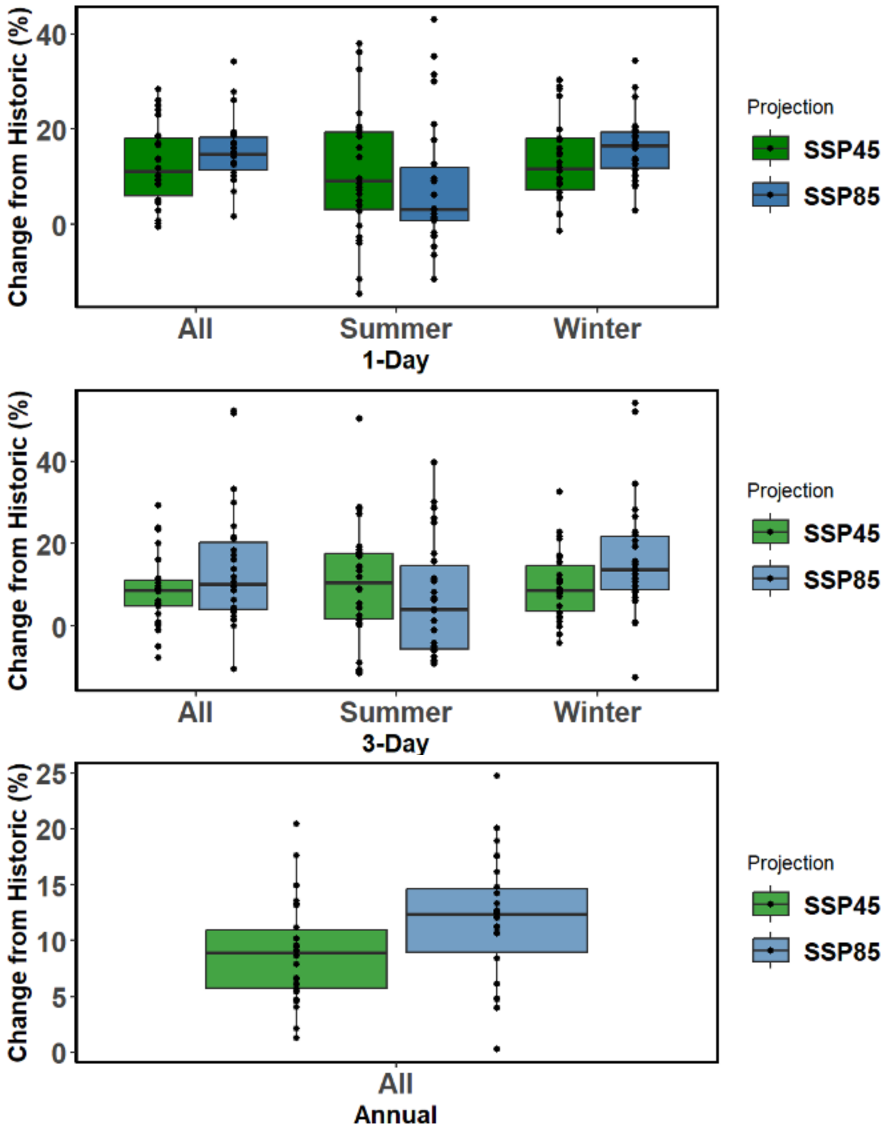


Figure 15.11: Change in maximum precipitation from current climate conditions for 1-day, 3-day, and annual durations in Region 1. Results are based on annual maximum frequency analysis.

Results indicate the most likely outcome is no change in precipitation within the range of uncertainty and an increase in temperature by the year 2100. All precipitation projections show the most likely outcomes are slight increases that are within the uncertainty and variability already included in the current observational record and design inputs. This is true for all durations investigated, with very similar amounts of change projected for each duration investigated. This is important because the projections do not show that the PMP depths are expected to change and that the probability depths up to 1000-year recurrence interval are projected to remain within the range of uncertainty already included in the outputs.

This follows expected trends in the region under a warming climate scenario. In this case, more moisture would be available from an overall perspective, allowing for general increases in seasonal and annual scales. However, this same change is not reflected in the most extreme rainfall events that control PMP depths. This can be related to the variance in atmospheric processes that convert moisture in the atmosphere to rainfall on the ground. These create both positive and negative feedback mechanisms where atmospheric instability at the most extreme levels are lessened in a warming environment because the thermal contrast between airmass is lessened. Therefore, there may be more frequent light rainfall events but less intense (PMP-type) rainfall events. Observational data of the storms which control PMP in the region confirm this as they do not show an increasing trend (Kappel et al., 2020a).

15.4.1 Application of Projections for Hydrologic Sensitivity

For hydrologic simulation and sensitivity, the recommended climate change adjustments that can be applied as a sensitivity for temperature and precipitation are provided in Table 15.2. AWA recommends using the median values from the SSP2-4.5 emission scenario. This represents the most likely outcome from an emission scenario and the median is the most useful application of the multi-model ensemble process.

The values shown are based on an evaluation of the rate of change from the current period through 2100 of each of the projections and taking an average of the outcomes. These values can be applied to a given period (i.e., 2050) by linear adjusting the climate change factors. For hydrologic simulation and sensitivity in Region 1, the recommended climate change adjustments and uncertainty values for monthly temperature are shown in Table 15.3 and precipitation in Table 15.4. An example of the scaling Region 1 results to the year 2050 is shown in Table 15.5. All four climate regions investigated had similar results to Region 1 and are shown in Tables 15.6 to Table 15.8. Additional details are provided in Appendix L.

Table 15.2: North Carolina climate change projections for Region 1, change from historic period (1950-2014) to future period (2015-2100)

	SSP45				SSP85			
	Mean	Median	10th	90th	Mean	Median	10th	90th
Temperature 1-Day; C	**2.0**	**1.8**	1.0	3.3	**3.9**	**3.4**	2.3	5.8
Temperature 1-Day Summer; C	**2.0**	**1.8**	1.0	3.3	**3.9**	**3.4**	2.3	5.8
Temperature 1-Day Winter PF; C	**2.7**	**2.0**	1.3	3.2	**4.5**	**3.6**	2.4	5.5
+ *Precipitation 1-Day PF; %	**12**	**11**	2	25	**15**	**15**	9	23
Precipitation 1-Day Summer PF; %	**11**	**9**	-4	28	**8**	**3**	-4	31
Precipitation 1-Day Winter PF; %	**14**	**12**	2	29	**16**	**17**	9	24
+ *Precipitation 3-Day PF; %	**9**	**9**	0	22	**14**	**10**	2	32
Precipitation 3-Day Summer PF; %	**11**	**10**	-10	28	**6**	**4**	-8	27
Precipitation 3-Day Winter PF; %	**10**	**9**	0	21	**16**	**14**	3	31
Precipitation 30-Day PF; %	**10**	**10**	-6	24	**16**	**15**	2	34
Precipitation 90-Day PF; %	**9**	**10**	-1	18	**15**	**14**	7	29
Precipitation Annual PF; %	**9**	**9**	4	14	**12**	**12**	5	18
Moisture Maximization 1-Day, %	**Potential Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

* Climate Change Projections from 2015 through 2100

\+ Note, SSP8.5 represent the most extreme, the 95-percentile of all model forcing simulations

Table 15.3: North Carolina monthly temperature (C) change from current climate (1950-2014) to 2015 through 2100 for Region 1

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	2.0	1.8	4.0	4.2	4.7	4.5	***2.1***	***2.7***	***2.5***	***2.8***
February	4.4	4.1	6.9	6.8	7.5	7.4	***2.5***	***3.1***	***2.7***	***3.3***
March	8.9	8.5	11.5	11.5	12.2	12.0	***2.6***	***3.3***	***3.0***	***3.6***
April	13.9	13.4	16.5	16.4	17.3	17.2	***2.6***	***3.4***	***3.0***	***3.8***
May	18.3	18.0	20.8	20.8	21.7	21.8	***2.5***	***3.4***	***2.8***	***3.8***
June	21.6	21.4	23.7	23.7	24.6	24.6	***2.1***	***3.0***	***2.4***	***3.2***
July	22.5	22.2	24.5	24.5	25.5	25.3	***2.0***	***2.9***	***2.3***	***3.1***
August	21.7	21.5	23.7	23.8	24.8	24.7	***2.0***	***3.1***	***2.3***	***3.2***
September	18.1	17.8	20.0	19.9	21.0	20.8	***1.9***	***2.9***	***2.1***	***3.0***
October	11.8	11.4	13.7	13.4	14.9	15.0	***1.9***	***3.1***	***2.0***	***3.6***
November	6.6	6.2	8.1	8.0	8.9	8.6	***1.6***	***2.4***	***1.9***	***2.5***
December	2.7	2.4	4.4	4.5	5.0	4.9	***1.7***	***2.3***	***2.1***	***2.5***

Table 15.4: North Carolina monthly precipitation (mm) change from current climate (1950-2014) to 2015 through 2100 for Region 1

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	103.7	102.7	113.3	114.1	119.8	119.7	*1.09*	*1.16*	*1.11*	*1.17*
February	98.4	98.5	109.2	109.7	113.1	113.2	*1.11*	*1.15*	*1.11*	*1.15*
March	116.7	117.3	124.7	125.6	128.8	128.9	*1.07*	*1.10*	*1.07*	*1.10*
April	105.7	104.9	114.0	113.0	109.9	109.6	*1.08*	*1.04*	*1.08*	*1.05*
May	119.1	119.0	125.4	125.4	124.9	121.3	*1.05*	*1.05*	*1.05*	*1.02*
June	114.5	114.7	123.1	121.2	123.1	121.2	*1.08*	*1.07*	*1.06*	*1.06*
July	125.1	125.6	134.3	135.5	138.7	136.4	*1.07*	*1.11*	*1.08*	*1.09*
August	108.7	109.6	118.2	116.5	120.7	120.1	*1.09*	*1.11*	*1.06*	*1.10*
September	90.8	90.0	97.2	97.6	93.3	92.1	*1.07*	*1.03*	*1.09*	*1.02*
October	82.0	81.8	82.6	80.7	83.8	84.4	*1.01*	*1.02*	*0.99*	*1.03*
November	96.8	96.7	103.6	102.0	106.7	104.8	*1.07*	*1.10*	*1.06*	*1.08*
December	107.1	106.4	114.7	111.8	121.2	120.9	*1.07*	*1.13*	*1.05*	*1.14*

Table 15.5: Example of scaling Region 1 climate change results to 2050 from 2100

	2050	2100
1-Day Summer PF; %	4	9
1-Day Winter PF; %	5	12
3-Day Summer PF; %	4	10
3-Day Winter PF; %	4	9
30-Day PF; %	4	10
90-Day PF; %	4	10

Table 15.6: Climate Change Projections for Region 2 from current climate (1950-2014) through 2100

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**1.9**	**1.8**	0.9	3.3	**3.8**	**3.3**	2.1	5.8
Temperature 1-Day Summer; C	**1.9**	**1.8**	0.9	3.3	**3.8**	**3.3**	2.1	5.8
Temperature 1-Day Winter PF; C	**2.7**	**1.9**	1.2	3.1	**4.5**	**3.6**	2.5	5.4
*Precipitation 1-Day PF; %	**12**	**11**	2	21	**14**	**13**	5	23
Precipitation 1-Day Summer PF; %	**11**	**12**	-1	24	**9**	**10**	-2	21
Precipitation 1-Day Winter PF; %	**13**	**12**	3	23	**15**	**15**	6	24
*Precipitation 3-Day PF; %	**8**	**8**	-3	22	**14**	**9**	-1	37
Precipitation 3-Day Summer PF; %	**9**	**9**	-8	24	**6**	**3**	-8	26
Precipitation 3-Day Winter PF; %	**9**	**9**	-3	22	**15**	**12**	1	36
Precipitation 30-Day PF; %	**11**	**12**	-8	25	**17**	**15**	2	28
Precipitation 90-Day PF; %	**10**	**12**	-3	19	**16**	**15**	6	27
Precipitation Annual PF; %	**9**	**9**	4	15	**12**	**12**	6	18
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**Potential Change**				**No Change**			

Table 15.7: Climate Change Projections for Region 3 from current climate (1950-2014) through 2100

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**1.8**	**1.8**	0.5	3.2	**3.8**	**3.4**	2.3	6.1
Temperature 1-Day Summer; C	**1.8**	**1.8**	0.5	3.2	**3.8**	**3.4**	2.3	6.1
Temperature 1-Day Winter PF; C	**1.8**	**2.1**	1.2	2.7	**3.5**	**3.4**	2.4	5.0
*Precipitation 1-Day PF; %	**8**	**8**	-7	23	**10**	**10**	-4	25
Precipitation 1-Day Summer PF; %	**5**	**5**	-13	28	**6**	**2**	-12	29
Precipitation 1-Day Winter PF; %	**12**	**12**	2	27	**15**	**14**	0	32
*Precipitation 3-Day PF; %	**8**	**7**	-6	22	**11**	**8**	1	30
Precipitation 3-Day Summer PF; %	**1**	**3**	-14	15	**3**	**0**	-13	24
Precipitation 3-Day Winter PF; %	**14**	**11**	-3	34	**17**	**17**	2	31
Precipitation 30-Day PF; %	**11**	**12**	-3	22	**17**	**17**	3	33
Precipitation 90-Day PF; %	**11**	**11**	0	23	**16**	**16**	7	27
Precipitation Annual PF; %	**10**	**10**	4	16	**12**	**12**	6	22
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

Table 15.8: Climate Change Projections for Region 4 from current climate (1950-2014) through 2100

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**1.7**	**1.8**	0.7	3.2	**4.7**	**3.0**	2.2	5.6
Temperature 1-Day Summer; C	**1.7**	**1.8**	0.7	3.2	**4.7**	**3.0**	2.2	5.6
Temperature 1-Day Winter PF; C	**1.6**	**1.8**	1.0	2.3	**3.1**	**3.2**	1.8	4.4
*Precipitation 1-Day PF; %	**3**	**0**	-7	14	**6**	**4**	-11	24
Precipitation 1-Day Summer PF; %	**0**	**-1**	-19	20	**2**	**0**	-18	26
Precipitation 1-Day Winter PF; %	**7**	**6**	-5	18	**9**	**8**	-3	21
*Precipitation 3-Day PF; %	**2**	**1**	-6	14	**6**	**6**	-6	17
Precipitation 3-Day Summer PF; %	**-1**	**-1**	-16	15	**3**	**1**	-18	22
Precipitation 3-Day Winter PF; %	**8**	**7**	-6	22	**13**	**13**	-3	28
Precipitation 30-Day PF; %	**6**	**4**	-5	15	**9**	**8**	0	17
Precipitation 90-Day PF; %	**7**	**7**	-3	16	**9**	**9**	1	18
Precipitation Annual PF; %	**8**	**8**	-2	15	**10**	**9**	2	18
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**Potential Change**			

16. Uncertainty and Limitations

16.1 Sensitivity of Parameters

In the process of deriving PMP depths, various assumptions and meteorological judgments were made. Additionally, various parameters and derived values were used in the calculations, which are standard to the PMP development process. It is of interest to assess the sensitivity of PMP to assumptions that were made and to the variability of parameter values.

16.2 Saturated Storm Atmosphere

Atmospheric air masses that provide available moisture to both the historic storm and the PMP storm are assumed to be saturated through the entire depth of the atmosphere and to contain the maximum moisture possible for a given storm event based on the surface dew point or SST. This assumes moist pseudo-adiabatic temperature profiles for both the historic storm and the PMP storm. Limited evaluation of this assumption in the EPRI Michigan/Wisconsin PMP study (Tomlinson, 1993) and the Blenheim Gilboa study (Tomlinson et al., 2008) indicated that historic storm atmospheric profiles are generally not entirely saturated and contain somewhat less precipitable water than is assumed in the PMP procedure. More detailed evaluations were completed by Ben Alaya et al., (2018) utilizing an uncertainty analysis and modeling framework. This again demonstrated that the assumption of a fully saturated atmosphere in conjunction with maximum storm efficiency may not be valid. However, this assumption does produce the most conservative combination of factors and resulting PMP depths.

It follows that the PMP storm (if it were to occur) would also have somewhat less precipitable water available than the assumed saturated PMP atmosphere would contain. The *ratio* of precipitable water associated with each storm is used in the PMP calculation procedure. If the precipitable water values for each storm scenario are both slightly overestimated, the ratio of these values will be essentially unchanged. For example, consider the case where instead of a historic storm with a storm representative dew point of 70°F having 2.25 inches of precipitable water and assuming a saturated atmosphere, it actually had 90% of that value or about 2.02 inches. The PMP procedure assumes the same type of storm with similar atmospheric characteristics for the maximized storm but with a higher dew point, say 76°F. The maximized storm, having similar atmospheric conditions, would have about 2.69 inches of precipitable water instead of the 2.99 inches associated with a saturated atmosphere with a dew point of 76°F. The maximization factor computed, using the assumed saturated atmospheric values, would be 2.99/2.25 = 1.33. If both storms were about 90% saturated, the maximization factor would be 2.69/2.02 = 1.33. Therefore, any potential inaccuracy of assuming saturated atmospheres (whereas the atmospheres may be somewhat less than saturated) should have a minimal impact on storm maximization and subsequent PMP calculations.

16.3 Maximum Storm Efficiency

The assumption is made that if a sufficient period of record is available for rainfall observations, at least a few storms would have been observed that attained or came close to attaining the maximum efficiency possible in nature for converting atmospheric moisture to rainfall for regions with similar climates and topography. The further assumption is made that if additional atmospheric moisture had been available, the storm would have maintained the same efficiency for converting atmospheric moisture to rainfall. The ratio of the maximized rainfall amounts to actual rainfall amounts would be the same as the ratio of precipitable water in the atmosphere associated with each storm.

There are two issues to be considered. The first relates to the assumption that a storm has a precipitation efficiency close to the maximum possible. Unfortunately, state-of-the-science in meteorology does not support a theoretical evaluation of storm efficiency. However, if the period of record is considered (generally over 100 years), along with the extended geographic region with transpositionable storms, it is accepted that there should have been at least one storm with dynamics that approached the maximum efficiency for rainfall production. The other issue is the assumption that storm efficiency does not change if additional moisture is available. Storm dynamics could potentially become more efficient or possibly less efficient depending on the interaction of cloud microphysical processes with the storm dynamics. Offsetting effects could indeed lead to the storm efficiency remaining essentially unchanged. For the present, the assumption of no change in storm efficiency seems acceptable.

16.4 Storm Representative Dew Point/SST and Maximum Dew Point/SST

The maximization factor depends on the determination of storm representative dew points or SST, along with maximum historical dew point or SST values. The magnitude of the maximization factor varies depending on the values used for the storm representative dew point/SST and the maximum dew point/SST. Holding all other variables constant, the maximization factor is smaller for higher storm representative dew points/SSTs as well as for lower maximum dew point/SST values. Likewise, larger maximization factors result from the use of lower storm representative dew points/SSTs and/or higher maximum dew points/SSTs. The magnitude of the change in the maximization factor varies depending on the dew point/SST values. For the range of dew point/SST values used in most PMP studies, the maximization factor for a particular storm will change about 5% for every 1°F difference between the storm representative and maximum dew point/SST values. The same sensitivity applies to the transposition factor, with about a 5% change for every 1°F change in either the in-place maximum dew point/SST or the transposition maximum dew point/SST.

16.5 Judgment and Effect on PMP

During the process of PMP development several aspects involve professional judgment:

- Storms used for PMP development
- Storm representative dew point/SST value and location
- Storm transposition limits
- Use of precipitation frequency climatologies to represent differences in precipitation processes (including orographic effects) between two locations

Each of these processes were discussed and evaluated during the PMP development process internally within AWA and with the NC DEQ and others involved in the project. The resulting PMP depths derived as part of the PMP development reflect the most defensible methods based on the data available and current scientific understanding. The PMP results represent defensible, reproducible, reasonable, and appropriately conservative estimates.

17. References

Alexander et al., 2015: The High-Resolution Rapid Refresh (HRRR): The operational implementation, in 95th Annual meeting of the American Meteorological Society.

Ben Alaya, M.A., F. Zwiers, and X. Zhang, 2018: Probable Maximum Precipitation: Its Estimation and Uncertainty Quantification Using Bivariate Extreme Value Analysis. *J. Hydrometeor.*, **19**, 679–694.

Beven, K.J., 2001. *Rainfall-runoff modelling: The Primer*. John Willey and Sons, Chichester, UK. pp 360.

Beven, K.J., 2006. A manifesto for the equifinality thesis. *Journal of Hydrology*, 320, 18-36.

Blösch, G., 1999. Scaling Issues in Snow Hydrology. *Hydrological Processes*, 13, 2149- 2175.

Bonnin, G., D. Martin, B. Lin, T. Parzybok, M. Yekta, and D. Riley, 2006: NOAA *Atlas 14 Volume 2*, *Precipitation-Frequency Atlas of the United States, Delaware, District of Columbia, Illinois, Indiana, Kentucky, North Carolina, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia*. NOAA, National Weather Service, Silver Spring, MD.

Bontà, V., 2003: Estimation of parameters characterizing frequency distributions of times between storms. Transactions of the ASAE. 46.

Brown, V.M., B.D. Keim, W.D. Kappel, D.M. Hultstrand, A.G. Peyrefitte, A.W. Black, K.M. Steinhilber, and G.A. Muhlestein, 2020: How Rare Was the August 2016 South-Central Louisiana Heavy Rainfall Event?. *J. Hydrometeor.*, **21**, 773–790, https://doi.org/10.1175/JHM-D-19-0225.1.

Brown, V. M., Black, A. W., Hultstrand, D. M., Kappel, W. D., Thompson, D. T., Bentley, A. M., … Keim, B. D., 2024: Rainfall analysis of the May 2021 southeastern Texas and southern Louisiana flood. *Physical Geography*, 1–24. https://doi.org/10.1080/02723646.2024.2384131

Chaing, S., Y. Tachikawa, and K. Takara, 2007. Hydrological model performance comparison through uncertainty recognition and quantification. *Hydrological Processes*, 21, 1179-1195.

Corps of Engineers, U.S. Army, 1945-1973: Storm Rainfall in the United States, Depth-Area-Duration Data. Office of Chief of Engineers, Washington, D.C.

Corrigan, P., D.D. Fenn, D.R. Kluck, and J.L. Vogel, 1999: Probable Maximum Precipitation for California, Hydrometeorological Report Number 59, National Weather Service, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, Silver Spring, MD, 392 pp.

Cudworth, A.G., 1989: Flood Hydrology Manual, Water Resources Technical Publication, United States Dept, of the Interior, United States Bureau of Reclamation, Denver office, 243pp.

Daly, C., R.P. Neilson, and D.L. Phillips, 1994: A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain. J. Appl. Meteor., 33, 140–158.

Daly, C., Taylor, G., and W. Gibson, 1997: The PRISM Approach to Mapping Precipitation and Temperature, 10th Conf. on Applied Climatology, Reno, NV, Amer. Meteor. Soc., 10-12.

Dickens, J., 2003: On the Retrieval of Drop Size Distribution by Vertically Pointing Radar. American Meteorological Society 32nd Radar Meteorology Conference, Albuquerque, NM, October 2005

Draxler, R.R. and Rolph, G.D., 2013: HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) NOAA Air Resources Laboratory, Silver Spring, MD. Model access via NOAA ARL READY Website, http://ready.arl.noaa.gov/HYSPLIT.php

Dwight, B.W., 1822; An Account of a Remarkable storm which occurred at Catskill, July 26, 1819, *in* The American Journal of Science and Arts, Vol. IV, Articl XII.

England, J. F., Julien, P. Y., & Vellleux, M. L., 2014: Physically-based extreme flood frequency with stochastic storm transposition and paleoflood data on large watersheds. *Journal of Hydrology*, *510*, 228–245.

Environmental Data Service, 1968: Maximum Persisting 12-Hour, 1000mb Dew Points (°F) Monthly and of Record. *Climate Atlas of the United States*, Env. Sci. Srv. Adm., U.S. Dept of Commerce, Washington, D.C., pp 59-60.

Environmental Systems Research Institute (ESRI), ArcGIS Version 10.1 Computer Software, 2012.

Gelber, Ben, 1992: *Pocono Weather,* Uriel Publishing, Stroudsburg, New Jersey, 291 pp.

Goodyear, H.V., and J.T., Riedel, 1965: Probable Maximum Precipitation, Susquehanna River Drainage Above Harrisburg, PA *Hydrometeorological Report Number 40*, Hydrometeorological Branch, Office of Hydrology, U.S. Weather Bureau, Washington, D.C., 78 pp.

GRASS (Geographic Resources Analysis Support System) GIS is an open source, free software GIS with raster, topological vector, image processing, and graphics production functionality that operates on various platforms. http://grass.itc.it/.

Guo, J.C.Y., 2012: Storm Centering Approach for Flood Predictions from Large Watersheds, Journal of Hydrologic Engineering.

Hansen, E.M, F.K. Schwarz, and J.T Reidel, 1977: Probable Maximum Precipitation Estimates. Colorado River and Great Basin Drainages. Hydrometeorological Report No. 49, NWS, NOAA, U.S. Department of Commerce, Silver Spring, MD, 161 pp.

Hansen, E.M, and F.K. Schwartz, 1981: Meteorology of Important Rainstorms in the Colorado River and Great Basin Drainages. Hydrometeorological Report No. 50, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 167 pp.

Hansen, E.M., L.C. Schreiner and J.F. Miller, 1982: Application of Probable Maximum Precipitation Estimates – United States East of the 105th Meridian. Hydrometeorological Report No. 52, U.S. Department of Commerce, Washington, D.C., 168 pp.

Hansen, E.M, Fenn, D.D., Schreiner, L.C., Stodt, R.W., and J.F., Miller, 1988: Probable Maximum Precipitation Estimates, United States between the Continental Divide and the 103rd Meridian, Hydrometeorological Report Number 55A, National weather Service, National Oceanic and Atmospheric Association, U.S. Dept. of Commerce, Silver Spring, MD, 242 pp.

Hansen, E.M, Schwarz, F.K., and J.T. Riedel, 1994: Probable Maximum Precipitation- Pacific Northwest States, Columbia River (Including portion of Canada), Snake River, and Pacific Drainages. Hydrometeorological Report No. 57, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 353 pp.

Hausfather, Zeke; Peters, Glen P., 2020: “Emissions – the 'business as usual' story is misleading". Nature. 577 (618–620). doi:10.1038/d41586-020-00177-3. Retrieved 2022-03-28.

Hershfield, D.M., 1961: *Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years*. Weather Bureau Technical Paper No. 40, U.S. Weather Bureau, Washington, D.C., 115 pp.

Heuvelink, G., 1998. *Error Propagation in Environmental Modelling with GIS*. CRC Press, 150 pp.

Hicks, N. S., J. A. Smith, A. J. Miller, *and* P. A. Nelson, 2005: Catastrophic flooding from an orographic thunderstorm in the central Appalachians, Water Resour. Res., 41, *W12428*

Hipel, K.W. and McLeod, A.I., 2005: Time Series Modelling of Water Resources and Environmental Systems. Electronic reprint of our book originally published in 1994. http://www.stats. uwo.ca/faculty/aim/1994Book/.

Hosking, J.R.M, 2015a. L-moments. R package, version 2.5. URL: http://CRAN.R-project.org/package=lmom.

Hosking, J.R.M, 2015b. Regional frequency analysis using L-moments. R package, version 3.0-1. URL: http://CRAN.R-project.org/package=lmomRFA.

Hosking, J.R.M. and J.R. Wallis, 1997: "Regional Frequency Analysis, An Approach Based on L-Moments," Cambridge University Press, 224 pp.

Huff, F.A., 1967: Time Distribution of Rainfall in Heavy Storms, Water Resources Research.

Hultstrand, D.M., and Kappel, W.D., 2017: The Storm Precipitation Analysis System (SPAS) Report. Nuclear Regulatory Commission (NRC) Inspection Report No 99901474/2016-201, Enercon Services, Inc., 95pp.

Hultstrand, D.M., S.R. Fassnacht, J.D. Stednick, and K. Suzuki, 2024: The Best Precipitation Estimates for a Hydrologic Model by Combining Gauge and Radar Data. *Geoöko*, XLV(1-4), 5-34.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., McGlone, D., E.M. Tomlinson, and T. Parzybok. July 2013: Probable Maximum Precipitation Study for Arizona. Prepared for the Arizona Dept. of Water Resources, Dam Safety Division.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., and D. McGlone, July 2014: Site-Specific Probable Maximum Precipitation (PMP) Study for the College Lake Basin, Colorado, prepared for Colorado State University.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., McGlone, D., Parzybok, T.W, and E.M. Tomlinson, December 2014: Statewide Probable Maximum Precipitation (PMP) Study for Wyoming.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., and McGlone, D., December 2015: Application of Temporal Patterns of PMP for Dam Design in Wyoming. Prepared for the Wyoming State Engineer's Office.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Steinhilber, K., McGlone, D., Rodel, J., and B. Lawrence, November 2015: Statewide Probable Maximum Precipitation or Virginia. Prepared for the Virginia Department of Conservation and Recreation.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., and McGlone, D, February 2016: Site-Specific Probable Maximum Precipitation for Hebgen Dam, MT.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., Rodel, J.T., McGlone, D., Parzybok, T.W., and B. Lawrence, September 2016: Statewide Probable Maximum Precipitation for Texas. Prepared for the Texas Commission of Environmental Quality.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Rodel, J.T., Steinhilber, K., McGlone, D., and Lawrence, B., May 2017: Site-Specific Probable Maximum Precipitation and Annual Exceedance Probability Assessment for the Gross Reservoir Basin, Colorado. Prepared for Denver Water.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Rodel, J.T., Steinhilber, K., and Lawrence, B., May 2018: Site-Specific Probable Maximum Precipitation and Annual Exceedance Probability Assessment for the Painted Rocks and East Fork Basins, Montana. Prepared for AECOM and Montana Dept. of Natural Resources.

Kappel, W.D., Rodel, J.T., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., and McGlone, D, June 2018: Site-Specific Probable Maximum Precipitation and Annual Exceedance Probability Assessment for the Catawba Wateree Basin. Prepared for Duke Energy.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., McGlone, D., and B. Lawrence, August 2018: Regional Probable Maximum Precipitation for the States of Colorado and New Mexico. Prepared for the Colorado Division of Water Resources and the New Mexico State Engineers Office.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Rodel, J.T., Steinhilber, K., and Lawrence, B., October 2018: Site-Specific Probable Maximum Precipitation for Mayo Reservoir basin, North Carolina. Prepared for Duke Energy.

Kappel W.D., and Hultstrand, D.M., 2018: Hurricane Harvey, *Journal of Dam Safety*, Vol. 16, No. 1, 25-34.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Steinhilber, K., McGlone, D., and B. Lawrence, March 2019: Statewide Probable Maximum Precipitation for Pennsylvania. Prepared for the Pennsylvania Department of Environmental Protection.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., Rodel, J., and B. Lawrence, August 2019: Regional Probable Maximum Precipitation for the states of Oklahoma, Arkansas, Louisiana, and Mississippi. Prepared for the Oklahoma Water Resources Board, Arkansas Dept. of Natural Resources, Louisiana Dept. of Transportation & Development, Mississippi Dept. of Environmental Quality.

Kappel, W.D., Hultstrand, D.M., Steinhilber, K., and J.T. Rodel, 2020a: Climate Change and PMP: Are These Storms Changing? *Journal of Dam Safety*, Vol. 17, No. 3.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Rodel, J.T., and. Steinhilber, K., November 2020: Site-Specific Probable Maximum Precipitation for the Mongaup System, New York. Prepared for Eagle Creek Renewable Energy.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., and Steinhilber, K., June 2021: Statewide Probable Maximum Precipitation for North Dakota. Prepared for the North Dakota State Water Commission.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, and Steinhilber, K., January 2022: Site-specific Probable Maximum Precipitation for the Lower Nelson River Basin, Manitoba, Canada. Prepared for Manitoba Hydro under subcontract to Hatch.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, and Steinhilber, K., February 2022: Site-specific Probable Maximum Precipitation for the Loch Dornie

Basin, North Carolina. Prepared for Grandfather Golf and Country Club under subcontract to Hazen and Sawyer.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, and Steinhilber, K., March 2022: Site-specific Probable Maximum Precipitation for Faro Mine, Yukon Territory. Prepared for SRK.

Kappel, W.D. and Hultstrand, D.M., April 2022: Annual Exceedance Probability and Meteorological Evaluation and Climate Change Review for Solitude and Russell Gulch Mines, Arizona. Prepared for KCB and BHP.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, and Steinhilber, K., August 2022: Site-specific Probable Maximum Precipitation for Seine River basin, Ontario, Canada. Prepared for Brookfield.

Kappel, W.D., Rodel, J., and Hultstrand, D.M., October 2022: Probable Maximum Precipitation, Annual Exceedance Probability and Meteorological Evaluation for the Lake Bronson Dam basin, MN. Prepared for BARR Engineering.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, and Steinhilber, K., October 2022: Site-specific Probable Maximum Precipitation for Montreal, Magpie, Michipicoten, and Mississagi basins, Ontario, Canada. Prepared for Brookfield.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, and Steinhilber, K., October 2022: Site-specific Probable Maximum Precipitation, Annual Exceedance Probability, and Climate Change Assessment for Kings Mountain, North Carolina. Prepared for SRK.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Venticinque, M, Rodel, J.T., and Steinhilber, K., December 2022: Site-specific Probable Maximum Precipitation, Meteorological Characterization, and Climate Change Assessment for the KSM Mine Complex, British Columbia. Prepared for Seabridge Gold.

Kappel W.D., February 2023: How Much Rainfall Must a Dam Withstand?, *Hydro Leader,* Vol. 4, Issue 2, 24-27.

Kappel, W.D., Rodel, J.T., Hultstrand, D.M., Muhlestein, G.A., Venticinque, M., and Steinhilber, K., June 2023: Site-Specific Probable Maximum Precipitation for the Avonlea Dam Basin. Prepared for Water Security Agency in partnership with Hatch.

Kappel, W.D., Rodel, J.T., Hultstrand, D.M., Muhlestein, G.A., Venticinque, M., and Steinhilber, K., June 2023: Site-Specific Probable Maximum Precipitation for the Junction Dam Basin. Prepared for Water Security Agency in partnership with Hatch.

Kappel, W.D, Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, Cheke, D., and Steinhilber, K., July 2023: Statewide Probable Maximum Precipitation for New Jersey. Prepared for the New Jersey Dept. of Environmental Protection Dam Safety.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Venticinque, M, Rodel, J.T., K., Steinhilber, and Cheke, D., December 2023: Site-specific Probable Maximum Precipitation, Meteorological Characterization, and Climate Change Assessment for the Nechako Mine Complex, British Columbia. Prepared for KCB and Rio Tinto.Keim, B. D., 1998: Record Precipitation Totals from the Coastal New England Rainstorm of 20-21 October 1996, *Bull. Amer. Meteo. Soc.*, **79**, 1061-1067.

Kappel, W.D., Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, Cheke, D., and Steinhilber, K., December 2024: Statewide Probable Maximum Precipitation for Maryland. Prepared for the Maryland Dept. of the environment, Dam Safety.

Keim, B.D., R.A. Muller, and G.W. Stone, 2007: Spatiotemporal Patterns and Return Periods of Tropical Storm and Hurricane Strikes from Texas to Maine. *J. Climate*, **20**, 3498–3509.
Keim, B.D., Kappel W.D., Muhlestein, G.A, Hultstrand, D.M., Parzybok, T.W., Lewis, A.B., Tomlinson, E.M., and A.W., Black, October 2018: Assessment of the Extreme Rainfall Event at Nashville, TN and the Surrounding Region on May 1-3, 2010, *Journal of the American Water Resources Associates*, Vol. 54, No. 5, 1001-1010.
Kent, E.C, Woodruff, S. D., and D. I. Berry, 2007: Metadata from WMO Publication No. 47 and an Assessment of Voluntary Observing Ship Observation Heights in ICOADS. *J. Atmos and Ocean Tech.*, **24(2)**, 214-234.
Konrad, C.E., 2001: The Most Extreme Precipitation Events over the Eastern United States from 1950 to 1996: Considerations of Scale. *J. Hydrometeor.*, **2**, 309–325.
Koren, V.I., B.D. Finnerty, J.C. Schaake, M.B. Smith, D.J. Seo, and Q. Duan, 1999. Scale dependencies of hydrologic models to spatial variability of precipitation. *Journal of Hydrology*, 217, 285-302.
Kunkel, K.E., T.R. Karl, D.R. Easterling, K. Redmond, J. Young, X. Yin, and Hennon, P., 2013: Probable Maximum Precipitation and Climate Change, *Geophys. Res. Lett*., **40**, 1402-1408.
Kunkel, K.E., T.R. Karl, H. Brooks, J. Kossin, J.H. Lawrimore, D. Arndt, L. Bosart, D. Changnon, S.L. Cutter, N. Doesken, K. Emanuel, P.Y. Groisman, R.W. Katz, T. Knutson, J. O'Brien, C.J. Paciorek, T.C. Peterson, K. Redmond, D. Robinson, J. Trapp, R. Vose, S. Weaver, M. Wehner, K. Wolter, and D. Wuebbles, 2013: Monitoring and Understanding Trends in Extreme Storms: State of Knowledge. *Bull. Amer. Meteor. Soc.*, **94**, 499–514.
Kunkel, K. E., and Champion, S. M., 2019: An assessment of rainfall from Hurricanes Harvey and Florence relative to other extremely wet storms in the United States. *Geophysical Research Letters*, 46, 13500– 13506. https://doi.org/10.1029/2019GL085034.
Kuczera G., 1982: Combining Site-Specific and Regional Information: An Empirical Bayes Approach, Water Resources Research, 18, No. 2, 306-314.
Lehner, F., Deser, C., Maher, N., Marotzke, J., Fischer, E. M., Brunner, L., Knutti, R., and Hawkins, E., 2020. Partitioning climate projection uncertainty with multiple large ensembles and CMIP5/6, Earth Syst. Dynam., 11, 491–508, https://doi.org/10.5194/esd-11-491-2020.
Letkewicz, C.E., M.D. Parker, 2010: Forecasting the Maintenance of Mesoscale Convective Systems Crossing the Appalachian Mountains. *Wea. Forecasting*, **25**, 1179–1195.
Mahoney, K., M. Alexander, J. D. Scott, and J. Barsugli, 2013: High-Resolution Downscaled Simulations of Warm-Season Extreme Precipitation Events in the Colorado Front Range under Past and Future Climates*. *J. Climate*, 26, 8671–8689.
Mahoney, K., 2016: Examining terrain elevation assumptions used in current extreme precipitation estimation practices: A modeling study of the 2013 Colorado Front Range floods. Amer. Meteor. Soc. 30th Conf. on Hydrology, January 2016, New Orleans, LA.
Mann, H.B., 1945: Nonparametric tests against trend, Econometric, 13, 245-259.
Martner, B.E, and V. Dubovskiy, 2005: Z-R Relations from Raindrop Disdrometers: Sensitivity to Regression Methods And DSD Data Refinements. 32nd Radar Meteorology Conference, Albuquerque, NM.
Masson-Delmotte, Valérie; Zhai, Panmao; Pirani, Anna; Connors, Sarah L.; Péan, Clotilde; Berger, Sophie; Caud, Nada; Chen, Yang; Goldfarb, Leah; Gomis, Melissa I.; Huang, Mengtian; Leitzell, Katherine; Lonnoy, Elisabeth; Matthews, J. B. Robin; Maycock, Tom

K.; Waterfield, Tim; Yelekçi, Ozge; Yu, Rong; Zhou, Baiquan, eds., 2021: "Summary for Policymakers". Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (PDF). IPCC / Cambridge University Press.

McLeod, A.I., 2015. Kendall: Kendall rank correlation and Mann-Kendall trend test. R package, version 2.2. URL: https://cran.r-project.org/web/packages/Kendall/index.html.

Miller, J.F., R.H. Frederick and R.S. Tracey, 1973: NOAA Atlas 2, Precipitation: Frequency Atlas of the Western United States. U.S. Dept. of Commerce, NOAA, National Weather Service, Washington DC.

Minty, L.J., Meighen, J. and Kennedy, M.R., 1996: Development of the Generalized Southeast Australia Method for Estimating Probable Maximum Precipitation, HRS Report No. 4, Hydrology Report Series, Bureau of Meteorology, Melbourne, Australia, August 1996.

National Climatic Data Center (NCDC). NCDC TD-3200 and TD-3206 datasets - Cooperative Summary of the Day

National Climatic Data Center (NCDC) Heavy Precipitation Page http://www.ncdc.noaa.gov/oa/climate/severeweather/rainfall.html#maps

National Oceanic and Atmospheric Association, Forecast Systems Laboratory FSL Hourly/Daily Rain Data, http://precip.fsl.noaa.gov/hourly_precip.html

Natural Resources Conservation Service (NRCS), Conservation Engineering Division. (2005, July). Earth Dams and Reservoirs, TR-60.

Ohara, N., Kavvas, M. L., Anderson, M. L., Chen, Z. Q., & Ishida, K., 2017: Characterization of extreme storm events using a numerical model based precipitation maximization procedure in Feather, Yuba, and American River watersheds in California. *Journal of Hydrometeorology*, *18*(5), 1413–1423.

Perica, S., Martin, D., Pavlovic, S., Roy, I., St. Laurent, M., Trypaluk, C., Unruh, D., Yetka, M., Bonnin, G., 2013: *NOAA Atlas 14 Volume 8 Version 2.0, Precipitation-Frequency Atlas of the United States, Midwestern States*. Tech. Rep., NOAA National Weather Service, Silver Spring, MD. http://hdsc.nws.noaa.gov/hdsc/pfds/

Perica, S. Martin, D., S. Pavlovic, I. Roy, C., Laurent, M.S., Trypaluk, D. Unruh, M. Yekta, and G. Bonnin, 2013: *NOAA Atlas 14 Volume 9 version 2, Precipitation-Frequency Atlas of the United States, Southeastern States* NOAA, National Weather Service, Silver Spring, MD.

Perica, S., Pavlovic, S., Laurent, M.S., Trypaluk, D. Unruh, Martin, D., and O. Wilhite, 2015: *NOAA Atlas 14 Volume 10 version 2, Precipitation-Frequency Atlas of the United States, Northeastern States*, NOAA, National Weather Service, Silver Spring, MD.

Pontrelli, M.D., Bryan, G., and J.M. Fritsch, 1999: The Madison County, Virginia, Flash Flood of 27 June 1995, *Weather and Forecasting.*, **14**, 384-404.

Pokorny S. et al., 2021. Cumulative Effects of Uncertainty on Simulated Streamflow in a Hydrologic Modeling Environment. Elementa: Science of the Anthropocene 9(1) 431. https://doi.org/10.1525/elementa.431.

PRISM Mapping Methodology, http://www.ocs.oregonstate.edu/prism/index.phtml

Reynolds, R.W., T.M. Smith, C. Liu, D.B. Chelton, K.S. Casey, and M.G. Schlax, 2007: Daily High-resolution Blended Analysis for Sea Surface Temperature. *J. Climate.*, **20**, 5473-5496.

Riedel, J.T., Appleby, J.F., and R.W. Schloemer, 1956: Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas from 10 to 1000 Square miles and Durations of 6, 12, 24, and 48 Hours, *Hydrometeorological Report 33*, US Department of Commerce, Weather Bureau, Washington, DC, 32pp.

Riedel, J.T., and L.C. Schreiner, 1980: Comparison of Generalized Estimates of Probable Maximum Precipitation with Greatest Observed Rainfalls, *NOAA Technical Report NWS 25*, US Department of Commerce, NOAA, Silver Spring, Md, 46 pp.

Robinson, D.A., I. Miyares, M. Pavlovskaya, G.A. Pope, 2001: Hurricane Floyd rainfall in New Jersey from the Hudson to the Hamptons: Snapshots of the New York Metropolitan Area.

Rolph, G., Stein, A., and Stunder, B., 2017: Real-time Environmental Applications and Display sYstem: READY. Environmental Modeling & Software, 95, 210-228.

Schaefer, M.G., B.L. Barker, G.H. Taylor and J.R. Wallis, 2006: *Regional Precipitation-Frequency Analysis and Spatial Mapping of Precipitation for 24-Hour and 2-Hour Durations in Eastern Washington*. Publication prepared for Washington State Department of Transportation, MGS Engineering Consultants.

Scharffenberg, B., Bartles, M., Brauer, T., Fleming, M., Karlovits, G. 2018. Hydrologic Modeling System HEC-HMS – User's Manual, Version 4.3. U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center (CEIWR-HEC), Davis, CA, USA.

Schreiner, L.C., and J.T. Riedel, 1978: Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. Hydrometeorological Report No. 51, U.S. Department of Commerce, Silver Spring, Md, 242 pp.

Schwartz, F.K,1965: Probable Maximum and TVA Precipitation over the Tennessee River Basin above Chattanooga. *Hydrometeorological Report No. 41*, Office of Hydrology, U.S. Weather Bureau, Washington, D.C., 153pp.

Segond, M.L., C. Onof, and H.S. Wheater, 2006. Spatial-temporal disaggregation of daily rainfall from a generalized linear model. *Journal of Hydrology*, 331, 674-689.

Smith, J.A., M.L. Baeck, M. Steiner, and A.J. Miller, 1996: Catastrophic Rainfall from an Upslope Thunderstorm in the Central Appalachians: The Rapidan Storm of June 27, 1995. *Water Res. Research*, **32**, 3099-3113.

Smith, J. A., M. L. Baeck, G. Villarini, and W. F. Krajewski, 2010: The Hydrology and Hydrometeorology of Flooding in the Delaware River Basin. J. Hydrometeor, **11**, 841-859.

Smith, J A., Gabriele Villarini, and Mary Lynn Baeck, 2011: Mixture Distributions and the Hydroclimatology of Extreme Rainfall and Flooding in the Eastern United States. *J. Hydrometeor*, **12**, 294–309.

Smith, J A., M. L. Baeck, A.A., Ntelekos, G. Villarini, and M. Syeiner, 2011: Extreme Rainfall and Flooding from Orographic Thunderstorms in the Central Appalachians. *Water Res. Research*, **47**, W04514, 24pp.

Stein, A. F., R. R. Draxler, G. D. Rolph, B. J. B. Stunder, M. D. Cohen, and F. Ngan, 2015: NOAA's HYSPLIT Atmospheric Transport and Dispersion Modeling System. Bull. Amer. Meteor. Soc., 96, 2059–2077.

Thaler, J.S., 1996: *Catskill Weather*, Purple Mountain Press, Ltd., Fleischmanns, NY, 167 pp.

Thrasher, B., Wang, W., Michaelis, A. Nemani, R., 2021: NEX-GDDP-CMIP6. NASA Center for Climate Simulation, doi:10.7917/OFSG3345.

Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T., Nemani, R., 2022: NASA Global Daily Downscaled Projections, CMIP6. Nature Scientific Data

Tomlinson, E.M., 1993: Probable Maximum Precipitation Study for Michigan and Wisconsin, Electric Power Research Institute, Palo Alto, CA, TR-101554, V1.

Tomlinson, E.M., Kappel W.D., and Muhlestein, G.A., August 2007: Reevaluation of the Smethport, PA July 1942 Rainfall, Prepared for the St. Mary's Water Authority

Tomlinson, E.M., Kappel W.D., and Parzybok, T.W., February 2008: Site-Specific Probable Maximum Precipitation (PMP) Study for the Magma FRS Drainage Basin, Prepared for AMEC, Tucson, Arizona.

Tomlinson, E.M., Kappel W.D., Parzybok, T.W., Hultstrand, D., Muhlestein, G., and P. Sutter, December 2008: Statewide Probable Maximum Precipitation (PMP) Study for the state of Nebraska, Prepared for Nebraska Dam Safety, Omaha, Nebraska.

Tomlinson, E.M., Kappel, W.D., and Parzybok, T.W., February 2011: Site-Specific Probable Maximum Precipitation (PMP) Study for the Magma FRS Drainage Basin, Arizona.

Tomlinson, E.M., Kappel, W.D., and Parzybok, T.W., March 2011: Site-Specific Probable Maximum Precipitation (PMP) Study for the Tarrant Regional Water District, Texas.

Tomlinson, E.M., Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., S. Lovisone, and Parzybok, T.W., March 2013: Statewide Probable Maximum Precipitation (PMP) Study for Ohio.

U.S. Navy Marine Climate Atlas of the World (NAVAIR50-1C-65), 1981: Volume IX, Naval Oceanographic Command Detachment, Asheville, NC.

U.S. Weather Bureau, 1946: Manual for Depth-Area-Duration analysis of storm precipitation. *Cooperative Studies Technical Paper No. 1*, U.S. Department of Commerce, Weather Bureau, Washington, D.C., 73pp.

U.S. Weather Bureau, 1951: Tables of Precipitable Water and Other Factors for a Saturated Pseudo-Adiabatic Atmosphere. *Technical Paper No. 14*, U.S. Department of Commerce, Weather Bureau, Washington, D.C., 27 pp.

U.S. Weather Bureau, 1952: *Maximum 24-Hour Precipitation in the United States*. Technical Paper No. 16, U.S. Department of Commerce, Hydro-meteorological Section.

Wagener, T., H.S. Wheather, and H.V. Gupta, 2004. *Rainfall-runoff modelling in gauged and ungauged catchments*. Imperial College Press, London pp 306.

Weather Bureau, 1940: Maximum Possible Precipitation Over The Ompompasoosuc Basin Above Union Village, Vermont, A Study of Meteorological Causes of Record Storms and Quantitative Estimates of Critical Precipitation Rates, Hydrometeorological Report 1, pp205.

Weather Underground, http://www.wunderground.com/stationmaps/

Weiss, L.L., 1964: Ratio of True to Fixed Interval Maximum Rainfall, Journal Hydraulics, ASCE, 90(HY1), pp77-82.

World Meteorological Organization, 1986: Manual for Estimation of Probable Maximum Precipitation, Operational Hydrology Report No 1, 2nd Edition, WMO, Geneva, 269 pp.

World Meteorological Organization, 2009: Manual for Estimation of Probable Maximum Precipitation, Operational Hydrology Report No 1045, WMO, Geneva, 259 pp.

Worley, S.J., S.D. Woodruff, R.W. Reynolds, S.J. Lubker, and N. Lott, 2005: ICOADS Release 2.1 data and products. *Int. J. Climatol. (CLIMAR-II Special Issue)*, **25**, 823-842.

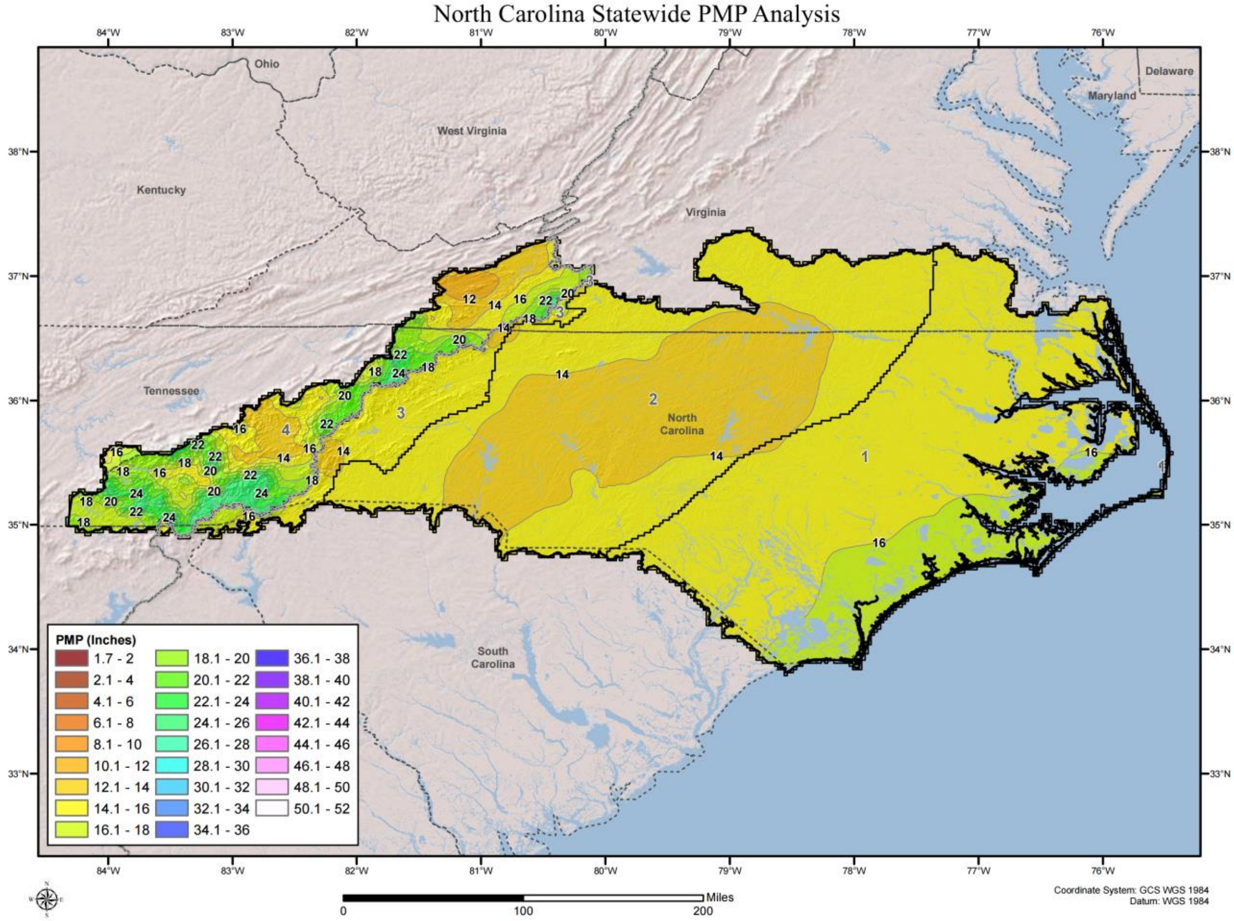
Young, B.C and B.M. McEnroe, 2003: Sampling Adjustment Factors for Rainfall Recorded at Fixed Time Intervals. Journal of Hydrologic Engineering, Vol8 (5).

Zehr, R.M. and V.A. Myers, 1984: NOAA Technical Memorandum NWS Hydro 40, *Depth-Area Ratios in the Semi-Arid Southwest United States*, Silver Spring, MD 55pp.

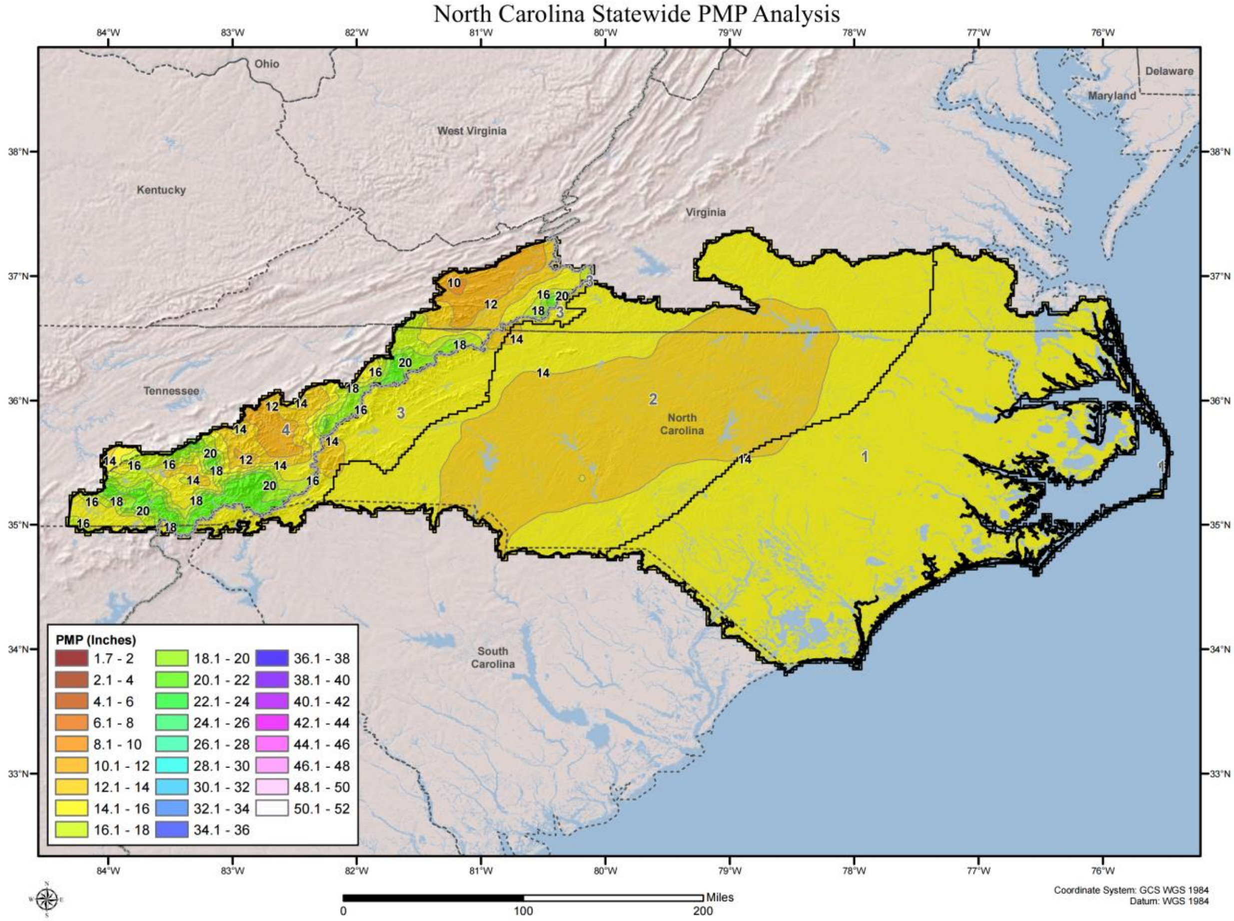
Appendix A
Probable Maximum Precipitation (PMP) Maps

General Storms

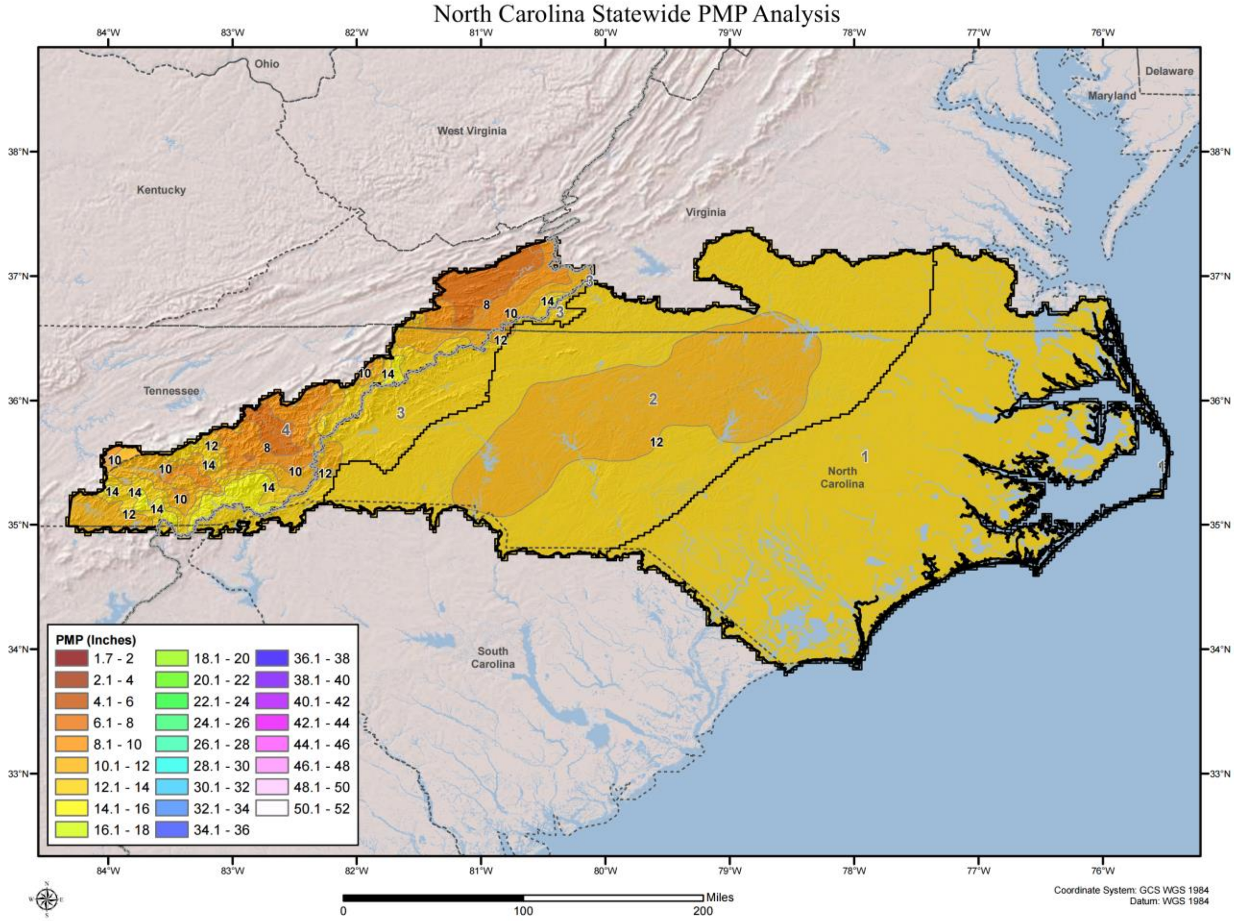
General Storm 6-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis



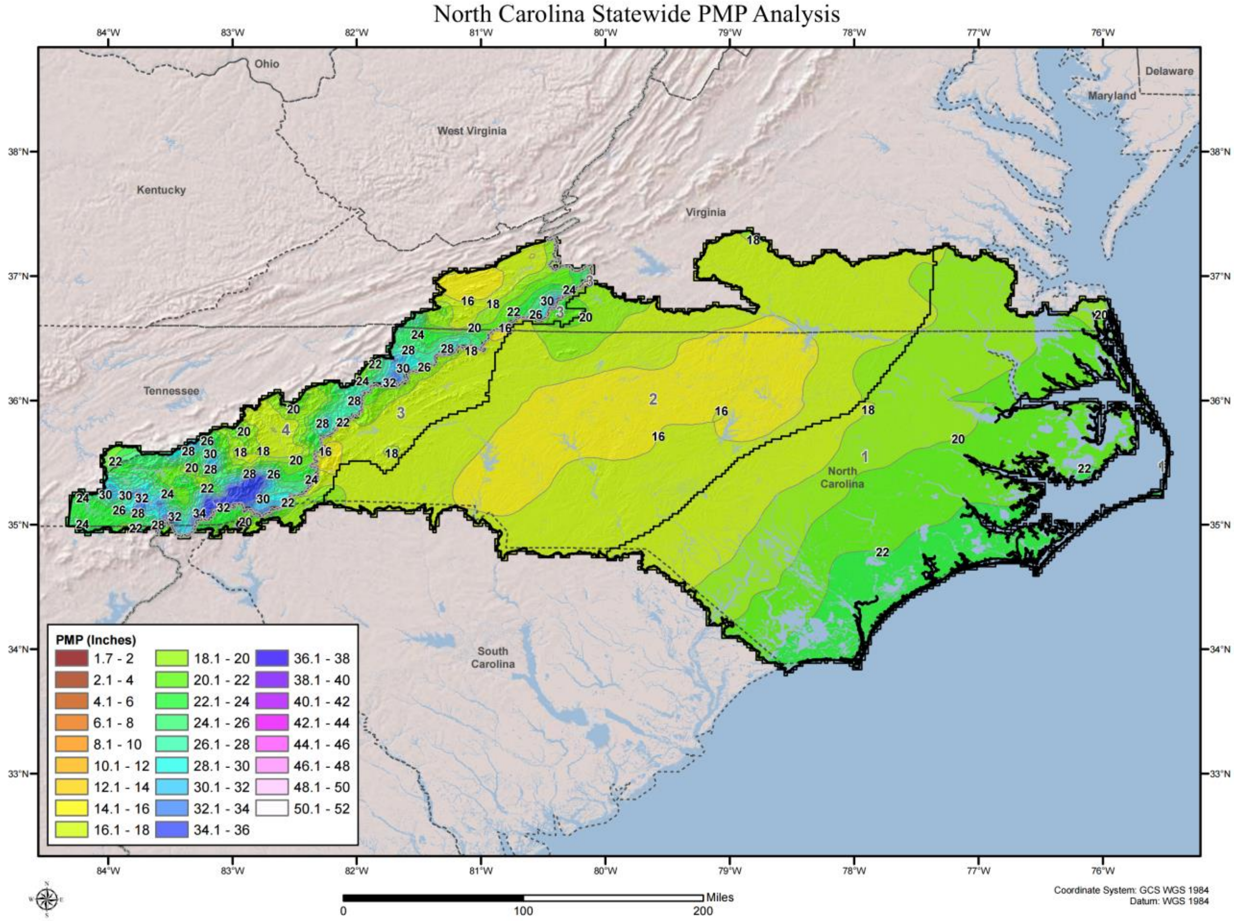
General Storm 6-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis



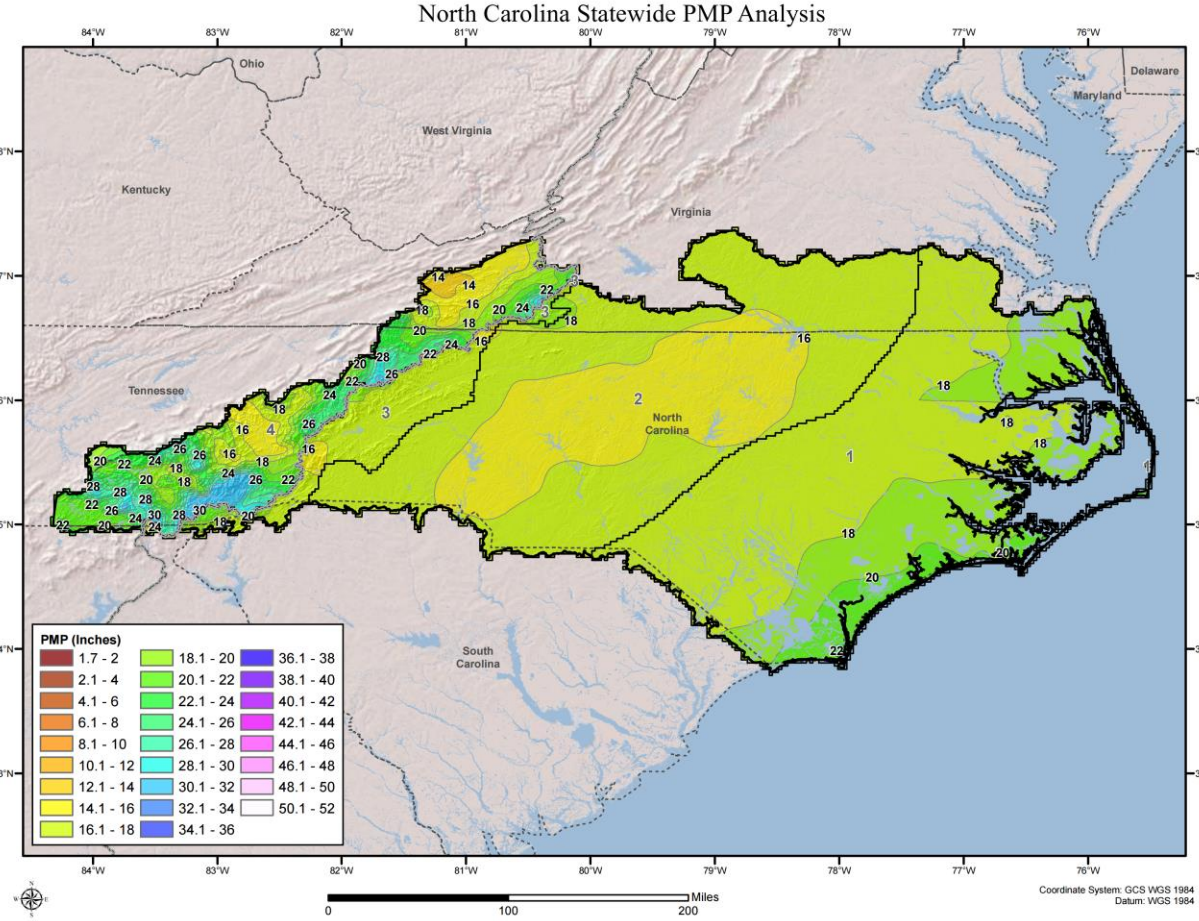
General Storm 6-Hour 1000 Square Mile PMP
North Carolina Statewide PMP Analysis



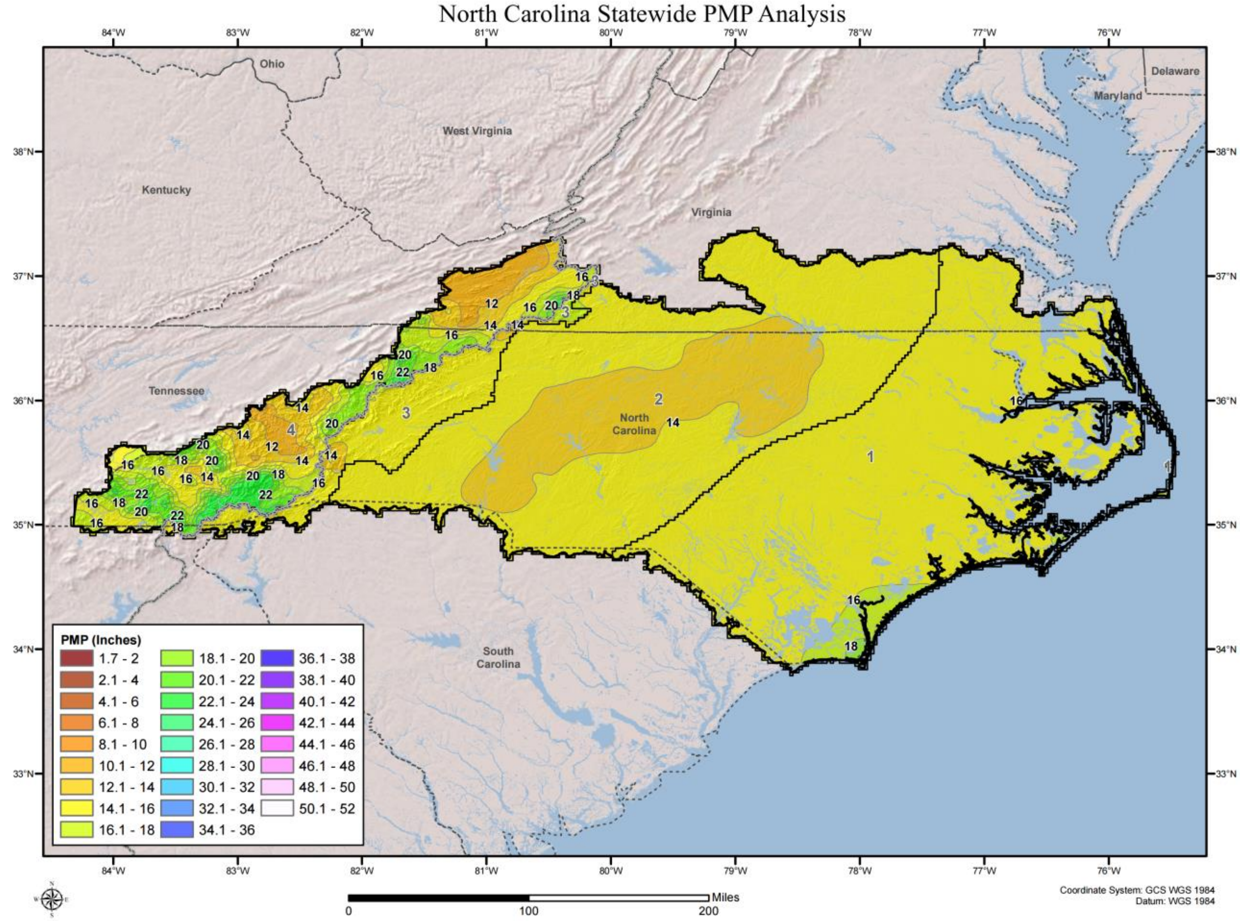
General Storm 24-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis



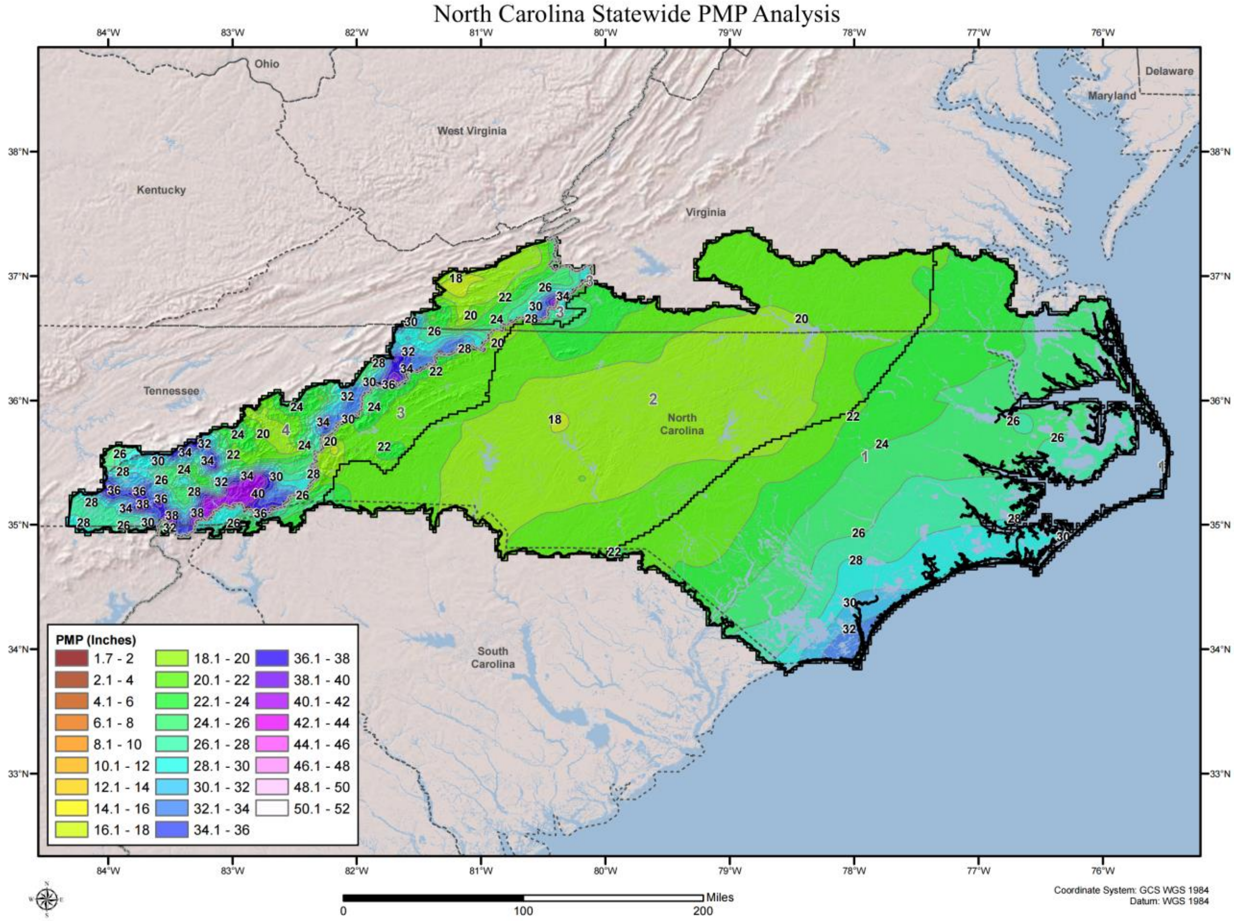
General Storm 24-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis



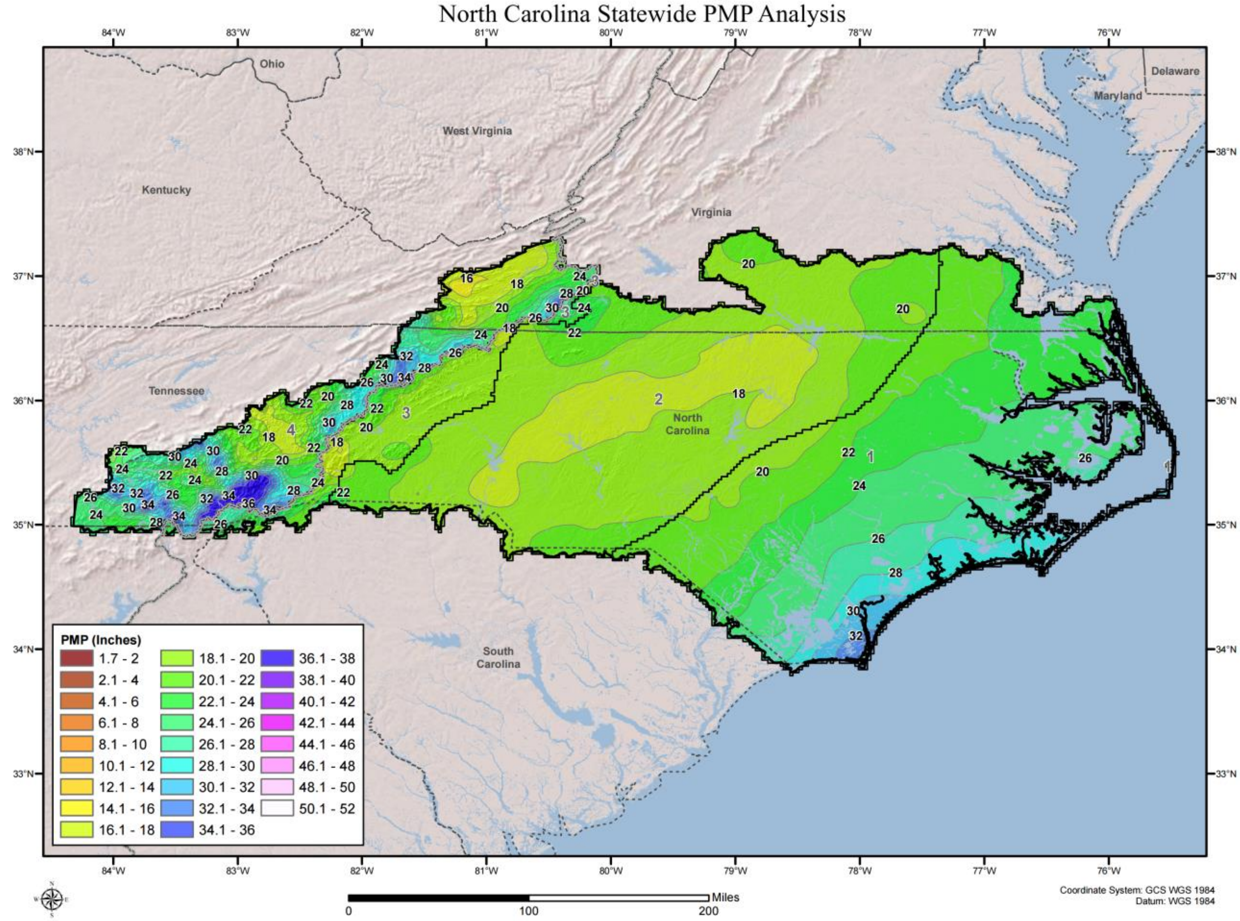
General Storm 24-Hour 1000 Square Mile PMP
North Carolina Statewide PMP Analysis



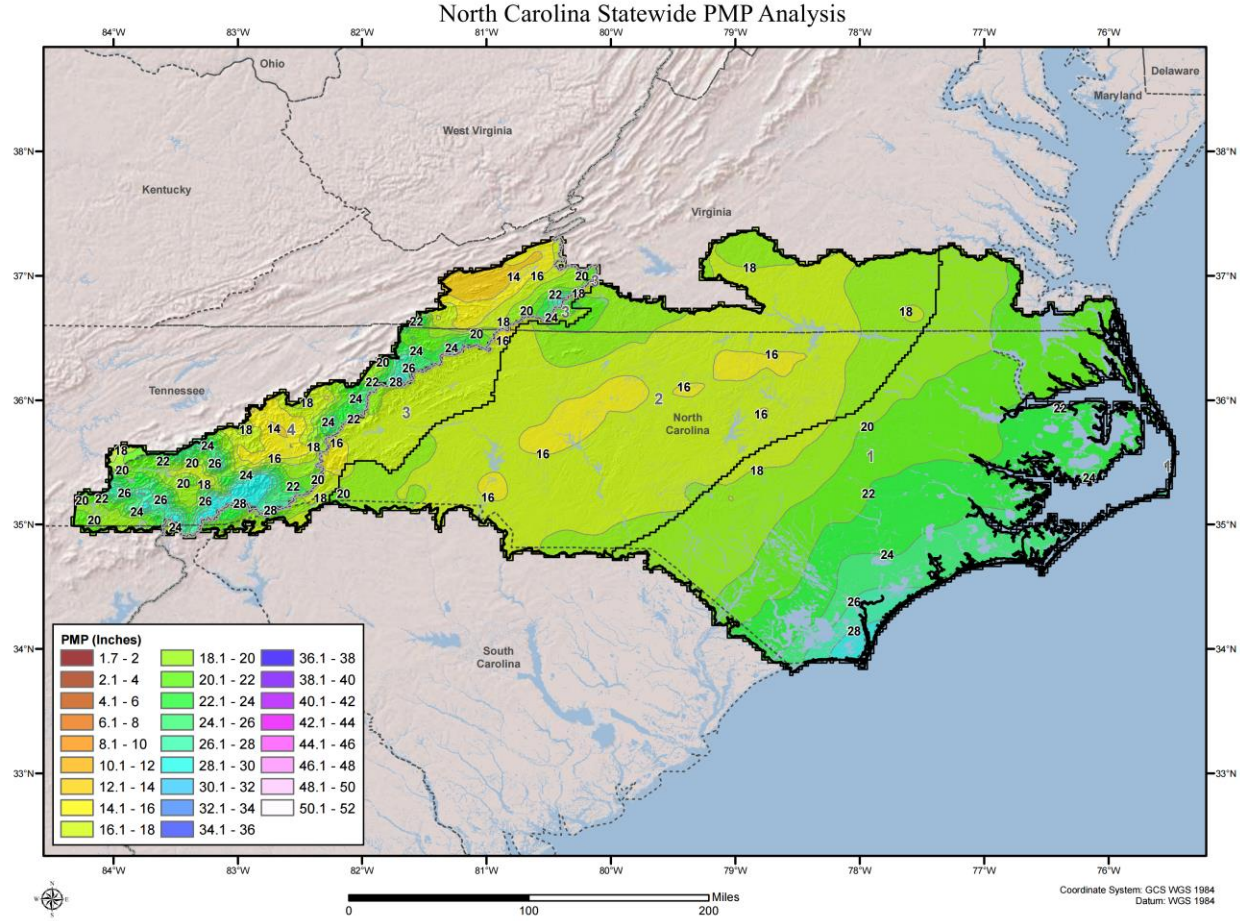
General Storm 72-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis



General Storm 72-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis

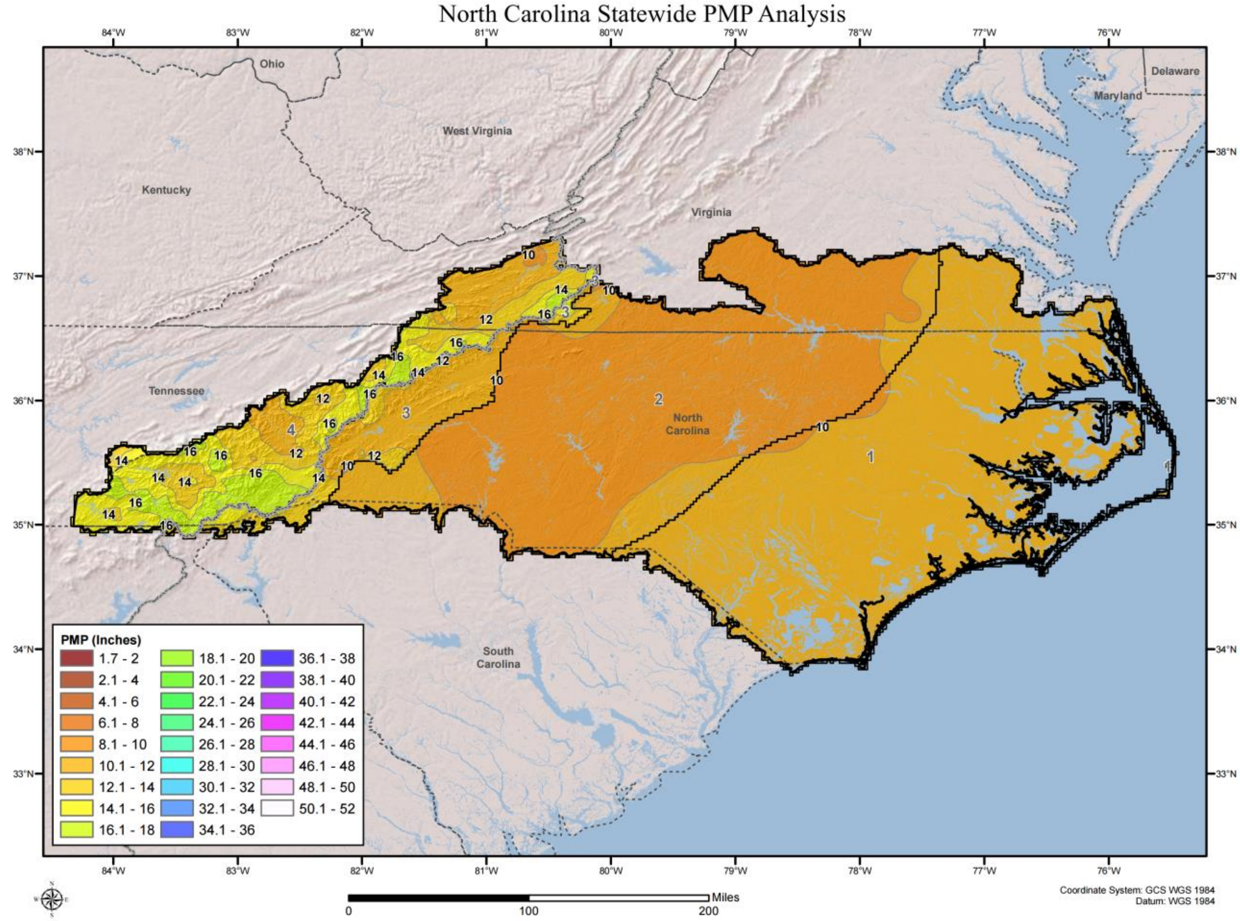


General Storm 72-Hour 1000 Square Mile PMP
North Carolina Statewide PMP Analysis

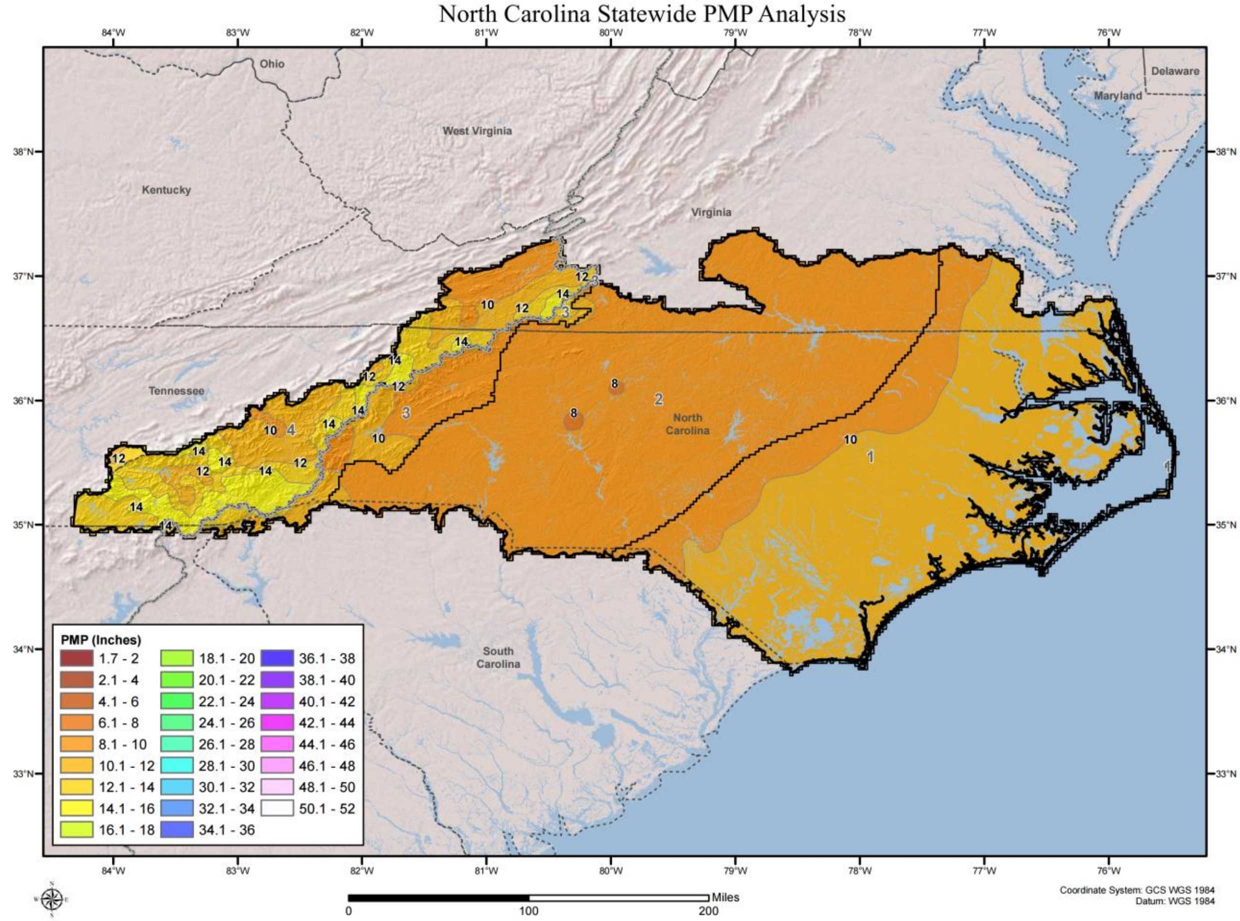


Local Storms

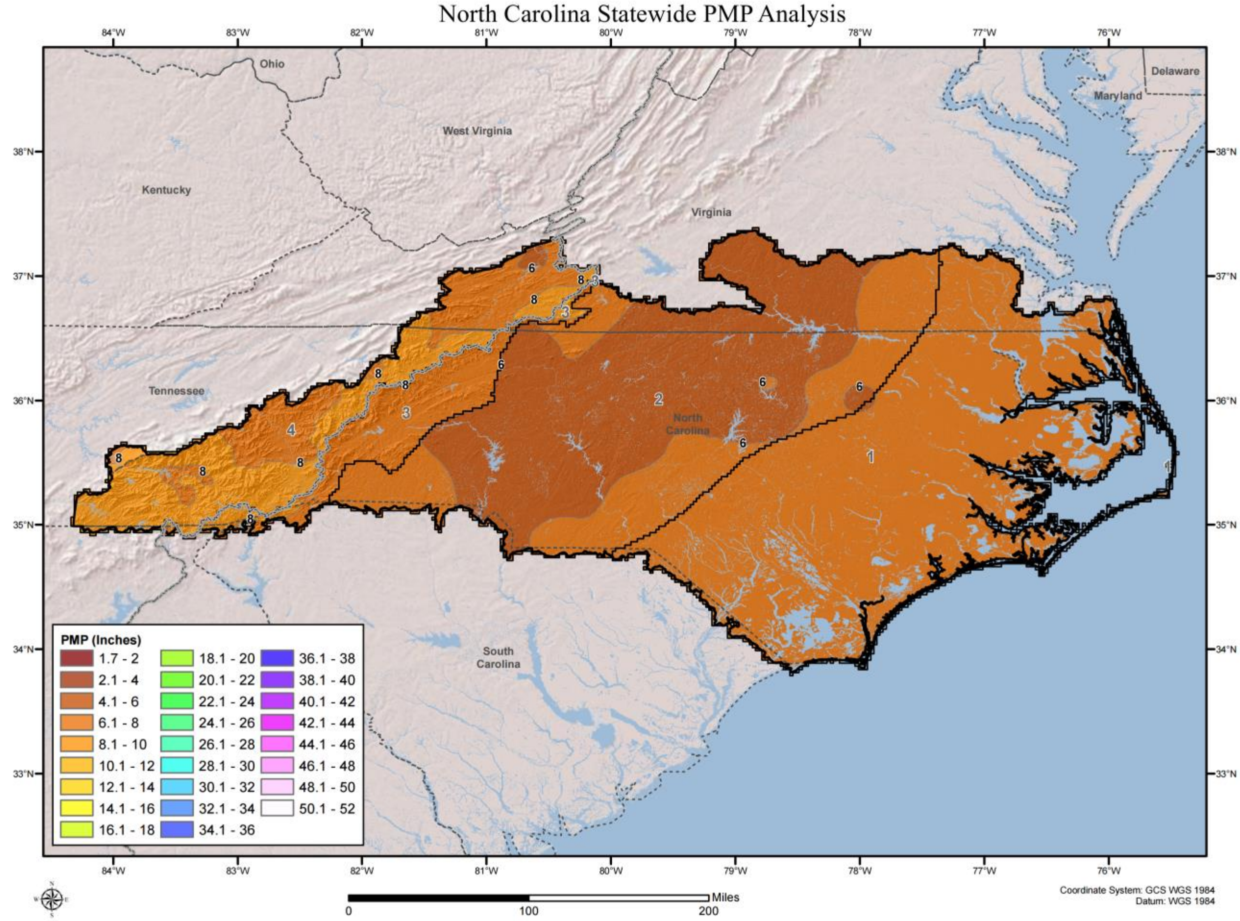
Local Storm 1-Hour 1 Square Mile PMP
North Carolina Statewide PMP Analysis



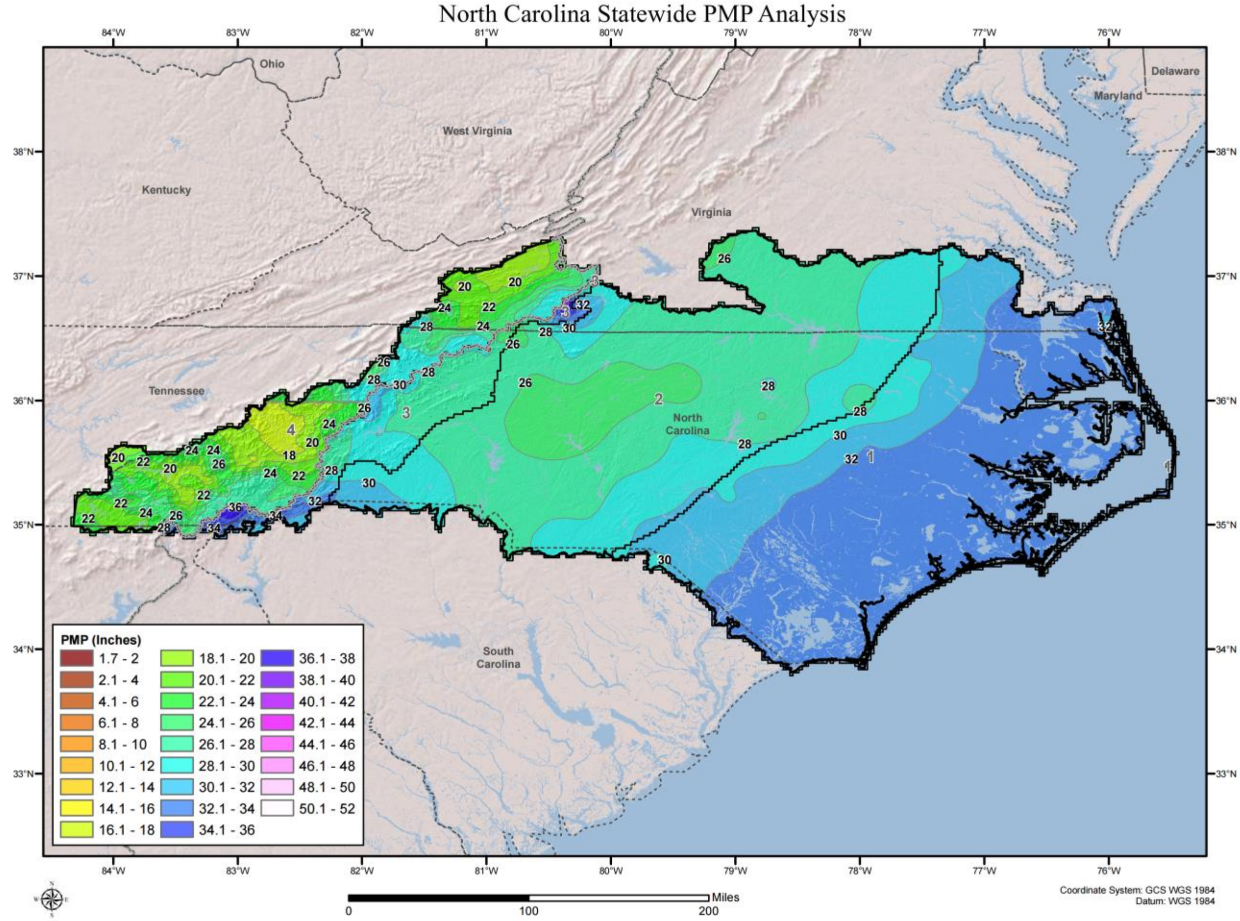
Local Storm 1-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis



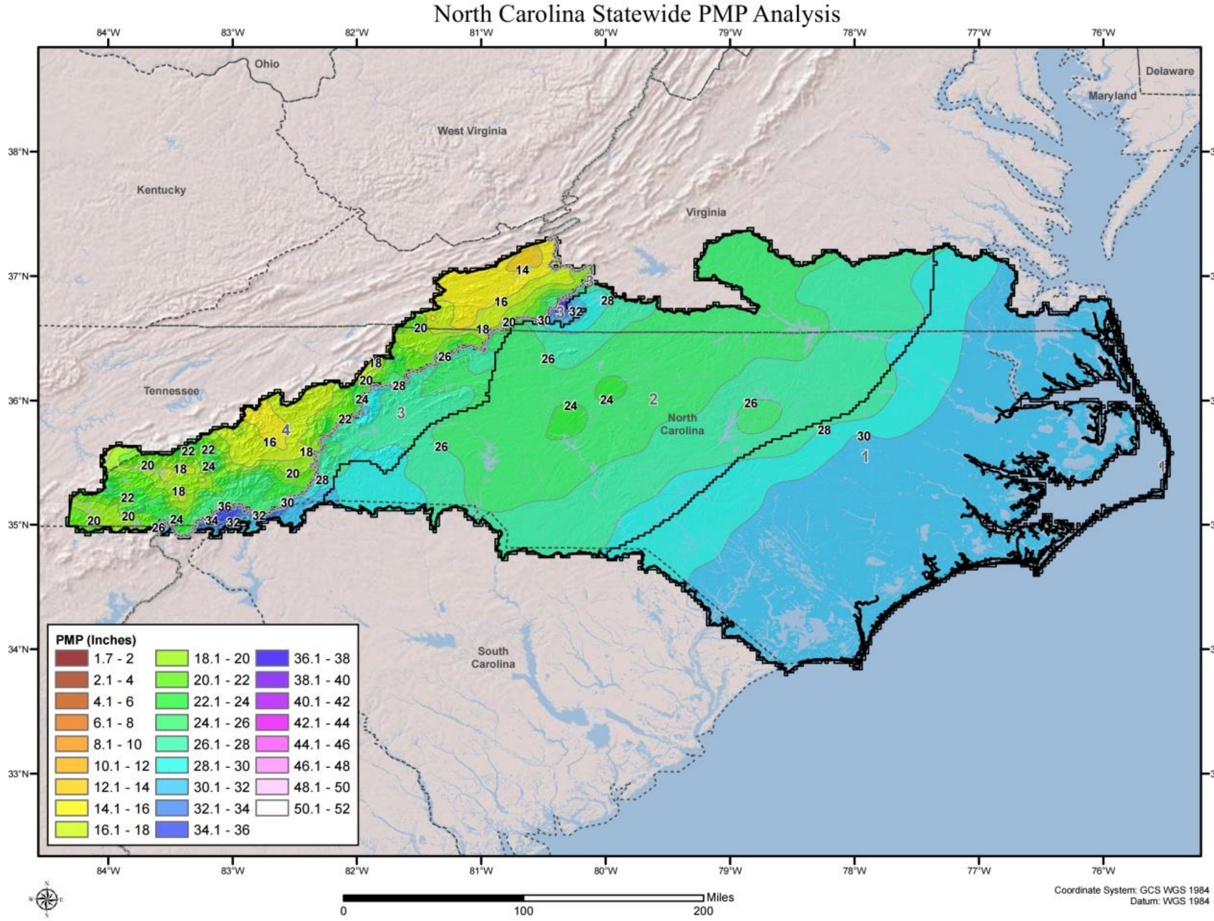
Local Storm 1-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis



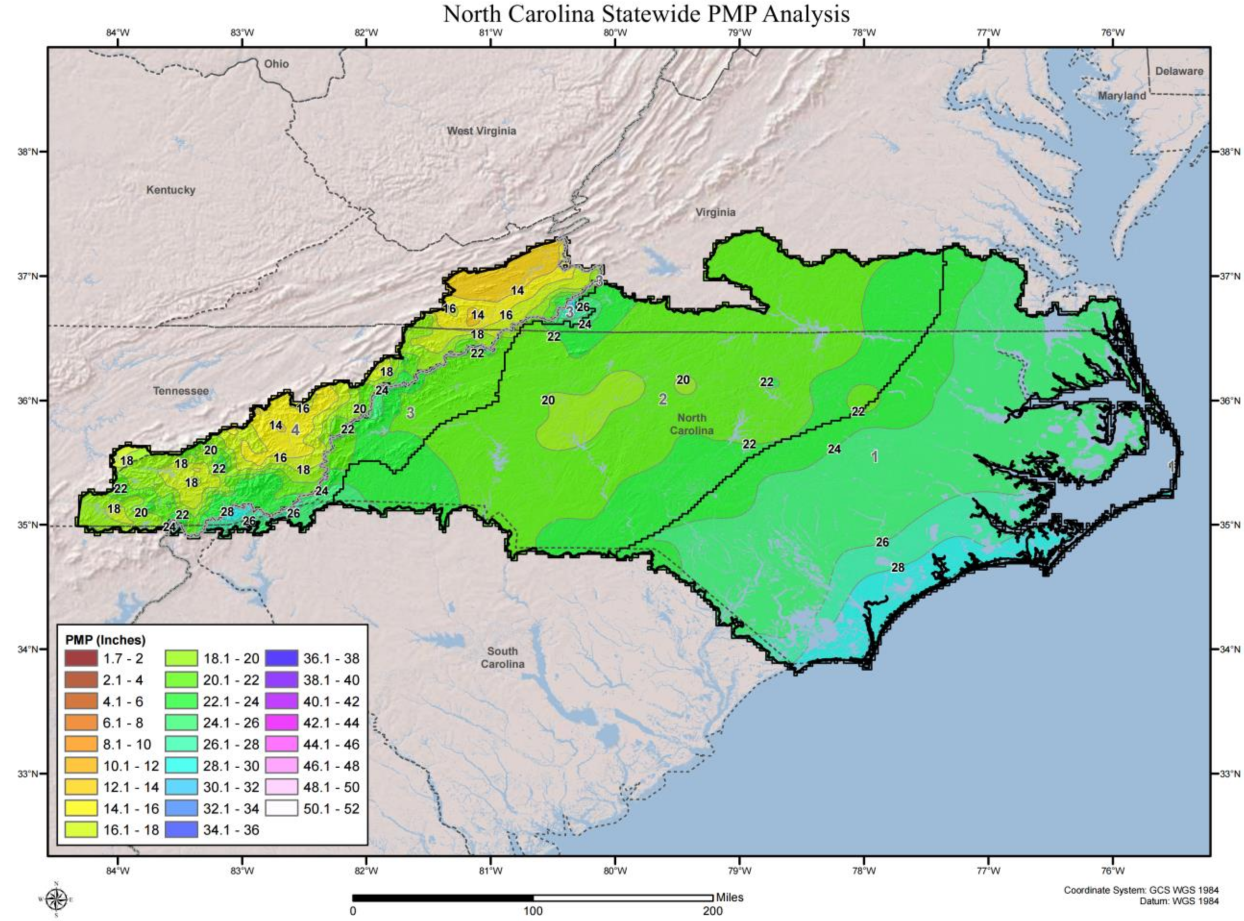
Local Storm 6-Hour 1 Square Mile PMP
North Carolina Statewide PMP Analysis



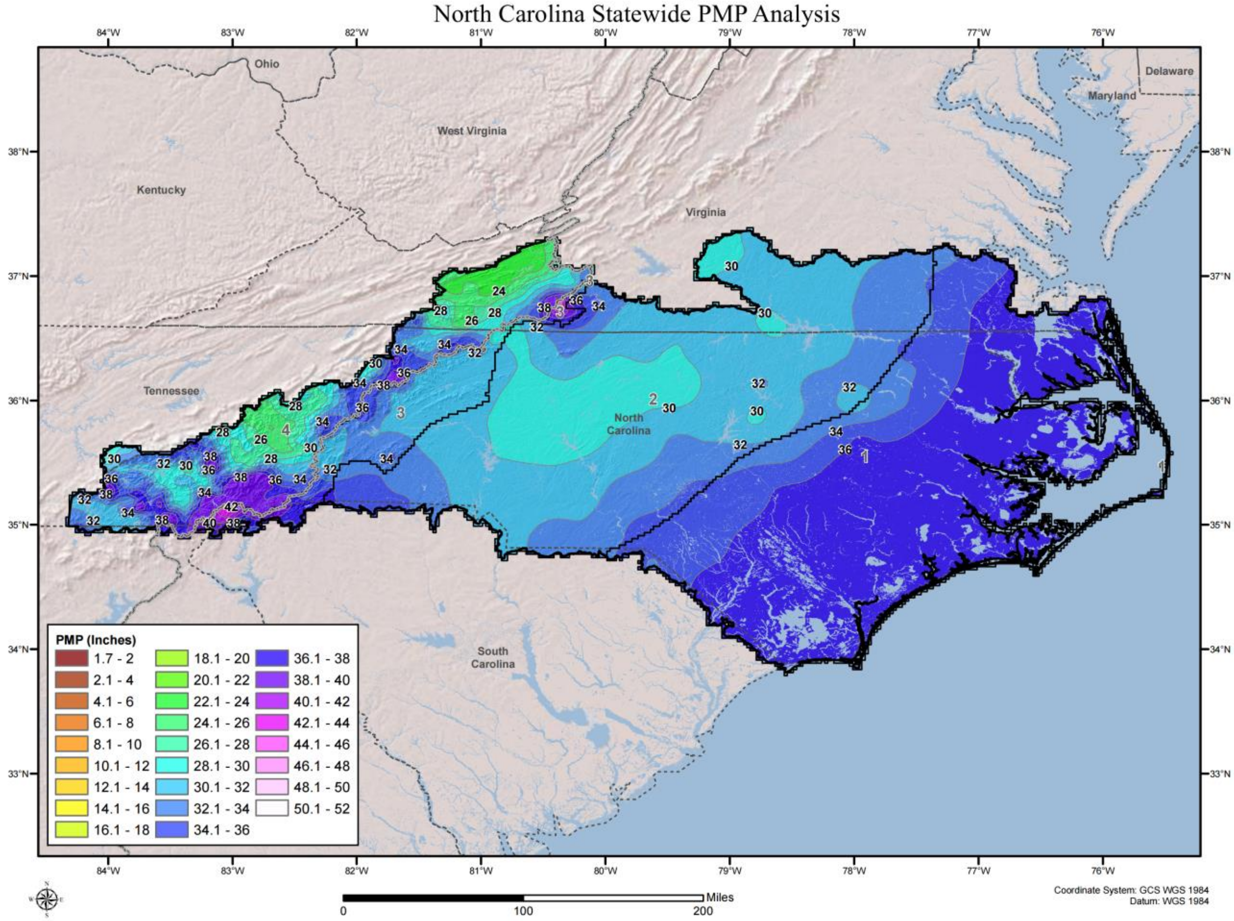
Local Storm 6-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis



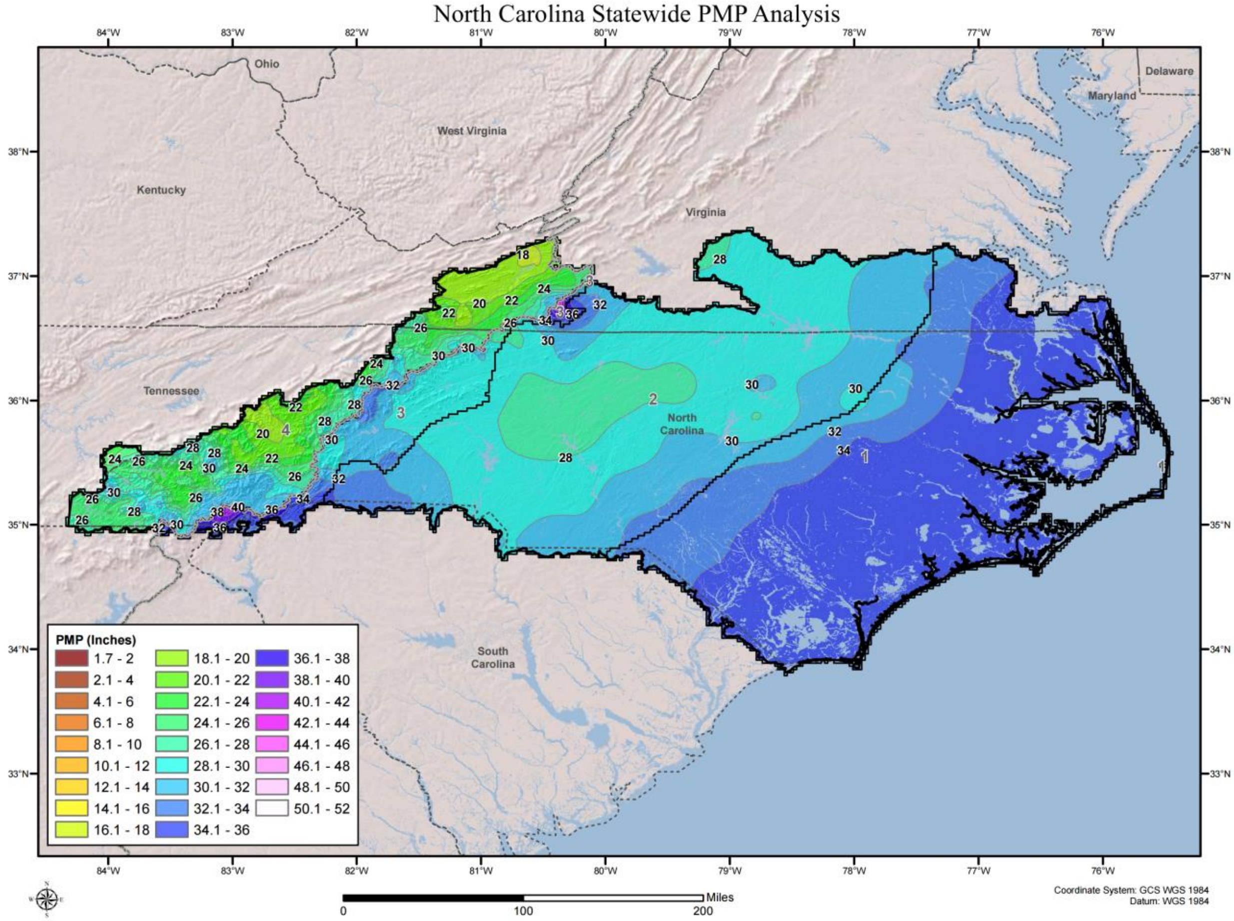
Local Storm 6-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis



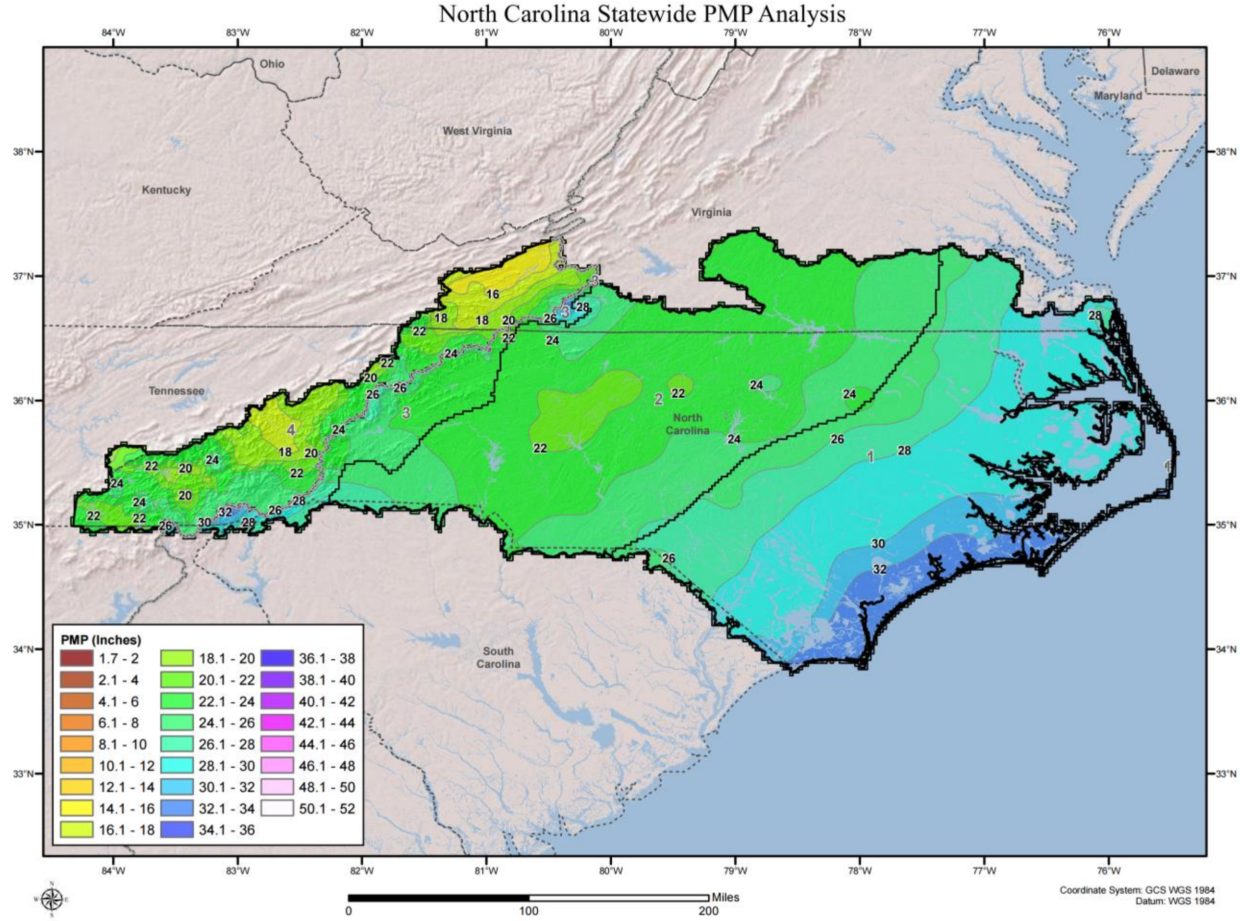
Local Storm 24-Hour 1 Square Mile PMP
North Carolina Statewide PMP Analysis



Local Storm 24-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis

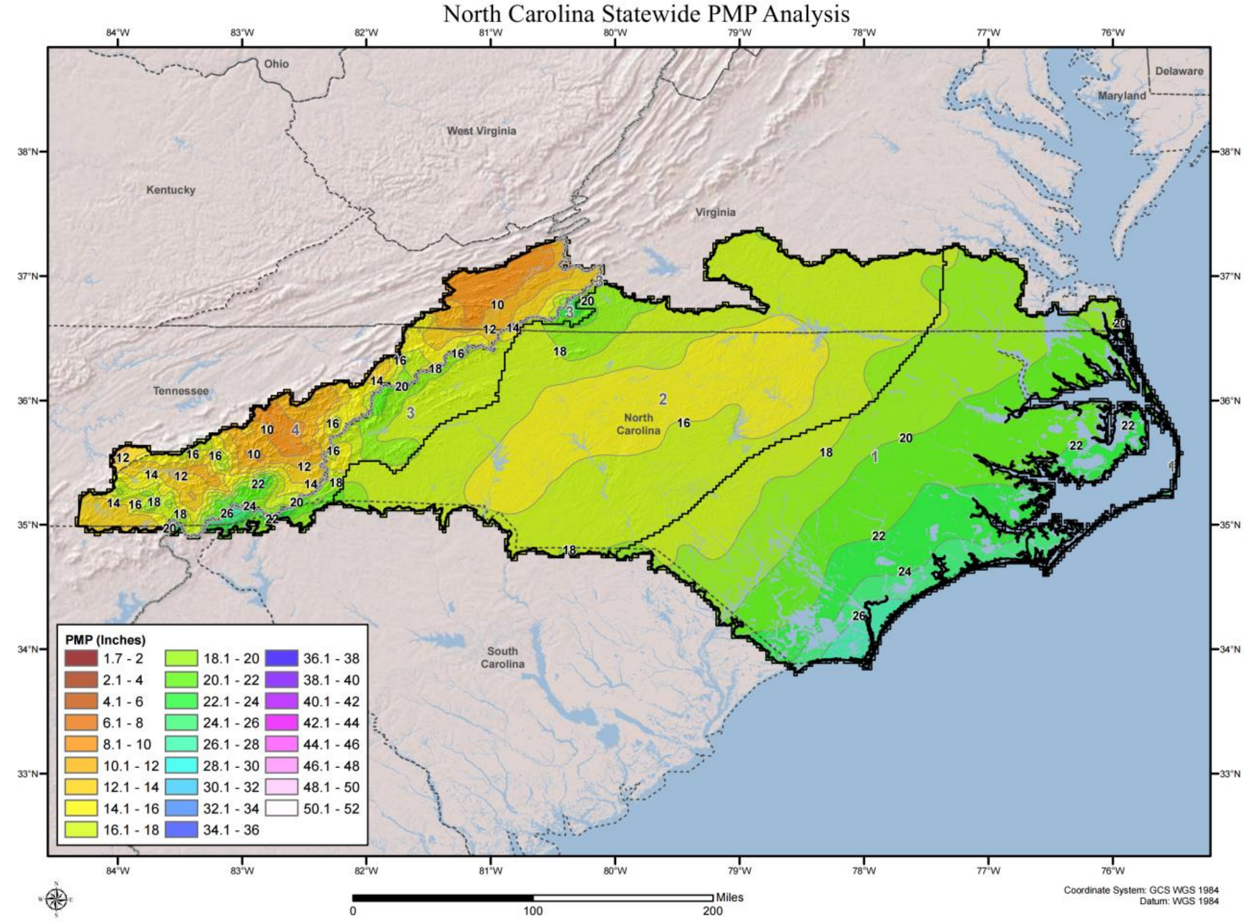


Local Storm 24-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis

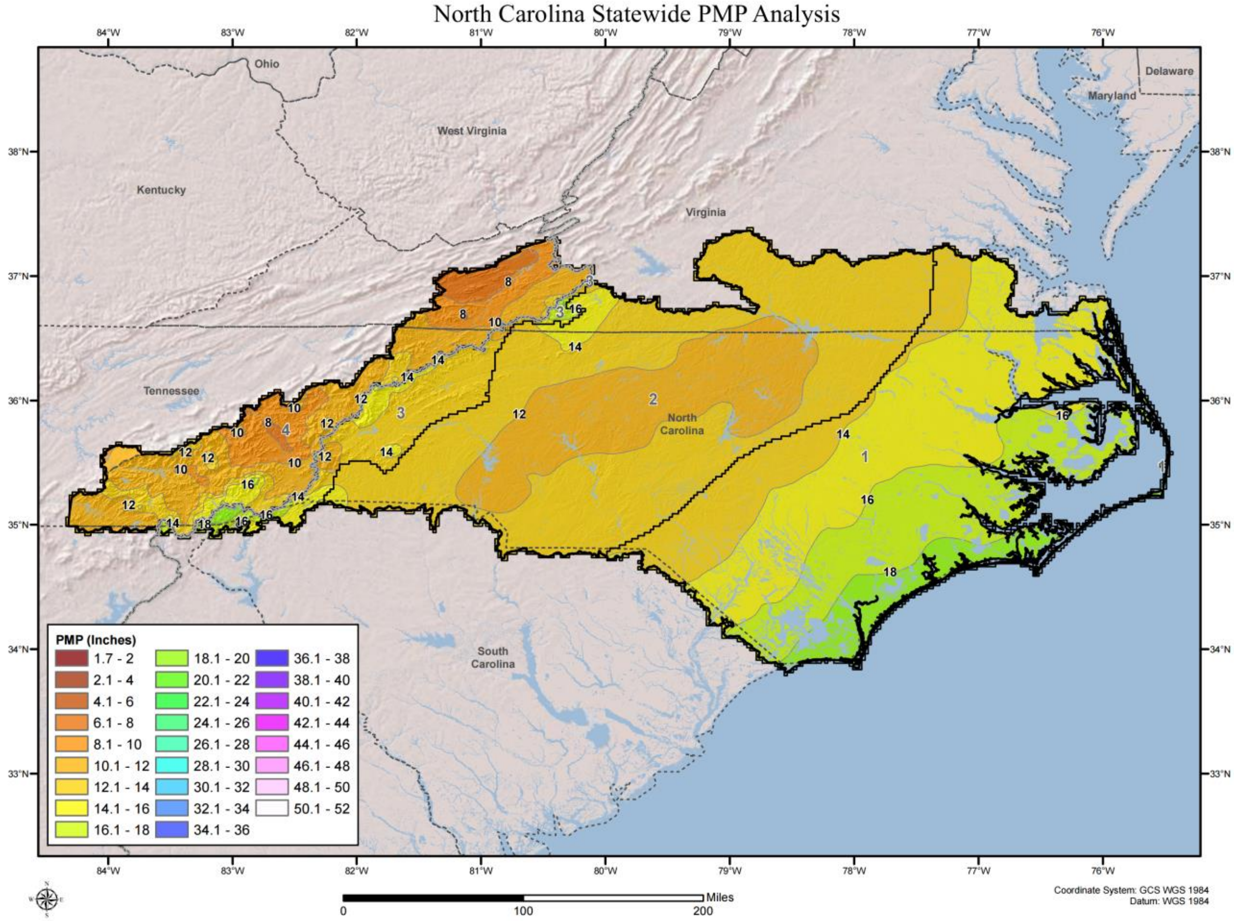


Tropical Storms

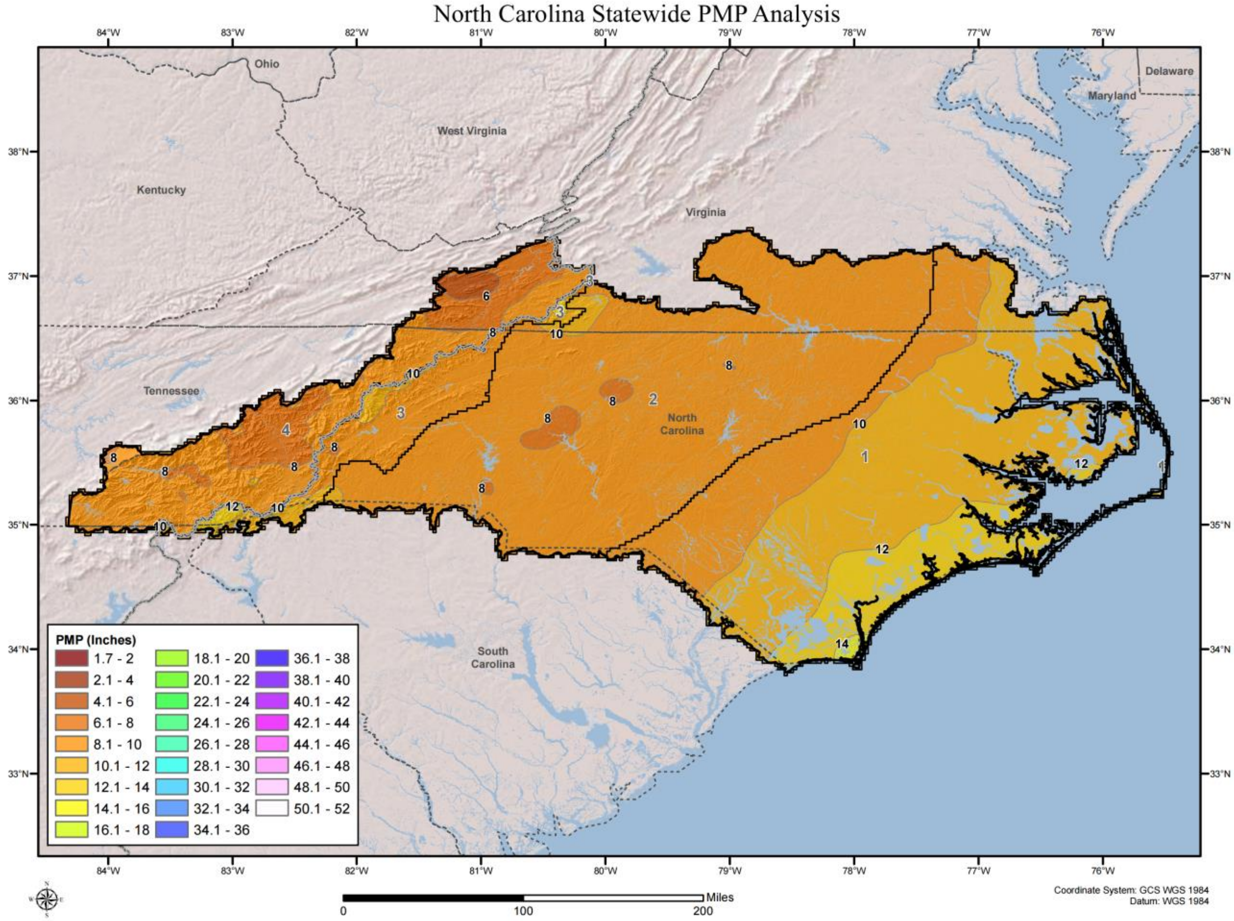
Tropical Storm 6-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis



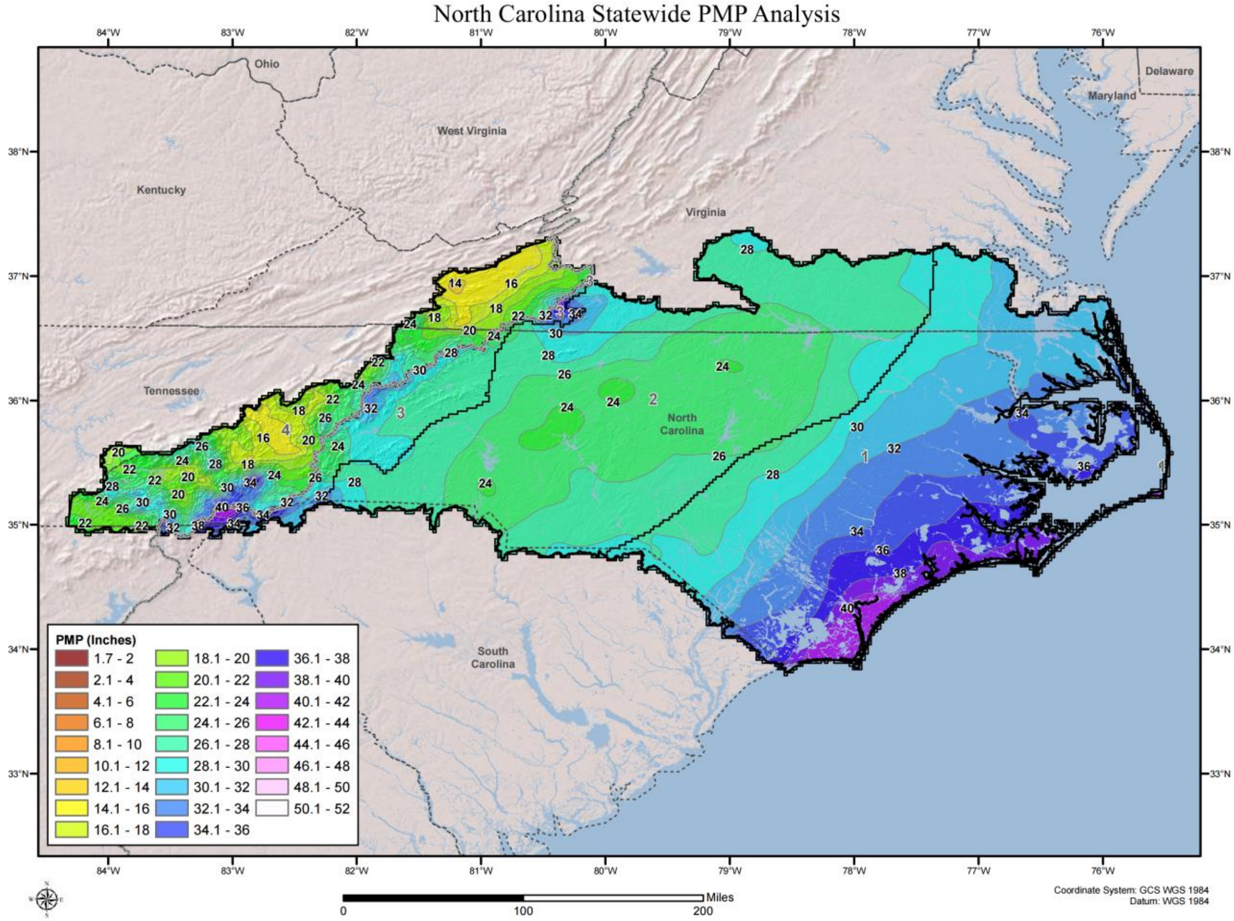
Tropical Storm 6-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis



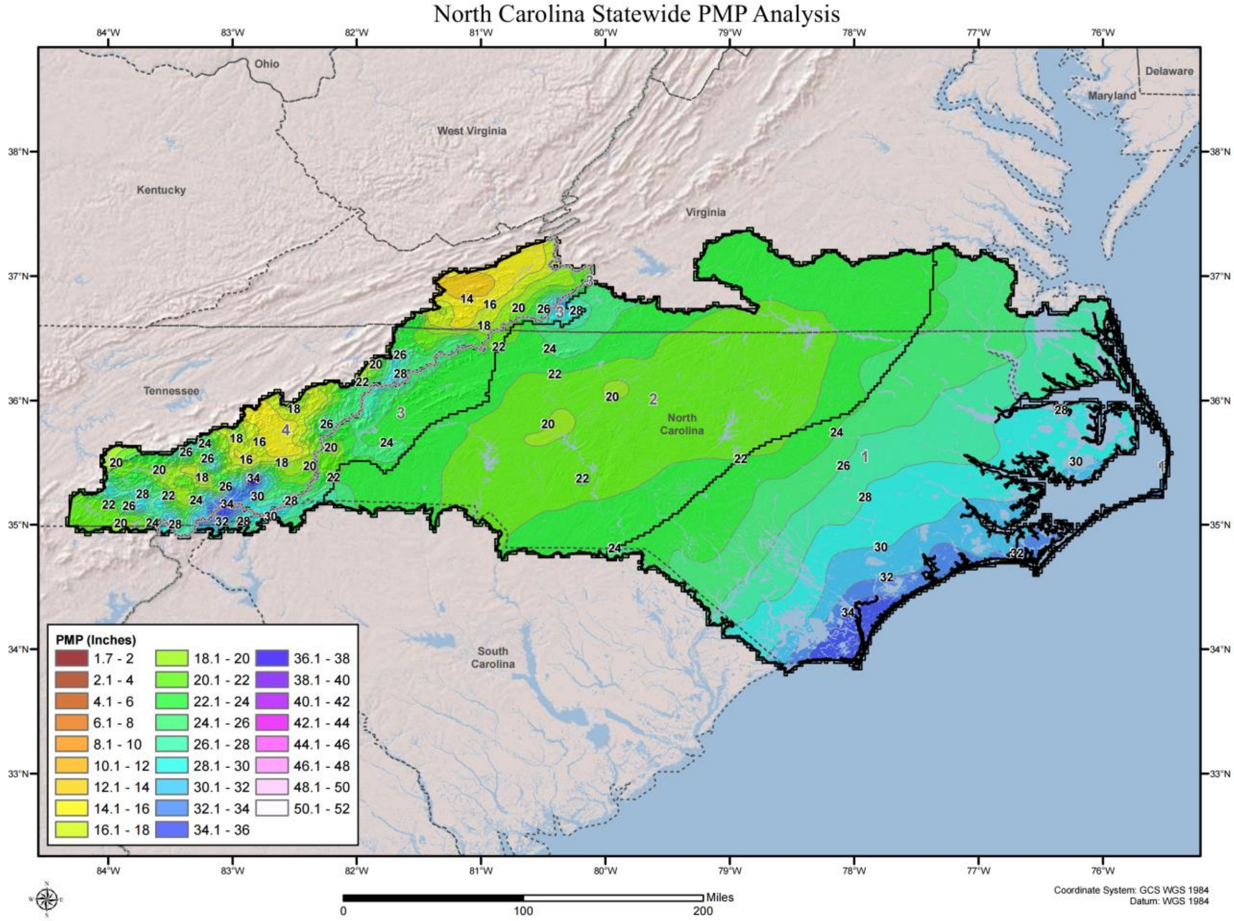
Tropical Storm 6-Hour 1000 Square Mile PMP
North Carolina Statewide PMP Analysis



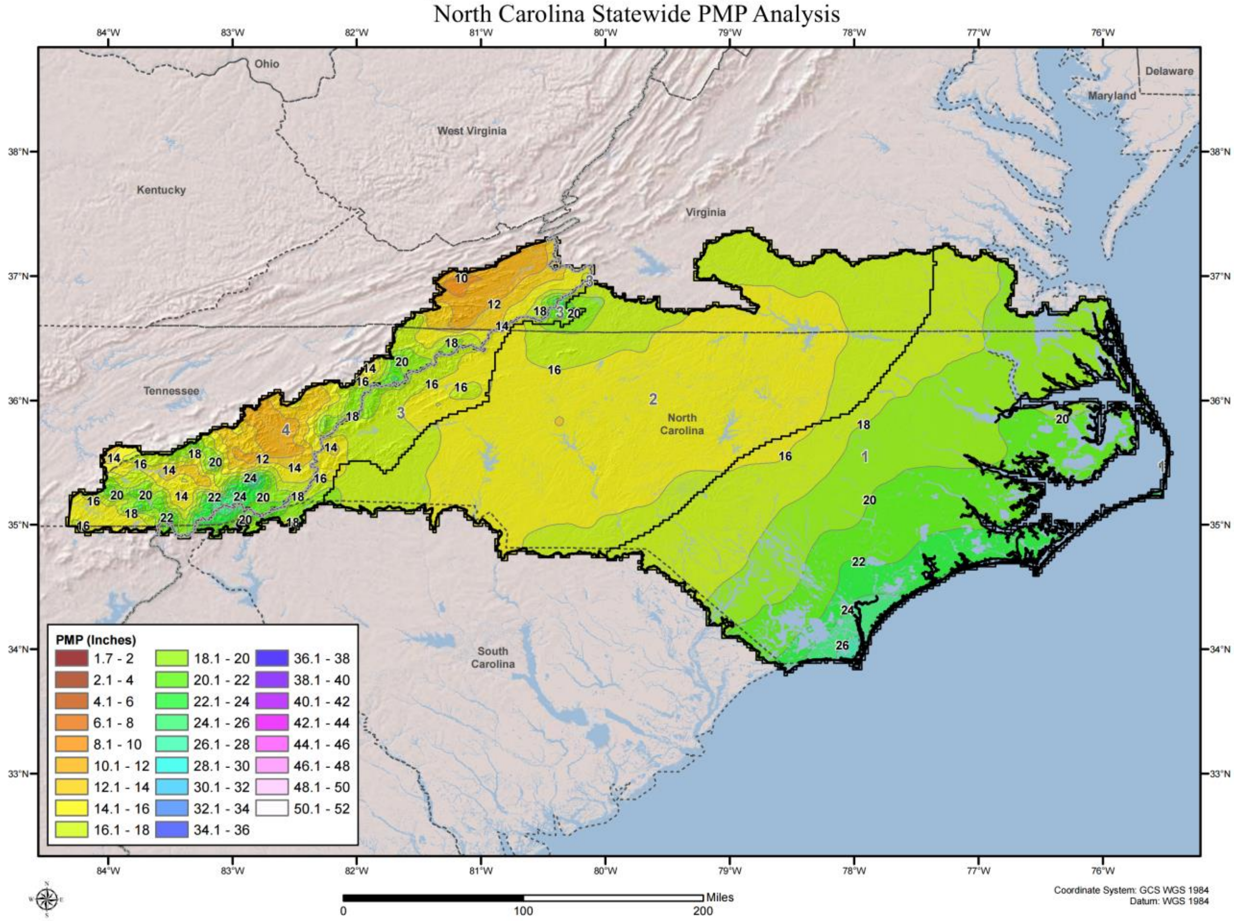
Tropical Storm 24-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis



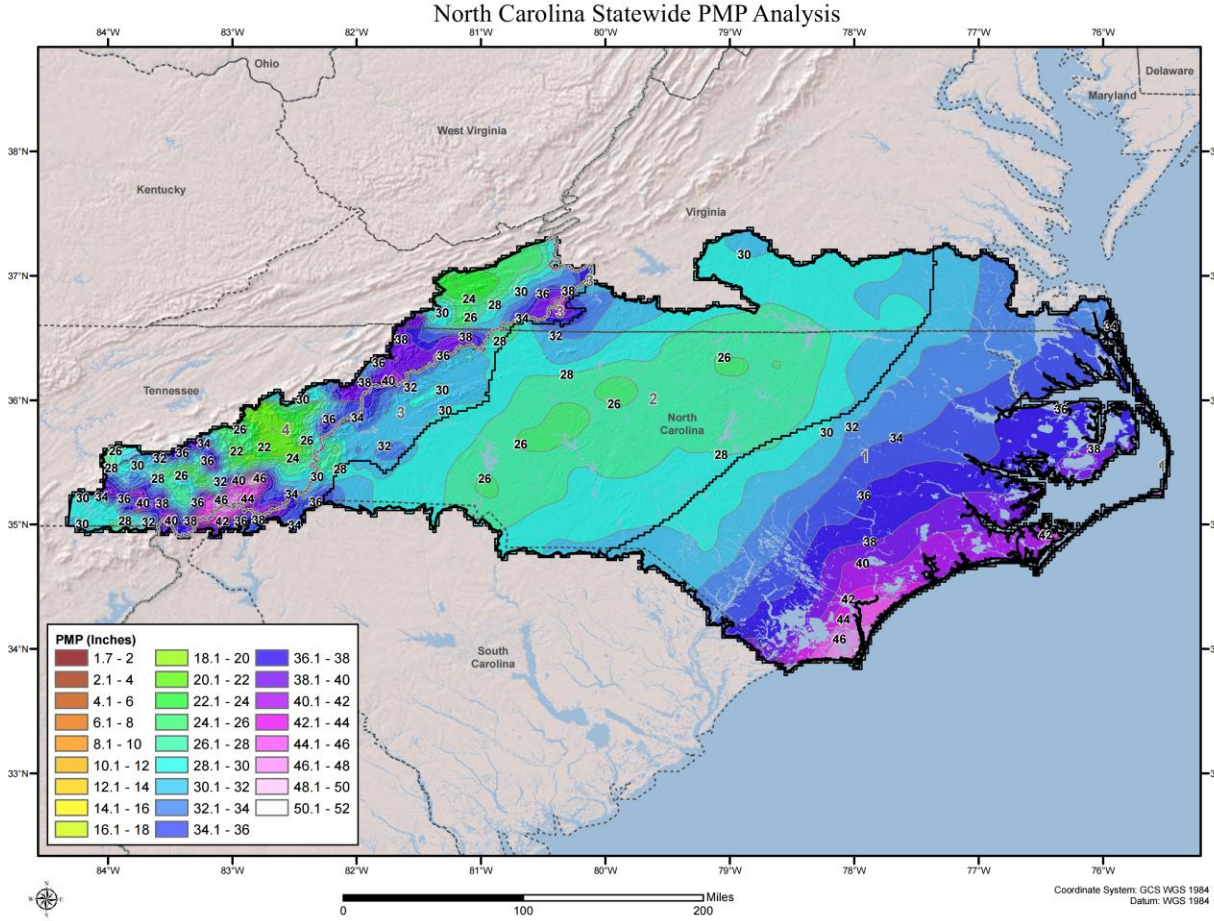
Tropical Storm 24-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis



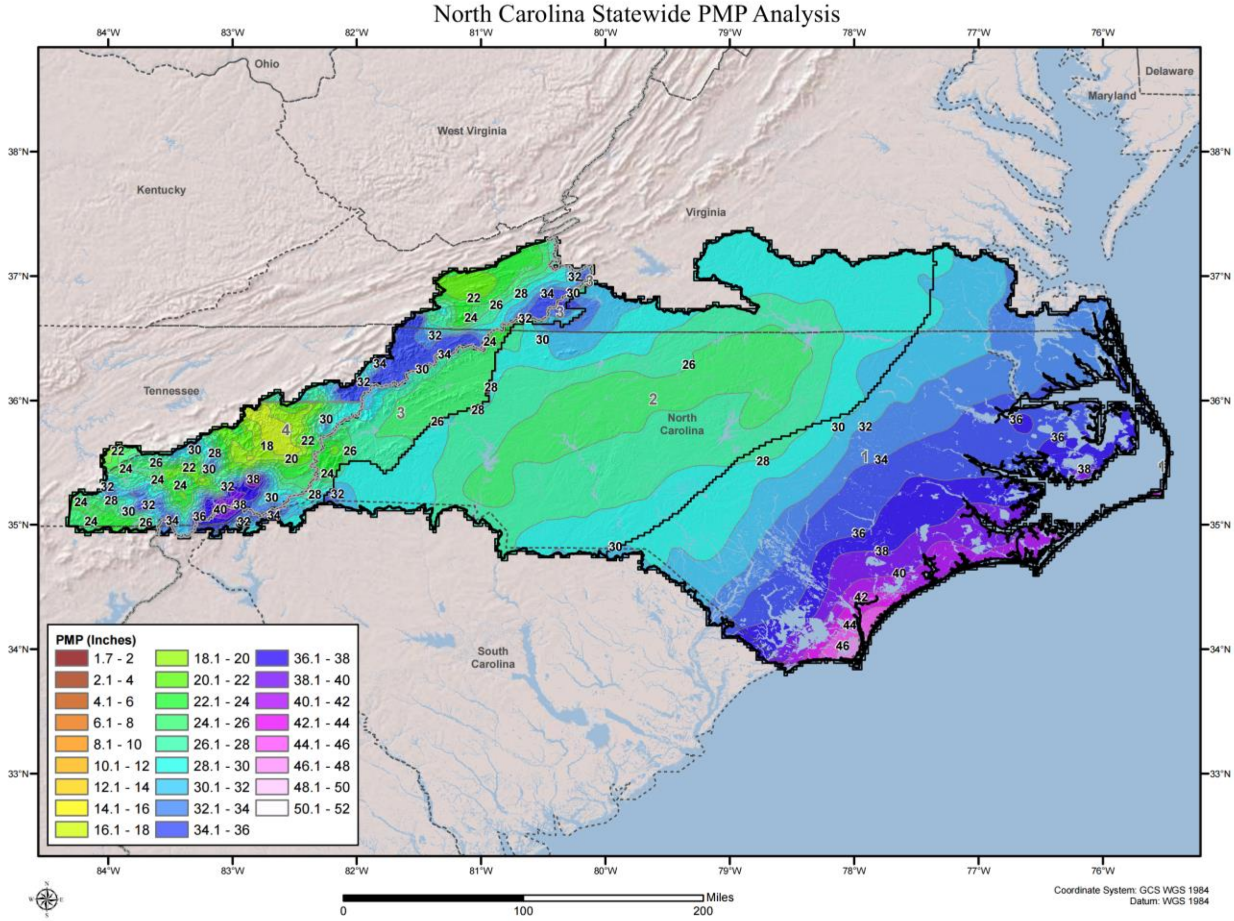
Tropical Storm 24-Hour 1000 Square Mile PMP
North Carolina Statewide PMP Analysis



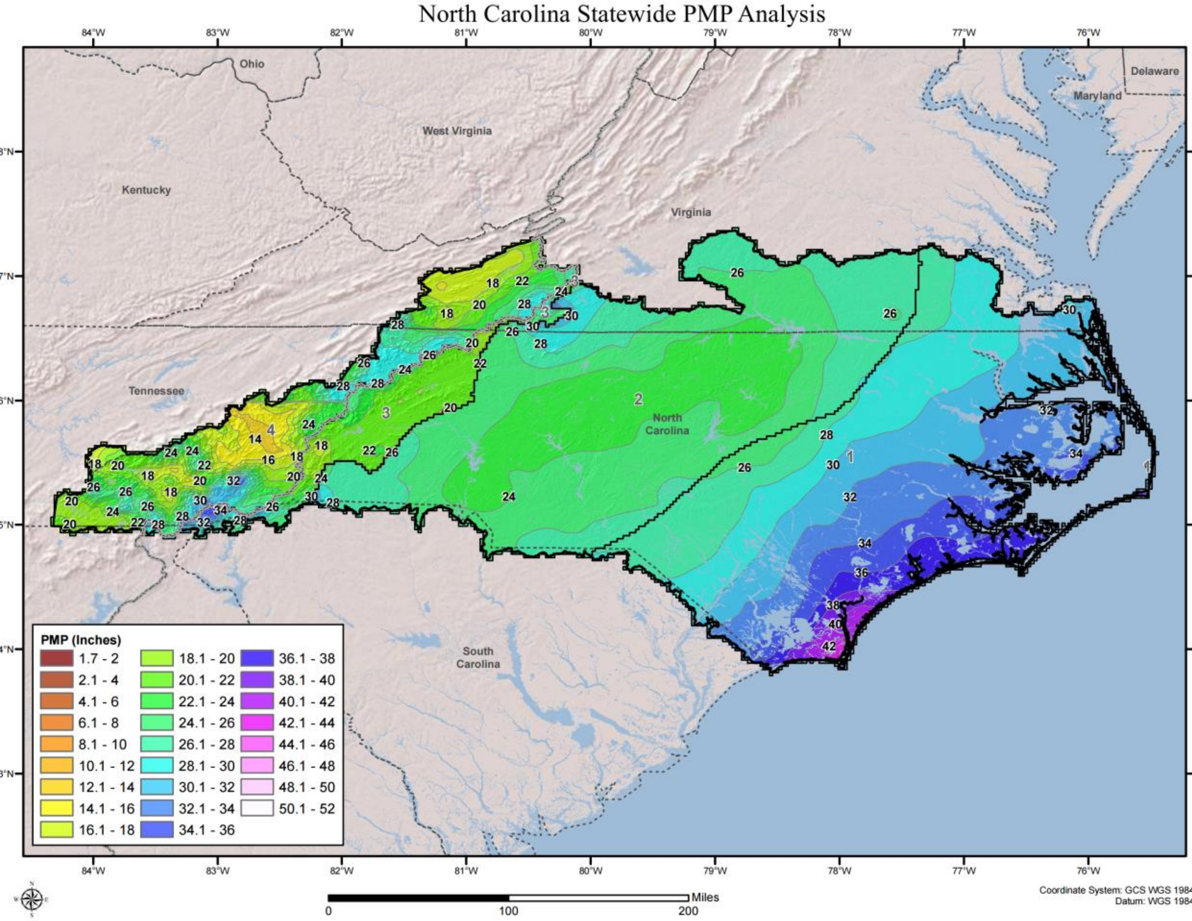
Tropical Storm 72-Hour 10 Square Mile PMP
North Carolina Statewide PMP Analysis



Tropical Storm 72-Hour 100 Square Mile PMP
North Carolina Statewide PMP Analysis

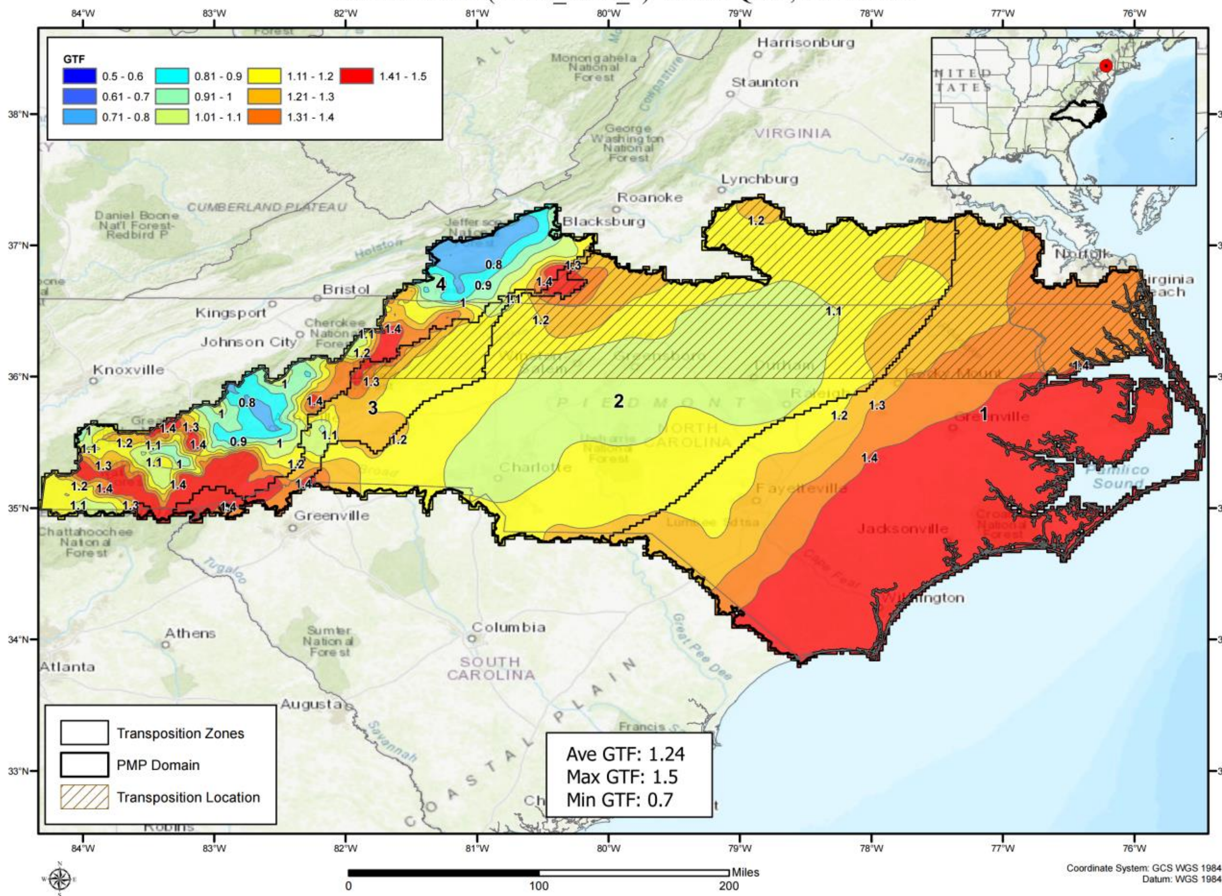


Tropical Storm 72-Hour 1000 Square Mile PMP
North Carolina Statewide PMP Analysis

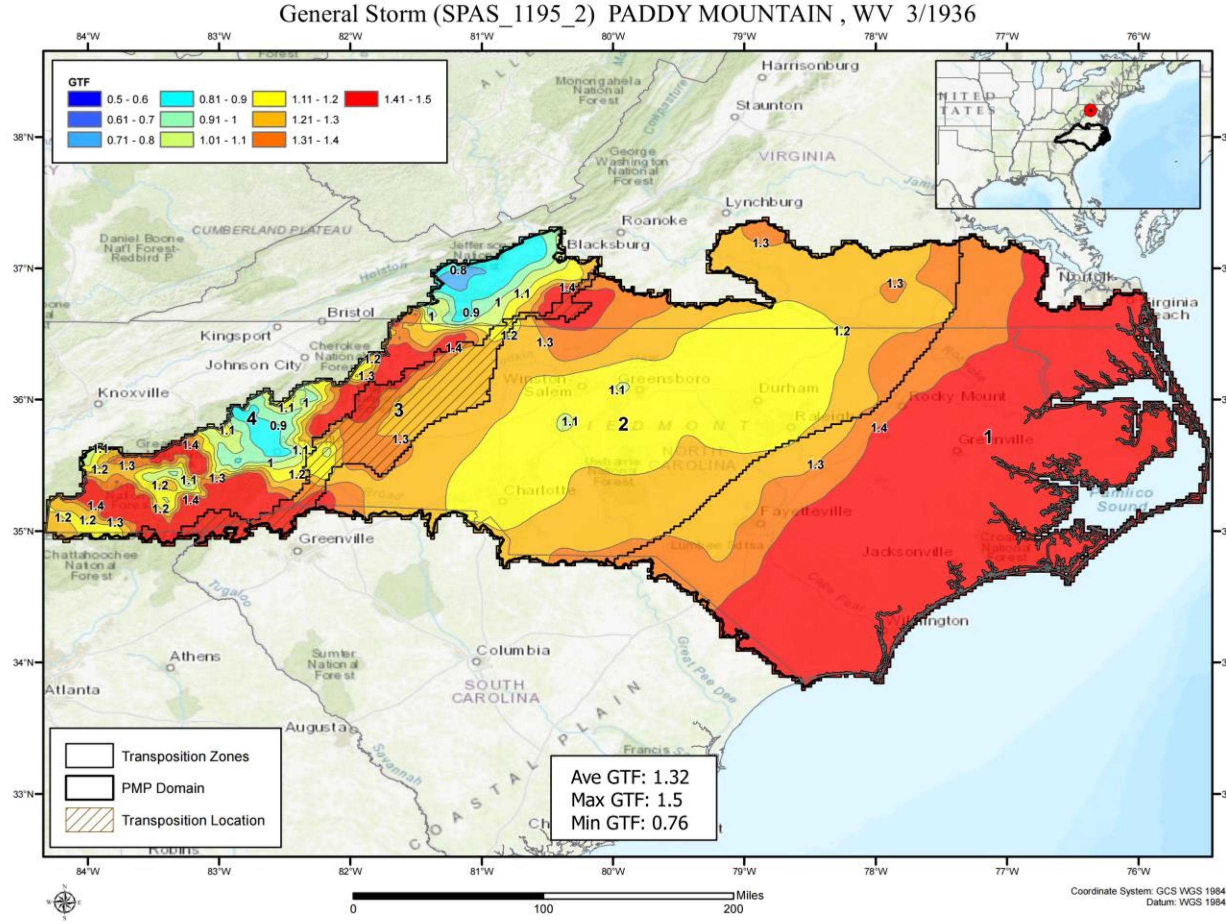


Appendix B
Geographic Transposition Factor (GTF) Maps

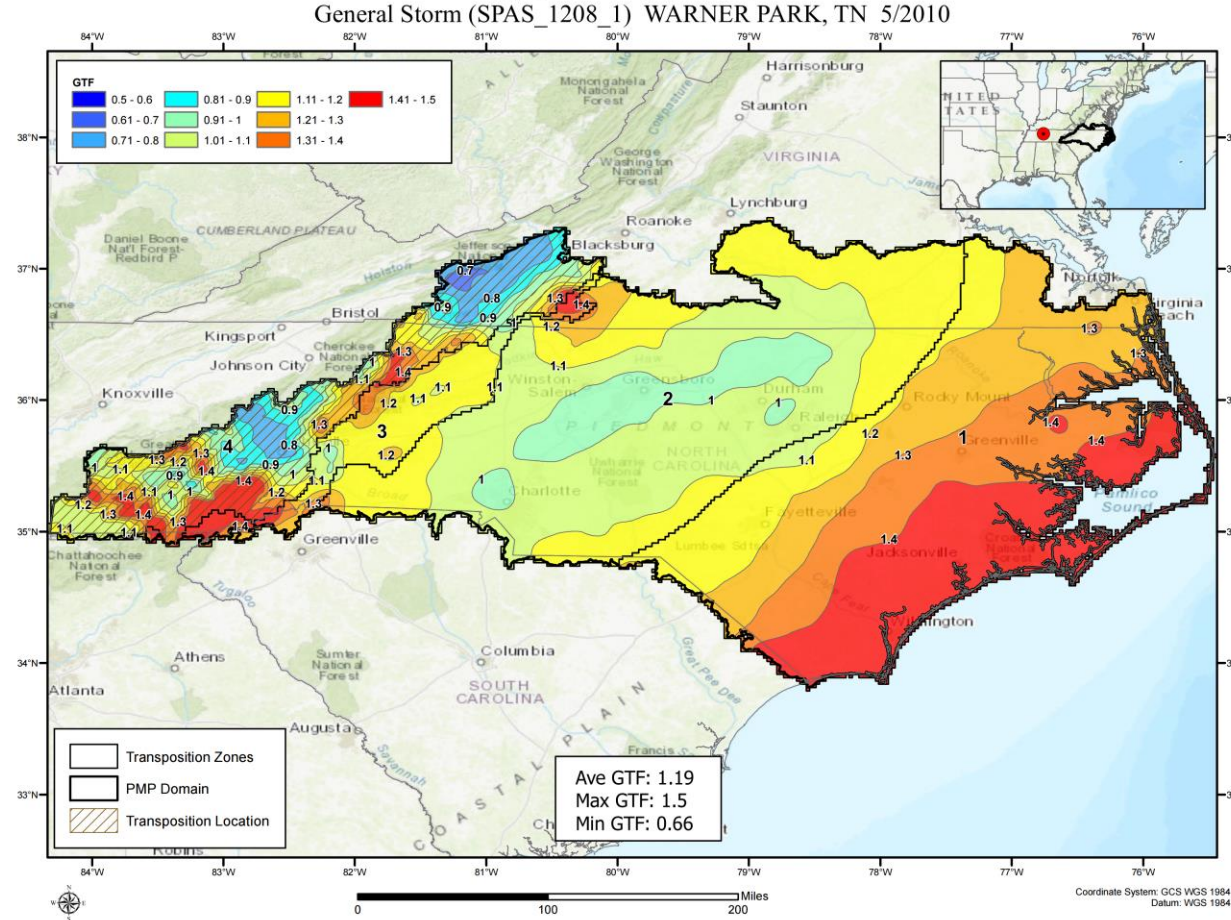
Geographic Transposition Factor
General Storm (SPAS_1047_1) TAMAQUA, PA 6/2006



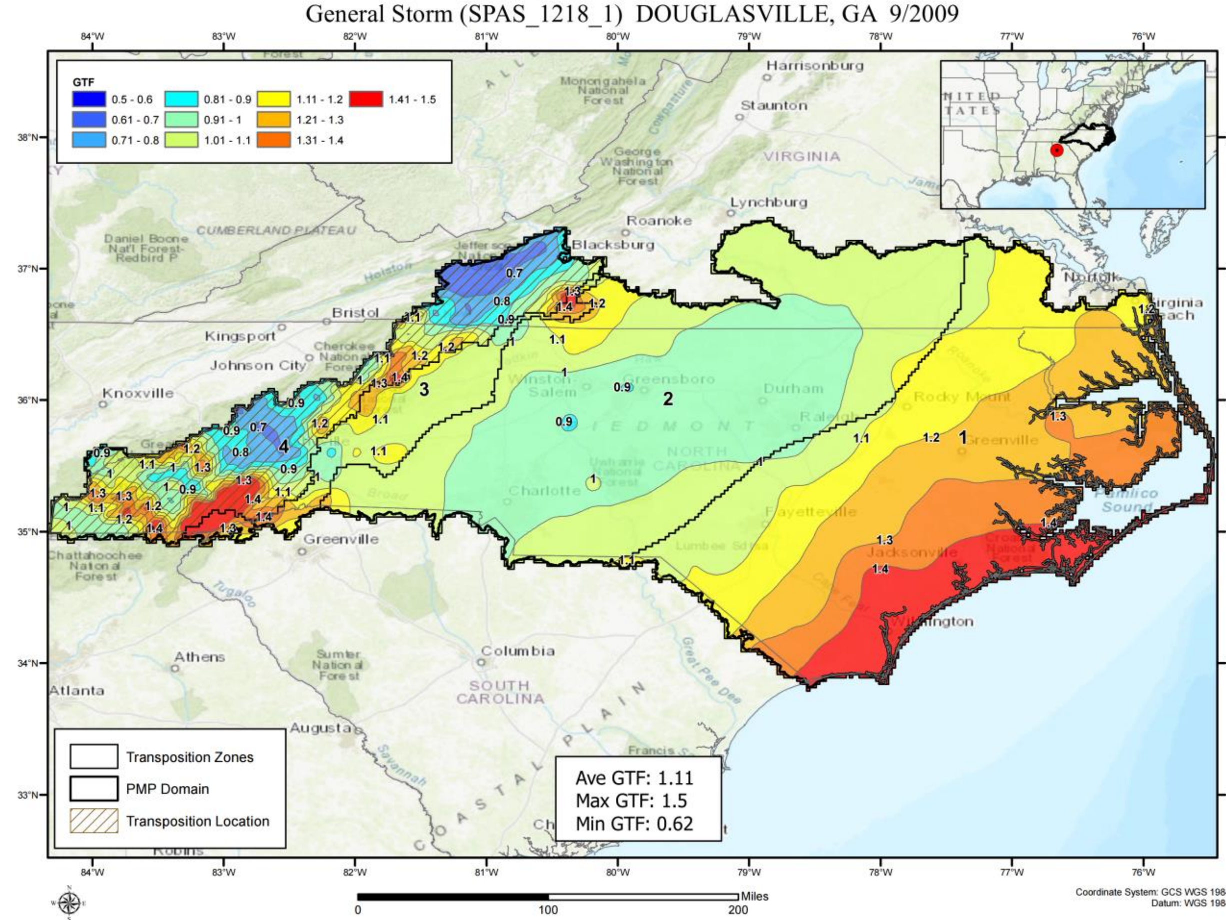
Geographic Transposition Factor
General Storm (SPAS_1195_2) PADDY MOUNTAIN , WV 3/1936



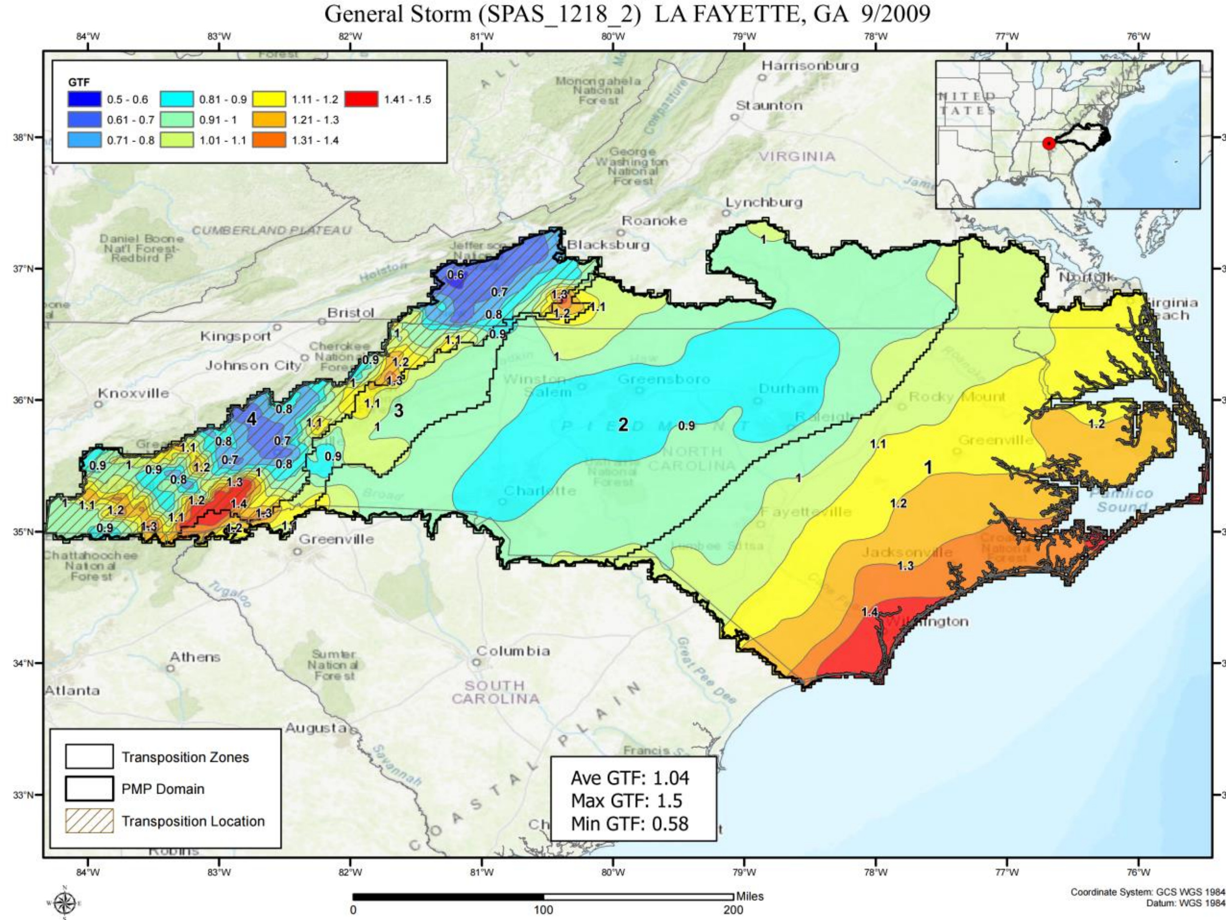
Geographic Transposition Factor
General Storm (SPAS_1208_1) WARNER PARK, TN 5/2010



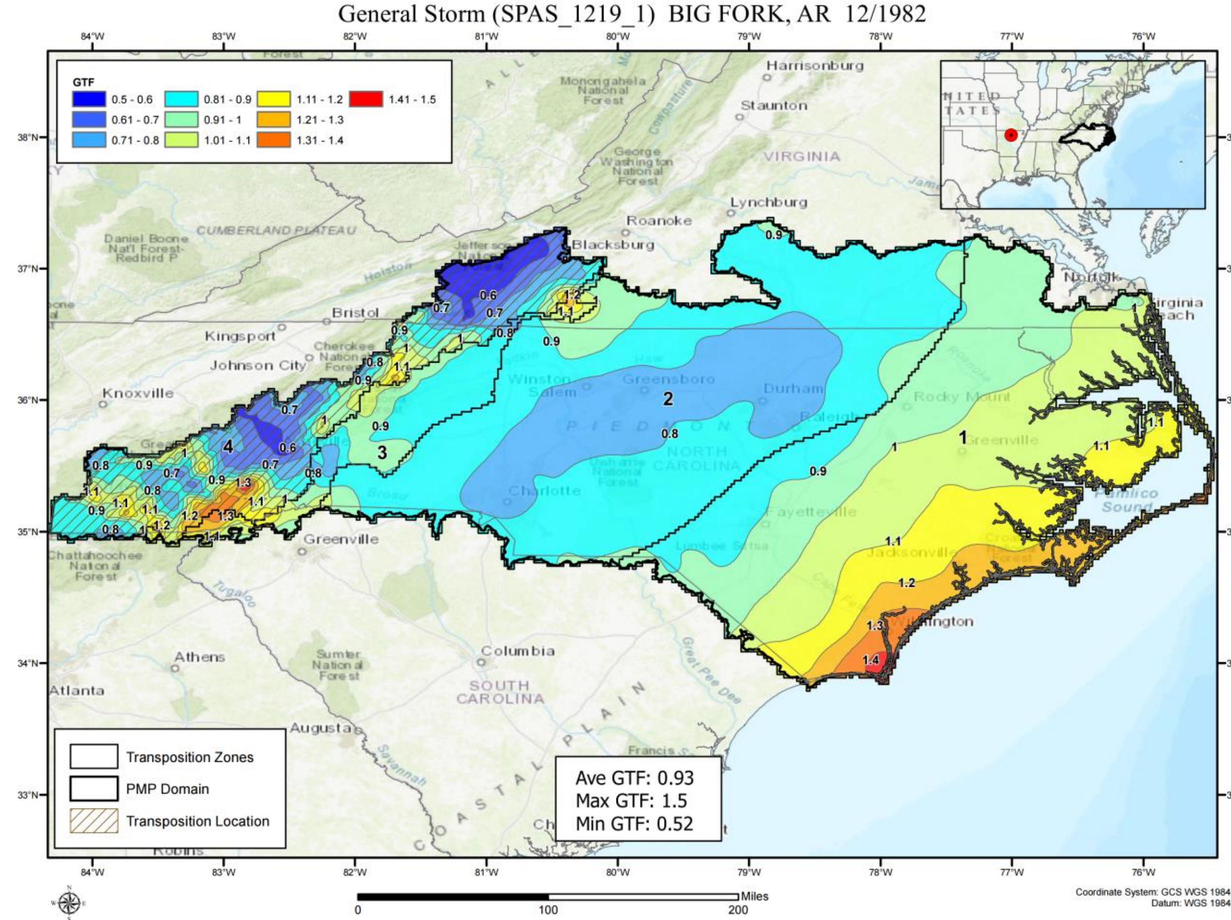
Geographic Transposition Factor
General Storm (SPAS_1218_1) DOUGLASVILLE, GA 9/2009



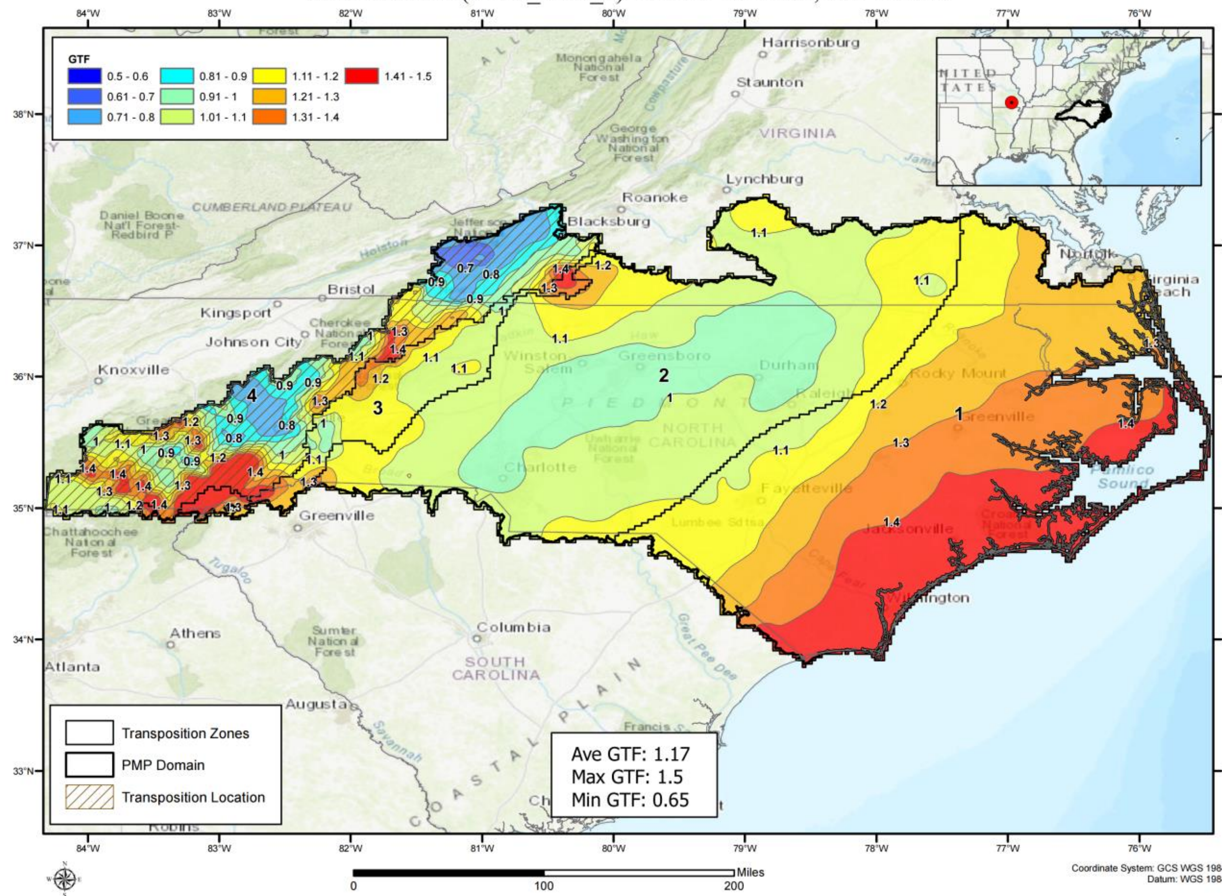
Geographic Transposition Factor
General Storm (SPAS_1218_2) LA FAYETTE, GA 9/2009



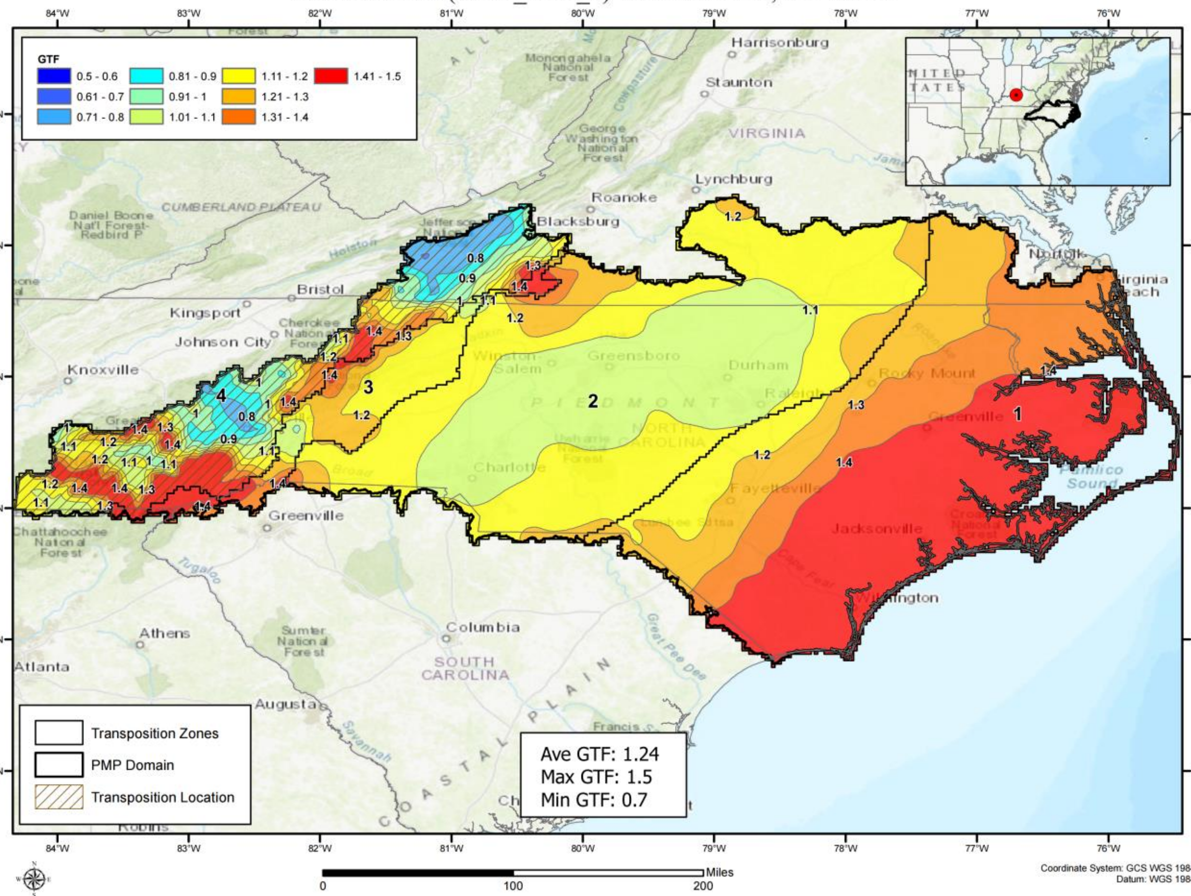
Geographic Transposition Factor
General Storm (SPAS_1219_1) BIG FORK, AR 12/1982



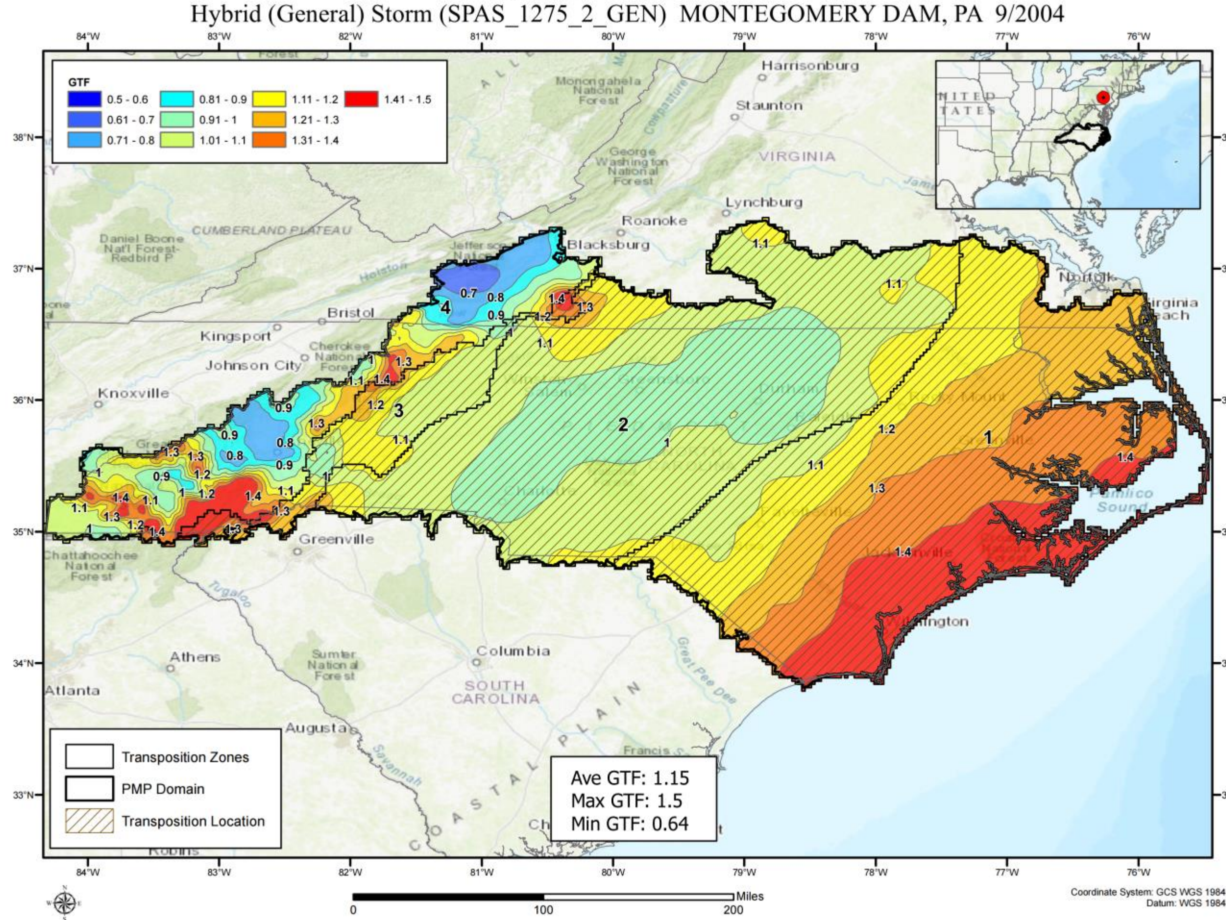
Geographic Transposition Factor
General Storm (SPAS_1242_1) ALLEY SPRING, MO 3/2008



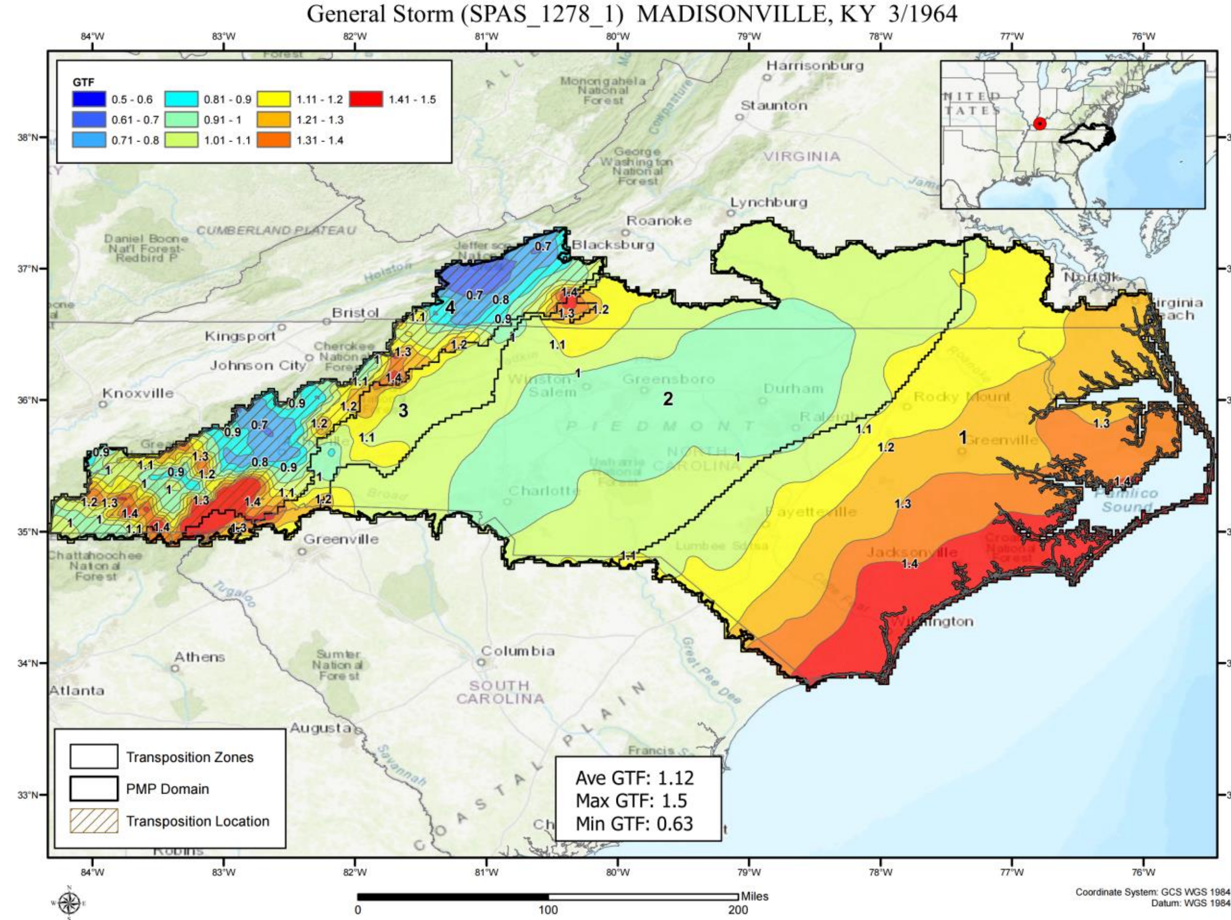
Geographic Transposition Factor
General Storm (SPAS_1244_1) LOUISVILLE, KY 2/1997



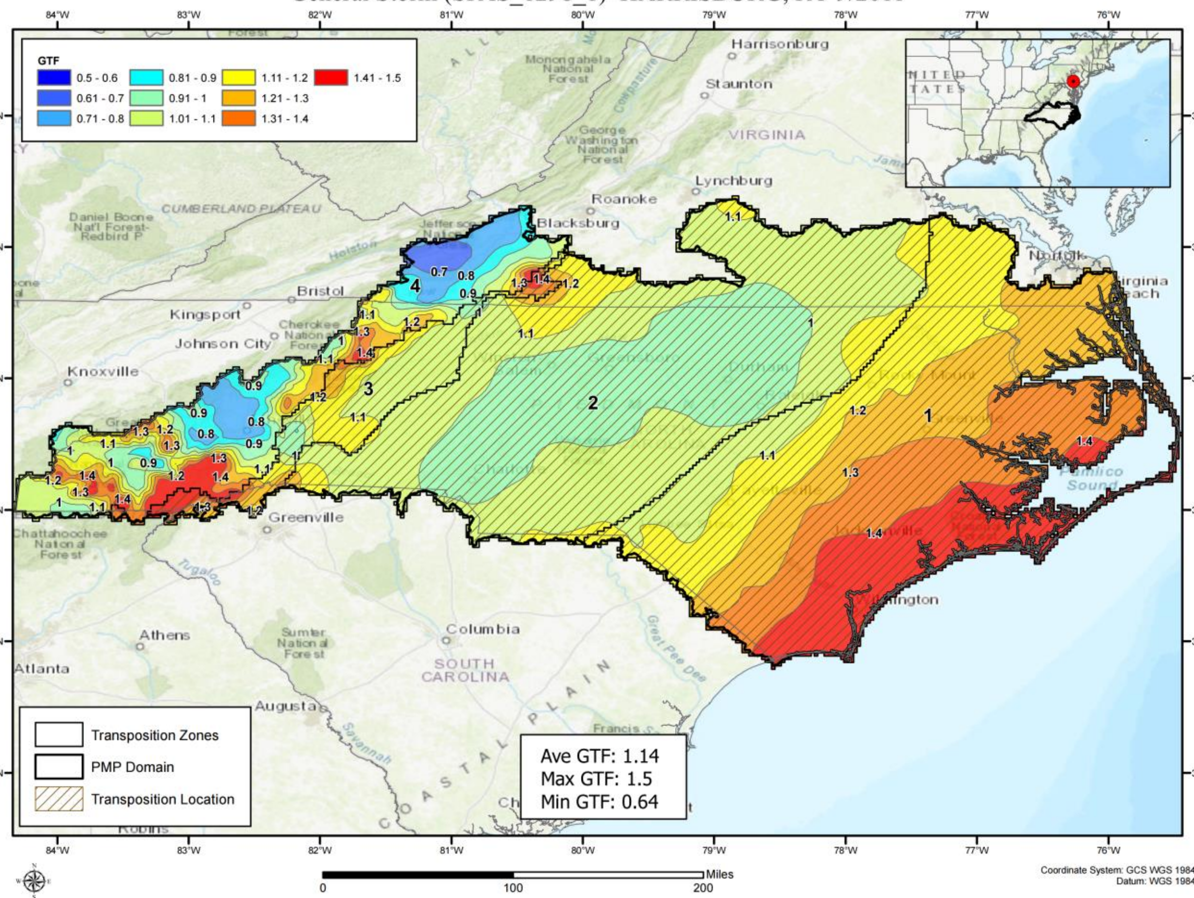
Geographic Transposition Factor
Hybrid (General) Storm (SPAS_1275_2_GEN) MONTEGOMERY DAM, PA 9/2004



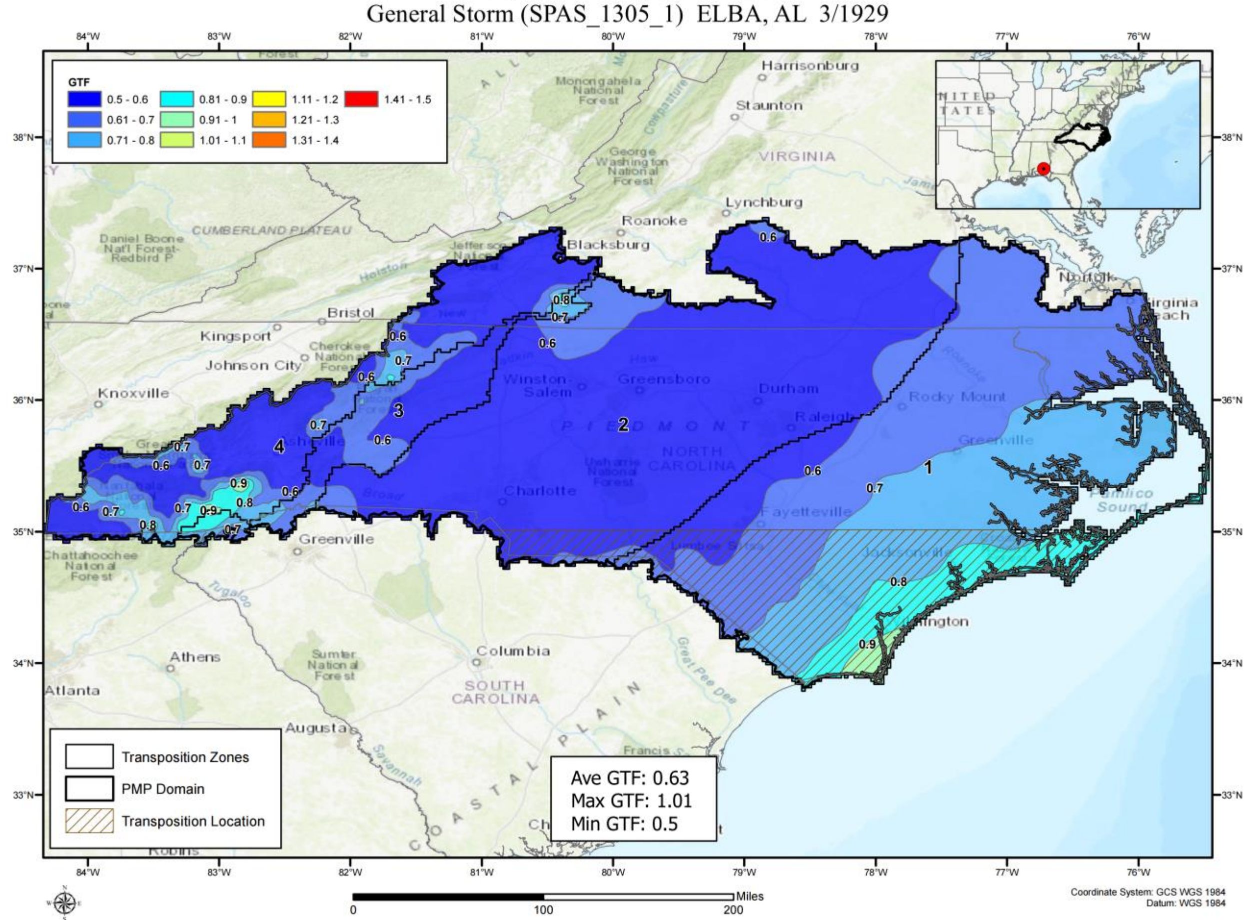
Geographic Transposition Factor
General Storm (SPAS_1278_1) MADISONVILLE, KY 3/1964



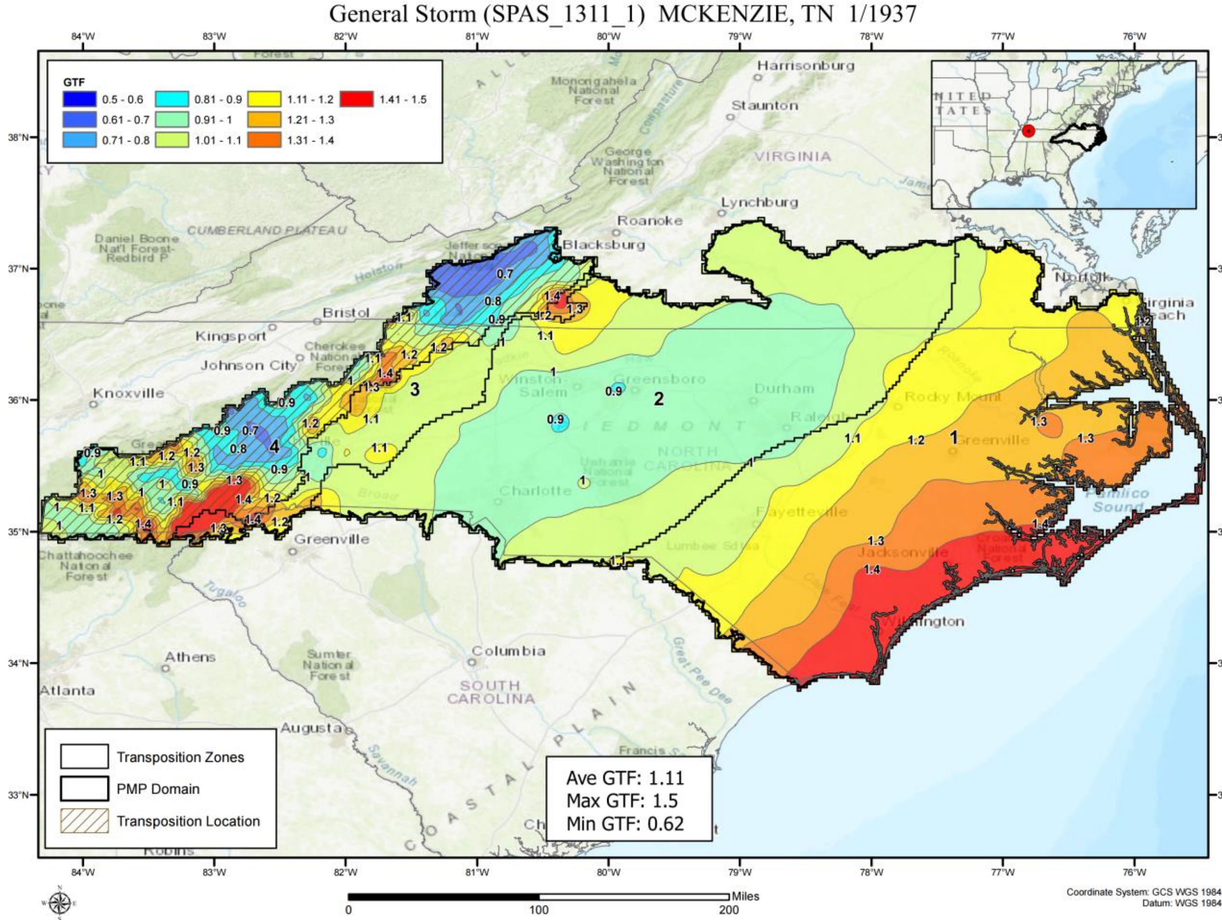
Geographic Transposition Factor
General Storm (SPAS_1298_1) HARRISBURG, PA 9/2011



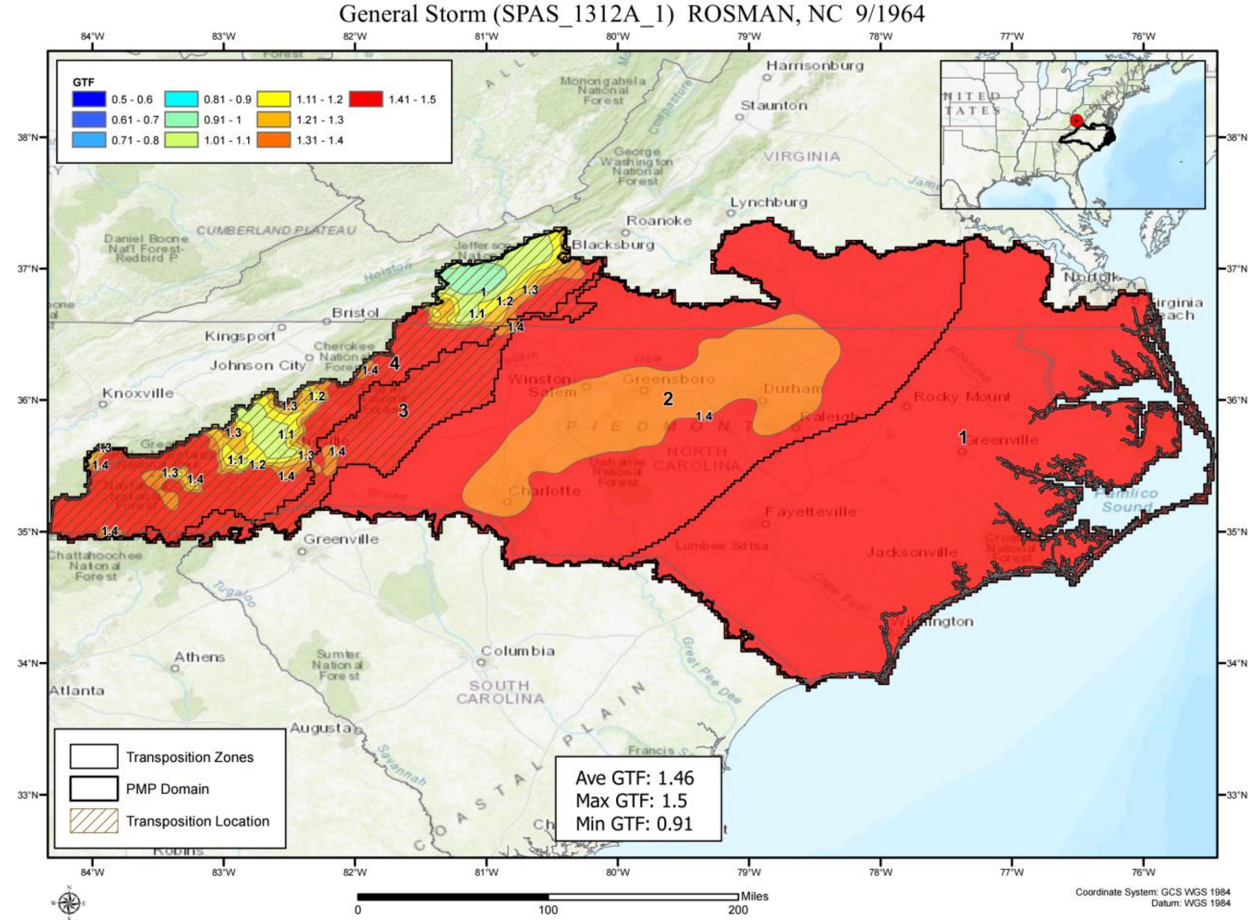
Geographic Transposition Factor
General Storm (SPAS_1305_1) ELBA, AL 3/1929



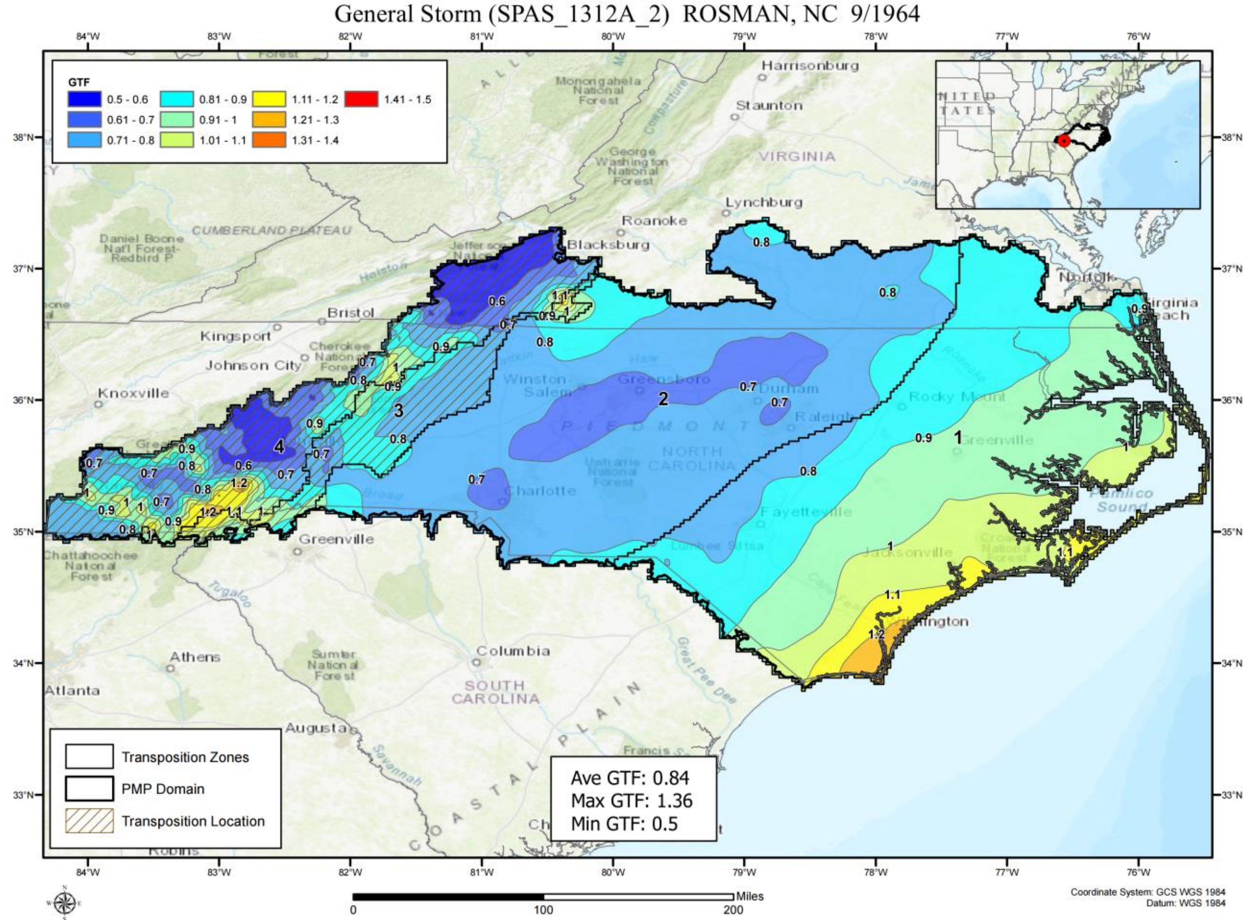
Geographic Transposition Factor
General Storm (SPAS_1311_1) MCKENZIE, TN 1/1937



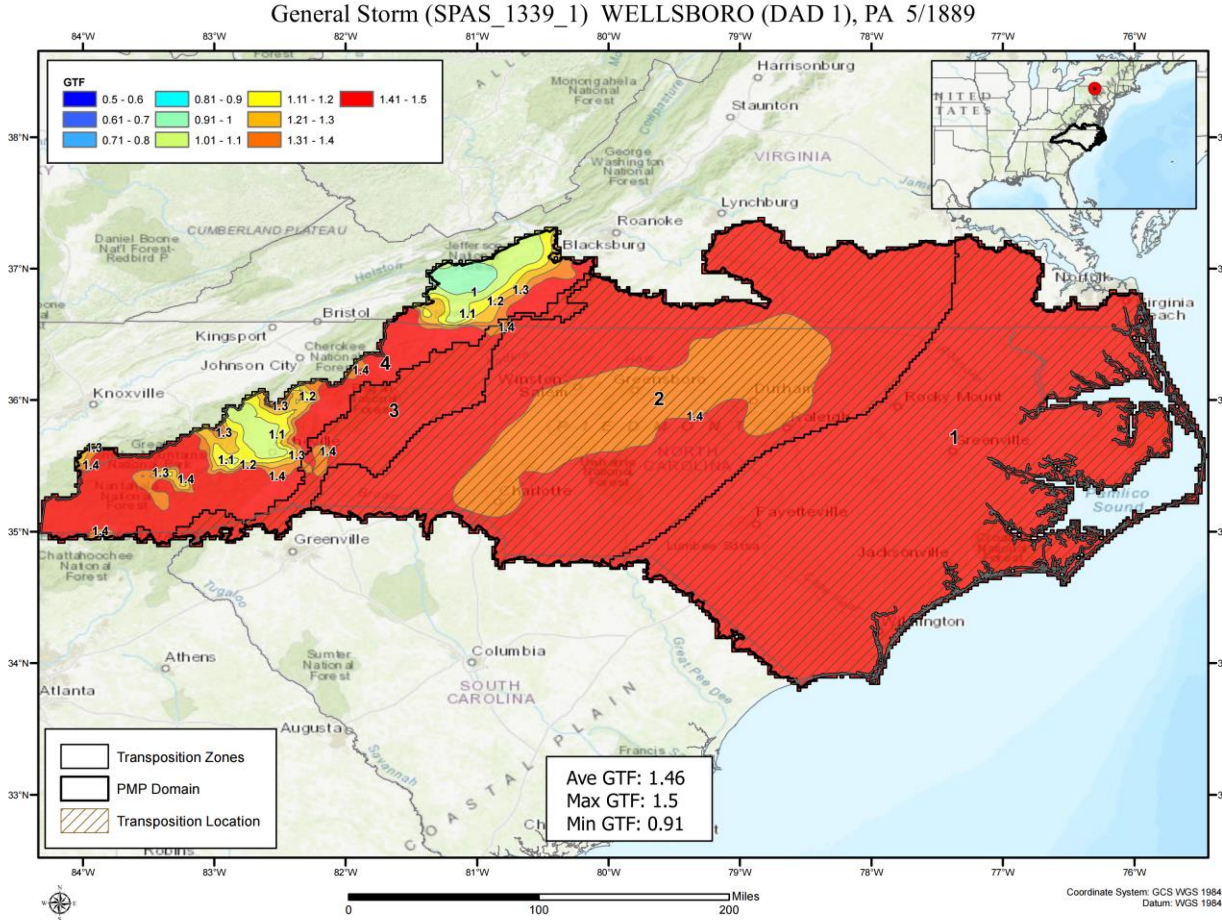
Geographic Transposition Factor
General Storm (SPAS_1312A_1) ROSMAN, NC 9/1964



Geographic Transposition Factor
General Storm (SPAS_1312A_2) ROSMAN, NC 9/1964



Geographic Transposition Factor
General Storm (SPAS_1339_1) WELLSBORO (DAD 1), PA 5/1889



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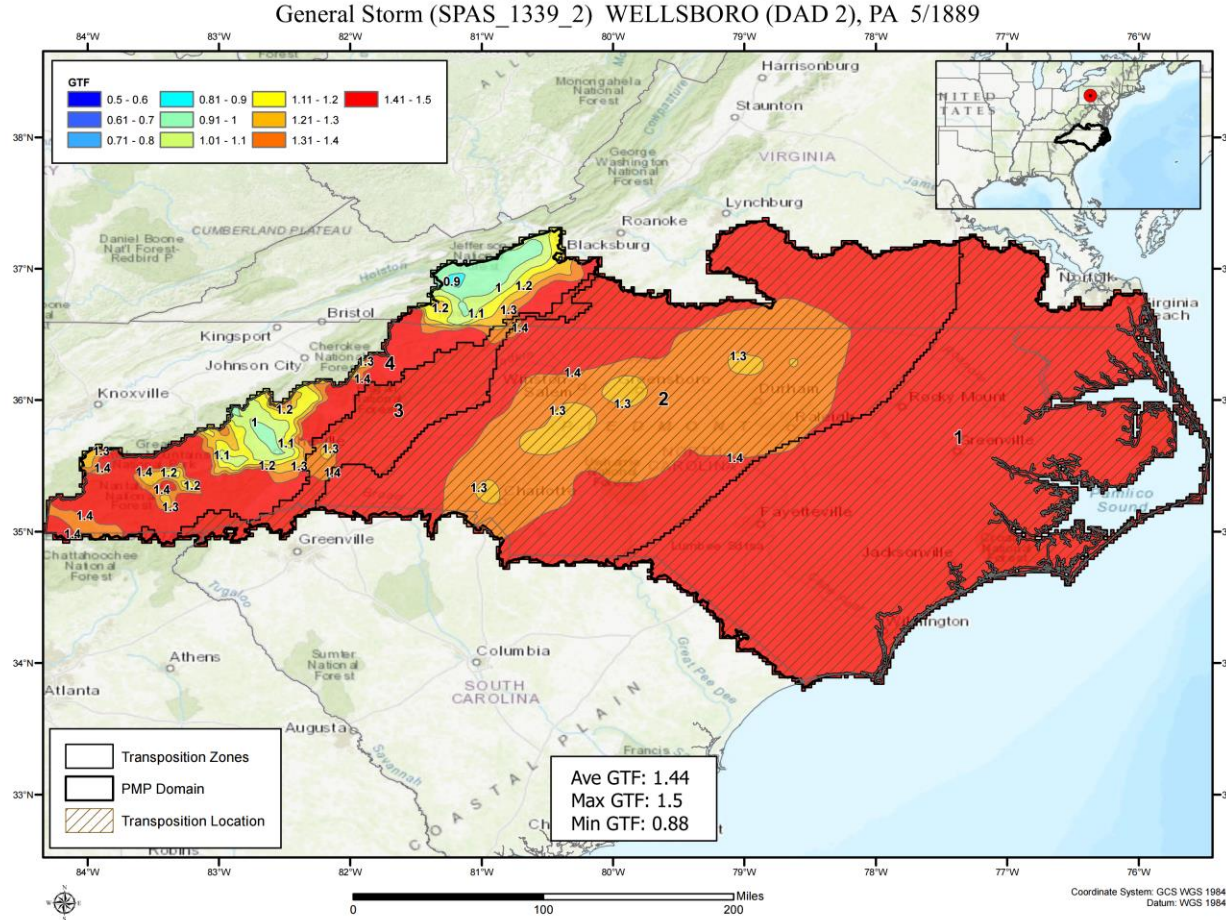

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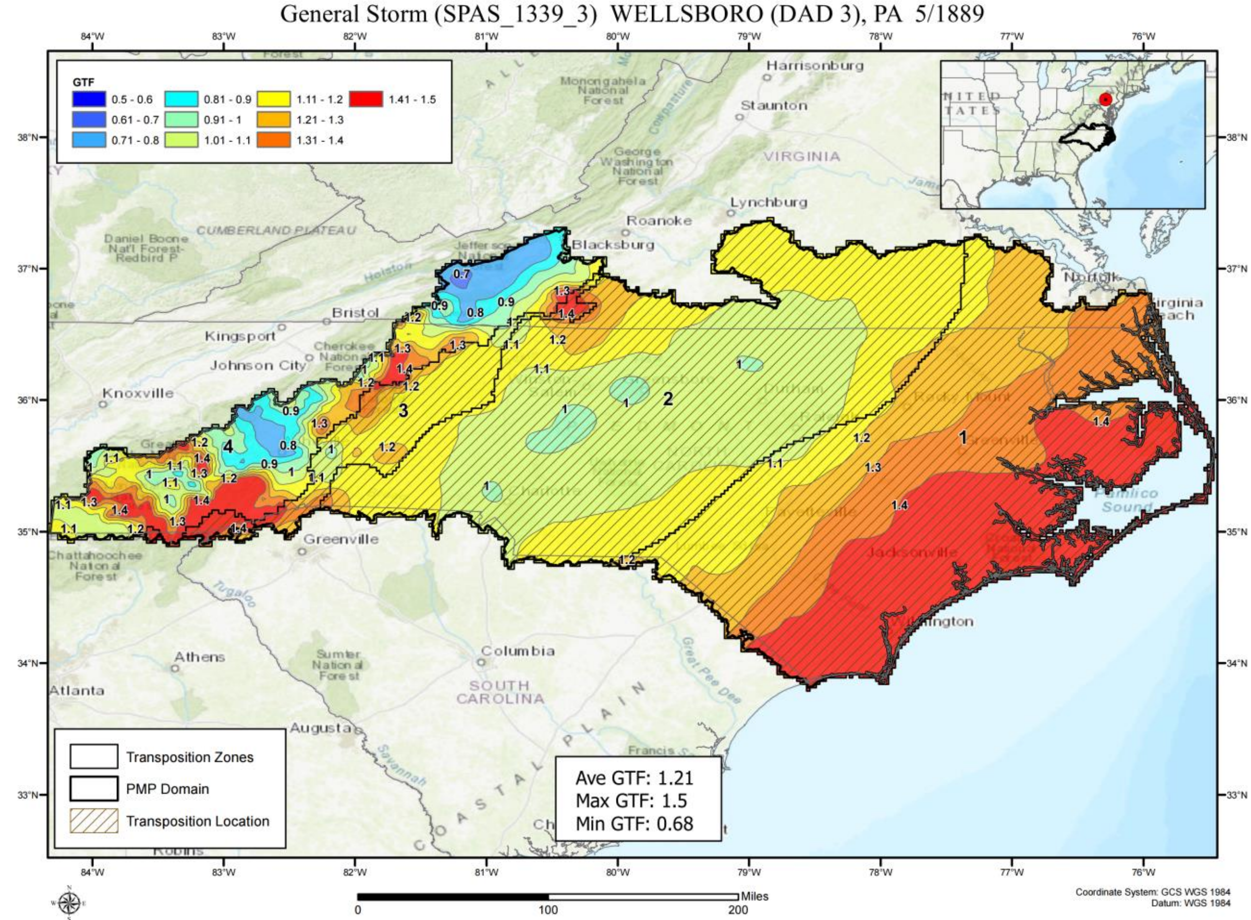
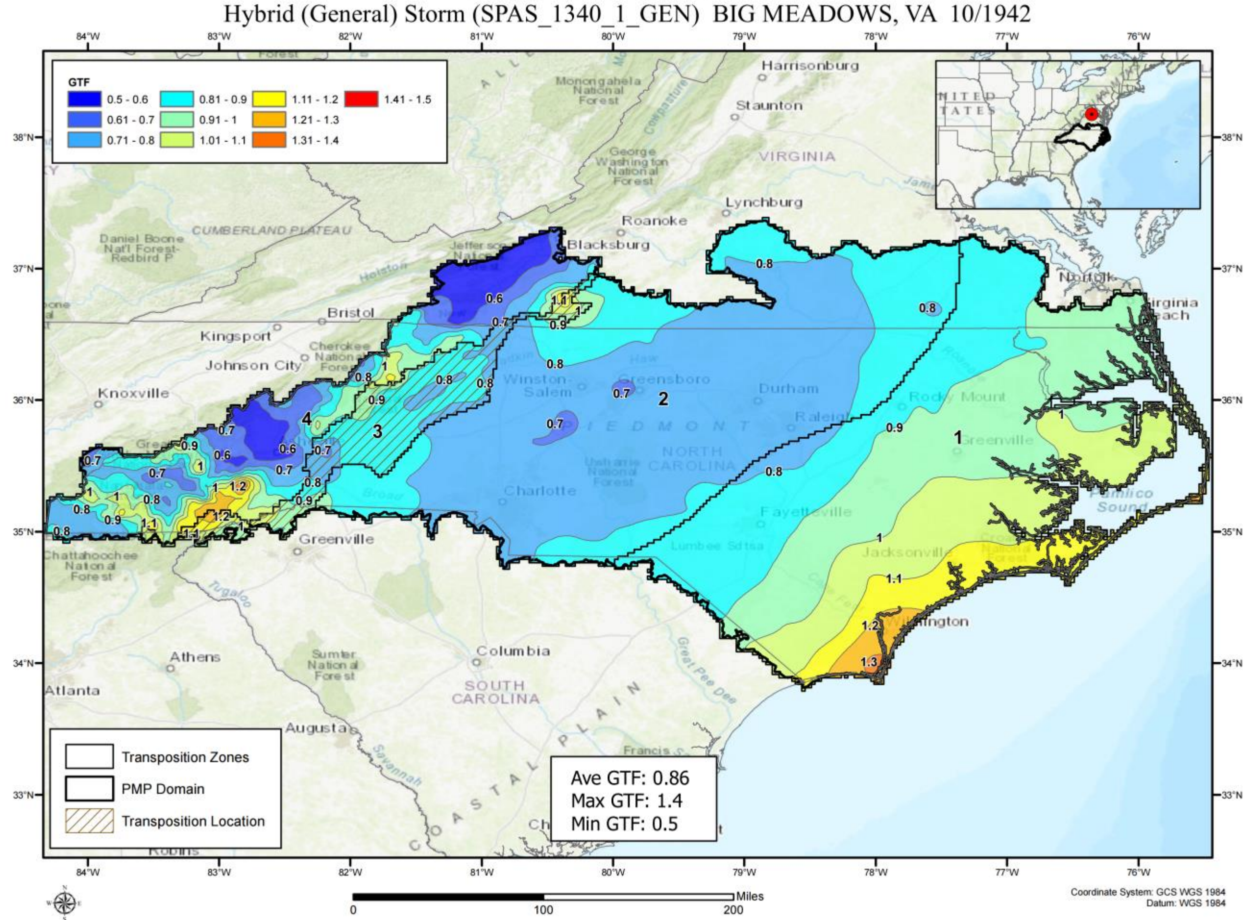
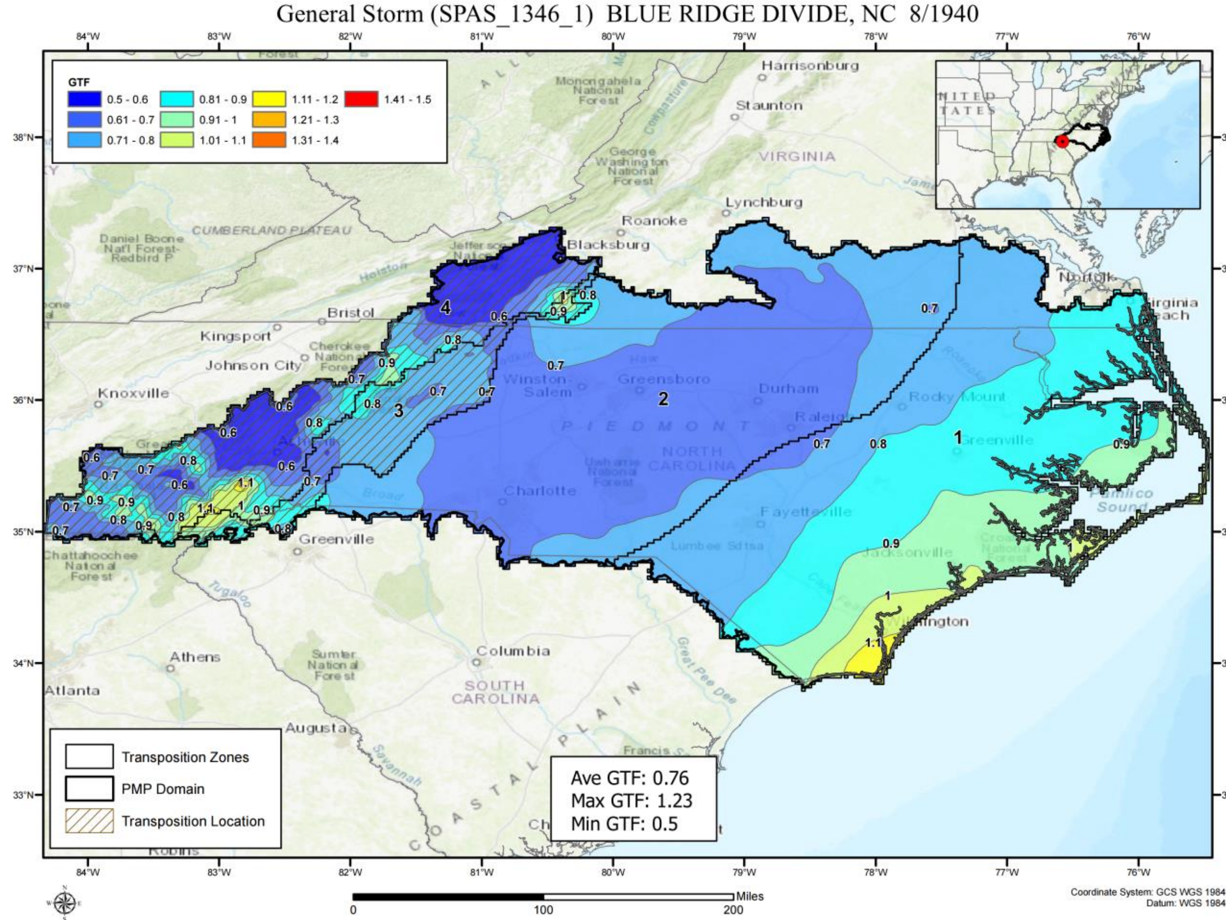


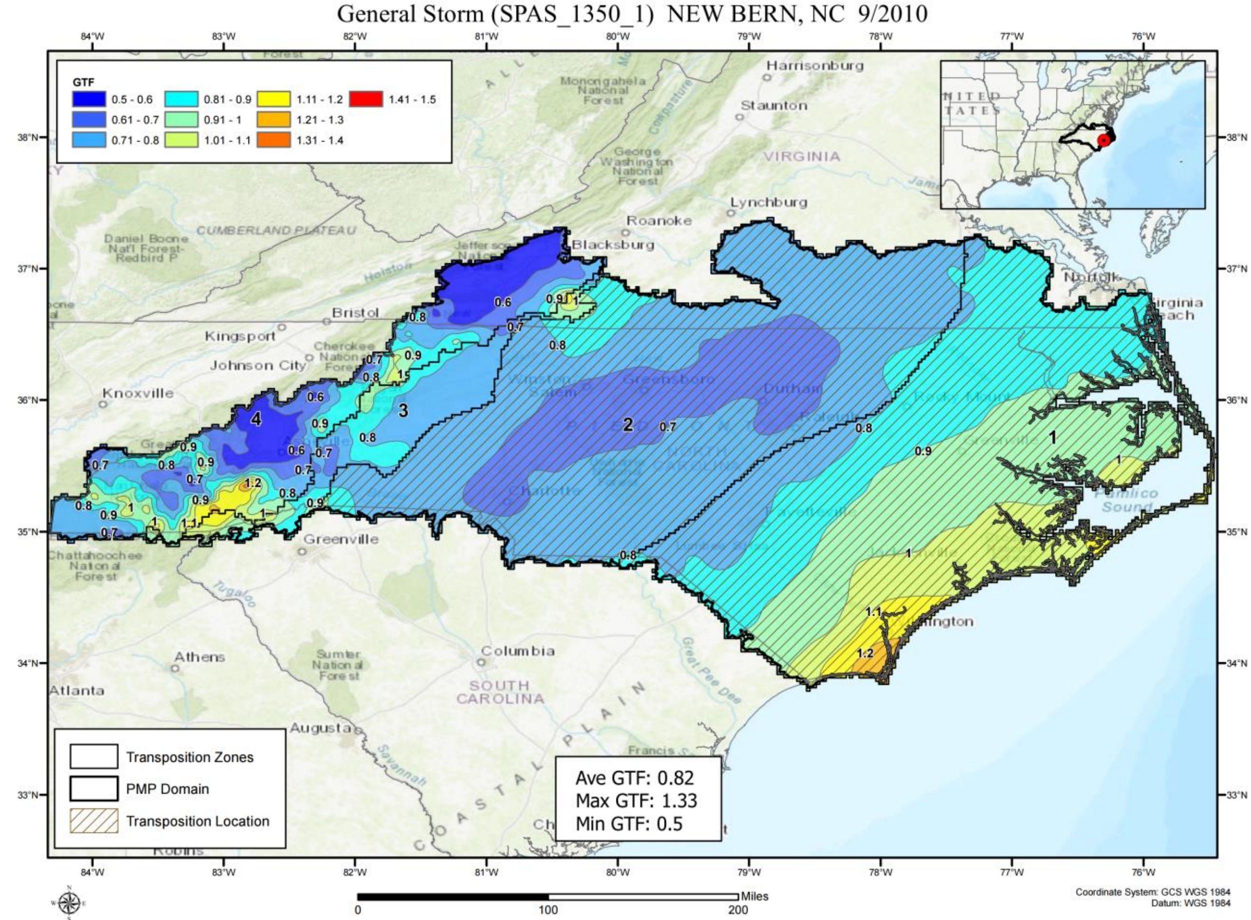
Geographic Transposition Factor
Hybrid (General) Storm (SPAS_1340_1_GEN) BIG MEADOWS, VA 10/1942



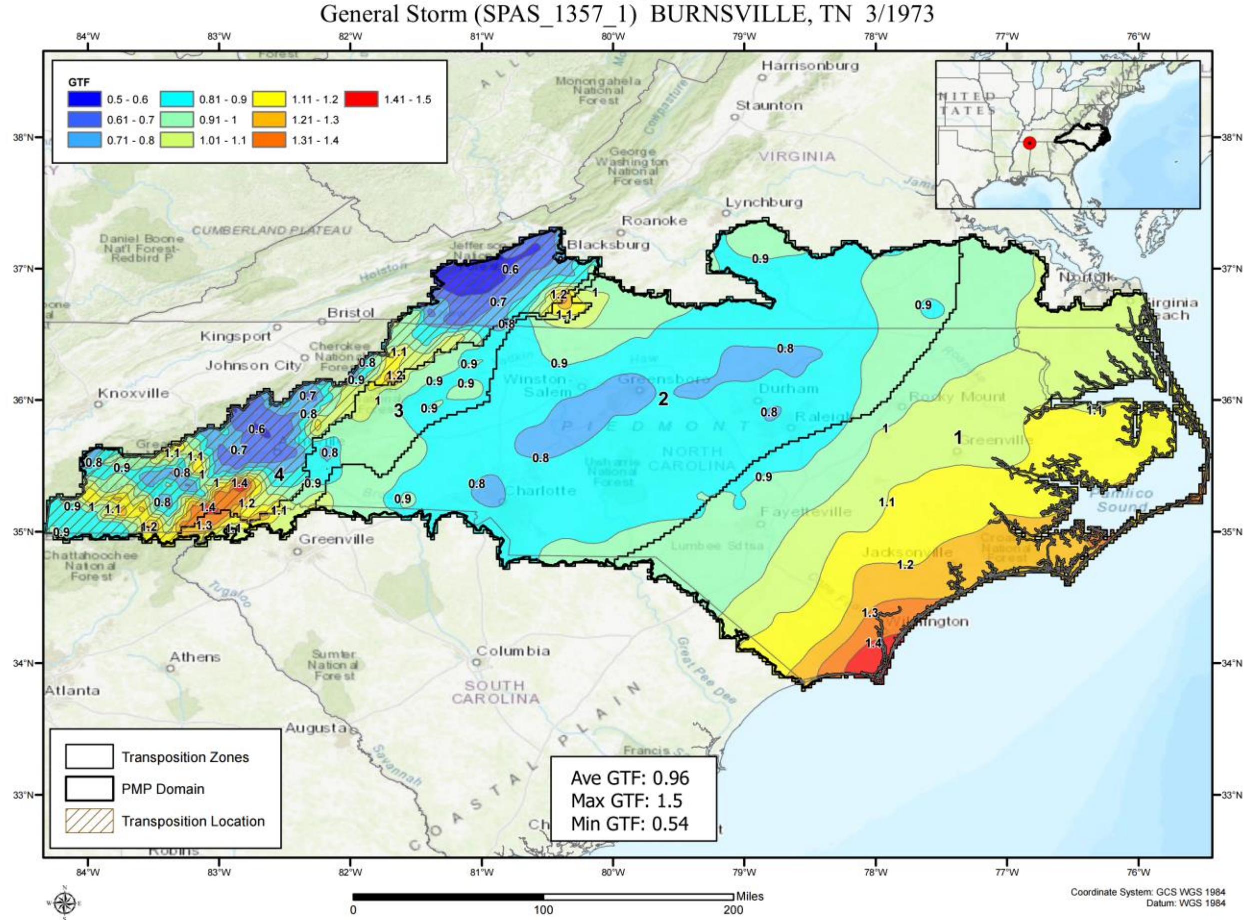
Geographic Transposition Factor
General Storm (SPAS_1346_1) BLUE RIDGE DIVIDE, NC 8/1940



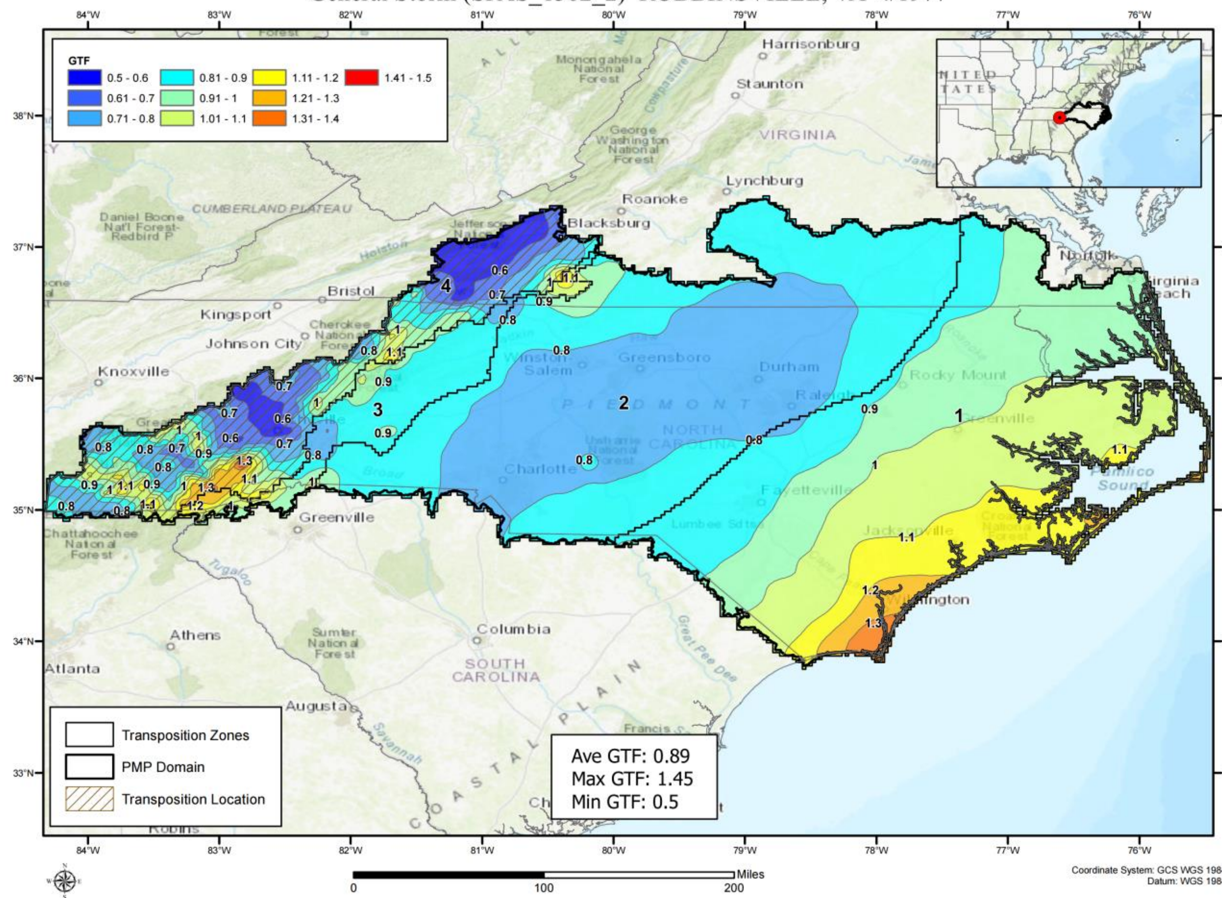
Geographic Transposition Factor
General Storm (SPAS_1350_1) NEW BERN, NC 9/2010



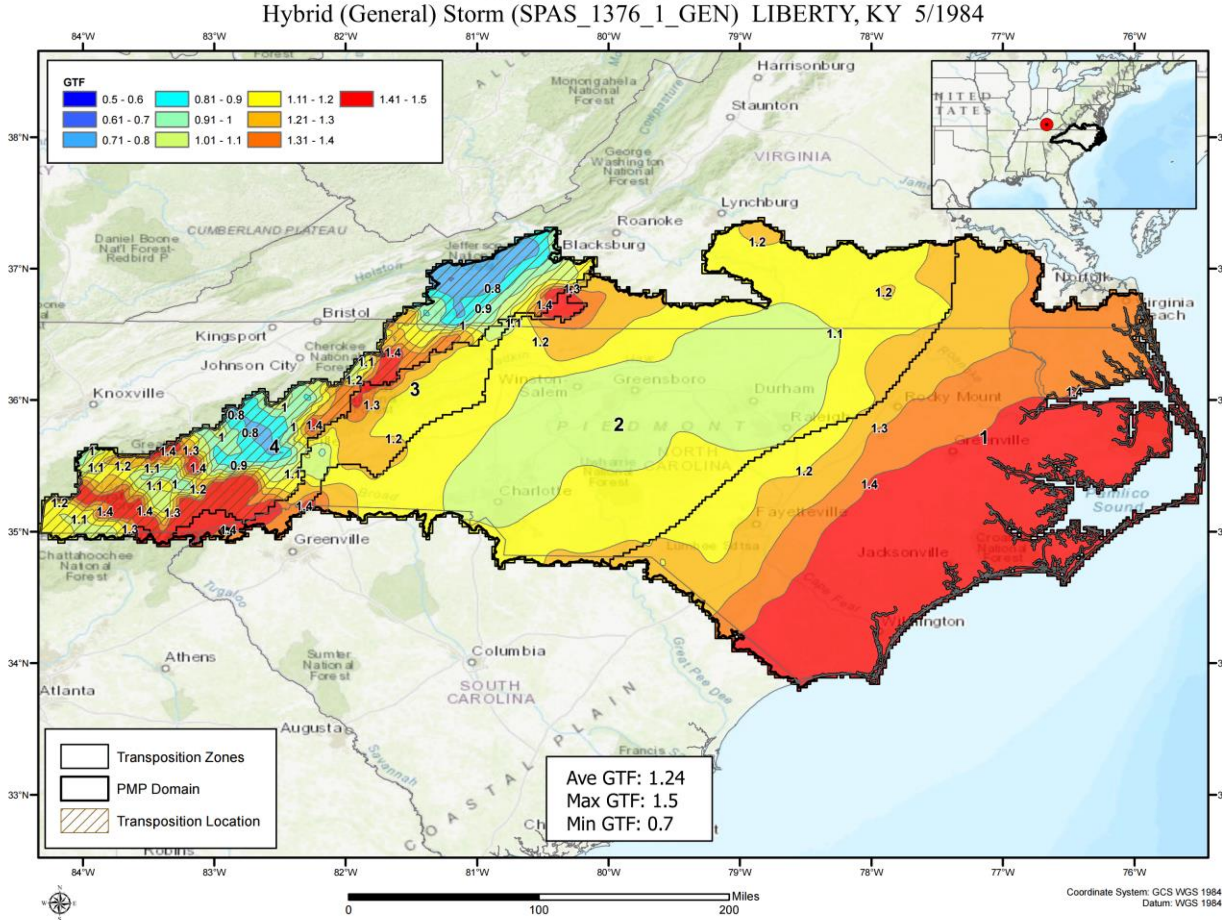
Geographic Transposition Factor
General Storm (SPAS_1357_1) BURNSVILLE, TN 3/1973



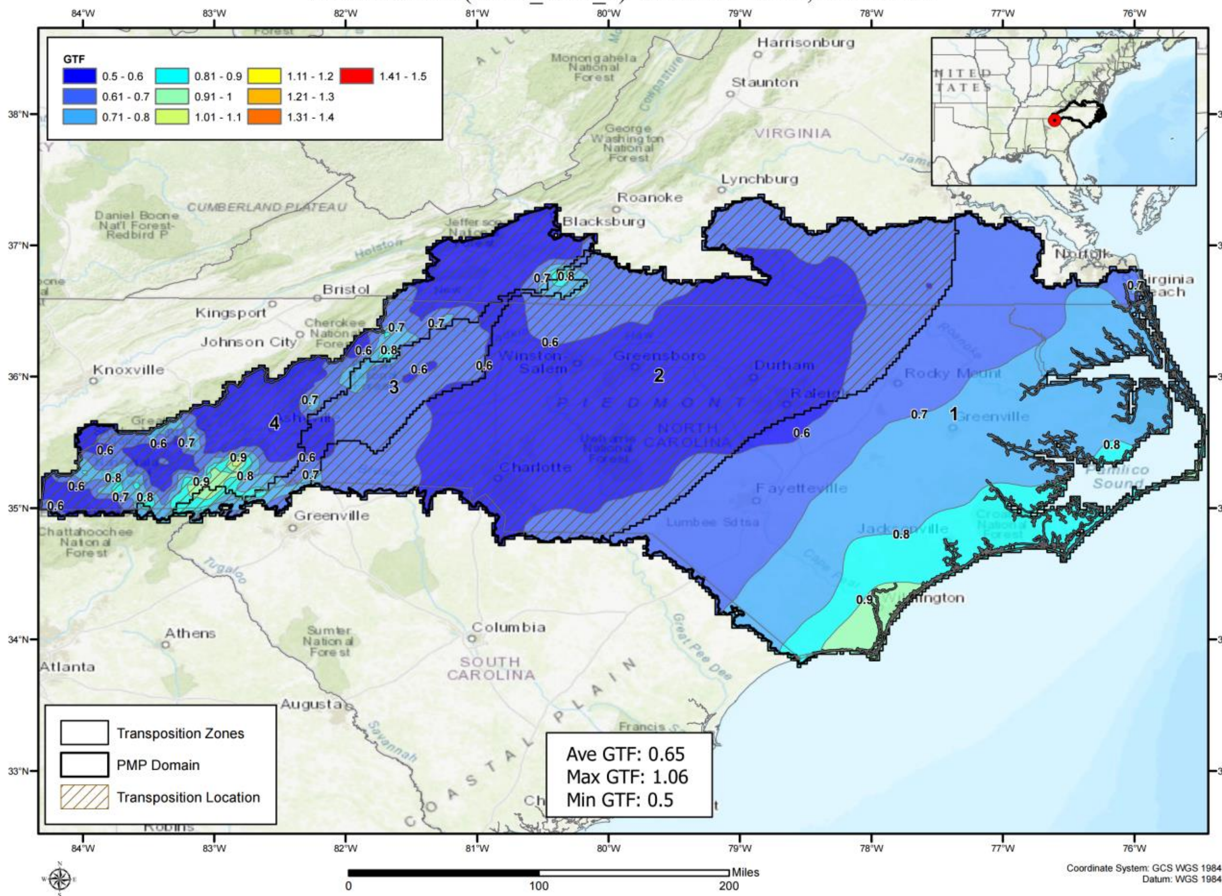
Geographic Transposition Factor
General Storm (SPAS_1362_2) ROBBINSVILLE, VA 4/1977



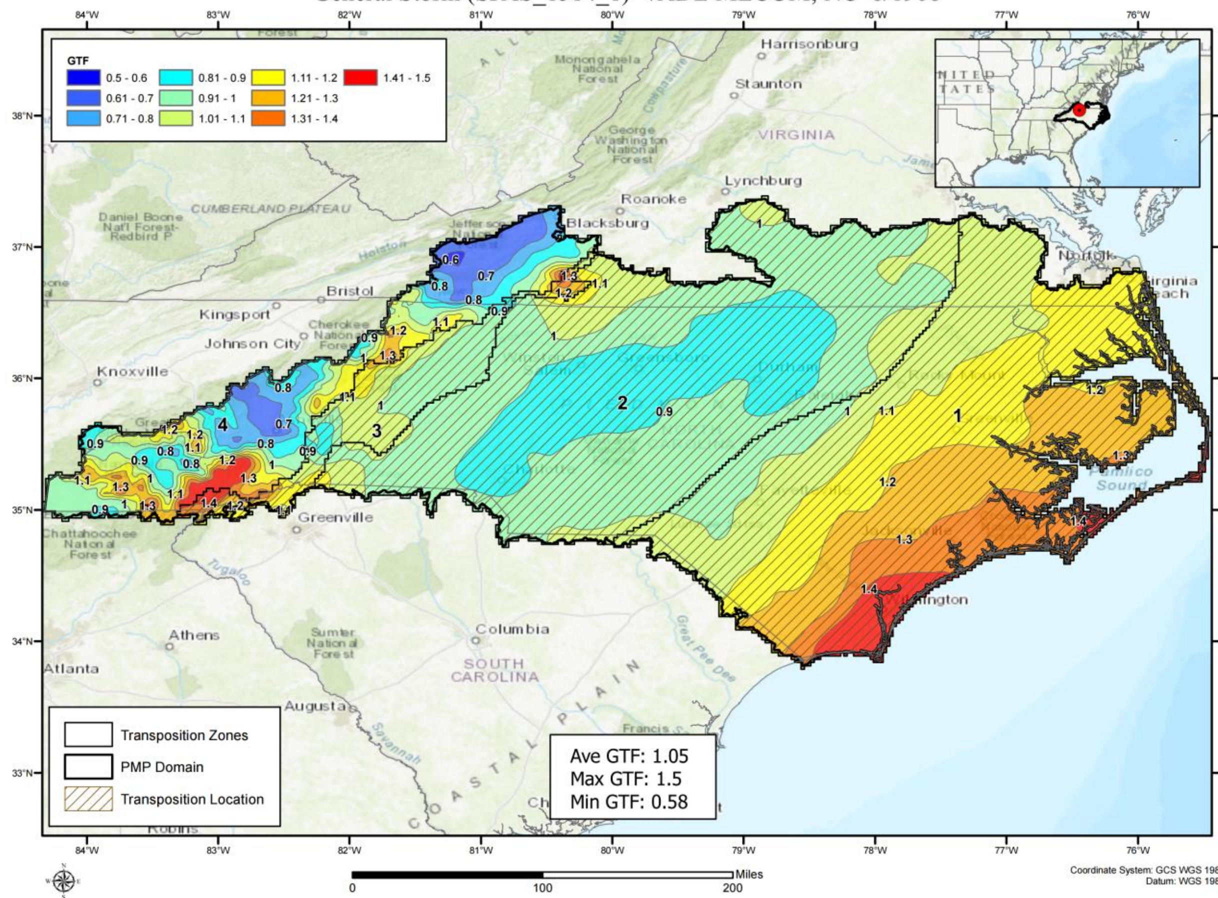
Geographic Transposition Factor
Hybrid (General) Storm (SPAS_1376_1_GEN) LIBERTY, KY 5/1984



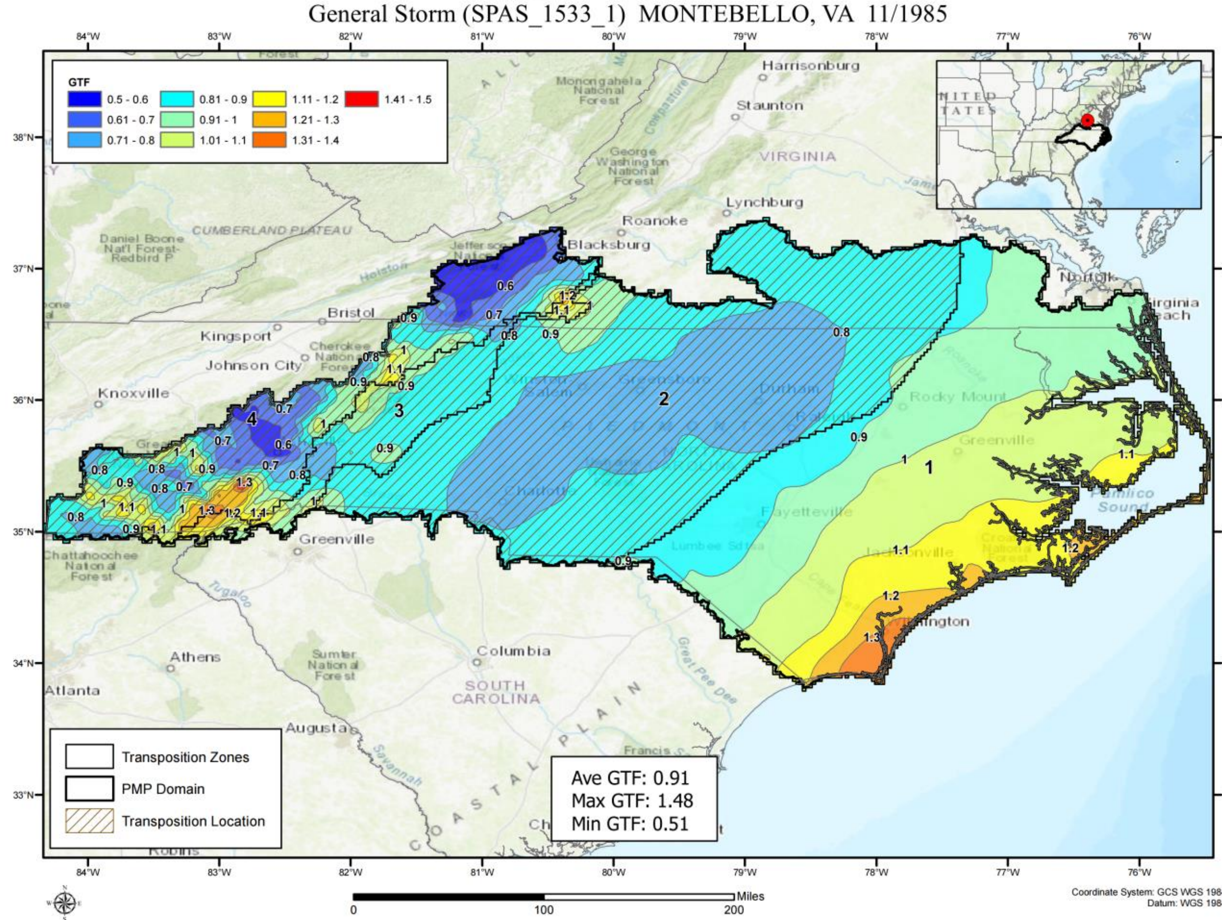
Geographic Transposition Factor
General Storm (SPAS_1380_1) BURTON DAM, GA 8/1967



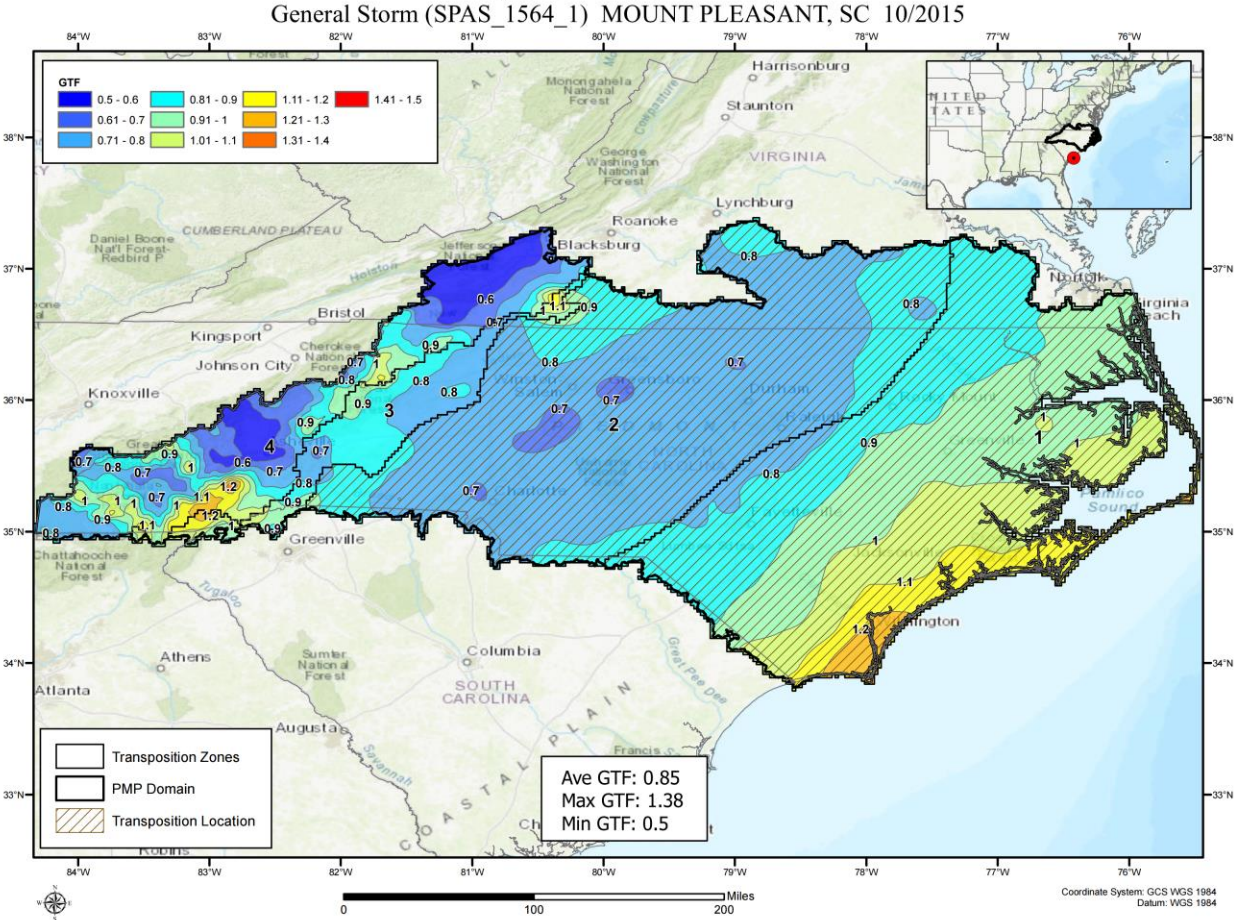
Geographic Transposition Factor
General Storm (SPAS_1514_1) VADE MECUM, NC 8/1908



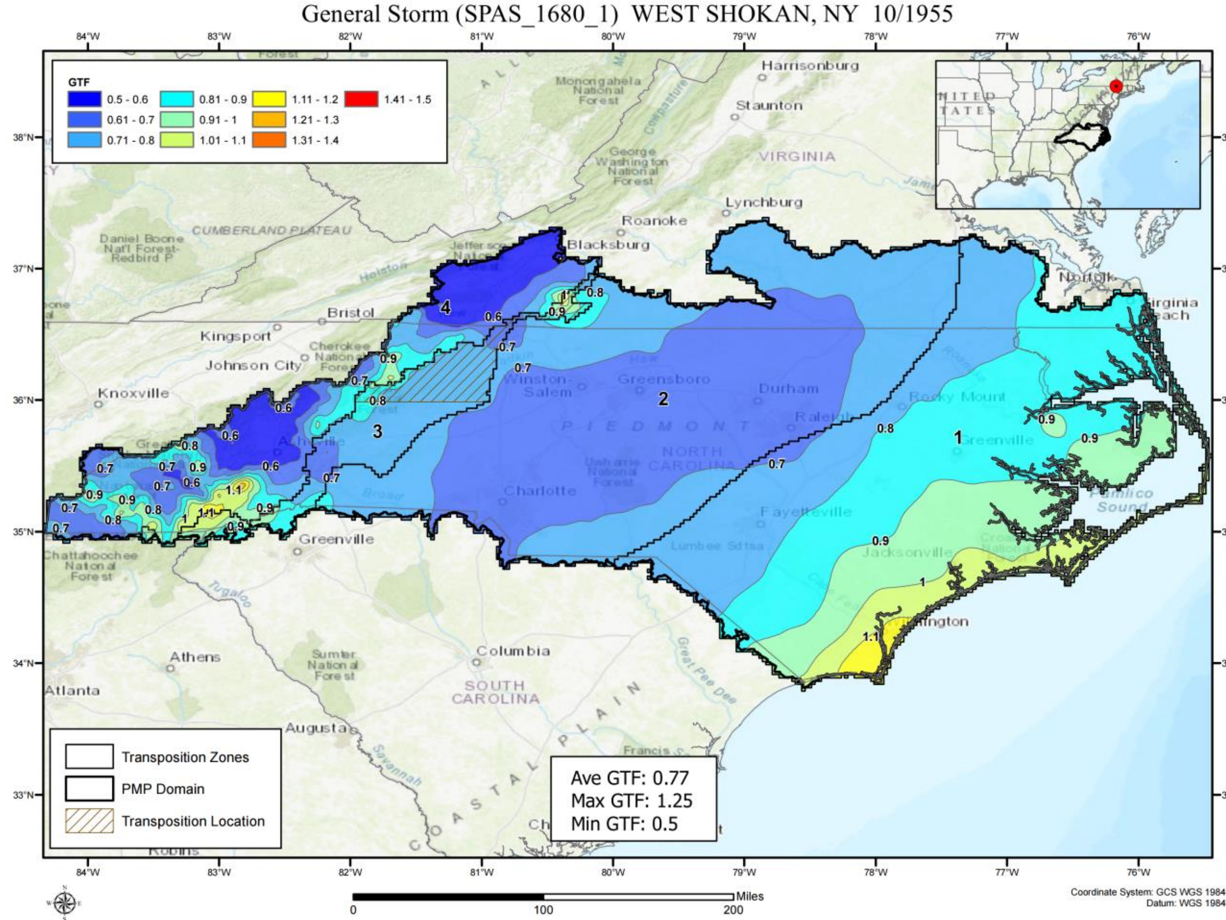
Geographic Transposition Factor
General Storm (SPAS_1533_1) MONTEBELLO, VA 11/1985



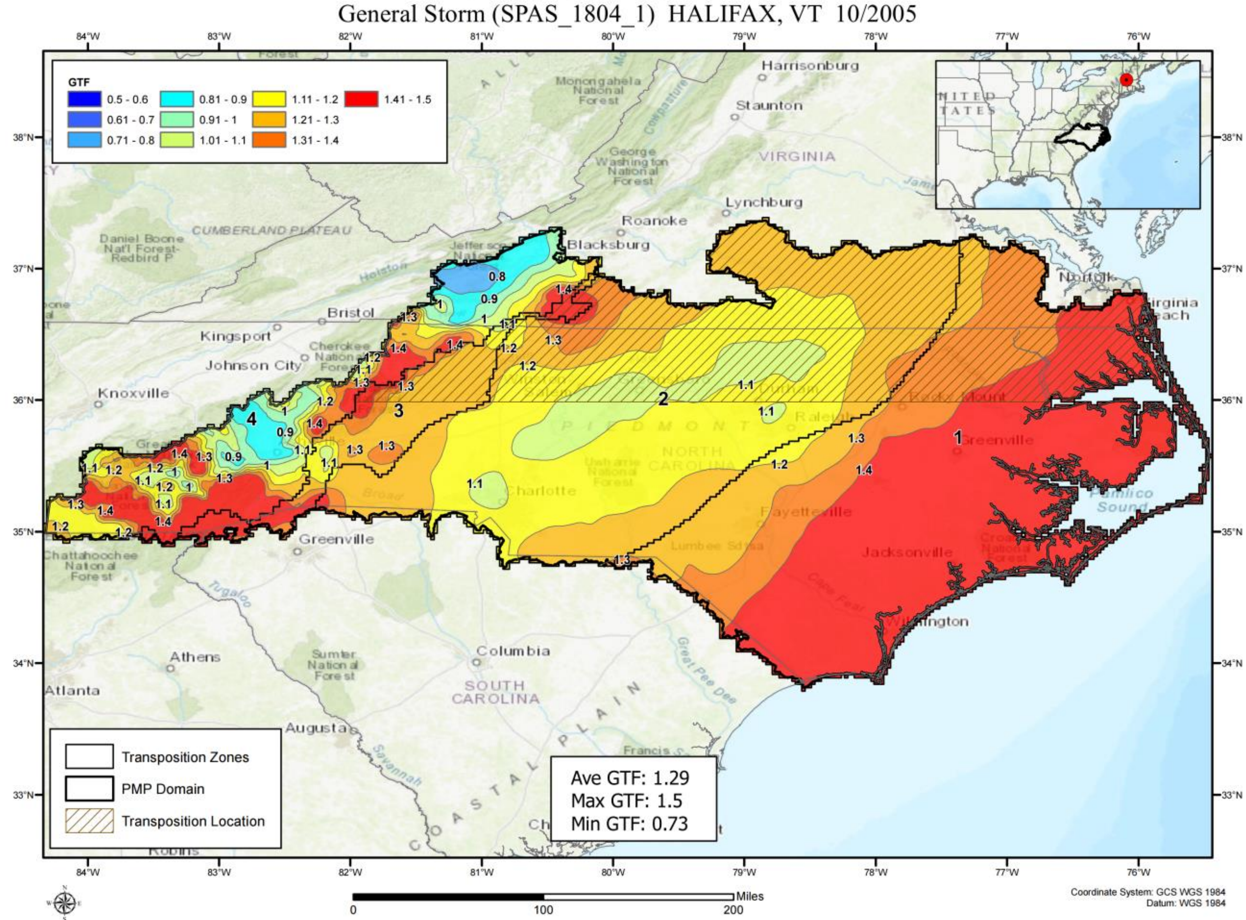
Geographic Transposition Factor
General Storm (SPAS_1564_1) MOUNT PLEASANT, SC 10/2015



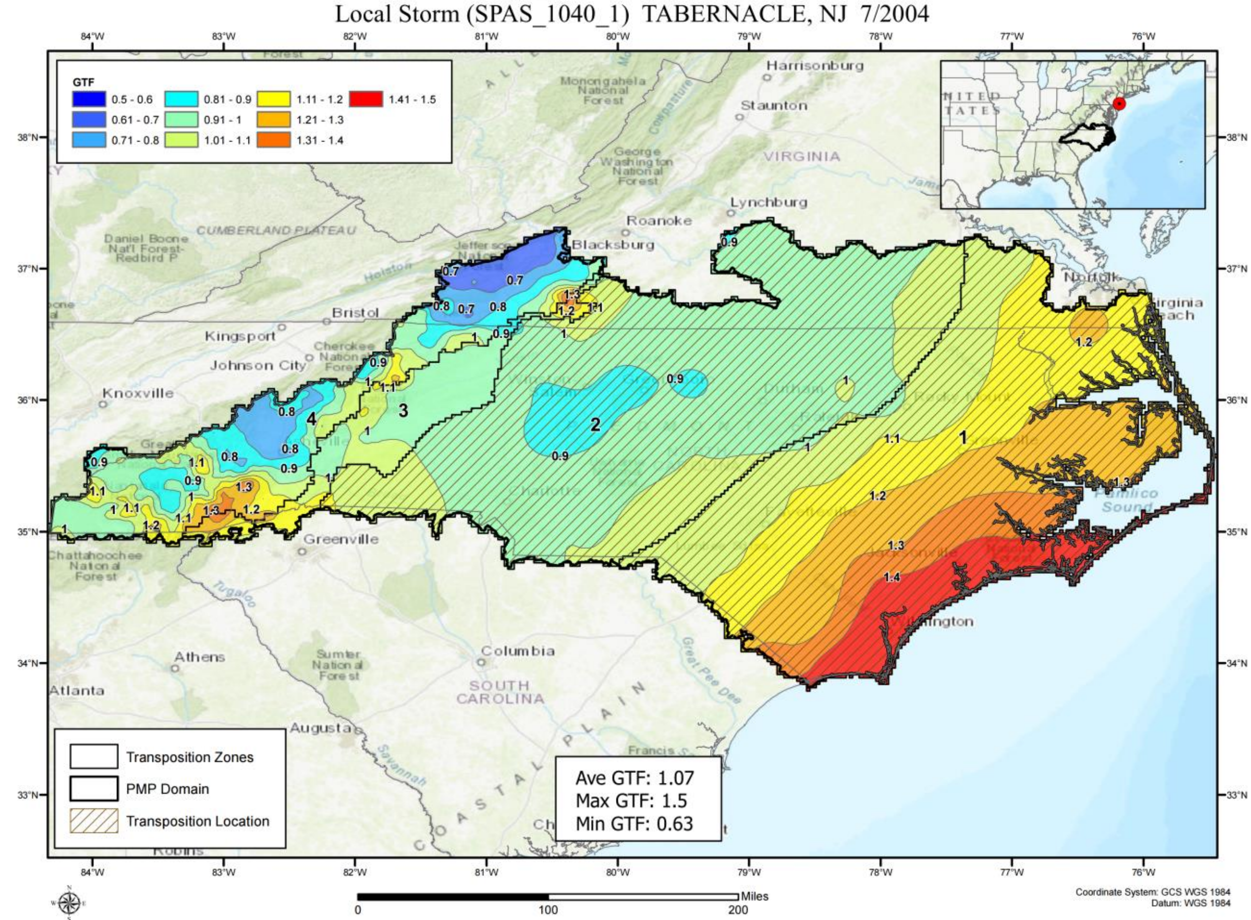
Geographic Transposition Factor
General Storm (SPAS_1680_1) WEST SHOKAN, NY 10/1955



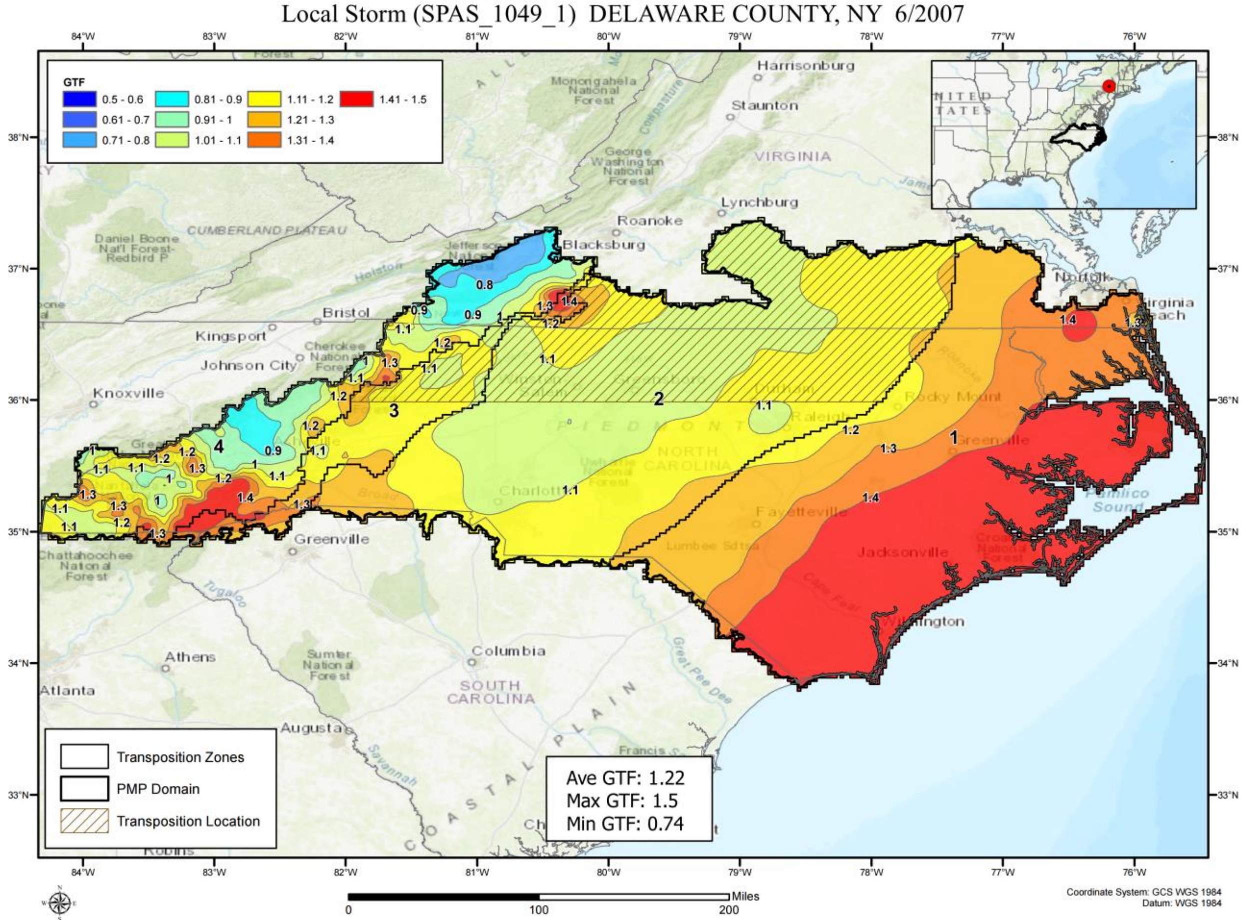
Geographic Transposition Factor
General Storm (SPAS_1804_1) HALIFAX, VT 10/2005



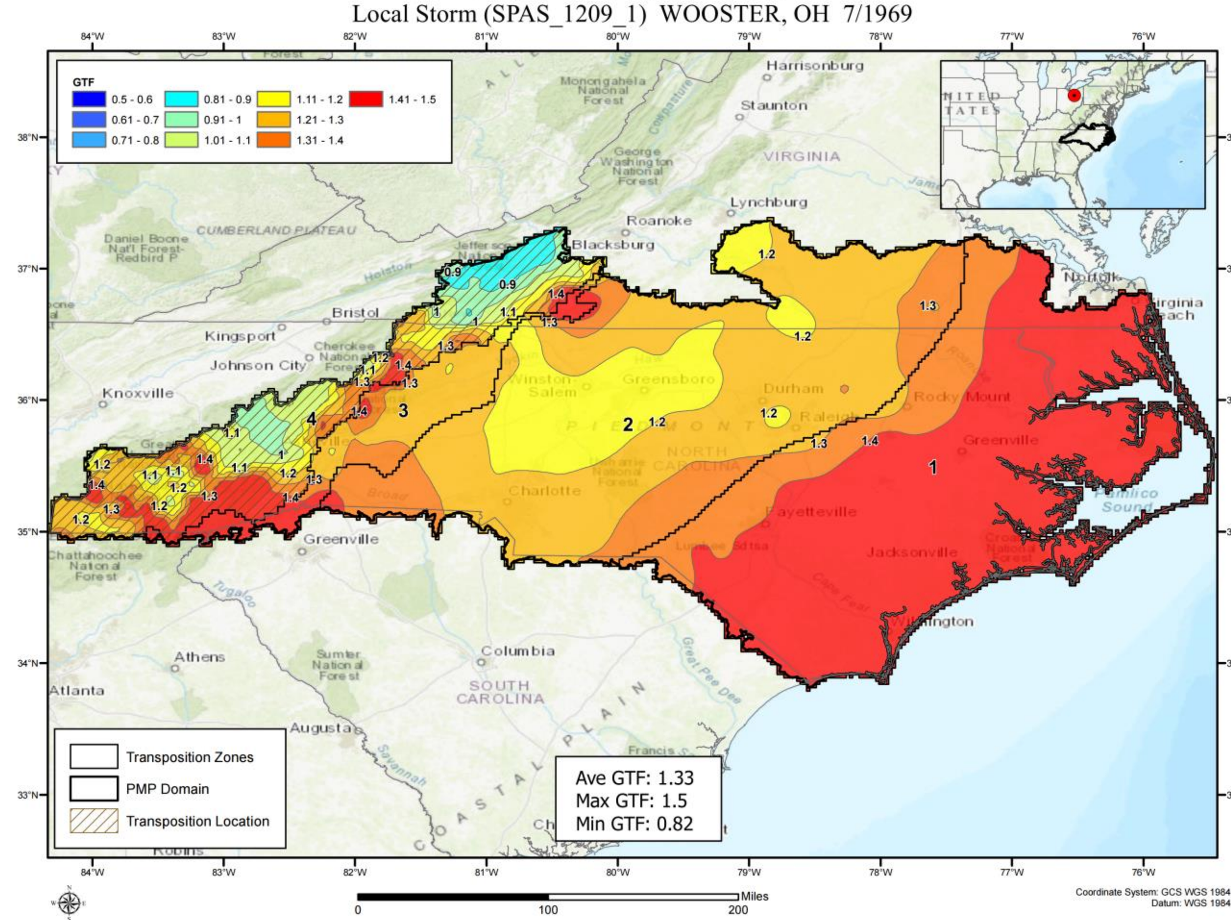
Geographic Transposition Factor
Local Storm (SPAS_1040_1) TABERNACLE, NJ 7/2004



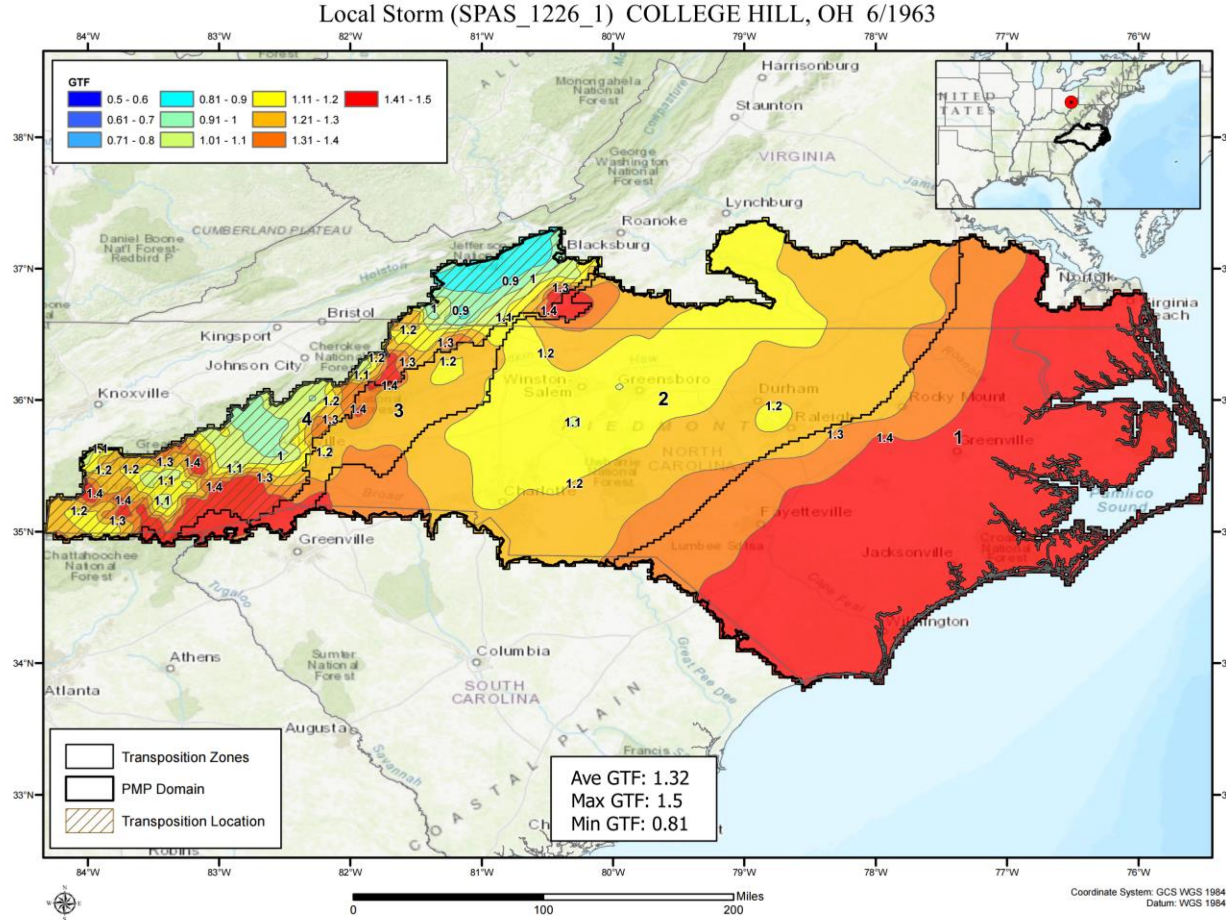
Geographic Transposition Factor
Local Storm (SPAS_1049_1) DELAWARE COUNTY, NY 6/2007



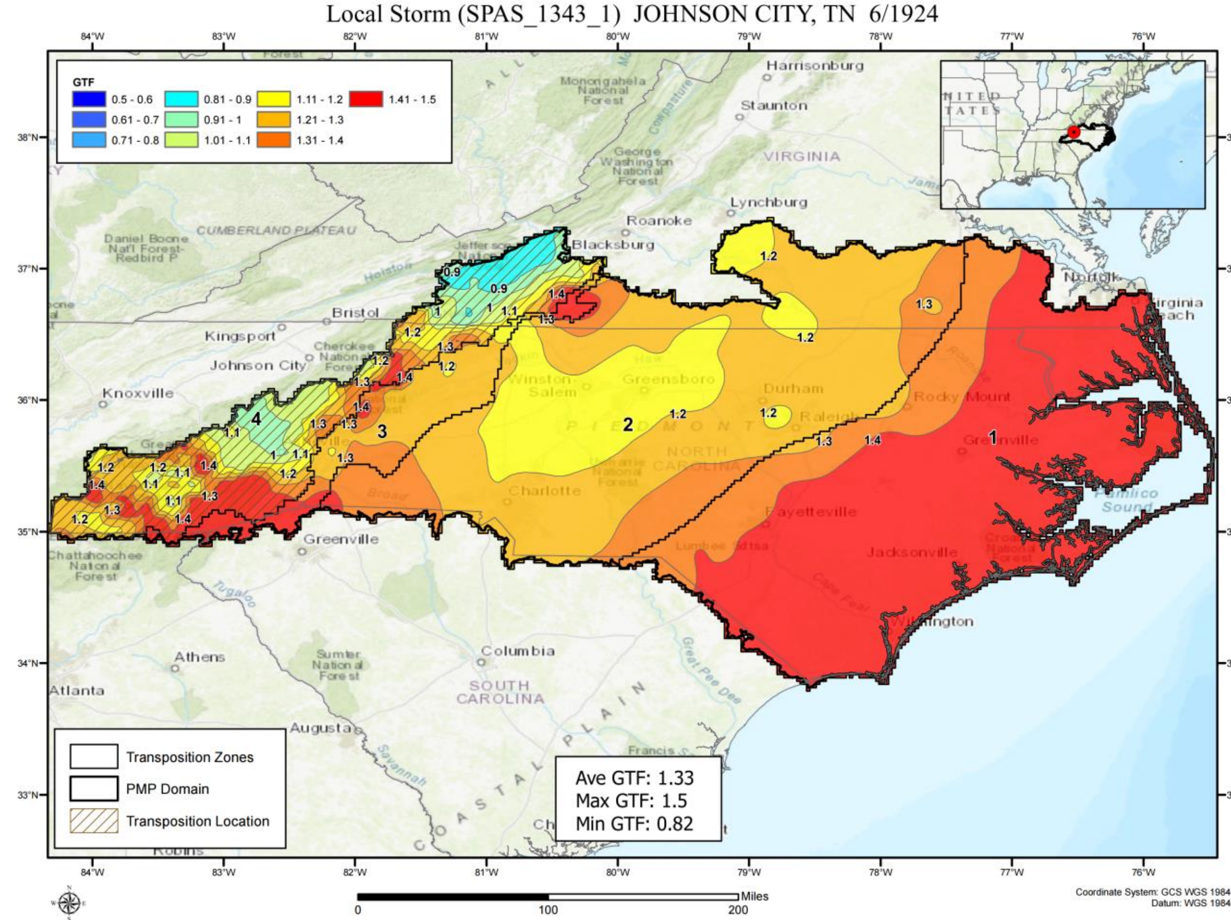
Geographic Transposition Factor
Local Storm (SPAS_1209_1) WOOSTER, OH 7/1969



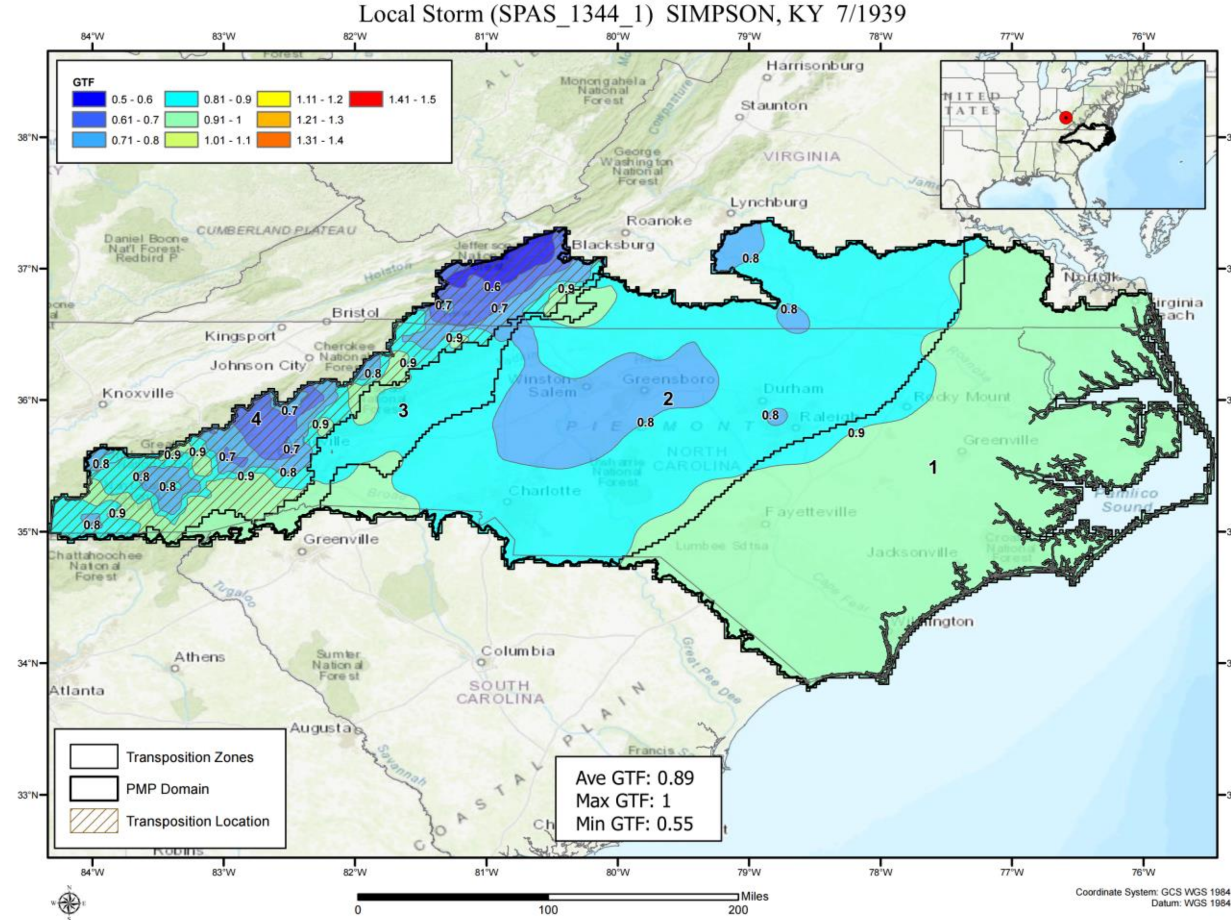
Geographic Transposition Factor
Local Storm (SPAS_1226_1) COLLEGE HILL, OH 6/1963



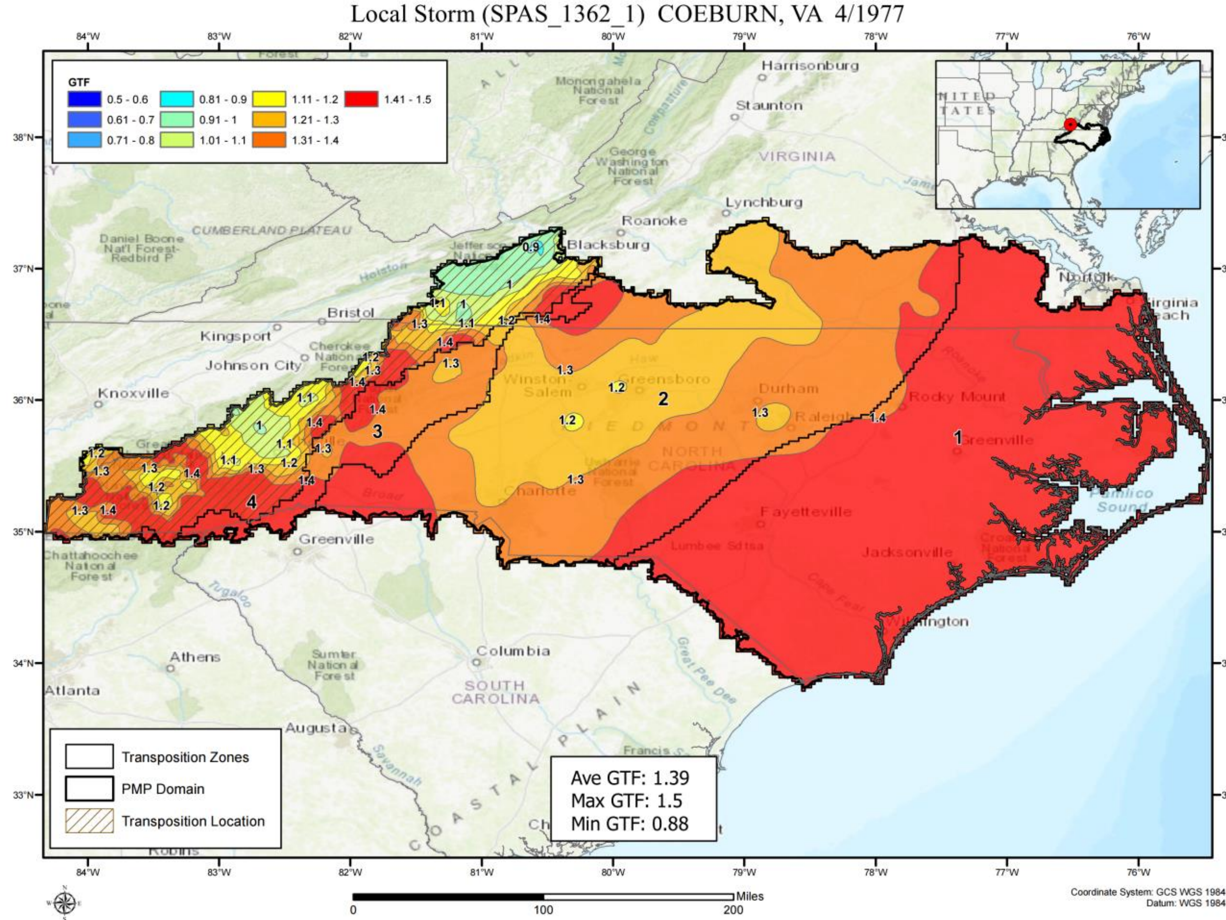
Geographic Transposition Factor
Local Storm (SPAS_1343_1) JOHNSON CITY, TN 6/1924



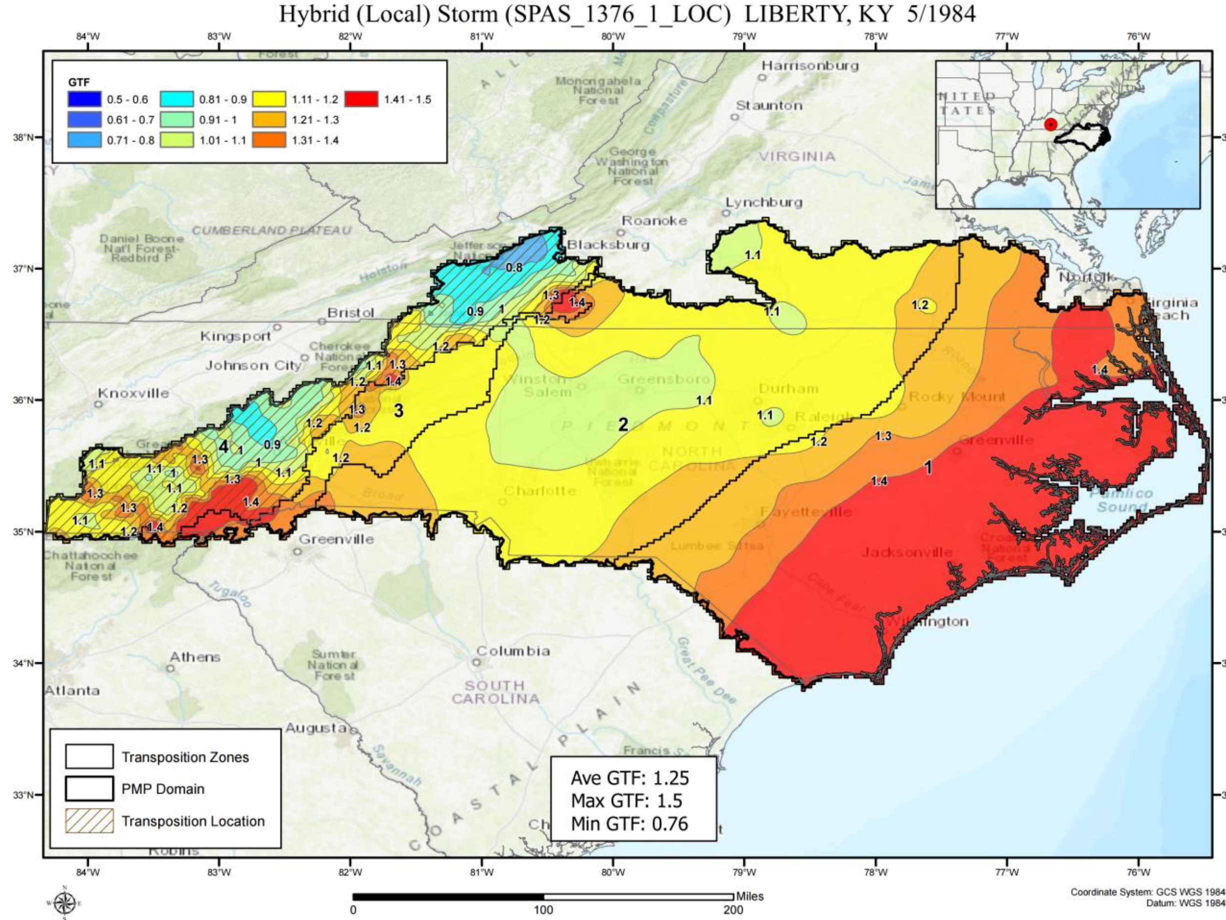
Geographic Transposition Factor
Local Storm (SPAS_1344_1) SIMPSON, KY 7/1939



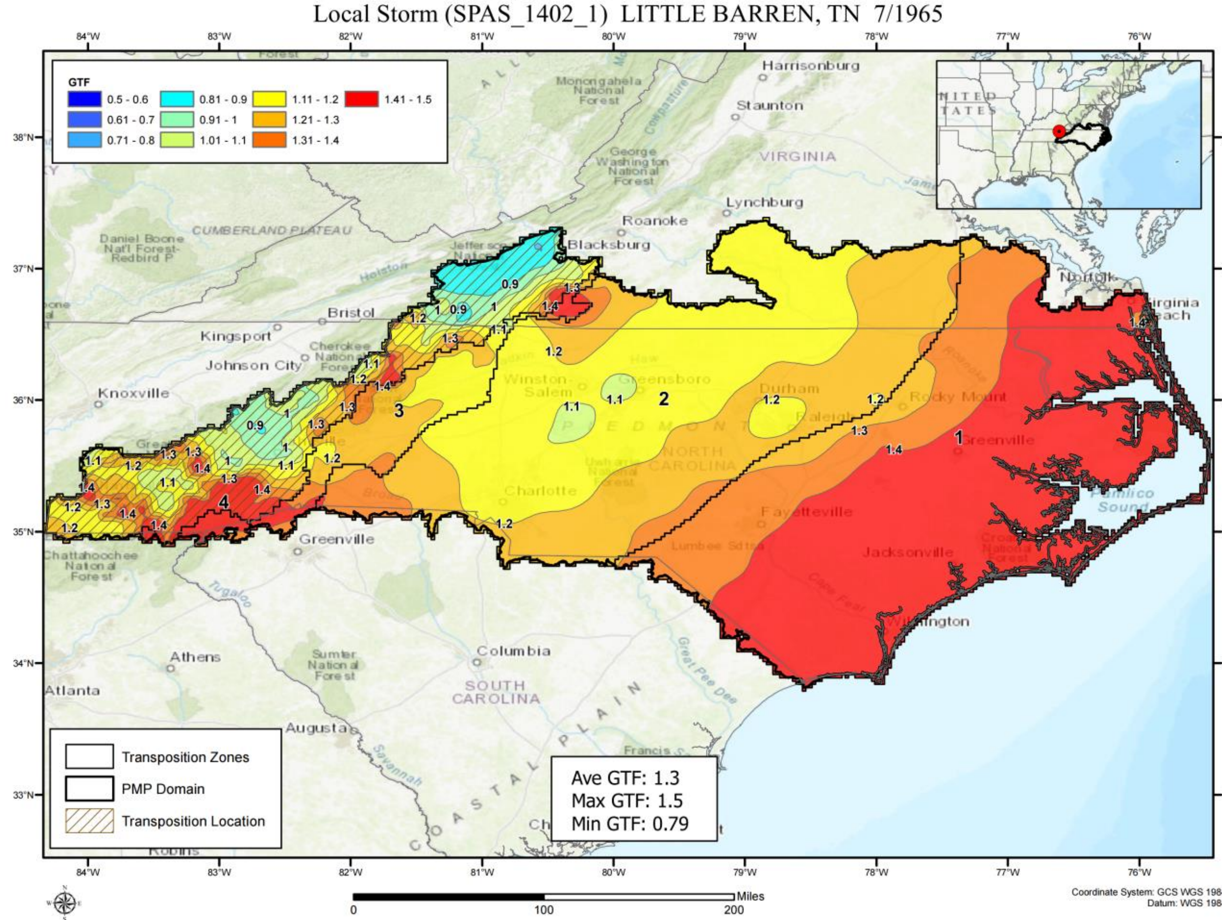
Geographic Transposition Factor
Local Storm (SPAS_1362_1) COEBURN, VA 4/1977



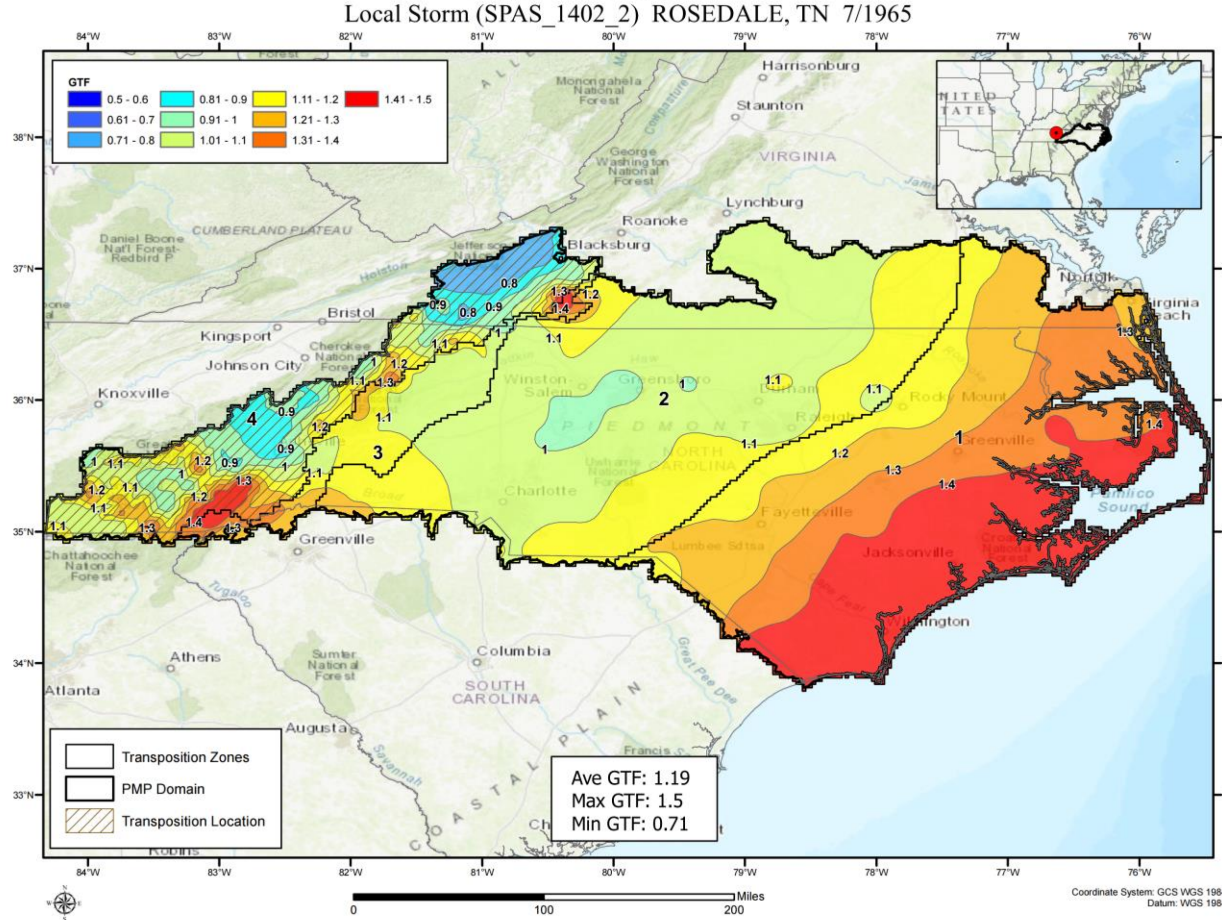
Geographic Transposition Factor
Hybrid (Local) Storm (SPAS_1376_1_LOC) LIBERTY, KY 5/1984



Geographic Transposition Factor
Local Storm (SPAS_1402_1) LITTLE BARREN, TN 7/1965



Geographic Transposition Factor
Local Storm (SPAS_1402_2) ROSEDALE, TN 7/1965



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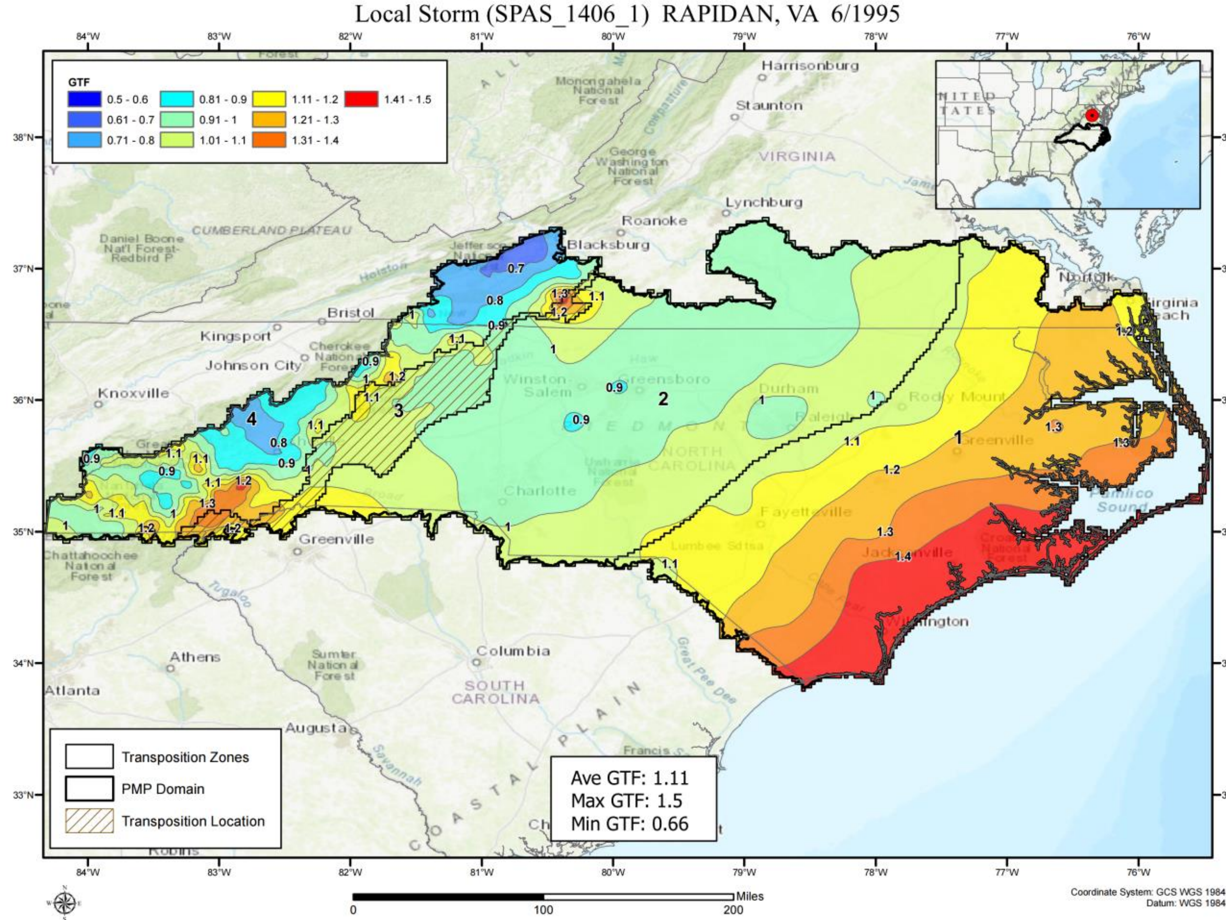
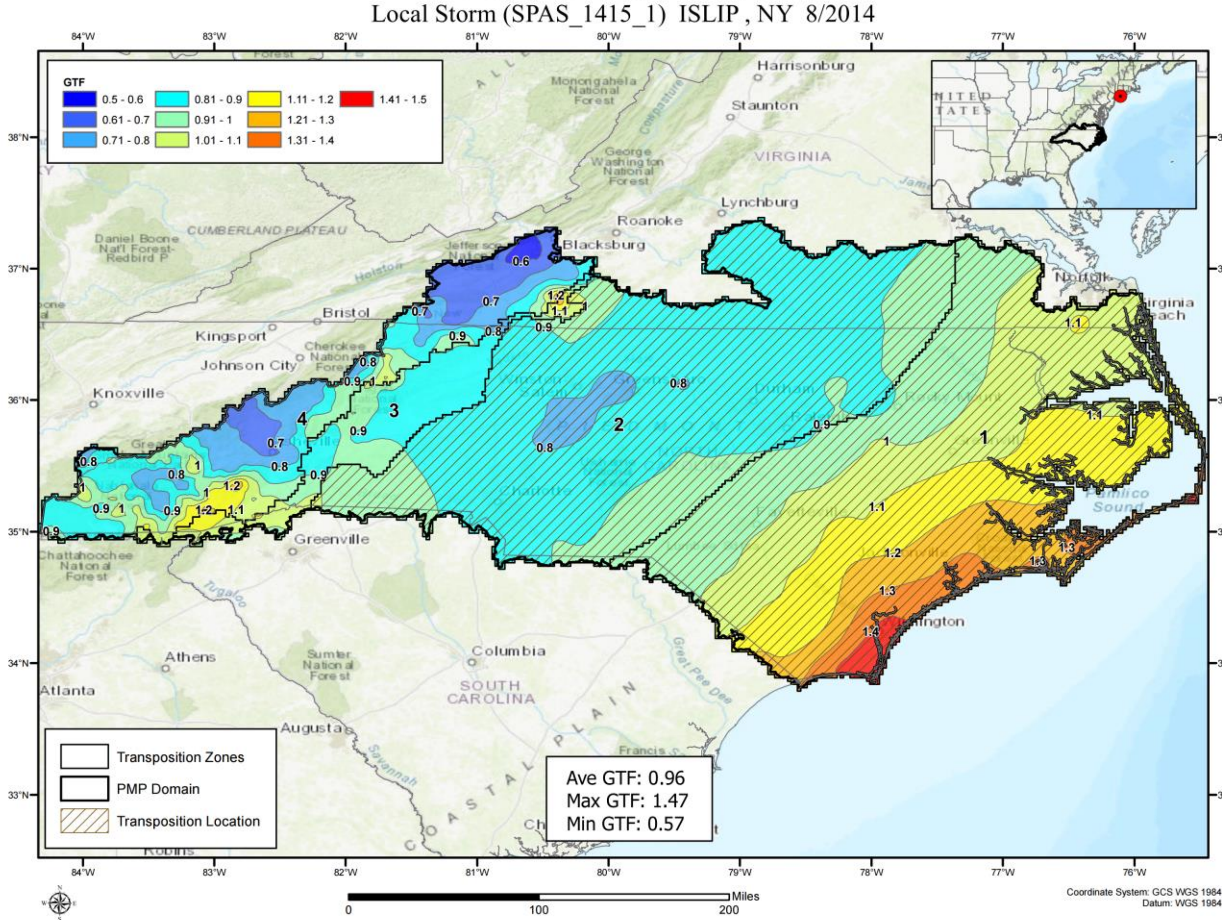
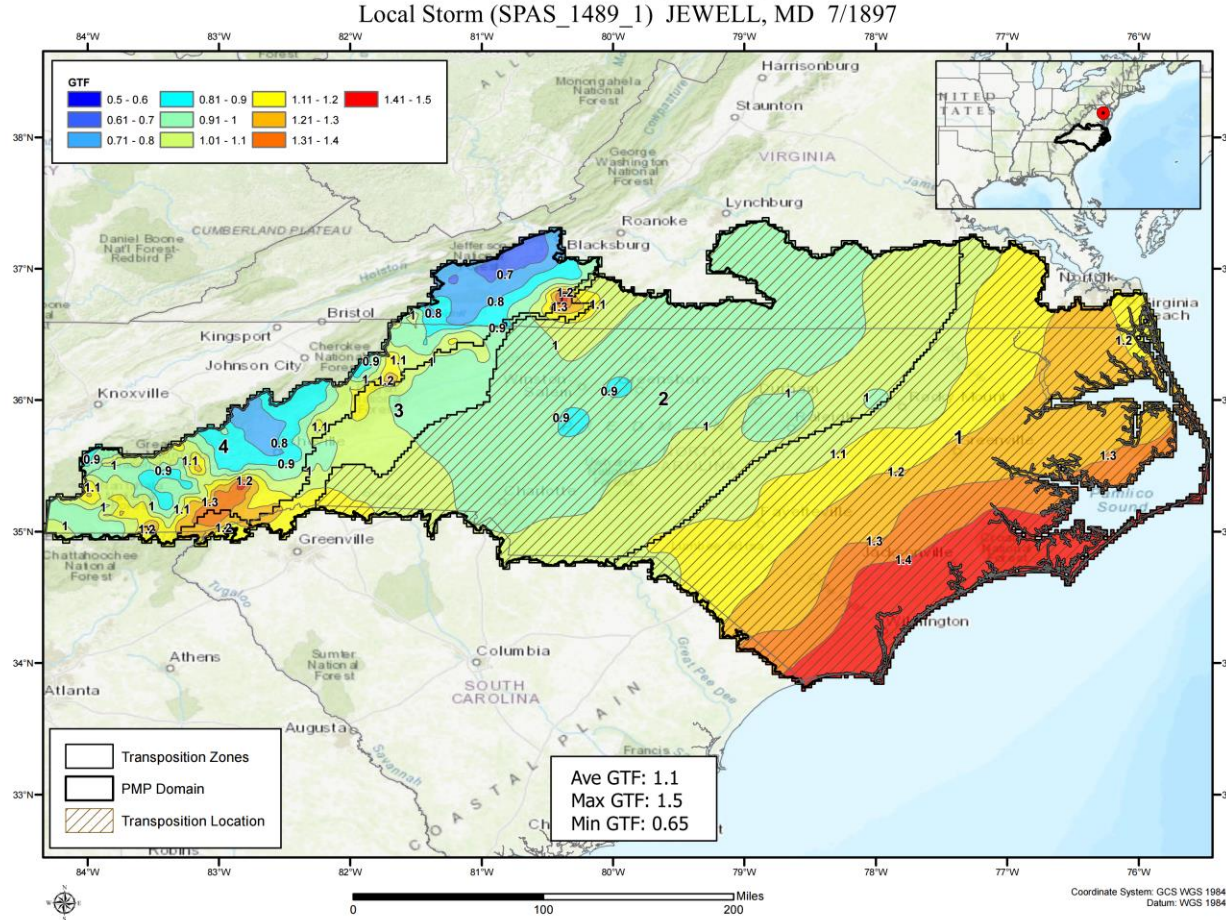
Local Storm (SPAS_1406_1) RAPIDAN, VA 6/1995



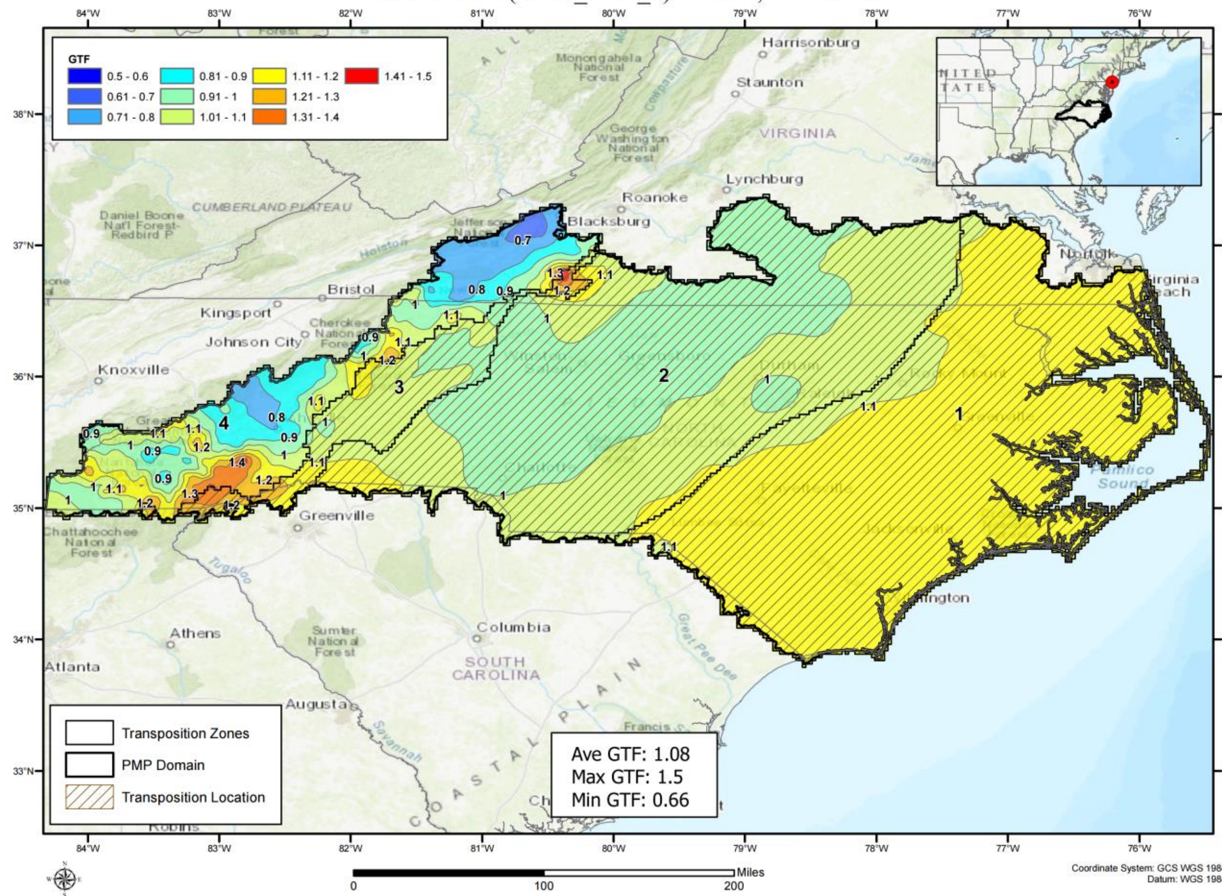
Geographic Transposition Factor
Local Storm (SPAS_1415_1) ISLIP , NY 8/2014



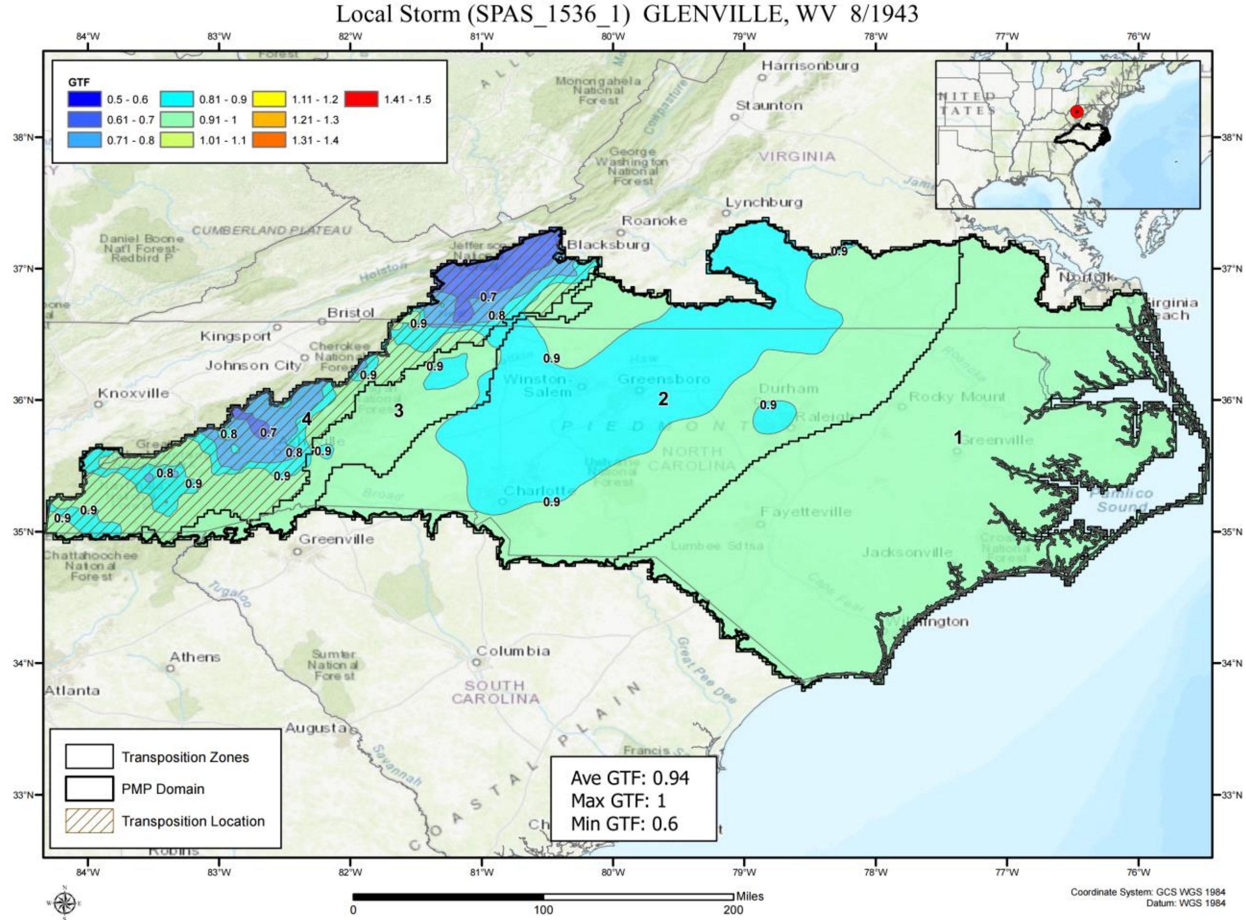
Geographic Transposition Factor
Local Storm (SPAS_1489_1) JEWELL, MD 7/1897



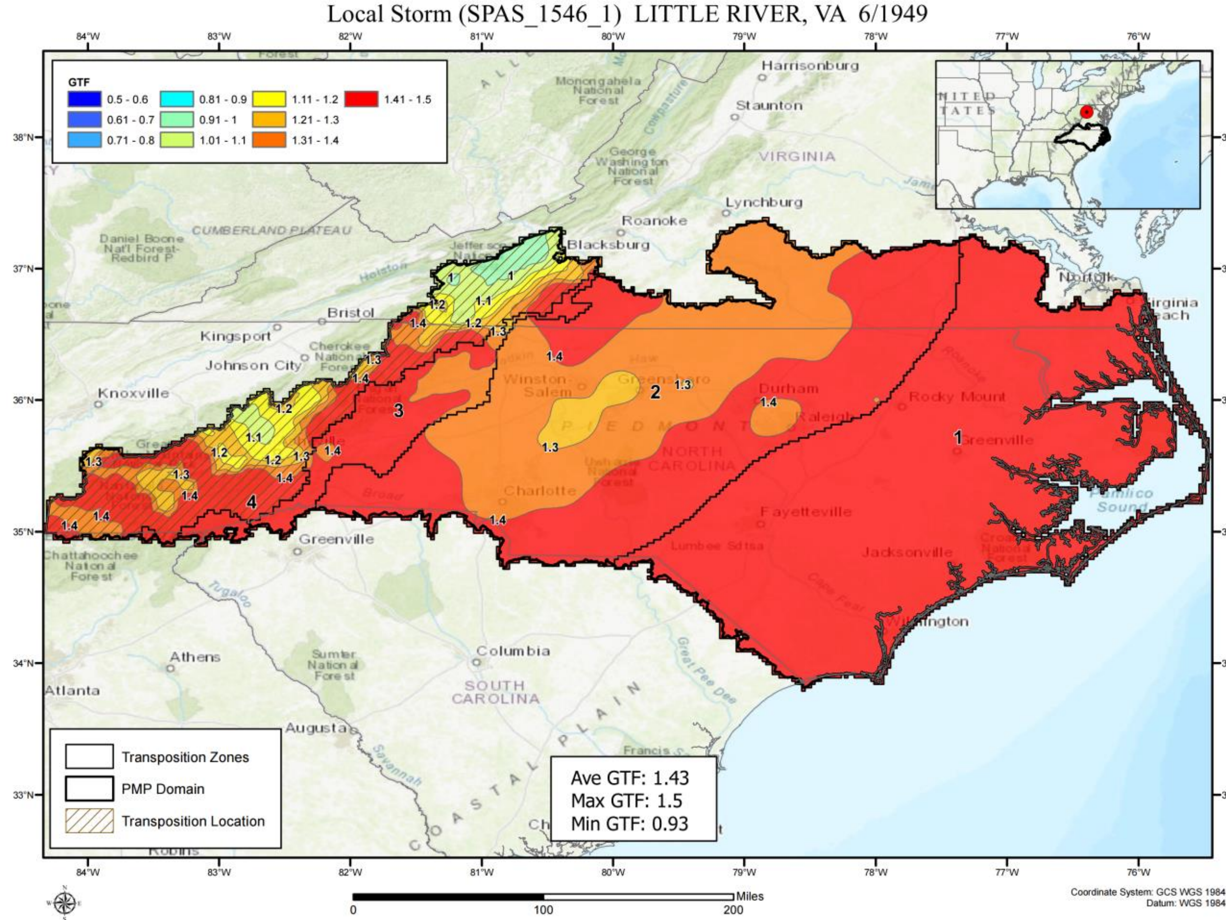
Geographic Transposition Factor
Local Storm (SPAS_1534_1) EWAN, NJ 9/1940



Geographic Transposition Factor
Local Storm (SPAS_1536_1) GLENVILLE, WV 8/1943



Geographic Transposition Factor
Local Storm (SPAS_1546_1) LITTLE RIVER, VA 6/1949



Geographic Transposition Factor
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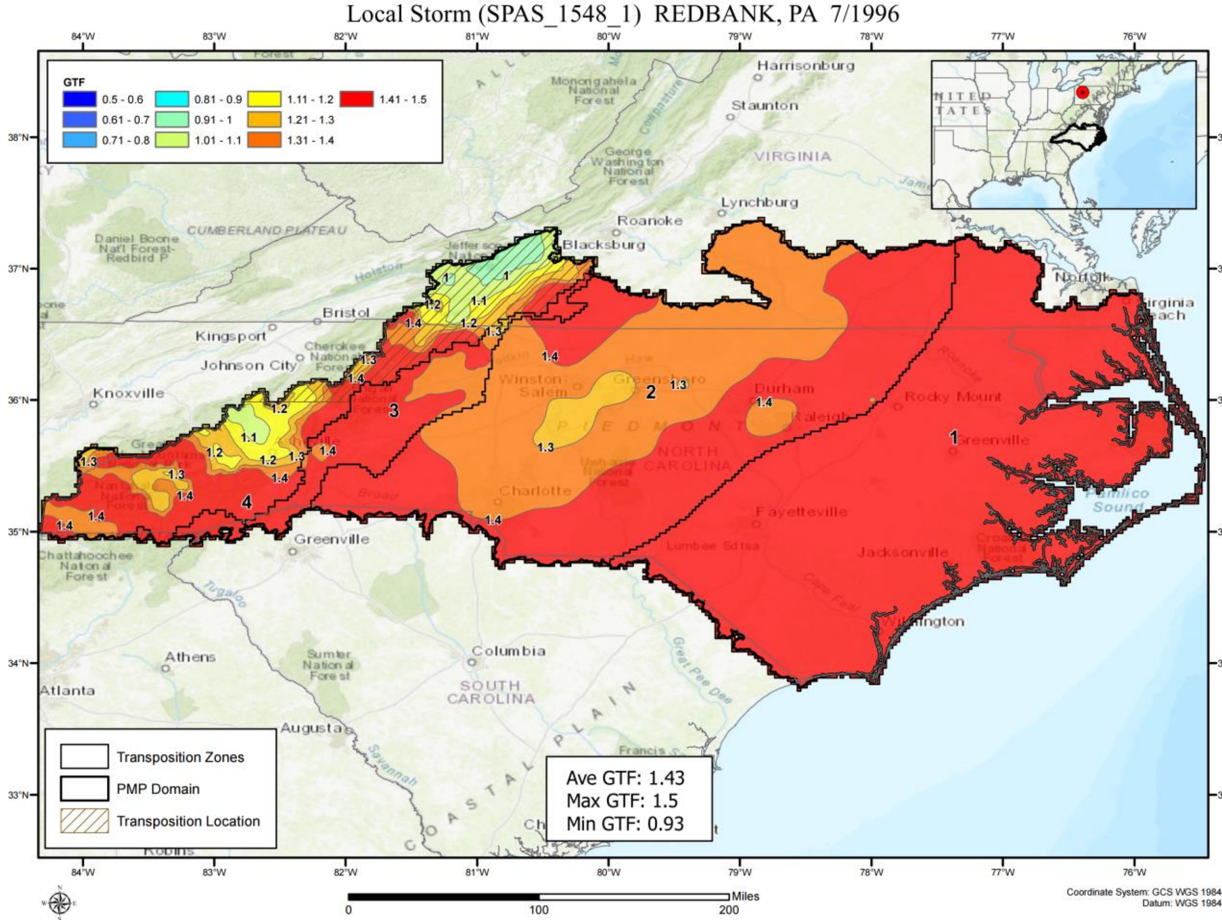
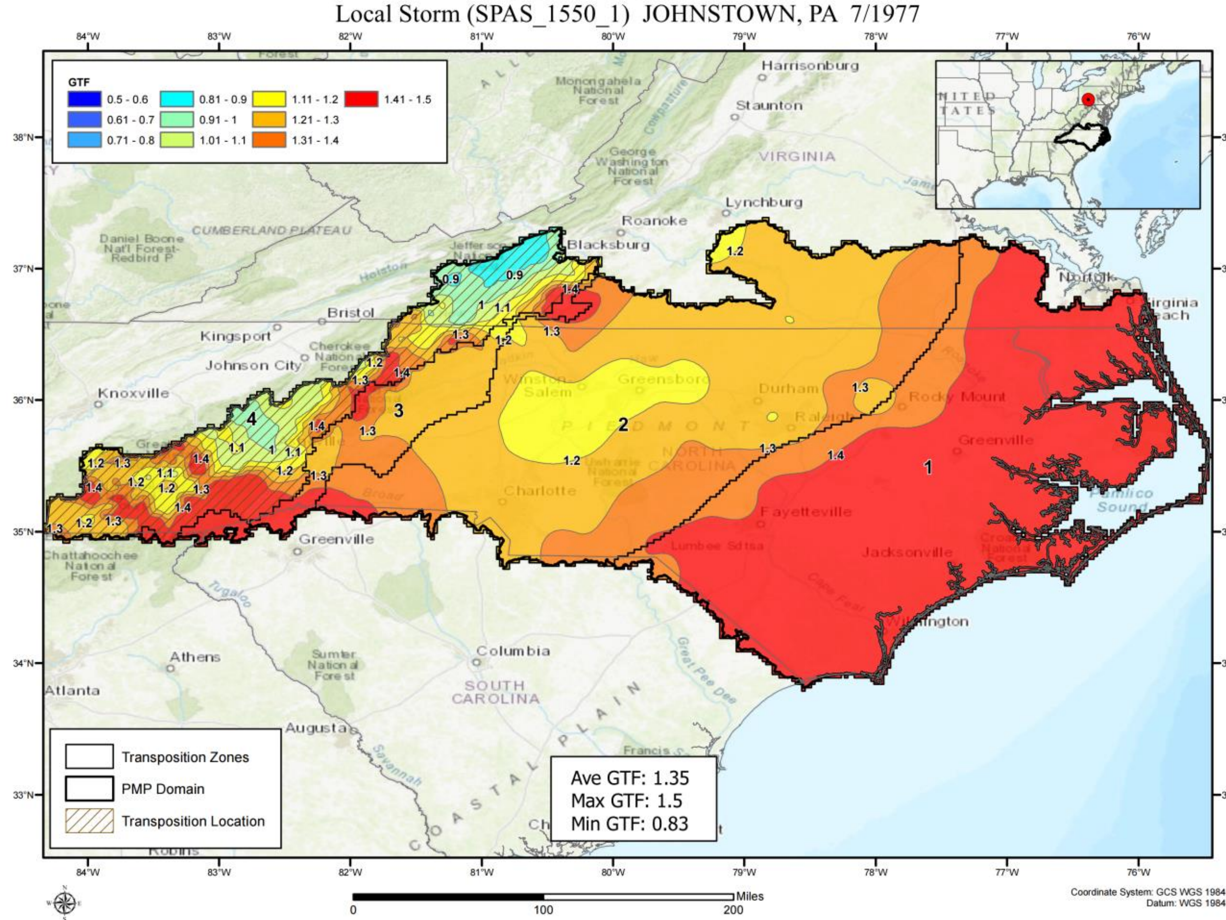
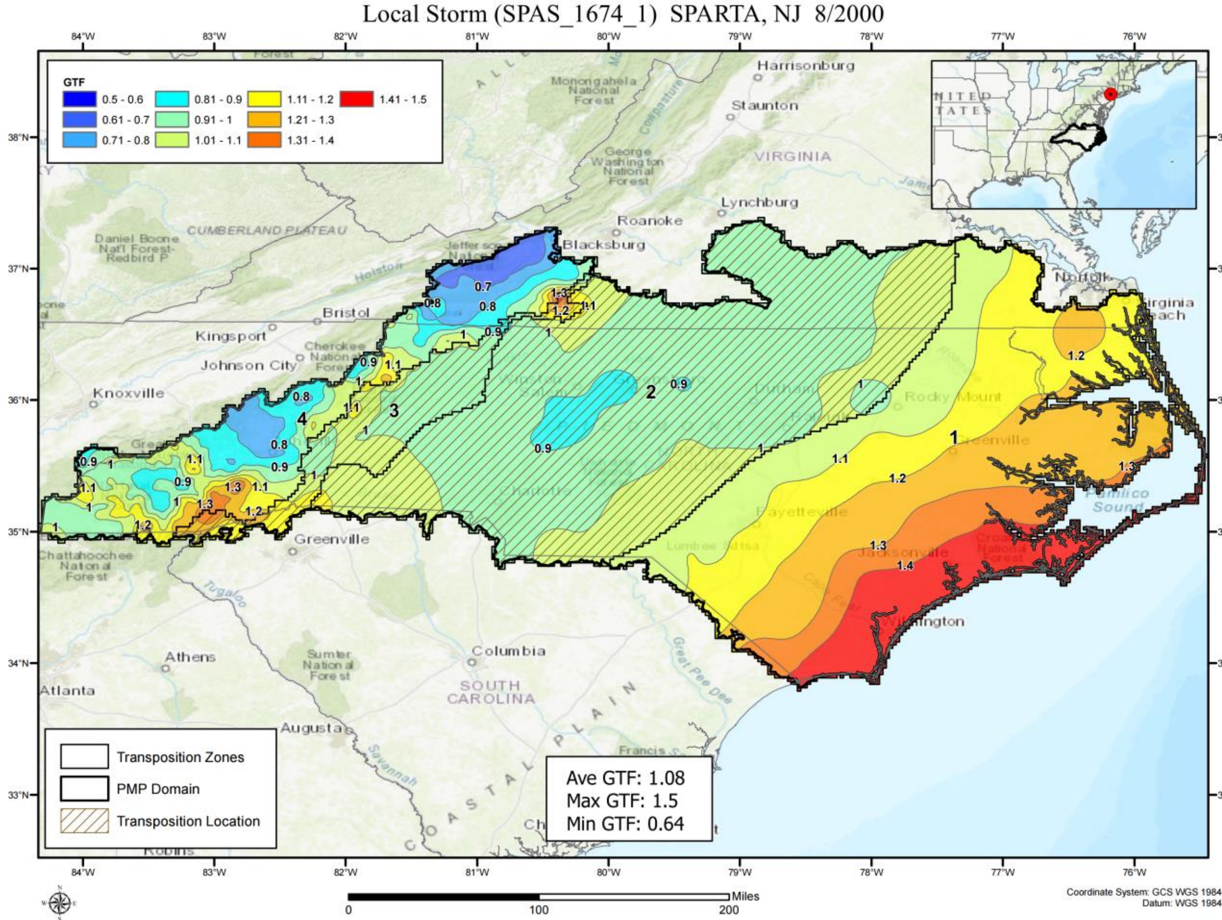


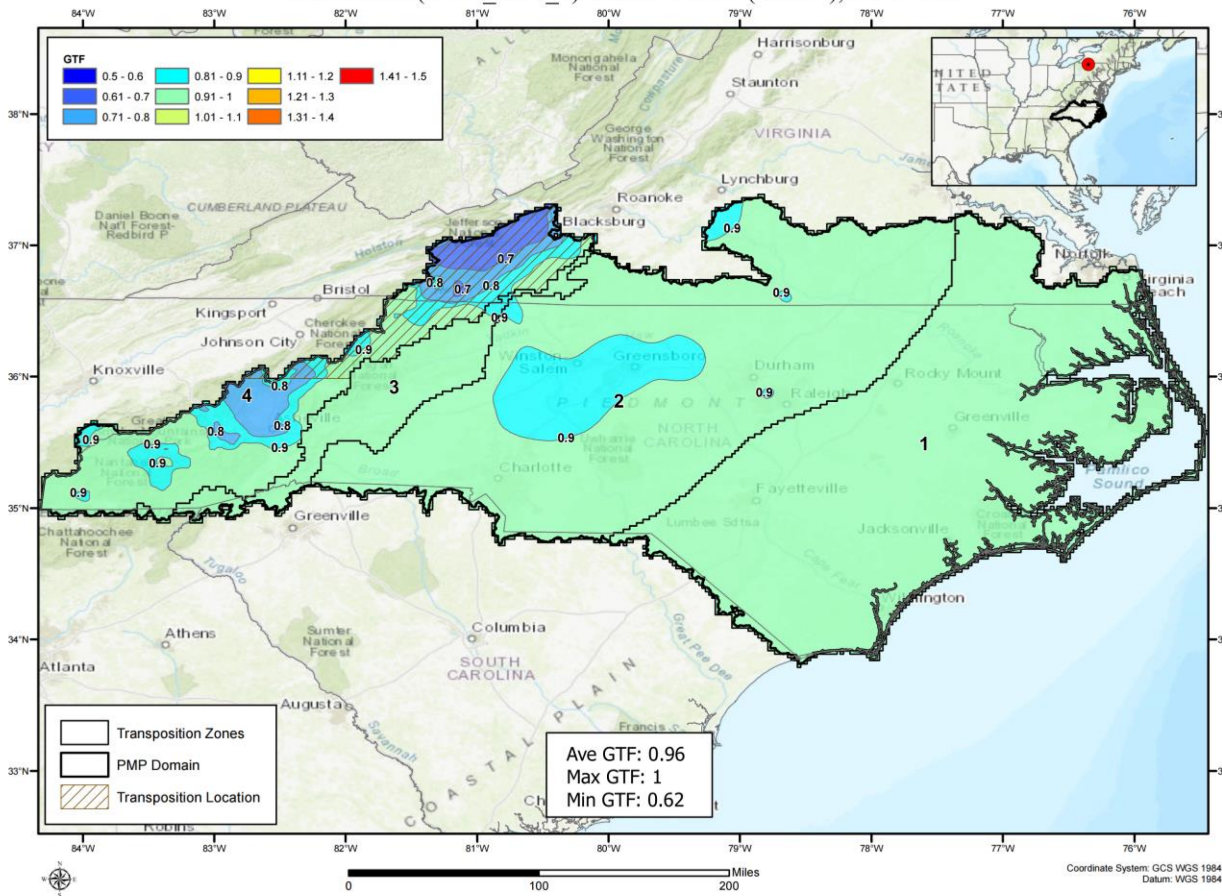
Geographic Transposition Factor
Local Storm (SPAS_1550_1) JOHNSTOWN, PA 7/1977



Geographic Transposition Factor
Local Storm (SPAS_1674_1) SPARTA, NJ 8/2000



Geographic Transposition Factor
Local Storm (SPAS_1681_1) SMETHPORT (DAD 1), PA 7/1942



Geographic Transposition Factor
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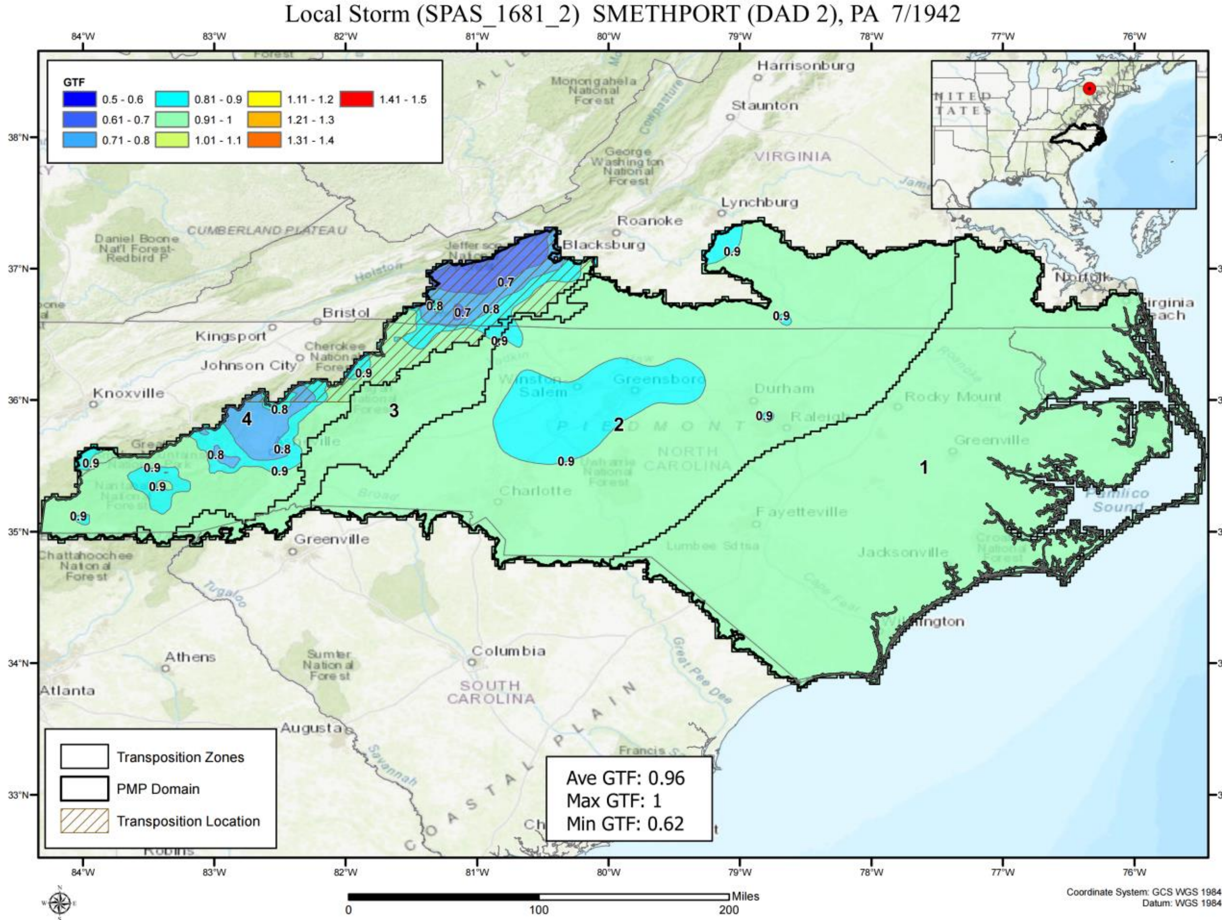

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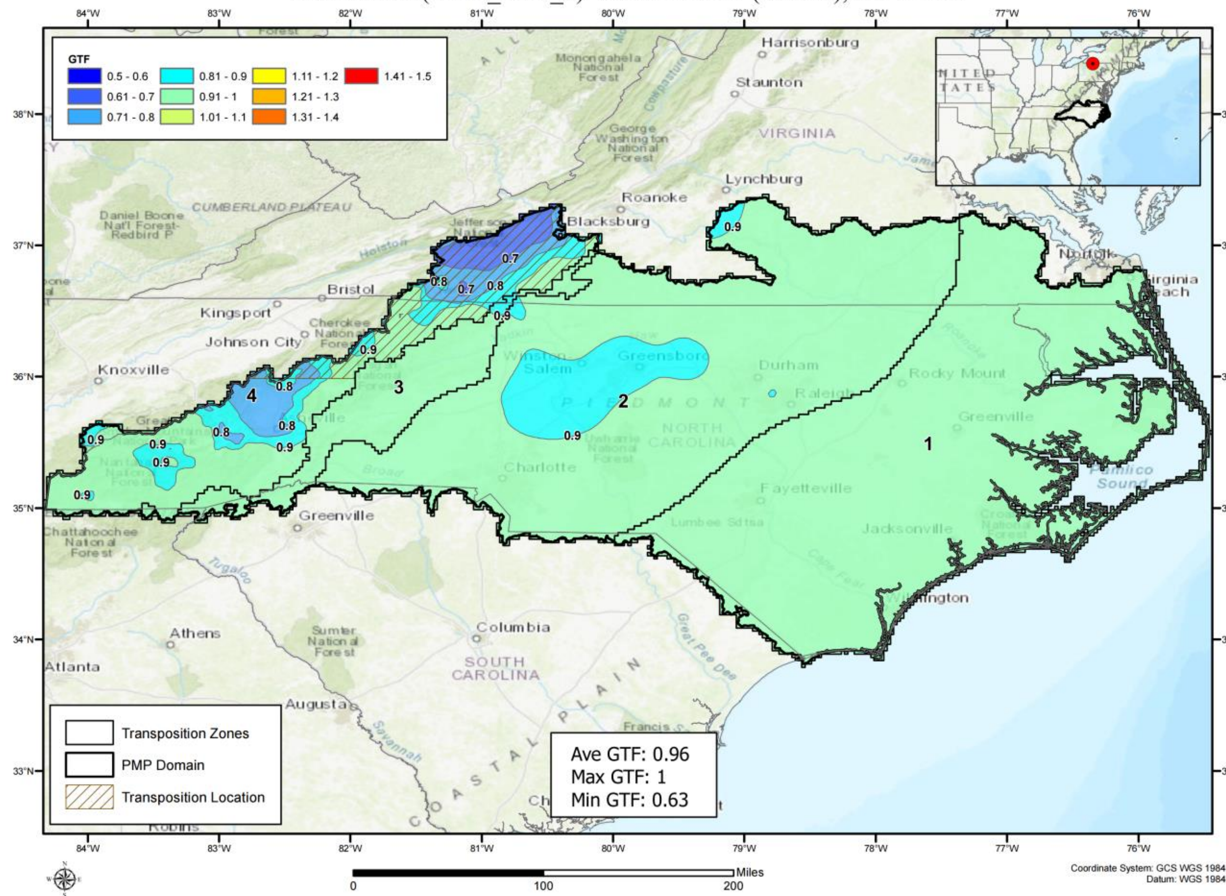

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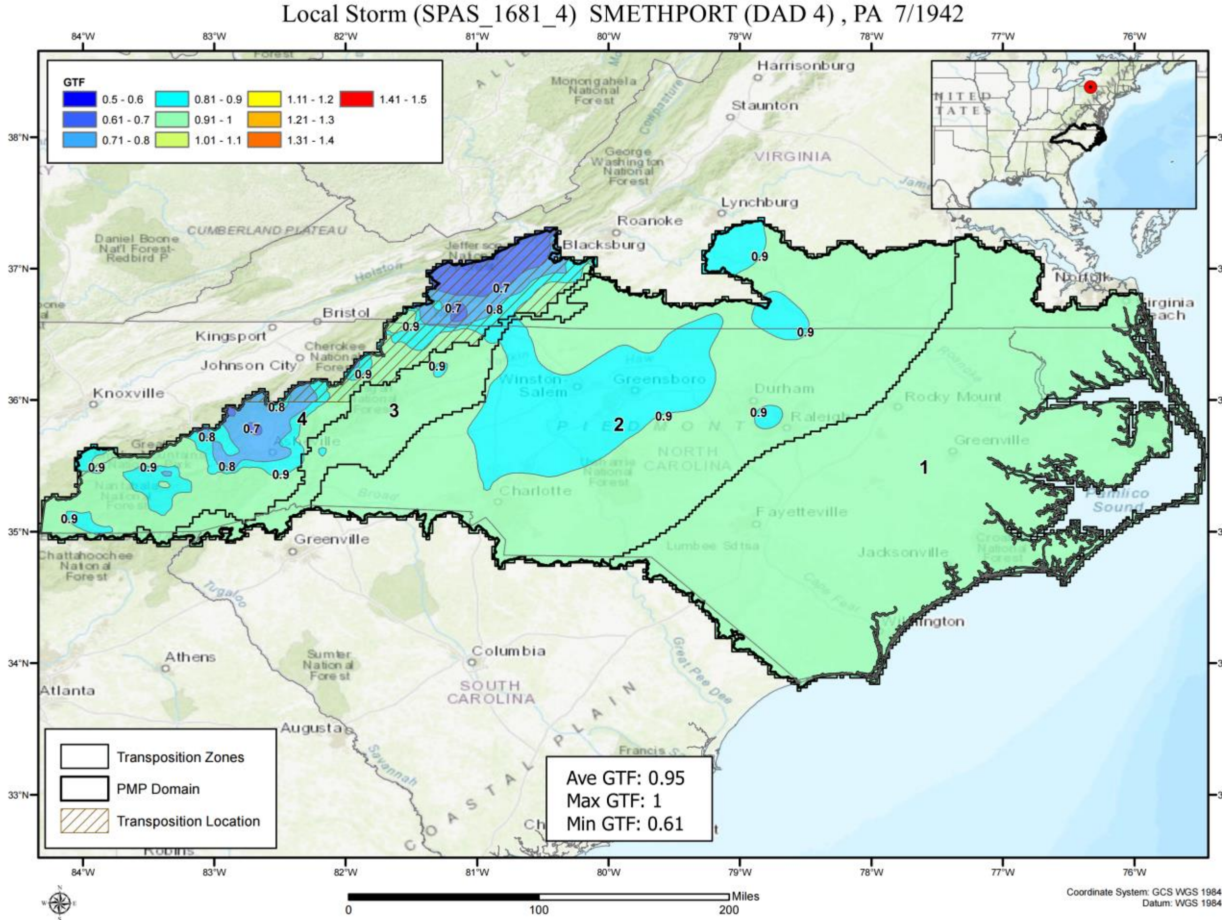
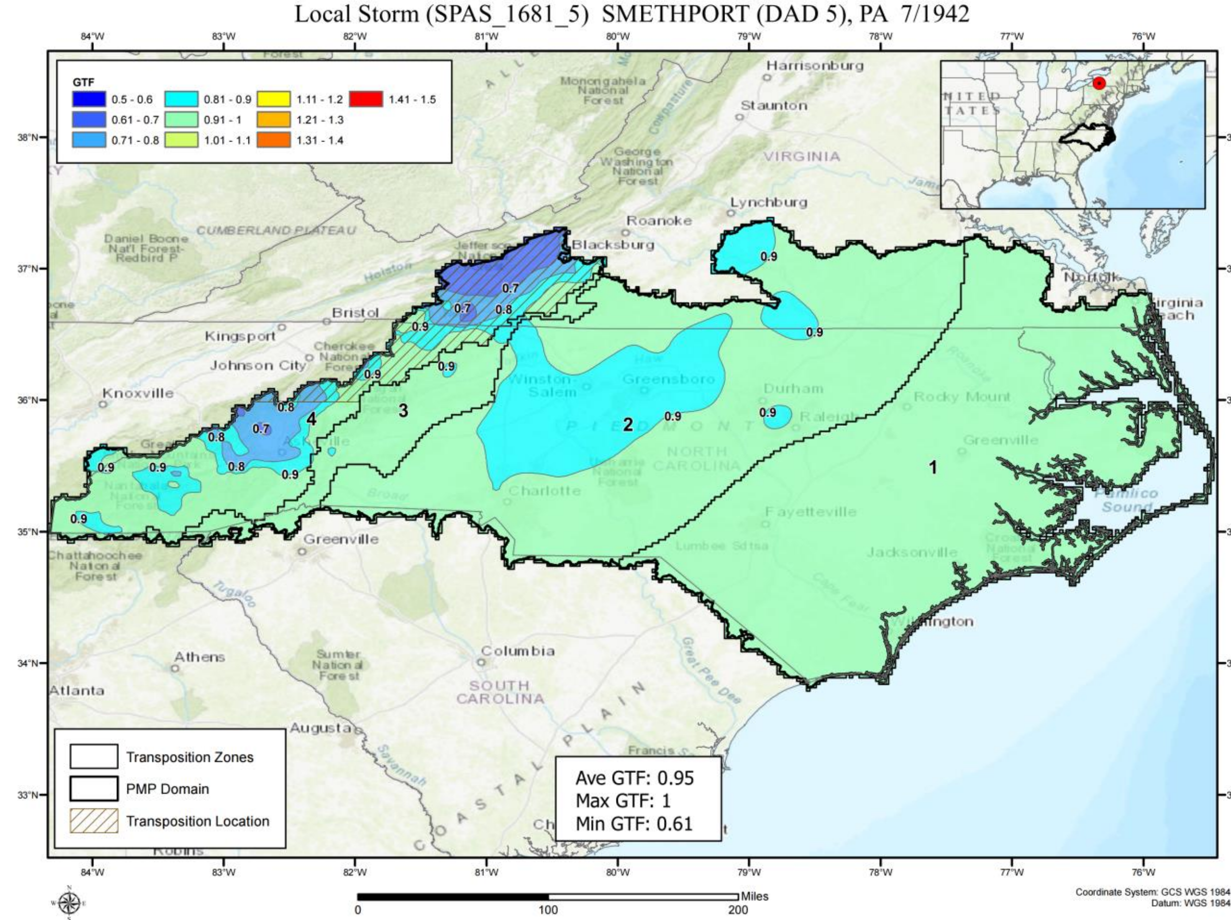
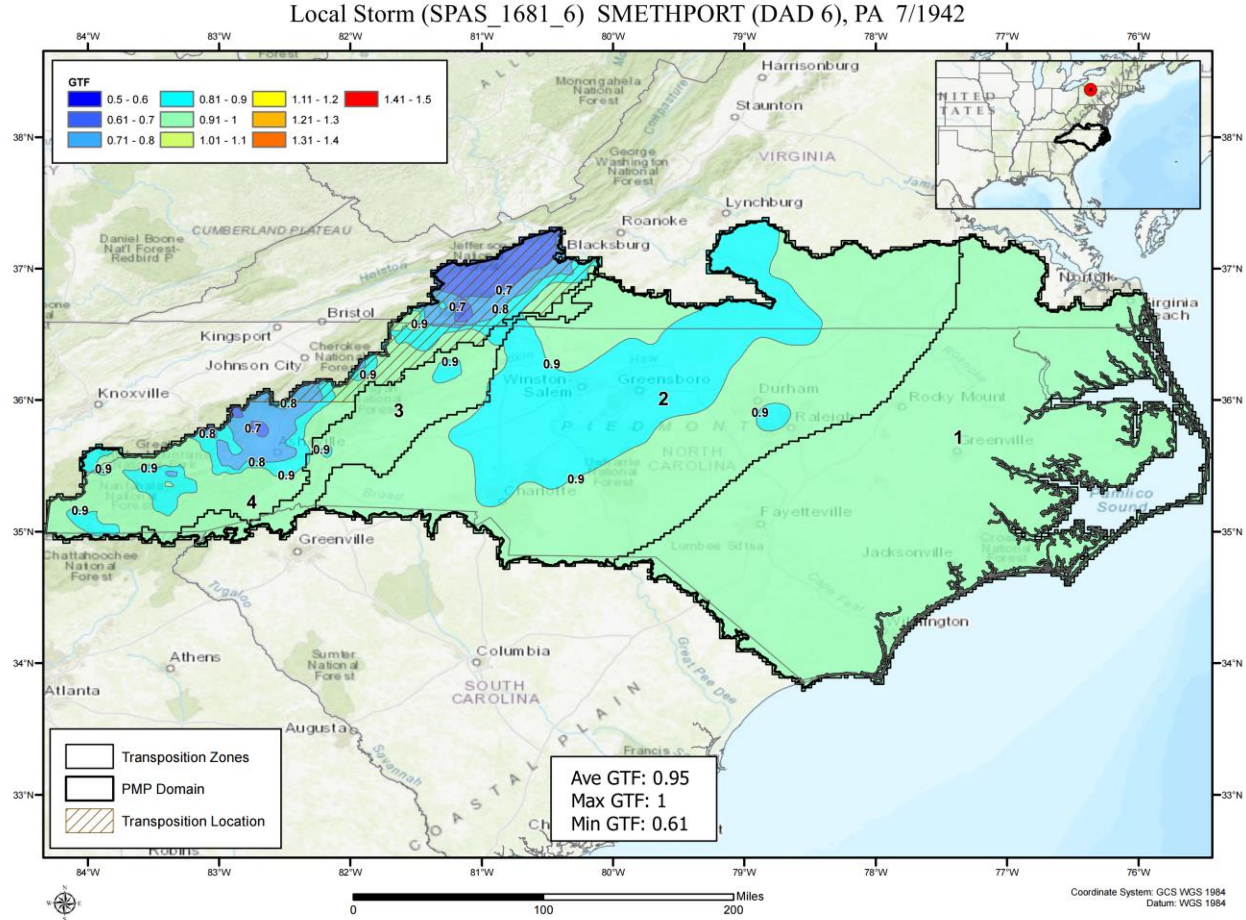


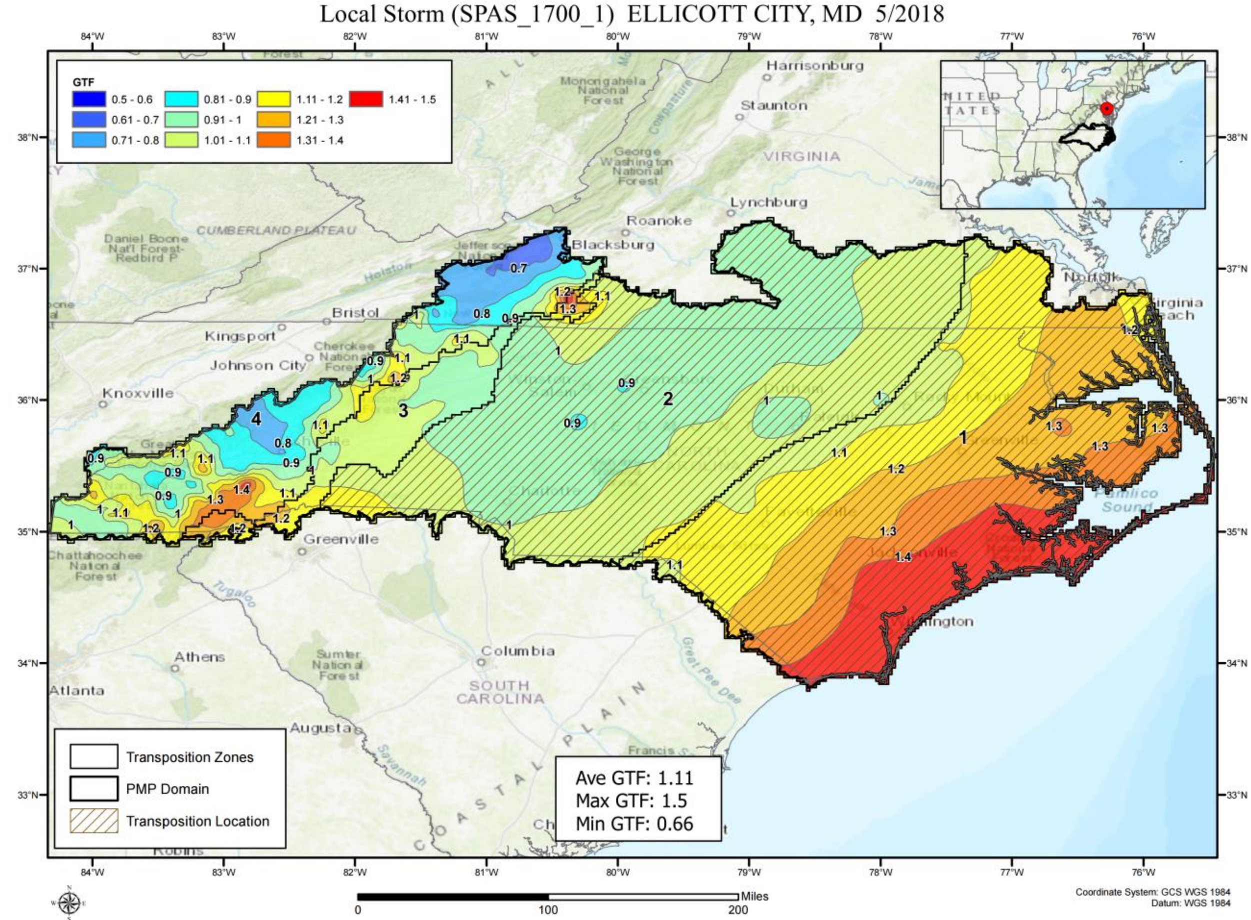
Geographic Transposition Factor
Local Storm (SPAS_1681_5) SMETHPORT (DAD 5), PA 7/1942



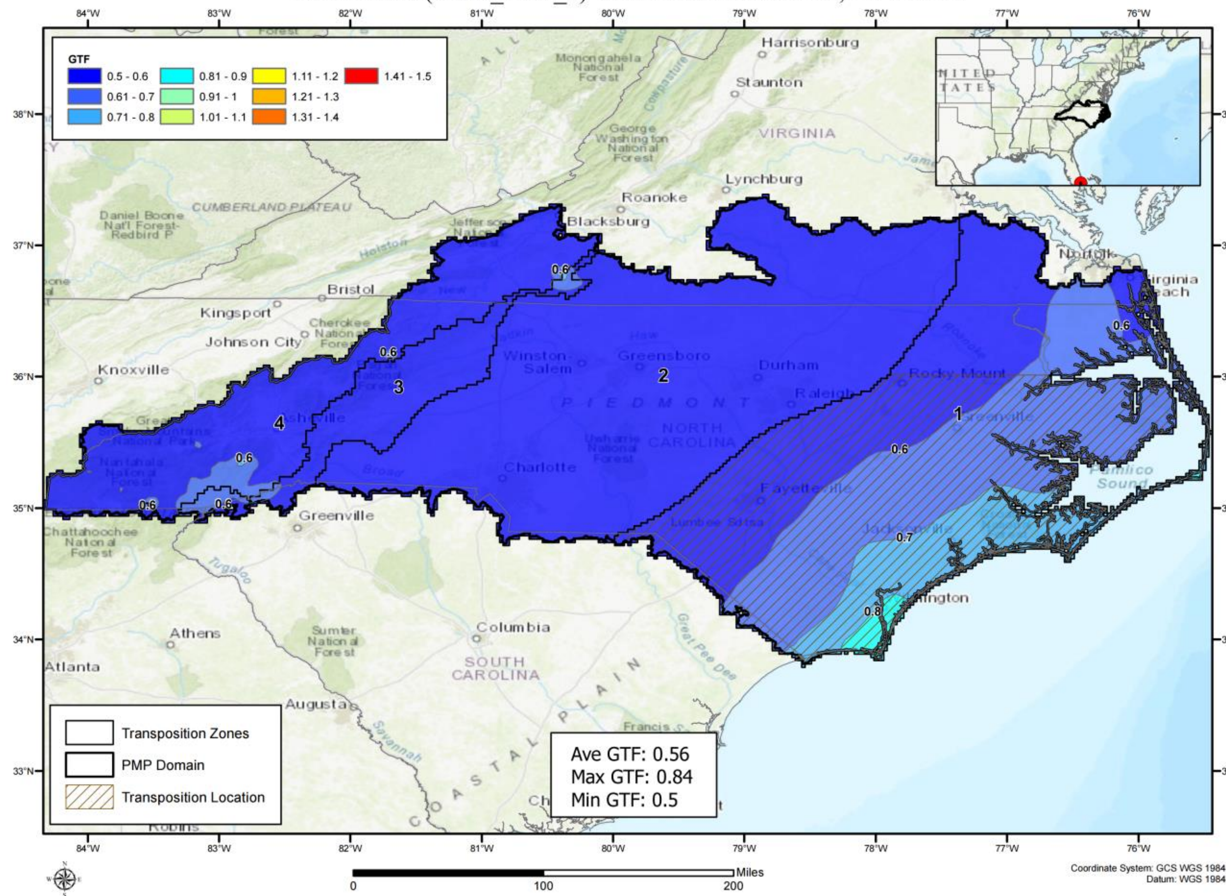
Geographic Transposition Factor
Local Storm (SPAS_1681_6) SMETHPORT (DAD 6), PA 7/1942



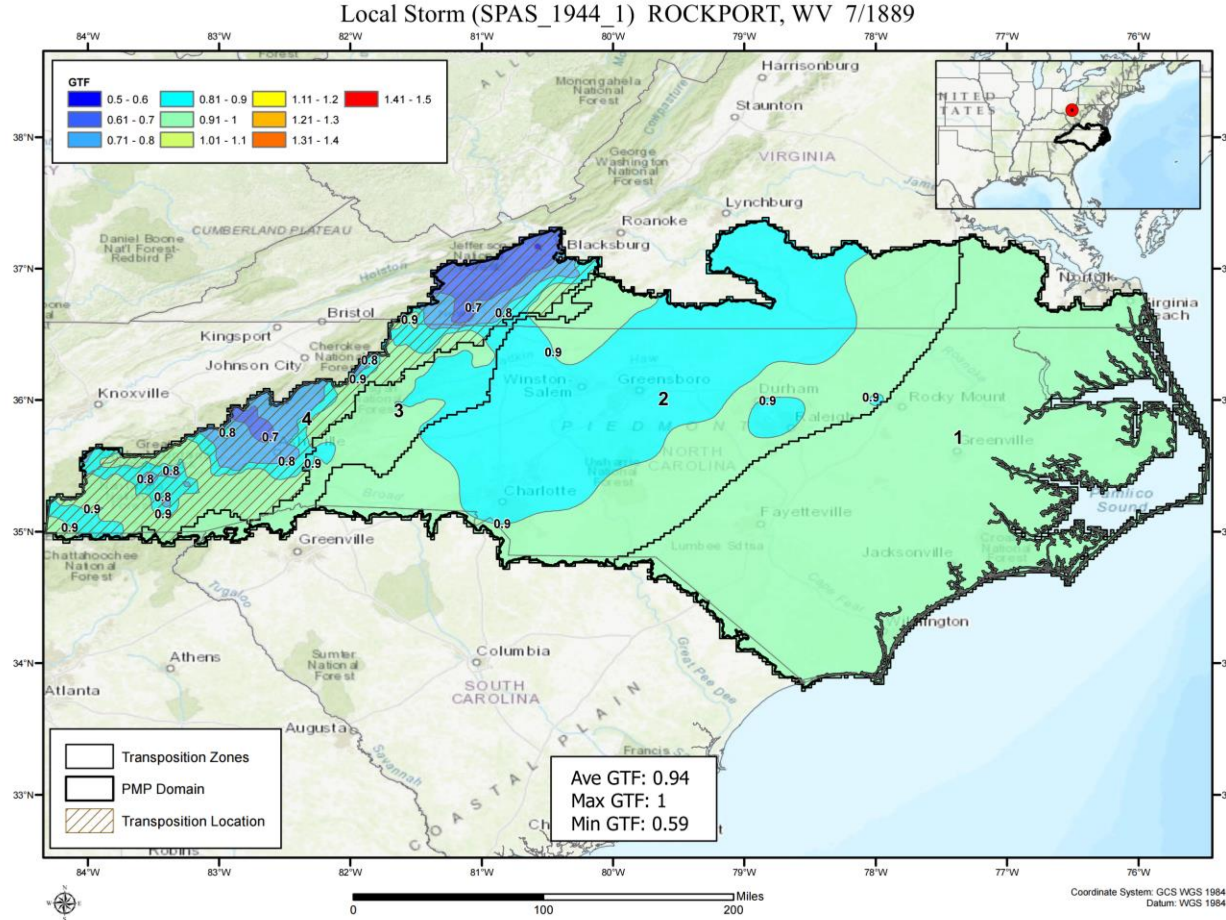
Geographic Transposition Factor
Local Storm (SPAS_1700_1) ELLICOTT CITY, MD 5/2018



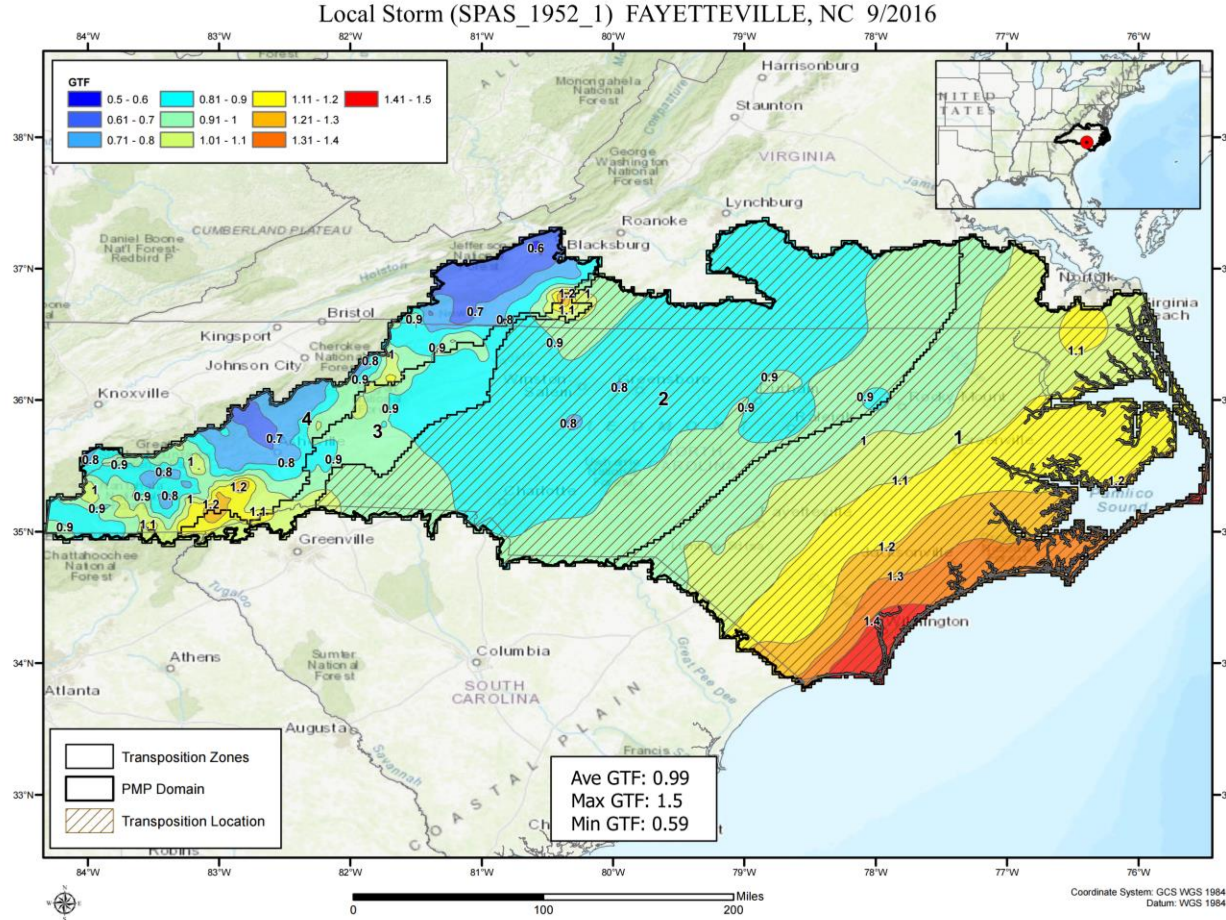
Geographic Transposition Factor
Local Storm (SPAS_1927_1) FORT LAUDERDALE, FL 4/2023



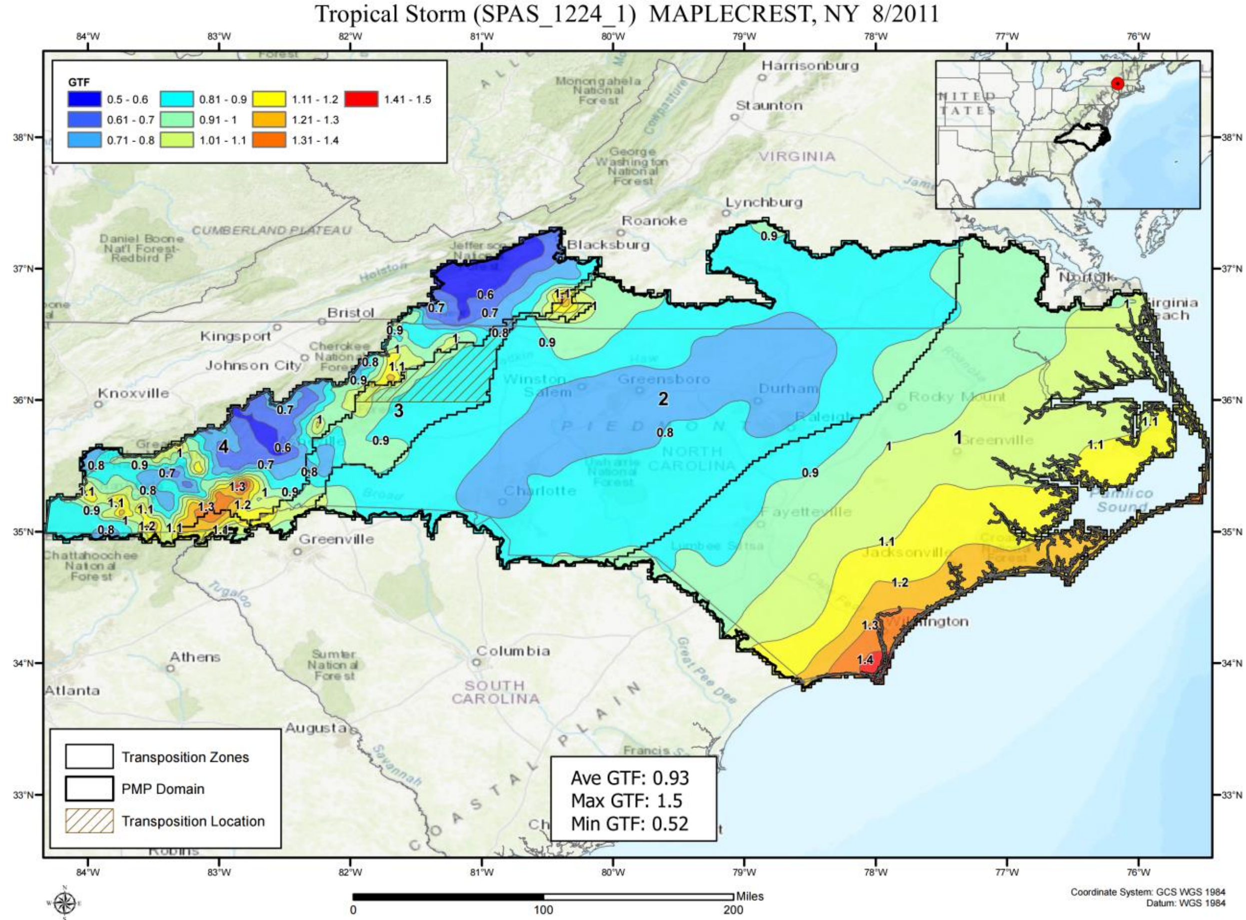
Geographic Transposition Factor
Local Storm (SPAS_1944_1) ROCKPORT, WV 7/1889



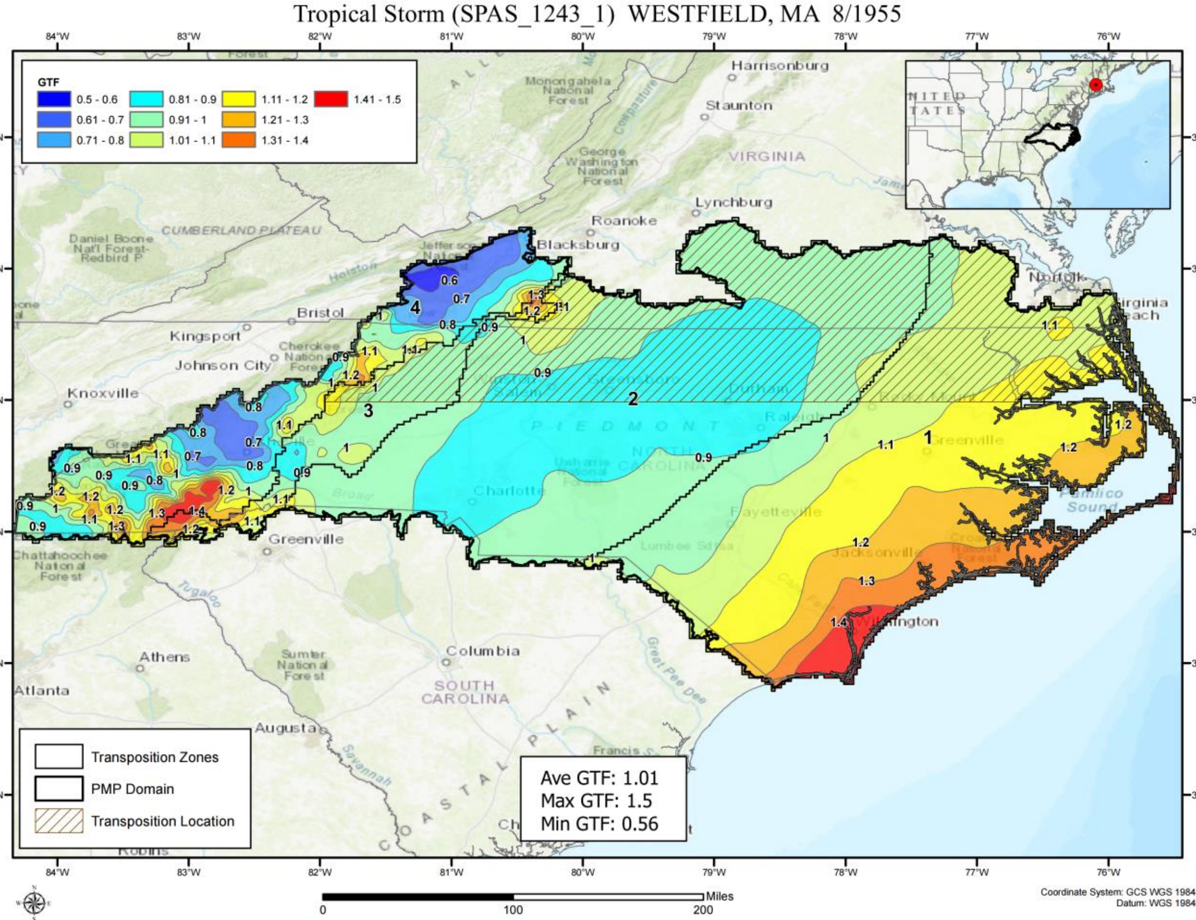
Geographic Transposition Factor
Local Storm (SPAS_1952_1) FAYETTEVILLE, NC 9/2016



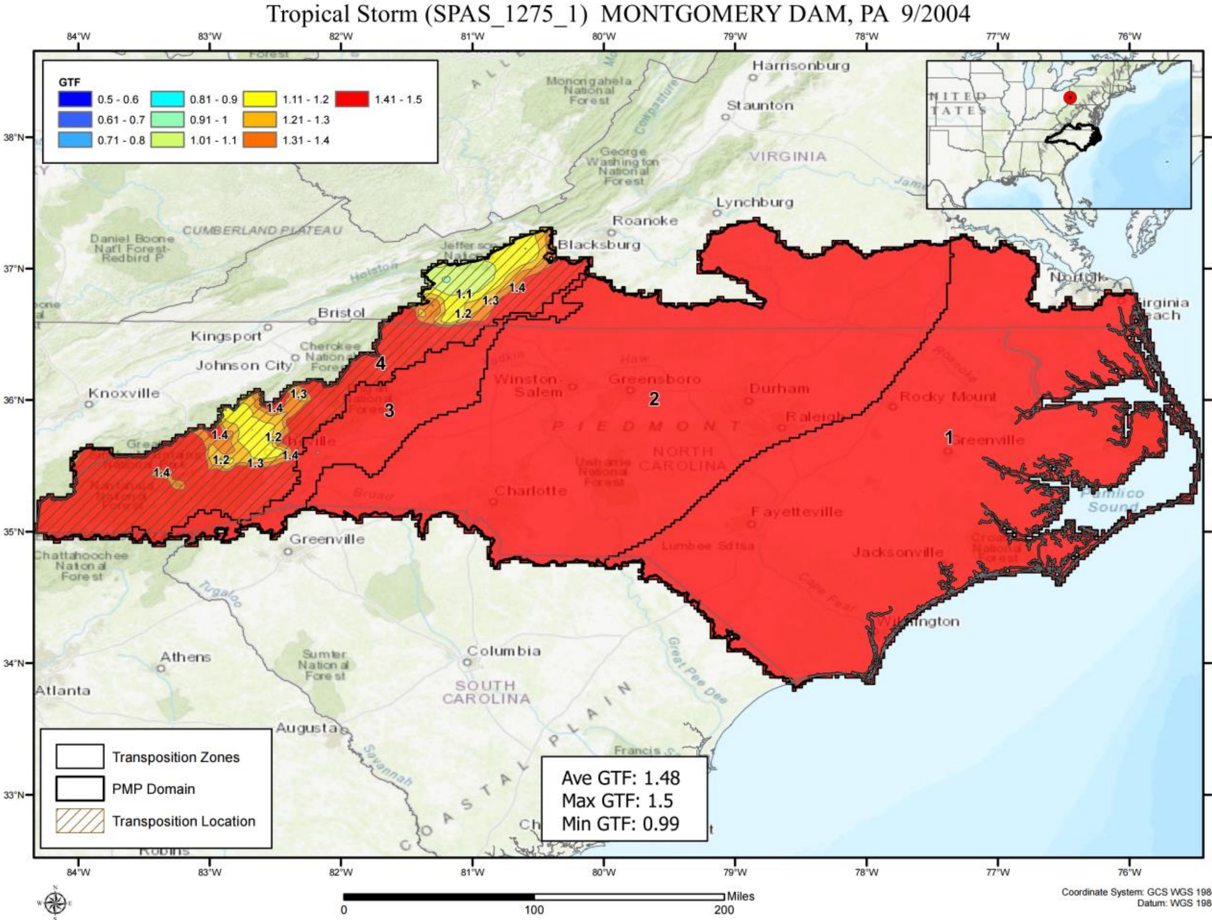
Geographic Transposition Factor
Tropical Storm (SPAS_1224_1) MAPLECREST, NY 8/2011



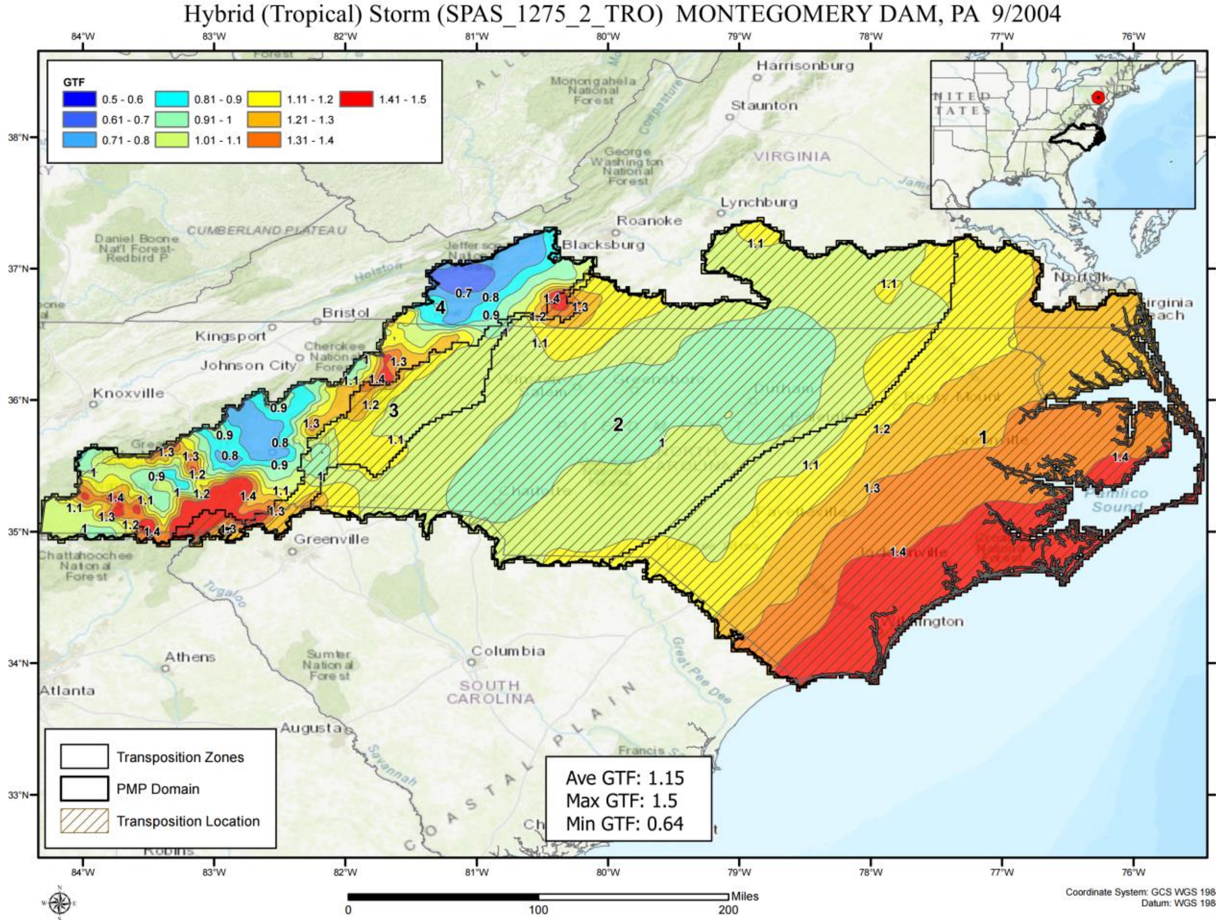
Geographic Transposition Factor
Tropical Storm (SPAS_1243_1) WESTFIELD, MA 8/1955



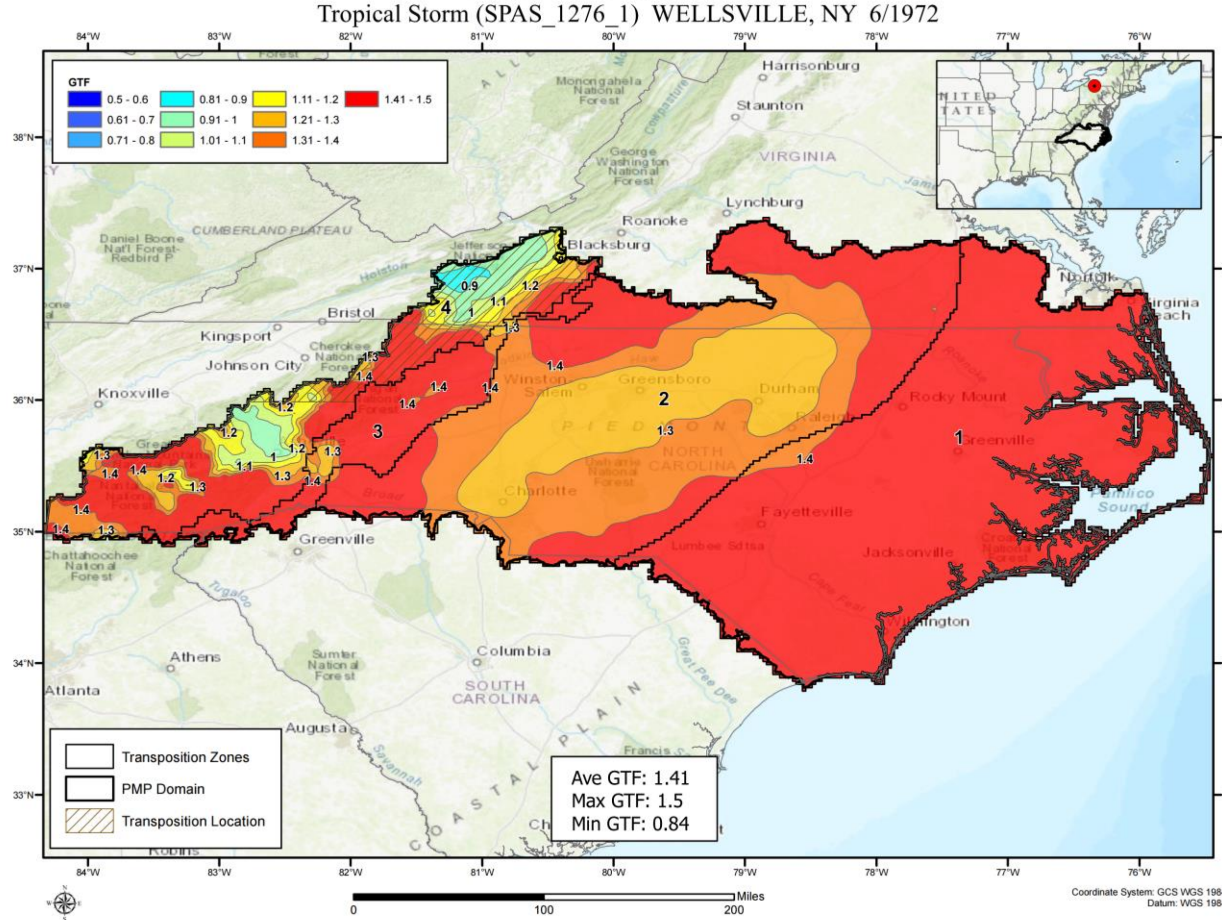
Geographic Transposition Factor
Tropical Storm (SPAS_1275_1) MONTGOMERY DAM, PA 9/2004



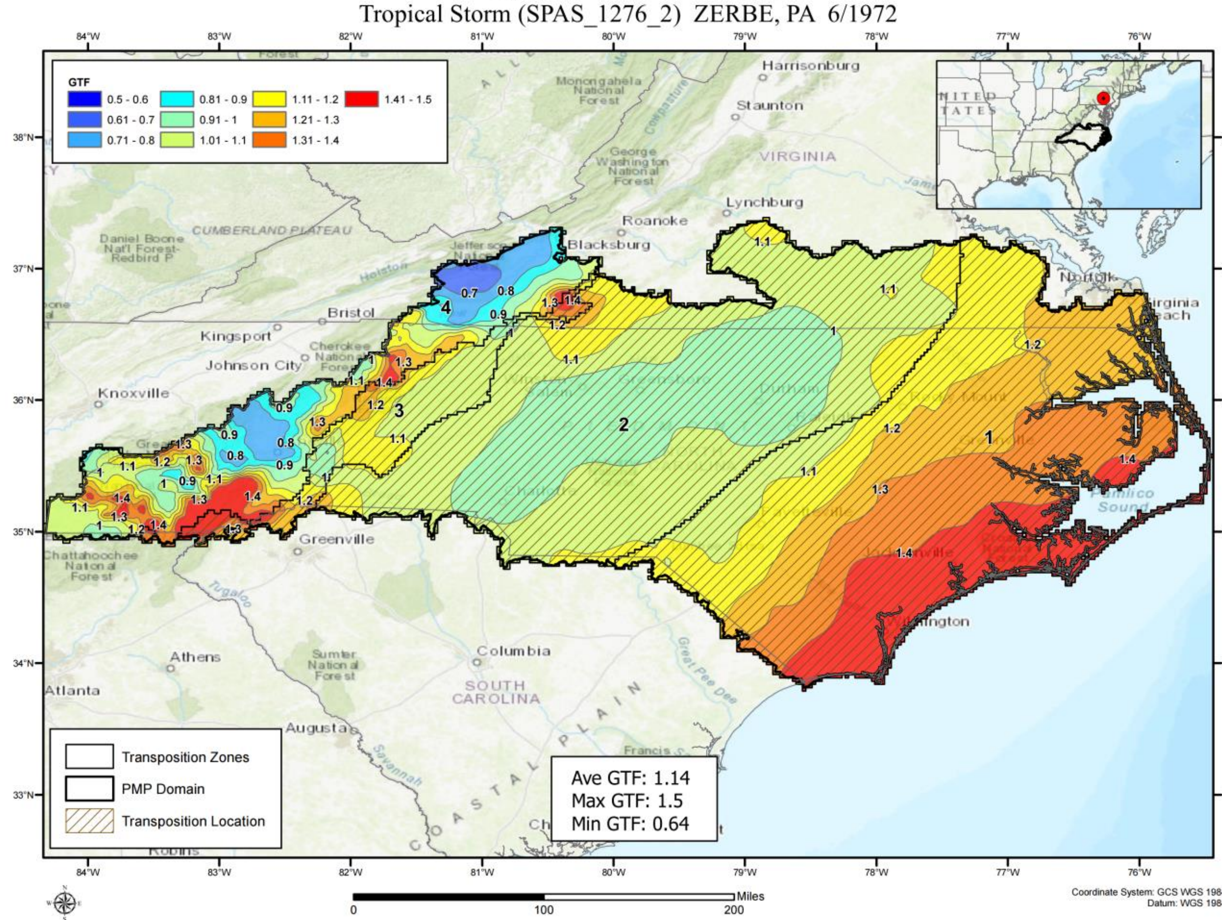
Geographic Transposition Factor
Hybrid (Tropical) Storm (SPAS_1275_2_TRO) MONTEGOMERY DAM, PA 9/2004



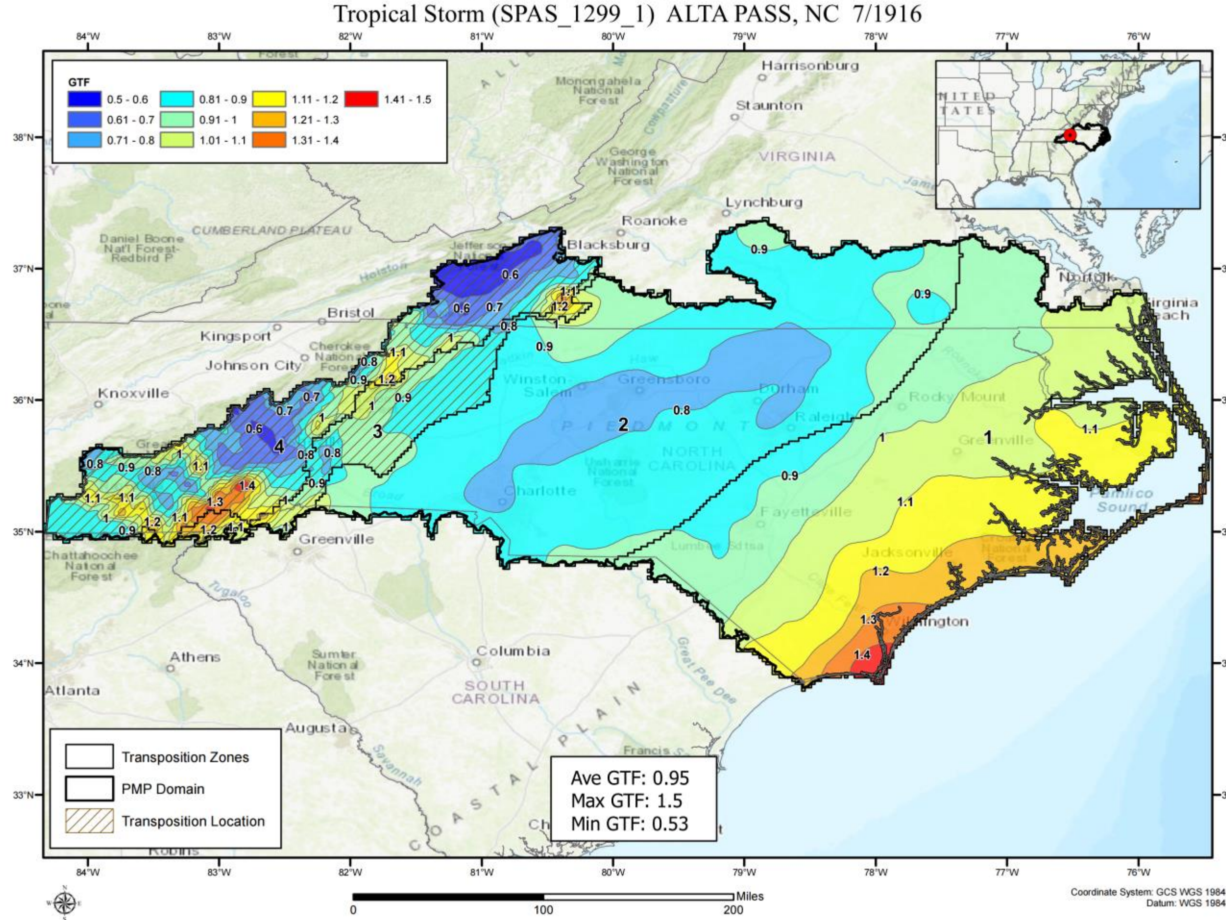
Geographic Transposition Factor
Tropical Storm (SPAS_1276_1) WELLSVILLE, NY 6/1972



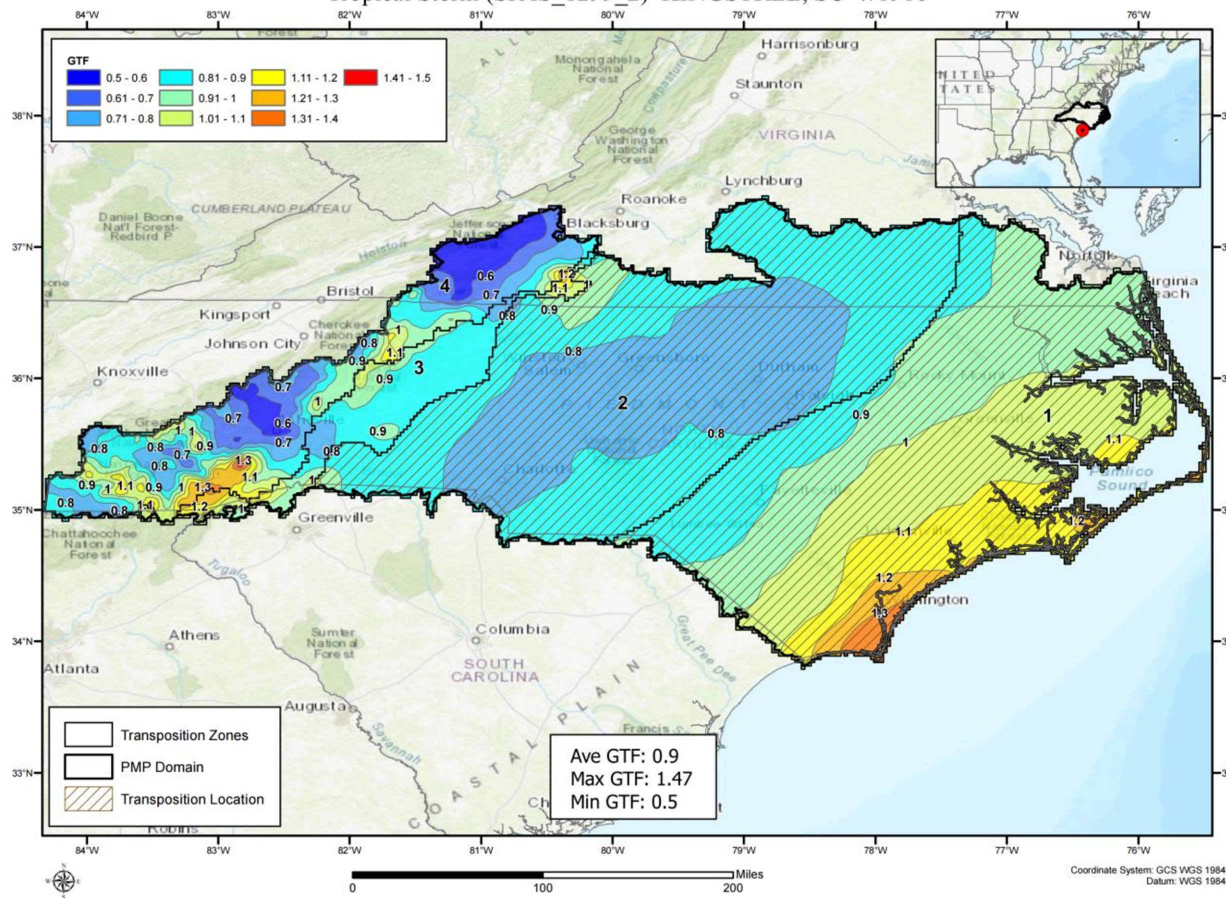
Geographic Transposition Factor
Tropical Storm (SPAS_1276_2) ZERBE, PA 6/1972



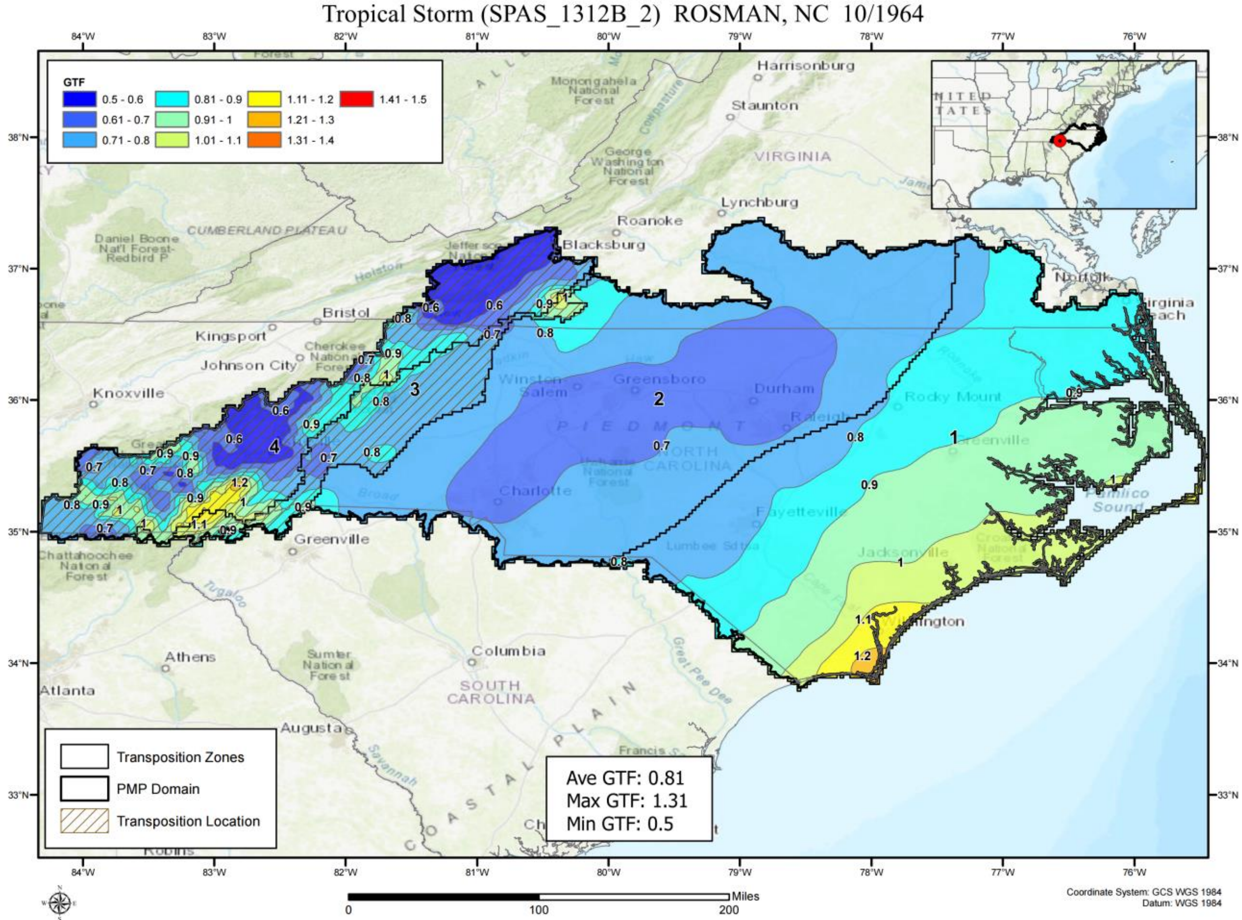
Geographic Transposition Factor
Tropical Storm (SPAS_1299_1) ALTA PASS, NC 7/1916



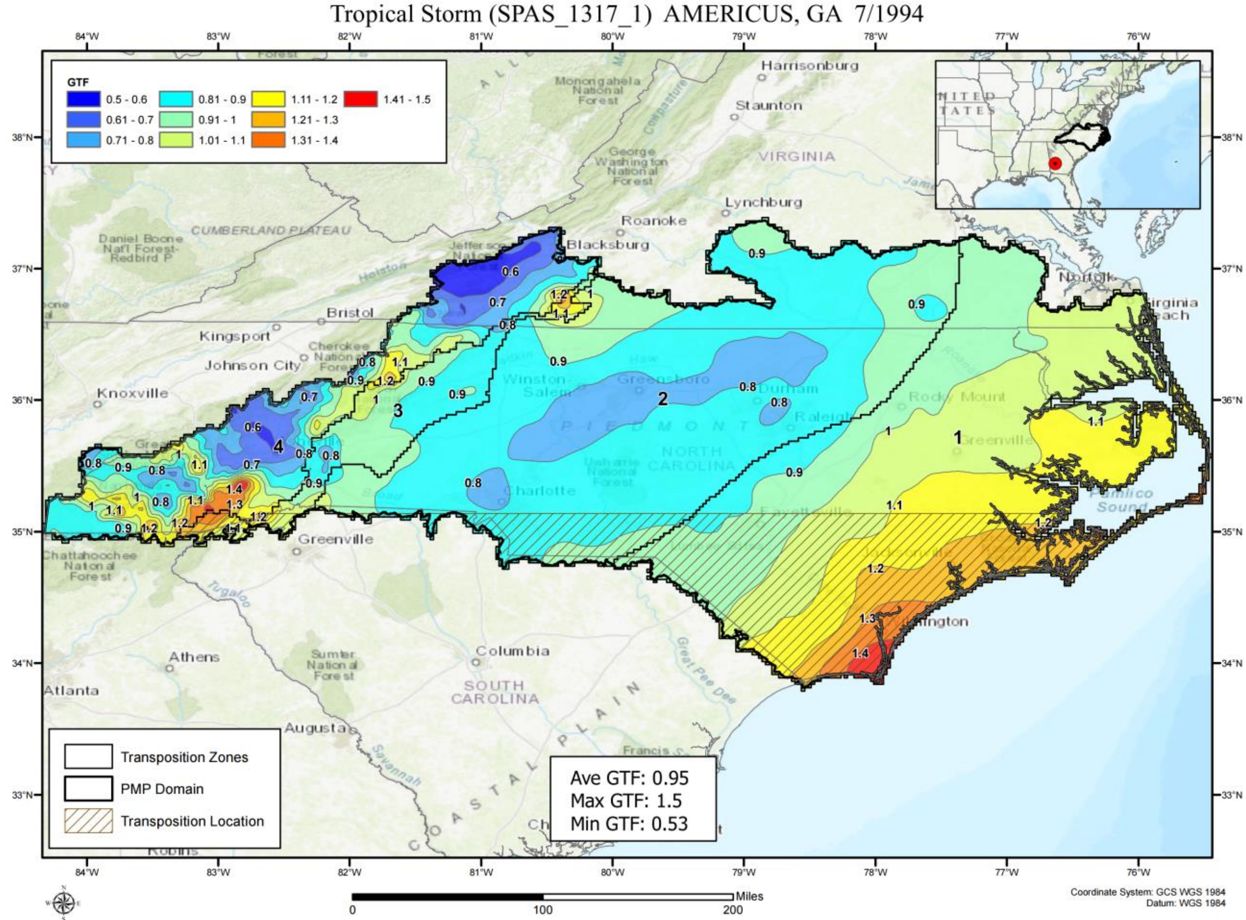
Geographic Transposition Factor
Tropical Storm (SPAS_1299_2) KINGSTREE, SC 7/1916



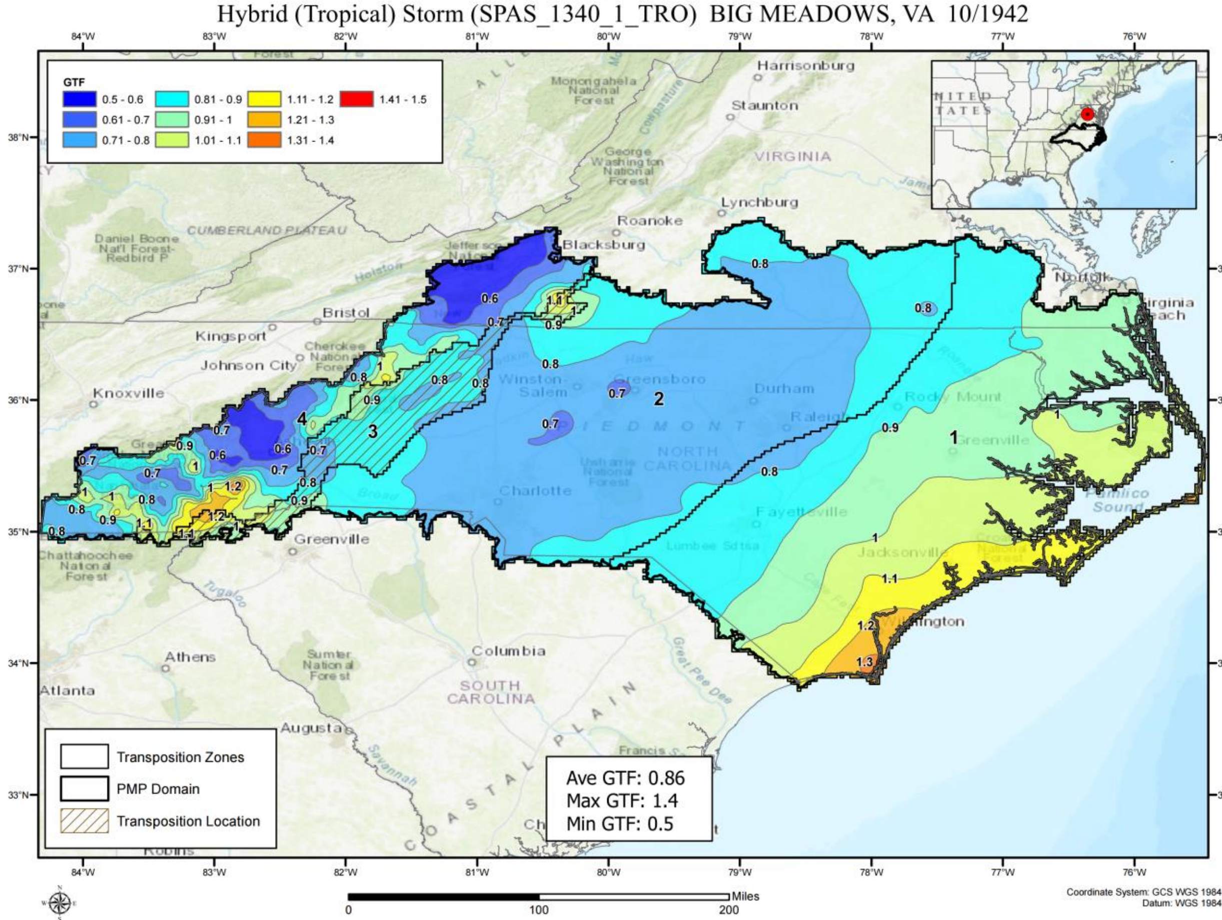
Geographic Transposition Factor
Tropical Storm (SPAS_1312B_2) ROSMAN, NC 10/1964



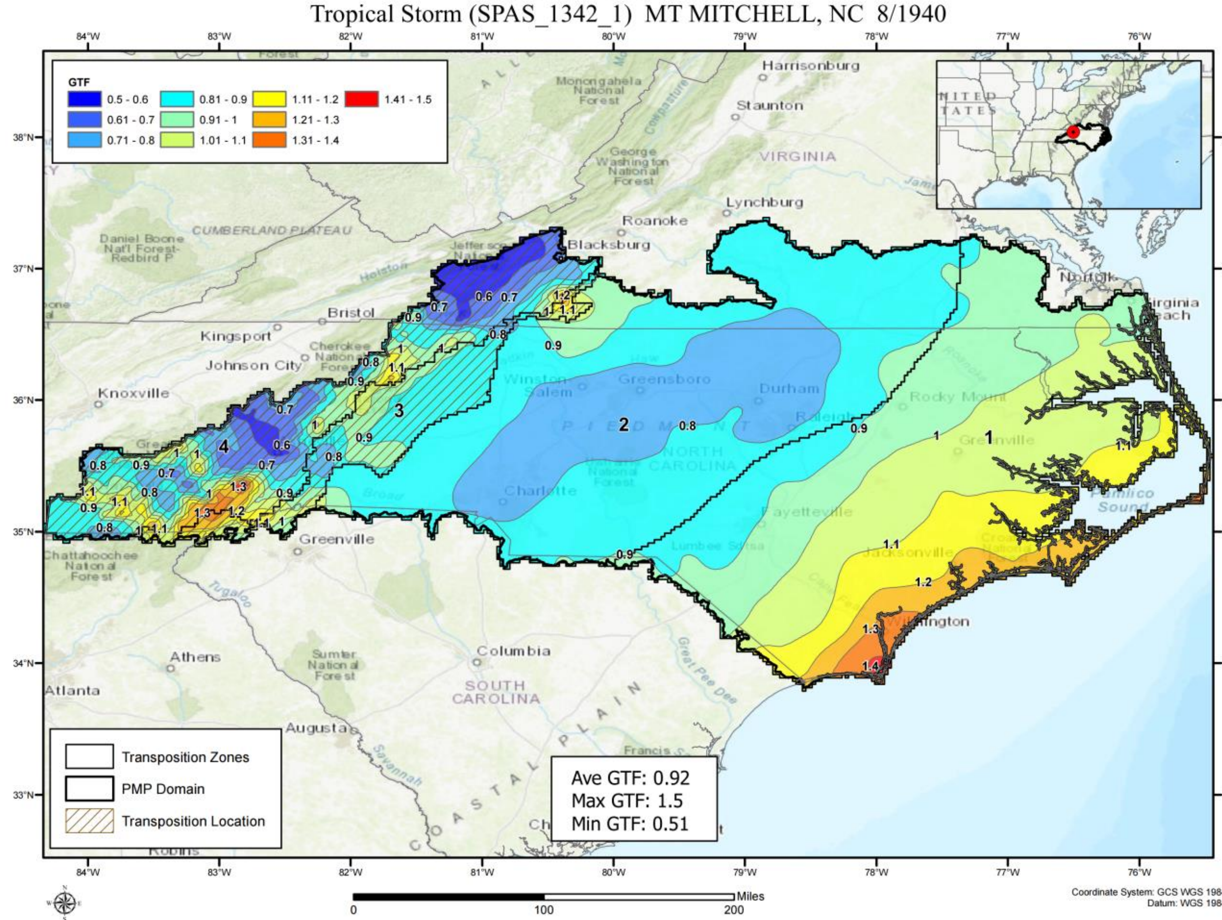
Geographic Transposition Factor
Tropical Storm (SPAS_1317_1) AMERICUS, GA 7/1994



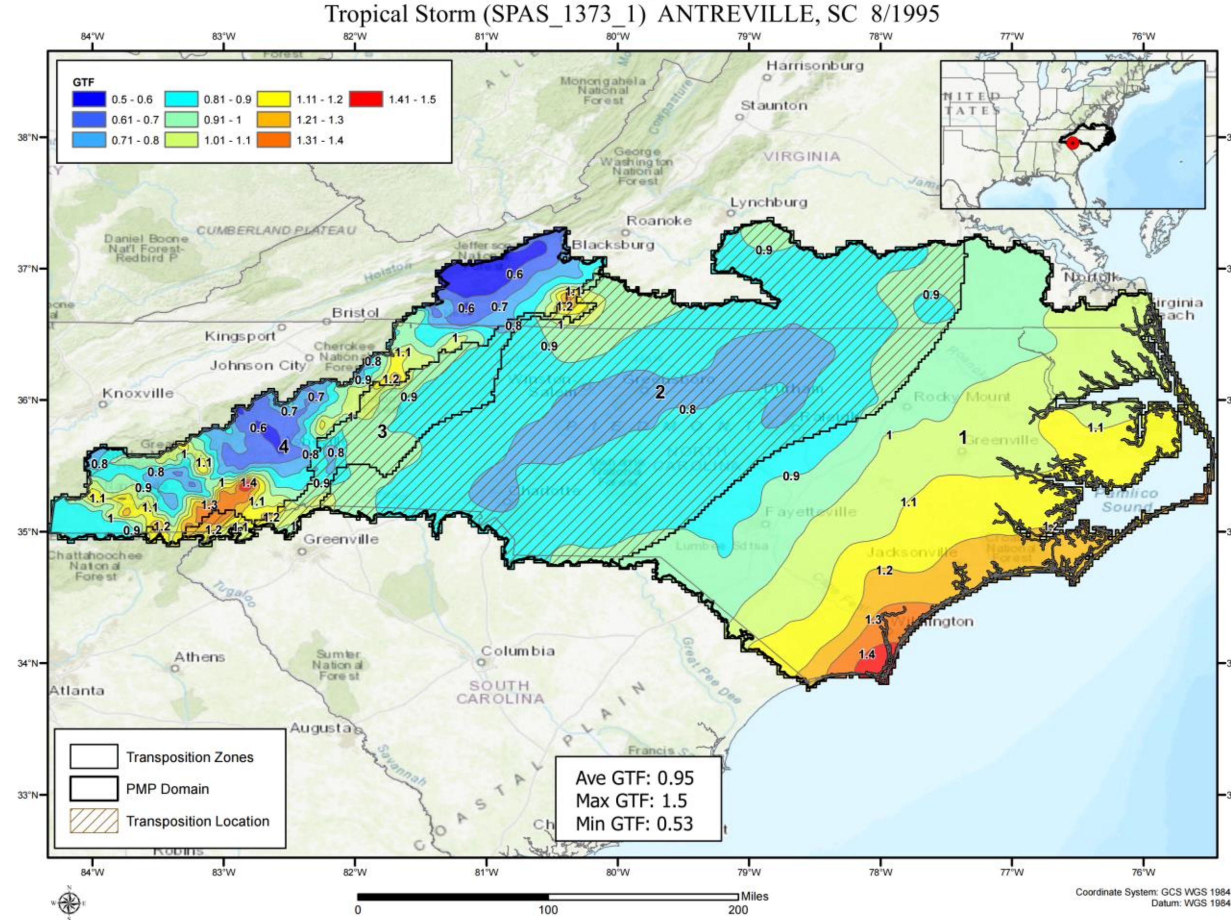
Geographic Transposition Factor
Hybrid (Tropical) Storm (SPAS_1340_1_TRO) BIG MEADOWS, VA 10/1942



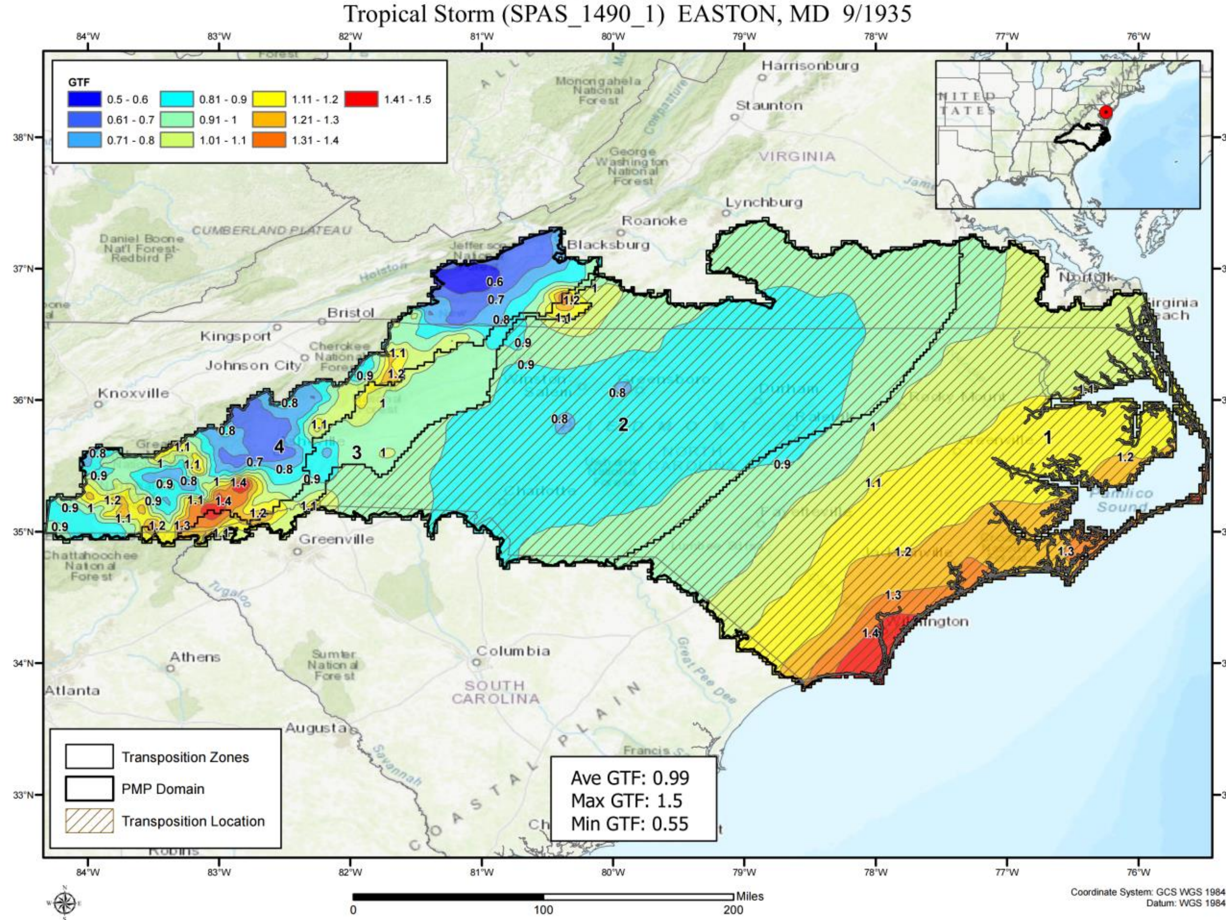
Geographic Transposition Factor
Tropical Storm (SPAS_1342_1) MT MITCHELL, NC 8/1940



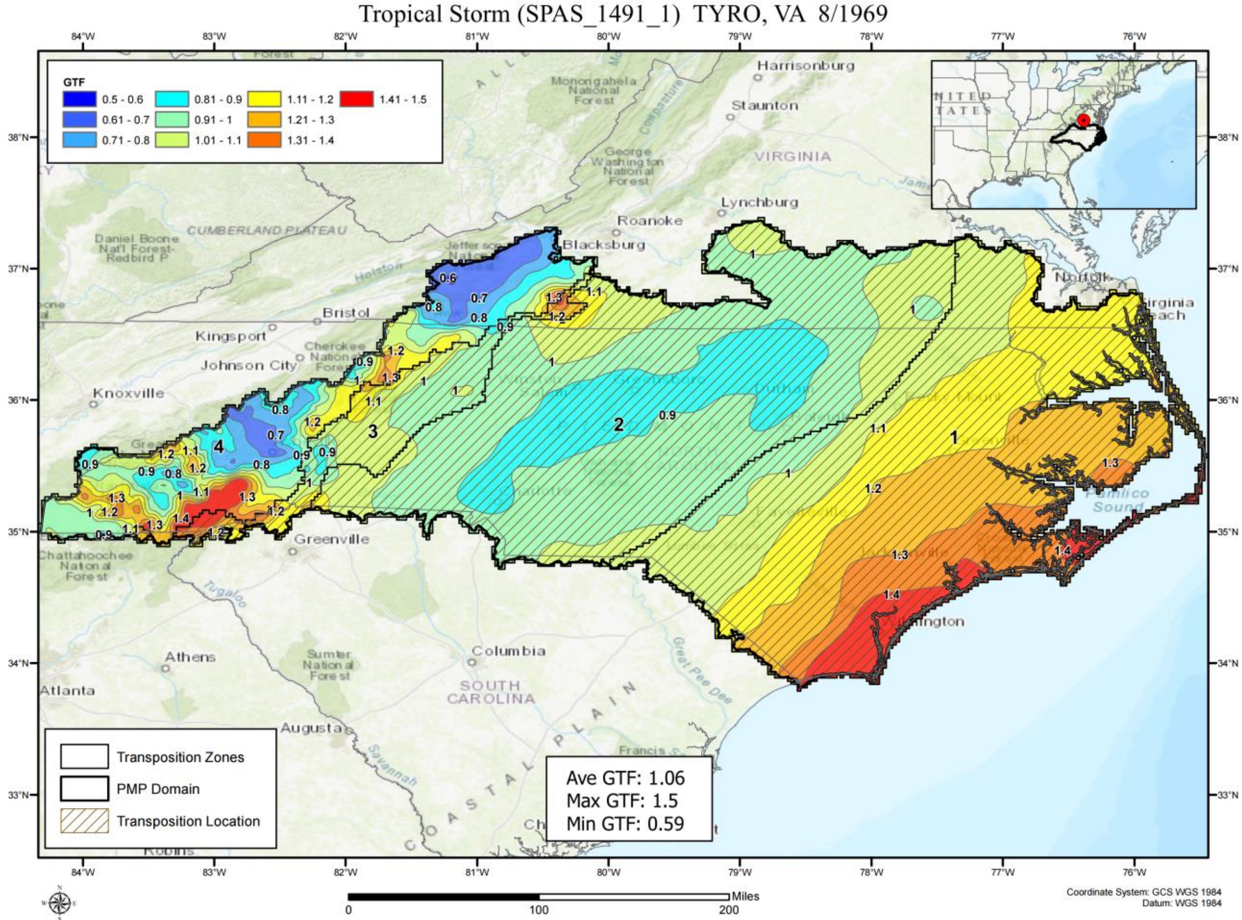
Geographic Transposition Factor
Tropical Storm (SPAS_1373_1) ANTREVILLE, SC 8/1995



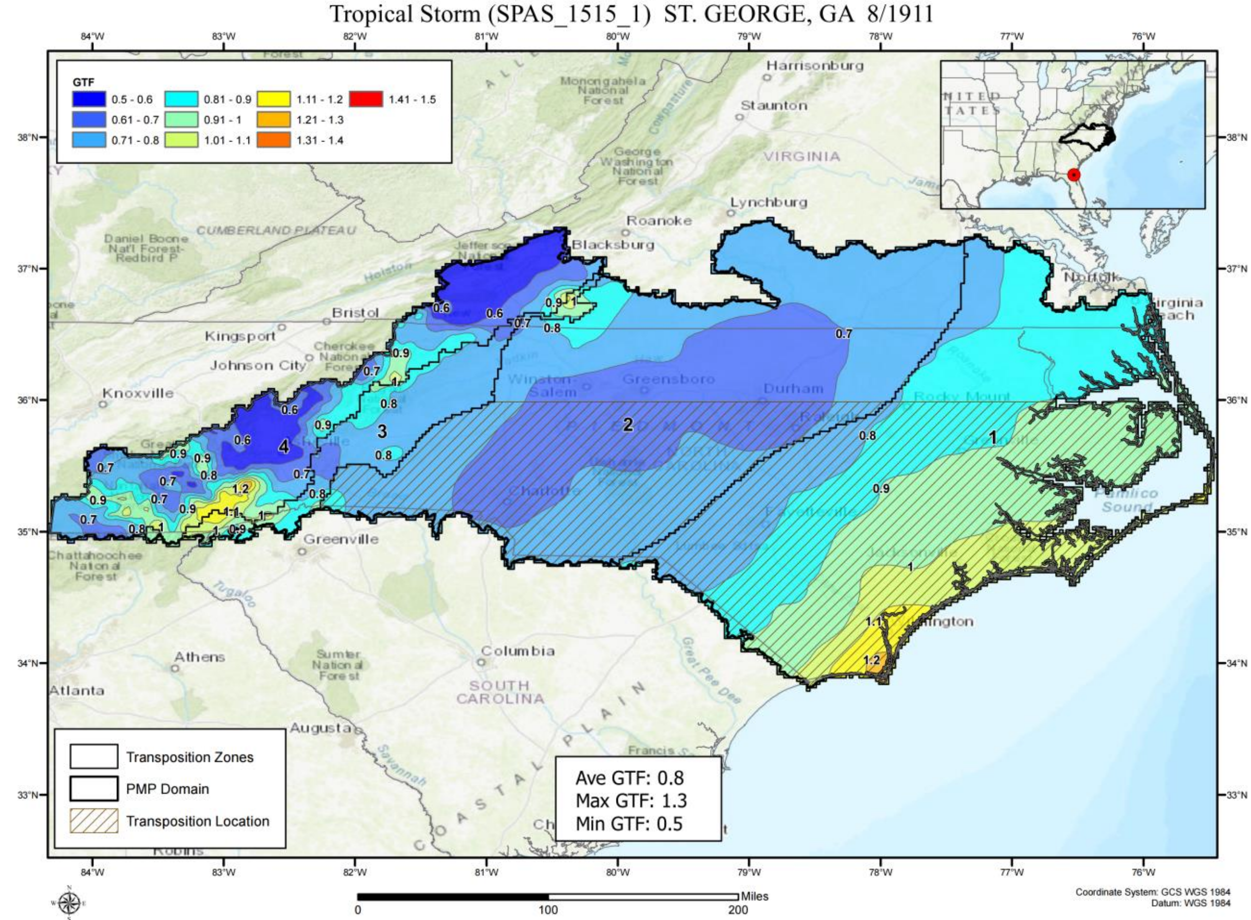
Geographic Transposition Factor
Tropical Storm (SPAS_1490_1) EASTON, MD 9/1935



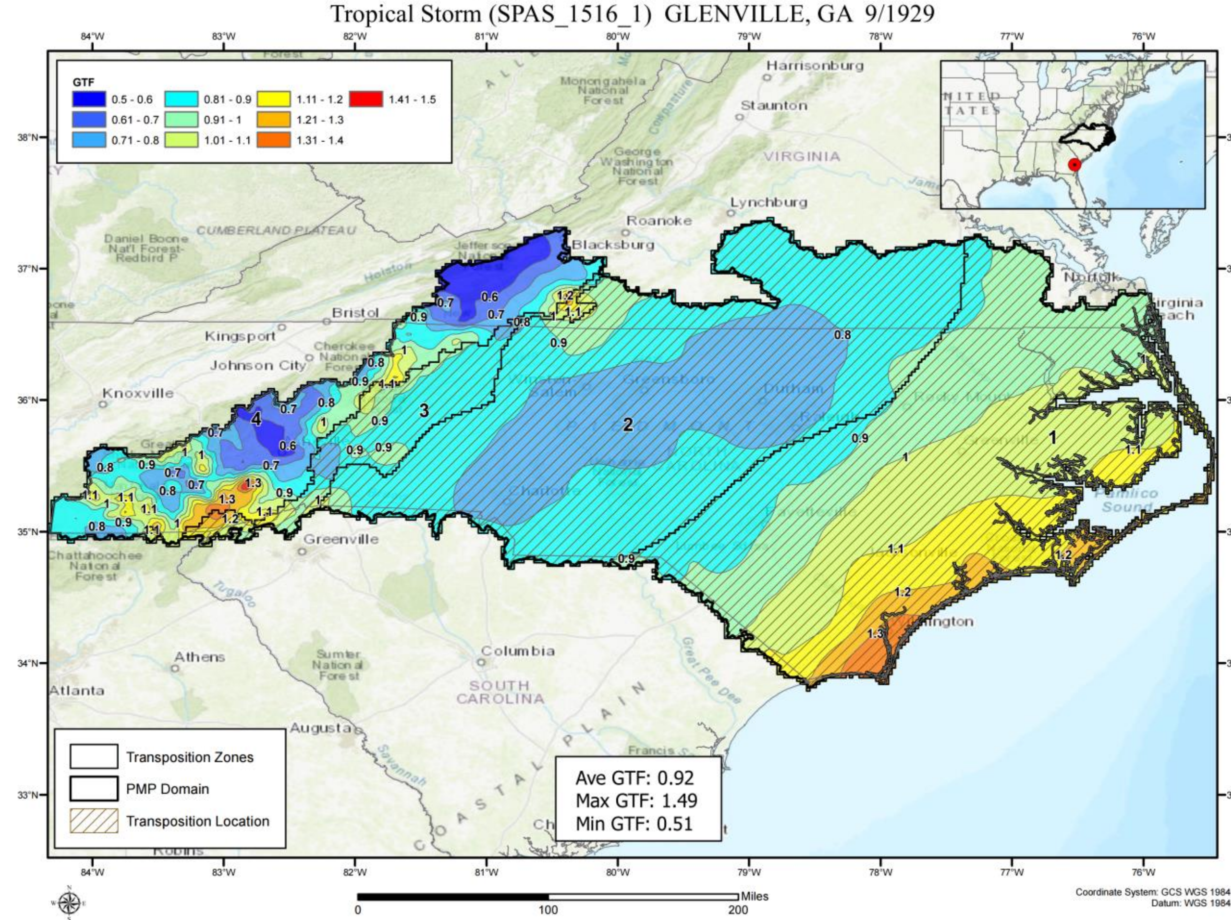
Geographic Transposition Factor
Tropical Storm (SPAS_1491_1) TYRO, VA 8/1969



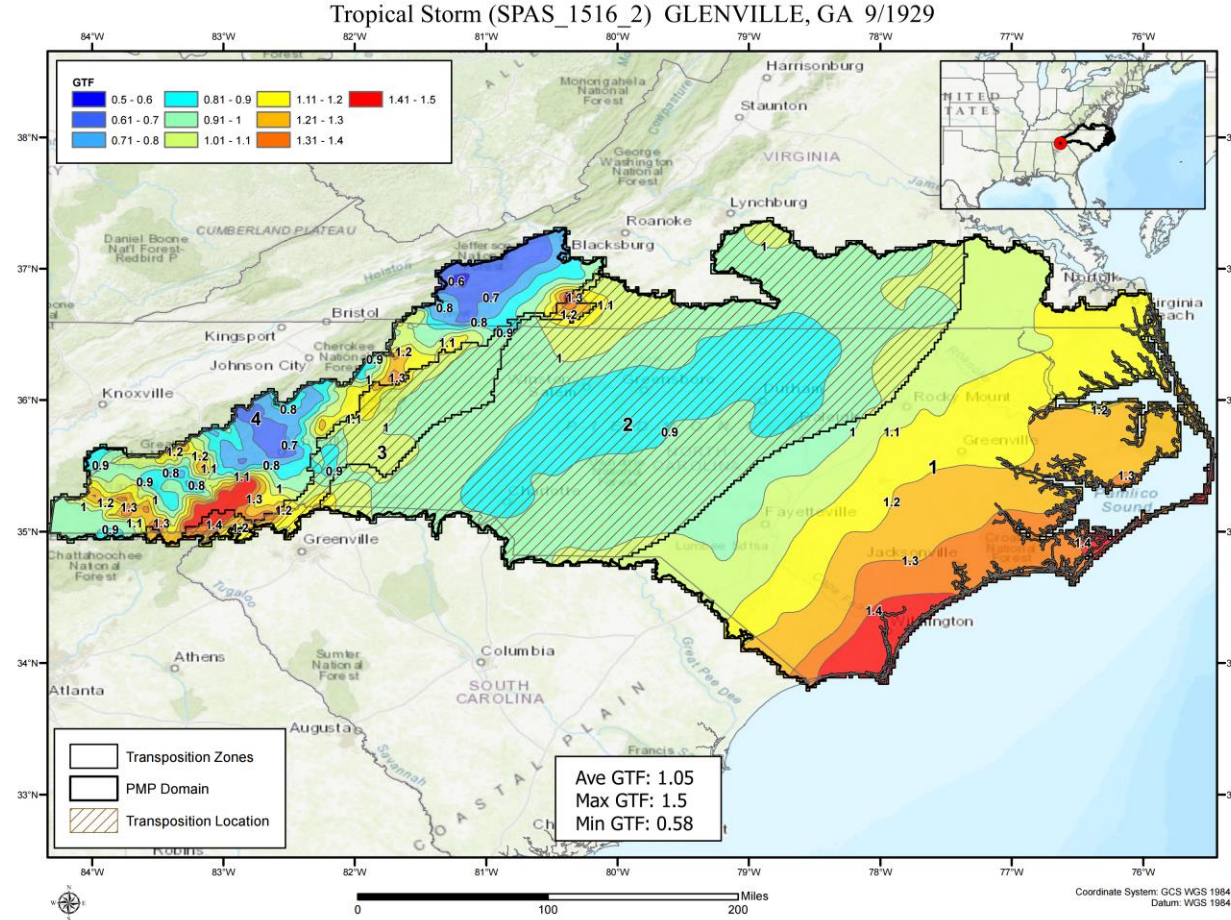
Geographic Transposition Factor
Tropical Storm (SPAS_1515_1) ST. GEORGE, GA 8/1911



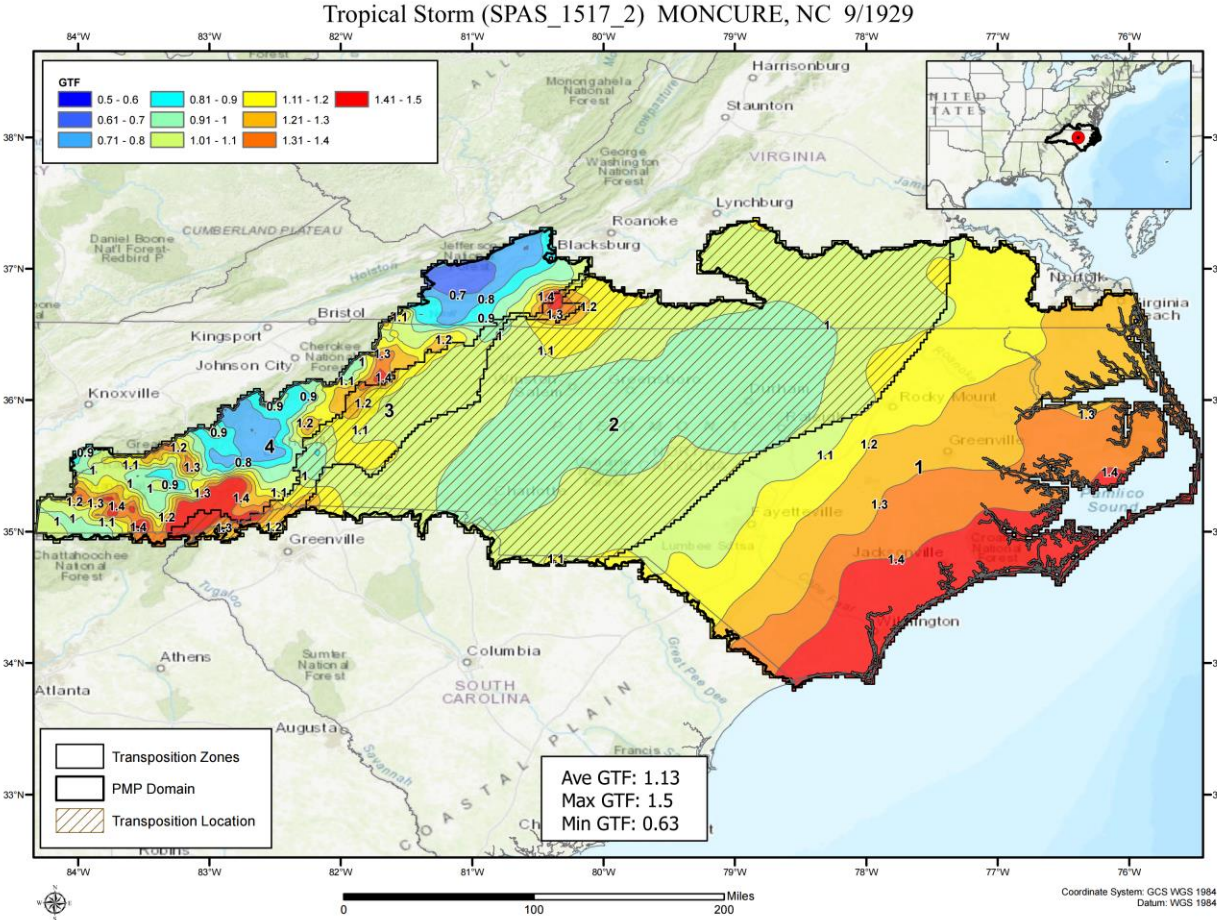
Geographic Transposition Factor
Tropical Storm (SPAS_1516_1) GLENVILLE, GA 9/1929



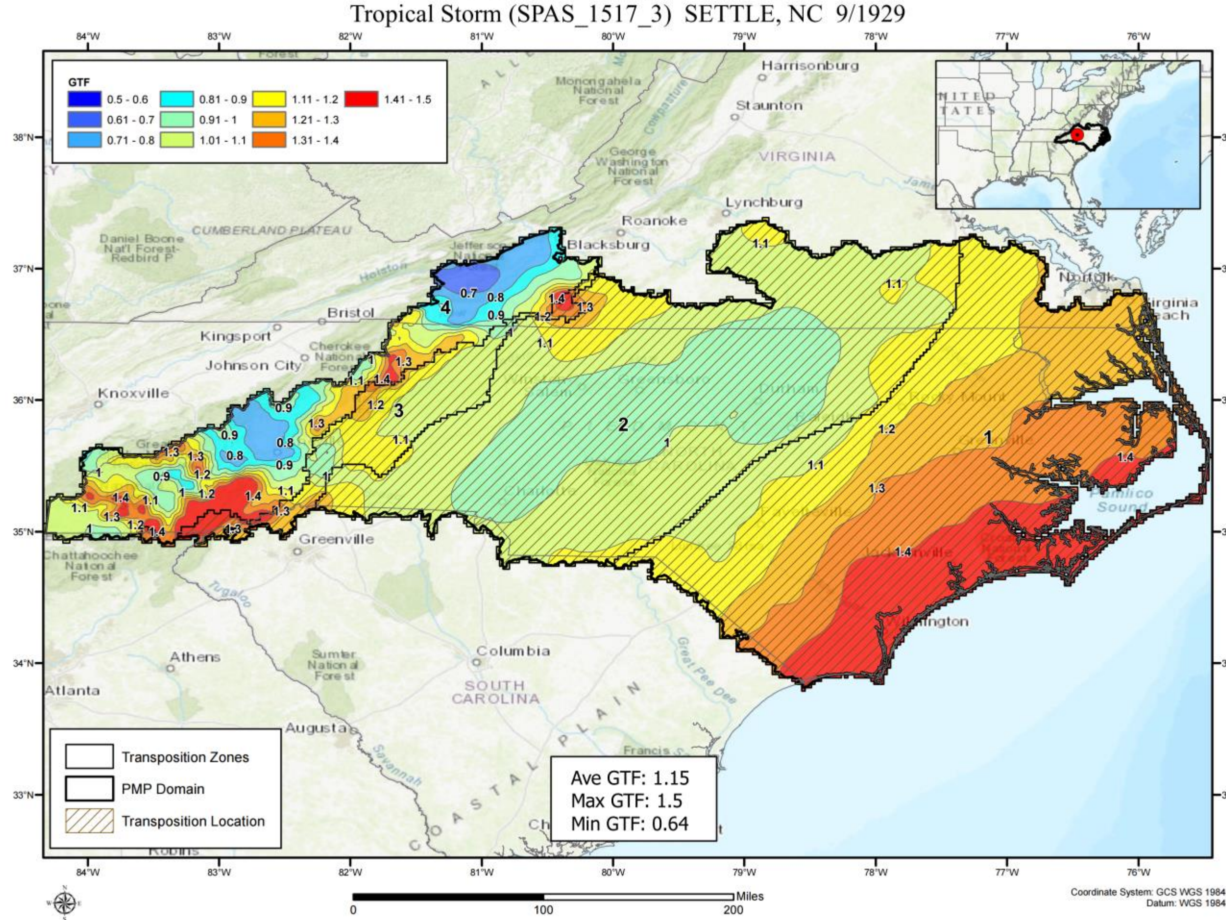
Geographic Transposition Factor
Tropical Storm (SPAS_1516_2) GLENVILLE, GA 9/1929



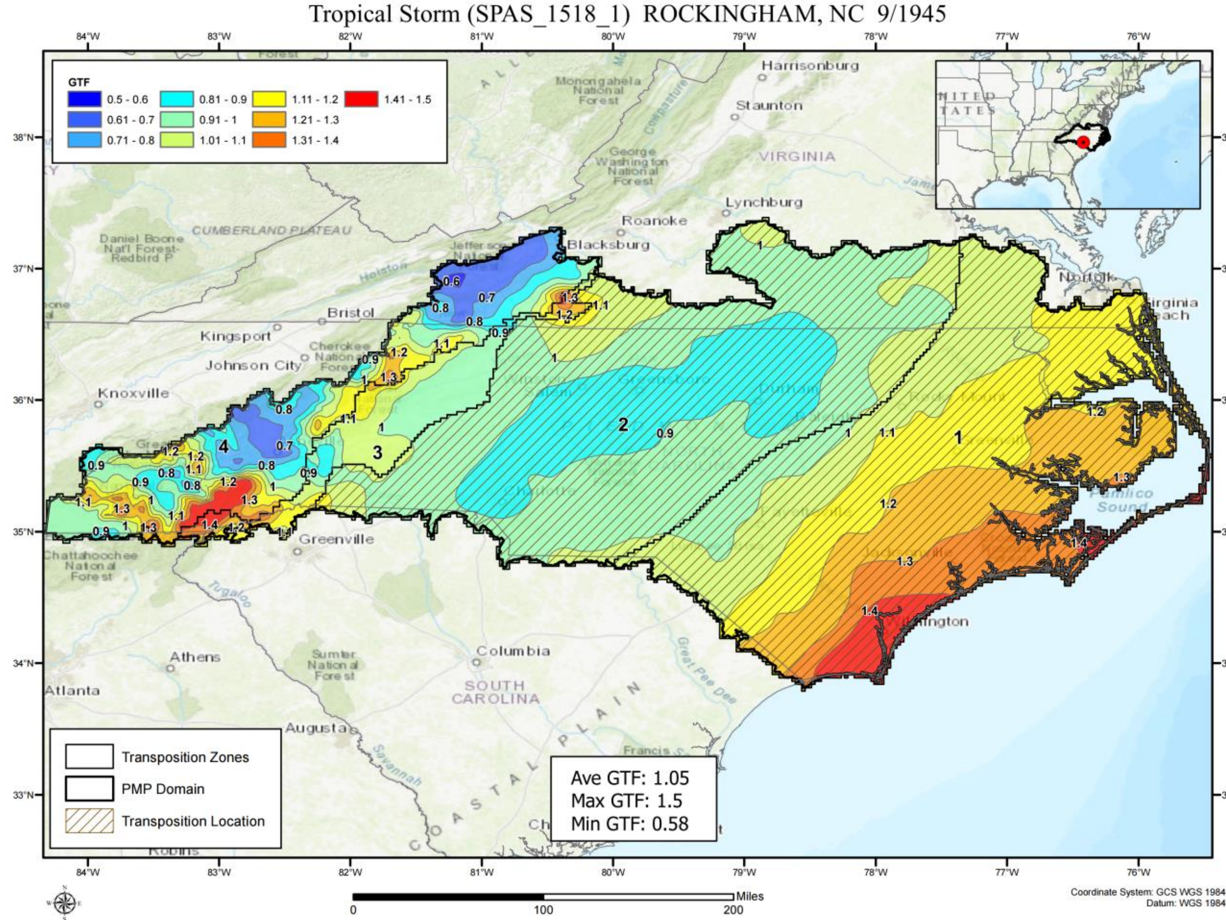
Geographic Transposition Factor
Tropical Storm (SPAS_1517_2) MONCURE, NC 9/1929



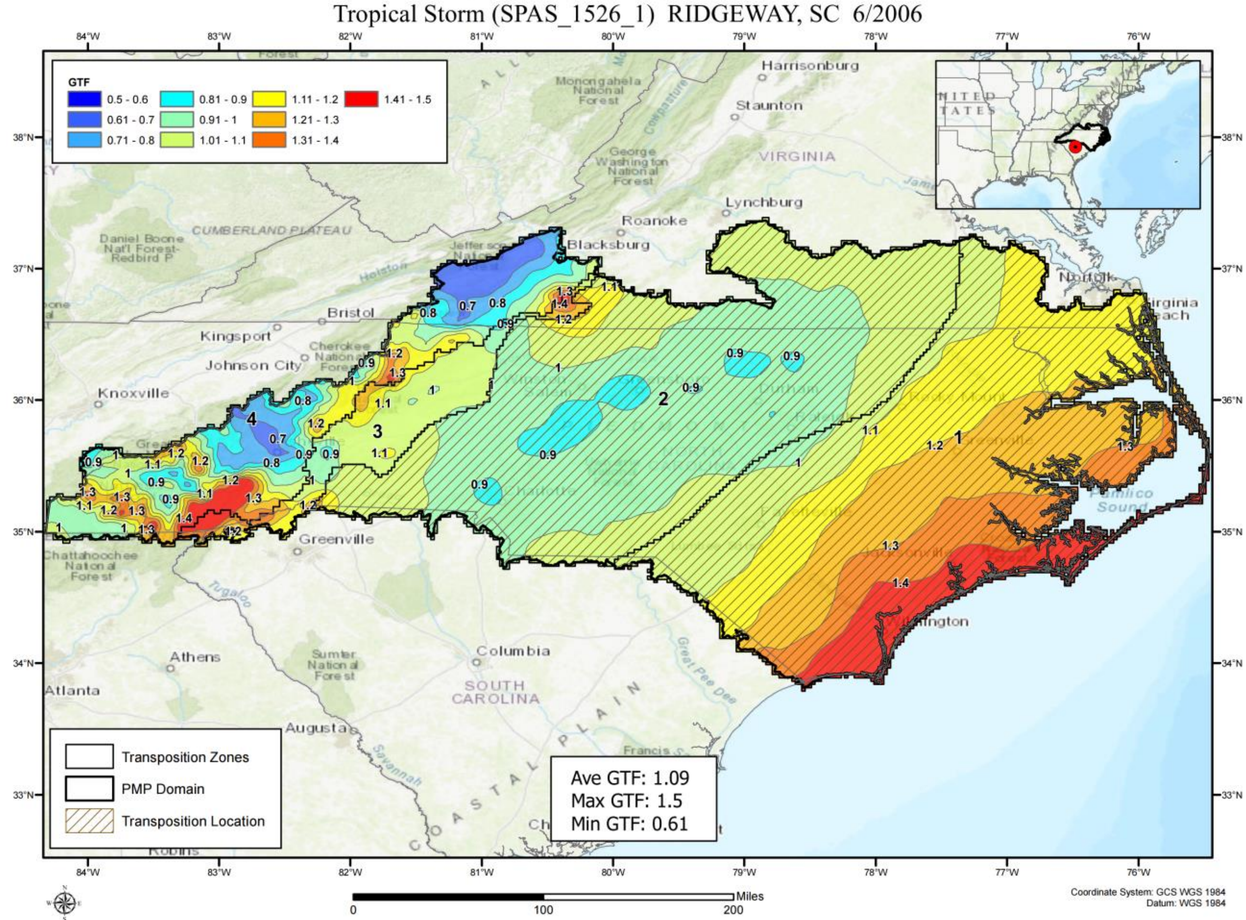
Geographic Transposition Factor
Tropical Storm (SPAS_1517_3) SETTLE, NC 9/1929



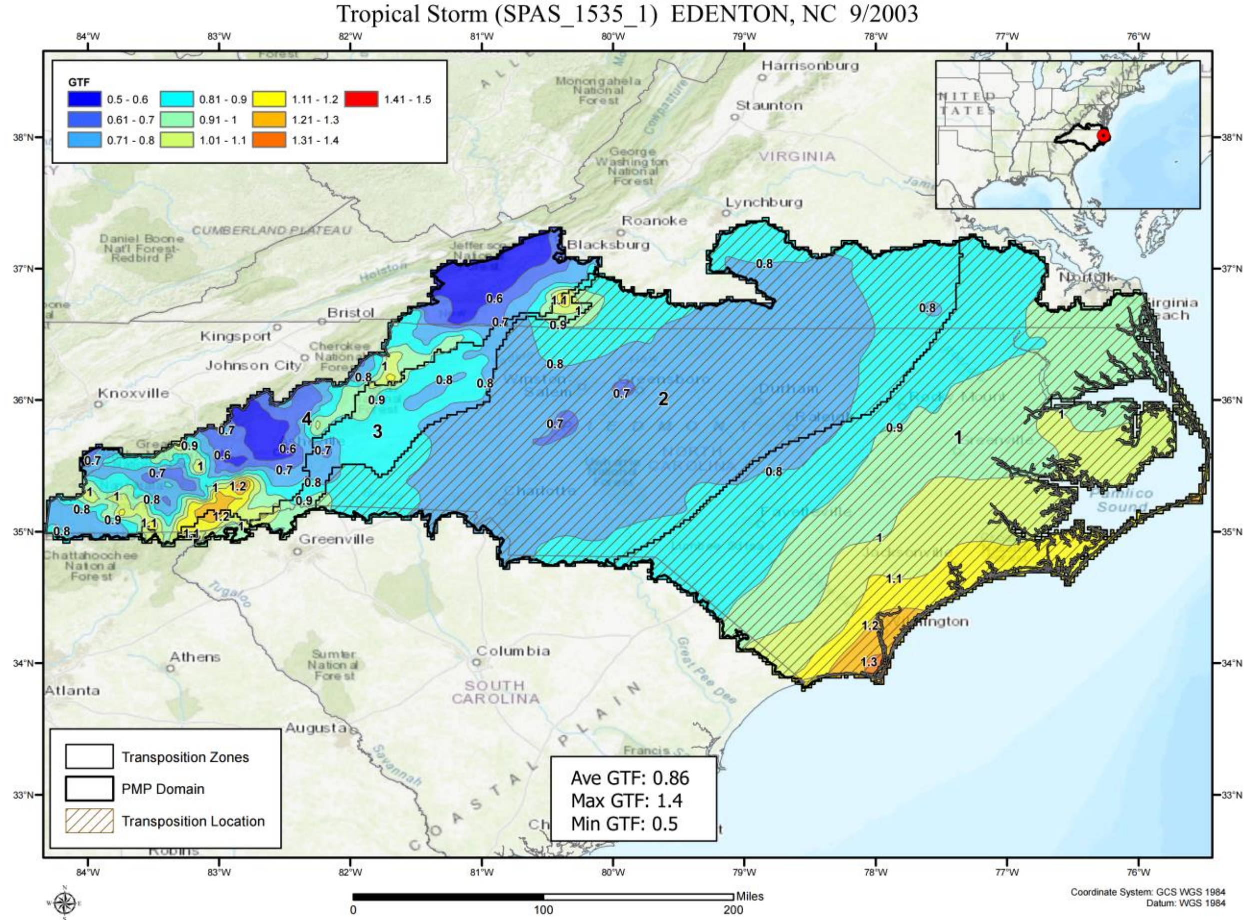
Geographic Transposition Factor
Tropical Storm (SPAS_1518_1) ROCKINGHAM, NC 9/1945



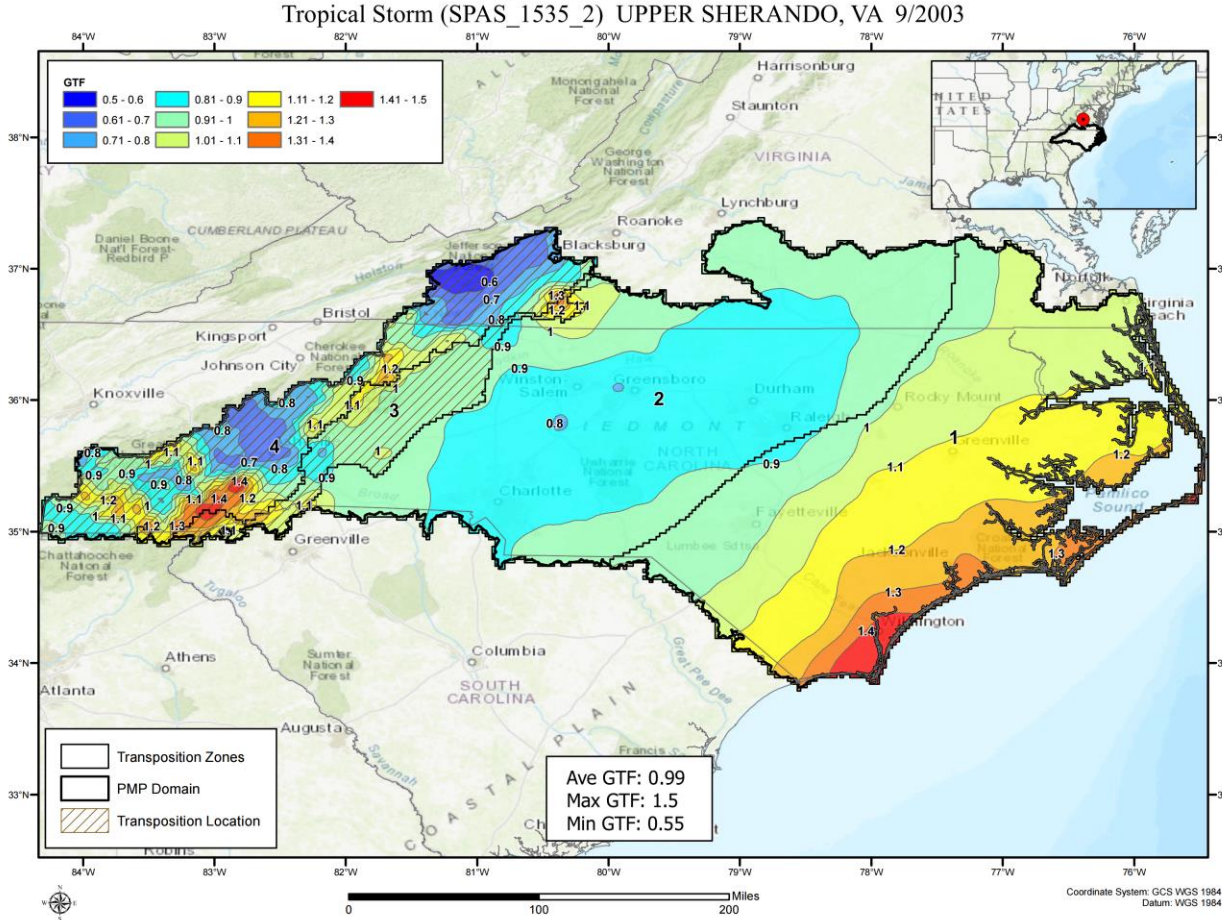
Geographic Transposition Factor
Tropical Storm (SPAS_1526_1) RIDGEWAY, SC 6/2006



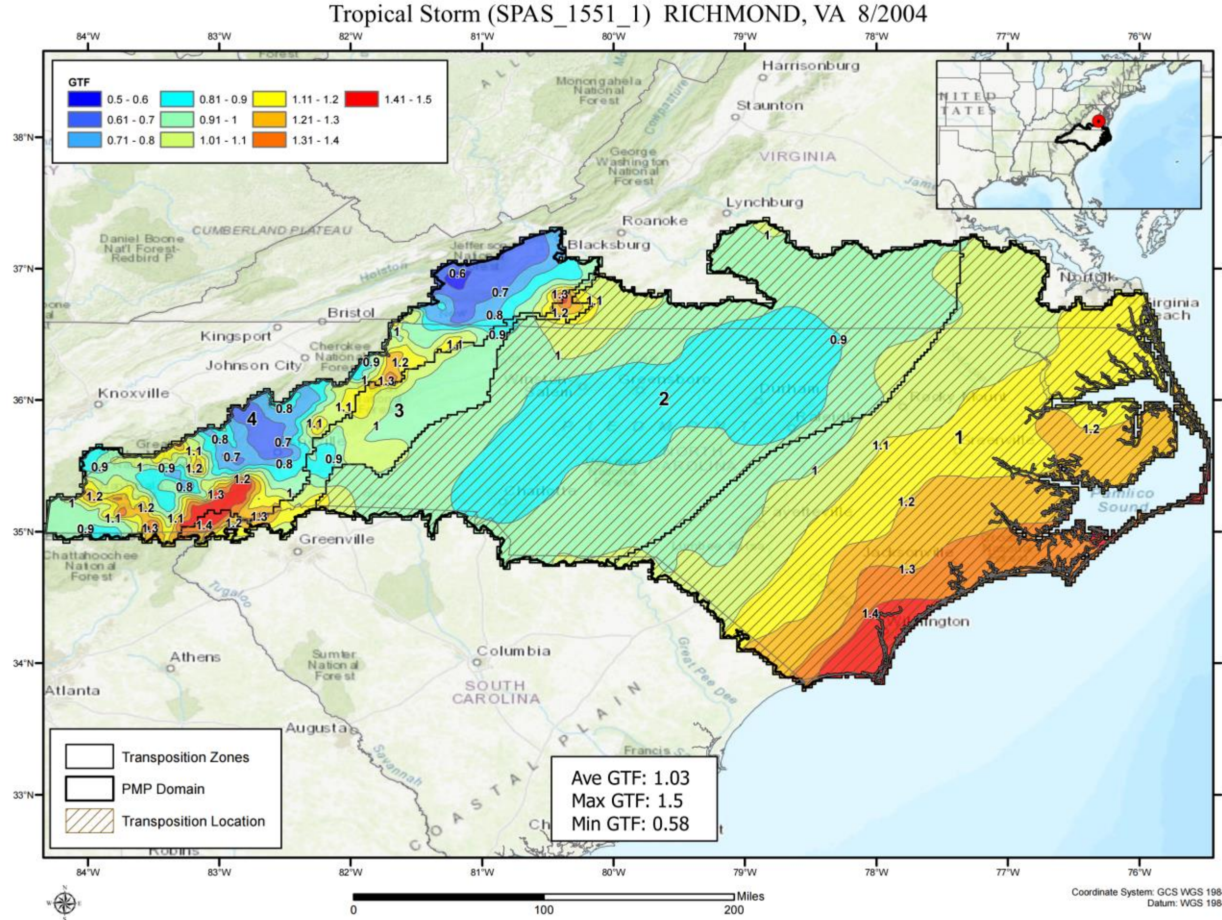
Geographic Transposition Factor
Tropical Storm (SPAS_1535_1) EDENTON, NC 9/2003



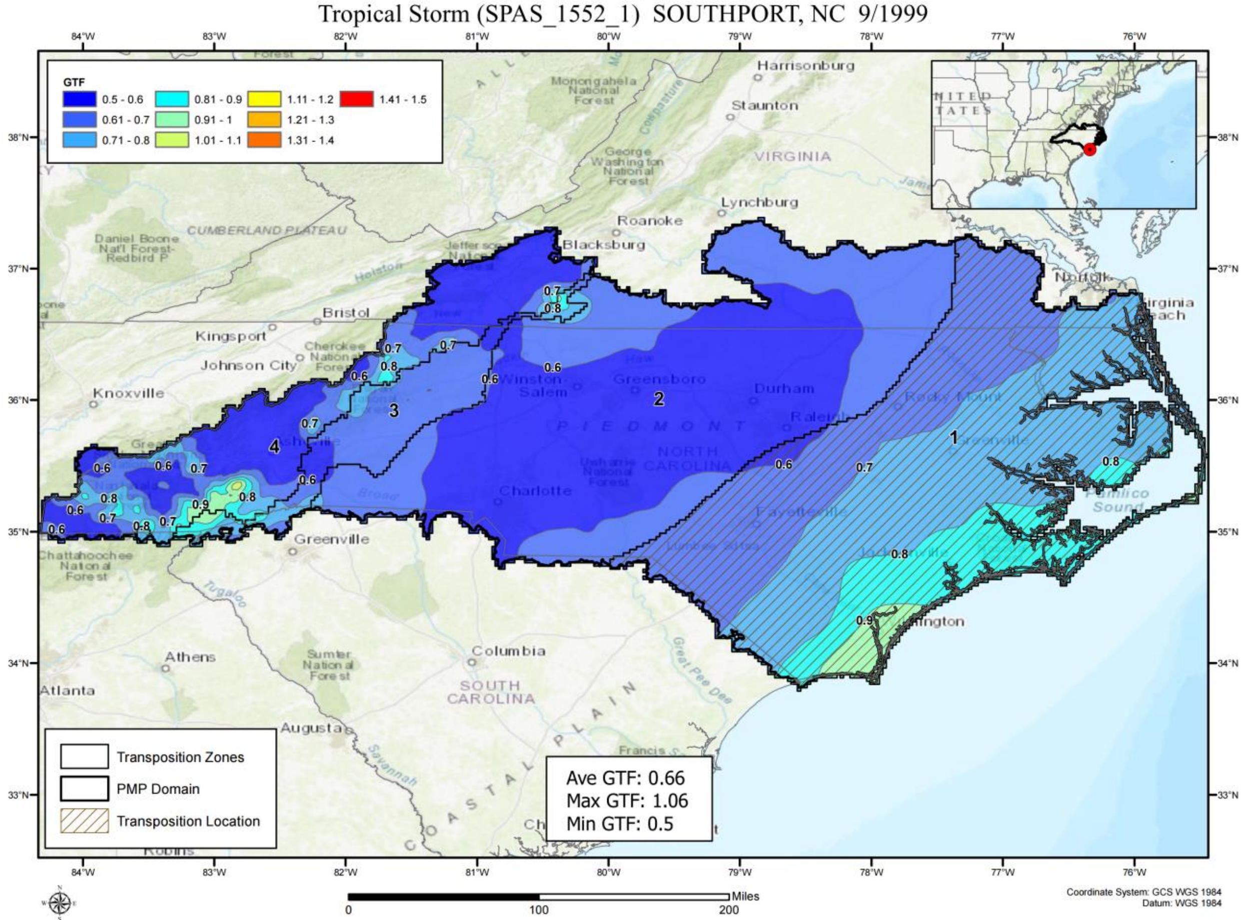
Geographic Transposition Factor
Tropical Storm (SPAS_1535_2) UPPER SHERANDO, VA 9/2003



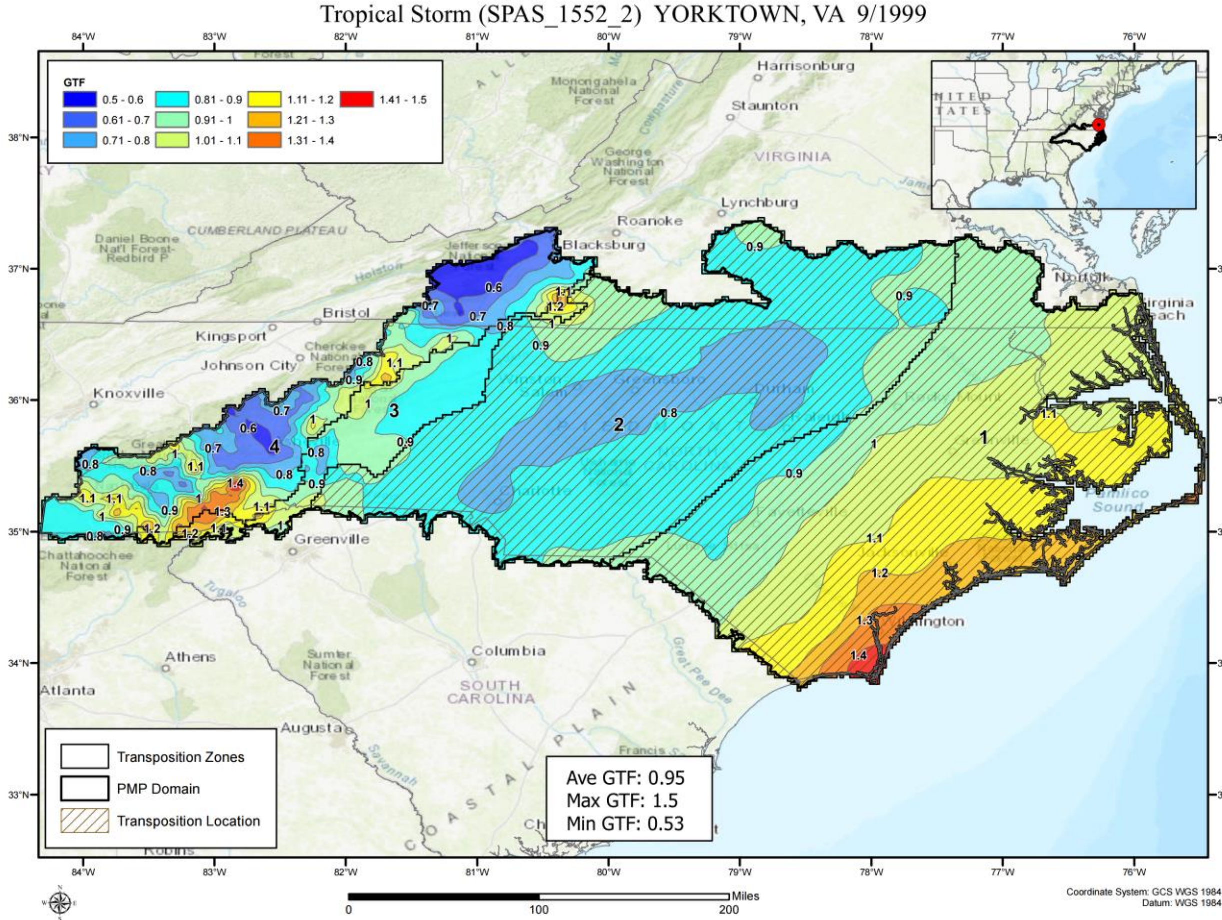
Geographic Transposition Factor
Tropical Storm (SPAS_1551_1) RICHMOND, VA 8/2004



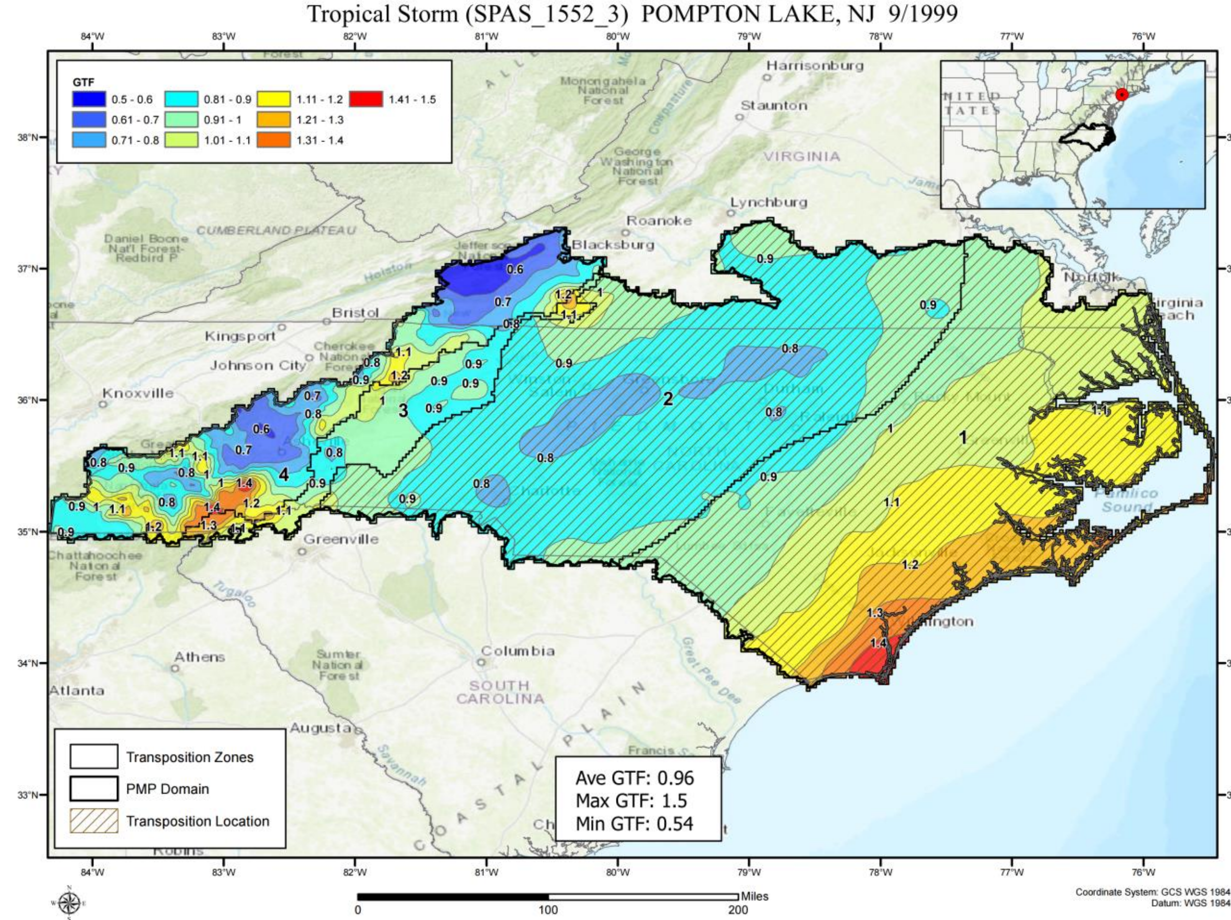
Geographic Transposition Factor
Tropical Storm (SPAS_1552_1) SOUTHPORT, NC 9/1999



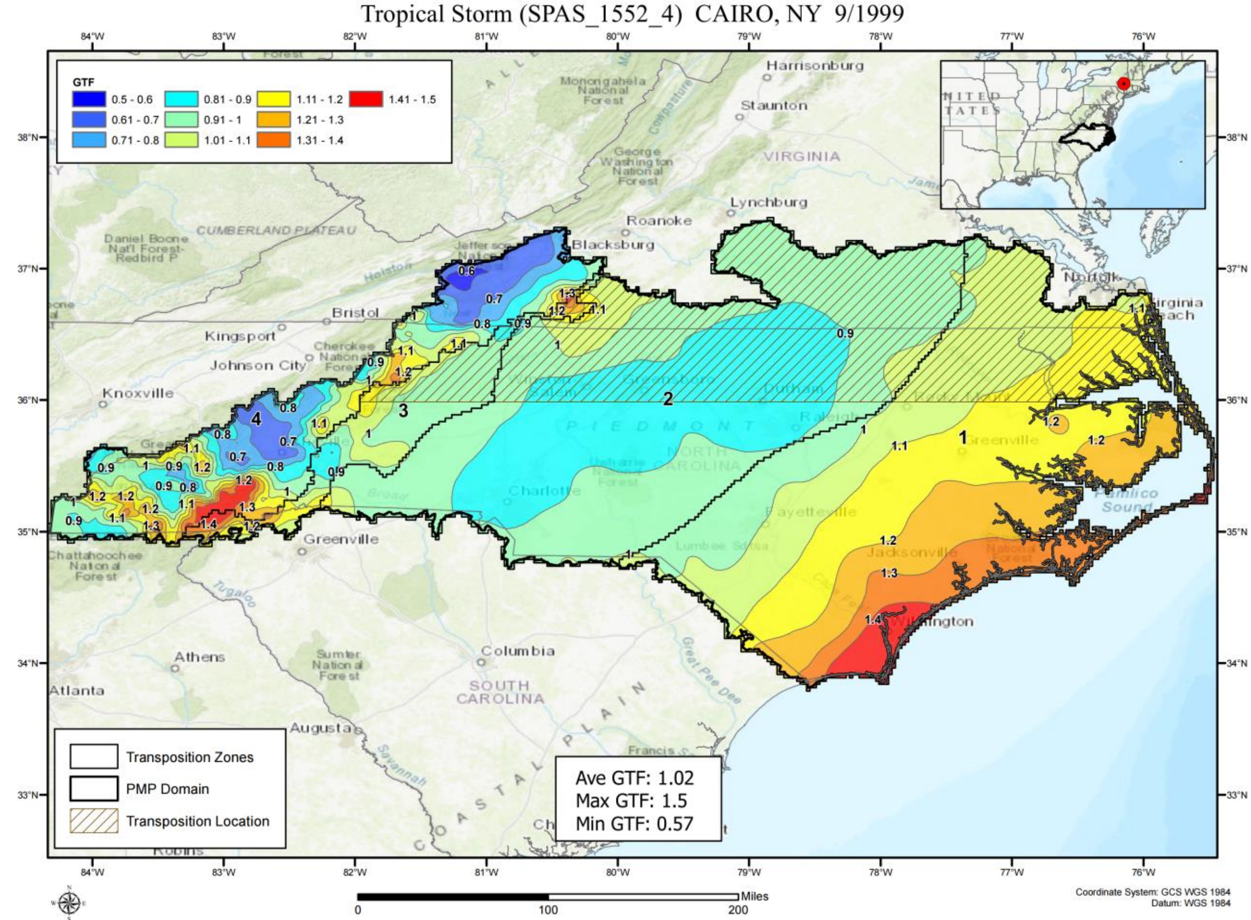
Geographic Transposition Factor
Tropical Storm (SPAS_1552_2) YORKTOWN, VA 9/1999



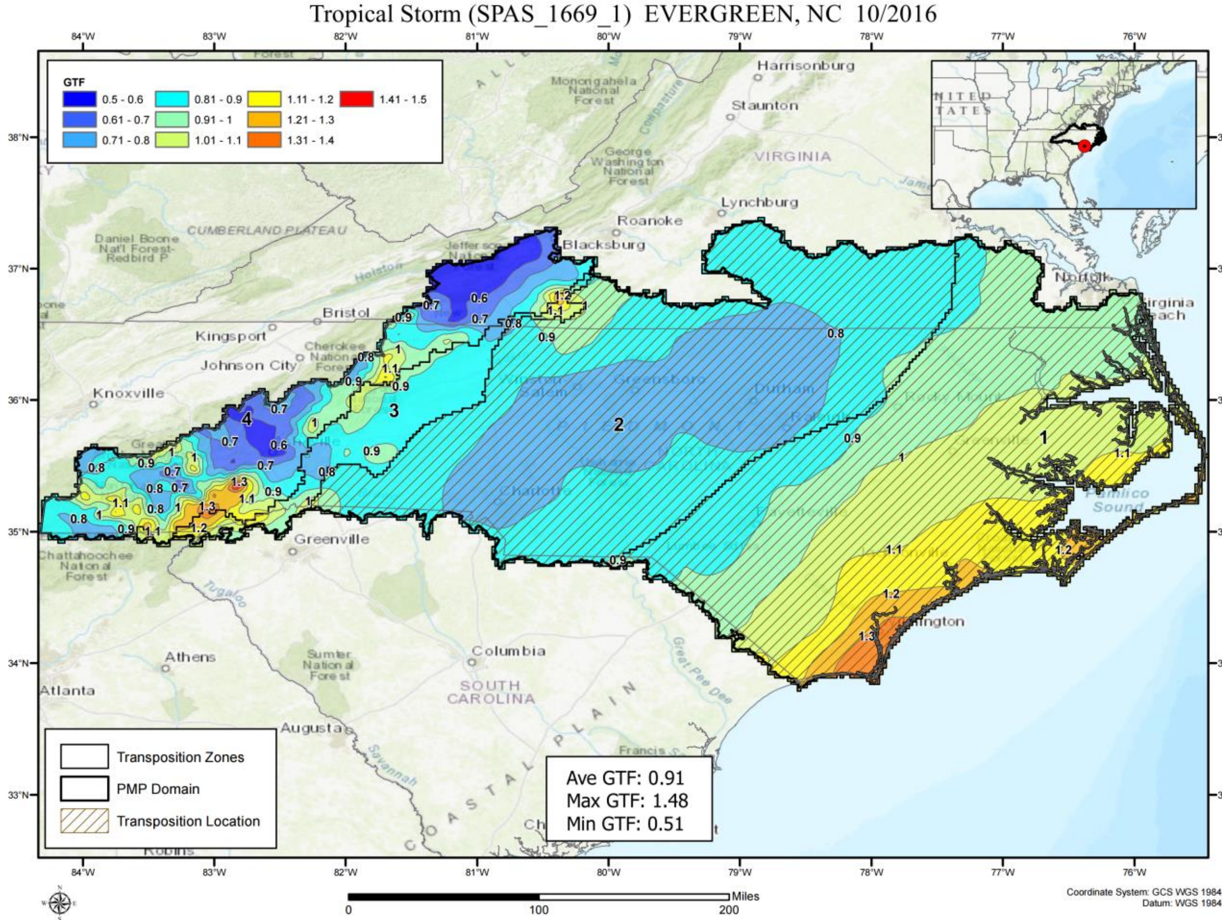
Geographic Transposition Factor
Tropical Storm (SPAS_1552_3) POMPTON LAKE, NJ 9/1999



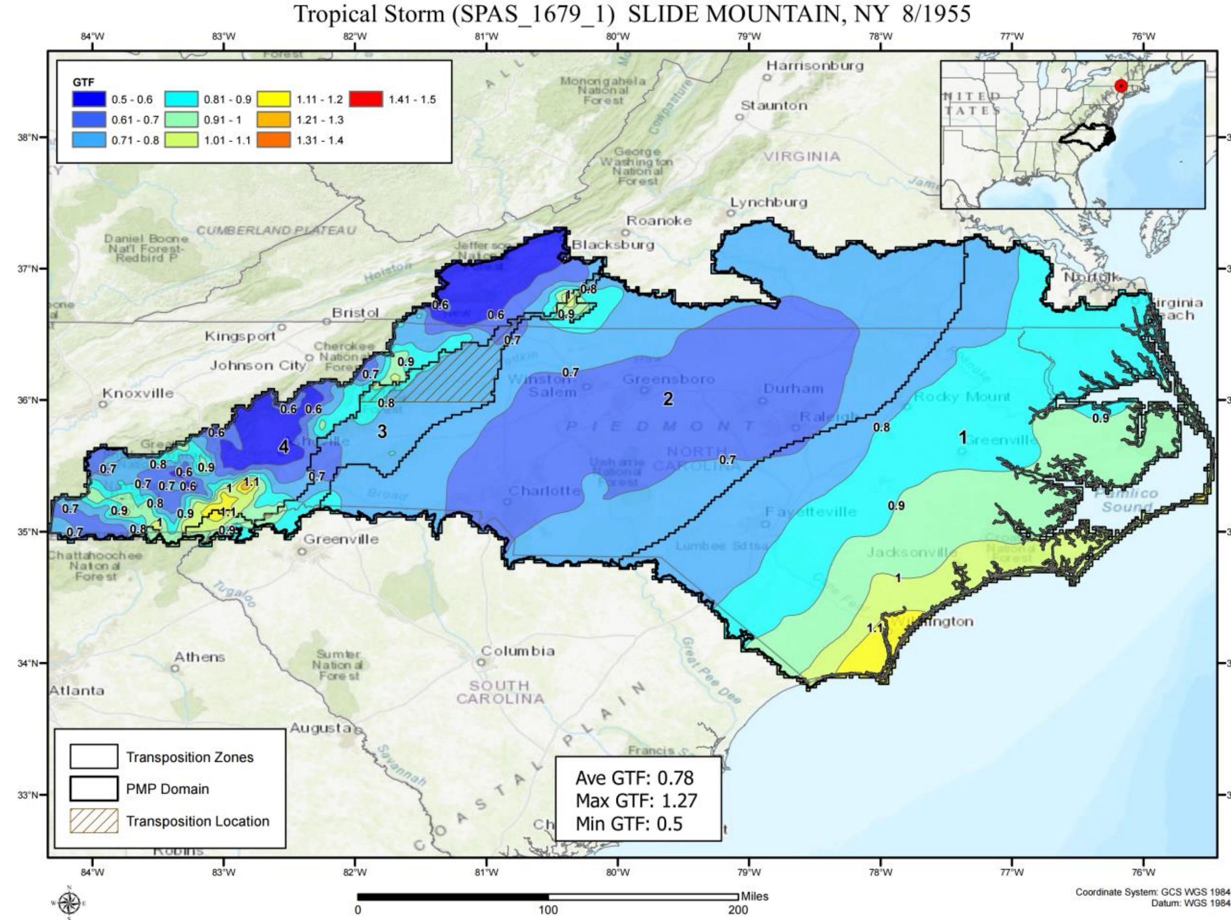
Geographic Transposition Factor
Tropical Storm (SPAS_1552_4) CAIRO, NY 9/1999



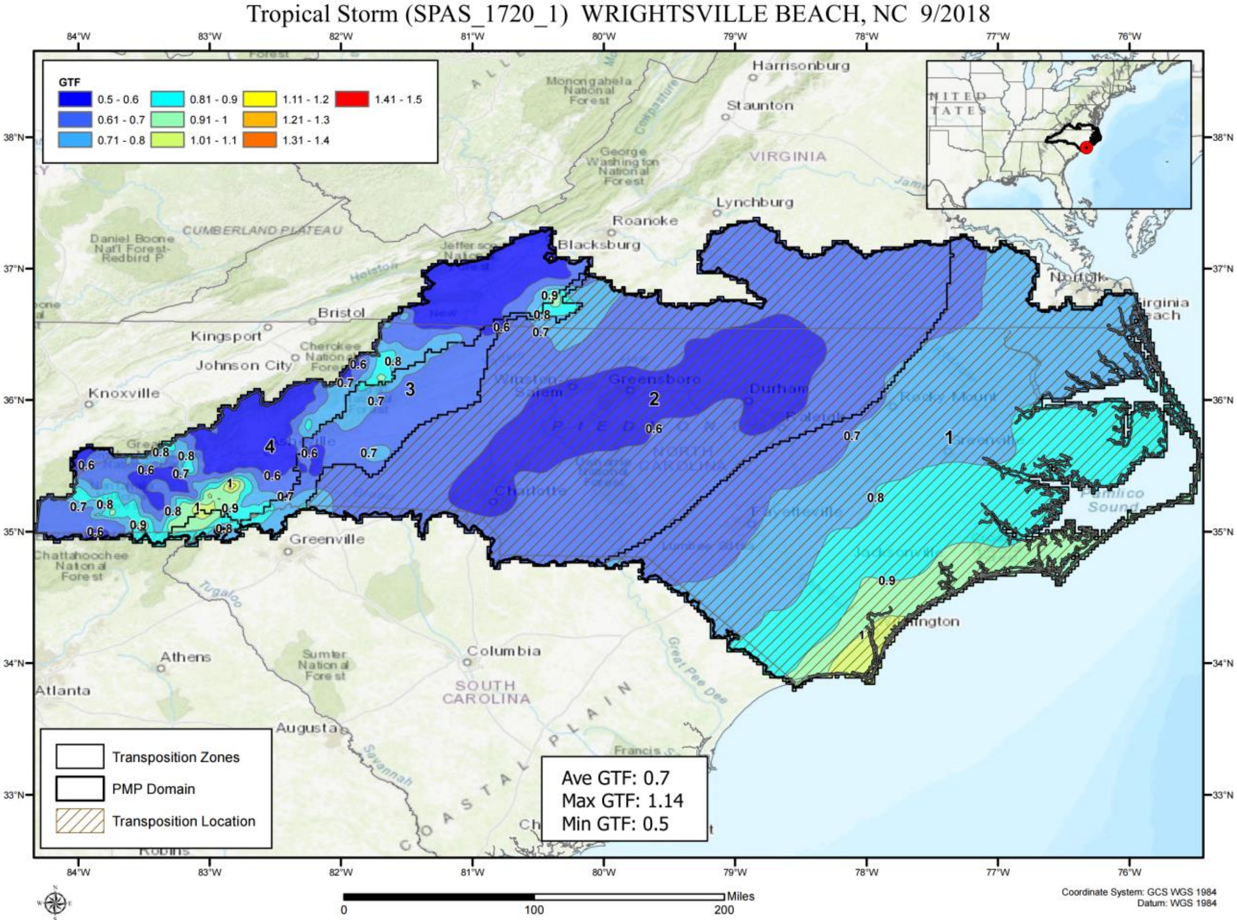
Geographic Transposition Factor
Tropical Storm (SPAS_1669_1) EVERGREEN, NC 10/2016



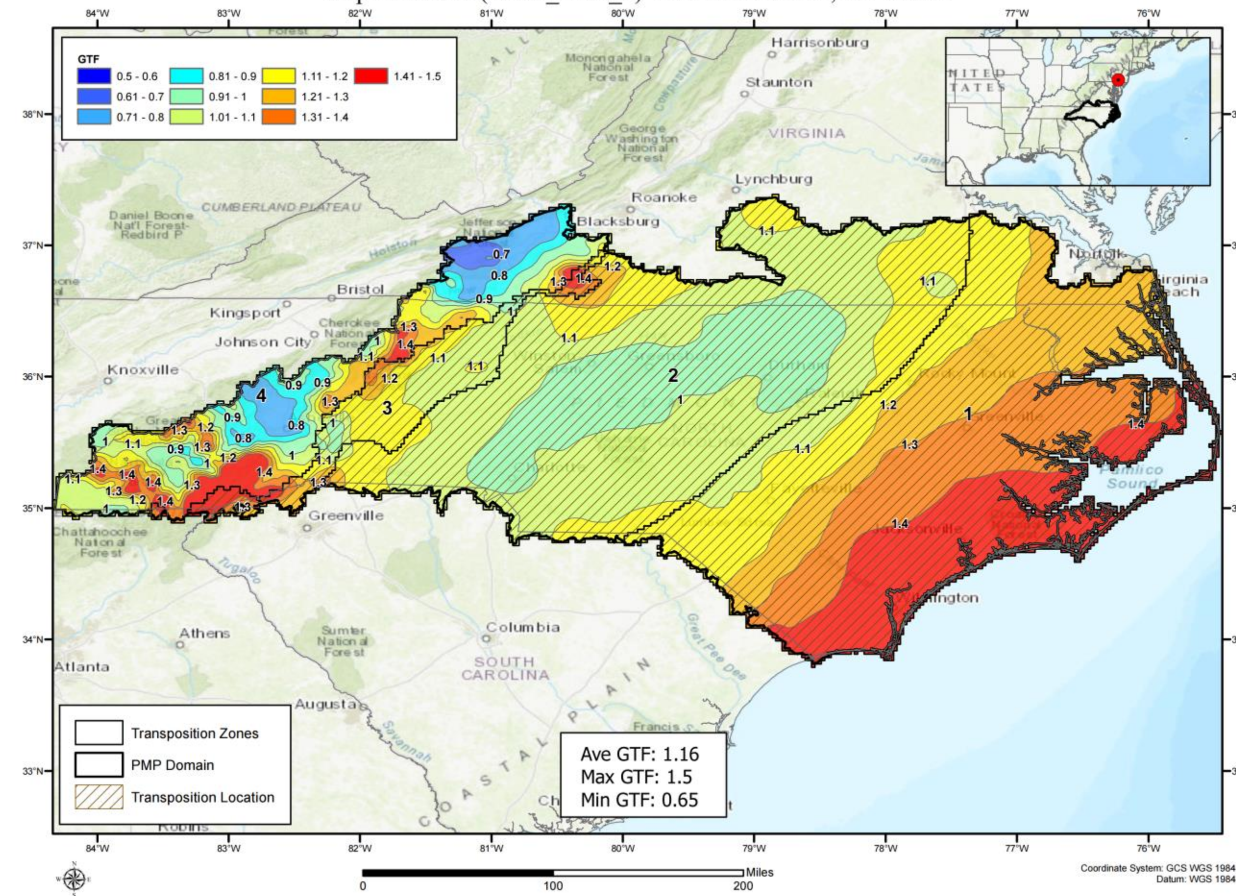
Geographic Transposition Factor
Tropical Storm (SPAS_1679_1) SLIDE MOUNTAIN, NY 8/1955



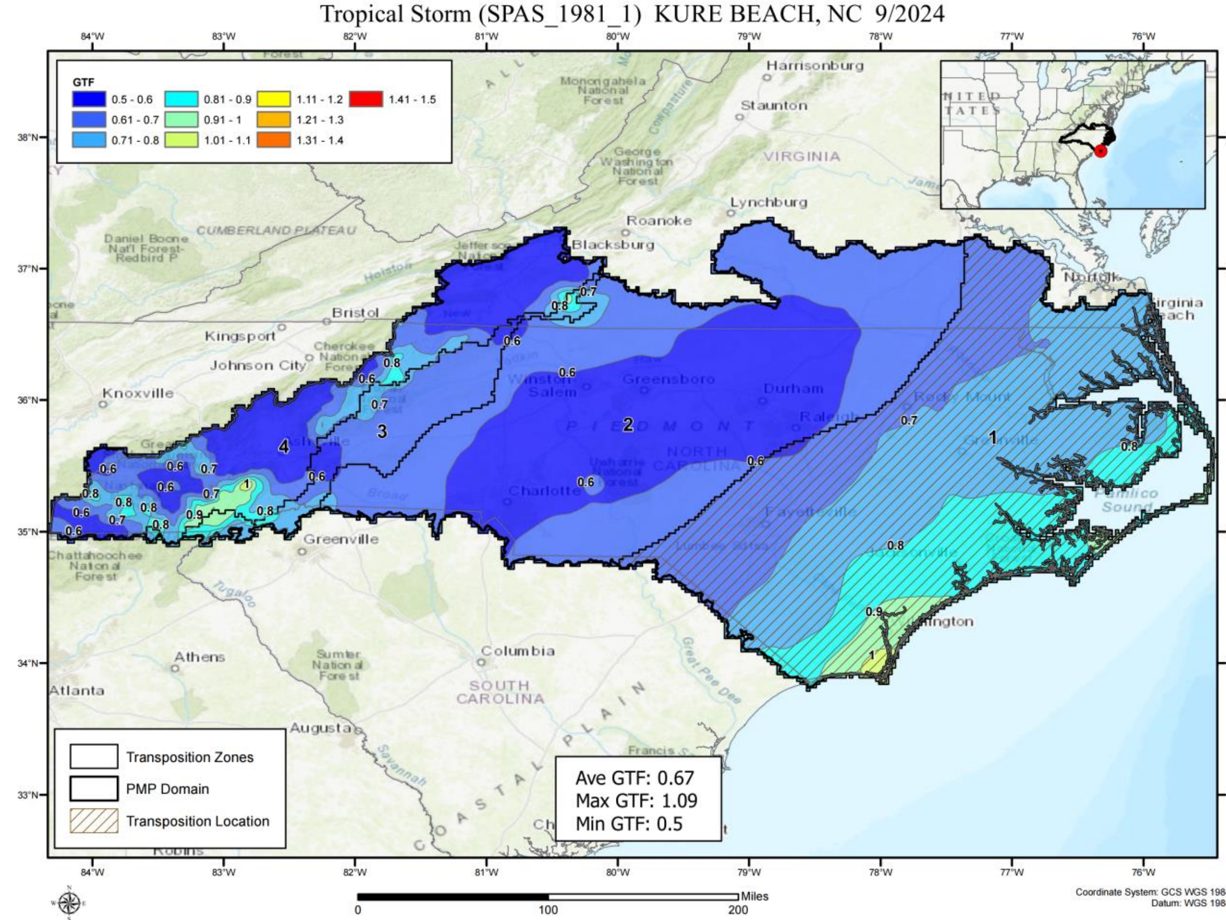
Geographic Transposition Factor
Tropical Storm (SPAS_1720_1) WRIGHTSVILLE BEACH, NC 9/2018



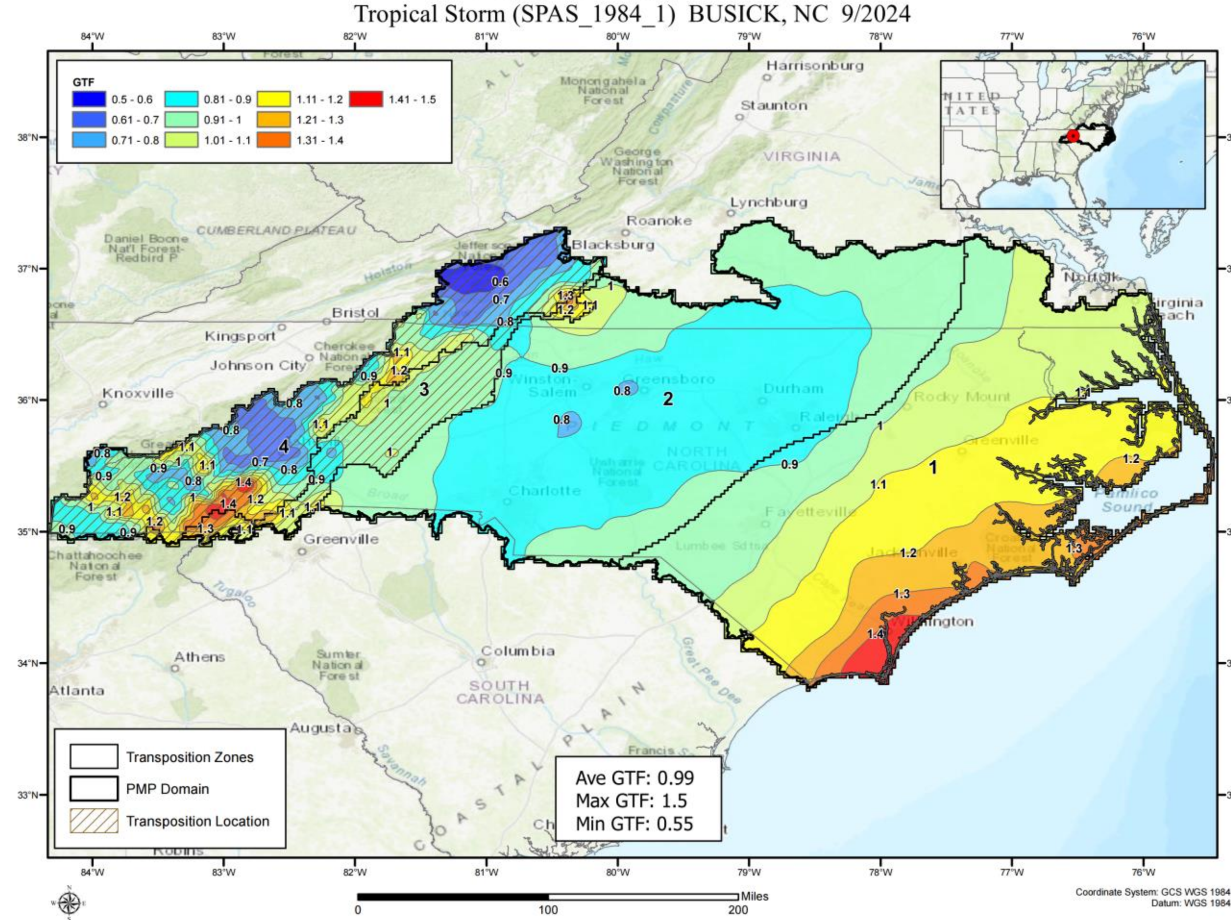
Geographic Transposition Factor
Tropical Storm (SPAS_1891_1) DOWNINGTON, PA 8/2021



Geographic Transposition Factor
Tropical Storm (SPAS_1981_1) KURE BEACH, NC 9/2024



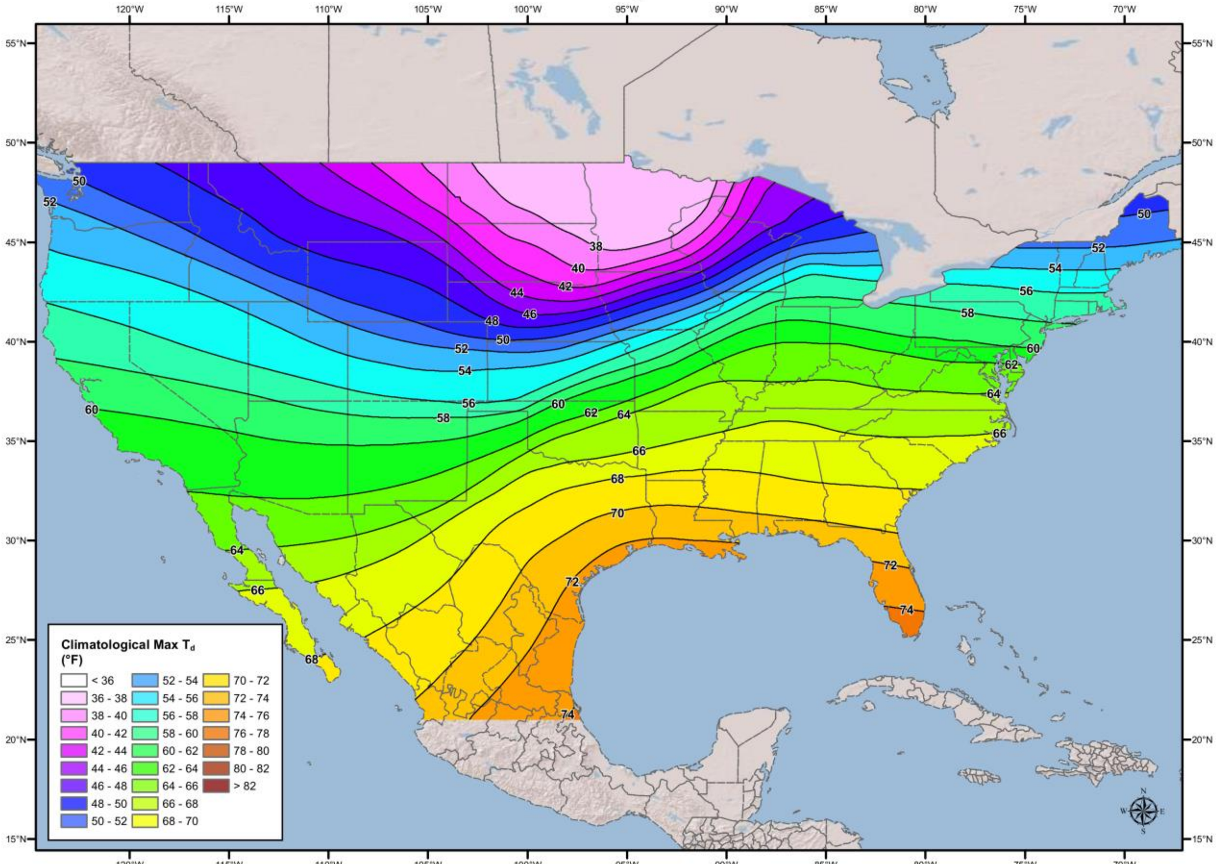
Geographic Transposition Factor
Tropical Storm (SPAS_1984_1) BUSICK, NC 9/2024



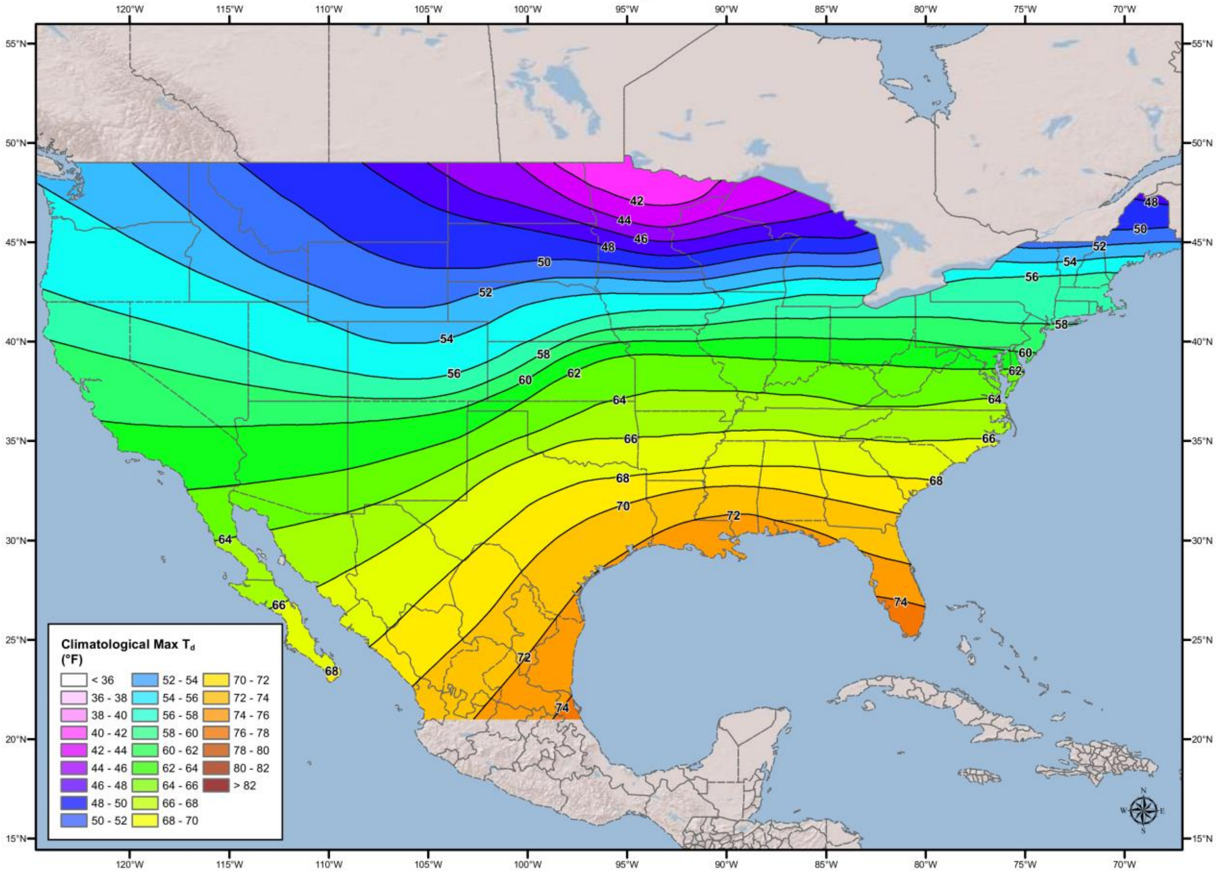
Appendix C
100-year Return Frequency Maximum Average Dew Point Temperature Climatology Maps

6-hour 1000mb Dew Point Maps

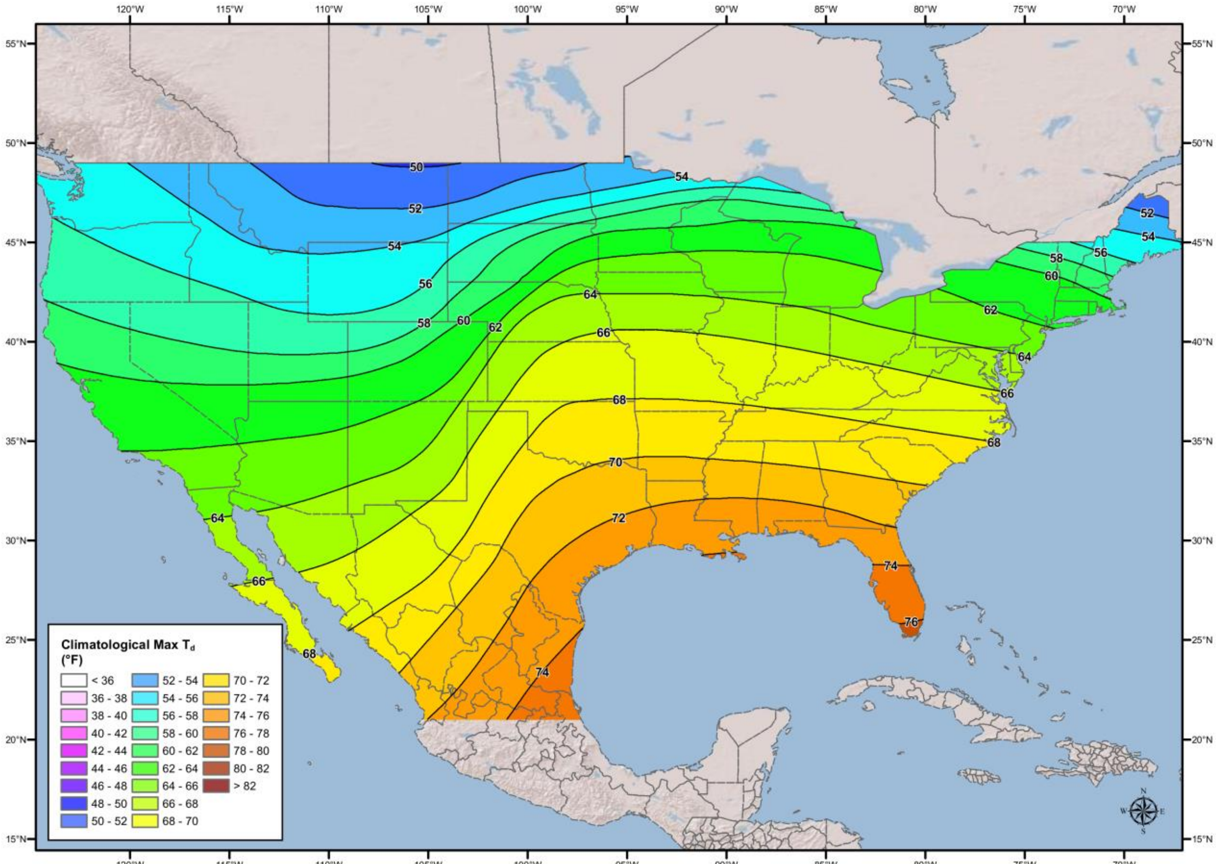
6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
January



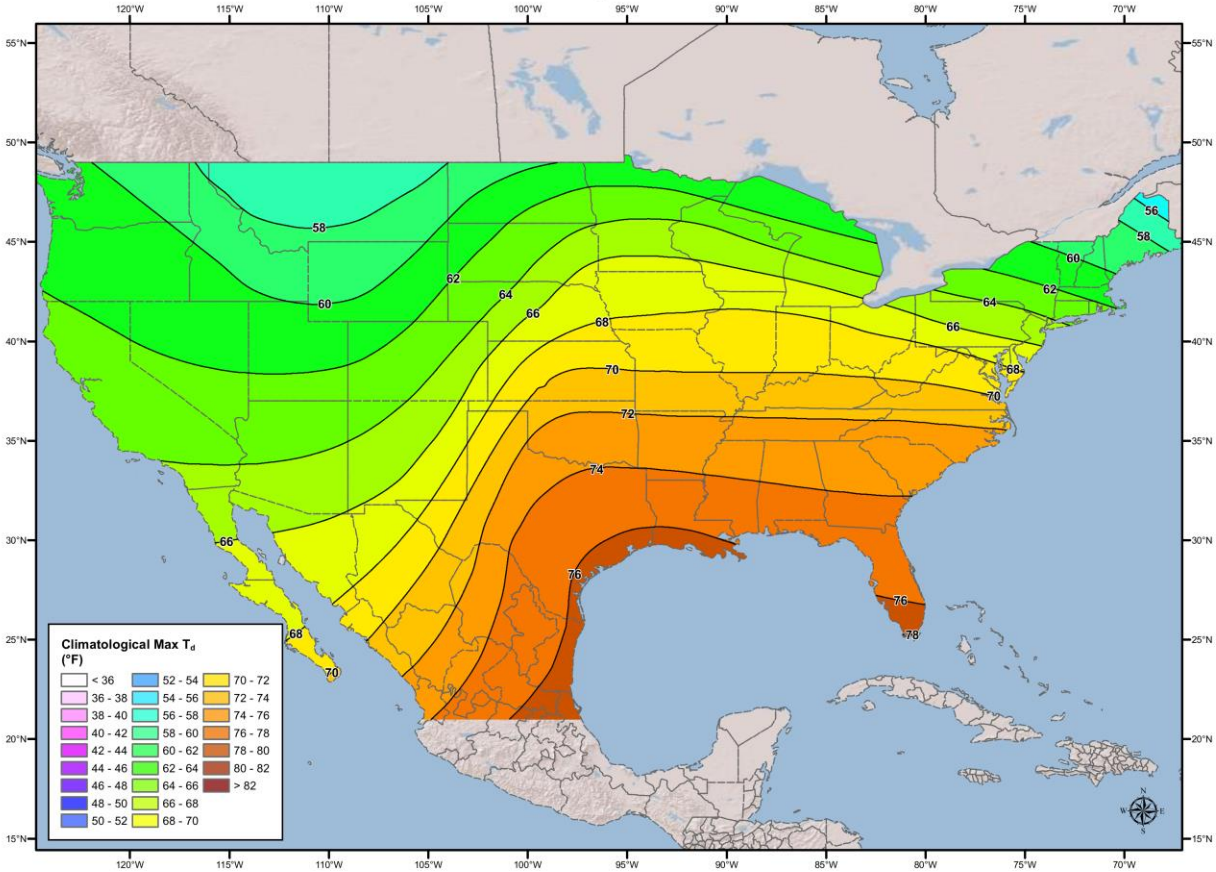
6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
February

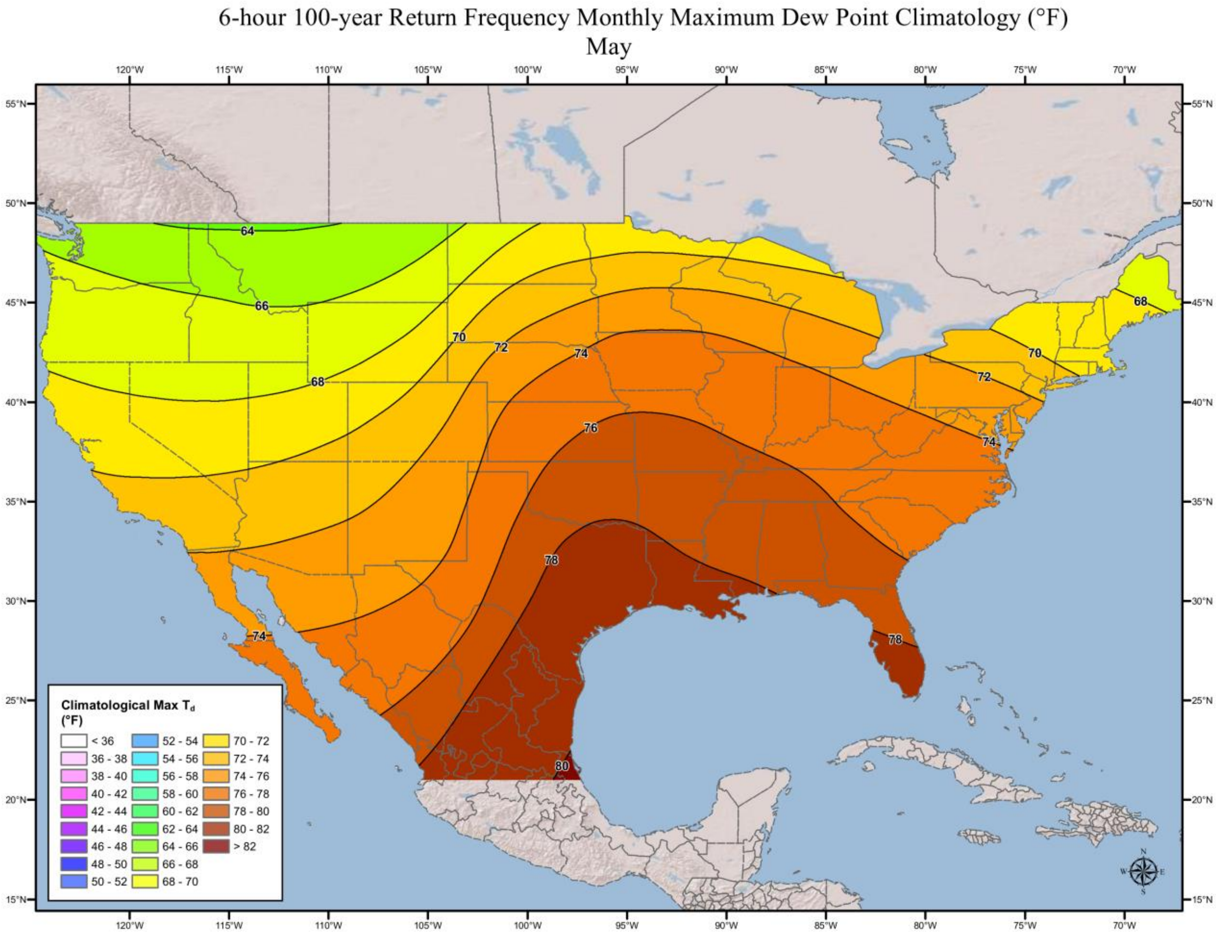


6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
March



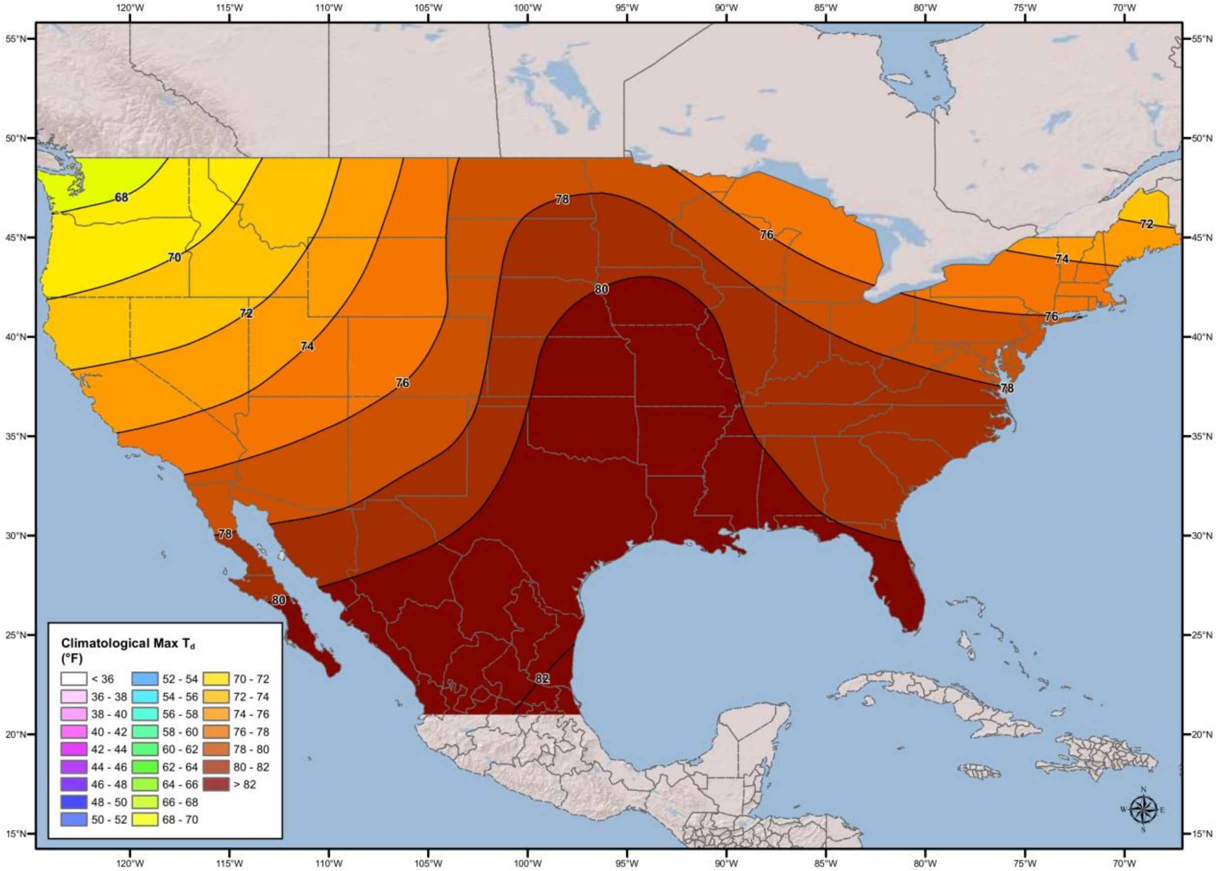
6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
April



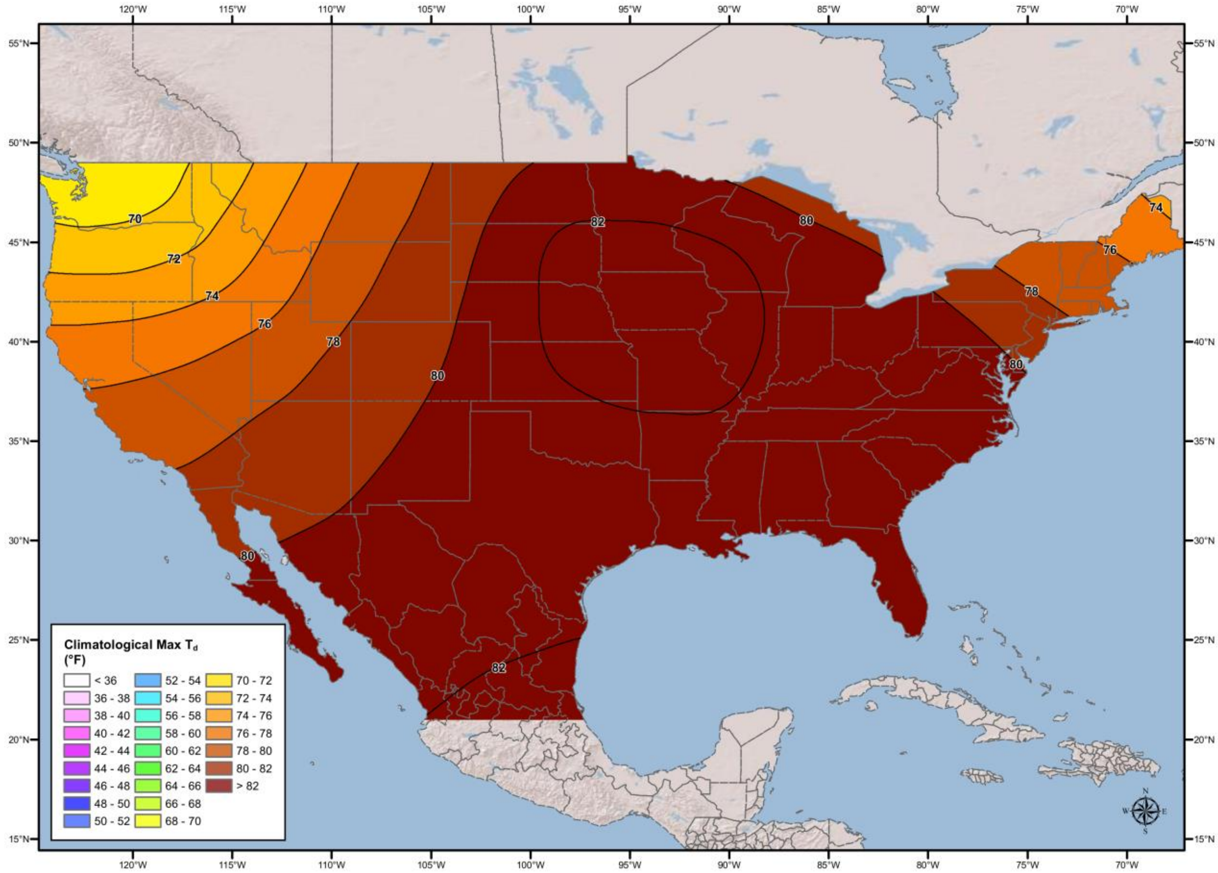


6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
May
Climatological Max T_d (°F)
< 36
36 - 38
38 - 40
40 - 42
42 - 44
44 - 46
46 - 48
48 - 50
50 - 52
52 - 54
54 - 56
56 - 58
58 - 60
60 - 62
62 - 64
64 - 66
66 - 68
68 - 70
70 - 72
72 - 74
74 - 76
76 - 78
78 - 80
80 - 82
> 82

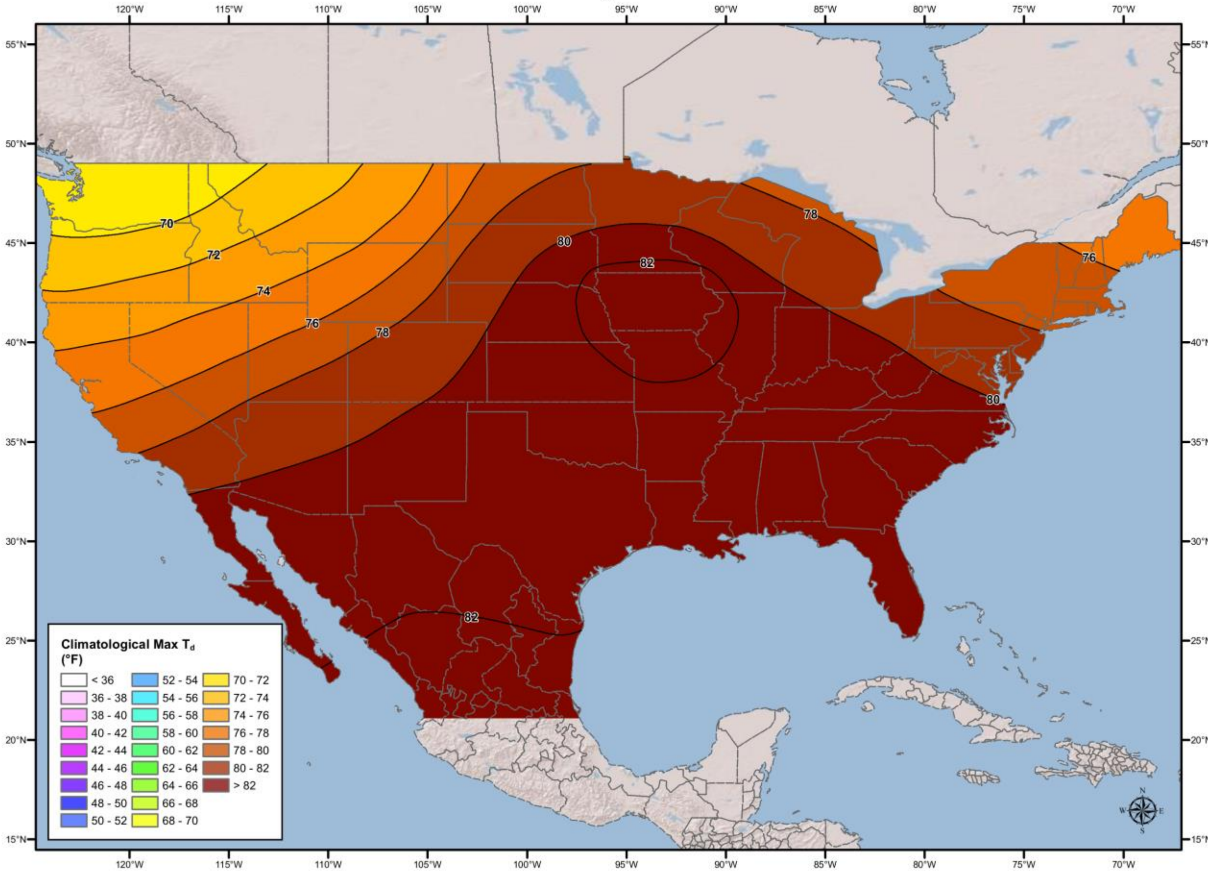
6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
June



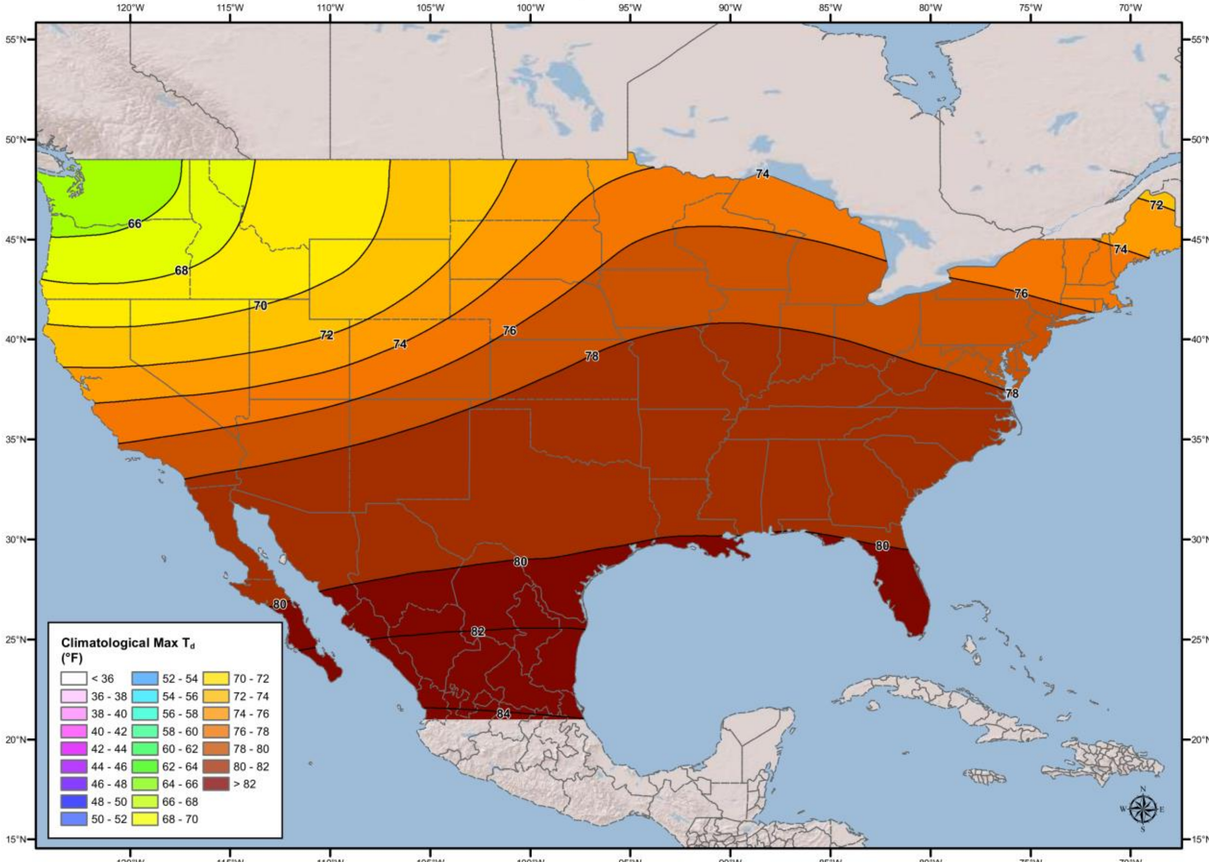
6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
July



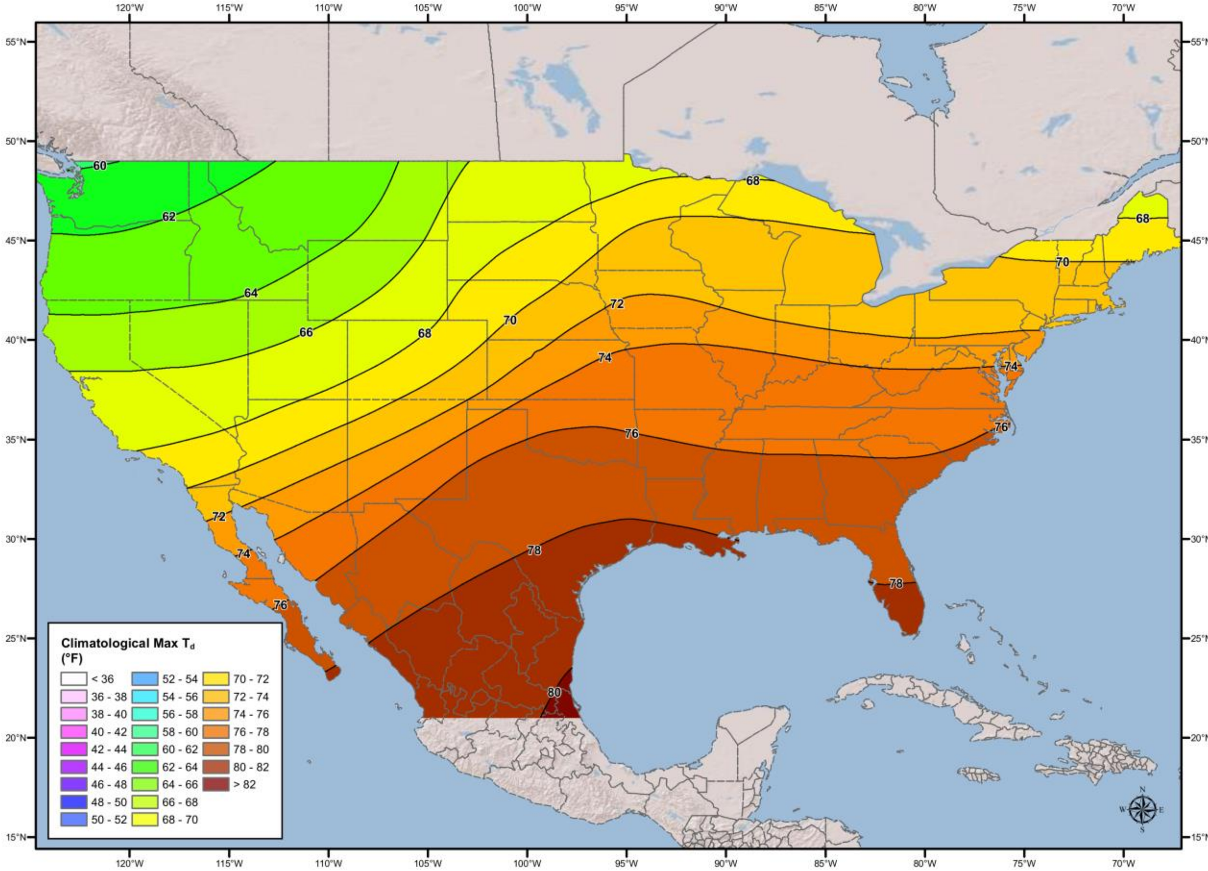
6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
August



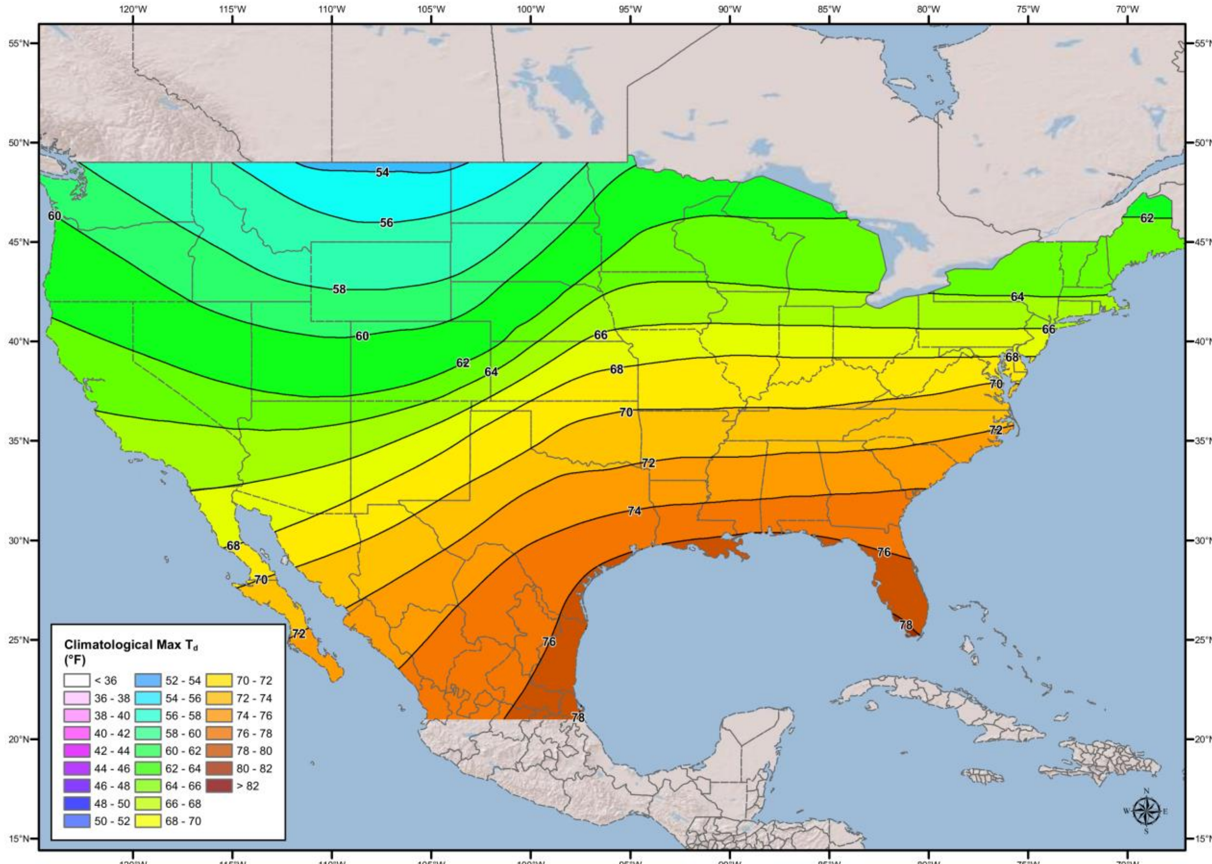
6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
September



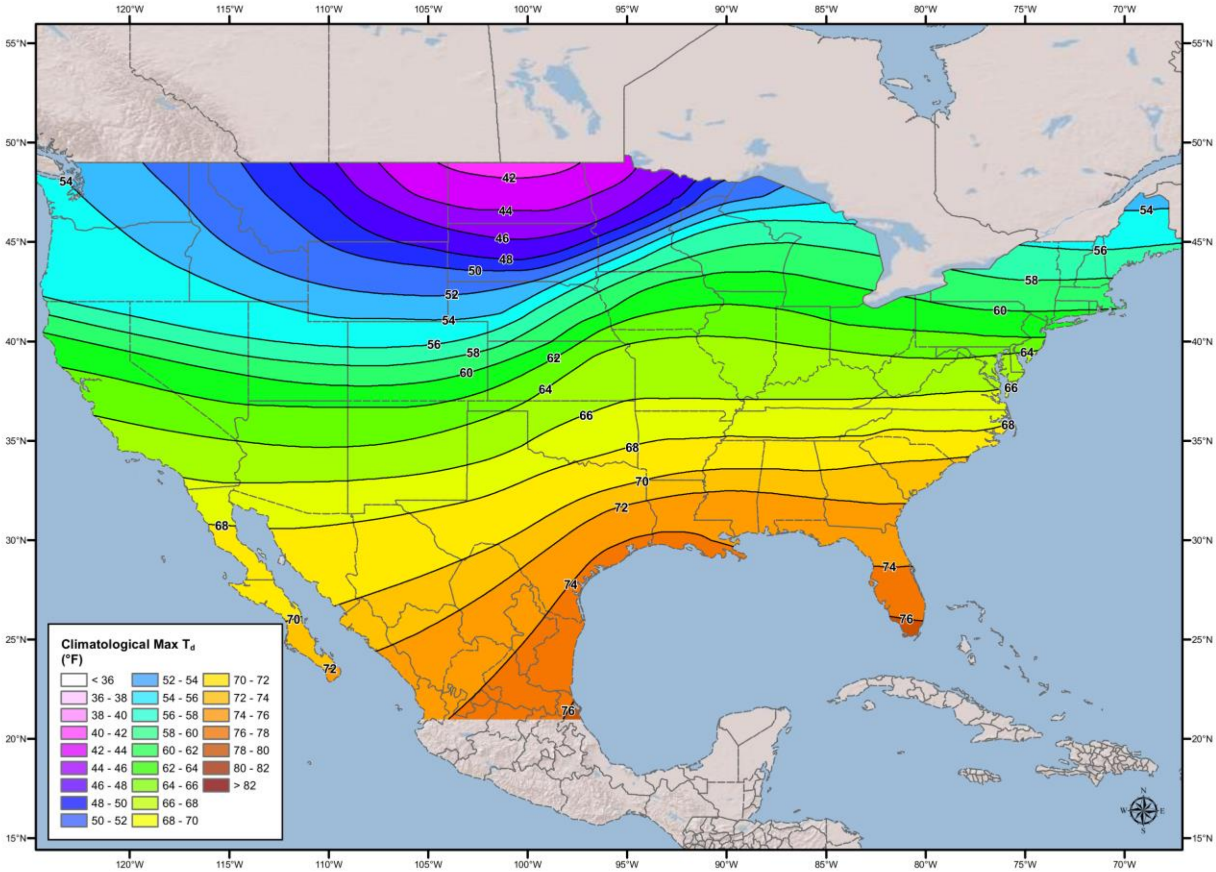
6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
October



6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
November

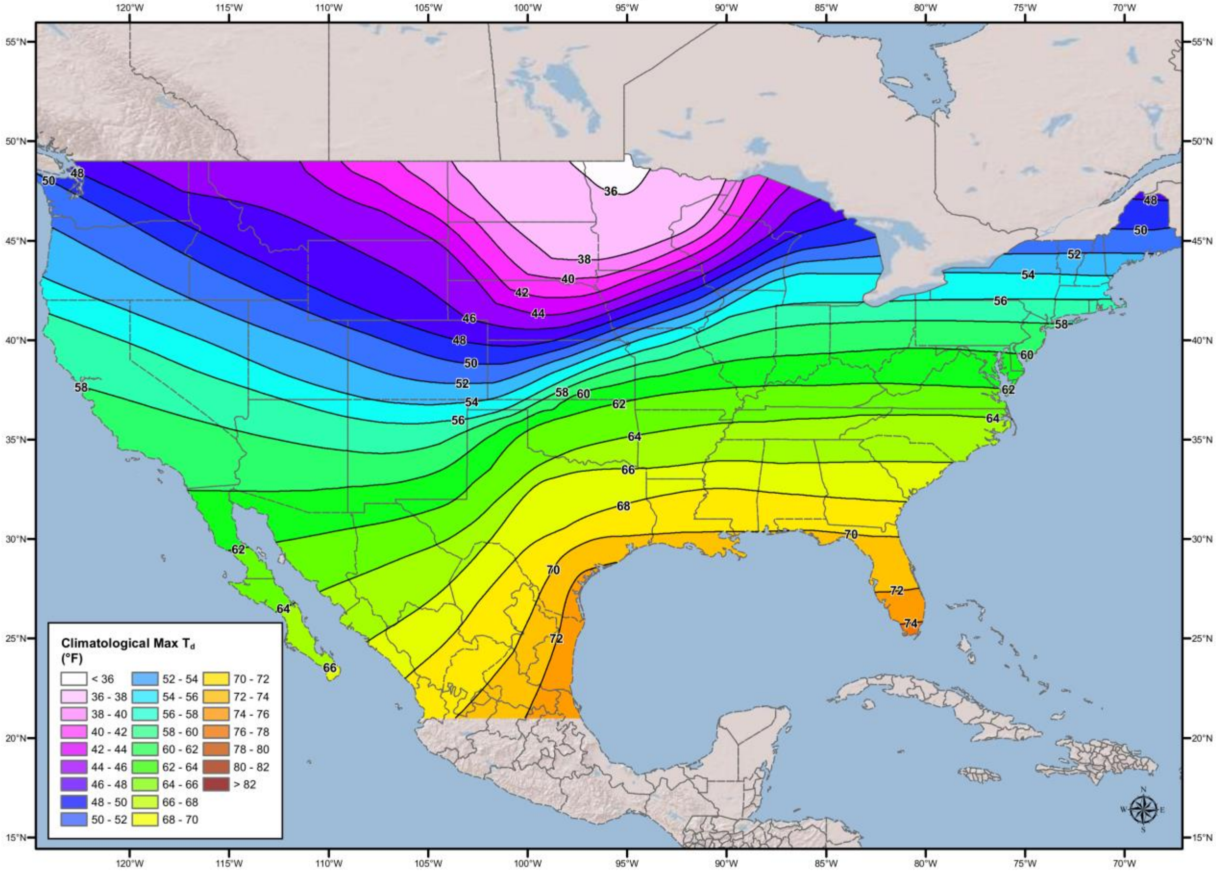


6-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
December

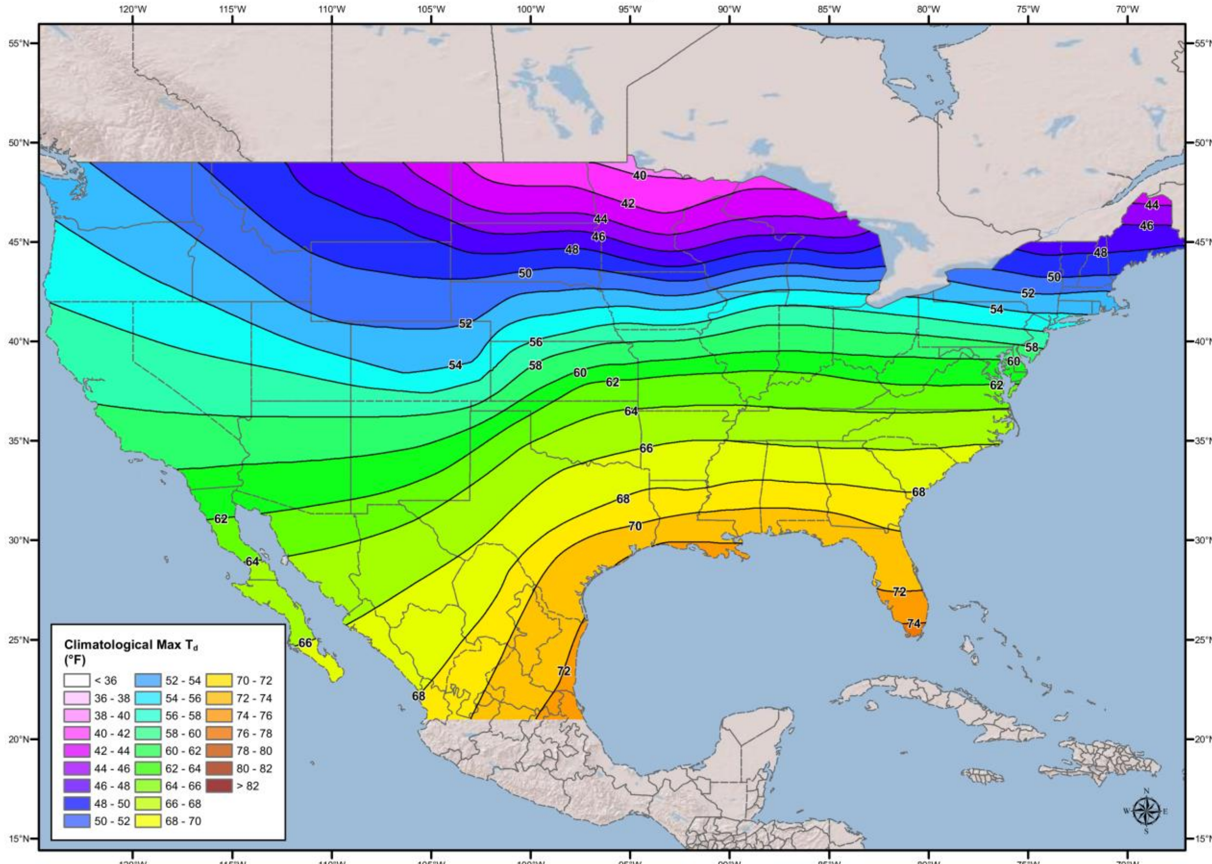


12-hour 1000mb Dew Point Maps

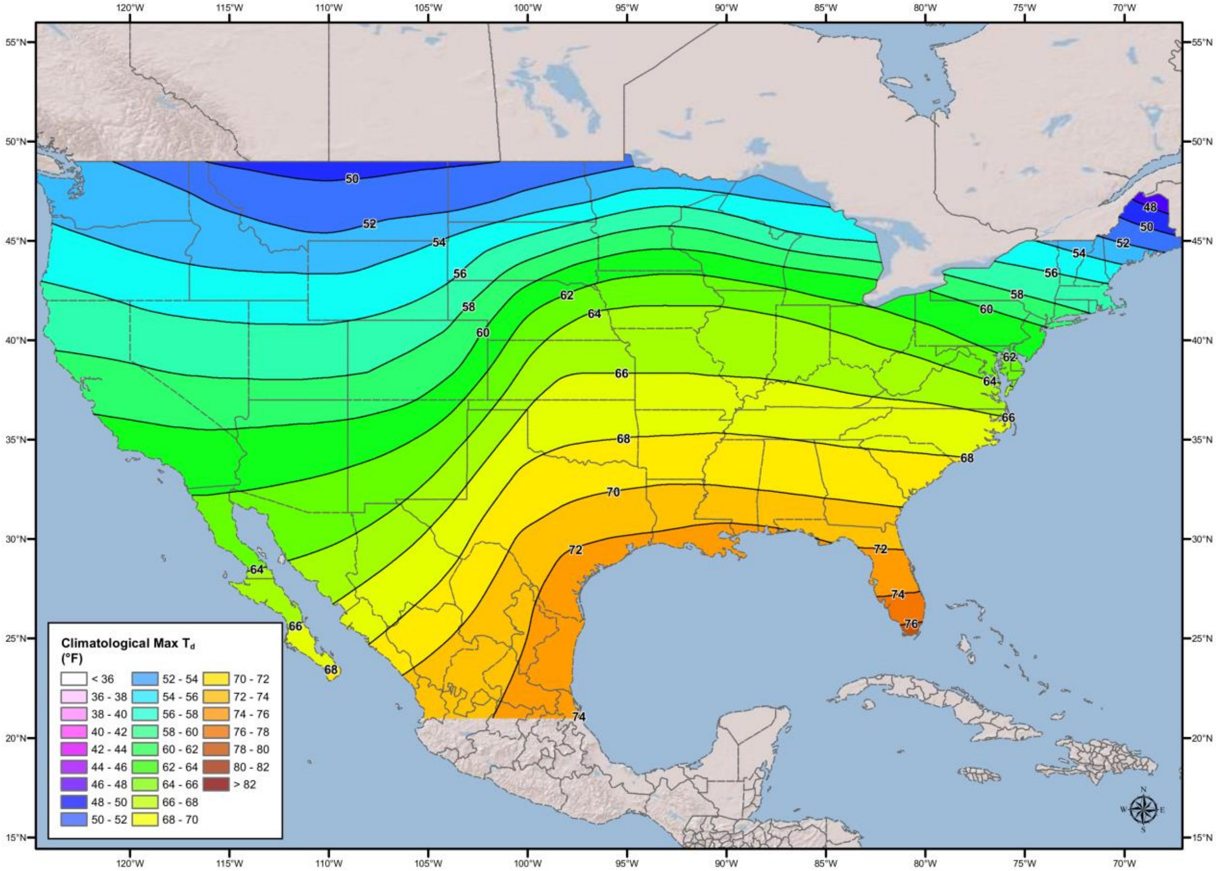
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
January



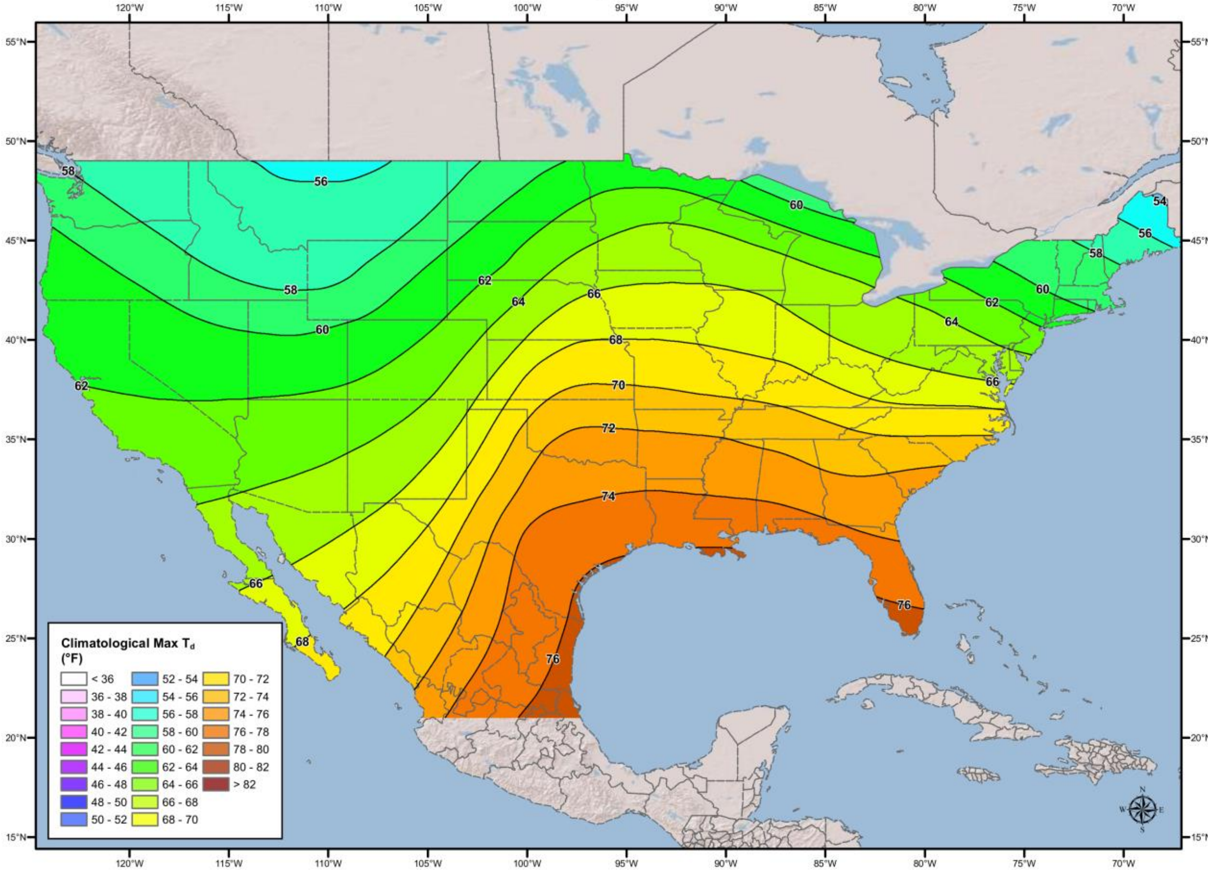
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
February



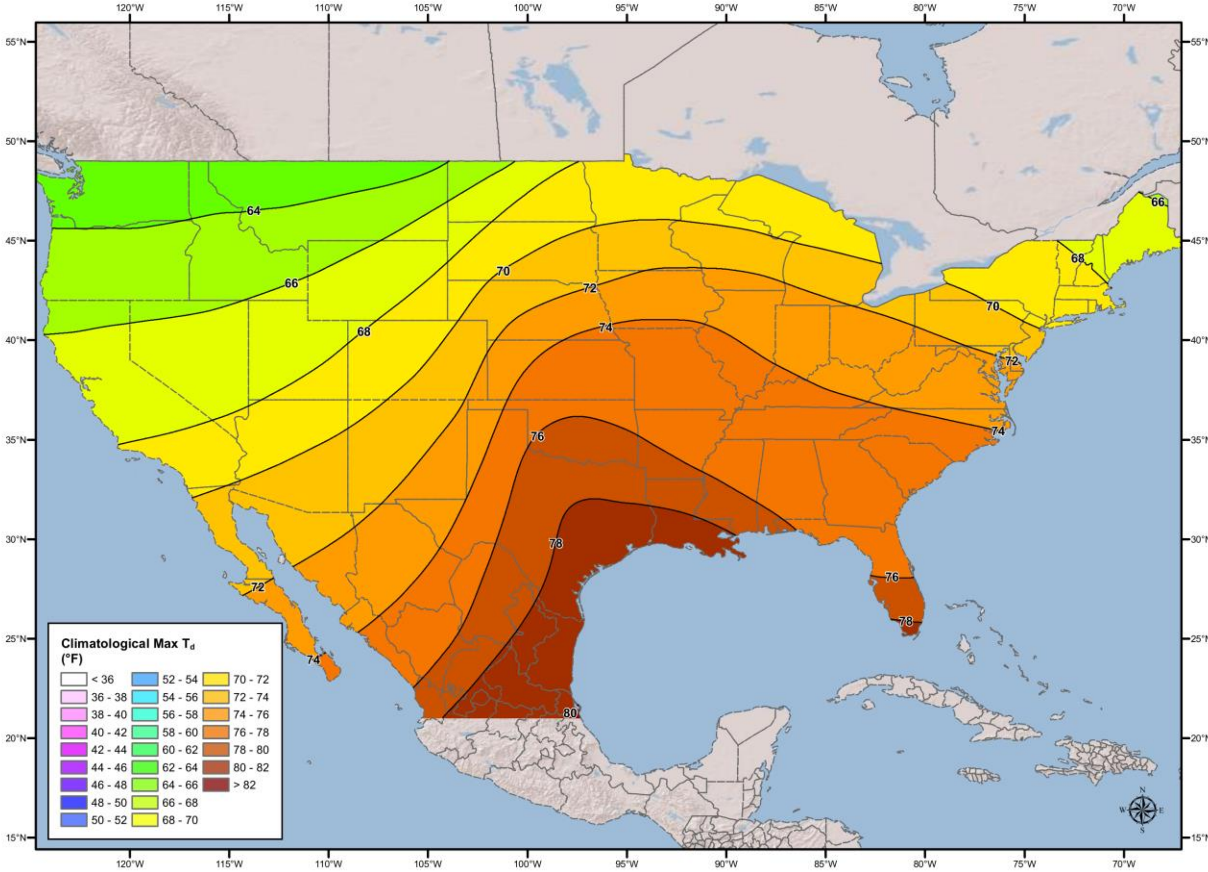
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
March



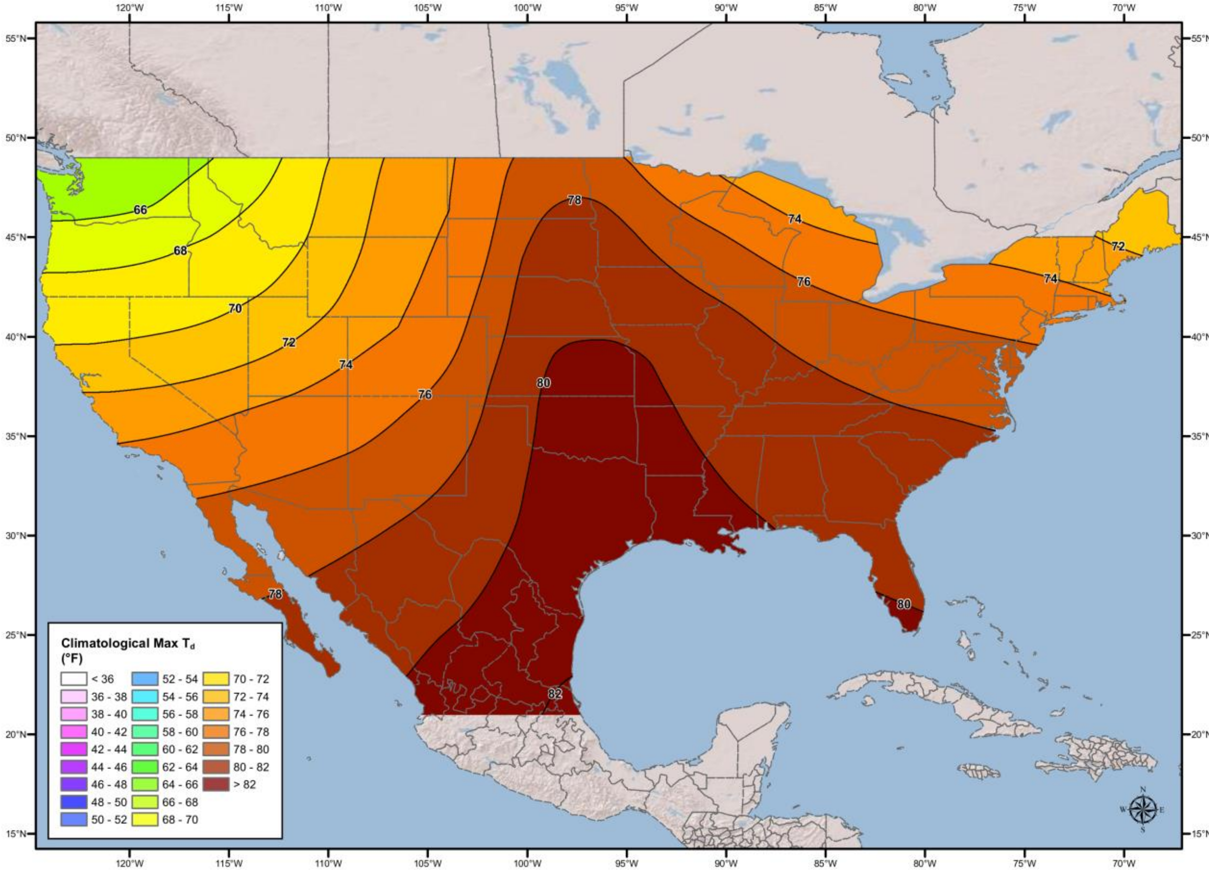
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
April



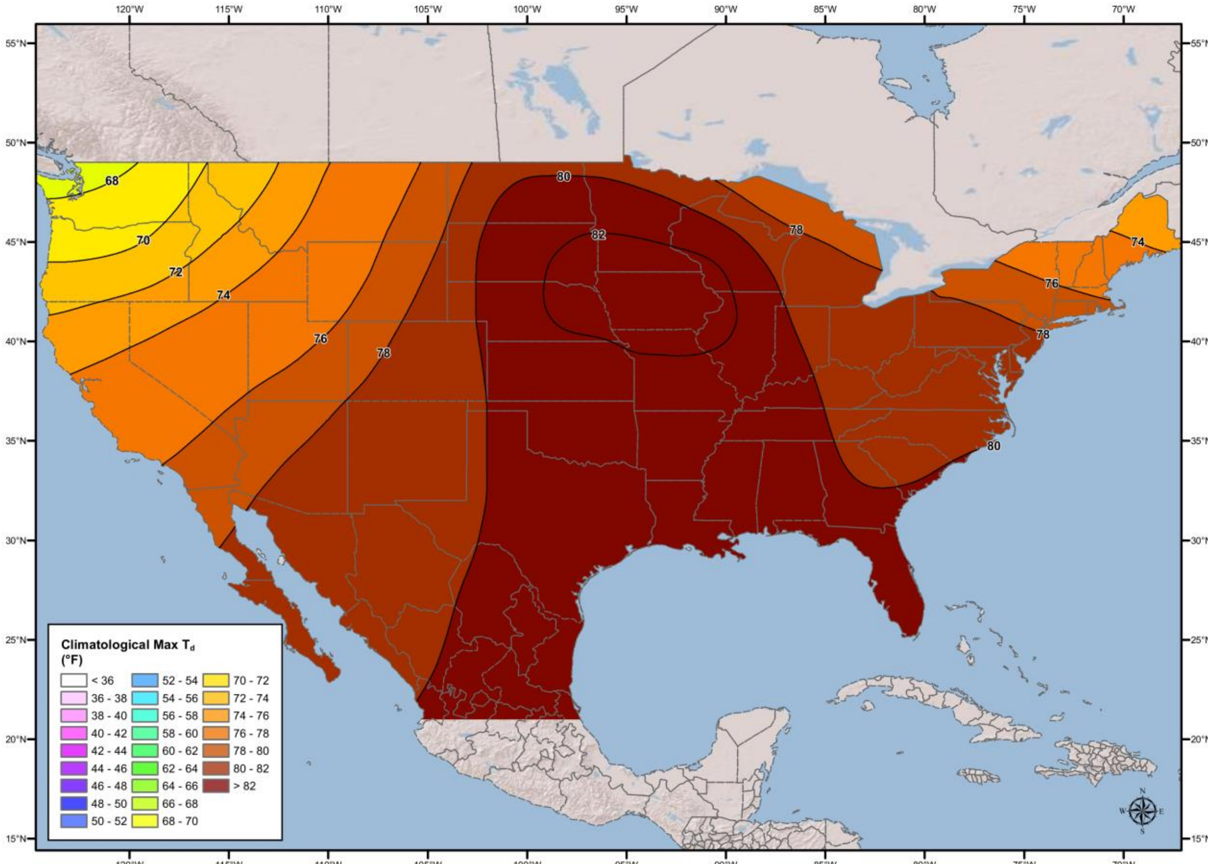
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
May



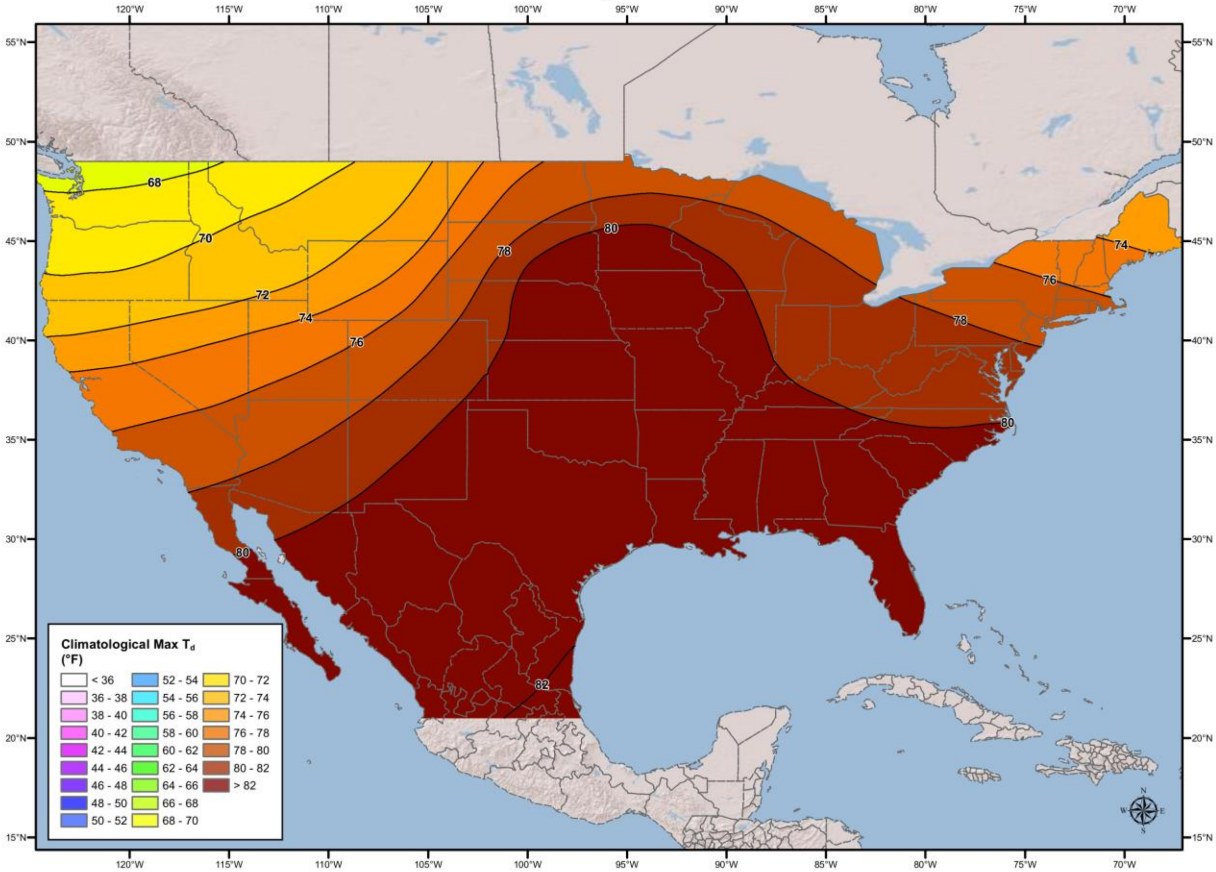
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
June



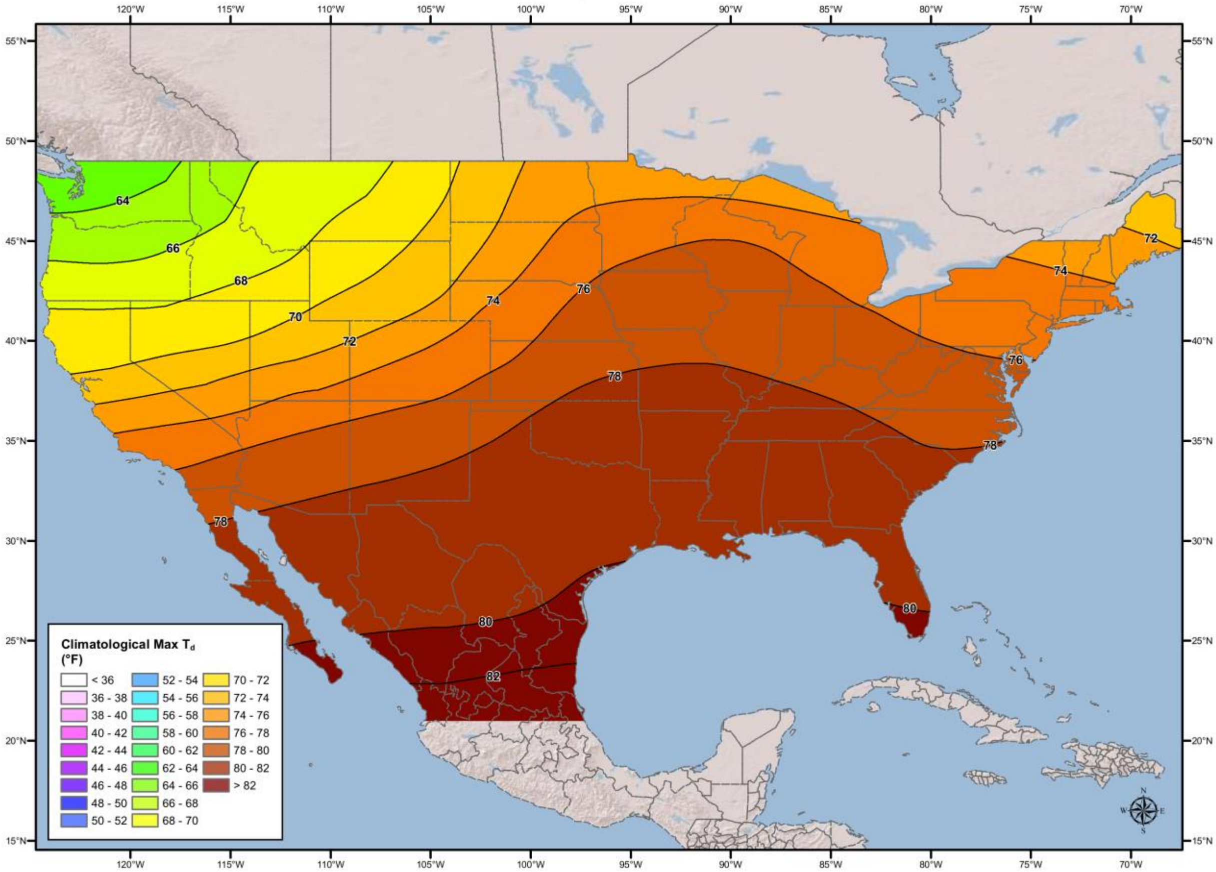
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
July



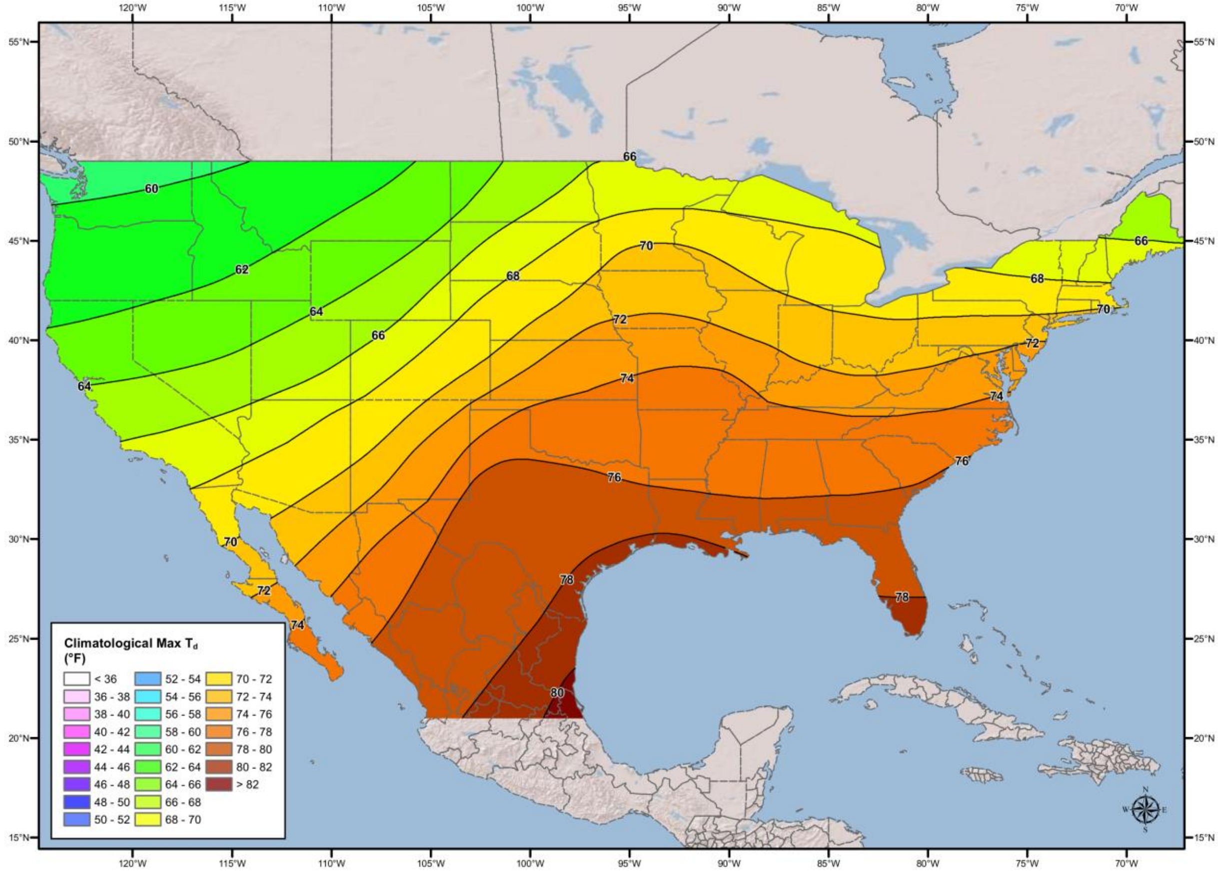
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
August



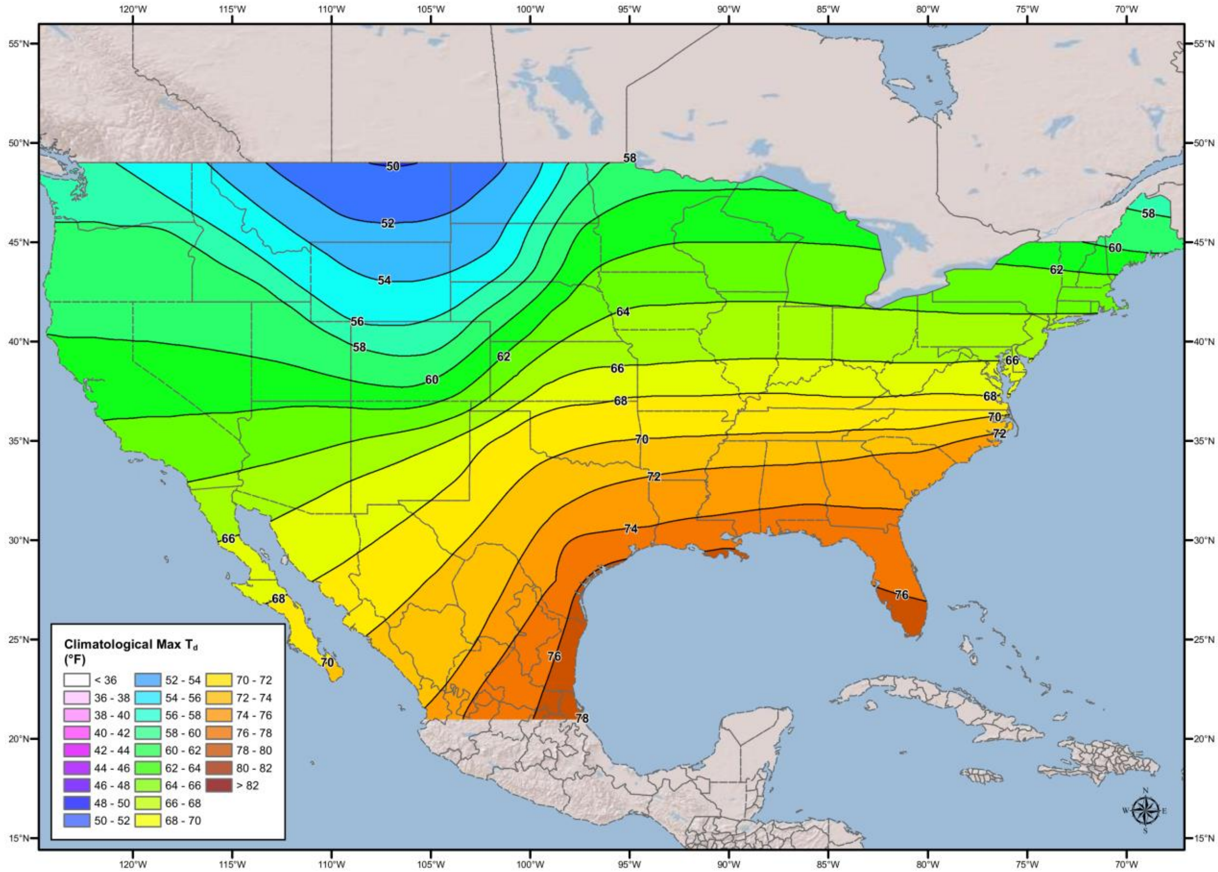
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
September



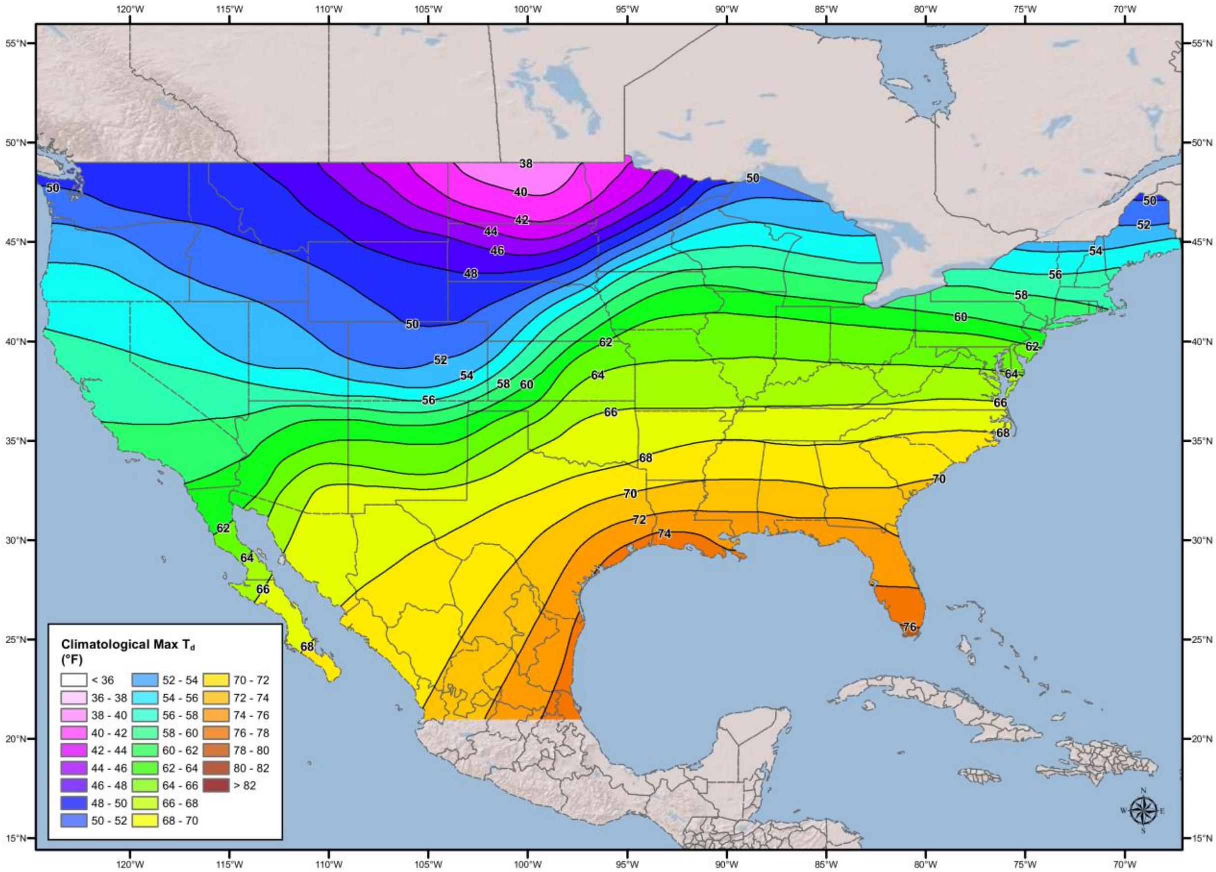
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
October



12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
November



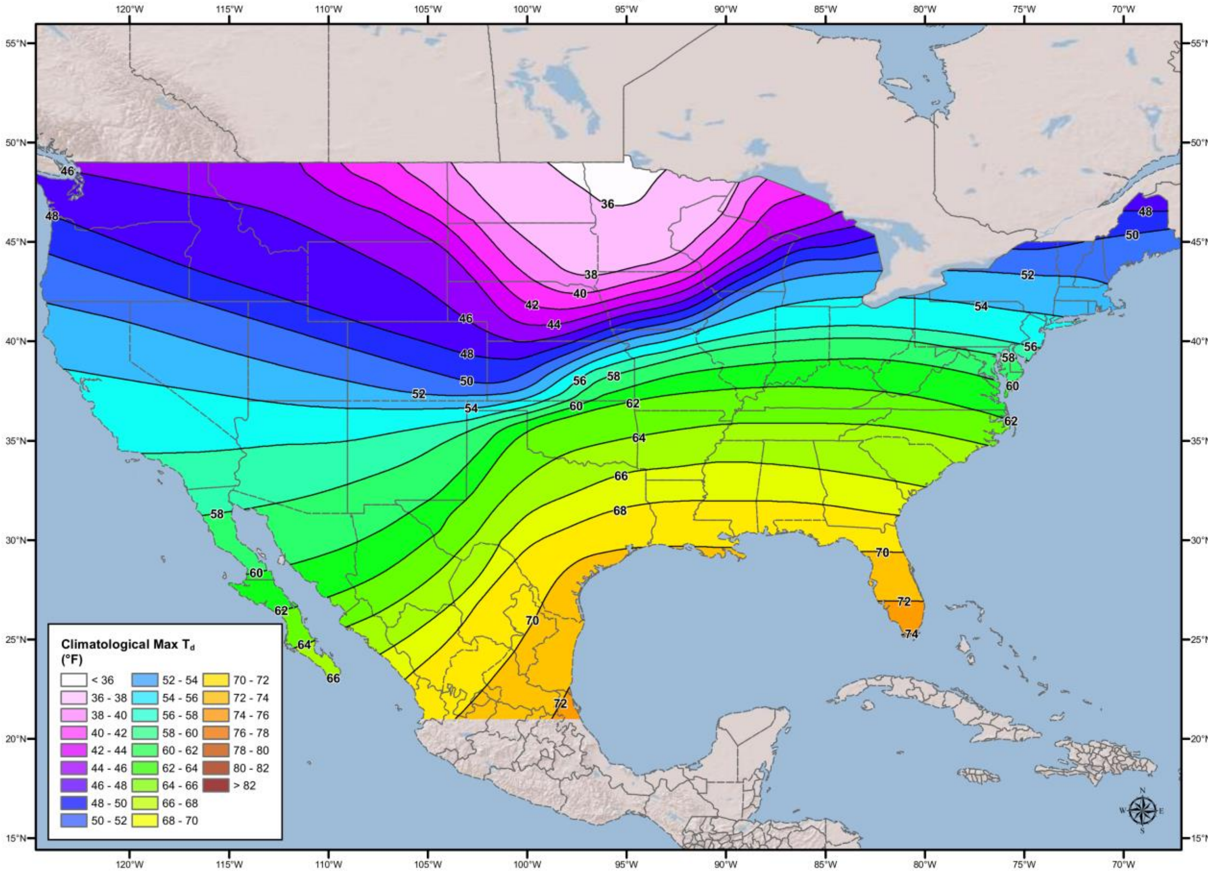
12-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
December



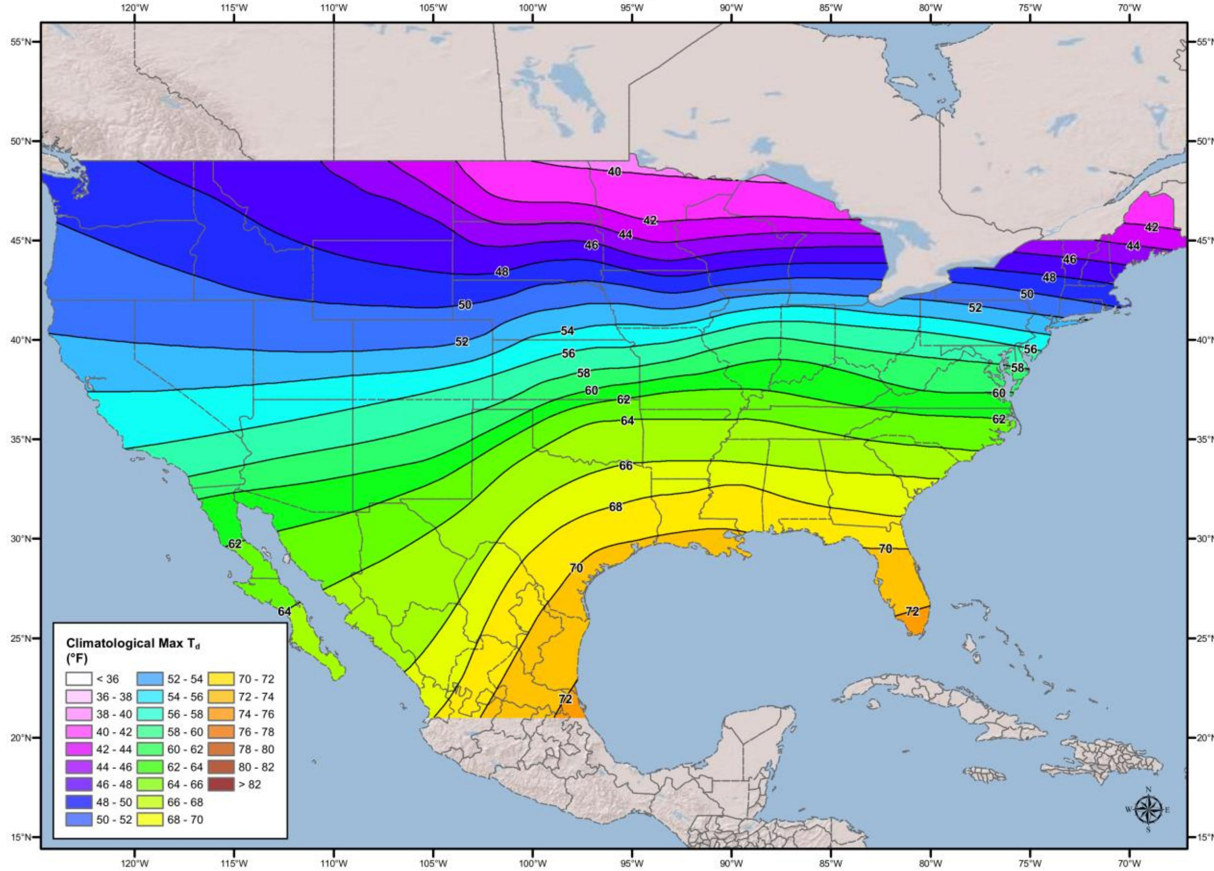
24-hour 1000mb Dew Point Maps

24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)

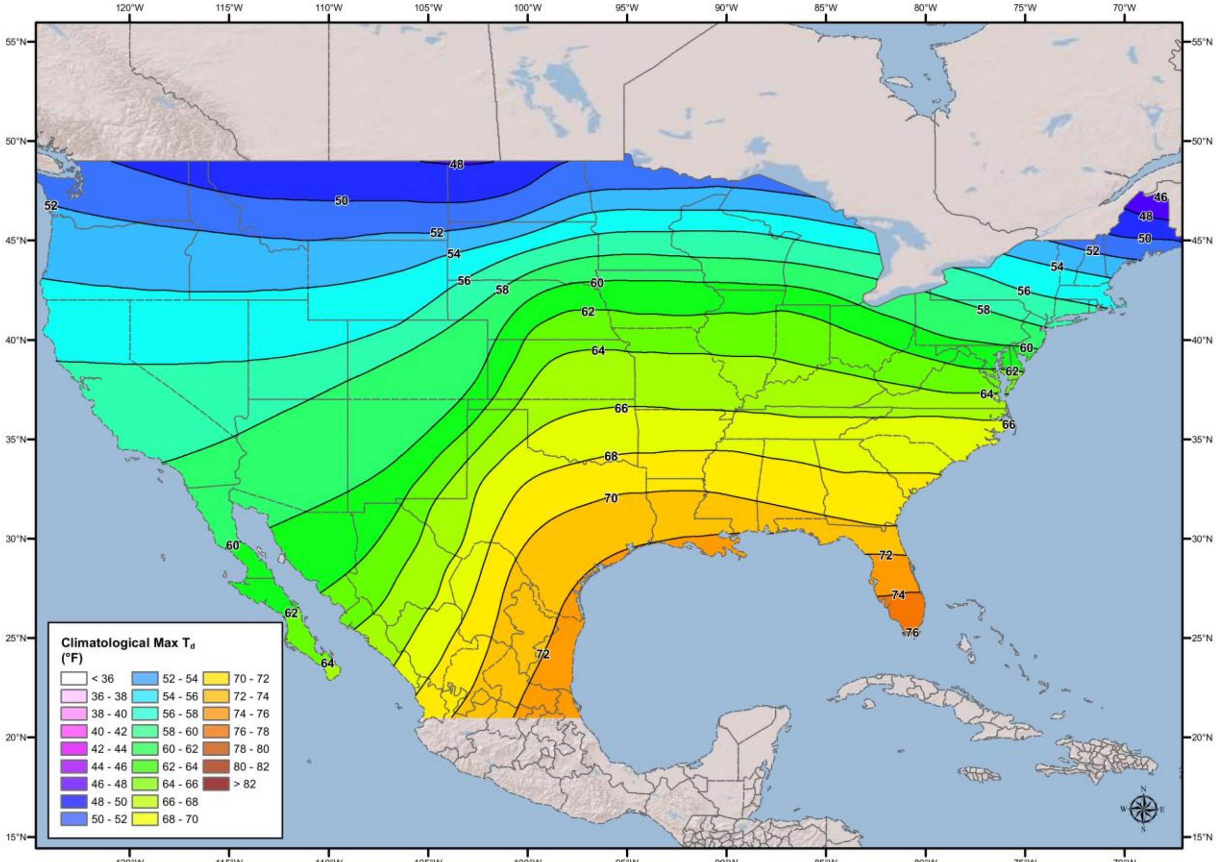
January



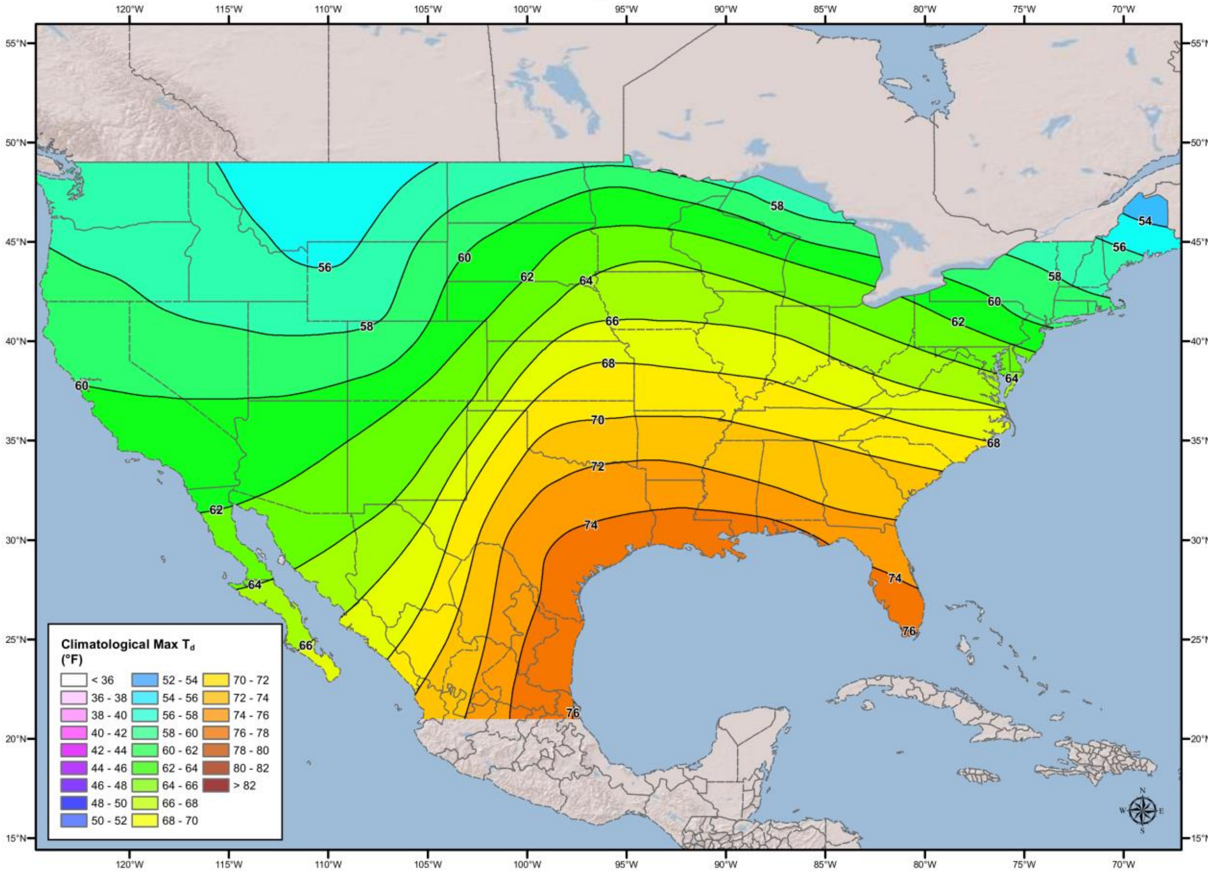
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
February



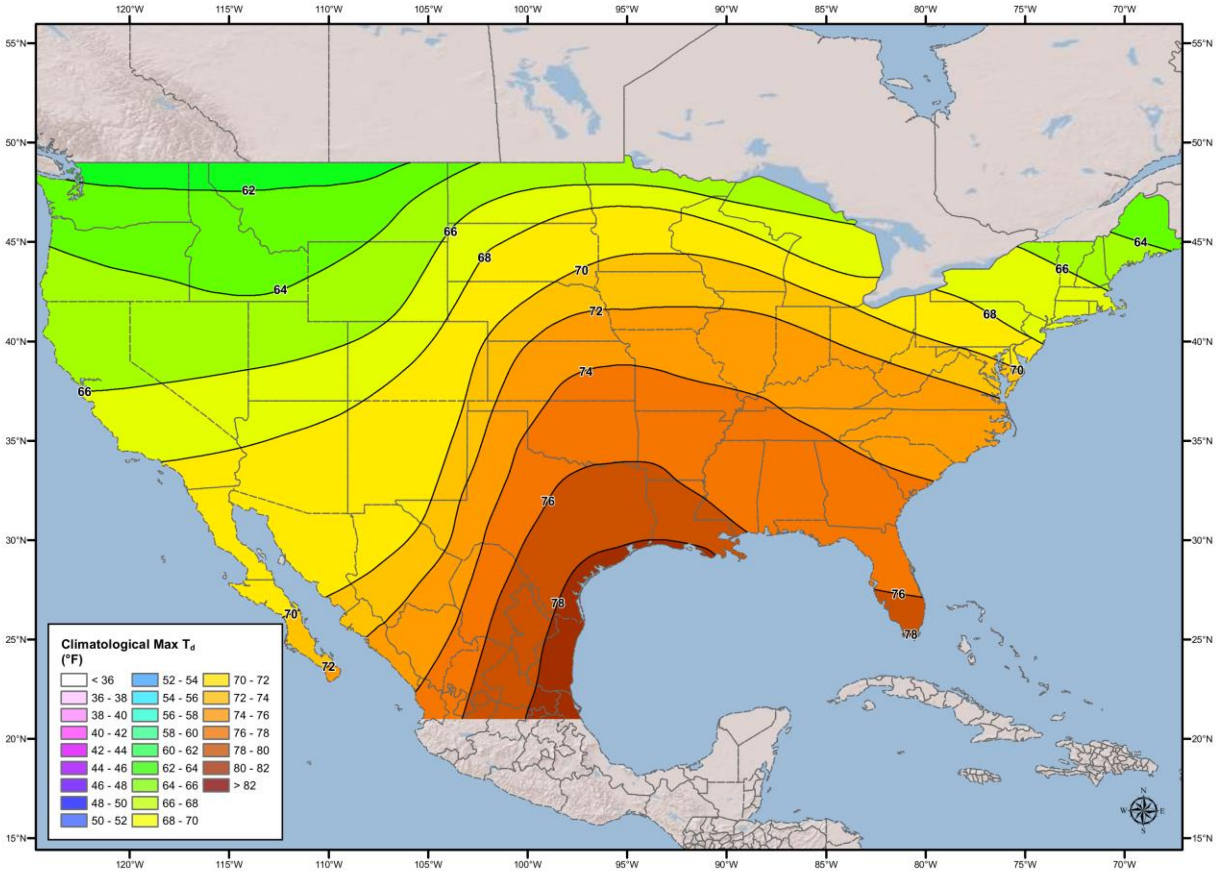
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
March



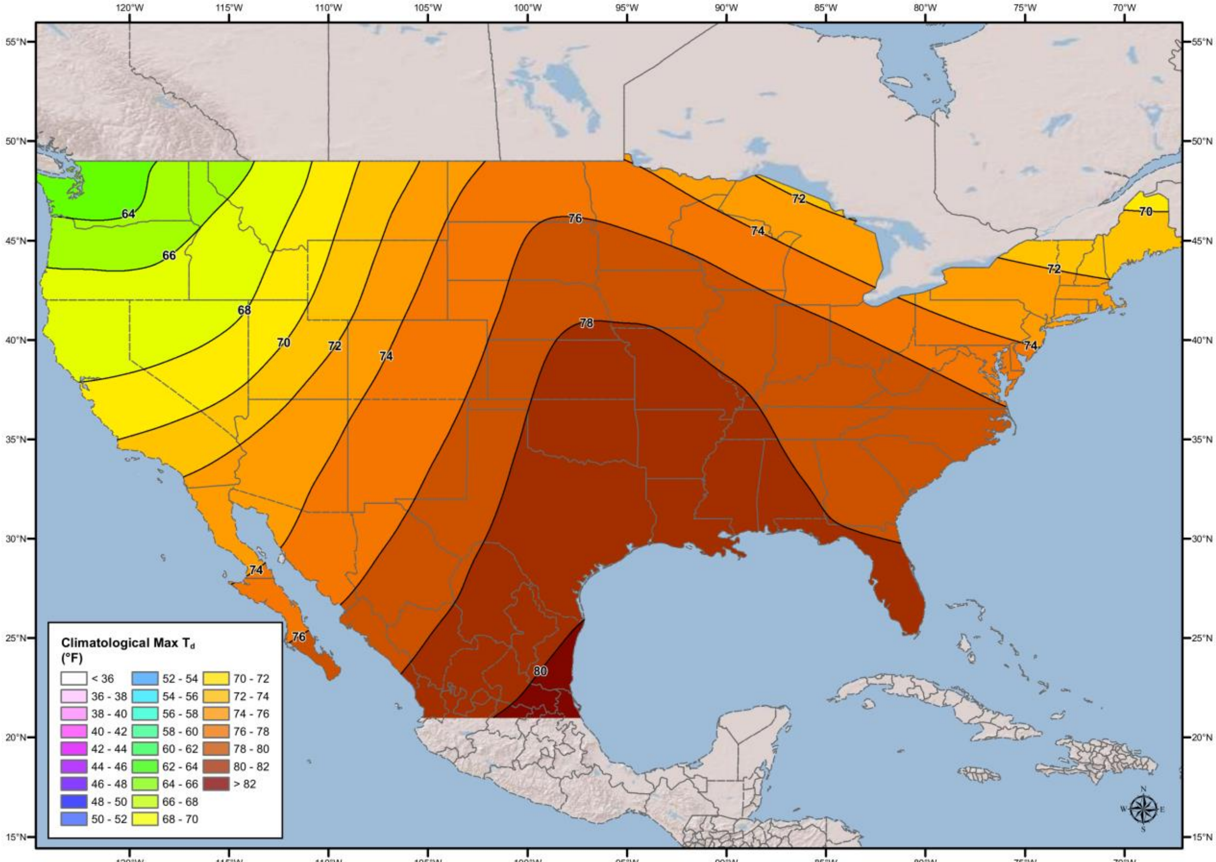
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
April



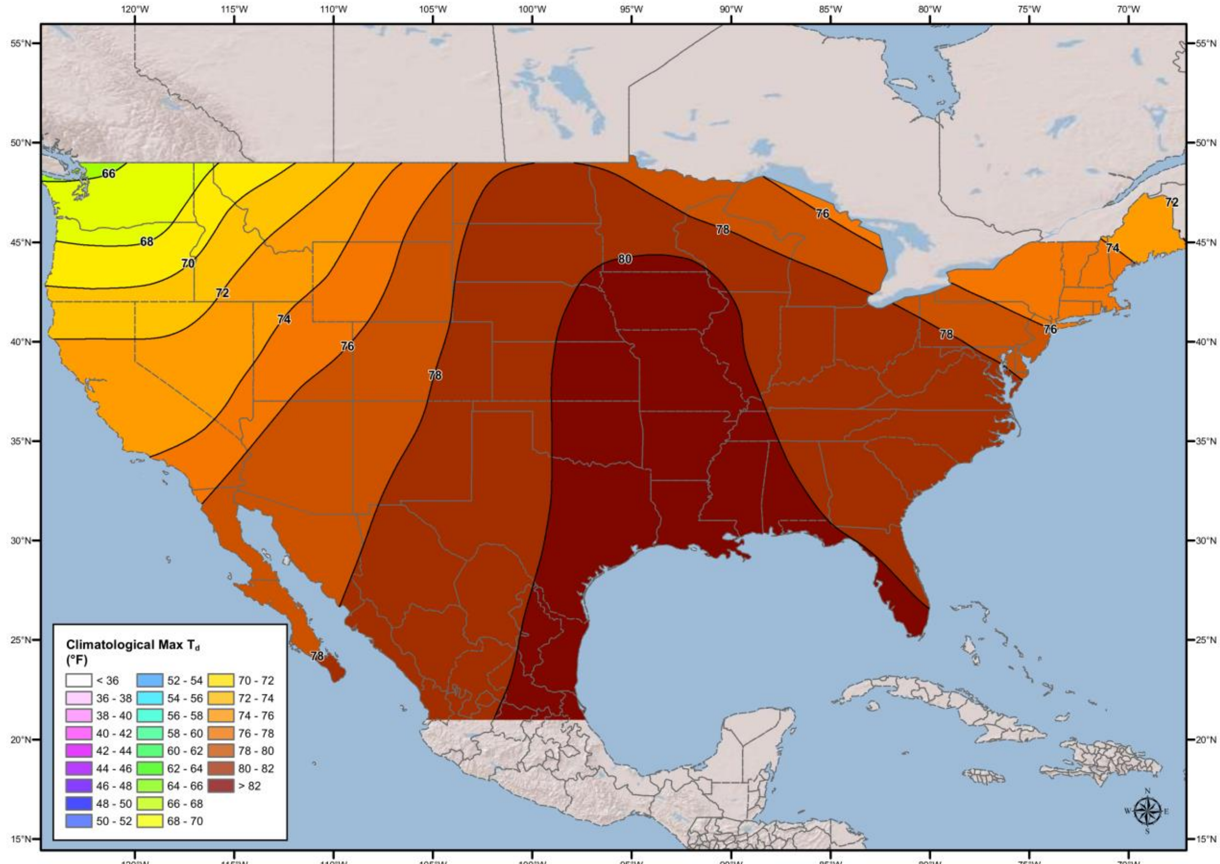
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
May



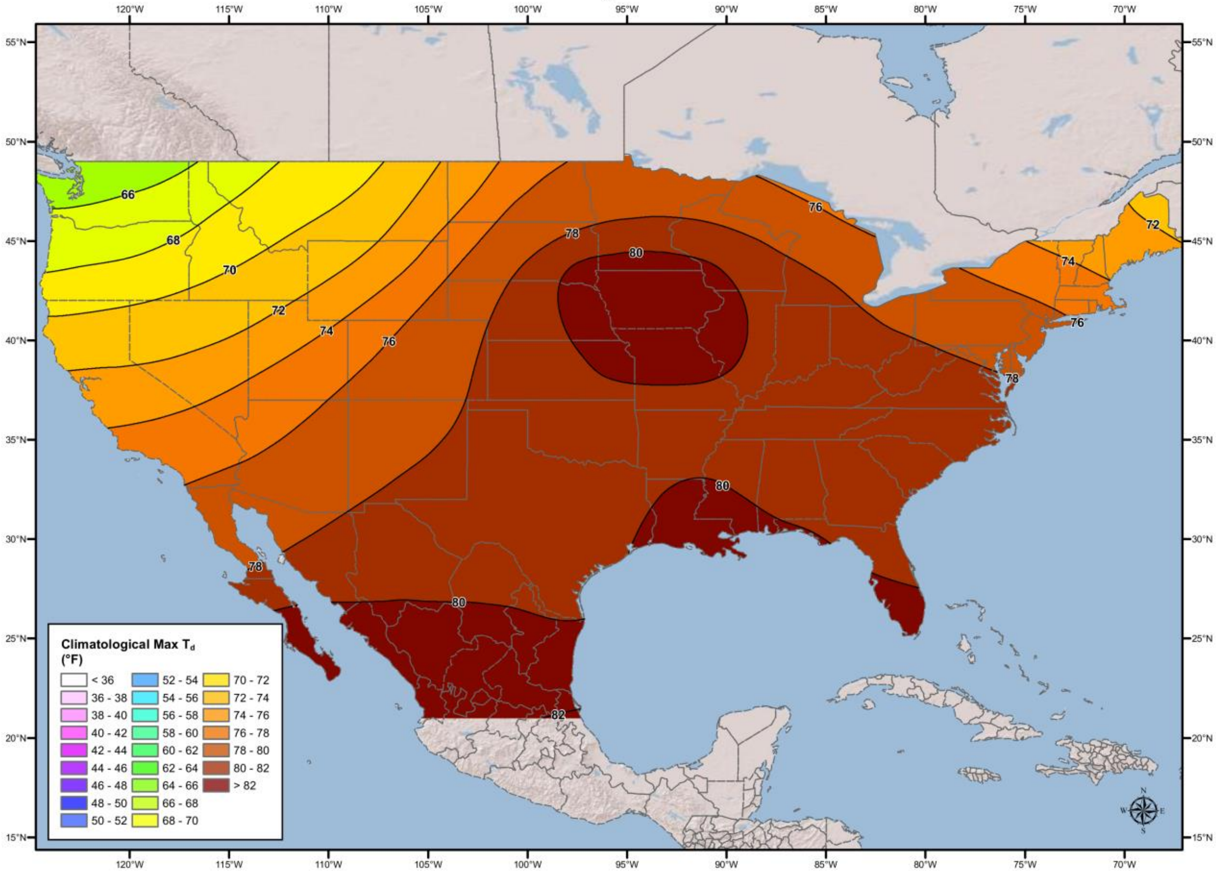
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
June



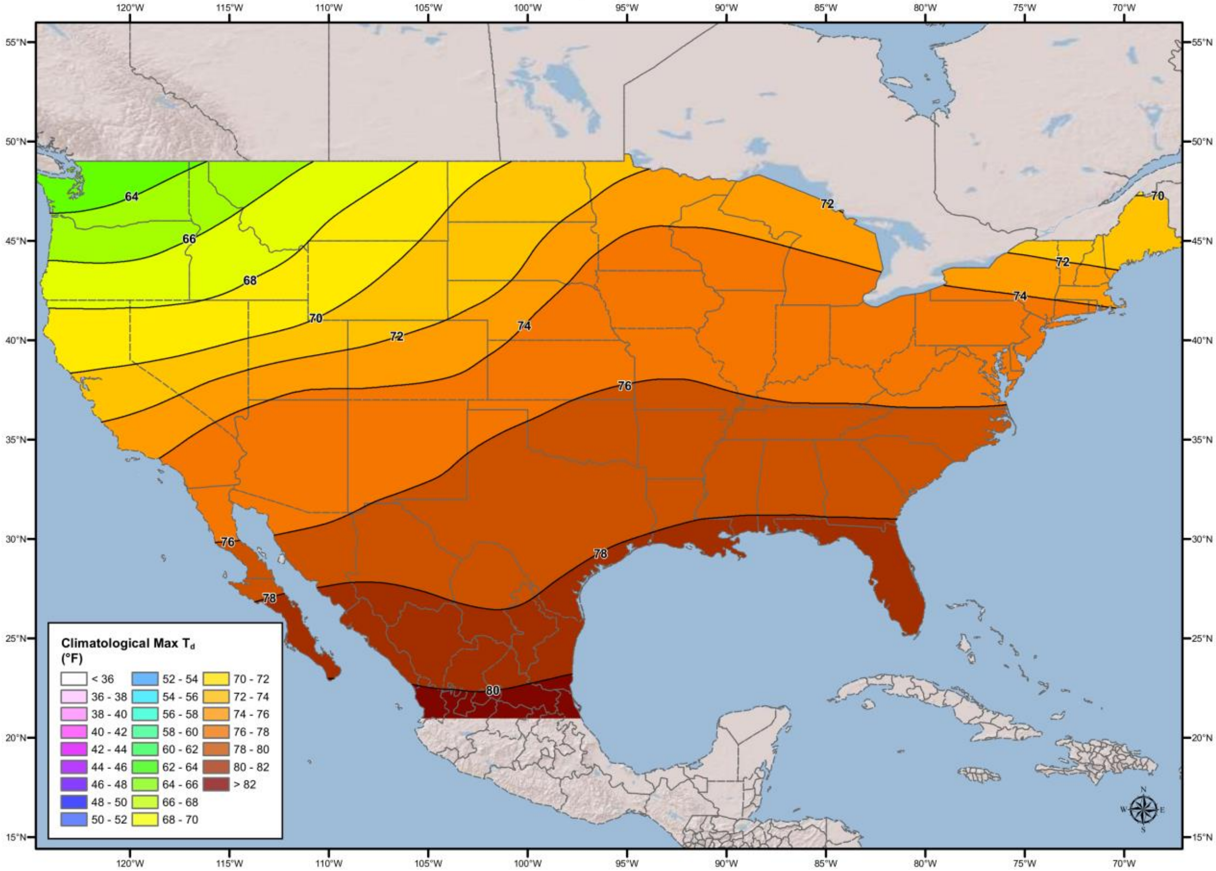
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
July



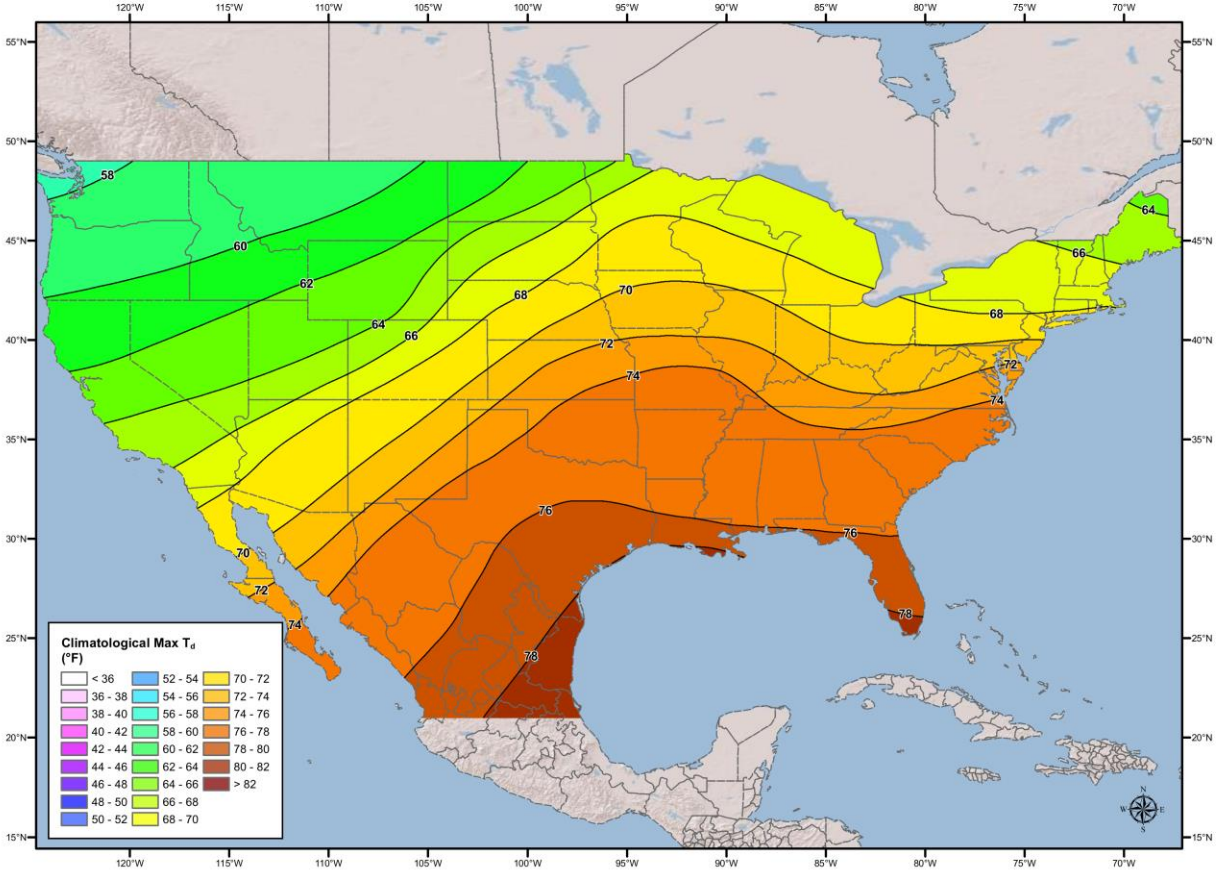
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
August



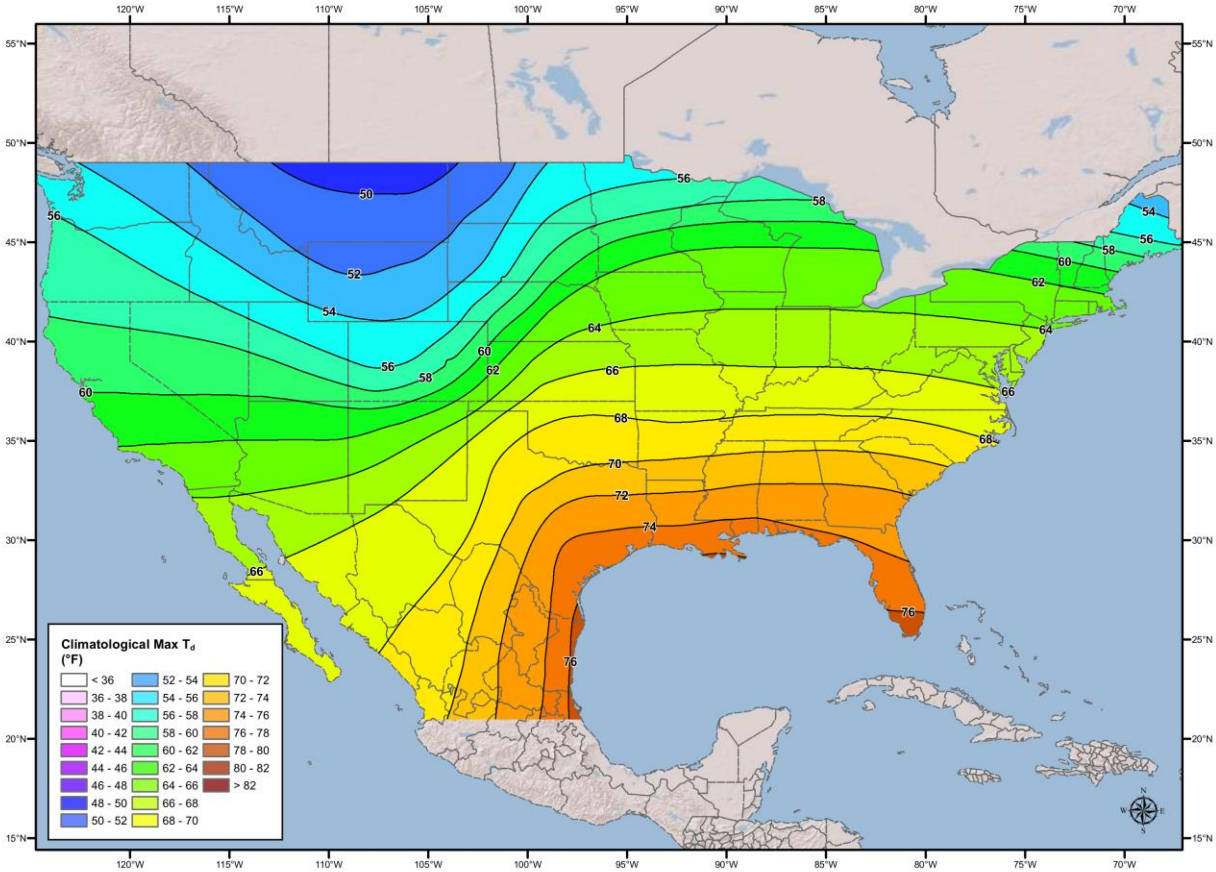
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
September



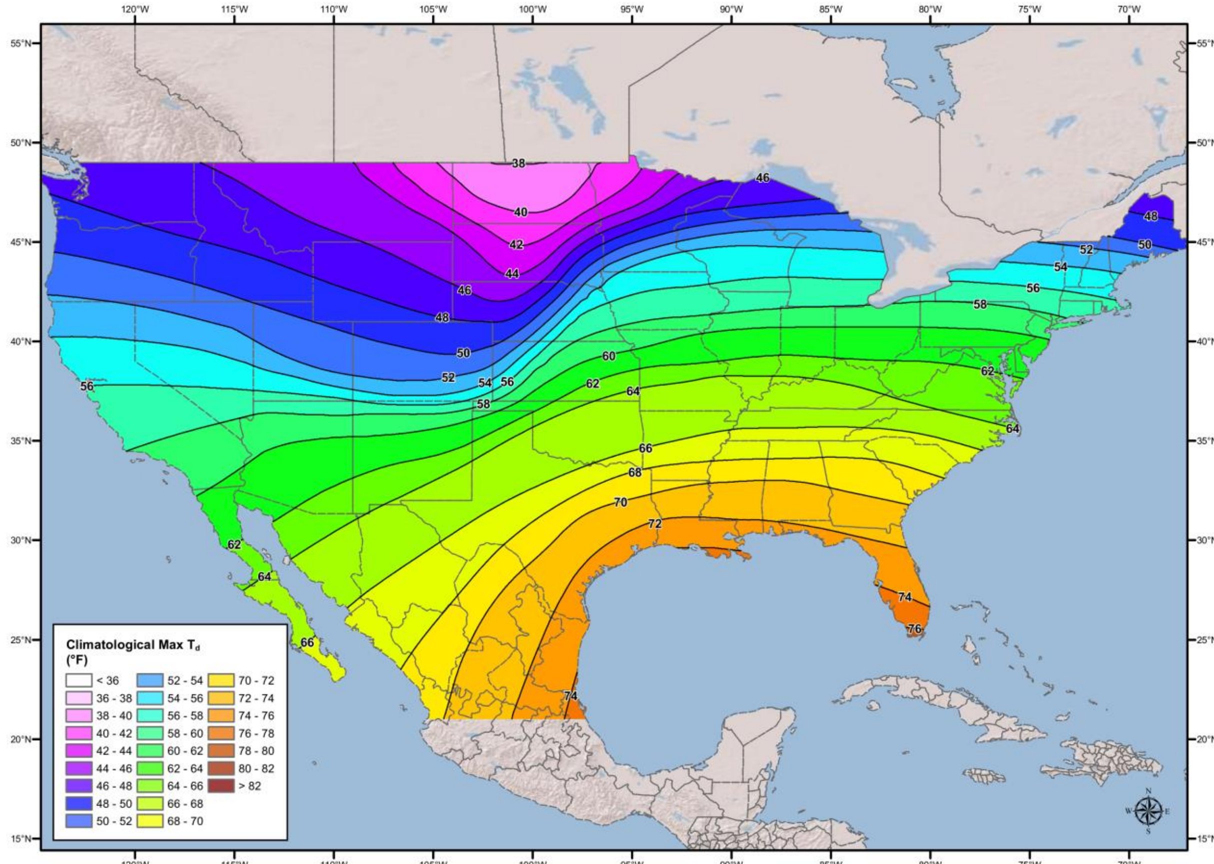
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
October



24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
November

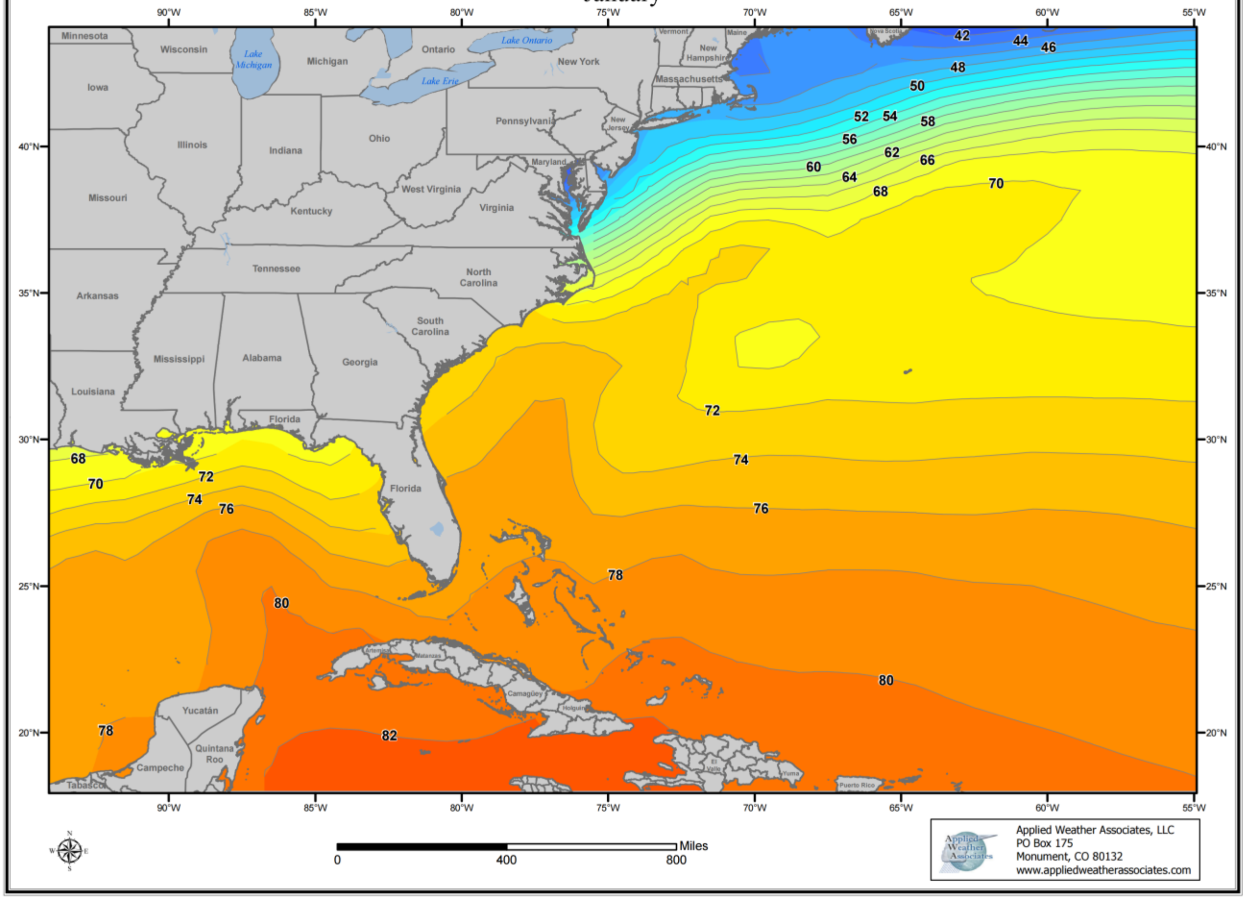


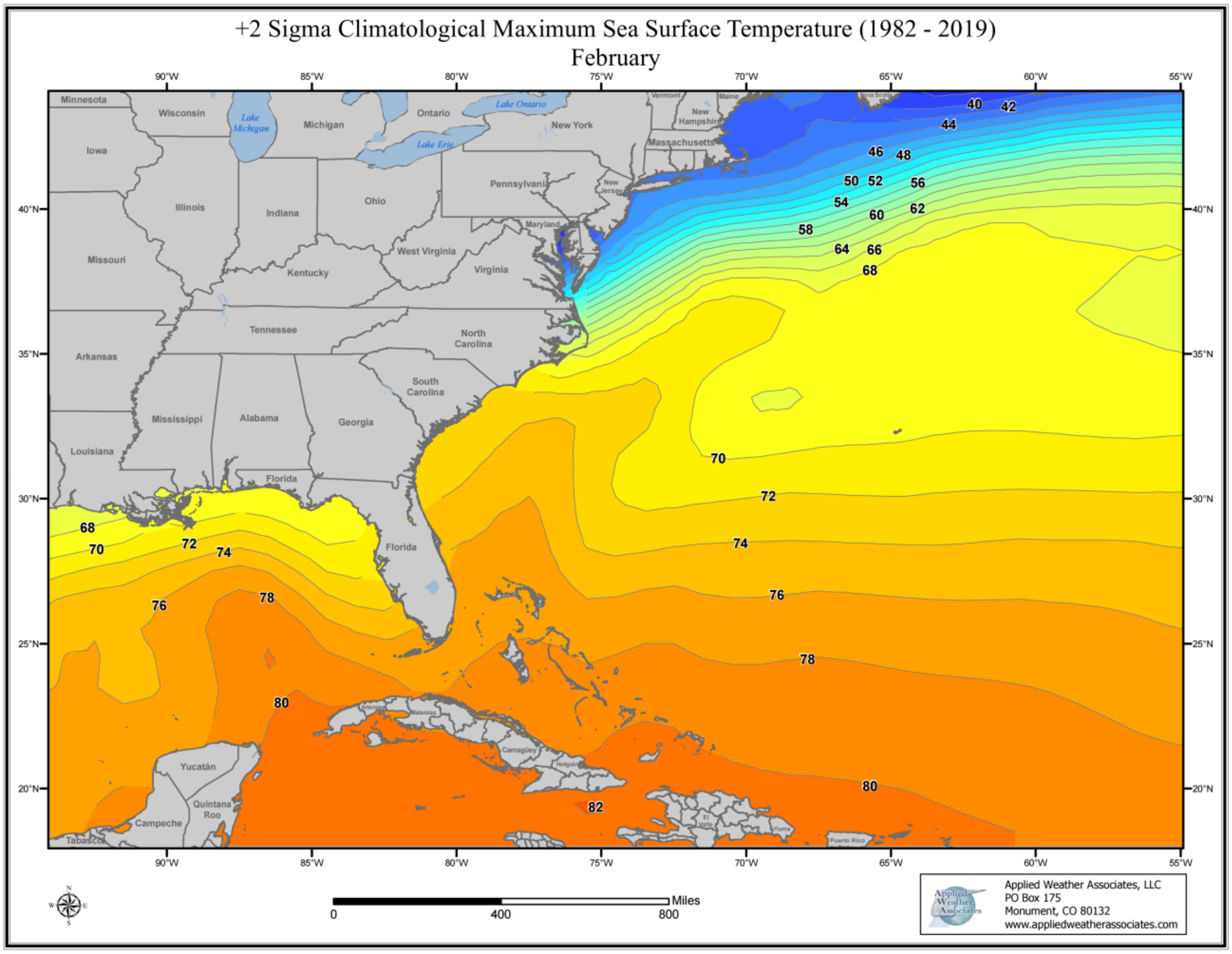
24-hour 100-year Return Frequency Monthly Maximum Dew Point Climatology (°F)
December



Appendix D
Sea Surface Temperature (SST) Climatology Maps
2-Sigma Sea Surface Temperature Maps

+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
January




+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
February
90°W
85°W
80°W
75°W
70°W
65°W
60°W
55°W
40°N
35°N
30°N
25°N
20°N
Minnesota
Wisconsin
Lake Michigan
Michigan
Ontario
Lake Ontario
New York
Vermont
Maine
New Hampshire
Massachusetts
Lake Erie
Iowa
Illinois
Indiana
Ohio
Pennsylvania
New Jersey
Maryland
Missouri
Kentucky
West Virginia
Virginia
Tennessee
North Carolina
Arkansas
South Carolina
Mississippi
Alabama
Georgia
Louisiana
Florida
Yucatán
Quintana Roo
Campeche
Tabasco
Camagüey
Holguín
Puerto Rico
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
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72
74
76
78
80
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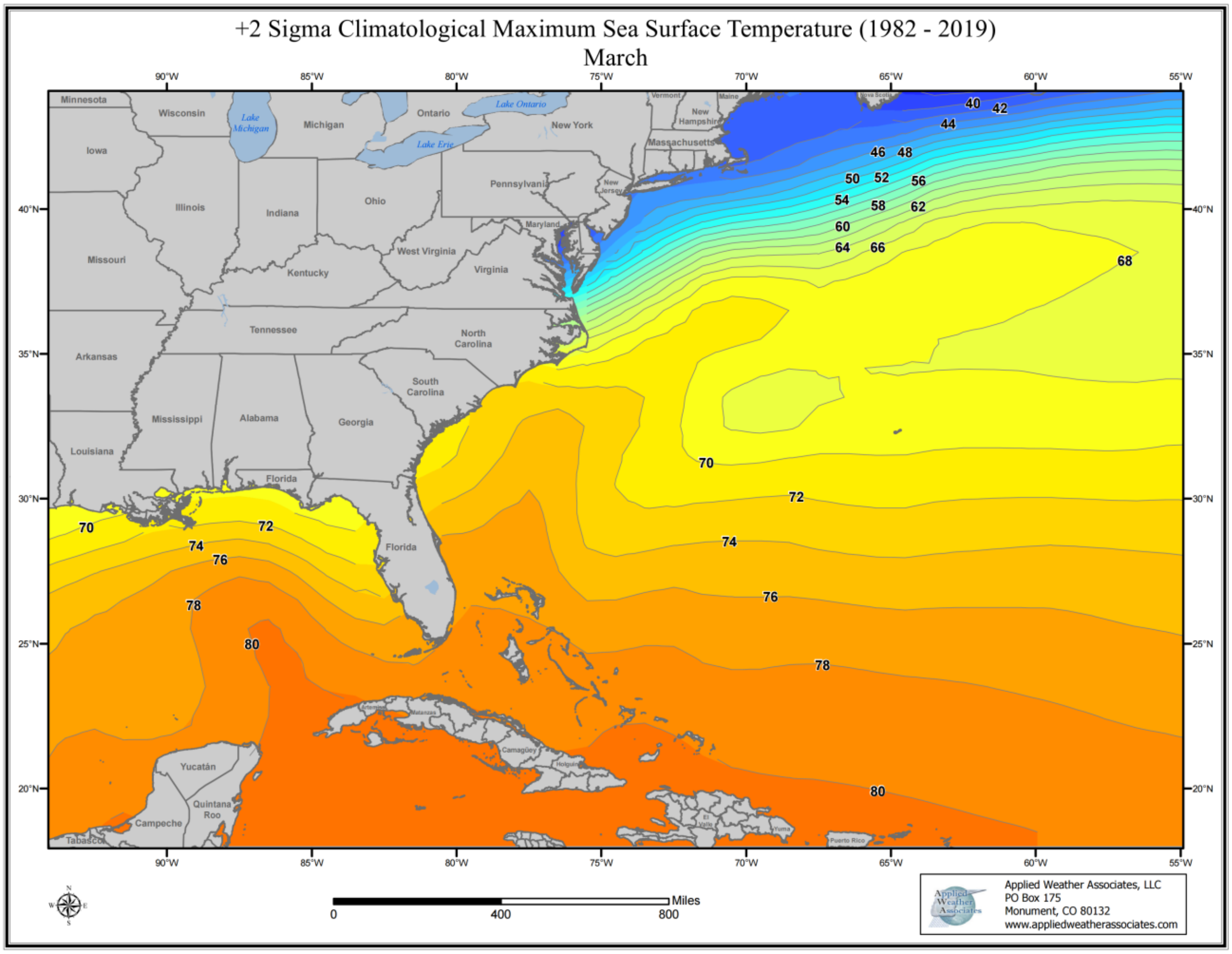
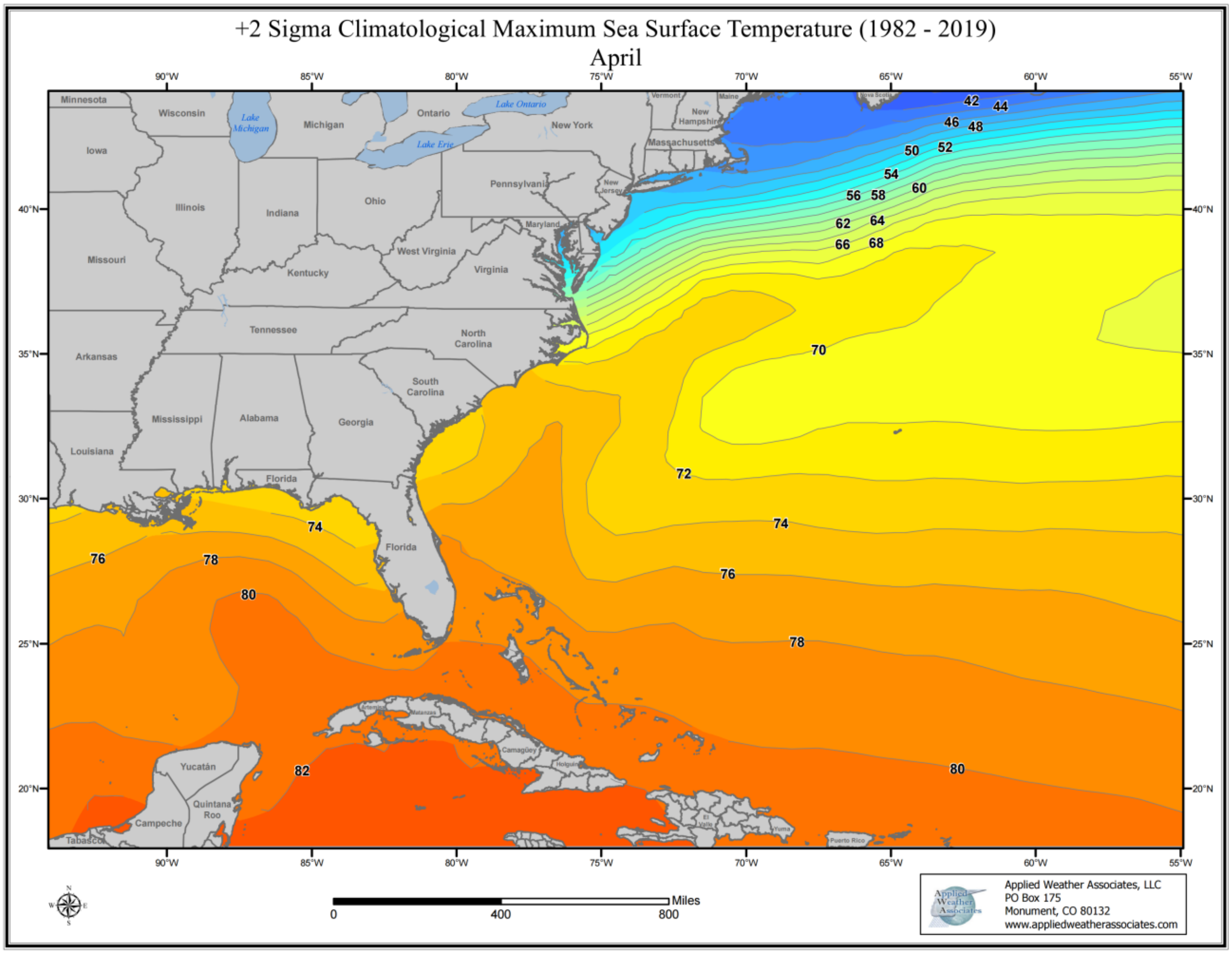

+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
March
Applied Weather Associates, LLC
PO Box 175
Monument, CO 80132
www.appliedweatherassociates.com
Miles
0
400
800


+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
April
Applied Weather Associates, LLC
PO Box 175
Monument, CO 80132
www.appliedweatherassociates.com
Miles
0
400
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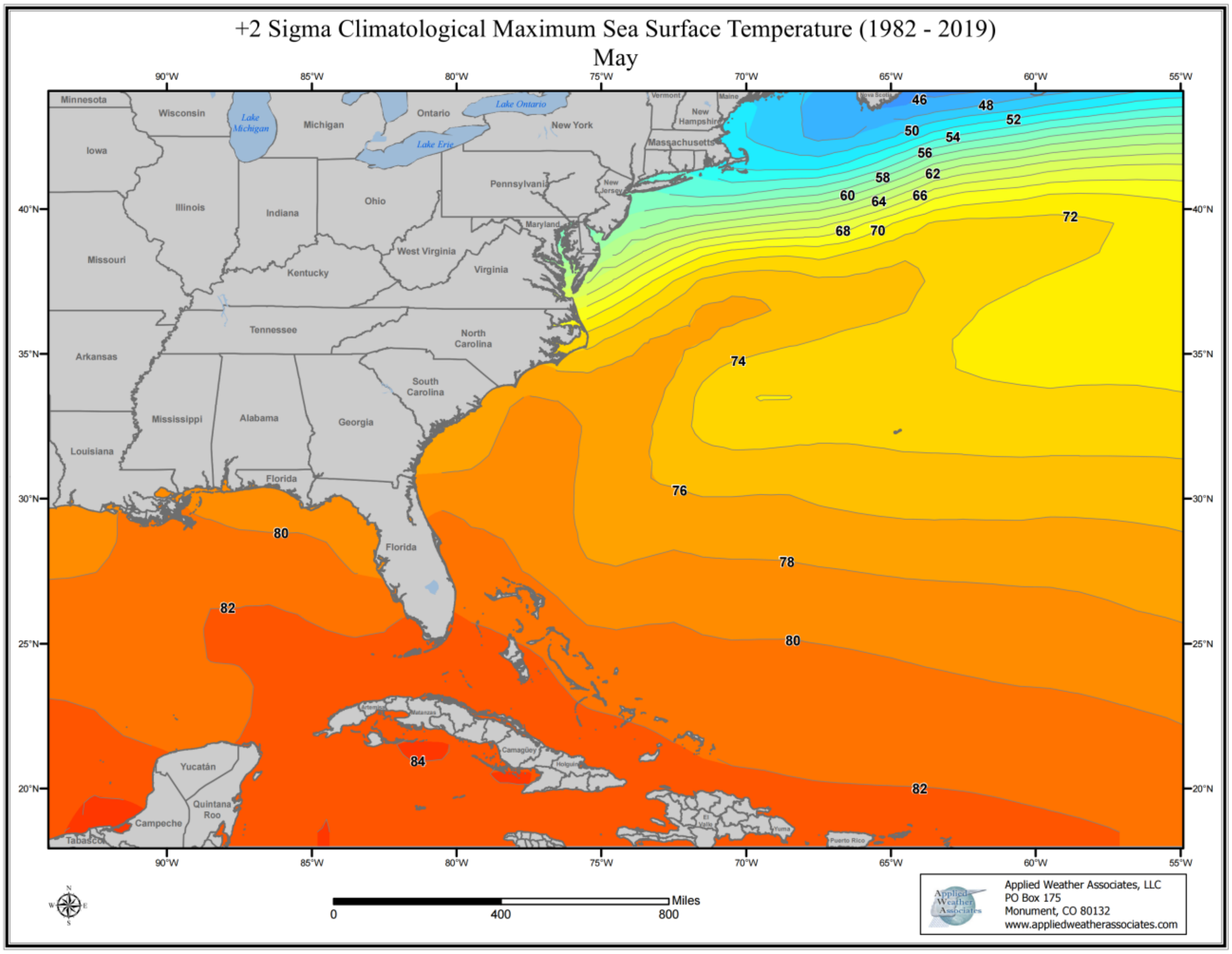
+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
May
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
80
82
82
84
Minnesota
Wisconsin
Michigan
Ontario
Lake Ontario
New York
Vermont
Maine
New Hampshire
Massachusetts
Iowa
Illinois
Indiana
Ohio
Pennsylvania
New Jersey
Maryland
Missouri
Kentucky
West Virginia
Virginia
Tennessee
North Carolina
Arkansas
South Carolina
Mississippi
Alabama
Georgia
Louisiana
Florida
Florida
Yucatán
Quintana Roo
Campeche
Tabasco
Camagüey
Holguín
Puerto Rico
Miles
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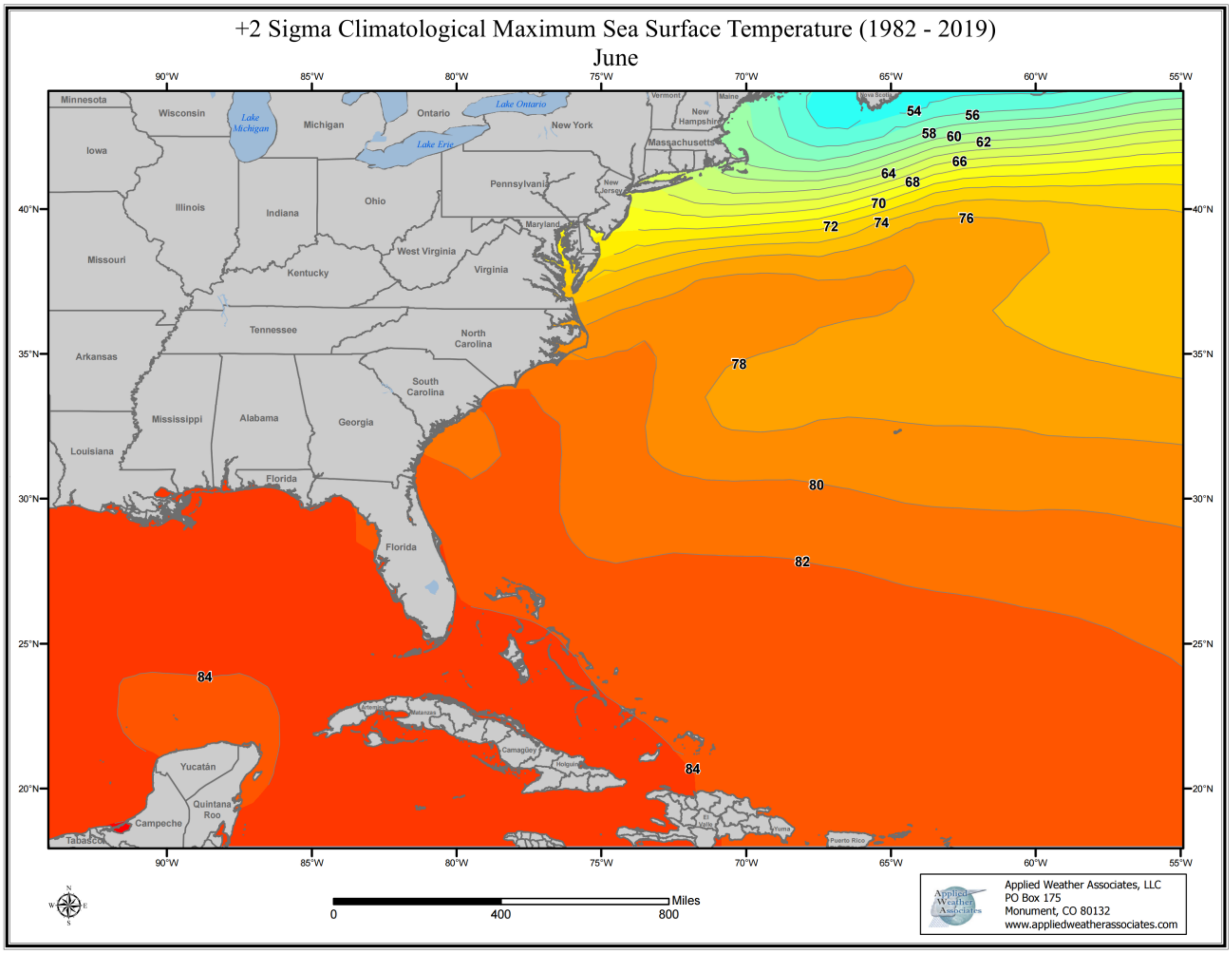
+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
June
90°W
85°W
80°W
75°W
70°W
65°W
60°W
55°W
40°N
35°N
30°N
25°N
20°N
Minnesota
Wisconsin
Lake Michigan
Michigan
Ontario
Lake Ontario
New York
Lake Erie
Vermont
Maine
New Hampshire
Massachusetts
Iowa
Illinois
Indiana
Ohio
Pennsylvania
New Jersey
Maryland
Missouri
West Virginia
Kentucky
Virginia
Tennessee
North Carolina
Arkansas
South Carolina
Mississippi
Alabama
Georgia
Louisiana
Florida
Yucatán
Quintana Roo
Campeche
Tabasco
Puerto Rico
54
56
58
60
62
64
66
68
70
72
74
76
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80
82
84
84
0
400
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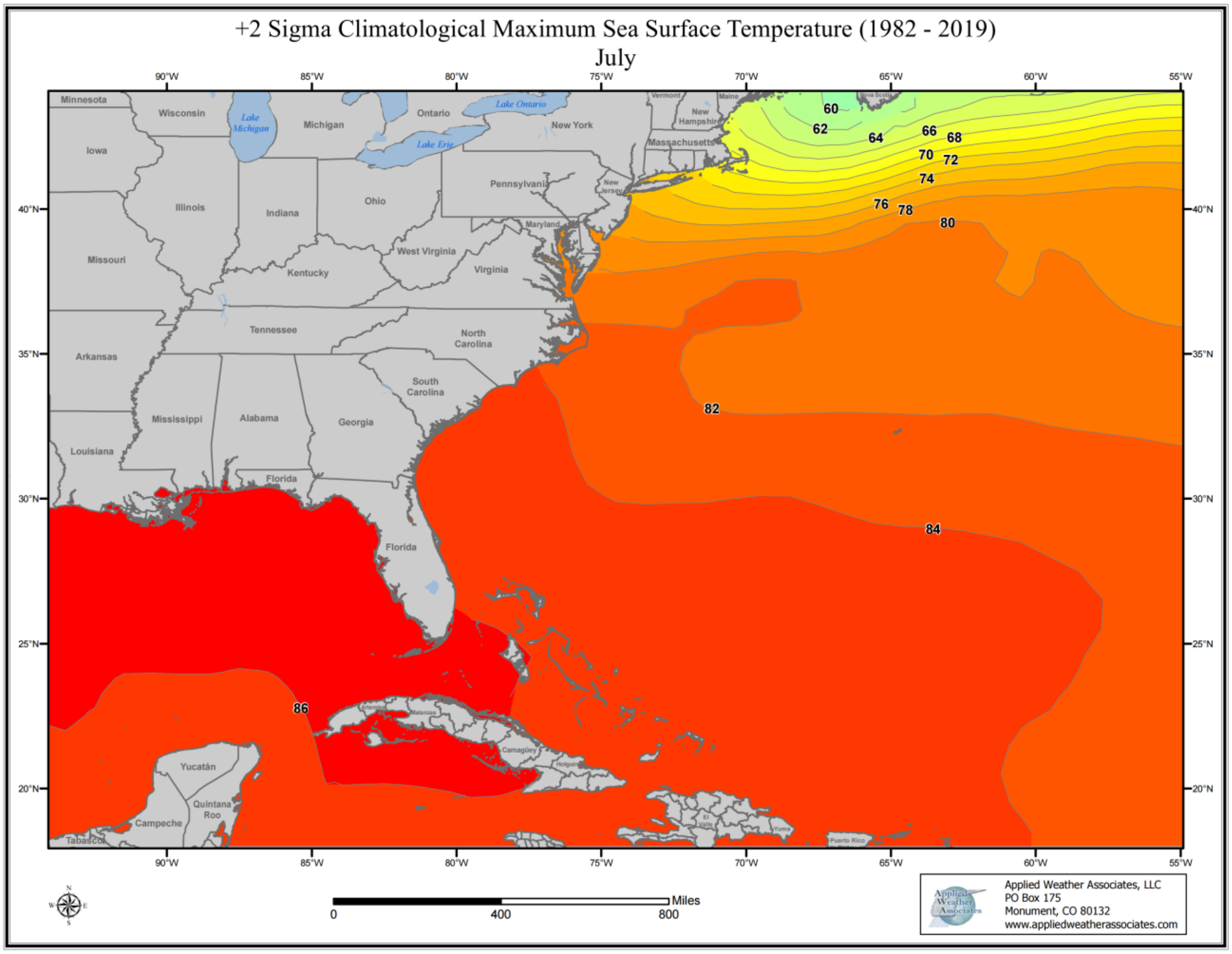
+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
July
60
62
64
66
68
70
72
74
76
78
80
82
84
86
Miles
0
400
800
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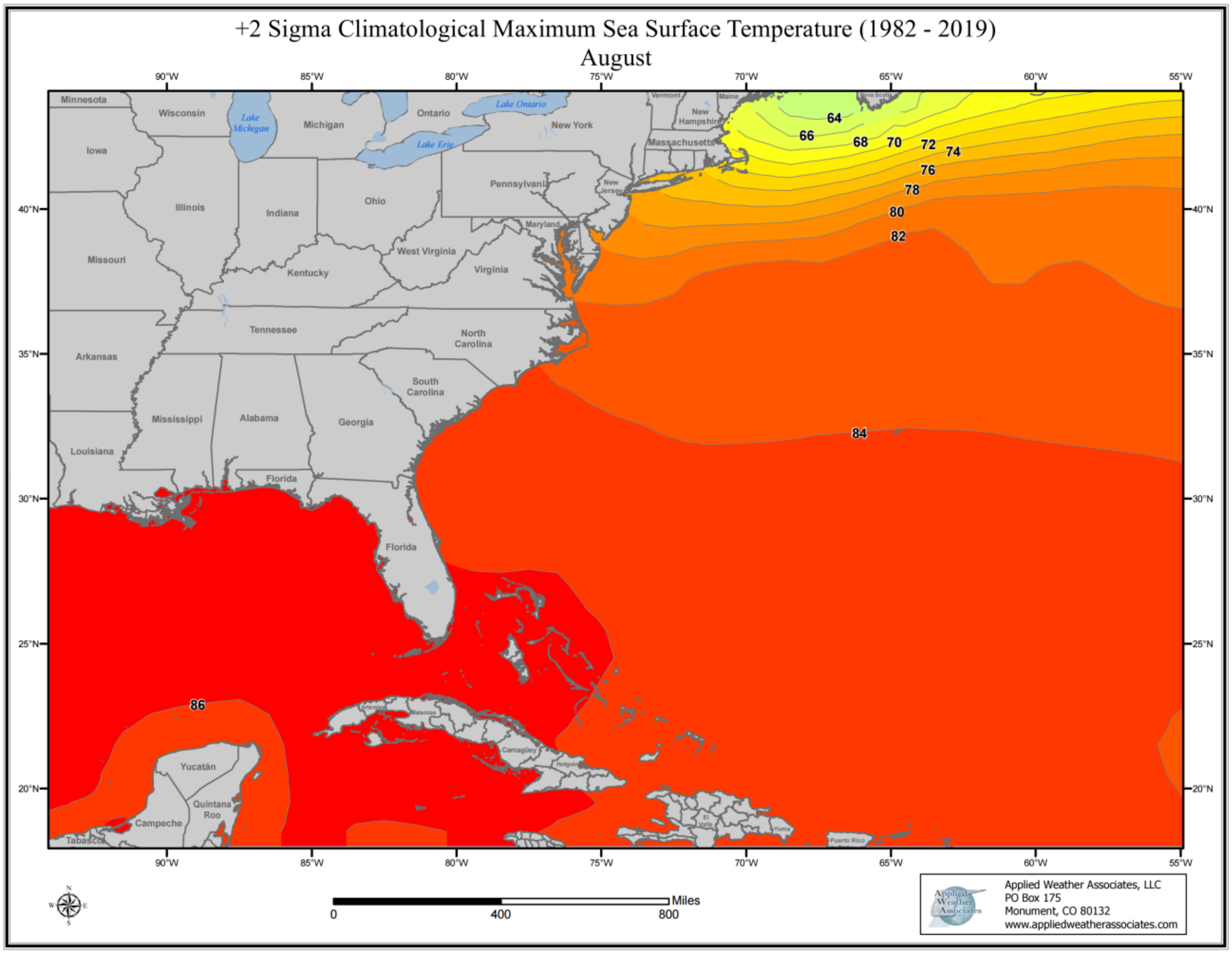
+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
August
64
66
68
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72
74
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80
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Applied Weather Associates, LLC
PO Box 175
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Miles
0
400
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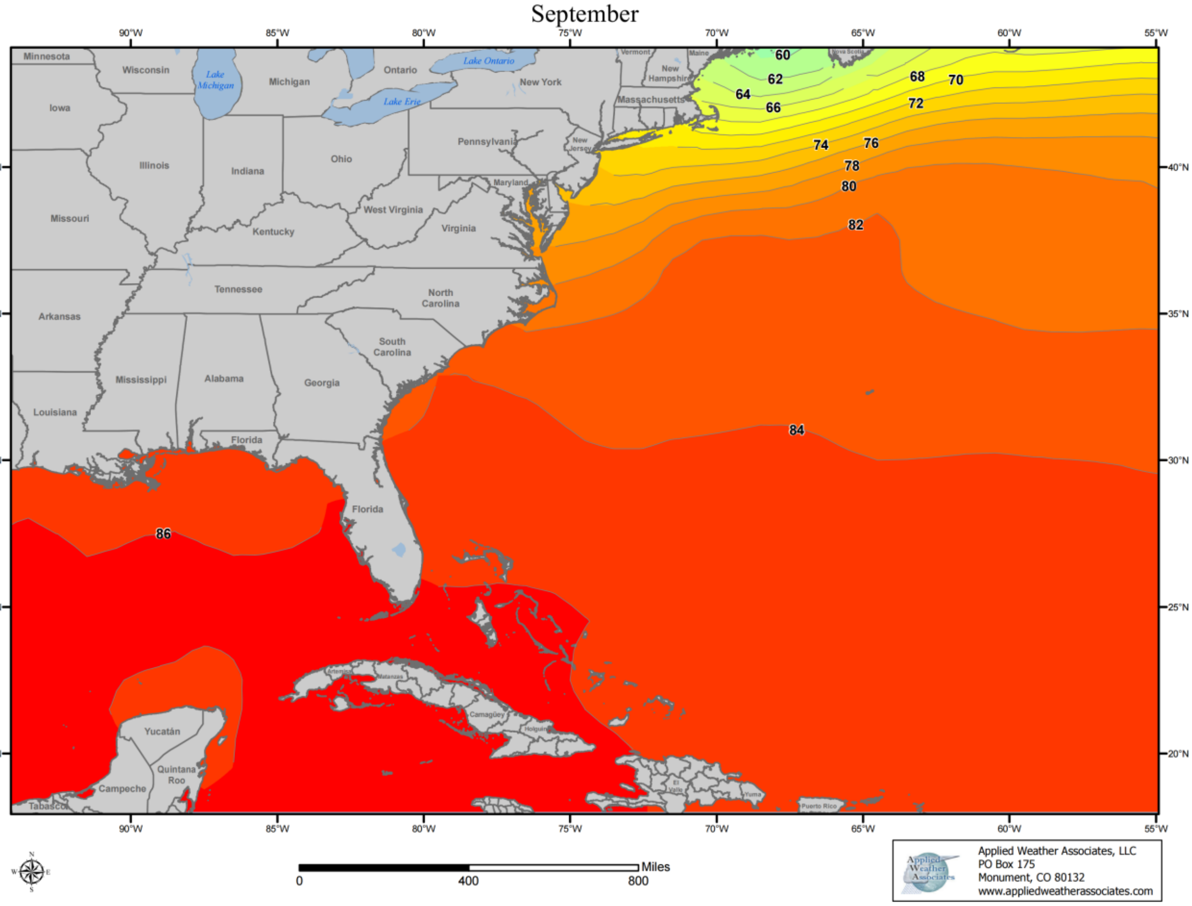
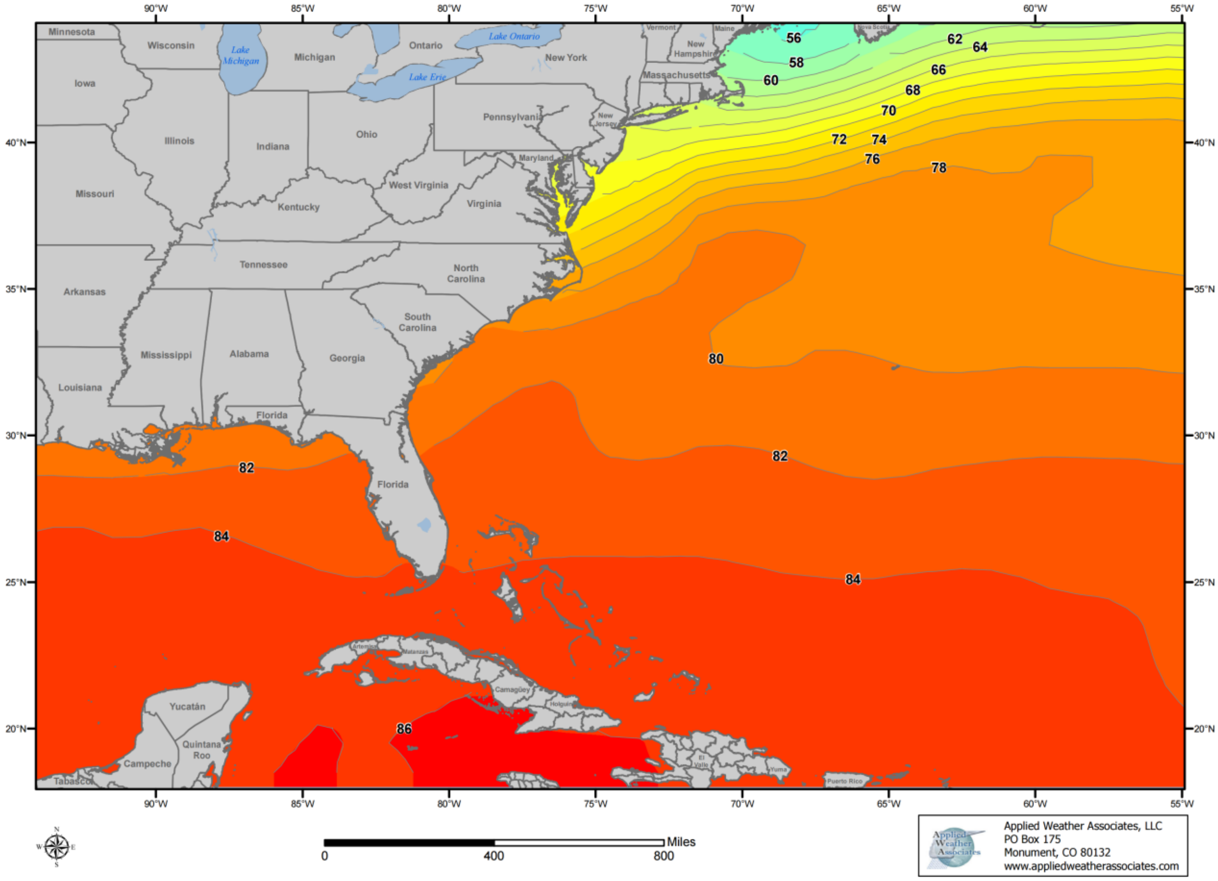
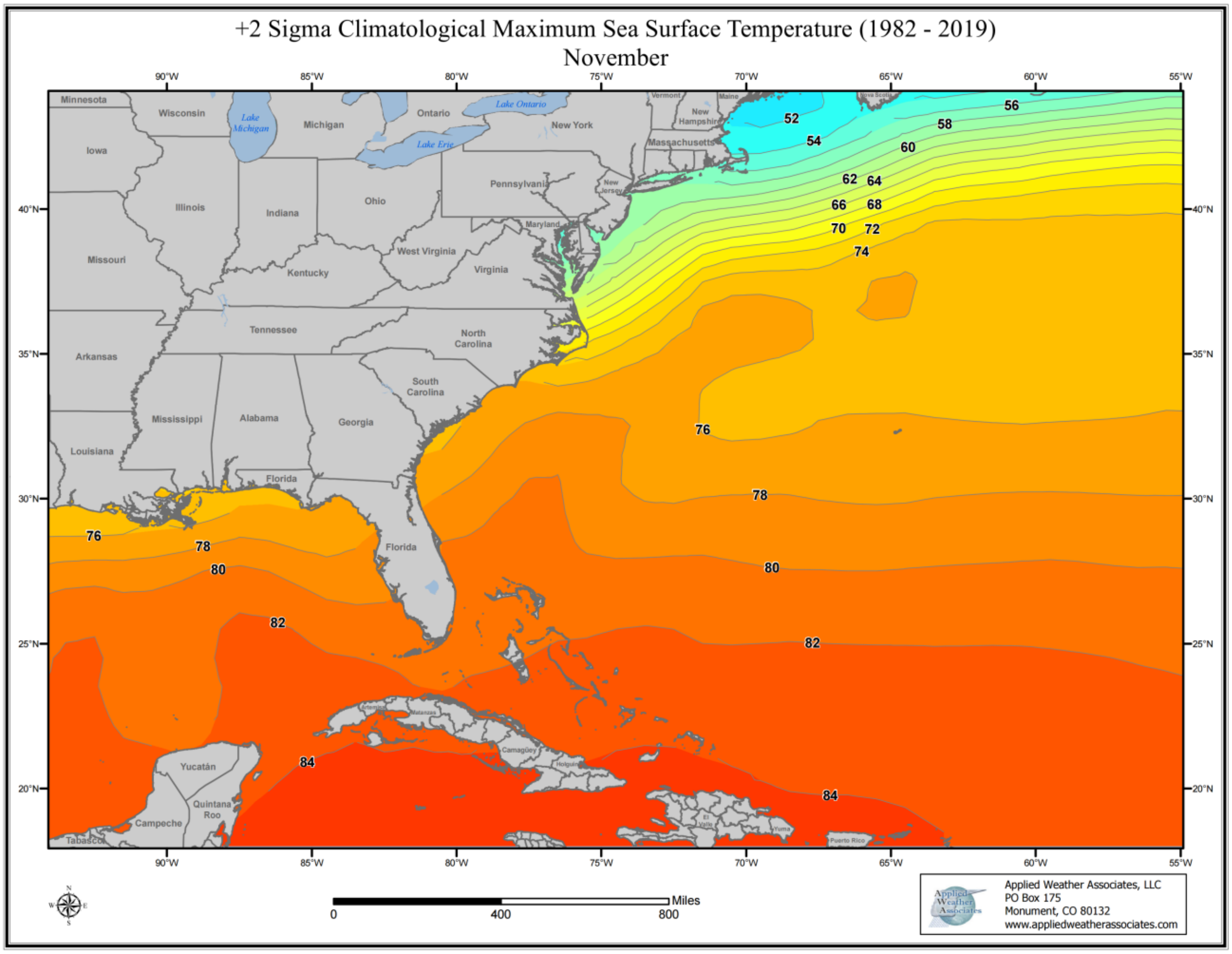
+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
September



+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
October




+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
November
52
54
56
58
60
62
64
66
68
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72
74
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78
80
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Miles
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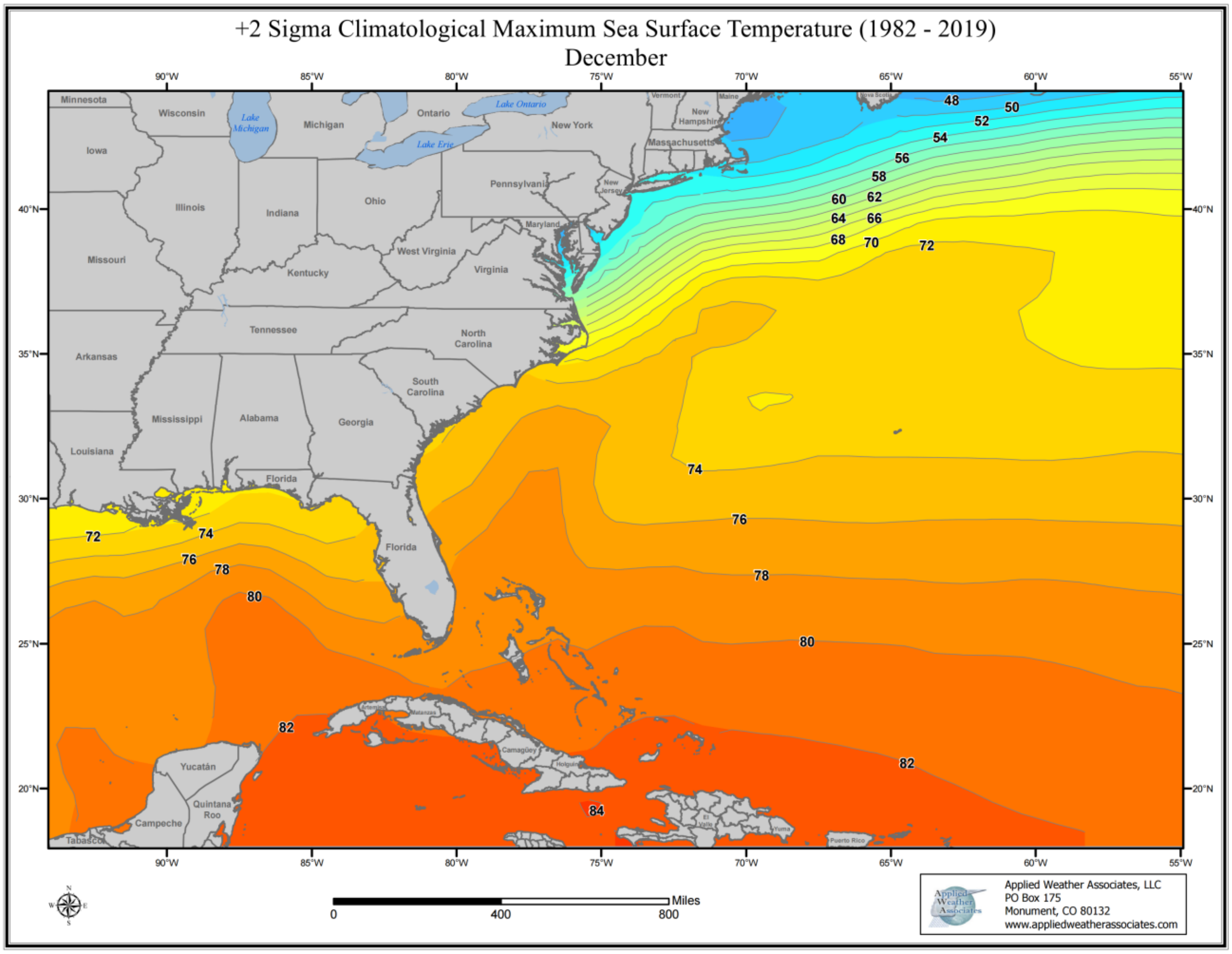
+2 Sigma Climatological Maximum Sea Surface Temperature (1982 - 2019)
December
48
50
52
54
56
58
60
62
64
66
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70
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74
76
78
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84
Miles
0
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Appendix E
Storm Precipitation Analysis System (SPAS) Description

Introduction

The Storm Precipitation Analysis System (SPAS) is grounded on years of scientific research with a demonstrated reliability in hundreds of post-storm precipitation analyses. It has evolved into a trusted hydrometeorological tool that provides accurate precipitation data at a high spatial and temporal resolution for use in a variety of sensitive hydrologic applications (Faulkner et al., 2004, Tomlinson et al., 2003-2012). Applied Weather Associates, LLC and METSTAT, Inc. initially developed SPAS in 2002 for use in producing Depth-Area-Duration values for Probable Maximum Precipitation (PMP) analyses. SPAS utilizes precipitation gauge data, basemaps and radar data (when available) to produce gridded precipitation at time intervals as short as 5 minutes, at spatial scales as fine as 1 km^2 and in a variety of customizable formats. To date (March 2015 SPAS has been used to analyze over 500 storm centers across all types of terrain, among highly varied meteorological settings and some occurring over 100-years ago.

SPAS output has many applications including, but not limited to: hydrologic model calibration/validation, flood event reconstruction, storm water runoff analysis, forensic cases and PMP studies. Detailed SPAS-computed precipitation data allow hydrologists to accurately model runoff from basins, particularly when the precipitation is unevenly distributed over the drainage basin or when rain gauge data are limited or not available. The increased spatial and temporal accuracy of precipitation estimates has eliminated the need for commonly made assumptions about precipitation characteristics (such as uniform precipitation over a watershed), thereby greatly improving the precision and reliability of hydrologic analyses.

To instill consistency in SPAS analyses, many of the core methods have remained consistent from the beginning. However, SPAS is constantly evolving and improving through new scientific advancements and as new data and improvements are incorporated. This write-up describes the current inner-workings of SPAS, but the reader should realize SPAS can be customized on a case-by-case basis to account for special circumstances; these adaptations are documented and included in the deliverables. The over-arching goal of SPAS is to combine the strengths of rain gauge data and radar data (when available) to provide sound, reliable and accurate spatial precipitation data.

Hourly precipitation observations are generally limited to a small number of locations, with many basins lacking observational precipitation data entirely. However, Next Generation Radar (NEXRAD) data provide valuable spatial and temporal information over data-sparse basins, which have historically lacked reliability for determining precipitation rates and reliable quantitative precipitation estimates (QPE). The improved reliability in SPAS is made possible by hourly calibration of the NEXRAD radar-precipitation relationship, combined with local hourly bias adjustments to force consistency between the final result and "ground truth" precipitation measurements. If NEXRAD radar data are available (generally for storm events since the mid-1990s), precipitation accumulation at temporal scales as frequent as 5-minutes can be analyzed. If no NEXRAD data are available, then precipitation data are analyzed in hourly increments. A summary of the general SPAS processes is shown in flow chart in Figure E.1.

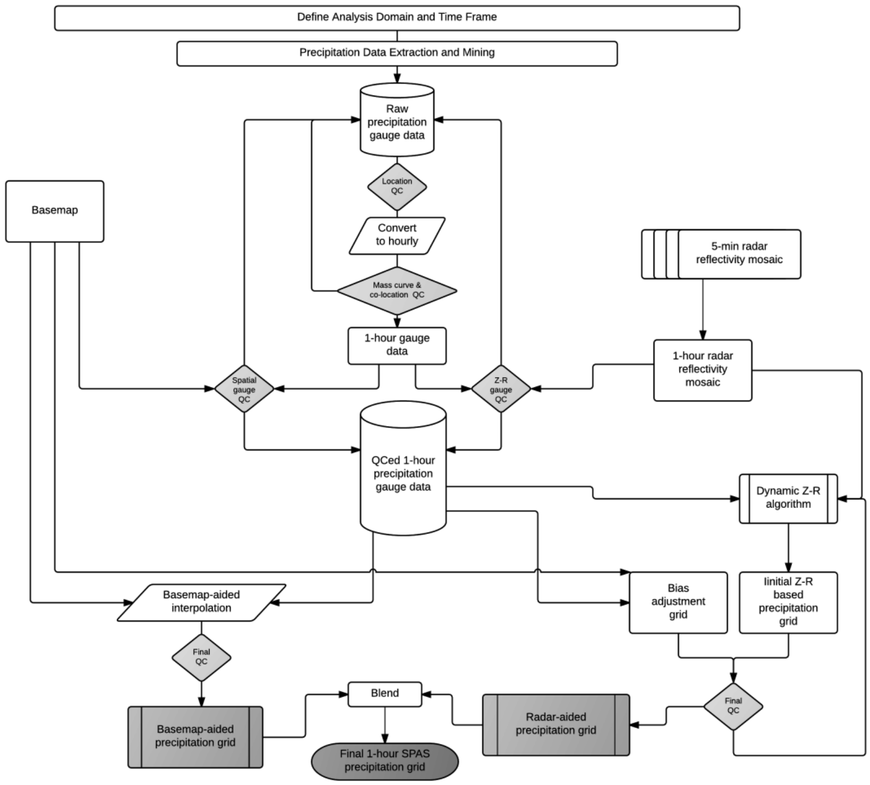


Figure E.1: SPAS flow chart

Setup

Prior to a SPAS analysis, careful definition of the storm analysis domain and time frame to be analyzed is established. Several considerations are made to ensure the domain (longitude-latitude box) and time frame are sufficient for the given application.

SPAS Analysis Domain

For PMP applications it is important to establish an analysis domain that completely encompasses a storm center, meanwhile hydrologic modeling applications are more concerned about a specific basin, watershed or catchment. If radar data are available, then it is also important to establish an area large enough to encompass enough stations (minimum of ~30) to adequately derive reliable radar-precipitation intensity relationships (discussed later). The domain is defined by evaluating existing documentation on the storm as well as plotting and evaluating initial precipitation gauge data on a map. The analysis domain is defined to include as many hourly recording gauges as possible given their importance in timing. The domain must include enough of a buffer to accurately model the nested domain of interest. The domain is defined as a longitude-latitude (upper left and lower right corner) rectangular region.

SPAS Analysis Time Frame

Ideally, the analysis time frame, also referred to as the Storm Precipitation Period (SPP), will extend from a dry period through the target wet period then back into another dry period. This is to ensure that total storm precipitation amounts can be confidently associated with the storm in question and not contaminated by adjacent wet periods. If this is not possible, a reasonable time period is selected that is bounded by relatively lighter precipitation. The time frame of the hourly data must be sufficient to capture the full range of daily gauge observational periods for the daily observations to be disaggregated into estimated incremental hourly values (discussed later). For example, if a daily gauge takes observations at 8:00 AM, then the hourly data must be available from 8:00 AM the day prior. Given the configuration of SPAS, the minimum SPP is 72 hours and aligns midnight to midnight.

The core precipitation period (CPP) is a sub-set of the SPP and represents the time period with the most precipitation and the greatest number of reporting gauges. The CPP represents the time period of interest and where our confidence in the results is highest.

Data

The foundation of a SPAS analysis is the “ground truth” precipitation measurements. In fact, the level of effort involved in “data mining” and quality control represent over half of the total level of effort needed to conduct a complete storm analysis. SPAS operates with three primary data sets: precipitation gauge data, a basemap and, if available, radar data. Table E.1 conveys the variety of precipitation gauges usable by SPAS. For each gauge, the following elements are gathered, entered and archived into SPAS database:

- Station ID
- Station name
- Station type (H=hourly, D=Daily, S=Supplemental, etc.)
- Longitude in decimal degrees
- Latitude in decimal degrees
- Elevation in feet above MSL
- Observed precipitation
- Observation times
- Source
- If unofficial, the measurement equipment and/or method is also noted.

Based on the SPP and analysis domain, hourly and daily precipitation gauge data are extracted from our in-house database as well as the Meteorological Assimilation Data Ingest System (MADIS). Our in-house database contains data dating back to the late 1800s, while the MADIS system (described below) contains archived data back to 2002.

Hourly Precipitation Data

Our hourly precipitation database is largely comprised of data from NCDC TD-3240, but also precipitation data from other mesonets and meteorological networks (e.g. ALERT, Flood Control Districts, etc.) that we have collected and archived as part of previous studies. Meanwhile, MADIS provides data from a large number of networks across the U.S., including NOAA’s HADS (Hydrometeorological Automated Data System), numerous mesonets, the Citizen Weather Observers Program (CWOP), departments of transportation, etc. (see http://madis.noaa.gov/mesonet_providers.html for a list of providers). Although our automatic data extraction is fast, cost-effective and efficient, it never captures all of the available precipitation data for a storm event. For this reason, a thorough “data mining” effort is undertaken to acquire all available data from sources such as U.S. Geological Survey (USGS), Remote Automated Weather Stations (RAWS), Community Collaborative Rain, Hail & Snow Network (CoCoRaHS), National Atmospheric Deposition Program (NADP), Clean Air Status and Trends Network (CASTNET), local observer networks, Climate Reference Network (CRN), Global Summary of the Day (GSD) and Soil Climate Analysis Network (SCAN). Unofficial hourly precipitation data are gathered to give guidance on either timing or magnitude in areas otherwise void of precipitation data. The WeatherUnderground and MesoWest, two of the largest weather databases on the Internet, contain a large proportion of official data, but also includes data from unofficial gauges.

Table E.1: Different precipitation gauge types used by SPAS

Precipitation Gauge Type	Description
Hourly	Hourly gauges with complete, or nearly complete, incremental hourly precipitation data.
Hourly estimated	Hourly gauges with some estimated hourly values, but otherwise reliable.
Hourly pseudo	Hourly gauges with reliable temporal precipitation data, but the magnitude is questionable in relation to co-located daily or supplemental gauge.
Daily	Daily gauge with complete data and known observation times.
Daily estimated	Daily gauges with some or all estimated data.
Supplemental	Gauges with unknown or irregular observation times, but reliable total storm precipitation data. (E.g. public reports, storms reports, “Bucket surveys”, etc.)
Supplemental estimated	Gauges with estimated total storm precipitation values based on other information (e.g. newspaper articles, stream flow discharge, inferences from nearby gauges, pre-existing total storm isohyetal maps, etc.)

Daily Precipitation Data

Our daily database is largely based on NCDC’s TD-3206 (pre-1948) and TD-3200 (1948 through present) as well as SNOTEL data from NRCS. Since the late 1990s, the CoCoRaHS network of more than 15,000 observers in the U.S. has become a very important daily precipitation source. Other daily data are gathered from similar, but smaller gauge networks, for instance the High Spatial Density Precipitation Network in Minnesota.

As part of the daily data extraction process, the time of observation accompanies each measured precipitation value. Accurate observation times are necessary for SPAS to disaggregate the daily precipitation into estimated incremental values (discussed later). Knowing the observation time also allows SPAS to maintain precipitation amounts within given time bounds, thereby retaining known precipitation intensities. Given the importance of observation times, efforts are taken to insure the observation times are accurate. Hardcopy reports of “Climatological Data,” scanned observational forms (available on-line from the NCDC) and/or gauge metadata forms have proven to be valuable and accurate resources for validating observation times. Furthermore, erroneous observation times are identified in the mass-curve quality-control procedure (discussed later) and can be corrected at that point in the process.

Supplemental Precipitation Gauge Data

For gauges with unknown or irregular observation times, the gauge is considered a “supplemental” gauge. A supplemental gauge can either be added to the storm database with a storm total and the associated SPP as the temporal bounds or as a gauge with the known, but irregular observation times and associated precipitation amounts. For instance, if all that is known is 3 inches fell between 0800-0900, then that information can be entered. Gauges or reports with nothing more than a storm total are often abundant, but to use them, it is important the precipitation is only from the storm period in question. Therefore, it is ideal to have the analysis time frame bounded by dry periods.

Perhaps the most important source of data, if available, is from “bucket surveys,” which provide comprehensive lists of precipitation measurements collected during a post-storm field exercise. Although some bucket survey amounts are not from conventional precipitation gauges, they provide important information, especially in areas lacking data. Particularly for PMP-storm analysis applications, it is customary to accept extreme, but valid non-standard precipitation values (such as bottles and other open containers that catch rainfall) to capture the highest precipitation values.

Basemap

“Basemaps” are independent grids of spatially distributed weather or climate variables that are used to govern the spatial patterns of the hourly precipitation. The basemap also governs the spatial resolution of the final SPAS grids, unless radar data are available/used to govern the spatial resolution. Note that a base map is not required as the hourly precipitation patterns can be based on station characteristics and an inverse distance weighting technique (discussed later). Basemaps in complex terrain are often based on the PRISM mean monthly precipitation (Figure E.2a) or Hydrometeorological Design Studies Center precipitation frequency grids (Figure E.2b) given they resolve orographic enhancement areas and micro-climates at a spatial resolution of 30-seconds (about 800 m). Basemaps of this nature in flat terrain are not as effective given the small terrain forced precipitation gradients. Therefore, basemaps for SPAS analyses in flat terrain are often developed from pre-existing (hand-drawn) isohyetal patterns (Figure E.2c), composite radar imagery or a blend of both.

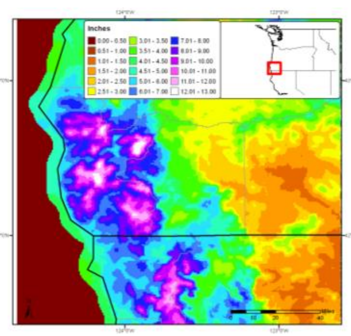
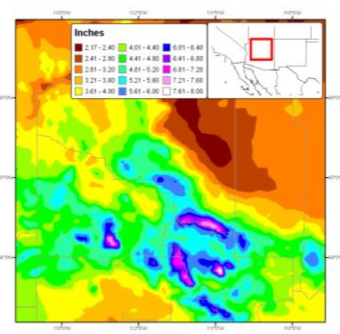
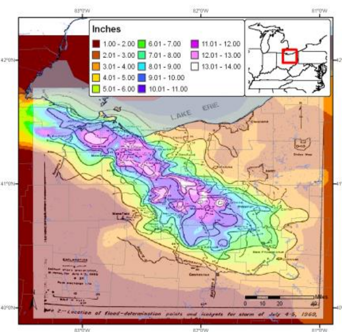
a)  b)  c) 

Figure E.2: Sample SPAS “basemaps:” (a) A pre-existing (USGS) isohyetal pattern across flat terrain (SPAS #1209), (b) PRISM mean monthly (October) precipitation (SPAS #1192) and (c) A 100-year 24-hour precipitation grid from NOAA Atlas 14 (SPAS #1138)

Radar Data

For storms occurring since approximately the mid-1990s, weather radar data are available to supplement the SPAS analysis. A fundamental requirement for high quality radar-estimated precipitation is a high quality radar mosaic, which is a seamless collection of concurrent weather radar data from individual radar sites, however in some cases a single radar is sufficient (i.e. for a small area size storm event such as a thunderstorm). Weather radar data have been in use by meteorologists since the 1960s to estimate precipitation depths, but it was not until the early 1990s that new, more accurate NEXRAD Doppler radar (WSR88D) was placed into service across the United States. Currently, efforts are underway to convert the WSR88D radars to dual polarization (DualPol) radar. Today, NEXRAD radar coverage of the contiguous United States is comprised of 159 operational sites and there are 30 in Canada. Each U.S. radar covers an approximate 285 mile (460 km) radial extent while Canadian radars have approximately 256 km (138 nautical miles) radial extent over which their radar can detect precipitation (see Figure E.3). The primary vendor of NEXRAD weather radar data for SPAS is Weather Decision Technologies, Inc. (WDT), who accesses, mosaics, archives and quality-controls NEXRAD radar data from NOAA and Environment Canada. SPAS utilizes Level II NEXRAD radar reflectivity data in units of dBZ, available every 5-minutes in the U.S. and 10-minutes in Canada.

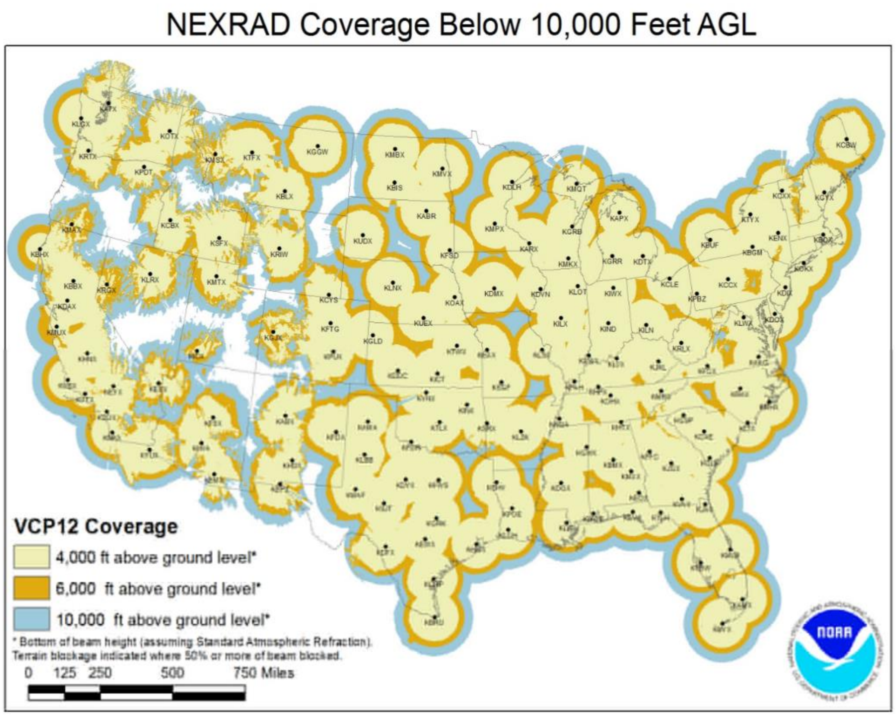


Figure E.3: U.S. radar locations and their radial extents of coverage below 10,000 feet above ground level (AGL). Each U.S. radar covers an approximate 285 mile radial extent over which the radar can detect precipitation.

The WDT and National Severe Storms Lab (NSSL) Radar Data Quality Control Algorithm (RDQC) removes non-precipitation artifacts from base Level–II radar data and remaps the data from polar coordinates to a Cartesian (latitude/longitude) grid. Non-precipitation artifacts include ground clutter, bright banding, sea clutter, anomalous propagation, sun strobes, clear air returns, chaff, biological targets, and electronic interference and hardware test patterns. The RDQC algorithm uses sophisticated data processing and a Quality Control Neural Network (QCNN) to delineate the precipitation echoes caused by radar artifacts (Lakshmanan and Valente 2004). Beam blockages due to terrain are mitigated by using 30 meter DEM data to compute and then discard data from a radar beam that clears the ground by less than 50 meters and incurs more than 50% power blockage. A clear-air echo removal scheme is applied to radars in clear-air mode when there is no precipitation reported from observation gauges within the vicinity of the radar. In areas of radar coverage overlap, a distance weighting scheme is applied to assign reflectivity to each grid cell, for multiple vertical levels. This scheme is applied to data from the nearest radar that is unblocked by terrain.

Once data from individual radars have passed through the RDQC, they are merged to create a seamless mosaic for the United States and southern Canada as shown in Figure E.4. A multi-sensor quality control can be applied by post-processing the mosaic to remove any remaining "false echoes." This technique uses observations of infra-red cloud top temperatures by GOES satellite and surface temperature to create a precipitation/no-precipitation mask. Figure E.4(b) shows the impact of WDT's quality control measures. Upon completing all QC, WDT converts the radar data from its native polar coordinate projection (1 degree x 1.0 km) into a longitude-latitude Cartesian grid (based on the WGS84 datum), at a spatial resolution of ~1/3rdmi^2 for processing in SPAS.

a) b)

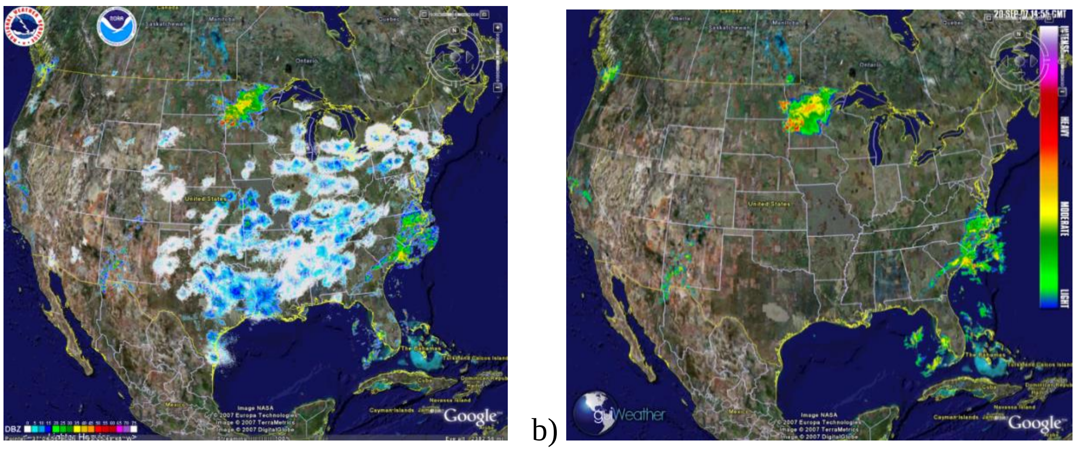


Figure E.4: (a) Level-II radar mosaic of CONUS radar with no quality control, (b) WDT quality controlled Level-II radar mosaic

SPAS conducts further QC on the radar mosaic by infilling areas contaminated by beam blockages. Beam blocked areas are objectively determined by evaluating total storm reflectivity grid which naturally amplifies areas of the SPAS analysis domain suffering from beam blockage as shown in Figure E.5.

a) b)

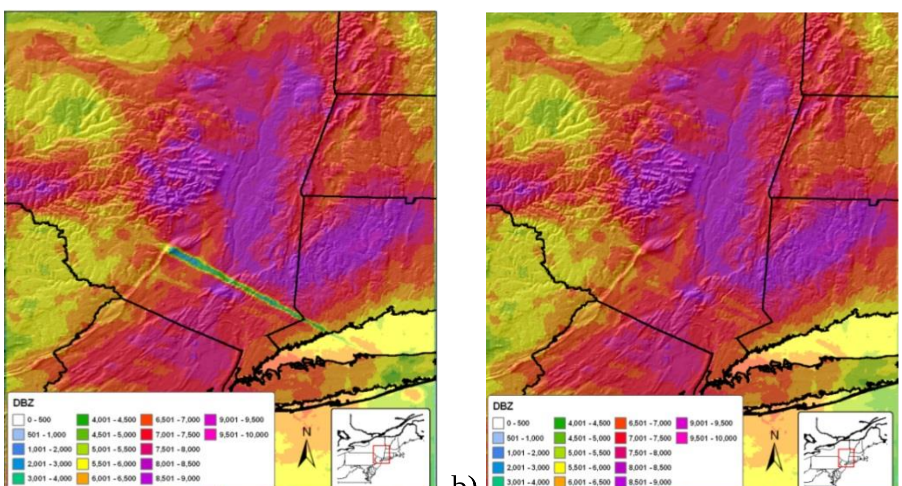


Figure E.5: Illustration of SPAS-beam blockage infilling where (a) is raw, blocked radar and (b) is filled for a 42-hour storm event

Methodology

Daily and Supplemental Precipitation to Hourly

To obtain one hour temporal resolutions and utilize all gauge data, it is necessary to disaggregate daily and supplemental precipitation observations into estimated hourly amounts. This process has traditionally been accomplished by distributing (temporally) the precipitation at each daily/supplemental gauge in accordance to a single nearby hourly gauge (Thiessen polygon approach). However, this may introduce biases and not correctly represent hourly precipitation at daily/supplemental gauges situated in-between hourly gauges. Instead, SPAS uses a spatial approach by which the estimated hourly precipitation at each daily and supplemental gauge is governed by a distance weighted algorithm of all nearby true hourly gauges.

To disaggregate (i.e. distribute) daily/supplemental gauge data into estimate hourly values, the true hourly gauge data are first evaluated and quality controlled using synoptic maps, nearby gauges, orographic effects, gauge history and other documentation on the storm. Any problems with the hourly data are resolved, and when possible/necessary accumulated hourly values are distributed. If an hourly value is missing, the analyst can choose to either estimate it or leave it missing for SPAS to estimate later based on nearby hourly gauges. At this point in the process, pseudo (hourly) gauges can be added to represent precipitation timing in topographically complex locations, areas with limited/no hourly data or to capture localized convention. Hourly Pseudo stations add additional detail on the timing of rainfall, either from COOP forms, radar reflectivity timing, and/or bucket survey reports with time increments. Hourly Pseudo stations are used only for the timing surrounding daily and supplemental stations and not for the magnitude. The limitations of Hourly Pseudo stations is that they are based on surrogate information, the quality of the information can be highly questionable (based on source) thus the importance of the station QC procedures are extremely important. To adequately capture the temporal variations of the precipitation, a pseudo hourly gauge is sometimes necessary. A pseudo gauge is created by distributing the precipitation at a co-located daily gauge or by creating a completely new pseudo gauge from other information such as inferences from COOP observation forms, METAR visibility data (if hourly precipitation are not already available), lightning data, satellite data, or radar data. Often radar data are the best/only choice for creating pseudo hourly gauges, but this is done cautiously given the potential differences (over-shooting of the radar beam equating to erroneous precipitation) between radar data and precipitation. In any case, the pseudo hourly gauge is flagged so SPAS only uses it for timing and not magnitude. Care is taken to ensure hourly pseudo gauges represent justifiably important physical and meteorological characteristics before being incorporated into the SPAS database. Although pseudo gauges provide a very important role, their use is kept to a minimum. The importance of insuring the reliability of every hourly gauge cannot be over emphasized. All of the final hourly gauge data, including pseudos, are included in the hourly SPAS precipitation database.

Using the hourly SPAS precipitation database, each hourly precipitation value is converted into a percentage that represents the incremental hourly precipitation divided by the total SPP precipitation. The GIS-ready x-y-z file is constructed for each hour and it includes the latitude (x), longitude(y) and the percent of precipitation (z) for a particular hour. Using the GRASS GIS, an inverse-distance-weighting squared (IDW) interpolation technique is applied to each of the hourly files. The result is a continuous grid with percentage values for the entire analysis domain, keeping the grid cells on which the hourly gauge resides faithful to the observed/actual percentage. Since the percentages typically have a high degree of spatial autocorrelation, the spatial interpolation has skill in determining the percentages between gauges, especially since the percentages are somewhat independent of the precipitation magnitude. The end result is a GIS grid for each hour that represents the percentage of the SPP precipitation that fell during that hour.

After the hourly percentage grids are generated and QC'd for the entire SPP, a program is executed that converts the daily/supplemental gauge data into incremental hourly data. The timing at each of the daily/supplemental gauges is based on (1) the daily/supplemental gauge observation time, (2) daily/supplemental precipitation amount and (3) the series of interpolated hourly percentages extracted from grids (described above).

This procedure is detailed in Figure E.6 below. In this example, a supplemental gauge reported 1.40" of precipitation during the storm event and is located equal distance from the three surrounding hourly recording gauges. The procedure steps are:

Step 1. For each hour, extract the percent of SPP from the hourly gauge-based percentage at the location of the daily/supplemental gauge. In this example, assume these values are the average of all the hourly gauges.

Step 2. Multiply the individual hourly percentages by the total storm precipitation at the daily/supplemental gauge to arrive at estimated hourly precipitation at the daily/supplemental gauge. To make the daily/supplemental accumulated precipitation data faithful to the daily/supplemental observations, it is sometimes necessary to adjust the hourly percentages so they add up to 100% and account for 100% of the daily observed precipitation.

	Hour						
Precipitation	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Hourly station 1	0.02	0.12	0.42	0.50	0.10	0.00	1.16
Hourly station 2	0.01	0.15	0.48	0.62	0.05	0.01	1.32
Hourly station 3	0.00	0.18	0.38	0.55	0.20	0.05	1.36
	Hour						
Percent of total storm precip.	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Hourly station 1	2%	10%	36%	43%	9%	0%	100%
Hourly station 2	1%	11%	36%	47%	4%	1%	100%
Hourly station 3	0%	13%	28%	40%	15%	4%	100%
Average	*1%*	*12%*	*34%*	*44%*	*9%*	*1%*	*100%*
Storm total precipitation at daily gauge				1.40			
	Hour						
Precipitation (estimated)	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Daily station	0.01	0.16	0.47	0.61	0.13	0.02	1.40

Figure E.6: Example of disaggregation of daily precipitation into estimated hourly precipitation based on three (3) surrounding hourly recording gauges

In cases where the hourly grids do not indicate any precipitation falling during the daily/supplemental gauge observational period, yet the daily/supplemental gauge reported precipitation, the daily/supplemental total precipitation is evenly distributed throughout the hours that make up the observational period; although this does not happen very often, this solution is consistent with NWS procedures. However, the SPAS analyst is notified of these cases in a comprehensive log file, and in most cases they are resolvable, sometimes with a pseudo hourly gauge.

Gauge Quality Control

Exhaustive quality control measures are taken throughout the SPAS analysis. Below are a few of the most significant QC measures taken.

Mass Curve Check

A mass curve-based QC-methodology is used to ensure the timing of precipitation at all gauges is consistent with nearby gauges. SPAS groups each gauge with the nearest four gauges (regardless of type) into a single file. These files are subsequently used in software for graphing and evaluation. Unusual characteristics in the mass curve are investigated and the gauge data corrected, if possible and warranted. See Figure E.7 for an example.

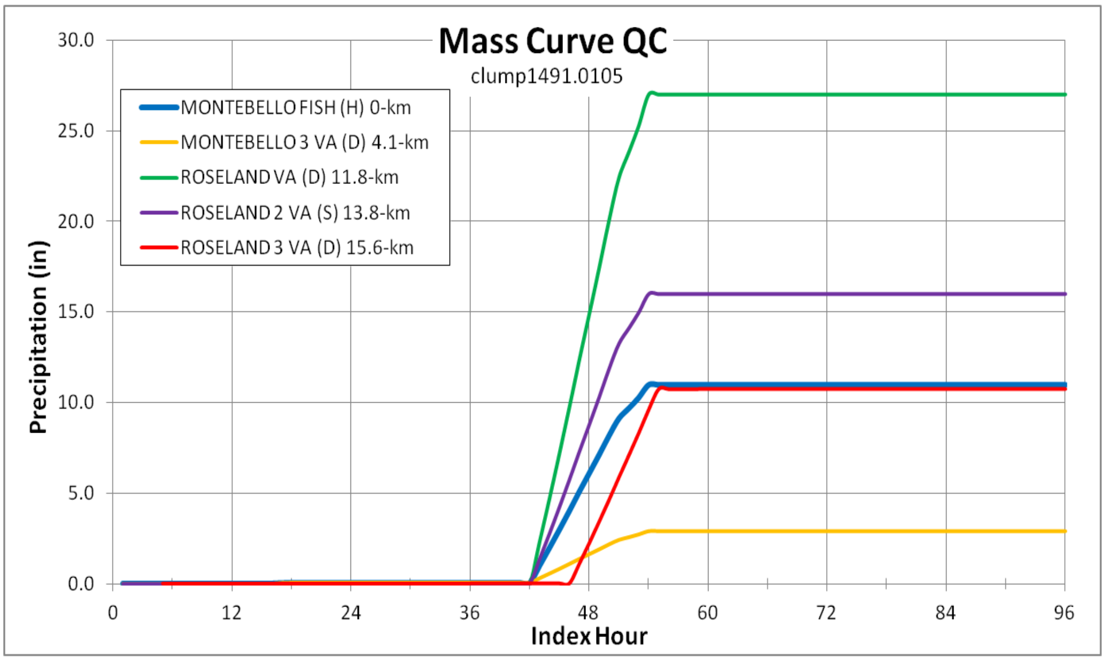


Figure E.7: Sample mass curve plot depicting a precipitation gauge with an erroneous observation time (red line). X-axis is the SPAS index hour and the y-axis is inches. The statistics in the upper left denote gauge type, and distance from target gauge (in km). In this example, the daily gauge (red line) was found to have an observation error/shift of 6-hours.

Gauge Mis-location Check

Although the gauge elevation is not explicitly used in SPAS, it is however used as a means of QC'ing gauge location. Gauge elevations are compared to a high-resolution 15-second DEM to identify gauges with large differences, which may indicate erroneous longitude and/or latitude values.

Co-located Gauge QC

Care is also taken to establish the most accurate precipitation depths at all co-located gauges. In general, where a co-located gauge pair exists, the highest precipitation is accepted (if deemed accurate). If the hourly gauge reports higher precipitation, then the co-located daily (or supplemental) is removed from the analysis since it would not add anything to the analysis. Often daily (or supplemental) gauges report greater precipitation than a co-located hourly station since hourly tipping bucket gauges tend to suffer from gauge under-catch, particularly during extreme events, due to loss of precipitation during tips. In these cases the daily/supplemental is retained for the magnitude and the hourly used as a pseudo hourly gauge for timing. Large discrepancies between any co-located gauges are investigated and resolved since SPAS can only utilize a single gauge magnitude at each co-located site.

Spatial Interpolation

At this point the QC'd observed hourly and disaggregated daily/supplemental hourly precipitation data are spatially interpolated into hourly precipitation grids. SPAS has three options for conducting the hourly precipitation interpolation, depending on the terrain and availability of radar data, thereby allowing SPAS to be optimized for any particular storm type or location. Figure E.8 depicts the results of each spatial interpolation methodology based on the same precipitation gauge data.

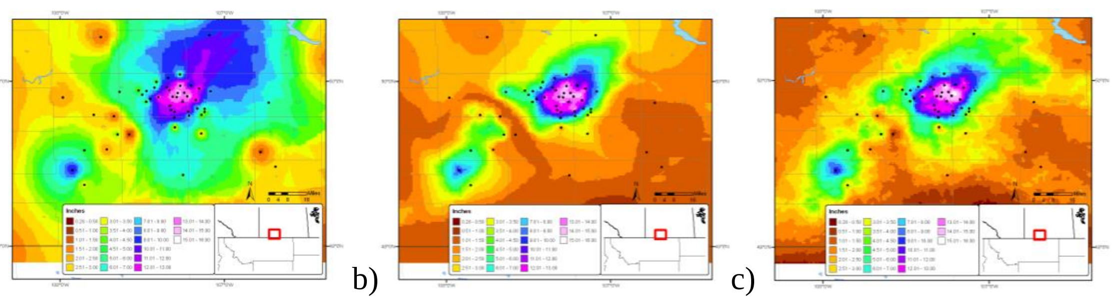

a) b) c)

Figure E.8: Depictions of total storm precipitation based on the three SPAS interpolation methodologies for a storm (SPAS #1177, Vanguard, Canada) across flat terrain: (a) no basemap, (b) basemap-aided and (c) radar

Basic Approach

The basic approach interpolates the hourly precipitation point values to a grid using an inverse distance weighting squared GIS algorithm. This is sometimes the best choice for convective storms over flat terrain when radar data are not available, yet high gauge density instills reliable precipitation patterns. This approach is rarely used.

Basemap Approach

Another option includes use of a basemap, also known as a climatologically-aided interpolation (Hunter 2005). As noted before, the spatial patterns of the basemap govern the interpolation between points of hourly precipitation estimates, while the actual hourly precipitation values govern the magnitude. This approach to interpolating point data across complex terrain is widely used. In fact, it was used extensively by the NWS during their storm analysis era from the 1940s through the 1970s (USACE 1973, Hansen et al., 1988, Corrigan et al., 1999).

In application, the hourly precipitation gauge values are first normalized by the corresponding grid cell value of the basemap before being interpolated. The normalization allows information and knowledge from the basemap to be transferred to the spatial distribution of the hourly precipitation. Using an IDW squared algorithm, the normalized hourly precipitation values are interpolated to a grid. The resulting grid is then multiplied by the basemap grid to produce the hourly precipitation grid. This is repeated each hour of the storm.

Radar Approach

The coupling of SPAS with NEXRAD provides the most accurate method of spatially and temporally distributing precipitation. To increase the accuracy of the results however, quality-controlled precipitation observations are used for calibrating the radar reflectivity to rain rate relationship (Z-R relationship) each hour instead of assuming a default Z-R relationship. Also, spatial variability in the Z-R relationship is accounted for through local bias corrections (described later). The radar approach involves several steps, each briefly described below. The radar approach cannot operate alone – either the basic or basemap approach must be completed before radar data can be incorporated. The SPAS general code is where the daily and supplemental station are timed to hourly data. Therefore, to get the correct timing of daily and supplemental stations, SPAS general needs to be run. The timed hourly data are used as input into SPAS-NEXRAD to derive the dynamic ZR relationship each hour.

Basemaps are only used to aid in the spatial interpolation. In regards to SPAS-NEXRAD, a basemap is used to interpolate the radar residuals (bias adjustments).

Z-R Relationship

SPAS derives high quality precipitation estimates by relating quality controlled level–II NEXRAD radar reflectivity radar data with quality-controlled precipitation gauge data to calibrate the Z-R (radar reflectivity, Z, and precipitation, R) relationship. Optimizing the Z-R relationship is essential for capturing temporal changes in the Z-R. Most current radar-derived precipitation techniques rely on a constant relationship between radar reflectivity and precipitation rate for a given storm type (e.g. tropical, convective), vertical structure of reflectivity and/or reflectivity magnitudes. This non-linear relationship is described by the Z-R equation below:

$$Z = A R^b \qquad (1)$$

Where Z is the radar reflectivity (measured in units of dBZ), R is the precipitation (precipitation) rate (millimeters per hour), A is the “multiplicative coefficient” and b is the “power coefficient”. Both A and b are directly related to the rain drop size distribution (DSD) and rain drop number distribution (DND) within a cloud (Martner and Dubovskiy 2005). The variability in the results of Z versus R is a direct result of differing DSD, DND and air mass characteristics (Dickens 2003). The DSD and DND are determined by complex interactions of microphysical processes that fluctuate regionally, seasonally, daily, hourly, and even within the same cloud. For these reasons, SPAS calculates an optimized Z-R relationship across the analysis domain each hour, based on observed precipitation rates and radar reflectivity (see Figure E.9).

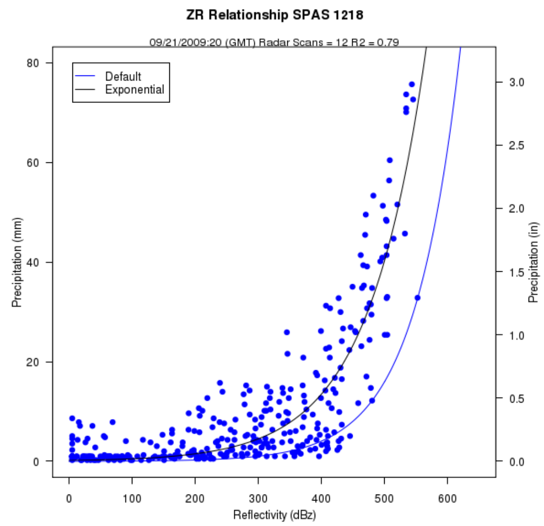


Figure E.9: Example SPAS (denoted as "Exponential") vs. default Z-R relationship (SPAS #1218, Georgia September 2009)

The National Weather Service (NWS) utilizes different default Z-R algorithms, depending on the type of precipitation event, to estimate precipitation from NEXRAD radar reflectivity data across the United States (see Figure E.10) (Baeck and Smith 1998 and Hunter 1999). A default Z-R relationship of Z = 300R1.4 is the primary algorithm used throughout the continental U.S. However, it is widely known that this, compared to unadjusted radar-aided estimates of precipitation, suffers from deficiencies that may lead to significant over or under-estimation of precipitation.

RELATIONSHIP	Optimum for:	Also recommended for:
Marshall-Palmer **($z=200R^{1.6}$)**	General stratiform precipitation	
East-Cool Stratiform **($z=130R^{2.0}$)**	Winter stratiform precipitation - east of continental divide	Orographic rain - East
West-Cool Stratiform **($z=75R^{2.0}$)**	Winter stratiform precipitation - west of continental divide	Orographic rain - West
WSR-88D Convective **($z=300R^{1.4}$)**	Summer deep convection	Other non-tropical convection
Rosenfeld Tropical **($z=250R^{1.2}$)**	Tropical convective systems	

Figure E.10: Commonly used Z-R algorithms used by the NWS

Instead of adopting a standard Z-R, SPAS utilizes a least squares fit procedure for optimizing the Z-R relationship each hour of the SPP. The process begins by determining if sufficient (minimum 12) observed hourly precipitation and radar data pairs are available to compute a reliable Z-R. If insufficient (<12) gauge pairs are available, then SPAS adopts the previous hour Z-R relationship, if available, or applies a user-defined default Z-R algorithm. If sufficient data are available, the one hour sum of NEXRAD reflectivity (Z) is related to the 1-hour precipitation at each gauge. A least-squares-fit exponential function using the data points is computed. The resulting best-fit, one hour-based Z-R is subjected to several tests to determine if the Z-R relationship and its resulting precipitation rates are within a certain tolerance based on the R-squared fit measure and difference between the derived and default Z-R precipitation results. Experience has shown the actual Z-R versus the default Z-R can be significantly different (Figure E.11). These Z-R relationships vary by storm type and location. A standard output of all SPAS analyses utilizing NEXRAD includes a file with each hour's adjusted Z-R relationship as calculated through the SPAS program.

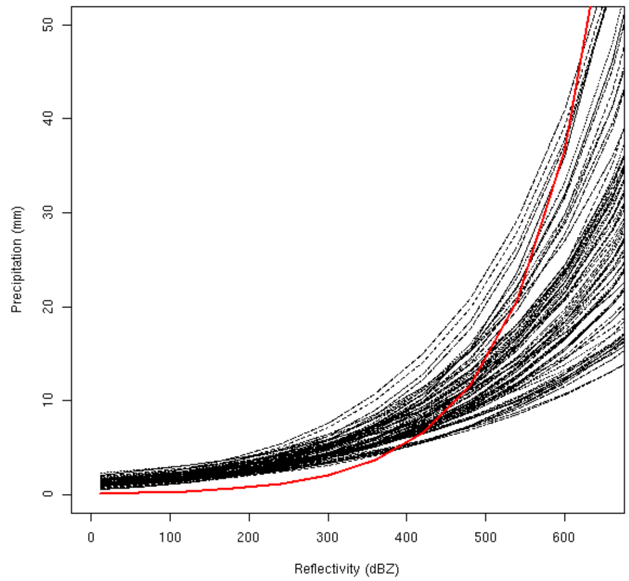


Figure E.11: Comparison of the SPAS optimized hourly Z-R relationships (black lines) versus a default Z=75R2.0 Z-R relationship (red line) for a period of 99 hours for a storm over southern California.

Radar-aided Hourly Precipitation Grids

Once a mathematically optimized hourly Z-R relationship is determined, it is applied to the total hourly Z grid to compute an initial precipitation rate (inches/hour) at each grid cell. To account for spatial differences in the Z-R relationship, SPAS computes residuals, the difference between the initial precipitation analysis (via the Z-R equation) and the actual "ground truth" precipitation (observed – initial analysis), at each gauge. The point residuals, also referred to as local biases, are normalized and interpolated to a residual grid using an inverse distance squared weighting algorithm. A radar-based hourly precipitation grid is created by adding the residual grid to the initial grid; this allows precipitation at the grid cells for which gauges are "on" to be true and faithful to the gauge measurement. The pre-final radar-aided precipitation grid is subject to some final, visual QC checks to ensure the precipitation patterns are consistent with the terrain; these checks are particularly important in areas of complex terrain where even QC'd radar data can be unreliable. The next incremental improvement with SPAS program will come as the NEXRAD radar sites are upgraded to dual-polarimetric capability.

Radar- and Basemap-Aided Hourly Precipitation Grids

At this stage of the radar approach, a radar- and basemap-aided hourly precipitation grid exists for each hour. At locations with precipitation gauges, the grids are equal, however elsewhere the grids can vary for a number of reasons. For instance, the basemap-aided hourly precipitation grid may depict heavy precipitation in an area of complex terrain, blocked by the radar, whereas the radar-aided hourly precipitation grid may suggest little, if any, precipitation fell in the same area. Similarly, the radar-aided hourly precipitation grid may depict an area of heavy precipitation in flat terrain that the basemap-approach missed since the area of heavy precipitation occurred in an area without gauges. SPAS uses an algorithm to compute the hourly precipitation at each pixel given the two results. Areas that are completely blocked from a radar signal are accounted for with the basemap-aided results (discussed earlier). Precipitation in areas with orographically effective terrain and reliable radar data are governed by a blend of the basemap- and radar-aided precipitation. Elsewhere, the radar-aided precipitation is used exclusively. This blended approach has proven effective for resolving precipitation in complex terrain, yet retaining accurate radar-aided precipitation across areas where radar data are reliable. Figure E.12 illustrates the evolution of final precipitation from radar reflectivity in an area of complex terrain in southern California.

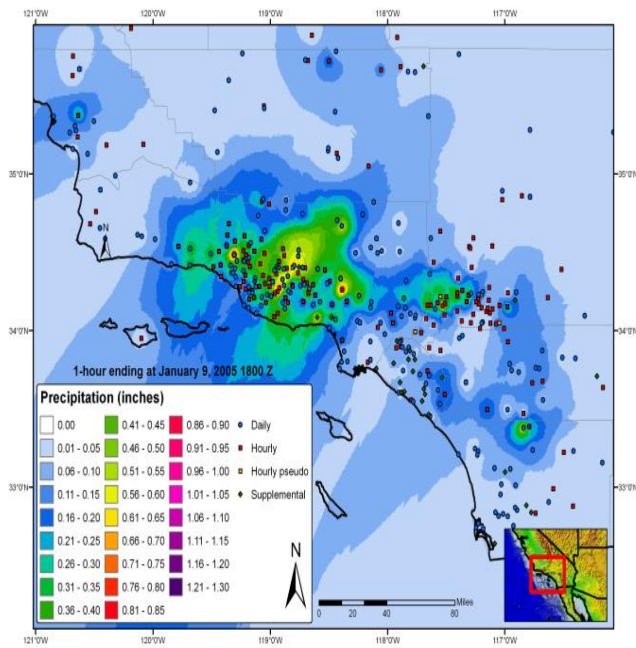


Figure E.12a: Map depicting 1-hour of precipitation utilizing inverse distance weighting of gauge precipitation for a January 2005 storm in southern California, USA

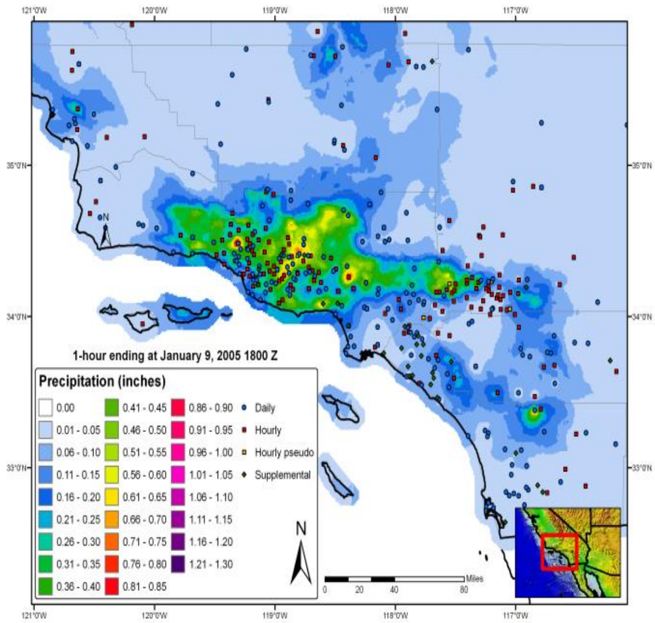


Figure E.12b: Map depicting 1-hour of precipitation utilizing gauge data together with a climatologically-aided interpolation scheme for a January 2005 storm in southern California, USA

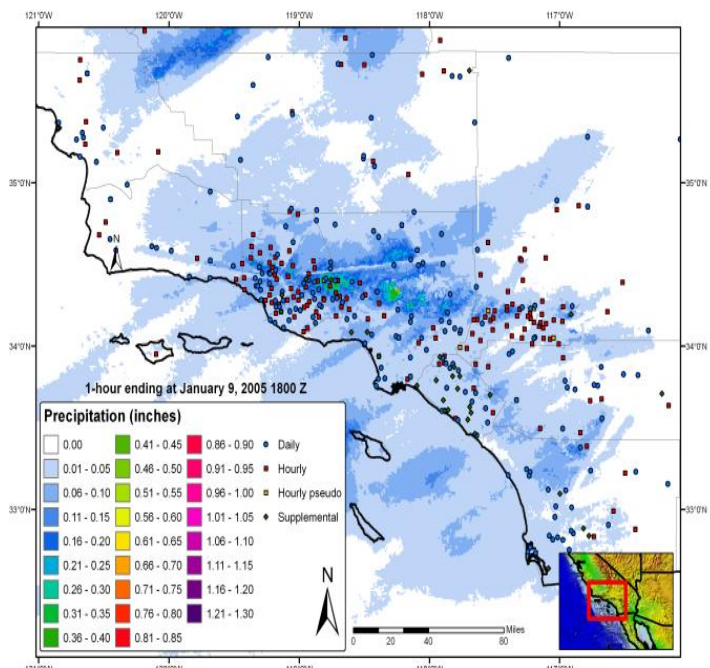


Figure E.12c: Map depicting 1-hour of precipitation utilizing default Z-R radar-estimated interpolation (no gauge correction) for a January 2005 storm in southern California, USA

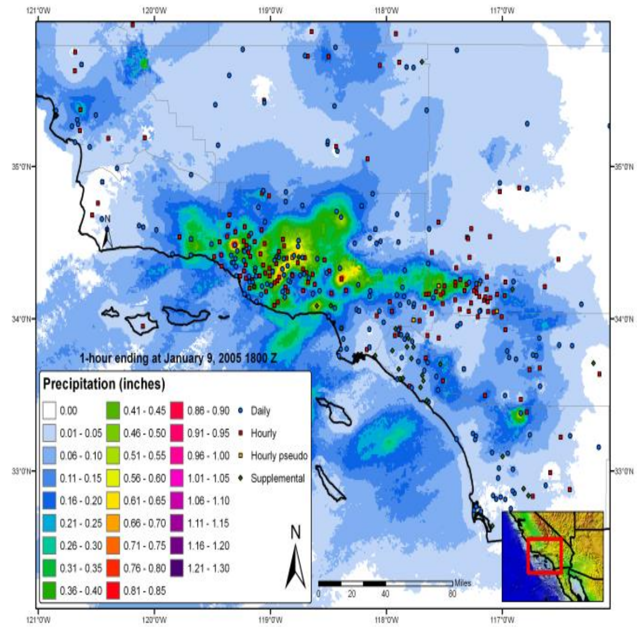


Figure E.12d: Map depicting 1-hour of precipitation utilizing SPAS precipitation for a January 2005 storm in southern California, USA

SPAS versus Gauge Precipitation

Performance measures are computed and evaluated each hour to detect errors and inconsistencies in the analysis. The measures include: hourly Z-R coefficients, observed hourly maximum precipitation, maximum gridded precipitation, hourly bias, hourly mean absolute error (MAE), root mean square error (RMSE), and hourly coefficient of determination (r^2).

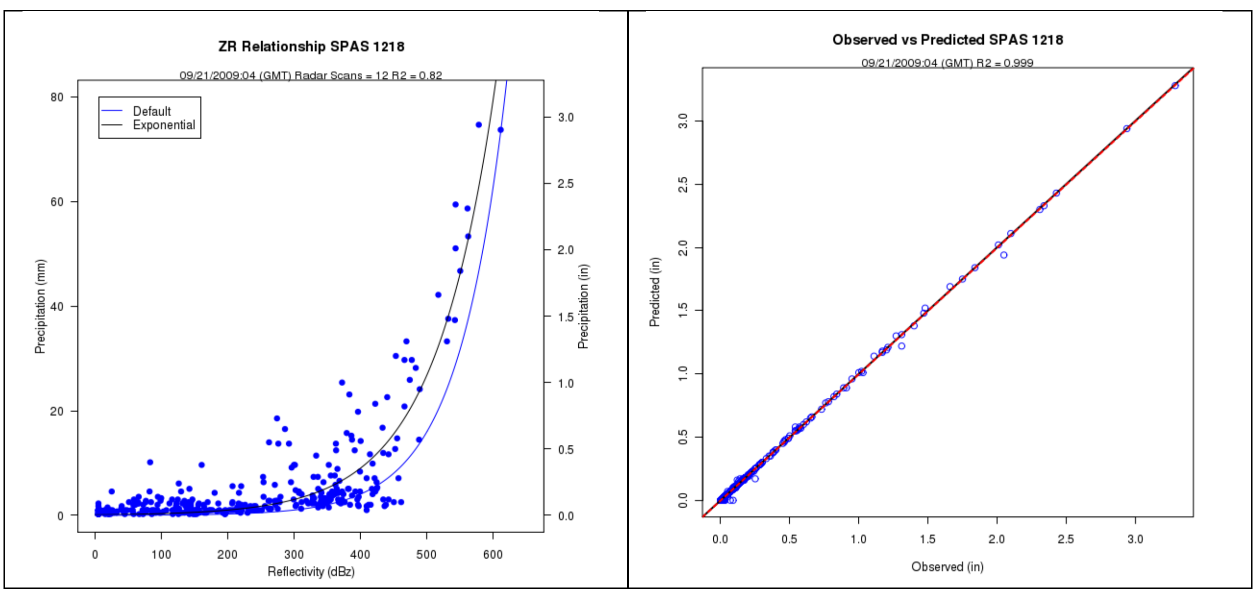


Figure E.13: Z-R plot (a), where the blue line is the SPAS derived Z-R and the black line is the default Z-R, and the (b) associated observed versus SPAS scatter plot at gauge locations.

Comparing SPAS-calculated precipitation (R_{spas}) to observed point precipitation depths at the gauge locations provides an objective measure of the consistency, accuracy and bias. Generally speaking SPAS is usually within 5% of the observed precipitation (see Figure E.13). Less-than-perfect correlations between SPAS precipitation depths and observed precipitation at gauged locations could be the result of any number of issues, including:

- **Point versus area:** A rain gauge observation represents a much smaller area than the area sampled by the radar. The area that the radar is sampling is approximately 1 km^2, whereas a standard rain gauge has an opening 8 inches in diameter, hence it only samples approximately $8.0x10^{-9}$ km^2. Furthermore, the radar data represent an average reflectivity (Z) over the grid cell, when in fact the reflectivity can vary across the 1 km^2 grid cell. Therefore, comparing a grid cell radar derived precipitation value to a gauge (point) precipitation depth measured may vary.
- **Precipitation gauge under-catch:** Although we consider gauge data "ground truth," we recognize gauges themselves suffer from inaccuracies. Precipitation gauges, shielded and unshielded, inherently underestimate total precipitation due to local airflow, wind under-catch, wetting, and evaporation. The wind under-catch errors are usually around 5% but can be as large as 40% in high winds (Guo et al., 2001, Duchon and Essenberg 2001, Ciach 2003, Tokay et al., 2010). Tipping buckets miss a small amount of precipitation during each tip of the bucket due to the bucket travel and tip time. As precipitation intensities increase, the volumetric loss of precipitation due to tipping tends to increase. Smaller tipping buckets can have higher volumetric losses due to higher tip frequencies, but on the other hand capture higher precision timing.
- **Radar Calibration:** NEXRAD radars calibrate reflectivity every volume scan, using an internally generated test. The test determines changes in internal variables such as beam power and path loss of the receiver signal processor since the last off-line calibration. If this value becomes large, it is likely that there is a radar calibration error that will translate into less reliable precipitation estimates. The calibration test is supposed to maintain a reflectivity precision of 1 dBZ. A 1 dBZ error can result in an error of up to 17% in R_{spas} using the default Z-R relationship $Z=300R^{1.4}$. Higher calibration errors will result in higher R_{spas} errors. However, by performing correlations each hour, the calibration issue is minimized in SPAS.
- **Attenuation:** Attenuation is the reduction in power of the radar beams' energy as it travels from the antenna to the target and back. It is caused by the absorption and the scattering of power from the beam by precipitation. Attenuation can result in errors in Z as large as 1 dBZ especially when the radar beam is sampling a large area of heavy precipitation. In some cases, storm precipitation is so intense (>12 inches/hour) that individual storm cells become "opaque" and the radar beam is totally attenuated. Armed with sufficient gauge data however, SPAS will overcome attenuation issues.
- **Range effects:** The curvature of Earth and radar beam refraction result in the radar beam becoming more elevated above the surface with increasing range. With the increased elevation of the radar beam comes a decrease in Z values due to the radar beam not sampling the main precipitation portion of the cloud (i.e. "over topping" the precipitation and/or cloud altogether). Additionally, as the radar beam gets further from the radar, it naturally samples a larger and larger area, therefore amplifying point versus area differences (described above).
- **Radar Beam Occultation/Ground Clutter:** Radar occultation (beam blockage) results when the radar beam's energy intersects terrain features as depicted in Figure E.14. The result is an increase in radar reflectivity values that can result in higher than normal precipitation estimates. The WDT processing algorithms account for these issues, but SPAS uses GIS spatial interpolation functions to infill areas suffering from poor or no radar coverage.
- **Anomalous Propagation (AP):** AP is false reflectivity echoes produced by unusual rates of refraction in the atmosphere. WDT algorithms remove most of the AP and false echoes, however in extreme cases the air near the ground may be so cold and dense that a radar beam that starts out moving upward is bent all the way down to the ground. This produces erroneously strong echoes at large distances from the radar. Again, equipped with sufficient gauge data, the SPAS bias corrections will overcome AP issues.

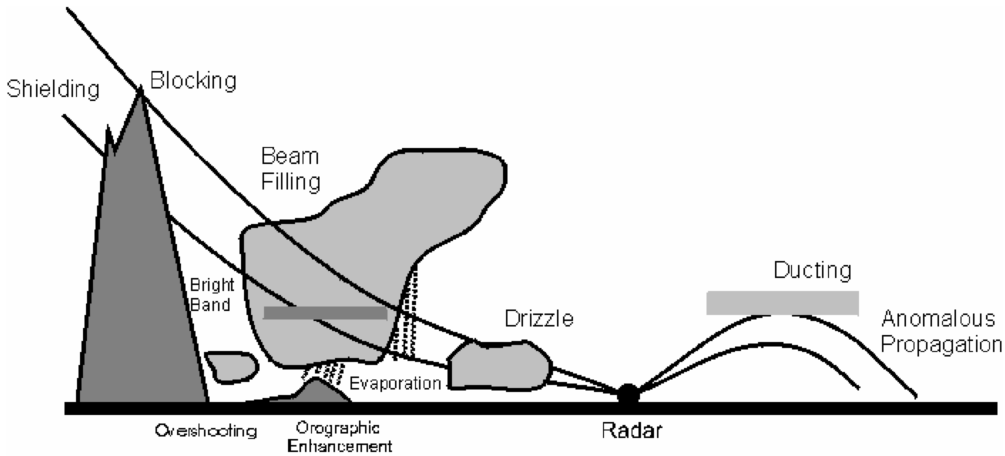


Figure E.14: Depiction of radar artifacts. (Source: Wikipedia)

SPAS is designed to overcome many of these short-comings by carefully using radar data for defining the spatial patterns and relative magnitudes of precipitation, but allowing measured precipitation values ("ground truth") at gauges to govern the magnitude. When absolutely necessary, the observed precipitation values at gauges are nudged up (or down) to force SPAS results to be consistent with observed gauge values. Nudging gauge precipitation values helps to promote better consistency between the gauge value and the grid-cell value, even though these two values sometimes should not be the same since they are sampling different area sizes. For reasons discussed in the "SPAS versus Gauge Precipitation" section, the gauge value and grid-cell value can vary. Plus, SPAS is designed to toss observed individual hourly values that are grossly inconsistent with radar data, hence driving a difference between the gauge and grid-cell. In general, when the gauge and grid-cell value differ by more than 15% and/or 0.50 inches, and the gauge data have been validated, then it is justified to artificially increase or decrease slightly the observed gauge value to "force" SPAS to derive a grid-cell value equal to the observed value. Sometimes simply shifting the gauge location to an adjacent grid-cell resolves the problems. Regardless, a large gauge versus grid-cell difference is a "red flag" and sometimes the result of an erroneous gauge value or a mis-located gauge, but in some cases the difference can only be resolved by altering the precipitation value.

Before results are finalized, a precipitation intensity check is conducted to ensure the spatial patterns and magnitudes of the maximum storm intensities at 1-, 6-, 12-, etc. hours are consistent with surrounding gauges and published reports. Any erroneous data are corrected and SPAS re-run. Considering all of the QA/QC checks in SPAS, it typically requires 5-15 basemap SPAS runs and, if radar data are available, another 5-15 radar-aided runs, to arrive at the final output.

Test Cases

To check the accuracy of the DAD software, three test cases were evaluated.

"Pyramidville" Storm

The first test was that of a theoretical storm with a pyramid shaped isohyetal pattern. This case was called the Pyramidville storm. It contained 361 hourly stations, each occupying a single grid-cell. The configuration of the Pyramidville storm (see Figure E.15) allowed for uncomplicated and accurate calculation of the analytical DA truth independent of the DAD software. The main motivation of this case was to verify that the DAD software was properly computing the area sizes and average depths.

1. Storm center: 39°N 104°W
2. Duration: 10-hours
3. Maximum grid-cell precipitation: 1.00”
4. Grid-cell resolution: 0.06 sq.-miles (361 total cells)
5. Total storm size: 23.11 sq-miles
6. Distribution of precipitation:

    Hour 1: Storm drops 0.10” at center (area 0.06 mi^2)

    Hour 2: Storm drops 0.10” over center grid-cell AND over one cell width around hour 1 center

    Hours 3-10:

    1. Storm drops 0.10” per hour at previously wet area, plus one cell width around previously wet area
    2. Area analyzed at every 0.10”
    3. Analysis resolution: 15-sec (~.25 mi^2)

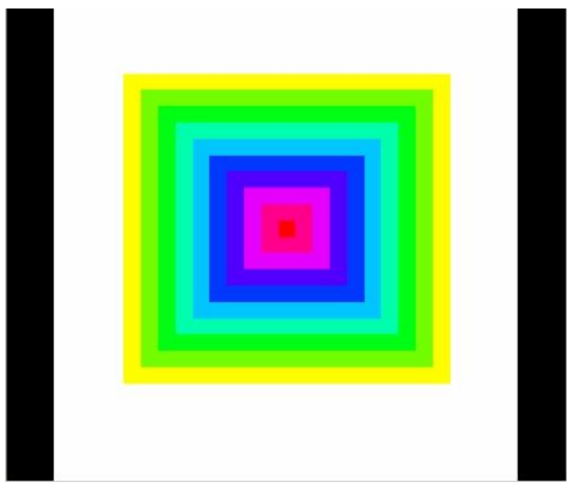


Figure E.15: "Pyramidville” Total precipitation. Center = 1.00”, Outside edge = 0.10”

The analytical truth was calculated independent of the DAD software, and then compared to the DAD output. The DAD software results were equal to the truth, thus demonstrating that the DA estimates were properly calculated (Figure E.16).

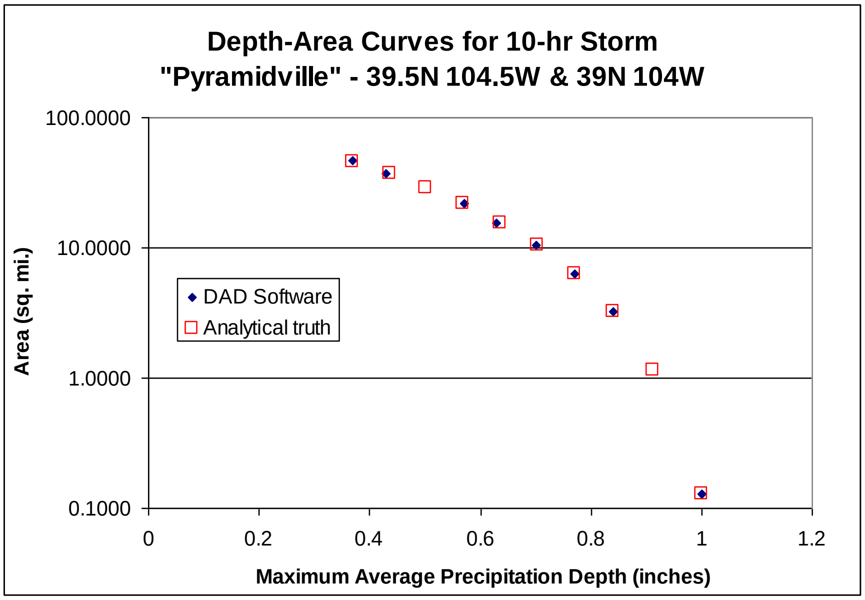


Figure E.16: 10-hour DA results for "Pyramidville"; truth vs. output from DAD software

The Pyramidville storm was then changed such that the mass curve and spatial interpolation methods would be stressed. Test cases included:

- Two-centers, each center with 361 hourly stations
- A single center with 36 hourly stations, 0 daily stations
- A single center with 3 hourly stations and 33 daily stations

As expected, results began shifting from the 'truth,' but minimally and within the expected uncertainty.

Ritter, Iowa Storm, June 7, 1953

Ritter, Iowa was chosen as a test case for a number of reasons. The NWS had completed a storm analysis, with available DAD values for comparison. The storm occurred over relatively flat terrain, so orographics were not an issue. An extensive "bucket survey" provided a great number of additional observations from this event. Of the hundreds of additional reports, about 30 of the most accurate reports were included in the DAD analysis. The DAD software results are very similar to the NWS DAD values (Table E.2).

Table E.2: The percent difference [(AWA-NWS)/NWS] between the AWA DA results and those published by the NWS for the 1953 Ritter, Iowa storm.

% Difference

		Duration (hours)			
Area (sq.mi.)		6	12	24	total
10		-15%	-7%	2%	2%
100		-7%	-6%	1%	1%
200		2%	0%	9%	9%
1000		-6%	-7%	4%	4%
5000		-13%	-8%	2%	2%
10000		-14%	-6%	0%	0%

Westfield, Massachusetts Storm, August 8, 1955

Westfield, Massachusetts was also chosen as a test case for a number of reasons. It is a probable maximum precipitation (PMP) driver for the northeastern United States. Also, the Westfield storm was analyzed by the NWS and the DAD values are available for comparison. Although this case proved to be more challenging than any of the others, the final results are very similar to those published by the NWS (Table E.3).

Table E.3: The percent difference [(AWA-NWS)/NWS] between the AWA DA results and those published by the NWS for the 1955 Westfield, Massachusetts storm

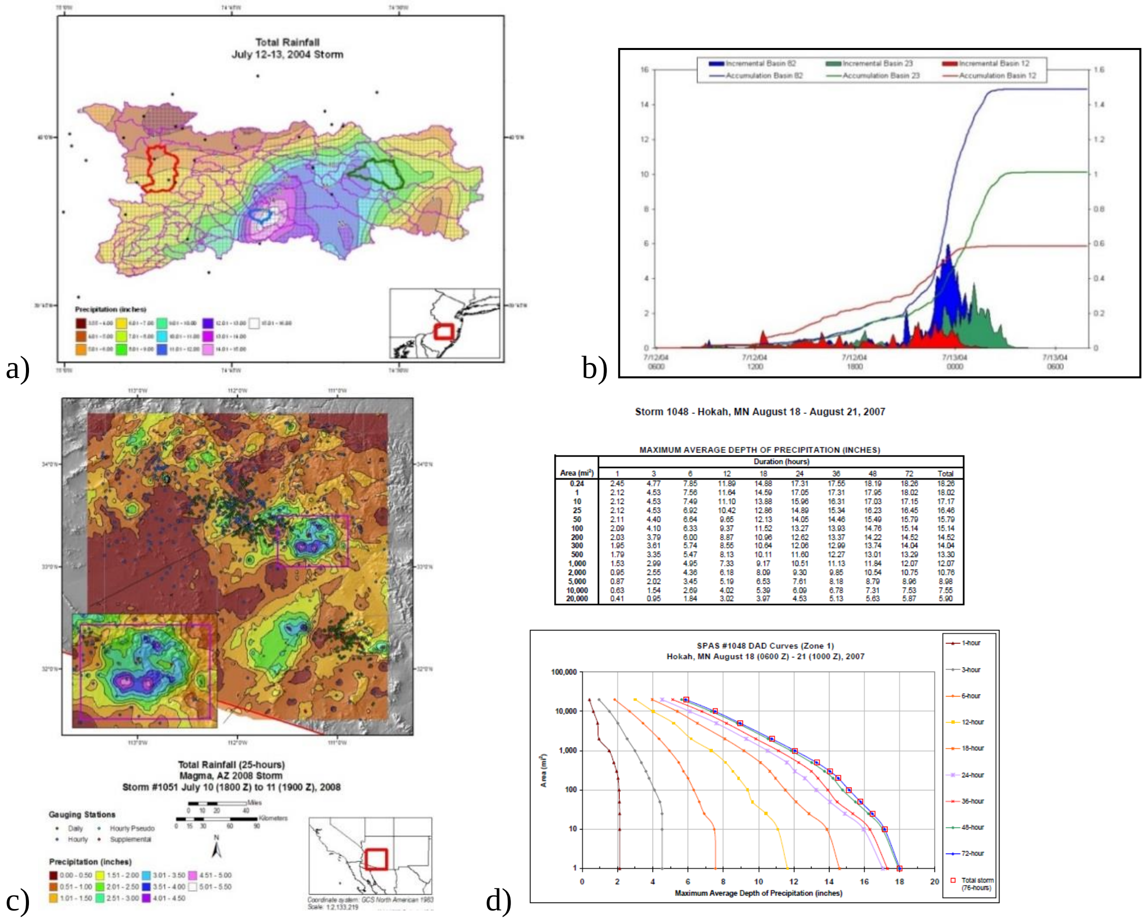
% Difference

	Duration (hours)							
Area (sq. mi.)		6	12	24	36	48	60	total
10		2%	3%	0%	1%	-1%	0%	2%
100		-5%	2%	4%	-2%	-6%	-4%	-3%
200		-6%	1%	1%	-4%	-7%	-5%	-5%
1000		-4%	-2%	1%	-6%	-7%	-6%	-3%
5000		3%	2%	-3%	-3%	-5%	-5%	0%
10000		4%	9%	-5%	-4%	-7%	-5%	1%
20000		7%	12%	-6%	-3%	-4%	-3%	3%

The primary components of SPAS are: storm search, data extraction, quality control (QC), conversion of daily precipitation data into estimated hourly data, hourly and total storm precipitation grids/maps and a complete storm-centered DAD analysis.

Output

Armed with accurate, high-resolution precipitation grids, a variety of customized output can be created (see Figures E.17A-D). Among the most useful outputs are sub-hourly precipitation grids for input into hydrologic models. Sub-hourly (i.e. 5-minute) precipitation grids are created by applying the appropriate optimized hourly Z-R (scaled down to be applicable for instantaneous Z) to each of the individual 5-minute radar scans; 5-minutes is often the native scan rate of the radar in the US. Once the scaled Z-R is applied to each radar scan, the resulting precipitation is summed up. The proportion of each 5-minute precipitation to the total 1-hour radar-aided precipitation is calculated. Each 5-minute proportion (%) is then applied to the quality controlled, bias corrected 1-hour total precipitation (created above) to arrive at the final 5 minute precipitation for each scan. This technique ensures the sum of 5-minute precipitation equals that of the quality controlled, bias corrected 1-hour total precipitation derived initially. Depth-area-duration (DAD) tables/plots, shown in Figure E.17d, are computed using a highly-computational extension to SPAS. DADs provide an objective three dimensional (magnitude, area size, and duration) perspective of a storms' precipitation. SPAS DADs are computed using the procedures outlined by the NWS Technical Paper 1 (1946).



Area (mi^2)	Duration (hours)									
	1	3	6	12	18	24	36	48	72	Total
0.24	2.45	4.77	7.85	11.89	14.88	17.31	17.55	18.19	18.26	18.26
1	2.12	4.53	7.56	11.64	14.59	17.05	17.31	17.95	18.02	18.02
10	2.12	4.53	7.49	11.10	13.88	15.96	16.31	17.03	17.15	17.17
25	2.12	4.53	6.92	10.42	12.86	14.89	15.34	16.23	16.45	16.46
50	2.11	4.40	6.64	9.65	12.13	14.05	14.46	15.49	15.79	15.79
100	2.09	4.10	6.33	9.37	11.52	13.27	13.93	14.76	15.14	15.14
200	2.03	3.79	6.00	8.87	10.96	12.62	13.37	14.22	14.52	14.52
300	1.95	3.61	5.74	8.55	10.64	12.06	12.99	13.74	14.04	14.04
500	1.79	3.35	5.47	8.13	10.11	11.60	12.27	13.01	13.29	13.30
1,000	1.53	2.99	4.95	7.33	9.17	10.51	11.13	11.84	12.07	12.07
2,000	0.95	2.55	4.36	6.18	8.09	9.30	9.85	10.54	10.75	10.76
5,000	0.87	2.02	3.45	5.19	6.53	7.61	8.18	8.79	8.96	8.98
10,000	0.63	1.54	2.69	4.02	5.39	6.09	6.78	7.31	7.53	7.55
20,000	0.41	0.95	1.84	3.02	3.97	4.53	5.13	5.63	5.87	5.90

Figure E.17: Various examples of SPAS output, including (a) total storm map and its associated (b) basin average precipitation time series, (c) total storm precipitation map, (d) depth-area-duration (DAD) table and plot

Summary

Grounded on years of scientific research with a demonstrated reliability in post-storm analyses, SPAS is a hydro-meteorological tool that provides accurate precipitation analyses for a variety of applications. SPAS has the ability to compute precise and accurate results by using sophisticated timing algorithms, basemaps, a variety of precipitation data and most importantly NEXRAD weather radar data (if available). The approach taken by SPAS relies on hourly, daily and supplemental precipitation gauge observations to provide quantification of the precipitation amounts while relying on basemaps and NEXRAD data (if available) to provide the spatial distribution of precipitation between precipitation gauge sites. By determining the most appropriate coefficients for the Z-R equation on an hourly basis, the approach anchors the precipitation amounts to accepted precipitation gauge data while using the NEXRAD data to distribute precipitation between precipitation gauges for each hour of the storm. Hourly Z-R coefficient computations address changes in the cloud microphysics and storm characteristics as the storm evolves. Areas suffering from limited or no radar coverage are estimated using the spatial patterns and magnitudes of the independently created basemap precipitation grids. Although largely automated, SPAS is flexible enough to allow hydro-meteorologists to make important adjustments and adapt to any storm situation.

References

Baeck M.L., Smith J.A., 1998: "Precipitation Estimation by the WSR-88D for Heavy Precipitation Events", *Weather and Forecasting*: Vol. 13, No. 2, pp. 416–436.

Ciach, G.J., 2003: Local Random Errors in Tipping-Bucket Rain Gauge Measurements. *J. Atmos. Oceanic Technol.*, **20**, 752–759.

Corps of Engineers, U.S. Army, 1945-1973: Storm Rainfall in the United States, Depth-Area-Duration Data. Office of Chief of Engineers, Washington, D.C.

Corrigan, P., Fenn, D.D., Kluck, D.R., and J.L. Vogel, 1999: Probable Maximum Precipitation Estimates for California. *Hydrometeorological Report No. 59*, U.S. National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 392 pp.

Dickens, J., 2003: "On the Retrieval of Drop Size Distribution by Vertically Pointing Radar", American Meteorological Society 32nd Radar Meteorology Conference, Albuquerque, NM, October 2005.

Duchon, C.E., and G.R. Essenberg, 2001: Comparative Precipitation Observations from Pit and Above Ground Rain Gauges with and without Wind Shields, *Water Resources Research*, Vol. 37, N. 12, 3253-3263.

Faulkner, E., T. Hampton, R.M. Rudolph, and Tomlinson, E.M., 2004: Technological Updates for PMP and PMF – Can They Provide Value for Dam Safety Improvements? Association of State Dam Safety Officials Annual Conference, Phoenix, Arizona, September 26-30, 2004.

Guo, J. C. Y., Urbonas, B., and Stewart, K., 2001: Rain Catch under Wind and Vegetal Effects. ASCE, *Journal of Hydrologic Engineering*, Vol. 6, No. 1.

Hansen, E.M., Fenn, D.D., Schreiner, L.C., Stodt, R.W., and J.F., Miller, 1988: Probable Maximum Precipitation Estimates, United States between the Continental Divide and the 103rd Meridian, *Hydrometeorological Report Number 55A*, National weather Service, National Oceanic and Atmospheric Association, U.S. Dept of Commerce, Silver Spring, MD, 242 pp.

Hunter, R.D. and R.K. Meentemeyer, 2005: Climatologically Aided Mapping of Daily Precipitation and Temperature, *Journal of Applied Meteorology*, October 2005, Vol. 44, pp. 1501-1510.

Hunter, S.M., 1999: Determining WSR-88D Precipitation Algorithm Performance Using The Stage III Precipitation Processing System, Next Generation Weather Radar Program, WSR-88D Operational Support Facility, Norman, OK.

Lakshmanan, V. and M. Valente, 2004: Quality control of radar reflectivity data using satellite data and surface observations, 20th Int'l Conf. on Inter. Inf. Proc. Sys. (IIPS) for Meteor., Ocean., and Hydr., Amer. Meteor. Soc., Seattle, CD-ROM, 12.2.

Martner, B.E, and V. Dubovskiy, 2005: Z-R Relations from Raindrop Disdrometers: Sensitivity To Regression Methods And DSD Data Refinements, 32nd Radar Meteorology Conference, Albuquerque, NM, October, 2005

Tokay, A., P.G. Bashor, and V.L. McDowell, 2010: Comparison of Rain Gauge Measurements in the Mid-Atlantic Region. *J. Hydrometeor.*, **11**, 553-565.

Tomlinson, E.M., W.D. Kappel, T.W. Parzybok, B. Rappolt, 2006: Use of NEXRAD Weather Radar Data with the Storm Precipitation Analysis System (SPAS) to Provide High Spatial

Resolution Hourly Precipitation Analyses for Runoff Model Calibration and Validation, ASDSO Annual Conference, Boston, MA.
Tomlinson, E.M., and T.W. Parzybok, 2004: Storm Precipitation Analysis System (SPAS), proceedings of Association of Dam Safety Officials Annual Conference, Technical Session II, Phoenix, Arizona.
Tomlinson, E.M., R.A. Williams, and T.W. Parzybok, September 2003: Site-Specific Probable Maximum Precipitation (PMP) Study for the Great Sacandaga Lake / Stewarts Bridge Drainage Basin, Prepared for Reliant Energy Corporation, Liverpool, New York.
Tomlinson, E.M., R.A. Williams, and T.W. Parzybok, September 2003: Site-Specific Probable Maximum Precipitation (PMP) Study for the Cherry Creek Drainage Basin, Prepared for the Colorado Water Conservation Board, Denver, CO.
Tomlinson, E.M., Kappel W.D., Parzybok, T.W., Hultstrand, D., Muhlestein, G., and B. Rappolt, May 2008: Site-Specific Probable Maximum Precipitation (PMP) Study for the Wanahoo Drainage Basin, Prepared for Olsson Associates, Omaha, Nebraska.
Tomlinson, E.M., Kappel W.D., Parzybok, T.W., Hultstrand, D., Muhlestein, G., and B. Rappolt, June 2008: Site-Specific Probable Maximum Precipitation (PMP) Study for the Blenheim Gilboa Drainage Basin, Prepared for New York Power Authority, White Plains, NY.
Tomlinson, E.M., Kappel W.D., and T.W. Parzybok, February 2008: Site-Specific Probable Maximum Precipitation (PMP) Study for the Magma FRS Drainage Basin, Prepared for AMEC, Tucson, Arizona.
Tomlinson, E.M., Kappel W.D., Parzybok, T.W., Hultstrand, D., Muhlestein, G., and P. Sutter, December 2008: Statewide Probable Maximum Precipitation (PMP) Study for the state of Nebraska, Prepared for Nebraska Dam Safety, Omaha, Nebraska.
Tomlinson, E.M., Kappel, W.D., and Tye W. Parzybok, July 2009: Site-Specific Probable Maximum Precipitation (PMP) Study for the Scoggins Dam Drainage Basin, Oregon.
Tomlinson, E.M., Kappel, W.D., and Tye W. Parzybok, February 2009: Site-Specific Probable Maximum Precipitation (PMP) Study for the Tuxedo Lake Drainage Basin, New York.
Tomlinson, E.M., Kappel, W.D., and Tye W. Parzybok, February 2010: Site-Specific Probable Maximum Precipitation (PMP) Study for the Magma FRS Drainage Basin, Arizona.
Tomlinson, E.M., Kappel W.D., Parzybok, T.W., Hultstrand, D.M., Muhlestein, G.A., March 2011: Site-Specific Probable Maximum Precipitation Study for the Tarrant Regional Water District, Prepared for Tarrant Regional Water District, Fort Worth, Texas.
Tomlinson, E.M., Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., and T. W. Parzybok, November 2011: Site-Specific Probable Maximum Precipitation (PMP) Study for the Lewis River basin, Washington State.
Tomlinson, E.M., Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., and T. W. Parzybok, December 2011: Site-Specific Probable Maximum Precipitation (PMP) Study for the Brassua Dam basin, Maine.
U.S. Weather Bureau, 1946: Manual for Depth-Area-Duration analysis of storm precipitation. *Cooperative Studies Technical Paper No. 1*, U.S. Department of Commerce, Weather Bureau, Washington, D.C., 73pp

Appendix F
Storm Data

North Carolina Storm List Appendix F

This appendix contains all the individual SPAS storm data and associated information used to calculate PMP depths. Information is provided representing the SPAS analyzed data, the information used to locate the storm representative dew point/SST location, and other pertinent information regarding the IPMF analyses. The adjustments applied to each storm to each grid point to calculate the TAF over the entire domain are contained in the separate PMP Tool database.

When HYSPLIT is not available, daily synoptic weather maps are provided for a period starting a few days before the storm (prior to 1948). Daily weather maps covering the period from 1871 through 2002 are from the U.S. Daily Weather Maps Archive, NOAA Climate Database Modernization Program (CDMP), National Climatic Data Center, Asheville, NC, and the NOAA Central Library Data Imaging Project. Daily synoptic weather maps from 2002 through the current day are from the NOAA Weather Prediction Center Daily Weather Maps web page, https://www.wpc.ncep.noaa.gov/dailywxmap/index.html

For all storms which had a USACE Storm Studies analysis previously completed, those pertinent data sheets are included. These data came from the USACE Storm Rainfall in the United States, Depth-Area-Duration Data files (USACE, 1973). In addition, there are several storms which include a hand drawn transposition limit map complete by the NWS. These maps were recovered from the Hydrometeorological Design Studies Center office in Silver Spring, MD and are archived on AWA's server. Descriptions of transposition limits of key storms are contained in several HMRs (e.g., HMR 52 Figure 26 and HMR 53 Table 2 (Ho and Reidel, 1980)).

Table F.1 Short storm list used for PMP Development.

General and Hybrid Storms

SPAS_ID	Storm Name	State	Lat	Lon	Year	Month	Day	Max Rainfall	Elevation	TYPE
SPAS_1339_1	WELLSBORO (DAD 1)	PA	41.7042	-77.2292	1889	5	30	10.11	1,842	General
SPAS_1339_2	WELLSBORO (DAD 2)	PA	40.9042	-78.5958	1889	5	30	8.99	1562	General
SPAS_1339_3	WELLSBORO (DAD 3)	PA	40.3958	-76.9292	1889	5	30	9.19	389	General
SPAS_1514_1	VADE MECUM	NC	36.3125	-80.2792	1908	8	23	18.00	803	General
SPAS_1305_1	ELBA	AL	31.3625	-86.1208	1929	3	12	29.73	308	General
SPAS_1195_2	PADDY MOUNTAIN	WV	39.0200	-78.5600	1936	3	16	8.32	2210	General
SPAS_1311_1	MCKENZIE	TN	36.4400	-87.9100	1937	1	17	19.86	666	General
SPAS_1346_1	BLUE RIDGE DIVIDE	NC	35.0375	-83.0792	1940	8	28	14.09	3267	General
SPAS_1680_1	WEST SHOKAN	NY	42.0042	-74.3958	1955	10	14	20.27	3548	General
SPAS_1278_1	MADISONVILLE	KY	37.3458	-87.4958	1964	3	8	11.67	449	General
SPAS_1312A_1	ROSMAN	NC	37.7375	-81.5958	1964	9	26	9.22	2132	General
SPAS_1312A_2	ROSMAN	NC	35.1458	-82.8042	1964	9	26	17.86	2270	General
SPAS_1380_1	BURTON DAM	GA	34.7958	-83.6958	1967	8	21	18.42	3720	General
SPAS_1357_1	BURNSVILLE	TN	34.8375	-88.3958	1973	3	14	12.15	591	General
SPAS_1362_2	ROBBINSVILLE	VA	35.3208	-83.6875	1977	4	2	9.21	4721	General
SPAS_1219_1	BIG FORK	AR	35.8708	-92.1208	1982	12	1	15.92	764	General
SPAS_1533_1	MONTEBELLO	VA	37.8125	-79.1625	1985	11	1	22.56	3892	General
SPAS_1244_1	LOUISVILLE	KY	38.1000	-85.6700	1997	2	28	13.51	551	General
SPAS_1804_1	HALIFAX	VT	42.7542	-72.7625	2005	10	7	15.53	1,485	General
SPAS_1047_1	TAMAQUA	PA	41.6750	-75.3750	2006	6	26	12.26	1260	General
SPAS_1242_1	ALLEY SPRING	MO	37.1150	-91.4450	2008	3	17	15.10	1050	General
SPAS_1218_1	DOUGLASVILLE	GA	33.8700	-84.7600	2009	9	19	25.37	939	General
SPAS_1218_2	LA FAYETTE	GA	34.7700	-85.2600	2009	9	19	19.61	898	General
SPAS_1208_1	WARNER PARK	TN	36.0611	-86.9056	2010	5	1	19.71	621	General
SPAS_1350_1	NEW BERN	NC	35.1750	-77.2150	2010	9	27	23.44	39	General
SPAS_1298_1	HARRISBURG	PA	39.9850	-76.4950	2011	9	4	18.32	226	General
SPAS_1564_1	MOUNT PLEASANT	SC	32.8950	-79.7650	2015	10	1	27.97	8	General
SPAS_1340_1	BIG MEADOWS	VA	38.5458	-78.4042	1942	10	12	19.77	3299	Hybrid (G/T)
SPAS_1376_1	LIBERTY	KY	37.2625	-84.9708	1984	5	7	9.62	804	Hybrid (G/L)
SPAS_1275_2	MONTEGOMERY DAM	PA	40.6050	-76.4650	2004	9	18	8.80	1602	Hybrid (G/T)

Local Storms

SPAS_ID	Storm Name	State	Lat	Lon	Year	Month	Day	Max Rainfall	Elevation	TYPE
SPAS_1944_1	ROCKPORT	WV	39.0625	-81.5375	1889	7	18	21.07	926	Local
SPAS_1489_1	JEWELL	MD	38.7290	-76.5710	1897	7	26	15.88	163	Local
SPAS_1343_1	JOHNSON CITY	TN	36.3042	-82.0625	1924	6	13	16.14	3137	Local
SPAS_1344_1	SIMPSON	KY	38.1042	-83.2958	1939	7	4	20.82	1104	Local
SPAS_1534_1	EWAN	NJ	39.6875	-75.1807	1940	9	1	24.30	103	Local
SPAS_1681_1	SMETHPORT (DAD 1)	PA	41.8438	-78.2687	1942	7	17	35.30	1799	Local
SPAS_1681_2	SMETHPORT (DAD 2)	PA	41.7188	-78.0812	1942	7	17	26.67	2236	Local
SPAS_1681_3	SMETHPORT (DAD 3)	PA	41.9729	-78.1937	1942	7	17	23.93	1571	Local
SPAS_1681_4	SMETHPORT (DAD 4)	PA	41.9146	-77.8979	1942	7	17	32.76	2038	Local
SPAS_1681_5	SMETHPORT (DAD 5)	PA	42.3563	-77.9479	1942	7	17	25.33	2111	Local
SPAS_1681_6	SMETHPORT (DAD 6)	PA	41.6021	-78.5729	1942	7	17	20.41	2,045	Local
SPAS_1536_1	GLENVILLE	WV	38.8958	-80.7708	1943	8	4	15.04	1,113	Local
SPAS_1546_1	LITTLE RIVER	VA	38.8625	-79.1875	1949	6	17	15.13	2,068	Local
SPAS_1226_1	COLLEGE HILL	OH	40.0854	-81.6479	1963	6	3	19.39	974	Local
SPAS_1402_1	LITTLE BARREN	TN	36.3625	-83.7208	1965	7	24	11.00	1077	Local
SPAS_1402_2	ROSEDALE	TN	36.1792	-84.2292	1965	7	24	13.32	2740	Local
SPAS_1209_1	WOOSTER	OH	40.9146	-81.9729	1969	7	4	14.95	1165	Local
SPAS_1362_1	COEBURN	VA	37.2792	-81.8042	1977	4	2	15.66	2296	Local
SPAS_1550_1	JOHNSTOWN	PA	40.3958	-78.9542	1977	7	18	12.64	2531	Local
SPAS_1406_1	RAPIDAN	VA	38.4150	-78.3350	1995	6	27	28.39	1288	Local
SPAS_1548_1	REDBANK	PA	41.2550	-79.1550	1996	7	19	9.42	1717	Local
SPAS_1674_1	SPARTA	NJ	41.0300	-74.6400	2000	8	11	16.70	796	Local
SPAS_1040_1	TABERNACLE	NJ	39.8812	-74.6895	2004	7	13	15.63	61	Local
SPAS_1049_1	DELAWARE COUNTY	NY	42.0100	-74.9000	2007	6	19	11.69	2157	Local
SPAS_1415_1	ISLIP	NY	40.8050	-73.0650	2014	8	13	14.23	80	Local
SPAS_1952_1	FAYETTEVILLE	NC	34.9450	-79.1450	2016	9	28	14.26	200	Local
SPAS_1700_1	ELLICOTT CITY	MD	39.2650	-76.7550	2018	5	27	14.22	404	Local
SPAS_1927_1	FORT LAUDERDALE	FL	26.0750	-80.1250	2023	4	12	26.88	7	Local

Tropical Storms

SPAS_ID	Storm Name	State	Lat	Lon	Year	Month	Day	Max Rainfall	Elevation	TYPE
SPAS_1515_1	ST. GEORGE	GA	30.5208	-82.0208	1911	8	28	19.12	32	Tropical
SPAS_1299_1	ALTA PASS	NC	35.8792	-81.8708	1916	7	13	24.90	1,968	Tropical
SPAS_1299_2	KINGSTREE	SC	33.6625	-79.8292	1916	7	13	16.79	44	Tropical
SPAS_1516_1	GLENVILLE	GA	31.9458	-81.8875	1929	9	23	21.20	99	Tropical
SPAS_1516_2	GLENVILLE	GA	34.8208	-84.1542	1929	9	23	20.88	2510	Tropical
SPAS_1517_2	MONCURE	NC	35.6042	-79.0708	1929	9	29	11.55	181	Tropical
SPAS_1517_3	SETTLE	NC	35.9458	-80.6958	1929	9	29	9.97	766	Tropical
SPAS_1490_1	EASTON	MD	38.8625	-76.0708	1935	9	4	17.00	55	Tropical
SPAS_1342_1	MT MITCHELL	NC	36.2875	-81.4792	1940	8	11	20.27	3236	Tropical
SPAS_1518_1	ROCKINGHAM	NC	34.9542	-79.7292	1945	9	13	14.97	370	Tropical
SPAS_1679_1	SLIDE MOUNTAIN	NY	42.0208	-74.3958	1955	8	11	15.20	2798	Tropical
SPAS_1243_1	WESTFIELD	MA	42.1961	-72.8246	1955	8	17	18.93	1,090	Tropical
SPAS_1312B_2	ROSMAN	NC	35.1375	-82.8375	1964	10	3	17.53	2440	Tropical
SPAS_1491_1	TYRO	VA	37.8125	-79.0042	1969	8	19	27.23	800	Tropical
SPAS_1276_1	WELLSVILLE	NY	42.0375	-78.0708	1972	6	18	18.78	2,398	Tropical
SPAS_1276_2	ZERBE	PA	40.5375	-76.6208	1972	6	18	18.79	1617	Tropical
SPAS_1317_1	AMERICUS	GA	32.0958	-84.2292	1994	7	4	28.09	466	Tropical
SPAS_1373_1	ANTREVILLE	SC	34.8550	-82.2250	1995	8	26	19.99	733	Tropical
SPAS_1552_1	SOUTHPORT	NC	34.0050	-77.9950	1999	9	14	24.30	31	Tropical
SPAS_1552_2	YORKTOWN	VA	37.2750	-76.5550	1999	9	14	19.22	0	Tropical
SPAS_1552_3	POMPTON LAKE	NJ	40.9950	-74.2850	1999	9	15	14.62	214	Tropical
SPAS_1552_4	CAIRO	NY	42.2950	-74.0050	1999	9	15	11.71	452	Tropical
SPAS_1535_1	EDENTON	NC	35.8625	-76.5042	2003	9	17	7.96	9	Tropical
SPAS_1535_2	UPPER SHERANDO	VA	37.9125	-79.0292	2003	9	17	20.22	2284	Tropical
SPAS_1551_1	RICHMOND	VA	37.7050	-77.3750	2004	8	30	14.38	182	Tropical
SPAS_1275_1	MONTGOMERY DAM	PA	40.6450	-80.3850	2004	9	18	8.79	1,050	Tropical
SPAS_1526_1	RIDGEWAY	SC	34.3350	-81.0050	2006	6	10	9.32	408	Tropical
SPAS_1224_1	MAPLECREST	NY	42.2999	-74.1600	2011	8	27	22.91	2,264	Tropical
SPAS_1669_1	EVERGREEN	NC	34.4550	-78.8650	2016	10	6	19.12	103	Tropical
SPAS_1720_1	WRIGHTSVILLE BEACH	NC	34.2350	-77.7650	2018	9	14	43.92	0	Tropical
SPAS_1891_1	DOWNINGTOWN	PA	39.9750	-75.6650	2021	8	31	10.29	290	Tropical
SPAS_1981_1	KURE BEACH	NC	33.7750	-77.7350	2024	9	12	32.41	24	Tropical
SPAS_1984_1	BUSICK (HELENE)	NC	35.7650	-82.1750	2024	9	24	32.76	3292	Tropical

Table of Contents

General Storms

Storm Precipitation Analysis System (SPAS) For Storm #1339_1 SPAS Analysis

General Storm Location: Wellsboro, PA region, caused the Johnstown Flood

Storm Dates: May 29 (0600) - June 3 (0500), 1889

Event: Flash Flood Event

DAD Zone 1

Latitude: 41.7042

Longitude: -77.2292

Max. Grid Rainfall Amount: 10.11"

Max. Observed Rainfall Amount: 9.80"

Number of Stations: 176 (33 Daily, 5 Hourly, and 138 Supplemental)

SPAS Version: 9.5

Basemap: Monthly Weather Report Isohyetal Grid

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

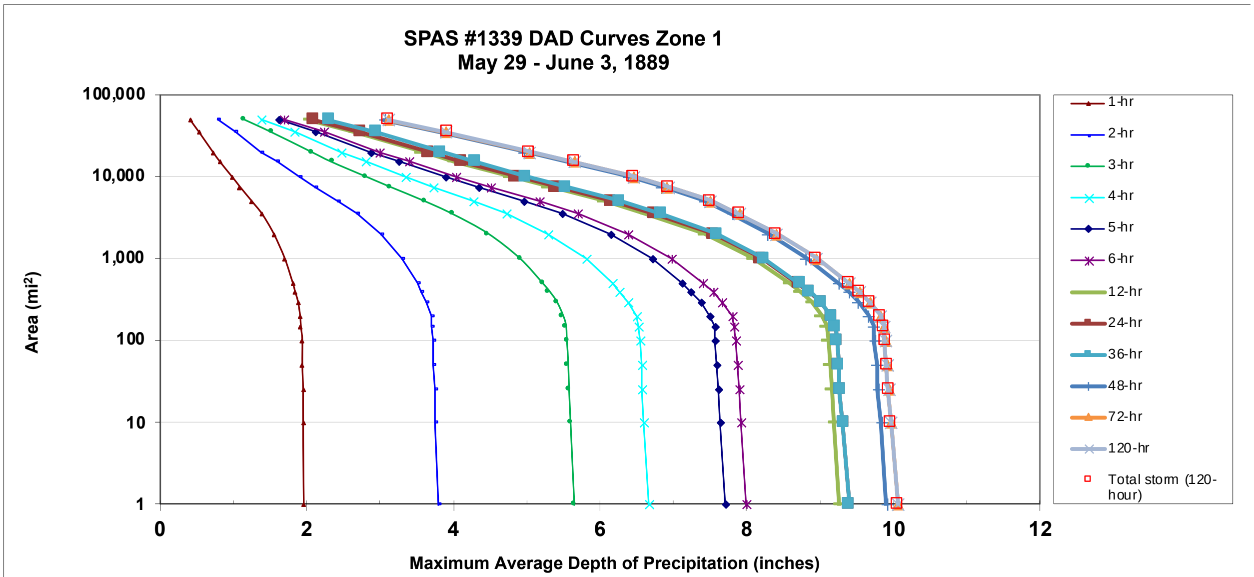
Radar Included: No

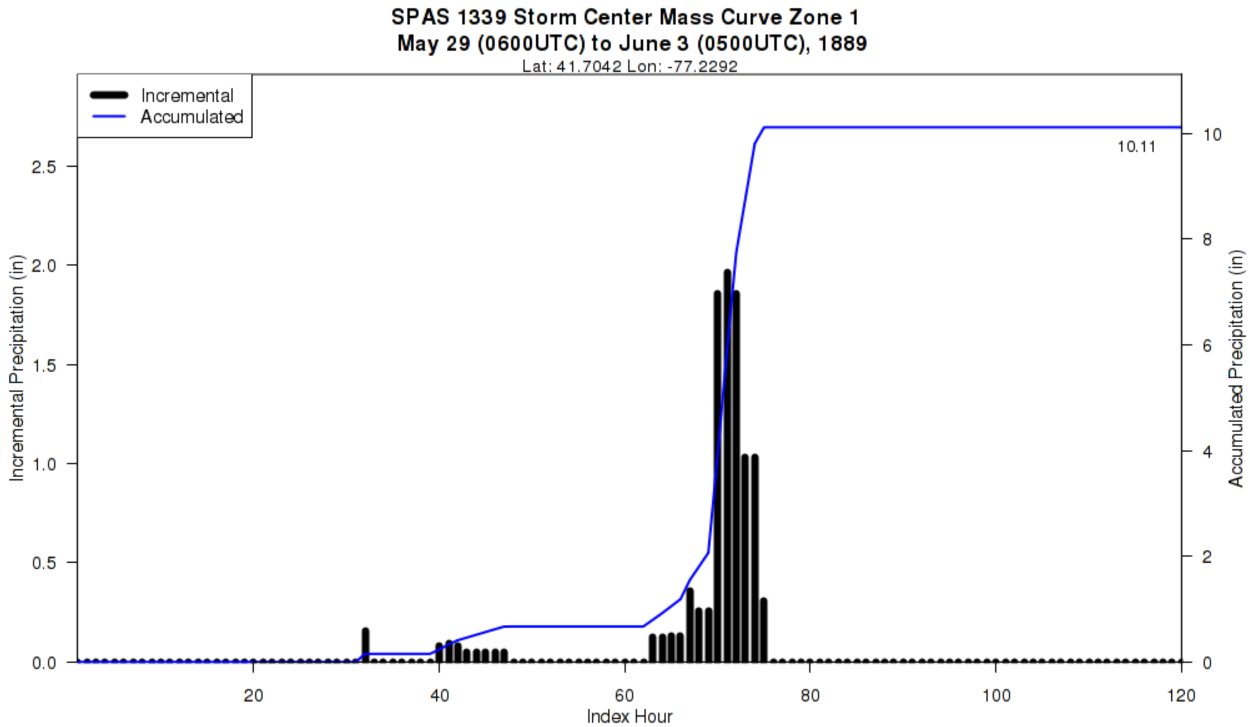
Depth-Area-Duration (DAD) analysis: Yes

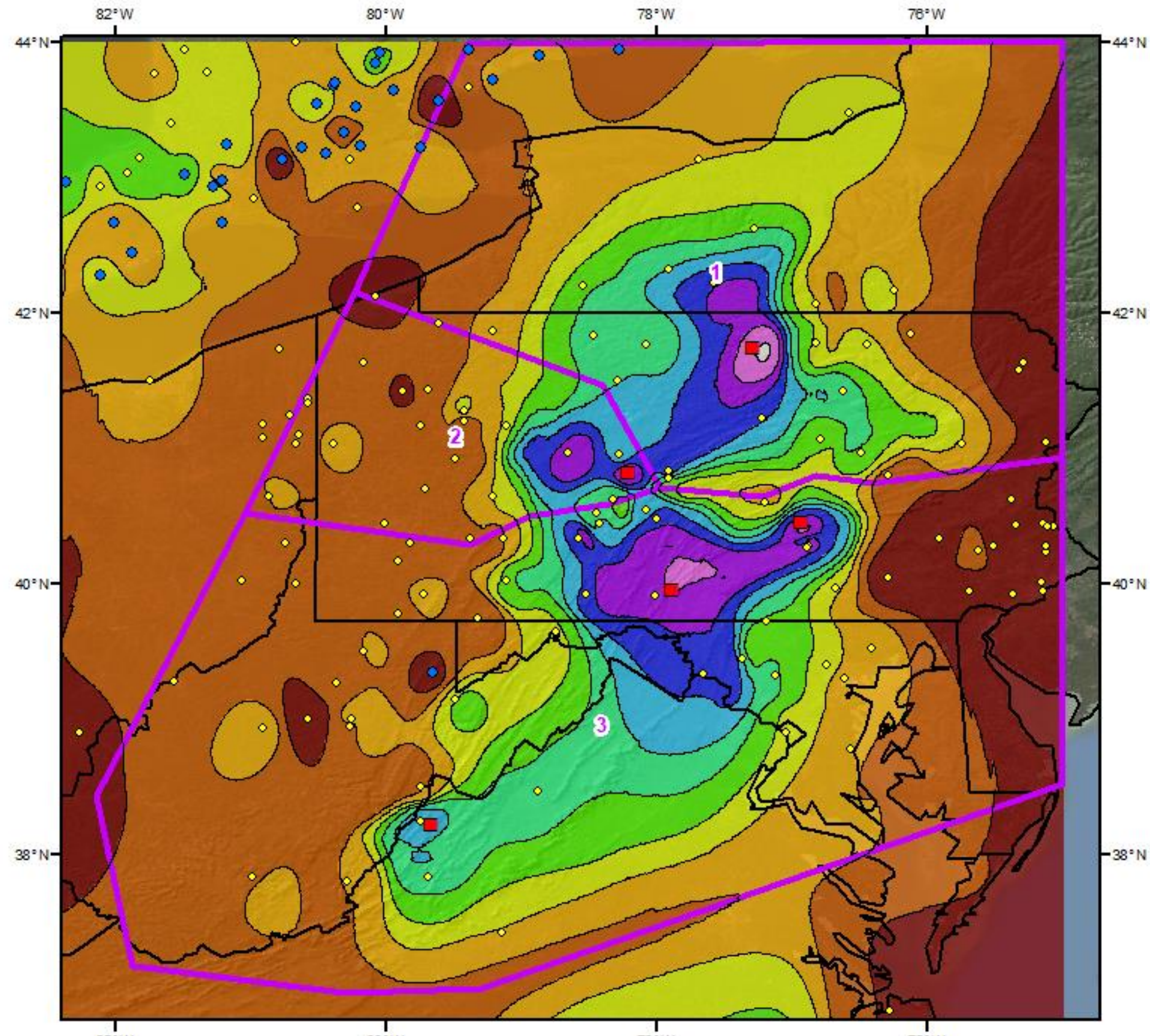
Reliability of results: This analysis was based on hourly data, daily data, and supplemental station. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on the basemap, and the timing is based on hourly stations. The timing of rainfall accumulation at sub daily timescales is uncertain because of the lack of hourly data available for the storm. The mass curve represents our best evaluation based on USACE analyses and bucket survey reports.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1339_1	-77.2292	41.7042	1,842	15-Jun	77.00	3.14	0.47	76	2.670	80.91	3.77	0.54	84	3.230	1.210

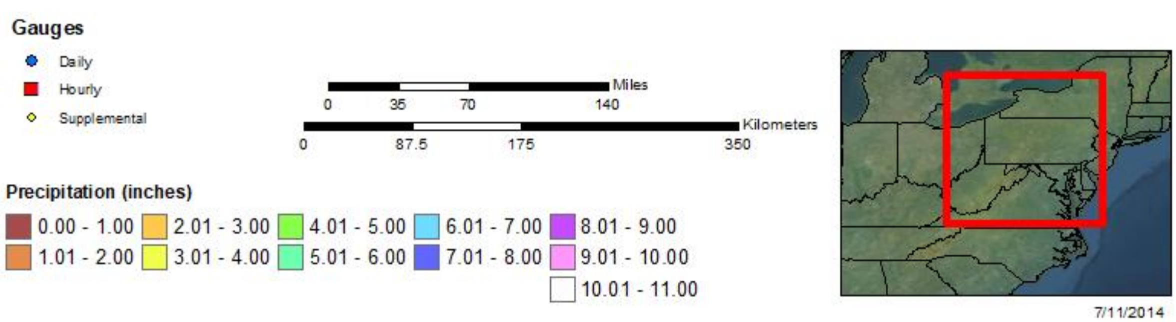
Storm 1339 Zone 1 - May 29 (0600 UTC) - Jun. 03 (0500 UTC), 1889													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
areasqmi	**Duration (hours)**												
	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	36-hr	48-hr	72-hr	120-hr	Total
0.4	1.96	3.81	5.66	6.69	7.72	8.03	9.30	9.42	9.42	9.94	10.09	10.09	10.09
1	1.95	3.79	5.64	6.67	7.70	8.00	9.27	9.39	9.39	9.91	10.06	10.06	10.06
10	1.94	3.76	5.59	6.60	7.64	7.92	9.19	9.31	9.31	9.83	9.97	9.97	9.97
25	1.94	3.74	5.57	6.58	7.61	7.89	9.16	9.27	9.27	9.79	9.93	9.93	9.93
50	1.93	3.73	5.56	6.56	7.59	7.87	9.13	9.25	9.25	9.77	9.91	9.91	9.91
100	1.93	3.72	5.54	6.54	7.57	7.85	9.11	9.23	9.23	9.74	9.88	9.88	9.88
150	1.91	3.71	5.53	6.53	7.56	7.83	9.09	9.21	9.21	9.73	9.87	9.87	9.87
200	1.90	3.70	5.49	6.50	7.49	7.80	9.02	9.15	9.15	9.66	9.82	9.82	9.82
300	1.87	3.63	5.40	6.39	7.38	7.67	8.89	9.00	9.01	9.52	9.67	9.67	9.67
400	1.83	3.57	5.30	6.27	7.24	7.53	8.72	8.84	8.85	9.38	9.53	9.53	9.53
500	1.80	3.51	5.21	6.17	7.12	7.41	8.59	8.70	8.72	9.25	9.39	9.39	9.39
1,000	1.69	3.30	4.90	5.80	6.70	6.97	8.08	8.19	8.22	8.80	8.94	8.94	8.94
2,000	1.54	3.01	4.47	5.29	6.14	6.37	7.42	7.53	7.58	8.28	8.40	8.40	8.40
3,500	1.38	2.68	3.98	4.72	5.47	5.69	6.63	6.74	6.83	7.80	7.89	7.89	7.89
5,000	1.24	2.42	3.60	4.28	4.96	5.16	6.04	6.14	6.25	7.42	7.50	7.50	7.50
7,500	1.08	2.11	3.13	3.73	4.33	4.51	5.29	5.39	5.52	6.84	6.91	6.92	6.92
10,000	0.97	1.89	2.80	3.34	3.88	4.04	4.76	4.85	4.97	6.37	6.45	6.45	6.46
15,000	0.81	1.58	2.34	2.80	3.26	3.39	4.02	4.11	4.30	5.57	5.64	5.64	5.64
20,000	0.71	1.39	2.06	2.47	2.88	3.00	3.57	3.65	3.83	4.96	5.02	5.03	5.04
35,000	0.52	1.02	1.51	1.82	2.12	2.22	2.66	2.73	2.95	3.83	3.89	3.90	3.92
49,524	0.40	0.78	1.15	1.38	1.62	1.69	2.04	2.09	2.30	3.06	3.10	3.11	3.12




SPAS 1339 Storm Center Mass Curve Zone 1
May 29 (0600UTC) to June 3 (0500UTC), 1889
Lat: 41.7042 Lon: -77.2292
Incremental
Accumulated
10.11
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
20
40
60
80
100
120



Total Storm (120-hr) Precipitation (inches)
May 29 (0600 UTC) - June 3 (0500 UTC), 1889
SPAS 1339 - Wellsboro, PA



DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

STORM STUDIES – PERTINENT DATA SHEET (REV.)

Storm of 30 May- 1 June 1889
Assignment SA 1-1
Location Pa., Md., Va., W. Va.
Study Prepared by:
Middle Atlantic Division
Baltimore District Office

Part I Reviewed by H. M. Sec. o
Weather Bureau, 7/15/41
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 3/29/43
Remarks: Center at Wellsboro, Penna.
Dewpt. 65° - Ref. Pt. 200 S
Grid D-6

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1:2,500,000

Precipitation data and mass curves:	(Number of Sheets)
Form 5001-C (Hourly precip. data)	-
Form 5001-B (24-hour " ")	22
Form 5001-D (" " " ")	-
Miscl. precip. records, meteorological data, etc.	-
Form 5002 (Mass rainfall curves)	22

PART II

Final isohyetal maps, in 1 sheet, scale 1:2,500,000

Data and computation sheets:	
Form S-10 (Data from mass rainfall curves)	3
Form S-11 (Depth-area data from isohyetal map)	1
Form S-12 (Maximum depth-duration data)	5
Maximum duration-depth-area curves	1
Data relating to periods of maximum rainfall	1

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours							
	6	12	18	24	30	36	48	60
10	7.4	8.6	9.1	9.2	9.2	9.7	9.8	9.8
100	7.2	8.3	8.9	9.0	9.0	9.5	9.6	9.6
200	7.1	8.2	8.7	8.8	8.8	9.3	9.4	9.4
500	7.0	8.0	8.5	8.6	8.6	9.0	9.1	9.1
1,000	6.7	7.7	8.2	8.3	8.3	8.7	8.8	8.8
2,000	5.8	6.5	7.7	7.8	8.0	8.4	8.5	8.5
5,000	3.9	4.9	6.4	6.8	7.5	8.0	8.1	8.1
10,000	2.8	4.0	5.0	5.7	7.0	7.6	7.7	7.7
20,000	2.1	3.2	4.0	4.7	6.3	6.8	7.0	7.0
50,000	1.4	2.4	3.1	3.6	4.8	5.4	5.6	5.6
82,000	1.0	1.8	2.4	2.8	3.7	4.1	4.4	4.4

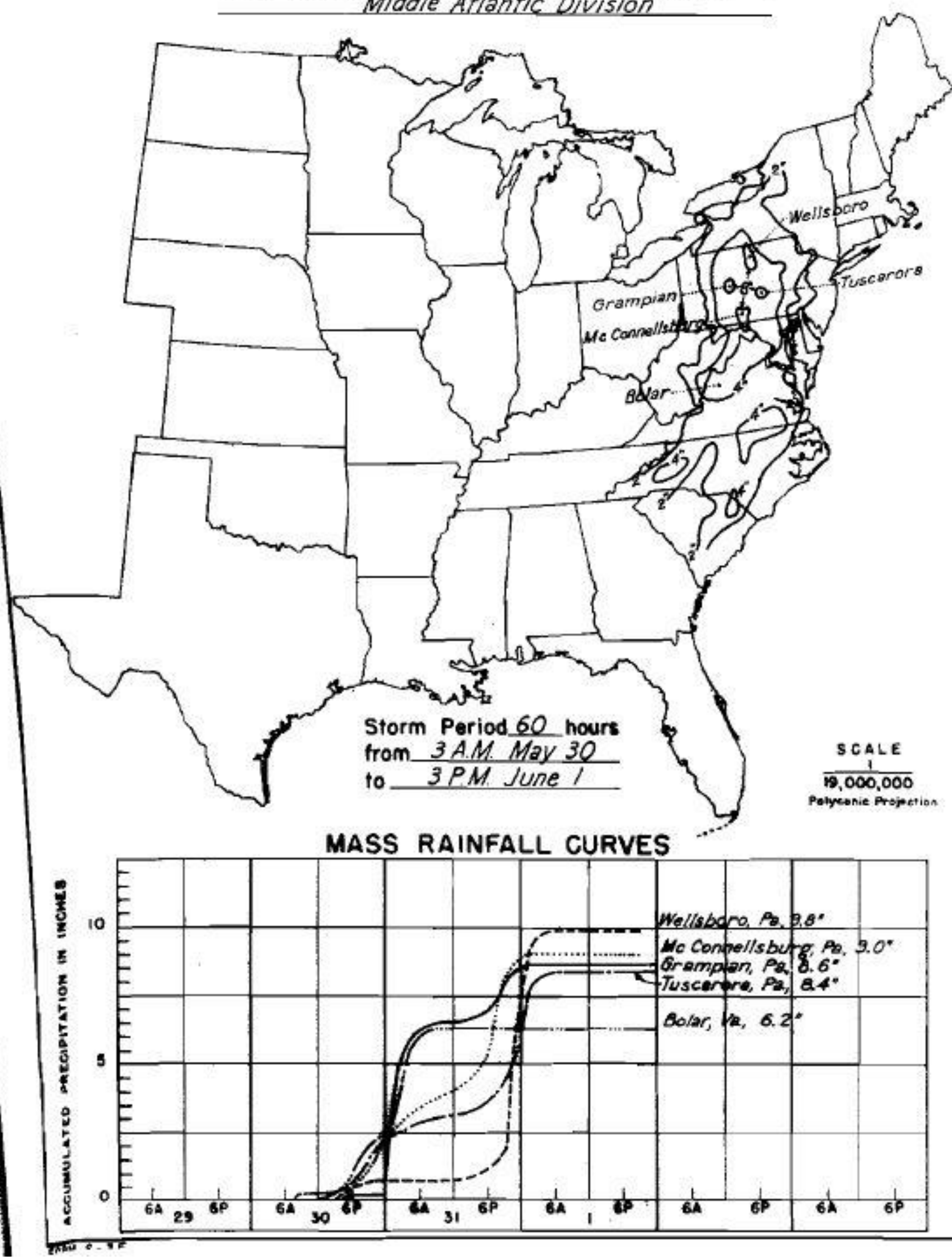
Form S-2

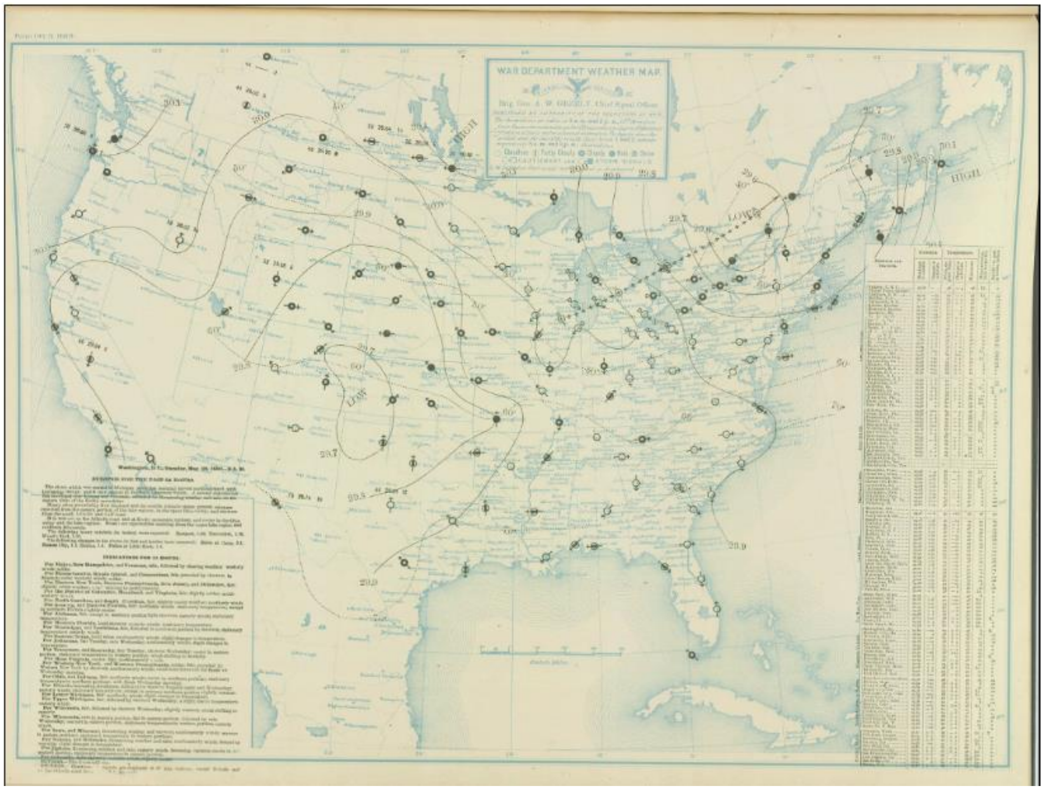
PART ENT OF THE ARMY — CORPS OF ENGINEERS

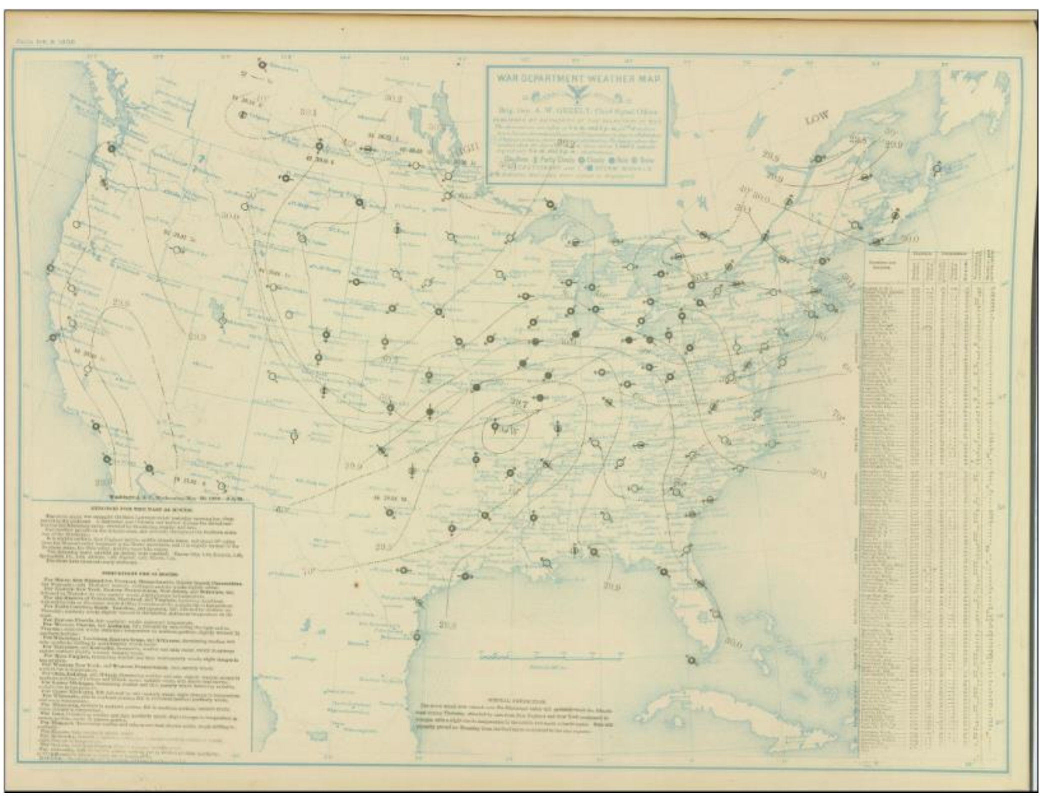
STORM STUDIES – ISOHYETAL MAP

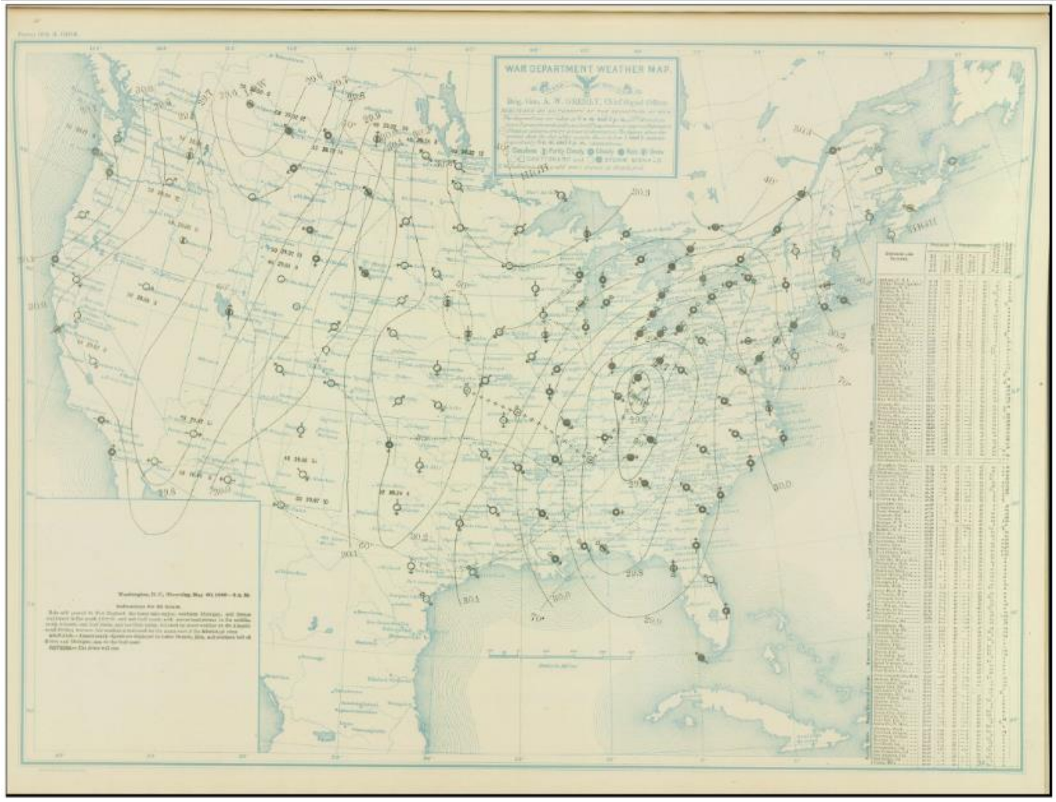
Storm of *May 30 - June 1, 1889* Assignment *SA-1-1*

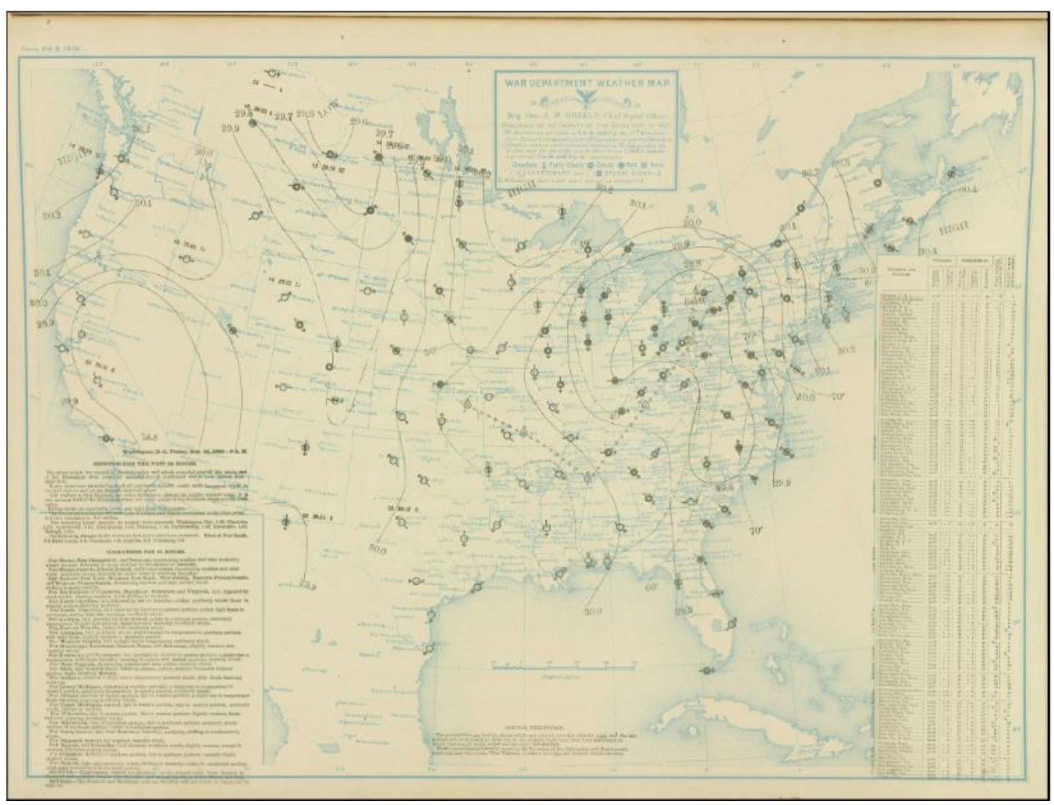
Study Prepared by: *Baltimore, Md. District*
Middle Atlantic Division

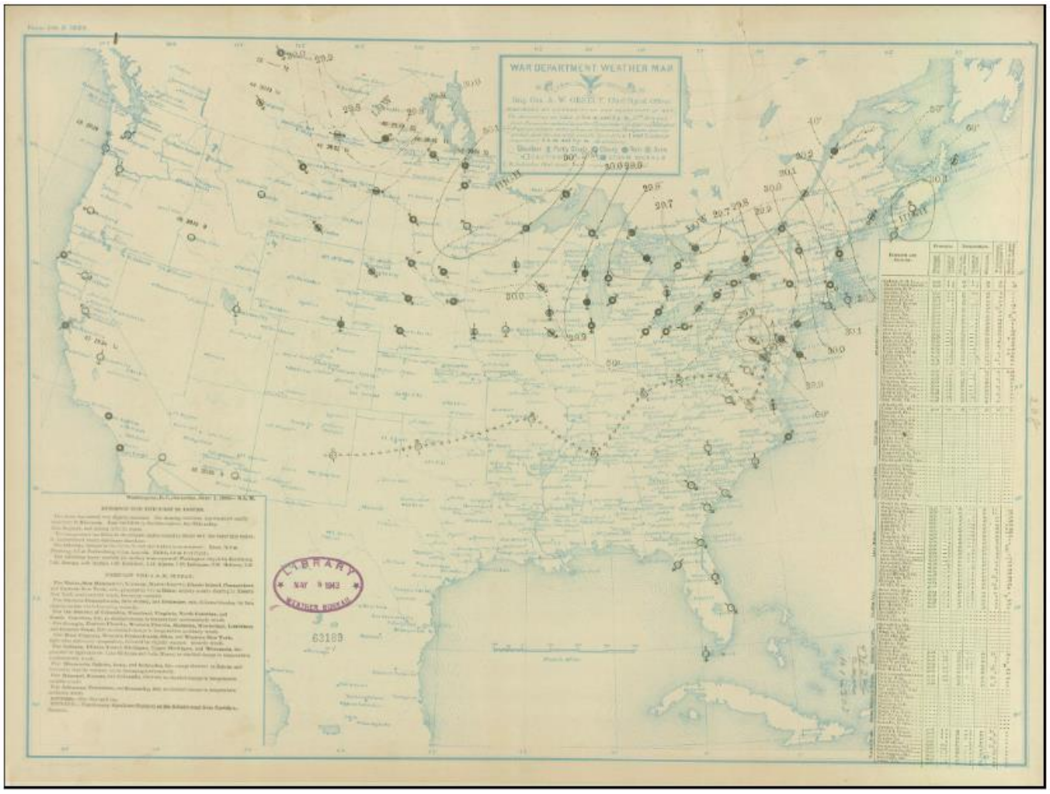


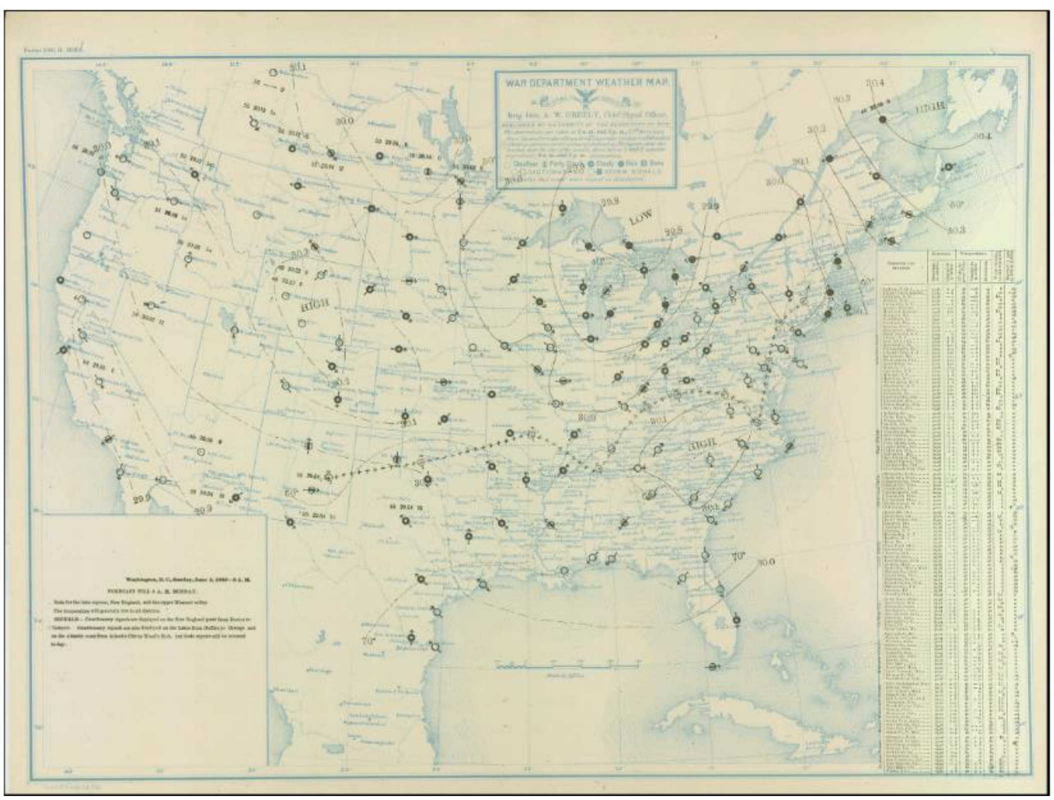

WAR DEPARTMENT WEATHER MAP
HIGH
LOW
HIGH
LOW

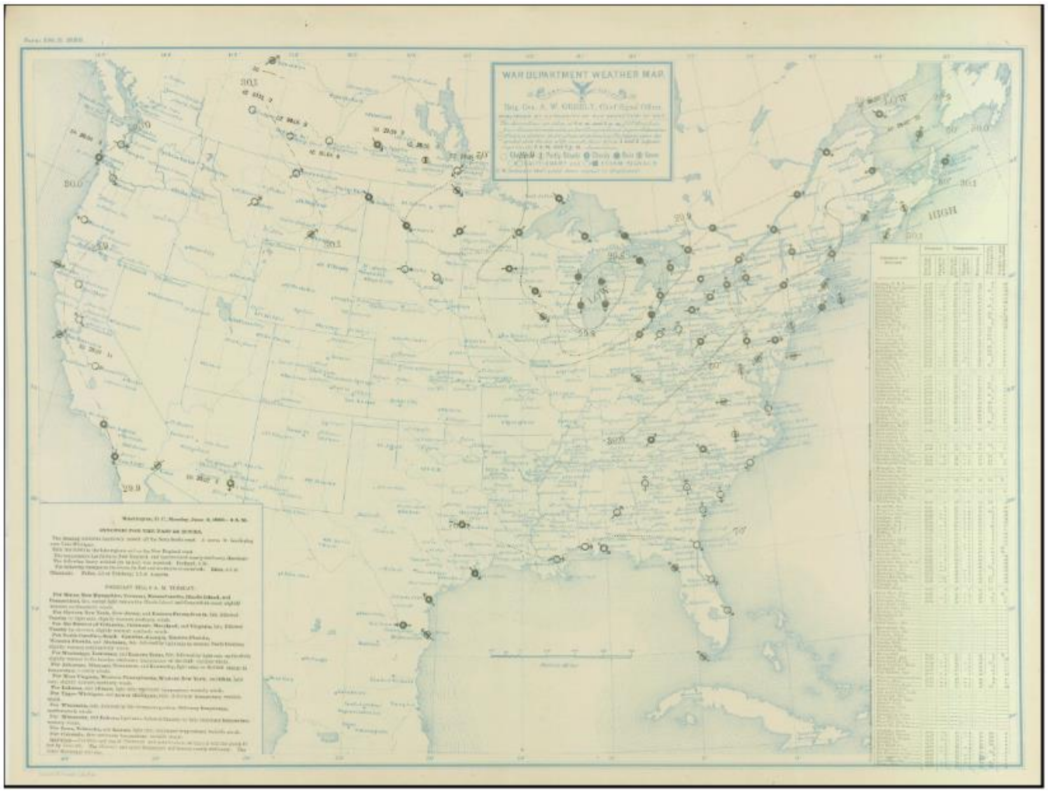

WAR DEPARTMENT WEATHER MAP
HIGH
LOW

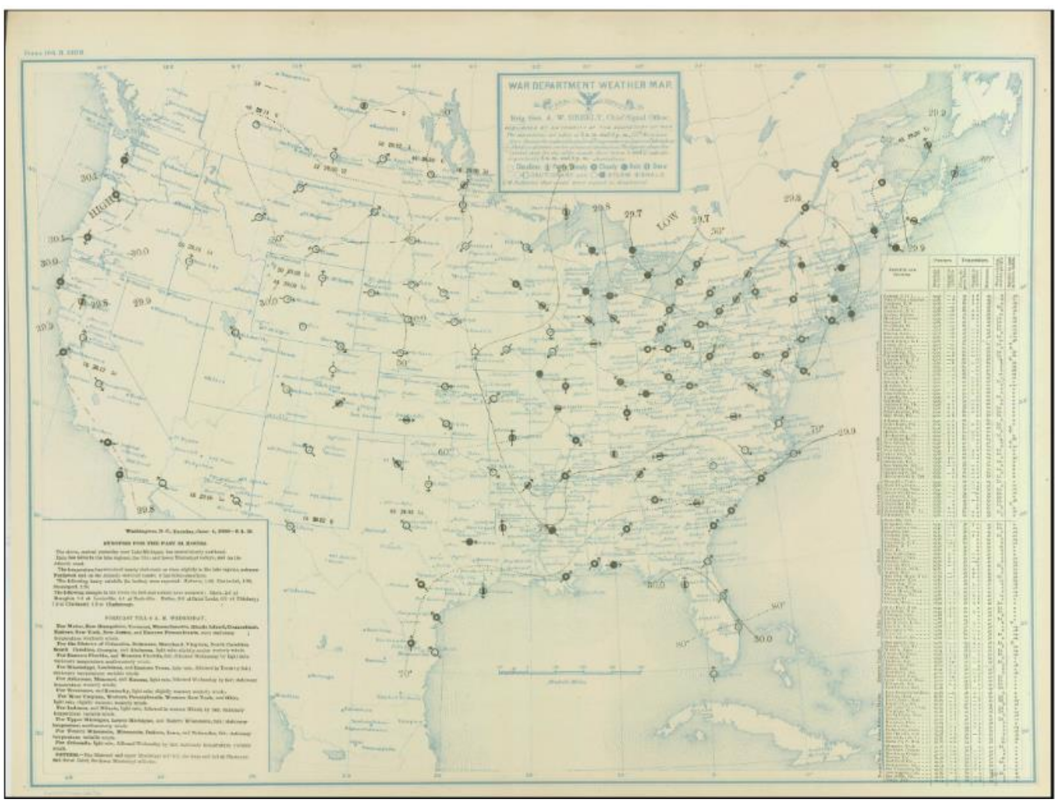

WAR DEPARTMENT WEATHER MAP.
HIGH


WAR DEPARTMENT WEATHER MAP.
HIGH

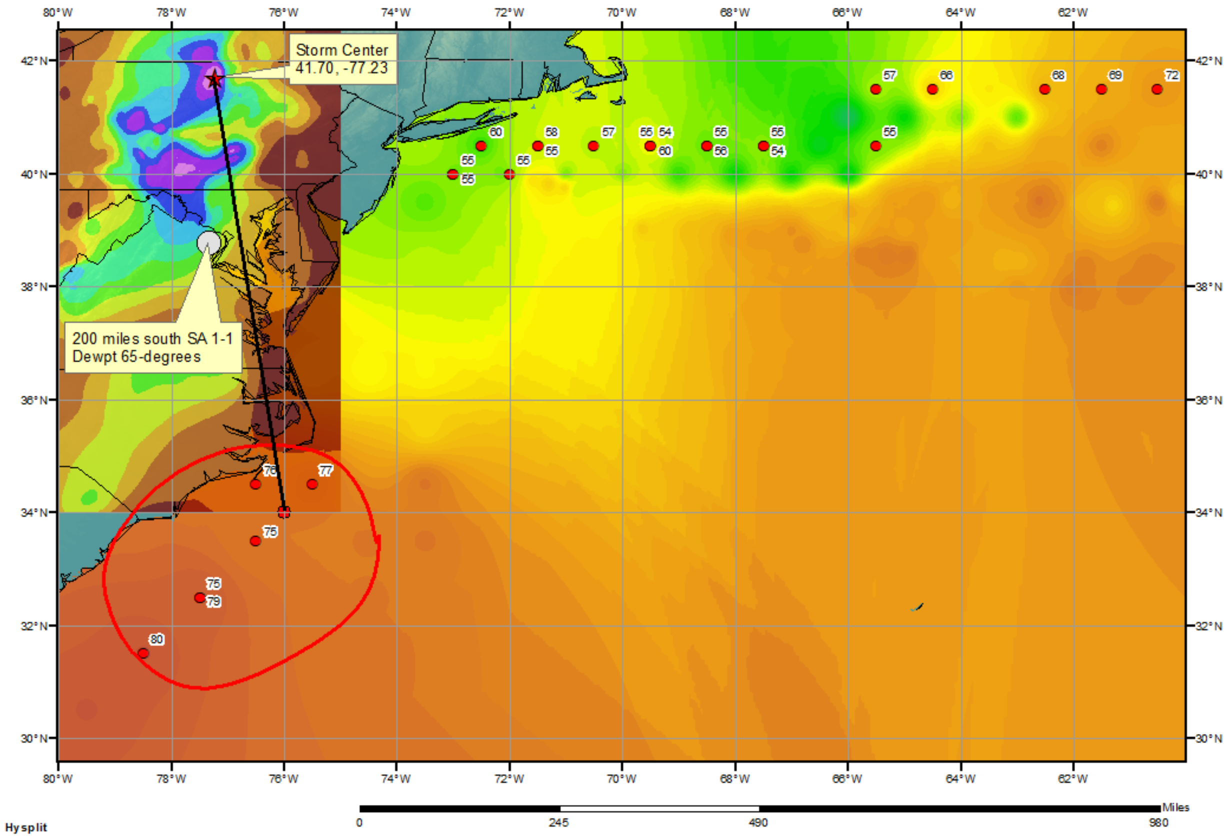

WAR DEPARTMENT WEATHER MAP
LOW
HIGH
LIBRARY
WEATHER BUREAU
63189


WAR DEPARTMENT WEATHER MAP
HIGH
LOW


WAR DEPARTMENT WEATHER MAP
LOW
HIGH
LOW

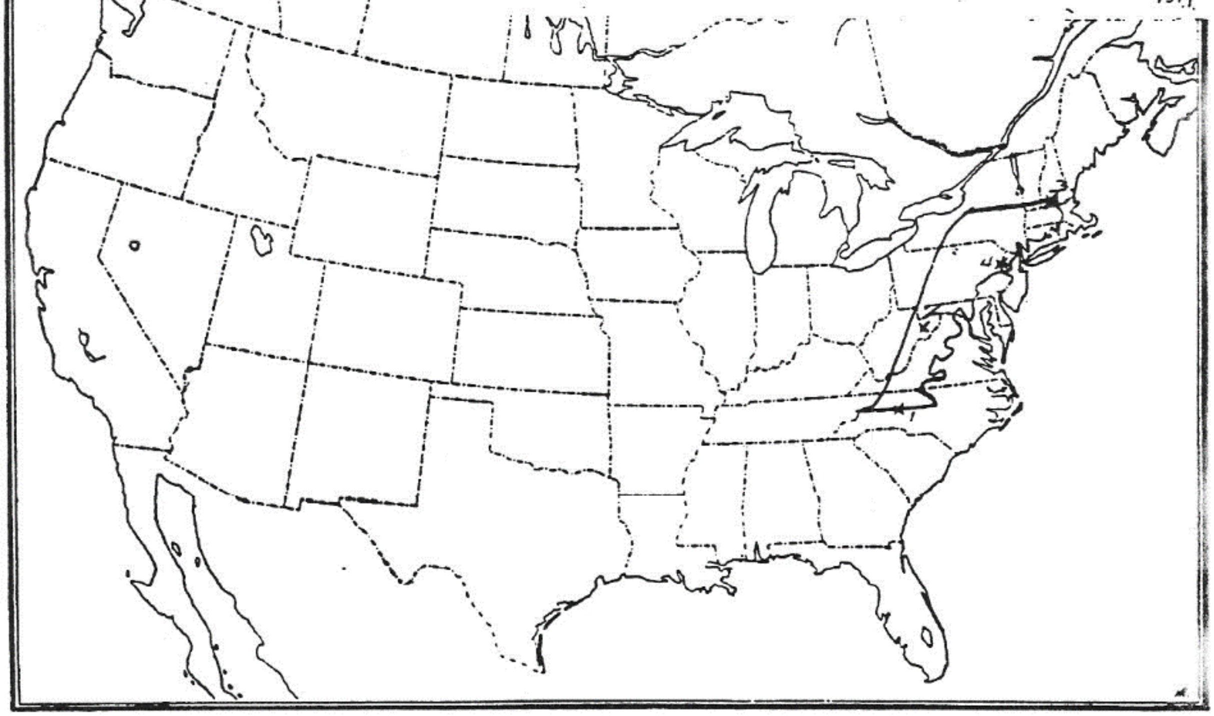

WAR DEPARTMENT WEATHER MAP
HIGH
LOW

SPAS 1339 Wellsboro, PA Storm Analysis
May 31, 1889



SA 1-1..May 30-June 1,1889..Wellsboro
12-hr. PTd 65(31st)..200 S..to 76, 56%.
North to: 43
South to: 34
East to: 500'
West to: divide

4145-771
1319



Storm Precipitation Analysis System (SPAS) For Storm #1339_2 SPAS Analysis

General Storm Location: Wellsboro, PA region, caused the Johnstown Flood

Storm Dates: May 29 (0600) - June 3 (0500), 1889

Event: Flash Flood Event

DAD Zone 1

Latitude: 40.9042

Longitude: -78.5958

Max. Grid Rainfall Amount: 8.99"

Number of Stations: 176 (33 Daily, 5 Hourly, and 138 Supplemental)

SPAS Version: 9.5

Basemap: Monthly Weather Report Isohyetal Grid

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

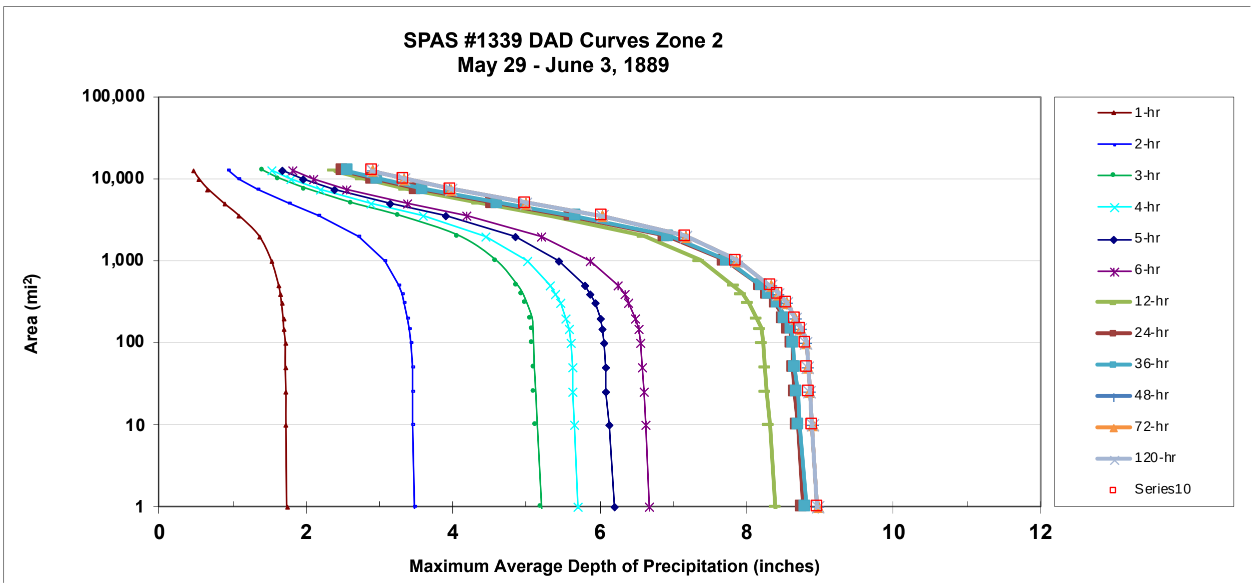
Radar Included: No

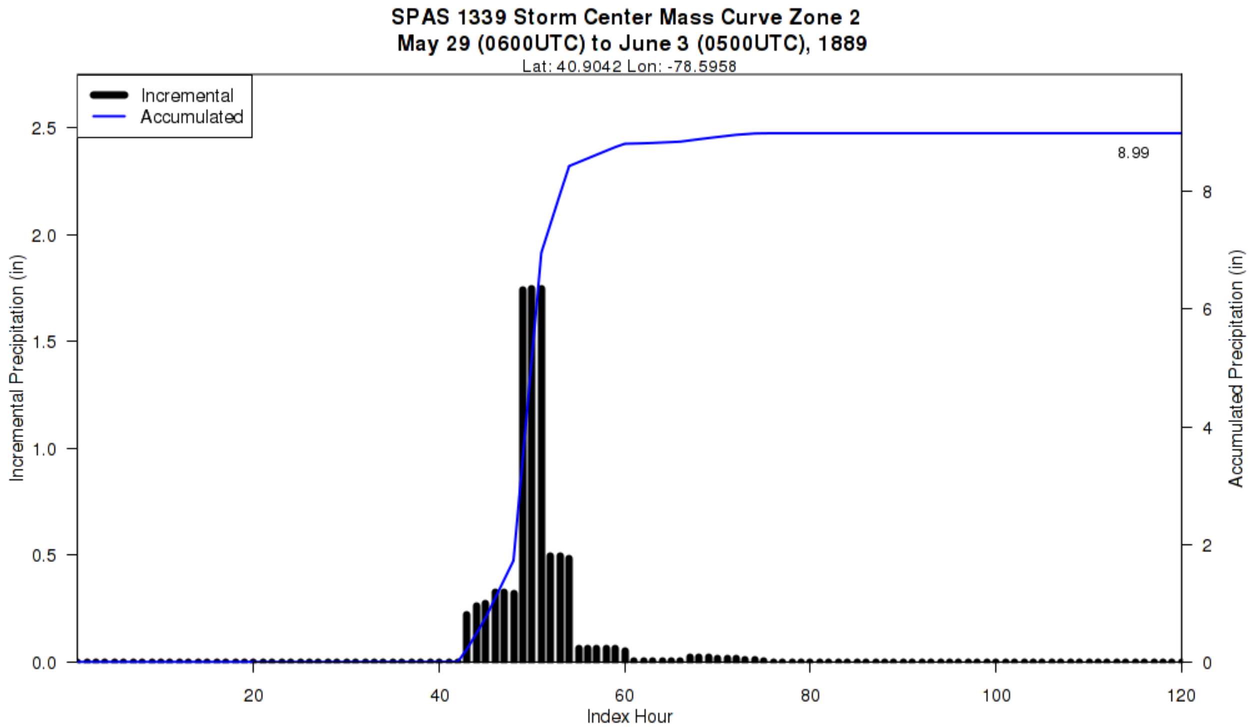
Depth-Area-Duration (DAD) analysis: Yes

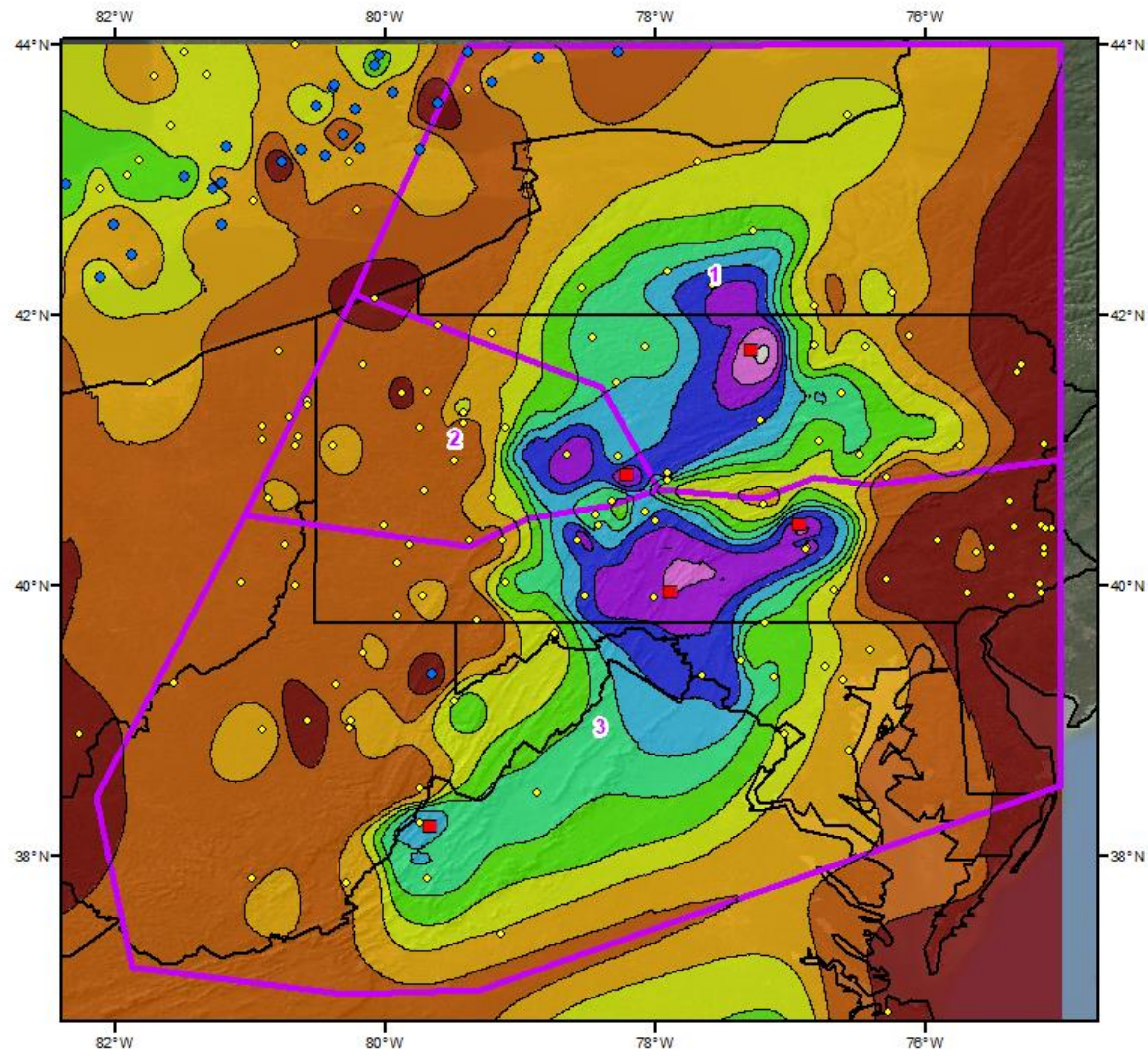
Reliability of results: This analysis was based on hourly data, daily data, and supplemental station. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on the basemap, and the timing is based on hourly stations. The timing of rainfall accumulation at sub daily timescales is uncertain because of the lack of hourly data available for the storm. The mass curve represents our best evaluation based on USACE analyses and bucket survey reports.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1339_2	-78.5958	40.9042	1,562	15-Jun	77.00	3.14	0.42	76	2.720	80.91	3.77	0.48	84	3.290	1.210

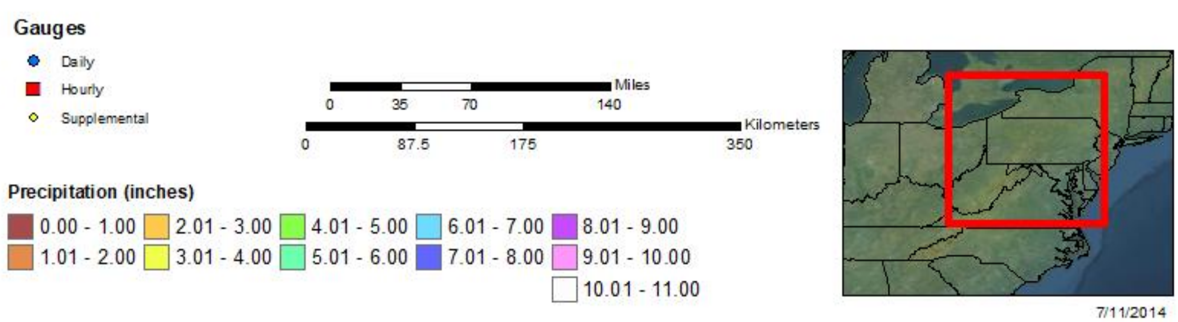
Storm 1339 Zone 2 - May 29 (0600 UTC) - Jun. 03 (0500 UTC), 1889													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
areasqmi	Duration (hours)												
	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	36-hr	48-hr	72-hr	120-hr	Total
0.4	1.75	3.49	5.22	5.73	6.21	6.70	8.43	8.80	8.84	8.99	8.99	8.99	8.99
1	1.74	3.48	5.20	5.71	6.19	6.68	8.40	8.77	8.81	8.97	8.97	8.97	8.97
10	1.73	3.46	5.14	5.66	6.12	6.62	8.31	8.69	8.72	8.89	8.89	8.89	8.89
25	1.73	3.45	5.12	5.63	6.09	6.60	8.27	8.66	8.69	8.86	8.86	8.86	8.86
50	1.72	3.44	5.10	5.62	6.07	6.58	8.25	8.64	8.66	8.83	8.83	8.83	8.83
100	1.72	3.43	5.09	5.60	6.05	6.56	8.22	8.62	8.64	8.81	8.81	8.81	8.81
150	1.70	3.40	5.08	5.58	6.04	6.53	8.20	8.57	8.61	8.74	8.74	8.74	8.74
200	1.69	3.38	5.07	5.54	6.02	6.48	8.14	8.50	8.53	8.66	8.66	8.66	8.66
300	1.67	3.34	5.00	5.47	5.94	6.40	8.03	8.40	8.42	8.55	8.55	8.55	8.55
400	1.65	3.30	4.94	5.40	5.87	6.33	7.94	8.29	8.32	8.43	8.43	8.43	8.43
500	1.63	3.26	4.87	5.33	5.79	6.24	7.83	8.19	8.21	8.33	8.33	8.33	8.33
1,000	1.53	3.06	4.58	5.01	5.44	5.87	7.37	7.70	7.73	7.86	7.86	7.86	7.86
2,000	1.36	2.72	4.07	4.45	4.84	5.21	6.59	6.89	6.94	7.17	7.17	7.17	7.17
3,500	1.09	2.18	3.27	3.58	3.89	4.19	5.35	5.60	5.67	6.04	6.04	6.04	6.04
5,000	0.88	1.76	2.62	2.88	3.13	3.37	4.34	4.54	4.62	5.00	5.00	5.00	5.00
7,500	0.66	1.33	1.99	2.19	2.38	2.56	3.35	3.50	3.59	3.95	3.96	3.96	3.96
10,000	0.54	1.09	1.62	1.79	1.95	2.10	2.76	2.90	2.97	3.32	3.32	3.32	3.33
12,432	0.47	0.93	1.40	1.54	1.68	1.81	2.39	2.51	2.57	2.90	2.90	2.90	2.91




SPAS 1339 Storm Center Mass Curve Zone 2
May 29 (0600UTC) to June 3 (0500UTC), 1889
Lat: 40.9042 Lon: -78.5958
Incremental
Accumulated
8.99
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
20
40
60
80
100
120



Total Storm (120-hr) Precipitation (inches)
May 29 (0600 UTC) - June 3 (0500 UTC), 1889
SPAS 1339 - Wellsboro, PA



DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

STORM STUDIES – PERTINENT DATA SHEET (REV.)

Storm of 30 May- 1 June 1889
Assignment SA 1-1
Location Pa., Md., Va., W. Va.,
Study Prepared by:
Middle Atlantic Division
Baltimore District Office

Part I Reviewed by H. M. Sec. o
Weather Bureau, 7/15/41
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 3/29/43
Remarks: Center at Wellsboro, Penna.
Dewpt. 65° - Ref. Pt. 200 S
Grid D-6

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1:2,500,000

Precipitation data and mass curves: (Number of Sheets)

Form 5001-C (Hourly precip. data)	-
Form 5001-B (24-hour " ")	22
Form 5001-D (" " " ")	-
Miscl. precip. records, meteorological data, etc.	-
Form 5002 (Mass rainfall curves)	22

PART II

Final isohyetal maps, in 1 sheet, scale 1:2,500,000

Data and computation sheets:

Form S-10 (Data from mass rainfall curves)	3
Form S-11 (Depth-area data from isohyetal map)	1
Form S-12 (Maximum depth-duration data)	5
Maximum duration-depth-area curves	1
Data relating to periods of maximum rainfall	1

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours									
	6	12	18	24	30	36	48	60		
10	7.4	8.6	9.1	9.2	9.2	9.7	9.8	9.8		
100	7.2	8.3	8.9	9.0	9.0	9.5	9.6	9.6		
200	7.1	8.2	8.7	8.8	8.8	9.3	9.4	9.4		
500	7.0	8.0	8.5	8.6	8.6	9.0	9.1	9.1		
1,000	6.7	7.7	8.2	8.3	8.3	8.7	8.8	8.8		
2,000	5.8	6.5	7.7	7.8	8.0	8.4	8.5	8.5		
5,000	3.9	4.9	6.4	6.8	7.5	8.0	8.1	8.1		
10,000	2.8	4.0	5.0	5.7	7.0	7.6	7.7	7.7		
20,000	2.1	3.2	4.0	4.7	6.3	6.8	7.0	7.0		
50,000	1.4	2.4	3.1	3.6	4.8	5.4	5.6	5.6		
82,000	1.0	1.8	2.4	2.8	3.7	4.1	4.4	4.4		

Form S-2

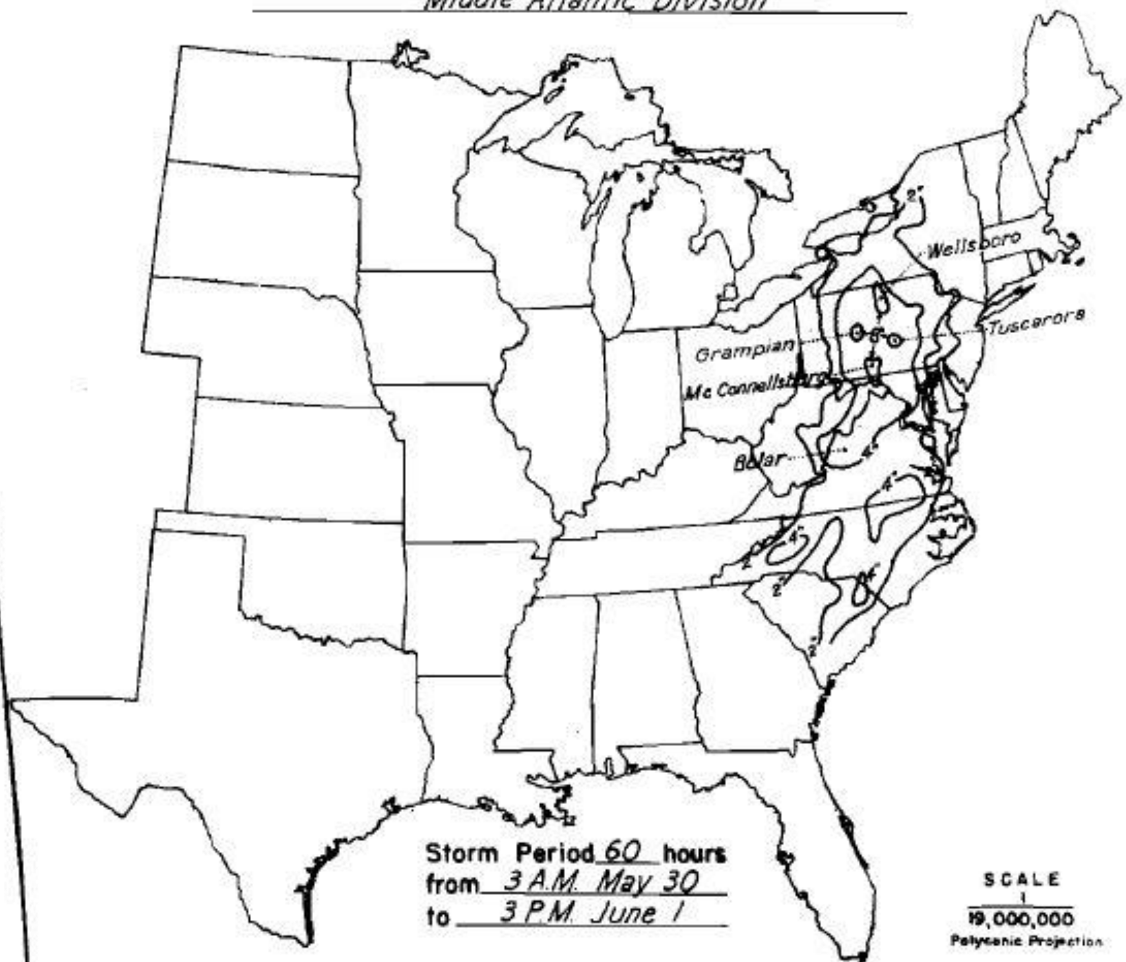
PART[illegible] [illegible]ENT OF THE ARMY CORPS OF ENGINEERS

STORM STUDIES – ISOHYETAL MAP

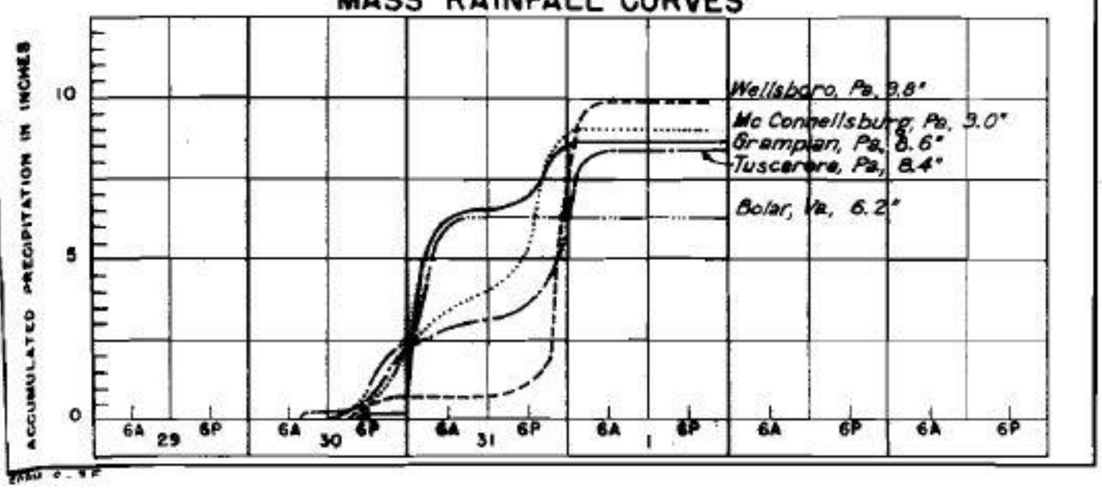
Storm of *May 30 - June 1, 1889* Assignment *SA-1-1*

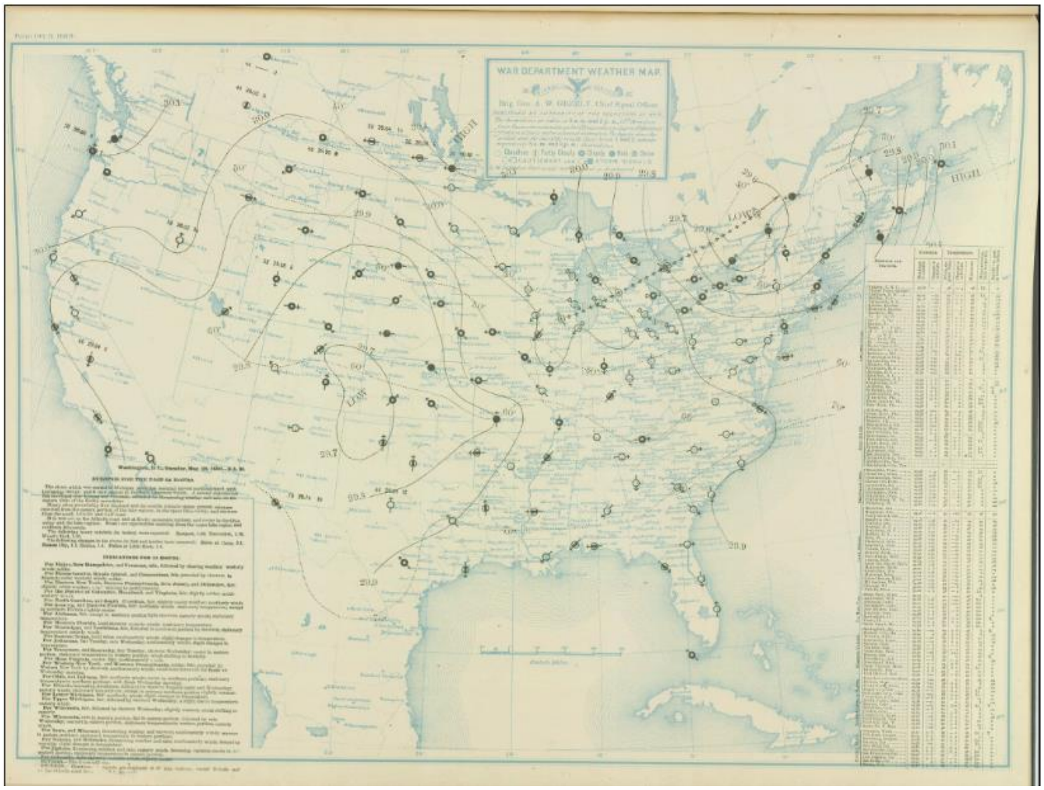
Study Prepared by: *Baltimore, Md. District*

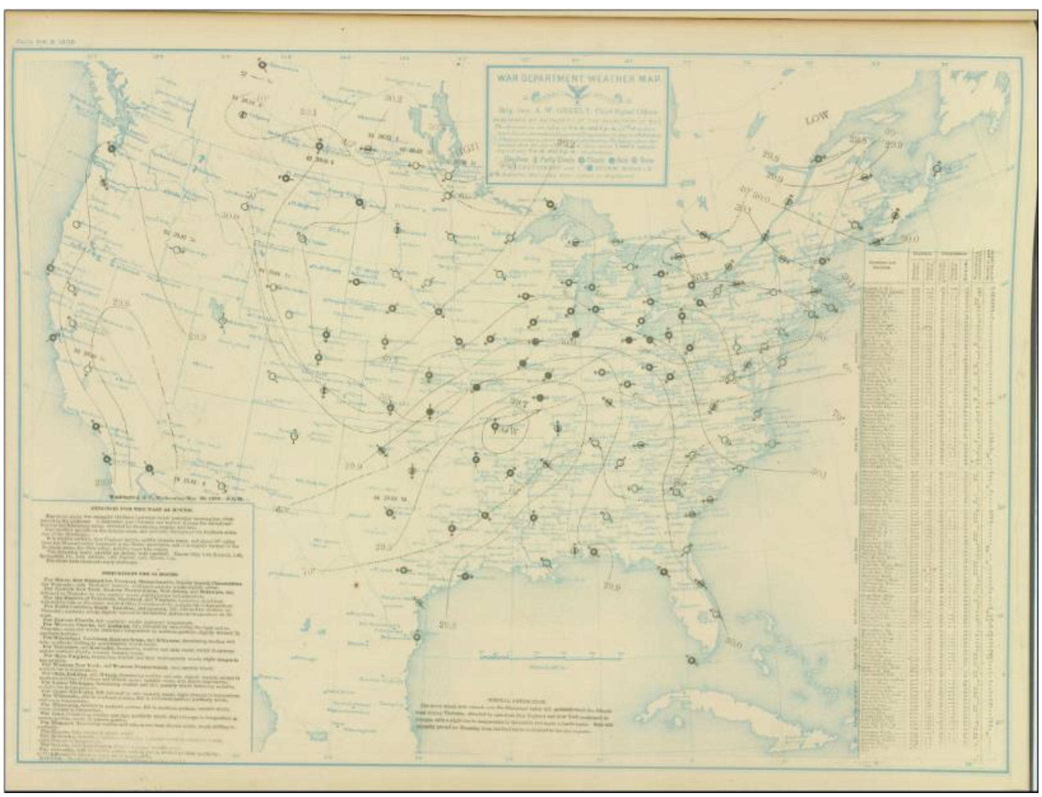
Middle Atlantic Division

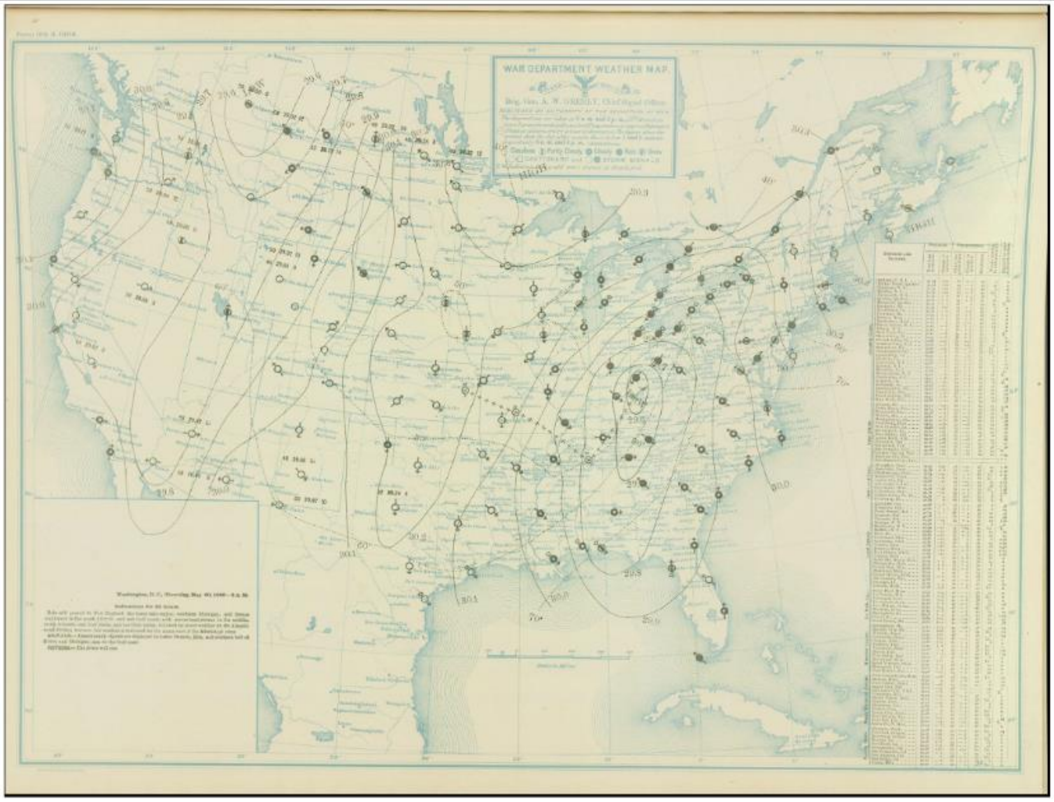


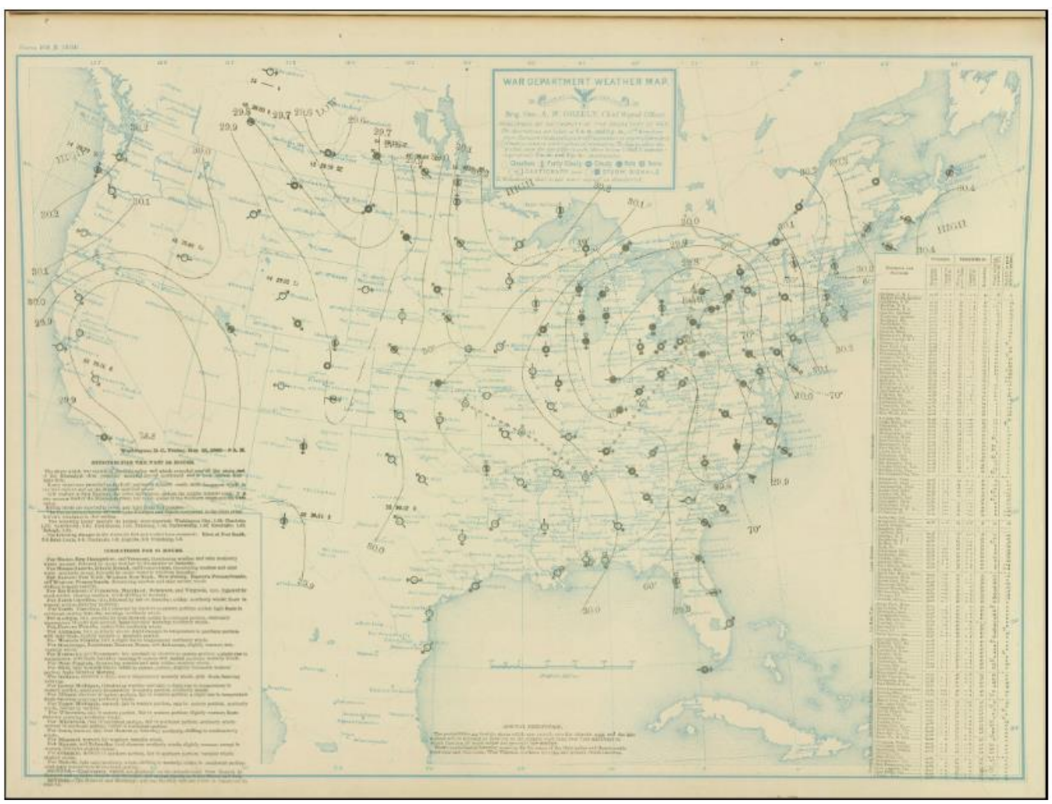
MASS RAINFALL CURVES

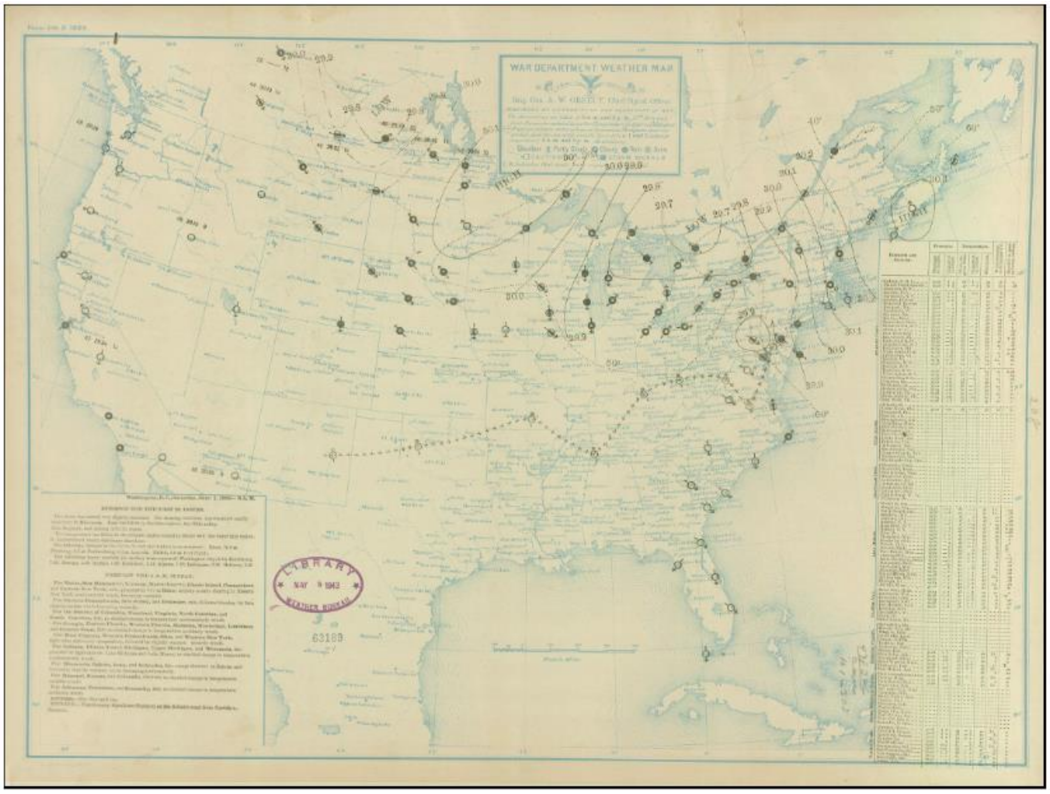


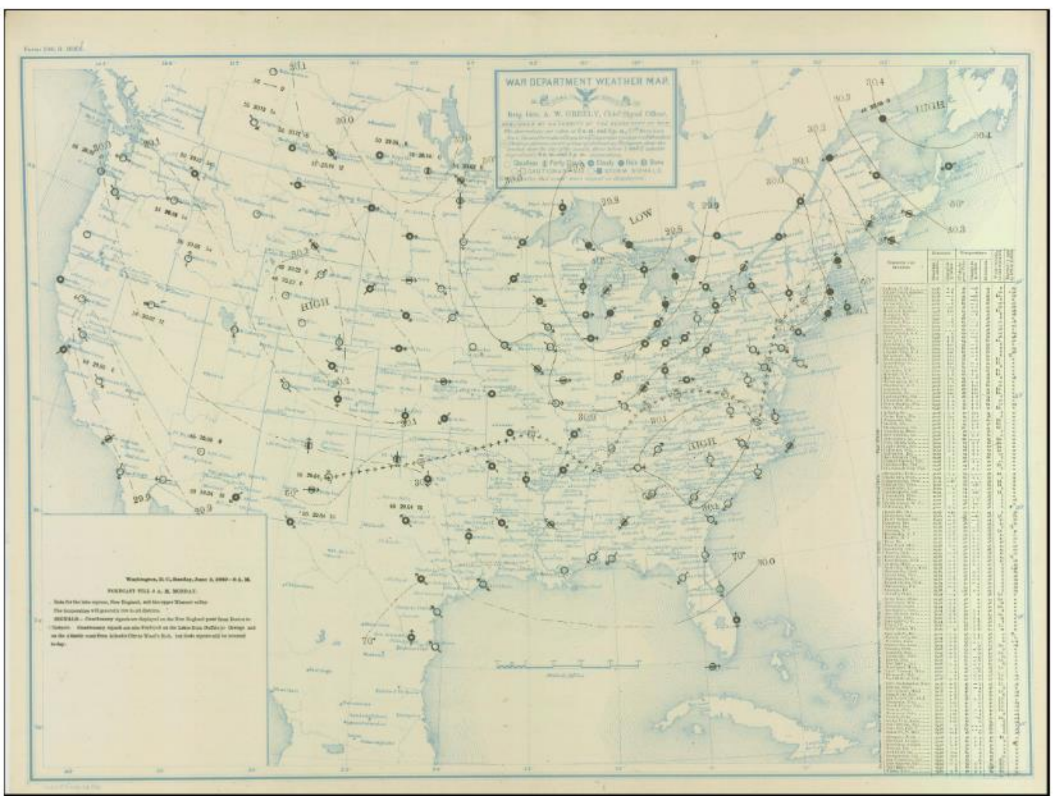

WAR DEPARTMENT WEATHER MAP
HIGH
LOW
HIGH
LOW

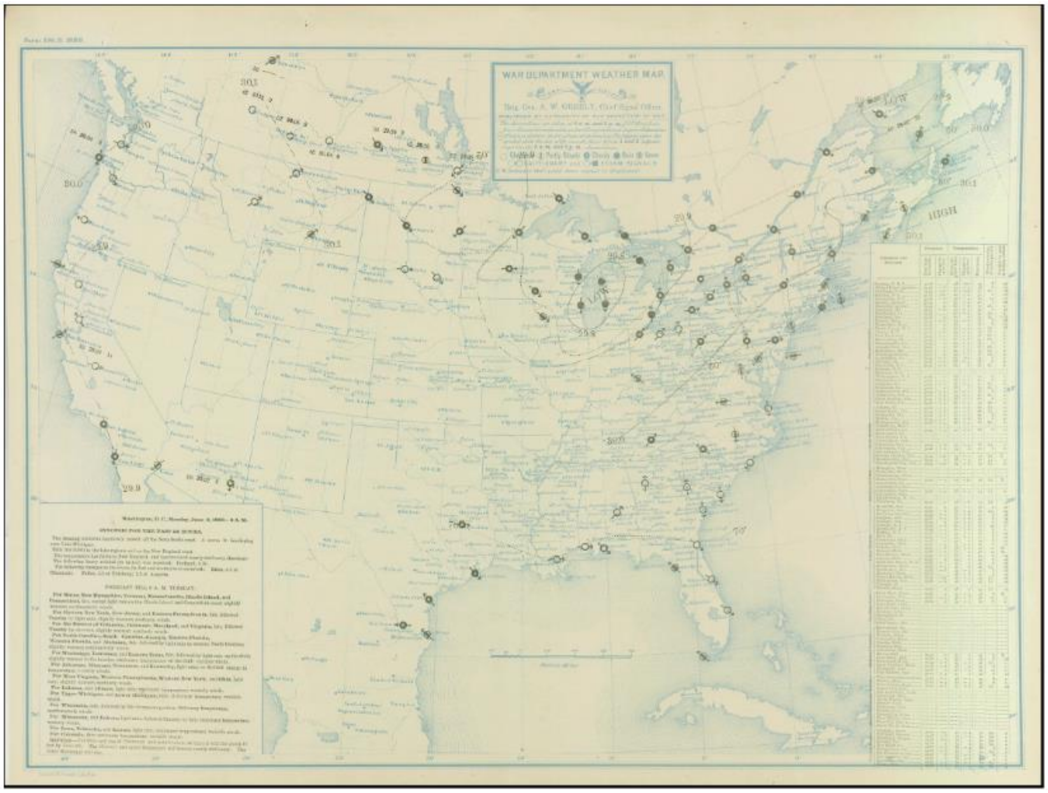

WAR DEPARTMENT WEATHER MAP
HIGH
LOW

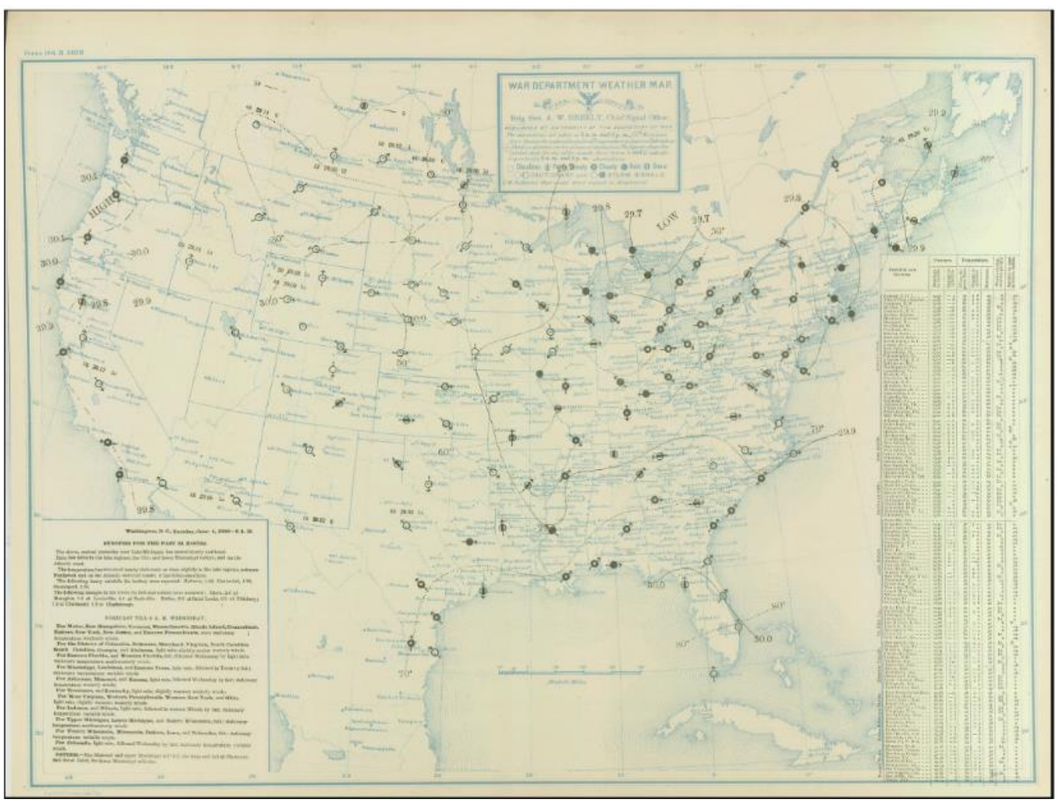

WAR DEPARTMENT WEATHER MAP
HIGH

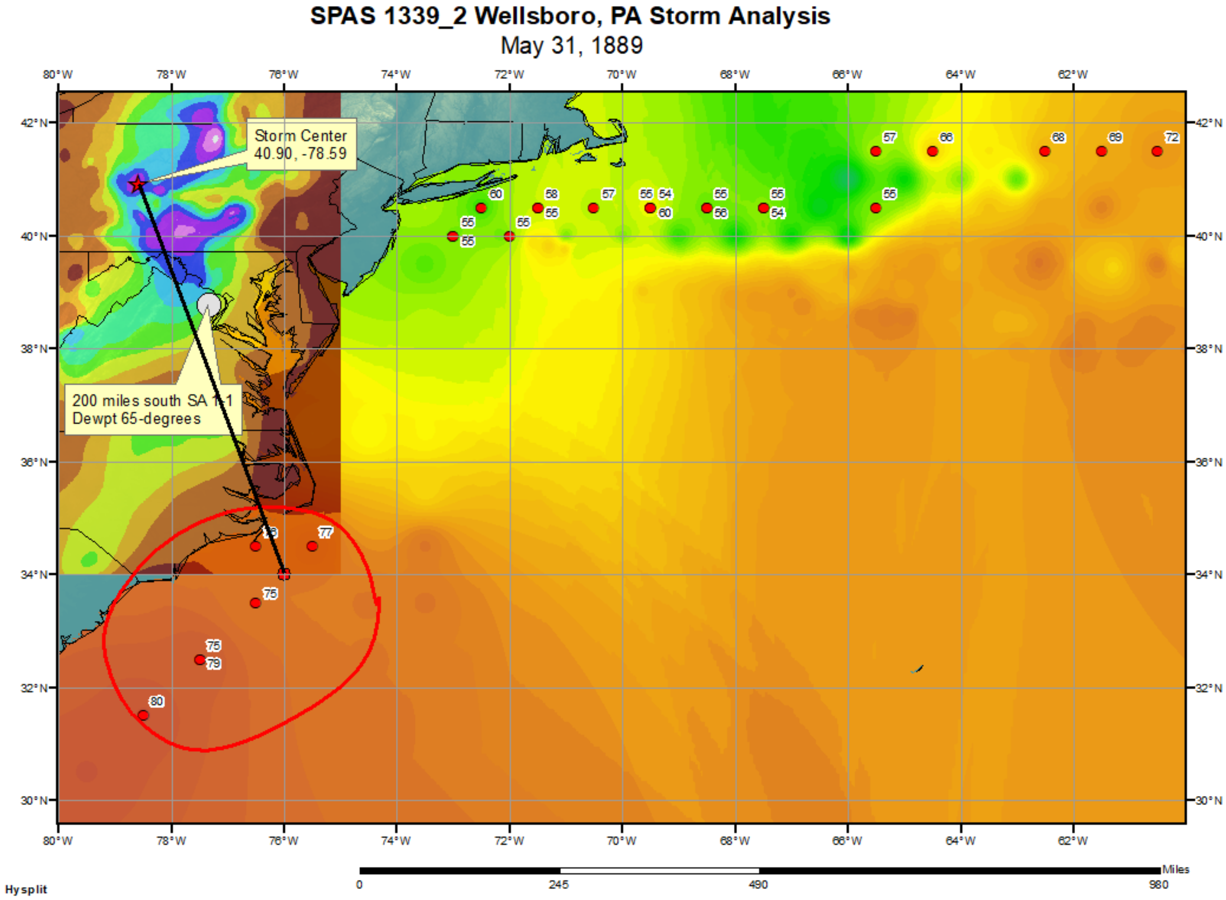

WAR DEPARTMENT WEATHER MAP
HIGH


WAR DEPARTMENT WEATHER MAP
HIGH
LIBRARY
63189


WAR DEPARTMENT WEATHER MAP
HIGH
LOW


WAR DEPARTMENT WEATHER MAP


WAR DEPARTMENT WEATHER MAP


SPAS 1339_2 Wellsboro, PA Storm Analysis
May 31, 1889
Storm Center
40.90, -78.59
200 miles south SA 1-1
Dewpt 65-degrees
Miles
0
245
490
980
Hysplit

Storm Precipitation Analysis System (SPAS) For Storm #1339_3 SPAS Analysis

General Storm Location: Wellsboro, PA region, caused the Johnstown Flood

Storm Dates: May 29 (0600) - June 3 (0500), 1889

Event: Flash Flood Event

DAD Zone 3

Latitude: 40.3958

Longitude: -76.9292

Max. Grid Rainfall Amount: 9.19"

Number of Stations: 176 (33 Daily, 5 Hourly, and 138 Supplemental)

SPAS Version: 9.5

Basemap: Monthly Weather Report Isohyetal Grid

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

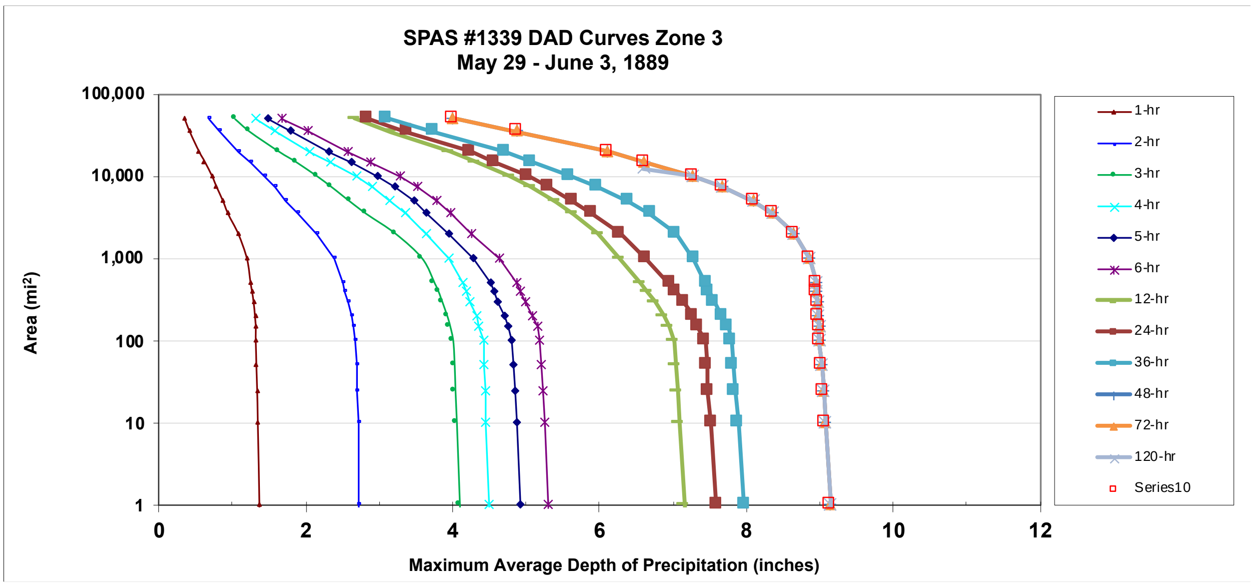
Radar Included: No

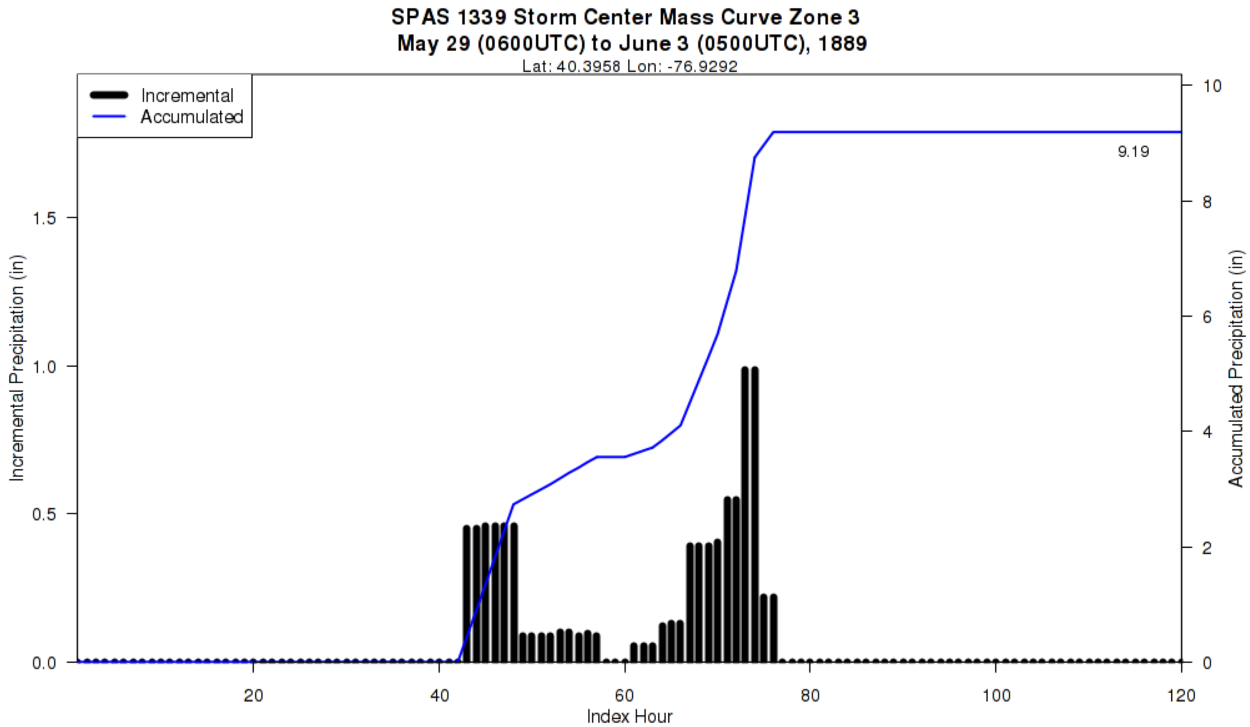
Depth-Area-Duration (DAD) analysis: Yes

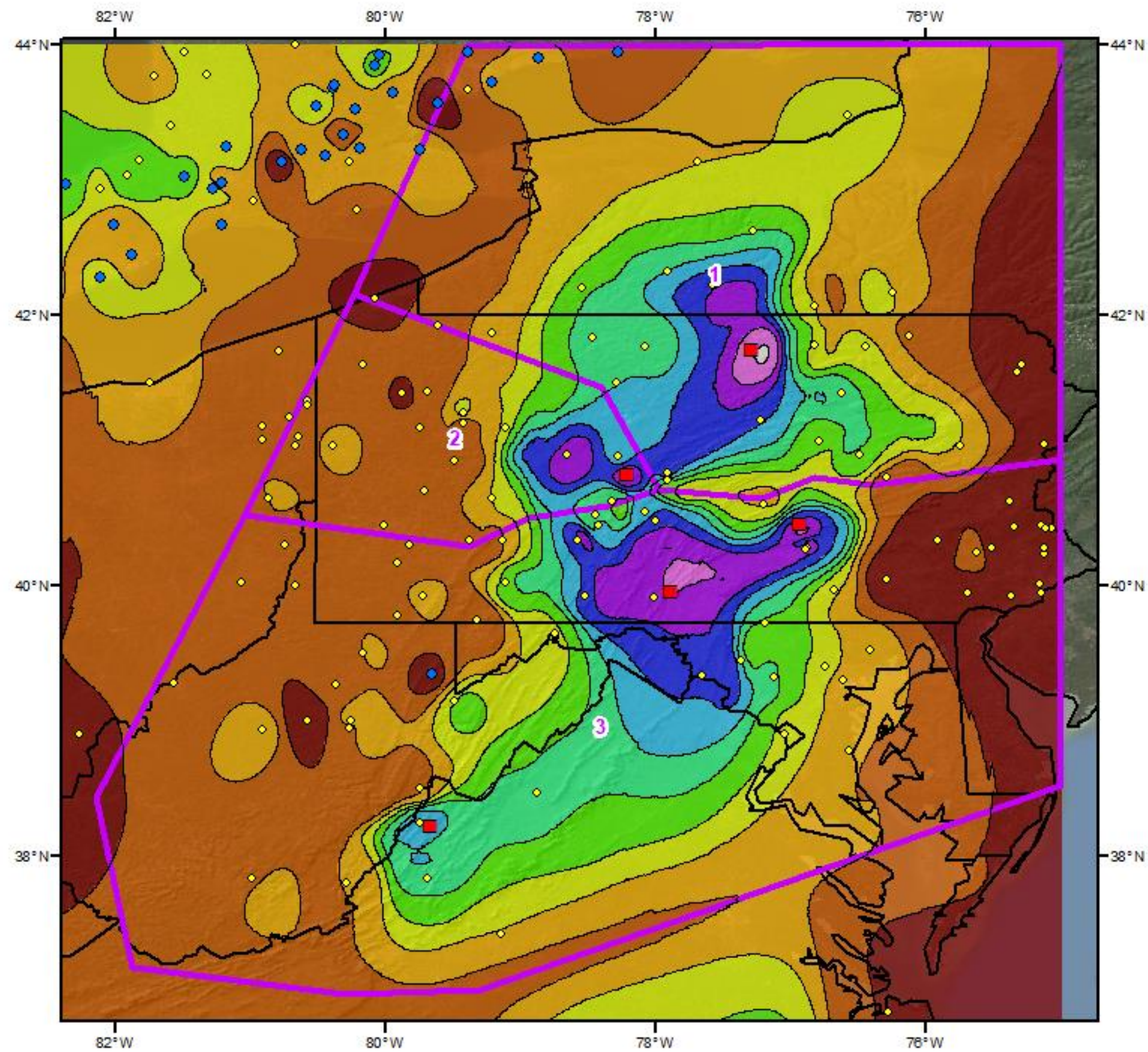
Reliability of results: This analysis was based on hourly data, daily data, and supplemental station. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on the basemap, and the timing is based on hourly stations. The timing of rainfall accumulation at sub daily timescales is uncertain because of the lack of hourly data available for the storm. The mass curve represents our best evaluation based on USACE analyses and bucket survey reports.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1339_3	-76.9292	40.3958	389	15-Jun	77.00	3.14	0.11	76	3.030	80.91	3.77	0.12	84	3.650	1.205

Storm 1339 Zone 3 - May 29 (0600 UTC) - Jun. 03 (0500 UTC), 1889													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
areasqmi	**Duration (hours)**												
	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	36-hr	48-hr	72-hr	120-hr	Total
0.4	1.37	2.74	4.11	4.52	4.93	5.34	7.19	7.62	8.01	9.18	9.18	9.18	9.18
1	1.37	2.73	4.09	4.50	4.92	5.31	7.16	7.60	7.98	9.15	9.15	9.15	9.15
10	1.35	2.71	4.05	4.46	4.87	5.25	7.09	7.52	7.89	9.08	9.08	9.08	9.08
25	1.34	2.70	4.03	4.44	4.86	5.23	7.06	7.48	7.85	9.05	9.05	9.05	9.05
50	1.33	2.69	4.02	4.43	4.84	5.21	7.04	7.46	7.82	9.03	9.03	9.03	9.03
100	1.32	2.68	4.00	4.42	4.81	5.19	7.02	7.44	7.80	9.00	9.00	9.00	9.00
150	1.32	2.64	3.96	4.36	4.75	5.15	6.94	7.34	7.75	8.99	8.99	8.99	8.99
200	1.31	2.62	3.92	4.32	4.71	5.09	6.87	7.27	7.67	8.98	8.98	8.98	8.98
300	1.29	2.57	3.85	4.24	4.62	5.00	6.75	7.15	7.56	8.97	8.97	8.97	8.97
400	1.27	2.54	3.80	4.18	4.56	4.93	6.65	7.04	7.49	8.96	8.96	8.96	8.96
500	1.25	2.51	3.75	4.13	4.51	4.87	6.56	6.95	7.45	8.96	8.96	8.96	8.96
1,000	1.20	2.39	3.58	3.94	4.29	4.65	6.28	6.63	7.29	8.86	8.86	8.86	8.86
2,000	1.08	2.15	3.22	3.64	3.94	4.26	5.98	6.28	7.04	8.65	8.65	8.65	8.65
3,500	0.94	1.89	2.82	3.35	3.65	3.98	5.64	5.90	6.70	8.37	8.37	8.37	8.37
5,000	0.87	1.73	2.59	3.14	3.47	3.78	5.40	5.64	6.40	8.10	8.10	8.1	8.1
7,500	0.78	1.57	2.34	2.91	3.21	3.52	5.06	5.30	5.96	7.67	7.67	7.67	7.67
10,000	0.72	1.44	2.15	2.70	2.99	3.29	4.78	5.02	5.59	7.26	7.26	7.26	7.26
15,000	0.62	1.24	1.86	2.35	2.62	2.89	4.31	4.56	5.07	6.60	6.60	6.6	6.6
20,000	0.54	1.09	1.63	2.06	2.31	2.58	3.96	4.24	4.70	6.11	6.11	6.11	6.11
35,000	0.41	0.83	1.23	1.57	1.79	2.02	3.16	3.38	3.74	4.88	4.88	4.88	4.88
50,000	0.34	0.68	1.03	1.31	1.49	1.68	2.66	2.83	3.11	4.00	4.00	4	4




SPAS 1339 Storm Center Mass Curve Zone 3
May 29 (0600UTC) to June 3 (0500UTC), 1889
Lat: 40.3958 Lon: -76.9292
Incremental
Accumulated
9.19
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
0
2
4
6
8
10
20
40
60
80
100
120



Total Storm (120-hr) Precipitation (inches)
May 29 (0600 UTC) - June 3 (0500 UTC), 1889
SPAS 1339 - Wellsboro, PA

Gauges

- Daily
- Hourly
- Supplemental

Miles: 0, 35, 70, 140

Kilometers: 0, 87.5, 175, 350

Precipitation (inches)

- 0.00 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 4.00
- 4.01 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 11.00

7/11/2014

DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

STORM STUDIES – PERTINENT DATA SHEET (REV.)

Storm of 30 May- 1 June 1889
Assignment SA 1-1
Location Pa., Md., Va., W. Va.
Study Prepared by:
Middle Atlantic Division
Baltimore District Office

Part I Reviewed by H. M. Sec. o Weather Bureau, 7/15/41
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 3/29/43
Remarks: Center at Wellsboro, Penna.
Dewpt. 65° - Ref. Pt. 200 S
Grid D-6

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet , scale 1:2,500,000

Precipitation data and mass curves:	(Number of Sheets)
Form 5001-C (Hourly precip. data)	-
Form 5001-B (24-hour " ")	22
Form 5001-D (" " " ")	-
Miscl. precip. records, meteorological data, etc.	-
Form 5002 (Mass rainfall curves)	22

PART II

Final isohyetal maps, in 1 sheet , scale 1:2,500,000

Data and computation sheets:	
Form S-10 (Data from mass rainfall curves)	3
Form S-11 (Depth-area data from isohyetal map)	1
Form S-12 (Maximum depth-duration data)	5
Maximum duration-depth-area curves	1
Data relating to periods of maximum rainfall	1

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60			
10	7.4	8.6	9.1	9.2	9.2	9.7	9.8	9.8			
100	7.2	8.3	8.9	9.0	9.0	9.5	9.6	9.6			
200	7.1	8.2	8.7	8.8	8.8	9.3	9.4	9.4			
500	7.0	8.0	8.5	8.6	8.6	9.0	9.1	9.1			
1,000	6.7	7.7	8.2	8.3	8.3	8.7	8.8	8.8			
2,000	5.8	6.5	7.7	7.8	8.0	8.4	8.5	8.5			
5,000	3.9	4.9	6.4	6.8	7.5	8.0	8.1	8.1			
10,000	2.8	4.0	5.0	5.7	7.0	7.6	7.7	7.7			
20,000	2.1	3.2	4.0	4.7	6.3	6.8	7.0	7.0			
50,000	1.4	2.4	3.1	3.6	4.8	5.4	5.6	5.6			
82,000	1.0	1.8	2.4	2.8	3.7	4.1	4.4	4.4			

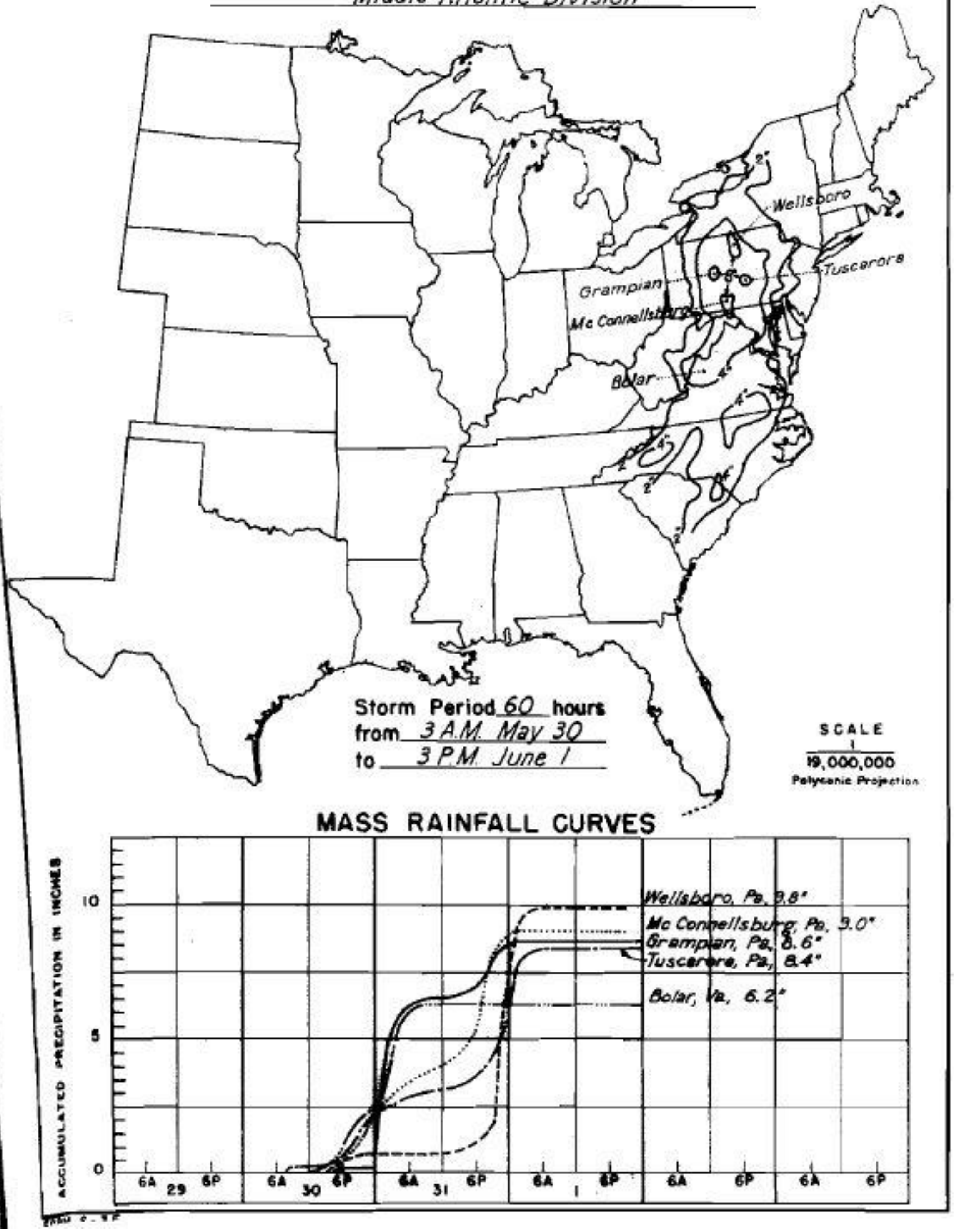
Form S-2

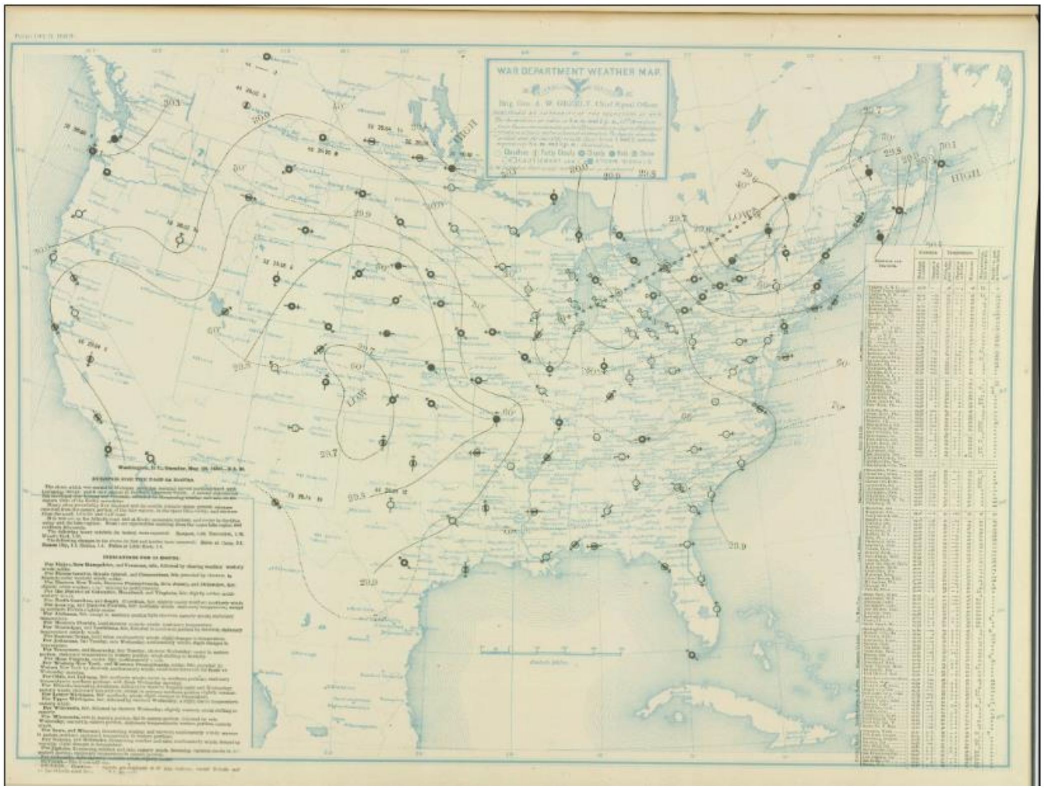
DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

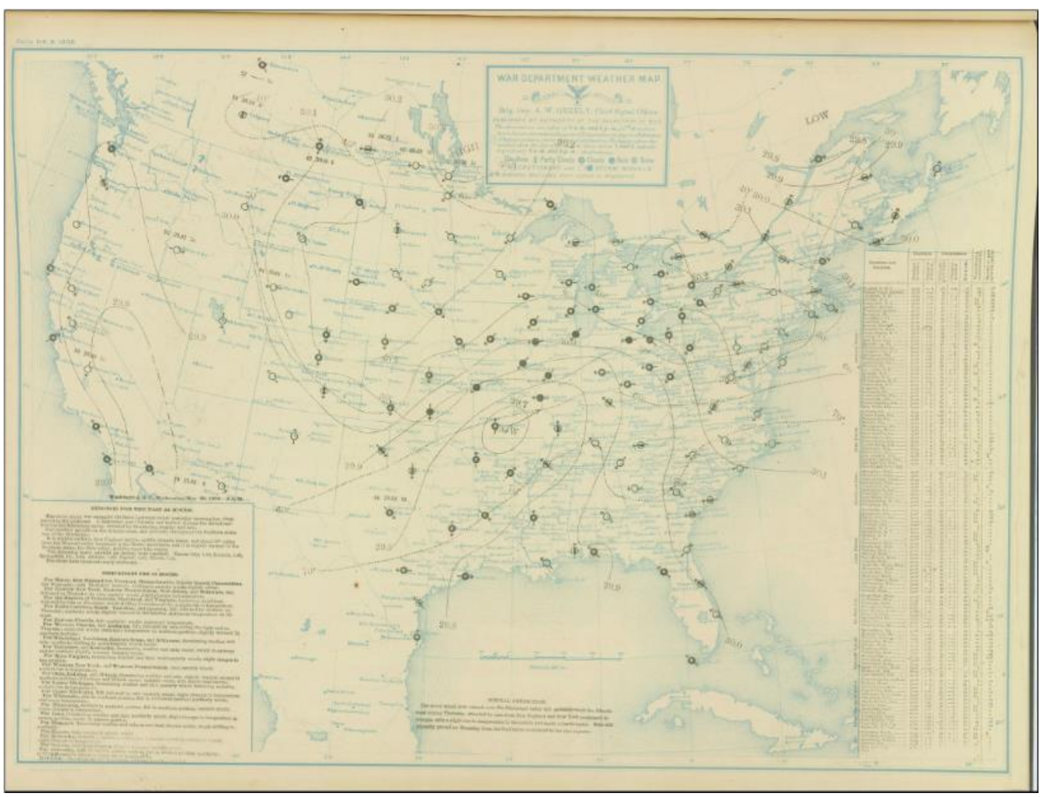
STORM STUDIES – ISOHYETAL MAP

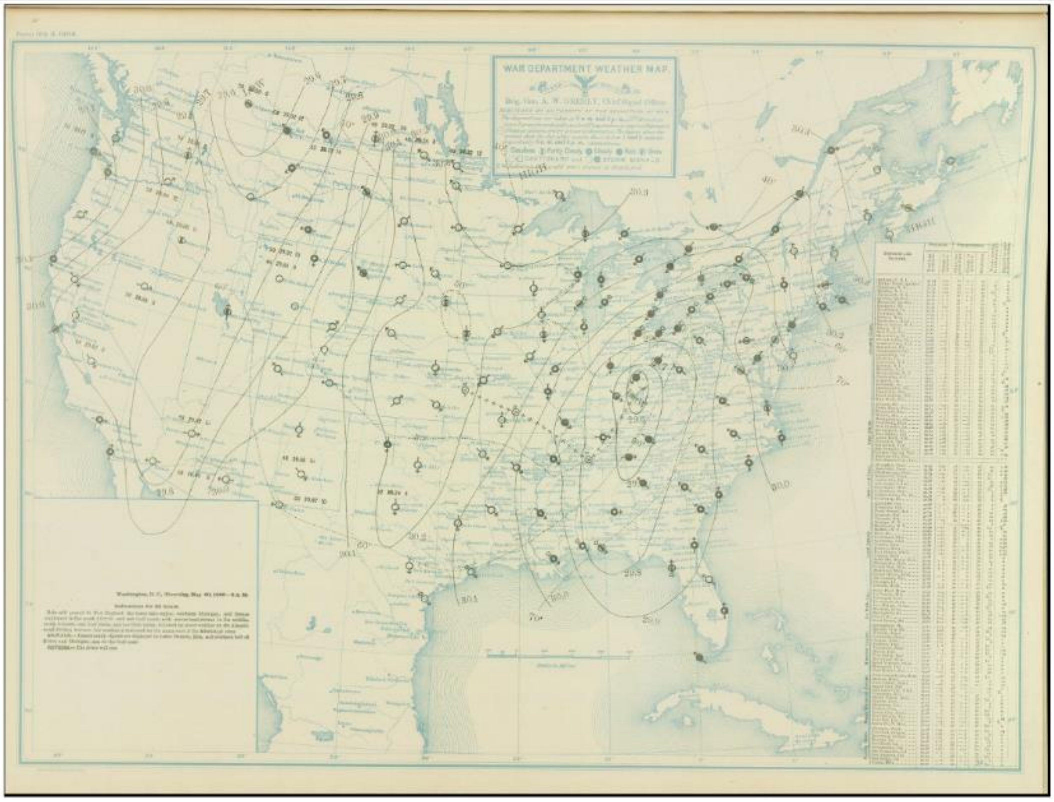
Storm of *May 30 - June 1, 1889* Assignment *SA-1-1*

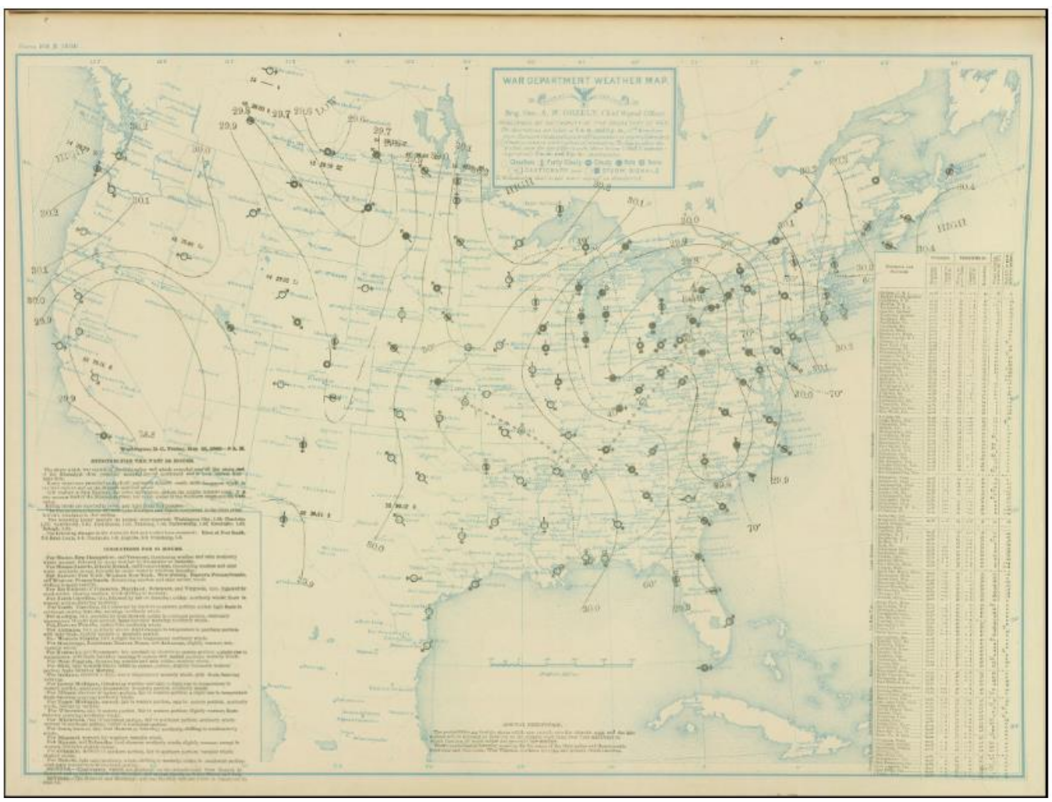
Study Prepared by: *Baltimore, Md. District*
Middle Atlantic Division

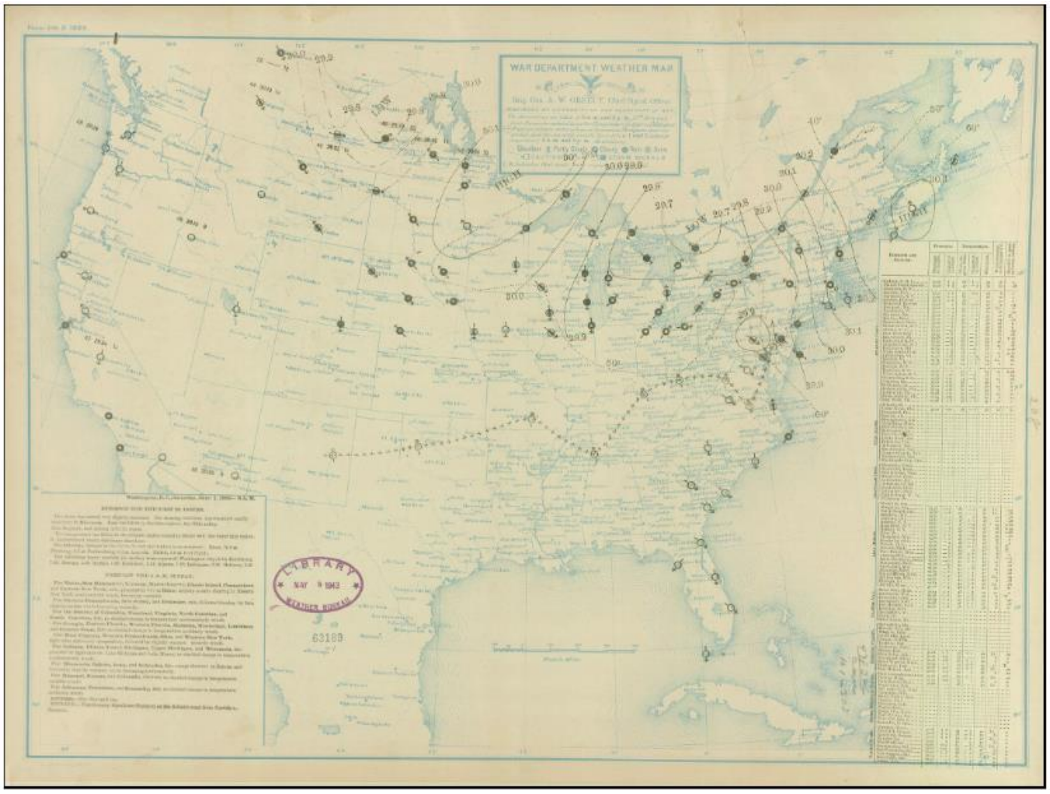


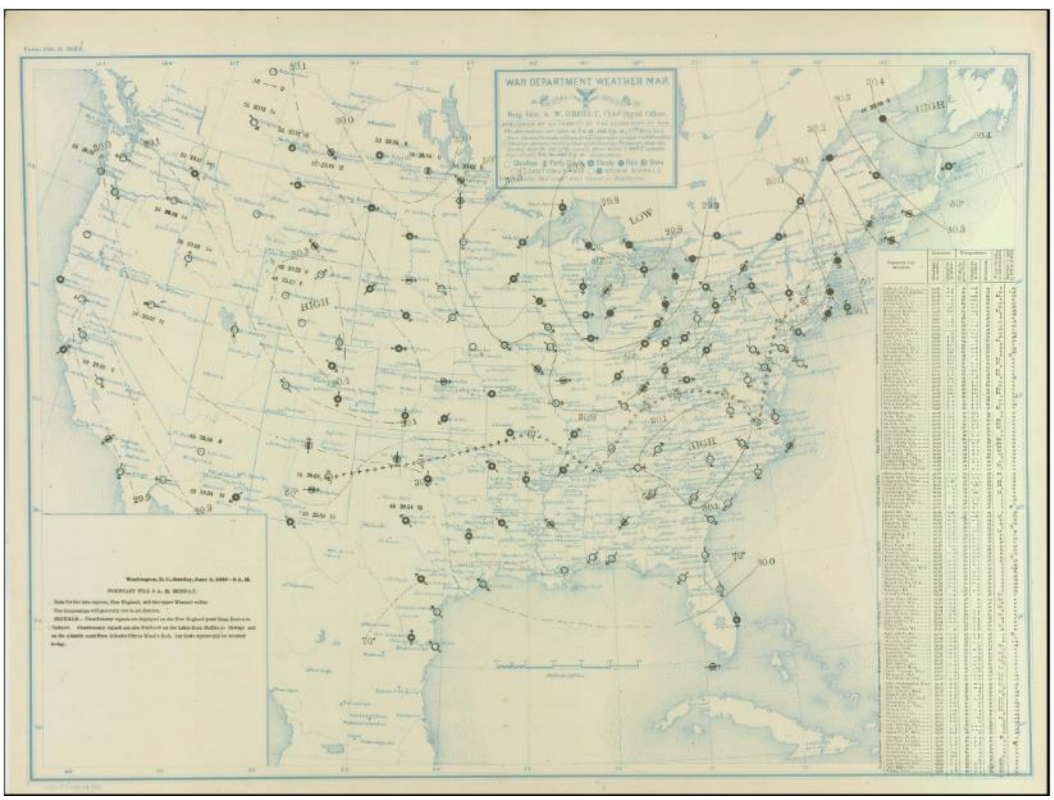

WAR DEPARTMENT WEATHER MAP
HIGH
LOW
HIGH
LOW
29.7
29.9
30.0

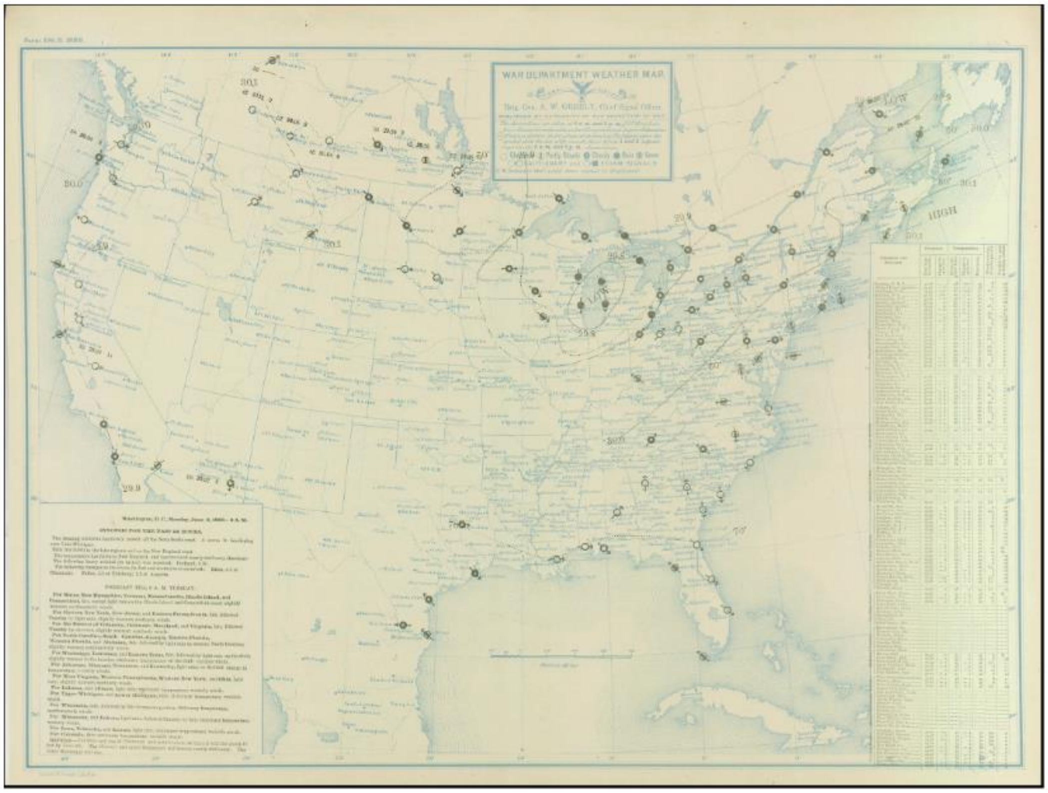

WAR DEPARTMENT WEATHER MAP
HIGH
LOW
29.9
30.0

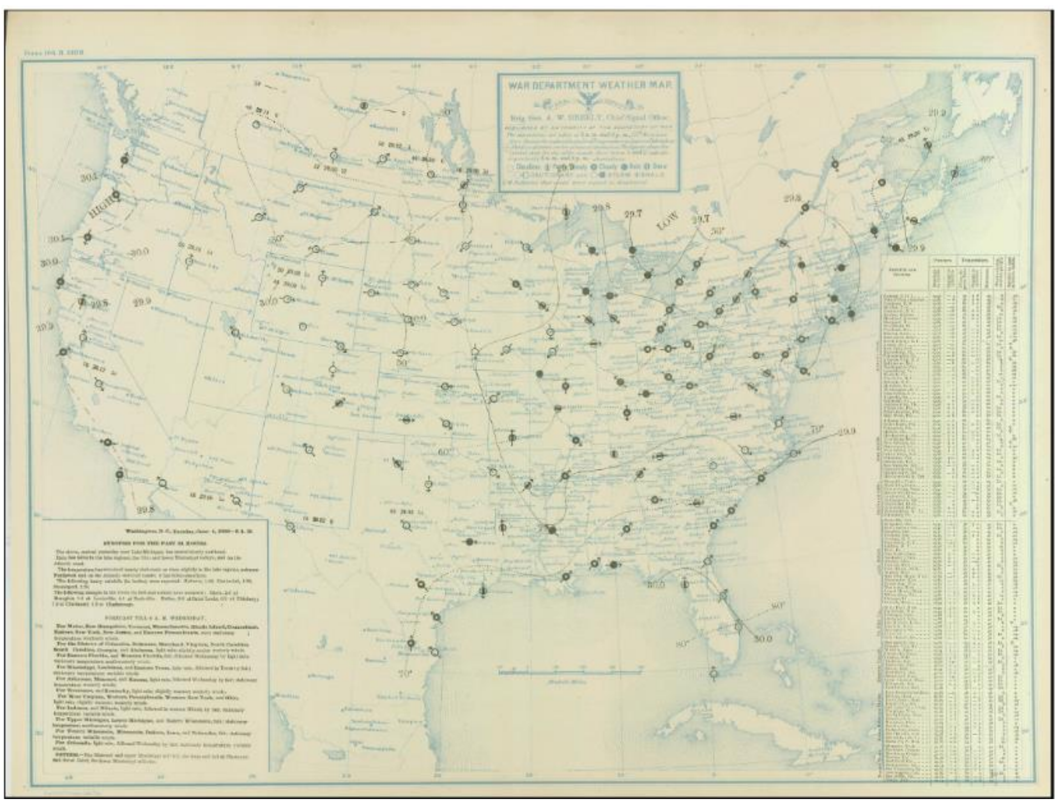

WAR DEPARTMENT WEATHER MAP.

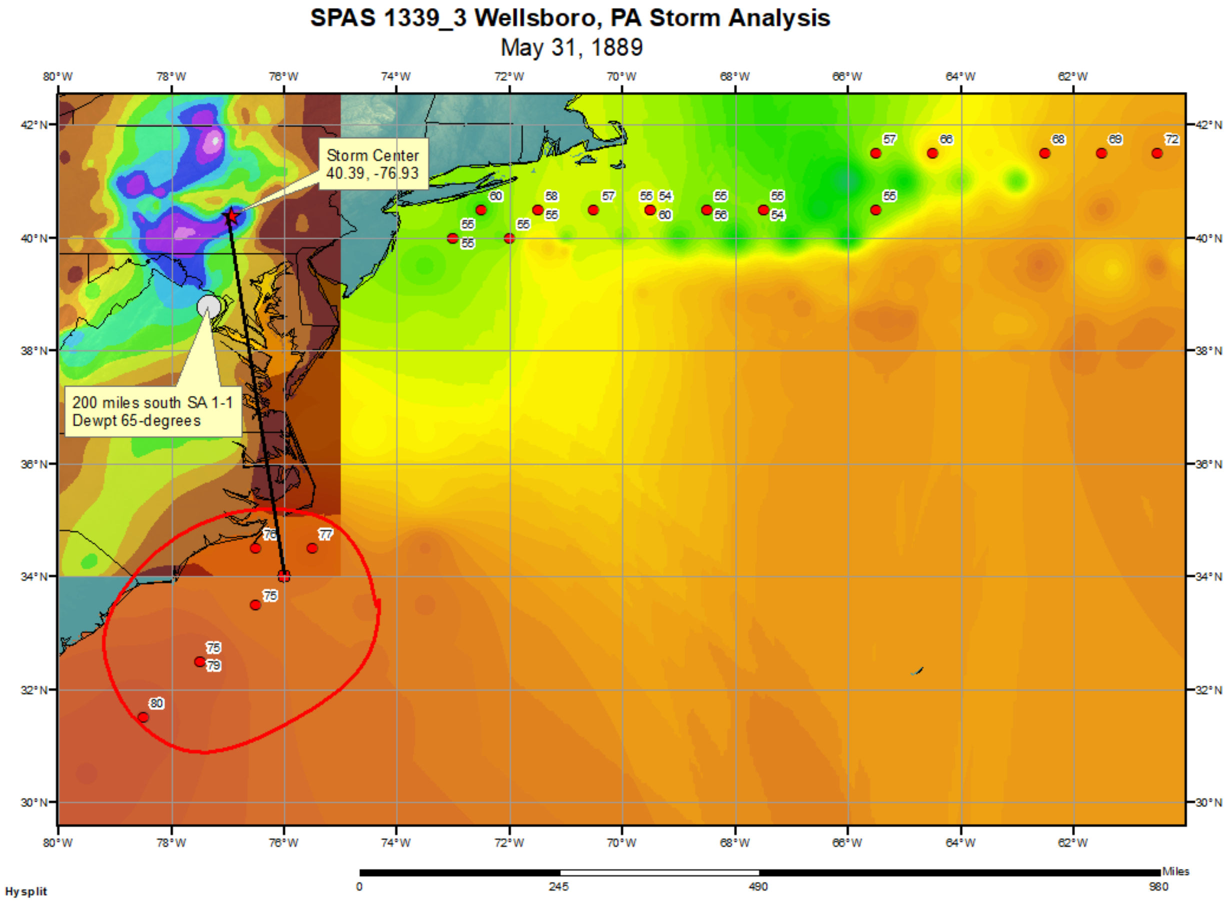

WAR DEPARTMENT WEATHER MAP.


WAR DEPARTMENT WEATHER MAP
HIGH
LOW
LIBRARY
WEATHER BUREAU
63189


WAR DEPARTMENT WEATHER MAP
HIGH
LOW


WAR DEPARTMENT WEATHER MAP
LOW
HIGH


WAR DEPARTMENT WEATHER MAP
HIGH
LOW


SPAS 1339_3 Wellsboro, PA Storm Analysis
May 31, 1889
Storm Center
40.39, -76.93
200 miles south SA 1-1
Dewpt 65-degrees
Hysplit
Miles
0
245
490
980

Storm Precipitation Analysis System (SPAS) For Storm #1305_1
SPAS Analysis

General Storm Location: Southern Alabama (Elba, AL)

Storm Dates: Mar 11-16, 1929

Event: Stalled Front

DAD Zone 1

Latitude: 31.3625

Longitude: -86.12083

Max. Grid Rainfall Amount: 29.73" (29.6" at Elba, AL)

Number of Stations: 118 (includes 3 omitted stations)

SPAS Version: 9.5

Base Map Used: NWS-MetStat Blended Isohyetal Map

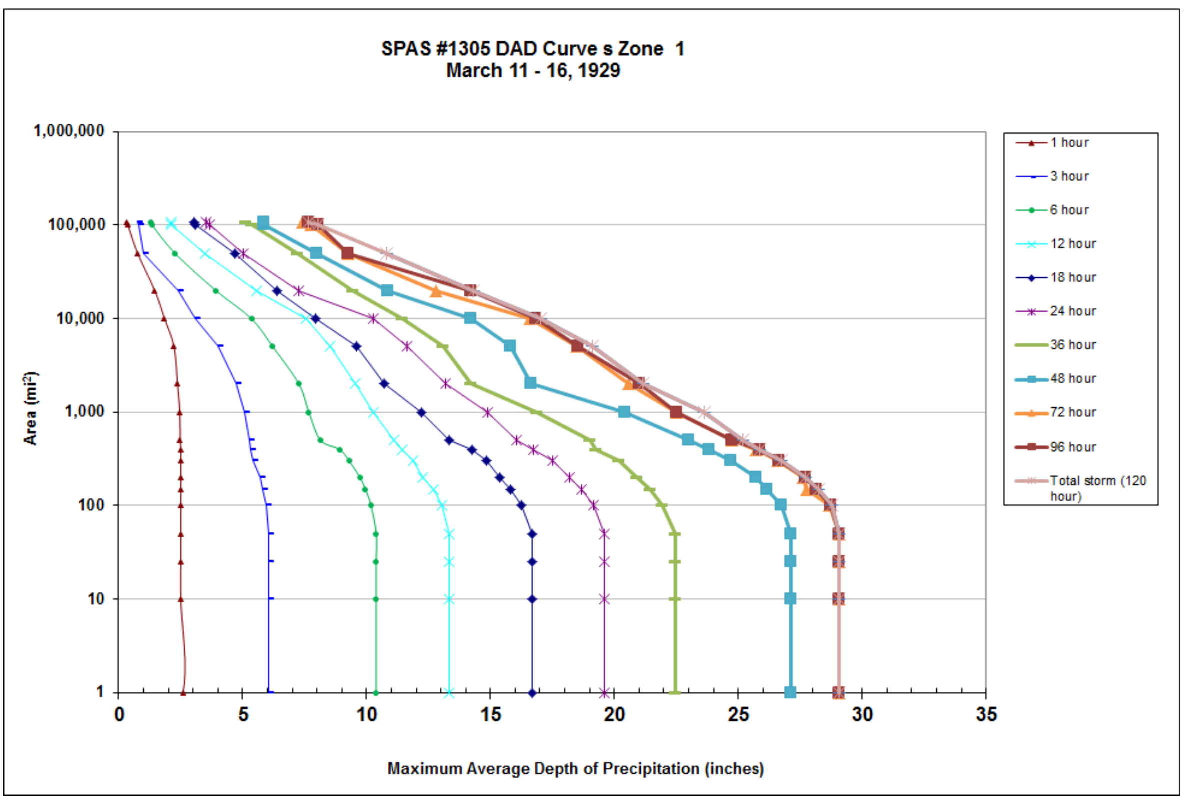
Spatial resolution: 30 seconds

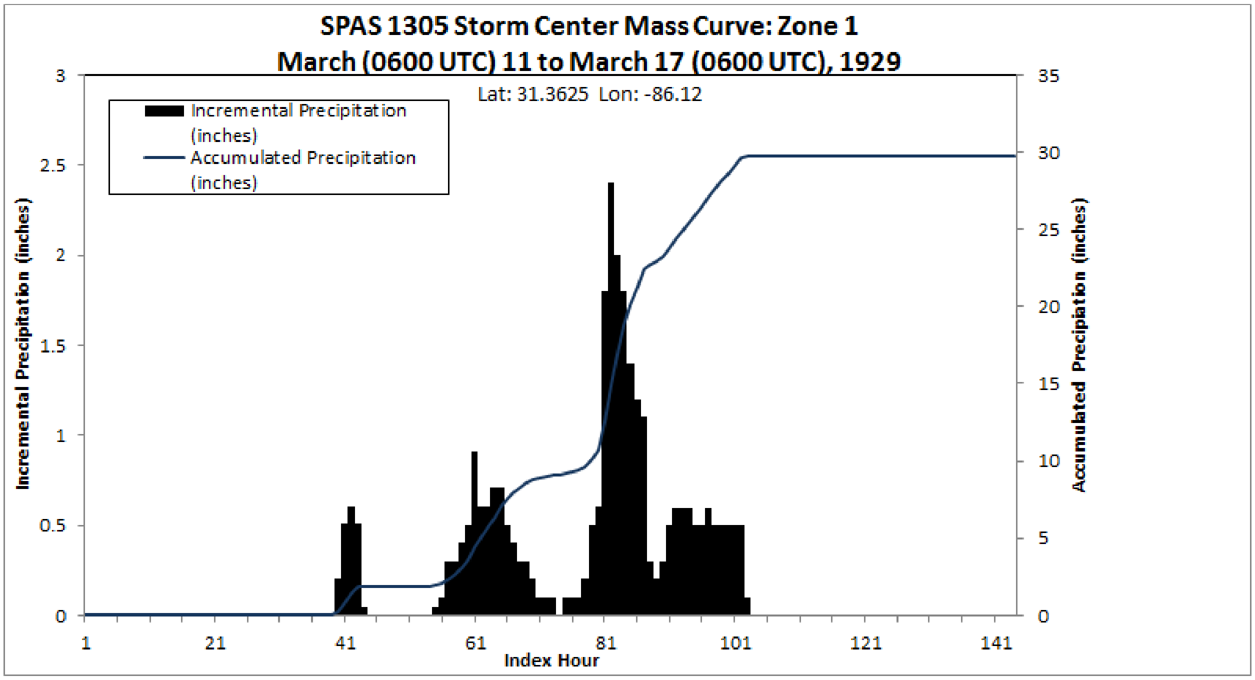
Radar Included: No

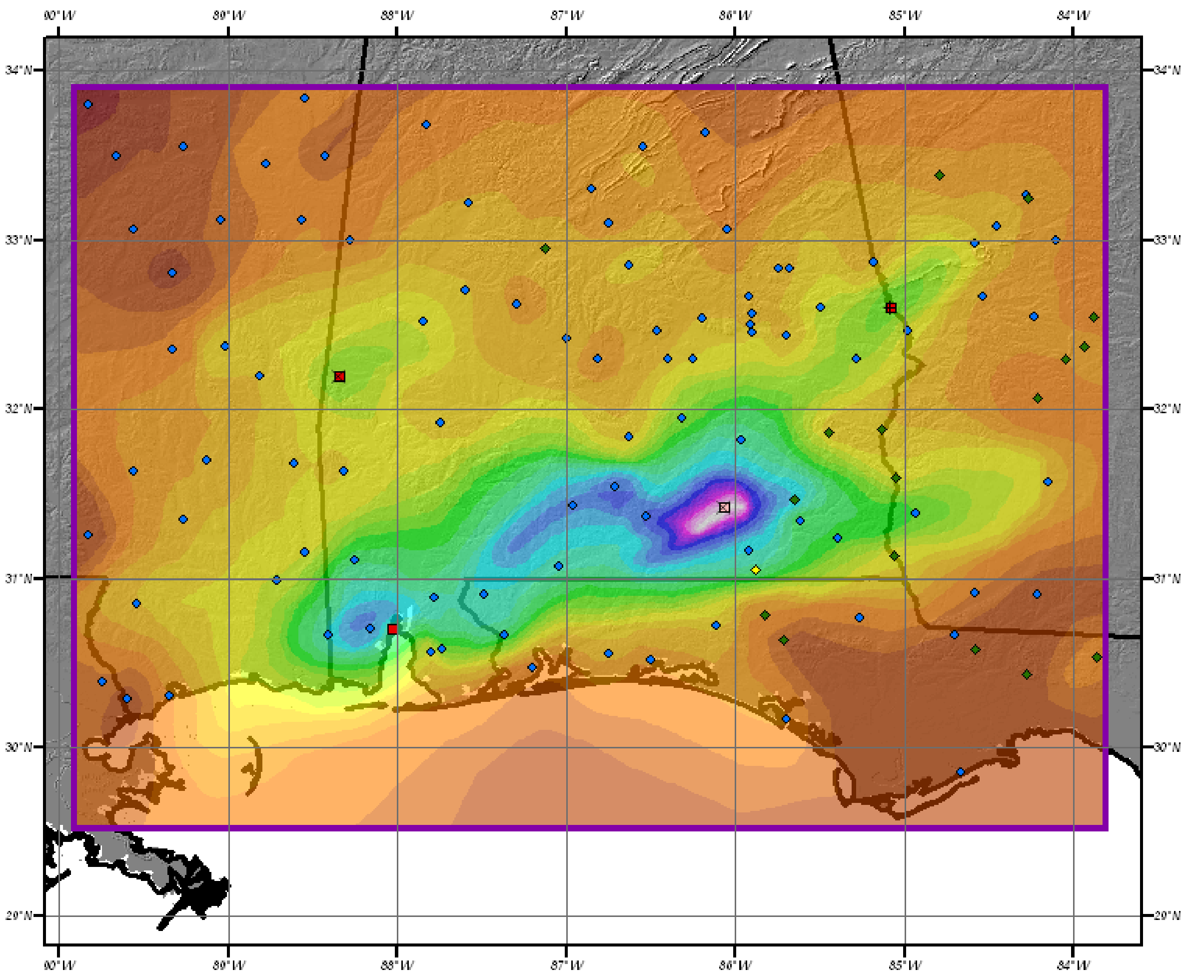
Depth-Area-Duration (DAD) analysis: Yes

Reliability of Results: Given the lack of hourly data (only 4 stations), there is limited confidence in the timing across much of the region. The timing of the storm center is tied entirely to the estimated hourly data from the USACE storm report. The extent and magnitude of the rainfall is moderately reliable given the surprising large number of daily rain gauges available. The exception to this is the precipitation exists across southern Mississippi where very little rain gauge data was available; We followed the trends of the NWS isohyetal pattern in this area.

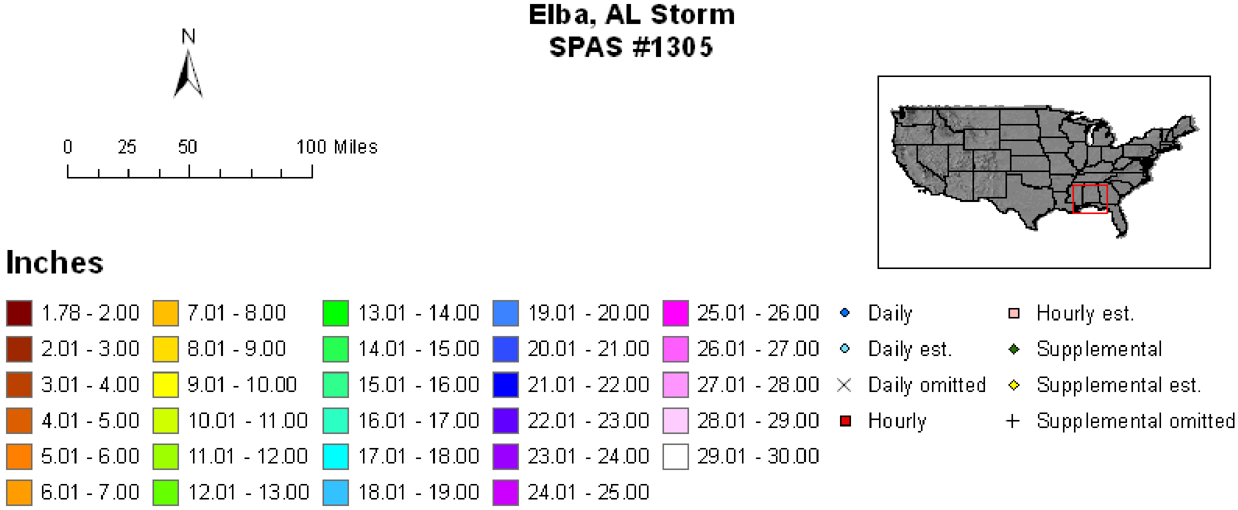
Storm 1305- March 11-16, 1929												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
	Duration (hours)											
area (mi sq)	1	3	6	12	18	24	36	48	72	96	120	Total
0.3	2.58	6.22	10.64	13.65	17.07	20.08	22.99	27.81	29.72	29.73	29.73	29.73
1	2.5	6.07	10.39	13.33	16.67	19.6	22.44	27.13	29.07	29.07	29.07	29.07
10	2.5	6.07	10.39	13.33	16.67	19.6	22.44	27.13	29.07	29.07	29.07	29.07
25	2.5	6.07	10.39	13.33	16.67	19.6	22.44	27.13	29.07	29.07	29.07	29.07
50	2.5	6.07	10.39	13.33	16.67	19.6	22.44	27.13	29.07	29.07	29.07	29.07
100	2.5	5.96	10.18	13.02	16.23	19.14	21.95	26.73	28.66	28.71	28.77	28.77
150	2.5	5.82	9.95	12.7	15.82	18.68	21.42	26.17	27.76	28.16	28.24	28.24
200	2.5	5.69	9.73	12.25	15.39	18.2	20.92	25.71	27.63	27.71	27.72	27.72
300	2.5	5.44	9.3	11.86	14.85	17.51	20.16	24.69	26.6	26.64	26.73	26.73
400	2.48	5.33	8.91	11.42	14.27	16.73	19.24	23.82	25.72	25.85	25.87	25.87
500	2.46	5.26	8.14	11.1	13.35	16.07	19.03	23.02	24.77	24.77	25.2	25.2
1000	2.37	5.07	7.67	10.26	12.21	14.87	16.87	20.41	22.5	22.5	23.61	23.61
2000	2.23	4.75	7.27	9.53	10.7	13.2	14.19	16.62	20.55	20.99	21.16	21.16
5000	1.85	4	6.22	8.51	9.58	11.63	13.07	15.82	18.5	18.52	19.1	19.1
10000	1.45	3.1	5.35	7.54	7.93	10.29	11.44	14.22	16.59	16.84	17.02	17.02
20000	0.76	2.42	3.92	5.56	6.38	7.26	9.47	10.86	12.8	14.2	14.3	14.3
50000	0.37	1.01	2.27	3.49	4.67	5.04	7.22	8.01	9.25	9.25	10.82	10.82
100000	0.3	0.82	1.35	2.14	3.09	3.66	5.39	5.87	7.77	8.04	8.04	8.04




SPAS 1305 Storm Center Mass Curve: Zone 1
March (0600 UTC) 11 to March 17 (0600 UTC), 1929
Lat: 31.3625 Lon: -86.12
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Incremental Precipitation (inches)
Accumulated Preciptation (inches)
Index Hour
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25
30
35
1
21
41
61
81
101
121
141



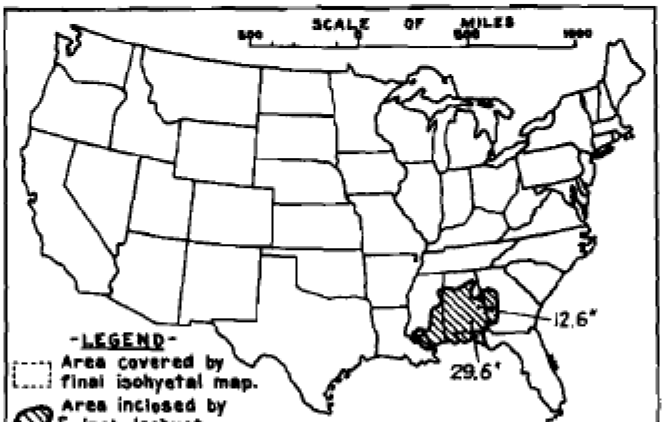
Total 6-day Precipitation (inches)
Mar 11-16, 1929
Elba, AL Storm
SPAS #1305



TWP Oct 30, 2013

WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – PERTINENT DATA SHEET



LOCATION MAP

Storm of March 11 – 16, 1929
Assignment L M V 2 – 20
Location Miss. Ala. and Ga.
Study Prepared by:
Lower Mississippi Valley Division
Vicksburg District Office
Part I Reviewed by H. M. Sec. of Weather Bureau, 1/9/39
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 3/24/43
Remarks: Centers at : Elba, Ala. and Spring Hill, Ala.

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in - sheet , scale -

Precipitation data and mass curves: (Number of Sheets)

Form 5001-C (Hourly precip. data)	15
Form 5001-B (24-hour " ")(Old W.B. Forms 5001-A)	24
Form 5001-D (" " " ")	-
Miscl. precip. records, meteorological data, etc.	212
Form 5002 (Mass rainfall curves)	56

PART II

Final isohyetal maps, in 1 sheet , scale 1 : 1,000,000

Data and computation sheets:

Form S-10 (Data from mass rainfall curves)	7
Form S-11 (Depth-area data from isohyetal map)	4
Form S-12 (Maximum depth-duration data)	15
Maximum duration-depth-area curves	1
Data relating to periods of maximum rainfall	2

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

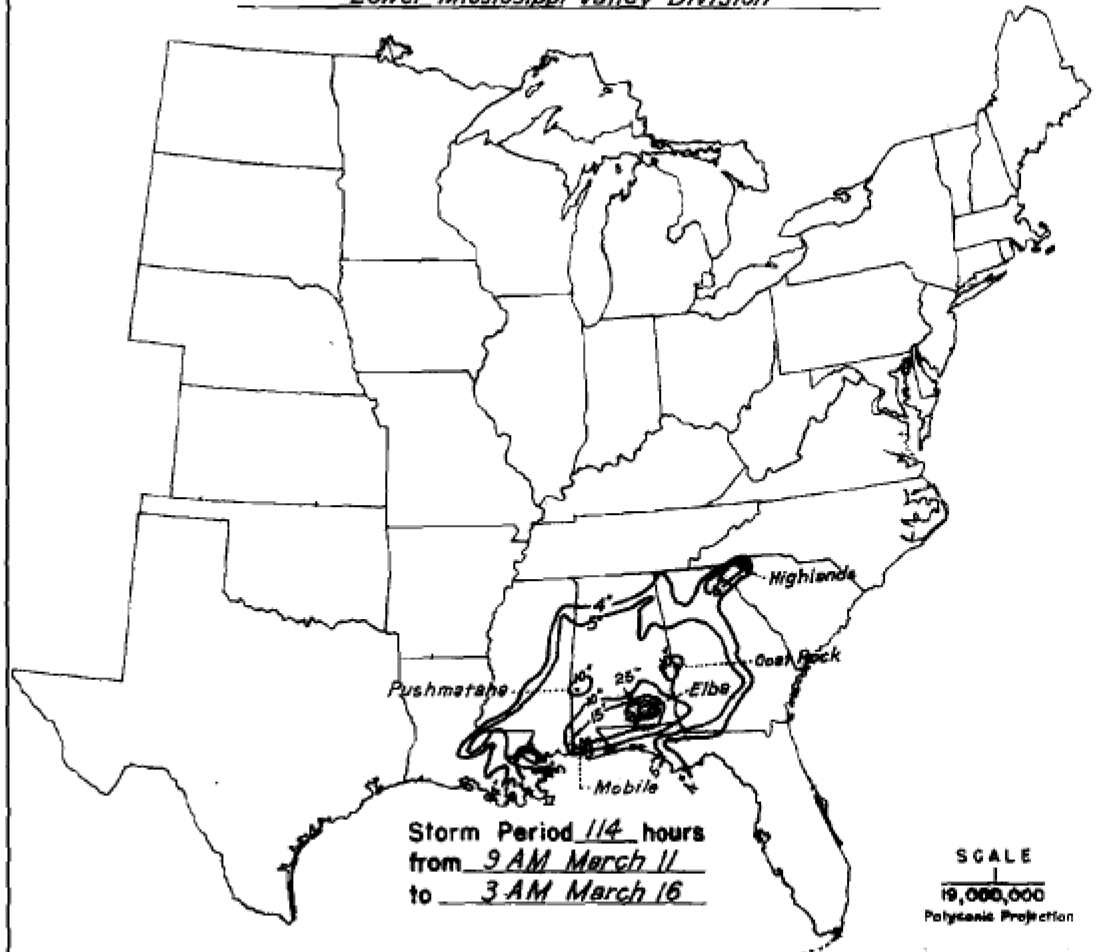
Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	72	96	114
10	14.0	15.4	19.5	20.0	21.4	23.8	27.4	28.0	29.6	29.6	29.6
100	13.6	14.9	18.9	19.3	20.7	22.9	26.1	26.6	28.4	28.4	28.4
200	13.1	14.4	18.3	18.6	20.0	22.2	25.5	26.0	27.6	27.6	27.6
500	11.6	13.2	16.7	17.2	18.3	20.2	24.0	24.7	26.1	26.1	26.1
1,000	10.2	11.8	15.4	16.1	17.0	18.6	22.1	22.9	24.4	24.6	24.6
2,000	8.9	10.4	14.1	15.0	15.7	17.0	20.0	20.8	22.3	22.5	22.5
5,000	7.1	8.6	12.2	13.5	13.9	14.8	17.3	18.1	19.4	19.7	19.7
10,000	5.6	7.2	10.1	12.1	12.5	13.1	15.2	15.9	17.1	17.5	17.5
20,000	3.8	5.4	7.9	9.6	10.1	11.0	12.5	13.3	14.3	14.7	14.7
50,000	2.5	3.6	5.3	6.3	7.1	7.9	8.9	9.7	10.5	10.8	10.8
100,000	1.6	2.4	3.5	4.3	5.0	5.6	6.5	7.2	7.8	8.2	8.2

Form S-2

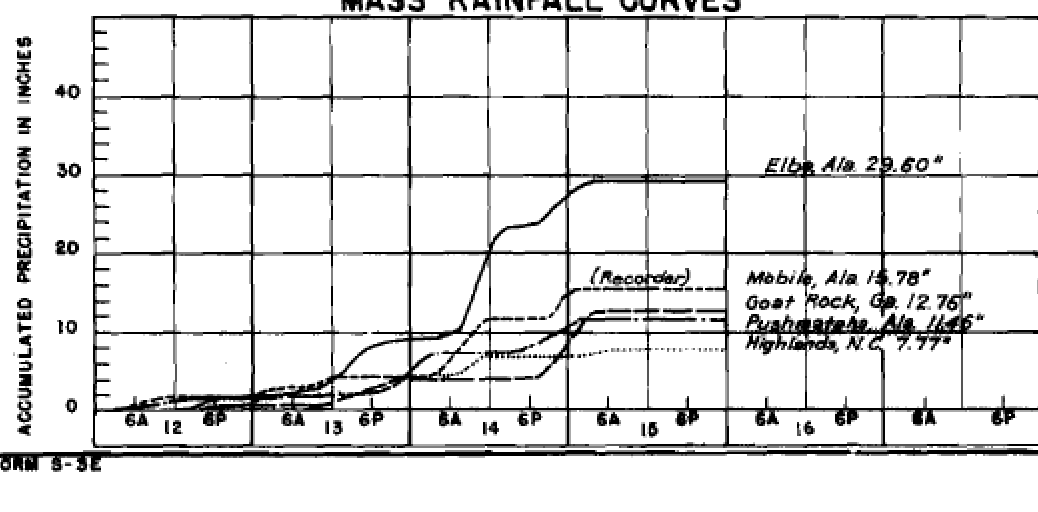
WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – ISOHYETAL MAP

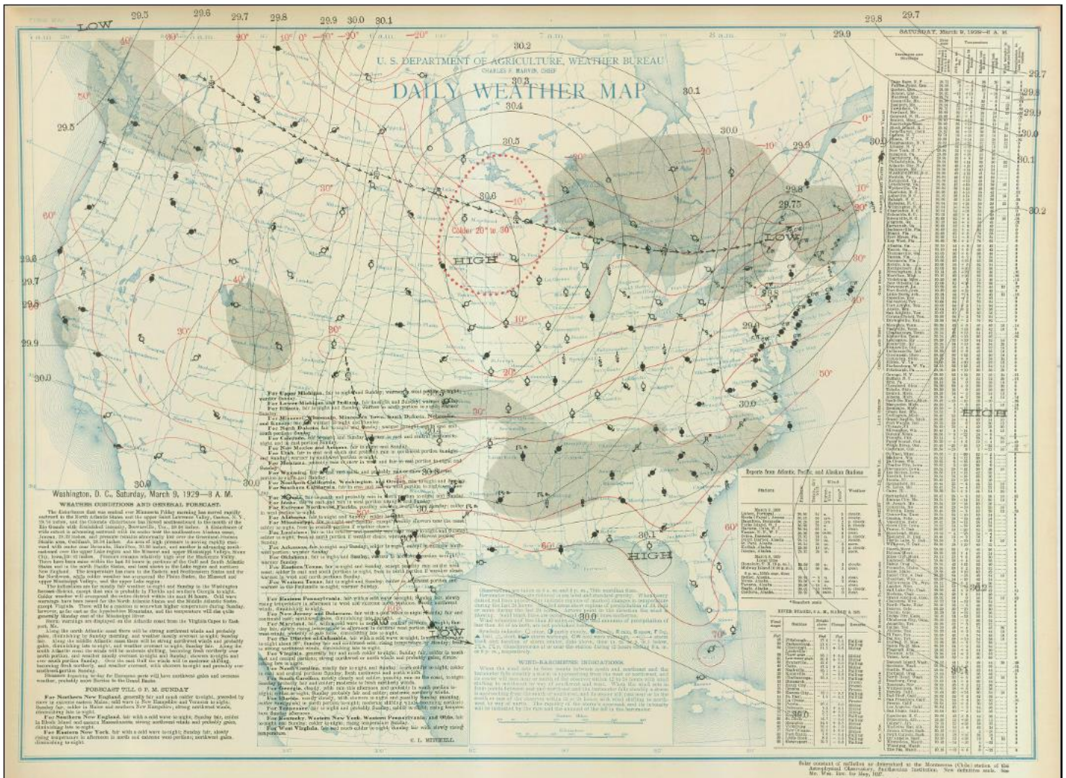
Storm of *March 11-16, 1929* Assignment *LMV 2-20*
Study Prepared by: *Vicksburg, Miss. District*
Lower Mississippi Valley Division



MASS RAINFALL CURVES

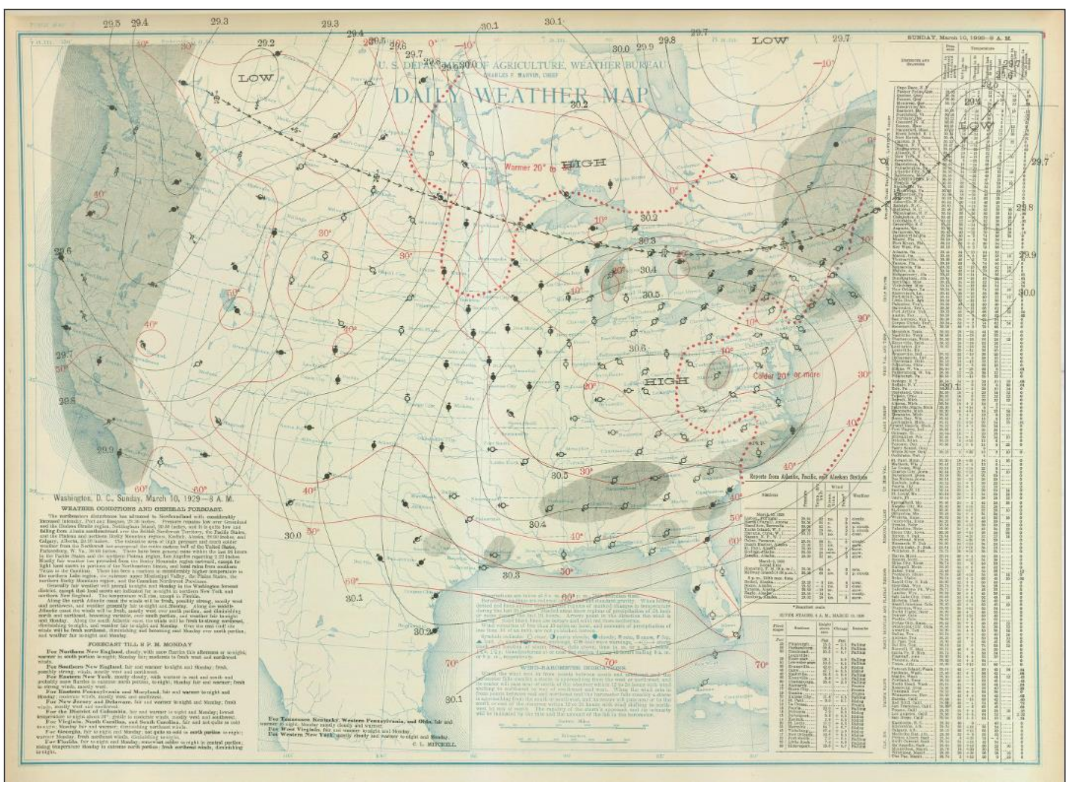


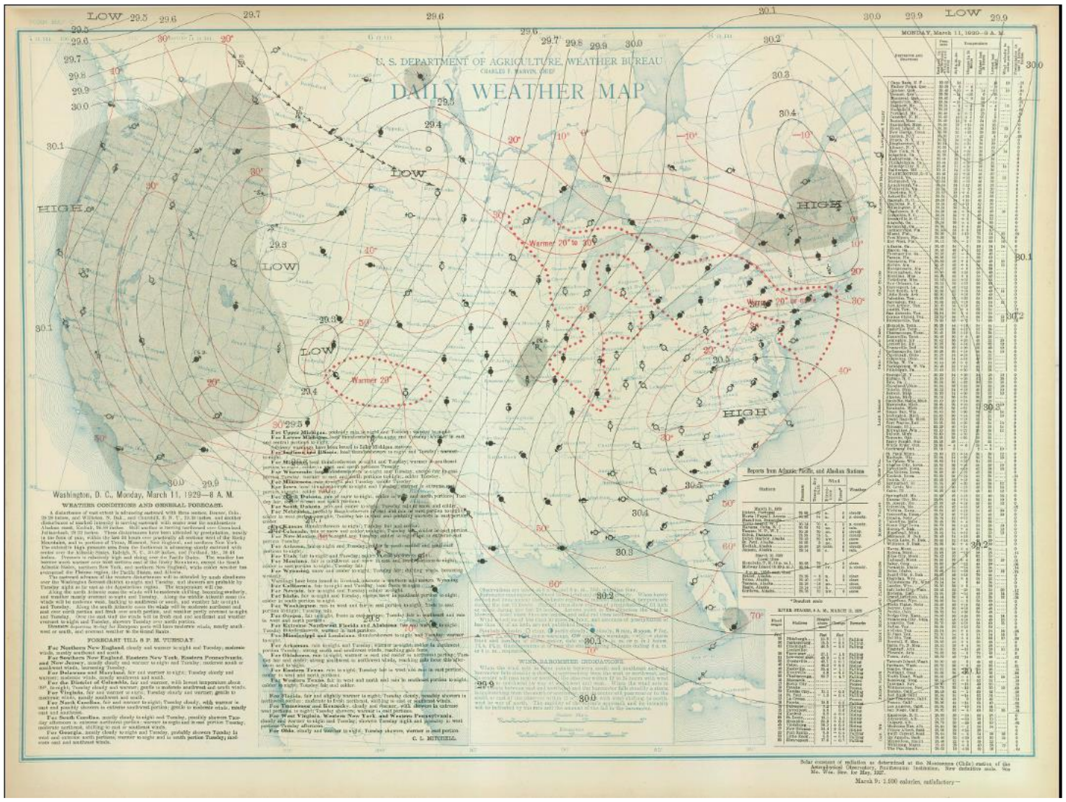
FORM S-3E

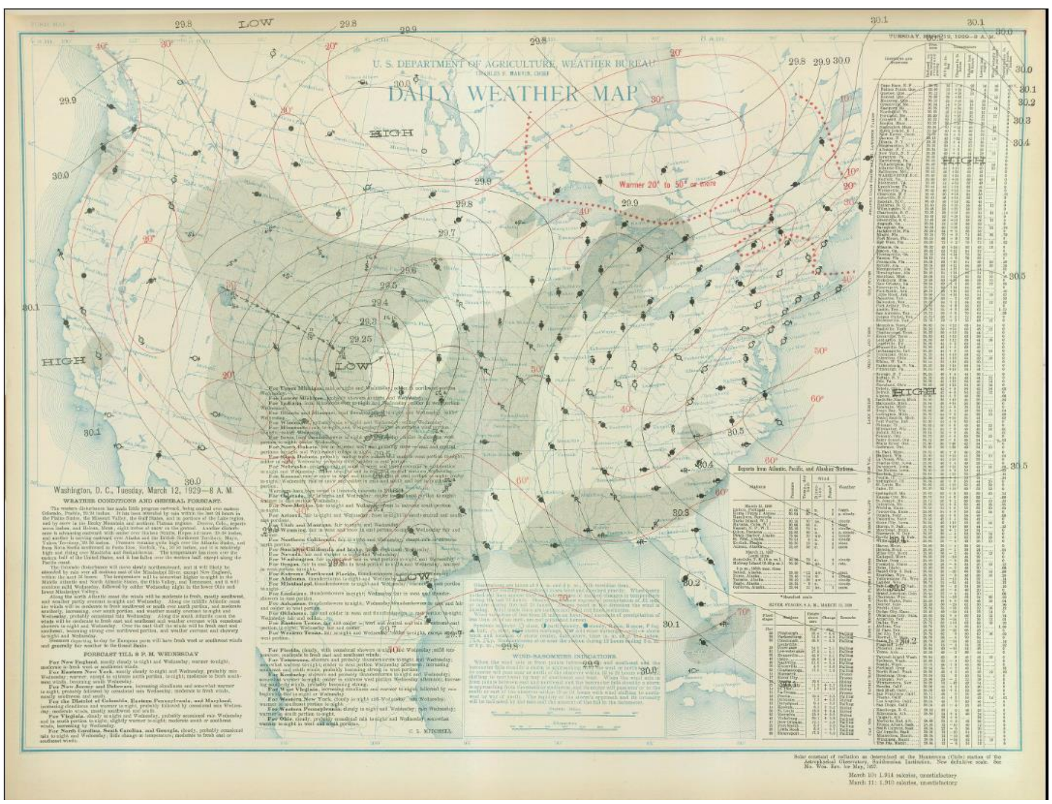


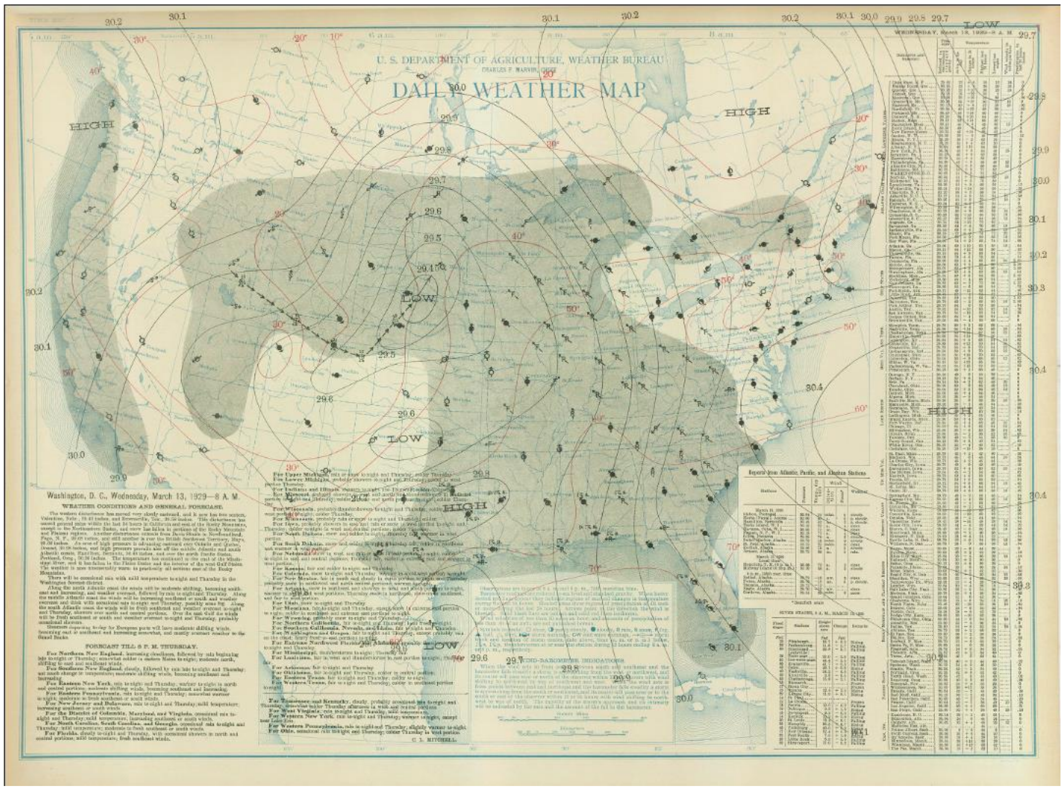
Solar constant of radiation as determined at the Montezuma (Chile) station of the Astrophysical Observatory, Smithsonian Institution. New definitive scale. See Mo. Wea. Rev. for May, 1927.

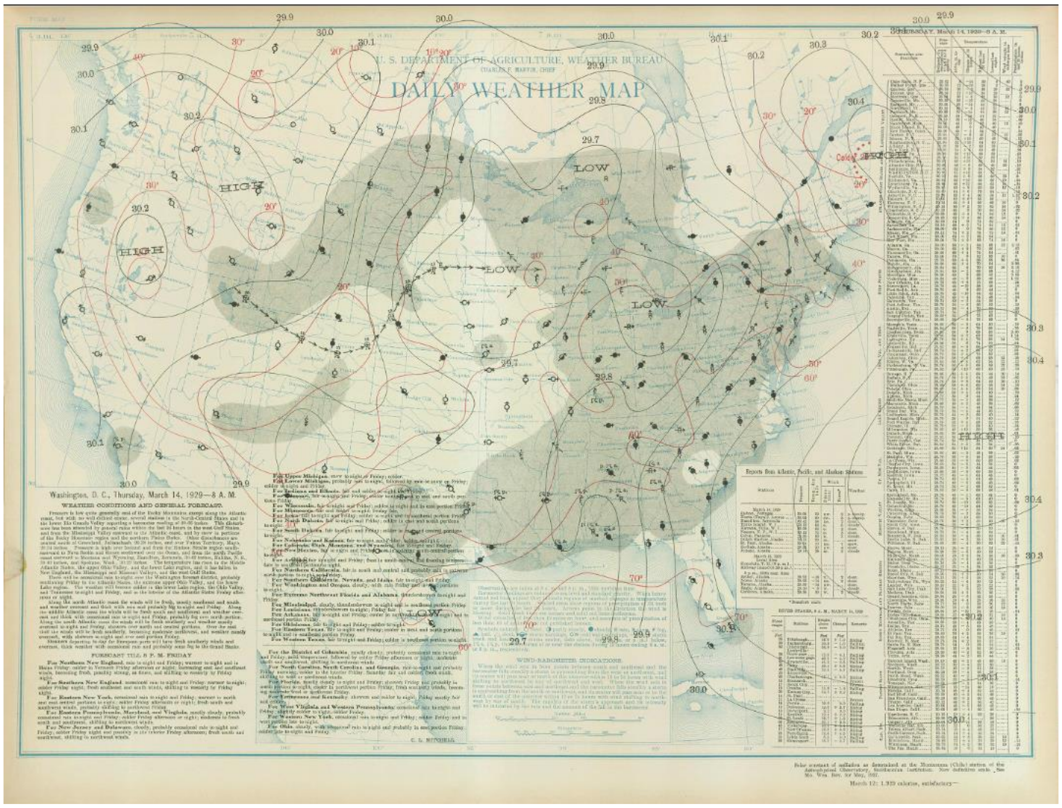
March 8: 1.920 calories, unsatisfactory



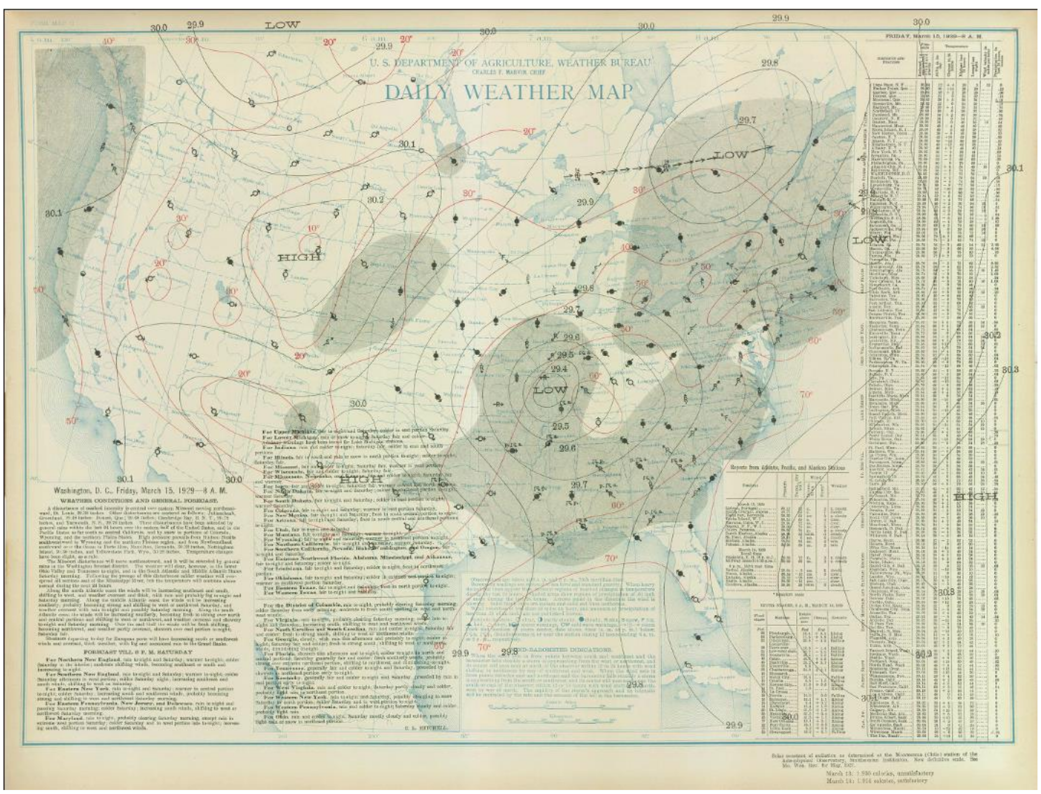

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Monday, March 11, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. TUESDAY.
HIGH
LOW
HIGH
LOW
LOW
HIGH
Warmer 20°
MONDAY, March 11, 1929—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Tuesday, March 12, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. WEDNESDAY.
HIGH
LOW
HIGH
HIGH
HIGH
LOW
Warmer 20° to 30° or more

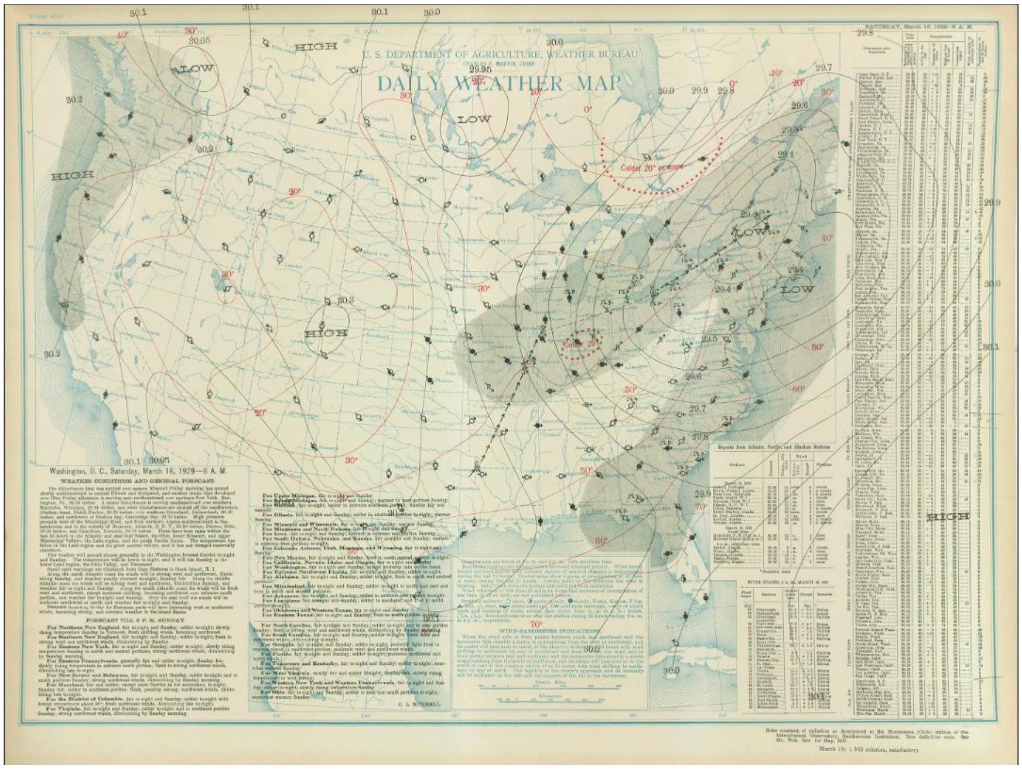

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Wednesday, March 13, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. THURSDAY.



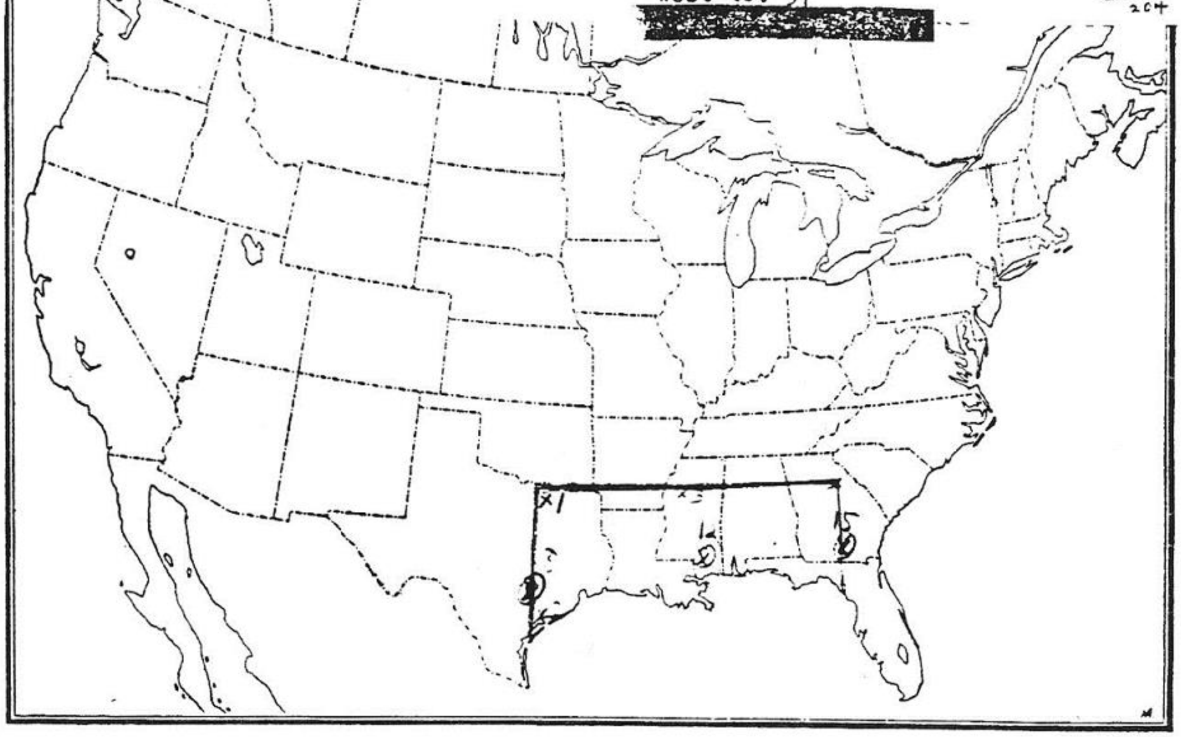
U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Thursday, March 14, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. FRIDAY
WIND-BAROMETER INDICATIONS.
HIGH
LOW



U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Friday, March 15, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. SATURDAY
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Saturday, March 16, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST
WIND-BAROMETER INDICATIONS
SATURDAY, March 16, 1929—8 A. M.

LMV 2-20..Mar. 11-16, 1929..Elba, Ala.
12-hr. rTd 67(14th)...75 S..to 75, 54%
North to: 34
South to: coast
East to: 83
West to: 97
[redacted]



Storm Precipitation Analysis System (SPAS) For Storm #1195_2 SPAS Analysis

General Storm Location: Northeastern U.S. and adjacent portions of Canada

Storm Dates: March 16– 21, 1936

Event: Synoptic (Major rain-on-snow event)

DAD Zone 2

Latitude: 39.0208

Longitude: -78.5625

Max. Grid Rainfall Amount: 8.31" in 126 hours (USACE SA-1-27: 10-sq-mi 7.9")

Number of Stations: 966 (696 Daily, 6 Hourly, 11 Hourly Pseudo, 252 Supplemental, and 1 Supplemental Estimated)

SPAS Version: 8.5

Base Map Used: Mean (1971-2000) PRISM March Precipitation (extrapolated into Canada)

Spatial resolution: 30 seconds

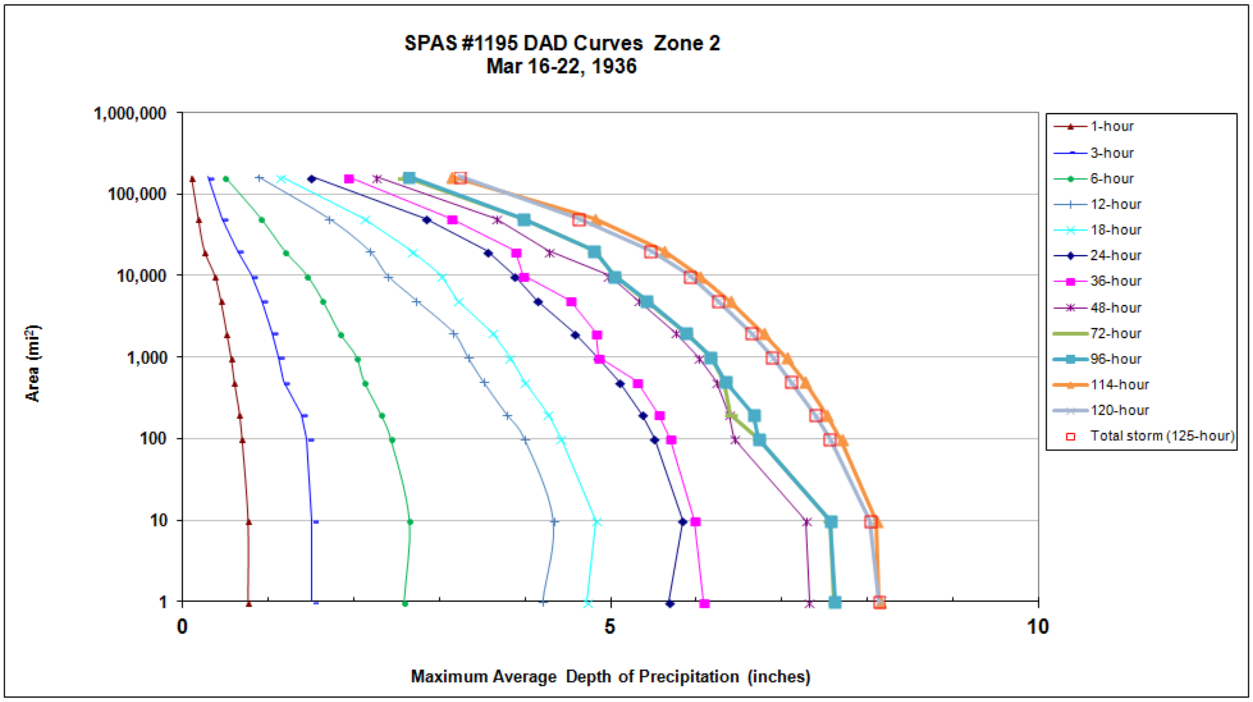
Radar Included: No

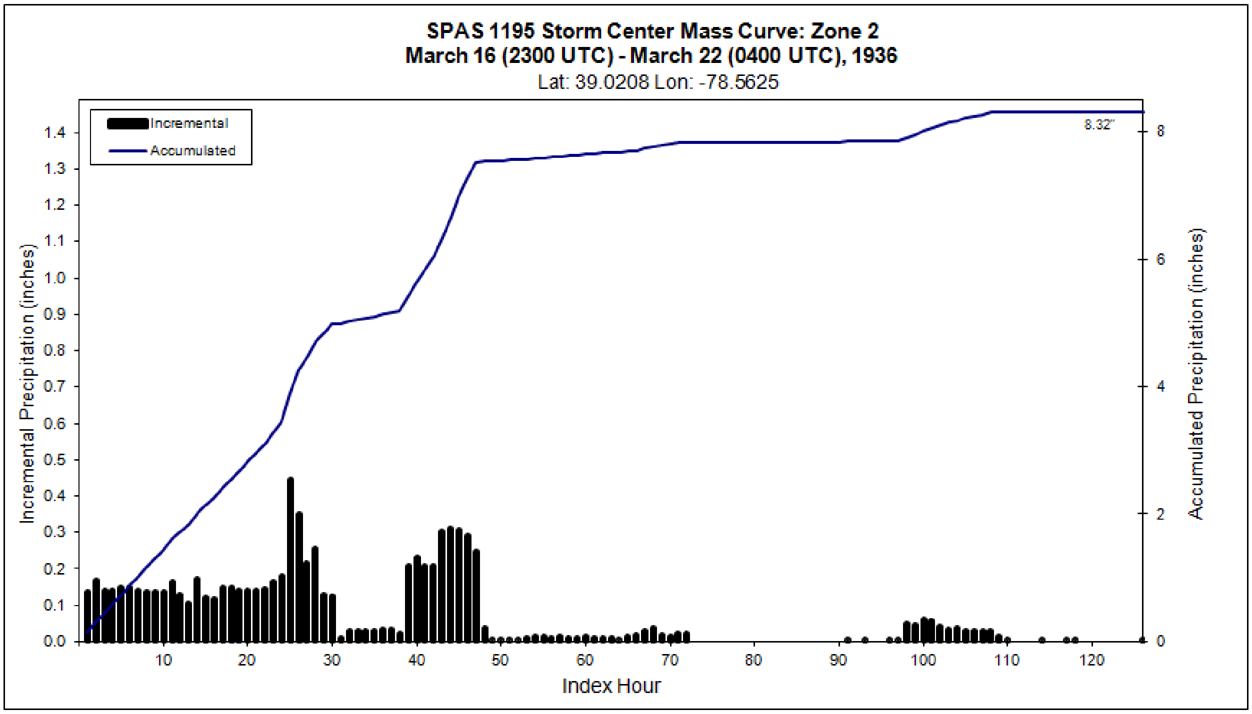
Depth-Area-Duration (DAD) analysis: Yes

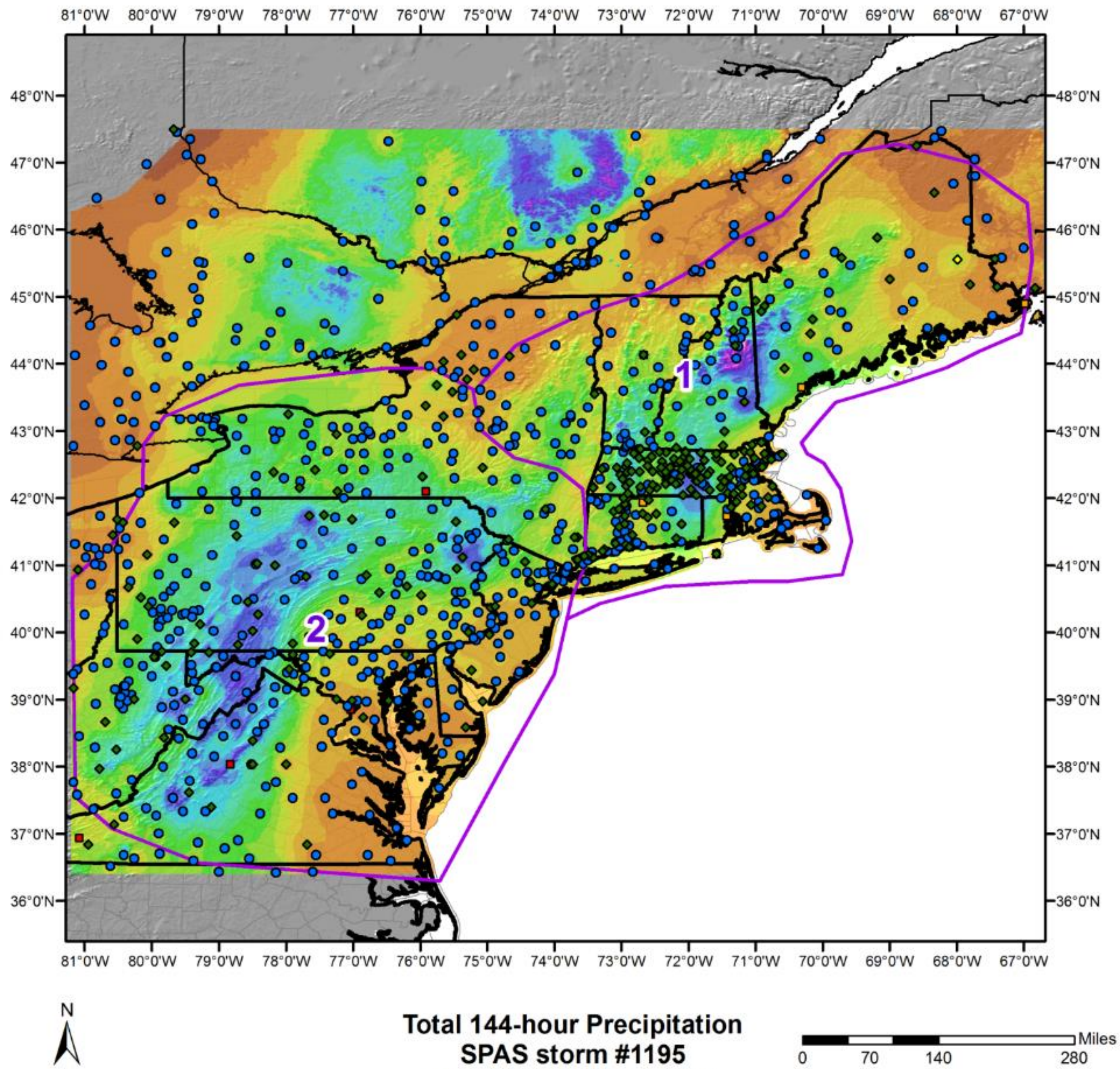
Reliability of Results: The lack of hourly data makes the temporal characteristics of this analysis less accurate than usual. However, a relatively high density of daily and supplemental stations provides good confidence in the magnitudes. At times, particularly at the highest elevations (above 3,000 feet) and across the northern most areas, snow and ice may have compromised the precipitation amounts given difficult in measurements.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1195_2	-78.5600	39.0200	2,210	1-Apr	68.00	2.05	0.42	58	1.630	72.25	2.54	0.49	67	2.050	1.258

Storm 1195 - March 16 (2300 UTC) - March 22 (0400 UTC),1936														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
	Duration (hours)													
Area (mi^2)	1	3	6	12	18	24	36	48	72	96	114	120	125	Total
0.3	0.78	1.61	2.67	4.36	4.93	5.88	6.29	7.54	7.84	7.85	8.31	8.32	8.32	8.32
1.0	0.76	1.51	2.59	4.21	4.73	5.68	6.09	7.32	7.61	7.62	8.14	8.14	8.14	8.14
10.0	0.76	1.51	2.65	4.33	4.83	5.84	5.98	7.28	7.56	7.57	8.1	8.03	8.03	8.03
100.0	0.69	1.45	2.43	3.99	4.42	5.51	5.7	6.44	6.73	6.73	7.69	7.56	7.56	7.56
200.0	0.66	1.38	2.31	3.78	4.27	5.37	5.56	6.39	6.4	6.67	7.52	7.39	7.39	7.39
500.0	0.6	1.18	2.12	3.51	3.99	5.1	5.3	6.24	6.33	6.34	7.27	7.11	7.11	7.11
1,000.0	0.56	1.12	2.03	3.33	3.82	4.84	4.86	6.02	6.17	6.17	7.05	6.89	6.89	6.89
2,000.0	0.51	1.04	1.83	3.16	3.62	4.58	4.83	5.76	5.88	5.88	6.78	6.64	6.64	6.64
5,000.0	0.44	0.92	1.63	2.72	3.21	4.14	4.53	5.32	5.41	5.42	6.39	6.25	6.25	6.25
10,000.0	0.37	0.8	1.45	2.39	3.02	3.87	3.97	4.97	5.04	5.04	6.03	5.92	5.92	5.92
20,000.0	0.25	0.63	1.19	2.18	2.68	3.56	3.88	4.28	4.81	4.81	5.62	5.47	5.47	5.47
50,000.0	0.18	0.45	0.91	1.7	2.12	2.84	3.13	3.66	3.98	3.98	4.81	4.63	4.63	4.63
161,541.0	0.1	0.29	0.49	0.88	1.14	1.5	1.93	2.26	2.58	2.64	3.14	3.24	3.24	3.24




SPAS 1195 Storm Center Mass Curve: Zone 2
March 16 (2300 UTC) - March 22 (0400 UTC), 1936
Lat: 39.0208 Lon: -78.5625
Incremental
Accumulated
8.32"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour

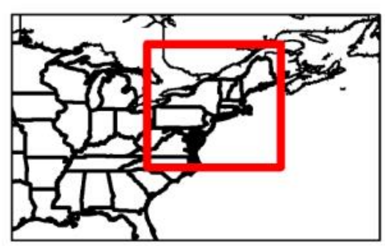


Total 144-hour Precipitation
SPAS storm #1195
03/16/1936 - 03/21/1936

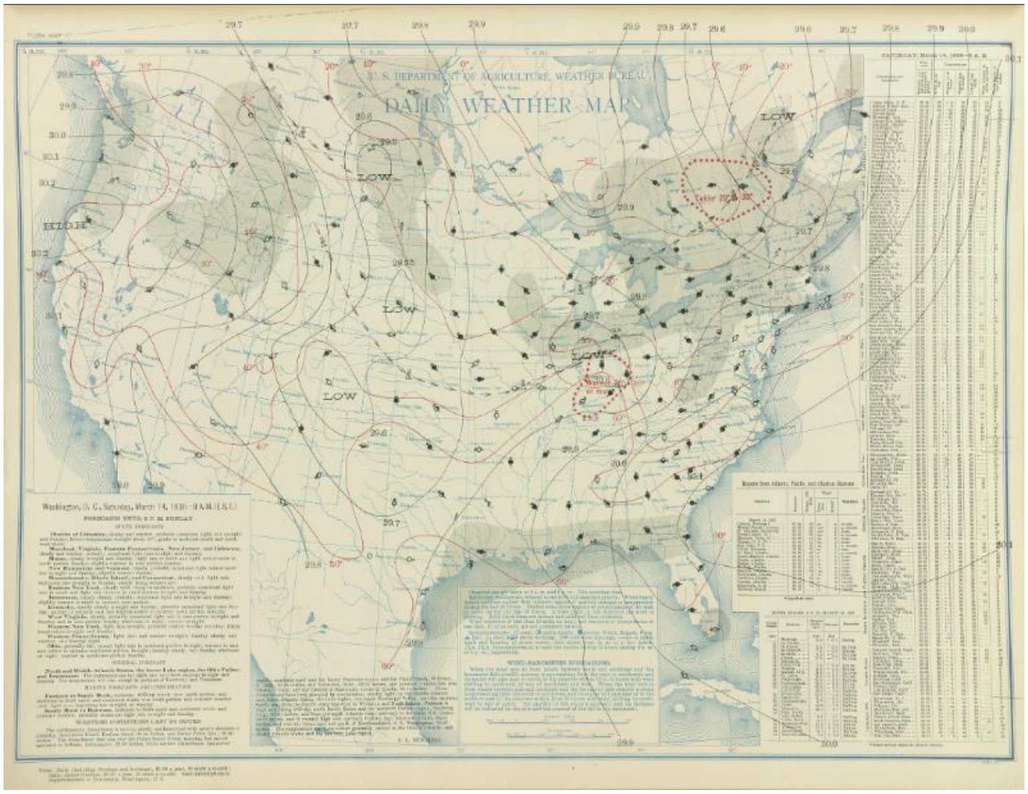
Precipitation (inches)

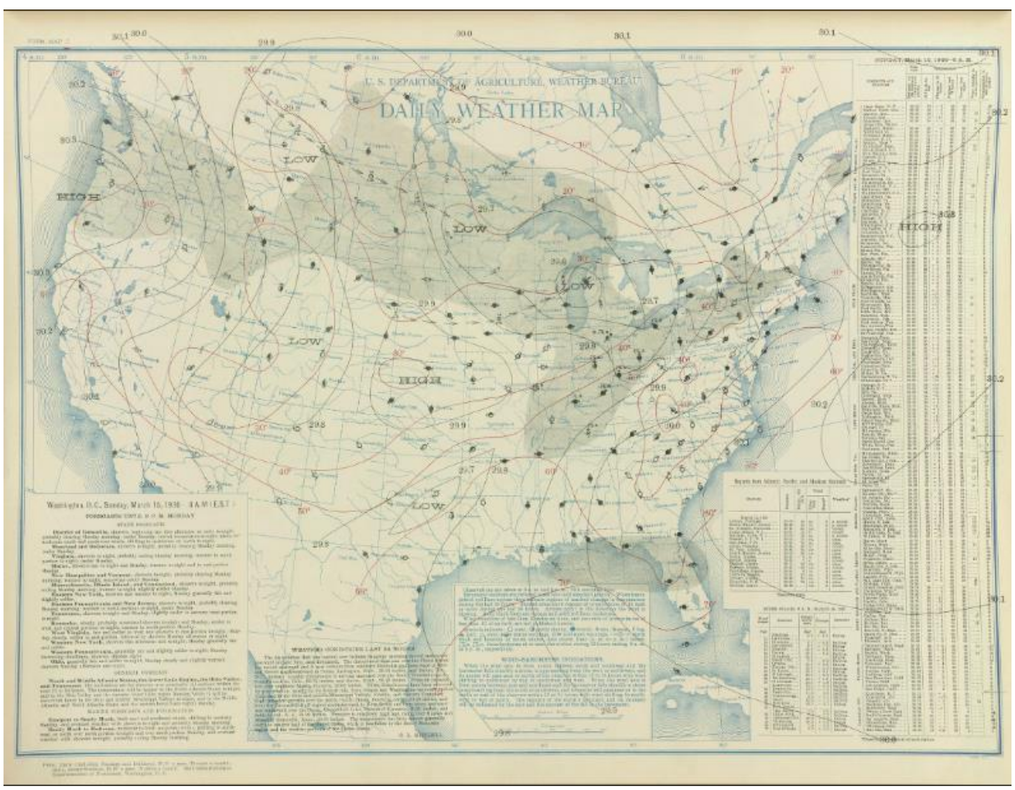
0.02
0.03 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00

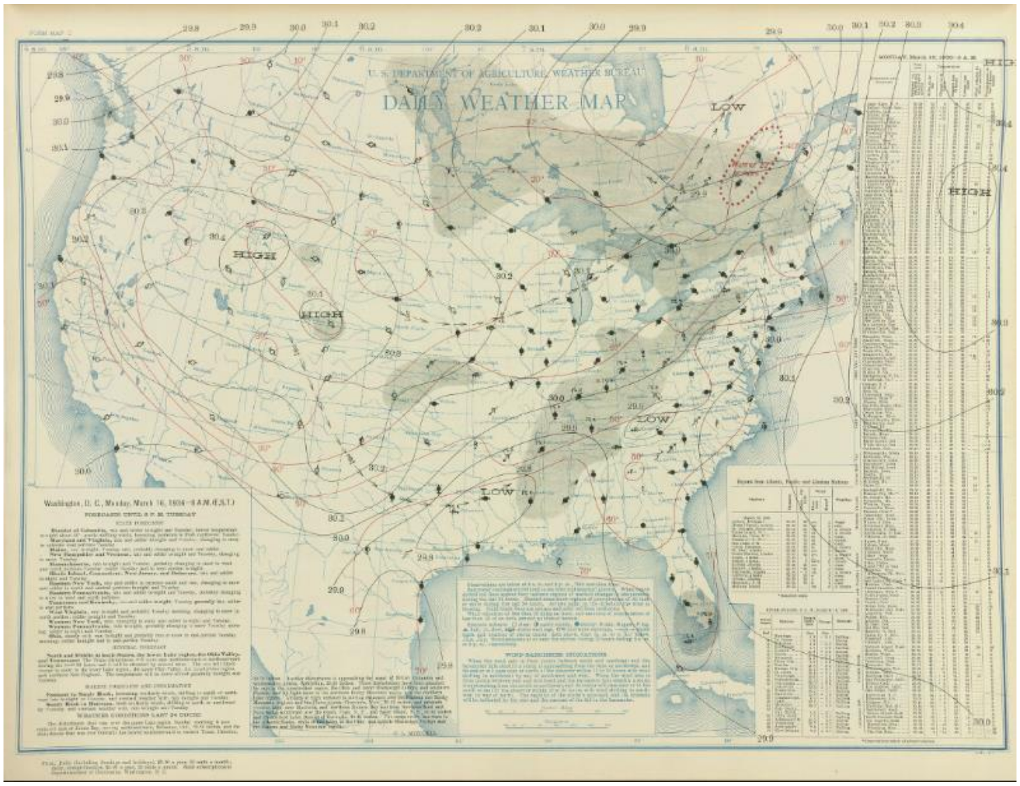
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Est.
DAD Zones

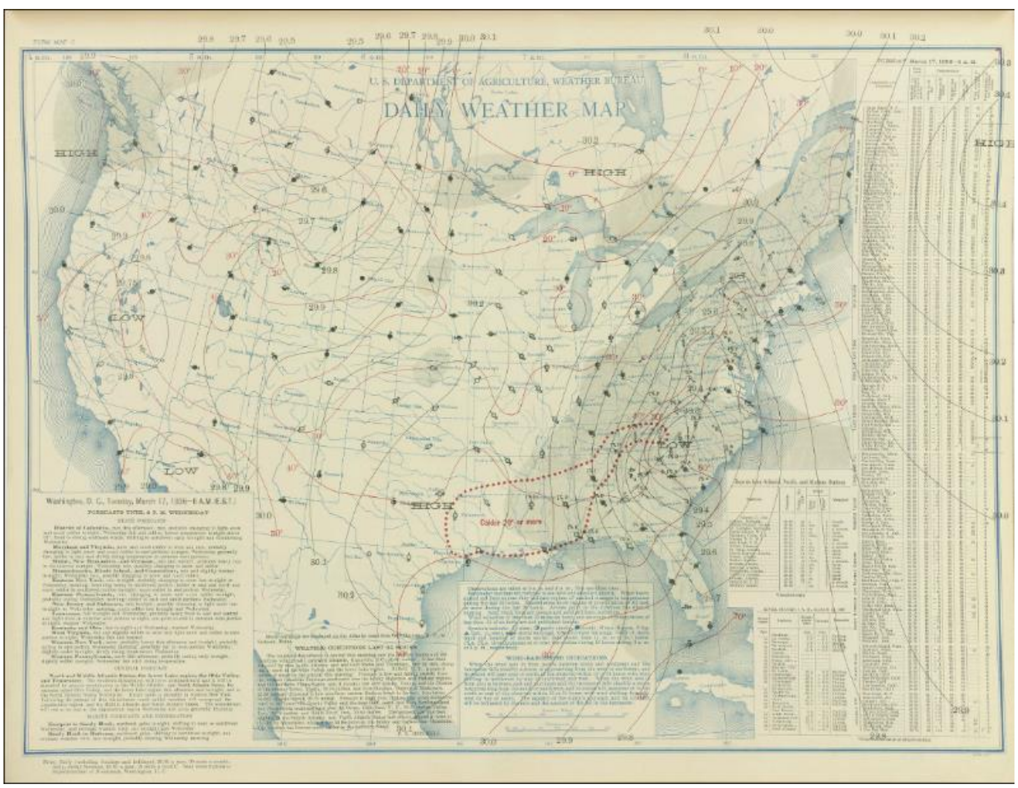


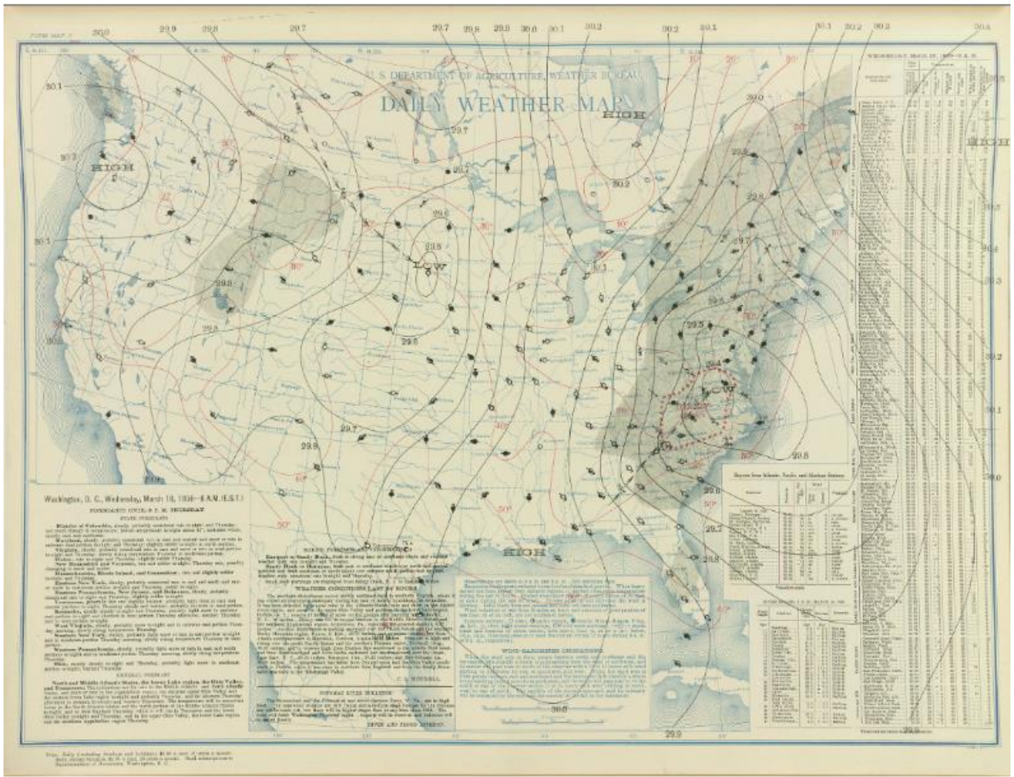
METSTAT, Inc. 11/12/2012

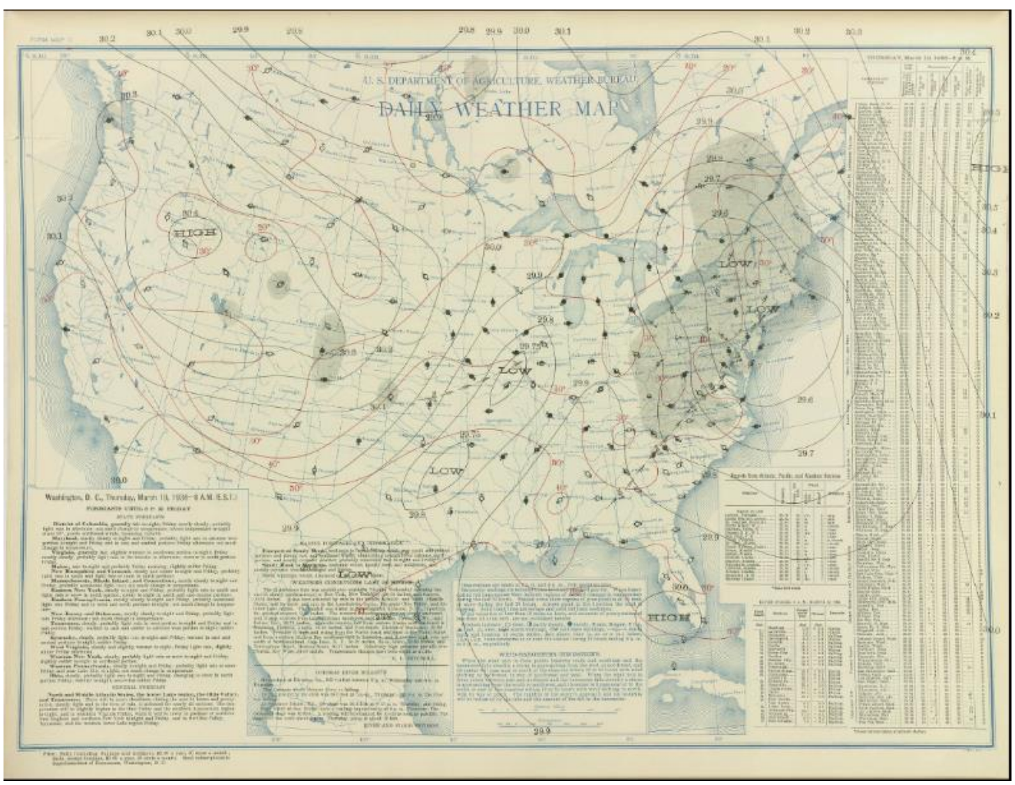

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.
DAILY WEATHER MAP
LOW
HIGH

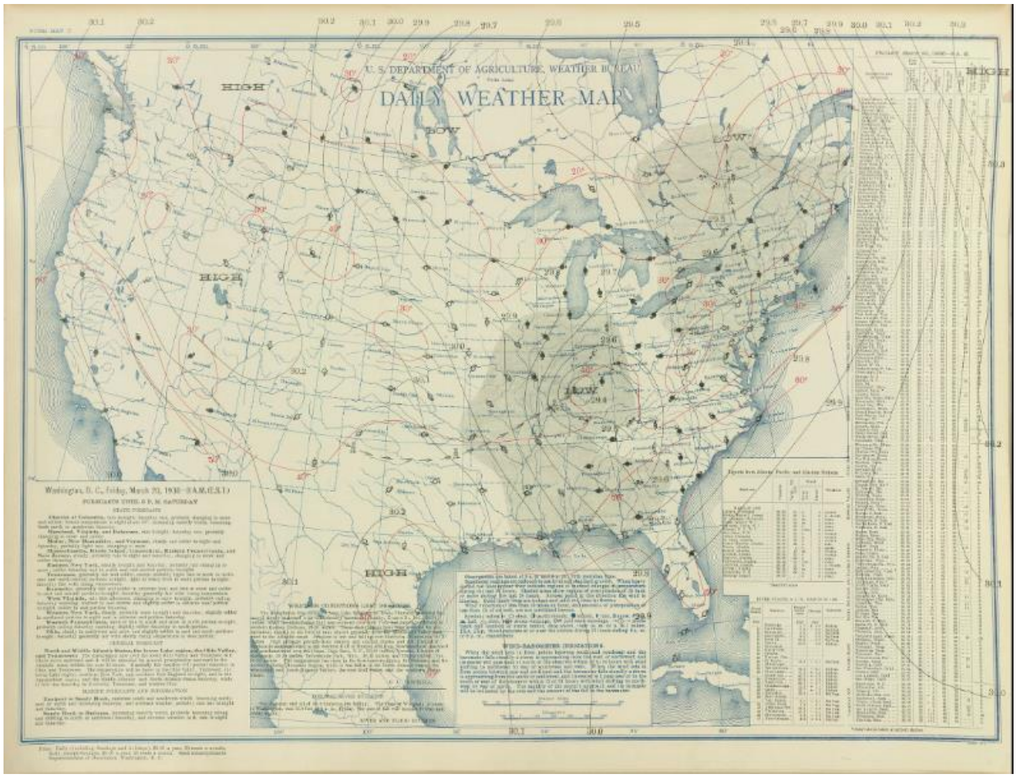

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.
DAILY WEATHER MAP
LOW
HIGH

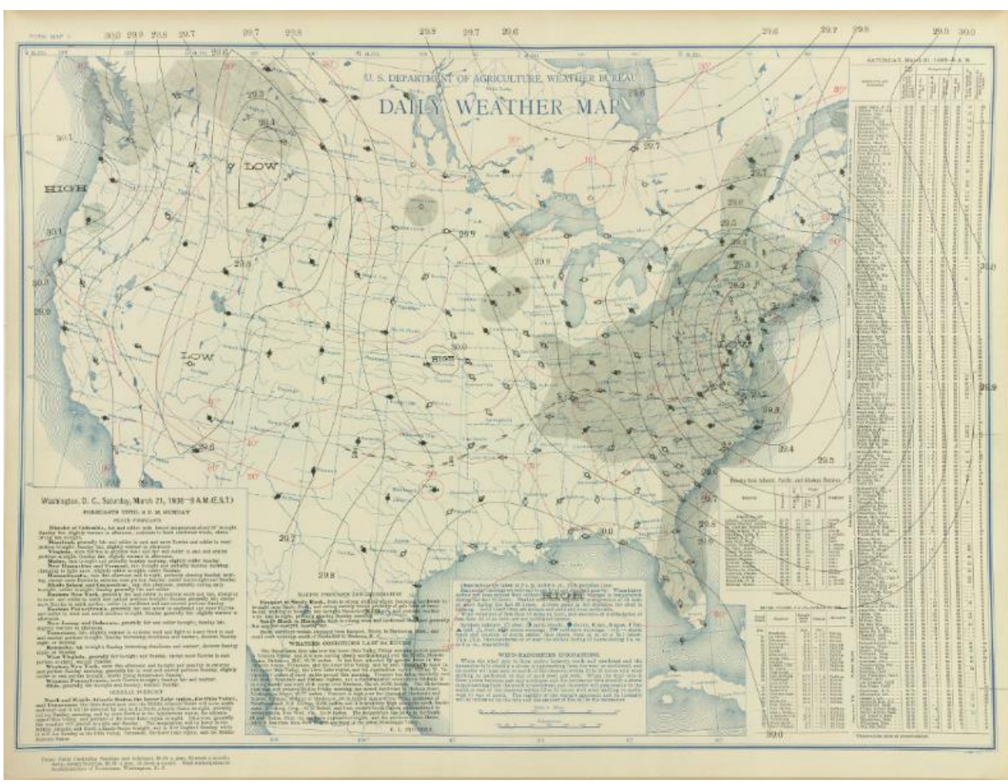

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW

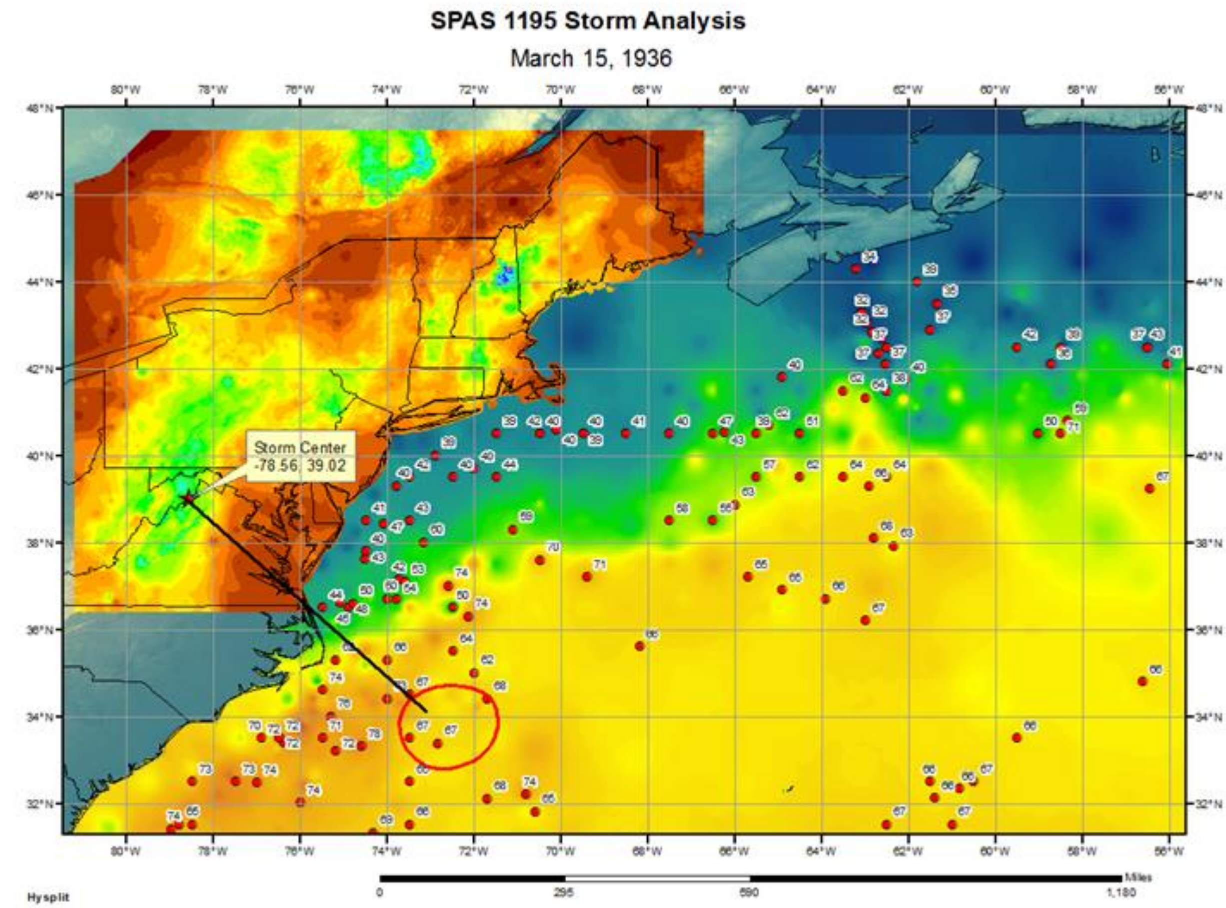

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Wednesday, March 18, 1936—8 A.M. (E.S.T.)
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Thursday, March 19, 1936—8 A.M. (E.S.T.)
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
LOW
HIGH


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
LOW
HIGH


SPAS 1195 Storm Analysis
March 15, 1936
Storm Center
-78.56, 39.02
Hysplit
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1311_1 SPAS Analysis

General Storm Location: Ohio River Basin

Storm Dates: January 17-25, 1937

Event: Frontal activity accompanied by almost continuous rain

DAD Zone 1

Latitude: 36.4375

Longitude: -87.9125

Max. Grid rainfall amount: 19.86"

Max. Observed rainfall amount: 19.75" (DOVER 1 NW, TN)

Number of Stations: 995

SPAS Version: 9.5

Base Map Used: Digitized TVA Isohyetal Map (storm total Jan 16-25)

Spatial resolution: 30 seconds

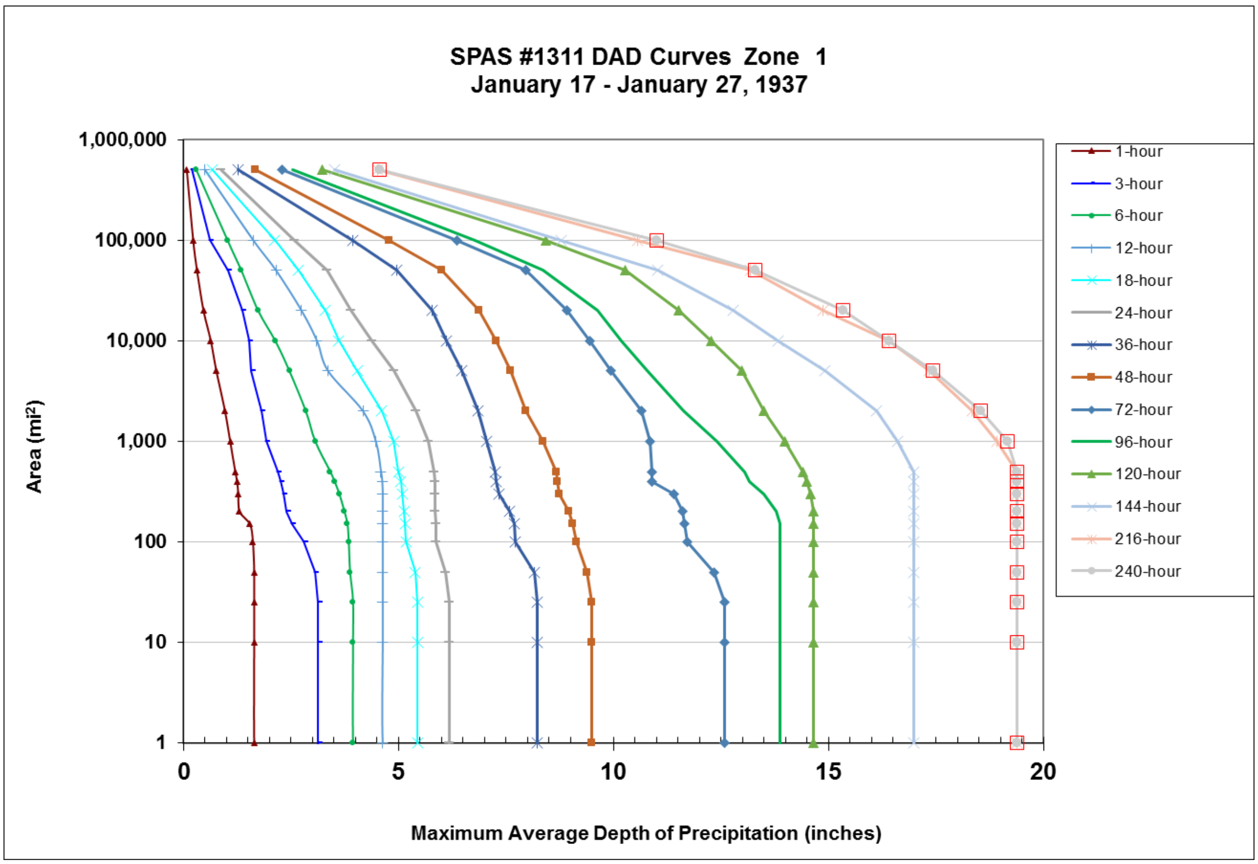
Radar Included: No

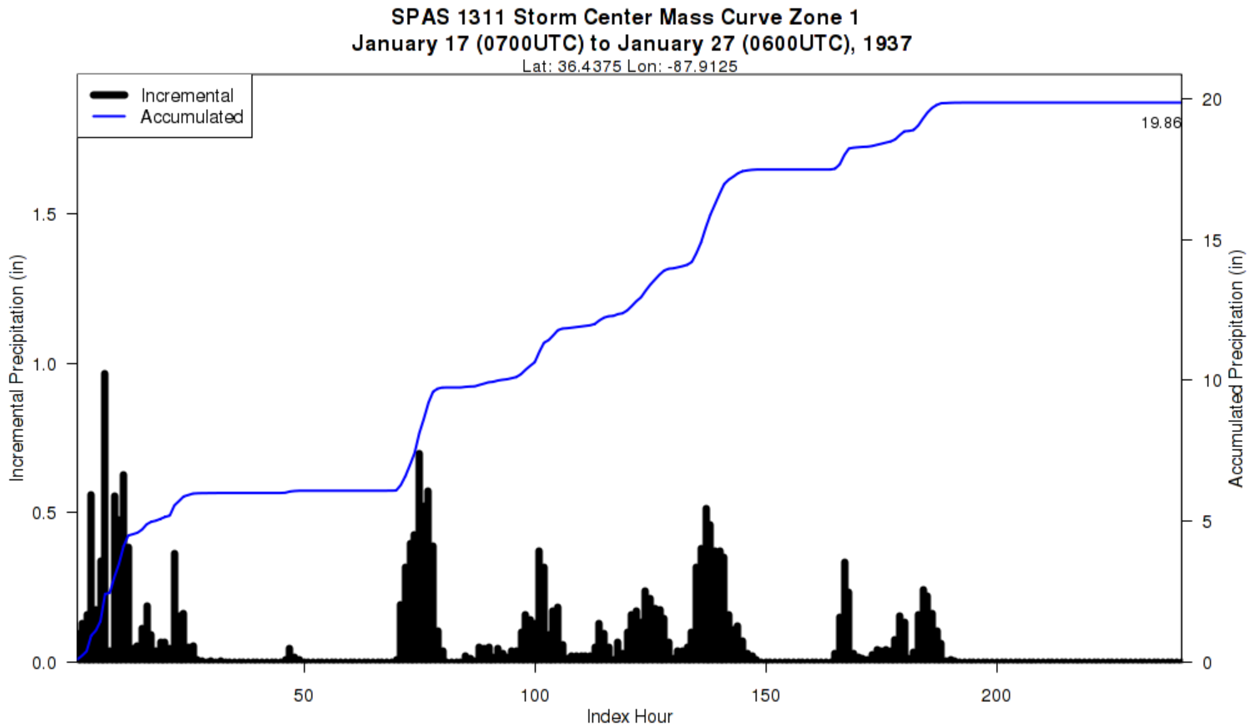
Depth-Area-Duration (DAD) analysis: Yes

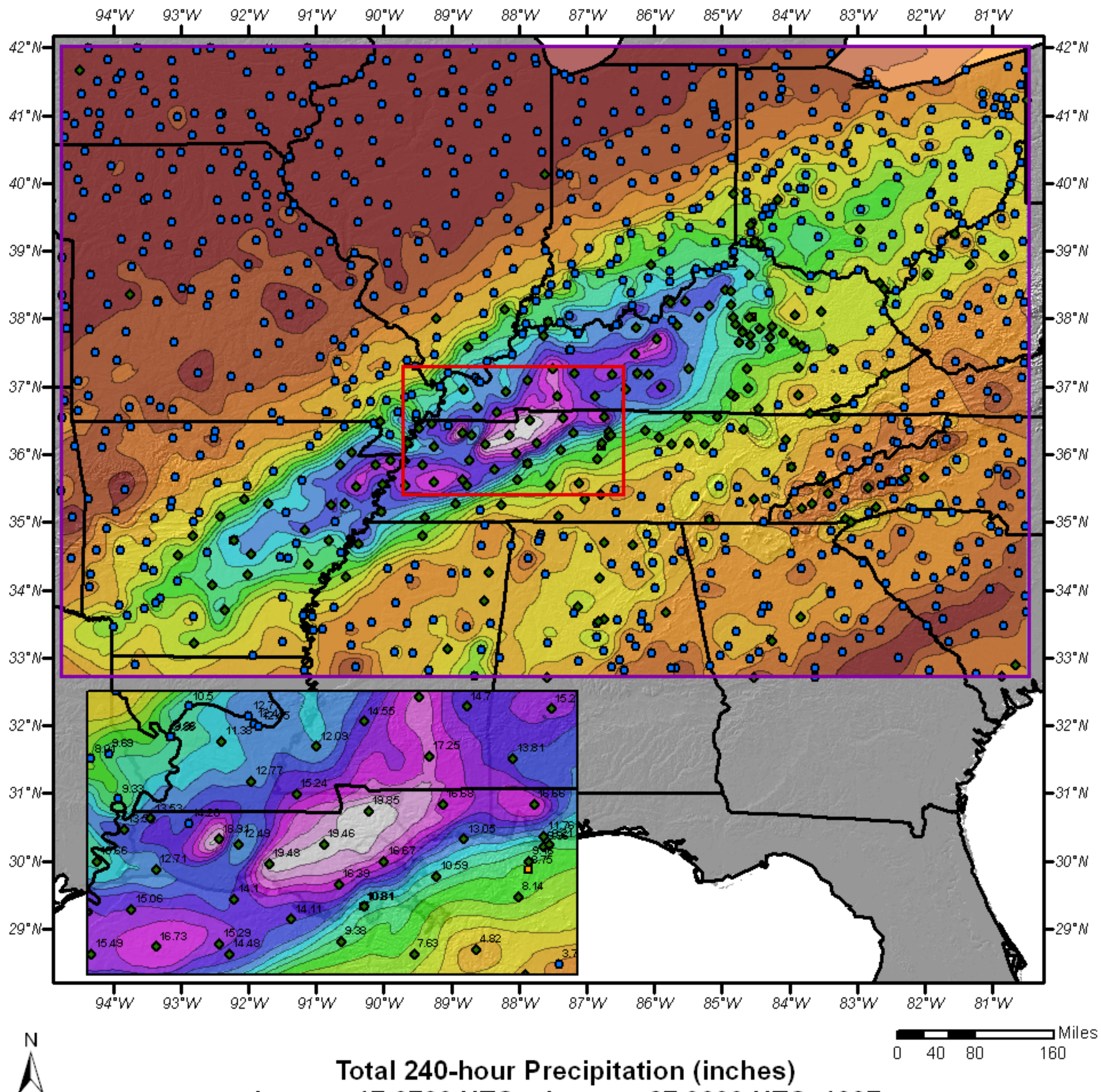
Reliability of Results: Although only 13 hourly stations were available, they resided at locations in/near the storm center, therefore increasing confidence amongst the heaviest precipitation. Given this was a synoptic storm with large areas of nearly continuous precipitation (rainfall), it's believed the temporal distribution of precipitation is reliable. A surprisingly high number (979) of daily and hourly stations, coupled with a total storm map prepared by TVA, provides a high degree of confidence in the spatial patterns and magnitude of precipitation.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1311_1	-87.9100	36.4400	666	700	1-Jan	65.50	1.82	0.13	53	1.685	68.93	69.0	2.14	0.15	60	1.990	1.181

Storm 1311 - January 17 (0700 UTC) - January 27 (0600 UTC), 1937															
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)															
Area (mi^2)	Duration (hours)														
	1	3	6	12	18	24	36	48	72	96	120	144	216	240	Total
0.3	1.69	3.19	4.04	4.79	5.60	6.33	8.45	9.73	12.94	14.25	15.14	17.41	19.86	19.86	19.86
1	1.64	3.13	3.94	4.63	5.44	6.17	8.23	9.50	12.58	13.87	14.65	16.99	19.39	19.39	19.39
10	1.64	3.13	3.94	4.63	5.44	6.17	8.23	9.50	12.58	13.87	14.65	16.99	19.39	19.39	19.39
25	1.64	3.13	3.94	4.63	5.44	6.17	8.23	9.50	12.58	13.87	14.65	16.99	19.39	19.39	19.39
50	1.64	3.05	3.87	4.63	5.39	6.10	8.16	9.39	12.34	13.87	14.65	16.99	19.39	19.39	19.39
100	1.61	2.80	3.84	4.63	5.17	5.87	7.71	9.13	11.71	13.87	14.65	16.99	19.39	19.39	19.39
150	1.54	2.52	3.81	4.63	5.15	5.86	7.69	9.05	11.65	13.87	14.65	16.99	19.39	19.39	19.39
200	1.30	2.40	3.74	4.63	5.13	5.85	7.57	8.96	11.60	13.79	14.65	16.99	19.39	19.39	19.39
300	1.27	2.32	3.62	4.63	5.09	5.85	7.34	8.73	11.40	13.49	14.59	16.99	19.39	19.39	19.39
400	1.24	2.25	3.51	4.62	5.05	5.84	7.26	8.70	10.90	13.15	14.49	16.99	19.39	19.39	19.39
500	1.20	2.18	3.41	4.59	5.00	5.83	7.25	8.68	10.89	13.06	14.40	16.99	19.39	19.39	19.39
1,000	1.08	1.92	3.06	4.47	4.89	5.70	7.04	8.35	10.84	12.40	13.99	16.60	18.92	19.17	19.17
2,000	0.96	1.81	2.84	4.17	4.61	5.41	6.84	7.95	10.66	11.62	13.50	16.12	18.34	18.54	18.54
5,000	0.76	1.57	2.46	3.36	4.04	4.89	6.46	7.61	9.93	10.79	12.99	14.91	17.33	17.42	17.42
10,000	0.63	1.52	2.13	3.10	3.61	4.38	6.12	7.27	9.45	10.19	12.27	13.82	16.40	16.41	16.41
20,000	0.46	1.36	1.73	2.74	3.30	3.90	5.79	6.86	8.92	9.63	11.51	12.79	14.87	15.35	15.35
50,000	0.31	1.03	1.34	2.15	2.67	3.33	4.96	6.00	7.97	8.35	10.26	11.02	13.18	13.29	13.29
100,000	0.22	0.61	1.02	1.62	2.12	2.59	3.93	4.79	6.36	6.78	8.42	8.79	10.57	11.00	11.00
504,363	0.07	0.18	0.29	0.49	0.66	0.86	1.26	1.67	2.30	2.53	3.23	3.51	4.52	4.55	4.55




SPAS 1311 Storm Center Mass Curve Zone 1
January 17 (0700UTC) to January 27 (0600UTC), 1937
Lat: 36.4375 Lon: -87.9125
Incremental
Accumulated
19.86
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
0
5
10
15
20
50
100
150
200



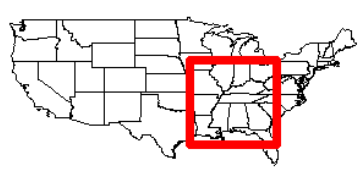
Total 240-hour Precipitation (inches)
January 17 0700 UTC - January 27 0600 UTC, 1937
SPAS #1311

Precipitation (inches)

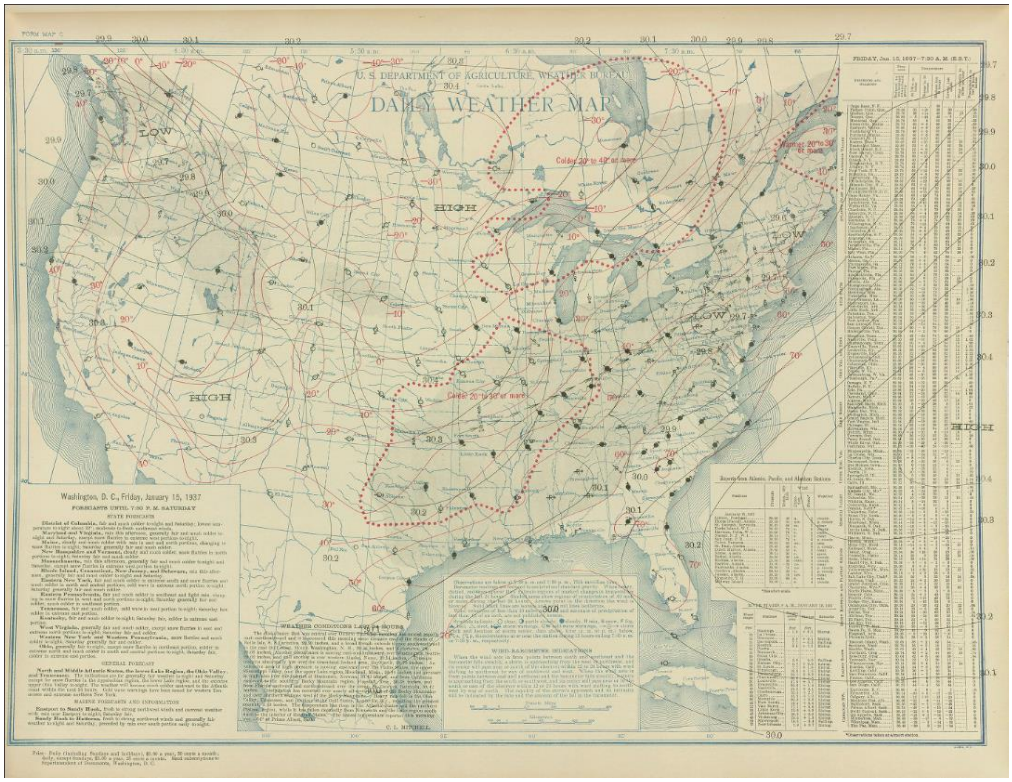
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00

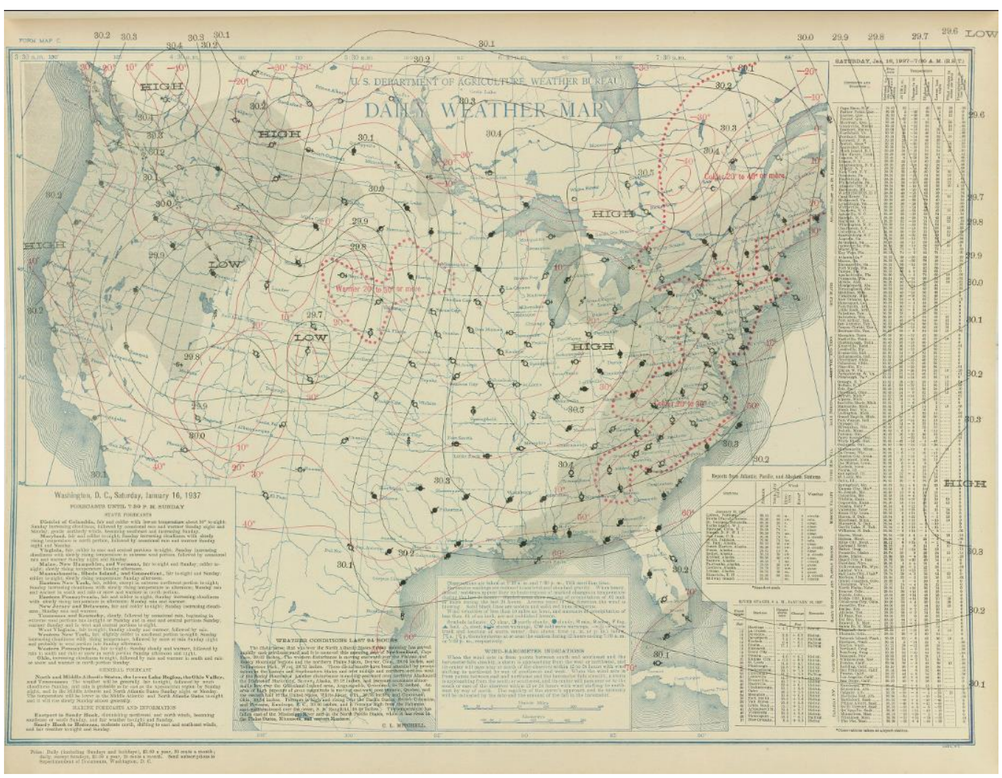
Stations

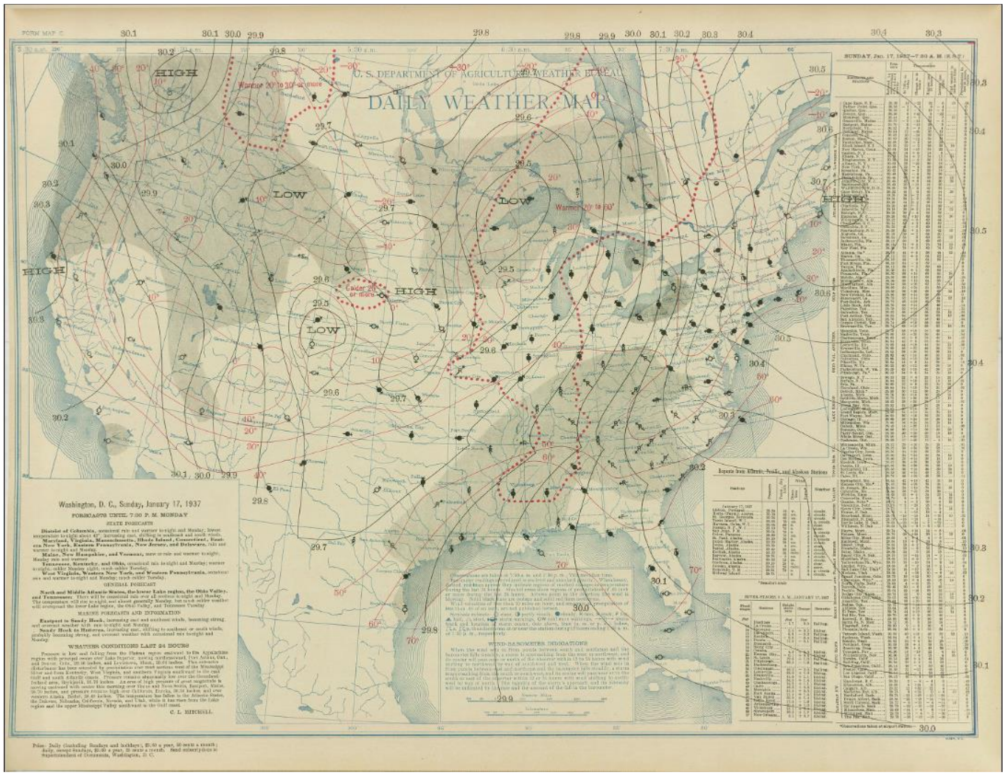
Daily
Hourly
Hourly Pseudo
Supplemental

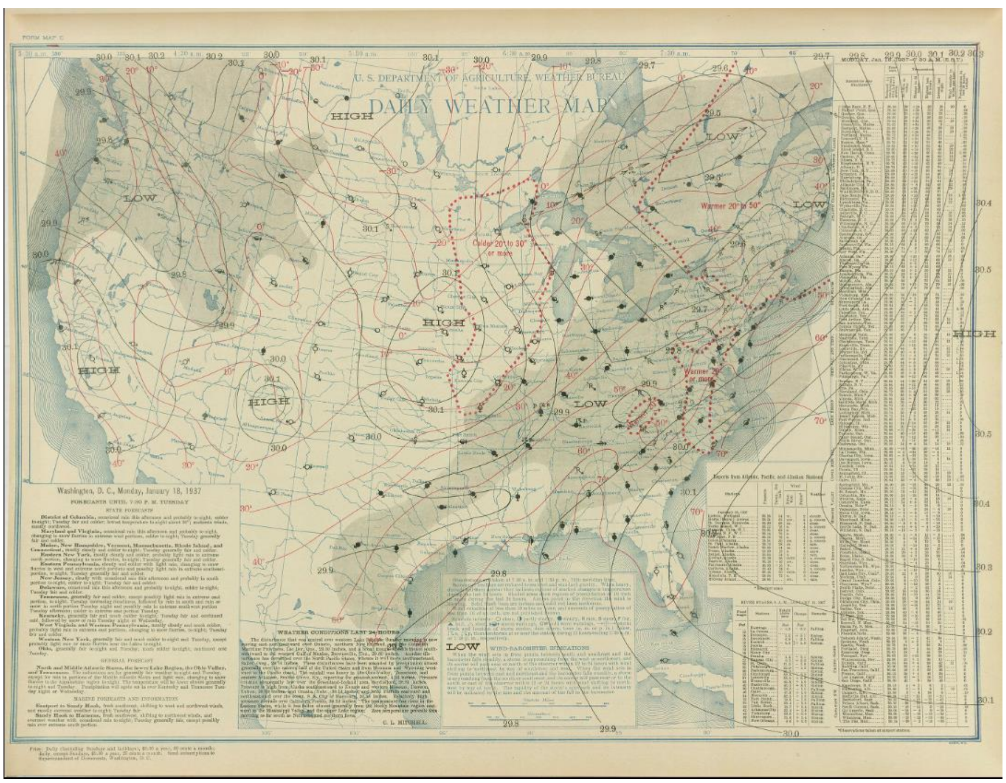


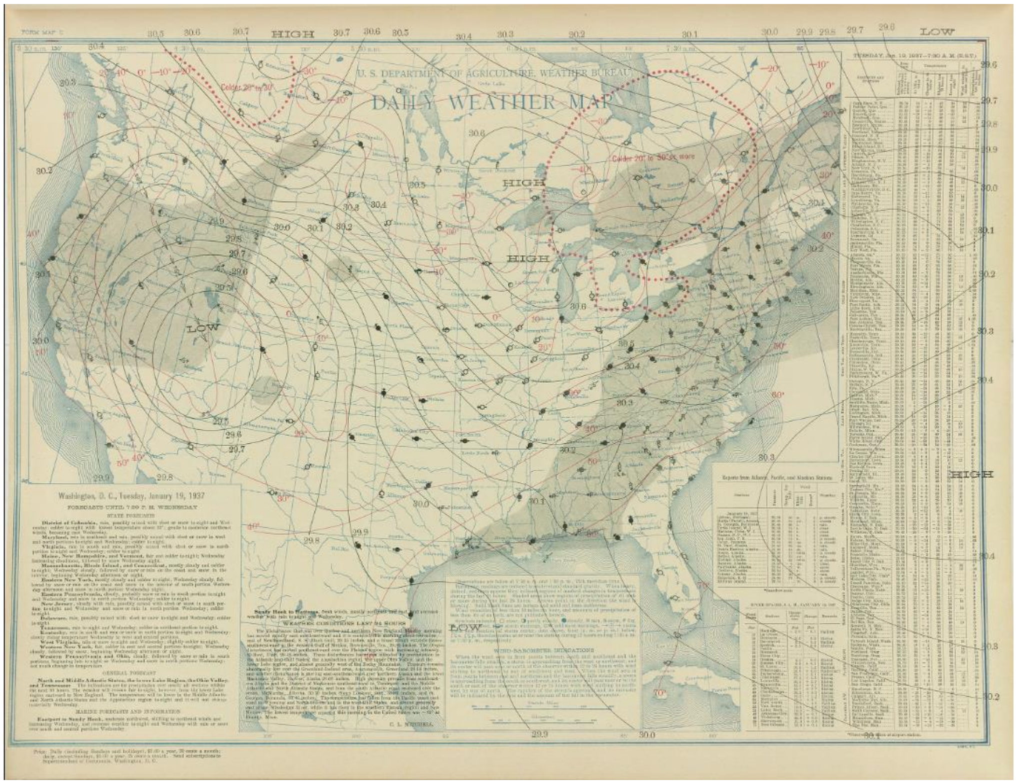
01/24/2014

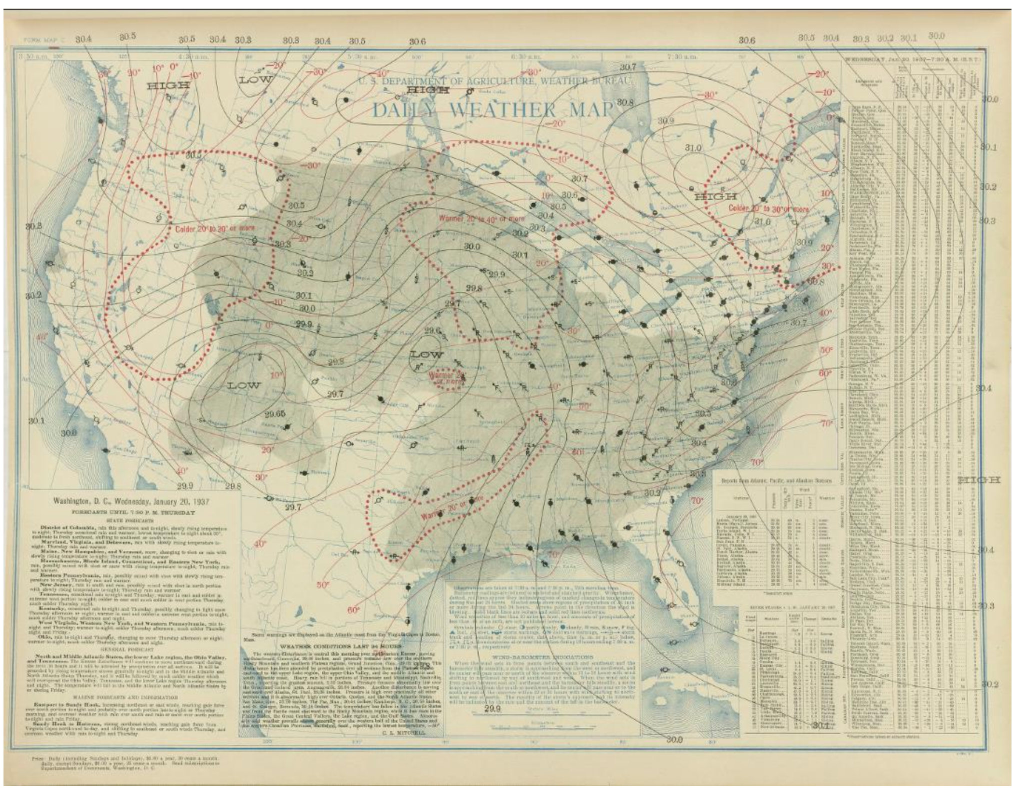

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Friday, January 15, 1937
FORECASTS UNTIL 7:30 P. M. SATURDAY
STATE FORECASTS
GENERAL FORECAST
WEATHER CONDITIONS LAST 24 HOURS
WIND-BAROMETER INDICATIONS
Colder 20° to 40° or more
Colder 20° to 30° or more
FRIDAY, Jan. 15, 1937—7:30 A. M. (E.S.T.)

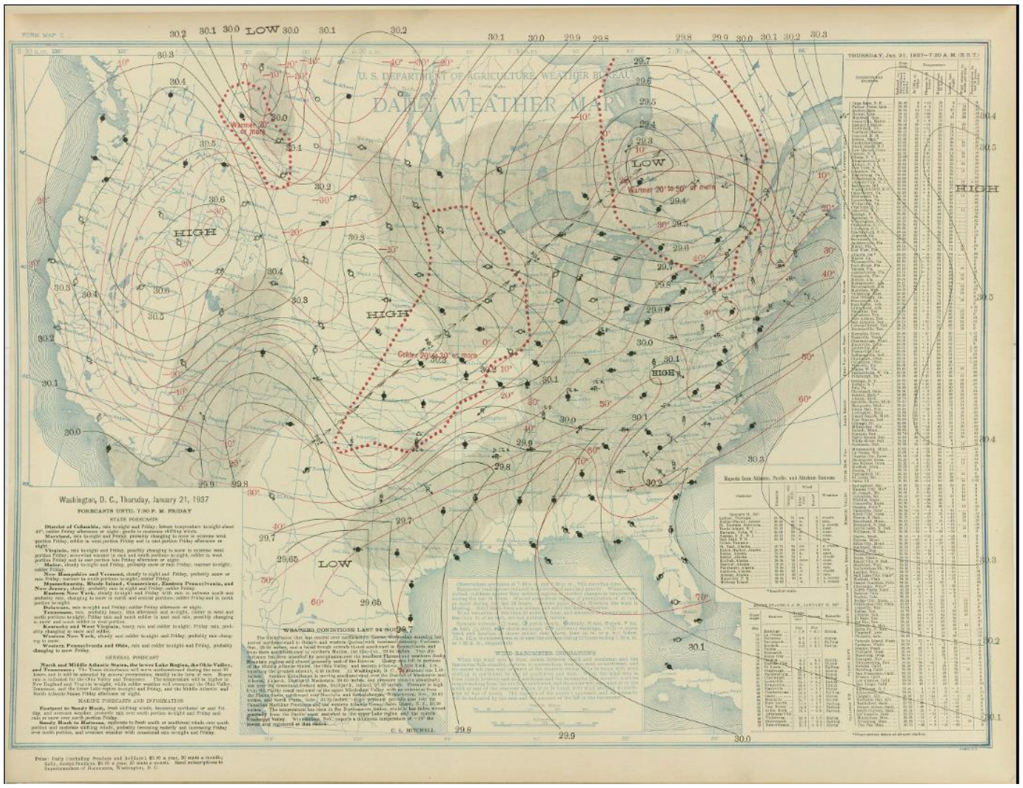

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Saturday, January 16, 1937
FORECASTS UNTIL 7:30 P. M. SUNDAY
STATE FORECASTS
GENERAL FORECAST
WEATHER CONDITIONS LAST 24 HOURS
WIND-BAROMETER INDICATIONS
SATURDAY, Jan. 16, 1937—7:30 A. M. (E.S.T.)

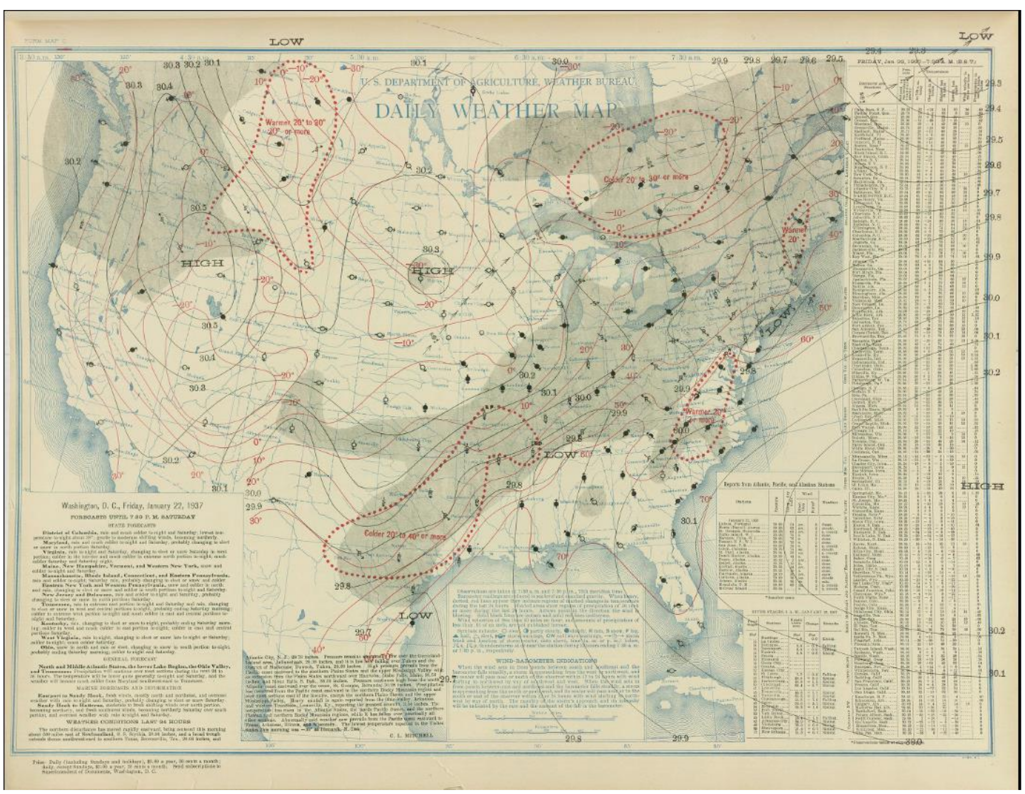

U. S. DEPARTMENT OF AGRICULTURE WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Sunday, January 17, 1937
FORECASTS UNTIL 7:30 P. M. MONDAY
WIND-BAROMETER INDICATIONS
C. L. MITCHELL

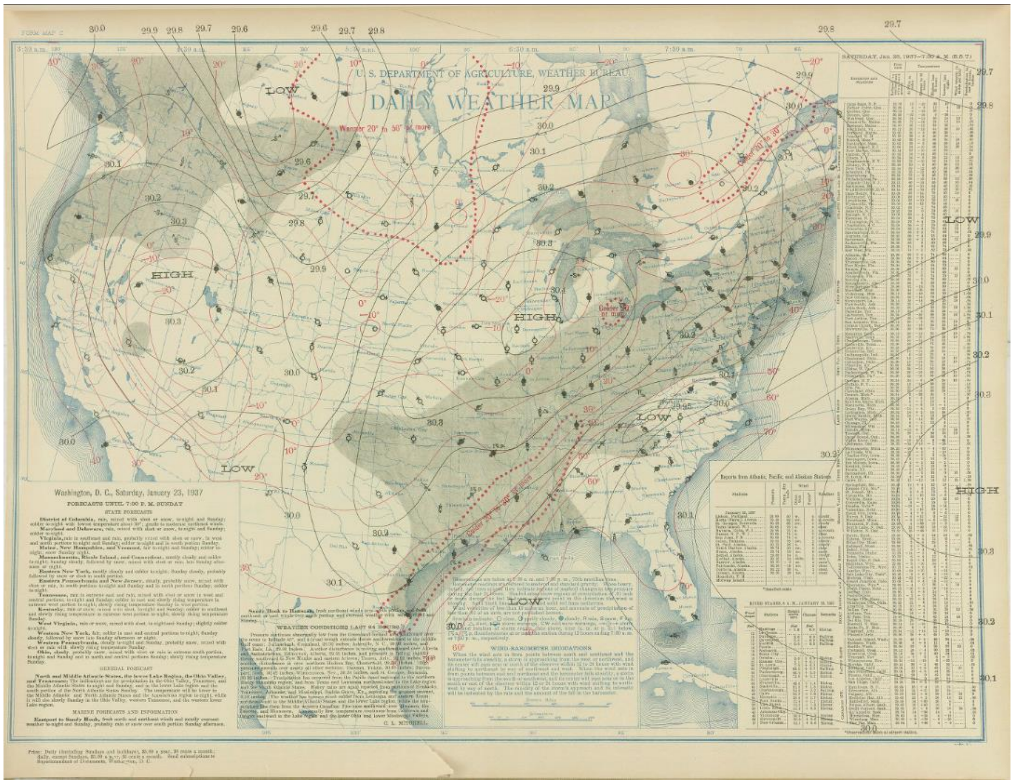

U. S. DEPARTMENT OF AGRICULTURE WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Monday, January 18, 1937
FORECASTS UNTIL 7:30 P. M. TUESDAY
WEATHER CONDITIONS LAST 24 HOURS
WIND-BAROMETER INDICATIONS
C. L. MITCHELL

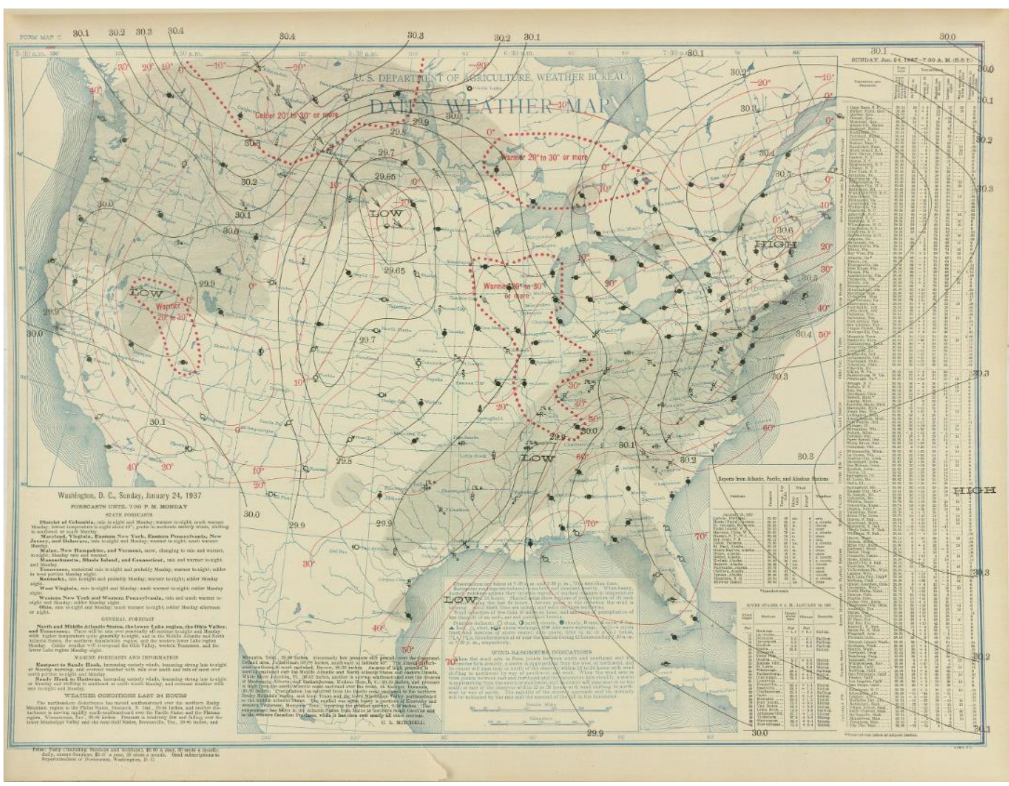

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Tuesday, January 19, 1937

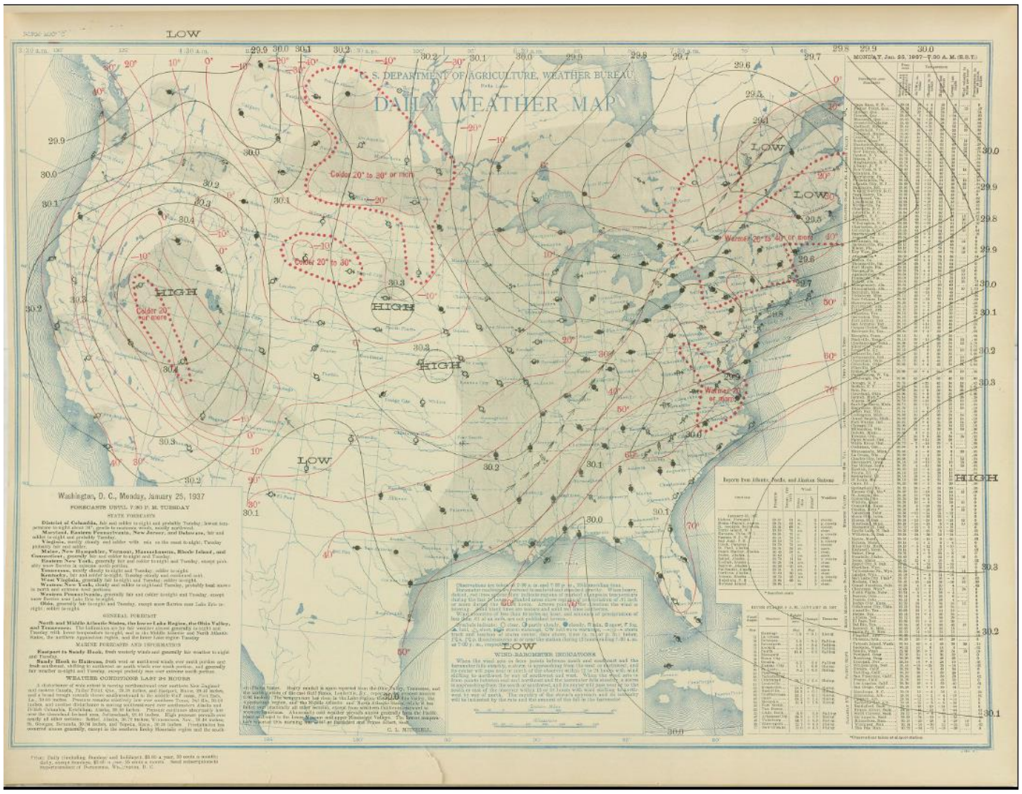

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Wednesday, January 20, 1937

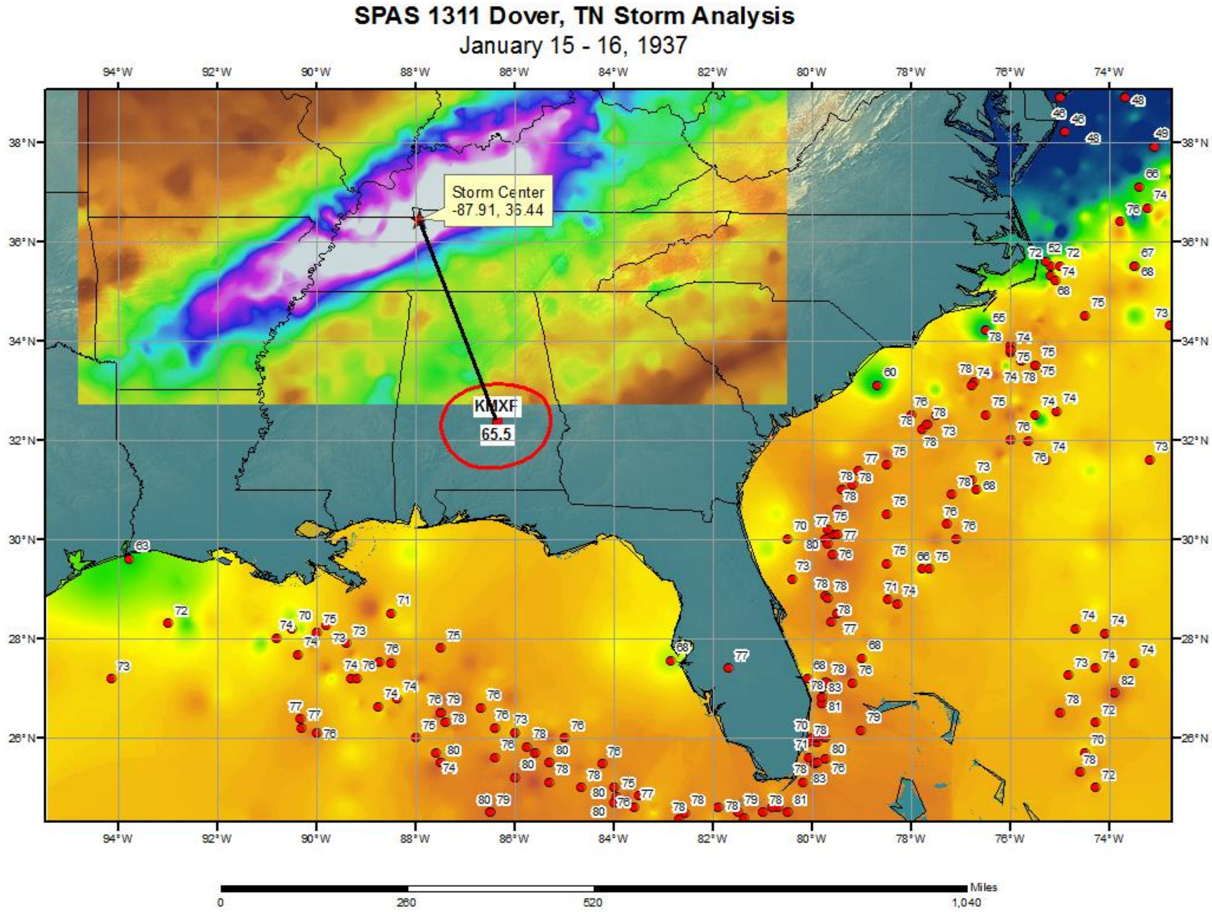

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Thursday, January 21, 1937
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Friday, January 22, 1937
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Saturday, January 23, 1937
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Sunday, January 24, 1937
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Monday, January 25, 1937
HIGH
LOW


SPAS 1311 Dover, TN Storm Analysis
January 15 - 16, 1937
Storm Center
-87.91, 36.44
KMXF
65.5
Miles
0
260
520
1,040

Storm Precipitation Analysis System (SPAS) For Storm #1346_1 SPAS Analysis

General Storm Location: Tennessee Valley 37.7, -84.8, 33.7, -80.0

Storm Dates: August 28 – August 31, 1940

Event: CORPS of Engineers, US Army Assignment HMB – 25

DAD Zone 1

Latitude: 35.0375

Longitude: -83.0792

Max. Grid rainfall amount: 14.09”

Max. Observed rainfall amount: 13.19” (Rock House, NC)

Number of Stations: 259

SPAS Version: 9.5

Base Map Used: Mean annual maximum 48-hour precipitation associated with MLCs

Spatial resolution: 0.2689

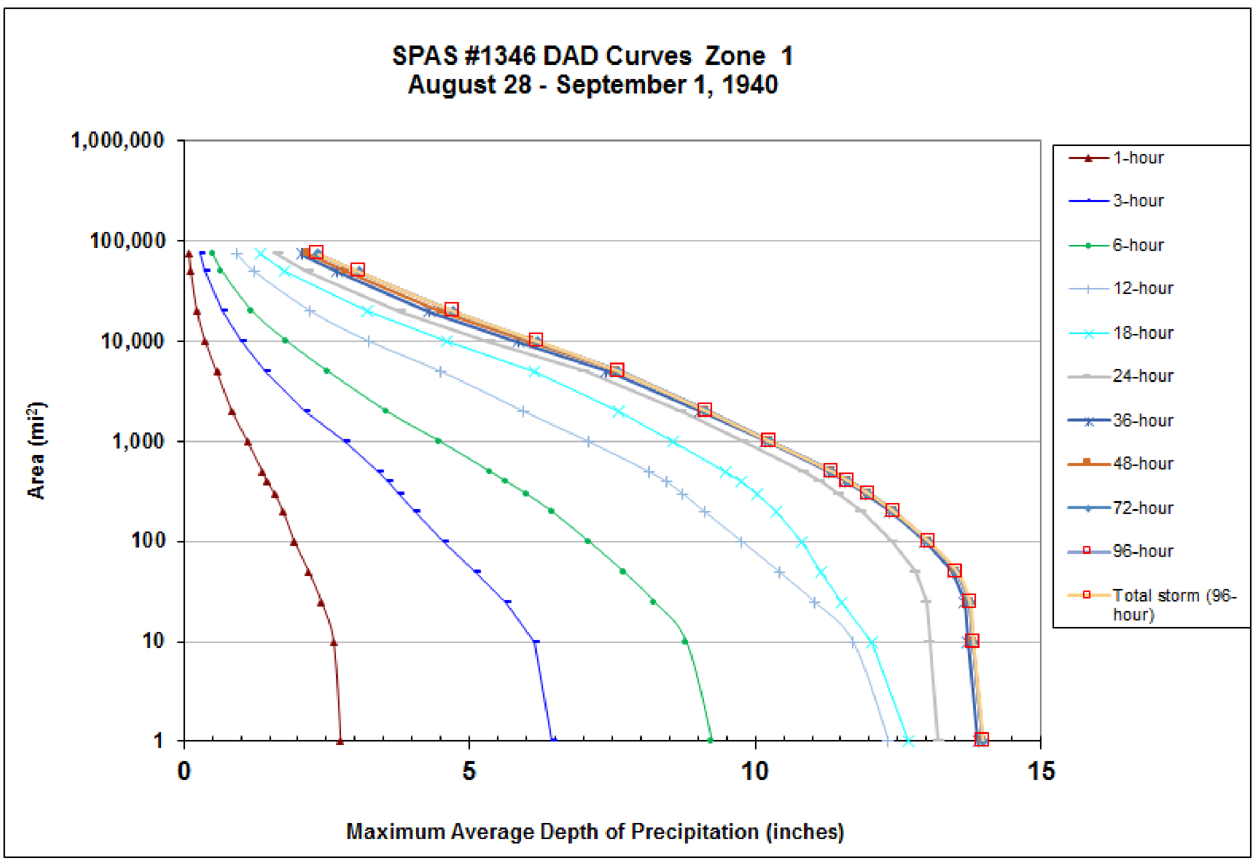
Radar Included: No

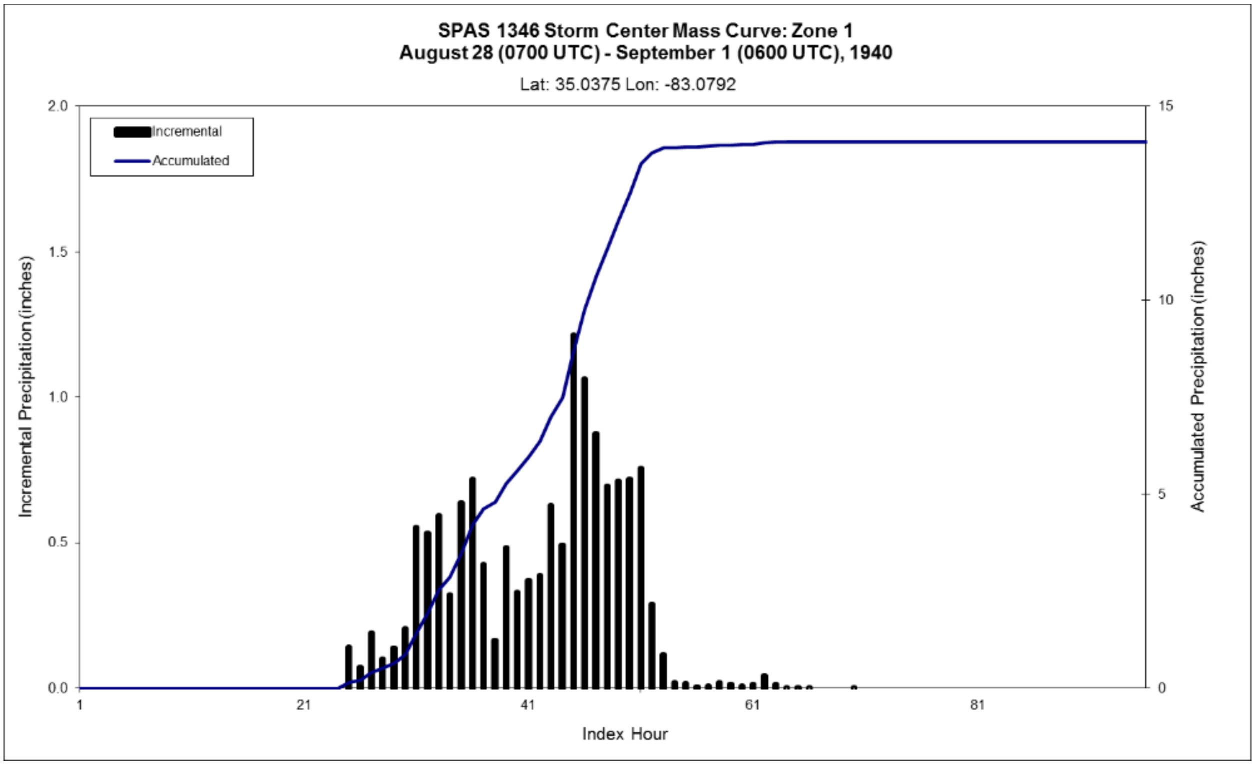
Depth-Area-Duration (DAD) analysis: Yes

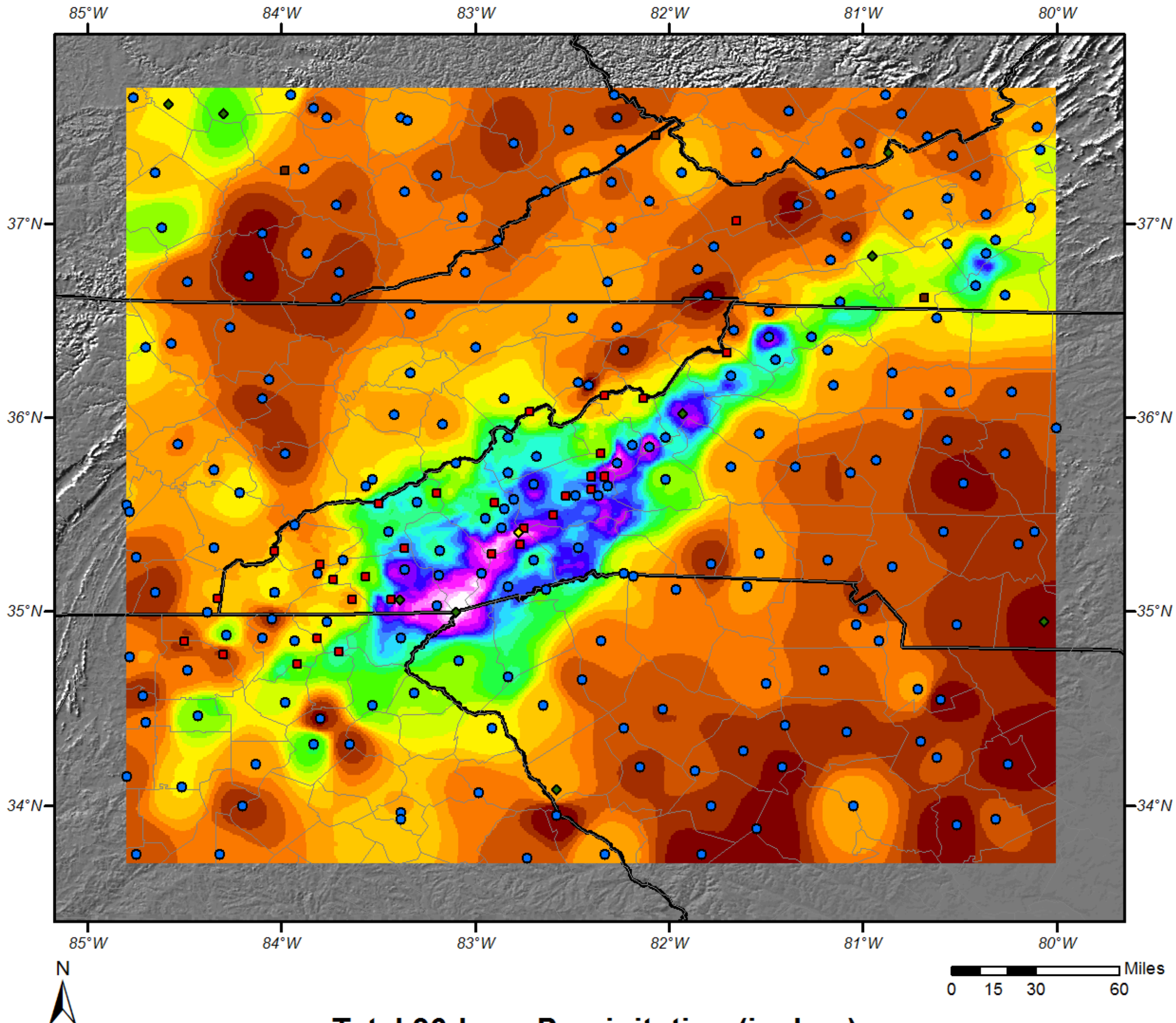
Reliability of Results: Of the 34 hourly stations used in this analysis, 30 were manually digitized from the TVA flood report and three were estimated from NCDC COOP data to fill in where there were areas without hourly stations nearby. This provided very high accuracy of the hourly data, which is essential in the timing of the daily and supplemental stations. With all of the data being thoroughly inspected, the precipitation pattern following closely to the isohyetal maps from the TVA report, and the precipitation totals for various periods throughout the storm being consistent with previous reports, this analysis is considered to be reliable.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1346_1	-83.0792	35.0375	3,267	15-Aug	76.00	2.99	0.79	74	2.200	81.08	3.77	0.93	84	2.840	1.291

Storm 1346 - August 28 (0700 UTC) - September 1 (0600 UTC), 1940											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	3	6	12	18	24	36	48	72	96	Total
0.4	2.76	6.49	9.33	12.45	12.79	13.27	13.98	14.06	14.06	14.06	14.06
1	2.74	6.44	9.24	12.33	12.68	13.21	13.91	13.99	13.99	13.99	13.99
10	2.62	6.15	8.79	11.71	12.04	13.06	13.73	13.82	13.82	13.82	13.82
25	2.41	5.65	8.24	11.04	11.52	13.00	13.67	13.76	13.76	13.76	13.76
50	2.19	5.12	7.70	10.42	11.14	12.81	13.46	13.53	13.53	13.53	13.53
100	1.94	4.56	7.09	9.77	10.83	12.40	12.97	13.04	13.04	13.04	13.04
200	1.74	4.04	6.44	9.11	10.36	11.85	12.36	12.43	12.43	12.43	12.43
300	1.59	3.77	5.99	8.73	10.04	11.45	11.93	11.99	11.99	11.99	11.99
400	1.46	3.57	5.64	8.44	9.75	11.13	11.58	11.64	11.64	11.64	11.64
500	1.38	3.40	5.36	8.14	9.47	10.84	11.29	11.35	11.35	11.35	11.35
1,000	1.12	2.82	4.48	7.08	8.55	9.78	10.18	10.26	10.26	10.26	10.26
2,000	0.85	2.13	3.55	5.95	7.62	8.69	9.03	9.16	9.16	9.16	9.16
5,000	0.58	1.42	2.52	4.50	6.14	7.01	7.40	7.60	7.62	7.62	7.62
10,000	0.38	1.01	1.80	3.24	4.60	5.35	5.85	6.08	6.19	6.20	6.20
20,000	0.24	0.67	1.19	2.22	3.20	3.79	4.29	4.52	4.72	4.73	4.73
50,000	0.13	0.37	0.66	1.23	1.76	2.17	2.69	2.86	3.06	3.06	3.06
74,426	0.10	0.28	0.50	0.93	1.34	1.64	2.06	2.19	2.36	2.36	2.36




SPAS 1346 Storm Center Mass Curve: Zone 1
August 28 (0700 UTC) - September 1 (0600 UTC), 1940
Lat: 35.0375 Lon: -83.0792
Incremental
Accumulated
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
2.0
1.5
1.0
0.5
0.0
15
10
5
0
1
21
41
61
81



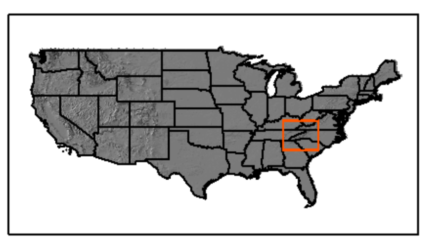
Total 96-hour Precipitation (inches)
August 28, 1940 0700 UTC - September 1,1940 0600 UTC
SPAS #1346

Precipitation (inches)

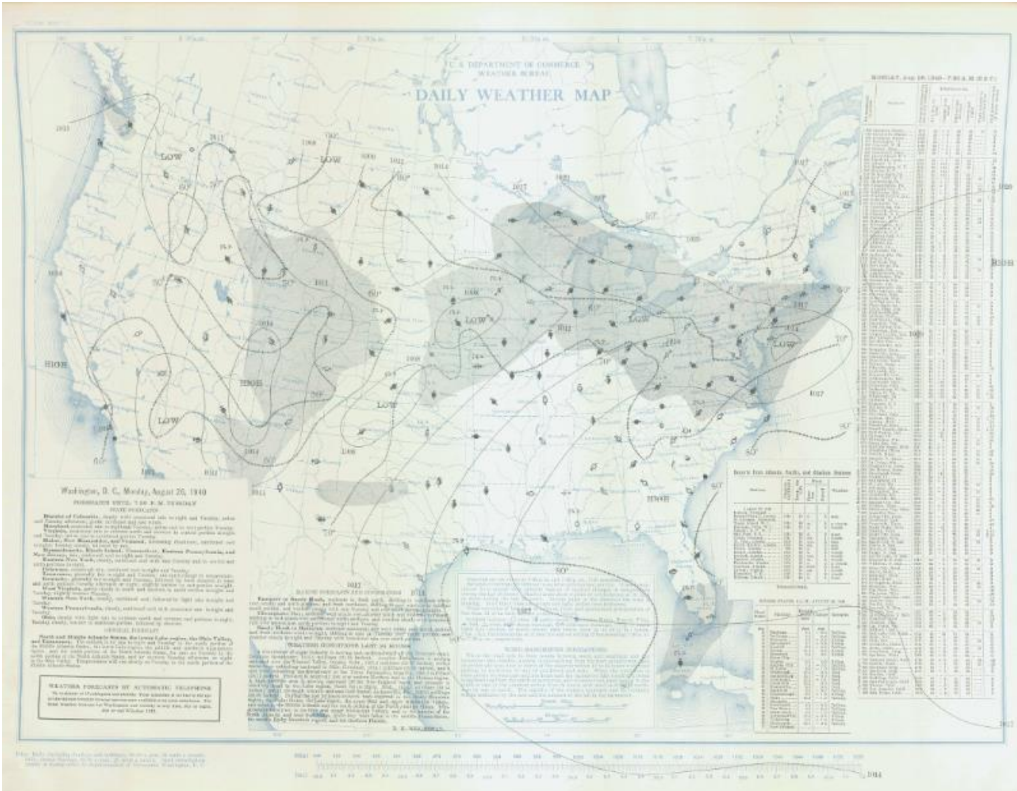
0.00 - 0.50	3.01 - 3.50	6.01 - 6.50	9.01 - 10.0
0.501 - 1.00	3.51 - 4.00	6.51 - 7.00	10.1 - 11.0
1.01 - 1.50	4.01 - 4.50	7.01 - 7.50	11.1 - 12.0
1.51 - 2.00	4.51 - 5.00	7.51 - 8.00	12.1 - 13.0
2.01 - 2.50	5.01 - 5.50	8.01 - 8.50	13.1 +
2.51 - 3.00	5.51 - 6.00	8.51 - 9.00	

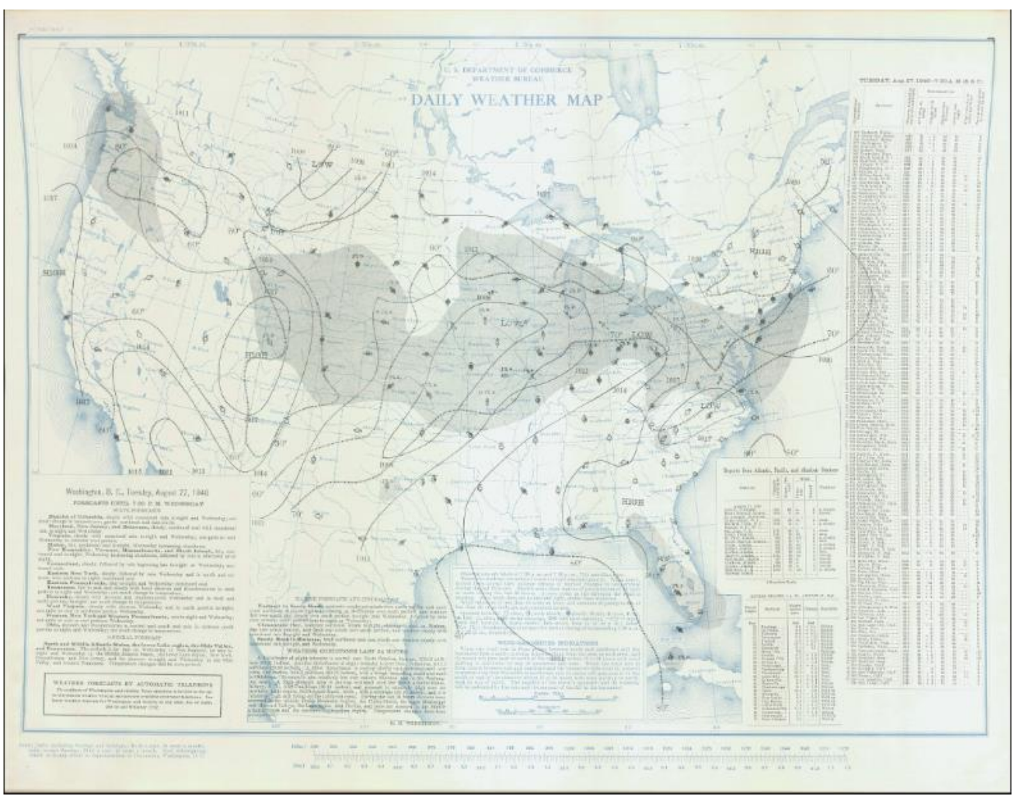
Stations

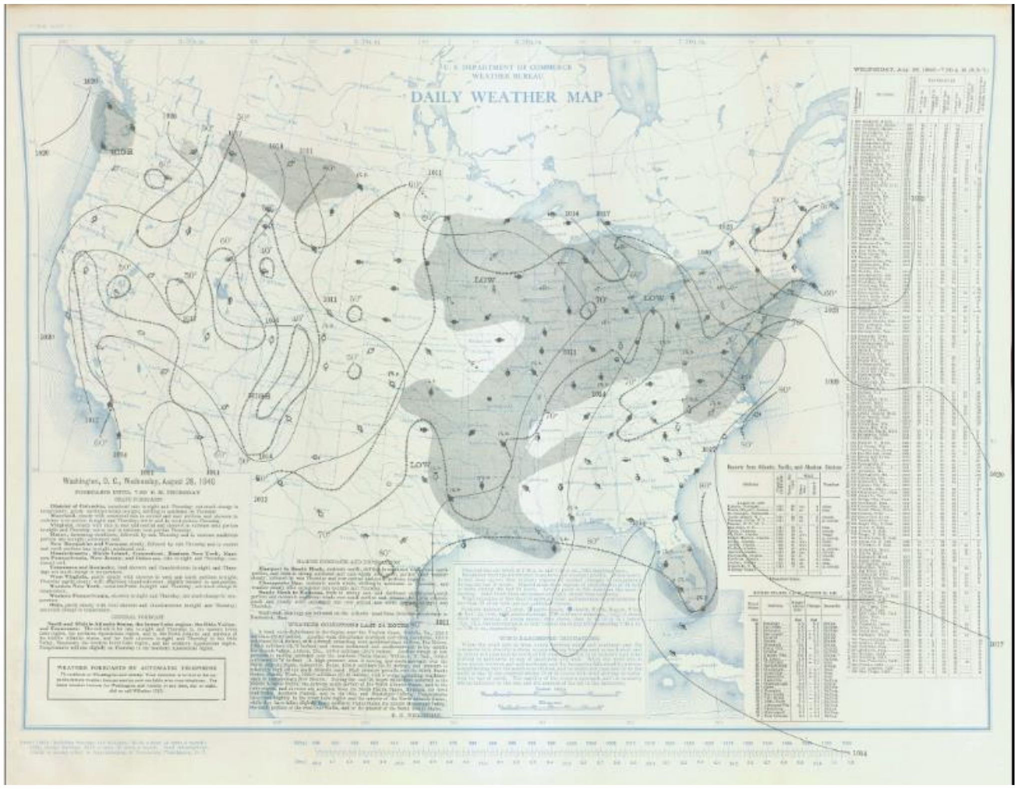
- Daily
- Hourly
- Hourly Estimated Pseudo
- Hourly Pseudo
- Supplemental
- Supplemental Estimated

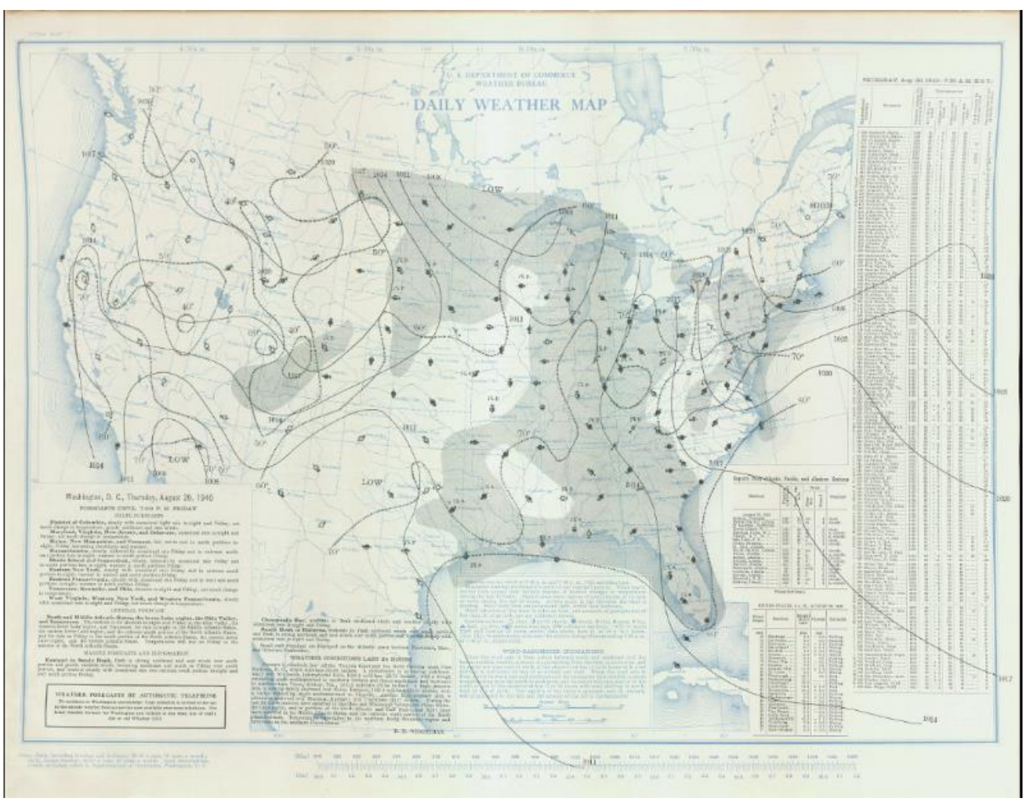


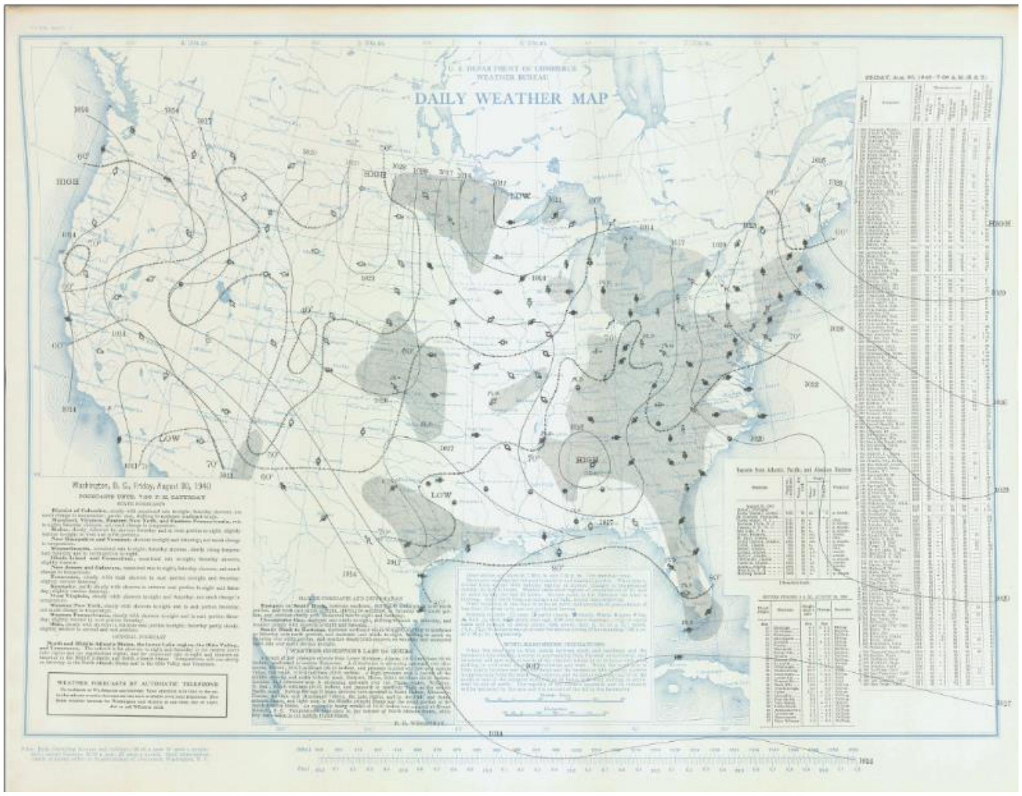
KLL 10/27/2014


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Monday, August 26, 1940

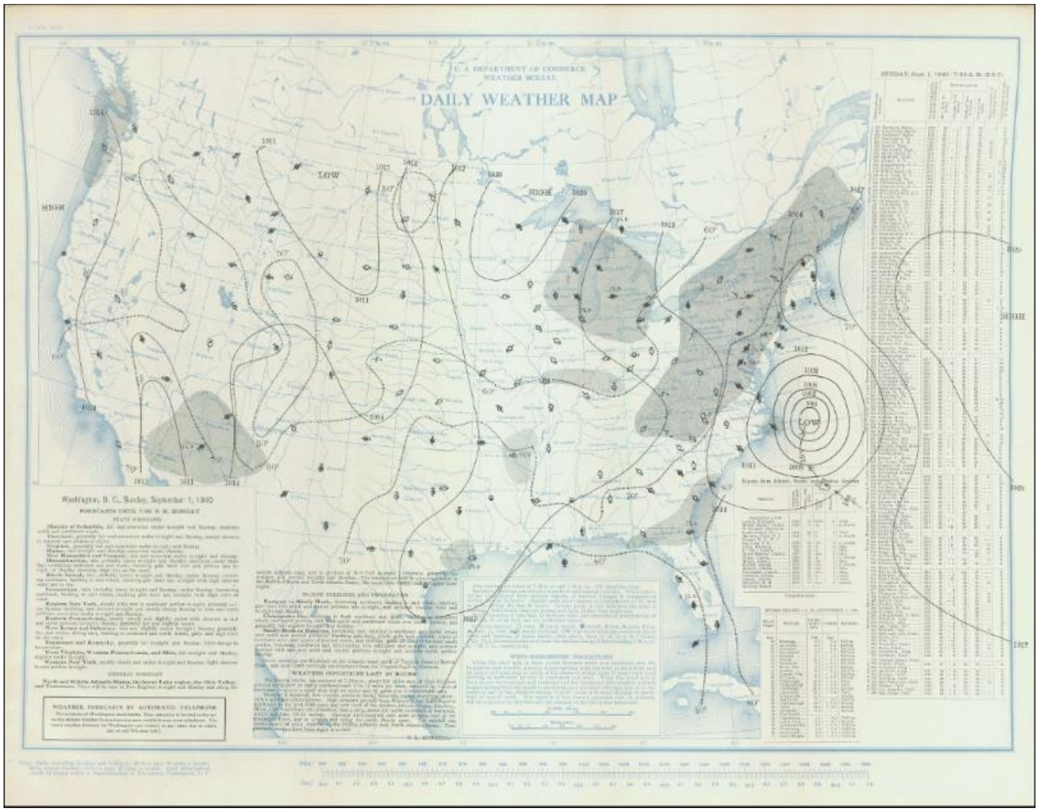

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Tuesday, August 27, 1940


DAILY WEATHER MAP

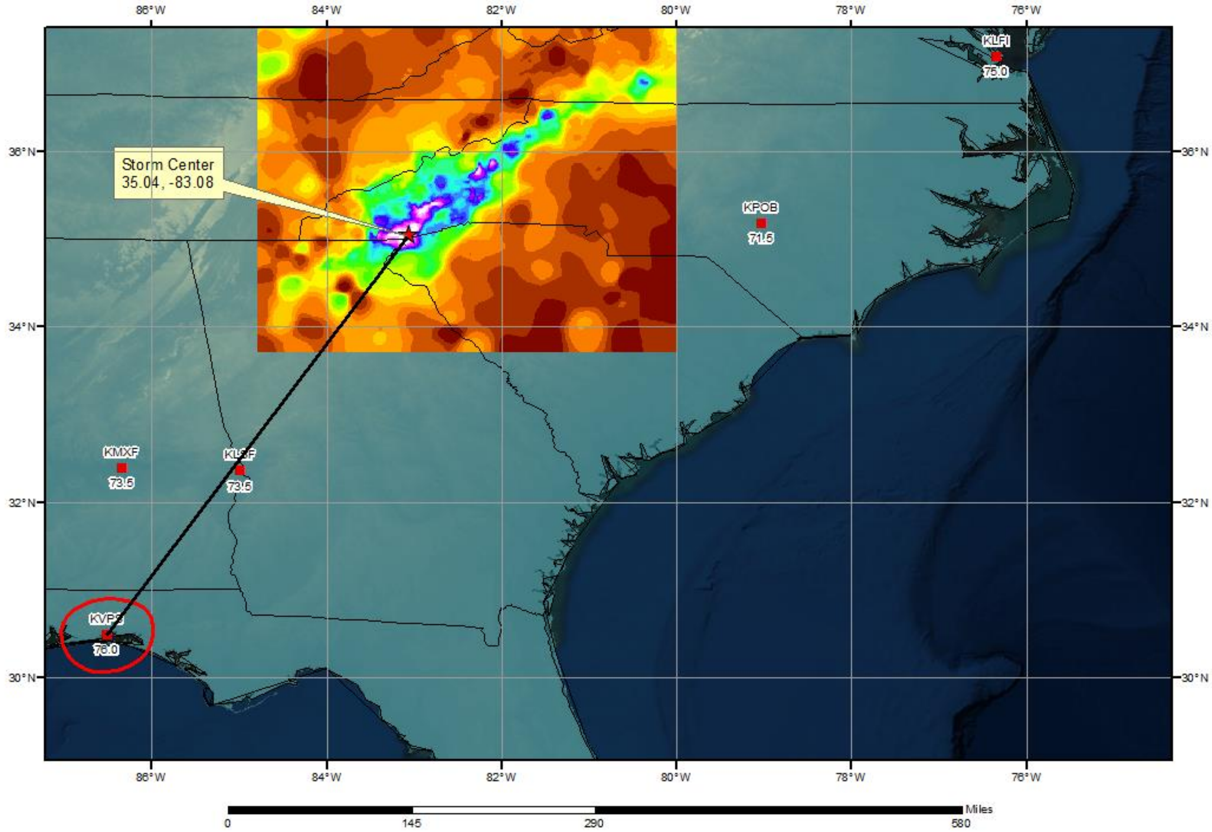

DAILY WEATHER MAP


DAILY WEATHER MAP
Washington, D. C., Friday, August 30, 1940


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Saturday, August 31, 1940


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP

SPAS 1346 Rock House, NC Storm Analysis
August 28, 1940



Storm Precipitation Analysis System (SPAS) for Storm #1680 (rerun of 1006_1)
SPAS Analysis

General Storm Location: West Shokan, NY

Storm Dates: October 14-17, 1955

Event: Rainfall associated with Hurricane Katie

DAD Zone 1

Latitude: 42.0042

Longitude: -74.3958

Max. Grid Rainfall Amount: 20.27"

Max. Observed Rainfall Amount: 19.00"

Number of Stations: 180

SPAS Version: 10.0

Basemap: PRISM_ppt_195510_in_sm2

Spatial resolution: 0.2466

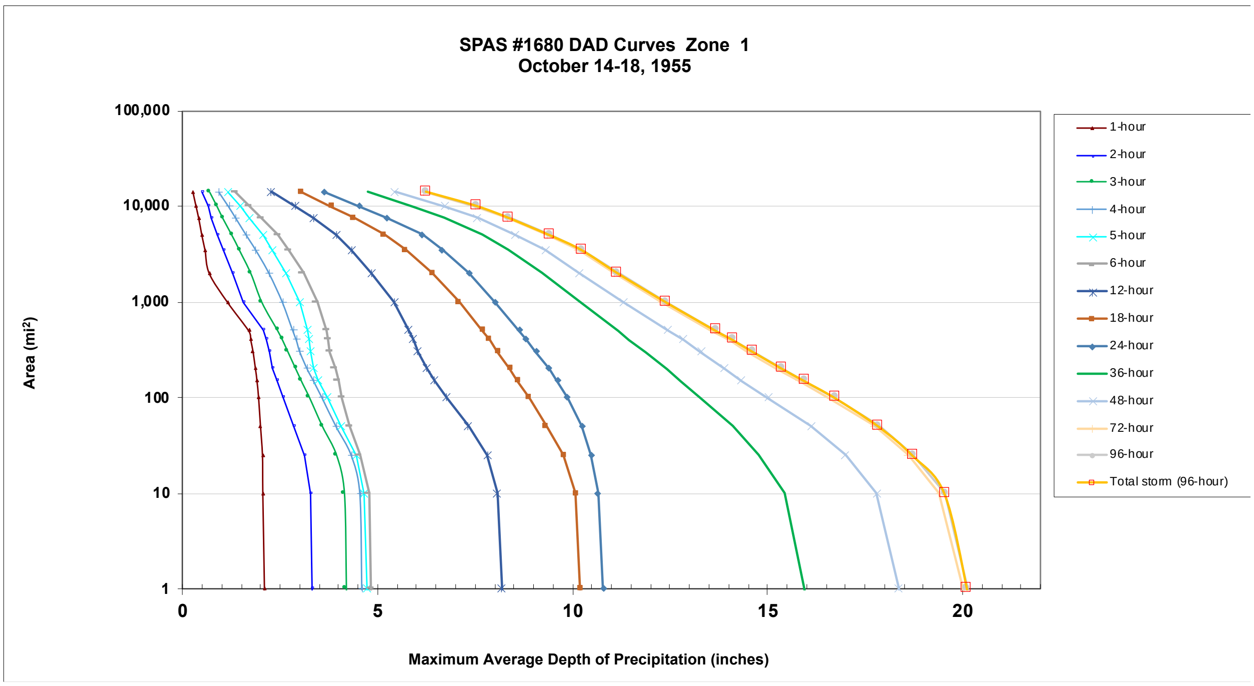
Radar Included: No

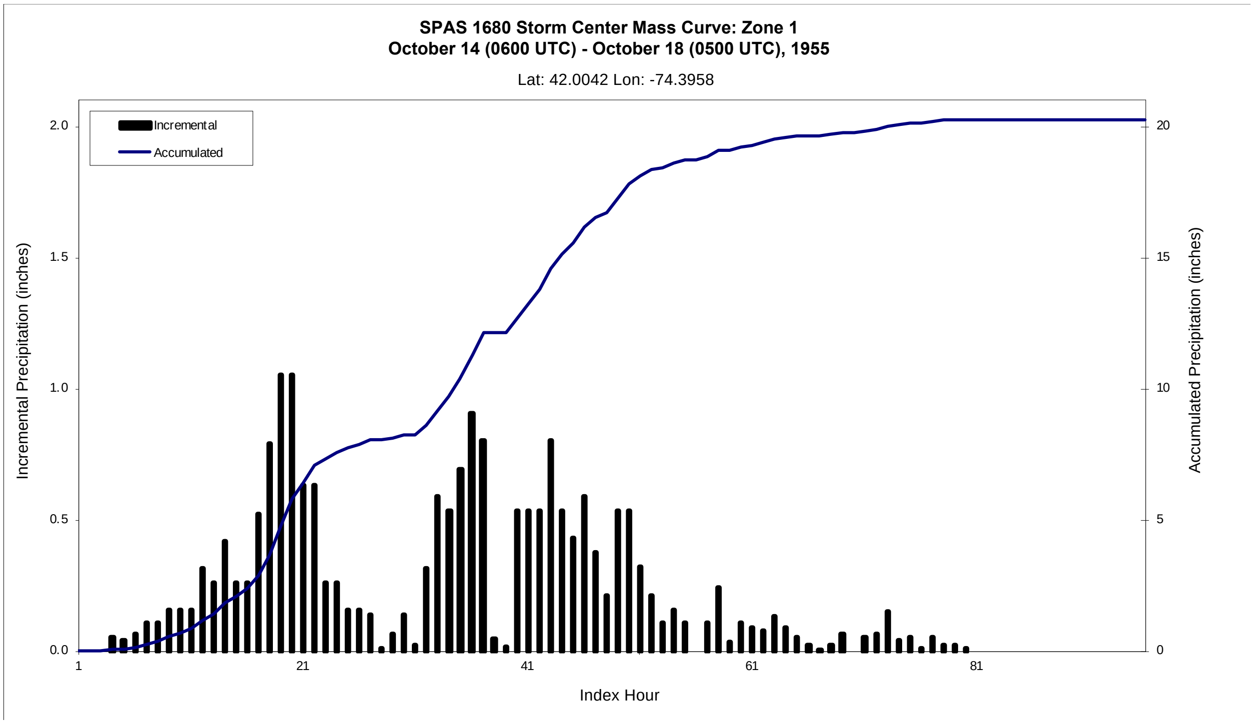
Depth-Area-Duration (DAD) analysis: Yes

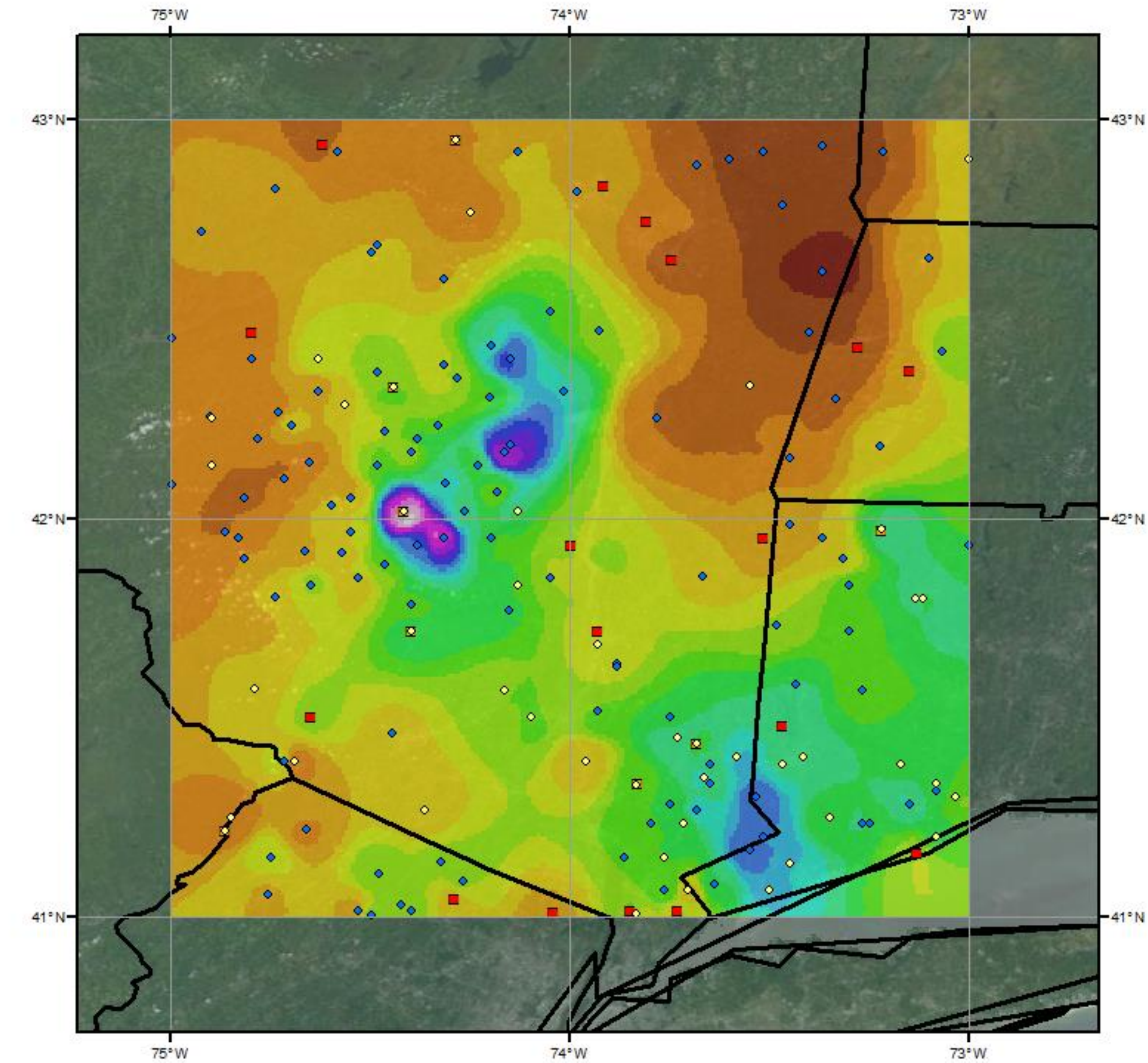
Reliability of results: This analysis was based on 180 hourly stations, hourly pseudo, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the PRISM basemap. Timing is based on the hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1680_1	-74.3958	42.0042	3,548	1-Oct	78.00	3.29	0.89	78	2.400	81.56	3.86	1.00	85	2.860	1.192

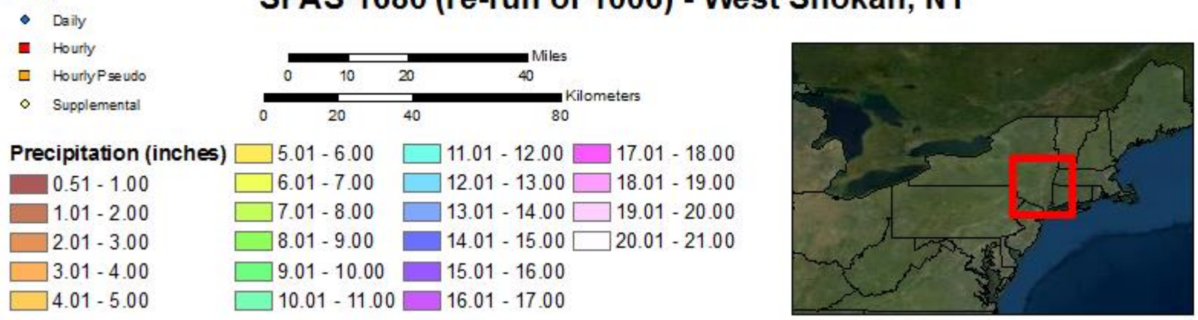
Storm 1680 - October 14 (0600 UTC) - October 18 (0500 UTC), 1955														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
Area (mi^2)	Duration (hours)													
	1	2	3	4	5	6	12	18	24	36	48	72	96	Total
0.4	2.11	3.34	4.22	4.63	4.75	4.85	8.22	10.25	10.83	16.03	18.48	20.15	20.27	20.27
1	2.10	3.32	4.20	4.61	4.73	4.83	8.18	10.21	10.78	15.93	18.36	20.02	20.13	20.13
10	2.06	3.28	4.15	4.56	4.67	4.78	8.07	10.09	10.65	15.43	17.79	19.41	19.55	19.55
25	2.05	3.13	3.95	4.34	4.45	4.55	7.81	9.77	10.48	14.77	16.99	18.60	18.73	18.73
50	2.00	2.85	3.59	3.95	4.06	4.28	7.32	9.32	10.24	14.10	16.12	17.73	17.86	17.86
100	1.95	2.58	3.26	3.59	3.70	4.10	6.78	8.88	9.87	13.29	15.01	16.58	16.73	16.73
150	1.91	2.42	3.05	3.37	3.48	4.00	6.46	8.60	9.61	12.77	14.34	15.81	15.95	15.95
200	1.87	2.30	2.91	3.21	3.35	3.91	6.26	8.39	9.40	12.43	13.91	15.25	15.39	15.39
300	1.81	2.22	2.71	3.02	3.29	3.78	6.04	8.08	9.06	11.86	13.30	14.51	14.64	14.64
400	1.75	2.15	2.57	2.93	3.25	3.74	5.91	7.87	8.82	11.46	12.84	14.01	14.12	14.12
500	1.70	2.08	2.45	2.84	3.21	3.70	5.80	7.69	8.63	11.17	12.46	13.57	13.68	13.68
1,000	1.15	1.57	2.04	2.57	2.99	3.45	5.42	7.08	8.01	10.18	11.29	12.28	12.39	12.39
2,000	0.68	1.27	1.76	2.23	2.65	3.10	4.84	6.40	7.35	9.22	10.16	11.06	11.16	11.16
3,500	0.57	1.05	1.47	1.89	2.31	2.73	4.32	5.72	6.65	8.37	9.30	10.15	10.23	10.23
5,000	0.49	0.89	1.28	1.65	2.05	2.44	3.93	5.16	6.14	7.68	8.52	9.33	9.41	9.41
7,500	0.41	0.74	1.05	1.38	1.70	2.02	3.34	4.39	5.23	6.71	7.55	8.32	8.38	8.38
10,000	0.34	0.64	0.90	1.19	1.46	1.72	2.90	3.82	4.54	5.93	6.74	7.51	7.56	7.56
14,212	0.26	0.50	0.71	0.94	1.15	1.35	2.28	3.03	3.62	4.75	5.44	6.19	6.24	6.24

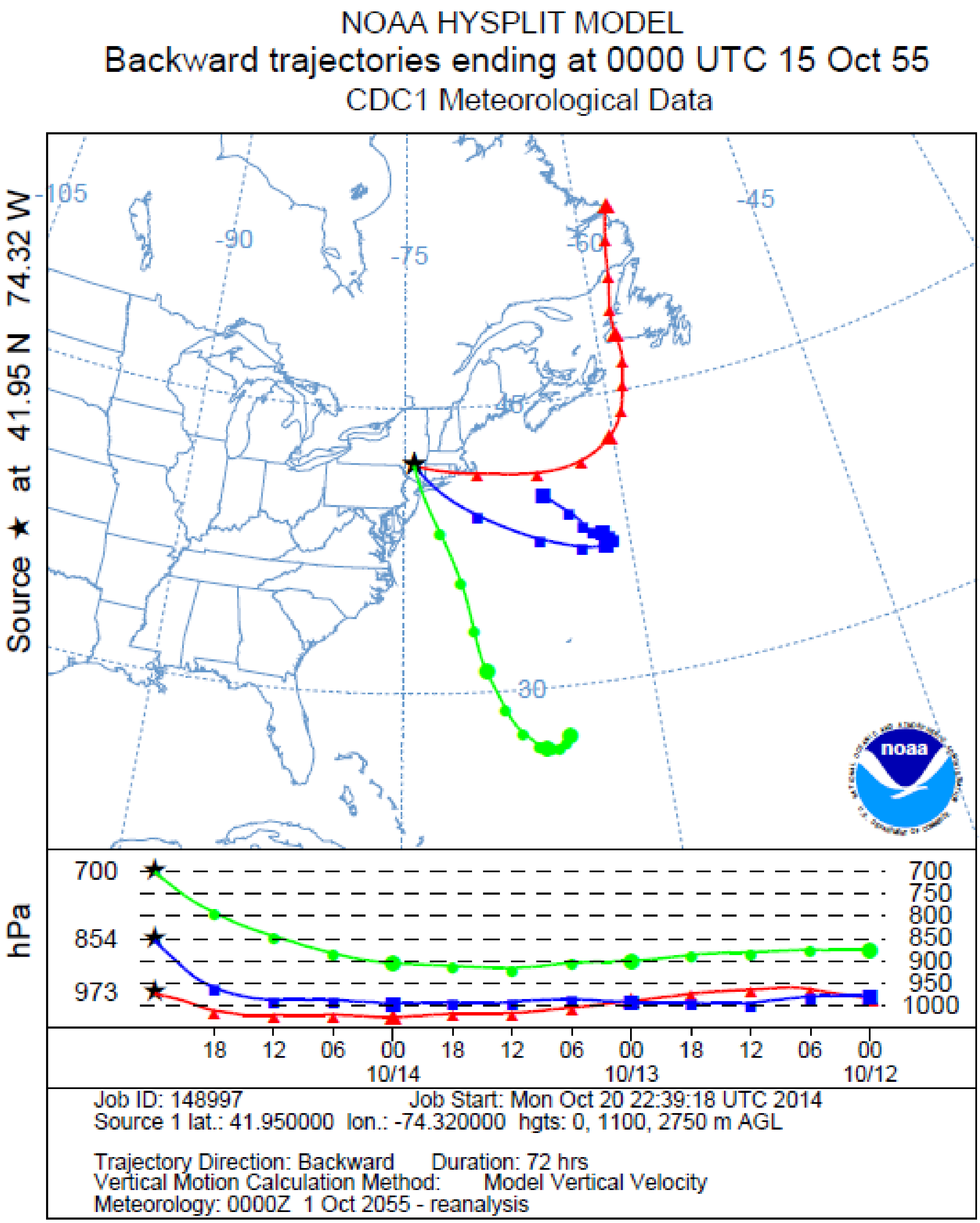



SPAS 1680 Storm Center Mass Curve: Zone 1
October 14 (0600 UTC) - October 18 (0500 UTC), 1955
Lat: 42.0042 Lon: -74.3958
Incremental
Accumulated
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
1
21
41
61
81

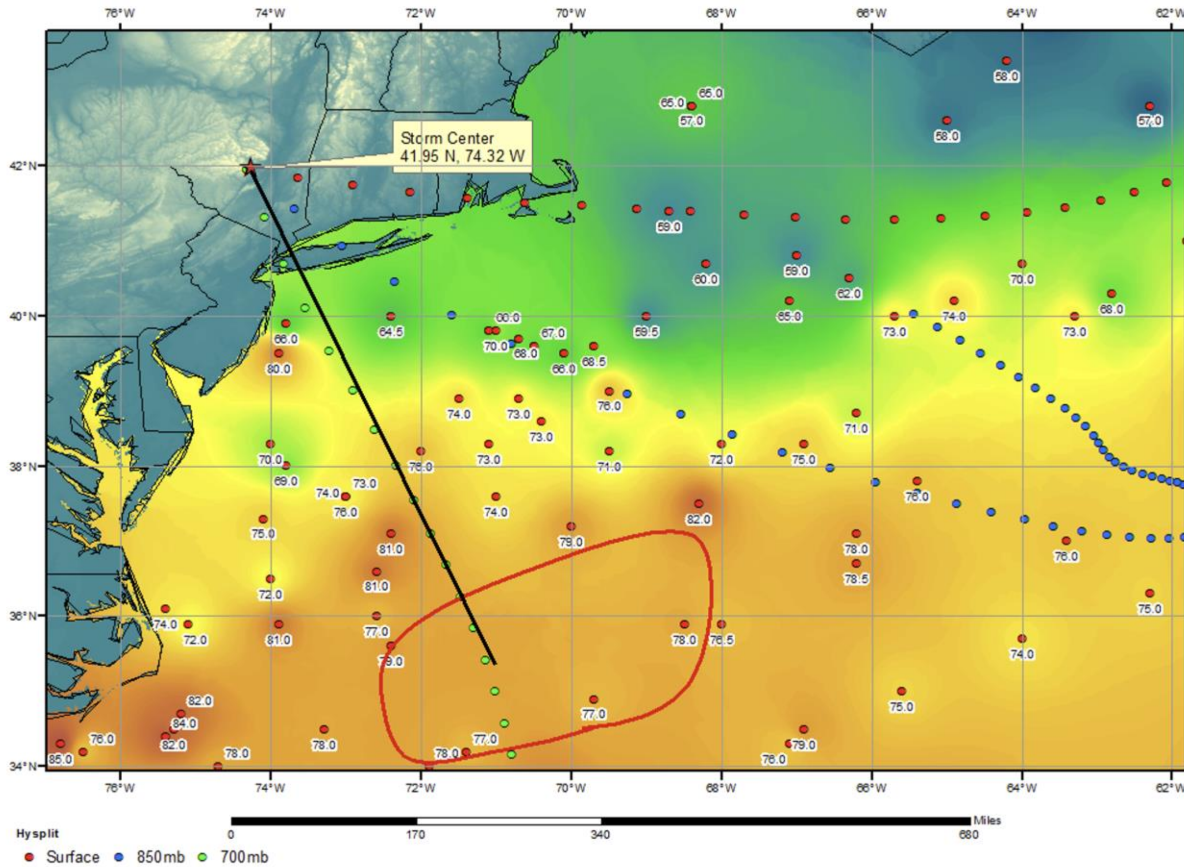


Total Storm (96-hours) Precipitation (inches)
October 14-17, 1955
SPAS 1680 (re-run of 1006) - West Shokan, NY




NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 15 Oct 55
CDC1 Meteorological Data
Source ★ at 41.95 N 74.32 W
hPa
700
854
973
700
750
800
850
900
950
1000
18 12 06 00 18 12 06 00 18 12 06 00
10/14
10/13
10/12
Job ID: 148997 Job Start: Mon Oct 20 22:39:18 UTC 2014
Source 1 lat.: 41.950000 lon.: -74.320000 hgts: 0, 1100, 2750 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Oct 2055 - reanalysis

SPAS 1680 West Shokan, NY Storm Analysis
October 13, 1955



Storm Precipitation Analysis System (SPAS) For Storm #1278_1 SPAS Analysis

General Storm Location: Kentucky, Ohio River Valley

Storm Dates: March 7-11, 1964

Event: Synoptic

DAD Zone 1

Latitude: 37.35

Longitude: -87.50

Max. Grid Rainfall Amount: 11.67"

Max. Observed Rainfall Amount: 11.63"

Number of Stations: 1291 (819 Daily, 252 Hourly, 109 Hourly Pseudo, and 111 Supplemental)

SPAS Version: 9.5

Basemap: PRISM 30-yr Mean (1971-2000) March Precipitation

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

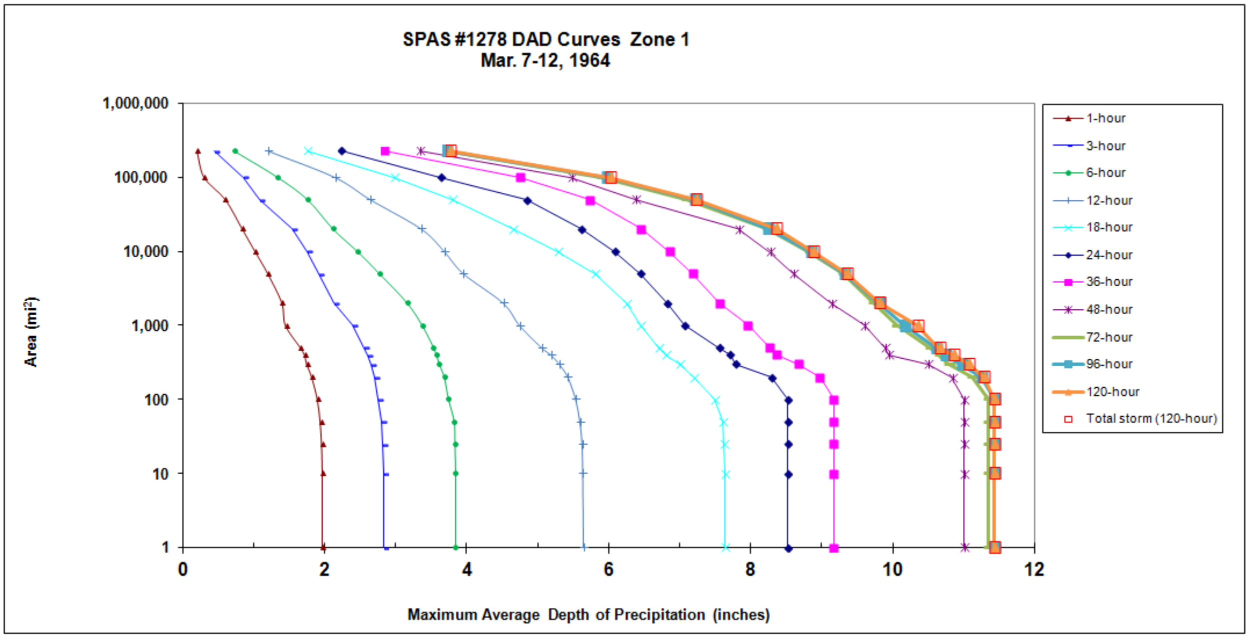
Radar Included: No

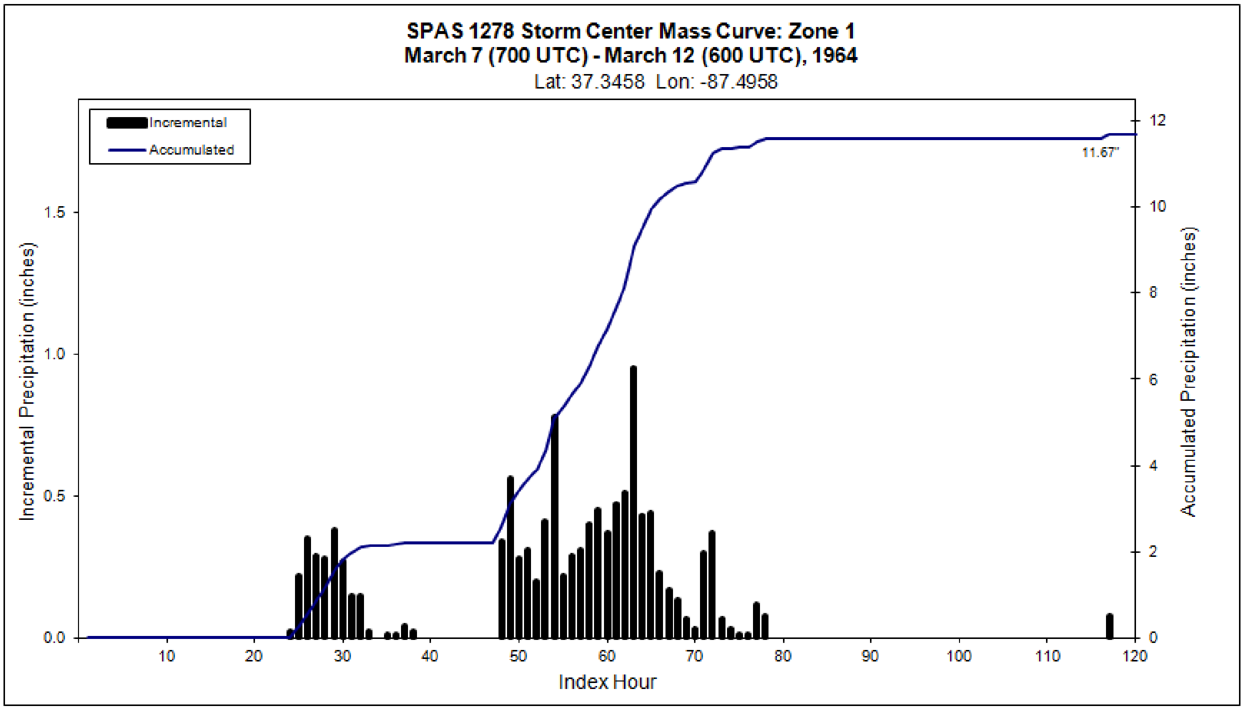
Depth-Area-Duration (DAD) analysis: Yes

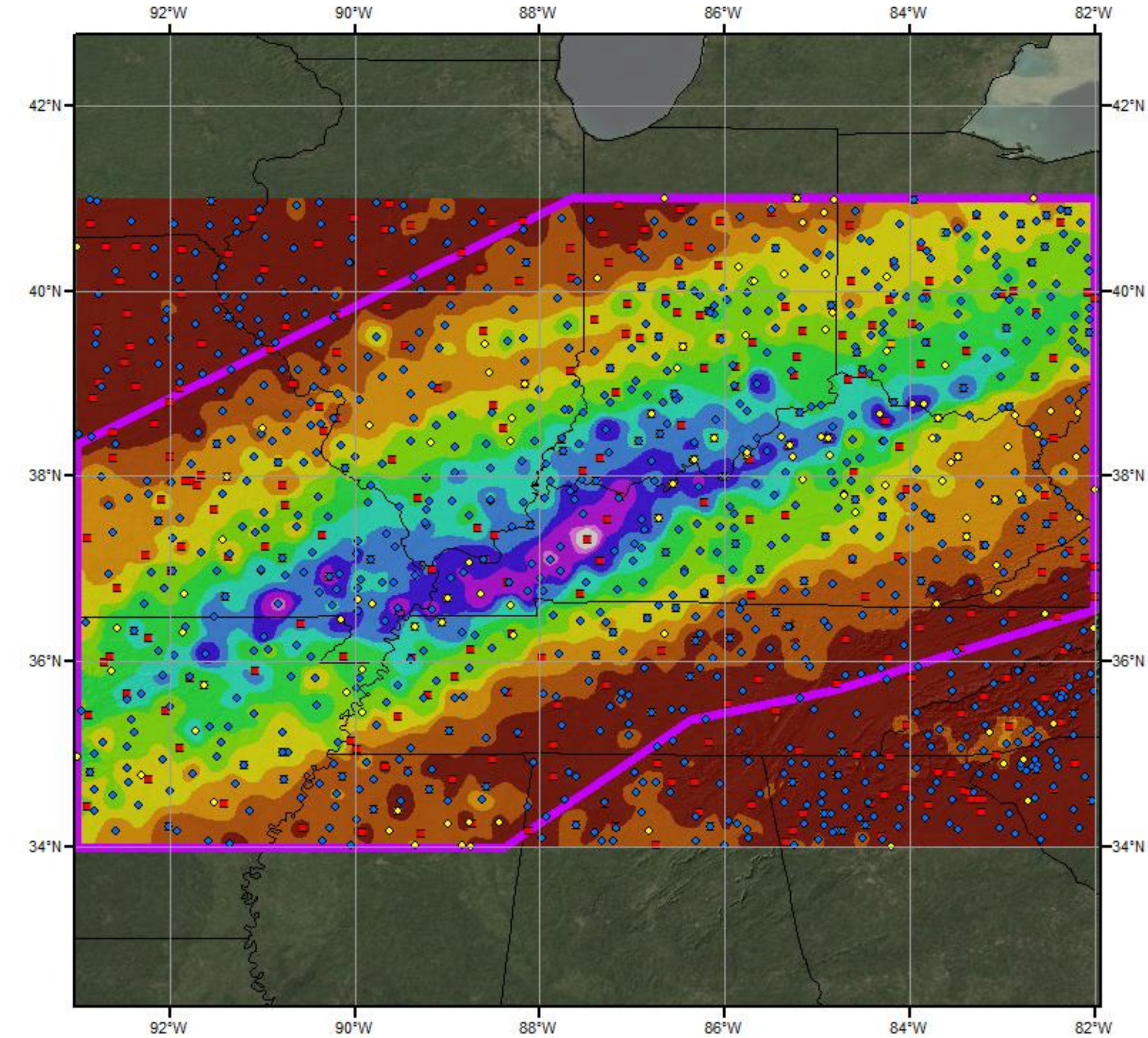
Reliability of results: This analysis was based on hourly data, daily data, and supplemental station data. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations. Results are similar to the analysis performed in the EPRI report for storm number 32.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1278_1	-87.4958	37.3458	449	400	25-Mar	70.00	2.25	0.09	62	2.160	73.37	73.5	2.67	0.10	69	2.565	1.188

Storm 1278 - March 7 (0700 UTC) - Mach 12 (0600 UTC), 1964												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
	Duration (hours)											
Area (mi^2)	1	3	6	12	18	24	36	48	72	96	120	Total
0.3	2	2.89	3.9	5.64	7.74	8.71	9.37	11.25	11.59	11.67	11.67	11.67
1	1.97	2.83	3.84	5.64	7.63	8.52	9.17	11	11.34	11.43	11.43	11.43
10	1.97	2.83	3.84	5.63	7.63	8.52	9.17	11	11.34	11.43	11.43	11.43
25	1.96	2.82	3.83	5.62	7.62	8.52	9.17	11	11.34	11.43	11.43	11.43
50	1.94	2.8	3.82	5.59	7.61	8.52	9.17	11	11.34	11.43	11.43	11.43
100	1.9	2.76	3.74	5.53	7.49	8.52	9.17	11	11.34	11.43	11.43	11.43
200	1.82	2.7	3.68	5.42	7.19	8.29	8.97	10.83	11.12	11.25	11.28	11.28
300	1.75	2.65	3.61	5.3	7	7.78	8.67	10.49	10.79	10.96	11.06	11.06
400	1.72	2.6	3.57	5.18	6.81	7.71	8.37	9.94	10.65	10.74	10.85	10.85
500	1.66	2.55	3.53	5.05	6.7	7.55	8.27	9.89	10.53	10.61	10.65	10.65
1,000	1.45	2.39	3.37	4.74	6.45	7.07	7.96	9.59	10.05	10.16	10.34	10.34
2,000	1.4	2.13	3.16	4.51	6.25	6.82	7.56	9.13	9.72	9.8	9.81	9.81
5,000	1.2	1.92	2.77	3.95	5.81	6.44	7.18	8.6	9.3	9.32	9.35	9.35
10,000	1.02	1.75	2.46	3.68	5.29	6.09	6.86	8.26	8.82	8.84	8.88	8.88
20,000	0.84	1.54	2.12	3.36	4.64	5.61	6.46	7.82	8.23	8.24	8.36	8.36
50,000	0.6	1.08	1.76	2.64	3.79	4.84	5.74	6.38	7.1	7.2	7.23	7.23
100,000	0.3	0.86	1.34	2.14	2.98	3.63	4.76	5.47	5.9	5.97	6.01	6.01
227,343	0.2	0.45	0.73	1.2	1.76	2.24	2.85	3.34	3.72	3.72	3.77	3.77




SPAS 1278 Storm Center Mass Curve: Zone 1
March 7 (700 UTC) - March 12 (600 UTC), 1964
Lat: 37.3458 Lon: -87.4958
Incremental
Accumulated
11.67"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



Total Storm (120-hr) Precipitation (inches)
March 7-11, 1964
SPAS 1278

Gauges

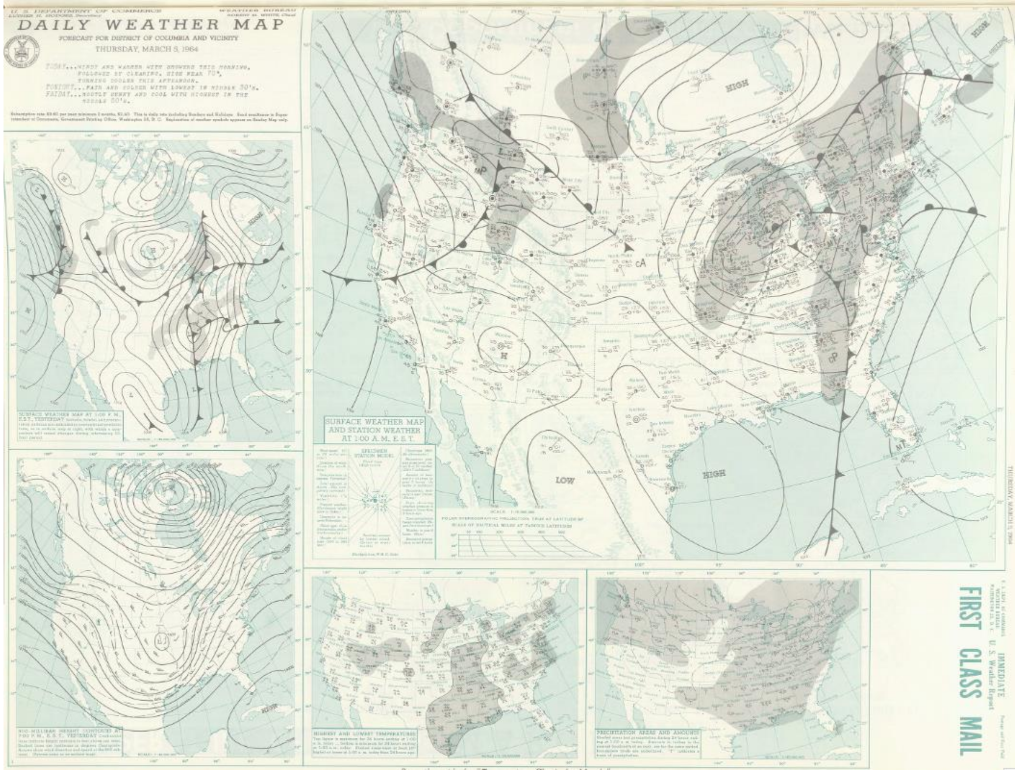
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

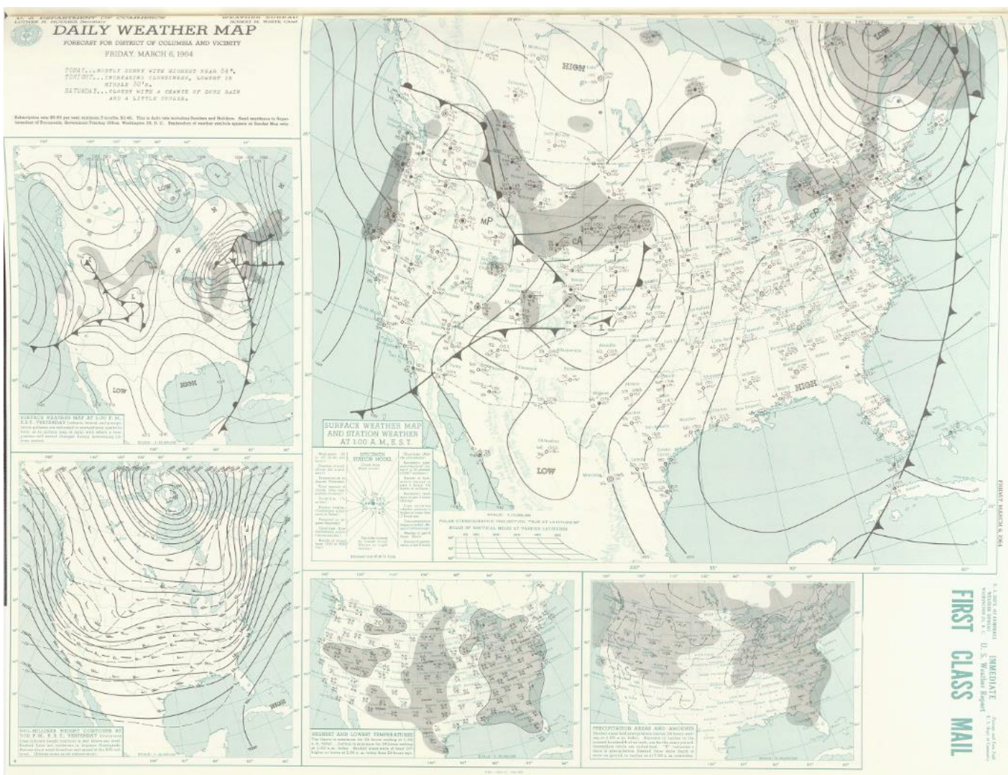
Miles: 0, 62.5, 125, 250
Kilometers: 0, 125, 250, 500

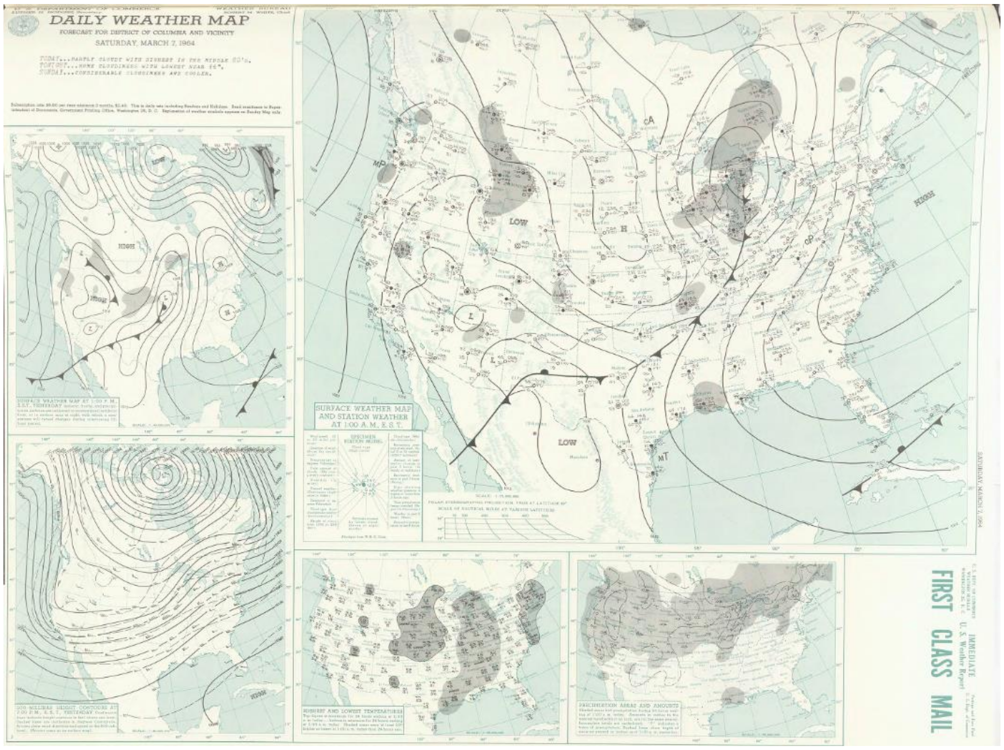
Precipitation (inches)

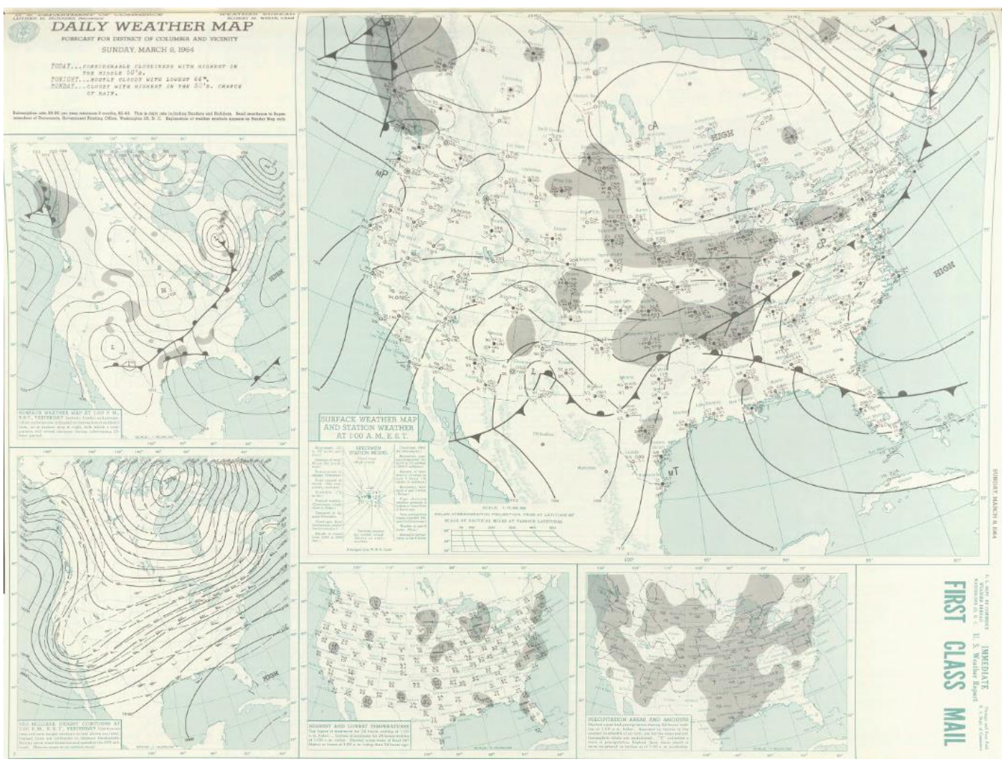
0.00 - 1.00	3.01 - 4.00	6.01 - 7.00	9.01 - 10.00
1.01 - 2.00	4.01 - 5.00	7.01 - 8.00	10.01 - 11.00
2.01 - 3.00	5.01 - 6.00	8.01 - 9.00	11.01 - 12.00

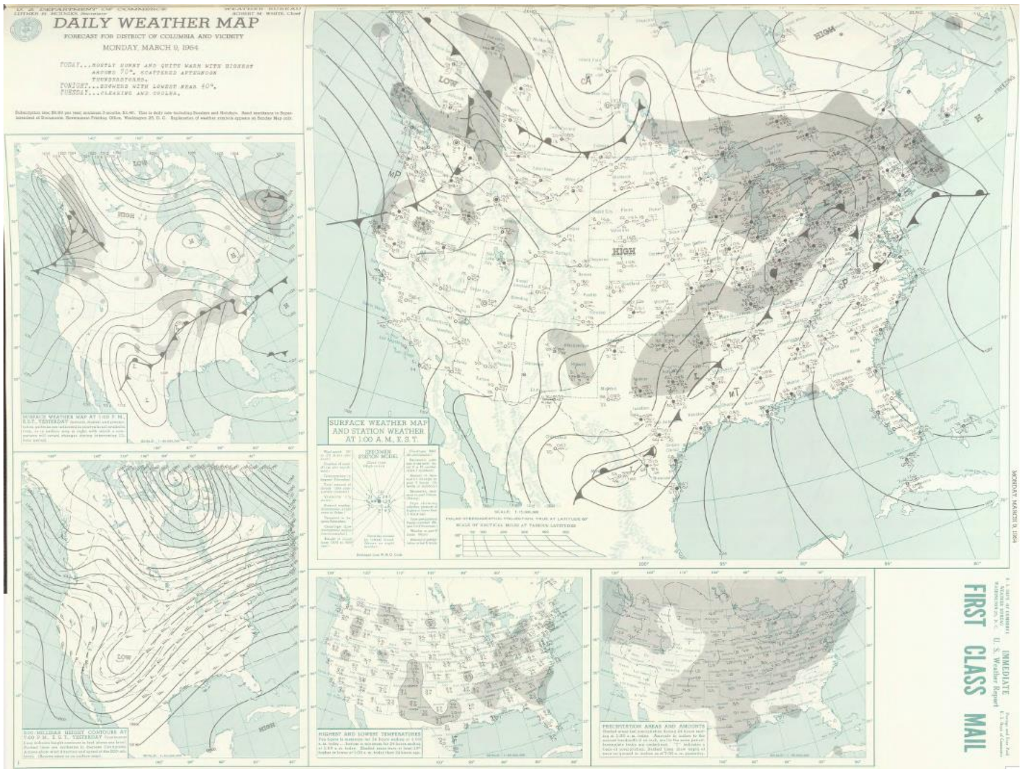
6/17/2013

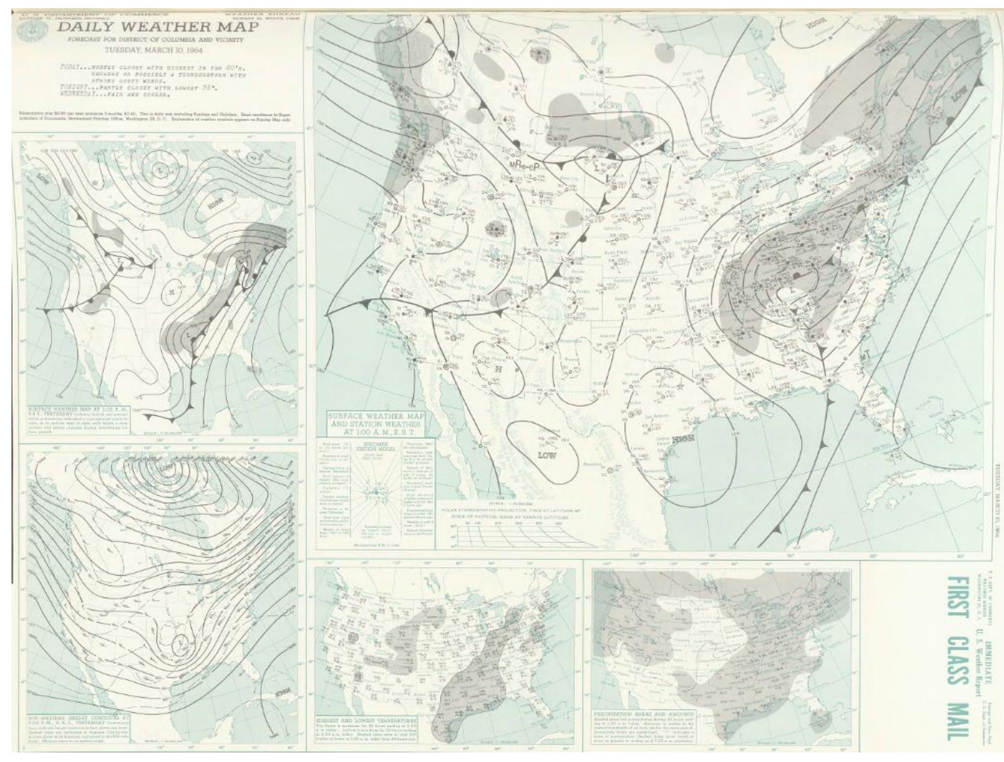

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECAST FOR DISTRICT OF COLUMBIA AND VICINITY
THURSDAY, MARCH 5, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
FIRST CLASS MAIL
IMMEDIATE
U. S. Weather Report

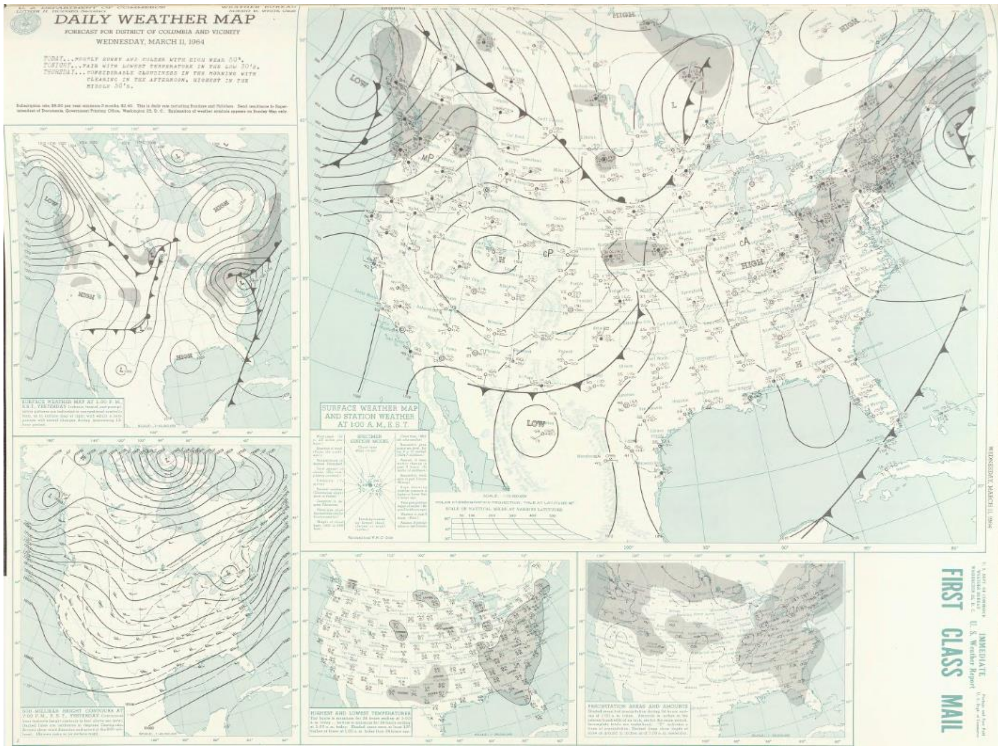

DAILY WEATHER MAP
FORECAST FOR DISTRICT OF COLUMBIA AND VICINITY
FRIDAY, MARCH 6, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
FIRST CLASS MAIL
IMMEDIATE
U. S. Weather Report

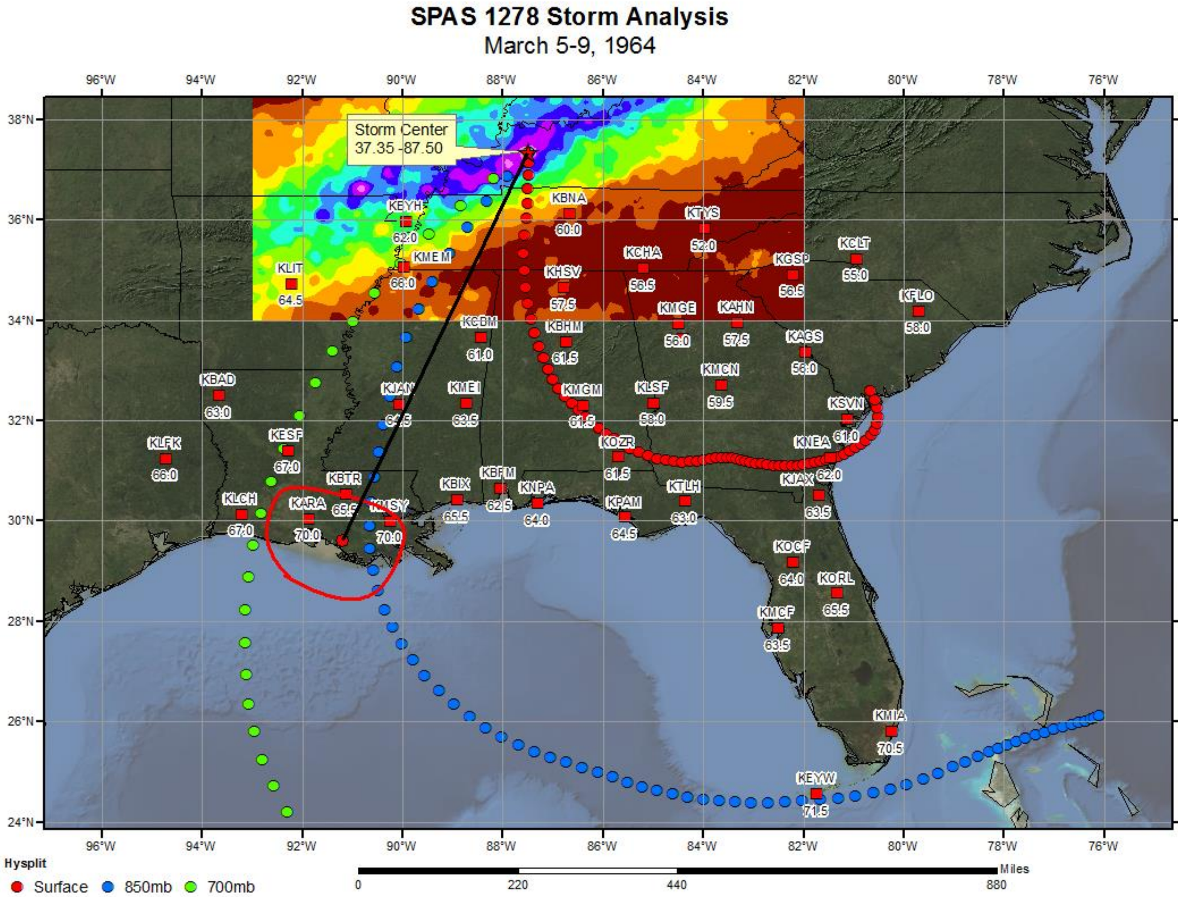

DAILY WEATHER MAP
FORECAST FOR DISTRICT OF COLUMBIA AND VICINITY
SATURDAY, MARCH 7, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
LOW
HIGH
FIRST CLASS MAIL


DAILY WEATHER MAP
FORECAST FOR DISTRICT OF COLUMBIA AND VICINITY
SUNDAY, MARCH 8, 1964
TODAY...CONSIDERABLE CLOUDINESS WITH HIGHEST IN THE MIDDLE 50'S.
TONIGHT...MOSTLY CLOUDY WITH LOWEST 44°.
MONDAY...CLOUDY WITH HIGHEST IN THE 50'S. CHANCE OF RAIN.
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
FIRST CLASS MAIL


DAILY WEATHER MAP
FORECAST FOR DISTRICT OF COLUMBIA AND VICINITY
MONDAY, MARCH 9, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
FIRST CLASS MAIL
IMMEDIATE
U. S. Weather Report


DAILY WEATHER MAP
FORECAST FOR DISTRICT OF COLUMBIA AND VICINITY
TUESDAY, MARCH 10, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
LOW
FIRST CLASS MAIL
IMMEDIATE
U. S. Weather Report


DAILY WEATHER MAP
FORECAST FOR DISTRICT OF COLUMBIA AND VICINITY
WEDNESDAY, MARCH 11, 1964
TONIGHT...FAIR WITH LOWEST TEMPERATURE IN THE LOW 30'S.
THURSDAY...CONSIDERABLE CLOUDINESS IN THE MORNING WITH CLEARING IN THE AFTERNOON. HIGHEST IN THE MIDDLE 50'S.
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
FIRST CLASS MAIL


SPAS 1278 Storm Analysis
March 5-9, 1964
Storm Center
37.35 -87.50
Hysplit
Surface
850mb
700mb
Miles
0
220
440
880

Storm Precipitation Analysis System (SPAS) For Storm #1312A_1 SPAS Analysis

General Storm Location: Rosman, NC has the max total of 35.38”

Storm Dates: September 26 – October 3, 1964

Event: Semi-stationary front

DAD Zone 1 - Northwest

Latitude: 37.7375

Longitude: -81.59583

Max. Grid Rainfall Amount: 9.22”

Number of Stations: 1,365 stations (325 of which are hourly)

SPAS Version: 9.5

Base Map Used: Digitized TVA Isohyetal Map (storm total Sept 28 – Oct 6); expanded using SPAS storm totals

Spatial resolution: 30 seconds

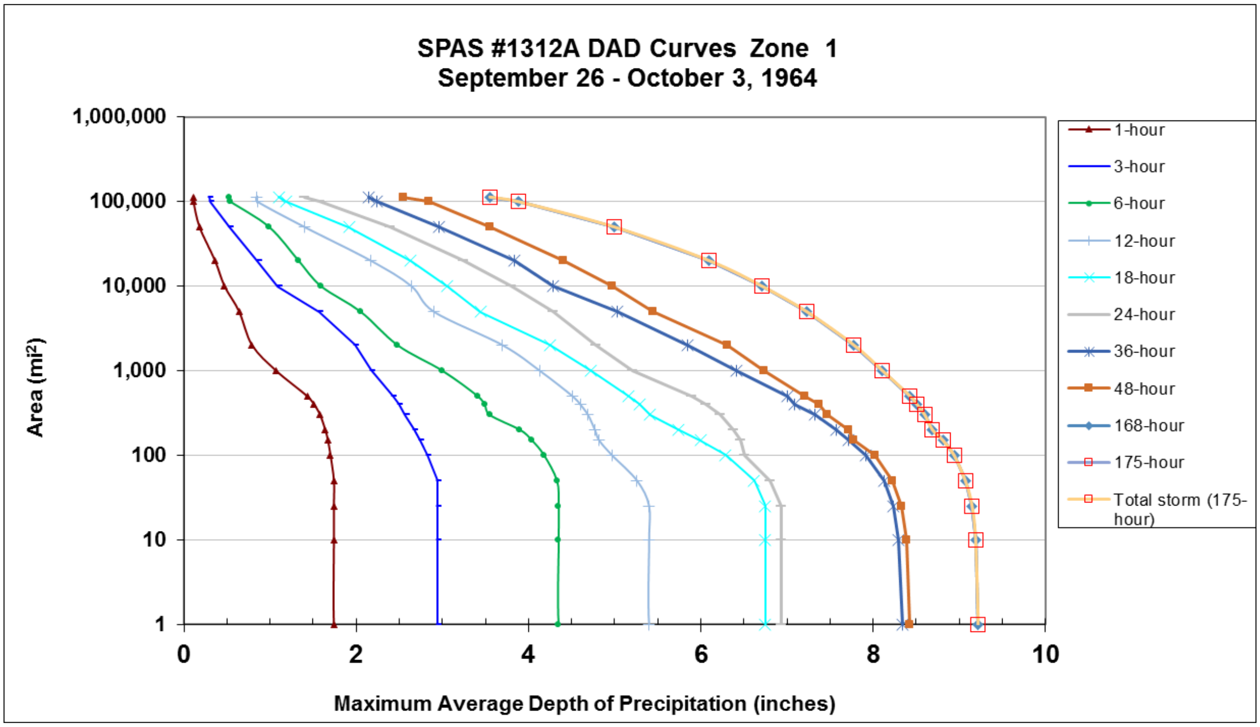
Radar Included: No

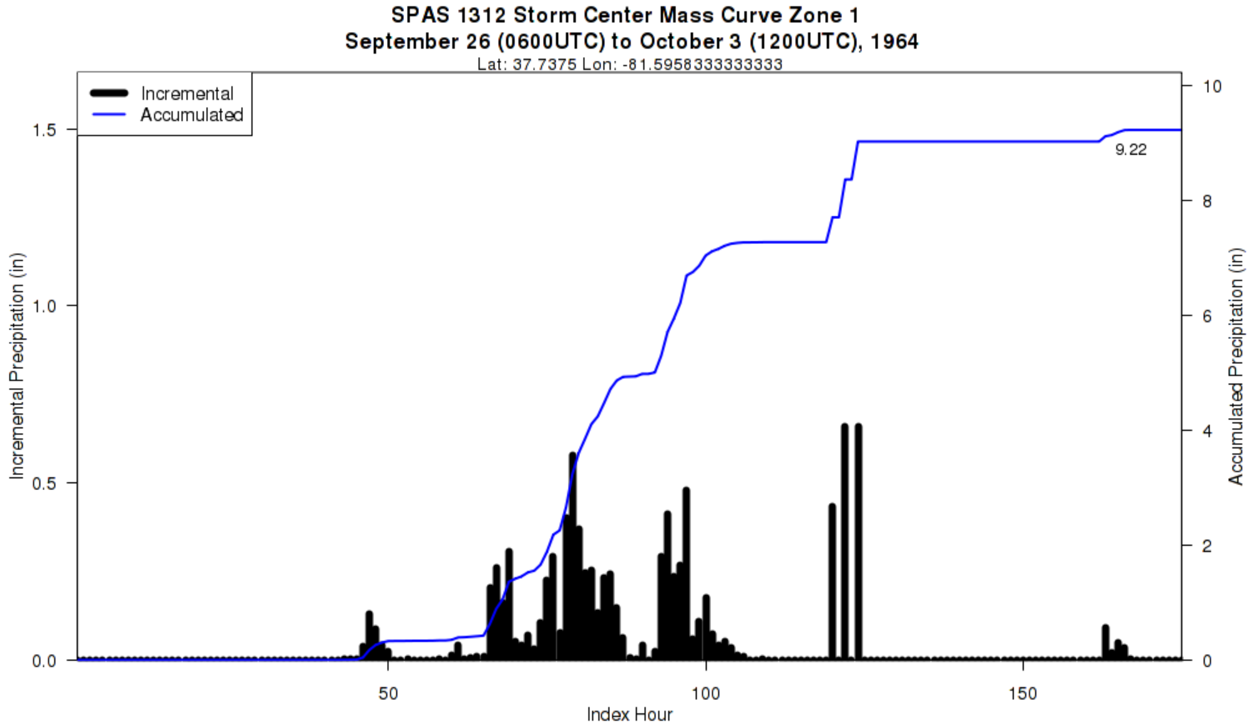
Depth-Area-Duration (DAD) analysis: Yes

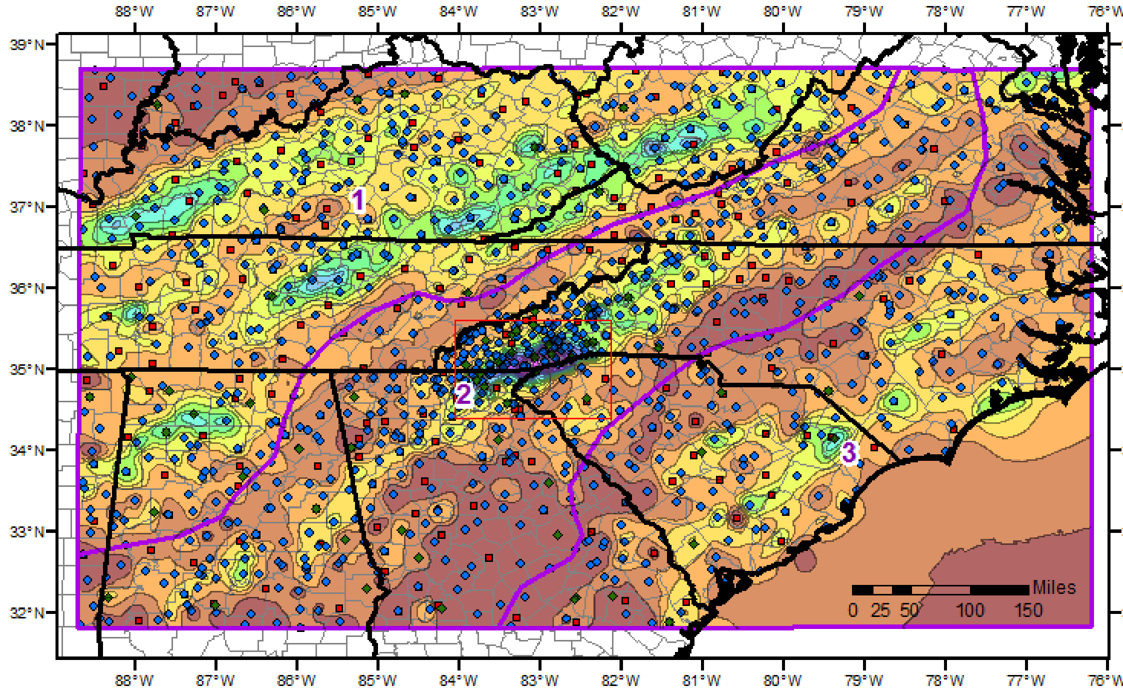
Reliability of Results: In addition to the 314 hourly stations from NCDC used in the whole project area, fourteen additional hourly stations were digitized from the TVA report adding more certainty to the timing of the storm center. The extent and magnitude of the rainfall is moderately reliable given the surprising large number of daily rain gauges available.

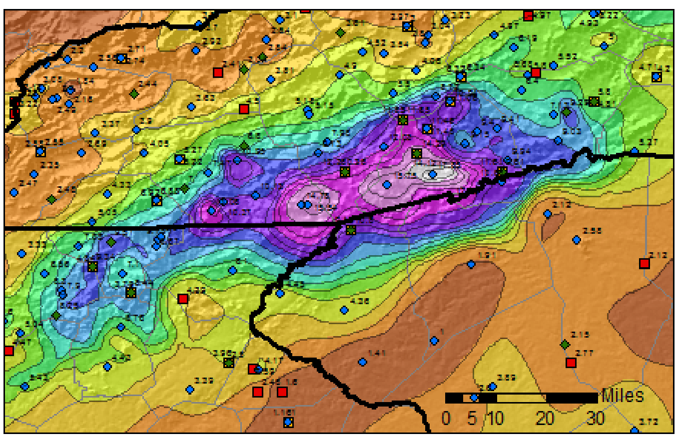
							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1312A_1	-81.5958	37.7375	2,132	2,100	15-Sep	74.50	2.79	0.50	71	2.290	78.11	78.0	3.29	0.56	78	2.730	1.192

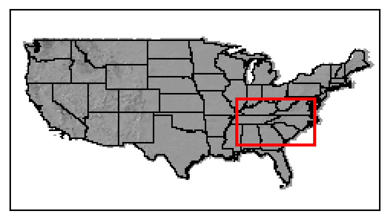
Storm 1312A - September 26 (0600 UTC) - October 3 (1200 UTC), 1964											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	3	6	12	18	24	36	48	168	175	Total
0.3	1.80	3.04	4.47	5.52	6.93	7.12	8.34	8.44	9.22	9.22	9.22
1	1.74	2.94	4.35	5.40	6.75	6.94	8.34	8.43	9.22	9.22	9.22
10	1.74	2.94	4.35	5.40	6.75	6.94	8.30	8.39	9.19	9.19	9.19
25	1.74	2.94	4.35	5.40	6.75	6.94	8.24	8.33	9.15	9.15	9.15
50	1.74	2.94	4.33	5.26	6.62	6.80	8.13	8.22	9.07	9.07	9.07
100	1.70	2.82	4.18	4.97	6.29	6.51	7.92	8.02	8.94	8.94	8.94
150	1.67	2.74	4.04	4.82	6.00	6.46	7.72	7.78	8.81	8.81	8.81
200	1.64	2.67	3.90	4.77	5.74	6.38	7.57	7.72	8.69	8.69	8.69
300	1.58	2.57	3.55	4.69	5.41	6.22	7.32	7.47	8.60	8.60	8.60
400	1.51	2.49	3.49	4.60	5.29	6.06	7.09	7.37	8.51	8.51	8.51
500	1.43	2.42	3.41	4.51	5.16	5.90	7.01	7.21	8.43	8.43	8.43
1,000	1.07	2.17	3.00	4.13	4.72	5.21	6.41	6.73	8.11	8.11	8.11
2,000	0.79	1.98	2.48	3.70	4.25	4.78	5.85	6.31	7.78	7.78	7.78
5,000	0.64	1.57	2.05	2.90	3.44	4.28	5.03	5.44	7.23	7.23	7.23
10,000	0.47	1.09	1.59	2.64	3.06	3.80	4.29	4.97	6.71	6.71	6.71
20,000	0.36	0.85	1.33	2.17	2.63	3.24	3.84	4.40	6.10	6.10	6.10
50,000	0.18	0.53	0.99	1.40	1.92	2.39	2.96	3.55	5.00	5.00	5.00
100,000	0.11	0.30	0.54	0.85	1.19	1.58	2.24	2.84	3.88	3.88	3.88
113,361	0.11	0.29	0.52	0.84	1.10	1.40	2.14	2.55	3.55	3.55	3.55




SPAS 1312 Storm Center Mass Curve Zone 1
September 26 (0600UTC) to October 3 (1200UTC), 1964
Lat: 37.7375 Lon: -81.5958333333333
Incremental
Accumulated
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
9.22
0.0
0.5
1.0
1.5
0
2
4
6
8
10
50
100
150







Total 175-hour Precipitation (inches)
September 26, 1964 0600 UTC - October 3, 1964 1200 UTC
SPAS #1312A

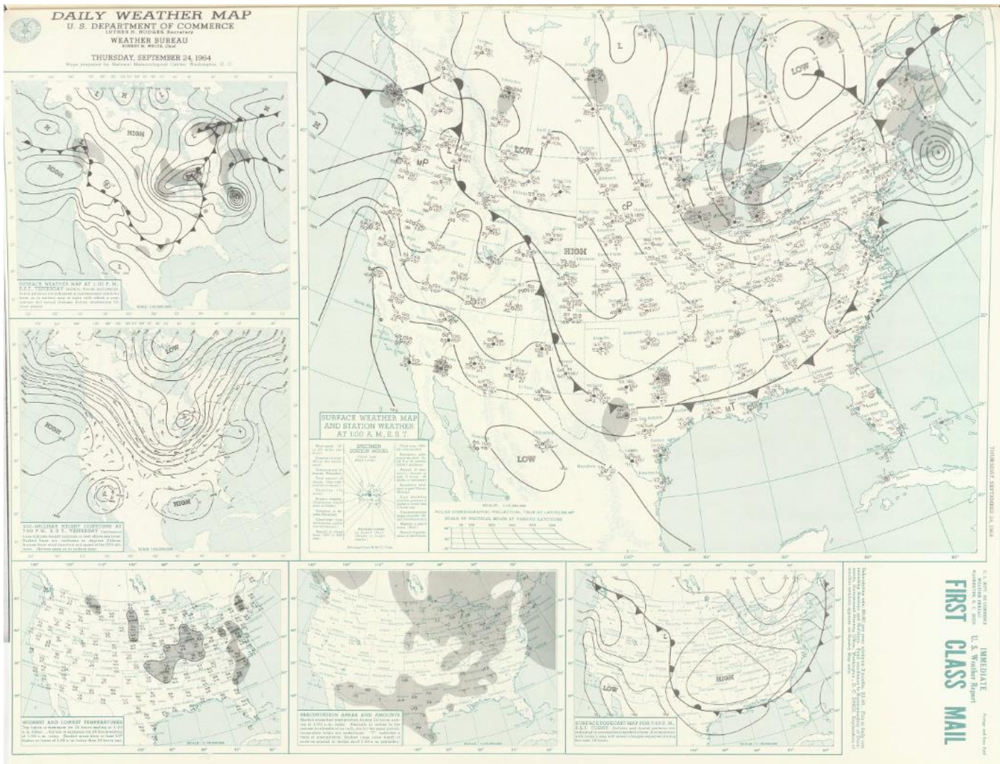
Precipitation (inches)

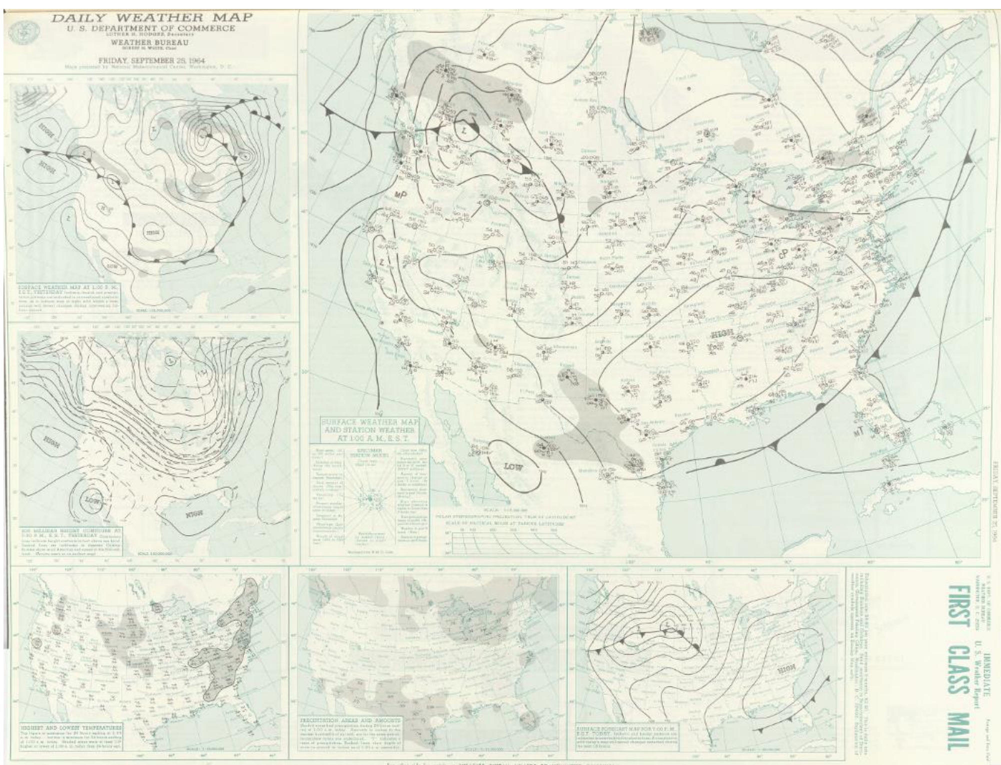
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 12.00
12.01 - 14.00
14.01 - 16.00
16.01 - 18.00

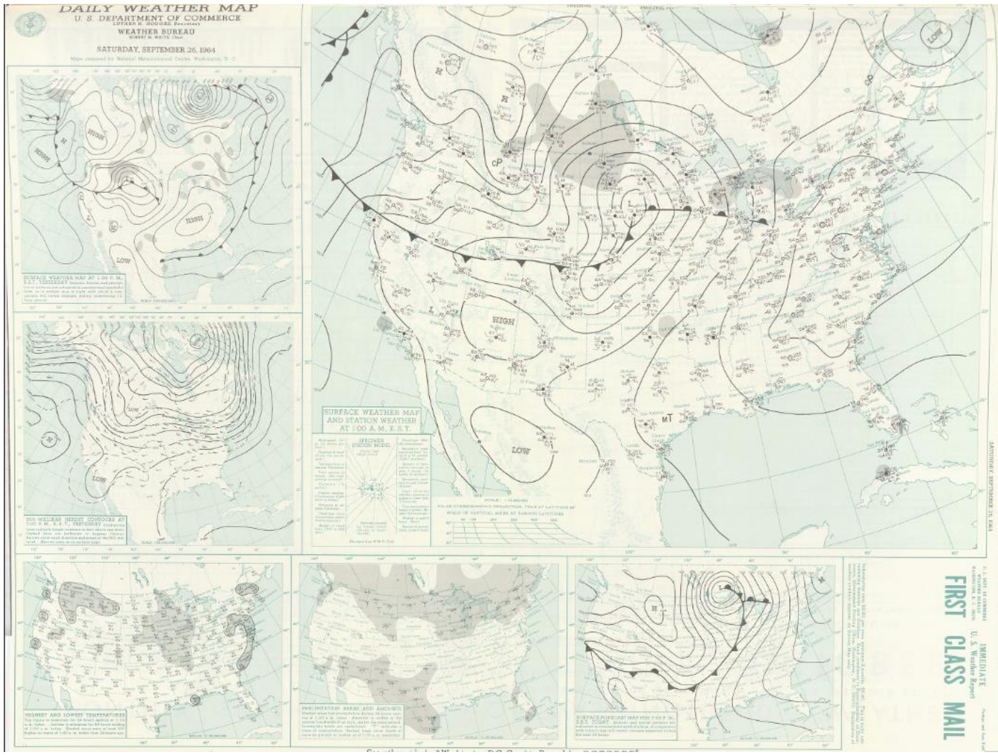
Stations

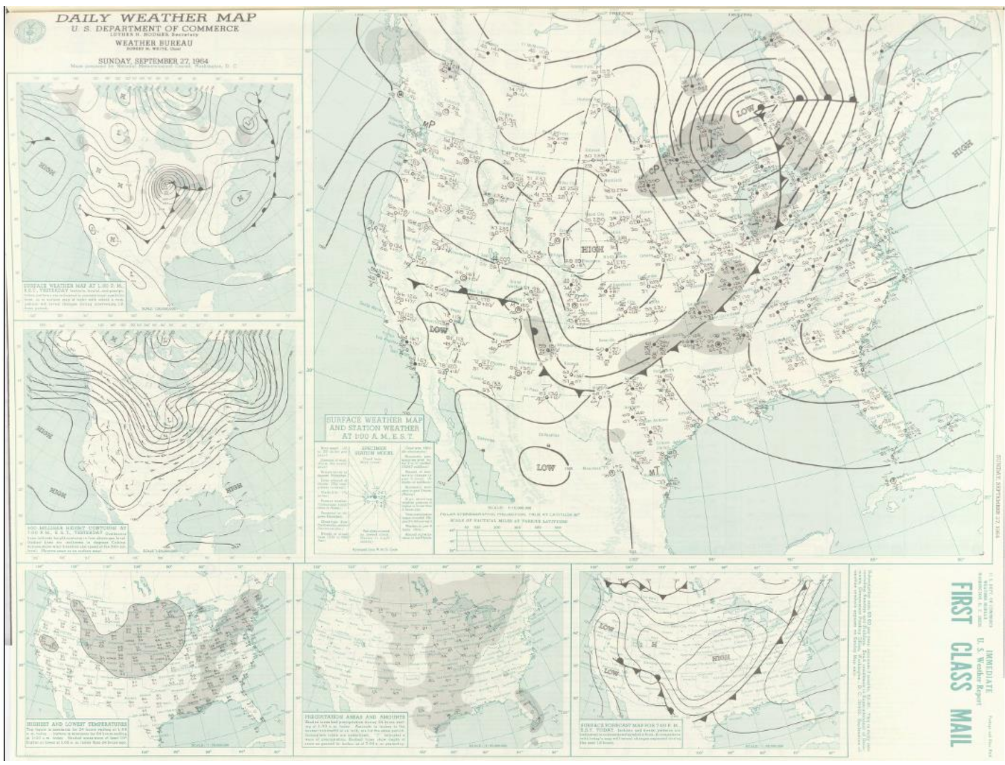
Daily
Hourly
Hourly Pseudo
Supplemental

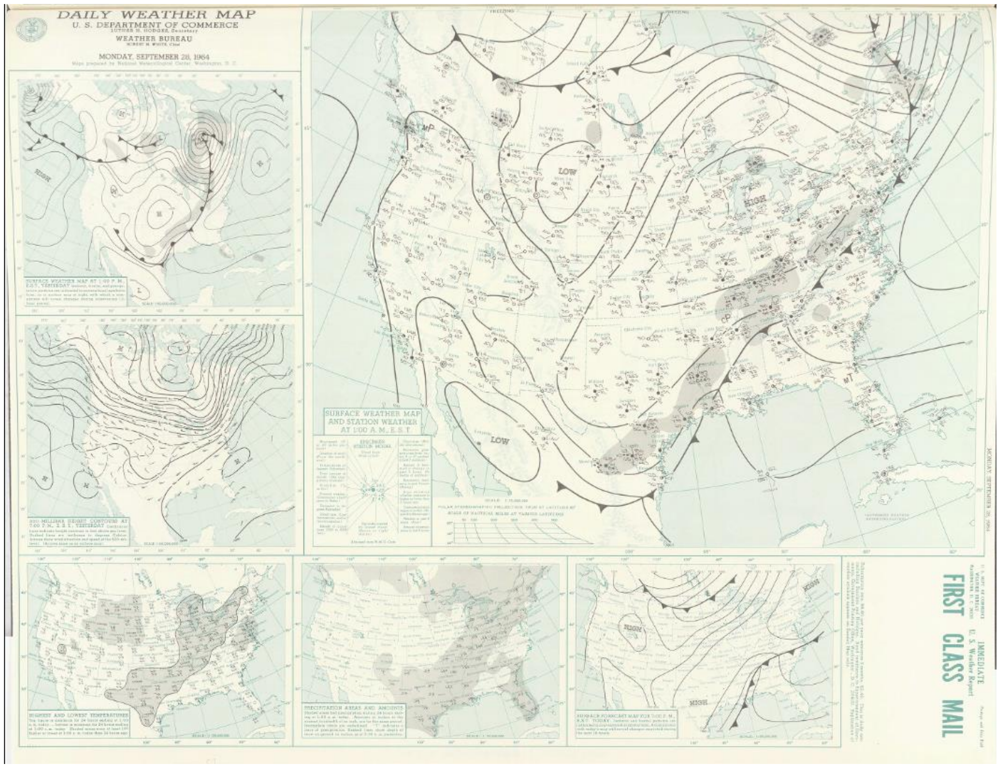
TWP 02/20/2014

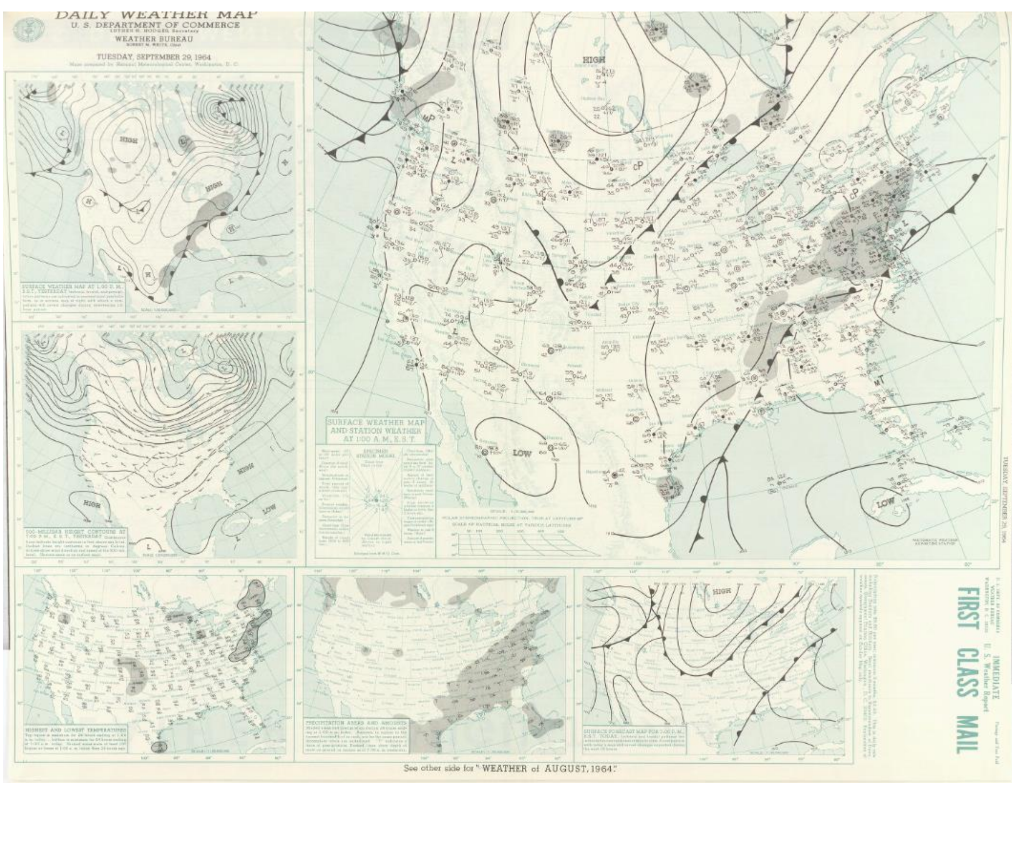

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary
WEATHER BUREAU
ROBERT M. WHITE, Chief
THURSDAY, SEPTEMBER 24, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGHEST AND LOWEST TEMPERATURES
PRECIPITATION AREAS AND AMOUNTS
FIRST CLASS MAIL
IMMEDIATE
U. S. Weather Report

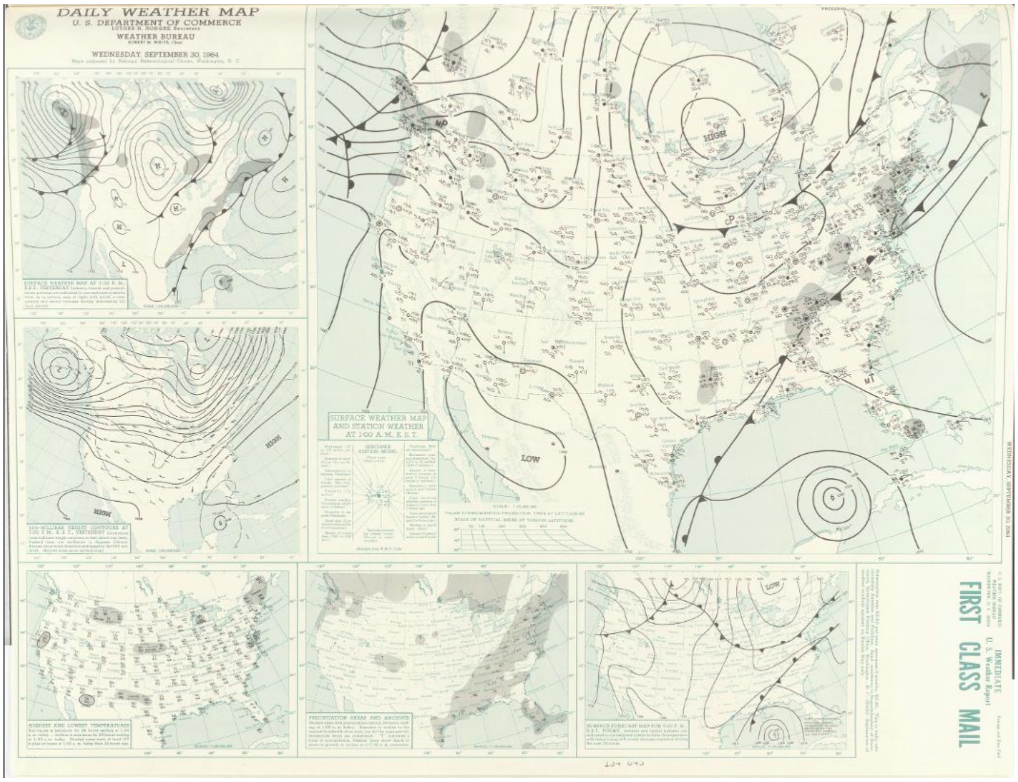

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary
WEATHER BUREAU
ROBERT M. WHITE, Chief
FRIDAY, SEPTEMBER 25, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGHEST AND LOWEST TEMPERATURES
PRECIPITATION AREAS AND AMOUNTS
FIRST CLASS MAIL
IMMEDIATE
U. S. Weather Report

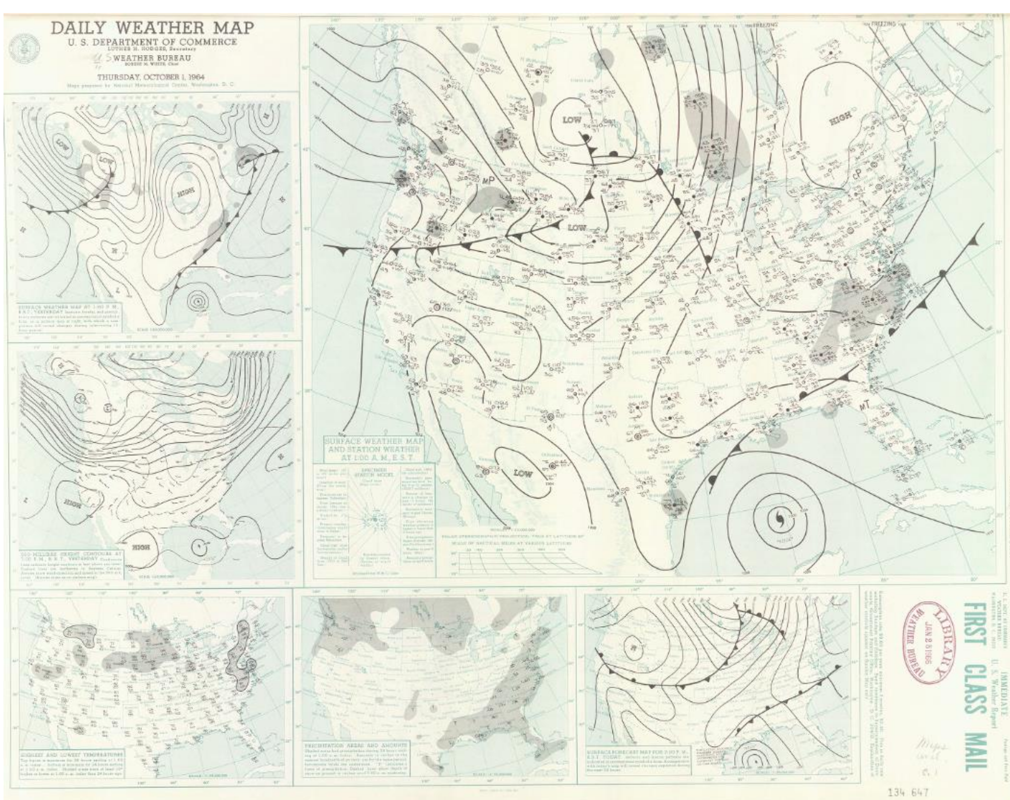

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
SATURDAY, SEPTEMBER 26, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
FIRST CLASS MAIL
IMMEDIATE
U. S. Weather Report

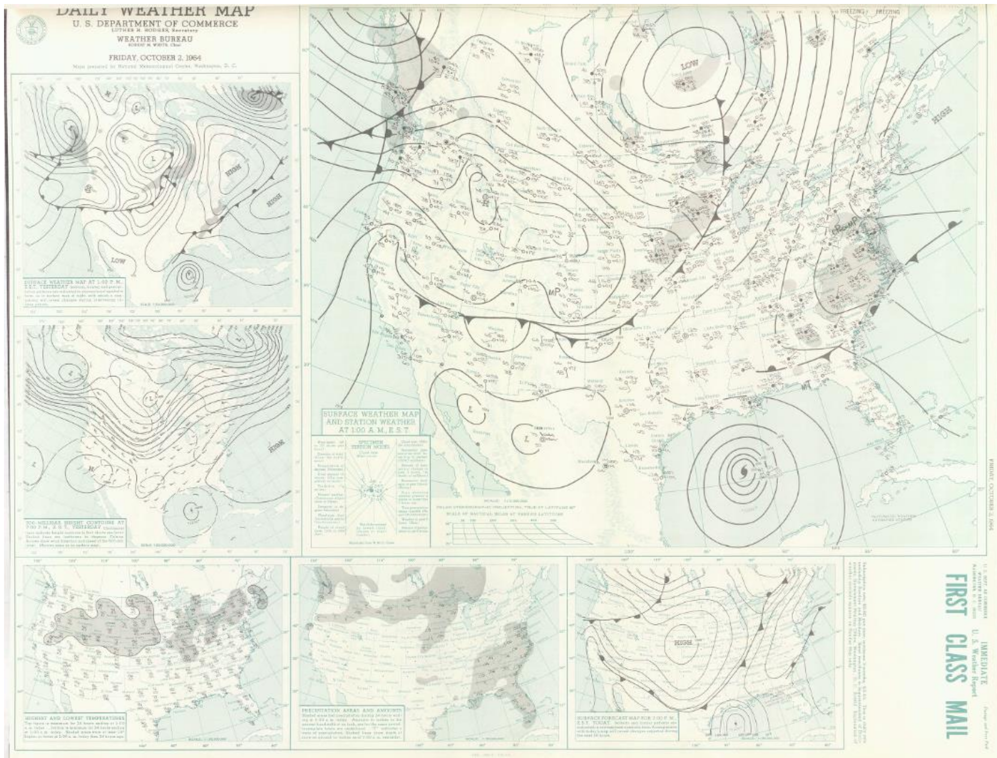

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary
WEATHER BUREAU
ROBERT M. WHITE, Chief
SUNDAY, SEPTEMBER 27, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
HIGHEST AND LOWEST TEMPERATURES
FIRST CLASS MAIL
IMMEDIATE
U. S. Weather Report

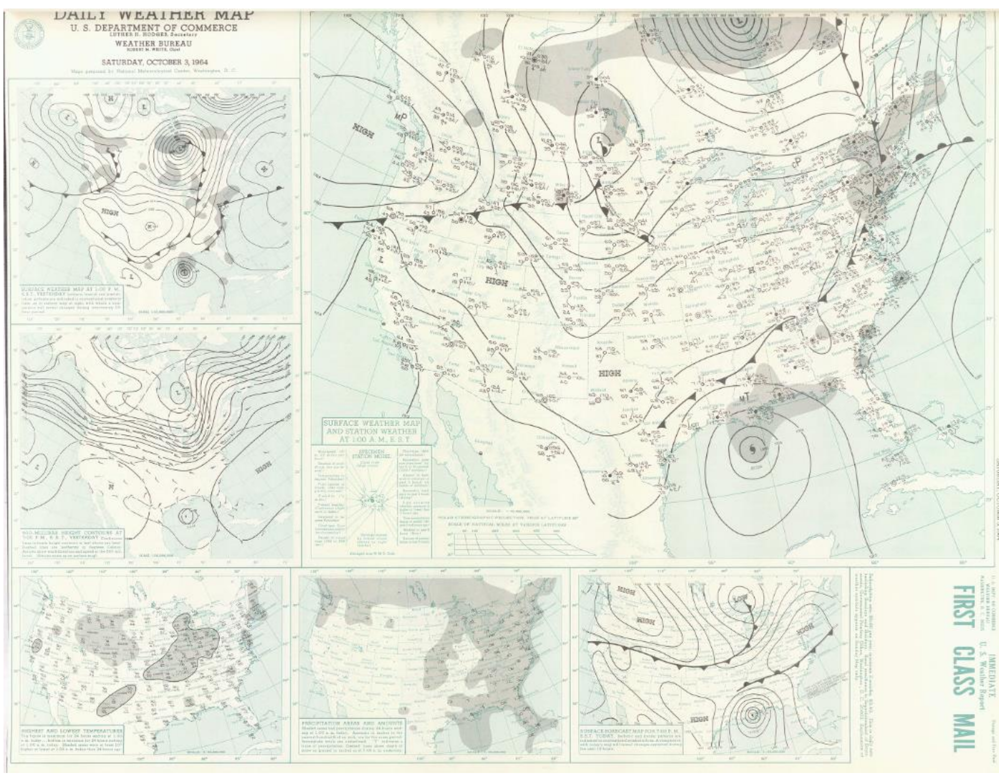

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
MONDAY, SEPTEMBER 28, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
LOW
HIGH
IMMEDIATE
U. S. Weather Report
FIRST CLASS MAIL


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
TUESDAY, SEPTEMBER 29, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
IMMEDIATE
U. S. Weather Report
FIRST CLASS MAIL
See other side for "WEATHER of AUGUST, 1964."

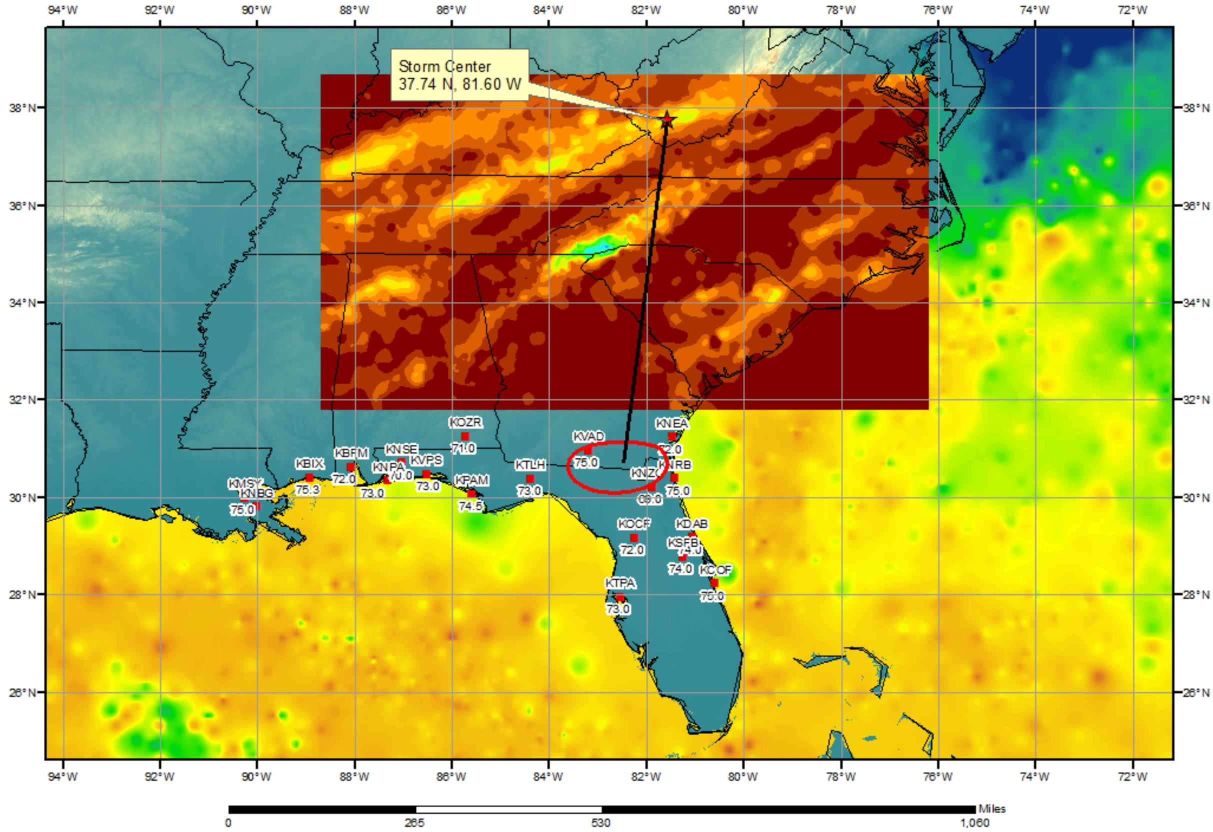

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary
WEATHER BUREAU
WEDNESDAY, SEPTEMBER 30, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
FIRST CLASS MAIL


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary
WEATHER BUREAU
THURSDAY, OCTOBER 1, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
LIBRARY
WEATHER BUREAU
FIRST CLASS MAIL
134 647


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
FRIDAY, OCTOBER 2, 1964
LOW
HIGH
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
IMMEDIATE
U. S. Weather Report
FIRST CLASS MAIL


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
SATURDAY, OCTOBER 3, 1964
HIGH
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
IMMEDIATE
U. S. Weather Report
FIRST CLASS MAIL

SPAS 1312 Rollins Branch, WV Storm Analysis
September 28 - 29, 1964



Storm Precipitation Analysis System (SPAS) For Storm #1312A_2 SPAS Analysis

General Storm Location: Rosman, NC has the max total of 35.38"

Storm Dates: September 26 – October 3, 1964

Event: Semi-stationary front

DAD Zone 2 - Central

Latitude: 35.14583

Longitude: -82.80416

Max. Grid Rainfall Amount: 17.86"

Number of Stations: 1,365 stations (325 of which are hourly)

SPAS Version: 9.5

Base Map Used: Digitized TVA Isohyetal Map (storm total Sept 28 – Oct 6); expanded using SPAS storm totals

Spatial resolution: 30 seconds

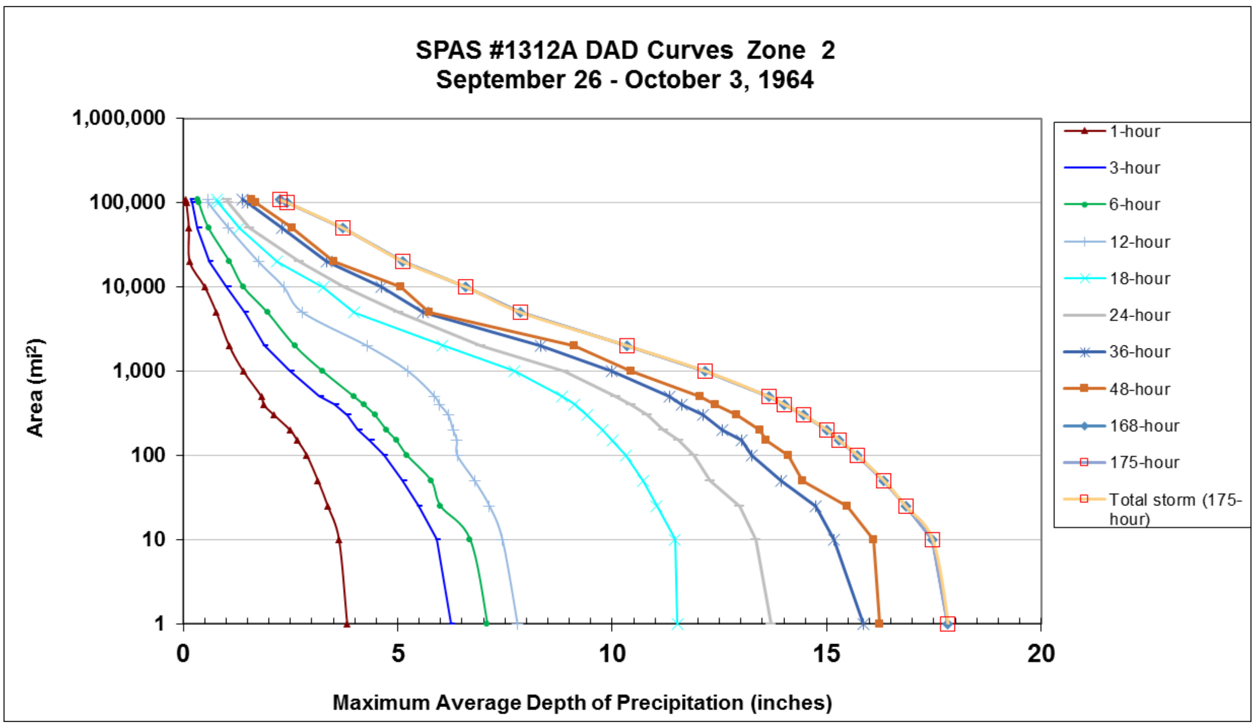
Radar Included: No

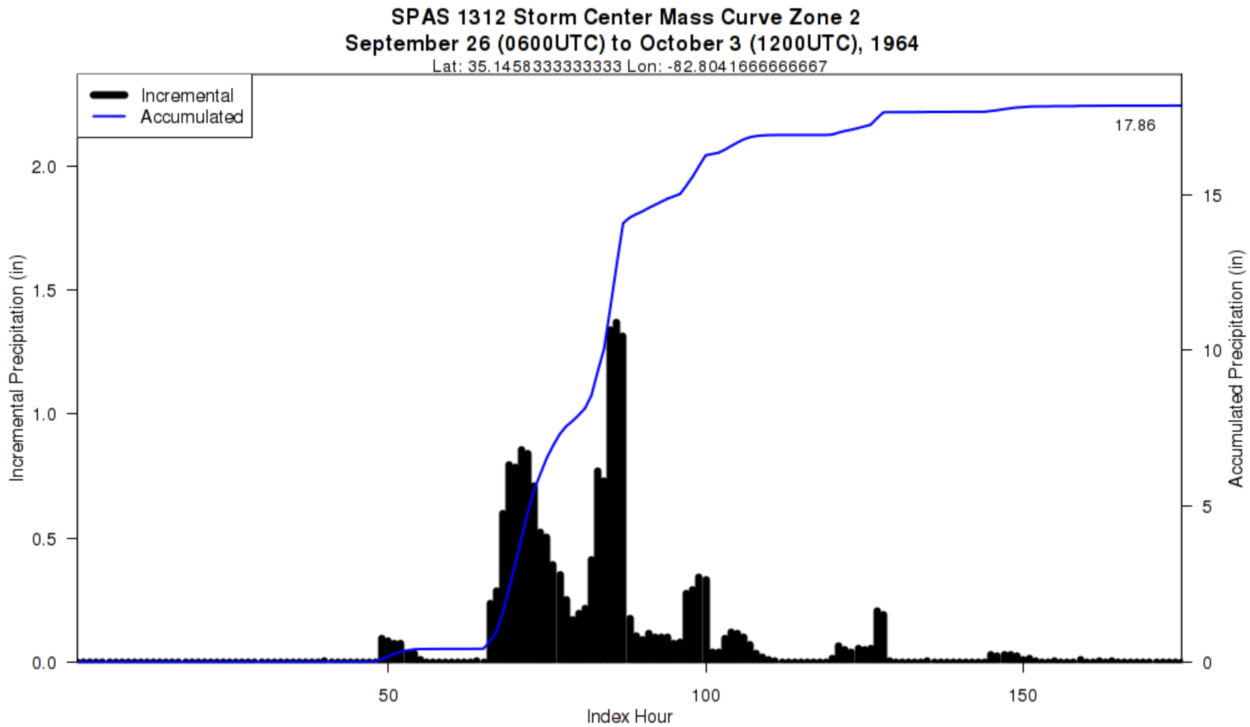
Depth-Area-Duration (DAD) analysis: Yes

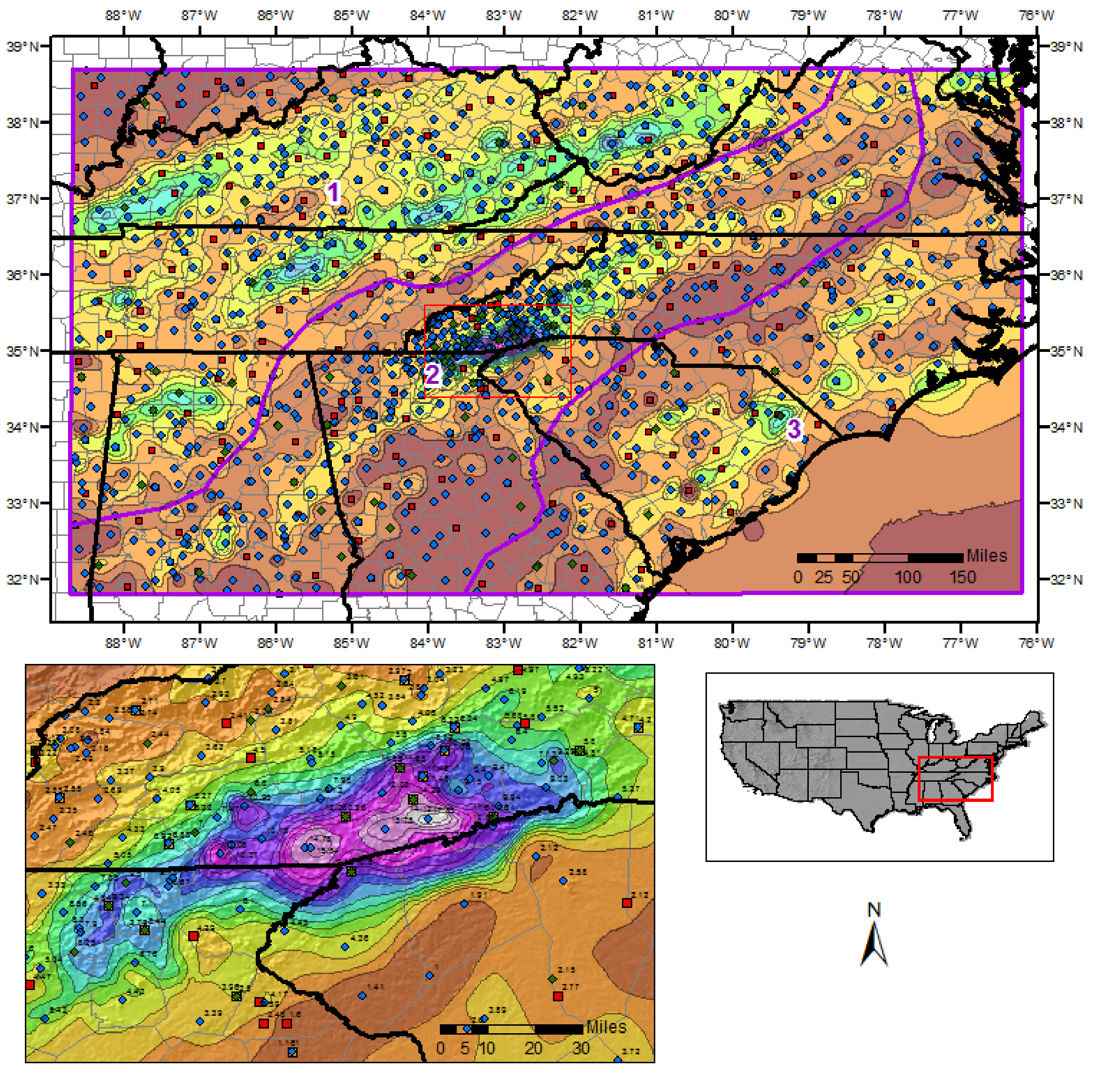
Reliability of Results: In addition to the 314 hourly stations from NCDC used in the whole project area, fourteen additional hourly stations were digitized from the TVA report adding more certainty to the timing of the storm center. The extent and magnitude of the rainfall is moderately reliable given the surprising large number of daily rain gauges available.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1312A_2	-82.8042	35.1458	2,271	15-Sep	74.50	2.79	0.54	71	2.250	78.11	3.29	0.61	78	2.680	1.191

Storm 1312A - September 26 (0600 UTC) - October 3 (1200 UTC), 1964											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	3	6	12	18	24	36	48	168	175	Total
0.3	3.92	6.38	7.23	7.94	11.75	13.94	15.88	16.49	17.86	17.86	17.86
1	3.82	6.24	7.09	7.79	11.52	13.70	15.86	16.24	17.83	17.83	17.83
10	3.63	5.90	6.69	7.44	11.46	13.35	15.16	16.10	17.47	17.47	17.47
25	3.37	5.48	6.00	7.14	11.04	12.97	14.74	15.48	16.84	16.84	16.84
50	3.14	5.11	5.78	6.79	10.72	12.29	13.94	14.44	16.34	16.34	16.34
100	2.88	4.67	5.22	6.39	10.31	11.91	13.26	14.10	15.72	15.72	15.72
150	2.66	4.36	4.97	6.38	10.01	11.55	13.01	13.58	15.30	15.30	15.30
200	2.49	4.07	4.74	6.29	9.77	11.20	12.58	13.45	15.01	15.01	15.01
300	2.12	3.82	4.47	6.18	9.42	10.83	12.11	12.91	14.47	14.47	14.47
400	1.87	3.53	4.21	5.98	9.12	10.44	11.62	12.40	14.02	14.02	14.02
500	1.82	3.17	3.98	5.86	8.82	10.09	11.35	12.04	13.65	13.65	13.65
1,000	1.40	2.49	3.25	5.24	7.71	8.89	9.99	10.45	12.17	12.17	12.17
2,000	1.07	1.88	2.60	4.28	6.05	6.93	8.34	9.12	10.35	10.35	10.35
5,000	0.77	1.43	1.96	2.78	3.99	5.02	5.58	5.73	7.86	7.86	7.86
10,000	0.50	1.02	1.40	2.34	3.27	3.75	4.62	5.06	6.59	6.59	6.59
20,000	0.15	0.61	1.08	1.75	2.19	2.71	3.34	3.51	5.12	5.12	5.12
50,000	0.13	0.33	0.59	1.06	1.32	1.55	2.31	2.55	3.72	3.72	3.72
100,000	0.07	0.20	0.36	0.58	0.82	1.04	1.50	1.68	2.42	2.42	2.42
108,165	0.06	0.18	0.33	0.58	0.78	1.02	1.38	1.59	2.25	2.25	2.25




SPAS 1312 Storm Center Mass Curve Zone 2
September 26 (0600UTC) to October 3 (1200UTC), 1964
Lat: 35.1458333333333 Lon: -82.8041666666667
Incremental
Accumulated
17.86
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
50
100
150



Total 175-hour Precipitation (inches)
September 26, 1964 0600 UTC - October 3, 1964 1200 UTC
SPAS #1312A

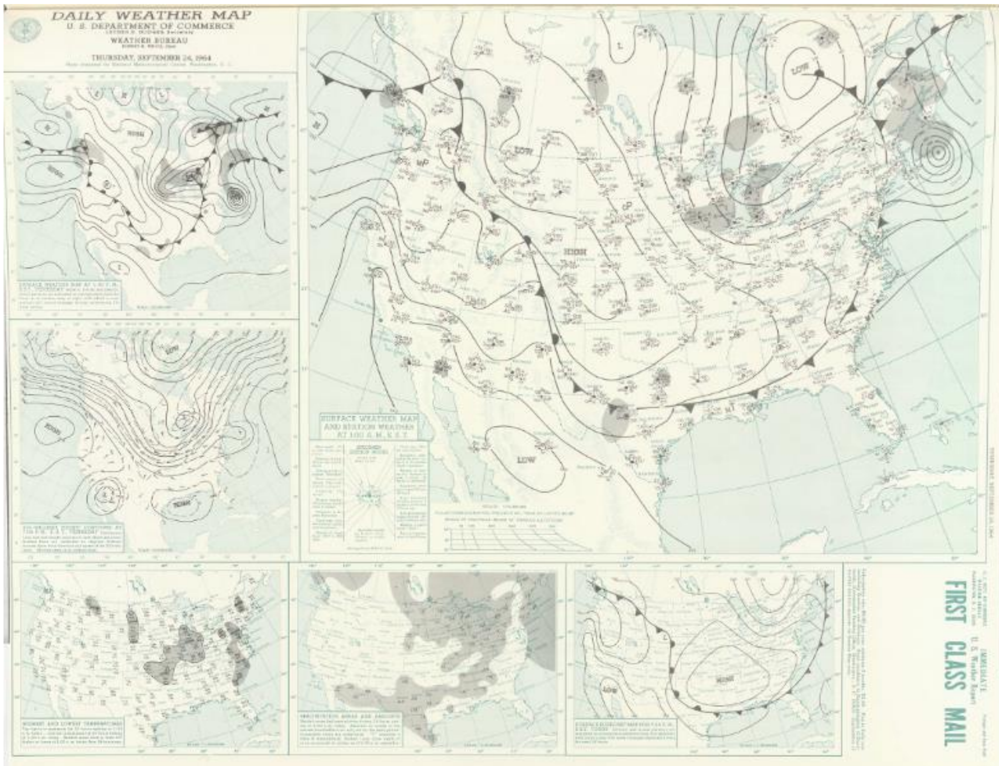
Precipitation (inches)

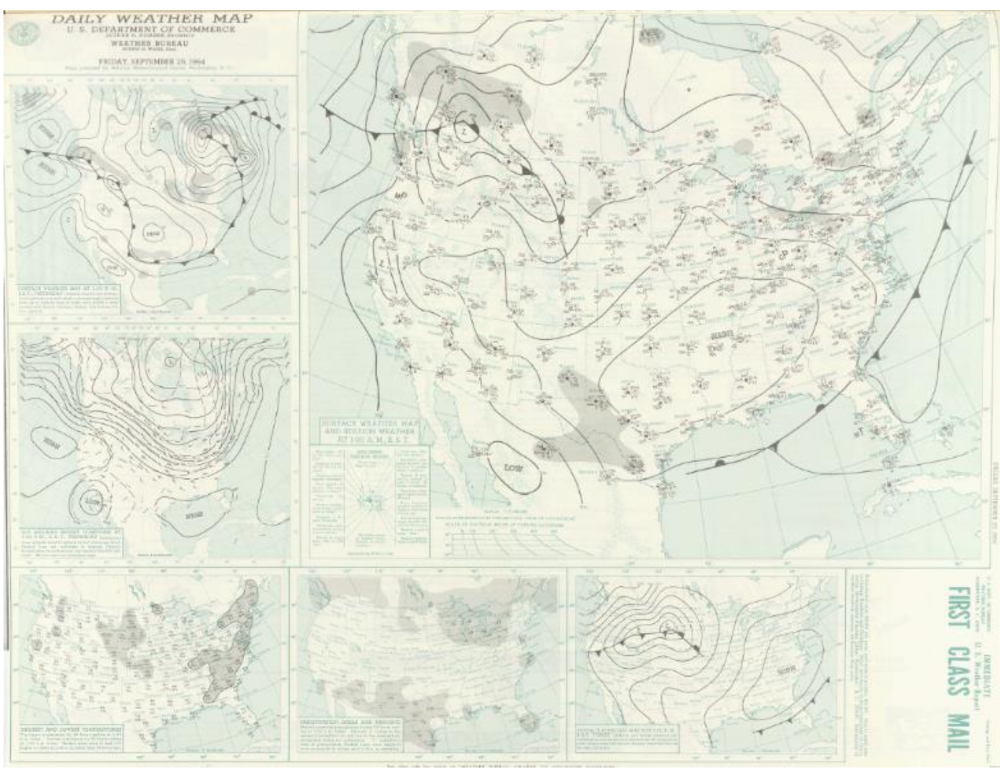
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 12.00
12.01 - 14.00
14.01 - 16.00
16.01 - 18.00

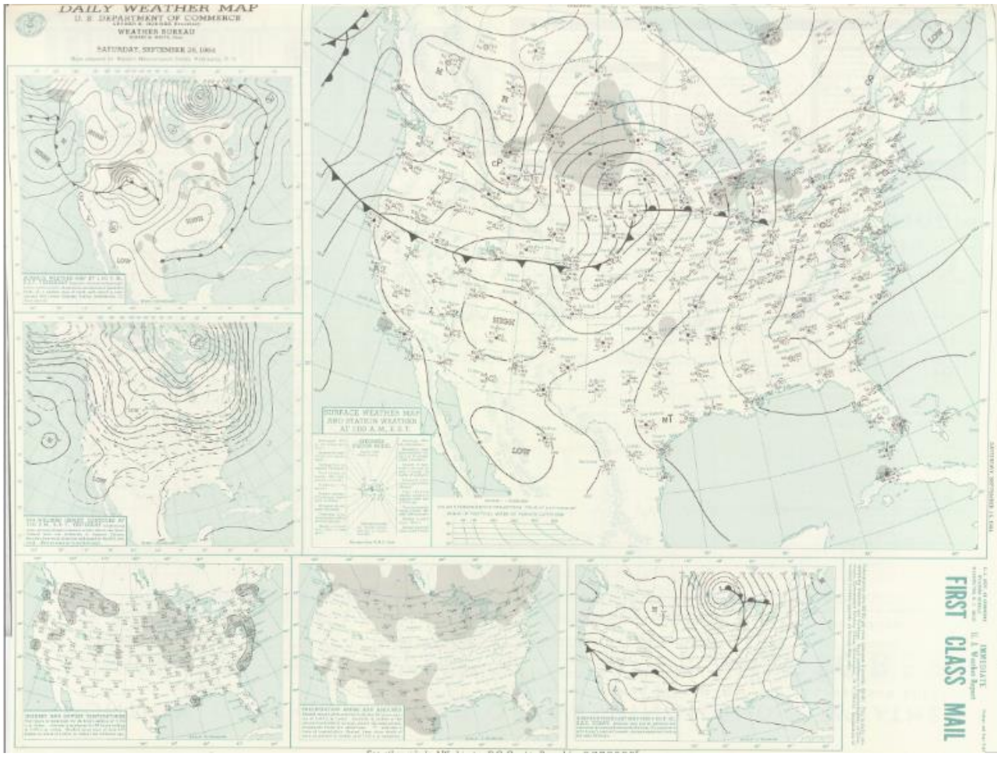
Stations

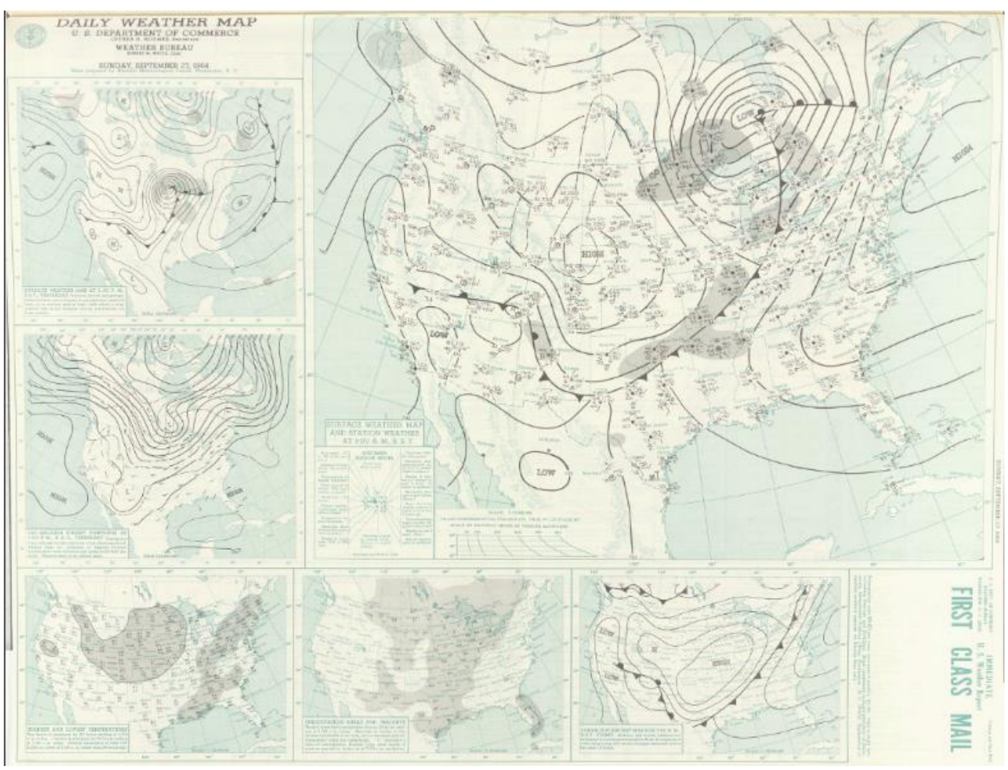
Daily
Hourly
Hourly Pseudo
Supplemental

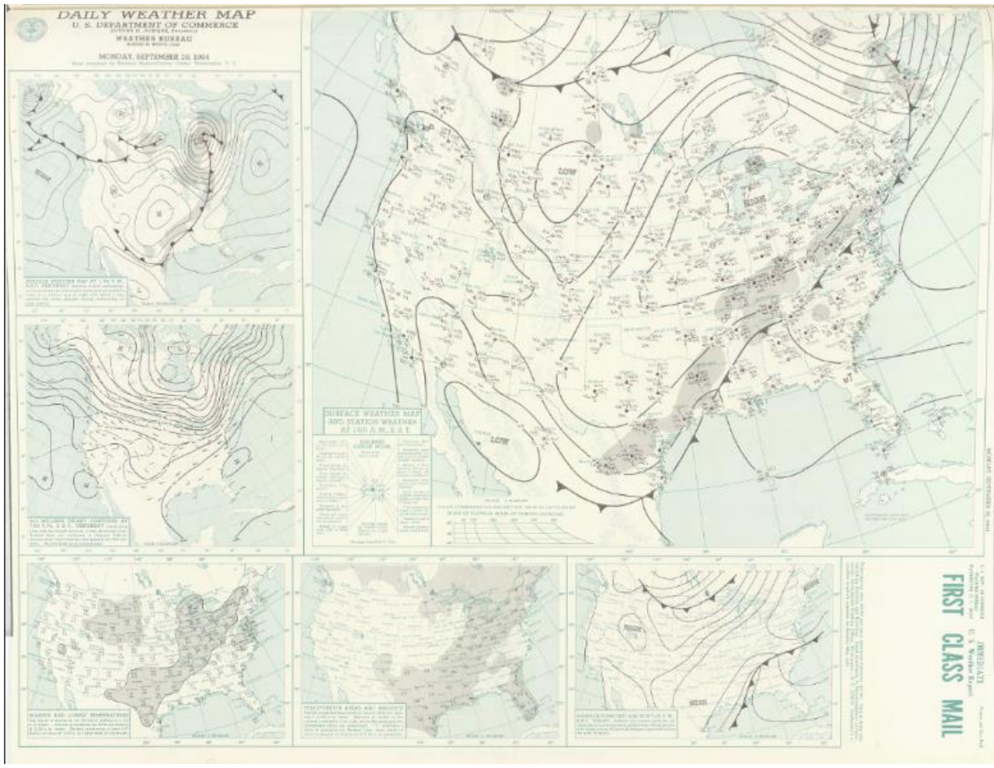
TWP 02/20/2014

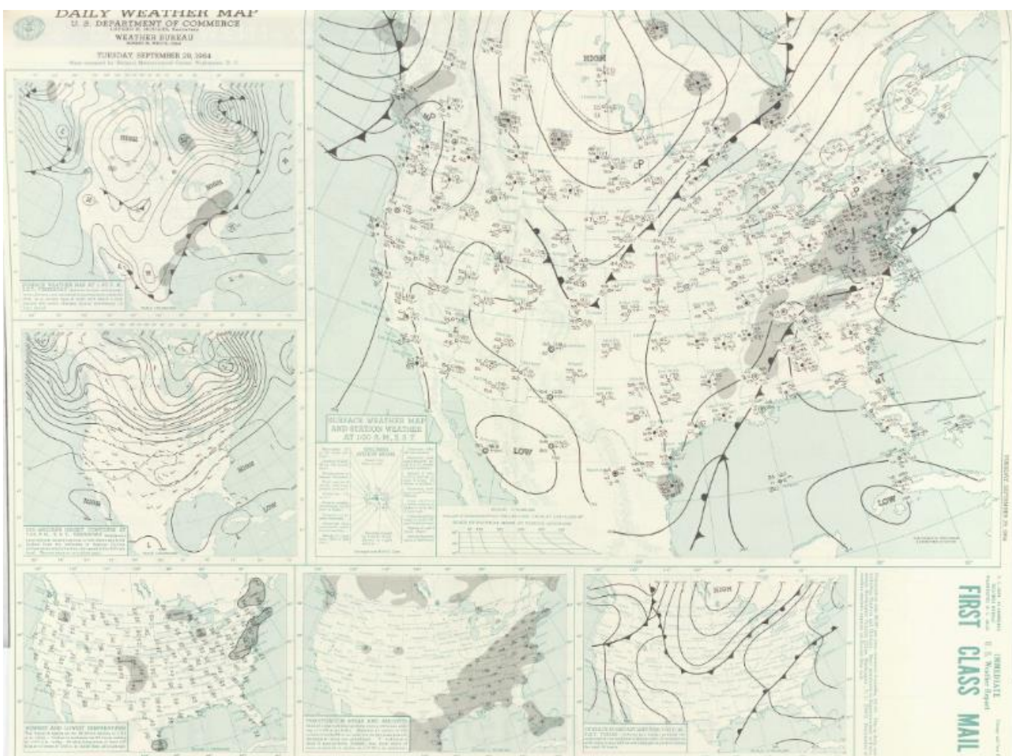

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
THURSDAY, SEPTEMBER 24, 1964
LOW
HIGH
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
FIRST CLASS MAIL


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
FRIDAY, SEPTEMBER 25, 1964
LOW
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
FIRST CLASS MAIL

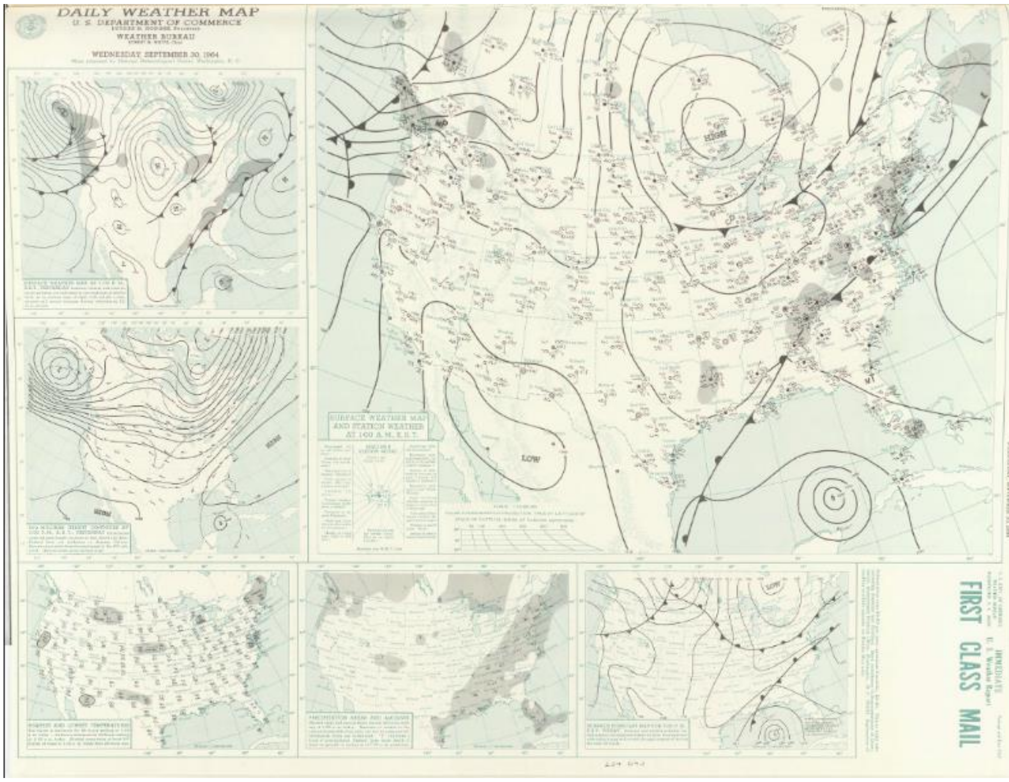

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
SATURDAY, SEPTEMBER 26, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
FIRST CLASS MAIL

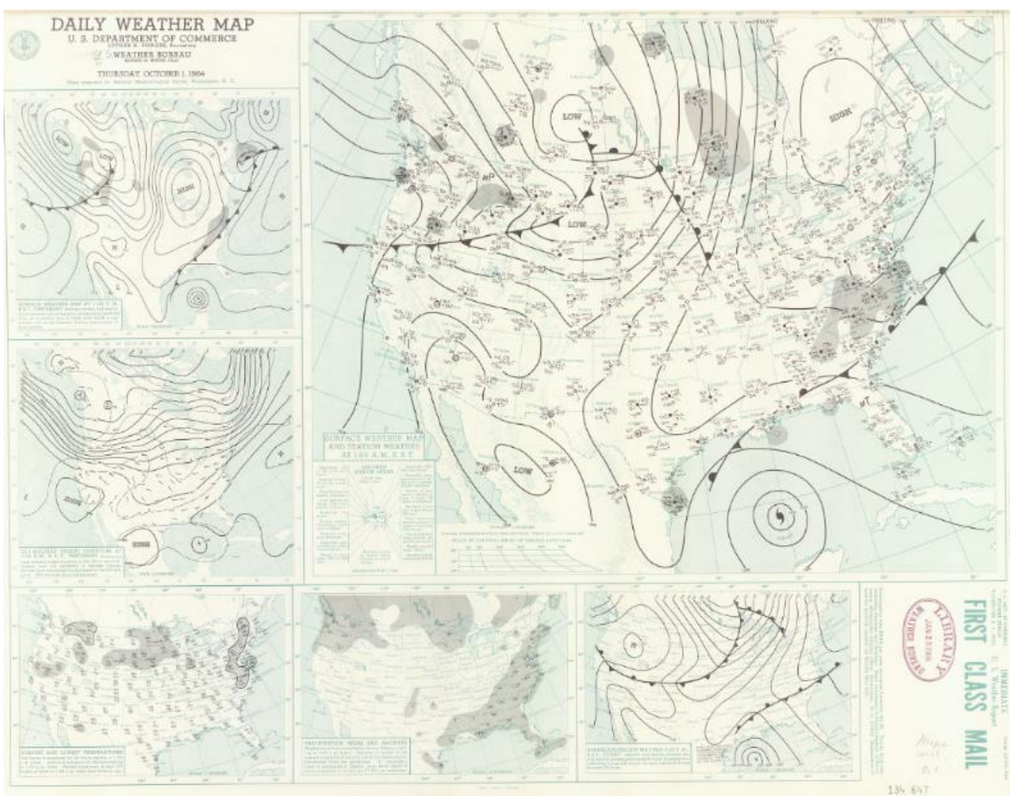

DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
SUNDAY, SEPTEMBER 27, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M., E.S.T.
HIGH
LOW
FIRST CLASS MAIL

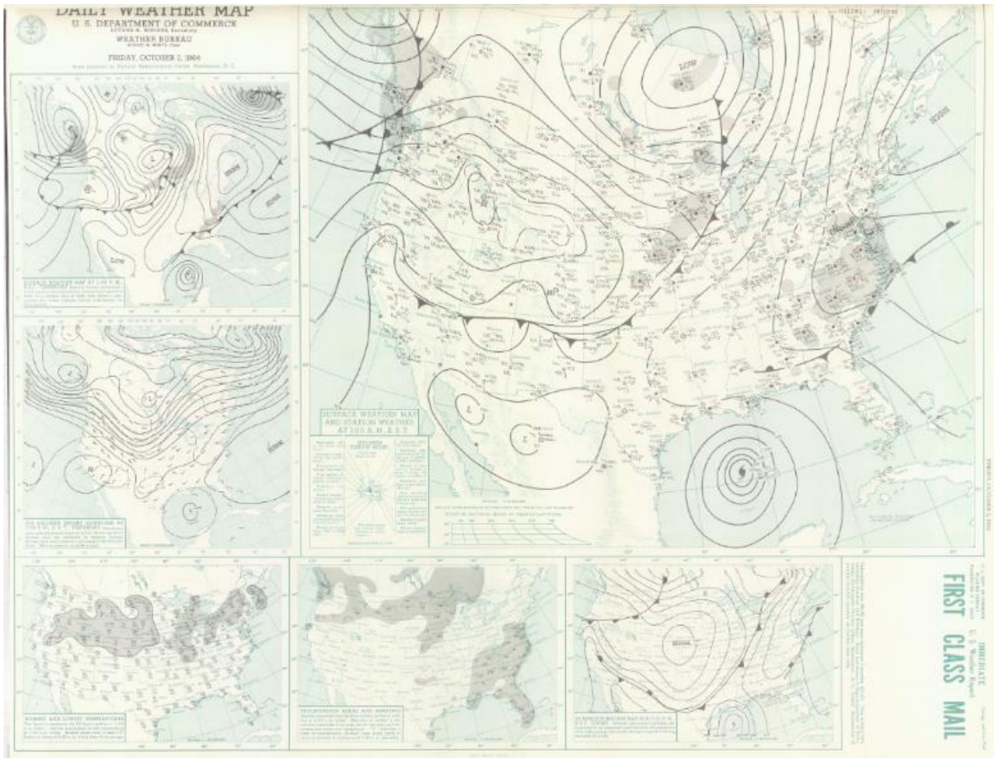


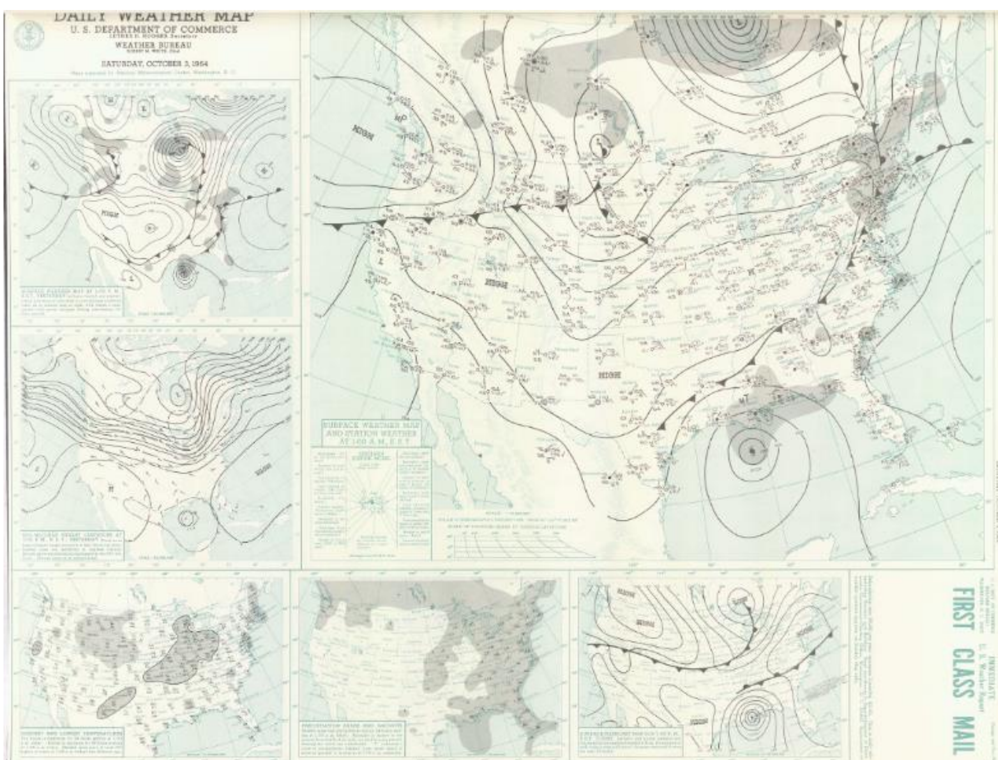


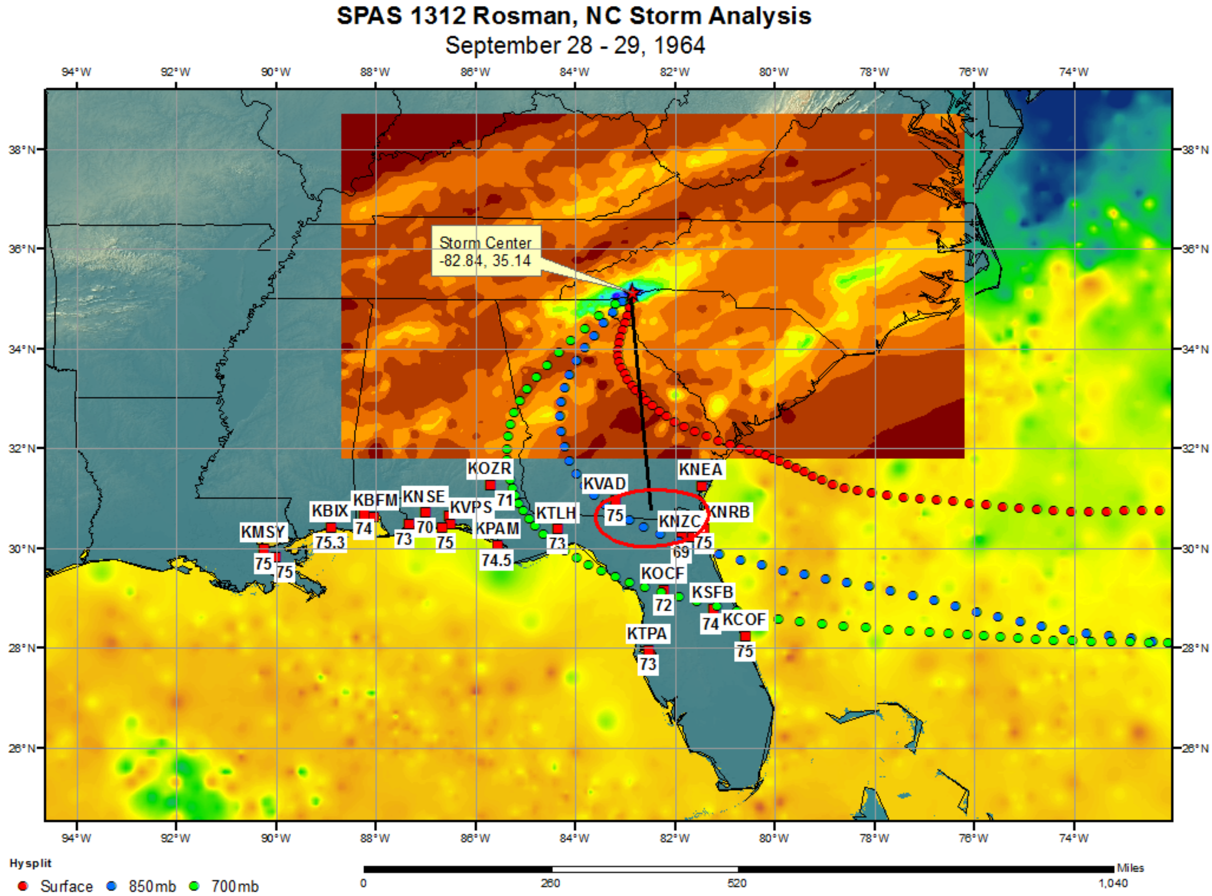
See other side for "WEATHER of AUGUST, 1964."


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
WEDNESDAY SEPTEMBER 30, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M. E.S.T.
LOW
FIRST CLASS MAIL


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
THURSDAY OCTOBER 1, 1964
SURFACE WEATHER MAP AND STATION WEATHER AT 1:00 A.M. E.S.T.
LOW
FIRST CLASS MAIL


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
FRIDAY, OCTOBER 2, 1964
FIRST CLASS MAIL


DAILY WEATHER MAP
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
SATURDAY, OCTOBER 3, 1964
FIRST CLASS MAIL


SPAS 1312 Rosman, NC Storm Analysis
September 28 - 29, 1964
Storm Center
-82.84, 35.14
KOZR
KNEA
KVAD
KBFM
KNSE
KBIX
KVPS
KTLH
KNRB
KNZC
KMSY
KPAM
KOCF
KSFB
KCOF
KTPA
Hysplit
Surface
850mb
700mb
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1380_1 SPAS Analysis

General Storm Location: Tennessee Valley (-88.6, 37.4, 34.0, -79.9)

Storm Dates: August 21 – August 24, 1967

Event: Mesoscale Storms with Embedded Convection (MEC)

DAD Zone 1

Latitude: 34.7958

Longitude: -83.6958

Max. Grid/Radar Rainfall Amount: 18.42"

Max. Observed Rainfall Amount: 18.42"

Number of Stations: 490

SPAS Version: 9.5

Base Map Used: Mean annual maximum 48-hour precipitation associated with MECs

Spatial resolution: 0.2690

Radar Included: No

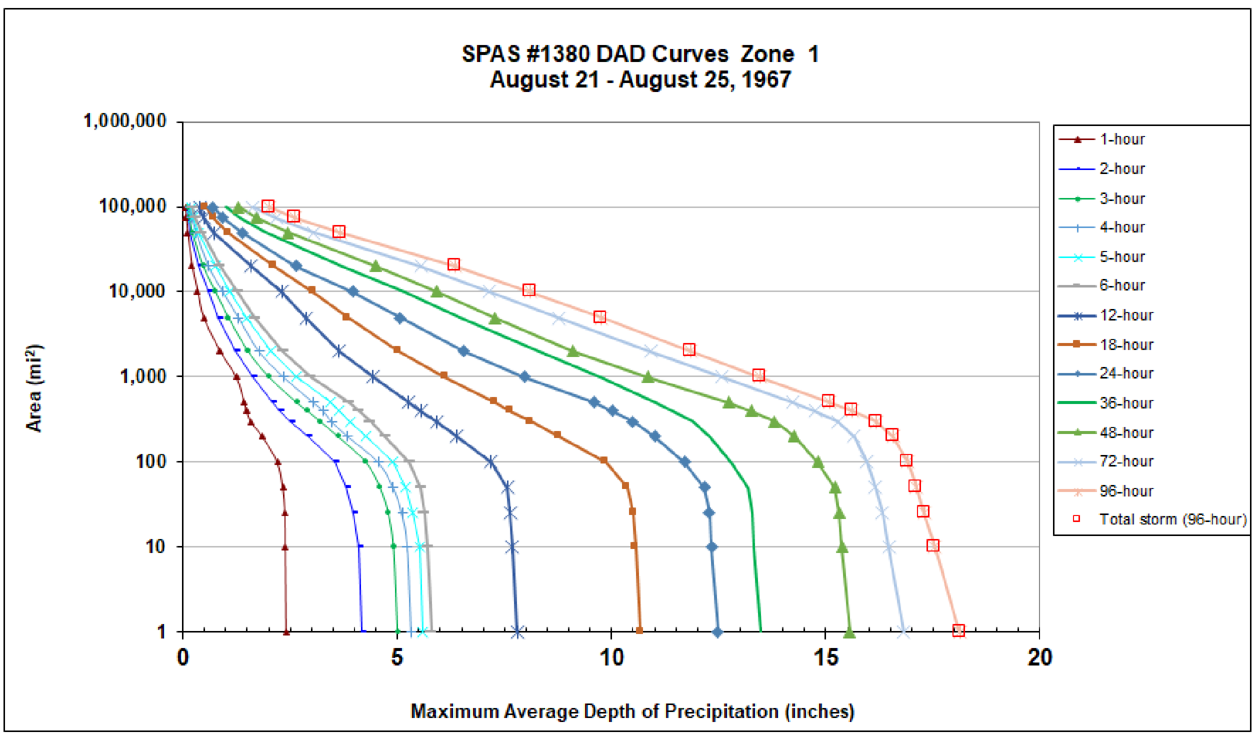
Depth-Area-Duration (DAD) analysis: Yes

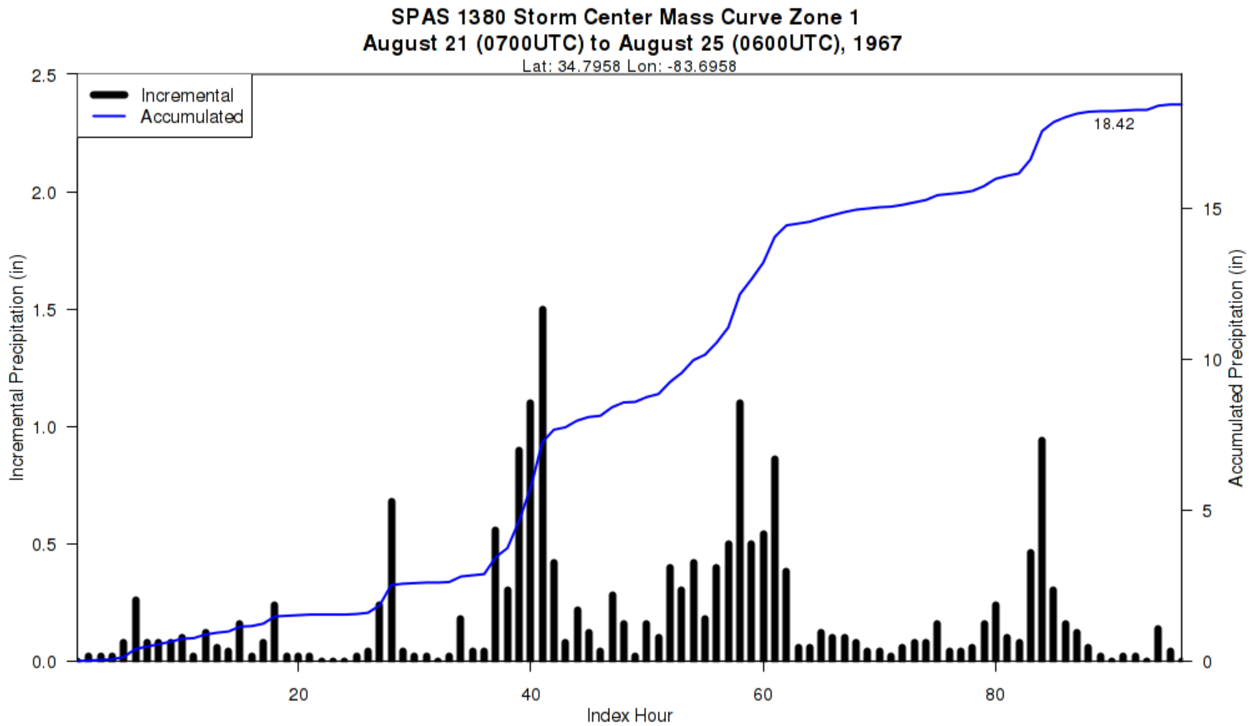
Reliability of results: In addition to the NCDC stations, seventeen supplemental stations were added to ensure the data matches what can actually occur and that the data more closely resemble reports from this storm. Due to the orientation and integrity of the station data, no additional stations were digitized. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the various reports, this analysis is deemed quite reliable.

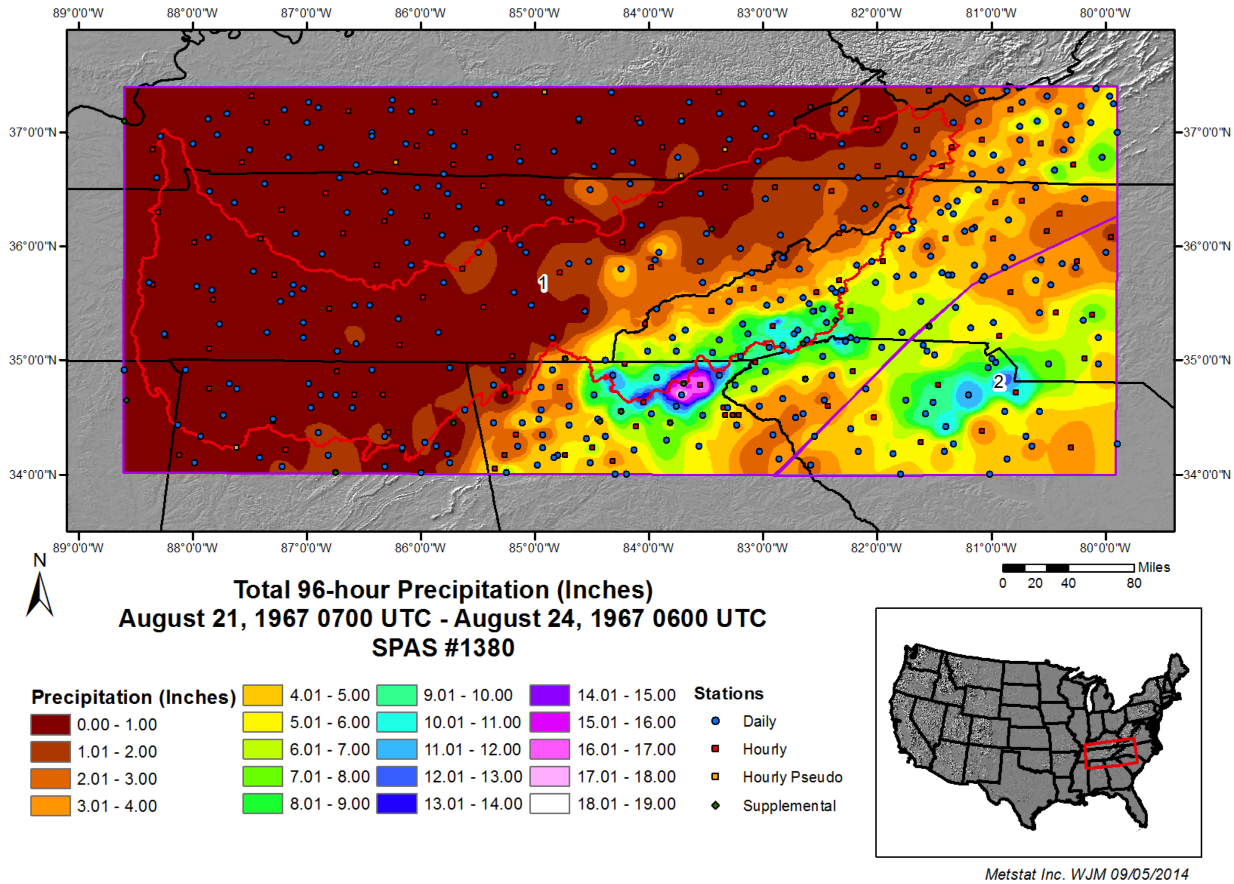
						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1380_1	-83.6958	34.7958	3,686	7-Aug	73.50	2.67	0.81	69	1.860	79.85	3.60	1.00	82	2.600	1.398

Storm 1380 - August 21 (0700 UTC) - August 25 (0600 UTC), 1967
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

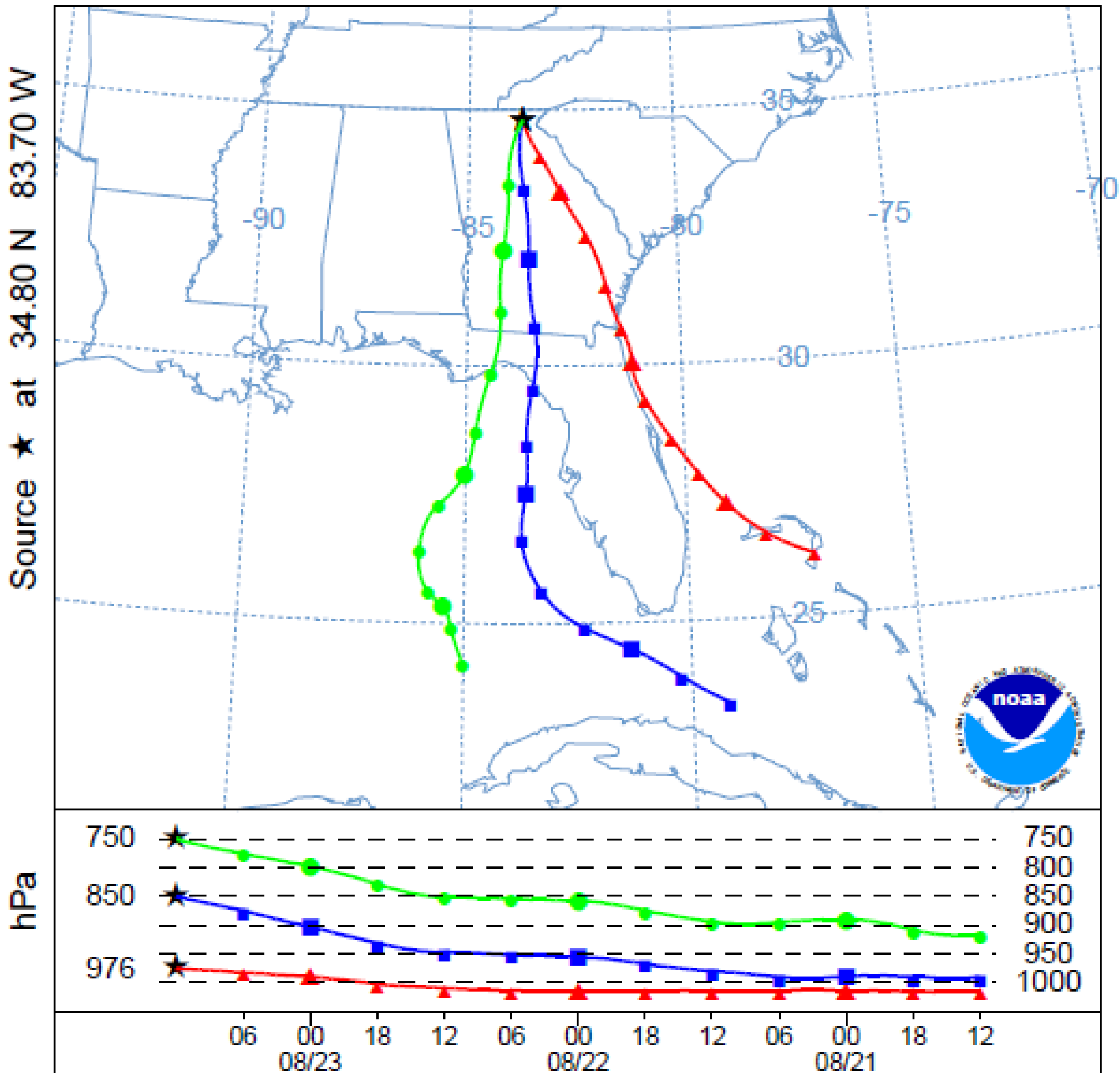
Area (mi^2)	Duration (hours)													
	1	2	3	4	5	6	12	18	24	36	48	72	96	Total
0.4	2.42	4.18	5.04	5.37	5.63	5.83	7.83	10.72	12.54	13.55	15.63	16.96	18.33	18.33
1	2.41	4.16	5.01	5.33	5.60	5.80	7.80	10.68	12.48	13.49	15.56	16.82	18.12	18.12
10	2.39	4.10	4.92	5.24	5.51	5.71	7.68	10.56	12.33	13.33	15.38	16.46	17.54	17.54
25	2.38	3.98	4.80	5.11	5.36	5.63	7.64	10.51	12.28	13.27	15.31	16.32	17.30	17.30
50	2.33	3.81	4.61	4.91	5.18	5.55	7.56	10.37	12.16	13.17	15.21	16.16	17.12	17.12
100	2.20	3.53	4.28	4.56	4.91	5.28	7.18	9.87	11.70	12.78	14.82	15.95	16.91	16.91
200	1.85	2.91	3.63	3.85	4.28	4.72	6.39	8.78	11.00	12.29	14.27	15.66	16.57	16.57
300	1.58	2.51	3.22	3.47	3.90	4.38	5.91	8.12	10.50	11.90	13.80	15.28	16.17	16.17
400	1.48	2.26	2.92	3.27	3.65	4.10	5.54	7.64	10.01	11.44	13.25	14.75	15.62	15.62
500	1.43	2.08	2.67	3.05	3.45	3.88	5.27	7.29	9.60	11.03	12.72	14.24	15.10	15.10
1,000	1.24	1.62	2.02	2.35	2.65	2.98	4.44	6.11	7.97	9.75	10.84	12.58	13.45	13.45
2,000	0.87	1.23	1.53	1.77	2.05	2.33	3.64	5.03	6.55	8.32	9.10	10.91	11.85	11.85
5,000	0.48	0.81	1.07	1.29	1.47	1.68	2.86	3.85	5.06	6.48	7.26	8.76	9.77	9.77
10,000	0.34	0.58	0.77	0.93	1.09	1.27	2.30	3.03	3.96	5.18	5.93	7.16	8.09	8.09
20,000	0.21	0.36	0.48	0.59	0.75	0.86	1.59	2.13	2.64	3.71	4.50	5.55	6.36	6.36
50,000	0.10	0.17	0.22	0.30	0.36	0.43	0.72	1.04	1.37	1.93	2.45	3.05	3.66	3.66
75,000	0.07	0.12	0.16	0.20	0.24	0.29	0.49	0.72	0.93	1.35	1.72	2.17	2.62	2.62
99,877	0.05	0.09	0.13	0.15	0.19	0.22	0.38	0.54	0.70	1.02	1.30	1.63	2.01	2.01




SPAS 1380 Storm Center Mass Curve Zone 1
August 21 (0700UTC) to August 25 (0600UTC), 1967
Lat: 34.7958 Lon: -83.6958
Incremental
Accumulated
18.42
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
40
60
80

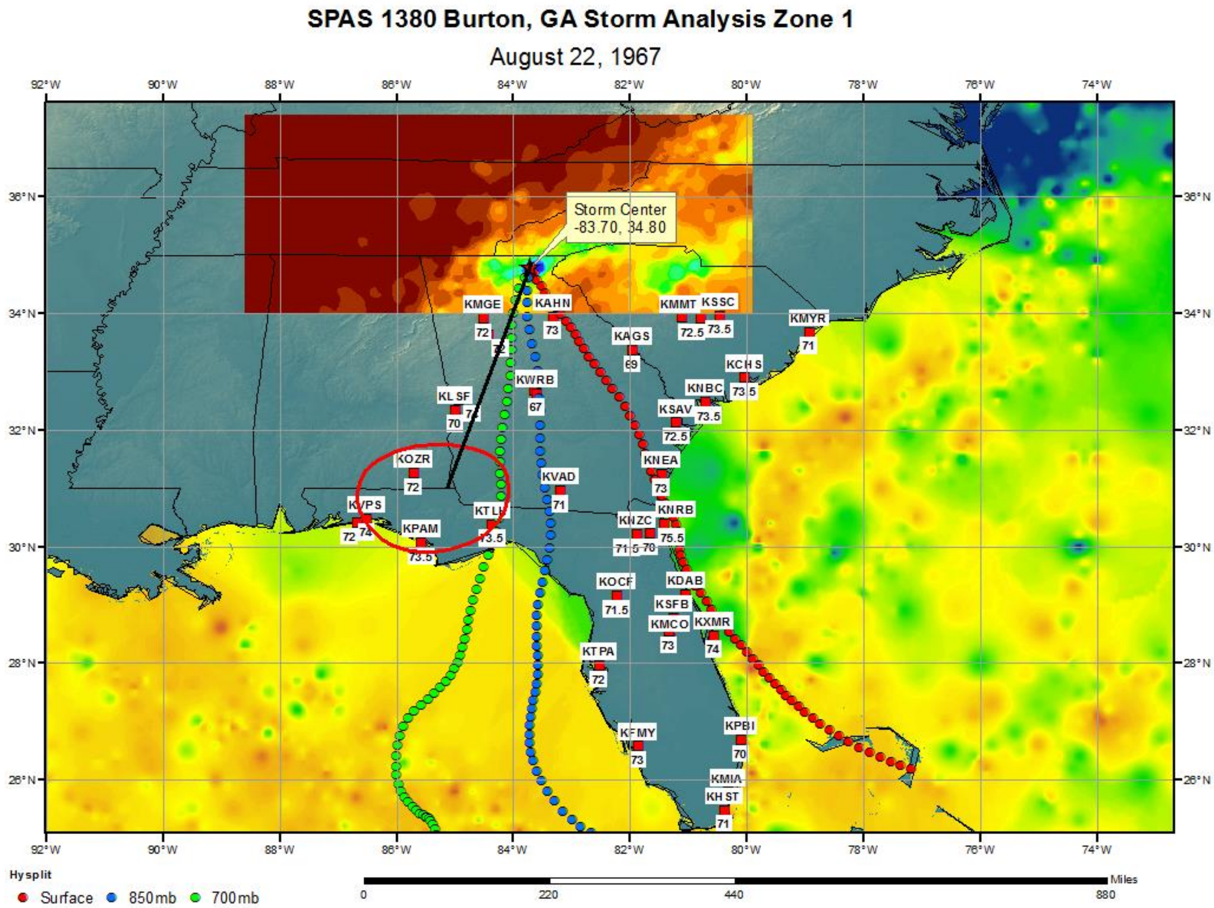

89°0'0"W
88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
37°0'0"N
36°0'0"N
35°0'0"N
34°0'0"N
1
2
N
Miles
0 20 40 80
Total 96-hour Precipitation (Inches)
August 21, 1967 0700 UTC - August 24, 1967 0600 UTC
SPAS #1380
Precipitation (Inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
Stations
Daily
Hourly
Hourly Pseudo
Supplemental
Metstat Inc. WJM 09/05/2014

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 23 Aug 67
CDC1 Meteorological Data



Job ID: 184368 Job Start: Sat Nov 8 20:07:36 UTC 2014
Source 1 lat.: 34.800000 lon.: -83.700000 hgts: 0, 1190, 2240 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Aug 2067 - reanalysis


SPAS 1380 Burton, GA Storm Analysis Zone 1
August 22, 1967
Storm Center
-83.70, 34.80
Hysplit
Surface
850mb
700mb
Miles
0
220
440
880

Storm Precipitation Analysis System (SPAS) For Storm #1357_1 SPAS Analysis

General Storm Location: Tennessee Valley (-91.0, 37.3, 33.0, -81.1)

Storm Dates: March 14 – March 17, 1973

Event: Mid-latitude cyclone (MLC)

DAD Zone 1

Latitude: 34.8375

Longitude: -88.3958

Max. Grid/Radar Rainfall Amount: 12.15”

Max. Observed Rainfall Amount: 12.11” (Glen, MS)

Number of Stations: 664

SPAS Version: 9.5

Base Map Used: Mean annual maximum 48-hour precipitation associated with MLCs

Spatial resolution: 0.2707

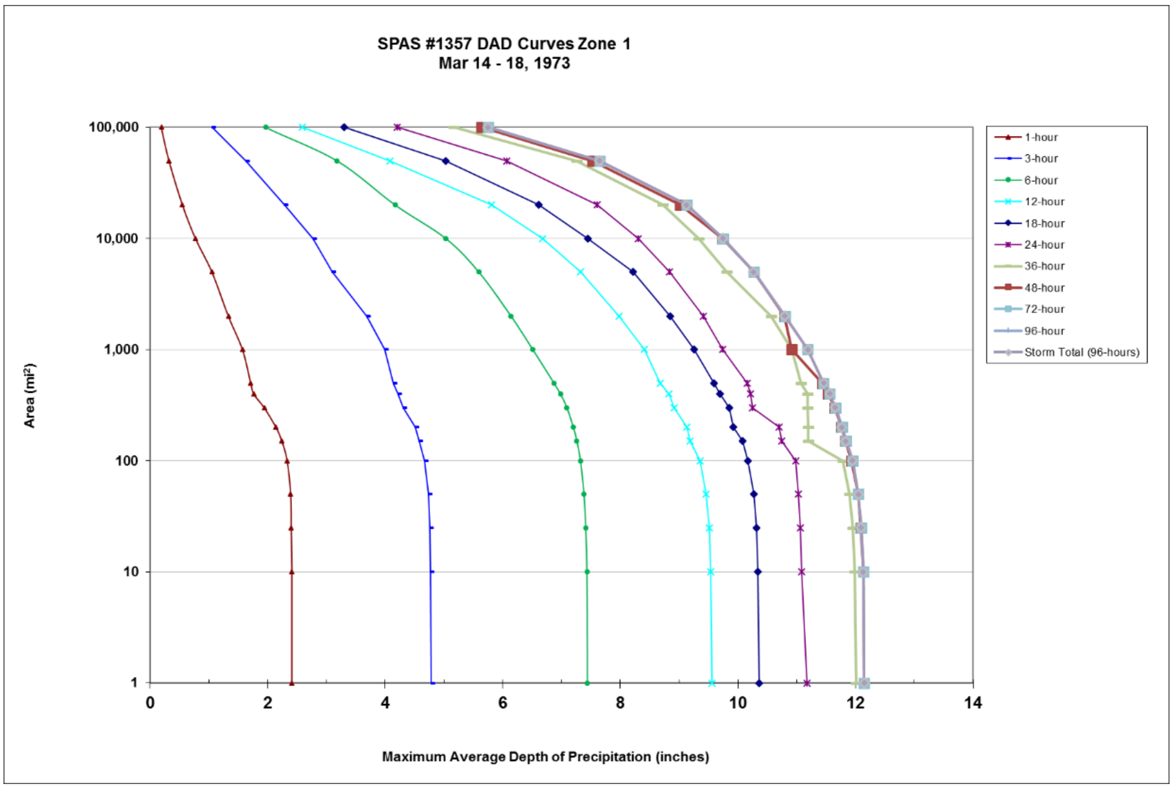
Radar Included: No

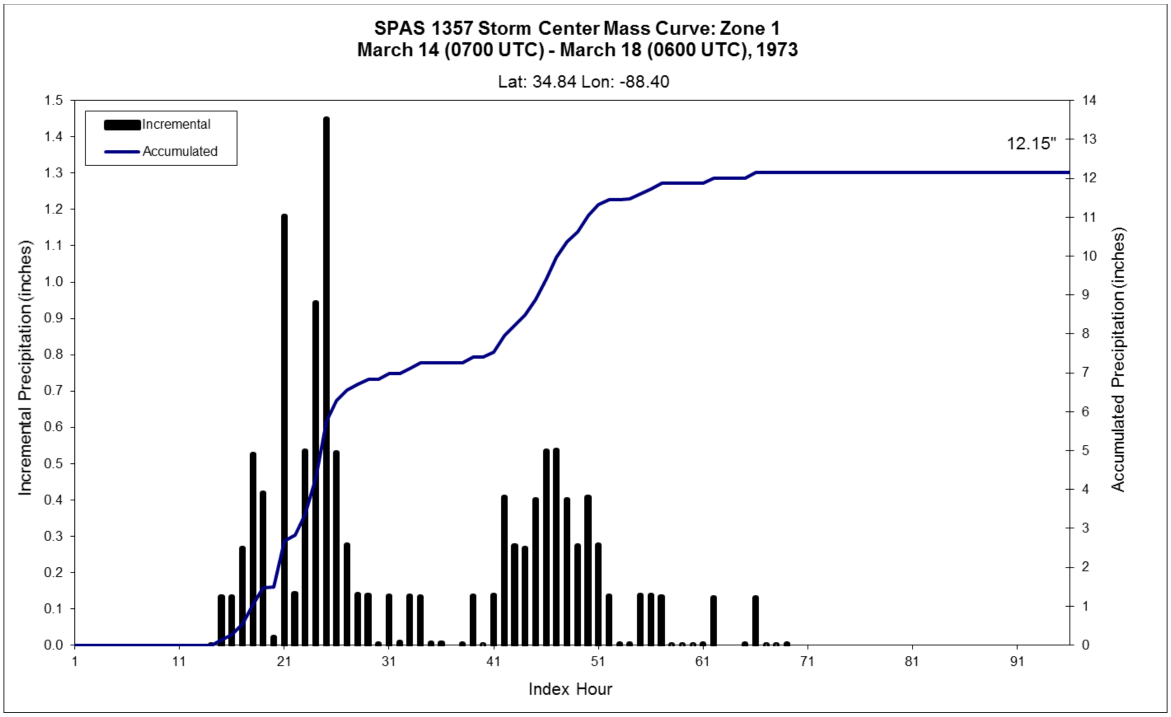
Depth-Area-Duration (DAD) analysis: Yes

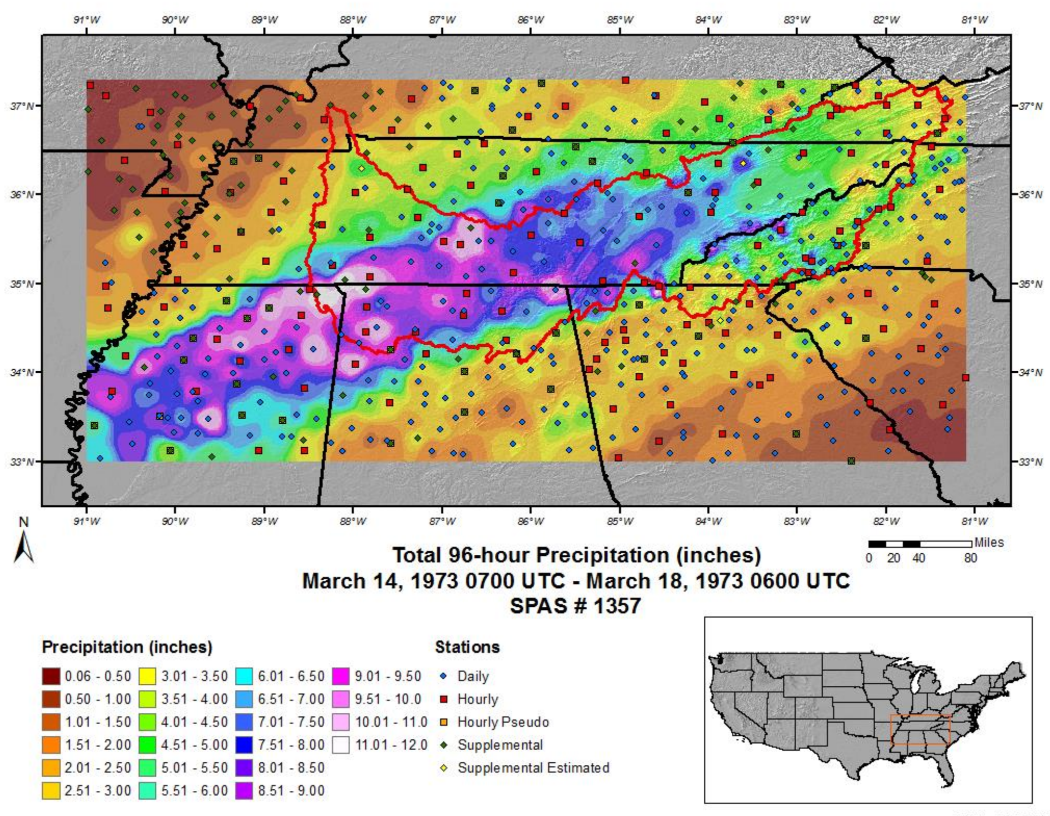
Reliability of results: In addition to the NCDC stations, there were three supplemental stations added to fill in where there was a lack of observations, in order to create a more realistic precipitation pattern. There were also four daily and seven hourly stations digitized and added from the TVA report. The added TVA data helped to enhance the accuracy of the timing of the storm center. Overall, this storm analysis is found to be reliable. Comparing the SPAS analysis to the TVA isohyetal map further validates the consistency of the magnitude and extent of the rainfall.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1357_1	-88.3958	34.8375	591	600	1-Apr	69.00	2.14	0.13	60	2.010	73.71	73.5	2.67	0.15	69	2.520	1.254

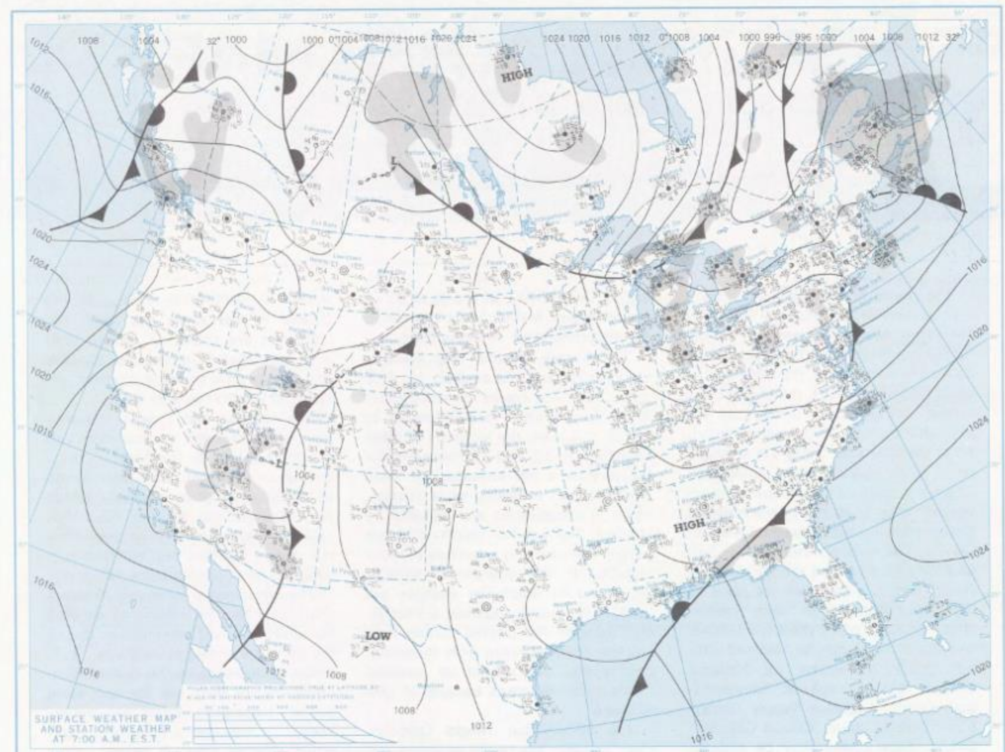
Storm 1357 Zone 1 - Mar 14 (0700 UTC) - Mar 18 (0600 UTC), 1973										
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
	Duration (hours)									
areasqmi	1	6	12	18	24	36	48	72	96	Total
0.3	2.41	4.78	7.44	9.56	10.36	11.38	12.01	12.15	12.15	12.15
1	2.41	4.78	7.44	9.56	10.36	11.17	12.01	12.15	12.15	12.15
10	2.41	4.77	7.43	9.54	10.34	11.08	11.99	12.13	12.13	12.13
25	2.40	4.76	7.41	9.51	10.32	11.06	11.95	12.09	12.10	12.10
50	2.39	4.73	7.38	9.46	10.27	11.03	11.90	12.04	12.05	12.05
100	2.33	4.67	7.32	9.36	10.17	10.98	11.79	11.93	11.95	11.95
150	2.24	4.58	7.26	9.19	10.08	10.75	11.20	11.83	11.84	11.84
200	2.14	4.51	7.20	9.13	9.92	10.70	11.20	11.76	11.77	11.77
300	1.94	4.31	7.09	8.91	9.85	10.25	11.19	11.65	11.66	11.66
400	1.76	4.22	6.98	8.82	9.70	10.21	11.19	11.54	11.56	11.56
500	1.71	4.14	6.87	8.68	9.59	10.16	11.07	11.43	11.46	11.46
1,000	1.57	3.99	6.51	8.41	9.25	9.74	10.91	10.91	11.19	11.19
2,000	1.33	3.68	6.14	7.98	8.85	9.41	10.56	10.79	10.80	10.80
5,000	1.05	3.10	5.59	7.32	8.22	8.84	9.81	10.27	10.27	10.27
10,000	0.77	2.77	5.03	6.68	7.45	8.31	9.33	9.74	9.75	9.75
20,000	0.55	2.28	4.17	5.81	6.61	7.60	8.72	9.02	9.13	9.13
50,000	0.32	1.63	3.18	4.08	5.03	6.07	7.25	7.53	7.65	7.65
100,000	0.19	1.05	1.97	2.59	3.30	4.20	5.17	5.64	5.75	5.75
166,120	0.12	0.67	1.26	1.73	2.28	2.99	3.53	4.03	4.08	4.08



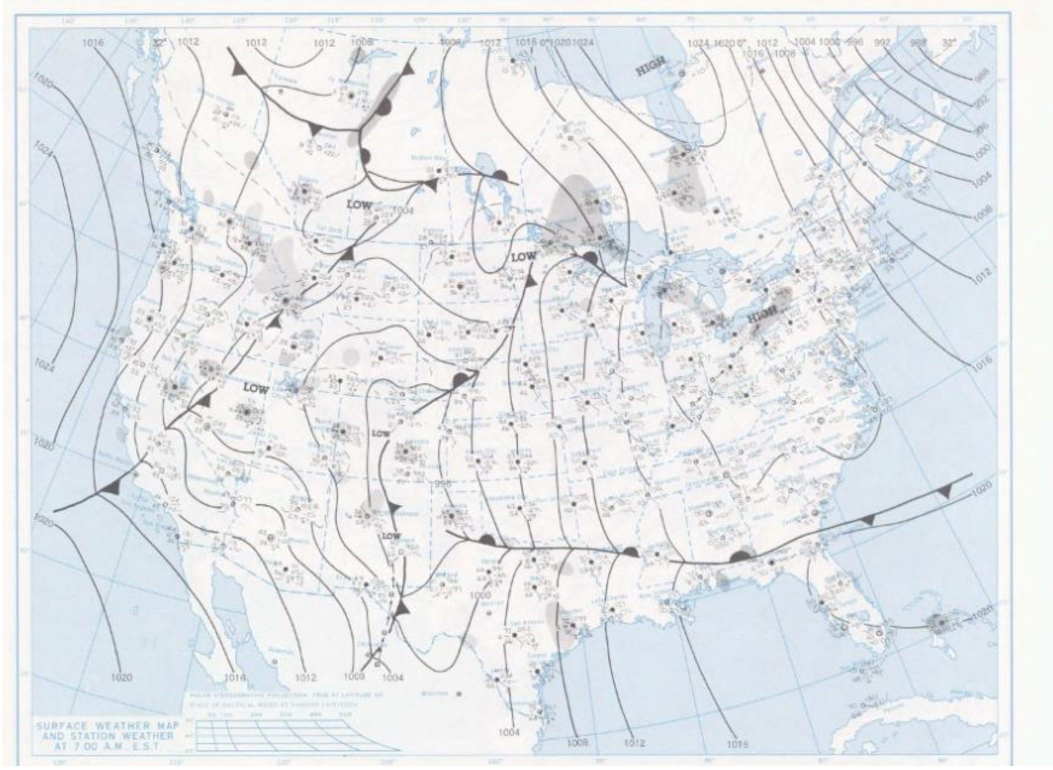

SPAS 1357 Storm Center Mass Curve: Zone 1
March 14 (0700 UTC) - March 18 (0600 UTC), 1973
Lat: 34.84 Lon: -88.40
Incremental
Accumulated
12.15"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour


Total 96-hour Precipitation (inches)
March 14, 1973 0700 UTC - March 18, 1973 0600 UTC
SPAS # 1357
Miles
0 20 40 80
Precipitation (inches)
0.06 - 0.50
0.50 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.0
10.01 - 11.0
11.01 - 12.0
Stations
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Estimated
MetStat Inc. KLL 09/03/2014

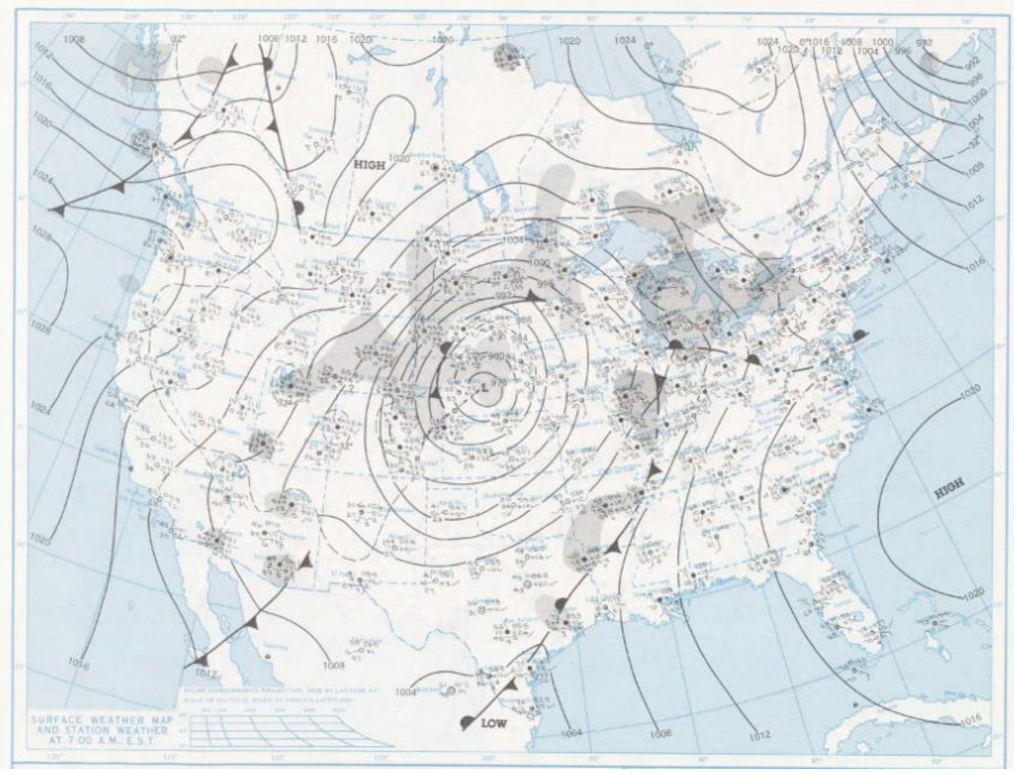
MONDAY, MARCH 12, 1973



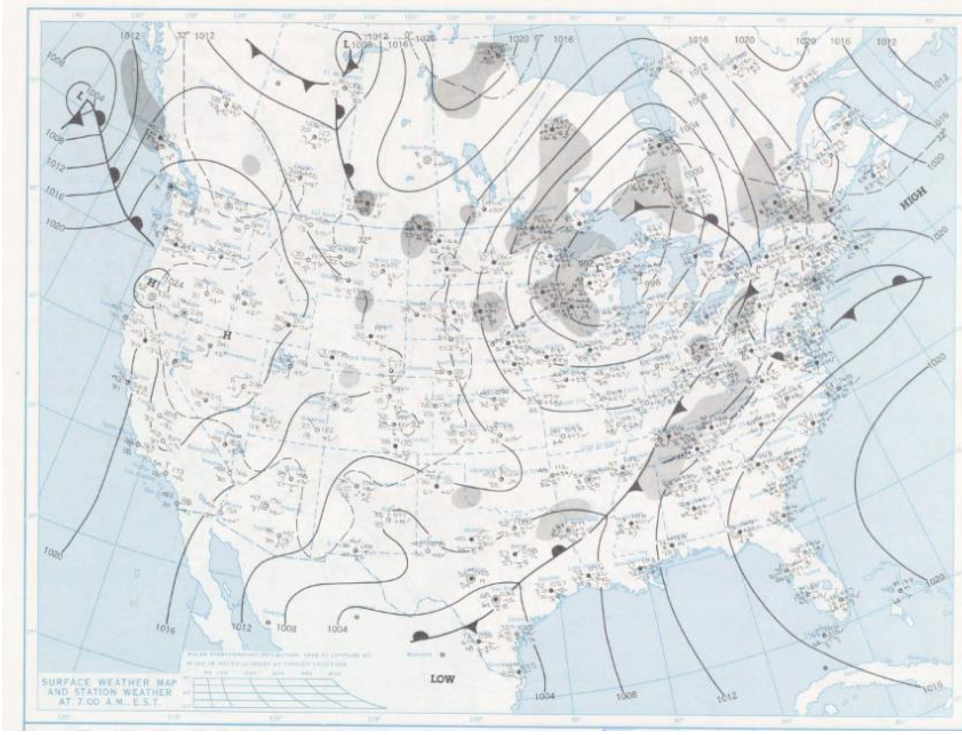
TUESDAY, MARCH 13, 1973



WEDNESDAY, MARCH 14, 1973 Lowest Pressure ever observed in Nebraska

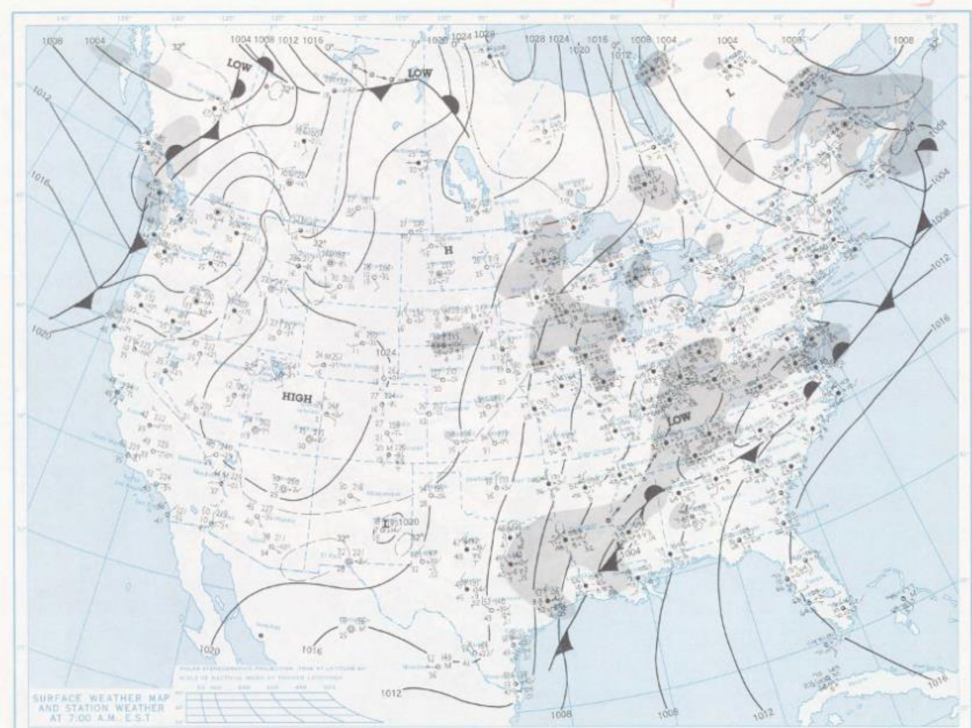


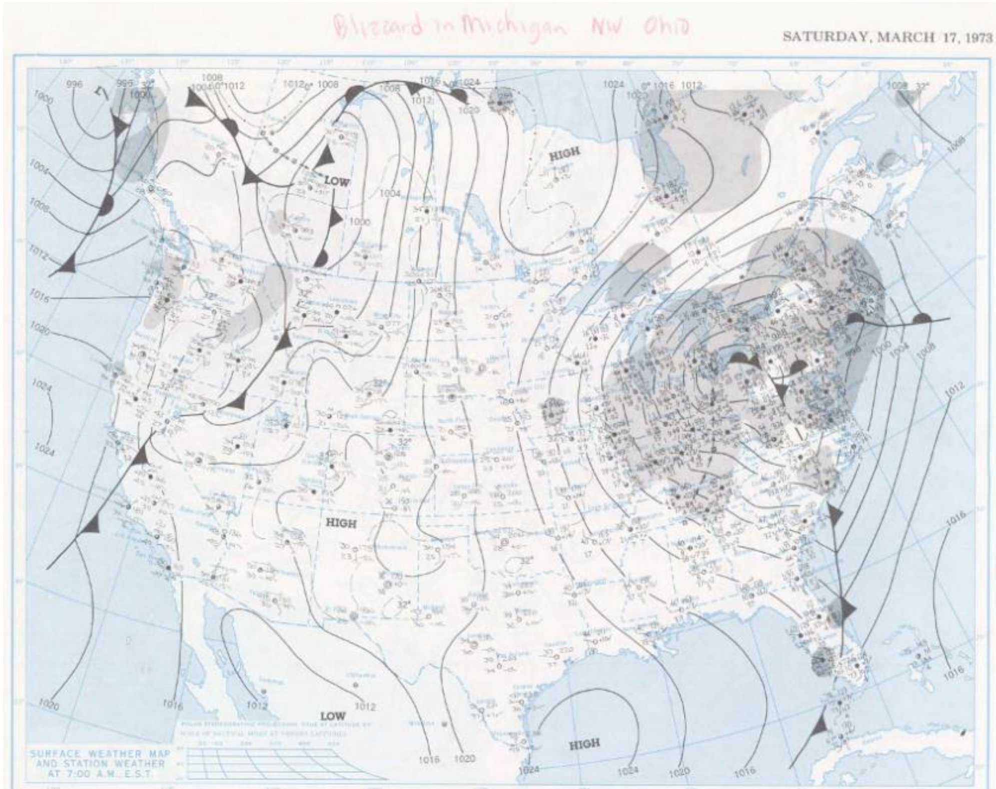
THURSDAY, MARCH 15, 1973



FRIDAY, MARCH 16, 1973

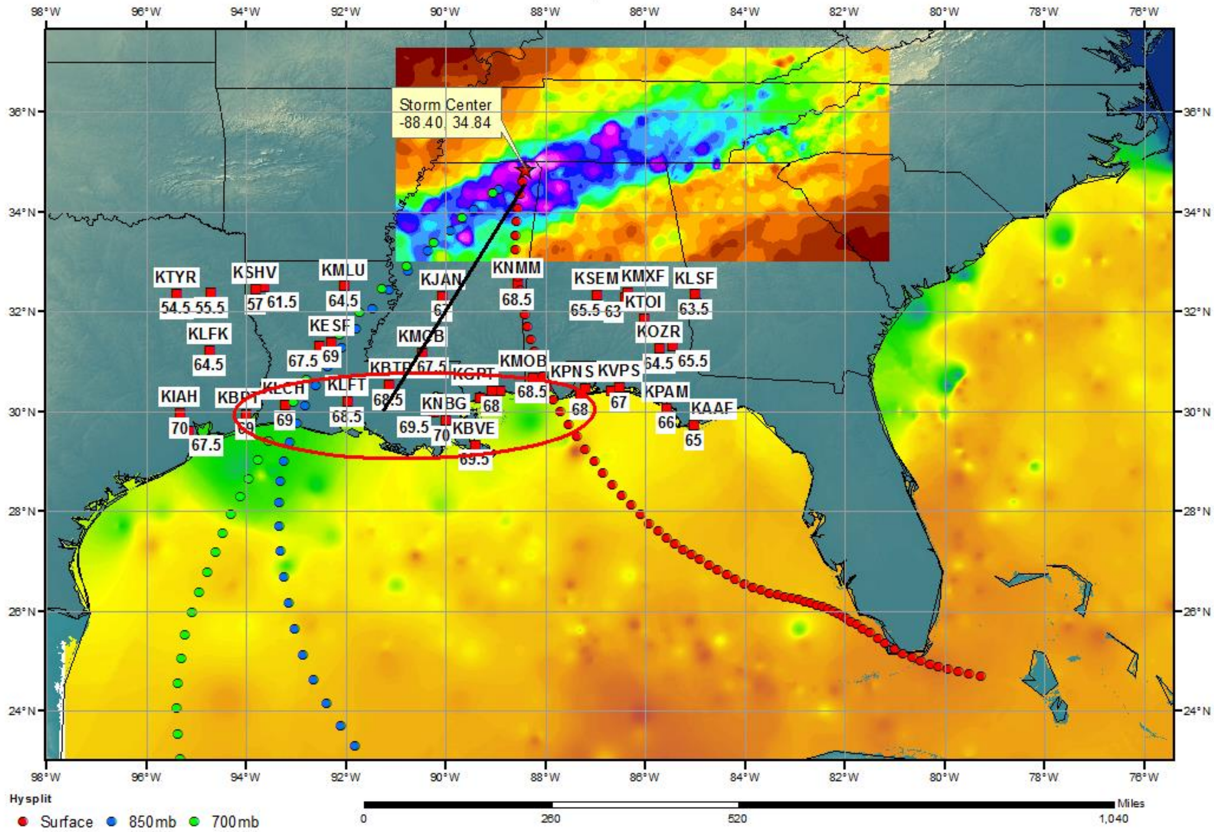
Floods in Southern Appalachians - Tenn. Valley




Blizzard in Michigan NW Ohio
SATURDAY, MARCH 17, 1973
HIGH
LOW
HIGH
LOW
HIGH
SURFACE WEATHER MAP
AND STATION WEATHER
AT 7:00 A.M., E.S.T.

SPAS 1357 - March 1973 Storm Analysis

March 14, 1973



Storm Precipitation Analysis System (SPAS) For Storm #1362_2 SPAS Analysis

General Storm Location: Tennessee Valley (-88.7, 37.9, 34.0, -81.2)

Storm Dates: April 2 – April 5, 1977

Event: Mid-latitude cyclone (MLC)

DAD Zone 2

Latitude: 35.3208

Longitude: -83.6875

Max. Grid/Radar Rainfall Amount: 9.21”

Max. Observed Rainfall Amount: 8.00”

Number of Stations: 461

SPAS Version: 9.5

Base Map Used: Mean annual maximum 48-hour precipitation associated with MLCs

Spatial resolution: 0.2681

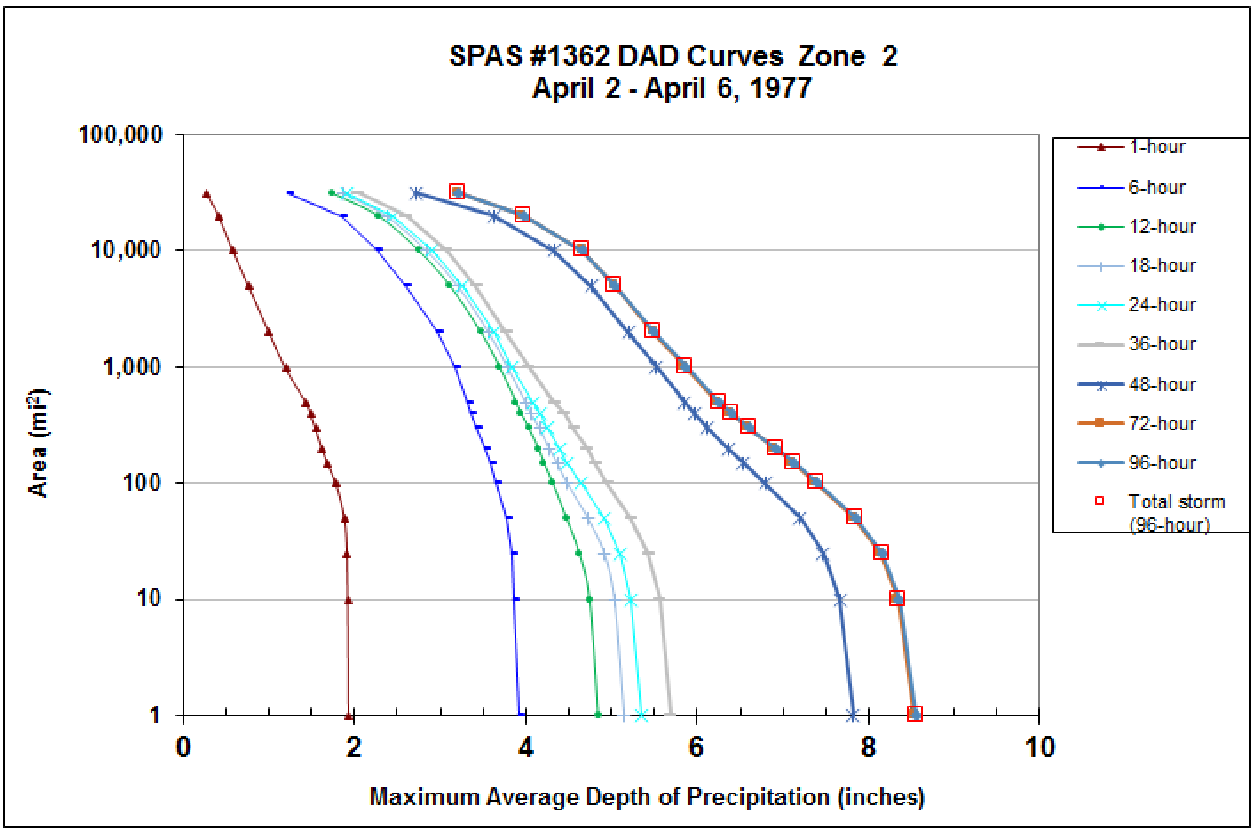
Radar Included: No

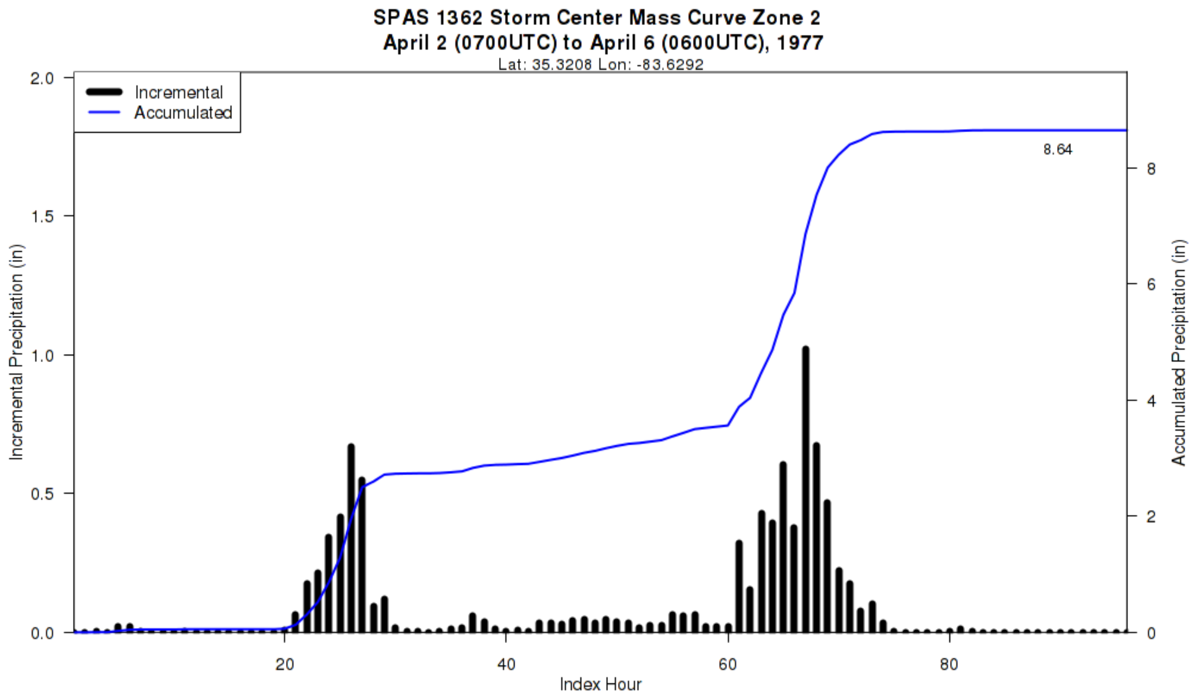
Depth-Area-Duration (DAD) analysis: Yes

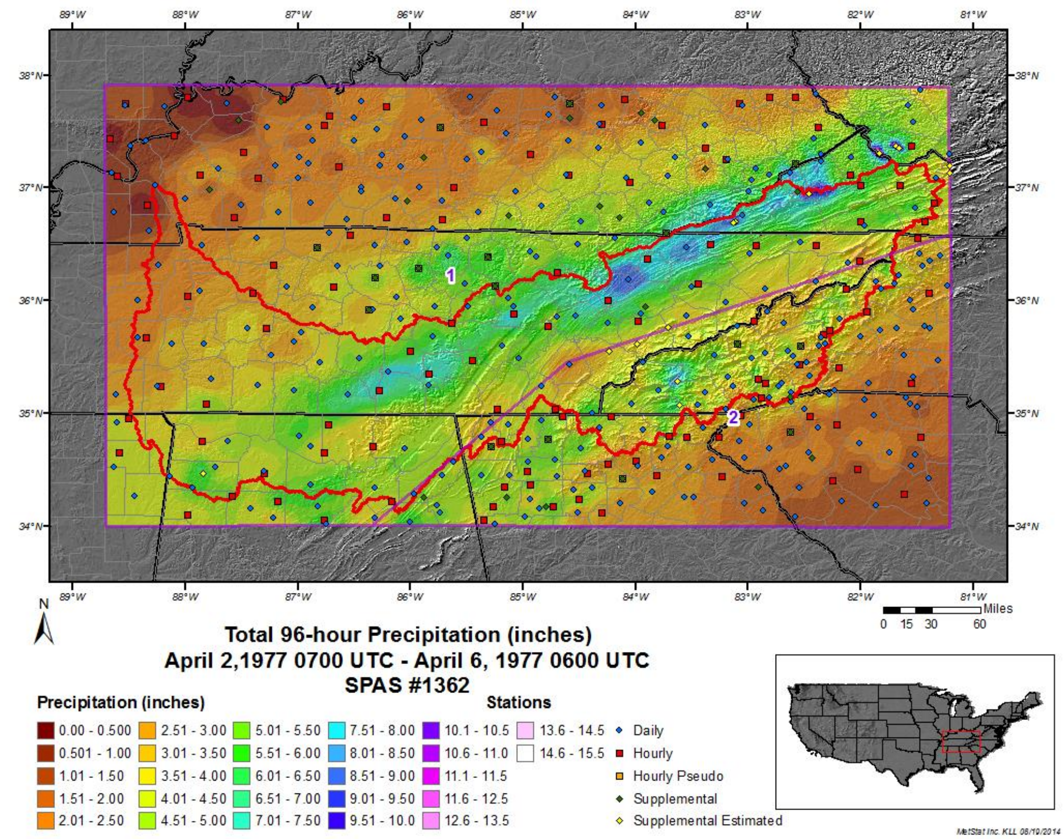
Reliability of results: In addition to the NCDC stations, seven supplemental stations were added to ensure the data matches what can actually occur and that the data more closely resemble what the TVA reported from this storm. There were also seven hourly stations added via digitizing some of the stations listed in the TVA report. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the TVA report, this analysis is deemed quite reliable.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1362_2	-83.6875	35.3208	4,727	20-Apr	72.50	2.54	0.95	67	1.585	75.29	2.92	1.06	73	1.865	1.177

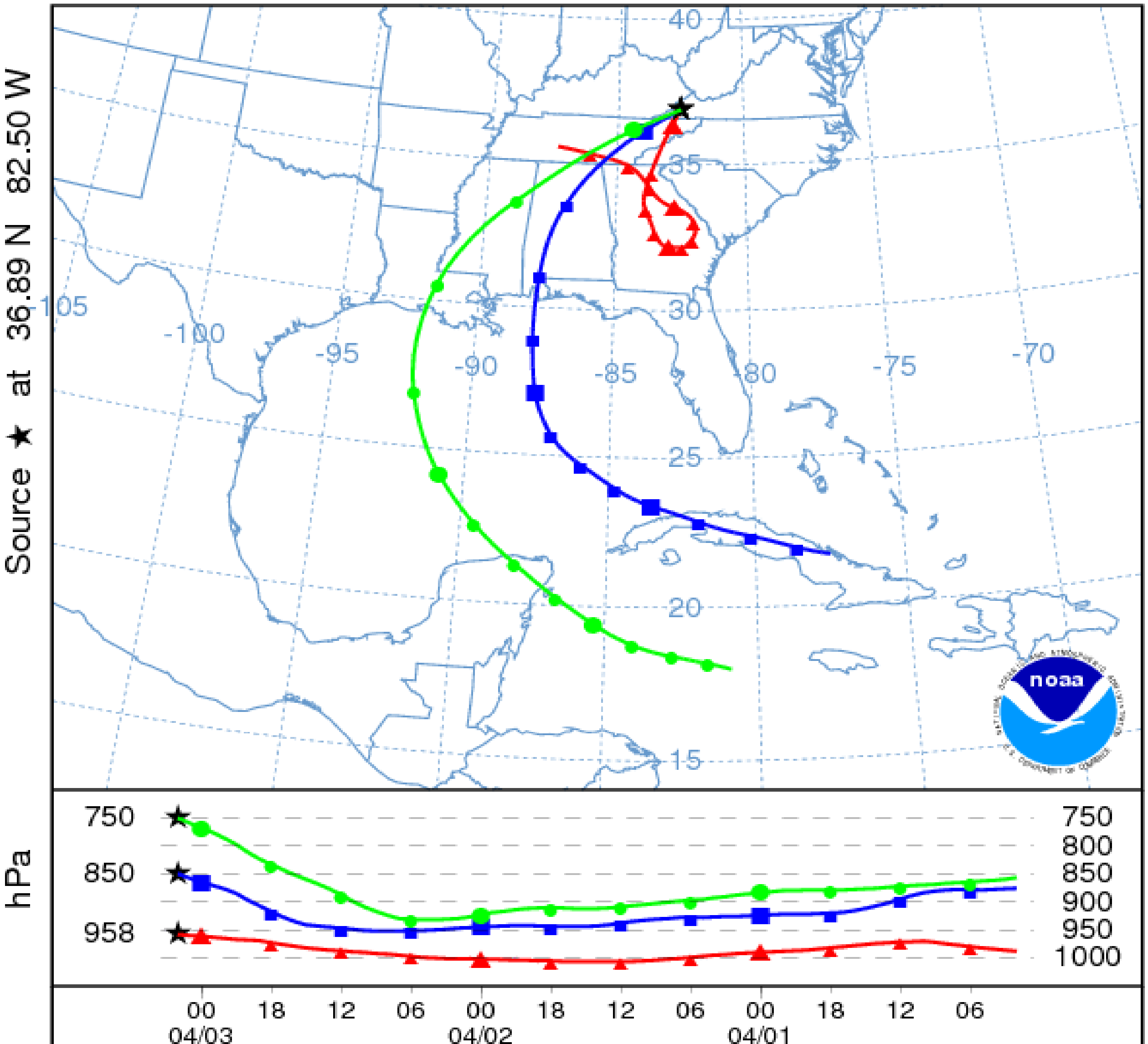
Storm 1362 - April 2 (0700 UTC) - April 6 (0600 UTC), 1977										
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
Area (mi²)	Duration (hours)									
	1	6	12	18	24	36	48	72	96	Total
0.4	1.94	3.94	4.90	5.19	5.39	5.73	7.89	8.59	8.62	8.62
1	1.94	3.92	4.85	5.15	5.35	5.69	7.82	8.54	8.56	8.56
10	1.93	3.86	4.75	5.04	5.23	5.56	7.66	8.34	8.36	8.36
25	1.92	3.83	4.63	4.92	5.11	5.43	7.47	8.14	8.16	8.16
50	1.89	3.77	4.48	4.73	4.91	5.22	7.20	7.83	7.85	7.85
100	1.79	3.65	4.32	4.49	4.64	4.95	6.79	7.39	7.41	7.41
150	1.69	3.59	4.22	4.37	4.49	4.81	6.54	7.12	7.14	7.14
200	1.63	3.52	4.15	4.28	4.39	4.71	6.36	6.91	6.92	6.92
300	1.55	3.43	4.04	4.16	4.26	4.56	6.12	6.60	6.61	6.61
400	1.49	3.37	3.95	4.06	4.16	4.44	5.97	6.39	6.40	6.40
500	1.44	3.32	3.89	4.00	4.08	4.33	5.85	6.24	6.26	6.26
1,000	1.20	3.17	3.70	3.79	3.84	4.03	5.52	5.85	5.87	5.87
2,000	1.01	2.96	3.48	3.57	3.63	3.77	5.20	5.49	5.50	5.50
5,000	0.77	2.59	3.12	3.21	3.26	3.42	4.77	5.04	5.04	5.04
10,000	0.59	2.27	2.76	2.85	2.90	3.08	4.33	4.66	4.66	4.66
20,000	0.42	1.84	2.29	2.38	2.45	2.60	3.63	3.97	3.98	3.98
31,760	0.28	1.23	1.74	1.87	1.92	2.04	2.71	3.21	3.21	3.21




SPAS 1362 Storm Center Mass Curve Zone 2
April 2 (0700UTC) to April 6 (0600UTC), 1977
Lat: 35.3208 Lon: -83.6292
Incremental
Accumulated
8.64
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
2.0
1.5
1.0
0.5
0.0
20
40
60
80
8
6
4
2
0


Total 96-hour Precipitation (inches)
April 2,1977 0700 UTC - April 6, 1977 0600 UTC
SPAS #1362
Precipitation (inches)
0.00 - 0.500
0.501 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.0
10.1 - 10.5
10.6 - 11.0
11.1 - 11.5
11.6 - 12.5
12.6 - 13.5
13.6 - 14.5
14.6 - 15.5
Stations
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Estimated
Miles
0 15 30 60
N
MetStat Inc. KLL 08/19/2014

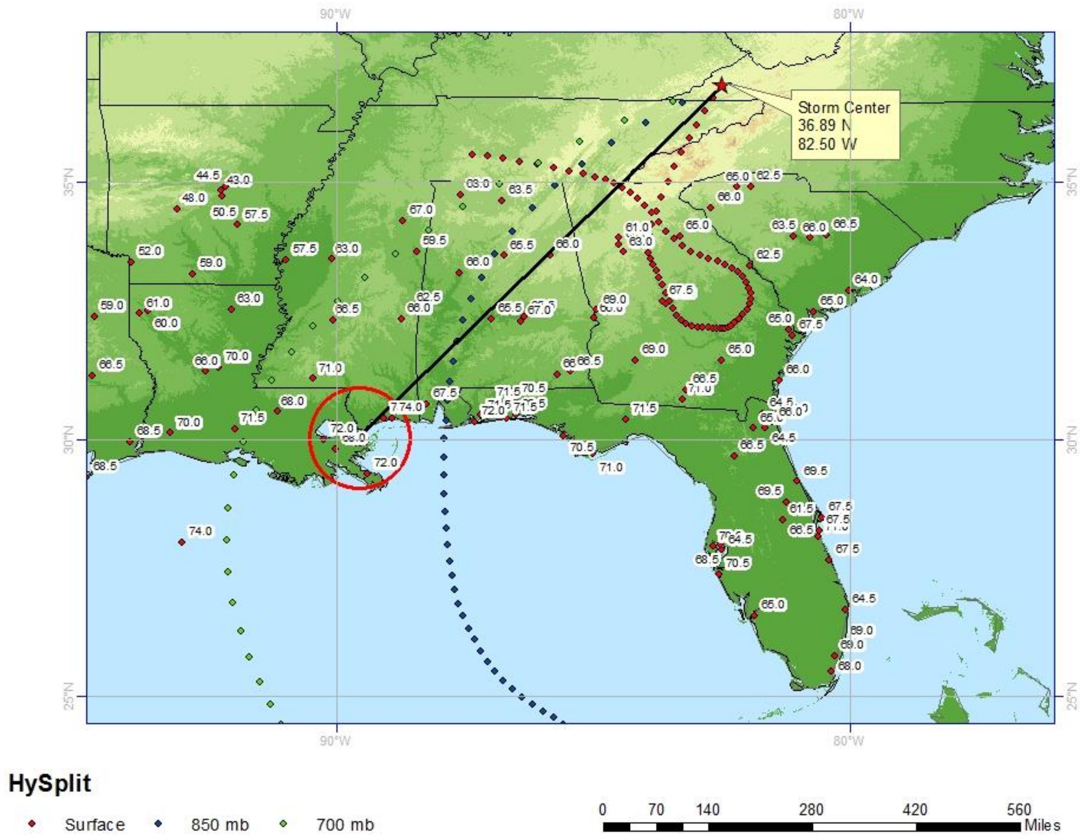
NOAA HYSPLIT MODEL
Backward trajectories ending at 0200 UTC 03 Apr 77
CDC1 Meteorological Data



Job ID: 115583 Job Start: Sun Sep 7 18:25:12 UTC 2014
Source 1 lat.: 36.890000 lon.: -82.500000 hgts: 0, 1020, 2060 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Apr 2077 - reanalysis

SPAS 1362
April 2-6, 1977



Storm Precipitation Analysis System (SPAS) For Storm #1219_1 SPAS Analysis

General Storm Location: Mountain View-Big Fork, AR

Storm Dates: December 1 (0600) **-** December 5 (0500), 1982

Event: Convective

DAD Zone 1

Latitude: 35.8708

Longitude: -92.1208

Max. Grid/Radar Rainfall Amount: 15.92"

Max. Observed Rainfall Amount: 15.59"

Number of Stations: 733 (524 Daily, 148 Hourly, 40 Hourly Pseudo, 21 Supplemental)

SPAS Version: 9.0

Base Map Used: Mean (1971-2000) PRISM July Precipitation

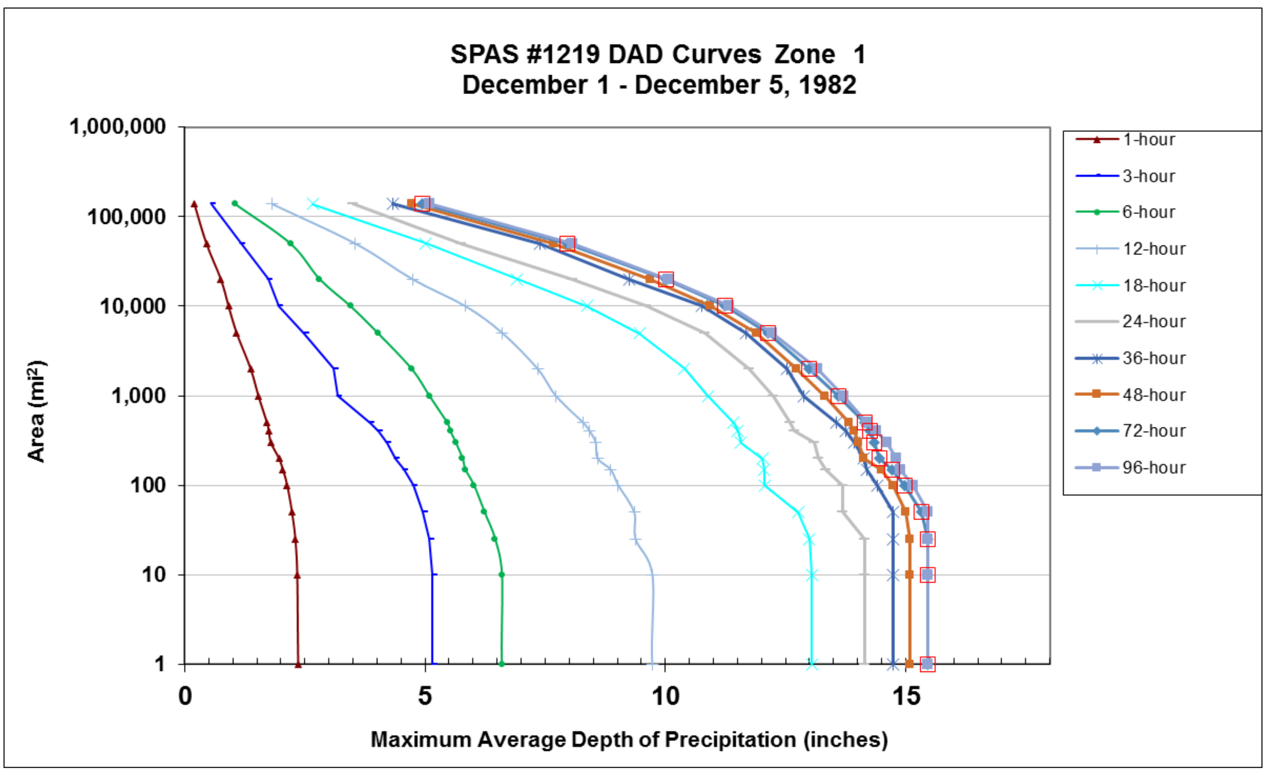
Spatial resolution: 0.30 sq-mi

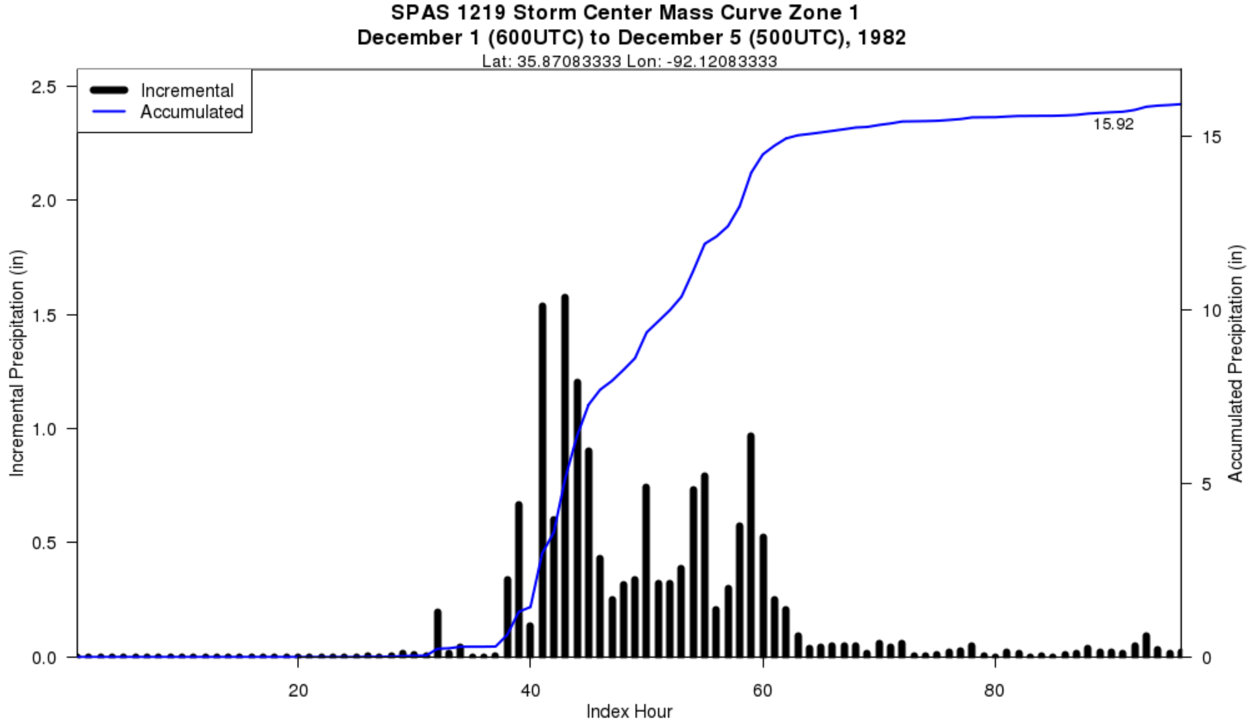
Radar Included: No

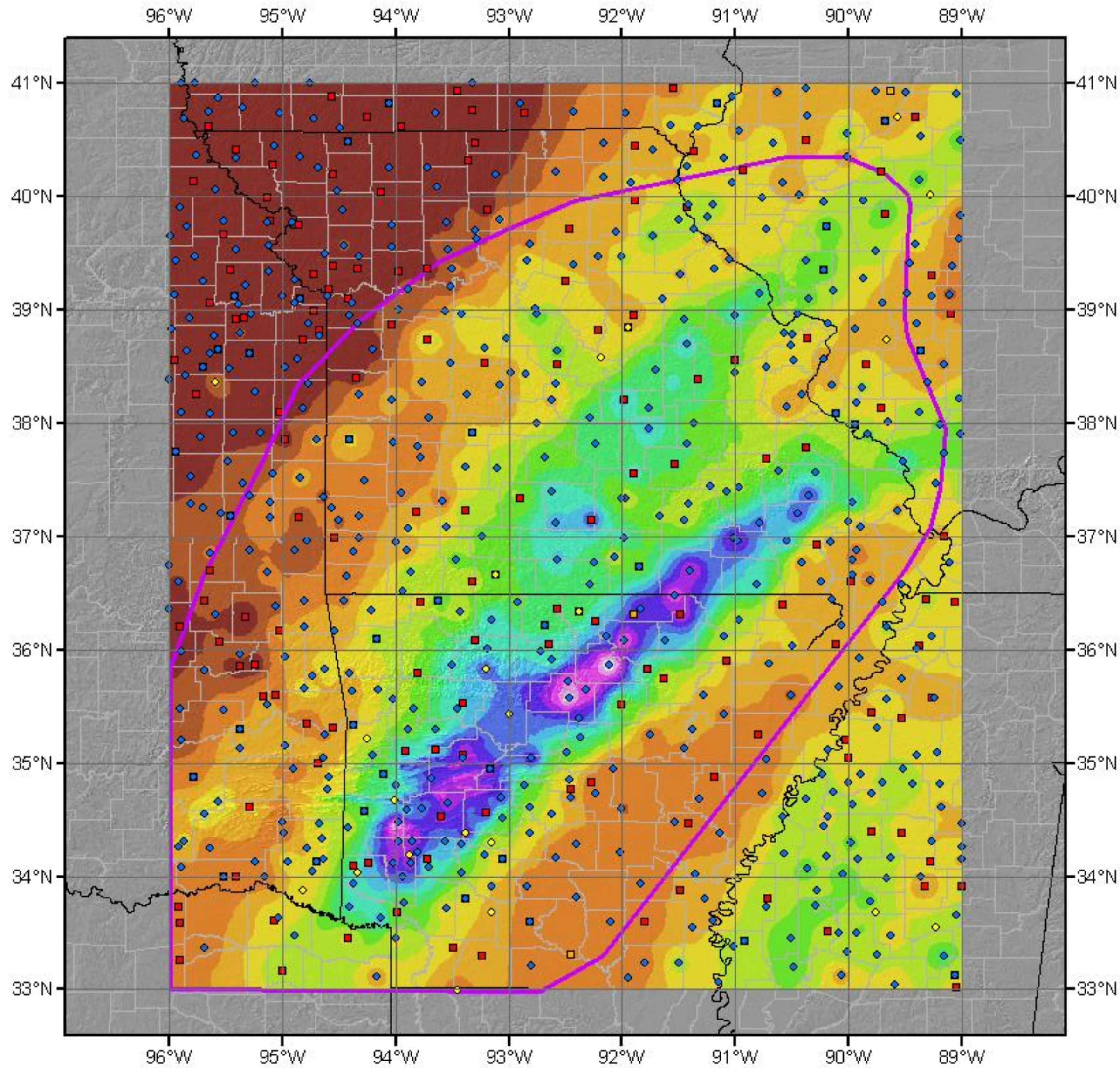
Depth-Area-Duration (DAD) analysis: Yes

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1219_1	-92.1208	35.8708	764	800	15-Nov	72.00	2.47	0.18	66	2.290	74.87	75.0	2.85	0.20	72	2.650	1.157

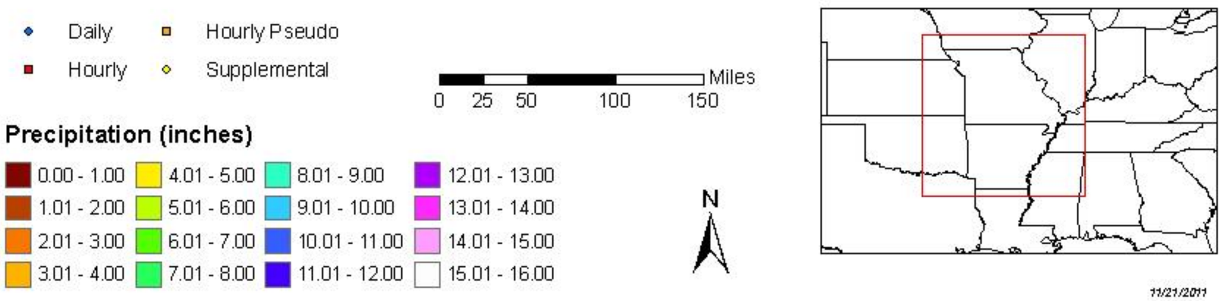
Storm 1219 - December 1 (0600 UTC) - December 5 (0500 UTC), 1982											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	3	6	12	18	24	36	48	72	96	Total
0.3	2.41	5.36	6.75	10.00	13.44	14.58	15.16	15.51	15.92	15.92	15.92
1	2.36	5.16	6.60	9.73	13.05	14.15	14.73	15.09	15.45	15.45	15.45
10	2.34	5.16	6.60	9.73	13.05	14.15	14.73	15.09	15.45	15.45	15.45
25	2.30	5.09	6.46	9.38	13.00	14.15	14.73	15.09	15.45	15.45	15.45
50	2.23	4.96	6.24	9.35	12.77	13.68	14.73	15.01	15.32	15.45	15.32
100	2.13	4.75	6.02	9.02	12.07	13.68	14.41	14.73	14.98	15.16	14.98
150	2.04	4.55	5.84	8.86	12.05	13.34	14.19	14.50	14.71	14.90	14.71
200	1.96	4.38	5.78	8.59	12.02	13.18	14.12	14.12	14.45	14.80	14.45
300	1.79	4.20	5.64	8.55	11.57	13.09	13.94	14.02	14.35	14.60	14.35
400	1.75	4.03	5.53	8.43	11.51	12.68	13.75	13.92	14.25	14.40	14.25
500	1.71	3.86	5.46	8.29	11.42	12.59	13.56	13.82	14.15	14.19	14.15
1,000	1.53	3.18	5.09	7.72	10.88	12.24	12.88	13.32	13.60	13.72	13.60
2,000	1.37	3.10	4.72	7.34	10.39	11.75	12.53	12.73	13.00	13.17	13.00
5,000	1.08	2.49	4.02	6.61	9.46	10.83	11.67	11.90	12.14	12.22	12.14
10,000	0.91	1.95	3.45	5.84	8.37	9.60	10.75	10.94	11.23	11.33	11.23
20,000	0.75	1.73	2.81	4.74	6.92	8.07	9.24	9.69	10.01	10.05	10.01
50,000	0.45	1.16	2.20	3.55	5.01	5.75	7.39	7.67	7.97	8.07	7.97
138,276	0.20	0.55	1.05	1.82	2.66	3.49	4.34	4.72	4.95	5.10	4.95



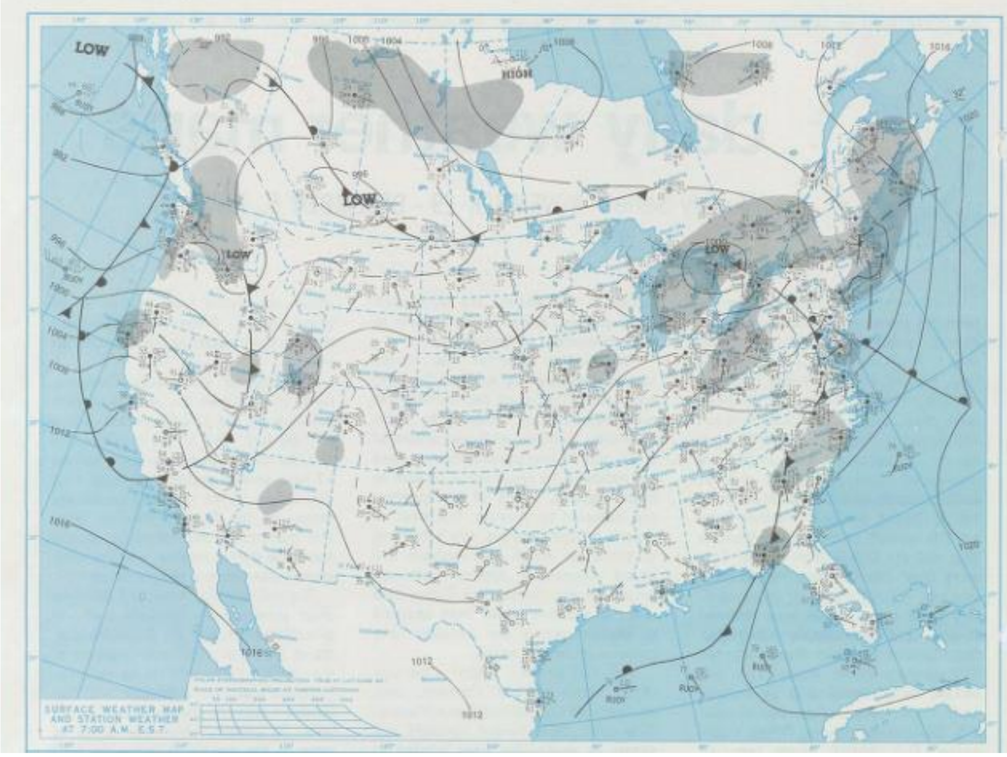

SPAS 1219 Storm Center Mass Curve Zone 1
December 1 (600UTC) to December 5 (500UTC), 1982
Lat: 35.87083333 Lon: -92.12083333
Incremental
Accumulated
15.92
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
40
60
80



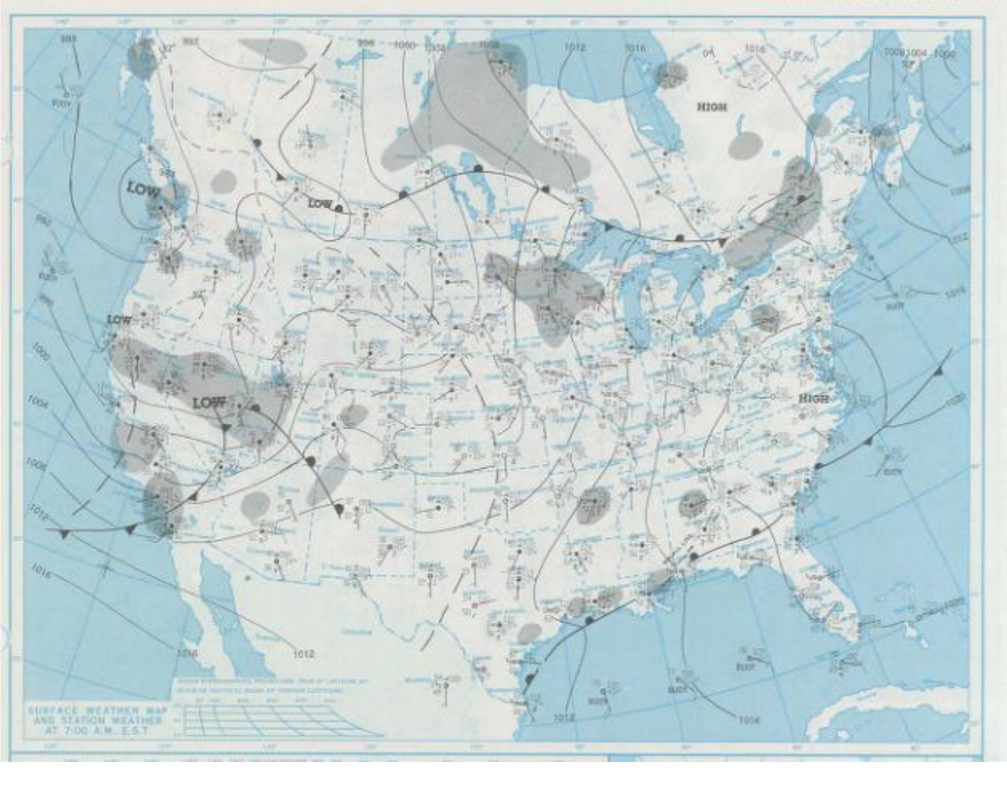
Total Precipitation (96 hours)
SPAS #1219
12/01/1982 0100 UTC - 12/05/1982 0500 UTC



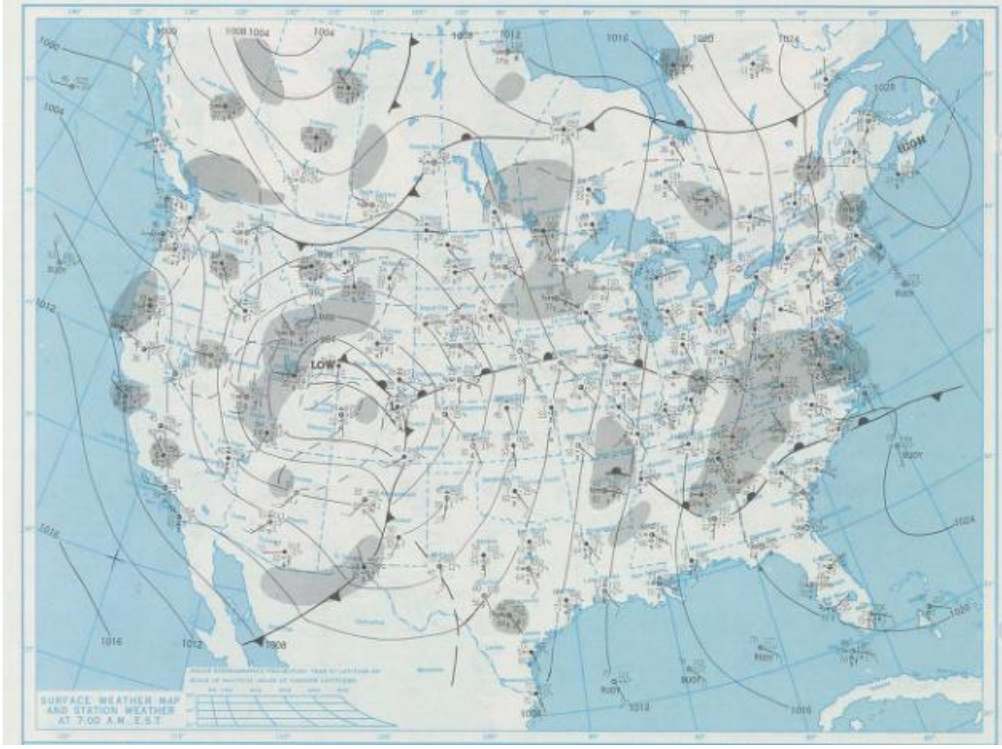
MONDAY, NOVEMBER 29, 1982



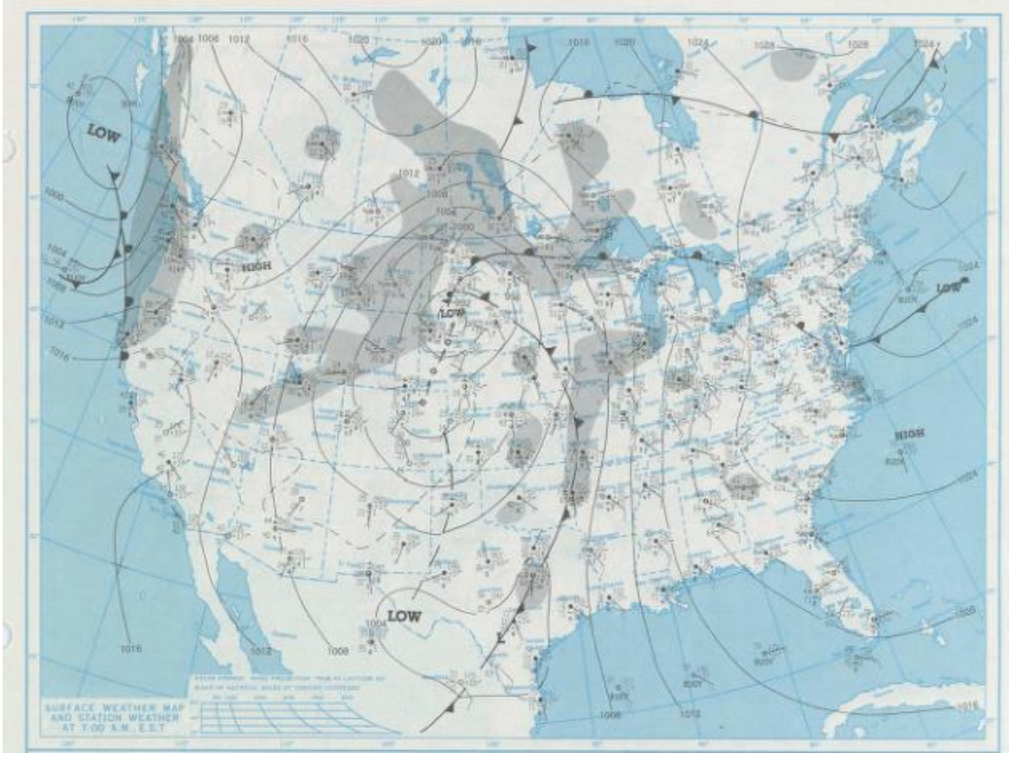
TUESDAY, NOVEMBER 30, 1982



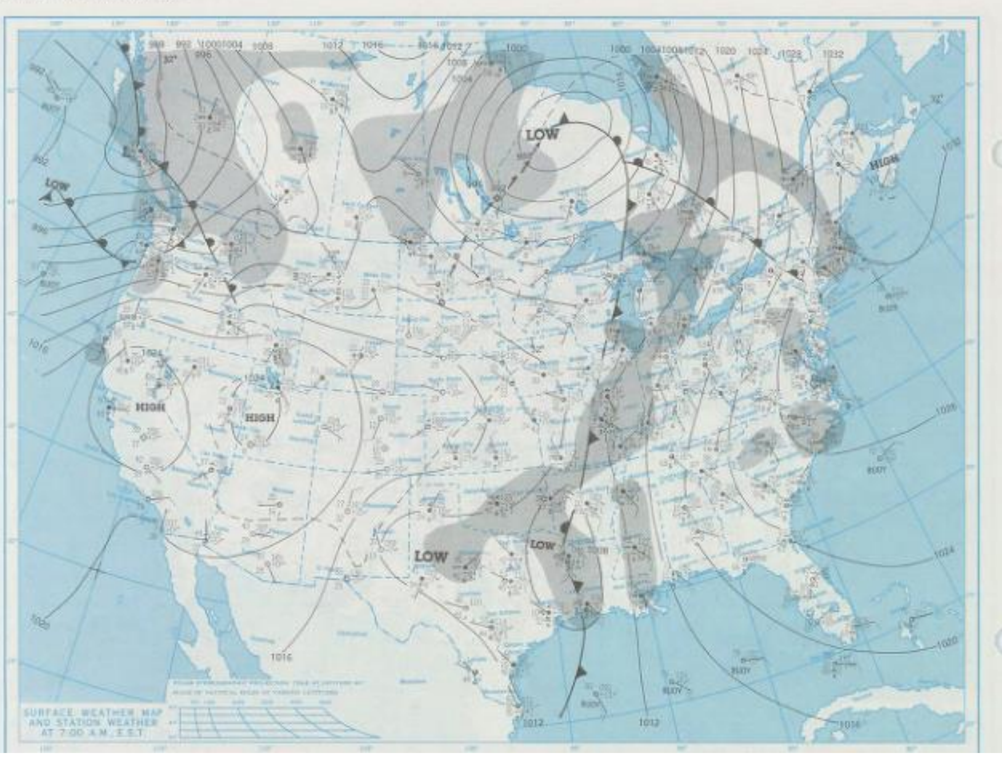
WEDNESDAY, DECEMBER 1, 1982



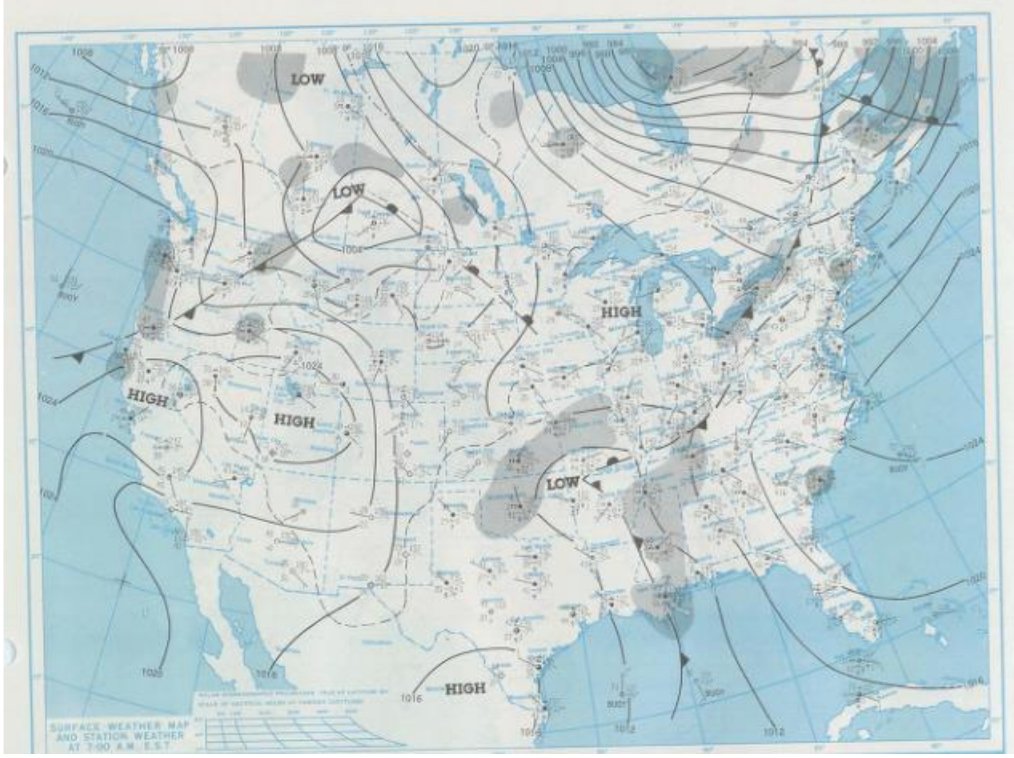
THURSDAY, DECEMBER 2, 1982



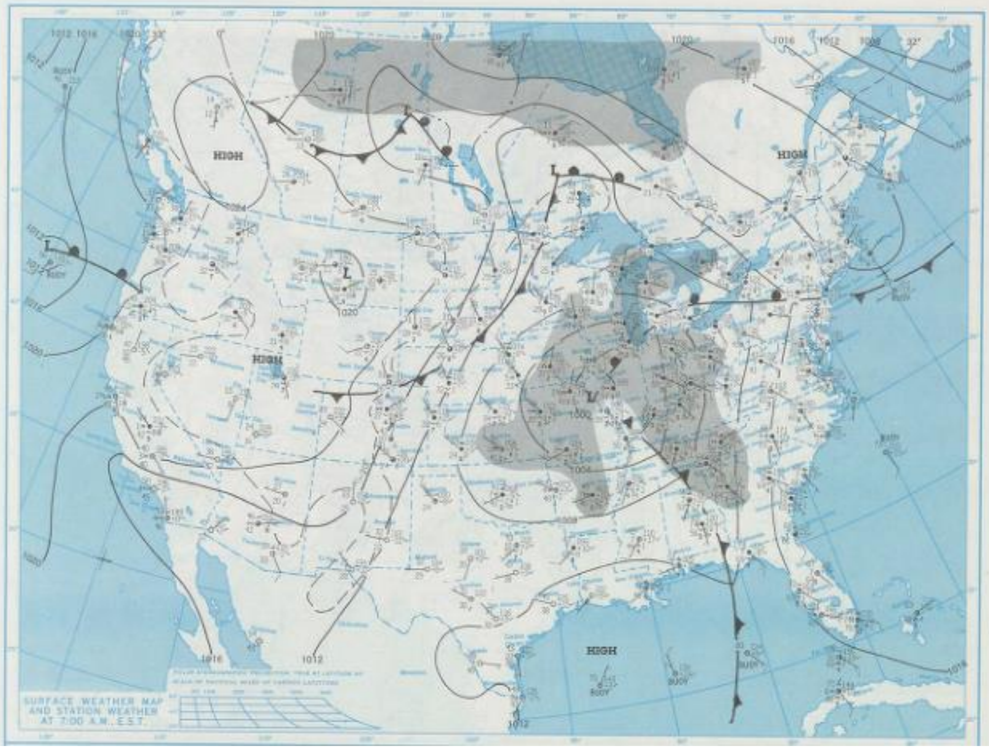
FRIDAY, DECEMBER 3, 1982



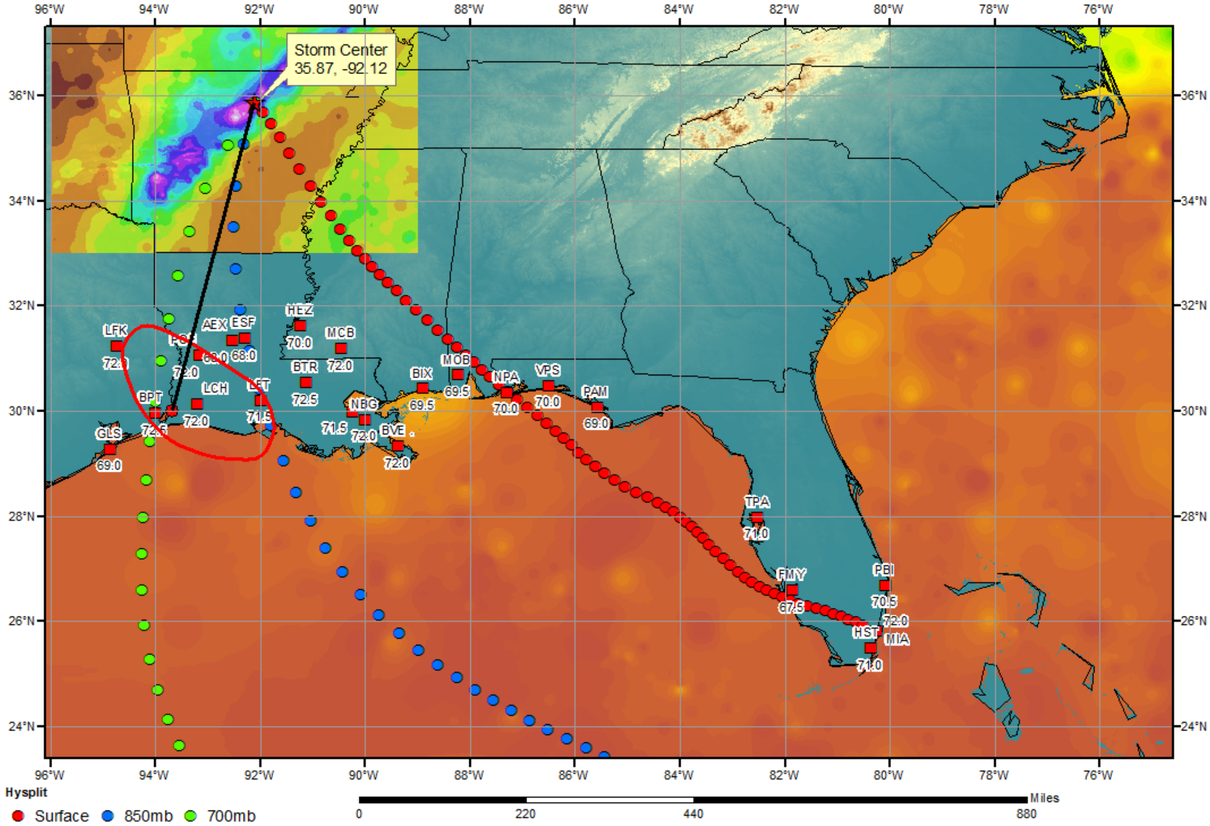
SATURDAY, DECEMBER 4, 1982



SUNDAY, DECEMBER 5, 1982



SPAS 1219 - Big Fork, AR Storm Analysis
November 30 - December 4, 1982



Storm Precipitation Analysis System (SPAS) For Storm #1533_1 SPAS Analysis

General Storm Location: Mid Atlantic, Montebello, VA

Storm Dates: October 31 – November 7, 1985

Event: Remnants of Hurricane Juan becoming an extratropical cyclone

DAD Zone 1

Latitude: 37.8125

Longitude: -79.1625

Max. Grid Rainfall Amount: 22.56”

Max. Observed Rainfall Amount: 19.76” at Montebello 3 NE, VA

Number of Stations: 1050 (696 Daily, 183 Hourly, 0 Hourly Estimated, 62 Hourly Pseudo, 109 Supplemental, and 0 Supplemental Estimated)

SPAS Version: 10.0

Base Map Used: PRISM July (1981-2010) precipitation

Spatial resolution: 0.2606

Radar Included: No

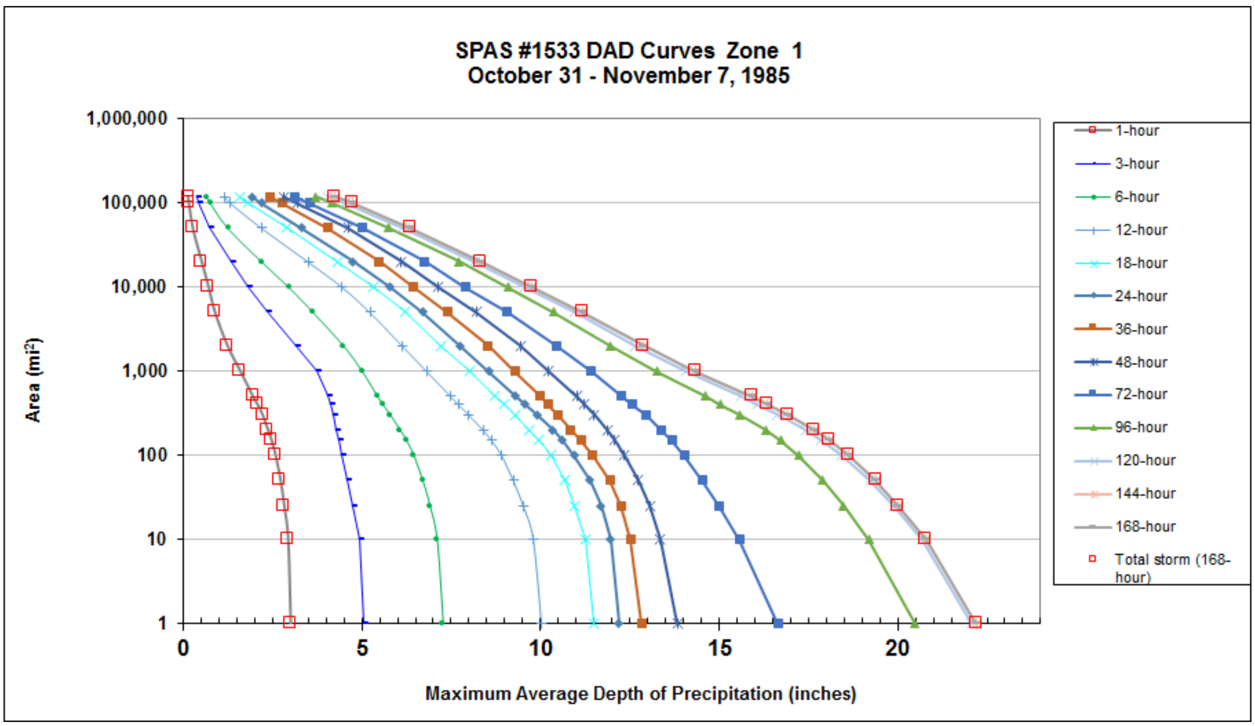
Depth-Area-Duration (DAD) analysis: Yes

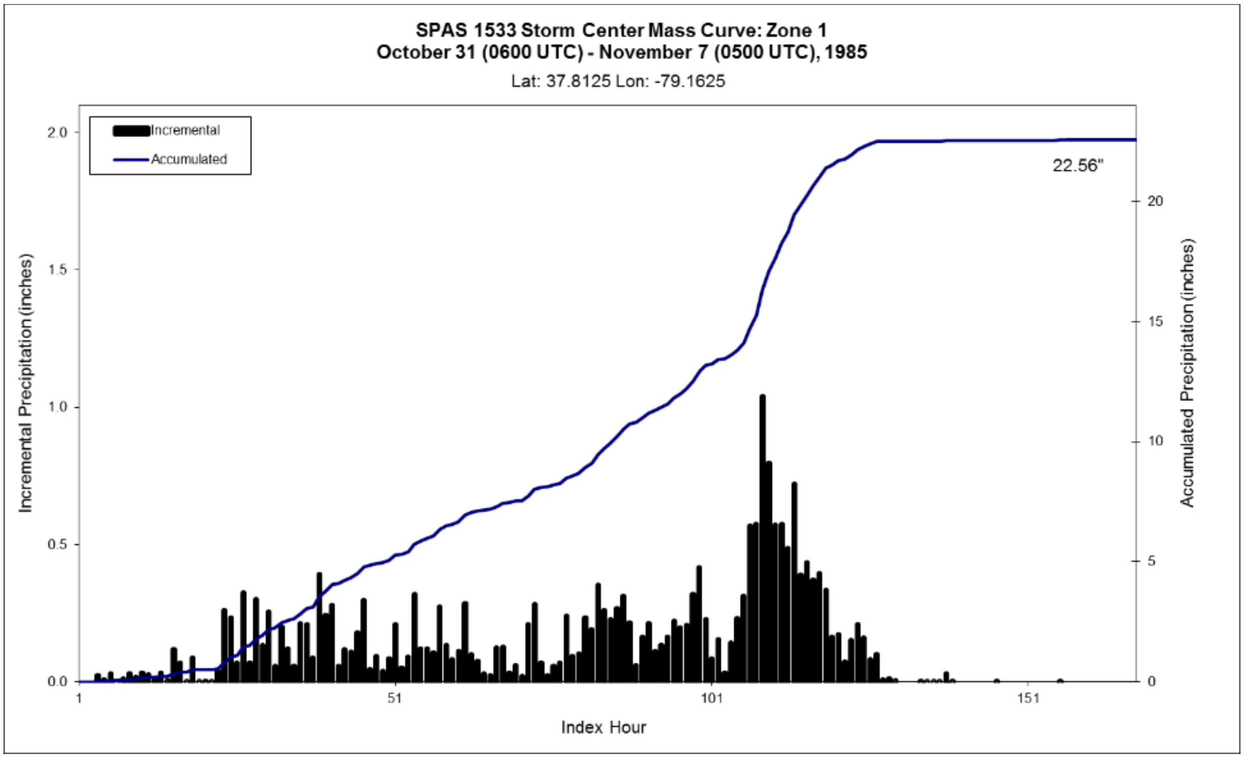
Reliability of results: With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the observations, this analysis is deemed quite reliable.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1533_1	-79.1625	37.8125	3,892	17-Oct	76.50	3.07	0.94	75	2.130	79.51	3.52	1.03	81	2.490	1.169

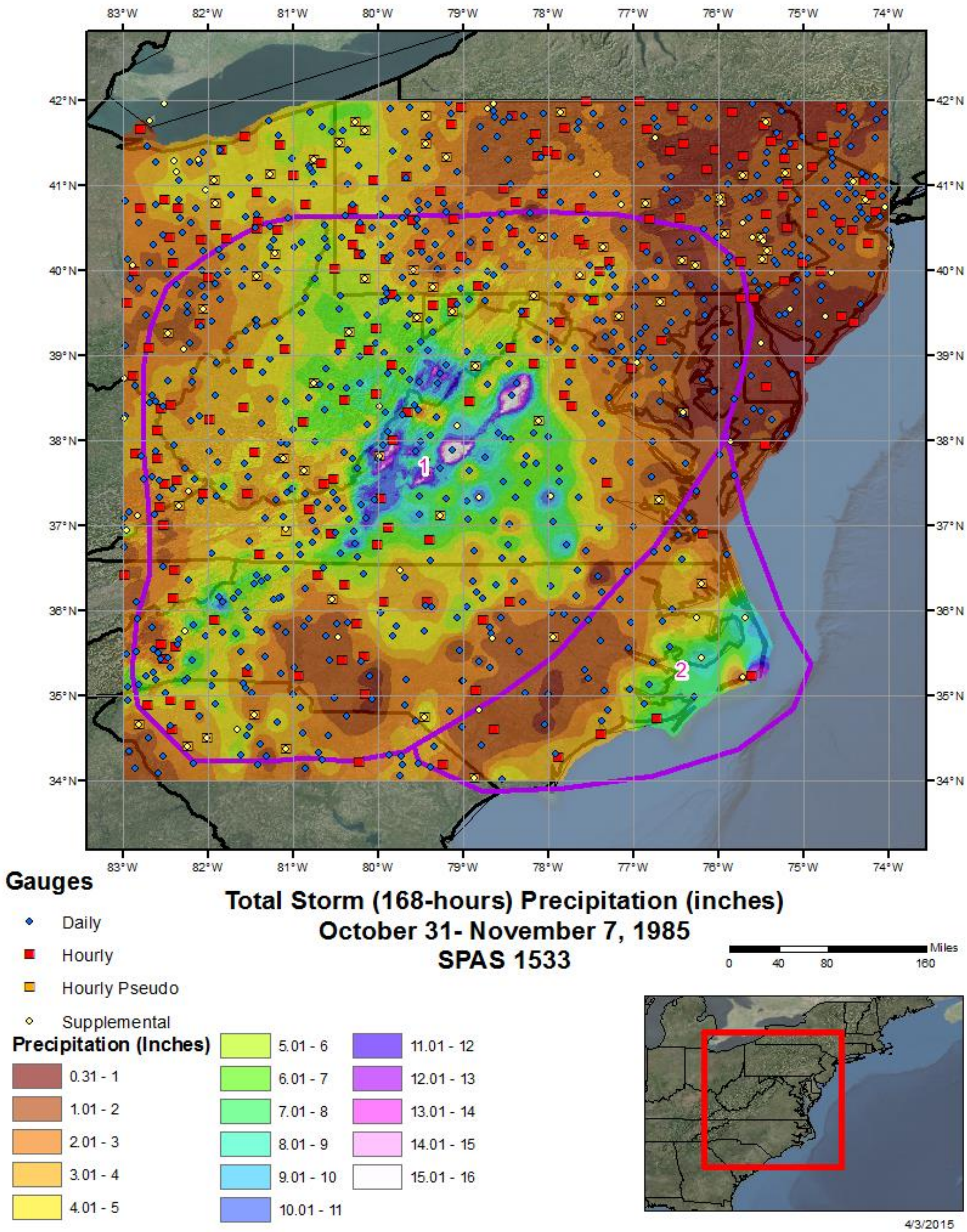
Storm 1533 - October 31 (0600 UTC) - November 7 (0500 UTC), 1985
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

Area (mi²)	Duration (hours)													
	1	3	6	12	18	24	36	48	72	96	120	144	168	Total
0.4	3.02	5.10	7.32	10.11	11.59	12.28	12.95	13.98	16.81	20.72	22.31	22.44	22.44	22.44
1	3.00	5.06	7.27	10.03	11.50	12.19	12.83	13.83	16.64	20.49	22.07	22.20	22.20	22.20
10	2.93	4.93	7.10	9.80	11.25	11.97	12.53	13.35	15.57	19.19	20.67	20.79	20.79	20.79
25	2.82	4.76	6.90	9.52	10.97	11.69	12.25	13.07	14.99	18.48	19.89	20.00	20.00	20.00
50	2.72	4.60	6.70	9.24	10.67	11.39	11.94	12.74	14.53	17.90	19.24	19.38	19.38	19.38
100	2.58	4.45	6.45	8.91	10.28	10.95	11.47	12.35	14.02	17.22	18.44	18.64	18.64	18.64
150	2.47	4.36	6.25	8.63	9.96	10.62	11.13	12.08	13.67	16.72	17.87	18.10	18.10	18.10
200	2.37	4.30	6.07	8.39	9.69	10.34	10.85	11.86	13.37	16.30	17.41	17.66	17.66	17.66
300	2.22	4.21	5.80	8.00	9.28	9.90	10.48	11.51	12.95	15.57	16.63	16.92	16.92	16.92
400	2.08	4.14	5.59	7.71	8.97	9.57	10.21	11.23	12.57	15.02	16.07	16.36	16.36	16.36
500	1.95	4.07	5.44	7.49	8.73	9.31	10.00	11.01	12.28	14.63	15.62	15.91	15.91	15.91
1,000	1.60	3.75	5.01	6.81	8.02	8.55	9.28	10.23	11.43	13.25	14.09	14.34	14.34	14.34
2,000	1.24	3.16	4.49	6.13	7.23	7.74	8.53	9.43	10.45	11.94	12.64	12.88	12.88	12.88
5,000	0.89	2.37	3.64	5.23	6.21	6.70	7.40	8.21	9.07	10.37	10.96	11.17	11.17	11.17
10,000	0.71	1.83	2.96	4.45	5.34	5.80	6.46	7.15	7.89	9.09	9.58	9.76	9.76	9.76
20,000	0.52	1.36	2.21	3.50	4.32	4.76	5.49	6.11	6.75	7.73	8.13	8.30	8.32	8.32
50,000	0.27	0.75	1.27	2.21	2.88	3.30	4.05	4.62	5.03	5.76	6.14	6.34	6.36	6.36
100,000	0.16	0.44	0.77	1.32	1.82	2.19	2.77	3.20	3.54	4.17	4.55	4.74	4.76	4.76
118,957	0.14	0.37	0.67	1.16	1.60	1.93	2.43	2.81	3.12	3.71	4.06	4.23	4.25	4.25



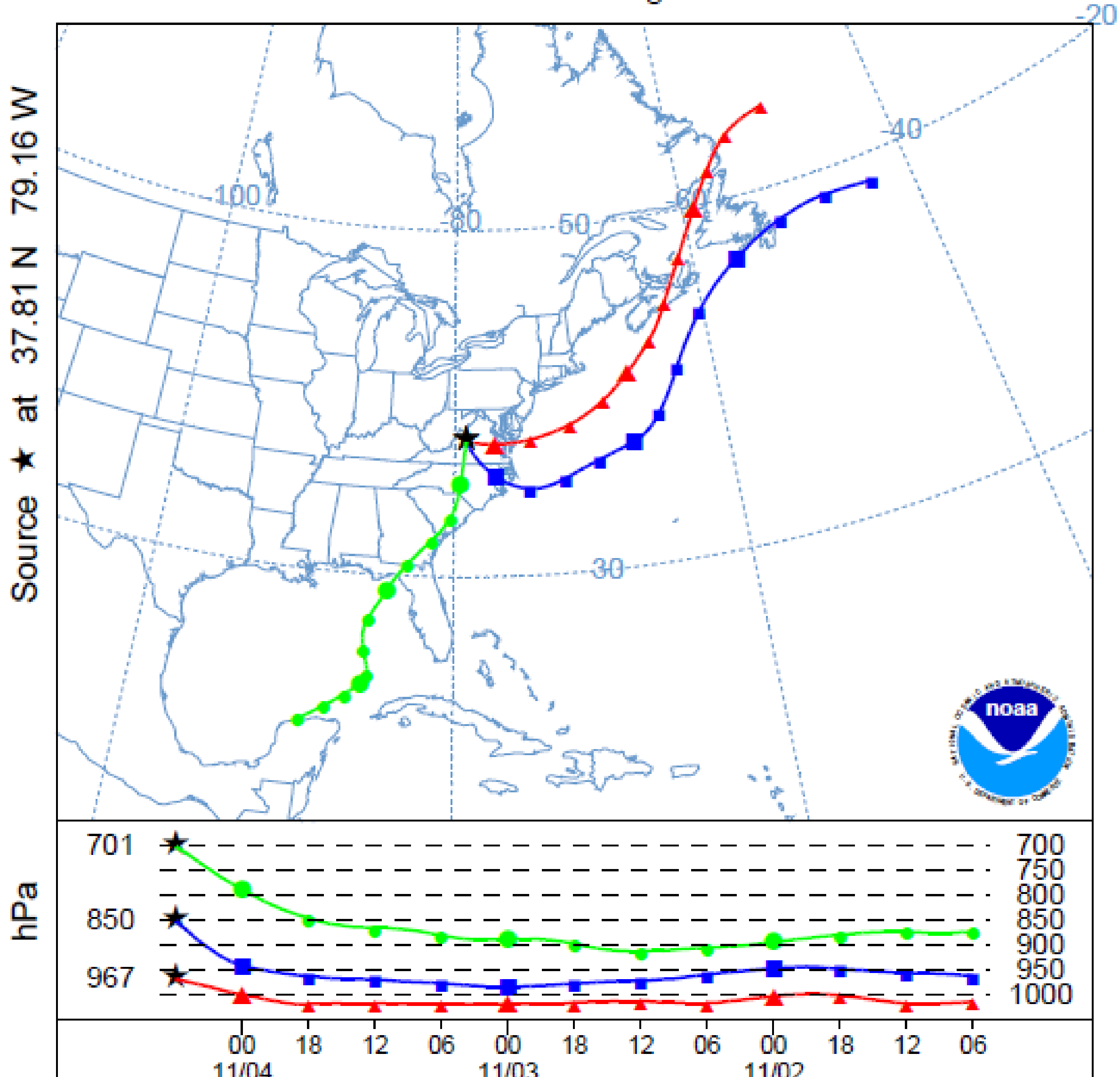


SPAS 1533 Storm Center Mass Curve: Zone 1
October 31 (0600 UTC) - November 7 (0500 UTC), 1985
Lat: 37.8125 Lon: -79.1625
Incremental
Accumulated
22.56"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
1
51
101
151



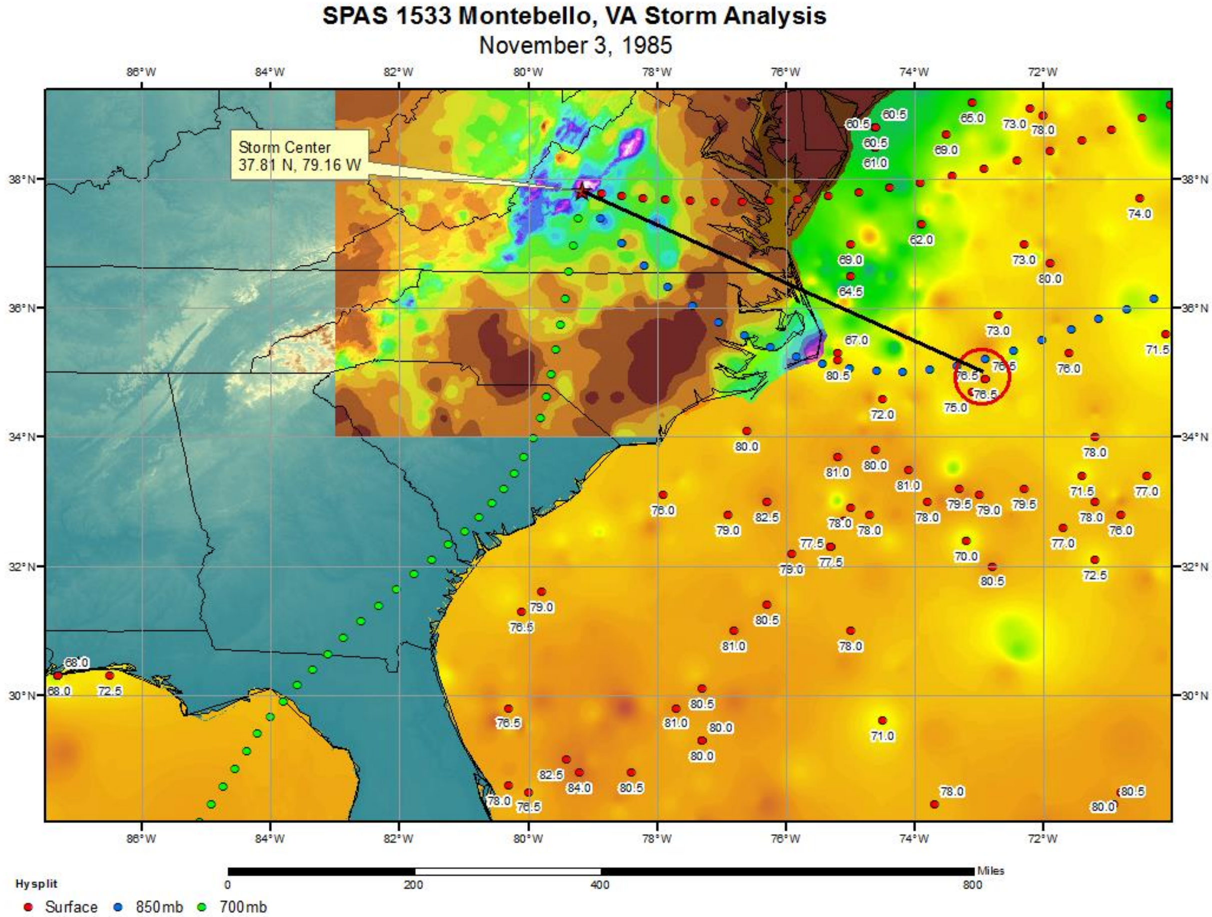
Total Storm (168-hours) Precipitation (inches)
October 31- November 7, 1985
SPAS 1533

NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 04 Nov 85
CDC1 Meteorological Data



Job ID: 185451 Job Start: Mon Sep 21 20:53:25 UTC 2015
Source 1 lat.: 37.812500 lon.: -79.162500 hgts: 0, 1090, 2680 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Nov 2085 - reanalysis


SPAS 1533 Montebello, VA Storm Analysis
November 3, 1985
Storm Center
37.81 N, 79.16 W
Hysplit
Surface
850mb
700mb
Miles
0
200
400
800

Storm Precipitation Analysis System (SPAS) For Storm #1244_1 SPAS-NEXRAD Analysis

General Storm Location: Mainly Kentucky and Tennessee.

Storm Dates: February 28 - March 4, 1997

Event: General storm

DAD Zone 1

Latitude: 38.1000

Longitude: -85.6700

Max. Grid Rainfall Amount: 13.51

Max. Observed Rainfall Amount: 13.04

Number of Stations: 872 (435 Daily, 118 Hourly, 0 Hourly Estimated, 48 Hourly Pseudo, 252 Supplemental, and 19 Supplemental Estimated)

SPAS Version: 9.5

Basemap: PRISM Mean (1971-2000) March precipitation and SPAS ippt precipitation

Spatial resolution: 36 seconds (~ 0.40 mi^2)

Radar Included: Yes

Depth-Area-Duration (DAD) analysis: Yes

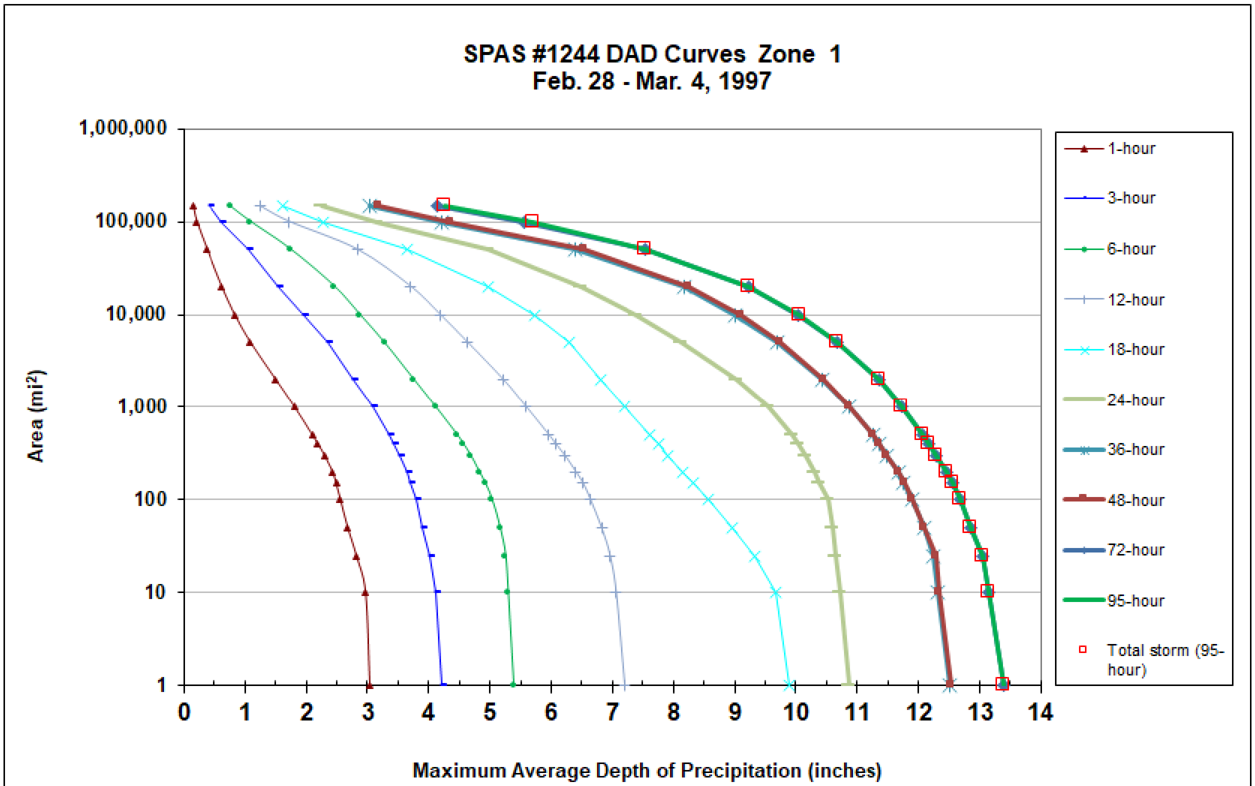
Reliability of results: This analysis was based on WDT NEXRAD data (unblocked) and extensive gauge data, we have a very high degree of confidence in the results. There were a few areas of radar beam blockage in the domain, these areas were adjusted using a beam blockage mask. The radar blocked areas did not affect the SPAS analysis. The Southeastern region was not included in the DAD, these region did not have radar coverage and the results are not completely accurate so they were not included in the analysis.

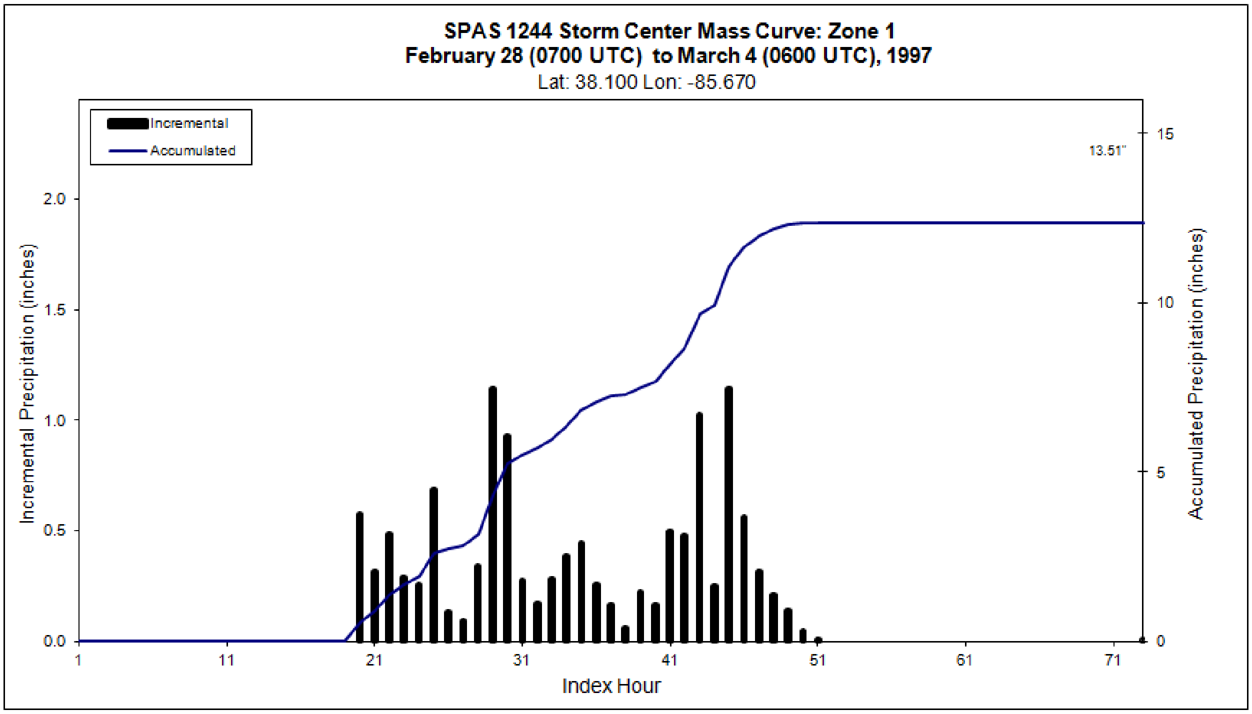
							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1244_1	-85.6700	38.1000	551	600	15-Mar	68.50	2.10	0.13	59	1.970	70.73	70.5	2.31	0.13	63	2.175	1.104

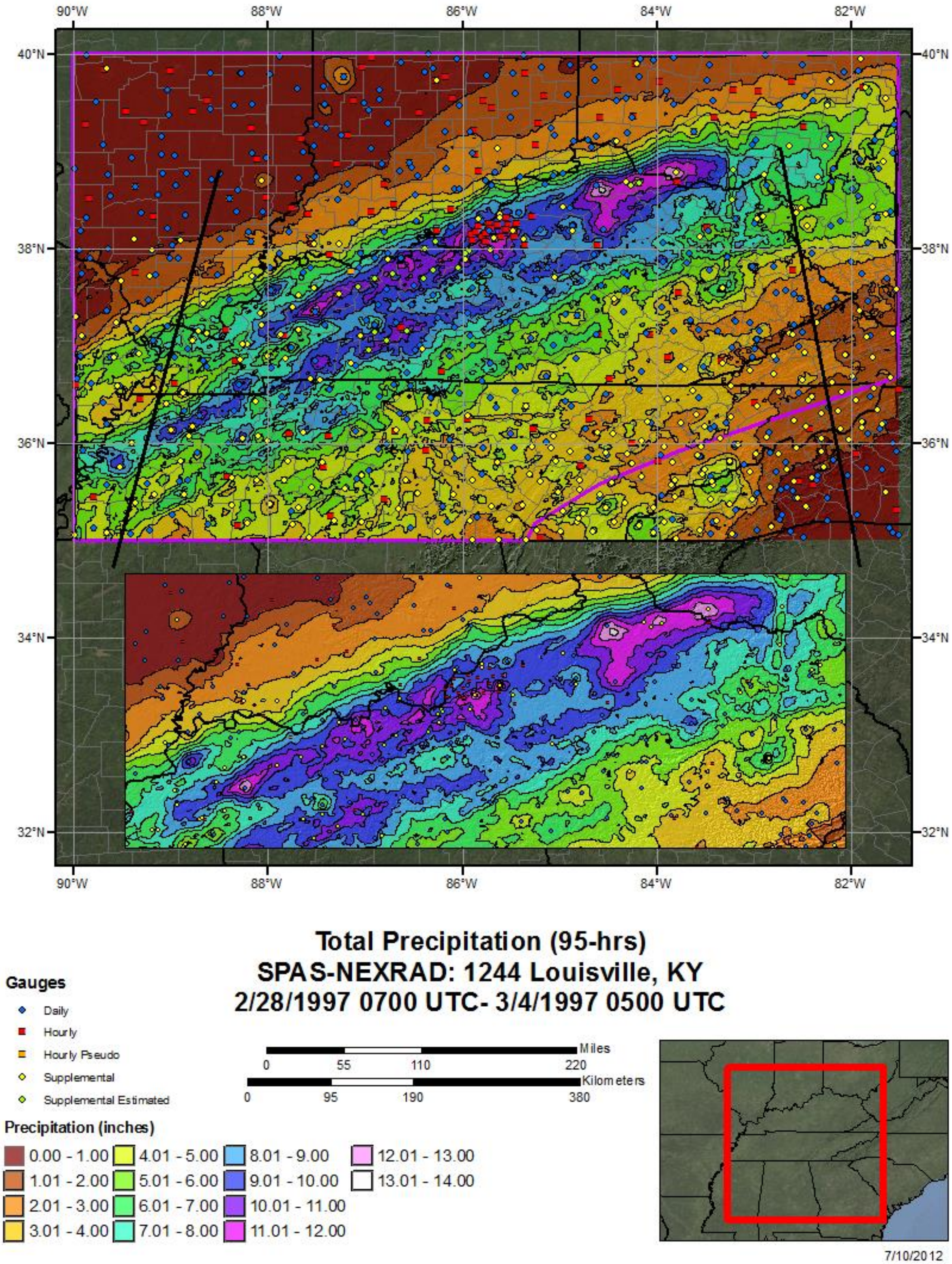
Storm 1244 - February 28 (0700 UTC) - March 4 (0500 UTC), 1997

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

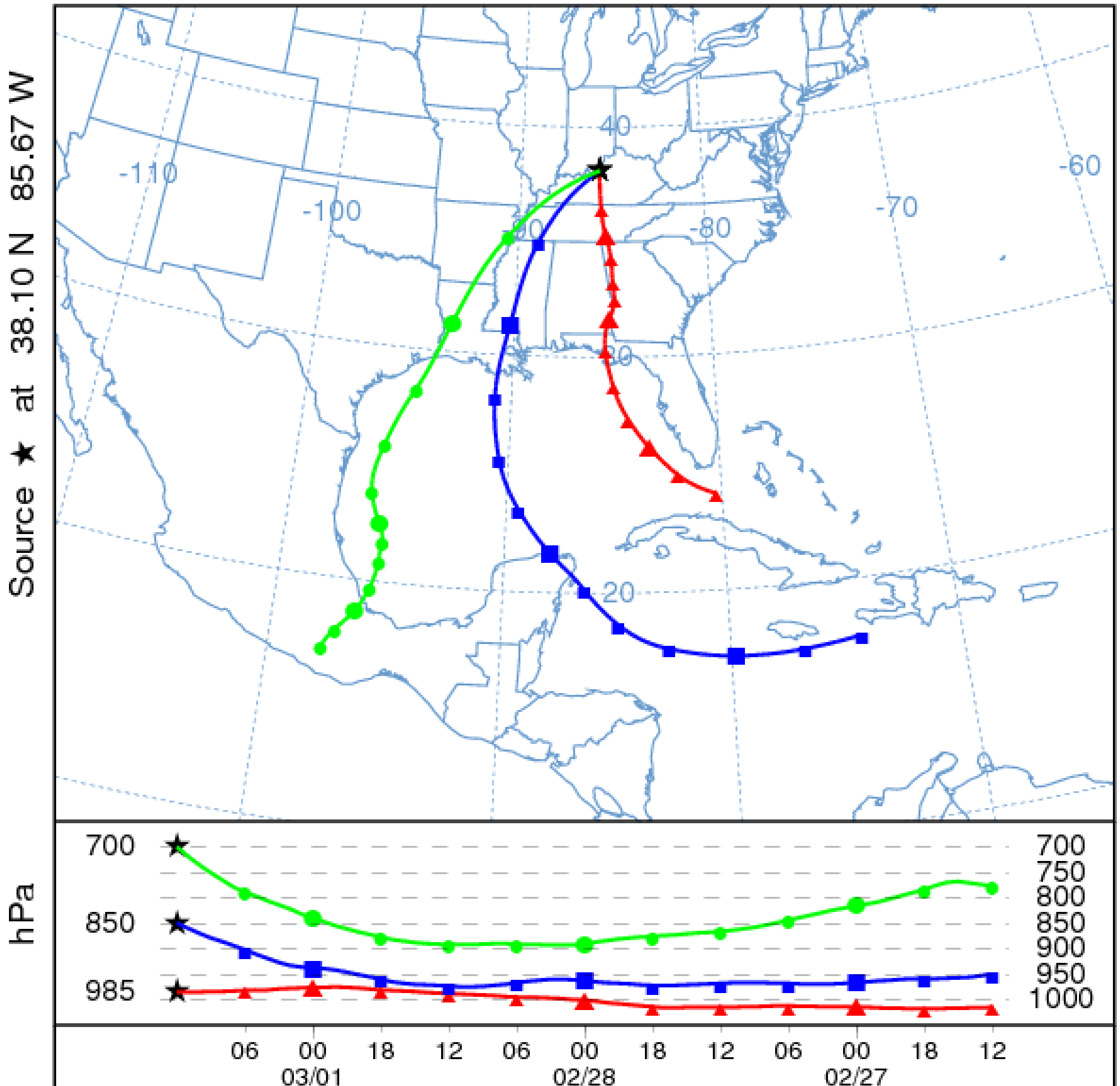
	Duration (hours)										
Area (mi²)	1	3	6	12	18	24	36	48	72	96	Total
0.4	3.06	4.27	5.42	7.25	9.96	10.94	12.60	12.61	13.50	13.50	13.50
1	3.04	4.22	5.38	7.20	9.88	10.87	12.52	12.53	13.40	13.40	13.40
10	2.97	4.11	5.29	7.06	9.66	10.72	12.32	12.35	13.15	13.15	13.15
25	2.82	4.01	5.25	6.96	9.33	10.65	12.24	12.28	13.04	13.04	13.04
50	2.68	3.90	5.16	6.82	8.95	10.61	12.10	12.10	12.85	12.85	12.85
100	2.56	3.79	5.03	6.64	8.56	10.52	11.89	11.89	12.67	12.67	12.67
150	2.49	3.71	4.92	6.52	8.32	10.39	11.76	11.78	12.57	12.57	12.57
200	2.43	3.64	4.82	6.40	8.16	10.30	11.68	11.68	12.45	12.45	12.45
300	2.30	3.53	4.68	6.22	7.92	10.17	11.49	11.49	12.28	12.28	12.28
400	2.19	3.44	4.56	6.07	7.75	10.04	11.36	11.37	12.16	12.16	12.16
500	2.10	3.36	4.46	5.96	7.62	9.94	11.26	11.27	12.06	12.06	12.06
1,000	1.81	3.08	4.11	5.59	7.20	9.55	10.88	10.88	11.72	11.72	11.72
2,000	1.50	2.77	3.75	5.21	6.81	9.03	10.43	10.45	11.35	11.35	11.35
5,000	1.09	2.34	3.27	4.63	6.30	8.14	9.70	9.74	10.68	10.68	10.68
10,000	0.83	1.97	2.87	4.18	5.73	7.40	9.00	9.10	10.05	10.06	10.06
20,000	0.62	1.55	2.46	3.70	4.96	6.50	8.17	8.26	9.24	9.24	9.24
50,000	0.38	1.05	1.75	2.83	3.64	4.96	6.38	6.54	7.53	7.55	7.55
100,000	0.21	0.61	1.09	1.71	2.27	3.15	4.21	4.37	5.55	5.71	5.71
146,019	0.15	0.42	0.76	1.24	1.62	2.25	3.04	3.18	4.15	4.26	4.26




SPAS 1244 Storm Center Mass Curve: Zone 1
February 28 (0700 UTC) to March 4 (0600 UTC), 1997
Lat: 38.100 Lon: -85.670
Incremental
Accumulated
13.51"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
1
11
21
31
41
51
61
71

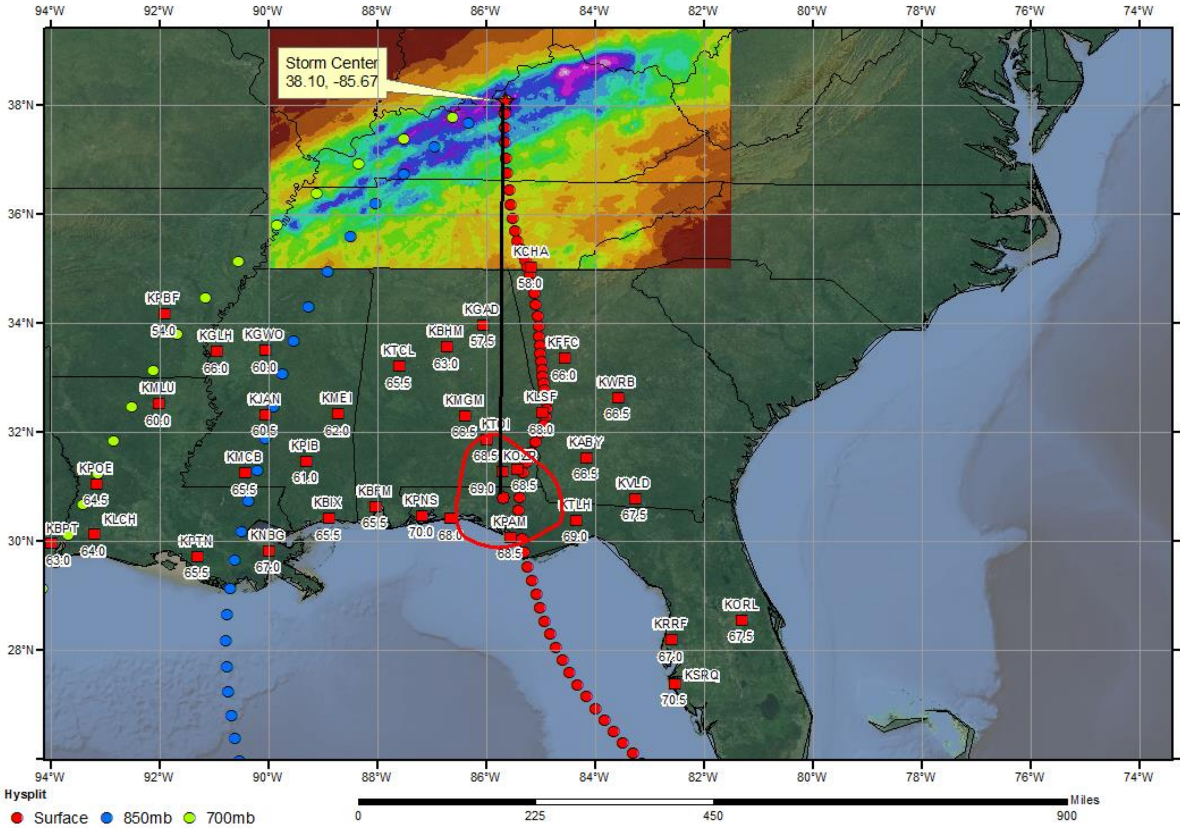

90°W
88°W
86°W
84°W
82°W
40°N
38°N
36°N
34°N
32°N
Total Precipitation (95-hrs)
SPAS-NEXRAD: 1244 Louisville, KY
2/28/1997 0700 UTC- 3/4/1997 0500 UTC
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Estimated
Miles
0 55 110 220
Kilometers
0 95 190 380
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
7/10/2012

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 01 Mar 97
CDC1 Meteorological Data



This is not a NOAA product. It was produced by a web user.
Job ID: 374196 Job Start: Tue Jul 10 16:18:39 UTC 2012
Source 1 lat.: 38.10 lon.: -85.67 hgts: 0, 1260, 2870 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Mar 2097 - reanalysis

SPAS 1244 Louisville, KY Storm Analysis
Feb. 26-28 1997



Storm Precipitation Analysis System (SPAS) For Storm #1804_1 SPAS-NEXRAD Analysis

General Storm Location: Halifax, VT (re-run of SPAS 1201)

Storm Dates: October 7-11, 2005

Event: Tropical TS Tammy Remnants

DAD Zone 1

Latitude: 42.7542

Longitude: -72.7625

Max. Grid Rainfall Amount: 15.53"

Max. Observed Rainfall Amount: 15.44"

Number of Stations: 998

SPAS Version: 10.0

Basemap: 90/10 weighted Radar vs. PRISM 30yr Climatology for 10/2005 basemap

Spatial resolution: 0.2463

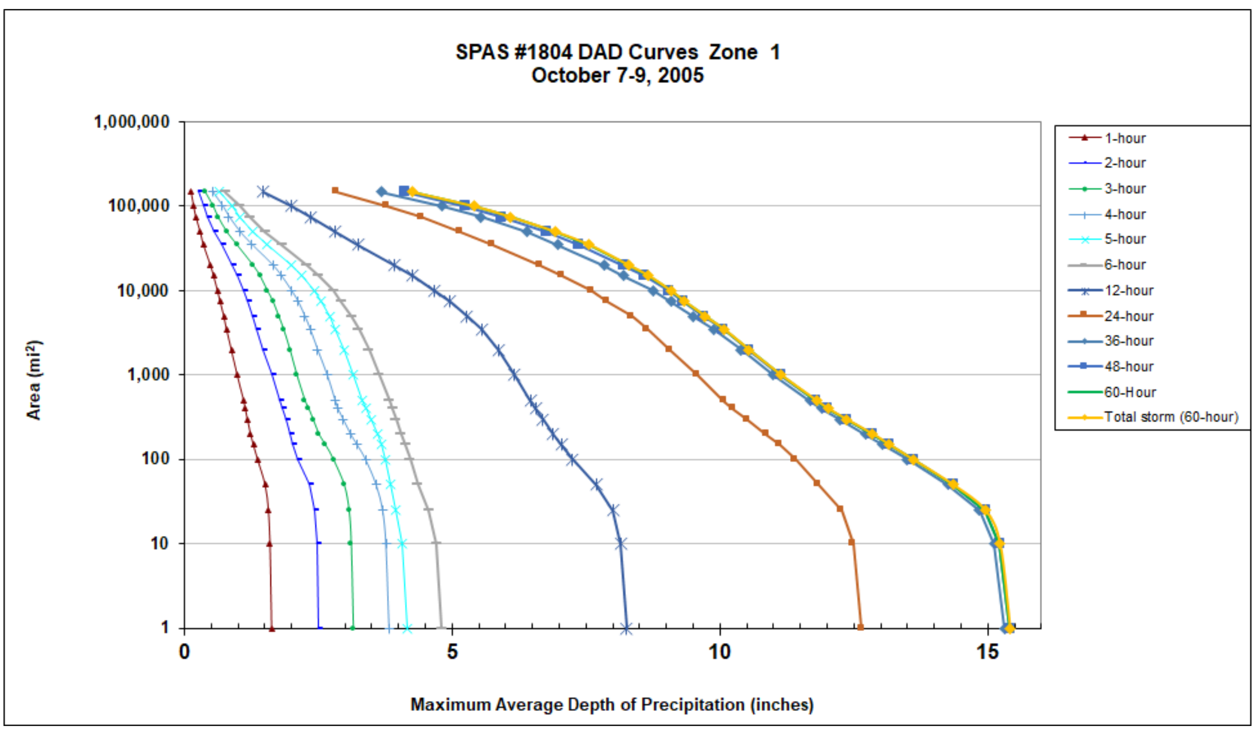
Radar Included: Yes

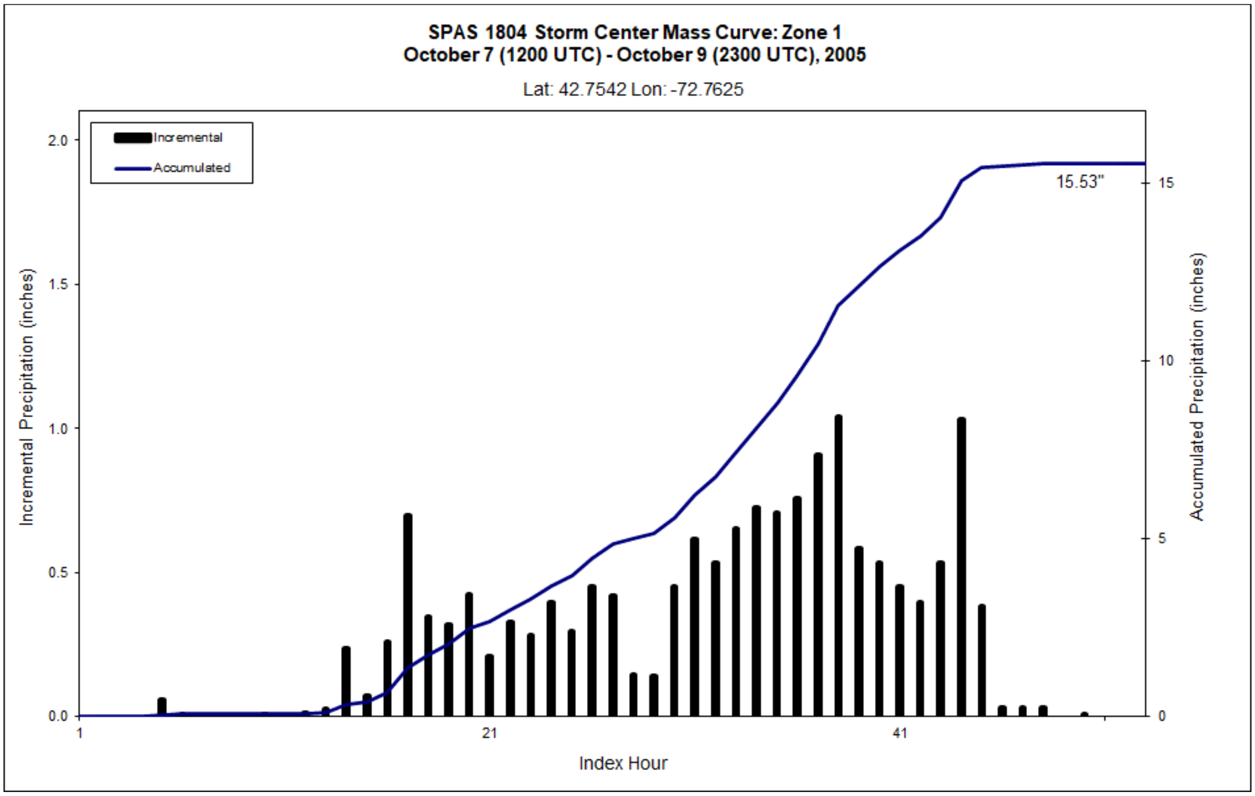
Depth-Area-Duration (DAD) analysis: Yes

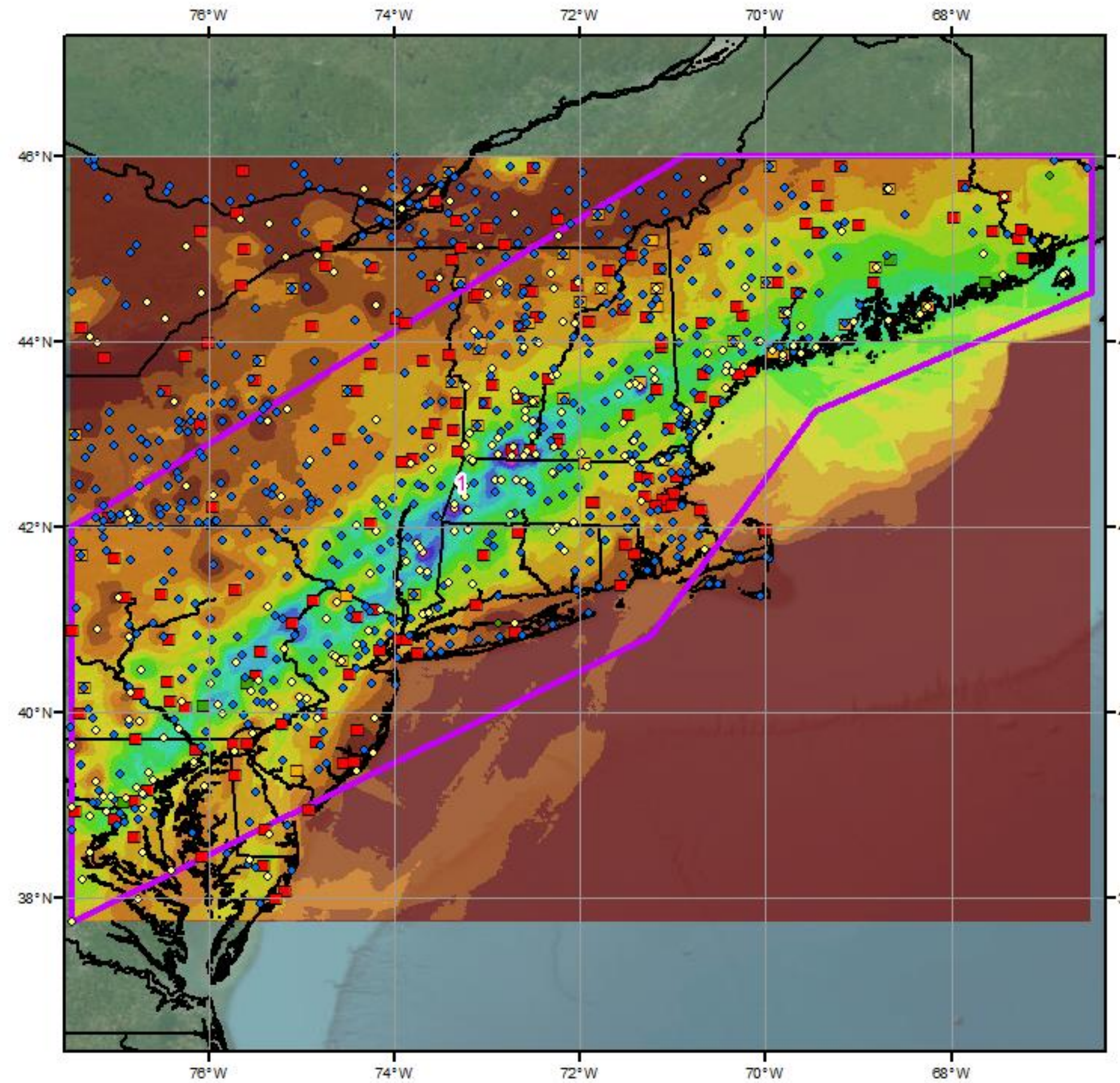
Reliability of results: This analysis was based on 998 hourly stations, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the radar grids, basemap and gauge stations. Timing is based on hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1804_1	-72.7625	42.7542	1,485	1,500	24-Sep	80.00	3.60	0.43	82	3.170	82.66	82.5	4.03	0.45	87	3.580	1.129

Storm 1804 - October 7 (1200 UTC) - October 9 (2300 UTC), 2005												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
Area (mi^2)	Duration (hours)											
	1	2	3	4	5	6	12	24	36	48	60	Total
0.4	1.64	2.53	3.17	3.86	4.17	4.84	8.30	12.72	15.39	15.49	15.49	15.49
1	1.63	2.51	3.15	3.83	4.15	4.81	8.26	12.65	15.31	15.41	15.41	15.41
10	1.60	2.48	3.11	3.77	4.07	4.71	8.15	12.49	15.12	15.22	15.22	15.22
25	1.57	2.42	3.07	3.71	3.94	4.56	8.00	12.27	14.85	14.95	14.95	14.95
50	1.51	2.34	2.98	3.59	3.86	4.36	7.69	11.84	14.25	14.35	14.35	14.35
100	1.37	2.13	2.78	3.39	3.76	4.22	7.25	11.41	13.50	13.60	13.60	13.60
150	1.29	2.02	2.63	3.23	3.68	4.13	7.04	11.12	13.04	13.16	13.16	13.16
200	1.24	1.97	2.51	3.11	3.62	4.05	6.89	10.87	12.72	12.85	12.85	12.85
300	1.18	1.90	2.40	2.97	3.50	3.95	6.69	10.50	12.24	12.35	12.36	12.36
400	1.14	1.84	2.32	2.87	3.40	3.89	6.56	10.24	11.90	12.01	12.02	12.02
500	1.11	1.79	2.25	2.82	3.33	3.83	6.46	10.07	11.68	11.79	11.80	11.80
1,000	0.99	1.63	2.10	2.67	3.15	3.64	6.16	9.58	11.00	11.13	11.14	11.14
2,000	0.88	1.48	1.97	2.49	2.99	3.45	5.86	9.06	10.39	10.53	10.54	10.54
3,500	0.79	1.35	1.85	2.35	2.82	3.26	5.55	8.64	9.88	10.06	10.07	10.07
5,000	0.74	1.28	1.76	2.25	2.72	3.12	5.28	8.35	9.50	9.69	9.72	9.72
7,500	0.67	1.18	1.65	2.12	2.56	2.93	4.96	7.90	9.09	9.31	9.34	9.34
10,000	0.62	1.11	1.55	2.00	2.43	2.78	4.66	7.60	8.75	9.04	9.08	9.08
15,000	0.55	0.98	1.41	1.81	2.19	2.51	4.27	7.05	8.20	8.59	8.67	8.67
20,000	0.49	0.90	1.28	1.65	1.99	2.29	3.93	6.65	7.83	8.20	8.30	8.30
35,000	0.36	0.69	0.98	1.26	1.53	1.82	3.24	5.75	6.97	7.37	7.56	7.56
50,000	0.30	0.56	0.79	1.03	1.27	1.51	2.82	5.15	6.40	6.76	6.93	6.93
75,000	0.22	0.43	0.63	0.83	1.03	1.22	2.35	4.42	5.54	5.91	6.09	6.09
100,000	0.18	0.36	0.54	0.71	0.89	1.04	2.00	3.78	4.82	5.24	5.42	5.42
147,851	0.13	0.26	0.39	0.52	0.65	0.77	1.48	2.85	3.68	4.12	4.26	4.26




SPAS 1804 Storm Center Mass Curve: Zone 1
October 7 (1200 UTC) - October 9 (2300 UTC), 2005
Lat: 42.7542 Lon: -72.7625
Incremental
Accumulated
15.53"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
2.0
1.5
1.0
0.5
0.0
15
10
5
0
1
21
41



Total Storm (60-hours) Precipitation (inches)
10/7/2005 1200 UTC - 10/9/2005 2300 UTC
SPAS-NEXRAD 1804 - Halifax, VT

Gauges

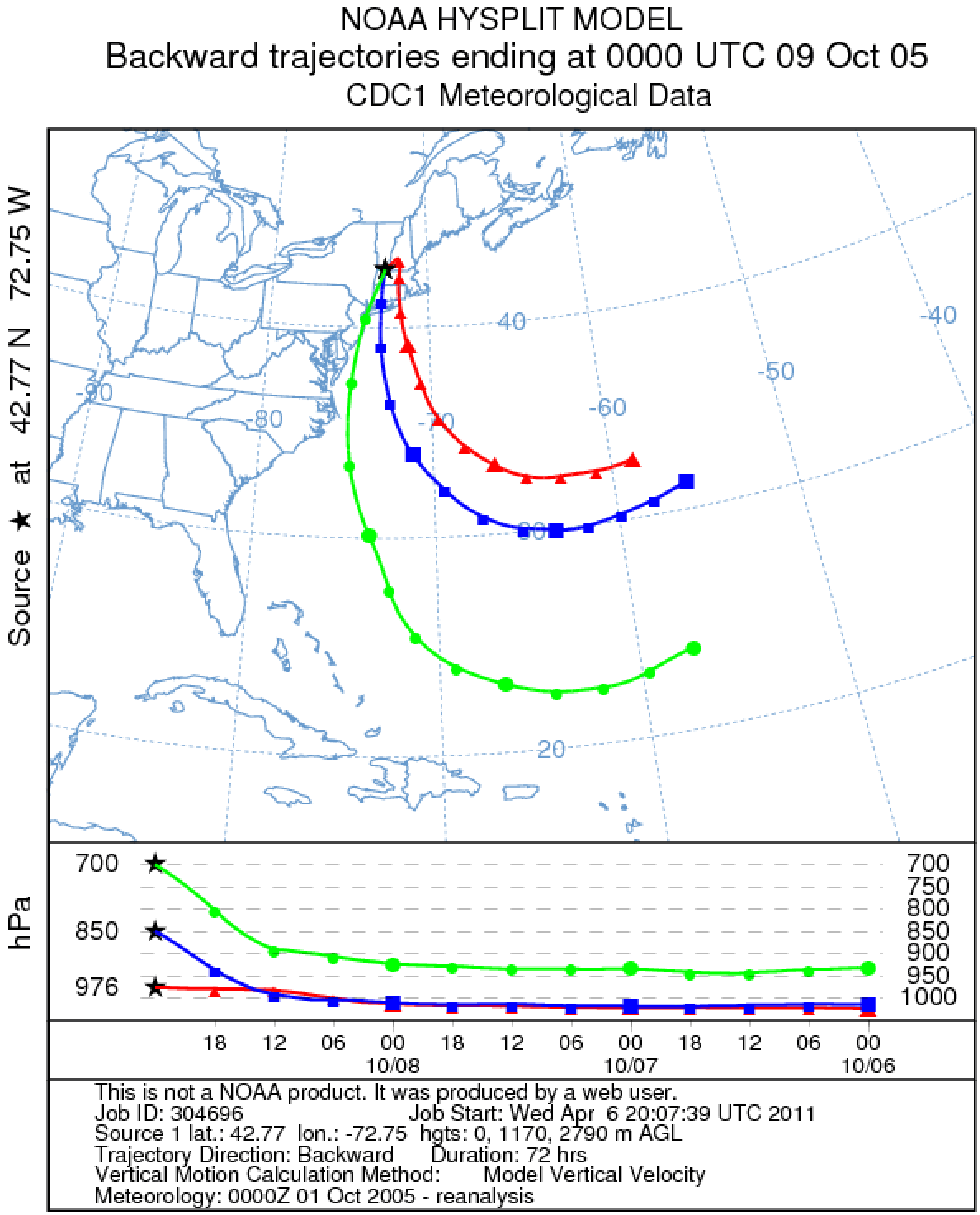
- Daily
- Hourly
- HEP
- Hourly Pseudo
- Supplemental
- SE

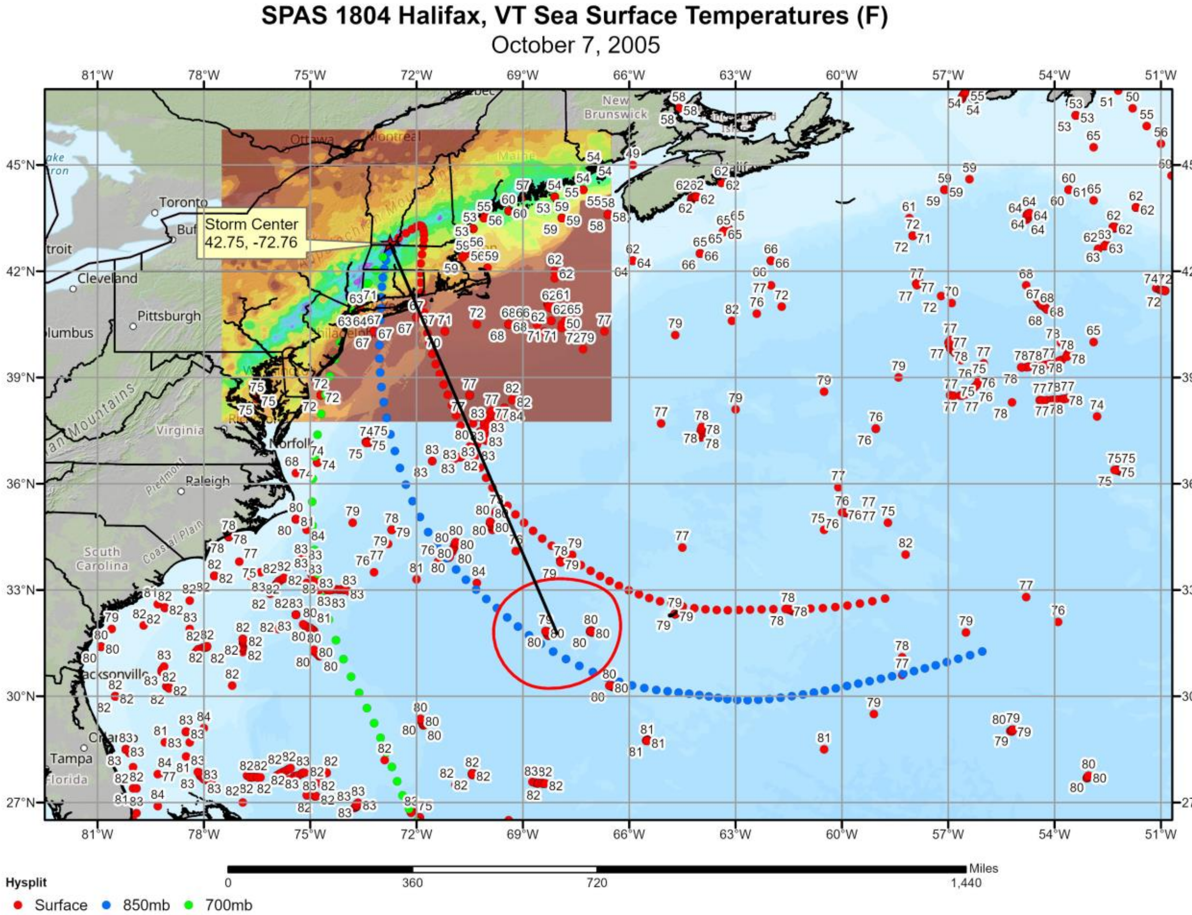
0 50 100 200 Miles
0 100 200 400 Kilometers

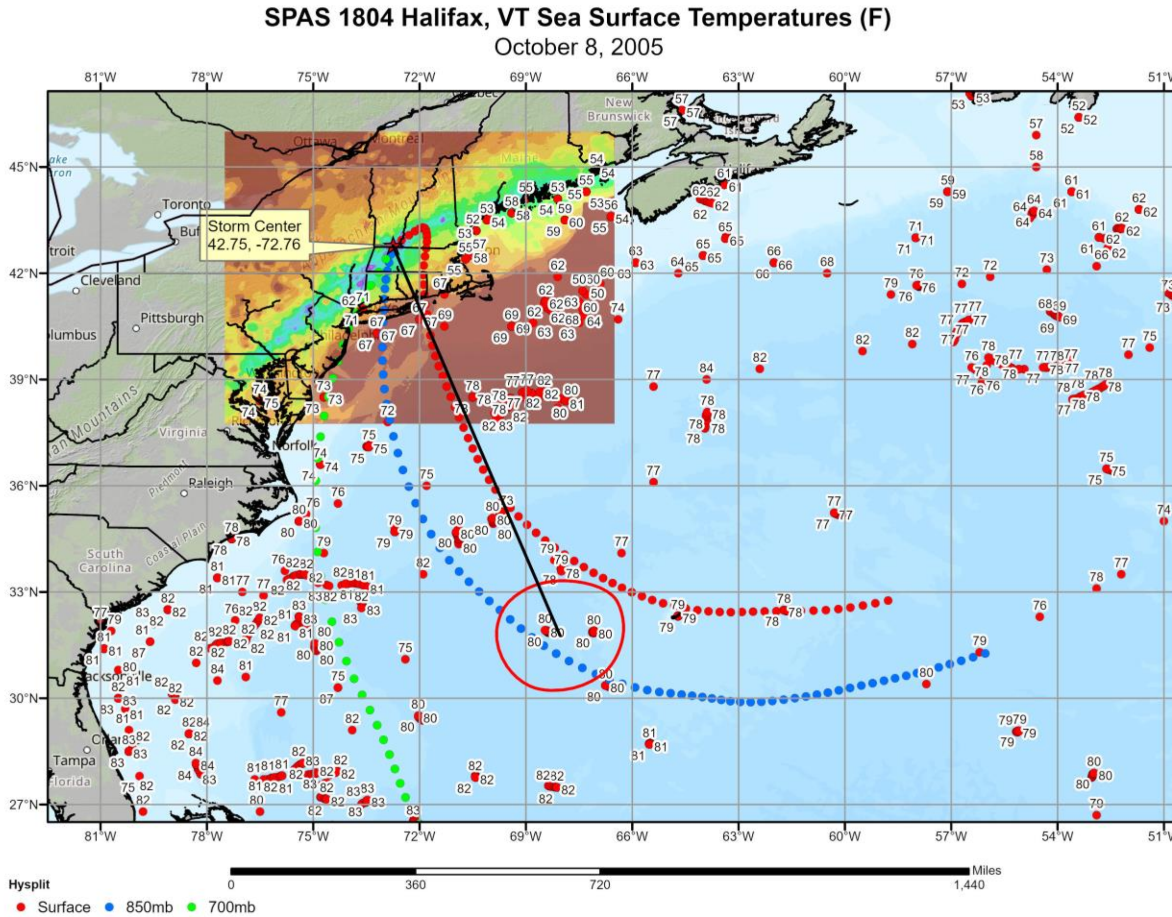
Precipitation (inches)

0.00 - 1.00	4.01 - 5.00	8.01 - 9.00	12.01 - 13.00
1.01 - 2.00	5.01 - 6.00	9.01 - 10.00	13.01 - 14.00
2.01 - 3.00	6.01 - 7.00	10.01 - 11.00	14.01 - 15.00
3.01 - 4.00	7.01 - 8.00	11.01 - 12.00	15.01 - 16.00

05/29/2023

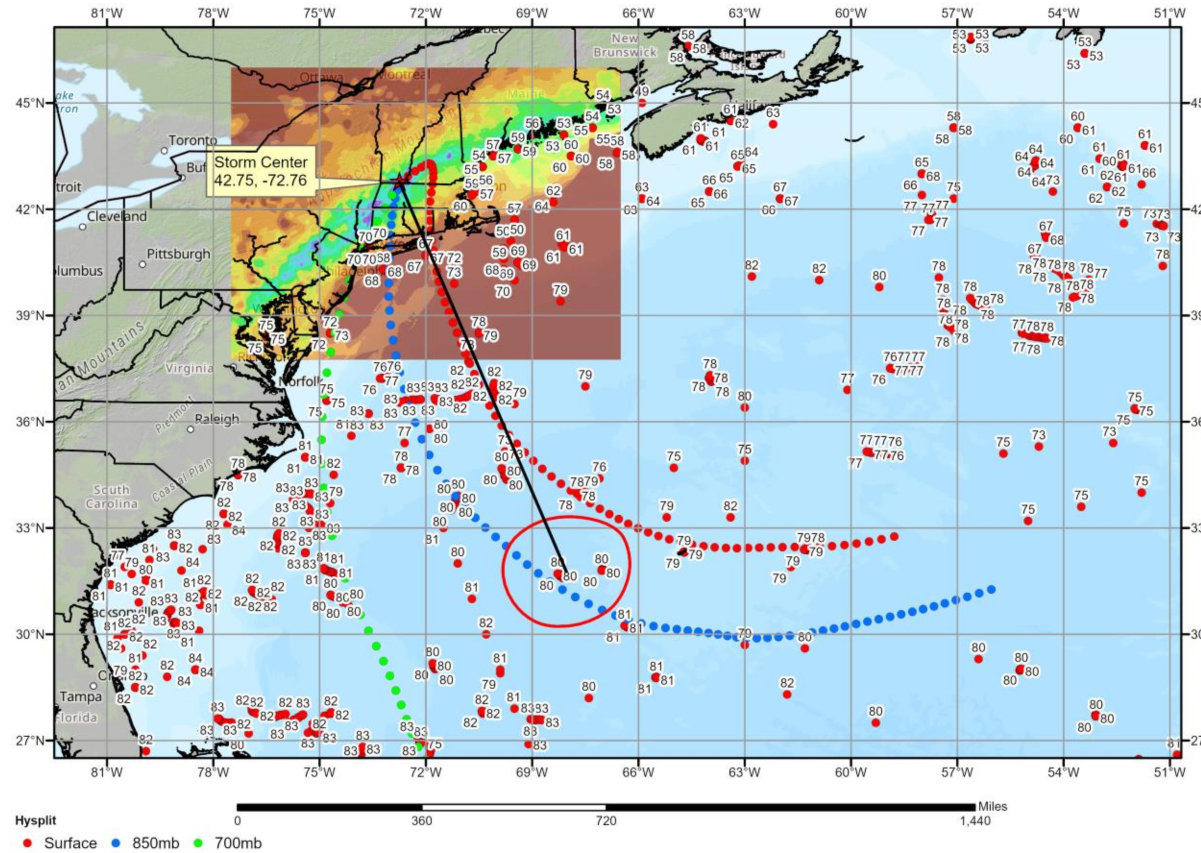

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 09 Oct 05
CDC1 Meteorological Data
Source ★ at 42.77 N 72.75 W
40
-40
-50
-90
-80
-70
-60
30
20
hPa
700
850
976
700
750
800
850
900
950
1000
18
12
06
00
10/08
18
12
06
00
10/07
18
12
06
00
10/06
This is not a NOAA product. It was produced by a web user.
Job ID: 304696
Job Start: Wed Apr 6 20:07:39 UTC 2011
Source 1 lat.: 42.77 lon.: -72.75 hgts: 0, 1170, 2790 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Oct 2005 - reanalysis


SPAS 1804 Halifax, VT Sea Surface Temperatures (F)
October 7, 2005
Storm Center
42.75, -72.76
Hysplit
Surface
850mb
700mb
Miles
0
360
720
1,440


SPAS 1804 Halifax, VT Sea Surface Temperatures (F)
October 8, 2005
Storm Center
42.75, -72.76
Hysplit
Surface
850mb
700mb
Miles
0
360
720
1,440

SPAS 1804 Halifax, VT Sea Surface Temperatures (F)

October 6, 2005



Storm Precipitation Analysis System (SPAS) For Storm #1047_1
SPAS-NEXRAD Analysis

General Storm Location: Tamaqua, PA

Storm Dates: 6/26/2006 0100Z – 6/28/2006 1000Z

Event: Frontal system-general storm

DAD Zone 1

Latitude: 41.675

Longitude: -75.375

Max. Grid/Radar Rainfall Amount: 12.26" (Grid/Pixel Point)

Max. Observed Rainfall Amount: 11.79" (11.97" grid cell at Aldenville, ALDP1)

Number of Stations: 491 (99-hourly, 21 hourly estimated, 78-daily 293-supplemental) gauging stations within the defined search domain.

SPAS Version: 4.0

Base Map Used: No

Spatial resolution: 0.36 mi^2

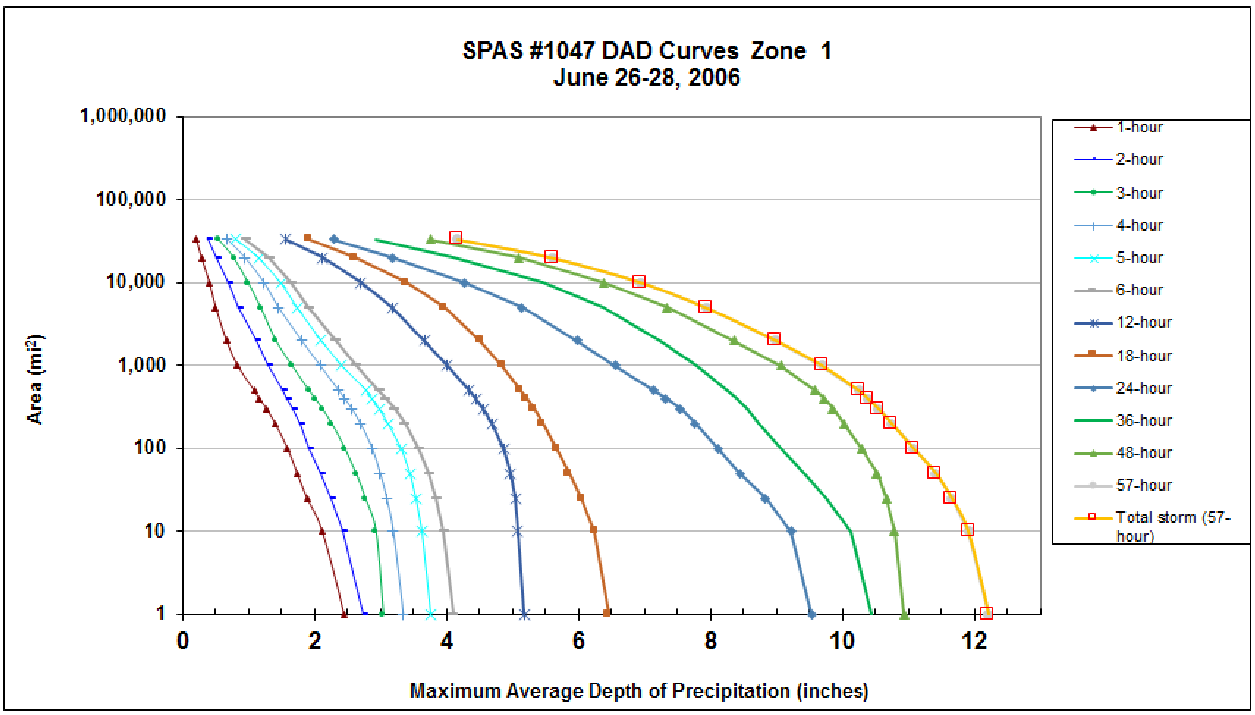
Radar Included: Yes (multiple stations were merged)

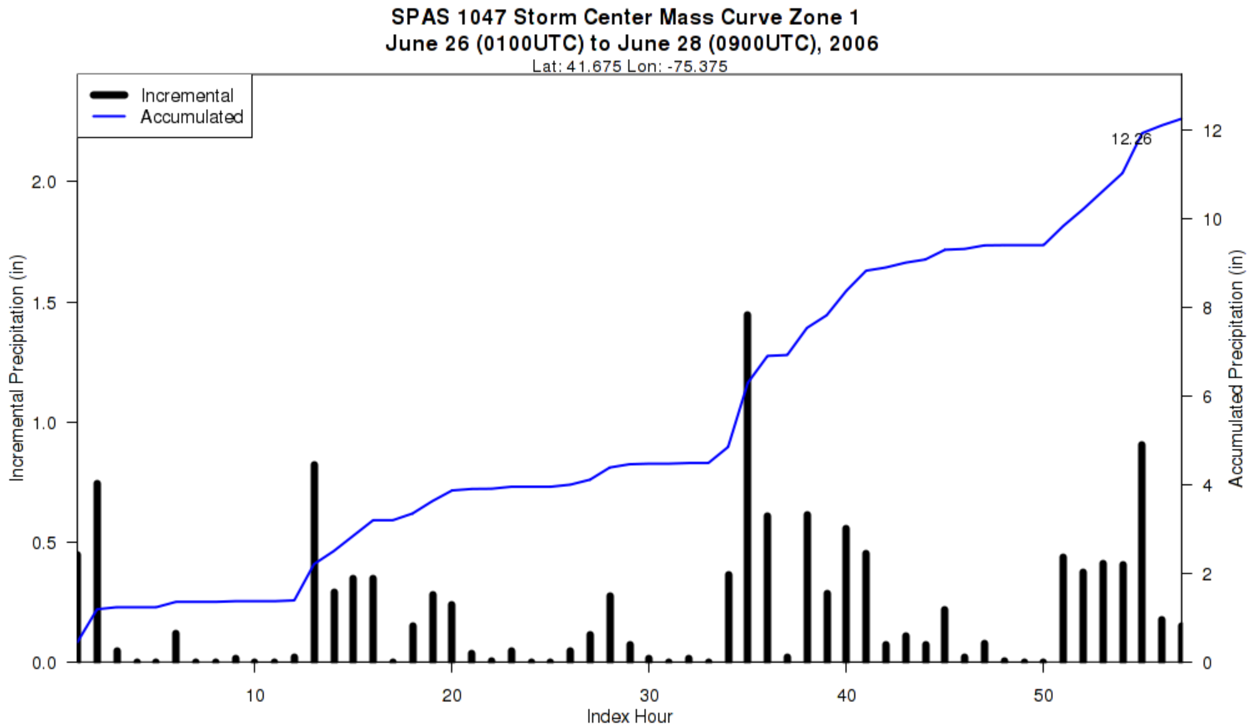
Depth-Area-Duration (DAD) analysis: Yes: 1, 2, 3, 4, 5, 6, 12, 18, 24, 36, 48, & 57 hours

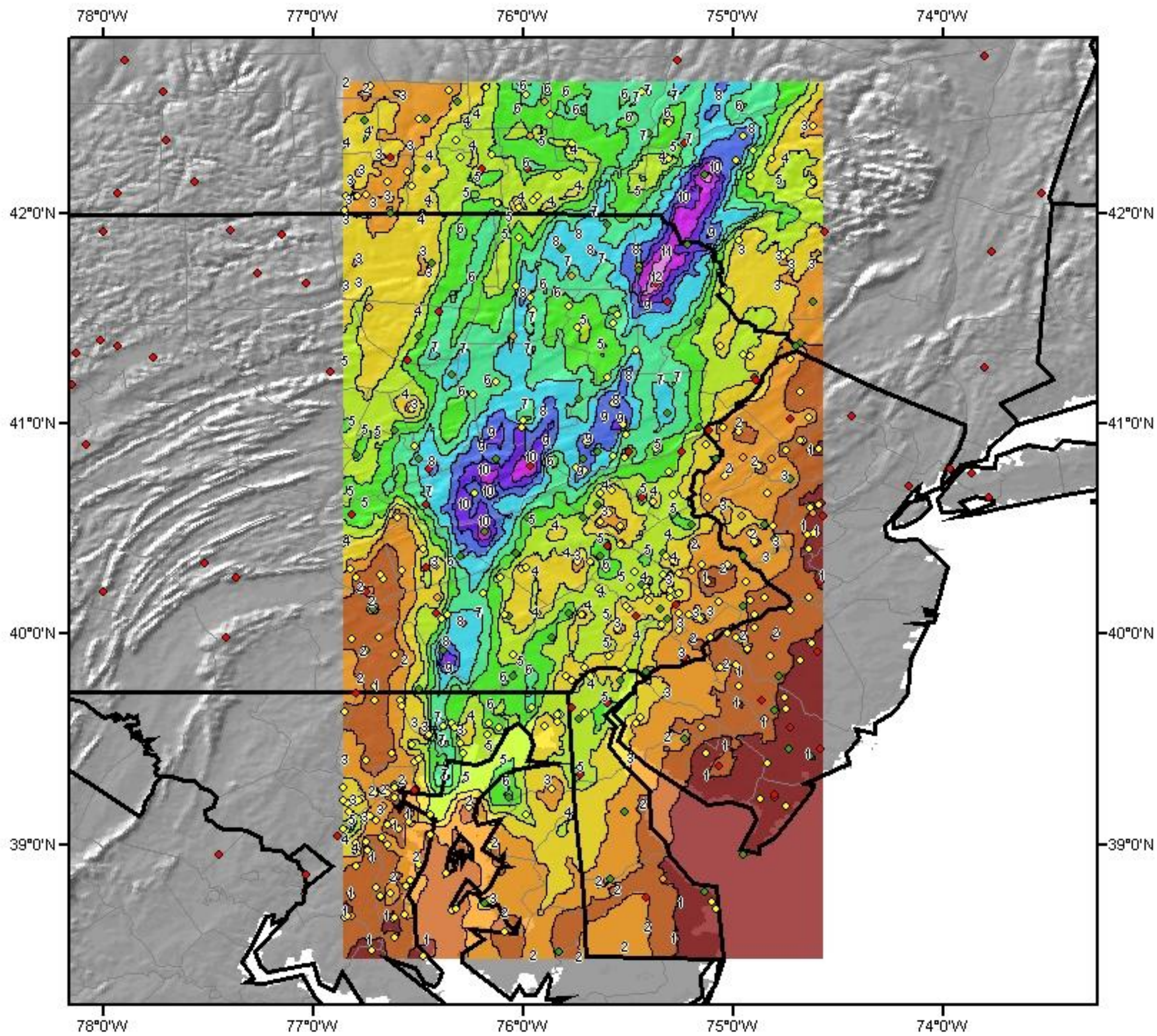
						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1047_1	-75.3750	41.6750	1,260	10-Jul	70.50	2.31	0.28	63	2.030	76.10	2.99	0.33	74	2.660	1.310

Area (mi²)	Duration (hours)												
	1	2	3	4	5	6	12	18	24	36	48	57	Total
0.4	2.49	2.77	3.06	3.38	3.79	4.15	5.23	6.49	9.57	10.49	10.98	12.26	12.26
1	2.45	2.73	3.03	3.34	3.76	4.10	5.18	6.45	9.54	10.45	10.94	12.22	12.22
10	2.12	2.42	2.92	3.19	3.63	3.95	5.08	6.24	9.22	10.13	10.79	11.91	11.91
25	1.89	2.24	2.76	3.09	3.54	3.84	5.04	6.04	8.83	9.76	10.67	11.66	11.66
50	1.74	2.09	2.62	2.99	3.44	3.73	4.97	5.86	8.45	9.41	10.52	11.42	11.42
100	1.59	1.92	2.45	2.87	3.31	3.58	4.86	5.67	8.11	9.07	10.29	11.08	11.08
200	1.40	1.77	2.25	2.69	3.12	3.36	4.69	5.46	7.77	8.74	10.03	10.75	10.75
300	1.27	1.67	2.11	2.56	2.99	3.21	4.55	5.32	7.54	8.55	9.86	10.55	10.55
400	1.16	1.59	2.00	2.45	2.88	3.08	4.44	5.21	7.32	8.40	9.72	10.39	10.39
500	1.08	1.51	1.91	2.36	2.77	2.97	4.34	5.12	7.14	8.27	9.59	10.25	10.25
1,000	0.83	1.30	1.65	2.08	2.40	2.63	4.01	4.84	6.56	7.79	9.07	9.69	9.69
2,000	0.66	1.12	1.41	1.80	2.10	2.32	3.66	4.51	5.98	7.24	8.36	8.99	8.99
5,000	0.50	0.85	1.18	1.45	1.74	1.91	3.17	3.97	5.14	6.37	7.34	7.93	7.93
10,000	0.40	0.69	0.99	1.23	1.49	1.64	2.70	3.39	4.26	5.46	6.38	6.95	6.95
20,000	0.28	0.52	0.77	0.94	1.16	1.31	2.12	2.61	3.18	4.10	5.10	5.60	5.60
33,237	0.20	0.37	0.54	0.67	0.81	0.95	1.56	1.92	2.29	2.93	3.75	4.17	4.17

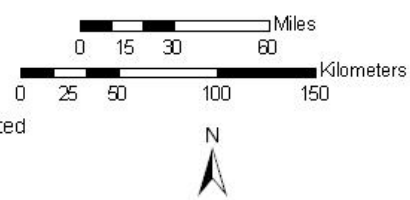
Table: **Storm 1047- June 26 (0100 UTC) - June 28 (0900 UTC), 2006** — **MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)**




SPAS 1047 Storm Center Mass Curve Zone 1
June 26 (0100UTC) to June 28 (0900UTC), 2006
Lat: 41.675 Lon: -75.375
Incremental
Accumulated
12.26
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
2
4
6
8
10
12
10
20
30
40
50



Total Rainfall (57-hours)
Tamaqua, PA 2006 Storm
Storm #1047 June 26 (0100 Z) to 28 (1000 Z), 2006

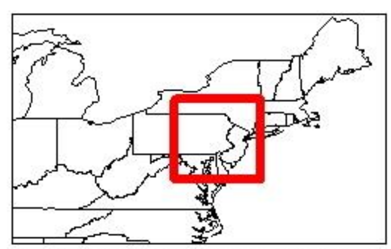


Gauging Stations

- Daily
- Hourly Estimated
- Hourly
- Supplemental

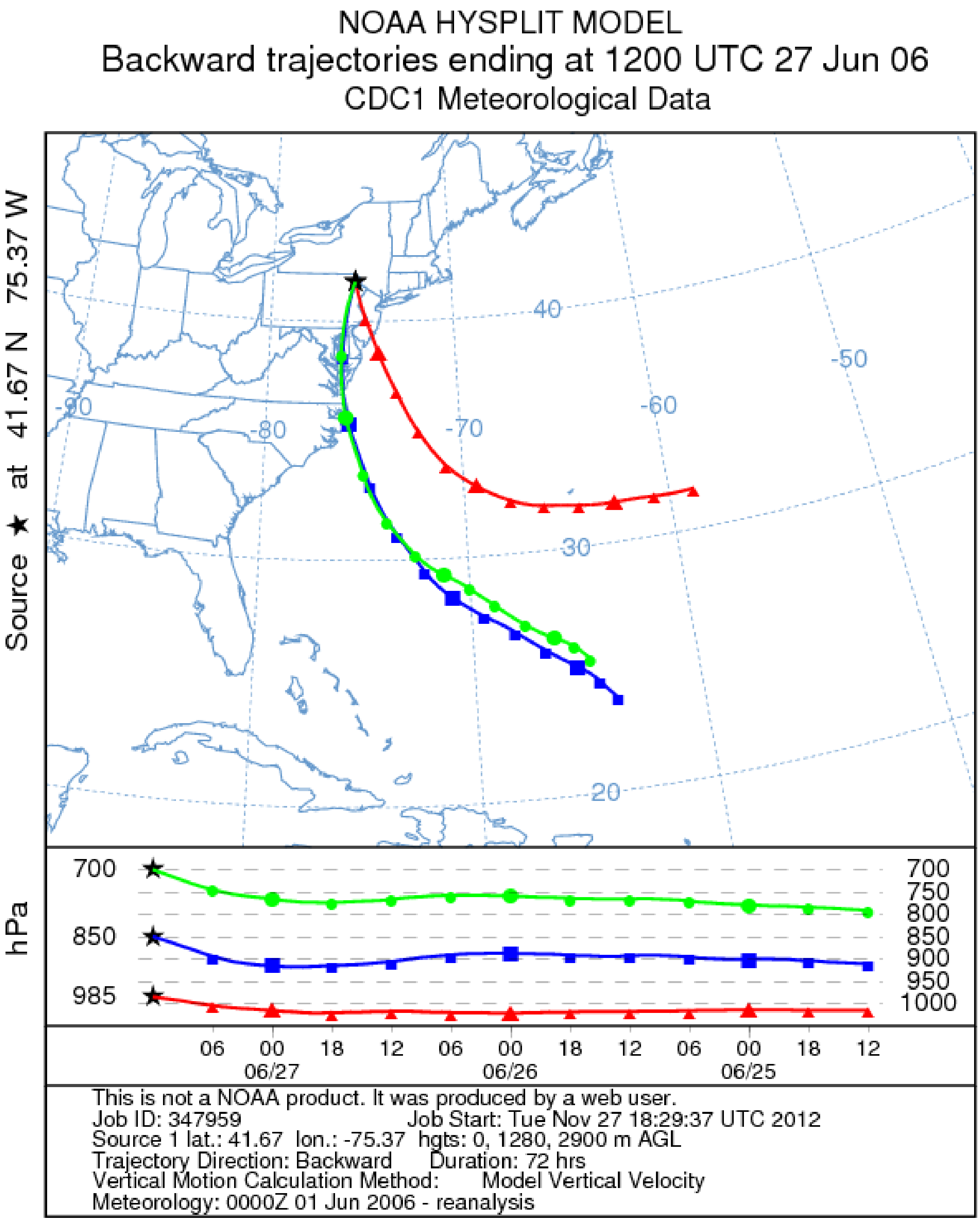
Precipitation (inches)

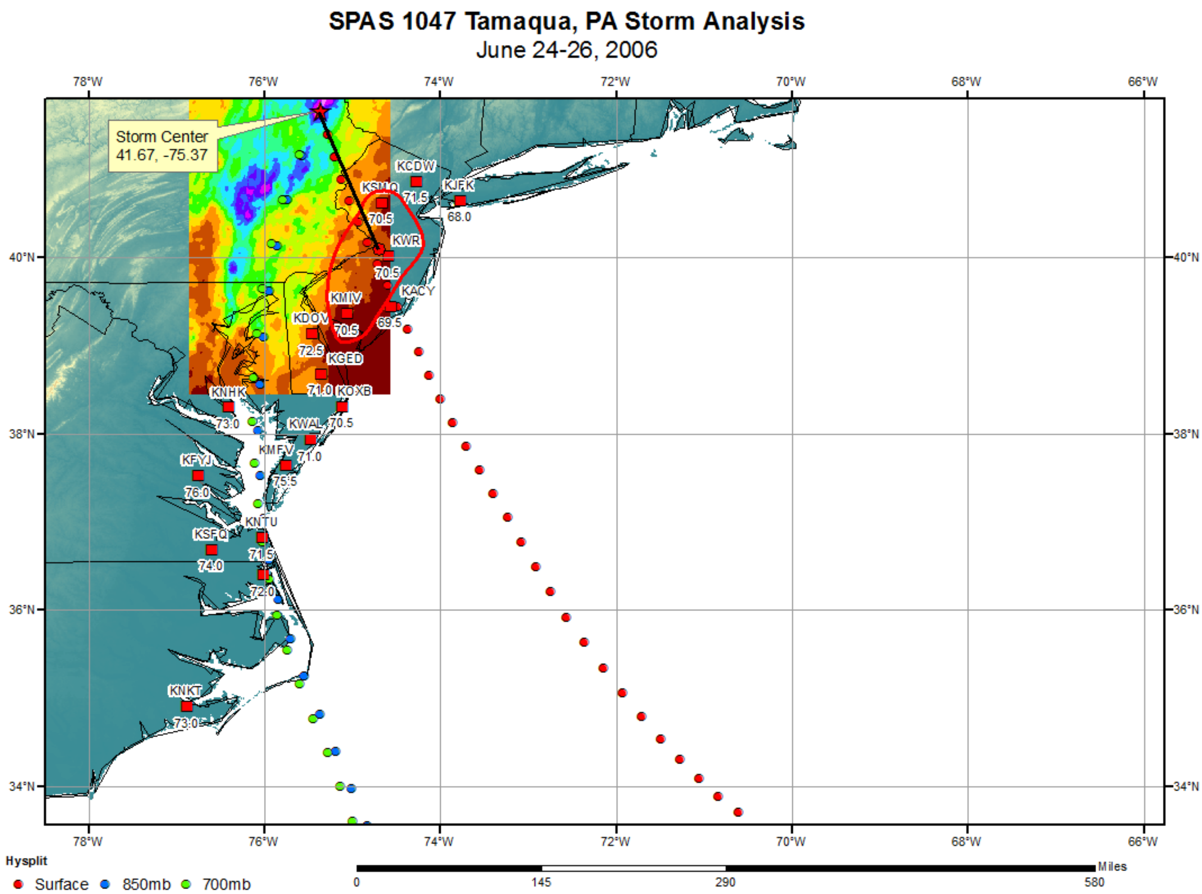
- 0.05 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 4.00
- 4.01 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 11.00
- 11.01 - 12.00
- 12.01 - 13.00



Coordinate system: GCS North American 1983
Scale: 1:2,975,355

MetStat/AWA December 20, 2007


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 27 Jun 06
CDC1 Meteorological Data
Source ★ at 41.67 N 75.37 W
40
-50
-60
-90
-80
-70
30
20
hPa
700
850
985
700
750
800
850
900
950
1000
06
00
18
12
06
00
18
12
06
00
18
12
06/27
06/26
06/25
This is not a NOAA product. It was produced by a web user.
Job ID: 347959 Job Start: Tue Nov 27 18:29:37 UTC 2012
Source 1 lat.: 41.67 lon.: -75.37 hgts: 0, 1280, 2900 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Jun 2006 - reanalysis



SPAS 1047 Tamaqua, PA Storm Analysis
June 24-26, 2006
Storm Center
41.67, -75.37
KCDW
KJFK
KSMQ
71.5
68.0
70.5
KWR
70.5
KACY
KMIV
KDOV
70.5
69.5
72.5
KGED
71.0
KOXB
KNHK
73.0
KWAL
70.5
KMFV
71.0
KFYJ
75.5
76.0
KNTU
KSFQ
71.5
74.0
72.0
KNKT
73.0
78°W
76°W
74°W
72°W
70°W
68°W
66°W
40°N
38°N
36°N
34°N
Hysplit
Surface
850mb
700mb
Miles
0
145
290
580

Storm Precipitation Analysis System (SPAS) For Storm #1242_1 SPAS-NEXRAD Analysis

General Storm Location: Mainly Missouri, Illinois, and northern Arkansas.

Storm Dates: March 17-20, 2008

Event: General storm

DAD Zone 1

Latitude: 37.155

Longitude: -91.445

Max. Grid Rainfall Amount: 15.09

Max. Observed Rainfall Amount: 15.10

Number of Stations: 1142 (474 Daily, 242 Hourly, 0 Hourly Estimated, 32 Hourly Pseudo, 390 Supplemental, and 4 Supplemental Estimated)

SPAS Version: 9.5

Basemap: PRISM Mean (1971-2000) March precipitation plus Stage IV 48-hr total rainfall

Spatial resolution: 36 seconds (~ 0.40 mi^2)

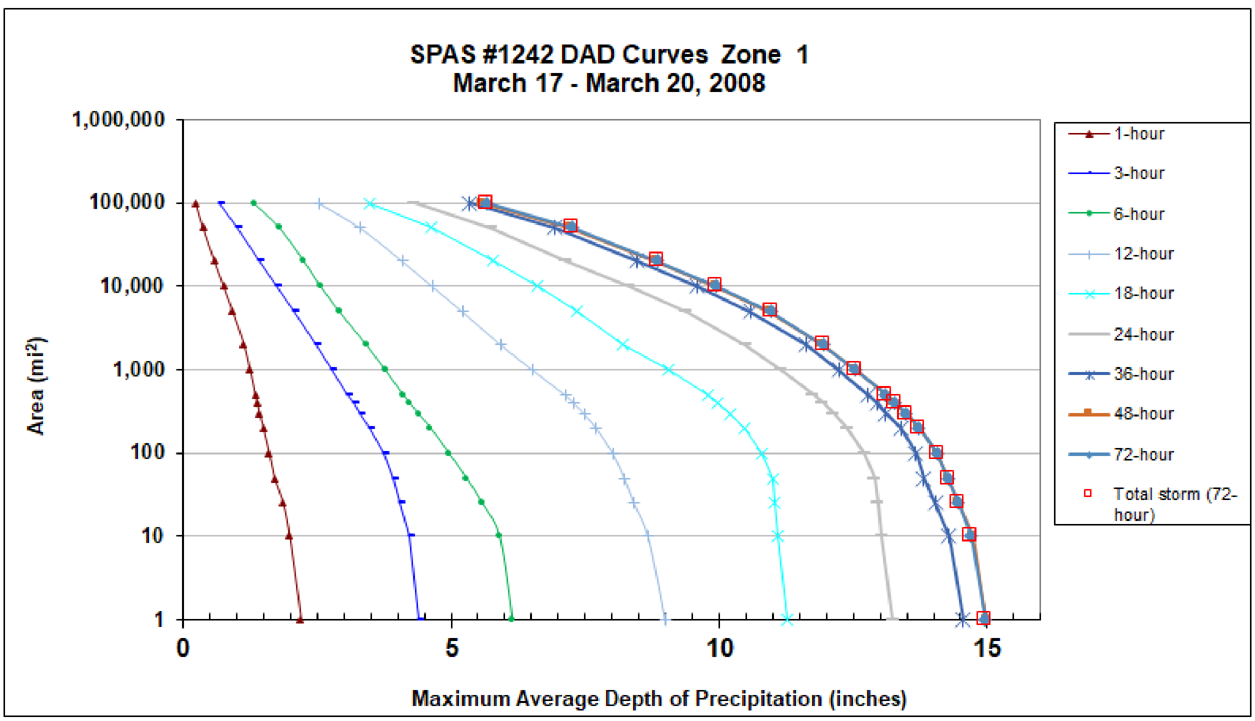
Radar Included: Yes

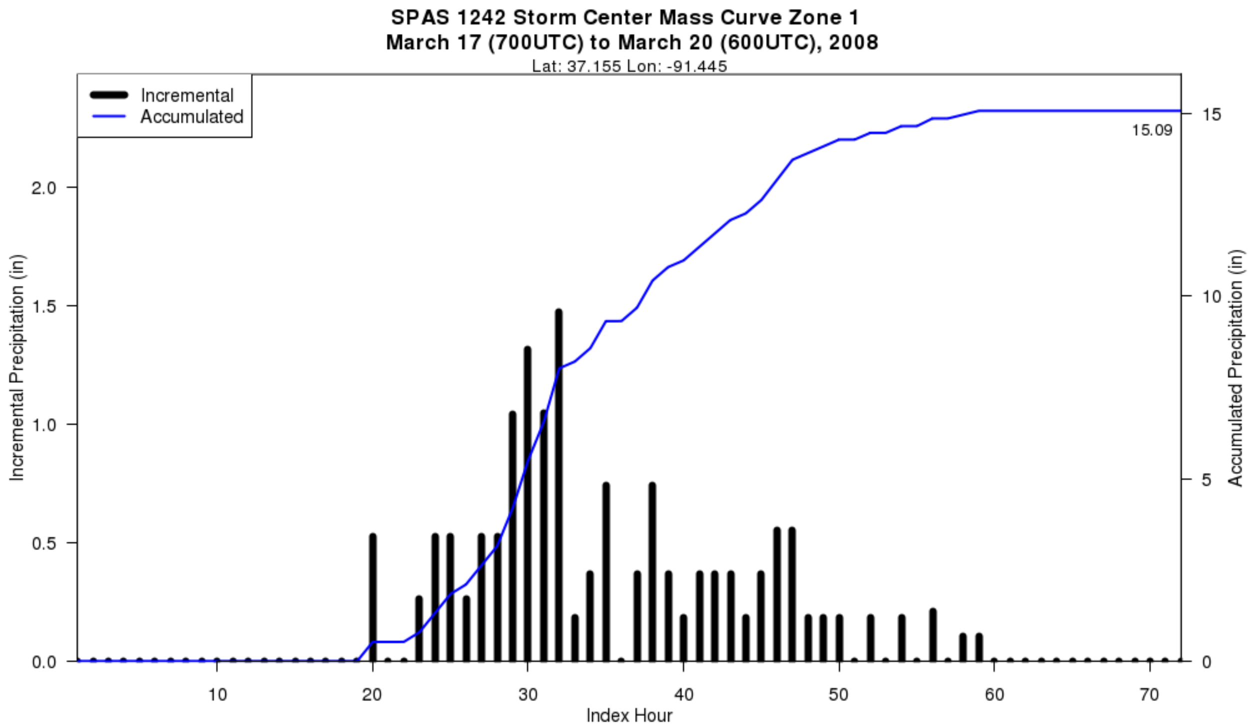
Depth-Area-Duration (DAD) analysis: Yes

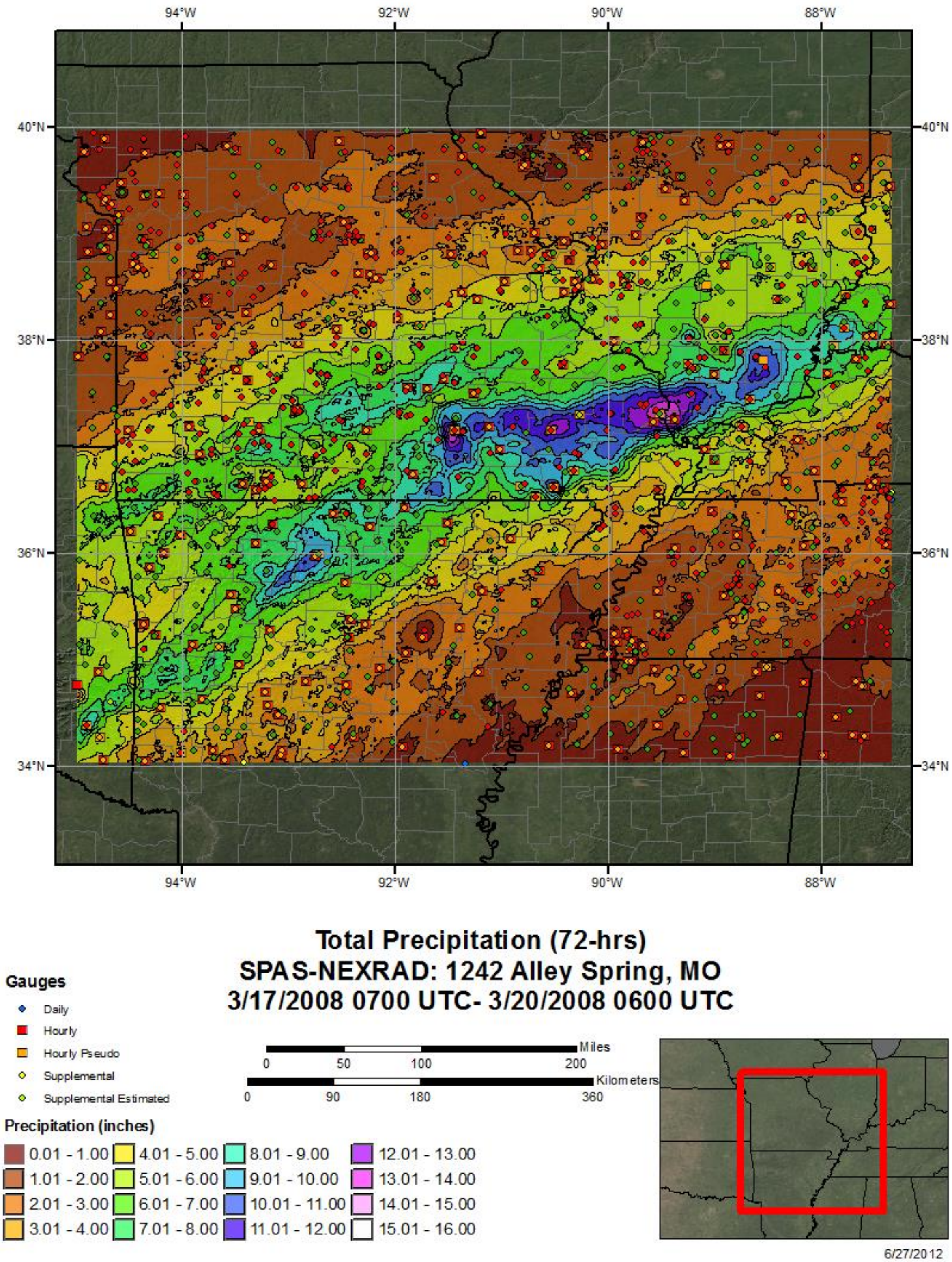
Reliability of results: This analysis was based on WDT NEXRAD data (unblocked) and extensive gauge data, we have a very high degree of confidence in the results. There were a few areas of radar beam blockage in the domain, these areas were adjusted using a beam blockage mask. The radar blocked areas did not affect the SPAS analysis.

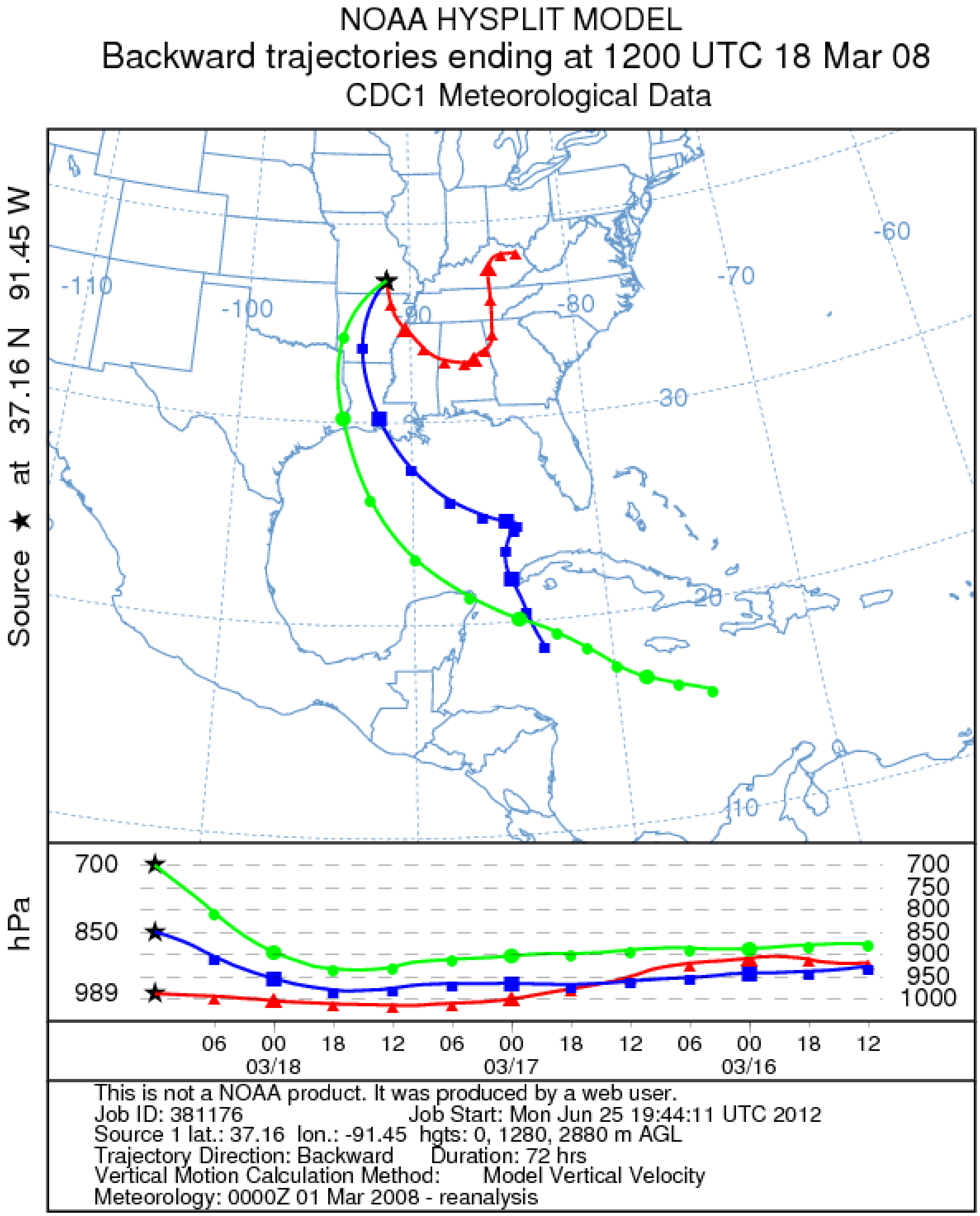
							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1242_1	-91.4450	37.1150	1,050	1,100	1-Apr	66.00	1.86	0.20	54	1.660	71.78	72.0	2.47	0.25	66	2.220	1.337

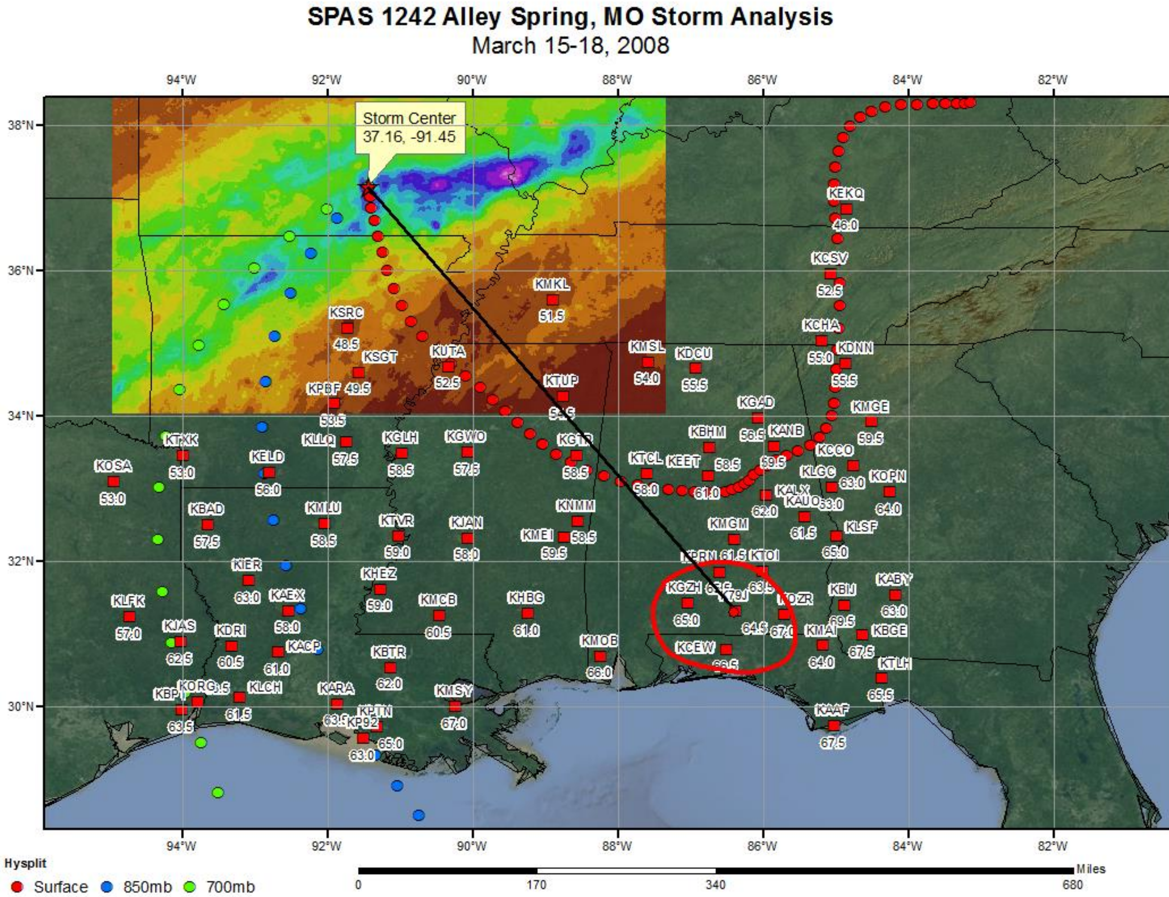
Storm 1242 - March 17 (0700 UTC) - March 20 (0600 UTC), 2008										
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
Area (mi^2)	Duration (hours)									
	1	3	6	12	18	24	36	48	72	Total
0.4	2.23	4.43	6.18	9.07	11.32	13.32	14.66	15.08	15.08	15.08
1	2.19	4.39	6.13	9.00	11.26	13.24	14.55	14.98	14.97	14.97
10	1.98	4.23	5.89	8.68	11.10	13.03	14.29	14.73	14.70	14.70
25	1.86	4.05	5.57	8.42	11.04	12.96	14.03	14.47	14.47	14.47
50	1.70	3.91	5.28	8.24	10.99	12.90	13.82	14.27	14.27	14.27
100	1.60	3.74	4.95	8.02	10.81	12.71	13.67	14.06	14.07	14.07
200	1.49	3.48	4.61	7.71	10.47	12.39	13.38	13.72	13.73	13.73
300	1.42	3.30	4.38	7.48	10.20	12.13	13.11	13.48	13.49	13.49
400	1.38	3.17	4.22	7.29	9.98	11.92	12.94	13.26	13.27	13.27
500	1.34	3.07	4.10	7.13	9.78	11.75	12.77	13.10	13.10	13.10
1,000	1.24	2.77	3.76	6.52	9.05	11.16	12.24	12.54	12.55	12.55
2,000	1.13	2.47	3.41	5.93	8.20	10.49	11.63	11.92	11.94	11.94
5,000	0.92	2.07	2.91	5.21	7.35	9.39	10.59	10.94	10.96	10.96
10,000	0.75	1.74	2.56	4.65	6.60	8.32	9.59	9.94	9.95	9.95
20,000	0.58	1.40	2.25	4.09	5.77	7.15	8.48	8.81	8.84	8.84
50,000	0.37	0.99	1.80	3.31	4.64	5.74	6.94	7.22	7.26	7.26
100,000	0.23	0.68	1.32	2.53	3.49	4.31	5.34	5.57	5.66	5.66




SPAS 1242 Storm Center Mass Curve Zone 1
March 17 (700UTC) to March 20 (600UTC), 2008
Lat: 37.155 Lon: -91.445
Incremental
Accumulated
15.09
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
10
20
30
40
50
60
70


94°W
92°W
90°W
88°W
40°N
38°N
36°N
34°N
Total Precipitation (72-hrs)
SPAS-NEXRAD: 1242 Alley Spring, MO
3/17/2008 0700 UTC- 3/20/2008 0600 UTC
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Estimated
Miles
0 50 100 200
Kilometers
0 90 180 360
Precipitation (inches)
0.01 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
6/27/2012


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 18 Mar 08
CDC1 Meteorological Data
Source ★ at 37.16 N 91.45 W
-110
-100
90
-80
-70
-60
40
30
20
10
hPa
700
850
989
700
750
800
850
900
950
1000
06 00 18 12 06 00 18 12 06 00 18 12
03/18
03/17
03/16
This is not a NOAA product. It was produced by a web user.
Job ID: 381176 Job Start: Mon Jun 25 19:44:11 UTC 2012
Source 1 lat.: 37.16 lon.: -91.45 hgts: 0, 1280, 2880 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Mar 2008 - reanalysis


SPAS 1242 Alley Spring, MO Storm Analysis
March 15-18, 2008
Storm Center
37.16, -91.45
Hysplit
Surface
850mb
700mb
Miles
0
170
340
680

Storm Precipitation Analysis System (SPAS) For Storm #1218_1 SPAS-NEXRAD Analysis

General Storm Location: Northwestern Georgia and portions of adjacent states

Storm Dates: September 19-22, 2009

Event: Thunderstorm

DAD Zone 1 (southern center)

Latitude: 33.87

Longitude: -84.76

Max. Grid Rainfall Amount: 25.37” (full storm period)

Max. Observed Rainfall Amount: 21.03” (24-hr total)

Number of Stations: 447 (59 Daily, 48 Hourly, 0 Hourly Estimated, 0 Hourly Estimated Pseudo, 62 Hourly Pseudo, 272 Supplemental, and 6 Supplemental Estimated)

SPAS Version: 8.5

Base Map Used: PRISM Mean (1971-2000) September precipitation

Spatial resolution: 36 seconds (~ 0.39 mi^2)

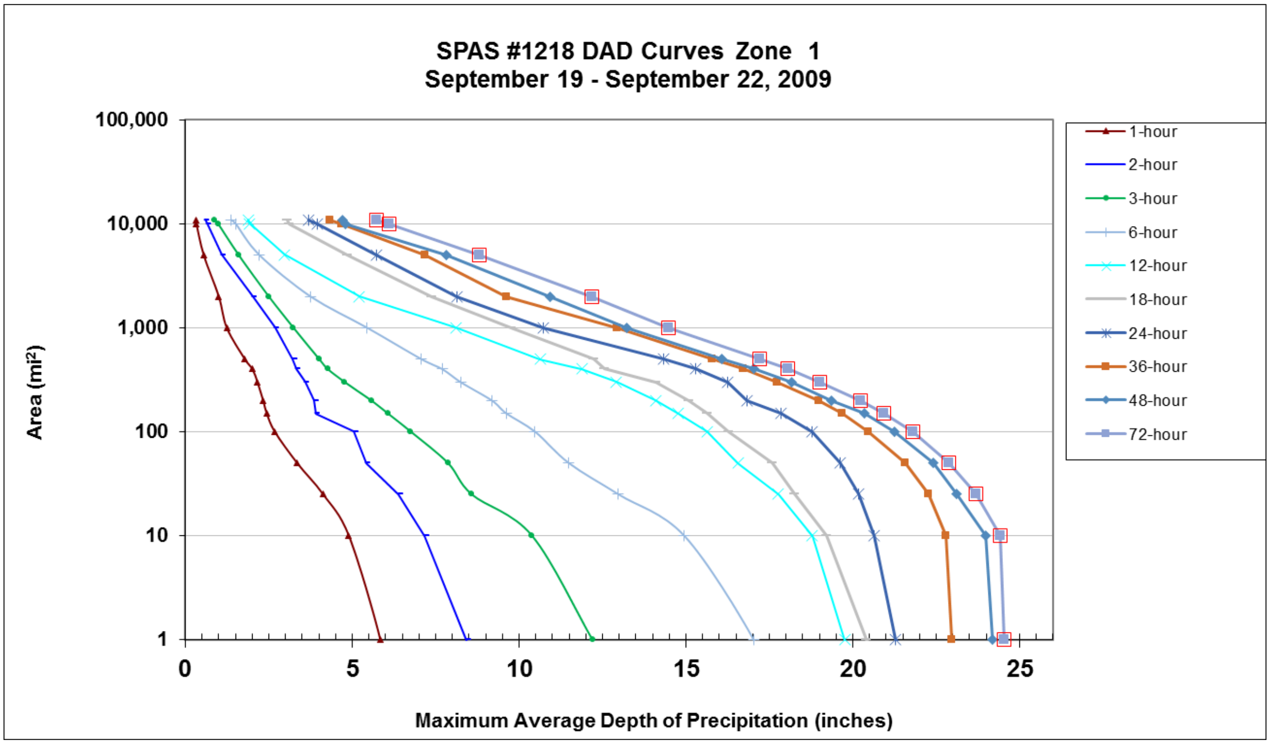
Radar Included: Yes

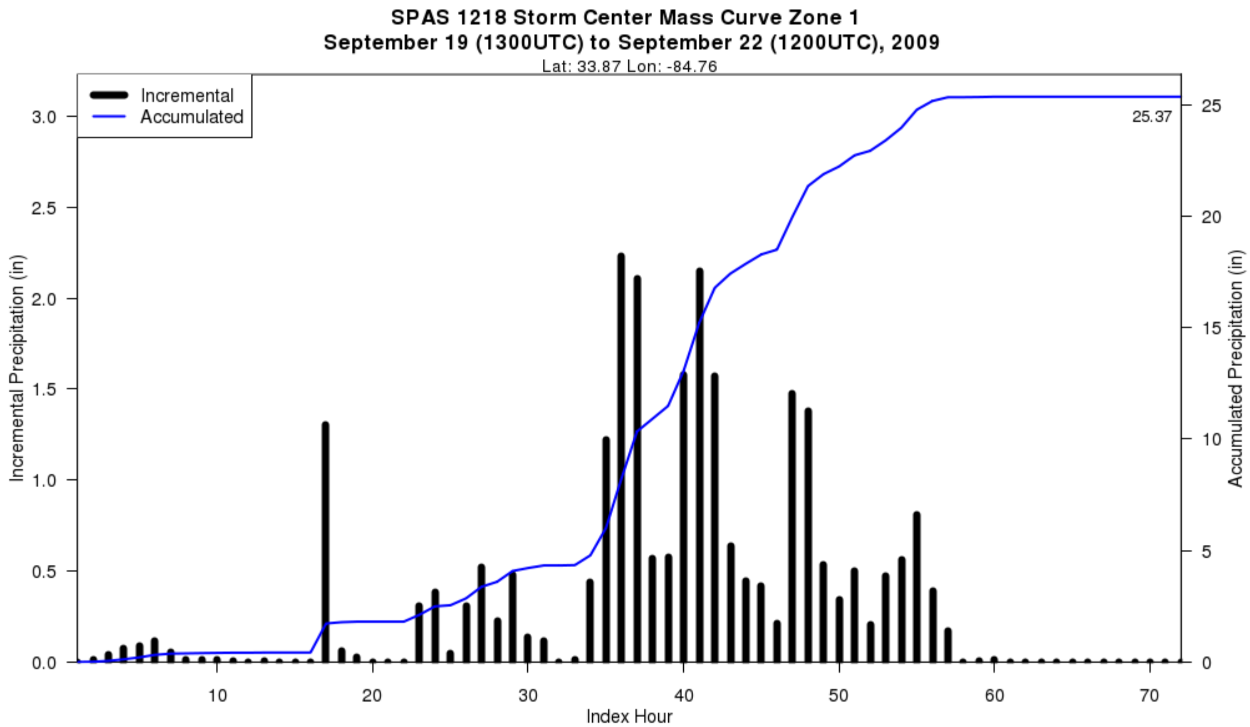
Depth-Area-Duration (DAD) analysis: Yes

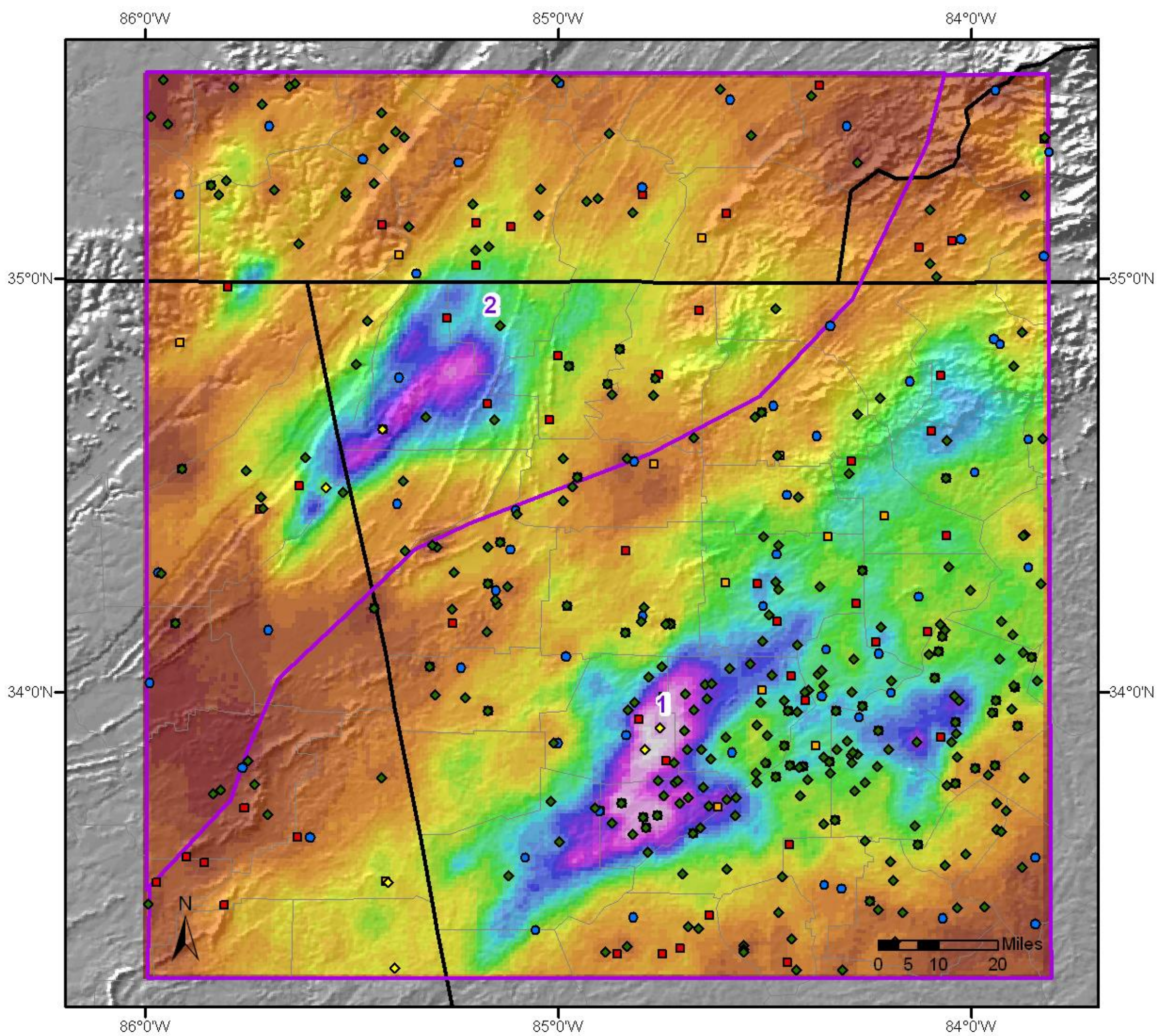
Reliability of results: Given the unblocked, clean and QC’ed radar data coupled with extensive gauge data, we have a very high degree of confidence in the results, particularly in DAD zone 1. We have slightly less confidence in the DAD results for Zone 2 given fewer stations sampled the peak rainfall center.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1218_1	-84.7600	33.8700	939	900	5-Sep	76.00	2.99	0.23	74	2.760	78.73	78.5	3.37	0.26	79	3.110	1.127

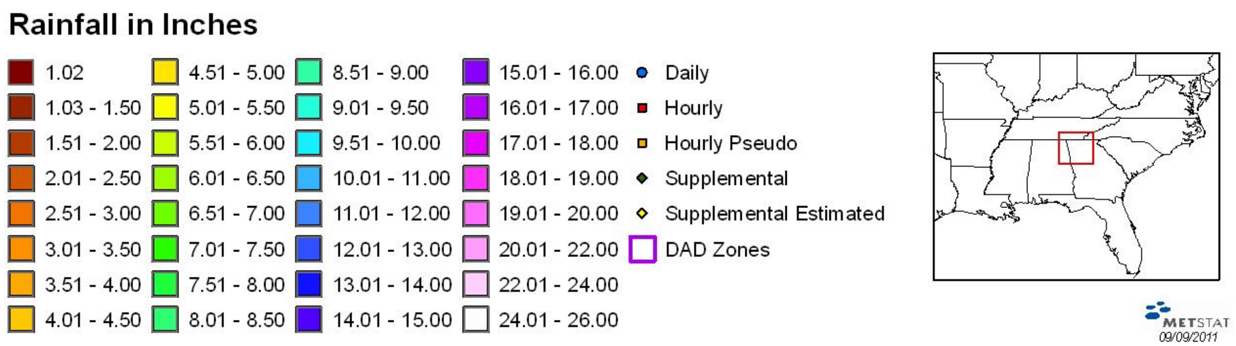
Storm 1218 - September 19 (1300 UTC) - September 22 (1200 UTC), 2009											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	2	3	6	12	18	24	36	48	72	Total
0.4	5.94	8.82	12.98	17.36	20.31	21.07	22.82	23.83	24.95	25.37	25.37
1	5.84	8.42	12.20	17.03	19.76	20.42	21.29	22.97	24.19	24.54	24.54
10	4.90	7.17	10.39	14.95	18.79	19.21	20.63	22.80	23.97	24.41	24.41
25	4.13	6.39	8.58	12.98	17.77	18.25	20.18	22.26	23.10	23.69	23.69
50	3.35	5.42	7.87	11.49	16.57	17.60	19.63	21.56	22.41	22.89	22.89
100	2.68	5.05	6.76	10.48	15.63	16.27	18.79	20.48	21.24	21.79	21.79
150	2.44	3.90	6.07	9.62	14.78	15.63	17.85	19.67	20.36	20.93	20.93
200	2.33	3.86	5.57	9.18	14.10	15.09	16.82	18.97	19.35	20.22	20.22
300	2.16	3.58	4.78	8.25	12.92	14.09	16.26	17.73	18.16	19.00	19.00
400	2.01	3.32	4.27	7.70	11.89	12.55	15.29	16.73	17.03	18.04	18.04
500	1.78	3.22	4.01	7.07	10.63	12.24	14.32	15.80	16.07	17.22	17.22
1,000	1.24	2.69	3.24	5.45	8.11	9.77	10.74	12.95	13.24	14.48	14.48
2,000	1.00	2.02	2.50	3.75	5.22	7.40	8.15	9.62	10.93	12.17	12.17
5,000	0.55	1.08	1.60	2.22	2.97	4.87	5.73	7.17	7.81	8.80	8.80
10,000	0.33	0.65	0.98	1.51	1.93	3.10	3.97	4.69	4.79	6.12	6.12
10,922	0.31	0.59	0.87	1.37	1.89	3.06	3.68	4.33	4.71	5.72	5.72



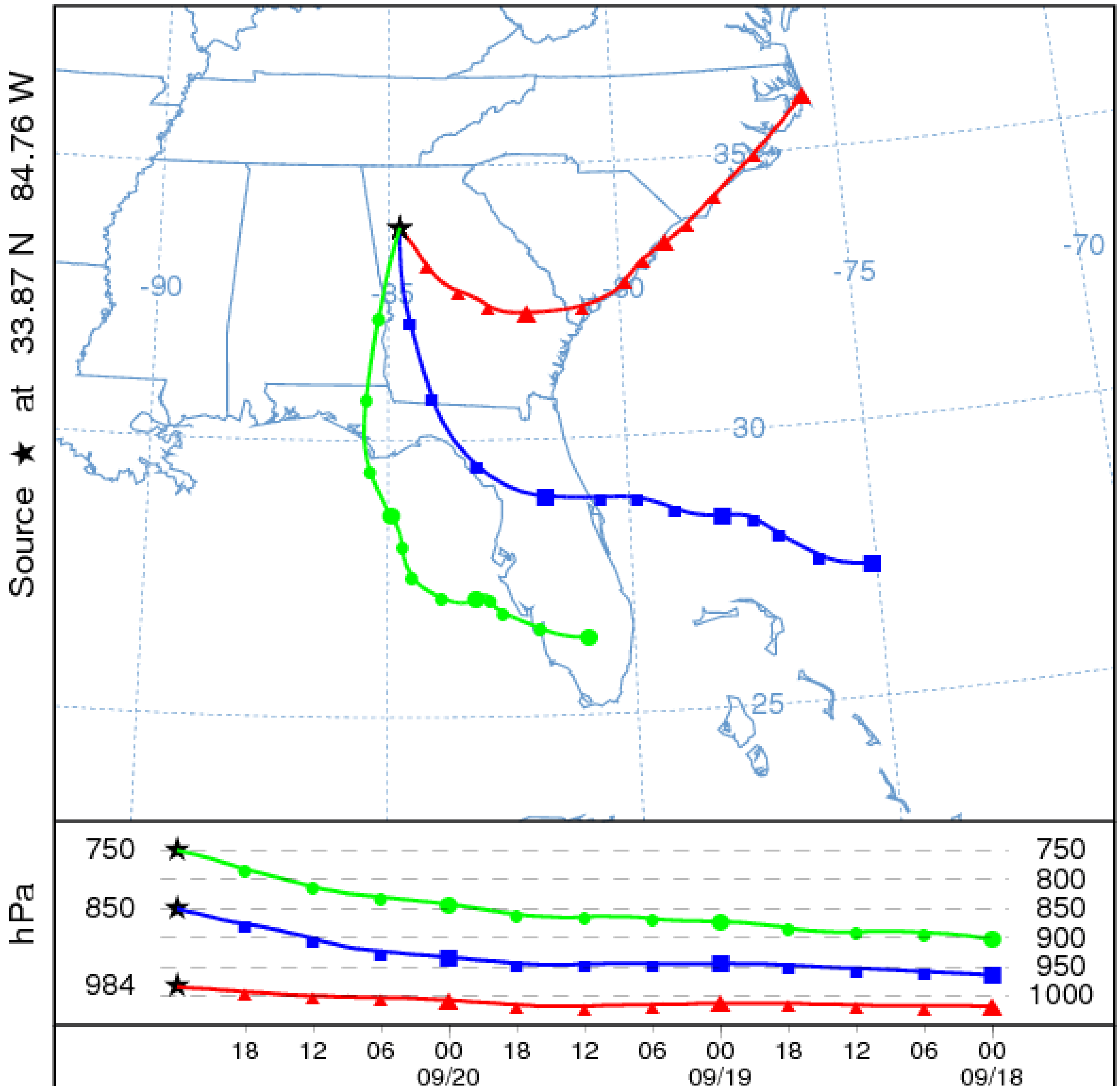

SPAS 1218 Storm Center Mass Curve Zone 1
September 19 (1300UTC) to September 22 (1200UTC), 2009
Lat: 33.87 Lon: -84.76
Incremental
Accumulated
25.37
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
15
20
25
10
20
30
40
50
60
70



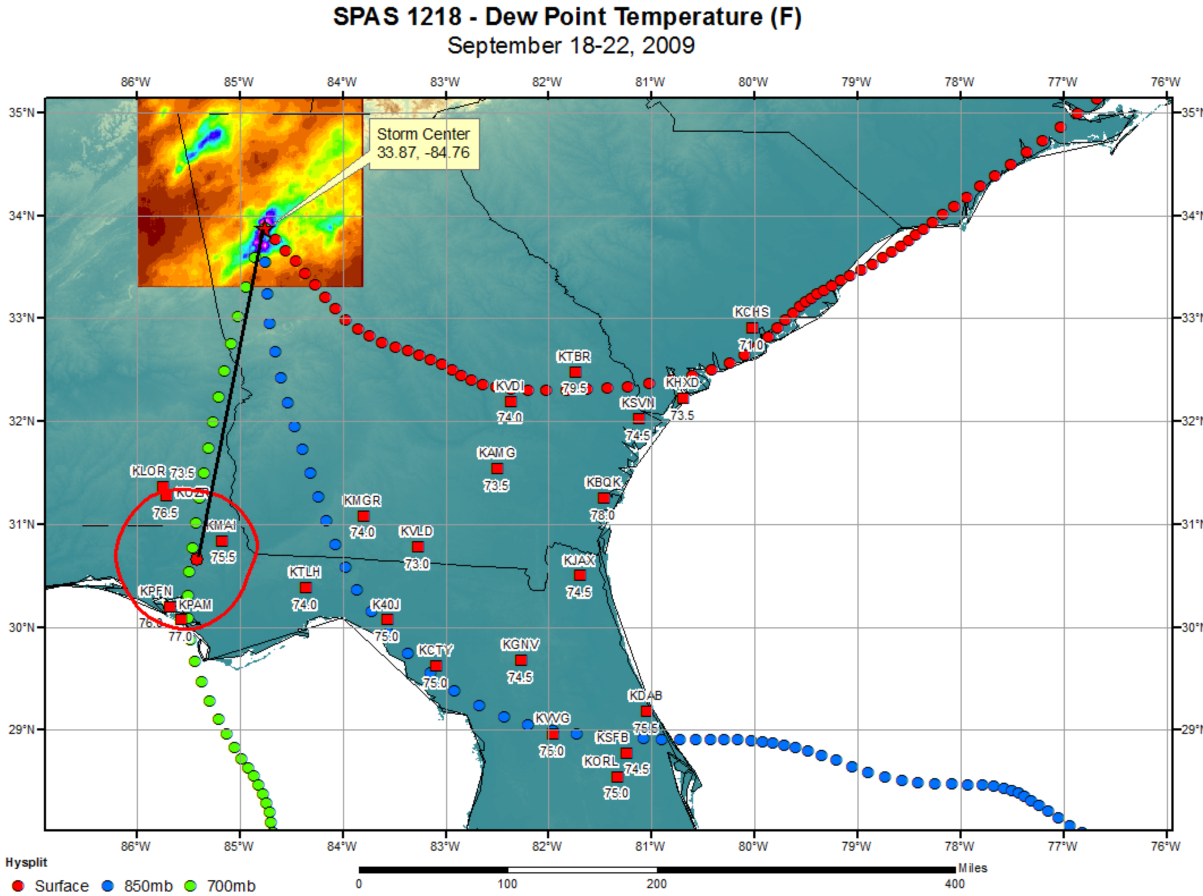
Total 72-hour Rainfall (Inches)
09/19/2009 1300 UTC - 09/22/2009 1300 UTC
SPAS #1218



NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 21 Sep 09
CDC1 Meteorological Data



This is not a NOAA product. It was produced by a web user.
Job ID: 349862 Job Start: Wed Sep 21 21:18:14 UTC 2011
Source 1 lat.: 33.87 lon.: -84.76 hgts: 0, 1280, 2330 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Sep 2009 - reanalysis


SPAS 1218 - Dew Point Temperature (F)
September 18-22, 2009
Storm Center
33.87, -84.76
KCHS
71.0
KTBR
79.5
KVDI
74.0
KHXD
73.5
KSVN
74.5
KAMG
73.5
KLOR 73.5
KOZR
76.5
KMGR
74.0
KBQK
76.0
KMAI
75.5
KVLD
73.0
KJAX
74.5
KTLH
74.0
KPFN
KPAM
77.0
K40J
75.0
KCTY
75.0
KGNV
74.5
KDAB
76.5
KVVG
76.0
KSFB
74.5
KORL
75.0
Hysplit
Surface
850mb
700mb
Miles
0
100
200
400

Storm Precipitation Analysis System (SPAS) For Storm #1218_2 SPAS-NEXRAD Analysis

General Storm Location: Northwestern Georgia and portions of adjacent states

Storm Dates: September 19-22, 2009

Event: Thunderstorm

DAD Zone 2 (northern center)

Latitude: 34.77

Longitude: -85.26

Max. Grid Rainfall Amount: 19.61"

Max. Observed Rainfall Amount: 12.44"

Number of Stations: 447 (59 Daily, 48 Hourly, 0 Hourly Estimated, 0 Hourly Estimated Pseudo, 62 Hourly Pseudo, 272 Supplemental, and 6 Supplemental Estimated)

SPAS Version: 8.5

Base Map Used: PRISM Mean (1971-2000) September precipitation

Spatial resolution: 36 seconds (~ 0.39 mi^2)

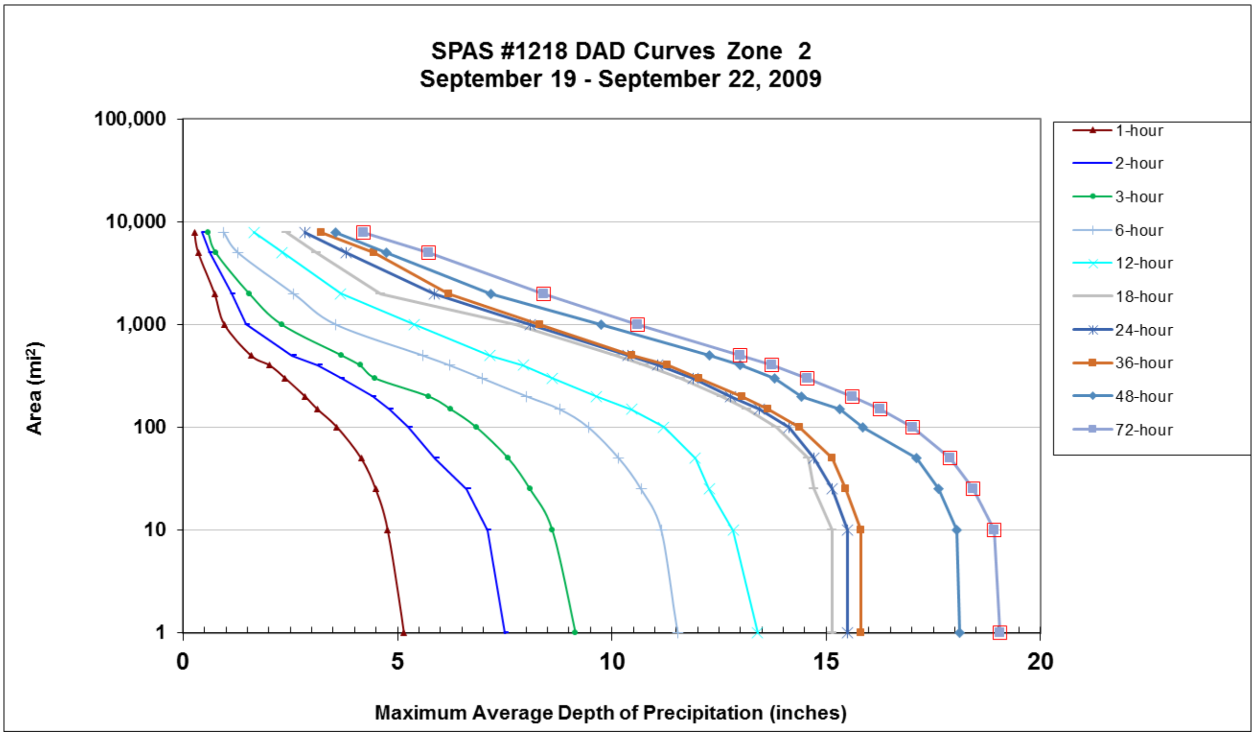
Radar Included: Yes

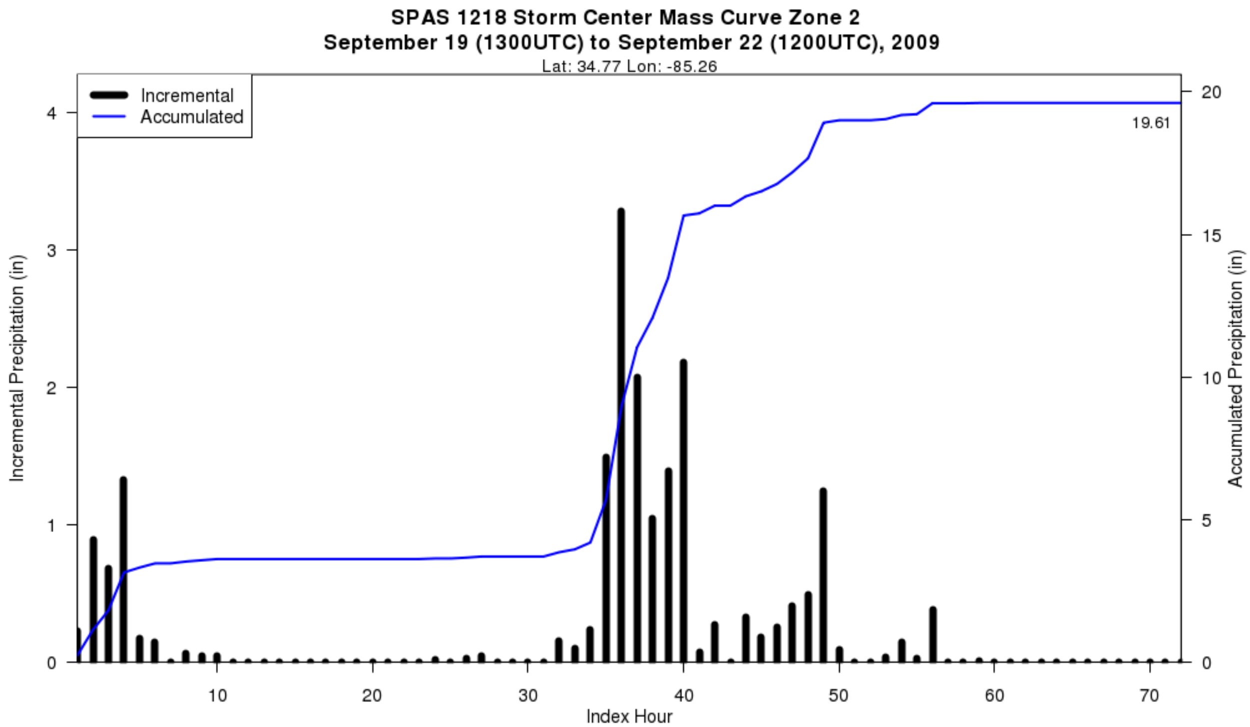
Depth-Area-Duration (DAD) analysis: Yes

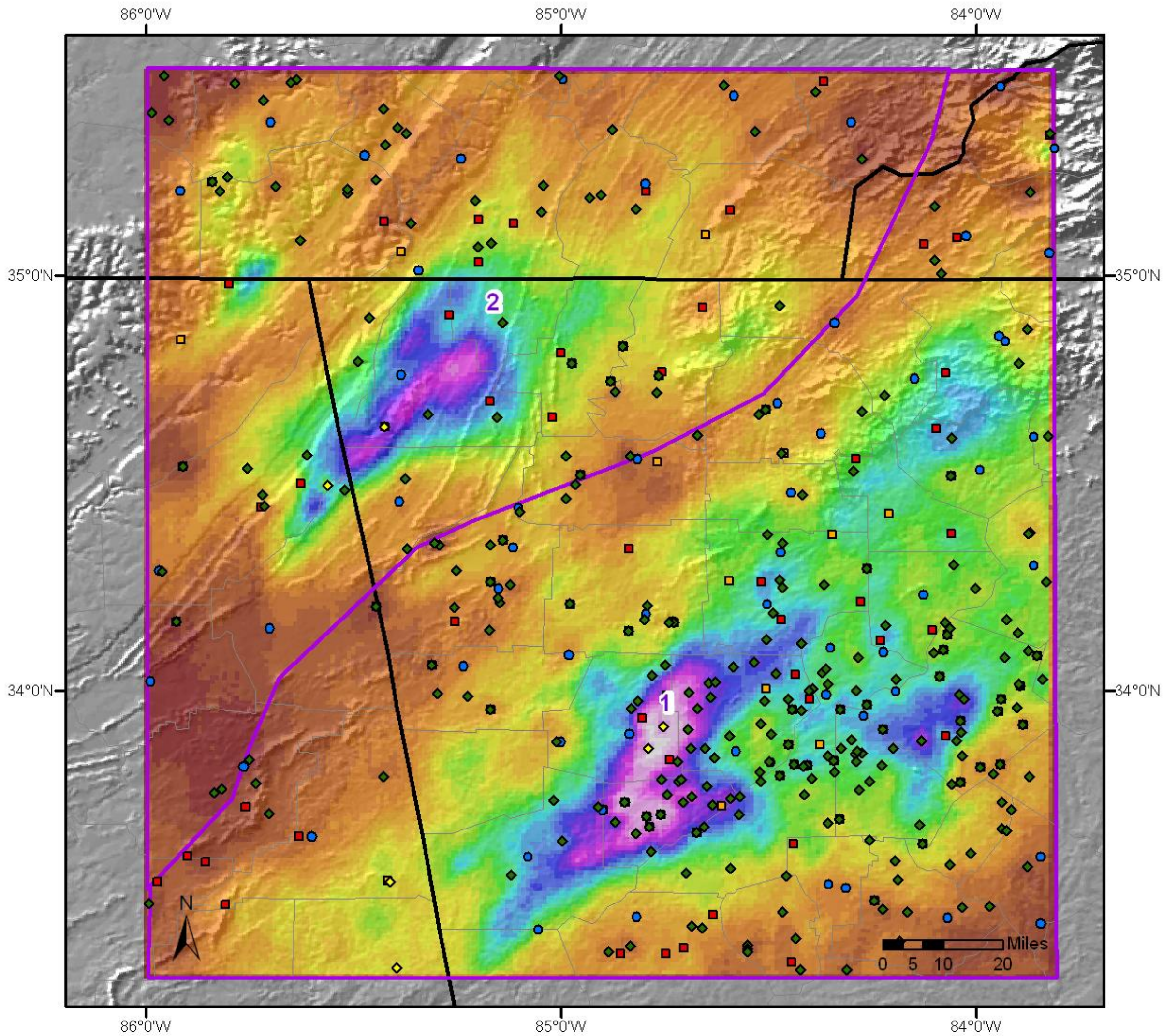
Reliability of results: Given the unblocked, clean and QC'ed radar data coupled with extensive gauge data, we have a very high degree of confidence in the results, particularly in DAD zone 1. We have slightly less confidence in the DAD results for Zone 2 given fewer stations sampled the peak rainfall center.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1218_2	-85.2600	34.7700	898	900	5-Sep	76.00	2.99	0.23	74	2.760	78.73	78.5	3.37	0.26	79	3.110	1.127

Storm 1218 - September 19 (1300 UTC) - September 22 (1200 UTC), 2009											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	2	3	6	12	18	24	36	48	72	Total
0.4	5.25	7.74	9.33	11.84	13.67	15.57	15.99	16.31	18.69	19.61	19.61
1	5.15	7.50	9.15	11.54	13.40	15.15	15.50	15.80	18.11	19.06	19.06
10	4.77	7.10	8.61	11.15	12.83	15.15	15.50	15.80	18.04	18.92	18.92
25	4.49	6.61	8.09	10.68	12.27	14.71	15.14	15.45	17.63	18.43	18.43
50	4.15	5.88	7.58	10.16	11.95	14.57	14.72	15.14	17.10	17.90	17.90
100	3.59	5.25	6.84	9.45	11.21	13.85	14.13	14.39	15.85	17.01	17.01
150	3.13	4.82	6.24	8.78	10.46	13.16	13.45	13.64	15.31	16.25	16.25
200	2.84	4.41	5.72	8.01	9.63	12.56	12.77	13.03	14.43	15.61	15.61
300	2.38	3.68	4.48	6.97	8.60	11.60	11.89	12.04	13.79	14.56	14.56
400	2.02	3.15	4.13	6.22	7.93	10.75	11.07	11.29	12.99	13.73	13.73
500	1.58	2.54	3.70	5.59	7.16	10.08	10.38	10.47	12.28	13.00	13.00
1,000	0.96	1.46	2.30	3.56	5.38	7.77	8.09	8.33	9.74	10.61	10.61
2,000	0.73	1.12	1.54	2.57	3.68	4.60	5.86	6.19	7.18	8.40	8.40
5,000	0.35	0.61	0.76	1.28	2.31	3.12	3.80	4.46	4.74	5.72	5.72
7,918	0.26	0.44	0.58	0.94	1.65	2.42	2.84	3.22	3.56	4.21	4.21



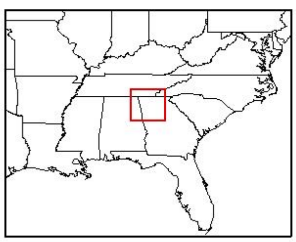

SPAS 1218 Storm Center Mass Curve Zone 2
September 19 (1300UTC) to September 22 (1200UTC), 2009
Lat: 34.77 Lon: -85.26
Incremental
Accumulated
19.61
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
0
5
10
15
20
10
20
30
40
50
60
70



Total 72-hour Rainfall (Inches)
09/19/2009 1300 UTC - 09/22/2009 1300 UTC
SPAS #1218

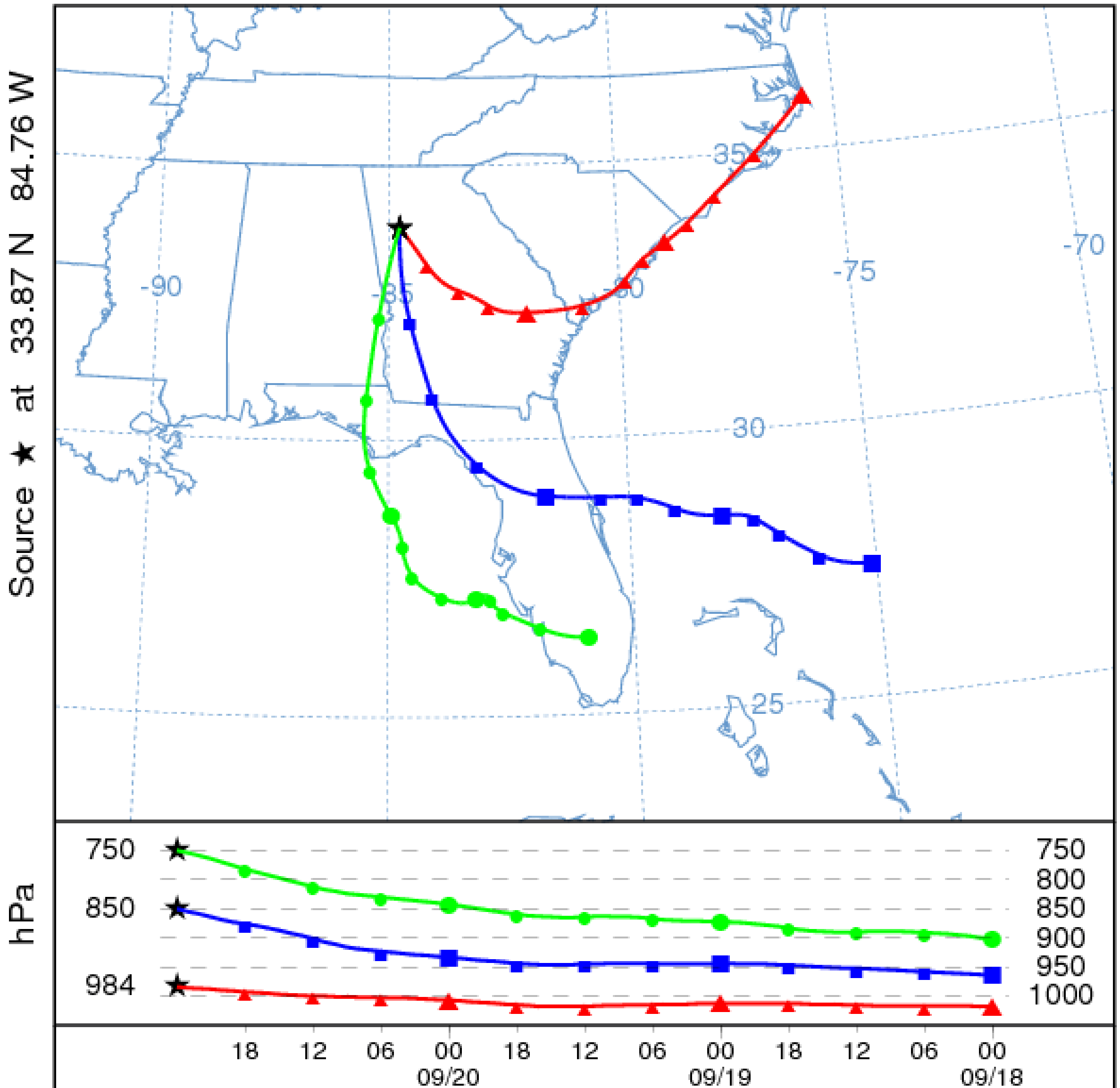
Rainfall in Inches

1.02	4.51 - 5.00	8.51 - 9.00	15.01 - 16.00	Daily
1.03 - 1.50	5.01 - 5.50	9.01 - 9.50	16.01 - 17.00	Hourly
1.51 - 2.00	5.51 - 6.00	9.51 - 10.00	17.01 - 18.00	Hourly Pseudo
2.01 - 2.50	6.01 - 6.50	10.01 - 11.00	18.01 - 19.00	Supplemental
2.51 - 3.00	6.51 - 7.00	11.01 - 12.00	19.01 - 20.00	Supplemental Estimated
3.01 - 3.50	7.01 - 7.50	12.01 - 13.00	20.01 - 22.00	DAD Zones
3.51 - 4.00	7.51 - 8.00	13.01 - 14.00	22.01 - 24.00	
4.01 - 4.50	8.01 - 8.50	14.01 - 15.00	24.01 - 26.00	



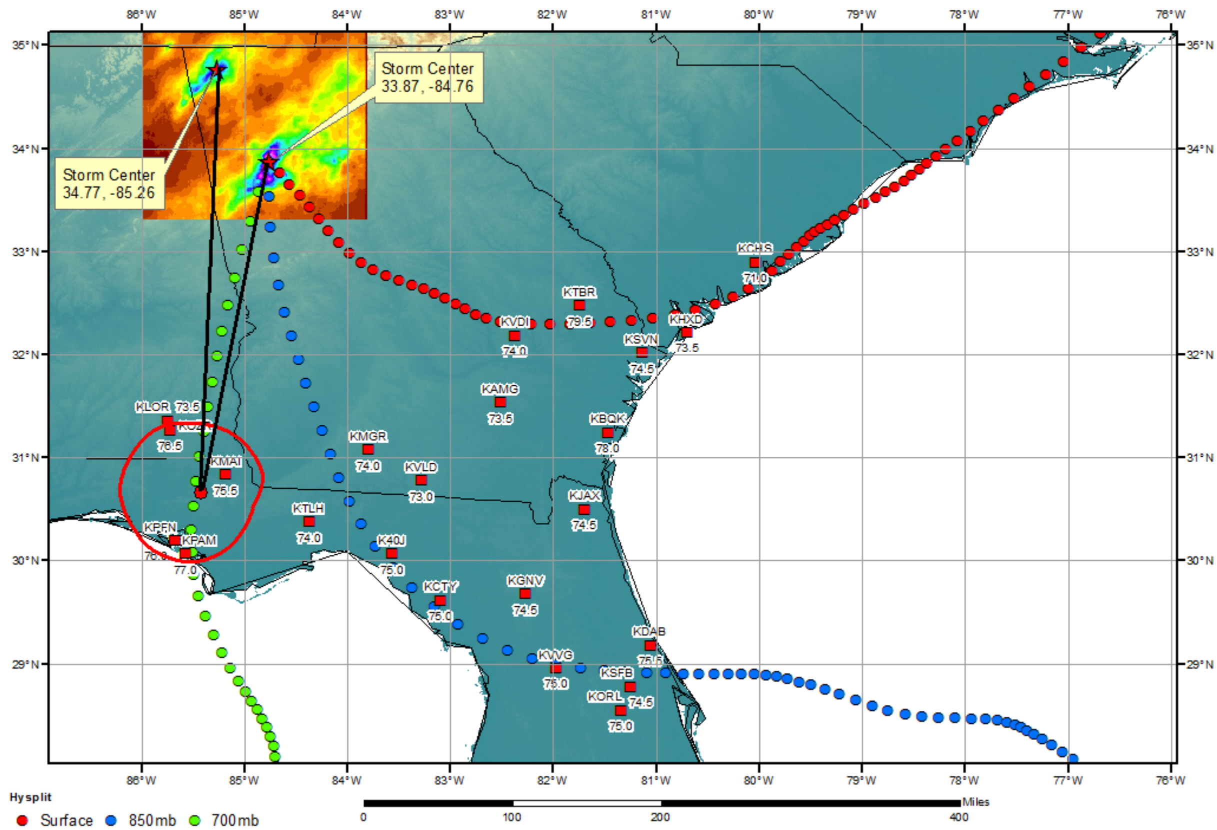
METSTAT
09/09/2011

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 21 Sep 09
CDC1 Meteorological Data



This is not a NOAA product. It was produced by a web user.
Job ID: 349862 Job Start: Wed Sep 21 21:18:14 UTC 2011
Source 1 lat.: 33.87 lon.: -84.76 hgts: 0, 1280, 2330 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Sep 2009 - reanalysis

SPAS 1218 - Dew Point Temperature (F)
September 18-22, 2009



Storm Precipitation Analysis System (SPAS) For Storm #1208_1 SPAS-NEXRAD Analysis

General Storm Location: Western and Central Tennessee, Southwestern Kentucky and adjacent portions of nearby states

Storm Dates: April 30 – May 3, 2010

Event: Synoptic

DAD Zone 1

Latitude: 36.06

Longitude: -86.91

Max. Grid Rainfall Amount: 19.71”

Max. Observed Rainfall Amount: 19.70” at WARNER PARK, TN, followed by 19.51” at USGS SR840 Rain gauge No. 4 near Bending Chestnut, TN followed by 19.41” at CoCoRaHS Camden 4.5 NW, TN.

Number of Stations: 753 (120 Daily, 52 Hourly, 46 Hourly Pseudo, 1 Hourly Estimated Pseudo, 5 Hourly Estimated, 521 Supplemental, and 8 Supplemental Estimated)

SPAS Version: 8.5

Base Map Used: Mean (1971-2000) PRISM May Precipitation

Spatial resolution: 36 seconds (0.39 sq-mi)

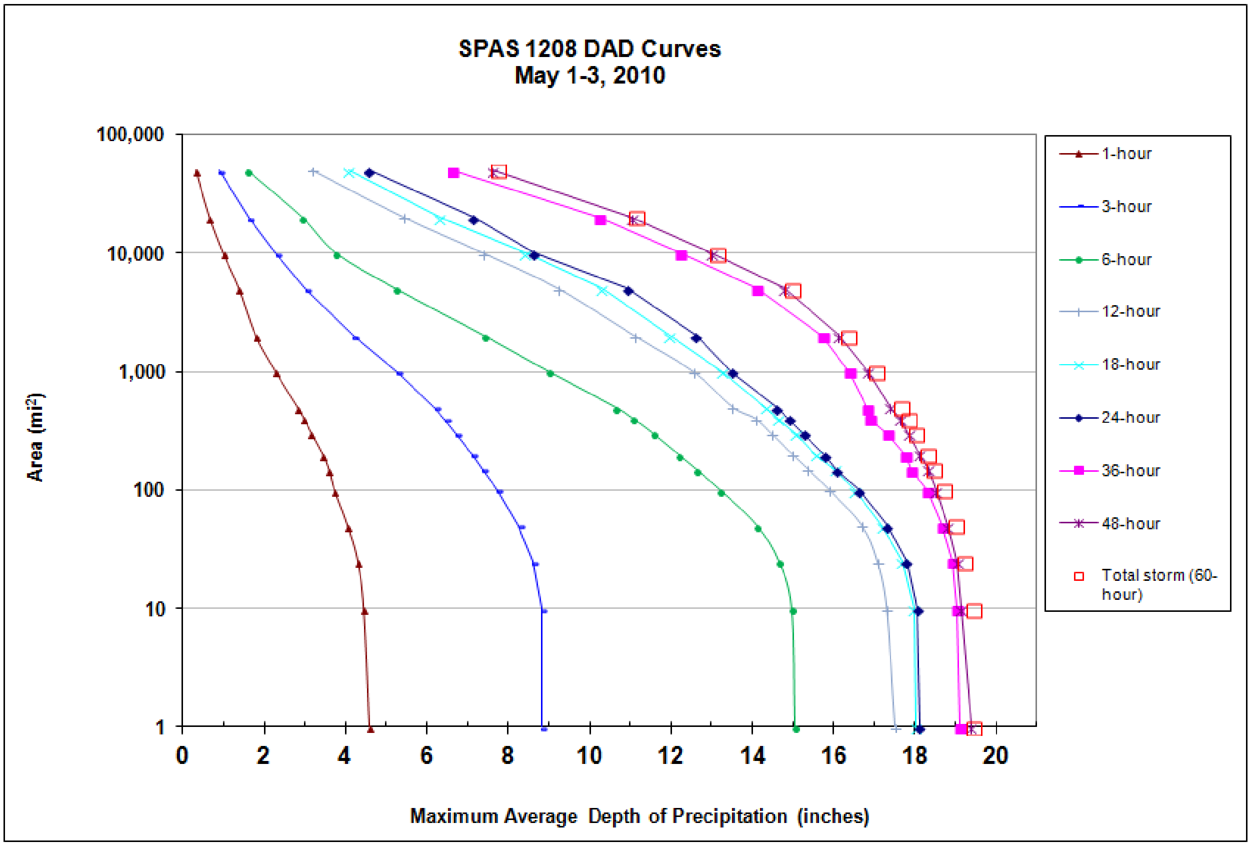
Radar Included: Yes

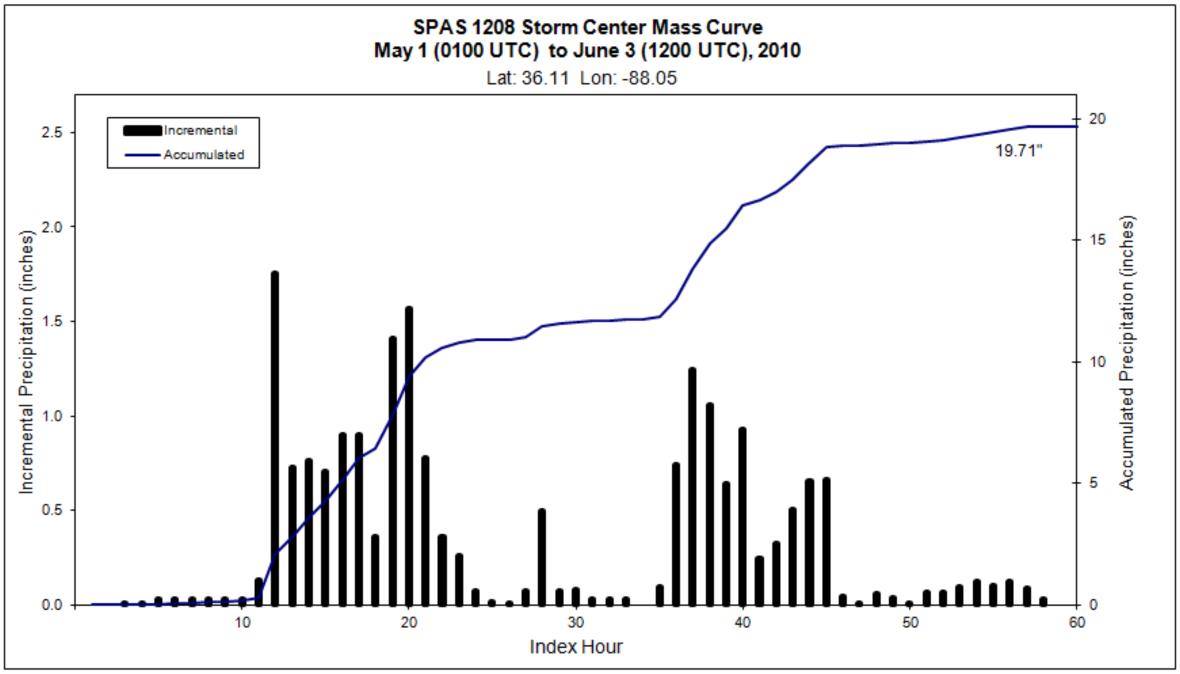
Depth-Area-Duration (DAD) analysis: Yes

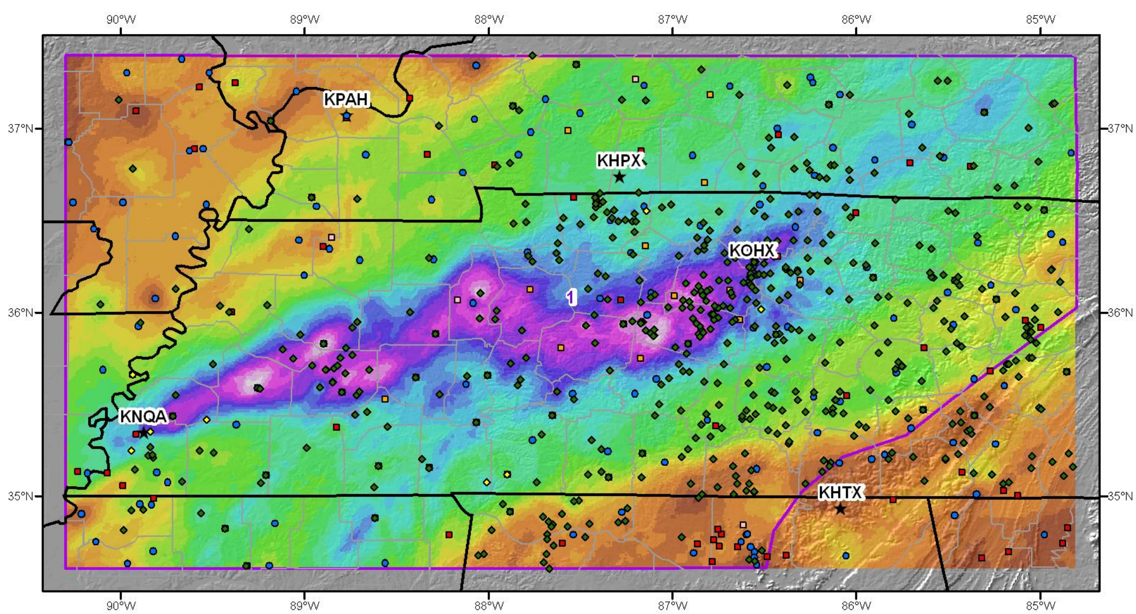
Degree of confidence in results: This was a difficult storm to analyze due to the extreme intensities, strong spatial rainfall gradients, large amount of data, relatively low radar reflectivity values across western Tennessee where among the heaviest rains fell. However, given this analysis was based on WDT NEXRAD data and a plethora of gauge data, our confidence in the results is high.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1208_1	-86.9056	36.0611	621	600	15-May	75.00	2.85	0.15	72	2.700	77.00	77.0	3.14	0.16	76	2.980	1.104

Storm 1208 - May 1 (0100 UTC) - May 3 (1200 UTC), 2010										
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
	Duration (hours)									
Area (mi^2)	1	3	6	12	18	24	36	48	60	Total
0.4	4.63	8.92	15.31	17.77	18.33	18.39	19.36	19.66	19.71	19.71
1	4.58	8.82	15.06	17.52	18.03	18.12	19.11	19.38	19.45	19.45
10	4.44	8.81	14.98	17.31	17.97	18.06	19.04	19.15	19.43	19.43
25	4.29	8.61	14.66	17.08	17.69	17.8	18.91	19.05	19.24	19.24
50	4.04	8.25	14.12	16.7	17.2	17.33	18.67	18.82	19.01	19.01
100	3.72	7.72	13.21	15.9	16.52	16.63	18.31	18.51	18.71	18.71
150	3.58	7.37	12.62	15.37	16.04	16.07	17.91	18.35	18.48	18.48
200	3.43	7.12	12.18	14.99	15.57	15.78	17.75	18.11	18.32	18.32
300	3.16	6.72	11.56	14.47	15.07	15.28	17.33	17.85	18.05	18.05
400	2.97	6.44	11.07	14.08	14.65	14.91	16.9	17.65	17.85	17.85
500	2.81	6.19	10.63	13.52	14.34	14.61	16.84	17.4	17.67	17.67
1,000	2.27	5.26	8.99	12.55	13.27	13.5	16.39	16.86	17.05	17.05
2,000	1.79	4.19	7.41	11.11	11.96	12.62	15.72	16.14	16.37	16.37
5,000	1.38	3	5.23	9.24	10.3	10.93	14.12	14.79	15	15.00
10,000	0.99	2.28	3.76	7.39	8.42	8.64	12.21	13	13.13	13.13
20,000	0.66	1.6	2.93	5.44	6.33	7.16	10.24	11.04	11.15	11.15
50,000	0.32	0.88	1.58	3.19	4.08	4.59	6.63	7.63	7.75	7.75







N

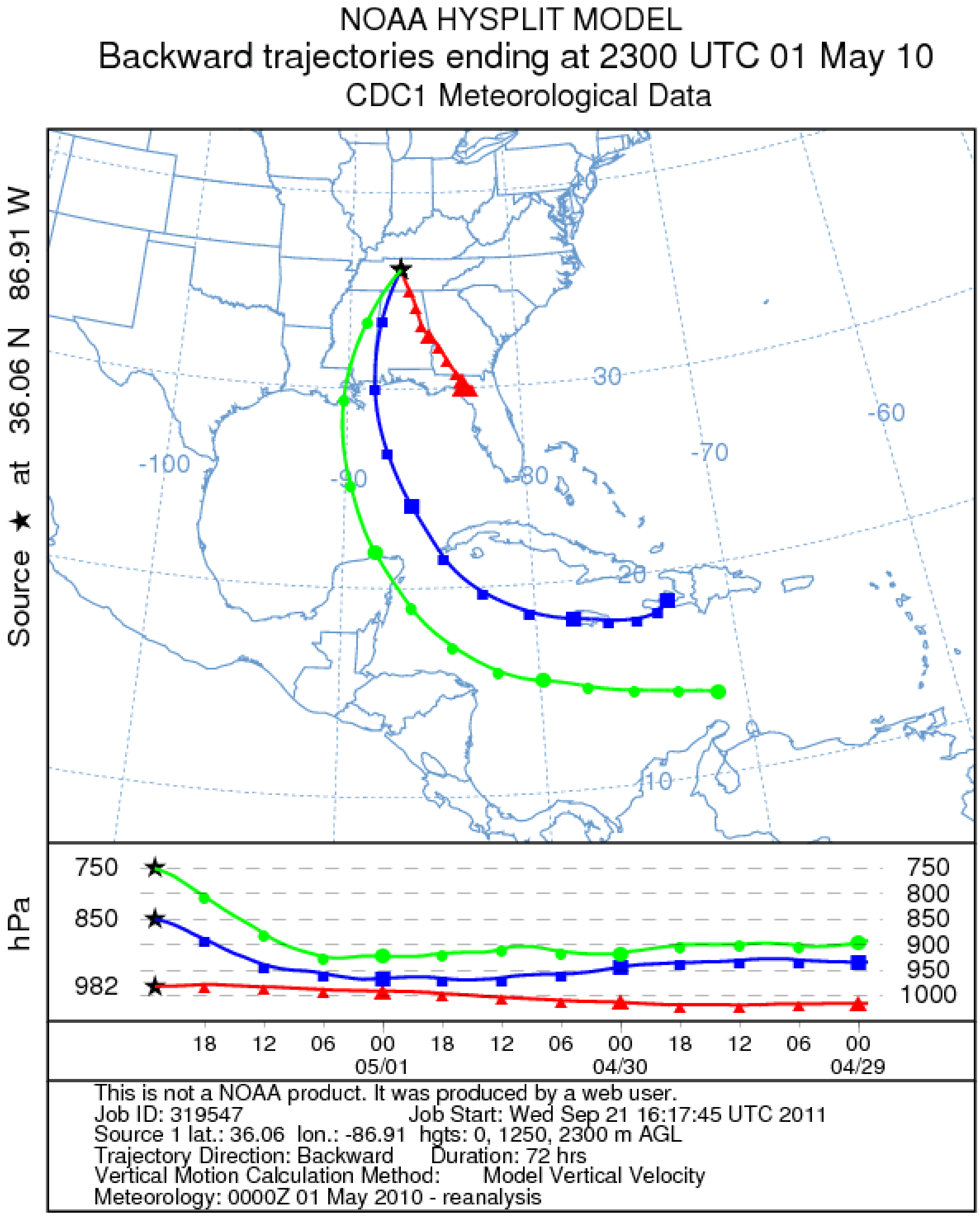
ISOHYETAL FROM SPAS #1208
Total 60-hour Rainfall (inches)
05/01/2010 0100 UTC - 05/03/2010 1200 UTC

0 130 260 520 Miles

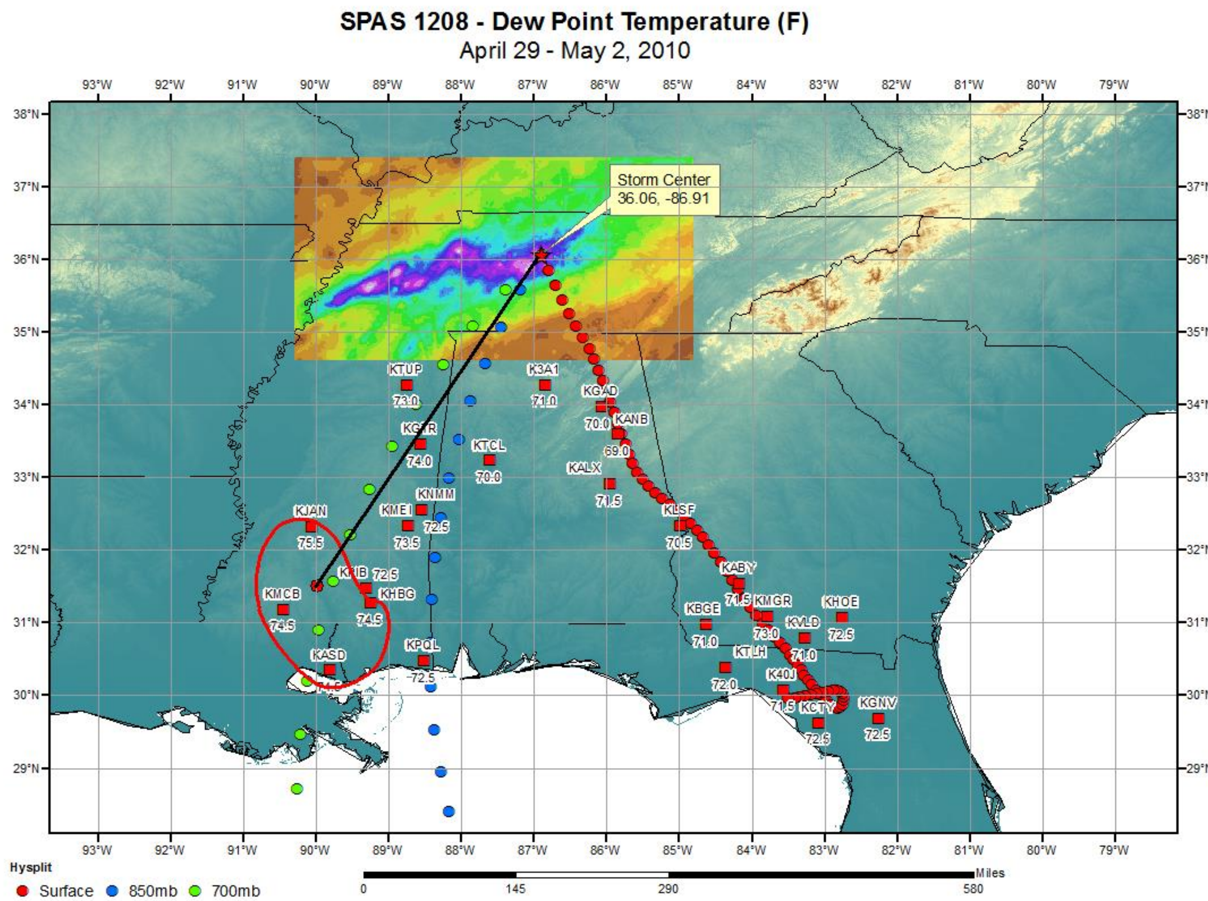
Precipitaiton (inches)

<= 1.50	4.01 - 4.50	9.01 - 10.00	15.01 - 16.00	Daily
1.51 - 2.00	4.51 - 5.00	10.01 - 11.00	16.01 - 17.00	Hourly
2.01 - 2.50	5.01 - 6.00	11.01 - 12.00	17.01 - 18.00	Hourly Est.
2.51 - 3.00	6.01 - 7.00	12.01 - 13.00	18.01 - 19.00	Hourly Est. Pseudo
3.01 - 3.50	7.01 - 8.00	13.01 - 14.00	19.01 - 19.71	Hourly Pseudo
3.51 - 4.00	8.01 - 9.00	14.01 - 15.00	US Radar Site	Supplemental
			DAD Zone	Supplemental Est.

METSTAT 05/06/2011



NOAA HYSPLIT MODEL
Backward trajectories ending at 2300 UTC 01 May 10
CDC1 Meteorological Data
Source ★ at 36.06 N 86.91 W
30
-60
-70
-100
-90
80
20
10
hPa
750
850
982
750
800
850
900
950
1000
18
12
06
00
05/01
18
12
06
00
04/30
18
12
06
00
04/29
This is not a NOAA product. It was produced by a web user.
Job ID: 319547 Job Start: Wed Sep 21 16:17:45 UTC 2011
Source 1 lat.: 36.06 lon.: -86.91 hgts: 0, 1250, 2300 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 May 2010 - reanalysis


SPAS 1208 - Dew Point Temperature (F)
April 29 - May 2, 2010
Storm Center
36.06, -86.91
KTUP
73.0
K3A1
71.0
KGAD
70.0
KANB
69.0
KGTR
74.0
KTCL
70.0
KALX
71.5
KNMM
KMEI
72.5
73.5
KJAN
75.5
KLSF
70.5
KHB
72.5
KHBG
74.5
KMCB
74.5
KABY
71.5
KMGR
73.0
KHOE
72.5
KBGE
71.0
KVLD
71.0
KTLH
72.0
KPQL
72.5
KASD
K40J
71.5
KCTY
72.5
KGNV
72.5
Hysplit
Surface
850mb
700mb
Miles
0
145
290
580

Storm Precipitation Analysis System (SPAS) For Storm #1350_1 SPAS-NEXRAD Analysis

General Storm Location: Portsmouth, NC

Storm Dates: September 26 - October 1, 2010

Event: Synoptic

DAD Zone 1

Latitude: 35.175

Longitude: -77.215

Max. Grid Rainfall Amount: 23.44"

Max. Observed Rainfall Amount: 22.54"

Number of Stations: 874 (475 Daily, 294 Hourly, 42 Hourly Pseudo, 55 Supplemental, and 8 Supplemental Estimated)

SPAS Version: 9.5

Basemap: NOAA Stage IV September 26-30, 2010 Precipitation

Spatial resolution: 0.01 (~ 0.40 mi^2)

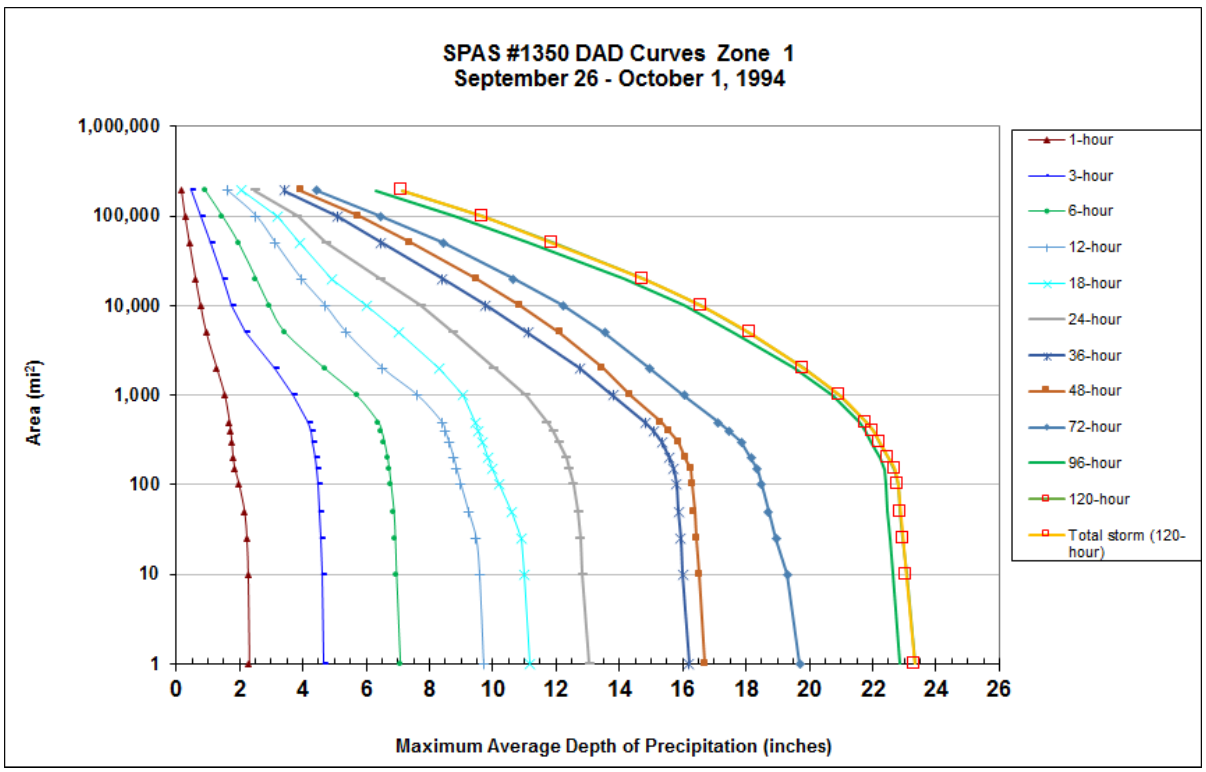
Radar Included: Yes

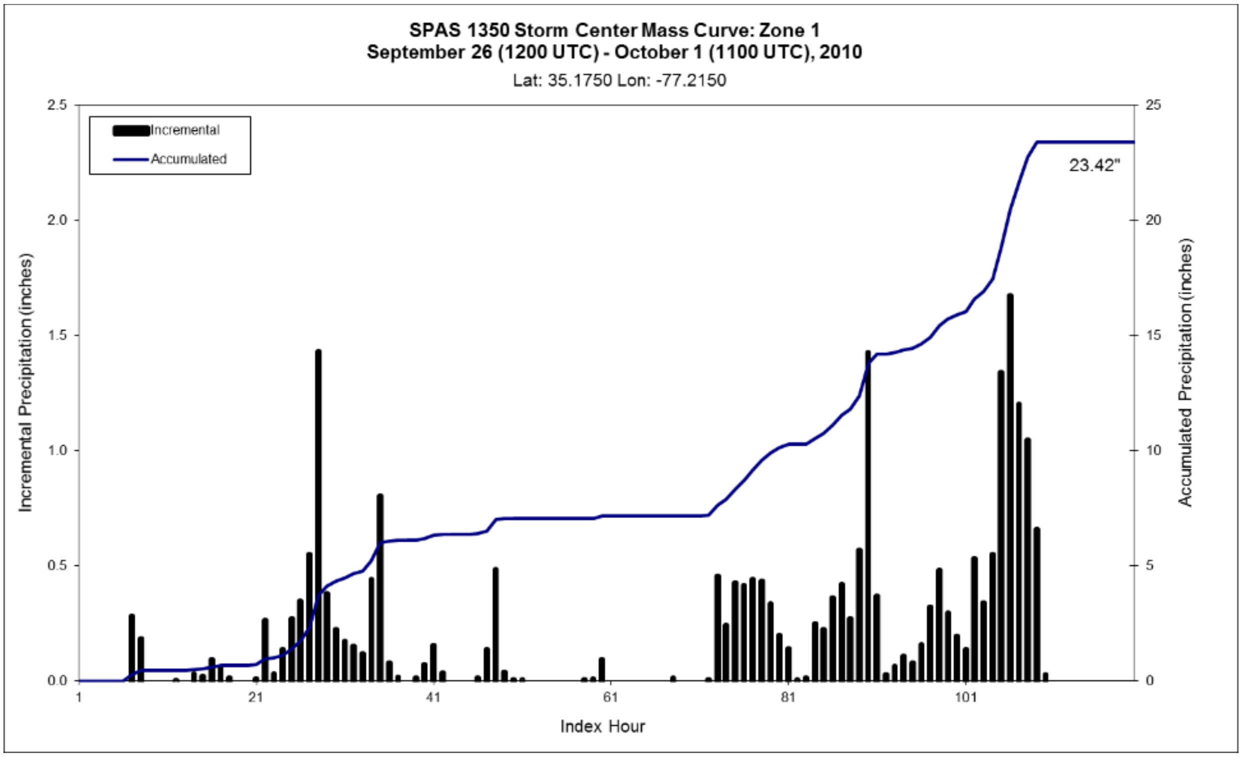
Depth-Area-Duration (DAD) analysis: Yes

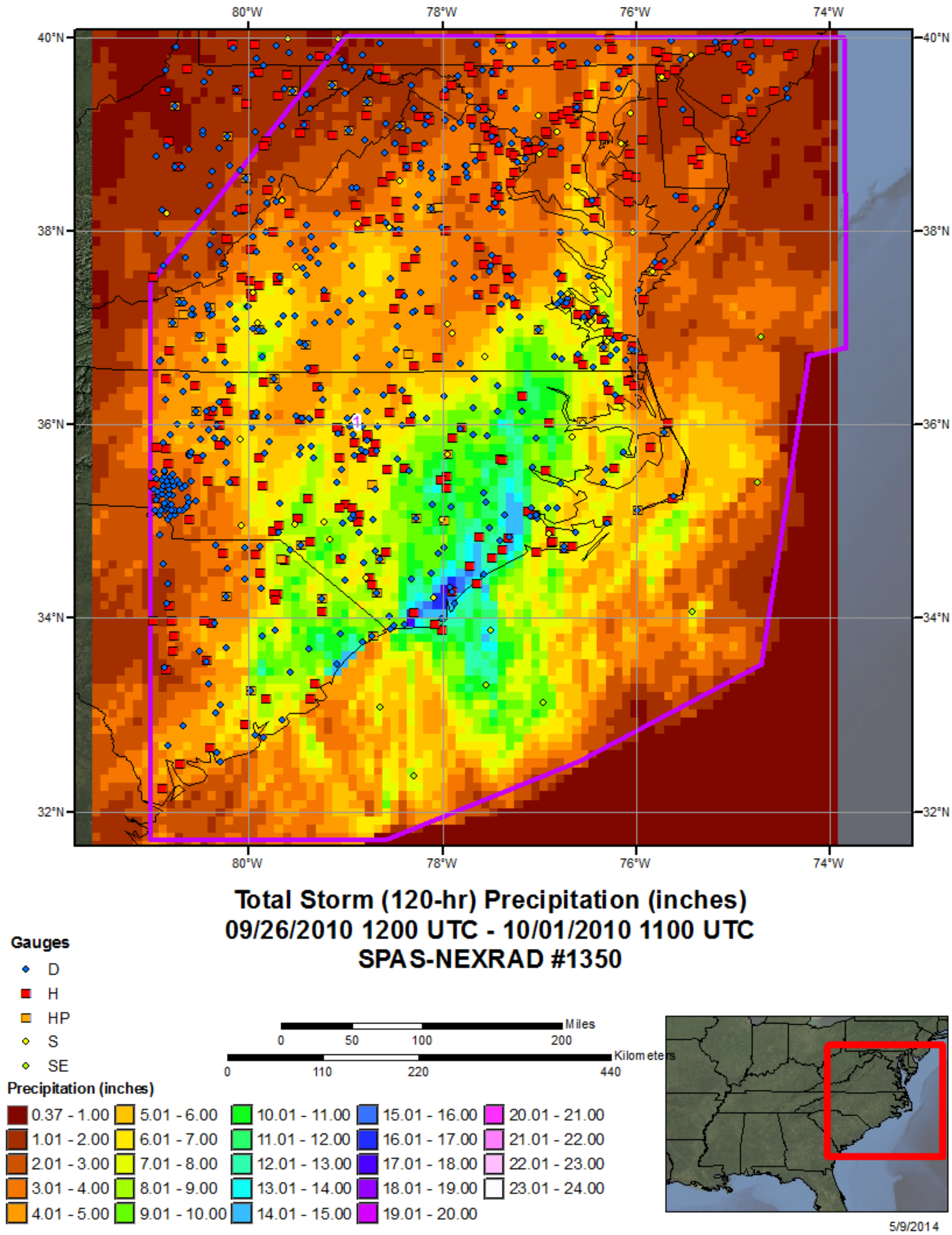
Reliability of results: This analysis was based on hourly data, daily data, supplemental station data and NEXRAD Radar. We have a high degree of confidence in the radar/station based storm total results, the spatial pattern is dependent on the radar data and basemap, and the timing is based on hourly and hourly pseudo stations.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1350_1	-77.2150	35.1750	39	15-Sep	81.50	3.86	0.00	85	3.860	84.20	4.30	0.00	90	4.300	1.114

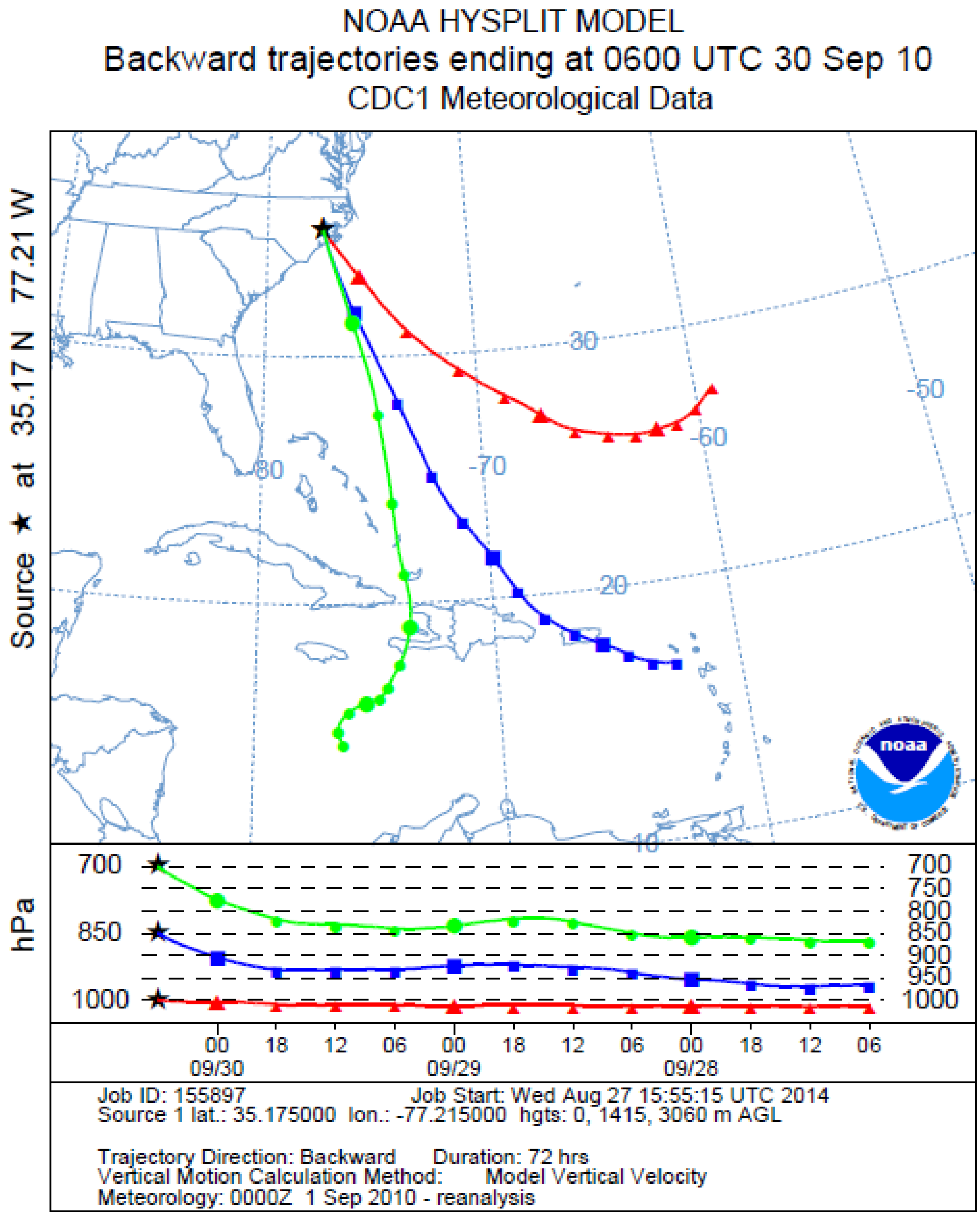
Storm 1350 - September 26 (1200 UTC) - October 1 (1100 UTC), 2010 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
Area (mi^2)	Duration (hours)											
	1	3	6	12	18	24	36	48	72	96	120	Total
0	2.31	4.71	7.11	9.75	11.27	13.14	16.29	16.79	19.87	22.94	23.43	23.43
1	2.30	4.67	7.07	9.70	11.19	13.05	16.21	16.71	19.71	22.85	23.33	23.33
10	2.26	4.59	6.95	9.57	11.01	12.84	16.01	16.52	19.31	22.63	23.06	23.06
25	2.22	4.56	6.91	9.47	10.91	12.76	15.93	16.44	18.96	22.54	22.96	22.96
50	2.15	4.54	6.87	9.23	10.62	12.70	15.87	16.38	18.72	22.48	22.88	22.88
100	1.98	4.49	6.78	8.99	10.22	12.55	15.81	16.32	18.48	22.41	22.80	22.80
150	1.85	4.44	6.72	8.85	10.00	12.42	15.72	16.26	18.35	22.37	22.70	22.70
200	1.79	4.40	6.67	8.76	9.86	12.32	15.59	16.10	18.17	22.24	22.50	22.50
300	1.75	4.31	6.57	8.61	9.68	12.08	15.35	15.86	17.85	21.95	22.22	22.22
400	1.71	4.25	6.48	8.49	9.56	11.90	15.08	15.57	17.46	21.75	22.02	22.02
500	1.68	4.17	6.38	8.39	9.46	11.71	14.81	15.31	17.12	21.59	21.79	21.79
1000	1.53	3.69	5.69	7.62	9.06	11.06	13.81	14.35	16.04	20.75	20.96	20.96
2000	1.28	3.12	4.68	6.52	8.30	10.03	12.74	13.48	14.95	19.51	19.81	19.81
5000	0.95	2.17	3.44	5.37	7.02	8.77	11.11	12.13	13.53	17.60	18.11	18.11
10000	0.77	1.76	2.93	4.70	6.00	7.72	9.78	10.86	12.22	16.02	16.58	16.58
20000	0.61	1.47	2.52	3.94	4.92	6.45	8.41	9.49	10.65	14.13	14.75	14.75
50000	0.42	1.09	1.96	3.12	3.91	4.74	6.48	7.39	8.44	11.12	11.89	11.89
100000	0.28	0.78	1.45	2.51	3.19	3.83	5.09	5.76	6.46	8.79	9.67	9.67
193233	0.17	0.48	0.91	1.60	2.05	2.49	3.42	3.95	4.44	6.32	7.14	7.14



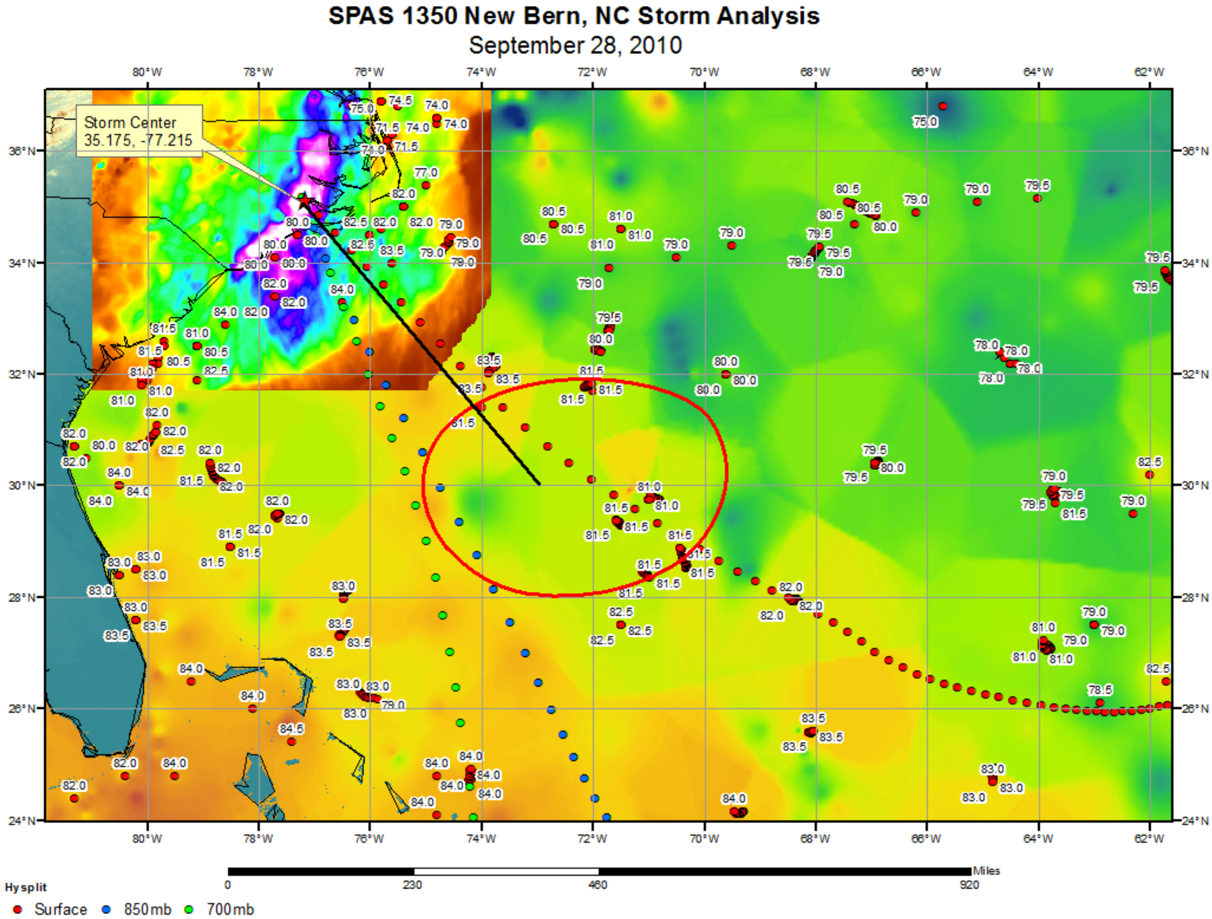

SPAS 1350 Storm Center Mass Curve: Zone 1
September 26 (1200 UTC) - October 1 (1100 UTC), 2010
Lat: 35.1750 Lon: -77.2150
Incremental
Accumulated
23.42"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
25
1
21
41
61
81
101



80°W
78°W
76°W
74°W
40°N
38°N
36°N
34°N
32°N
Total Storm (120-hr) Precipitation (inches)
09/26/2010 1200 UTC - 10/01/2010 1100 UTC
SPAS-NEXRAD #1350
Gauges
D
H
HP
S
SE
Miles
0 50 100 200
Kilometers
0 110 220 440
Precipitation (inches)
0.37 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00
20.01 - 21.00
21.01 - 22.00
22.01 - 23.00
23.01 - 24.00
5/9/2014



NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 30 Sep 10
CDC1 Meteorological Data
Source ★ at 35.17 N 77.21 W
30
-50
-60
80
-70
20
10
hPa
700
850
1000
700
750
800
850
900
950
1000
00 18 12 06 00 18 12 06 00 18 12 06
09/30
09/29
09/28
Job ID: 155897
Job Start: Wed Aug 27 15:55:15 UTC 2014
Source 1 lat.: 35.175000 lon.: -77.215000 hgts: 0, 1415, 3060 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2010 - reanalysis


SPAS 1350 New Bern, NC Storm Analysis
September 28, 2010
Storm Center
35.175, -77.215
Hysplit
Surface
850mb
700mb
Miles
0
230
460
920

Storm Precipitation Analysis System (SPAS) For Storm #1298_1 SPAS-NEXRAD Analysis

General Storm Location: Harrisburg, PA, Mid-Atlantic States

Storm Dates: September 4, 2011 – September 9, 2011 (96-hours analyzed)

Event: Front Systems Pulling in Moisture from Remnants of Tropical Storm Lee

DAD Zone 1

Latitude: 39.985

Longitude: -76.495

Max. Grid Rainfall Amount: 18.32”

Number of Stations: 3135 (522 Daily, 1118 Hourly, 7 Hourly Estimated, 179 Hourly Pseudo, 1304 Supplemental, 5 Supplemental Estimated)

SPAS Version: 9.5

Base Map Used: NWS Stage 4 Storm Total Precipitation 4-km grid

Spatial resolution: 36 seconds

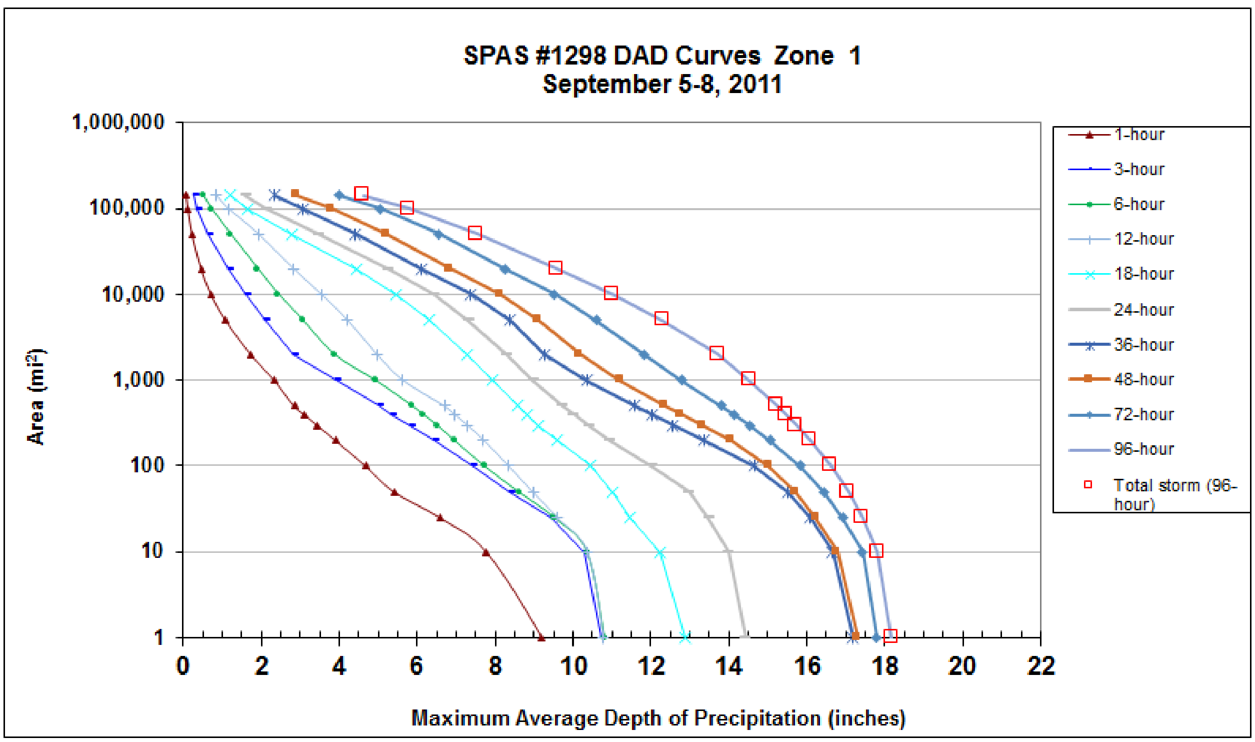
Radar Included: Yes

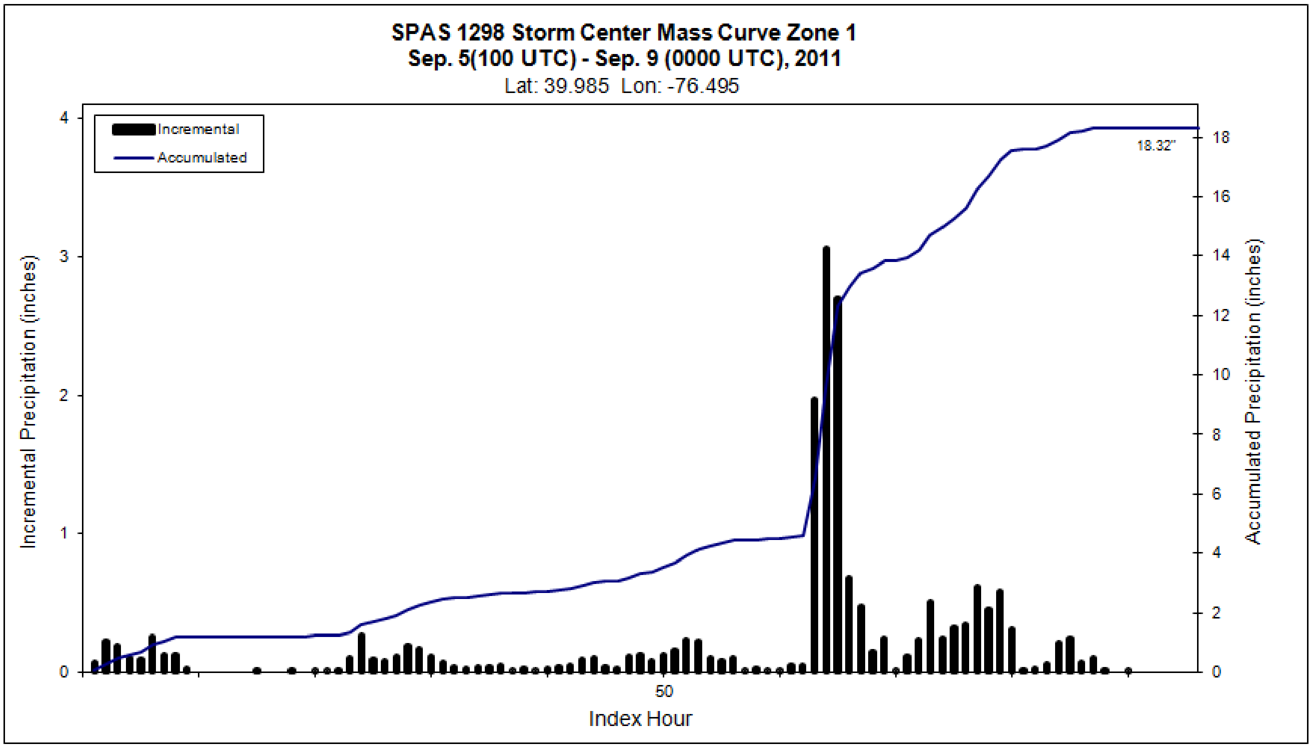
Depth-Area-Duration (DAD) analysis: Yes

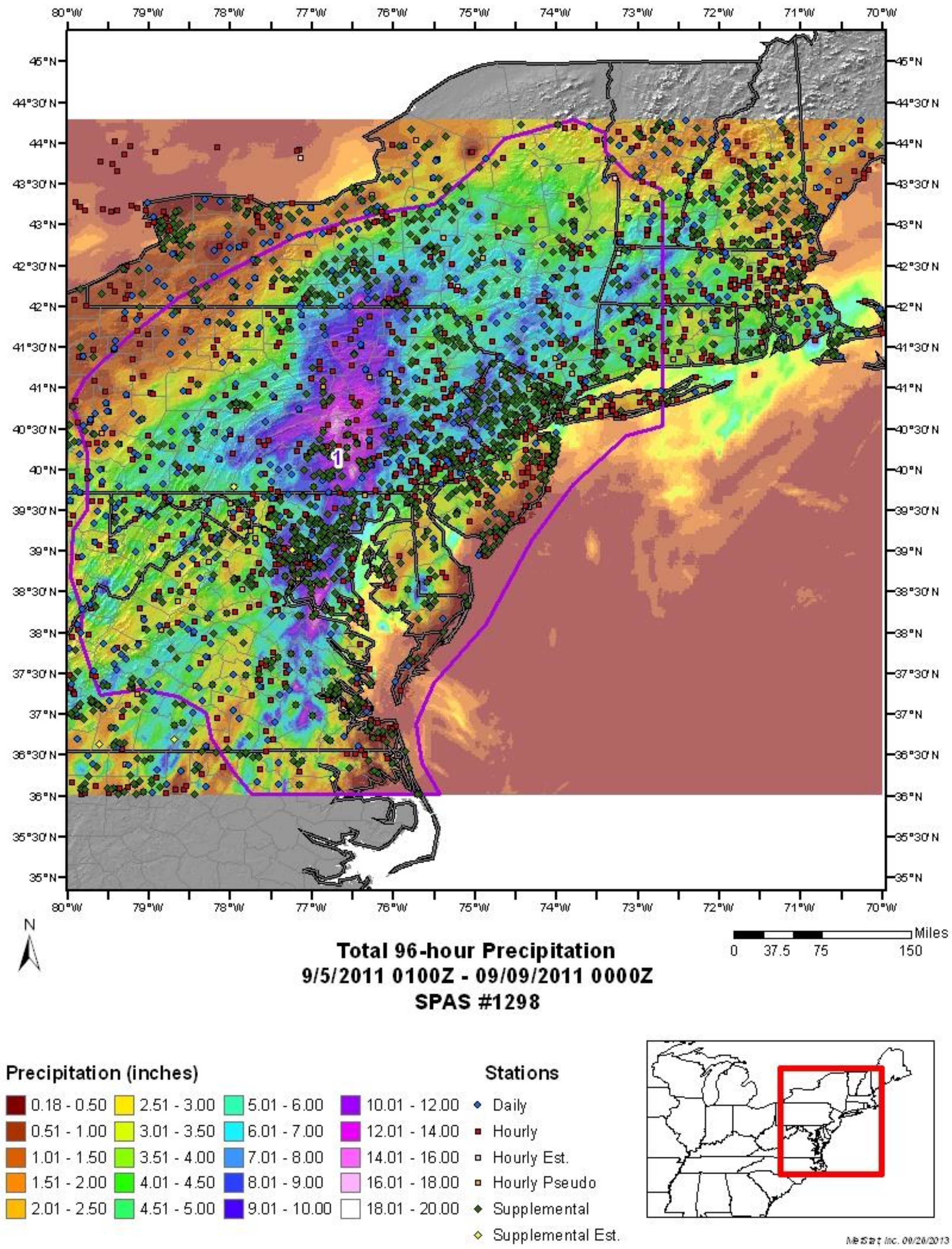
Reliability of Results: This storm was particularly difficult given large amount of data that required extensive QC. A great deal of effort was put into QCing the hourly data. When in doubt, the station was often simply removed. Fortunately, this storm occurred during the CoCoRaHS era, so it coupled with NCDC data, provided a spatially dense sample size for anchoring the precipitation magnitudes. Good radar data was also available and helped overcome the limited hourly data, particularly in areas where pseudo hourly gauges (based on the radar data and SPAS-generated ZRs) were added to the analysis. All in all, however, we are confident in the results of this analysis with the exception of areas across southeastern Virginia, where the analysis struggled with the extremely heavy rain from thunderstorms late in the analysis period occurred. The number of high hourly estimates (station data only) and the use of the dynamic and/or Tropical storm ZR relationship to create the estimated gridded precipitation created higher 1-hour precipitation values than is typically observed in a SPAS analysis. Again, this can be attributed to the estimated station hourly values, the Tropical storm ZR and residual adjustments, the large storm domain, the tropical and convective mix of precipitation that occurred during the storm within the large domain. Then, for DAD calculations, the hourly grids (with numerous high precipitation estimates) are used to calculate the DAD information.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1298_1	-76.4950	39.9850	226	20-Aug	81.50	3.86	0.06	85	3.800	83.79	4.30	0.07	90	4.230	1.113

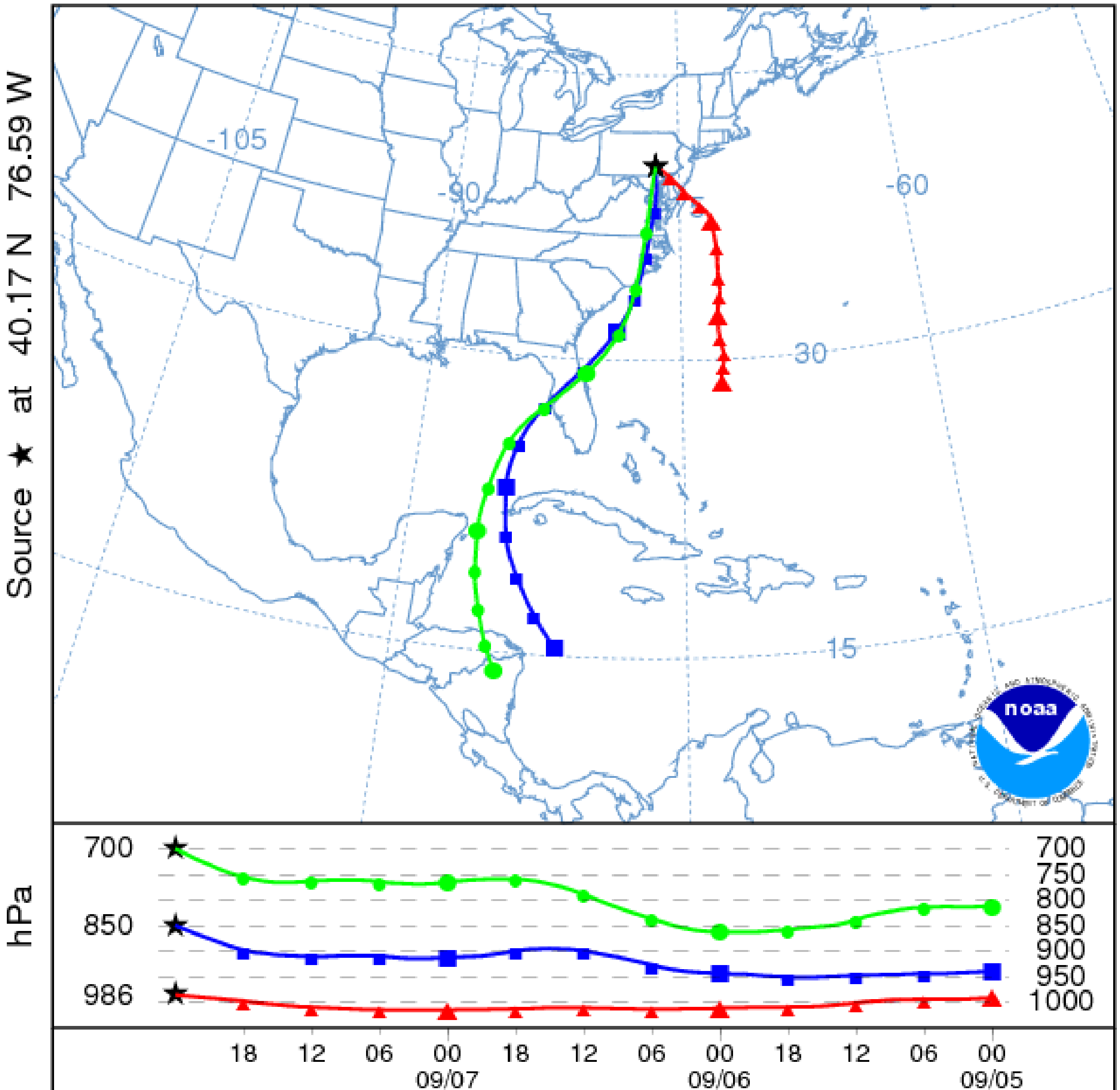
Storm 1298 - September 5 (0100 UTC) - September 9 (0000 UTC), 2011											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	3	6	12	18	24	36	48	72	96	Total
0.4	9.44	10.84	10.89	10.89	12.99	14.56	17.37	17.47	17.94	18.31	18.31
1	9.21	10.75	10.80	10.79	12.87	14.44	17.19	17.30	17.80	18.17	18.17
10	7.79	10.30	10.36	10.37	12.23	13.98	16.67	16.79	17.44	17.82	17.82
25	6.60	9.44	9.53	9.60	11.46	13.47	16.09	16.23	16.93	17.43	17.43
50	5.42	8.38	8.61	8.97	11.00	12.97	15.51	15.70	16.44	17.06	17.06
100	4.69	7.40	7.73	8.35	10.43	12.02	14.65	15.02	15.82	16.62	16.62
200	3.91	6.43	6.95	7.71	9.59	10.95	13.37	14.07	15.05	16.09	16.09
300	3.44	5.82	6.51	7.29	9.11	10.39	12.57	13.31	14.53	15.73	15.73
400	3.11	5.34	6.15	6.96	8.81	10.02	12.01	12.77	14.13	15.46	15.46
500	2.85	5.00	5.88	6.70	8.59	9.73	11.59	12.37	13.80	15.25	15.25
1,000	2.34	3.92	4.92	5.63	7.93	8.97	10.35	11.21	12.78	14.54	14.54
2,000	1.74	2.83	3.87	4.97	7.29	8.28	9.26	10.17	11.82	13.73	13.73
5,000	1.09	2.11	3.06	4.21	6.32	7.31	8.39	9.13	10.61	12.30	12.30
10,000	0.72	1.62	2.44	3.54	5.47	6.42	7.38	8.13	9.52	11.01	11.01
20,000	0.47	1.15	1.90	2.82	4.45	5.25	6.10	6.86	8.25	9.58	9.58
50,000	0.24	0.64	1.21	1.93	2.77	3.47	4.42	5.20	6.57	7.54	7.54
100,000	0.13	0.37	0.71	1.15	1.65	2.12	3.06	3.81	5.07	5.80	5.80
141,829	0.09	0.26	0.50	0.84	1.20	1.61	2.35	2.92	4.02	4.62	4.62




SPAS 1298 Storm Center Mass Curve Zone 1
Sep. 5(100 UTC) - Sep. 9 (0000 UTC), 2011
Lat: 39.985 Lon: -76.495
Incremental
Accumulated
18.32"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
50
0
1
2
3
4
0
2
4
6
8
10
12
14
16
18

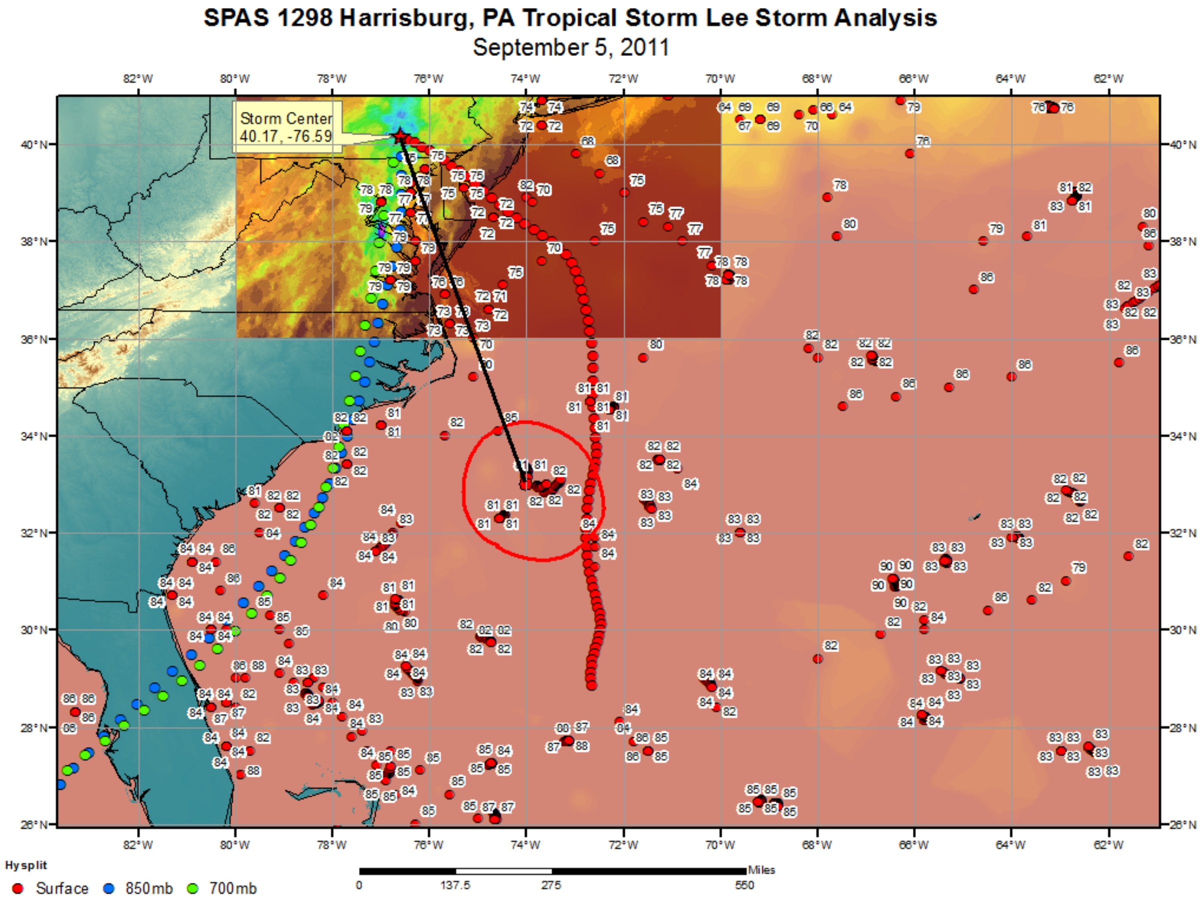

80°W
79°W
78°W
77°W
76°W
75°W
74°W
73°W
72°W
71°W
70°W
45°N
44°30'N
44°N
43°30'N
43°N
42°30'N
42°N
41°30'N
41°N
40°30'N
40°N
39°30'N
39°N
38°30'N
38°N
37°30'N
37°N
36°30'N
36°N
35°30'N
35°N
1
N
Miles
0 37.5 75 150
Total 96-hour Precipitation
9/5/2011 0100Z - 09/09/2011 0000Z
SPAS #1298
Precipitation (inches)
0.18 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 12.00
12.01 - 14.00
14.01 - 16.00
16.01 - 18.00
18.01 - 20.00
Stations
Daily
Hourly
Hourly Est.
Hourly Pseudo
Supplemental
Supplemental Est.
MetStat Inc. 09/20/2013

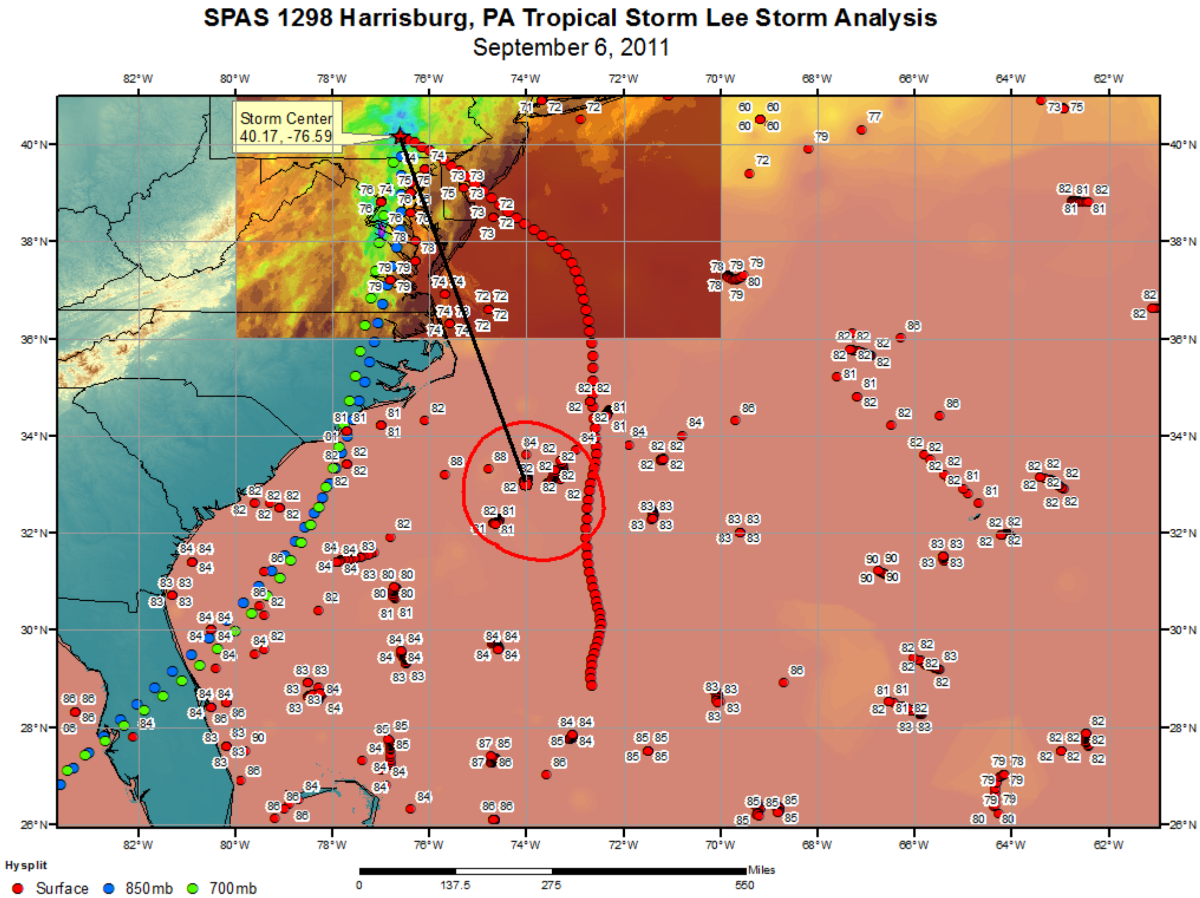
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 08 Sep 11
CDC1 Meteorological Data



Job ID: 18968 Job Start: Wed Sep 18 20:25:13 UTC 2013
Source 1 lat.: 40.170000 lon.: -76.590000 hgts: 0, 1290, 2910 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2011 - reanalysis


SPAS 1298 Harrisburg, PA Tropical Storm Lee Storm Analysis
September 5, 2011
Storm Center
40.17, -76.59
Hysplit
Surface
850mb
700mb
Miles
0
137.5
275
550


SPAS 1298 Harrisburg, PA Tropical Storm Lee Storm Analysis
September 6, 2011
Storm Center
40.17, -76.59
Hysplit
Surface
850mb
700mb
Miles
0
137.5
275
550

Storm Precipitation Analysis System (SPAS) For Storm #1564_1 SPAS-NEXRAD Analysis

General Storm Location: Mount Pleasant, SC

Storm Dates: October 1-6, 2015

Event: Synoptic

DAD Zone 1

Latitude: 32.8950

Longitude: -79.7650

Max. Grid Rainfall Amount: 27.97”

Max. Observed Rainfall Amount: 26.92” (120hrs)

Number of Stations: 1342

SPAS Version: 10.0

Basemap: NWS Stage IV Total Precipitation

Spatial resolution: 00:00:30

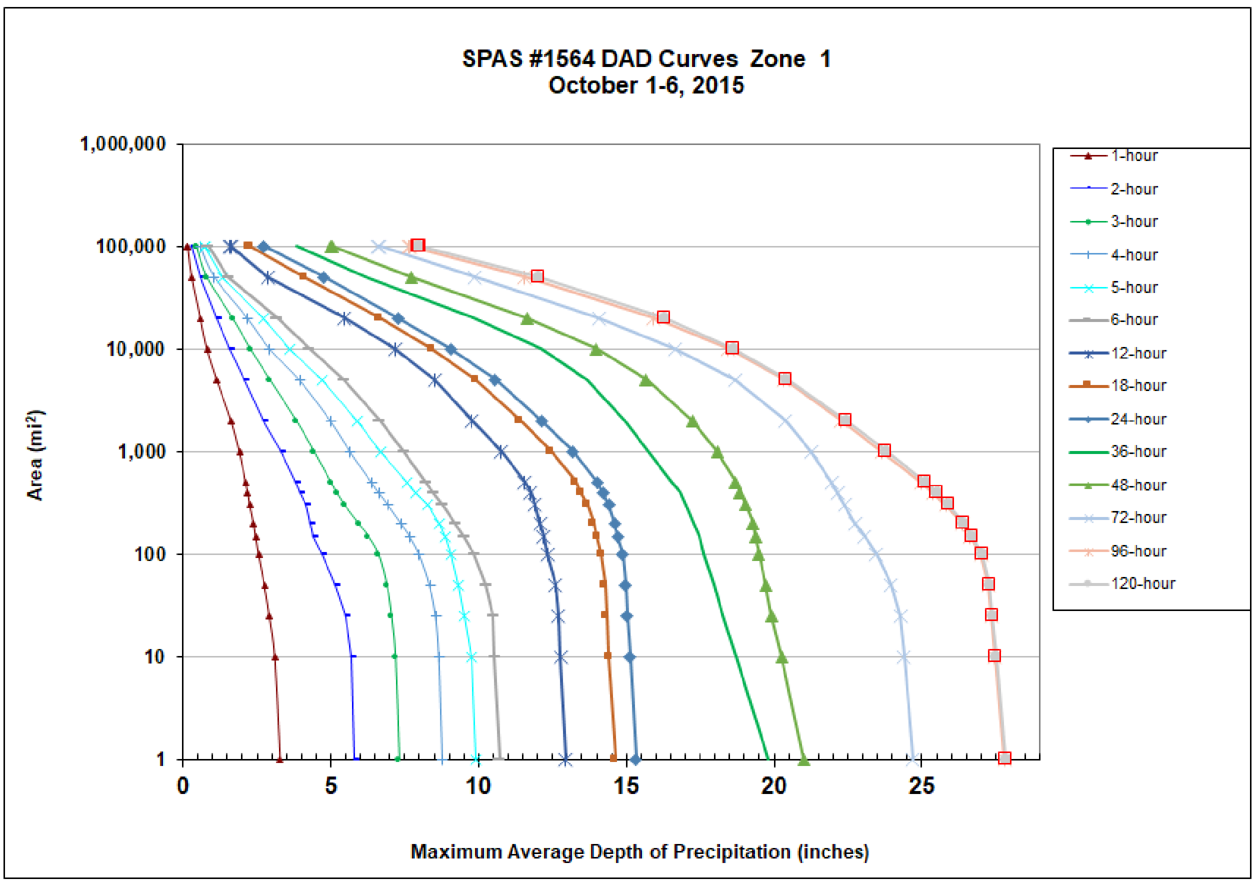
Radar Included: Yes

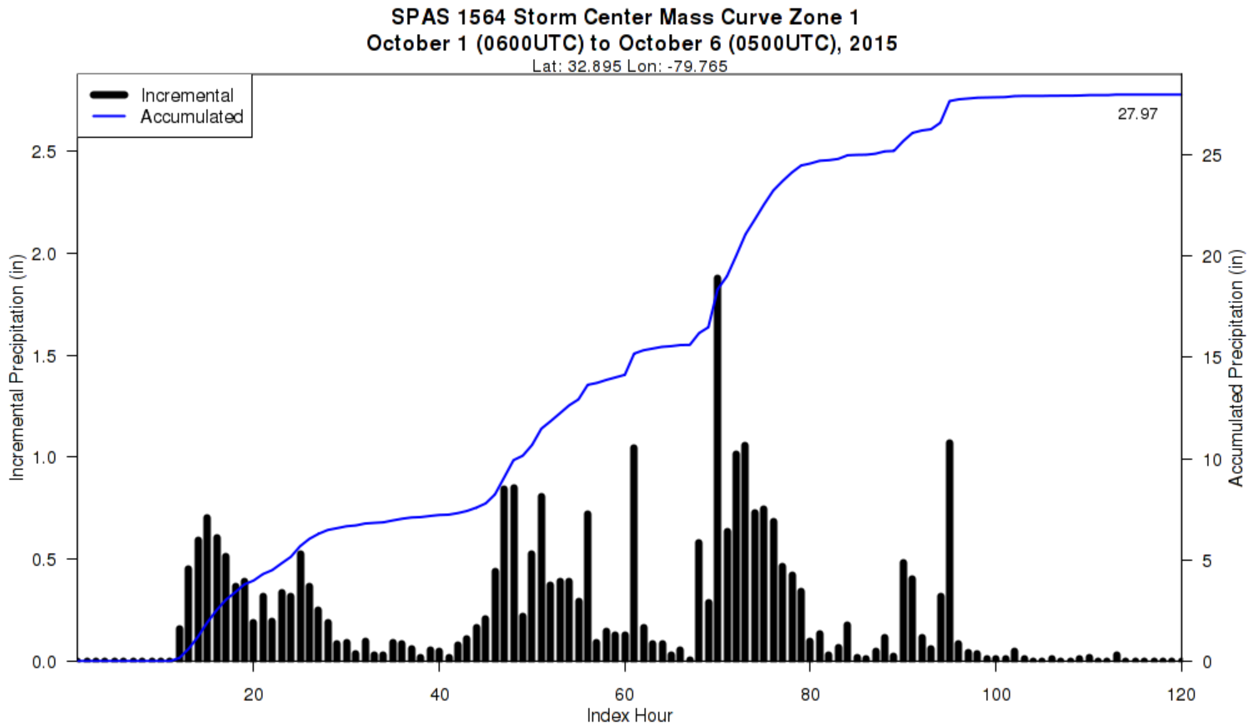
Depth-Area-Duration (DAD) analysis: Yes

Reliability of results: This analysis was based on 1342 hourly stations, daily data, supplemental station data, and radar data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the radar data, gauge data, and basemap. There is a good degree of confidence with the timing based on the hourly stations near the storm center. Some daily stations were moved to supplemental due to timing issues.

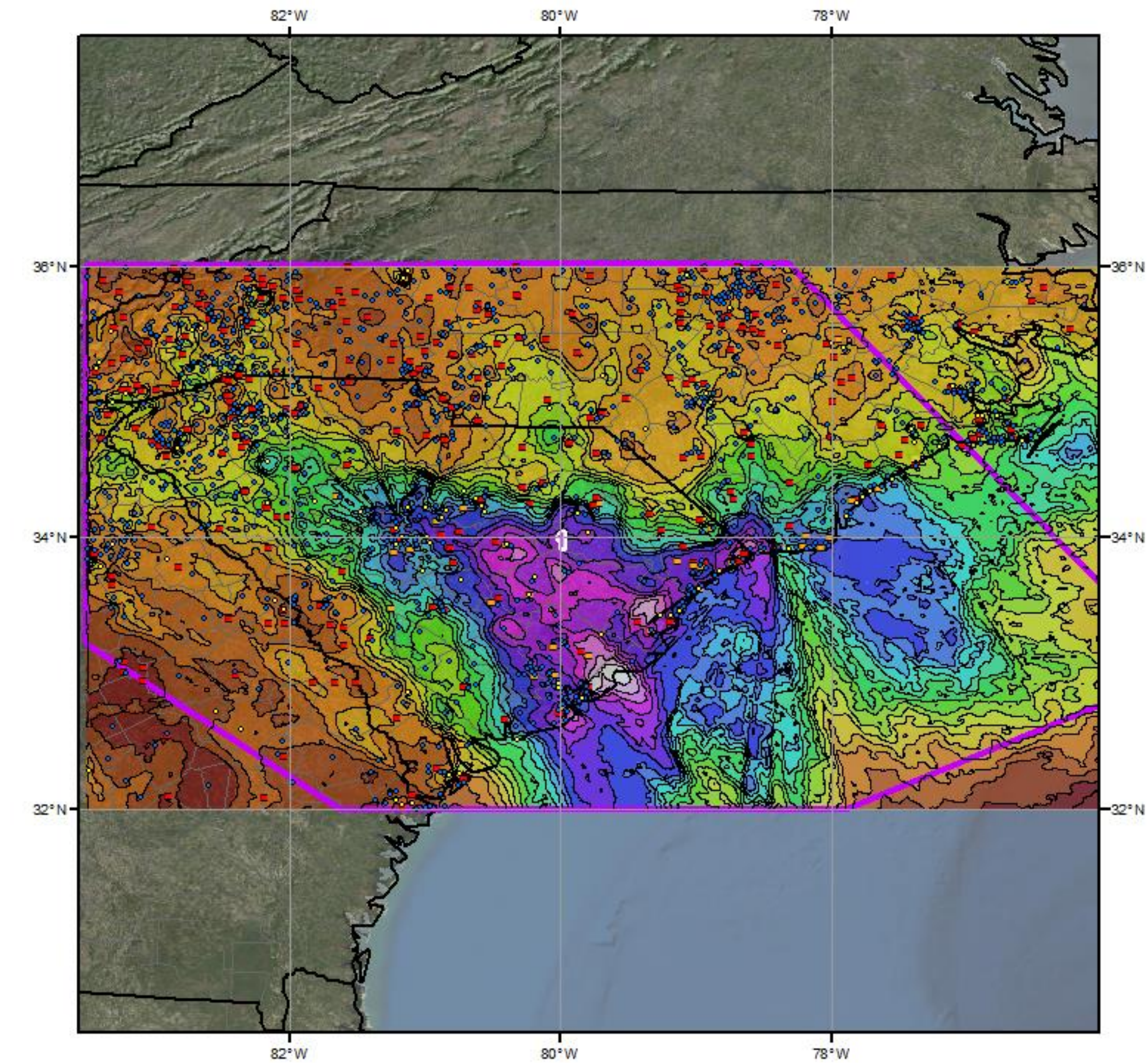
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1564_1	-79.7650	32.8950	8	17-Sep	83.00	4.12	0.00	88	4.120	84.30	4.39	0.00	91	4.390	1.066

Storm 1564 - October 1 (0600 UTC) - October 6 (0500 UTC), 2015															
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)															
Area (mi^2)	Duration (hours)														
	1	2	3	4	5	6	12	18	24	36	48	72	96	120	Total
0.4	3.33	5.83	7.36	8.84	9.98	10.77	13.02	14.70	15.41	19.97	21.23	24.81	27.91	27.97	27.97
1	3.29	5.79	7.30	8.79	9.92	10.71	12.95	14.62	15.33	19.78	20.99	24.69	27.78	27.84	27.84
10	3.11	5.68	7.17	8.67	9.74	10.55	12.78	14.42	15.12	18.72	20.25	24.39	27.47	27.52	27.52
25	2.93	5.49	7.04	8.56	9.53	10.49	12.71	14.34	15.04	18.28	19.92	24.27	27.35	27.39	27.39
50	2.76	5.17	6.88	8.35	9.31	10.25	12.60	14.28	14.98	17.95	19.70	23.94	27.25	27.29	27.29
100	2.56	4.72	6.60	8.00	9.06	9.86	12.32	14.16	14.87	17.63	19.48	23.46	26.99	27.06	27.06
150	2.46	4.42	6.26	7.68	8.87	9.50	12.19	14.00	14.71	17.45	19.36	23.06	26.63	26.69	26.69
200	2.39	4.33	5.93	7.39	8.67	9.20	12.09	13.88	14.60	17.28	19.28	22.74	26.38	26.43	26.43
300	2.27	4.15	5.47	6.96	8.27	8.77	11.91	13.68	14.42	17.03	19.04	22.38	25.80	25.91	25.91
400	2.20	3.97	5.19	6.63	7.87	8.46	11.75	13.46	14.20	16.80	18.84	22.13	25.37	25.51	25.51
500	2.13	3.79	5.00	6.39	7.57	8.21	11.57	13.29	14.01	16.55	18.70	21.94	24.97	25.11	25.11
1,000	1.91	3.34	4.43	5.66	6.69	7.47	10.76	12.46	13.19	15.71	18.07	21.24	23.64	23.80	23.80
2,000	1.63	2.71	3.83	4.99	5.87	6.66	9.77	11.40	12.14	14.92	17.23	20.38	22.26	22.43	22.43
5,000	1.15	2.09	2.94	3.94	4.71	5.43	8.52	9.90	10.57	13.66	15.67	18.68	20.32	20.44	20.44
10,000	0.82	1.57	2.28	2.93	3.63	4.26	7.17	8.40	9.05	12.10	13.99	16.65	18.44	18.62	18.62
20,000	0.59	1.14	1.67	2.17	2.71	3.18	5.47	6.64	7.28	9.86	11.63	14.05	15.91	16.28	16.28
50,000	0.30	0.59	0.81	1.06	1.34	1.53	2.87	4.10	4.76	6.18	7.71	9.88	11.57	12.04	12.04
100,000	0.16	0.30	0.44	0.57	0.73	0.85	1.61	2.26	2.73	3.85	5.03	6.64	7.67	8.02	8.02
100,549	0.15	0.30	0.43	0.57	0.72	0.85	1.60	2.25	2.71	3.84	5.01	6.61	7.64	7.99	7.99

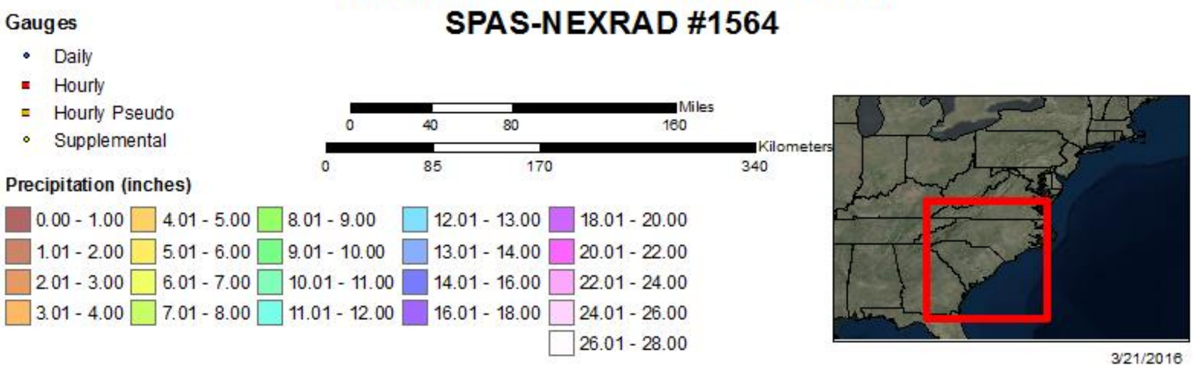


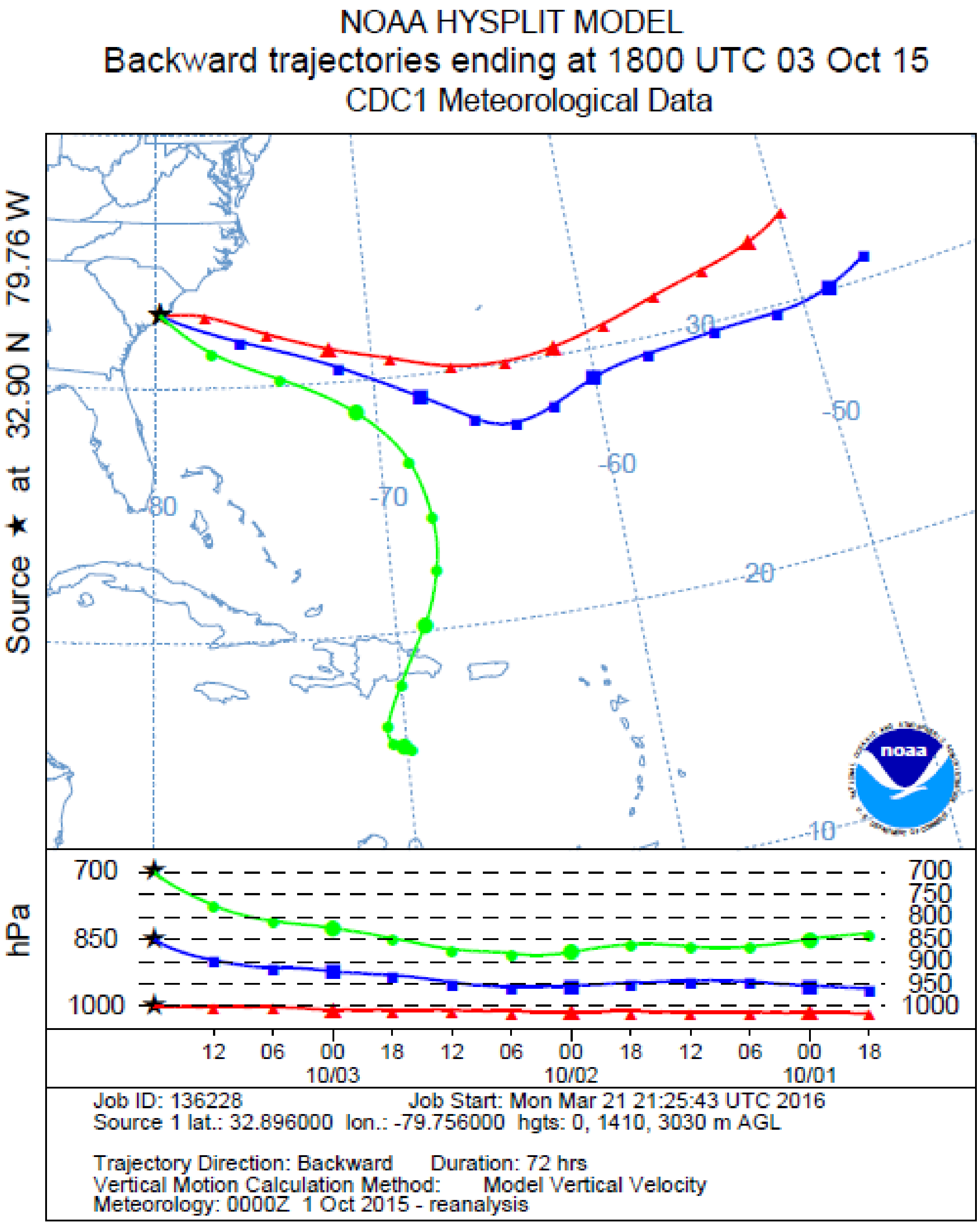


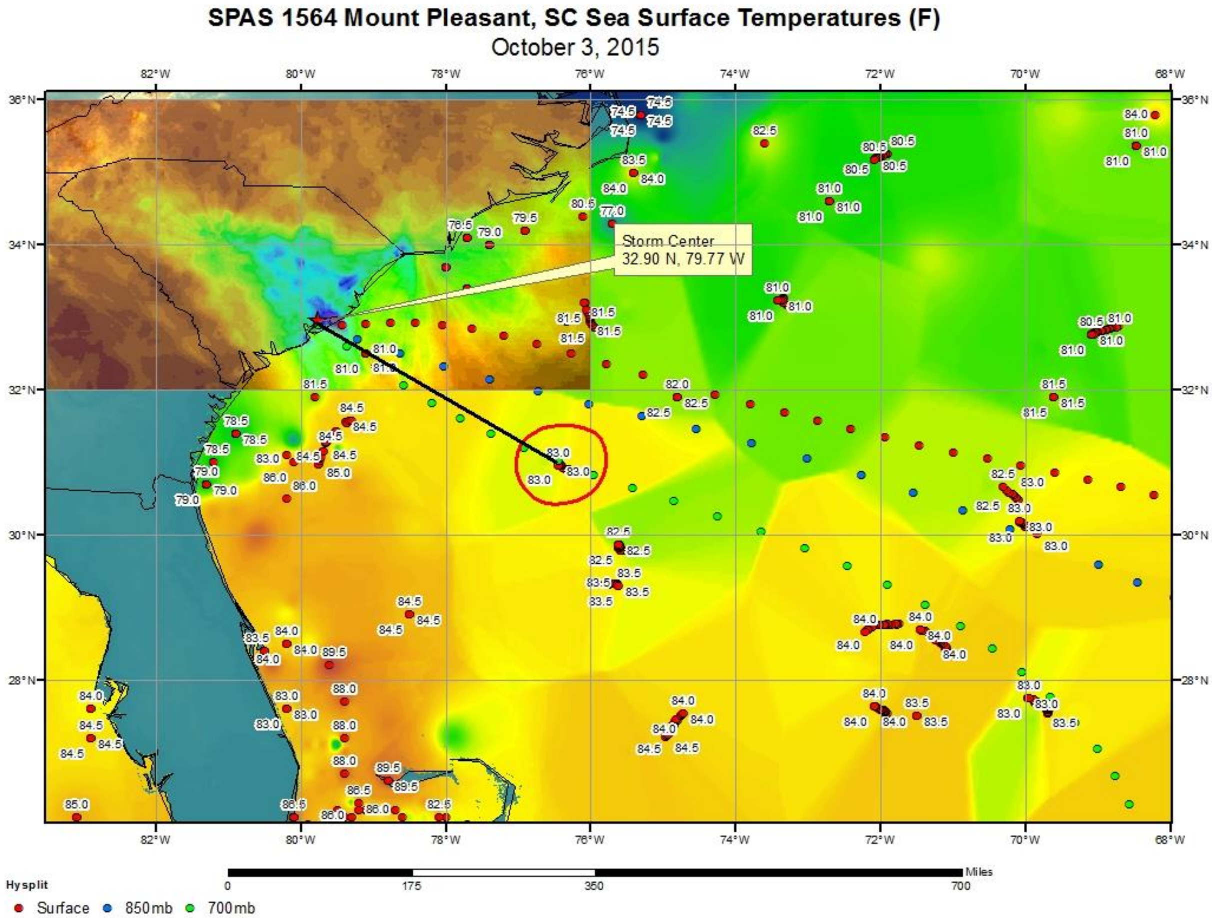
SPAS 1564 Storm Center Mass Curve Zone 1
October 1 (0600UTC) to October 6 (0500UTC), 2015
Lat: 32.895 Lon: -79.765
Incremental
Accumulated
27.97
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
25
20
40
60
80
100
120



Total Storm (120-hours) Precipitation (inches)
10/1/2015 0600 UTC - 10/6/2015 0500
SPAS-NEXRAD #1564




NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 03 Oct 15
CDC1 Meteorological Data
Source ★ at 32.90 N 79.76 W
30
-50
-60
-70
-80
20
10
noaa
hPa
700
850
1000
700
750
800
850
900
950
1000
12 06 00 18 12 06 00 18 12 06 00 18
10/03
10/02
10/01
Job ID: 136228 Job Start: Mon Mar 21 21:25:43 UTC 2016
Source 1 lat.: 32.896000 lon.: -79.756000 hgts: 0, 1410, 3030 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Oct 2015 - reanalysis


SPAS 1564 Mount Pleasant, SC Sea Surface Temperatures (F)
October 3, 2015
Storm Center
32.90 N, 79.77 W
Hysplit
Surface
850mb
700mb
Miles
0
175
350
700

Hybrid Storms

Storm Precipitation Analysis System (SPAS) For Storm #1340_1 SPAS Analysis

General Storm Location: Big Meadows, VA (USACE SA 1-28a)

Storm Dates: October 12-17, 1942

Event: This storm had characteristics of both a general storm and was enhanced by remnant tropical moisture from a system well offshore.

DAD Zone 1

Latitude: 38.5458

Longitude: -78.4042

Max. Grid Rainfall Amount: 19.77"

Max. Observed Rainfall Amount: 18.92"

Number of Stations: 587 (423 Daily, 2 Hourly, 3 Hourly Pseudo, and 159 Supplemental)

SPAS Version: 9.5

Basemap: PRISM October 1942 Precipitation

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

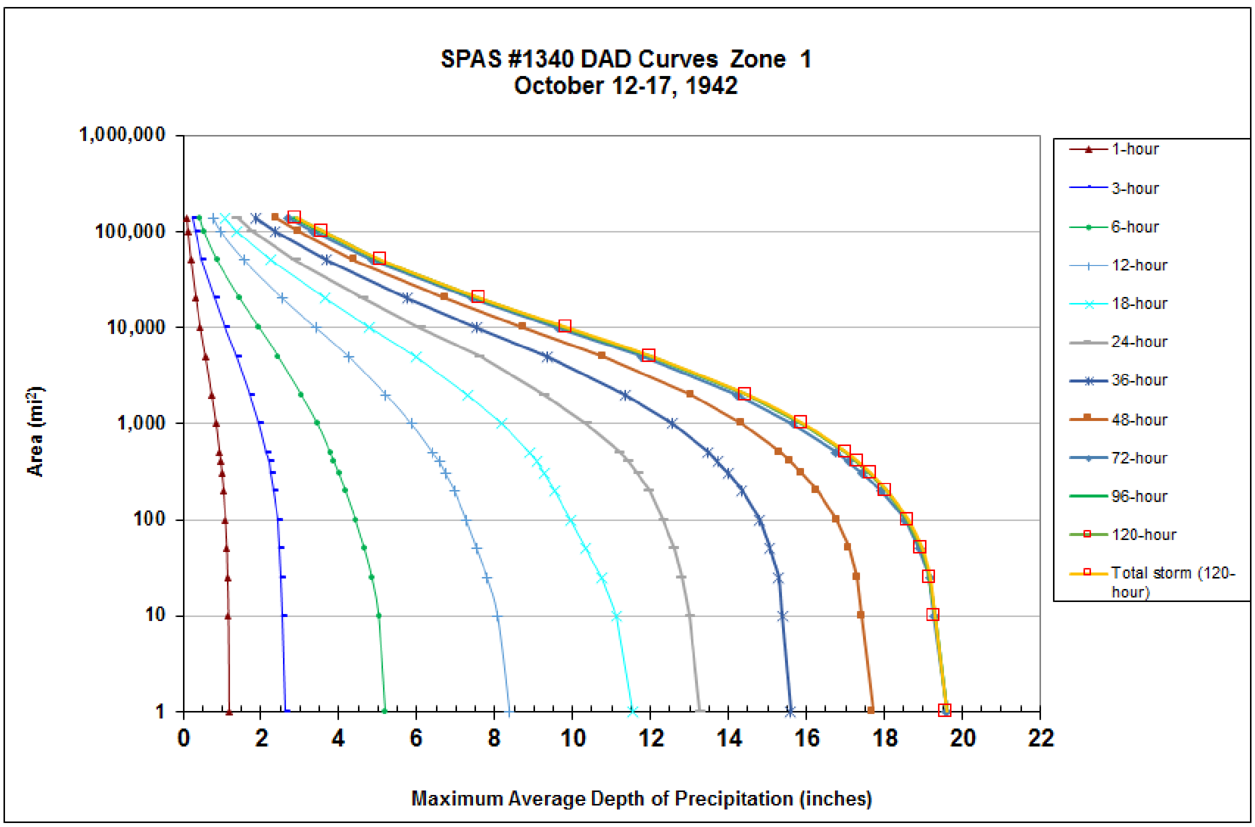
Radar Included: No

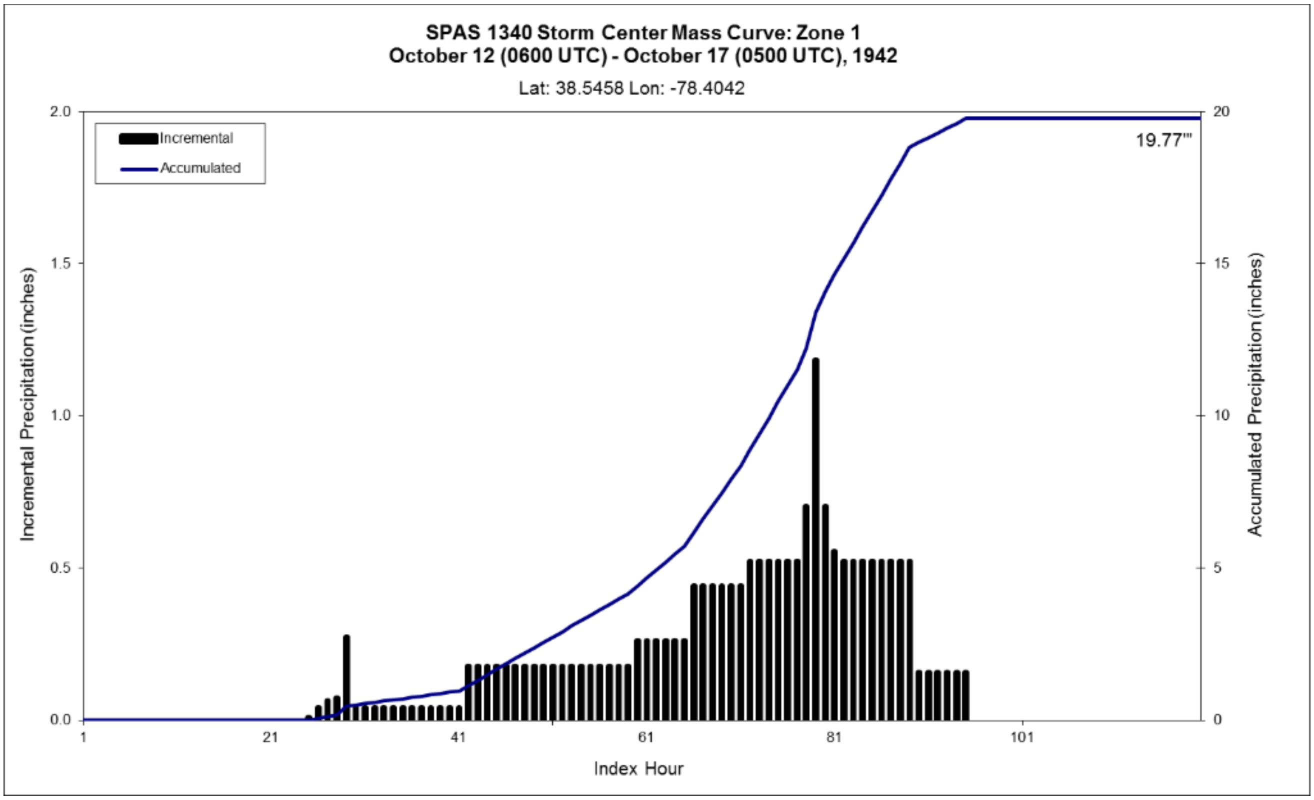
Depth-Area-Duration (DAD) analysis: Yes

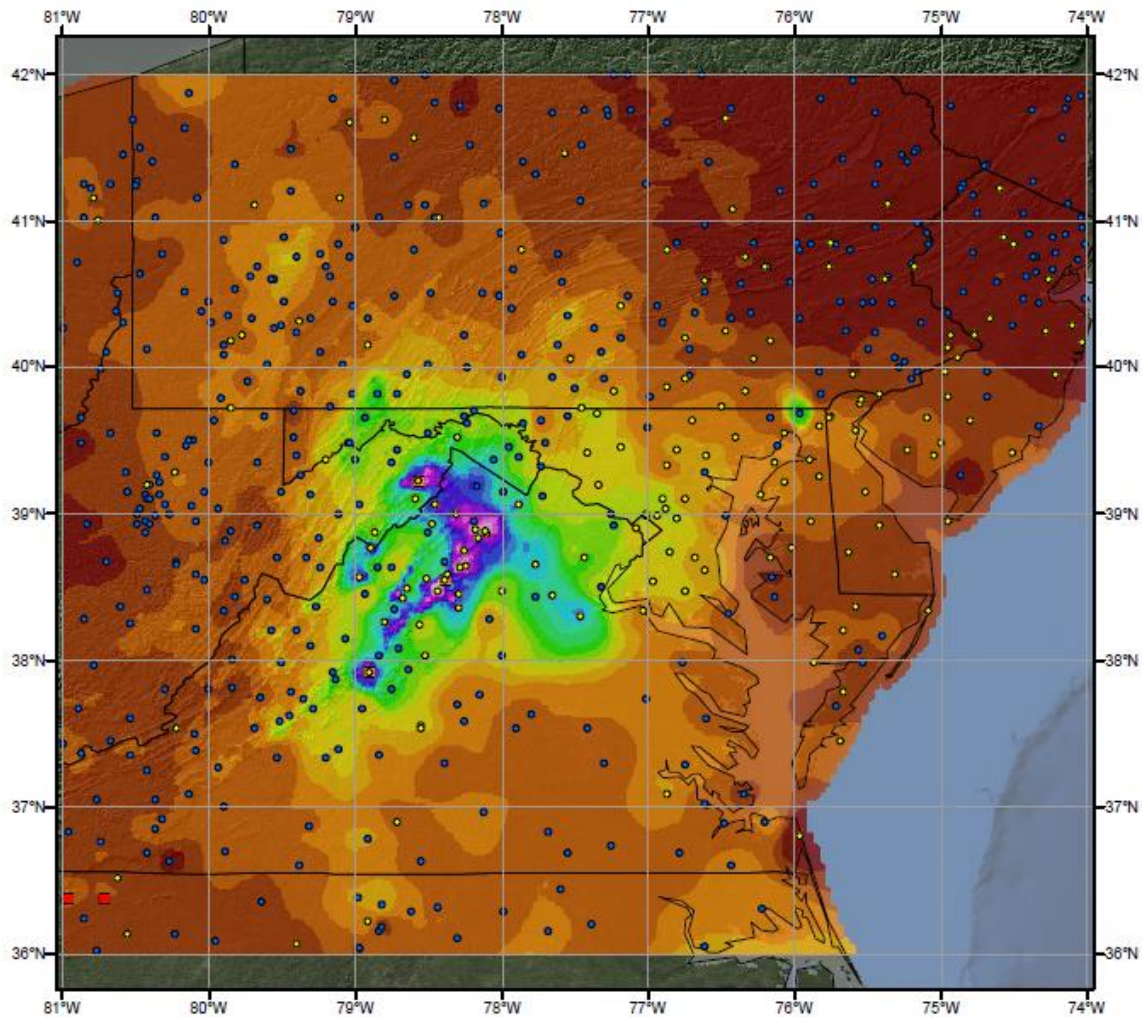
Reliability of results: This analysis was based on digitized hourly data from the USACE SA 1-28a mass curves, daily data, and supplemental station data. The lack of hourly data and having to digitize the USACE mass curves resulted in SPAS mass curves which are smoothed and are likely not representative of the true hourly accumulation. We have a good degree of confidence in the station based storm total results, the spatial pattern is dependent on the basemap, and the timing is based on hourly stations.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1340_1_GEN	-78.4042	38.5458	3,299	1-Oct	78.00	3.29	0.84	78	2.450	81.25	3.86	0.95	85	2.910	1.188

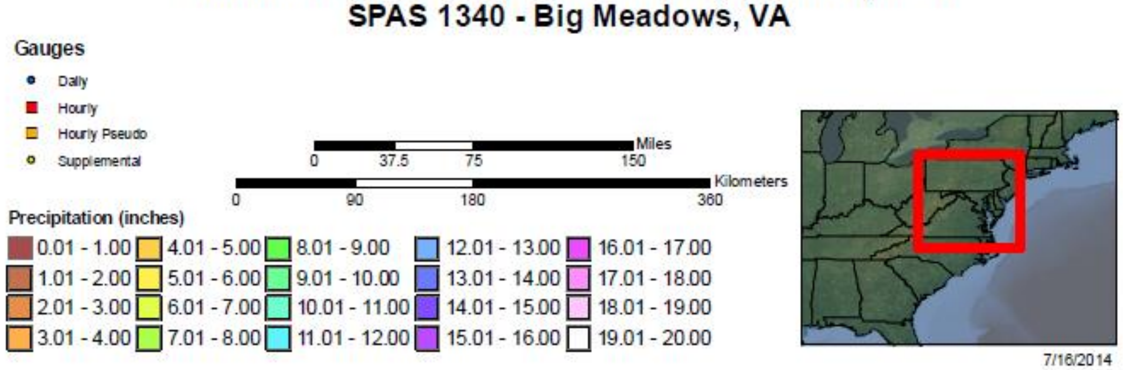
Storm 1340 - October 12 (0600 UTC) - October 17 (0500 UTC), 1942												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
Area (mi^2)	Duration (hours)											
	1	3	6	12	18	24	36	48	72	96	120	Total
0.4	1.18	2.63	5.25	8.44	11.63	13.37	15.70	17.82	19.71	19.71	19.71	19.71
1	1.18	2.62	5.21	8.37	11.54	13.27	15.60	17.71	19.59	19.59	19.59	19.59
10	1.16	2.56	5.03	8.07	11.12	13.01	15.38	17.43	19.28	19.29	19.29	19.29
25	1.14	2.52	4.86	7.80	10.73	12.79	15.29	17.32	19.16	19.17	19.17	19.17
50	1.12	2.49	4.67	7.53	10.35	12.60	15.07	17.10	18.89	18.96	18.96	18.96
100	1.08	2.42	4.44	7.26	9.97	12.33	14.80	16.79	18.54	18.60	18.60	18.60
200	1.03	2.32	4.18	6.96	9.54	11.96	14.35	16.27	17.92	18.05	18.05	18.05
300	0.99	2.25	4.02	6.74	9.26	11.68	14.01	15.89	17.44	17.65	17.65	17.65
400	0.96	2.20	3.89	6.58	9.07	11.43	13.73	15.59	17.08	17.31	17.31	17.31
500	0.93	2.15	3.79	6.40	8.88	11.21	13.47	15.32	16.76	17.01	17.01	17.01
1,000	0.84	1.96	3.46	5.86	8.18	10.36	12.57	14.34	15.65	15.90	15.90	15.90
2,000	0.73	1.72	3.04	5.21	7.31	9.27	11.34	13.04	14.22	14.46	14.46	14.46
5,000	0.57	1.38	2.45	4.25	5.99	7.63	9.34	10.78	11.78	11.99	12.00	12.00
10,000	0.44	1.08	1.96	3.40	4.79	6.10	7.54	8.75	9.62	9.81	9.83	9.83
20,000	0.33	0.80	1.46	2.56	3.63	4.63	5.77	6.76	7.44	7.60	7.62	7.62
50,000	0.20	0.47	0.87	1.57	2.24	2.88	3.69	4.39	4.87	5.03	5.08	5.08
100,000	0.12	0.31	0.53	0.96	1.38	1.77	2.35	2.95	3.34	3.50	3.58	3.58
138,434	0.09	0.23	0.42	0.76	1.09	1.39	1.86	2.38	2.7	2.82	2.89	2.89

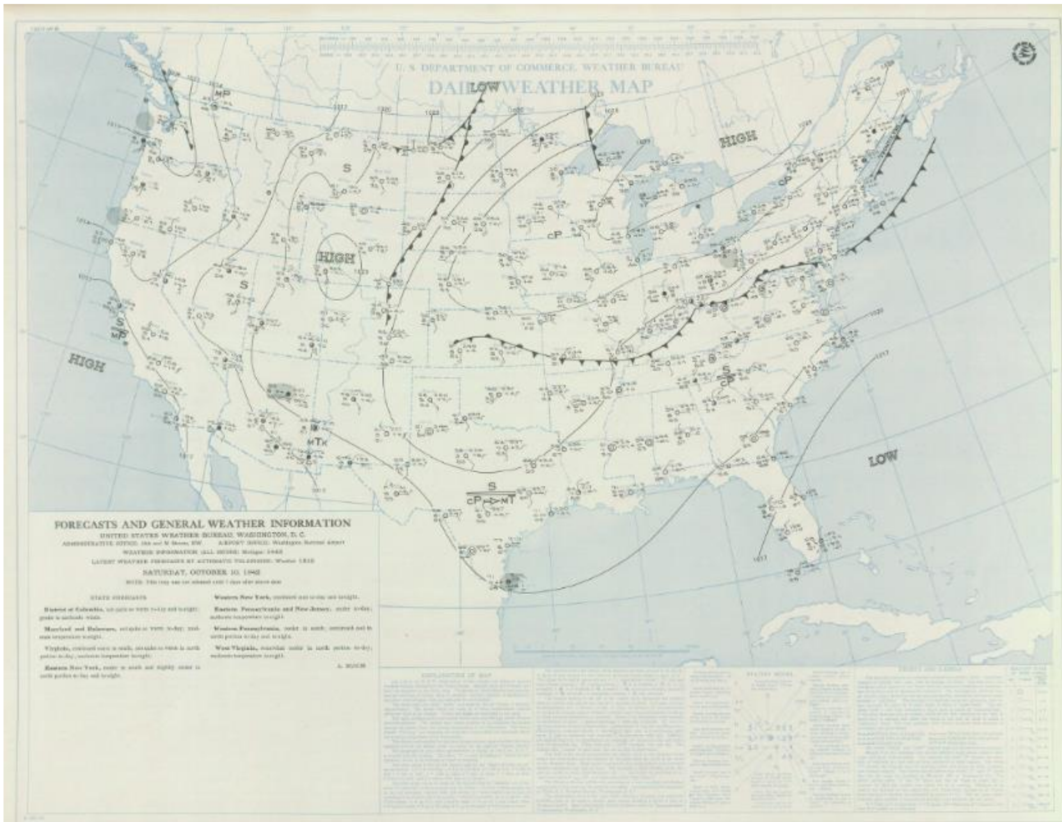


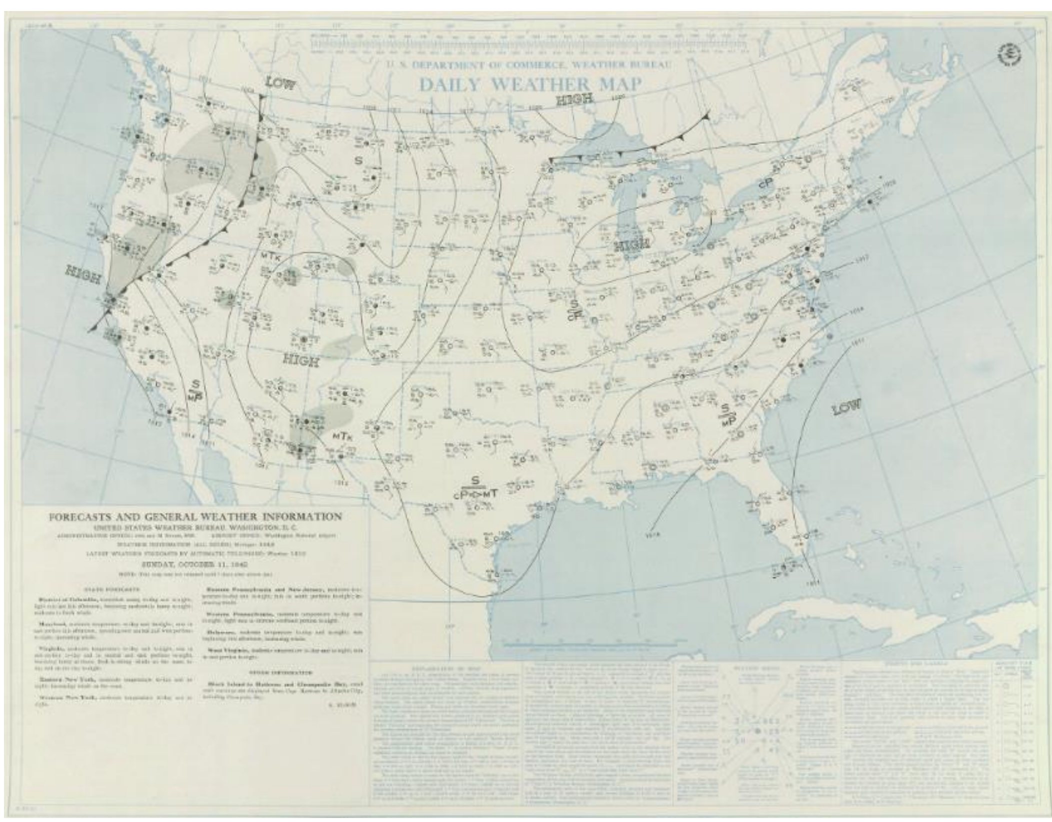

SPAS 1340 Storm Center Mass Curve: Zone 1
October 12 (0600 UTC) - October 17 (0500 UTC), 1942
Lat: 38.5458 Lon: -78.4042
Incremental
Accumulated
19.77"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
2.0
1.5
1.0
0.5
0.0
20
15
10
5
0
1
21
41
61
81
101

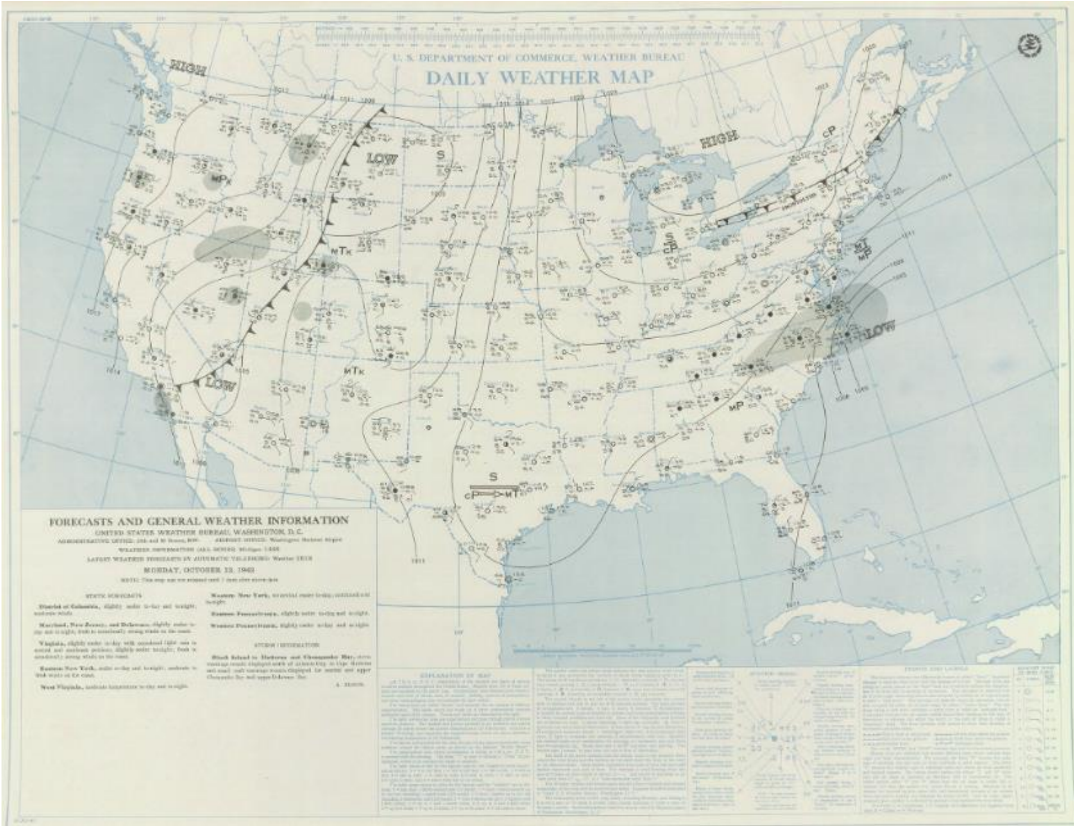


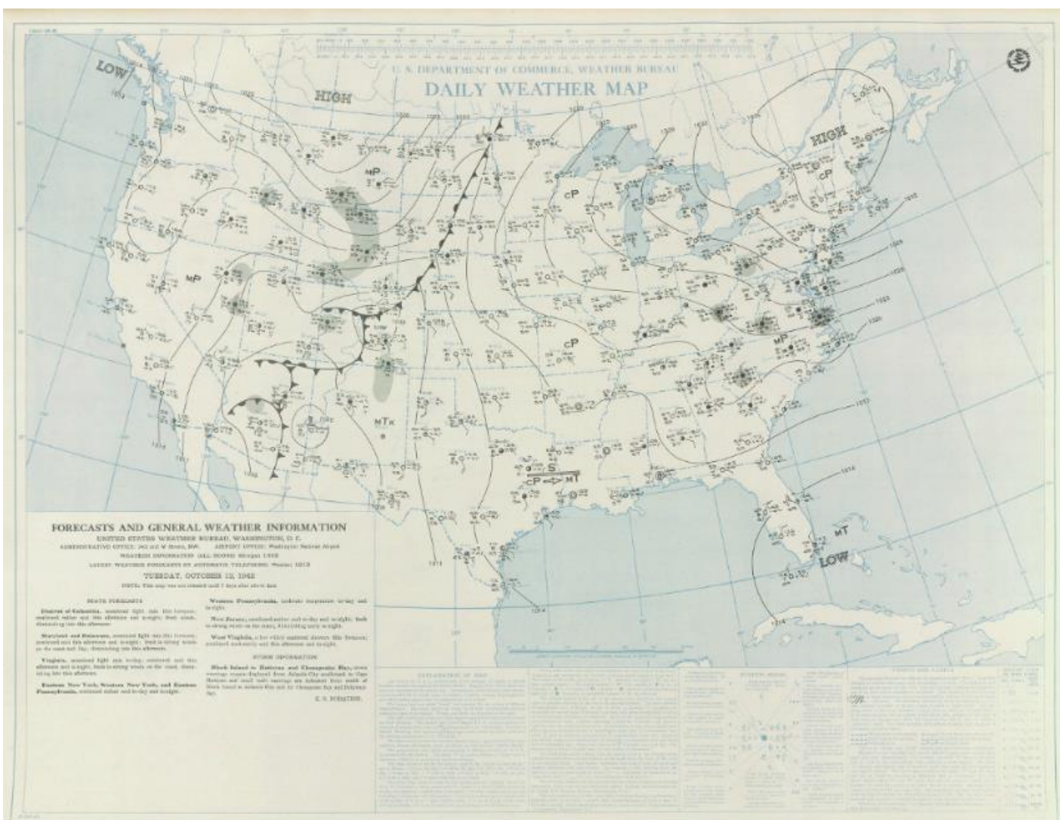
Total Storm (120-hr) Precipitation (inches)
October 12 (0600 UTC) - October 17 (0500 UTC), 1942
SPAS 1340 - Big Meadows, VA

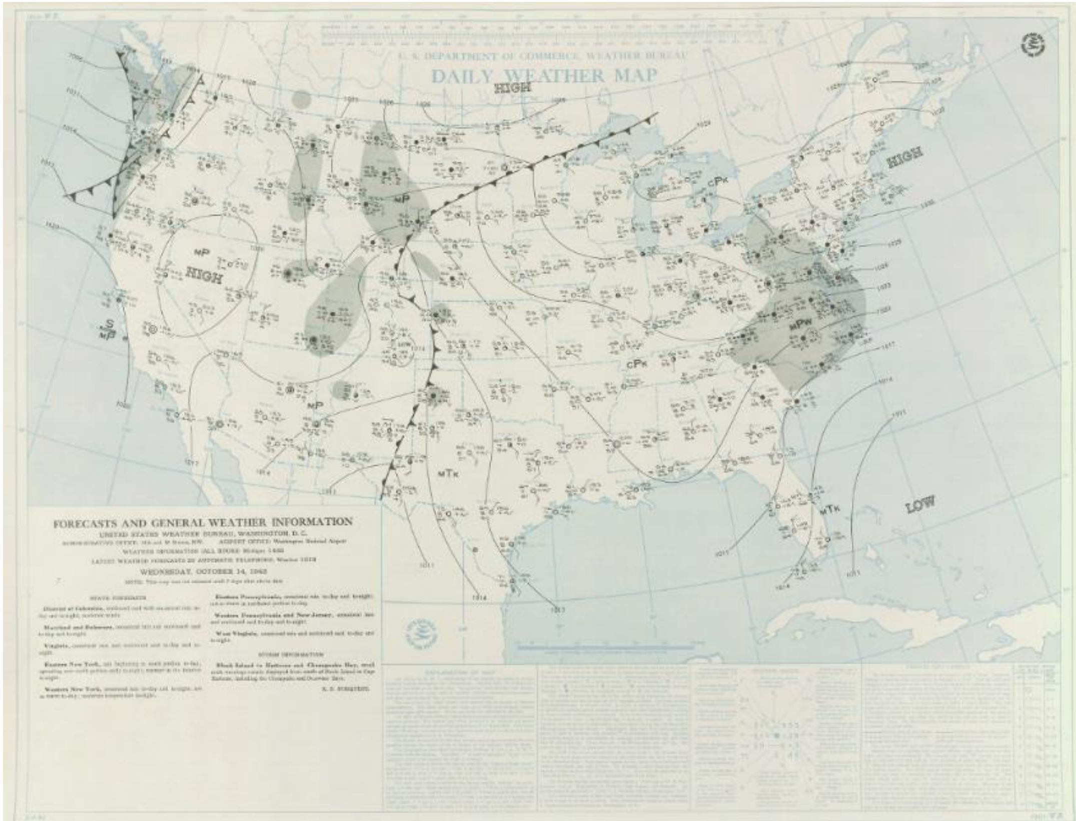


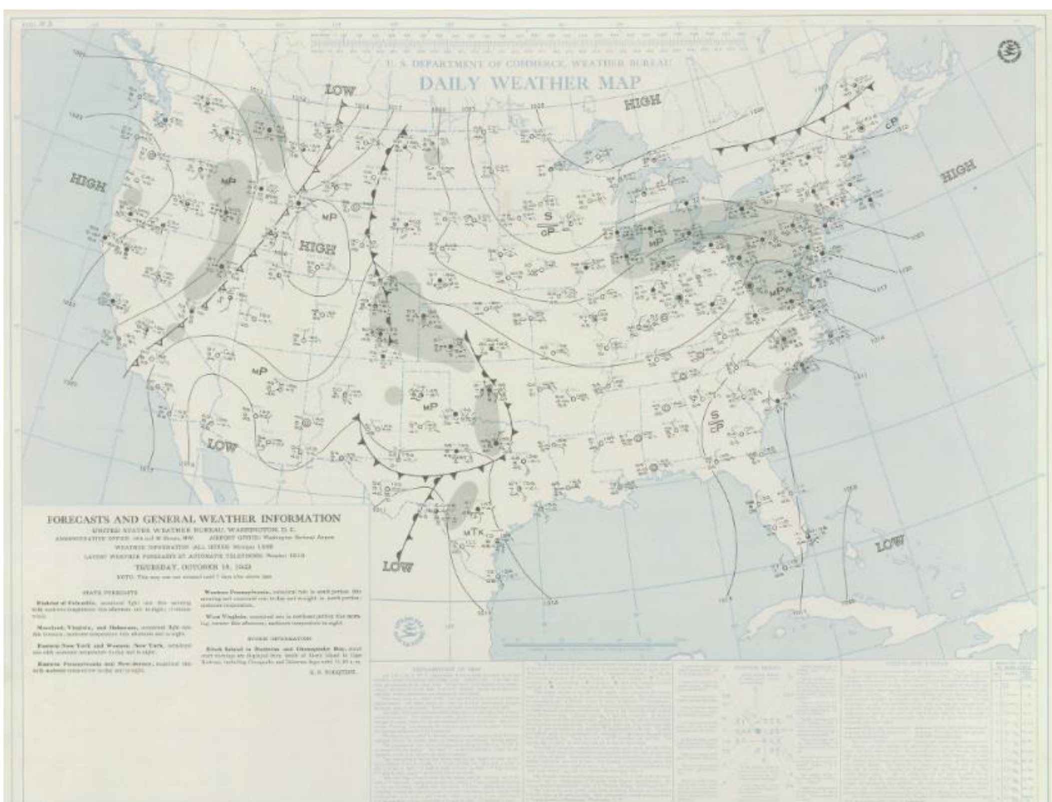

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SATURDAY, OCTOBER 10, 1942

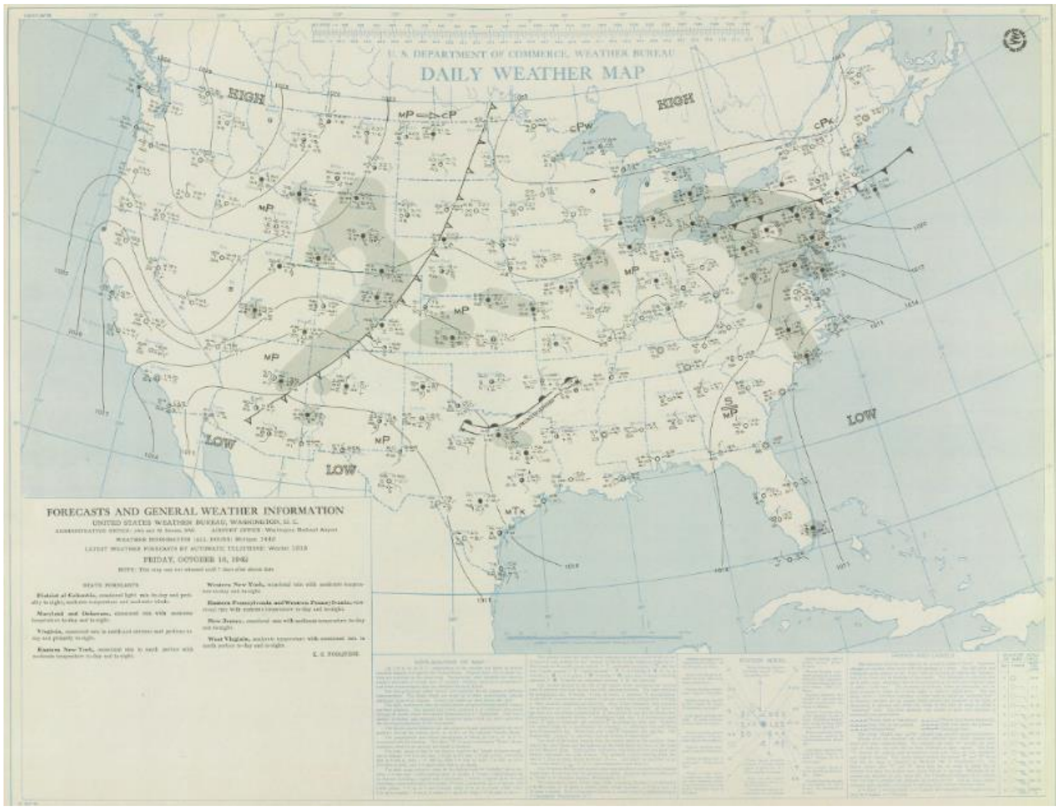

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SUNDAY, OCTOBER 11, 1942

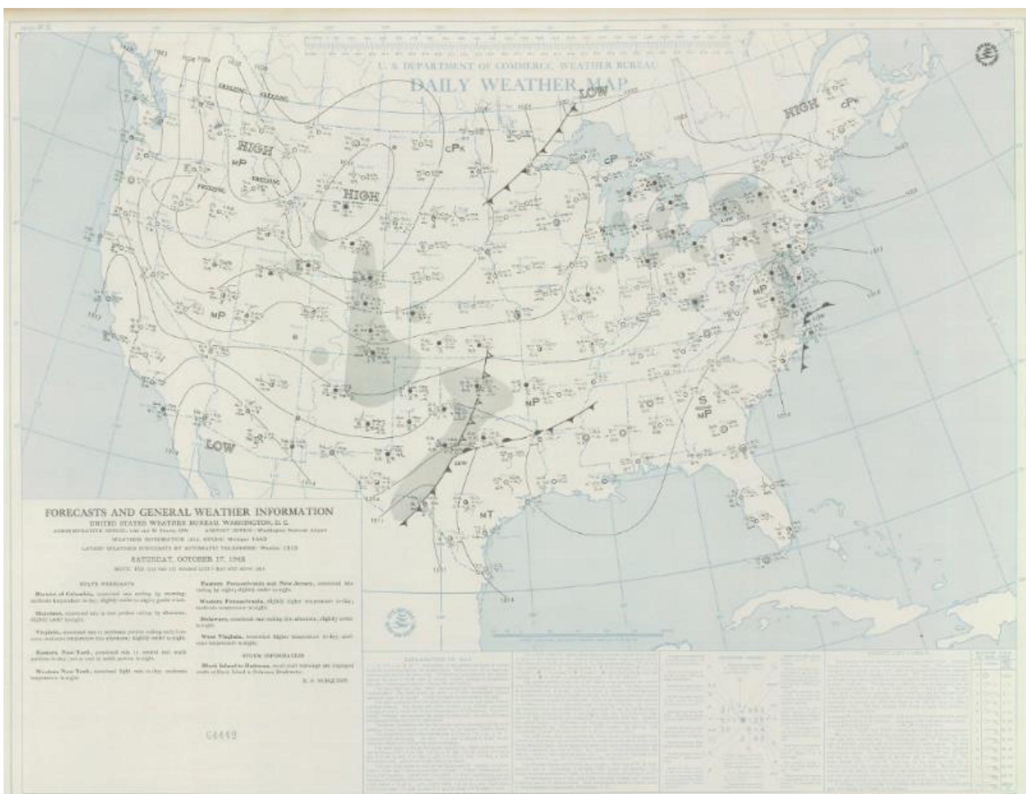

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
LOW
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

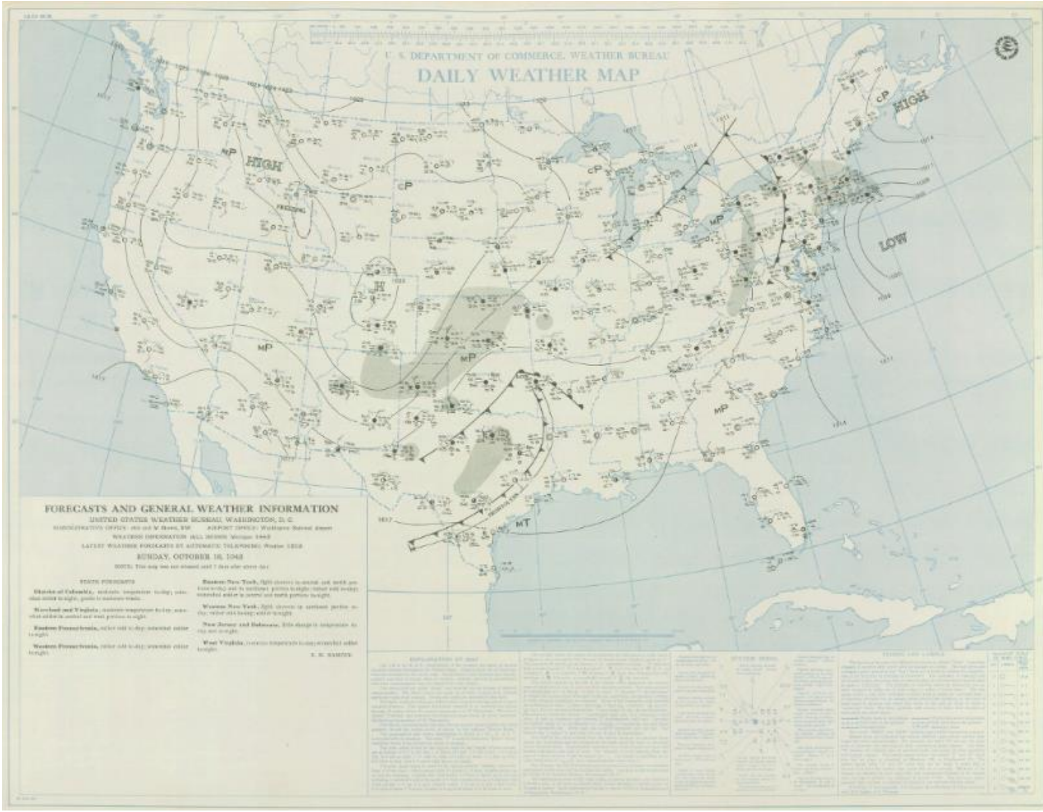

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION

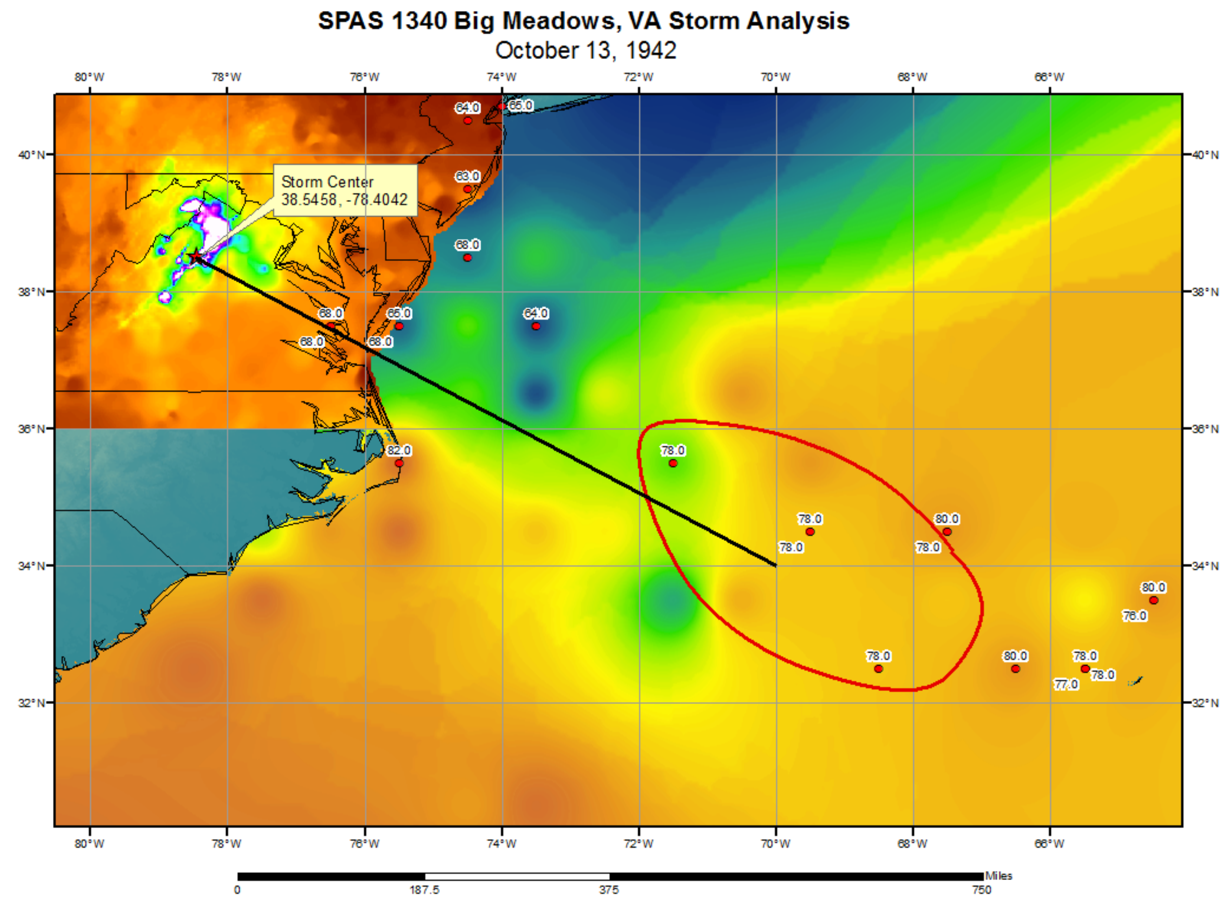

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
HIGH
HIGH
HIGH
LOW
LOW
LOW
FORECASTS AND GENERAL WEATHER INFORMATION


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
LOW
LOW
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
HIGH
LOW
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION


SPAS 1340 Big Meadows, VA Storm Analysis
October 13, 1942
Storm Center
38.5458, -78.4042
80°W
78°W
76°W
74°W
72°W
70°W
68°W
66°W
40°N
38°N
36°N
34°N
32°N
64.0
65.0
63.0
68.0
68.0
65.0
64.0
68.0
68.0
82.0
78.0
78.0
80.0
78.0
78.0
80.0
76.0
78.0
80.0
78.0
78.0
77.0
Miles
0
187.5
375
750

Storm Precipitation Analysis System (SPAS) For Storm #1376_1 SPAS Analysis

General Storm Location: Tennessee Valley (-88.6, 38.1, 34.0, -81.2)

Storm Dates: May 5 – May 8, 1984

Event: Mesoscale Event with Embedded Convection (MEC)

DAD Zone 1

Latitude: 37.2625

Longitude: -84.9708

Max. Grid/Radar Rainfall Amount: 9.62"

Max. Observed Rainfall Amount: 9.50"

Number of Stations: 428

SPAS Version: 9.5

Base Map Used: Mean annual maximum 48-hour precipitation associated with MEC's

Spatial resolution: 0.2678 sq.mi.

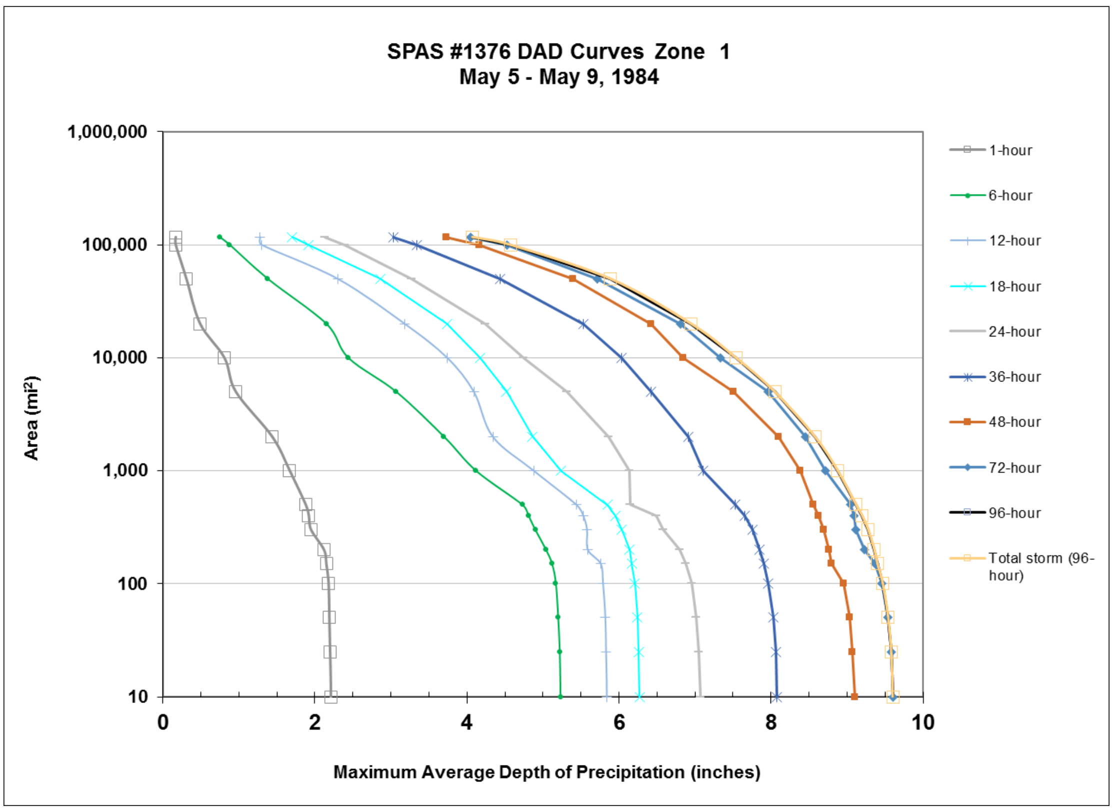
Radar Included: No

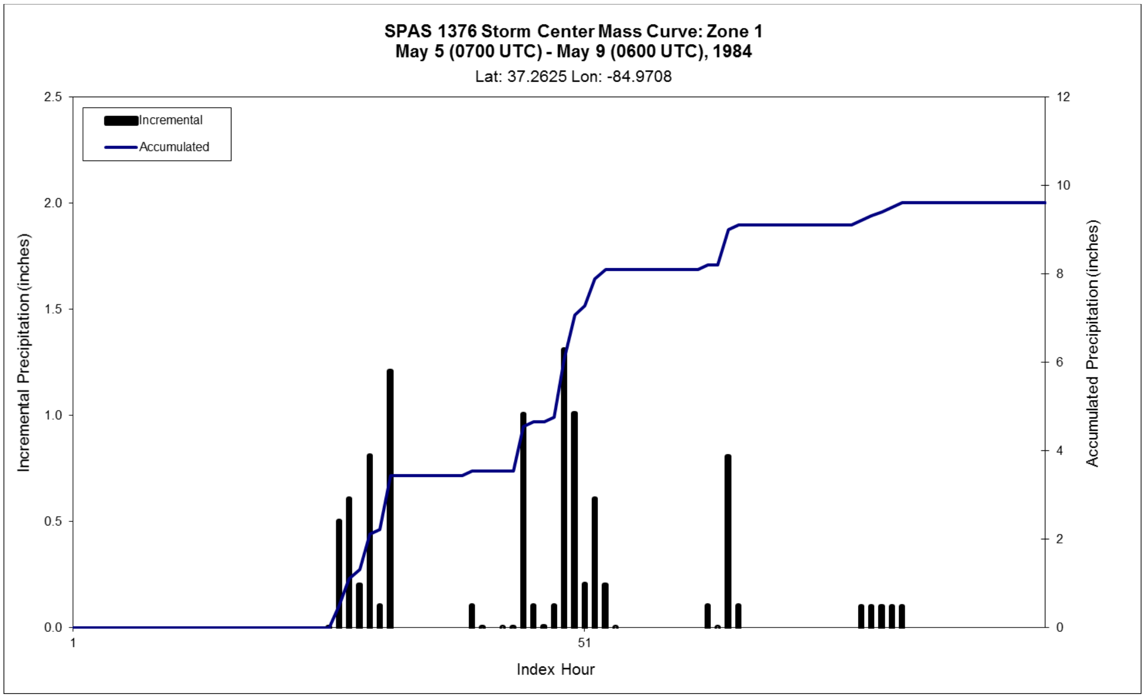
Depth-Area-Duration (DAD) analysis: Yes

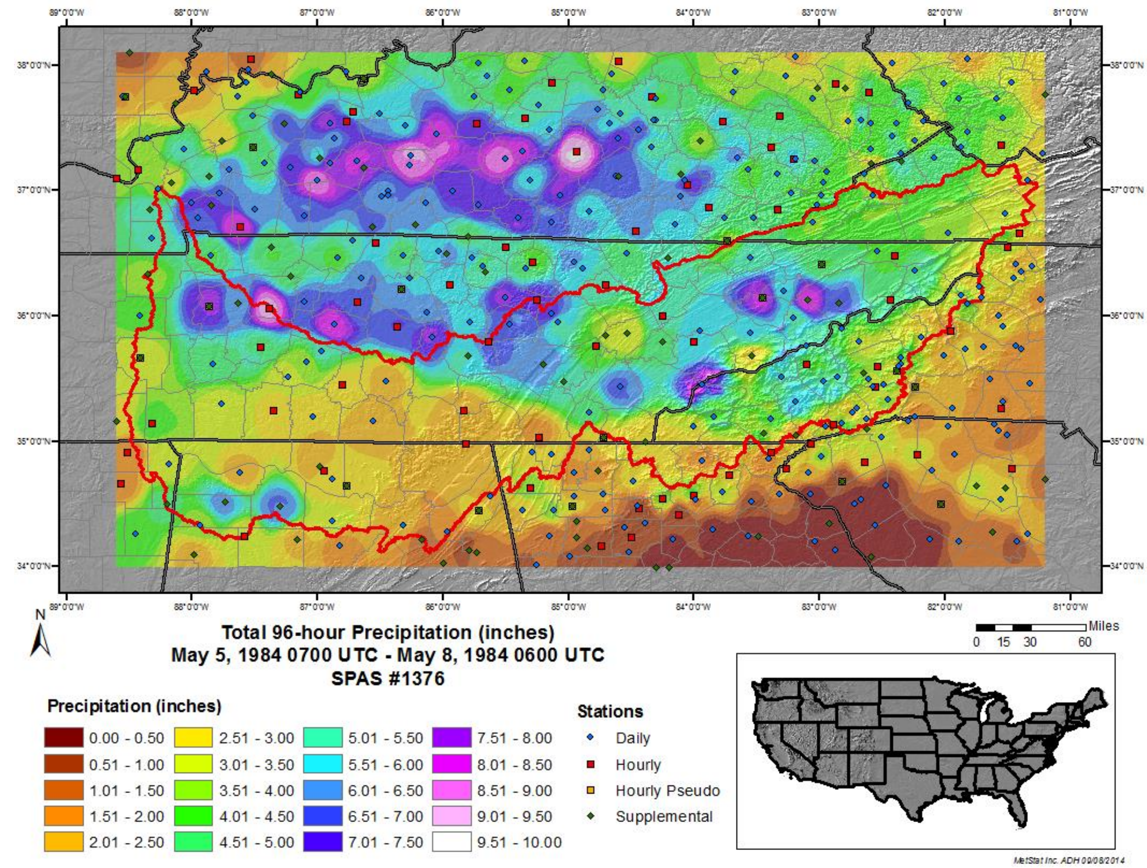
Reliability of Results: In addition to the NCDC stations, six supplemental stations were added to ensure data were consistent with what TVA and NOAA reported for this storm. A large number of the hourly stations used for this analysis had a lower precision than that of similar hourly or daily stations, and thus resulted in accumulations and slight timing problems when low values were reported. With the density of stations available for this storm, the resulting SPAS analysis is deemed quite reasonable.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1376_1_GEI	-84.9708	37.2625	804	800	20-May	72.50	2.54	0.19	67	2.350	75.94	76.0	2.99	0.21	74	2.780	1.183

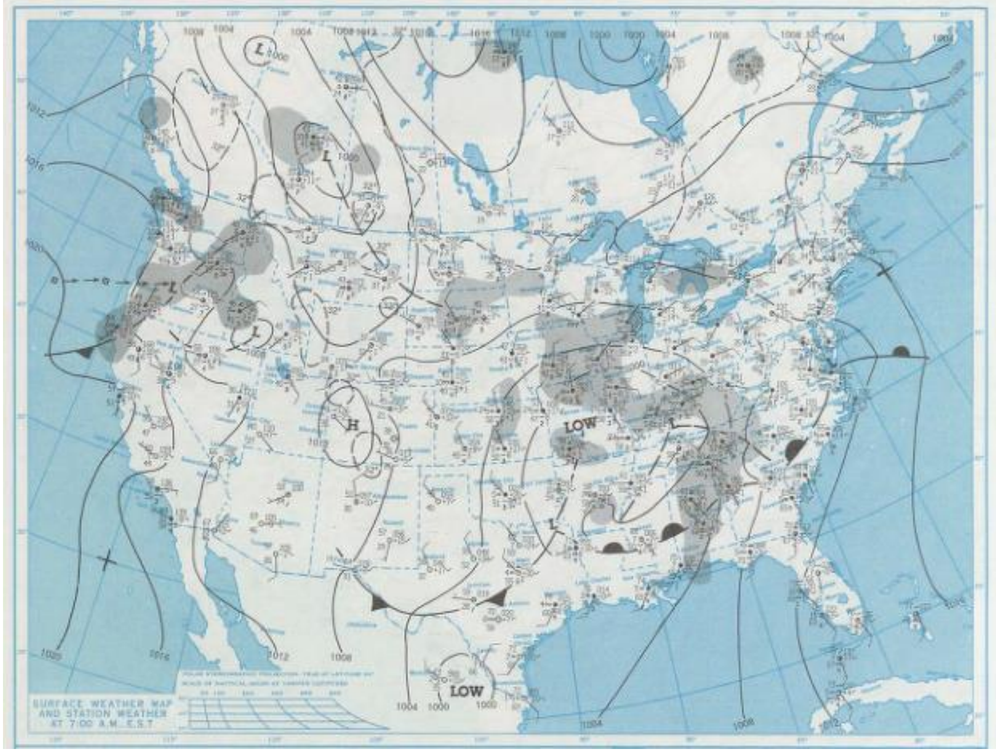
Storm 1376 - May 5 (0700 UTC) - May 9 (0600 UTC), 1984										
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
Area (mi^2)	Duration (hours)									
	1	6	12	18	24	36	48	72	96	Total
0.3	2.21	5.24	5.85	6.28	7.08	8.10	9.11	9.62	9.62	9.62
1	2.21	5.24	5.85	6.28	7.08	8.10	9.11	9.62	9.62	9.62
10	2.21	5.23	5.84	6.27	7.07	8.08	9.10	9.60	9.60	9.60
25	2.20	5.22	5.83	6.26	7.05	8.06	9.07	9.58	9.58	9.58
50	2.19	5.20	5.82	6.24	7.02	8.03	9.04	9.54	9.54	9.54
100	2.18	5.17	5.79	6.21	6.96	7.96	8.96	9.46	9.47	9.47
150	2.15	5.12	5.76	6.17	6.88	7.90	8.79	9.37	9.40	9.40
200	2.12	5.04	5.59	6.14	6.80	7.85	8.76	9.23	9.36	9.36
300	1.95	4.90	5.58	6.04	6.58	7.76	8.69	9.12	9.28	9.28
400	1.92	4.81	5.53	5.95	6.49	7.65	8.62	9.09	9.20	9.20
500	1.88	4.73	5.44	5.85	6.15	7.53	8.56	9.05	9.12	9.12
1,000	1.67	4.12	4.88	5.24	6.14	7.11	8.39	8.72	8.88	8.88
2,000	1.44	3.70	4.34	4.86	5.86	6.91	8.10	8.45	8.58	8.58
5,000	0.96	3.07	4.09	4.52	5.31	6.42	7.51	7.96	8.05	8.05
10,000	0.81	2.44	3.74	4.17	4.74	6.03	6.85	7.34	7.54	7.54
20,000	0.49	2.15	3.18	3.74	4.24	5.53	6.42	6.81	6.95	6.95
50,000	0.31	1.38	2.30	2.86	3.27	4.44	5.39	5.72	5.89	5.89
100,000	0.17	0.88	1.30	1.91	2.39	3.34	4.16	4.53	4.57	4.57
117,097	0.17	0.75	1.28	1.70	2.13	3.03	3.73	4.05	4.07	4.07



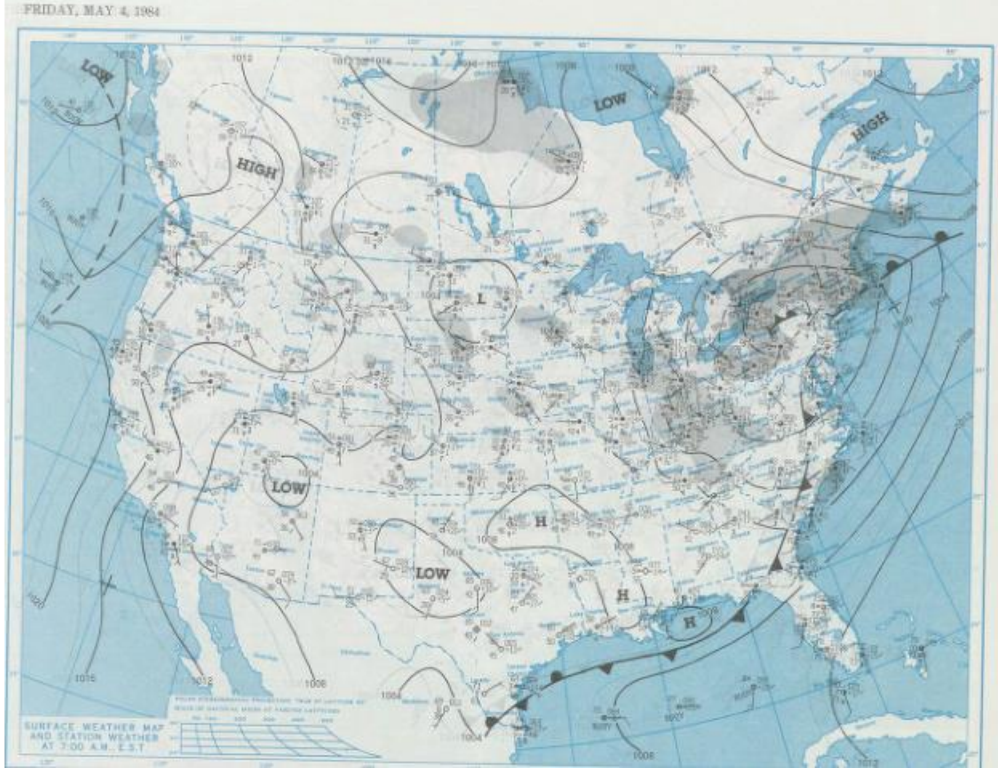

SPAS 1376 Storm Center Mass Curve: Zone 1
May 5 (0700 UTC) - May 9 (0600 UTC), 1984
Lat: 37.2625 Lon: -84.9708
Incremental
Accumulated
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
2.5
2.0
1.5
1.0
0.5
0.0
12
10
8
6
4
2
0
1
51


Total 96-hour Precipitation (inches)
May 5, 1984 0700 UTC - May 8, 1984 0600 UTC
SPAS #1376
N
Miles
0 15 30 60
Precipitation (inches)
0.00 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.00
Stations
Daily
Hourly
Hourly Pseudo
Supplemental
MetStat Inc. ADH 09/08/2014

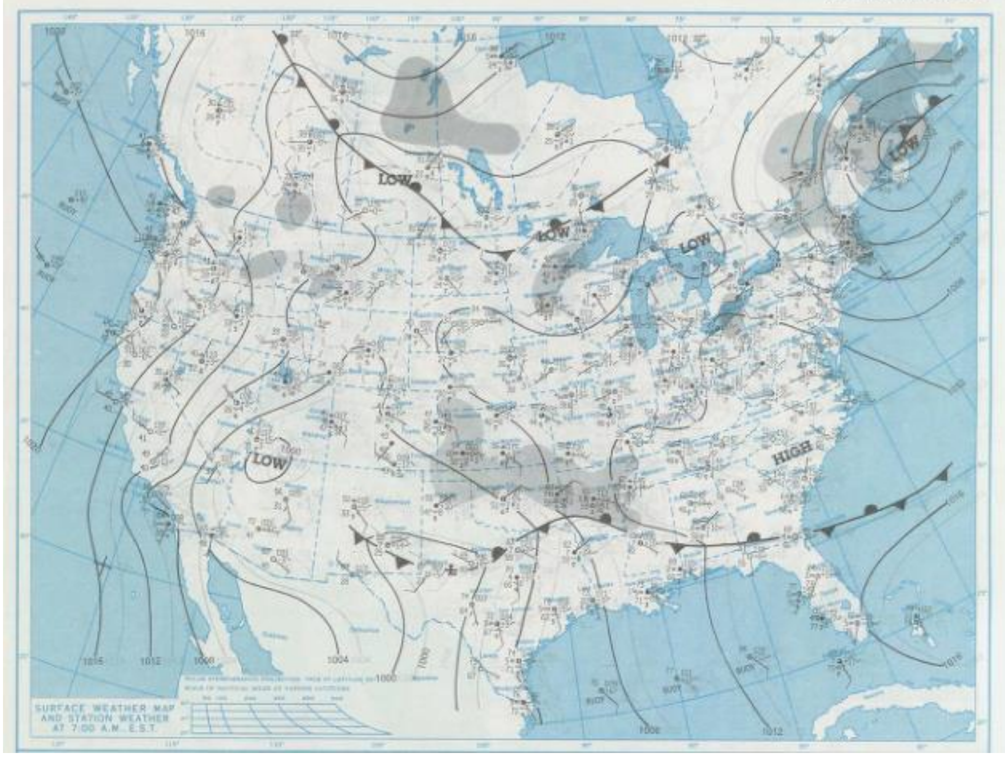
THURSDAY, MAY 3, 1984



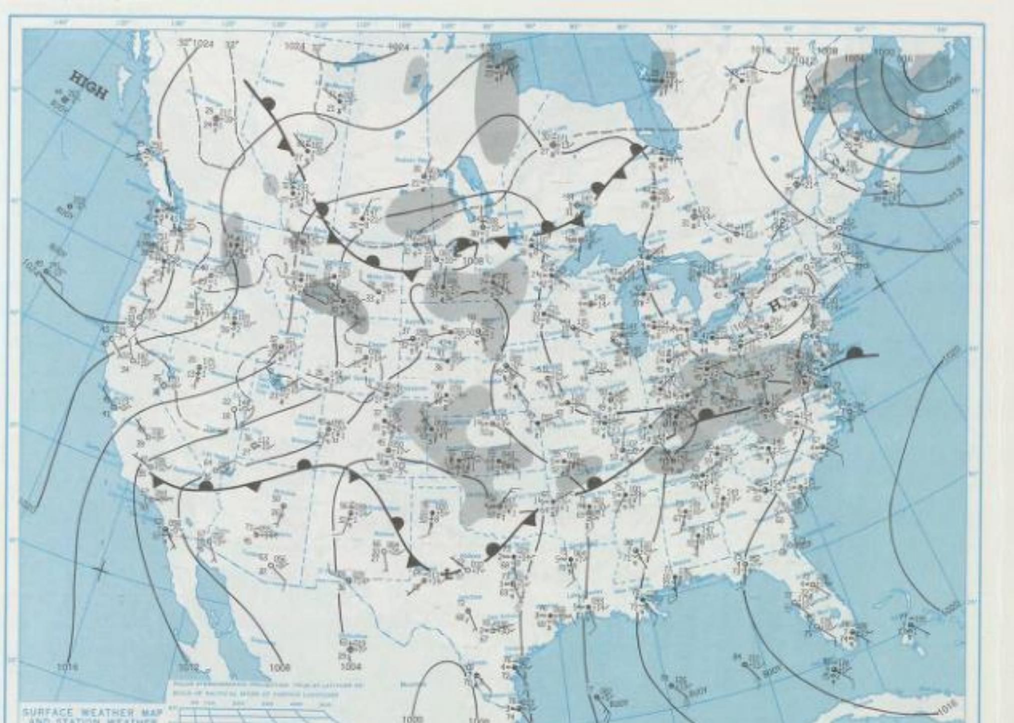
FRIDAY, MAY 4, 1984

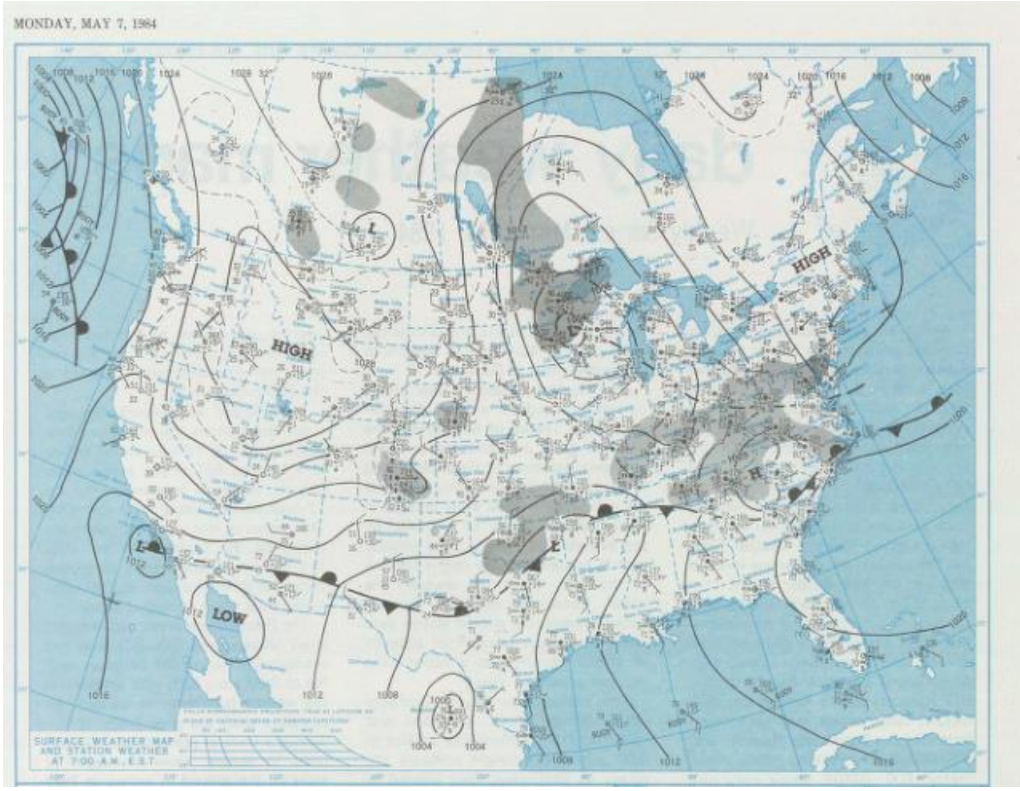


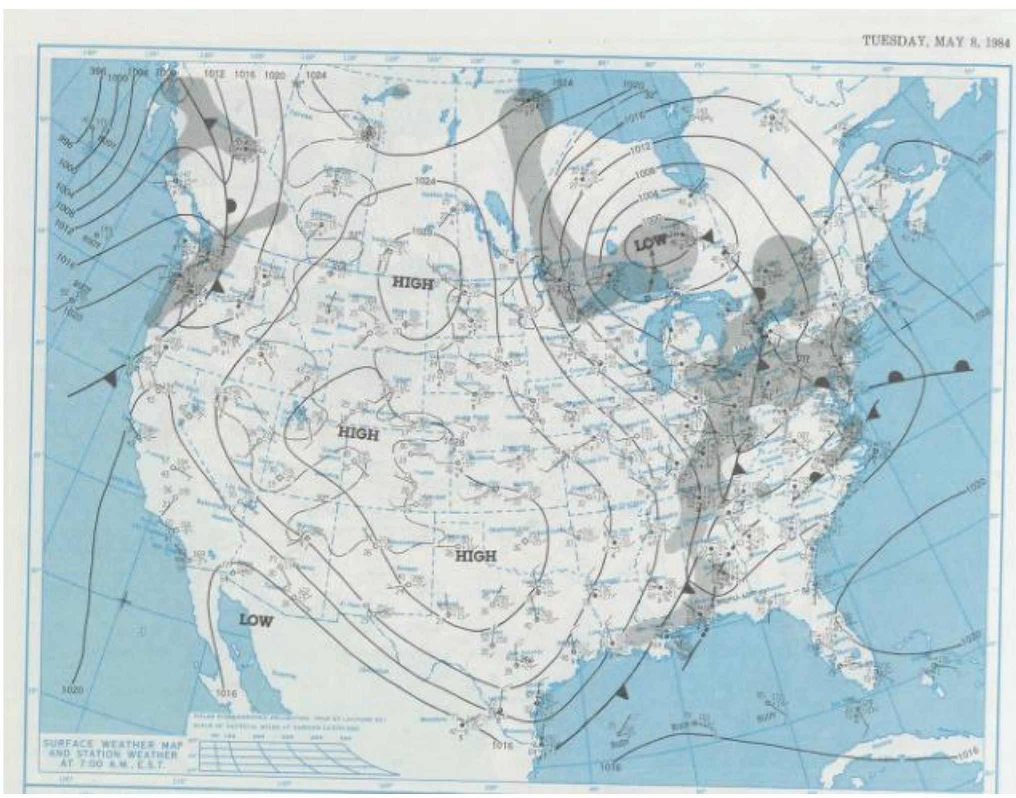
SATURDAY, MAY 5, 1984

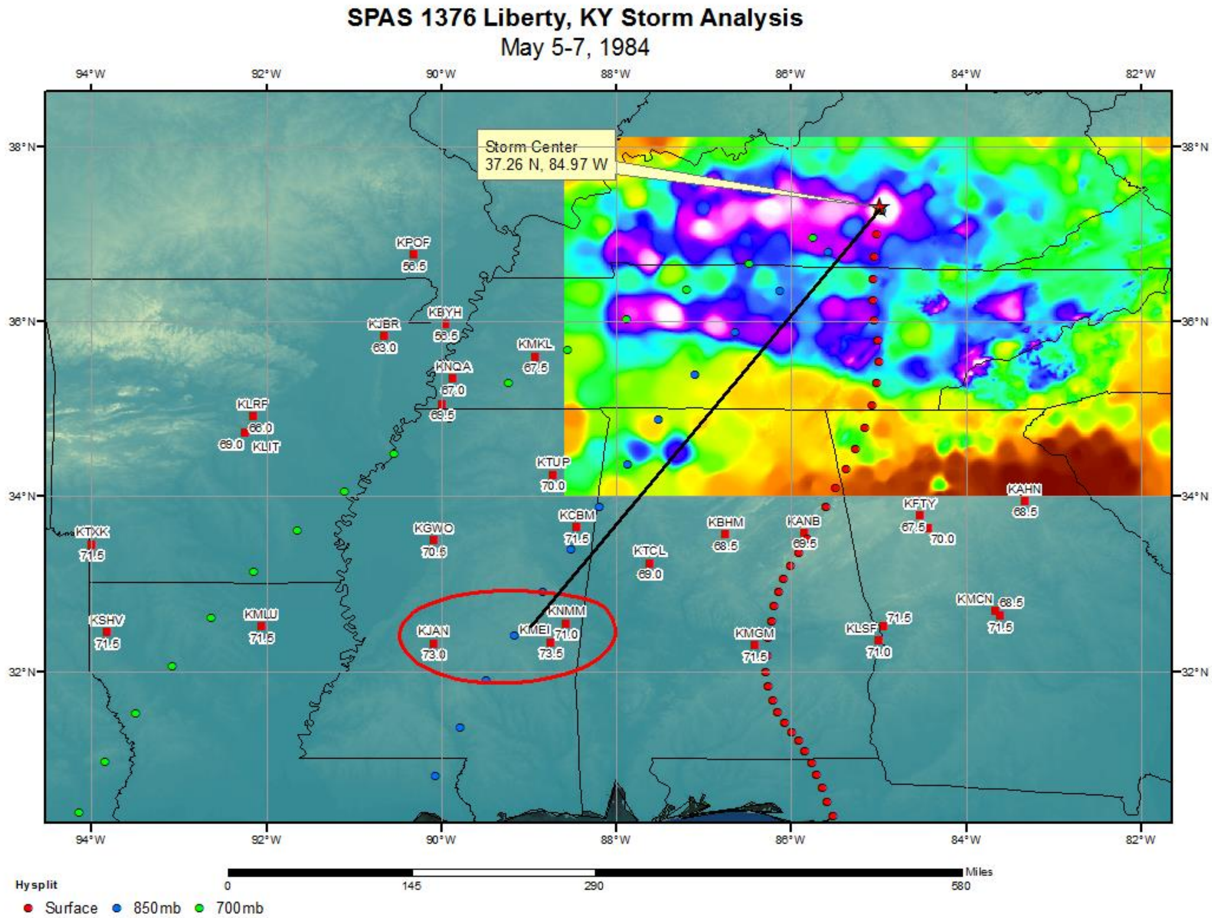


SUNDAY, MAY 6, 1984




MONDAY, MAY 7, 1984
HIGH
HIGH
LOW
SURFACE WEATHER MAP
AND STATION WEATHER
AT 7:00 A.M., E.S.T.


TUESDAY, MAY 8, 1984
LOW
HIGH
HIGH
HIGH
LOW
SURFACE WEATHER MAP
AND STATION WEATHER
AT 7:00 A.M., E.S.T.


SPAS 1376 Liberty, KY Storm Analysis
May 5-7, 1984
Storm Center
37.26 N, 84.97 W
KPOF
66.5
KJBR
63.0
KBYH
66.5
KMKL
67.5
KNQA
67.0
68.5
KLRF
66.0
69.0
KLIT
KTUP
70.0
KTXK
71.5
KGWO
70.5
KCBM
71.5
KTCL
69.0
KBHM
68.5
KANB
69.5
KFTY
67.5
70.0
KAHN
68.5
KSHV
71.5
KMLU
71.5
KJAN
73.0
KMEI
73.5
KNMM
71.0
KMGM
71.5
KLSF
71.5
71.0
KMCN
68.5
71.5
Hysplit
Surface
850mb
700mb
0
145
290
580
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1275_2 SPAS-NEXRAD Analysis

General Storm Location: Montgomery Dam, PA, Pennsylvania, West Virginia, Virginia, Ohio, New York, Kentucky

Storm Dates: September 17-19, 2004

Event: Hurricane Ivan Extratropical Transition Interacting with a Front

DAD Zone 2

Latitude: 40.605

Longitude: -76.465

Max. Grid Rainfall Amount: 8.80"

Max. Observed Rainfall Amount: 8.80"

Number of Stations: 955 (550 Daily, 183 Hourly, 62 Hourly Pseudo, and 160 Supplemental)

SPAS Version: 9.5

Basemap: PRISM 30-yr Mean (1981-2010) September Precipitation

Spatial resolution: 0.01 (~ 0.40 mi^2)

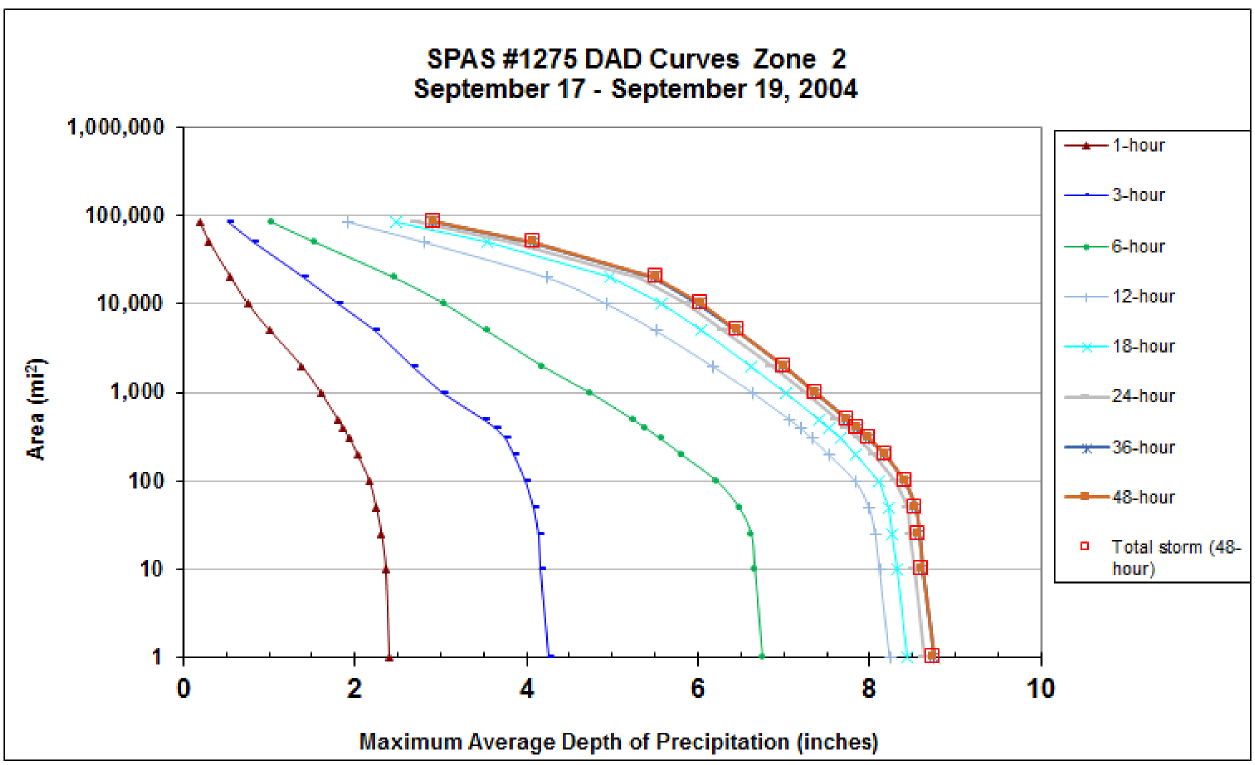
Radar Included: Yes

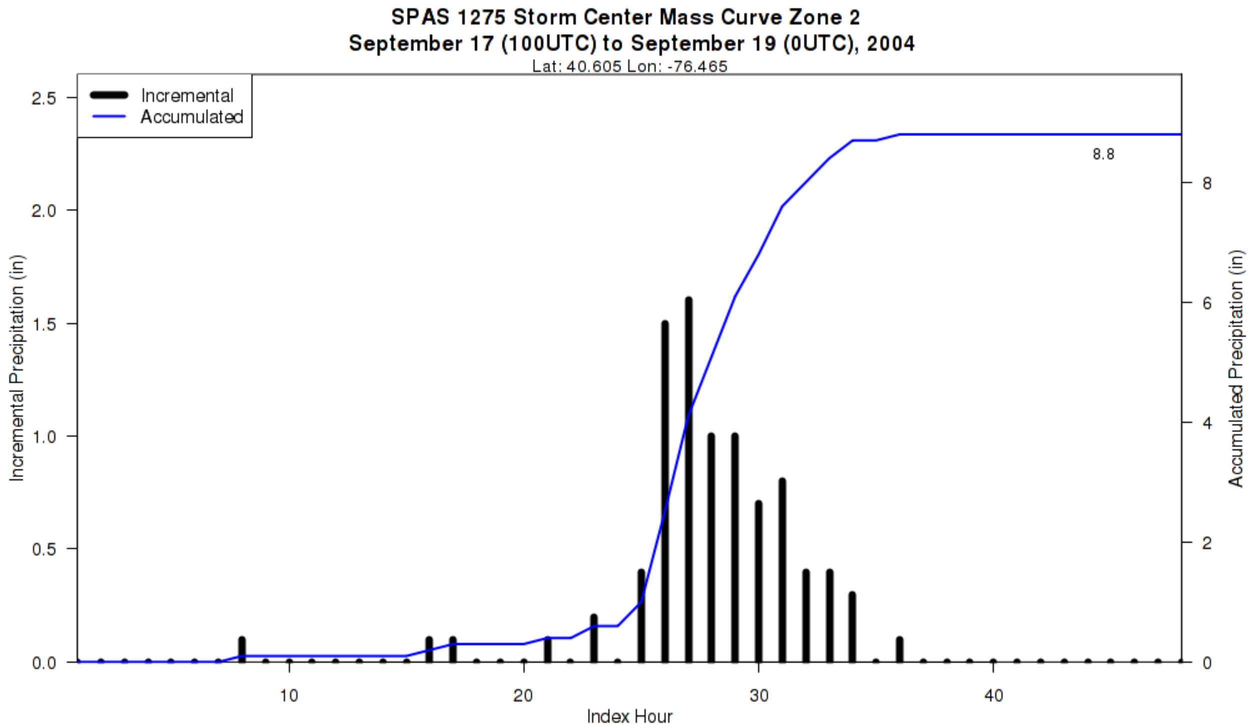
Depth-Area-Duration (DAD) analysis: Yes

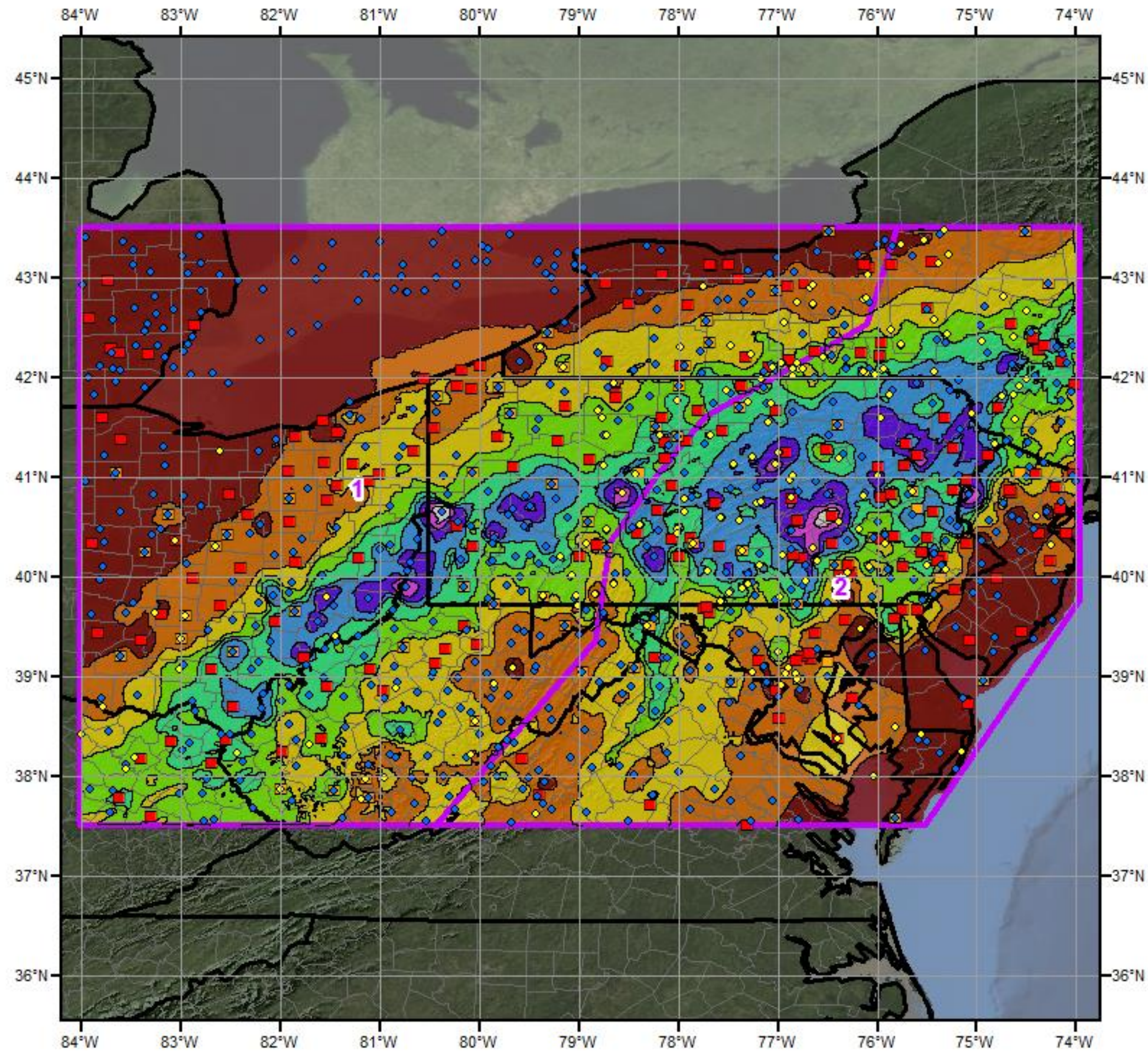
Reliability of results: This analysis was based on hourly data, daily data, supplemental station data and NEXRAD Radar. We have a high degree of confidence in the radar/station based storm total results, the spatial pattern is dependent on the radar data and basemap, and the timing is based on hourly and hourly pseudo stations.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1275_2	-76.4650	40.6050	1,602	1-Sep	72.00	2.47	0.36	66	2.110	77.29	3.22	0.43	77	2.790	1.322

Storm 1275 - September 17 (0100 UTC) - September 19 (0000 UTC), 2004									
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)									
Area (mi^2)	Duration (hours)								
	1	3	6	12	18	24	36	48	Total
0.4	2.42	4.26	6.79	8.29	8.49	8.69	8.79	8.79	8.79
1	2.40	4.25	6.75	8.24	8.44	8.64	8.75	8.75	8.75
10	2.36	4.17	6.66	8.12	8.32	8.52	8.62	8.62	8.62
25	2.31	4.14	6.62	8.07	8.27	8.47	8.58	8.58	8.58
50	2.25	4.08	6.48	8.00	8.23	8.44	8.54	8.54	8.54
100	2.17	3.99	6.22	7.84	8.10	8.30	8.41	8.41	8.41
200	2.03	3.86	5.81	7.53	7.83	8.05	8.17	8.18	8.18
300	1.94	3.76	5.57	7.34	7.66	7.87	7.99	8.00	8.00
400	1.86	3.65	5.39	7.20	7.52	7.73	7.85	7.86	7.86
500	1.80	3.51	5.24	7.07	7.41	7.61	7.74	7.74	7.74
1,000	1.60	3.03	4.74	6.64	7.02	7.25	7.37	7.37	7.37
2,000	1.38	2.68	4.19	6.17	6.62	6.86	6.99	7.00	7.00
5,000	1.01	2.22	3.54	5.51	6.03	6.30	6.46	6.46	6.46
10,000	0.75	1.80	3.05	4.94	5.57	5.88	6.02	6.04	6.04
20,000	0.55	1.39	2.46	4.24	4.98	5.32	5.49	5.51	5.51
50,000	0.30	0.81	1.54	2.81	3.55	3.85	4.08	4.09	4.09
84,744	0.19	0.53	1.03	1.92	2.48	2.71	2.90	2.92	2.92




SPAS 1275 Storm Center Mass Curve Zone 2
September 17 (100UTC) to September 19 (0UTC), 2004
Lat: 40.605 Lon: -76.465
Incremental
Accumulated
8.8
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
20
30
40

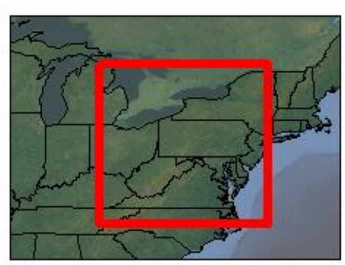


Total Storm (48-hr) Precipitation (inches)
September 17 (0100 UTC) - 19 (0000 UTC), 2004
SPAS-NEXRAD 1275

Gauges

- Daily
- Hourly
- Hourly Pseudo
- Supplemental

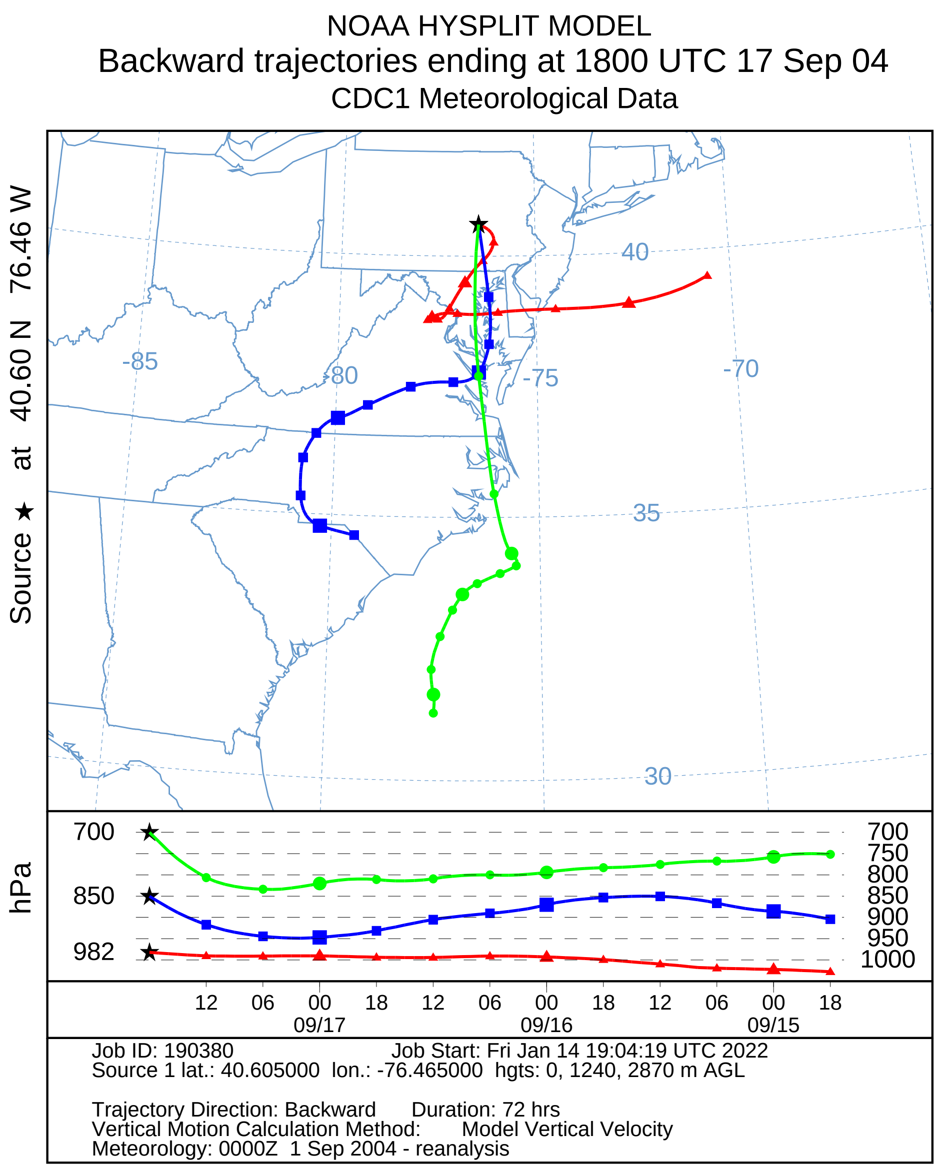
Miles: 0, 60, 120, 240
Kilometers: 0, 115, 230, 460



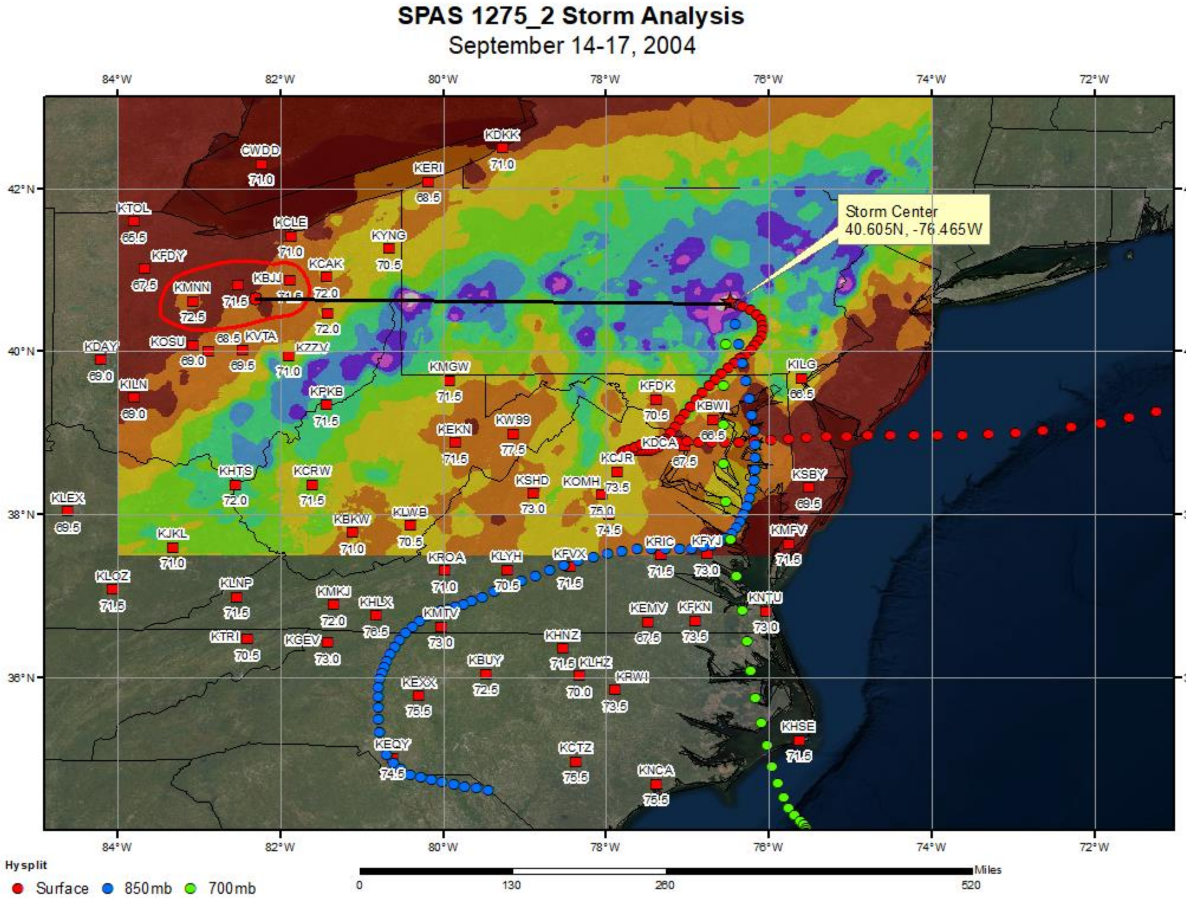
Precipitation (inches)

0.00 - 1.00 | 1.01 - 2.00 | 2.01 - 3.00 | 3.01 - 4.00 | 4.01 - 5.00 | 5.01 - 6.00 | 6.01 - 7.00 | 7.01 - 8.00 | 8.01 - 9.00

5/14/2013



NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 17 Sep 04
CDC1 Meteorological Data
Source ★ at 40.60 N 76.46 W
-85
-80
-75
-70
40
35
30
hPa
700
850
982
700
750
800
850
900
950
1000
12 06 00 18 12 06 00 18 12 06 00 18
09/17
09/16
09/15
Job ID: 190380 Job Start: Fri Jan 14 19:04:19 UTC 2022
Source 1 lat.: 40.605000 lon.: -76.465000 hgts: 0, 1240, 2870 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2004 - reanalysis


SPAS 1275_2 Storm Analysis
September 14-17, 2004
Storm Center
40.605N, -76.465W
Hysplit
Surface
850mb
700mb
Miles
0
130
260
520

Local Storms

Storm Precipitation Analysis System (SPAS) For Storm #1944_1 SPAS Analysis

General Storm Location: Limestone Hill, WV

Storm Dates: July 18 – July 19, 1889

Event: General

DAD Zone 1

Latitude: 39.0625

Longitude: -81.5375

Max. Grid Rainfall Amount: 21.74"

Max. Observed Rainfall Amount: 19.10"

Number of Stations: 9

SPAS Version: 10.0

Base Map Used: 00_bm_final_EDADS_30sec_interp_sm9 (Smoothing factor of 9 applied)

Spatial resolution: 30 seconds

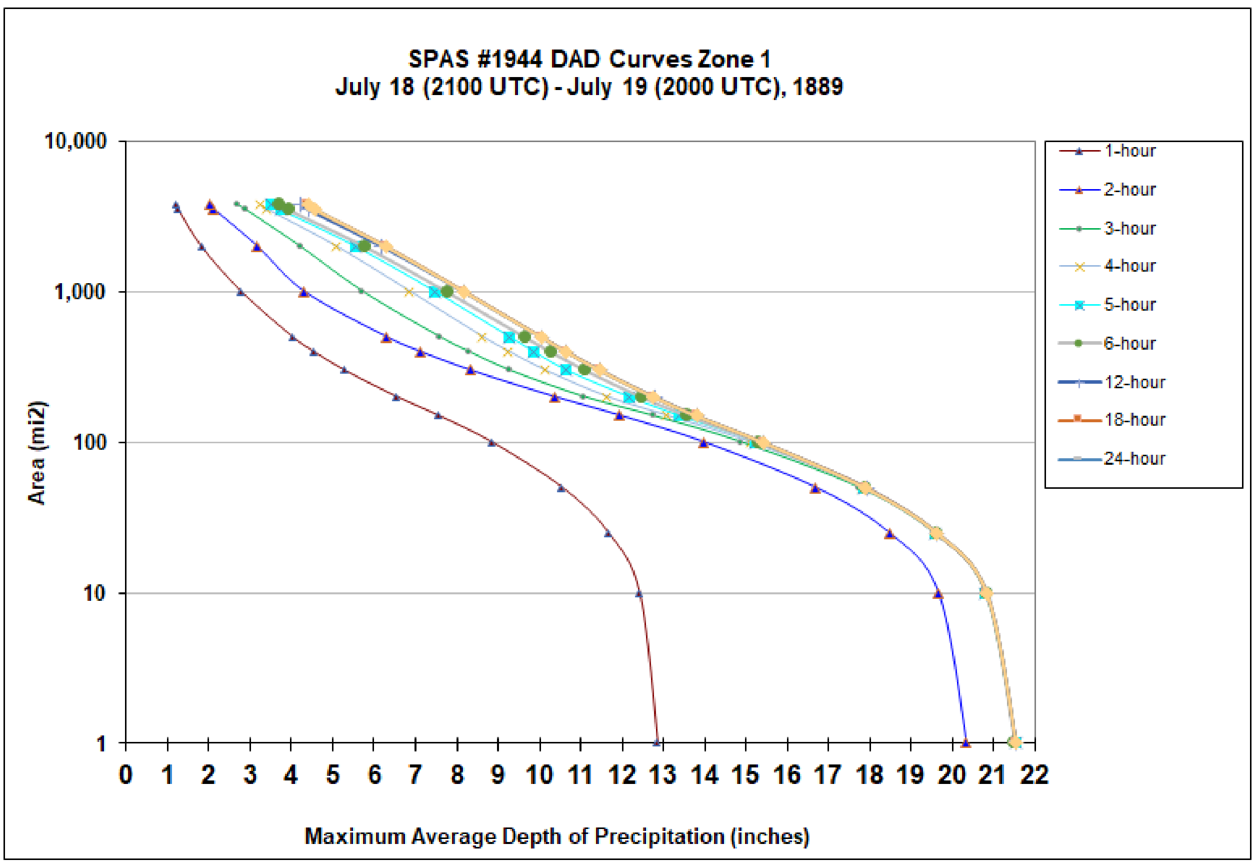
Radar Included: No

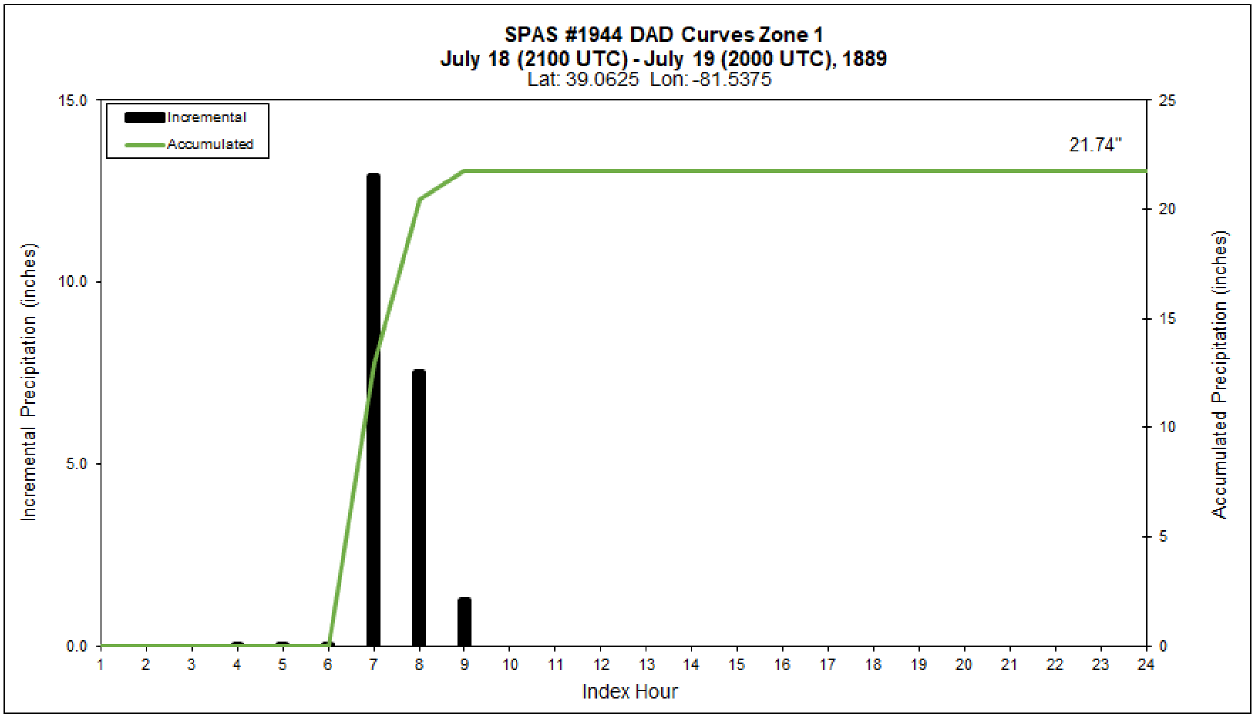
Depth-Area-Duration (DAD) analysis: Yes

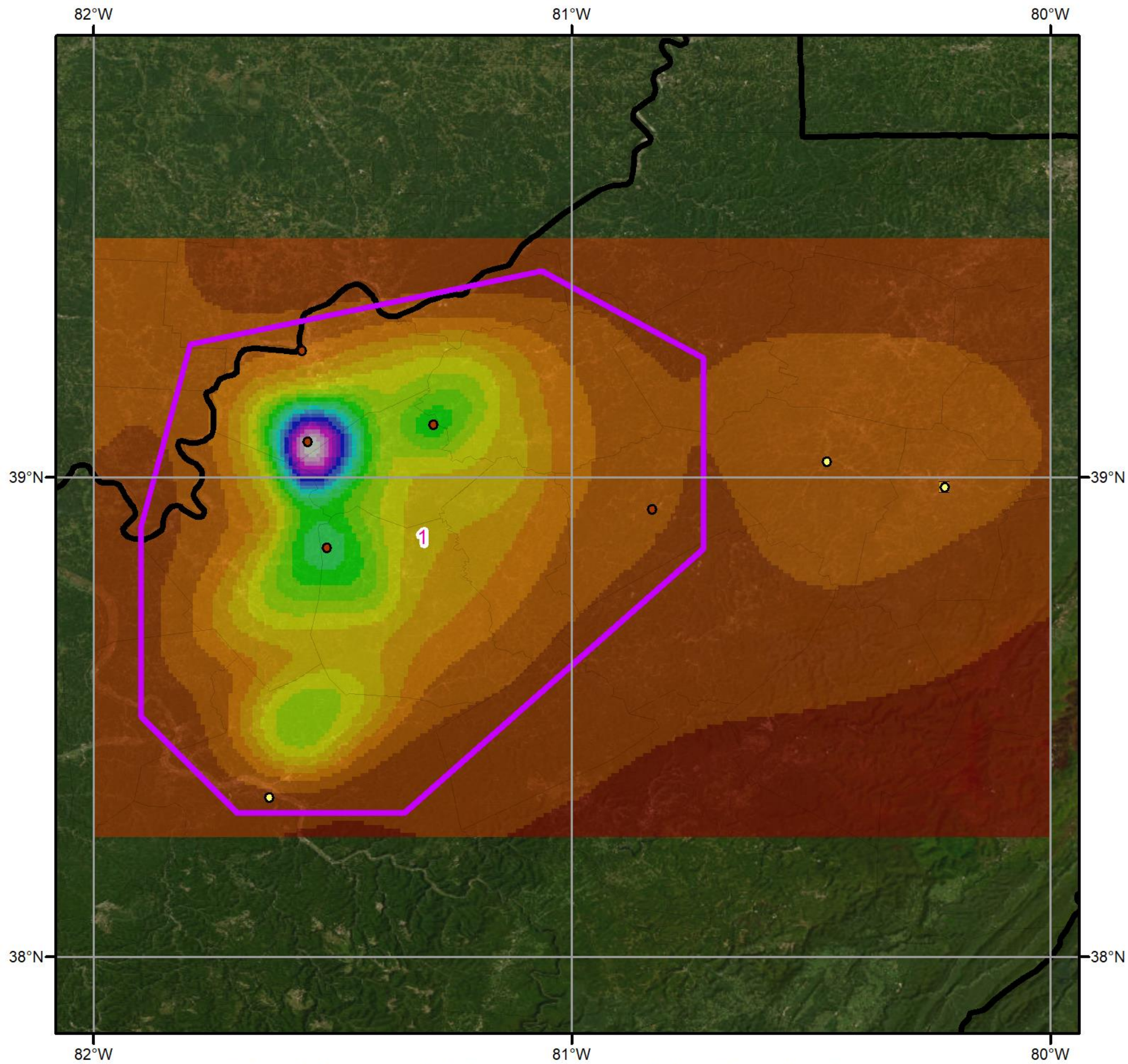
Reliability of Results: The final analysis included data from 5 hourly estimated stations, 1 hourly pseudo station, and 1 supplemental station. The spatial pattern is dependent on the surface observations and base map. Timing is based on hourly stations. All of the hourly estimated/pseudo observations were derived from information contained in the precipitation temporal distributions from the NOAA Atlas 14 Volume 2 PMP document, and the publication titled "The Disastrous Flood of Wood, Wirt, and Jackson Counties" by Lenora Low published April, 1989. There were arguably four observations that were "official", and these even had questionable aspects. Although many educated estimates and assumptions were necessary to generate this analysis, the evaluation of local and regional synoptic patterns responsible for documented extreme precipitation events, available observations and accounts of the event, and anecdotal evidence have left us confident that the magnitude and spatial pattern of total precipitation generated by this SPAS analysis represents an event that could have occurred.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1944_1	-81.5375	39.0625	926	900	15-Jul	79.50	3.52	0.27	81	3.255	81.40	81.5	3.86	0.27	85	3.590	1.103

Storm 1944 - July 18 (2100 UTC) - July 19 (2000 UTC), 1889										
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
Area (mi^2)	Duration (hours)									
	1	2	3	4	5	6	12	18	24	Total
0.4	12.94	20.47	21.66	21.67	21.67	21.67	21.67	21.67	21.67	21.67
1	12.85	20.33	21.52	21.52	21.52	21.51	21.53	21.53	21.53	21.53
10	12.41	19.65	20.79	20.80	20.80	20.81	20.82	20.82	20.82	20.82
25	11.66	18.46	19.55	19.58	19.59	19.60	19.62	19.62	19.62	19.62
50	10.54	16.68	17.74	17.81	17.85	17.88	17.91	17.90	17.88	17.88
100	8.84	13.98	14.89	15.09	15.24	15.32	15.41	15.41	15.41	15.41
150	7.55	11.95	12.75	13.08	13.37	13.59	13.81	13.80	13.80	13.80
200	6.54	10.36	11.08	11.63	12.16	12.48	12.78	12.77	12.77	12.77
300	5.28	8.33	9.29	10.13	10.66	11.13	11.48	11.48	11.48	11.48
400	4.53	7.11	8.29	9.25	9.86	10.28	10.65	10.65	10.65	10.65
500	4.02	6.29	7.59	8.62	9.28	9.66	10.04	10.05	10.05	10.05
1,000	2.78	4.30	5.72	6.86	7.48	7.77	8.17	8.19	8.19	8.19
2,000	1.81	3.16	4.20	5.07	5.55	5.78	6.19	6.29	6.29	6.29
3,500	1.26	2.12	2.88	3.41	3.74	3.94	4.42	4.57	4.59	4.59
3,773	1.20	2.01	2.68	3.22	3.53	3.70	4.22	4.38	4.40	4.40




SPAS #1944 DAD Curves Zone 1
July 18 (2100 UTC) - July 19 (2000 UTC), 1889
Lat: 39.0625 Lon: -81.5375
Incremental
Accumulated
21.74"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
15.0
10.0
5.0
0.0
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24



Total Storm (24-hours) Precipitation (inches)
Jul 18 (2000 UTC) - July 19 (1900 UTC), 1889
SPAS 1944

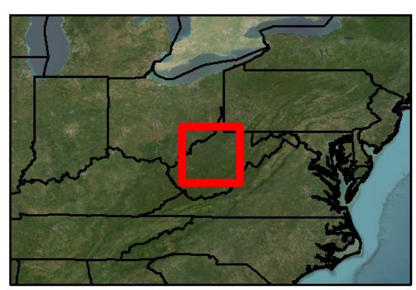
Gauges

- <all other values>
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Kilometers: 0, 15, 30, 60
Miles: 0, 5, 10, 20

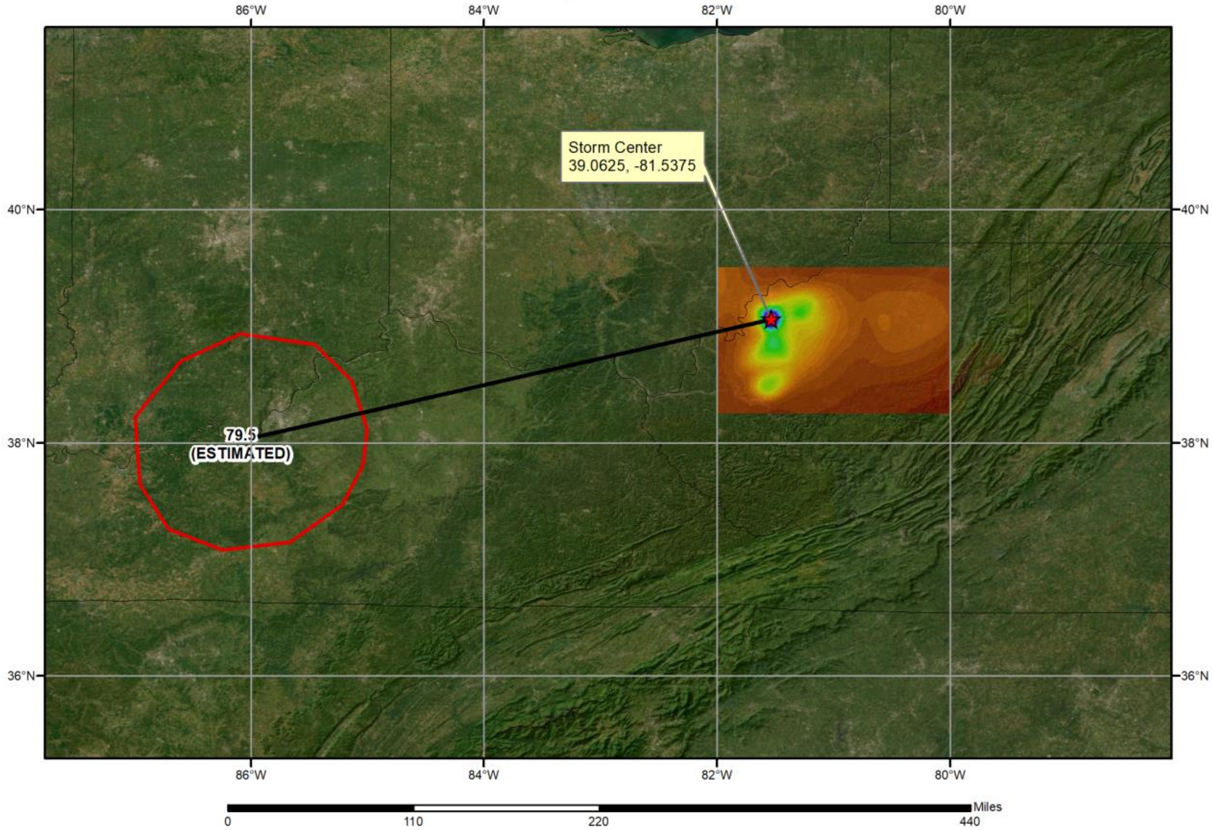
Precipitation (inches)

0.22 - 1.00	5.01 - 6.00	10.01 - 11.00	15.01 - 16.00	20.01 - 21.00
1.01 - 2.00	6.01 - 7.00	11.01 - 12.00	16.01 - 17.00	21.01 - 22.00
2.01 - 3.00	7.01 - 8.00	12.01 - 13.00	17.01 - 18.00	
3.01 - 4.00	8.01 - 9.00	13.01 - 14.00	18.01 - 19.00	
4.01 - 5.00	9.01 - 10.00	14.01 - 15.00	19.01 - 20.00	



12/6/2023

SPAS 1944 Rockport, WV - Storm Analysis, Estimated Adjusted Surface Dew Point Temperatures (F)
July 18, 1889



Storm Precipitation Analysis System (SPAS) For Storm #1489_1 SPAS Analysis

General Storm Location: Jewell, MD

Storm Dates: July 25-30, 1897

Event: Local Convective

DAD Zone 1

> **Latitude**: 38.729
>
> **Longitude**: -76.571
>
> **Max. Grid Rainfall Amount**: 15.88"
>
> **Max. Observed Rainfall Amount**: 14.70"

Number of Stations: 312

SPAS Version: 10.0

Base Map Used: Conus_prism_ppt_in_1981_2010_07

Spatial resolution: 30 seconds

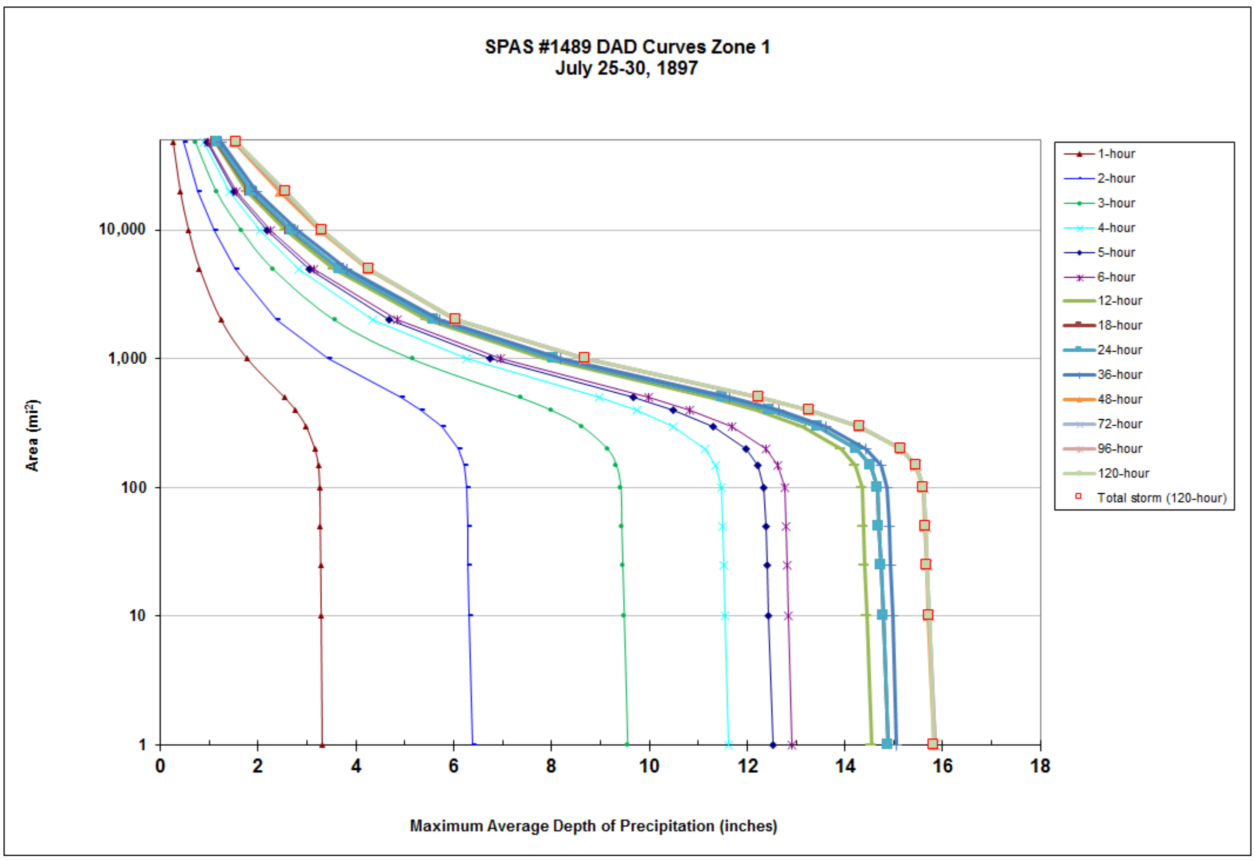
Radar Included: No

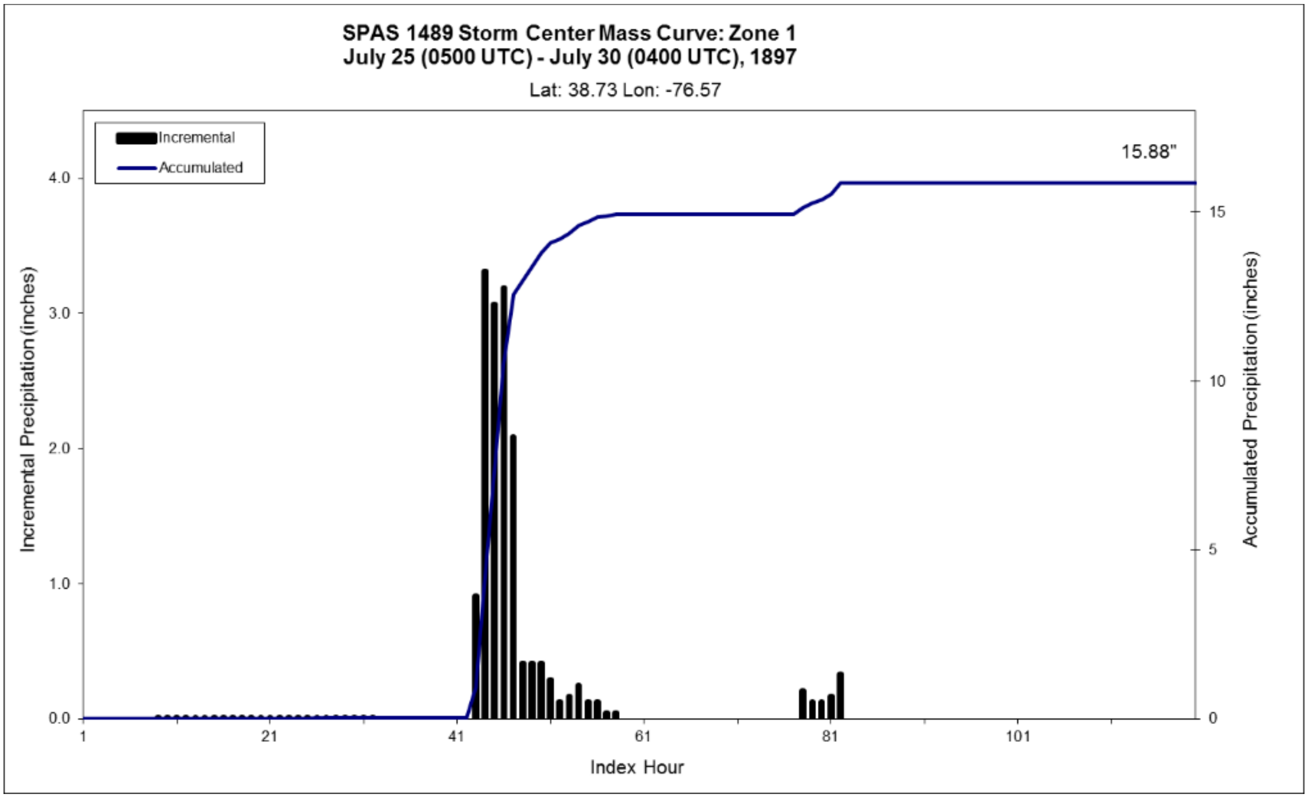
Depth-Area-Duration (DAD) analysis: Yes

Reliability of Results: This storm is originally USACE NA 1-7a and 1-7b. This analysis was based on hourly pseudo data, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the basemap and we have a high degree of confidence with the timing based on the location of the four hourly pseudo stations (see below). One hourly USACE mass curve captured the largest storm center at Jewell, MD allowing high confidence in the spatiotemporal isohyetal pattern of this critical location. Many daily stations lacked timing, so they had to be converted into supplemental stations. Due to the four hourly pseudo stations being consistent in timing, there isn't much issue with having to turn so many daily stations into supplemental stations.

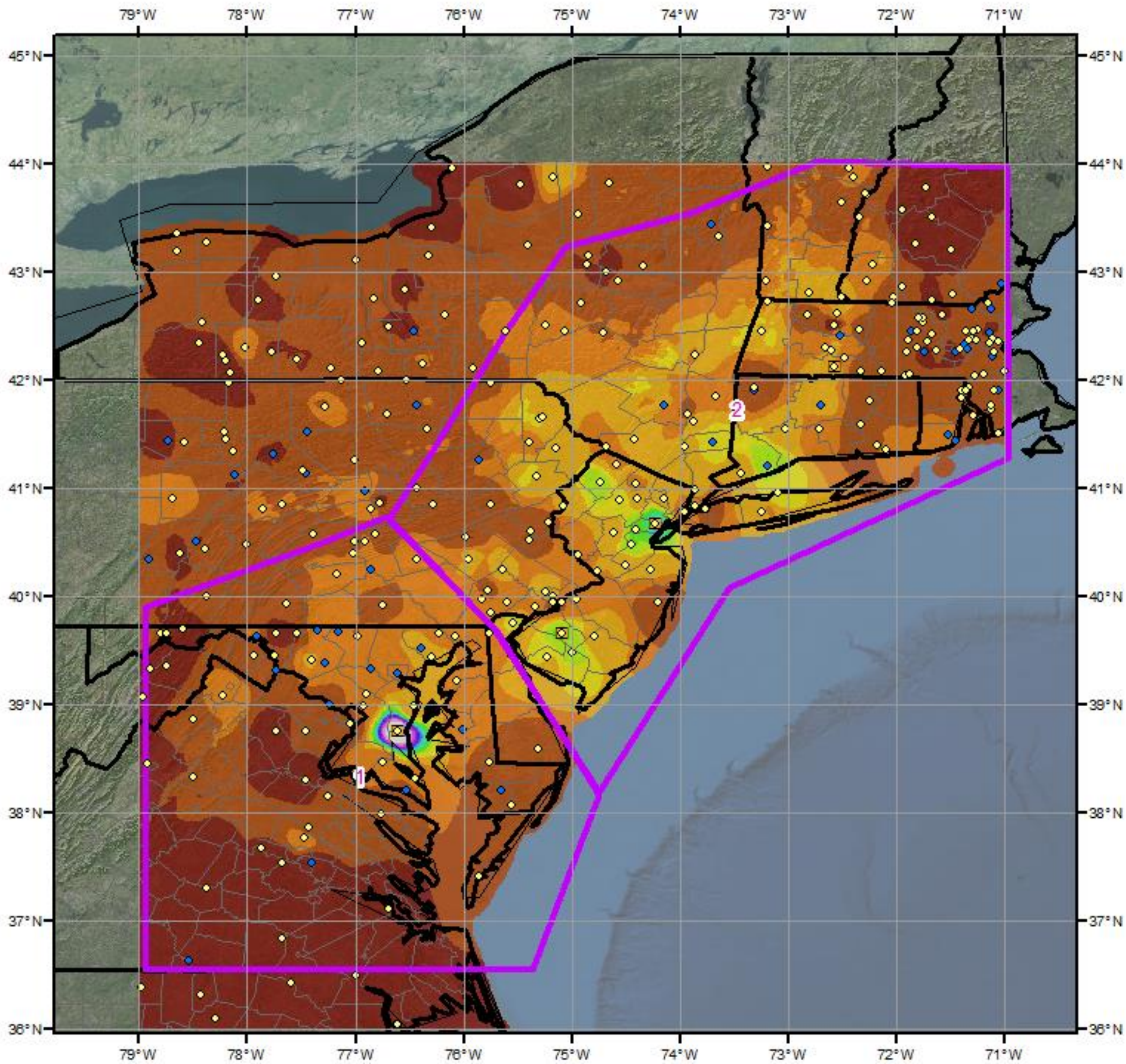
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1489_1	-76.5710	38.7290	163	10-Aug	71.50	2.42	0.05	65	2.365	80.31	3.68	0.06	83	3.620	1.500

Storm 1489 Zone 1 - Jul. 25 (0500 UTC) - Jul. 30 (0400 UTC), 1897															
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)															
	Duration (hours)														
areasqmi	1	2	3	4	5	6	12	18	24	36	48	72	96	120	Total
0.4	3.31	6.38	9.57	11.66	12.56	12.95	14.59	14.92	14.92	15.10	15.85	15.87	15.87	15.86	15.86
1	3.31	6.38	9.55	11.63	12.53	12.92	14.56	14.89	14.89	15.06	15.82	15.84	15.84	15.82	15.82
10	3.29	6.32	9.48	11.55	12.44	12.84	14.45	14.78	14.78	14.97	15.71	15.73	15.73	15.72	15.72
25	3.28	6.30	9.45	11.52	12.41	12.81	14.41	14.73	14.73	14.93	15.67	15.68	15.68	15.68	15.68
50	3.27	6.28	9.43	11.49	12.38	12.79	14.38	14.70	14.70	14.90	15.64	15.65	15.65	15.65	15.65
100	3.26	6.27	9.41	11.47	12.35	12.76	14.35	14.67	14.67	14.87	15.60	15.61	15.61	15.61	15.61
150	3.23	6.22	9.32	11.35	12.23	12.63	14.21	14.53	14.53	14.73	15.44	15.46	15.46	15.46	15.46
200	3.16	6.09	9.14	11.13	11.99	12.38	13.93	14.24	14.24	14.44	15.14	15.16	15.16	15.16	15.16
300	2.98	5.75	8.62	10.50	11.31	11.68	13.14	13.44	13.44	13.62	14.29	14.30	14.31	14.31	14.31
400	2.77	5.33	8.00	9.74	10.49	10.83	12.19	12.46	12.47	12.64	13.26	13.27	13.28	13.28	13.28
500	2.55	4.91	7.37	8.97	9.67	9.98	11.24	11.49	11.49	11.65	12.23	12.24	12.25	12.25	12.25
1,000	1.78	3.43	5.15	6.27	6.75	6.97	7.85	8.04	8.05	8.18	8.67	8.69	8.70	8.70	8.70
2,000	1.24	2.37	3.57	4.35	4.69	4.85	5.45	5.59	5.60	5.71	6.02	6.04	6.05	6.05	6.05
5,000	0.80	1.53	2.31	2.83	3.04	3.14	3.56	3.67	3.68	3.81	4.24	4.27	4.28	4.28	4.28
10,000	0.57	1.10	1.66	2.03	2.18	2.25	2.57	2.66	2.68	2.80	3.27	3.30	3.32	3.32	3.32
20,000	0.40	0.76	1.15	1.41	1.51	1.56	1.78	1.84	1.87	1.97	2.45	2.51	2.56	2.56	2.56
48,380	0.25	0.47	0.72	0.88	0.95	0.98	1.12	1.15	1.17	1.24	1.50	1.53	1.56	1.56	1.56





SPAS 1489 Storm Center Mass Curve: Zone 1
July 25 (0500 UTC) - July 30 (0400 UTC), 1897
Lat: 38.73 Lon: -76.57
Incremental
Accumulated
15.88"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



Total Storm (120-hours) Precipitation (inches)
July 25 - 29, 1897
SPAS 1489 - Jewell, MD

Gauges

- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 40, 80, 160
Kilometers: 0, 80, 160, 320

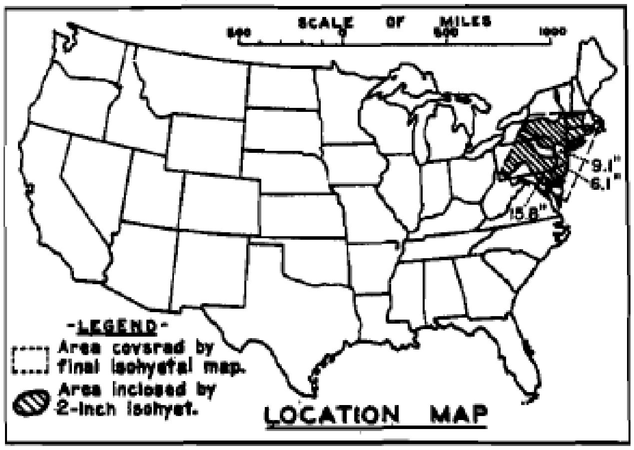
Precipitation (inches)

0.00 - 1.00	4.01 - 5.00	8.01 - 9.00	12.01 - 13.00
1.01 - 2.00	5.01 - 6.00	9.01 - 10.00	13.01 - 14.00
2.01 - 3.00	6.01 - 7.00	10.01 - 11.00	14.01 - 15.00
3.01 - 4.00	7.01 - 8.00	11.01 - 12.00	15.01 - 16.00

4/2/2015

WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES - PERTINENT DATA SHEET



Storm of 26-29 July 1897
Assignment NA 1-7
Location Northeast U. S.
Study Prepared by:
North Atlantic Division
New York District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 3/1/40
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 12/27/46
Remarks: TOTAL STORM Centers at Jewell, Md., Elizabeth and Clayton, N. J.

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1:2,500,000

Precipitation data and mass curves: (Number of Sheets)

Form 5001-C (Hourly precip. data)	13
Form 5001-B (24-hour " ")	74
Form 5001-D (" " " ")	—
Miscl. precip. records, meteorological data, etc.	3
Form 5002 (Mass rainfall curves)	42

PART II

Final isohyetal maps, in 1 sheet, scale 1:1,000,000

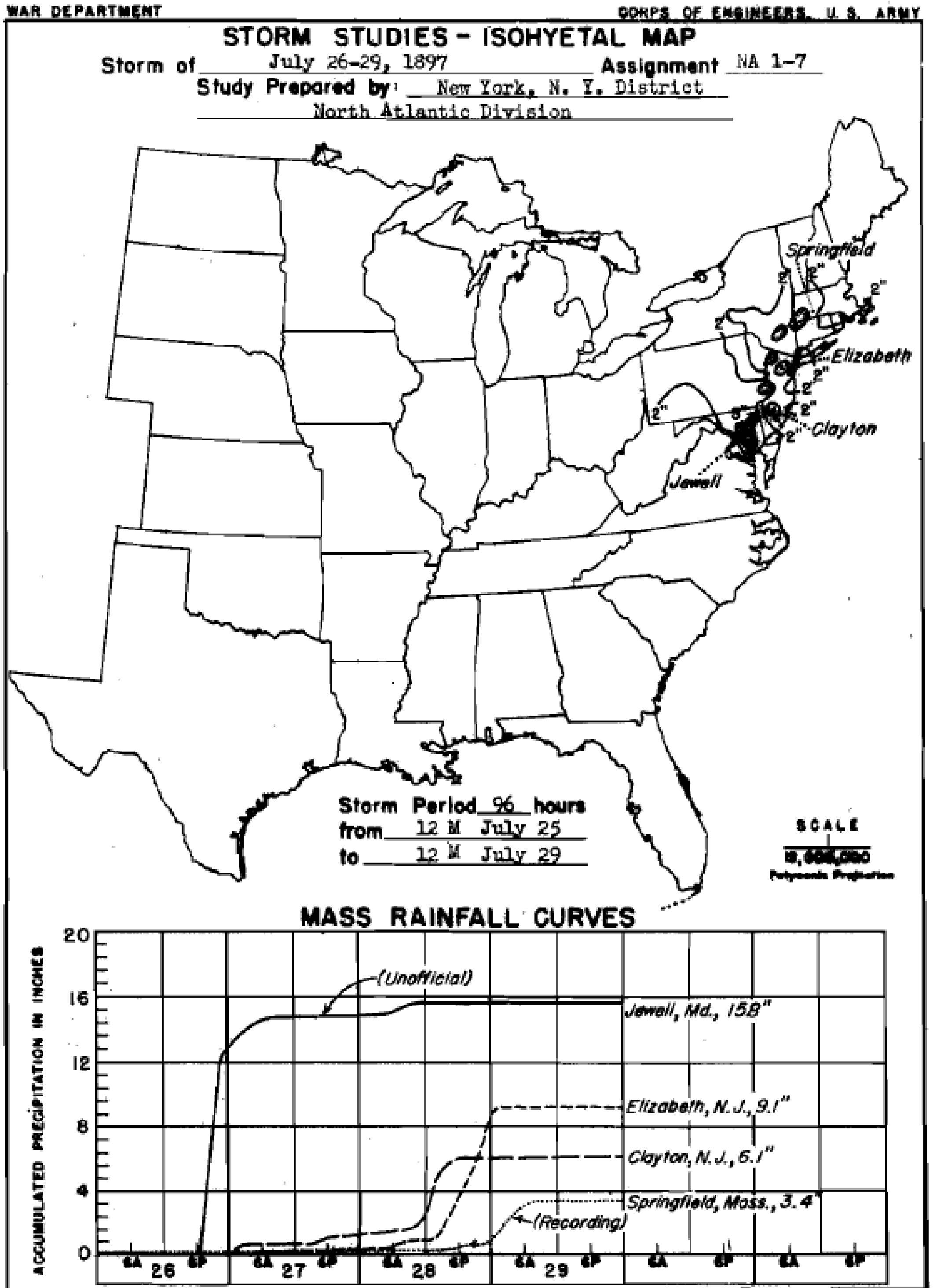
Data and computation sheets:

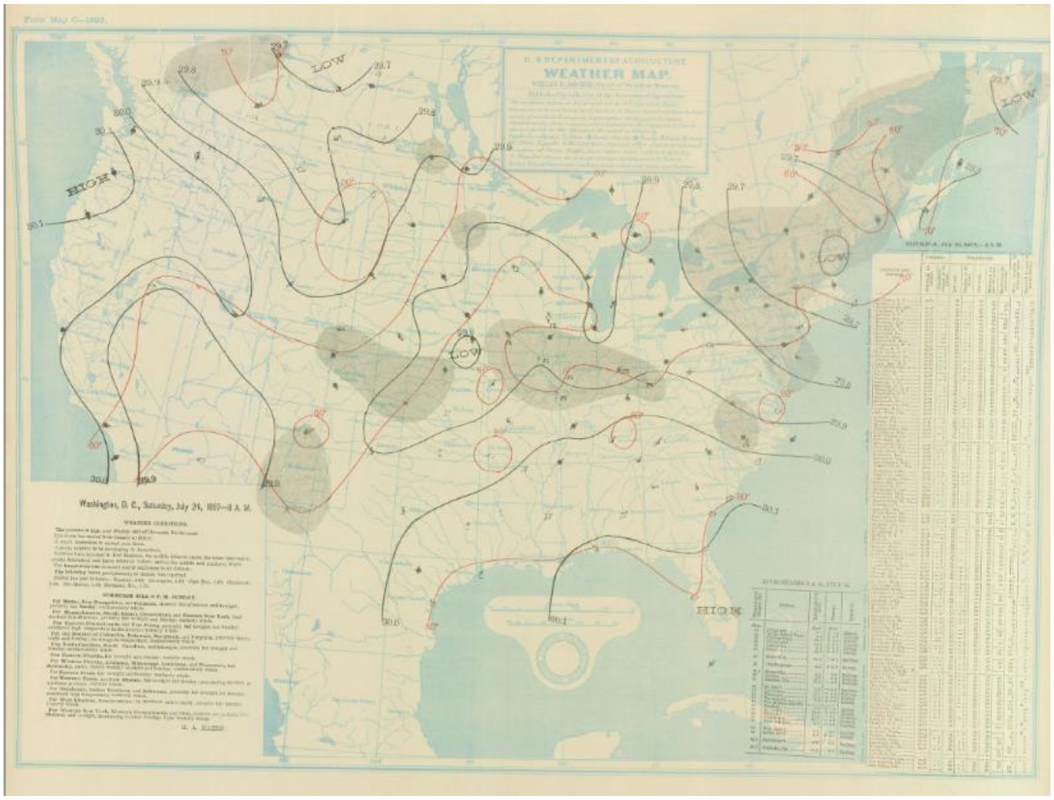
Form S-10 (Data from mass rainfall curves)	5
Form S-11 (Depth-area data from isohyetal map)	2
Form S-12 (Maximum depth-duration data)	5
Maximum duration-depth-area curves	3
Data relating to periods of maximum rainfall	2

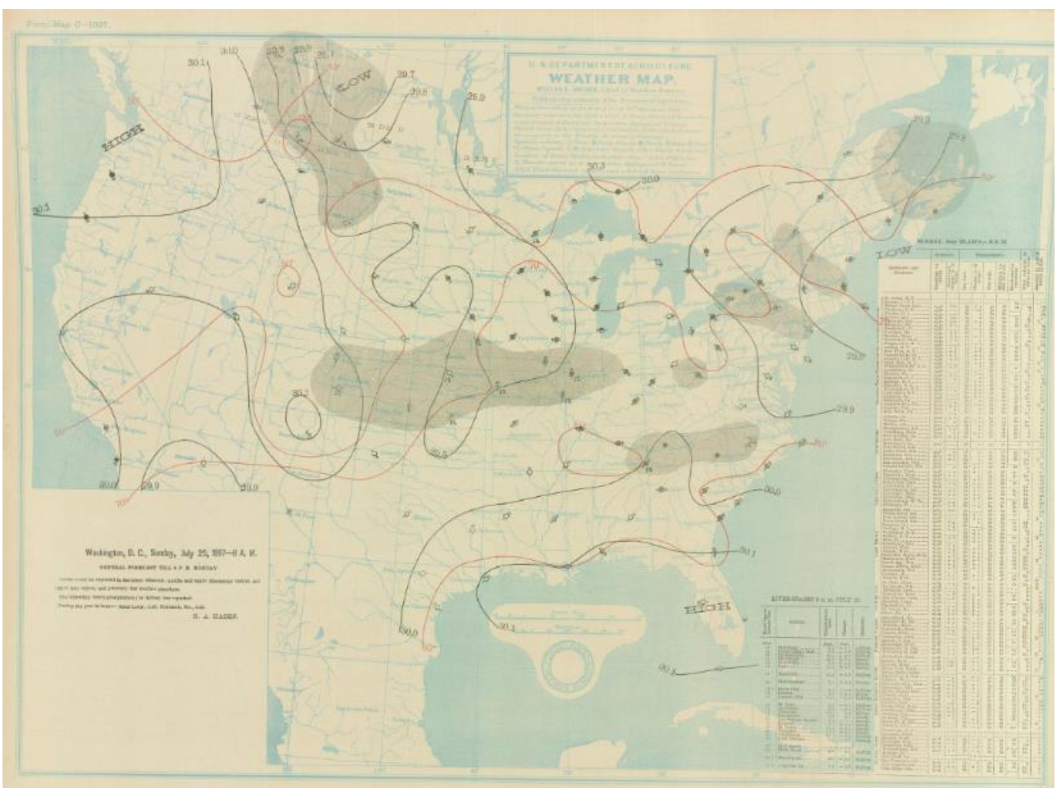
MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

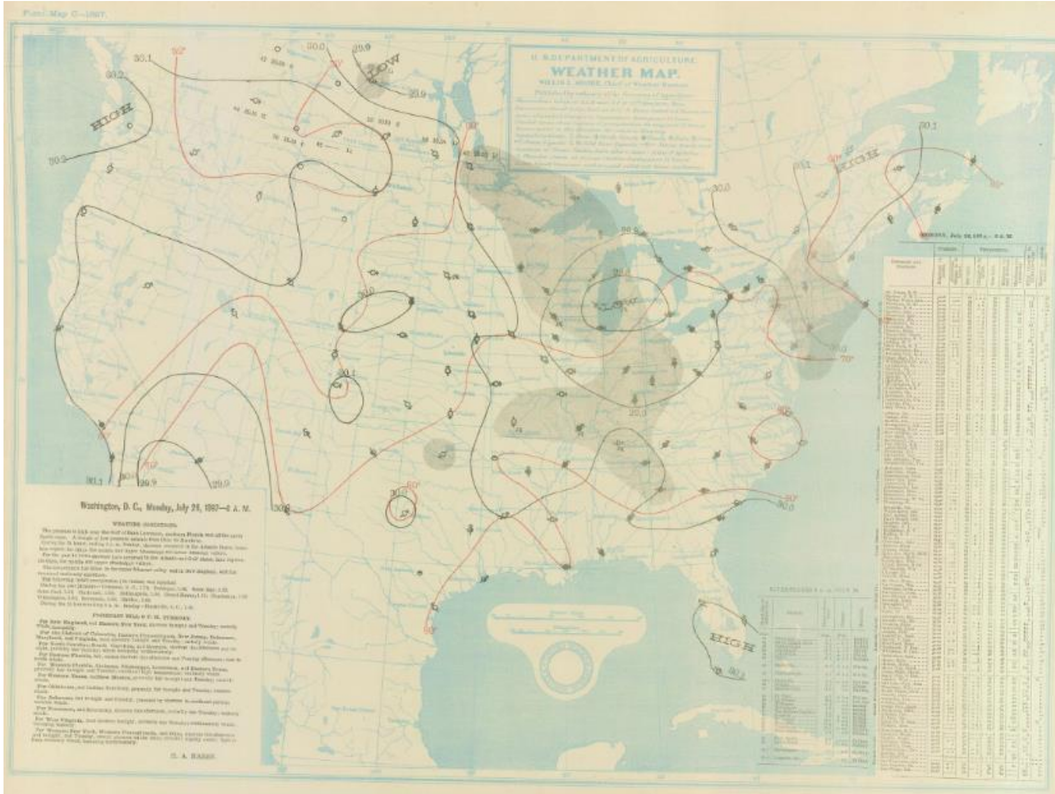
Area in Sq. Mi.	Duration of Rainfall in Hours									
	6	12	18	24	30	36	48	60	72	96
10	13.0	14.5	14.7	14.7	14.7	14.7	15.8	15.8	15.8	15.8
100	10.5	11.7	11.9	11.9	11.9	11.9	12.8	12.8	12.8	12.8
200	9.4	10.5	10.6	10.6	10.6	10.6	11.5	11.5	11.5	11.5
500	7.5	8.3	8.5	8.5	8.5	8.5	9.2	9.2	9.2	9.2
1,000	5.5	6.0	6.2	6.2	6.2	6.2	7.0	7.0	7.0	7.0
2,000	3.7	4.2	4.5	4.6	4.7	4.7	5.2	5.2	5.2	5.2
5,000	2.3	3.1	3.3	3.3	3.4	3.7	3.8	3.9	4.0	4.1
10,000	1.5	2.6	2.8	2.9	2.9	3.3	3.5	3.6	3.7	3.8
20,000	1.1	2.1	2.4	2.5	2.6	3.0	3.2	3.5	3.6	3.6
32,000	0.9	1.7	1.9	2.0	2.1	2.5	2.8	3.3	3.4	3.4

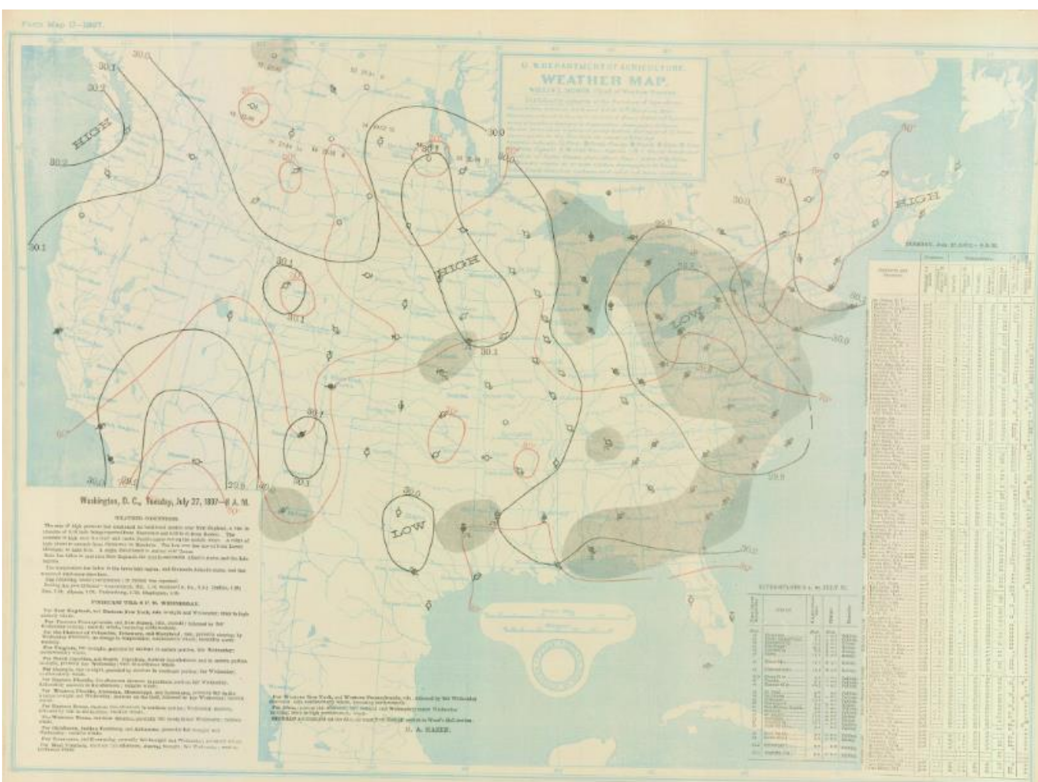
Form S-2

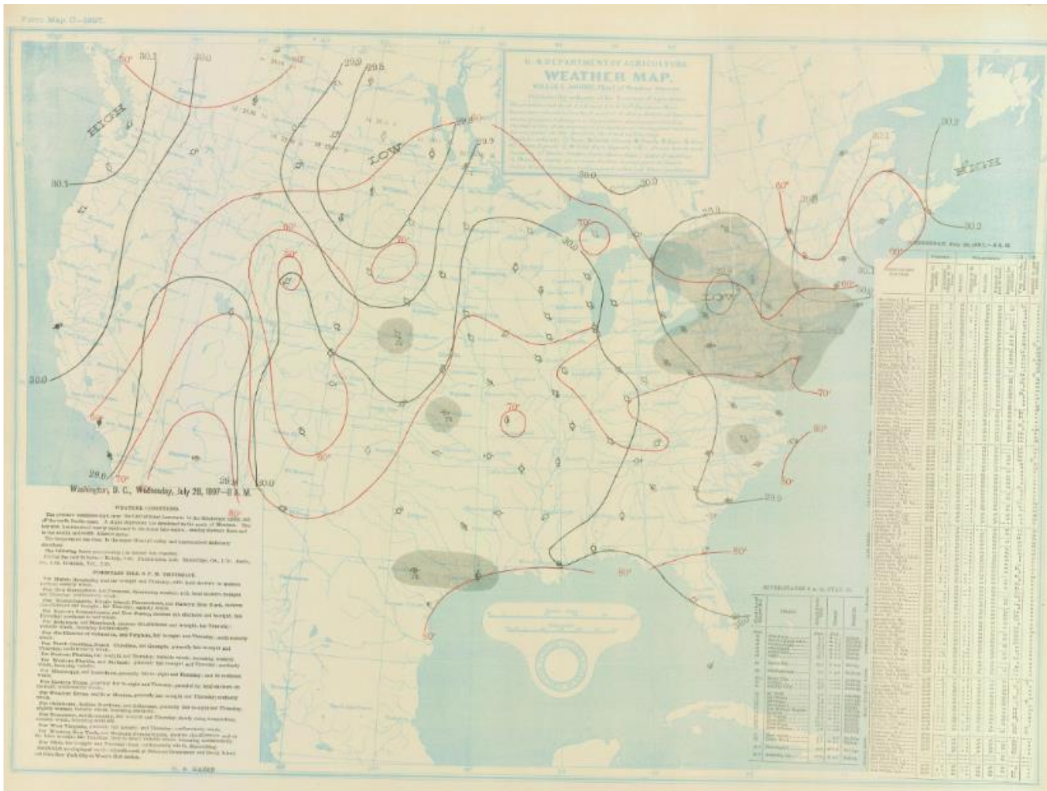

WAR DEPARTMENT
CORPS OF ENGINEERS, U. S. ARMY
STORM STUDIES - ISOHYETAL MAP
Storm of July 26-29, 1897 Assignment NA 1-7
Study Prepared by: New York, N. Y. District
North Atlantic Division
Springfield
Elizabeth
Clayton
Jewell
2"
Storm Period 96 hours
from 12 M July 25
to 12 M July 29
SCALE
Polyconic Projection
MASS RAINFALL CURVES
ACCUMULATED PRECIPITATION IN INCHES
(Unofficial)
Jewell, Md., 15.8"
Elizabeth, N.J., 9.1"
Clayton, N.J., 6.1"
Springfield, Mass., 3.4"
(Recording)
0
4
8
12
16
20
6A 26 6P
6A 27 6P
6A 28 6P
6A 29 6P
6A 6P
6A 6P
FORM 3-3E

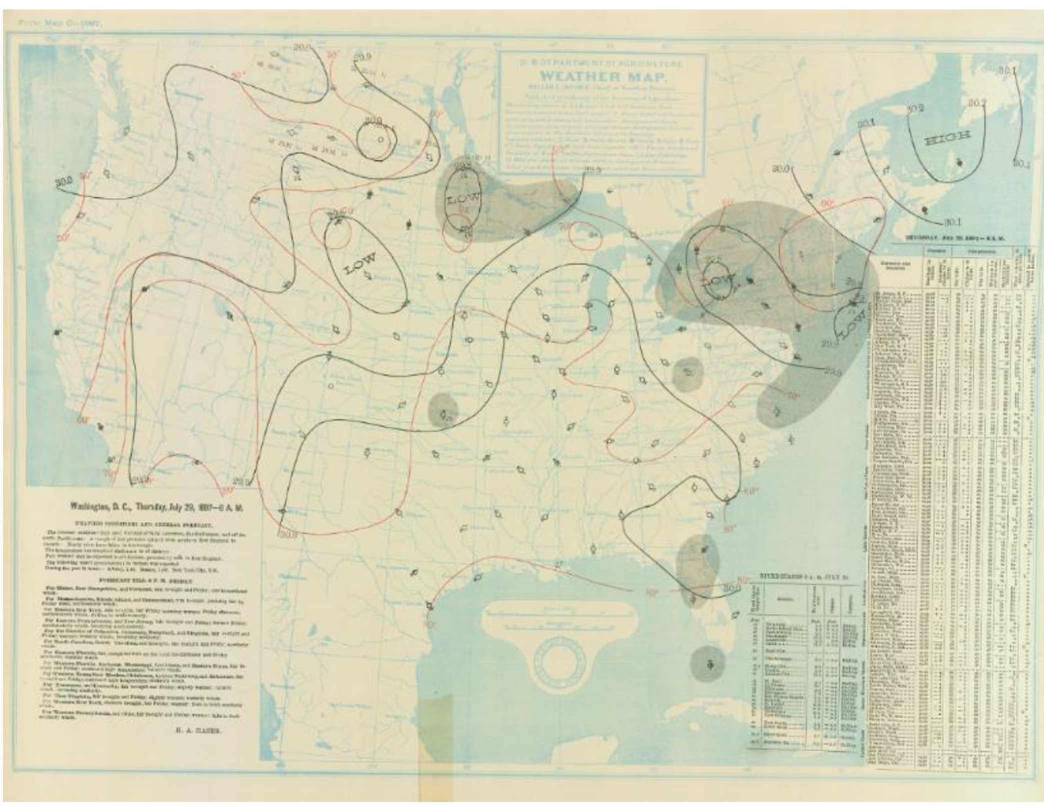

WEATHER MAP.
HIGH
LOW
LOW
HIGH
Washington, D. C., Saturday, July 24, 1897—8 A. M.

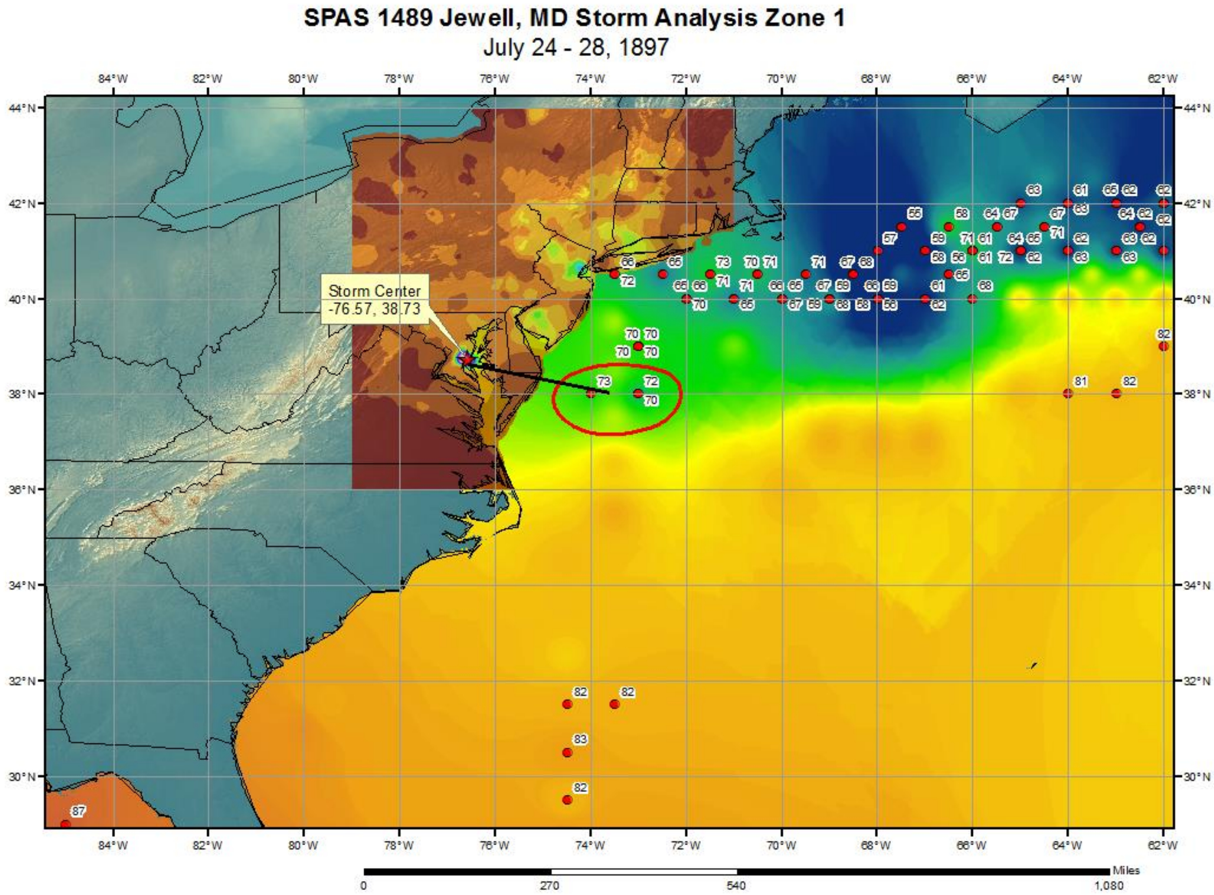

WEATHER MAP.
HIGH
LOW
LOW
HIGH
Washington, D. C., Sunday, July 25, 1897—8 A. M.
H. A. HAZEN.


WEATHER MAP.
HIGH
LOW
HIGH
LOW
HIGH
Washington, D. C., Monday, July 26, 1897—8 A. M.

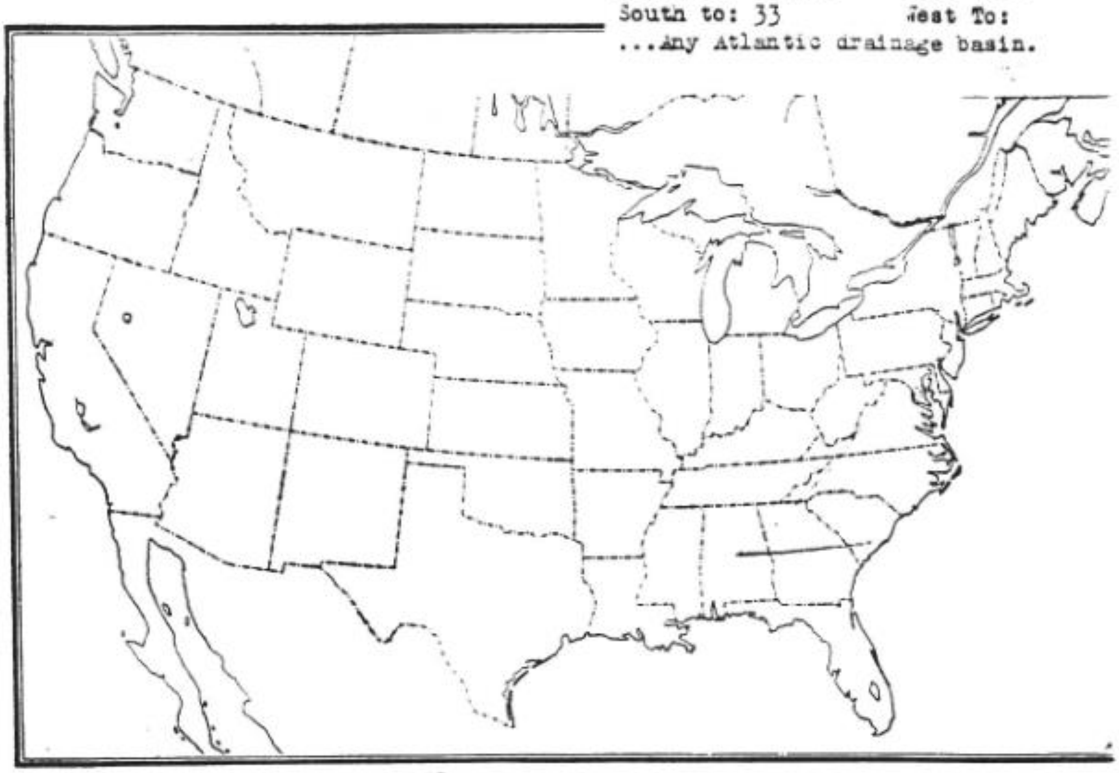

WEATHER MAP.
HIGH
HIGH
HIGH
LOW
LOW
Washington, D. C., Tuesday, July 27, 1897—8 A. M.


WEATHER MAP.
HIGH
LOW
HIGH
LOW
Washington, D. C., Wednesday, July 28, 1897—8 A. M.


WEATHER MAP.
LOW
LOW
HIGH
LOW
LOW
Washington, D. C., Thursday, July 29, 1897—8 A. M.


SPAS 1489 Jewell, MD Storm Analysis Zone 1
July 24 - 28, 1897
Storm Center
-76.57, 38.73
Miles
0
270
540
1,080

MA 1-7...July 26-29, 1897...Jewell, ..
12-hr. rfl 70(27th)..70 ESE..to 78,
North to: border East to:
South to: 33 West To:
...Any Atlantic drainage basin.



Storm Precipitation Analysis System (SPAS) For Storm # 1343_1 SPAS Analysis

General Storm Location: Watauga, TN

Storm Dates: Storm of June 13 (0600 UTC) – June 15 (0500 UTC), 1924

Event: Local/Convective

DAD Zone 1

Latitude: 36.3042

Longitude: -82.0625

Max. Grid Rainfall Amount: 16.41”

Max. Observed Rainfall Amount: 15.25”

Number of Stations: 206

SPAS Version: 10.0

Basemap: Mean June Precipitation

Spatial resolution: 30 seconds

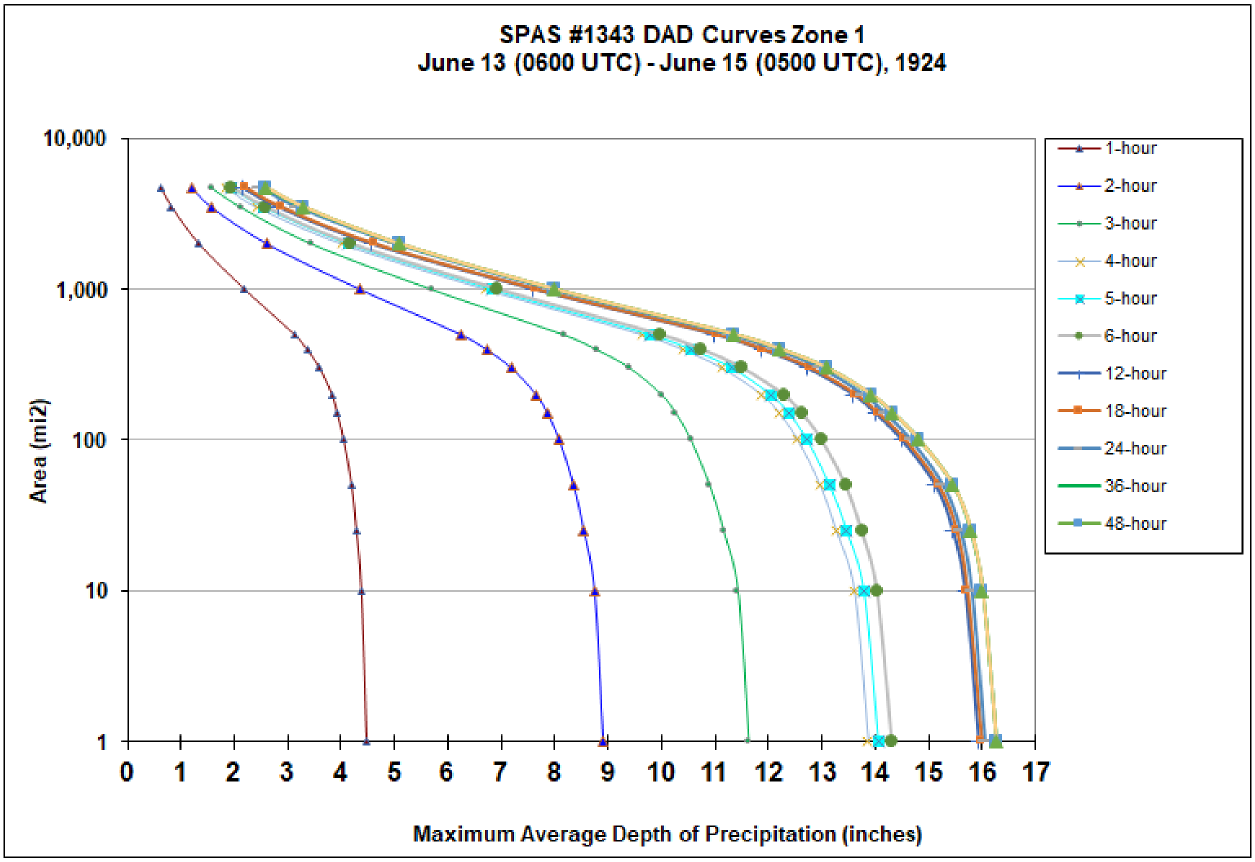
Radar Included: No

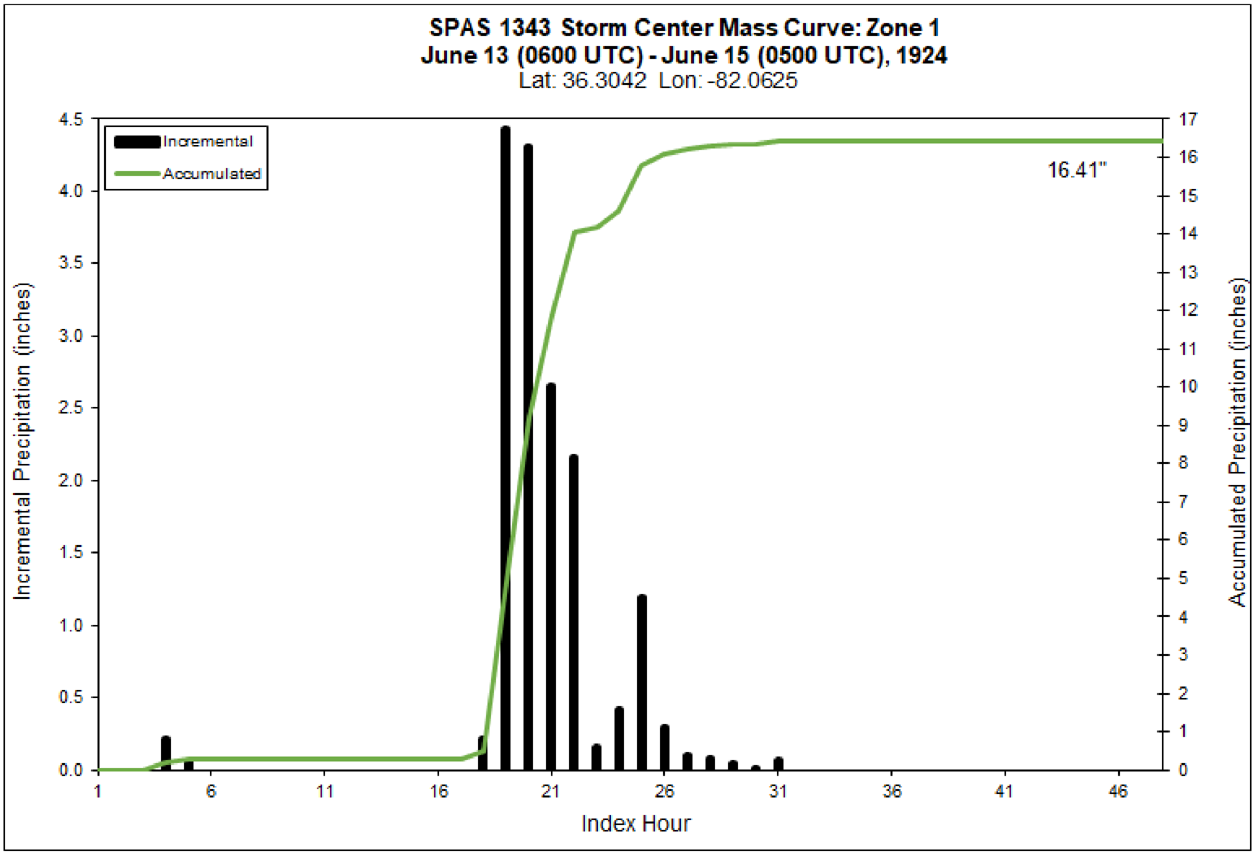
Depth-Area-Duration (DAD) analysis: Yes

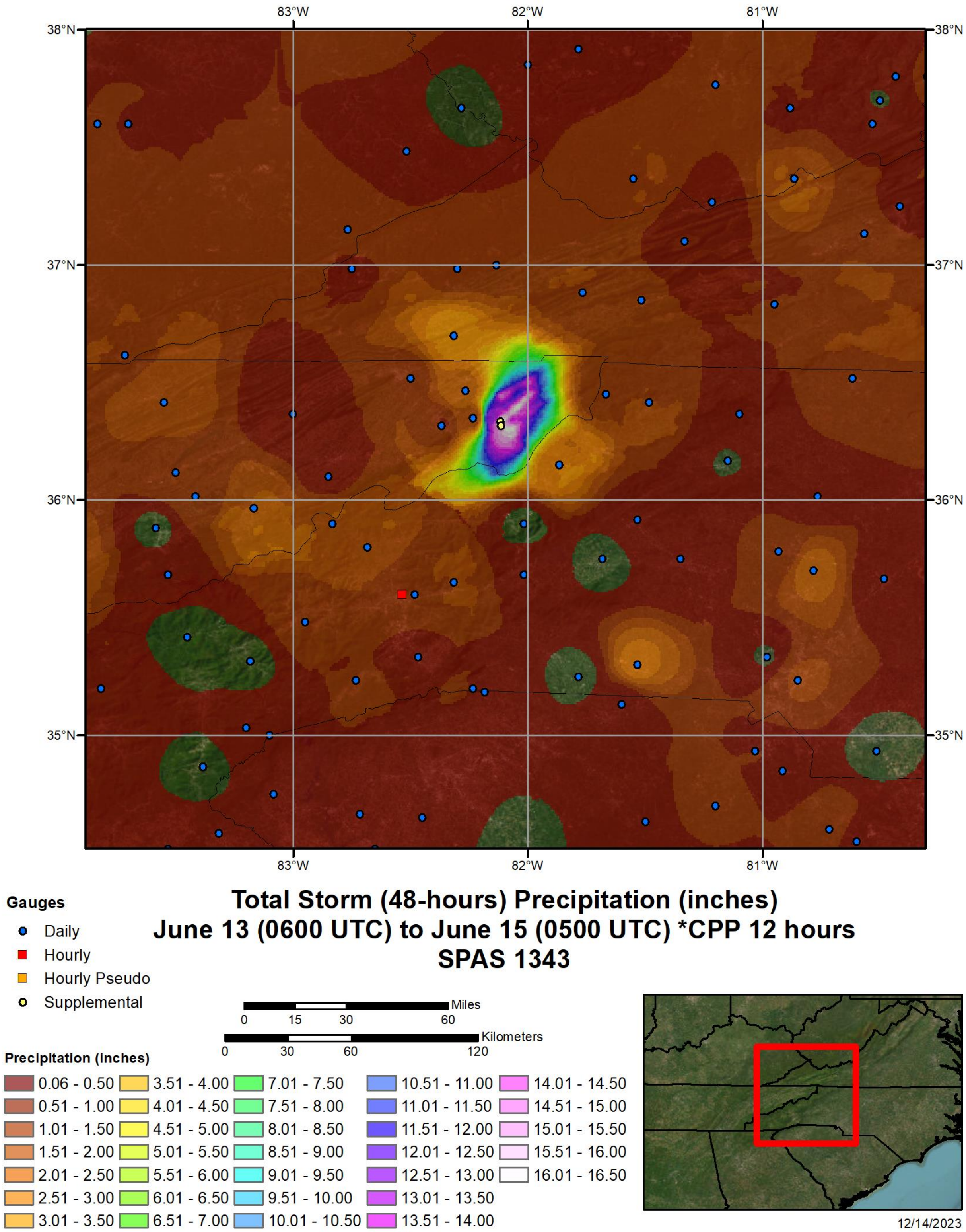
Reliability of results: We have a moderate degree of confidence in this analysis. A decent write-up in the Monthly Weather Review (MWR) provided some important details for quantifying the timing and magnitude of rainfall of this event – which was described as “one of the most terrific rainstorms ever recorded in eastern Tennessee.” In fact, the MWR report provided enough information to support the creation of 2 pseudo hourly stations near the storm center; although the exact 1-hour time steps of rainfall are uncertain, the 3 to 8-hour accumulations are reliable given the details provided in the MWR report. The individual hourly rainfall was distributed using the temporal distributions provided in NOAA Atlas 14 Volume 2. The basemap initially drove the storm center value up to 17.62”, which we felt to be too high. We constrained the storm total to be 16.14” (1.16” more than highest observed) to account for the local orographic enhancement that likely caused slightly higher rainfalls northeast of the observed maximums. This analysis is only reliable in/near the storm center – the lack of hourly data outside of this are too limited to accurately time the daily precipitation data.

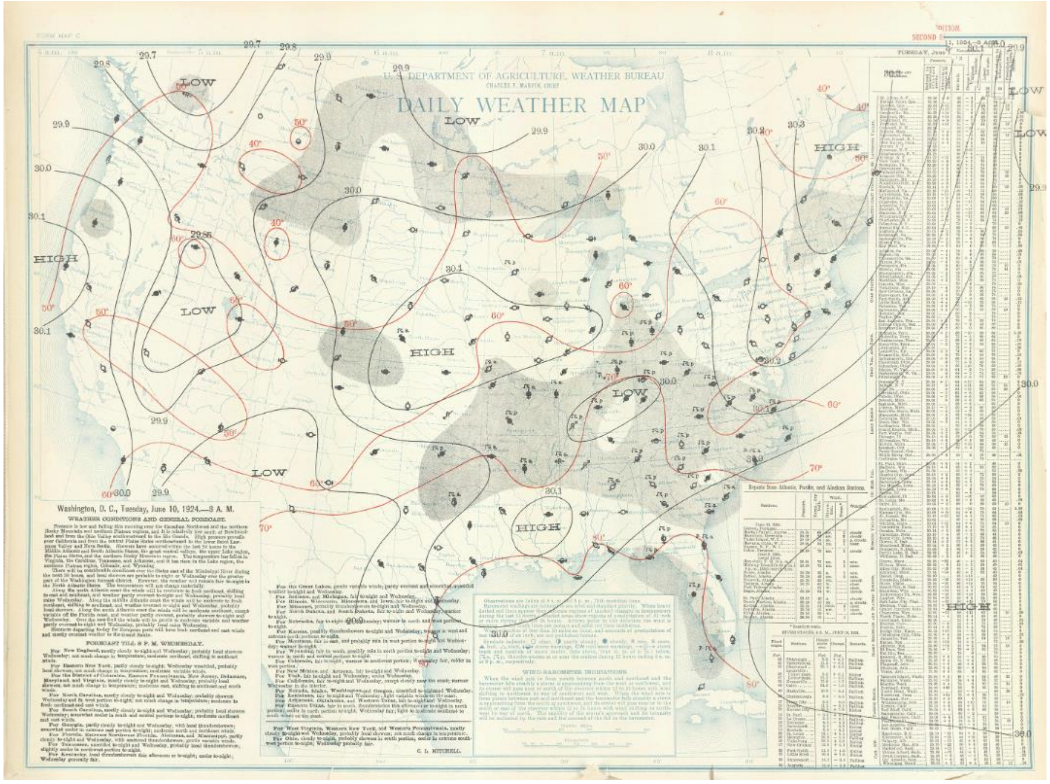
							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1343_1	-82.0625	36.3042	3,137	3,100	27-Jun	77.50	3.22	0.79	77	2.430	80.94	81.0	3.77	0.88	84	2.890	1.160

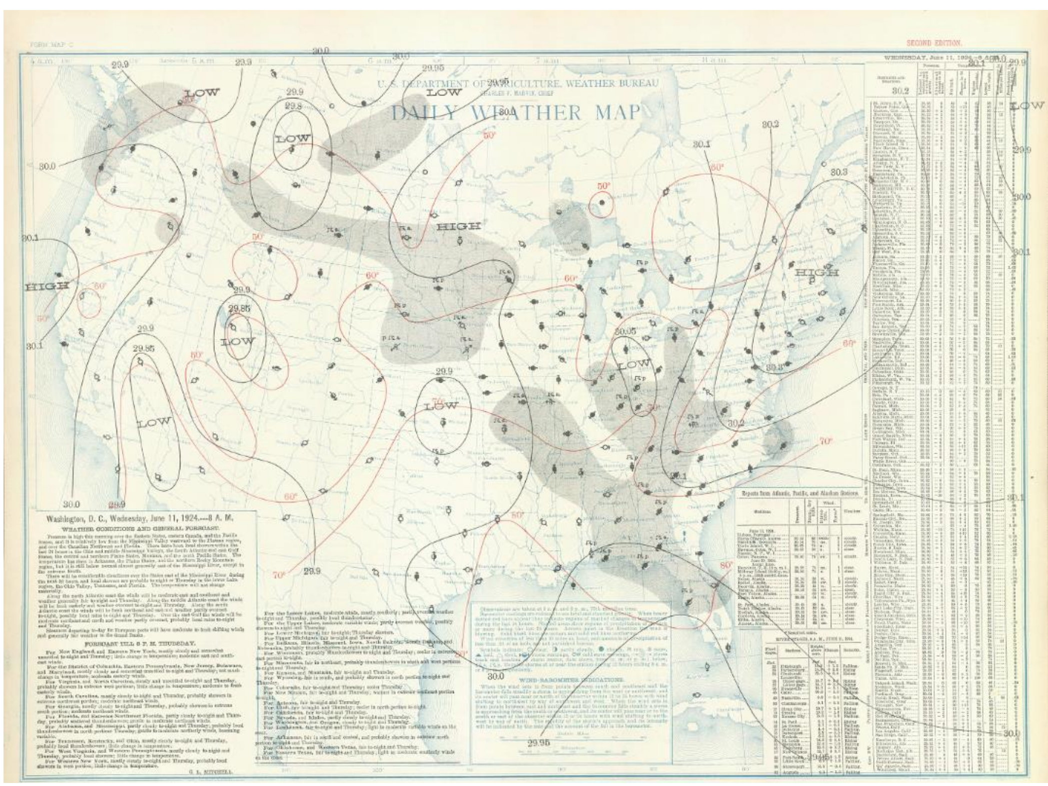
Storm 1343 - June 13 (0600 UTC) - June 15 (0500 UTC), 1924												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
Area (mi	Duration (hours)											
	1	2	3	4	5	6	12	18	24	36	48	Total
0.4	4.51	8.96	11.70	13.96	14.15	14.43	16.02	16.09	16.16	16.36	16.36	16.36
1	4.48	8.90	11.62	13.86	14.05	14.32	15.92	15.99	16.06	16.26	16.26	16.26
10	4.38	8.74	11.42	13.60	13.78	14.04	15.67	15.72	15.81	16.00	16.00	16.00
25	4.29	8.54	11.15	13.26	13.46	13.75	15.44	15.52	15.60	15.77	15.78	15.78
50	4.20	8.35	10.89	12.96	13.14	13.45	15.11	15.18	15.27	15.45	15.45	15.45
100	4.05	8.08	10.54	12.54	12.72	13.00	14.48	14.55	14.66	14.81	14.81	14.81
150	3.93	7.86	10.26	12.20	12.38	12.63	13.99	14.05	14.18	14.32	14.32	14.32
200	3.83	7.65	9.99	11.87	12.04	12.28	13.57	13.63	13.77	13.90	13.91	13.91
300	3.60	7.19	9.40	11.13	11.32	11.51	12.71	12.78	12.96	13.08	13.08	13.08
400	3.36	6.72	8.77	10.39	10.55	10.74	11.85	11.89	12.10	12.20	12.21	12.21
500	3.13	6.25	8.16	9.65	9.80	9.97	10.99	11.03	11.25	11.35	11.36	11.36
1,000	2.19	4.36	5.69	6.71	6.83	6.93	7.60	7.64	7.89	7.97	7.98	7.98
2,000	1.33	2.62	3.45	4.03	4.14	4.18	4.57	4.62	5.00	5.06	5.07	5.07
3,500	0.82	1.58	2.12	2.44	2.55	2.58	2.83	2.88	3.16	3.26	3.28	3.28
4,726	0.61	1.21	1.57	1.86	1.93	1.95	2.15	2.21	2.46	2.55	2.58	2.58

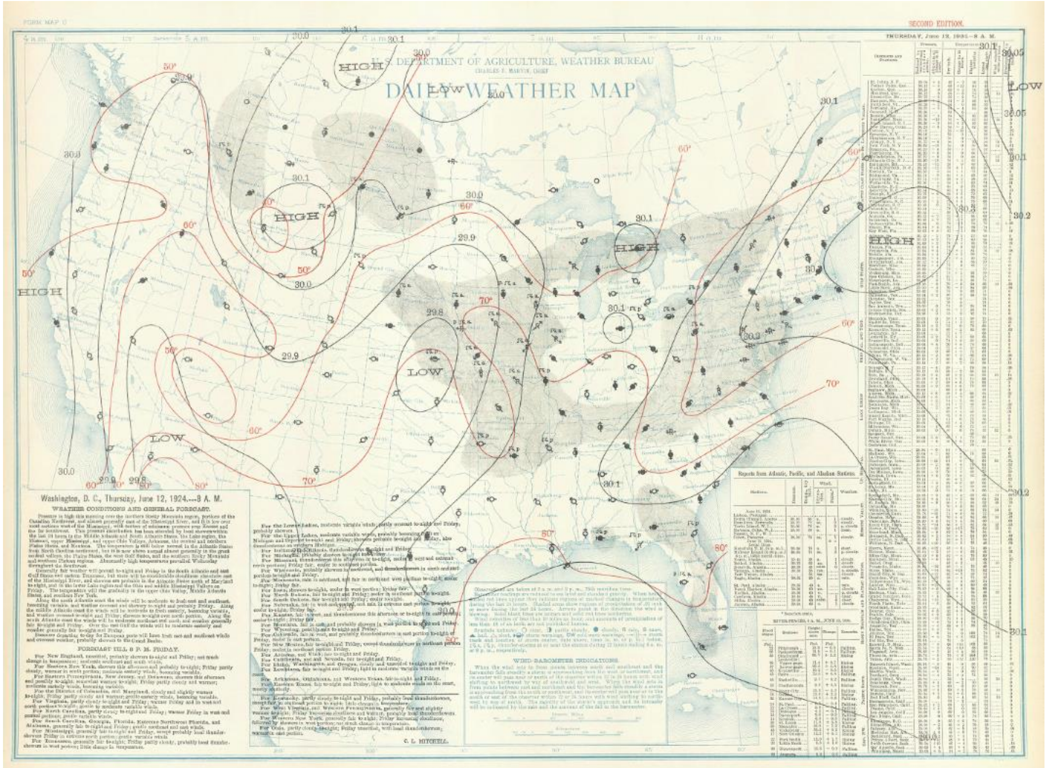


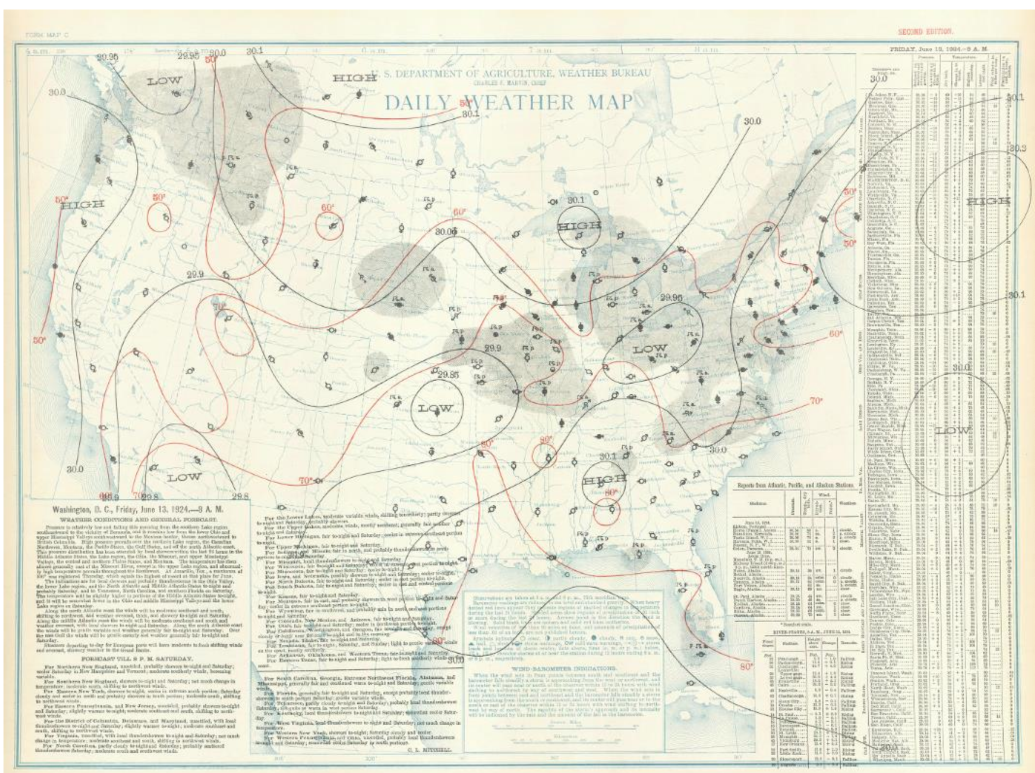

SPAS 1343 Storm Center Mass Curve: Zone 1
June 13 (0600 UTC) - June 15 (0500 UTC), 1924
Lat: 36.3042 Lon: -82.0625
Incremental
Accumulated
16.41"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
6
11
16
21
26
31
36
41
46

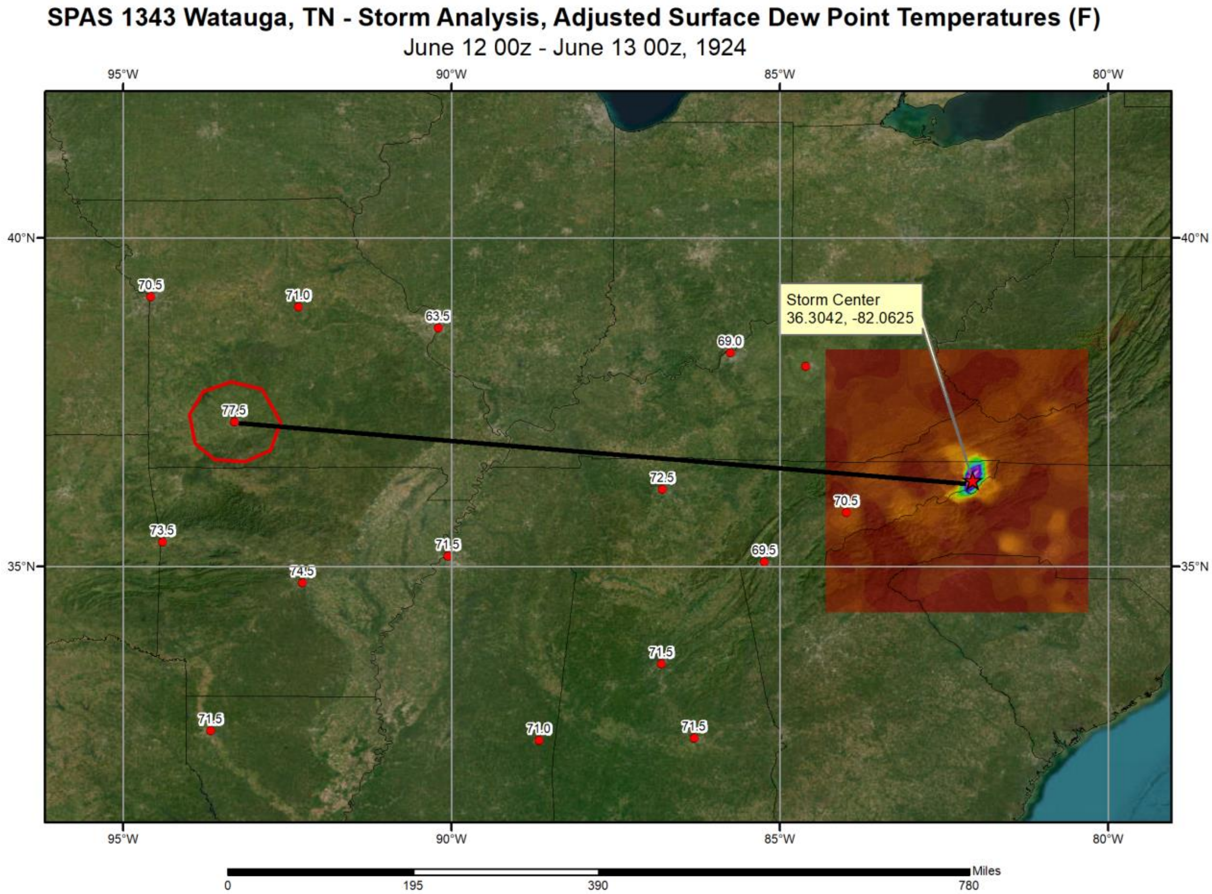

83°W
82°W
81°W
38°N
37°N
36°N
35°N
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Total Storm (48-hours) Precipitation (inches)
June 13 (0600 UTC) to June 15 (0500 UTC) *CPP 12 hours
SPAS 1343
0 15 30 60 Miles
0 30 60 120 Kilometers
Precipitation (inches)
0.06 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.00
10.01 - 10.50
10.51 - 11.00
11.01 - 11.50
11.51 - 12.00
12.01 - 12.50
12.51 - 13.00
13.01 - 13.50
13.51 - 14.00
14.01 - 14.50
14.51 - 15.00
15.01 - 15.50
15.51 - 16.00
16.01 - 16.50
12/14/2023


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
Washington, D. C., Tuesday, June 10, 1924—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. WEDNESDAY.
WIND-BAROMETER INDICATIONS.


SECOND EDITION.
U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
Washington, D. C., Wednesday, June 11, 1924—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. THURSDAY.
WIND-BAROMETER INDICATIONS.


FORM MAP C
SECOND EDITION.
U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
CHARLES F. MARVIN, CHIEF
DAILY WEATHER MAP
THURSDAY, June 12, 1924—8 A. M.
Washington, D. C., Thursday, June 12, 1924.—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. FRIDAY.
WIND-BAROMETER INDICATIONS.
Reports from Atlantic, Pacific, and Alaskan Stations.
C. L. MITCHELL.
HIGH
LOW
30.0
30.1
29.9
29.8
60°
70°
80°


FORM MAP C
SECOND EDITION.
U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
CHARLES F. MARVIN, CHIEF
DAILY WEATHER MAP
FRIDAY, June 13, 1924—8 A. M.
Washington, D. C., Friday, June 13, 1924.—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. SATURDAY.
WIND-BAROMETER INDICATIONS.
Reports from Atlantic, Pacific, and Alaskan Stations.
C. L. MITCHELL.
HIGH
LOW
30.0
30.1
29.9
29.8
60°
70°
80°



SPAS 1343 Watauga, TN - Storm Analysis, Adjusted Surface Dew Point Temperatures (F)
June 12 00z - June 13 00z, 1924
95°W
90°W
85°W
80°W
40°N
35°N
Storm Center
36.3042, -82.0625
70.5
71.0
63.5
69.0
77.5
72.5
70.5
73.5
71.5
69.5
74.5
71.5
71.5
71.0
71.5
Miles
0
195
390
780

Storm Precipitation Analysis System (SPAS) For Storm #1344_1 SPAS Analysis

General Storm Location: Simpson, KY

Storm Dates: July 3-7, 1939

Event: Simpson, KY HMR 52 Tale 21, HMR 45 Table 2-2, HMR 2

DAD Zone 1

Latitude: 38.1042

Longitude: -83.2958

Max. Grid Rainfall Amount: 20.82"

Max. Observed Rainfall Amount: 20.50"

Number of Stations: 276 (137 Daily, 3 Hourly Estimated, 1 Hourly Estimated Pseudo, and 135 Supplemental)

SPAS Version: 9.5

Basemap: USGS total storm isohyetal

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

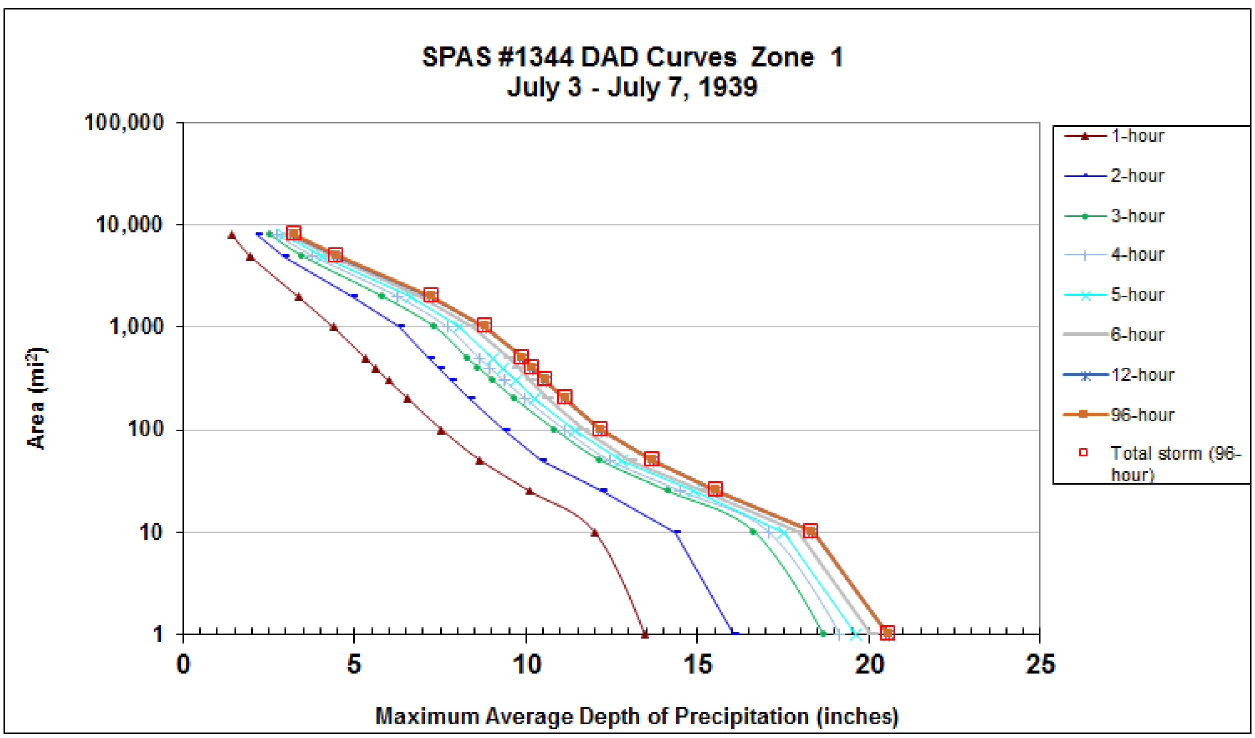
Radar Included: No

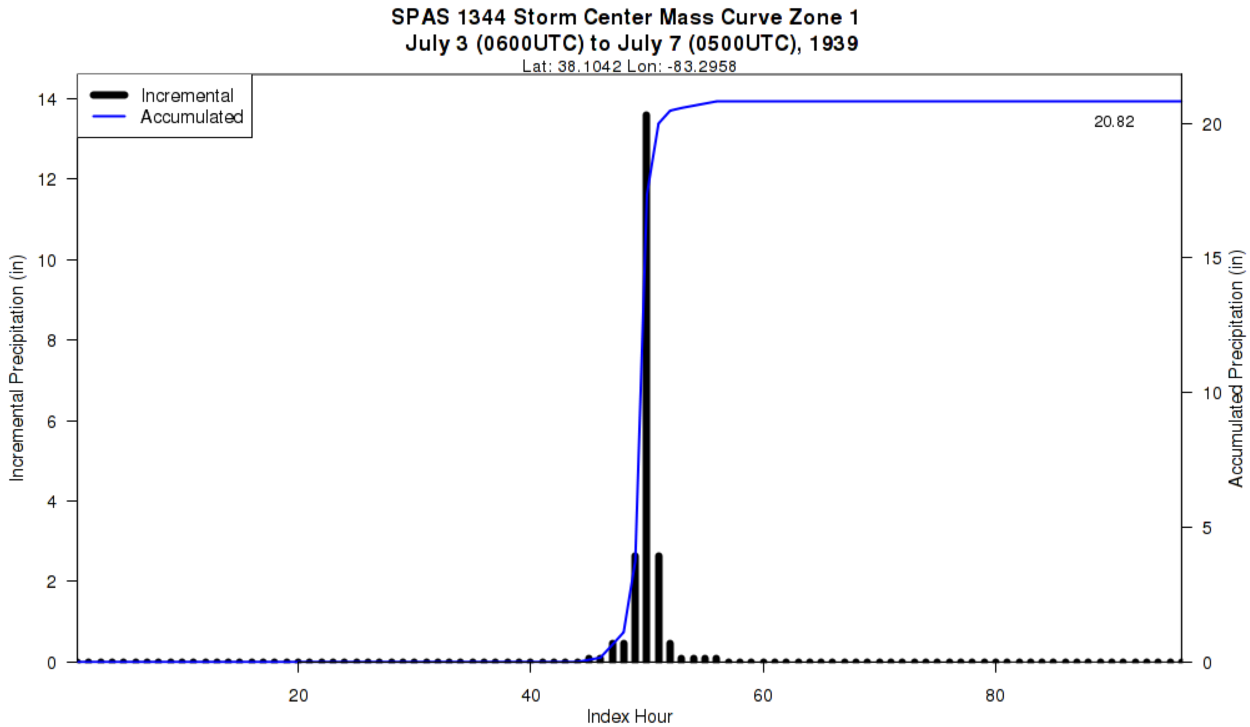
Depth-Area-Duration (DAD) analysis: Yes

Reliability of results: This analysis was based on hourly data, hourly pseudo data HMR reports and supplemental information), daily data, and supplemental station data (USGS report). We have a decent degree of confidence in the station based storm total results, the spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations.

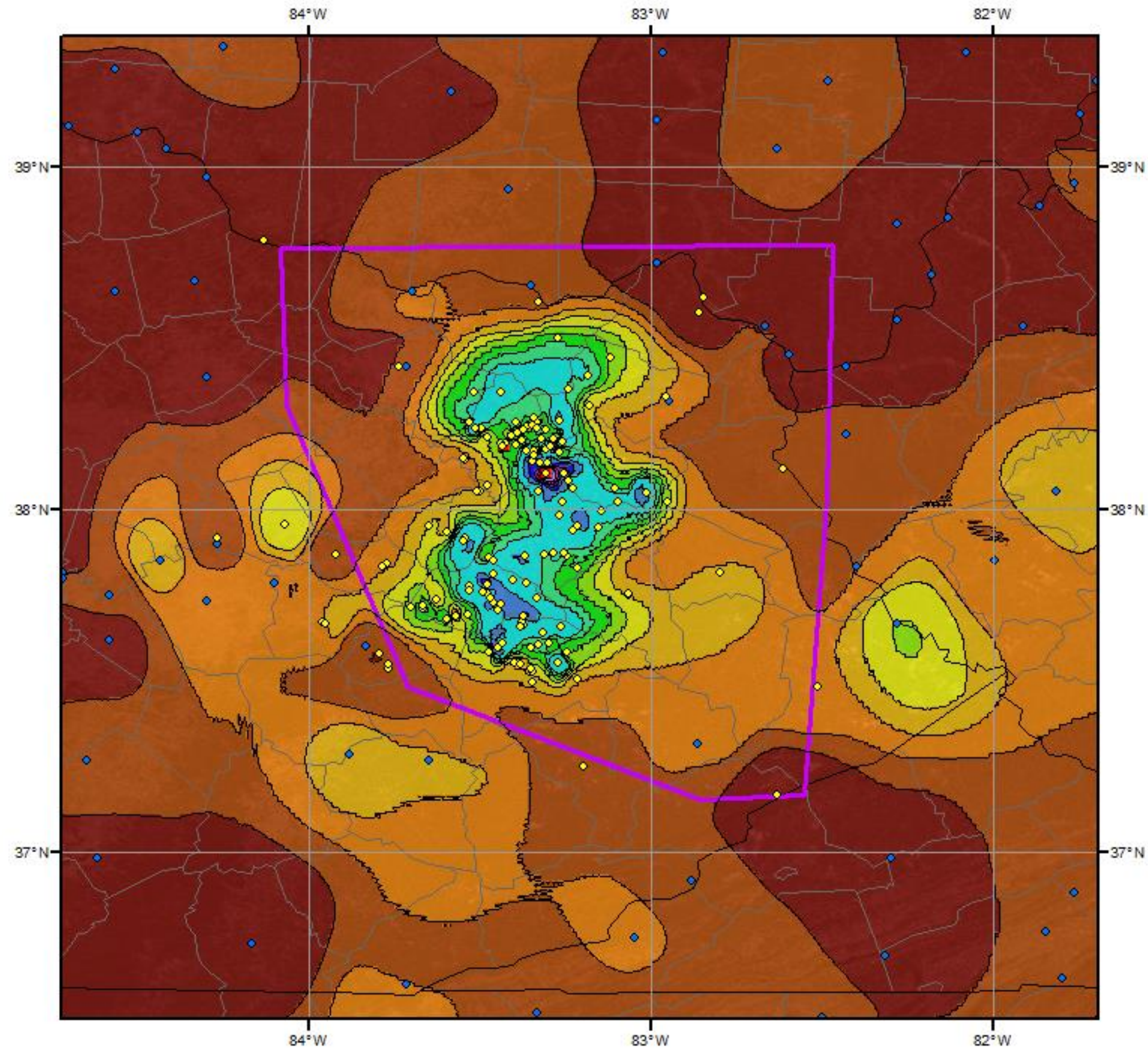
						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1344_1	-83.2958	38.1042	1,101	18-Jul	75.50	2.92	0.28	73	2.640	80.85	3.77	0.33	84	3.440	1.303

Storm 1344 - July 3 (0600 UTC) - July 7 (0500 UTC), 1939 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)									
Area (mi^2)	Duration (hours)								
	1	2	3	4	5	6	12	96	Total
0.4	13.56	16.19	18.82	19.30	19.77	20.24	20.74	20.74	20.74
1	13.45	16.06	18.67	19.15	19.62	20.08	20.58	20.58	20.58
10	11.99	14.33	16.66	17.08	17.50	17.92	18.36	18.36	18.36
25	10.10	12.18	14.15	14.51	14.86	15.21	15.58	15.58	15.58
50	8.66	10.45	12.16	12.43	12.80	13.07	13.72	13.72	13.72
100	7.54	9.35	10.84	11.13	11.43	11.67	12.19	12.20	12.20
200	6.56	8.36	9.66	9.98	10.24	10.65	11.15	11.16	11.16
300	5.99	7.83	9.04	9.37	9.69	10.13	10.58	10.59	10.59
400	5.61	7.46	8.61	8.95	9.31	9.78	10.20	10.21	10.21
500	5.32	7.17	8.28	8.63	9.03	9.51	9.91	9.92	9.92
1,000	4.38	6.29	7.34	7.70	8.05	8.48	8.82	8.83	8.83
2,000	3.35	4.92	5.80	6.24	6.63	6.97	7.26	7.28	7.28
5,000	1.96	2.91	3.45	3.77	4.05	4.31	4.48	4.51	4.51
7,975	1.44	2.13	2.53	2.74	2.92	3.10	3.23	3.28	3.28





SPAS 1344 Storm Center Mass Curve Zone 1
July 3 (0600UTC) to July 7 (0500UTC), 1939
Lat: 38.1042 Lon: -83.2958
Incremental
Accumulated
20.82
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
2
4
6
8
10
12
14
20
40
60
80
0
5
10
15
20



Total Storm (96-hr) Precipitation (inches)
07/03/1939 0600 UTC - 07/07/1939 0500 UTC
SPAS #1344

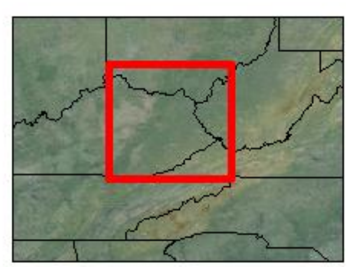
Gauges

- Daily
- Hourly Estimated
- Hourly Estimated Pseudo
- Supplemental

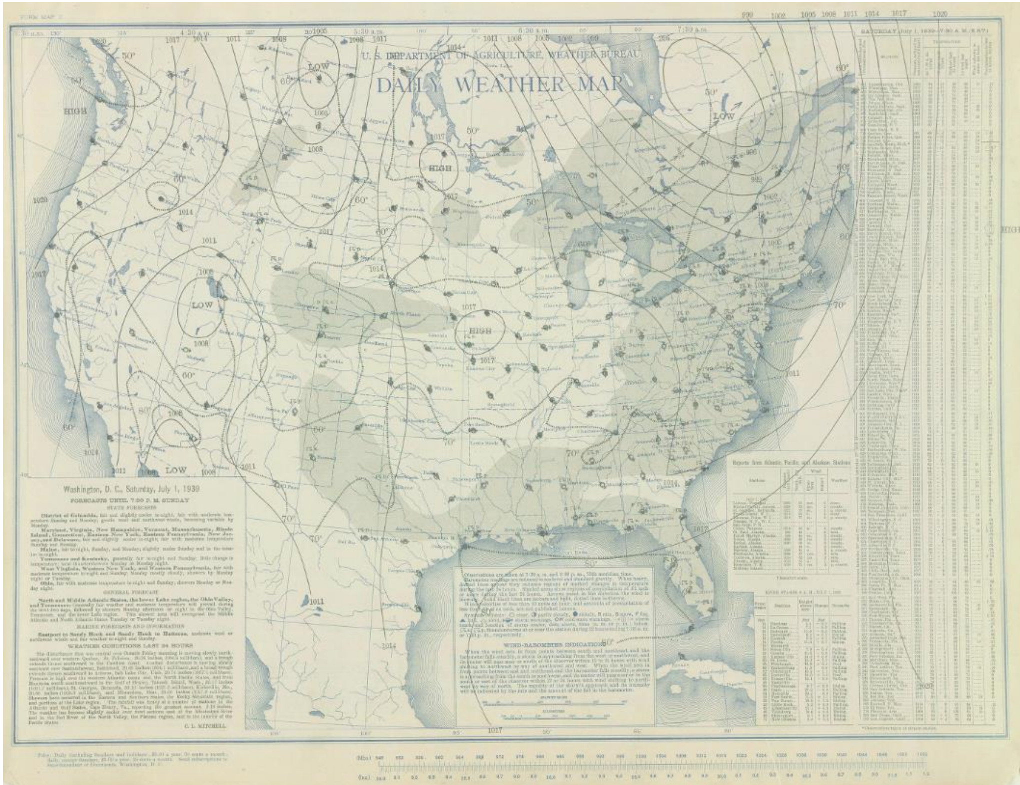
Miles: 0, 12.5, 25, 50
Kilometers: 0, 30, 60, 120

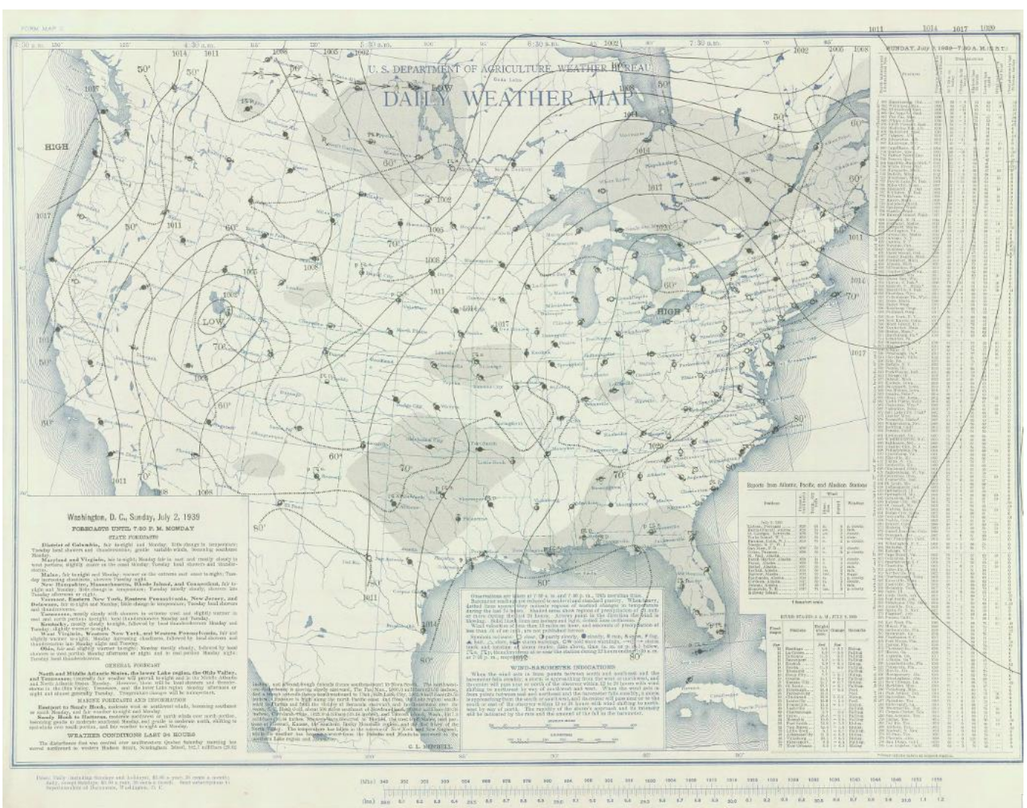
Precipitation (inches)

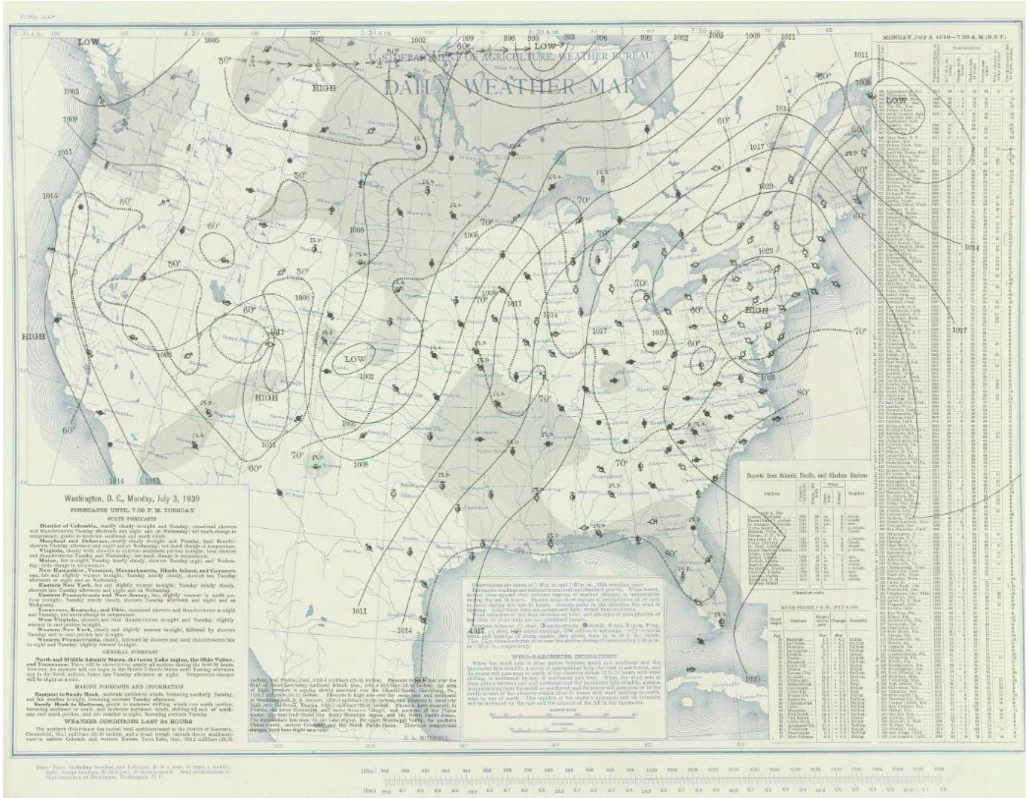
0.00 - 1.00	3.01 - 4.00	6.01 - 7.00	10.01 - 12.00	16.01 - 18.00
1.01 - 2.00	4.01 - 5.00	7.01 - 8.00	12.01 - 14.00	18.01 - 21.00
2.01 - 3.00	5.01 - 6.00	8.01 - 10.00	14.01 - 16.00	21.01 - 22.00

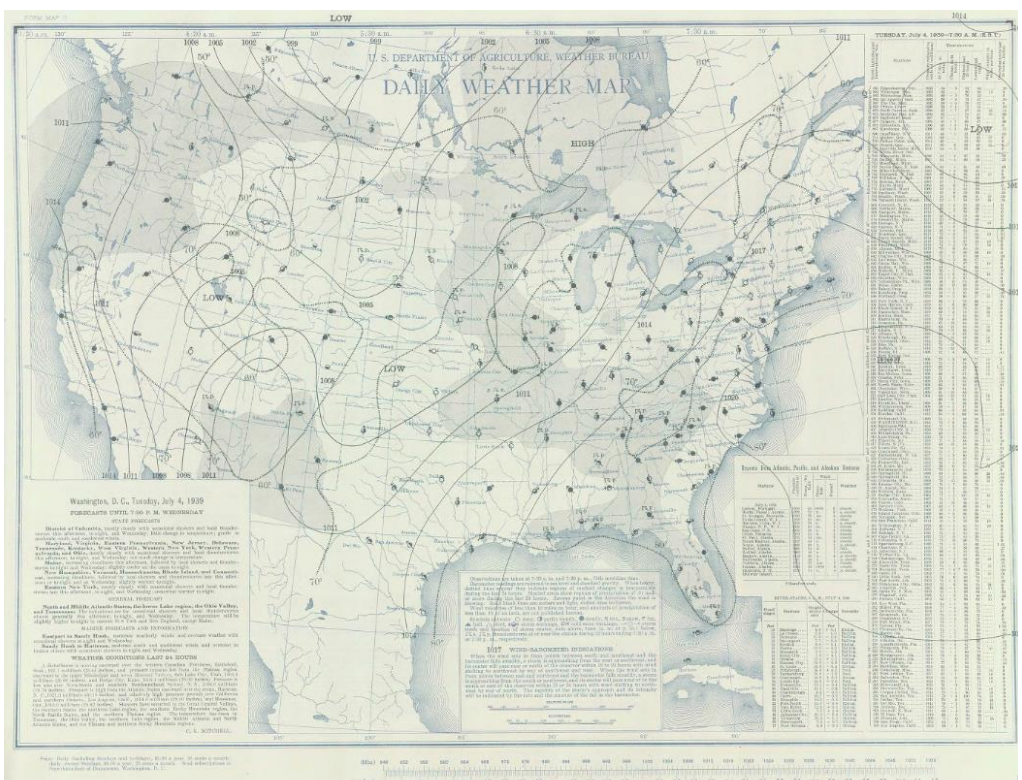


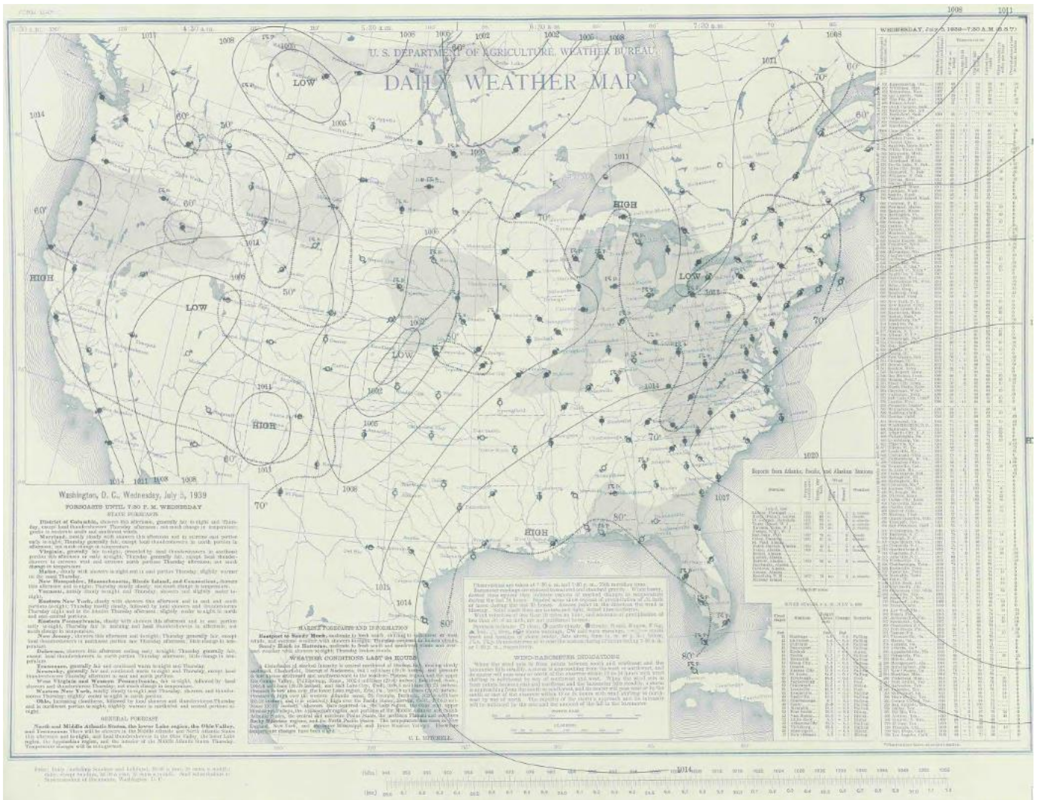
10/24/2014


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Saturday, July 1, 1939
HIGH
LOW
HIGH
LOW
HIGH
LOW
LOW
HIGH

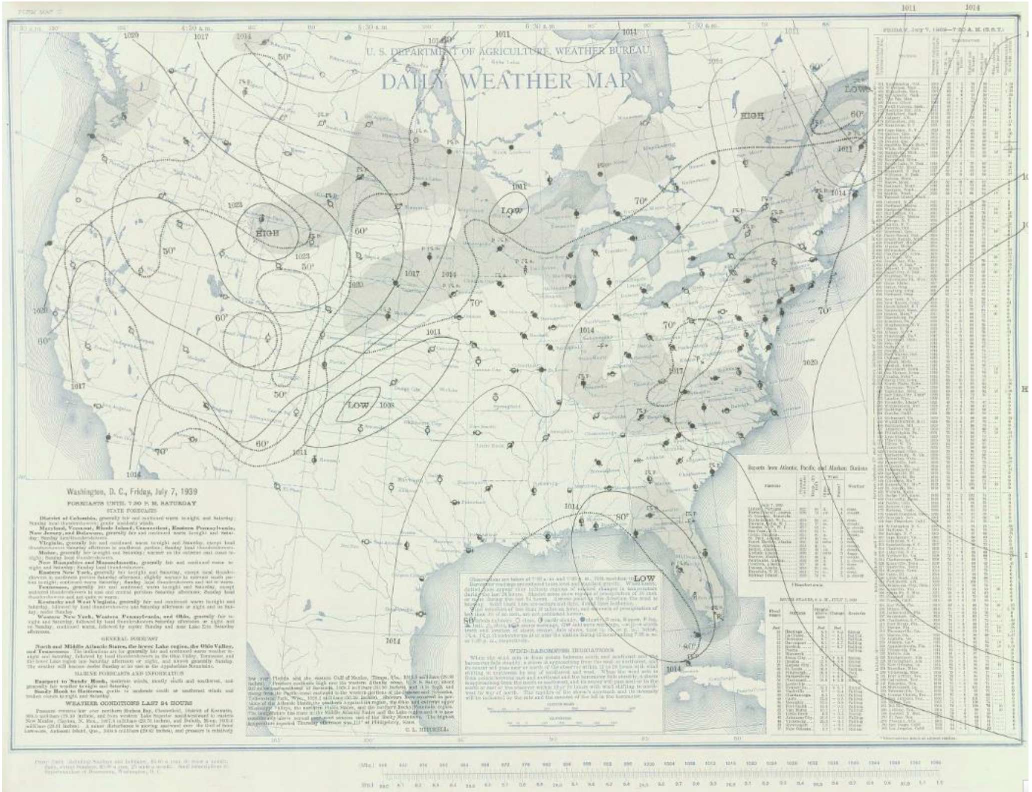

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Sunday, July 2, 1939
HIGH
LOW
LOW
HIGH

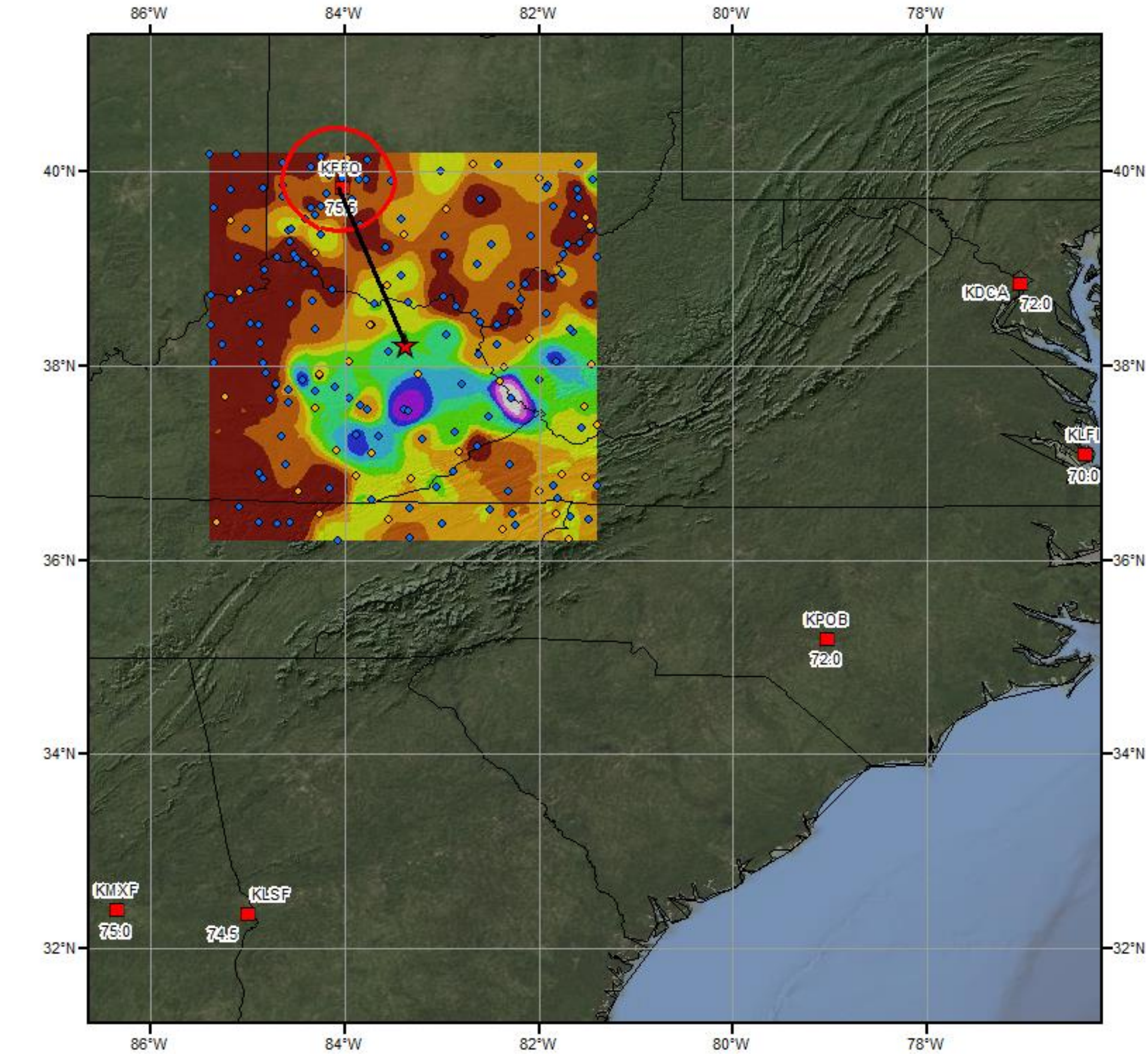

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Monday, July 3, 1939


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Tuesday, July 4, 1939

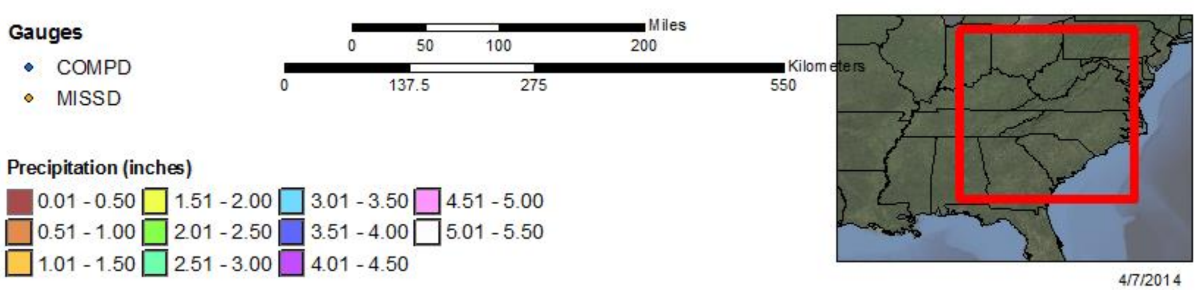

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Wednesday, July 5, 1939


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Thursday, July 6, 1939


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Friday, July 7, 1939
FORECASTS UNTIL 7:30 P. M. SATURDAY
STATE FORECASTS
HIGH
LOW
HIGH
LOW
LOW
LOW
WEATHER CONDITIONS LAST 24 HOURS
GENERAL FORECAST
WIND-BAROMETER INDICATIONS



SPAS-Lite: 6143
Lat/Lon box: 40.2 -85.4 36.2 -81.4
Begin date: 07/3/1939 for hourly stations, 7/4/1939 for daily
End date: 07/06/1939



Storm Precipitation Analysis System (SPAS) For Storm #1534_1 SPAS Analysis

General Storm Location: Ewan, NJ (USACE NA 2-4), re-run SPAS 1023

Storm Dates: August 31 - September 2, 1940

Event: Hurricane

DAD Zone 1

Latitude: 39.6875

Longitude: -75.1807

Max. Grid Rainfall Amount: 24.30"

Max. Observed Rainfall Amount: 24.00"

Number of Stations: 58 (2 Daily, 27 Hourly, 1 Hourly Pseudo, and 28 Supplemental)

SPAS Version: 10.0

Basemap: Blended PRISM September 1940 Ppt with SPAS Ppt

Spatial resolution: 0:00:30 second (~ 0.3 mi^2)

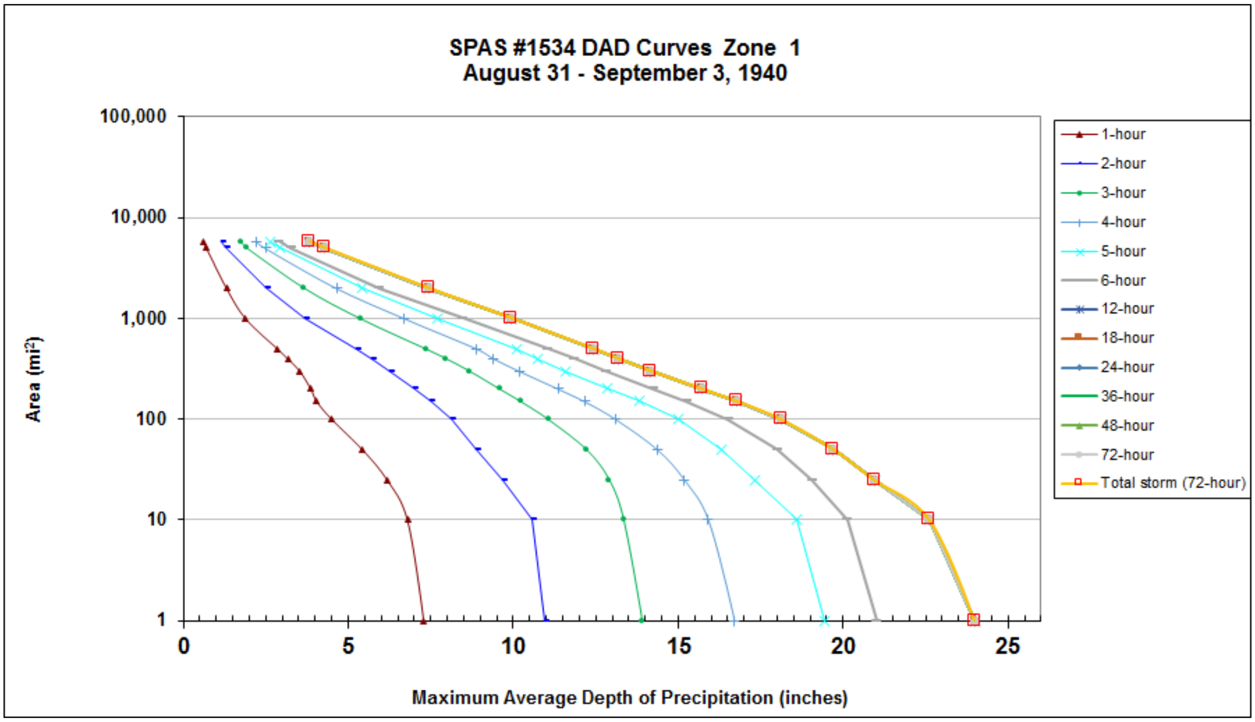
Radar Included: No

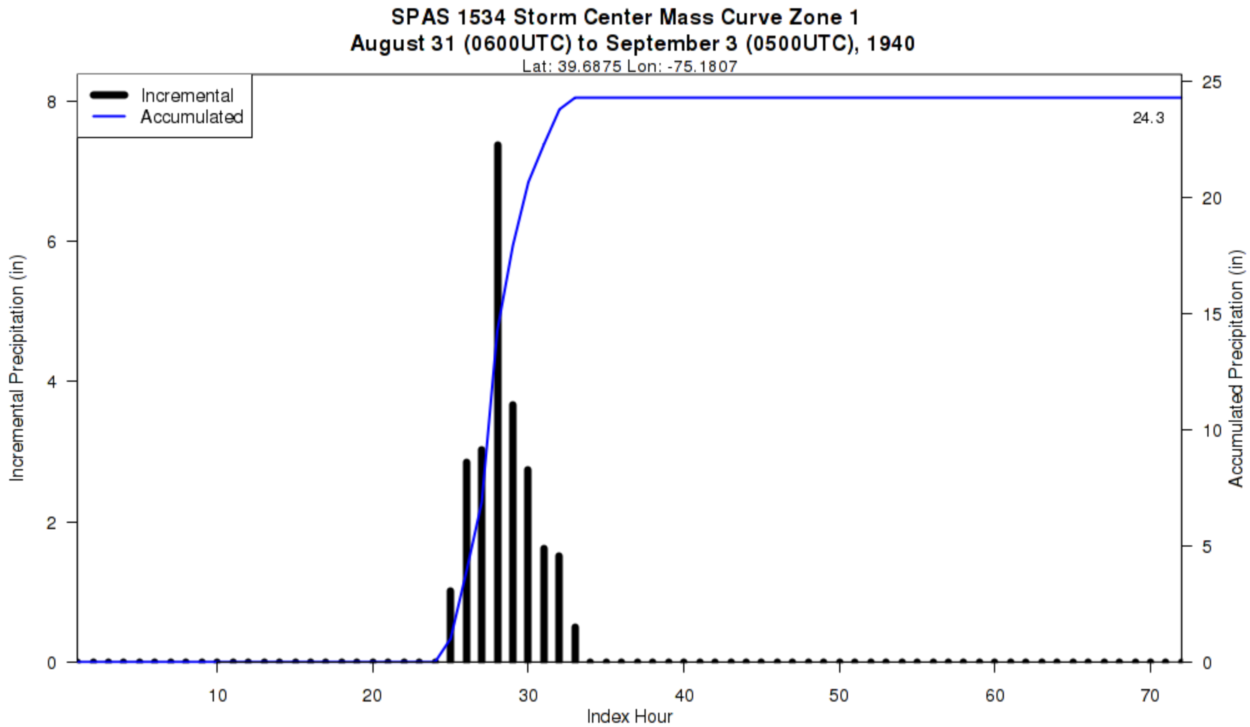
Depth-Area-Duration (DAD) analysis: Yes

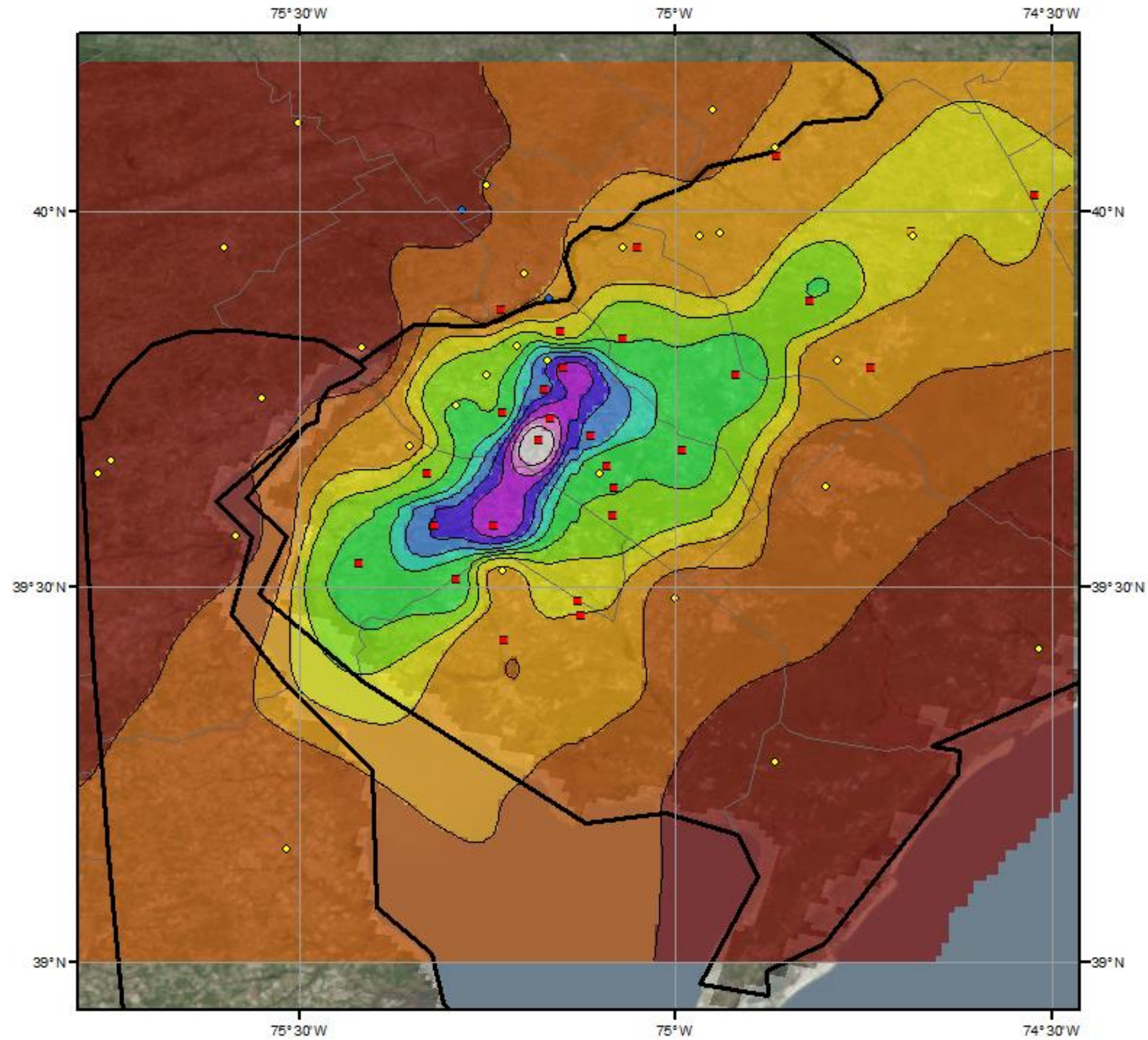
Reliability of results: This analysis was based on hourly data, daily data, supplemental station data and bucket survey data. Twenty-seven hourly station, from the USACE NA 2-4 report, were digitized and used in the analysis. Data from SPAS 1023 were used in the analysis, additional data extraction was also completed. We have a good degree of confidence in the station based storm total results, the spatial pattern is dependent on the station data and the basemap, the timing is based on hourly and hourly pseudo stations.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1534_1	-75.1807	39.6875	103	15-Aug	76.00	2.99	0.03	74	2.960	81.41	3.86	0.03	85	3.830	1.294

Storm 1534- August 31 (0600 UTC) - September 3 (0500 UTC), 1940													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
Area (mi²)	Duration (hours)												
	1	2	3	4	5	6	12	18	24	36	48	72	Total
0.4	7.35	11.02	14.02	16.85	19.58	21.20	24.20	24.20	24.20	24.20	24.20	24.20	24.20
1	7.29	10.95	13.90	16.70	19.42	21.02	23.99	23.99	23.99	23.99	23.99	23.99	23.99
10	6.80	10.59	13.34	15.91	18.60	20.13	22.62	22.62	22.62	22.62	22.62	22.62	22.62
25	6.19	9.69	12.91	15.19	17.33	19.05	20.94	20.94	20.94	20.94	20.94	20.94	20.94
50	5.44	8.89	12.22	14.37	16.32	18.00	19.71	19.71	19.71	19.71	19.71	19.71	19.71
100	4.51	8.12	11.06	13.11	14.99	16.51	18.11	18.11	18.11	18.11	18.11	18.11	18.11
150	4.05	7.50	10.23	12.17	13.83	15.25	16.78	16.78	16.78	16.78	16.78	16.78	16.78
200	3.87	6.99	9.59	11.37	12.87	14.24	15.71	15.71	15.71	15.71	15.71	15.71	15.71
300	3.54	6.28	8.68	10.19	11.57	12.79	14.18	14.18	14.18	14.18	14.18	14.18	14.18
400	3.17	5.70	7.97	9.41	10.76	11.85	13.18	13.18	13.18	13.18	13.18	13.18	13.18
500	2.86	5.25	7.35	8.90	10.11	11.05	12.42	12.43	12.43	12.43	12.43	12.43	12.43
1,000	1.89	3.68	5.36	6.71	7.70	8.47	9.96	9.96	9.96	9.96	9.96	9.96	9.96
2,000	1.31	2.51	3.66	4.65	5.41	5.94	7.43	7.43	7.43	7.43	7.43	7.43	7.43
5,000	0.70	1.30	1.92	2.49	2.94	3.25	4.28	4.28	4.28	4.28	4.28	4.28	4.28




SPAS 1534 Storm Center Mass Curve Zone 1
August 31 (0600UTC) to September 3 (0500UTC), 1940
Lat: 39.6875 Lon: -75.1807
Incremental
Accumulated
24.3
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
2
4
6
8
10
20
30
40
50
60
70
0
5
10
15
20
25



Total Storm (72-hr) Precipitation (inches)
08/31/1940 0600 UTC - 09/03/1940 0500 UTC
SPAS- #1534

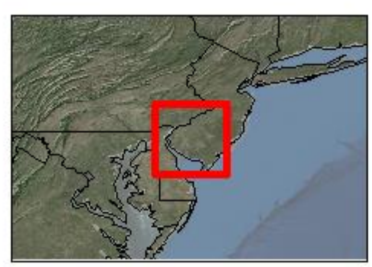
Gauges

- Daily
- Hourly
- Hourly Pseudo
- Supplemental

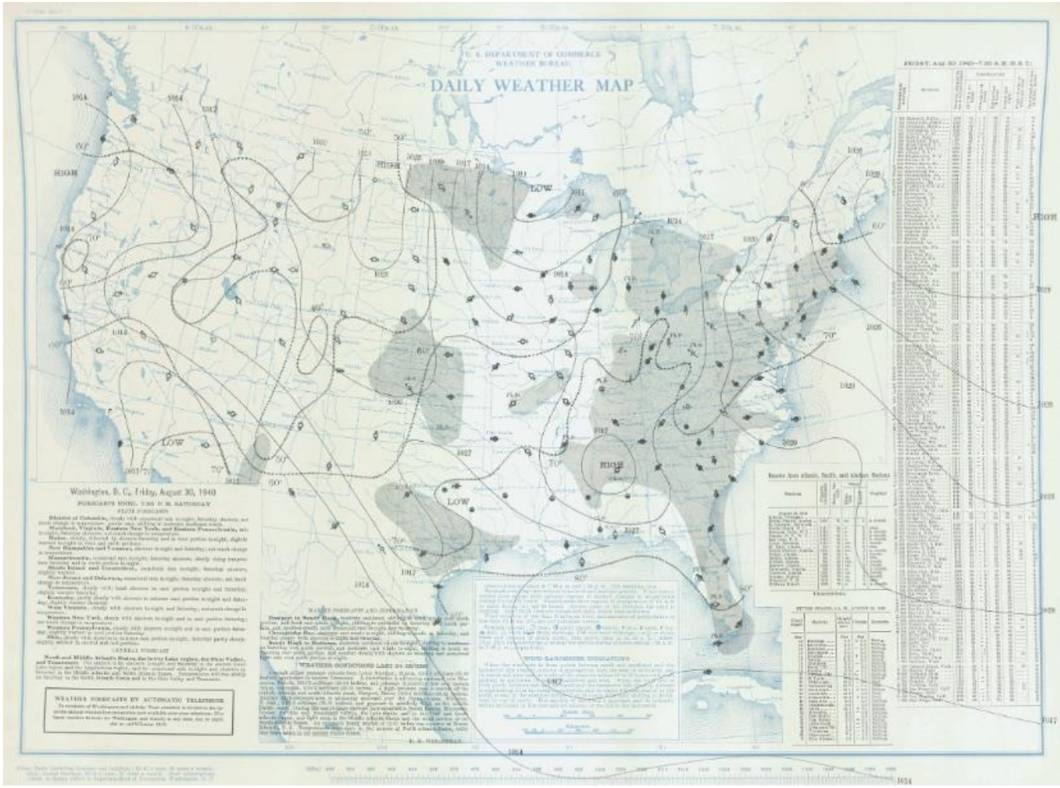
Miles: 0, 5, 10, 20
Kilometers: 0, 15, 30, 60

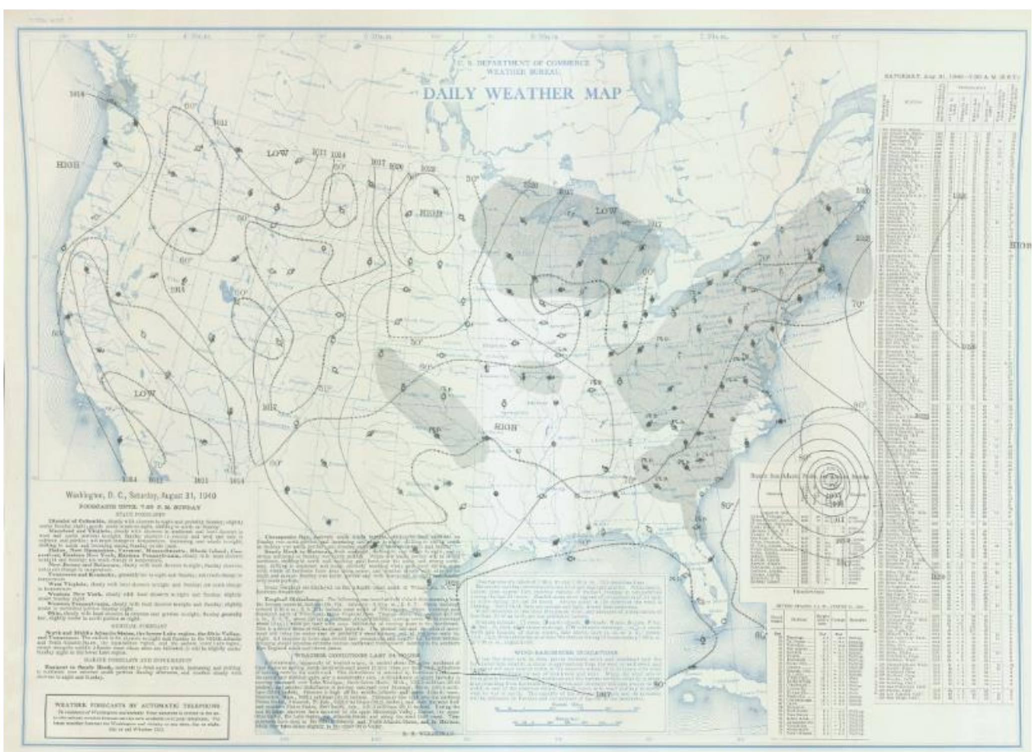
Precipitation (inches)

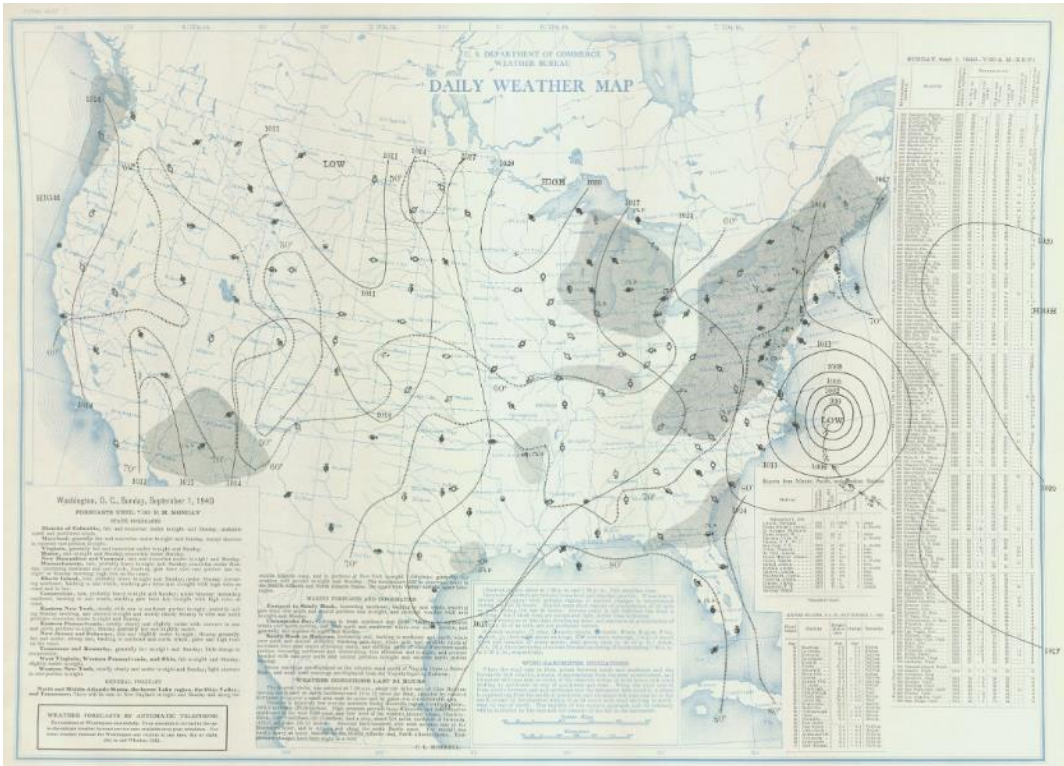
0.06 - 2.00	6.01 - 8.00	12.01 - 14.00	18.01 - 20.00
2.01 - 4.00	8.01 - 10.00	14.01 - 16.00	20.01 - 22.00
4.01 - 6.00	10.01 - 12.00	16.01 - 18.00	22.01 - 26.00



6/8/2015

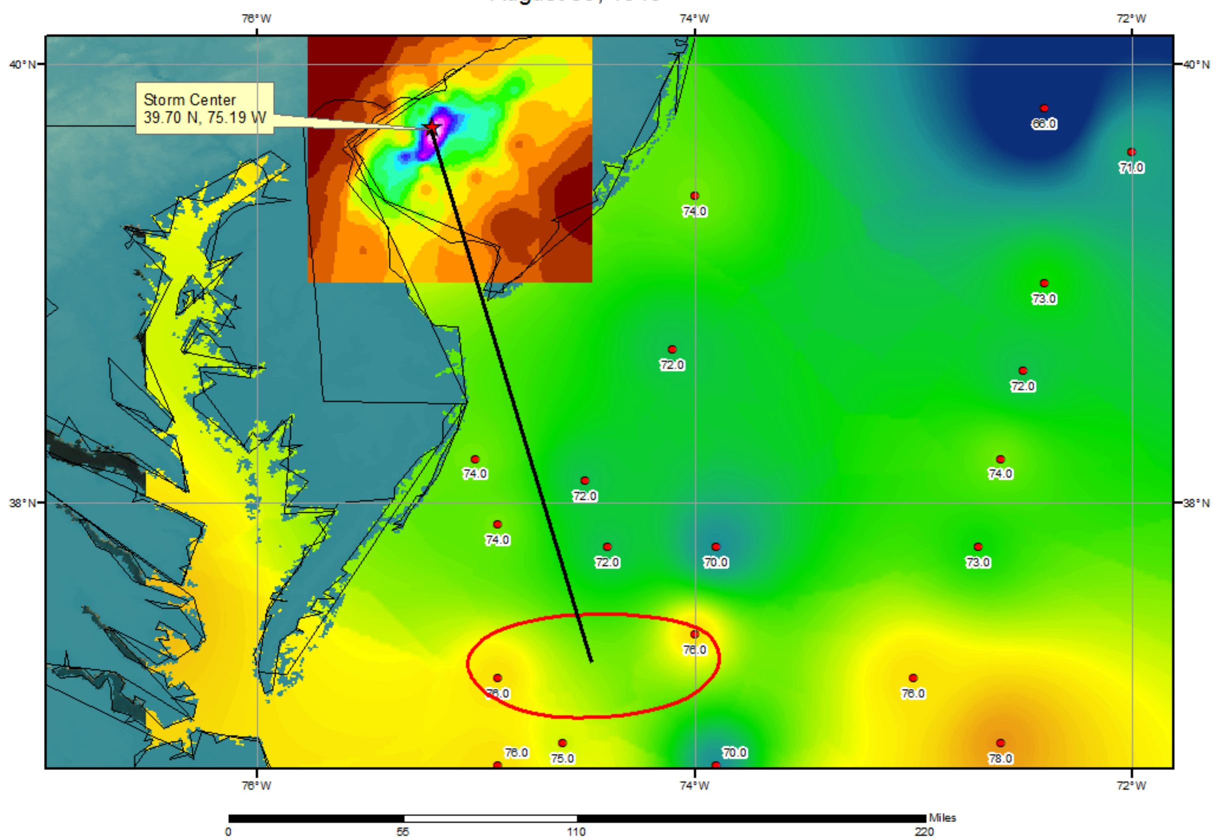

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Friday, August 30, 1940

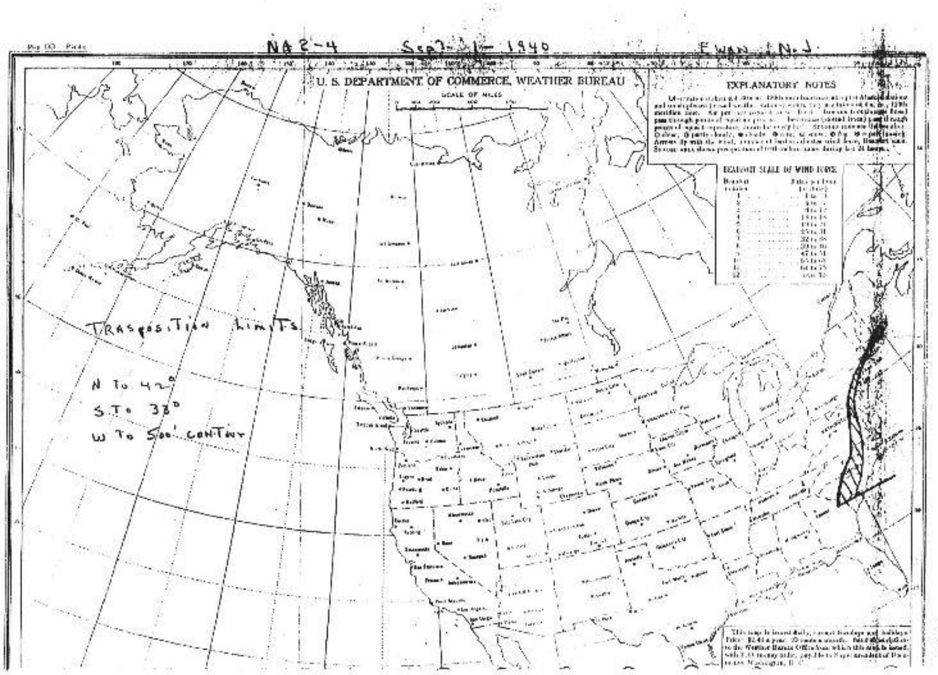

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Saturday, August 31, 1940


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
LOW
HIGH
Washington, D. C., Sunday, September 1, 1940

SPAS 1023 Ewan, NJ Storm Analysis

August 30, 1940




NA 2-4
Sept 1 1940
Ewan N.J.
U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
SCALE OF MILES
EXPLANATORY NOTES
BEAUFORT SCALE OF WIND FORCE
TRASPOSITION LIMITS
N To 42°
S To 33°
W To 500' CONTOUR

Storm Precipitation Analysis System (SPAS) For Storm #1681_1
SPAS Analysis

General Storm Location: Smethport, PA

Storm Dates: July 16-20, 1942

Event:

DAD Zone 1

Latitude: 41.8438

Longitude: -78.2687

Max. Grid Rainfall Amount: 35.3”

Max. Observed Rainfall Amount:

Number of Stations:

SPAS Version: 10.0

Basemap:

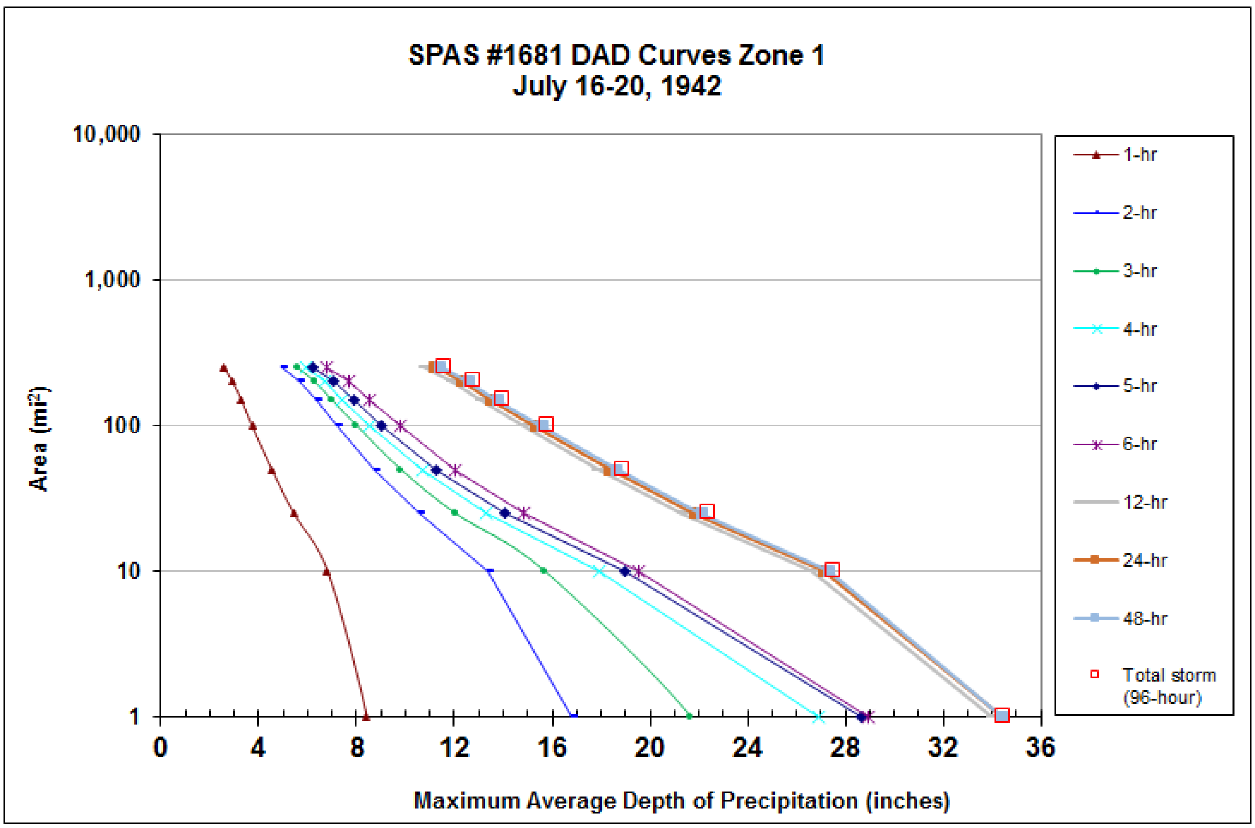
Spatial resolution:

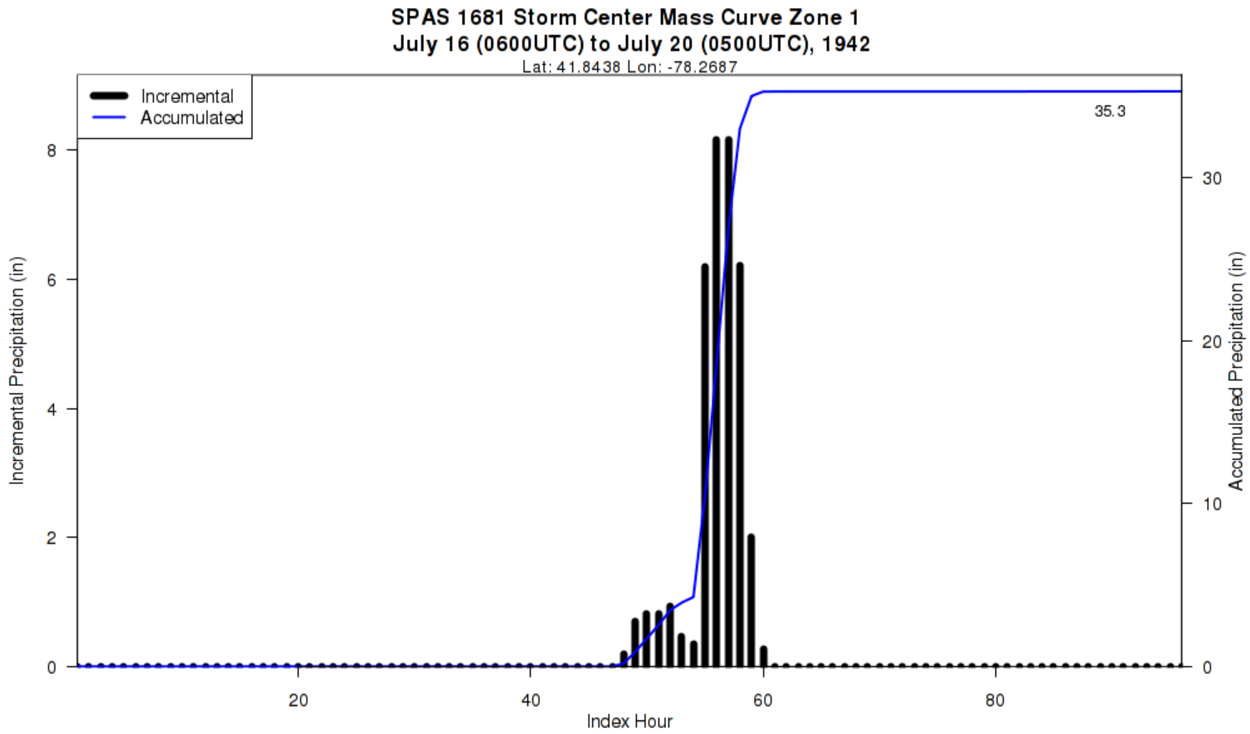
Radar Included: No

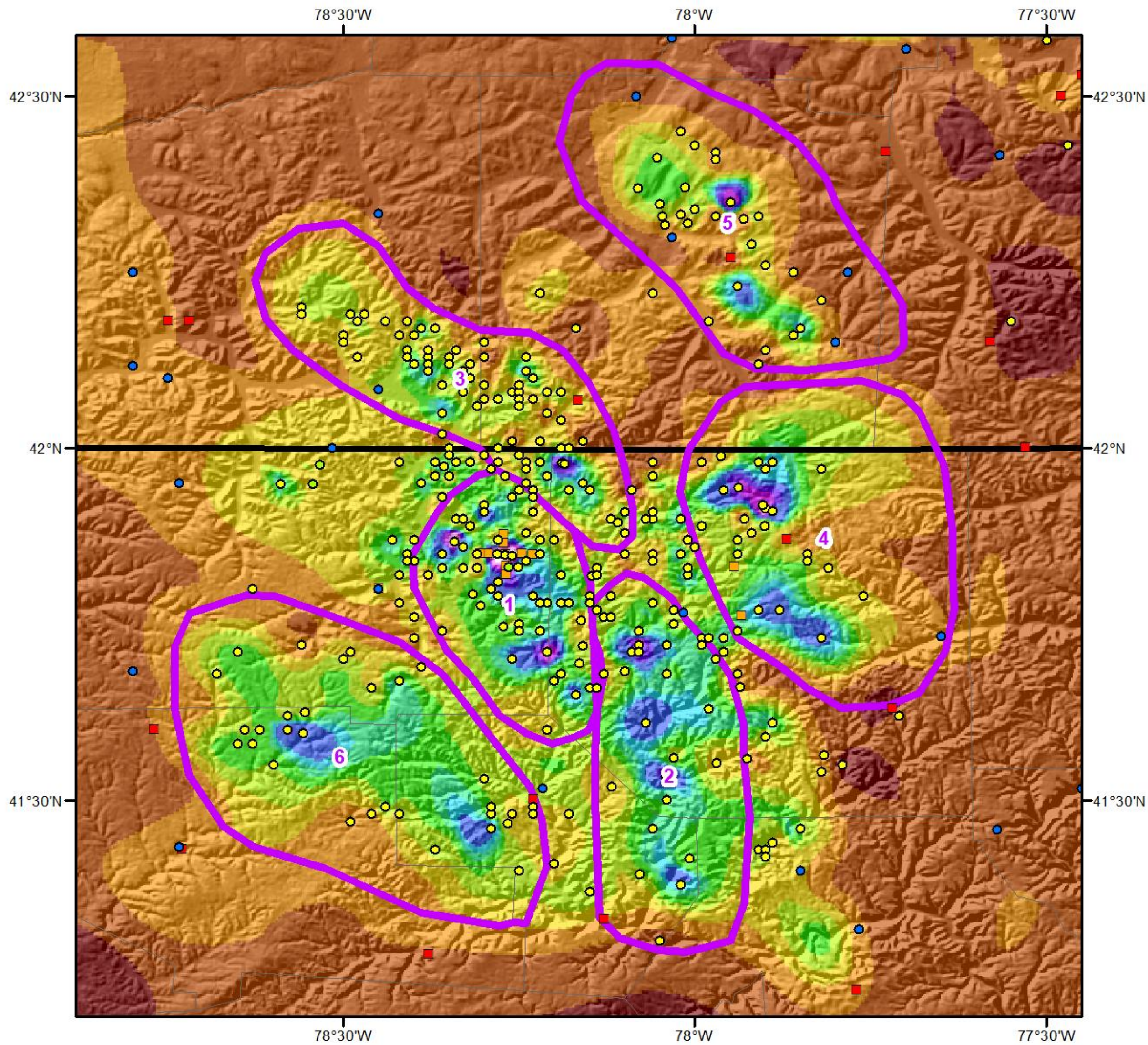
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1681_1	-78.2687	41.8438	1,799	15-Jul	77.50	3.22	0.48	77	2.740	78.00	3.29	0.48	78	2.810	1.026

Storm 1681 Zone 1 - July 16 (0600 UTC) - July 20 (0500 UTC), 1942											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
areasqmi	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	48-hr	96-hr	Total
0.4	8.53	17.01	22.08	27.97	29.89	30.22	34.46	34.75	34.82	34.80	34.80
1	8.41	16.78	21.67	26.88	28.66	28.97	33.98	34.37	34.40	34.45	34.45
10	6.81	13.34	15.71	17.92	18.96	19.51	26.56	27.09	27.31	27.53	27.53
25	5.43	10.54	12.05	13.30	14.06	14.84	21.33	21.84	22.13	22.42	22.42
50	4.54	8.75	9.81	10.70	11.27	12.05	17.86	18.35	18.65	18.94	18.94
100	3.73	7.17	8.00	8.54	8.99	9.82	14.87	15.32	15.59	15.83	15.83
150	3.30	6.34	6.98	7.44	7.89	8.51	13.11	13.52	13.78	14.01	14.01
200	2.94	5.65	6.29	6.74	7.05	7.69	11.92	12.35	12.57	12.82	12.82
252	2.58	4.97	5.56	5.91	6.25	6.79	10.77	11.21	11.42	11.64	11.64
400											
500											
1,000											
2,000											
3,500											
5,000											
7,500											




SPAS 1681 Storm Center Mass Curve Zone 1
July 16 (0600UTC) to July 20 (0500UTC), 1942
Lat: 41.8438 Lon: -78.2687
Incremental
Accumulated
35.3
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
2
4
6
8
10
20
30
40
60
80



Total Storm (96-hr) Precipitation (inches)
07/16/1942 0600 UTC - 07/20/1942 0500 UTC
SPAS #1681 - Version 10

Gauges

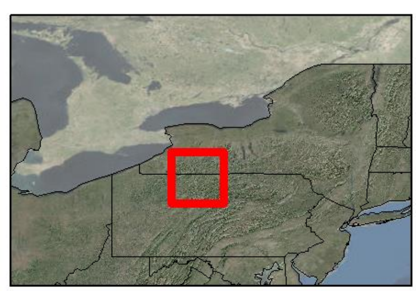
- D
- H
- HP
- S
- SE

Miles: 0, 3.5, 7, 14

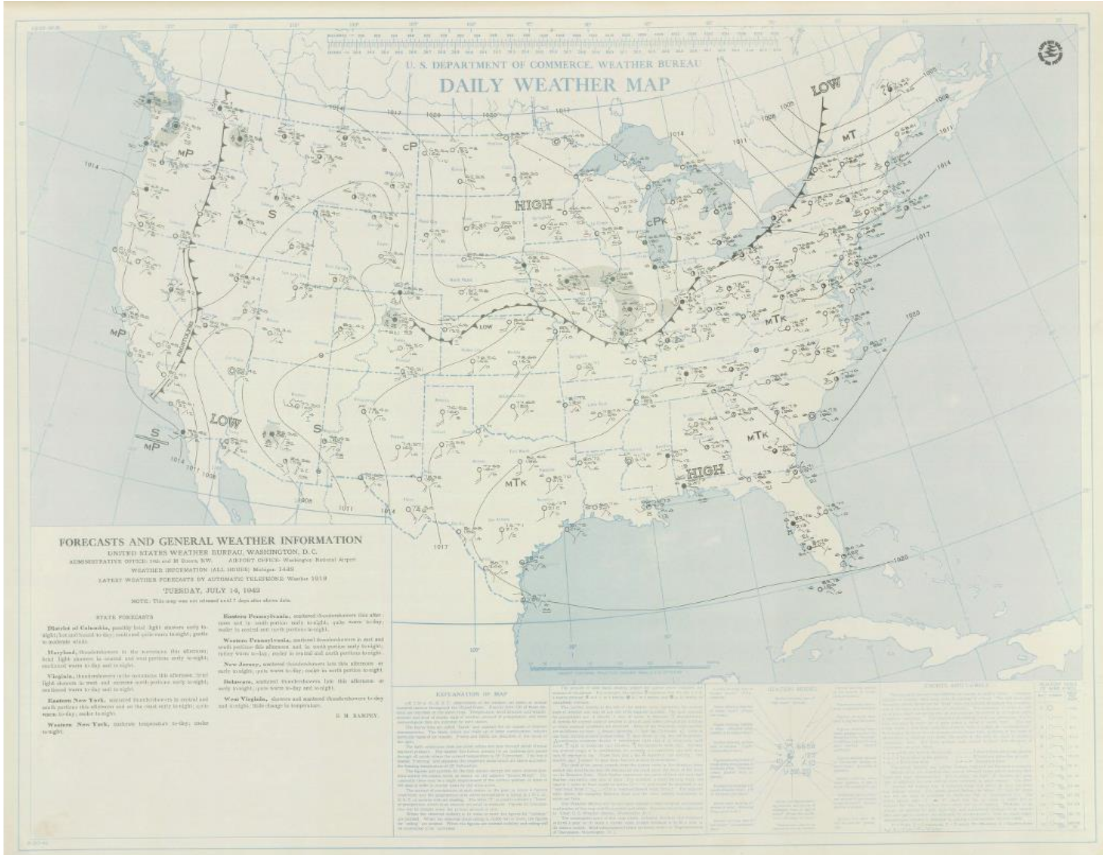
Kilometers: 0, 10, 20, 40

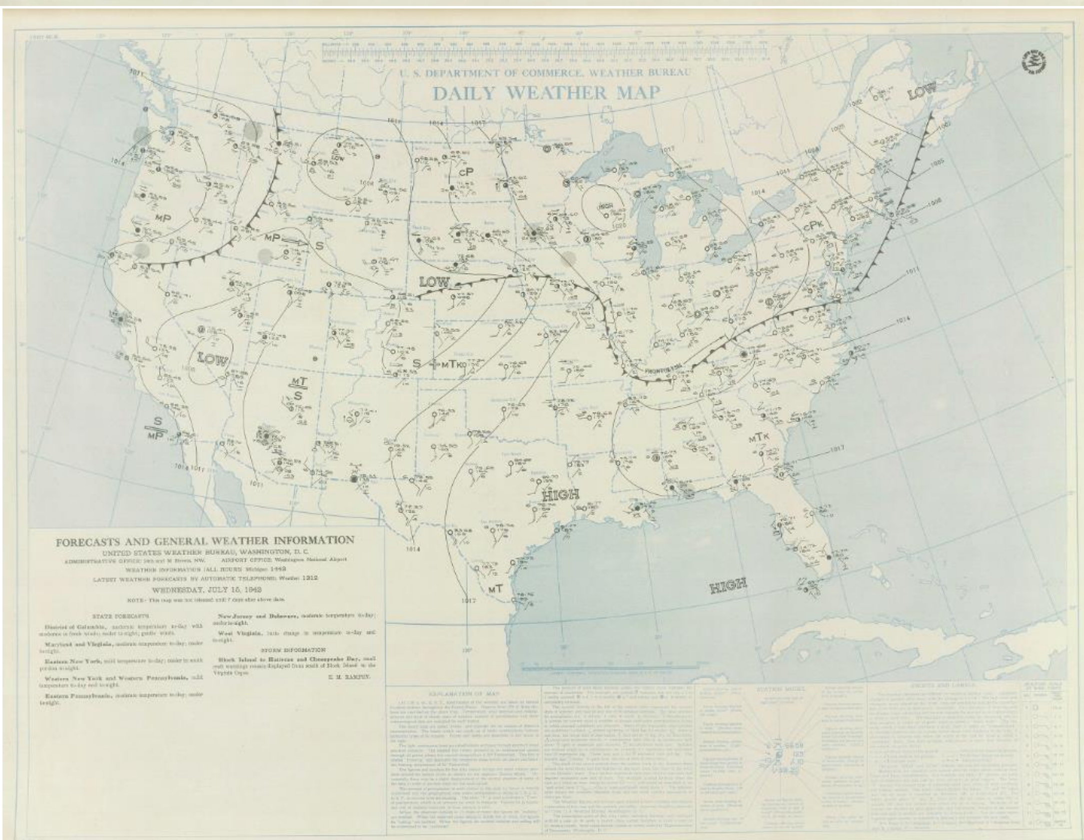
Precipitation (inches)

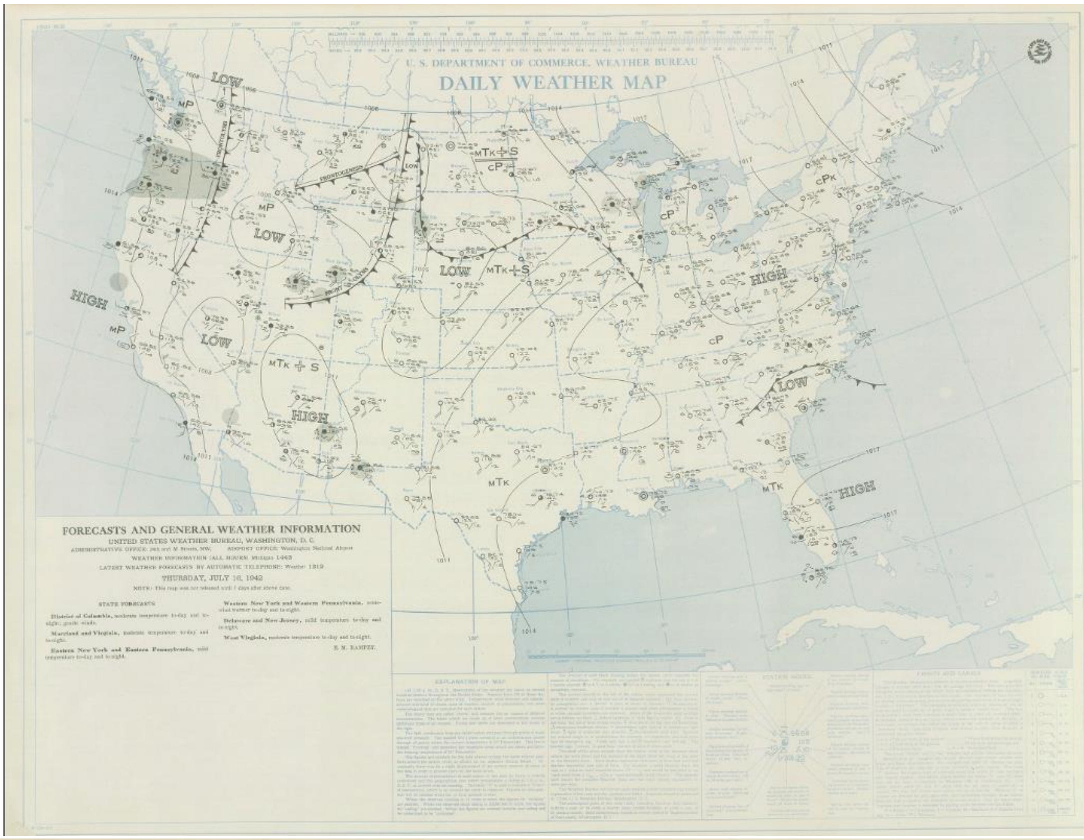
0.00 - 2.00	6.01 - 8.00	12.01 - 14.00	20.01 - 24.00	32.01 - 36.00
2.01 - 4.00	8.01 - 10.00	14.01 - 16.00	24.01 - 28.00	
4.01 - 6.00	10.01 - 12.00	16.01 - 20.00	28.01 - 32.00	

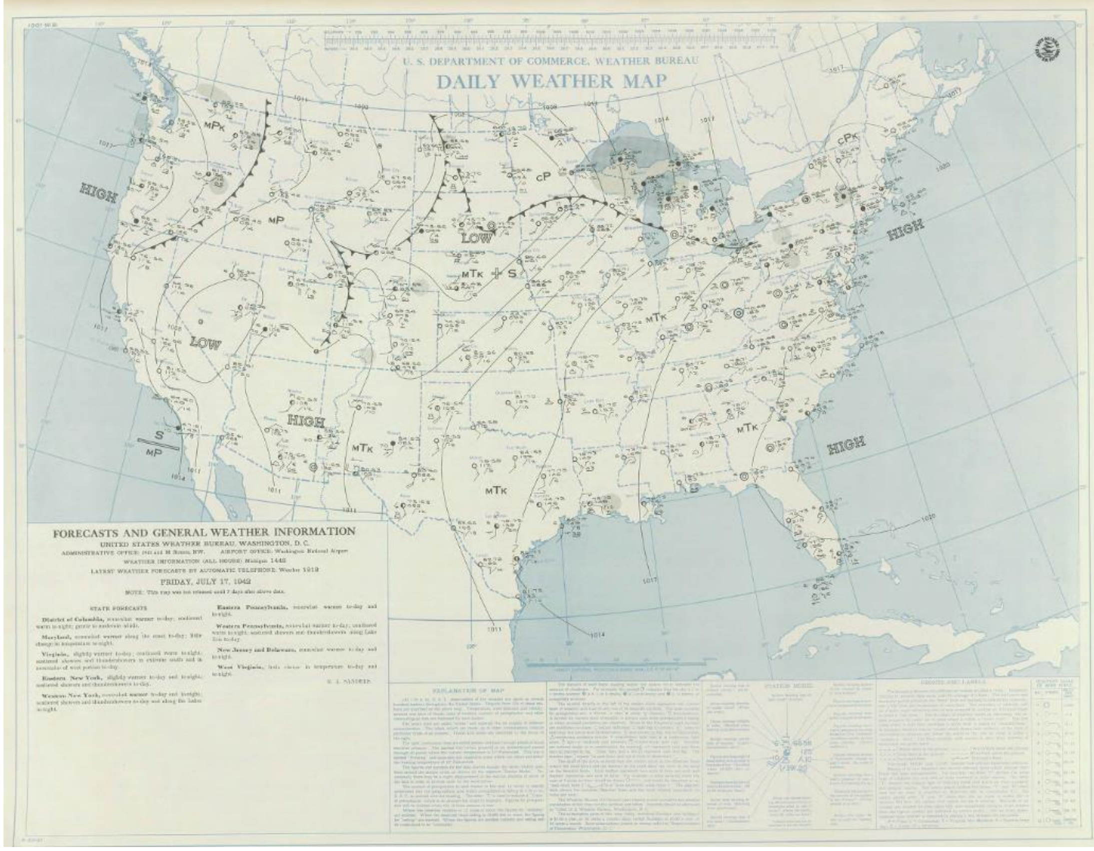


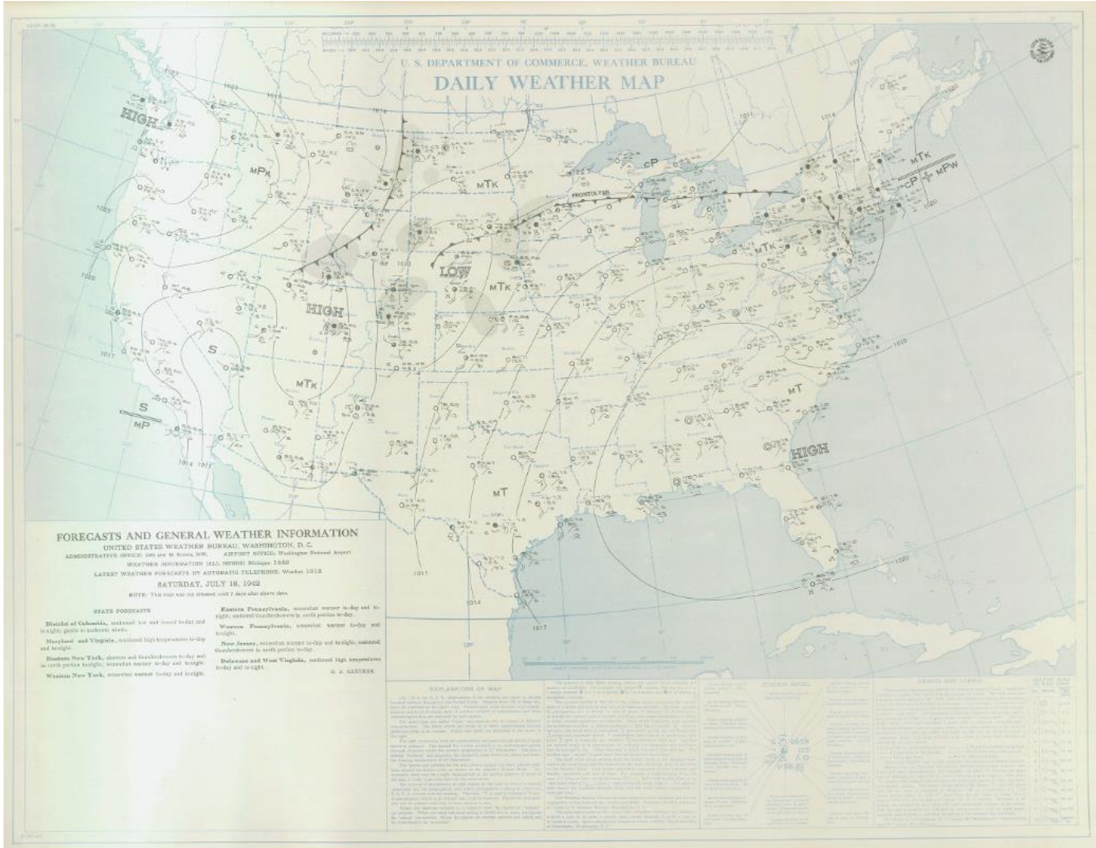
10/8/2018

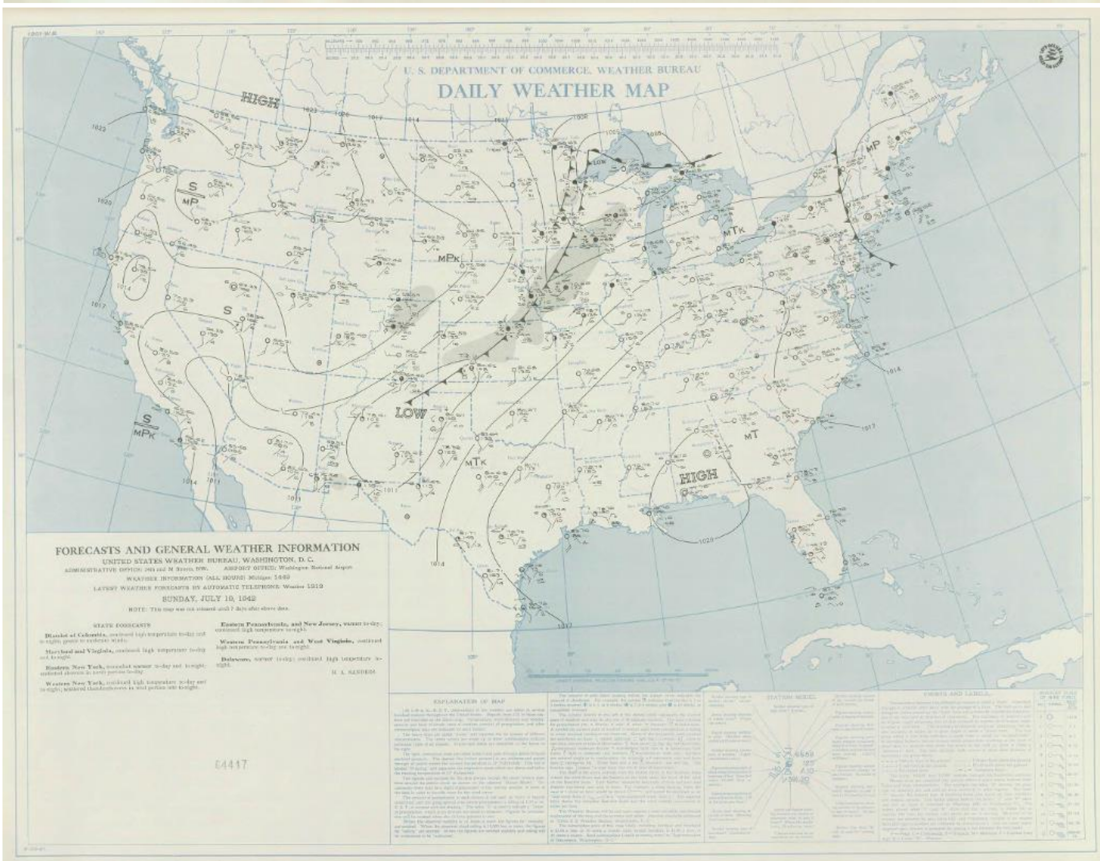

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
TUESDAY, JULY 14, 1942
STATE FORECASTS
E. H. BARPEY.

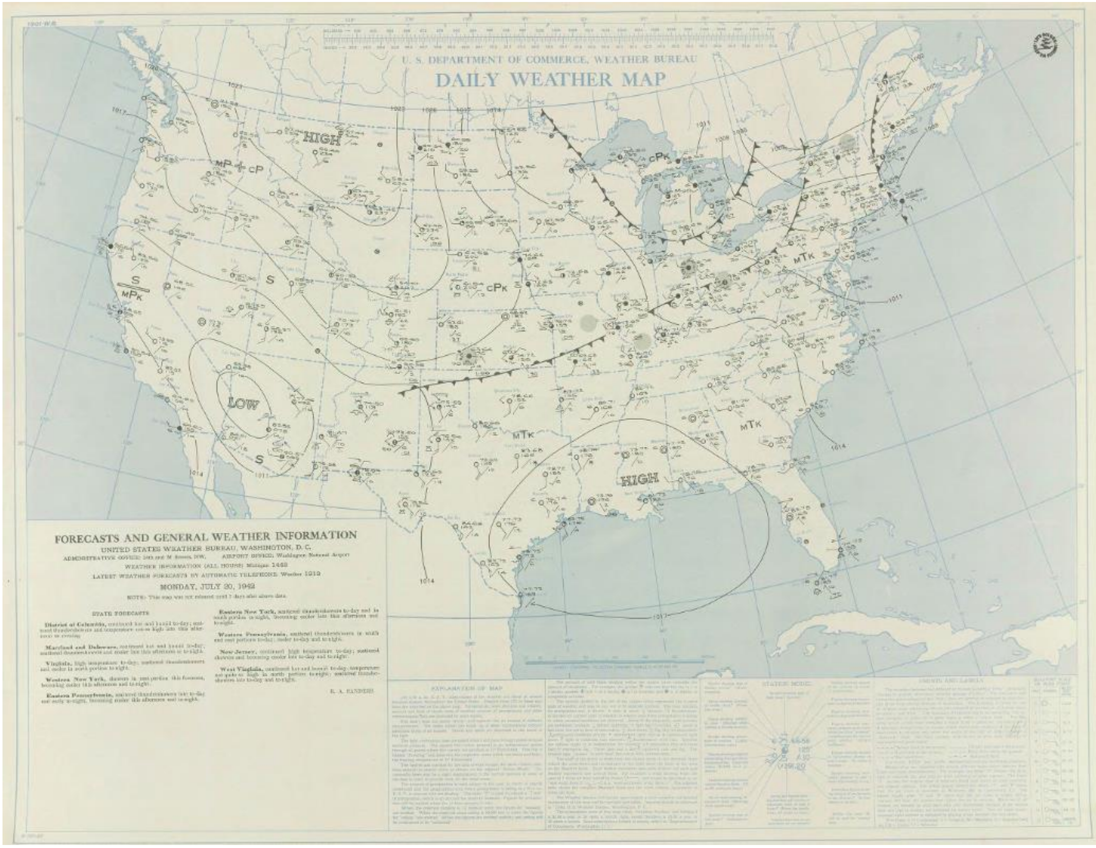

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
WEDNESDAY, JULY 15, 1942
STATE FORECASTS
STORM INFORMATION

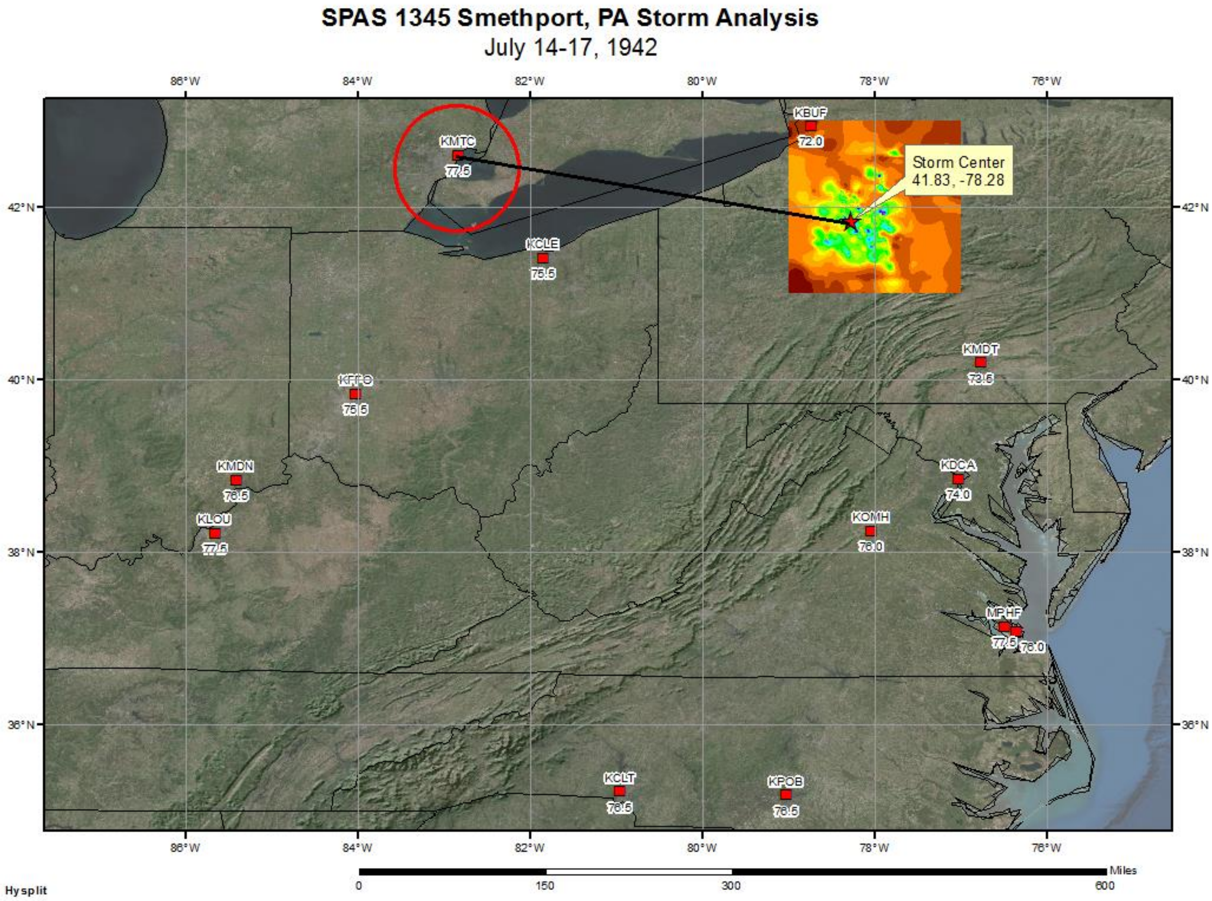

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
THURSDAY, JULY 16, 1942
STATE FORECASTS
West Virginia, moderate temperature to-day and to-night.
E. M. BANPTZ.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
FRIDAY, JULY 17, 1942
STATE FORECASTS


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
STATE FORECASTS


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
STATE FORECASTS
E4417


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
MONDAY, JULY 20, 1942
STATE FORECASTS
EXPLANATION OF MAP
STATION MODEL


SPAS 1345 Smethport, PA Storm Analysis
July 14-17, 1942
Storm Center
41.83, -78.28
KBUF
72.0
KMTC
77.5
KCLE
76.5
KMDT
73.5
KFFO
76.5
KMDN
76.5
KLOU
77.5
KDCA
74.0
KOMH
76.0
MPHF
77.5
76.0
KCLT
76.5
KPOB
76.5
86°W
84°W
82°W
80°W
78°W
76°W
42°N
40°N
38°N
36°N
Miles
0
150
300
600
Hysplit

Storm Precipitation Analysis System (SPAS) For Storm #1681_2 SPAS Analysis

General Storm Location: Smethport, PA

Storm Dates: July 16-20, 1942

Event:

DAD Zone 2

Latitude: 41.7188

Longitude: -78.0812

Max. Grid Rainfall Amount: 26.67”

Max. Observed Rainfall Amount:

Number of Stations:

SPAS Version: 10.0

Basemap:

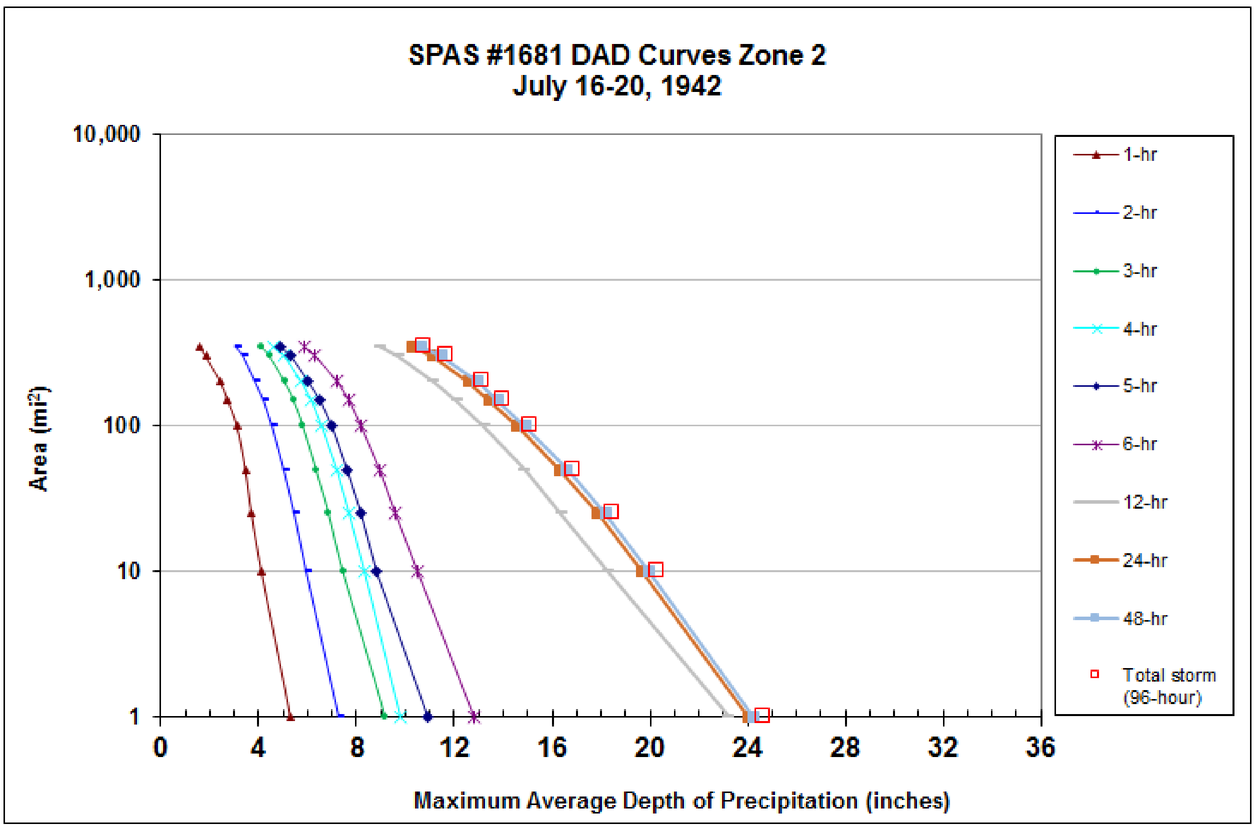
Spatial resolution:

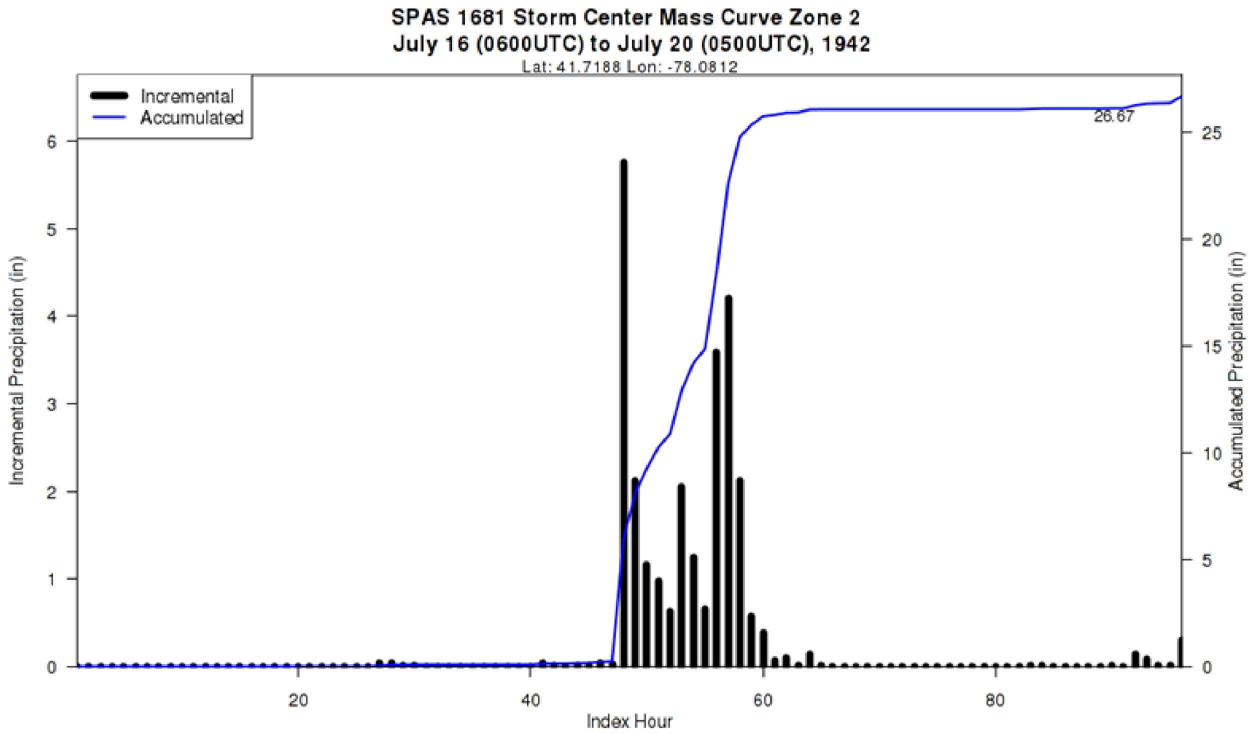
Radar Included: No

Depth-Area-Duration (DAD) analysis: Yes

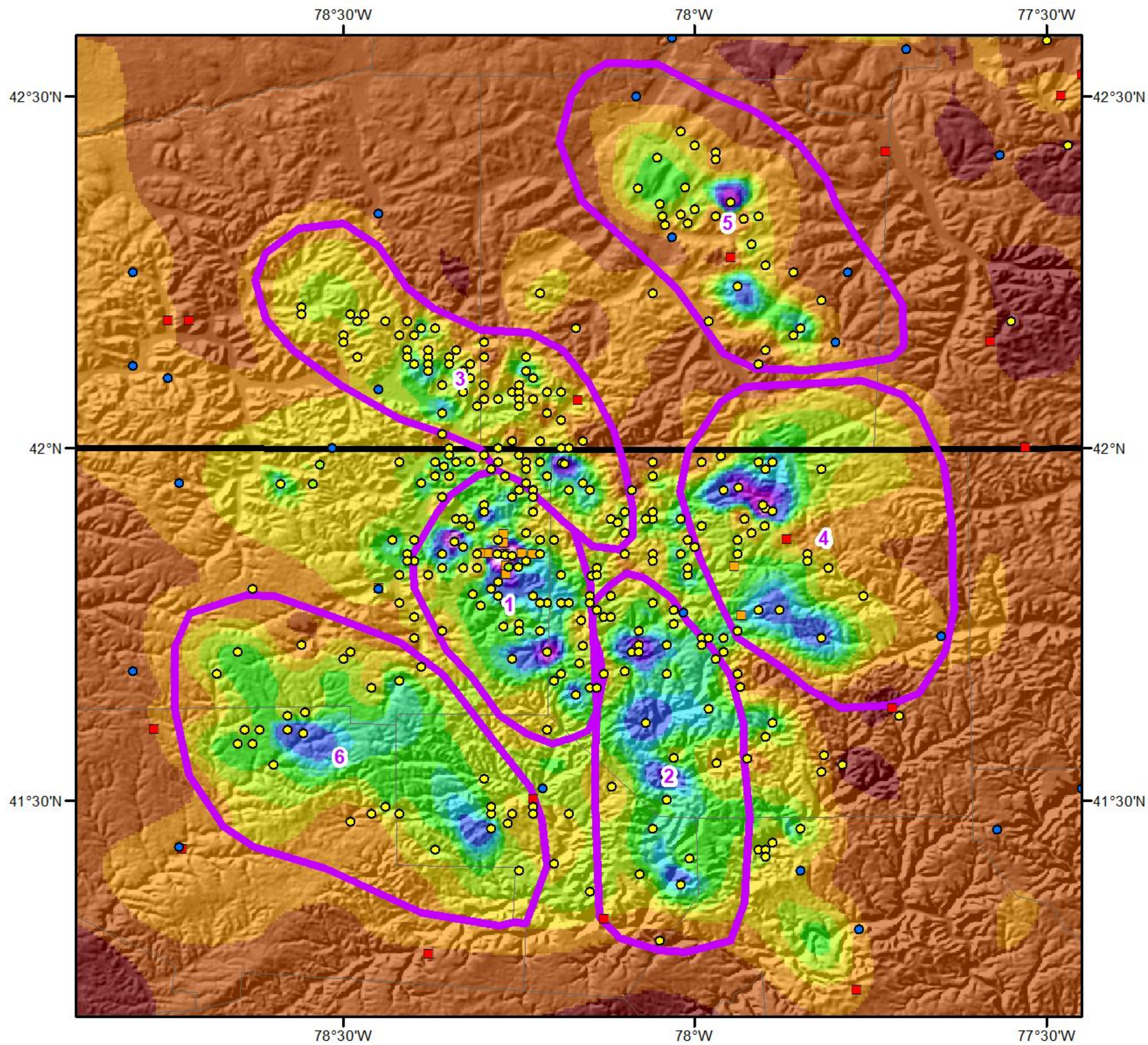
						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1681_2	-78.0812	41.7188	2,236	15-Jul	77.50	3.22	0.57	77	2.645	78.00	3.29	0.58	78	2.710	1.025

Storm 1681 Zone 2 - July 16 (0600 UTC) - July 20 (0500 UTC), 1942											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
areasqmi	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	48-hr	96-hr	Total
0.4	5.60	7.68	9.68	10.33	11.54	13.52	24.45	25.31	25.51	26.01	26.01
1	5.30	7.27	9.19	9.80	10.93	12.83	23.20	24.02	24.21	24.69	24.69
10	4.12	5.95	7.47	8.31	8.84	10.47	18.26	19.65	19.93	20.28	20.28
25	3.71	5.44	6.88	7.68	8.16	9.61	16.36	17.87	18.18	18.48	18.48
50	3.46	5.03	6.37	7.20	7.64	8.94	14.86	16.29	16.60	16.87	16.87
100	3.11	4.54	5.83	6.60	6.99	8.20	13.22	14.59	14.90	15.15	15.15
150	2.74	4.15	5.45	6.13	6.49	7.68	12.09	13.42	13.77	13.99	13.99
200	2.44	3.85	5.09	5.70	6.03	7.18	11.15	12.59	12.98	13.19	13.19
300	1.84	3.35	4.47	5.01	5.29	6.32	9.71	11.10	11.47	11.66	11.66
351	1.60	3.08	4.14	4.61	4.87	5.85	8.92	10.26	10.61	10.80	10.80
500											
1,000											
2,000											
3,500											
5,000											
7,500											





SPAS 1681 Storm Center Mass Curve Zone 2
July 16 (0600UTC) to July 20 (0500UTC), 1942
Lat: 41.7188 Lon: -78.0812
Incremental
Accumulated
26.67
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour



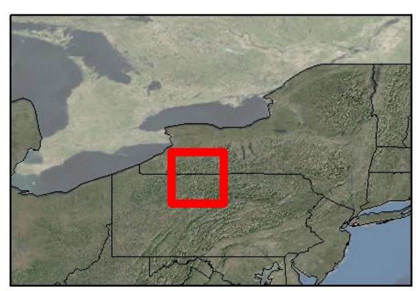
Total Storm (96-hr) Precipitation (inches)
07/16/1942 0600 UTC - 07/20/1942 0500 UTC
SPAS #1681 - Version 10

Gauges
- D
- H
- HP
- S
- SE

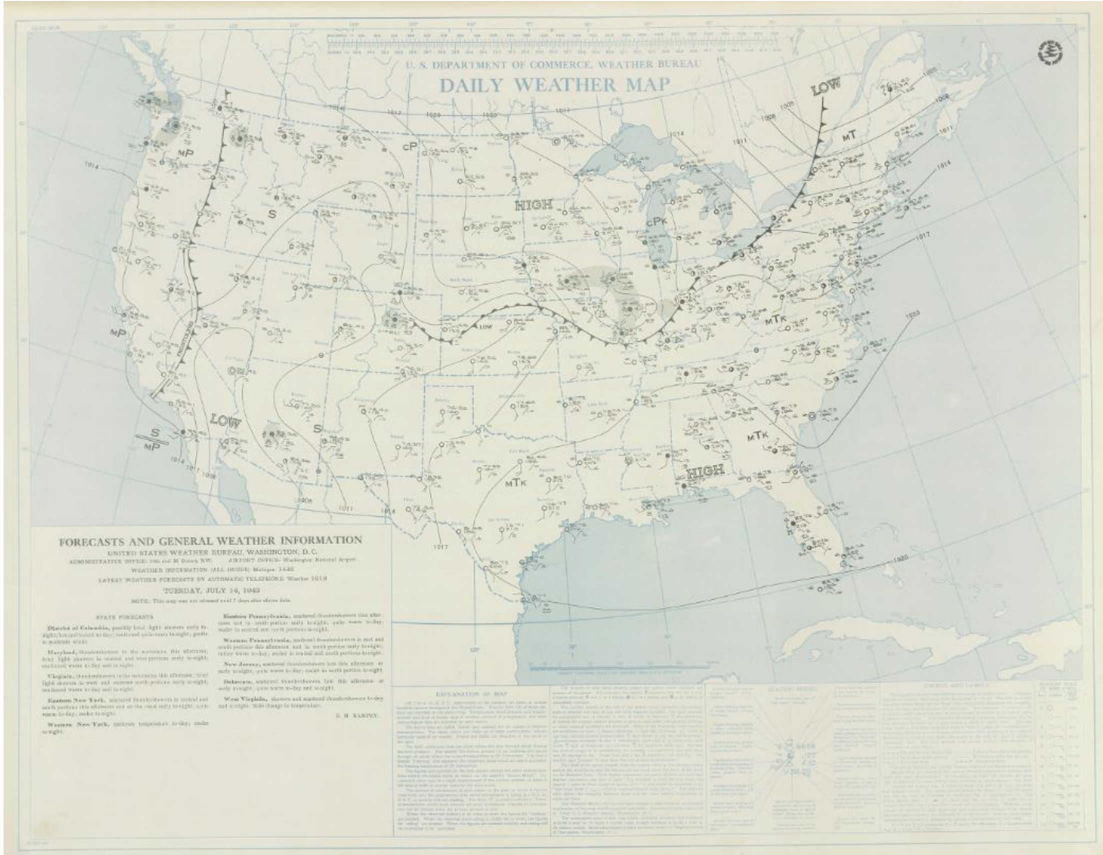
Miles: 0 3.5 7 14
Kilometers: 0 10 20 40

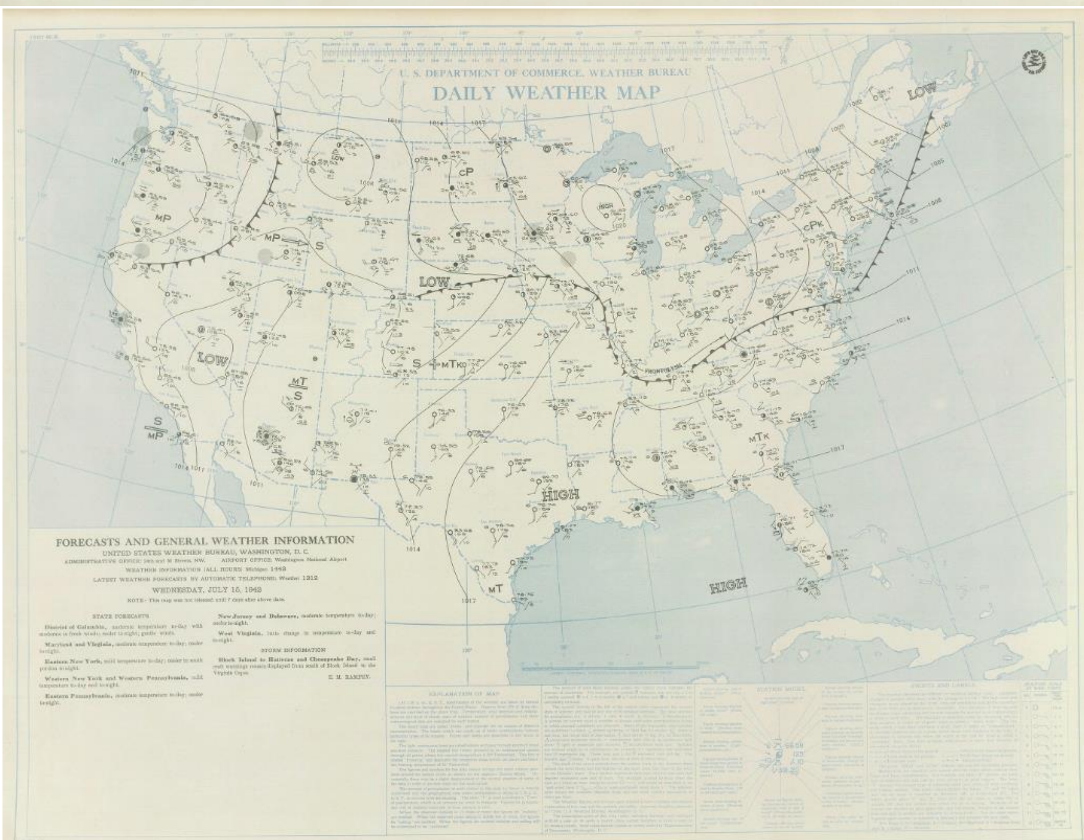
Precipitation (inches)

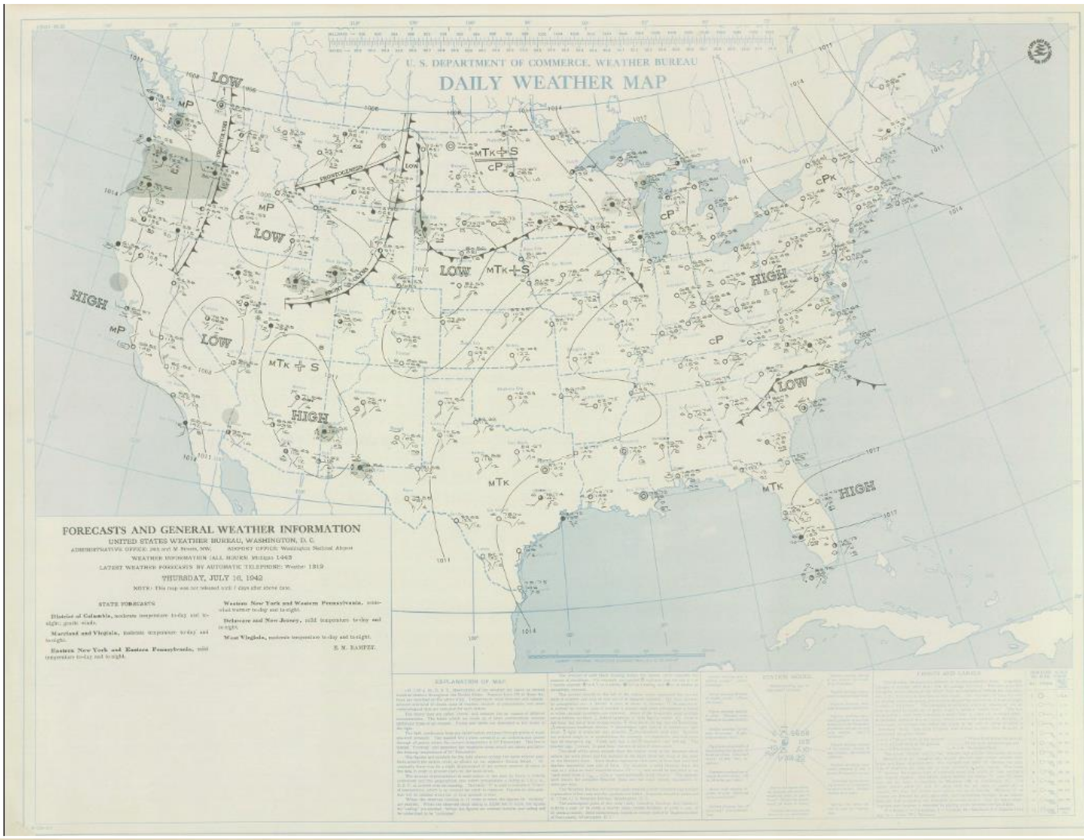
0.00 - 2.00	6.01 - 8.00	12.01 - 14.00	20.01 - 24.00	32.01 - 36.00
2.01 - 4.00	8.01 - 10.00	14.01 - 16.00	24.01 - 28.00	
4.01 - 6.00	10.01 - 12.00	16.01 - 20.00	28.01 - 32.00	

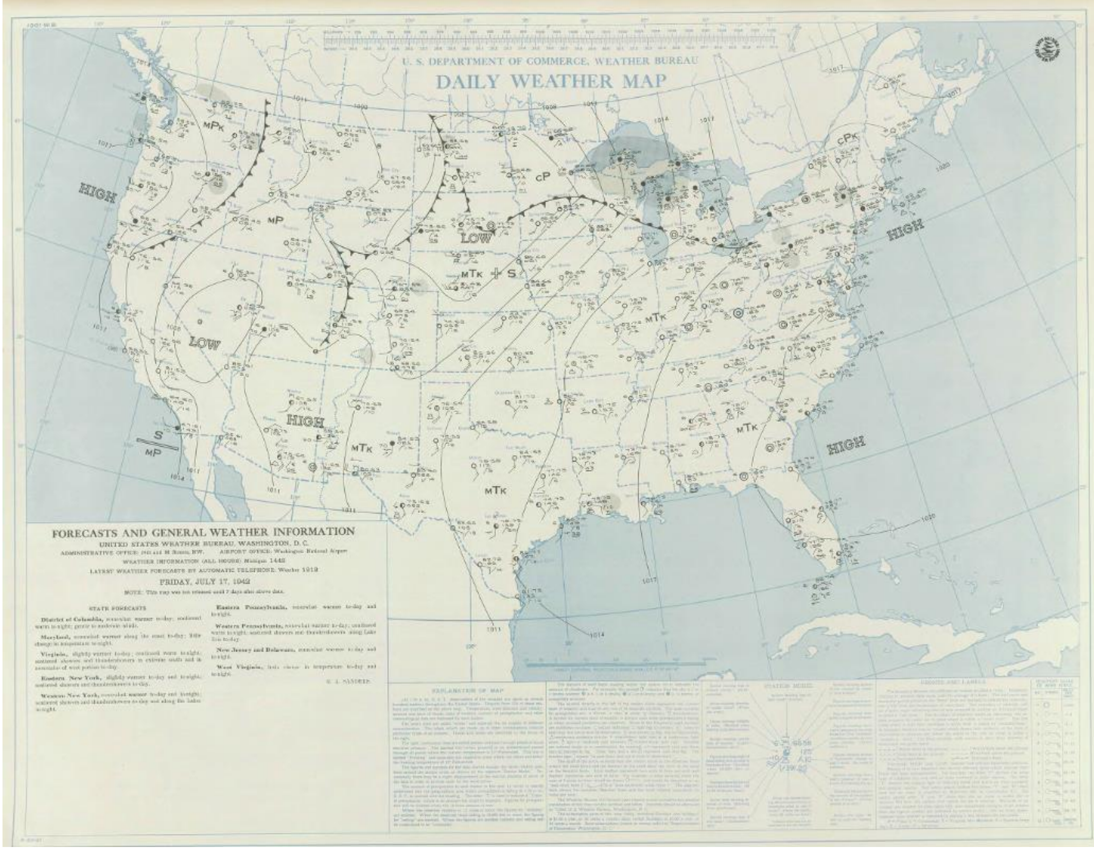


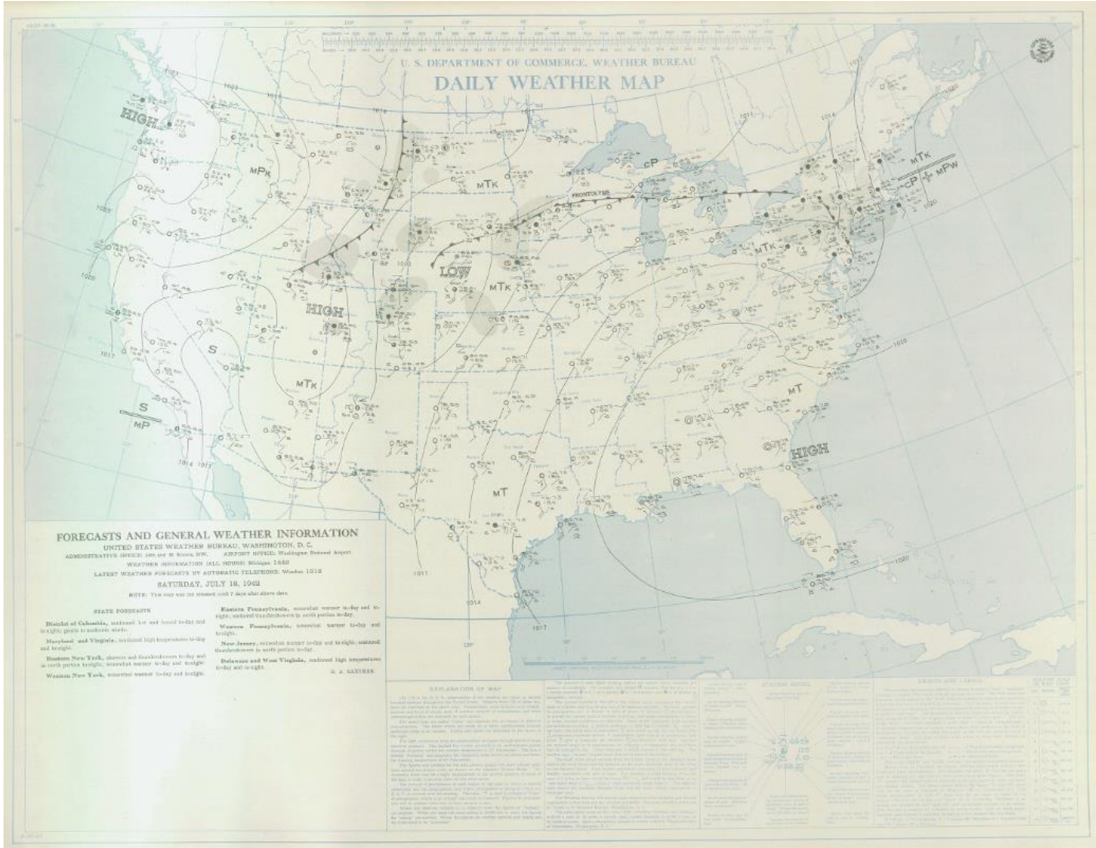
10/8/2018

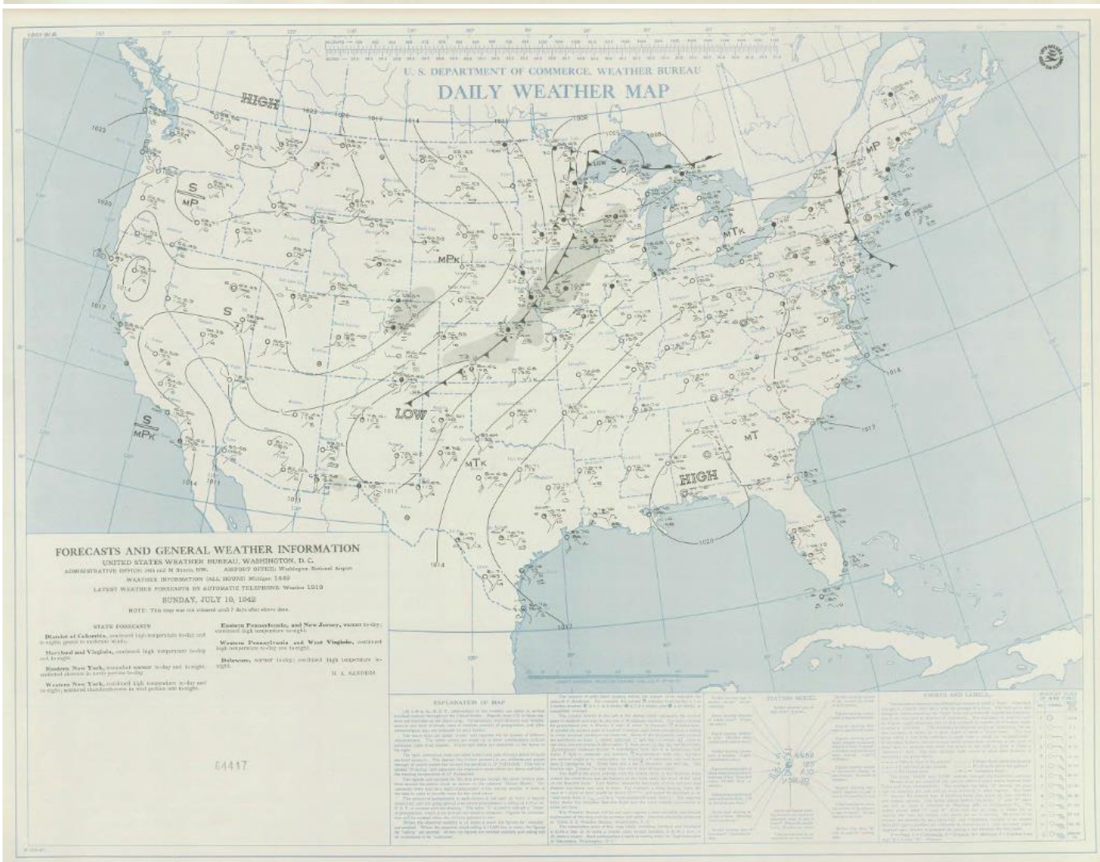

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
TUESDAY, JULY 14, 1942
STATE FORECASTS
District of Columbia,
Maryland,
Virginia,
Eastern New York,
Western New York,
Eastern Pennsylvania,
Western Pennsylvania,
New Jersey,
Delaware,
West Virginia,
EXPLANATION OF MAP

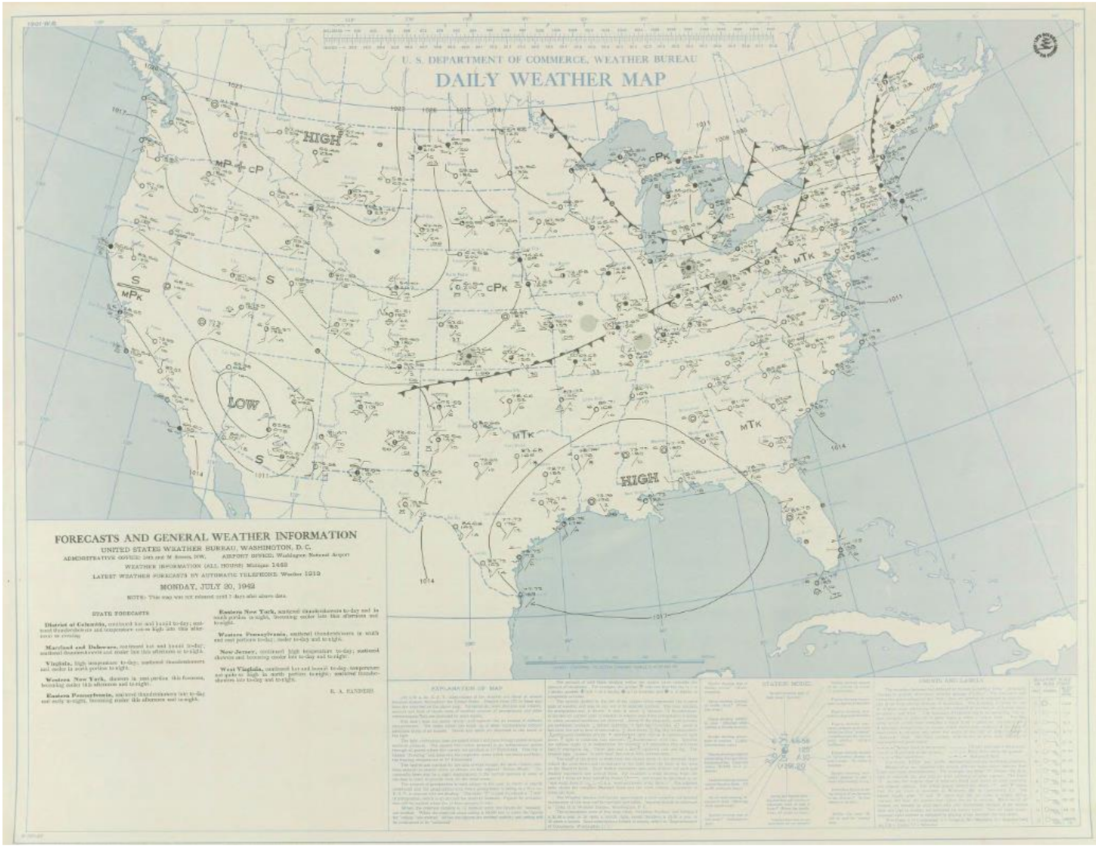

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
LOW
LOW
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
WEDNESDAY, JULY 15, 1942
STATE FORECASTS
District of Columbia,
Maryland and Virginia,
Eastern New York,
Western New York and Western Pennsylvania,
Eastern Pennsylvania,
New Jersey and Delaware,
West Virginia,
STORM INFORMATION
E. M. RAMPEY.
EXPLANATION OF MAP

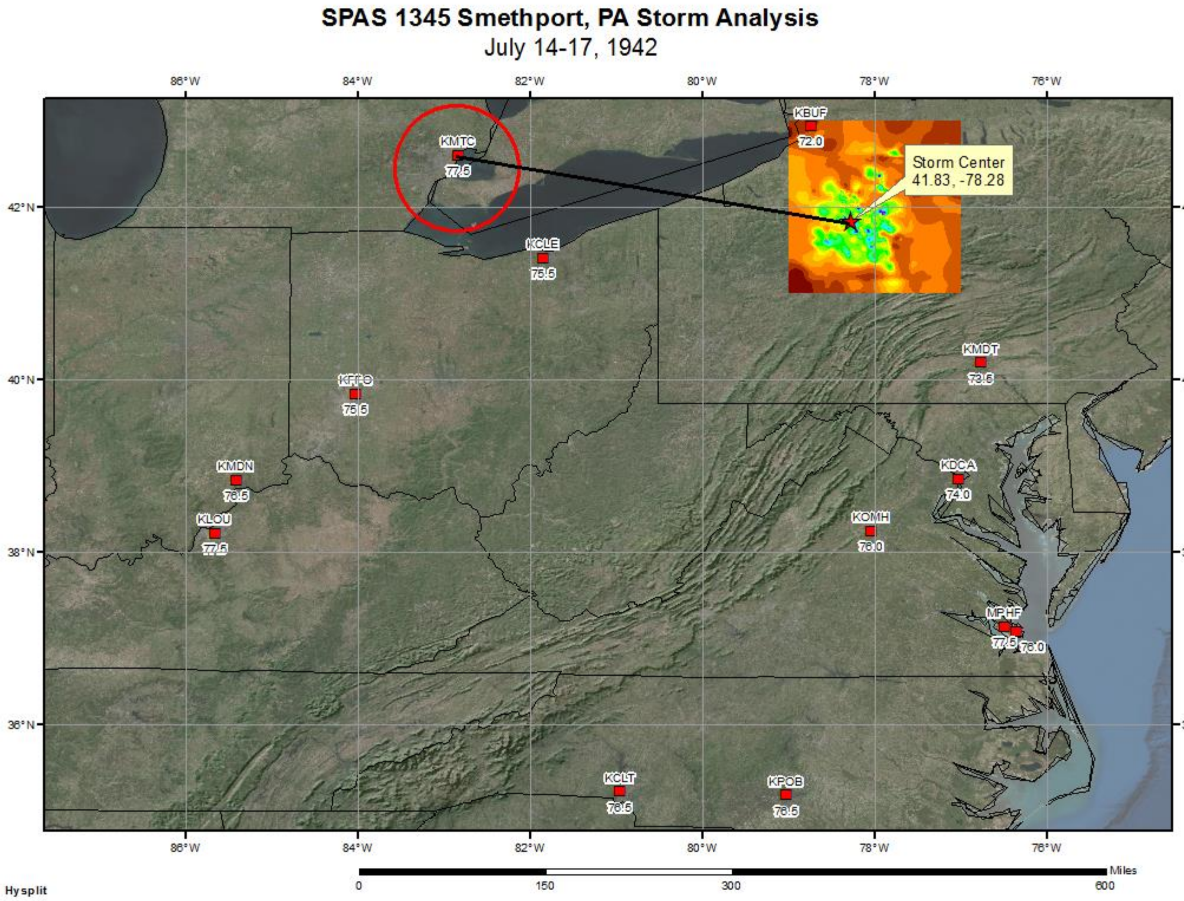

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
THURSDAY, JULY 16, 1942
STATE FORECASTS
EXPLANATION OF MAP
STATION MODEL


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
WEATHER INFORMATION (ALL HOURS) Michigan 1442
LATEST WEATHER FORECASTS BY AUTOMATIC TELEPHONE: Weather 1919
FRIDAY, JULY 17, 1942
STATE FORECASTS
EXPLANATION OF MAP
STATION MODEL


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SATURDAY, JULY 18, 1942
STATE FORECASTS
District of Columbia, continued hot and humid to-day and to-night; gentle to moderate winds.
Maryland and Virginia, continued high temperature to-day and to-night.
Eastern New York, showers and thundershowers to-day and in north portion to-night; somewhat warmer to-day and to-night.
Western New York, somewhat warmer to-day and to-night.
Eastern Pennsylvania, somewhat warmer to-day and to-night; scattered thundershowers in north portion to-day.
Western Pennsylvania, somewhat warmer to-day and to-night.
New Jersey, somewhat warmer to-day and to-night; scattered thundershowers in north portion to-day.
Delaware and West Virginia, continued high temperature to-day and to-night.
EXPLANATION OF MAP


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SUNDAY, JULY 19, 1942
STATE FORECASTS
Eastern Pennsylvania, and New Jersey, warmer to-day; continued high temperature to-night.
Western Pennsylvania and West Virginia, continued high temperature to-day and to-night.
EXPLANATION OF MAP
E4417


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
MONDAY, JULY 20, 1942
STATE FORECASTS
EXPLANATION OF MAP
STATION MODEL


SPAS 1345 Smethport, PA Storm Analysis
July 14-17, 1942
Storm Center
41.83, -78.28
KBUF
72.0
KMTC
77.5
KCLE
76.5
KMDT
73.5
KFFO
76.5
KMDN
76.5
KLOU
77.5
KDCA
74.0
KOMH
76.0
MPHF
77.5
76.0
KCLT
76.5
KPOB
76.5
86°W
84°W
82°W
80°W
78°W
76°W
42°N
40°N
38°N
36°N
Hysplit
0
150
300
600
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1681_3 SPAS Analysis

General Storm Location: Smethport, PA

Storm Dates: July 16-20, 1942

Event:

DAD Zone 3

Latitude: 41.9729

Longitude: -78.1937

Max. Grid Rainfall Amount: 23.93”

Max. Observed Rainfall Amount:

Number of Stations:

SPAS Version: 10.0

Basemap:

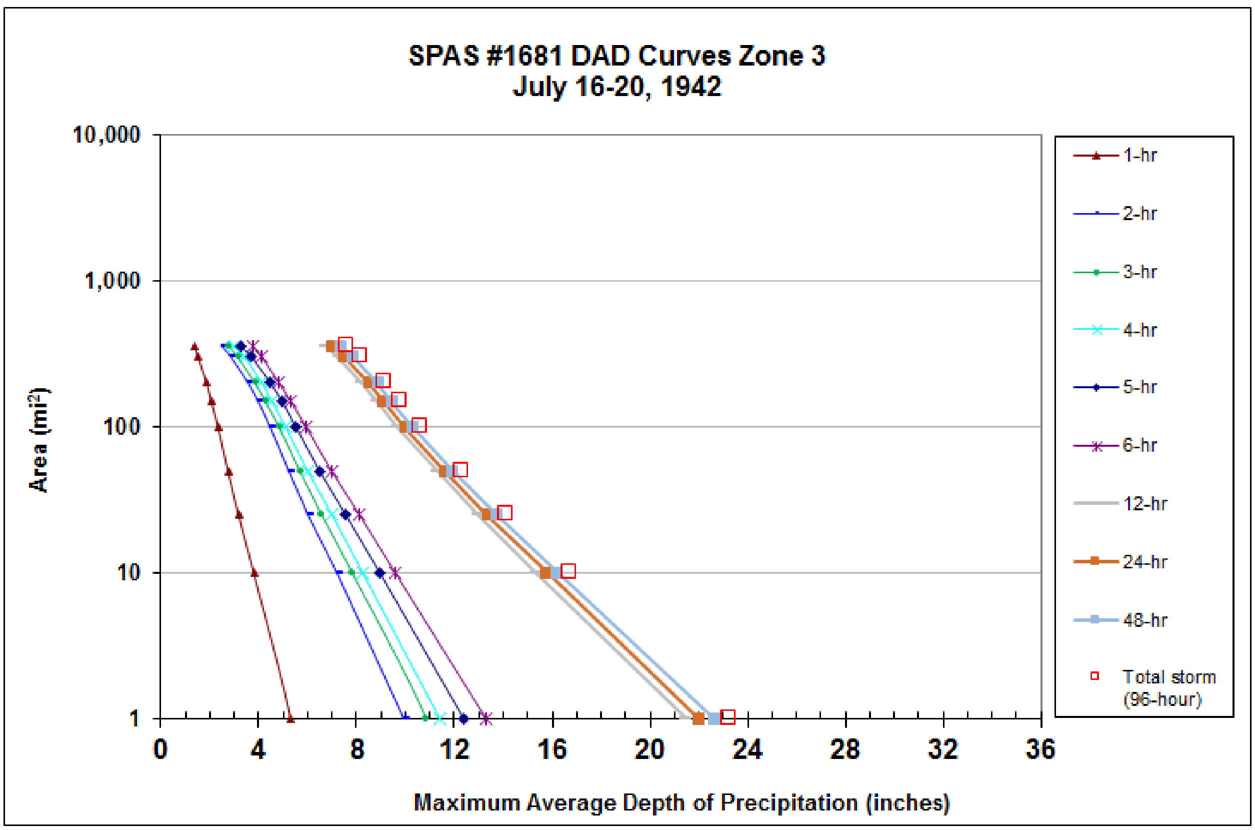
Spatial resolution:

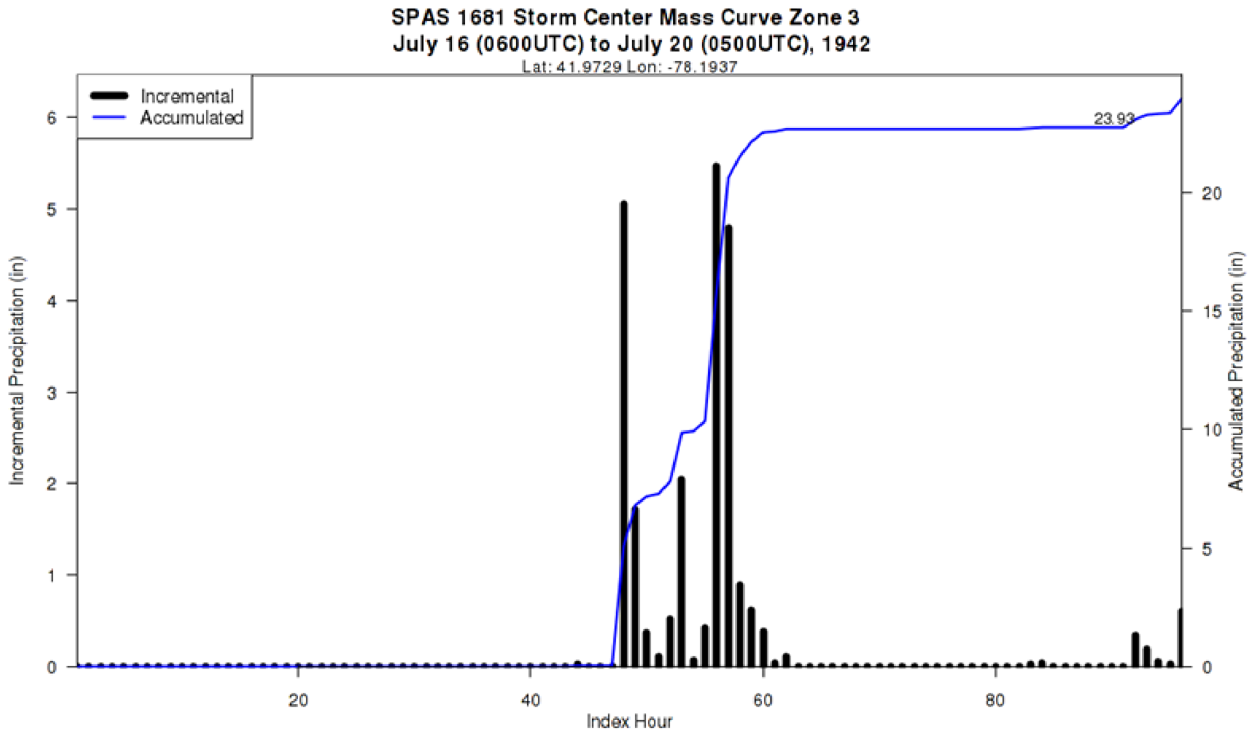
Radar Included: No

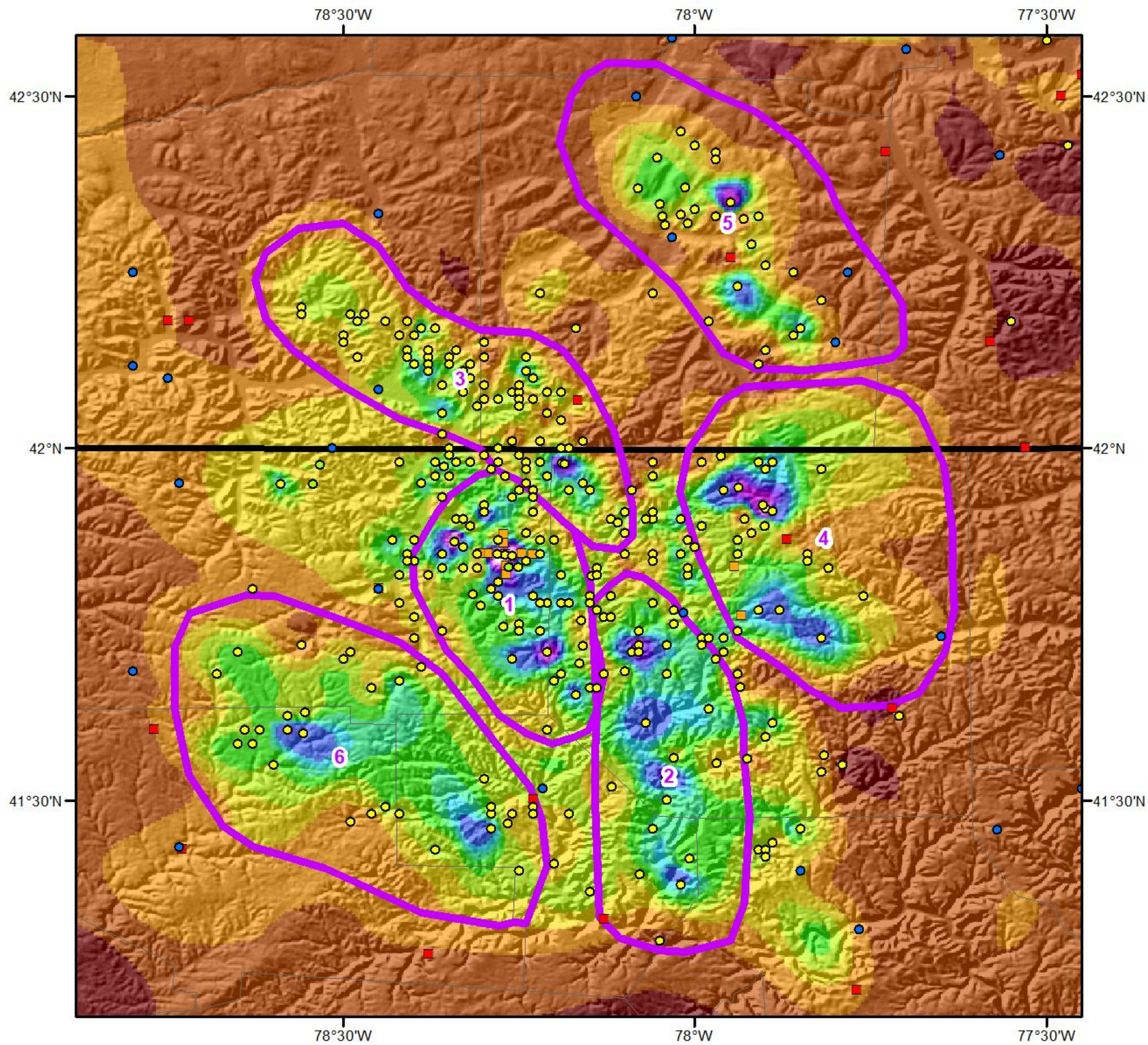
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1681_3	-78.1937	41.9729	1,571	15-Jul	77.50	3.22	0.43	77	2.790	78.00	3.29	0.43	78	2.860	1.025

Storm 1681 Zone 3 - July 16 (0600 UTC) - July 20 (0500 UTC), 1942											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
areasqmi	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	48-hr	96-hr	Total
0.4	5.37	10.10	10.97	11.57	12.59	13.47	21.73	22.29	22.92	23.55	23.55
1	5.31	9.96	10.82	11.43	12.42	13.29	21.44	21.99	22.61	23.24	23.24
10	3.81	7.19	7.83	8.26	8.96	9.61	15.32	15.76	16.20	16.73	16.73
25	3.19	6.04	6.59	6.97	7.53	8.08	12.98	13.35	13.73	14.17	14.17
50	2.76	5.22	5.70	6.03	6.51	6.99	11.27	11.60	11.92	12.32	12.32
100	2.35	4.45	4.85	5.13	5.54	5.94	9.67	9.97	10.29	10.64	10.64
150	2.08	3.95	4.30	4.55	4.95	5.32	8.82	9.10	9.42	9.76	9.76
200	1.89	3.54	3.88	4.11	4.46	4.78	8.21	8.50	8.86	9.18	9.18
300	1.55	2.88	3.19	3.39	3.68	4.10	7.26	7.51	7.85	8.17	8.17
362	1.40	2.52	2.81	2.98	3.26	3.76	6.74	6.98	7.31	7.60	7.60
500											
1,000											
2,000											
3,500											
5,000											
7,500											




SPAS 1681 Storm Center Mass Curve Zone 3
July 16 (0600UTC) to July 20 (0500UTC), 1942
Lat: 41.9729 Lon: -78.1937
Incremental
Accumulated
23.93
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
6
20
40
60
80
0
5
10
15
20



Total Storm (96-hr) Precipitation (inches)
07/16/1942 0600 UTC - 07/20/1942 0500 UTC
SPAS #1681 - Version 10

Gauges

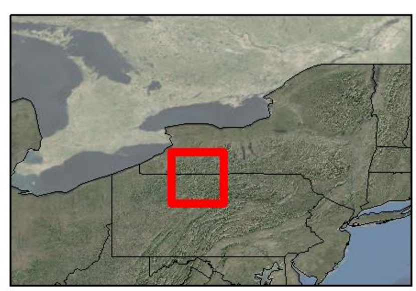
- D
- H
- HP
- S
- SE

Miles: 0 3.5 7 14

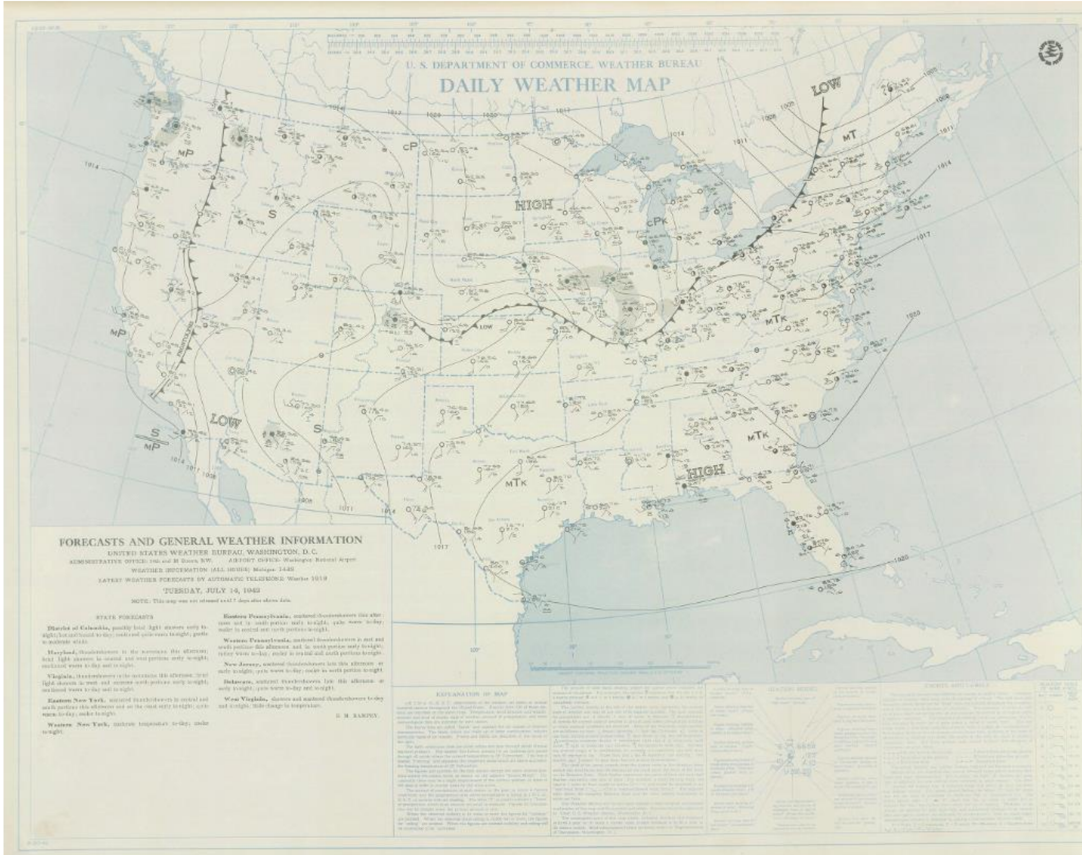
Kilometers: 0 10 20 40

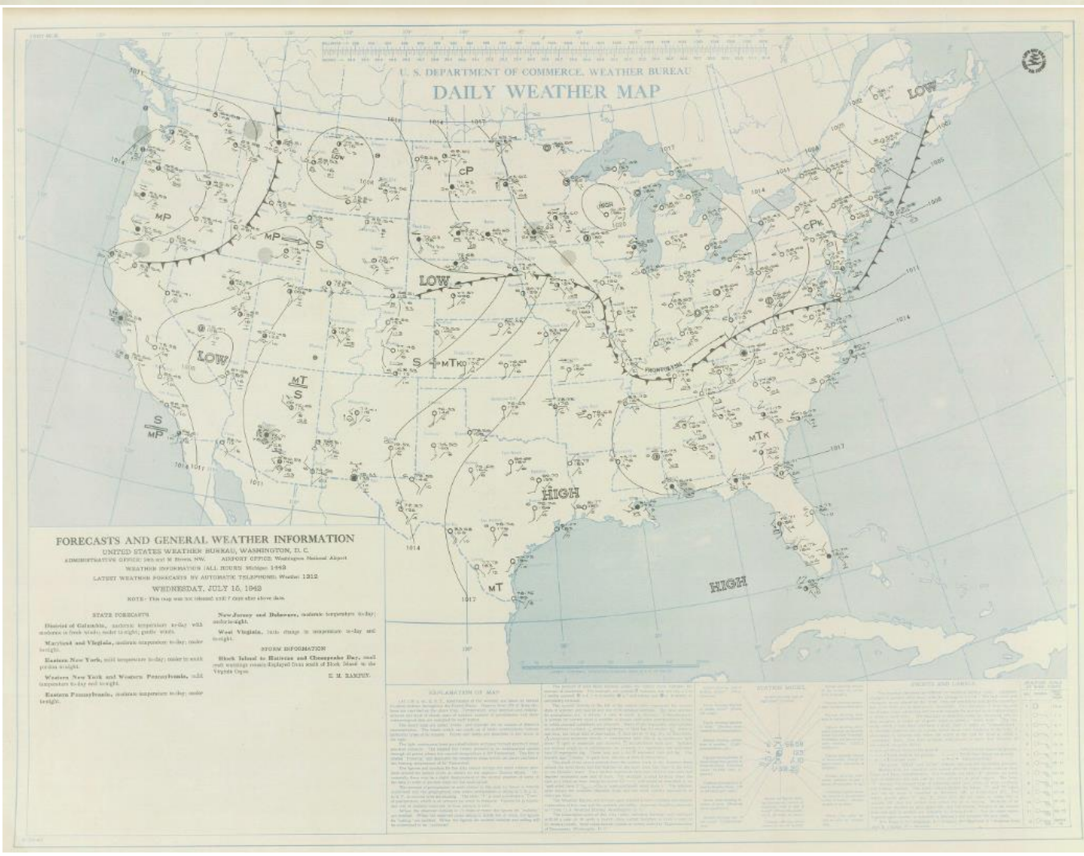
Precipitation (inches)

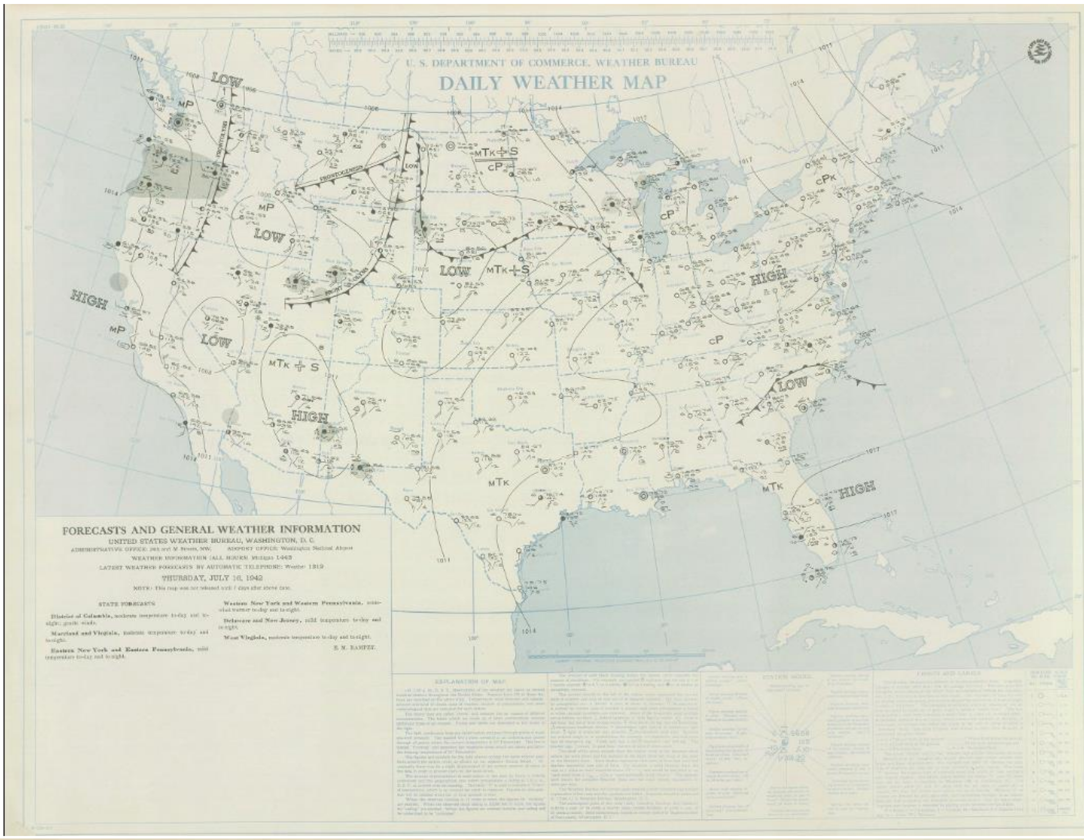
0.00 - 2.00	6.01 - 8.00	12.01 - 14.00	20.01 - 24.00	32.01 - 36.00
2.01 - 4.00	8.01 - 10.00	14.01 - 16.00	24.01 - 28.00	
4.01 - 6.00	10.01 - 12.00	16.01 - 20.00	28.01 - 32.00	



10/8/2018


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
TUESDAY, JULY 14, 1942
STATE FORECASTS
EXPLANATION OF MAP


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
LOW
LOW
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
WEDNESDAY, JULY 15, 1942
STATE FORECASTS
STORM INFORMATION
EXPLANATION OF MAP



FORECASTS AND GENERAL WEATHER INFORMATION

UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

ADMINISTRATIVE OFFICE: 24th and M Streets, NW. AIRPORT OFFICE: Washington National Airport

WEATHER INFORMATION (ALL HOURS): Michigan 1443

LATEST WEATHER FORECASTS BY AUTOMATIC TELEPHONE: Weather 1212

THURSDAY, JULY 16, 1942

NOTE: This map was not released until 7 days after above date.

STATE FORECASTS

District of Columbia, moderate temperature to-day and to-night; gentle winds.

Maryland and Virginia, moderate temperature to-day and to-night.

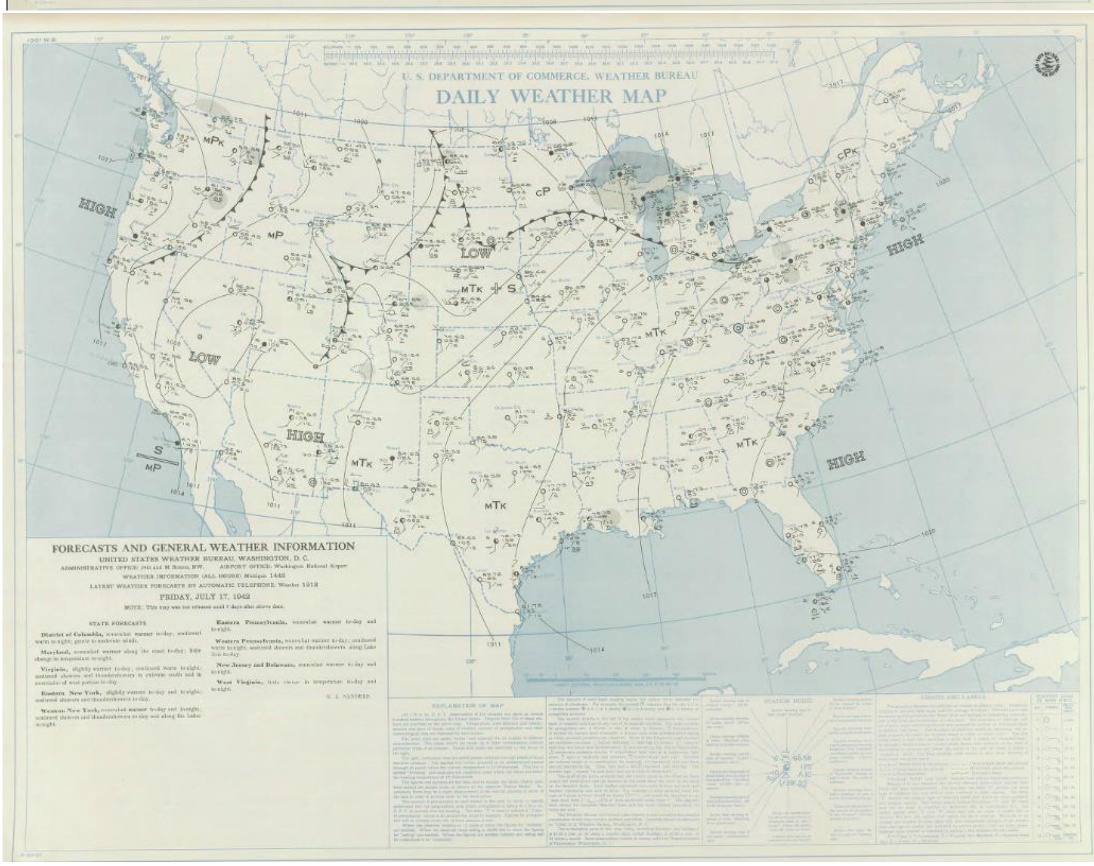
Eastern New York and Eastern Pennsylvania, mild temperature to-day and to-night.

Western New York and Western Pennsylvania, somewhat warmer to-day and to-night.

Delaware and New Jersey, mild temperature to-day and to-night.

West Virginia, moderate temperature to-day and to-night.

E. M. RAMPEY.



FORECASTS AND GENERAL WEATHER INFORMATION

UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

ADMINISTRATIVE OFFICE: 24th and M Streets, NW. AIRPORT OFFICE: Washington National Airport

WEATHER INFORMATION (ALL HOURS): Michigan 1443

LATEST WEATHER FORECASTS BY AUTOMATIC TELEPHONE: Weather 1212

FRIDAY, JULY 17, 1942

NOTE: This map was not released until 7 days after above date.

STATE FORECASTS

District of Columbia, somewhat warmer to-day; continued warm to-night; gentle to moderate winds.

Maryland, somewhat warmer along the coast to-day; little change in temperature to-night.

Virginia, slightly warmer to-day; continued warm to-night; scattered showers and thundershowers in extreme south and in mountains of west portion to-day.

Eastern New York, slightly warmer to-day and to-night; scattered showers and thundershowers to-day.

Western New York, somewhat warmer to-day and to-night; scattered showers and thundershowers to-day and along the lakes to-night.

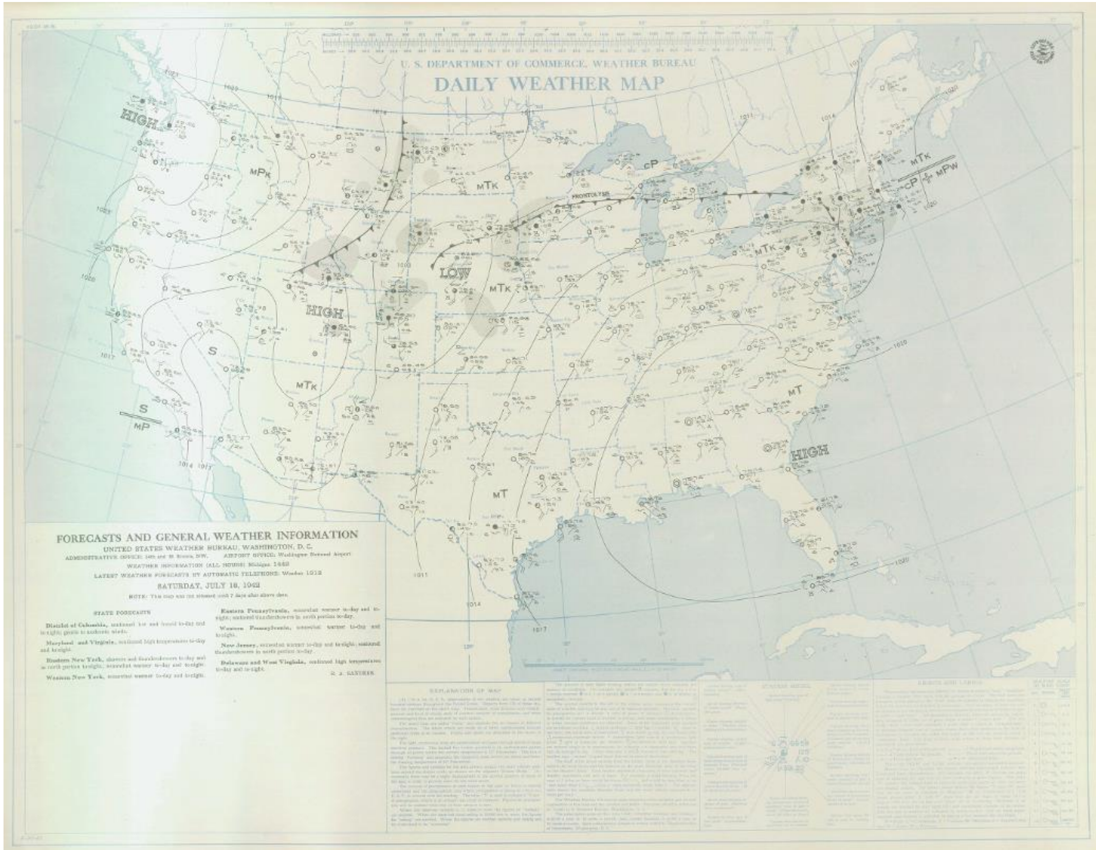
Eastern Pennsylvania, somewhat warmer to-day and to-night.

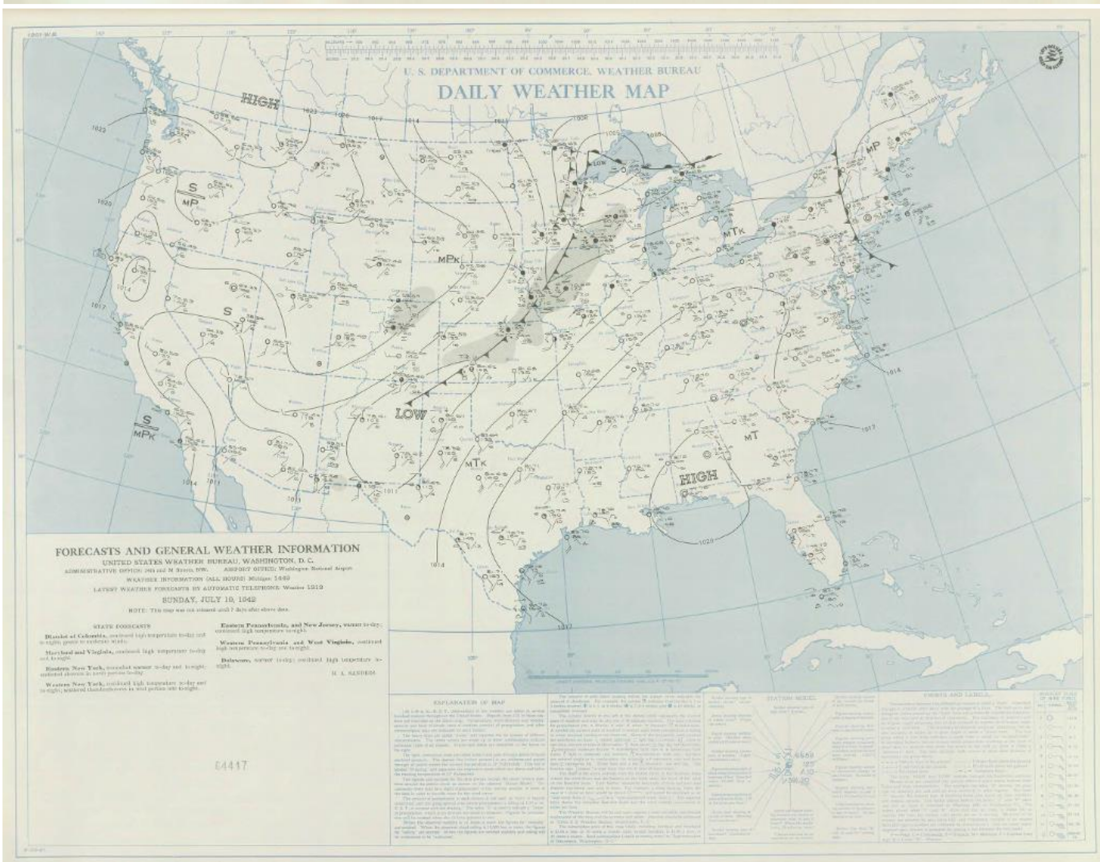
Western Pennsylvania, somewhat warmer to-day; continued warm to-night; scattered showers and thundershowers along Lake Erie to-day.

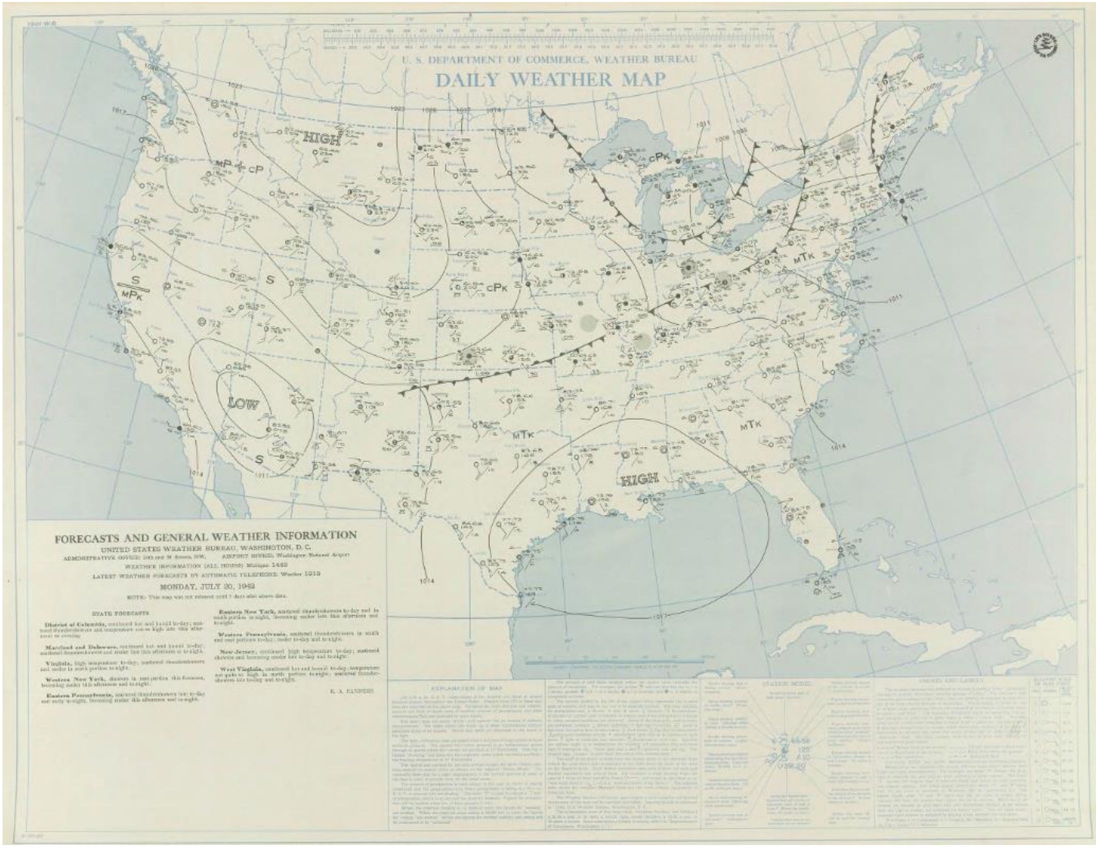
New Jersey and Delaware, somewhat warmer to-day and to-night.

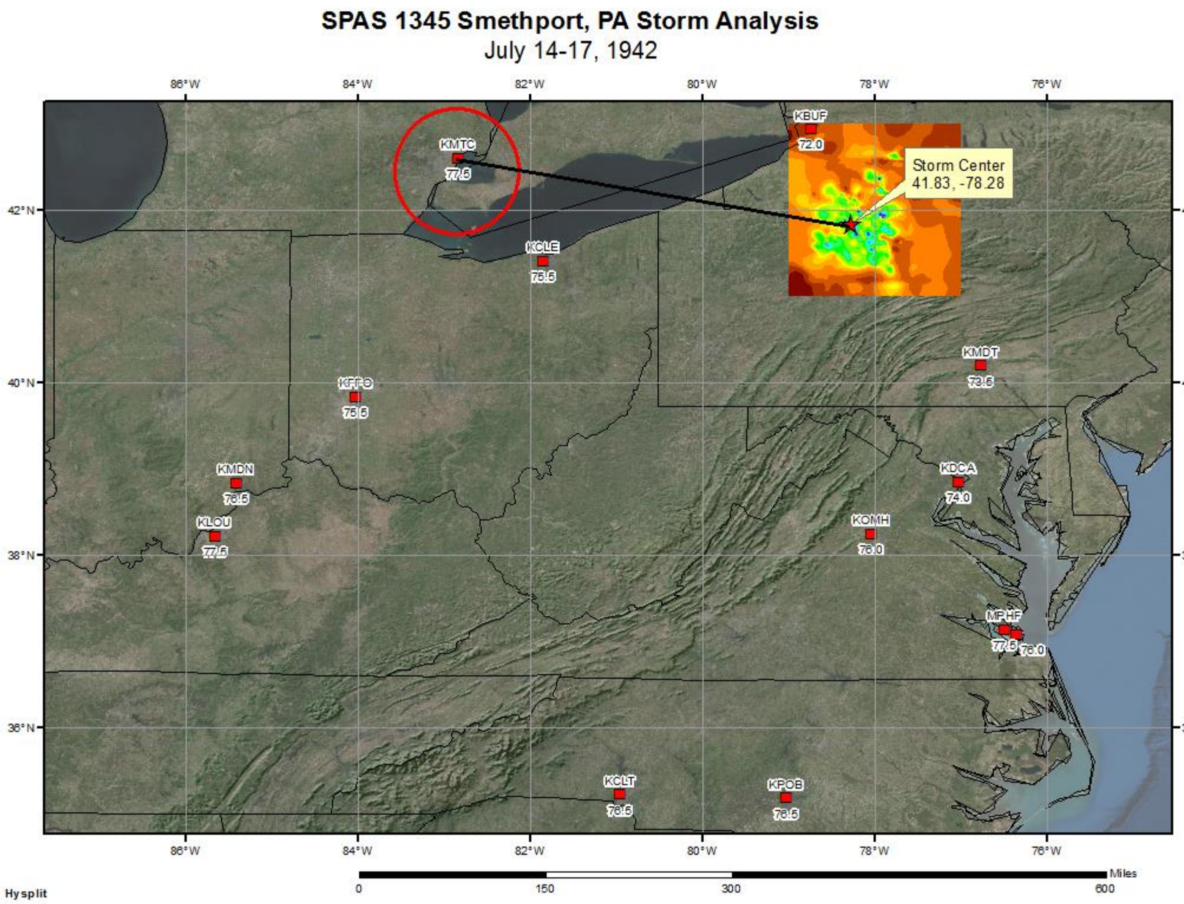
West Virginia, little change in temperature to-day and to-night.

G. L. SANDERS.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
MPK
MTK
cP
MTK
cP
MPW
LOW
MTK
HIGH
S
MTK
S
MP
MT
HIGH
MT
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SATURDAY, JULY 18, 1942
STATE FORECASTS
EXPLANATION OF MAP


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
S
MP
MP
MTK
MPK
S
LOW
S
MPK
MTK
MT
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SUNDAY, JULY 19, 1942
STATE FORECASTS
EXPLANATION OF MAP
54417


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
MONDAY, JULY 20, 1942
STATE FORECASTS


SPAS 1345 Smethport, PA Storm Analysis
July 14-17, 1942
Storm Center
41.83, -78.28
KBUF
72.0
KMTC
77.5
KCLE
76.5
KMDT
73.5
KFFO
76.5
KMDN
76.5
KLOU
77.5
KDCA
74.0
KOMH
76.0
MPHF
77.5
76.0
KCLT
76.5
KPOB
76.5
86°W
84°W
82°W
80°W
78°W
76°W
42°N
40°N
38°N
36°N
Miles
0
150
300
600
Hysplit

Storm Precipitation Analysis System (SPAS) For Storm #1681_4 SPAS Analysis

General Storm Location: Smethport, PA

Storm Dates: July 16-20, 1942

Event:

DAD Zone 4

Latitude: 41.9146

Longitude: -77.8979

Max. Grid Rainfall Amount: 32.76”

Max. Observed Rainfall Amount:

Number of Stations:

SPAS Version: 10.0

Basemap:

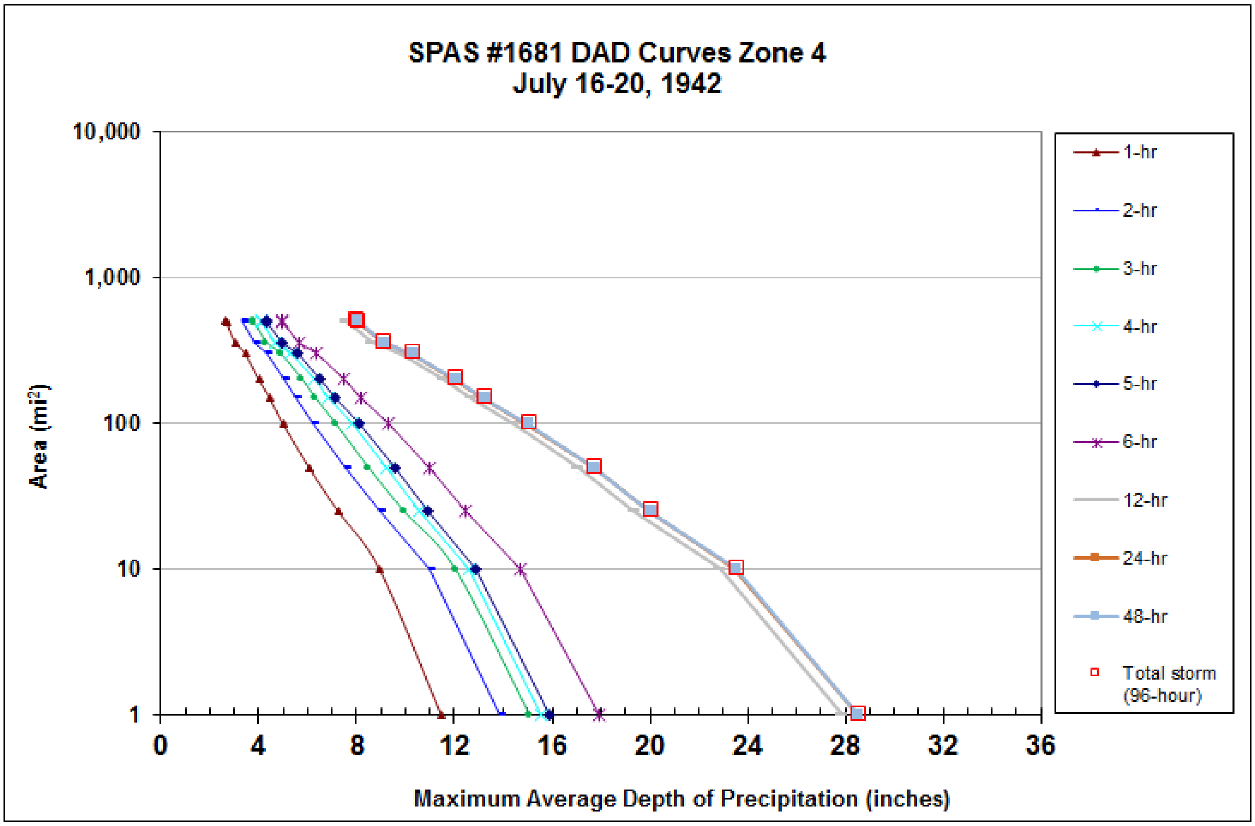
Spatial resolution:

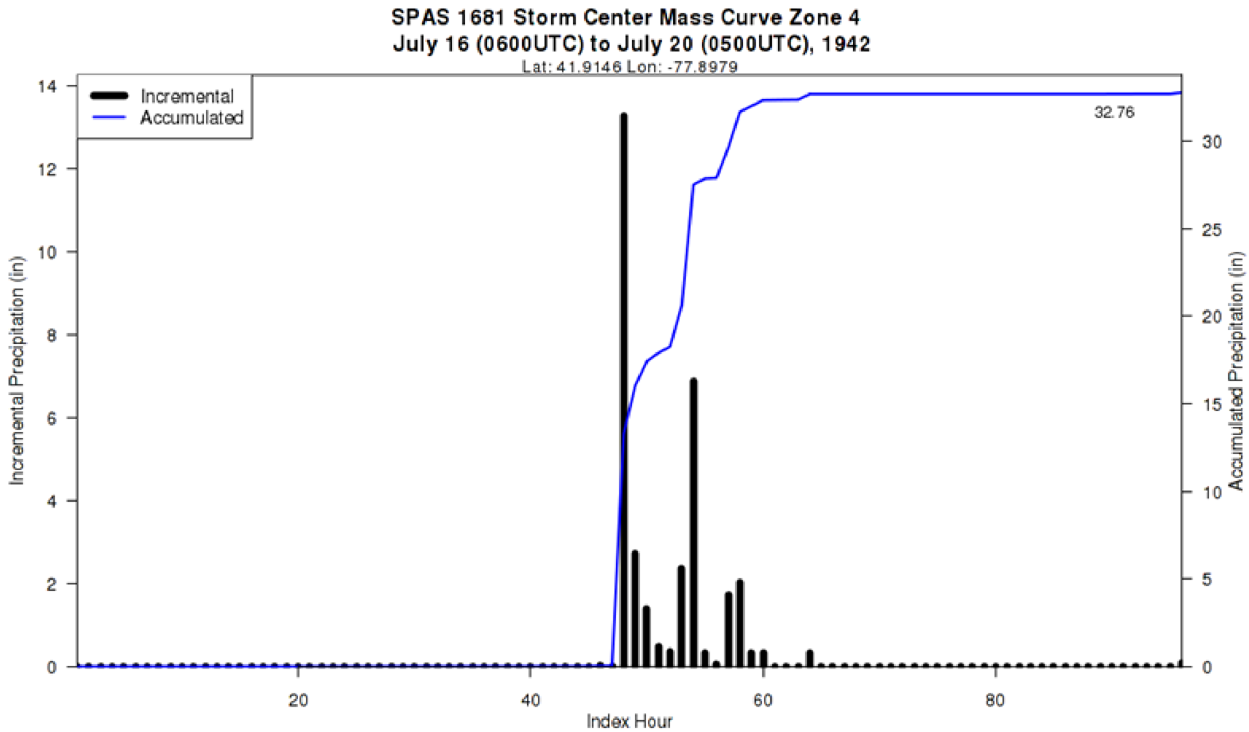
Radar Included: No

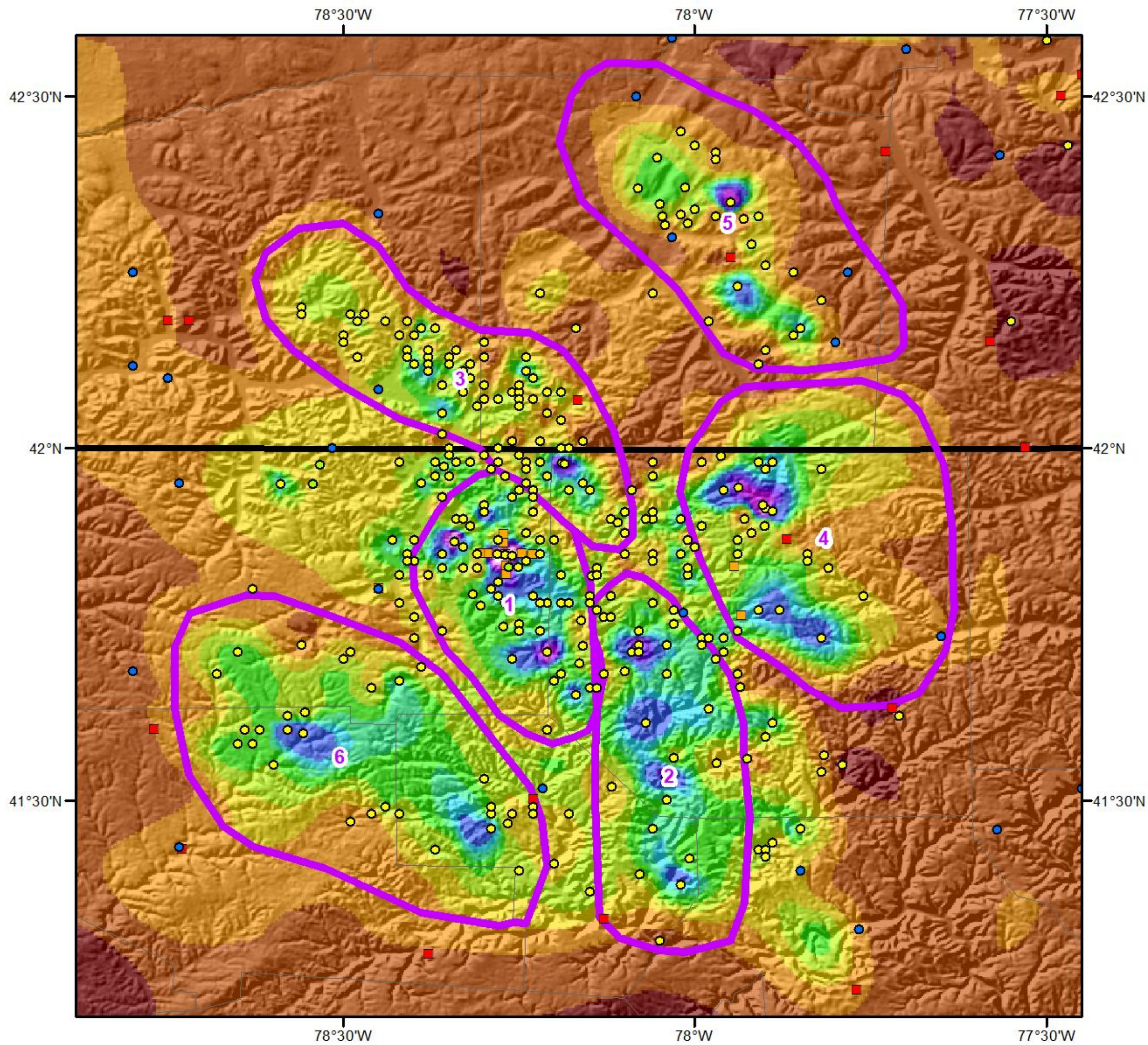
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1681_4	-77.8979	41.9146	2,038	15-Jul	77.50	3.22	0.53	77	2.690	78.00	3.29	0.53	78	2.760	1.026

Storm 1681 Zone 4 - July 16 (0600 UTC) - July 20 (0500 UTC), 1942											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
areasqmi	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	48-hr	96-hr	Total
0.4	12.55	15.14	16.45	16.92	17.25	19.49	30.26	30.94	30.94	31.03	31.03
1	11.49	13.87	15.08	15.52	15.86	17.91	27.83	28.47	28.47	28.57	28.57
10	8.96	10.99	12.03	12.57	12.88	14.67	22.85	23.46	23.48	23.62	23.62
25	7.26	8.98	9.92	10.57	10.89	12.43	19.35	19.97	20.00	20.13	20.13
50	6.07	7.55	8.46	9.26	9.61	10.96	17.05	17.66	17.69	17.80	17.80
100	5.00	6.25	7.11	7.81	8.12	9.27	14.43	14.97	15.01	15.10	15.10
150	4.46	5.55	6.29	6.87	7.15	8.16	12.68	13.18	13.21	13.30	13.30
200	4.02	5.06	5.75	6.28	6.53	7.46	11.57	12.02	12.05	12.13	12.13
300	3.46	4.32	4.87	5.32	5.56	6.35	9.80	10.22	10.26	10.33	10.33
362	3.04	3.80	4.28	4.70	4.94	5.63	8.63	9.03	9.06	9.13	9.13
500	2.68	3.34	3.75	4.13	4.34	4.98	7.58	7.99	8.06	8.11	8.11
505	2.67	3.32	3.73	4.1	4.32	4.95	7.54	7.94	8.01	8.06	8.06
2,000											
3,500											
5,000											
7,500											




SPAS 1681 Storm Center Mass Curve Zone 4
July 16 (0600UTC) to July 20 (0500UTC), 1942
Lat: 41.9146 Lon: -77.8979
Incremental
Accumulated
32.76
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
2
4
6
8
10
12
14
20
40
60
80
5
15
25
30



Total Storm (96-hr) Precipitation (inches)
07/16/1942 0600 UTC - 07/20/1942 0500 UTC
SPAS #1681 - Version 10

Gauges

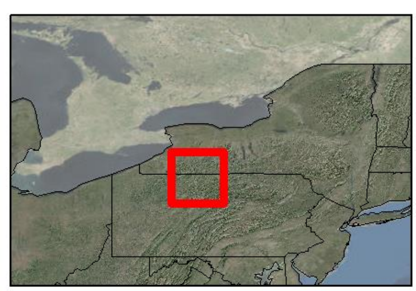
- D
- H
- HP
- S
- SE

Miles: 0 3.5 7 14

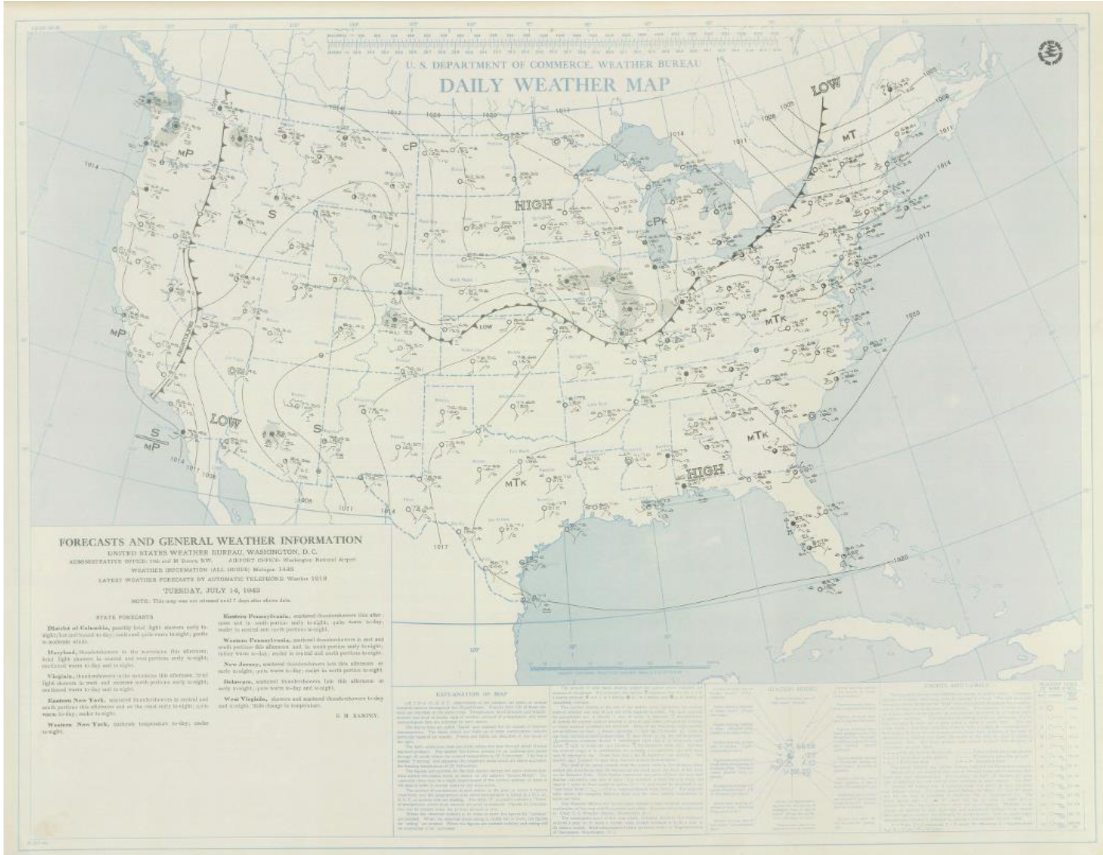
Kilometers: 0 10 20 40

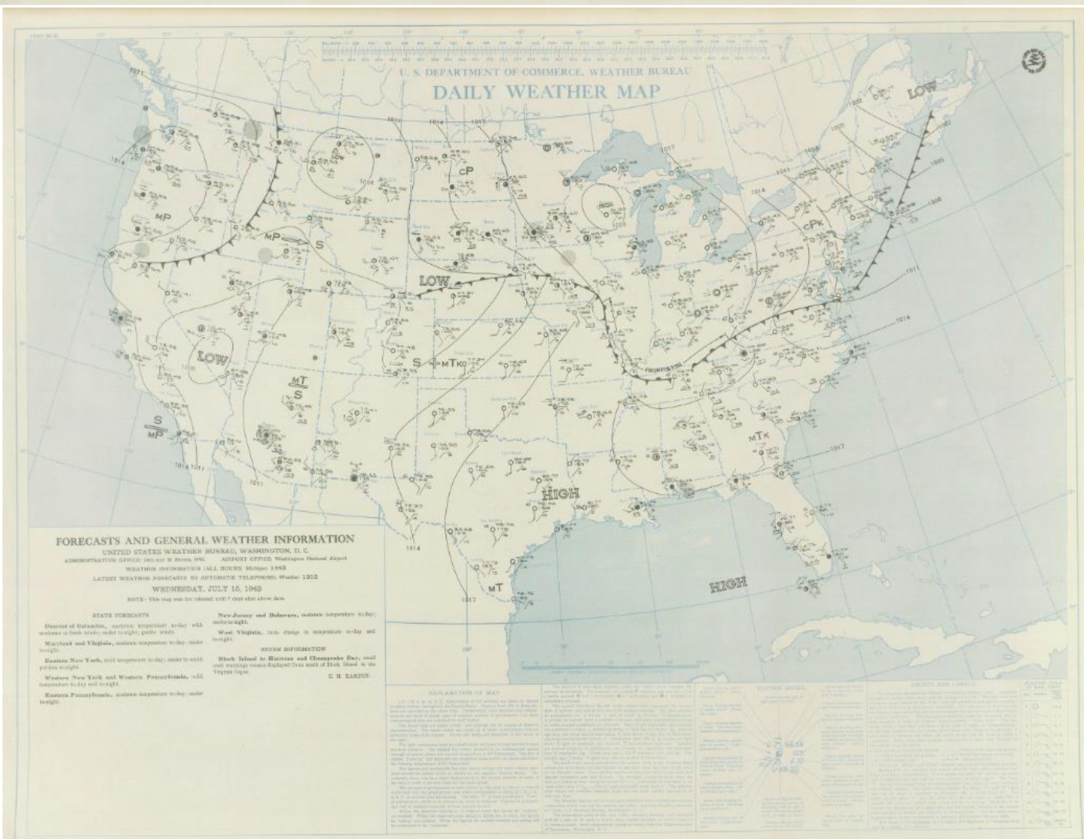
Precipitation (inches)

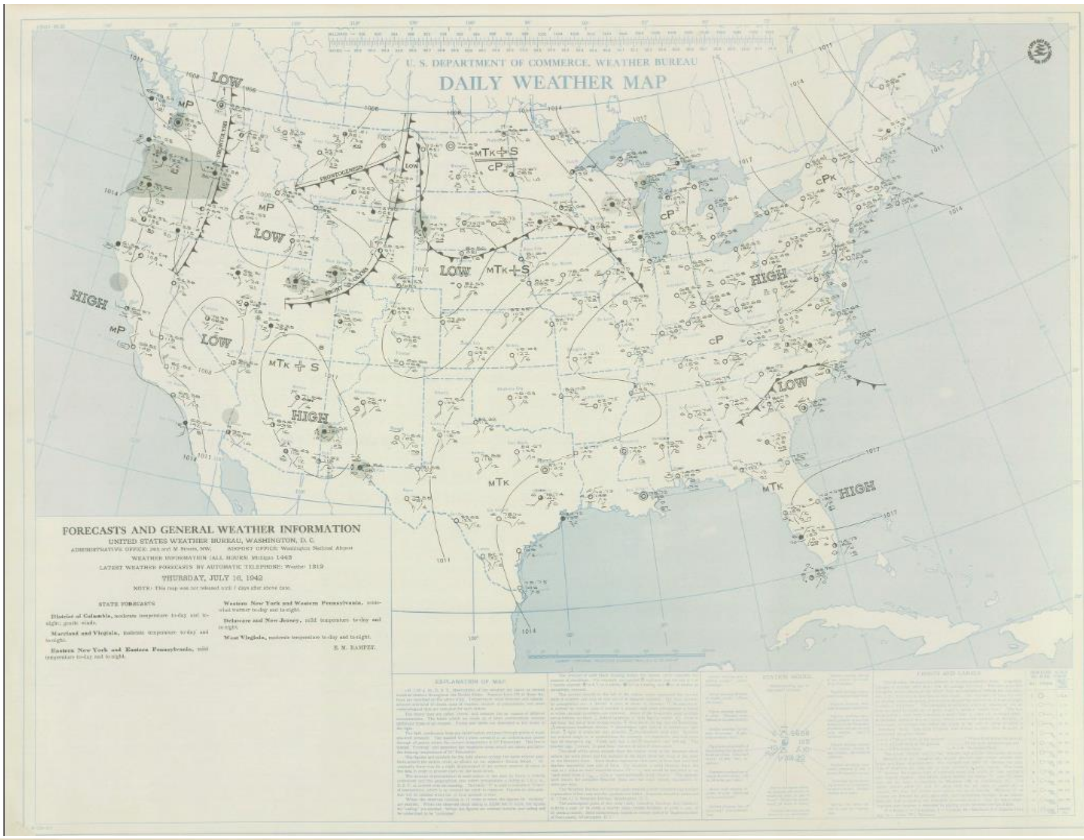
- 0.00 - 2.00
- 2.01 - 4.00
- 4.01 - 6.00
- 6.01 - 8.00
- 8.01 - 10.00
- 10.01 - 12.00
- 12.01 - 14.00
- 14.01 - 16.00
- 16.01 - 20.00
- 20.01 - 24.00
- 24.01 - 28.00
- 28.01 - 32.00
- 32.01 - 36.00

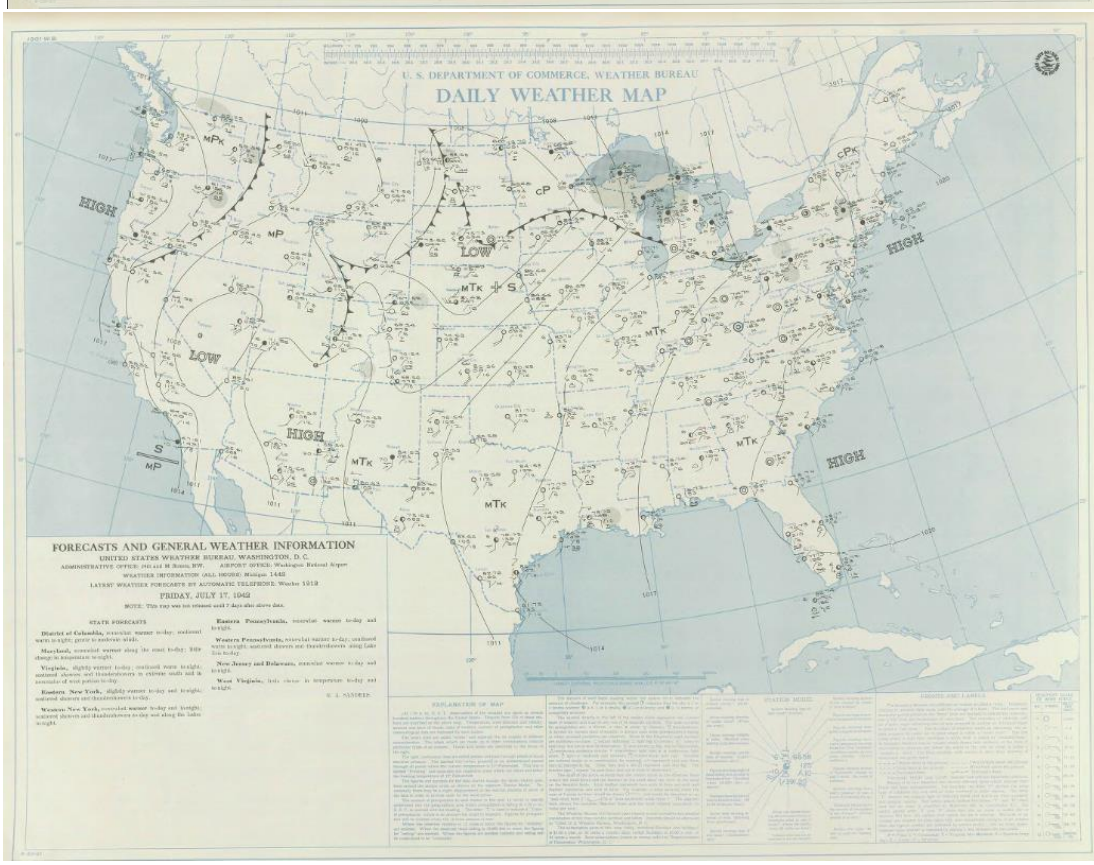


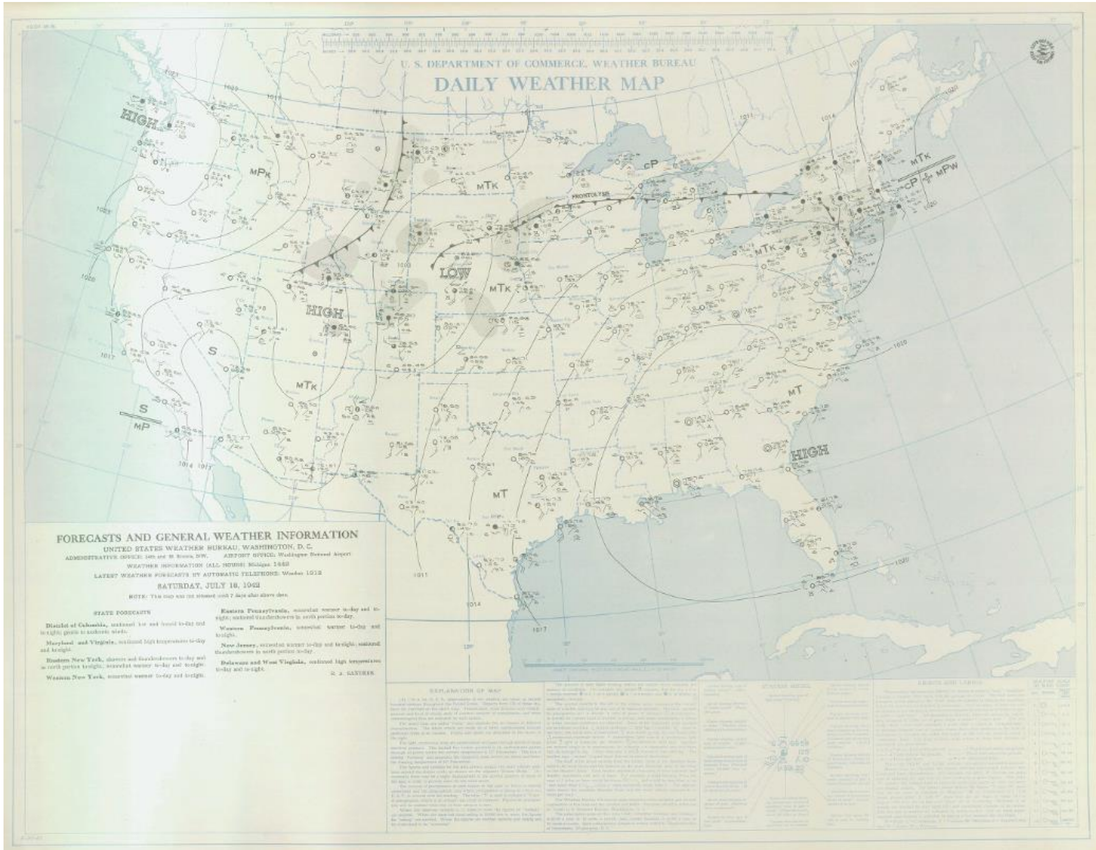
10/8/2018

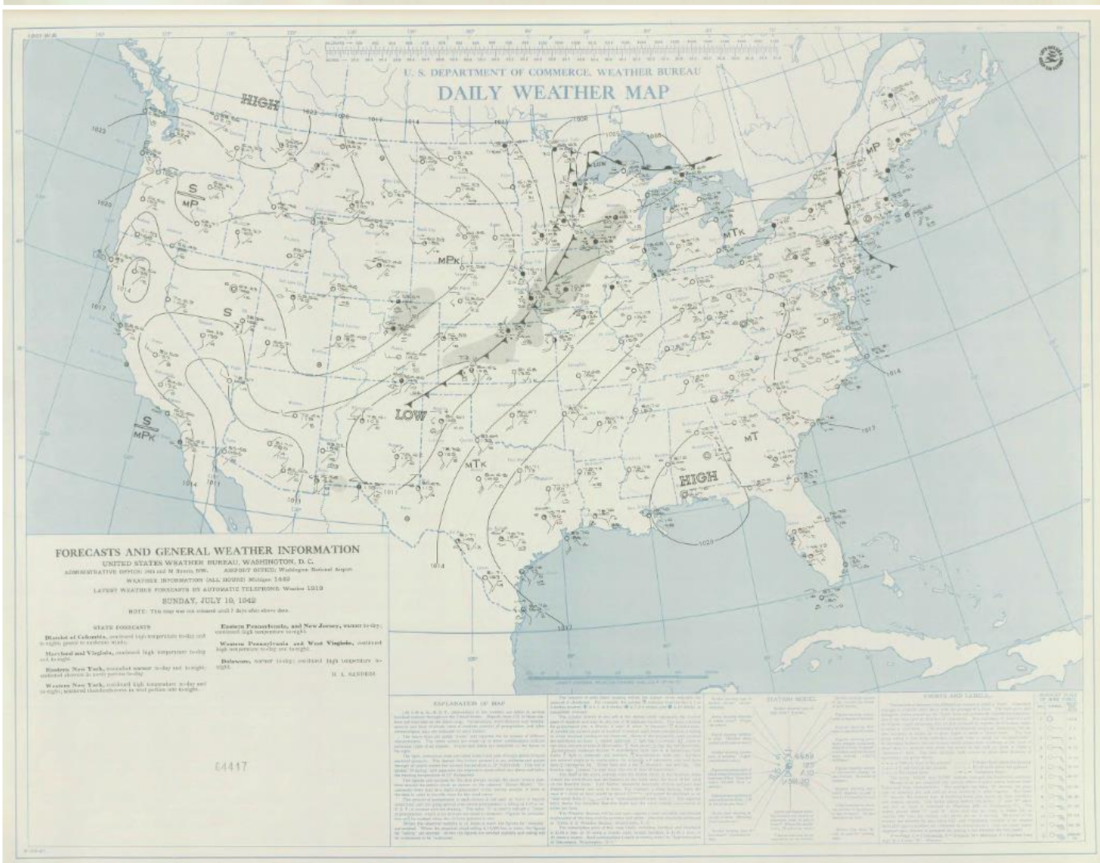

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D.C.
TUESDAY, JULY 14, 1942
STATE FORECASTS

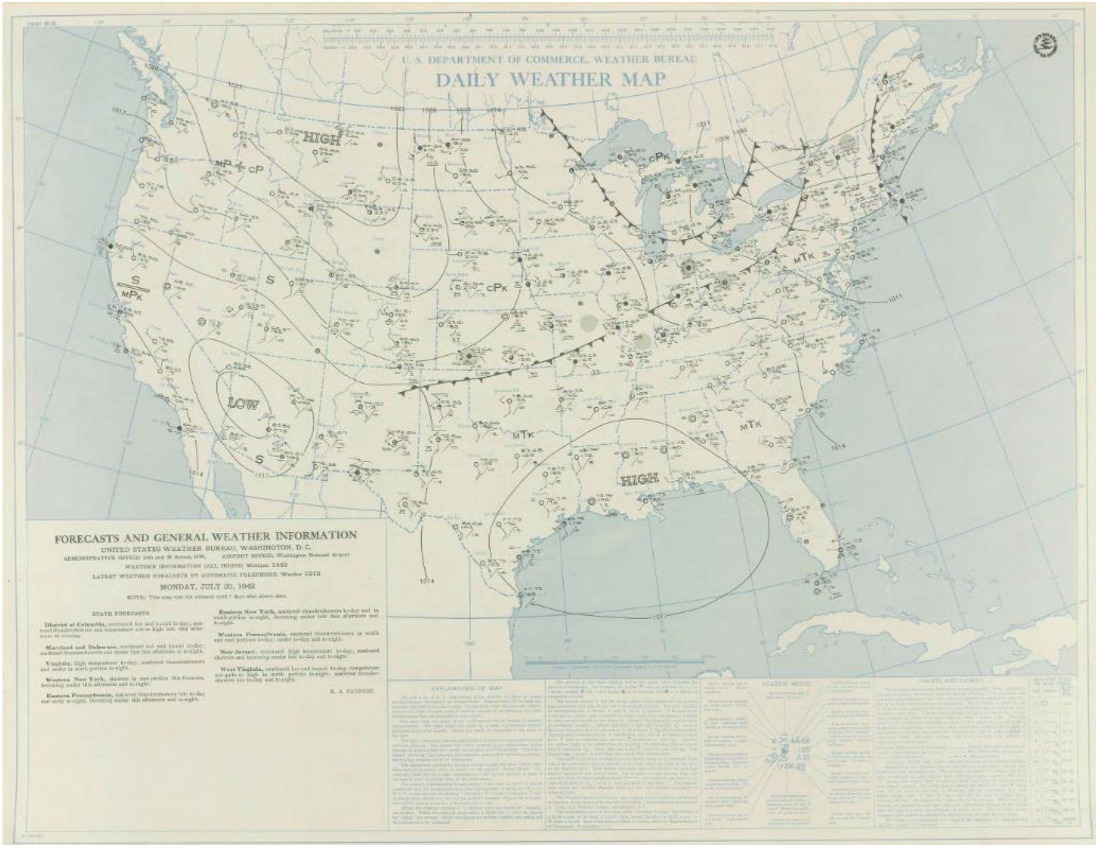

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
LOW
LOW
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D.C.
WEDNESDAY, JULY 15, 1942
STATE FORECASTS
STORM INFORMATION


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
THURSDAY, JULY 16, 1942
STATE FORECASTS
West Virginia, moderate temperature to-day and to-night.
EXPLANATION OF MAP


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
FRIDAY, JULY 17, 1942
STATE FORECASTS
EXPLANATION OF MAP

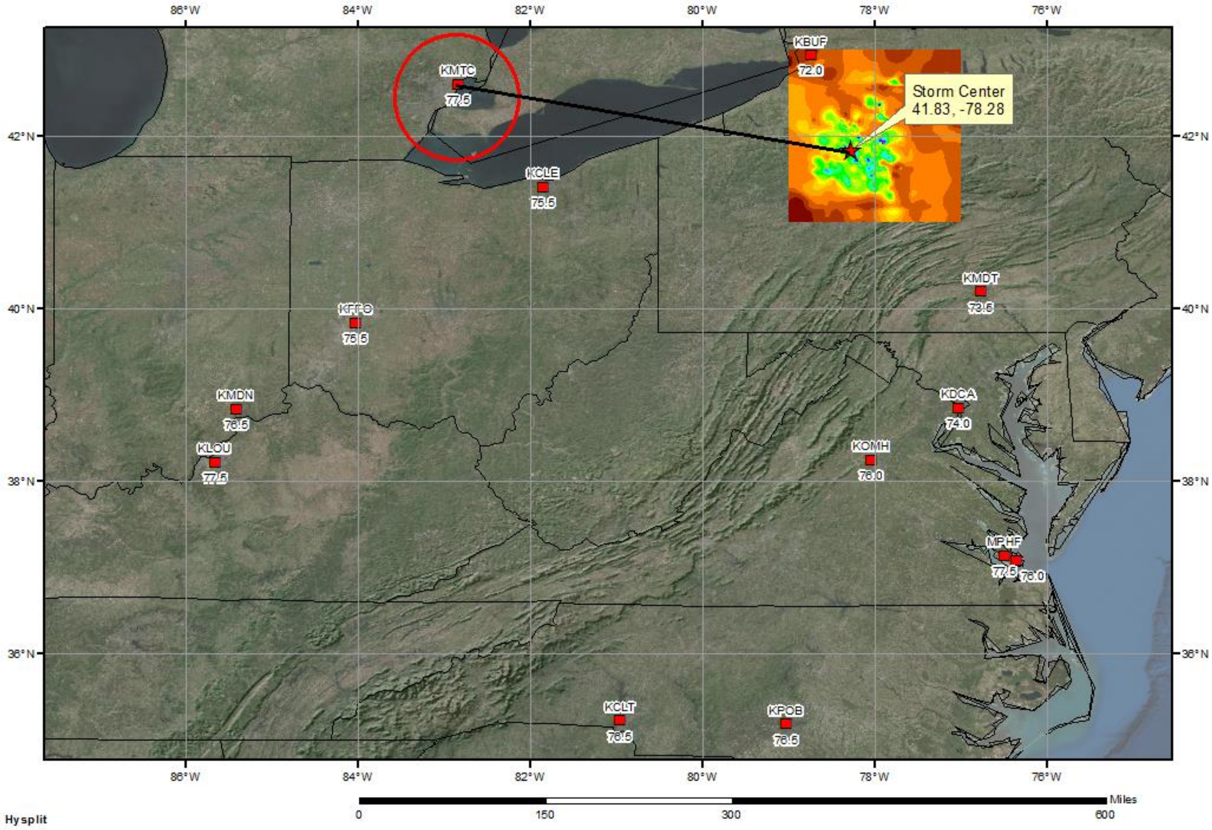

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SATURDAY, JULY 18, 1942
STATE FORECASTS
EXPLANATION OF MAP


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SUNDAY, JULY 19, 1942
STATE FORECASTS
EXPLANATION OF MAP
E4417


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
MONDAY, JULY 20, 1942
STATE FORECASTS

SPAS 1345 Smethport, PA Storm Analysis

July 14-17, 1942



Storm Precipitation Analysis System (SPAS) For Storm #1681_5 SPAS Analysis

General Storm Location: Smethport, PA

Storm Dates: July 16-20, 1942

Event:

DAD Zone 5

Latitude: 42.3563

Longitude: -77.9479

Max. Grid Rainfall Amount: 25.33”

Max. Observed Rainfall Amount:

Number of Stations:

SPAS Version: 10.0

Basemap:

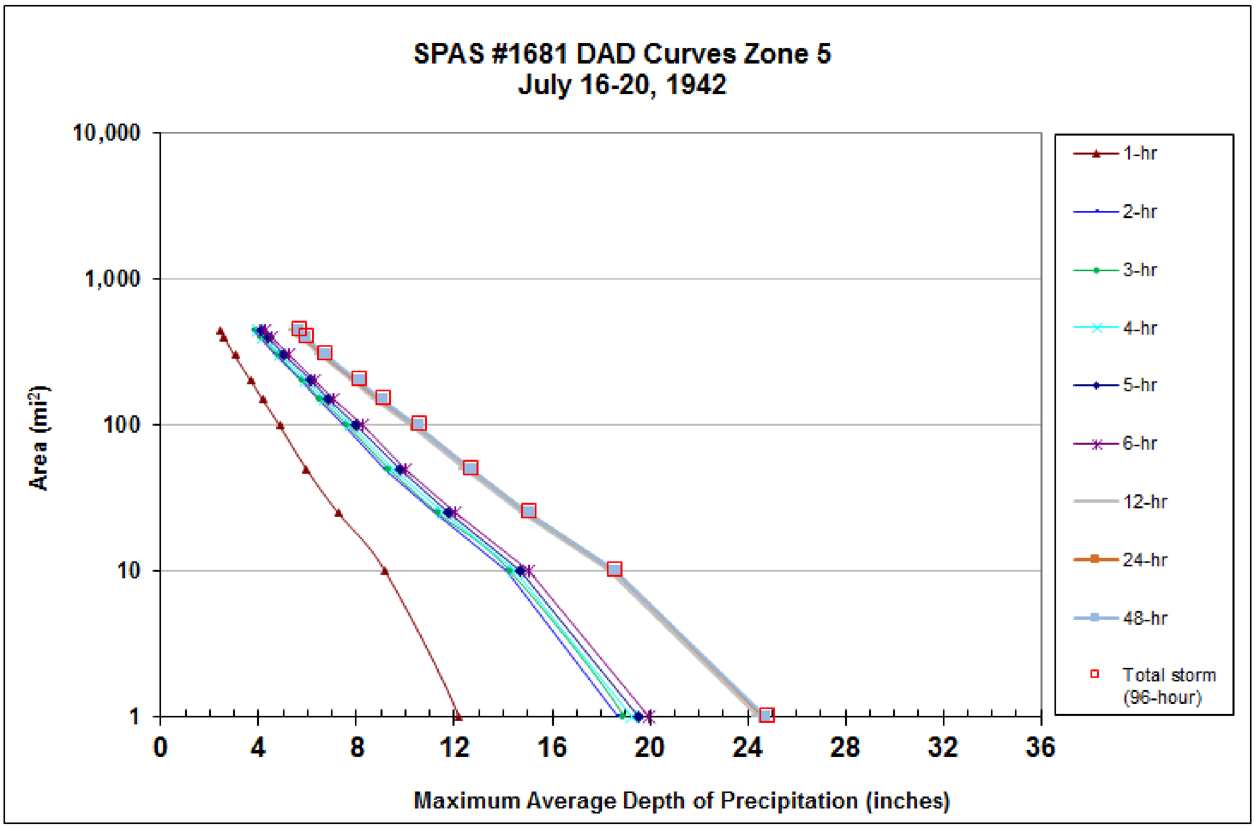
Spatial resolution:

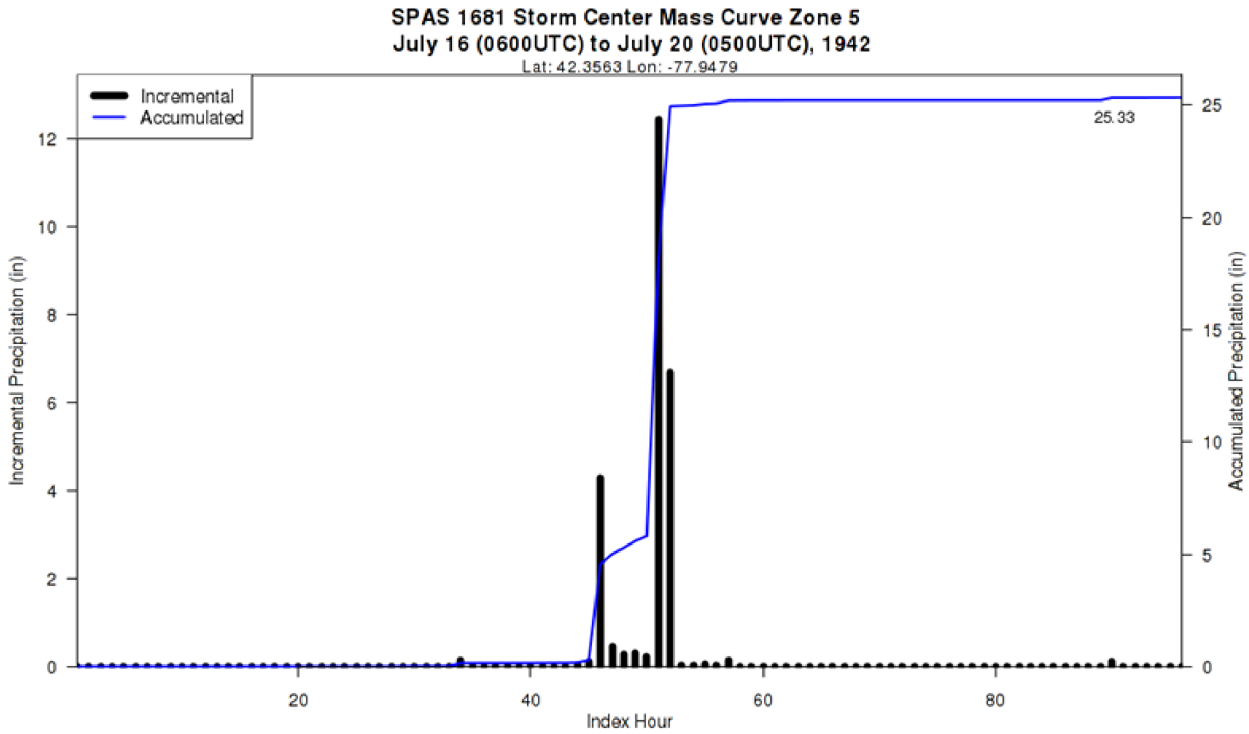
Radar Included: No

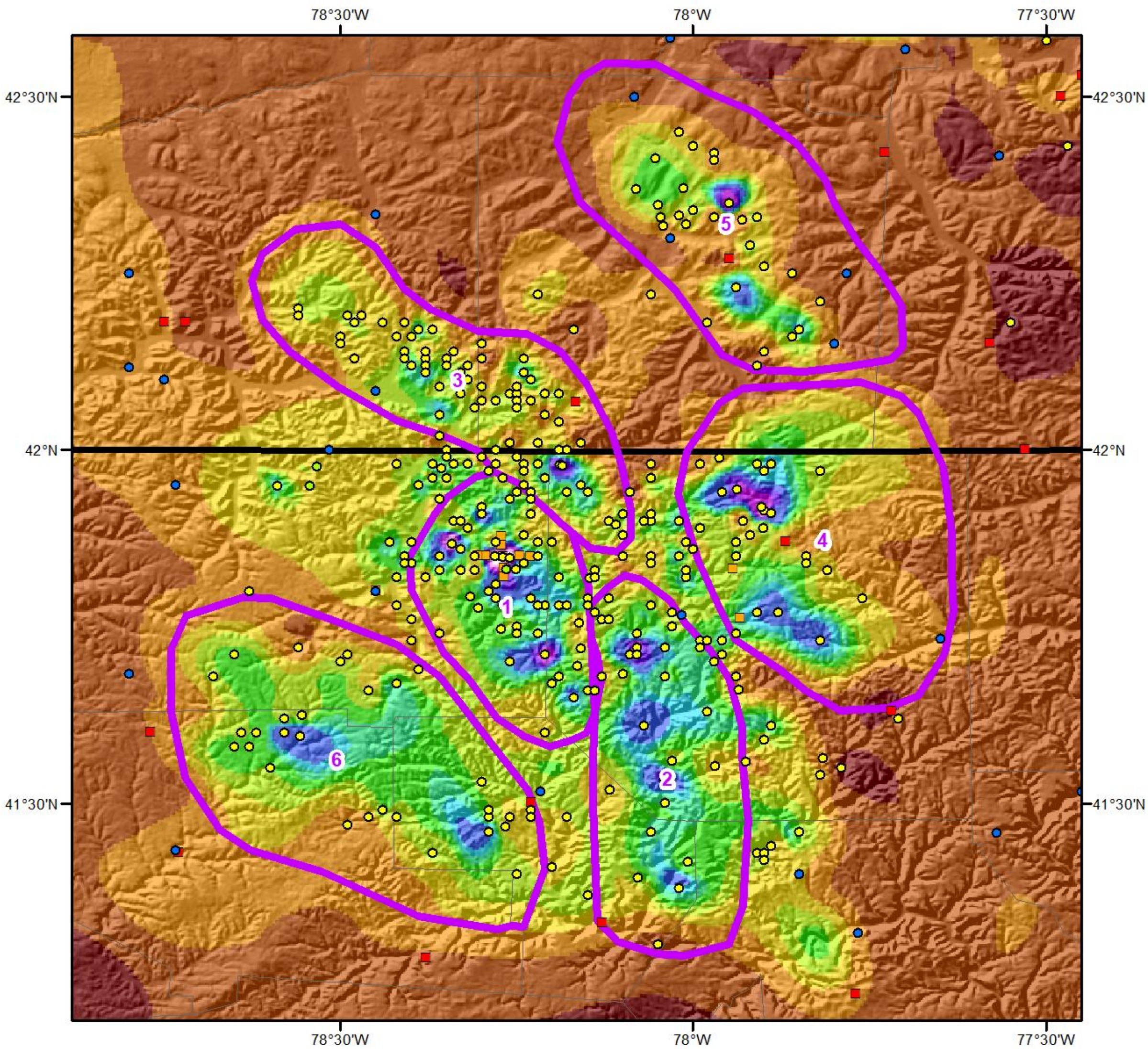
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1681_5	-77.9479	42.3563	2,111	15-Jul	77.50	3.22	0.55	77	2.665	78.00	3.29	0.56	78	2.730	1.024

Storm 1681 Zone 5 - July 16 (0600 UTC) - July 20 (0500 UTC), 1942											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
areasqmi	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	48-hr	96-hr	Total
0.4	12.26	18.84	19.06	19.38	19.66	20.10	24.56	24.83	24.85	25.00	25.00
1	12.18	18.71	18.93	19.24	19.53	19.96	24.39	24.66	24.67	24.84	24.84
10	9.17	14.11	14.26	14.49	14.69	15.02	18.34	18.51	18.53	18.60	18.60
25	7.26	11.19	11.32	11.53	11.76	12.05	14.81	15.00	15.04	15.13	15.13
50	5.96	9.19	9.32	9.51	9.77	10.03	12.41	12.60	12.66	12.77	12.77
100	4.86	7.49	7.60	7.77	8.00	8.22	10.23	10.44	10.49	10.62	10.62
150	4.17	6.43	6.53	6.68	6.88	7.07	8.81	9.00	9.05	9.17	9.17
200	3.71	5.71	5.81	5.94	6.13	6.30	7.87	8.03	8.09	8.18	8.18
300	3.03	4.69	4.78	4.88	5.05	5.21	6.52	6.67	6.72	6.81	6.81
400	2.60	4.02	4.11	4.21	4.36	4.52	5.70	5.85	5.89	5.99	5.99
447	2.45	3.79	3.88	3.98	4.13	4.28	5.42	5.56	5.6	5.7	5.70
500											
2,000											
3,500											
5,000											
7,500											




SPAS 1681 Storm Center Mass Curve Zone 5
July 16 (0600UTC) to July 20 (0500UTC), 1942
Lat: 42.3563 Lon: -77.9479
Incremental
Accumulated
25.33
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour



Total Storm (96-hr) Precipitation (inches)
07/16/1942 0600 UTC - 07/20/1942 0500 UTC
SPAS #1681 - Version 10

Gauges

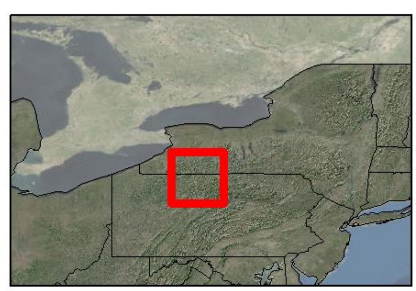
- D
- H
- HP
- S
- SE

Miles: 0, 3.5, 7, 14

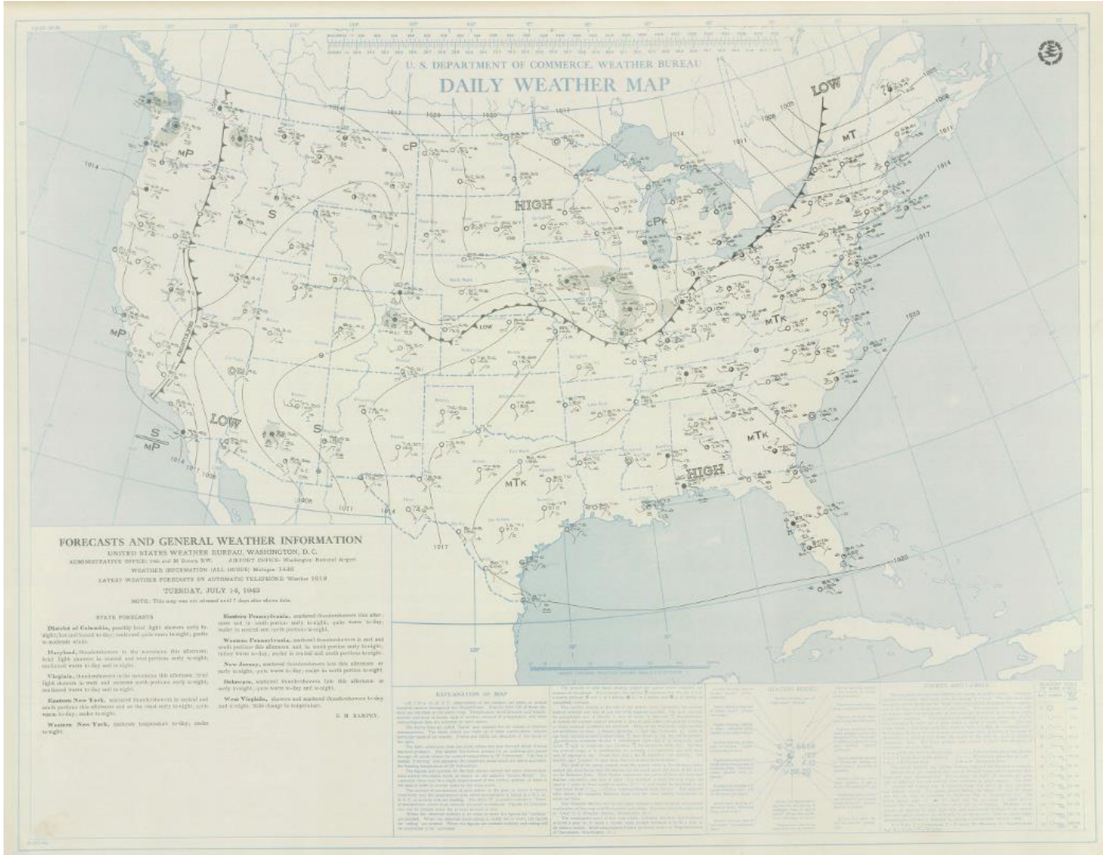
Kilometers: 0, 10, 20, 40

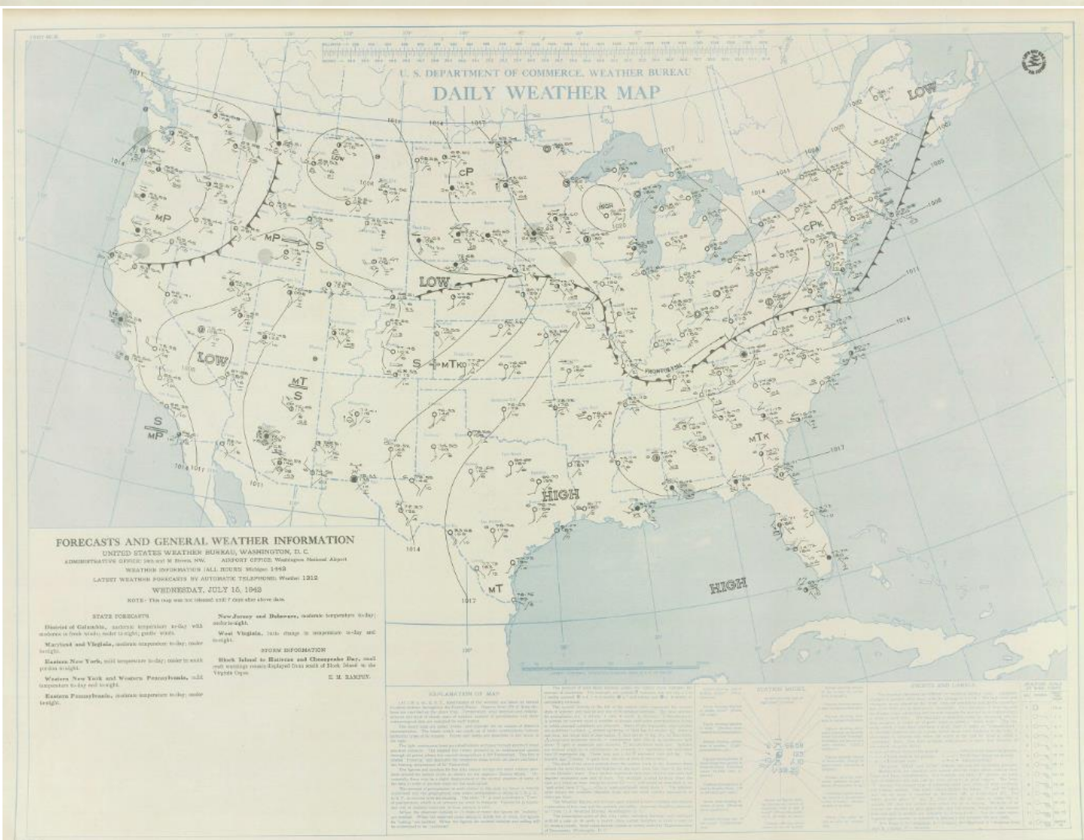
Precipitation (inches)

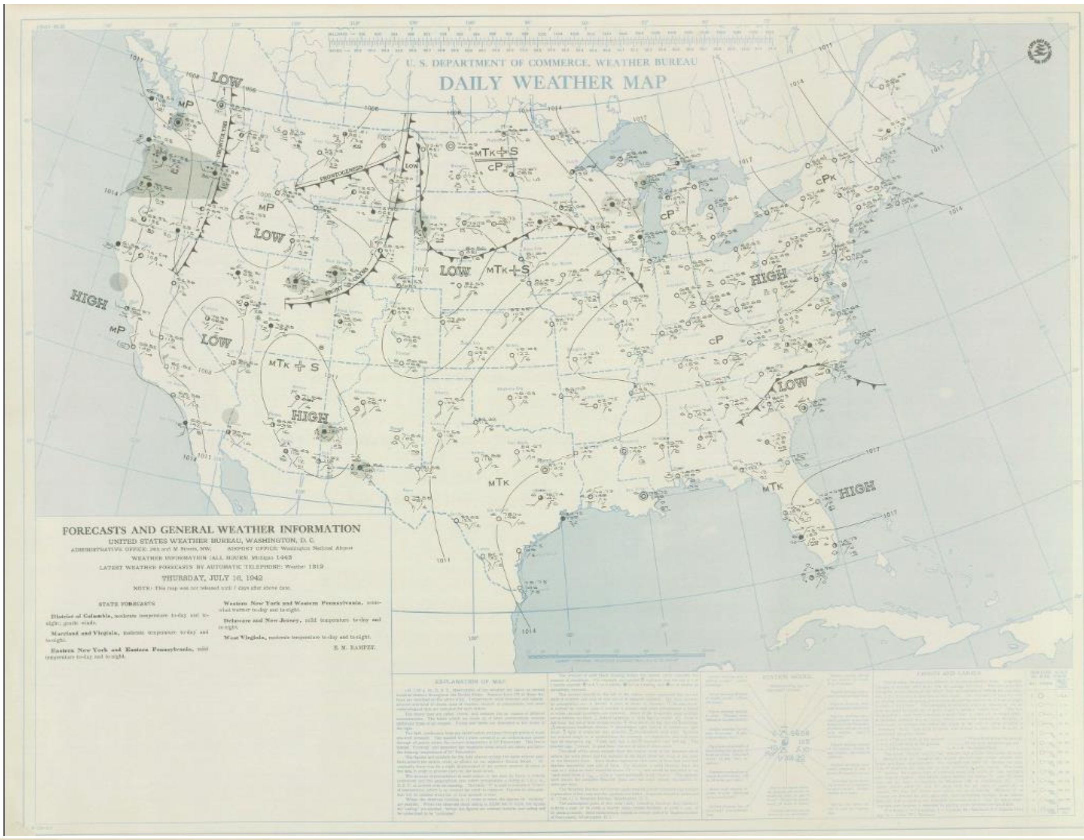
0.00 - 2.00	6.01 - 8.00	12.01 - 14.00	20.01 - 24.00	32.01 - 36.00
2.01 - 4.00	8.01 - 10.00	14.01 - 16.00	24.01 - 28.00	
4.01 - 6.00	10.01 - 12.00	16.01 - 20.00	28.01 - 32.00	

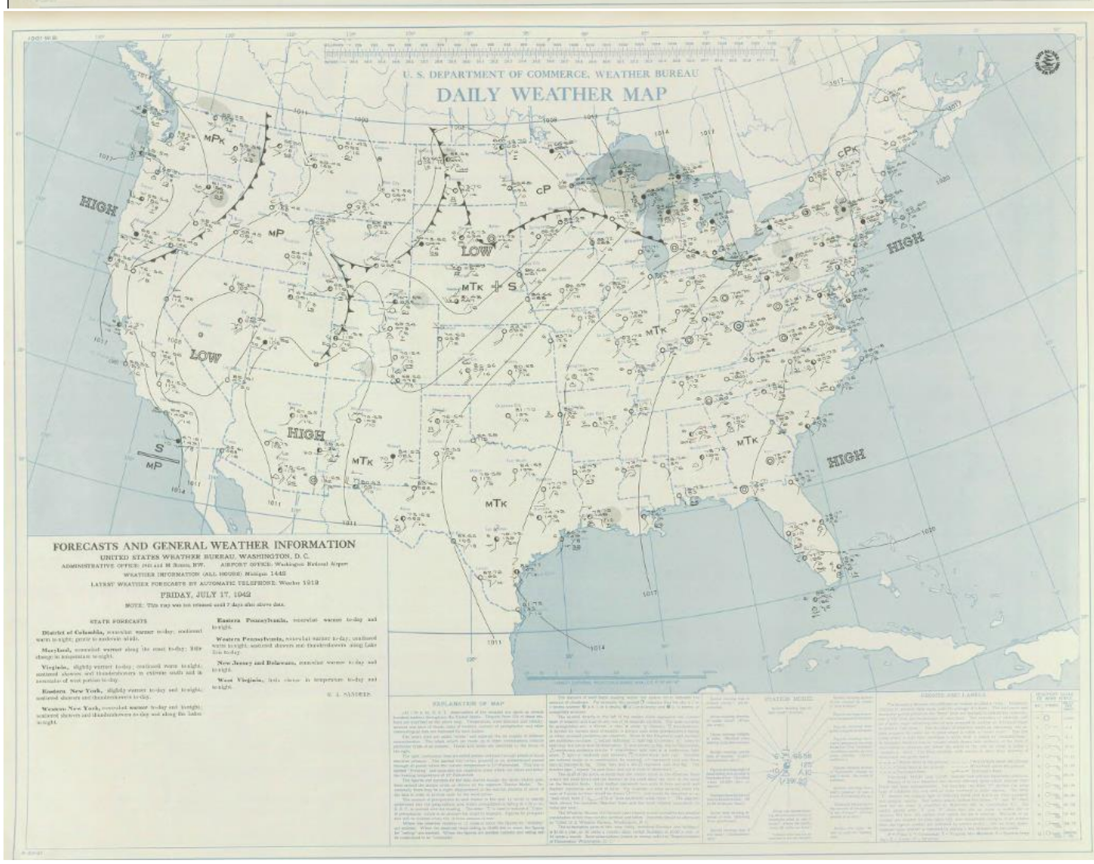


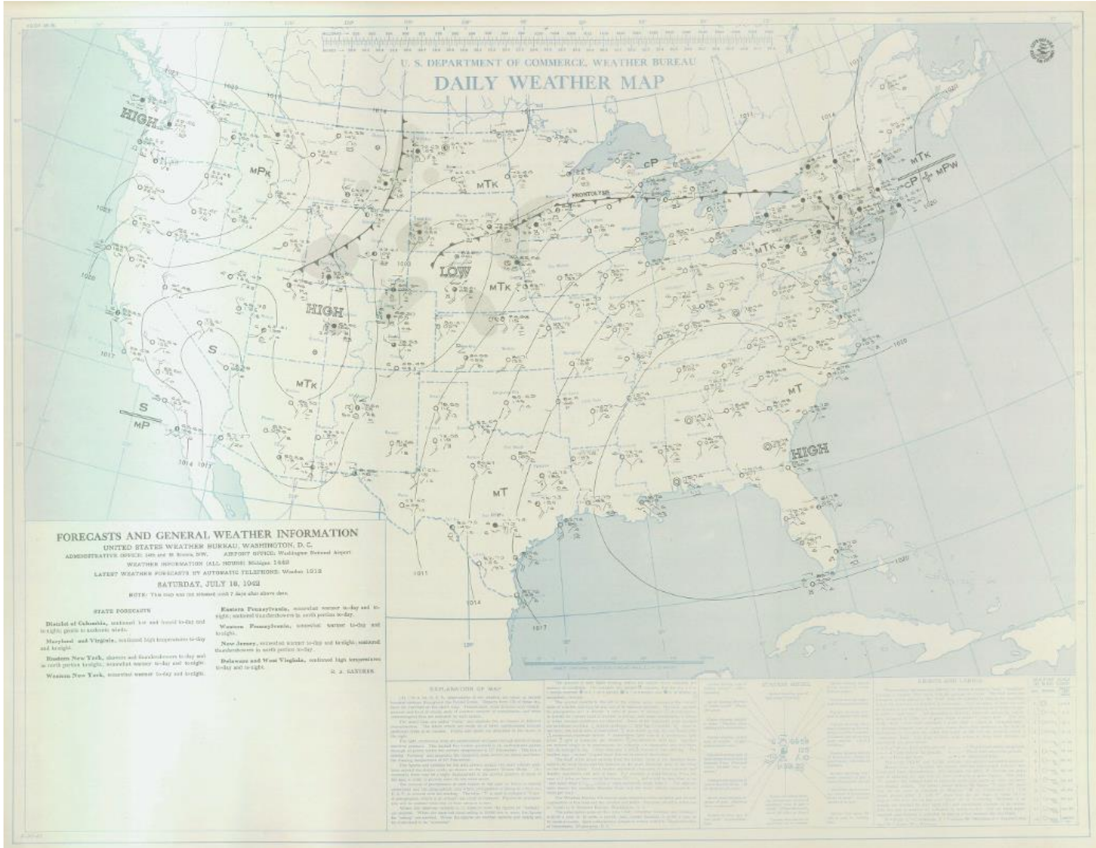
10/8/2018

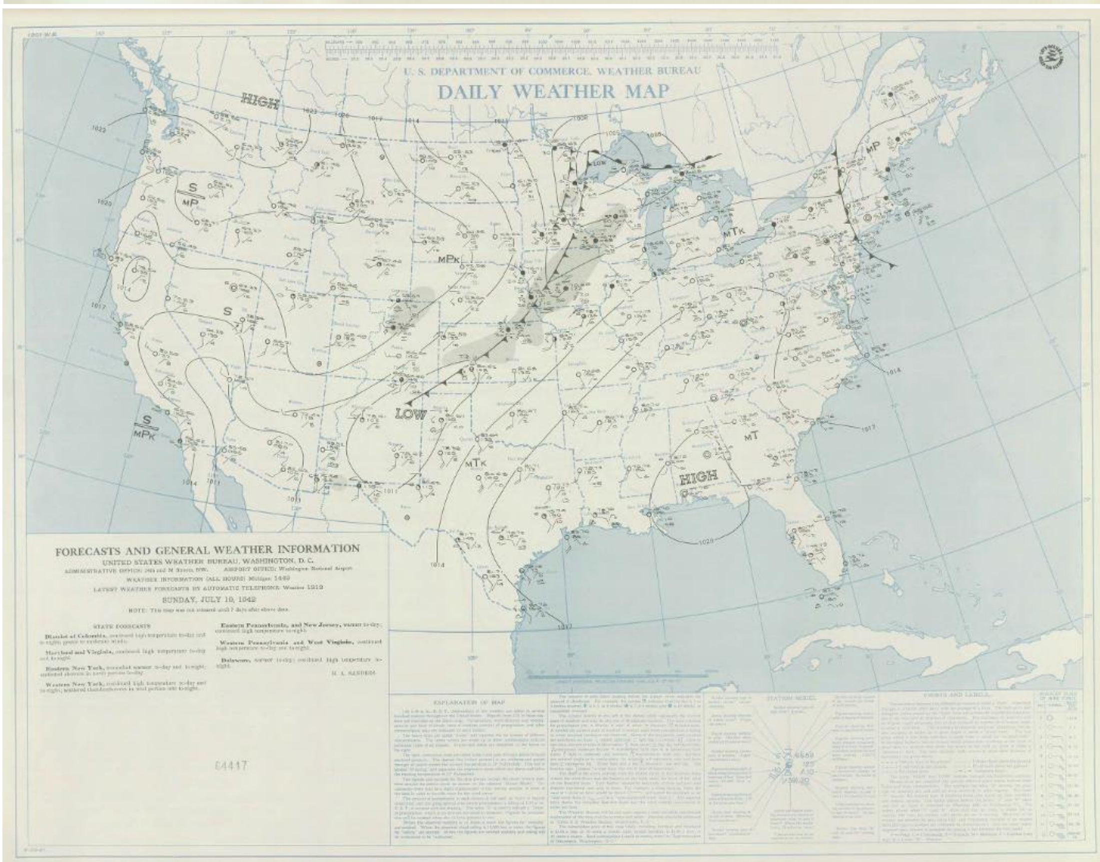

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
TUESDAY, JULY 14, 1942
STATE FORECASTS
District of Columbia,
Maryland,
Virginia,
Eastern New York,
Western New York,
Eastern Pennsylvania,
Western Pennsylvania,
New Jersey,
Delaware,
West Virginia,
HIGH
LOW
cP
mT
mP
cPk
mTk
S

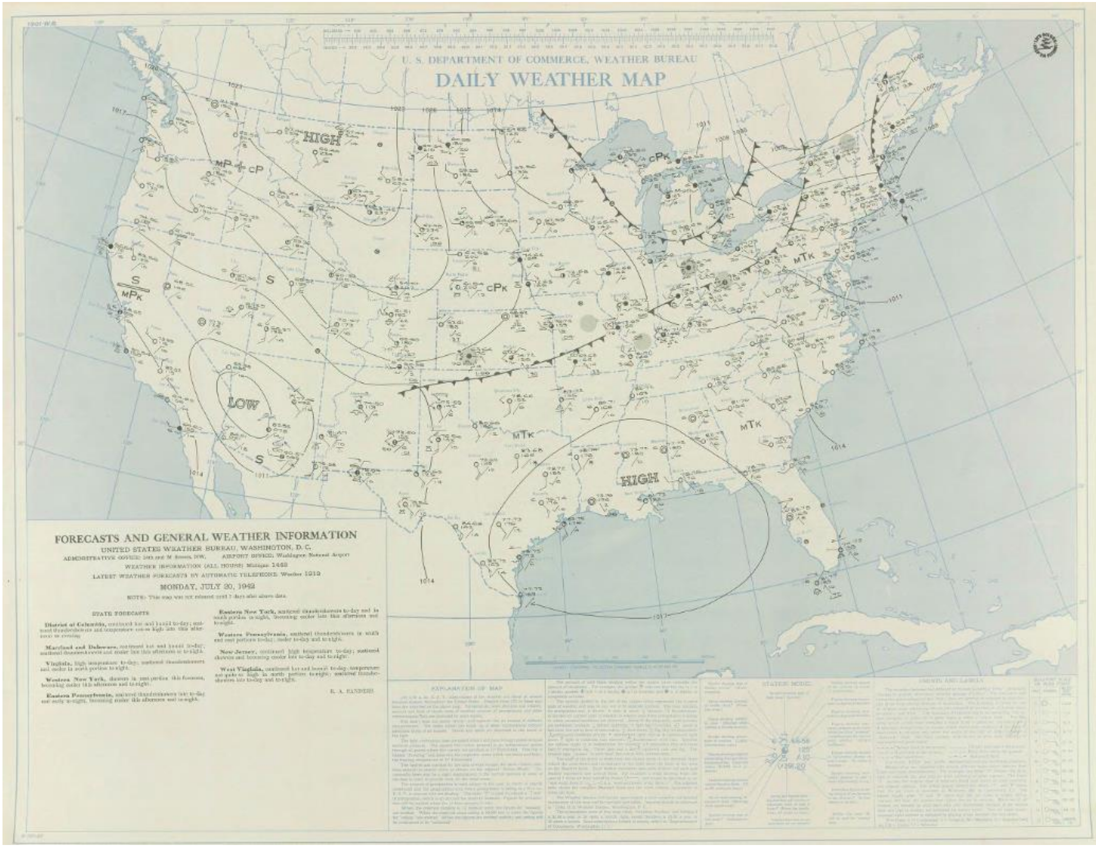

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
LATEST WEATHER FORECASTS BY AUTOMATIC TELEPHONE: Weather 1212
WEDNESDAY, JULY 15, 1942
STATE FORECASTS
District of Columbia,
Maryland and Virginia,
Eastern New York,
Western New York and Western Pennsylvania,
Eastern Pennsylvania,
New Jersey and Delaware,
West Virginia,
STORM INFORMATION
Block Island to Hatteras and Chesapeake Bay,
HIGH
LOW
cP
mT
mP
cPk
mTk
S


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
THURSDAY, JULY 16, 1942
STATE FORECASTS
LOW
HIGH
MTK
MP
CP

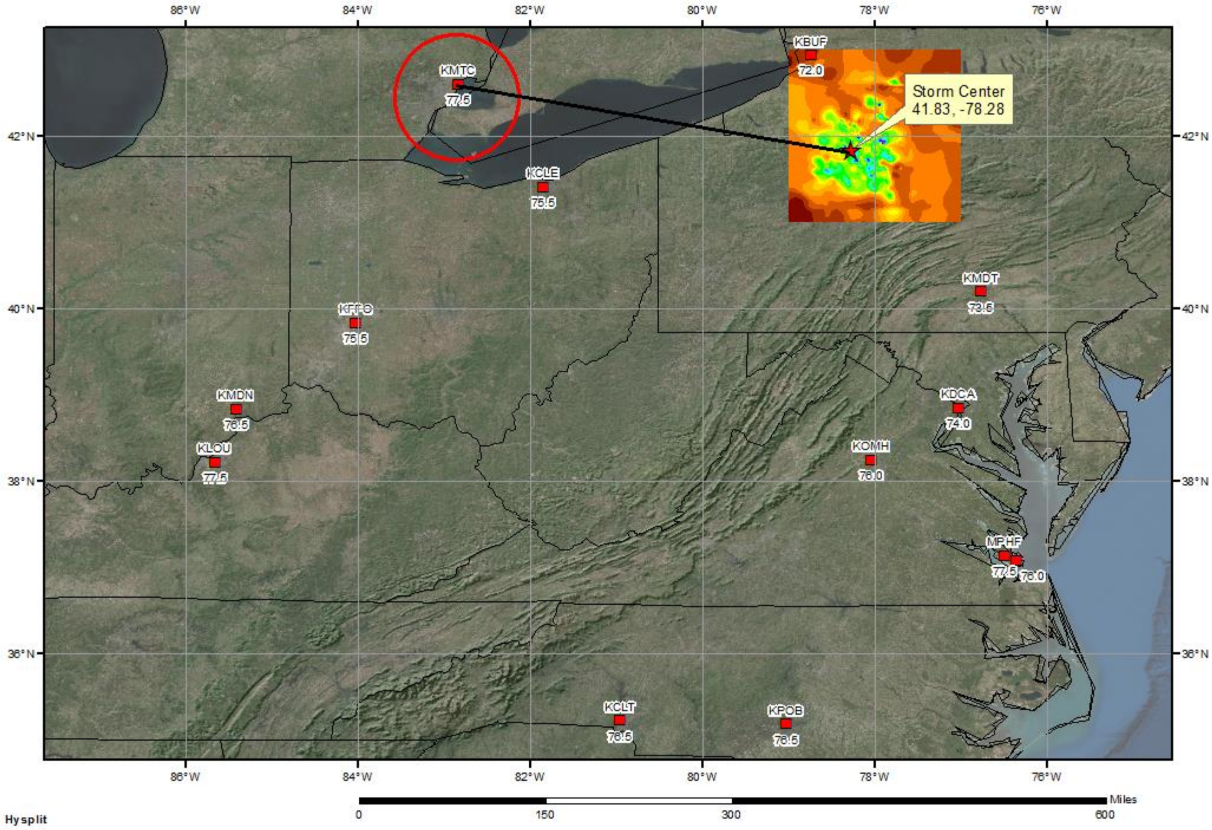

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
FRIDAY, JULY 17, 1942
STATE FORECASTS
LOW
HIGH
MTK
MP
CP


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SATURDAY, JULY 18, 1942
STATE FORECASTS
EXPLANATION OF MAP


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SUNDAY, JULY 19, 1942
STATE FORECASTS
EXPLANATION OF MAP
E4417


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
mP
cP
cPk
S
mPk
LOW
mTk
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
MONDAY, JULY 20, 1942
STATE FORECASTS
District of Columbia,
Maryland and Delaware,
Virginia,
Western New York,
Eastern Pennsylvania,
Eastern New York,
Western Pennsylvania,
New Jersey,
West Virginia,
EXPLANATION OF MAP
STATION MODEL

SPAS 1345 Smethport, PA Storm Analysis
July 14-17, 1942



Storm Precipitation Analysis System (SPAS) For Storm #1681_6 SPAS Analysis

General Storm Location: Smethport, PA

Storm Dates: July 16-20, 1942

Event:

DAD Zone 6

Latitude: 41.6021

Longitude: -78.5729

Max. Grid Rainfall Amount: 29.41"

Max. Observed Rainfall Amount:

Number of Stations:

SPAS Version: 10.0

Basemap:

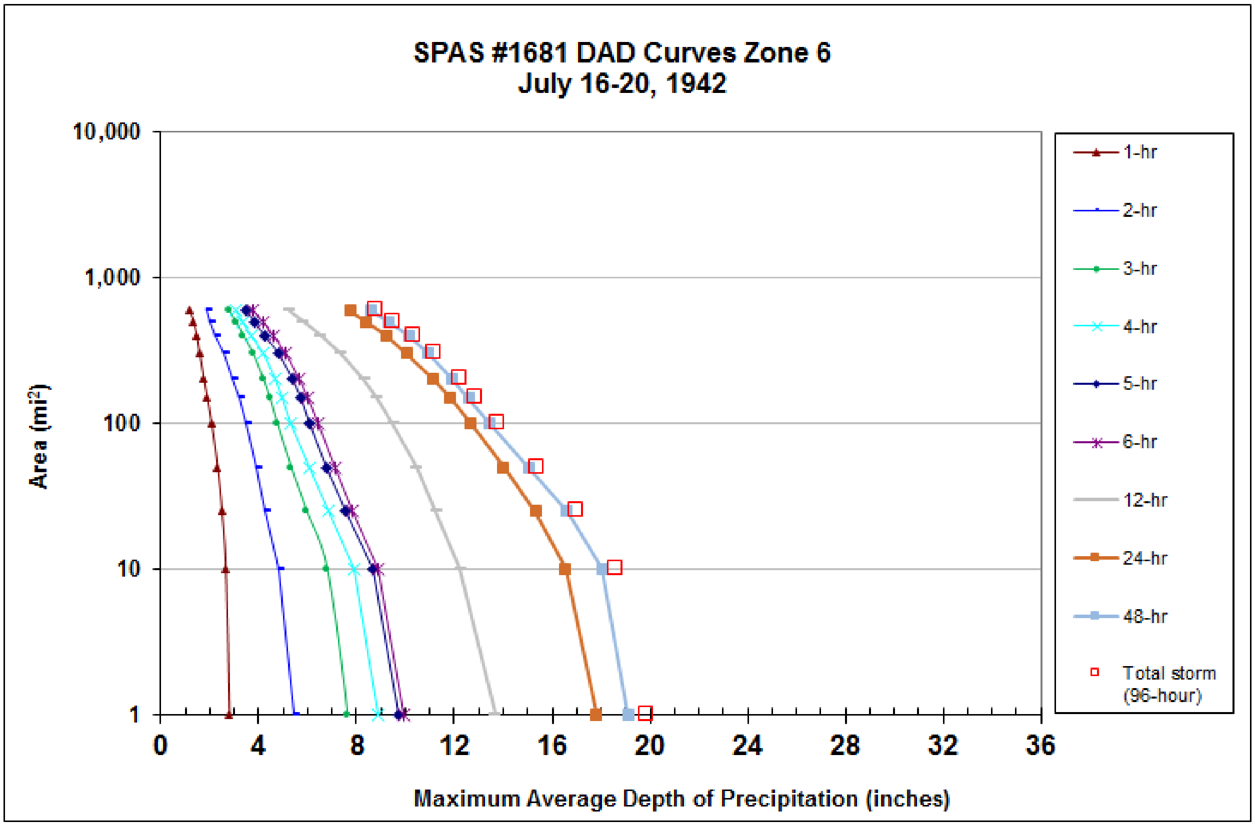
Spatial resolution:

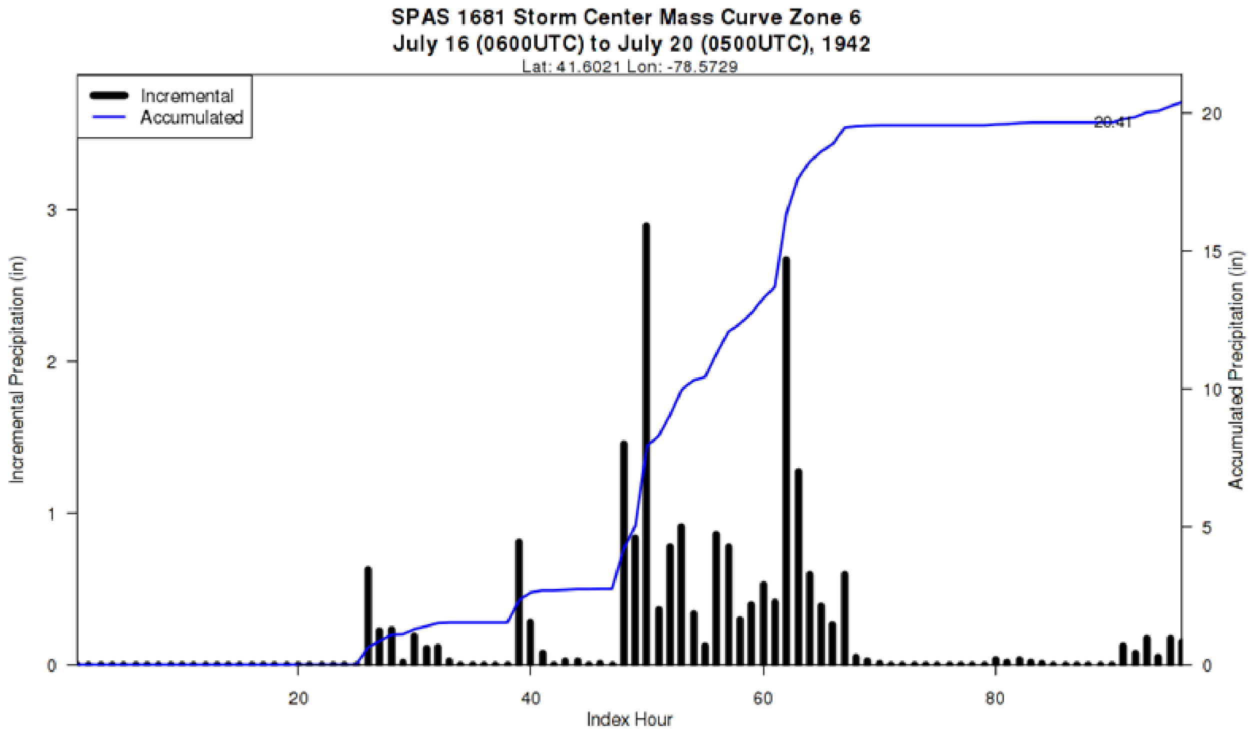
Radar Included: No

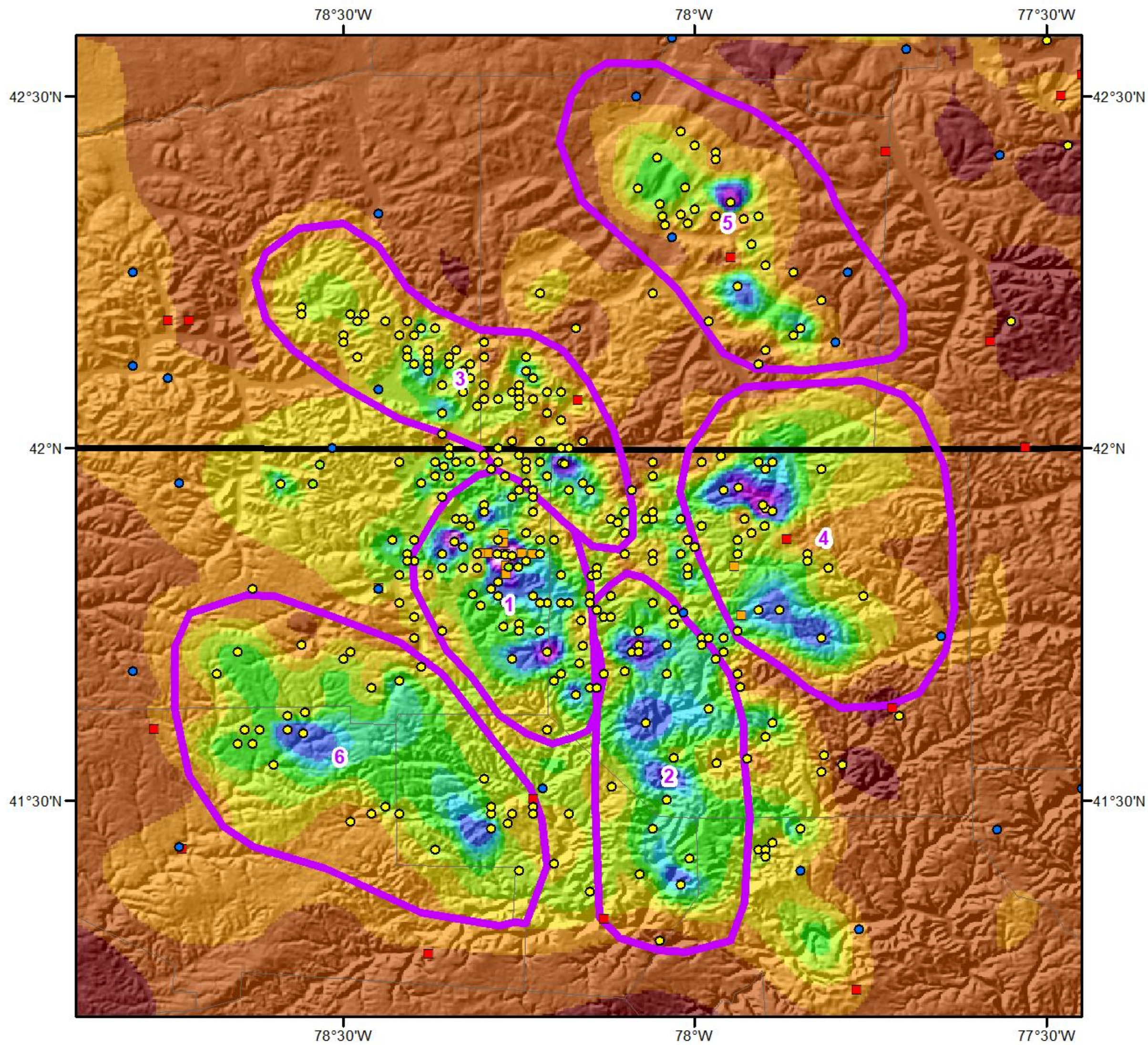
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1681_6	-78.5729	41.6021	2,045	15-Jul	77.50	3.22	0.53	77	2.690	78.00	3.29	0.53	78	2.760	1.026

Storm 1681 Zone 6 - July 16 (0600 UTC) - July 20 (0500 UTC), 1942											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
areasqmi	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	12-hr	24-hr	48-hr	96-hr	Total
0.4	2.84	5.46	7.68	8.91	9.78	10.02	13.76	17.94	19.31	20.05	20.05
1	2.79	5.42	7.63	8.85	9.72	9.96	13.67	17.82	19.11	19.88	19.88
10	2.64	4.79	6.80	7.89	8.65	8.86	12.22	16.56	18.05	18.60	18.60
25	2.48	4.27	5.96	6.87	7.56	7.85	11.25	15.33	16.63	17.04	17.04
50	2.30	3.89	5.32	6.05	6.80	7.14	10.45	14.02	15.03	15.41	15.41
100	2.05	3.47	4.75	5.34	6.11	6.46	9.49	12.70	13.45	13.80	13.80
150	1.87	3.17	4.44	4.95	5.70	6.04	8.83	11.83	12.57	12.90	12.90
200	1.73	2.95	4.18	4.67	5.37	5.69	8.29	11.13	11.92	12.23	12.23
300	1.56	2.57	3.75	4.17	4.81	5.11	7.35	10.07	10.95	11.22	11.22
400	1.43	2.20	3.36	3.72	4.28	4.59	6.51	9.22	10.12	10.38	10.38
500	1.3	2.01	3.04	3.36	3.85	4.15	5.83	8.39	9.3	9.54	9.54
591	1.14	1.84	2.77	3.06	3.49	3.78	5.26	7.73	8.62	8.84	8.84
2,000											
3,500											
5,000											
7,500											




SPAS 1681 Storm Center Mass Curve Zone 6
July 16 (0600UTC) to July 20 (0500UTC), 1942
Lat: 41.6021 Lon: -78.5729
Incremental
Accumulated
20.41
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
5
10
15
20
40
60
80



Total Storm (96-hr) Precipitation (inches)
07/16/1942 0600 UTC - 07/20/1942 0500 UTC
SPAS #1681 - Version 10

Gauges

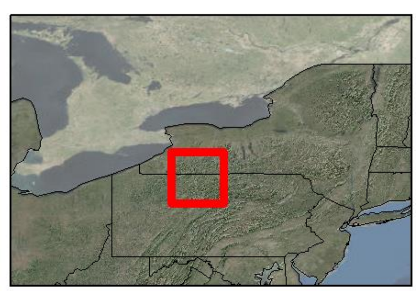
- D
- H
- HP
- S
- SE

Miles: 0 3.5 7 14

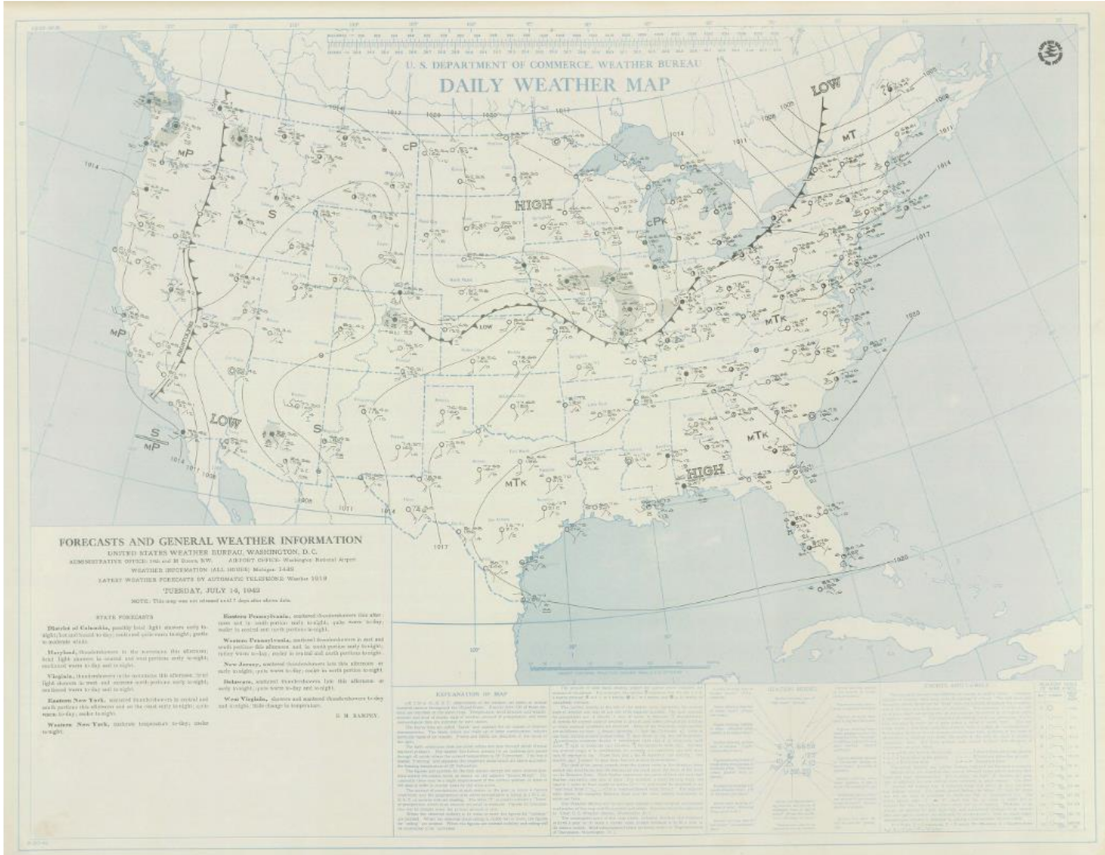
Kilometers: 0 10 20 40

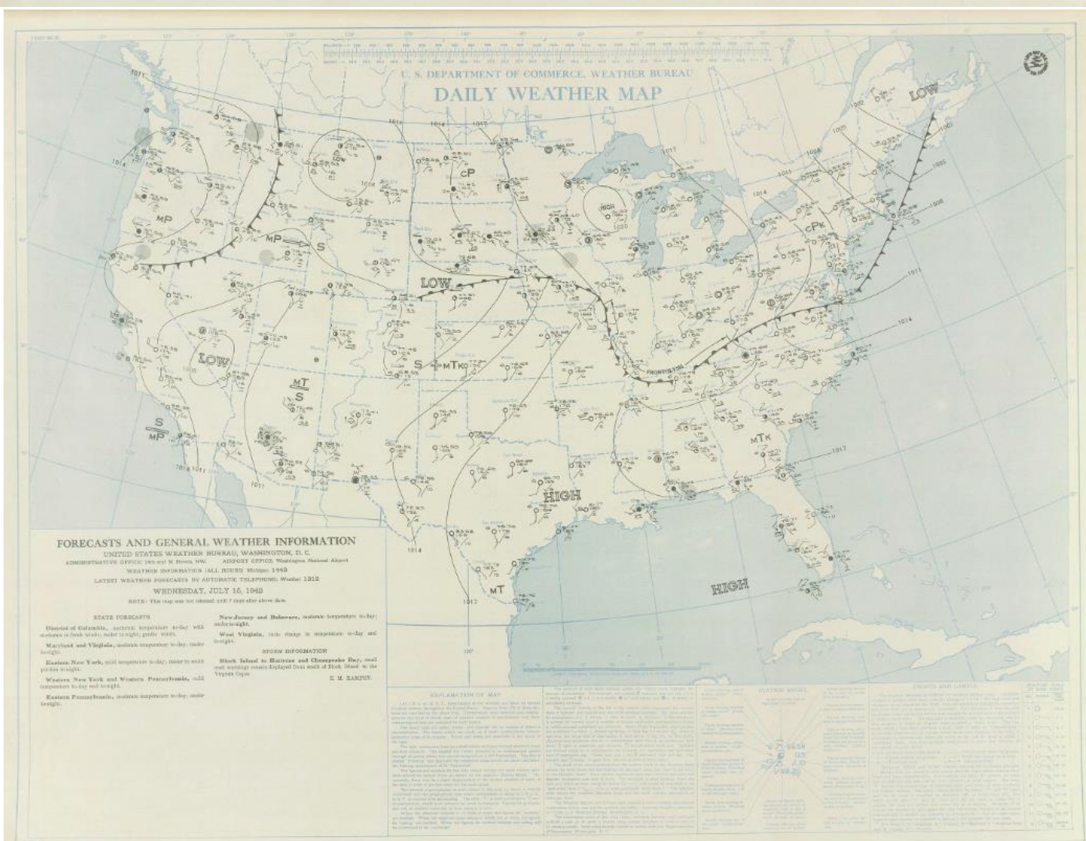
Precipitation (inches)

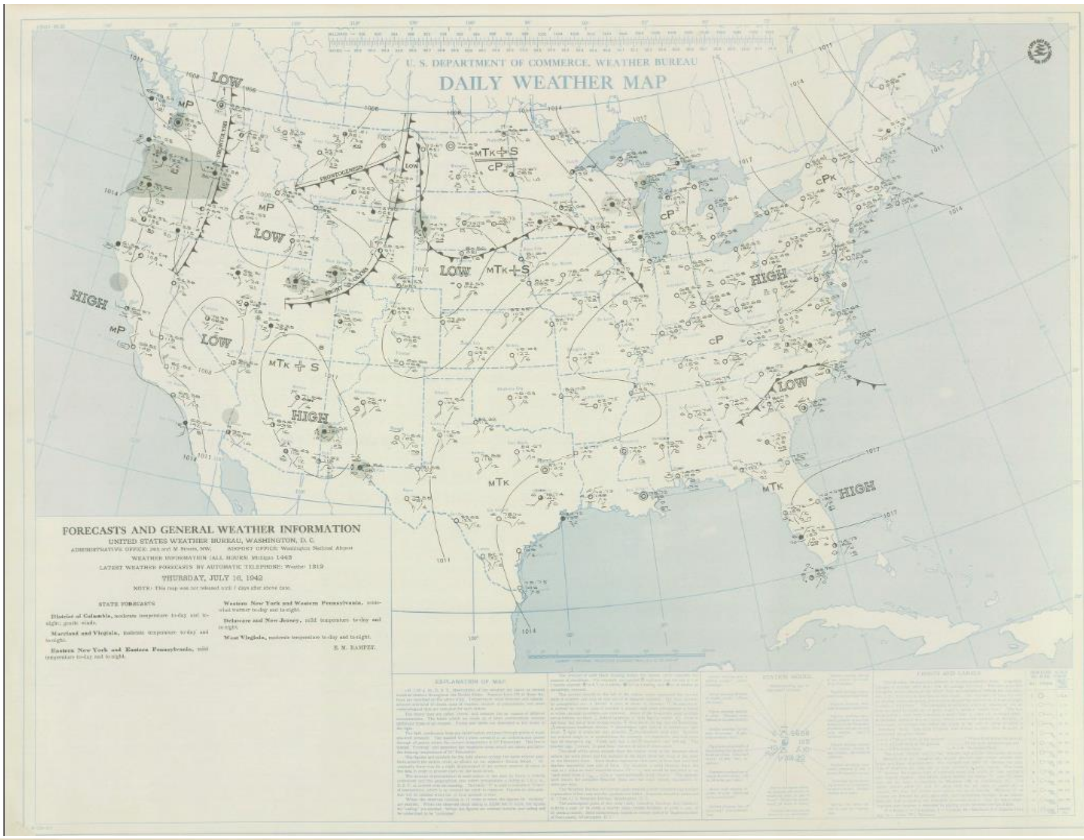
0.00 - 2.00	6.01 - 8.00	12.01 - 14.00	20.01 - 24.00	32.01 - 36.00
2.01 - 4.00	8.01 - 10.00	14.01 - 16.00	24.01 - 28.00	
4.01 - 6.00	10.01 - 12.00	16.01 - 20.00	28.01 - 32.00	

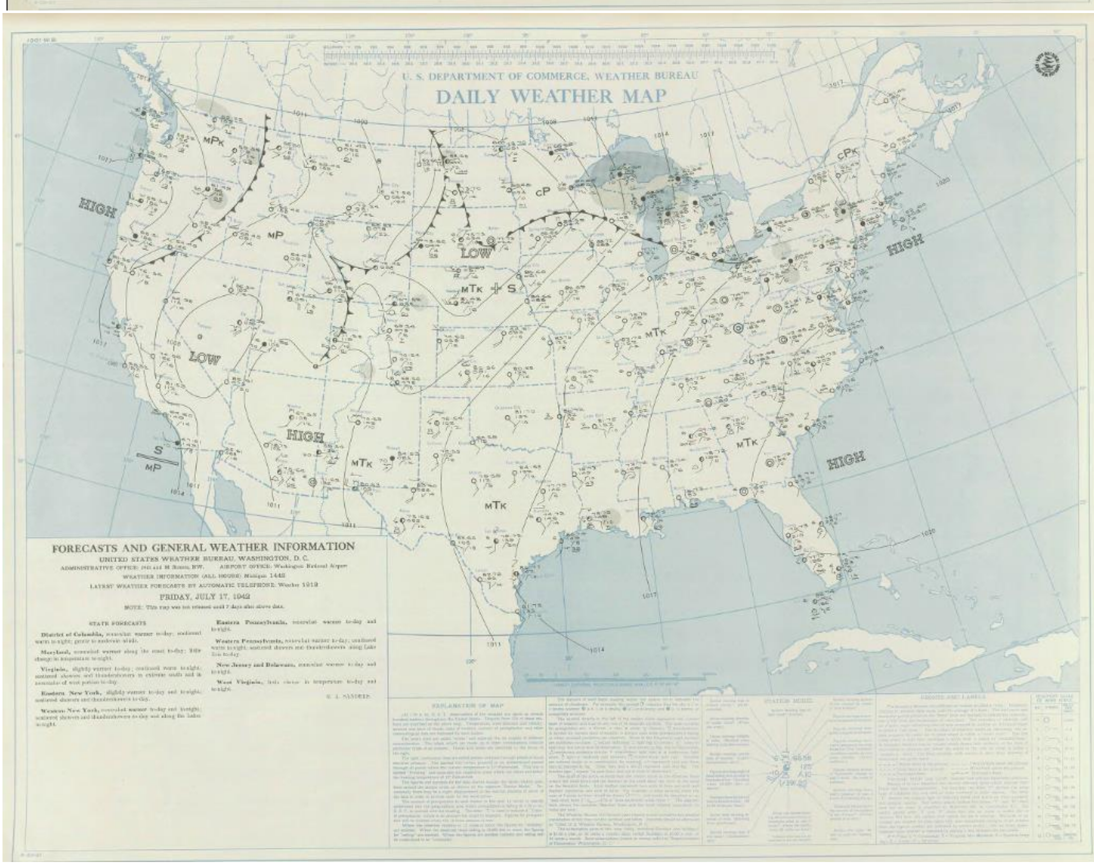


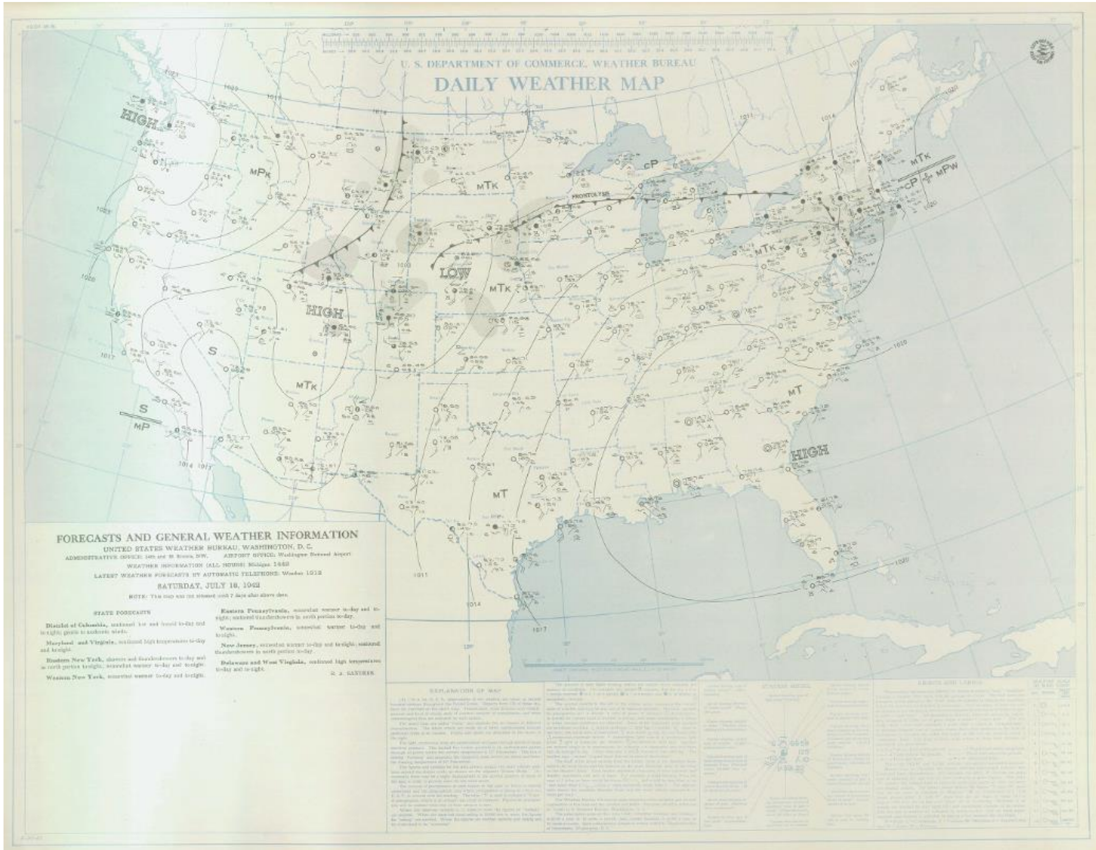
10/8/2018

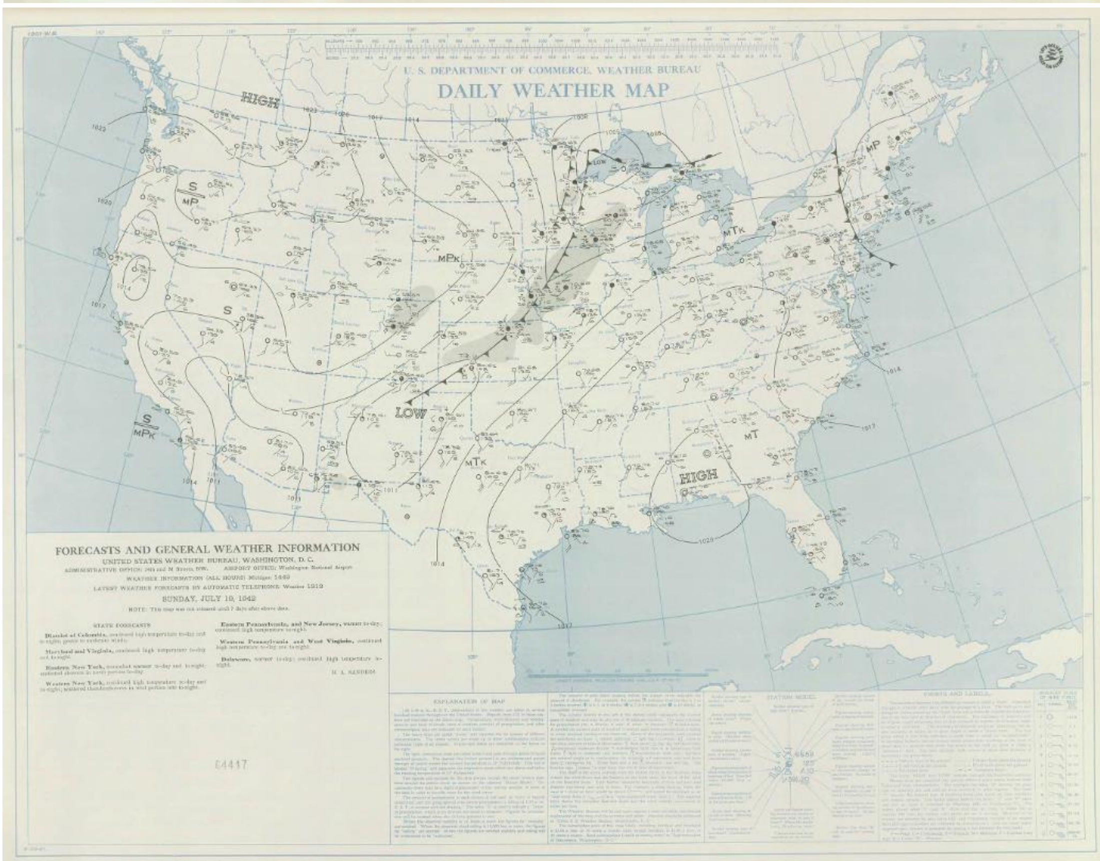

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
LOW
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
TUESDAY, JULY 14, 1942
STATE FORECASTS
E. M. RAMPEY

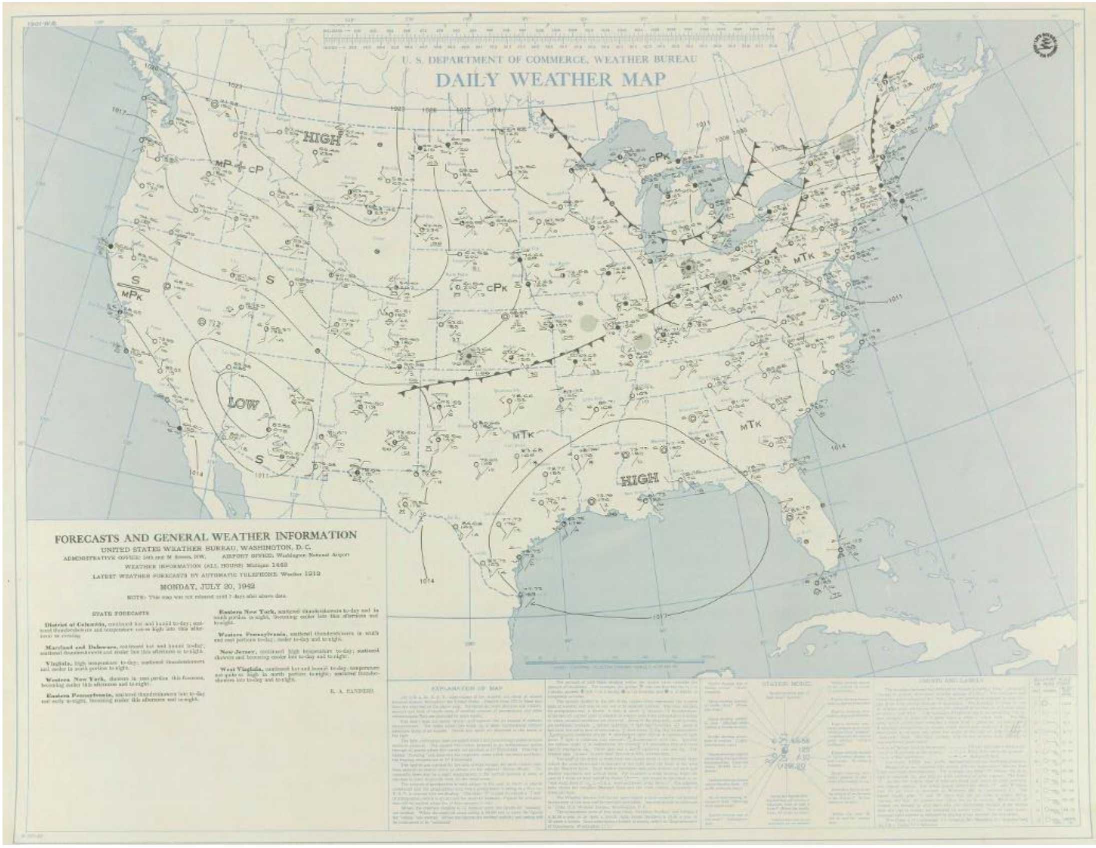

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
LOW
LOW
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
WEDNESDAY, JULY 15, 1942
STATE FORECASTS
STORM INFORMATION
E. M. RAMPEY


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
MP
cP
cPK
MTK
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
THURSDAY, JULY 16, 1942
STATE FORECASTS
West Virginia, moderate temperature to-day and to-night.
EXPLANATION OF MAP

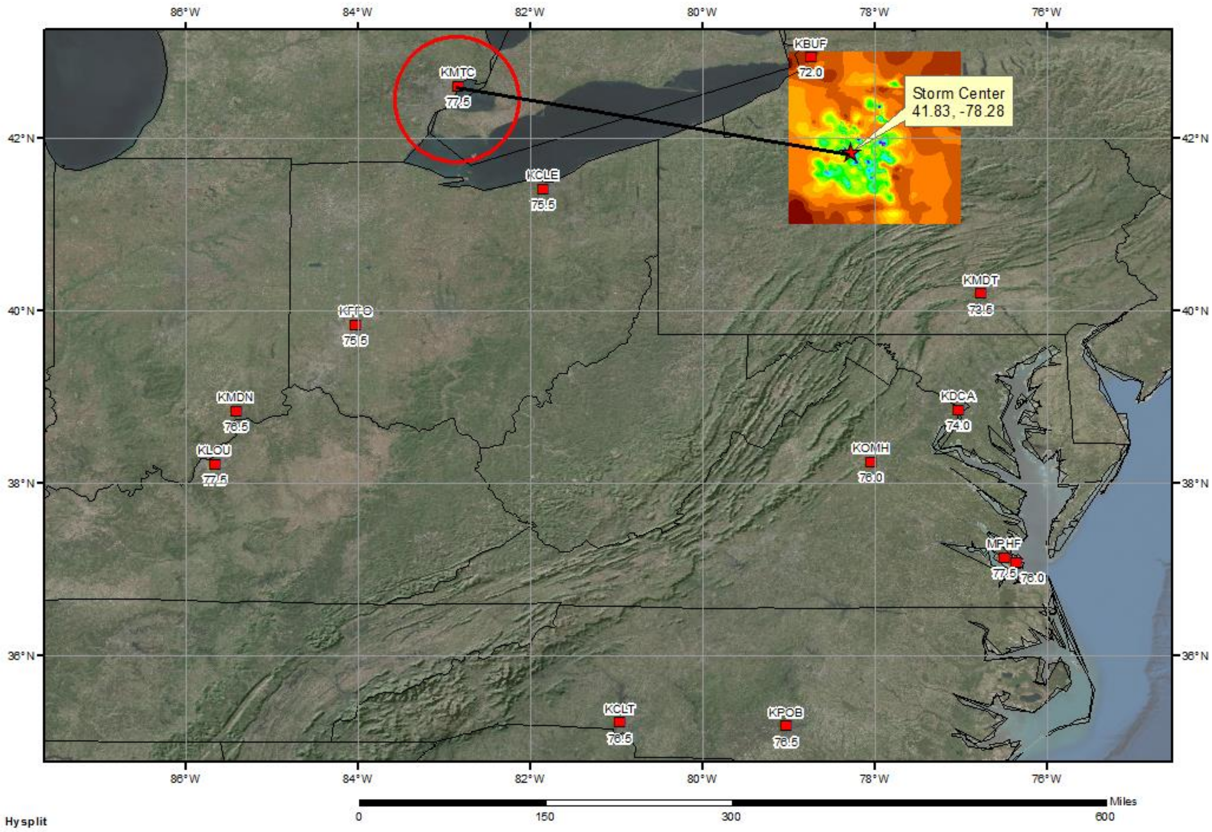

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
MPK
MP
cP
cPK
MTK
S
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
ADMINISTRATIVE OFFICE
AIRPORT OFFICE
FRIDAY, JULY 17, 1942
STATE FORECASTS
EXPLANATION OF MAP


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
HIGH
mPk
mTk
cP
MTk
mPw
S
mP
mT
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SATURDAY, JULY 18, 1942
STATE FORECASTS


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
LOW
HIGH
S
mP
mPk
mTk
mT
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
SUNDAY, JULY 19, 1942
STATE FORECASTS
E4417


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
MP
cP
cPK
S
MPK
LOW
MTK
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
MONDAY, JULY 20, 1942
STATE FORECASTS
EXPLANATION OF MAP
STATION MODEL

SPAS 1345 Smethport, PA Storm Analysis
July 14-17, 1942



Storm Precipitation Analysis System (SPAS) For Storm #1536_1 SPAS Analysis

General Storm Location: West Virginia

Storm Dates: August 4 – August 5, 1943

Event: USACE_OR_3_30

DAD Zone 1

Latitude: 38.8958

Longitude: -80.7708

Max. Grid Rainfall Amount: 15.04”

Max. Observed Rainfall Amount: 15.00”

Number of Stations: 148

SPAS Version: 10.0

Basemap: Isohyetal basemap from USGS Notable Local Floods report

Spatial resolution: 0.2564

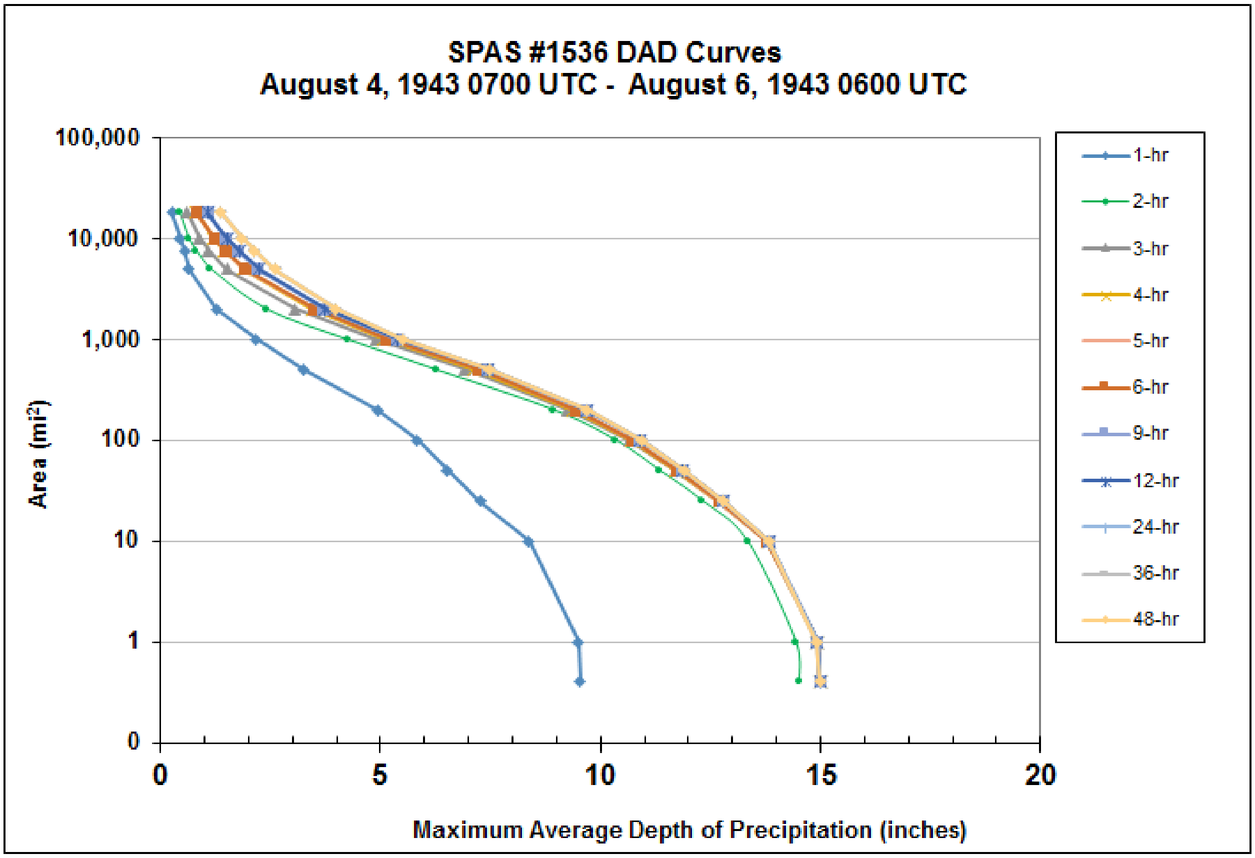
Radar Included: No

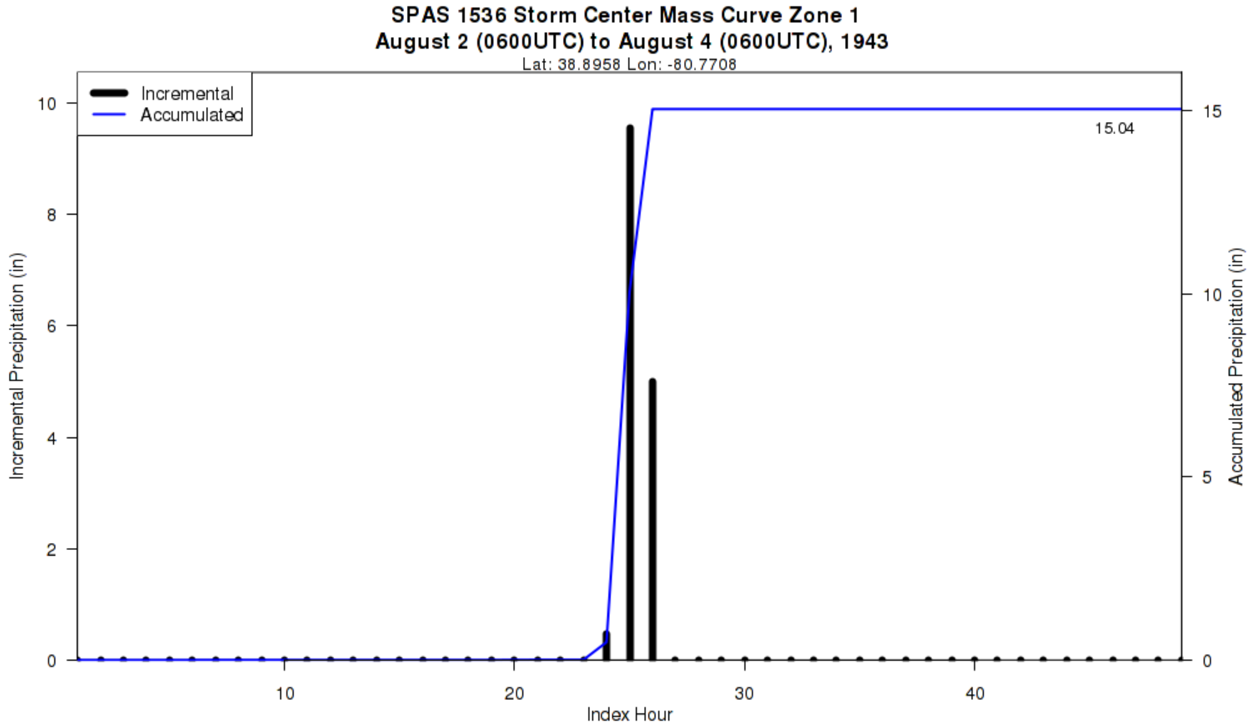
Depth-Area-Duration (DAD) analysis: Yes

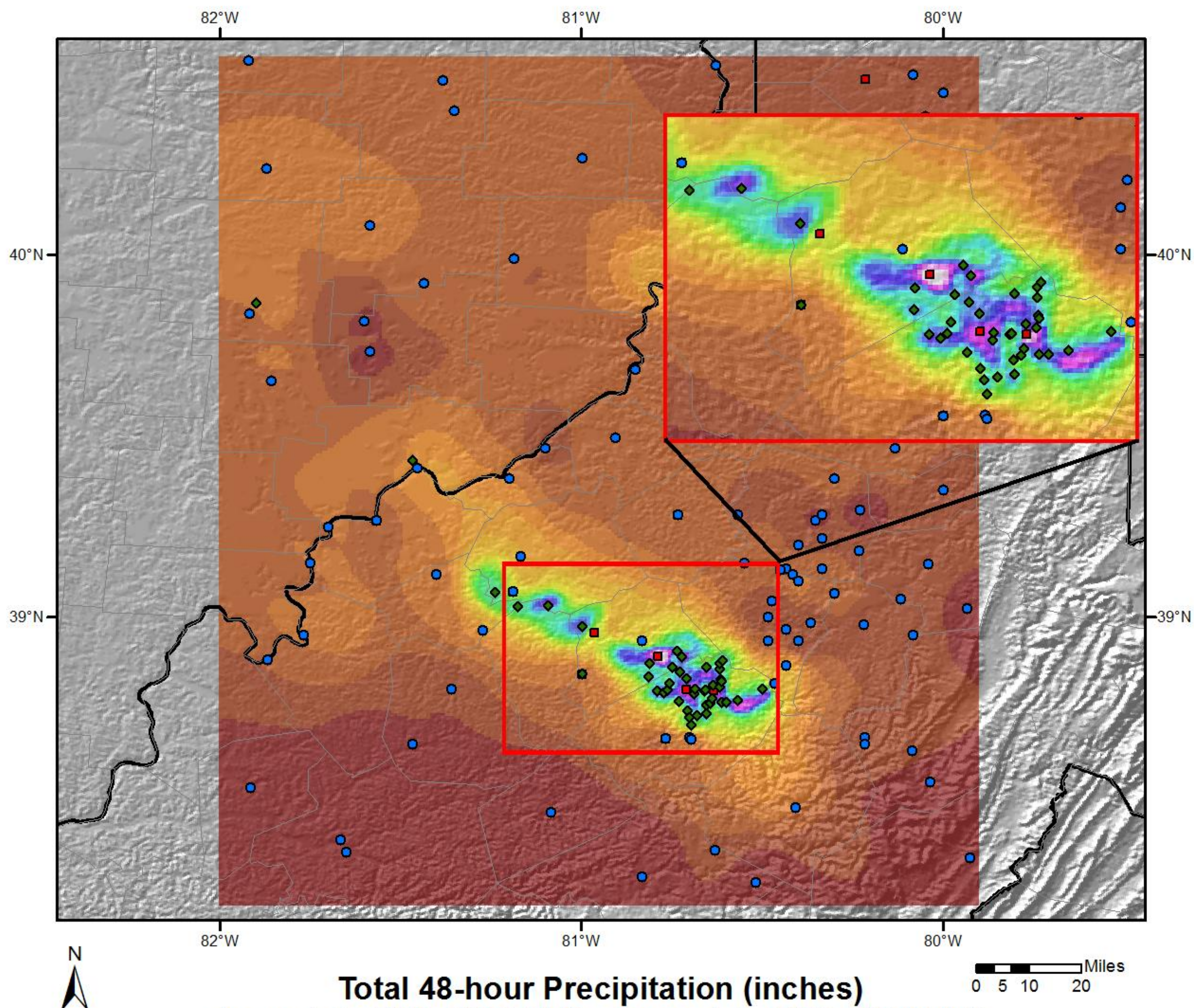
Reliability of results: Three of the 44 supplemental stations were converted from the daily type due to questionable observation times. The remaining 41 supplemental stations were digitized from the USGS Notable Floods report. While there were additional supplemental stations added from the USGS report, they were subsequently removed from the analysis due to inconsistencies with the isohyetal map from said report. This isohyetal map was also digitized and used as the basemap for this storm in order to fully represent this previous analysis. Ten of the eleven hourly stations were digitized from the USGS report along with data from the USACE report OR 3-30. With the amount of data pulled from these trusted sources, and the consistency of the results of this analysis against those previously published, this analysis is considered to be reliable.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1536_1	-80.7708	38.8950	1,113	15-Aug	74.00	2.73	0.27	70	2.460	80.44	3.68	0.33	83	3.350	1.362

Storm 1536 - August 4 (0700 UTC) - August 6 (0600 UTC), 1943											
	Duration (hours)										
areasqmi	1	2	3	4	5	6	9	12	24	36	48
0.4	9.54	14.52	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
1	9.50	14.44	14.93	14.93	14.93	14.93	14.93	14.93	14.93	14.91	14.91
10	8.37	13.34	13.78	13.78	13.78	13.79	13.82	13.82	13.83	13.83	13.83
25	7.26	12.32	12.69	12.70	12.70	12.72	12.80	12.80	12.80	12.80	12.80
50	6.52	11.35	11.69	11.70	11.72	11.74	11.87	11.88	11.89	11.89	11.89
100	5.84	10.35	10.65	10.69	10.71	10.73	10.90	10.90	10.93	10.93	10.93
200	4.93	8.93	9.26	9.35	9.45	9.45	9.68	9.69	9.71	9.71	9.71
500	3.24	6.27	6.92	7.11	7.22	7.22	7.44	7.45	7.47	7.47	7.47
1000	2.18	4.24	4.89	5.07	5.16	5.16	5.38	5.39	5.49	5.49	5.49
2000	1.27	2.40	3.07	3.45	3.50	3.51	3.71	3.75	3.99	3.99	3.99
5000	0.65	1.14	1.51	1.90	1.92	1.93	2.22	2.25	2.61	2.61	2.61
7500	0.54	0.82	1.10	1.46	1.48	1.48	1.76	1.79	2.13	2.13	2.13
10000	0.45	0.64	0.89	1.21	1.22	1.23	1.50	1.52	1.85	1.85	1.85
18227	0.26	0.42	0.61	0.82	0.83	0.83	1.07	1.08	1.37	1.37	1.37




SPAS 1536 Storm Center Mass Curve Zone 1
August 2 (0600UTC) to August 4 (0600UTC), 1943
Lat: 38.8958 Lon: -80.7708
Incremental
Accumulated
15.04
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
2
4
6
8
10
5
15
10
20
30
40



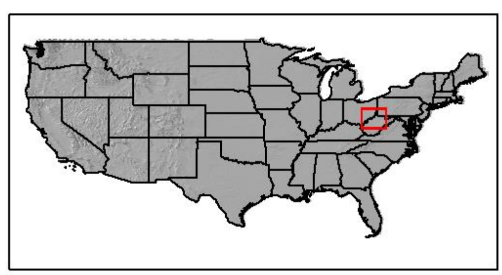
Total 48-hour Precipitation (inches)
August 4, 1943 0600 UTC - August 6, 1943 0600 UTC
SPAS #1536

Precipitation (inches)

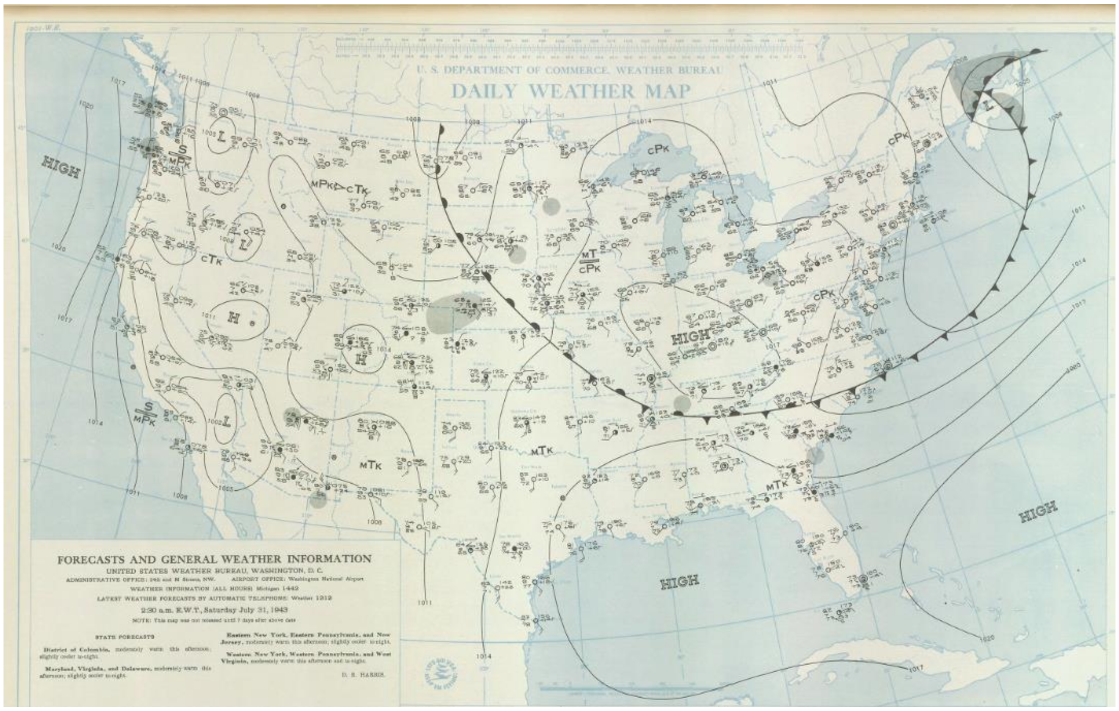
- 0.04 - 0.50
- 0.51 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- 2.51 - 3.00
- 3.01 - 3.50
- 3.51 - 4.00
- 4.01 - 4.50
- 4.51 - 5.00
- 5.01 - 5.50
- 5.51 - 6.00
- 6.01 - 6.50
- 6.51 - 7.00
- 7.01 - 7.50
- 7.51 - 8.00
- 8.01 - 8.50
- 8.51 - 9.00
- 9.01 - 9.50
- 9.51 - 10.00
- 10.01 - 10.50
- 10.51 - 11.00
- 11.01 - 11.50
- 11.51 - 12.00
- 12.01 - 12.50
- 12.51 - 13.00
- 13.01 - 13.50
- 13.51 - 14.00
- 14.01 - 14.50
- 14.51 - 15.00

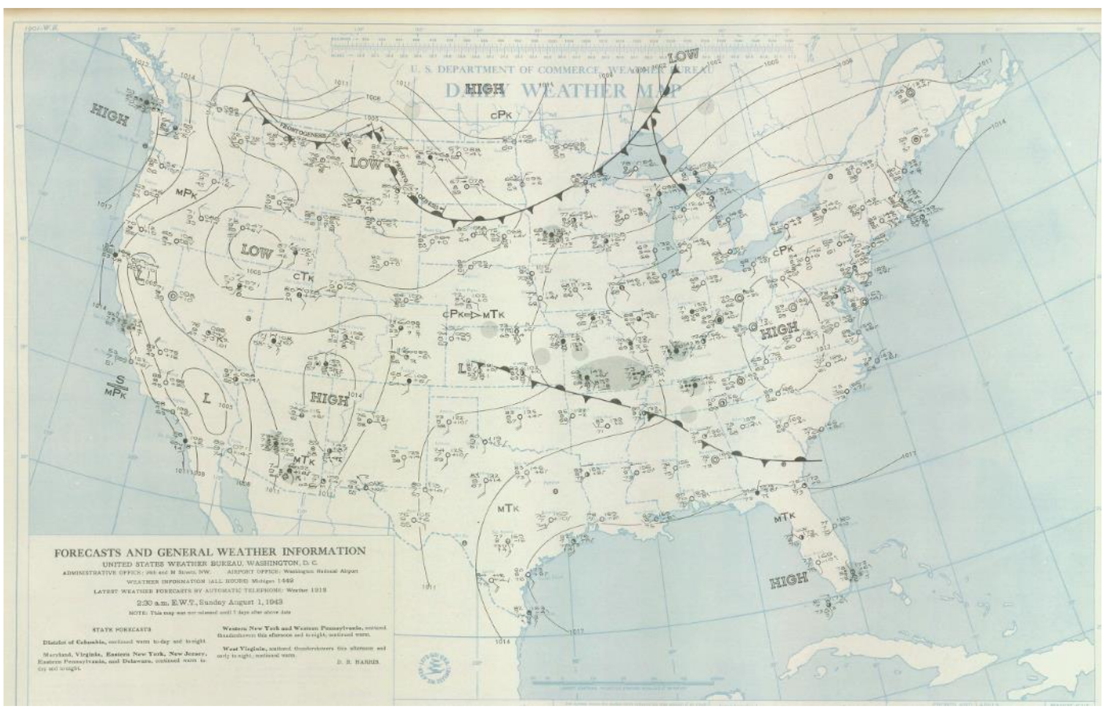
Stations

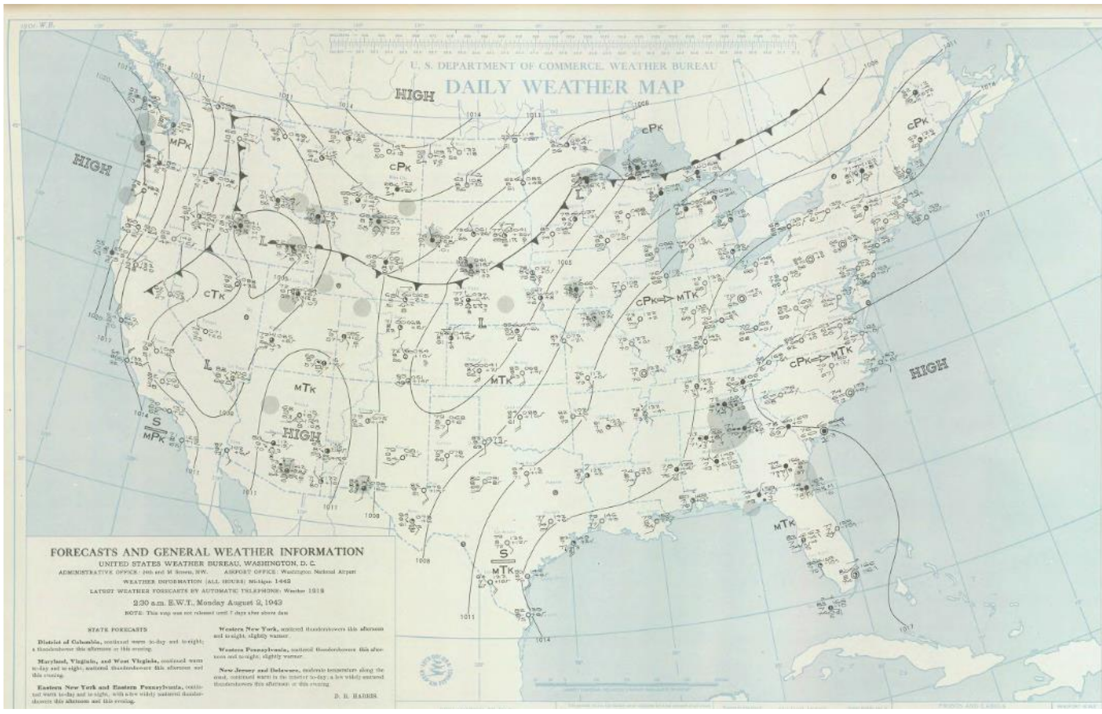
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

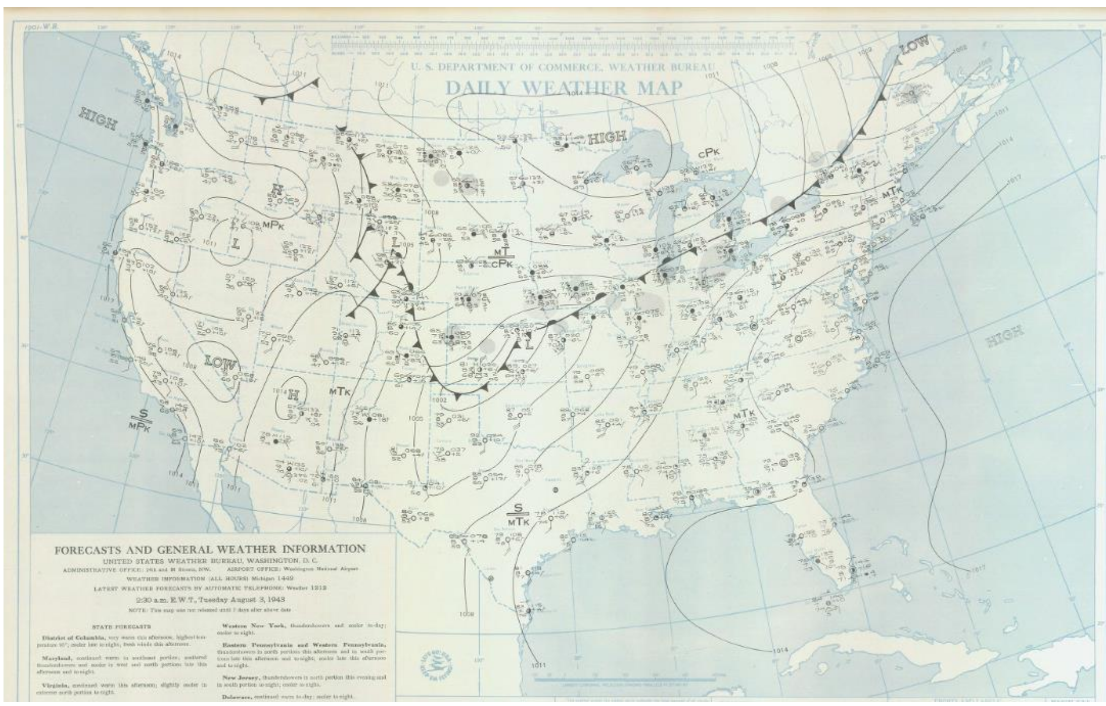


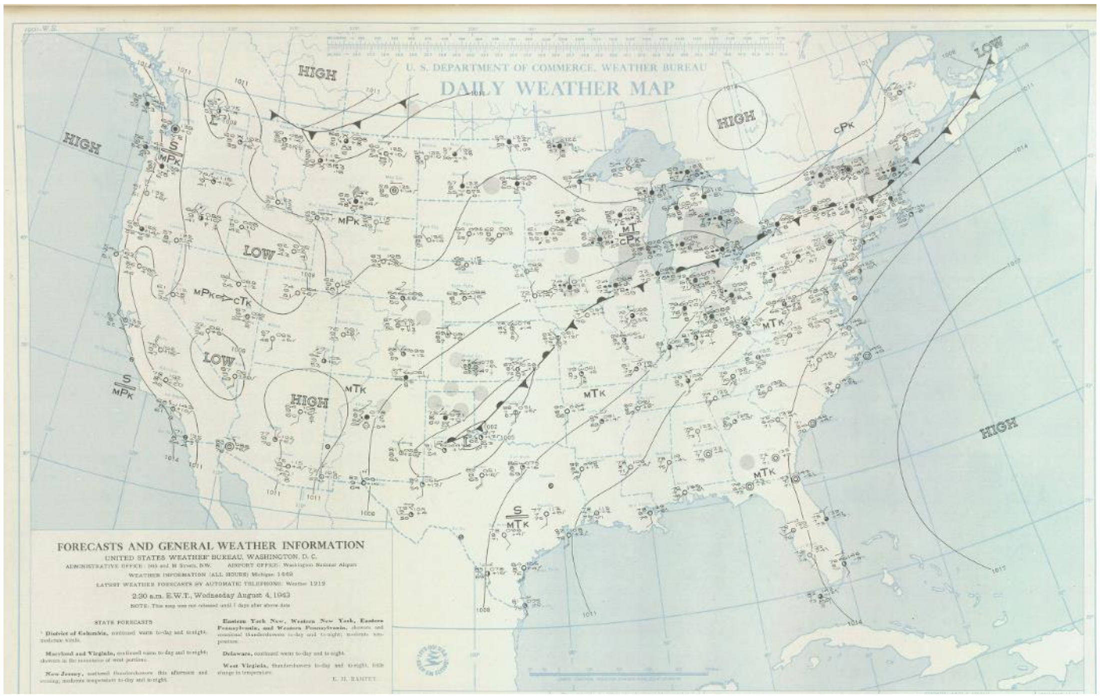
KLL 07/15/2015

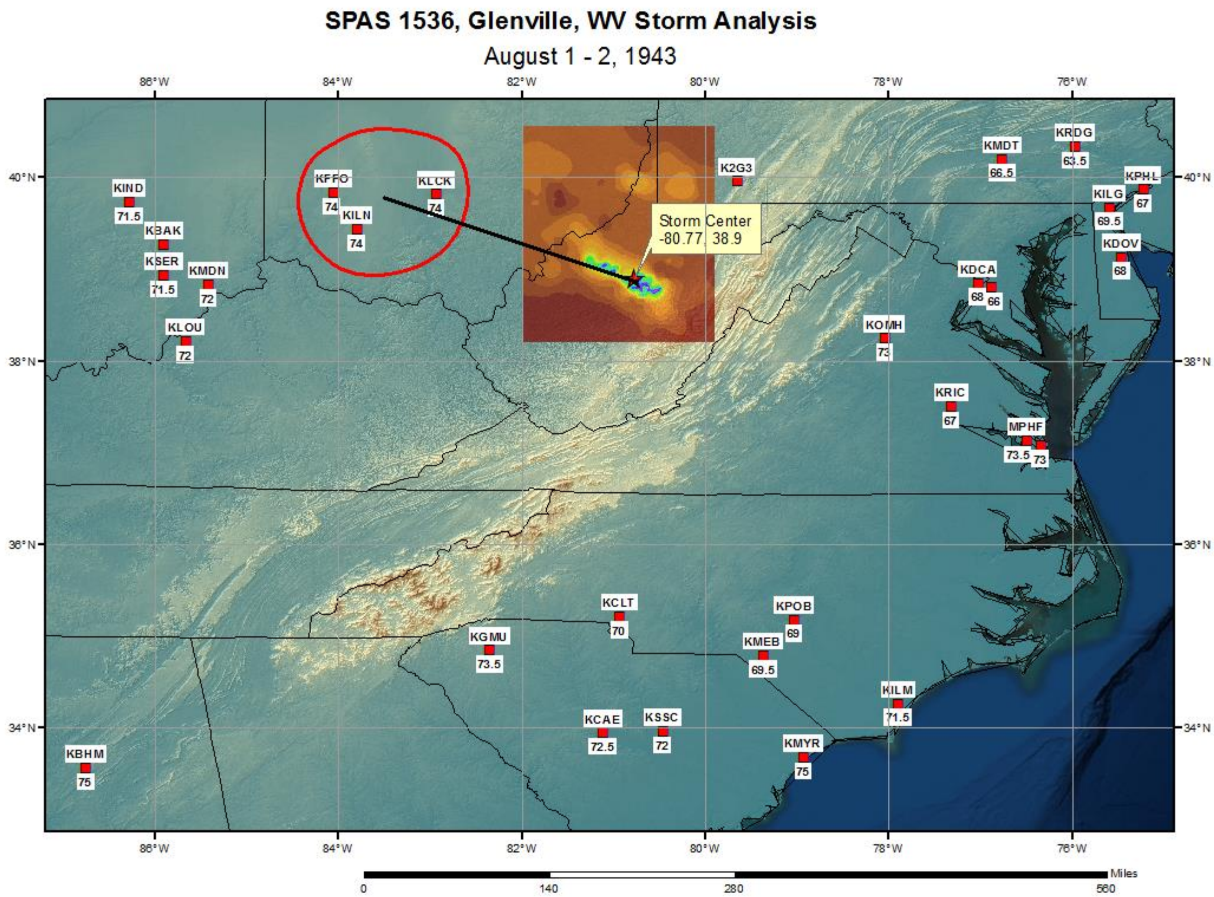

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
2:30 a.m. E.W.T., Saturday July 31, 1943
STATE FORECASTS
District of Columbia, moderately warm this afternoon; slightly cooler to-night.
Maryland, Virginia, and Delaware, moderately warm this afternoon; slightly cooler to-night.
Eastern New York, Eastern Pennsylvania, and New Jersey, moderately warm this afternoon; slightly cooler to-night.
Western New York, Western Pennsylvania, and West Virginia, moderately warm this afternoon and to-night.
D. B. HARRIS.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
LOW
LOW
HIGH
HIGH
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
2:30 a.m. E.W.T., Sunday August 1, 1943
STATE FORECASTS
District of Columbia, continued warm to-day and to-night.
Maryland, Virginia, Eastern New York, New Jersey, Eastern Pennsylvania, and Delaware, continued warm to-day and to-night.
Western New York and Western Pennsylvania, scattered thundershowers this afternoon and to-night; continued warm.
West Virginia, scattered thundershowers this afternoon and early to-night; continued warm.
D. B. HARRIS


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
2:30 a.m. E.W.T., Monday August 2, 1943
STATE FORECASTS
District of Columbia,
Maryland, Virginia, and West Virginia,
Eastern New York and Eastern Pennsylvania,
Western New York,
Western Pennsylvania,
New Jersey and Delaware,
D. B. HARRIS


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
2:30 a.m. E.W.T., Tuesday August 3, 1943
STATE FORECASTS
District of Columbia,
Maryland,
Virginia,
Western New York,
Eastern Pennsylvania and Western Pennsylvania,
New Jersey,
Delaware,


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
2:30 a.m. E.W.T., Wednesday August 4, 1943
STATE FORECASTS
District of Columbia,
Maryland and Virginia,
New Jersey,
Delaware,
West Virginia,


SPAS 1536, Glenville, WV Storm Analysis
August 1 - 2, 1943
Storm Center
-80.77, 38.9
KIND 71.5
KBAK
KSER 71.5
KMDN 72
KLOU 72
KFFO 74
KLCK 74
KILN 74
K2G3
KMDT 66.5
KRDG 63.5
KPHL 67
KILG 69.5
KDOV 68
KDCA 68 66
KOMH 73
KRIC 67
MPHF 73.5 73
KCLT 70
KGMU 73.5
KPOB 69
KMEB 69.5
KILM 71.5
KCAE 72.5
KSSC 72
KMYR 75
KBHM 75
86°W
84°W
82°W
80°W
78°W
76°W
40°N
38°N
36°N
34°N
Miles
0
140
280
560

Storm Precipitation Analysis System (SPAS) For Storm #1546_1 SPAS Analysis

General Storm Location: Virginia/West Virginia Border

Storm Dates: June 16-19, 1949

Event: Tropical Remnants

DAD Zone 1

Latitude: 38.8625

Longitude: -79.1875

Max. Grid/Radar Rainfall Amount: 15.13”

Max. Observed Rainfall Amount: 14.26” at Brushy Run, VA

Number of Stations: 112

SPAS Version: 10.0

Base Map Used: PRISM Mean June 1971-2000

Spatial resolution: 0.2577

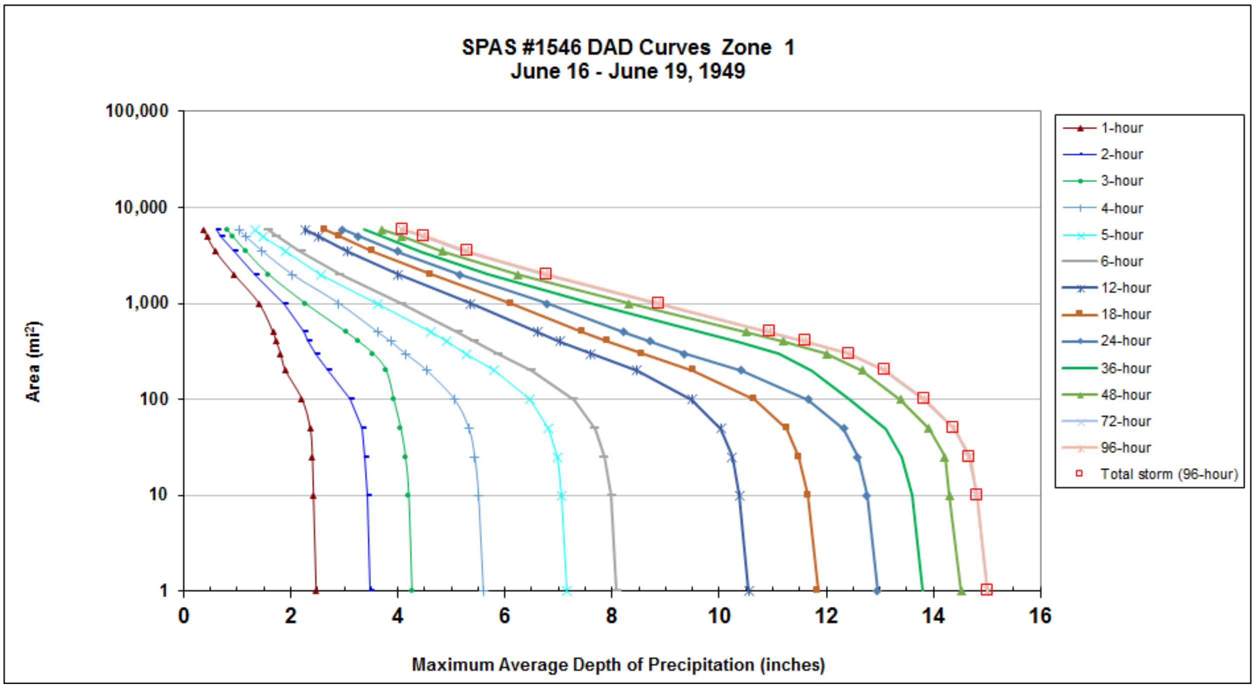
Radar Included: No

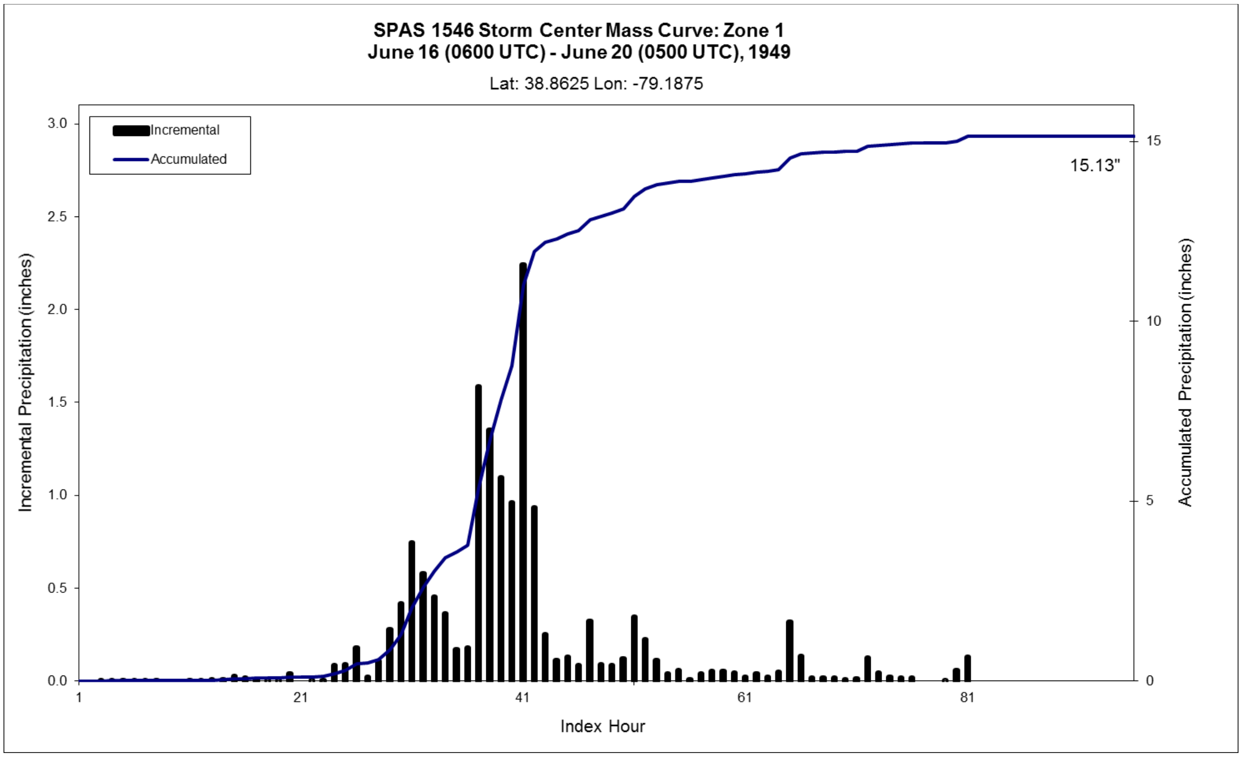
Depth-Area-Duration (DAD) analysis: Yes

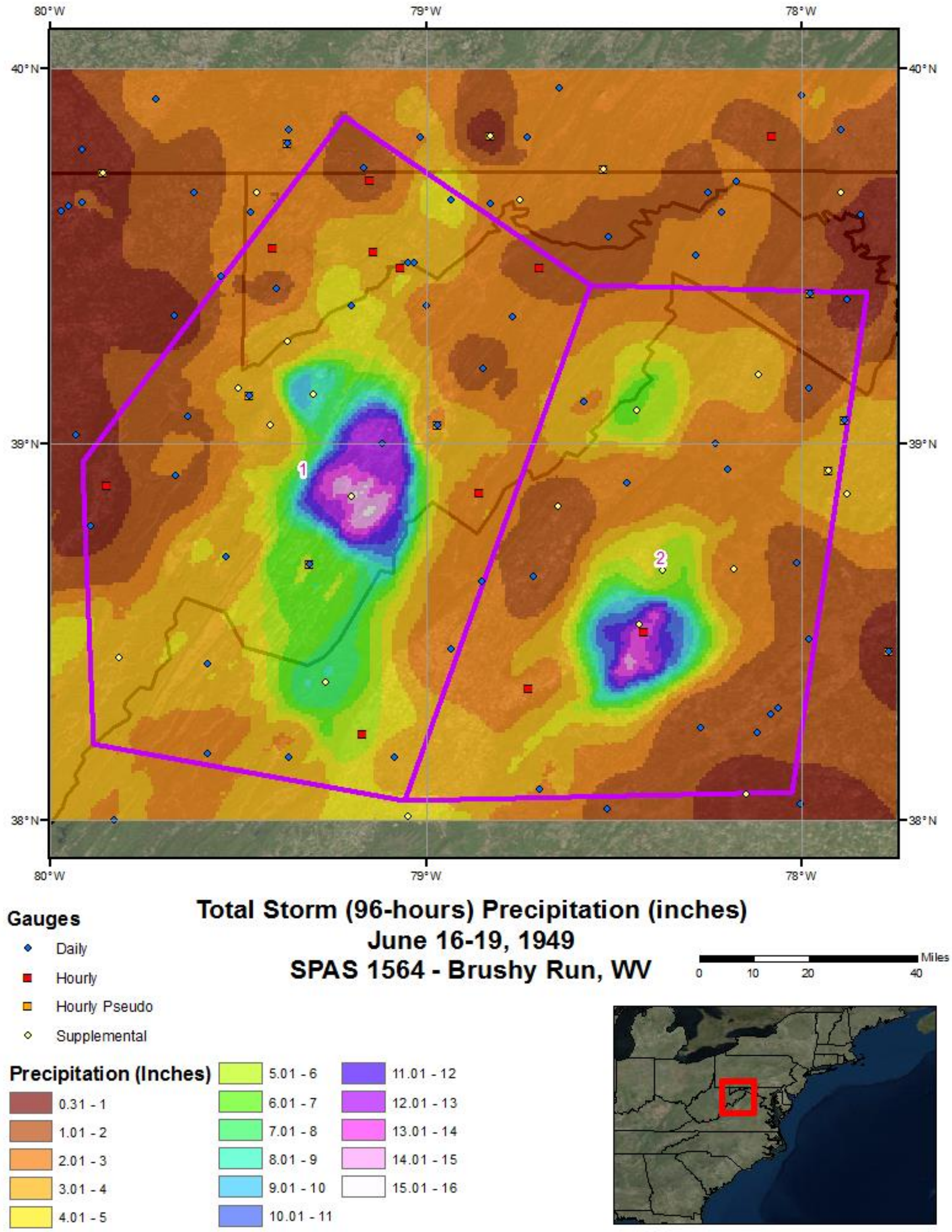
Reliability of results: This analysis was based on hourly data, daily data, and supplemental station data. We have a high degree of confidence in the station based storm total results. The spatial pattern is dependent on the basemap, and the timing is based on hourly and hourly pseudo stations. An additional twenty-two supplemental stations were created to ensure data consistency.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1546_1	-79.1875	38.8625	2,068	30-Jun	70.50	2.31	0.44	63	1.870	76.60	3.07	0.53	75	2.535	1.356

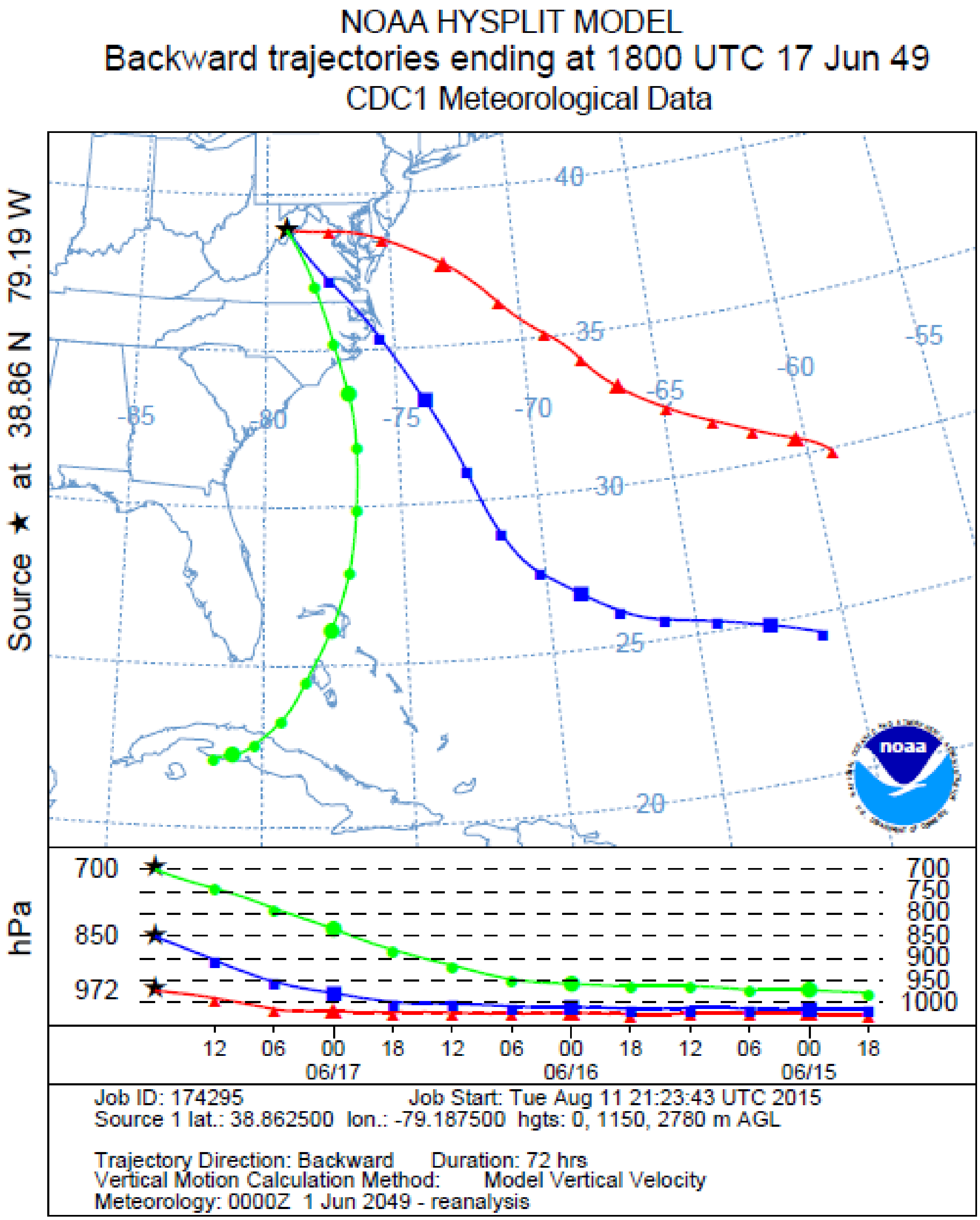
Storm 1546 - June 16 (0600 UTC) - June 20 (0500 UTC), 1949														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
Area (mi^2)	Duration (hours)													
	1	2	3	4	5	6	12	18	24	36	48	72	96	Total
0.4	2.49	3.51	4.29	5.63	7.21	8.14	10.62	11.92	13.05	13.88	14.60	15.09	15.10	15.10
1	2.47	3.49	4.26	5.60	7.16	8.09	10.55	11.85	12.96	13.79	14.52	15.01	15.01	15.01
10	2.42	3.43	4.20	5.51	7.05	7.98	10.38	11.66	12.76	13.59	14.30	14.80	14.81	14.81
25	2.40	3.38	4.14	5.44	6.97	7.85	10.24	11.49	12.58	13.40	14.21	14.66	14.68	14.68
50	2.36	3.34	4.05	5.33	6.82	7.68	10.03	11.26	12.32	13.12	13.91	14.38	14.38	14.38
100	2.21	3.12	3.92	5.06	6.47	7.28	9.49	10.66	11.66	12.45	13.38	13.83	13.84	13.84
200	1.90	2.70	3.78	4.54	5.80	6.50	8.47	9.52	10.41	11.73	12.67	13.09	13.10	13.10
300	1.81	2.47	3.54	4.14	5.27	5.86	7.60	8.56	9.36	11.11	12.01	12.42	12.43	12.43
400	1.73	2.33	3.27	3.87	4.91	5.43	7.03	7.92	8.71	10.34	11.20	11.61	11.62	11.62
500	1.67	2.24	3.04	3.63	4.61	5.12	6.62	7.45	8.22	9.67	10.51	10.93	10.95	10.95
1,000	1.41	1.88	2.27	2.90	3.63	4.07	5.36	6.11	6.79	7.60	8.32	8.83	8.87	8.87
2,000	0.95	1.34	1.59	2.03	2.56	2.92	4.00	4.62	5.15	5.69	6.23	6.73	6.78	6.78
3,500	0.60	0.93	1.16	1.47	1.89	2.19	3.07	3.54	3.99	4.43	4.84	5.26	5.31	5.31
5,000	0.44	0.70	0.91	1.15	1.48	1.74	2.51	2.91	3.27	3.69	4.06	4.46	4.50	4.50
5,833	0.38	0.61	0.81	1.03	1.33	1.57	2.27	2.63	2.97	3.37	3.70	4.06	4.09	4.09

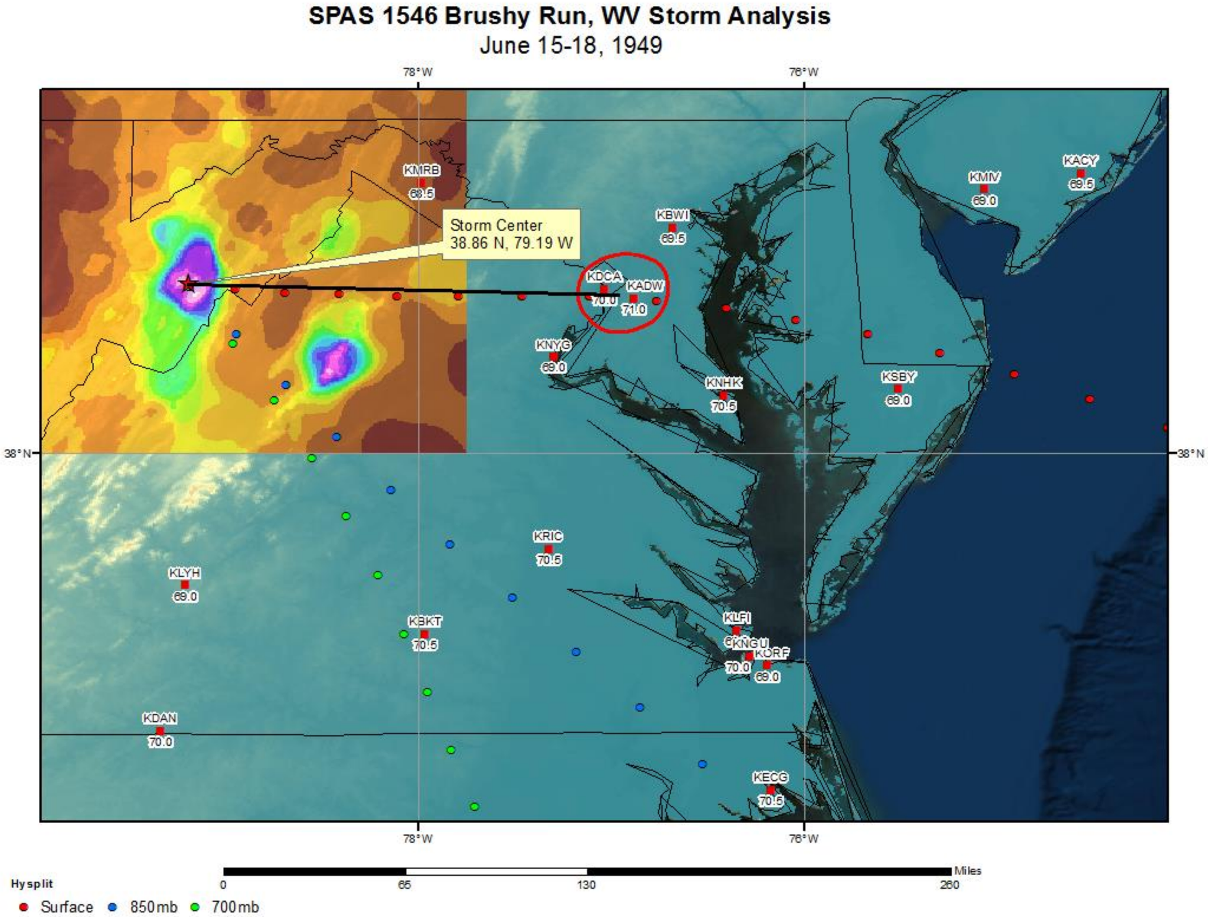



SPAS 1546 Storm Center Mass Curve: Zone 1
June 16 (0600 UTC) - June 20 (0500 UTC), 1949
Lat: 38.8625 Lon: -79.1875
Incremental
Accumulated
15.13"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
3.0
2.5
2.0
1.5
1.0
0.5
0.0
15
10
5
0
1
21
41
61
81



Total Storm (96-hours) Precipitation (inches)
June 16-19, 1949
SPAS 1564 - Brushy Run, WV


NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 17 Jun 49
CDC1 Meteorological Data
Source ★ at 38.86 N 79.19 W
40
35
30
25
20
-85
-80
-75
-70
-65
-60
-55
hPa
700
850
972
700
750
800
850
900
950
1000
12
06
00
18
12
06
00
18
12
06
00
18
06/17
06/16
06/15
Job ID: 174295
Job Start: Tue Aug 11 21:23:43 UTC 2015
Source 1 lat.: 38.862500 lon.: -79.187500 hgts: 0, 1150, 2780 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2049 - reanalysis


SPAS 1546 Brushy Run, WV Storm Analysis
June 15-18, 1949
78°W
76°W
38°N
Storm Center
38.86 N, 79.19 W
KMRB
68.5
KBWI
69.5
KMIV
69.0
KACY
69.5
KDCA
70.0
KADW
71.0
KNYG
69.0
KNHK
70.5
KSBY
69.0
KRIC
70.5
KLYH
69.0
KBKT
70.5
KLFI
KNGU
70.0
KORF
69.0
KDAN
70.0
KECG
70.5
Hysplit
Surface
850mb
700mb
0
65
130
260
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1226_1 SPAS Analysis

General Storm Location: College Hill, OH

Storm Dates: June 4 (0600) - June 5 (0600), 1963

Event: Convective

Latitude: 40.0854

Longitude: -81.6479

Max. Grid/Radar Rainfall Amount: 19.39"

Max. Observed Rainfall Amount: 19.37"

Number of Stations: 132 (53 Daily, 15 Hourly, 6 Hourly Pseudo, 1 Hourly Estimated, 57 Supplemental)

SPAS Version: 9.0

Base Map Used: A basemap/grid was created based on USGS isohyetal.

Spatial resolution: 15 seconds*

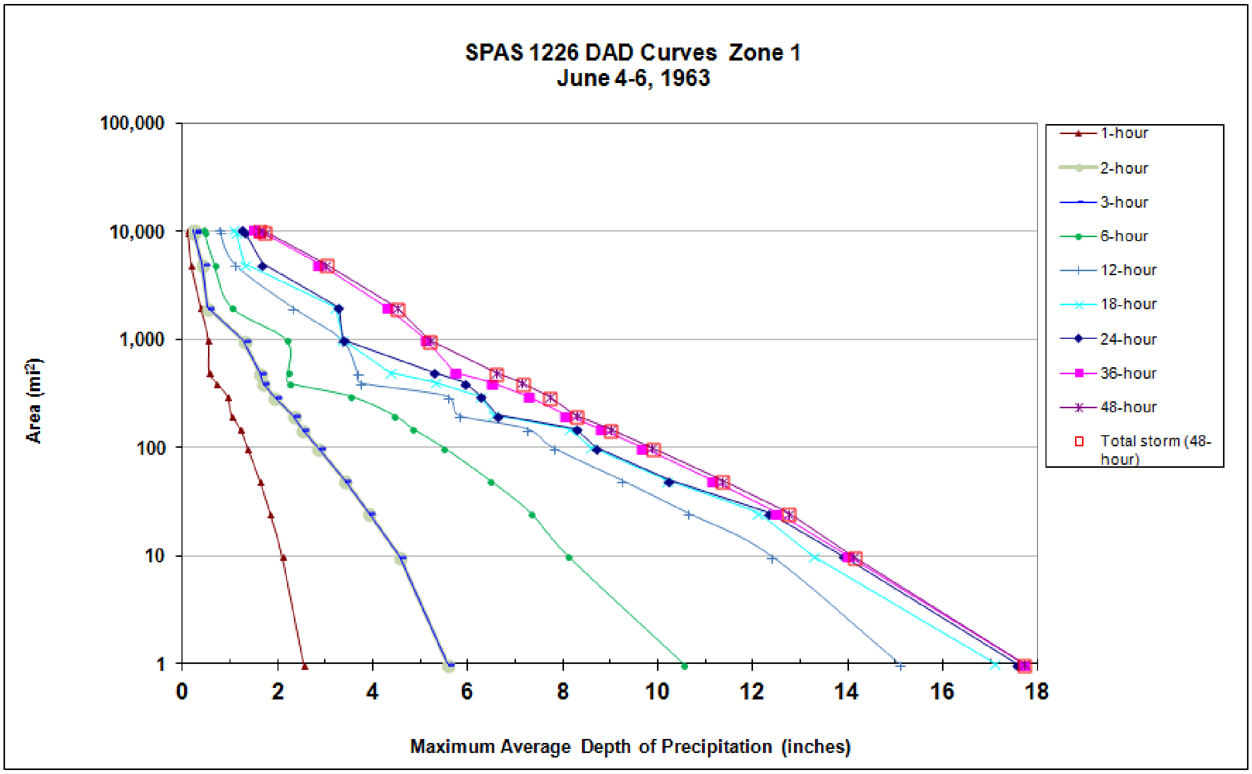
Radar Included: No

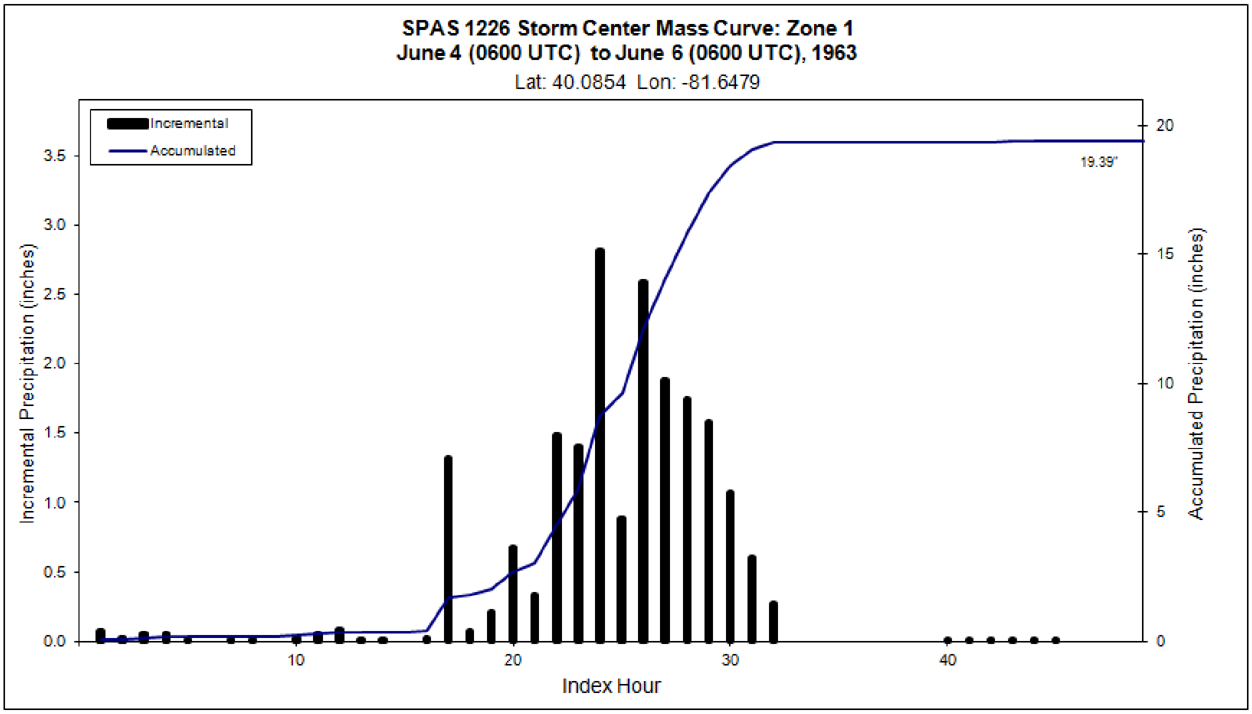
Depth-Area-Duration (DAD) analysis: Yes

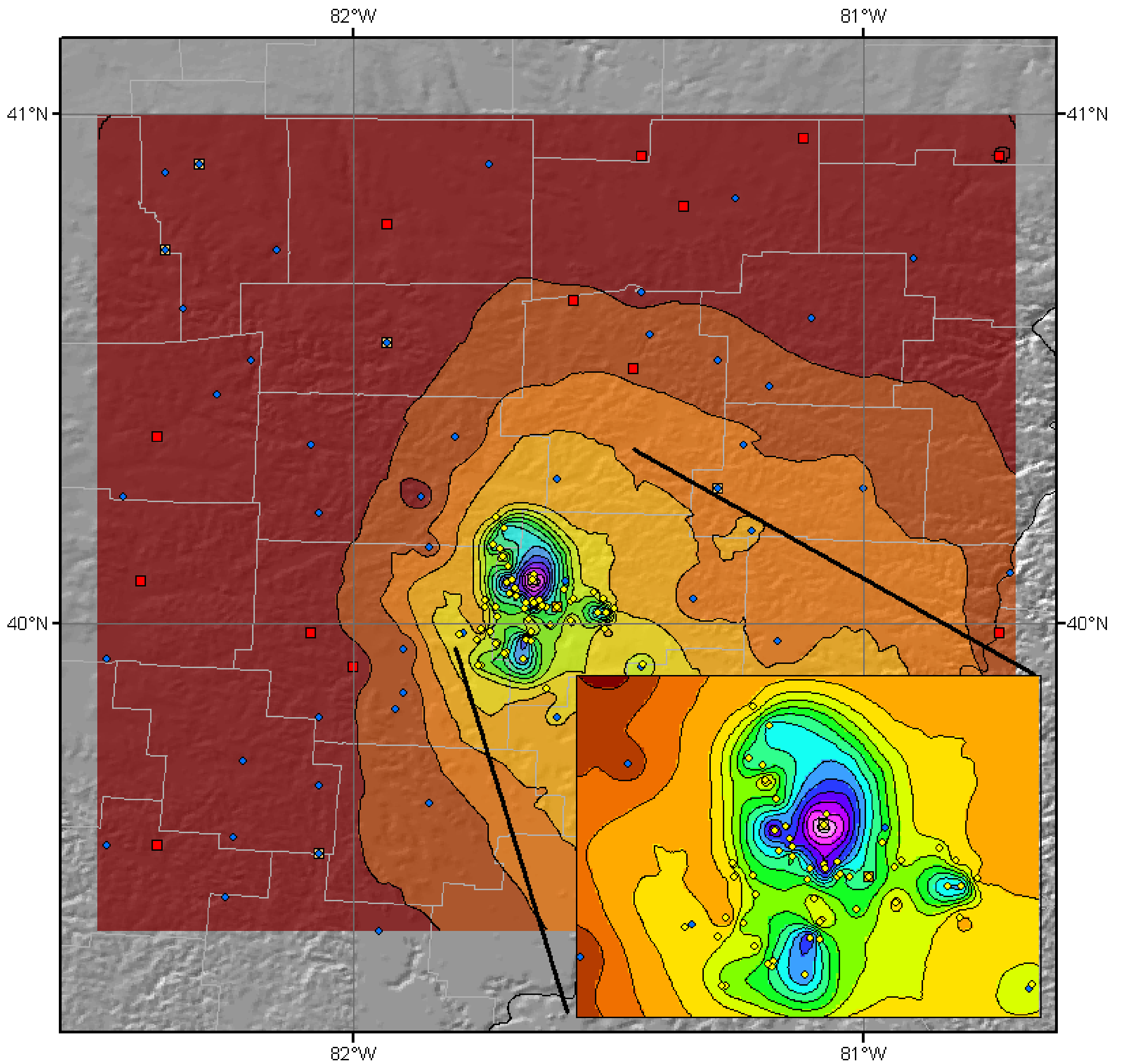
*A higher spatial resolution (15-sec vs. 30-sec) was used in this analysis to better capture the spatial details.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1226_1	-81.6479	40.0854	974	1,000	15-Jun	68.50	2.10	0.21	59	1.890	77.18	77.0	3.14	0.27	76	2.870	1.500

Storm 1226 - June 4 (0600 UTC) - June 6 (0600 UTC), 1963									
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)									
	Duration (hours)								
Area (mi^2)	1	3	6	12	18	24	36	48	Total
0.1	2.81	6.28	11.5	17.08	18.99	19.16	19.37	19.39	19.39
1	2.54	5.56	10.53	15.07	17.09	17.56	17.7	17.7	17.70
10	2.08	4.56	8.1	12.37	13.28	13.9	14	14.11	14.11
25	1.83	3.9	7.32	10.61	12.1	12.33	12.49	12.72	12.72
50	1.61	3.4	6.46	9.23	10.18	10.23	11.13	11.34	11.34
100	1.36	2.85	5.5	7.79	8.59	8.69	9.66	9.86	9.86
150	1.2	2.5	4.85	7.23	8.14	8.28	8.79	8.98	8.98
200	1.02	2.32	4.45	5.8	6.54	6.62	8.06	8.26	8.26
300	0.93	1.93	3.54	5.55	6.26	6.28	7.28	7.7	7.70
400	0.7	1.67	2.24	3.73	5.31	5.93	6.5	7.13	7.13
500	0.55	1.61	2.23	3.66	4.37	5.28	5.73	6.57	6.57
1,000	0.53	1.28	2.18	3.34	3.37	3.39	5.12	5.19	5.19
2,000	0.37	0.52	1.03	2.3	3.22	3.28	4.3	4.5	4.50
5,000	0.17	0.41	0.67	1.09	1.31	1.67	2.86	3	3.00
10,000	0.1	0.24	0.46	0.78	1.12	1.3	1.61	1.7	1.70
10,512	0.1	0.24	0.44	0.75	1.08	1.26	1.5	1.6	1.60



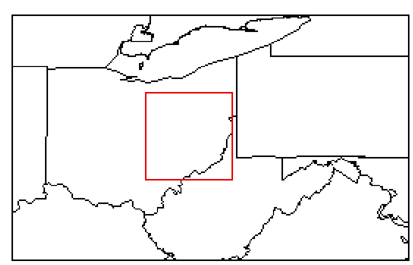

SPAS 1226 Storm Center Mass Curve: Zone 1
June 4 (0600 UTC) to June 6 (0600 UTC), 1963
Lat: 40.0854 Lon: -81.6479
Incremental
Accumulated
19.39"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
5
10
15
20
10
20
30
40



Total Precipitation (48 hours)
SPAS #1226
6/04/1963 0600 UTC - 6/06/1963 0600 UTC

Daily
Hourly
Hourly Estimated
Hourly Pseudo
Supplemental

Miles
0 5 10 20 30



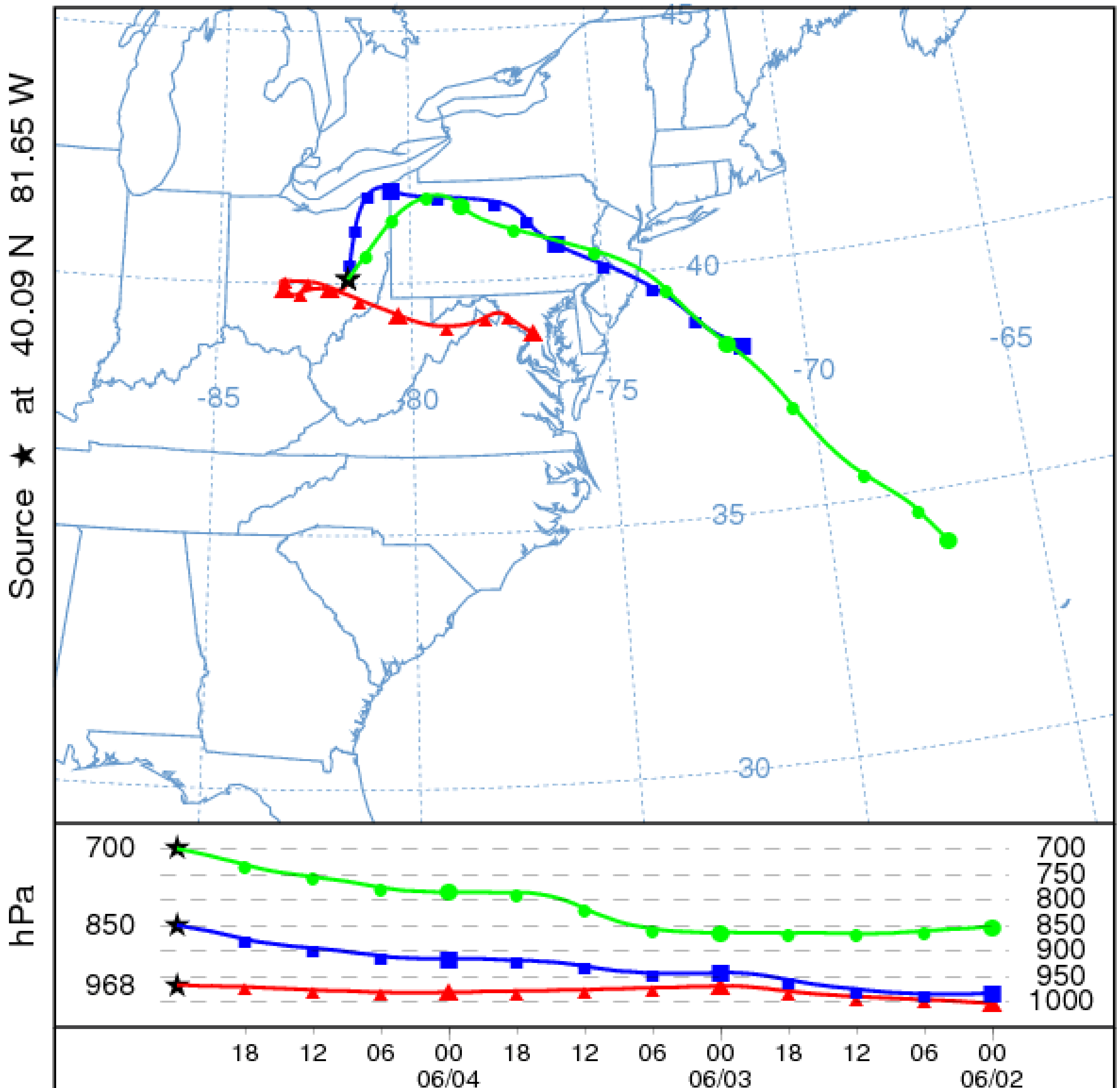
Precipitation (inches)

0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 16.00
16.01 - 18.00
18.01 - 20.00

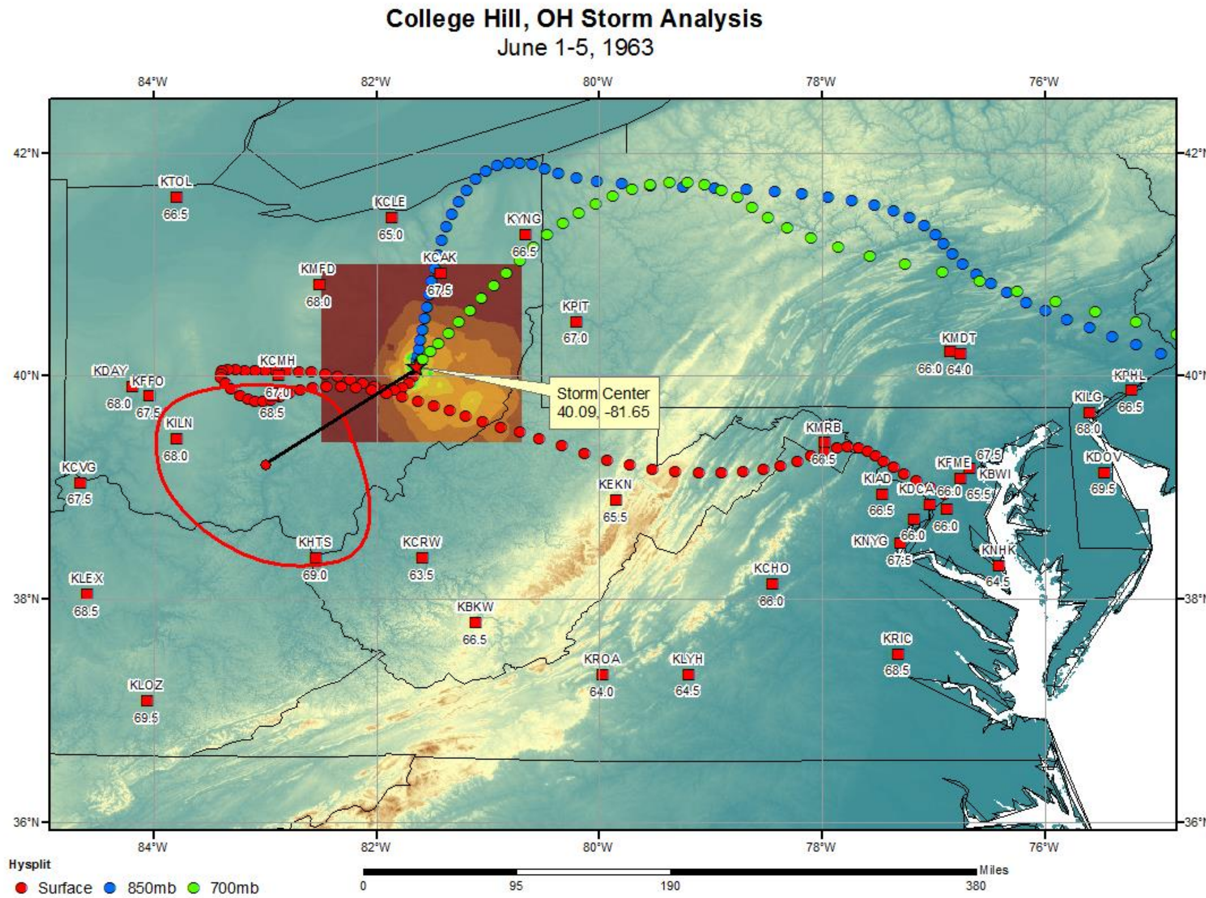
N

11/25/2011

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 05 Jun 63
CDC1 Meteorological Data



This is not a NOAA product. It was produced by a web user.
Job ID: 332823 Job Start: Mon Nov 7 21:29:05 UTC 2011
Source 1 lat.: 40.09 lon.: -81.65 hgts: 0, 1110, 2720 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Jun 2063 - reanalysis


College Hill, OH Storm Analysis
June 1-5, 1963
Storm Center
40.09, -81.65
KTOL 66.5
KCLE 65.0
KYNG 66.5
KCAK 67.5
KMFD 68.0
KPIT 67.0
KDAY 68.0
KFFO 67.5
KCMH 67.0 68.5
KILN 68.0
KCVG 67.5
KHTS 69.0
KCRW 63.5
KEKN 65.5
KBKW 66.5
KLEX 68.5
KLOZ 69.5
KROA 64.0
KLYH 64.5
KCHO 68.0
KMRB 68.5
KIAD 66.5
KDCA 66.0
KNYG 67.5
KFME 67.5
KBWI 65.5
KMDT 66.0 64.0
KILG 68.0
KPHL 66.5
KDOV 69.5
KNHK 64.5
KRIC 68.5
Hysplit
Surface 850mb 700mb
Miles
0 95 190 380

Storm Precipitation Analysis System (SPAS) For Storm #1402_1 SPAS Analysis

General Storm Location: Tennessee Valley (-85.5, 37.8, 35.1, -82.0)

Storm Dates: July 22 – July 23, 1965

Event: Mesoscale Event with Embedded Convection (MEC) Convective

DAD Zone 1

Latitude: 36.3625

Longitude: -83.7208

Max. Grid/Radar Rainfall Amount: 11.00”

Max. Observed Rainfall Amount: 11.00”

Number of Stations: 154

SPAS Version: 9.5

Base Map Used: Combined manually contoured base map with mean annual maximum 48-hour precipitation associated with MEC’s

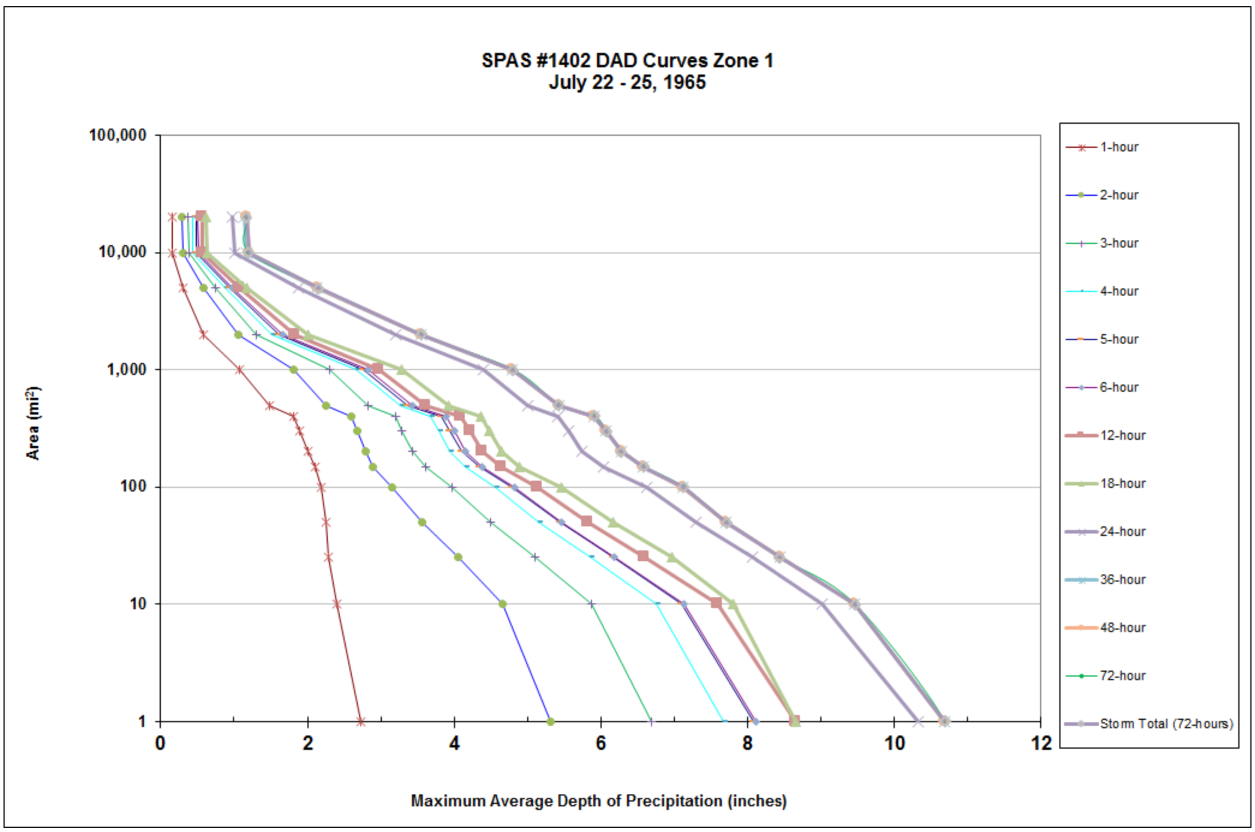
Spatial resolution: 0.2666 sq.mi.

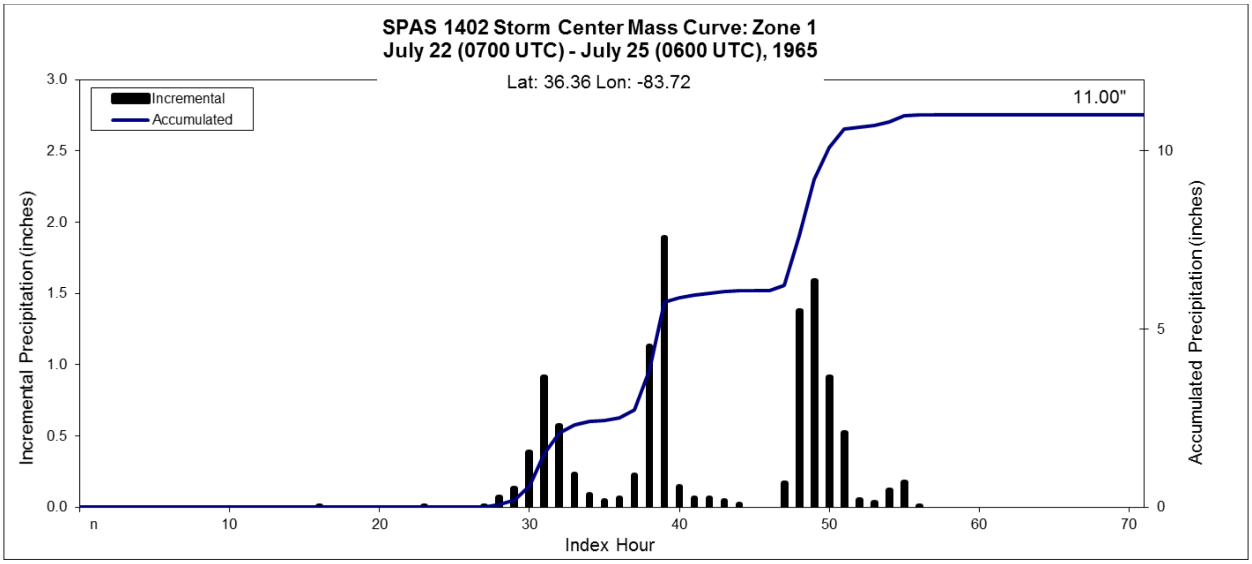
Radar Included: No

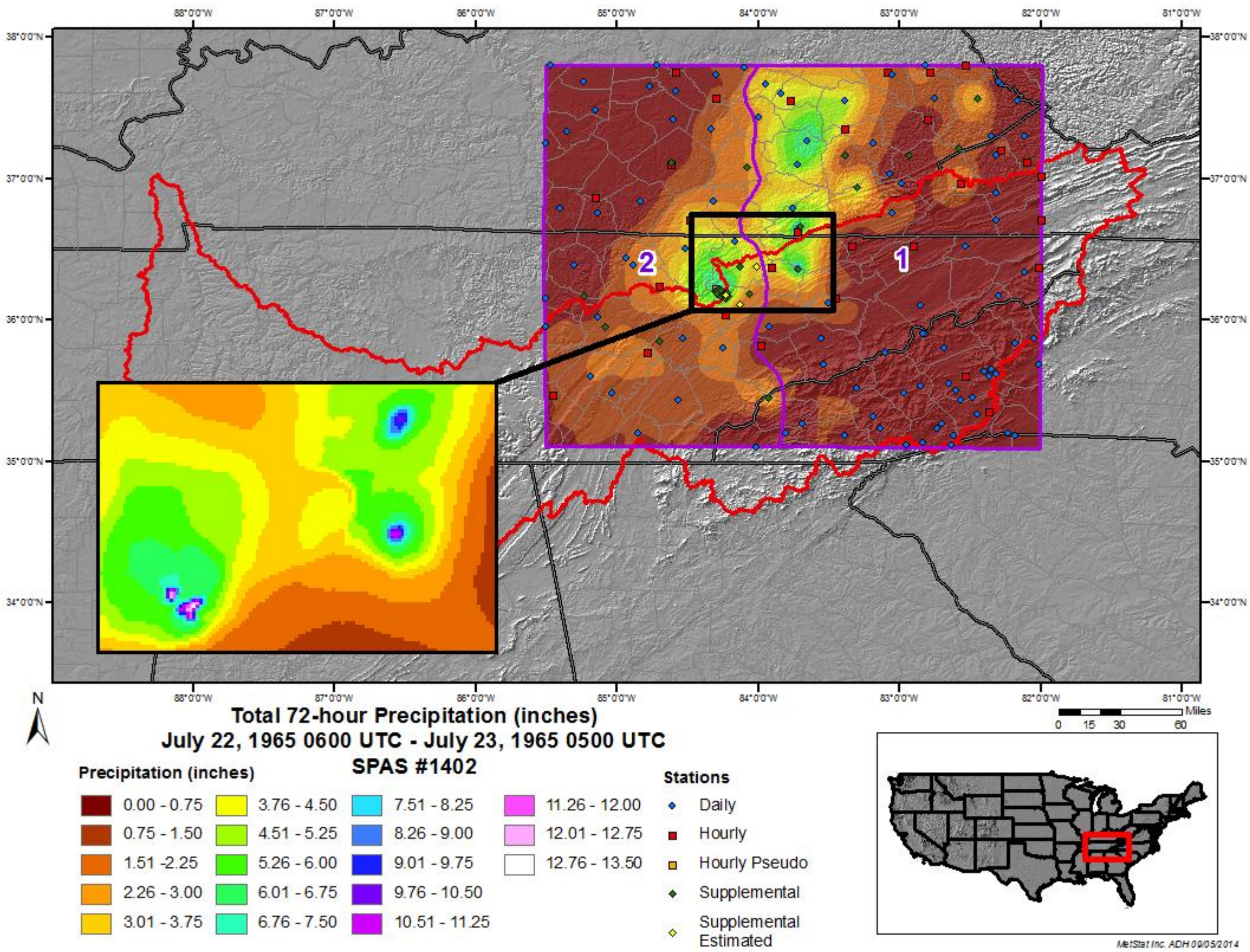
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1402_1	-83.7208	36.3625	1,066	8-Aug	77.00	3.14	0.29	76	2.850	81.28	3.86	0.33	85	3.530	1.239

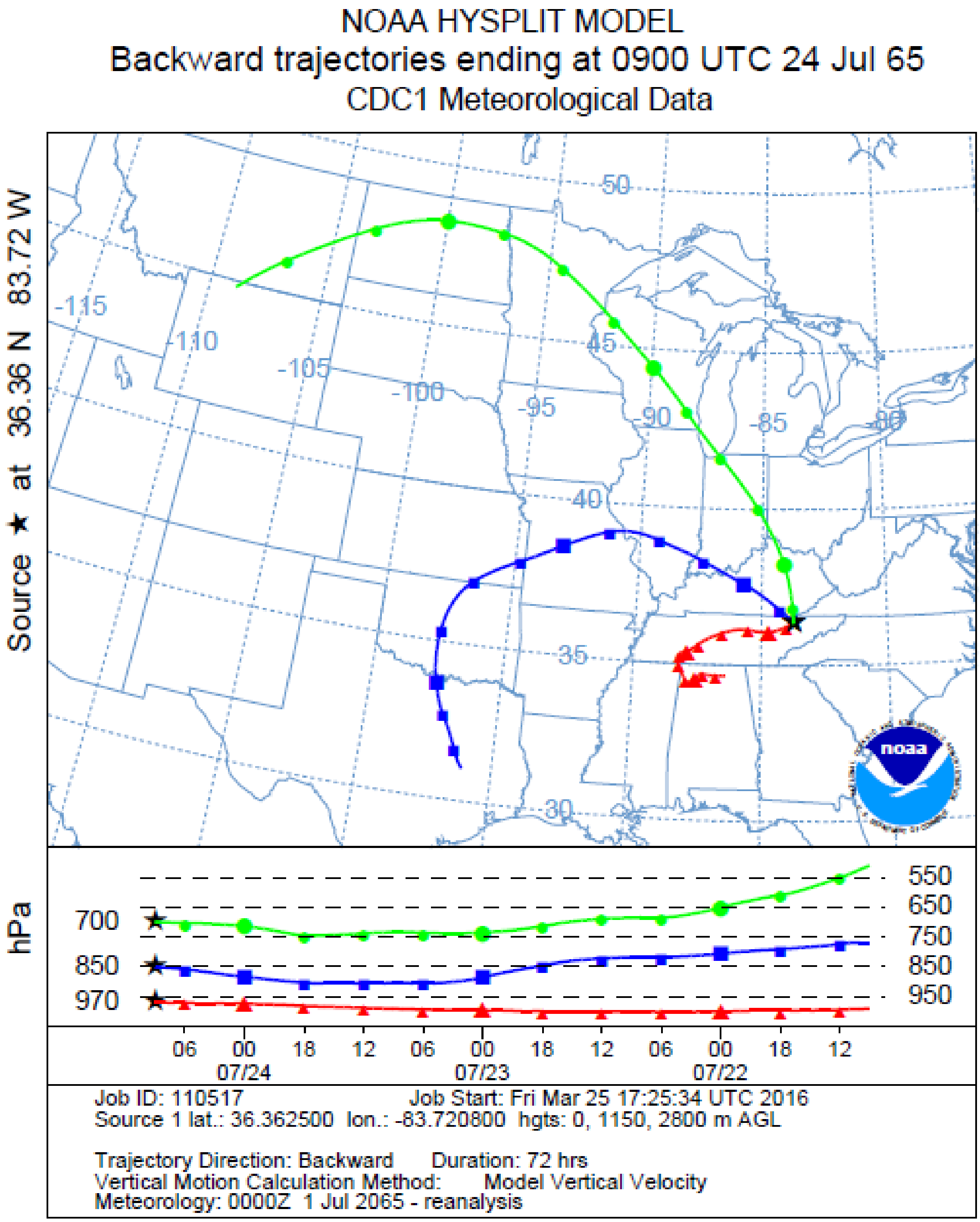
Storm 1402 Zone 1 - July 22 (0700 UTC) - July 25 (0600 CST), 1965													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
	Duration (hours)												
areasqmi	1	2	3	4	5	6	12	18	24	36	48	72	Total
0.3	2.7	5.3	6.7	7.7	8.1	8.2	8.7	8.7	10.5	10.9	10.9	10.9	10.90
1	2.7	5.3	6.7	7.7	8.1	8.1	8.7	8.7	10.3	10.7	10.7	10.7	10.69
10	2.4	4.7	5.9	6.8	7.1	7.1	7.6	7.8	9.0	9.5	9.5	9.5	9.46
25	2.3	4.1	5.1	5.9	6.2	6.2	6.6	7.0	8.1	8.4	8.4	8.4	8.44
50	2.3	3.6	4.5	5.2	5.4	5.5	5.8	6.2	7.3	7.7	7.7	7.7	7.71
100	2.2	3.2	4.0	4.6	4.8	4.8	5.1	5.5	6.6	7.1	7.1	7.1	7.13
150	2.1	2.9	3.6	4.2	4.4	4.4	4.7	4.9	6.0	6.6	6.6	6.6	6.58
200	2.0	2.8	3.4	3.9	4.1	4.2	4.4	4.6	5.8	6.3	6.3	6.3	6.28
300	1.9	2.7	3.3	3.8	3.9	4.0	4.2	4.5	5.6	6.1	6.1	6.1	6.07
400	1.8	2.6	3.2	3.7	3.8	3.9	4.1	4.4	5.4	5.9	5.9	5.9	5.91
500	1.5	2.3	2.8	3.3	3.4	3.4	3.6	3.9	5.0	5.4	5.4	5.4	5.43
1,000	1.1	1.8	2.3	2.7	2.8	2.8	3.0	3.3	4.4	4.8	4.8	4.8	4.80
2,000	0.6	1.1	1.3	1.5	1.6	1.7	1.8	2.0	3.2	3.6	3.6	3.6	3.55
5,000	0.3	0.6	0.7	0.9	0.9	1.0	1.1	1.2	1.9	2.1	2.1	2.2	2.15
10,000	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.6	1.0	1.2	1.2	1.2	1.20
20,000	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.6	1.0	1.1	1.2	1.2	1.17




SPAS 1402 Storm Center Mass Curve: Zone 1
July 22 (0700 UTC) - July 25 (0600 UTC), 1965
Lat: 36.36 Lon: -83.72
11.00"
Incremental
Accumulated
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10
5
0
n
10
20
30
40
50
60
70

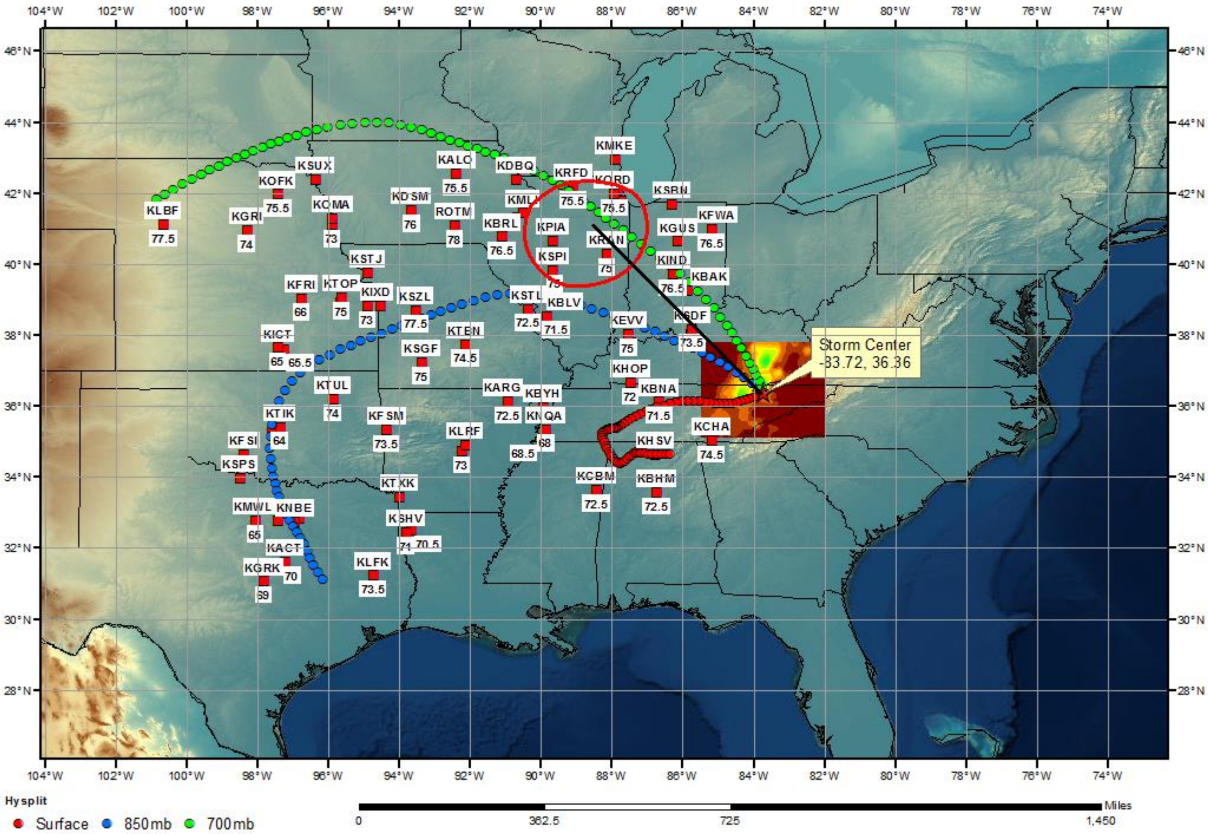


1
2
N
Total 72-hour Precipitation (inches)
July 22, 1965 0600 UTC - July 23, 1965 0500 UTC
SPAS #1402
Precipitation (inches)
0.00 - 0.75
0.75 - 1.50
1.51 -2.25
2.26 - 3.00
3.01 - 3.75
3.76 - 4.50
4.51 - 5.25
5.26 - 6.00
6.01 - 6.75
6.76 - 7.50
7.51 - 8.25
8.26 - 9.00
9.01 - 9.75
9.76 - 10.50
10.51 - 11.25
11.26 - 12.00
12.01 - 12.75
12.76 - 13.50
Stations
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Estimated
Miles
0 15 30 60
MetStat Inc. ADH 09/05/2014


NOAA HYSPLIT MODEL
Backward trajectories ending at 0900 UTC 24 Jul 65
CDC1 Meteorological Data
Source ★ at 36.36 N 83.72 W
hPa
700
850
970
550
650
750
850
950
06 00 18 12 06 00 18 12 06 00 18 12
07/24
07/23
07/22
Job ID: 110517 Job Start: Fri Mar 25 17:25:34 UTC 2016
Source 1 lat.: 36.362500 lon.: -83.720800 hgts: 0, 1150, 2800 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2065 - reanalysis

SPAS 1402 New Tazewell, TN Storm Analysis Zone 1

July 23, 1965



Storm Precipitation Analysis System (SPAS) For Storm #1402_2 SPAS Analysis

General Storm Location: Tennessee Valley (-85.5, 37.8, 35.1, -82.0)

Storm Dates: July 22 – July 23, 1965

Event: Mesoscale Event with Embedded Convection (MEC) Convective

DAD Zone 2

Latitude: 36.1792

Longitude: -84.2292

Max. Grid/Radar Rainfall Amount: 13.32”

Max. Observed Rainfall Amount: 12.50”

Number of Stations: 154

SPAS Version: 9.5

Base Map Used: Combined manually contoured base map with mean annual maximum 48-hour precipitation associated with MEC’s

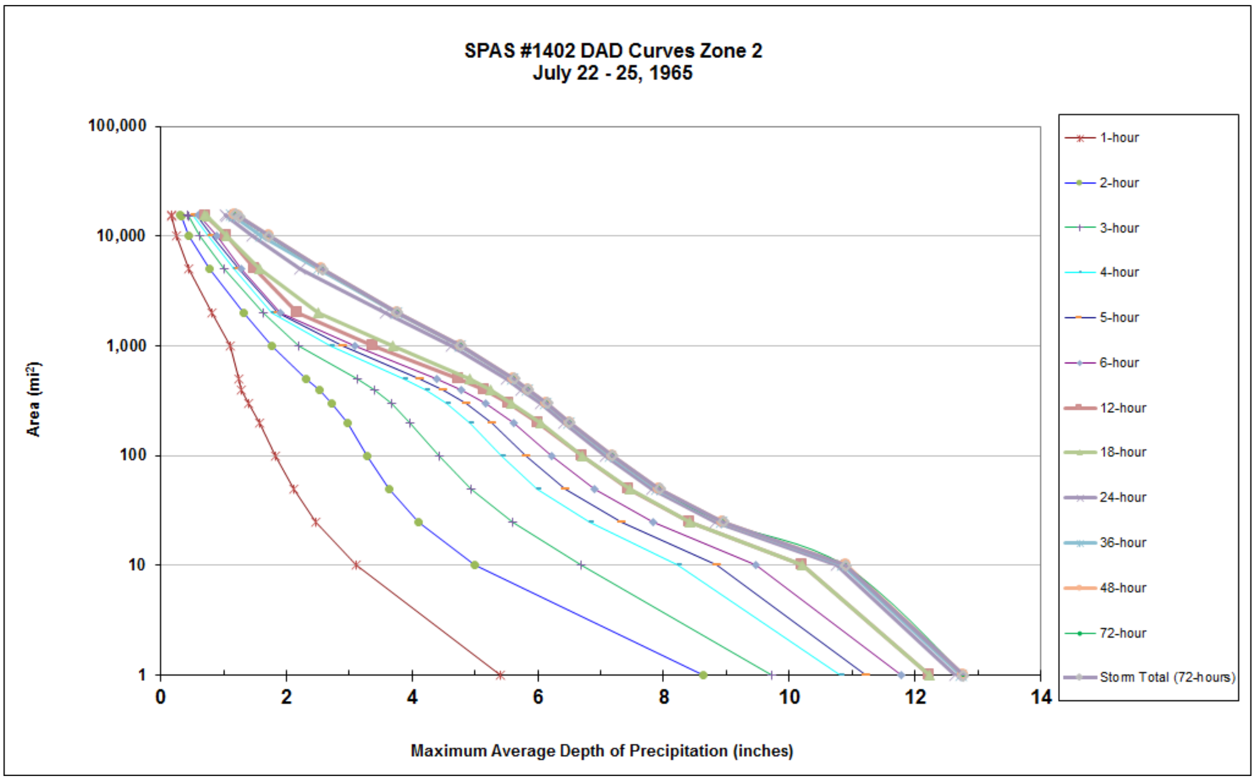
Spatial resolution: 0.2666 sq.mi.

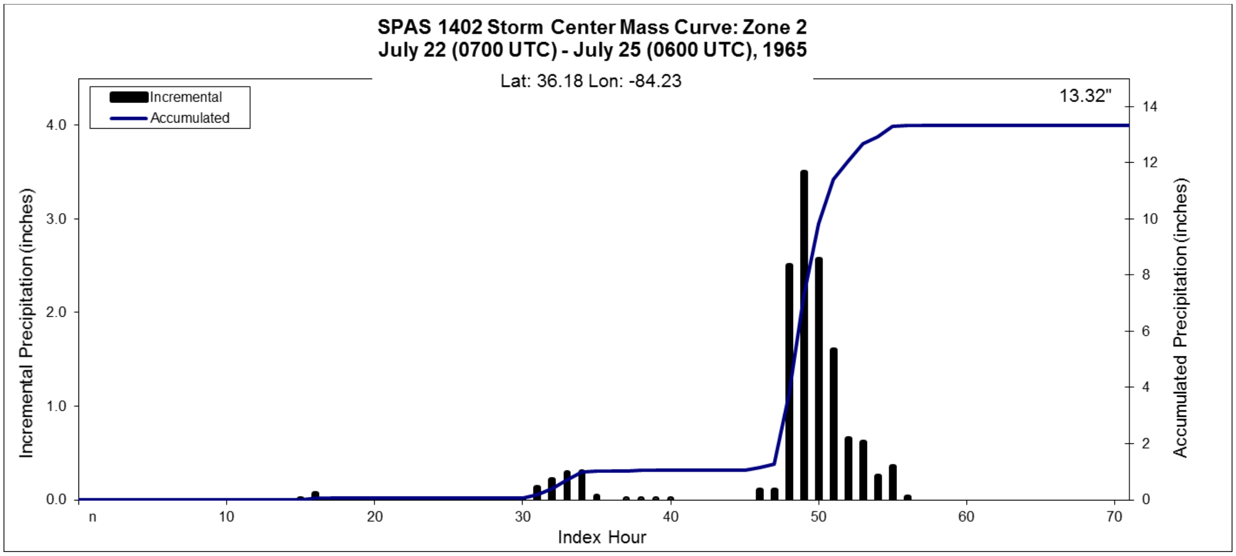
Radar Included: No

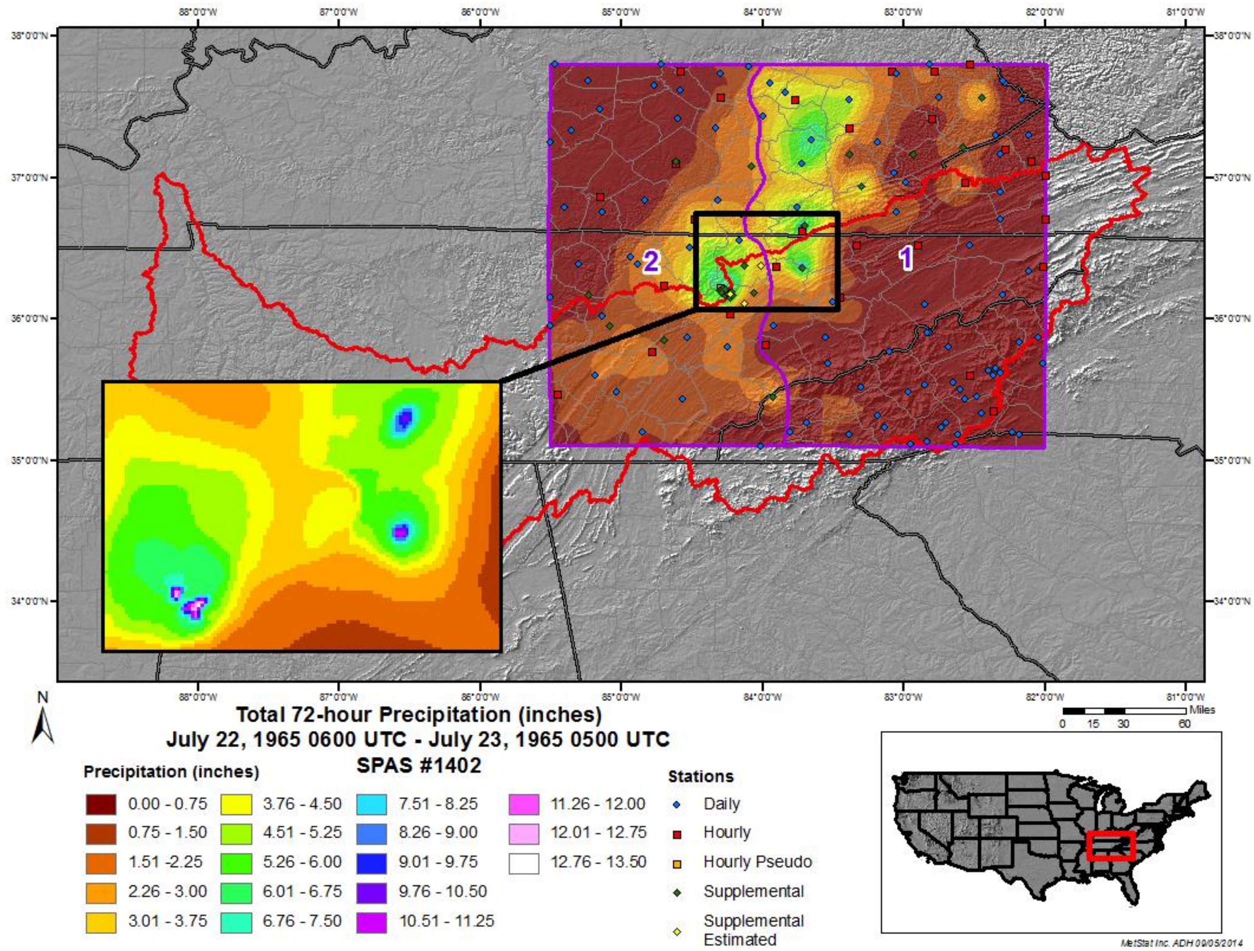
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1402_2	-84.2292	36.1792	2,731	8-Aug	77.00	3.14	0.68	76	2.460	81.28	3.86	0.79	85	3.070	1.248

Storm 1402 Zone 2 - July 22 (0700 UTC) - July 25 (0600 CST), 1965													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
	Duration (hours)												
areasqmi	1	2	3	4	5	6	12	18	24	36	48	72	Total
0.4	5.61	8.97	10.10	11.22	11.65	12.23	12.56	12.56	12.99	13.10	13.15	13.15	13.15
1	5.40	8.64	9.73	10.81	11.22	11.78	12.24	12.24	12.64	12.73	12.77	12.77	12.77
10	3.11	5.00	6.68	8.23	8.85	9.47	10.20	10.20	10.76	10.85	10.91	10.89	10.89
25	2.47	4.11	5.59	6.82	7.33	7.83	8.42	8.42	8.83	8.92	8.95	8.95	8.95
50	2.11	3.63	4.94	5.99	6.44	6.91	7.45	7.46	7.82	7.89	7.94	7.94	7.94
100	1.83	3.28	4.43	5.43	5.82	6.23	6.70	6.71	7.08	7.15	7.19	7.19	7.19
200	1.58	2.97	3.97	4.92	5.26	5.61	6.01	6.04	6.41	6.49	6.51	6.51	6.51
300	1.40	2.73	3.67	4.54	4.86	5.17	5.55	5.58	6.05	6.13	6.15	6.15	6.15
400	1.28	2.52	3.40	4.21	4.50	4.78	5.15	5.25	5.73	5.83	5.85	5.85	5.85
500	1.24	2.32	3.13	3.86	4.13	4.40	4.75	4.91	5.50	5.60	5.62	5.62	5.62
1,000	1.10	1.77	2.20	2.70	2.90	3.09	3.38	3.70	4.63	4.77	4.78	4.78	4.78
2,000	0.82	1.33	1.63	1.76	1.87	1.90	2.17	2.50	3.57	3.75	3.77	3.77	3.77
5,000	0.45	0.77	1.01	1.17	1.25	1.28	1.50	1.58	2.21	2.50	2.57	2.57	2.57
10,000	0.26	0.45	0.63	0.76	0.82	0.89	1.04	1.05	1.45	1.60	1.72	1.72	1.72
15,000	0.18	0.32	0.44	0.53	0.58	0.62	0.72	0.73	1.05	1.17	1.25	1.25	1.25
15,715	0.17	0.31	0.42	0.50	0.55	0.60	0.69	0.70	1.02	1.13	1.19	1.19	1.19

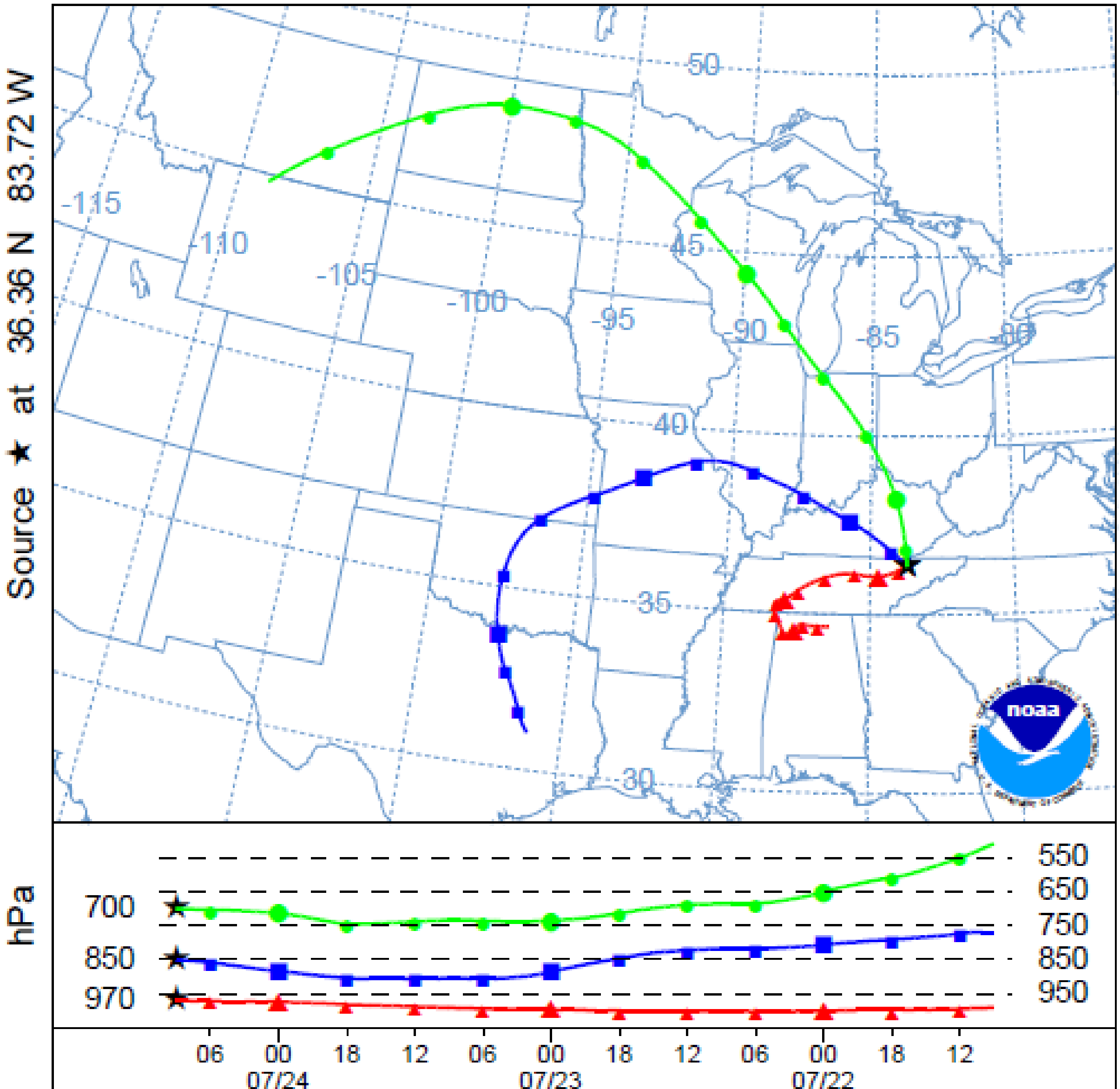



SPAS 1402 Storm Center Mass Curve: Zone 2
July 22 (0700 UTC) - July 25 (0600 UTC), 1965
Lat: 36.18 Lon: -84.23
Incremental
Accumulated
13.32"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



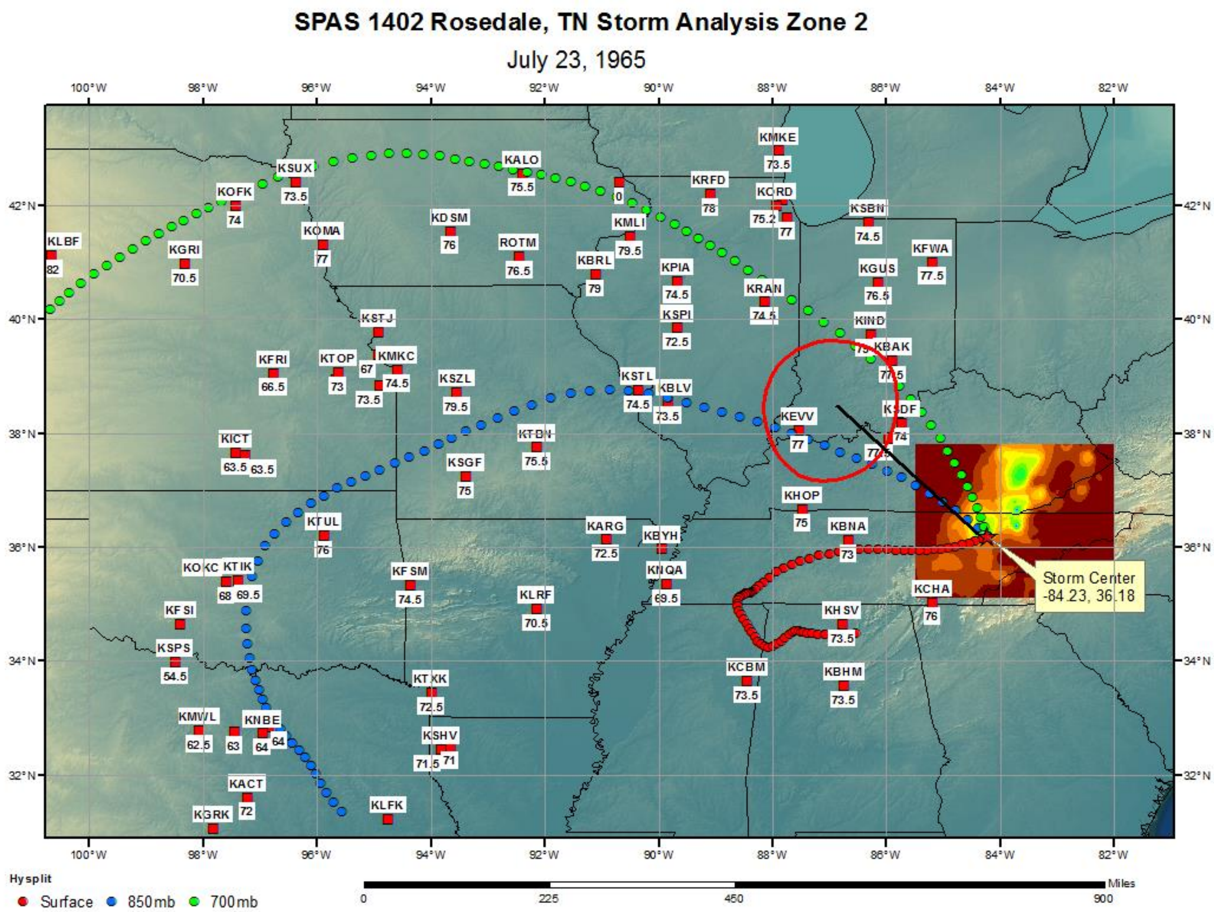
88°0'0"W
87°0'0"W
86°0'0"W
85°0'0"W
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
38°0'0"N
37°0'0"N
36°0'0"N
35°0'0"N
34°0'0"N
1
2
N
Total 72-hour Precipitation (inches)
July 22, 1965 0600 UTC - July 23, 1965 0500 UTC
SPAS #1402
Precipitation (inches)
0.00 - 0.75
0.75 - 1.50
1.51 -2.25
2.26 - 3.00
3.01 - 3.75
3.76 - 4.50
4.51 - 5.25
5.26 - 6.00
6.01 - 6.75
6.76 - 7.50
7.51 - 8.25
8.26 - 9.00
9.01 - 9.75
9.76 - 10.50
10.51 - 11.25
11.26 - 12.00
12.01 - 12.75
12.76 - 13.50
Stations
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Estimated
Miles
0 15 30 60
MetStat Inc. ADH 09/05/2014

NOAA HYSPLIT MODEL
Backward trajectories ending at 0900 UTC 24 Jul 65
CDC1 Meteorological Data



Job ID: 110517 Job Start: Fri Mar 25 17:25:34 UTC 2016
Source 1 lat.: 36.362500 lon.: -83.720800 hgts: 0, 1150, 2800 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2065 - reanalysis


SPAS 1402 Rosedale, TN Storm Analysis Zone 2
July 23, 1965
Storm Center
-84.23, 36.18
Hysplit
Surface 850mb 700mb
Miles
0 225 450 900

Storm Precipitation Analysis System (SPAS) For Storm #1209_1 SPAS Analysis

General Storm Location: Wooster, Ohio – the "Independence Day storm"

Storm Dates: July 4-6, 1969 (July 4, 1969 0600 UTC – July 7, 1969 0500 UTC: 72 hours)

Event: Thunderstorm

DAD Zone 1

Latitude: 40.91458

Longitude: 81.9729

Max. Grid Rainfall Amount: 14.95”***

Max. Observed Rainfall Amount: 14.82” at Wooster 8 NNW***

Number of Stations: 509 (77 Daily, 46 Hourly, 2 Hourly Estimated, 3 Hourly Estimated Pseudo, 14 Hourly Pseudo, 360 Supplemental, and 7 Supplemental Estimated)

SPAS Version: 8.5

Base Map Used: Blended USGS, USACE, NWS and SPAS total storm isohyetal converted into a grid.

Spatial resolution: 15 seconds* (~ 0.25 mi^2)

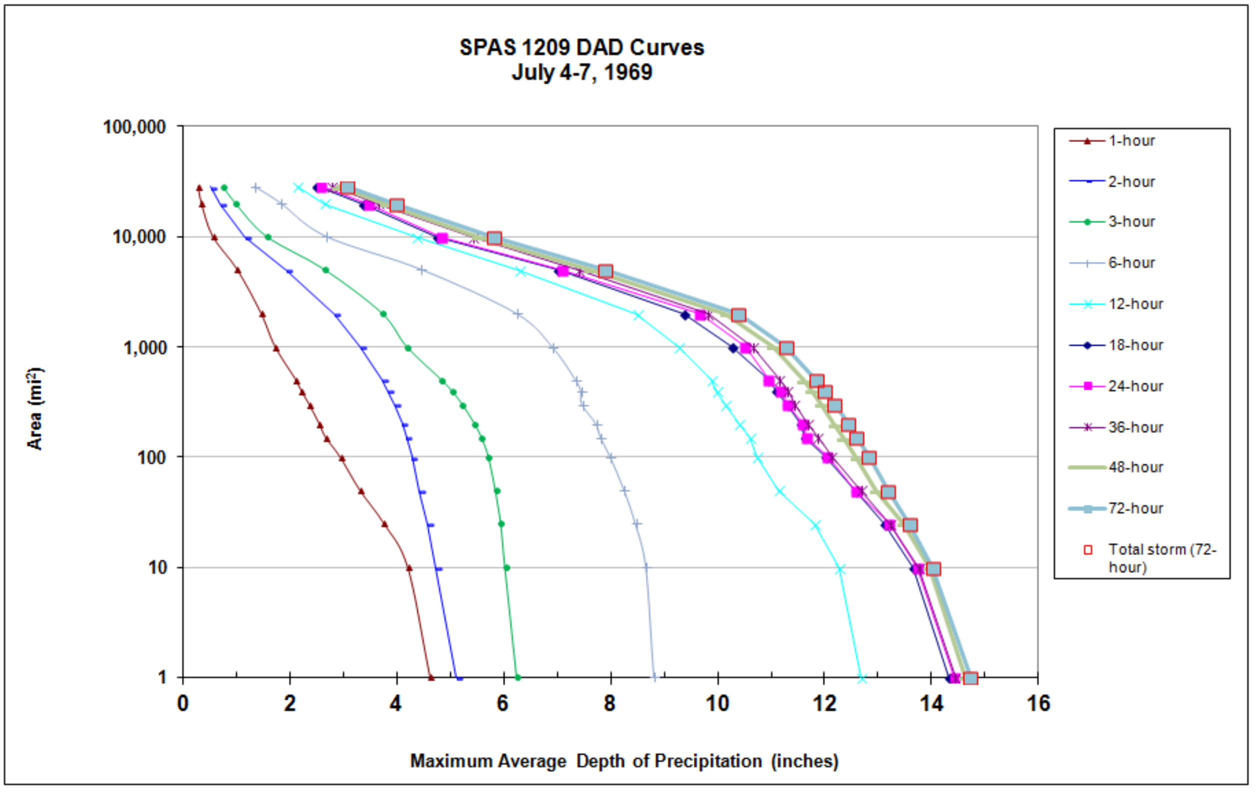
Radar Included: No

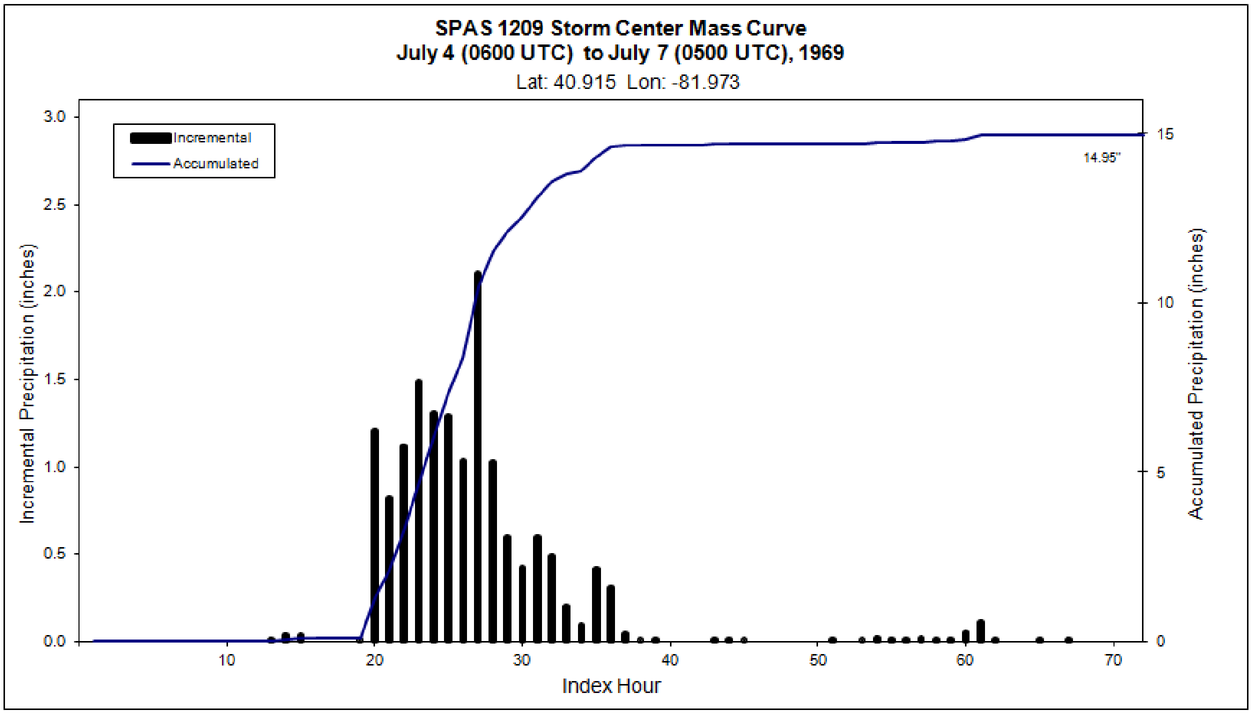
Depth-Area-Duration (DAD) analysis: Yes**

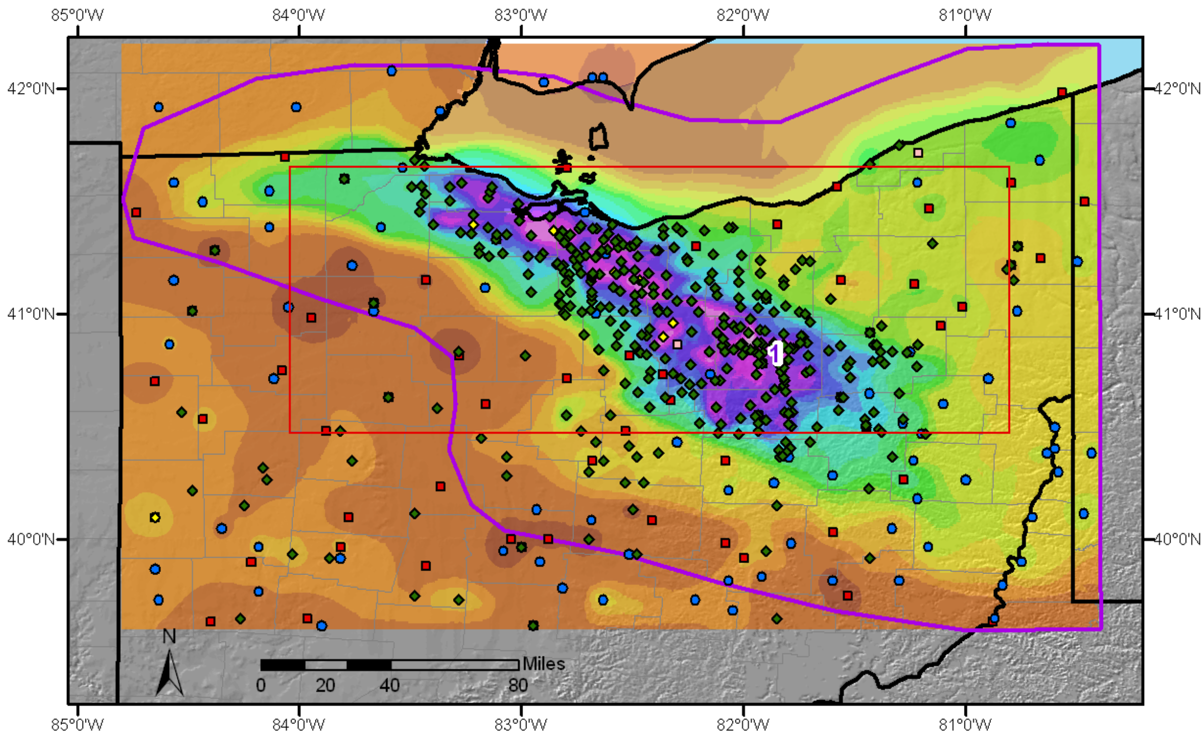
Reliability of results: Although this storm analysis obviously did not use radar data, the abundant gauge data and well positioned hourly rain gauges provided excellent spatial and temporal information and therefore a very high degree of confidence in the final results.

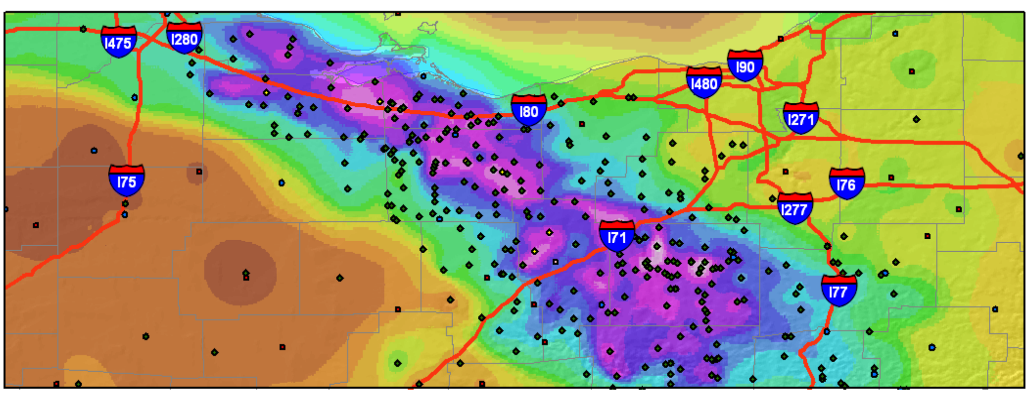
							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1209_1	-81.9729	40.9146	1,165	1,200	15-Jul	76.00	2.99	0.31	74	2.680	78.83	79.0	3.44	0.34	80	3.100	1.157

Storm 1209 - July 4 (0600 UTC) - July 7 (0500 UTC),1969											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
Area (mi^2)	1	2	3	6	12	18	24	36	48	72	Total
0.3	4.82	5.33	6.41	8.95	13.02	14.58	14.67	14.69	14.94	14.95	14.95
1	4.62	5.11	6.24	8.81	12.67	14.32	14.44	14.45	14.63	14.73	14.73
10	4.2	4.72	6.02	8.66	12.26	13.66	13.74	13.77	13.97	14.02	14.02
25	3.75	4.56	5.94	8.46	11.81	13.13	13.21	13.23	13.47	13.58	13.58
50	3.3	4.42	5.84	8.25	11.14	12.57	12.59	12.69	12.97	13.19	13.19
100	2.93	4.27	5.71	7.99	10.72	12.02	12.06	12.14	12.59	12.83	12.83
150	2.66	4.17	5.58	7.81	10.59	11.63	11.66	11.88	12.35	12.6	12.60
200	2.54	4.09	5.45	7.72	10.4	11.56	11.6	11.69	12.18	12.44	12.44
300	2.35	3.96	5.22	7.46	10.14	11.3	11.3	11.44	11.94	12.19	12.19
400	2.2	3.83	5.02	7.44	9.97	11.1	11.18	11.31	11.75	12	12.00
500	2.1	3.72	4.83	7.34	9.88	10.95	10.96	11.16	11.61	11.84	11.84
1,000	1.71	3.31	4.18	6.9	9.27	10.28	10.52	10.66	11.04	11.27	11.27
2,000	1.45	2.82	3.72	6.23	8.48	9.38	9.67	9.83	10.15	10.39	10.39
5,000	1	1.93	2.64	4.45	6.27	7.02	7.09	7.4	7.62	7.9	7.90
10,000	0.54	1.14	1.55	2.66	4.35	4.74	4.83	5.42	5.52	5.81	5.81
20,000	0.33	0.69	0.97	1.82	2.64	3.37	3.47	3.65	3.78	3.98	3.98
28,279	0.27	0.51	0.74	1.33	2.13	2.5	2.59	2.79	2.89	3.06	3.06




SPAS 1209 Storm Center Mass Curve
July 4 (0600 UTC) to July 7 (0500 UTC), 1969
Lat: 40.915 Lon: -81.973
Incremental
Accumulated
14.95"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
3.0
2.5
2.0
1.5
1.0
0.5
0.0
15
10
5
0
10
20
30
40
50
60
70





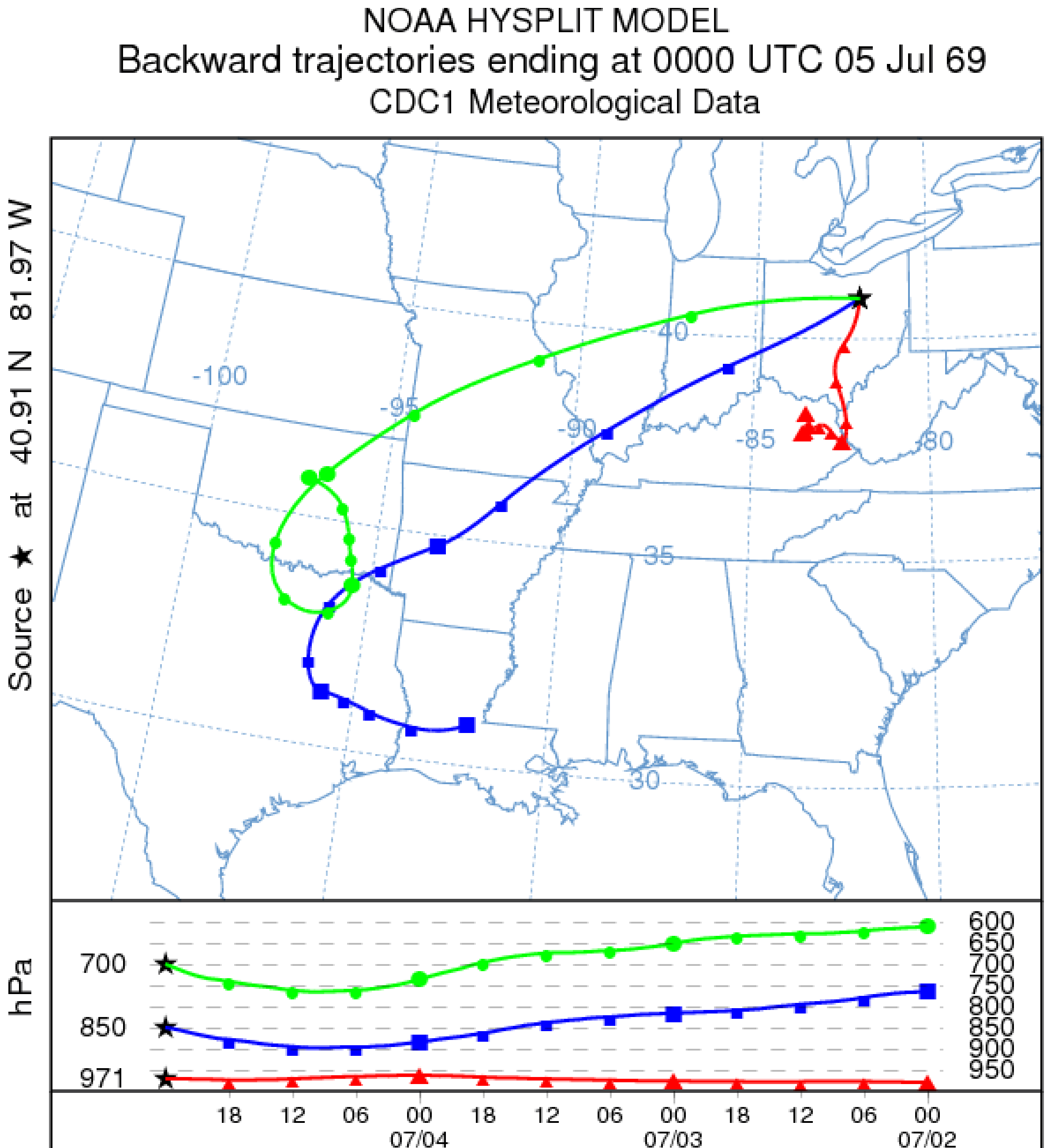
Wooster, Ohio "Independence Day storm" - ISOHYETAL FROM SPAS

Total 72-hour Rainfall (inches)
07/04/1969 0600 UTC - 07/07/1969 0500 UTC
SPAS #1209

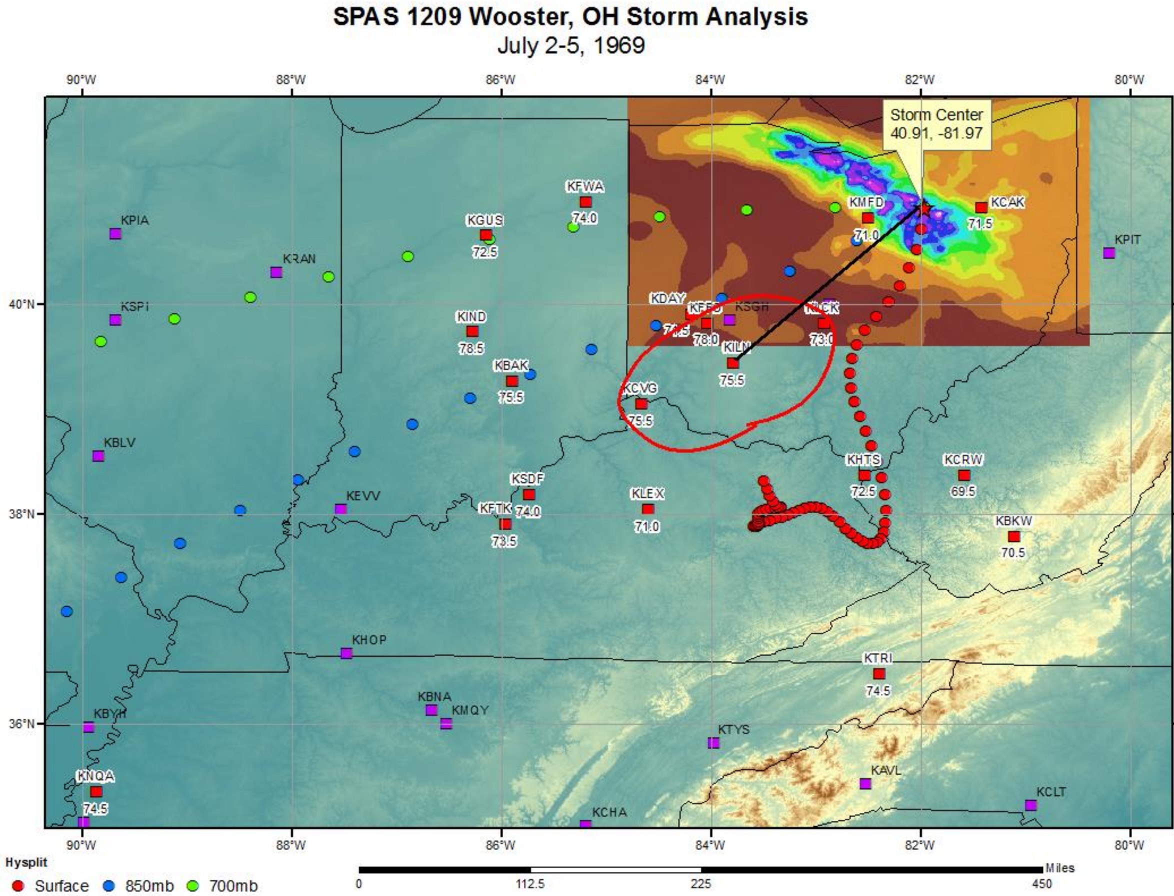
Inches

0.00	3.01 - 3.50	9.01 - 10.00	Daily
0.01 - 0.50	3.51 - 4.00	10.01 - 11.00	Hourly
0.51 - 1.00	4.01 - 5.00	11.01 - 12.00	Hourly Est.
1.01 - 1.50	5.01 - 6.00	12.01 - 13.00	Hourly Est. Pseudo
1.51 - 2.00	6.01 - 7.00	13.01 - 14.00	Hourly Pseudo
2.01 - 2.50	7.01 - 8.00	>14.00	Supplemental
2.51 - 3.00	8.01 - 9.00	DAD zone	Supplemental Est.

06/15/2011 METSTAT



This is not a NOAA product. It was produced by a web user.
Job ID: 317608 Job Start: Tue Nov 29 01:16:31 UTC 2011
Source 1 lat.: 40.91 lon.: -81.97 hgts: 0, 1160, 2820 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Jul 2069 - reanalysis


SPAS 1209 Wooster, OH Storm Analysis
July 2-5, 1969
Storm Center
40.91, -81.97
KFWA
74.0
KGUS
72.5
KPIA
KRAN
KSPI
KIND
78.5
KBAK
75.5
KDAY
KFFO
78.0
KSGH
KCMH
73.0
KILN
75.5
KMFD
71.0
KCAK
71.5
KPIT
KCVG
75.5
KBLV
KEVV
KSDF
74.0
KFTK
73.5
KLEX
71.0
KHTS
72.5
KCRW
69.5
KBKW
70.5
KHOP
KTRI
74.5
KBNA
KMQY
KBYH
KTYS
KAVL
KCLT
KNQA
74.5
KCHA
90°W
88°W
86°W
84°W
82°W
80°W
40°N
38°N
36°N
Hysplit
Surface
850mb
700mb
0
112.5
225
450
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1362_1 SPAS Analysis

General Storm Location: Tennessee Valley (-88.7, 37.9, 34.0, -81.2)

Storm Dates: April 2 – April 5, 1977

Event: Mid-latitude cyclone (MLC)

DAD Zone 1

Latitude: 37.2792

Longitude: -81.8042

Max. Grid/Radar Rainfall Amount: 15.66”

Max. Observed Rainfall Amount: 15.5”

Number of Stations: 461

SPAS Version: 9.5

Base Map Used: Mean annual maximum 48-hour precipitation associated with MLCs

Spatial resolution: 0.2681

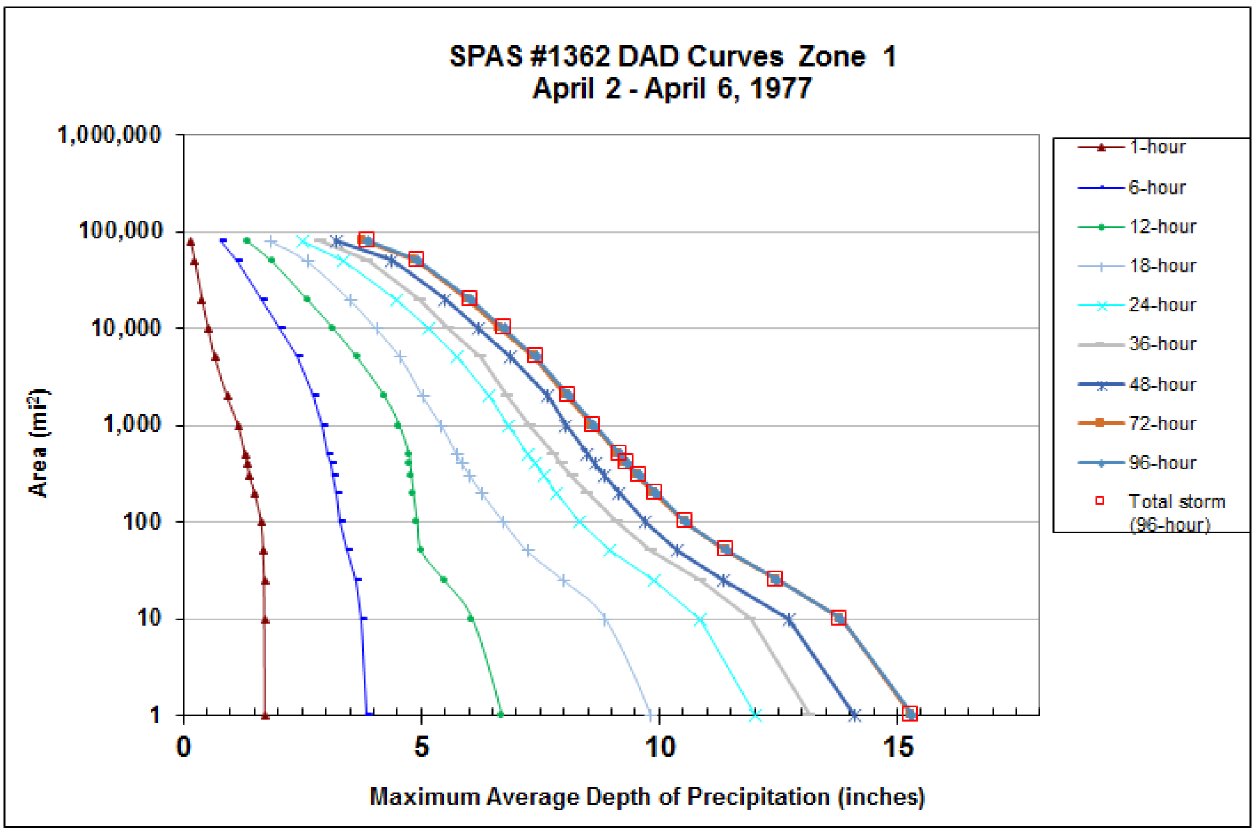
Radar Included: No

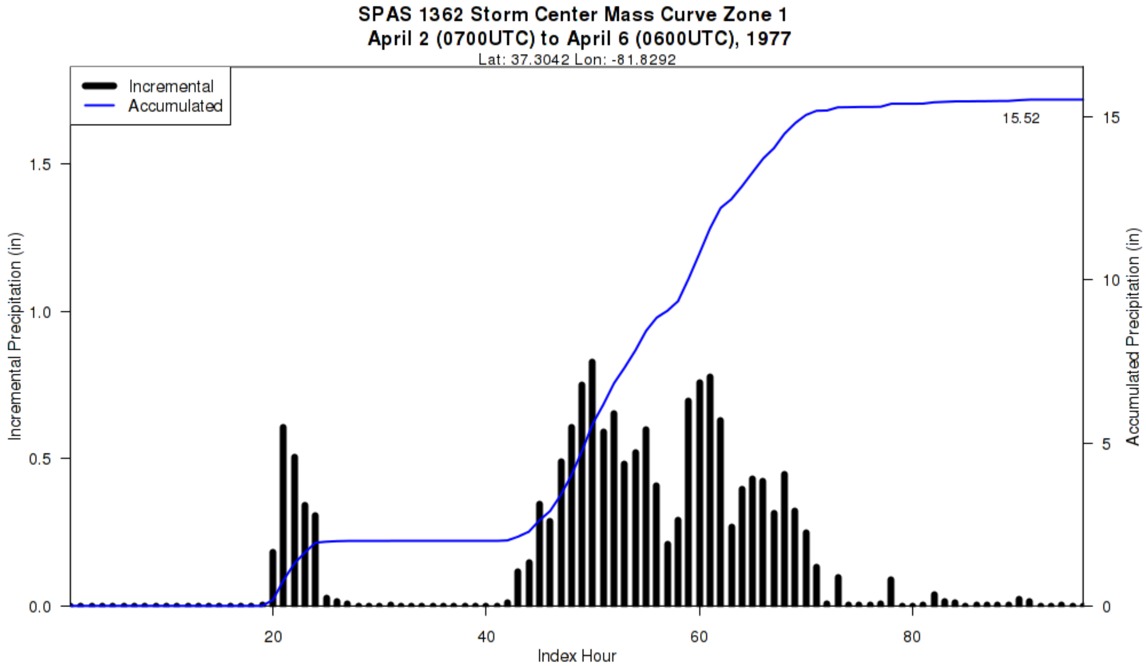
Depth-Area-Duration (DAD) analysis: Yes

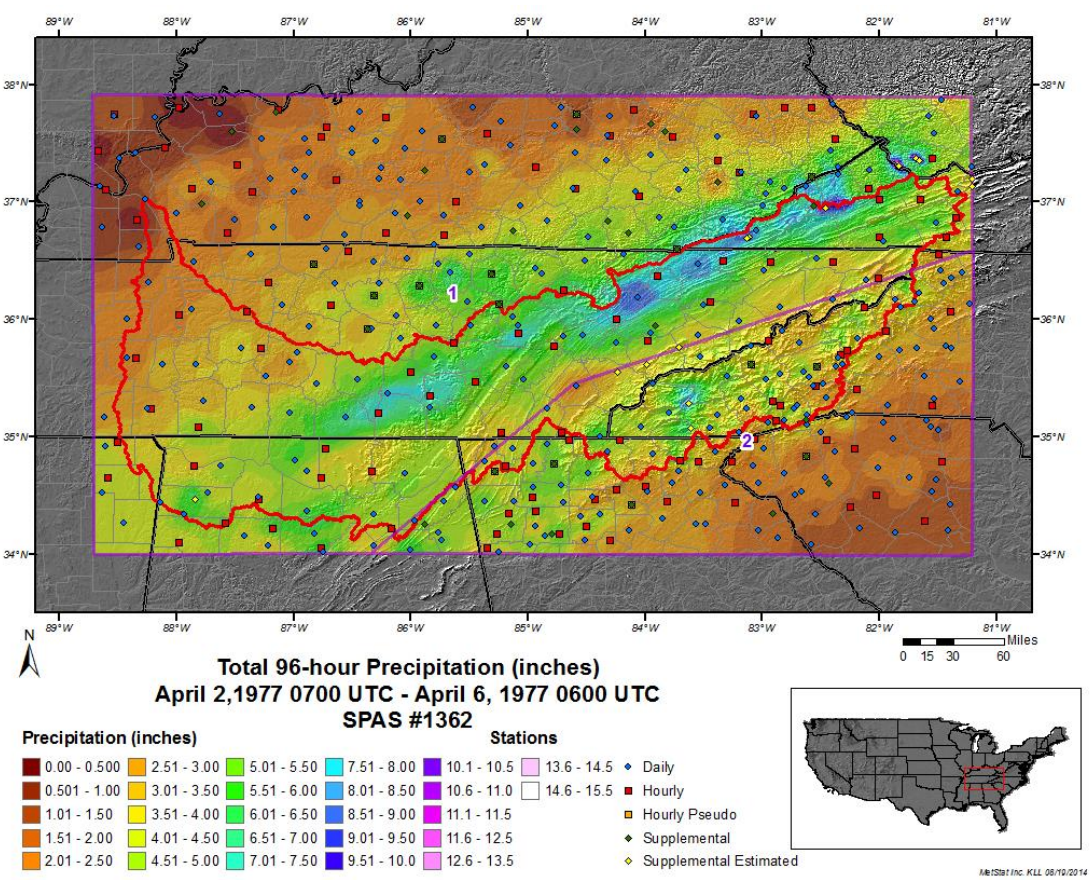
Reliability of results: In addition to the NCDC stations, seven supplemental stations were added. There were also seven hourly stations added via digitizing some of the stations listed in the TVA report. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the TVA report, this analysis is deemed quite reliable.

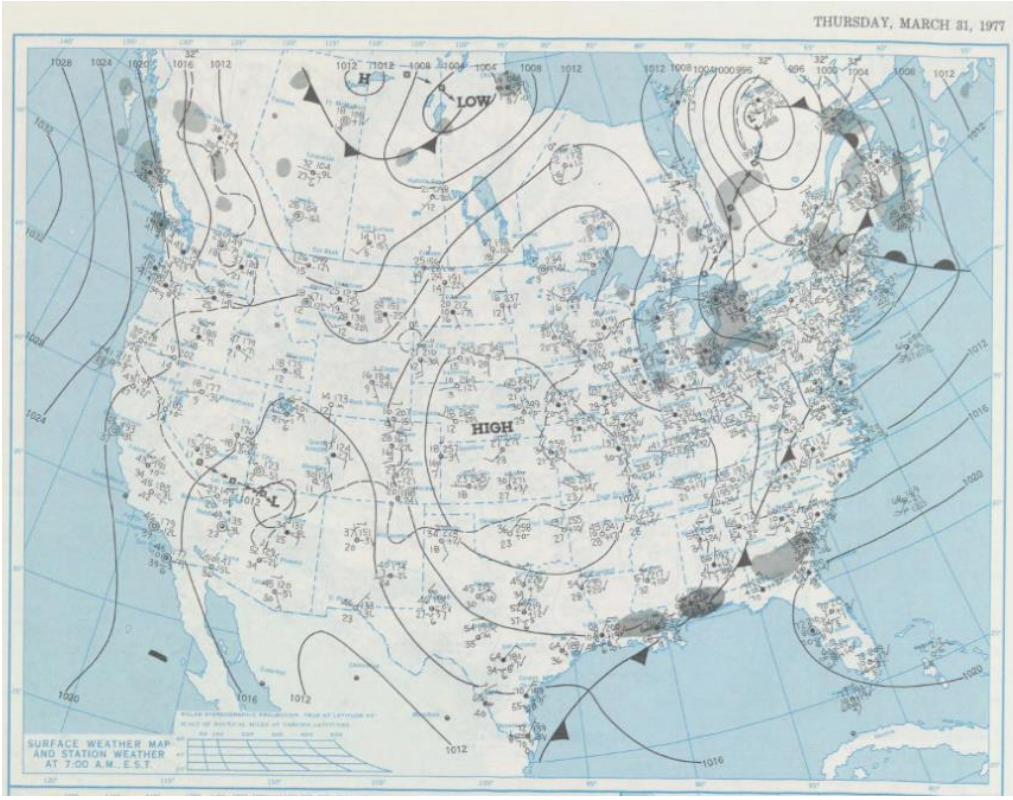
						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1362_1	-81.8042	37.2792	2,296	20-Apr	72.50	2.54	0.51	67	2.025	75.29	2.92	0.56	73	2.360	1.165

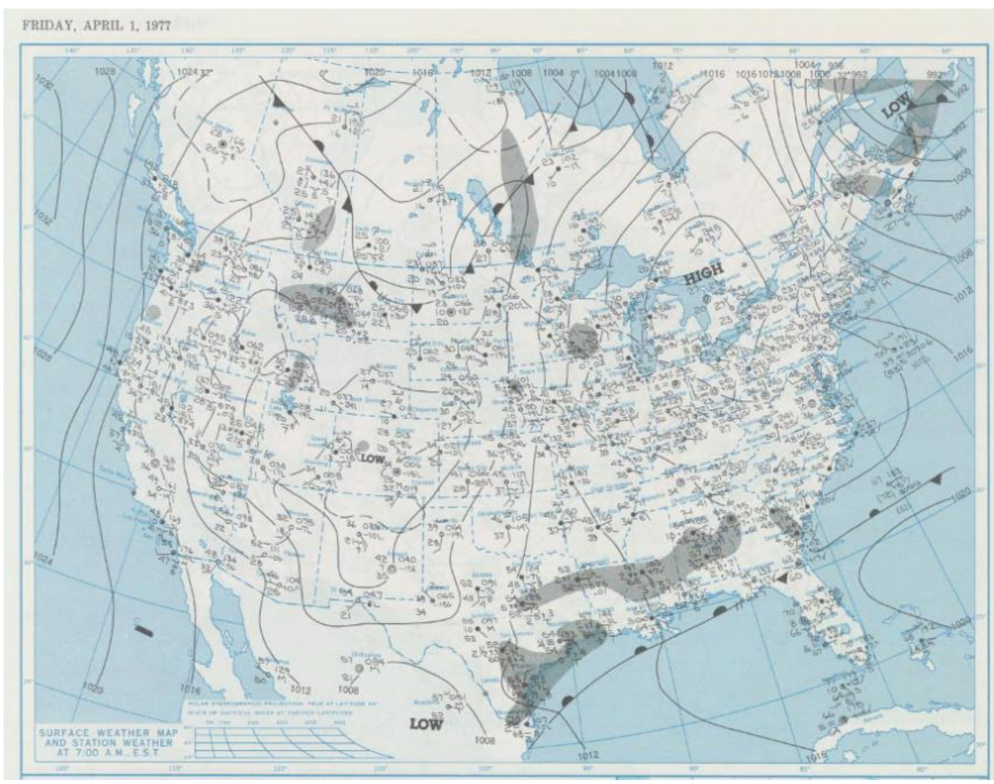
Storm 1362 - April 2 (0700 UTC) - April 6 (0600 UTC), 1977 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
Area (mi^2)	Duration (hours)									
	1	6	12	18	24	36	48	72	96	Total
0.4	1.74	3.89	6.78	9.91	12.15	13.31	14.23	15.45	15.45	15.45
1	1.73	3.84	6.69	9.81	12.03	13.14	14.09	15.29	15.30	15.30
10	1.72	3.73	6.07	8.86	10.86	11.91	12.72	13.81	13.82	13.82
25	1.71	3.63	5.48	7.98	9.88	10.85	11.33	12.48	12.48	12.48
50	1.69	3.46	5.00	7.23	8.97	9.83	10.39	11.42	11.43	11.43
100	1.65	3.31	4.91	6.73	8.31	9.11	9.71	10.55	10.55	10.55
200	1.51	3.20	4.83	6.27	7.83	8.49	9.16	9.89	9.93	9.93
300	1.40	3.15	4.79	6.03	7.57	8.17	8.86	9.55	9.59	9.59
400	1.36	3.10	4.76	5.86	7.38	7.94	8.65	9.31	9.35	9.35
500	1.31	3.05	4.74	5.75	7.24	7.77	8.49	9.13	9.17	9.17
1,000	1.16	2.92	4.54	5.42	6.82	7.27	8.03	8.60	8.64	8.64
2,000	0.93	2.75	4.23	5.03	6.41	6.80	7.66	8.06	8.11	8.11
5,000	0.67	2.40	3.66	4.57	5.77	6.24	6.88	7.38	7.43	7.43
10,000	0.53	2.03	3.16	4.06	5.15	5.58	6.21	6.66	6.75	6.75
20,000	0.40	1.64	2.61	3.50	4.49	4.96	5.51	5.96	6.04	6.04
50,000	0.25	1.14	1.86	2.61	3.38	3.86	4.38	4.86	4.92	4.92
80,939	0.16	0.80	1.35	1.85	2.50	2.87	3.20	3.77	3.88	3.88



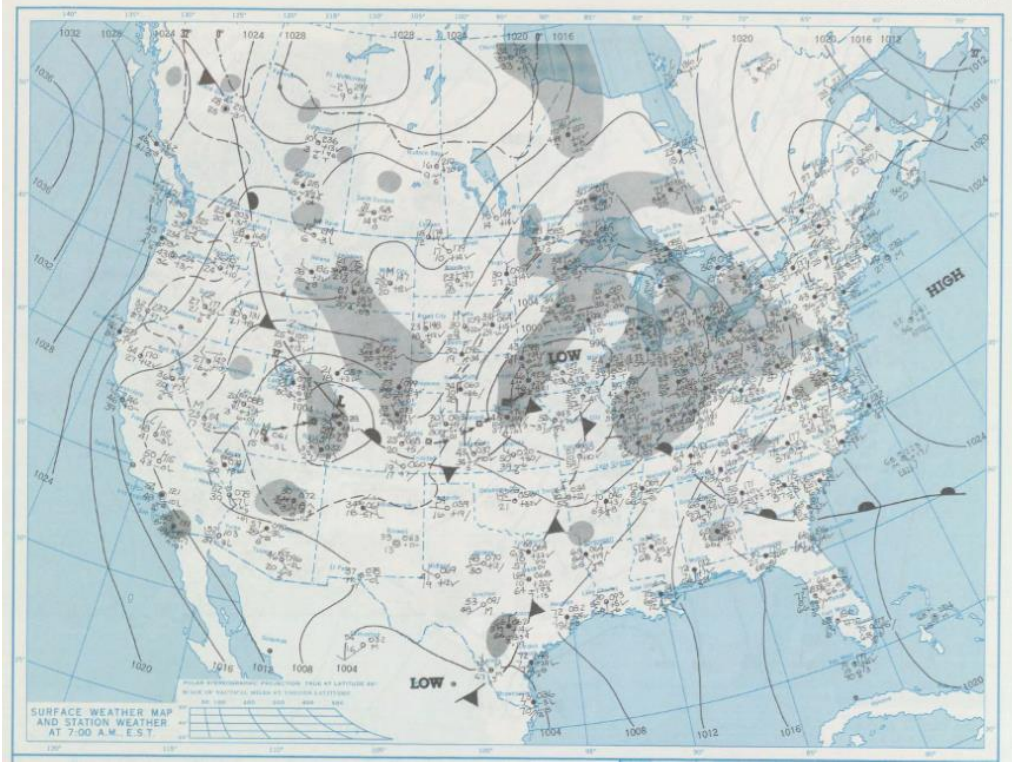

SPAS 1362 Storm Center Mass Curve Zone 1
April 2 (0700UTC) to April 6 (0600UTC), 1977
Lat: 37.3042 Lon: -81.8292
Incremental
Accumulated
15.52
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour


Total 96-hour Precipitation (inches)
April 2,1977 0700 UTC - April 6, 1977 0600 UTC
SPAS #1362
Precipitation (inches)
0.00 - 0.500
0.501 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.0
10.1 - 10.5
10.6 - 11.0
11.1 - 11.5
11.6 - 12.5
12.6 - 13.5
13.6 - 14.5
14.6 - 15.5
Stations
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Estimated
Miles
0 15 30 60
MetStat Inc. KLL 08/19/2014

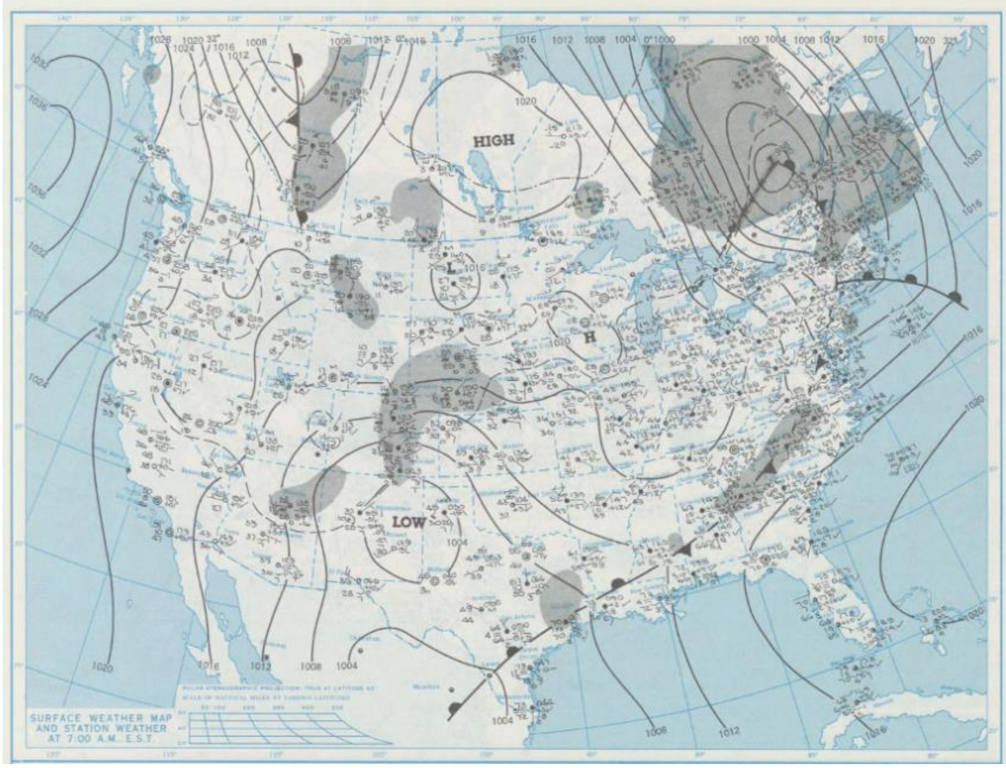

THURSDAY, MARCH 31, 1977
HIGH
LOW
SURFACE WEATHER MAP
AND STATION WEATHER
AT 7:00 A.M., E.S.T.


FRIDAY, APRIL 1, 1977
HIGH
LOW
LOW
LOW
SURFACE WEATHER MAP
AND STATION WEATHER
AT 7:00 A.M., E.S.T.

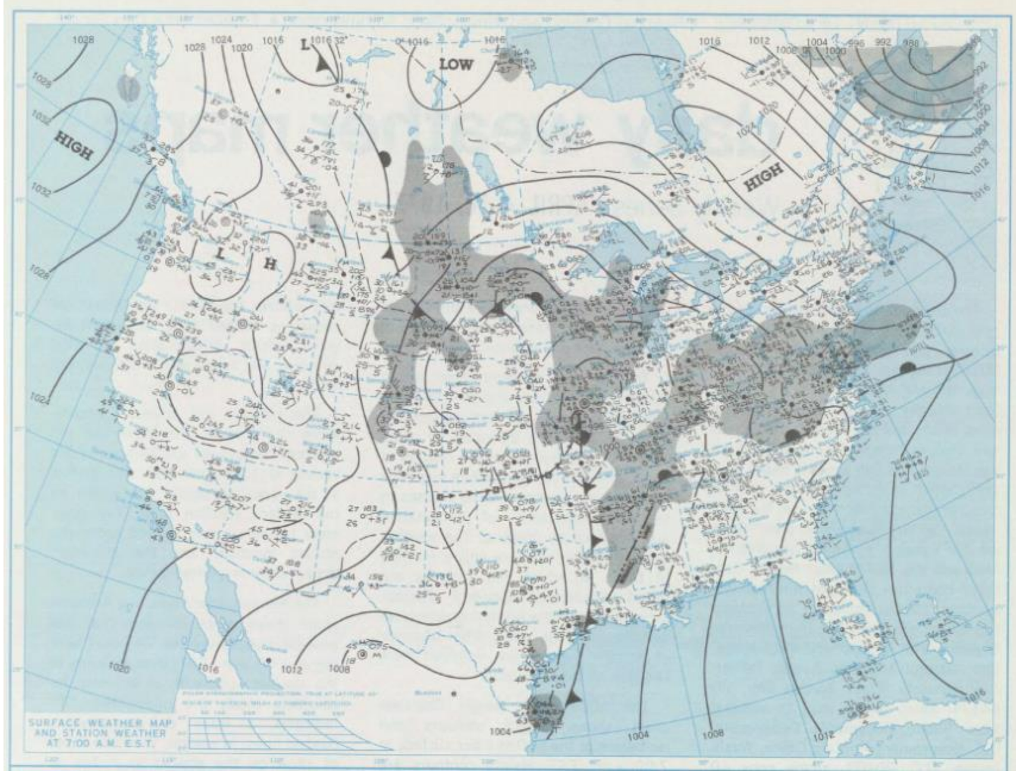
SATURDAY, APRIL 2, 1977



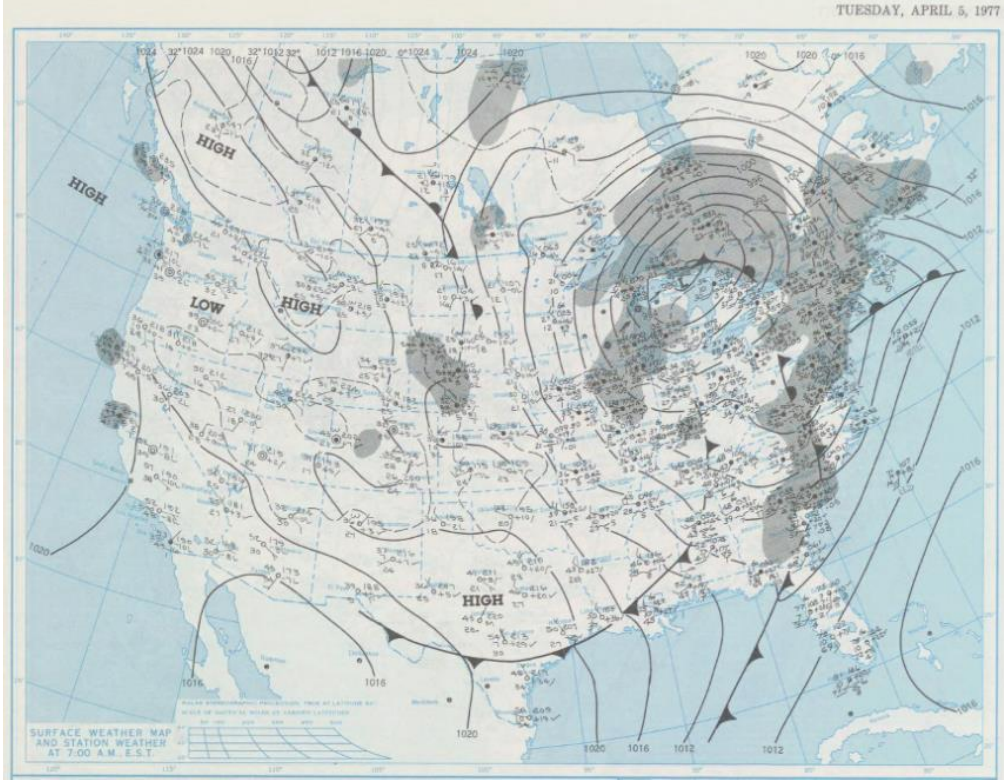
SUNDAY, APRIL 3, 1977



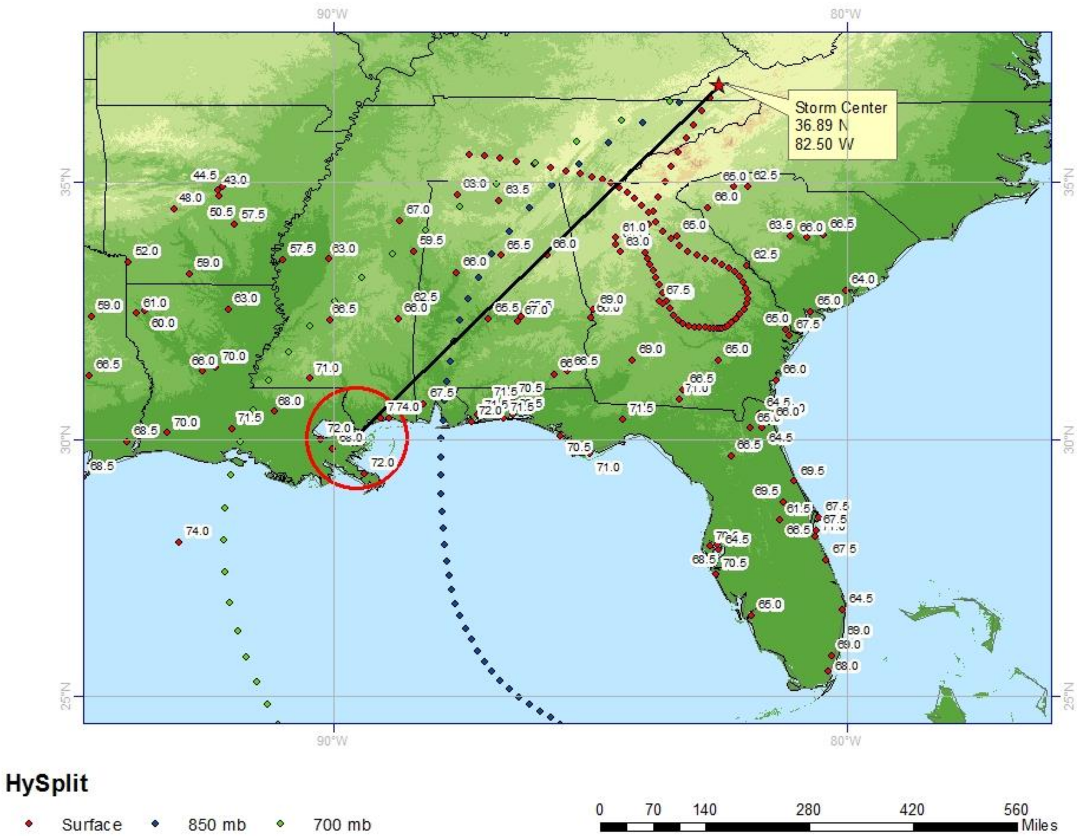
MONDAY, APRIL 4, 1977



TUESDAY, APRIL 5, 1977



SPAS 1362
April 2-6, 1977



Storm Precipitation Analysis System (SPAS) For Storm #1550_1 SPAS Analysis

General Storm Location: Johnstown, PA

Storm Dates: July 18-19, 1977 (72-hours)

Event: Synoptic/Convective

DAD Zone 1

Latitude: 40.3958

Longitude: -78.9542

Max. Grid Rainfall Amount: 12.64”

Max. Observed Rainfall Amount: 12.06” North of Johnstown, PA

Number of Stations: 263 (146 Daily, 72 Hourly, 15 Hourly Pseudo and 30 Supplemental)

SPAS Version: 10

Basemap: us_ppt_in_map_1961_1990_usda_northamerica

Spatial resolution: 00:00:30

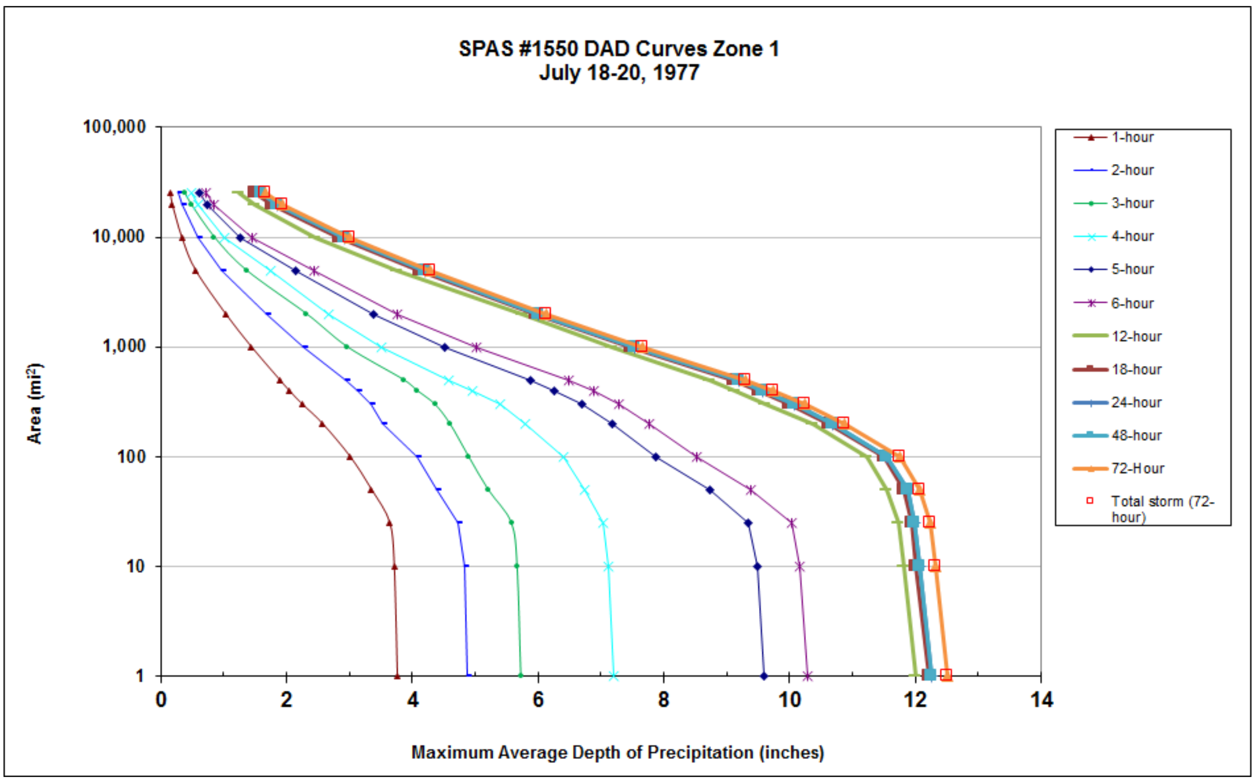
Radar Included: No

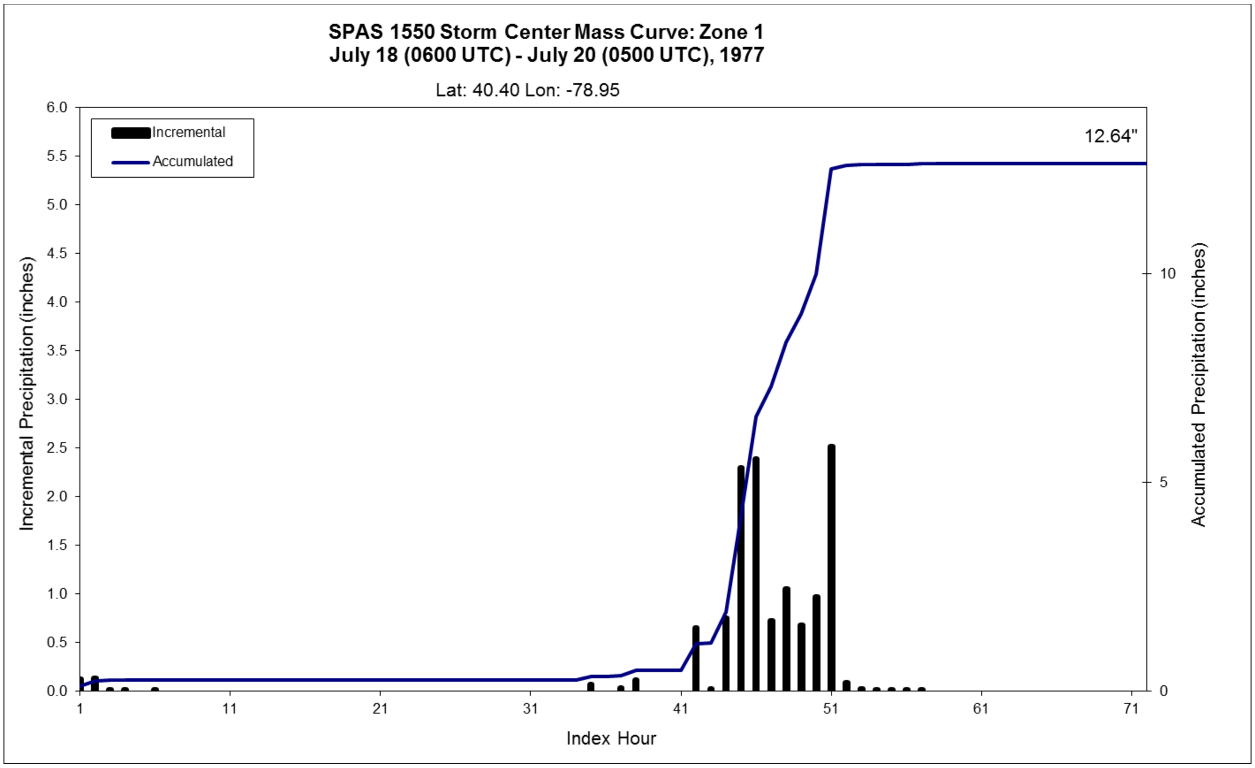
Depth-Area-Duration (DAD) analysis: Yes

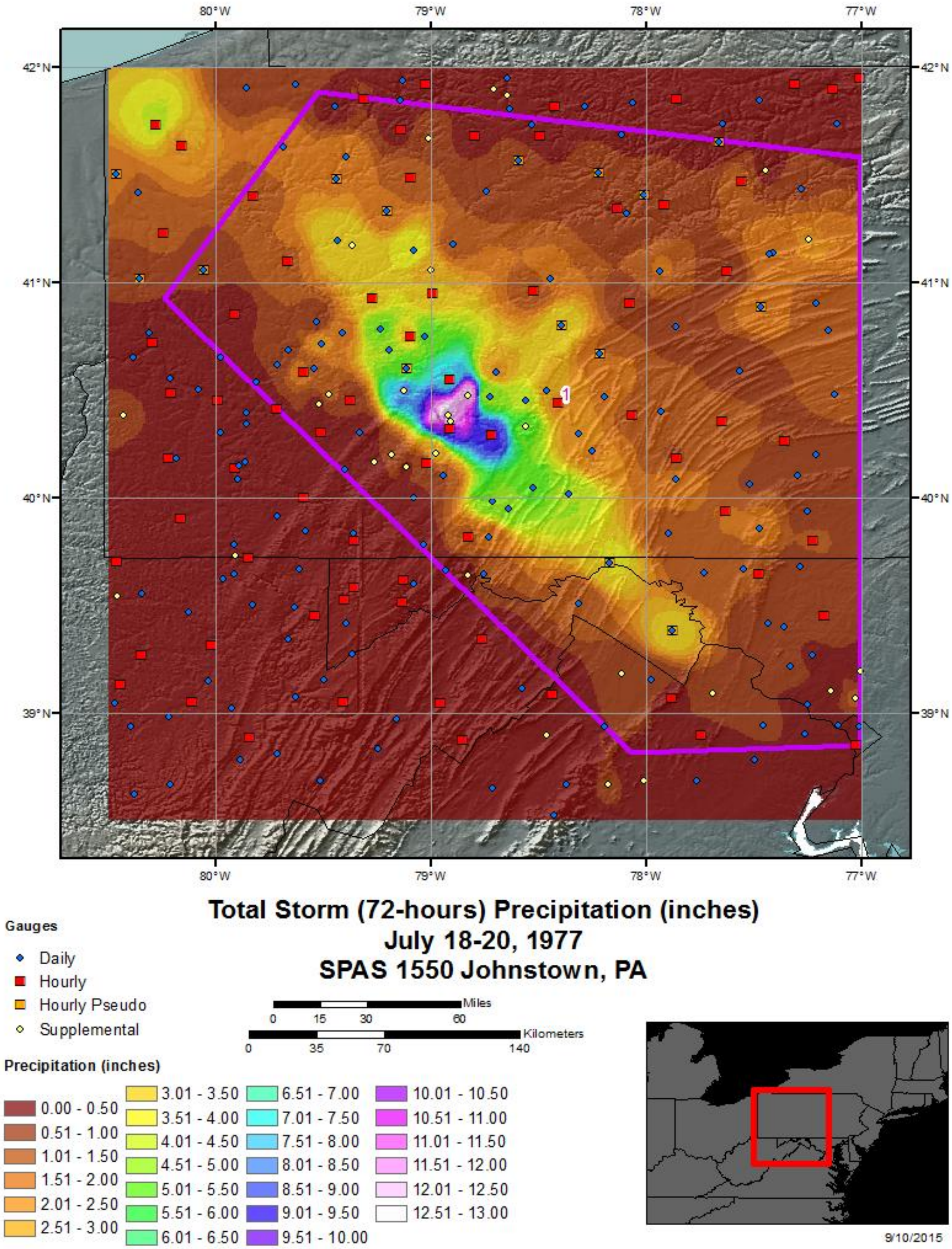
Reliability of results: This analysis was based on several hourly data, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the basemap (us_ppt_in_map_1961_1990_usda_northamerica). It matches well with the rainfall analysis from USGS (see below; https://archive.org/details/meteorologicalan00atmo). There is a high degree of confidence with the timing based on the several hourly stations in and around the storm center. Some daily stations were moved to supplemental due to timing issues or removed due to duplicate storm precipitation observations. Additional details can be found in the “read_me_1550.txt” file.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1550_1	-78.9542	40.3958	2,531	15-Jul	75.00	2.85	0.60	72	2.250	78.61	3.37	0.67	79	2.695	1.198

Storm 1550 Zone 1 - Jul. 18 (0600 UTC) - Jul. 20 (0500 UTC), 1977												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
	Duration (hours)											
areasqmi	1	2	3	4	5	6	12	18	24	48	72	Total
0.4	3.78	4.90	5.76	7.23	9.65	10.34	12.09	12.29	12.33	12.33	12.60	12.60
1	3.76	4.88	5.73	7.20	9.60	10.29	12.01	12.21	12.26	12.26	12.52	12.52
10	3.71	4.82	5.67	7.12	9.49	10.17	11.81	12.01	12.06	12.06	12.32	12.32
25	3.64	4.73	5.58	7.04	9.35	10.03	11.73	11.94	11.99	11.99	12.24	12.24
50	3.35	4.38	5.21	6.74	8.74	9.39	11.54	11.82	11.89	11.89	12.06	12.06
100	3.01	4.08	4.90	6.40	7.88	8.52	11.23	11.50	11.55	11.55	11.75	11.75
200	2.57	3.53	4.60	5.80	7.19	7.76	10.36	10.62	10.69	10.69	10.88	10.88
300	2.25	3.34	4.36	5.39	6.69	7.28	9.62	9.99	10.08	10.08	10.25	10.25
400	2.04	3.13	4.08	4.95	6.26	6.88	9.13	9.51	9.58	9.58	9.75	9.75
500	1.89	2.94	3.87	4.57	5.88	6.48	8.74	9.12	9.20	9.20	9.31	9.31
1,000	1.44	2.26	2.97	3.51	4.51	5.02	7.19	7.47	7.53	7.53	7.66	7.66
2,000	1.03	1.68	2.32	2.67	3.38	3.75	5.75	5.97	6.01	6.01	6.14	6.14
5,000	0.55	0.96	1.36	1.74	2.15	2.43	3.77	4.11	4.20	4.20	4.28	4.28
10,000	0.33	0.59	0.85	1.02	1.26	1.45	2.46	2.84	2.93	2.93	3.00	3.00
20,000	0.18	0.34	0.48	0.60	0.73	0.85	1.49	1.76	1.86	1.86	1.93	1.93
25,225	0.15	0.28	0.38	0.48	0.61	0.71	1.25	1.49	1.59	1.59	1.66	1.66

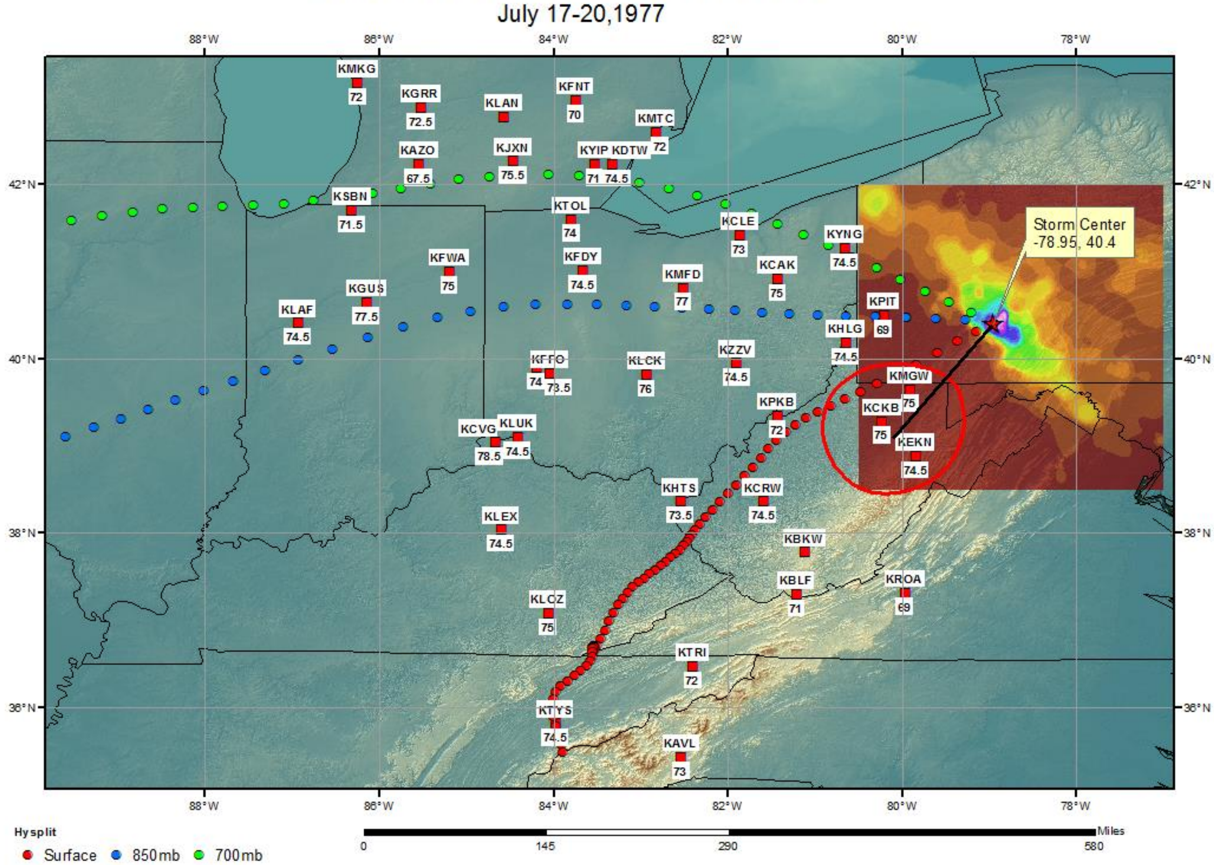



SPAS 1550 Storm Center Mass Curve: Zone 1
July 18 (0600 UTC) - July 20 (0500 UTC), 1977
Lat: 40.40 Lon: -78.95
Incremental
Accumulated
12.64"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
0
5
10
1
11
21
31
41
51
61
71


80°W
79°W
78°W
77°W
42°N
41°N
40°N
39°N
1
Total Storm (72-hours) Precipitation (inches)
July 18-20, 1977
SPAS 1550 Johnstown, PA
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Miles
0 15 30 60
Kilometers
0 35 70 140
Precipitation (inches)
0.00 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.00
10.01 - 10.50
10.51 - 11.00
11.01 - 11.50
11.51 - 12.00
12.01 - 12.50
12.51 - 13.00
9/10/2015

SPAS 1550 Johnstown, PA Storm Analysis

July 17-20,1977



Storm Precipitation Analysis System (SPAS) For Storm #1406_1 SPAS-NEXRAD Analysis

General Storm Location: Rapidan, VA - Marion County

Storm Dates: June 26 – 27, 1995

Event: Orographic

DAD Zone 1

Latitude: 38.415

Longitude: -78.335

Max. Grid Rainfall Amount: 28.39" in 41 hours

Max. Observed Rainfall Amount: 27.4" – Storm Center as indicated by Sterling WSR-88D in Smith et al., 1995 Catastrophic rainfall from an upslope thunderstorm in the central Appalachians: The Rapidan storm of June 27, 1995

Number of Stations: 295 (220 Daily, 48 Hourly, 18 Hourly Pseudo and 9 Supplemental)

SPAS Version: 10

Basemap: PRISM June 1981-2010; ippt_allsites_1406_sum_in (SPAS-NEXRAD hrly basemap)

Spatial resolution: 00:00:36

Radar Included: Yes

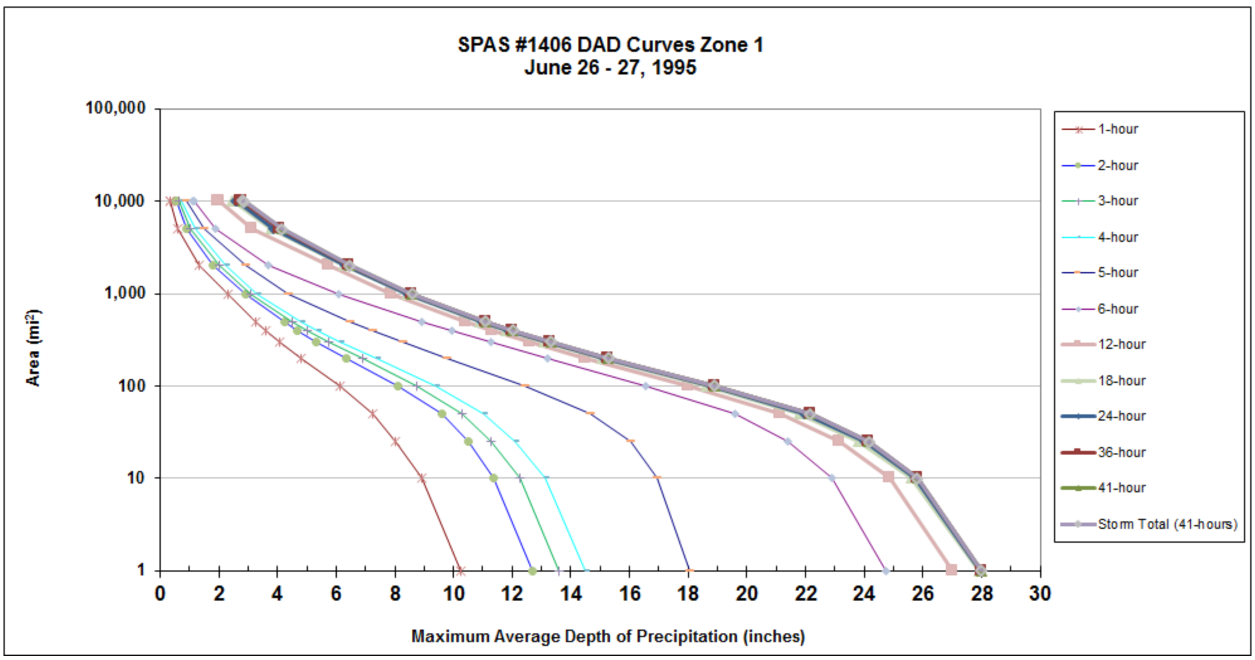
Radar Beam-Blockage shapefile created: Yes

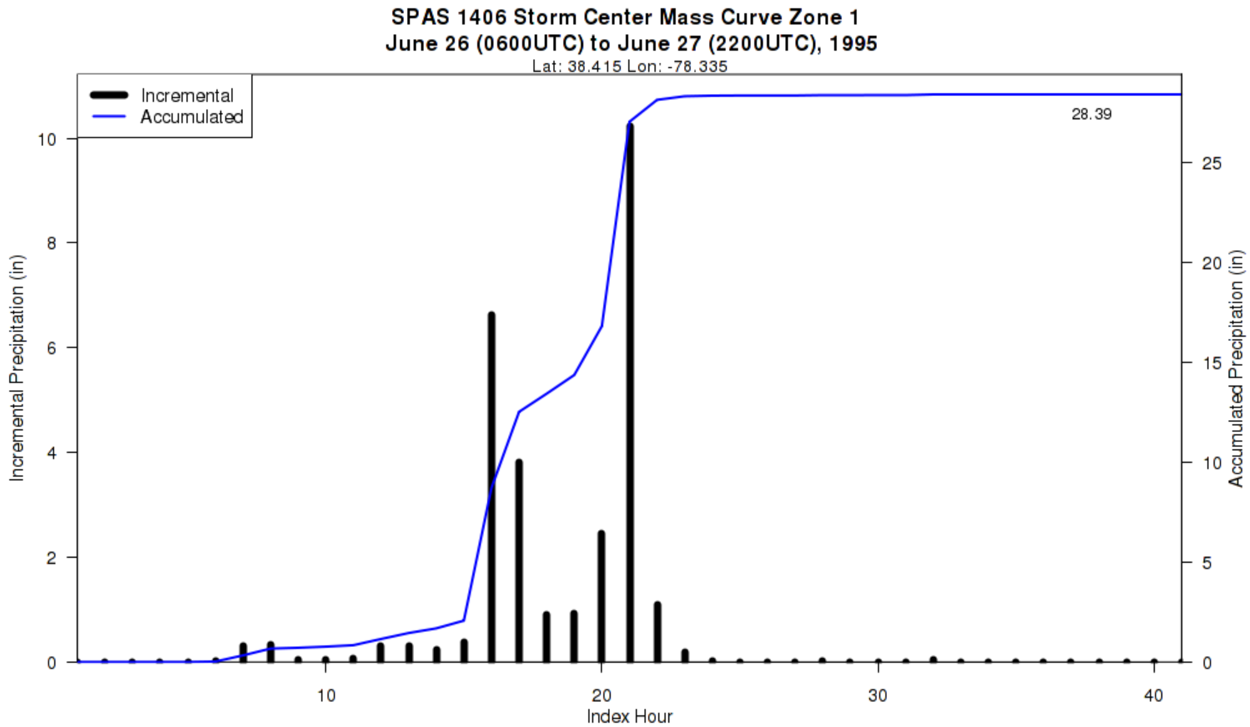
Depth-Area-Duration (DAD) analysis: Yes

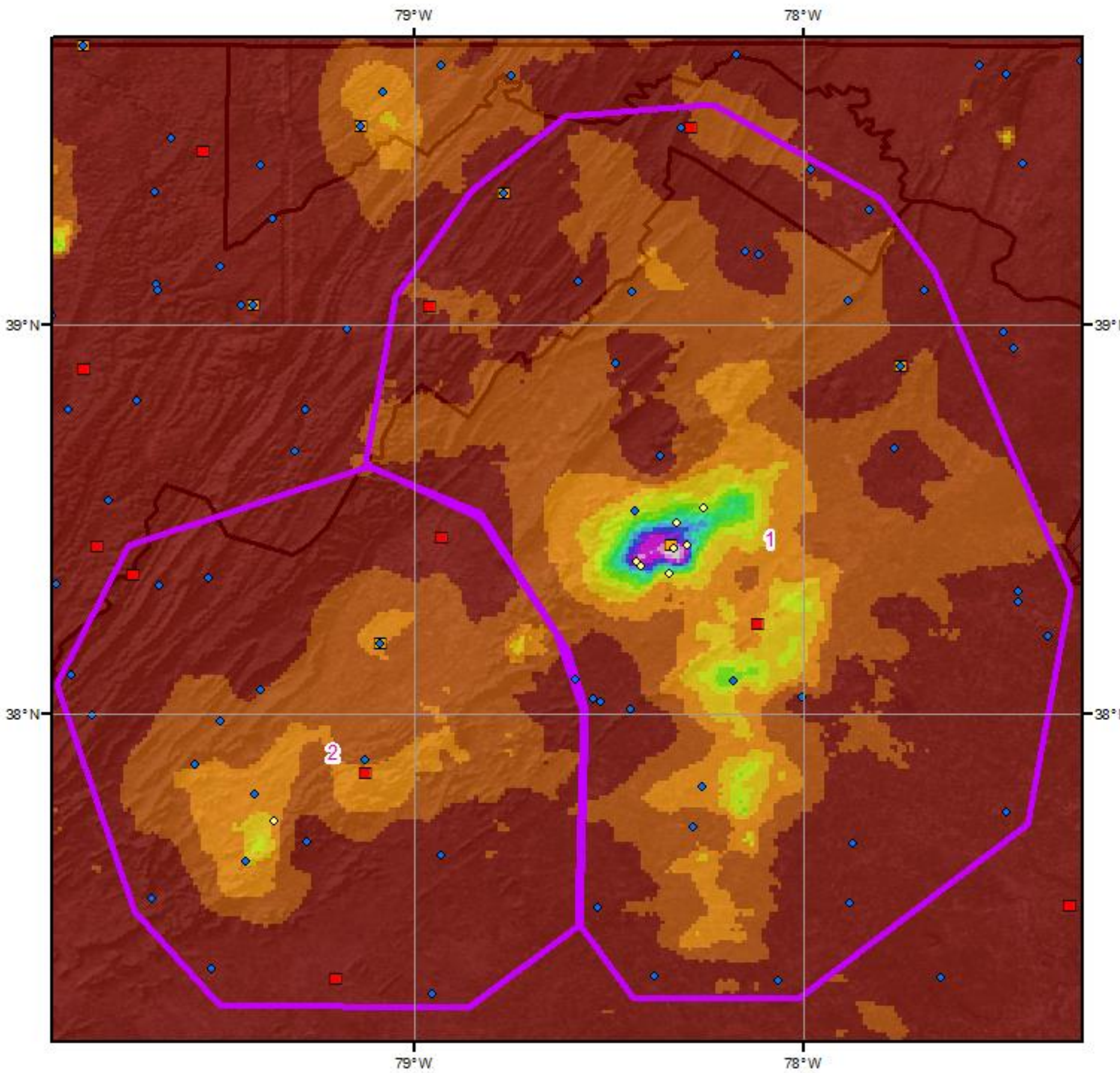
Reliability of results: This analysis was based on hourly data, daily data and supplemental station data paired with SPAS-NEXRAD. We have a high degree of confidence for the radar and station based storm total results. The spatial pattern dependent on the basemap and radar data with a high degree of confidence with the timing based on hourly and hourly pseudo stations.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1406_1	-78.3350	38.4150	1,288	10-Jul	82.00	3.95	0.39	86	3.560	83.84	4.30	0.42	90	3.880	1.090

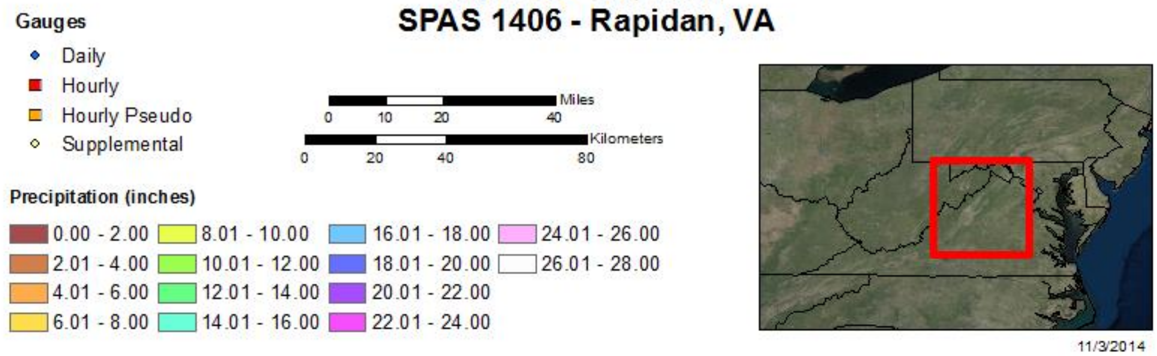
Storm 1406 Zone 1 - June 26 (0600 UTC) - June 27 (2200 UTC), 1995												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
	Duration (hours)											
areasqmi	1	2	3	4	5	6	12	18	24	36	41	Total
0.4	10.4	12.9	13.8	14.7	18.3	25.1	27.4	28.3	28.3	28.4	28.4	28.4
1	10.3	12.7	13.6	14.5	18.1	24.8	27.0	27.9	28.0	28.0	28.0	28.0
10	8.9	11.4	12.3	13.1	16.9	22.9	24.9	25.6	25.7	25.8	25.8	25.8
25	8.0	10.5	11.3	12.1	16.0	21.4	23.2	23.8	24.0	24.2	24.2	24.2
50	7.2	9.6	10.3	11.0	14.7	19.6	21.2	21.8	21.9	22.2	22.2	22.2
100	6.1	8.1	8.8	9.4	12.4	16.6	18.0	18.6	18.8	18.9	18.9	18.9
200	4.8	6.3	6.9	7.4	9.8	13.2	14.5	15.0	15.2	15.3	15.3	15.3
300	4.1	5.3	5.8	6.2	8.3	11.3	12.6	13.1	13.2	13.3	13.3	13.3
400	3.6	4.7	5.0	5.4	7.3	10.0	11.3	11.8	11.9	12.0	12.0	12.0
500	3.3	4.2	4.5	4.8	6.5	8.9	10.4	10.9	11.0	11.1	11.1	11.1
1,000	2.3	2.9	3.1	3.3	4.4	6.1	7.9	8.4	8.5	8.6	8.6	8.6
2,000	1.3	1.8	2.0	2.2	2.9	3.7	5.8	6.3	6.3	6.4	6.5	6.5
5,000	0.6	0.9	1.1	1.2	1.5	1.9	3.2	3.8	3.9	4.1	4.2	4.2
10,000	0.4	0.6	0.6	0.7	0.9	1.2	2.0	2.5	2.6	2.8	2.9	2.9
10,196	0.4	0.6	0.6	0.7	0.9	1.1	2.0	2.5	2.6	2.8	2.8	2.8

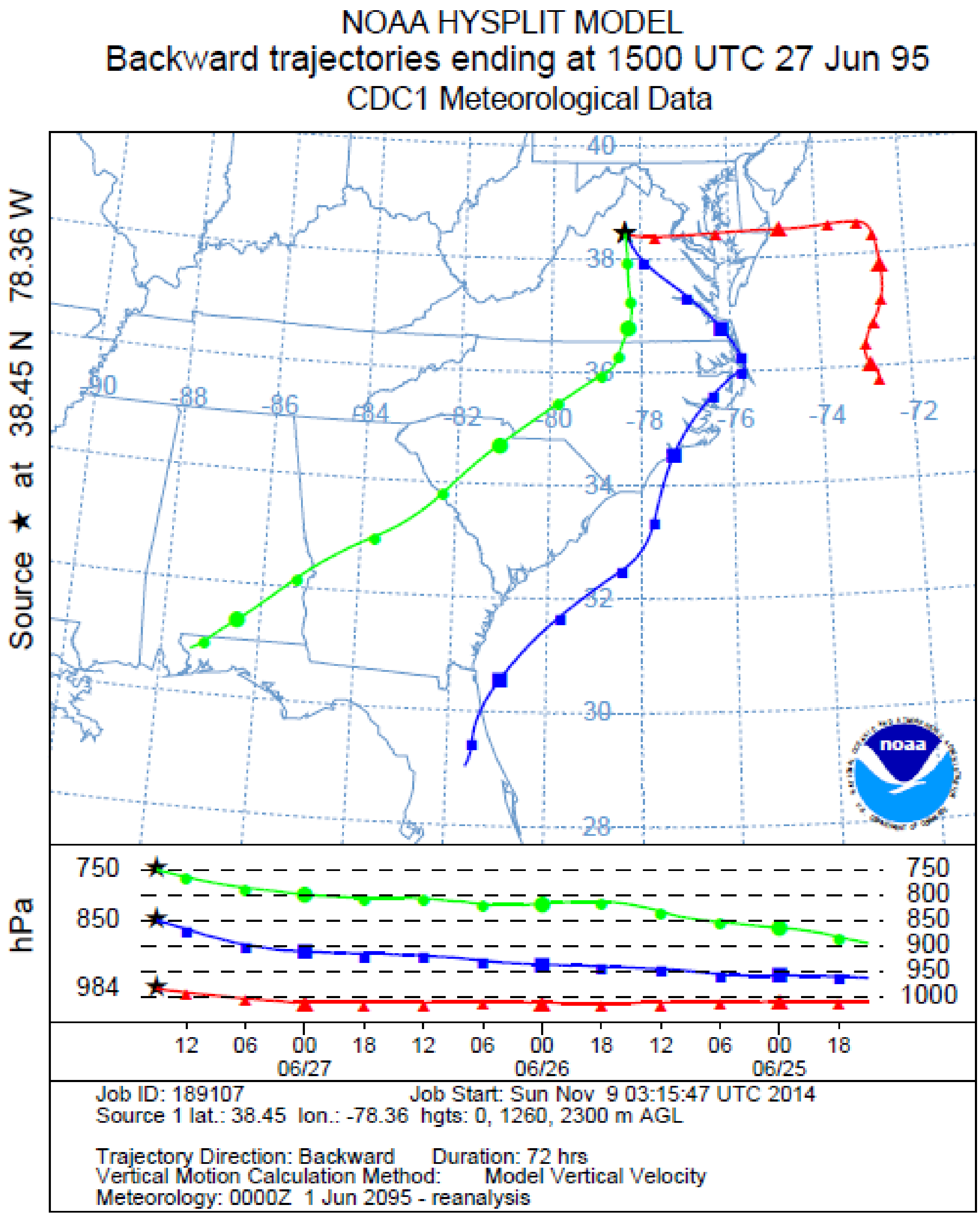


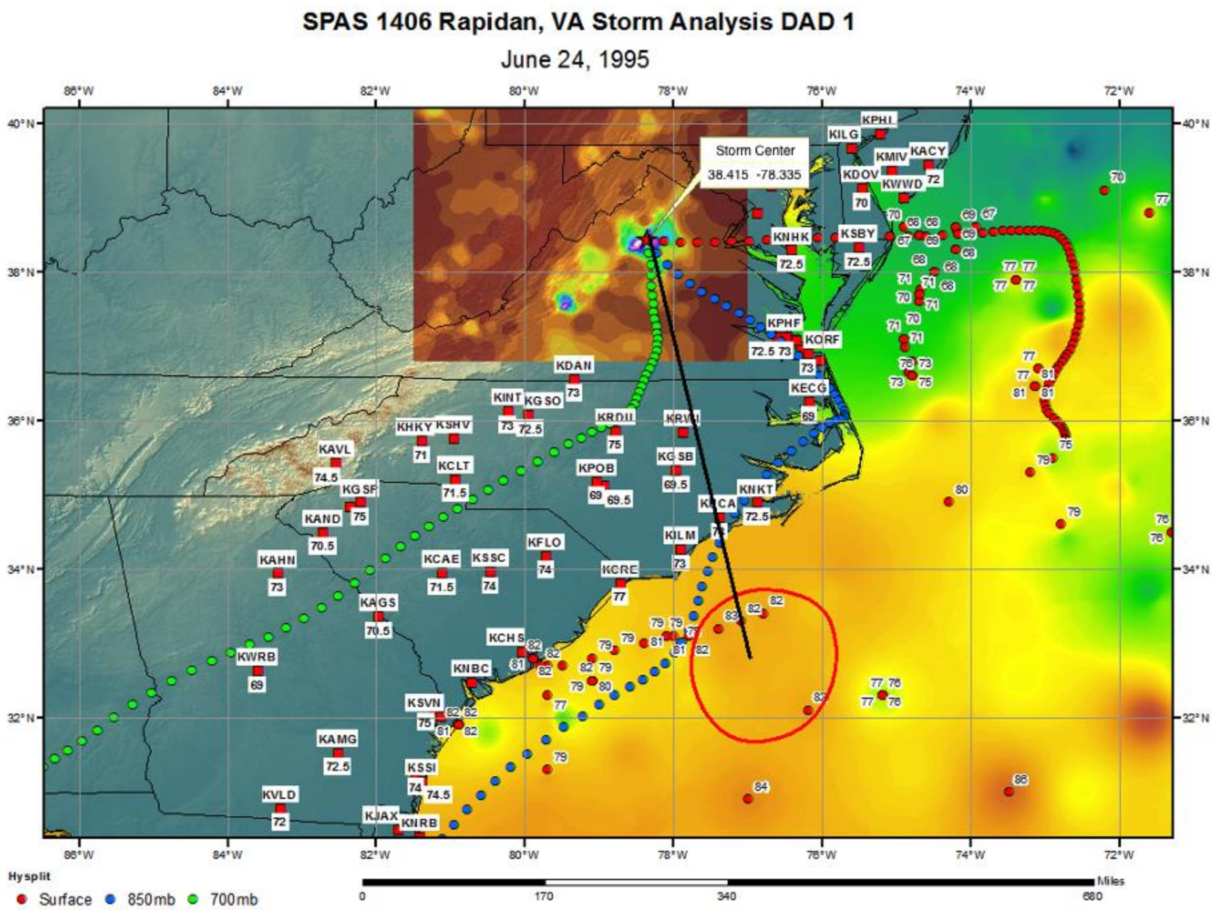

SPAS 1406 Storm Center Mass Curve Zone 1
June 26 (0600UTC) to June 27 (2200UTC), 1995
Lat: 38.415 Lon: -78.335
Incremental
Accumulated
28.39
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
2
4
6
8
10
5
15
20
25
10
20
30
40



Total Storm (41-hours) Precipitation (inches)
June 26 - 27, 1995
SPAS 1406 - Rapidan, VA




NOAA HYSPLIT MODEL
Backward trajectories ending at 1500 UTC 27 Jun 95
CDC1 Meteorological Data
Source ★ at 38.45 N 78.36 W
40
38
36
34
32
30
28
-90
-88
-86
-84
-82
-80
-78
-76
-74
-72
hPa
750
850
984
750
800
850
900
950
1000
12
06
00
18
12
06
00
18
12
06
00
18
06/27
06/26
06/25
Job ID: 189107
Job Start: Sun Nov 9 03:15:47 UTC 2014
Source 1 lat.: 38.45 lon.: -78.36 hgts: 0, 1260, 2300 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2095 - reanalysis



SPAS 1406 Rapidan, VA Storm Analysis DAD 1
June 24, 1995
Storm Center
38.415 -78.335
Hysplit
Surface 850mb 700mb
Miles
0 170 340 680

Storm Precipitation Analysis System (SPAS) For Storm #1548_1 SPAS-NEXRAD Analysis

General Storm Location: Redbank, PA

Storm Dates: July 19, 1996

Event: Local

DAD Zone 1

Latitude: 41.2550

Longitude: -79.1550

Max Grid Precipitation Amount: 9.42”

Max Observed Precipitation Amount: 9.371”

Number of Stations: 178

Base Map Used:

SPAS Version: 10.0

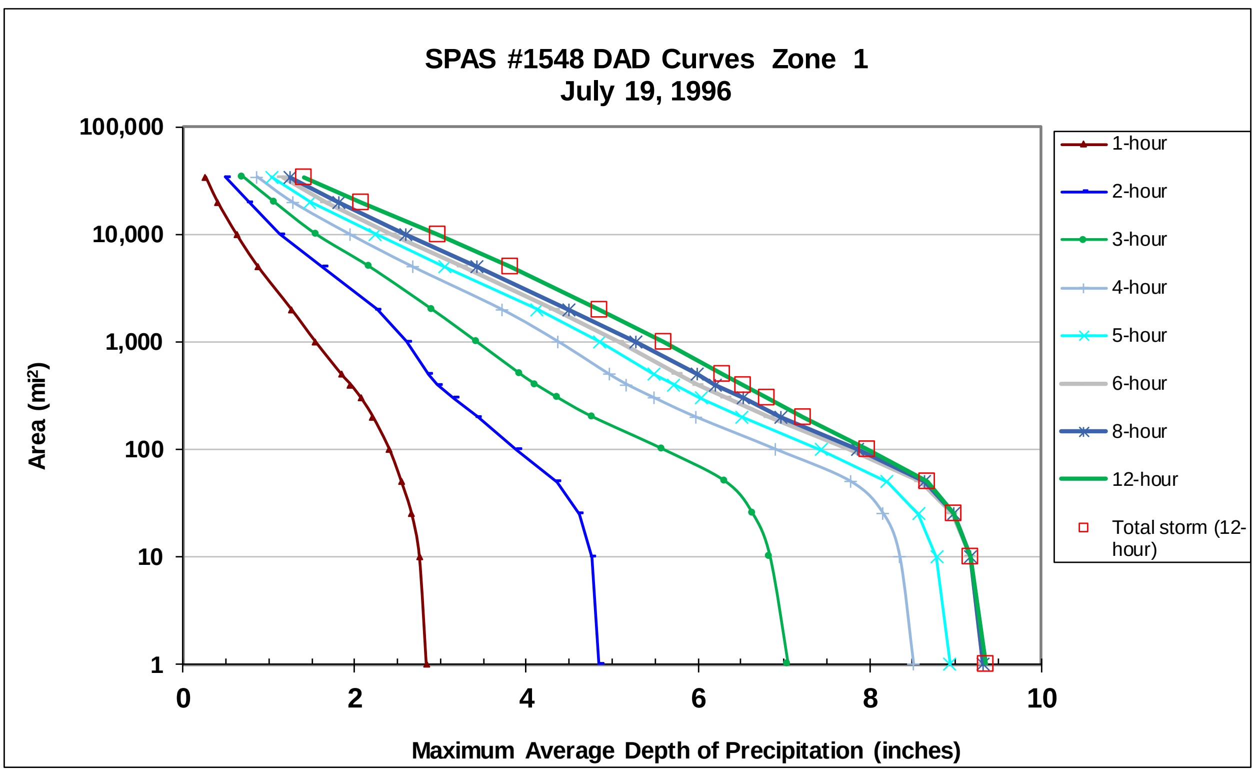
Spatial resolution: 0.3600

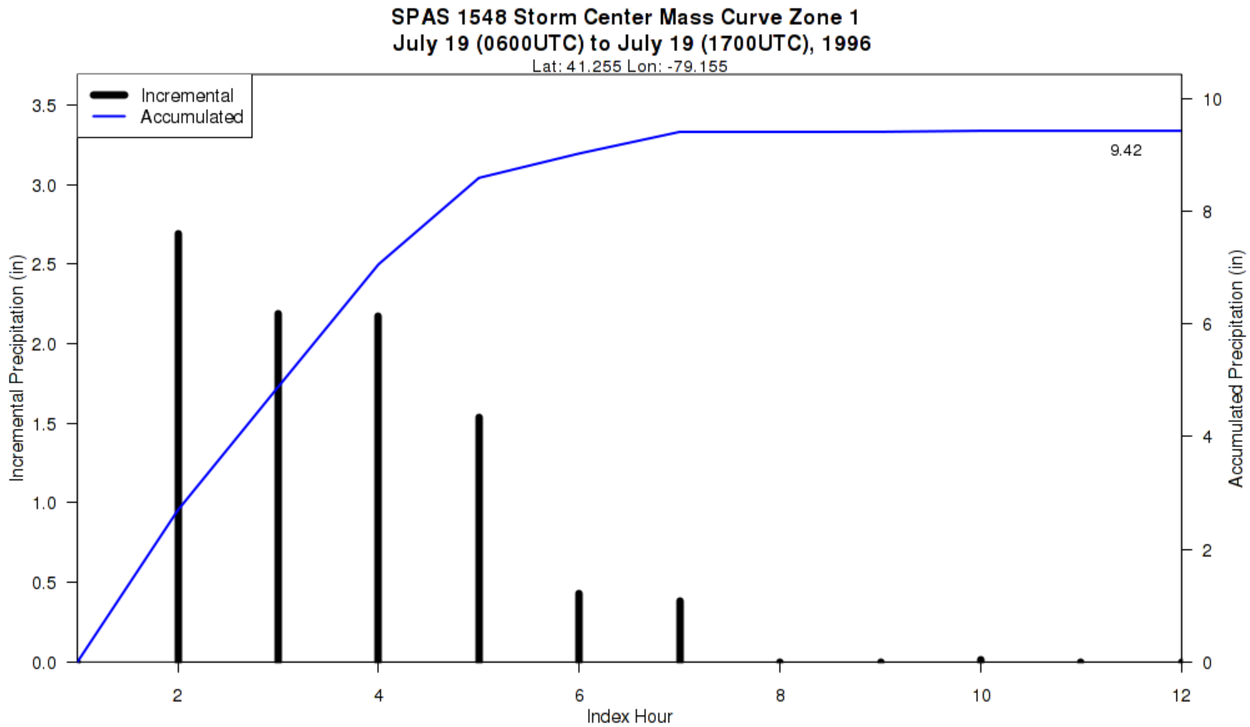
Radar Included: Yes

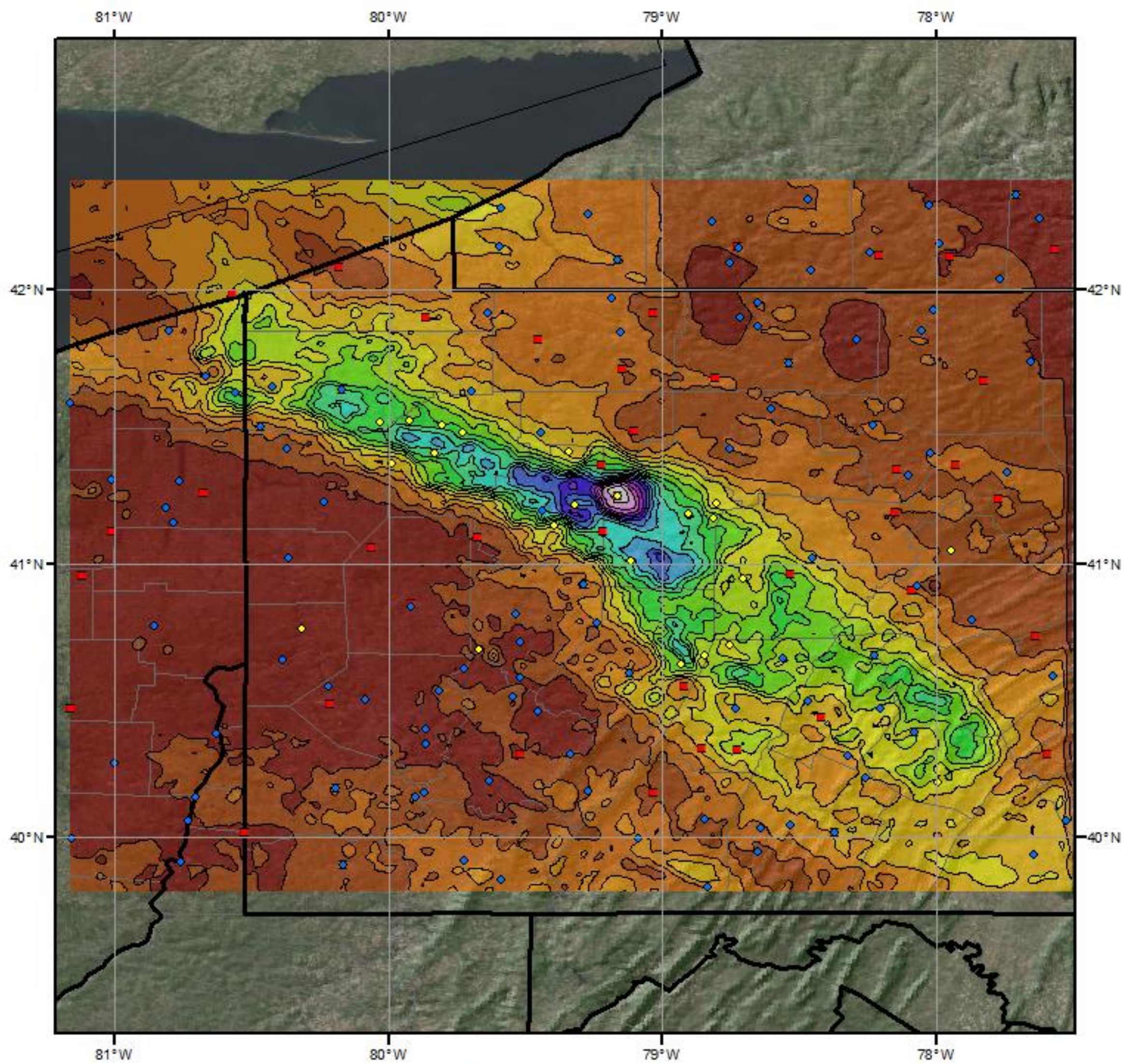
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1548_1	-79.1550	41.2550	1,737	15-Jul	74.00	2.73	0.40	70	2.330	78.60	3.37	0.47	79	2.900	1.245

Storm 1548 - July 19 (0600 UTC) - July 19 (1700 UTC), 1996									
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)									
Area (mi^2)	Duration (hours)								
	1	2	3	4	5	6	8	12	Total
0.4	2.86	4.89	7.12	8.58	9.01	9.40	9.40	9.41	9.41
1	2.83	4.85	7.05	8.51	8.94	9.33	9.33	9.35	9.35
10	2.75	4.76	6.84	8.35	8.78	9.17	9.17	9.18	9.18
25	2.66	4.61	6.64	8.16	8.57	8.96	8.98	8.99	8.99
50	2.54	4.35	6.32	7.78	8.21	8.59	8.64	8.67	8.67
100	2.40	3.89	5.59	6.90	7.43	7.77	7.86	7.97	7.97
200	2.21	3.43	4.77	5.97	6.51	6.83	6.97	7.22	7.22
300	2.07	3.16	4.37	5.49	6.04	6.34	6.52	6.81	6.81
400	1.95	2.96	4.11	5.17	5.72	6.01	6.21	6.52	6.52
500	1.84	2.86	3.93	4.96	5.49	5.77	5.99	6.29	6.29
1,000	1.54	2.61	3.42	4.37	4.85	5.08	5.28	5.60	5.60
2,000	1.26	2.26	2.90	3.71	4.13	4.33	4.50	4.85	4.85
5,000	0.87	1.63	2.17	2.67	3.05	3.26	3.42	3.82	3.82
10,000	0.62	1.13	1.55	1.94	2.24	2.43	2.60	2.97	2.97
20,000	0.40	0.76	1.06	1.27	1.48	1.66	1.82	2.08	2.08
34,275	0.26	0.49	0.70	0.86	1.03	1.16	1.25	1.41	1.41




SPAS 1548 Storm Center Mass Curve Zone 1
July 19 (0600UTC) to July 19 (1700UTC), 1996
Lat: 41.255 Lon: -79.155
Incremental
Accumulated
9.42
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour



Total Storm (12-hr) Precipitation (inches)
07/19/1996 0505 UTC - 07/19/1996 1700 UTC
SPAS-NEXRAD #1548

Gauges

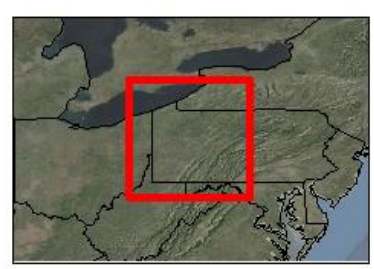
- Daily
- Hourly
- Hourly Estimated Pseudo
- Hourly Pseudo
- Supplemental

Miles: 0, 15, 30, 60

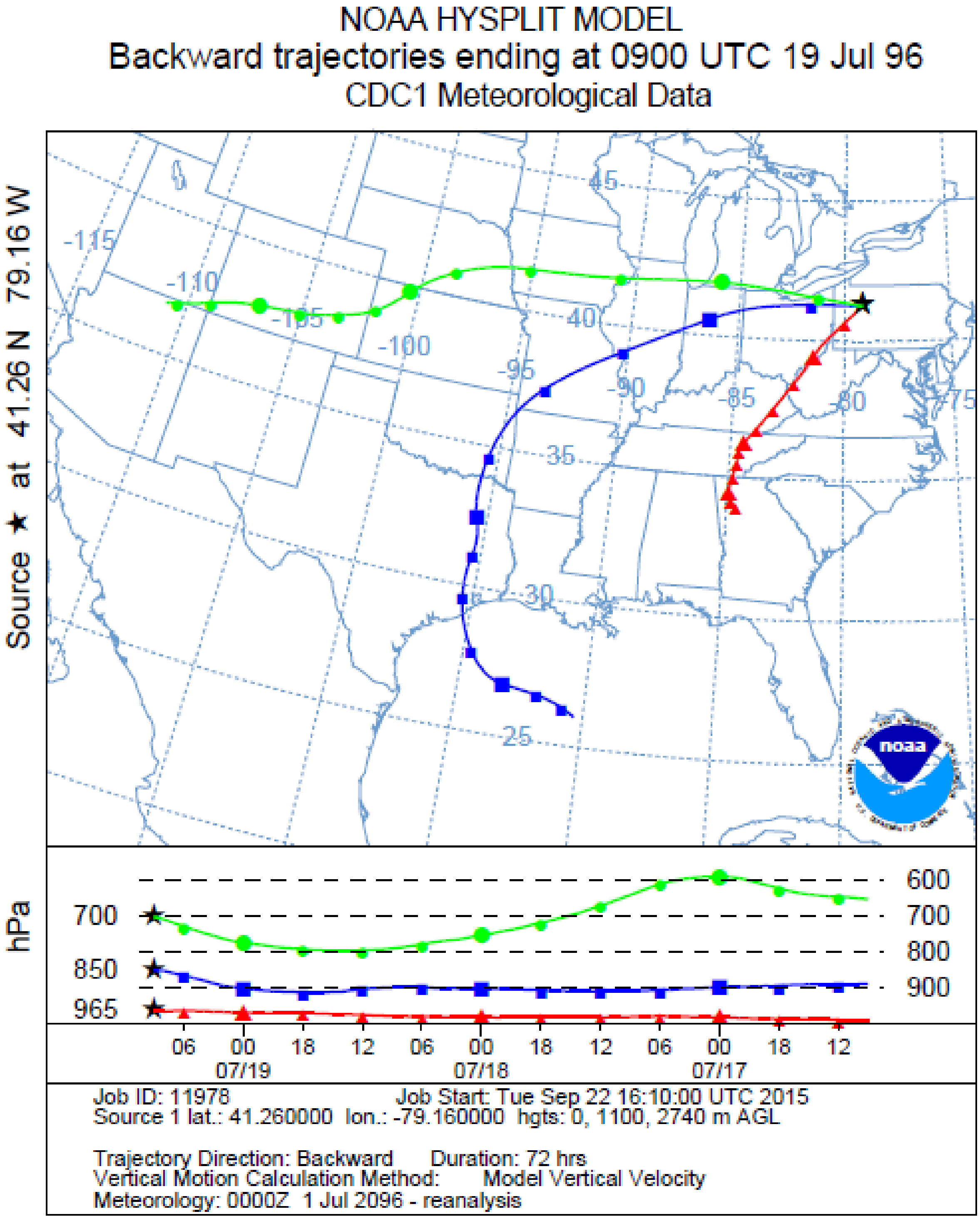
Kilometers: 0, 40, 80, 160

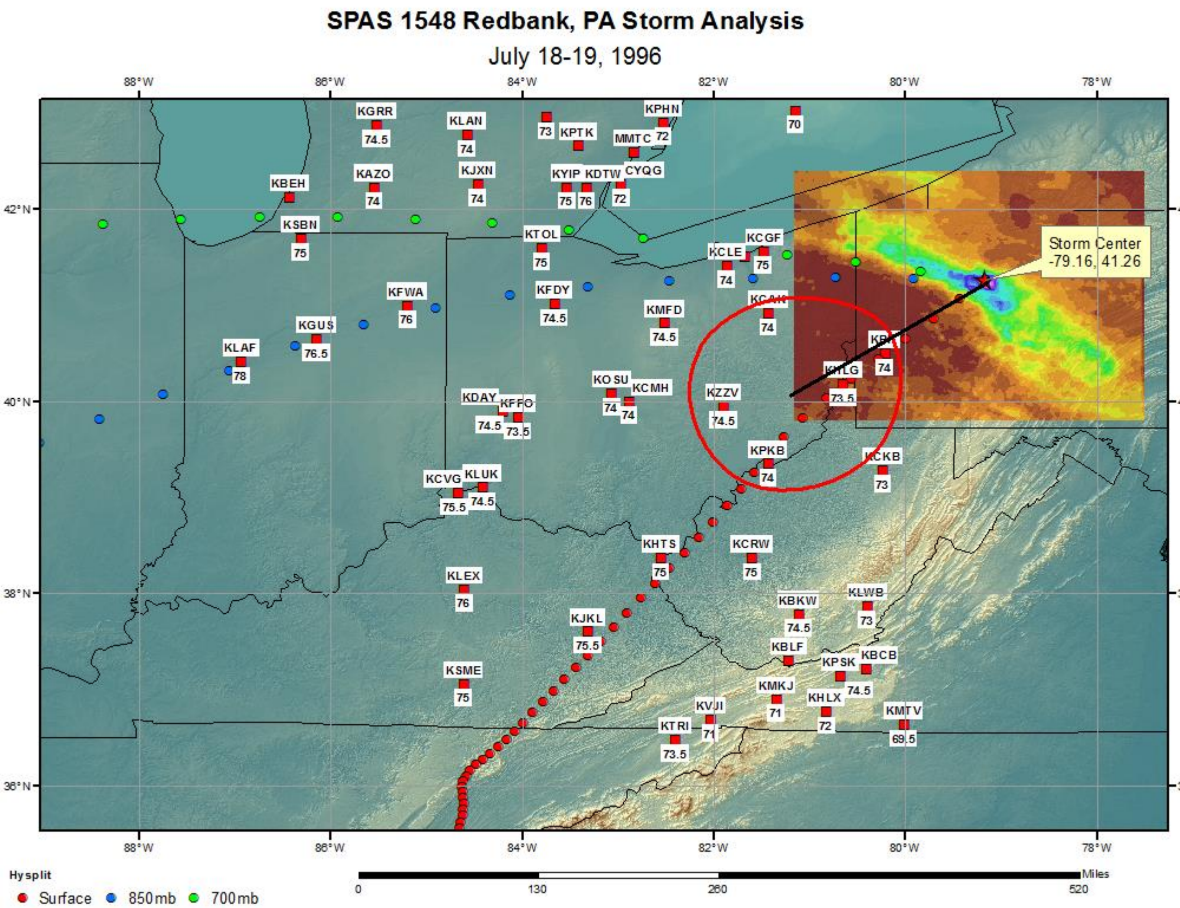
Precipitation (inches)

0.00 - 0.50; 0.51 - 1.00; 1.01 - 1.50; 1.51 - 2.00; 2.01 - 2.50; 2.51 - 3.00; 3.01 - 3.50; 3.51 - 4.00; 4.01 - 4.50; 4.51 - 5.00; 5.01 - 5.50; 5.51 - 6.00; 6.01 - 6.50; 6.51 - 7.00; 7.01 - 7.50; 7.51 - 8.00; 8.01 - 8.50; 8.51 - 9.00; 9.01 - 9.50



9/21/2015


NOAA HYSPLIT MODEL
Backward trajectories ending at 0900 UTC 19 Jul 96
CDC1 Meteorological Data
Source ★ at 41.26 N 79.16 W
hPa
700
850
965
600
700
800
900
06 00 18 12 06 00 18 12 06 00 18 12
07/19 07/18 07/17
Job ID: 11978 Job Start: Tue Sep 22 16:10:00 UTC 2015
Source 1 lat.: 41.260000 lon.: -79.160000 hgts: 0, 1100, 2740 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2096 - reanalysis


SPAS 1548 Redbank, PA Storm Analysis
July 18-19, 1996
Storm Center
-79.16, 41.26
Hysplit
Surface 850mb 700mb
0 130 260 520 Miles

Storm Precipitation Analysis System (SPAS) For Storm #1674_1 SPAS-NEXRAD Analysis

General Storm Location: Jefferson Township, NJ

Storm Dates: August 11-14, 2000

Event: General

DAD Zone 1

Latitude: 41.0

Longitude: -74.6

Max. Grid Rainfall Amount: 19.32”

Max. Observed Rainfall Amount: 18.648”

Number of Stations: 206

SPAS Version: 10

Basemap: 85/15 weighted Radar vs. Basemap

Spatial resolution: 00:00:36

Radar Included: Yes

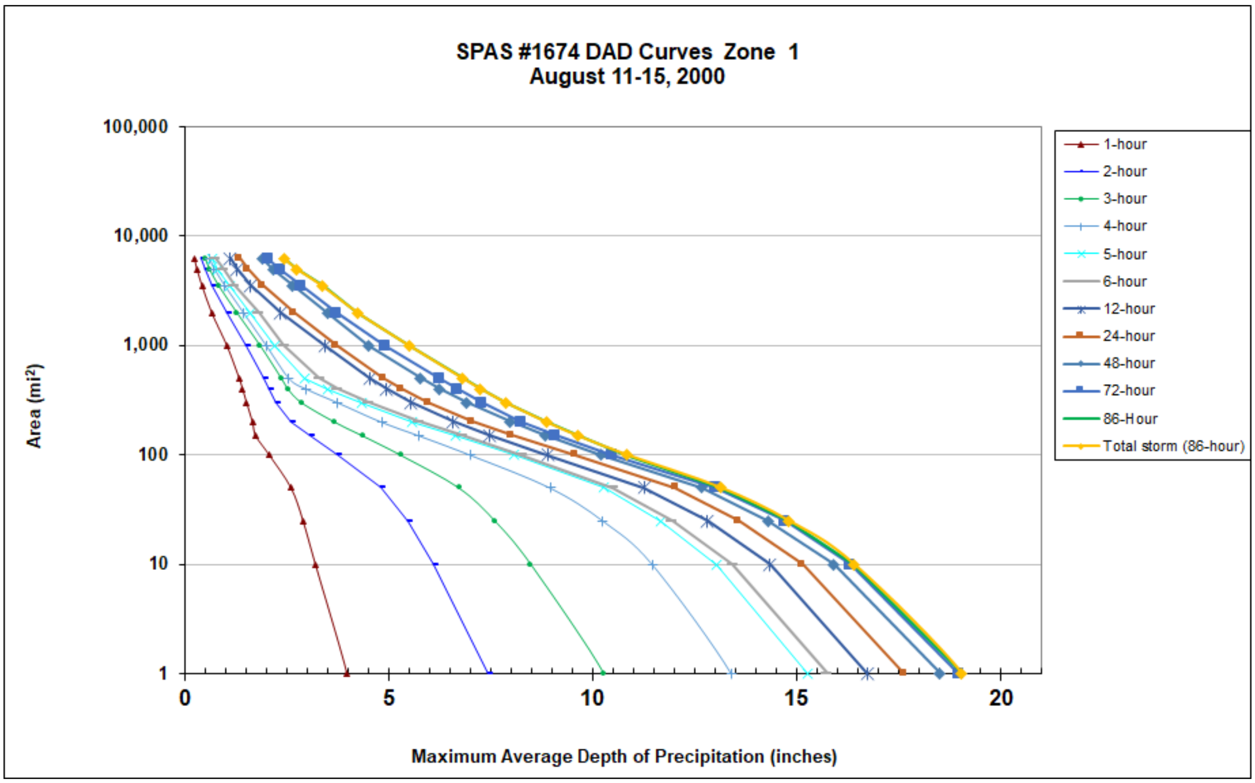
Radar Beam-Blockage shapefile created: Yes

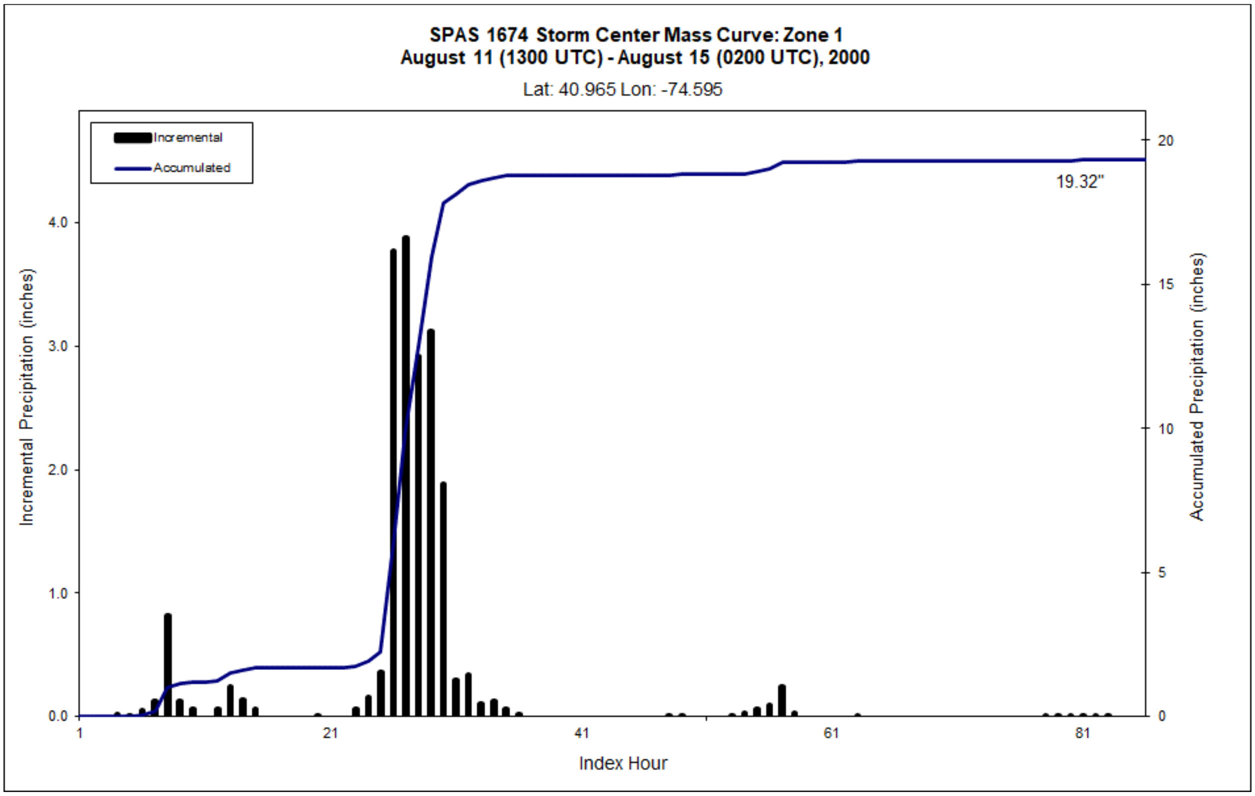
Depth-Area-Duration (DAD) analysis: Yes

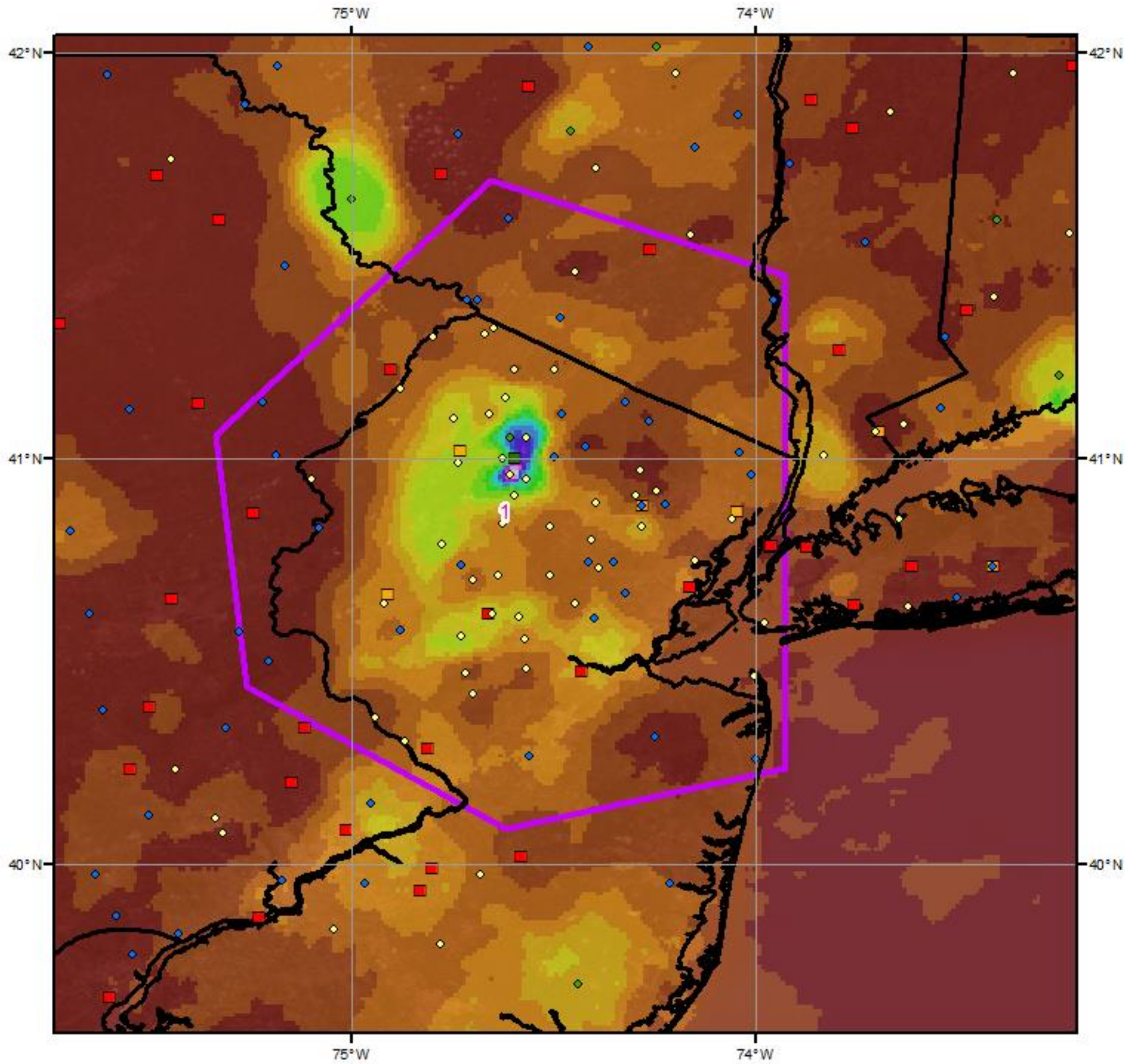
Reliability of results: This analysis was based on 206 hourly stations, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the basemap and gauge stations. Timing is based on hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1674_1	-74.6400	41.0300	796	800	15-Aug	68.00	2.05	0.16	58	1.890	77.07	77.0	3.14	0.21	76	2.930	1.500

Storm 1674 - August 11 (1300 UTC) - August 15 (0200 UTC), 2000												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
Area (mi^2)	Duration (hours)											
	1	2	3	4	5	6	12	24	48	72	86	Total
0.4	4.13	7.63	10.54	13.66	15.55	15.91	16.99	17.91	18.77	19.24	19.30	19.30
1	3.97	7.45	10.28	13.40	15.28	15.75	16.73	17.63	18.51	18.97	19.04	19.04
10	3.20	6.11	8.49	11.46	13.04	13.43	14.34	15.15	15.92	16.32	16.40	16.40
25	2.90	5.47	7.61	10.25	11.69	11.95	12.82	13.59	14.30	14.72	14.80	14.80
50	2.61	4.80	6.73	8.96	10.27	10.50	11.27	12.03	12.68	13.02	13.14	13.14
100	2.08	3.75	5.30	7.00	8.08	8.27	8.90	9.59	10.21	10.48	10.84	10.84
150	1.75	3.08	4.37	5.75	6.63	6.81	7.47	8.02	8.83	9.08	9.63	9.63
200	1.67	2.60	3.69	4.83	5.57	5.75	6.59	7.06	7.98	8.23	8.86	8.86
300	1.53	2.26	2.88	3.76	4.36	4.52	5.55	5.97	6.92	7.29	7.87	7.87
400	1.43	2.09	2.54	2.99	3.50	3.75	4.95	5.32	6.25	6.68	7.26	7.26
500	1.35	1.95	2.38	2.56	2.95	3.30	4.53	4.87	5.79	6.24	6.82	6.82
1,000	1.05	1.52	1.86	2.00	2.21	2.44	3.44	3.72	4.50	4.90	5.50	5.50
2,000	0.68	1.04	1.29	1.44	1.63	1.82	2.35	2.69	3.51	3.72	4.24	4.24
3,500	0.45	0.69	0.85	0.99	1.12	1.23	1.63	1.92	2.66	2.86	3.38	3.38
5,000	0.32	0.50	0.62	0.73	0.83	0.95	1.29	1.56	2.17	2.33	2.76	2.76
6,280	0.26	0.40	0.51	0.60	0.69	0.76	1.12	1.36	1.91	2.04	2.43	2.43




SPAS 1674 Storm Center Mass Curve: Zone 1
August 11 (1300 UTC) - August 15 (0200 UTC), 2000
Lat: 40.965 Lon: -74.595
Incremental
Accumulated
19.32"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
1.0
2.0
3.0
4.0
0
5
10
15
20
1
21
41
61
81



Total Storm (86-hours) Precipitation (inches)
8/11/2000 1300Z - 8/15/2000 0200Z
SPAS-NEXRAD 1674 - Jefferson Township, NJ

Gauges

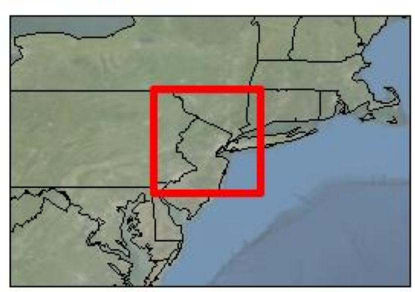
- Daily
- Hourly
- HEP
- Hourly Pseudo
- Supplemental
- SE

Miles: 0 10 20 40

Kilometers: 0 20 40 80

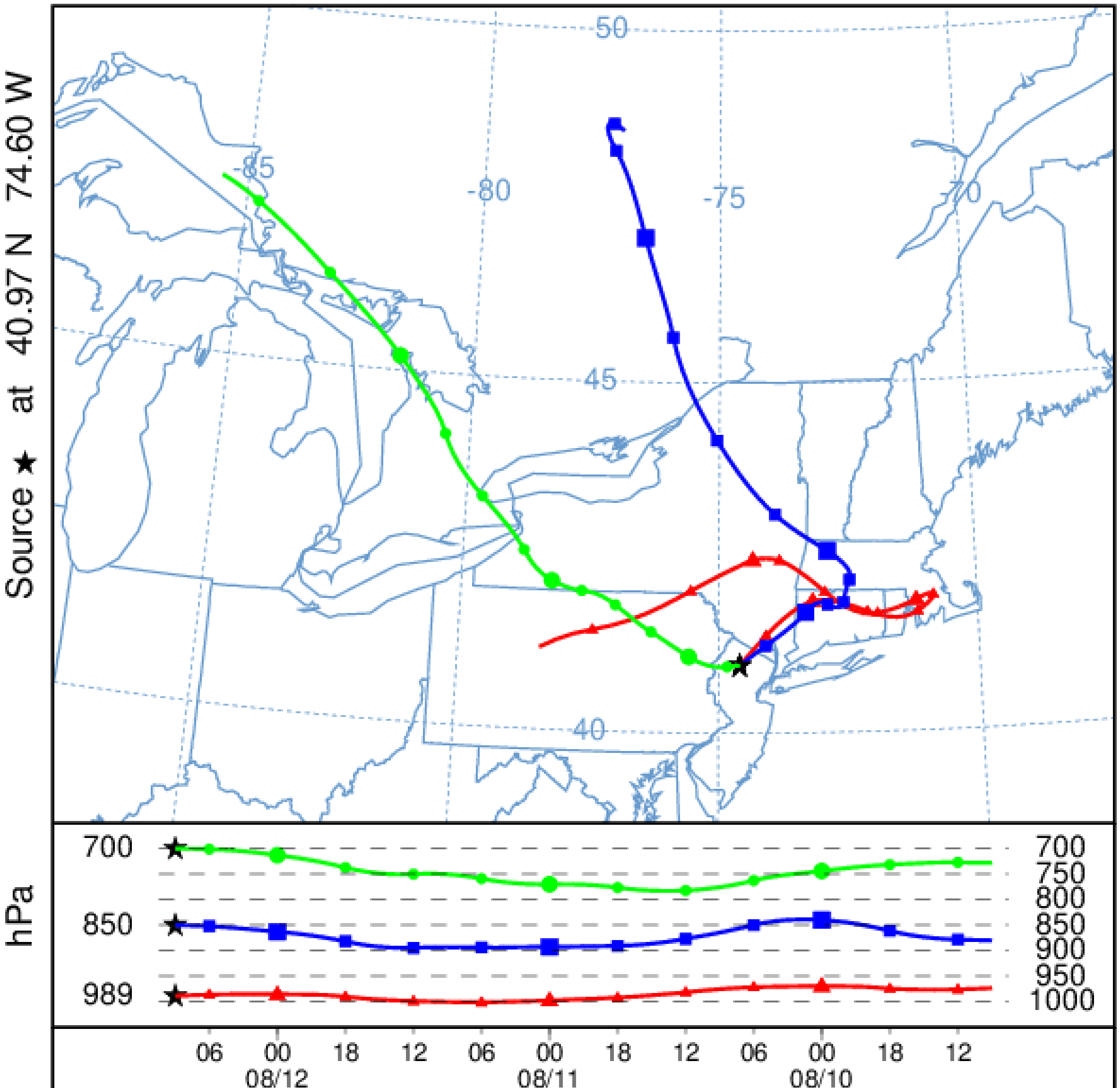
Precipitation (inches)

0.00 - 1.00	5.01 - 6.00	10.01 - 11.00	15.01 - 16.00
1.01 - 2.00	6.01 - 7.00	11.01 - 12.00	16.01 - 17.00
2.01 - 3.00	7.01 - 8.00	12.01 - 13.00	17.01 - 18.00
3.01 - 4.00	8.01 - 9.00	13.01 - 14.00	18.01 - 19.00
4.01 - 5.00	9.01 - 10.00	14.01 - 15.00	19.01 - 20.00



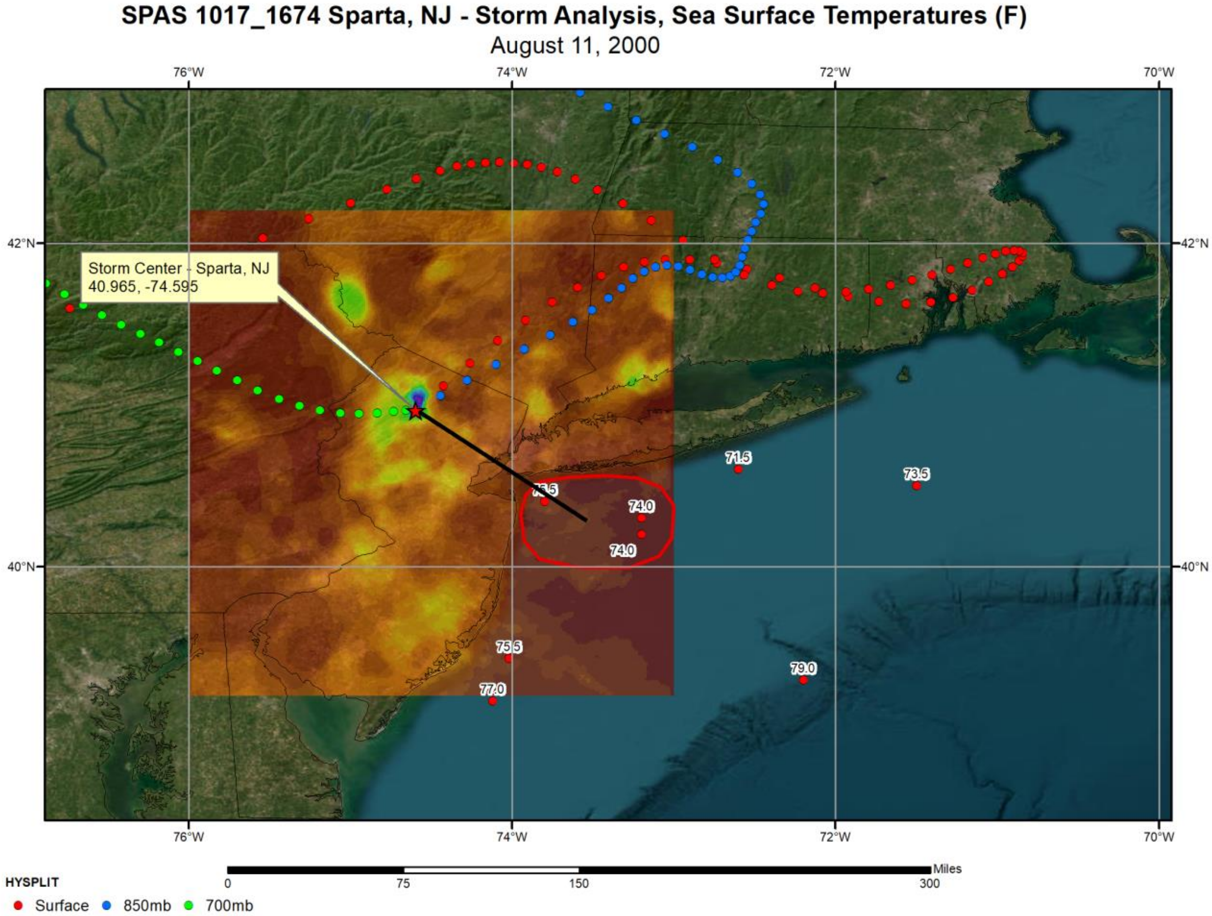
10/20/2022

NOAA HYSPLIT MODEL
Backward trajectories ending at 0900 UTC 12 Aug 00
CDC1 Meteorological Data



Job ID: 197479 Job Start: Sun May 5 21:14:55 UTC 2024
Source 1 lat.: 40.965 lon.: -74.595 hgts: 0, 1290, 2890 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Aug 2000 - reanalysis


SPAS 1017_1674 Sparta, NJ - Storm Analysis, Sea Surface Temperatures (F)
August 11, 2000
76°W
74°W
72°W
70°W
42°N
40°N
Storm Center - Sparta, NJ
40.965, -74.595
71.5
73.5
74.0
74.0
75.5
77.0
79.0
Miles
0
75
150
300
HYSPLIT
Surface
850mb
700mb

Storm Precipitation Analysis System (SPAS) For Storm #1040_1 SPAS-NEXRAD Analysis

General Storm Location: Tabernacle, NJ

Storm Dates: 7/12/2004 0600Z – 7/13/2004 0800Z

Event: Convective Thunderstorm

DAD Zone 1

Latitude: 39.88

Longitude: -74.69

Rainfall Amount: 15.63” (Grid/Pixel Point)

Number of Stations: 319 (131-hourly, 2-hourly pseudo, 118-daily, and 68-supplemental) gauging stations within the defined search domain.

SPAS Version: 3.0

Base Map Used: No

Spatial resolution: 0.005944 decimal degrees (21.386139 seconds)

Radar Included: Yes

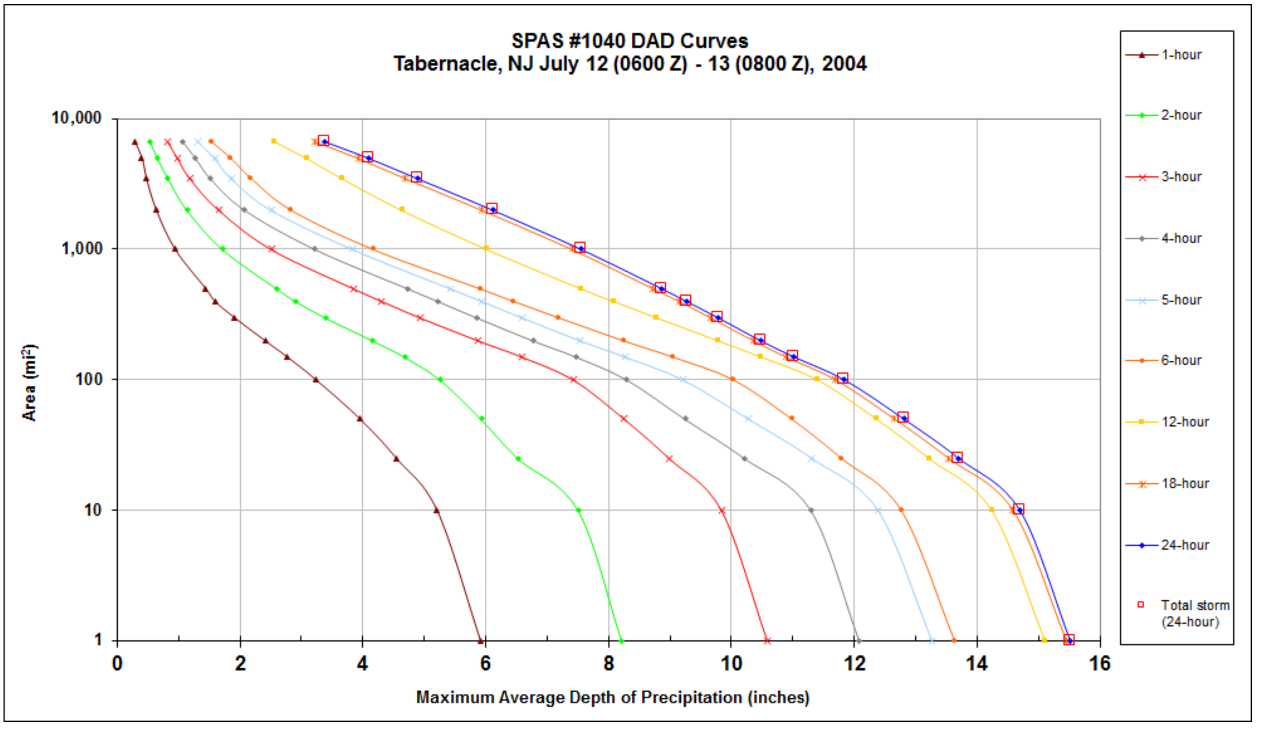
Depth-Area-Duration (DAD) analysis: Yes

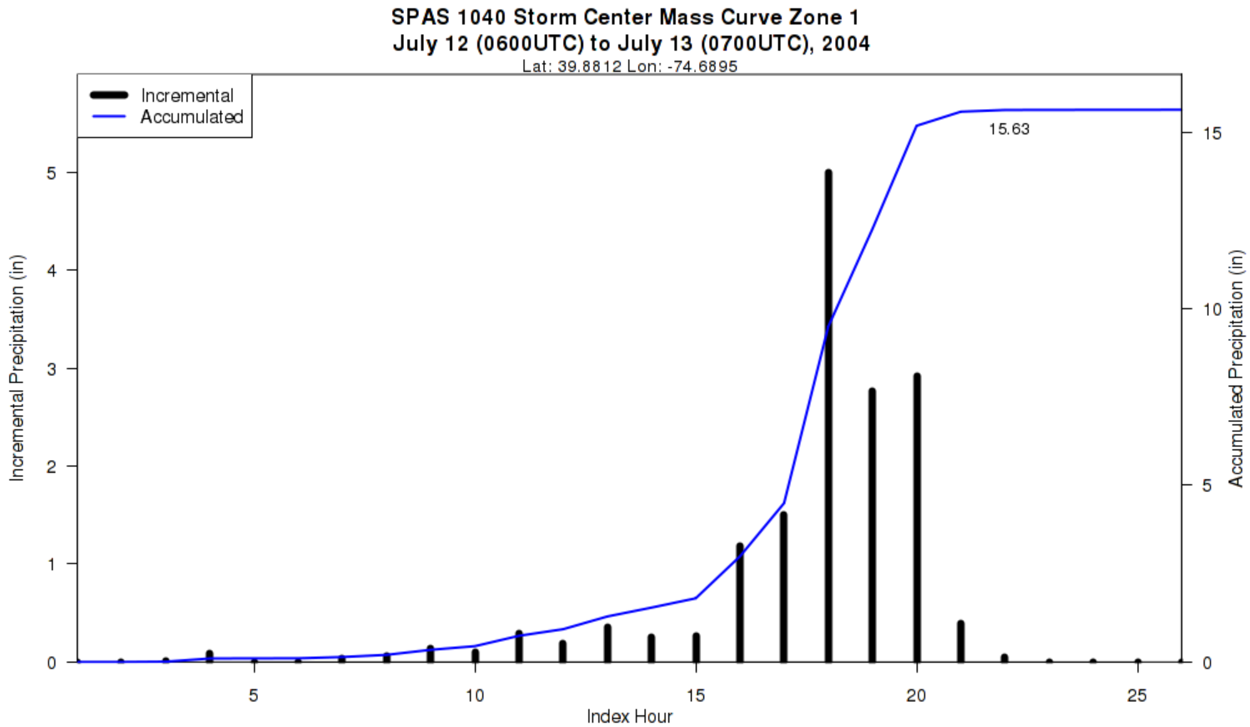
						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1040_1	-74.6895	39.8812	61	30-Jul	74.00	2.73	0.03	70	2.700	79.65	3.52	0.03	81	3.490	1.293

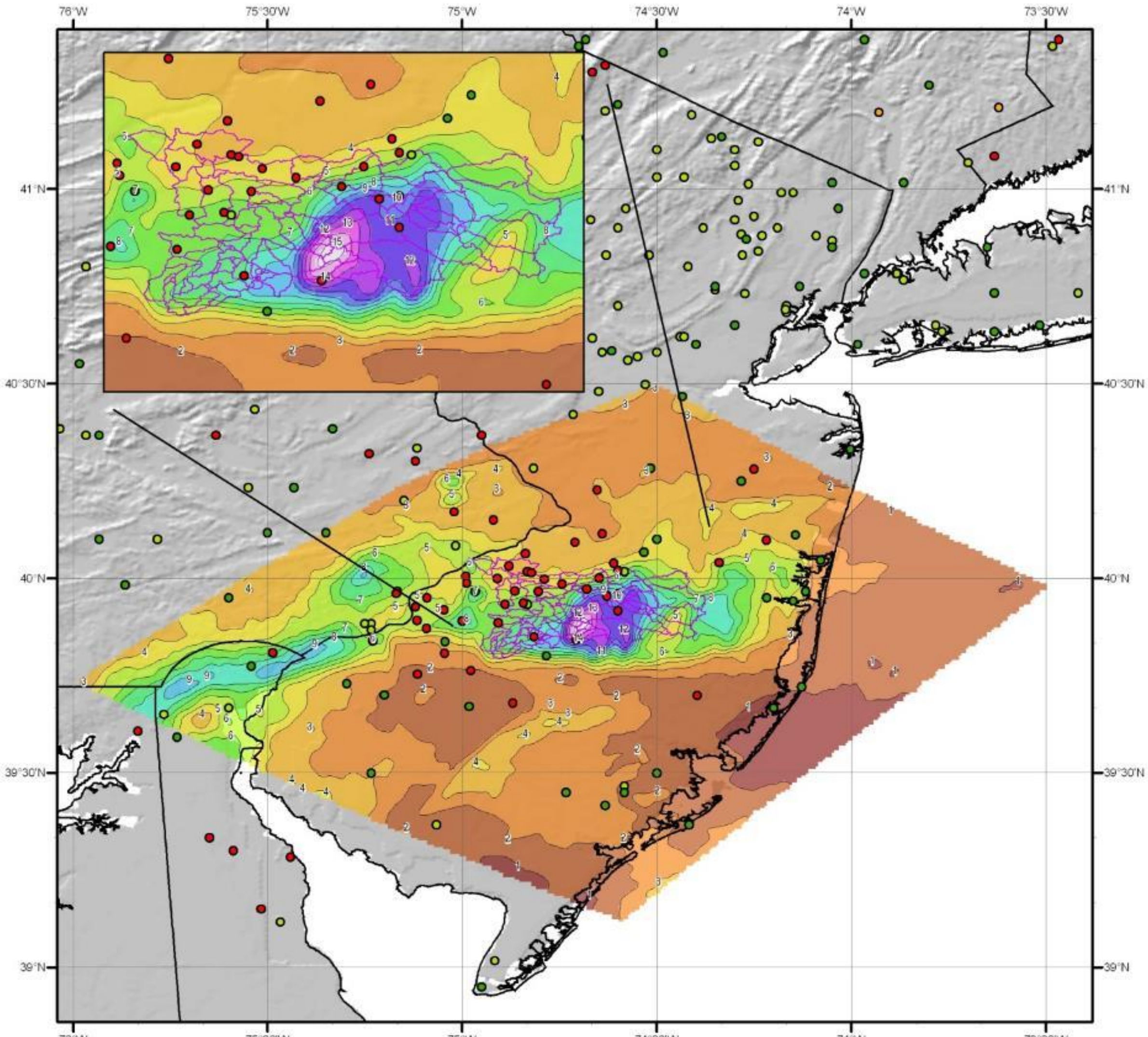
July 12-13, 2004 Storm

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

	Duration (hours)									
Area (mi^2)	1	2	3	4	5	6	12	18	24	total
1	5.9	8.2	10.6	12.1	13.3	13.6	15.1	15.5	15.5	15.51
10	5.2	7.5	9.8	11.3	12.4	12.8	14.2	14.6	14.7	14.69
25	4.6	6.5	9.0	10.2	11.3	11.8	13.2	13.5	13.7	13.70
50	4.0	5.9	8.3	9.3	10.3	11.0	12.4	12.7	12.8	12.81
100	3.2	5.3	7.4	8.3	9.2	10.0	11.4	11.7	11.8	11.84
150	2.8	4.7	6.6	7.5	8.3	9.1	10.5	10.9	11.0	11.02
200	2.4	4.2	5.9	6.8	7.5	8.3	9.8	10.4	10.5	10.48
300	1.9	3.4	4.9	5.9	6.6	7.2	8.8	9.7	9.8	9.78
400	1.6	2.9	4.3	5.2	5.9	6.5	8.1	9.2	9.3	9.27
500	1.4	2.6	3.9	4.7	5.4	5.9	7.6	8.7	8.9	8.87
1,000	0.9	1.7	2.5	3.2	3.8	4.2	6.0	7.4	7.6	7.56
2,000	0.6	1.1	1.7	2.1	2.5	2.8	4.6	5.9	6.1	6.12
3,500	0.5	0.8	1.2	1.5	1.9	2.2	3.7	4.7	4.9	4.89
5,000	0.4	0.7	1.0	1.3	1.6	1.9	3.1	3.9	4.1	4.10
6,721	0.3	0.5	0.8	1.1	1.3	1.5	2.6	3.2	3.4	3.38




SPAS 1040 Storm Center Mass Curve Zone 1
July 12 (0600UTC) to July 13 (0700UTC), 2004
Lat: 39.8812 Lon: -74.6895
Incremental
Accumulated
15.63
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
10
15
20
25

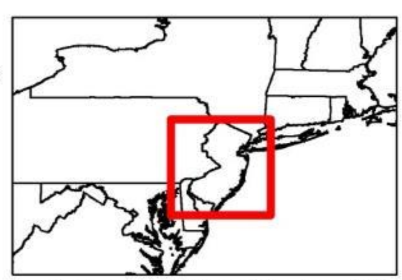


Total Rainfall (26-hours)
Tabernacle, New Jersey Storm
SPAS Storm #1040- July 12 (0600 Z) to 13 (0800 Z), 2004

N

Miles: 0 5 10 20 30

Kilometers: 0 12.5 25 50 75



Legend

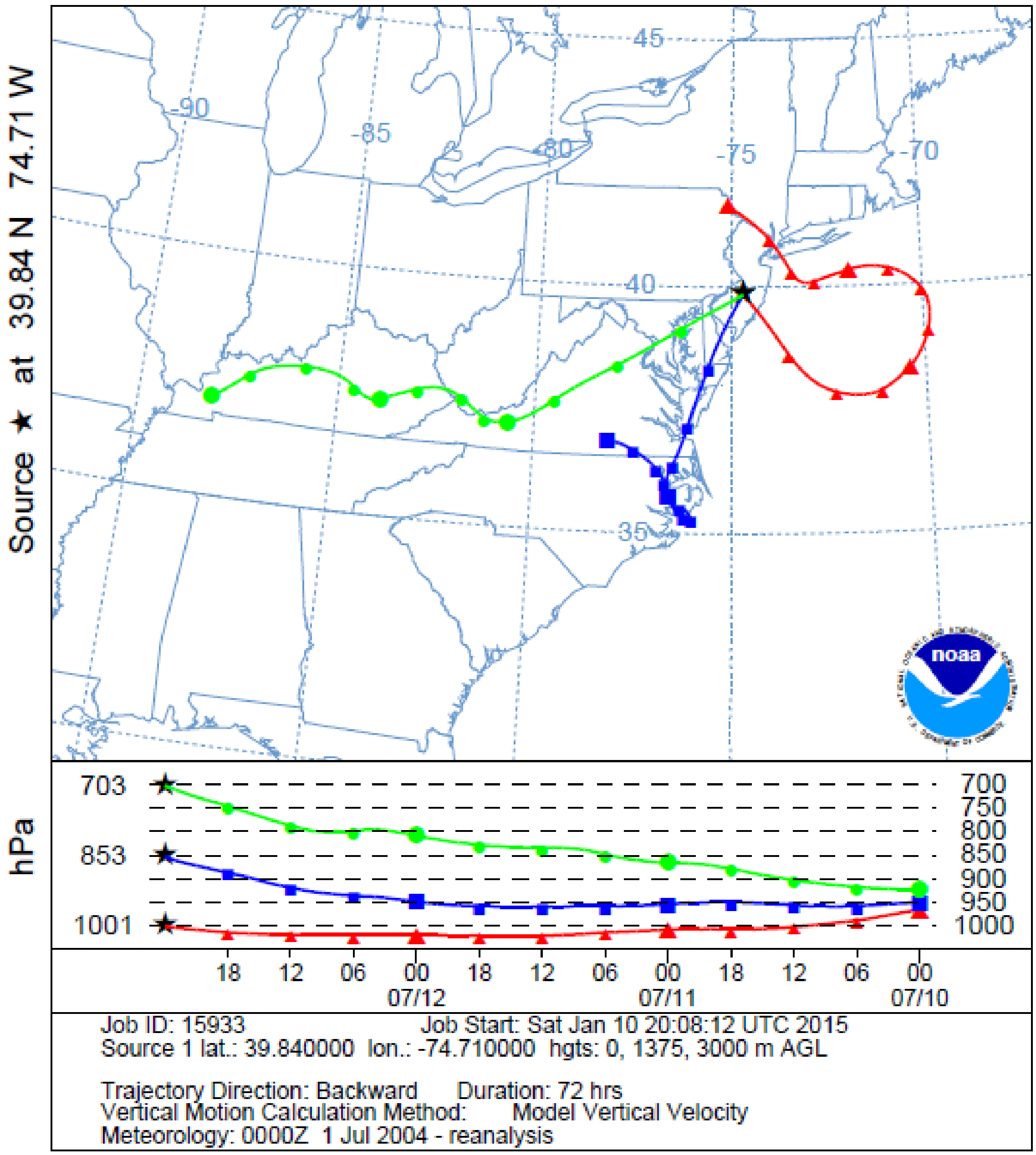
Daily
Supplemental
Hourly
Supplemental estimated

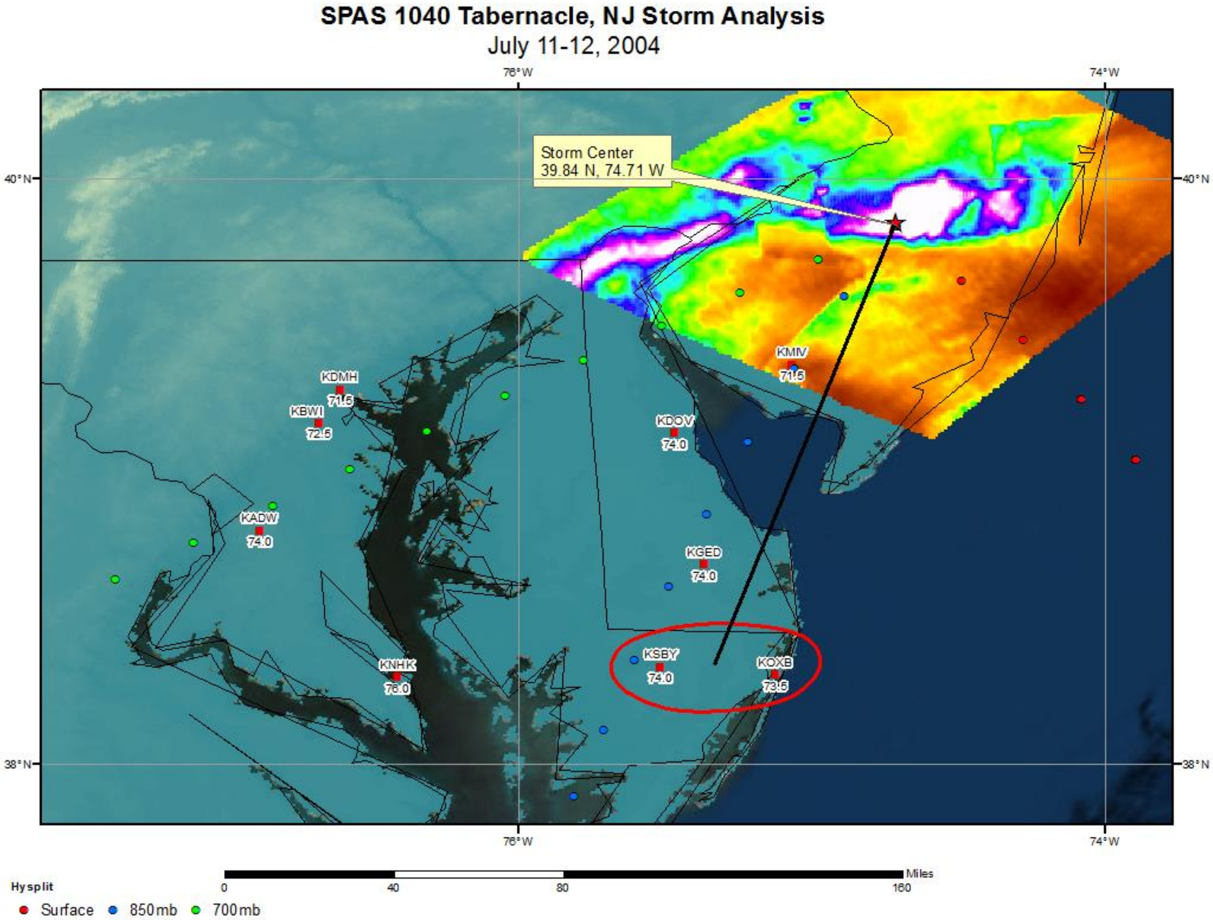
Precipitation (inches)

0.49 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00

Coordinate system: GCS North American 1983
Scale: 1:1,556,659
Metstat/AWA August 13, 2007

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 13 Jul 04
CDC1 Meteorological Data




SPAS 1040 Tabernacle, NJ Storm Analysis
July 11-12, 2004
76°W
74°W
40°N
38°N
Storm Center
39.84 N, 74.71 W
KMIV
71.5
KDMH
71.5
KBWI
72.5
KDOV
74.0
KADW
74.0
KGED
74.0
KSBY
74.0
KOXB
73.5
KNHK
76.0
Hysplit
Surface
850mb
700mb
0
40
80
160
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1049_1 SPAS-NEXRAD Analysis

General Storm Location: Delaware County, NY

Storm Dates: 6/19/2007 1600Z – 6/20/2007 0700Z

Event: Cloudburst Thunderstorm

DAD Zone 1

Latitude: 42.01

Longitude: -74.90

Max. Grid/Radar Rainfall Amount: 11.69” (Grid/Pixel Point)

Max. Observed Rainfall Amount: 11.10” (9.58” grid cell at Bucket Data 6 “Upper Spring Brook”, this station is located at a large precipitation gradient. Bucket Data 7 “Lower Spring Brook” Max. Obs 11.00” 10.38 Grid Cell)

Number of Stations: 65 (17-hourly, 1 hourly pseudo, 29-daily, 18-daily supplemental) gauging stations within the defined search domain.

SPAS Version: 5.0

Base Map Used: No

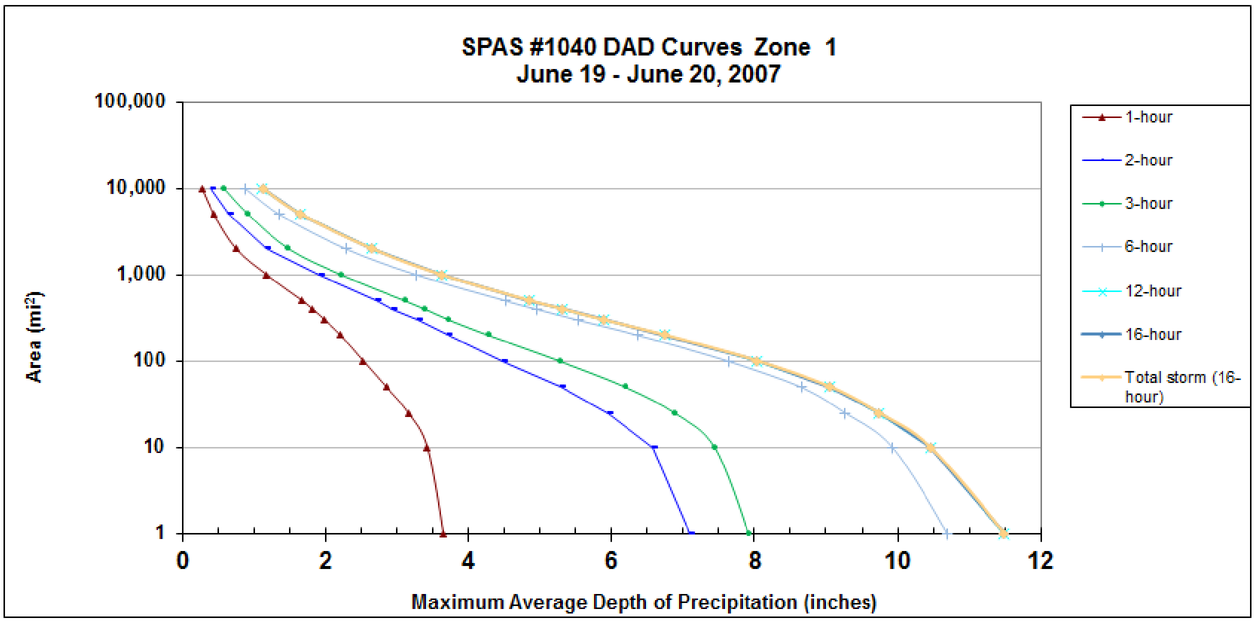
Spatial resolution: 0.36 mi^2

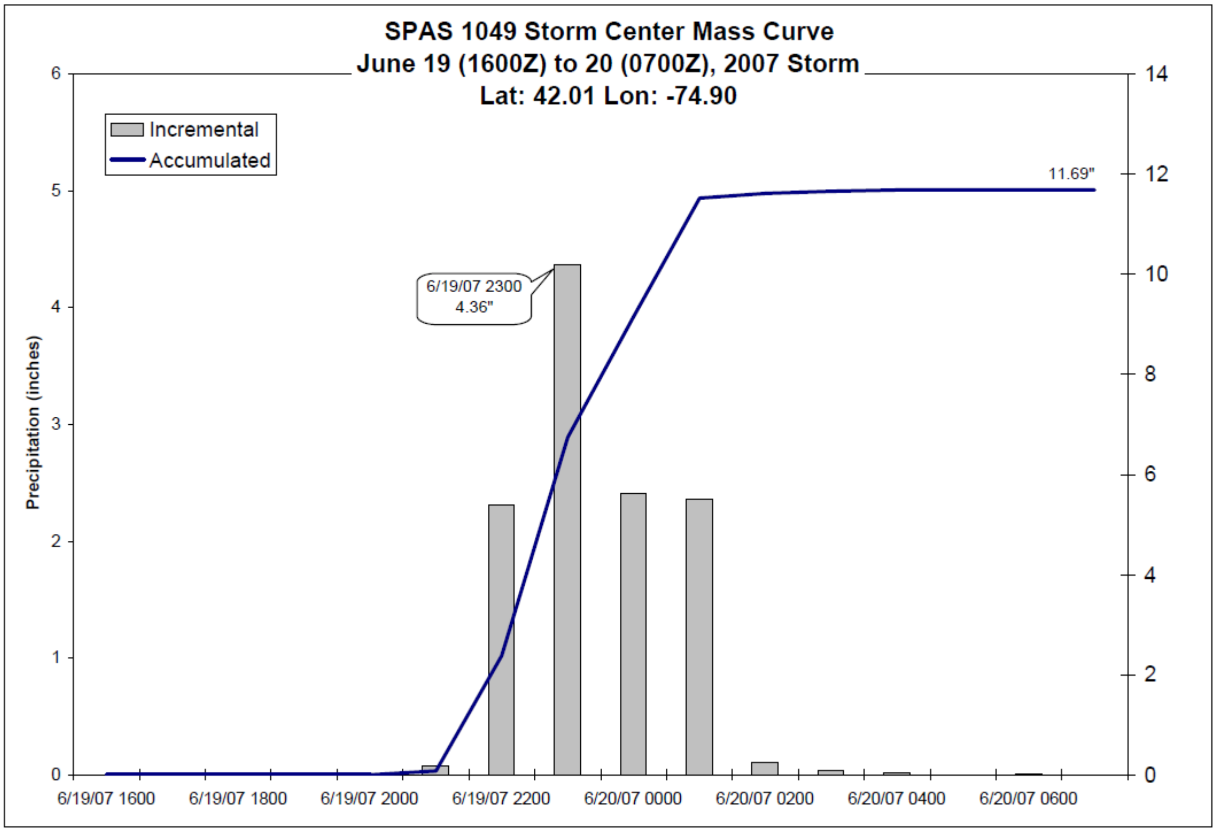
Radar Included: Yes, Weather Decision Technologies (WDT) Level-II radar reflectivity data based on Binghamton, NY (KBGM) NEXRAD.

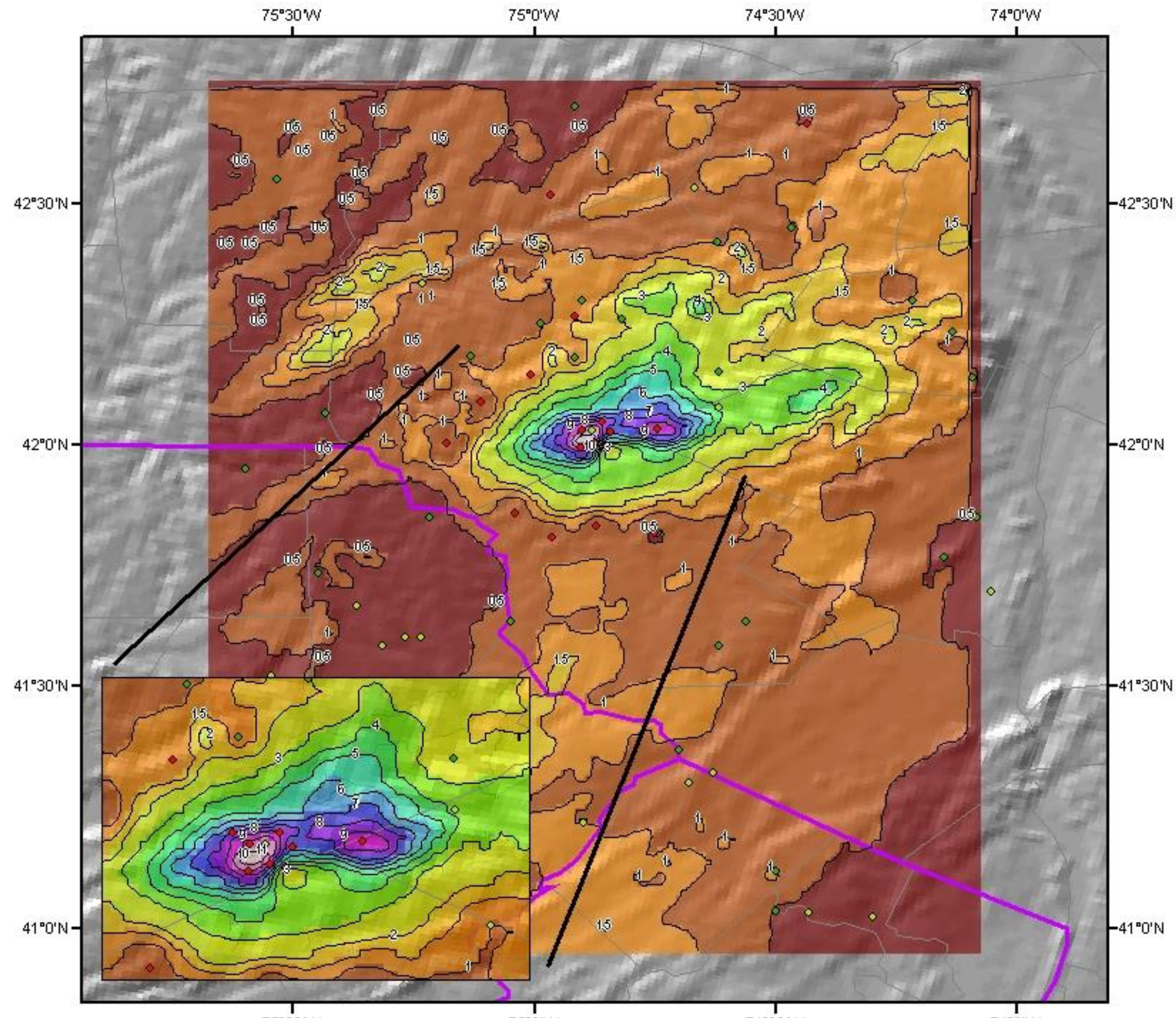
Depth-Area-Duration (DAD) analysis: Yes: 1, 2, 3, 4, 5, 6, 12, & 16 hours

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1049_1	-74.9000	42.0100	2,157	1-Jul	71.00	2.36	0.46	64	1.900	77.34	3.22	0.57	77	2.645	1.392

Storm 1049 - June 19 (1700 UTC) - June 20 (0800 UTC), 2007							
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)							
Area (mi^2)	Duration (hours)						
	1	2	3	6	12	16	Total
0.4	3.67	7.19	8.00	10.82	11.69	11.69	11.69
1	3.63	7.10	7.92	10.69	11.49	11.49	11.49
10	3.41	6.57	7.45	9.93	10.46	10.46	10.46
25	3.15	5.94	6.89	9.27	9.74	9.74	9.74
50	2.84	5.28	6.20	8.65	9.06	9.06	9.06
100	2.52	4.48	5.28	7.63	8.04	8.04	8.04
200	2.20	3.70	4.28	6.37	6.74	6.74	6.74
300	1.98	3.28	3.73	5.53	5.88	5.88	5.88
400	1.81	2.94	3.39	4.95	5.31	5.31	5.31
500	1.67	2.71	3.11	4.52	4.85	4.85	4.85
1,000	1.17	1.91	2.22	3.27	3.61	3.61	3.61
2,000	0.74	1.17	1.48	2.28	2.63	2.64	2.64
5,000	0.43	0.63	0.91	1.35	1.64	1.65	1.65
10,000	0.26	0.39	0.57	0.86	1.09	1.11	1.11




SPAS 1049 Storm Center Mass Curve
June 19 (1600Z) to 20 (0700Z), 2007 Storm
Lat: 42.01 Lon: -74.90
Incremental
Accumulated
Precipitation (inches)
6/19/07 2300
4.36"
11.69"
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
6/19/07 1600
6/19/07 1800
6/19/07 2000
6/19/07 2200
6/20/07 0000
6/20/07 0200
6/20/07 0400
6/20/07 0600



Total Rainfall (16-hours)
Delaware County, NY 2007 Storm
Storm #1049 June 19 (1600 Z) to 20 (0700 Z), 2007

Miles: 0 5 10 20 30
Kilometers: 0 12.5 25 50 75

Gauging Stations

Daily · Hourly · Hourly Pseudo · Supplemental

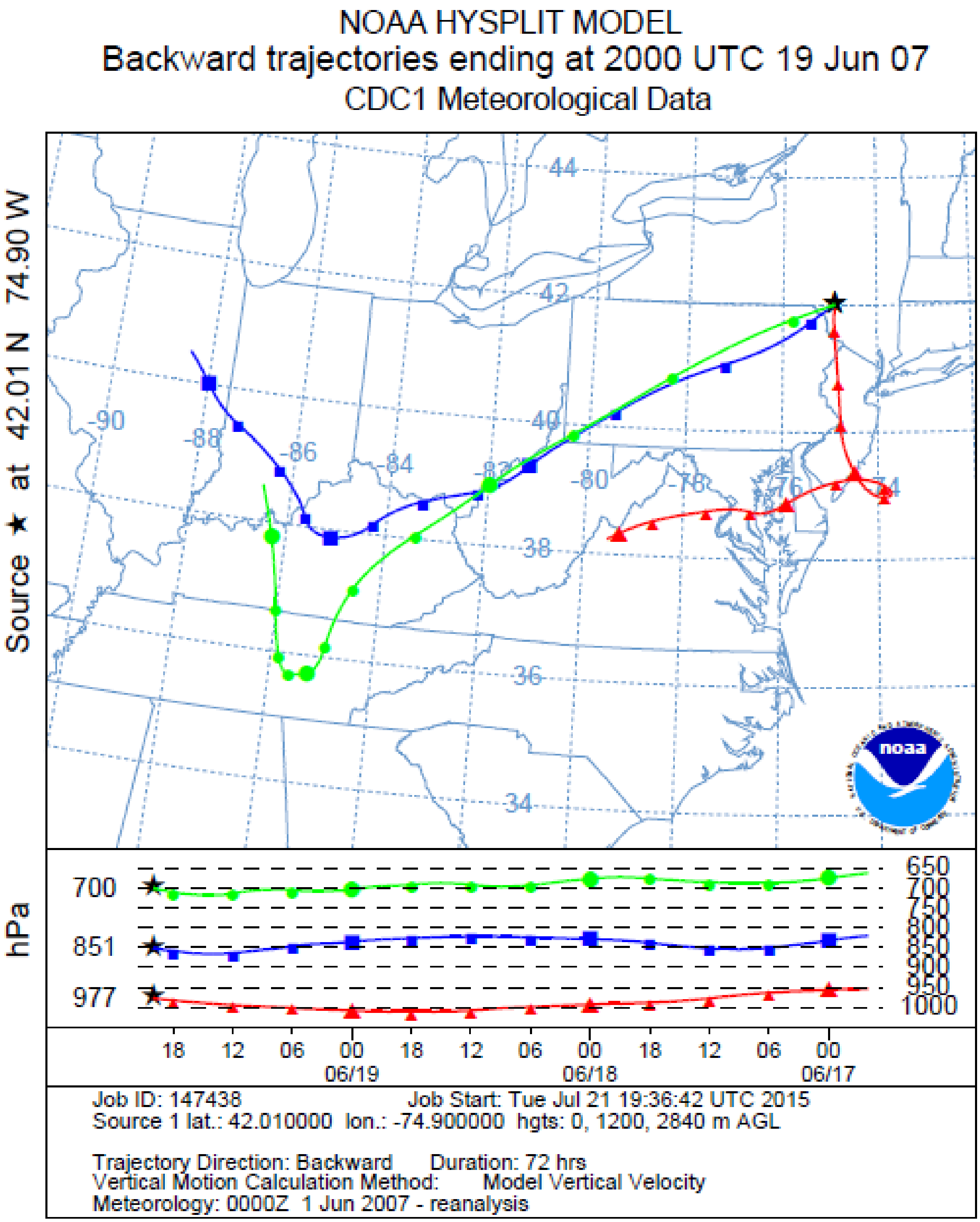
Precipitation (inches)

0.03 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00

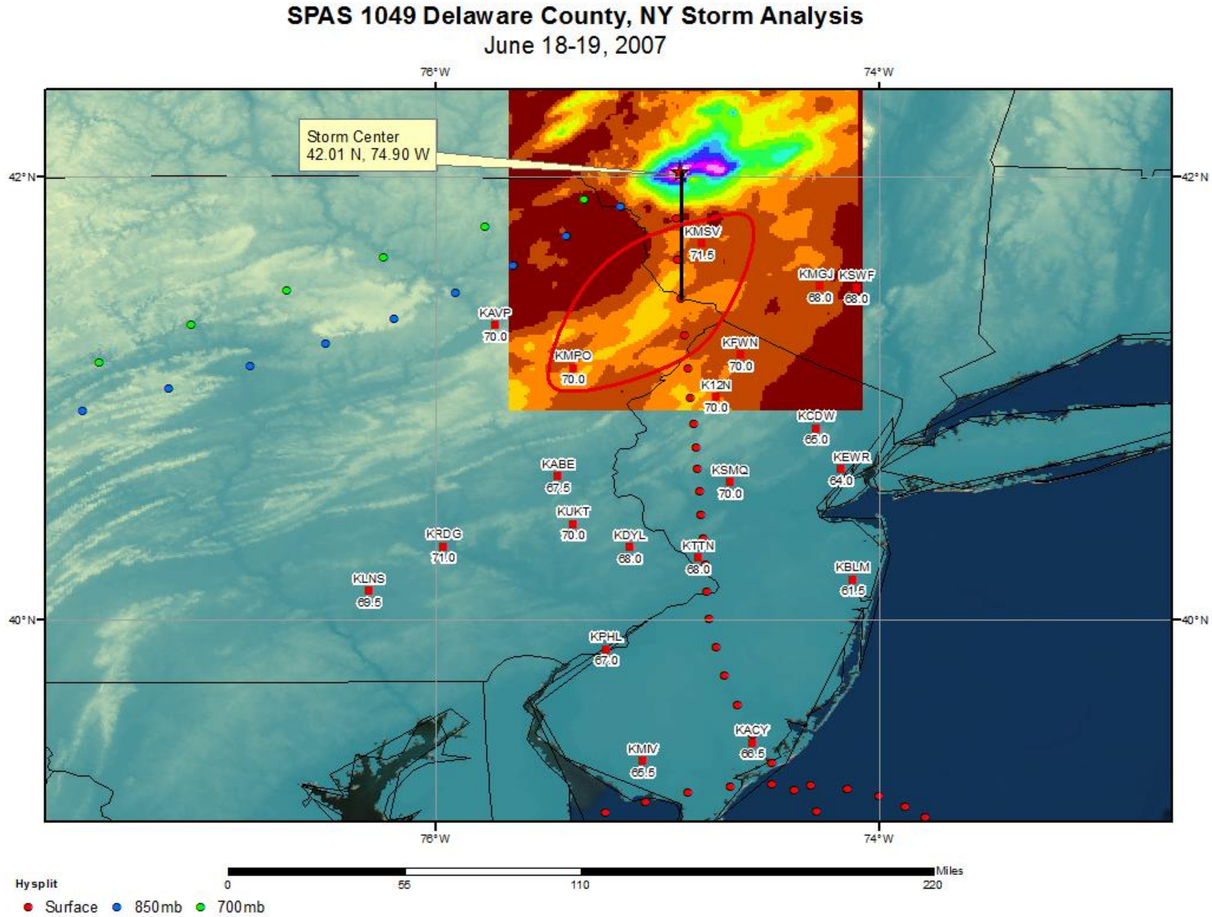
N

Coordinate system: GCS North American 1983
Scale: 1:1,290,388

MetStat/AWA May 5, 2008



NOAA HYSPLIT MODEL
Backward trajectories ending at 2000 UTC 19 Jun 07
CDC1 Meteorological Data
Source ★ at 42.01 N 74.90 W
44
42
40
38
36
34
-90
-88
-86
-84
-82
-80
-78
-76
-74
hPa
700
851
977
650
700
750
800
850
900
950
1000
18
12
06
00
18
12
06
00
18
12
06
00
06/19
06/18
06/17
Job ID: 147438
Job Start: Tue Jul 21 19:36:42 UTC 2015
Source 1 lat.: 42.010000 lon.: -74.900000 hgts: 0, 1200, 2840 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2007 - reanalysis


SPAS 1049 Delaware County, NY Storm Analysis
June 18-19, 2007
Storm Center
42.01 N, 74.90 W
76°W
74°W
42°N
40°N
KMSV
71.5
KMGJ
68.0
KSWF
68.0
KAVP
70.0
KFWN
70.0
KMPO
70.0
K12N
70.0
KCDW
65.0
KEWR
64.0
KABE
67.5
KSMQ
70.0
KUKT
70.0
KRDG
71.0
KDYL
68.0
KTTN
68.0
KBLM
61.5
KLNS
69.5
KPHL
67.0
KACY
66.5
KMIV
65.5
Miles
0
55
110
220
Hysplit
Surface
850mb
700mb

Storm Precipitation Analysis System (SPAS) For Storm #1415_1
SPAS-NEXRAD Analysis

General Storm Location: Islip, NY

Storm Dates: August 13, 2014

Event: Convective

DAD Zone 1

Latitude: 40.805

Longitude: -73.065

Max. Grid Rainfall Amount: 14.23"

Max. Observed Rainfall Amount: 13.51"

Number of Stations: 253 (96 Daily, 97 Hourly, 11 Hourly Pseudo, 49 Supplemental, and 0 Supplemental Estimated)

SPAS Version: 9.5/10.0

Basemap: Default ZR Radar Estimated Rainfall

Spatial resolution: 0.01 (~ 0.40 mi^2)

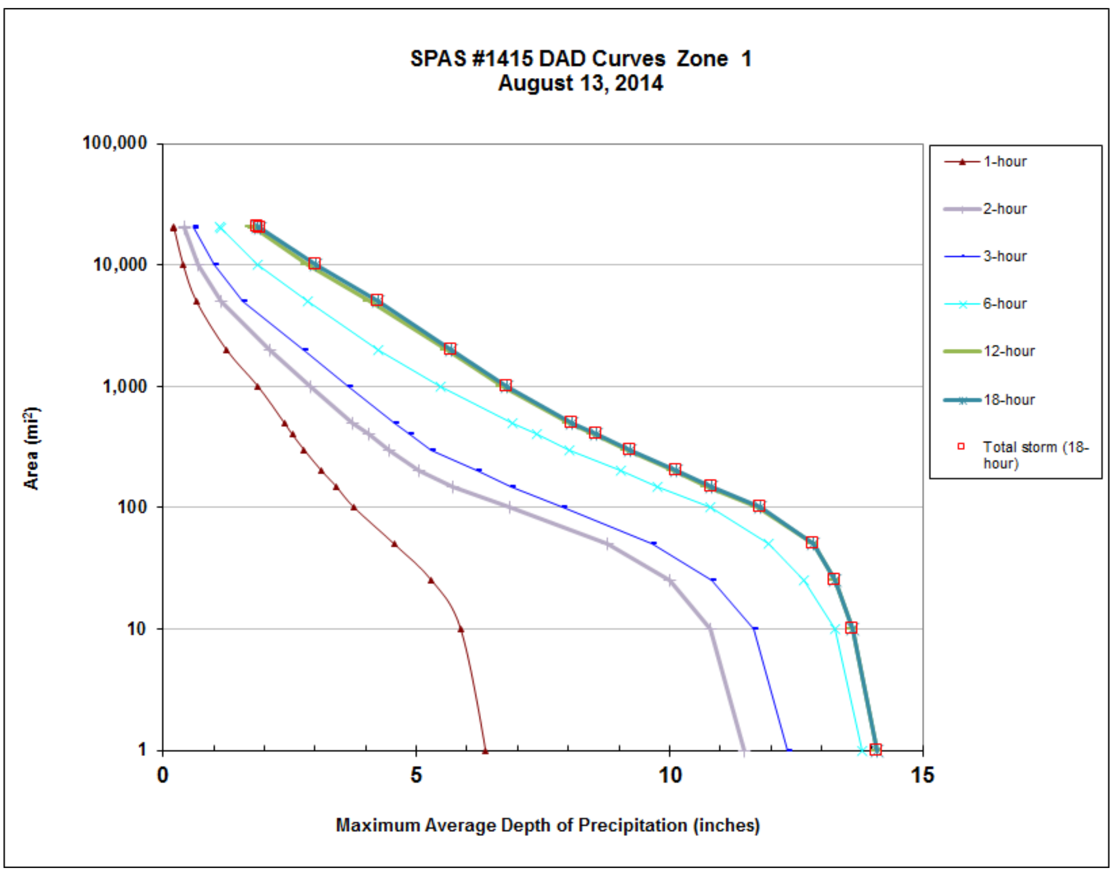
Radar Included: Yes

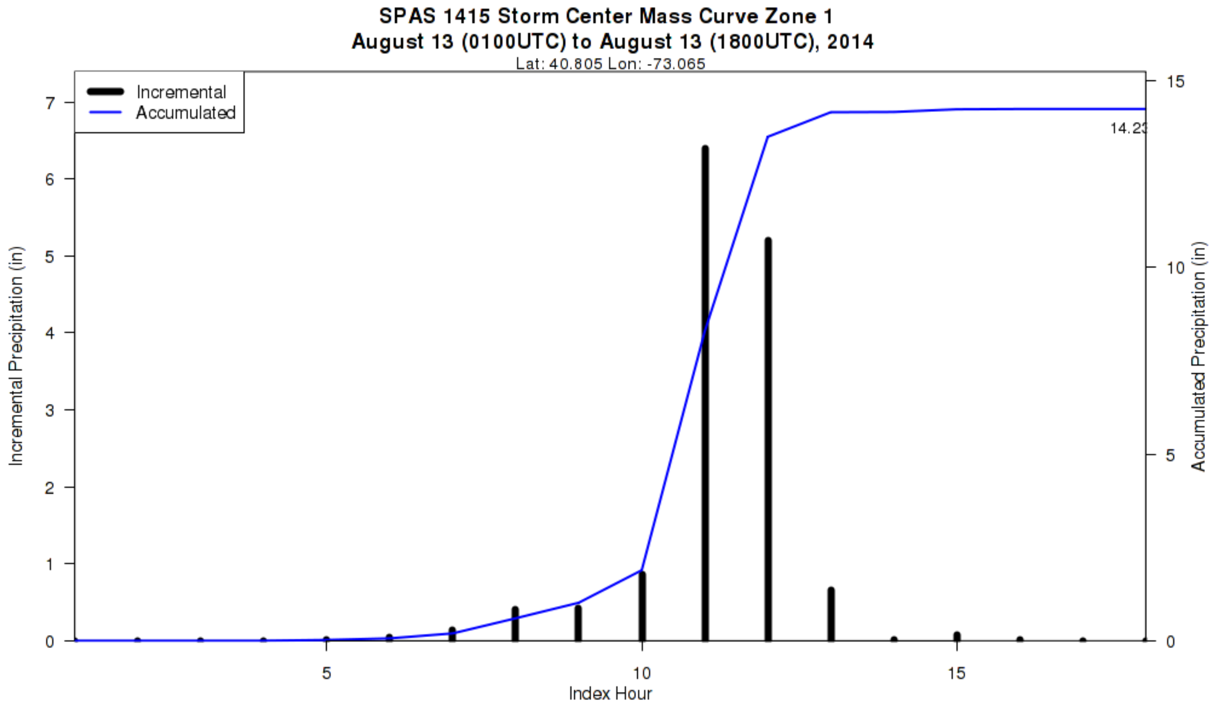
Depth-Area-Duration (DAD) analysis: Yes

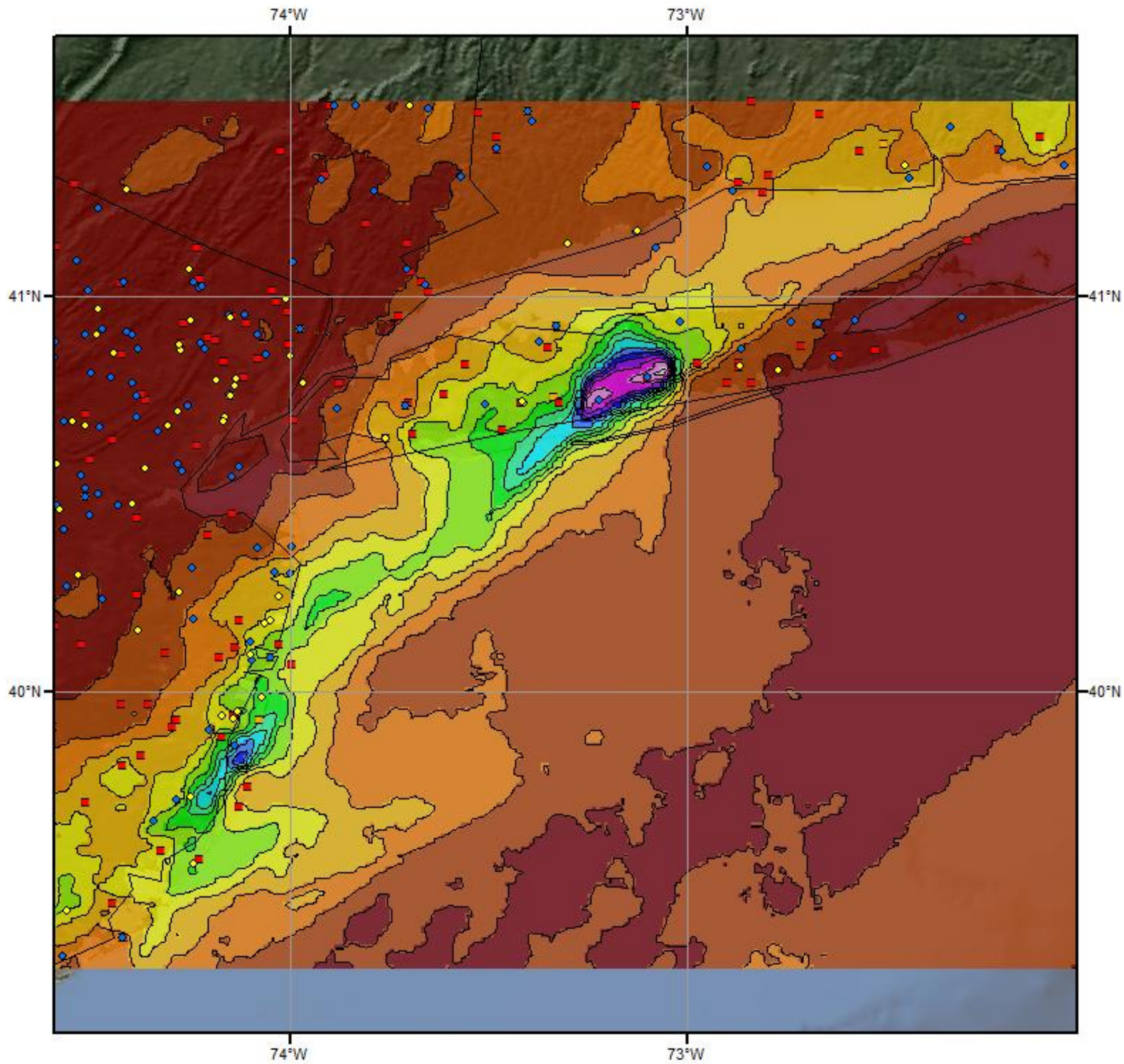
Reliability of results: This analysis was based on hourly data, daily data, supplemental station data and NEXRAD Radar. We have a high degree of confidence in the radar/station based storm total results, the spatial pattern is dependent on the radar data and basemap, and the timing is based on hourly and hourly pseudo stations.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1415_1	-73.0650	40.8050	80	15-Aug	76.50	3.07	0.03	75	3.035	79.75	3.60	0.03	82	3.570	1.176

SPAS 1415 - August 13 (0100 UTC) - August 13 (1800 UTC), 2014							
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)							
	Duration (hours)						
Area (mi^2)	1	2	3	6	12	18	Total
0.4	6.43	11.59	12.46	13.94	14.22	14.22	14.22
1	6.36	11.46	12.33	13.81	14.09	14.09	14.09
10	5.87	10.79	11.66	13.27	13.60	13.61	13.61
25	5.30	10.00	10.84	12.64	13.26	13.27	13.27
50	4.56	8.77	9.66	11.96	12.84	12.85	12.85
100	3.77	6.83	7.88	10.81	11.75	11.78	11.78
150	3.41	5.72	6.87	9.75	10.76	10.83	10.83
200	3.13	5.05	6.20	9.03	10.08	10.14	10.14
300	2.78	4.46	5.28	8.03	9.16	9.23	9.23
400	2.55	4.06	4.86	7.37	8.50	8.56	8.56
500	2.39	3.74	4.56	6.89	8.01	8.08	8.08
1,000	1.87	2.91	3.65	5.49	6.72	6.79	6.79
2,000	1.25	2.11	2.78	4.24	5.60	5.69	5.69
5,000	0.66	1.14	1.58	2.85	4.10	4.24	4.24
10,000	0.40	0.70	1.01	1.87	2.85	3.01	3.01
20,000	0.22	0.43	0.62	1.15	1.81	1.91	1.91
20,565	0.21	0.42	0.60	1.13	1.77	1.87	1.87




SPAS 1415 Storm Center Mass Curve Zone 1
August 13 (0100UTC) to August 13 (1800UTC), 2014
Lat: 40.805 Lon: -73.065
Incremental
Accumulated
14.23
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
6
7
0
5
10
15
5
10
15



Total Storm (18-hr) Precipitation (inches)
08/13/2014 0005 UTC - 08/13/2014 1800 UTC
SPAS-NEXRAD #1415

Gauges

- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 12.5, 25, 50

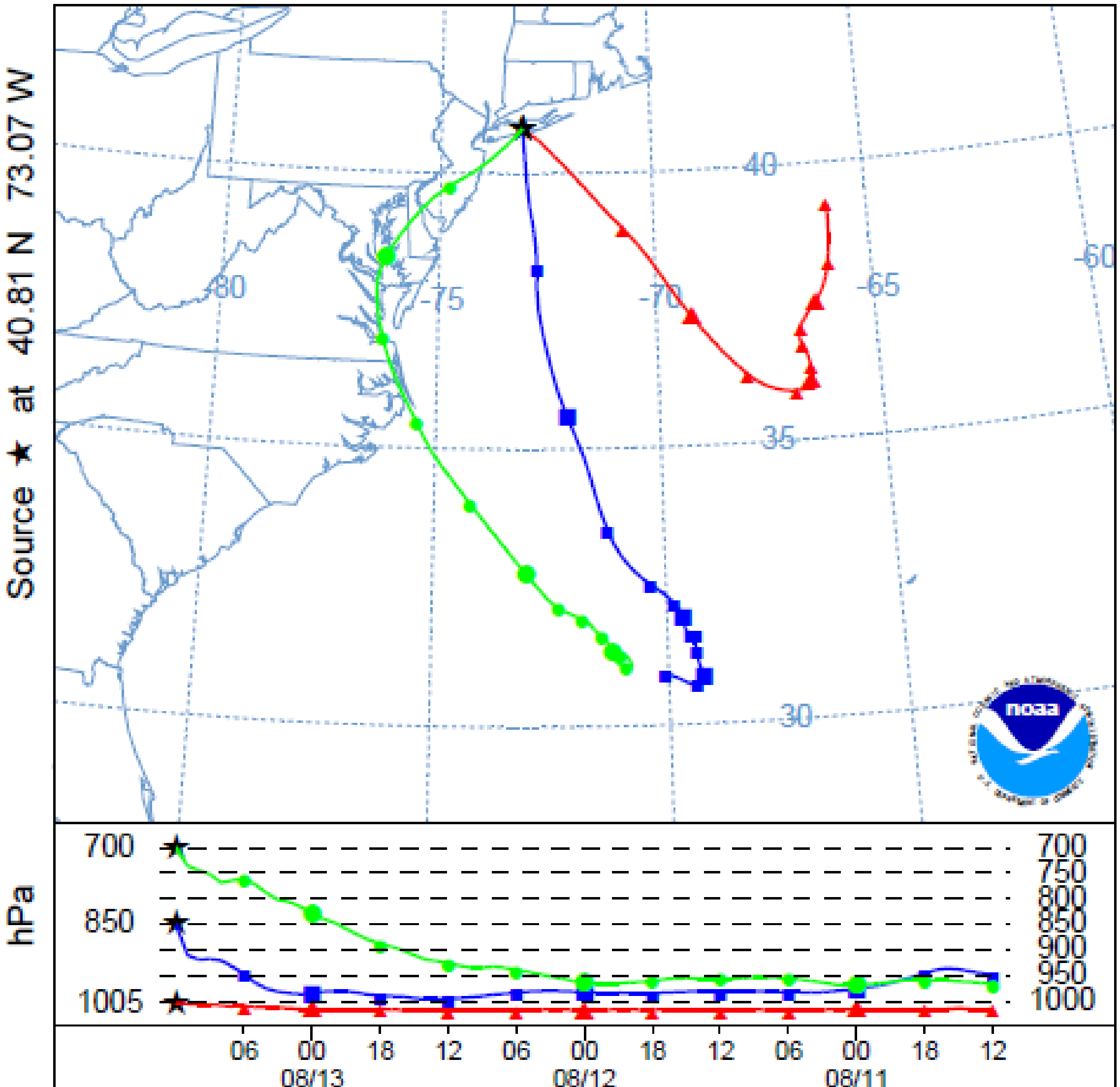
Kilometers: 0, 30, 60, 120

Precipitation (inches)

0.00 - 1.00	3.01 - 4.00	6.01 - 7.00	9.01 - 10.00	12.01 - 13.00
1.01 - 2.00	4.01 - 5.00	7.01 - 8.00	10.01 - 11.00	13.01 - 14.00
2.01 - 3.00	5.01 - 6.00	8.01 - 9.00	11.01 - 12.00	14.01 - 15.00

9/28/2014

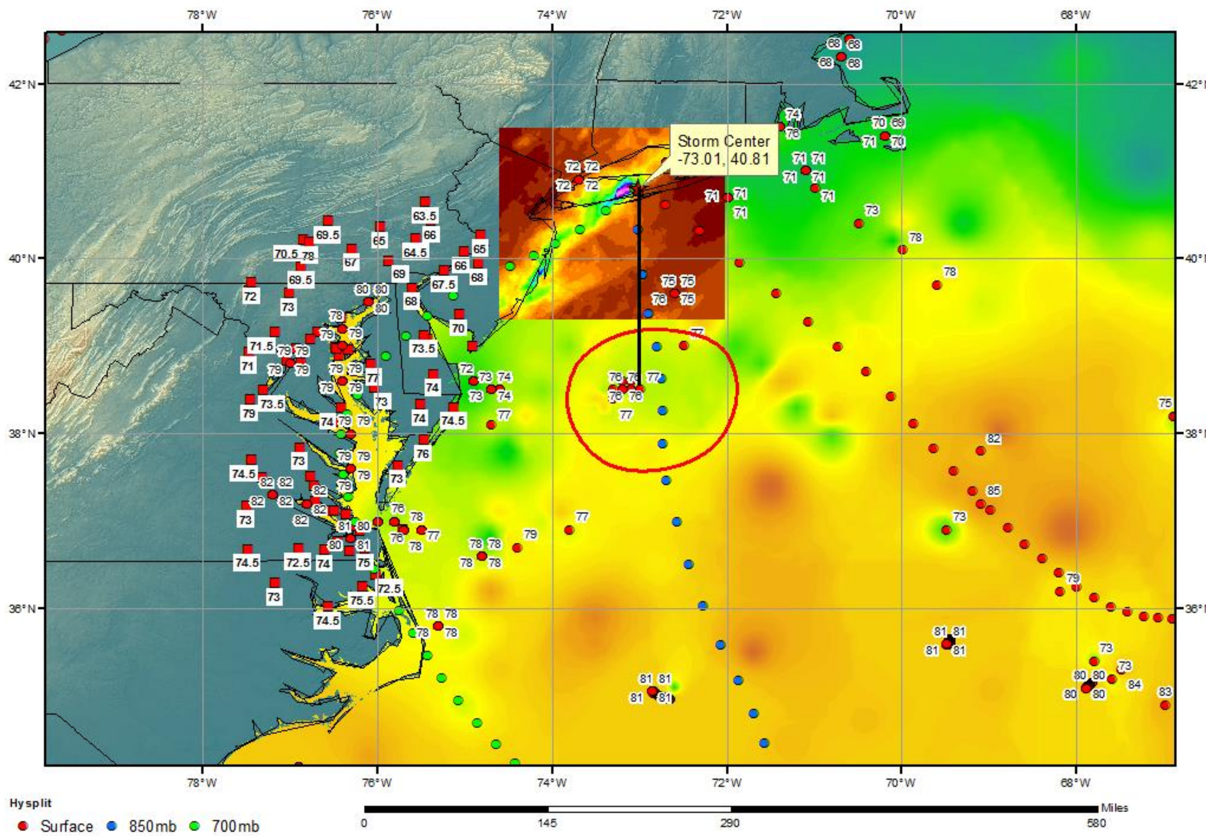
NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 13 Aug 14
GDAS Meteorological Data



Job ID: 122585 Job Start: Mon Sep 29 02:36:13 UTC 2014
Source 1 lat.: 40.805000 lon.: -73.065000 hgts: 0, 1460, 3080 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 8 Aug 2014 - GDAS1

SPAS 1415 Islip, NY Storm Analysis
August 12, 2014



Storm Precipitation Analysis System (SPAS) For Storm #1952_1 SPAS-NEXRAD Analysis

General Storm Location: Fayetteville, NC

Storm Dates: September 28th – September 30th, 2016

Event: Local

DAD Zone 1

Latitude: 34.9450

Longitude: -79.1450

Max. Grid Rainfall Amount: 14.26”

Max. Observed Rainfall Amount: 10.63”

Number of Stations: 286

SPAS Version: 10.0

Basemap: 00_bm_radar_WSR88D

Spatial resolution: 0.3896

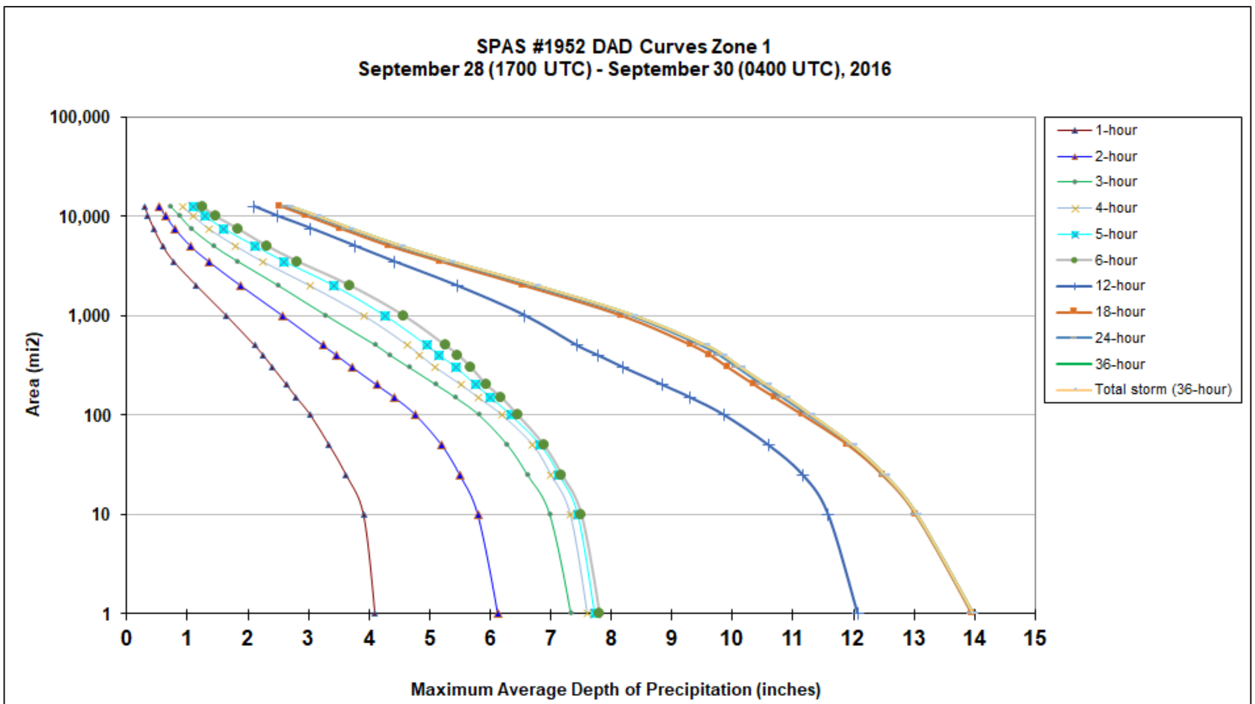
Radar Included: Yes

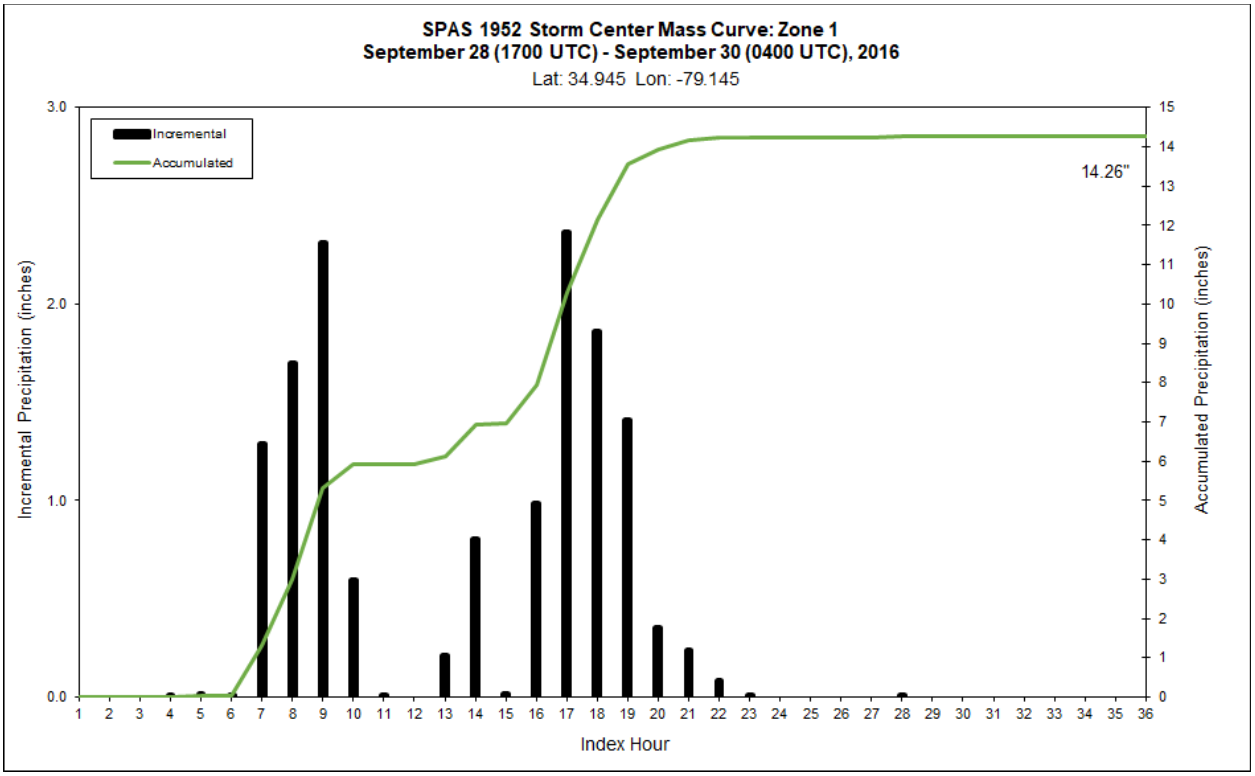
Depth-Area-Duration (DAD) analysis: Yes

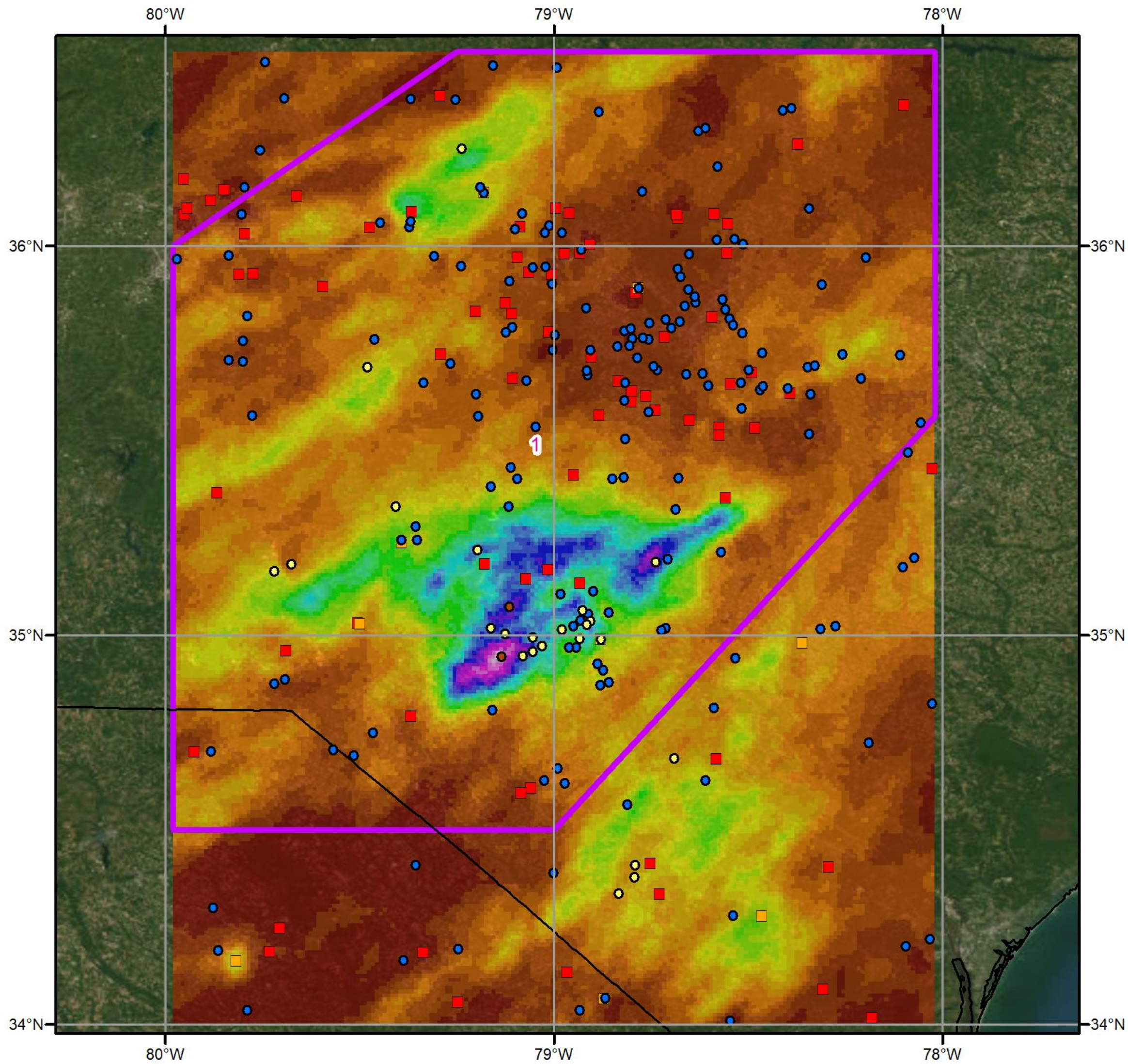
Reliability of results: This final analysis included data from 78 hourly stations, 9 hourly pseudo stations, 5 hourly estimated pseudo stations, 171 daily stations, and 23 supplemental stations. The spatial pattern is dependent on radar, surface observations and base map. Timing is based on hourly, hourly pseudo, and hourly estimated pseudo stations. Radar beam blockage is inconsequential. Analysis of the synoptic weather pattern, available observations, radar, and base maps have left us confident that the magnitude and spatial pattern of total precipitation generated by this SPAS analysis is reasonable and captures the most important aspects of this storm.

							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1952_1	-79.1450	34.9450	200	200	15-Sep	82.00	3.95	0.06	86	3.890	83.92	84.0	4.30	0.07	90	4.230	1.087

Storm 1952 - September 28 (1700 UTC) - September 30 (0400 UTC), 2016											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	2	3	4	5	6	12	18	24	36	Total
0.4	4.14	6.18	7.40	7.67	7.81	7.87	12.26	14.24	14.25	14.26	14.26
1	4.10	6.13	7.34	7.60	7.73	7.80	12.07	13.96	13.97	13.98	13.98
10	3.91	5.80	6.99	7.32	7.45	7.50	11.58	13.03	13.04	13.05	13.05
25	3.62	5.50	6.62	7.00	7.14	7.18	11.16	12.48	12.51	12.52	12.52
50	3.34	5.20	6.29	6.70	6.83	6.88	10.59	11.91	11.97	11.98	11.98
100	3.03	4.77	5.82	6.19	6.34	6.45	9.86	11.16	11.25	11.30	11.30
150	2.80	4.42	5.43	5.80	6.01	6.18	9.30	10.70	10.82	10.89	10.89
200	2.64	4.13	5.12	5.52	5.77	5.94	8.85	10.37	10.50	10.57	10.57
300	2.41	3.73	4.67	5.10	5.44	5.68	8.20	9.93	10.08	10.14	10.14
400	2.25	3.46	4.35	4.84	5.16	5.47	7.77	9.63	9.78	9.85	9.85
500	2.11	3.24	4.12	4.64	4.96	5.26	7.43	9.33	9.48	9.56	9.56
1,000	1.64	2.57	3.30	3.91	4.26	4.57	6.57	8.16	8.31	8.37	8.37
2,000	1.15	1.88	2.51	3.02	3.42	3.69	5.45	6.55	6.69	6.76	6.76
3,500	0.77	1.35	1.84	2.24	2.60	2.82	4.41	5.17	5.30	5.35	5.35
5,000	0.59	1.05	1.44	1.80	2.12	2.32	3.77	4.33	4.47	4.52	4.52
7,500	0.44	0.79	1.07	1.35	1.60	1.83	3.04	3.52	3.64	3.69	3.69
10,000	0.35	0.64	0.88	1.10	1.29	1.47	2.49	2.97	3.09	3.14	3.14
12,495	0.29	0.53	0.73	0.92	1.09	1.25	2.10	2.54	2.65	2.69	2.69




SPAS 1952 Storm Center Mass Curve: Zone 1
September 28 (1700 UTC) - September 30 (0400 UTC), 2016
Lat: 34.945 Lon: -79.145
Incremental
Accumulated
14.26"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



Gauges

- <all other values>
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

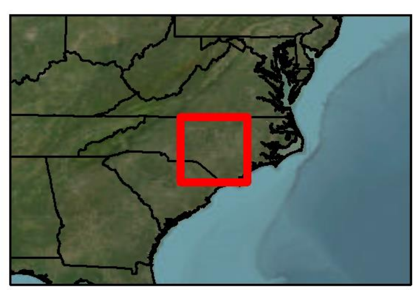
Total Storm (36-hours) Precipitation (inches)
9/28 (1700 UTC) - 9/30 (0400 UTC), 2016
SPAS 1952

Miles: 0 10 20 40

Kilometers: 0 20 40 80

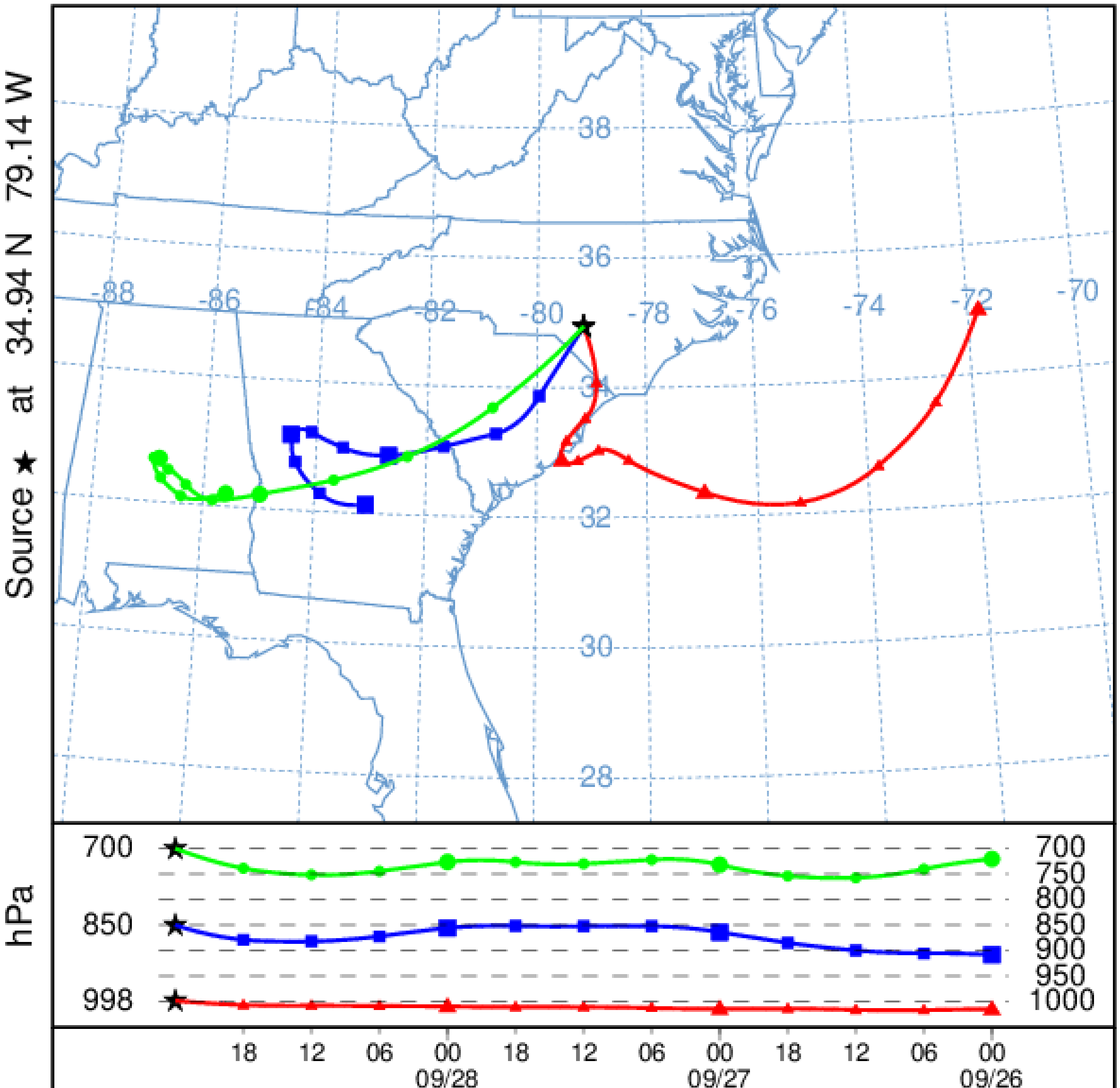
Precipitation (inches)

0.00 - 0.50	3.01 - 3.50	6.01 - 6.50	9.01 - 9.50	12.01 - 12.50
0.51 - 1.00	3.51 - 4.00	6.51 - 7.00	9.51 - 10.00	12.51 - 13.00
1.01 - 1.50	4.01 - 4.50	7.01 - 7.50	10.01 - 10.50	13.01 - 13.50
1.51 - 2.00	4.51 - 5.00	7.51 - 8.00	10.51 - 11.00	13.51 - 14.00
2.01 - 2.50	5.01 - 5.50	8.01 - 8.50	11.01 - 11.50	14.01 - 14.50
2.51 - 3.00	5.51 - 6.00	8.51 - 9.00	11.51 - 12.00	



01/12/2024

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 29 Sep 16
CDC1 Meteorological Data

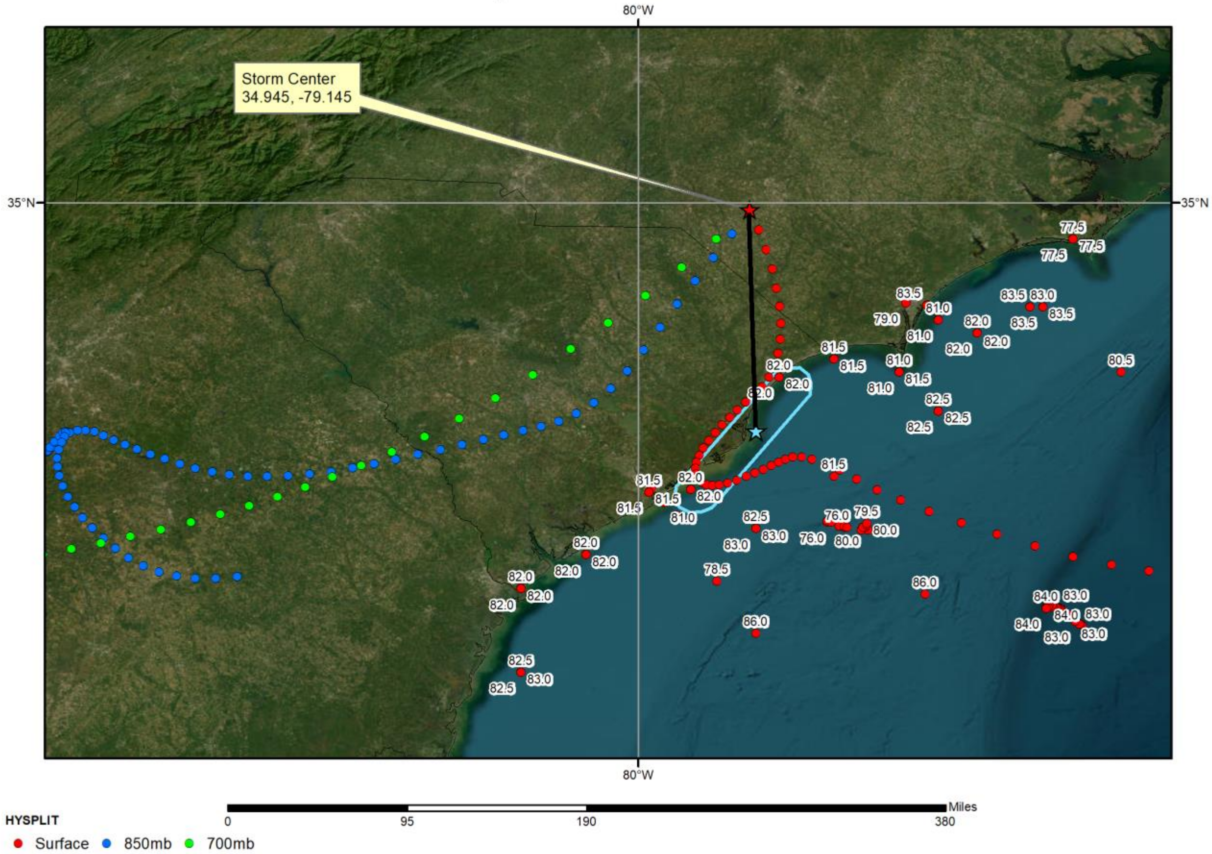


Job ID: 187893 Job Start: Mon Jan 15 19:59:10 UTC 2024
Source 1 lat.: 34.945000 lon.: -79.145000 hgts: 0, 1400, 3030 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2016 - reanalysis

SPAS 1952 Fayetteville, NC - Storm Analysis, Sea Surface Temperatures (F)

September 28, 2016



Storm Precipitation Analysis System (SPAS) For Storm #1700_1 SPAS-NEXRAD Analysis

General Storm Location: Ellicott City, MD

Storm Dates: May 27-28, 2018

Event: Convective

DAD Zone 1

Latitude: 39.2650

Longitude: -76.7550

Max. Grid Rainfall Amount: 14.22”

Max. Observed Rainfall Amount: 13.38”

Number of Stations: 963

SPAS Version: 10.0

Basemap: Precipitation derived from SPAS Default ZR

Spatial resolution: 0.01 decimal degree (0.37-sqmi)

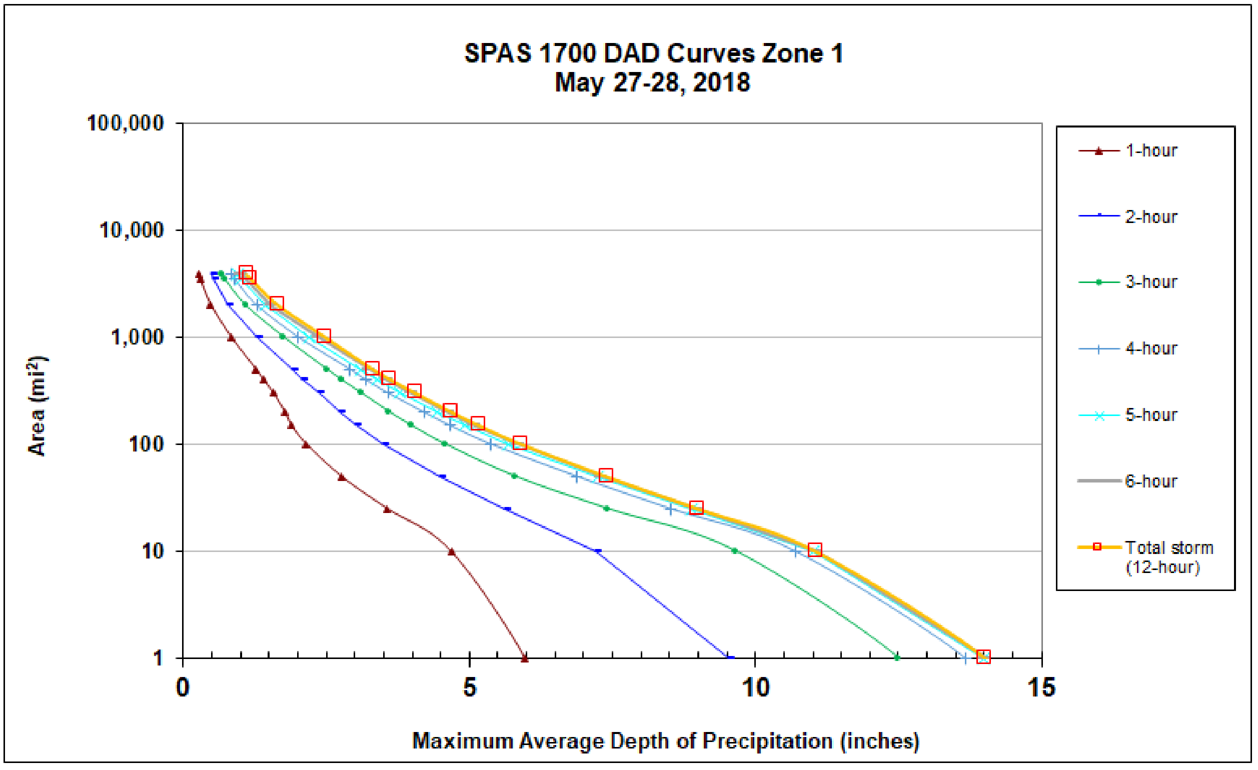
Radar Included: Yes

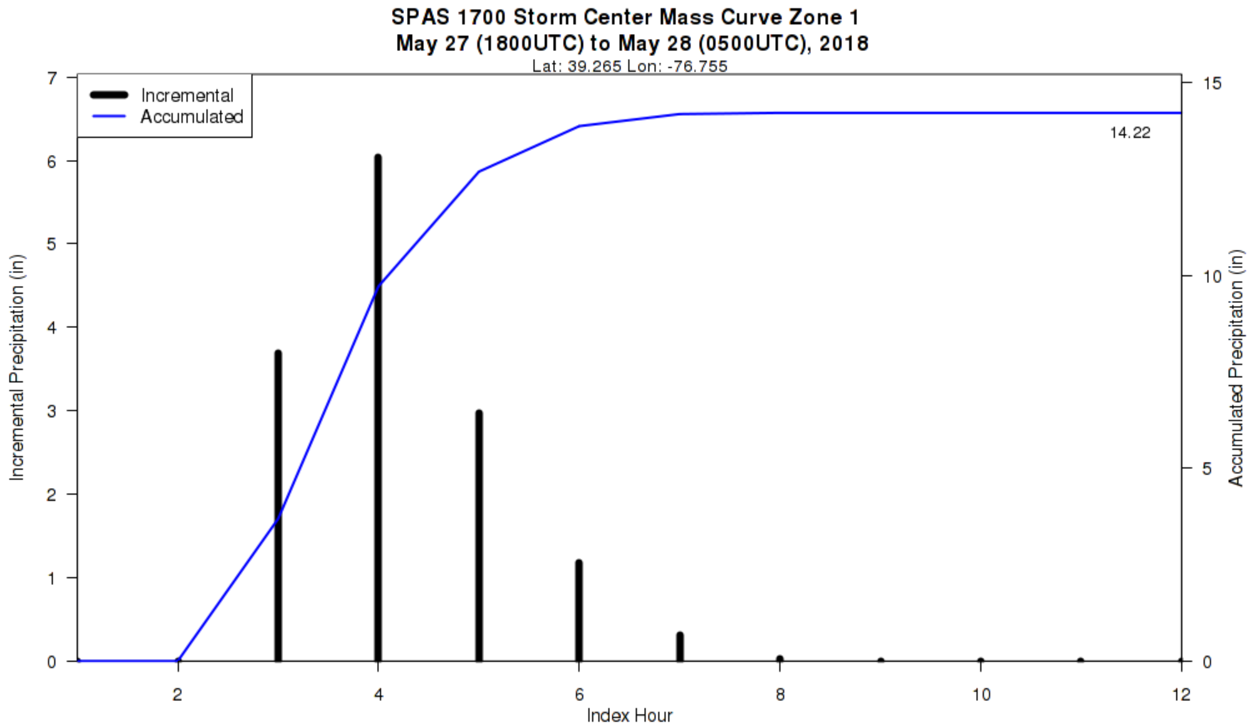
Depth-Area-Duration (DAD) analysis: Yes

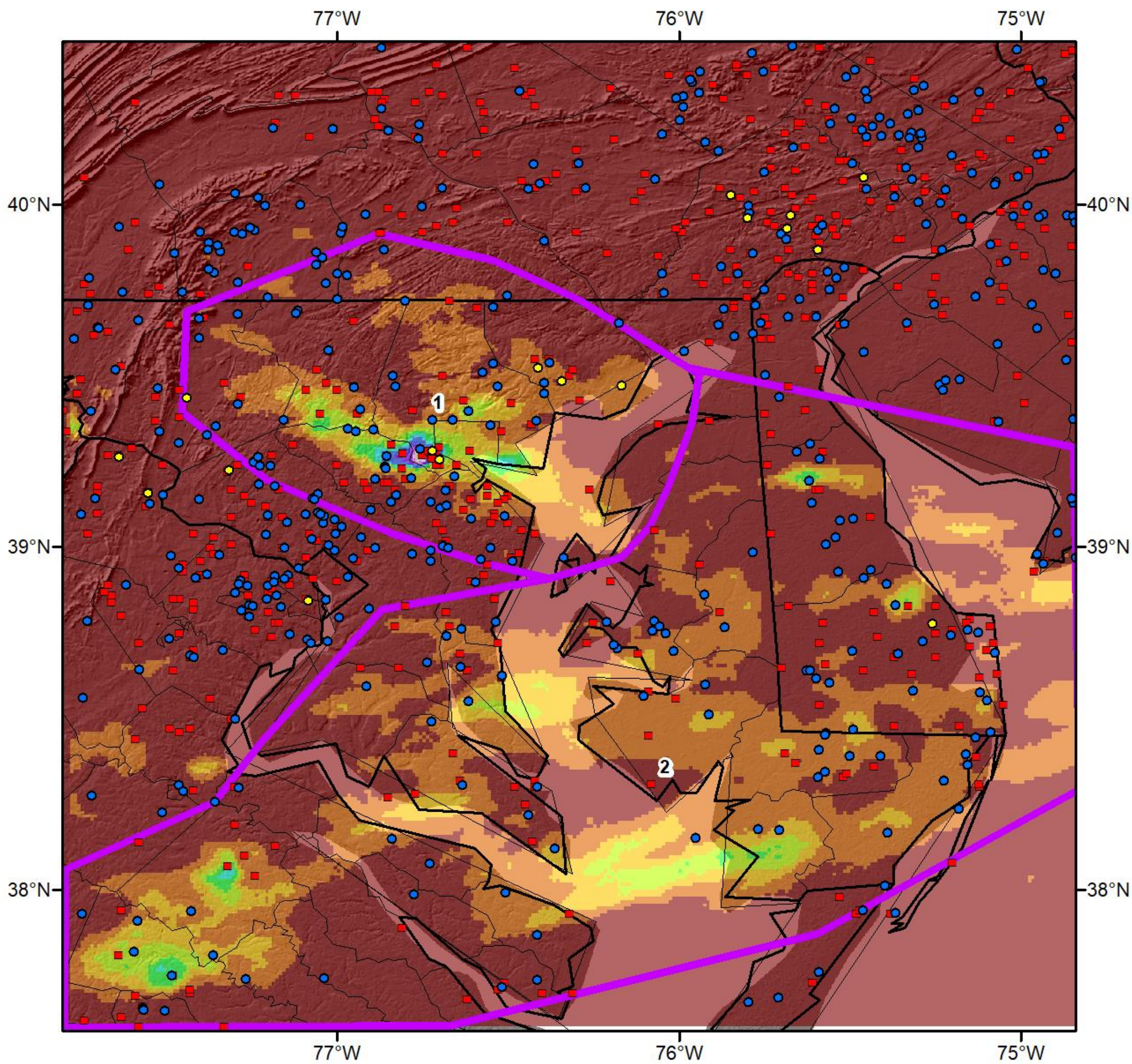
Reliability of results: This analysis was based on 963 hourly stations, daily data, supplemental station data, and radar data. We have a good degree of confidence for the radar adjusted and station based storm total results. The spatial pattern is dependent on the radar data, gauge data, and basemap. There is a good degree of confidence with the timing based on the hourly stations near the storm center. Some daily stations were moved to supplemental due to timing issues.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1700_1	-76.7550	39.2650	404	10-Jun	73.50	2.67	0.10	69	2.565	77.10	3.14	0.11	76	3.030	1.181

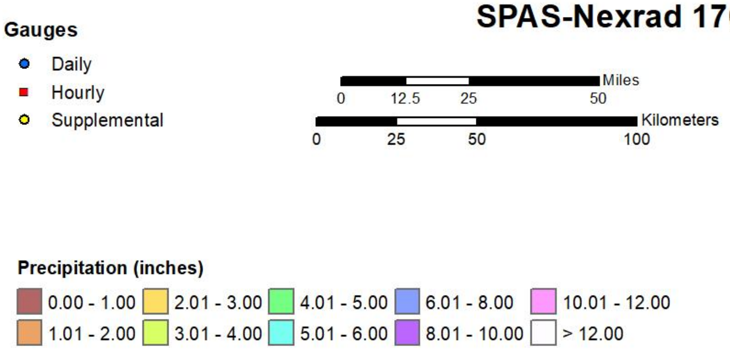
Storm 1700- May 27 (1800 UTC) - May 28 (0500 UTC), 2018								
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)								
Area (mi^2)	Duration (hours)							
	1	2	3	4	5	6	12	Total
0.4	6.03	9.72	12.68	13.86	14.17	14.21	14.21	14.21
1	5.97	9.55	12.50	13.67	13.99	14.02	14.02	14.02
10	4.68	7.21	9.66	10.70	11.00	11.05	11.06	11.06
25	3.56	5.64	7.41	8.51	8.90	8.97	9.00	9.00
50	2.76	4.49	5.80	6.88	7.24	7.31	7.40	7.40
100	2.15	3.50	4.58	5.38	5.68	5.85	5.92	5.92
150	1.89	3.02	3.98	4.66	4.92	5.10	5.17	5.17
200	1.77	2.73	3.60	4.20	4.45	4.64	4.69	4.69
300	1.57	2.36	3.11	3.58	3.79	3.99	4.06	4.06
400	1.40	2.09	2.76	3.19	3.39	3.56	3.63	3.63
500	1.27	1.92	2.51	2.92	3.10	3.26	3.32	3.32
1,000	0.83	1.30	1.75	2.01	2.19	2.36	2.48	2.48
2,000	0.48	0.78	1.08	1.28	1.42	1.54	1.65	1.65
3,500	0.29	0.52	0.72	0.90	1.00	1.10	1.18	1.18
3,826	0.27	0.49	0.67	0.85	0.94	1.02	1.11	1.11

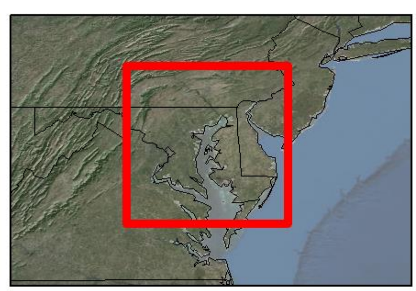



SPAS 1700 Storm Center Mass Curve Zone 1
May 27 (1800UTC) to May 28 (0500UTC), 2018
Lat: 39.265 Lon: -76.755
Incremental
Accumulated
14.22
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour

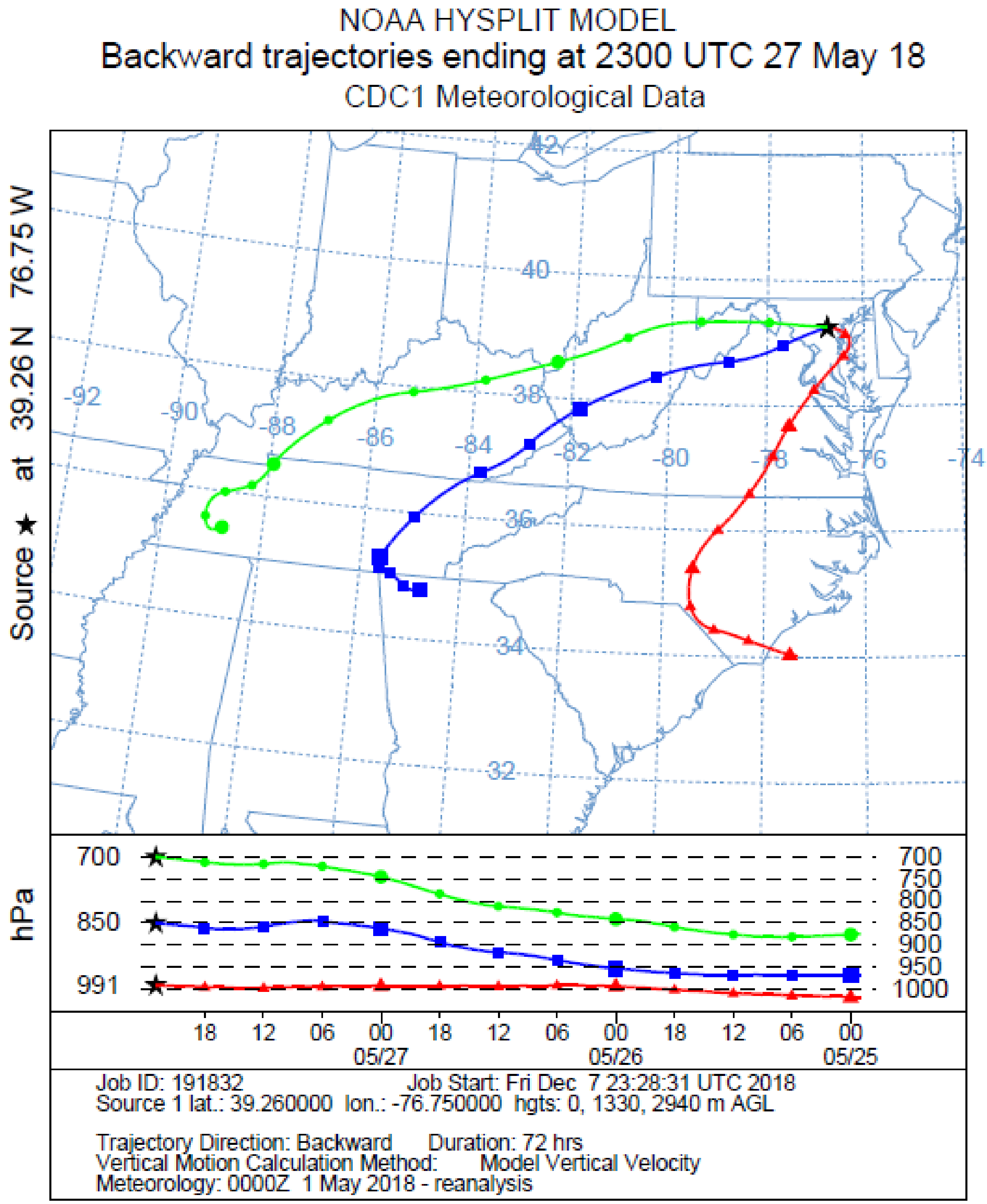


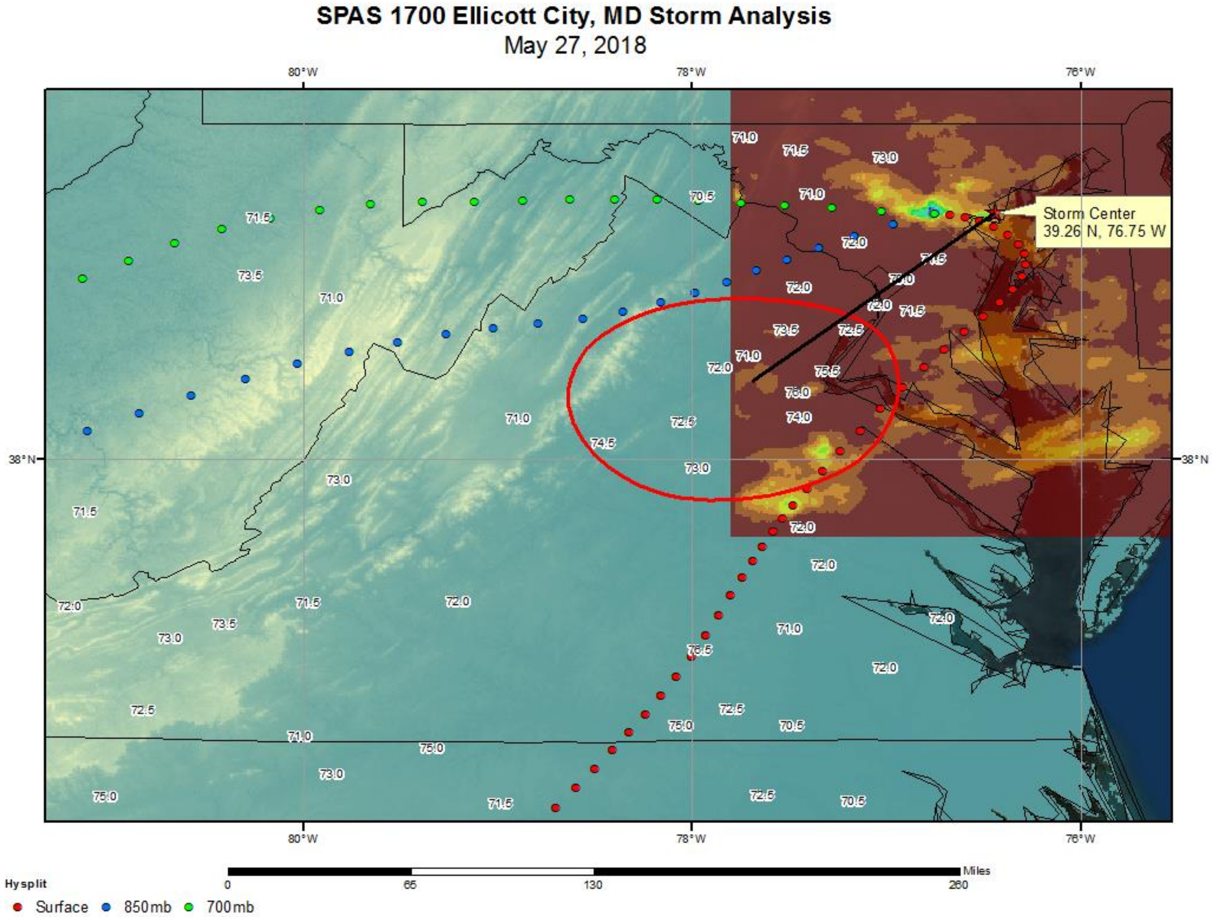
Total 12-hour Rainfall (inches)
05/27/2018 1800 UTC - 05/28/2018 0500 UTC
SPAS-Nexrad 1700





12/10/2018


NOAA HYSPLIT MODEL
Backward trajectories ending at 2300 UTC 27 May 18
CDC1 Meteorological Data
Source ★ at 39.26 N 76.75 W
42
40
38
36
34
32
-92
-90
-88
-86
-84
-82
-80
-78
-76
-74
hPa
700
850
991
700
750
800
850
900
950
1000
18
12
06
00
05/27
18
12
06
00
05/26
18
12
06
00
05/25
Job ID: 191832
Job Start: Fri Dec 7 23:28:31 UTC 2018
Source 1 lat.: 39.260000 lon.: -76.750000 hgts: 0, 1330, 2940 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 May 2018 - reanalysis


SPAS 1700 Ellicott City, MD Storm Analysis
May 27, 2018
80°W
78°W
76°W
38°N
Storm Center
39.26 N, 76.75 W
Miles
0
65
130
260
Hysplit
Surface
850mb
700mb

Storm Precipitation Analysis System (SPAS) For Storm #1927_1 SPAS-NEXRAD Analysis

General Storm Location: Fort Lauderdale, Florida

Storm Dates: April 12th (0600 UTC) – April 13th (0500 UTC), 2023

Event: Convective

DAD Zone 1

Latitude: 26.0750

Longitude: -80.1250

Max. Grid Rainfall Amount: 26.88”

Max. Observed Rainfall Amount: 25.78”

Number of Stations: 424

SPAS Version: 10.0

Basemap: 00_bm_MRMS_sm5 (Smoothing factor of 5 applied)

Spatial resolution: 0.4278

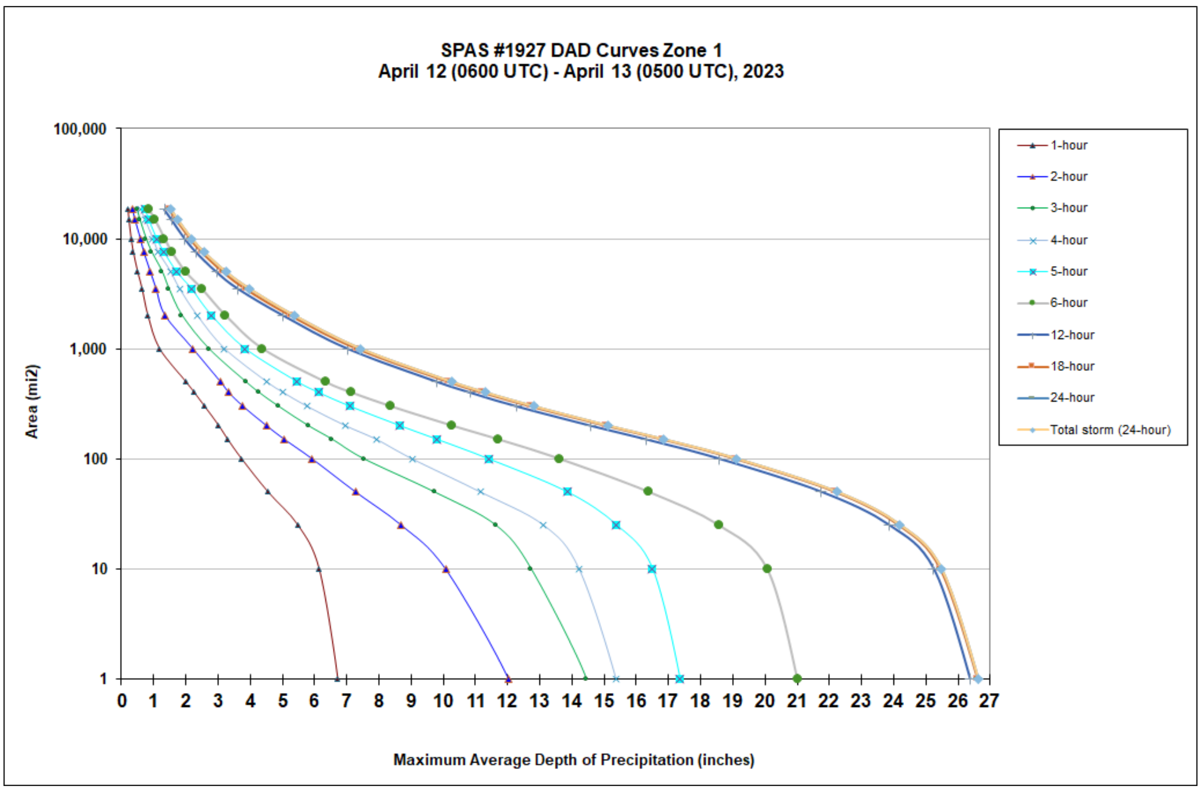
Radar Included: Yes

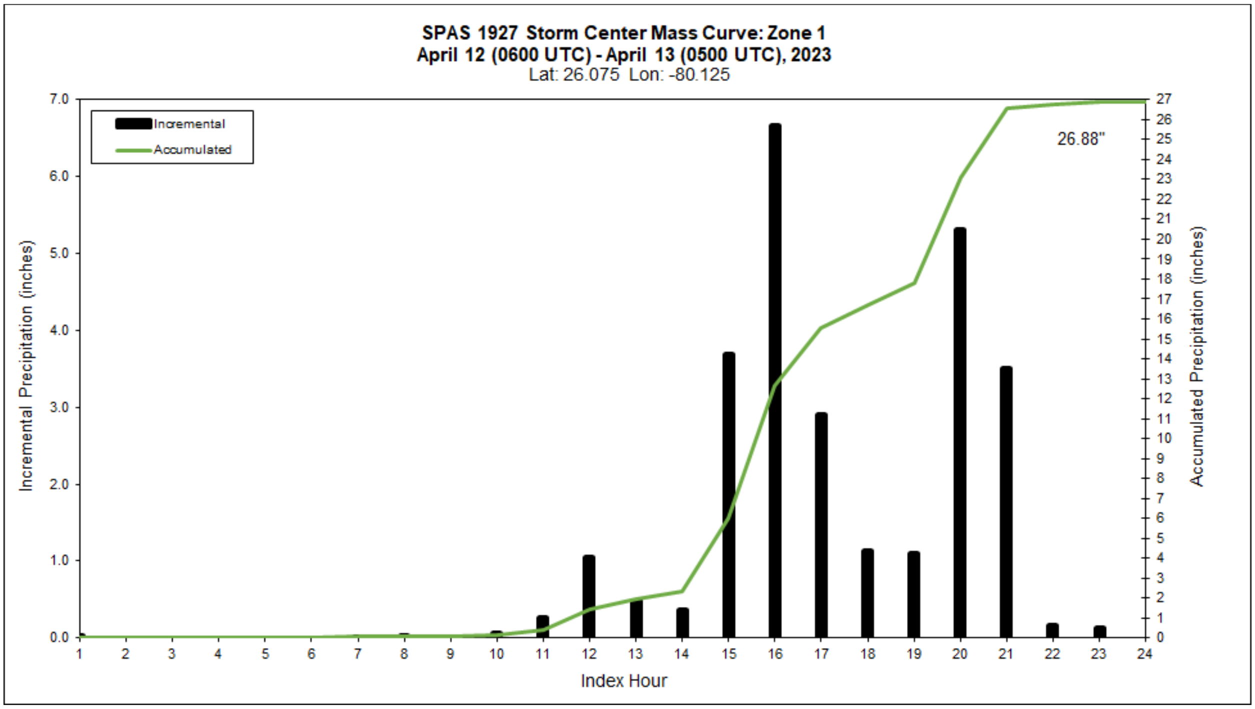
Depth-Area-Duration (DAD) analysis: Yes

Reliability of results: The final analysis included data from 156 hourly, 22 hourly pseudo, 1 hourly estimated pseudo, 231 daily, and 14 supplemental stations. The spatial pattern is dependent on radar, surface observations and base map. Timing is based on hourly, hourly pseudo, and hourly pseudo estimated stations. Radar beam blockage is insignificant over the primary area of precipitation. Analysis of the synoptic weather pattern, available observations and accounts of the event, anecdotal evidence, radar, and base maps have left us confident that the magnitude, spatial pattern, and timing of precipitation generated by SPAS is reasonable and captures the most important aspects of this storm.

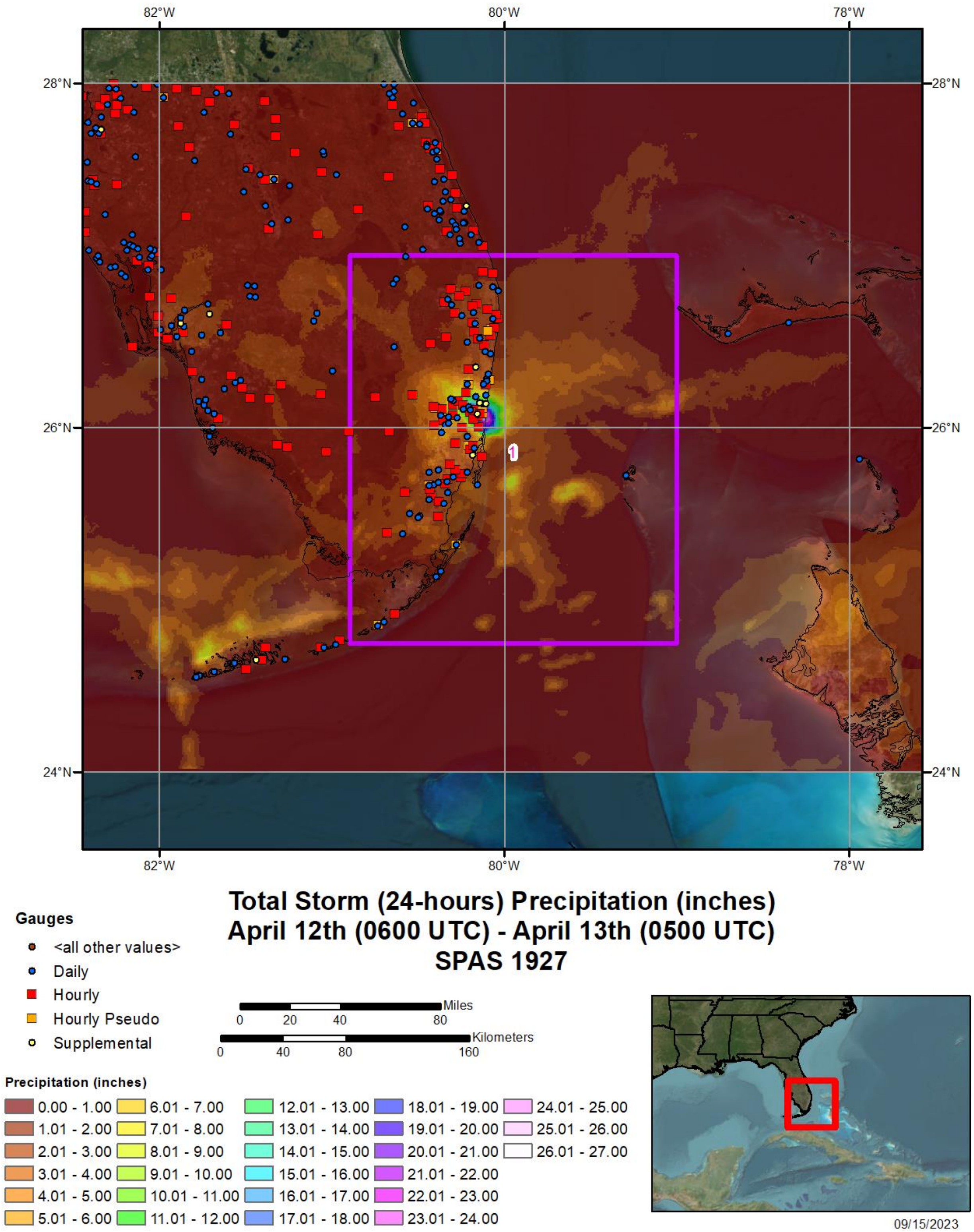
							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1927_1	-80.1250	26.0750	7	0	26-Apr	78.50	3.37	0.00	79	3.365	80.00	80.0	3.60	0.00	82	3.600	1.070

Storm 1927 - April 12 (0600 UTC) - April 13 (0500 UTC), 2023										
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
Area (mi²)	Duration (hours)									
	1	2	3	4	5	6	12	18	24	Total
0.4	6.77	12.27	14.48	15.55	17.44	21.19	26.63	26.85	26.88	26.88
1	6.71	12.03	14.44	15.38	17.35	21.01	26.36	26.59	26.61	26.61
10	6.13	10.07	12.72	14.23	16.50	20.07	25.23	25.43	25.47	25.47
25	5.47	8.69	11.62	13.12	15.39	18.56	23.85	24.14	24.19	24.19
50	4.54	7.27	9.71	11.15	13.85	16.39	21.75	22.17	22.23	22.23
100	3.72	5.92	7.52	9.03	11.40	13.61	18.58	19.06	19.12	19.12
150	3.29	5.06	6.54	7.92	9.80	11.72	16.30	16.80	16.86	16.86
200	3.01	4.50	5.79	6.95	8.64	10.28	14.57	15.04	15.12	15.12
300	2.57	3.77	4.86	5.76	7.09	8.37	12.27	12.71	12.81	12.81
400	2.25	3.33	4.26	5.02	6.12	7.15	10.83	11.21	11.31	11.31
500	1.99	3.07	3.85	4.51	5.46	6.33	9.81	10.17	10.26	10.26
1,000	1.17	2.21	2.70	3.20	3.84	4.38	7.03	7.32	7.43	7.43
2,000	0.81	1.35	1.87	2.35	2.80	3.23	5.03	5.26	5.37	5.37
3,500	0.63	1.07	1.46	1.80	2.17	2.49	3.63	3.86	3.98	3.98
5,000	0.49	0.89	1.25	1.52	1.71	1.98	2.95	3.16	3.24	3.24
7,500	0.36	0.69	0.93	1.14	1.32	1.56	2.33	2.51	2.57	2.57
10,000	0.29	0.58	0.75	0.97	1.09	1.33	1.97	2.14	2.18	2.18
15,000	0.22	0.41	0.55	0.72	0.84	1.02	1.55	1.70	1.73	1.73
18,326	0.19	0.34	0.47	0.59	0.74	0.85	1.34	1.49	1.54	1.54

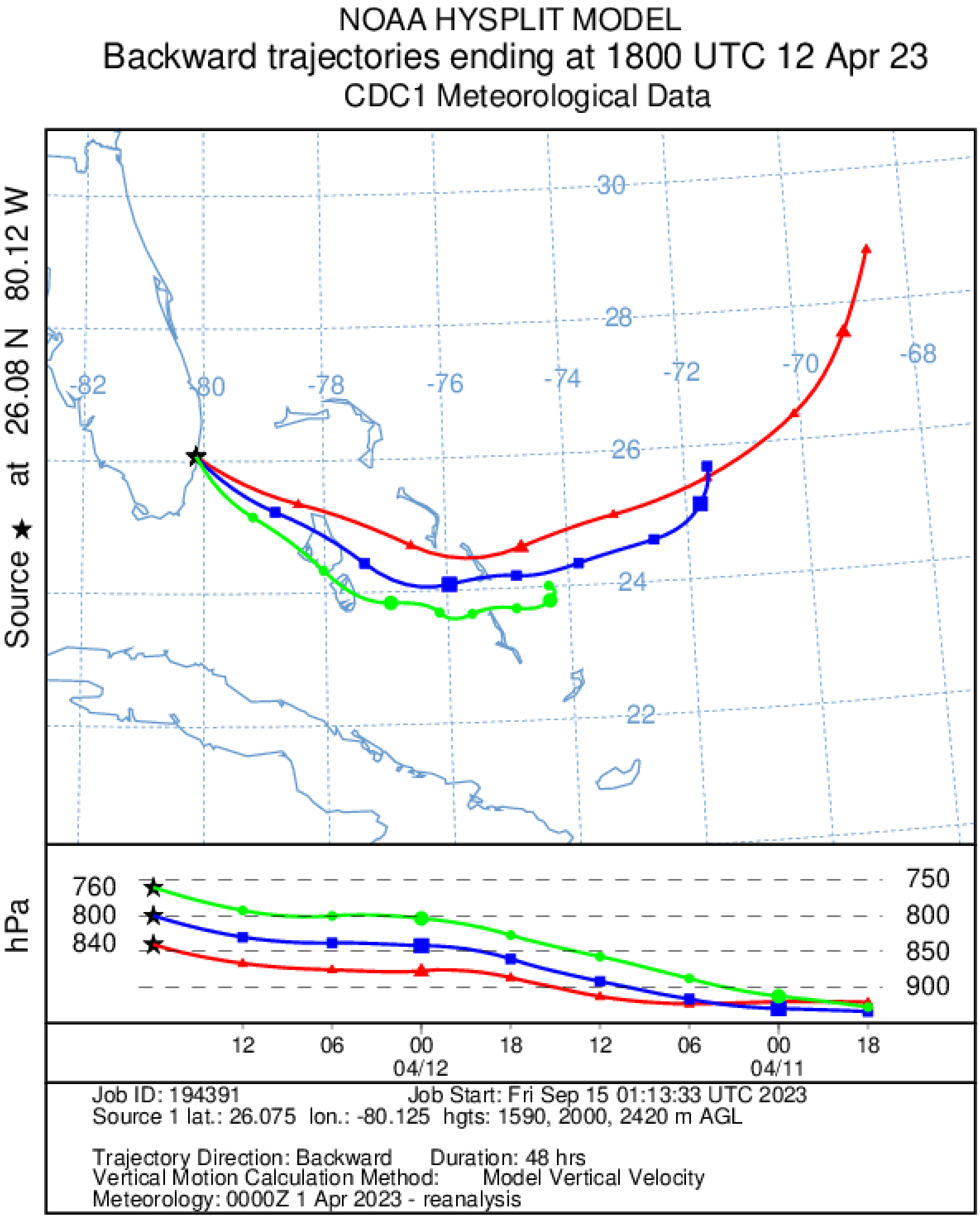


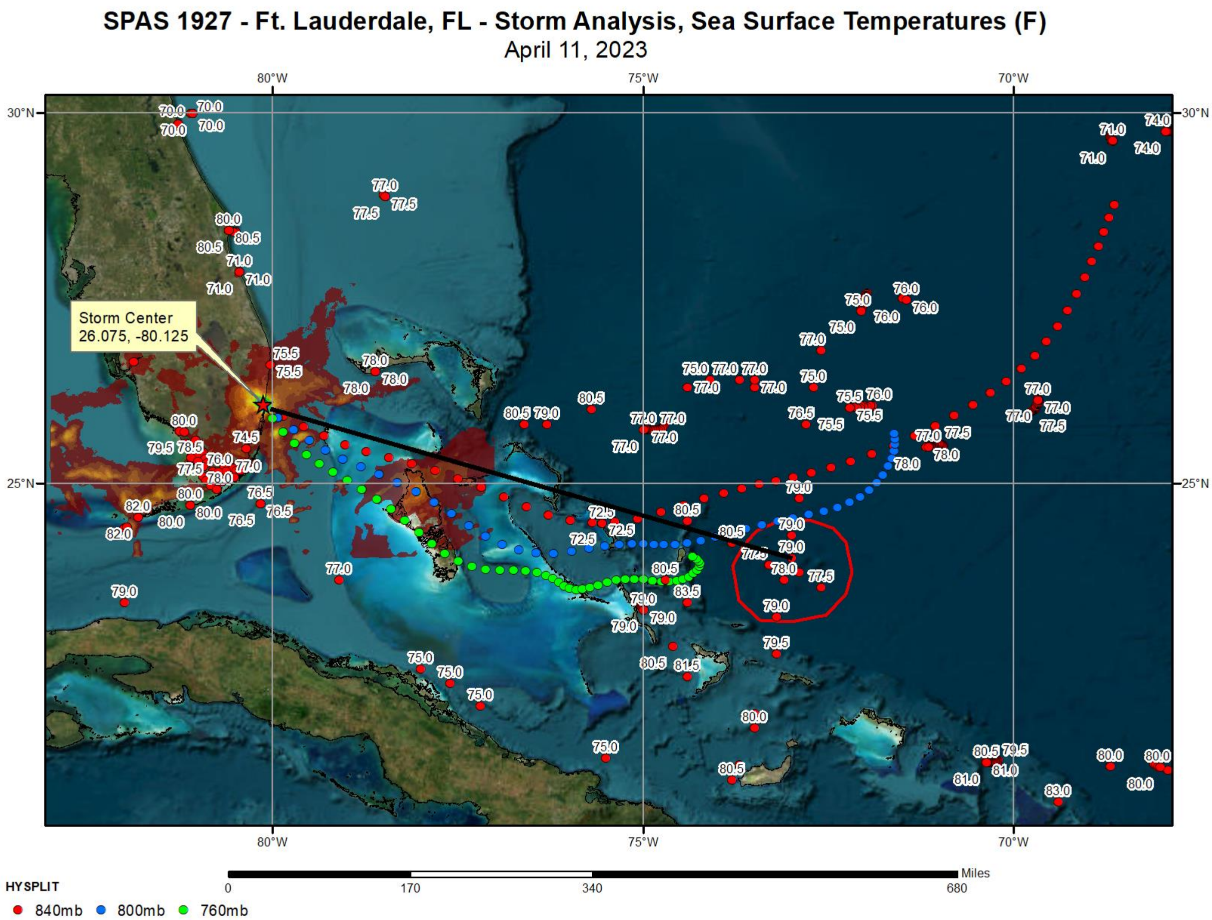


SPAS 1927 Storm Center Mass Curve: Zone 1
April 12 (0600 UTC) - April 13 (0500 UTC), 2023
Lat: 26.075 Lon: -80.125
Incremental
Accumulated
26.88"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



Total Storm (24-hours) Precipitation (inches)
April 12th (0600 UTC) - April 13th (0500 UTC)
SPAS 1927


NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 12 Apr 23
CDC1 Meteorological Data
Source ★ at 26.08 N 80.12 W
30
28
26
24
22
-82
-80
-78
-76
-74
-72
-70
-68
hPa
760
800
840
750
800
850
900
12
06
00
18
12
06
00
18
04/12
04/11
Job ID: 194391
Job Start: Fri Sep 15 01:13:33 UTC 2023
Source 1 lat.: 26.075 lon.: -80.125 hgts: 1590, 2000, 2420 m AGL
Trajectory Direction: Backward
Duration: 48 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Apr 2023 - reanalysis


SPAS 1927 - Ft. Lauderdale, FL - Storm Analysis, Sea Surface Temperatures (F)
April 11, 2023
Storm Center
26.075, -80.125
80°W
75°W
70°W
30°N
25°N
HYSPLIT
840mb
800mb
760mb
Miles
0
170
340
680

Tropical Storms

Storm Precipitation Analysis System (SPAS) For Storm #1515_1 SPAS Analysis

General Storm Location: Florida, Georgia, South Carolina

Storm Dates: August 28 – August 31, 1911

Event: Tropical Cyclone and Synoptic Event

DAD Zone 1

Latitude: 30.5208

Longitude: -82.0208

Max. Grid Rainfall Amount: 19.12”

Max. Observed Rainfall Amount: 19.10”

Number of Stations: 109

SPAS Version: 10.0

Basemap: Combined manually contoured basemap with August 1911 monthly precipitation grid

Spatial resolution: 0.2824

Radar Included: No

Depth-Area-Duration (DAD) analysis: Yes

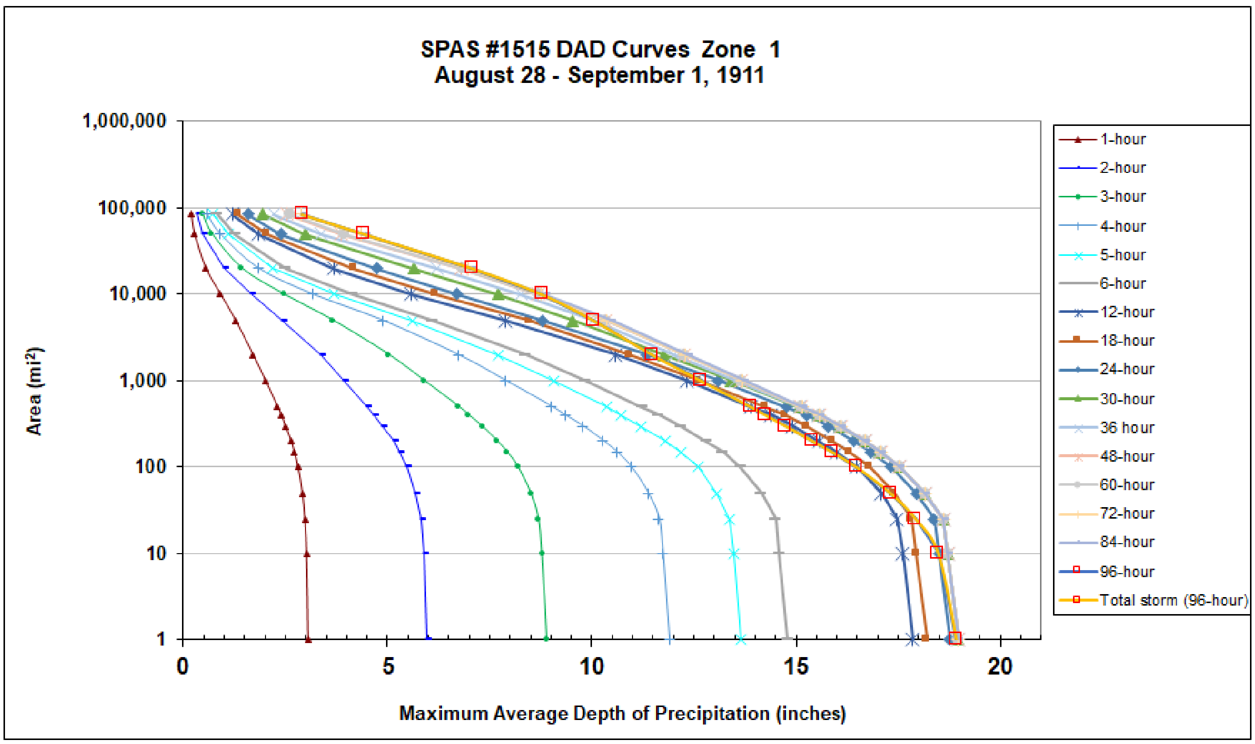
Reliability of results: While no NCDC hourly stations were available for this storms, six estimated hourly stations were digitized from the U.S. Army Corp of Engineers (USACE) Storm Study 3-11 Pertinent Data Sheet. These six stations provided all the SPAS timing and included the storm centers at St. George, Florida and Lumber City, Georgia; there were no official hourly recorder stations for this event. In order to confine the storm center, the USACE isohyetal map was reproduced and combined with PRISM monthly precipitation for use in the basemap, and three estimated stations were added surrounding St. George, FL. Reported timing for precipitation at Lumber City, GA is conflicting between the USACE mass curve, which has approximately 9 of 14 inches falling on the 8/29 and then approximately 2 inches on 8/30, and the AMS Monthly Weather Review (MWR), which reports 4.15 inches on 8/29 and 9.37 inches on the morning 8/30. Given the less-detailed timing of the precipitation from MWR and the similarity in timing between the mass curve at Lumber City and Jasper, FL, the USACE reported timing was used. Extensive efforts were done to match the SPAS DAD with the USACE DAD as close as possible. At the smallest area sizes, results are comparable, however given discrepancies in timing and lack of complete information from the USACE Data Sheet, a complete match between SPAS and USACE is not feasible. In order to continue this analysis, the USACE full report would be necessary, however it is currently unavailable. Given these conditions, the analysis is deemed reasonable and provides and accurate depiction of the storm event.

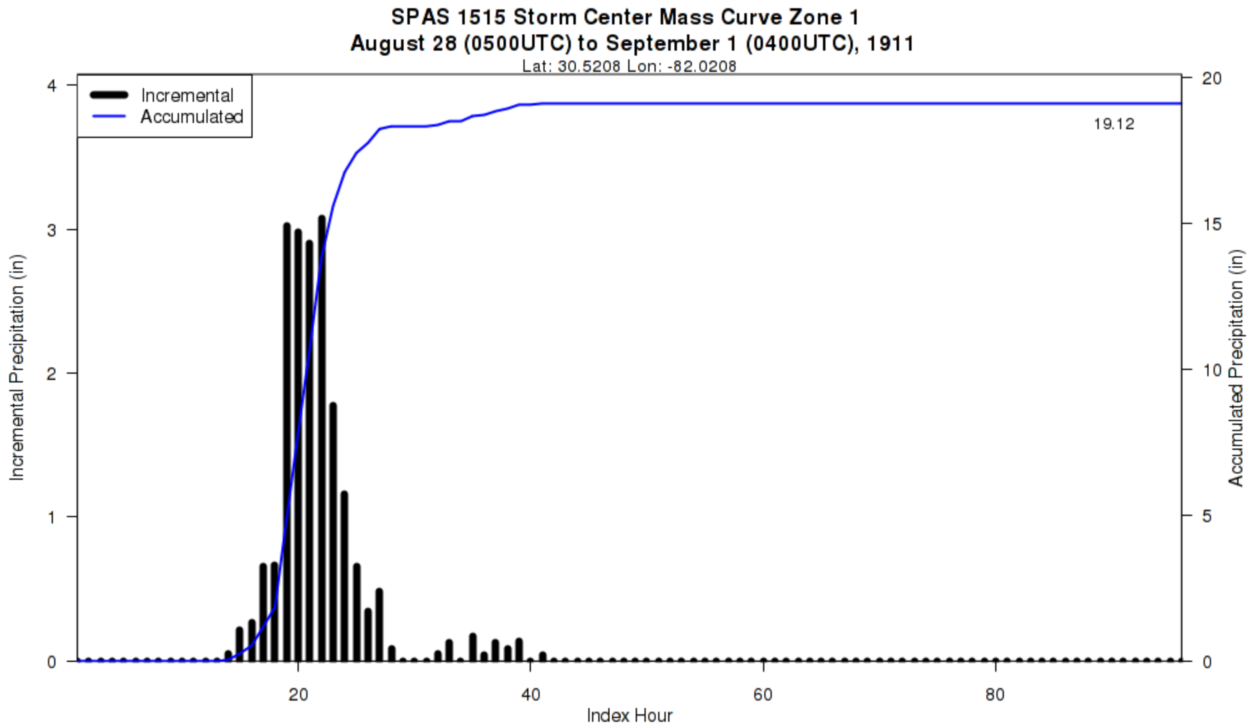
							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1515_1	-82.0208	30.5208	32	0	15-Aug	83.50	4.21	0.00	89	4.210	86.17	86.0	4.67	0.00	94	4.670	1.109

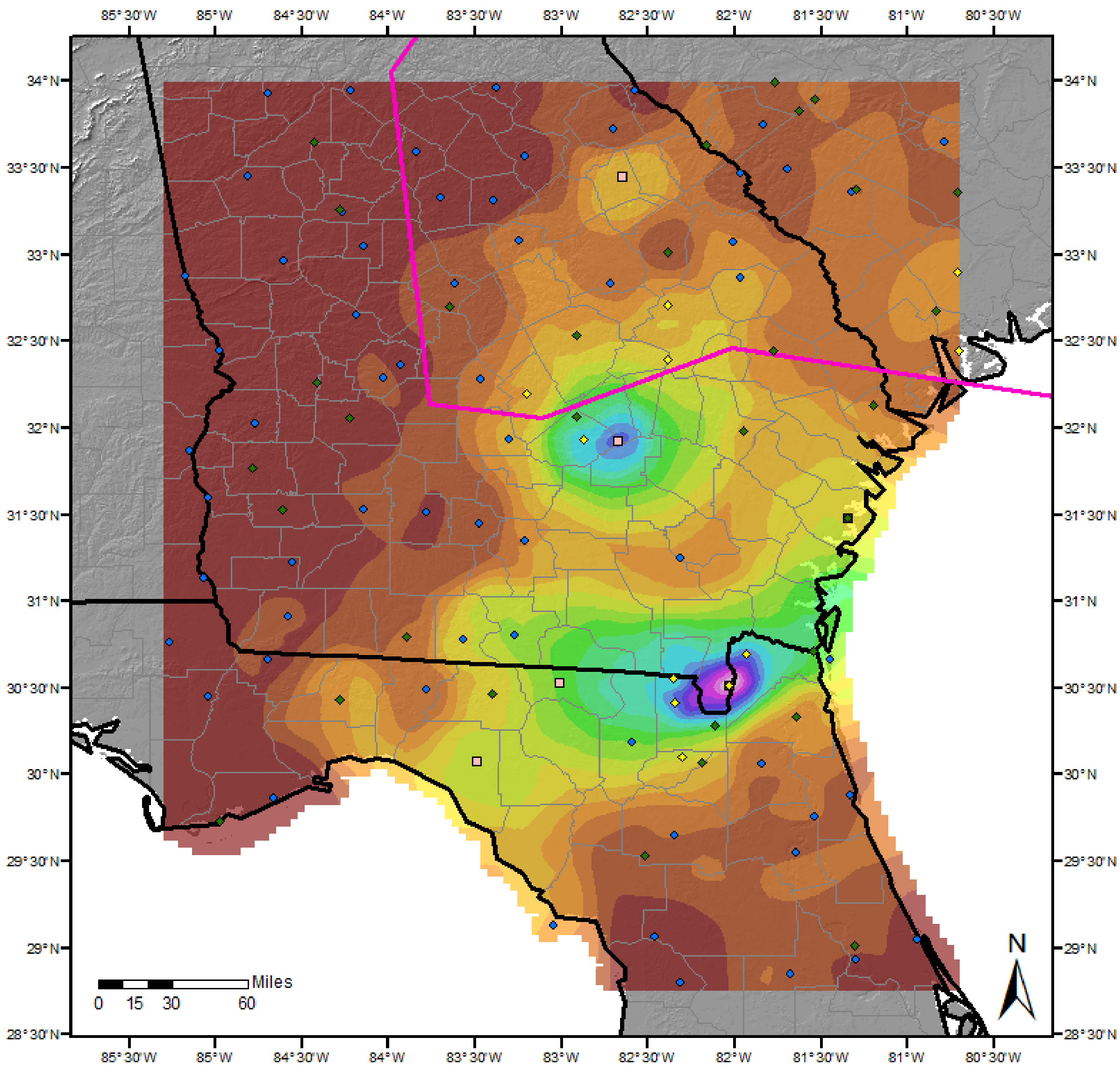
Storm 1515 - August 28 (0500 UTC) - September 1 (0400 UTC), 1911

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

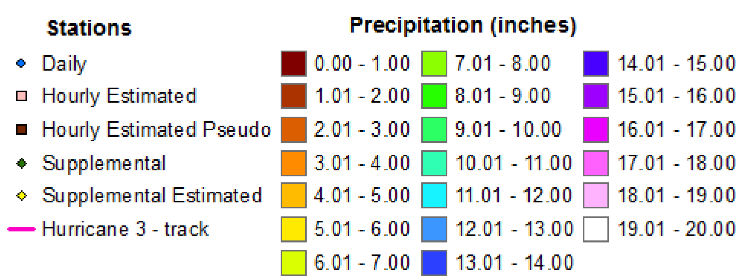
Area (mi²)	Duration (hours)															
	1	2	3	4	5	6	12	18	24	30	36	48	60	72	84	96	Total
0.4	3.07	5.99	8.94	11.96	13.73	14.89	17.95	18.30	18.86	19.08	19.08	19.08	19.08	19.08	19.08	19.05	19.05
1	3.06	5.96	8.90	11.89	13.65	14.80	17.85	18.20	18.76	18.98	18.98	18.98	18.98	18.98	18.98	18.92	18.92
10	3.02	5.88	8.78	11.73	13.47	14.59	17.61	17.95	18.50	18.72	18.72	18.72	18.72	18.72	18.72	18.48	18.48
25	2.98	5.83	8.70	11.64	13.37	14.51	17.48	17.83	18.38	18.60	18.60	18.60	18.60	18.60	18.60	17.93	17.93
50	2.92	5.70	8.51	11.37	13.06	14.15	17.08	17.41	17.94	18.16	18.16	18.16	18.16	18.16	18.16	17.31	17.31
100	2.81	5.49	8.20	10.96	12.59	13.65	16.49	16.81	17.33	17.54	17.55	17.55	17.55	17.55	17.55	16.48	16.48
150	2.72	5.31	7.93	10.60	12.18	13.20	15.99	16.31	16.83	17.05	17.06	17.07	17.07	17.07	17.07	15.88	15.88
200	2.64	5.15	7.69	10.28	11.80	12.80	15.57	15.90	16.43	16.68	16.70	16.70	16.70	16.71	16.71	15.41	15.41
300	2.50	4.89	7.31	9.77	11.22	12.17	14.92	15.25	15.79	16.06	16.08	16.09	16.09	16.09	16.10	14.74	14.74
400	2.40	4.68	6.99	9.34	10.73	11.64	14.39	14.73	15.26	15.53	15.55	15.57	15.57	15.57	15.59	14.26	14.26
500	2.31	4.51	6.75	9.02	10.36	11.24	13.90	14.26	14.76	15.07	15.10	15.13	15.13	15.14	15.16	13.89	13.89
1,000	2.01	3.94	5.90	7.89	9.06	9.83	12.31	12.61	13.11	13.41	13.50	13.67	13.67	13.69	13.74	12.68	12.68
2,000	1.70	3.36	5.03	6.72	7.72	8.38	10.58	10.92	11.35	11.75	12.00	12.26	12.26	12.28	12.35	11.48	11.48
5,000	1.27	2.45	3.66	4.87	5.60	6.09	7.88	8.47	8.78	9.54	10.03	10.34	10.35	10.38	10.48	10.04	10.04
10,000	0.90	1.68	2.46	3.17	3.68	4.16	5.58	6.19	6.71	7.70	8.27	8.68	8.69	8.75	8.86	8.78	8.78
20,000	0.54	0.99	1.43	1.84	2.20	2.52	3.69	4.18	4.74	5.64	6.22	6.82	6.83	6.98	7.09	7.07	7.07
50,000	0.26	0.49	0.70	0.91	1.11	1.28	1.85	2.05	2.39	2.99	3.39	3.88	3.94	4.37	4.46	4.43	4.43
84,151	0.18	0.33	0.47	0.59	0.72	0.84	1.21	1.34	1.59	1.96	2.21	2.54	2.61	2.88	2.94	2.92	2.92

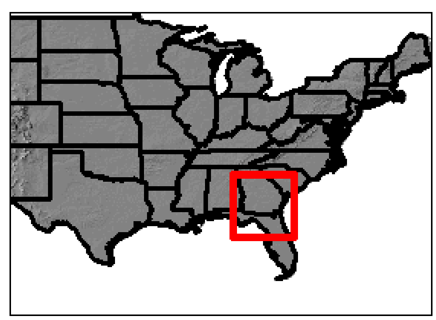



SPAS 1515 Storm Center Mass Curve Zone 1
August 28 (0500UTC) to September 1 (0400UTC), 1911
Lat: 30.5208 Lon: -82.0208
Incremental
Accumulated
19.12
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
10
15
20
40
60
80



Total 96-hour Precipitation (inches)
August 28, 1911 (0500 UTC) - September 1, 1911 (0400 UTC)
SPAS #1515

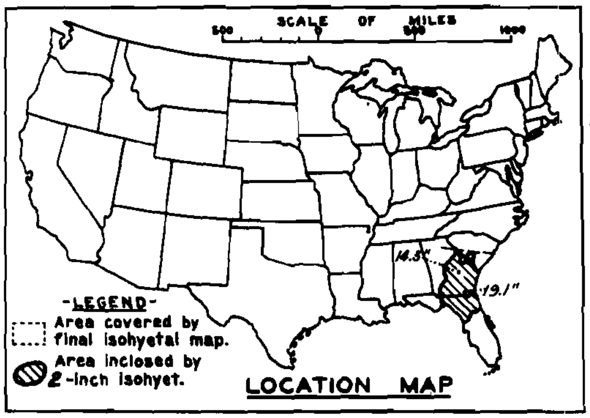




ADH 04/03/2015

DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

STORM STUDIES – PERTINENT DATA SHEET



Storm of 26-31 August 1911
Assignment SA 3-11
Location Ga. & Fla.
Study Prepared by:
South Atlantic Division
Savannah District

Part I Reviewed by H. M. Sec. of Weather Bureau, 11/9/45
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 12/29/47
Remarks: Centers at St. George & Lumber City, Ga.
Dewpt. 74°- Ref. Pt. 100S
Grid J-8

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1:2,500,000

Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) 8
- Form 5001-B (24-hour " ") 11
- Form 5001-D (" " " ") .... -
- Miscl. precip. records, meteorological data, etc. .... -
- Form 5002 (Mass rainfall curves) 12

PART II

Final isohyetal maps, in 1 sheet, scale 1:1,000,000

Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) 2
- Form S-11 (Depth-area data from isohyetal map) 1
- Form S-12 (Maximum depth-duration data) 5
- Maximum duration-depth-area curves 1
- Data relating to periods of maximum rainfall 2

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	72	84	
10	14.9	17.2	18.0	19.0	19.1	19.1	19.1	19.1	19.1	19.1	
100	13.4	15.6	16.7	17.2	17.8	17.8	17.8	17.8	17.8	17.8	
200	12.7	14.9	16.1	16.4	17.1	17.1	17.1	17.1	17.1	17.1	
500	11.4	13.5	14.7	15.0	15.9	15.9	15.9	16.0	16.1	16.1	
1,000	9.8	11.9	13.1	13.5	14.5	14.6	14.6	14.7	14.8	14.8	
2,000	7.4	9.5	10.6	11.3	12.4	12.7	12.8	12.9	13.0	13.1	
5,000	4.7	6.1	7.1	8.0	9.2	10.2	10.4	10.5	10.7	10.8	
10,000	3.3	4.4	5.3	6.1	7.2	8.2	8.5	8.7	8.9	9.0	
20,000	2.2	3.1	3.8	4.5	5.4	6.2	6.6	6.8	7.1	7.3	
39,000	1.4	2.0	2.5	3.1	3.8	4.3	4.6	4.9	5.2	5.3	

Form S-2

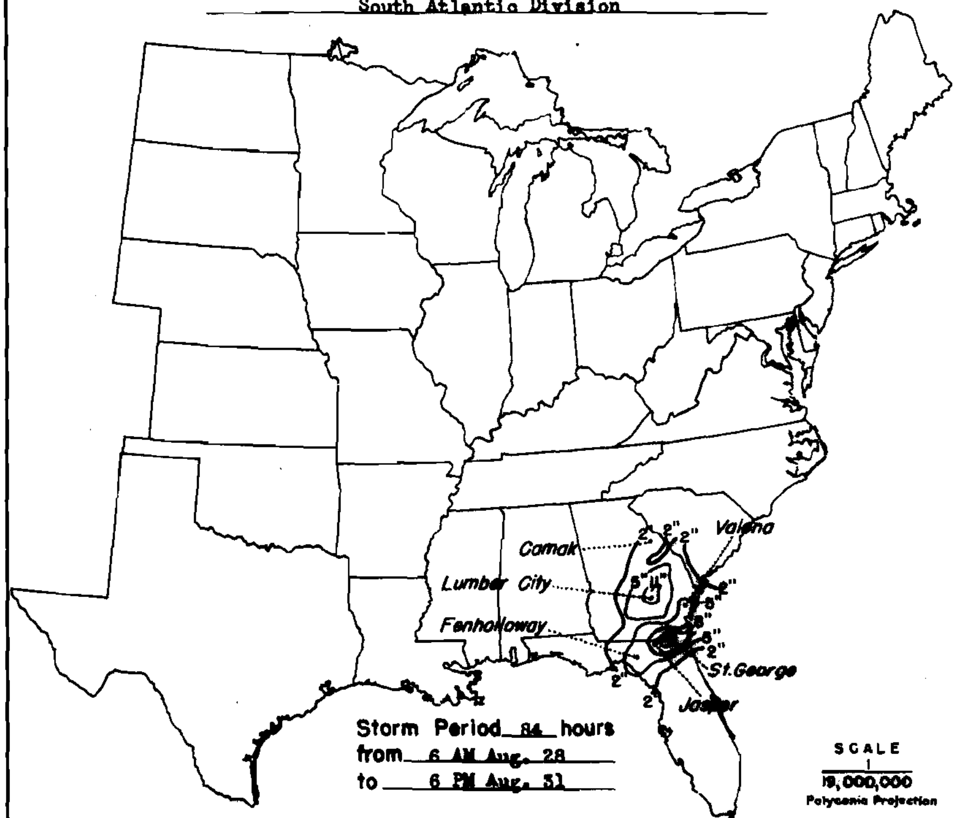
DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

STORM STUDIES – ISOHYETAL MAP

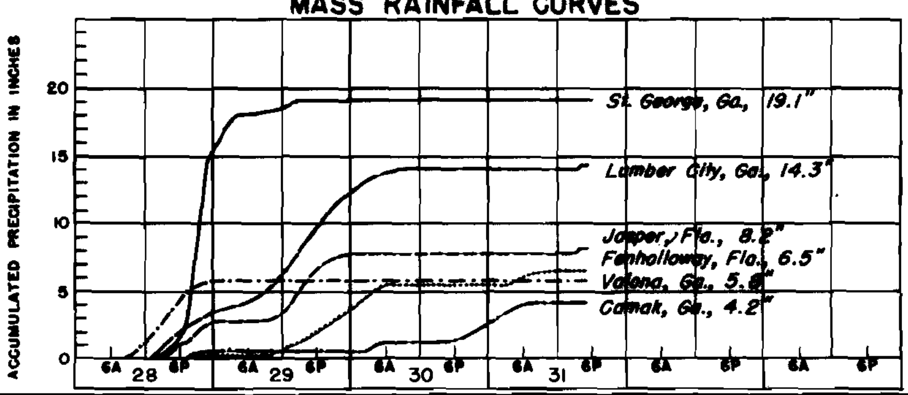
Storm of 28-31 August 1911 Assignment SA 3-11

Study Prepared by: Savannah, Ga. District

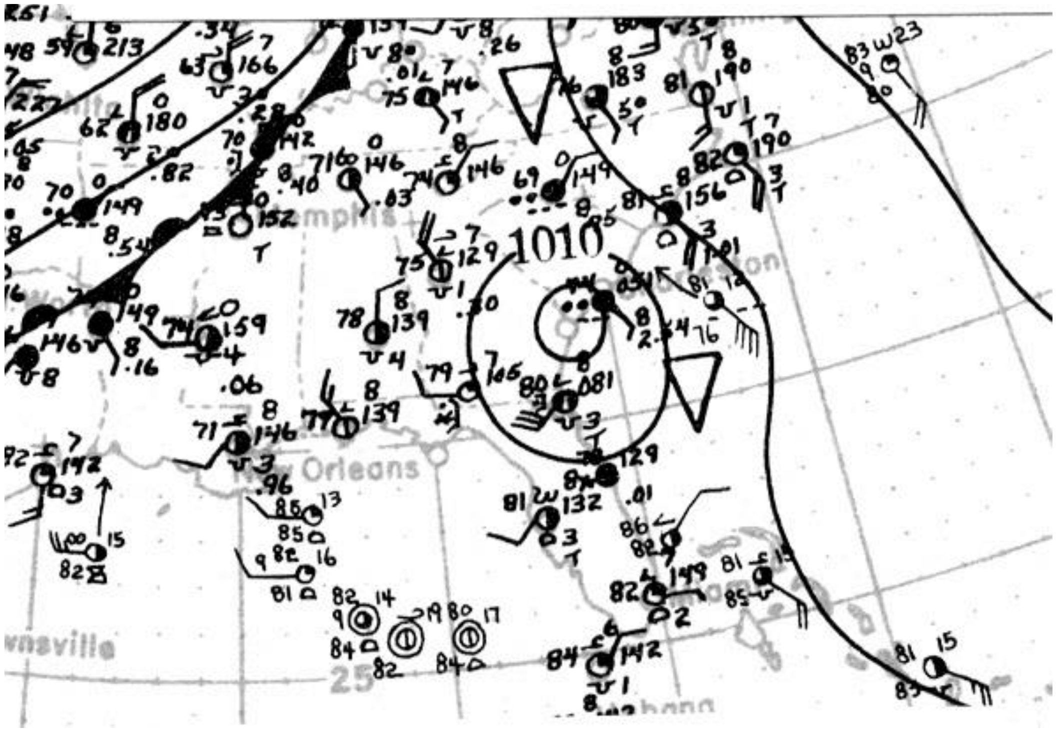
South Atlantic Division

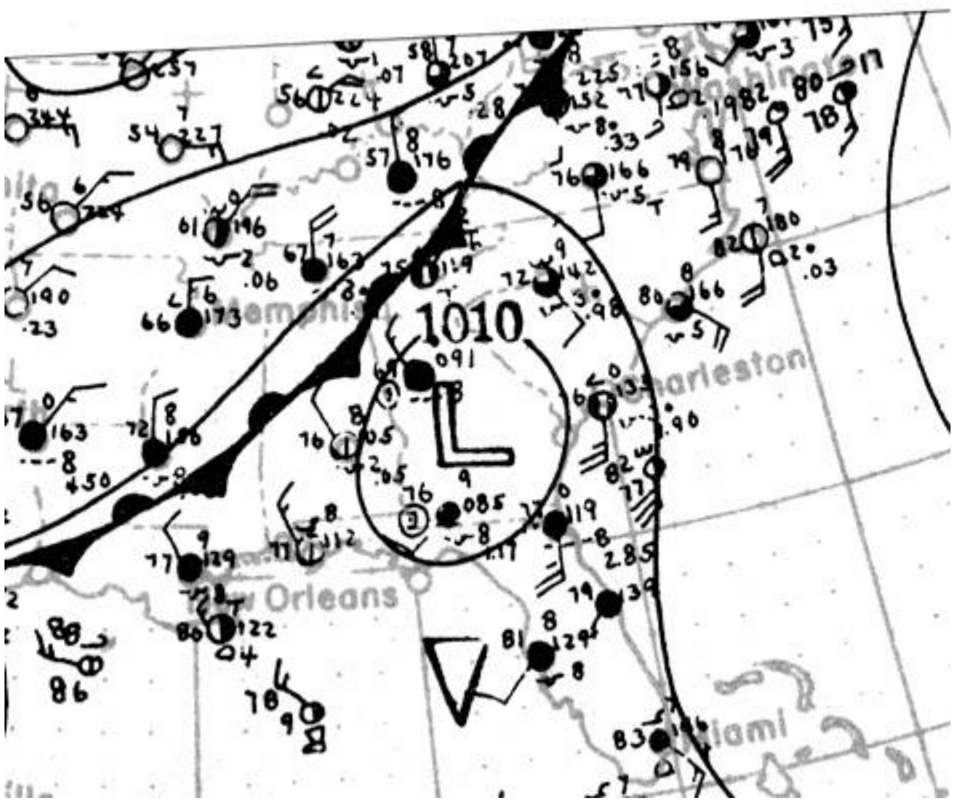


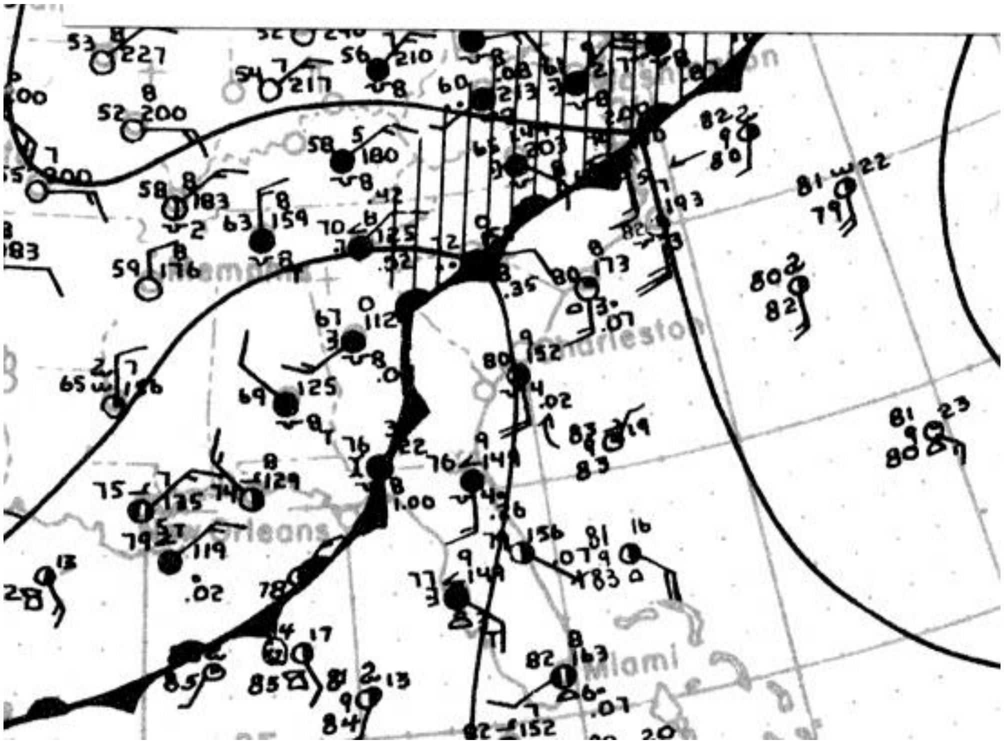
MASS RAINFALL CURVES

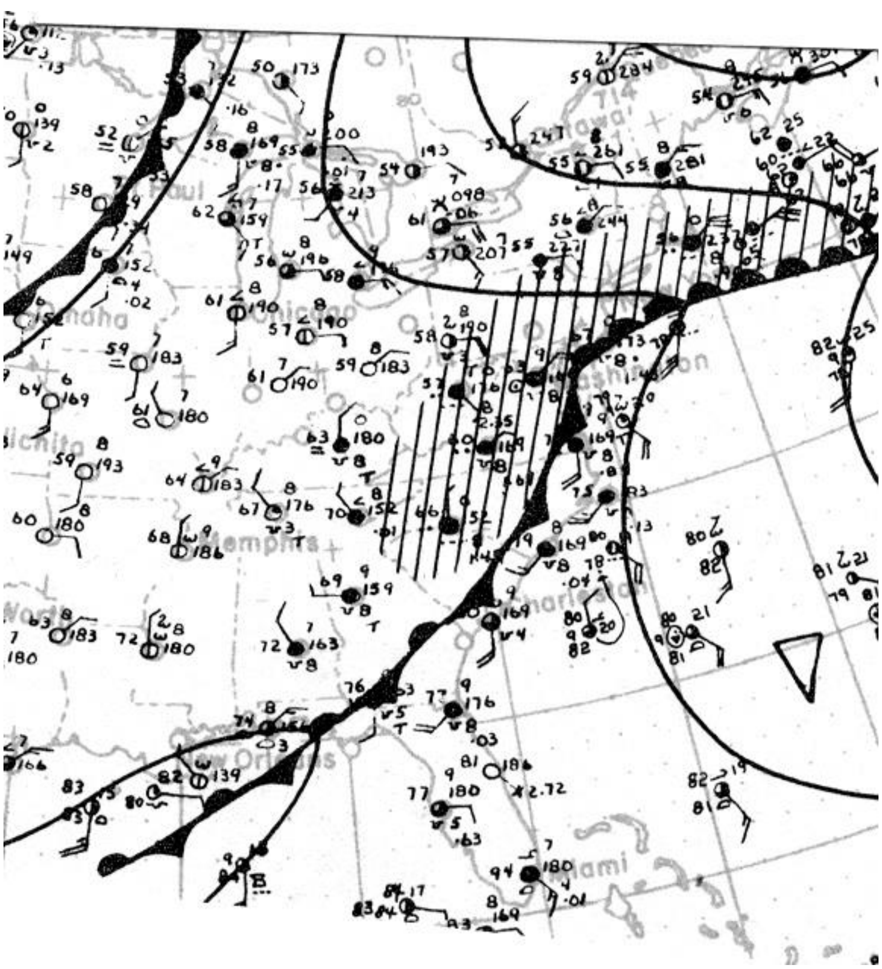


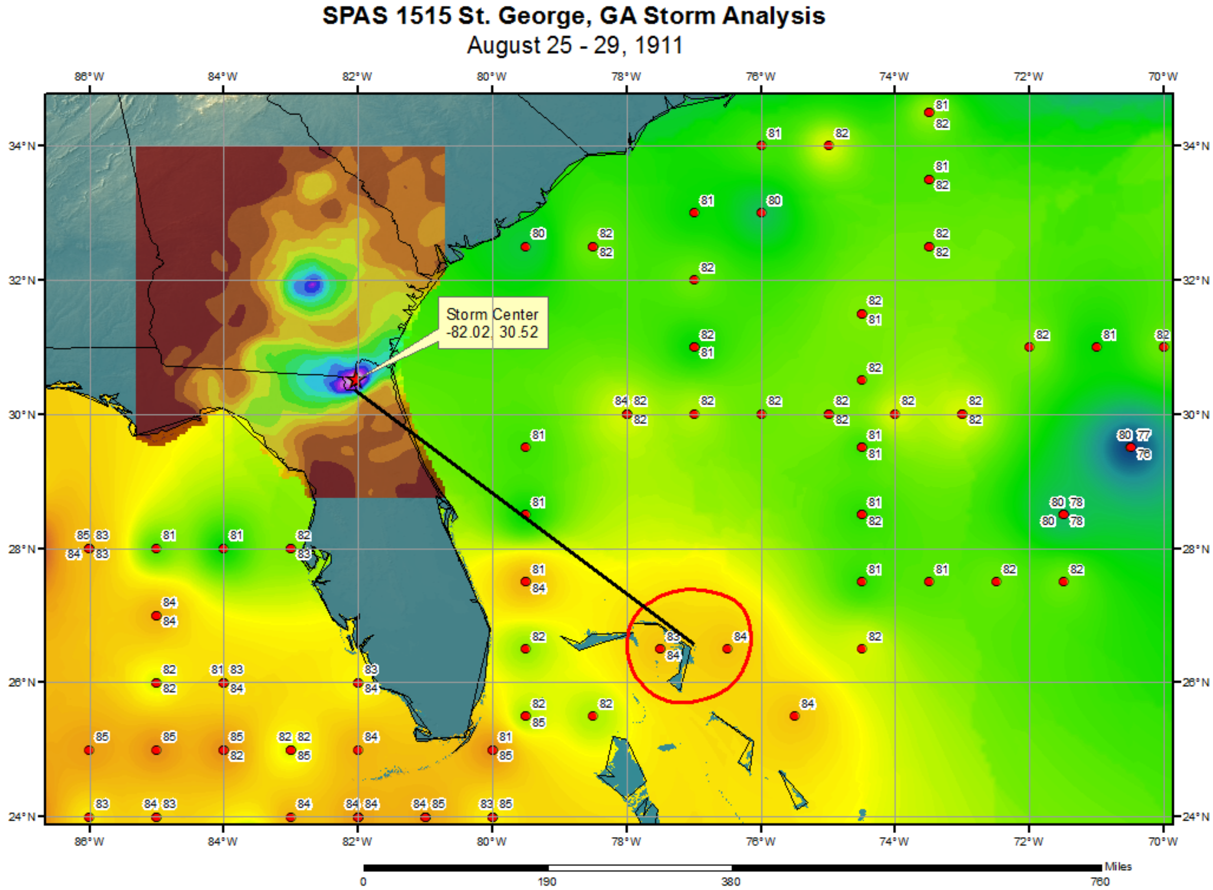
FORM S-3E


1010
New Orleans


1010
L
Memphis
Charleston
New Orleans
Miami


Miami




SPAS 1515 St. George, GA Storm Analysis
August 25 - 29, 1911
Storm Center
-82.02, 30.52
Miles
0
190
380
760

Storm Precipitation Analysis System (SPAS) For Storm #1299_1 SPAS Analysis

General Storm Location: North Carolina and South Carolina

Storm Dates: July 13-17, 1916

Event: Alta Pass, NC (SA 2-9) and Kingstree, SC (SA 2-9a)

DAD Zone 1

Latitude: 35.8792

Longitude: -81.8708

Max. Grid Rainfall Amount: 24.90"

Max. Observed Rainfall Amount: 23.73"

Number of Stations: 240 (194 Daily, 1 Hourly, 6 Hourly Pseudo, and 39 Supplemental)

SPAS Version: 9.5

Basemap: PRISM July 1916 Precipitation

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

Radar Included: No

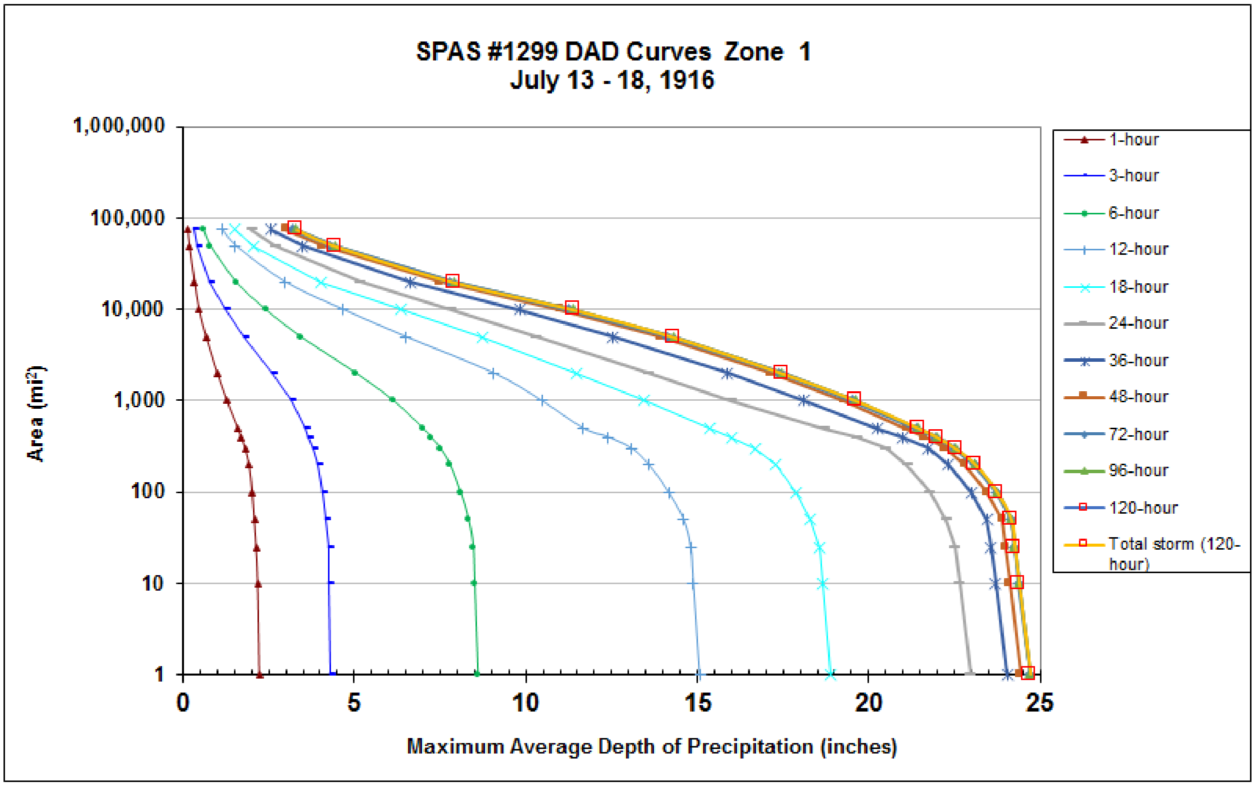
Depth-Area-Duration (DAD) analysis: Yes

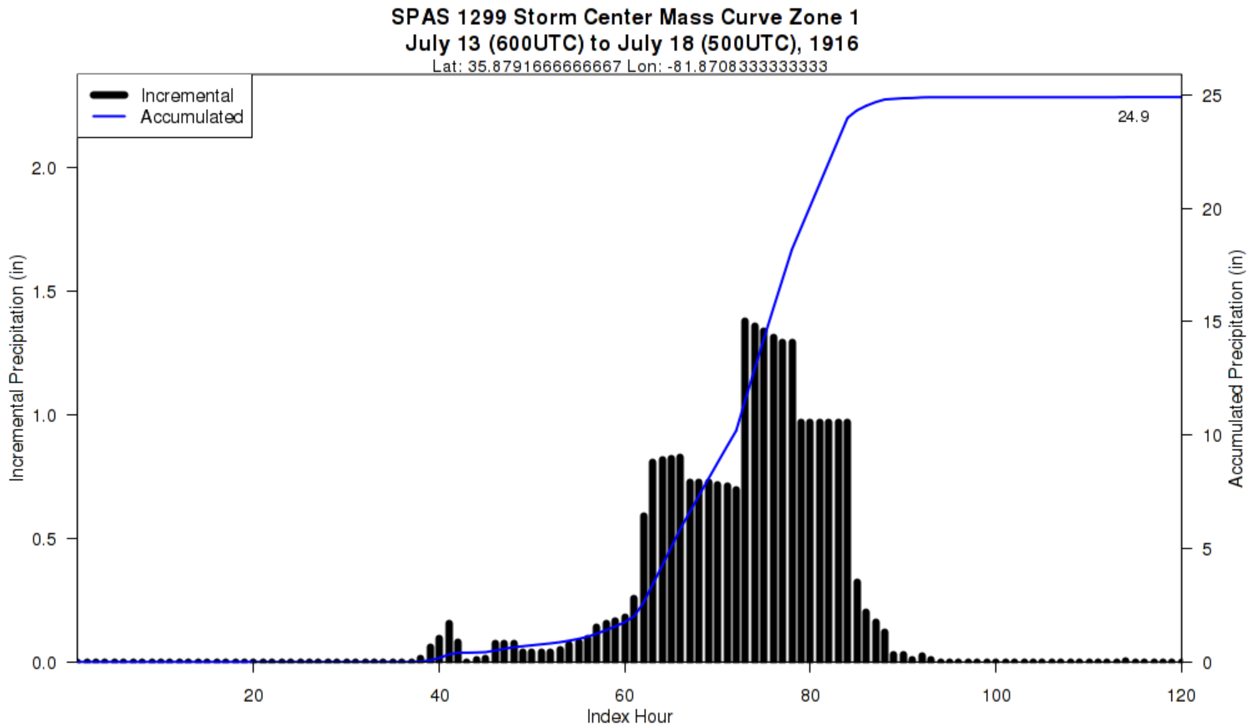
Reliability of results: This analysis was based on hourly data, Hourly pseudo data (derived from storm study mass curves), daily data, and supplemental station data. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations.

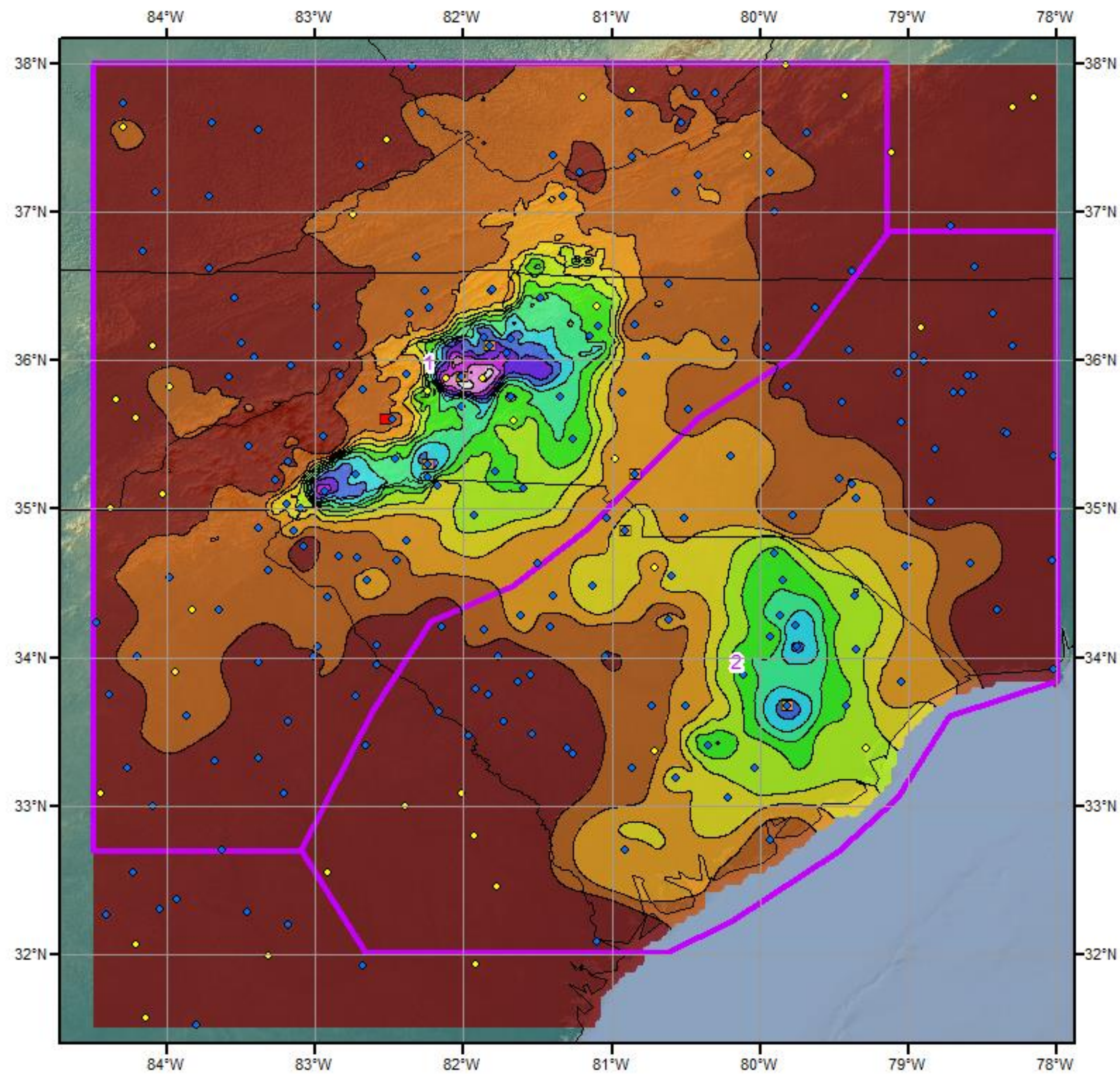
							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1299_1	-81.8708	35.8792	1,968	2,000	30-Jul	81.50	3.86	0.60	85	3.260	83.88	84.0	4.30	0.63	90	3.670	1.126

Storm 1299 - July 13 (0600 UTC) - July 18 (0500 UTC), 1916
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

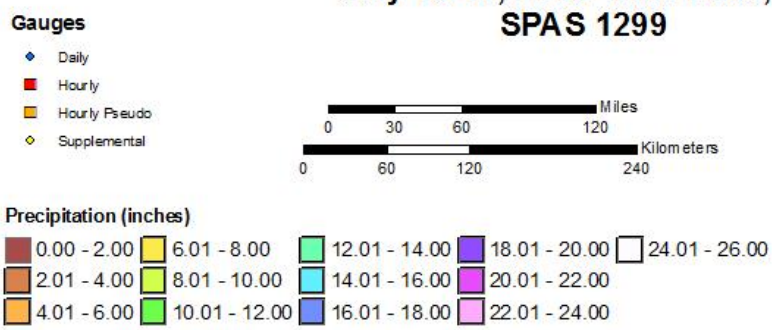
Area (mi^2)	Duration (hours)										
	1	3	6	12	18	24	36	48	72	96	120	Total
0.4	2.26	4.33	8.65	15.14	18.98	23.10	24.17	24.57	24.84	24.84	24.84	24.84
1	2.24	4.31	8.61	15.07	18.89	22.97	24.04	24.44	24.70	24.71	24.71	24.71
10	2.19	4.26	8.51	14.88	18.65	22.64	23.70	24.12	24.37	24.38	24.38	24.38
25	2.14	4.23	8.47	14.81	18.55	22.51	23.57	24.00	24.24	24.25	24.25	24.25
50	2.09	4.18	8.34	14.60	18.29	22.25	23.46	23.90	24.15	24.15	24.15	24.15
100	2.03	4.07	8.10	14.16	17.88	21.78	22.99	23.44	23.72	23.74	23.74	23.74
200	1.94	3.93	7.79	13.58	17.27	21.11	22.34	22.82	23.09	23.11	23.11	23.11
300	1.82	3.79	7.52	13.09	16.71	20.49	21.73	22.23	22.50	22.54	22.54	22.54
400	1.71	3.66	7.24	12.41	16.01	19.66	20.99	21.64	21.93	22.00	22.00	22.00
500	1.61	3.56	7.00	11.67	15.37	18.72	20.28	21.11	21.39	21.46	21.46	21.46
1,000	1.29	3.16	6.14	10.46	13.43	16.00	18.12	19.28	19.52	19.64	19.64	19.64
2,000	1.01	2.61	5.05	9.07	11.47	13.57	15.88	17.13	17.37	17.49	17.49	17.49
5,000	0.68	1.78	3.44	6.51	8.74	10.31	12.55	13.93	14.15	14.31	14.31	14.31
10,000	0.47	1.24	2.40	4.66	6.34	7.83	9.82	11.01	11.24	11.39	11.39	11.39
20,000	0.34	0.78	1.54	2.97	4.01	5.18	6.63	7.52	7.76	7.89	7.89	7.89
50,000	0.19	0.41	0.79	1.52	2.04	2.69	3.49	4.07	4.31	4.42	4.42	4.42
75,378	0.14	0.30	0.58	1.12	1.51	1.99	2.58	3.01	3.20	3.31	3.31	3.31

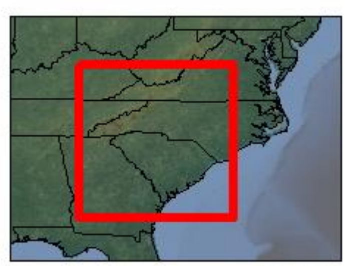



SPAS 1299 Storm Center Mass Curve Zone 1
July 13 (600UTC) to July 18 (500UTC), 1916
Lat: 35.8791666666667 Lon: -81.8708333333333
Incremental
Accumulated
24.9
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25
20
40
60
80
100
120



Total Storm (120-hr) Precipitation (inches)
July 13-17, 1916 - Alta Pass, NC
SPAS 1299

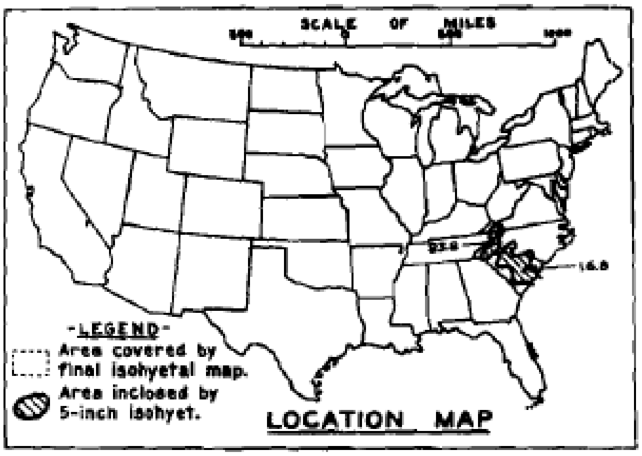




9/06/2013

WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – PERTINENT DATA SHEET



Storm of July 13 – 17, 1916
Assignment S A 2 – 9
Location N.C. and S.C.
Study Prepared by:
South Atlantic Division
Charleston District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 10/18/39
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 6/16/45
Remarks: TOTAL STORM AREA
Centers at; Altapass, N.C. and Kingstree, S.C.

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1 : 1,000,000

Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) 10
- Form 5001-B (24-hour " ") 27
- Form 5001-D (" " " ") .... -
- Miscl. precip. records, meteorological data, etc. .... -
- Form 5002 (Mass rainfall curves) 26

PART II

Final isohyetal maps, in 1 sheet, scale 1 : 1,000,000

Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) 3
- Form S-11 (Depth-area data from isohyetal map) 3
- Form S-12 (Maximum depth-duration data) 12
- Maximum duration-depth-area curves 1
- Data relating to periods of maximum rainfall 2

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	72	96	108
10	8.0	12.6	17.0	22.2	22.9	23.0	23.2	23.7	23.7	23.8	23.8
100	7.2	12.0	15.6	19.3	20.8	21.1	21.7	22.1	22.1	22.2	22.2
200	6.9	11.7	15.0	18.3	19.9	20.3	20.9	21.3	21.4	21.4	21.4
500	6.4	11.1	13.9	16.6	18.3	18.8	19.5	19.8	20.1	20.1	20.1
1,000	5.9	10.4	12.9	15.0	16.7	17.3	18.1	18.4	18.6	18.7	18.7
2,000	5.1	9.3	11.6	13.3	14.9	15.5	16.3	16.6	16.8	16.9	16.9
5,000	3.9	7.4	9.3	10.9	12.0	12.6	13.4	13.6	13.8	14.0	14.0
10,000	3.0	5.5	7.2	8.6	9.4	9.9	10.6	10.8	11.0	11.2	11.2
20,000	2.1	3.8	5.0	5.9	6.6	7.3	8.0	8.2	8.4	8.6	8.6
37,000	1.3	2.2	3.0	3.8	4.7	5.6	7.0	7.5	7.8	8.1	8.1

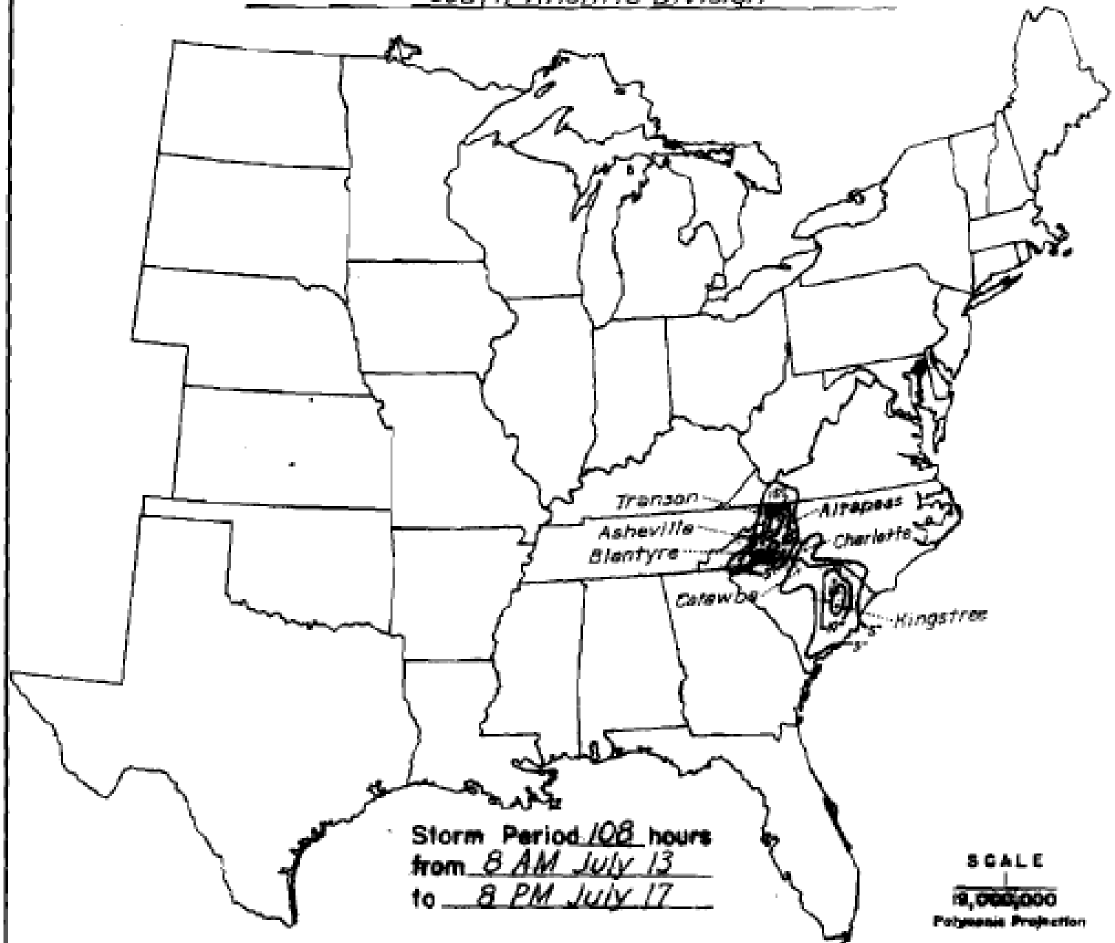
Form S-2

WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

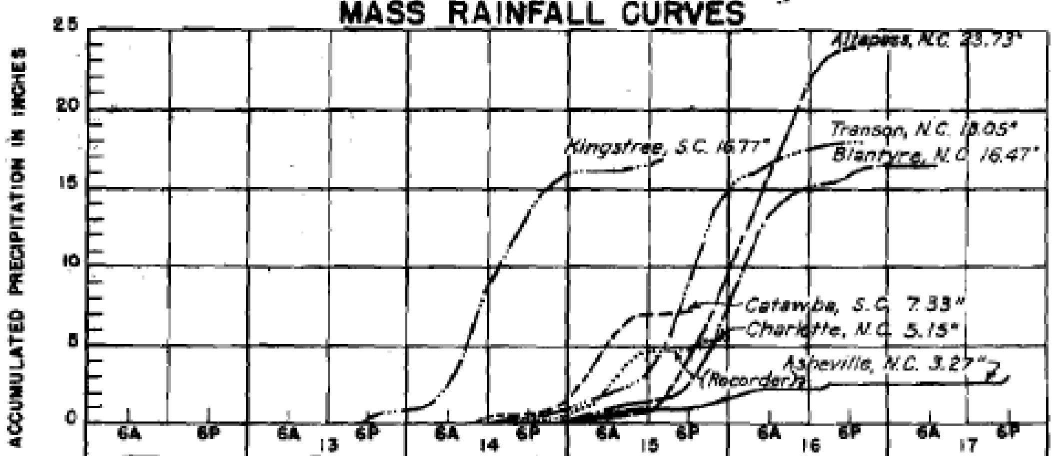
STORM STUDIES – ISOHYETAL MAP

Storm of *July 13-17, 1916* Assignment *SA 2-9*

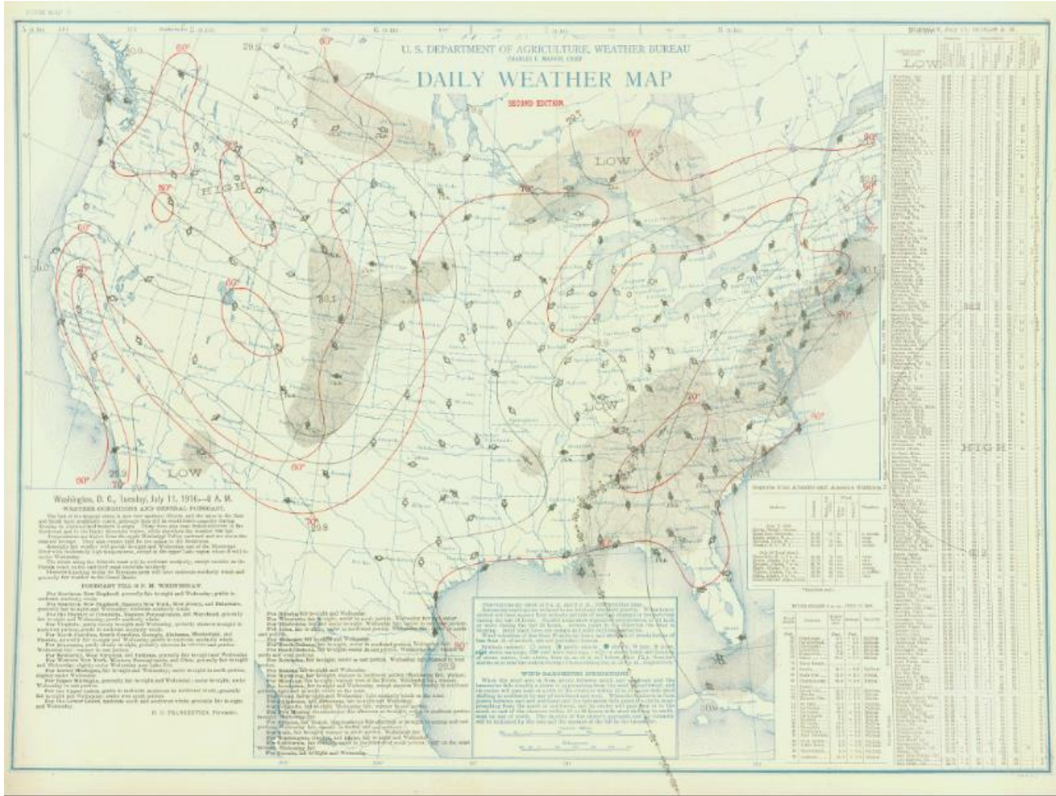
Study Prepared by: *Charleston S.C. District*
South Atlantic Division

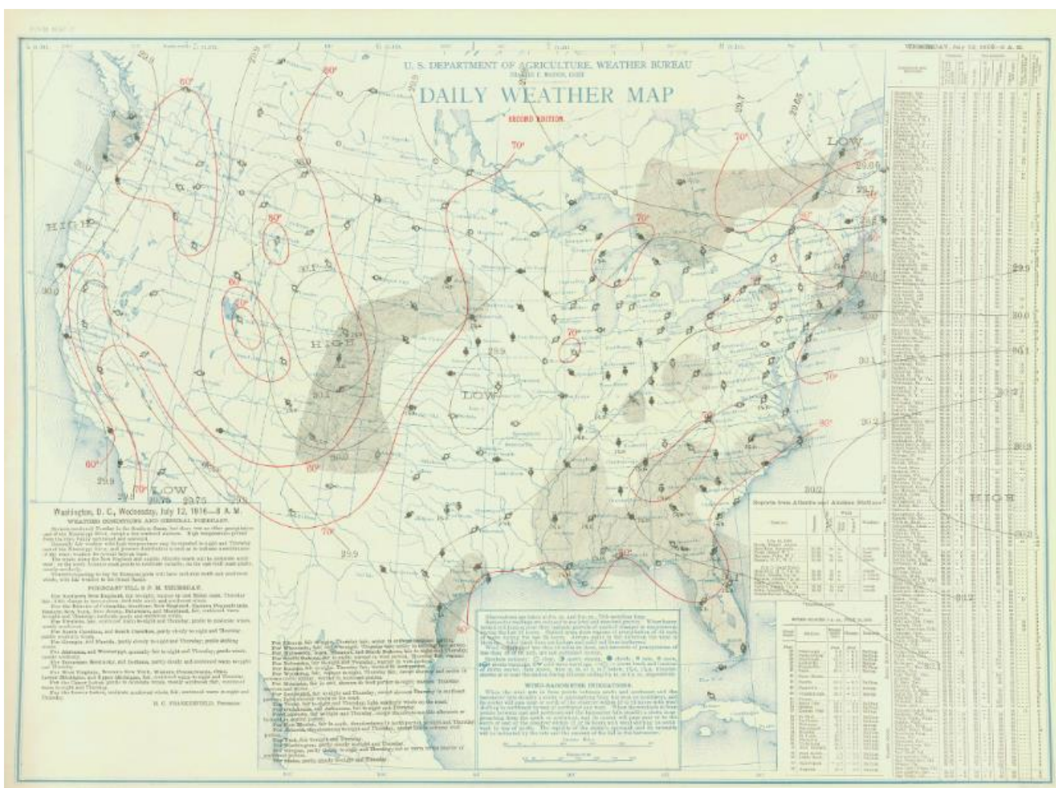


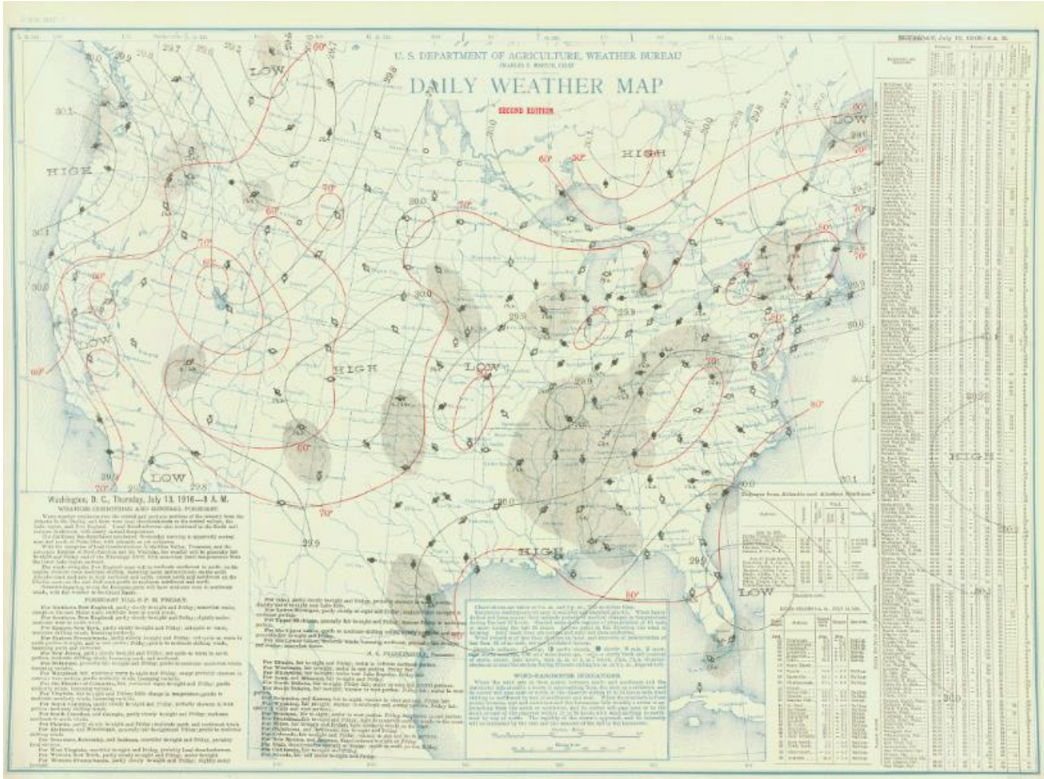
MASS RAINFALL CURVES

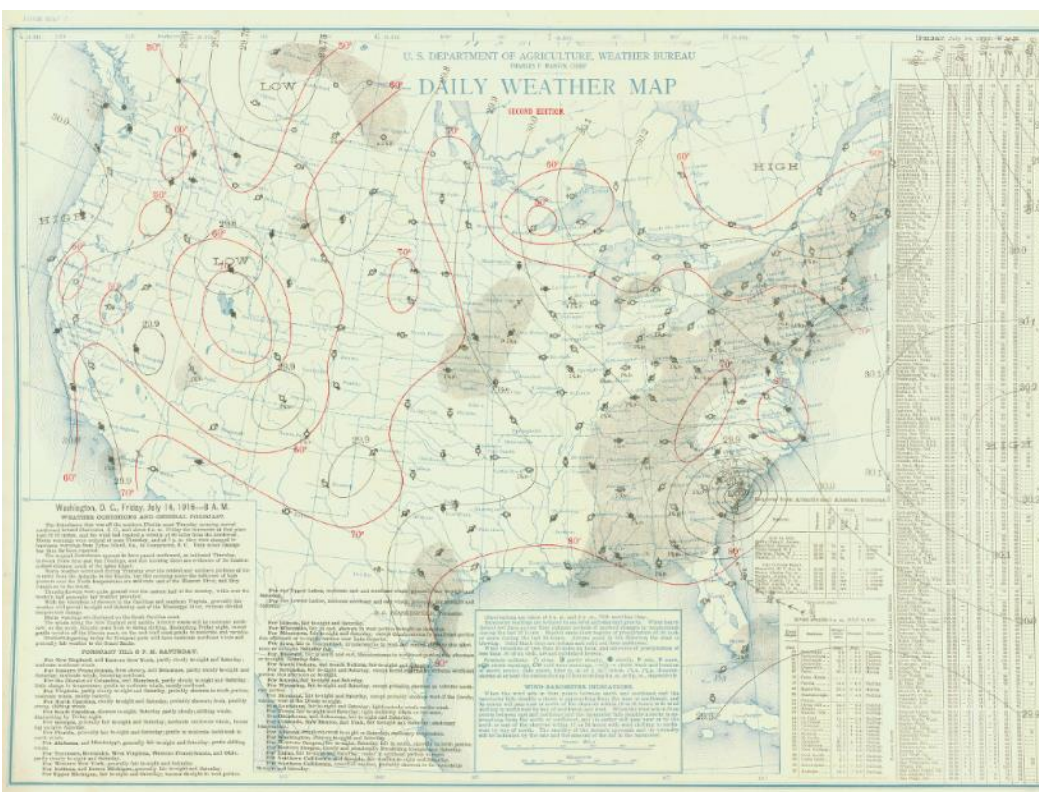


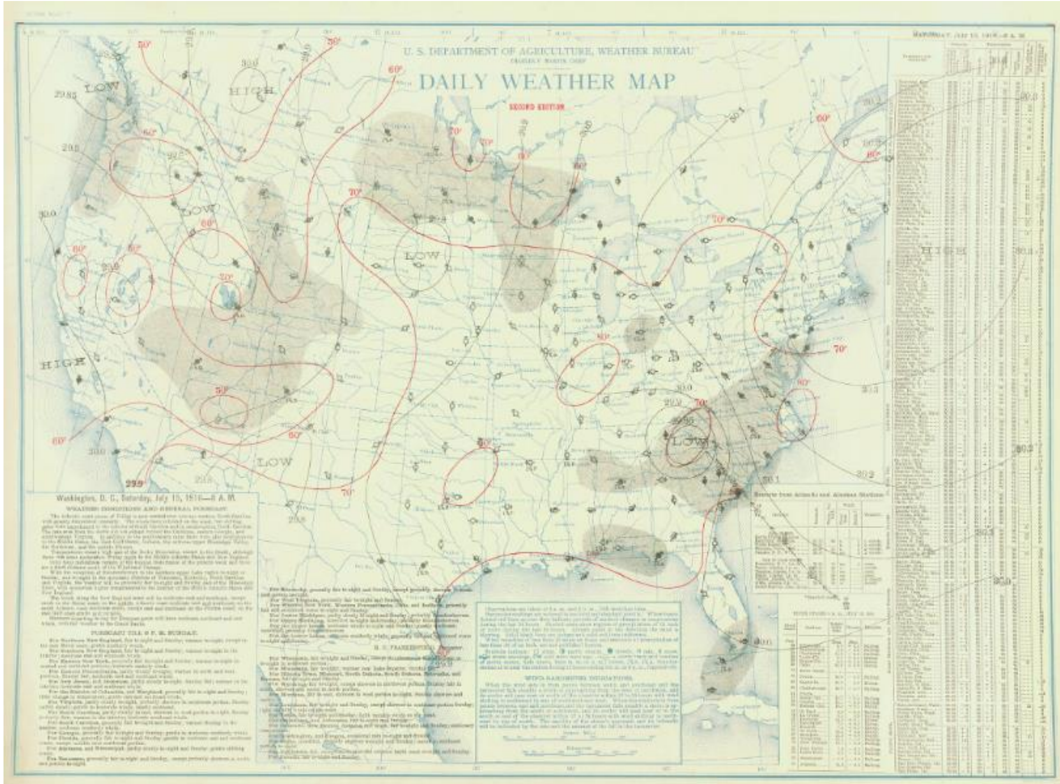
FORM S-3E

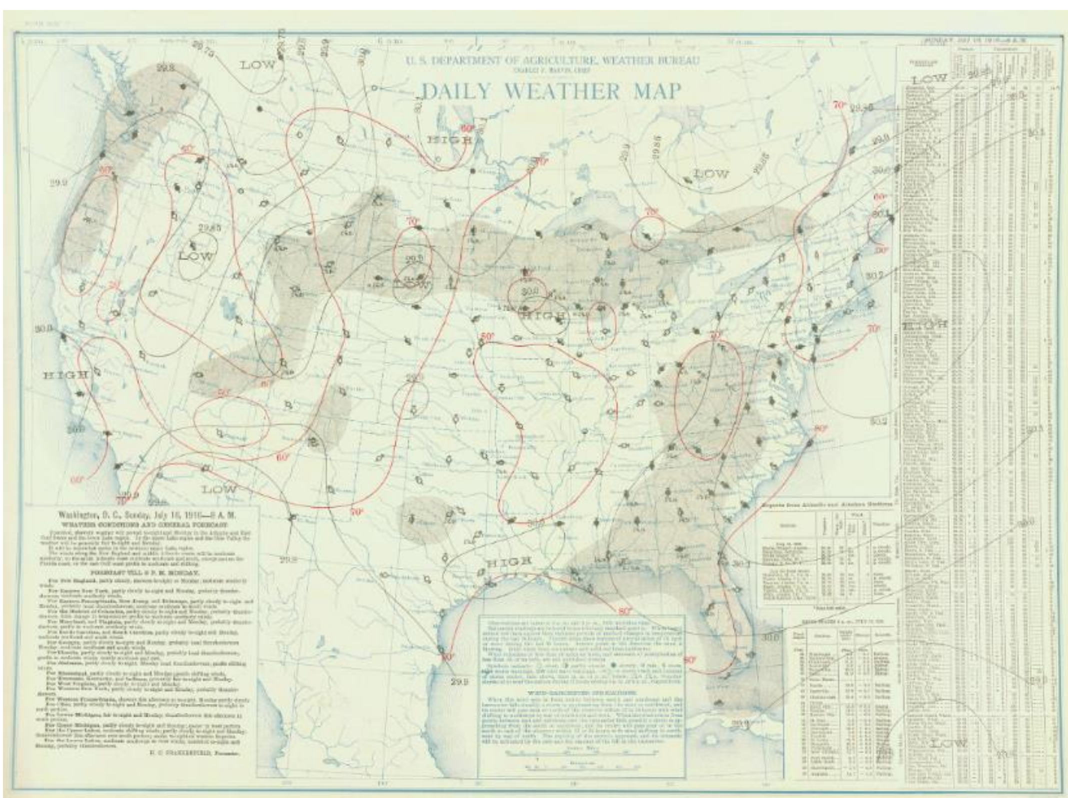

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
LOW
LOW
HIGH
Washington, D. C., Tuesday, July 11, 1916—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. WEDNESDAY.
WIND-BAROMETER INDICATIONS

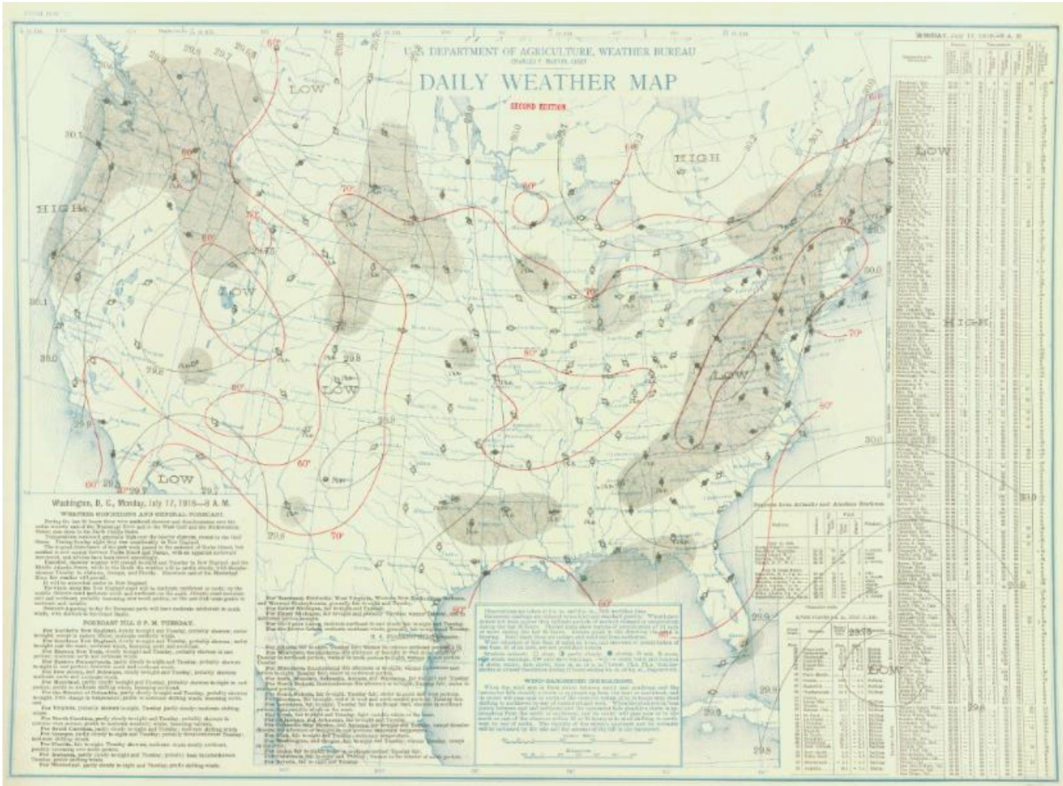

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
LOW
HIGH
HIGH
LOW
LOW
HIGH
Washington, D. C., Wednesday, July 12, 1916—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. THURSDAY.
WIND-BAROMETER INDICATIONS

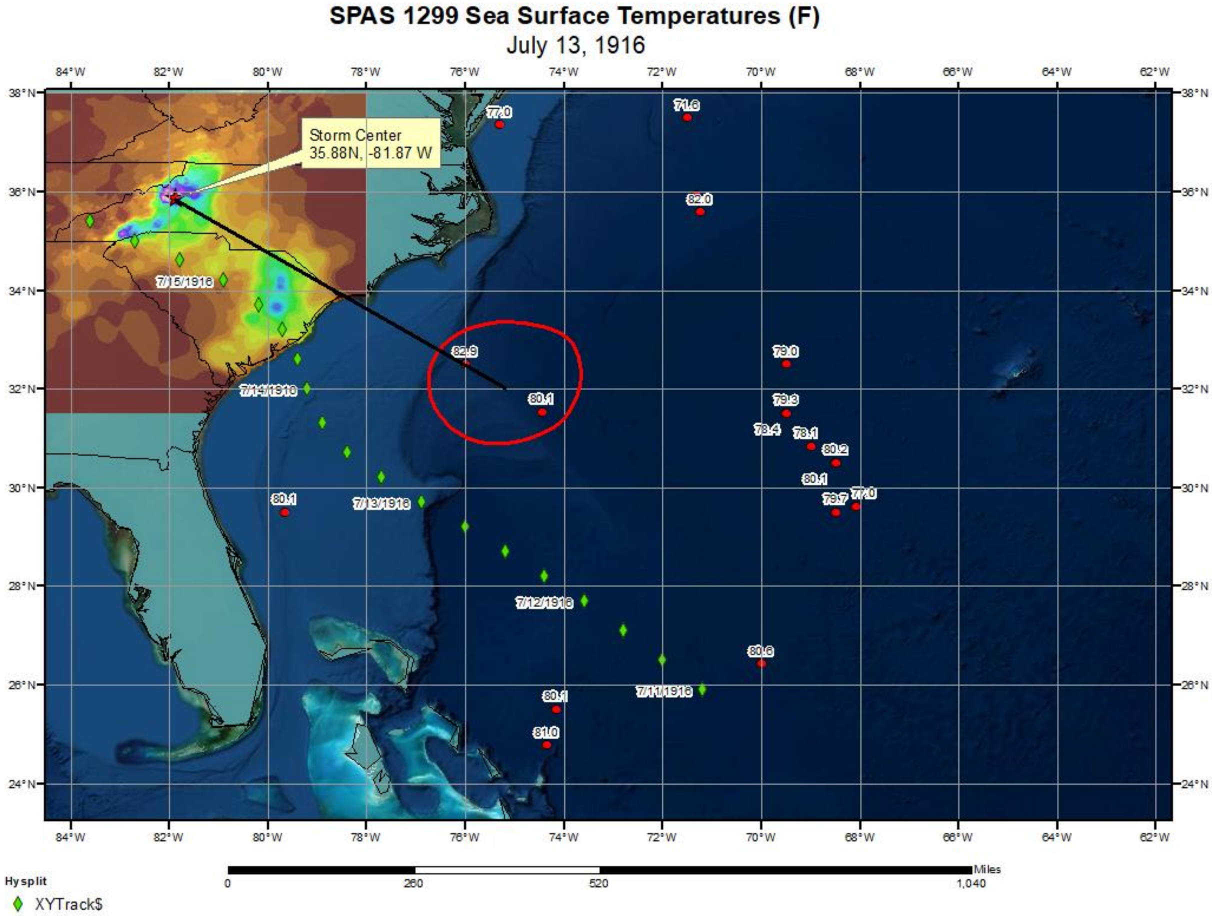

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
Washington, D. C., Thursday, July 13, 1916—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
Washington, D. C., Friday, July 14, 1916—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
Washington, D. C., Saturday, July 15, 1916—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Sunday, July 16, 1916—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
Washington, D. C., Monday, July 17, 1916—8 A. M.



SPAS 1299 Sea Surface Temperatures (F)
July 13, 1916
Storm Center
35.88N, -81.87 W
7/15/1916
7/14/1916
7/13/1916
7/12/1916
7/11/1916
77.0
71.6
82.0
82.9
80.1
79.0
79.3
78.4
78.1
80.2
80.1
79.7
77.0
80.1
80.6
80.1
81.0
Hysplit
XYTrack$
Miles
0
260
520
1,040

TVA 3414 (WCP-2-46)
Tennessee Valley Authority

Hydraulic Data Division

Observed and Maximum Factors of
Storm Adjustment and Transposition

Storm of July 13-17, 1916 Adjusted to Storm Date

Area Of Observed Storm	Area Of Transposition
Location Western North Carolina	Basin French Broad above Asheville
Inflow Direction SE-310	Inflow Direction SSE
Inflow Barrier H= 1600 Ft.	Inflow Barrier H'= 2000 Ft.
Dew Point Station Charlotte, N. C.	Maximum Dew Point Location From Inflow
Distance to Barrier 70 Miles	Barrier 50 Miles NNE of Augusta, Ga.

(1) T Hours	(2) DP(obs) Degrees	(3) DP(max) Degrees	(4) We(obs) Inches H= 1600	(5) We(max) Inches H'= 2000			(6) R	(7) D(obs) Inches	(8) D(max) Inches
1									
3									
6	74.8	76.9	1.42	1.57			1.104	6.0	6.6
12	74.5	76.6	1.40	1.55			1.107	10.4	11.5
18	74.2	76.3	1.37	1.51			1.101	13.0	14.3
24	74.0	76.1	1.35	1.49			1.103	15.1	16.7
30	73.8	75.9	1.33	1.47			1.105	16.8	18.6
36	73.6	75.7	1.31	1.45			1.107	17.4	19.3
42	73.6	75.7	1.31	1.45			1.107	18.1	20.0
48	73.5	75.6	1.30	1.44			1.108	18.2	20.2
54									
60									
66									
72	72.9	75.0	1.25	1.39			1.111	18.7	20.8
78									
84									
96									

Computed by JEH Checked by AGK

FIGURE 47.—*Example of method used to adjust and transpose storms.*

Storm Precipitation Analysis System (SPAS) For Storm #1299_2 SPAS Analysis

General Storm Location: North Carolina and South Carolina

Storm Dates: July 13-17, 1916

Event: Alta Pass, NC (SA 2-9) and Kingstree, SC (SA 2-9a)

DAD Zone 2

Latitude: 33.6625

Longitude: -79.8292

Max. Grid Rainfall Amount: 16.79"

Max. Observed Rainfall Amount: 16.77"

Number of Stations: 240 (194 Daily, 1 Hourly, 6 Hourly Pseudo, and 39 Supplemental)

SPAS Version: 9.5

Basemap: PRISM July 1916 Precipitation

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

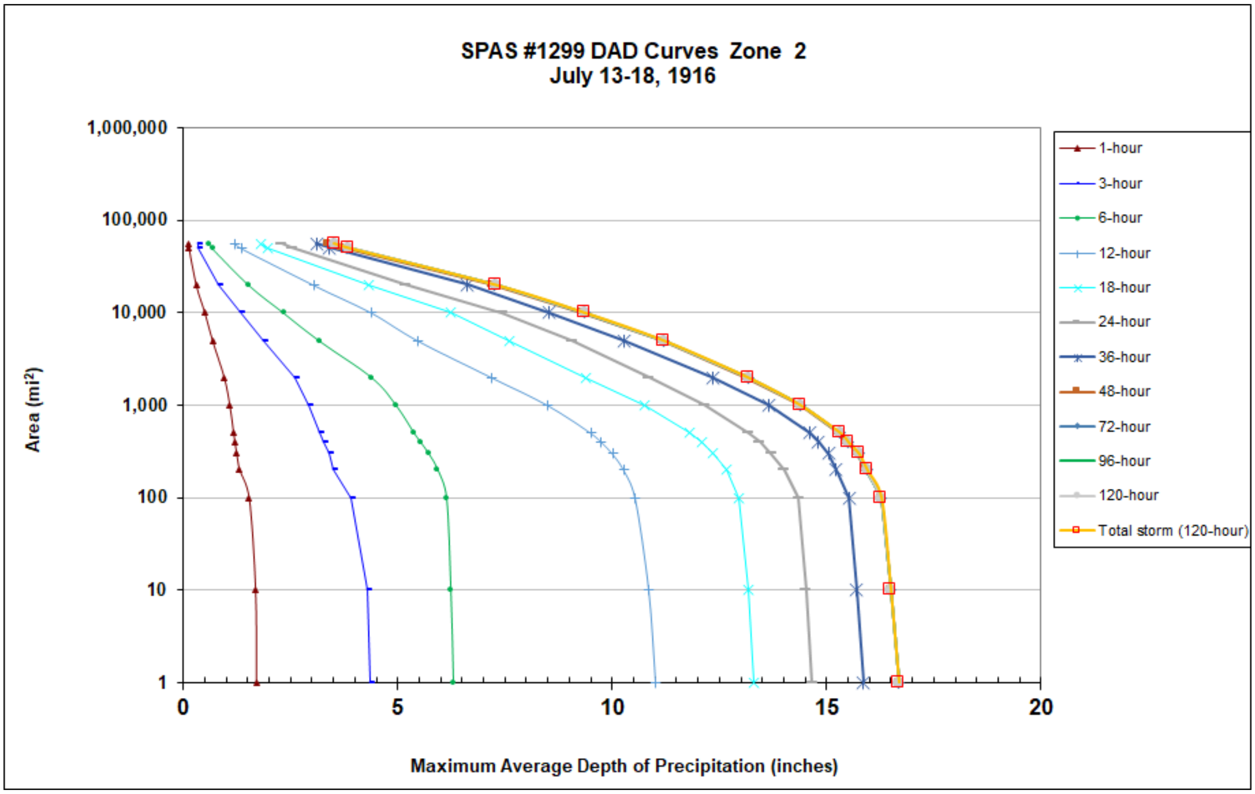
Radar Included: No

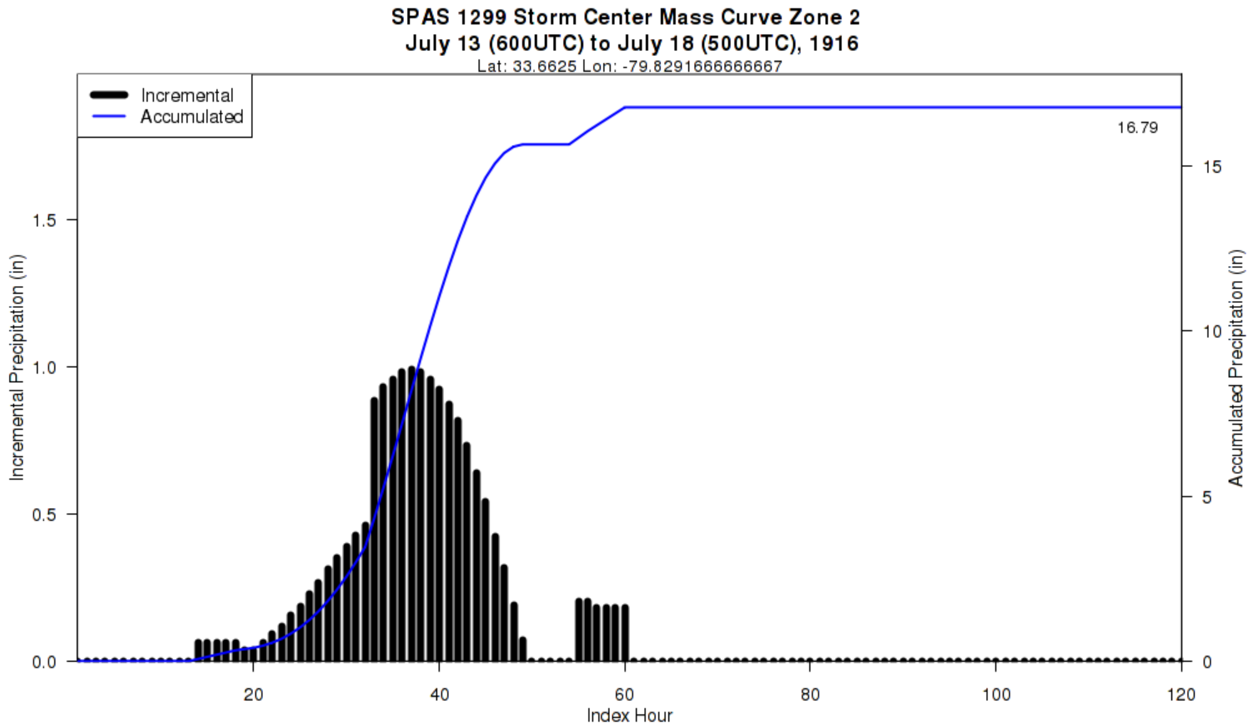
Depth-Area-Duration (DAD) analysis: Yes

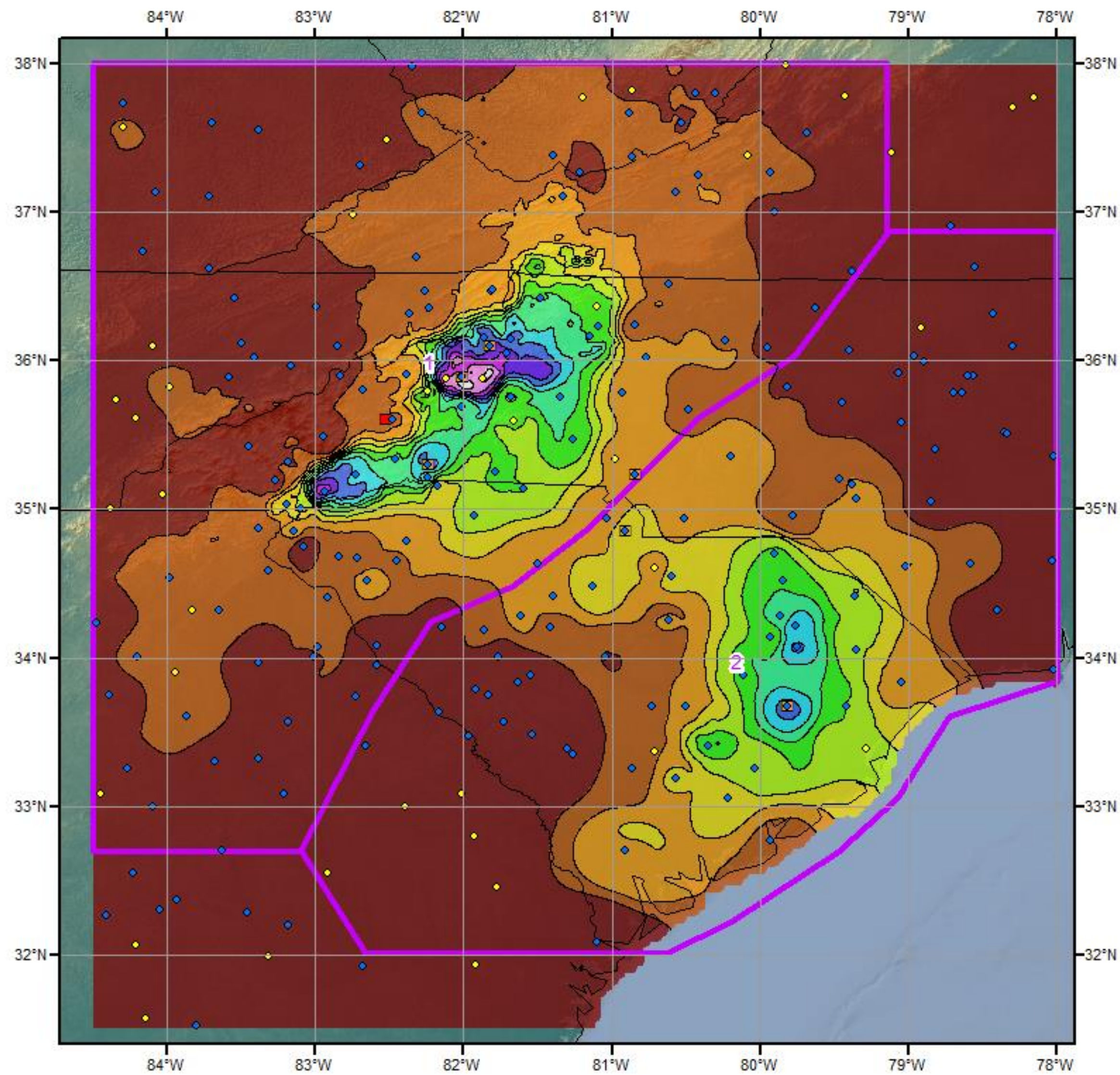
Reliability of results: This analysis was based on hourly data, Hourly pseudo data (derived from storm study mass curves), daily data, and supplemental station data. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1299_2	-79.8292	33.6625	44	0	15-Jul	76.00	2.99	0.00	74	2.990	78.95	79.0	3.44	0.00	80	3.440	1.151

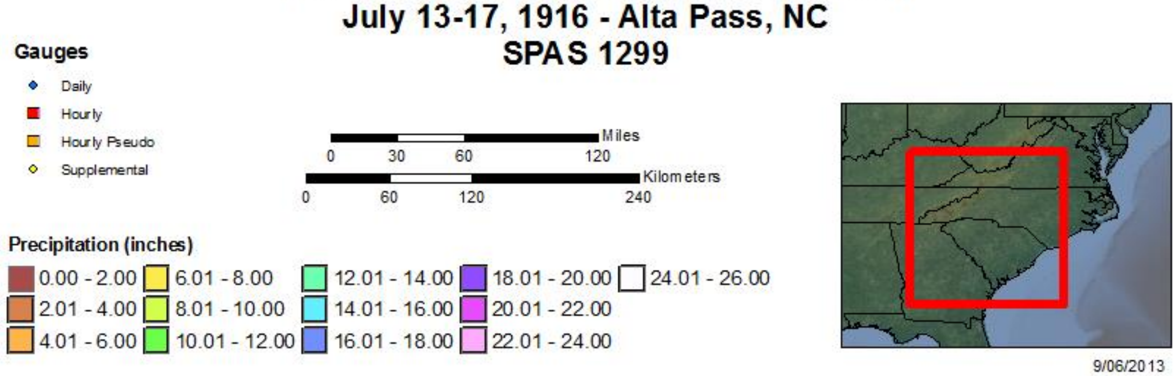
Storm 1299 - July 13 (0600 UTC) - July 18 (0500 UTC), 1916 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
Area (mi²)	Duration (hours)											
	1-hr	3-hr	6-hr	12-hr	18-hr	24-hr	36-hr	48-hr	72-hr	96-hr	120-hr	Total
1	1.70	4.35	6.29	11.02	13.31	14.67	15.86	16.68	16.68	16.68	16.68	16.68
10	1.68	4.30	6.23	10.86	13.16	14.52	15.69	16.49	16.49	16.49	16.49	16.49
100	1.53	3.92	6.13	10.54	12.95	14.35	15.52	16.27	16.27	16.27	16.27	16.27
200	1.31	3.51	5.93	10.27	12.66	14.01	15.22	15.92	15.94	15.94	15.94	15.94
300	1.24	3.39	5.72	10.01	12.36	13.71	15.04	15.71	15.74	15.74	15.75	15.75
400	1.20	3.27	5.53	9.75	12.08	13.44	14.81	15.47	15.50	15.50	15.50	15.50
500	1.17	3.19	5.38	9.51	11.82	13.18	14.62	15.29	15.32	15.32	15.32	15.32
1000	1.08	2.94	4.96	8.50	10.74	12.15	13.65	14.36	14.39	14.39	14.39	14.39
2000	0.95	2.60	4.39	7.19	9.38	10.86	12.34	13.11	13.16	13.16	13.16	13.16
5000	0.68	1.87	3.17	5.47	7.60	9.06	10.27	11.16	11.20	11.20	11.20	11.20
10,000	0.50	1.34	2.34	4.39	6.22	7.43	8.53	9.30	9.35	9.36	9.36	9.36
20,000	0.30	0.82	1.53	3.04	4.32	5.18	6.63	7.18	7.26	7.27	7.28	7.28
50,000	0.13	0.36	0.68	1.35	1.98	2.53	3.41	3.69	3.82	3.84	3.86	3.86
55,916	0.12	0.33	0.61	1.21	1.80	2.30	3.10	3.36	3.49	3.51	3.52	3.52




SPAS 1299 Storm Center Mass Curve Zone 2
July 13 (600UTC) to July 18 (500UTC), 1916
Lat: 33.6625 Lon: -79.8291666666667
Incremental
Accumulated
16.79
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
0
5
10
15
20
40
60
80
100
120

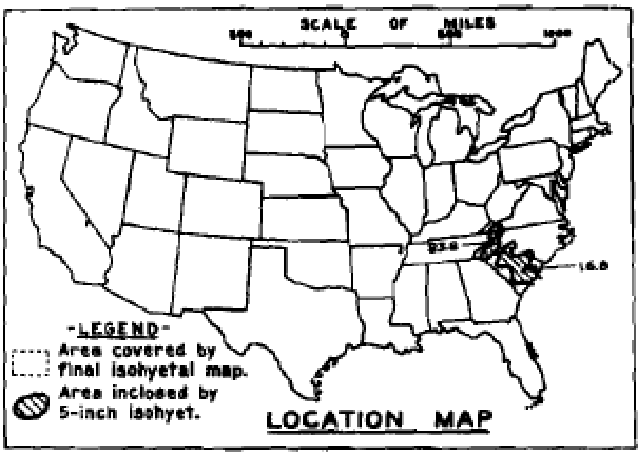


Total Storm (120-hr) Precipitation (inches)
July 13-17, 1916 - Alta Pass, NC
SPAS 1299



WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – PERTINENT DATA SHEET



LOCATION MAP

Storm of July 13 – 17, 1916
Assignment S A 2 – 9
Location N.C. and S.C.
Study Prepared by:
South Atlantic Division
Charleston District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 10/18/39
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 6/16/45
Remarks: TOTAL STORM AREA
Centers at: Altapass, N.C. and Kingstree, S.C.

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1 : 1,000,000

Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) 10
- Form 5001-B (24-hour " ") 27
- Form 5001-D (" " " ") .... -
- Miscl. precip. records, meteorological data, etc. .... -
- Form 5002 (Mass rainfall curves) 26

PART II

Final isohyetal maps, in 1 sheet, scale 1 : 1,000,000

Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) 3
- Form S-11 (Depth-area data from isohyetal map) 3
- Form S-12 (Maximum depth-duration data) 12
- Maximum duration-depth-area curves 1
- Data relating to periods of maximum rainfall 2

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	72	96	108
10	8.0	12.6	17.0	22.2	22.9	23.0	23.2	23.7	23.7	23.8	23.8
100	7.2	12.0	15.6	19.3	20.8	21.1	21.7	22.1	22.1	22.2	22.2
200	6.9	11.7	15.0	18.3	19.9	20.3	20.9	21.3	21.4	21.4	21.4
500	6.4	11.1	13.9	16.6	18.3	18.8	19.5	19.8	20.1	20.1	20.1
1,000	5.9	10.4	12.9	15.0	16.7	17.3	18.1	18.4	18.6	18.7	18.7
2,000	5.1	9.3	11.6	13.3	14.9	15.5	16.3	16.6	16.8	16.9	16.9
5,000	3.9	7.4	9.3	10.9	12.0	12.6	13.4	13.6	13.8	14.0	14.0
10,000	3.0	5.5	7.2	8.6	9.4	9.9	10.6	10.8	11.0	11.2	11.2
20,000	2.1	3.8	5.0	5.9	6.6	7.3	8.0	8.2	8.4	8.6	8.6
37,000	1.3	2.2	3.0	3.8	4.7	5.6	7.0	7.5	7.8	8.1	8.1

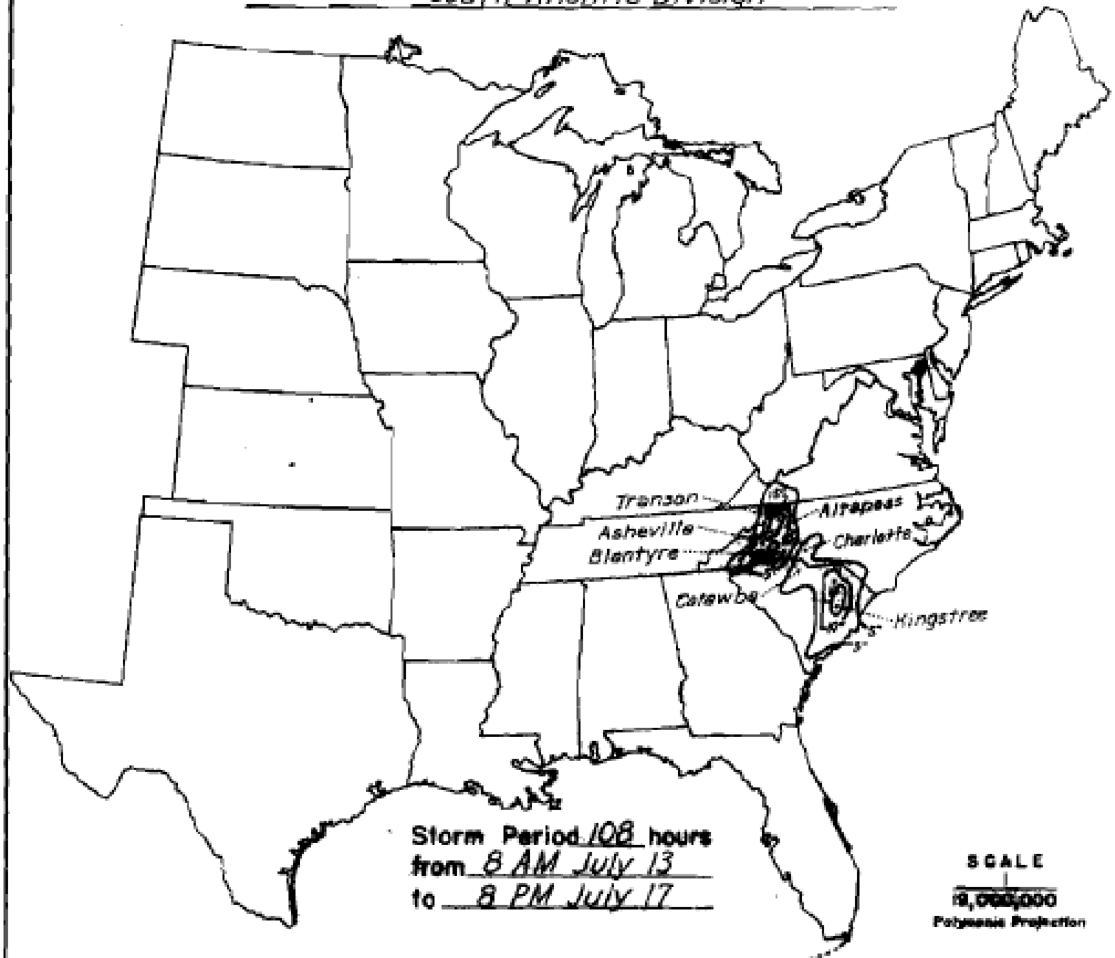
Form S-2

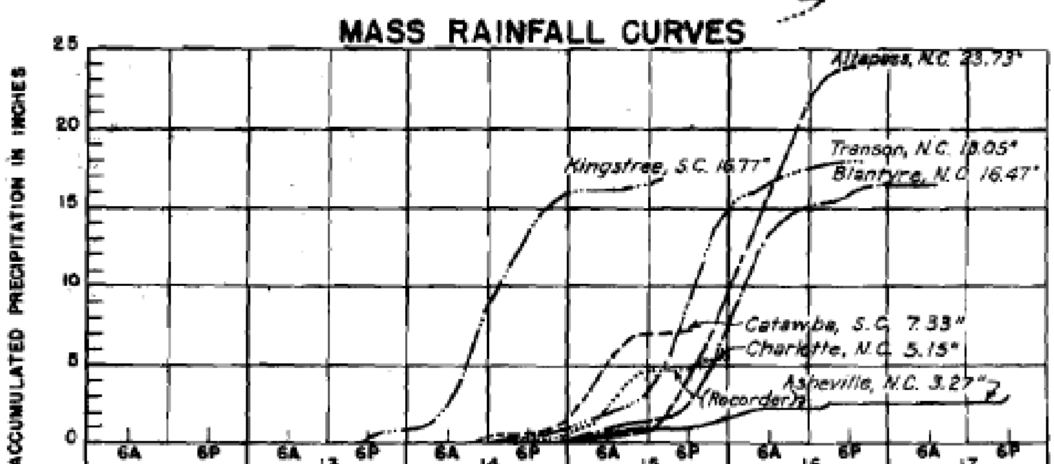
WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – ISOHYETAL MAP

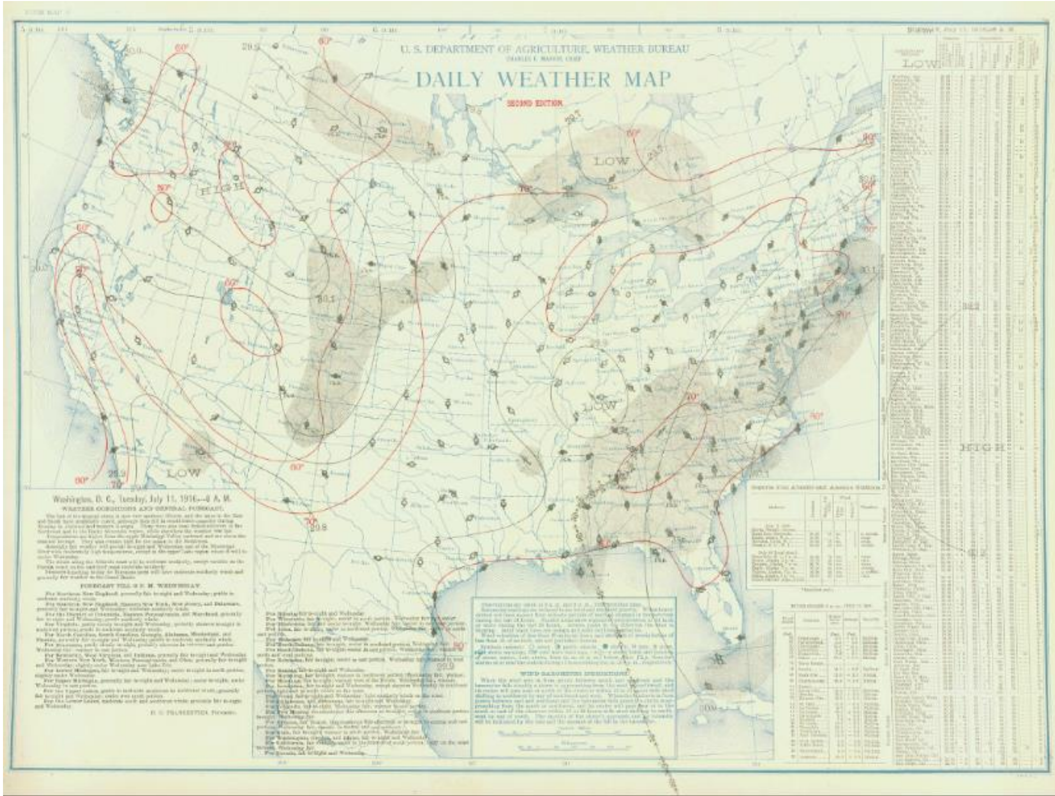
Storm of July 13-17, 1916 Assignment SA 2-9

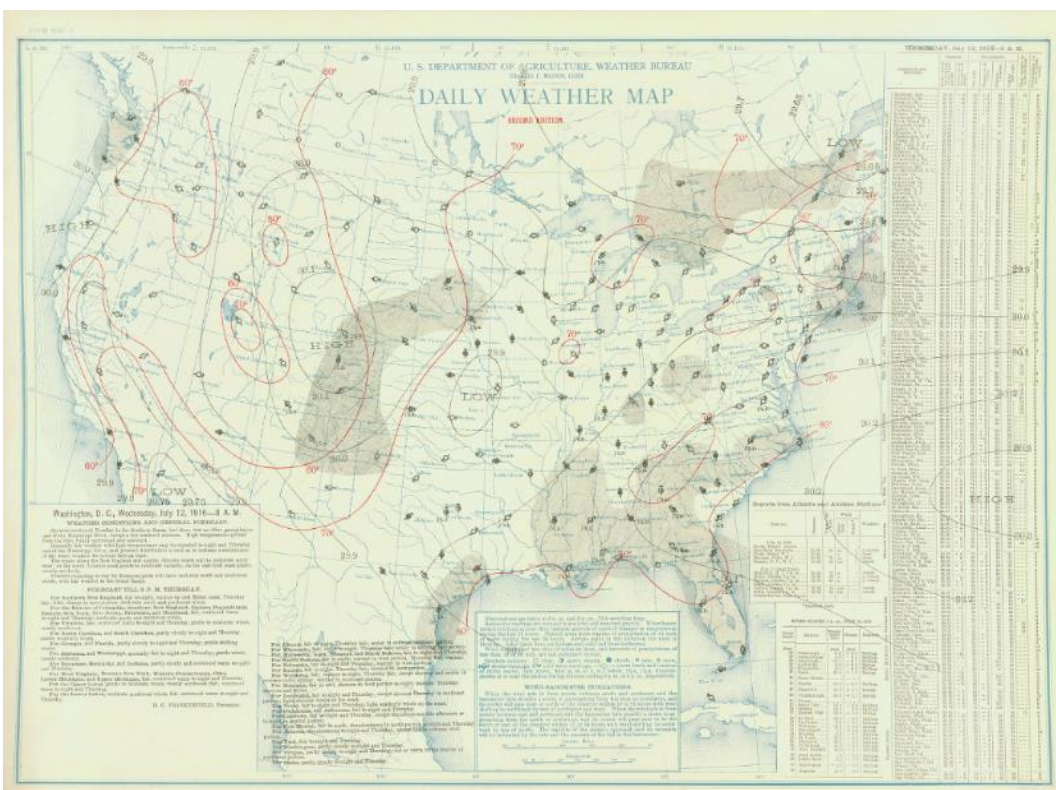
Study Prepared by: Charleston S.C. District, South Atlantic Division

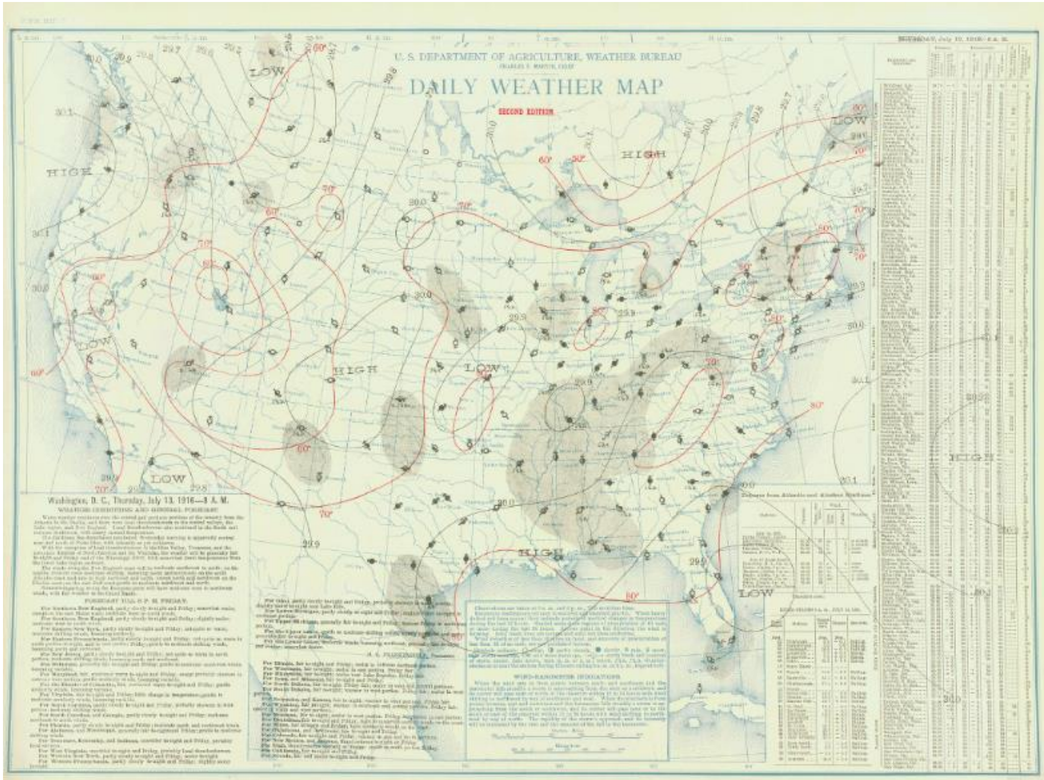


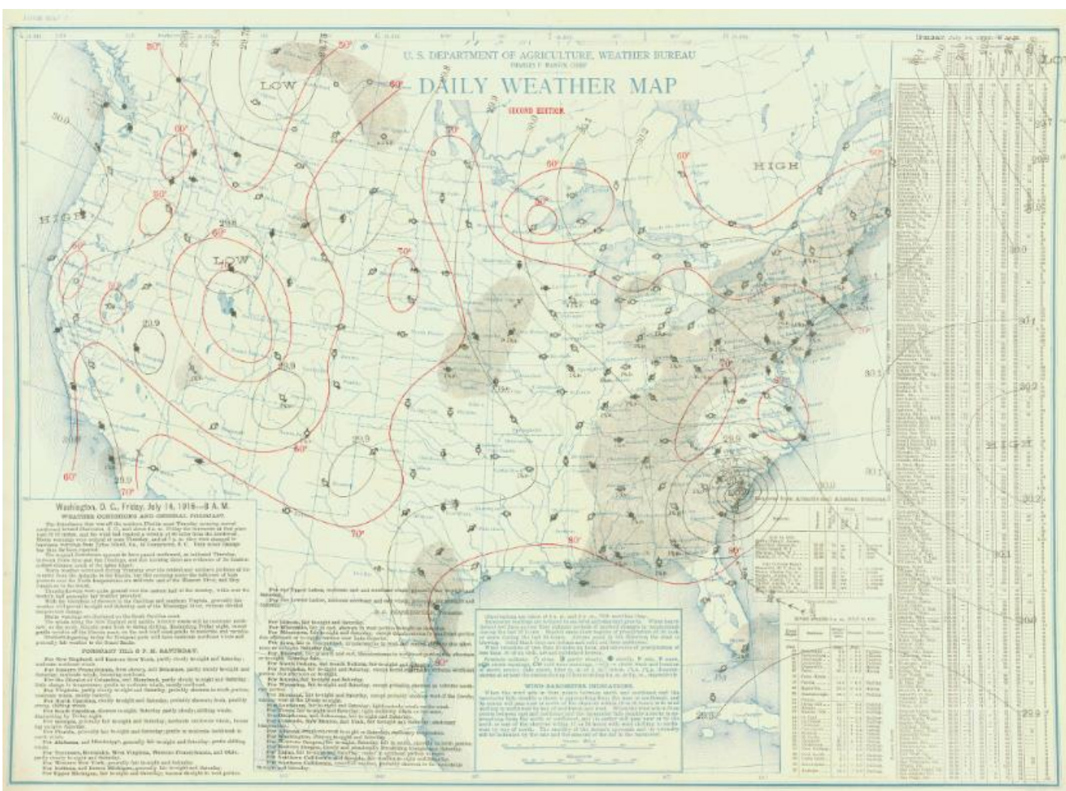


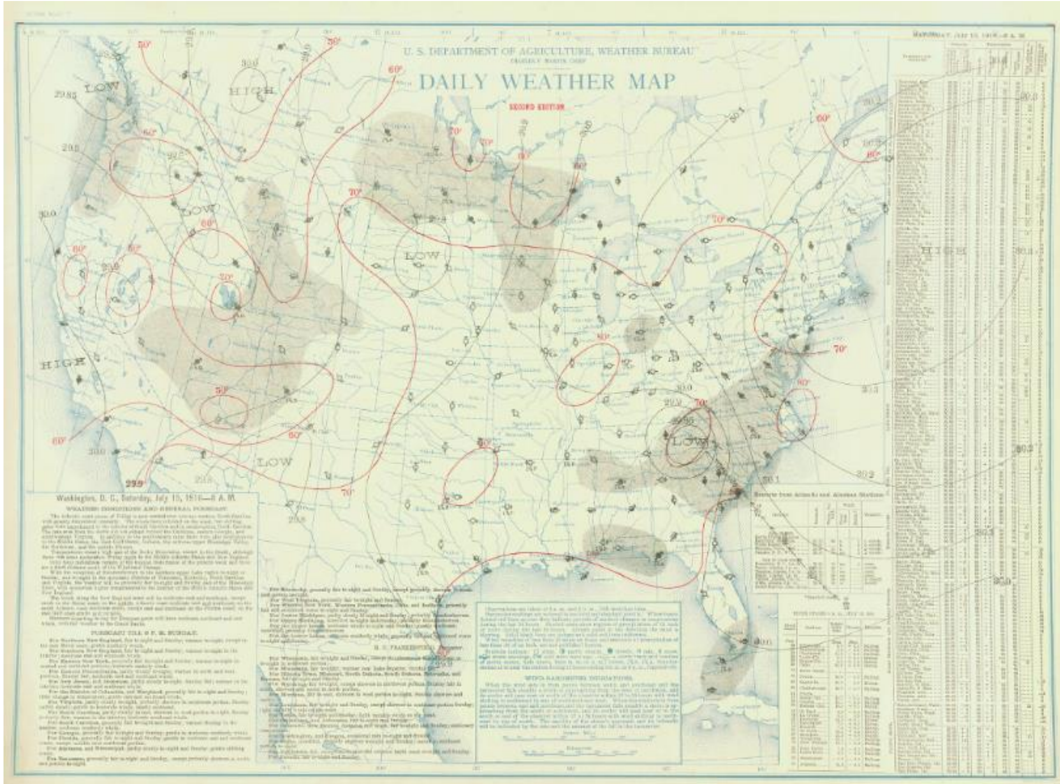
FORM S-3E

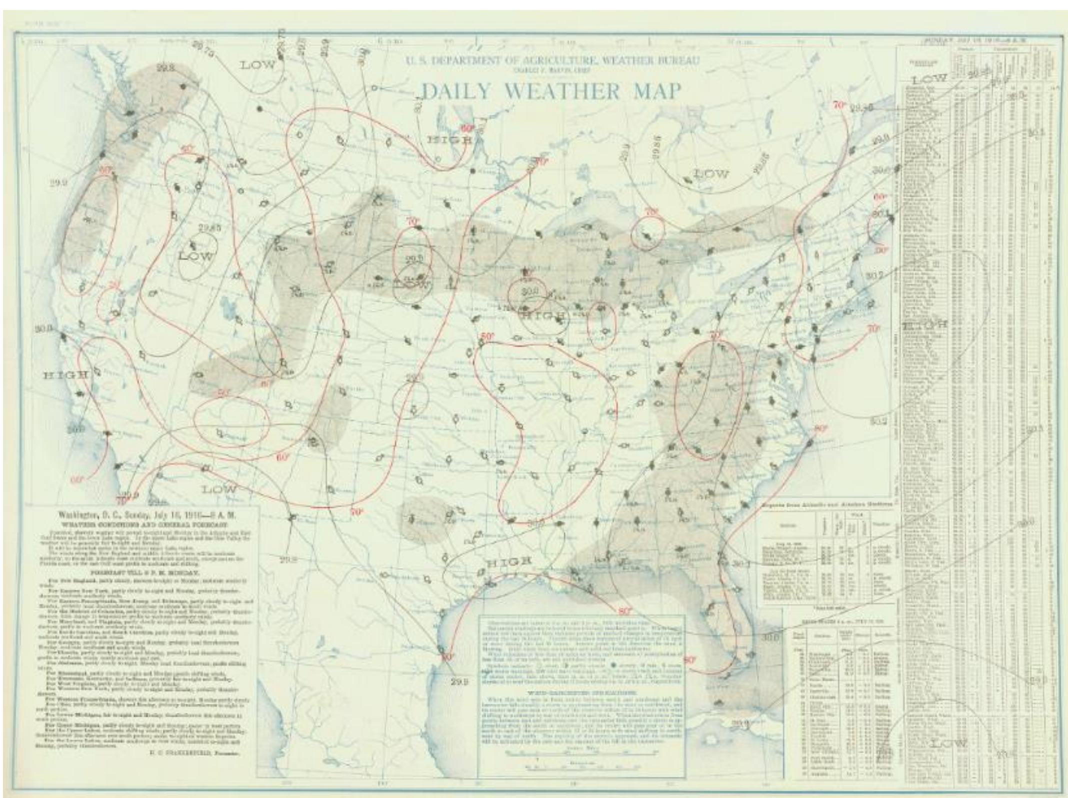

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
LOW
HIGH
Washington, D. C., Tuesday, July 11, 1916—8 A. M.

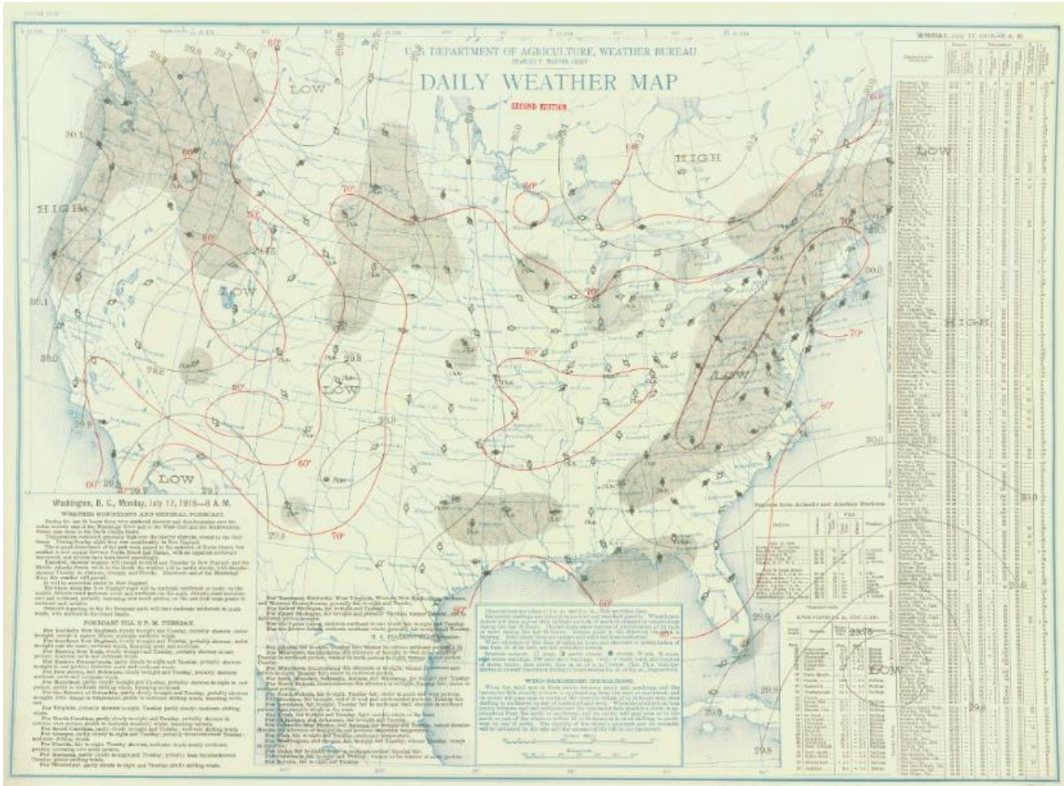

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
LOW
HIGH
Washington, D. C., Wednesday, July 12, 1916—8 A. M.

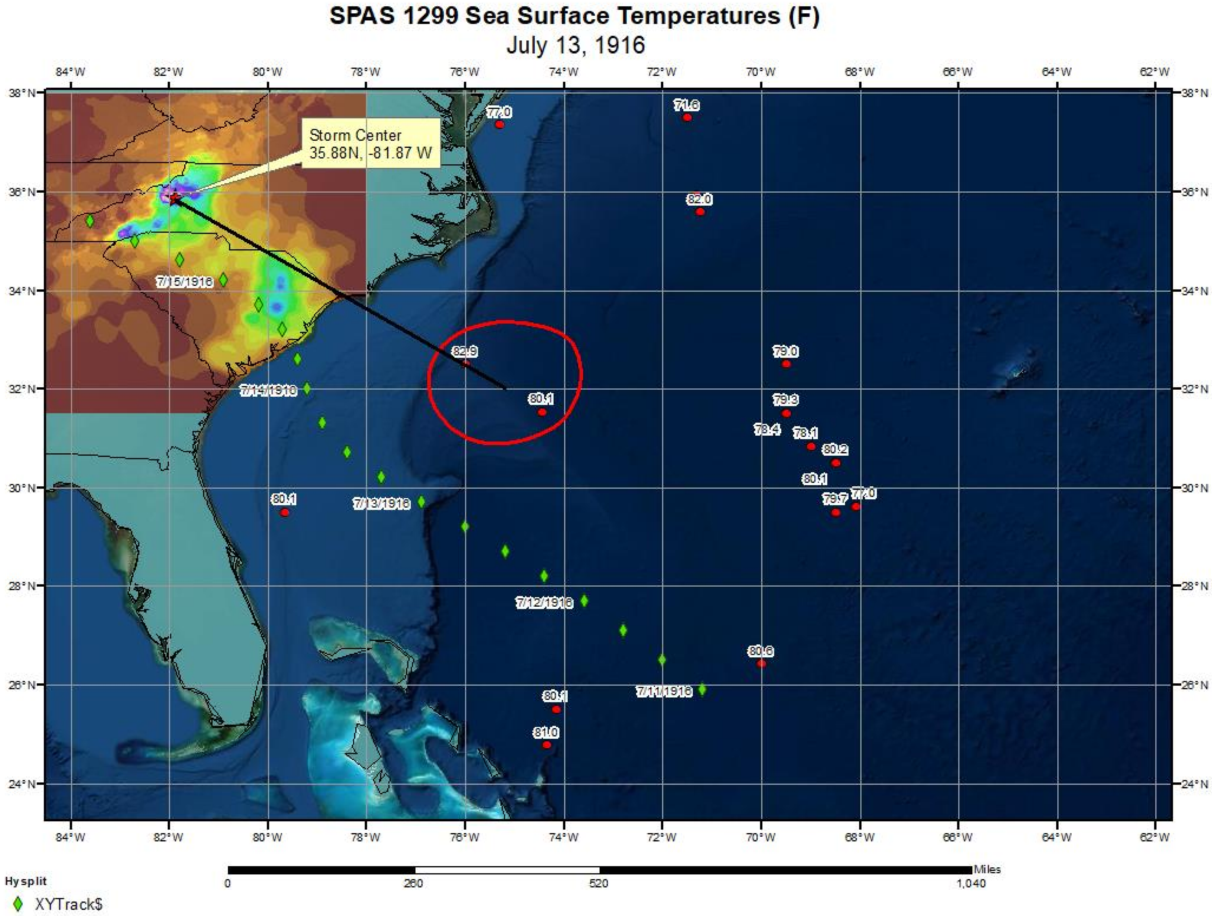

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
Washington, D. C., Thursday, July 13, 1916—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
Washington, D. C., Friday, July 14, 1916—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
HIGH
LOW
LOW
LOW
HIGH


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
LOW
LOW
HIGH
HIGH
LOW
HIGH
HIGH
LOW
LOW


U.S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW


SPAS 1299 Sea Surface Temperatures (F)
July 13, 1916
Storm Center
35.88N, -81.87 W
7/15/1916
7/14/1916
7/13/1916
7/12/1916
7/11/1916
Hysplit
XYTrack$
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1516_1 SPAS Analysis

General Storm Location: Washington and Glenville, GA

Storm Dates: September 23-28, 1929

Event: Extreme Precipitation Event

DAD Zone 1

Latitude: 34.9458

Longitude: -81.8875

Max. Grid Rainfall Amount: 21.2"

Number of Stations: 215

SPAS Version: 10.0

Base Map Used: PRISM Monthly Basemap for September 1929(us_ppt_1941_09_30sec_in)

Spatial resolution: .2775

Radar Included: No

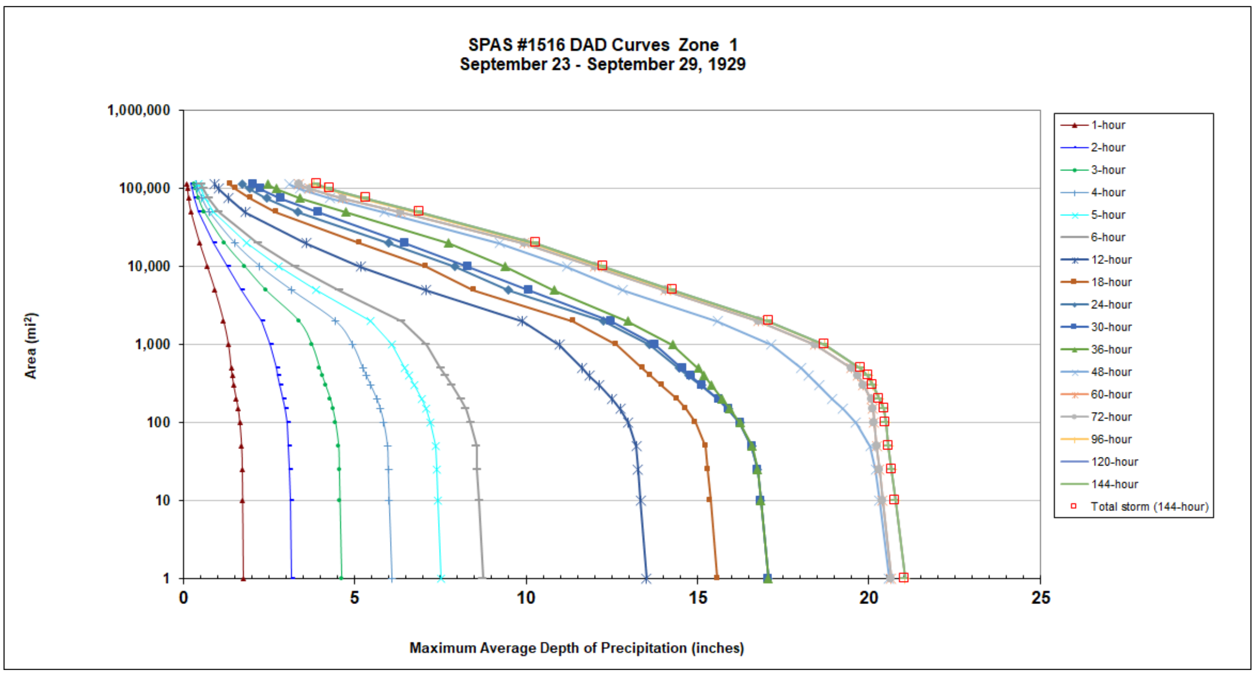
Depth-Area-Duration (DAD) analysis: No

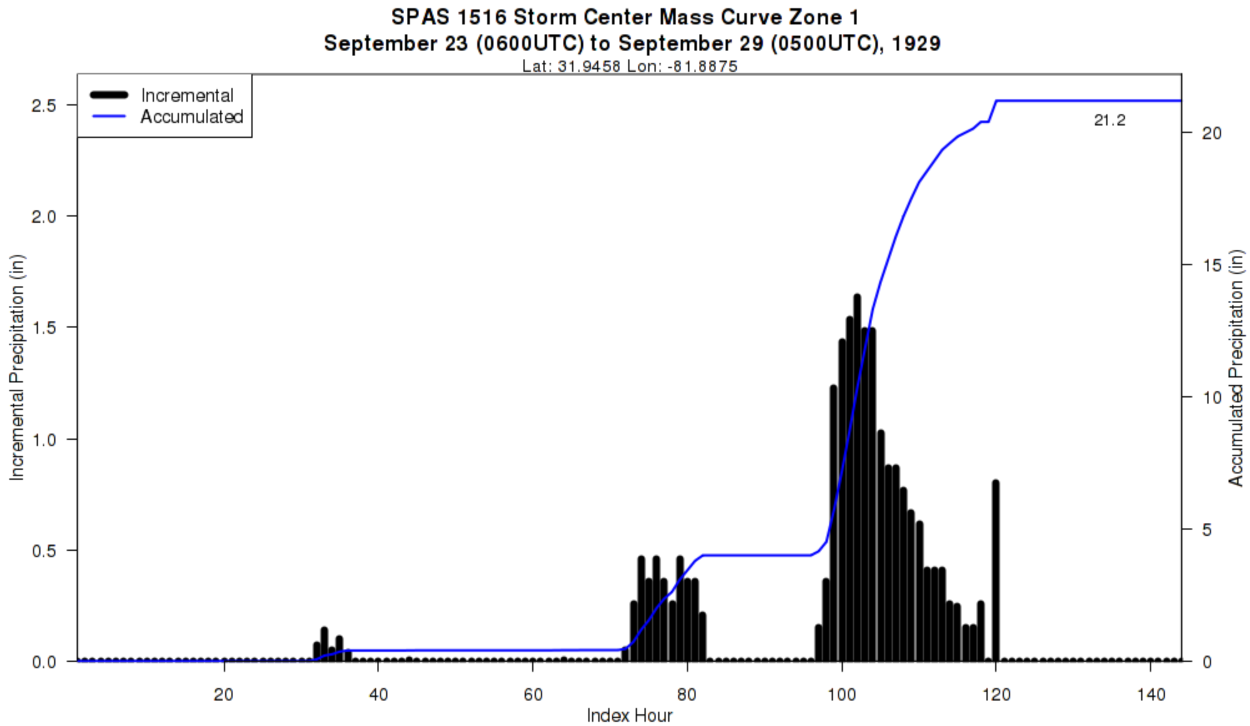
Reliability of Results: Thirty supplemental stations were added to ensure data consistency. Due to the amount and integrity of the U.S. Army Corps of Engineers (USACE) report, five hourly stations were digitized based on the mass rainfall curves from the USACE report. With the density of stations available and the consistency of the resulting SPAS analysis to the U.S. Army Corps of Engineers report, this analysis is deemed quite reliable to the fact that this analysis only had six hourly stations. Attempts were made to the USACE branches for the full storm reports to no avail.

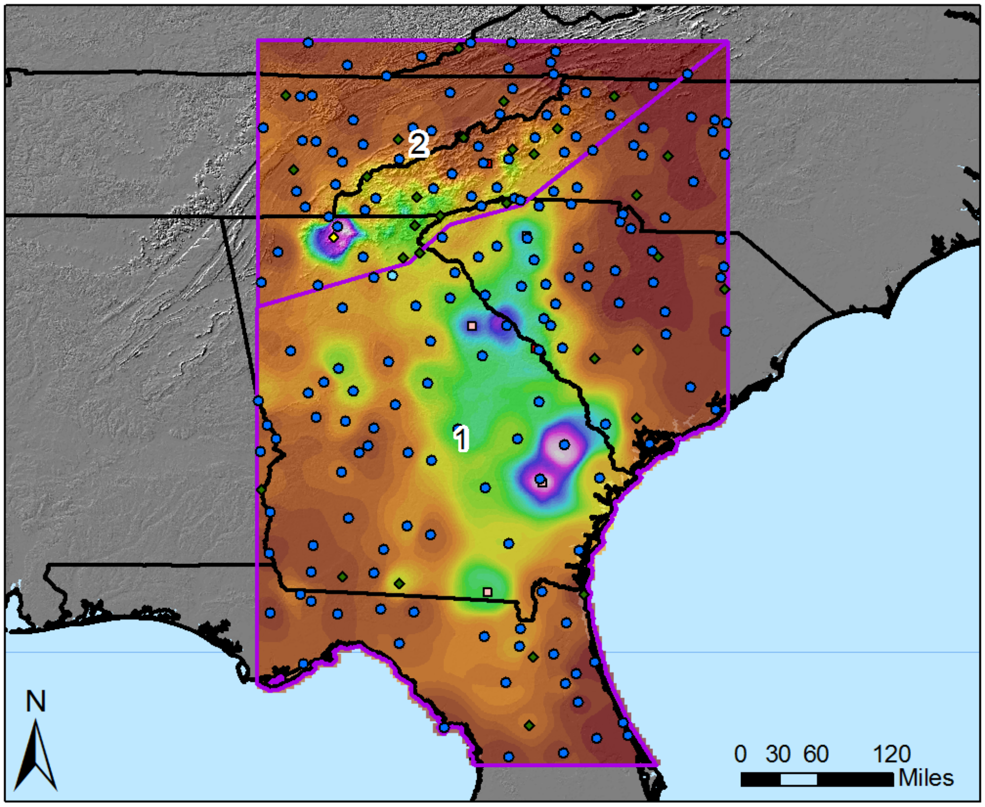
							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1516_1	-81.8875	34.9458	99	100	10-Sep	82.00	3.95	0.03	86	3.920	85.03	85.0	4.48	0.04	92	4.440	1.133

Storm 1516 - September 23 (0600 UTC) - September 29 (0500 UTC), 1929
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

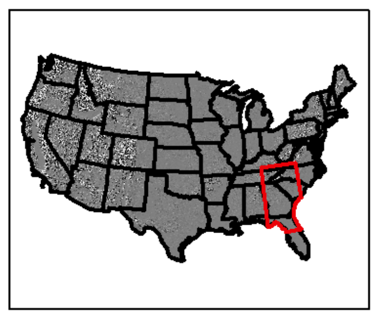
Area (mi^2)	Duration (hours)																	
	1	2	3	4	5	6	12	18	24	30	36	48	60	72	96	120	144	Total
0.4	1.75	3.17	4.65	6.12	7.55	8.78	13.58	15.66	17.16	17.16	17.16	20.69	20.75	20.75	21.16	21.16	21.16	21.16
1	1.75	3.15	4.62	6.09	7.52	8.74	13.51	15.58	17.07	17.07	17.07	20.58	20.65	20.65	21.05	21.05	21.05	21.05
10	1.73	3.12	4.57	6.01	7.42	8.63	13.34	15.38	16.84	16.84	16.84	20.30	20.40	20.40	20.77	20.77	20.77	20.77
25	1.72	3.11	4.55	5.98	7.39	8.58	13.27	15.30	16.75	16.75	16.75	20.19	20.30	20.30	20.66	20.66	20.66	20.66
50	1.70	3.08	4.53	5.96	7.36	8.55	13.22	15.24	16.58	16.58	16.59	20.04	20.22	20.22	20.57	20.57	20.57	20.57
100	1.65	3.03	4.44	5.85	7.22	8.39	12.98	14.94	16.24	16.24	16.24	19.62	20.15	20.15	20.49	20.49	20.49	20.49
150	1.60	2.97	4.36	5.75	7.09	8.24	12.75	14.66	15.90	15.90	15.95	19.24	20.11	20.11	20.43	20.44	20.44	20.44
200	1.55	2.92	4.29	5.65	6.97	8.10	12.52	14.41	15.61	15.62	15.72	18.94	20.07	20.07	20.30	20.31	20.31	20.31
300	1.47	2.83	4.15	5.47	6.75	7.84	12.14	13.96	15.12	15.13	15.41	18.54	19.84	19.84	20.10	20.11	20.11	20.11
400	1.43	2.76	4.05	5.34	6.58	7.65	11.85	13.64	14.75	14.80	15.20	18.25	19.68	19.68	19.97	19.98	19.98	19.98
500	1.40	2.71	3.98	5.24	6.47	7.52	11.64	13.40	14.47	14.56	15.02	18.03	19.49	19.49	19.75	19.76	19.76	19.76
1,000	1.32	2.55	3.75	4.94	6.09	7.09	10.98	12.64	13.61	13.76	14.28	17.16	18.43	18.43	18.70	18.71	18.71	18.71
2,000	1.18	2.30	3.37	4.44	5.48	6.38	9.89	11.38	12.26	12.48	12.96	15.59	16.79	16.79	17.04	17.08	17.08	17.08
5,000	0.93	1.69	2.40	3.15	3.89	4.55	7.09	8.48	9.50	10.09	10.82	12.83	14.06	14.06	14.21	14.29	14.29	14.29
10,000	0.71	1.30	1.79	2.24	2.77	3.27	5.18	7.10	7.93	8.31	9.40	11.19	12.00	12.00	12.18	12.26	12.26	12.26
20,000	0.49	0.88	1.20	1.50	1.85	2.19	3.59	5.16	6.00	6.47	7.75	9.23	9.95	9.95	10.20	10.29	10.29	10.29
50,000	0.24	0.45	0.61	0.76	0.89	1.05	1.81	2.71	3.36	3.95	4.75	5.86	6.34	6.34	6.80	6.90	6.90	6.90
75,000	0.17	0.33	0.44	0.55	0.64	0.76	1.33	1.96	2.43	2.84	3.42	4.29	4.65	4.66	5.21	5.32	5.33	5.33
100,000	0.14	0.25	0.35	0.43	0.51	0.59	1.03	1.53	1.93	2.25	2.71	3.40	3.70	3.71	4.17	4.27	4.27	4.27
112,054	0.12	0.23	0.32	0.39	0.46	0.53	0.92	1.38	1.74	2.05	2.47	3.10	3.38	3.39	3.82	3.91	3.91	3.91




SPAS 1516 Storm Center Mass Curve Zone 1
September 23 (0600UTC) to September 29 (0500UTC), 1929
Lat: 31.9458 Lon: -81.8875
Incremental
Accumulated
21.2
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
20
40
60
80
100
120
140



Total 144-hour Precipitation (Inches)
September 23, 1929 0600 UTC - September 29, 1929 0500 UTC
SPAS #1516



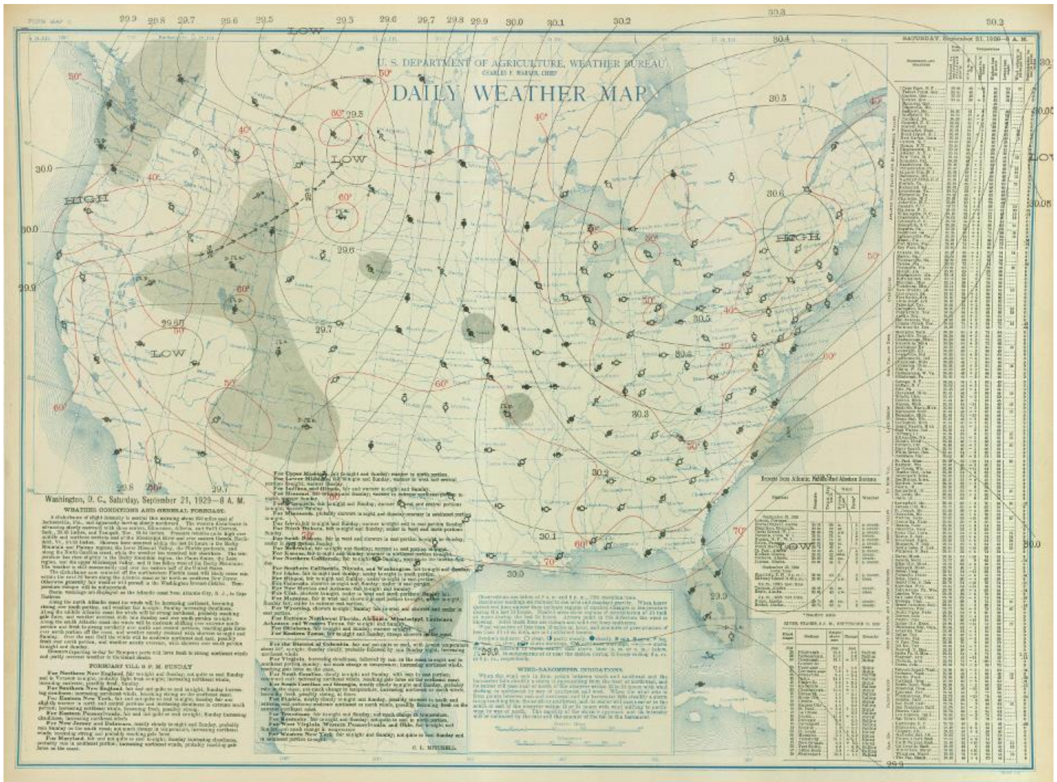
Precipitation (Inches)

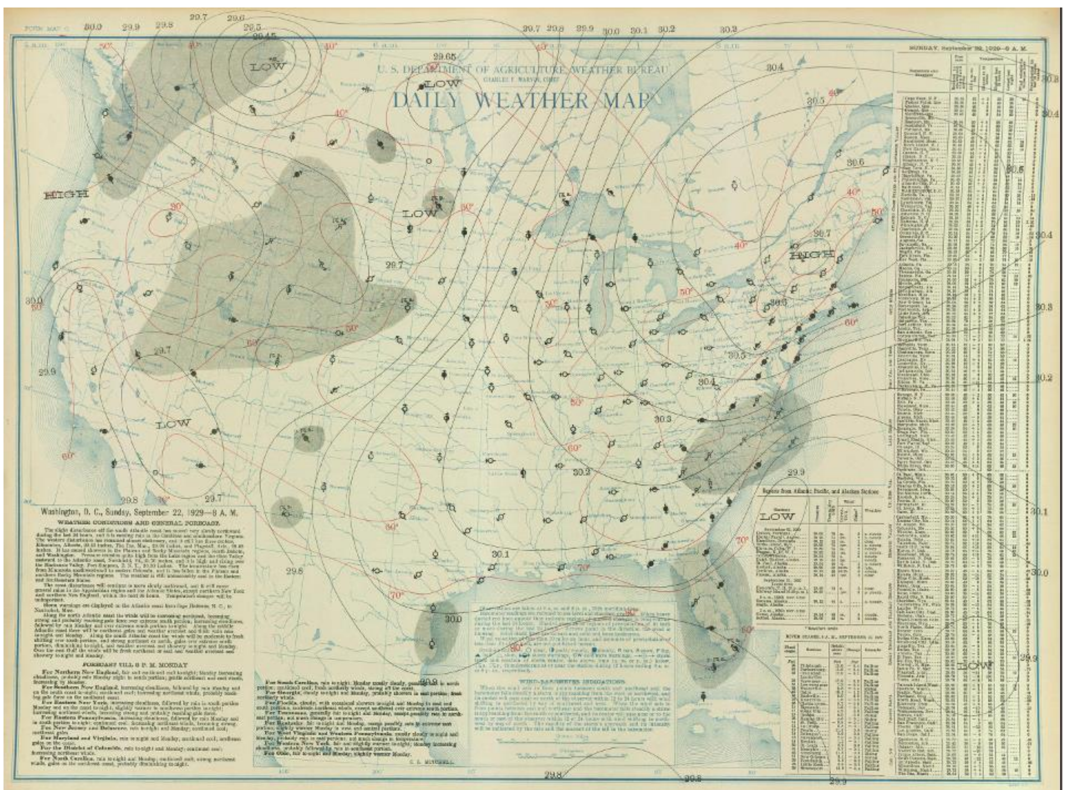
0.00 - 0.50	5.01 - 5.50	10.51 - 11.00	16.01 - 16.50
0.51 - 1.00	5.51 - 6.00	11.01 - 11.50	16.51 - 17.00
1.01 - 1.50	6.01 - 6.50	11.51 - 12.00	17.01 - 17.50
1.51 - 2.00	6.51 - 7.00	12.01 - 12.50	17.51 - 18.00
2.01 - 2.50	7.01 - 7.50	12.51 - 13.00	18.01 - 18.50
2.51 - 3.00	7.51 - 8.00	13.01 - 13.50	18.51 - 19.00
3.01 - 3.50	8.01 - 8.50	13.51 - 14.00	19.01 - 19.50
3.51 - 4.00	8.51 - 9.00	14.01 - 14.50	19.51 - 20.00
4.01 - 4.50	9.01 - 9.50	14.51 - 15.00	20.01 - 20.50
4.51 - 5.00	9.51 - 10.00	15.01 - 15.50	20.51 - 21.00
	10.01 - 10.50	15.51 - 16.00	

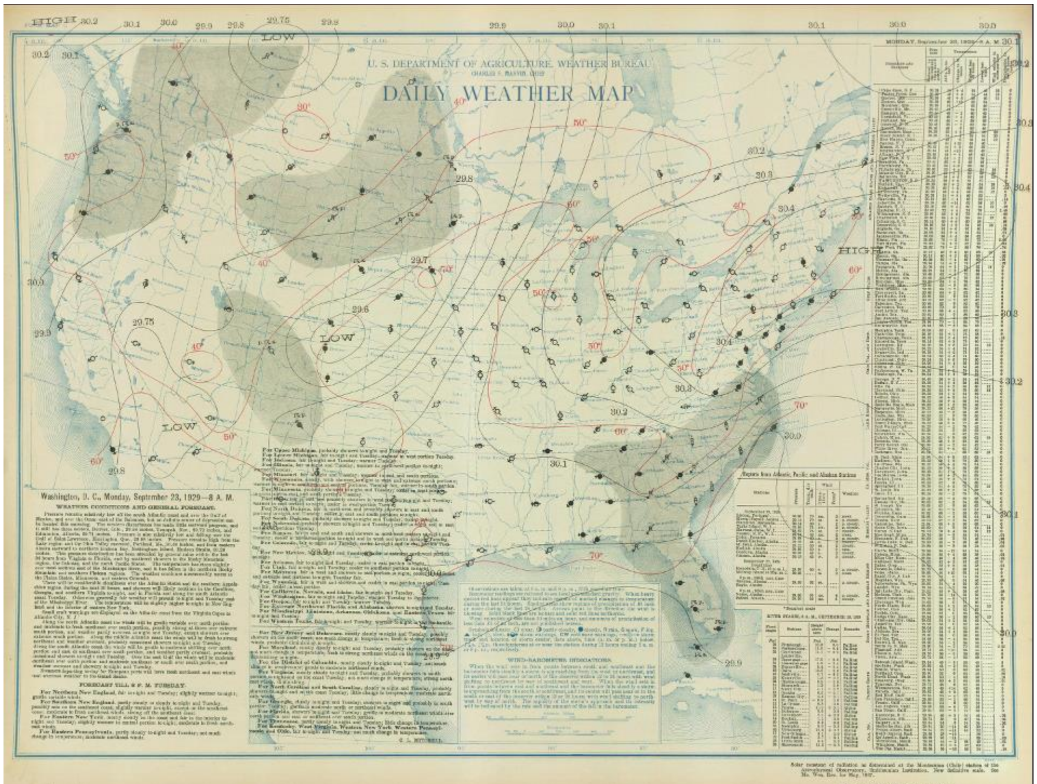
Stations

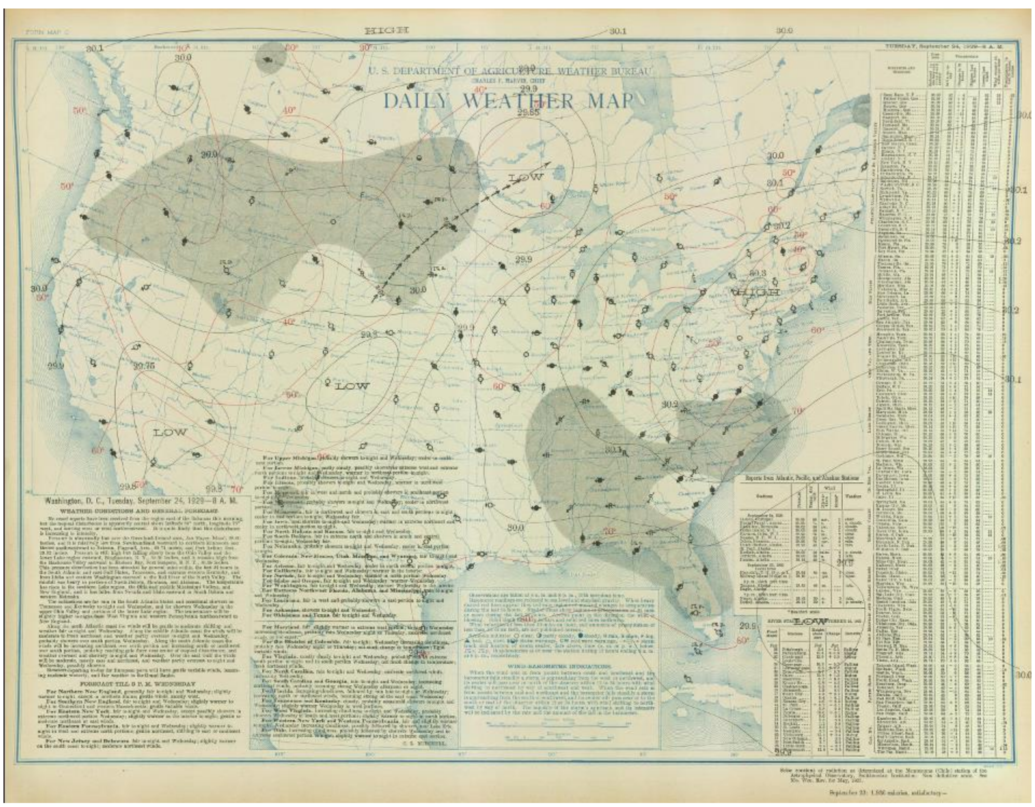
- Daily
- Daily Estimated
- Hourly
- Hourly Estimated
- Supplemental
- Supplemental Estimated

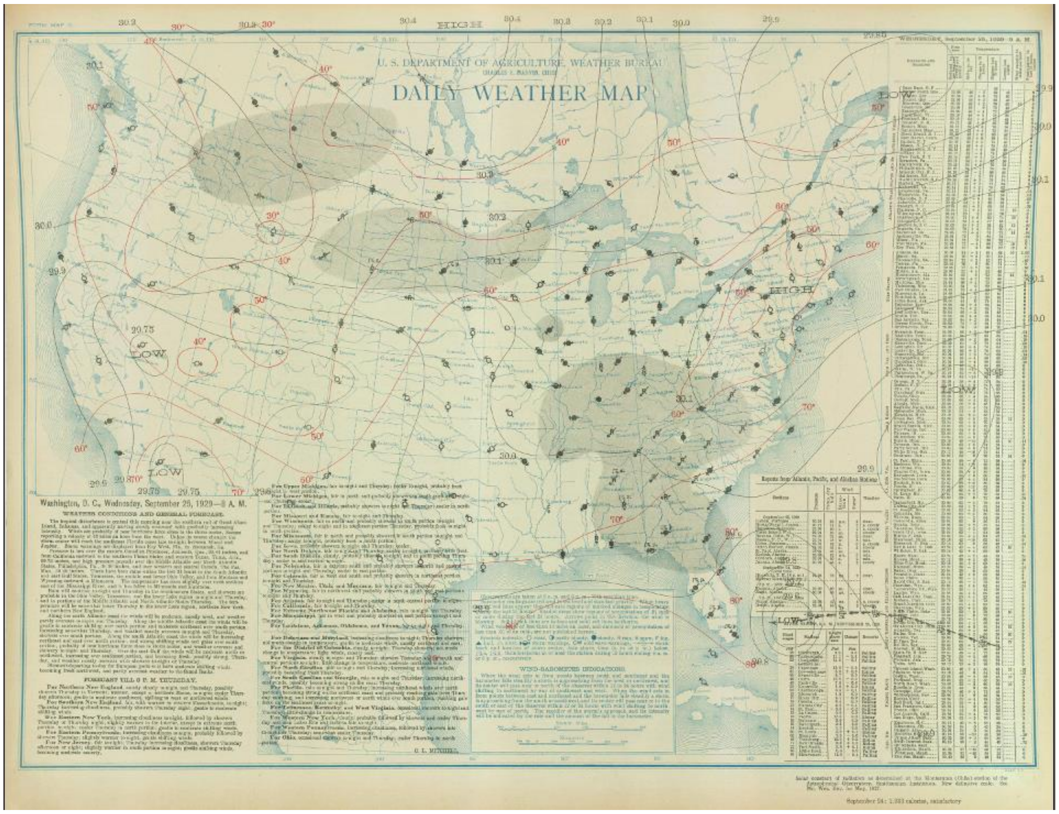
WJM 03/26/2015

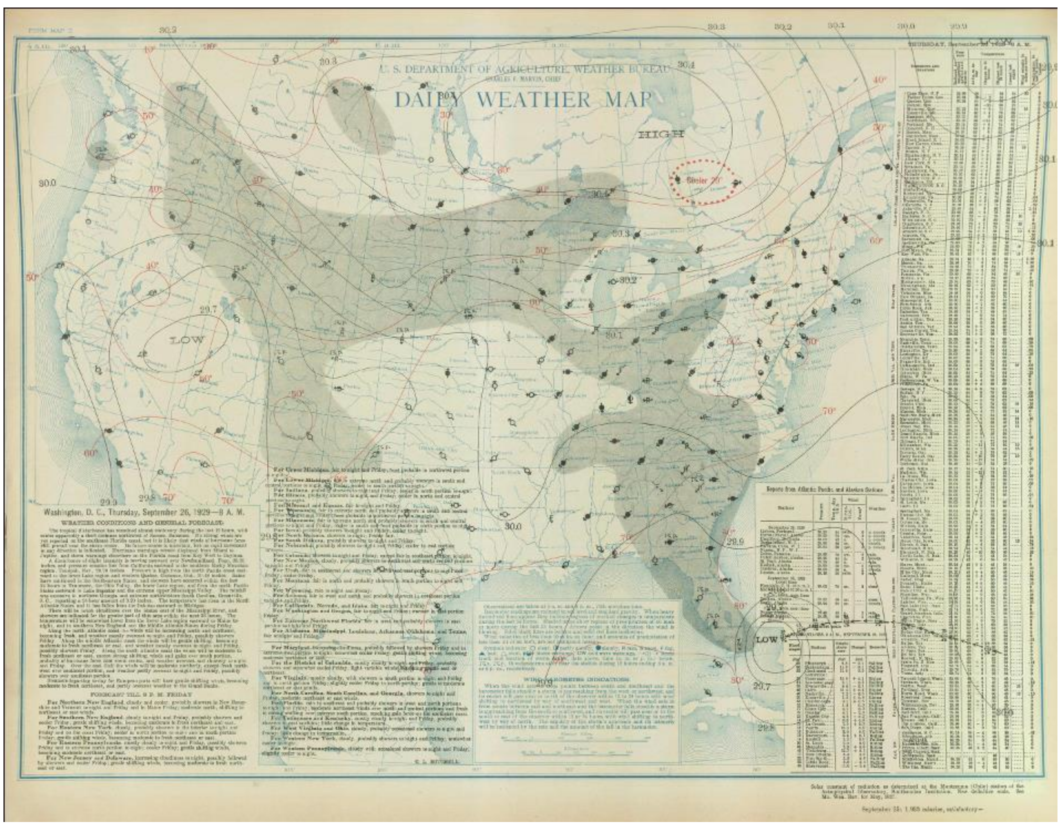

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Saturday, September 21, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST
FORECAST TILL 8 P. M. SUNDAY
WIND-BAROMETER INDICATIONS

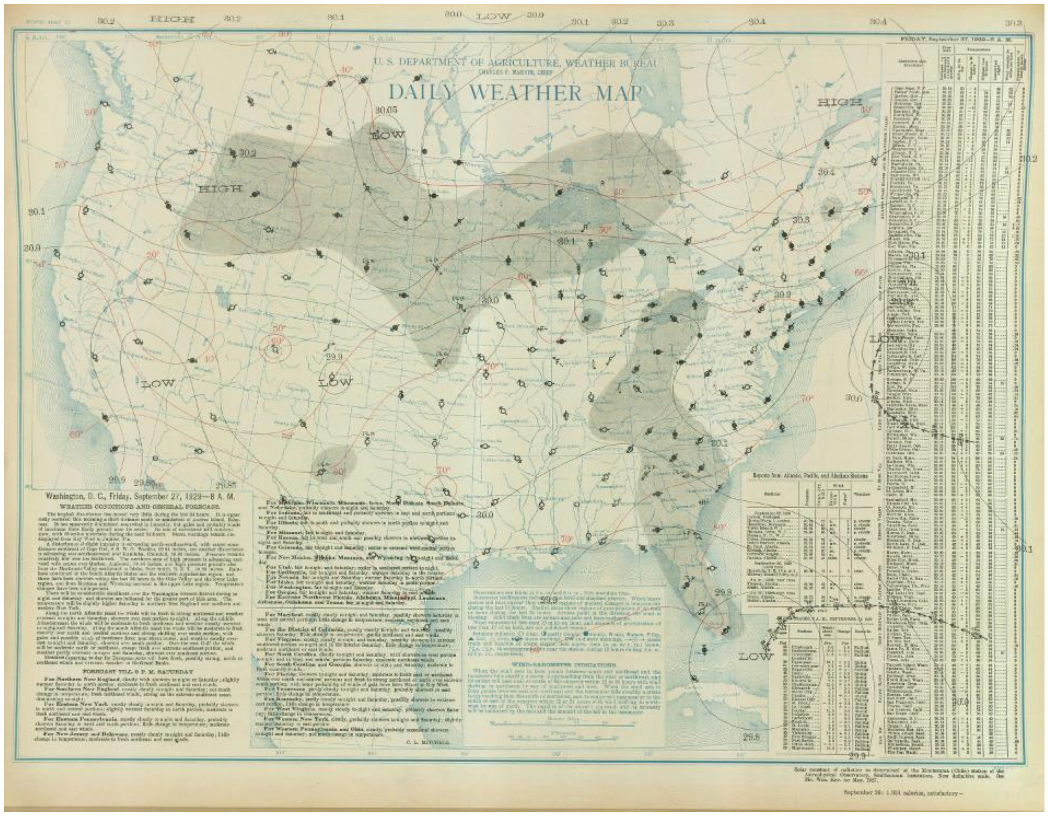

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Sunday, September 22, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST
FORECAST TILL 8 P. M. MONDAY
WIND-BAROMETER INDICATIONS

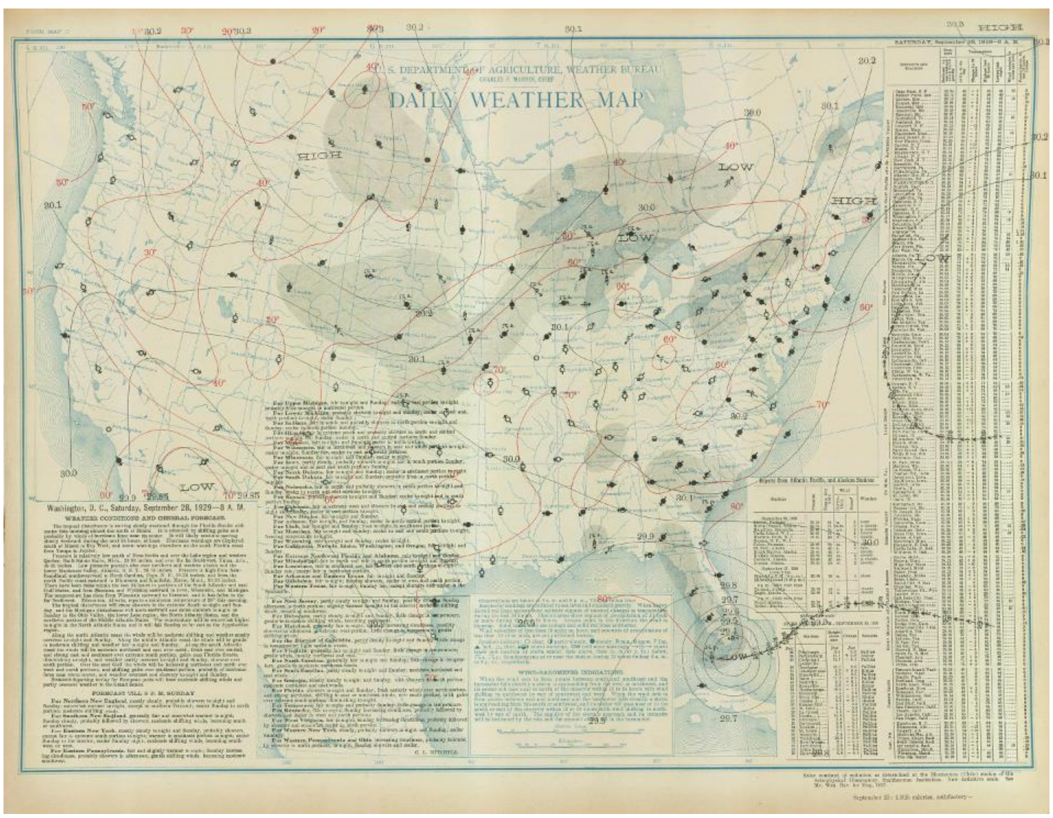

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Monday, September 23, 1929—8 A. M.

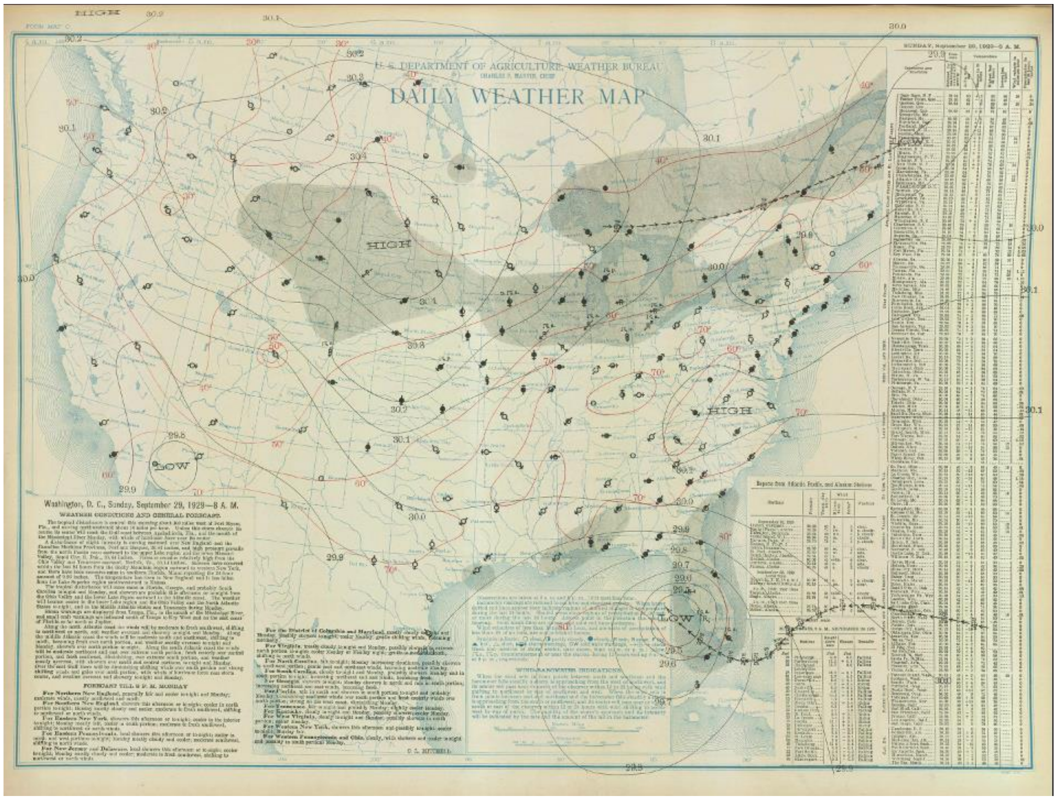

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Tuesday, September 24, 1929—8 A. M.

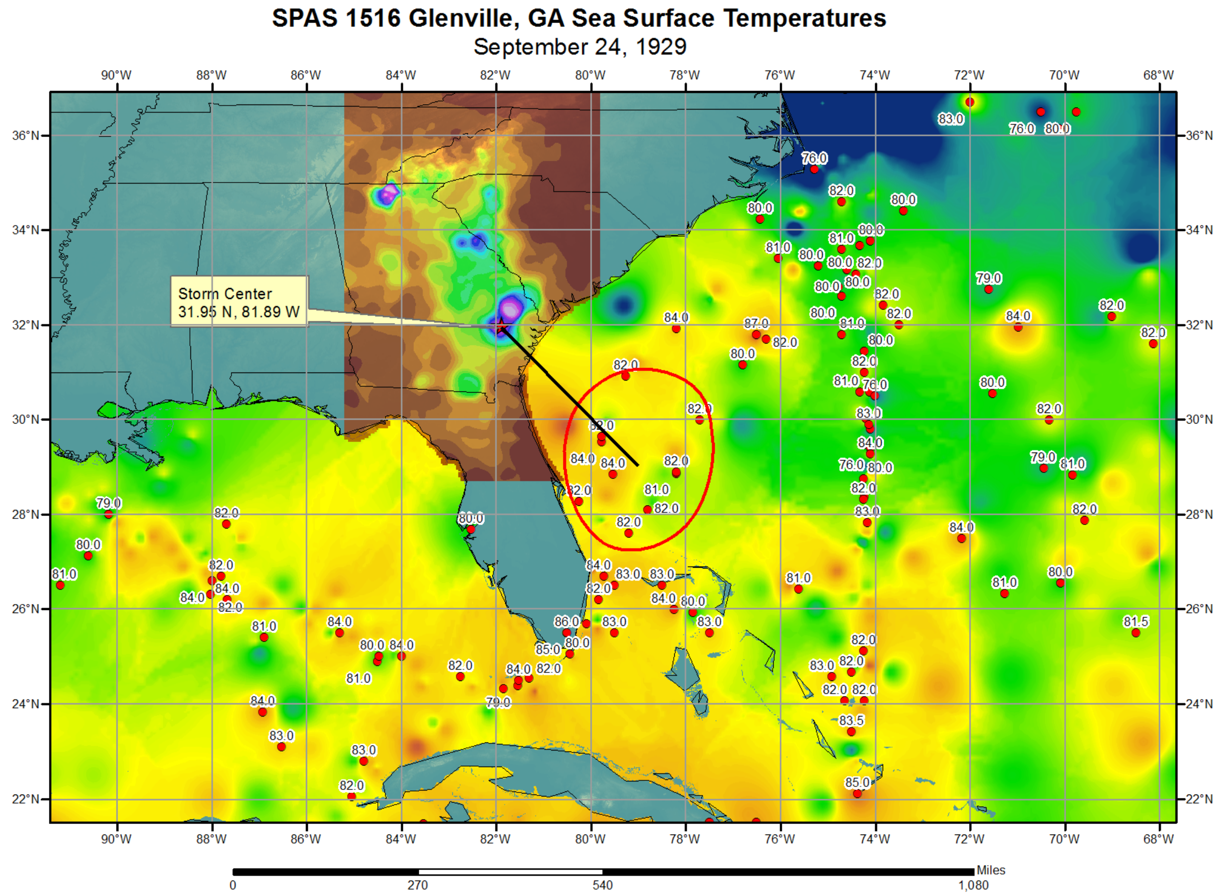

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Wednesday, September 25, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
WIND-BAROMETER INDICATIONS


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Thursday, September 26, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
WIND-BAROMETER INDICATIONS


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Friday, September 27, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. SATURDAY
WIND-BAROMETER INDICATIONS
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Saturday, September 28, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
FORECAST TILL 8 P. M. SUNDAY
WIND-BAROMETER INDICATIONS
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
HIGH
LOW
LOW
Washington, D. C., Sunday, September 29, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST
FORECAST TILL 8 P. M. MONDAY


SPAS 1516 Glenville, GA Sea Surface Temperatures
September 24, 1929
Storm Center
31.95 N, 81.89 W
Miles
0
270
540
1,080

Storm Precipitation Analysis System (SPAS) For Storm #1516_2 SPAS Analysis

General Storm Location: Washington and Glenville, GA

Storm Dates: September 23-28, 1929

Event: Extreme Precipitation Event

DAD Zone 2

Latitude: 34.8208

Longitude: -84.1542

Max. Grid Rainfall Amount: 20.88"

Number of Stations: 215

SPAS Version: 10.0

Base Map Used: PRISM Monthly Basemap for September 1929(us_ppt_1941_09_30sec_in)

Spatial resolution: .2775

Radar Included: No

Depth-Area-Duration (DAD) analysis: No

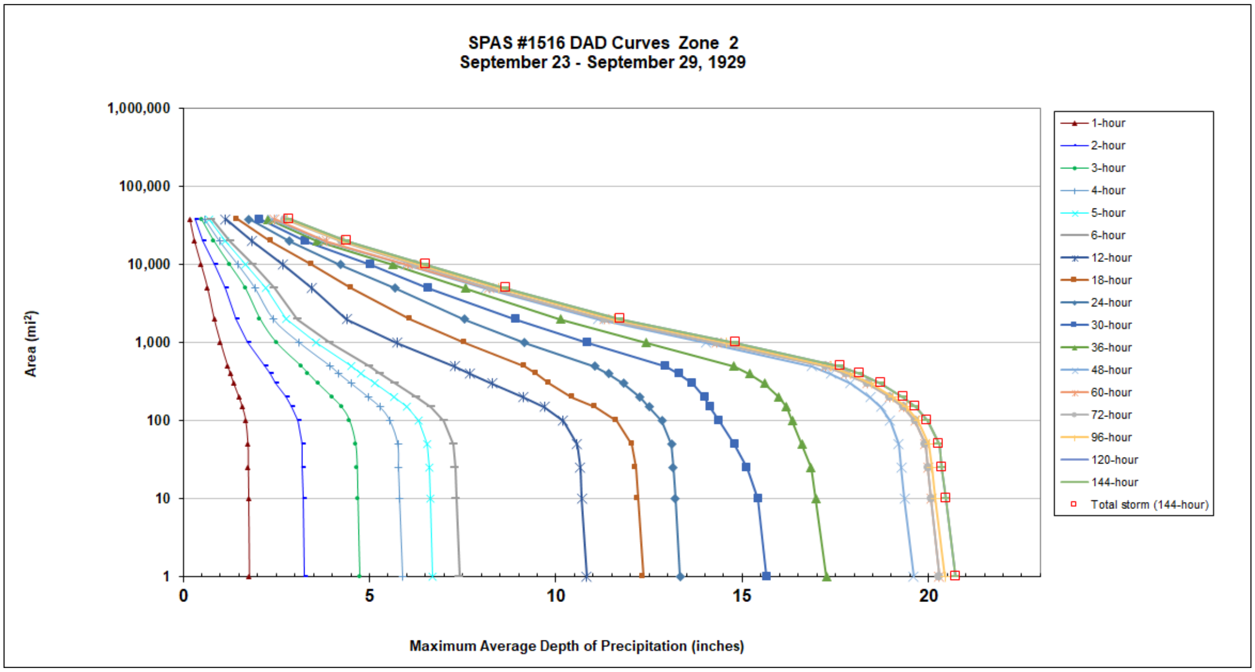
Reliability of Results: Thirty supplemental stations were added to ensure data consistency. Due to the amount and integrity of the U.S. Army Corps of Engineers (USACE) report, five hourly stations were digitized based on the mass rainfall curves from the USACE report. With the density of stations available and the consistency of the resulting SPAS analysis to the U.S. Army Corps of Engineers report, this analysis is deemed quite reliable to the fact that this analysis only had six hourly stations. Attempts were made to the USACE branches for the full storm reports to no avail.

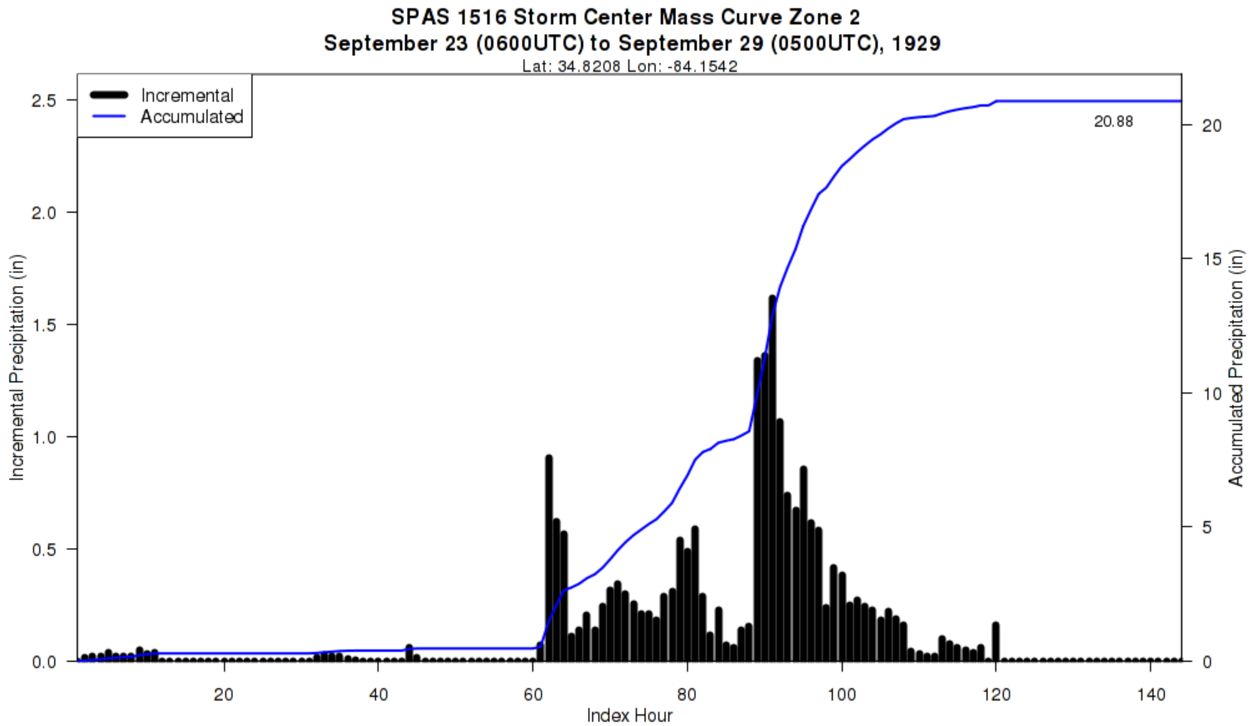
							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1516_2	-84.1542	34.8208	2,510	2,500	10-Sep	82.00	3.95	0.74	86	3.210	85.03	85.0	4.48	0.81	92	3.670	1.143

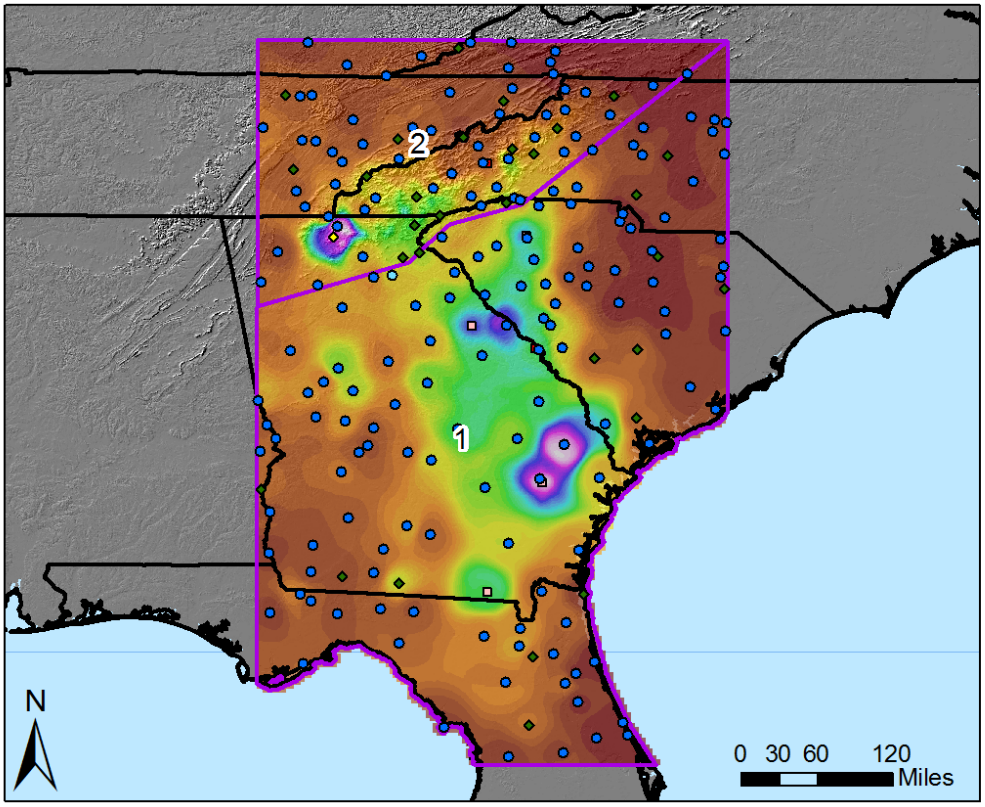
Storm 1516 - September 23 (0600 UTC) - September 29 (0500 UTC), 1929

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

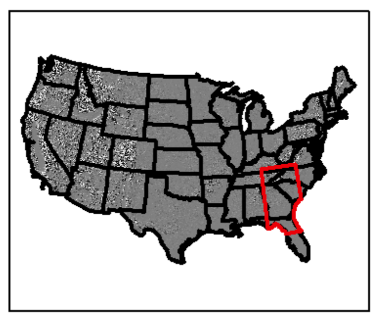
Area (mi²)	Duration (hours)																
	1	2	3	4	5	6	12	18	24	30	36	48	60	72	96	120	144	Total
0.4	1.78	3.27	4.76	5.92	6.73	7.46	10.87	12.39	13.39	15.75	17.38	19.70	20.37	20.37	20.55	20.83	20.83	20.83
1	1.77	3.25	4.73	5.89	6.70	7.42	10.82	12.34	13.33	15.66	17.26	19.60	20.29	20.29	20.45	20.73	20.73	20.73
10	1.75	3.21	4.68	5.81	6.63	7.33	10.70	12.20	13.20	15.43	16.98	19.36	20.07	20.07	20.19	20.47	20.47	20.47
25	1.74	3.19	4.66	5.78	6.60	7.30	10.65	12.15	13.15	15.12	16.85	19.27	19.99	19.99	20.09	20.36	20.36	20.36
50	1.73	3.18	4.62	5.76	6.54	7.26	10.57	12.04	13.11	14.79	16.60	19.20	19.92	19.92	20.02	20.29	20.29	20.29
100	1.67	3.07	4.46	5.55	6.31	7.00	10.20	11.63	12.85	14.38	16.34	18.97	19.64	19.64	19.72	19.97	19.97	19.97
150	1.58	2.92	4.24	5.28	6.00	6.66	9.70	11.06	12.50	14.14	16.18	18.73	19.32	19.32	19.41	19.66	19.66	19.66
200	1.49	2.75	3.99	4.97	5.65	6.27	9.14	10.44	12.26	13.99	15.98	18.44	18.97	18.97	19.06	19.33	19.33	19.33
300	1.35	2.49	3.61	4.51	5.13	5.69	8.29	9.82	11.82	13.66	15.60	17.90	18.37	18.37	18.46	18.73	18.73	18.73
400	1.26	2.32	3.35	4.18	4.77	5.29	7.70	9.48	11.42	13.31	15.20	17.37	17.78	17.78	17.89	18.16	18.16	18.16
500	1.19	2.19	3.16	3.95	4.50	5.00	7.28	9.16	11.04	12.94	14.78	16.87	17.24	17.24	17.37	17.64	17.64	17.64
1,000	1.00	1.73	2.50	3.12	3.56	3.95	5.74	7.56	9.16	10.86	12.43	14.04	14.31	14.31	14.58	14.83	14.83	14.83
2,000	0.83	1.43	2.06	2.42	2.76	3.07	4.39	6.10	7.55	8.92	10.13	11.14	11.31	11.31	11.55	11.75	11.75	11.75
5,000	0.65	1.14	1.66	1.93	2.21	2.46	3.46	4.52	5.70	6.59	7.57	8.12	8.21	8.24	8.48	8.66	8.66	8.66
10,000	0.48	0.85	1.24	1.47	1.67	1.88	2.69	3.46	4.22	5.04	5.64	5.98	6.03	6.24	6.36	6.52	6.52	6.52
20,000	0.30	0.53	0.82	0.98	1.14	1.26	1.85	2.35	2.86	3.28	3.60	3.78	3.85	4.25	4.31	4.41	4.40	4.40
37,777	0.18	0.32	0.49	0.59	0.69	0.76	1.14	1.45	1.77	2.06	2.27	2.38	2.46	2.73	2.79	2.86	2.86	2.86




SPAS 1516 Storm Center Mass Curve Zone 2
September 23 (0600UTC) to September 29 (0500UTC), 1929
Lat: 34.8208 Lon: -84.1542
Incremental
Accumulated
20.88
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
20
40
60
80
100
120
140



Total 144-hour Precipitation (Inches)
September 23, 1929 0600 UTC - September 29, 1929 0500 UTC
SPAS #1516



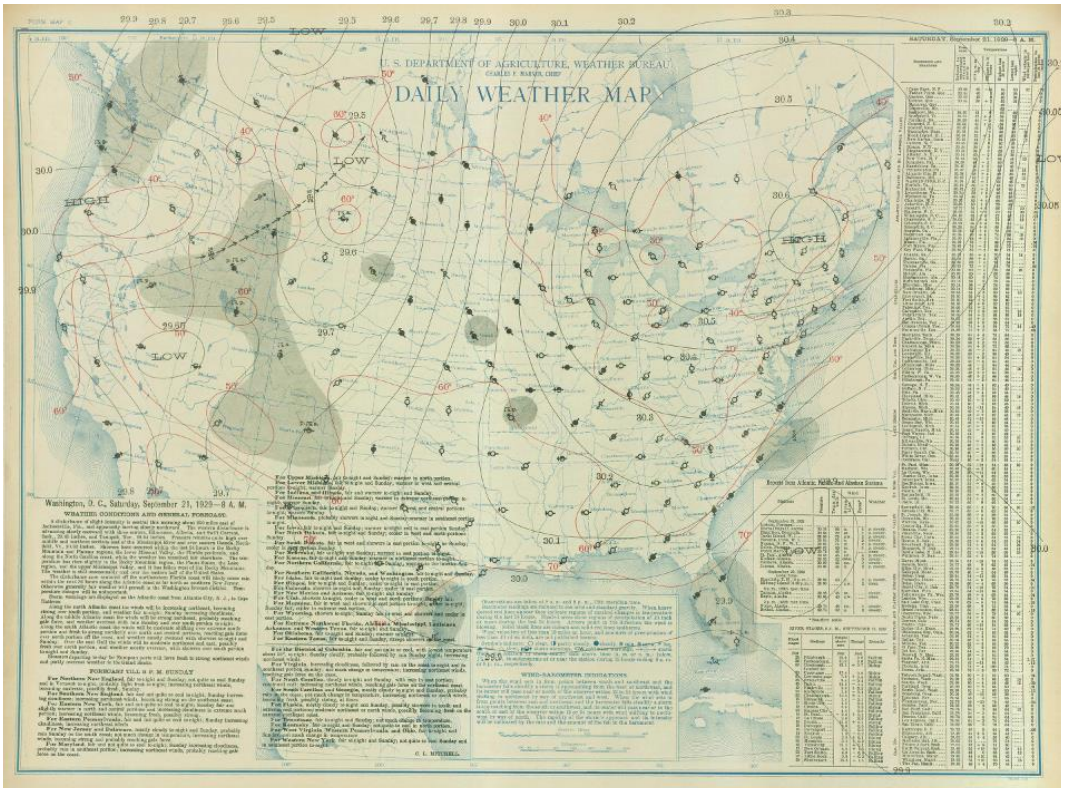
Precipitation (Inches)

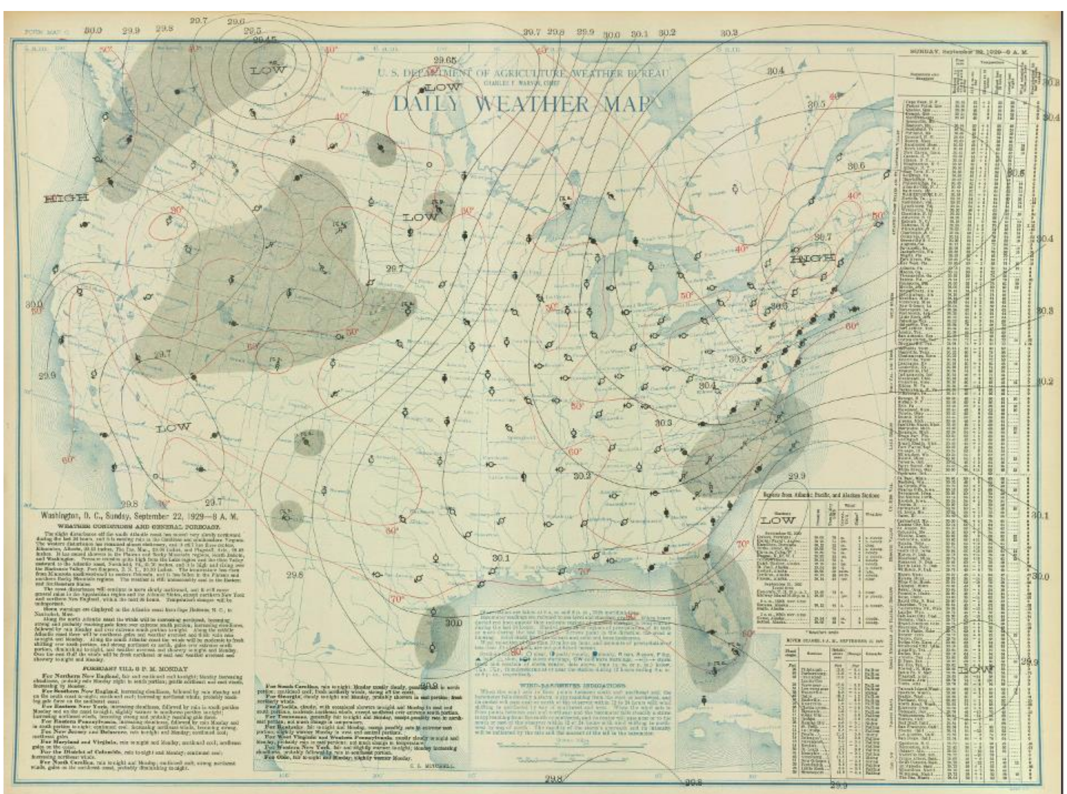
0.00 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.00
10.01 - 10.50
10.51 - 11.00
11.01 - 11.50
11.51 - 12.00
12.01 - 12.50
12.51 - 13.00
13.01 - 13.50
13.51 - 14.00
14.01 - 14.50
14.51 - 15.00
15.01 - 15.50
15.51 - 16.00
16.01 - 16.50
16.51 - 17.00
17.01 - 17.50
17.51 - 18.00
18.01 - 18.50
18.51 - 19.00
19.01 - 19.50
19.51 - 20.00
20.01 - 20.50
20.51 - 21.00

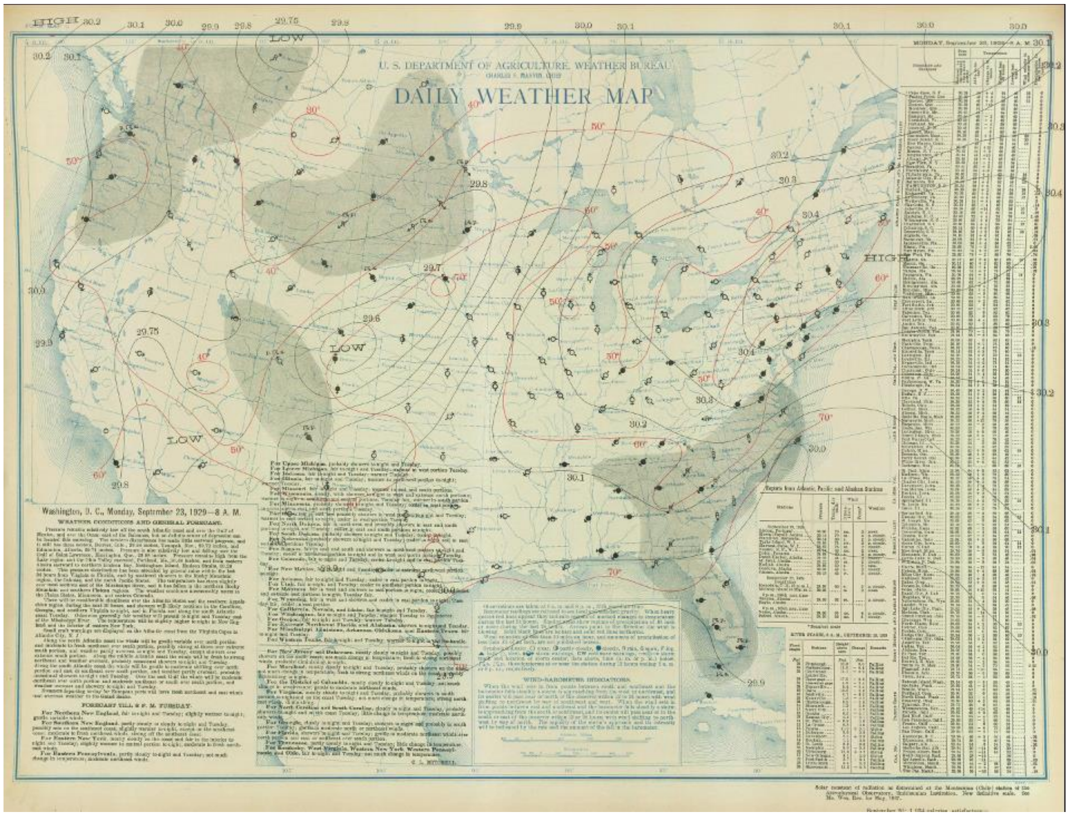
Stations

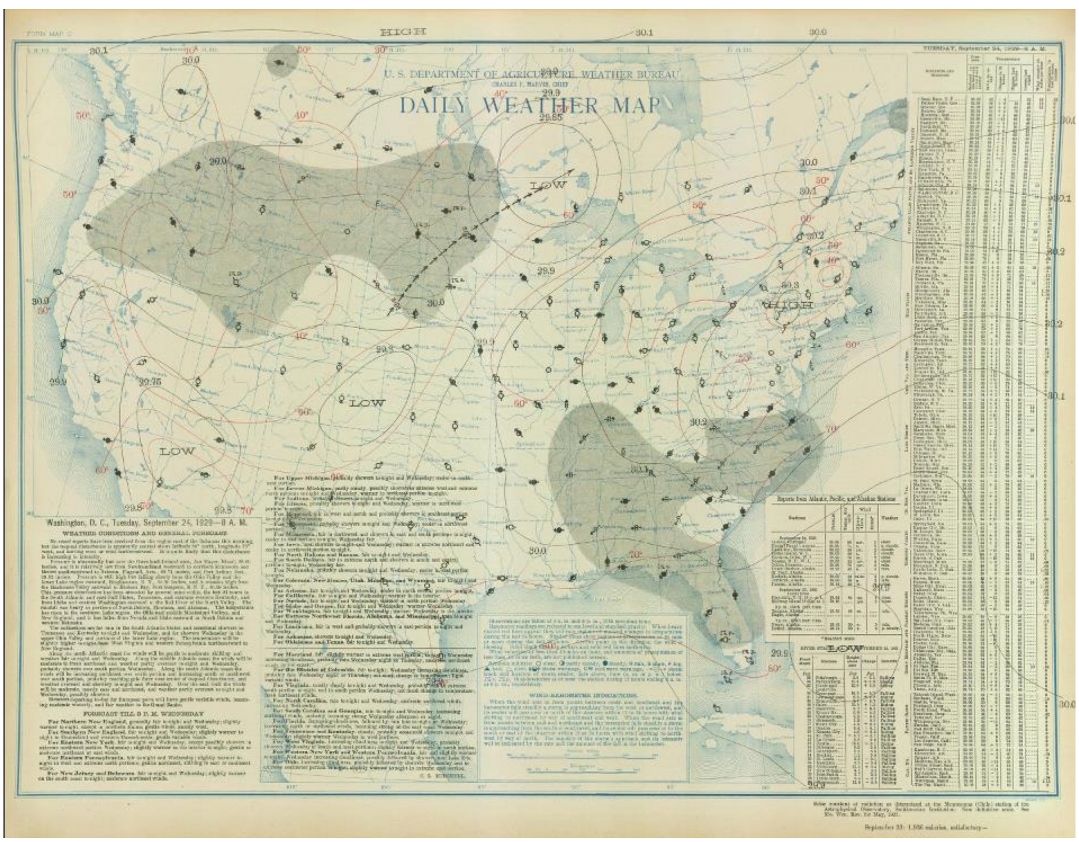
Daily
Daily Estimated
Hourly
Hourly Estimated
Supplemental
Supplemental Estimated

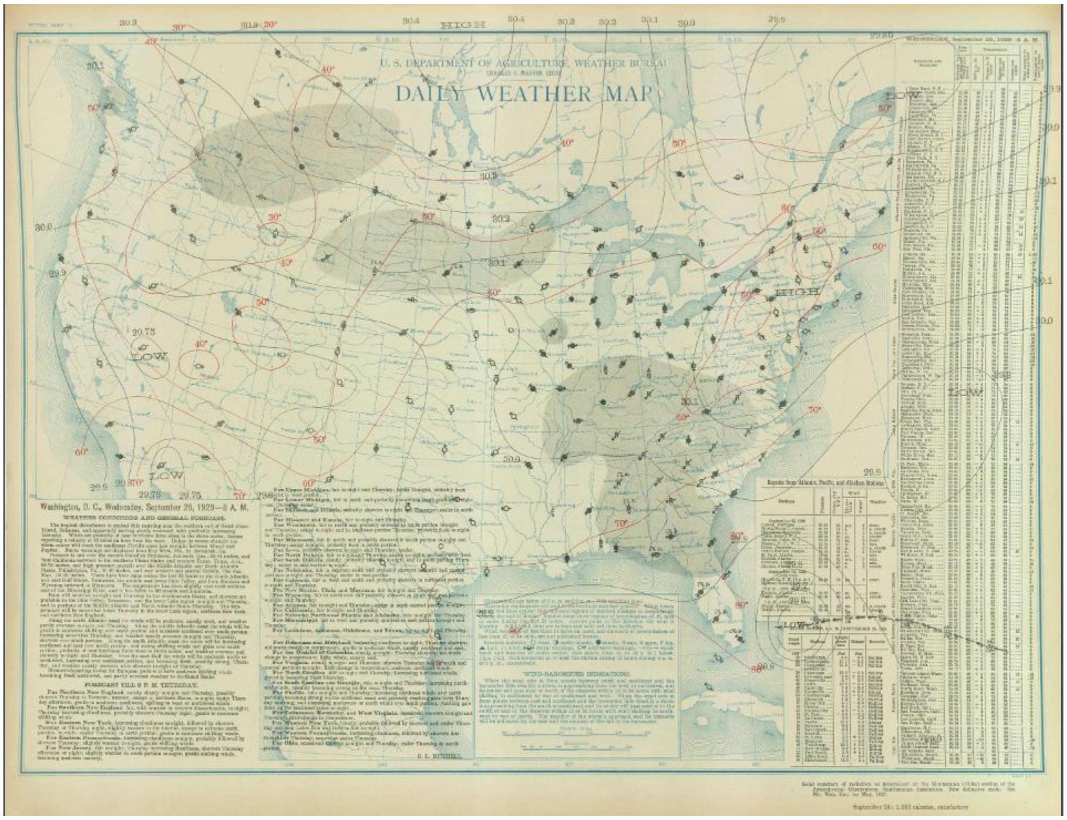
WJM 03/26/2015

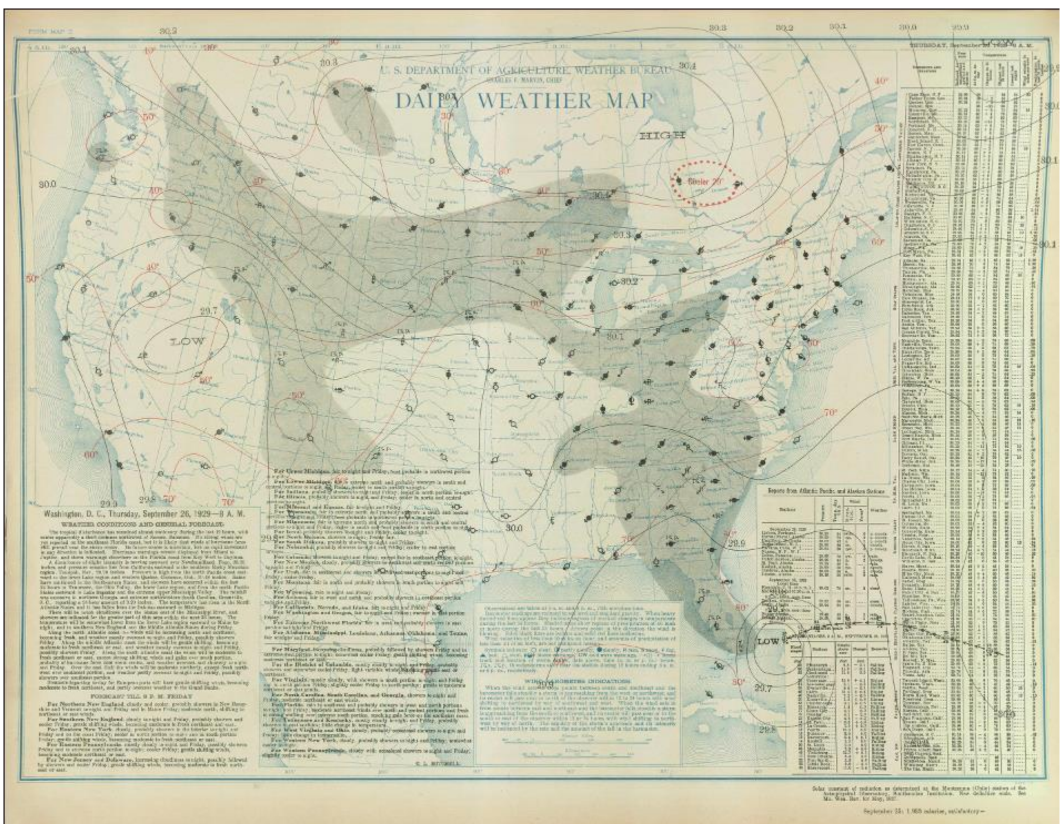

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Saturday, September 21, 1929—8 A. M.

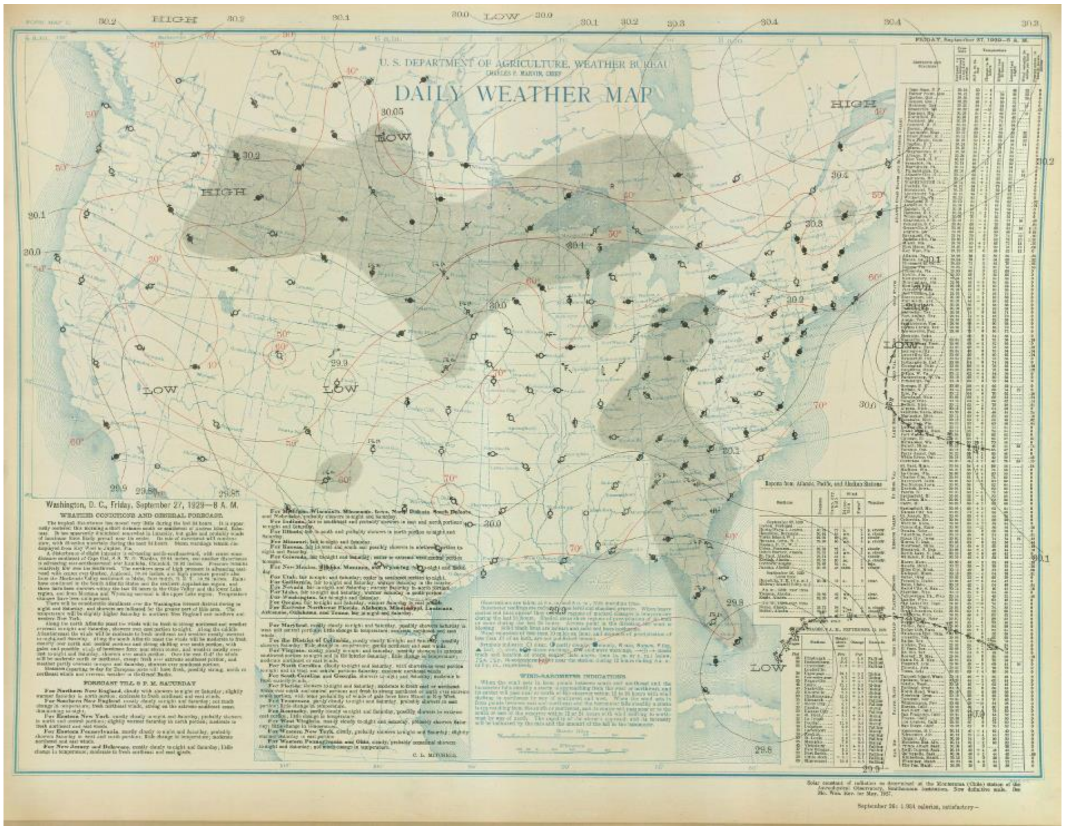

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Sunday, September 22, 1929—8 A. M.

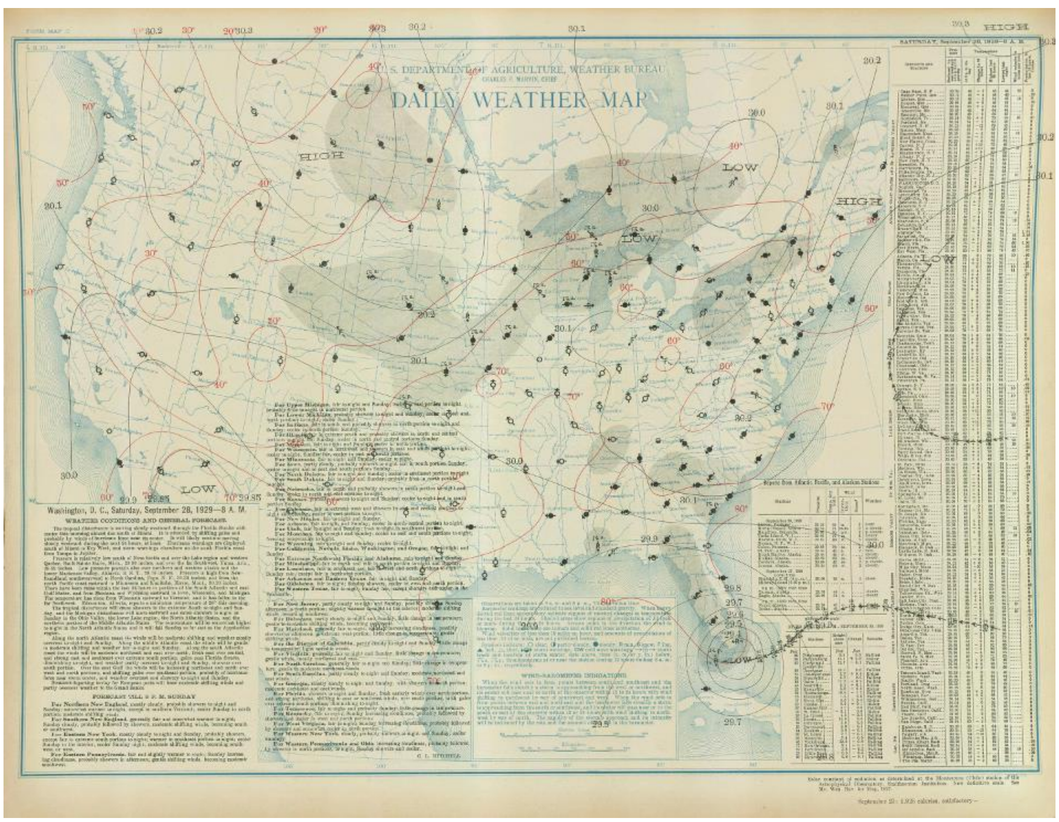

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Monday, September 23, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
WIND-BAROMETER INDICATIONS.

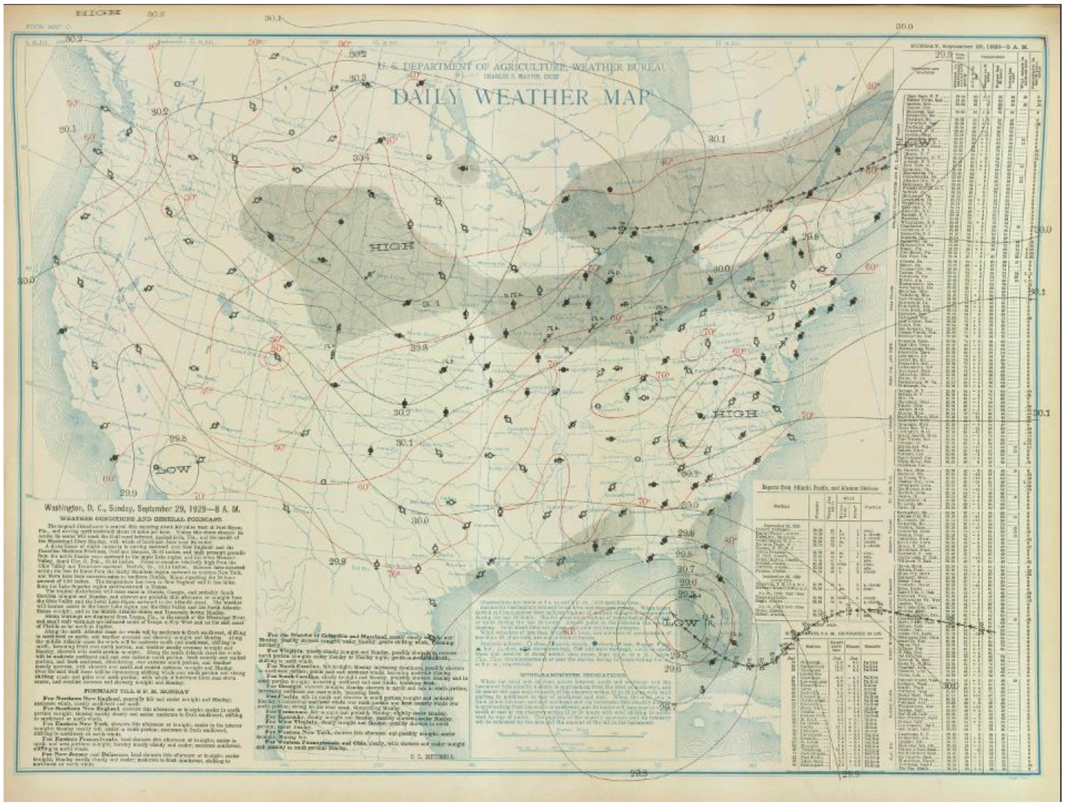

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Tuesday, September 24, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
WIND-BAROMETER INDICATIONS.

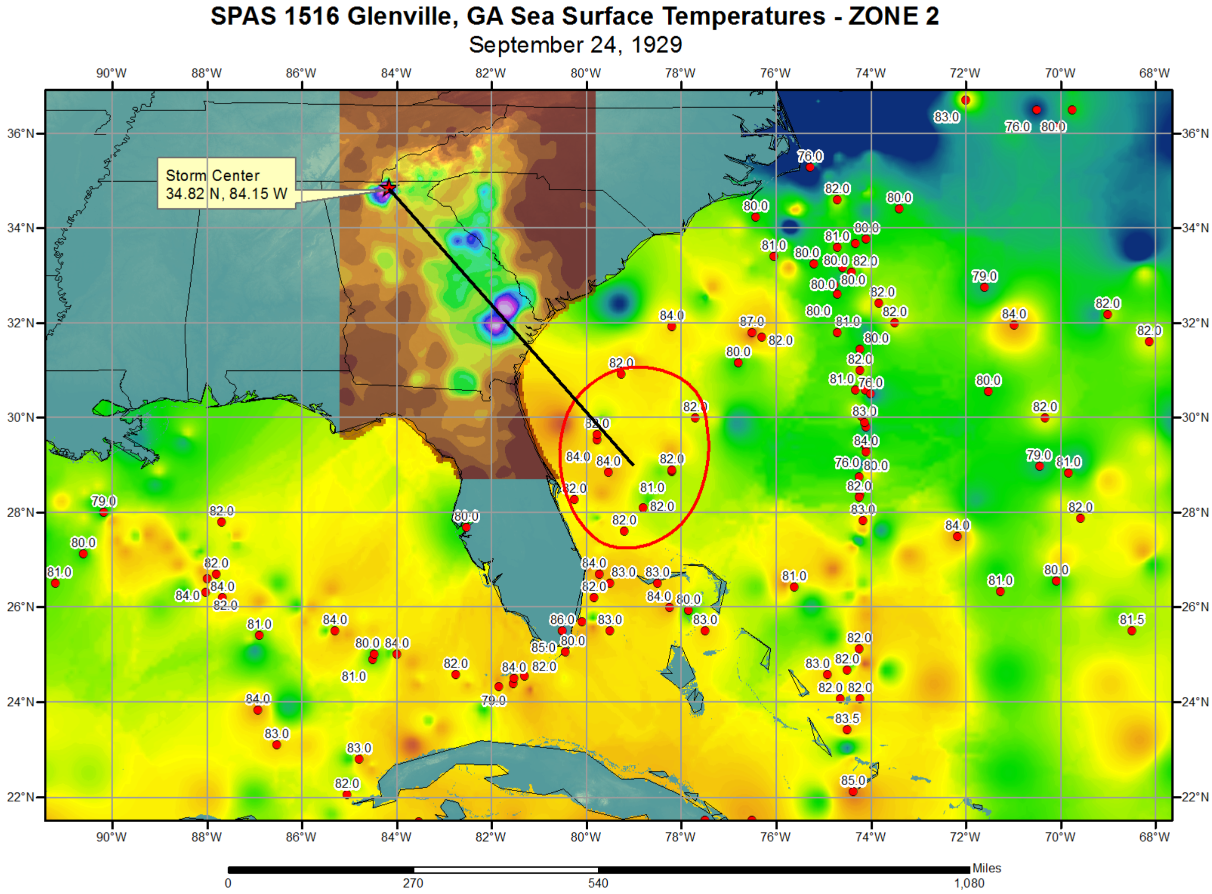

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Wednesday, September 25, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
WIND-BAROMETER INDICATIONS.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Thursday, September 26, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST.
WIND-BAROMETER INDICATIONS.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Friday, September 27, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECASTS.
FORECAST TILL 8 P. M. SATURDAY
WIND-BAROMETER INDICATIONS
Reports from Atlantic, Pacific, and Alaskan Stations


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Saturday, September 28, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECASTS.
FORECAST TILL 8 P. M. SUNDAY
WIND-BAROMETER INDICATIONS
Reports from Atlantic, Pacific, and Alaskan Stations


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
LOW
Washington, D. C., Sunday, September 29, 1929—8 A. M.


SPAS 1516 Glenville, GA Sea Surface Temperatures - ZONE 2
September 24, 1929
Storm Center
34.82 N, 84.15 W
Miles
0
270
540
1,080

Storm Precipitation Analysis System (SPAS) For Storm #1517_2 SPAS Analysis

General Storm Location: Vernon, FL

Storm Dates: September 29 – October 3, 1929

Event: Extreme Precipitation Event

DAD Zone 2

Latitude: 35.6042

Longitude: -79.0708

Max. Grid Rainfall Amount: 11.55”

Max. Observed Rainfall Amount: 11.55” (Moncure, NC)

Number of Stations: 516

SPAS Version: 10.0

Base Map Used: USACE Report SA 3-23 Isohyetal Basemap (nwsmetstat_isohyetal_spas1517_surf_surf_sm)

Spatial resolution: .2739

Radar Included: No

Depth-Area-Duration (DAD) analysis: No

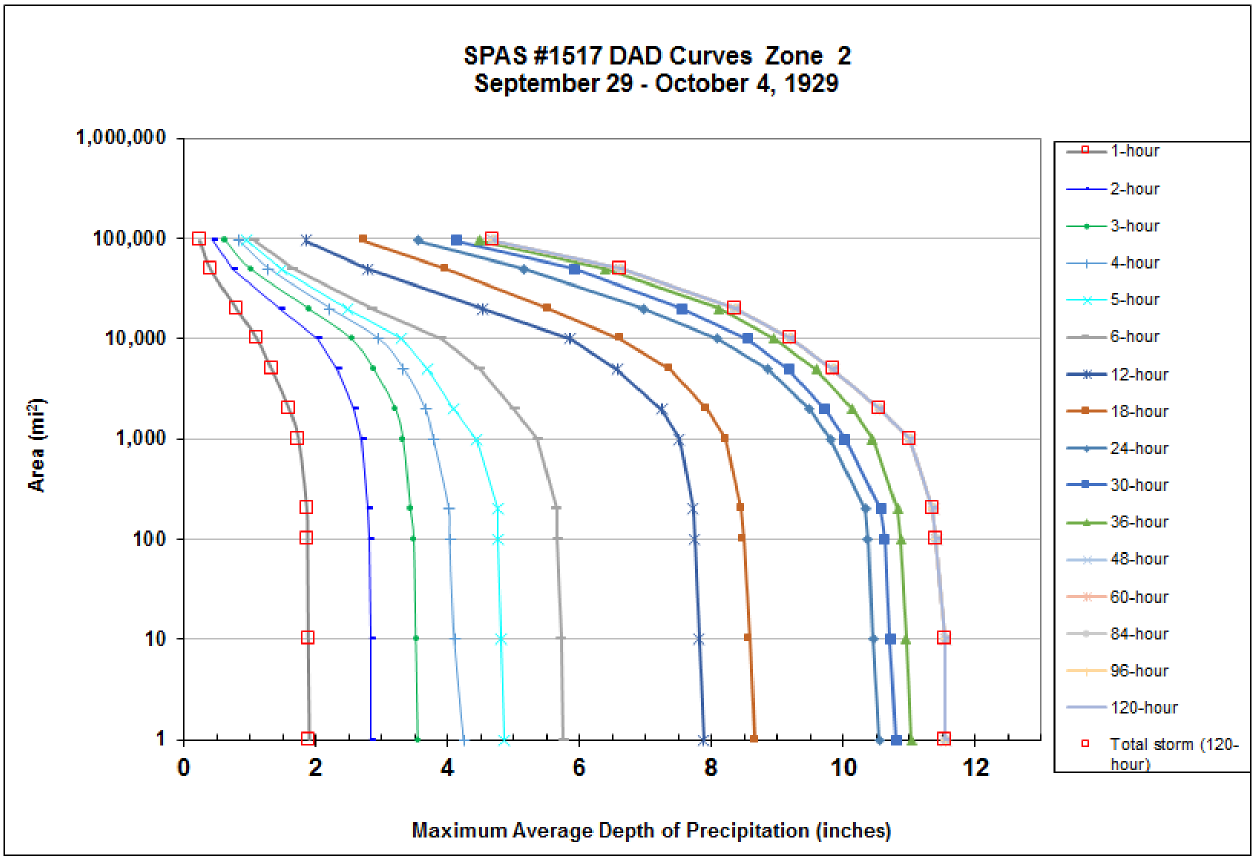
Reliability of Results: Seventy-six supplemental stations were added to ensure data consistency. Due to the amount and integrity of the U.S. Army Corps of Engineers (USACE) report, five hourly stations were digitized based on the mass rainfall curves from the USACE report. With the density of stations available and the consistency of the resulting SPAS analysis to the U.S. Army Corps of Engineers report, this analysis is deemed quite reliable to the fact that this analysis had only 6 hourly stations on the eastern side of the Appalachian Mountains. Attempts were made to the USACE branches for the full storm reports to no avail.

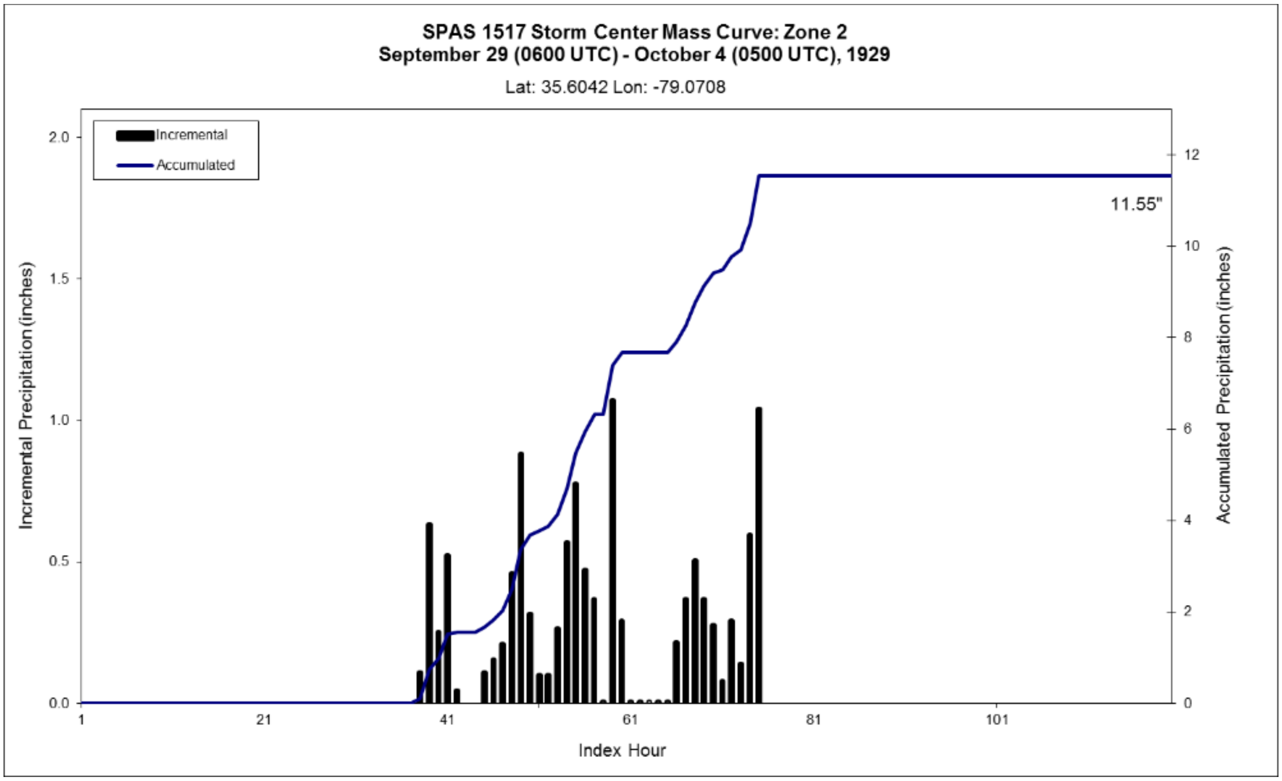
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1517_2	-79.0708	35.6042	181	15-Sep	80.00	3.60	0.06	82	3.540	84.48	4.39	0.07	91	4.320	1.220

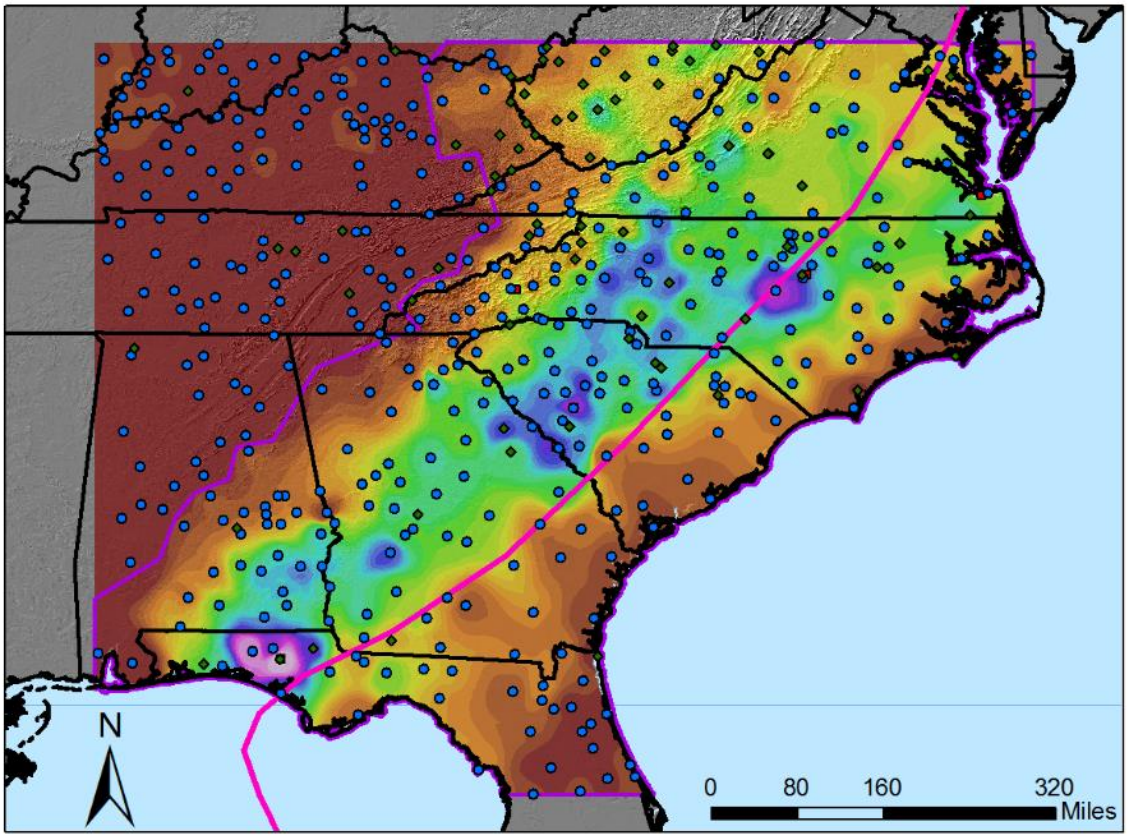
Storm 1517 - September 29 (0600 UTC) - October 4 (0500 UTC), 1929

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

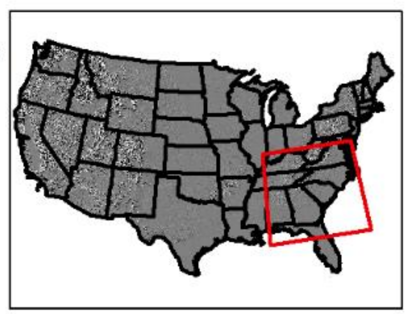
Area (mi^2)	Duration (hours)															
	1	2	3	4	5	6	12	18	24	30	36	48	60	84	96	120	Total
0.4	1.92	2.84	3.56	4.30	4.89	5.76	7.90	8.71	10.58	10.82	11.07	11.55	11.55	11.55	11.55	11.55	11.55
1	1.91	2.84	3.55	4.24	4.85	5.76	7.88	8.67	10.55	10.80	11.04	11.55	11.55	11.55	11.55	11.55	11.55
10	1.89	2.82	3.52	4.10	4.80	5.72	7.81	8.58	10.46	10.71	10.96	11.55	11.55	11.55	11.55	11.55	11.55
100	1.88	2.80	3.49	4.03	4.77	5.66	7.74	8.49	10.37	10.63	10.87	11.41	11.41	11.41	11.41	11.41	11.41
200	1.87	2.79	3.44	4.02	4.76	5.65	7.72	8.46	10.34	10.57	10.83	11.36	11.36	11.36	11.36	11.36	11.36
1000	1.74	2.69	3.33	3.78	4.44	5.36	7.51	8.22	9.81	10.02	10.45	11.01	11.01	11.01	11.01	11.01	11.01
2000	1.60	2.57	3.21	3.66	4.08	5.01	7.25	7.93	9.49	9.72	10.14	10.56	10.56	10.56	10.56	10.56	10.56
5000	1.33	2.31	2.88	3.33	3.69	4.49	6.57	7.37	8.86	9.18	9.59	9.85	9.85	9.85	9.85	9.85	9.85
10000	1.11	2.01	2.54	2.95	3.30	3.91	5.86	6.62	8.09	8.55	8.96	9.21	9.21	9.21	9.21	9.21	9.21
20000	0.80	1.46	1.89	2.21	2.49	2.85	4.52	5.52	6.97	7.55	8.12	8.35	8.36	8.36	8.36	8.36	8.36
50,000	0.40	0.74	1.01	1.28	1.47	1.65	2.78	3.97	5.15	5.92	6.39	6.62	6.62	6.63	6.63	6.63	6.63
95,317	0.24	0.44	0.63	0.82	0.94	1.07	1.85	2.73	3.55	4.13	4.49	4.67	4.69	4.70	4.70	4.70	4.70




SPAS 1517 Storm Center Mass Curve: Zone 2
September 29 (0600 UTC) - October 4 (0500 UTC), 1929
Lat: 35.6042 Lon: -79.0708
Incremental
Accumulated
11.55"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
2
4
6
8
10
12
1
21
41
61
81
101



Total 120-hour Precipitation (Inches)
September 29, 1929 0600 UTC - October 4, 1929 0500 UTC
SPAS #1517-Hurricane #2



Precipitation (Inches)

0.00 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.00
10.01 - 10.50
10.51 - 11.00
11.01 - 11.50
11.51 - 12.00
12.01 - 12.50
12.51 - 13.00
13.01 - 13.50
13.51 - 14.00

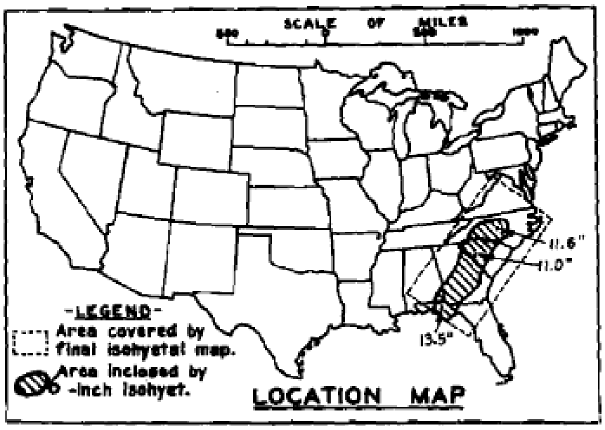
Statoins

Daily
Hourly
Hourly Estimated
Supplemental
Hurricane #2 Track

WJM 03/26/2015

WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES - PERTINENT DATA SHEET



LOCATION MAP

Storm of Sept.29 - Oct.3,1929
Assignment SA 3 - 23
Location N.C., S.C., Ga. Fla.
Study Prepared by:
South Atlantic Division
Savannah District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 10/23/40
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 2/19/44
Remarks: Centers at Vernon, Fla., Moncure, N.C. and Saluda, S.C.

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1 : 2,500,000

Precipitation data and mass curves: (Number of Sheets)

Form 5001-C (Hourly precip. data)	20
Form 5001-B (24-hour " ")	52
Form 5001-D (" " ")	0
Miscl. precip. records, meteorological data, etc.	2
Form 5002 (Mass rainfall curves)	55

PART II

Final isohyetal maps, in 1 sheet, scale 1 : 1,000,000

Data and computation sheets:

Form S-10 (Data from mass rainfall curves)	7
Form S-11 (Depth-area data from isohyetal map)	3
Form S-12 (Maximum depth-duration data)	11
Maximum duration-depth-area curves	1
Data relating to periods of maximum rainfall	2

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

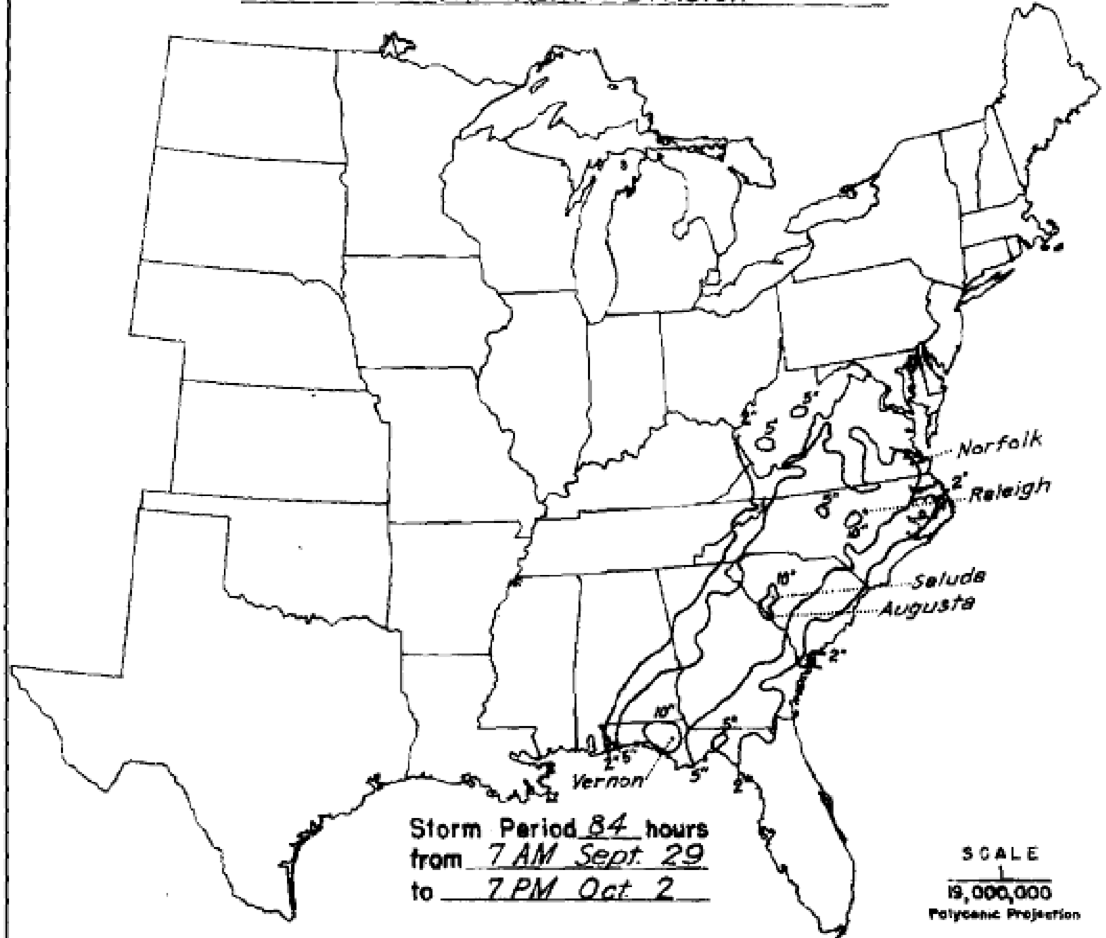
Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	84		
10	6.1	7.8	8.9	11.1	13.1	13.5	13.5	13.5	13.5		
100	5.7	7.6	8.5	10.5	12.8	13.5	13.5	13.5	13.5		
200	5.6	7.5	8.3	10.3	12.7	13.4	13.4	13.4	13.4		
500	5.4	7.4	8.2	9.8	12.2	13.1	13.1	13.1	13.1		
1,000	5.2	7.3	7.9	9.3	11.6	12.7	12.7	12.7	12.7		
2,000	4.8	6.7	7.5	8.8	10.8	11.8	11.9	11.9	11.9		
5,000	3.9	5.7	6.7	8.0	9.4	10.2	10.5	10.5	10.5		
10,000	3.3	4.9	6.0	7.2	8.3	9.1	9.5	9.5	9.5		
20,000	2.7	4.1	5.3	6.4	7.3	8.2	8.8	8.9	8.9		
50,000	1.8	3.1	4.2	5.3	6.1	7.2	7.9	8.2	8.2		
70,000	1.5	2.7	3.7	4.8	5.6	6.7	7.4	7.7	7.7		
103,000	1.2	2.2	3.3	4.2	5.0	5.9	6.5	6.8	6.8		

Form S-2

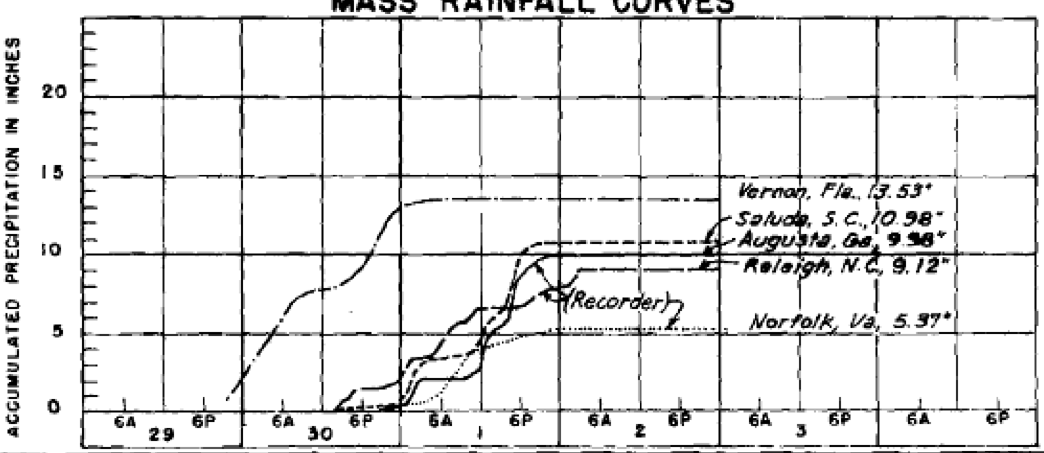
WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES - ISOHYETAL MAP

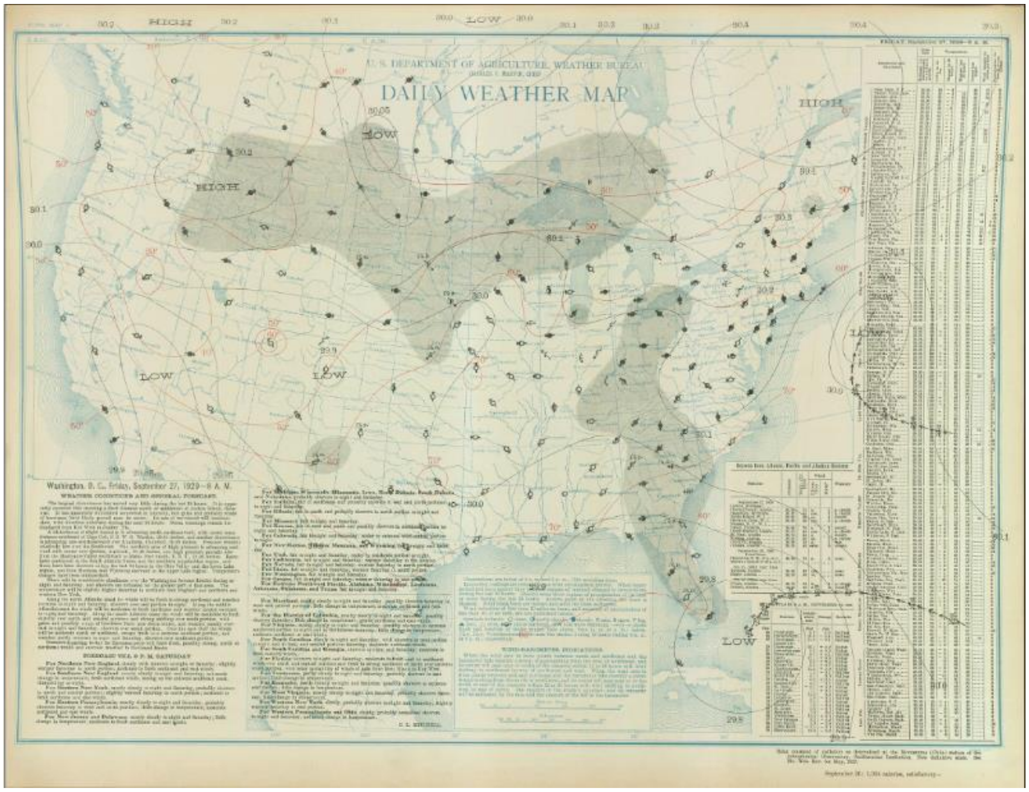
Storm of *September 29 - October 3, 1929* Assignment *SA 3-23*
Study Prepared by: *Savannah, Ga. District*
South Atlantic Division

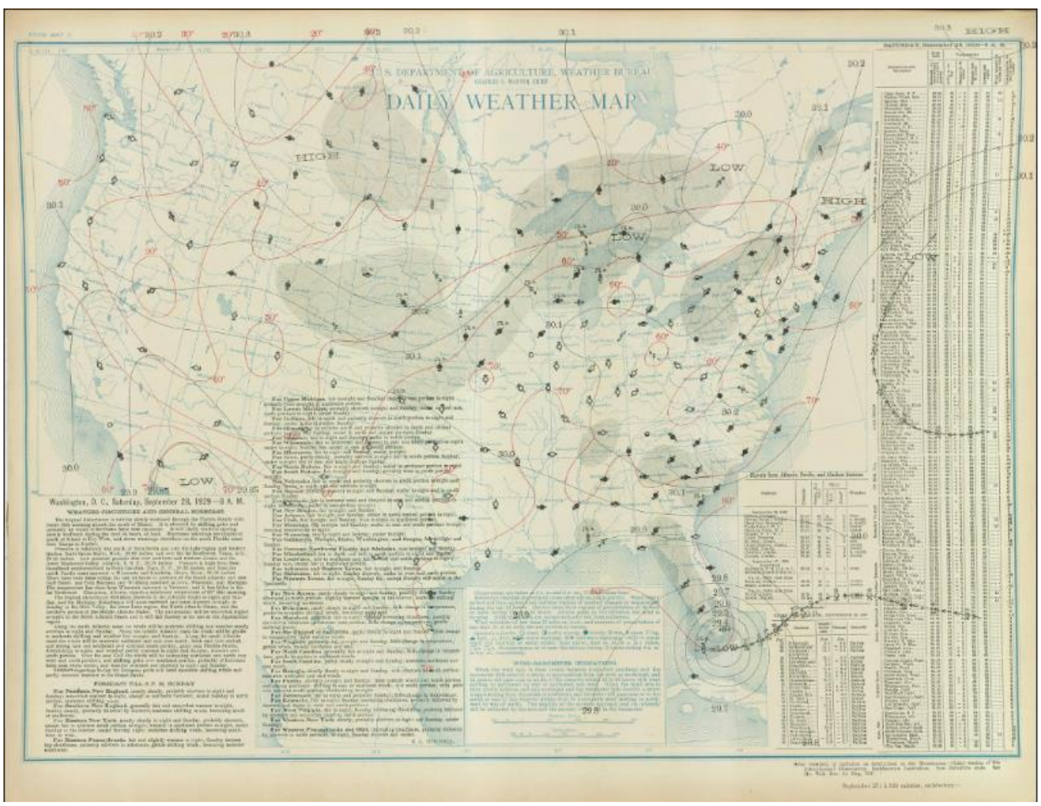


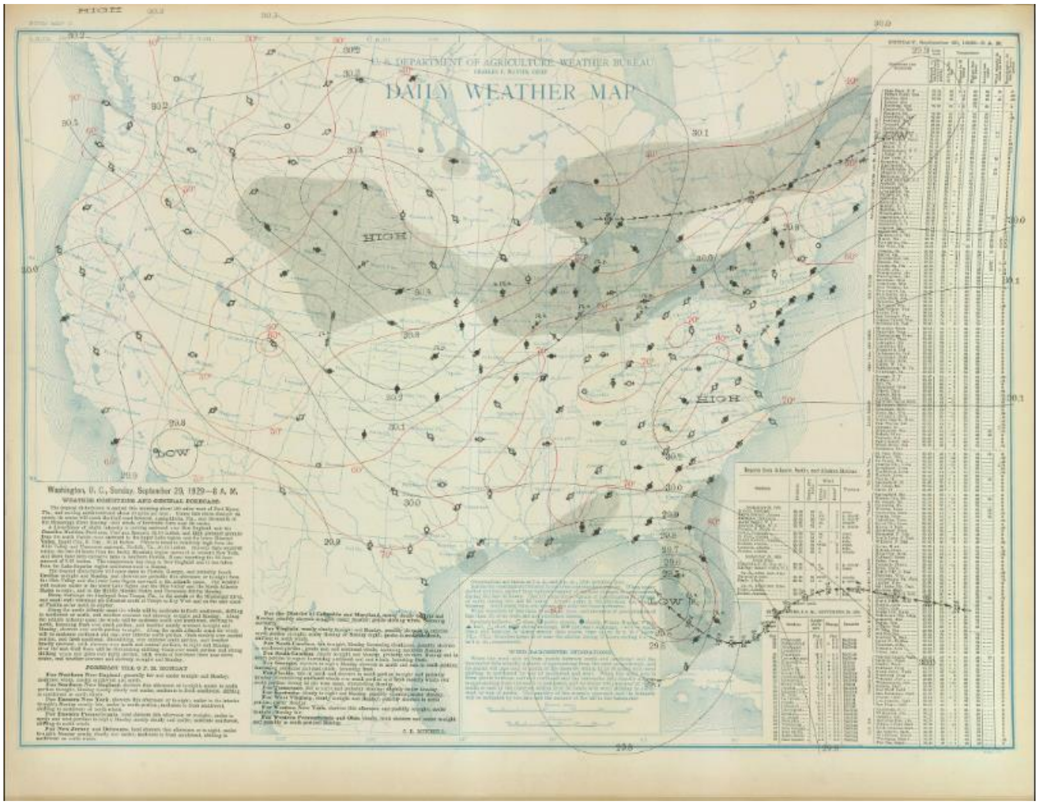
MASS RAINFALL CURVES

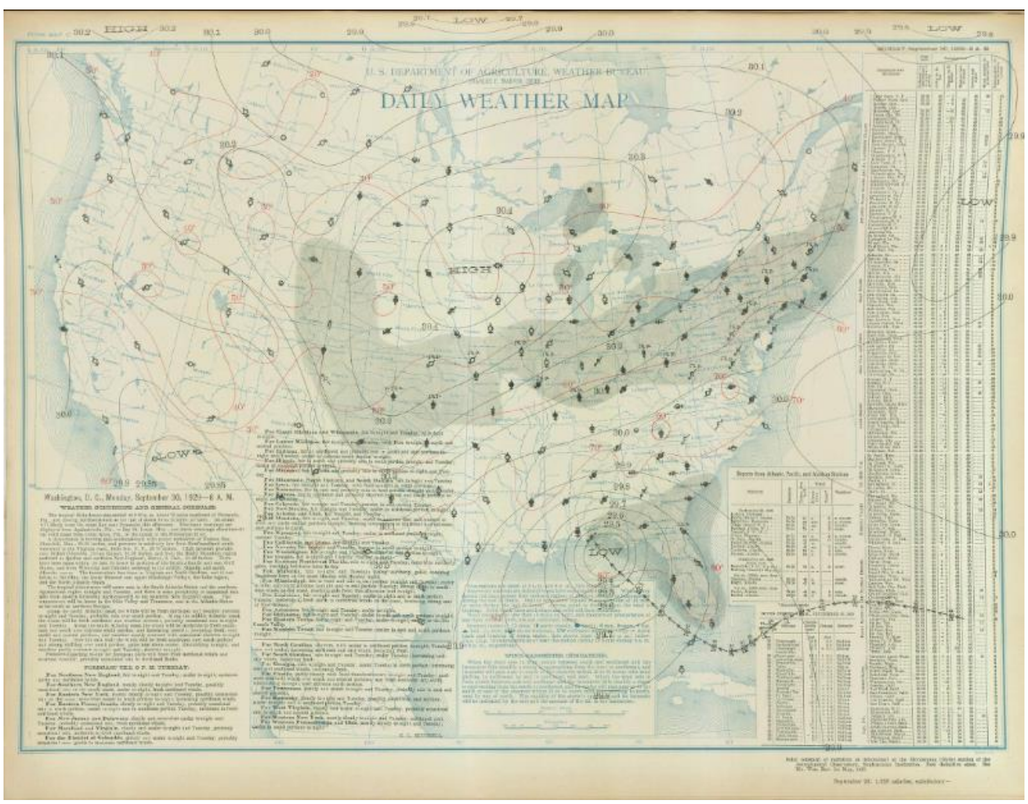


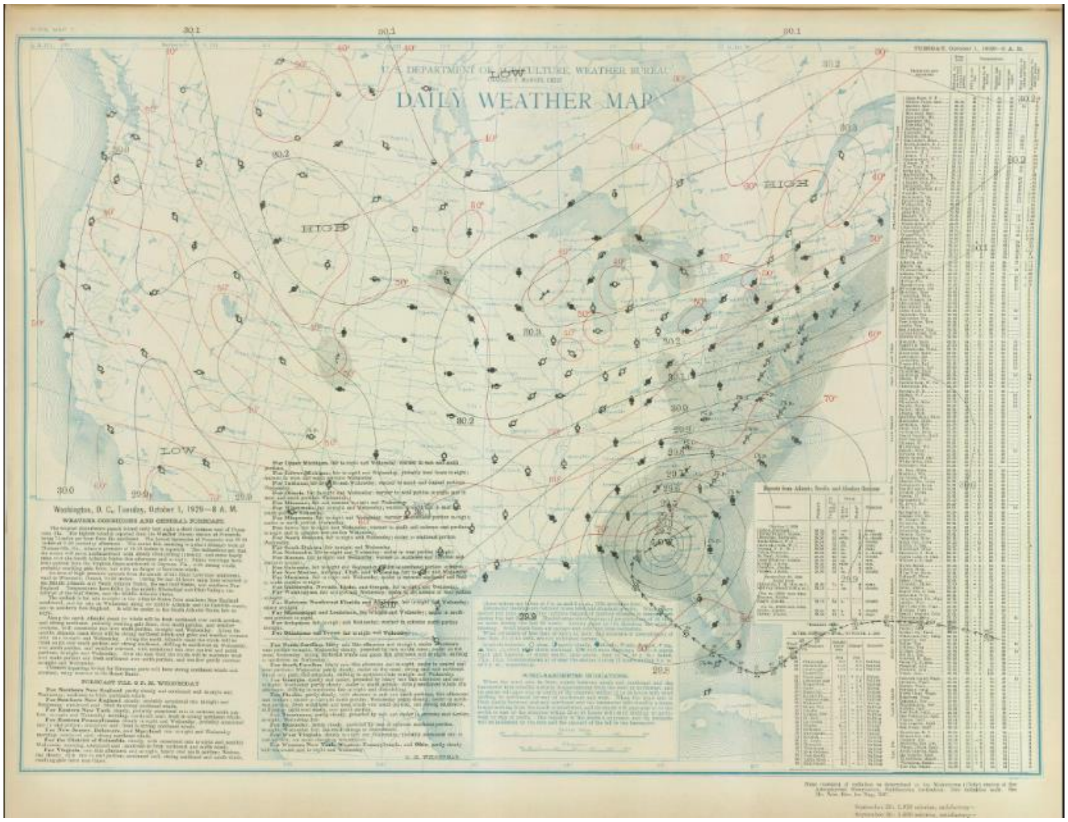
FORM S-3E

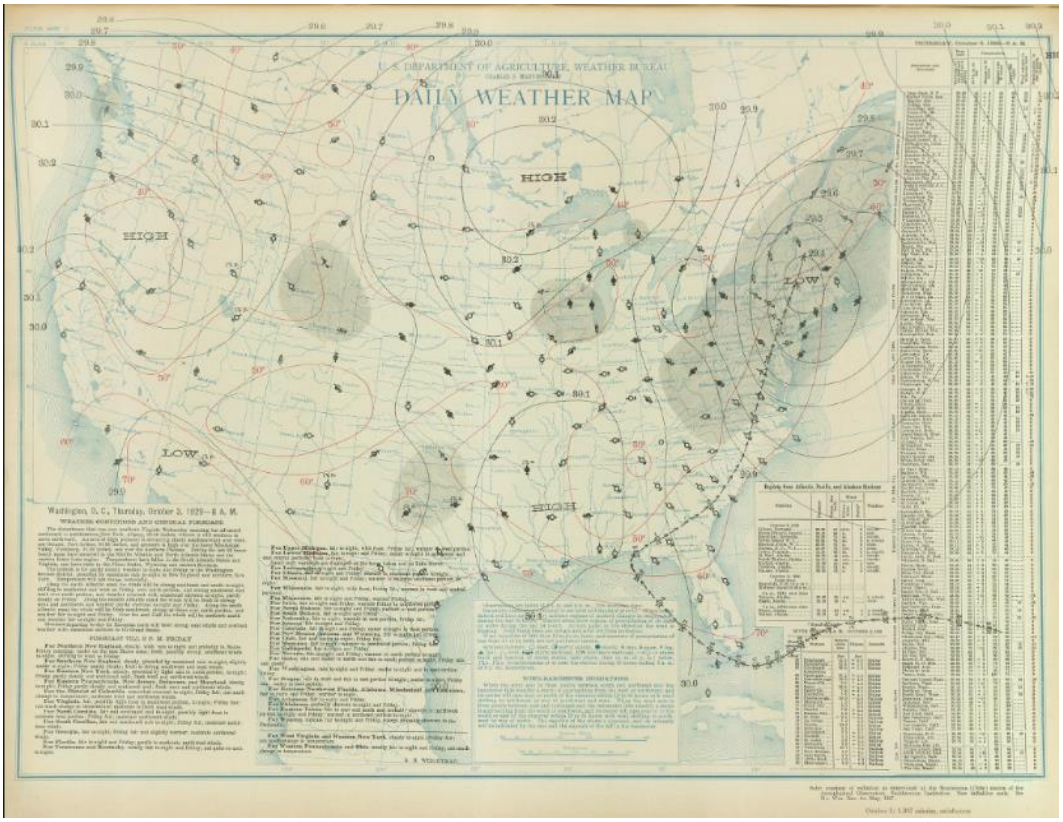

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Friday, September 27, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST

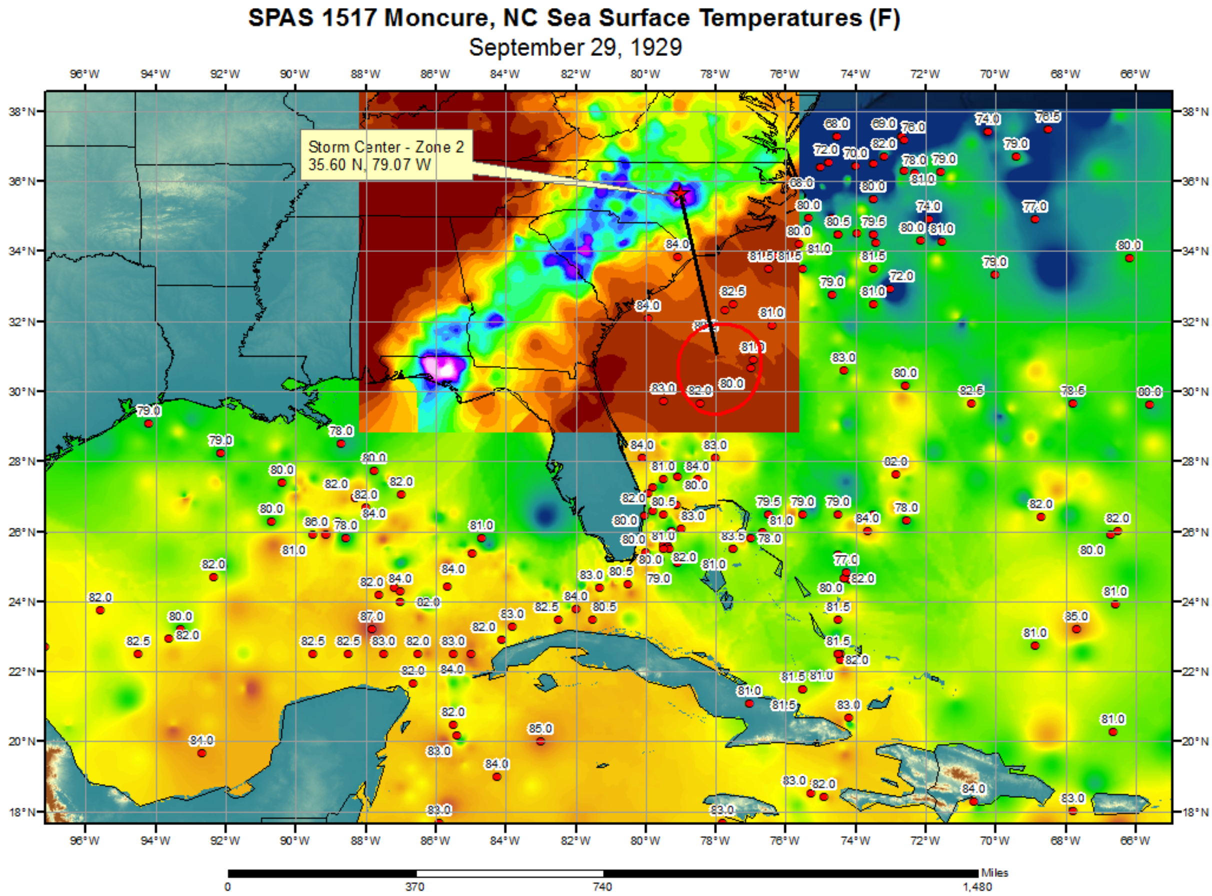

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Saturday, September 28, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST

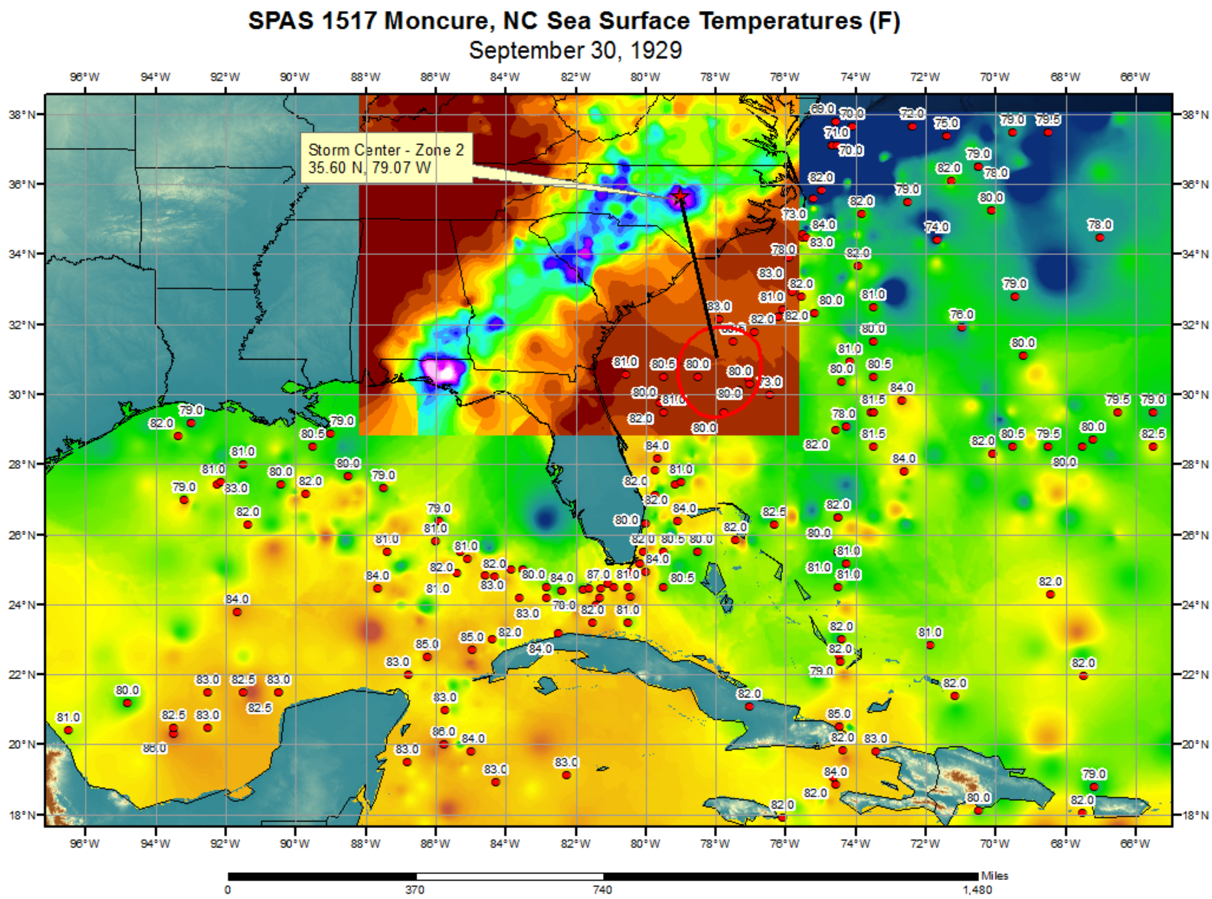

U.S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
LOW
LOW
Washington, D. C., Sunday, September 29, 1929—8 A. M.


U.S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
LOW
LOW
LOW
LOW
Washington, D. C., Monday, September 30, 1929—8 A. M.


DAILY WEATHER MAP
HIGH
HIGH
LOW
Washington, D. C., Tuesday, October 1, 1929—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
HIGH
LOW
LOW


SPAS 1517 Moncure, NC Sea Surface Temperatures (F)
September 29, 1929
Storm Center - Zone 2
35.60 N, 79.07 W
Miles
0
370
740
1,480


SPAS 1517 Moncure, NC Sea Surface Temperatures (F)
September 30, 1929
Storm Center - Zone 2
35.60 N, 79.07 W
Miles
0
370
740
1,480

Storm Precipitation Analysis System (SPAS) For Storm #1517_3 SPAS Analysis

General Storm Location: Vernon, FL

Storm Dates: September 29 – October 3, 1929

Event: Extreme Precipitation Event

DAD Zone 3

Latitude: 35.9458

Longitude: -80.6958

Max. Grid Rainfall Amount: 9.97"

Max. Observed Rainfall Amount: 9.63" (Settle, NC)

Number of Stations: 516

SPAS Version: 10.0

Base Map Used: USACE Report SA 3-23 Isohyetal Basemap (nwsmetstat_isohyetal_spas1517_surf_surf_sm)

Spatial resolution: .2739

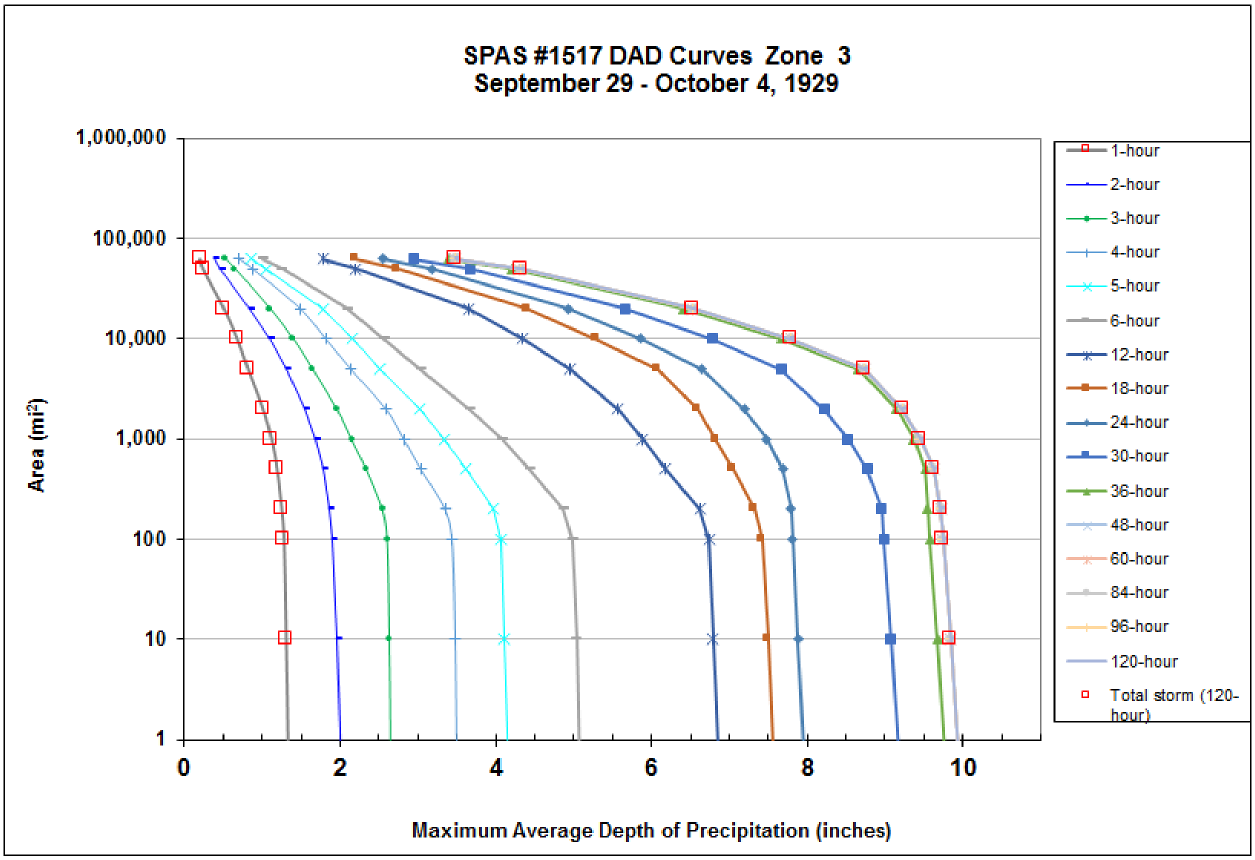
Radar Included: No

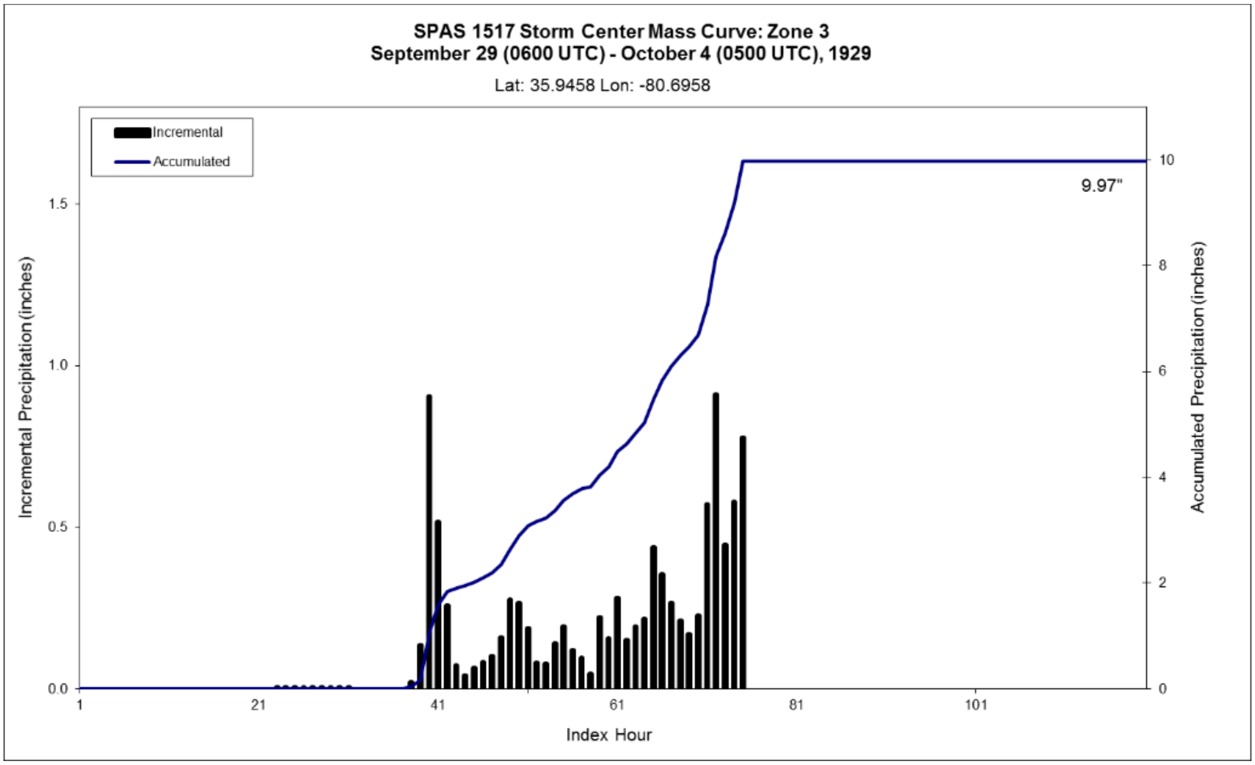
Depth-Area-Duration (DAD) analysis: No

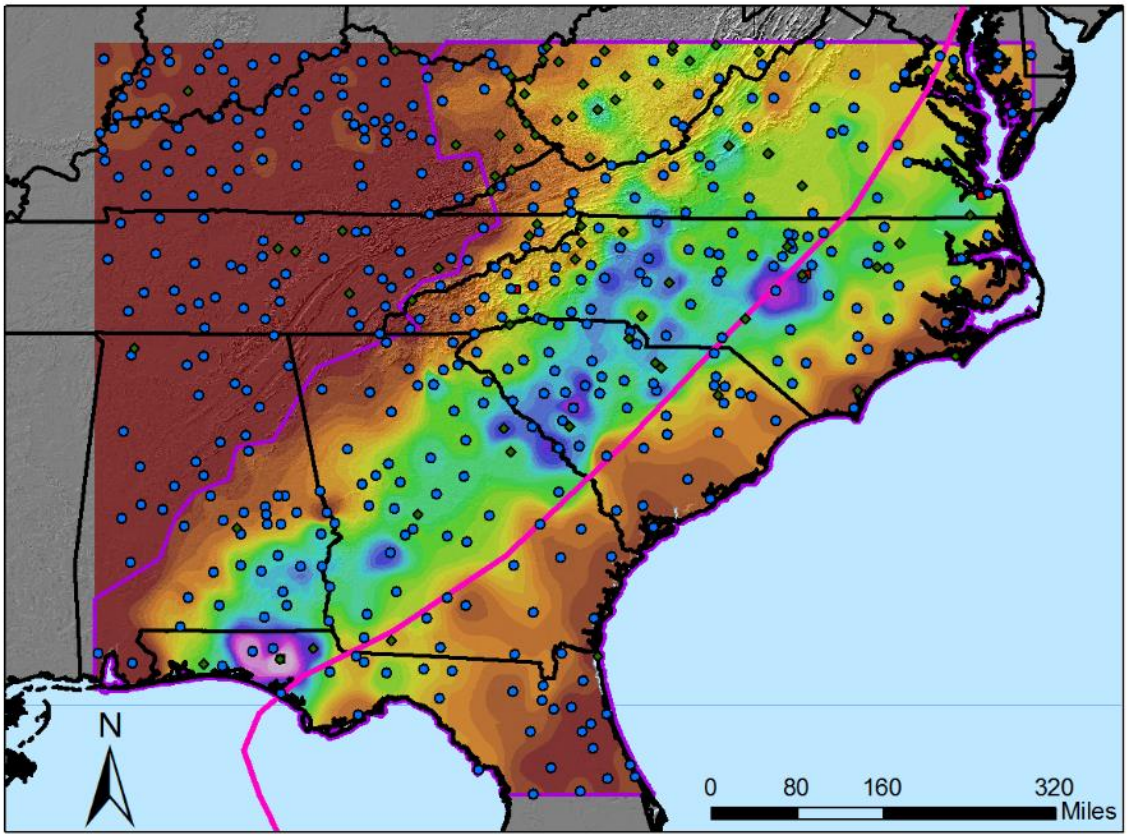
Reliability of Results: Seventy-six supplemental stations were added to ensure data consistency. Due to the amount and integrity of the U.S. Army Corps of Engineers (USACE) report, five hourly stations were digitized based on the mass rainfall curves from the USACE report. With the density of stations available and the consistency of the resulting SPAS analysis to the U.S. Army Corps of Engineers report, this analysis is deemed quite reliable to the fact that this analysis had only 6 hourly stations on the eastern side of the Appalachian Mountains. Attempts were made to the USACE branches for the full storm reports to no avail.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1517_3	-80.6958	35.9458	766	15-Sep	80.00	3.60	0.24	82	3.360	84.48	4.39	0.28	91	4.110	1.223

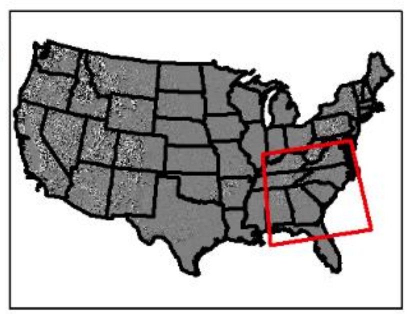
Storm 1517 - September 29 (0600 UTC) - October 4 (0500 UTC), 1929																	
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)																	
Area (mi^2)	Duration (hours)																
	1	2	3	4	5	6	12	18	24	30	36	48	60	84	96	120	Total
0.4	1.34	2.03	2.66	3.50	4.16	5.09	6.87	7.59	7.98	9.19	9.79	9.97	9.97	9.97	9.97	9.97	9.97
10	1.31	1.97	2.64	3.48	4.11	5.04	6.79	7.50	7.88	9.07	9.67	9.84	9.84	9.84	9.84	9.84	9.84
100	1.28	1.91	2.61	3.44	4.06	4.99	6.74	7.42	7.81	8.99	9.58	9.74	9.74	9.74	9.74	9.74	9.74
200	1.25	1.87	2.55	3.35	3.97	4.87	6.62	7.32	7.79	8.96	9.55	9.71	9.71	9.71	9.71	9.71	9.71
500	1.19	1.79	2.34	3.04	3.61	4.44	6.18	7.05	7.69	8.77	9.52	9.63	9.63	9.63	9.63	9.63	9.63
1000	1.12	1.69	2.15	2.82	3.33	4.08	5.88	6.82	7.48	8.52	9.37	9.45	9.45	9.45	9.45	9.45	9.45
2000	1.01	1.55	1.96	2.59	3.02	3.67	5.57	6.59	7.19	8.22	9.15	9.22	9.22	9.22	9.22	9.22	9.22
5000	0.82	1.32	1.65	2.14	2.52	3.04	4.96	6.08	6.65	7.67	8.66	8.74	8.74	8.74	8.74	8.74	8.74
10000	0.68	1.09	1.40	1.82	2.16	2.57	4.35	5.28	5.86	6.78	7.67	7.78	7.78	7.78	7.78	7.78	7.78
20000	0.51	0.83	1.10	1.49	1.78	2.09	3.65	4.40	4.93	5.66	6.41	6.51	6.52	6.53	6.53	6.53	6.53
50,000	0.24	0.46	0.65	0.88	1.06	1.26	2.20	2.73	3.18	3.67	4.20	4.29	4.31	4.32	4.32	4.32	4.32
62,591	0.20	0.38	0.52	0.71	0.85	1.01	1.78	2.20	2.56	2.94	3.39	3.46	3.48	3.48	3.48	3.48	3.48




SPAS 1517 Storm Center Mass Curve: Zone 3
September 29 (0600 UTC) - October 4 (0500 UTC), 1929
Lat: 35.9458 Lon: -80.6958
Incremental
Accumulated
9.97"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
0
2
4
6
8
10
1
21
41
61
81
101



Total 120-hour Precipitation (Inches)
September 29, 1929 0600 UTC - October 4, 1929 0500 UTC
SPAS #1517-Hurricane #2



Precipitation (Inches)

0.00 - 0.50	3.51 - 4.00	7.01 - 7.50	10.51 - 11.00
0.51 - 1.00	4.01 - 4.50	7.51 - 8.00	11.01 - 11.50
1.01 - 1.50	4.51 - 5.00	8.01 - 8.50	11.51 - 12.00
1.51 - 2.00	5.01 - 5.50	8.51 - 9.00	12.01 - 12.50
2.01 - 2.50	5.51 - 6.00	9.01 - 9.50	12.51 - 13.00
2.51 - 3.00	6.01 - 6.50	9.51 - 10.00	13.01 - 13.50
3.01 - 3.50	6.51 - 7.00	10.01 - 10.50	13.51 - 14.00

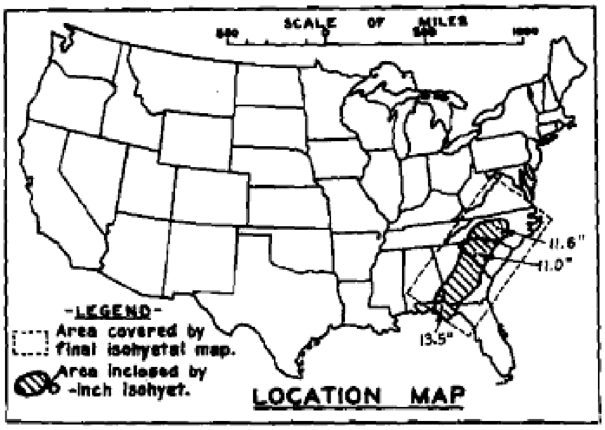
Statoins

- Daily
- Hourly
- Hourly Estimated
- Supplemental
- Hurricane #2 Track

WJM 03/26/2015

WAR DEPARTMENT | CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – PERTINENT DATA SHEET



LOCATION MAP

Storm of Sept. 29 – Oct. 3, 1929
Assignment SA 3 – 23
Location N.C., S.C., Ga. Fla.
Study Prepared by:
South Atlantic Division
Savannah District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 10/23/40
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 2/19/44
Remarks: Centers at Vernon, Fla., Moncure, N.C. and Saluda, S.C.

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1 : 2,500,000

Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) ---------- 20
- Form 5001-B (24-hour " ") ---------- 52
- Form 5001-D (" " " ") ---------- 0
- Miscl. precip. records, meteorological data, etc. ---------- 2
- Form 5002 (Mass rainfall curves) ---------- 55

PART II

Final isohyetal maps, in 1 sheet, scale 1 : 1,000,000

Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) ---------- 7
- Form S-11 (Depth-area data from isohyetal map) ---------- 3
- Form S-12 (Maximum depth-duration data) ---------- 11
- Maximum duration-depth-area curves ---------- 1
- Data relating to periods of maximum rainfall ---------- 2

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	84		
10	6.1	7.8	8.9	11.1	13.1	13.5	13.5	13.5	13.5		
100	5.7	7.6	8.5	10.5	12.8	13.5	13.5	13.5	13.5		
200	5.6	7.5	8.3	10.3	12.7	13.4	13.4	13.4	13.4		
500	5.4	7.4	8.2	9.8	12.2	13.1	13.1	13.1	13.1		
1,000	5.2	7.3	7.9	9.3	11.6	12.7	12.7	12.7	12.7		
2,000	4.8	6.7	7.5	8.8	10.8	11.8	11.9	11.9	11.9		
5,000	3.9	5.7	6.7	8.0	9.4	10.2	10.5	10.5	10.5		
10,000	3.3	4.9	6.0	7.2	8.3	9.1	9.5	9.5	9.5		
20,000	2.7	4.1	5.3	6.4	7.3	8.2	8.8	8.9	8.9		
50,000	1.8	3.1	4.2	5.3	6.1	7.2	7.9	8.2	8.2		
70,000	1.5	2.7	3.7	4.8	5.6	6.7	7.4	7.7	7.7		
103,000	1.2	2.2	3.3	4.2	5.0	5.9	6.5	6.8	6.8		

Form S-2

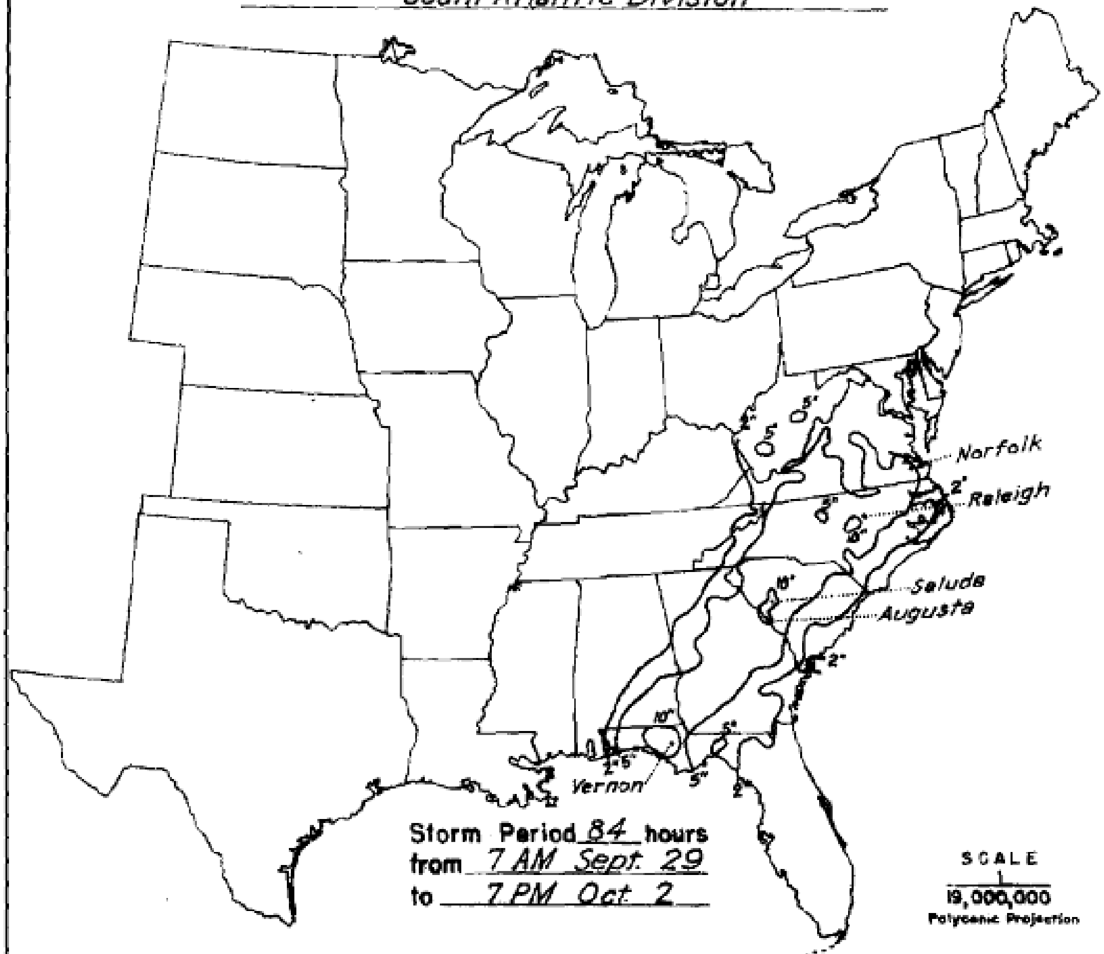
WAR DEPARTMENT | CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – ISOHYETAL MAP

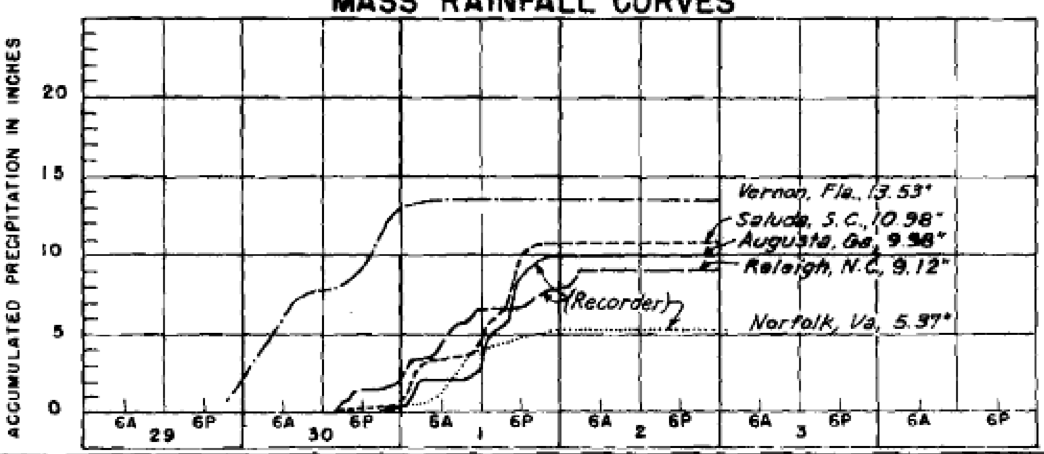
Storm of *September 29 - October 3, 1929* Assignment *SA 3-23*

Study Prepared by: *Savannah, Ga. District*

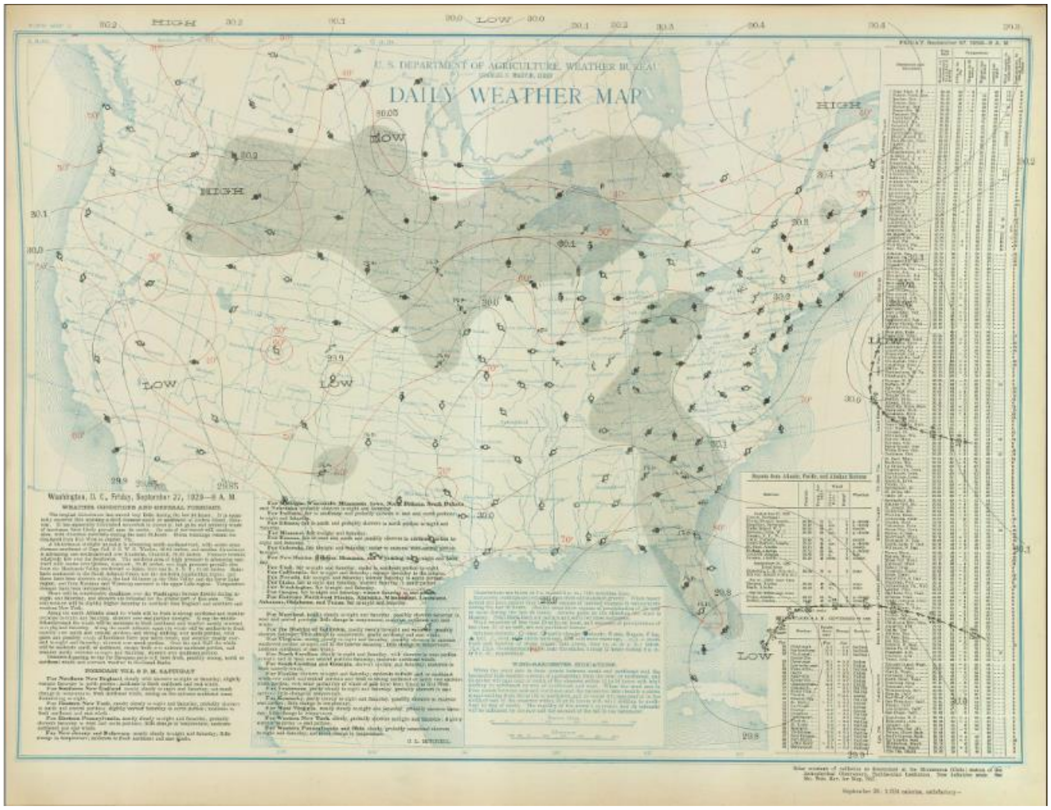
South Atlantic Division

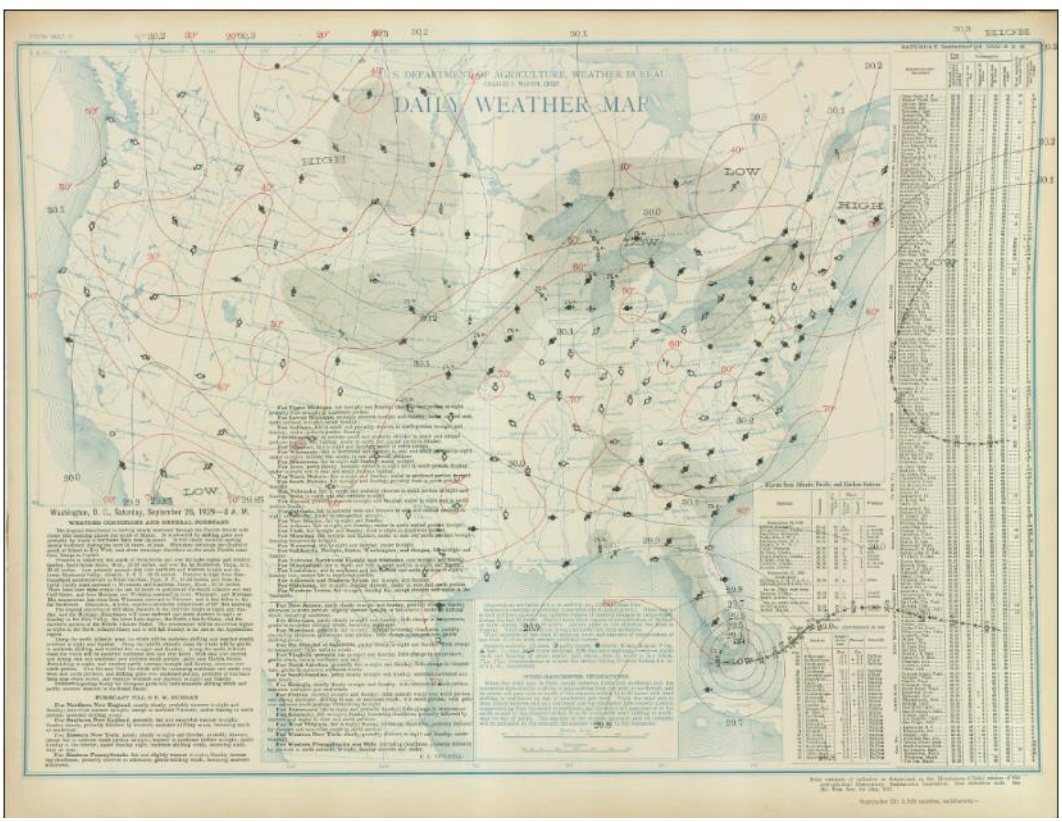


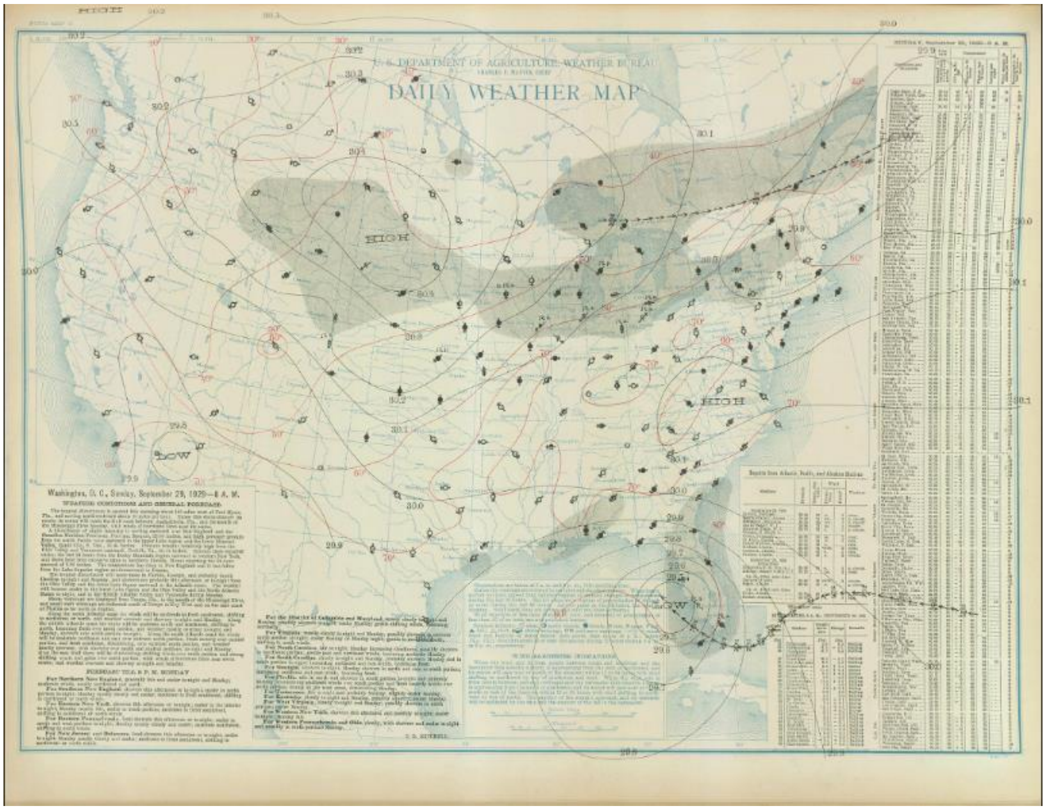
MASS RAINFALL CURVES

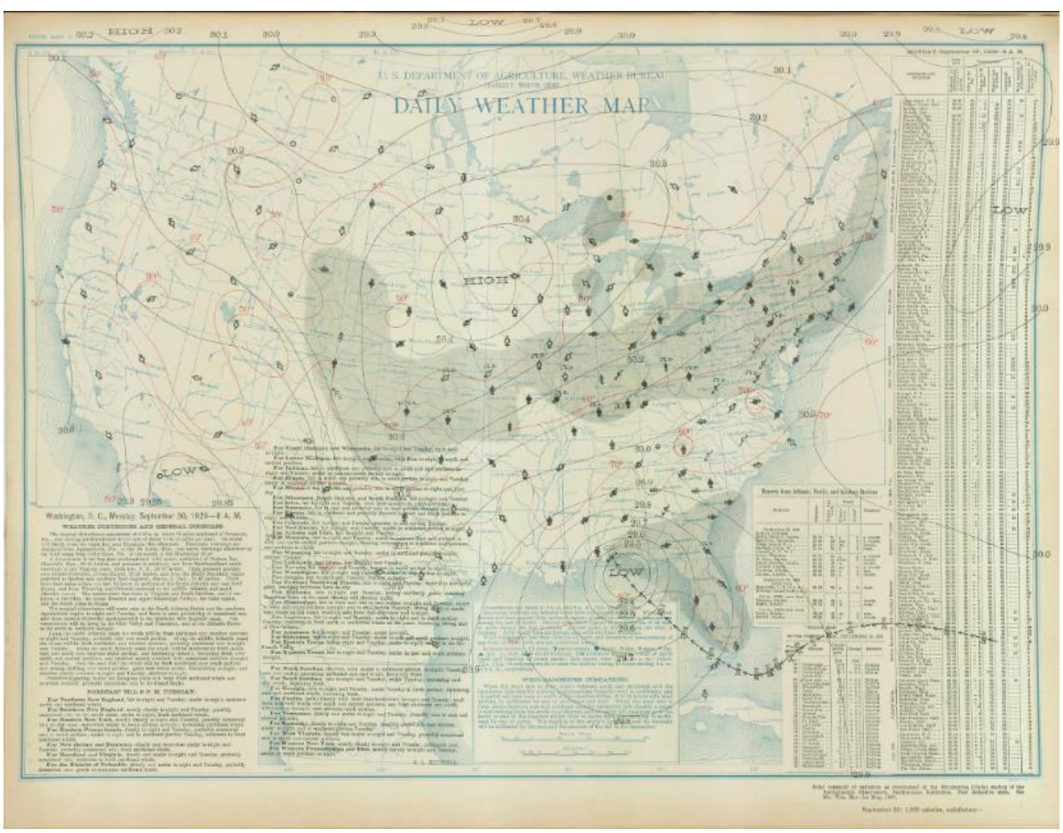


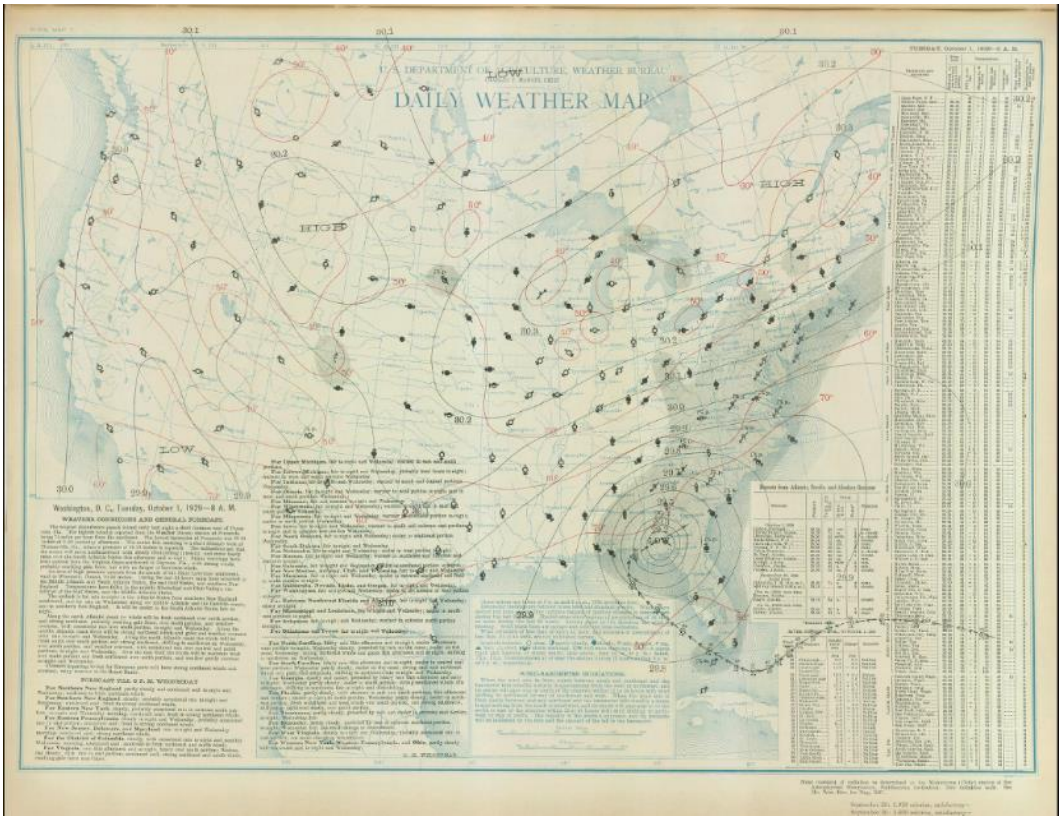
FORM S-3E

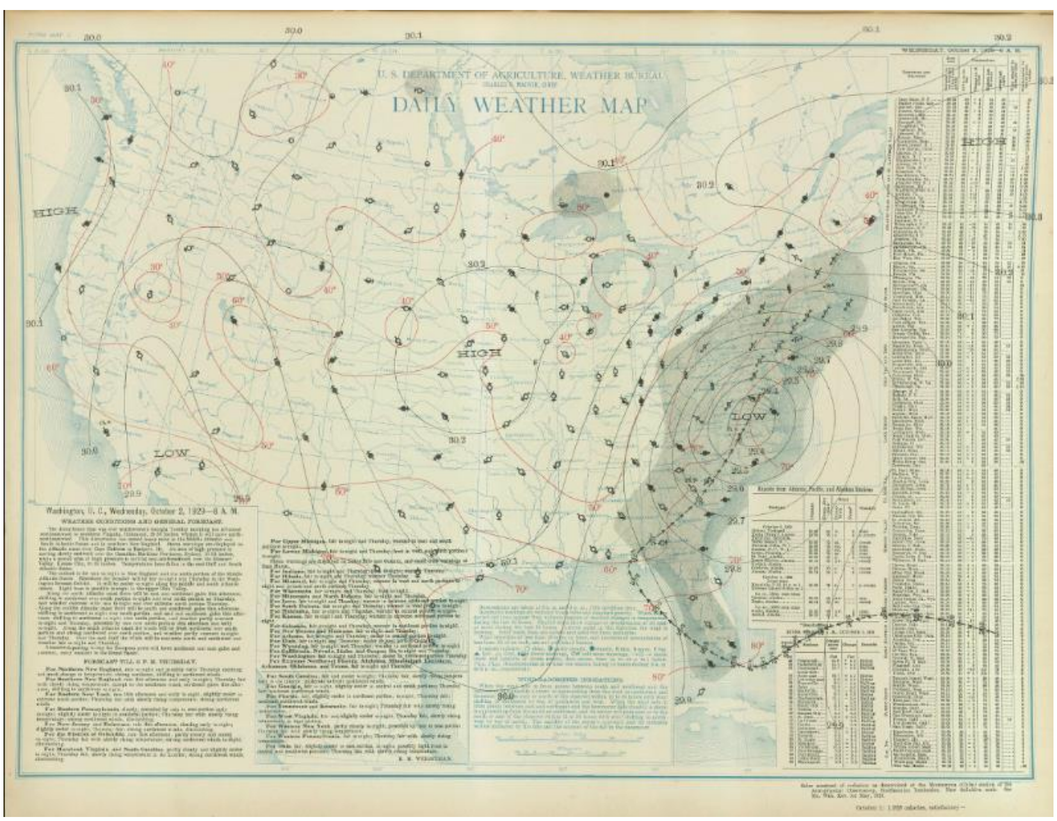

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Friday, September 27, 1929—8 A. M.

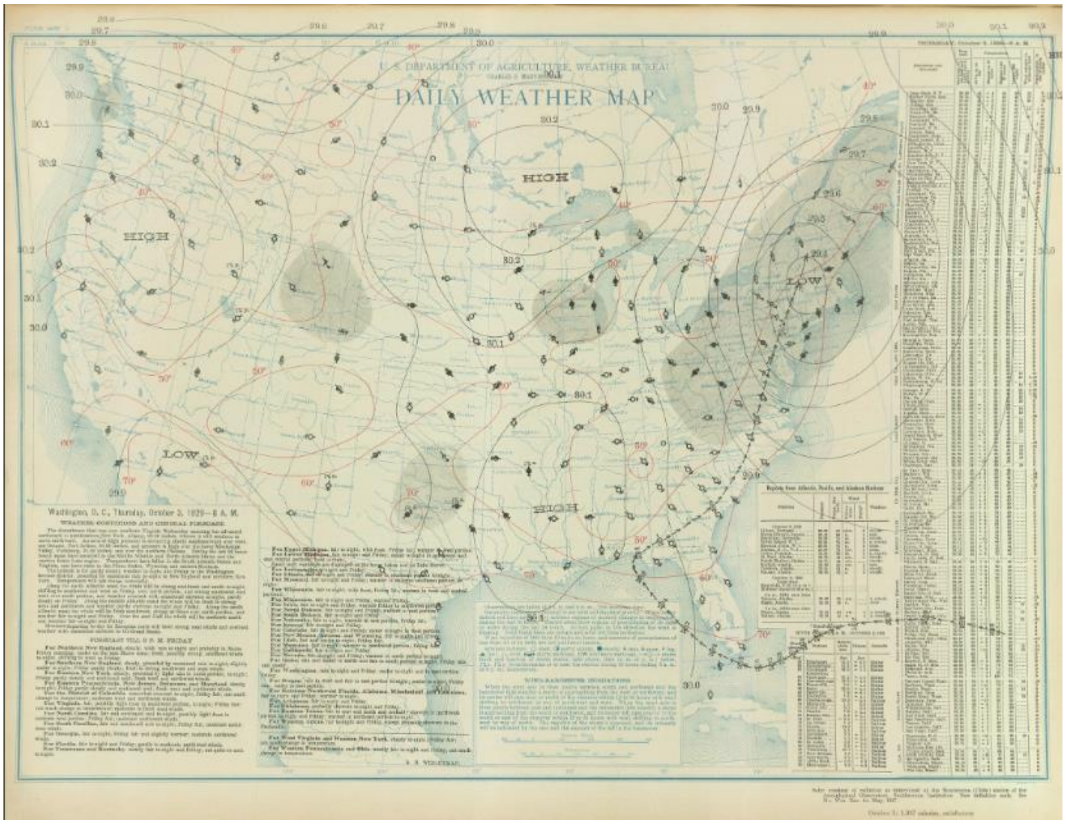

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Saturday, September 28, 1929—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Sunday, September 29, 1929—8 A. M.

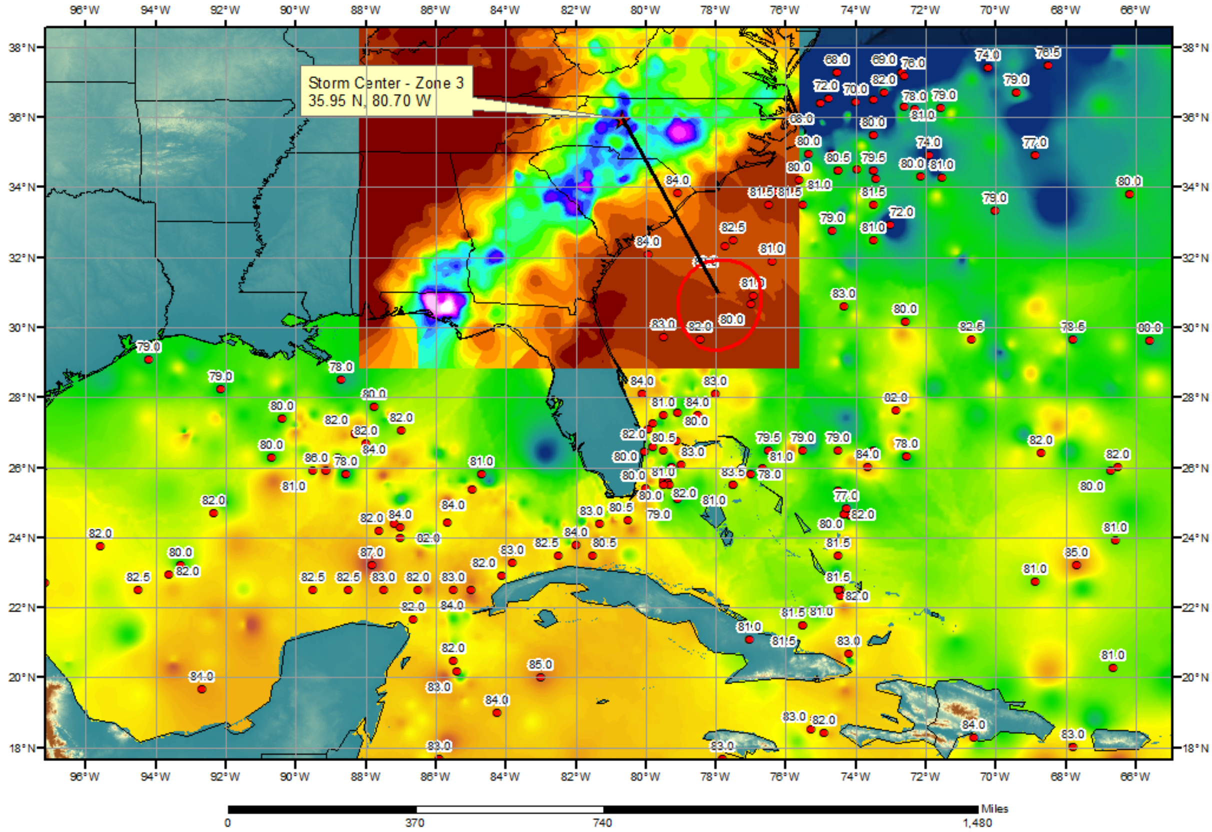

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Monday, September 30, 1929—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
LOW
Washington, D. C., Tuesday, October 1, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST
FORECAST TILL 8 P. M. WEDNESDAY


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
HIGH
LOW
LOW
Washington, D. C., Wednesday, October 2, 1929—8 A. M.
WEATHER CONDITIONS AND GENERAL FORECAST
FORECAST TILL 8 P. M. THURSDAY


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
HIGH
LOW
LOW

SPAS 1517 Settle, NC Sea Surface Temperatures (F)
September 29, 1929



Storm Precipitation Analysis System (SPAS) For Storm #1490_1 SPAS Analysis

General Storm Location: Easton, MD

Storm Dates: September 2 -9, 1935

Event: Hurricane

DAD Zone 1

Latitude: 38.8625

Longitude: -76.0708

Max. Grid Rainfall Amount: 17.00”

Max. Observed Rainfall Amount: 16.70” at Easton, MD

Number of Stations: 441

SPAS Version: 10.0

Basemap: Conus_prism_ppt_in_1981_2010_09

Spatial resolution: 00:00:30

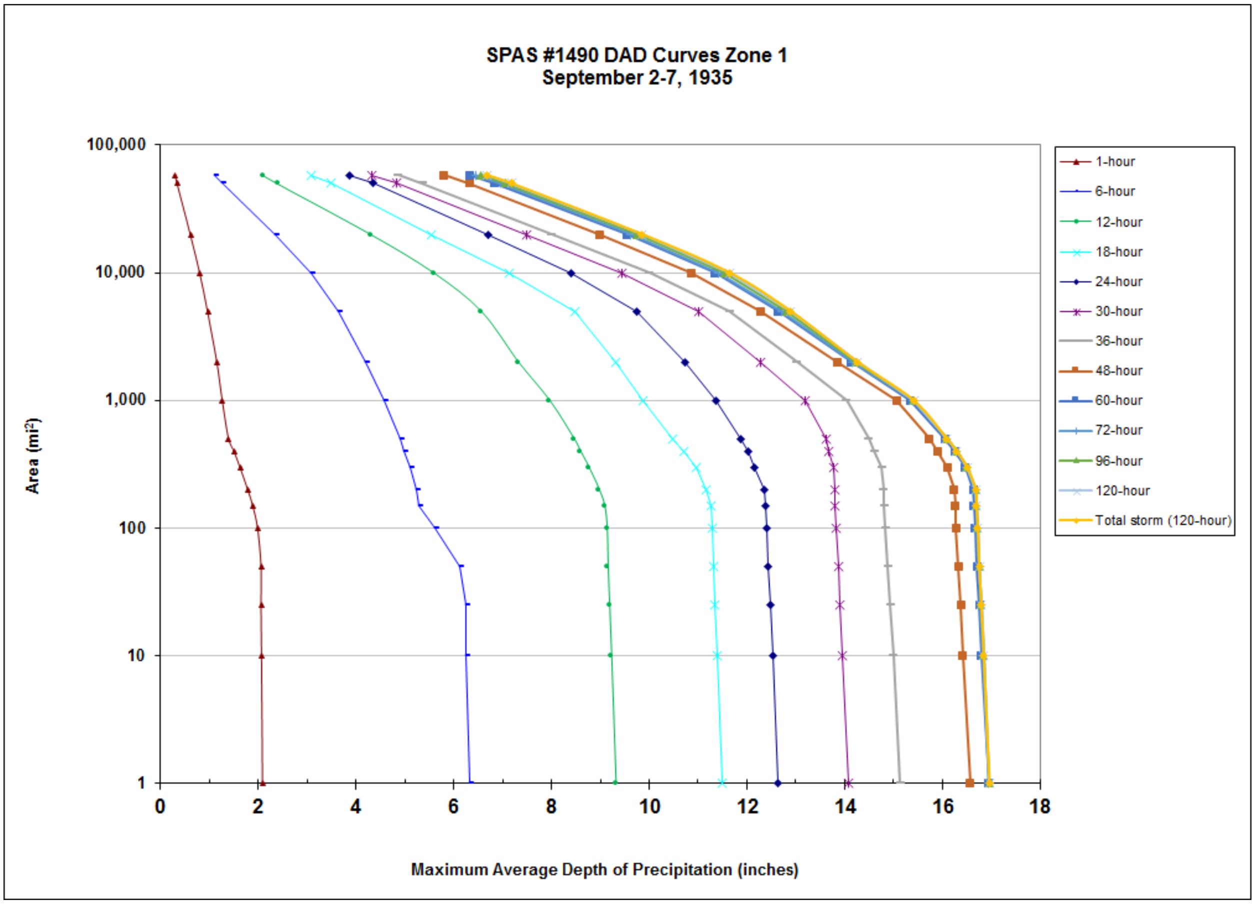
Radar Included: No

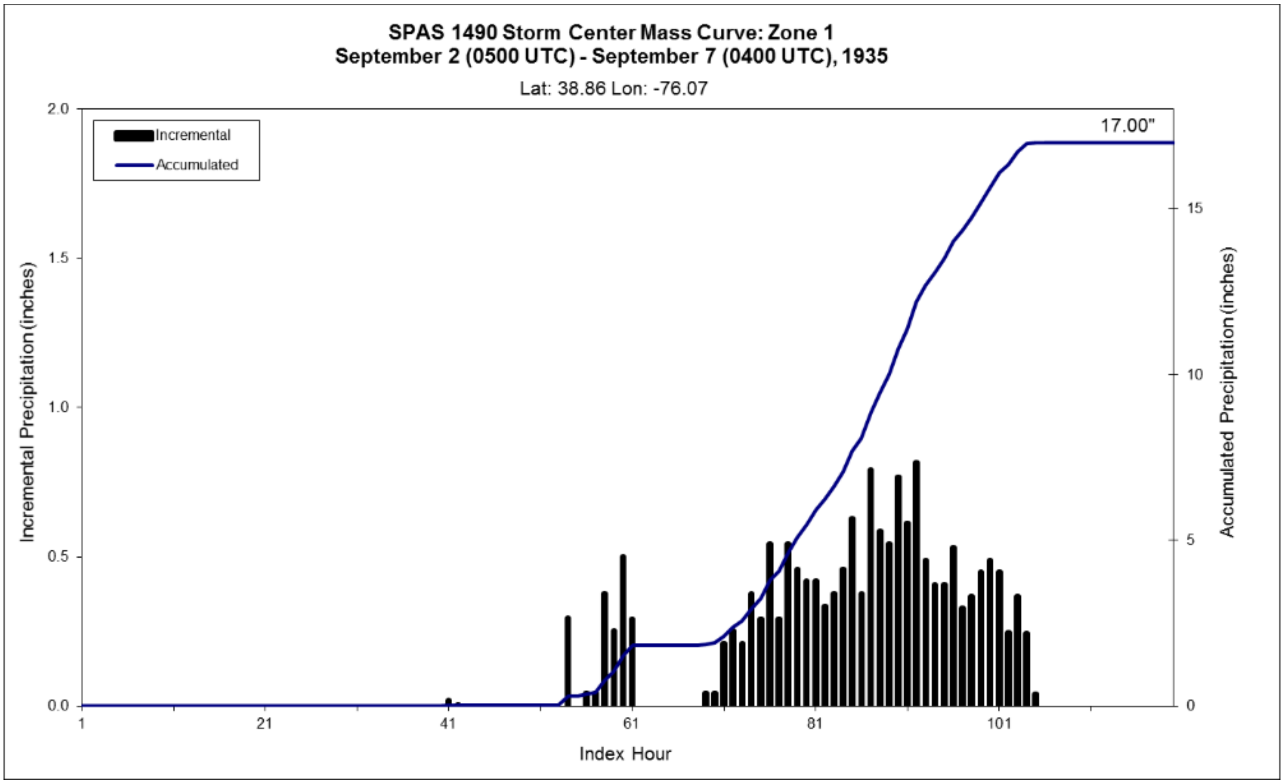
Depth-Area-Duration (DAD) analysis: Yes

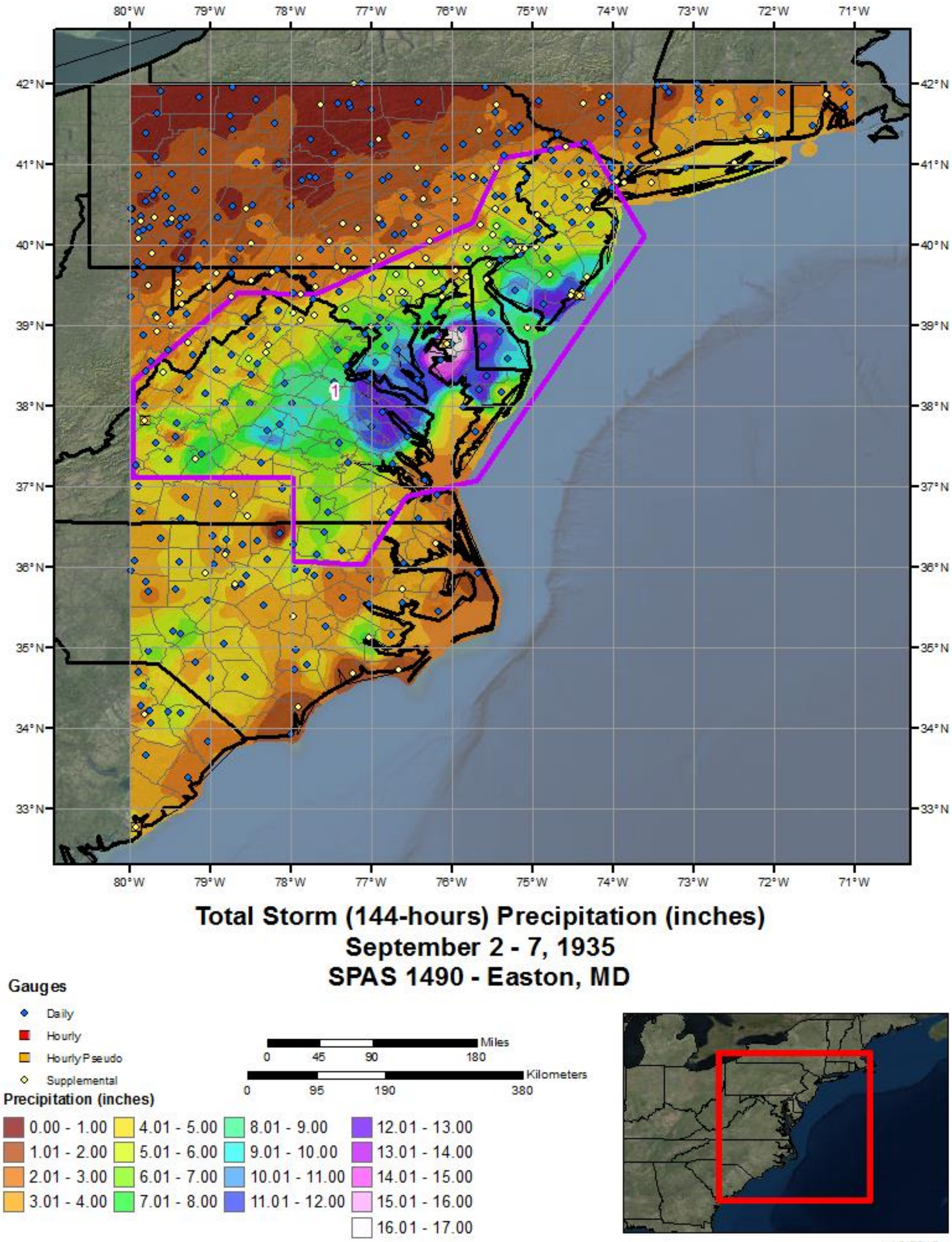
Reliability of results: This storm is originally USACE SA 1-26. This analysis was based on hourly pseudo data, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the basemap and we have a high degree of confidence with the timing based on the location of the five hourly pseudo stations (see below). One hourly USACE mass curve captured the largest storm center at Easton, MD allowing high confidence in the spatiotemporal isohyetal pattern of this critical location. Some daily stations lacked timing, so they had to be converted into supplemental stations. The five hourly pseudo stations were consistent in timing with one another. There was no hourly data after the 6th, but so timing of the supplemental stations thereafter is linear in trend. There isn’t much if any precipitation that SPAS has falling on the 7th (no more than 0.5” at the very most).

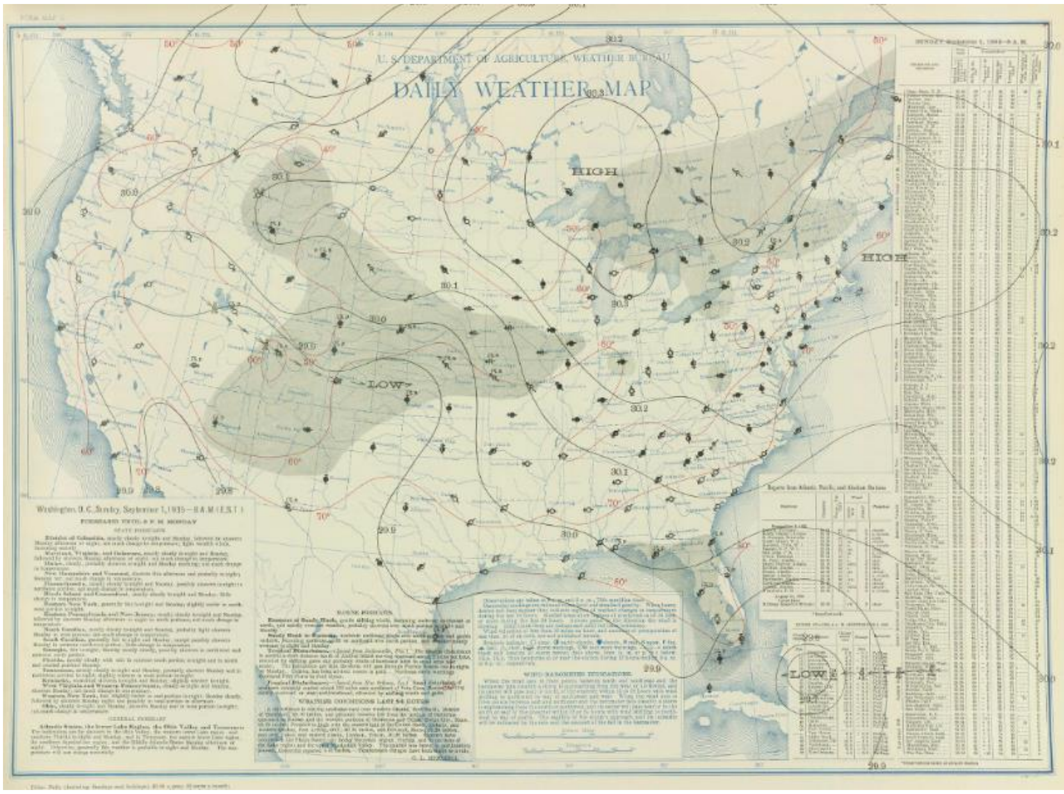
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1490_1	-76.0708	38.8625	55	20-Aug	80.50	3.68	0.03	83	3.650	82.91	4.12	0.03	88	4.090	1.121

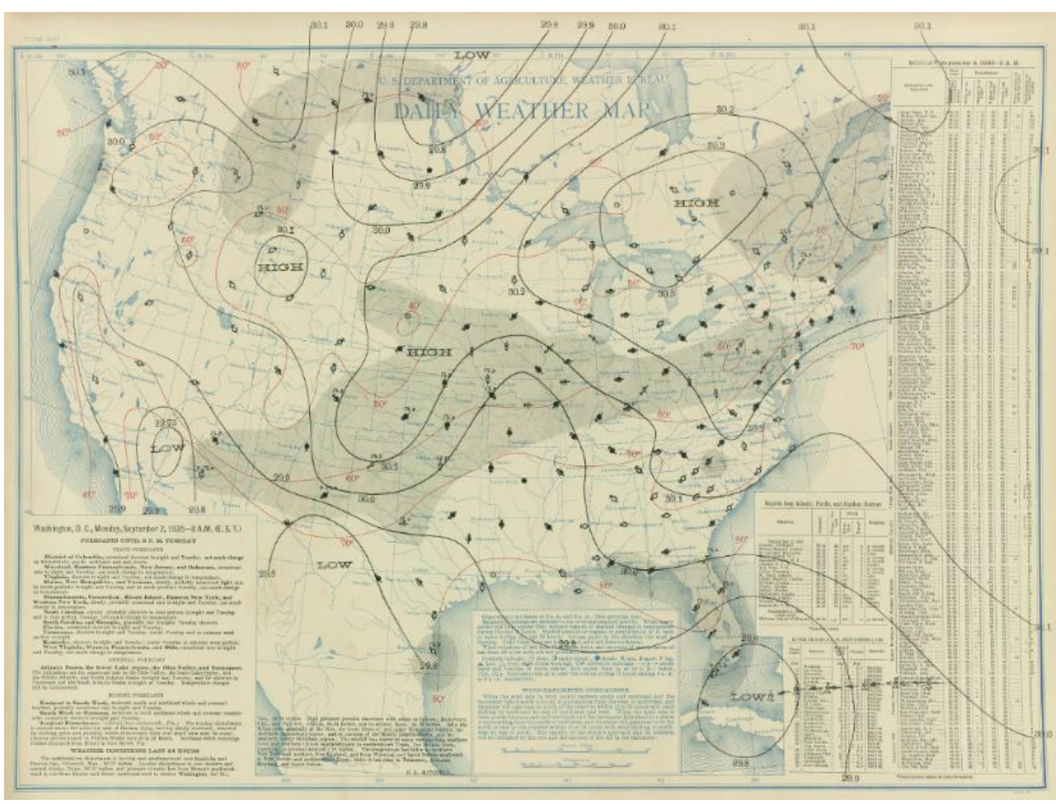
Storm 1490 Zone 1 - Sep. 2 (0500 UTC) - Sep. 7 (0400 UTC), 1935 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
	Duration (hours)													
areasqmi	1	6	12	18	24	30	36	48	60	72	96	120		Total
0.4	2.10	6.35	9.33	11.53	12.69	14.13	15.14	16.60	16.98	16.98	17.00	17.00		17.00
1	2.09	6.33	9.31	11.49	12.64	14.08	15.14	16.56	16.94	16.95	16.96	16.96		16.96
10	2.07	6.26	9.22	11.39	12.52	13.96	14.99	16.42	16.80	16.82	16.84	16.84		16.84
25	2.06	6.24	9.18	11.35	12.47	13.91	14.93	16.37	16.75	16.78	16.79	16.79		16.79
50	2.06	6.12	9.15	11.32	12.43	13.87	14.88	16.32	16.71	16.75	16.75	16.75		16.75
100	1.99	5.62	9.13	11.29	12.40	13.83	14.83	16.28	16.67	16.71	16.72	16.72		16.72
150	1.89	5.30	9.08	11.27	12.38	13.81	14.81	16.26	16.64	16.69	16.69	16.69		16.69
200	1.79	5.24	8.97	11.17	12.36	13.80	14.79	16.24	16.63	16.68	16.68	16.68		16.68
300	1.63	5.10	8.76	10.95	12.16	13.77	14.75	16.10	16.46	16.49	16.49	16.50		16.50
400	1.51	4.99	8.59	10.71	12.02	13.68	14.60	15.89	16.25	16.29	16.29	16.29		16.29
500	1.40	4.90	8.46	10.49	11.87	13.61	14.49	15.73	16.05	16.08	16.09	16.09		16.09
1,000	1.27	4.59	7.96	9.87	11.36	13.18	14.03	15.06	15.34	15.39	15.40	15.41		15.41
2,000	1.16	4.19	7.32	9.31	10.74	12.29	13.02	13.84	14.13	14.16	14.22	14.26		14.26
5,000	0.97	3.64	6.56	8.49	9.75	11.01	11.64	12.27	12.64	12.70	12.81	12.89		12.89
10,000	0.81	3.08	5.59	7.15	8.41	9.45	10.00	10.86	11.35	11.41	11.54	11.64		11.64
20,000	0.62	2.35	4.30	5.54	6.71	7.50	8.00	8.98	9.55	9.63	9.75	9.85		9.85
50,000	0.35	1.26	2.39	3.48	4.34	4.82	5.36	6.32	6.84	6.96	7.06	7.18		7.18
57,977	0.31	1.11	2.10	3.09	3.88	4.32	4.86	5.80	6.32	6.45	6.56	6.67		6.67

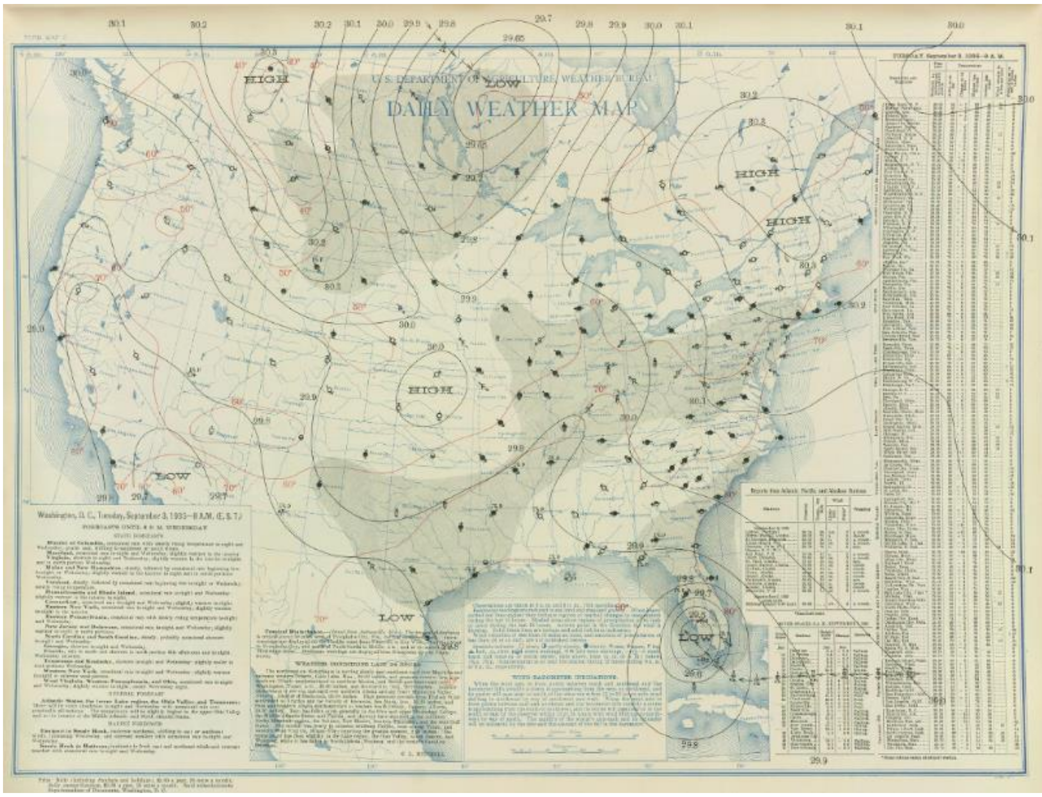


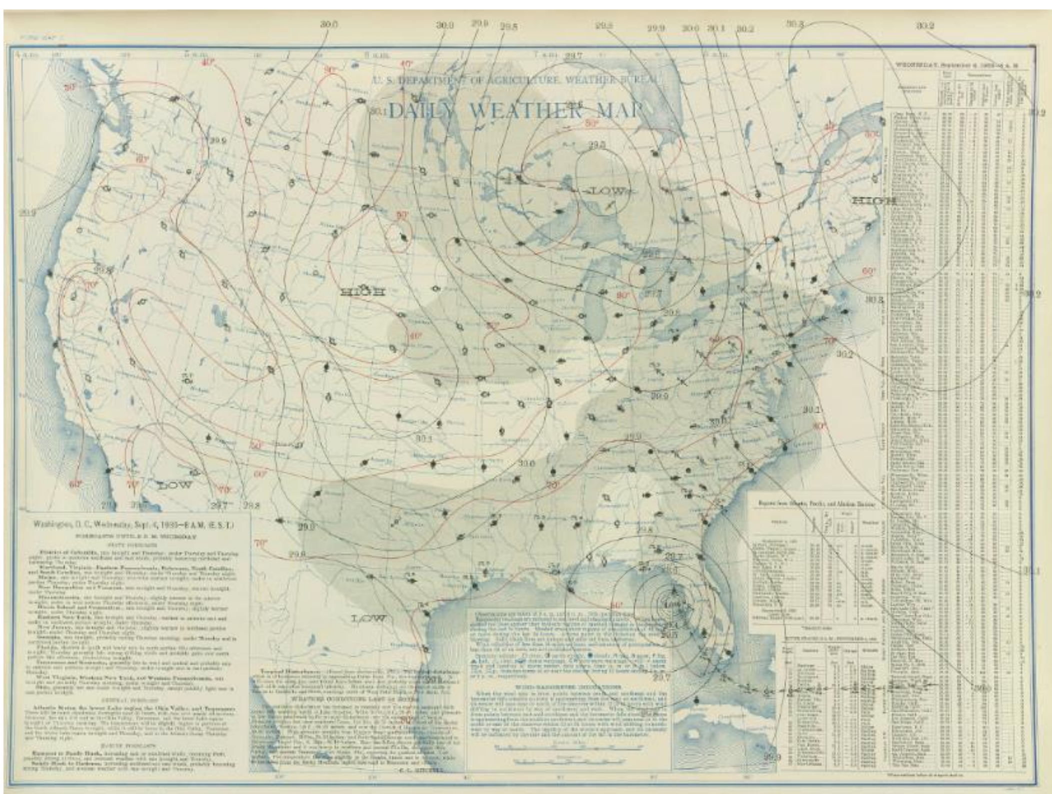

SPAS 1490 Storm Center Mass Curve: Zone 1
September 2 (0500 UTC) - September 7 (0400 UTC), 1935
Lat: 38.86 Lon: -76.07
Incremental
Accumulated
17.00"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour

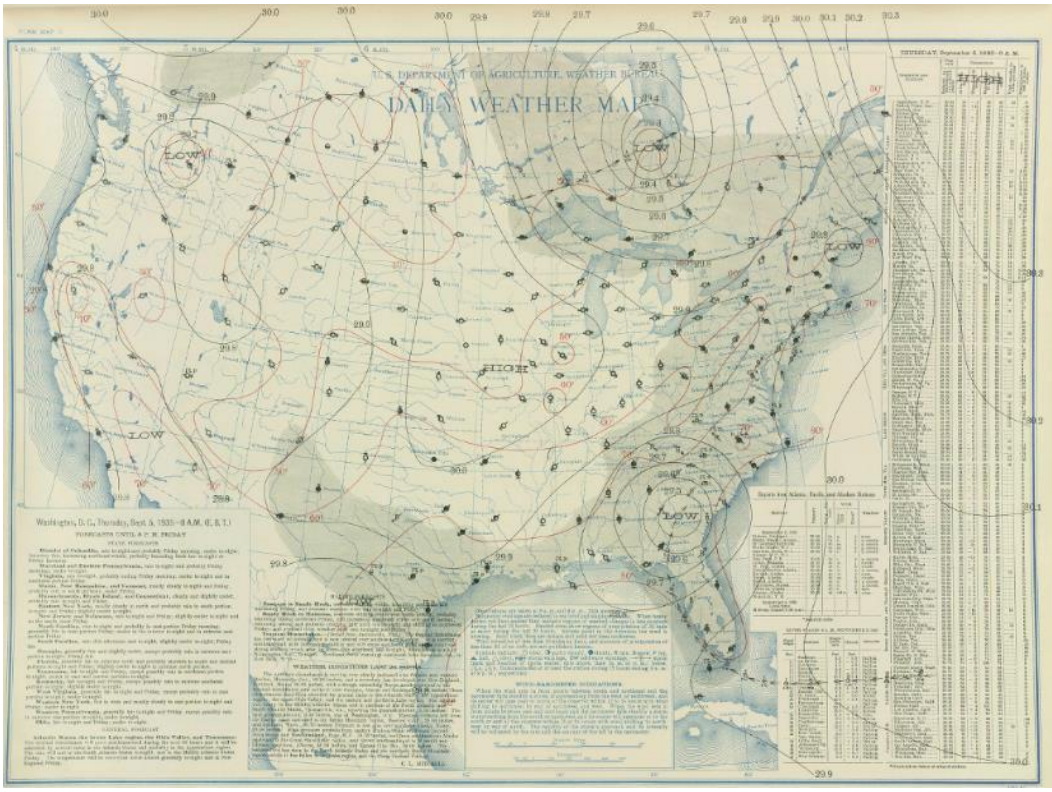

80°W
79°W
78°W
77°W
76°W
75°W
74°W
73°W
72°W
71°W
42°N
41°N
40°N
39°N
38°N
37°N
36°N
35°N
34°N
33°N
1
Total Storm (144-hours) Precipitation (inches)
September 2 - 7, 1935
SPAS 1490 - Easton, MD
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
0 45 90 180 Miles
0 95 190 380 Kilometers
4/3/2015

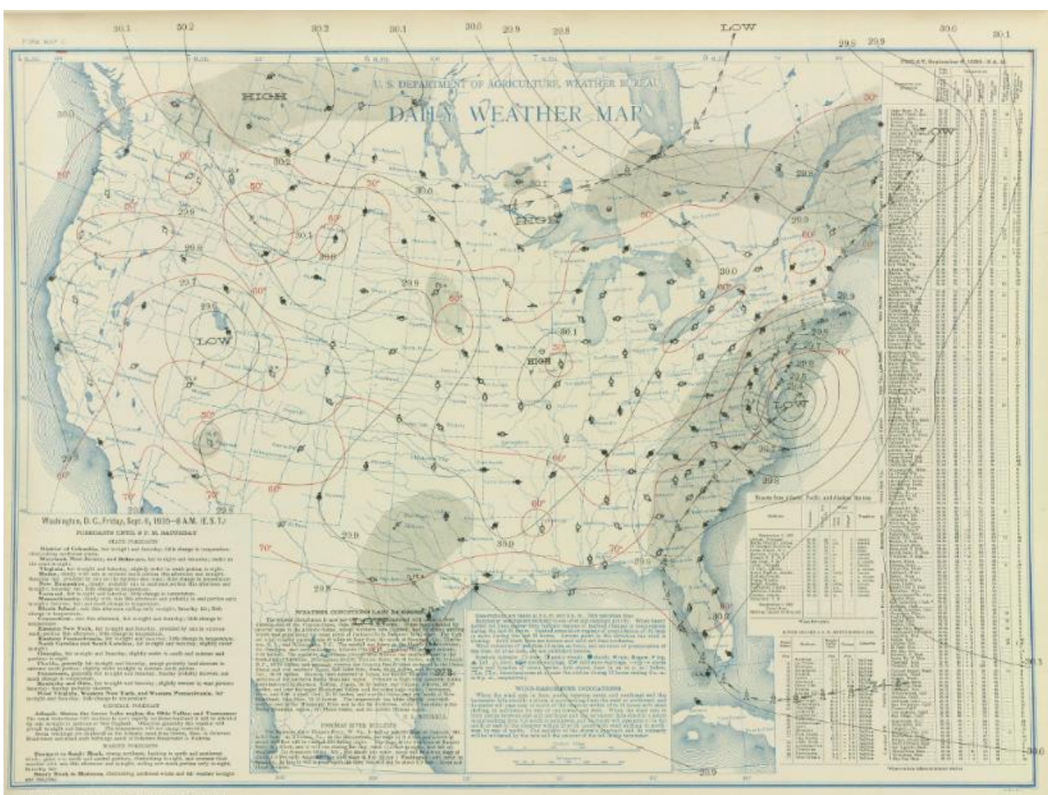

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
LOW
LOW
Washington, D.C., Sunday, September 1, 1935—8 A.M. (E.S.T.)
FORECASTS UNTIL 8 P.M. MONDAY
WEATHER CONDITIONS LAST 24 HOURS
WIND-BAROMETER INDICATIONS

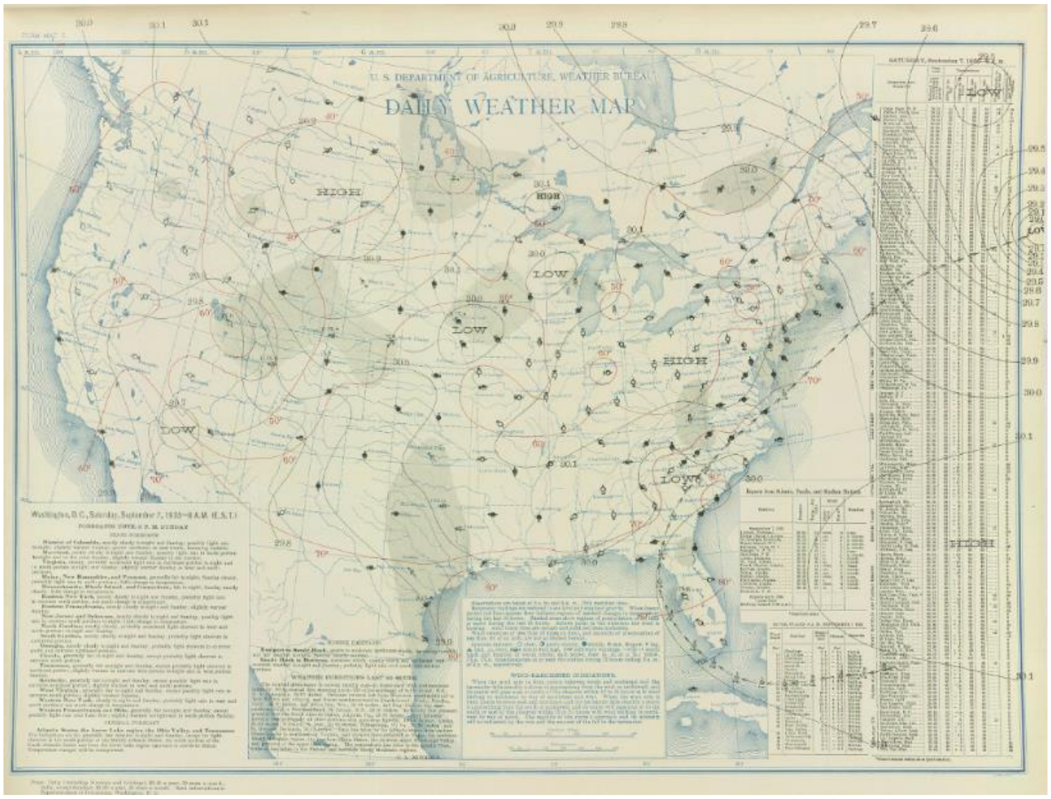

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
HIGH
HIGH
LOW
LOW
LOW
Washington, D.C., Monday, September 2, 1935—8 A.M. (E.S.T.)
WEATHER CONDITIONS LAST 24 HOURS
WIND-BAROMETER INDICATIONS

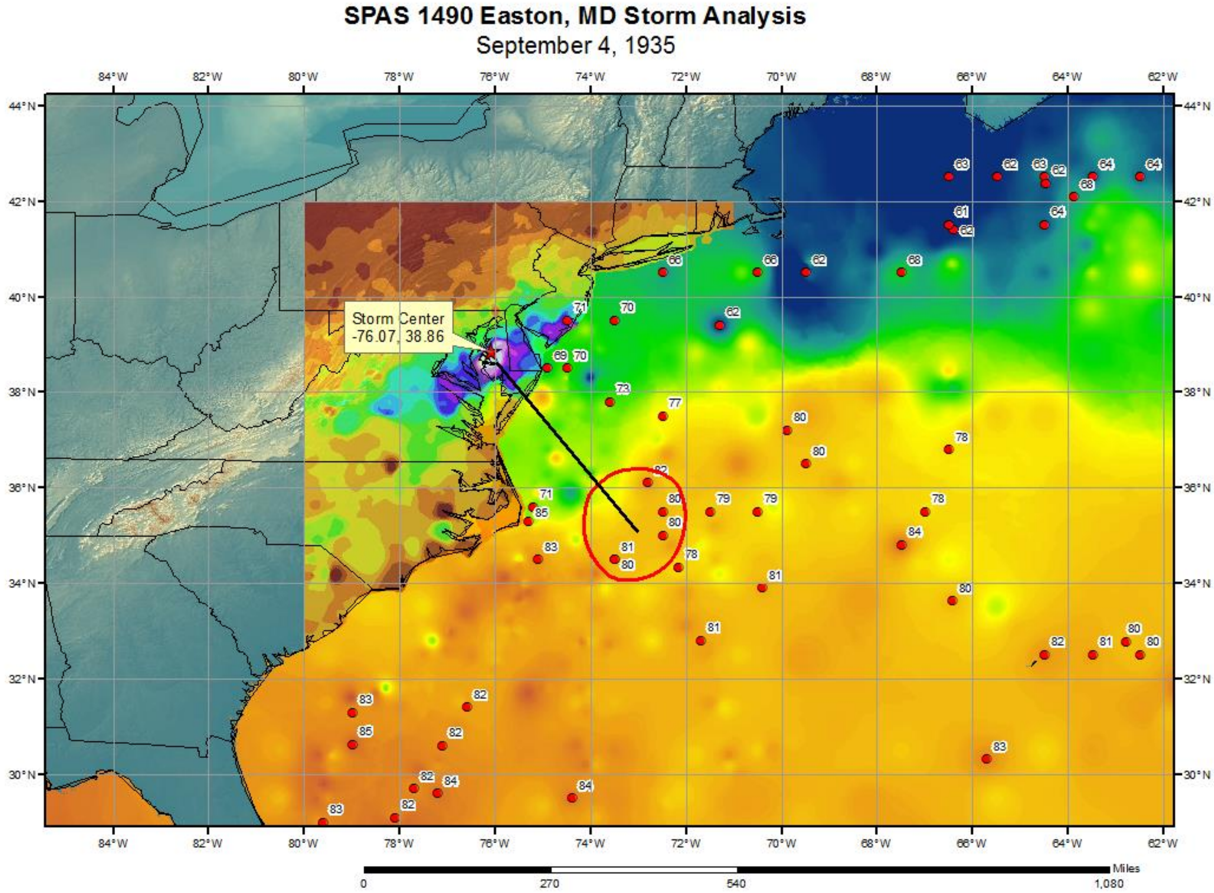

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
HIGH
HIGH
LOW
LOW
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
HIGH
LOW
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Thursday, Sept. 5, 1935—8 A.M. (E. S. T.)
FORECASTS UNTIL 8 P. M. FRIDAY
LOW
HIGH


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
Washington, D. C., Friday, Sept. 6, 1935—8 A.M. (E. S. T.)
FORECASTS UNTIL 8 P. M. SATURDAY
LOW
HIGH


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
HIGH
HIGH
LOW
LOW
LOW
LOW


SPAS 1490 Easton, MD Storm Analysis
September 4, 1935
Storm Center
-76.07, 38.86
Miles
0
270
540
1,080

Storm Precipitation Analysis System (SPAS) For Storm #1342_1 SPAS Analysis

General Storm Location: Idlewild, North Carolina (40.0, -86.0, 31.0, -74.0)

Storm Dates: August 10-August 16, 1940

Event: Extreme Precipitation Event

DAD Zone 1

Latitude: 36.3

Longitude: -81.45

Max. Grid Rainfall Amount: 20.27"

Max. Observed Rainfall Amount: 20.03"

Number of Stations: 823

SPAS Version: 10.0

Basemap: Continental United States 2-yr 24-hr (conus_0002y24h)

Spatial resolution: 0.2679

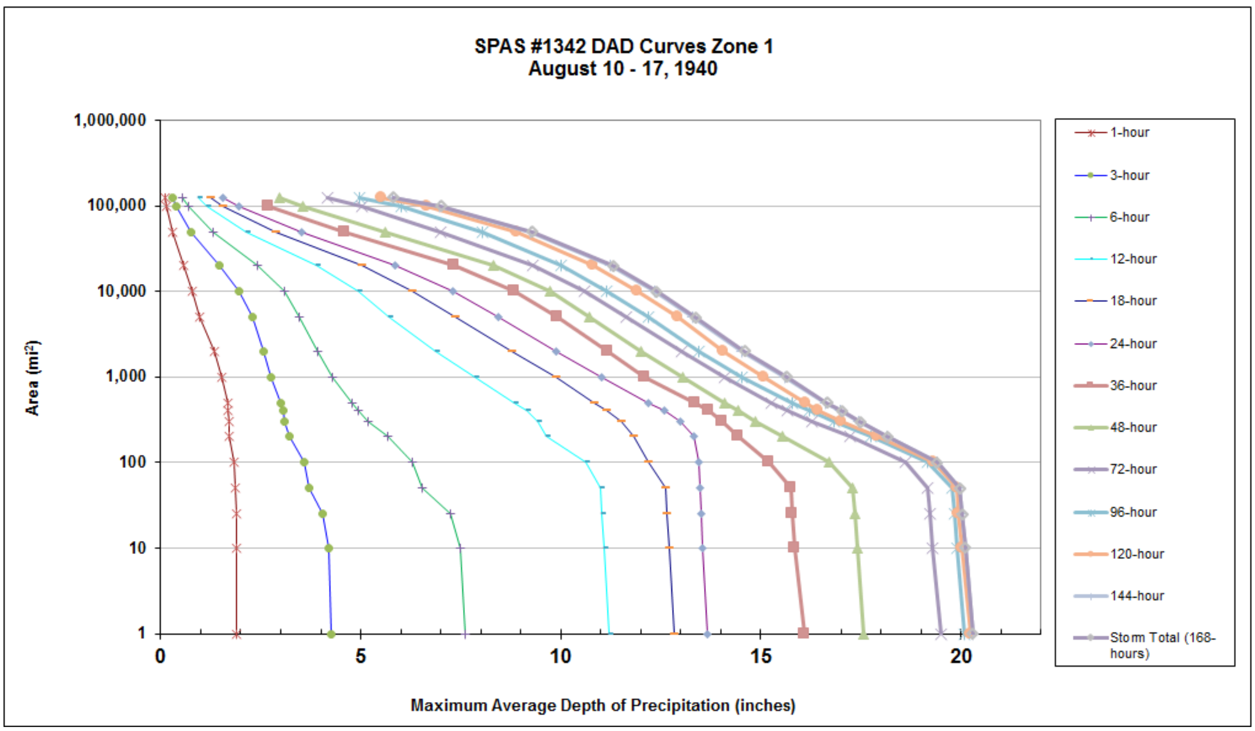
Radar Included: No

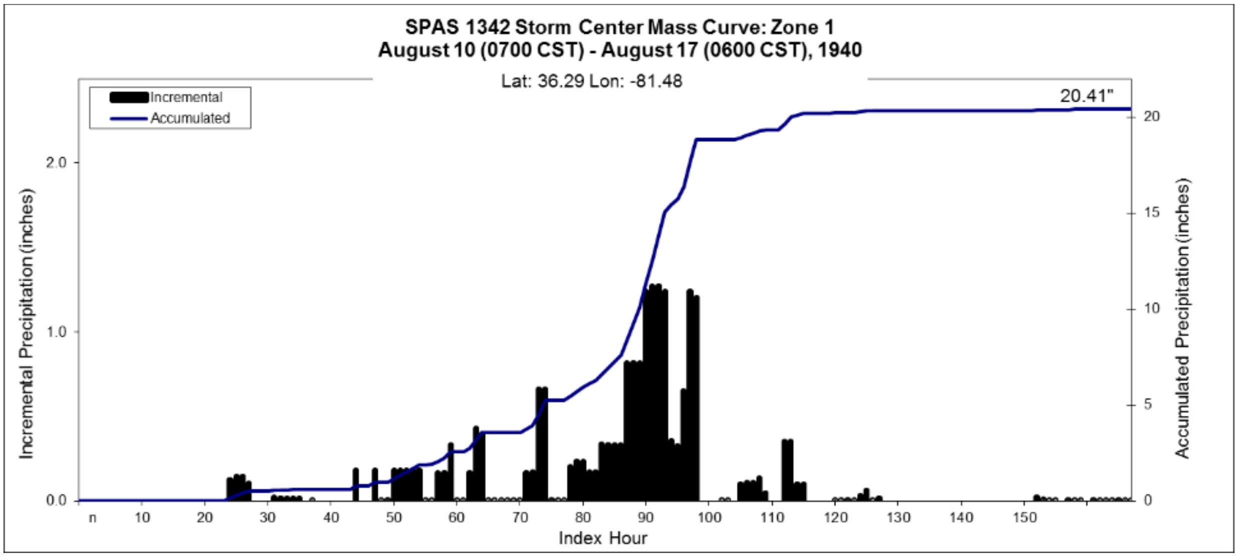
Depth-Area-Duration (DAD) analysis: Yes

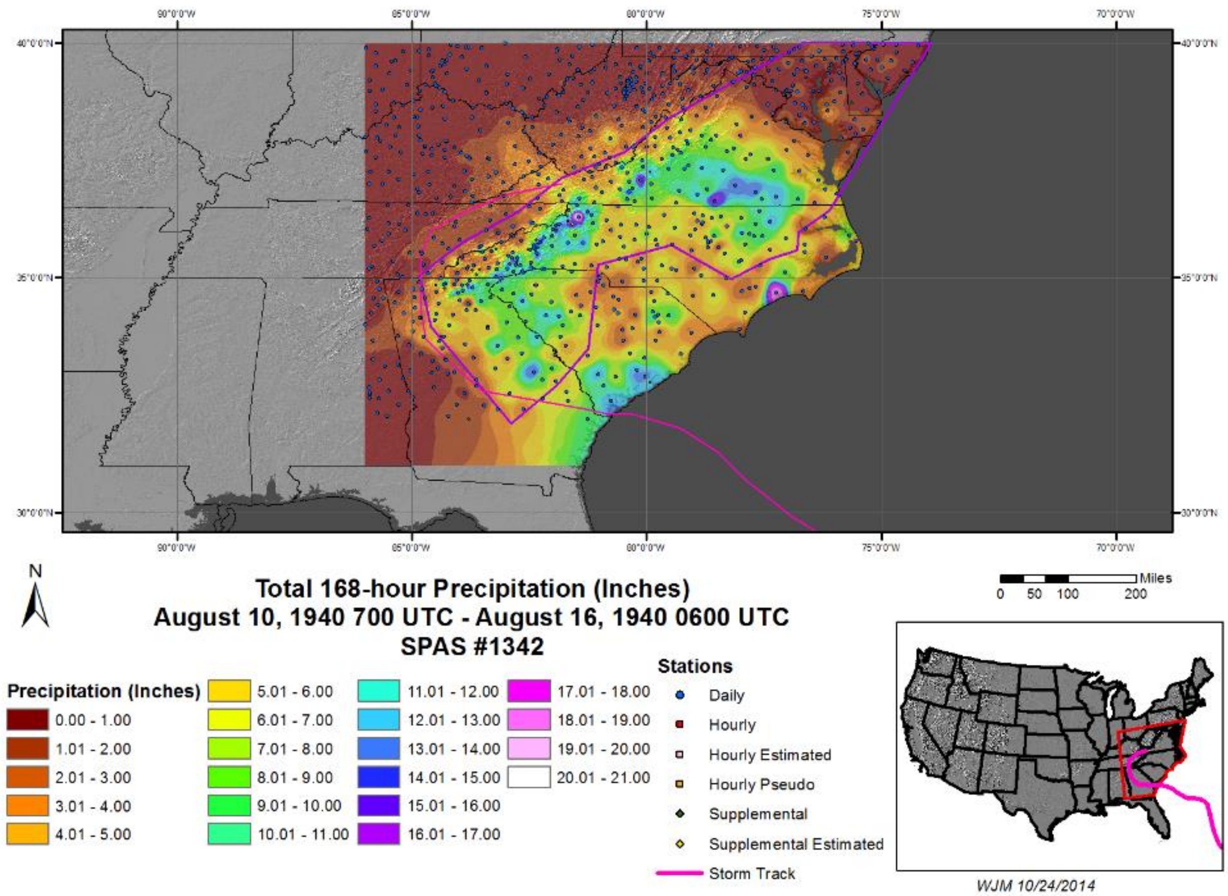
Reliability of results: In addition to the NCDC stations, eighteen supplemental stations along with one supplemental estimated station were added to ensure data consistency. Due to the amount and integrity of the Tennessee Valley Authority (TVA), no stations within the main storm area had hourly data available to time precipitation on the last two days of the storm analysis. Upon further inspection of a Department of Interior (DOI) report, several hourly stations were found and entered in. Looking in NCDC local climatology, four hourly stations were found but in the northeast extent of the storm domain that were used for timing of the precipitation. With the density of stations available and the consistency of the resulting SPAS analysis, this analysis is deemed quite reliable in and near the storm center.

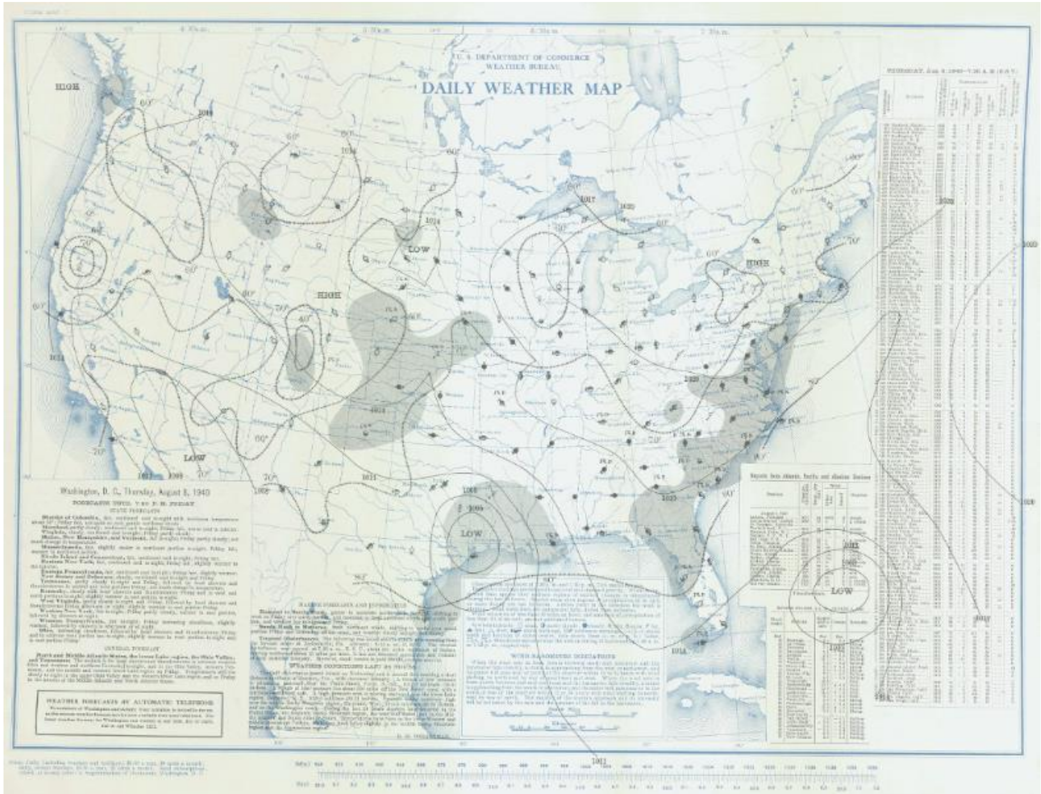
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1342_1	-81.4500	36.3000	3,064	15-Aug	82.00	3.95	0.91	86	3.040	83.90	4.30	0.96	90	3.340	1.099

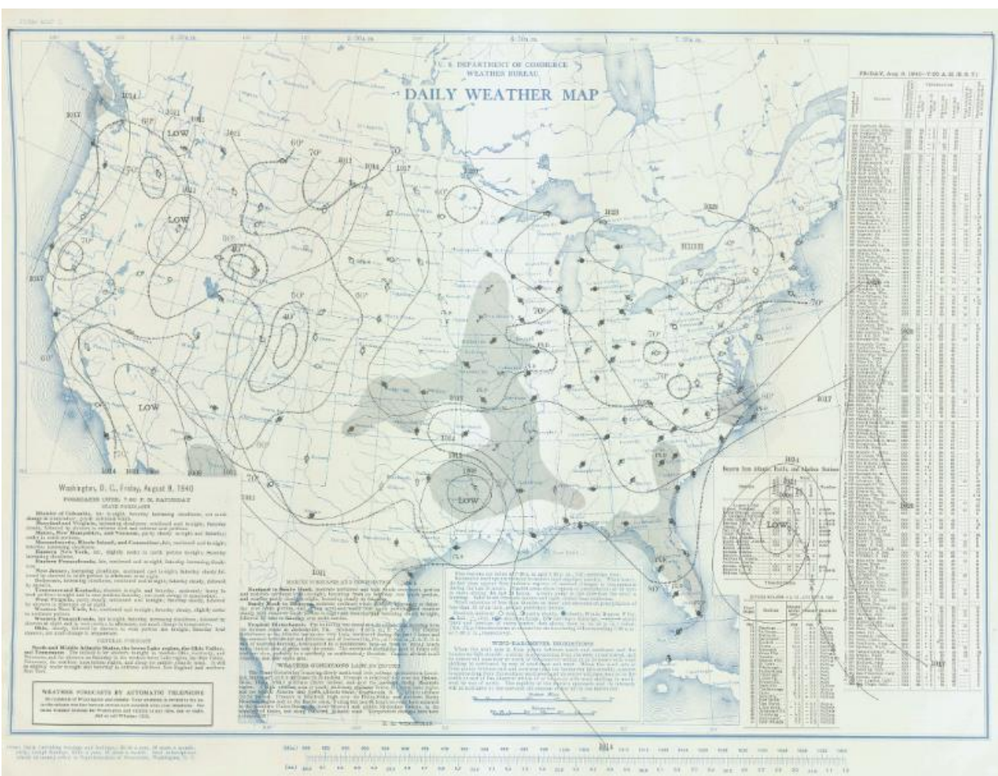
Storm 1342 Zone 1 - August 10 (0700 CST) - August 17 (0600 CST), 1940														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
	Duration (hours)													
areasqmi	1	3	6	12	18	24	36	48	72	96	120	144	168	Total
0.4	1.91	4.29	7.68	11.25	12.89	13.69	16.23	17.64	19.57	20.18	20.31	20.38	20.38	20.38
1	1.90	4.27	7.62	11.21	12.84	13.65	16.10	17.57	19.50	20.10	20.23	20.30	20.30	20.30
10	1.88	4.19	7.49	11.08	12.71	13.55	15.86	17.40	19.30	19.91	20.03	20.11	20.11	20.11
25	1.88	4.04	7.23	11.03	12.66	13.51	15.80	17.34	19.23	19.83	19.95	20.03	20.03	20.03
50	1.87	3.70	6.53	10.99	12.62	13.48	15.75	17.28	19.17	19.77	19.90	19.98	19.98	19.98
100	1.82	3.57	6.28	10.61	12.19	13.45	15.19	16.71	18.60	19.18	19.31	19.40	19.40	19.40
200	1.72	3.22	5.66	9.64	11.81	13.33	14.44	15.55	17.22	17.76	17.91	18.15	18.16	18.16
300	1.71	3.08	5.17	9.41	11.51	12.99	14.03	14.86	16.27	16.83	17.01	17.46	17.48	17.48
400	1.69	3.05	4.95	9.14	11.16	12.59	13.69	14.42	15.65	16.22	16.44	16.98	17.02	17.02
500	1.67	3.01	4.79	8.84	10.84	12.18	13.35	14.11	15.26	15.78	16.12	16.62	16.66	16.66
1,000	1.51	2.75	4.29	7.85	9.89	11.01	12.09	13.06	14.11	14.53	15.07	15.60	15.66	15.66
2,000	1.33	2.58	3.93	6.88	8.79	9.87	11.19	12.01	13.02	13.44	14.08	14.53	14.59	14.59
5,000	0.96	2.28	3.47	5.72	7.37	8.43	9.93	10.70	11.65	12.20	12.92	13.31	13.36	13.36
10,000	0.79	1.95	3.08	4.93	6.29	7.29	8.83	9.72	10.59	11.14	11.91	12.34	12.39	12.39
20,000	0.58	1.47	2.42	3.90	5.02	5.87	7.34	8.31	9.30	10.00	10.82	11.24	11.30	11.30
50,000	0.29	0.76	1.30	2.13	2.87	3.51	4.59	5.61	7.00	8.04	8.89	9.25	9.29	9.29
100,000	0.15	0.39	0.68	1.15	1.55	1.95	2.68	3.55	5.02	6.01	6.67	6.97	7.00	7.00
124,364	0.12	0.31	0.55	0.93	1.26	1.57	2.23	2.97	4.17	4.98	5.53	5.79	5.82	5.82

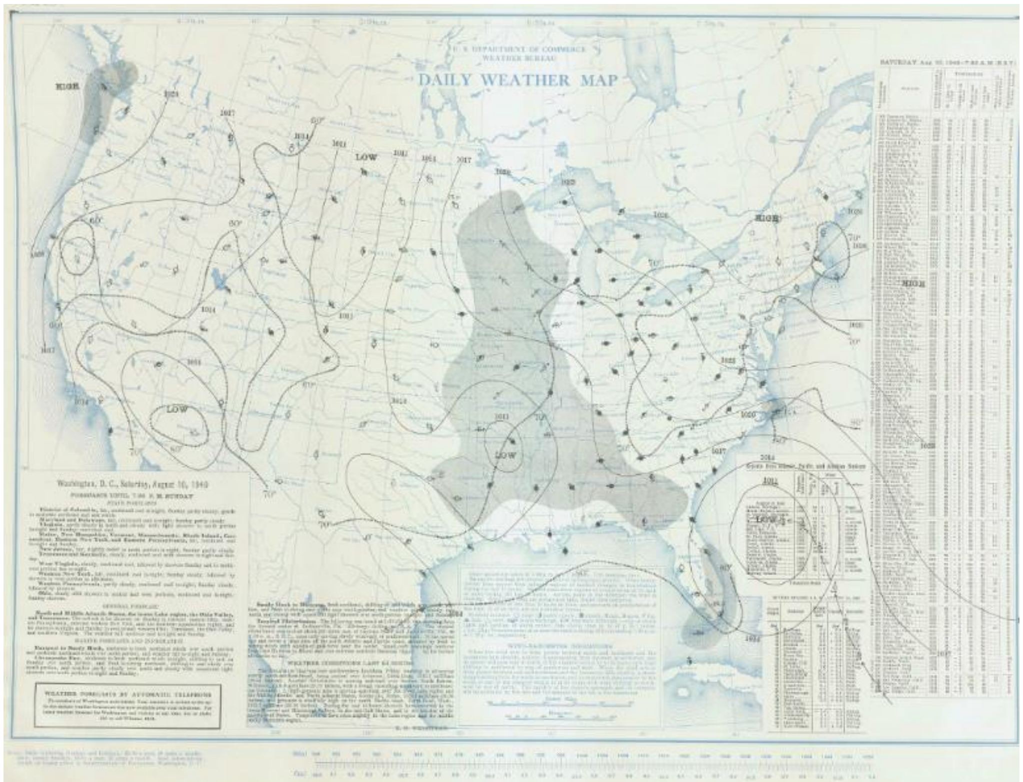


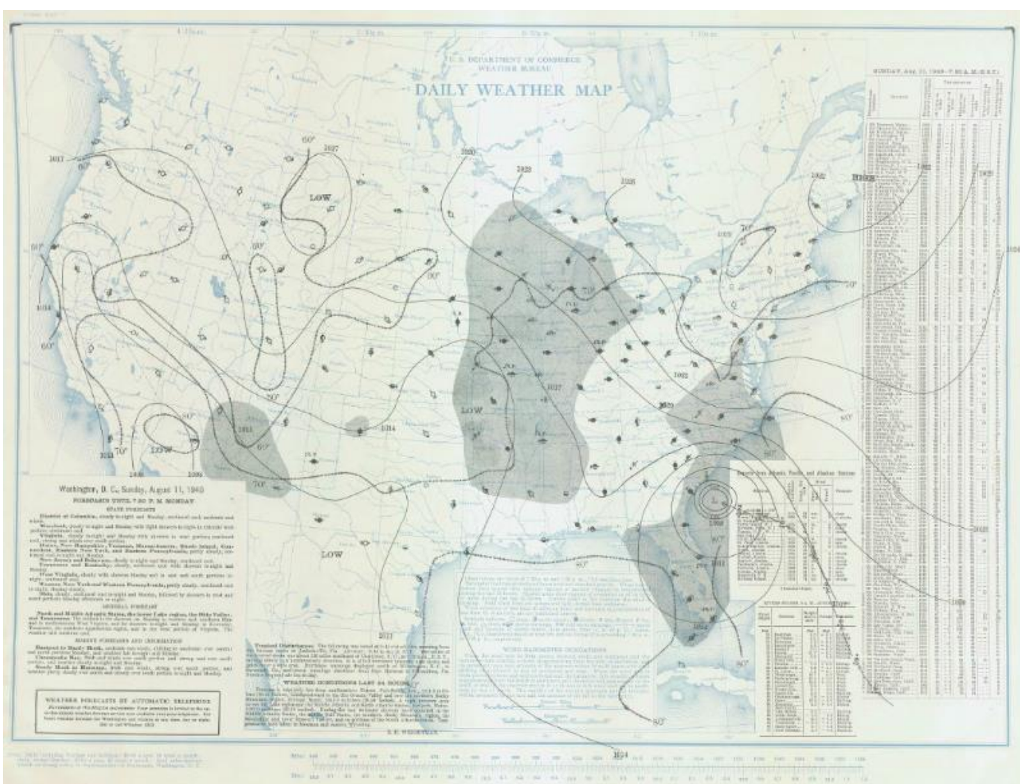

SPAS 1342 Storm Center Mass Curve: Zone 1
August 10 (0700 CST) - August 17 (0600 CST), 1940
Lat: 36.29 Lon: -81.48
Incremental
Accumulated
20.41"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour

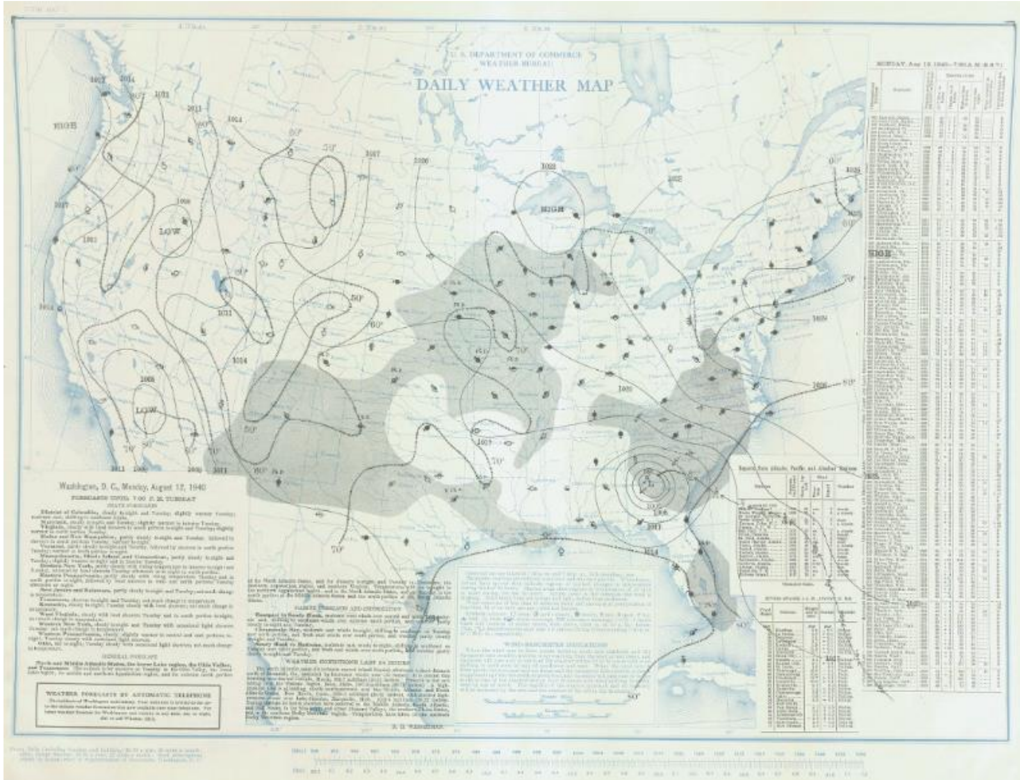

Total 168-hour Precipitation (Inches)
August 10, 1940 700 UTC - August 16, 1940 0600 UTC
SPAS #1342
Precipitation (Inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00
20.01 - 21.00
Stations
Daily
Hourly
Hourly Estimated
Hourly Pseudo
Supplemental
Supplemental Estimated
Storm Track
Miles
0 50 100 200
N
WJM 10/24/2014

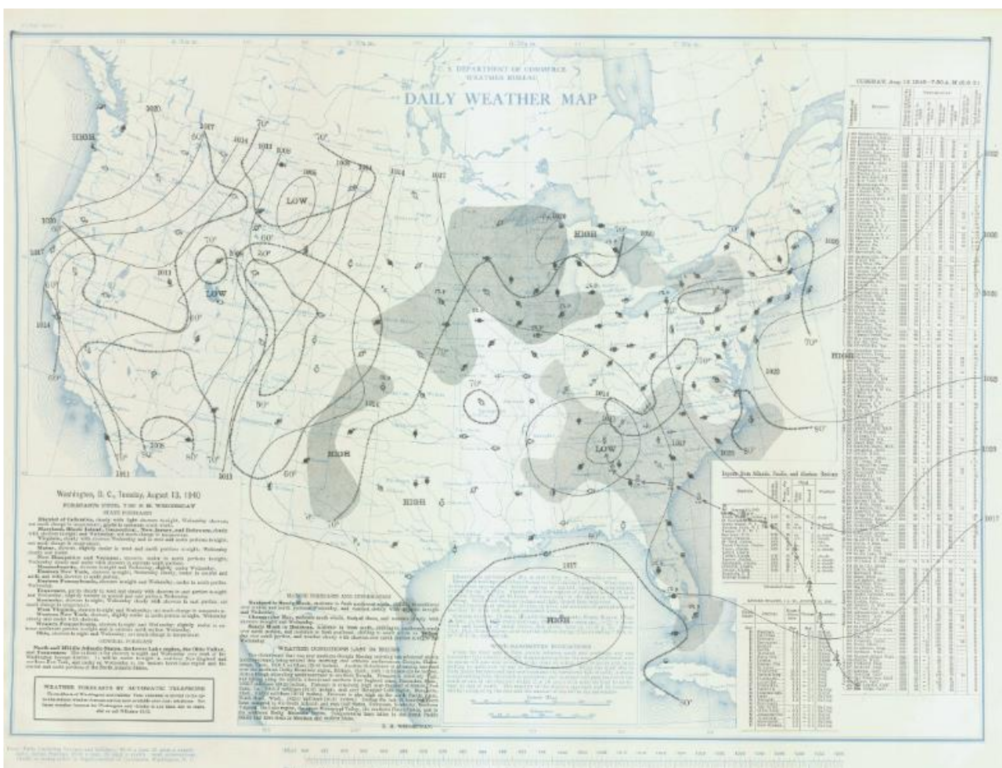

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
HIGH
LOW
LOW
Washington, D. C., Thursday, August 8, 1940

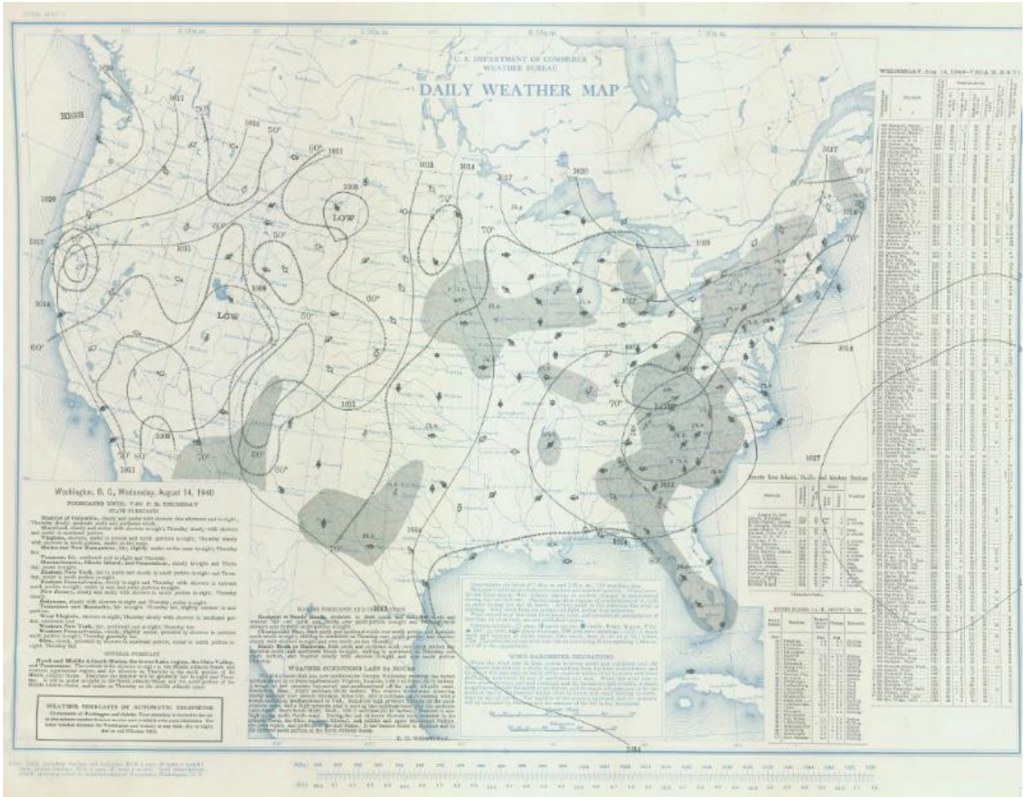

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
LOW
LOW
LOW
HIGH
LOW
LOW
Washington, D. C., Friday, August 9, 1940

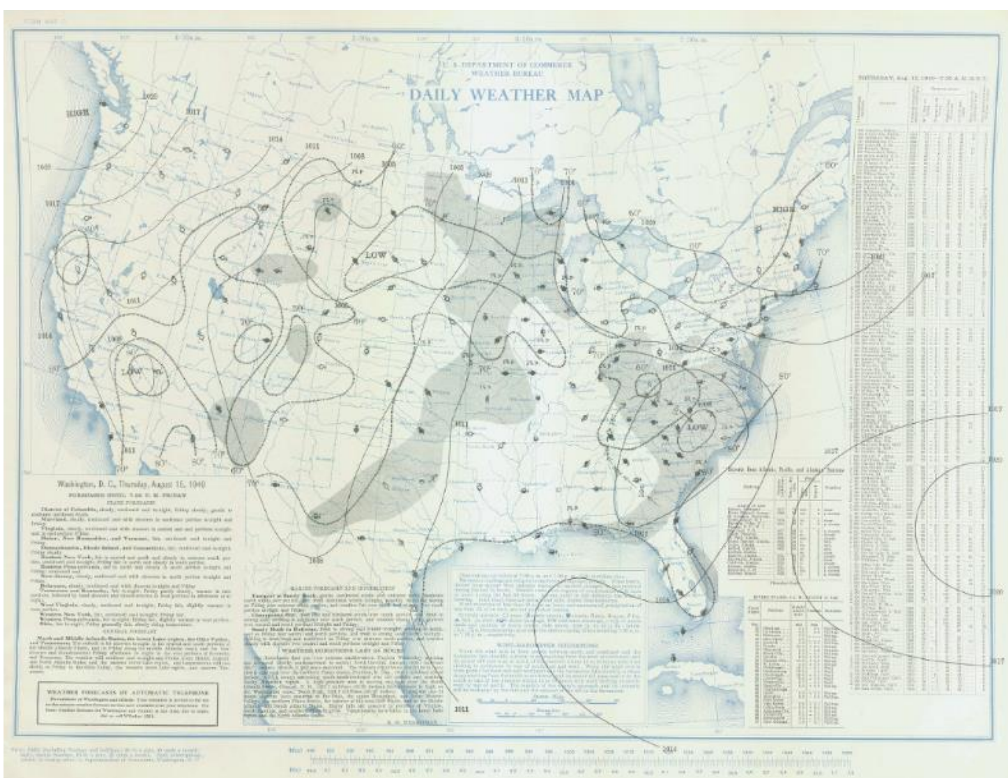

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
HIGH
HIGH
LOW
LOW
Washington, D. C., Saturday, August 10, 1940

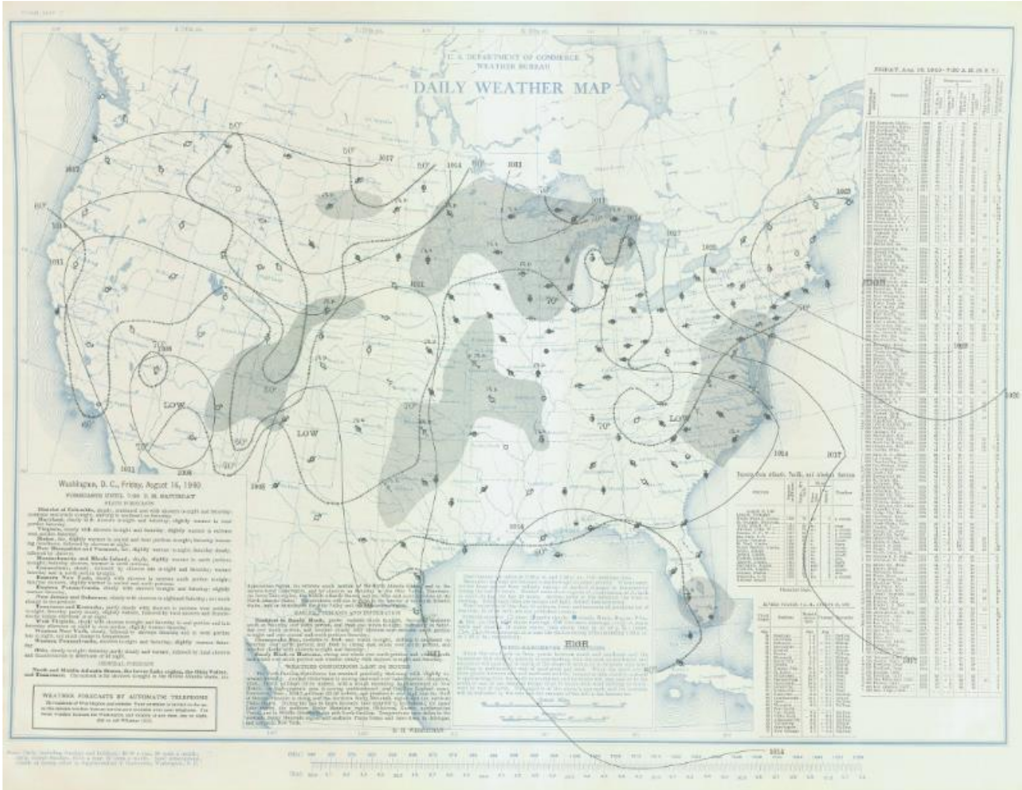

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
LOW
HIGH
LOW
LOW
LOW
Washington, D. C., Sunday, August 11, 1940
FORECASTS UNTIL 7:30 P. M. MONDAY
STATE FORECASTS

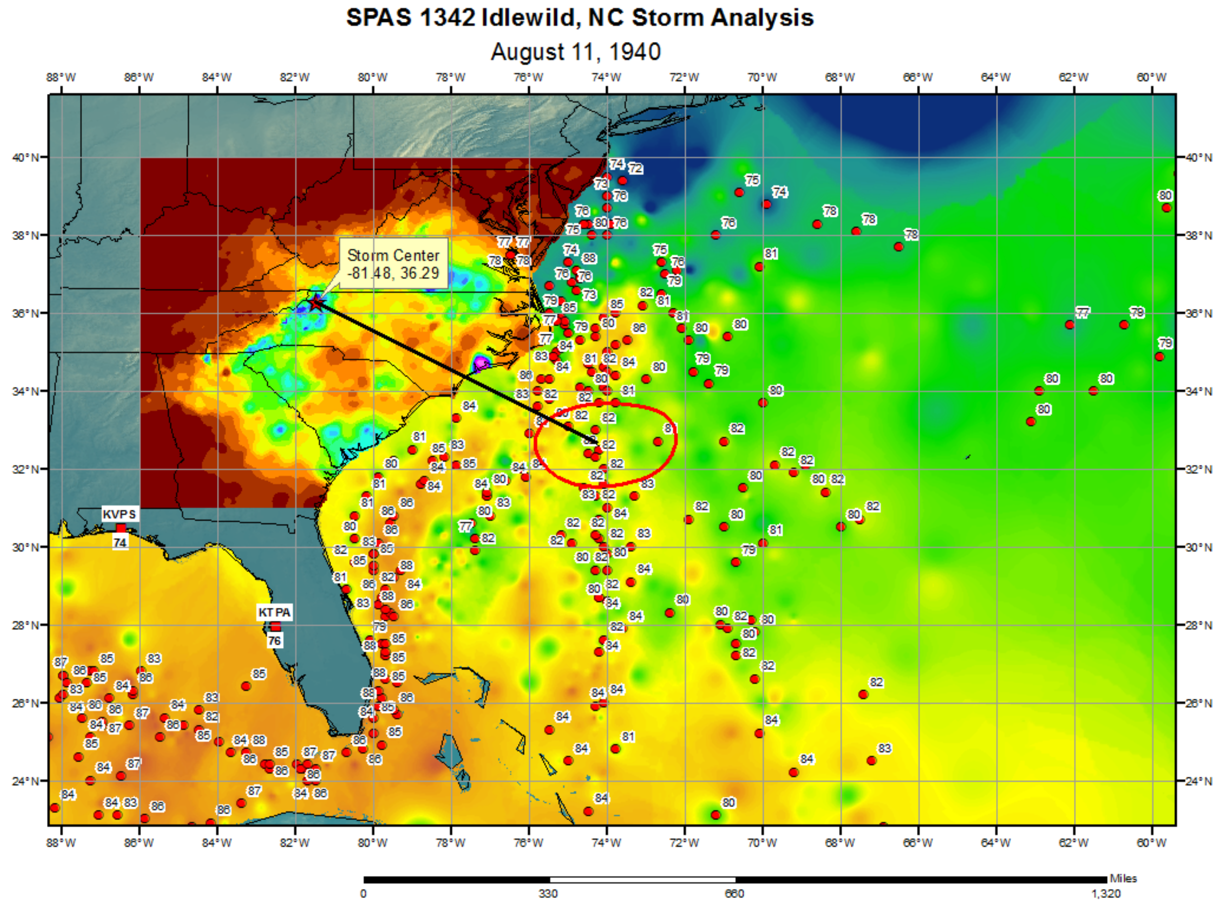

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Monday, August 12, 1940
GENERAL FORECASTS
WEATHER FORECASTS BY AUTOMATIC TELEPHONE


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Tuesday, August 13, 1940
GENERAL FORECASTS
WEATHER FORECASTS BY AUTOMATIC TELEPHONE


U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Wednesday, August 14, 1940


U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Thursday, August 15, 1940


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
LOW
LOW
LOW
HIGH
Washington, D. C., Friday, August 16, 1940


SPAS 1342 Idlewild, NC Storm Analysis
August 11, 1940
Storm Center
-81.48, 36.29
KVPS
KTPA
Miles
0
330
660
1,320

Storm Precipitation Analysis System (SPAS) For Storm #1518_1 SPAS Analysis

General Storm Location: Southeast U.S.

Storm Dates: September 13-18, 1945

Event: “Homestead” Hurricane

DAD Zone 1

Latitude: 34.9542

Longitude: -79.7292

Max. Grid Rainfall Amount: 14.97”

Max Observed Rainfall Amount: 14.91” (Rockingham, NC)

Number of Stations: 556

SPAS Version: 10.0

Base Map Used: Prism Conus 2-year 24-hour climatological base map

Spatial resolution: .2733

Radar Included: No

Depth-Area-Duration (DAD) analysis: No

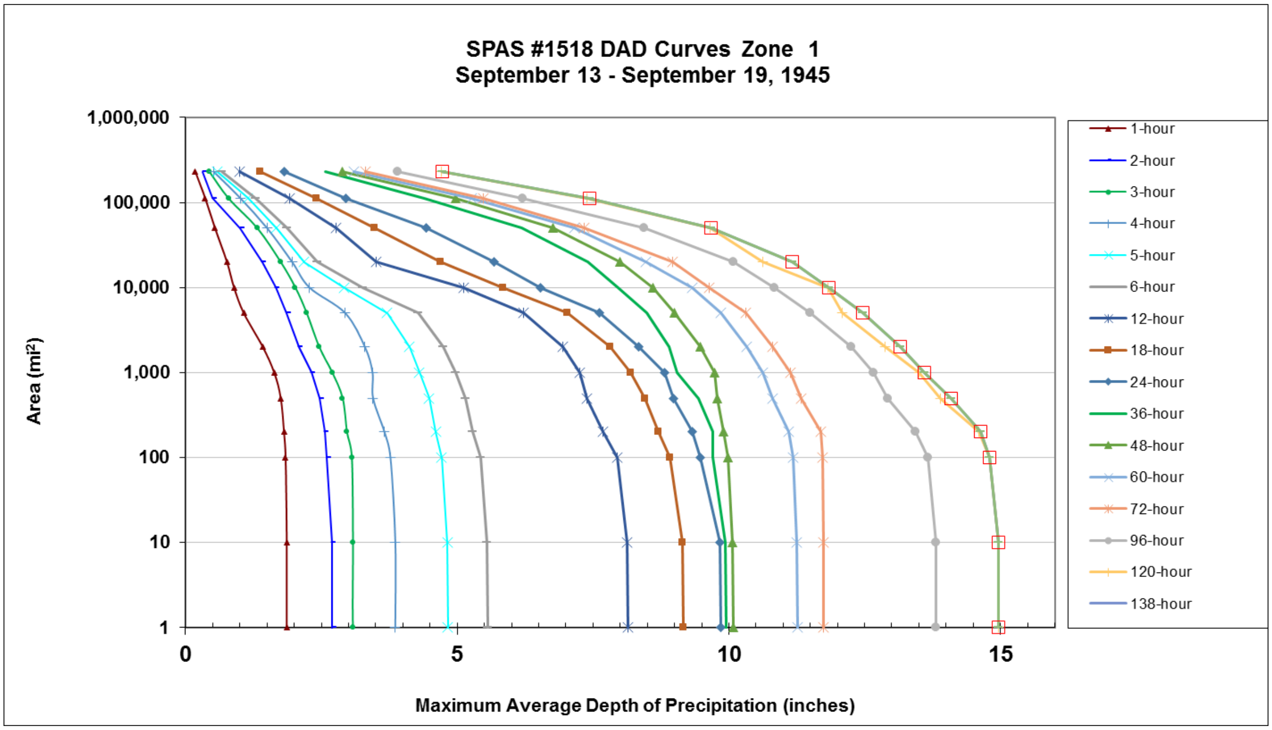
Reliability of Results: Three of the 12 hourly stations were manually digitized from the pertinent data sheet of the SA 5-27 CORPS of engineers report. Given that these three stations were all recorder stations, the data is considered highly reliable. An additional hourly station was converted to pseudo due to co-location with a supplemental station. While this hourly station’s magnitude has been rejected, the timing from this station is essential for maintaining the integrity of the surrounding supplemental and daily stations. 83 of the 127, or roughly 65% of the supplemental stations were converted from daily due to the need for an additional day’s observation. The daily timing of these 83 stations was preserved, meaning that even though they were in the supplemental file they were still, by definition, daily stations. With all of the data being thoroughly inspected, the precipitation pattern and DAD table following closely to the CORP report, and the precipitation totals for various periods throughout the storm being consistent with previous reports, this analysis is considered to be reliable.

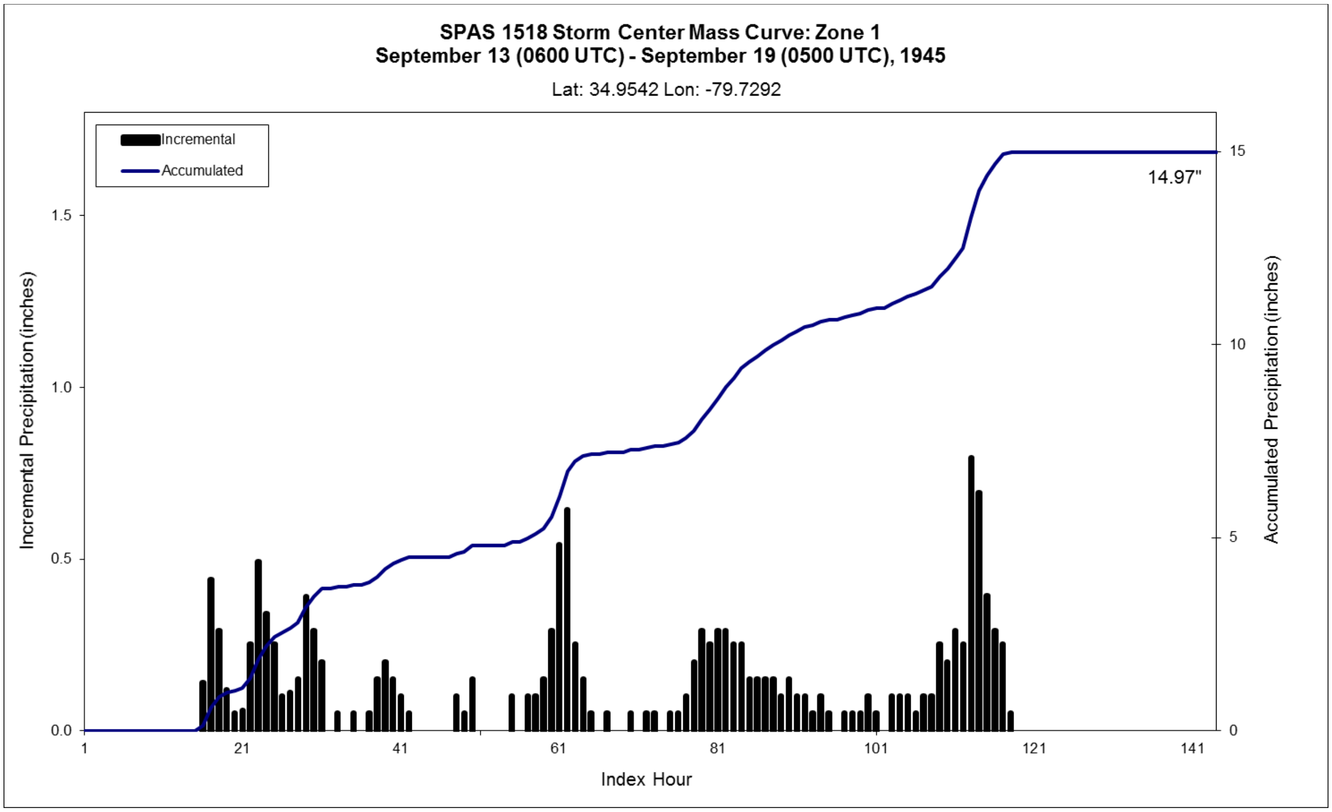
							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1518_1	-79.7292	34.9542	370	400	1-Sep	75.00	2.85	0.10	72	2.750	78.68	78.5	3.37	0.12	79	3.250	1.182

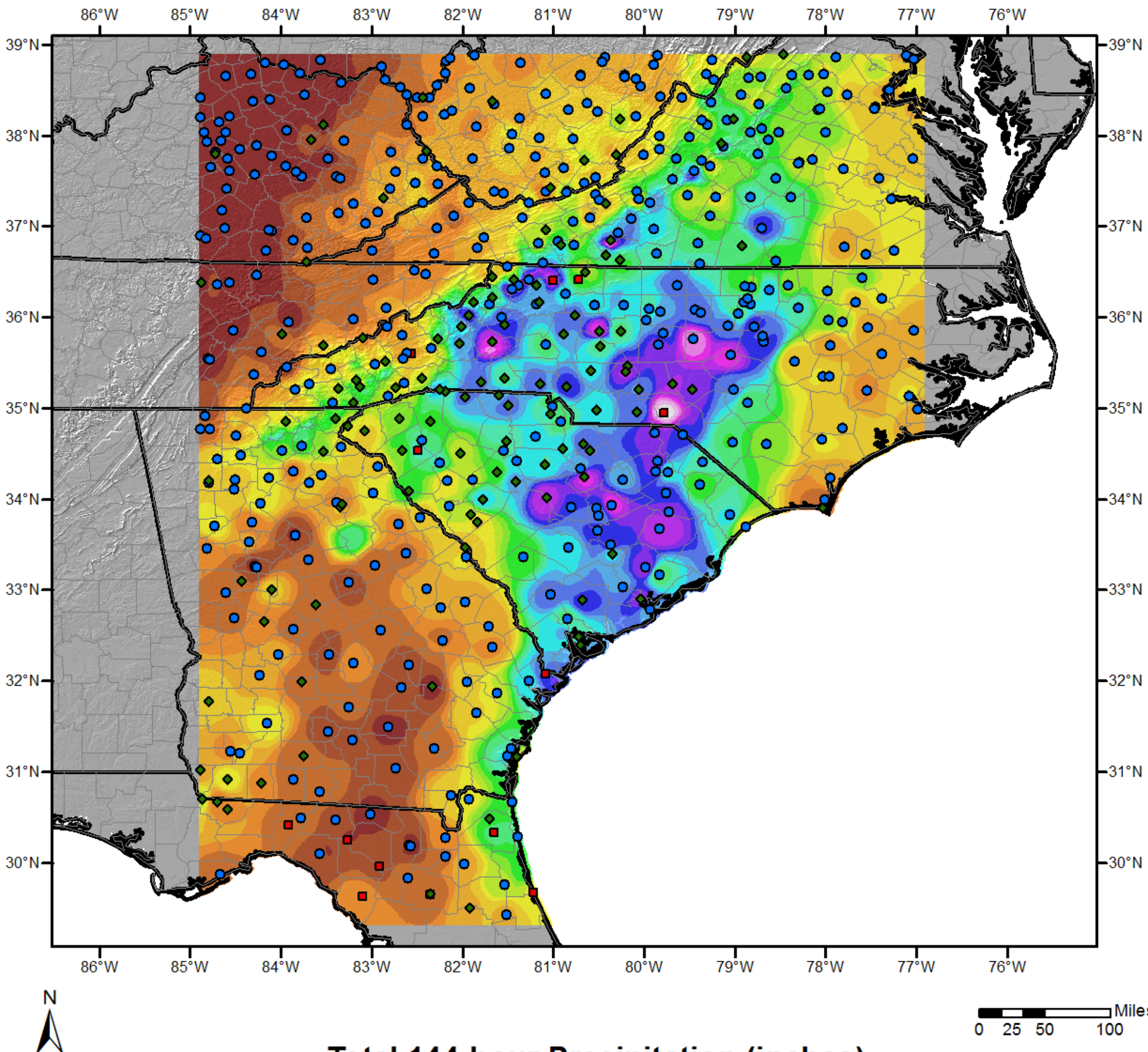
Storm 1518 - September 13 (0600 UTC) - September 19 (0500 UTC), 1945

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

Area (mi^2)	Duration (hours)																
	1	2	3	4	5	6	12	18	24	36	48	60	72	96	120	138	144	Total
0.3	1.86	2.70	3.16	3.87	4.83	5.57	8.15	9.17	9.86	9.96	10.09	11.26	11.94	13.82	14.97	14.97	14.97	14.97
1	1.86	2.70	3.08	3.86	4.83	5.57	8.14	9.17	9.85	9.95	10.08	11.26	11.75	13.82	14.97	14.97	14.97	14.97
10	1.86	2.69	3.08	3.86	4.82	5.55	8.13	9.15	9.83	9.93	10.07	11.25	11.75	13.81	14.96	14.96	14.96	14.96
100	1.84	2.60	3.06	3.77	4.71	5.43	7.94	8.92	9.47	9.71	9.99	11.18	11.72	13.67	14.80	14.80	14.80	14.80
200	1.81	2.56	2.97	3.66	4.61	5.29	7.69	8.71	9.33	9.71	9.91	11.11	11.69	13.43	14.60	14.63	14.63	14.63
500	1.75	2.47	2.89	3.45	4.48	5.15	7.39	8.45	8.98	9.44	9.79	10.81	11.34	12.92	13.89	14.09	14.09	14.09
1000	1.63	2.31	2.70	3.44	4.30	4.97	7.25	8.19	8.82	9.04	9.74	10.63	11.14	12.66	13.51	13.60	13.60	13.60
2000	1.42	2.08	2.46	3.30	4.12	4.75	6.94	7.81	8.34	8.90	9.48	10.33	10.81	12.26	12.88	13.15	13.15	13.15
5000	1.07	1.86	2.23	2.94	3.71	4.28	6.22	7.03	7.62	8.49	9.00	9.85	10.31	11.50	12.09	12.46	12.46	12.46
10000	0.89	1.66	2.02	2.28	2.91	3.27	5.12	5.84	6.54	7.96	8.60	9.33	9.64	10.84	11.83	11.85	11.85	11.85
20,000	0.76	1.41	1.75	1.96	2.18	2.42	3.51	4.69	5.68	7.40	7.99	8.47	8.97	10.09	10.62	11.16	11.16	11.16
50,000	0.54	1.01	1.32	1.50	1.67	1.86	2.77	3.47	4.43	6.18	6.76	7.15	7.34	8.44	9.66	9.68	9.68	9.68
112,200	0.36	0.50	0.79	1.01	1.15	1.29	1.91	2.41	2.95	4.39	4.98	5.27	5.48	6.21	7.39	7.43	7.43	7.43
229,258	0.18	0.32	0.44	0.52	0.59	0.66	0.99	1.38	1.82	2.57	2.88	3.10	3.31	3.90	4.71	4.73	4.73	4.73




SPAS 1518 Storm Center Mass Curve: Zone 1
September 13 (0600 UTC) - September 19 (0500 UTC), 1945
Lat: 34.9542 Lon: -79.7292
Incremental
Accumulated
14.97"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
0
5
10
15
1
21
41
61
81
101
121
141



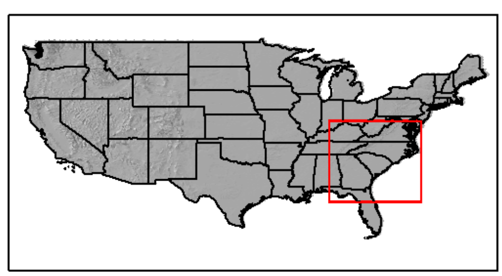
Total 144-hour Precipitation (inches)
September 13, 1945 0600 UTC - September 19, 1945 0500 UTC
SPAS #1518

Precipitation (inches)

0.01 - 0.70	5.61 - 6.30	11.3 - 11.9
0.71 - 1.40	6.31 - 7.00	12.0 - 12.6
1.41 - 2.10	7.01 - 7.70	12.7 - 13.3
2.11 - 2.80	7.71 - 8.40	13.4 - 14.0
2.81 - 3.50	8.41 - 9.10	14.1 - 14.7
3.51 - 4.20	9.11 - 9.80	14.8 - 15.0
4.21 - 4.90	9.81 - 10.5	
4.91 - 5.60	10.6 - 11.2	

Stations

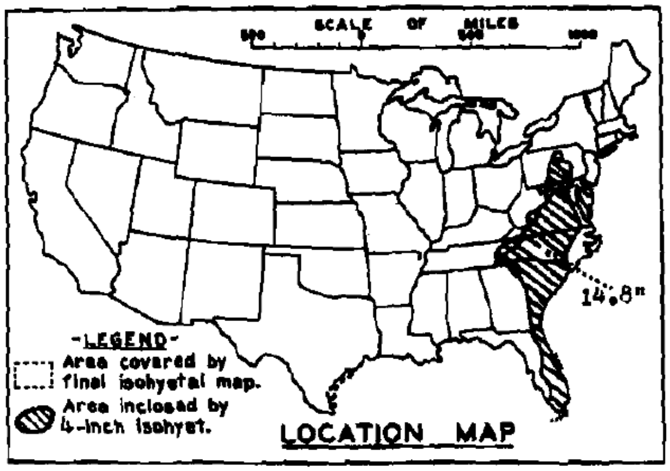
- Daily
- Hourly
- Hourly Pseudo
- Supplemental



KLL 03/16/2015

DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

STORM STUDIES - PERTINENT DATA SHEET



Storm of 13-18 Sept. 1945
Assignment SA 5-27
Location Southeastern U.S.
Study Prepared by:
South Atlantic Division
Wilmington, N. C. District

Part I Reviewed by H. M. Sec. of Weather Bureau, 8-24-48
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 6-7-61
Remarks: Center at Rockingham, N. C.
Rep. Dewpoint 74°, Ref Pt. 80 SSW

Grid H-7

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1:2,500,000

Precipitation data and mass curves:	(Number of Sheets)
Form 5001-C (Hourly precip. data)	232
Form 5001-B (24-hour " ")	0
Form 5001-D (" " " ")	49
Miscl. precip. records, meteorological data, etc.	52
Form 5002 (Mass rainfall curves)	155

PART II

Final isohyetal maps, in 1 sheet, scale 1:1,000,000

Data and computation sheets:	
Form S-10 (Data from mass rainfall curves)	29
Form S-11 (Depth-area data from isohyetal map)	6
Form S-12 (Maximum depth-duration data)	14
Maximum duration-depth-area curves	1
Data relating to periods of maximum rainfall	4

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

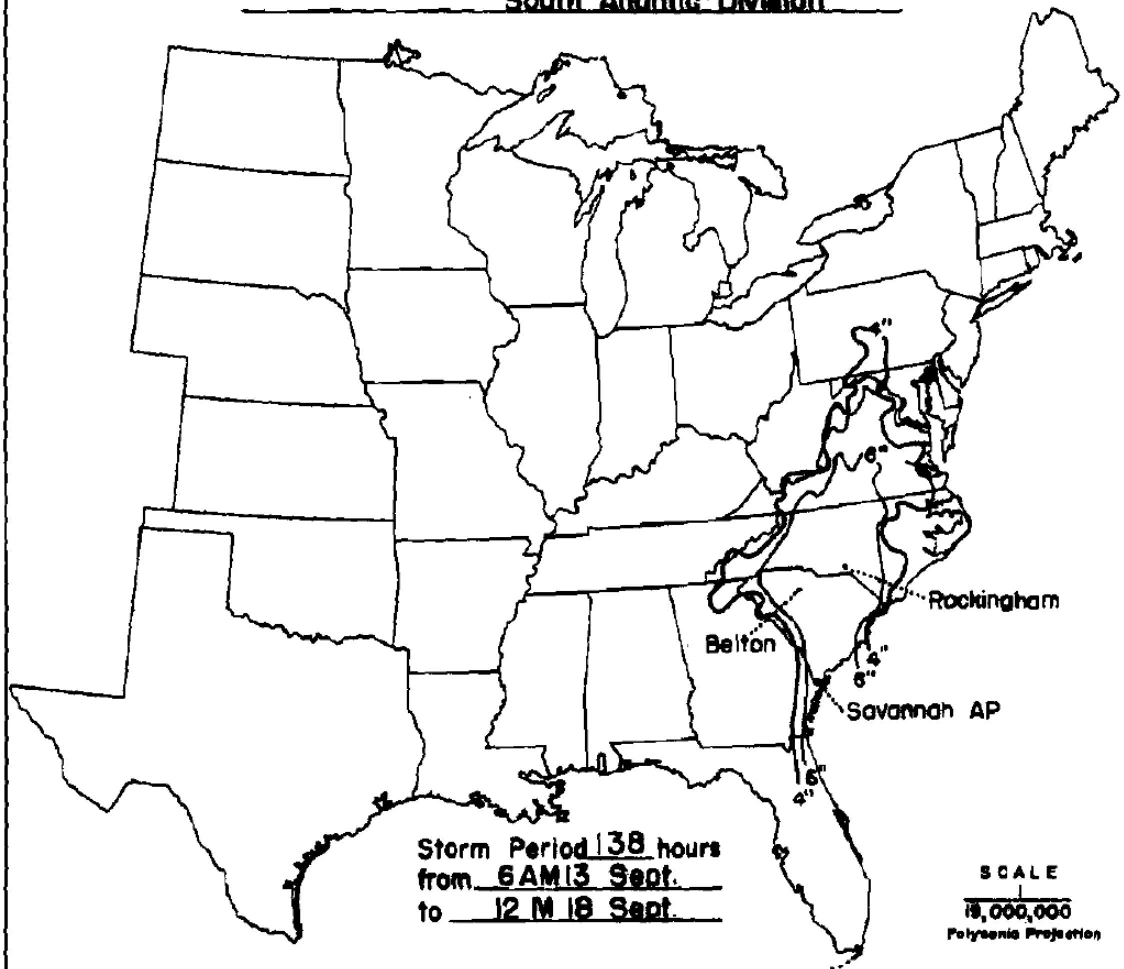
Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	36	48	60	72	96	120	138
10	5.8	7.6	8.3	9.2	9.9	10.7	11.3	12.1	13.7	14.8	14.8
100	4.8	6.8	7.8	9.1	9.9	10.5	11.2	11.8	13.2	13.9	13.9
200	4.4	6.6	7.6	9.1	9.9	10.5	11.1	11.7	13.0	13.6	13.6
500	4.0	6.2	7.3	9.0	9.9	10.3	10.8	11.4	12.7	13.2	13.2
1,000	3.7	5.8	7.0	8.7	9.7	10.0	10.6	11.1	12.4	12.8	12.8
2,000	3.3	5.4	6.6	8.1	9.3	9.6	10.1	10.6	12.0	12.5	12.5
5,000	2.8	4.8	5.9	7.1	8.5	8.9	9.4	10.0	11.4	11.9	11.9
10,000	2.4	4.2	5.2	6.2	7.7	8.2	8.7	9.3	10.8	11.4	11.4
20,000	2.0	3.5	4.3	5.2	6.7	7.3	7.8	8.5	9.9	10.7	10.7
50,000	1.3	2.4	3.1	3.9	5.3	6.0	6.4	6.9	8.1	9.3	9.3
112 200	0.7	1.4	2.0	2.6	3.6	4.3	4.5	4.7	5.7	6.9	7.0

DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

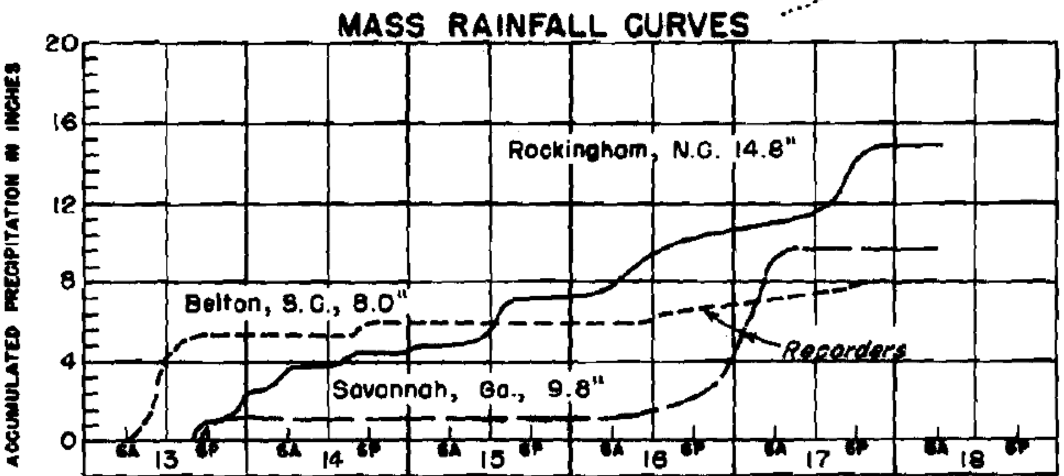
STORM STUDIES – ISOHYETAL MAP

Storm of 13-18 September 1945 Assignment SA 5-27

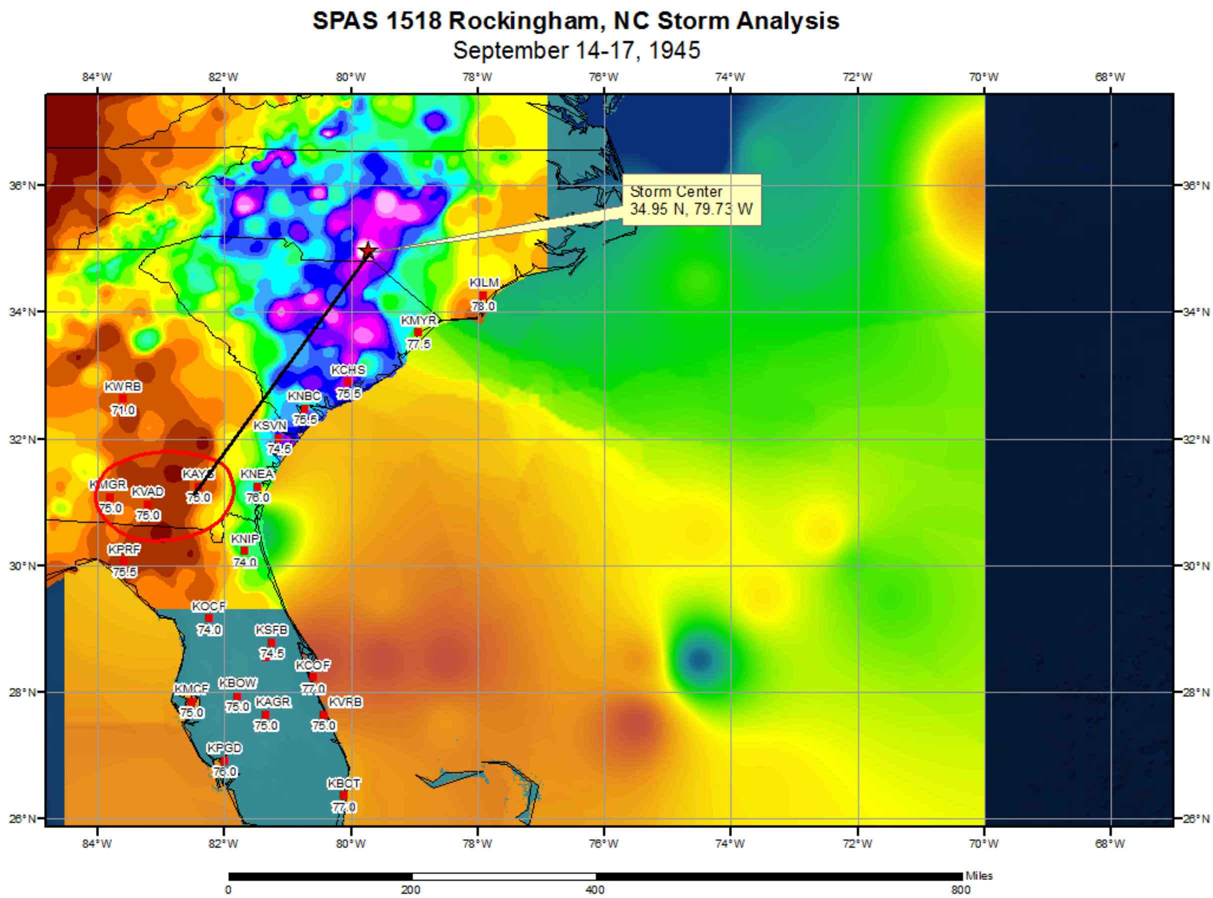
Study Prepared by: Wilmington, N.C., District
South Atlantic Division



MASS RAINFALL CURVES



FORM 5-3E


SPAS 1518 Rockingham, NC Storm Analysis
September 14-17, 1945
Storm Center
34.95 N, 79.73 W
KILM
78.0
KMYR
77.5
KCHS
75.5
KNBC
75.5
KSVN
74.5
KWRB
71.0
KAYS
75.0
KNEA
76.0
KMGR
75.0
KVAD
75.0
KNIP
74.0
KPRF
75.5
KOCF
74.0
KSFB
74.5
KCOF
77.0
KMCF
75.0
KBOW
75.0
KAGR
75.0
KVRB
75.0
KPGD
76.0
KBCT
77.0
Miles
0
200
400
800

Storm Precipitation Analysis System (SPAS) For Storm #1679_1 SPAS Analysis

General Storm Location: Slide Mountain, NY

Storm Dates: August 10-15, 1955

Event: Hurricane Connie Remnants

DAD Zone 1

Latitude: 42.0208

Longitude: -74.3958

Max. Grid Rainfall Amount: 15.20”

Max. Observed Rainfall Amount: 15.15”

Number of Stations: 292

SPAS Version: 10.0

Basemap: Isohyetal Map

Spatial resolution: 0.2479

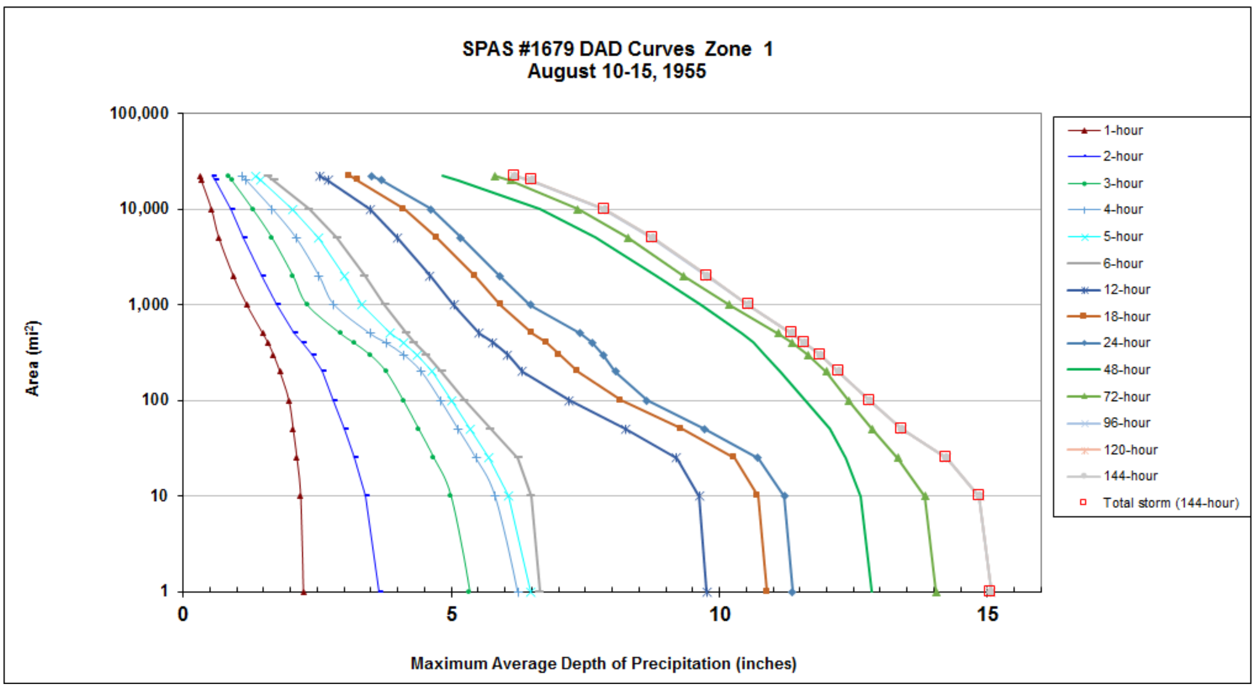
Radar Included: No

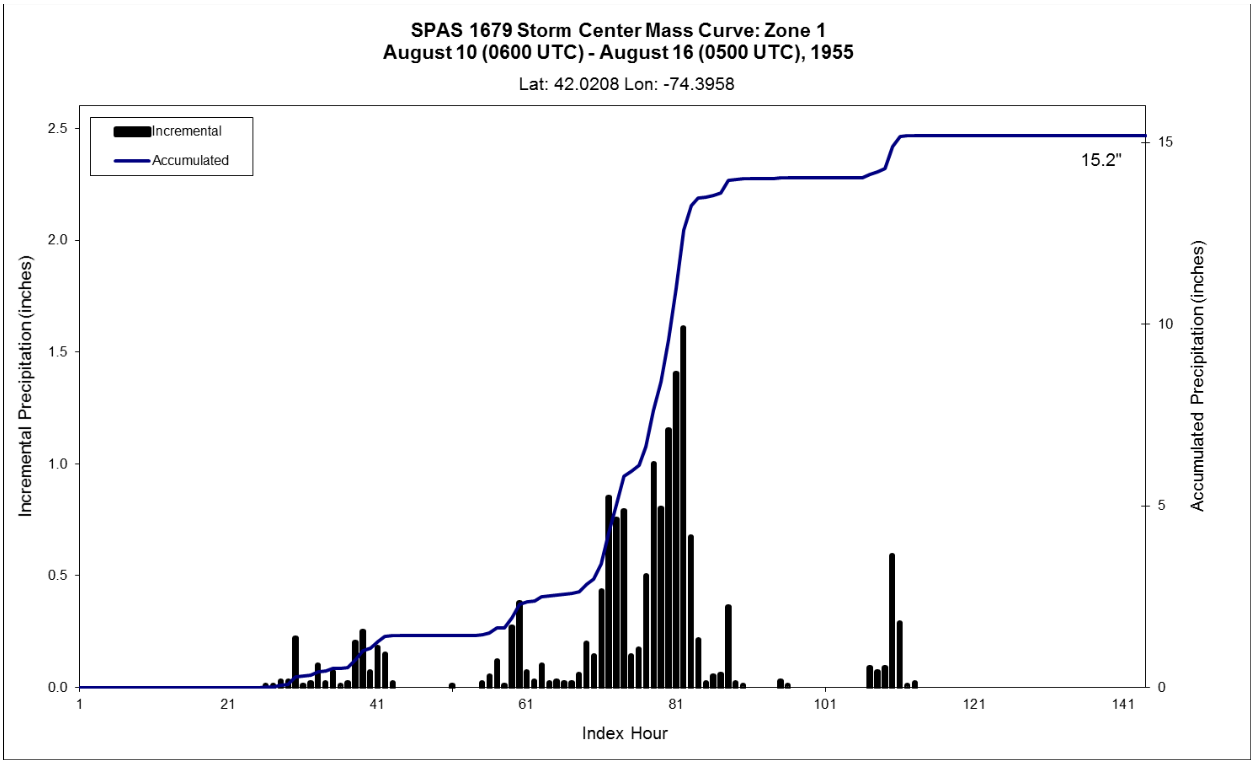
Depth-Area-Duration (DAD) analysis: Yes

Reliability of results: This analysis was based on 292 hourly stations, hourly pseudo, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the isohyetal basemap. Timing is based on the hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

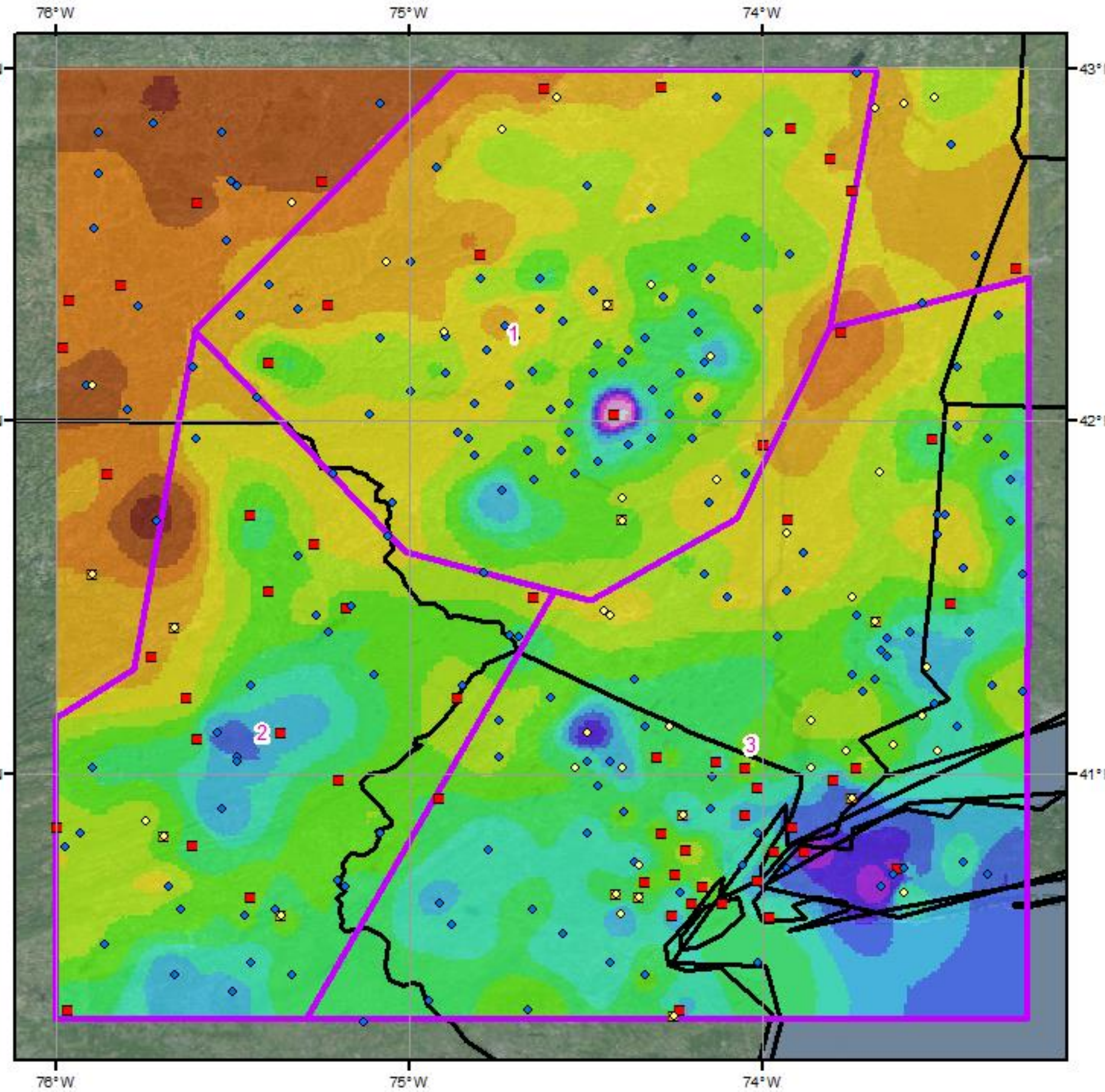
						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1679_1	-74.3958	42.0208	2,798	5-Aug	73.00	2.60	0.62	68	1.980	76.13	2.99	0.68	74	2.310	1.167

Storm 1679 - August 10 (0600 UTC) - August 16 (0500 UTC), 1955															
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)															
Area (mi^2)	Duration (hours)														
	1	2	3	4	5	6	12	18	24	48	72	96	120	144	Total
0.4	2.25	3.68	5.38	6.29	6.55	6.70	9.82	10.95	11.42	12.90	14.12	15.15	15.15	15.15	15.15
1	2.24	3.64	5.34	6.24	6.49	6.65	9.76	10.89	11.36	12.83	14.04	15.07	15.07	15.07	15.07
10	2.19	3.40	4.99	5.82	6.07	6.49	9.62	10.72	11.21	12.64	13.83	14.85	14.85	14.85	14.85
25	2.12	3.19	4.67	5.46	5.69	6.24	9.20	10.28	10.72	12.35	13.33	14.24	14.24	14.24	14.24
50	2.05	3.00	4.39	5.13	5.36	5.73	8.25	9.29	9.72	12.05	12.84	13.40	13.40	13.40	13.40
100	1.97	2.80	4.10	4.80	5.01	5.24	7.20	8.16	8.65	11.60	12.41	12.80	12.80	12.80	12.80
200	1.80	2.59	3.78	4.44	4.65	4.82	6.32	7.36	8.06	11.14	11.99	12.23	12.23	12.23	12.23
300	1.68	2.42	3.48	4.11	4.36	4.53	6.05	7.01	7.83	10.85	11.65	11.88	11.88	11.88	11.88
400	1.58	2.23	3.18	3.78	4.10	4.30	5.77	6.77	7.63	10.64	11.35	11.57	11.58	11.58	11.58
500	1.48	2.06	2.93	3.48	3.85	4.16	5.52	6.51	7.41	10.43	11.10	11.34	11.35	11.35	11.35
1,000	1.18	1.75	2.31	2.81	3.32	3.76	5.05	5.92	6.47	9.67	10.19	10.53	10.54	10.54	10.54
2,000	0.93	1.47	2.05	2.53	3.00	3.38	4.60	5.44	5.90	8.82	9.33	9.76	9.78	9.78	9.78
5,000	0.66	1.13	1.66	2.10	2.53	2.86	3.99	4.73	5.18	7.69	8.29	8.72	8.75	8.75	8.75
10,000	0.52	0.90	1.30	1.66	2.04	2.35	3.48	4.12	4.62	6.66	7.36	7.82	7.85	7.85	7.85
20,000	0.33	0.60	0.91	1.17	1.44	1.69	2.70	3.26	3.70	5.14	6.11	6.48	6.50	6.50	6.50
22,085	0.31	0.55	0.85	1.09	1.35	1.58	2.54	3.11	3.51	4.83	5.81	6.17	6.18	6.18	6.18





SPAS 1679 Storm Center Mass Curve: Zone 1
August 10 (0600 UTC) - August 16 (0500 UTC), 1955
Lat: 42.0208 Lon: -74.3958
Incremental
Accumulated
15.2"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour

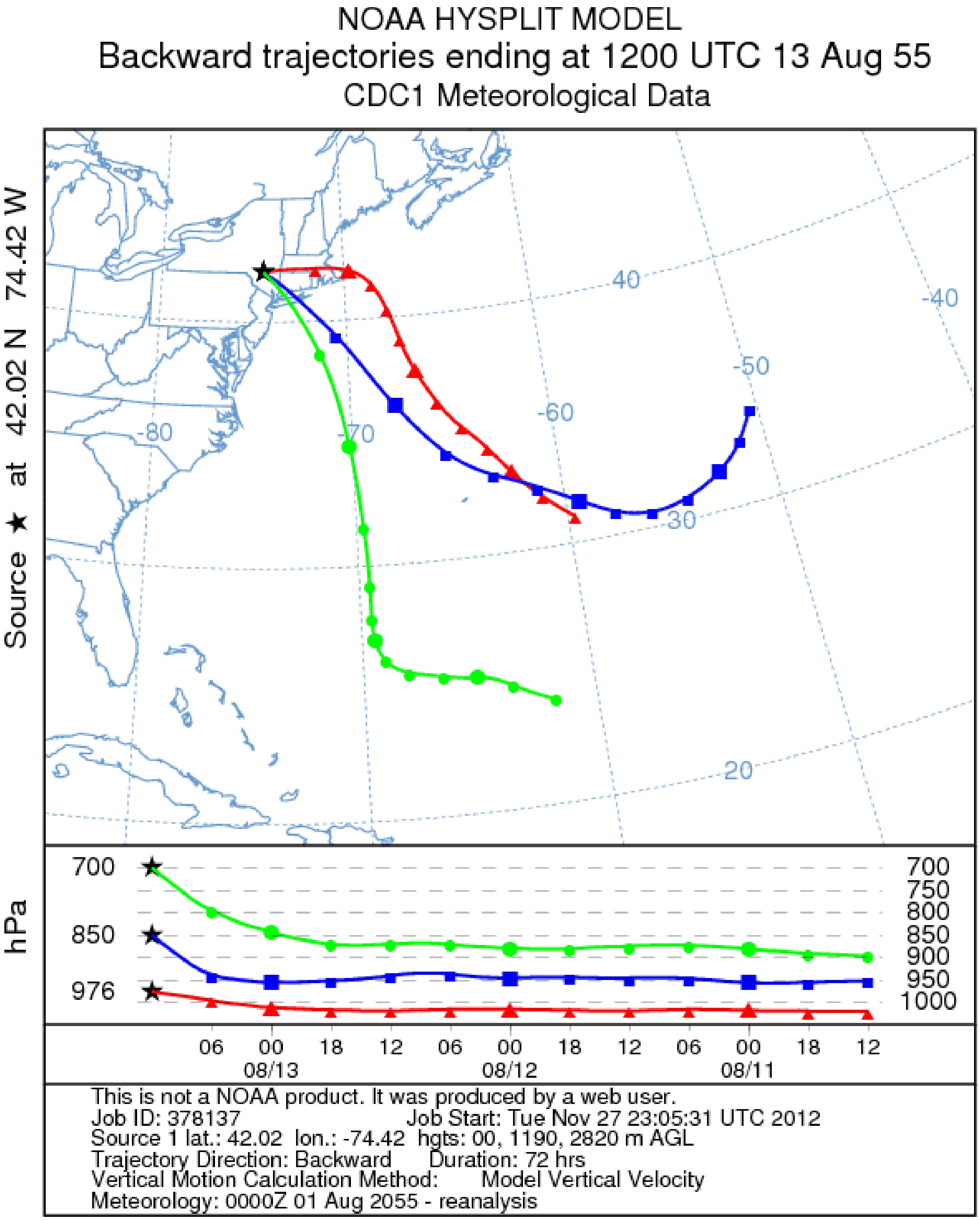


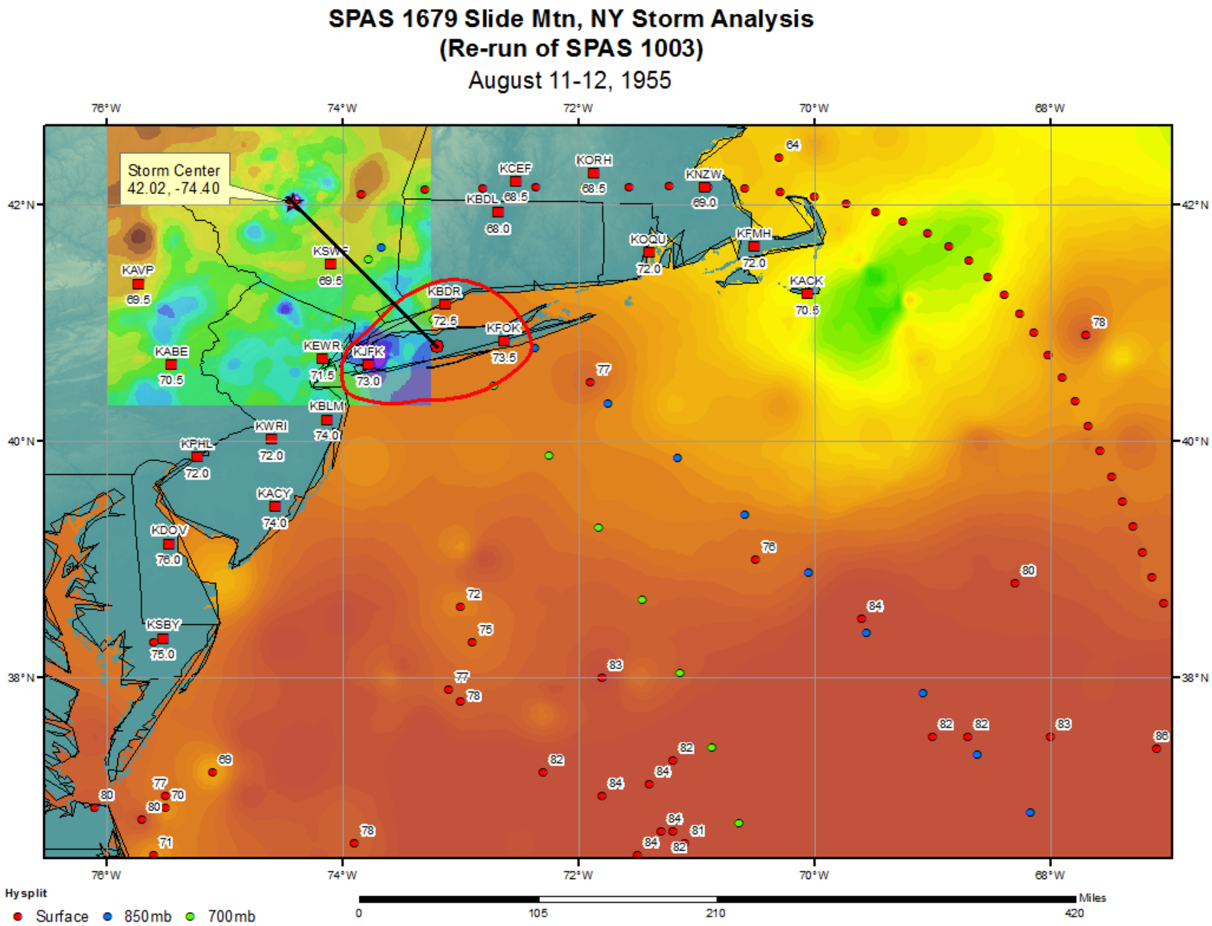
Total Storm (144-hours) Precipitation (inches)
August 10-15, 1955
SPAS 1679 (re-run of 1003) - Slide Mountain, NY

Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 12.5, 25, 50
Kilometers: 0, 25, 50, 100

Precipitation (inches)
- 0.79 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 4.00
- 4.01 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 11.00
- 11.01 - 12.00
- 12.01 - 13.00
- 13.01 - 14.00
- 14.01 - 15.00
- 15.01 - 16.00


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 13 Aug 55
CDC1 Meteorological Data
Source ★ at 42.02 N 74.42 W
40
-40
-50
-60
-80
-70
30
20
hPa
700
850
976
700
750
800
850
900
950
1000
06
00
18
12
06
00
18
12
06
00
18
12
08/13
08/12
08/11
This is not a NOAA product. It was produced by a web user.
Job ID: 378137 Job Start: Tue Nov 27 23:05:31 UTC 2012
Source 1 lat.: 42.02 lon.: -74.42 hgts: 00, 1190, 2820 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Aug 2055 - reanalysis


SPAS 1679 Slide Mtn, NY Storm Analysis
(Re-run of SPAS 1003)
August 11-12, 1955
Storm Center
42.02, -74.40
KAVP
69.5
KABE
70.5
KSWF
69.5
KEWR
71.5
KJFK
73.0
KBLM
74.0
KWRI
72.0
KPHL
72.0
KACY
74.0
KDOV
76.0
KSBY
75.0
KBDR
72.5
KFOK
73.5
KCEF
68.5
KBDL
68.0
KORH
68.5
KNZW
69.0
KOQU
72.0
KFMH
72.0
KACK
70.5
Hysplit
Surface
850mb
700mb
Miles

Storm Precipitation Analysis System (SPAS) For Storm #1243_1 SPAS Analysis

General Storm Location: Westfield, MA

Storm Dates: August 15-24, 1955

Event: Tropical, Hurricane Diane

DAD Zone 1

Latitude: 42.12

Longitude: -72.70007

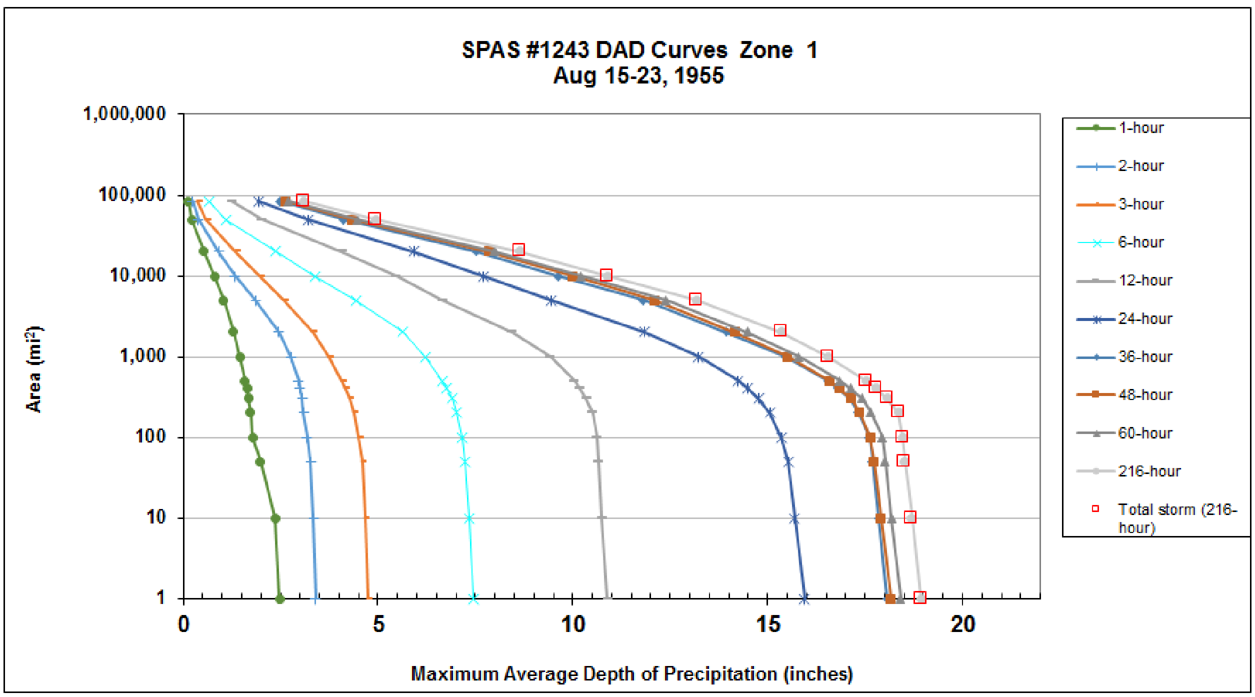
Max. Grid Rainfall Amount: 18.93”

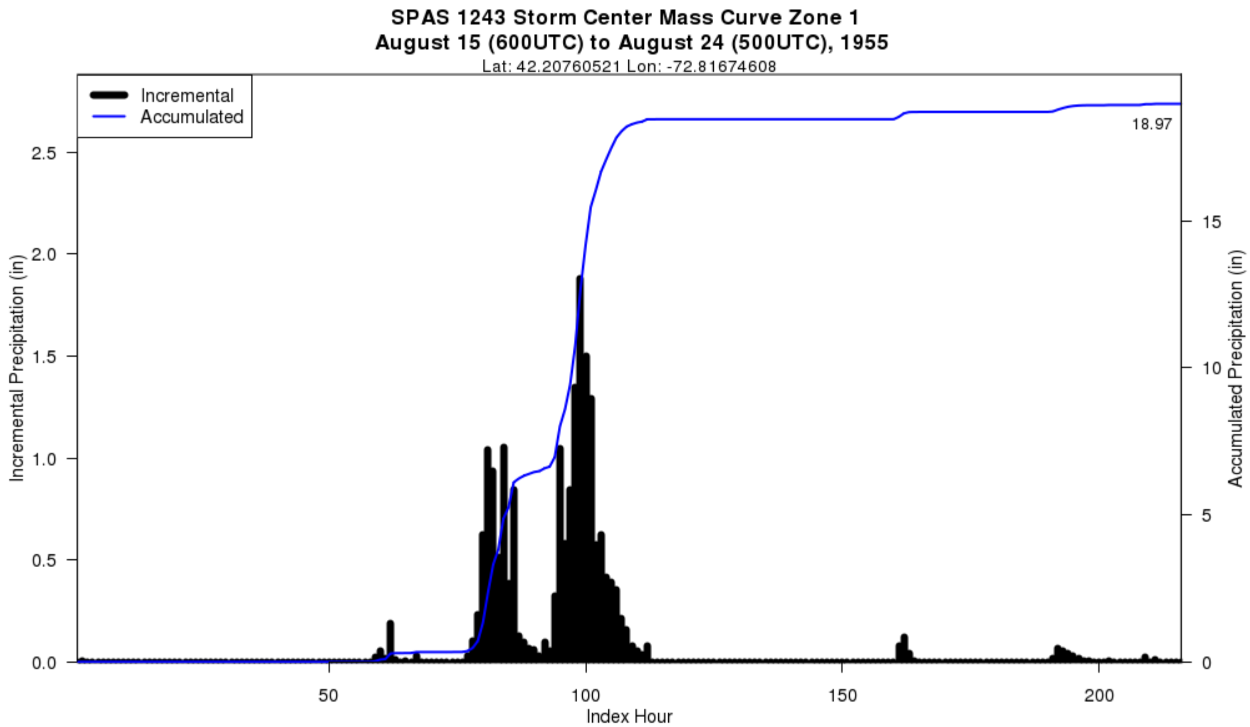
Radar Included: No

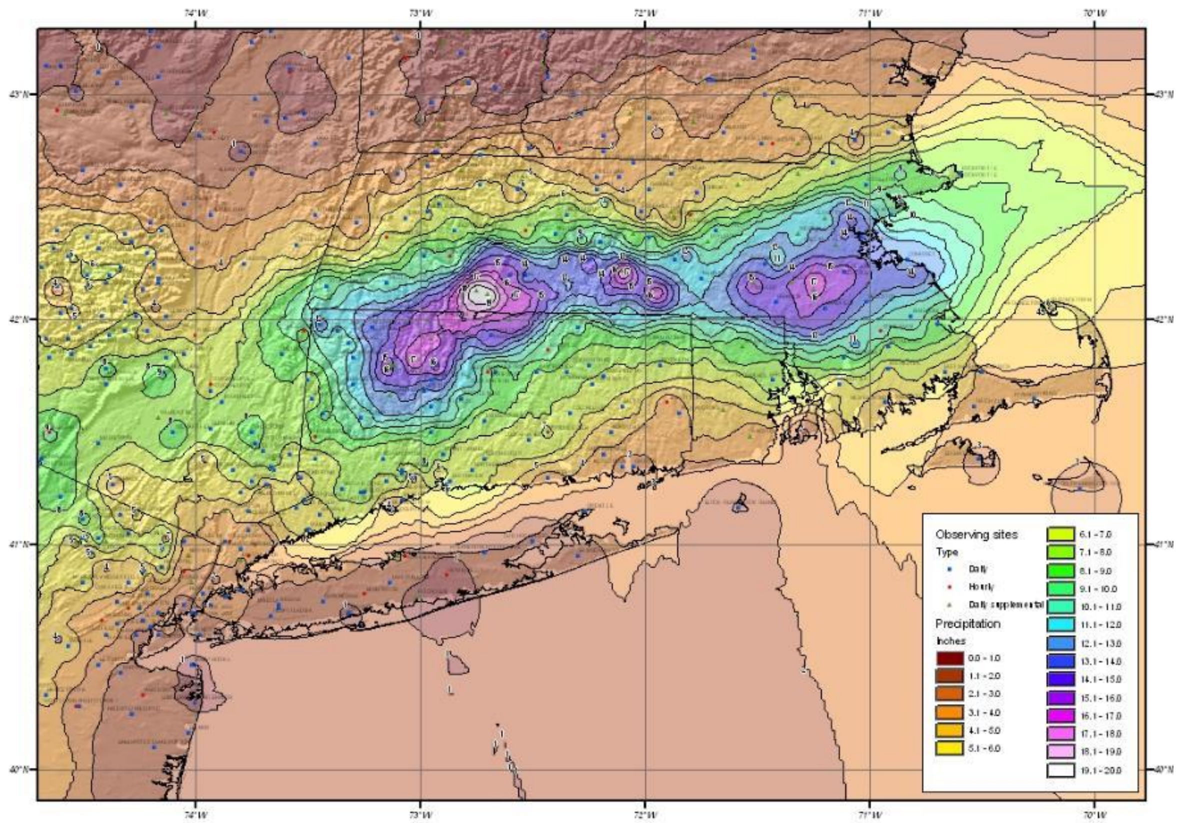
Depth-Area-Duration (DAD) analysis: Yes

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1243_1	-72.7000	42.1200	265	15-Aug	75.00	2.85	0.08	72	2.770	76.77	3.14	0.08	76	3.060	1.105

Storm 1243- Aug 15 (0600 UTC) - Aug 24 (0500 UTC), 1955 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	1	2	3	6	12	24	36	48	60	216	Total
0.4	2.48	3.40	4.74	7.46	10.89	15.95	18.08	18.16	18.42	18.93	18.93
1	2.48	3.40	4.74	7.46	10.89	15.95	18.07	18.16	18.41	18.93	18.93
10	2.37	3.35	4.67	7.33	10.75	15.70	17.85	17.90	18.18	18.70	18.70
50	1.99	3.27	4.60	7.24	10.66	15.53	17.69	17.72	18.01	18.53	18.53
100	1.78	3.18	4.51	7.17	10.62	15.35	17.62	17.64	17.94	18.46	18.46
200	1.72	3.09	4.37	7.02	10.50	15.05	17.33	17.36	17.66	18.35	18.35
300	1.67	3.05	4.26	6.89	10.35	14.76	17.12	17.15	17.44	18.07	18.07
400	1.63	3.00	4.16	6.77	10.18	14.50	16.81	16.84	17.13	17.80	17.80
500	1.59	2.96	4.07	6.65	10.03	14.24	16.54	16.58	16.86	17.52	17.52
1000	1.45	2.77	3.75	6.23	9.41	13.23	15.45	15.52	15.80	16.55	16.55
2,000	1.29	2.45	3.32	5.64	8.43	11.84	13.93	14.15	14.48	15.34	15.34
5,000	1.04	1.85	2.58	4.43	6.64	9.43	11.81	12.09	12.39	13.17	13.17
10,000	0.80	1.33	1.96	3.40	5.46	7.70	9.62	9.99	10.21	10.89	10.89
20,000	0.54	0.91	1.35	2.39	4.07	5.92	7.54	7.84	8.01	8.64	8.64
50,000	0.23	0.39	0.58	1.10	2.01	3.20	4.12	4.33	4.47	4.94	4.94
84,856	0.14	0.24	0.36	0.65	1.23	1.93	2.49	2.62	2.71	3.09	3.09




SPAS 1243 Storm Center Mass Curve Zone 1
August 15 (600UTC) to August 24 (500UTC), 1955
Lat: 42.20760521 Lon: -72.81674608
Incremental
Accumulated
18.97
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
50
100
150
200

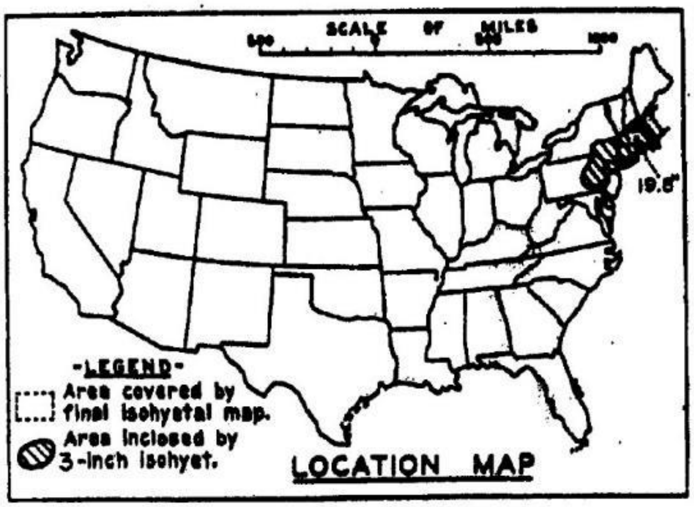


Total Storm Precipitation
Westfield, MA Storm Center
August 15-23, 1955

TWP June 3, 2003

DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

STORM STUDIES - PERTINENT DATA SHEET



Storm of 17-20 Aug. 1955
Assignment MA 2-22A
Location Mass. to Maryland
Study Prepared by:
New England Division

Part I Reviewed by H. M. Sec. of Weather Bureau, Dec. 1955
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 1/8/59
Remarks: Center at Westfield, Mass., Dewpt 74°, Ref. Pt. 105 S.
Grid D-3

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1:1,000,000

Precipitation data and mass curves:	(Number of Sheets)
Form 5001-C (Hourly precip. data)	280
Form 5001-B (24-hour " ")	0
Form 5001-D (" " " ")	91
Miscl. precip. records, meteorological data, etc.	0
Form 5002 (Mass rainfall curves)	689

PART II

Final isohyetal maps, in 1 sheet, scale 1:1,000,000

Data and computation sheets:	
Form S-10 (Data from mass rainfall curves)	4
Form S-11 (Depth-area data from isohyetal map)	3
Form S-12 (Maximum depth-duration data)	9
Maximum duration-depth-area curves	2
Data relating to periods of maximum rainfall	0

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

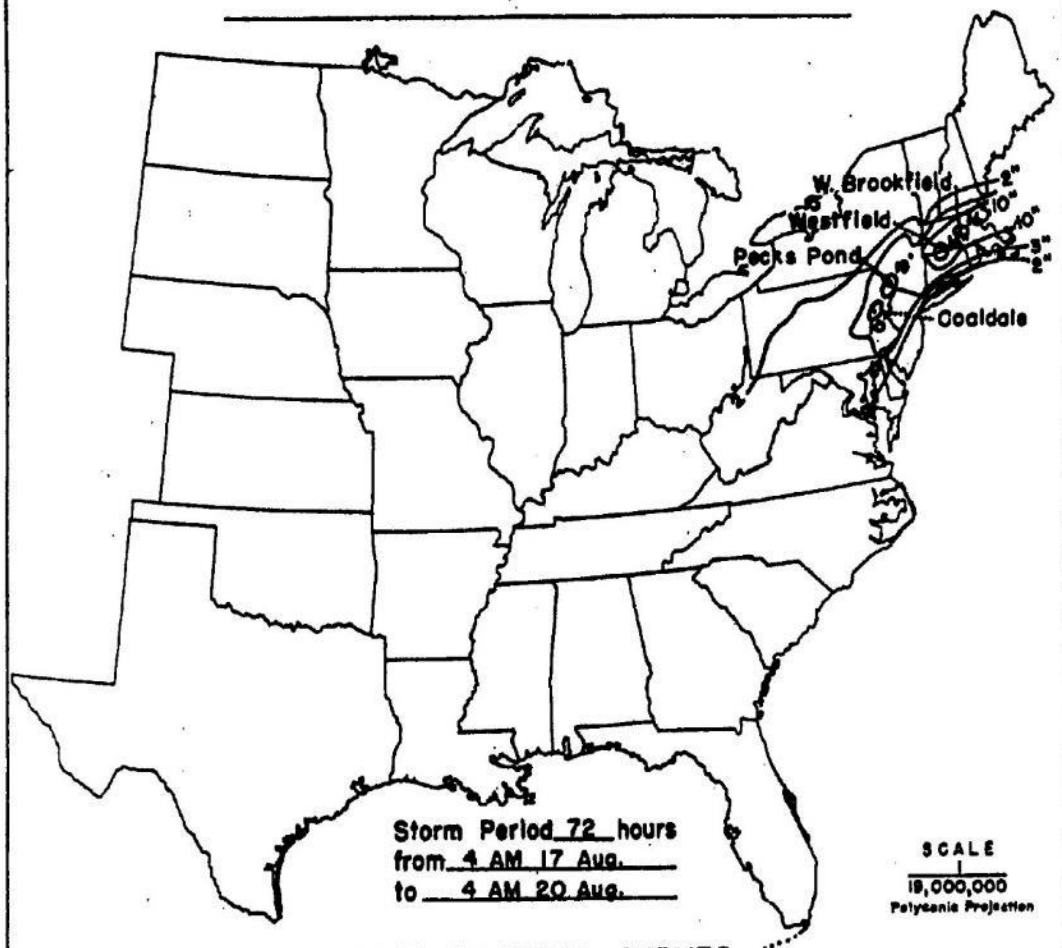
Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	72		
Max. Station	7.9	11.7	14.3	18.2	19.4	19.5	19.8	19.8	19.8		
10	7.8	11.1	13.0	16.4	18.5	18.9	19.4	19.6	19.6		
100	7.6	10.5	11.6	14.6	17.6	18.1	18.8	19.0	19.0		
200	7.4	10.2	11.4	14.2	17.1	17.6	18.2	18.4	18.4		
500	6.8	9.7	10.8	13.4	16.3	16.8	17.2	17.3	17.3		
1,000	6.2	9.2	10.2	12.4	15.4	15.9	16.2	16.4	16.4		
2,000	5.4	8.0	9.4	11.2	14.0	14.5	14.9	15.2	15.2		
5,000	4.0	6.3	7.9	9.5	11.7	12.1	12.6	13.0	13.0		
10,000	3.1	5.0	6.5	8.0	9.7	10.0	10.6	10.8	10.8		
20,000	2.1	3.6	4.9	6.3	7.6	7.9	8.3	8.5	8.5		
35,000	1.3	2.5	3.6	4.7	5.6	6.0	6.4	6.5	6.5		

DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

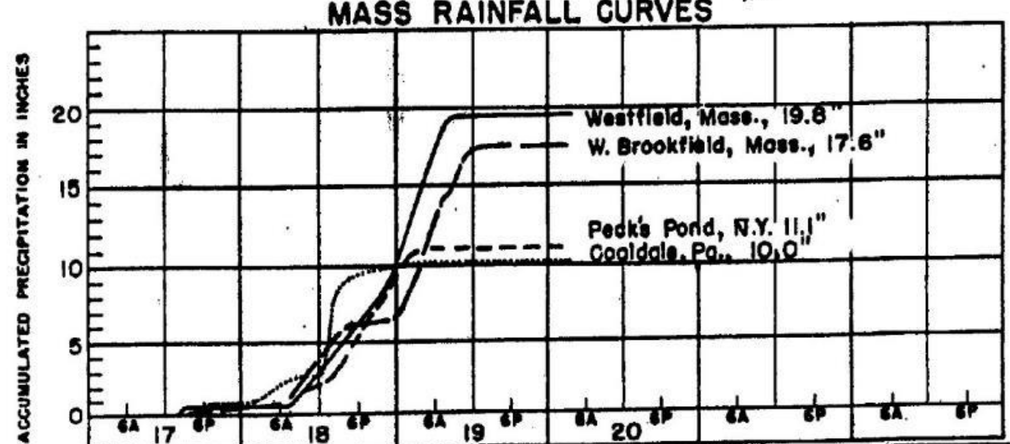
STORM STUDIES – ISOHYETAL MAP

Storm of 17–20 August 1955 Assignment NA 2-22A

Study Prepared by: New England Division

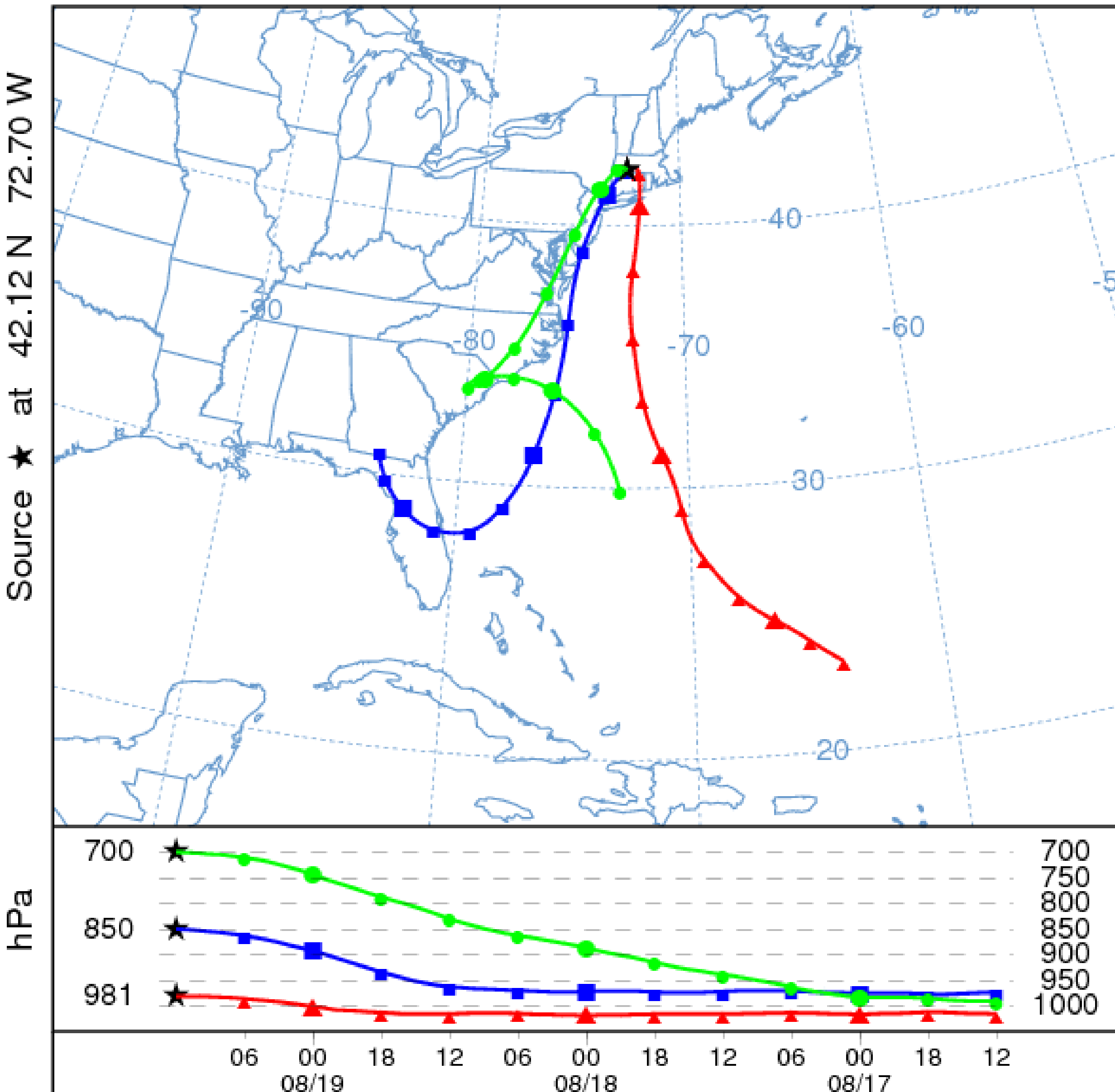


MASS RAINFALL CURVES

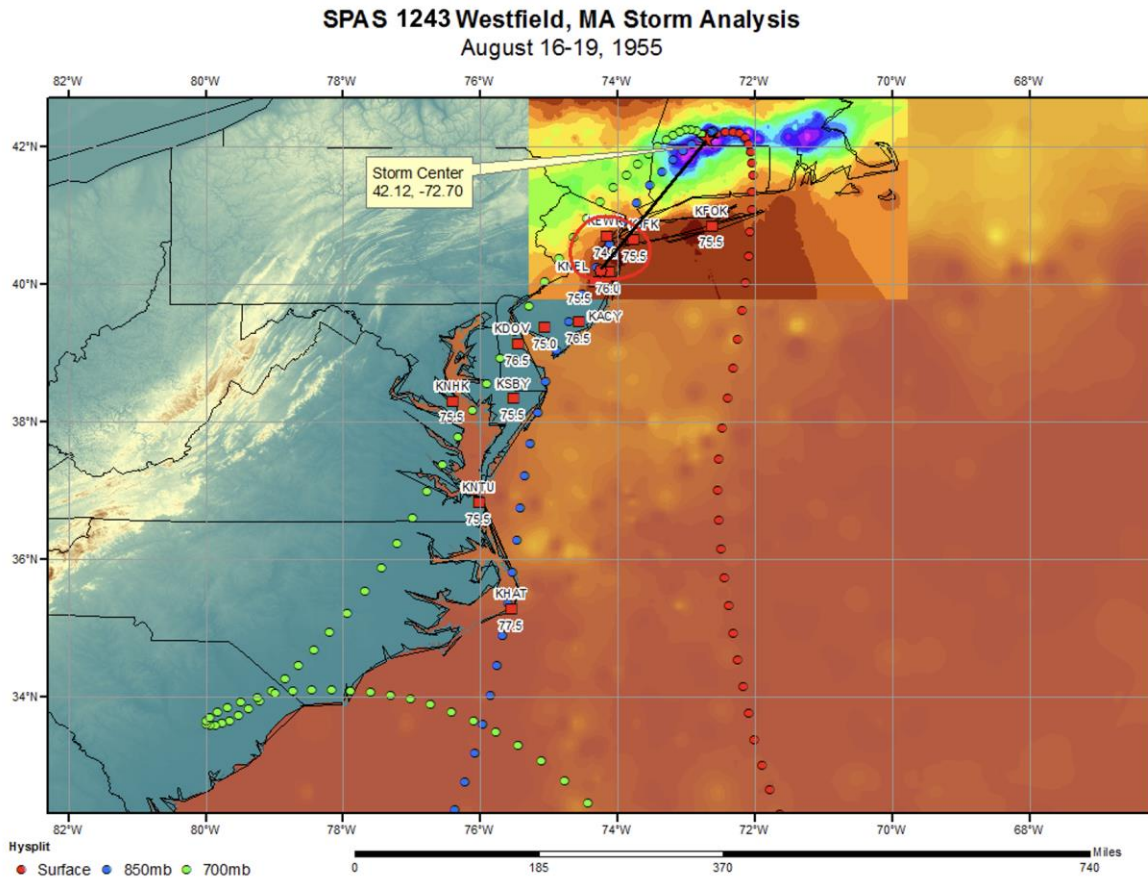


FORM S-3E

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 19 Aug 55
CDC1 Meteorological Data

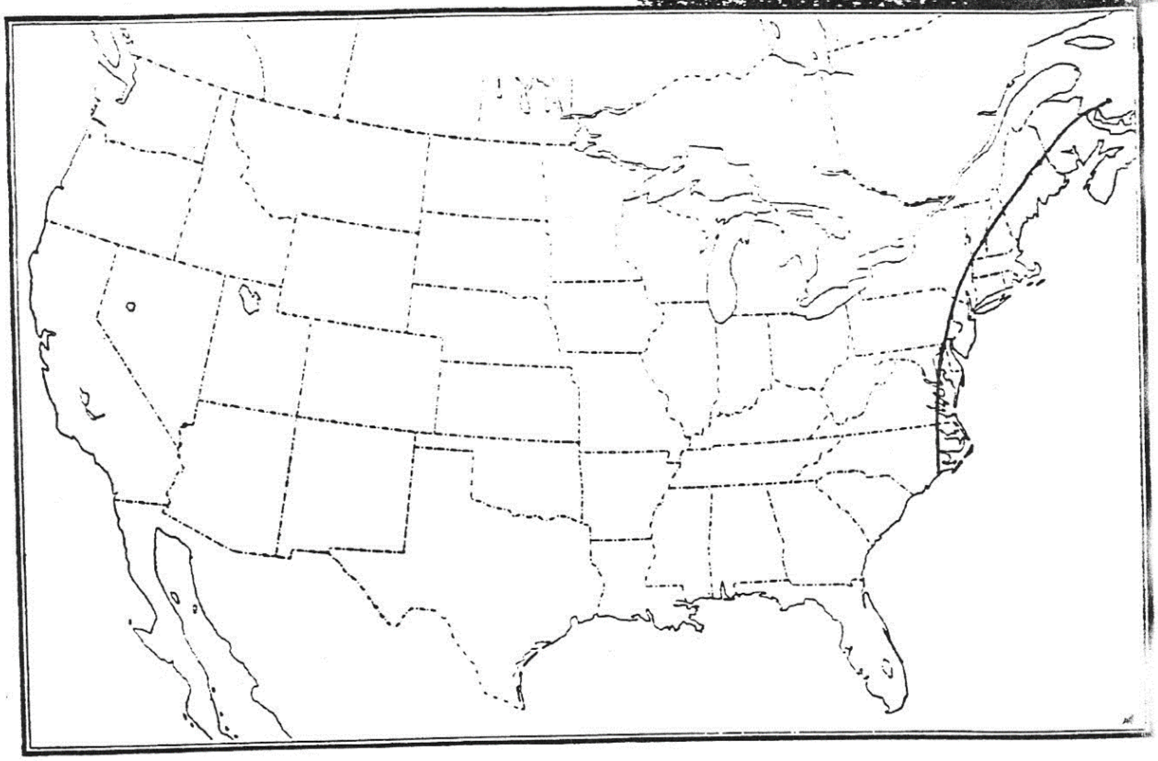


This is not a NOAA product. It was produced by a web user.
Job ID: 318058 Job Start: Tue Nov 27 20:56:20 UTC 2012
Source 1 lat.: 42.12 lon.: -72.70 hgts: 0, 1230, 2860 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Aug 2055 - reanalysis



SPAS 1243 Westfield, MA Storm Analysis
August 16-19, 1955
Storm Center
42.12, -72.70
KEWR
KJFK
KFOK
KNEL
KACY
KDOV
KNHK
KSBY
KNTU
KHAT
Hysplit
Surface
850mb
700mb
Miles
0
185
370
740

[illegible] [redacted]
Westfield, Mass 105 S 74°



Storm Precipitation Analysis System (SPAS) For Storm #1312B_2 SPAS Analysis

General Storm Location: Rosman, NC has the max total of 35.38"

Storm Dates: October 3 – October 6, 1964

Event: Heavy frontal rain with moisture from Hurricane Hilda

DAD Zone 2 - Central

Latitude: 35.1375

Longitude: -82.8375

Max. Grid Rainfall Amount: 17.53

Number of Stations: 1,365 stations (325 of which are hourly)

SPAS Version: 9.5

Base Map Used: Digitized TVA Isohyetal Map (storm total Sept 28 – Oct 6); expanded using SPAS storm totals

Spatial resolution: 30 seconds

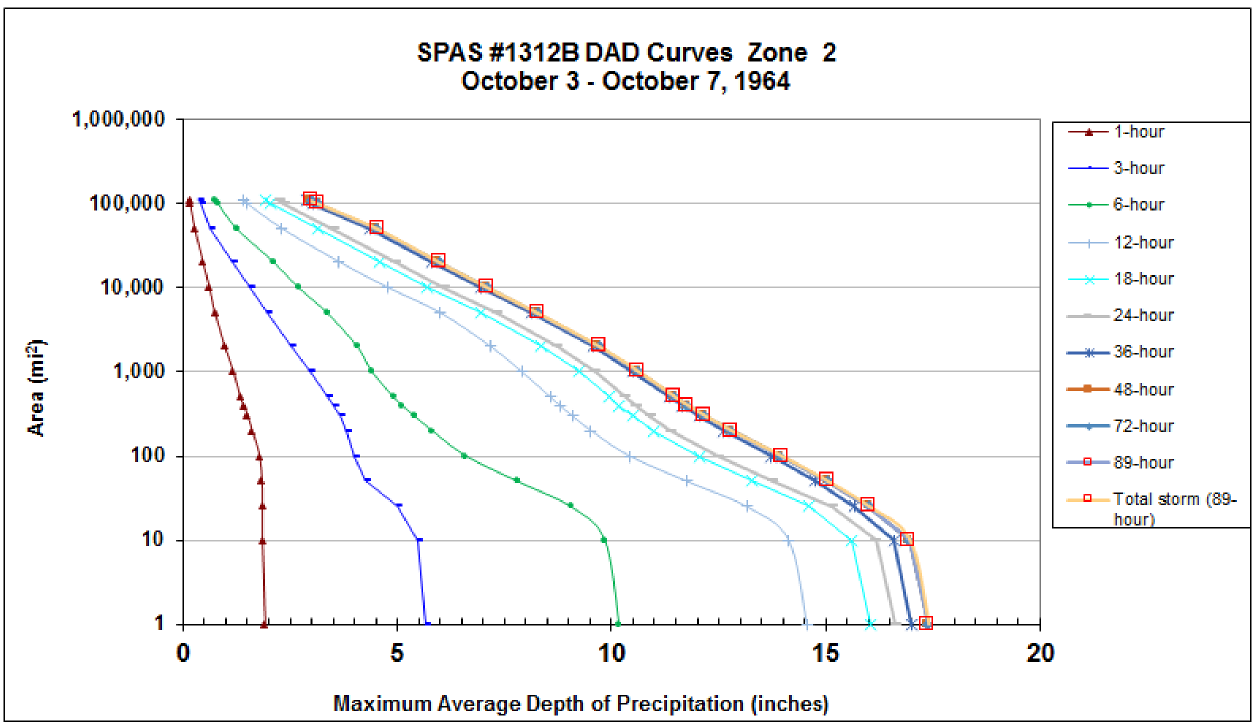
Radar Included: No

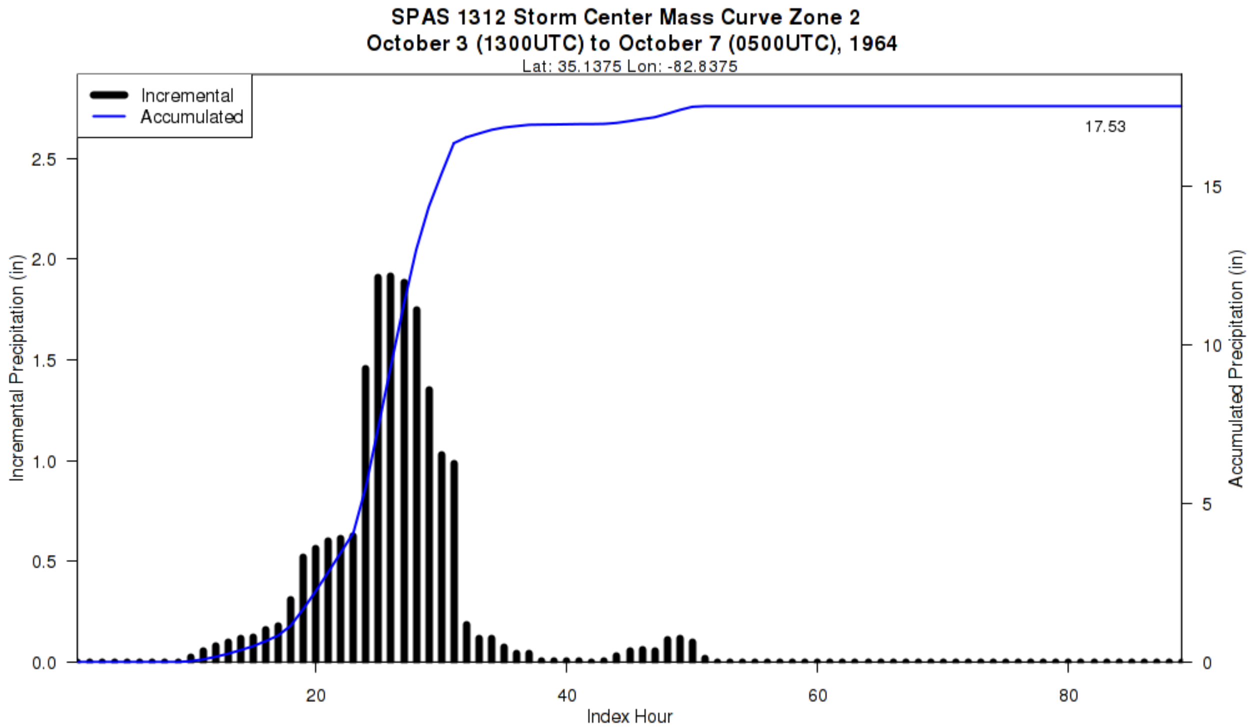
Depth-Area-Duration (DAD) analysis: Yes

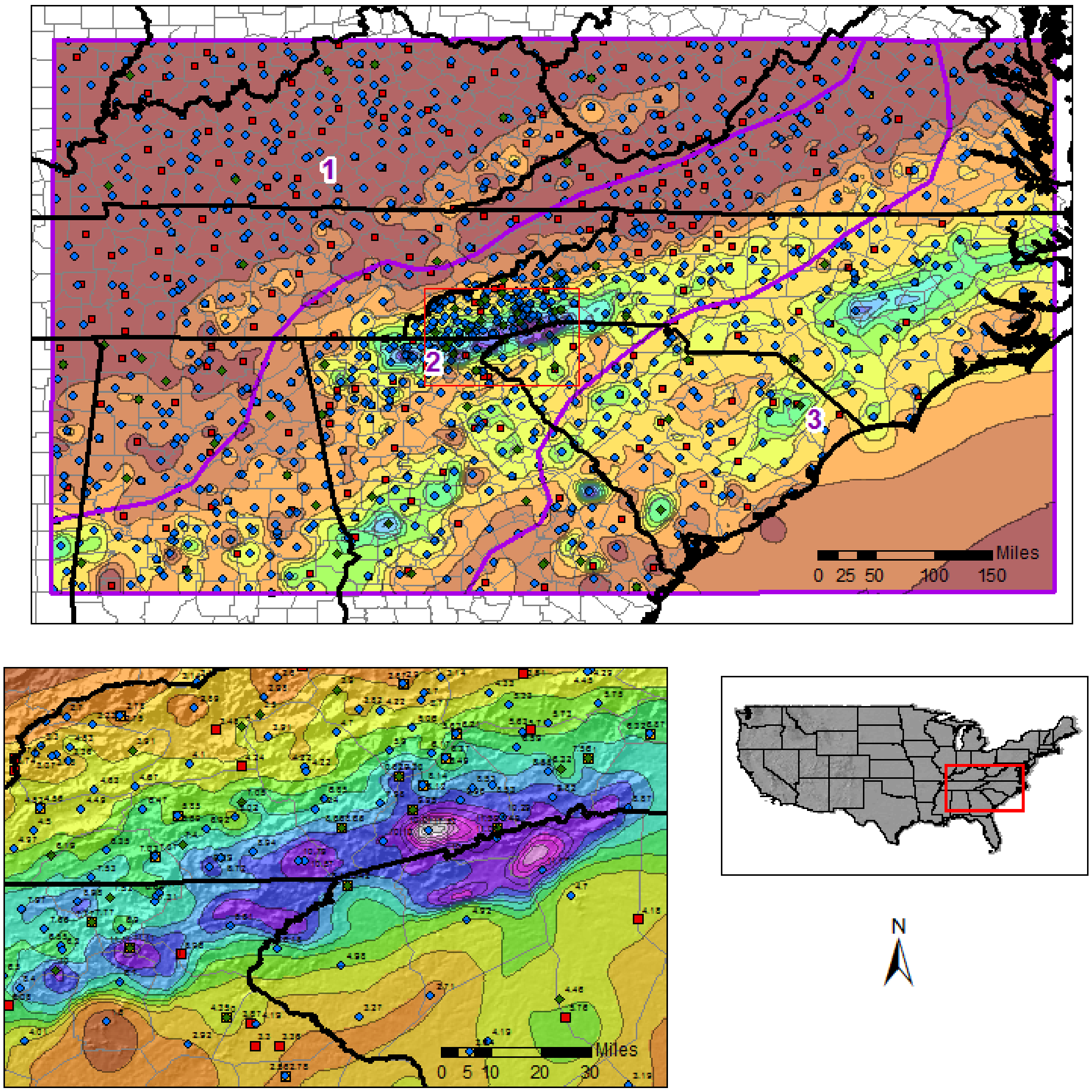
Reliability of Results: In addition to the 314 hourly stations from NCDC used in the whole project area, fourteen additional hourly stations were digitized from the TVA report adding more certainty to the timing of the storm center. The extent and magnitude of the rainfall is moderately reliable given the surprising large number of daily rain gauges available.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1312B_2	-82.8375	35.1375	2,440	20-Sep	75.50	2.92	0.59	73	2.335	77.73	3.22	0.62	77	2.595	1.111

Storm 1312B - October 3 (1300 UTC) - October 7 (0500 UTC), 1964											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	3	6	12	18	24	36	48	72	89	Total
0.4	1.91	5.69	10.24	14.65	16.13	16.73	17.10	17.48	17.48	17.49	17.49
1	1.90	5.65	10.17	14.56	16.03	16.63	17.00	17.39	17.39	17.39	17.39
10	1.84	5.47	9.84	14.14	15.59	16.17	16.59	16.95	16.95	16.95	16.95
25	1.84	5.01	9.05	13.16	14.60	15.15	15.66	16.00	16.00	16.00	16.00
50	1.83	4.26	7.80	11.76	13.26	13.76	14.77	15.04	15.04	15.04	15.04
100	1.77	4.01	6.60	10.42	12.05	12.49	13.73	13.95	13.95	13.96	13.96
200	1.60	3.81	5.81	9.52	10.97	11.37	12.61	12.80	12.80	12.79	12.79
300	1.49	3.65	5.39	9.08	10.50	10.89	12.04	12.18	12.18	12.18	12.18
400	1.40	3.50	5.11	8.79	10.18	10.57	11.65	11.77	11.77	11.77	11.77
500	1.32	3.37	4.91	8.57	9.95	10.33	11.36	11.48	11.48	11.48	11.48
1,000	1.16	2.95	4.41	7.90	9.24	9.62	10.50	10.63	10.63	10.63	10.63
2,000	0.96	2.53	4.06	7.17	8.36	8.74	9.59	9.70	9.71	9.71	9.71
5,000	0.73	1.97	3.36	6.00	6.97	7.33	8.15	8.27	8.27	8.27	8.27
10,000	0.60	1.55	2.69	4.77	5.69	6.10	6.97	7.10	7.11	7.11	7.11
20,000	0.45	1.14	2.11	3.64	4.58	4.96	5.82	5.97	5.98	5.98	5.98
50,000	0.26	0.65	1.25	2.30	3.13	3.51	4.38	4.52	4.53	4.54	4.54
100,000	0.15	0.40	0.81	1.47	2.02	2.36	3.03	3.14	3.14	3.15	3.15
108,165	0.14	0.38	0.75	1.40	1.92	2.25	2.87	2.97	2.98	2.98	2.98




SPAS 1312 Storm Center Mass Curve Zone 2
October 3 (1300UTC) to October 7 (0500UTC), 1964
Lat: 35.1375 Lon: -82.8375
Incremental
Accumulated
17.53
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
40
60
80



Total 89-hour Precipitation (inches)
October 3, 1964 1300 UTC - October 7, 1964 0500 UTC
SPAS #1312B

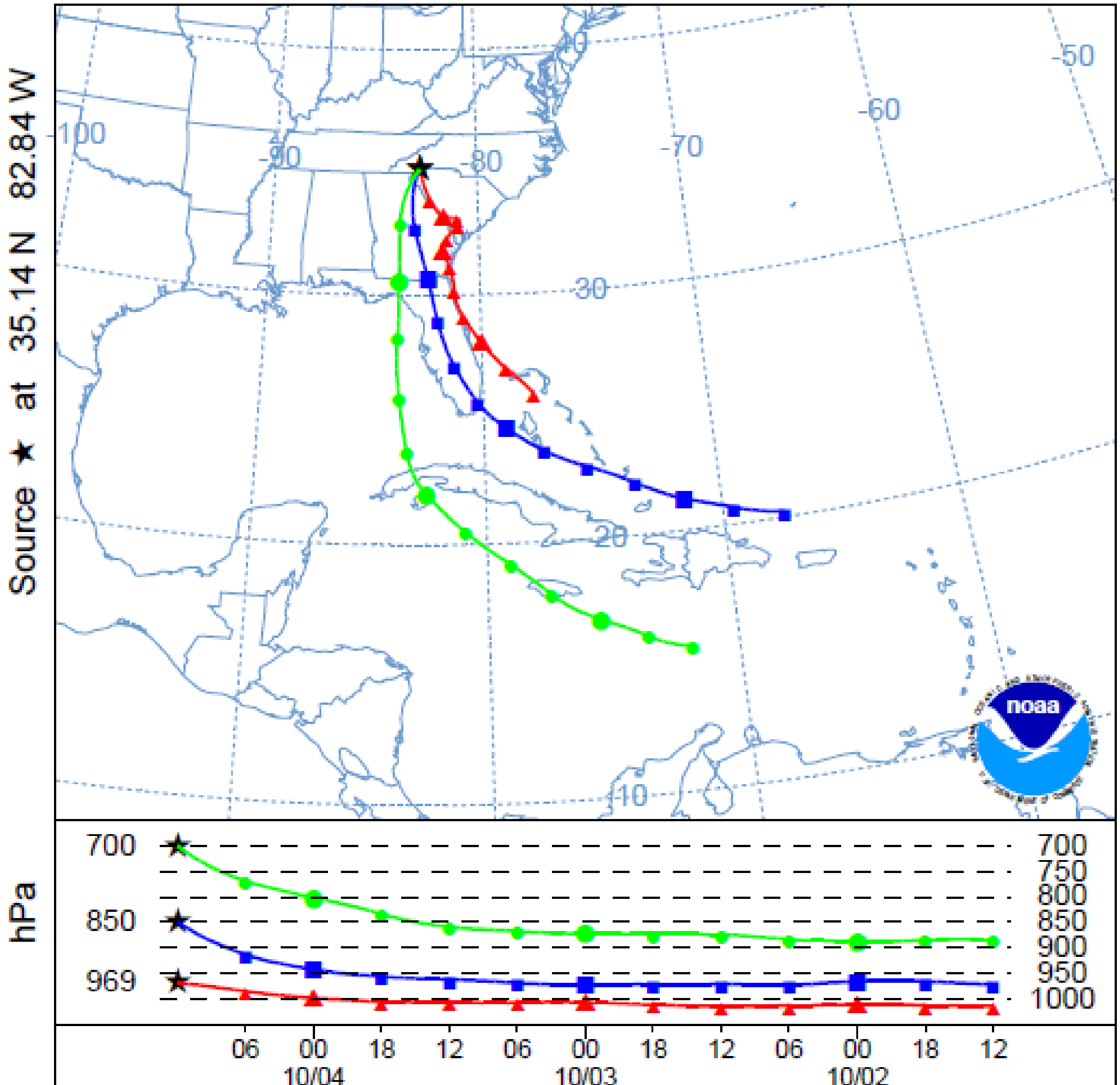
Precipitation (inches)

0.00 - 1.00	3.01 - 4.00	6.01 - 7.00	9.01 - 10.00	14.01 - 16.00
1.01 - 2.00	4.01 - 5.00	7.01 - 8.00	10.01 - 12.00	16.01 - 18.00
2.01 - 3.00	5.01 - 6.00	8.01 - 9.00	12.01 - 14.00	

Stations

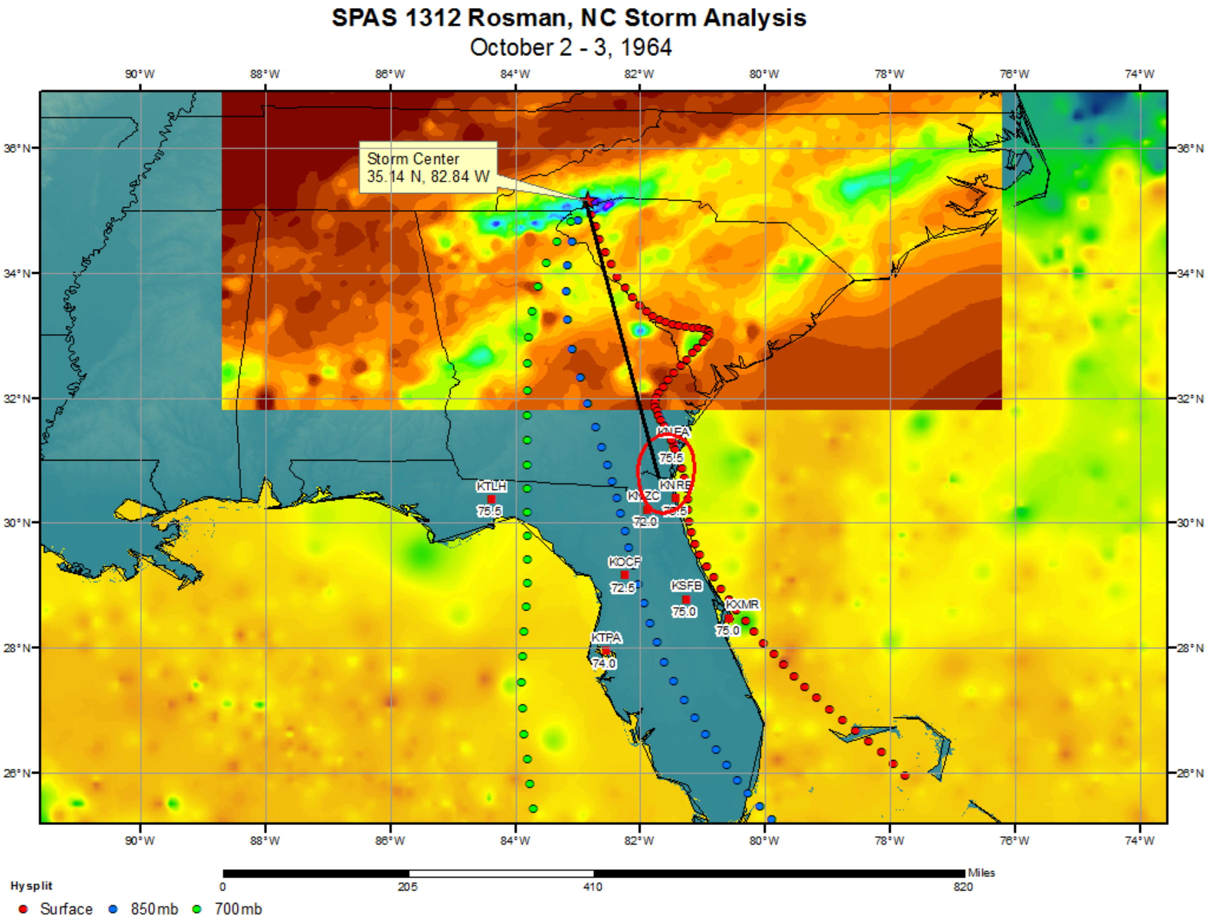
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 04 Oct 64
CDC1 Meteorological Data



Job ID: 155631 Job Start: Wed Feb 19 17:38:19 UTC 2014
Source 1 lat.: 35.14 lon.: -82.84 hgts: 0, 1130, 2770 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Oct 2064 - reanalysis


SPAS 1312 Rosman, NC Storm Analysis
October 2 - 3, 1964
Storm Center
35.14 N, 82.84 W
KTLH
75.5
KNZC
72.0
KNRB
KDCF
72.5
KSFB
75.0
KXMR
75.0
KTPA
74.0
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820

Storm Precipitation Analysis System (SPAS) For Storm #1491_1 SPAS Analysis

General Storm Location: Tyro, VA (Tropical Storm Camille)

Storm Dates: August 18-20, 1969

Event: Tropical Storm Camille

DAD Zone 1

Latitude: 37.8125

Longitude: -79.0042

Max. Grid Rainfall Amount: 27.23"

Max. Observed Rainfall Amount: 27.00"

Number of Stations: 512 (363 Daily, 75 Hourly, 33 Hourly Pseudo, and 41 Supplemental)

SPAS Version: 10.0

Basemap: Blended USGS total storm map and PRISM August 1969 Precipitation

Spatial resolution: 0:00:30 second (~ 0.3 mi^2)

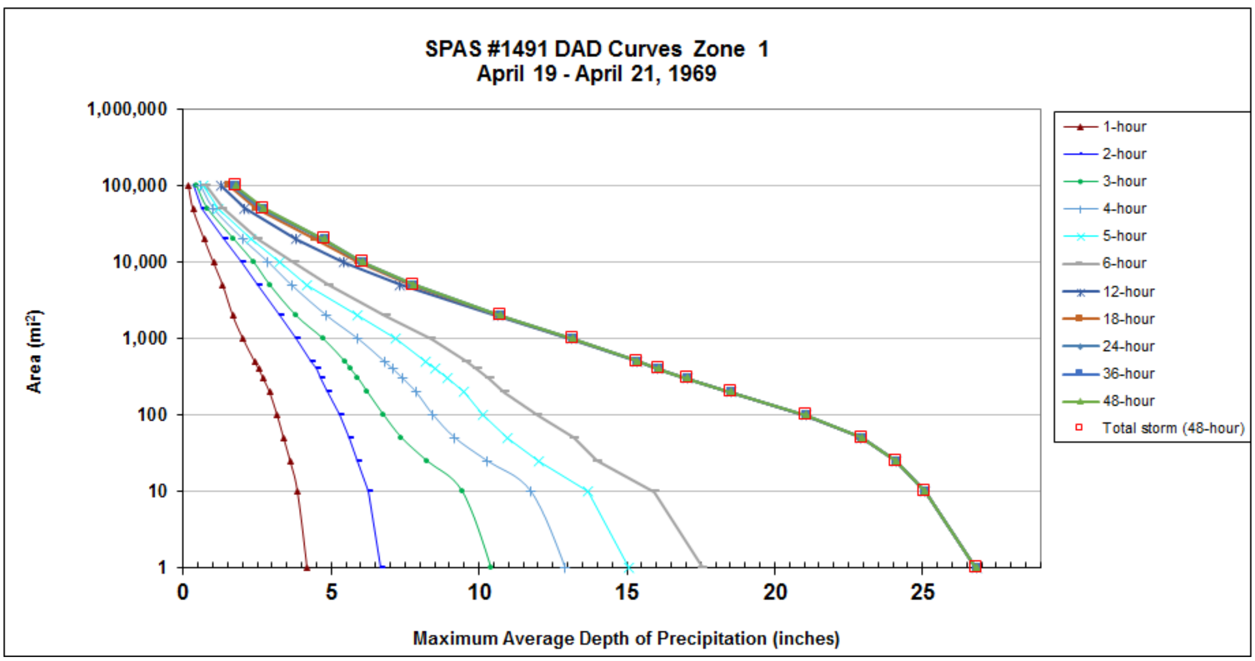
Radar Included: No

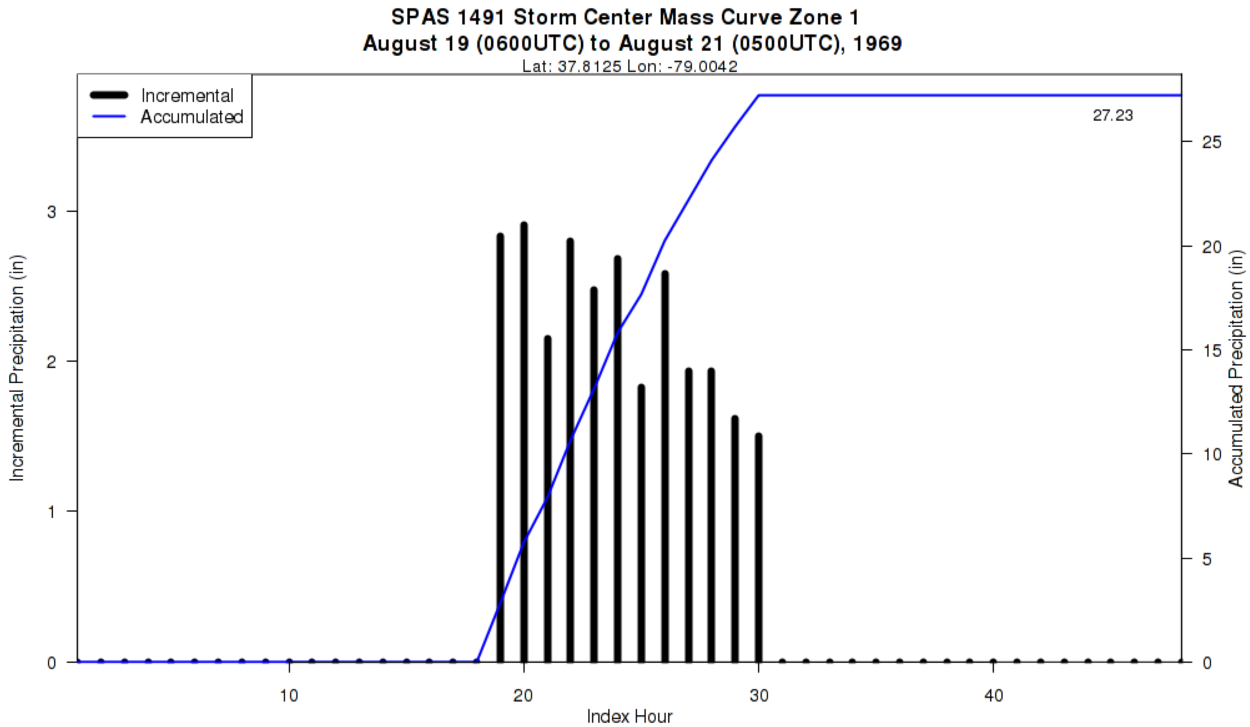
Depth-Area-Duration (DAD) analysis: Yes

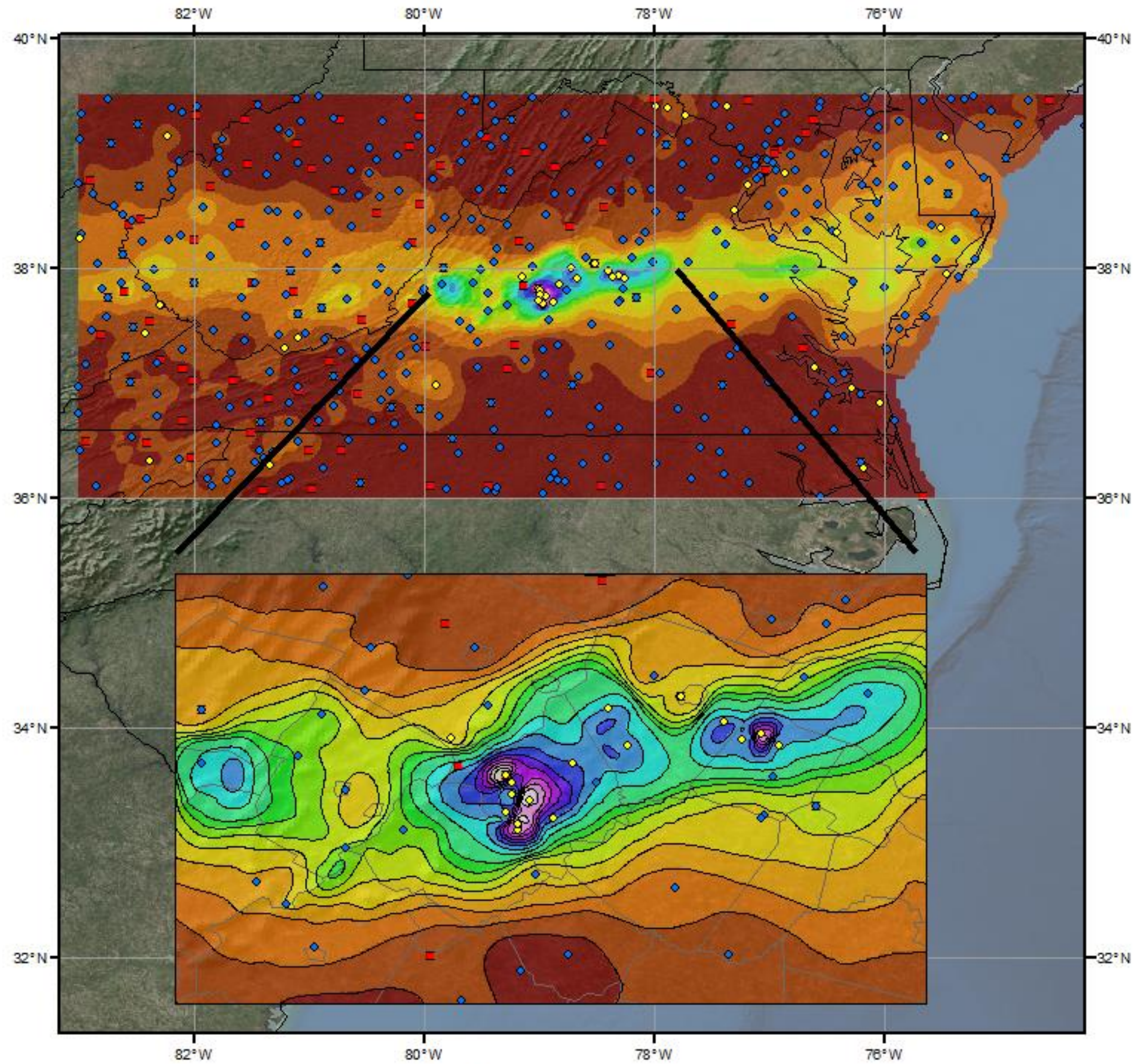
Reliability of results: This analysis was based on hourly data, daily data, supplemental station data and bucket survey data. Hourly station USACE Tyro, VA was digitized from the USACE Storm Studies report. Bucket survey rainfall timing and magnitude at the storm center (Tyro, VA) were diligently recorded and utilized in the SPAS storm analysis. We have a good degree of confidence in the station based storm total results, the spatial pattern is dependent on the station data and the USGS basemap, the timing is based on hourly and hourly pseudo stations. *** Could not match the 22.0" rainfall amount in 6-hours based on the USACE Storm Study report (Listed as Station R, "Tyro, VA").

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1491_1	-79.0042	37.8125	800	5-Aug	77.50	3.22	0.22	77	3.000	79.68	3.52	0.24	81	3.285	1.095

Storm 1491 - August 19 (0600 UTC) - August 21 (0500 UTC), 1969												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
Area (mi²)	Duration (hours)											
	1	2	3	4	5	6	12	18	24	36	48	Total
0.4	4.24	6.74	10.51	13.07	15.22	17.76	27.11	27.11	27.11	27.11	27.11	27.11
1	4.19	6.67	10.39	12.91	15.05	17.57	26.83	26.83	26.83	26.83	26.83	26.83
10	3.87	6.25	9.42	11.75	13.68	15.94	25.09	25.09	25.09	25.09	25.09	25.09
25	3.62	5.91	8.23	10.27	12.02	14.00	24.11	24.11	24.11	24.11	24.11	24.11
50	3.40	5.60	7.38	9.18	10.97	13.21	22.93	22.93	22.93	22.94	22.94	22.94
100	3.18	5.28	6.77	8.44	10.15	11.99	21.05	21.06	21.06	21.07	21.07	21.07
200	2.92	4.88	6.22	7.86	9.47	10.86	18.51	18.52	18.52	18.52	18.52	18.52
300	2.71	4.65	5.91	7.41	8.92	10.34	17.04	17.05	17.05	17.05	17.05	17.05
400	2.55	4.49	5.65	7.08	8.54	9.93	16.05	16.07	16.07	16.08	16.08	16.08
500	2.42	4.33	5.46	6.79	8.20	9.57	15.33	15.35	15.36	15.36	15.36	15.36
1,000	2.02	3.82	4.72	5.89	7.18	8.38	13.13	13.17	13.17	13.18	13.18	13.18
2,000	1.68	3.26	3.81	4.83	5.88	6.84	10.63	10.69	10.72	10.74	10.74	10.74
5,000	1.34	2.54	2.93	3.65	4.18	4.90	7.34	7.67	7.74	7.78	7.78	7.78
10,000	1.02	1.98	2.38	2.86	3.26	3.75	5.44	5.94	6.03	6.09	6.09	6.09
20,000	0.71	1.38	1.71	2.00	2.29	2.53	3.83	4.47	4.70	4.76	4.77	4.77
50,000	0.33	0.63	0.83	1.01	1.20	1.34	2.06	2.47	2.60	2.70	2.72	2.72
100,000	0.18	0.35	0.45	0.57	0.67	0.77	1.28	1.57	1.65	1.75	1.76	1.76




SPAS 1491 Storm Center Mass Curve Zone 1
August 19 (0600UTC) to August 21 (0500UTC), 1969
Lat: 37.8125 Lon: -79.0042
Incremental
Accumulated
27.23
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
0
5
10
15
20
25
10
20
30
40



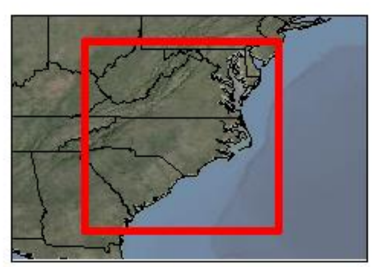
Total Storm (48-hr) Precipitation (inches)
08/19/1969 0600 UTC - 08/21/1969 0500 UTC
SPAS- #1491

Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 45, 90, 180
Kilometers: 0, 105, 210, 420

Precipitation (inches)

0.00 - 1.00	4.01 - 5.00	8.01 - 10.00	16.01 - 18.00	24.01 - 28.00
1.01 - 2.00	5.01 - 6.00	10.01 - 12.00	18.01 - 20.00	
2.01 - 3.00	6.01 - 7.00	12.01 - 14.00	20.01 - 22.00	
3.01 - 4.00	7.01 - 8.00	14.01 - 16.00	22.01 - 24.00	



3/31/2015

WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – PERTINENT DATA SHEET

Storm of 19-20 August 1969

Assignment NA 2-23

Location W. Va., Va., Md., & Del.

Study Prepared by:
North Atlantic Division
Norfolk District Office

Part I Reviewed by Hydromet. Sec. of Weather Bureau 10/22/70

Part II Approved by Office, Chief of Engineers for distribution of factual data, 5-8-73

Remarks Center near Tyro, Va.
Dewpoint 76° - Ref. Pt. 150
South
Grid

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet scale 1:500,000

Precipitation data and mass curves: (Number of Sheets)

Form 5001-C (Hourly precip. data)	–
Form 5001-B (24-hour " ")	–
Form 5001-D (" " " ")	11
Miscl. precip. records, meteorological data, etc.	11
Form 5002 (Mass rainfall curves)	30

PART II

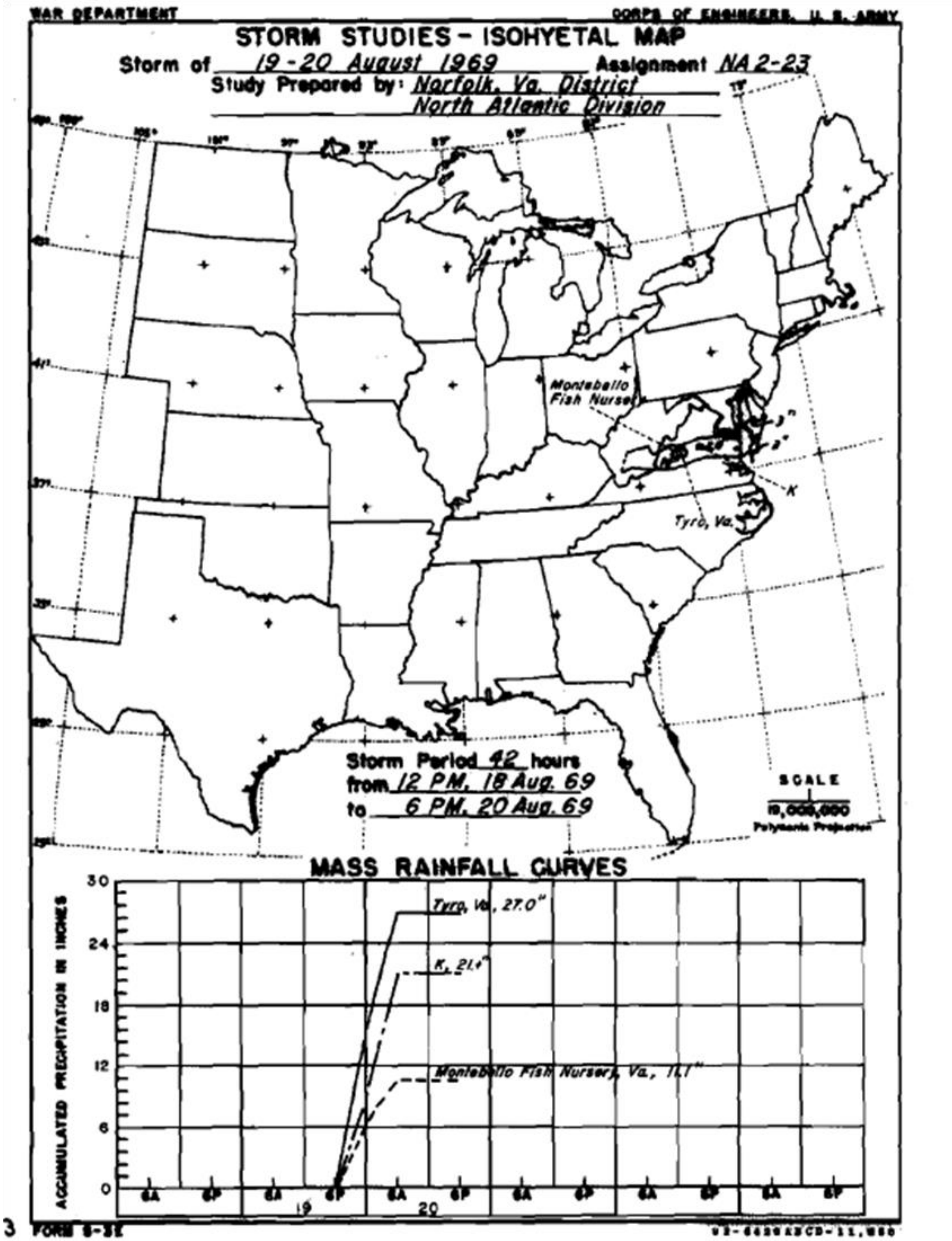
Final isohyetal maps, in 1 sheet scale 1:500,000

Data and computation sheets:

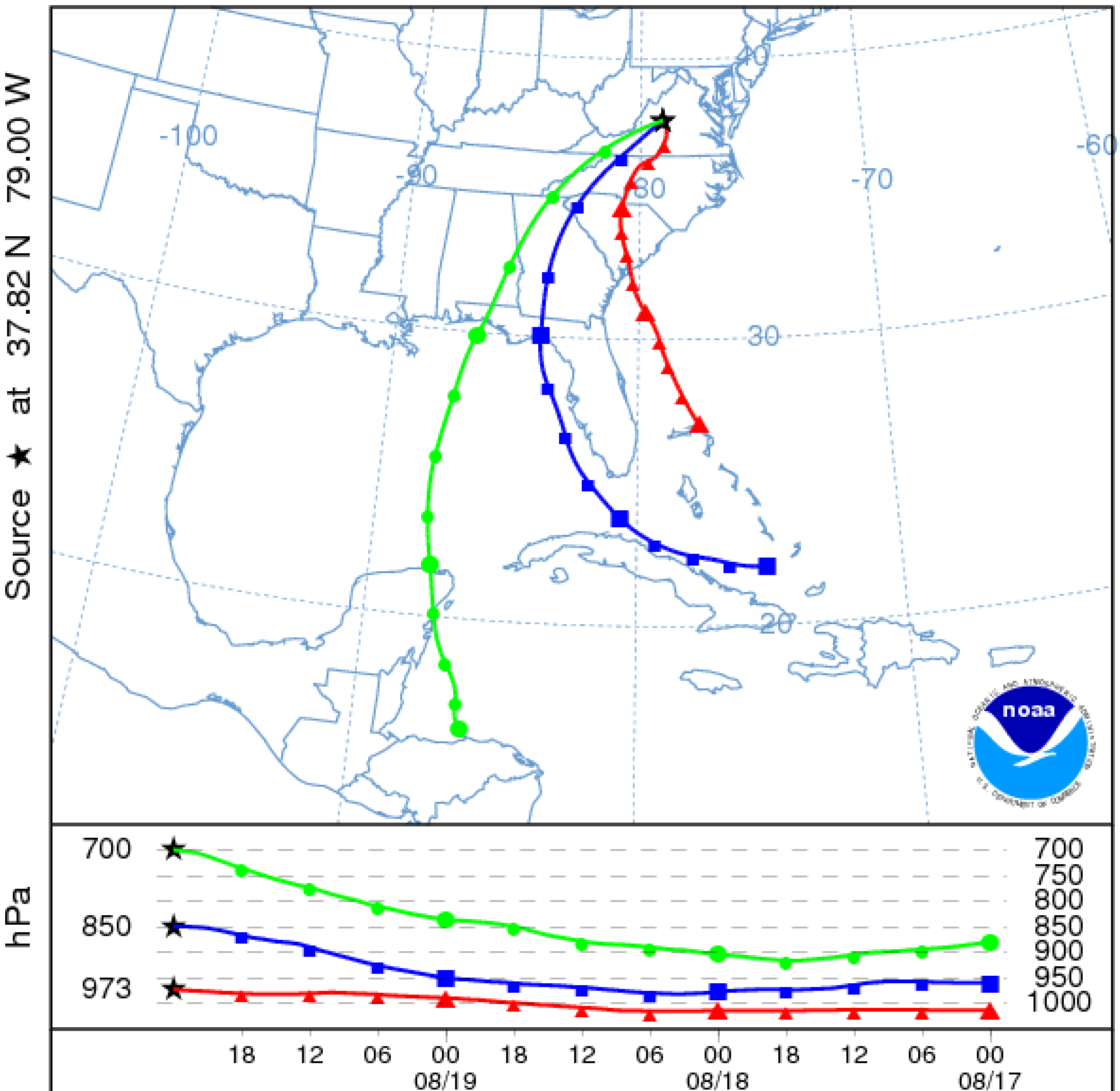
Form S-10 (Data from mass rainfall curves)	5
Form S-11 (Depth-area data from isohyetal map)	1
Form S-12 (Maximum depth-duration data)	16
Maximum duration-depth-area curves	1
Data relating to periods of maximum rainfall	3

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Miles	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	72	96	120
Max. Station	22.0	27.0	27.0	27.0	27.0	27.0	27.0				
10	14.2	25.4	25.4	25.4	25.4	25.4	25.4				
50	13.5	23.2	23.2	23.2	23.2	23.2	23.2				
100	12.9	21.7	21.7	21.7	21.7	21.7	21.7				
200	11.7	19.6	19.6	19.6	19.6	19.6	19.6				
500	9.8	16.3	16.3	16.3	16.3	16.3	16.3				
1,000	8.1	13.5	13.5	13.5	13.5	13.5	13.5				
2,000	6.3	10.7	10.9	10.9	10.9	10.9	10.9				
5,000	4.4	7.5	8.0	8.0	8.0	8.0	8.0				
10,000	3.3	5.8	6.3	6.3	6.3	6.3	6.3				
15,000	2.8	4.9	5.3	5.3	5.3	5.3	5.3				

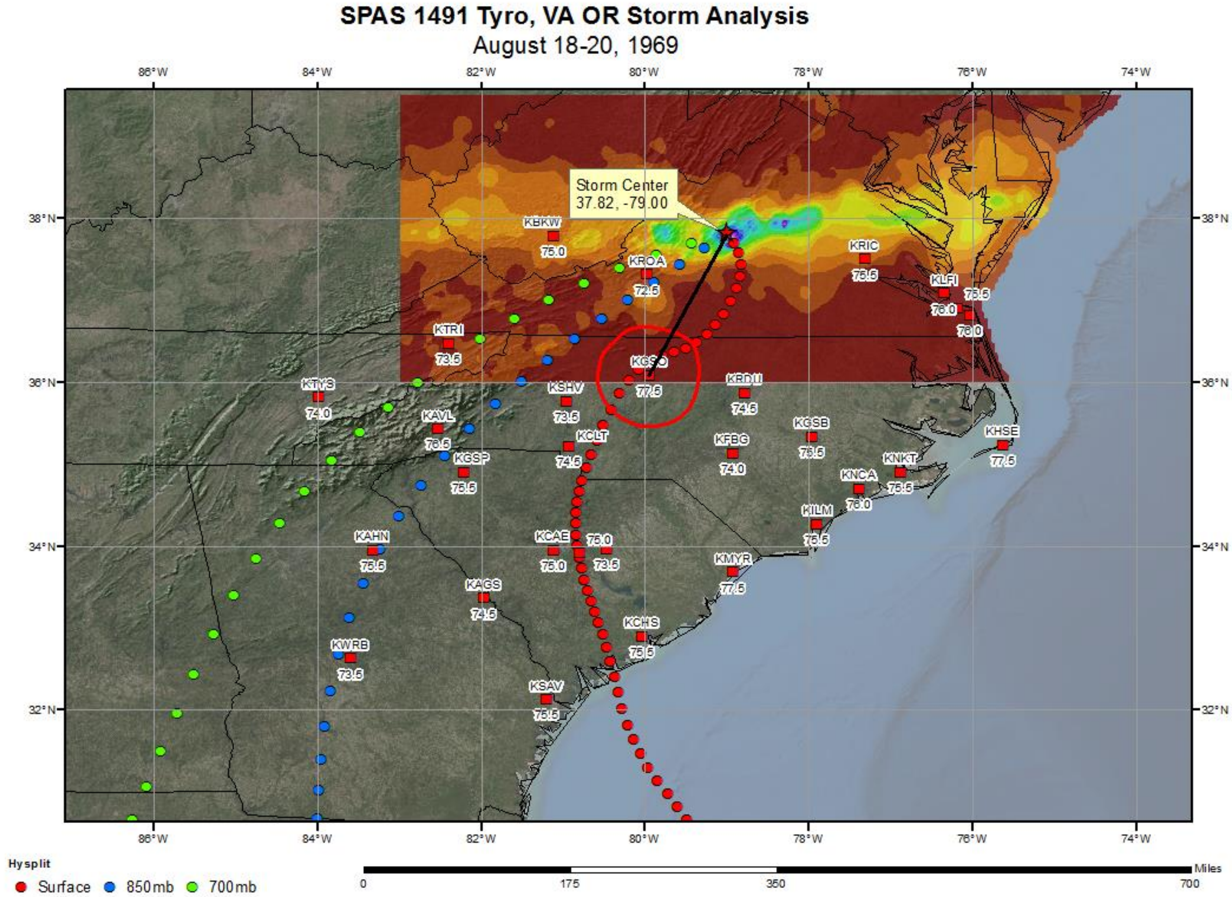

WAR DEPARTMENT
CORPS OF ENGINEERS, U. S. ARMY
STORM STUDIES - ISOHYETAL MAP
Storm of 19-20 August 1969 Assignment NA 2-23
Study Prepared by: Norfolk, Va. District
North Atlantic Division
Montebello Fish Nursery
Tyro, Va.
K
Storm Period 42 hours
from 12 PM, 18 Aug. 69
to 6 PM, 20 Aug. 69
SCALE
1/10,000,000
Polyconic Projection
MASS RAINFALL CURVES
ACCUMULATED PRECIPITATION IN INCHES
30
24
18
12
6
0
Tyro, Va., 27.0"
K, 21.+"
Montebello Fish Nursery, Va., 11.1"
6A
6P
19
20
FORM 5-32

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 20 Aug 69
CDC1 Meteorological Data



Job ID: 159838 Job Start: Tue Mar 31 20:06:59 UTC 2015
Source 1 lat.: 37.820000 lon.: -79.000000 hgts: 0, 1175, 2810 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Aug 2069 - reanalysis


SPAS 1491 Tyro, VA OR Storm Analysis
August 18-20, 1969
Storm Center
37.82, -79.00
Hysplit
Surface
850mb
700mb
Miles
0
175
350
700

Storm Precipitation Analysis System (SPAS) For Storm #1276_1 SPAS Analysis

General Storm Location: Pennsylvania, New York

Storm Dates: June 18-24, 1972

Event: Hurricane Agnes

DAD Zone 1

Latitude: 42.0375

Longitude: -78.0708

Max. Grid Rainfall Amount: 18.78"

Max. Observed Rainfall Amount: 18.13"

Number of Stations: 1272 (874 Daily, 173 Hourly, 51 Hourly Pseudo, and 174 Supplemental)

SPAS Version: 9.5

Basemap: PRISM 30-yr Mean (1971-2000) June Precipitation

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

Radar Included: No

Depth-Area-Duration (DAD) analysis: Yes

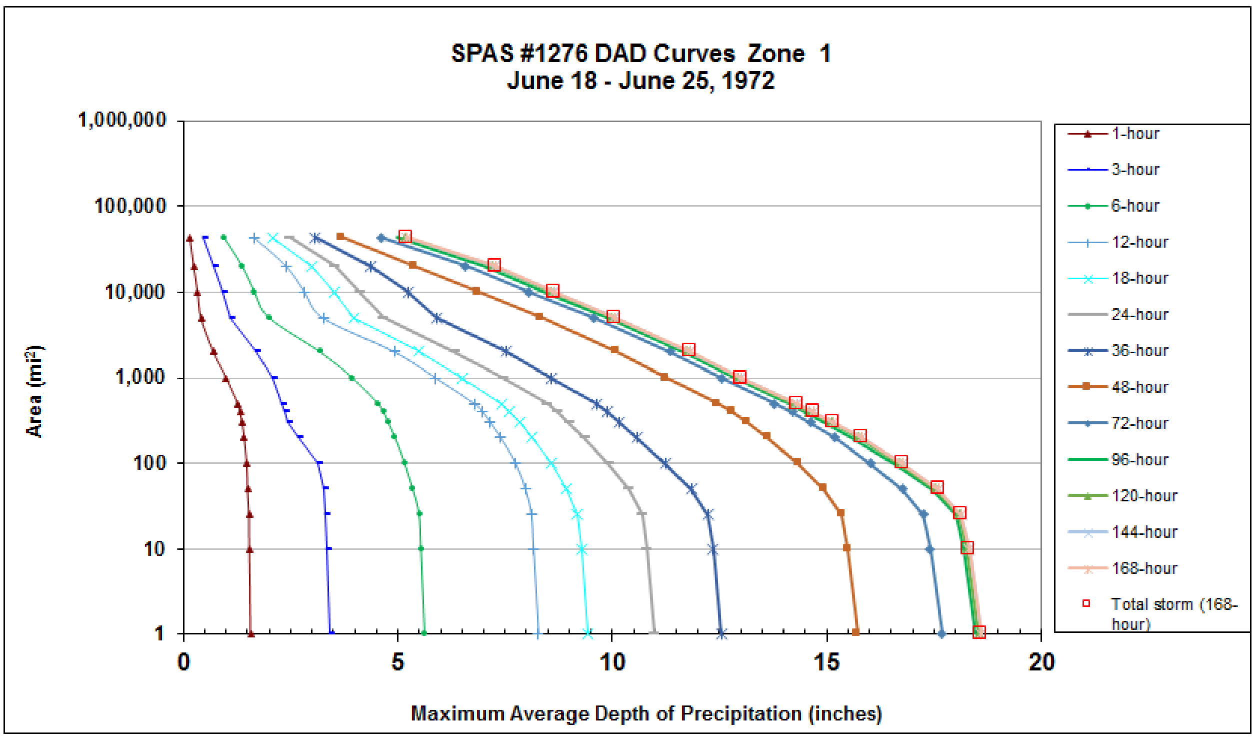
Reliability of results: This analysis was based on hourly data, daily data, supplemental station data and bucket survey data from the USGS report. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations.

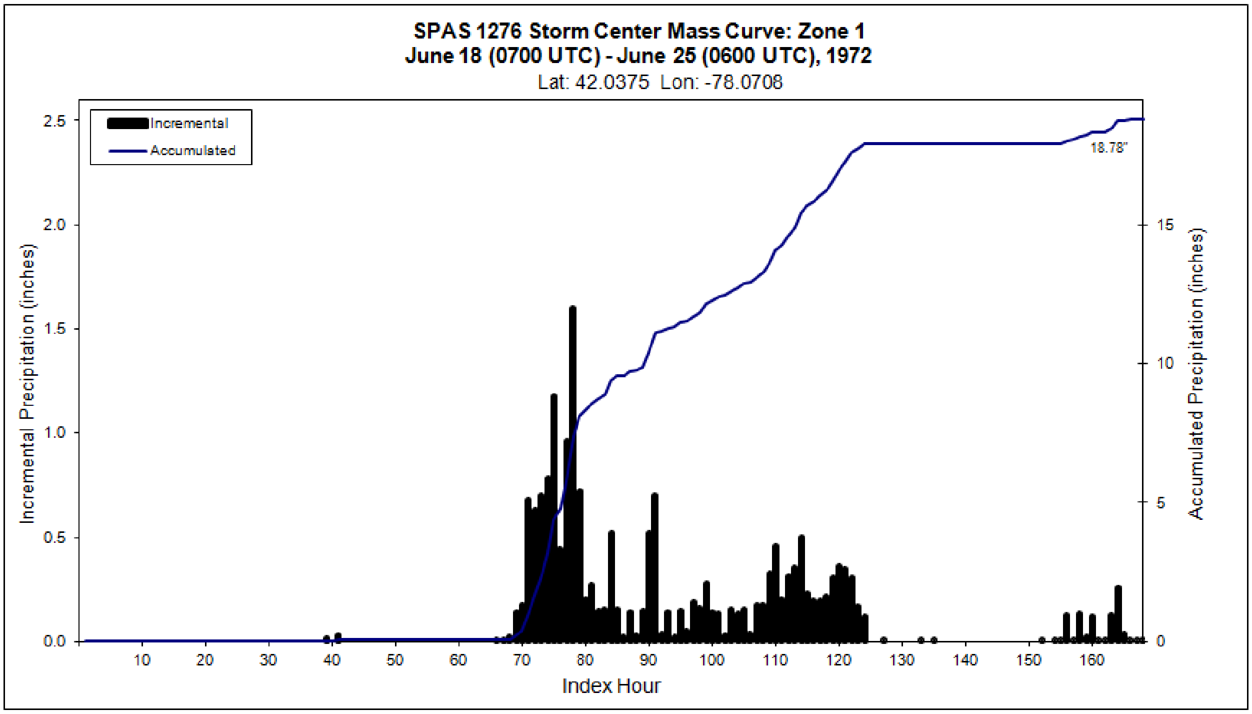
							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1276_1	-78.0708	42.0375	2,398	2,400	5-Jul	72.50	2.54	0.53	67	2.005	80.25	80.5	3.68	0.69	83	2.990	1.491

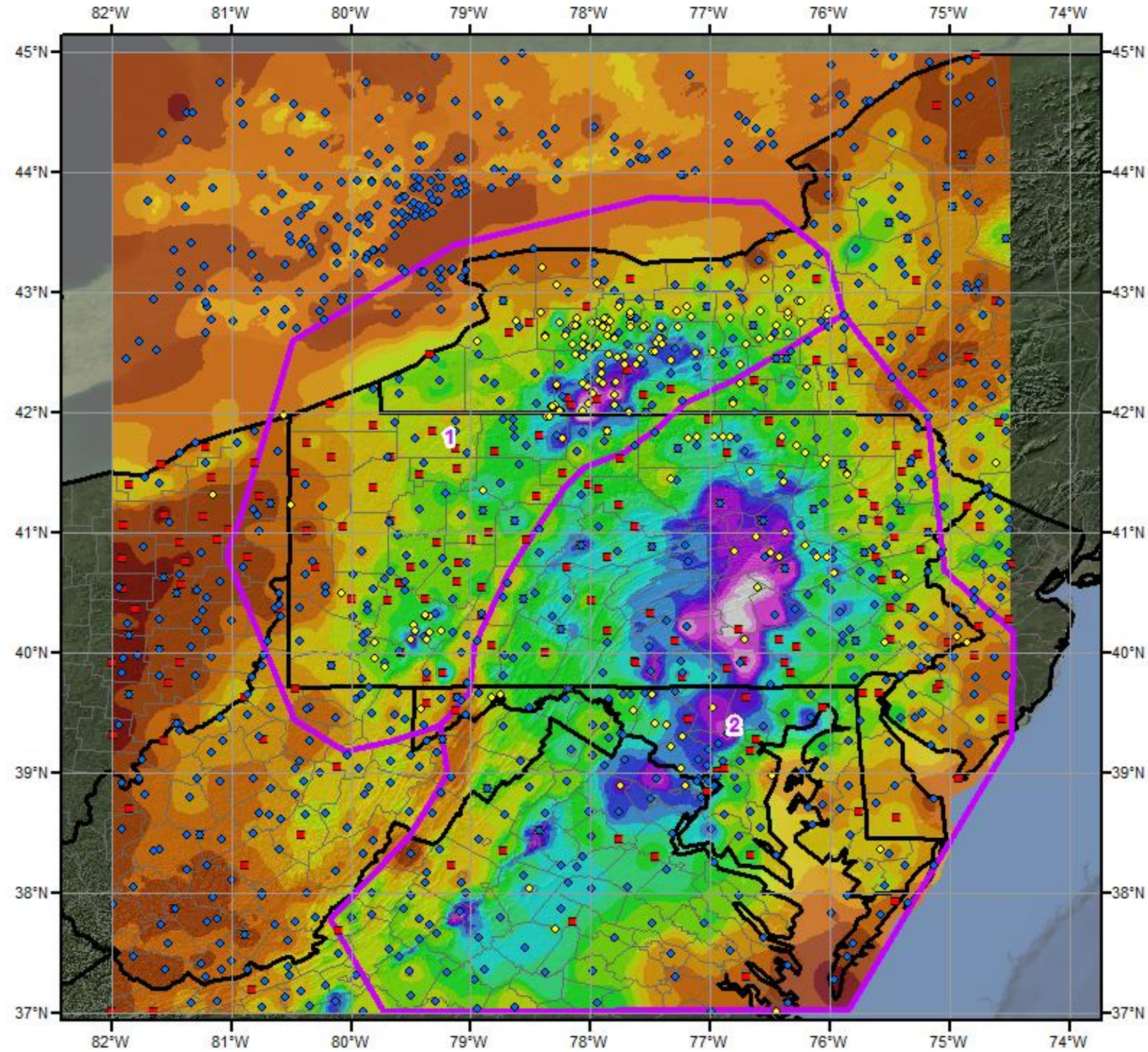
Storm 1276- June 18 (0700 UTC) - June 25 (0600 UTC), 1972

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

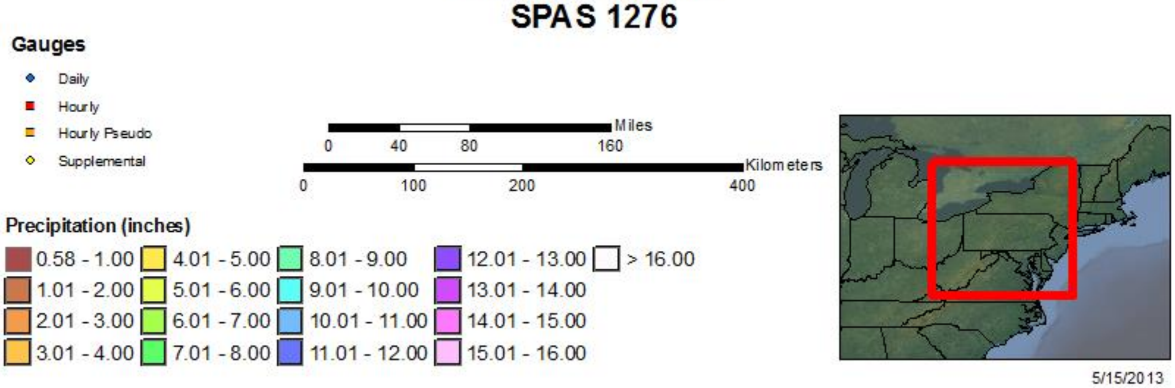
Area (mi²)	Duration (hours)													
	1	3	6	12	18	24	36	48	72	96	120	144	168	Total
0.4	1.60	3.44	5.68	8.33	9.47	11.04	12.63	15.83	17.80	18.59	18.67	18.72	18.72	18.72
1	1.58	3.41	5.64	8.28	9.42	10.98	12.55	15.73	17.69	18.48	18.55	18.61	18.61	18.61
10	1.55	3.35	5.55	8.16	9.28	10.81	12.36	15.49	17.42	18.19	18.27	18.33	18.33	18.33
25	1.54	3.32	5.51	8.11	9.18	10.70	12.23	15.36	17.26	18.01	18.09	18.13	18.13	18.13
50	1.51	3.27	5.36	7.97	8.95	10.39	11.85	14.94	16.76	17.44	17.54	17.60	17.60	17.60
100	1.49	3.13	5.17	7.74	8.57	9.91	11.24	14.34	16.03	16.56	16.69	16.76	16.76	16.76
200	1.43	2.69	4.94	7.39	8.12	9.34	10.58	13.63	15.19	15.60	15.76	15.83	15.83	15.83
300	1.38	2.44	4.78	7.15	7.83	8.99	10.17	13.16	14.61	14.97	15.11	15.17	15.17	15.17
400	1.33	2.36	4.67	6.97	7.61	8.73	9.89	12.80	14.19	14.52	14.60	14.69	14.69	14.69
500	1.28	2.31	4.54	6.78	7.41	8.49	9.62	12.46	13.80	14.12	14.19	14.29	14.30	14.30
1,000	1.01	2.07	3.95	5.88	6.50	7.45	8.57	11.26	12.55	12.84	12.95	12.99	13.00	13.00
2,000	0.71	1.69	3.19	4.92	5.50	6.32	7.54	10.10	11.35	11.65	11.76	11.81	11.82	11.82
5,000	0.42	1.10	2.00	3.26	3.99	4.66	5.91	8.35	9.56	9.85	10.00	10.03	10.05	10.05
10,000	0.34	0.91	1.66	2.83	3.52	4.11	5.23	6.87	8.04	8.40	8.58	8.62	8.64	8.64
20,000	0.25	0.72	1.37	2.40	3.00	3.53	4.35	5.37	6.59	7.00	7.21	7.24	7.27	7.27
43,043	0.16	0.48	0.95	1.67	2.08	2.48	3.07	3.70	4.60	4.99	5.17	5.20	5.22	5.22

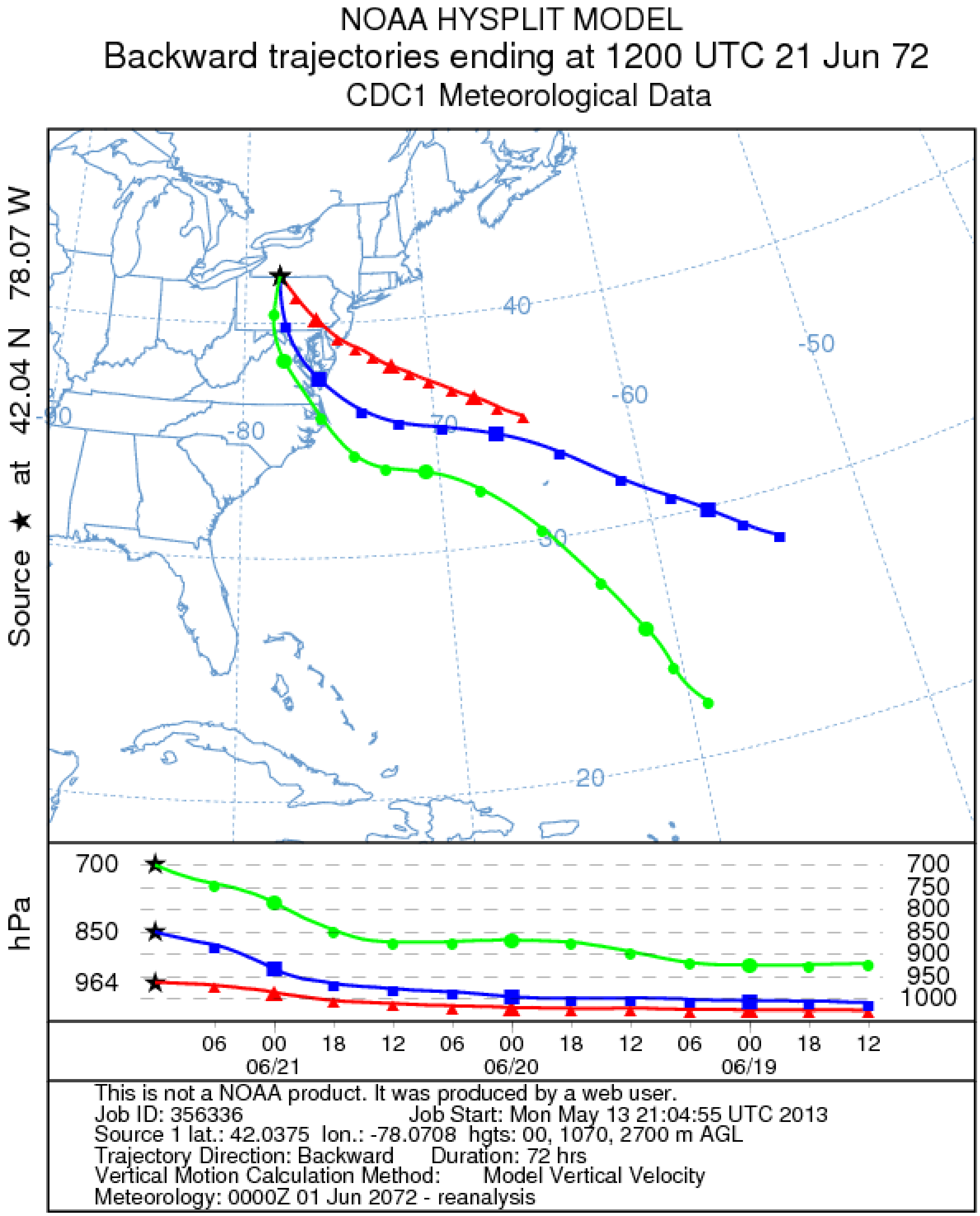



SPAS 1276 Storm Center Mass Curve: Zone 1
June 18 (0700 UTC) - June 25 (0600 UTC), 1972
Lat: 42.0375 Lon: -78.0708
Incremental
Accumulated
18.78"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

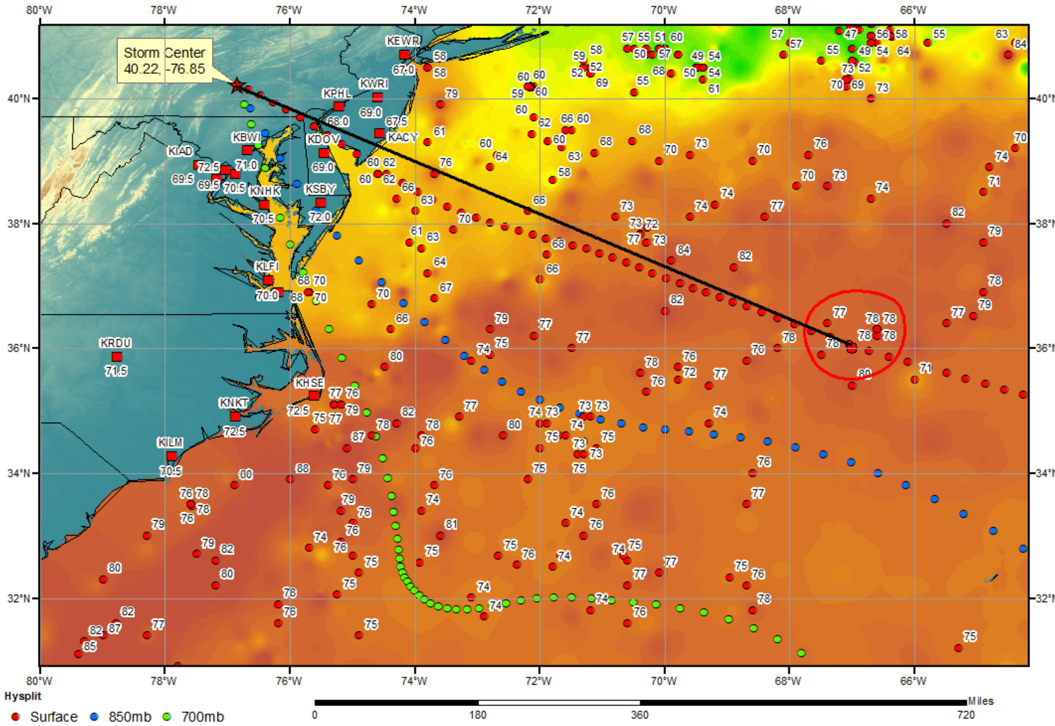


Total Storm (168-hr) Precipitation (inches)
June 18-24, 1972
SPAS 1276

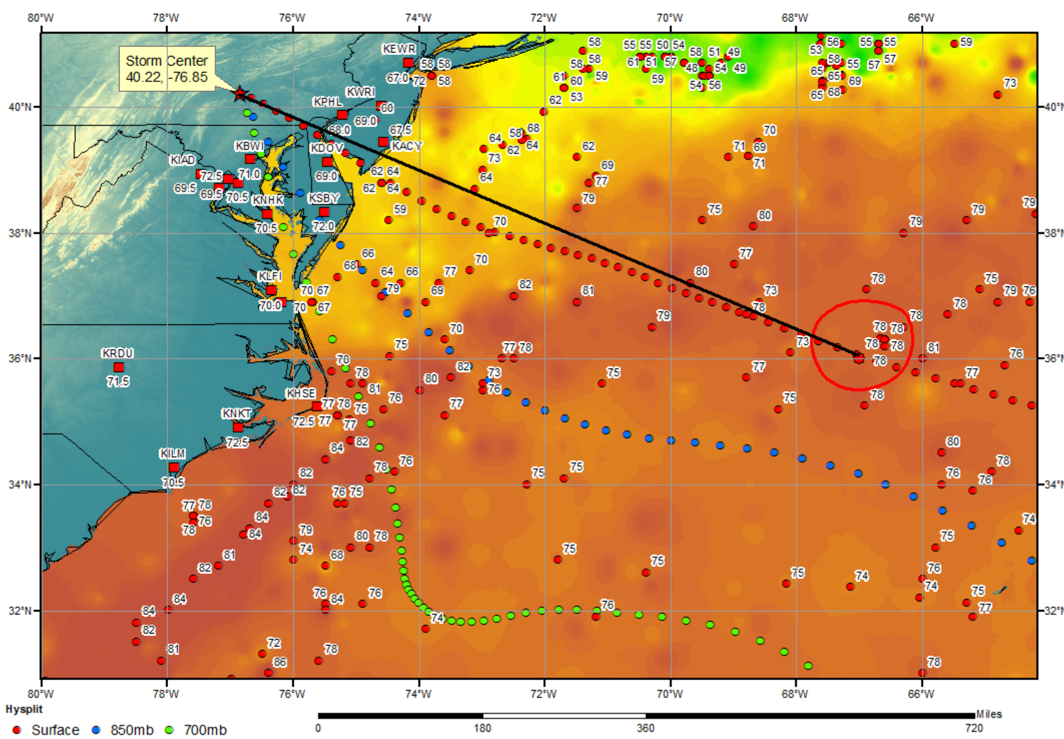


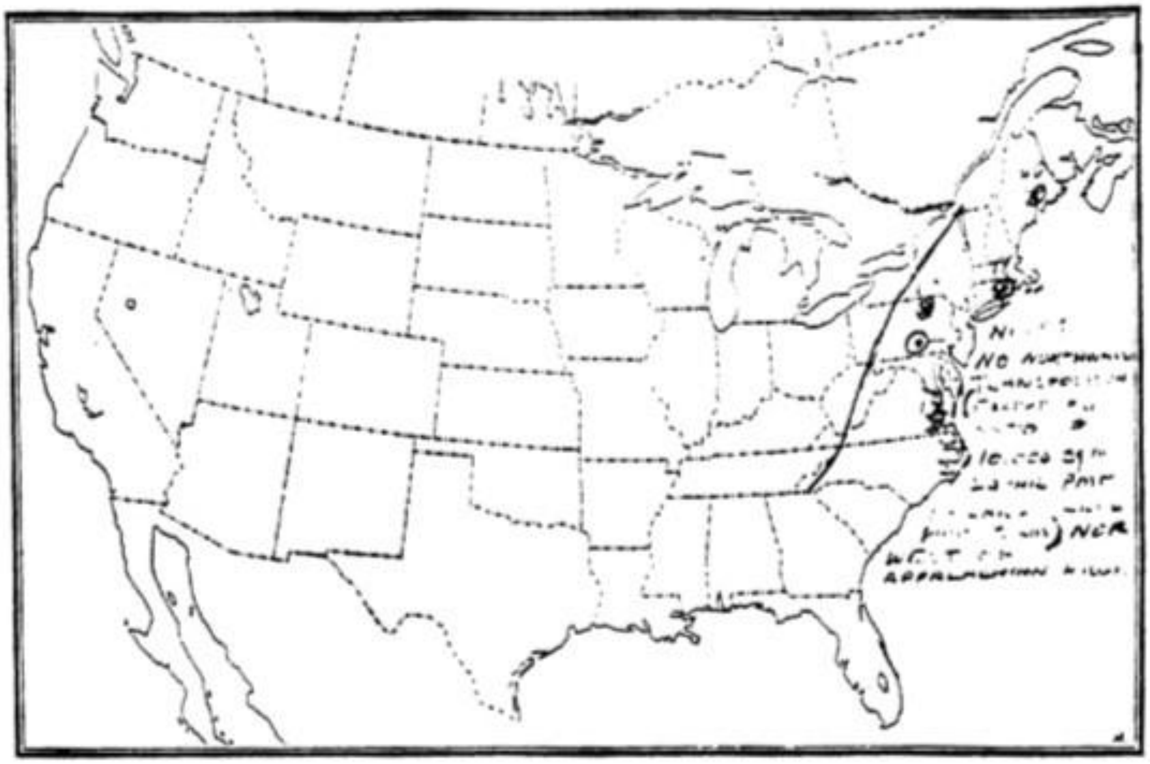

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 21 Jun 72
CDC1 Meteorological Data
Source ★ at 42.04 N 78.07 W
40
-50
-60
-90
-80
70
30
20
hPa
700
850
964
700
750
800
850
900
950
1000
06 00 18 12 06 00 18 12 06 00 18 12
06/21
06/20
06/19
This is not a NOAA product. It was produced by a web user.
Job ID: 356336 Job Start: Mon May 13 21:04:55 UTC 2013
Source 1 lat.: 42.0375 lon.: -78.0708 hgts: 00, 1070, 2700 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Jun 2072 - reanalysis

USACE NA 2-24A Zerbe, PA Storm Analysis
June 18, 1972



USACE NA 2-24A Zerbe, PA Storm Analysis
June 19, 1972




NO
NCR
APPALACHIAN

Storm Precipitation Analysis System (SPAS) For Storm #1276_2 SPAS Analysis

General Storm Location: Zerbe, Pennsylvania

Storm Dates: June 18-24, 1972

Event: Hurricane Agnes

DAD Zone 2

Latitude: 40.5375

Longitude: -76.6208

Max. Grid Rainfall Amount: 18.79"

Max. Observed Rainfall Amount: 18.50"

Number of Stations: 1272 (874 Daily, 173 Hourly, 51 Hourly Pseudo, and 174 Supplemental)

SPAS Version: 9.5

Basemap: PRISM 30-yr Mean (1971-2000) June Precipitation

Spatial resolution: 00:00:30 (~ 0.30 mi^2)

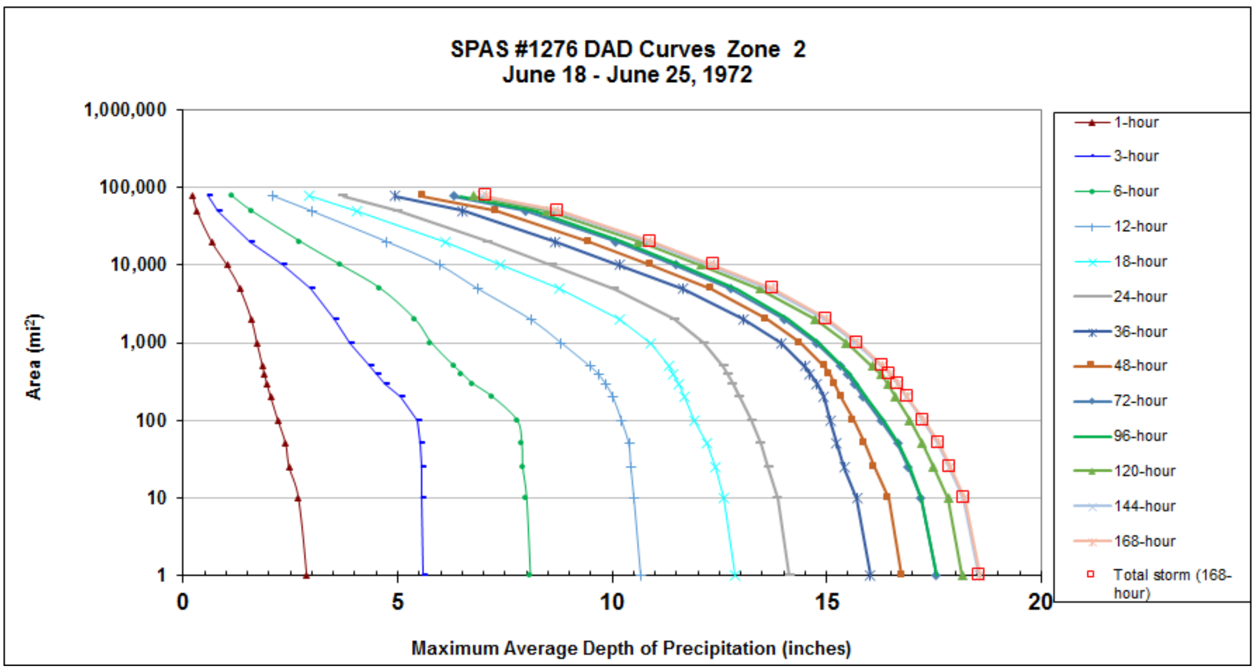
Radar Included: No

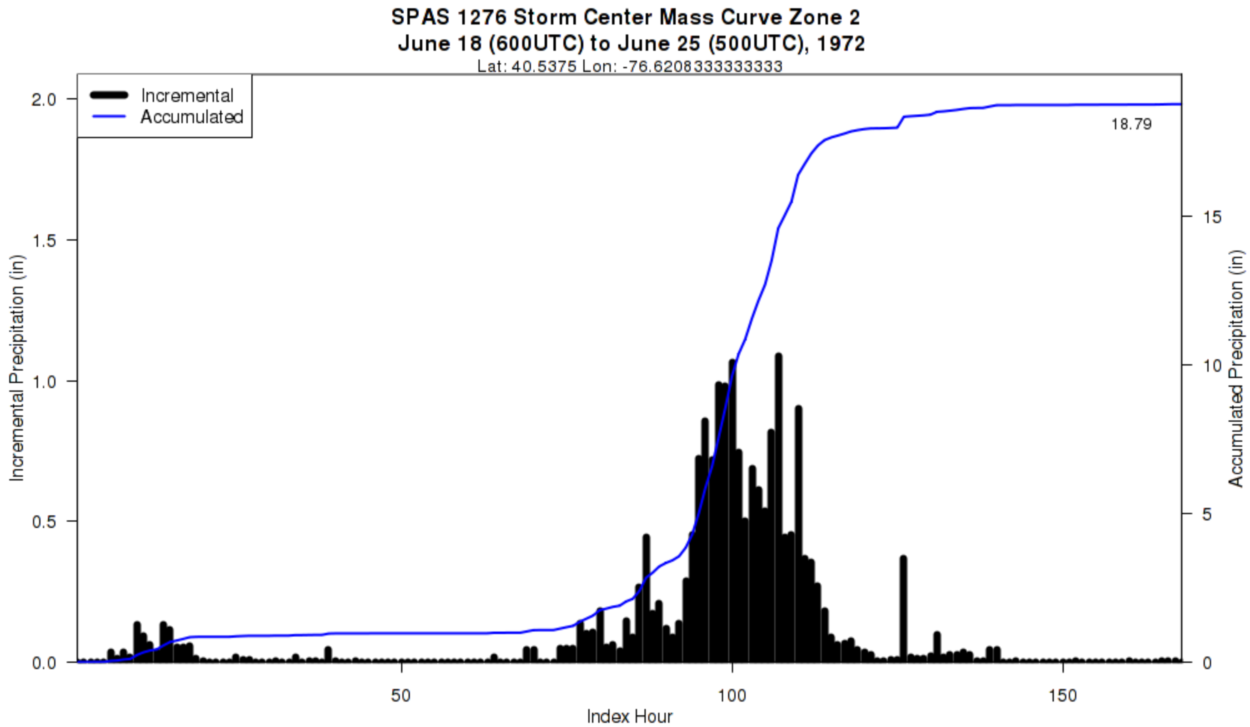
Depth-Area-Duration (DAD) analysis: Yes

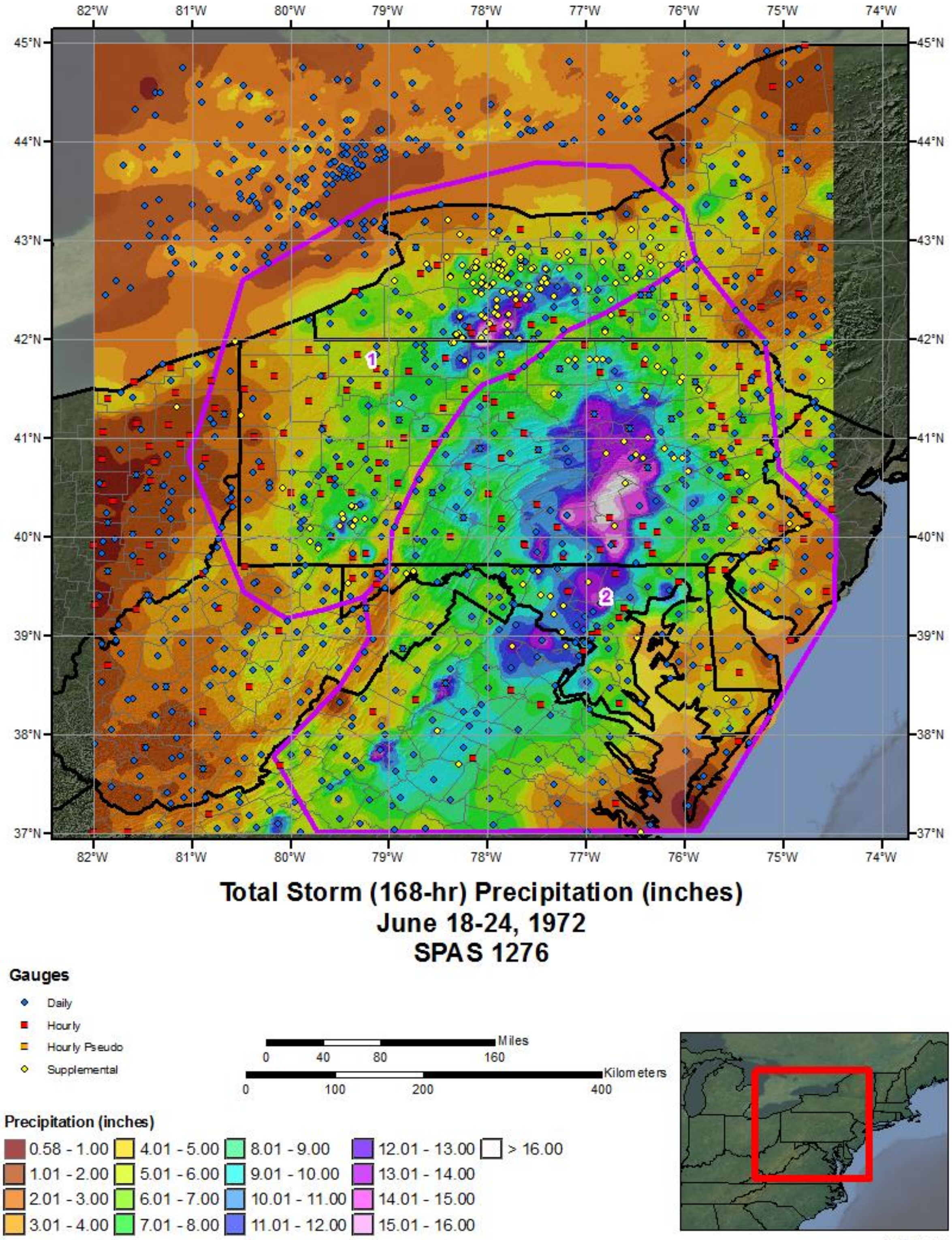
Reliability of results: This analysis was based on hourly data, daily data, supplemental station data and bucket survey data from the USGS report. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1276_2	-76.6208	40.5375	1,617	5-Jul	78.00	3.29	0.43	78	2.860	80.25	3.68	0.48	83	3.200	1.119

Storm 1276- June 18 (0700 UTC) - June 25 (0600 UTC), 1972														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
Area (mi^2)	Duration (hours)													
	1	3	6	12	18	24	36	48	72	96	120	144	168	Total
0.4	2.90	5.62	8.10	10.74	12.96	14.25	16.13	16.89	17.69	17.73	18.31	18.69	18.72	18.72
1	2.88	5.60	8.08	10.67	12.86	14.14	16.01	16.76	17.55	17.58	18.17	18.56	18.58	18.58
10	2.69	5.57	7.99	10.51	12.59	13.86	15.70	16.44	17.19	17.21	17.83	18.19	18.22	18.22
25	2.47	5.55	7.90	10.44	12.40	13.64	15.41	16.12	16.90	16.95	17.49	17.87	17.88	17.88
50	2.39	5.54	7.88	10.39	12.21	13.46	15.23	15.88	16.65	16.68	17.23	17.61	17.63	17.63
100	2.21	5.45	7.77	10.22	11.92	13.25	15.08	15.62	16.26	16.31	16.93	17.24	17.26	17.26
200	2.04	5.05	7.20	10.02	11.69	12.97	14.93	15.34	15.86	15.92	16.61	16.87	16.89	16.89
300	1.95	4.72	6.73	9.84	11.55	12.81	14.78	15.18	15.64	15.70	16.42	16.66	16.68	16.68
400	1.89	4.50	6.49	9.67	11.43	12.69	14.61	15.06	15.48	15.53	16.26	16.47	16.48	16.48
500	1.85	4.34	6.30	9.48	11.31	12.59	14.49	14.96	15.33	15.38	16.07	16.29	16.32	16.32
1,000	1.72	3.88	5.77	8.81	10.89	12.13	13.93	14.38	14.76	14.82	15.46	15.66	15.72	15.72
2,000	1.59	3.54	5.39	8.10	10.19	11.44	13.06	13.60	14.00	14.08	14.72	14.93	15.00	15.00
5,000	1.32	2.97	4.58	6.86	8.78	10.06	11.66	12.32	12.78	12.90	13.45	13.67	13.76	13.76
10,000	1.02	2.30	3.66	5.98	7.39	8.59	10.17	10.91	11.48	11.60	12.07	12.27	12.37	12.37
20,000	0.66	1.56	2.72	4.75	6.11	7.11	8.66	9.45	10.08	10.23	10.61	10.80	10.90	10.90
50,000	0.32	0.82	1.58	2.99	4.05	4.99	6.52	7.28	7.97	8.16	8.47	8.64	8.75	8.75
77,770	0.22	0.57	1.12	2.10	2.95	3.73	4.94	5.58	6.30	6.46	6.76	6.97	7.05	7.05

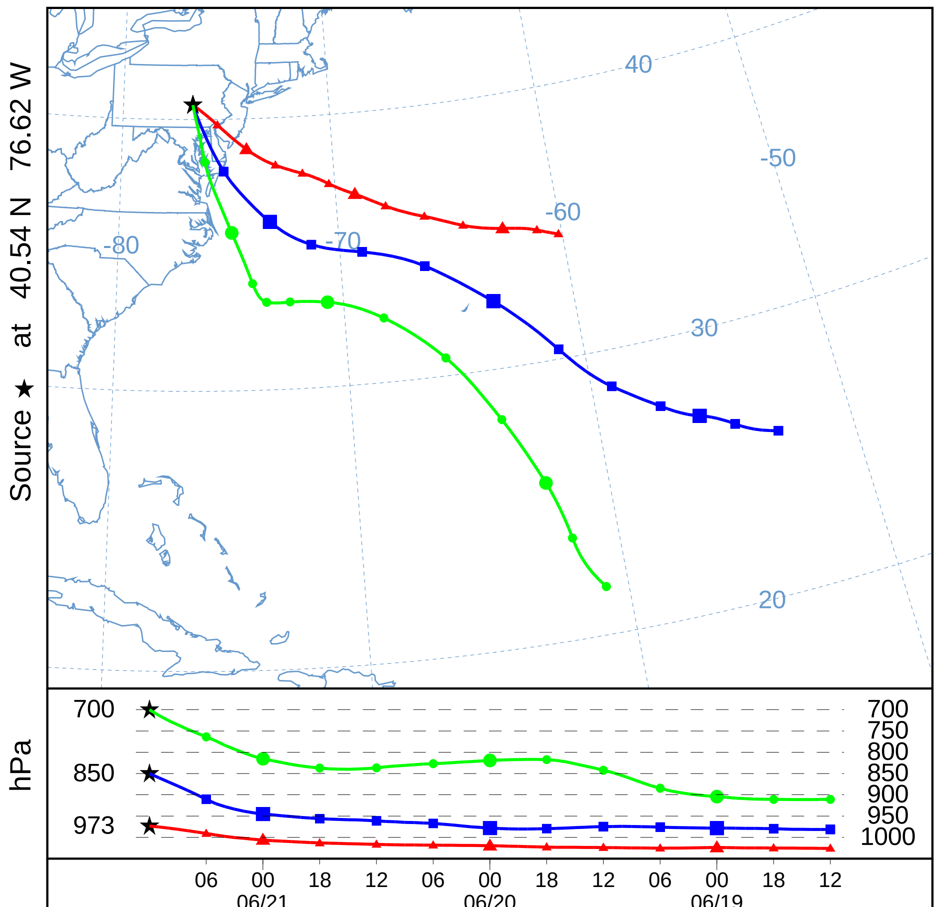



SPAS 1276 Storm Center Mass Curve Zone 2
June 18 (600UTC) to June 25 (500UTC), 1972
Lat: 40.5375 Lon: -76.6208333333333
Incremental
Accumulated
18.79
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
2.0
1.5
1.0
0.5
0.0
15
10
5
0
50
100
150



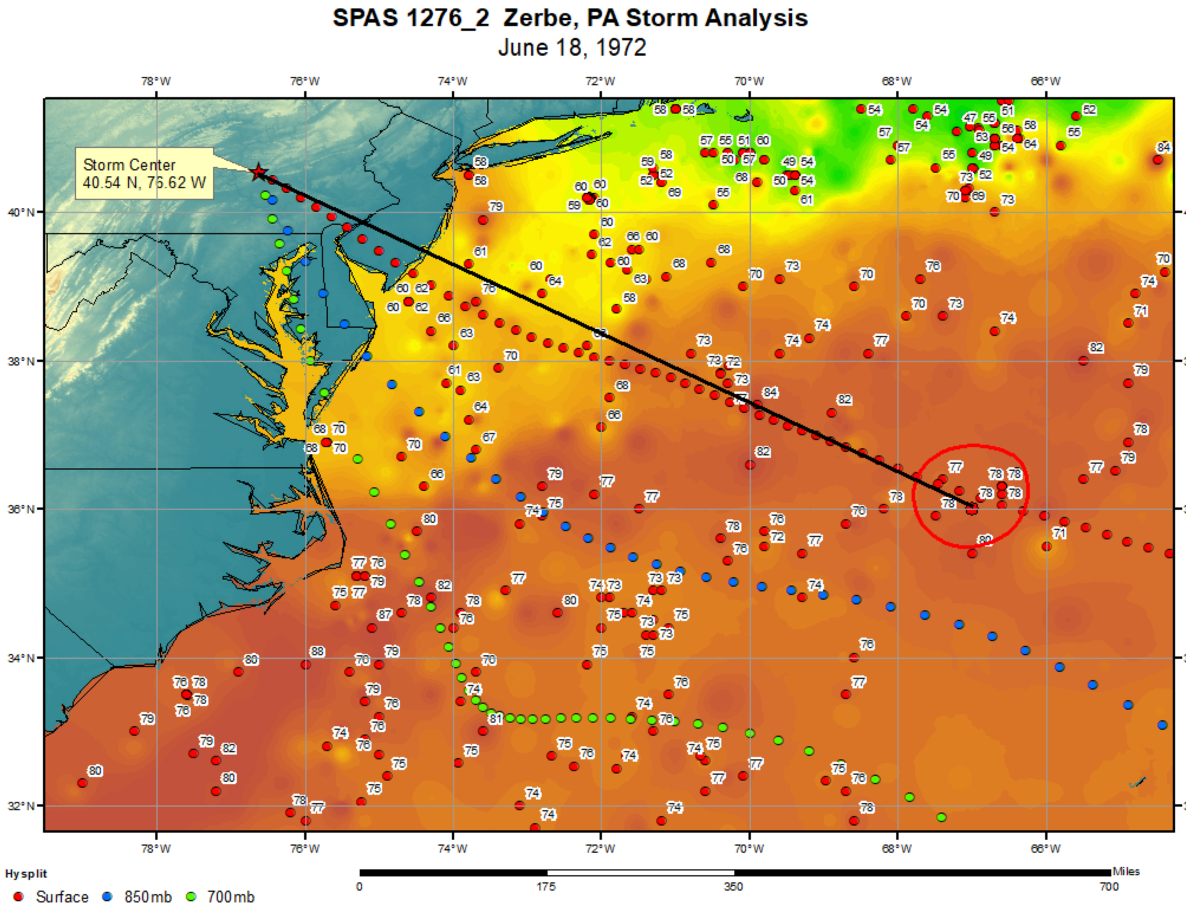
Total Storm (168-hr) Precipitation (inches)
June 18-24, 1972
SPAS 1276

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 21 Jun 72
CDC1 Meteorological Data

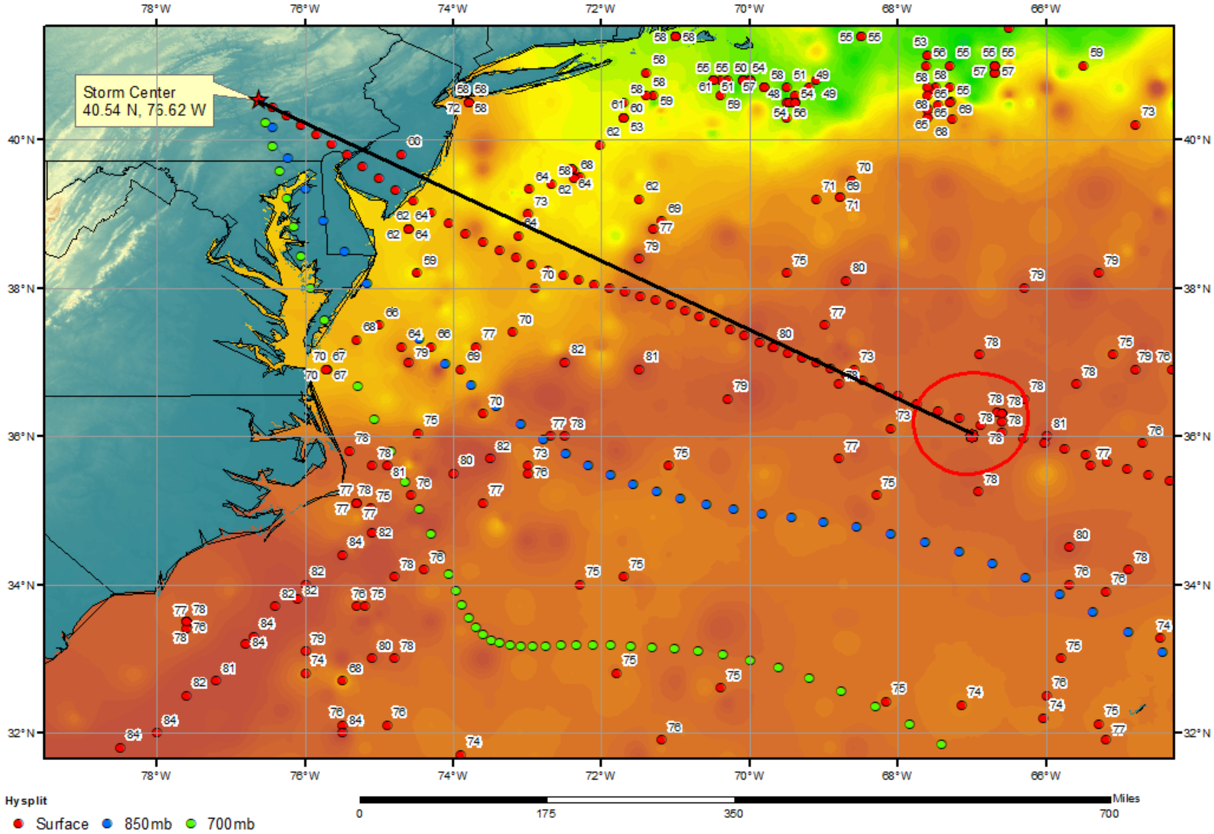


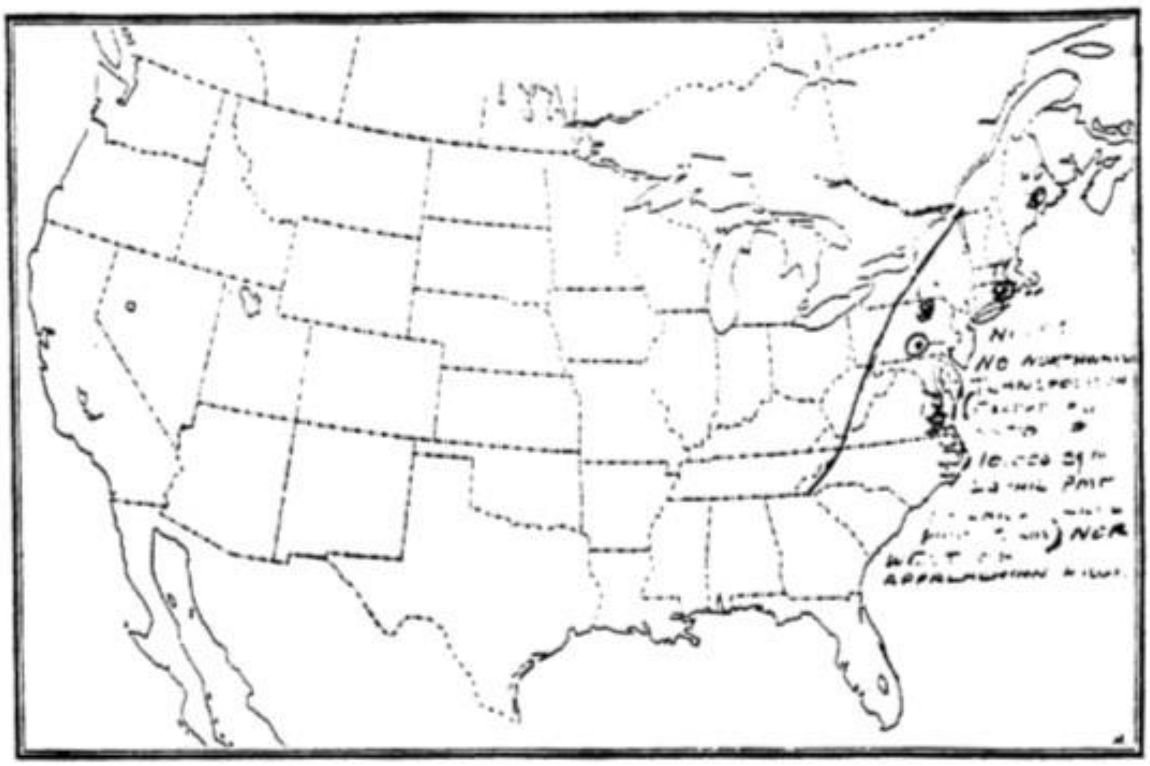
Job ID: 186156 Job Start: Fri Jan 14 15:17:45 UTC 2022
Source 1 lat.: 40.537500 lon.: -76.620800 hgts: 0, 1160, 2790 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2072 - reanalysis


SPAS 1276_2 Zerbe, PA Storm Analysis
June 18, 1972
Storm Center
40.54 N, 76.62 W
78°W
76°W
74°W
72°W
70°W
68°W
66°W
40°N
38°N
36°N
34°N
32°N
Hysplit
Surface
850mb
700mb
Miles
0
175
350
700

SPAS 1276_2 Zerbe, PA Storm Analysis
June 19, 1972





Storm Precipitation Analysis System (SPAS) For Storm #1317_1 SPAS Analysis

General Storm Location: Americus, GA

Storm Dates: June 30-July 7, 1994

Event: Tropical Storm Alberto

DAD Zone 1

Latitude: 32.0958

Longitude: -84.2292

Max. Grid Rainfall Amount: 28.09"

Max. Observed Rainfall Amount: 27.85"

Number of Stations: 272 stations (189 daily, 44 hourly, 13 hourly pseudo, and 26 supplemental)

SPAS Version: 9.5

Base Map Used: Digitized NWS Isohyetal Map (storm total Jun 30 - Jul 8, 1994)

Spatial resolution: 30 seconds

Radar Included: No

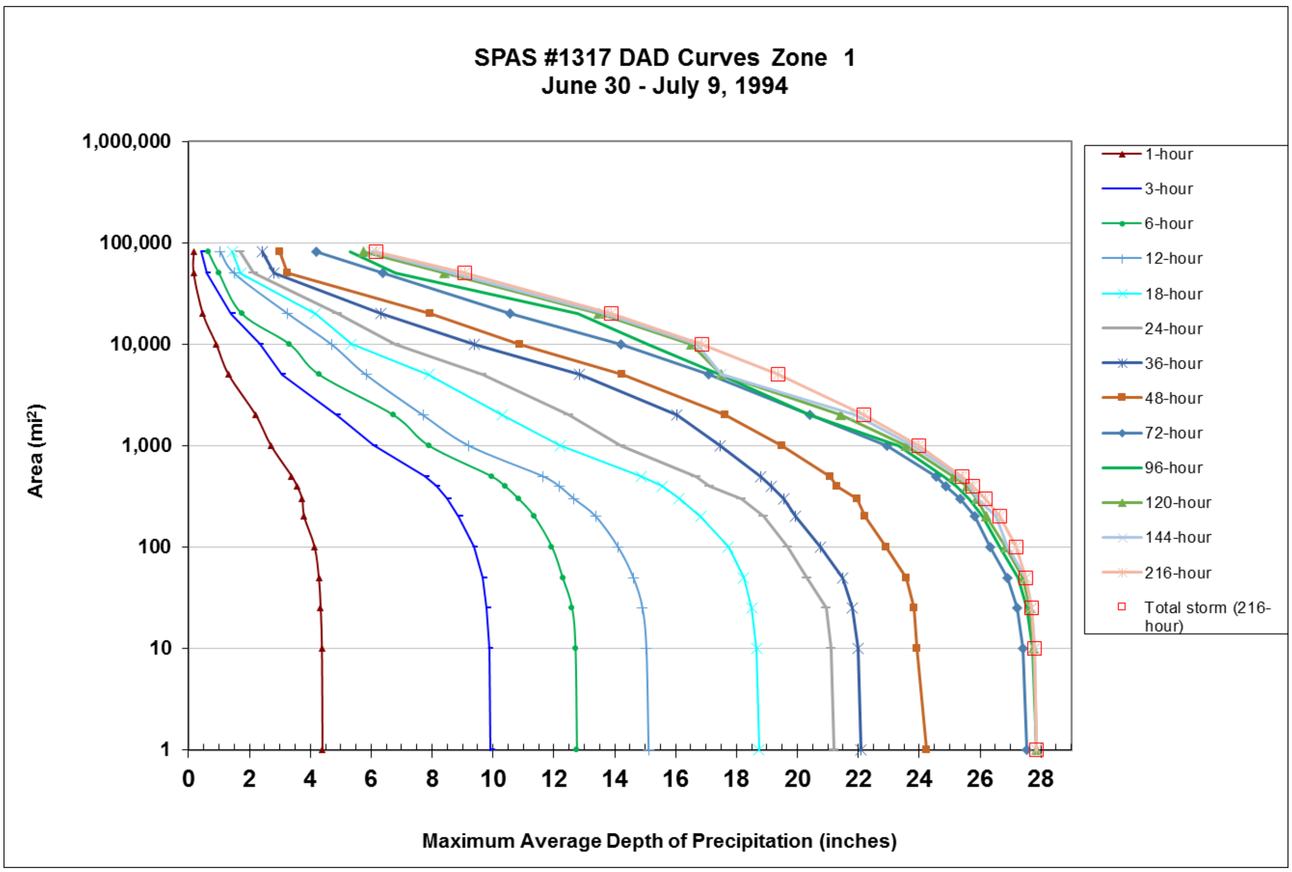
Depth-Area-Duration (DAD) analysis: Yes

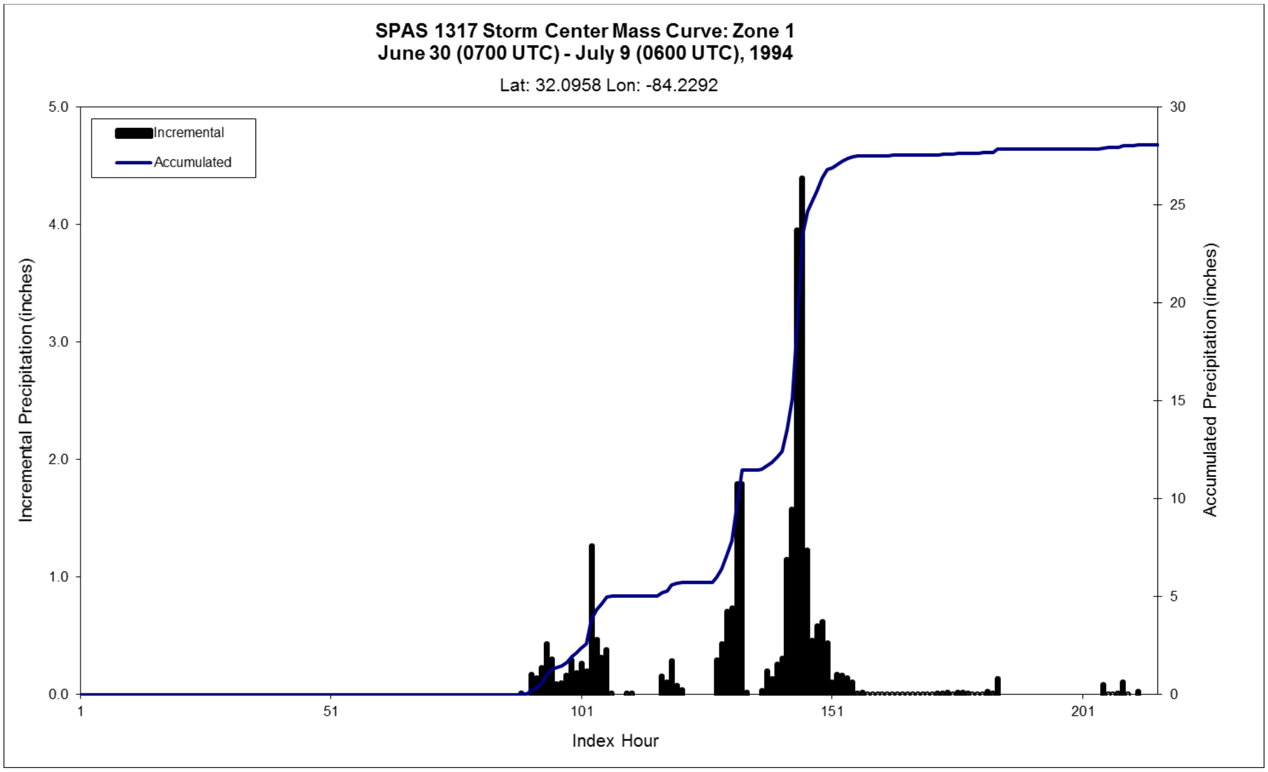
Reliability of Results: This analysis was based on hourly data, daily data, supplemental station data and NWS total storm basemap. We have a good level of confidence in the station based storm total results, the spatial pattern is dependent on the station data and NWS basemap. The timing is based on hourly and hourly pseudo stations.

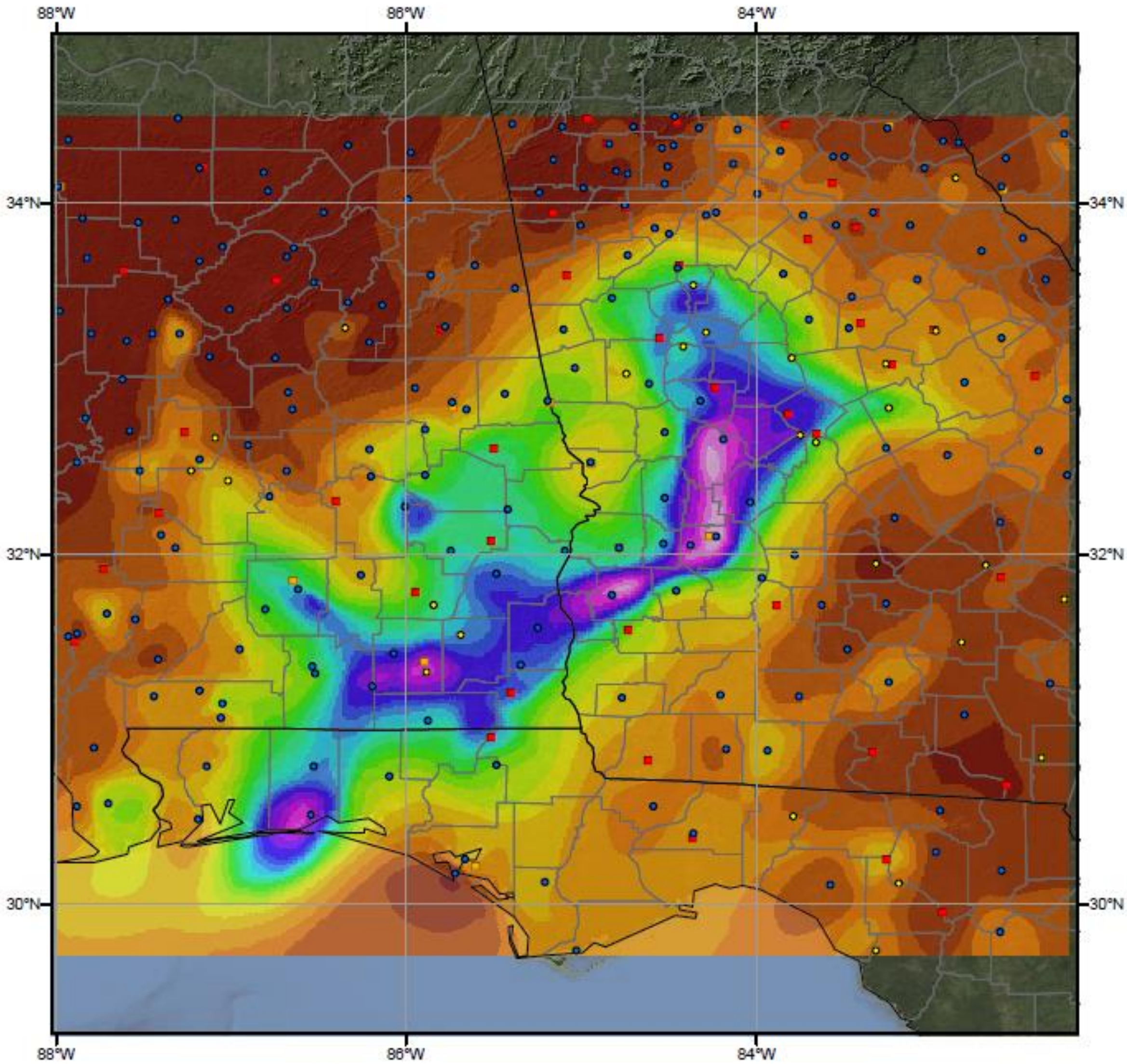
							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1317_1	-84.2292	32.0958	466	500	15-Jul	84.00	4.30	0.18	90	4.120	86.51	86.5	4.77	0.18	95	4.590	1.114

Area (mi^2)	Duration (hours)														
	1	**2**	**3**	**6**	**12**	**18**	**24**	**36**	**48**	**72**	**96**	**120**	**144**	**216**	**Total**
0.3	4.42	8.35	9.93	12.76	15.11	18.74	21.20	22.08	24.23	27.53	27.85	28.05	28.09	28.09	28.09
1	4.40	8.35	9.93	12.76	15.11	18.74	21.20	22.08	24.23	27.53	27.85	27.85	27.85	27.85	27.85
10	4.38	8.31	9.88	12.71	15.04	18.66	21.11	21.99	23.93	27.42	27.74	27.77	27.79	27.79	27.79
25	4.34	8.24	9.80	12.60	14.91	18.51	20.95	21.82	23.82	27.23	27.55	27.63	27.68	27.68	27.68
50	4.28	8.13	9.67	12.29	14.61	18.24	20.31	21.50	23.57	26.91	27.24	27.40	27.50	27.50	27.50
100	4.14	7.87	9.37	11.94	14.11	17.72	19.67	20.76	22.90	26.32	26.66	26.84	26.89	27.19	27.19
200	3.80	7.44	8.88	11.36	13.38	16.82	18.89	19.94	22.22	25.82	26.07	26.22	26.52	26.64	26.64
300	3.73	7.11	8.49	10.84	12.66	16.12	18.16	19.57	21.97	25.36	25.63	25.90	25.92	26.17	26.17
400	3.56	6.78	8.13	10.39	12.17	15.56	17.13	19.13	21.30	24.89	25.21	25.58	25.67	25.77	25.77
500	3.39	6.46	7.77	9.95	11.64	14.86	16.66	18.81	21.07	24.55	24.80	25.12	25.31	25.41	25.41
1,000	2.71	5.22	6.08	7.90	9.21	12.20	14.19	17.47	19.49	22.93	23.32	23.57	23.81	23.98	23.98
2,000	2.21	3.98	4.87	6.74	7.70	10.32	12.49	16.03	17.64	20.40	20.41	21.43	21.90	22.19	22.19
5,000	1.32	2.37	3.06	4.30	5.83	7.89	9.64	12.83	14.25	17.10	17.42	17.49	17.49	19.37	19.37
10,000	0.91	1.59	2.34	3.32	4.69	5.34	6.78	9.38	10.89	14.20	15.08	16.51	16.72	16.88	16.88
20,000	0.47	0.73	1.41	1.75	3.26	4.18	4.89	6.32	7.94	10.56	12.78	13.48	13.68	13.89	13.89
50,000	0.17	0.46	0.59	1.00	1.50	1.72	2.14	2.79	3.25	6.39	6.80	8.41	8.67	9.07	9.07
81,682	0.17	0.28	0.42	0.64	1.04	1.44	1.69	2.43	2.98	4.20	5.32	5.74	6.03	6.15	6.15

Table title: **Storm 1317 - June 30 (0700 UTC) - July 9 (0600 UTC), 1994** — **MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)**




SPAS 1317 Storm Center Mass Curve: Zone 1
June 30 (0700 UTC) - July 9 (0600 UTC), 1994
Lat: 32.0958 Lon: -84.2292
Incremental
Accumulated
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
5.0
4.0
3.0
2.0
1.0
0.0
30
25
20
15
10
5
0
1
51
101
151
201



Total Storm (216-hr) Precipitation (inches)
June 30 - July 8, 1994
SPAS 1317

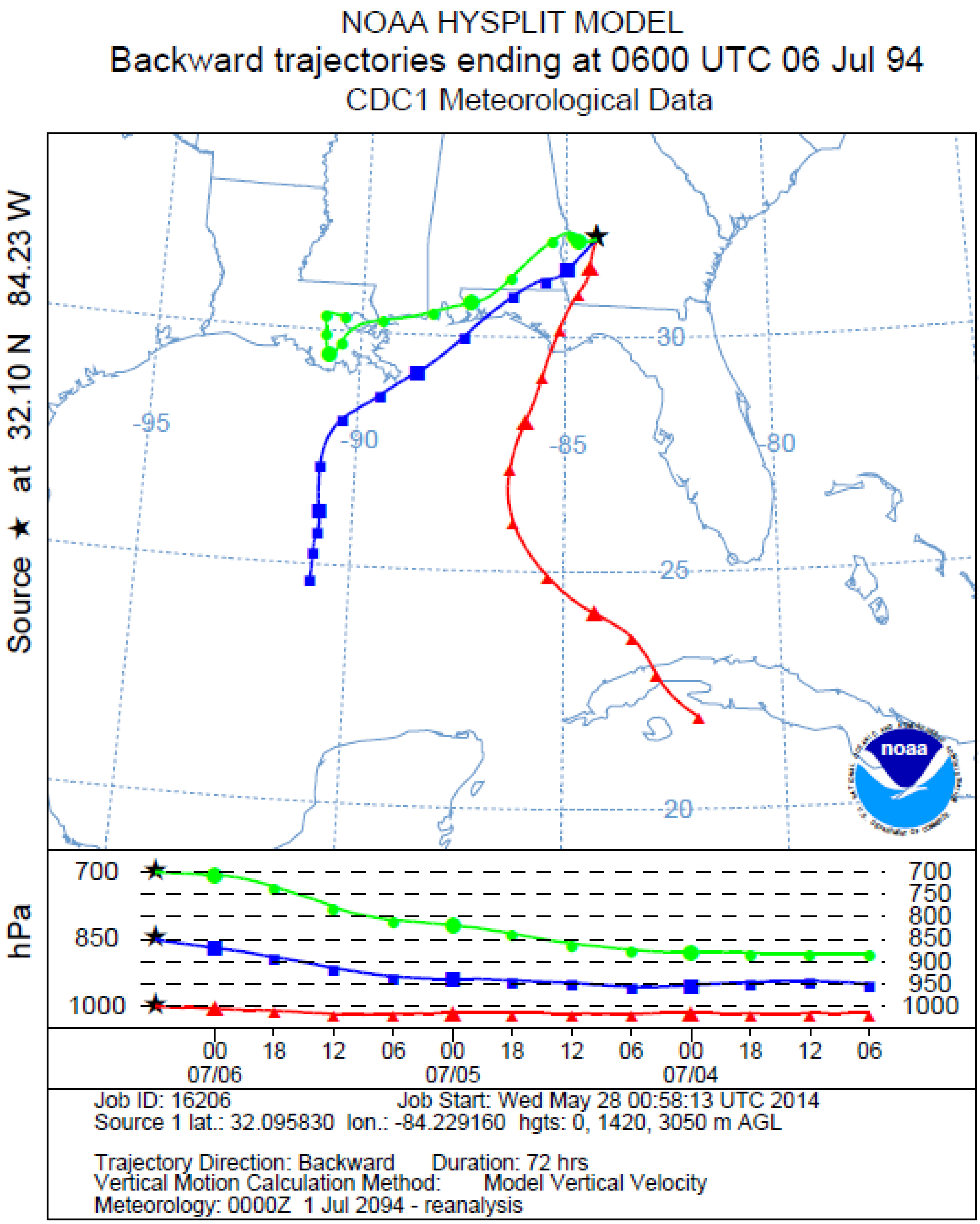
Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 35, 70, 140
Kilometers: 0, 70, 140, 280

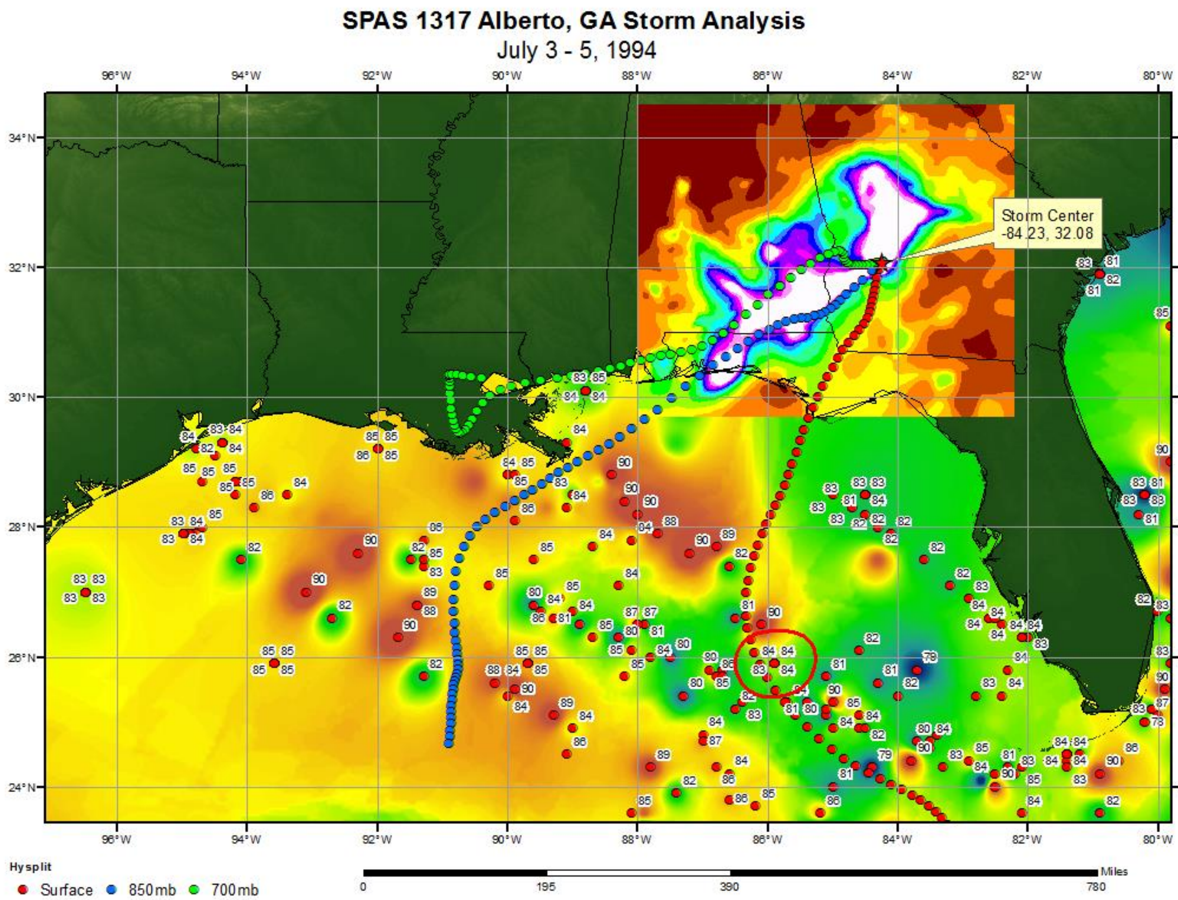
Precipitation (inches)

0.15 - 1	5.01 - 6	10.01 - 11	15.01 - 16	24.01 - 26
1.01 - 2	6.01 - 7	11.01 - 12	16.01 - 18	26.01 - 28
2.01 - 3	7.01 - 8	12.01 - 13	18.01 - 20	28.01 - 29
3.01 - 4	8.01 - 9	13.01 - 14	20.01 - 22	
4.01 - 5	9.01 - 10	14.01 - 15	22.01 - 24	

12/22/2013



NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 06 Jul 94
CDC1 Meteorological Data
Source ★ at 32.10 N 84.23 W
30
25
20
-95
-90
-85
-80
noaa
hPa
700
850
1000
700
750
800
850
900
950
1000
00 18 12 06 00 18 12 06 00 18 12 06
07/06
07/05
07/04
Job ID: 16206 Job Start: Wed May 28 00:58:13 UTC 2014
Source 1 lat.: 32.095830 lon.: -84.229160 hgts: 0, 1420, 3050 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2094 - reanalysis


SPAS 1317 Alberto, GA Storm Analysis
July 3 - 5, 1994
Storm Center
-84.23, 32.08
Hysplit
Surface
850mb
700mb
Miles
0
195
390
780

Storm Precipitation Analysis System (SPAS) For Storm #1373_1 SPAS-NEXRAD Analysis

General Storm Location: Tennessee Valley

Storm Dates: August 25 – 28, 1995

Event: Tropical Storm Remnant-Tropical Storm Jerry

DAD Zone 1

> **Latitude**: 34.8550
>
> **Longitude**: -82.2250
>
> **Max. Grid Rainfall Amount**: 20.01”
>
> **Max. Observed Rainfall Amount**: 20.00” at Pelham, SC

Number of Stations: 485 (207 Daily, 60 Hourly, 7 Hourly Pseudo, 208 Supplemental, and 3 Supplemental Estimated)

SPAS Version: 10.0

Base Map Used: Mean annual maximum 48-hour precipitation associated with TSRs

Spatial resolution: 0.3876

Radar Included: Yes

Depth-Area-Duration (DAD) analysis: Yes

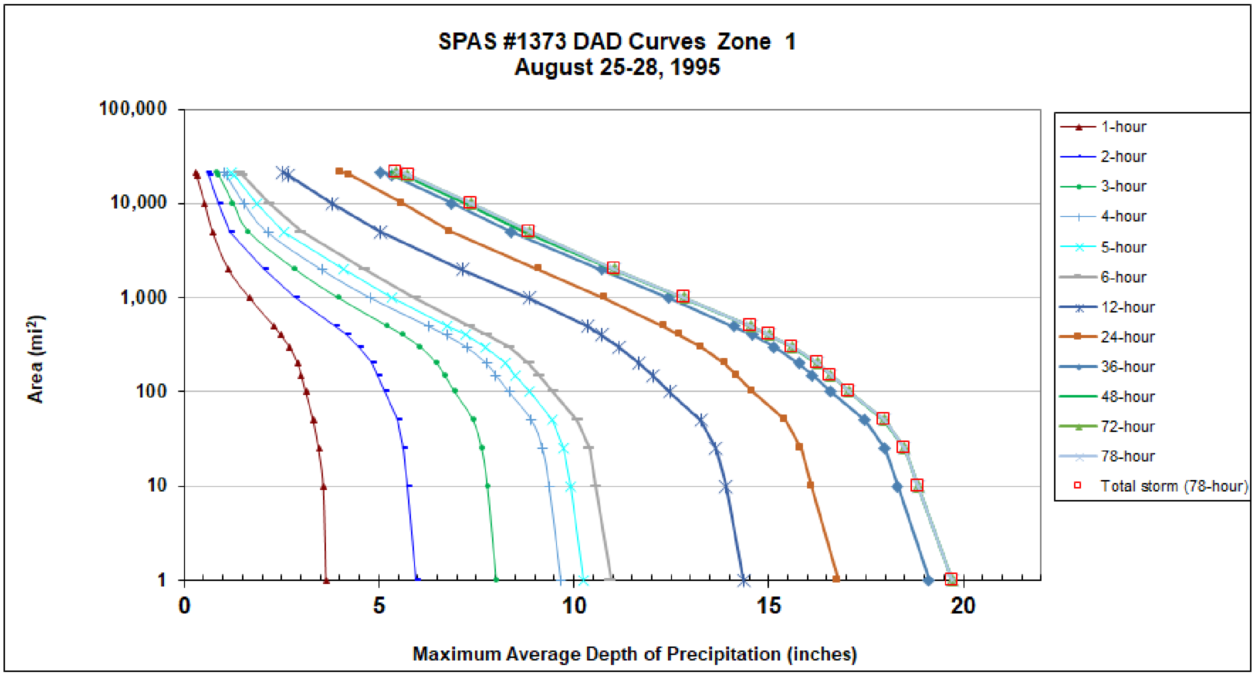
Reliability of results: Two-hundred eight supplemental stations were added to ensure data consistency. Due to the amount and integrity of the data, one supplemental estimated station was added based off of a storm report mentioning twenty inches of precipitation falling during the event of Tropical Storm Jerry in Pelham, SC. The actual report is located in the storm report section later in this document. No additional timing information was available for the Pelham, SC report. To constrain the supplemental estimated station precipitation, two additional supplemental estimated stations were added. With the density of stations available and the consistency of the resulting SPAS analysis to the various reports, this analysis is deemed quite reliable.

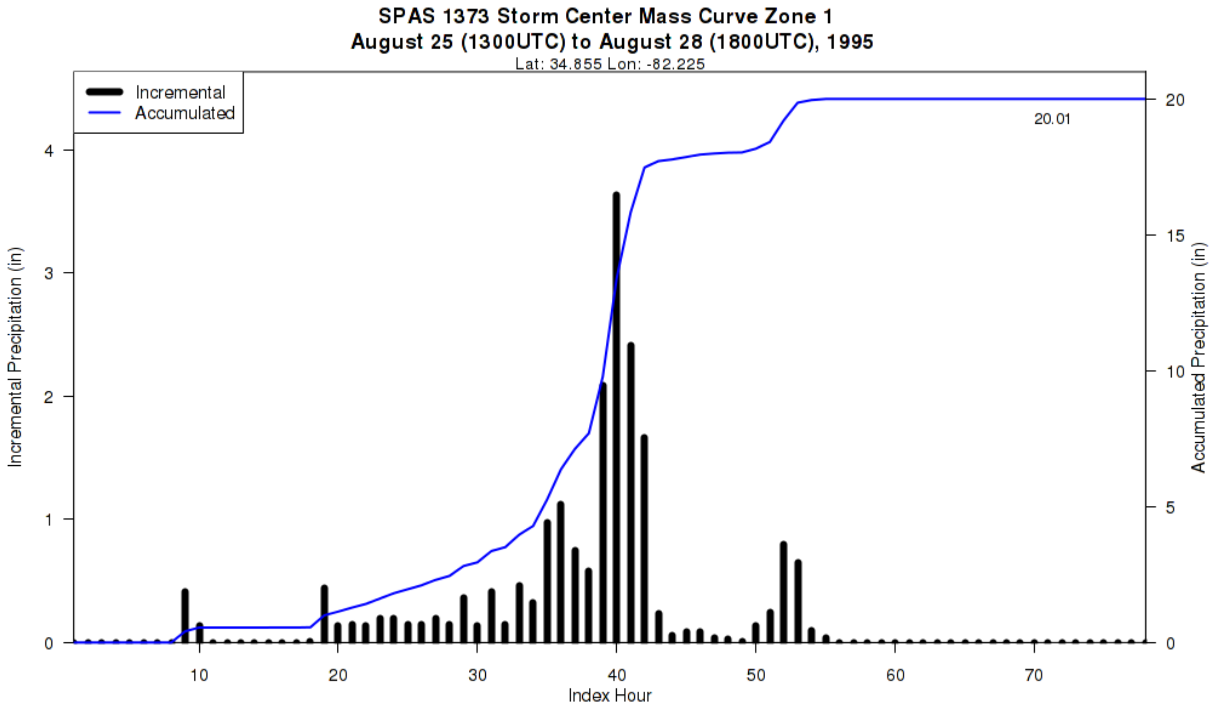
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1373_1	-82.2250	34.8550	733	15-Aug	82.50	4.03	0.21	87	3.820	85.55	4.58	0.25	93	4.330	1.134

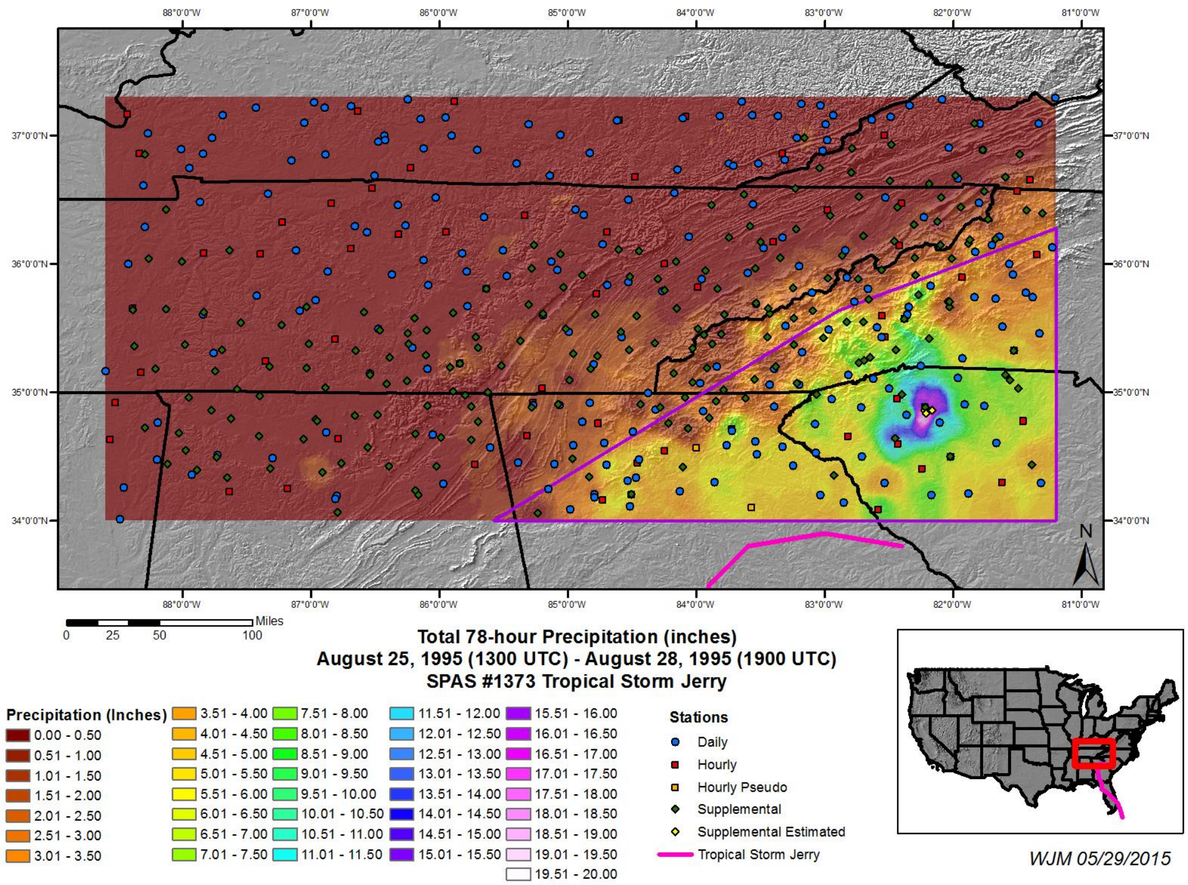
Storm 1373 - August 25 (1300 UTC) - August 28 (1800 UTC), 1995

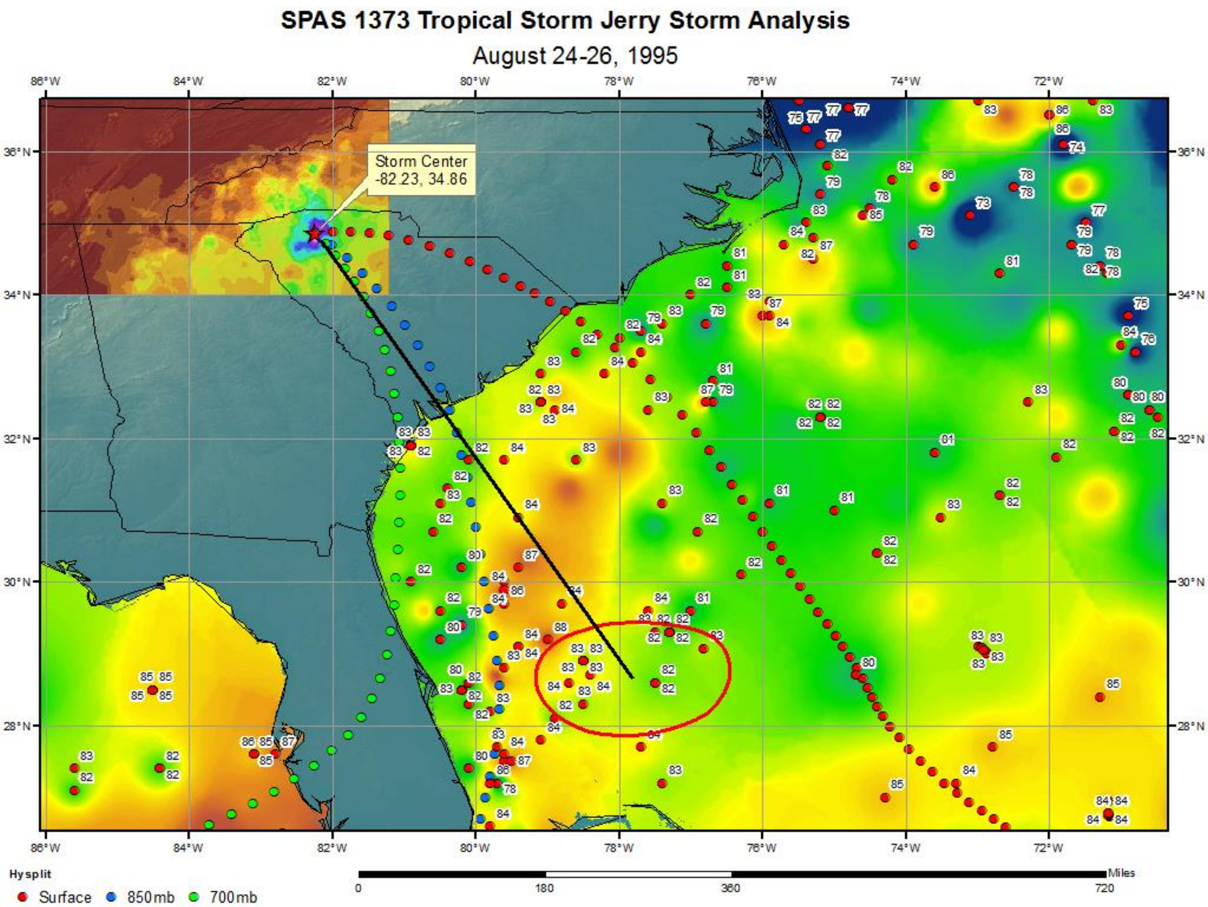
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

Area (mi²)	Duration (hours)												
	1	2	3	4	5	6	12	24	36	48	72	78	Total
0.4	3.67	6.04	8.12	9.78	10.36	11.10	14.53	17.05	19.40	20.00	20.00	20.00	20.00
1	3.65	5.95	8.03	9.67	10.24	10.96	14.36	16.78	19.11	19.71	19.71	19.71	19.71
10	3.58	5.73	7.80	9.37	9.93	10.58	13.90	16.11	18.31	18.85	18.85	18.85	18.85
25	3.46	5.64	7.65	9.20	9.75	10.41	13.65	15.84	17.99	18.50	18.50	18.50	18.50
50	3.32	5.48	7.43	8.92	9.46	10.10	13.26	15.43	17.48	17.97	17.98	17.98	17.98
100	3.13	5.15	6.96	8.34	8.86	9.48	12.47	14.60	16.60	17.08	17.08	17.08	17.08
150	3.02	4.96	6.70	8.01	8.51	9.12	12.02	14.18	16.13	16.60	16.61	16.61	16.61
200	2.93	4.82	6.50	7.77	8.26	8.86	11.69	13.88	15.78	16.26	16.27	16.27	16.27
300	2.72	4.49	6.08	7.25	7.74	8.34	11.15	13.27	15.15	15.60	15.61	15.61	15.61
400	2.50	4.16	5.64	6.74	7.22	7.79	10.72	12.73	14.60	15.00	15.01	15.01	15.01
500	2.32	3.86	5.24	6.28	6.75	7.34	10.37	12.32	14.11	14.56	14.57	14.57	14.57
1,000	1.69	2.85	3.97	4.80	5.34	5.94	8.86	10.79	12.44	12.82	12.85	12.85	12.85
2,000	1.15	2.05	2.86	3.54	4.09	4.65	7.14	9.11	10.71	11.03	11.07	11.07	11.07
5,000	0.74	1.18	1.66	2.15	2.58	3.02	5.04	6.83	8.38	8.72	8.87	8.87	8.87
10,000	0.54	0.90	1.26	1.56	1.88	2.19	3.79	5.59	6.88	7.22	7.36	7.36	7.36
20,000	0.33	0.64	0.89	1.11	1.30	1.49	2.67	4.25	5.32	5.61	5.75	5.76	5.76
21,605	0.31	0.60	0.84	1.05	1.23	1.42	2.53	4.03	5.04	5.32	5.46	5.46	5.46




SPAS 1373 Storm Center Mass Curve Zone 1
August 25 (1300UTC) to August 28 (1800UTC), 1995
Lat: 34.855 Lon: -82.225
Incremental
Accumulated
20.01
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour


Total 78-hour Precipitation (inches)
August 25, 1995 (1300 UTC) - August 28, 1995 (1900 UTC)
SPAS #1373 Tropical Storm Jerry
Miles
0 25 50 100
N
Precipitation (Inches)
0.00 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 8.50
8.51 - 9.00
9.01 - 9.50
9.51 - 10.00
10.01 - 10.50
10.51 - 11.00
11.01 - 11.50
11.51 - 12.00
12.01 - 12.50
12.51 - 13.00
13.01 - 13.50
13.51 - 14.00
14.01 - 14.50
14.51 - 15.00
15.01 - 15.50
15.51 - 16.00
16.01 - 16.50
16.51 - 17.00
17.01 - 17.50
17.51 - 18.00
18.01 - 18.50
18.51 - 19.00
19.01 - 19.50
19.51 - 20.00
Stations
Daily
Hourly
Hourly Pseudo
Supplemental
Supplemental Estimated
Tropical Storm Jerry
WJM 05/29/2015


SPAS 1373 Tropical Storm Jerry Storm Analysis
August 24-26, 1995
Storm Center
-82.23, 34.86
Hysplit
Surface
850mb
700mb
Miles
0
180
360
720

Storm Precipitation Analysis System (SPAS) For Storm #1552_1 SPAS-NEXRAD Analysis

General Storm Location: Eastern Seaboard

Storm Dates: September 13, 1999 – September 17, 1999

Event: Hurricane Floyd

DAD Zone 1

Latitude: 34.005

Longitude: -77.9950

Max. Grid Rainfall Amount: 24.30”

Max. Observed Rainfall Amount: 24.06” at Southport 5 N, NC

Number of Stations: 974 (430 Daily, 97 Hourly, 46 Hourly Pseudo, 1 Hourly Estimated Pseudo, 397 Supplemental, and 3 Supplemental Estimated)

SPAS Version: 10.0

Base Map Used: Continental United States 2-year 24-hour basemap (conus_0002y24h)

Spatial resolution: 0.3736

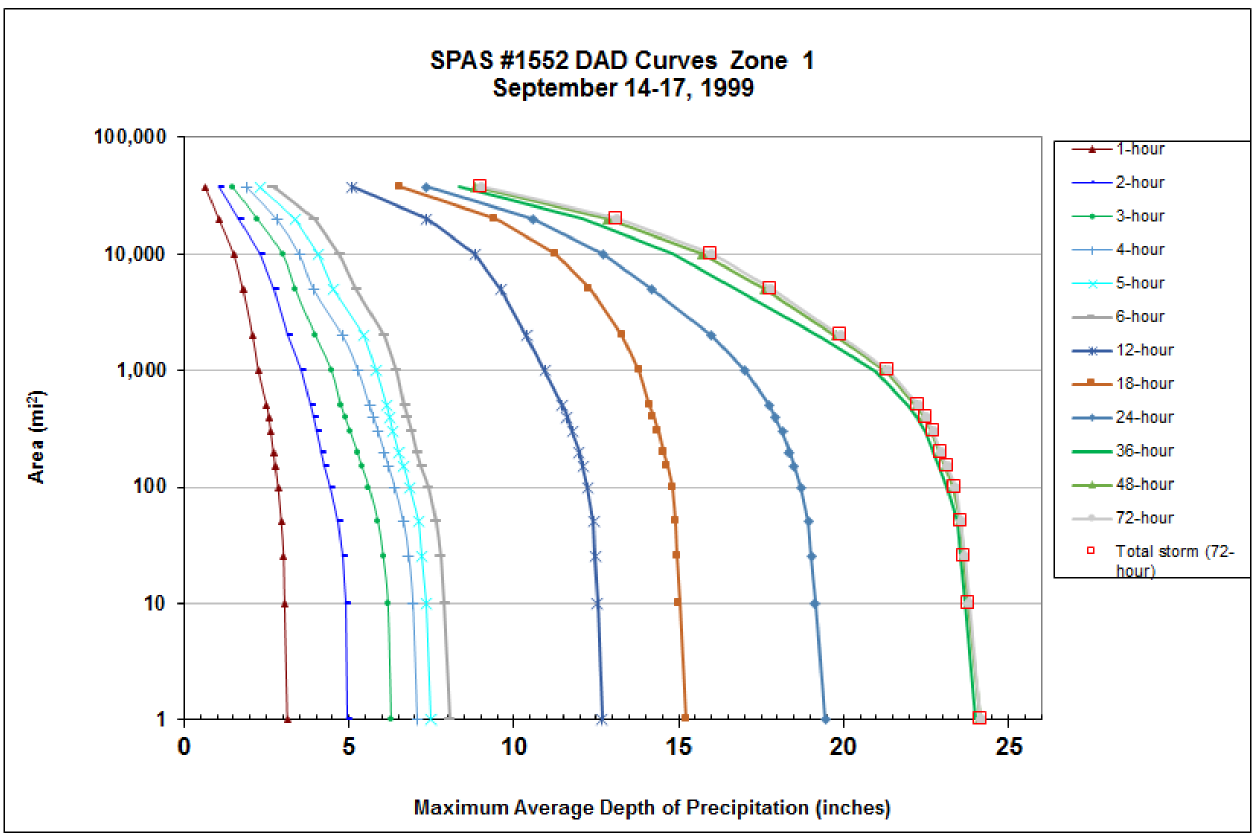
Radar Included: Yes

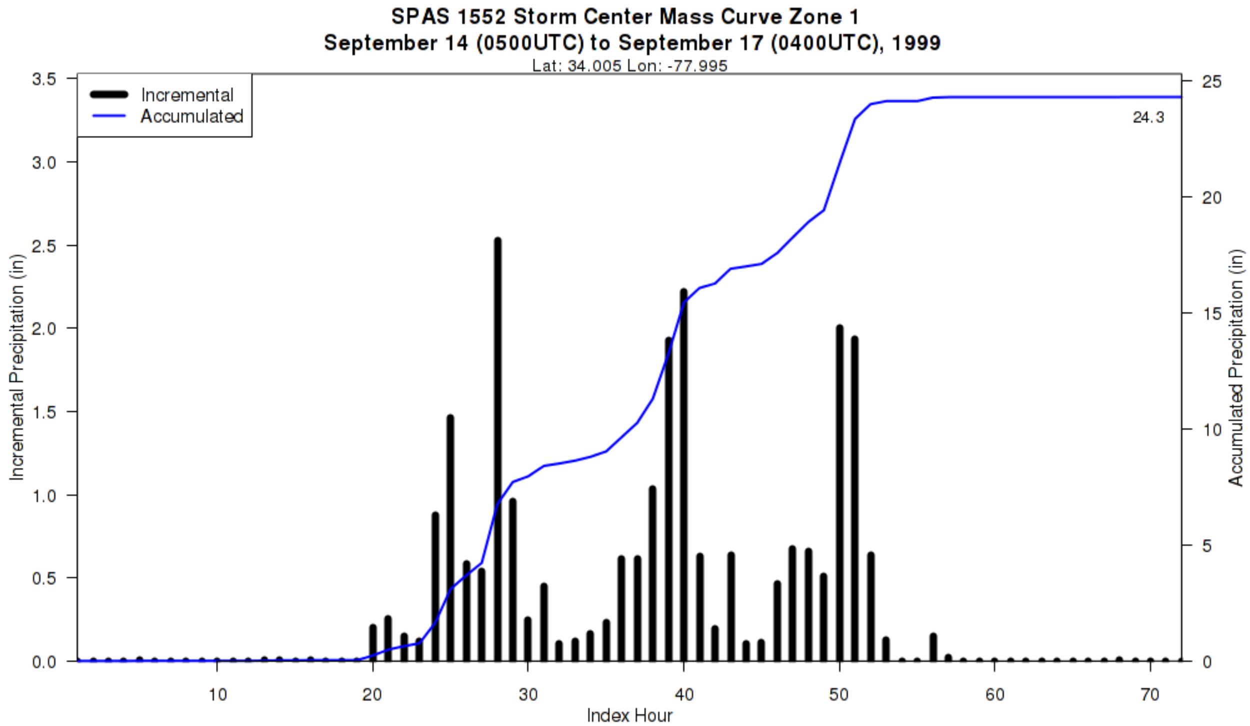
Depth-Area-Duration (DAD) analysis: Yes

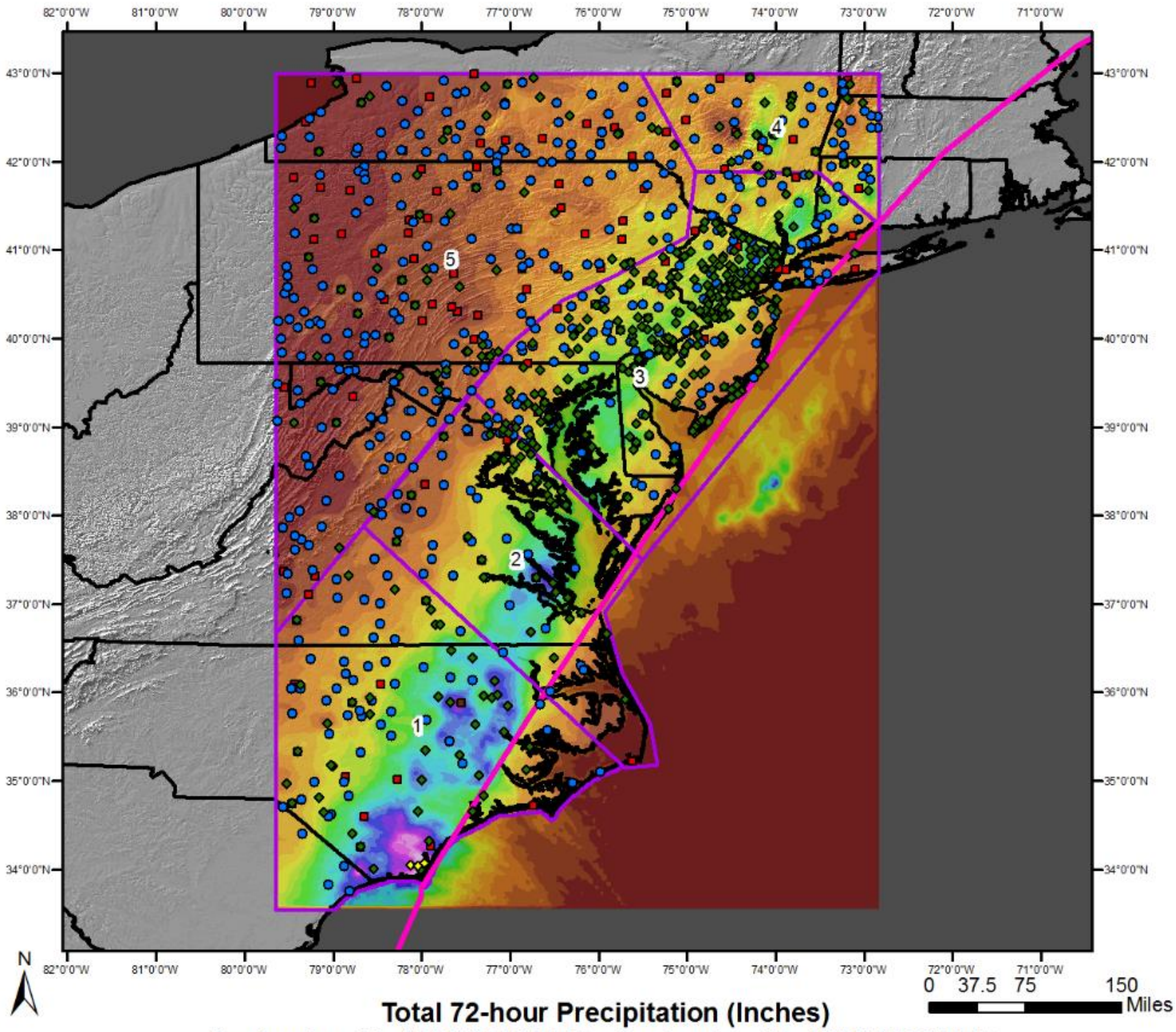
Reliability of results: 397 supplemental stations were added to ensure the data matches what can actually occur and that the data more closely resemble reports from this storm. Many of these stations were incorporated from previous analyses of Hurricane Floyd (SPAS storms 1002 and 1012) along with other storm data reports. Due to the orientation and integrity of the station data, three additional stations were incorporated. Lack of hourly stations in east central North Carolina forced the creation of a radar estimated hourly pseudo station to assist in timing and intensity. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the storm data report, this analysis is deemed quite reliable.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1552_1	-77.9950	34.0050	31	1-Sep	78.00	3.29	0.00	78	3.290	82.81	4.12	0.00	88	4.120	1.252

Storm 1552 - September 14 (0500 UTC) - September 17 (0400 UTC), 1999													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
Area (mi^2)	Duration (hours)												
	1	2	3	4	5	6	12	18	24	36	48	72	Total
0.4	3.15	4.97	6.33	7.11	7.54	8.12	12.75	15.31	19.56	24.16	24.29	24.30	24.30
1	3.13	4.95	6.28	7.06	7.48	8.06	12.68	15.23	19.44	24.02	24.14	24.16	24.16
10	3.05	4.88	6.18	6.93	7.35	7.89	12.53	15.04	19.14	23.68	23.79	23.81	23.81
25	3.02	4.80	6.04	6.81	7.23	7.77	12.46	14.97	19.02	23.54	23.65	23.67	23.67
50	2.95	4.66	5.88	6.65	7.10	7.64	12.42	14.91	18.93	23.44	23.54	23.57	23.57
100	2.85	4.44	5.61	6.39	6.83	7.40	12.23	14.82	18.70	23.15	23.33	23.40	23.40
150	2.77	4.27	5.40	6.20	6.65	7.21	12.09	14.66	18.50	22.90	23.09	23.15	23.15
200	2.72	4.18	5.26	6.07	6.53	7.07	11.99	14.55	18.36	22.73	22.92	22.97	22.97
300	2.64	4.04	5.04	5.88	6.35	6.89	11.78	14.39	18.15	22.48	22.69	22.73	22.73
400	2.58	3.94	4.88	5.74	6.22	6.77	11.62	14.24	17.93	22.19	22.43	22.50	22.50
500	2.52	3.86	4.76	5.63	6.13	6.69	11.48	14.13	17.77	21.98	22.22	22.28	22.28
1,000	2.26	3.54	4.48	5.28	5.83	6.43	10.95	13.80	17.02	20.95	21.28	21.36	21.36
2,000	2.08	3.13	3.99	4.81	5.44	6.07	10.39	13.31	16.00	19.23	19.78	19.90	19.90
5,000	1.79	2.71	3.38	3.93	4.52	5.21	9.60	12.30	14.17	16.72	17.59	17.81	17.81
10,000	1.51	2.31	2.99	3.50	4.05	4.70	8.81	11.26	12.69	14.80	15.70	16.01	16.01
20,000	1.06	1.67	2.24	2.82	3.37	3.95	7.37	9.44	10.58	12.07	12.83	13.13	13.13
38,002	0.65	1.05	1.48	1.90	2.32	2.69	5.10	6.55	7.37	8.36	8.82	9.02	9.02

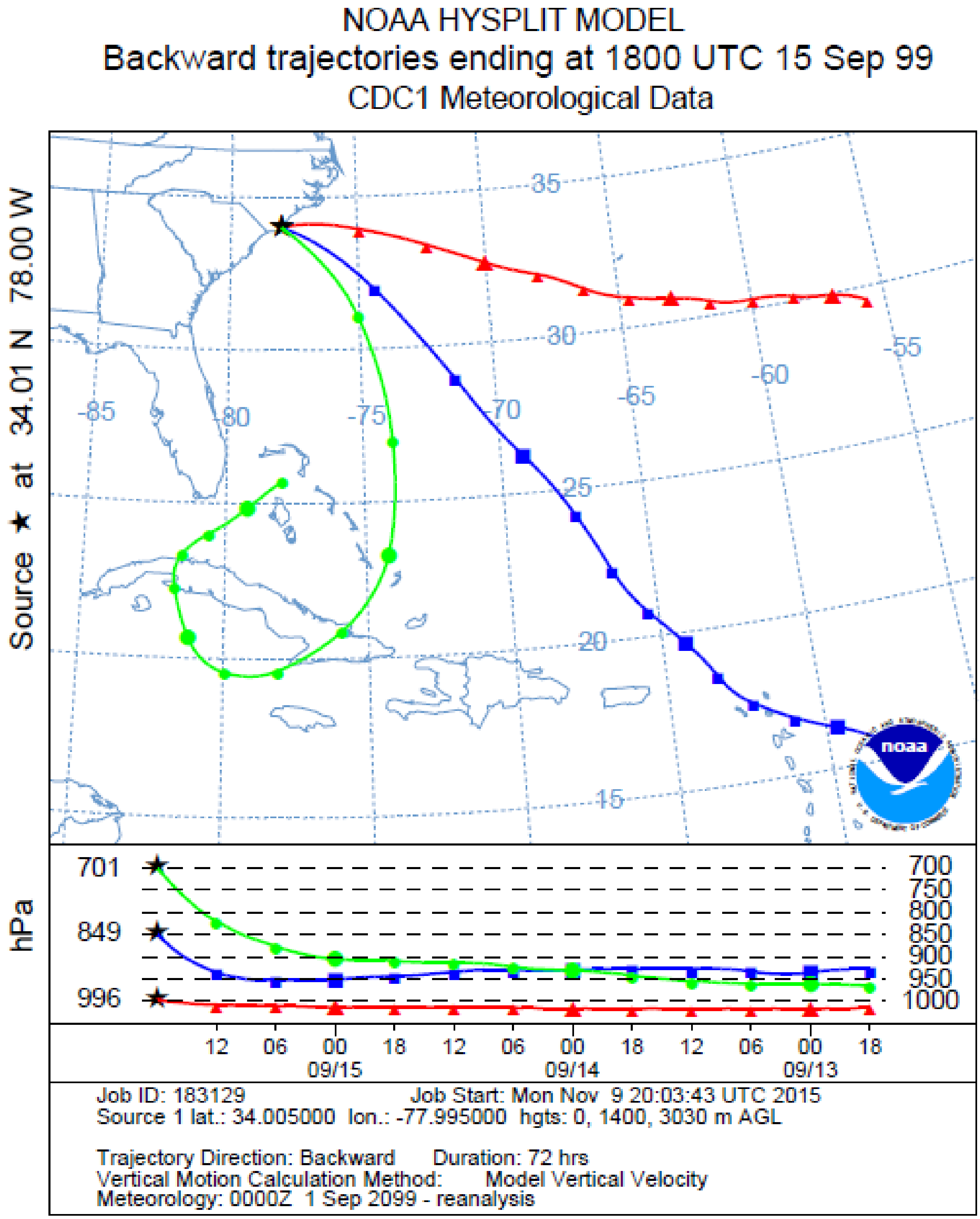


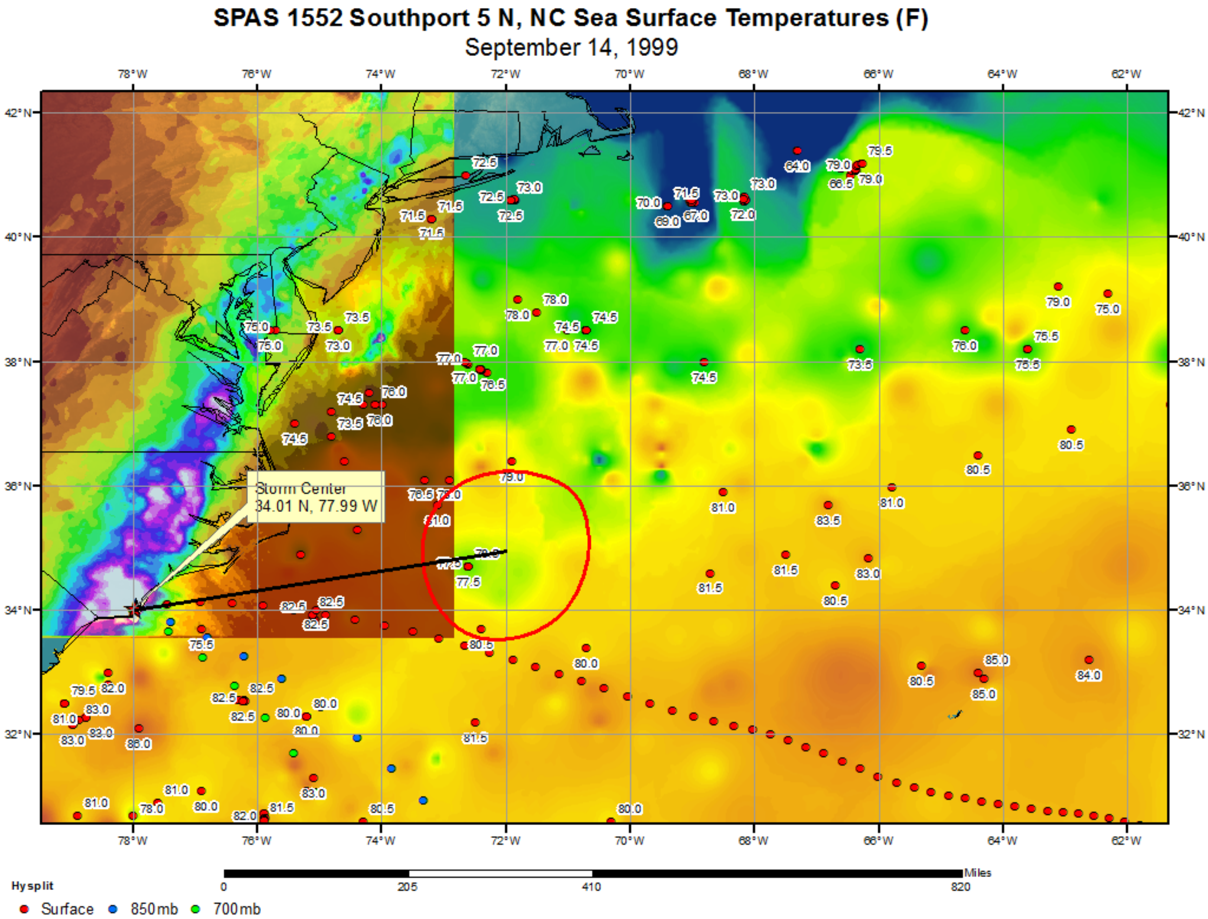

SPAS 1552 Storm Center Mass Curve Zone 1
September 14 (0500UTC) to September 17 (0400UTC), 1999
Lat: 34.005 Lon: -77.995
Incremental
Accumulated
24.3
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
5
10
15
20
25
10
20
30
40
50
60
70

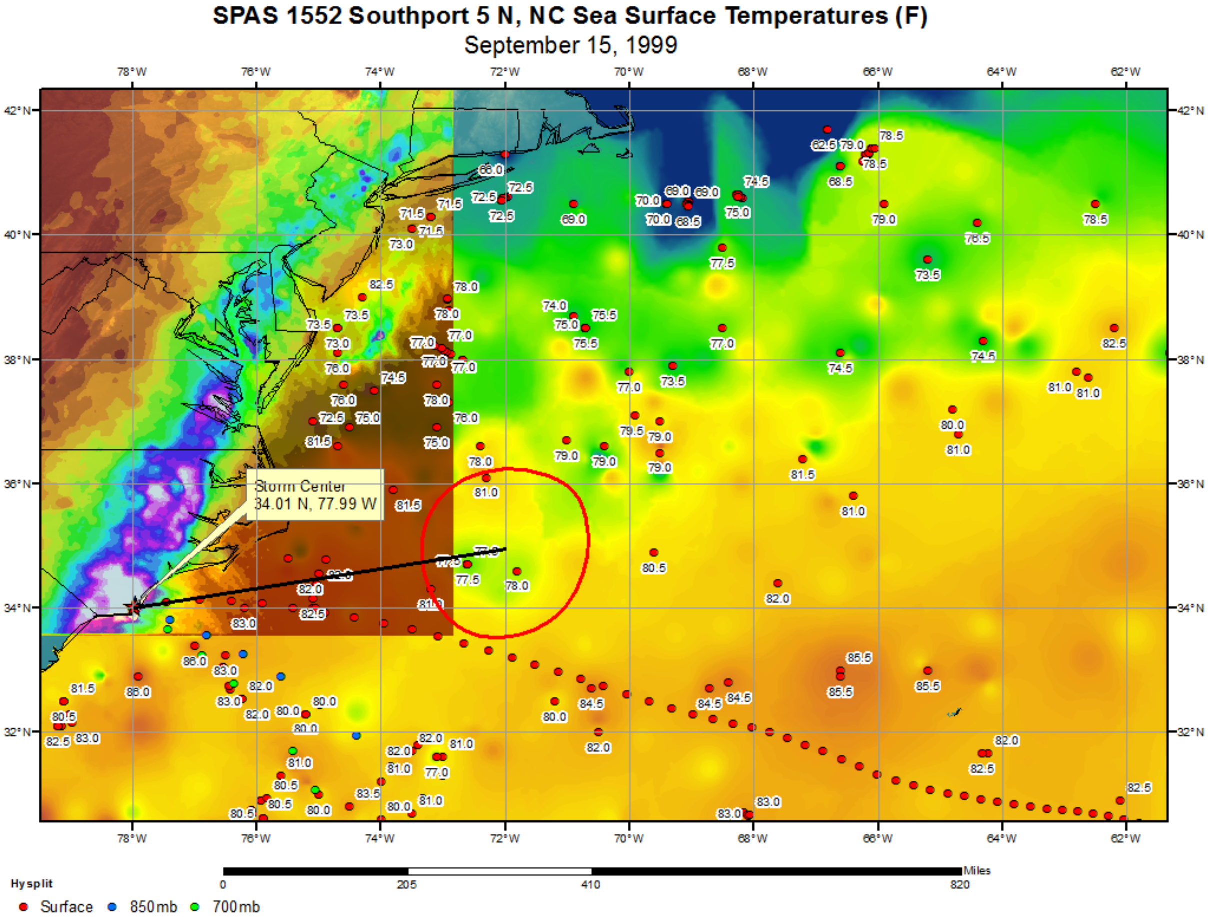


Total 72-hour Precipitation (Inches)
September 14, 1999 0500 UTC - September 17, 1999 0500 UTC
SPAS #1552 - Hurricane Floyd

WJM 09/14/2015


NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 15 Sep 99
CDC1 Meteorological Data
Source ★ at 34.01 N 78.00 W
-35
-30
-25
-20
-15
-85
-80
-75
-70
-65
-60
-55
hPa
701
849
996
700
750
800
850
900
950
1000
12
06
00
18
12
06
00
18
12
06
00
18
09/15
09/14
09/13
Job ID: 183129
Job Start: Mon Nov 9 20:03:43 UTC 2015
Source 1 lat.: 34.005000 lon.: -77.995000 hgts: 0, 1400, 3030 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2099 - reanalysis


SPAS 1552 Southport 5 N, NC Sea Surface Temperatures (F)
September 14, 1999
Storm Center
34.01 N, 77.99 W
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820


SPAS 1552 Southport 5 N, NC Sea Surface Temperatures (F)
September 15, 1999
Storm Center
34.01 N, 77.99 W
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820

Storm Precipitation Analysis System (SPAS) For Storm #1552_2 SPAS-NEXRAD Analysis

General Storm Location: Eastern Seaboard

Storm Dates: September 13, 1999 – September 17, 1999

Event: Hurricane Floyd

DAD Zone 2

Latitude: 37.2750

Longitude: -76.5550

Max. Grid Rainfall Amount: 19.22”

Max. Observed Rainfall Amount: 18.13” at Yorktown, VA

Number of Stations: 974 (430 Daily, 97 Hourly, 46 Hourly Pseudo, 1 Hourly Estimated Pseudo, 397 Supplemental, and 3 Supplemental Estimated)

SPAS Version: 10.0

Base Map Used: Continental United States 2-year 24-hour basemap (conus_0002y24h)

Spatial resolution: 0.3736

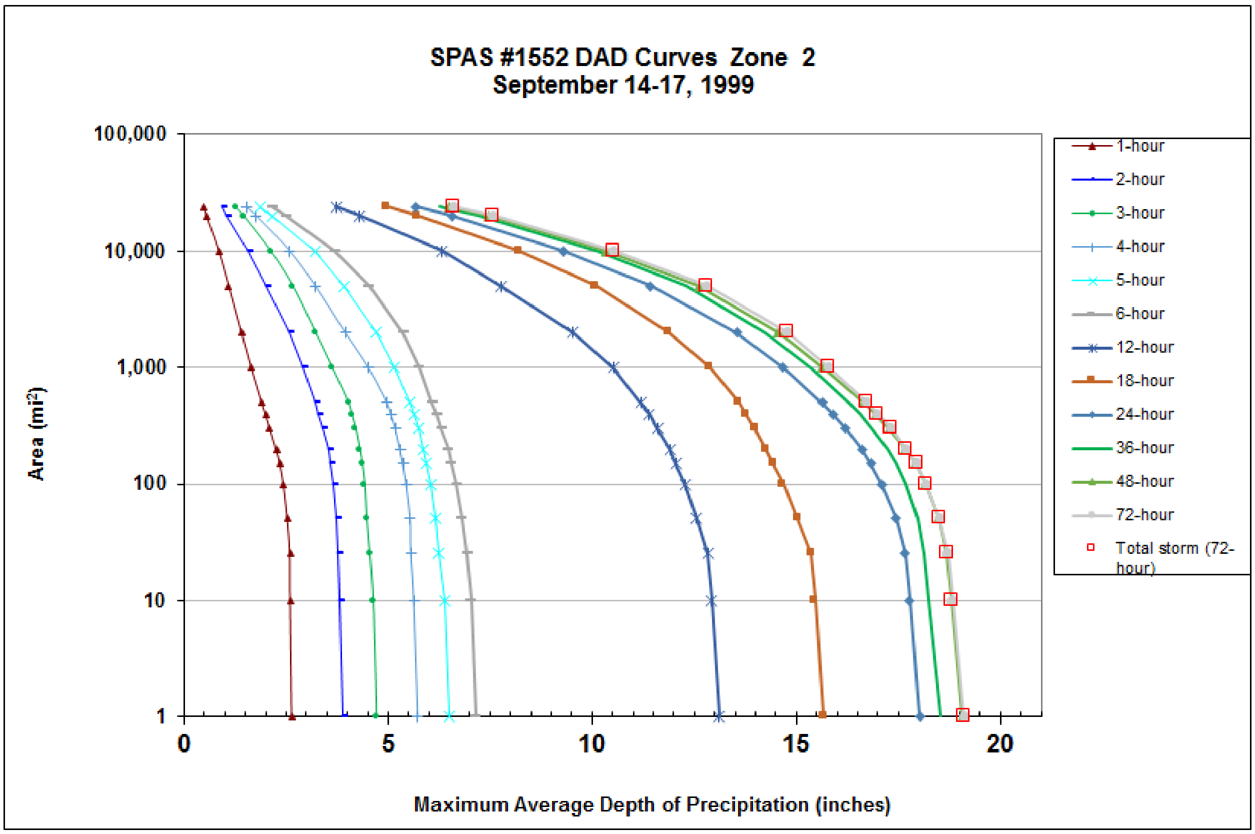
Radar Included: Yes

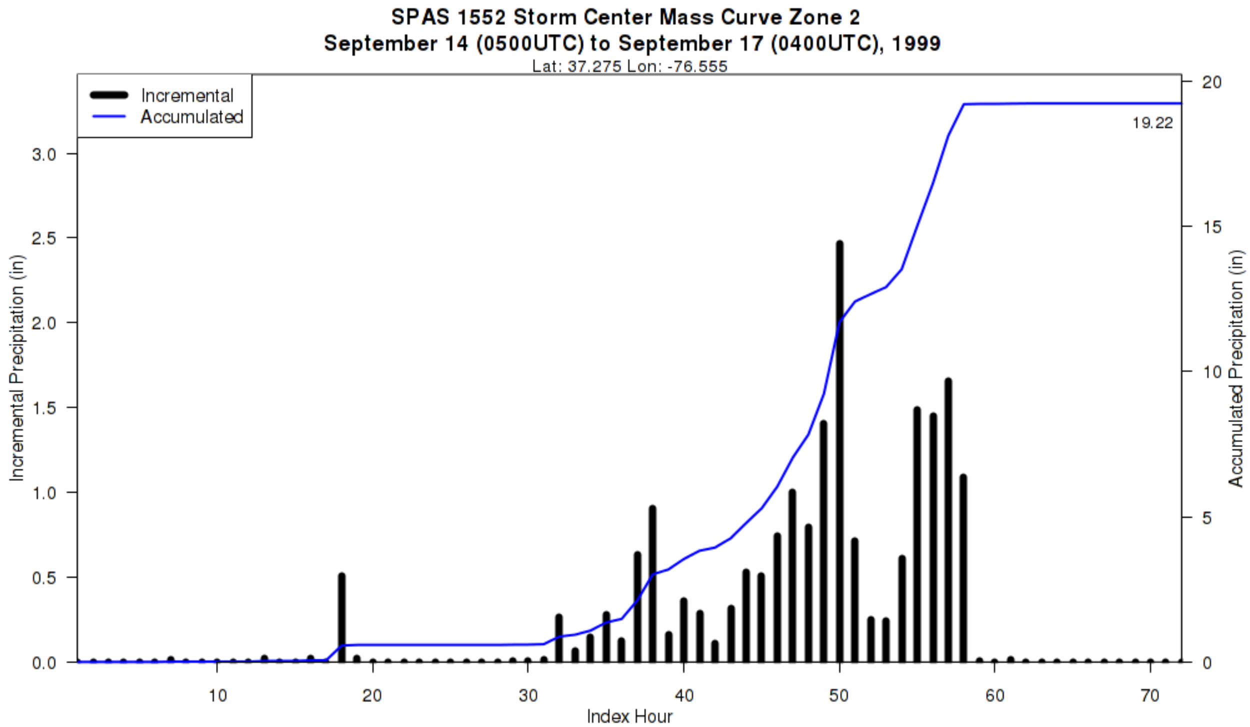
Depth-Area-Duration (DAD) analysis: Yes

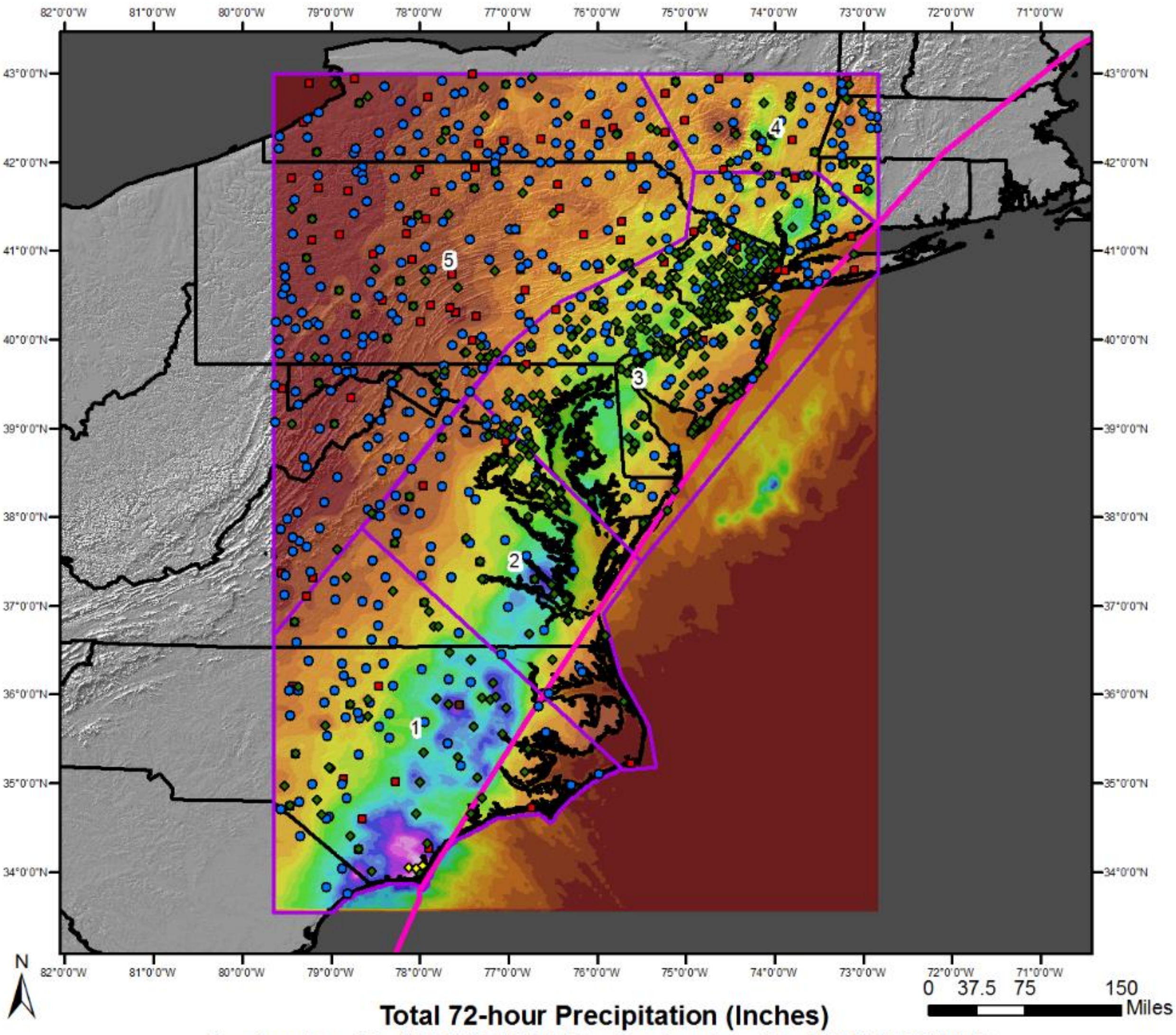
Reliability of results: 397 supplemental stations were added to ensure the data matches what can actually occur and that the data more closely resemble reports from this storm. Many of these stations were incorporated from previous analyses of Hurricane Floyd (SPAS storms 1002 and 1012) along with other storm data reports. Due to the orientation and integrity of the station data, three additional stations were incorporated. Lack of hourly stations in east central North Carolina forced the creation of a radar estimated hourly pseudo station to assist in timing and intensity. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the storm data report, this analysis is deemed quite reliable.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1552_2	-76.5550	37.2750	0	1-Sep	78.00	3.29	0.00	78	3.290	82.81	4.12	0.00	88	4.120	1.252

Storm 1552 - September 14 (0500 UTC) - September 17 (0400 UTC), 1999													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
Area (mi^2)	Duration (hours)												
	1	2	3	4	5	6	12	18	24	36	48	72	Total
0.4	2.67	3.90	4.73	5.76	6.54	7.18	13.19	15.76	18.13	18.64	19.18	19.21	19.21
1	2.65	3.87	4.70	5.73	6.50	7.14	13.12	15.67	18.03	18.53	19.07	19.10	19.10
10	2.61	3.80	4.62	5.63	6.39	7.03	12.93	15.46	17.77	18.25	18.80	18.82	18.82
25	2.60	3.78	4.54	5.56	6.23	6.93	12.83	15.37	17.67	18.14	18.69	18.71	18.71
50	2.54	3.73	4.47	5.54	6.16	6.81	12.56	15.03	17.44	17.99	18.48	18.51	18.51
100	2.44	3.66	4.42	5.44	6.03	6.67	12.27	14.68	17.09	17.68	18.15	18.17	18.17
150	2.35	3.59	4.36	5.36	5.95	6.55	12.05	14.43	16.83	17.47	17.92	17.94	17.94
200	2.26	3.53	4.30	5.29	5.86	6.46	11.90	14.26	16.60	17.22	17.67	17.69	17.69
300	2.11	3.41	4.20	5.18	5.74	6.30	11.61	13.99	16.22	16.86	17.28	17.34	17.34
400	2.00	3.30	4.10	5.07	5.62	6.19	11.39	13.77	15.89	16.54	16.94	17.00	17.00
500	1.91	3.21	4.02	4.97	5.51	6.08	11.19	13.59	15.63	16.29	16.66	16.74	16.74
1,000	1.65	2.90	3.63	4.52	5.16	5.76	10.52	12.89	14.69	15.38	15.66	15.80	15.80
2,000	1.41	2.56	3.22	3.95	4.72	5.36	9.53	11.89	13.55	14.24	14.56	14.79	14.79
5,000	1.10	2.03	2.67	3.22	3.91	4.52	7.76	10.09	11.43	12.31	12.60	12.81	12.81
10,000	0.85	1.57	2.13	2.59	3.20	3.69	6.31	8.20	9.29	10.10	10.33	10.51	10.51
20,000	0.55	1.06	1.47	1.77	2.17	2.50	4.31	5.73	6.56	7.24	7.45	7.58	7.58
23,888	0.48	0.92	1.27	1.52	1.88	2.16	3.72	4.98	5.68	6.27	6.49	6.60	6.60




SPAS 1552 Storm Center Mass Curve Zone 2
September 14 (0500UTC) to September 17 (0400UTC), 1999
Lat: 37.275 Lon: -76.555
Incremental
Accumulated
19.22
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
15
20
10
20
30
40
50
60
70



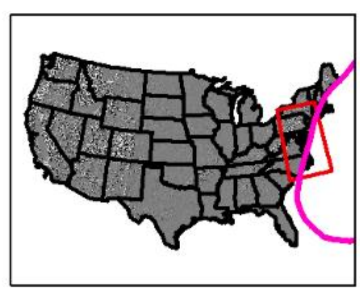
Total 72-hour Precipitation (Inches)
September 14, 1999 0500 UTC - September 17, 1999 0500 UTC
SPAS #1552 - Hurricane Floyd

Precipitation (inches)

- 0.00 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 4.00
- 4.01 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 11.00
- 11.01 - 12.00
- 12.01 - 13.00
- 13.01 - 14.00
- 14.01 - 15.00
- 15.01 - 16.00
- 16.01 - 17.00
- 17.01 - 18.00
- 18.01 - 19.00
- 19.01 - 20.00
- 20.01 - 21.00
- 21.01 - 22.00
- 22.01 - 23.00
- 23.01 - 24.00
- 24.01 - 25.00

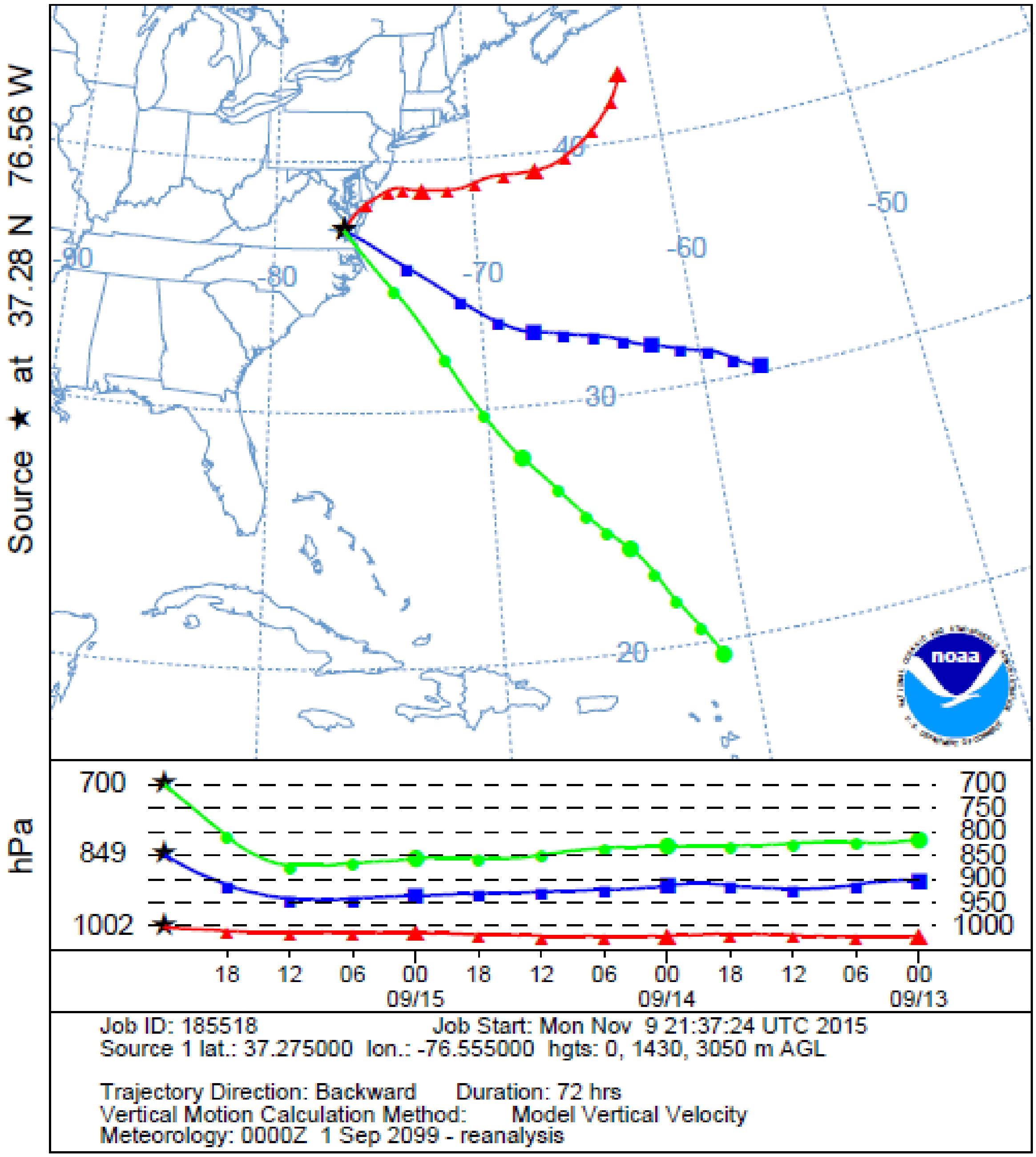
Stations

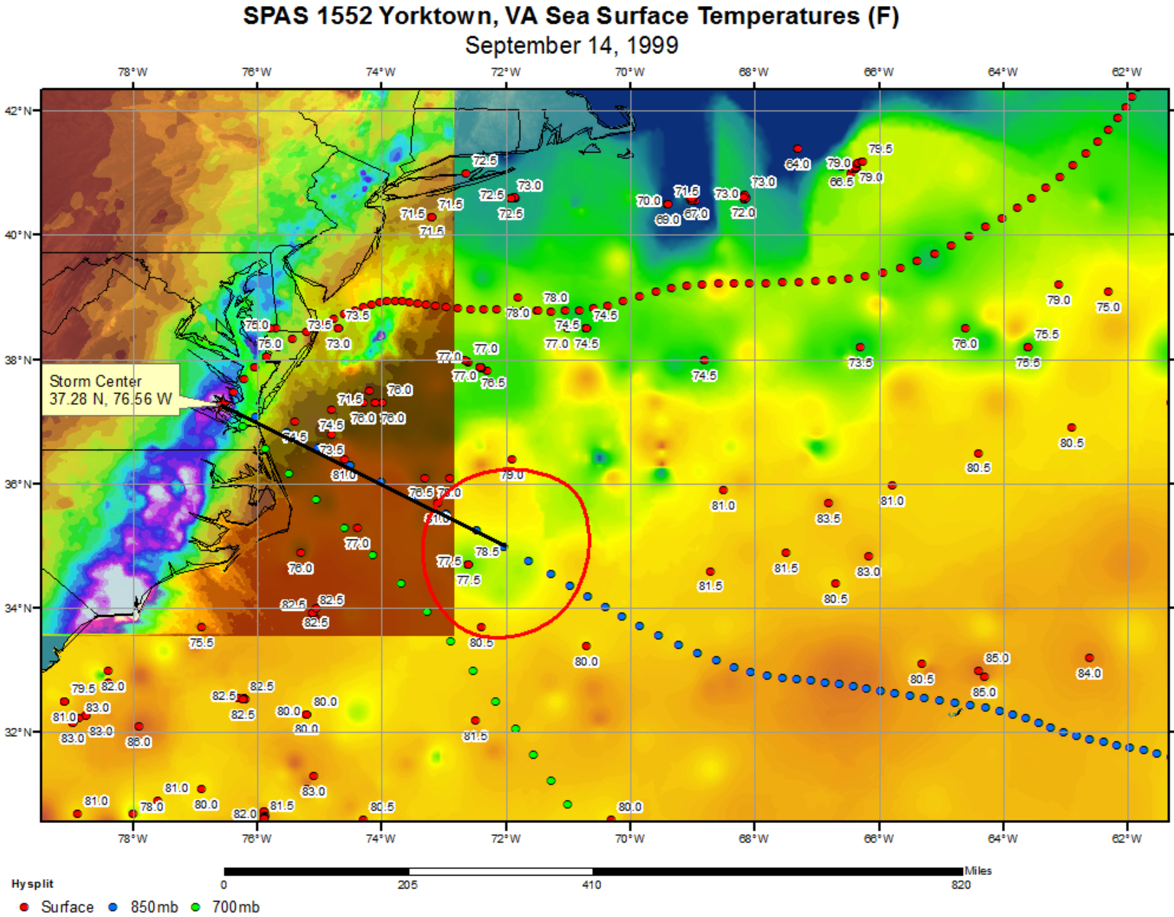
- Daily
- Hourly
- Hourly Estimated Pseudo
- Hourly Pseudo
- Supplemental
- Supplemental Estimated



WJM 09/14/2015

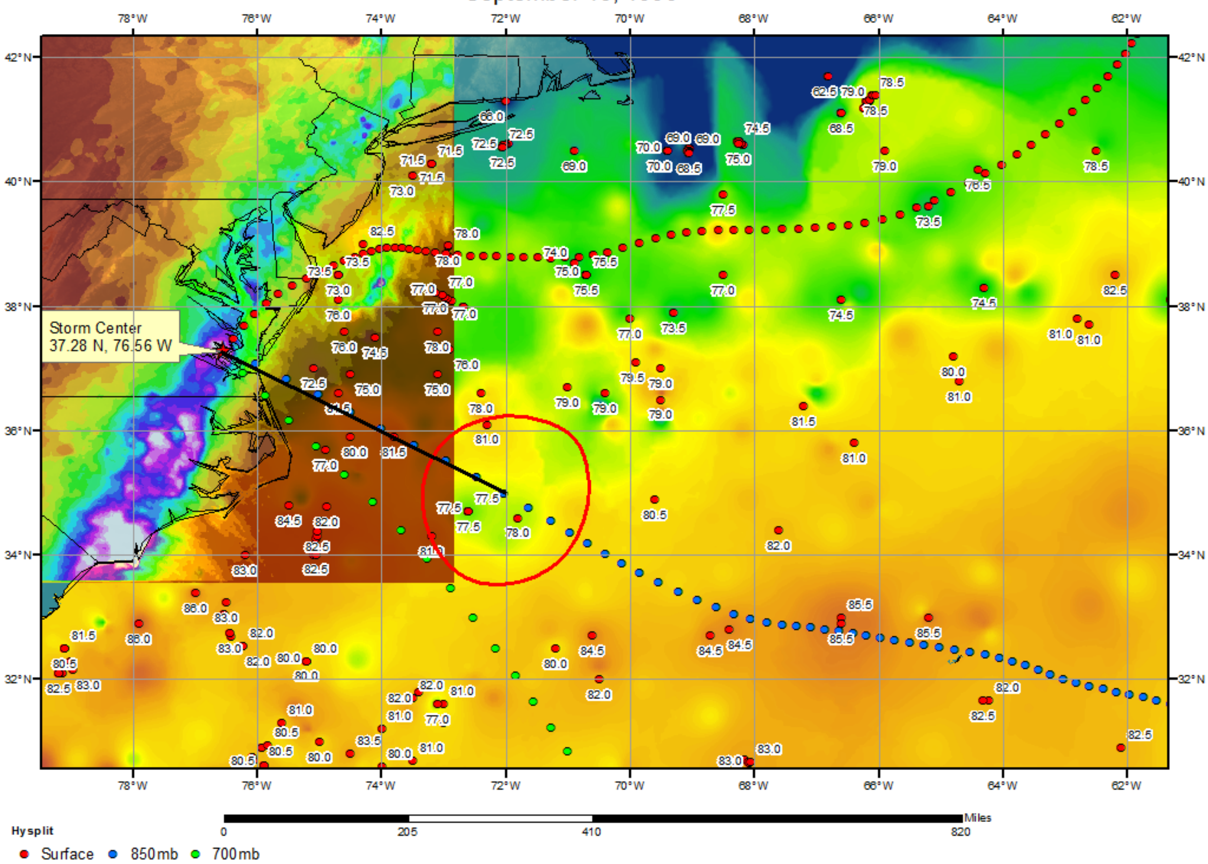
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 16 Sep 99
CDC1 Meteorological Data




SPAS 1552 Yorktown, VA Sea Surface Temperatures (F)
September 14, 1999
Storm Center
37.28 N, 76.56 W
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820

SPAS 1552 Yorktown, VA Sea Surface Temperatures (F)

September 15, 1999



Storm Precipitation Analysis System (SPAS) For Storm #1552_3 SPAS-NEXRAD Analysis

General Storm Location: Eastern Seaboard-Pompton Lake, NJ center

Storm Dates: September 13, 1999 – September 17, 1999

Event: Hurricane Floyd

DAD Zone 3

Latitude: 40.9950

Longitude: -74.2850

Max. Grid Rainfall Amount: 14.62”

Max. Observed Rainfall Amount: 14.45” at Pompton Lake, NJ

Number of Stations: 974 (430 Daily, 97 Hourly, 46 Hourly Pseudo, 1 Hourly Estimated Pseudo, 397 Supplemental, and 3 Supplemental Estimated)

SPAS Version: 10.0

Base Map Used: Continental United States 2-year 24-hour basemap (conus_0002y24h)

Spatial resolution: 0.3736

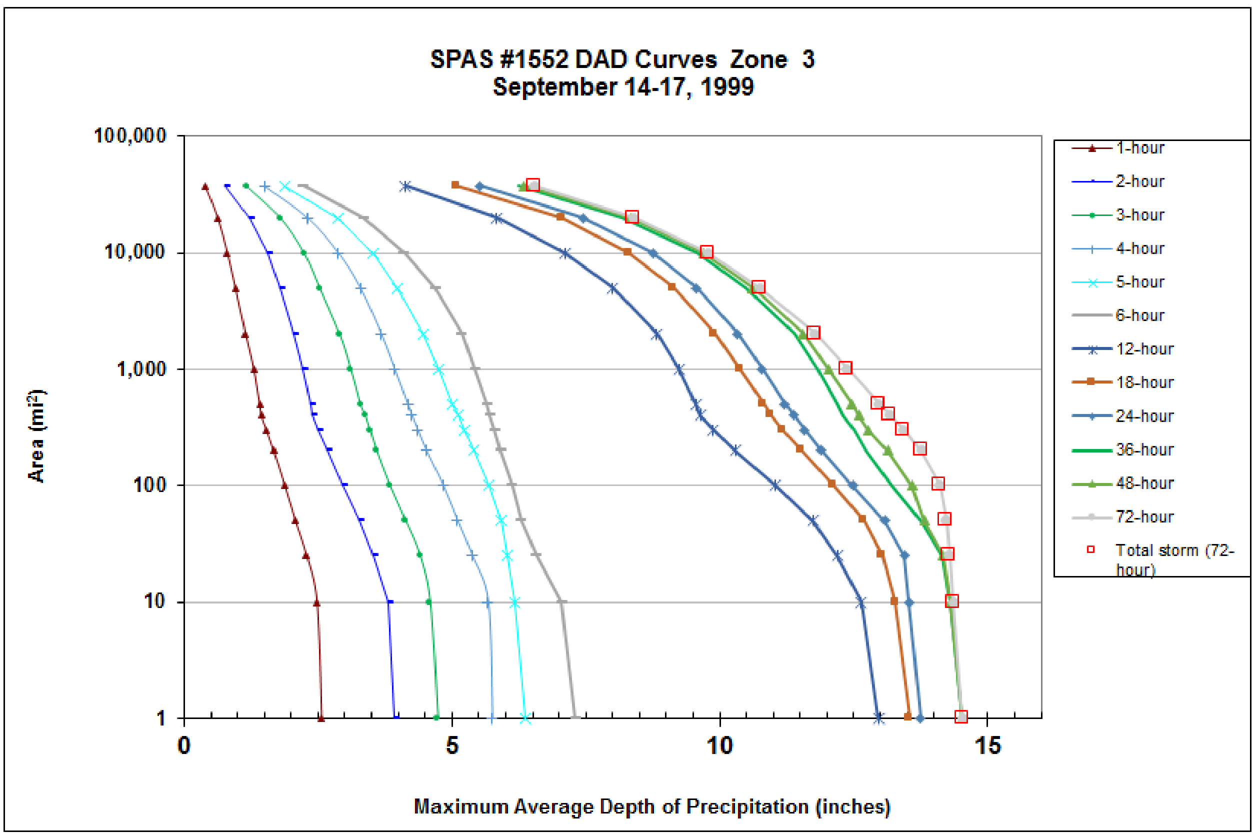
Radar Included: Yes

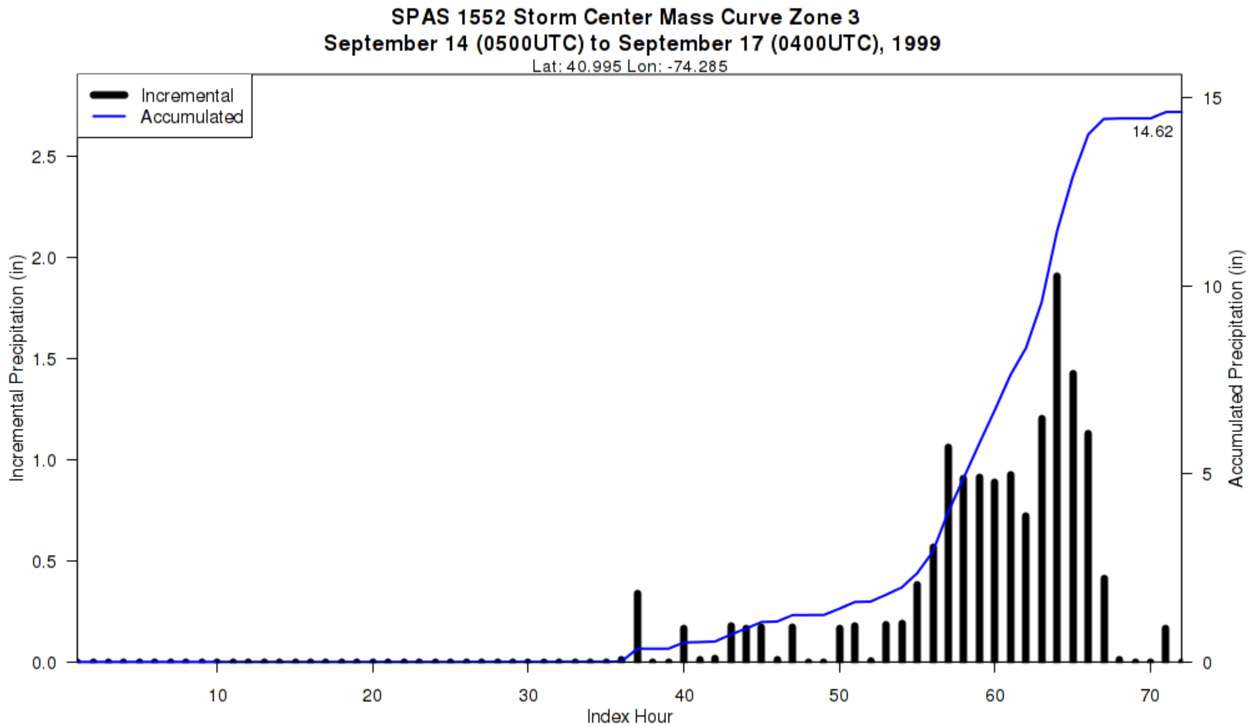
Depth-Area-Duration (DAD) analysis: Yes

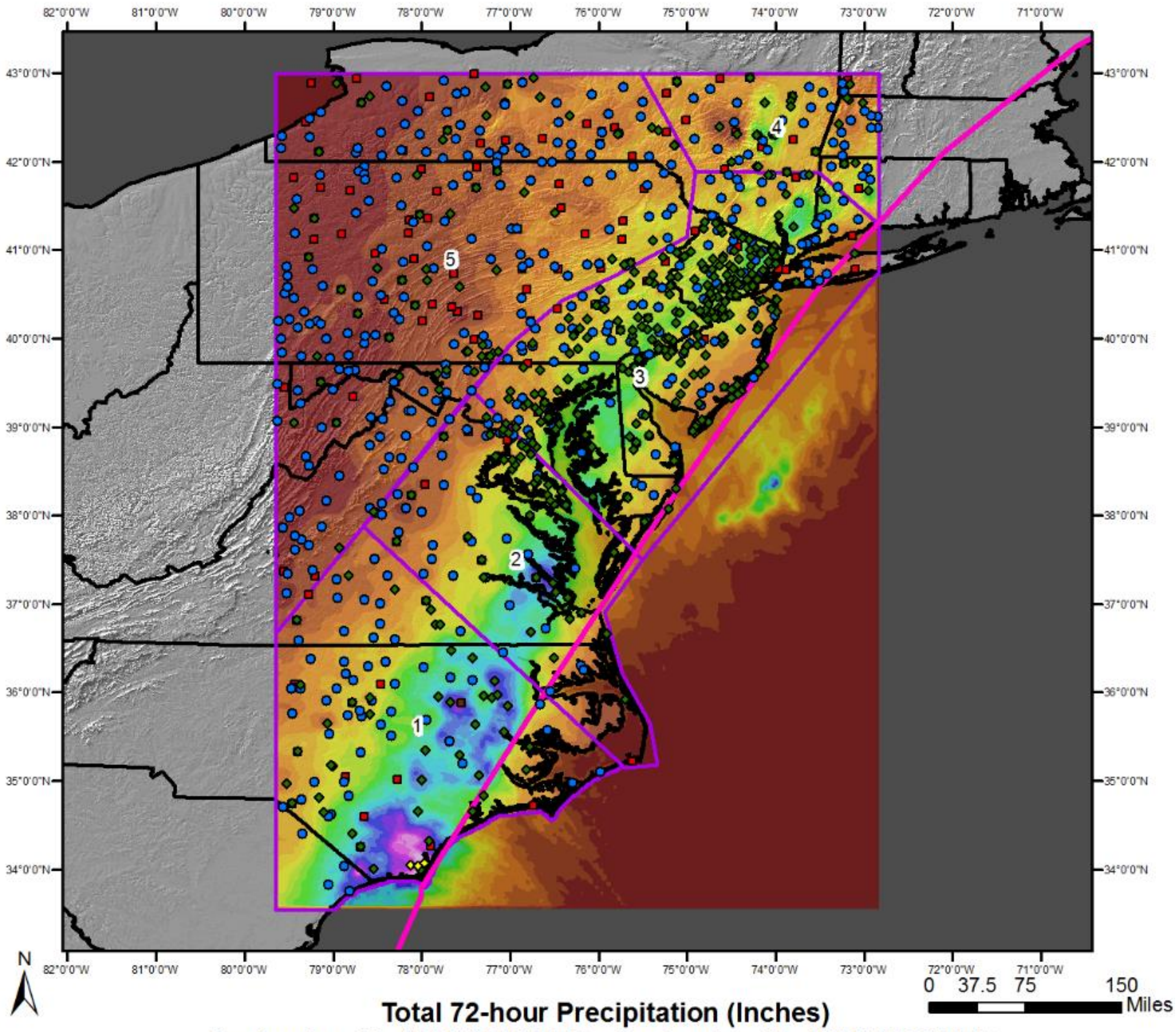
Reliability of results: 397 supplemental stations were added to ensure the data matches what can actually occur and that the data more closely resemble reports from this storm. Many of these stations were incorporated from previous analyses of Hurricane Floyd (SPAS storms 1002 and 1012) along with other storm data reports. Due to the orientation and integrity of the station data, three additional stations were incorporated. Lack of hourly stations in east central North Carolina forced the creation of a radar estimated hourly pseudo station to assist in timing and intensity. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the storm data report, this analysis is deemed quite reliable.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1552_3	-74.2850	40.9950	214	1-Sep	77.50	3.22	0.06	77	3.155	82.34	4.03	0.06	87	3.970	1.258

Storm 1552 - September 14 (0500 UTC) - September 17 (0400 UTC), 1999													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
Area (mi^2)	Duration (hours)												
	1	2	3	4	5	6	12	18	24	36	48	72	Total
0.4	2.59	3.96	4.77	5.79	6.42	7.37	13.04	13.64	13.83	14.60	14.61	14.61	14.61
1	2.57	3.93	4.73	5.75	6.37	7.30	12.96	13.54	13.74	14.51	14.52	14.53	14.53
10	2.48	3.80	4.59	5.67	6.17	7.04	12.64	13.27	13.53	14.28	14.30	14.35	14.35
25	2.29	3.54	4.40	5.37	6.03	6.58	12.20	13.04	13.45	14.14	14.17	14.28	14.28
50	2.08	3.26	4.13	5.10	5.91	6.29	11.74	12.69	13.08	13.76	13.82	14.23	14.23
100	1.88	2.96	3.84	4.83	5.69	6.12	11.05	12.12	12.48	13.21	13.59	14.12	14.12
200	1.67	2.67	3.59	4.52	5.40	5.91	10.29	11.52	11.90	12.74	13.14	13.76	13.76
300	1.54	2.51	3.47	4.36	5.23	5.79	9.87	11.17	11.59	12.49	12.77	13.43	13.43
400	1.44	2.40	3.38	4.25	5.11	5.71	9.64	10.96	11.38	12.31	12.59	13.17	13.17
500	1.41	2.35	3.29	4.17	5.02	5.65	9.55	10.81	11.22	12.19	12.46	12.97	12.97
1,000	1.30	2.23	3.11	3.93	4.75	5.43	9.24	10.37	10.79	11.82	12.03	12.38	12.38
2,000	1.15	2.05	2.90	3.68	4.47	5.19	8.83	9.90	10.33	11.38	11.56	11.78	11.78
5,000	0.96	1.79	2.53	3.29	3.99	4.69	8.00	9.14	9.57	10.48	10.62	10.75	10.75
10,000	0.81	1.57	2.24	2.88	3.52	4.10	7.11	8.30	8.75	9.56	9.69	9.78	9.78
20,000	0.63	1.23	1.80	2.31	2.86	3.35	5.84	7.04	7.45	8.19	8.32	8.40	8.40
37,520	0.40	0.78	1.17	1.51	1.88	2.22	4.13	5.08	5.53	6.24	6.35	6.53	6.53




SPAS 1552 Storm Center Mass Curve Zone 3
September 14 (0500UTC) to September 17 (0400UTC), 1999
Lat: 40.995 Lon: -74.285
Incremental
Accumulated
14.62
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour



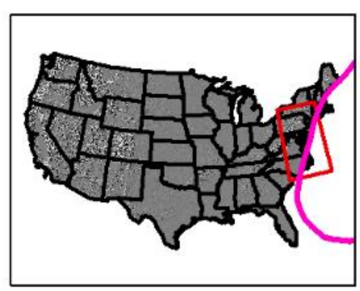
Total 72-hour Precipitation (Inches)
September 14, 1999 0500 UTC - September 17, 1999 0500 UTC
SPAS #1552 - Hurricane Floyd

Precipitation (inches)

0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00
20.01 - 21.00
21.01 - 22.00
22.01 - 23.00
23.01 - 24.00
24.01 - 25.00

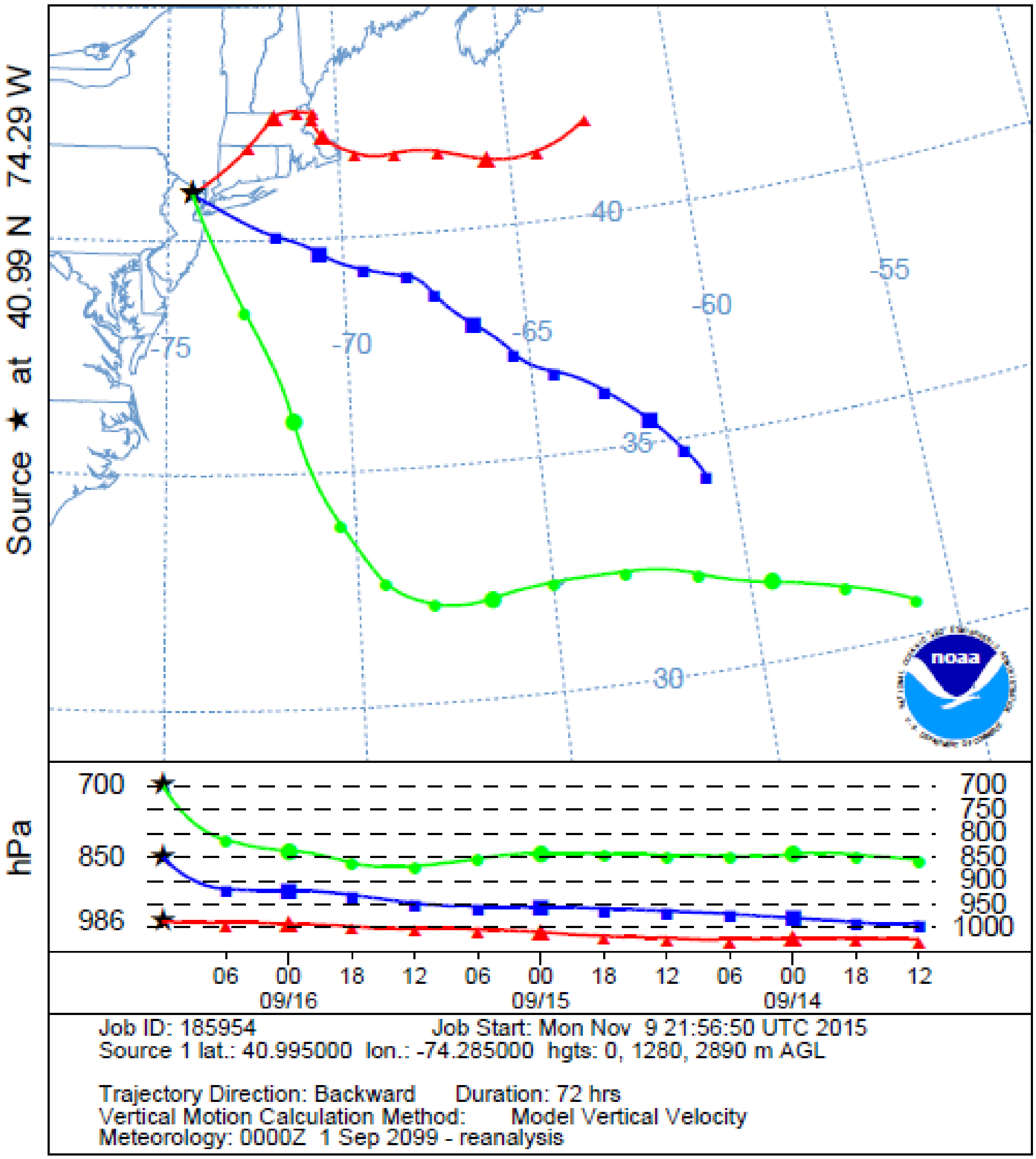
Stations

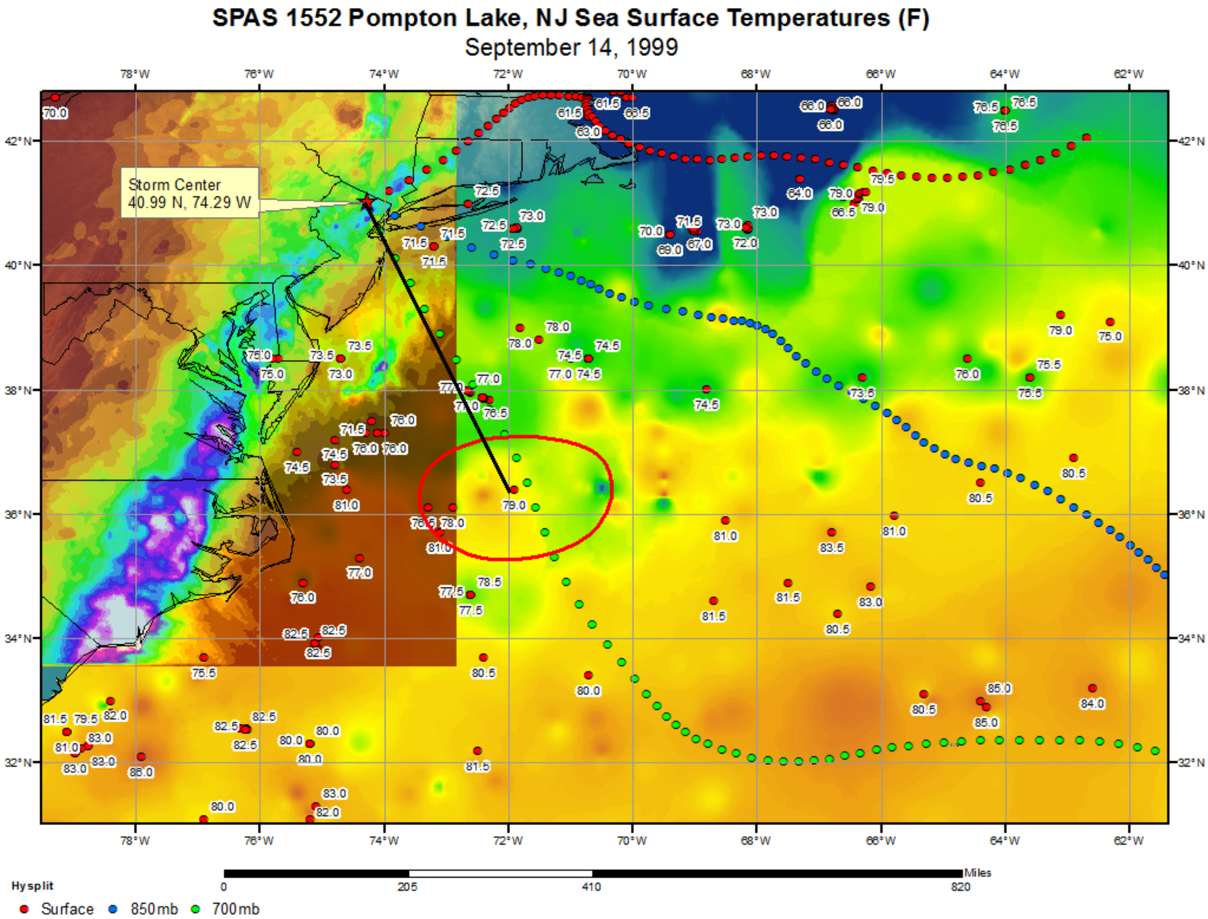
Daily
Hourly
Hourly Estimated Pseudo
Hourly Pseudo
Supplemental
Supplemental Estimated

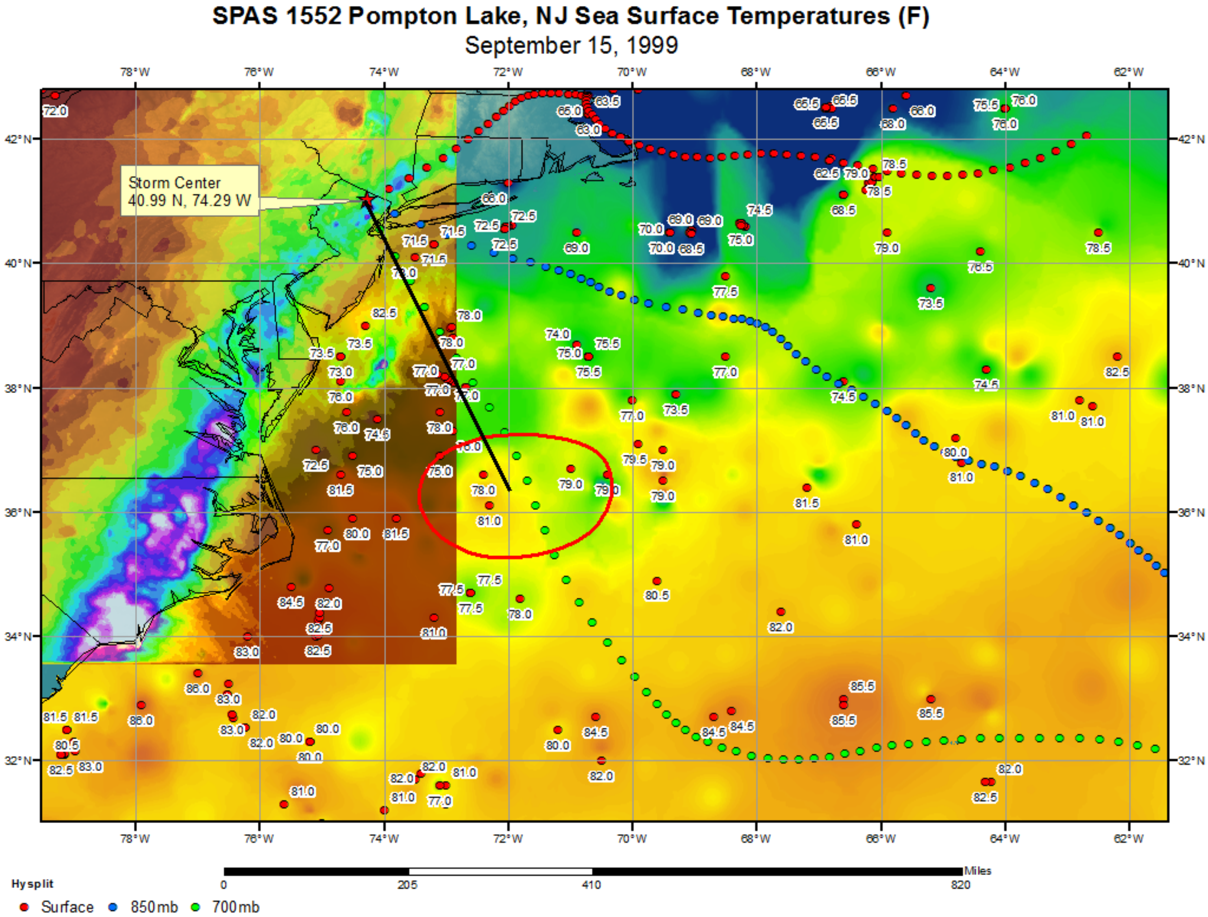


WJM 09/14/2015

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 16 Sep 99
CDC1 Meteorological Data




SPAS 1552 Pompton Lake, NJ Sea Surface Temperatures (F)
September 14, 1999
Storm Center
40.99 N, 74.29 W
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820


SPAS 1552 Pompton Lake, NJ Sea Surface Temperatures (F)
September 15, 1999
Storm Center
40.99 N, 74.29 W
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820

Storm Precipitation Analysis System (SPAS) For Storm #1552_4 SPAS-NEXRAD Analysis

General Storm Location: Eastern Seaboard-Cairo, NY center

Storm Dates: September 13, 1999 – September 17, 1999

Event: Hurricane Floyd

DAD Zone 4

Latitude: 42.2950

Longitude: -74.0050

Max. Grid Rainfall Amount: 11.71”

Max. Observed Rainfall Amount: 11.74” Cairo, NY

Number of Stations: 974 (430 Daily, 97 Hourly, 46 Hourly Pseudo, 1 Hourly Estimated Pseudo, 397 Supplemental, and 3 Supplemental Estimated)

SPAS Version: 10.0

Base Map Used: Continental United States 2-year 24-hour basemap (conus_0002y24h)

Spatial resolution: 0.3736

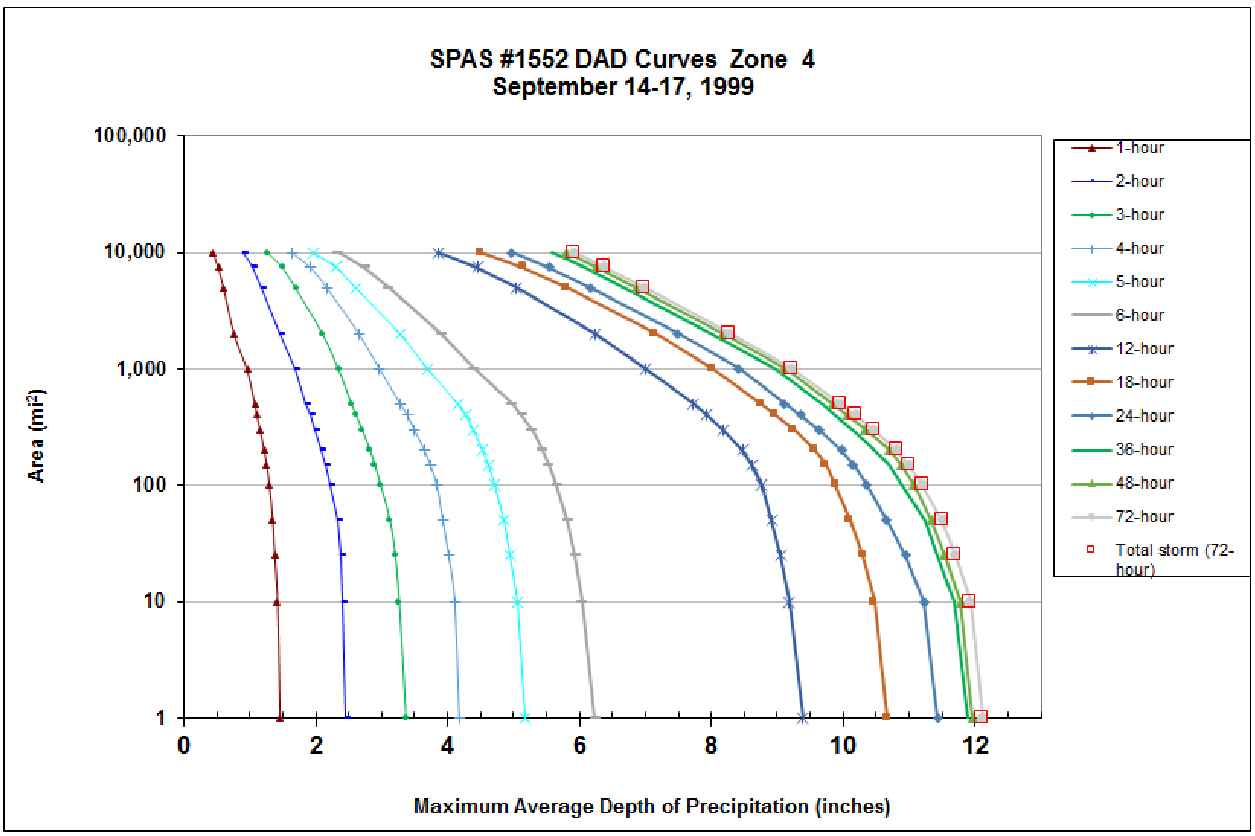
Radar Included: Yes

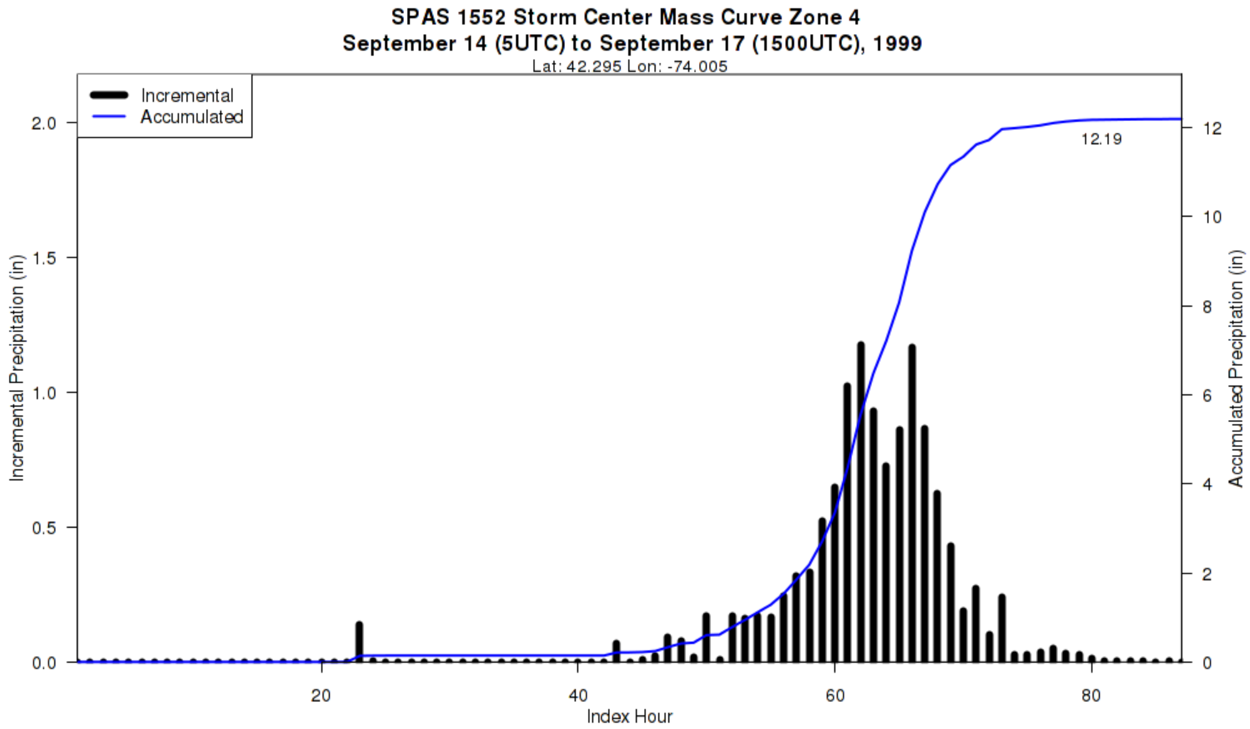
Depth-Area-Duration (DAD) analysis: Yes

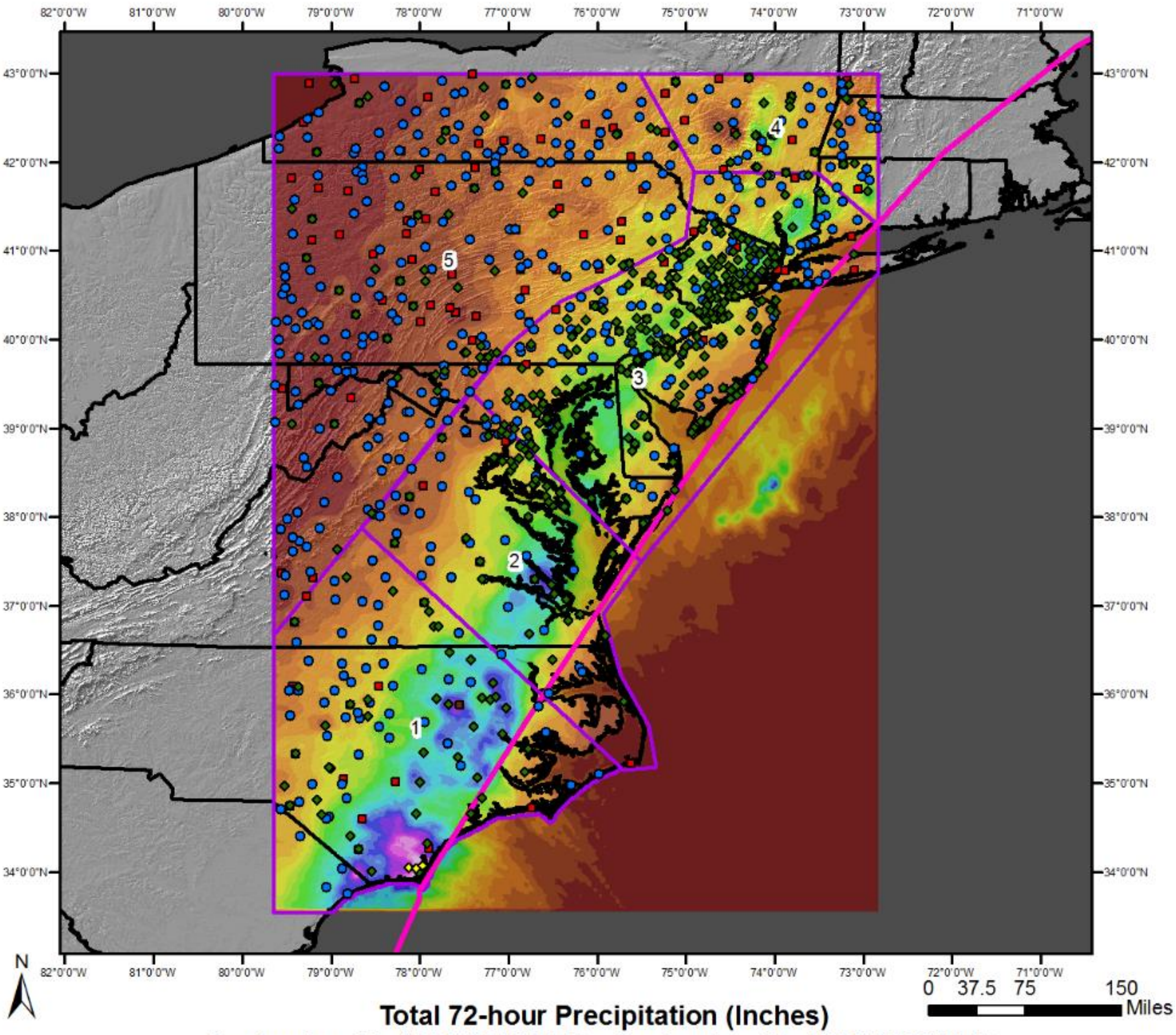
Reliability of results: 397 supplemental stations were added to ensure the data matches what can actually occur and that the data more closely resemble reports from this storm. Many of these stations were incorporated from previous analyses of Hurricane Floyd (SPAS storms 1002 and 1012) along with other storm data reports. Due to the orientation and integrity of the station data, three additional stations were incorporated. Lack of hourly stations in east central North Carolina forced the creation of a radar estimated hourly pseudo station to assist in timing and intensity. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the storm data report, this analysis is deemed quite reliable.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1552_4	-74.0050	42.2950	412	1-Sep	77.50	3.22	0.11	77	3.105	82.34	4.03	0.12	87	3.910	1.259

Storm 1552 - September 14 (0500 UTC) - September 17 (0400 UTC), 1999													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
Area (mi^2)	Duration (hours)												
	1	2	3	4	5	6	12	18	24	36	48	72	Total
0.4	1.48	2.46	3.40	4.21	5.22	6.28	9.47	10.74	11.51	11.97	12.03	12.18	12.18
1	1.46	2.45	3.37	4.18	5.17	6.23	9.39	10.67	11.43	11.90	11.96	12.11	12.11
10	1.42	2.40	3.27	4.11	5.05	6.04	9.18	10.47	11.22	11.69	11.78	11.93	11.93
25	1.38	2.38	3.21	4.02	4.95	5.93	9.05	10.30	10.95	11.43	11.54	11.70	11.70
50	1.35	2.33	3.13	3.93	4.86	5.82	8.91	10.11	10.66	11.24	11.34	11.50	11.50
100	1.30	2.22	2.99	3.84	4.71	5.66	8.77	9.88	10.36	10.90	11.07	11.20	11.20
150	1.26	2.14	2.90	3.74	4.63	5.53	8.62	9.73	10.15	10.68	10.88	11.00	11.00
200	1.22	2.08	2.83	3.65	4.54	5.44	8.47	9.57	9.98	10.49	10.70	10.81	10.81
300	1.16	1.98	2.71	3.50	4.39	5.27	8.18	9.25	9.63	10.14	10.34	10.46	10.46
400	1.11	1.91	2.62	3.39	4.27	5.12	7.93	8.97	9.35	9.87	10.07	10.19	10.19
500	1.08	1.86	2.55	3.29	4.16	4.97	7.72	8.75	9.11	9.67	9.84	9.96	9.96
1,000	0.96	1.69	2.35	2.97	3.70	4.40	7.00	8.01	8.42	8.95	9.11	9.22	9.22
2,000	0.77	1.46	2.11	2.66	3.28	3.90	6.23	7.15	7.49	7.99	8.18	8.28	8.28
5,000	0.61	1.19	1.70	2.17	2.62	3.10	5.04	5.81	6.16	6.66	6.86	6.98	6.98
7,500	0.53	1.05	1.50	1.92	2.31	2.74	4.46	5.15	5.54	6.10	6.27	6.39	6.39
10,000	0.45	0.90	1.28	1.64	1.97	2.34	3.85	4.50	4.98	5.59	5.79	5.92	5.92




SPAS 1552 Storm Center Mass Curve Zone 4
September 14 (5UTC) to September 17 (1500UTC), 1999
Lat: 42.295 Lon: -74.005
Incremental
Accumulated
12.19
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
2
4
6
8
10
12
20
40
60
80



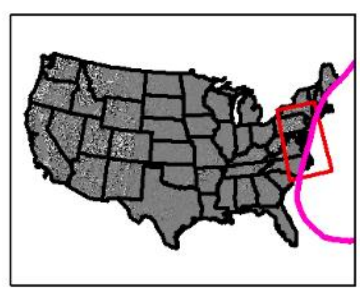
Total 72-hour Precipitation (Inches)
September 14, 1999 0500 UTC - September 17, 1999 0500 UTC
SPAS #1552 - Hurricane Floyd

Precipitation (inches)

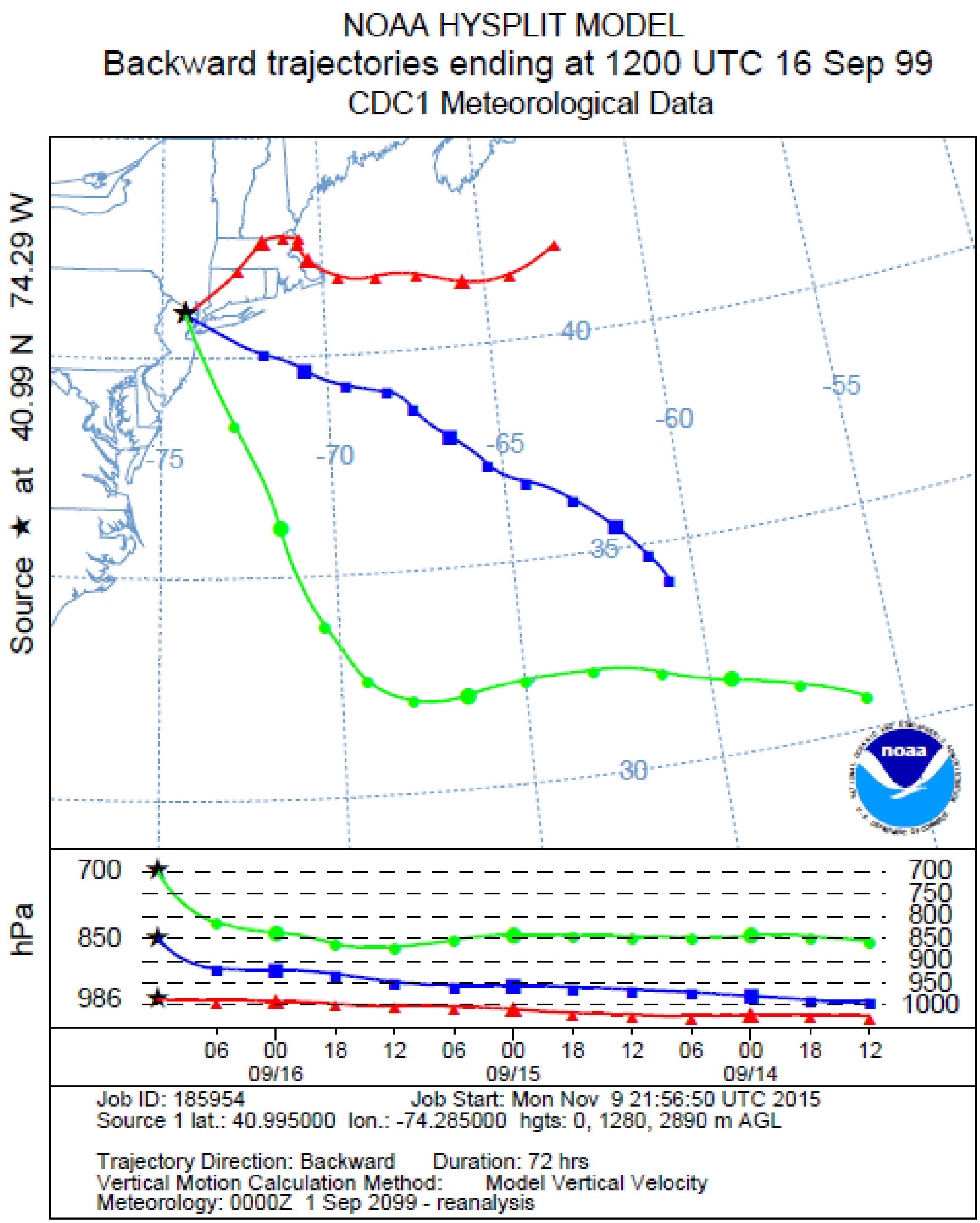
- 0.00 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 4.00
- 4.01 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 11.00
- 11.01 - 12.00
- 12.01 - 13.00
- 13.01 - 14.00
- 14.01 - 15.00
- 15.01 - 16.00
- 16.01 - 17.00
- 17.01 - 18.00
- 18.01 - 19.00
- 19.01 - 20.00
- 20.01 - 21.00
- 21.01 - 22.00
- 22.01 - 23.00
- 23.01 - 24.00
- 24.01 - 25.00

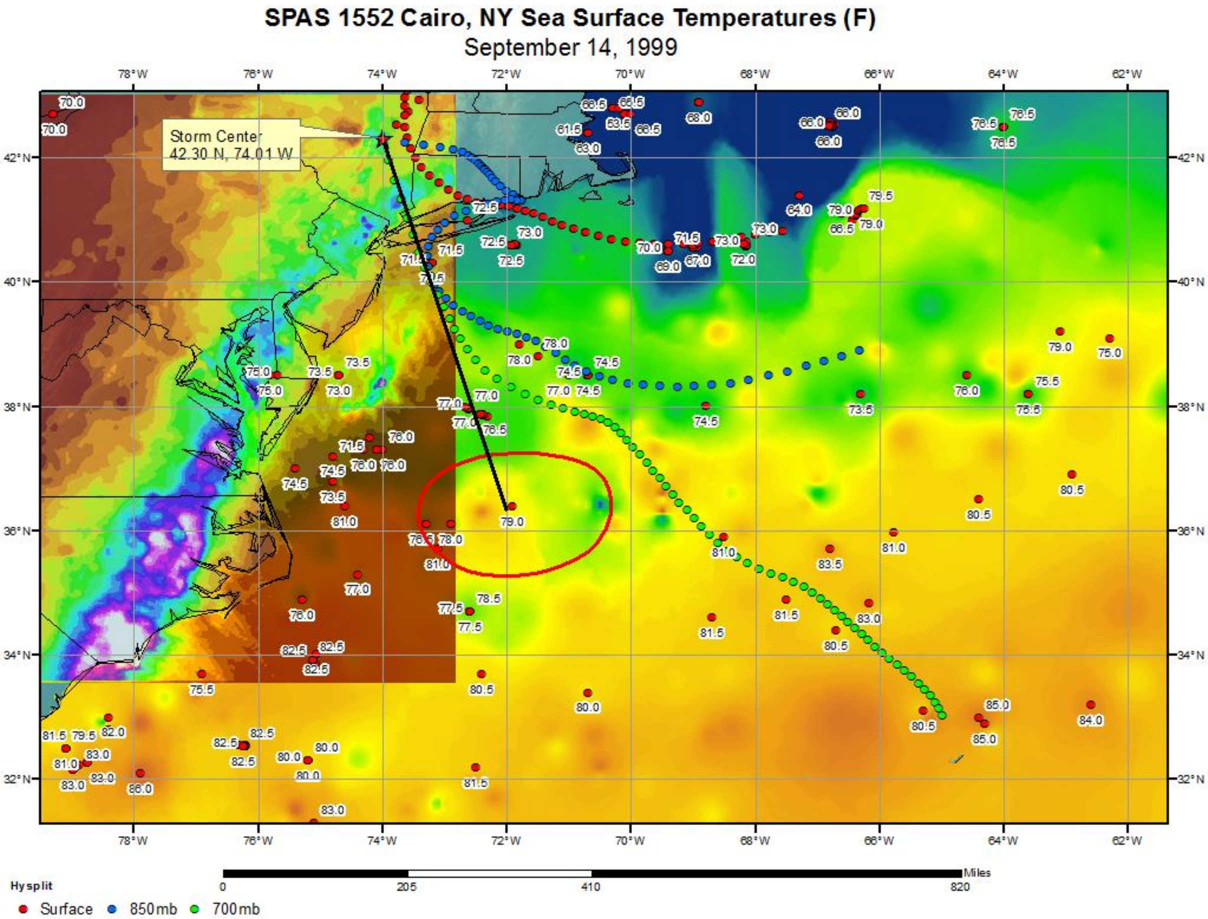
Stations

- Daily
- Hourly
- Hourly Estimated Pseudo
- Hourly Pseudo
- Supplemental
- Supplemental Estimated

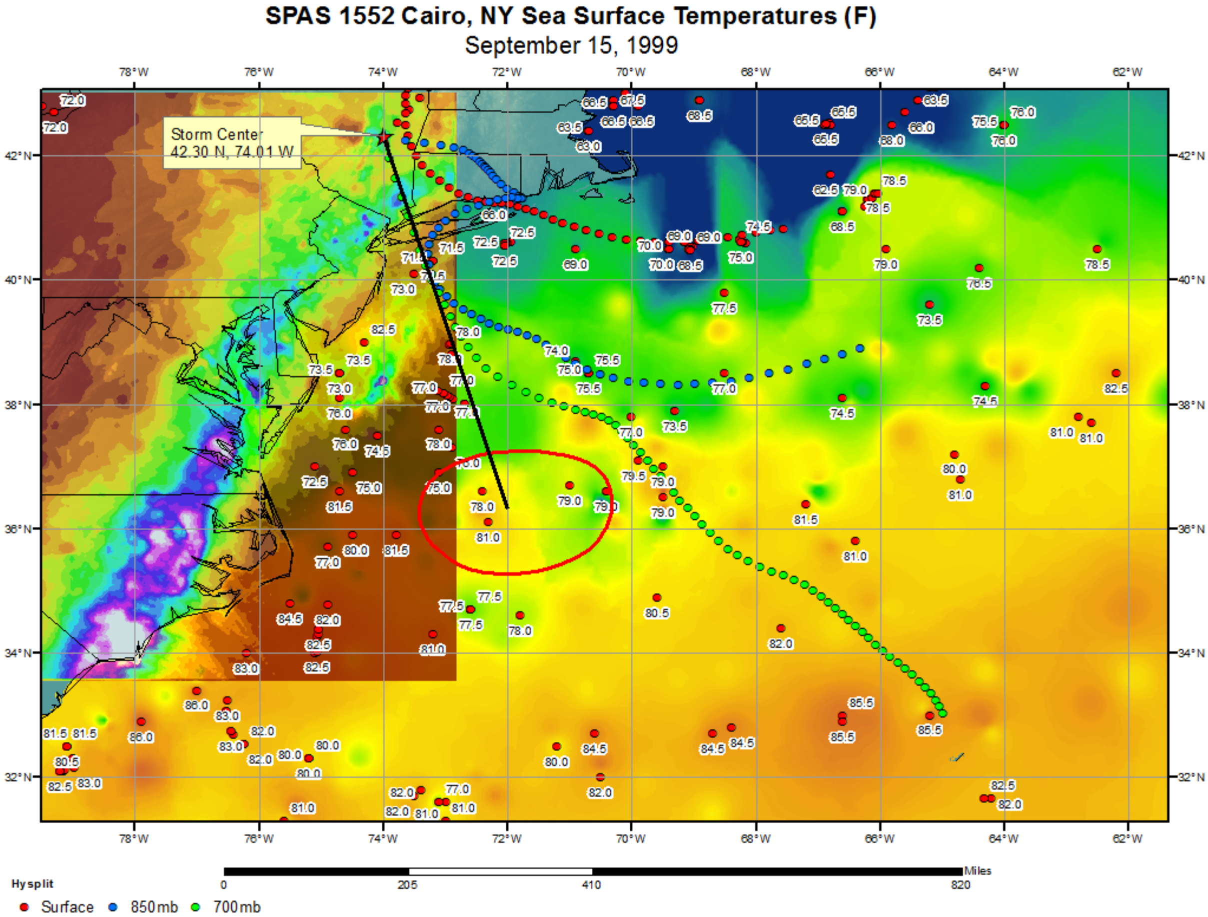


WJM 09/14/2015


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 16 Sep 99
CDC1 Meteorological Data
Source ★ at 40.99 N 74.29 W
-75
-70
-65
-60
-55
40
35
30
hPa
700
850
986
700
750
800
850
900
950
1000
06 00 18 12 06 00 18 12 06 00 18 12
09/16
09/15
09/14
Job ID: 185954 Job Start: Mon Nov 9 21:56:50 UTC 2015
Source 1 lat.: 40.995000 lon.: -74.285000 hgts: 0, 1280, 2890 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2099 - reanalysis



SPAS 1552 Cairo, NY Sea Surface Temperatures (F)
September 14, 1999
Storm Center
42.30 N, 74.01 W
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820


SPAS 1552 Cairo, NY Sea Surface Temperatures (F)
September 15, 1999
Storm Center
42.30 N, 74.01 W
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820

Storm Precipitation Analysis System (SPAS) For Storm #1535_1 SPAS-NEXRAD Analysis

General Storm Location: MidAtlantic States-Hurricane Isabel

Storm Dates: September 17 – September 20, 2003

Event: Hurricane Isabel

DAD Zone 1

Latitude: 35.8625

Longitude: -76.5042

Max. Grid Rainfall Amount: 7.96”

Max. Observed Rainfall Amount: 7.74”

Number of Stations: 1085 (681 Daily, 157 Hourly, 51 Hourly Pseudo, and 196 Supplemental)

SPAS Version: 10.0

Basemap: Mean annual maximum 48-hour precipitation associated with MLCs

Spatial resolution: 0.2606

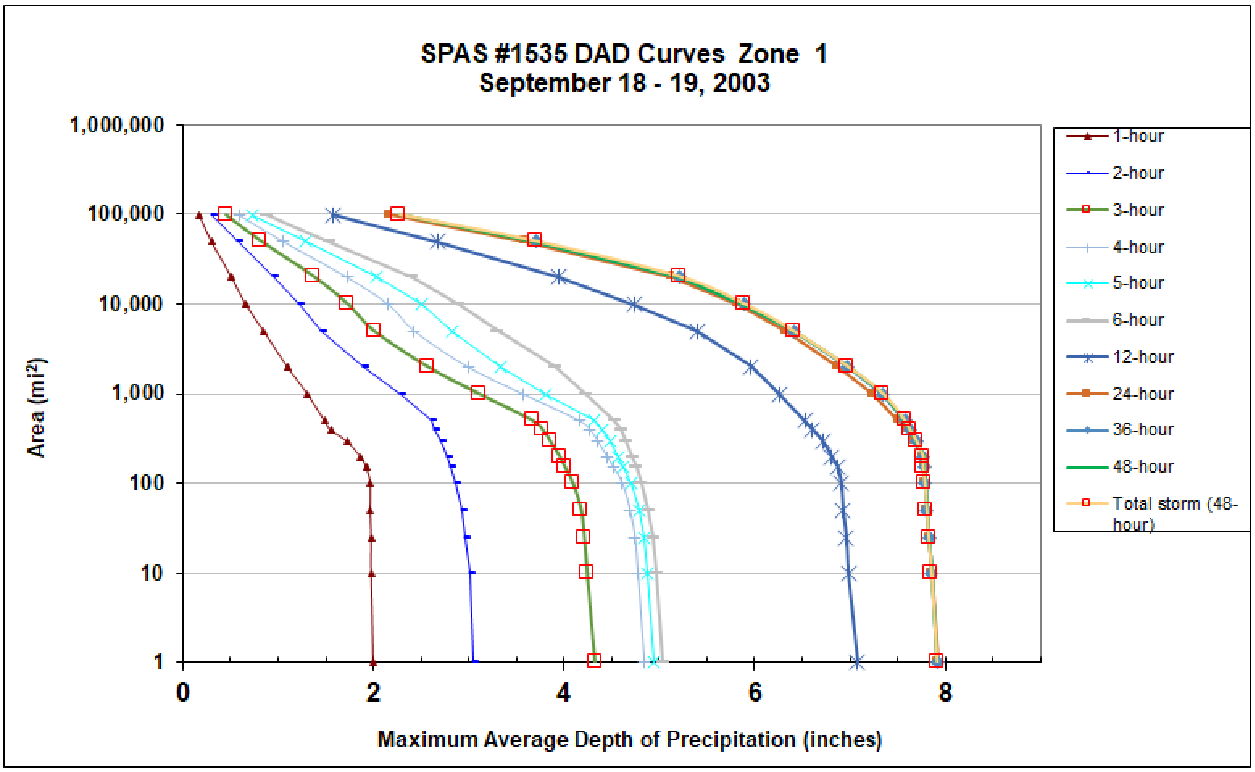
Radar Included: Yes

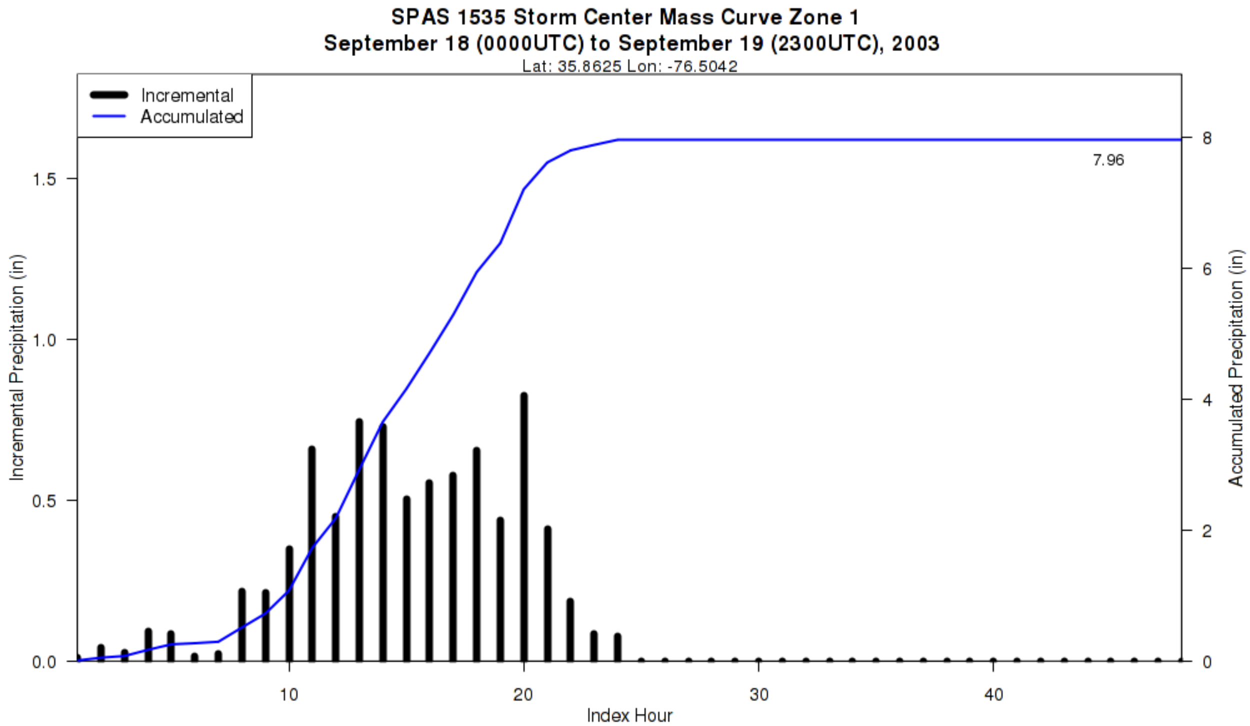
Depth-Area-Duration (DAD) analysis: Yes

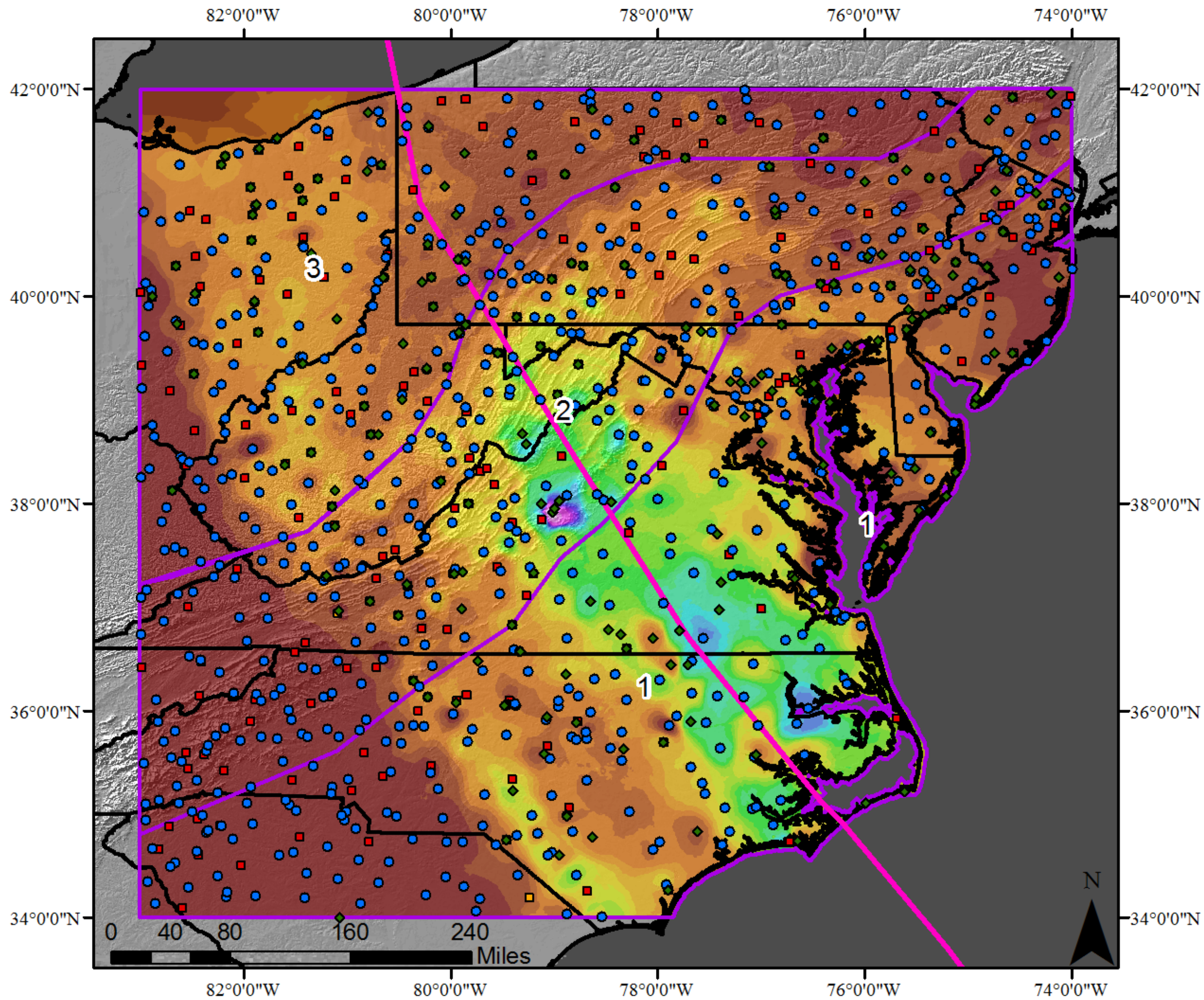
Reliability of results: One Hundred ninety-six supplemental stations were added to ensure the data matches what can actually occur and that the data more closely resemble reports from this storm. Due to the orientation and integrity of the station and radar data, these stations were retained to depict the storm precipitation pattern and intensity. A radar beam blockage mask was applied for regions of the storm domain where radar coverage was not available along with blocked radar beams from the Appalachian Mountains. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the storm data report, this analysis is deemed quite reliable.

							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1535_1	-76.5042	35.8625	9	0	3-Sep	80.50	3.68	0.00	83	3.680	83.23	83.0	4.12	0.00	88	4.120	1.120

Storm 1535- September 18 (0000 UTC) - September 19 (2300 UTC), 2003											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi²)	Duration (hours)										
	1	2	3	4	5	6	12	24	36	48	Total
0.4	2.00	3.05	4.35	4.87	4.97	5.06	7.12	7.95	7.95	7.95	7.95
1	2.00	3.04	4.33	4.84	4.94	5.04	7.08	7.93	7.92	7.92	7.92
10	1.98	3.01	4.25	4.77	4.87	4.97	6.99	7.86	7.86	7.86	7.86
25	1.98	2.97	4.22	4.74	4.84	4.94	6.96	7.83	7.83	7.83	7.83
50	1.97	2.93	4.19	4.69	4.79	4.89	6.93	7.81	7.81	7.81	7.81
100	1.97	2.87	4.10	4.61	4.70	4.81	6.91	7.79	7.79	7.79	7.79
150	1.93	2.81	4.02	4.52	4.63	4.76	6.88	7.78	7.78	7.77	7.77
200	1.87	2.77	3.96	4.45	4.57	4.72	6.81	7.77	7.77	7.77	7.77
300	1.72	2.71	3.86	4.35	4.49	4.65	6.72	7.68	7.70	7.70	7.70
400	1.55	2.65	3.78	4.27	4.41	4.60	6.61	7.61	7.63	7.63	7.63
500	1.49	2.60	3.68	4.17	4.31	4.53	6.53	7.51	7.58	7.58	7.58
1,000	1.31	2.28	3.11	3.57	3.81	4.23	6.26	7.24	7.34	7.35	7.35
2,000	1.10	1.89	2.57	2.99	3.33	3.91	5.96	6.87	6.97	6.98	6.98
5,000	0.85	1.45	2.01	2.43	2.82	3.31	5.40	6.33	6.41	6.41	6.41
10,000	0.66	1.22	1.73	2.15	2.50	2.90	4.74	5.83	5.89	5.89	5.89
20,000	0.51	0.95	1.38	1.72	2.03	2.41	3.95	5.13	5.22	5.22	5.22
50,000	0.30	0.57	0.82	1.05	1.29	1.54	2.67	3.59	3.70	3.70	3.70
98,196	0.17	0.31	0.45	0.59	0.73	0.88	1.57	2.17	2.26	2.27	2.27




SPAS 1535 Storm Center Mass Curve Zone 1
September 18 (0000UTC) to September 19 (2300UTC), 2003
Lat: 35.8625 Lon: -76.5042
Incremental
Accumulated
7.96
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
0
2
4
6
8
10
20
30
40



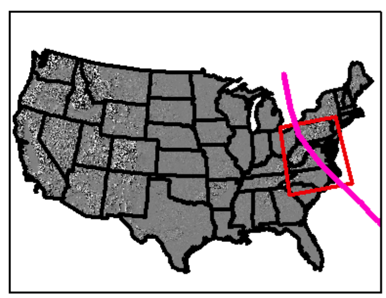
Total 48-hour Precipitation (Inches)
September 18, 2003 0000 UTC - September 20, 2003 0000 UTC
SPAS #1535-Hurricane Isabel

Precipitation (Inches)

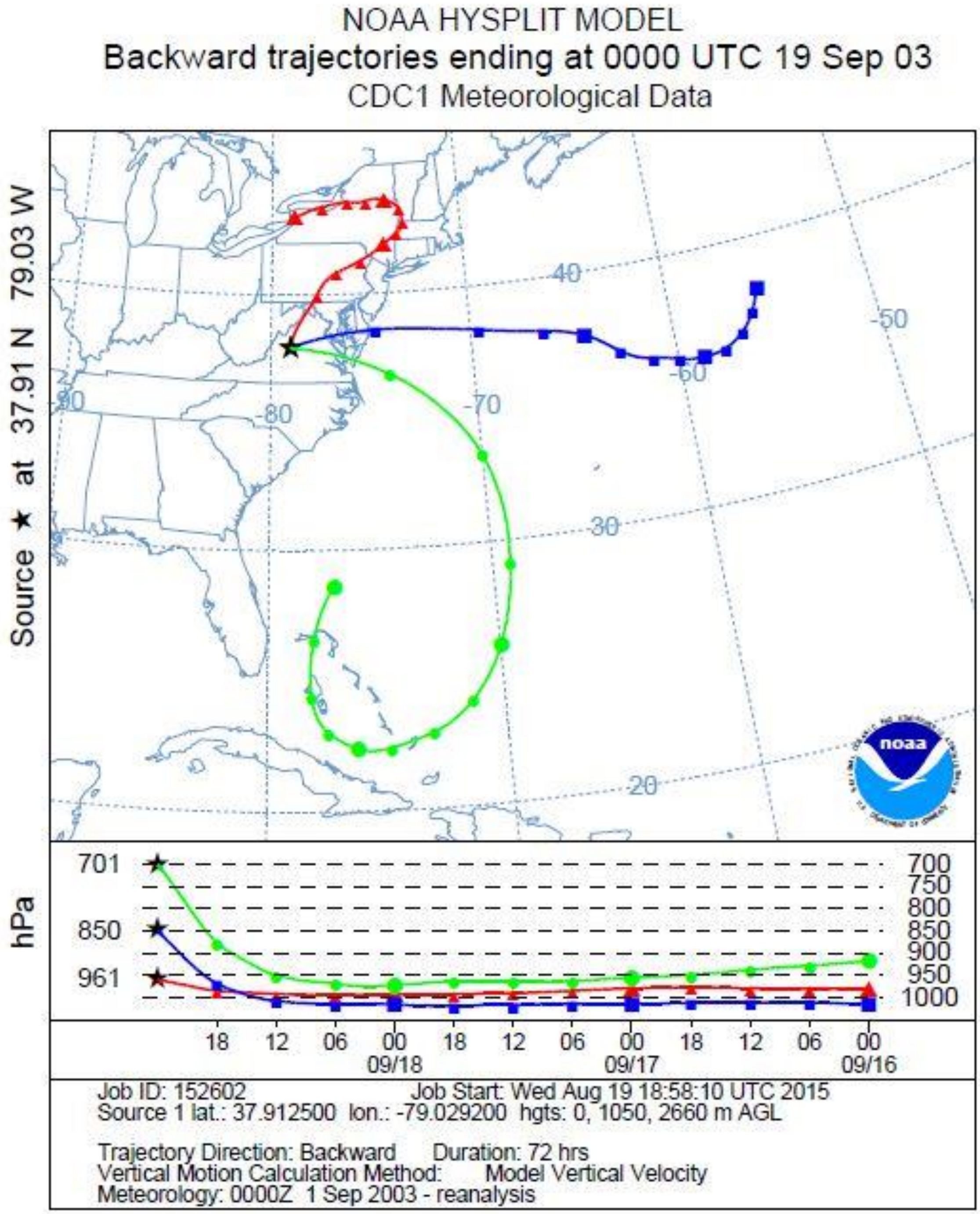
- 0.00 - 0.50
- 0.51 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- 2.51 - 3.00
- 3.01 - 3.50
- 3.51 - 4.00
- 4.01 - 4.50
- 4.51 - 5.00
- 5.01 - 5.50
- 5.51 - 6.00
- 6.01 - 6.50
- 6.51 - 7.00
- 7.01 - 7.50
- 7.51 - 8.00
- 8.01 - 8.50
- 8.51 - 9.00
- 9.01 - 9.50
- 9.51 - 10.00
- 10.01 - 13.00
- 13.01 - 16.00
- 16.01 - 19.00
- 19.01 - 20.50

Stations

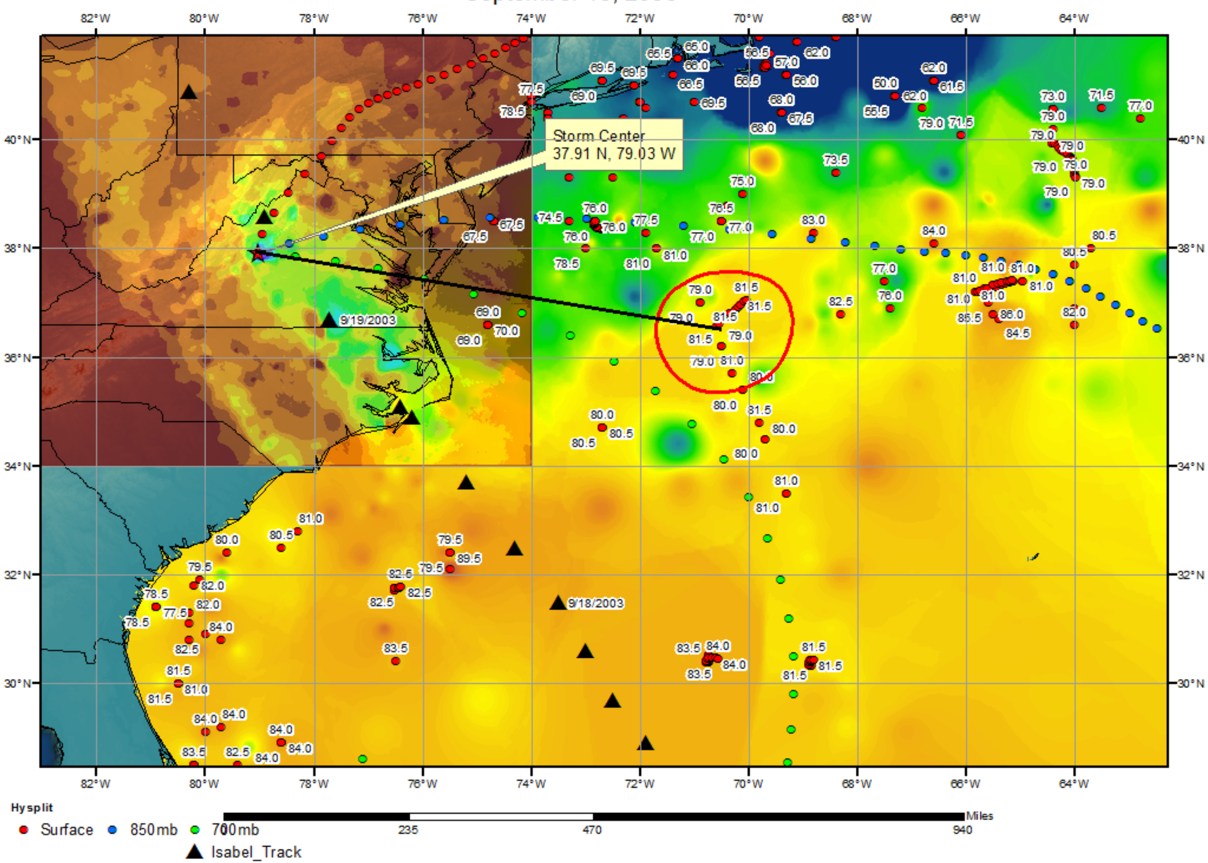
- Daily
- Hourly
- Hourly Pseudo
- Supplemental
- Isabel



WJM 08/10/2015


NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 19 Sep 03
CDC1 Meteorological Data
Source ★ at 37.91 N 79.03 W
40
50
60
70
80
90
30
20
hPa
701
850
961
700
750
800
850
900
950
1000
18
12
06
00
09/18
09/17
09/16
Job ID: 152602 Job Start: Wed Aug 19 18:58:10 UTC 2015
Source 1 lat.: 37.912500 lon.: -79.029200 hgts: 0, 1050, 2660 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2003 - reanalysis

SPAS 1535 Upper Sherando, VA Sea Surface Temperatures (F)
September 18, 2003



Storm Precipitation Analysis System (SPAS) For Storm #1535_2 SPAS-NEXRAD Analysis

General Storm Location: MidAtlantic States-Hurricane Isabel

Storm Dates: September 17 – September 20, 2003

Event: Hurricane Isabel

DAD Zone 2

Latitude: 37.9125

Longitude: -79.0292

Max. Grid Rainfall Amount: 20.22”

Max. Observed Rainfall Amount: 20.20” at Upper Sherando, VA

Number of Stations: 1085 (681 Daily, 157 Hourly, 51 Hourly Pseudo, and 196 Supplemental)

SPAS Version: 10.0

Basemap: Mean annual maximum 48-hour precipitation associated with MLCs

Spatial resolution: 0.2606

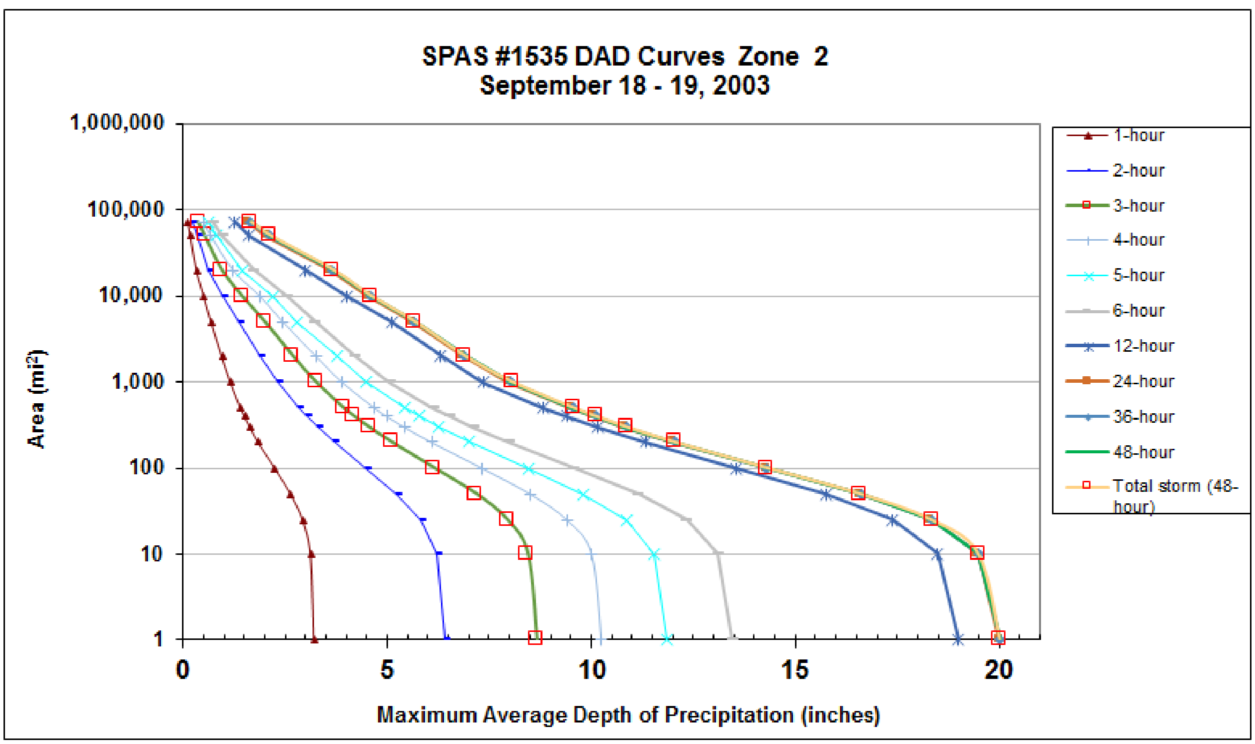
Radar Included: Yes

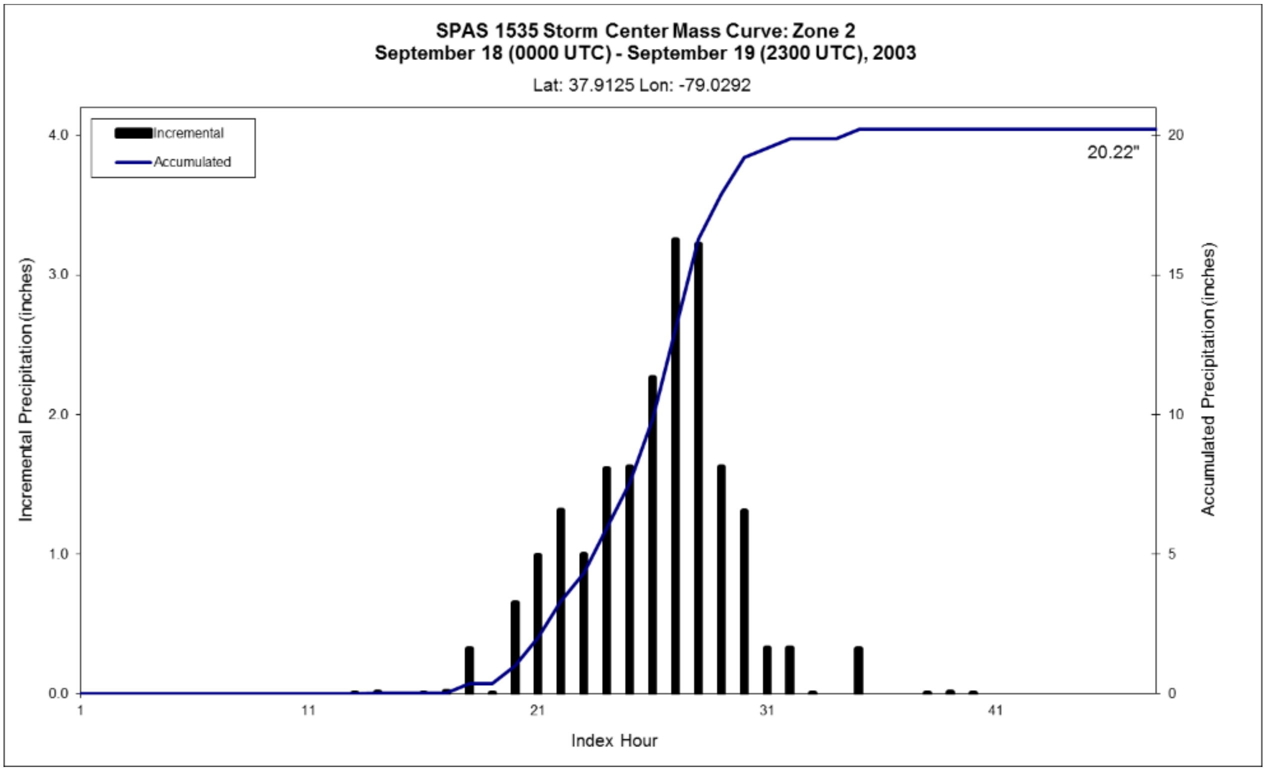
Depth-Area-Duration (DAD) analysis: Yes

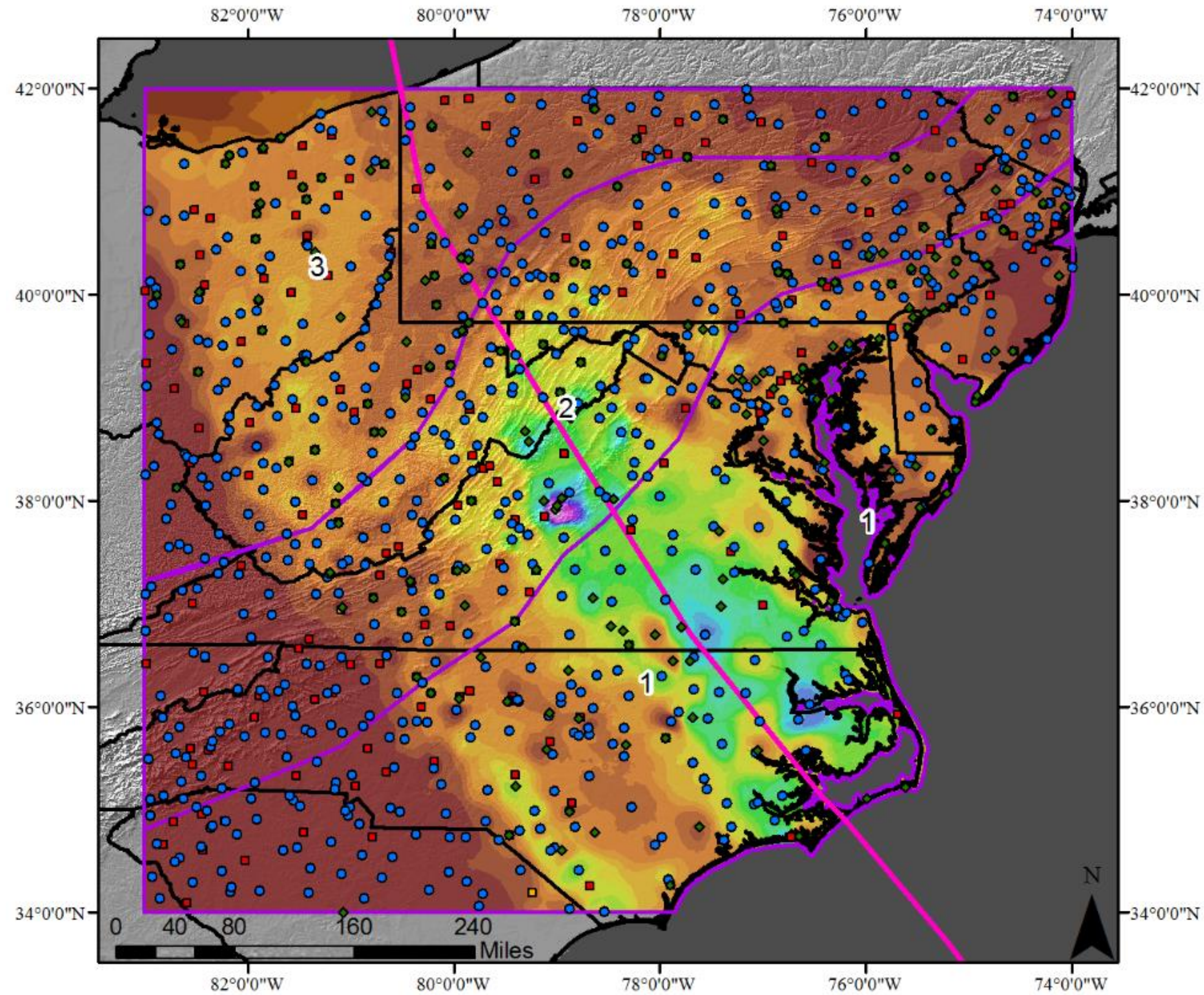
Reliability of results: One Hundred ninety-six supplemental stations were added to ensure the data matches what can actually occur and that the data more closely resemble reports from this storm. Due to the orientation and integrity of the station and radar data, these stations were retained to depict the storm precipitation pattern and intensity. A radar beam blockage mask was applied for regions of the storm domain where radar coverage was not available along with blocked radar beams from the Appalachian Mountains. With the density of stations available for this storm and with how closely the resulting SPAS analysis was to the storm data report, this analysis is deemed quite reliable.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1535_2	-79.0292	37.9125	2,284	3-Sep	80.50	3.68	0.67	83	3.010	83.23	4.12	0.70	88	3.420	1.136

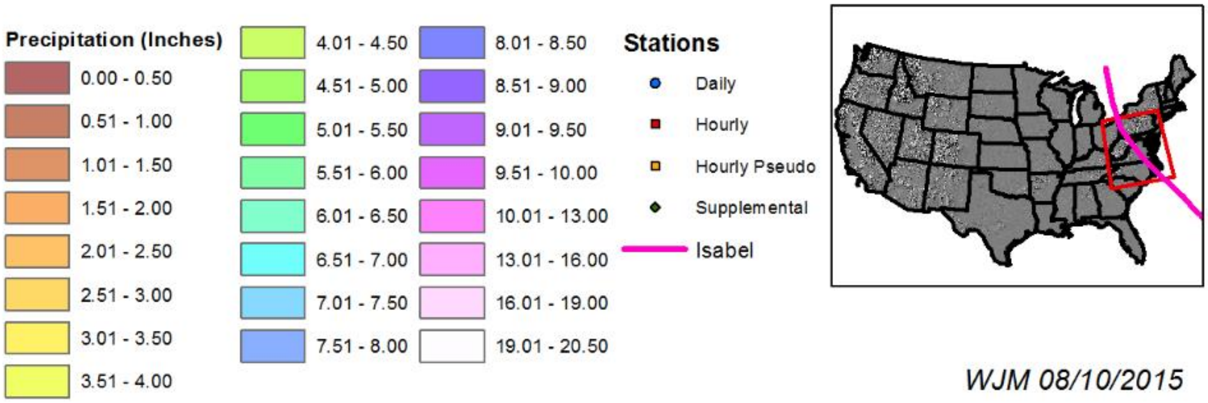
Storm 1535- September 18 (0000 UTC) - September 19 (2300 UTC), 2003											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
Area (mi^2)	Duration (hours)										
	1	2	3	4	5	6	12	24	36	48	Total
0.4	3.24	6.45	8.71	10.33	11.94	13.55	19.13	20.14	20.16	20.16	20.16
1	3.21	6.41	8.66	10.26	11.87	13.47	19.00	20.01	20.02	20.02	20.02
10	3.13	6.23	8.44	10.02	11.56	13.11	18.48	19.48	19.49	19.49	19.49
25	2.94	5.84	7.94	9.42	10.87	12.33	17.39	18.33	18.34	18.34	18.34
50	2.65	5.25	7.18	8.52	9.82	11.15	15.74	16.60	16.61	16.59	16.59
100	2.26	4.48	6.15	7.33	8.45	9.59	13.54	14.30	14.31	14.31	14.31
200	1.85	3.70	5.11	6.09	7.02	7.98	11.33	12.01	12.04	12.04	12.04
300	1.65	3.29	4.55	5.42	6.26	7.12	10.17	10.82	10.86	10.86	10.86
400	1.52	3.03	4.19	4.99	5.77	6.54	9.40	10.06	10.11	10.11	10.11
500	1.42	2.84	3.93	4.69	5.42	6.13	8.84	9.51	9.56	9.57	9.57
1,000	1.17	2.32	3.25	3.89	4.50	5.06	7.36	7.98	8.05	8.06	8.06
2,000	0.96	1.89	2.69	3.25	3.76	4.21	6.30	6.85	6.91	6.91	6.91
5,000	0.70	1.37	2.00	2.44	2.81	3.24	5.11	5.62	5.68	5.68	5.68
10,000	0.52	0.99	1.44	1.87	2.19	2.55	4.00	4.52	4.60	4.60	4.60
20,000	0.34	0.63	0.95	1.21	1.45	1.73	2.99	3.59	3.66	3.67	3.67
50,000	0.19	0.35	0.53	0.67	0.84	0.97	1.62	2.04	2.12	2.14	2.14
71,969	0.13	0.25	0.37	0.49	0.61	0.73	1.27	1.58	1.64	1.66	1.66



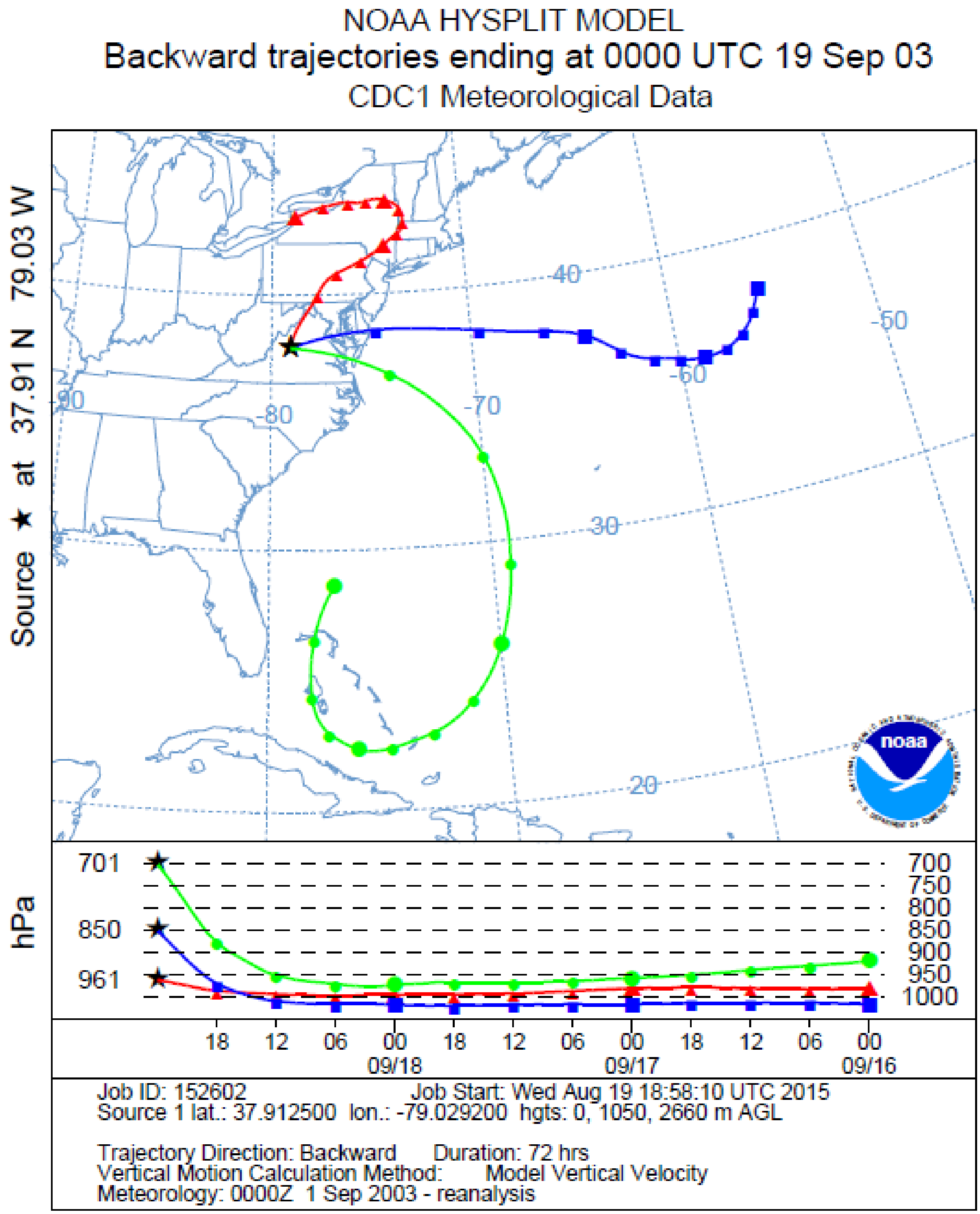

SPAS 1535 Storm Center Mass Curve: Zone 2
September 18 (0000 UTC) - September 19 (2300 UTC), 2003
Lat: 37.9125 Lon: -79.0292
Incremental
Accumulated
20.22"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
1.0
2.0
3.0
4.0
0
5
10
15
20
1
11
21
31
41

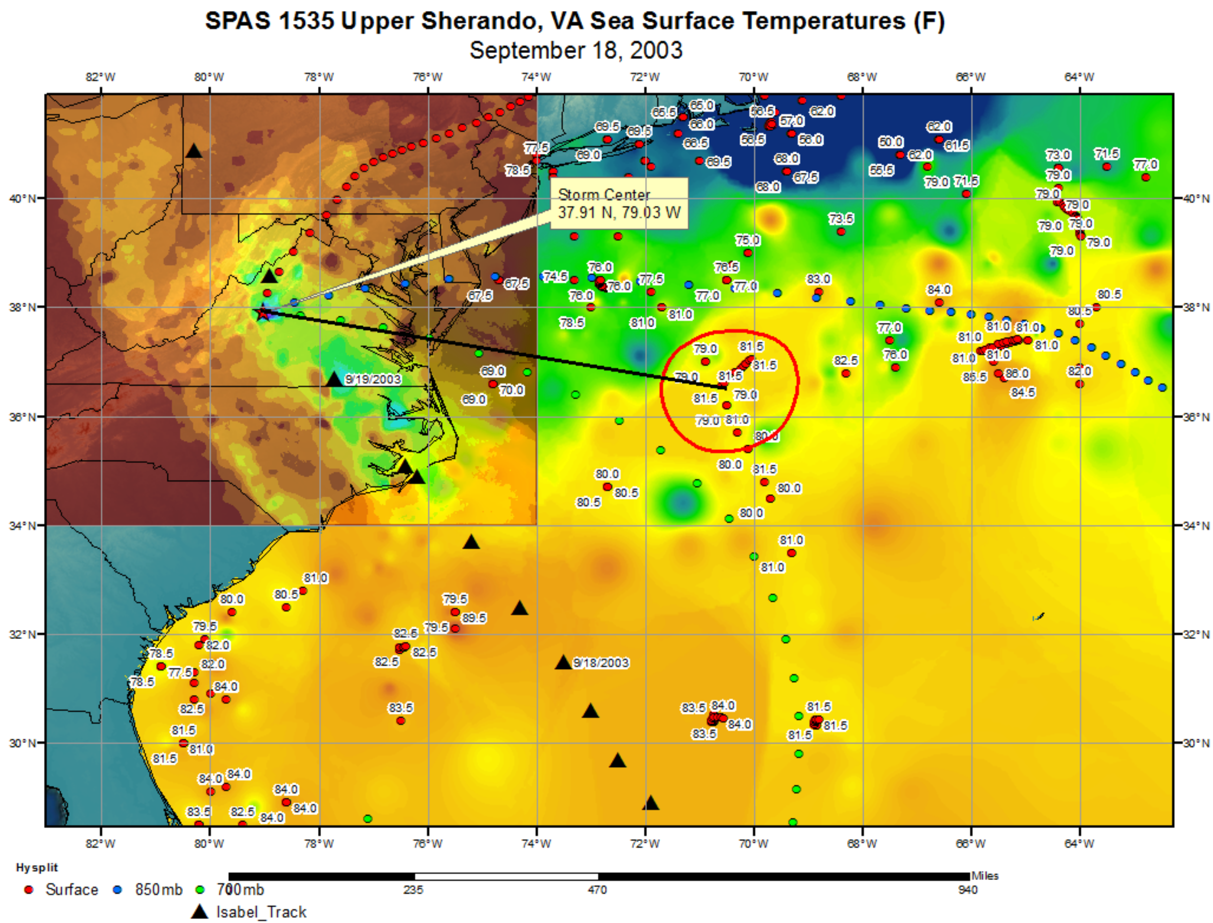


Total 48-hour Precipitation (Inches)
September 18, 2003 0000 UTC - September 20, 2003 0000 UTC
SPAS #1535-Hurricane Isabel



WJM 08/10/2015


NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 19 Sep 03
CDC1 Meteorological Data
Source ★ at 37.91 N 79.03 W
40
-50
-60
-90
-80
-70
30
20
noaa
hPa
701
850
961
700
750
800
850
900
950
1000
18 12 06 00 18 12 06 00 18 12 06 00
09/18
09/17
09/16
Job ID: 152602 Job Start: Wed Aug 19 18:58:10 UTC 2015
Source 1 lat.: 37.912500 lon.: -79.029200 hgts: 0, 1050, 2660 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2003 - reanalysis


SPAS 1535 Upper Sherando, VA Sea Surface Temperatures (F)
September 18, 2003
Storm Center
37.91 N, 79.03 W
9/19/2003
9/18/2003
Hysplit
Surface
850mb
700mb
Isabel_Track
Miles
235
470
940

Storm Precipitation Analysis System (SPAS) For Storm #1551_1 SPAS-NEXRAD Analysis

General Storm Location: Virginia, North Carolina, Maryland

Storm Dates: August 30-31, 2004

Event: Convective/Remnants of Hurricane Gaston

DAD Zone 1

Latitude: 37.705

Longitude: -77.375

Max. Grid Rainfall Amount: 14.38”

Max. Observed Rainfall Amount: 12.60” at Richmond, VA

Number of Stations: 199 (108 Daily, 46 Hourly, 14 Hourly Pseudo, 1 Hourly Estimated Pseudo and 30 Supplemental)

SPAS Version: 10.0

Basemap: us_ppt_in_map_1961_1990_usda_northamerica

Spatial resolution: 00:00:36

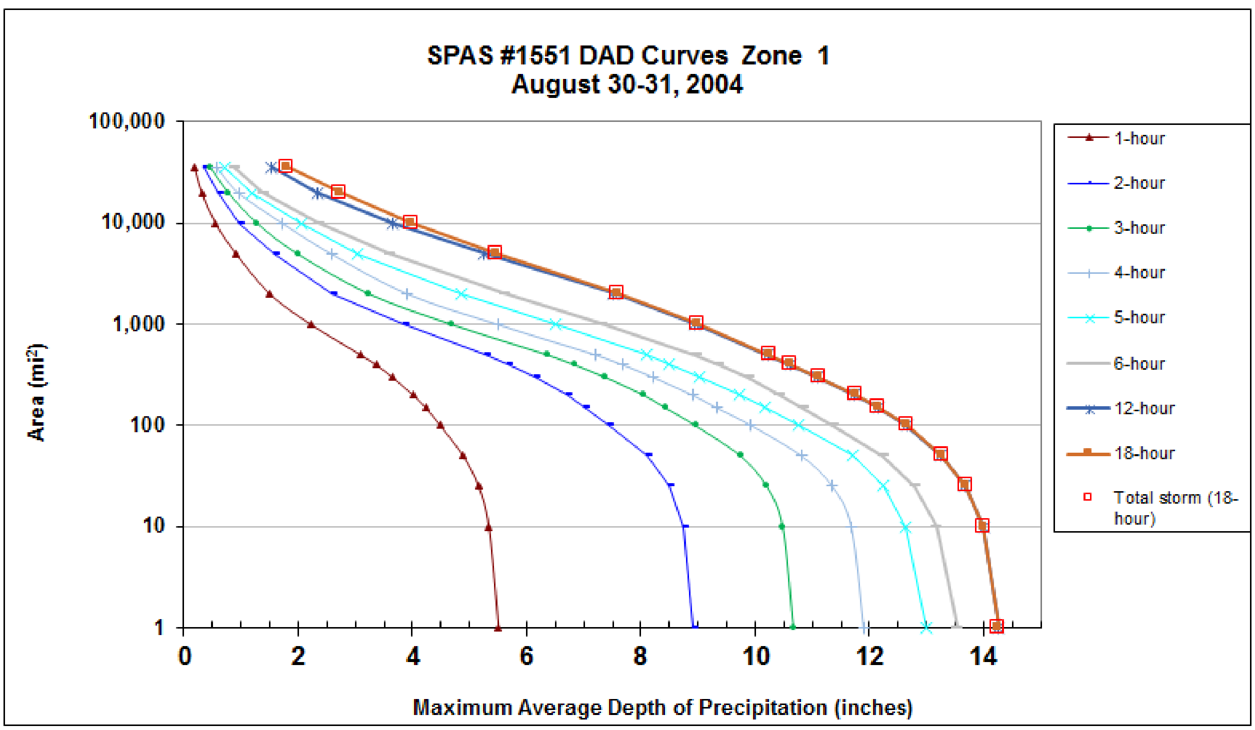
Radar Included: Yes

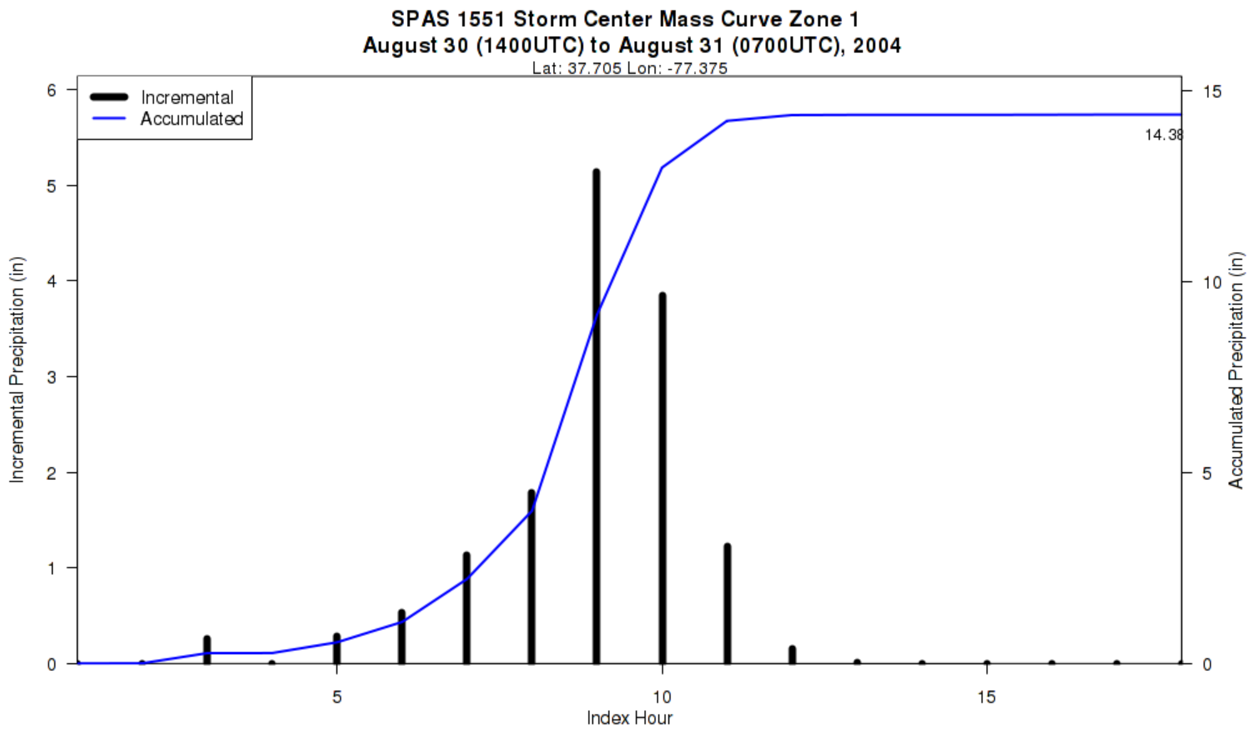
Depth-Area-Duration (DAD) analysis: Yes

Reliability of results: This analysis was based on several hourly data, daily data, supplemental station data and one hourly estimated pseudo station. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the basemap (us_ppt_in_map_1961_1990_usda_northamerica). The radar data was also excellent with very little beam blockage. There is a high degree of confidence with the timing based on the several hourly and hourly pseudo stations. Some daily stations were moved to supplemental due to timing issues or removed due to erroneous storm precipitation observations. A couple hourly stations were changed to hourly pseudo stations due to values being too low (affecting the integrity of the spatial pattern) when compared to nearby hourly stations.

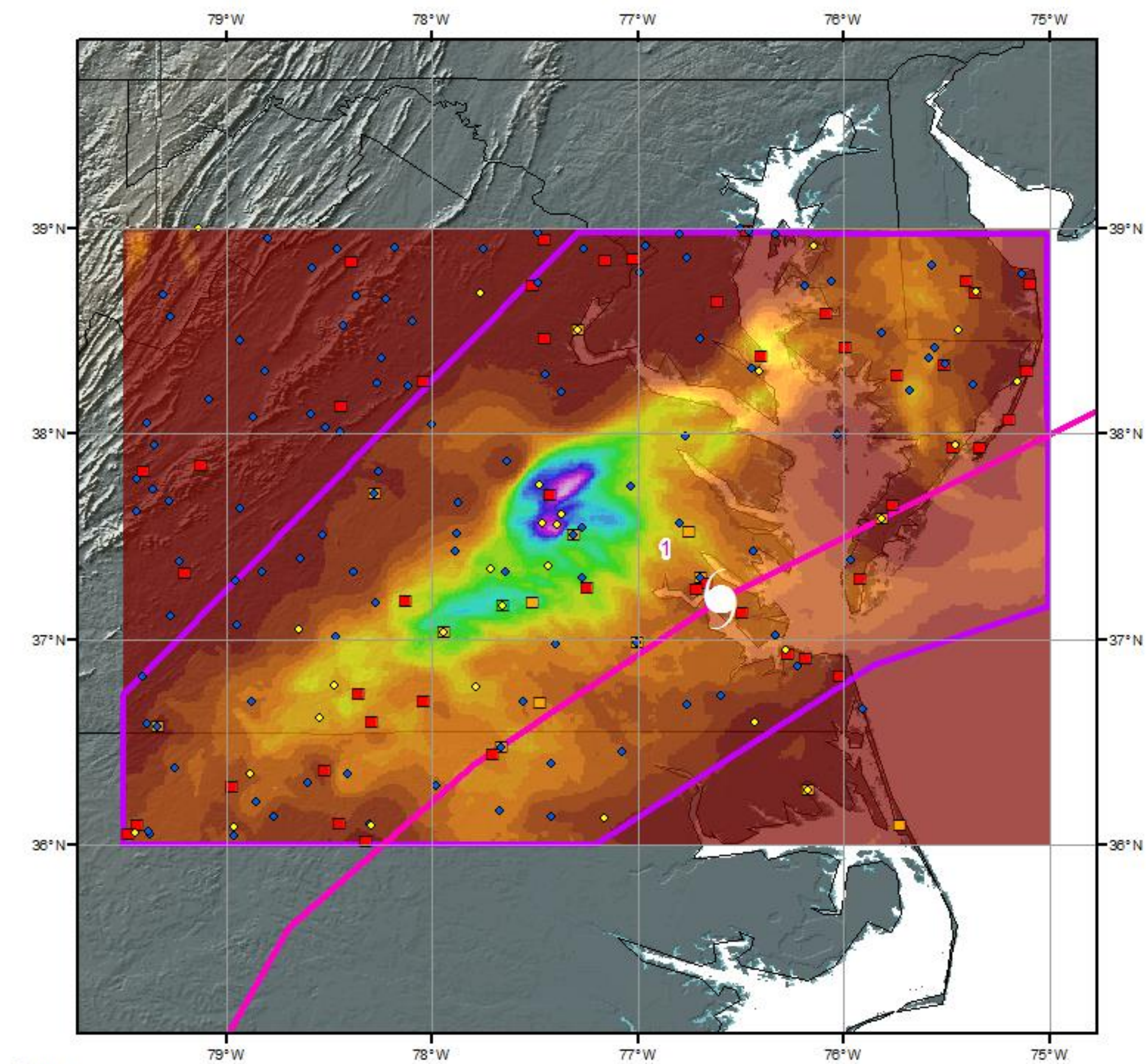
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1551_1	-77.3750	37.7050	182	15-Aug	81.00	3.77	0.06	84	3.710	83.15	4.12	0.06	88	4.060	1.094

Storm 1551 - August 30 (1400 UTC) - August 31 (0700 UTC), 2004									
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)									
Area (mi^2)	Duration (hours)								
	1	2	3	4	5	6	12	18	Total
0.4	5.56	8.98	10.77	11.99	13.12	13.65	14.36	14.37	14.37
1	5.51	8.91	10.68	11.90	13.00	13.53	14.26	14.26	14.26
10	5.34	8.75	10.49	11.68	12.64	13.17	14.00	14.00	14.00
25	5.16	8.49	10.21	11.35	12.25	12.79	13.67	13.69	13.69
50	4.89	8.09	9.75	10.81	11.70	12.23	13.25	13.27	13.27
100	4.49	7.44	8.96	9.93	10.77	11.37	12.65	12.67	12.67
150	4.23	7.01	8.43	9.32	10.17	10.84	12.16	12.17	12.17
200	4.01	6.71	8.05	8.90	9.72	10.43	11.75	11.77	11.77
300	3.65	6.14	7.38	8.21	9.01	9.89	11.10	11.12	11.12
400	3.36	5.68	6.83	7.67	8.49	9.36	10.61	10.63	10.63
500	3.09	5.28	6.36	7.20	8.10	8.96	10.22	10.25	10.25
1,000	2.22	3.86	4.69	5.49	6.52	7.31	8.94	8.99	8.99
2,000	1.50	2.58	3.24	3.91	4.86	5.61	7.52	7.59	7.59
5,000	0.91	1.59	1.99	2.58	3.05	3.59	5.25	5.47	5.47
10,000	0.55	0.97	1.28	1.73	2.06	2.36	3.65	3.98	3.98
20,000	0.31	0.59	0.78	0.96	1.18	1.38	2.33	2.74	2.74
35,657	0.18	0.34	0.46	0.58	0.71	0.87	1.53	1.81	1.81





SPAS 1551 Storm Center Mass Curve Zone 1
August 30 (1400UTC) to August 31 (0700UTC), 2004
Lat: 37.705 Lon: -77.375
Incremental
Accumulated
14.38
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
6
5
10
15
0
5
10
15



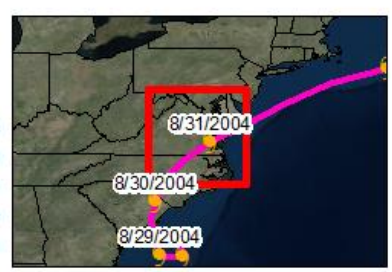
Total Storm (18-hours) Precipitation (inches)
August 30-31, 2004
SPAS 1551 Richmond, VA

Gauges
- D
- H
- HEP
- HP
- S
- Hurricane Gaston Track

Miles: 0, 20, 40, 80
Kilometers: 0, 40, 80, 160

Precipitation (inches)

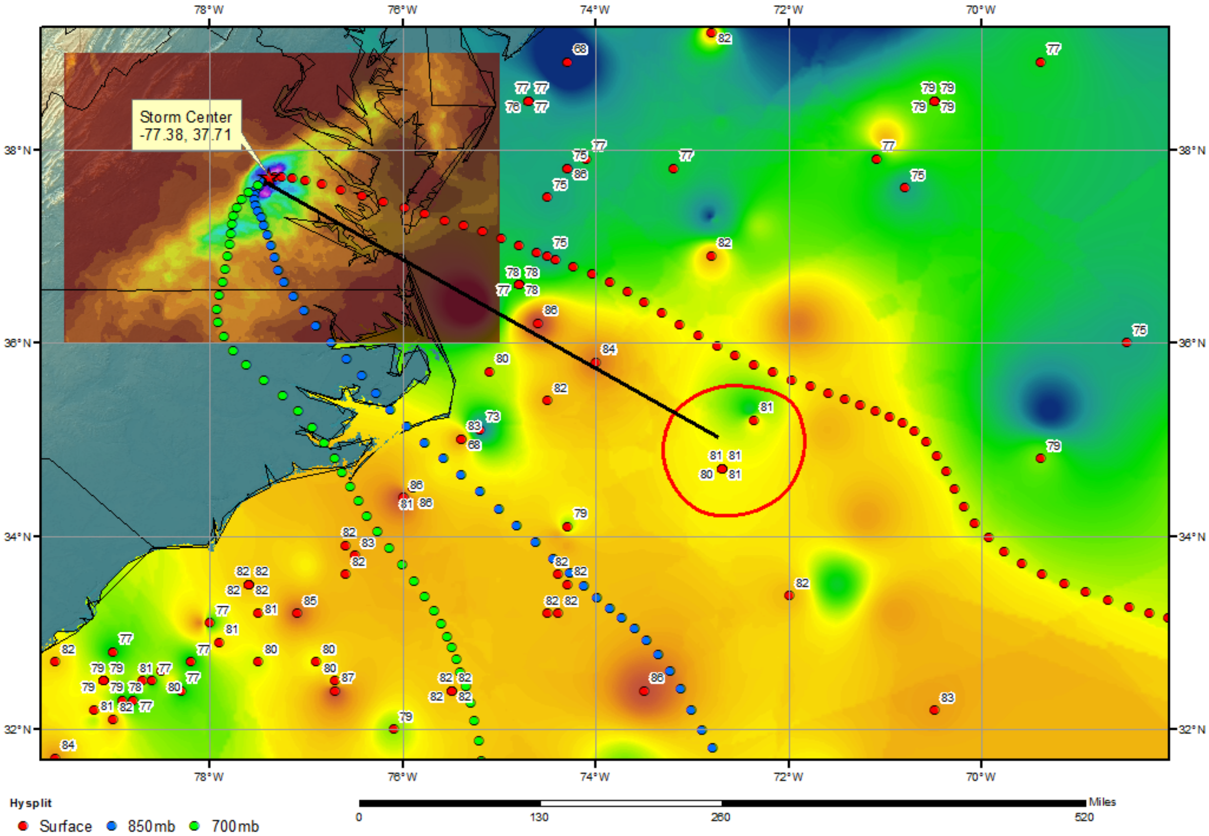
0.00 - 0.50	2.51 - 3.00	5.51 - 6.00	8.51 - 9.00	11.51 - 12.00
0.51 - 1.00	3.01 - 3.50	6.01 - 6.50	9.01 - 9.50	12.01 - 12.50
1.01 - 1.50	3.51 - 4.00	6.51 - 7.00	9.51 - 10.00	12.51 - 13.00
1.51 - 2.00	4.01 - 4.50	7.01 - 7.50	10.01 - 10.50	13.01 - 13.50
2.01 - 2.50	4.51 - 5.00	7.51 - 8.00	10.51 - 11.00	13.51 - 14.00
	5.01 - 5.50	8.01 - 8.50	11.01 - 11.50	14.01 - 14.50



8/31/2015

SPAS 1551 Richmond, VA Storm Analysis

August 29-30, 2004



Storm Precipitation Analysis System (SPAS) For Storm #1275_1 SPAS-NEXRAD Analysis

General Storm Location: Pennsylvania, West Virginia, Virginia, Ohio, New York, Kentucky

Storm Dates: September 17-19, 2004

Event: Hurricane Ivan

DAD Zone 1

Latitude: 40.645

Longitude: -80.385

Max. Grid Rainfall Amount: 8.79"

Max. Observed Rainfall Amount: 8.79"

Number of Stations: 955 (550 Daily, 183 Hourly, 62 Hourly Pseudo, and 160 Supplemental)

SPAS Version: 9.5

Basemap: PRISM 30-yr Mean (1981-2010) September Precipitation

Spatial resolution: 0.01 (~ 0.40 mi^2)

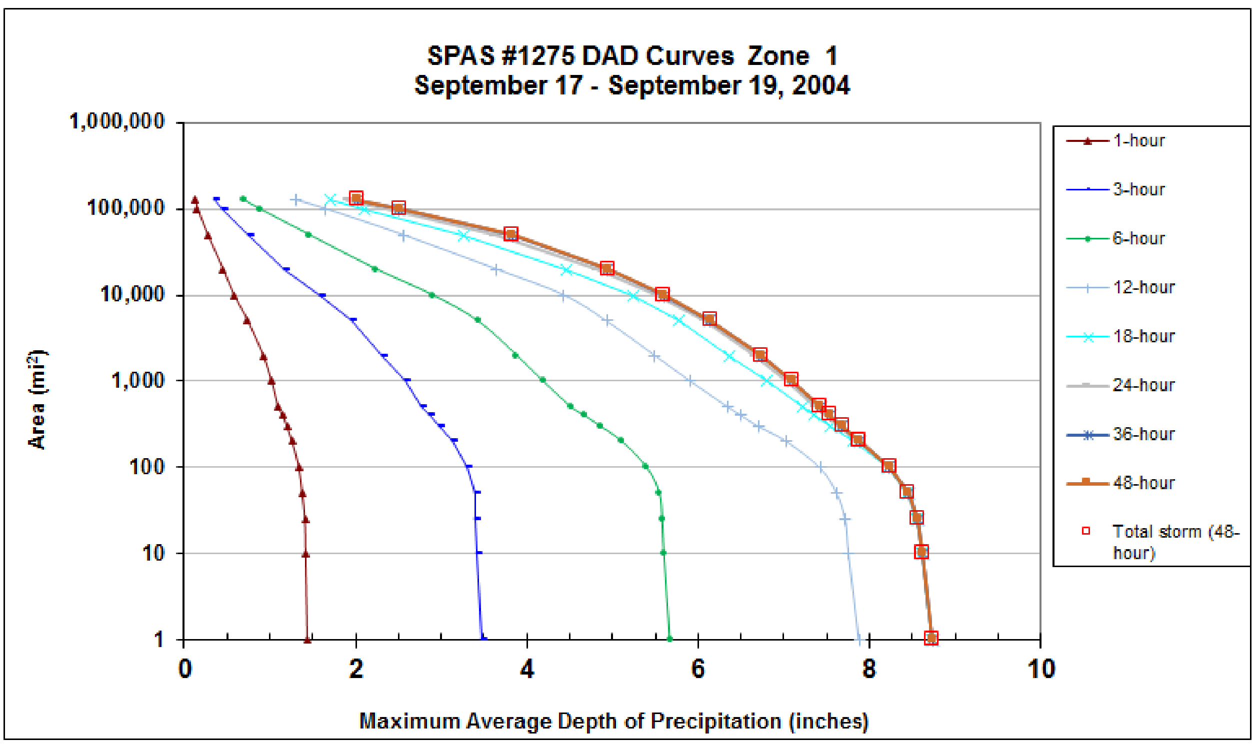
Radar Included: Yes

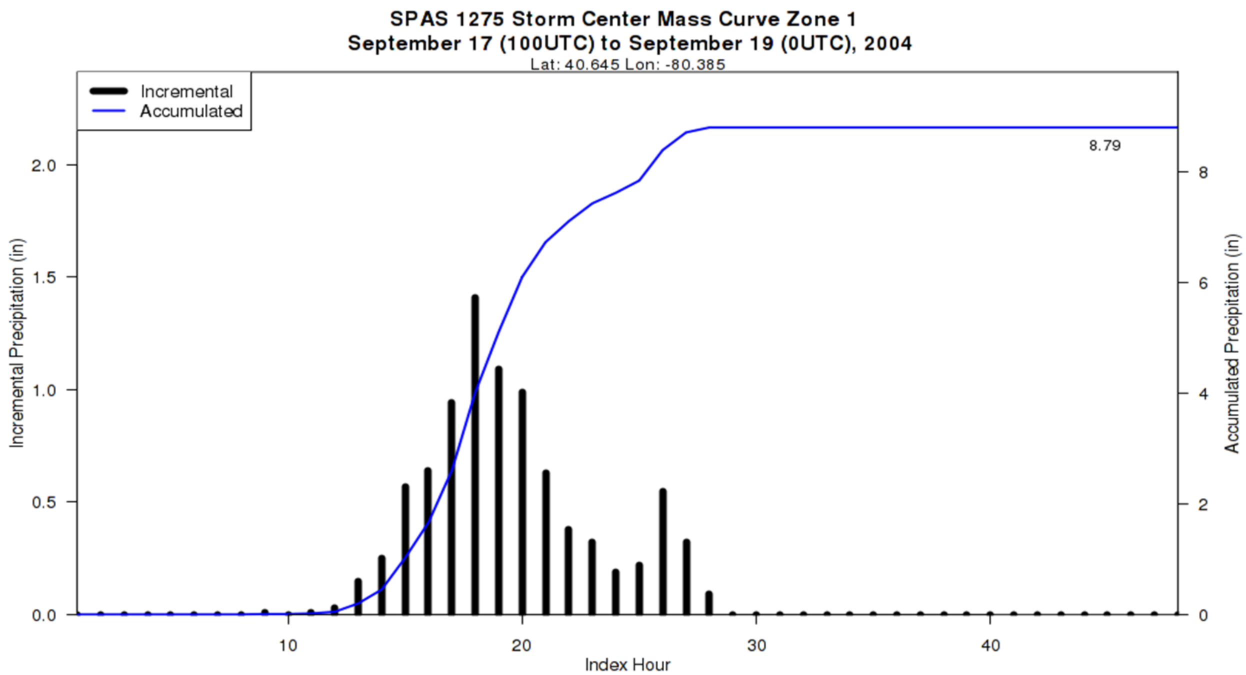
Depth-Area-Duration (DAD) analysis: Yes

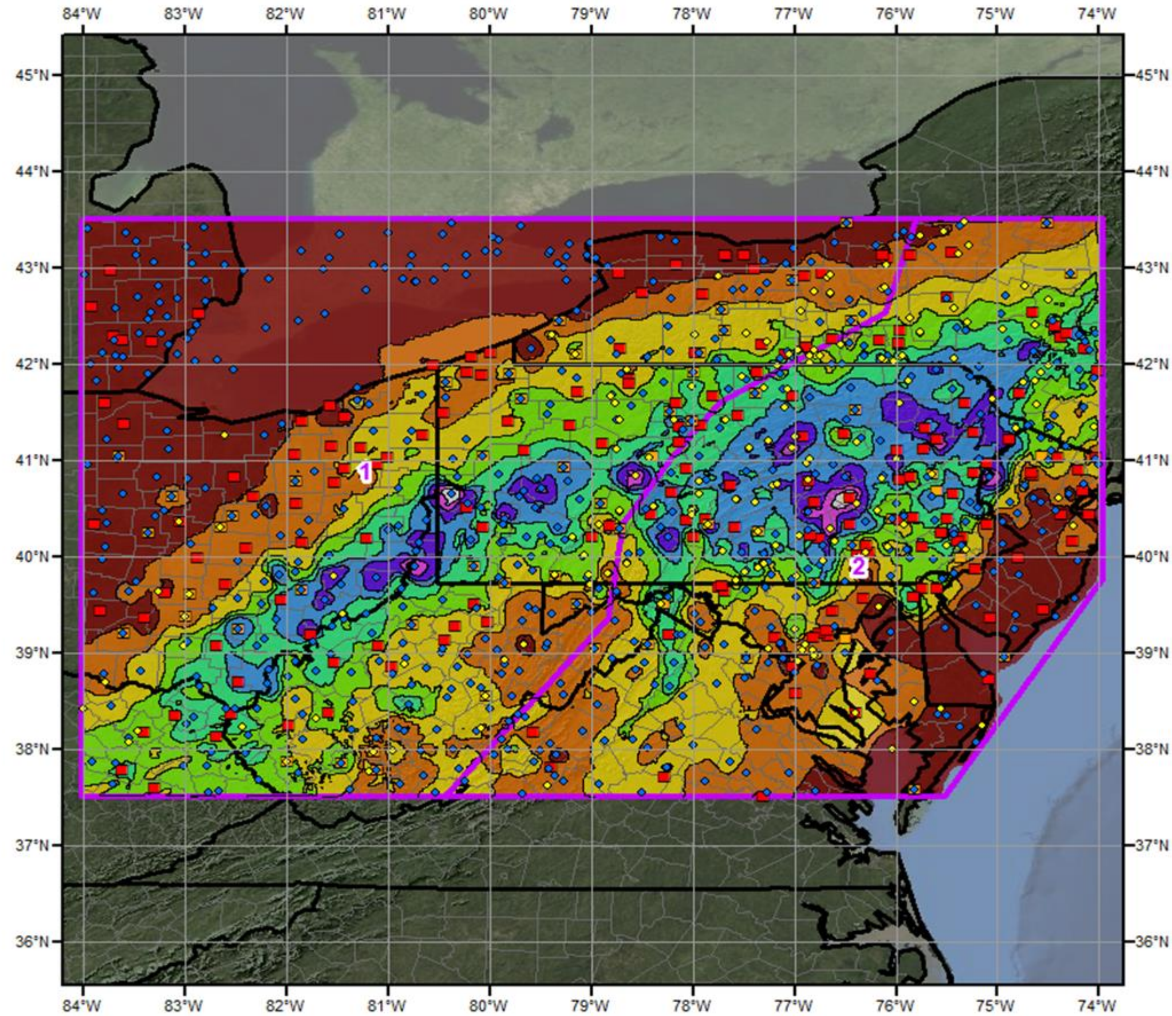
Reliability of results: This analysis was based on hourly data, daily data, supplemental station data and NEXRAD Radar. We have a high degree of confidence in the radar/station based storm total results, the spatial pattern is dependent on the radar data and basemap, and the timing is based on hourly and hourly pseudo stations.

						Storm Rep. Dew Point					Climatological Max. Dew Point					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1275_1	-80.3850	40.6450	1,055	1-Sep	72.00	2.47	0.25	66	2.220	77.29	3.22	0.30	77	2.920	1.315

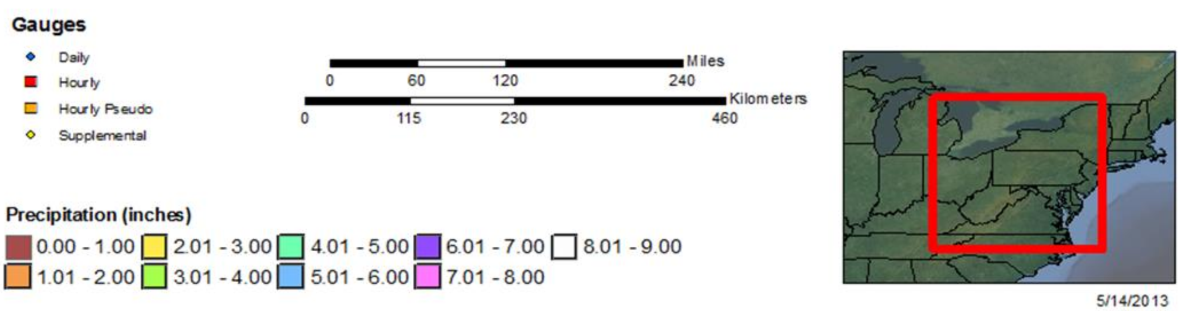
Storm 1275 - September 17 (0100 UTC) - September 19 (0000 UTC), 2004									
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)									
Area (mi^2)	Duration (hours)								
	1	3	6	12	18	24	36	48	Total
0.4	1.44	3.49	5.70	7.93	8.77	8.78	8.78	8.78	8.78
1	1.44	3.47	5.67	7.88	8.73	8.74	8.74	8.74	8.74
10	1.42	3.42	5.60	7.76	8.60	8.61	8.62	8.62	8.62
25	1.41	3.40	5.58	7.72	8.56	8.57	8.57	8.57	8.57
50	1.38	3.39	5.55	7.62	8.44	8.45	8.46	8.46	8.46
100	1.34	3.31	5.40	7.42	8.21	8.23	8.23	8.24	8.24
200	1.26	3.13	5.11	7.03	7.81	7.87	7.89	7.89	7.89
300	1.20	2.98	4.86	6.70	7.54	7.65	7.68	7.69	7.69
400	1.15	2.87	4.67	6.50	7.36	7.50	7.54	7.54	7.54
500	1.10	2.77	4.52	6.35	7.22	7.38	7.43	7.43	7.43
1,000	1.02	2.57	4.19	5.91	6.80	7.04	7.10	7.10	7.10
2,000	0.92	2.32	3.88	5.49	6.37	6.66	6.74	6.74	6.74
5,000	0.74	1.95	3.43	4.93	5.78	6.08	6.14	6.15	6.15
10,000	0.58	1.58	2.90	4.43	5.24	5.51	5.60	5.61	5.61
20,000	0.45	1.18	2.24	3.64	4.46	4.82	4.94	4.95	4.95
50,000	0.27	0.75	1.46	2.55	3.26	3.63	3.83	3.84	3.84
100,000	0.15	0.44	0.88	1.65	2.10	2.36	2.51	2.52	2.52
125,829	0.12	0.36	0.70	1.31	1.70	1.91	2.03	2.03	2.03

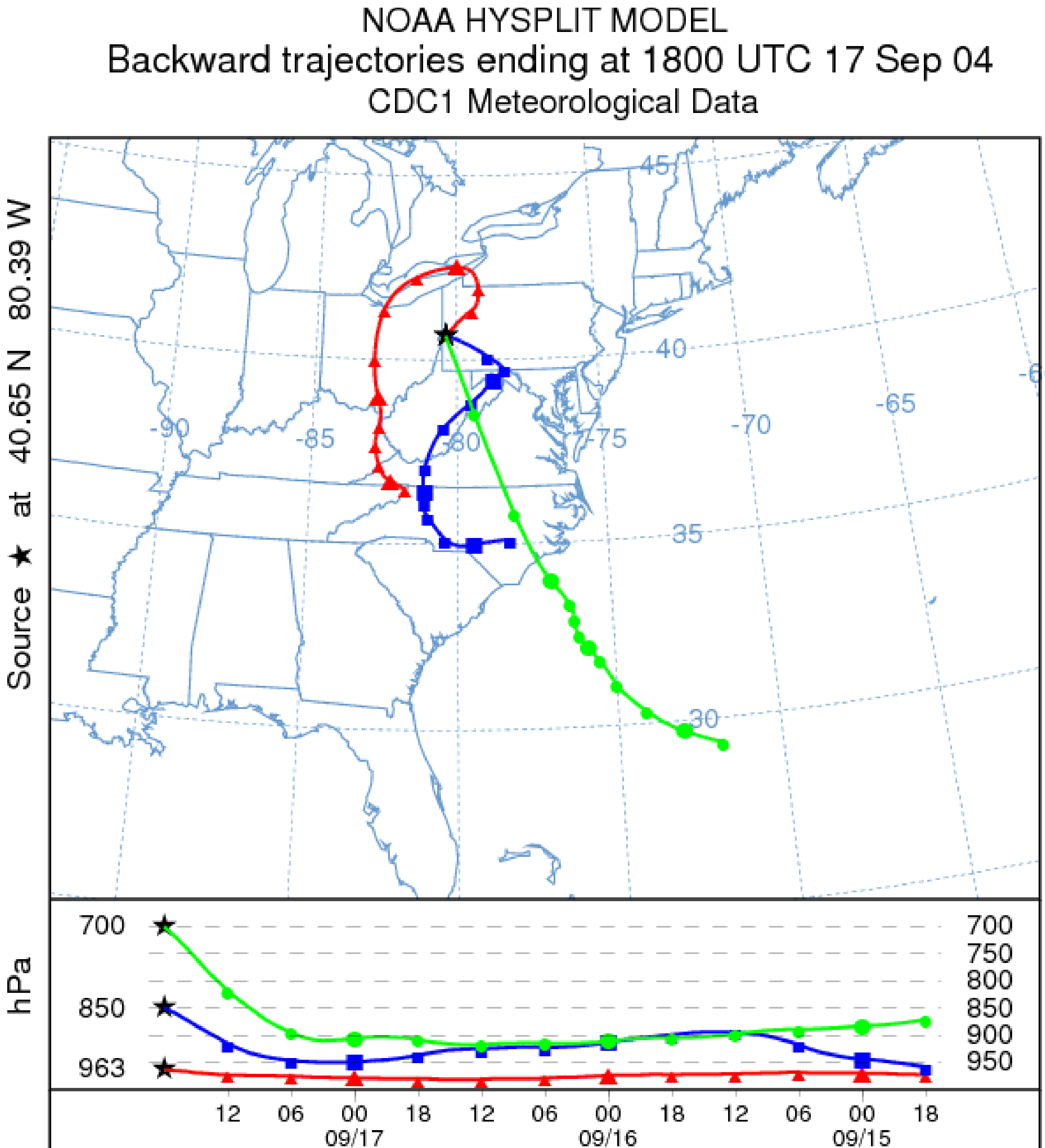



SPAS 1275 Storm Center Mass Curve Zone 1
September 17 (100UTC) to September 19 (0UTC), 2004
Lat: 40.645 Lon: -80.385
Incremental
Accumulated
8.79
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
2
4
6
8
10
20
30
40

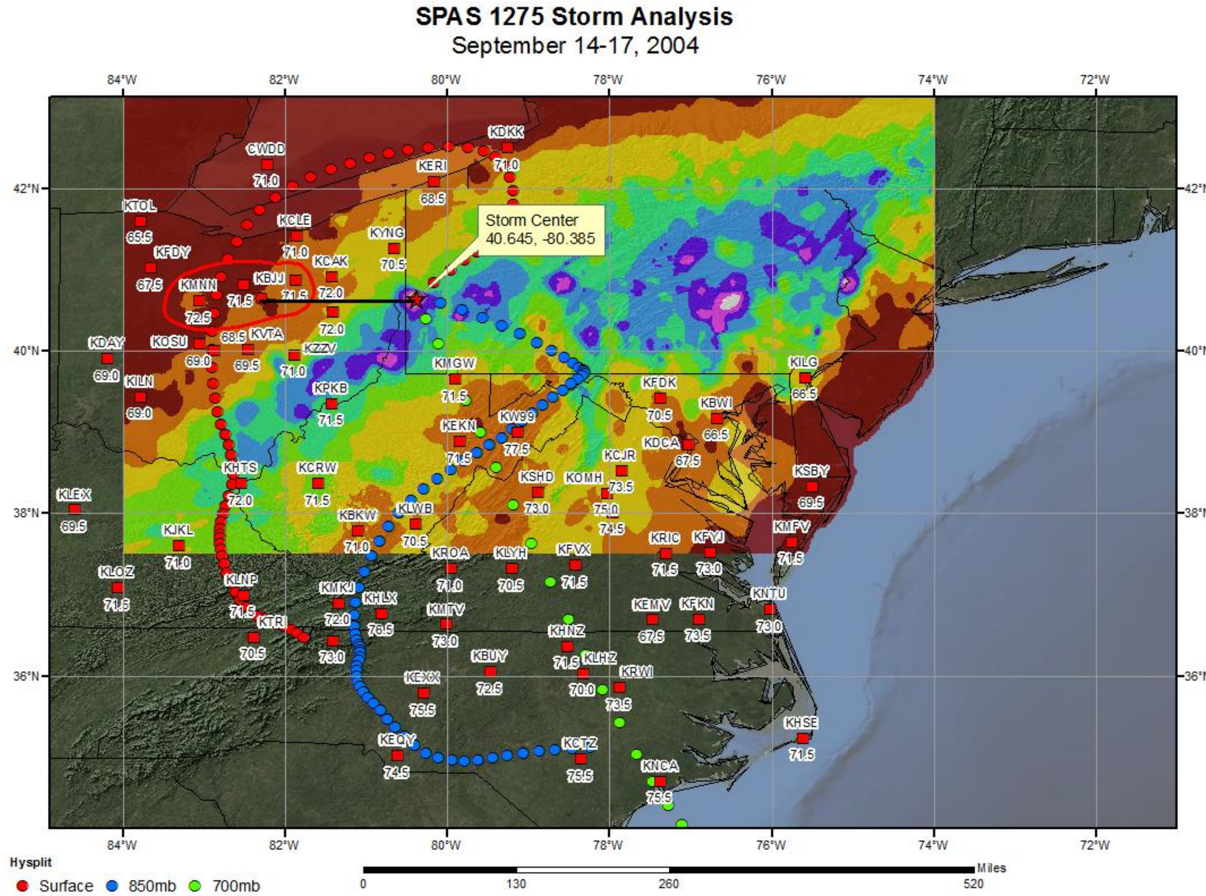


Total Storm (48-hr) Precipitation (inches)
September 17 (0100 UTC) - 19 (0000 UTC), 2004
SPAS-NEXRAD 1276





This is not a NOAA product. It was produced by a web user.
Job ID: 399670 Job Start: Tue May 14 20:15:37 UTC 2013
Source 1 lat.: 40.645 lon.: -80.385 hgts: 0, 1060, 2690 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Sep 2004 - reanalysis


SPAS 1275 Storm Analysis
September 14-17, 2004
Storm Center
40.645, -80.385
Hysplit
Surface
850mb
700mb
Miles
0
130
260
520

Storm Precipitation Analysis System (SPAS) For Storm #1526_1 SPAS-NEXRAD Analysis

General Storm Location: Southeast United States

Storm Dates: June 13 – June 15, 2006

Event: Tropical Storm Alberto

DAD Zone 1 –

Latitude: 34.3350

Longitude: -81.0050

Max. Grid Rainfall Amount: 9.32"

Max. Observed Rainfall Amount: 8.77" at Raleigh, NC

Number of Stations: 1170 (718 Daily, 292 Hourly, 1 Hourly Estimated Pseudo, 50 Hourly Pseudo and 109 Supplemental) * Note: The DAD zone ** Note: Given the recentness of this storm event, daily data from our internal/NCDC-based database was not available..

SPAS Version: 10.0

Basemap: Prism Conus 2-year 24-hour climatological base map

Spatial resolution: 0.3898

Radar Included: Yes

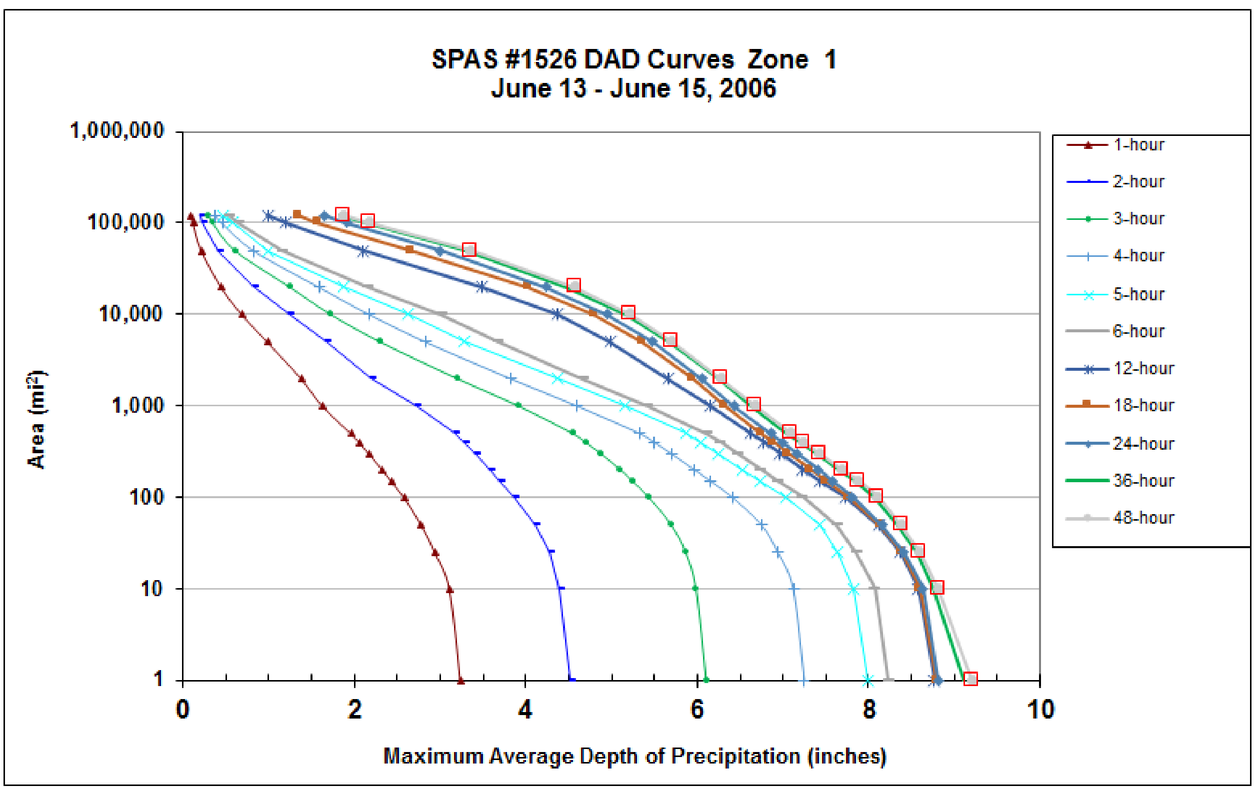
Depth-Area-Duration (DAD) analysis: Yes

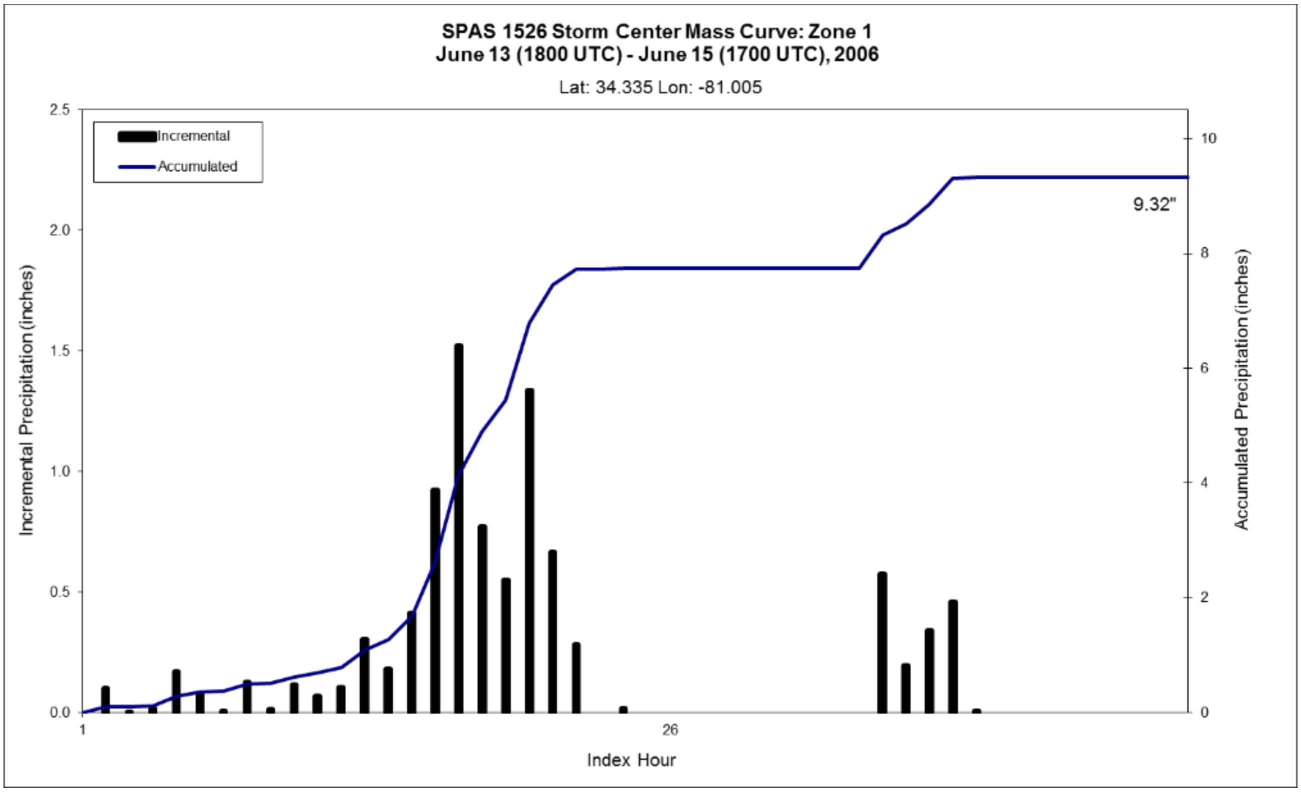
Reliability of results: Nearly half, or 50 of the 109, supplemental stations were co-located with hourly pseudo stations. The timing of these stations is therefore as reliable as possible. There were also 165 additional USGS daily stations incorporated, a significant contribution to the reliability and density of stations in this analysis. With the vast number of stations, the thorough inspection of data, and the precipitation totals for various periods throughout the storm being consistent with previous reports, this analysis is considered to be reliable.

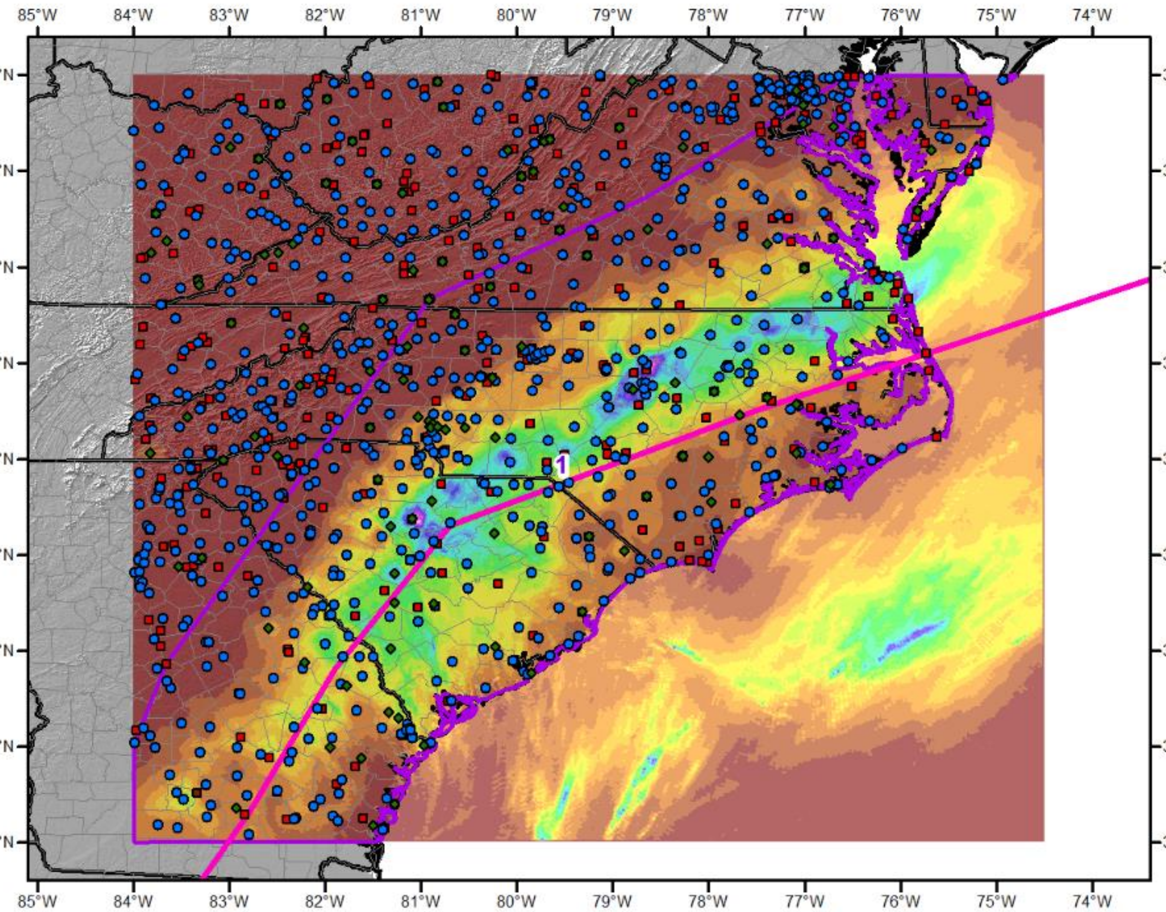
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1526_1	-81.0050	34.3350	408	29-Jun	81.00	3.77	0.12	84	3.650	83.60	4.21	0.13	89	4.080	1.118

Storm 1526 - June 13 (1800 UTC) - June 15 (1700 UTC), 2006
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

Area (mi²)	Duration (hours)											
	1	2	3	4	5	6	12	18	24	36	48	Total
0.4	3.27	4.55	6.16	7.30	8.06	8.30	8.83	8.86	8.89	9.22	9.32	9.32
1	3.24	4.52	6.11	7.25	8.00	8.23	8.77	8.79	8.81	9.10	9.21	9.21
10	3.11	4.39	5.99	7.12	7.82	8.07	8.58	8.60	8.63	8.75	8.81	8.81
25	2.94	4.27	5.87	6.94	7.64	7.86	8.37	8.39	8.41	8.57	8.60	8.60
50	2.78	4.11	5.70	6.75	7.42	7.63	8.12	8.14	8.16	8.34	8.38	8.38
100	2.58	3.86	5.44	6.41	7.03	7.23	7.72	7.76	7.81	8.06	8.11	8.11
150	2.43	3.70	5.25	6.16	6.74	6.94	7.42	7.50	7.57	7.84	7.88	7.88
200	2.33	3.59	5.11	5.97	6.53	6.74	7.23	7.32	7.41	7.65	7.69	7.69
300	2.17	3.41	4.88	5.70	6.25	6.47	6.96	7.06	7.16	7.38	7.42	7.42
400	2.06	3.28	4.70	5.50	6.04	6.27	6.78	6.89	6.99	7.19	7.24	7.24
500	1.96	3.17	4.55	5.33	5.87	6.11	6.63	6.75	6.86	7.05	7.10	7.10
1,000	1.63	2.72	3.92	4.60	5.16	5.43	6.16	6.33	6.43	6.64	6.68	6.68
2,000	1.38	2.20	3.20	3.82	4.37	4.67	5.66	5.95	6.05	6.25	6.28	6.28
5,000	0.99	1.66	2.31	2.84	3.29	3.68	4.98	5.36	5.48	5.68	5.71	5.71
10,000	0.69	1.23	1.73	2.18	2.63	3.01	4.37	4.80	4.95	5.17	5.22	5.22
20,000	0.45	0.83	1.25	1.59	1.87	2.16	3.49	4.03	4.23	4.48	4.57	4.57
50,000	0.22	0.41	0.61	0.83	1.00	1.16	2.10	2.66	3.00	3.29	3.36	3.36
100,000	0.12	0.23	0.35	0.46	0.57	0.65	1.20	1.57	1.91	2.14	2.18	2.18
121,119	0.10	0.20	0.30	0.38	0.47	0.54	0.99	1.34	1.64	1.83	1.87	1.87




SPAS 1526 Storm Center Mass Curve: Zone 1
June 13 (1800 UTC) - June 15 (1700 UTC), 2006
Lat: 34.335 Lon: -81.005
Incremental
Accumulated
9.32"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
1
26



N

Miles
0 25 50 100

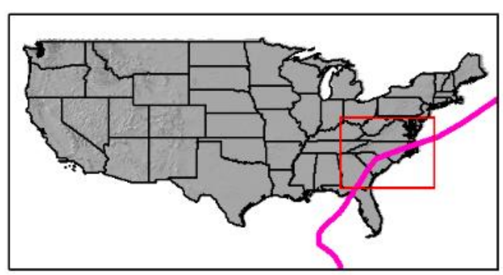
Total 48-hour Precipitation (inches)
June 13, 2006 1700 UTC - June 15, 2006 1700 UTC
SPAS #1526

Precipitation (inches)

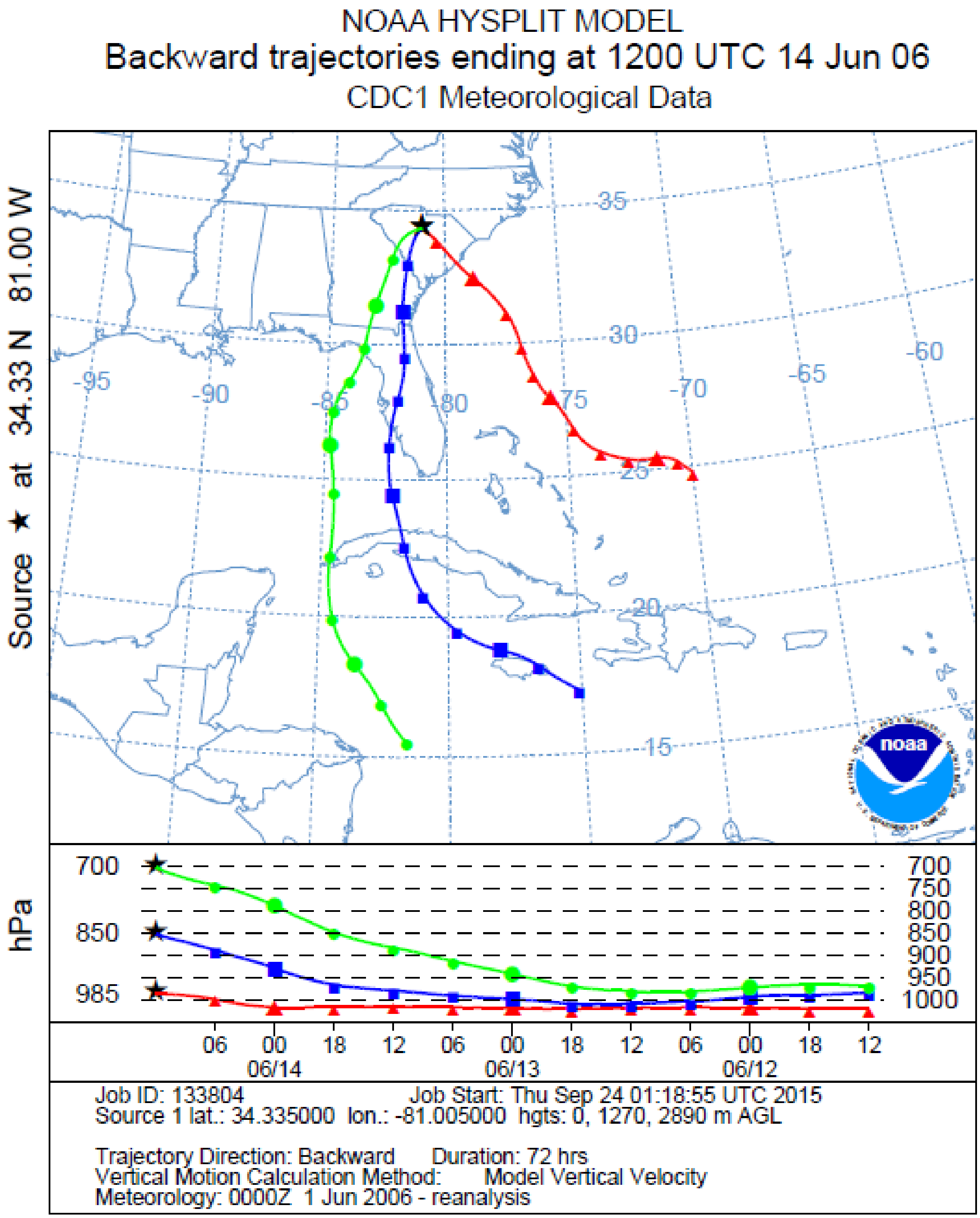
- 0.00 - 0.50
- 0.51 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- 2.51 - 3.00
- 3.01 - 3.50
- 3.51 - 4.00
- 4.01 - 4.50
- 4.51 - 5.00
- 5.01 - 5.50
- 5.51 - 6.00
- 6.01 - 6.50
- 6.51 - 7.00
- 7.01 - 7.50
- 7.51 - 8.00
- 8.01 - 8.50
- 8.51 - 9.00
- 9.01 - 9.50

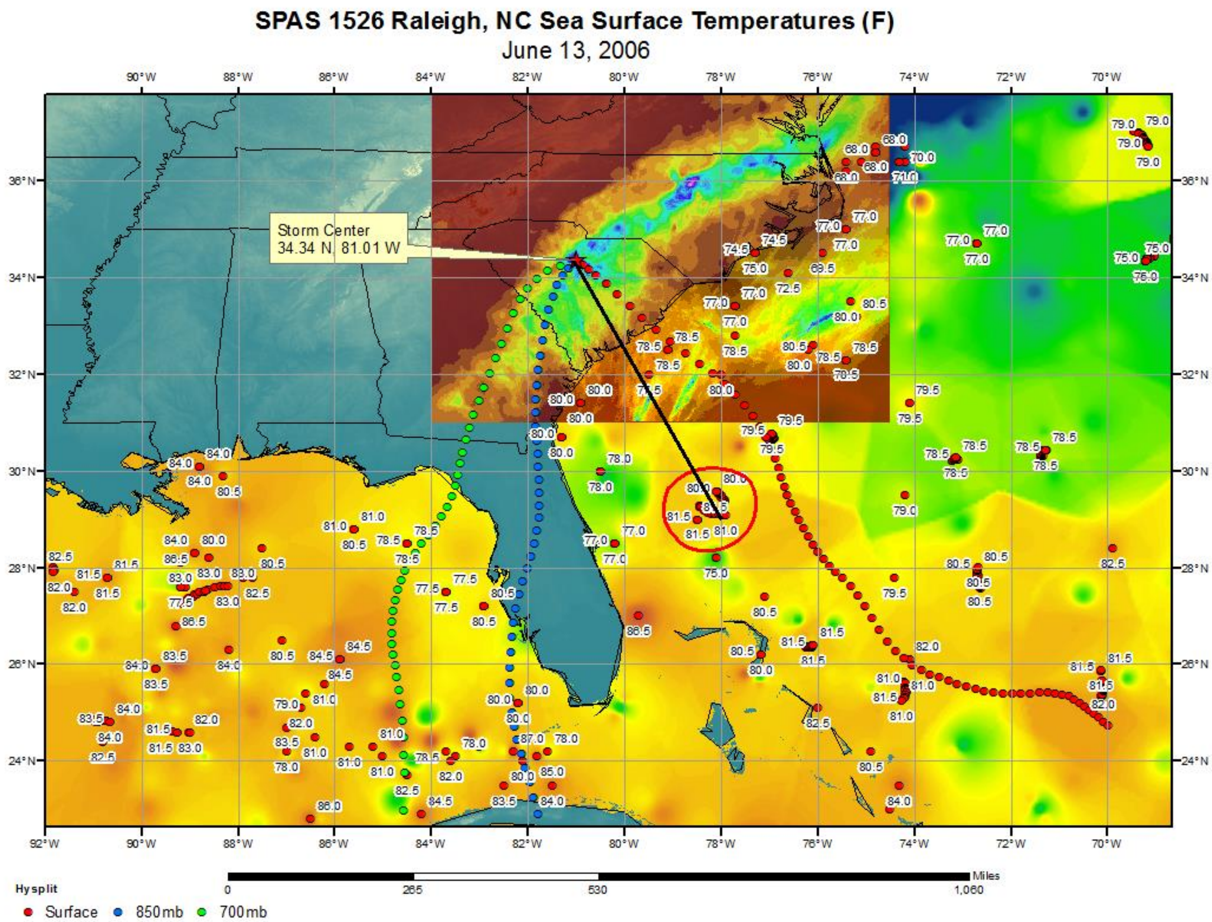
Stations

- Daily
- Hourly
- HEP
- Hourly Pseudo
- Supplemental



KLL 05/18/2015


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 14 Jun 06
CDC1 Meteorological Data
Source ★ at 34.33 N 81.00 W
35
30
25
20
15
-95
-90
-85
-80
-75
-70
-65
-60
noaa
hPa
700
850
985
700
750
800
850
900
950
1000
06 00 18 12 06 00 18 12 06 00 18 12
06/14
06/13
06/12
Job ID: 133804
Job Start: Thu Sep 24 01:18:55 UTC 2015
Source 1 lat.: 34.335000 lon.: -81.005000 hgts: 0, 1270, 2890 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2006 - reanalysis


SPAS 1526 Raleigh, NC Sea Surface Temperatures (F)
June 13, 2006
Storm Center
34.34 N, 81.01 W
Hysplit
Surface
850mb
700mb
Miles
0
265
530
1,060

Storm Precipitation Analysis System (SPAS) For Storm #1224_1 SPAS-NEXRAD Analysis

General Storm Location: Maplecrest, NY-Northern New Jersey, southeastern New York, extreme eastern Pennsylvania, western Connecticut, western Massachusetts and southwestern Vermont.

Storm Dates: Aug. 27, 2011 12Z - Aug. 29, 2011 05Z (42-hours)

Event: Hurricane Irene

DAD Zone 1 – Catskills and portions of south-western NY

Latitude: 42.30

Longitude: -74.16

Max. Grid Rainfall Amount: 22.91”

Max. Grid Rainfall Amount: 10.96”

* Note: The DAD zone 3 storm center is situated on the eastern boundary of the DAD zone and should be considered carefully given entire storm around the center was NOT analyzed.

Number of Stations: 797 (1 Daily**, 228 Hourly, 0 Hourly Estimated, 0 Hourly Estimated Pseudo, 71 Hourly Pseudo, 493 Supplemental, and 4 Supplemental Estimated) * Note: The DAD zone ** Note: Given the recentness of this storm event, daily data from our internal/NCDC-based database was not available.

SPAS Version: 9.0

Basemap: PRISM Mean (1971-2000) August precipitation

Spatial resolution: 36 seconds (~0.36 mi^2)

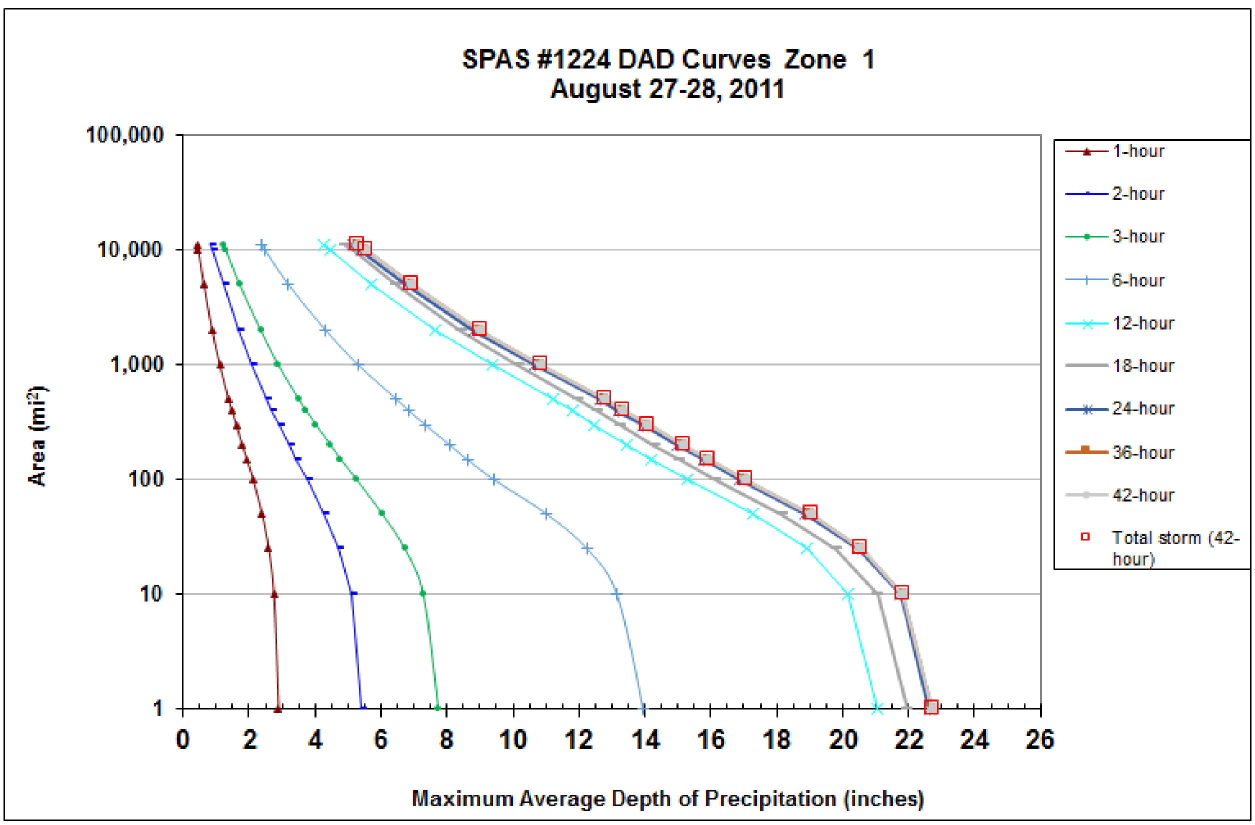
Radar Included: Yes

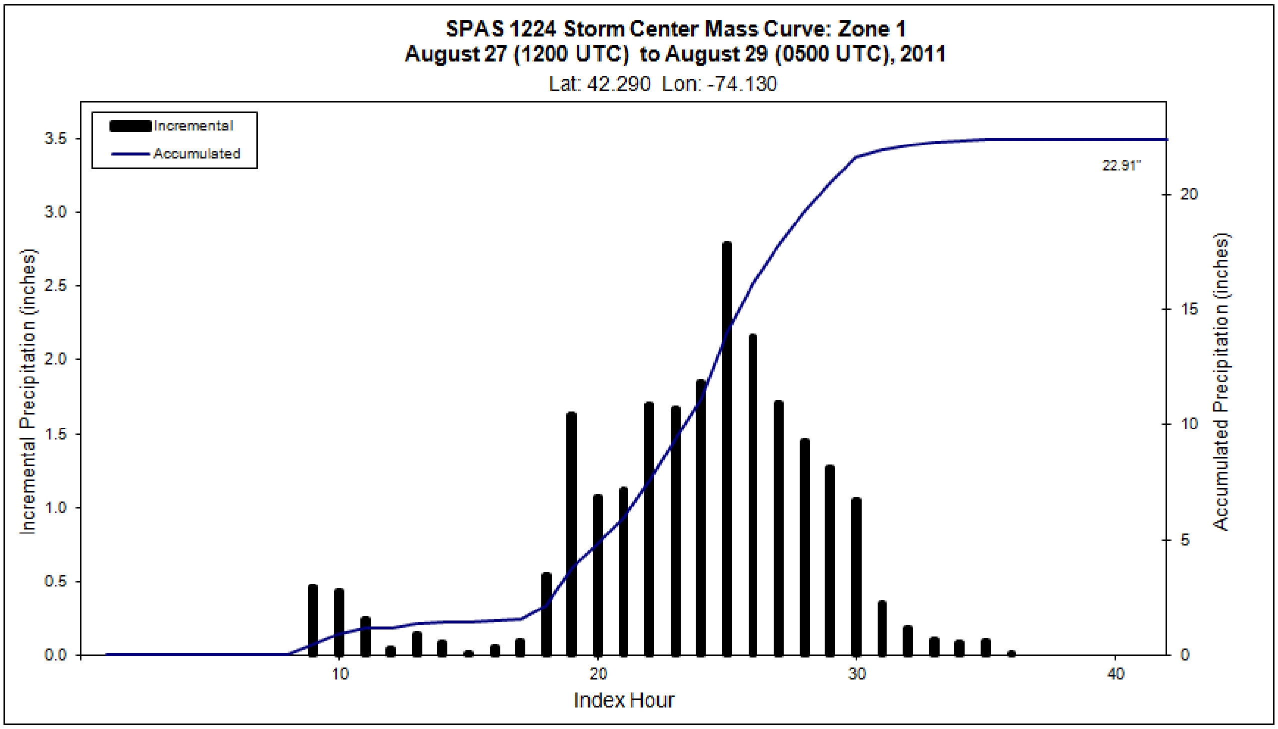
Depth-Area-Duration (DAD) analysis: Yes

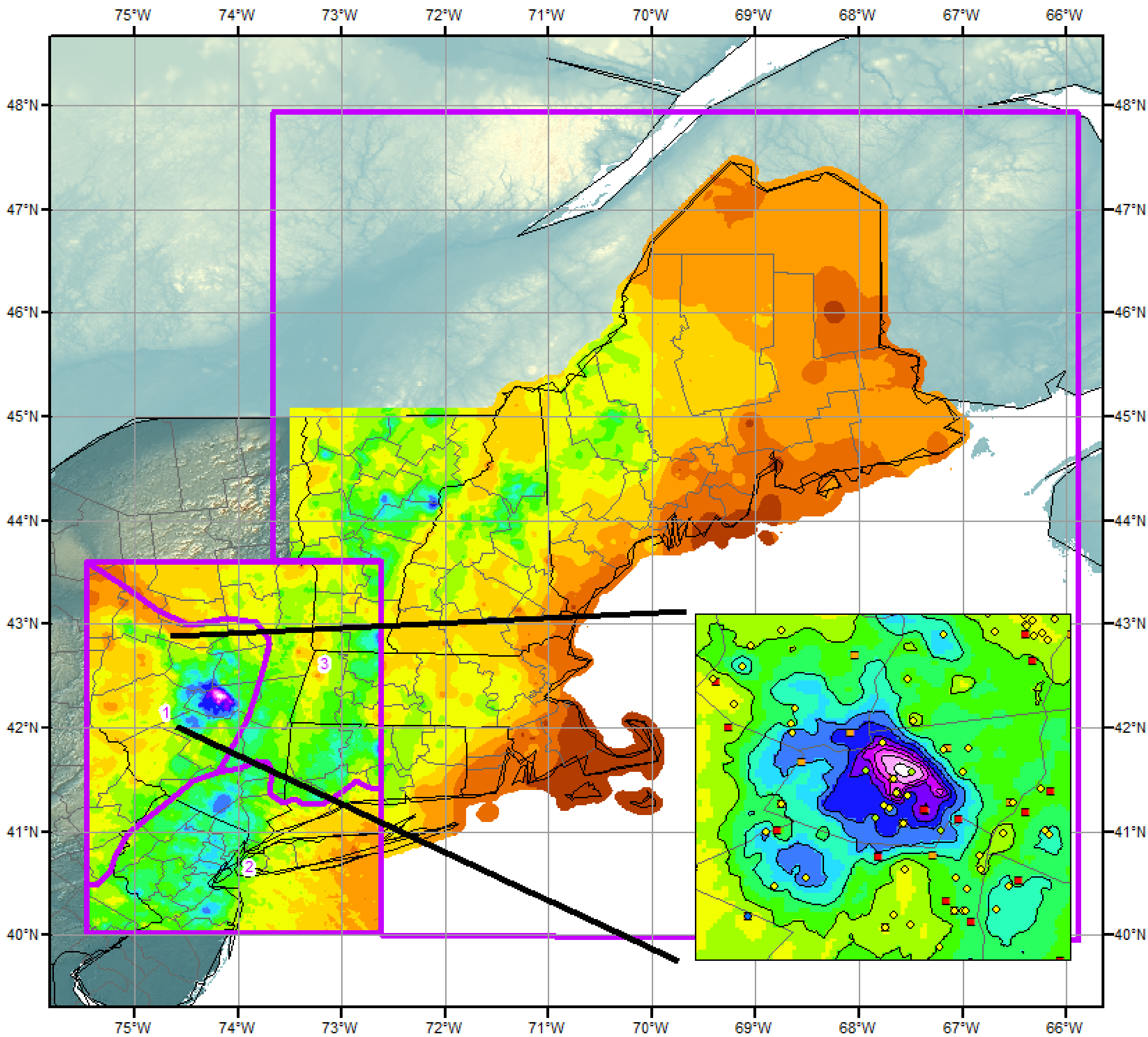
Reliability of results: Given the largely unblocked, clean and QC’d radar data coupled with extensive gauge data, we have a high degree of confidence in the results of this analysis.

						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1224_1	-74.1600	42.3000	2,264	15-Aug	81.50	3.86	0.68	85	3.180	83.32	4.21	0.71	89	3.500	1.101

Storm 1224 - August 27 (1200 UTC) - August 29 (0500 UTC), 2011										
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)										
Area (mi^2)	Duration (hours)									
	1	2	3	6	12	18	24	36	42	Total
0.4	2.92	5.44	7.84	14.11	21.24	22.14	22.79	22.89	22.89	22.89
1	2.89	5.39	7.74	13.96	21.05	21.96	22.63	22.72	22.72	22.72
10	2.75	5.09	7.28	13.16	20.14	21.06	21.76	21.84	21.84	21.84
25	2.59	4.71	6.72	12.25	18.89	19.79	20.46	20.57	20.57	20.57
50	2.39	4.27	6.04	11.03	17.26	18.15	18.88	19.05	19.05	19.05
100	2.12	3.75	5.26	9.43	15.27	16.14	16.90	17.07	17.07	17.07
150	1.93	3.43	4.78	8.61	14.18	15.03	15.76	15.93	15.93	15.93
200	1.79	3.21	4.47	8.08	13.46	14.29	15.00	15.17	15.17	15.17
300	1.61	2.91	4.03	7.34	12.46	13.25	13.94	14.10	14.10	14.10
400	1.48	2.69	3.73	6.83	11.80	12.56	13.20	13.36	13.36	13.36
500	1.38	2.52	3.51	6.47	11.19	11.98	12.66	12.82	12.82	12.82
1,000	1.11	2.06	2.88	5.30	9.37	10.17	10.68	10.86	10.86	10.86
2,000	0.88	1.67	2.35	4.31	7.66	8.42	8.83	9.01	9.01	9.01
5,000	0.63	1.21	1.71	3.18	5.70	6.47	6.77	6.95	6.95	6.95
10,000	0.46	0.89	1.29	2.47	4.46	5.17	5.40	5.57	5.57	5.57
11,085	0.44	0.85	1.23	2.36	4.26	4.93	5.14	5.29	5.30	5.30




SPAS 1224 Storm Center Mass Curve: Zone 1
August 27 (1200 UTC) to August 29 (0500 UTC), 2011
Lat: 42.290 Lon: -74.130
Incremental
Accumulated
22.91"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
5
10
15
20
10
20
30
40



Total Storm Precipitation
Hurricane Irene August 27-29, 2011
SPAS 1224

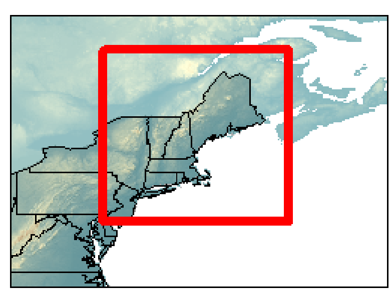
Gauges

- Daily
- Hourly
- Hourly Pseudo
- Supplemental
- Supplemental Estimated

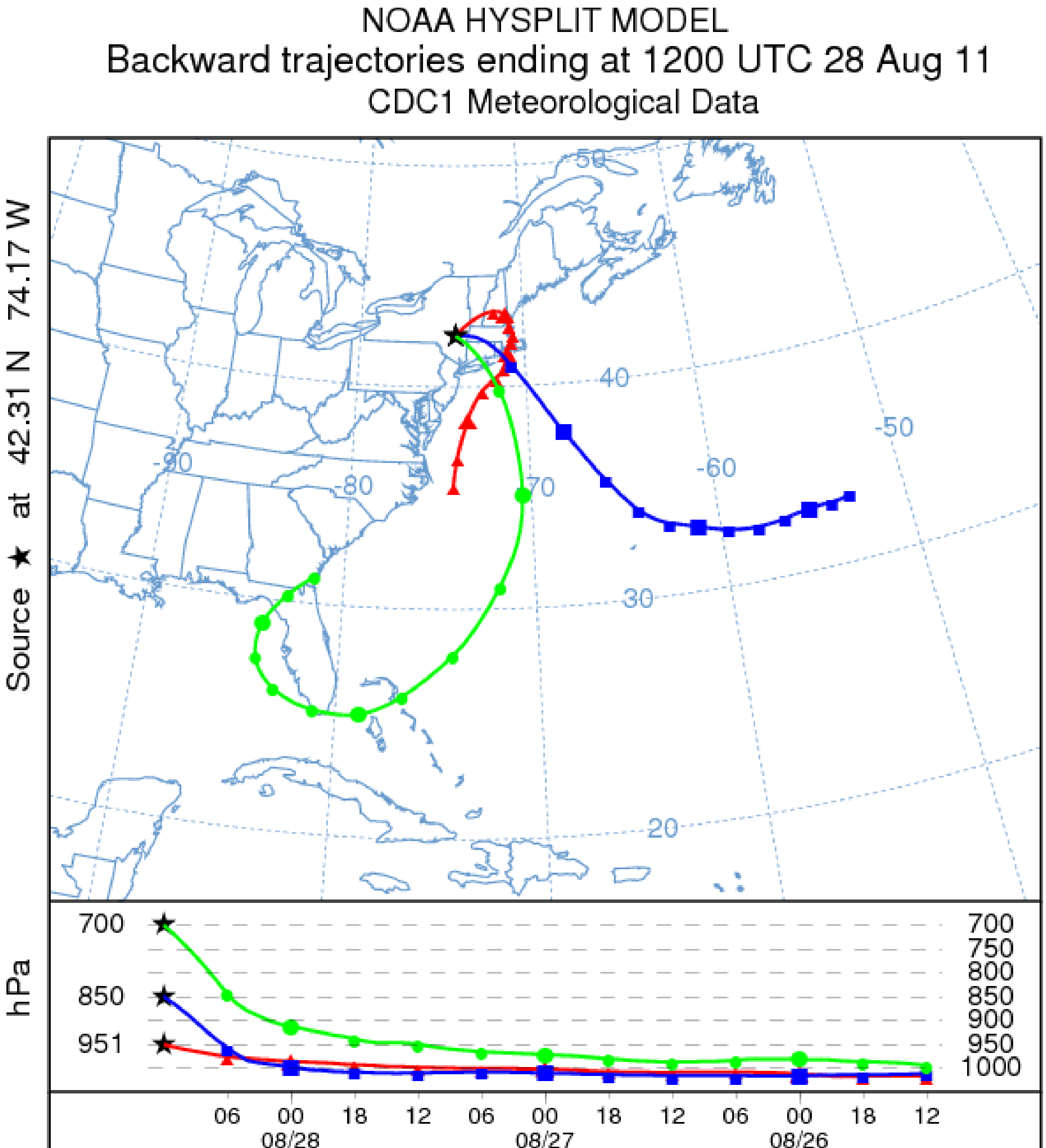
Miles: 0, 40, 80, 160
Kilometers: 0, 80, 160, 320

Precipitation (inches)

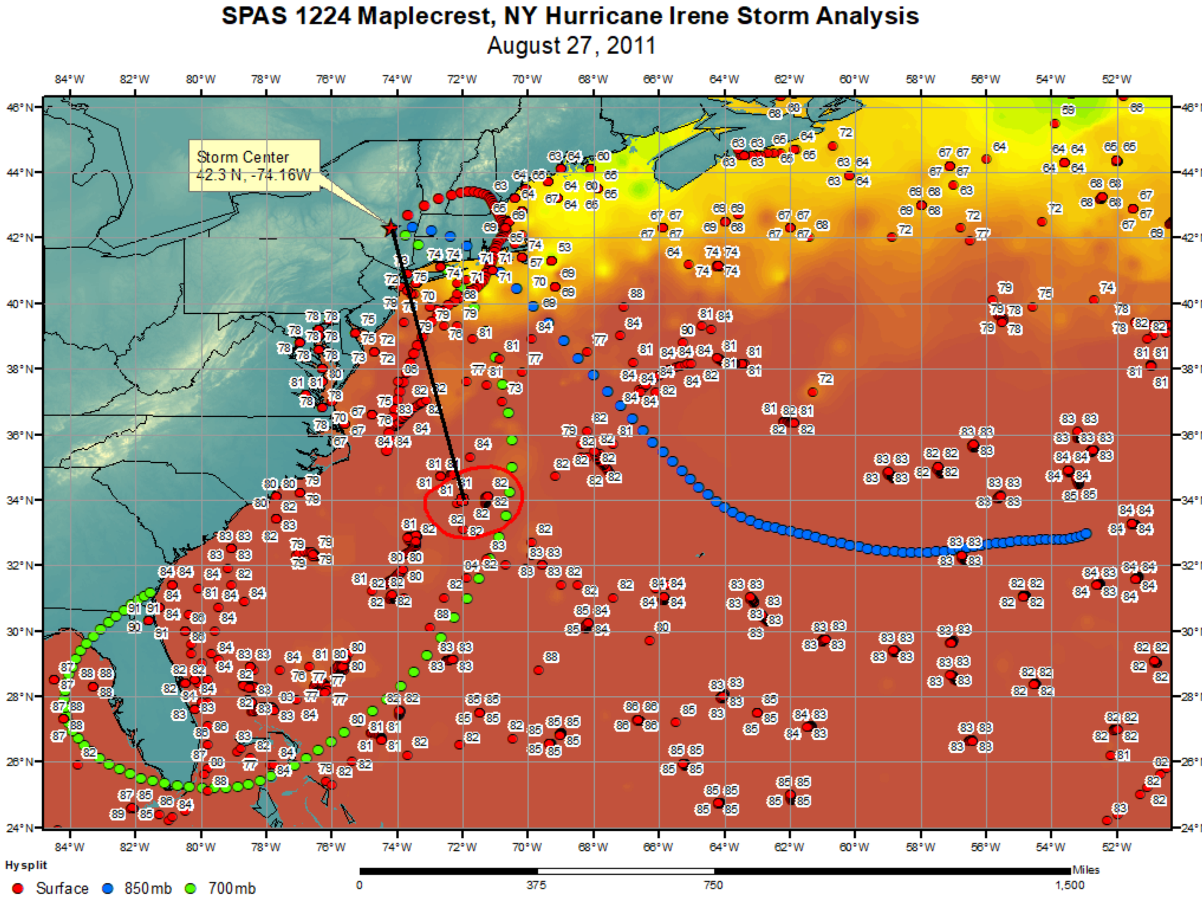
0.00 - 0.01	3.01 - 4.00	7.01 - 8.00	12.01 - 14.00	20.01 - 22.00
0.02 - 1.00	4.01 - 5.00	8.01 - 9.00	14.01 - 16.00	22.01 - 24.00
1.01 - 2.00	5.01 - 6.00	9.01 - 10.00	16.01 - 18.00	
2.01 - 3.00	6.01 - 7.00	10.01 - 12.00	18.01 - 20.00	



1/15/2013



This is not a NOAA product. It was produced by a web user.
Job ID: 346006 Job Start: Tue Sep 25 20:29:31 UTC 2012
Source 1 lat.: 42.31 lon.: -74.17 hgts: 0, 970, 2600 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Aug 2011 - reanalysis


SPAS 1224 Maplecrest, NY Hurricane Irene Storm Analysis
August 27, 2011
Storm Center
42.3 N, -74.16W
Hysplit
Surface
850mb
700mb
Miles
0
375
750
1,500

Storm Precipitation Analysis System (SPAS) For Storm #1669_1 SPAS-NEXRAD Analysis

General Storm Location: East Coast

Storm Dates: October 6-9, 2016

Event: Hurricane Matthew

DAD Zone 1

Latitude: 34.4550

Longitude: -78.8650

Max. Grid Rainfall Amount: 19.12”

Number of Stations: 1738

SPAS Version: 10.0

Base Map Used: Default Radar

Spatial resolution: 0.3893

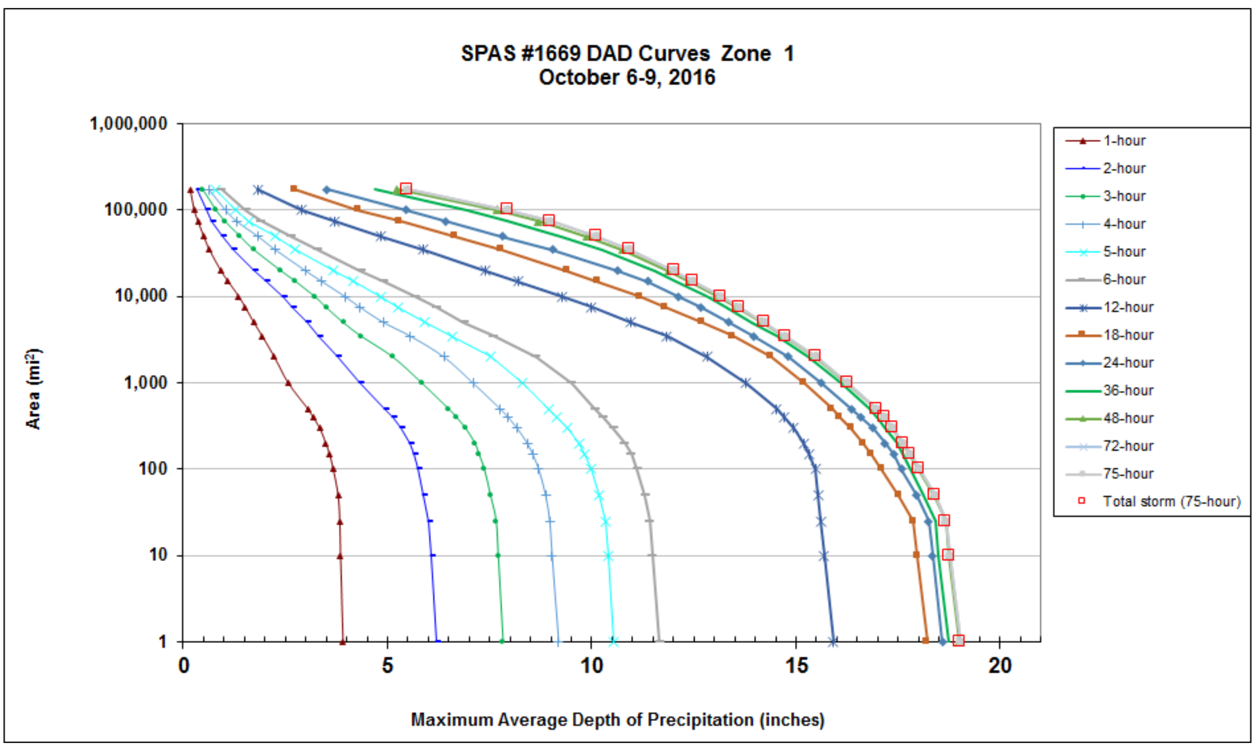
Radar Included: Yes

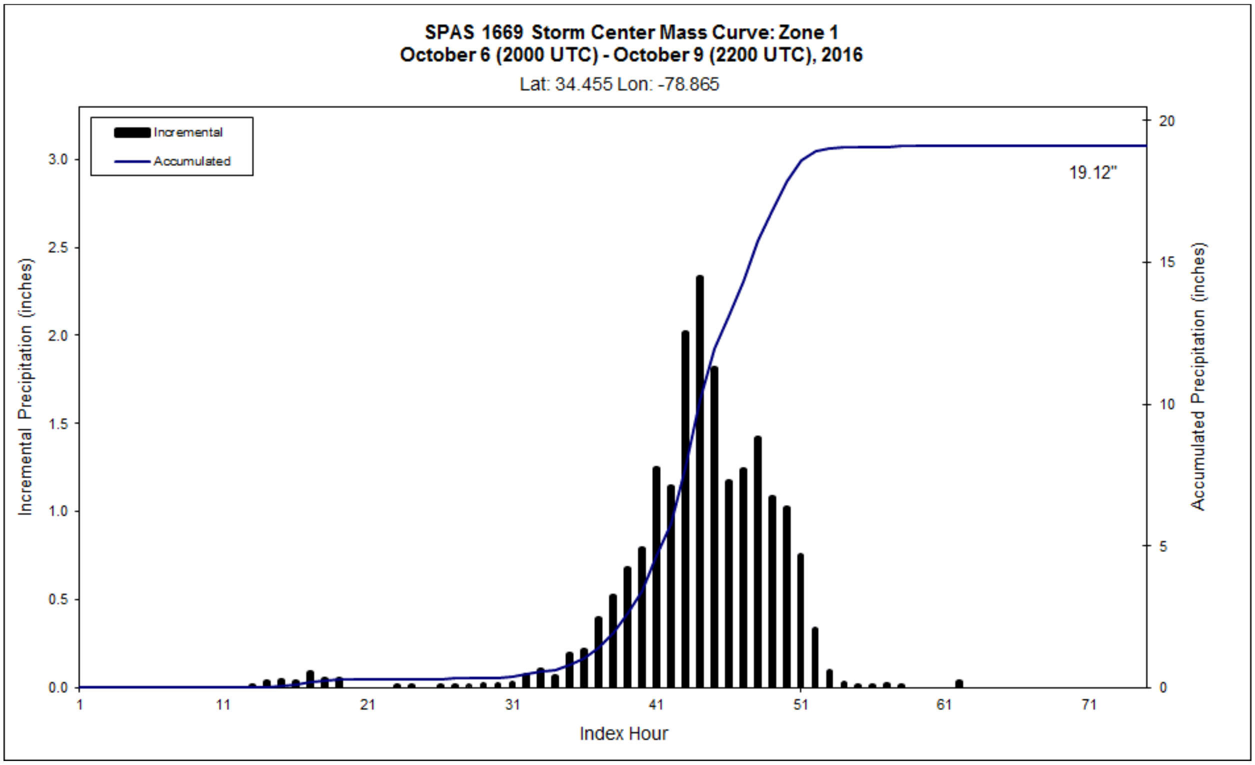
Depth-Area-Duration (DAD) analysis: Yes

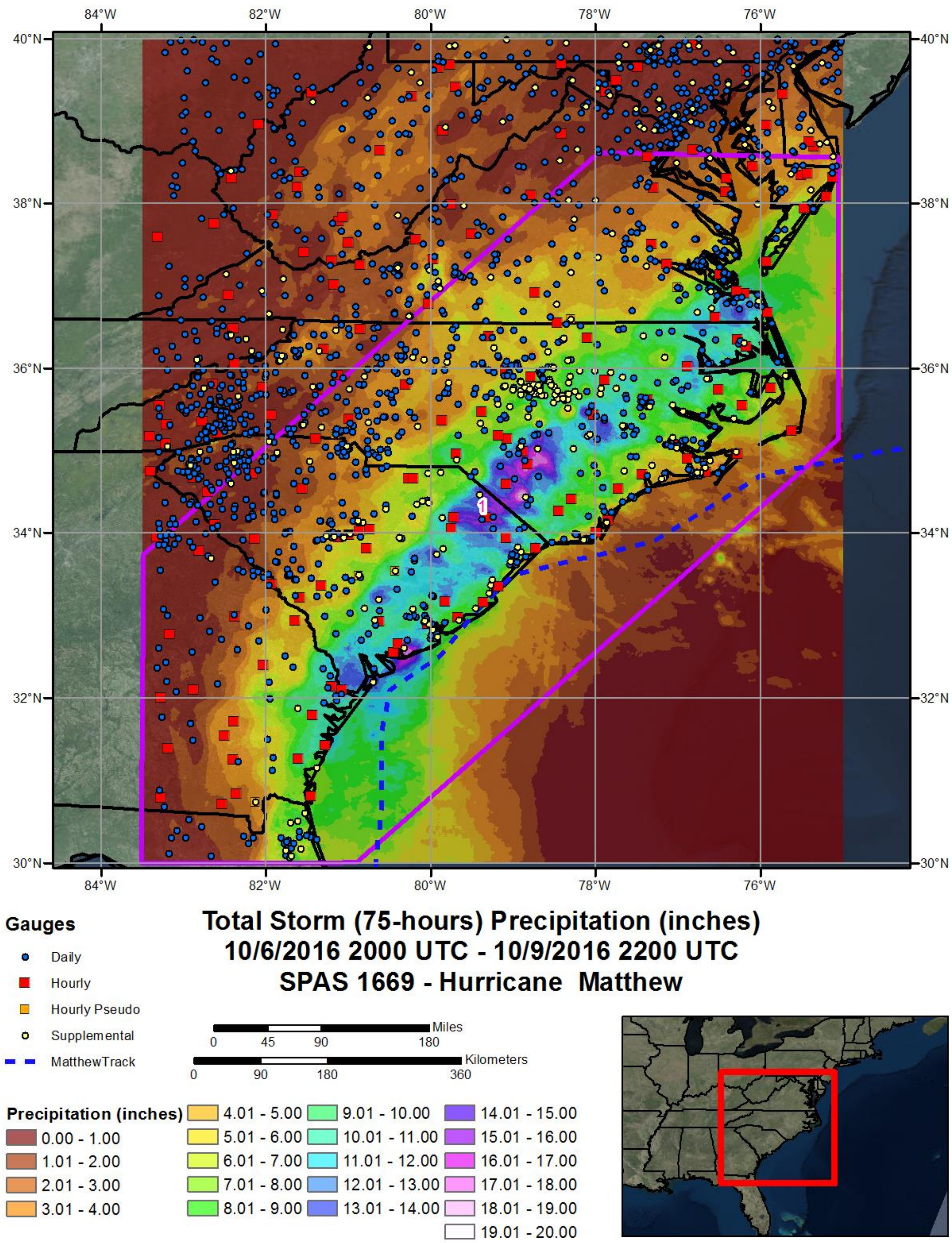
Reliability of Results: This analysis was based on 1738 hourly stations, daily data, supplemental station data and NEXRAD Radar. We have a good degree of confidence for the radar/station based storm total results. The spatial pattern is dependent on the radar data and basemap. Timing is based on the hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

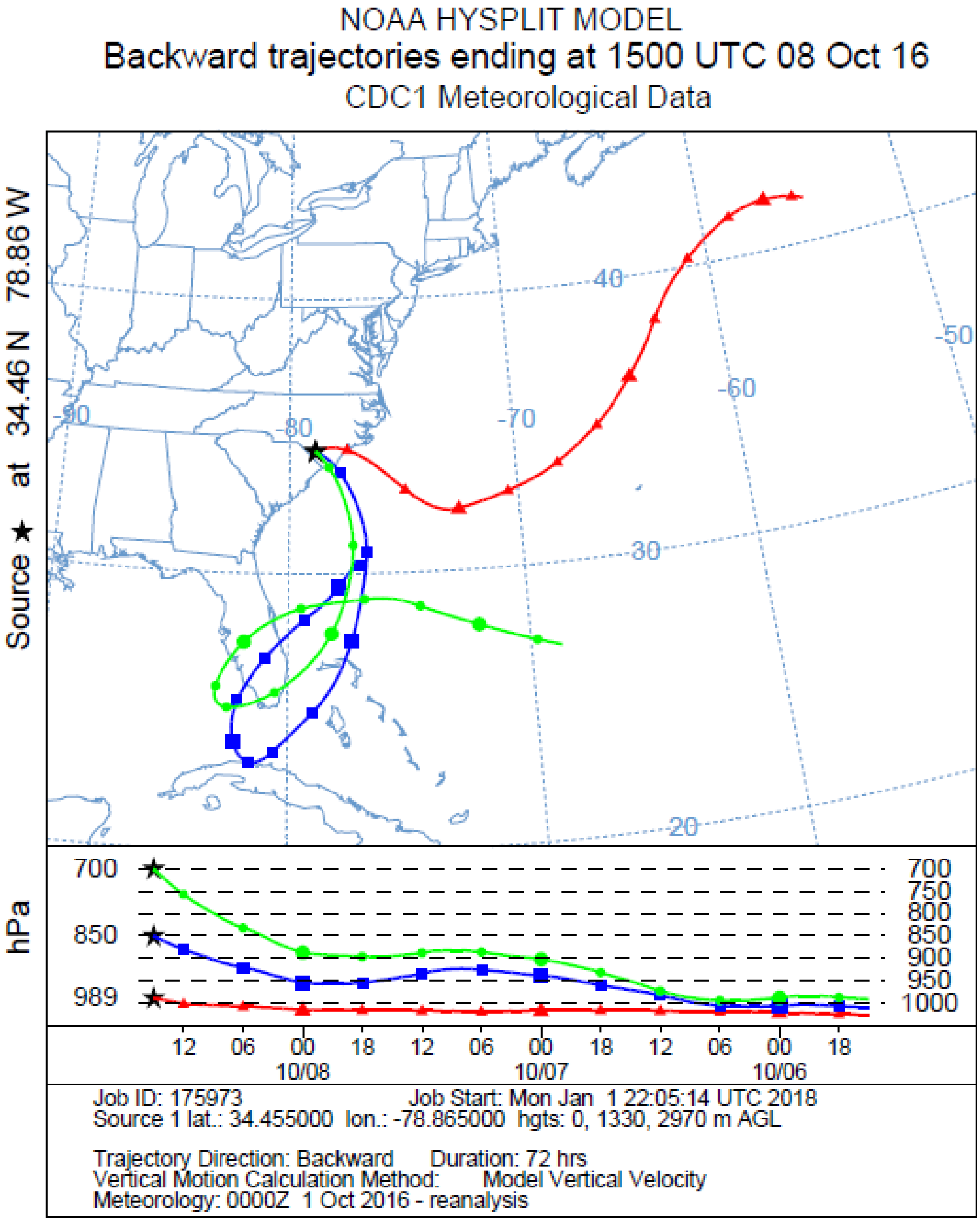
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1669_1	-78.8650	34.4550	103	22-Sep	82.50	4.03	0.03	87	4.000	84.19	4.30	0.04	90	4.260	1.065

Storm 1669 - October 6 (2000 UTC) - October 9 (2200 UTC), 2016 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
Area (mi^2)	Duration (hours)													
	1	2	3	4	5	6	12	18	24	36	48	72	75	Total
0.4	3.93	6.25	7.88	9.25	10.62	11.73	16.00	18.31	18.68	18.83	19.09	19.12	19.12	19.12
1	3.91	6.20	7.83	9.19	10.55	11.66	15.91	18.21	18.58	18.73	18.99	19.02	19.02	19.02
10	3.85	6.08	7.71	9.03	10.39	11.48	15.69	17.97	18.34	18.49	18.75	18.77	18.77	18.77
25	3.83	6.00	7.66	8.97	10.33	11.41	15.61	17.87	18.24	18.40	18.66	18.67	18.67	18.67
50	3.79	5.88	7.52	8.87	10.18	11.31	15.54	17.51	17.95	18.12	18.37	18.40	18.40	18.40
100	3.67	5.74	7.37	8.70	9.99	11.11	15.48	17.09	17.59	17.80	17.99	18.02	18.02	18.02
150	3.58	5.64	7.24	8.55	9.82	10.97	15.32	16.84	17.39	17.61	17.78	17.80	17.80	17.80
200	3.49	5.54	7.14	8.42	9.68	10.81	15.19	16.64	17.18	17.48	17.61	17.63	17.63	17.63
300	3.34	5.34	6.91	8.17	9.39	10.52	14.95	16.36	16.88	17.20	17.34	17.36	17.36	17.36
400	3.18	5.14	6.69	7.95	9.14	10.28	14.71	16.08	16.60	17.00	17.15	17.17	17.17	17.17
500	3.05	4.95	6.50	7.76	8.94	10.07	14.52	15.88	16.36	16.80	16.95	16.96	16.96	16.96
1,000	2.57	4.33	5.84	7.09	8.30	9.50	13.78	15.21	15.63	16.11	16.25	16.27	16.27	16.27
2,000	2.23	3.76	5.13	6.38	7.53	8.63	12.83	14.40	14.82	15.31	15.48	15.50	15.50	15.50
3,500	1.93	3.32	4.35	5.55	6.60	7.60	11.83	13.45	13.96	14.52	14.70	14.74	14.74	14.74
5,000	1.73	3.02	3.92	4.91	5.90	6.87	10.97	12.71	13.36	13.92	14.17	14.21	14.21	14.21
7,500	1.52	2.67	3.50	4.33	5.27	6.19	9.99	11.79	12.67	13.28	13.54	13.60	13.60	13.60
10,000	1.36	2.43	3.22	3.96	4.84	5.68	9.27	11.17	12.11	12.82	13.09	13.16	13.16	13.16
15,000	1.10	2.03	2.75	3.39	4.16	4.91	8.20	10.14	11.37	12.07	12.38	12.48	12.48	12.48
20,000	0.92	1.72	2.39	2.99	3.66	4.35	7.41	9.39	10.64	11.54	11.89	12.01	12.01	12.01
35,000	0.64	1.22	1.73	2.25	2.75	3.29	5.89	7.80	9.04	10.26	10.75	10.93	10.93	10.93
50,000	0.50	0.94	1.39	1.82	2.25	2.65	4.84	6.66	7.81	9.25	9.88	10.13	10.13	10.13
75,000	0.36	0.71	1.02	1.30	1.60	1.90	3.70	5.30	6.42	7.93	8.70	8.99	8.99	8.99
100,000	0.27	0.57	0.81	1.04	1.27	1.53	2.90	4.28	5.47	6.95	7.70	7.94	7.94	7.94
173,422	0.17	0.33	0.48	0.63	0.78	0.93	1.82	2.73	3.52	4.70	5.24	5.50	5.50	5.50



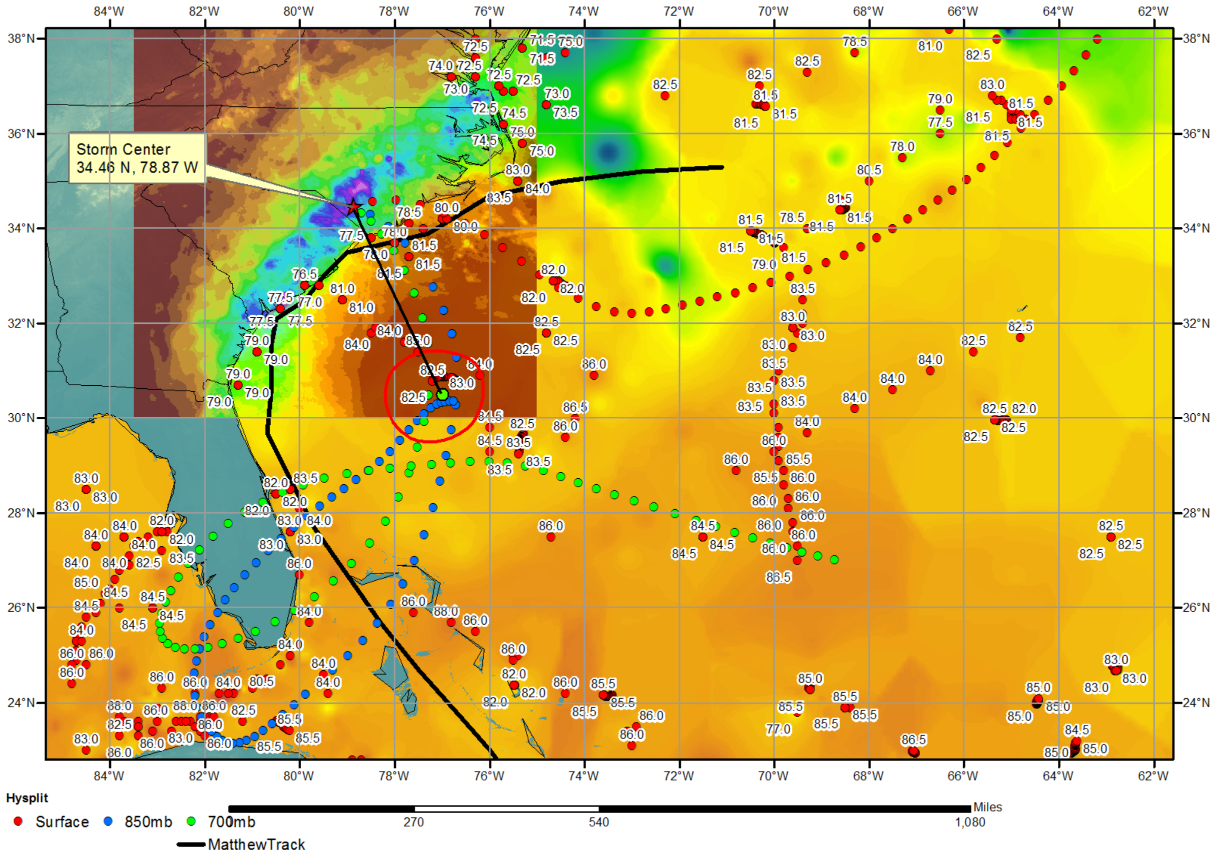

SPAS 1669 Storm Center Mass Curve: Zone 1
October 6 (2000 UTC) - October 9 (2200 UTC), 2016
Lat: 34.455 Lon: -78.865
Incremental
Accumulated
19.12"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
15
20
1
11
21
31
41
51
61
71

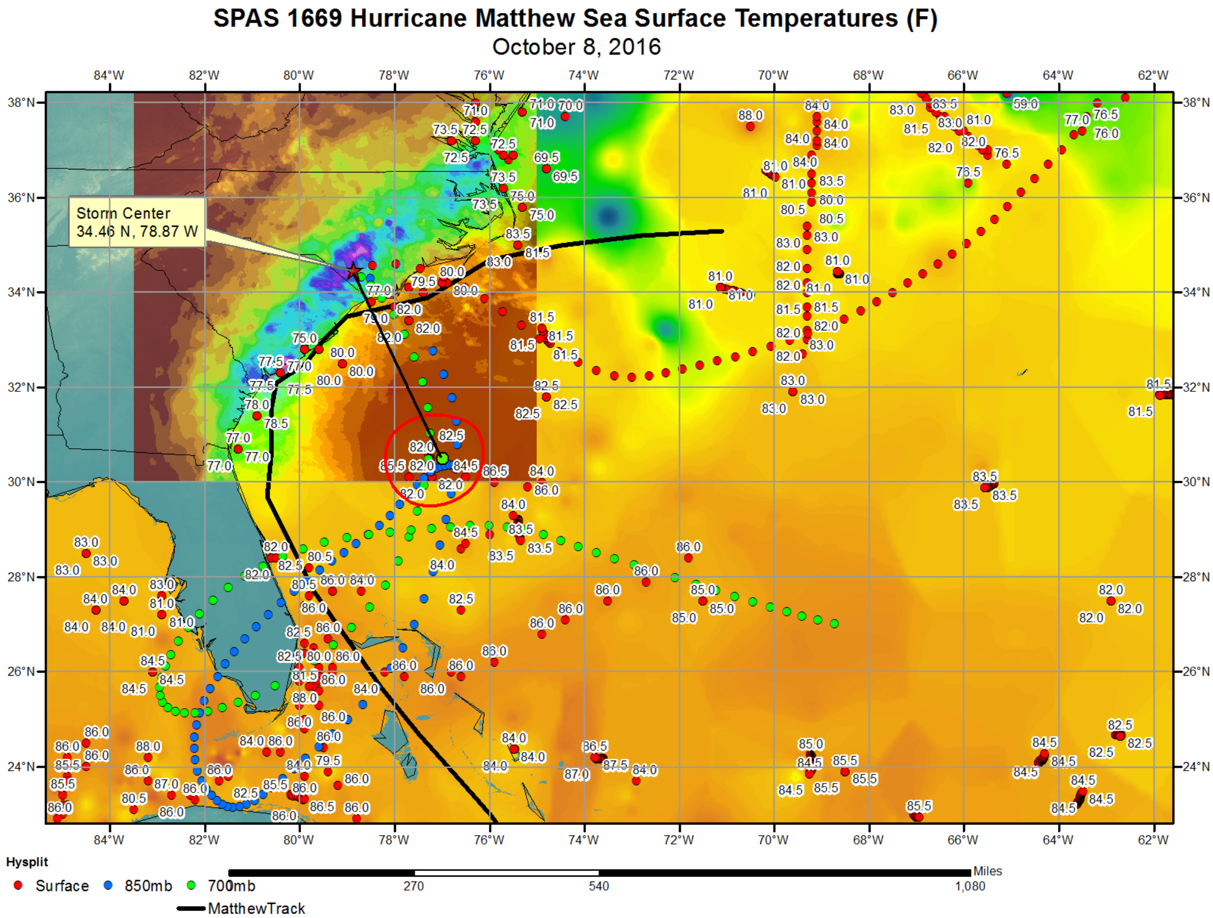

84°W
82°W
80°W
78°W
76°W
40°N
38°N
36°N
34°N
32°N
30°N
1
Total Storm (75-hours) Precipitation (inches)
10/6/2016 2000 UTC - 10/9/2016 2200 UTC
SPAS 1669 - Hurricane Matthew
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
MatthewTrack
Miles
0 45 90 180
Kilometers
0 90 180 360
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00


NOAA HYSPLIT MODEL
Backward trajectories ending at 1500 UTC 08 Oct 16
CDC1 Meteorological Data
Source ★ at 34.46 N 78.86 W
-40
-50
-60
-70
-80
-90
-30
-20
hPa
700
850
989
700
750
800
850
900
950
1000
12
06
00
18
12
06
00
18
12
06
00
18
10/08
10/07
10/06
Job ID: 175973
Job Start: Mon Jan 1 22:05:14 UTC 2018
Source 1 lat.: 34.455000 lon.: -78.865000 hgts: 0, 1330, 2970 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Oct 2016 - reanalysis

SPAS 1669 Hurricane Matthew Sea Surface Temperatures (F)

October 7, 2016




SPAS 1669 Hurricane Matthew Sea Surface Temperatures (F)
October 8, 2016
Storm Center
34.46 N, 78.87 W
Hysplit
Surface
850mb
700mb
MatthewTrack
Miles
270
540
1,080

Storm Precipitation Analysis System (SPAS) For Storm #1720_1 SPAS-NEXRAD Analysis

General Storm Location: East Coast

Storm Dates: September 13-18, 2018

Event: Hurricane Florence

DAD Zone 1

Latitude: 34.235

Longitude: -77.765

Max. Grid Rainfall Amount: 43.95”

Number of Stations:

SPAS Version: 10.0

Base Map Used: Default Radar

Spatial resolution:

Radar Included: Yes

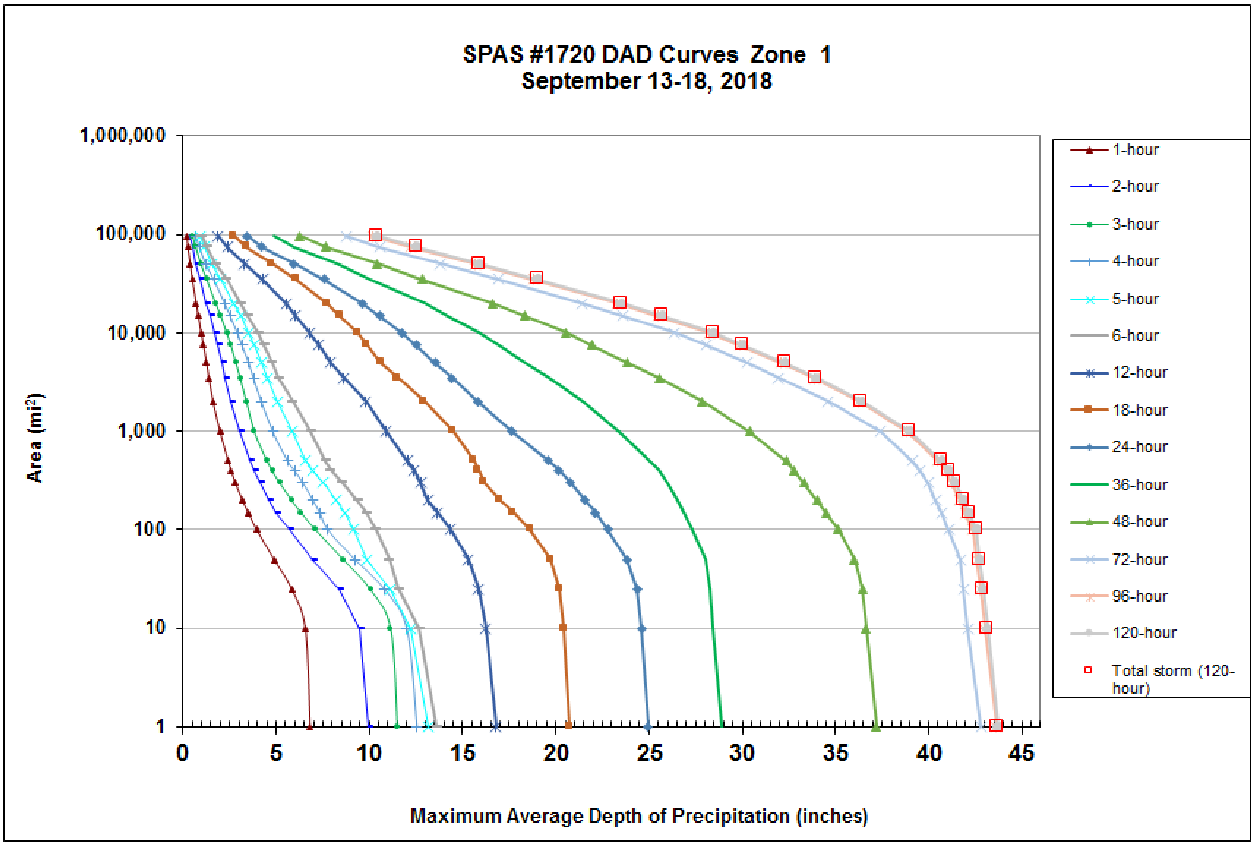
Depth-Area-Duration (DAD) analysis: Yes

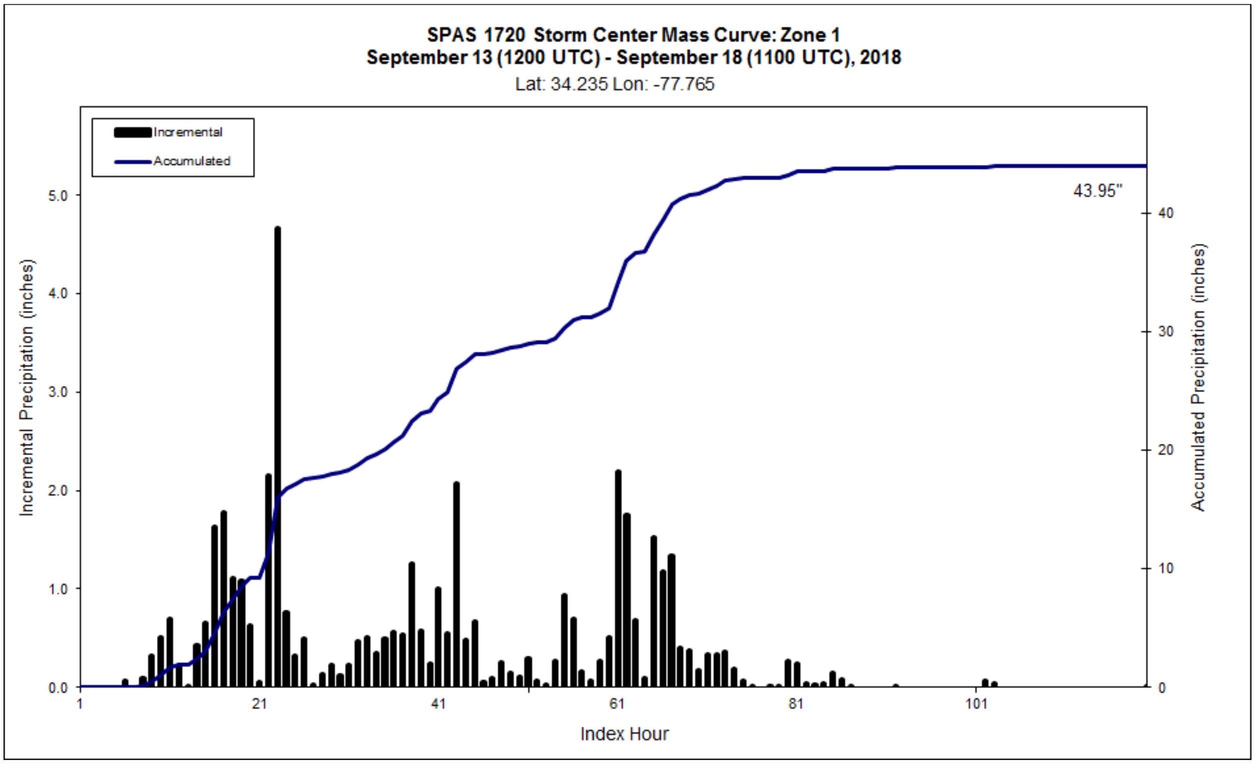
						Storm Rep. SST					Climatological Max. SST					
	SPAS Storm ID	LON	LAT	ELEV	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1720_1	-77.7650	34.2350	0	31-Aug	82.00	3.95	0.00	86	3.950	83.23	4.12	0.00	88	4.120	1.043

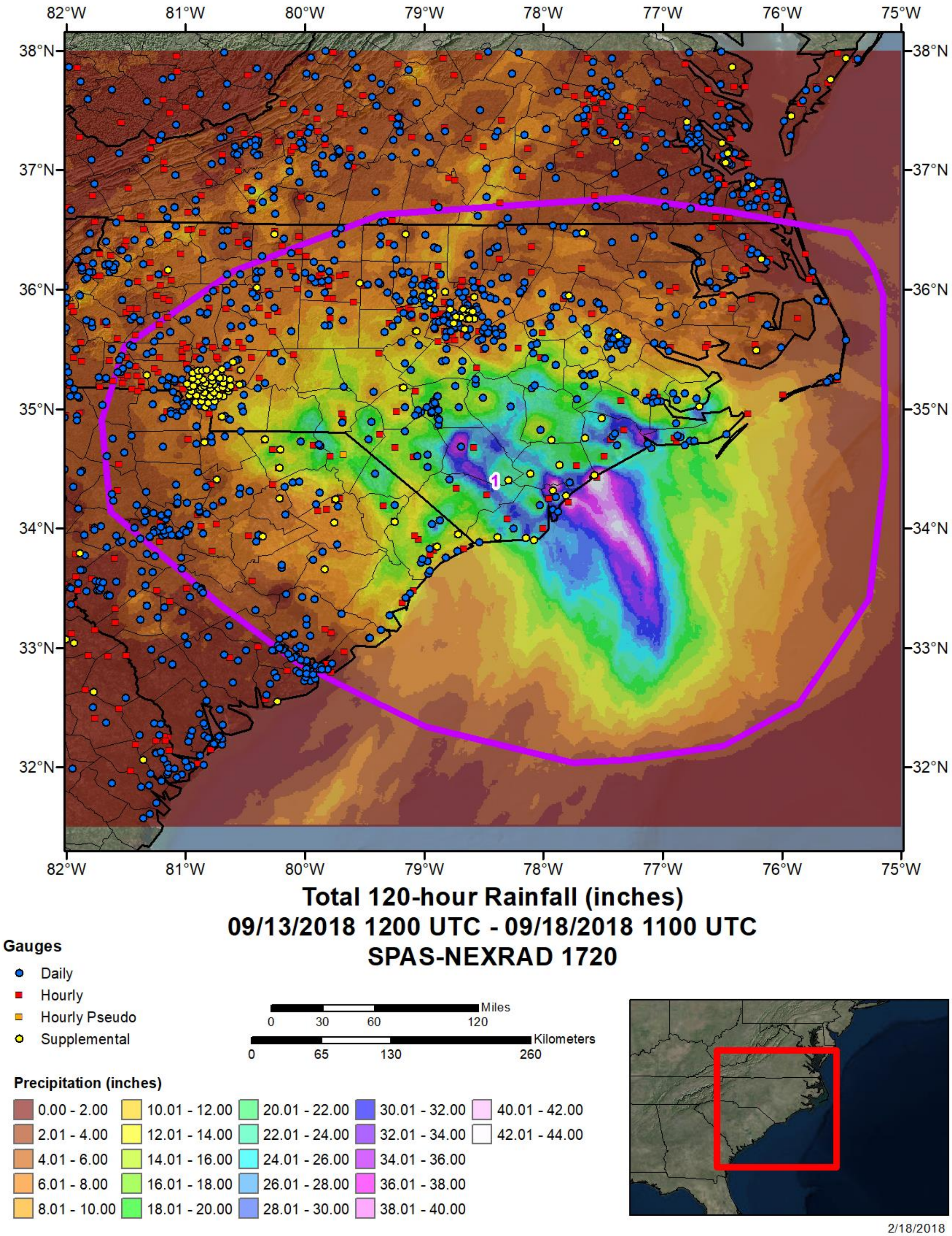
Storm 1720 - September 13 (1200 UTC) - September 18 (1100 UTC), 2018

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

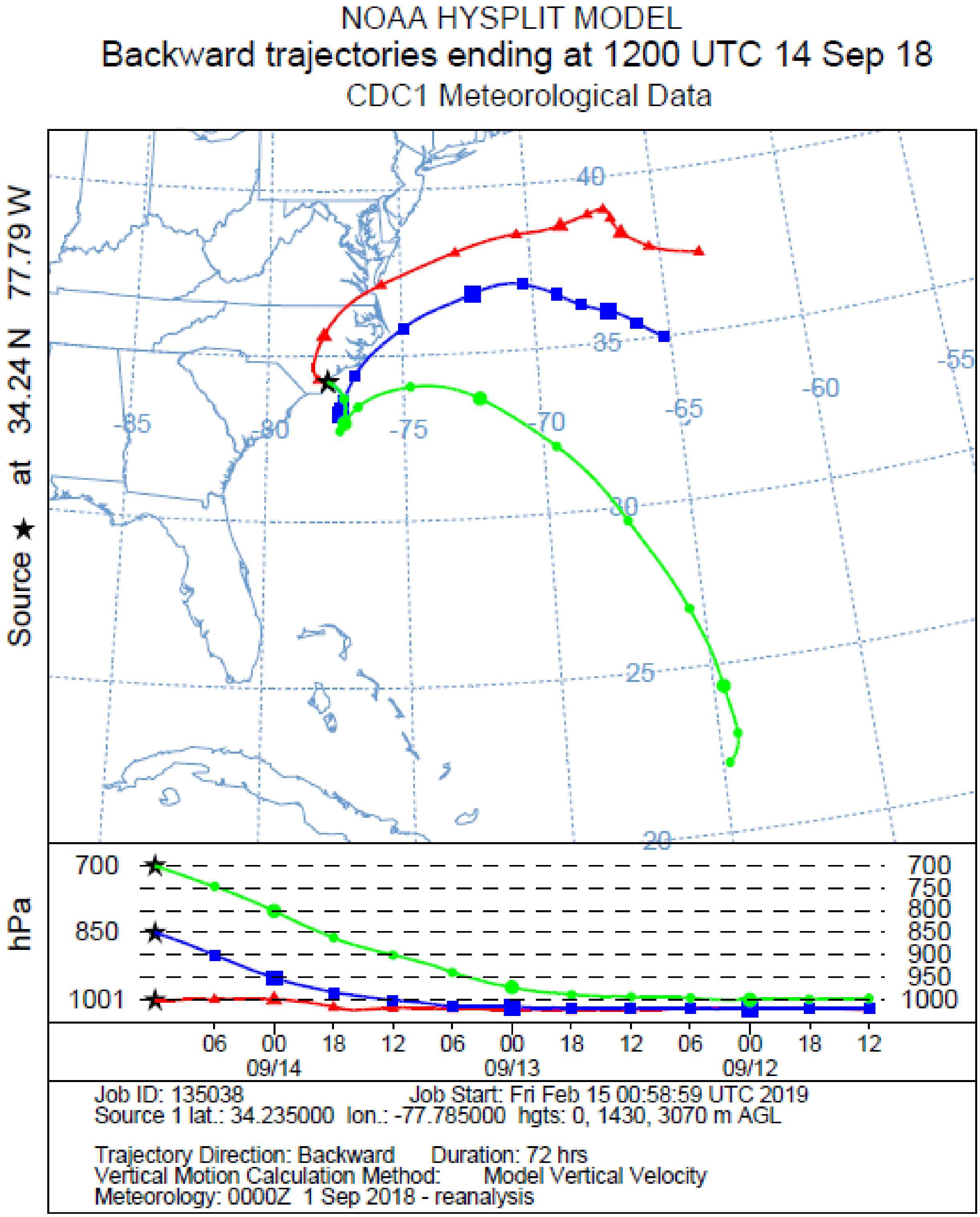
Area (mi²)	Duration (hours)														
	1	2	3	4	5	6	12	18	24	36	48	72	96	120	Total
0.4	6.88	10.04	11.60	12.65	13.33	13.81	16.94	20.86	25.12	29.06	37.42	43.10	43.88	43.95	43.95
1	6.82	9.94	11.51	12.51	13.17	13.63	16.79	20.74	24.97	28.88	37.20	42.81	43.61	43.72	43.72
10	6.56	9.51	11.15	11.97	12.24	12.65	16.23	20.42	24.60	28.44	36.66	42.11	42.99	43.14	43.14
25	5.85	8.41	10.07	10.80	11.09	11.57	15.84	20.20	24.35	28.27	36.45	41.87	42.75	42.92	42.92
50	4.90	6.97	8.63	9.23	9.86	11.05	15.31	19.75	23.80	28.00	36.03	41.69	42.57	42.74	42.74
100	3.97	5.71	7.15	7.78	9.16	10.35	14.37	18.62	22.80	27.34	35.17	41.09	42.38	42.57	42.57
150	3.50	5.03	6.36	7.33	8.66	9.85	13.67	17.72	22.12	26.88	34.48	40.68	41.96	42.16	42.16
200	3.20	4.61	5.86	6.98	8.24	9.37	13.14	17.03	21.58	26.53	34.00	40.39	41.66	41.85	41.85
300	2.82	4.14	5.22	6.44	7.48	8.53	12.74	16.18	20.79	26.03	33.30	39.98	41.25	41.42	41.42
400	2.59	3.86	4.81	6.00	6.99	7.93	12.38	15.83	20.16	25.50	32.76	39.51	40.91	41.10	41.10
500	2.43	3.59	4.54	5.62	6.58	7.65	12.06	15.60	19.62	25.03	32.35	39.12	40.49	40.67	40.67
1,000	1.99	3.02	3.85	4.83	5.89	6.86	10.89	14.52	17.67	23.41	30.42	37.41	38.85	39.01	39.01
2,000	1.62	2.55	3.43	4.22	5.07	5.88	9.79	12.95	15.82	21.45	27.87	34.59	36.27	36.40	36.40
3,500	1.39	2.28	3.09	3.79	4.56	5.14	8.63	11.53	14.45	19.64	25.55	31.95	33.84	33.99	33.99
5,000	1.26	2.10	2.86	3.53	4.21	4.77	7.91	10.64	13.52	18.37	23.87	30.30	32.11	32.28	32.28
7,500	1.10	1.86	2.60	3.18	3.84	4.35	7.28	9.90	12.53	16.96	21.93	28.10	29.84	30.06	30.06
10,000	0.98	1.71	2.37	2.94	3.51	4.02	6.79	9.36	11.72	15.89	20.56	26.35	28.22	28.46	28.46
15,000	0.82	1.44	2.05	2.55	3.08	3.50	6.05	8.43	10.57	14.25	18.35	23.62	25.46	25.72	25.72
20,000	0.72	1.26	1.79	2.26	2.70	3.11	5.52	7.72	9.62	12.97	16.59	21.38	23.29	23.54	23.54
35,000	0.50	0.90	1.30	1.68	2.00	2.36	4.29	6.06	7.56	10.05	12.84	16.93	18.78	19.01	19.01
50,000	0.39	0.70	1.00	1.25	1.54	1.77	3.29	4.77	5.97	8.25	10.43	13.80	15.64	15.89	15.89
75,000	0.26	0.49	0.71	0.91	1.13	1.29	2.37	3.41	4.25	5.99	7.67	10.57	12.25	12.57	12.57
96,675	0.21	0.38	0.55	0.71	0.88	1.03	1.87	2.73	3.43	4.89	6.29	8.75	10.16	10.44	10.44

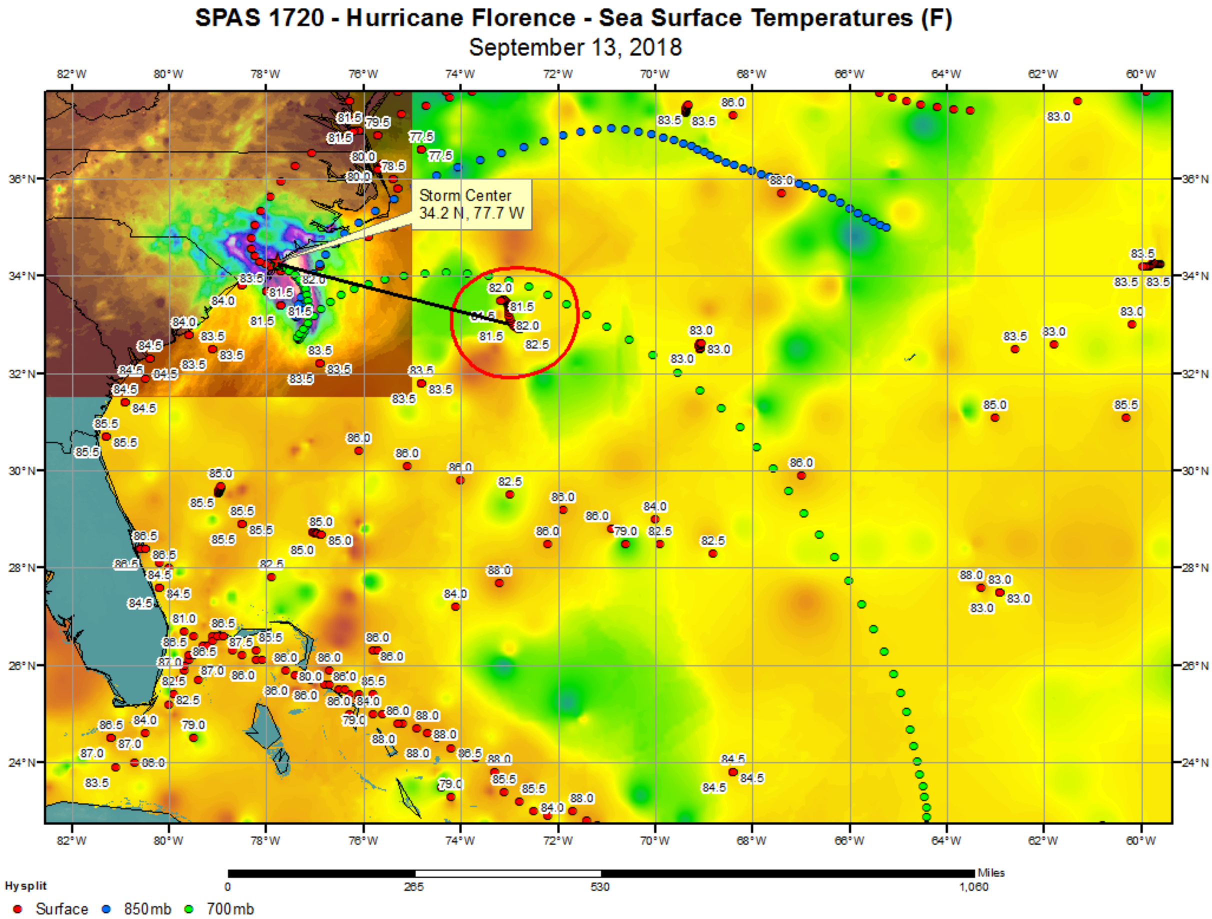



SPAS 1720 Storm Center Mass Curve: Zone 1
September 13 (1200 UTC) - September 18 (1100 UTC), 2018
Lat: 34.235 Lon: -77.765
Incremental
Accumulated
43.95"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
1.0
2.0
3.0
4.0
5.0
0
10
20
30
40
1
21
41
61
81
101



82°W
81°W
80°W
79°W
78°W
77°W
76°W
75°W
38°N
37°N
36°N
35°N
34°N
33°N
32°N
1
Total 120-hour Rainfall (inches)
09/13/2018 1200 UTC - 09/18/2018 1100 UTC
SPAS-NEXRAD 1720
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Miles
0 30 60 120
Kilometers
0 65 130 260
Precipitation (inches)
0.00 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 8.00
8.01 - 10.00
10.01 - 12.00
12.01 - 14.00
14.01 - 16.00
16.01 - 18.00
18.01 - 20.00
20.01 - 22.00
22.01 - 24.00
24.01 - 26.00
26.01 - 28.00
28.01 - 30.00
30.01 - 32.00
32.01 - 34.00
34.01 - 36.00
36.01 - 38.00
38.01 - 40.00
40.01 - 42.00
42.01 - 44.00
2/18/2018


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 14 Sep 18
CDC1 Meteorological Data
Source ★ at 34.24 N 77.79 W
40
35
30
25
20
-85
-80
-75
-70
-65
-60
-55
hPa
700
850
1001
700
750
800
850
900
950
1000
06
00
18
12
06
00
18
12
06
00
18
12
09/14
09/13
09/12
Job ID: 135038
Job Start: Fri Feb 15 00:58:59 UTC 2019
Source 1 lat.: 34.235000 lon.: -77.785000 hgts: 0, 1430, 3070 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2018 - reanalysis


SPAS 1720 - Hurricane Florence - Sea Surface Temperatures (F)
September 13, 2018
Storm Center
34.2 N, 77.7 W
Hysplit
Surface
850mb
700mb
Miles
0
265
530
1,060

Storm Precipitation Analysis System (SPAS) For Storm #1891_1 SPAS-NEXRAD Analysis

General Storm Location: Downington, PA

Storm Dates: August 30 – September 3, 2021

Event: Hurricane Ida

DAD Zone 1

Latitude: 39.9750

Longitude: -75.6650

Max. Grid Rainfall Amount: 10.29"

Max. Observed Rainfall Amount: 10.09"

Number of Stations: 3316

SPAS Version: 10.0

Base Map Used: 90/10 weighted Radar vs. Basemap

Spatial resolution: 0.3618

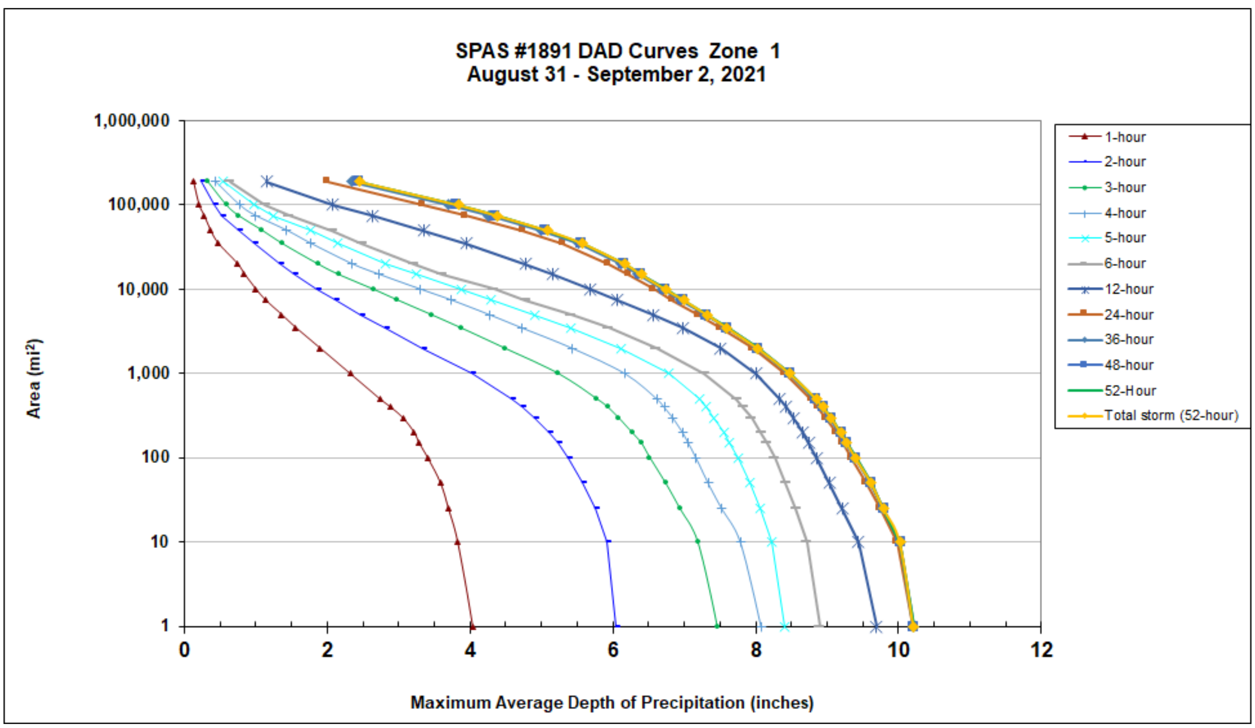
Radar Included: Yes

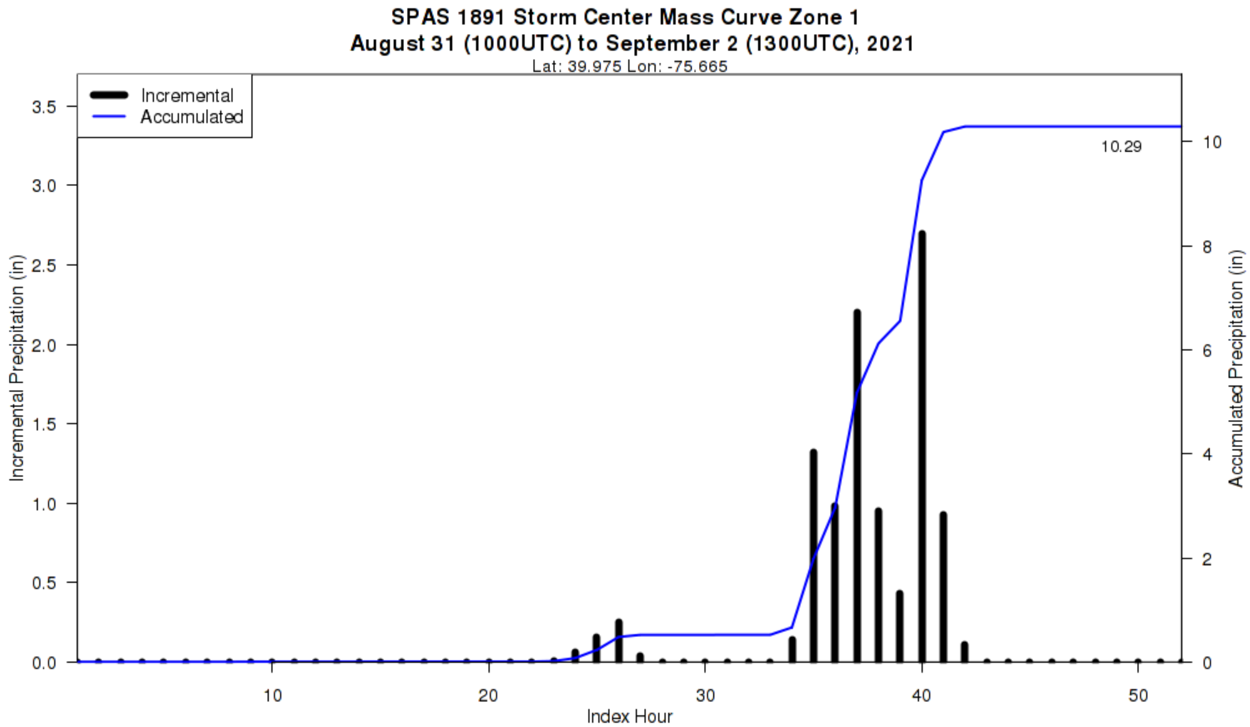
Depth-Area-Duration (DAD) analysis: Yes

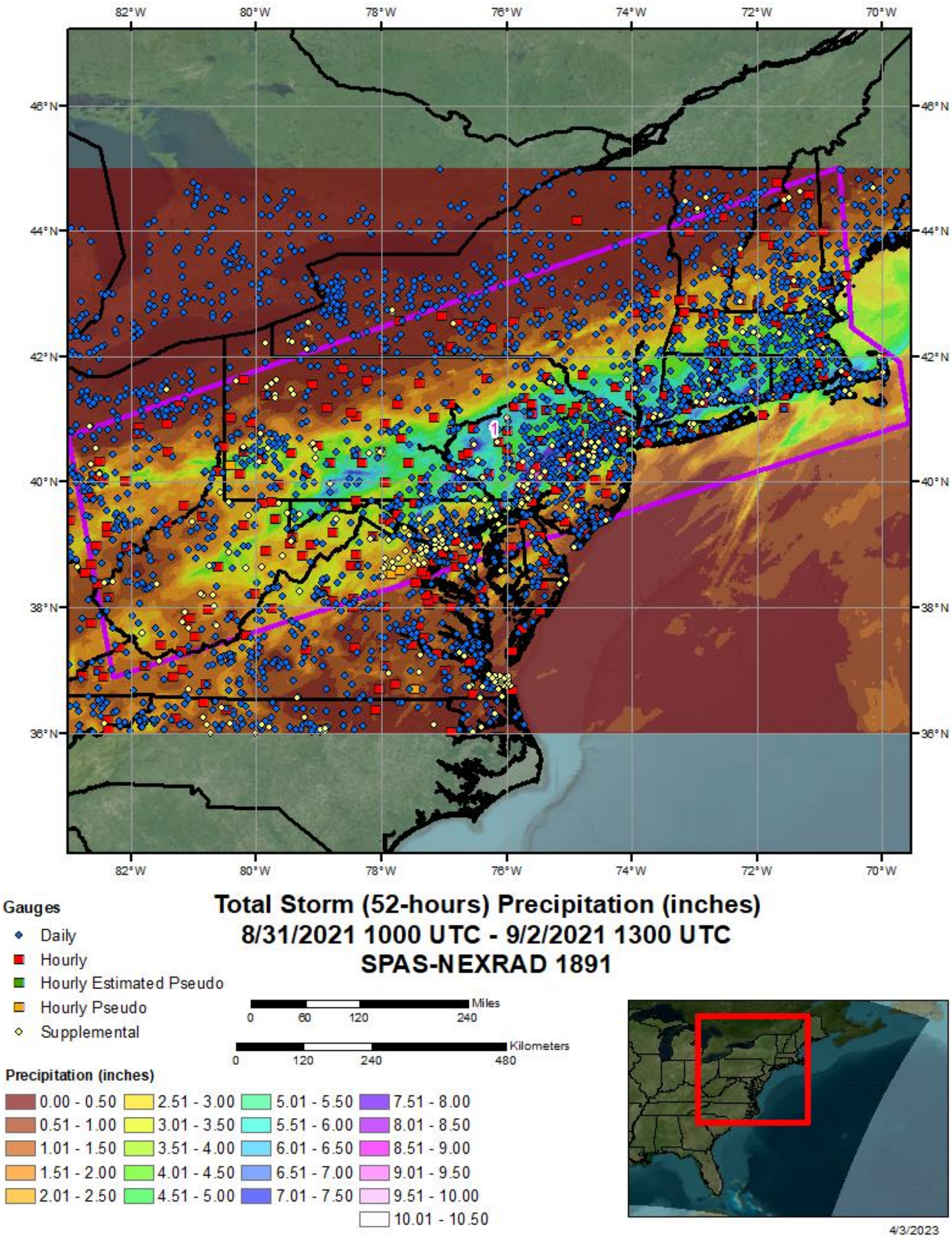
Reliability of Results: This analysis was based on 3316 hourly stations, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the radar grids, basemap and gauge stations. Timing is based on hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

							Storm Rep. Dew Point					Climatological Max. Dew Point						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	T_d	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	T_d	T_d Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1891_1	-75.6650	39.9750	290	300	18-Aug	78.00	3.29	0.08	78	3.210	79.89	80.0	3.60	0.09	82	3.510	1.093

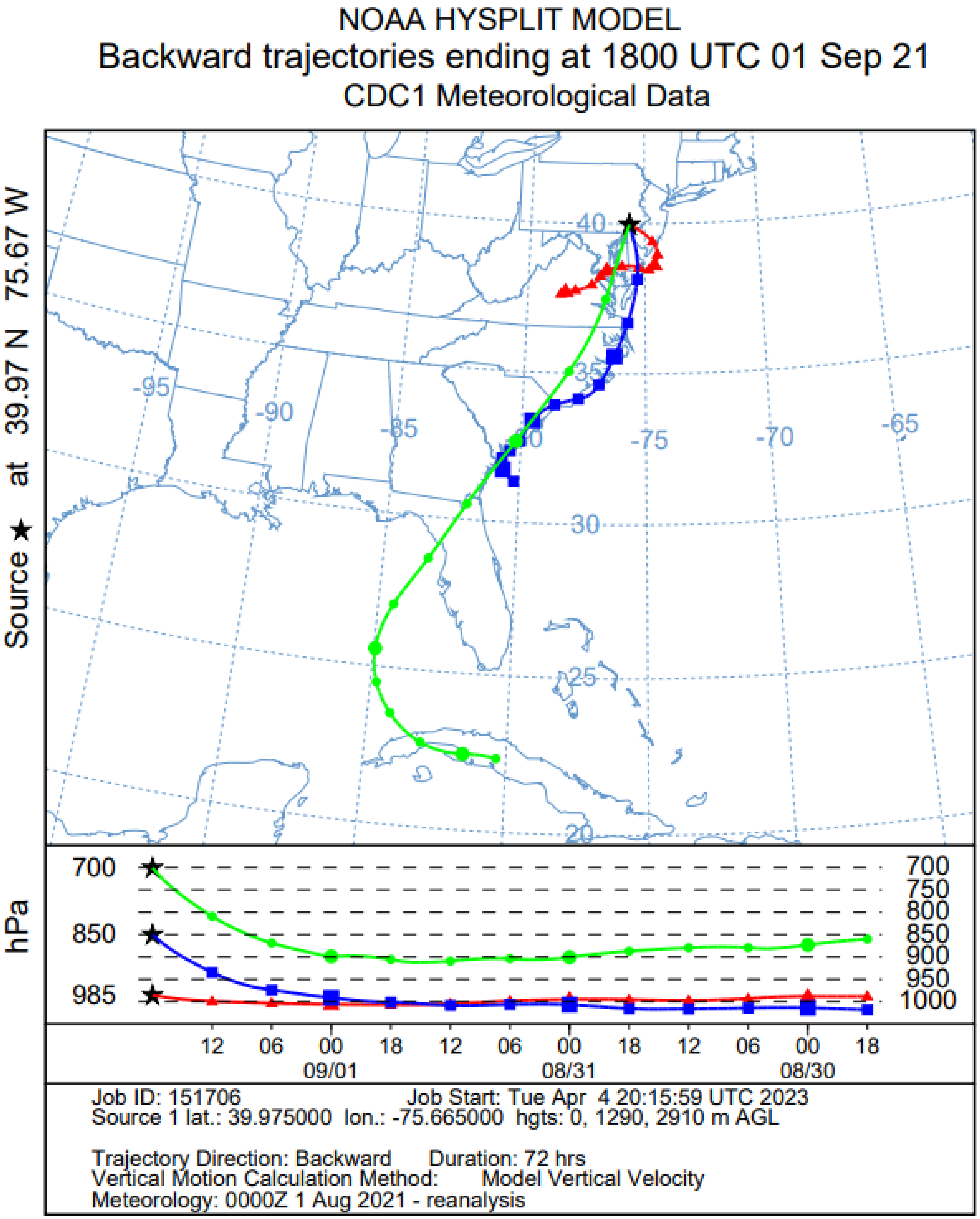
Storm 1891 - August 31 (1000 UTC) - September 2 (1300 UTC), 2021												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
Area (mi^2)	Duration (hours)											
	1	2	3	4	5	6	12	24	36	48	52	Total
0.4	4.08	6.08	7.52	8.16	8.46	8.97	9.76	10.27	10.28	10.28	10.28	10.28
1	4.04	6.04	7.46	8.08	8.40	8.90	9.69	10.20	10.20	10.21	10.21	10.21
10	3.83	5.92	7.19	7.79	8.23	8.72	9.44	9.98	10.02	10.02	10.02	10.02
25	3.70	5.75	6.94	7.53	8.06	8.56	9.21	9.74	9.78	9.79	9.79	9.79
50	3.59	5.57	6.74	7.34	7.91	8.42	9.03	9.55	9.60	9.62	9.62	9.62
100	3.41	5.37	6.52	7.17	7.75	8.27	8.85	9.34	9.38	9.40	9.40	9.40
150	3.29	5.23	6.40	7.06	7.63	8.16	8.74	9.22	9.26	9.28	9.28	9.28
200	3.22	5.11	6.27	6.98	7.56	8.08	8.66	9.13	9.18	9.19	9.19	9.19
300	3.06	4.90	6.08	6.84	7.42	7.94	8.53	8.98	9.03	9.05	9.06	9.06
400	2.89	4.73	5.93	6.72	7.30	7.82	8.43	8.87	8.92	8.94	8.94	8.94
500	2.74	4.59	5.78	6.62	7.21	7.73	8.34	8.78	8.83	8.84	8.85	8.85
1,000	2.32	4.03	5.24	6.17	6.79	7.28	8.00	8.41	8.47	8.48	8.48	8.48
2,000	1.90	3.33	4.49	5.43	6.12	6.61	7.51	7.96	8.02	8.03	8.03	8.03
3,500	1.56	2.81	3.87	4.72	5.41	5.94	6.98	7.50	7.58	7.60	7.60	7.60
5,000	1.36	2.47	3.46	4.27	4.90	5.42	6.56	7.19	7.29	7.30	7.32	7.32
7,500	1.13	2.12	2.98	3.73	4.30	4.78	6.07	6.83	6.95	6.98	6.99	6.99
10,000	1.00	1.86	2.65	3.31	3.87	4.33	5.68	6.57	6.69	6.73	6.74	6.74
15,000	0.84	1.53	2.16	2.73	3.24	3.61	5.16	6.22	6.35	6.39	6.40	6.40
20,000	0.74	1.33	1.87	2.35	2.82	3.22	4.78	5.94	6.12	6.16	6.17	6.17
35,000	0.47	0.97	1.37	1.77	2.15	2.49	3.95	5.30	5.52	5.56	5.58	5.58
50,000	0.36	0.76	1.09	1.43	1.77	2.07	3.35	4.74	5.00	5.06	5.08	5.08
75,000	0.27	0.53	0.76	0.99	1.24	1.47	2.63	3.94	4.26	4.35	4.38	4.38
100,000	0.20	0.41	0.59	0.77	0.98	1.13	2.08	3.34	3.70	3.81	3.84	3.84
189,402	0.12	0.23	0.33	0.43	0.54	0.64	1.15	2.01	2.34	2.43	2.45	2.45

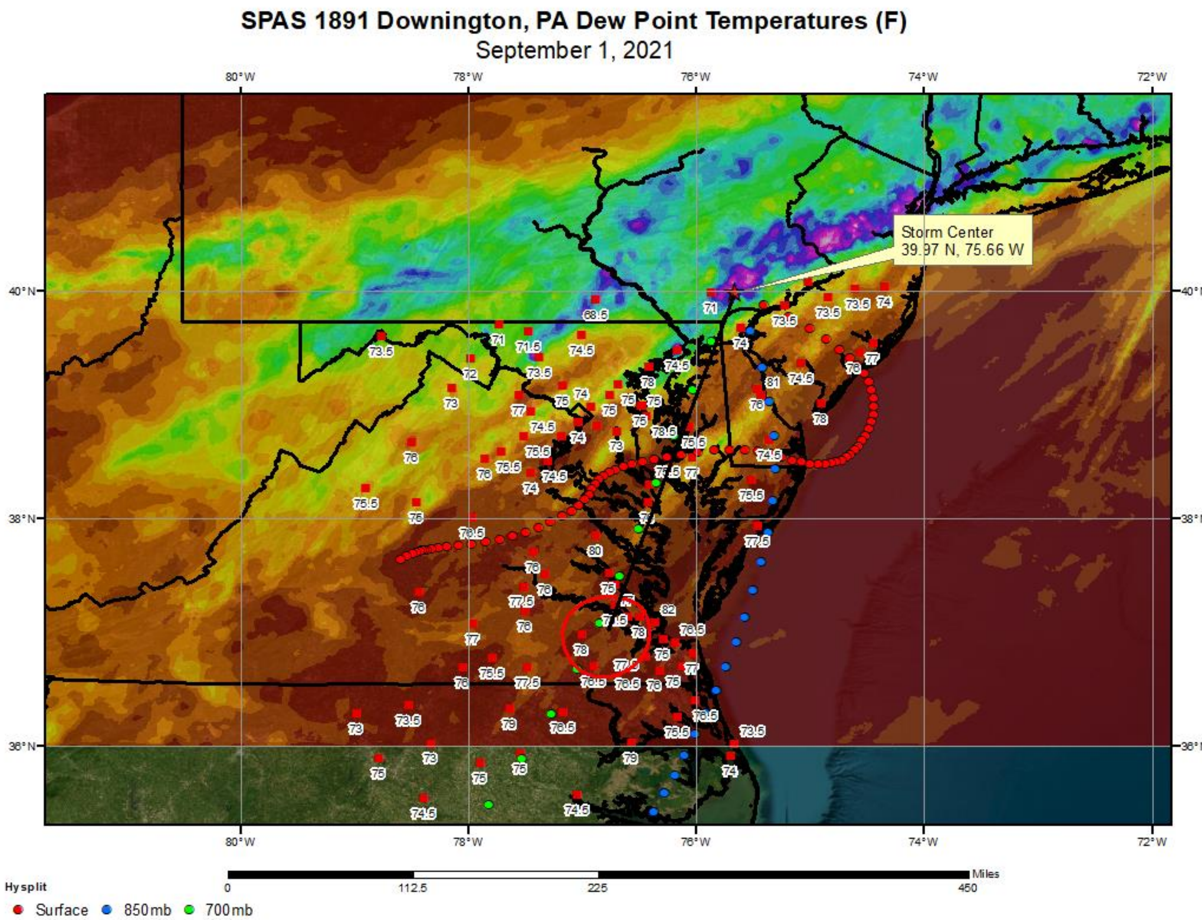



SPAS 1891 Storm Center Mass Curve Zone 1
August 31 (1000UTC) to September 2 (1300UTC), 2021
Lat: 39.975 Lon: -75.665
Incremental
Accumulated
10.29
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
2
4
6
8
10
10
20
30
40
50



Total Storm (52-hours) Precipitation (inches)
8/31/2021 1000 UTC - 9/2/2021 1300 UTC
SPAS-NEXRAD 1891


NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 01 Sep 21
CDC1 Meteorological Data
Source ★ at 39.97 N 75.67 W
40
35
30
25
20
-95
-90
-85
-80
-75
-70
-65
hPa
700
850
985
700
750
800
850
900
950
1000
12
06
00
18
12
06
00
18
12
06
00
18
09/01
08/31
08/30
Job ID: 151706 Job Start: Tue Apr 4 20:15:59 UTC 2023
Source 1 lat.: 39.975000 lon.: -75.665000 hgts: 0, 1290, 2910 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Aug 2021 - reanalysis



SPAS 1891 Downington, PA Dew Point Temperatures (F)
September 1, 2021
Storm Center
39.97 N, 75.66 W
80°W
78°W
76°W
74°W
72°W
40°N
38°N
36°N
Miles
0
112.5
225
450
Hysplit
Surface
850mb
700mb

Storm Precipitation Analysis System (SPAS) For Storm #1981_1 SPAS-NEXRAD Analysis

General Storm Location: Kure Beach, NC

Storm Dates: September 12 (1800 UTC) – September 18 (1700 UTC), 2024

Event: General

DAD Zone 1

Latitude: 33.775

Longitude: -77.735

Max. Grid Rainfall Amount: 32.41”

Max. Observed Rainfall Amount: 27.14” Ocean Est. / 25.61” Kure Beach

Number of Stations: 1565

SPAS Version: 10.0

Base Map Used: 00_bm_radar_est_only_bl_sm7 (Smoothing factor of 7 applied)

Spatial resolution: 0.3927

Radar Included: Yes

Depth-Area-Duration (DAD) analysis: Yes

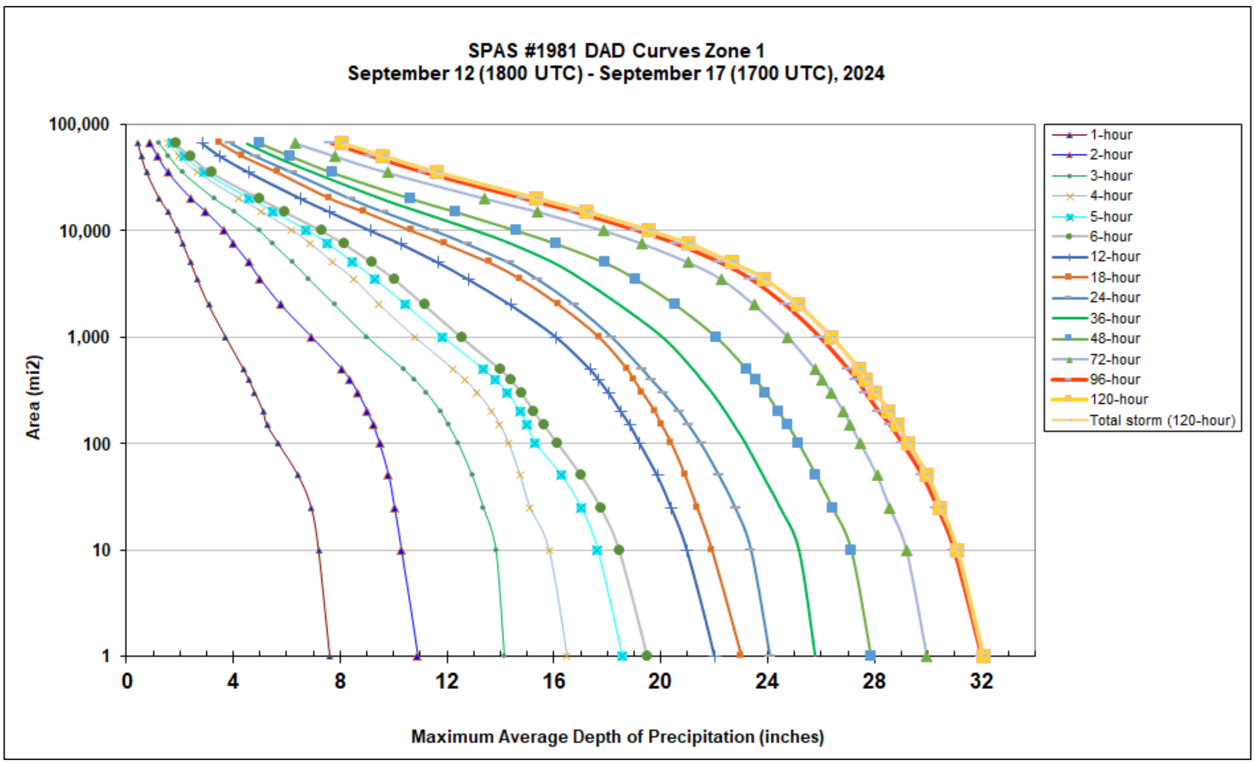
Reliability of Results: This final analysis included data from 227 hourly, 48 hourly pseudo, 1 hourly estimated pseudo, 1172 daily, 112 supplemental, and 5 supplemental estimated stations. The spatial pattern is dependent on the surface observations, radar and base map. Timing is based on hourly stations and radar. Regardless of lack of ocean based observations, analysis of the synoptic weather pattern, available remote and stations observations, base maps and accounts of this event have left us confident that the total magnitude, spatial pattern and timing of precipitation generated by SPAS is reasonable and captures the most important aspects of this storm.

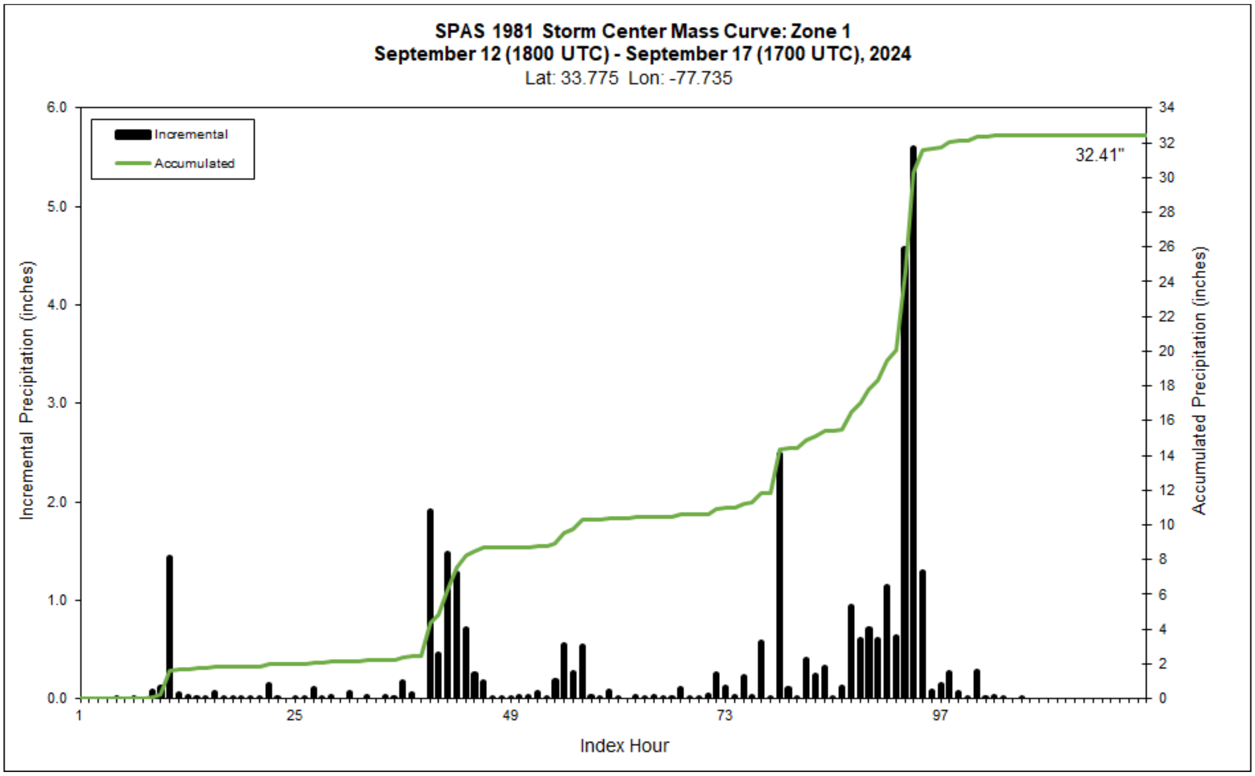
							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1981_1	-77.7350	33.7750	24	0	2-Sep	80.50	3.68	0.00	83	3.680	83.00	83.0	4.12	0.00	88	4.120	1.120

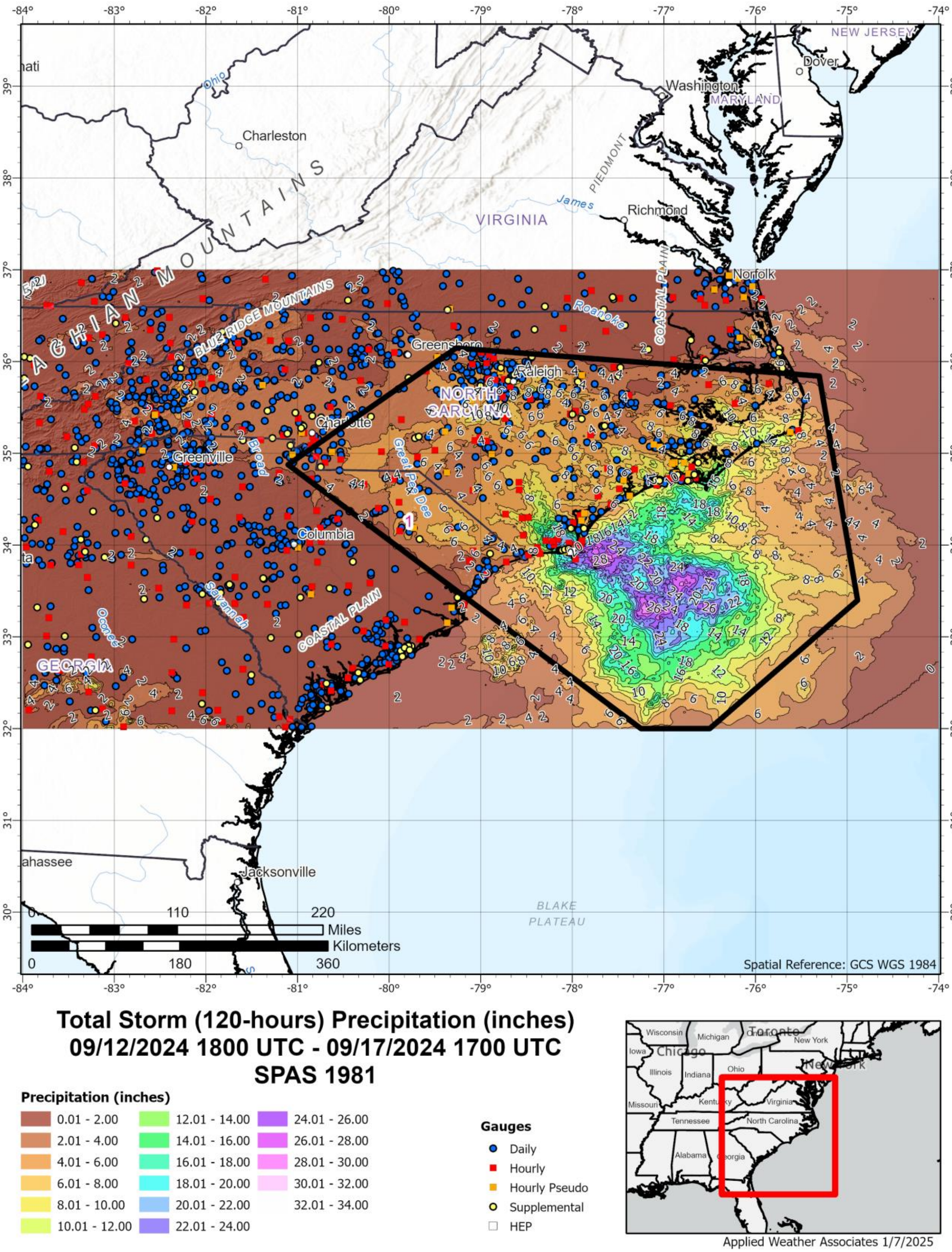
Storm 1981 - September 12 (1800 UTC) - September 17 (1700 UTC), 2024

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

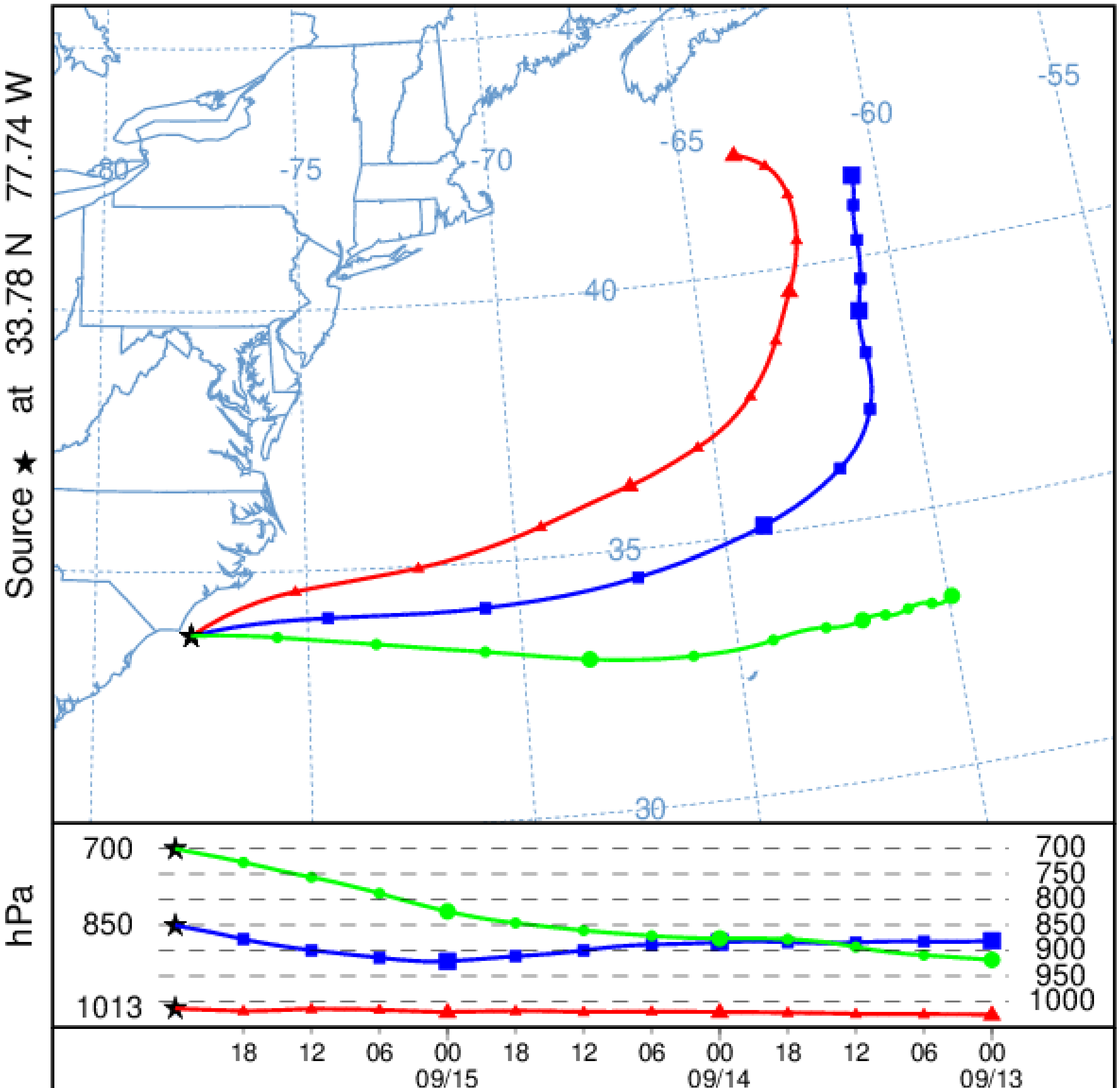
Area (mi^2)	Duration (hours)													
	1	2	3	4	5	6	12	18	24	36	48	72	96	120	Total
0.4	7.81	11.02	14.31	16.67	18.79	19.77	22.25	23.38	24.33	26.00	28.12	30.26	32.39	32.40	32.40
1	7.61	10.90	14.16	16.49	18.54	19.49	22.01	23.02	24.09	25.77	27.85	29.95	32.02	32.05	32.05
10	7.19	10.29	13.84	15.81	17.63	18.44	20.98	21.91	23.38	25.16	27.11	29.18	30.99	31.07	31.07
25	6.92	10.03	13.37	15.10	17.00	17.75	20.39	21.36	22.79	24.46	26.41	28.56	30.36	30.46	30.46
50	6.43	9.81	12.95	14.73	16.27	17.03	19.87	20.91	22.19	23.82	25.80	28.09	29.80	29.96	29.96
100	5.68	9.47	12.43	14.30	15.30	16.15	19.22	20.40	21.51	23.17	25.15	27.47	29.05	29.25	29.25
150	5.26	9.23	12.05	13.97	14.99	15.62	18.84	20.03	21.04	22.73	24.73	27.09	28.58	28.84	28.84
200	5.12	9.01	11.76	13.67	14.72	15.26	18.51	19.78	20.69	22.41	24.39	26.84	28.17	28.52	28.52
300	4.81	8.66	11.24	13.13	14.23	14.79	18.05	19.32	20.11	21.92	23.92	26.39	27.67	28.02	28.02
400	4.58	8.35	10.78	12.65	13.80	14.39	17.67	18.99	19.65	21.51	23.53	26.04	27.34	27.67	27.67
500	4.38	8.06	10.37	12.21	13.33	13.99	17.35	18.74	19.31	21.20	23.20	25.77	27.02	27.41	27.41
1,000	3.72	6.93	9.01	10.78	11.83	12.54	16.09	17.69	18.17	20.07	22.06	24.75	25.95	26.36	26.36
2,000	3.08	5.78	7.80	9.46	10.43	11.16	14.39	16.20	16.77	18.47	20.55	23.50	24.67	25.12	25.12
3,500	2.66	5.01	6.84	8.50	9.29	10.03	12.79	14.75	15.39	17.04	19.06	22.25	23.37	23.84	23.84
5,000	2.41	4.57	6.23	7.72	8.47	9.20	11.68	13.59	14.33	16.00	17.89	21.05	22.22	22.64	22.64
7,500	2.12	4.02	5.48	6.89	7.53	8.15	10.27	11.92	12.75	14.43	16.08	19.32	20.57	21.01	21.01
10,000	1.92	3.66	4.97	6.19	6.74	7.29	9.14	10.66	11.52	13.09	14.58	17.84	19.10	19.53	19.53
15,000	1.56	2.98	4.04	5.05	5.49	5.95	7.61	8.91	9.63	11.00	12.31	15.40	16.75	17.20	17.20
20,000	1.24	2.42	3.28	4.19	4.60	4.99	6.53	7.63	8.38	9.54	10.63	13.42	14.84	15.31	15.31
35,000	0.77	1.56	2.11	2.65	2.90	3.19	4.61	5.67	6.23	7.03	7.71	9.77	11.17	11.63	11.63
50,000	0.57	1.17	1.59	1.98	2.16	2.39	3.51	4.35	4.83	5.54	6.13	7.79	9.16	9.58	9.58
65,833	0.45	0.89	1.24	1.56	1.72	1.86	2.84	3.52	3.92	4.52	5.00	6.34	7.68	8.08	8.08




SPAS 1981 Storm Center Mass Curve: Zone 1
September 12 (1800 UTC) - September 17 (1700 UTC), 2024
Lat: 33.775 Lon: -77.735
Incremental
Accumulated
32.41"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
6.0
5.0
4.0
3.0
2.0
1.0
0.0
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1
25
49
73
97

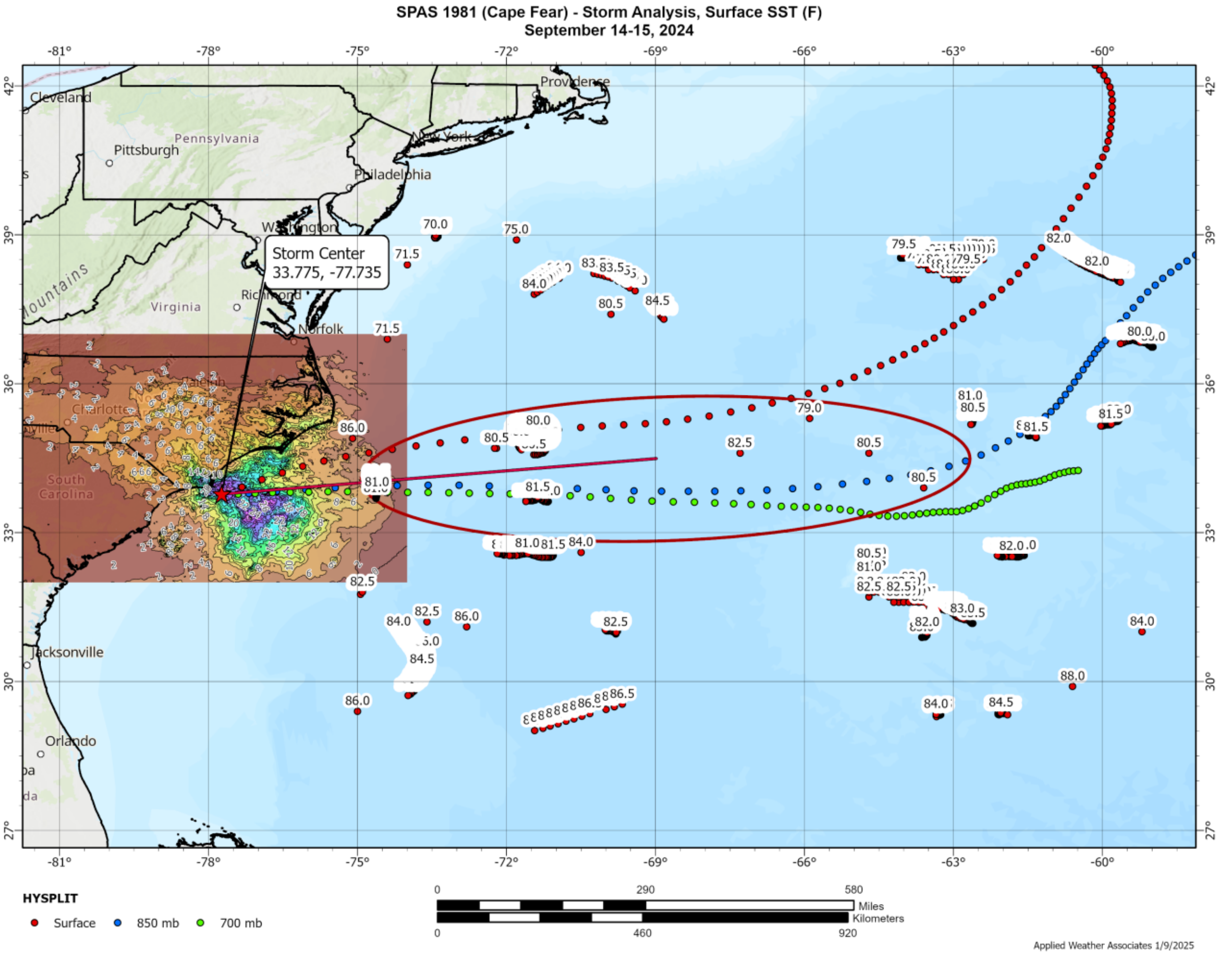

Total Storm (120-hours) Precipitation (inches)
09/12/2024 1800 UTC - 09/17/2024 1700 UTC
SPAS 1981
Precipitation (inches)
0.01 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 8.00
8.01 - 10.00
10.01 - 12.00
12.01 - 14.00
14.01 - 16.00
16.01 - 18.00
18.01 - 20.00
20.01 - 22.00
22.01 - 24.00
24.01 - 26.00
26.01 - 28.00
28.01 - 30.00
30.01 - 32.00
32.01 - 34.00
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
HEP
Spatial Reference: GCS WGS 1984
Miles
Kilometers
VIRGINIA
NORTH CAROLINA
GEORGIA
MARYLAND
NEW JERSEY
Washington
Richmond
Norfolk
Charleston
Greensboro
Raleigh
Charlotte
Greenville
Columbia
Jacksonville
Dover
BLUE RIDGE MOUNTAINS
COASTAL PLAIN
PIEDMONT
BLAKE PLATEAU
Applied Weather Associates 1/7/2025

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 16 Sep 24
CDC1 Meteorological Data



Job ID: 119273 Job Start: Thu Jan 9 00:10:39 UTC 2025
Source 1 lat.: 33.775000 lon.: -77.735000 hgts: 0, 1520, 3140 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2024 - reanalysis


SPAS 1981 (Cape Fear) - Storm Analysis, Surface SST (F)
September 14-15, 2024
Storm Center
33.775, -77.735
HYSPLIT
Surface
850 mb
700 mb
Miles
Kilometers
Applied Weather Associates 1/9/2025

Storm Precipitation Analysis System (SPAS) For Storm #1984_1 SPAS-NEXRAD Analysis

General Storm Location: Busick, NC

Storm Dates: September 24 – September 27, 2024

Event: General

DAD Zone 1

Latitude: 35.765

Longitude: -82.175

Max. Grid Rainfall Amount: 32.76”

Max. Observed Rainfall Amount: 31.60”

Number of Stations: 1439

SPAS Version: 10.0

Base Map Used: 00_bm_mrms_in_radar_bl_sm7 (Smoothing factor of 7 applied)

Spatial resolution: 0.3892

Radar Included: Yes

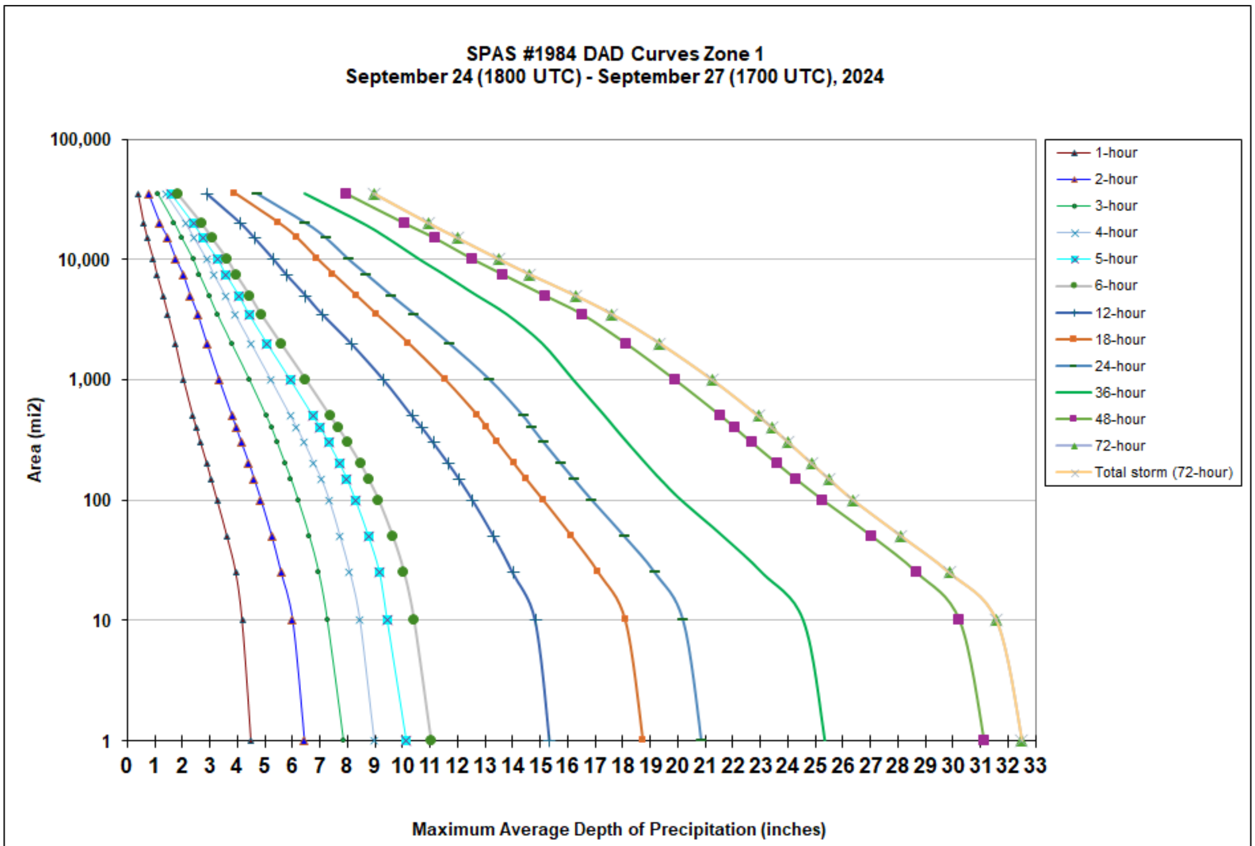
Depth-Area-Duration (DAD) analysis: Yes

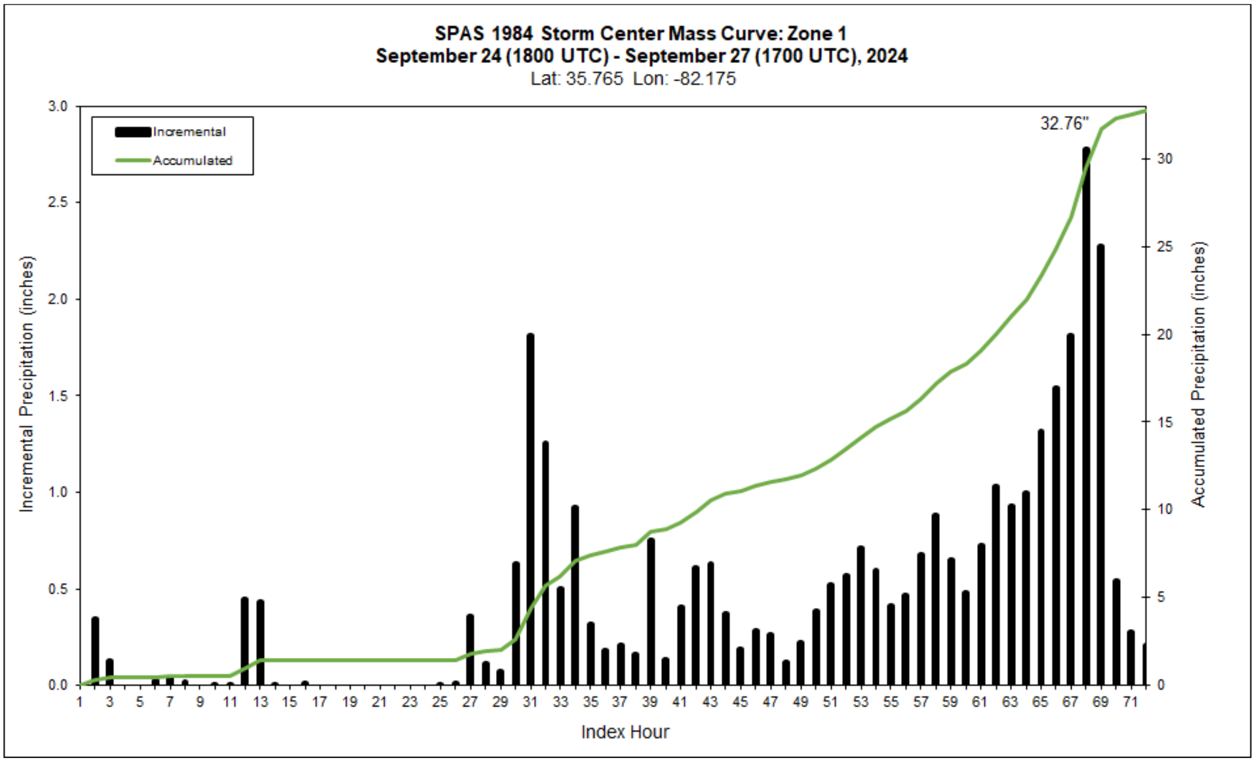
Reliability of Results: The final analysis included data from 323 hourly, 53 hourly pseudo, 3 hourly estimated pseudo, 996 daily, and 64 supplemental stations. The spatial pattern is dependent on the surface observations, radar, and base map. Timing is based on hourly stations and radar.

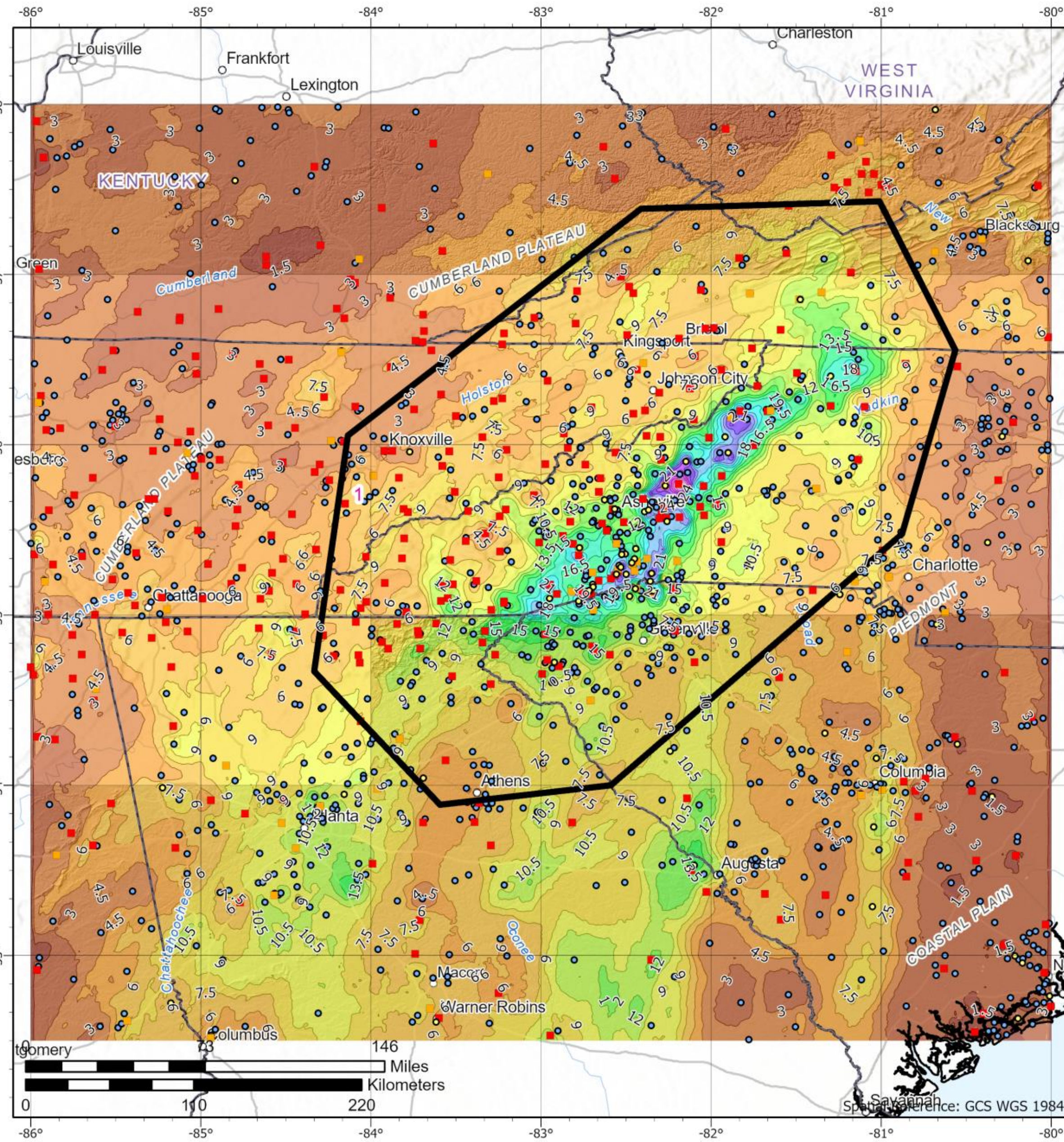
There were many stations with missing data due to the internet and/or power outages associated with the event. AWA went to great lengths to fill in missing data where possible. Significant beam blockage exists over mountainous areas where intense precipitation was occurring, so radar/base map weighting was adjusted to compensate. Analysis of the synoptic weather pattern, available remote and stations observations, base maps and accounts of this event have left us confident that the total magnitude, spatial pattern and timing of precipitation generated by SPAS is reasonable and captures the most important aspects of this storm.

							Storm Rep. SST					Climatological Max. SST						
	SPAS Storm ID	LON	LAT	ELEV	ELEV Round	Trans Date	SST	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	SST	SST Round	Precip. Water @ 30,000 ft	Precip. Water @ Storm Elev.	PW Lookup Table Column	Avail. Moisture	IPMF
Storm Center Location	1984_1	-82.1750	35.7650	3,292	3,300	12-Sep	85.00	4.48	1.06	92	3.420	86.00	86.0	4.67	1.11	94	3.560	1.041

Storm 1984 - September 24 (1800 UTC) - September 27 (1700 UTC), 2024													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
Area (mi^2)	Duration (hours)												
	1	2	3	4	5	6	12	18	24	36	48	72	Total
0.4	4.55	6.60	8.07	9.20	10.41	11.34	15.48	18.89	21.02	25.51	31.35	32.75	32.75
1	4.50	6.43	7.87	8.96	10.13	11.03	15.36	18.75	20.88	25.33	31.13	32.51	32.51
10	4.18	6.00	7.28	8.44	9.44	10.41	14.84	18.11	20.22	24.55	30.24	31.58	31.58
25	3.95	5.58	6.97	8.08	9.16	10.05	14.02	17.13	19.19	23.05	28.69	29.87	29.87
50	3.63	5.24	6.63	7.72	8.76	9.64	13.33	16.16	18.08	21.64	27.06	28.13	28.13
100	3.27	4.85	6.22	7.33	8.29	9.13	12.56	15.12	16.90	20.12	25.28	26.38	26.38
150	3.05	4.60	5.96	7.04	7.98	8.76	12.07	14.50	16.24	19.35	24.29	25.49	25.49
200	2.90	4.42	5.75	6.78	7.72	8.47	11.69	14.07	15.78	18.85	23.62	24.88	24.88
300	2.67	4.14	5.46	6.42	7.32	8.01	11.13	13.47	15.15	18.17	22.70	24.03	24.03
400	2.51	3.95	5.25	6.15	7.02	7.66	10.72	13.06	14.72	17.70	22.07	23.42	23.42
500	2.39	3.80	5.06	5.92	6.75	7.37	10.36	12.75	14.40	17.35	21.57	22.93	22.93
1,000	2.05	3.33	4.45	5.21	5.93	6.49	9.32	11.56	13.18	16.20	19.90	21.25	21.25
2,000	1.75	2.89	3.80	4.49	5.09	5.59	8.14	10.23	11.71	15.07	18.12	19.35	19.35
3,500	1.48	2.55	3.28	3.91	4.44	4.87	7.09	9.06	10.44	13.78	16.52	17.61	17.61
5,000	1.30	2.29	2.98	3.56	4.07	4.46	6.49	8.33	9.60	12.70	15.17	16.28	16.28
7,500	1.08	2.02	2.63	3.14	3.60	3.96	5.78	7.50	8.69	11.50	13.64	14.62	14.62
10,000	0.95	1.77	2.40	2.88	3.30	3.64	5.32	6.92	8.04	10.61	12.56	13.51	13.51
15,000	0.73	1.47	2.00	2.43	2.78	3.09	4.63	6.18	7.22	9.45	11.17	12.00	12.00
20,000	0.60	1.19	1.72	2.11	2.41	2.70	4.11	5.51	6.48	8.54	10.06	10.94	10.94
34,990	0.39	0.77	1.12	1.40	1.62	1.84	2.89	3.93	4.71	6.46	7.96	8.97	8.97




SPAS 1984 Storm Center Mass Curve: Zone 1
September 24 (1800 UTC) - September 27 (1700 UTC), 2024
Lat: 35.765 Lon: -82.175
Incremental
Accumulated
32.76"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



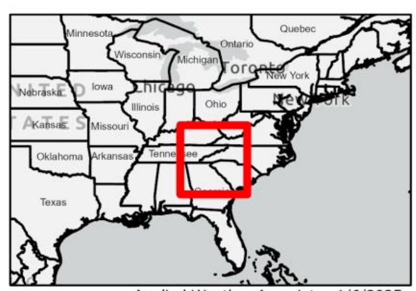
Total Storm (72-hours) Precipitation (inches)
09/24/2024 1800 UTC - 09/27/2024 1700 UTC
SPAS 1984

Precipitation (inches)

0.18 - 1.50
1.51 - 3.00
3.01 - 4.50
4.51 - 6.00
6.01 - 7.50
7.51 - 9.00
9.01 - 10.50
10.51 - 12.00
12.01 - 13.50
13.51 - 15.00
15.01 - 16.50
16.51 - 18.00
18.01 - 19.50
19.51 - 21.00
21.01 - 22.50
22.51 - 24.00
24.01 - 25.50
25.51 - 27.00
27.01 - 28.50
28.51 - 30.00
30.01 - 31.50
31.51 - 33.00

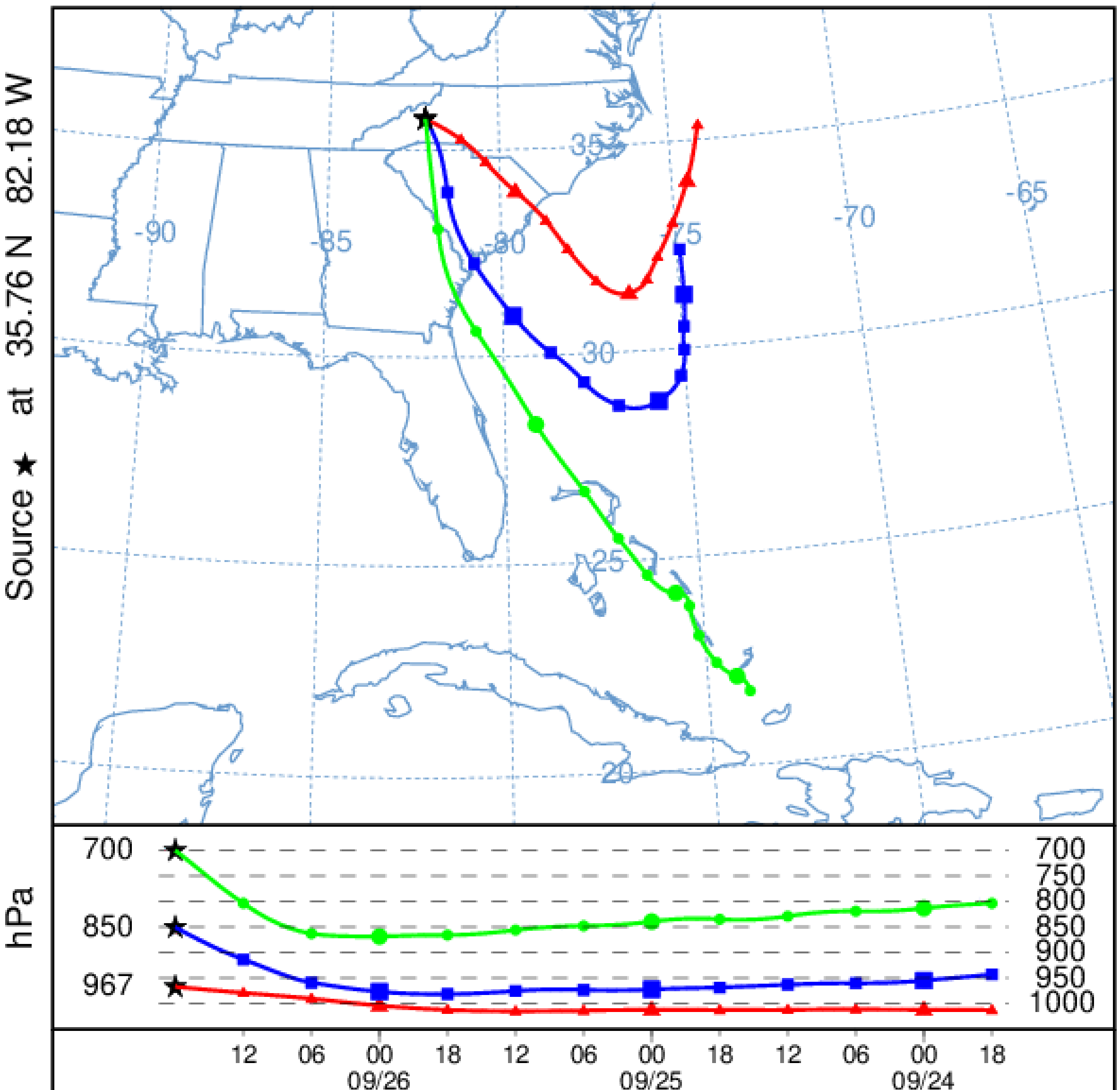
Gauges

Daily
Hourly
Hourly Pseudo
Supplemental



Applied Weather Associates 1/6/2025

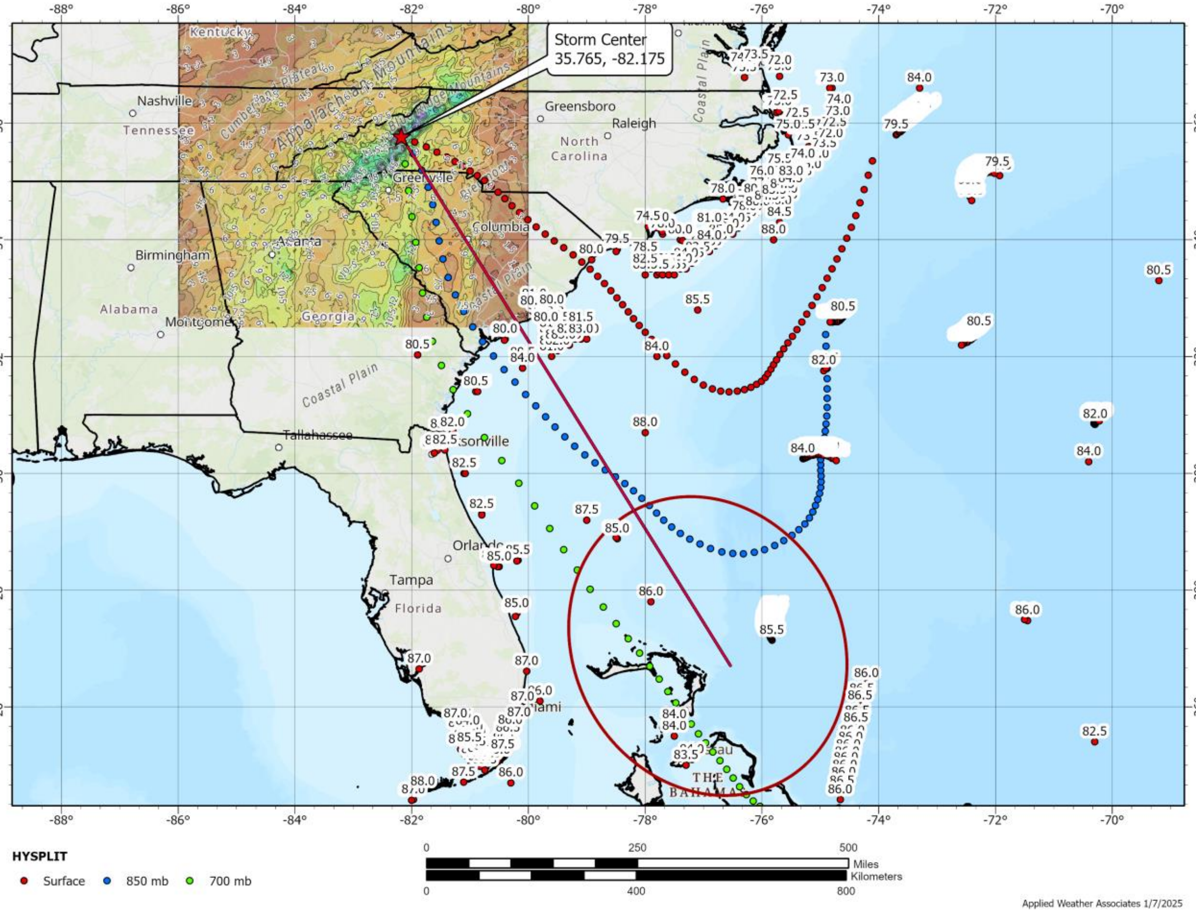
NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 26 Sep 24
CDC1 Meteorological Data



Job ID: 181931 Job Start: Sun Jan 5 23:42:48 UTC 2025
Source 1 lat.: 35.765000 lon.: -82.175000 hgts: 0, 1110, 2740 m AGL

Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2024 - reanalysis

SPAS 1984 (Busick, NC) - Storm Analysis, Sea Surface Temperatures (F)
September 25, 2024



Appendix G
GIS PMP Tool Documentation

1. PMP Tools Description and Usage

The PMP Evaluation Tool employed in this study is based on a Python script designed to run within the ArcGIS environment. ESRI's ArcGIS Pro software is required to run the tool. The spatial Analyst extension is also required for some of the optional temporal functions. It is recommended that the most current version of the software is used. The PMP tool provides gridded output at a spatial resolution of 90 arc-seconds (equivalent to .025 x .025 decimal degrees) for a user-designated basin or area at user-specified durations. Standard outputs include gridded and basin average PMP depths and temporally distributed accumulations.

1.1 File Structure

The PMP tool, source script, and the storm databases are stored within the 'PMP_Evaluation_Tool' project folder. The file and directory structure within the 'PMP_Evaluation_Tool' folder should be maintained as provided, as the script will locate various data based on its relative location within the project folder. If the subfolders or geodatabases within are relocated or renamed, then the script must be updated to account for these changes.

The file structure consists of three subfolders: Input, Output, and Script. The 'Input' folder contains all input GIS files (Figure 1.1). There are four ArcGIS file geodatabase containers within the 'Input' folder: AEP.gdb, DAD_Tables.gdb, Non_Storm_Data.gdb, and Storm_Adj_Factors.gdb. The AEP.gdb contains all of the precipitation frequency raster files for the various return frequencies used in the AEP tool. The DAD_Tables.gdb contains the DAD tables (in file geodatabase table format) for each of the SPAS-analyzed storm DAD zones included in the storm database. The Storm_Adj_Factors.gdb contains a point feature class for each storm and stores the adjustment factors for each grid point as a separate feature. These feature classes are organized into feature datasets, according to storm type (General, Local, and Tropical). The storm adjustment factor feature classes share their name with their DAD Table counterpart. The naming convention is SPAS_XXXX_Y, where XXXX is the SPAS storm ID number and Y is the DAD zone number. In the case of a hybrid storm (i.e., a storm that is run as both a general and local storm type), there will be a suffix "_gen" or "_loc" to differentiate the storm type specific to the adjustment factors in the feature class. The Non_Storm_Data.gdb contains spatial data not directly relating to the input rainfall depth or adjustment factors such as the grid network vector files or transposition zones feature class.

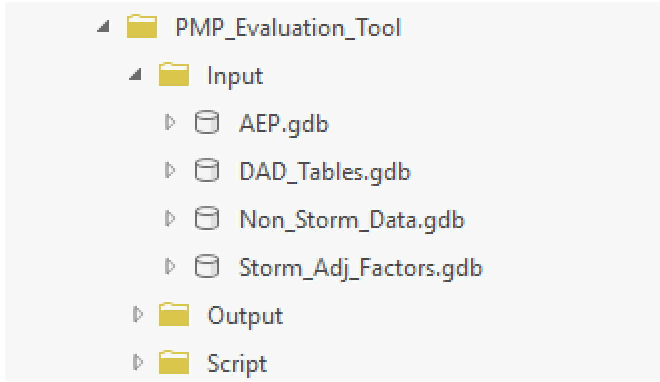


Figure 1.1: PMP tool file structure

The 'Script' folder contains an ArcToolbox called NorthCarolina_Final_PMP_Tools.tbx. The toolbox contains a script tool called 'Gridded PMP Tool' that is used to calculate PMP. The PMP Tool will calculate gridded all-season PMP depths in inches for a basin or user specified area size.

ArcGIS should be used for viewing the GIS tools file structure and interacting with the input and output geospatial data. A typical operating system's file browser does not allow access to the geodatabase containers and cannot be used to directly run the tool.

The tools are stored within the NorthCarolina_Final_PMP_Tools.tbx. ArcToolbox opens and runs the script within the ArcGIS Pro environment. In addition to running as a standalone tool, the tool can be incorporated into Model Builder or be called as a sub-function of another script.

To run the tools, the user navigates to North Carolina_Final_PMP_Tools toolbox, expands it, and opens the Gridded PMP tool. The dialogue window opens, and the user populates input parameters and clicks the 'OK' button. The tool will run in the foreground and display text output in the Messages window. Processing time can vary greatly depending on area of interest (AOI) size, the number of durations selected, and computer hardware. Most basins generally take 5 to 10 minutes to analyze all three storm types on a typical computer interface. The tools produce PMP output described in Section 1.4.

1.2 PMP Tool Usage

The tool requires several parameters as input to define the area and durations to be analyzed. The first parameter required by the tool dialogue is a feature layer, such as a basin shapefile or feature class, designed to outline the AOI for the PMP analysis. If the feature layer has multiple features (or polygons), the tool will use the combined area as the analysis region. Only the selected polygons will be used if the tool is run from the ArcMap environment with selected features highlighted. If the AOI shapefile extends beyond the project analysis domain, PMP will only be calculated for grid cells inside the project domain. The AOI shapefile or feature class should not have any spaces or symbol characters in the filename. The user then will need to set the 'Output Folder' path which provides the tool with the location to create the output PMP files. The user must have read/write privileges for this folder location. Note, the tool will overwrite the previous output if all input parameters are the same. The user then selects the durations to be run for each storm type. Individual durations can be run by checking each individual box or all durations can be run by clicking the "Select All" option (Figure 1.2).

The next parameter allows the user to either use the basins calculated area size or override the default to enter a custom area (in square miles) for areal-average PMP calculations. The user then has the option to have the tool perform a weighted analysis on the grid cells underlying the AOI boundary. If this option is checked each grid cell along the basin's boundary will be weighted by the portion of the cell's area inside the basin for the purpose of the basin average PMP table calculations. It is checked by default. If this option is disabled, the tool will output a basin average of all grid cells equally that intersect the basin boundary. There is an option to include sub-basin averages. This will calculate an average PMP depth for each feature in the input basin feature class from the overall basin PMP. The average sub-basin depths will be based on the exact area-size of the overall basin. If the 'weighted' option was selected above, it will also be applied to the sub-basin averages. The user must select a field within the AOI to be used to identify each sub-basin. The field can be of numeric or text data type but must have a unique ID for each polygon. This option is disabled by default. The user can also choose to include a depth-duration chart .png image in the output folder for each storm type.

Finally, the user can select the option to apply the appropriate temporal distribution patterns to the basin average PMP for each storm type. This function needs all durations of PMP to be calculated, so if this option is selected the tool will automatically run all durations for all storm types regardless of what durations were selected by the user in the previous steps. If temporal distributions are applied, the user then has the option to export them to ascii or NetCDF format. The ascii or NetCDF functions do require the Spatial Analyst extension to run.

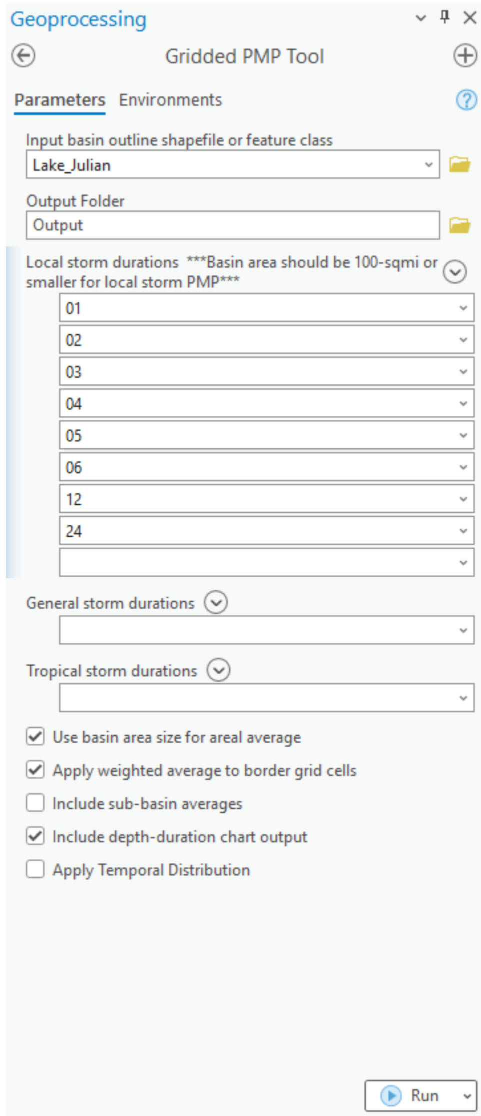


Figure 1.2: PMP tool input/output parameters with all local storm durations set to run.

1.3 PMP Tool Output

Once the tool has been run, the output folder will be populated with the model results. The GIS files can then be brought into an ArcMap, or other compatible GIS environments, for mapping and analysis.

Note, the tool is set to have overwrite capabilities; if output data exists, it will be overwritten the next time the tool is run, if the same output folder and same parameters are used.

A separate output folder is created for each storm type and the output is organized within sub folders by output type. Each output file geodatabase contains a feature class which stores each grid point centroid within the basin as a separate feature. Each feature has a field for the grid ID, latitude, longitude, analysis zone, elevation, PMP (for each duration), and the contributing storm ID and name. PMP raster files are also stored within the file geodatabase. The naming convention for the raster files is the storm type and duration (L for Local, G for General, and T for Tropical), followed by the input basin feature name, and ending with the rounded off basin area (in square miles). If temporal patterns were applied, the output tables would also be in the geodatabase along with a folder for the ascii and NetCDF files. A folder named CSV is also created and all the geodatabase tables are exported to csv files. An example of the output file structure is shown in Figure 1.8.

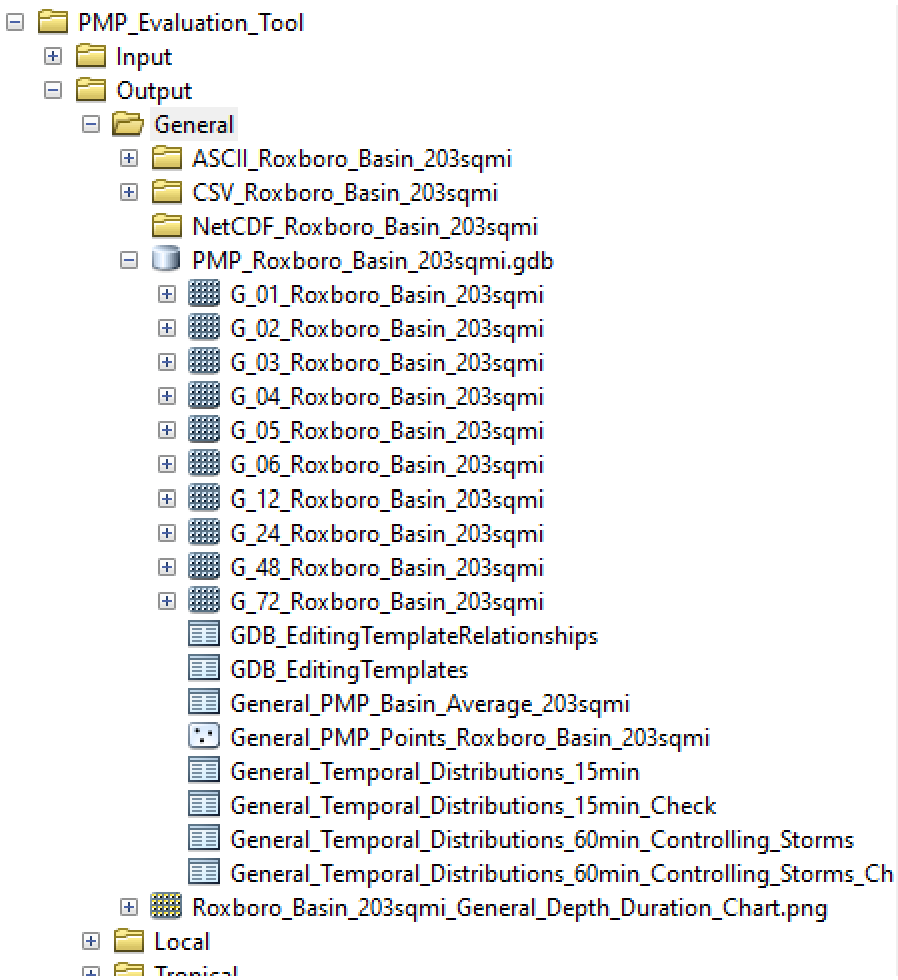


Figure 1.8: Example of the PMP tool output file structure

If the temporal patterns were applied, you will see a table named Temporal_Distribution_Check in the csv folder and in the geodatabase. This is important as it evaluates the temporally distributed PMP values for each duration against the PMP value for that duration. The table has an "exceed" or "ok" check. If the temporally distributed PMP value exceeds the PMP at a given duration, the table will have "exceed" for that duration and this temporal pattern should not be applied when other temporal patterns are available for a given storm type which do not "exceed". However, in some situations all temporal patterns for a given storm type may exceed the temporal check. In this case, the user can check the percentage of exceedance by investigating the table and comparing the temporally distributed values against the PMP depth for that duration(s). For durations where the exceedance is within 5% of the PMP for that duration(s), that temporal pattern can be applied. An example is shown in Figure 1.9. The Critically Stacked Temporal Pattern (USBR method) is to be used only if all other Temporal Patterns fail the checking process.

	PATTERN	PMP_01	MAX_01	CHEC...	PMP_02	MAX_02	CHECK...	PMP_03	MAX_03	CHECK_03	PMP_04	MAX_04	CHECK_04	PMP_05	MAX_05	CHECK_05	PMP_06	MAX_06	CHECK_06
1	GS_24HR_10TH_PERCENTILE	4.15	1.21	OK	5.38	2.35	OK	9.09	3.44	OK	9.09	4.48	OK	9.59	5.46	OK	12.91	6.37	OK
2	GS_24HR_90TH_PERCENTILE	4.15	0.99	OK	5.38	1.93	OK	9.09	2.84	OK	9.09	3.71	OK	9.59	4.54	OK	12.91	5.33	OK
3	GS_24HR_SYNTHETIC	4.15	1.36	OK	5.38	2.61	OK	9.09	3.83	OK	9.09	5.05	OK	9.59	6.12	OK	12.91	7.17	OK
4	Critically_Stacked_24h	4.15	4.14	OK	5.38	7.86	EXCEED	9.09	11.18	EXCEED	9.09	12.41	EXCEED	9.59	12.91	EXCEED	12.91	13.24	OK
5	GS_48HR_10TH_PERCENTILE	4.15	1.21	OK	5.38	2.35	OK	9.09	3.44	OK	9.09	4.48	OK	9.59	5.46	OK	12.91	6.37	OK
6	GS_48HR_90TH_PERCENTILE	4.15	0.99	OK	5.38	1.93	OK	9.09	2.84	OK	9.09	3.71	OK	9.59	4.54	OK	12.91	5.33	OK
7	GS_48HR_SYNTHETIC	4.15	1.36	OK	5.38	2.61	OK	9.09	3.83	OK	9.09	5.05	OK	9.59	6.12	OK	12.91	7.17	OK
8	Critically_Stacked_48h	4.15	4.15	OK	5.38	7.86	EXCEED	9.09	11.18	EXCEED	9.09	12.41	EXCEED	9.59	12.91	EXCEED	12.91	13.24	OK
9	GS_72HR_10TH_PERCENTILE	4.15	1.21	OK	5.38	2.35	OK	9.09	3.45	OK	9.09	4.48	OK	9.59	5.46	OK	12.91	6.37	OK
10	GS_72HR_90TH_PERCENTILE	4.15	0.99	OK	5.38	1.93	OK	9.09	2.84	OK	9.09	3.71	OK	9.59	4.54	OK	12.91	5.33	OK
11	GS_72HR_SYNTHETIC	4.15	1.36	OK	5.38	2.61	OK	9.09	3.83	OK	9.09	5.05	OK	9.59	6.12	OK	12.91	7.17	OK
12	Critically_Stacked_72h	4.15	4.15	OK	5.38	7.86	EXCEED	9.09	11.18	EXCEED	9.09	12.41	EXCEED	9.59	12.91	EXCEED	12.91	13.24	OK
	Click to add new row.																		

Figure 1.9: Example of the temporal check results

1.6 Known Issues and Troubleshooting

The GIS PMP tool has undergone a beta testing program during development. One goal of the beta testing program was to identify possible issues with the GIS tool. The following guidelines may prevent issues with running the GIS tool.

- Ensure ArcGIS Desktop is up to date with the most recent version release and maintenance is current.
- Ensure all file and path names do not have spaces or non-alphanumeric symbols (e.g., #, $, %). Underscores are acceptable and a good alternative to using spaces.
- Close any other applications or instances of ArcMap that may interfere with the current session, files, or file paths that will be used by the tool.
- Ensure that all file paths, input and output files, and ArcGIS Environment settings (including the Default.gdb and Scratch.gdb) are local and not set to a network location.

If the points above have been verified and issues persist, the user may try the following actions to address the issue:

- Close out all ArcMap sessions and all ArcGIS applications and restart session.
- Restart computer. This may be required to completely clear any locks on files or memory.
- Run the Repair Geometry tool on the AOI shapefile or feature class to correct any geometry issues within the file.
- Rename AOI file. Change tool and/or output folder paths.

If issues persist it may be necessary to contact ESRI support or perform a clean ArcGIS installation or upgrade.

Appendix H
AEP Tool Documentation

1. AEP Tool Description and Usage

The Basin AEP Tool extracts 6-hour and 24-hour basin-average precipitation for Annual Exceedance Probabilities (AEP) and corresponding Average Recurrence Intervals (ARI) estimates, and 5% and 95% confidence interval estimates, for user-defined drainage basin area. The development of the Annual Exceedance Probability is detailed in the report of the Probable Maximum Precipitation Study for North Carolina (2025).

The tool calculates an areal-reduction factor (ARF) based on duration and the basin location using a three-parameter log-logistic function. The tool exports Excel spreadsheet tables of basin average precipitation estimates for AEPs of 1 to $1x10^{-10}$. The tool also calculates the AEP of PMP for the basin using user-input PMP datasets. The resulting precipitation frequency estimates and AEP of PMP are plotted on charts as .png images.

The tool is compatible with ArcGIS Pro. It is recommended that the most current version of the software is used. The tool is accessed from the NorthCarolina_Final_PMP_Tools.tbx toolbox within the ArcGIS desktop environment.

1.1 File Structure

The Basin AEP Tool, and the gridded precipitation frequency datasets it utilizes are contained within the 'PMP_Evaluation_Tool' folder. The 'AEP.gdb' file geodatabase contains the precipitation frequency gridded datasets for each duration for every available return period. The AEP.gdb is located within the 'Input' sub folder. The script tool is located within the 'Script' subfolder, along with the PMP tool. See the PMP tool documentation for more information on the PMP tool and the overall file structure.

1.2 Usage

As a prerequisite to the AEP tool usage, the user should have downloaded the 'PMP_Evaluation_Tool' to a location on their local file system. A polygon feature class or basin shapefile is needed for input. Running the PMP tool with the basin is not required unless the user chooses the option to calculate the AEP of PMP.

1.3 Input Parameters

The tool accepts the following input parameters.

Table 1 - AEP Tool input parameters

Parameter # (in script)	Display Name	Data Type	Type	Direction	MultiValue
0	Input basin outline shapefile or feature class	Feature Layer	Required	Input	No
1	AEP Durations	String	Required	Input	Yes
2	Output Folder Path	Folder	Required	Input	No
3	Estimate AEP of PMP	Boolean	Optional	Input	No
4	"PMP Points" feature class for each storm type	Feature Layer	Optional	Input	Yes

Table 1 shows tool input parameters. The first parameter required by the tool dialogue is a feature layer, such as a basin shapefile o r feature class, designed to outline the area of interest (AOI) for the precipitation frequency estimates. The tool will calculate the basin area size in square miles. If the feature layer has multiple features (or polygons), the tool will use the combined area as the analysis region. Only the selected polygons will be used if the tool is run from the ArcPro environment with selected features highlighted. If the AOI shapefile extends beyond the project analysis domain, AEP will only be evaluated for grid cells inside the project domain. The AOI shapefile or feature class should not have any spaces or symbol characters in the filename or the file path.

The user then selects the precipitation durations to be evaluated. At least one duration is needed.

The user will need to set the 'Output Folder' path which provides the tool with the location to create the output AEP files. The user must have read/write privileges for this folder location.

Finally, the user has the option to calculate the AEP of PMP for the basin. If the user selects this option, they will need to provide the "PMP_Point" feature class(es) produced by the Basin PMP Tool. The tool can accept a separate feature class for each storm type (see example in Figure 1).

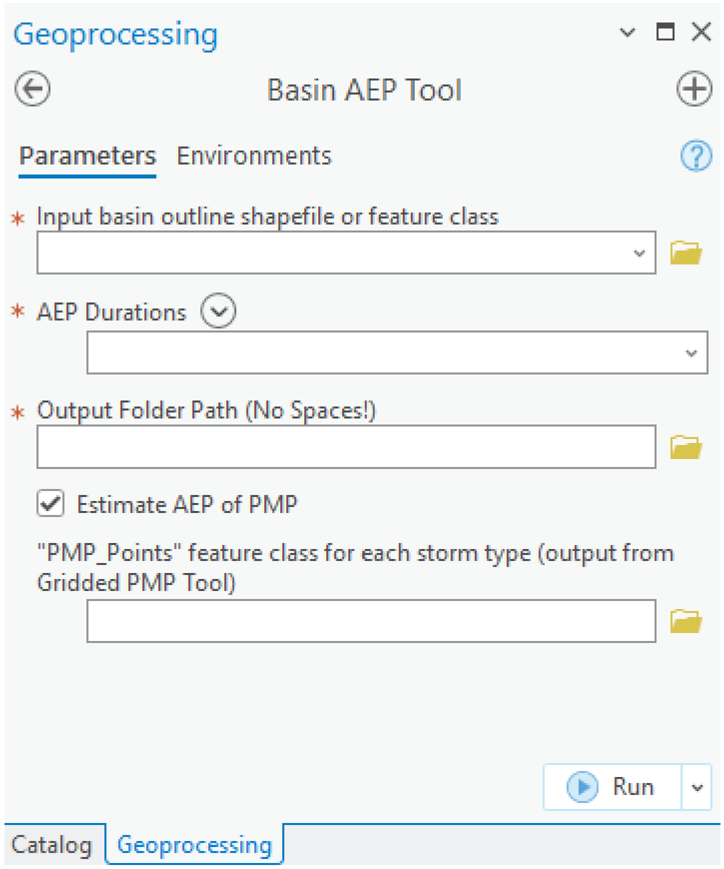


Figure 1 - The Basin AEP Tool input dialogue window

1.4 Tool Output

Once the tool has been run, the output folder will be populated with the results. For each duration the tool will produce an Excel (.xls) spreadsheet containing the basin average precipitation frequency estimates. An example is shown in Table 2. The tool will also produce a logarithmic frequency curve plot showing the basin average precipitation and the 95% confidence bounds. Additionally, if the option to calculate the AEP of PMP was chosen, the PMP depths will be plotted on the chart and a table of the AEP of PMP values will be plotted on the image. An example of this plot is shown in Figure 2.

Table 2 - Example basin AEP table output

OBJECTID	Annual Exceedance Probability	Precip (in) 50% conf.	Precip (in) 5% conf.	Precip (in) 95% conf.
1	1	1.36	1.19	1.52
2	0.5	2.63	2.38	2.92
3	0.2	3.56	3.25	3.93
4	0.1	4.26	3.87	4.69
5	0.04	5.26	4.72	5.76
6	0.02	6.08	5.4	6.72
7	0.01	6.99	6.14	7.79
8	0.005	7.98	6.93	8.98
9	0.002	9.43	8.05	10.7
10	0.001	10.67	8.99	12.22
11	0.0002	14.02	11.43	16.31
12	0.0001	15.7	12.61	18.59
13	0.00001	22.61	17.27	28.47
14	0.000001	32.08	23.15	43.11
15	0.0000001	45.06	30.68	64.62
16	0.00000001	62.87	40.25	96.77
17	0.000000001	87.27	52.41	144.62
18	1E-10	120.74	67.9	215.65

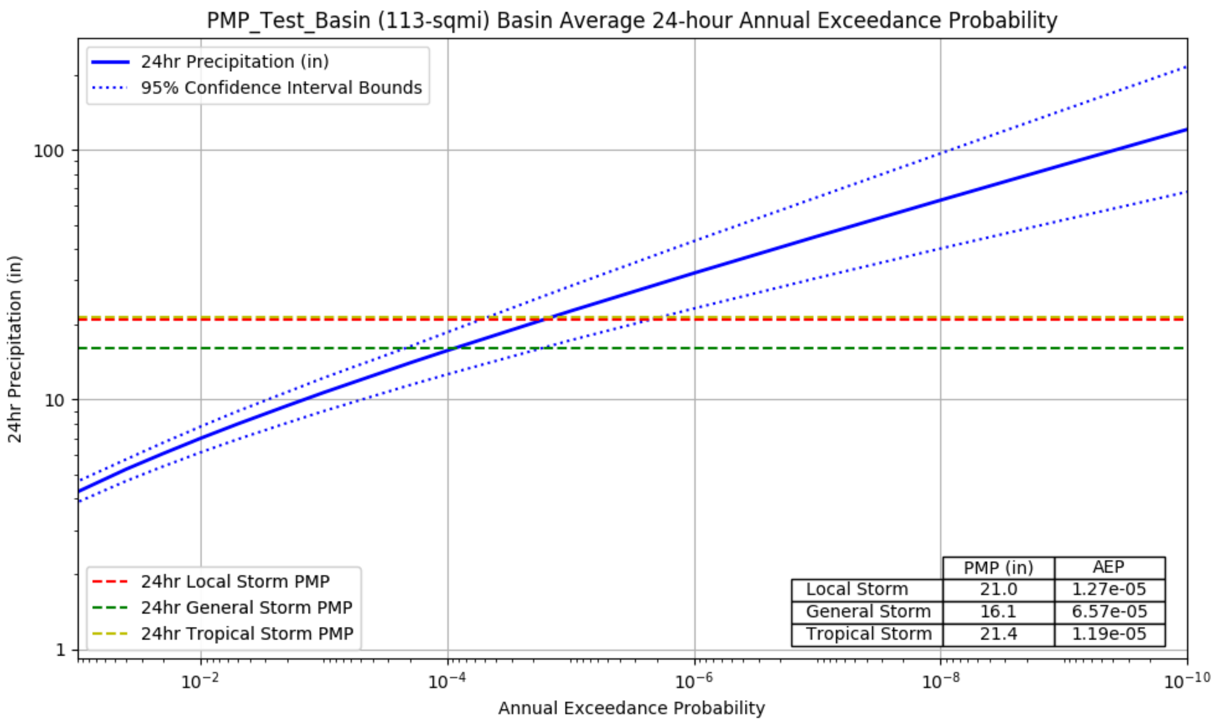


Figure 2 - Example basin precipitation frequency curve and AEP of PMP plot output

1.5 Recommendation for Temporal Patterns

The AEP Tool does not provide Temporal Patterns. The same temporal patterns developed for the PMP (for the most critical storm type) are recommended to be applied to the AEP for recurrence intervals of 100-year or rarer. For more frequent recurrence intervals (50-yr, 25-yr, 10yr, etc), applying NOAA Altas 14 (or similar documents that replace NOAA Atlas 14) temporal patterns is recommended.

Appendix I
PMP Version Log: Changes to Storm Database and Adjustment Factors

Version 1.0 – (3/4/2024)

- Created 4 Transposition zones. Added transposition constraints to all storms
- Initial run; included GTF upper limit of 1.50 and lower limit 0.50
- MTF was set to 1 to remove from total adjustment factor.
- Previous transposition limits from the adjacent Pennsylvania, Virginia, Mayland, New Jersey, TVA, NGH, and several site-specific studies in the region were utilized as a starting point when storms were common to these other studies.
- Initial GTF calculations for sensitivities. This provides explicit data from which to make decisions on transposition limits and/or support decisions made

Initial Storm List

General Storms

- SPAS_1047_1 TAMAQUA PA 1,2,3
- SPAS_1048_1 HOKAH MN 4
- SPAS_1181_1 GLADEWATER TX 4
- SPAS_1195_2 PADDY MOUNTAIN WV 3
- SPAS_1206_1 BIG RAPIDS MI 4
- SPAS_1208_1 WARNER PARK TN 4
- SPAS_1218_1 DOUGLASVILLE GA 4
- SPAS_1218_2 LA FAYETTE GA 4
- SPAS_1219_1 BIG FORK AR 4
- SPAS_1227_1 LOUISVILLE MS 1,2
- SPAS_1242_1 ALLEY SPRING MO 4
- SPAS_1244_1 LOUISVILLE KY 4
- SPAS_1277_1 GILBERTSVILLE KY 4
- SPAS_1278_1 MADISONVILLE KY 4
- SPAS_1305_1 ELBA AL 1,2
- SPAS_1311_1 MCKENZIE TN 4
- SPAS_1312A_1 ROSMAN NC 3,4
- SPAS_1312A_2 ROSMAN NC 3,4
- SPAS_1339_1 WELLSBORO (DAD 1) PA 1,2,3

- SPAS_1339_2 WELLSBORO (DAD 2) PA 1,2,3
- SPAS_1339_3 WELLSBORO (DAD 3) PA 1,2,3
- SPAS_1346_1 BLUE RIDGE DIVIDE NC 3,4
- SPAS_1350_1 NEW BERN NC 1,2
- SPAS_1357_1 BURNSVILLE TN 4
- SPAS_1362_2 ROBBINSVILLE VA 3,4
- SPAS_1380_1 BURTON DAM GA 2,3,4
- SPAS_1428_1 FAIRFIELD TX 4
- SPAS_1430_1 HEMPSTEAD TX 4
- SPAS_1431_1 WARNER OK 4
- SPAS_1433_1 COLLINSVILLE IL 4
- SPAS_1435_1 HARRISONBURG DAM LA 4
- SPAS_1514_1 VADE MECUM NC 1,2
- SPAS_1533_1 MONTEBELLO VA 2,3,4
- SPAS_1564_1 MOUNT PLEASANT SC 1,2
- SPAS_1680_1 WEST SHOKAN NY 3
- SPAS_1804_1 HALIFAX VT 2,3,4

Hybrid Storms

- SPAS_1183_1 EDGERTON MO 4
- SPAS_1228_1 FALL RIVER KS 4
- SPAS_1286_1 AURORA COLLEGE IL 4
- SPAS_1376_1 LIBERTYKY 4
- SPAS_1275_2 MONTEGOMERY DAM PA 1,2,3
- SPAS_1340_1 BIG MEADOWS VA 3

Local Storms

- SPAS_1030_1 DAVID CITY NE 4
- SPAS_1034_1 ENID OK 4
- SPAS_1040_1 TABERNACLE NJ 1,2
- SPAS_1049_1 DELAWARE COUNTY NY 2,3
- SPAS_1209_1 WOOSTER OH 4
- SPAS_1220_1 DUBUQUE IA 4
- SPAS_1226_1 COLLEGE HILL OH 4
- SPAS_1343_1 JOHNSON CITY TN 4
- SPAS_1344_1 SIMPSON KY 4
- SPAS_1362_1 COEBURN VA 4
- SPAS_1402_1 LITTLE BARREN TN 4
- SPAS_1402_2 ROSEDALE TN 4
- SPAS_1406_1 RAPIDAN VA 3

- SPAS_1415_1 ISLIP NY 1,2
- SPAS_1426_1 COOPER MI 4
- SPAS_1427_1 BOYDEN IA 4
- SPAS_1429_2 HALLETT OK 4
- SPAS_1432_1 MOUNDS OK 4
- SPAS_1434_1 HOLT MO 4
- SPAS_1489_1 JEWELL MD 1,2
- SPAS_1534_1 EWAN NJ 1,2
- SPAS_1536_1 GLENVILLE WV 4
- SPAS_1546_1 LITTLE RIVER VA 4
- SPAS_1548_1 REDBANK PA 4
- SPAS_1550_1 JOHNSTOWN PA 4
- SPAS_1674_1 SPARTA NJ 2,3
- SPAS_1700_1 ELLICOTT CITY MD 1,2
- SPAS_1944_1 ROCKPORT WV 4
- SPAS_1952_1 FAYETTEVILLE NC 1,2

Tropical Storms

- SPAS_1182_1 LARTO LAKE LA 4
- SPAS_1224_1 MAPLECREST NY 3
- SPAS_1243_1 WESTFIELD MA 1,2,3
- SPAS_1275_1 MONTGOMERY DAM PA 4
- SPAS_1276_1 WELLSVILLE NY 4
- SPAS_1276_2 ZERBE PA 1,2,3
- SPAS_1298_1 HARRISBURG PA 1,2,3
- SPAS_1299_1 ALTA PASS NC 3,4
- SPAS_1299_2 KINGSTREE SC 1,2
- SPAS_1312B_1 DEKALB MS 1,2
- SPAS_1312B_2 ROSMAN NC 3,4
- SPAS_1317_1 AMERICUS GA 1,2
- SPAS_1342_1 MT MITCHELL NC 3,4
- SPAS_1373_1 ANTREVILLE SC 2,3
- SPAS_1490_1 EASTON MD 1,2
- SPAS_1491_1 TYRO VA 1,2,3
- SPAS_1515_1 ST. GEORGE GA 1,2
- SPAS_1516_1 GLENVILLE GA 1,2,3
- SPAS_1516_2 GLENVILLE GA 2,3
- SPAS_1517_2 MONCURE NC 2,3
- SPAS_1517_3 SETTLE NC 1,2,3
- SPAS_1518_1 ROCKINGHAM NC 1,2

- SPAS_1526_1 RIDGEWAY SC 1,2
- SPAS_1535_1 EDENTON NC 1,2
- SPAS_1535_2 UPPER SHERANDO VA 3,4
- SPAS_1551_1 RICHMOND VA 1,2
- SPAS_1552_1 SOUTHPORT NC 1
- SPAS_1552_2 YORKTOWN VA 1,2
- SPAS_1552_3 POMPTON LAKE NJ 1,2
- SPAS_1552_4 CAIRO NY 1,2,3
- SPAS_1628_1 JEFFERSON OH 4
- SPAS_1669_1 EVERGREEN NC 1,2
- SPAS_1679_1 SLIDE MOUNTAIN NY 3
- SPAS_1720_1 WRIGHTSVILLE BEACH NC 1,2
- SPAS_1891_1 DOWNINGTON PA 1,2,3

Version 2.0 – (3/11/2024)

Local Storms

- Added SPAS 1681 (Smethport, PA) to Local storms. Added to zone 4 only. Scaled GTF to a maximum of 1.
- Scaled GTF for SPAS 1344_1 to a maximum of 1.
- Scaled GTF for SPAS 1536_1 to a maximum of 1.
- Scaled GTF for SPAS 1944_1 to a maximum of 1.

Version 3.0 – (6/13/2024)

- Updated SPAS analysis for SPAS 1343_1
- Added SPAS 1927_1 to Local storm list

Version 4.0 – (7/1/2024)

General Storms

- Removed SPAS 1048_1 (Hokah, MN) from list
- Removed SPAS 1181_1 (Gladewater, TX) from list
- Removed SPAS 1206_1 (Big Rapids, MI) from list
- Removed SPAS 1428_1 (Fairfield, TX) from list
- Removed SPAS 1430_1 (Hempstead, TX) from list
- Removed SPAS 1431_1 (Warner, OK) from list
- Removed SPAS 1433_1 (Collinsville, IL) from list

- Removed SPAS 1435_1 (Harrisonburg Dam, LA) from list
- Removed SPAS 1227_1 (Louisville, MS) from list
- Removed SPAS 1277_1 (Gilbertsville, KY) from list
- Updated SPAS 1305_1 (Elba, AL) Updated transposition limits from zone 4 to zone 1,2 South of °35N
- Updated SPAS 1514_1 (Vade Mecum, NC) from 1,2 to 1,2,3. This storm was only used in zones 1,2 for MD and NJ, but was used near the crest in Virginia. Was also used in Loch Dornie and North Georgia Hydro.
- SPAS 1339_1 (Wellsboro, PA) Limited transposition Lat to within 5° of storm center
- SPAS 1047_1 (Tamaqua, PA) Limited transposition Lat to within 5° of storm center
- SPAS 1680_1 (West Shokan, NY) Limited transposition Lat to within 5° of storm center
- SPAS 1804_1 (Halifax, VT) Limited transposition Lat to within 5° of storm center
-

Hybrid Storms

- Removed SPAS 1228_1 (Fall River, KS) from list
- Removed SPAS 1183_1 (Edgerton, MO) from list
- Removed SPAS 1286_1 (Aurora College, IL) from list

Tropical Storms

- Removed SPAS 1312B_1 from storm list.
- Removed SPAS 1182_1 (Larto Lake, LA) from storm list
- Updated SPAS 1317_1 (Americus, GA) Updated transposition limits from zones 1,2 to zone 1,2,3 South of °35.14N
- Updated SPAS 1298_1 (Harrisburg, PA) from Topical storm to General storm and moved to zones 1,2,3 to match what was done in MD and NJ.
- SPAS 1224_1 (Maplecrest, NY) Limited transposition Lat to within 5° of storm center
- SPAS 1243_1 (Westfield, MA) Limited transposition Lat to within 5° of storm center
- SPAS 1276_1 (Wellsville, NY) Limited transposition Lat to within 5° of storm center
- SPAS 1515_1 (St George, GA) Limited transposition Lat to within 5° of storm center
- SPAS 1552_4 (Cairo, NY) Limited transposition Lat to within 5° of storm center
- SPAS 1628_1 (Jefferson, OH) Limited transposition Lat to within 5° of storm center
- SPAS 1679_1 (Slide Mountain, NY) Limited transposition Lat to within 5° of storm center
-

Local Storms

- Removed SPAS 1030_1 (David City, NE) from list
- Removed SPAS 1034_1 (Enid, OK) from list
- Removed SPAS 1426_1 (Cooper, MI) from list.
- Removed SPAS 1427_1(Boyden, IA from list

- Removed SPAS 1429_2 (Hallett, OK) from list
- Removed SPAS 1432_1 (Mounds, OK) from list
- Removed SPAS 1434_1 (Holt, MO) from list
- Removed SPAS 1220_1 (Dubuque, IA) from list
- SPAS 1049_1 (Delaware County, NY) Limited transposition Lat to within 5° of storm center
- SPAS 1548_1 (Redbank, PA) Limited transposition Lat to within 5° of storm center
- SPAS 1674_1 (Sparta, NJ) Limited transposition Lat to within 5° of storm center
- SPAS 1681 (Smethport, PA) Limited transposition Lat to within 5° of storm center
- SPAS 1927_1 (Fort Lauderdale, FL) Limited transposition Lat to within 5° of storm center

Version 4a – (7/28/2024)

General Storms

- SPAS 1339_1 (Wellsboro, PA) Removed 5° limit on transposition

Local Storms

- SPAS 1674_1 (Sparta, NJ) Removed 5° limit on transposition
- SPAS 1534_1 (Ewan, NJ) Allowed to go into transposition zone 3 to smooth out some of the lower values in that area. This storm was only allowed in coastal areas for previous statewide studies.

Tropical Storms

- SPAS 1628_1 (Jefferson, OH) Removed 5° limit on transposition

Version 4b – (7/29/2024)

Tropical Storms

- SPAS 1628_1 (Jefferson, OH) Removed from storm list

Questions for v5

- *Do we bring SPAS 1514 into zone 3? Currently it is*
- *Do we bring SPAS 1343_1 east of the app crest? Currently it is not. It was not used in NJ or MD. It was only used west of crest in Virginia. It was used in Loch Dornie.*
- *Local storm: How do we deal with the low area in zone 3 for local storms (especially at 3 and 4hrs? Can we smooth one 4 into one 3 to make a better transition?*
- *Local storm: Sparta, NJ SPAS 1674 move further south or leave out*
- *Bring each 1339 DAD zone all the way thru*
- *Remove SPAS 1628 or go everywhere*

- *Move SPAS 1518 to zone 3*
- *Move SPAS 1276 to all of zone 4?*
- *Move SPAS 1243 to all of zones 1, 2, 3*
- *Move SPAS 1224 to all of zone 3, and did we use it in zone 1 and 2 in PA, VA, NJ, MD?*
- *SPAS 1339 DAD zones 1 and 2, should we limit to only zone 3?*
- *Remove (SPAS 1219, 1242, 1244, 1278, 1376, 1311, etc)?*

Version 5 – (9/26/2024)

Used v4b with these changes

Local Storms

- SPAS 1534_1 (Ewan, NJ) Capped GTF at 1.2 in coastal areas. All grid points within transposition zone 1 were capped at a GTF of 1.2.

Version 6 – (1/13/2025)

Used v5 with these changes

Tropical Storms

- Added SPAS_1981_1 (Kure Beach, NC) to storm list – Applied to zone 1
- Added SPAS_1984_1 (Busick, NC) to storm list – Applied to zones 3 & 4

Appendix J
Precipitable Water Depths

Elev_FT	40.0	40.5	41.0	41.5	42.0	42.5	43.0	43.5	44.0	44.5	45.0	45.5	46.0	46.5	47.0	47.5	48.0	48.5	49.0	49.5
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
200	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
300	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
400	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
500	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06
600	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07
700	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08
800	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09
900	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.10
1,000	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11
1,100	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12
1,200	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.13
1,300	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14
1,400	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15
1,500	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16
1,600	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.17
1,700	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.18
1,800	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.18
1,900	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.19	0.19	0.19
2,000	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.20
2,100	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.20	0.21
2,200	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.22
2,300	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22	0.23
2,400	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24
2,500	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25
2,600	0.17	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26
2,700	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.26
2,800	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.24	0.24	0.25	0.25	0.26	0.26	0.27
2,900	0.19	0.20	0.20	0.21	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28
3,000	0.20	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29
3,100	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30
3,200	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30
3,300	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31
3,400	0.22	0.23	0.23	0.24	0.24	0.24	0.24	0.25	0.25	0.26	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32
3,500	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.32	0.33
3,600	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33
3,700	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34
3,800	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.33	0.34	0.34	0.35
3,900	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.35	0.36
4,000	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.33	0.34	0.34	0.35	0.35	0.36
4,100	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.35	0.36	0.36	0.37
4,200	0.26	0.27	0.27	0.28	0.28	0.28	0.28	0.29	0.30	0.31	0.31	0.32	0.33	0.34	0.34	0.35	0.35	0.36	0.37	0.38
4,300	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38
4,400	0.26	0.27	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39
4,500	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.32	0.33	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.39	0.40
4,600	0.27	0.28	0.28	0.29	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40
4,700	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.33	0.34	0.34	0.35	0.35	0.36	0.37	0.38	0.38	0.39	0.40	0.41
4,800	0.28	0.29	0.29	0.30	0.31	0.32	0.32	0.33	0.33	0.34	0.35	0.36	0.36	0.37	0.37	0.38	0.39	0.40	0.41	0.42
4,900	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.35	0.35	0.36	0.37	0.38	0.38	0.39	0.40	0.41	0.41	0.42
5,000	0.29	0.30	0.30	0.31	0.31	0.32	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.39	0.40	0.40	0.41	0.42	0.43
5,500	0.31	0.32	0.32	0.33	0.33	0.34	0.35	0.36	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.43	0.44	0.45	0.46
6,000	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.39	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.47	0.48
6,500	0.34	0.35	0.36	0.37	0.37	0.38	0.39	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51
7,000	0.36	0.37	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.52	0.53	0.54
7,500	0.37	0.38	0.39	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.52	0.53	0.54	0.55	0.56
8,000	0.39	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.55	0.56	0.57	0.58
8,500	0.40	0.41	0.42	0.43	0.43	0.44	0.45	0.46	0.47	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.58	0.59	0.60
9,000	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.55	0.56	0.57	0.58	0.60	0.61	0.62
9,500	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.55	0.56	0.57	0.59	0.60	0.61	0.62	0.64
10,000	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.53	0.54	0.55	0.56	0.58	0.59	0.60	0.61	0.63	0.64	0.66
10,500	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.55	0.56	0.57	0.59	0.60	0.62	0.63	0.64	0.65	0.67
11,000	0.44	0.45	0.46	0.48	0.49	0.50	0.51	0.52	0.53	0.55	0.56	0.58	0.59	0.60	0.61	0.63	0.64	0.66	0.67	0.69
11,500	0.45	0.46	0.47	0.48	0.49	0.51	0.52	0.53	0.54	0.56	0.57	0.59	0.60	0.61	0.62	0.64	0.65	0.67	0.68	0.70
12,000	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.55	0.57	0.58	0.59	0.60	0.62	0.63	0.65	0.66	0.68	0.69	0.71
12,500	0.46	0.47	0.48	0.50	0.51	0.52	0.53	0.55	0.56	0.57	0.58	0.60	0.61	0.63	0.64	0.66	0.67	0.69	0.70	0.72
13,000	0.47	0.48	0.49	0.50	0.51	0.53	0.54	0.55	0.56	0.58	0.59	0.61	0.62	0.64	0.65	0.67	0.68	0.70	0.71	0.73
13,500	0.47	0.48	0.49	0.51	0.52	0.53	0.54	0.56	0.57	0.59	0.60	0.62	0.63	0.65	0.66	0.68	0.69	0.71	0.72	0.74
14,000	0.47	0.49	0.50	0.51	0.52	0.54	0.55	0.57	0.58	0.59	0.60	0.62	0.63	0.65	0.66	0.68	0.69	0.71	0.73	0.75
14,500	0.48	0.49	0.50	0.52	0.53	0.54	0.55	0.57	0.58	0.60	0.61	0.63	0.64	0.66	0.67	0.69	0.70	0.72	0.74	0.76
15,000	0.48	0.50	0.51	0.52	0.53	0.55	0.56	0.58	0.59	0.60	0.61	0.63	0.65	0.66	0.67	0.69	0.71	0.73	0.74	0.76
30,000	0.50	0.52	0.53	0.55	0.56	0.58	0.59	0.61	0.62	0.64	0.65	0.67	0.68	0.70	0.72	0.74	0.76	0.78	0.79	0.82

Elev_FT	50.0	50.5	51.0	51.5	52.0	52.5	53.0	53.5	54.0	54.5	55.0	55.5	56.0	56.5	57.0	57.5	58.0	58.5	59.0	59.5
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
200	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
300	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05
400	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
500	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08
600	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09
700	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11
800	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12
900	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14
1,000	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15
1,100	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17
1,200	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18
1,300	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20
1,400	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.20	0.21
1,500	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.22	0.22	0.22
1,600	0.17	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24
1,700	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.25
1,800	0.18	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.26
1,900	0.19	0.20	0.20	0.21	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28
2,000	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29
2,100	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30
2,200	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.26	0.26	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32
2,300	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33
2,400	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34
2,500	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35
2,600	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.36	0.37
2,700	0.26	0.27	0.27	0.28	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38
2,800	0.27	0.28	0.28	0.29	0.29	0.30	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.37	0.38	0.38	0.39
2,900	0.28	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40
3,000	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40	0.40	0.41
3,100	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.35	0.36	0.36	0.37	0.37	0.38	0.39	0.40	0.40	0.41	0.41	0.42
3,200	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.38	0.39	0.40	0.41	0.41	0.42	0.43	0.44
3,300	0.31	0.32	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40	0.41	0.42	0.42	0.43	0.44	0.45
3,400	0.32	0.33	0.33	0.34	0.35	0.36	0.36	0.37	0.37	0.38	0.39	0.40	0.40	0.41	0.42	0.43	0.43	0.44	0.45	0.46
3,500	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.38	0.39	0.40	0.41	0.41	0.42	0.43	0.44	0.44	0.45	0.46	0.47
3,600	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.45	0.46	0.47	0.48
3,700	0.34	0.35	0.36	0.37	0.37	0.38	0.39	0.40	0.40	0.41	0.42	0.43	0.43	0.44	0.45	0.46	0.46	0.47	0.48	0.49
3,800	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.49	0.50
3,900	0.36	0.37	0.37	0.38	0.39	0.40	0.40	0.41	0.42	0.43	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.50	0.51
4,000	0.37	0.38	0.38	0.39	0.40	0.41	0.41	0.42	0.43	0.44	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.51	0.52
4,100	0.37	0.38	0.39	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.52	0.53
4,200	0.38	0.39	0.39	0.40	0.41	0.42	0.43	0.44	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.51	0.53	0.54	0.55
4,300	0.39	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56
4,400	0.39	0.40	0.41	0.42	0.43	0.44	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57
4,500	0.40	0.41	0.42	0.43	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.52	0.53	0.54	0.56	0.57	0.58
4,600	0.41	0.42	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.48	0.49	0.51	0.52	0.53	0.53	0.54	0.55	0.57	0.58	0.59
4,700	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.58	0.59	0.60
4,800	0.42	0.43	0.44	0.45	0.46	0.47	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.59	0.60	0.61
4,900	0.43	0.44	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.62
5,000	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.63
5,500	0.47	0.48	0.48	0.49	0.50	0.51	0.52	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.63	0.64	0.65	0.66	0.68
6,000	0.49	0.50	0.51	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.62	0.63	0.64	0.65	0.67	0.68	0.69	0.70	0.72
6,500	0.52	0.53	0.54	0.56	0.57	0.58	0.59	0.60	0.61	0.63	0.64	0.66	0.67	0.68	0.69	0.71	0.72	0.74	0.75	0.77
7,000	0.55	0.56	0.57	0.59	0.60	0.61	0.62	0.63	0.64	0.66	0.67	0.69	0.70	0.72	0.73	0.75	0.76	0.78	0.79	0.81
7,500	0.57	0.58	0.59	0.61	0.62	0.64	0.65	0.66	0.67	0.69	0.70	0.72	0.73	0.75	0.76	0.78	0.79	0.81	0.82	0.84
8,000	0.59	0.61	0.62	0.64	0.65	0.66	0.67	0.69	0.70	0.72	0.73	0.75	0.76	0.78	0.79	0.81	0.82	0.84	0.86	0.88
8,500	0.61	0.63	0.64	0.66	0.67	0.69	0.70	0.72	0.73	0.75	0.76	0.78	0.79	0.81	0.82	0.84	0.86	0.88	0.89	0.91
9,000	0.63	0.65	0.66	0.68	0.69	0.71	0.72	0.74	0.75	0.77	0.78	0.80	0.82	0.84	0.85	0.87	0.89	0.91	0.92	0.94
9,500	0.65	0.67	0.68	0.70	0.71	0.73	0.74	0.76	0.77	0.79	0.81	0.83	0.84	0.86	0.88	0.90	0.91	0.93	0.95	0.97
10,000	0.67	0.69	0.70	0.72	0.73	0.75	0.76	0.78	0.79	0.81	0.83	0.85	0.87	0.89	0.90	0.92	0.94	0.96	0.98	1.00
10,500	0.68	0.70	0.71	0.73	0.75	0.77	0.78	0.80	0.81	0.83	0.85	0.87	0.89	0.91	0.92	0.95	0.97	0.99	1.01	1.03
11,000	0.70	0.72	0.73	0.75	0.76	0.78	0.80	0.82	0.83	0.85	0.87	0.89	0.91	0.93	0.95	0.97	0.99	1.01	1.03	1.06
11,500	0.71	0.73	0.74	0.76	0.78	0.80	0.81	0.83	0.85	0.87	0.89	0.91	0.93	0.95	0.97	0.99	1.01	1.03	1.05	1.08
12,000	0.72	0.74	0.76	0.78	0.79	0.81	0.83	0.85	0.87	0.89	0.90	0.93	0.95	0.97	0.99	1.01	1.03	1.06	1.08	1.10
12,500	0.74	0.76	0.77	0.79	0.81	0.83	0.84	0.86	0.88	0.90	0.92	0.94	0.96	0.98	1.00	1.03	1.05	1.08	1.10	1.13
13,000	0.75	0.77	0.78	0.80	0.82	0.84	0.85	0.87	0.89	0.91	0.93	0.96	0.98	1.00	1.02	1.05	1.07	1.09	1.11	1.14
13,500	0.75	0.77	0.79	0.81	0.83	0.85	0.87	0.89	0.91	0.93	0.95	0.97	0.99	1.02	1.04	1.06	1.08	1.11	1.13	1.16
14,000	0.76	0.78	0.80	0.82	0.84	0.86	0.88	0.90	0.92	0.94	0.96	0.99	1.01	1.03	1.05	1.08	1.10	1.13	1.15	1.18
14,500	0.77	0.79	0.81	0.83	0.85	0.87	0.89	0.91	0.93	0.95	0.97	1.00	1.02	1.04	1.06	1.09	1.11	1.14	1.16	1.19
15,000	0.78	0.80	0.81	0.84	0.86	0.88	0.89	0.92	0.94	0.96	0.98	1.01	1.03	1.05	1.07	1.10	1.13	1.16	1.18	1.21
30,000	0.84	0.86	0.88	0.90	0.92	0.95	0.97	1.00	1.02	1.05	1.07	1.10	1.13	1.16	1.19	1.22	1.25	1.28	1.31	1.35

Elev_FT	60.0	60.5	61.0	61.5	62.0	62.5	63.0	63.5	64.0	64.5	65.0	65.5	66.0	66.5	67.0	67.5	68.0	68.5	69.0	69.5	70.0	70.5	71.0	71.5	72.0	72.5	73.0	73.5	74.0	74.5	75.0	75.5	76.0	76.5	77.0	77.5	78.0	78.5	79.0	79.5
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
200	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
300	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09
400	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12
500	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15
600	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18
700	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.21
800	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24
900	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27
1,000	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.28	0.28	0.29
1,100	0.17	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32
1,200	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35
1,300	0.20	0.20	0.20	0.21	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38
1,400	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.38	0.39	0.39	0.40
1,500	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.37	0.38	0.38	0.39	0.39	0.40	0.41	0.42	0.42	0.43
1,600	0.24	0.25	0.25	0.26	0.26	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.35	0.36	0.36	0.37	0.37	0.38	0.38	0.39	0.39	0.40	0.41	0.42	0.42	0.43	0.43	0.44	0.45	0.46
1,700	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.37	0.38	0.38	0.39	0.39	0.40	0.40	0.41	0.42	0.43	0.43	0.44	0.44	0.45	0.46	0.47	0.47	0.48
1,800	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.36	0.37	0.37	0.38	0.39	0.40	0.40	0.41	0.41	0.42	0.43	0.44	0.44	0.45	0.45	0.46	0.47	0.48	0.48	0.49	0.50	0.51
1,900	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.37	0.38	0.38	0.39	0.39	0.40	0.41	0.42	0.42	0.43	0.43	0.44	0.45	0.45	0.46	0.47	0.48	0.49	0.49	0.50	0.51	0.52	0.53	0.54
2,000	0.29	0.30	0.30	0.31	0.31	0.32	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.37	0.38	0.38	0.39	0.40	0.41	0.41	0.42	0.42	0.43	0.44	0.45	0.45	0.46	0.47	0.48	0.48	0.49	0.50	0.51	0.52	0.53	0.53	0.54	0.55	0.56
2,100	0.30	0.31	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40	0.40	0.41	0.42	0.43	0.43	0.44	0.44	0.45	0.46	0.47	0.47	0.48	0.49	0.50	0.51	0.52	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59
2,200	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.37	0.38	0.38	0.39	0.39	0.40	0.41	0.42	0.42	0.43	0.43	0.44	0.45	0.46	0.46	0.47	0.48	0.49	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.56	0.57	0.58	0.59	0.60	0.61
2,300	0.33	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.38	0.39	0.39	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.45	0.46	0.47	0.48	0.48	0.49	0.50	0.51	0.52	0.53	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64
2,400	0.34	0.35	0.36	0.37	0.37	0.38	0.38	0.39	0.40	0.41	0.41	0.42	0.42	0.43	0.44	0.45	0.45	0.46	0.47	0.48	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.57	0.59	0.60	0.61	0.61	0.62	0.63	0.64	0.65	0.67
2,500	0.36	0.37	0.37	0.38	0.38	0.39	0.40	0.41	0.42	0.43	0.43	0.44	0.44	0.45	0.46	0.47	0.47	0.48	0.49	0.50	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69
2,600	0.37	0.38	0.38	0.39	0.40	0.41	0.41	0.42	0.43	0.44	0.44	0.45	0.46	0.47	0.47	0.48	0.49	0.50	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.72
2,700	0.38	0.39	0.40	0.41	0.41	0.42	0.43	0.44	0.44	0.45	0.46	0.47	0.47	0.48	0.49	0.50	0.51	0.52	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.70	0.71	0.72	0.73	0.74
2,800	0.39	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.45	0.46	0.47	0.48	0.49	0.50	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.72	0.73	0.74	0.75	0.77
2,900	0.41	0.42	0.42	0.43	0.44	0.45	0.45	0.46	0.47	0.48	0.49	0.50	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.57	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.72	0.73	0.74	0.75	0.77	0.78	0.79
3,000	0.42	0.43	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.50	0.51	0.52	0.53	0.54	0.55	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.72	0.73	0.74	0.75	0.77	0.78	0.79	0.80	0.82
3,100	0.43	0.44	0.45	0.46	0.46	0.47	0.48	0.49	0.50	0.51	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.67	0.68	0.69	0.70	0.71	0.72	0.74	0.75	0.76	0.77	0.79	0.80	0.82	0.83	0.84
3,200	0.44	0.45	0.46	0.47	0.48	0.49	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.74	0.76	0.77	0.78	0.79	0.81	0.82	0.84	0.85	0.87
3,300	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.70	0.71	0.73	0.74	0.76	0.77	0.78	0.79	0.81	0.82	0.83	0.84	0.86	0.87	0.89
3,400	0.47	0.48	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.68	0.69	0.70	0.71	0.72	0.73	0.75	0.76	0.78	0.79	0.80	0.81	0.83	0.84	0.86	0.87	0.89	0.90	0.92
3,500	0.48	0.49	0.50	0.51	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.72	0.73	0.74	0.75	0.77	0.78	0.80	0.81	0.82	0.83	0.85	0.86	0.88	0.89	0.91	0.92	0.94
3,600	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.56	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.69	0.70	0.71	0.72	0.74	0.75	0.76	0.77	0.79	0.80	0.82	0.83	0.84	0.85	0.87	0.88	0.90	0.91	0.93	0.94	0.96
3,700	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.70	0.71	0.73	0.74	0.75	0.76	0.78	0.79	0.81	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.92	0.94	0.96	0.97	0.99
3,800	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.65	0.66	0.67	0.68	0.69	0.70	0.72	0.73	0.74	0.75	0.77	0.78	0.80	0.81	0.83	0.84	0.86	0.87	0.89	0.90	0.91	0.92	0.94	0.96	0.98	0.99	1.01
3,900	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.62	0.63	0.64	0.65	0.66	0.67	0.69	0.70	0.71	0.72	0.73	0.74	0.76	0.77	0.79	0.80	0.82	0.83	0.85	0.86	0.88	0.89	0.91	0.92	0.94	0.95	0.97	0.98	1.00	1.01	1.03
4,000	0.53	0.54	0.55	0.56	0.57	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.68	0.69	0.70	0.71	0.72	0.73	0.75	0.76	0.78	0.79	0.81	0.82	0.83	0.84	0.86	0.87	0.89	0.90	0.92	0.94	0.96	0.97	0.99	1.00	1.02	1.03	1.05
4,100	0.54	0.55	0.56	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.67	0.68	0.69	0.70	0.72	0.73	0.74	0.75	0.77	0.78	0.80	0.81	0.82	0.83	0.85	0.86	0.88	0.89	0.91	0.92	0.94	0.96	0.98	0.99	1.01	1.02	1.04	1.06	1.08
4,200	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.74	0.76	0.77	0.78	0.79	0.81	0.82	0.84	0.85	0.87	0.88	0.90	0.91	0.93	0.94	0.96	0.98	1.00	1.01	1.03	1.04	1.06	1.08	1.10
4,300	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.65	0.66	0.67	0.68	0.69	0.70	0.72	0.73	0.75	0.76	0.77	0.78	0.80	0.81	0.83	0.84	0.86	0.87	0.89	0.90	0.92	0.93	0.95	0.96	0.98	1.00	1.02	1.03	1.05	1.07	1.09	1.10	1.12
4,400	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.74	0.76	0.77	0.79	0.80	0.81	0.82	0.84	0.85	0.87	0.88	0.90	0.92	0.93	0.94	0.96	0.98	1.00	1.02	1.04	1.05	1.07	1.09	1.11	1.12	1.14
4,500	0.59	0.60	0.61	0.62	0.63	0.65	0.66	0.67	0.68	0.70	0.71	0.72	0.73	0.75	0.76	0.78	0.79	0.80	0.81	0.83	0.84	0.86	0.87	0.89	0.90	0.92	0.93	0.95	0.97	0.99	1.00	1.02	1.04	1.06	1.07	1.09	1.11	1.13	1.14	1.16
4,600	0.60	0.61	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.74	0.76	0.77	0.79	0.80	0.82	0.83	0.85	0.86	0.88	0.89	0.91	0.92	0.94	0.95	0.97	0.98	1.00	1.02	1.04	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19
4,700	0.61	0.62	0.62	0.64	0.65	0.67	0.68	0.69	0.70	0.72	0.73	0.75	0.76	0.77	0.78	0.80	0.81	0.83	0.84	0.86	0.87	0.89	0.90	0.92	0.93	0.95	0.97	0.99	1.00	1.02	1.04	1.06	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.21
4,800	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.74	0.76	0.77	0.79	0.80	0.82	0.83	0.85	0.86	0.88	0.89	0.91	0.92	0.94	0.95	0.97	0.98	1.00	1.02	1.04	1.06	1.08	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23
4,900	0.63	0.64	0.65	0.67	0.68	0.69	0.70	0.72	0.73	0.75	0.76	0.77	0.78	0.80	0.81	0.83	0.84	0.86	0.87	0.89	0.90	0.92	0.93	0.95	0.97	0.99	1.00	1.02	1.04	1.06	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.25
5,000	0.64	0.65	0.66	0.68	0.69	0.70	0.71	0.73	0.74	0.76	0.77	0.79	0.80	0.81	0.82	0.84	0.86	0.87	0.88	0.90	0.92	0.94	0.95	0.97	0.98	1.00	1.02	1.04	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.25	1.27
5,500	0.69	0.70	0.71	0.73	0.74	0.76	0.77	0.79	0.80	0.82	0.83	0.85	0.86	0.88	0.89	0.91	0.92	0.94	0.95	0.97	0.99	1.01	1.03	1.05	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.22	1.25	1.27	1.29	1.31	1.33	1.35	1.38
6,000	0.73	0.75	0.76	0.78	0.79	0.81	0.82	0.84	0.85	0.87	0.89	0.91	0.92	0.94	0.95	0.97	0.99	1.01	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.22	1.25	1.27	1.29	1.31	1.34	1.36	1.39	1.41	1.43	1.45	1.48
6,500	0.78	0.80	0.81	0.83	0.84	0.86	0.87	0.89	0.91	0.93	0.94	0.96	0.97	0.99	1.01	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.25	1.28	1.30	1.33	1.35	1.38	1.40	1.43	1.45	1.48	1.50	1.53	1.55	1.58
7,000	0.82	0.84	0.85	0.87	0.88	0.90	0.92	0.94	0.95	0.97	0.99	1.01	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.22	1.24	1.26	1.28	1.31	1.33	1.36	1.38	1.41	1.43	1.46	1.48	1.51	1.53	1.56	1.59	1.62	1.64	1.67
7,500	0.86	0.88	0.89	0.91	0.93	0.95	0.96	0.98	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.15	1.17	1.19	1.21	1.23	1.25	1.28	1.30	1.33	1.35	1.38	1.40	1.43	1.45	1.48	1.50	1.53	1.56	1.59	1.61	1.64	1.67	1.70	1.73	1.76
8,000	0.89	0.91	0.93	0.95	0.97	0.99	1.01	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.20	1.22	1.24	1.26	1.29	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.49	1.52	1.55	1.57	1.60	1.63	1.66	1.69	1.72	1.74	1.78	1.82	1.85
8,500	0.93	0.95	0.97	0.99	1.01	1.03	1.05	1.07	1.09	1.11	1.13	1.16	1.18	1.20	1.22	1.25	1.27	1.30	1.32	1.35	1.37	1.40	1.42	1.45	1.47	1.50	1.53	1.56	1.59	1.62	1.64	1.68	1.71	1.74	1.77	1.81	1.84	1.87	1.90	1.94
9,000	0.96	0.98	1.00	1.02	1.04	1.07	1.09	1.11	1.13	1.15	1.17	1.20	1.22	1.25	1.27	1.30	1.32	1.35	1.37	1.40	1.42	1.45	1.48	1.51	1.53	1.56	1.59	1.62	1.65	1.68	1.71	1.75	1.78	1.81	1.84	1.88	1.91	1.95	1.98	2.02
9,500	0.99	1.01	1.03	1.06	1.08	1.10	1.12	1.15	1.17	1.19	1.21	1.24	1.26	1.29	1.31	1.34	1.37	1.40	1.42	1.45	1.47	1.50	1.53	1.56	1.59	1.62	1.65	1.68	1.71	1.75	1.78	1.81	1.84	1.88	1.91	1.95	1.98	2.02	2.06	2.10
10,000	1.02	1.05	1.07	1.09	1.11	1.13	1.14	1.17	1.20	1.23	1.25	1.28	1.30	1.33	1.35	1.38	1.41	1.44	1.46	1.49	1.52	1.55	1.58	1.61	1.64	1.67	1.70	1.74	1.77	1.81	1.84	1.88	1.91	1.95	1.98	2.02	2.06	2.10	2.13	2.17
10,500	1.05	1.07	1.09	1.12	1.14	1.17	1.19	1.22	1.24	1.27	1.29	1.32	1.34	1.37	1.39	1.42	1.45	1.48	1.51	1.54	1.57	1.60	1.63	1.66	1.69	1.73	1.76	1.80	1.83	1.87	1.90	1.94	1.97	2.01	2.04	2.08	2.12	2.16	2.20	2.24
11,000	1.08	1.10	1.12	1.15	1.17	1.20	1.22	1.25	1.27	1.30	1.32	1.35	1.38	1.41	1.43	1.46	1.49	1.52	1.55	1.58	1.61	1.65	1.68	1.71	1.74	1.78	1.81	1.85	1.88	1.92	1.95	1.99	2.03	2.07	2.11	2.15	2.19	2.23	2.27	2.31
11,500	1.10	1.13	1.15	1.18	1.20	1.23	1.25	1.28	1.30	1.33	1.35	1.38	1.41	1.44	1.47	1.50	1.53	1.56	1.59	1.62	1.65	1.69	1.72	1.76	1.79	1.83	1.86	1.90	1.93	1.97	2.01	2.05	2.09	2.13	2.17	2.21	2.25	2.29	2.33	2.38
12,000	1.12	1.15	1.17	1.20	1.22	1.25	1.27	1.30	1.33	1.36	1.39	1.42	1.44	1.47	1.50	1.54	1.57	1.60	1.63	1.66	1.69	1.73	1.76	1.80	1.83	1.87	1.90	1.94	1.98	2.02	2.06	2.10	2.14	2.18	2.22	2.27	2.31	2.36	2.40	2.45
12,500	1.15	1.17	1.19	1.22	1.25	1.28	1.30	1.33	1.36	1.39	1.41	1.44	1.47	1.51	1.54	1.57	1.60	1.63	1.66	1.70	1.73	1.77	1.80	1.84	1.87	1.91	1.95	1.99	2.03	2.07	2.11	2.15	2.19	2.24	2.28	2.33	2.37	2.42	2.46	2.51
13,000	1.16	1.19	1.22	1.25	1.27	1.30	1.33	1.36	1.38	1.41	1.44	1.47	1.50	1.54	1.57	1.60	1.63	1.67	1.70	1.74	1.77	1.81	1.84	1.88	1.91	1.95	1.99	2.03	2.07	2.11	2.15	2.20	2.24	2.29	2.33	2.38	2.42	2.47	2.51	2.56
13,500	1.18	1.21	1.24	1.27	1.29	1.32	1.35	1.38	1.41	1.44	1.47	1.50	1.53	1.56	1.59	1.63	1.66	1.70	1.73	1.77	1.80	1.84	1.88	1.92	1.96	2.00	2.03	2.08	2.12	2.16	2.20	2.25	2.29	2.34	2.38	2.43	2.48	2.53	2.57	2.62
14,000	1.20	1.23	1.25	1.28	1.31	1.34	1.37	1.40	1.43	1.46	1.49	1.53	1.56	1.59	1.62	1.66	1.69	1.73	1.76	1.80	1.83	1.87	1.91	1.95	1.99	2.03	2.07	2.12	2.16	2.20	2.24	2.29	2.33	2.38	2.43	2.48	2.53	2.58	2.62	2.68
14,500	1.22	1.25	1.27	1.30	1.33	1.36	1.39	1.42	1.45	1.48	1.51	1.55	1.58	1.62	1.65	1.69	1.72	1.76	1.79	1.83	1.86	1.90	1.94	1.98	2.02	2.07	2.11	2.16	2.20	2.24	2.28	2.33	2.38	2.43	2.47	2.52	2.57	2.62	2.67	2.73
15,000	1.23	1.26	1.29	1.32	1.35	1.38	1.41	1.44	1.47	1.50	1.53	1.57	1.60	1.64	1.67	1.71	1.74	1.78	1.82	1.86	1.89	1.93	1.97	2.02	2.06	2.10	2.14	2.19	2.23	2.28	2.32	2.37	2.42	2.47	2.52	2.57	2.62	2.67	2.72	2.78
30,000	1.38	1.42	1.45	1.49	1.52	1.56	1.60	1.64	1.68	1.73	1.77	1.82	1.86	1.91	1.95	2.00	2.05	2.10	2.14	2.20	2.25	2.31	2.36	2.42	2.47	2.54	2.60	2.67	2.73	2.79	2.85	2.92	2.99	3.07	3.14	3.22	3.29	3.37	3.44	3.52

Elev_FT	80.0	80.5	81.0	81.5	82.0	82.5	83.0	83.5	84.0	84.5	85.0	85.5	86.0	86.5	87.0	87.5	88.0	88.5	89.0	89.5	90.0
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
200	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
300	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
400	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
500	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.19
600	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.20	0.21	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
700	0.21	0.21	0.21	0.21	0.21	0.21	0.22	0.23	0.24	0.25	0.25	0.25	0.25	0.25	0.26	0.26	0.26	0.26	0.26	0.26	0.27
800	0.24	0.24	0.24	0.24	0.24	0.24	0.25	0.26	0.27	0.28	0.28	0.29	0.29	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.31
900	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.29	0.30	0.31	0.32	0.32	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.36
1,000	0.29	0.30	0.30	0.30	0.30	0.30	0.31	0.32	0.33	0.34	0.35	0.35	0.36	0.37	0.37	0.38	0.39	0.39	0.40	0.40	0.41
1,100	0.32	0.33	0.33	0.33	0.33	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.40	0.41	0.42	0.43	0.43	0.44	0.45	0.46
1,200	0.35	0.36	0.36	0.36	0.36	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51
1,300	0.38	0.39	0.39	0.39	0.39	0.39	0.40	0.41	0.42	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55
1,400	0.40	0.42	0.42	0.42	0.42	0.42	0.43	0.44	0.45	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.58	0.59
1,500	0.43	0.45	0.45	0.45	0.45	0.45	0.46	0.47	0.48	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.61	0.62
1,600	0.46	0.48	0.48	0.48	0.48	0.48	0.49	0.50	0.51	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.64	0.65
1,700	0.48	0.50	0.51	0.51	0.51	0.51	0.52	0.53	0.54	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.67	0.68
1,800	0.52	0.53	0.54	0.54	0.54	0.54	0.55	0.56	0.57	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.70	0.71
1,900	0.54	0.55	0.57	0.57	0.57	0.57	0.58	0.59	0.60	0.62	0.63	0.64	0.65	0.66	0.66	0.67	0.68	0.69	0.70	0.71	0.71
2,000	0.57	0.58	0.60	0.60	0.60	0.60	0.61	0.62	0.63	0.65	0.66	0.67	0.67	0.68	0.68	0.68	0.69	0.70	0.71	0.72	0.72
2,100	0.60	0.61	0.62	0.63	0.63	0.63	0.64	0.65	0.66	0.68	0.69	0.70	0.70	0.70	0.70	0.71	0.71	0.72	0.72	0.73	0.73
2,200	0.62	0.64	0.65	0.65	0.66	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.73	0.73	0.73	0.74	0.74	0.75	0.75	0.76	0.76
2,300	0.65	0.67	0.67	0.68	0.69	0.69	0.70	0.71	0.72	0.74	0.75	0.76	0.76	0.76	0.76	0.77	0.77	0.78	0.78	0.79	0.79
2,400	0.68	0.69	0.70	0.71	0.71	0.72	0.73	0.74	0.75	0.77	0.78	0.79	0.79	0.79	0.79	0.80	0.80	0.81	0.81	0.82	0.82
2,500	0.70	0.72	0.73	0.73	0.74	0.75	0.76	0.77	0.78	0.80	0.81	0.82	0.82	0.82	0.82	0.83	0.83	0.84	0.84	0.85	0.85
2,600	0.73	0.74	0.75	0.76	0.77	0.78	0.79	0.80	0.81	0.83	0.84	0.85	0.85	0.85	0.85	0.86	0.86	0.87	0.87	0.88	0.88
2,700	0.75	0.76	0.78	0.79	0.80	0.81	0.82	0.83	0.84	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.92	0.94	0.94	0.95	0.96
2,800	0.78	0.79	0.80	0.82	0.83	0.84	0.85	0.86	0.87	0.89	0.90	0.92	0.93	0.94	0.96	0.97	0.98	1.00	1.01	1.02	1.04
2,900	0.80	0.81	0.83	0.84	0.86	0.87	0.88	0.89	0.90	0.92	0.93	0.95	0.97	0.98	1.00	1.01	1.03	1.04	1.06	1.07	1.09
3,000	0.83	0.84	0.85	0.87	0.89	0.90	0.91	0.92	0.93	0.95	0.97	0.98	1.00	1.02	1.03	1.05	1.07	1.08	1.10	1.12	1.13
3,100	0.85	0.86	0.88	0.90	0.91	0.93	0.94	0.95	0.96	0.98	1.00	1.02	1.04	1.05	1.07	1.09	1.11	1.13	1.15	1.16	1.18
3,200	0.88	0.88	0.90	0.92	0.94	0.96	0.97	0.98	0.99	1.01	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23
3,300	0.90	0.91	0.93	0.95	0.97	0.99	1.00	1.01	1.02	1.04	1.06	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.25	1.27
3,400	0.93	0.93	0.95	0.97	1.00	1.02	1.03	1.04	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.25	1.27	1.29
3,500	0.95	0.96	0.98	1.00	1.02	1.04	1.05	1.07	1.08	1.10	1.12	1.14	1.15	1.17	1.19	1.21	1.23	1.24	1.26	1.28	1.30
3,600	0.97	0.98	1.00	1.02	1.04	1.06	1.08	1.10	1.11	1.13	1.15	1.16	1.18	1.20	1.21	1.23	1.25	1.26	1.28	1.29	1.31
3,700	1.00	1.00	1.02	1.05	1.07	1.09	1.11	1.12	1.14	1.16	1.17	1.19	1.20	1.22	1.23	1.25	1.26	1.28	1.29	1.31	1.32
3,800	1.02	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.20	1.21	1.23	1.24	1.25	1.27	1.28	1.30	1.31	1.32	1.34
3,900	1.05	1.05	1.07	1.09	1.12	1.14	1.16	1.18	1.20	1.22	1.23	1.24	1.25	1.26	1.28	1.29	1.30	1.31	1.33	1.34	1.35
4,000	1.07	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.23	1.24	1.25	1.27	1.28	1.29	1.31	1.32	1.33	1.34	1.36	1.37	1.38
4,100	1.09	1.10	1.12	1.14	1.16	1.19	1.21	1.23	1.25	1.27	1.28	1.30	1.31	1.32	1.34	1.35	1.37	1.38	1.40	1.41	1.42
4,200	1.12	1.12	1.14	1.17	1.19	1.21	1.23	1.25	1.27	1.29	1.31	1.32	1.34	1.36	1.37	1.39	1.40	1.42	1.43	1.45	1.47
4,300	1.14	1.15	1.17	1.19	1.21	1.23	1.26	1.28	1.30	1.32	1.33	1.35	1.37	1.39	1.40	1.42	1.44	1.46	1.47	1.49	1.51
4,400	1.16	1.17	1.19	1.21	1.24	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.46	1.47	1.49	1.51	1.53	1.55
4,500	1.18	1.19	1.22	1.24	1.26	1.28	1.30	1.32	1.35	1.37	1.39	1.41	1.43	1.45	1.47	1.49	1.51	1.53	1.55	1.57	1.59
4,600	1.21	1.22	1.24	1.26	1.28	1.31	1.33	1.35	1.37	1.39	1.41	1.44	1.46	1.48	1.50	1.52	1.55	1.57	1.59	1.61	1.63
4,700	1.23	1.24	1.26	1.29	1.31	1.33	1.35	1.37	1.39	1.42	1.44	1.46	1.48	1.50	1.53	1.55	1.57	1.59	1.61	1.64	1.66
4,800	1.25	1.27	1.29	1.31	1.33	1.35	1.38	1.40	1.42	1.44	1.46	1.48	1.51	1.53	1.55	1.57	1.59	1.62	1.64	1.66	1.68
4,900	1.27	1.29	1.31	1.33	1.36	1.38	1.40	1.42	1.44	1.46	1.49	1.51	1.53	1.55	1.57	1.60	1.62	1.64	1.66	1.68	1.71
5,000	1.29	1.31	1.34	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.51	1.53	1.55	1.58	1.60	1.62	1.64	1.66	1.69	1.71	1.73
5,500	1.40	1.43	1.46	1.48	1.50	1.52	1.54	1.56	1.59	1.61	1.64	1.66	1.69	1.71	1.74	1.77	1.79	1.82	1.84	1.87	1.89
6,000	1.50	1.55	1.57	1.59	1.61	1.64	1.66	1.68	1.71	1.74	1.77	1.80	1.83	1.87	1.90	1.93	1.96	1.99	2.03	2.06	2.09
6,500	1.60	1.64	1.66	1.68	1.70	1.73	1.76	1.79	1.82	1.86	1.89	1.92	1.95	1.99	2.02	2.05	2.08	2.12	2.15	2.18	2.22
7,000	1.70	1.73	1.76	1.78	1.81	1.84	1.88	1.91	1.94	1.98	2.01	2.04	2.07	2.11	2.14	2.17	2.20	2.24	2.27	2.30	2.34
7,500	1.79	1.82	1.85	1.88	1.91	1.95	1.98	2.01	2.05	2.08	2.11	2.14	2.18	2.21	2.24	2.28	2.31	2.34	2.37	2.41	2.44
8,000	1.88	1.91	1.94	1.98	2.01	2.04	2.08	2.11	2.14	2.18	2.21	2.24	2.27	2.31	2.34	2.37	2.41	2.44	2.47	2.50	2.54
8,500	1.97	2.00	2.04	2.08	2.12	2.16	2.20	2.23	2.26	2.30	2.33	2.36	2.39	2.43	2.46	2.49	2.53	2.56	2.59	2.62	2.66
9,000	2.05	2.09	2.13	2.17	2.21	2.26	2.29	2.32	2.35	2.39	2.43	2.47	2.51	2.55	2.59	2.63	2.67	2.71	2.75	2.79	2.83
9,500	2.13	2.17	2.22	2.26	2.30	2.35	2.38	2.41	2.44	2.48	2.53	2.57	2.62	2.66	2.70	2.74	2.79	2.83	2.87	2.91	2.96
10,000	2.21	2.25	2.30	2.34	2.39	2.43	2.46	2.50	2.53	2.57	2.62	2.66	2.71	2.75	2.79	2.83	2.88	2.92	2.96	3.01	3.05
10,500	2.28	2.32	2.36	2.40	2.45	2.49	2.53	2.58	2.62	2.66	2.71	2.75	2.80	2.84	2.88	2.93	2.97	3.01	3.06	3.10	3.15
11,000	2.35	2.40	2.45	2.49	2.54	2.58	2.62	2.67	2.71	2.75	2.80	2.84	2.89	2.93	2.97	3.02	3.06	3.10	3.15	3.19	3.24
11,500	2.42	2.47	2.52	2.56	2.60	2.65	2.70	2.75	2.80	2.84	2.89	2.93	2.98	3.02	3.06	3.11	3.15	3.20	3.24	3.29	3.33
12,000	2.49	2.53	2.58	2.62	2.66	2.71	2.77	2.82	2.87	2.92	2.97	3.02	3.07	3.11	3.16	3.21	3.26	3.30	3.35	3.40	3.45
12,500	2.55	2.59	2.64	2.68	2.73	2.77	2.83	2.88	2.94	2.99	3.05	3.10	3.16	3.21	3.26	3.32	3.37	3.43	3.48	3.54	3.59
13,000	2.61	2.65	2.70	2.76	2.81	2.86	2.92	2.97	3.03	3.08	3.14	3.19	3.25	3.30	3.35	3.41	3.46	3.52	3.57	3.63	3.68
13,500	2.67	2.71	2.77	2.82	2.88	2.93	2.98	3.04	3.09	3.15	3.20	3.26	3.31	3.37	3.42	3.48	3.53	3.59	3.64	3.70	3.75
14,000	2.73	2.77	2.83	2.88	2.94	2.99	3.04	3.10	3.15	3.21	3.26	3.32	3.37	3.43	3.48	3.54	3.59	3.65	3.70	3.76	3.81
14,500	2.78	2.83	2.89	2.94	3.00	3.05	3.10	3.16	3.21	3.27	3.33	3.38	3.44	3.49	3.55	3.60	3.66	3.72	3.77	3.83	3.88
15,000	2.83	2.89	2.95	3.00	3.06	3.11	3.16	3.22	3.27	3.33	3.40	3.46	3.53	3.59	3.65	3.72	3.78	3.84	3.91	3.97	4.03
30,000	3.60	3.68	3.77	3.86	3.95	4.03	4.12	4.21	4.30	4.39	4.48	4.58	4.67	4.77	4.86	4.96	5.05	5.15	5.24	5.34	5.43

Appendix K
AEP Method Presentation

North Carolina Precipitation Frequency Analysis

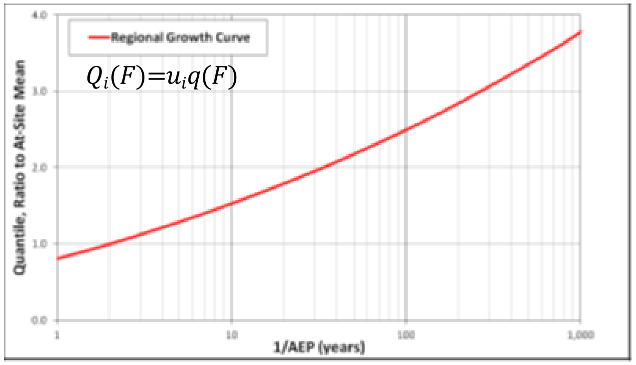
Applied Weather Associates (AWA)

Doug Hultstrand, PhD
Bill Kappel
Jake Rodel

March 2025

1

Regional L-moments



- Regional L-moments
  - Annual maximum series (AMS) extraction
    - AMS s easonality
  - Homogeneous Regions
    - Trade space for time
  - Identification of Regional Probability distribution
    - Goodness-of-fit
  - Spatial mapping of at-site mean annual maximum (MAM)
  - Derivation of Uncertainty bounds
  - Develop Areal Reduction Factors (ARF)
  - Estimate Annual Exceedance Probabilities (AEP)

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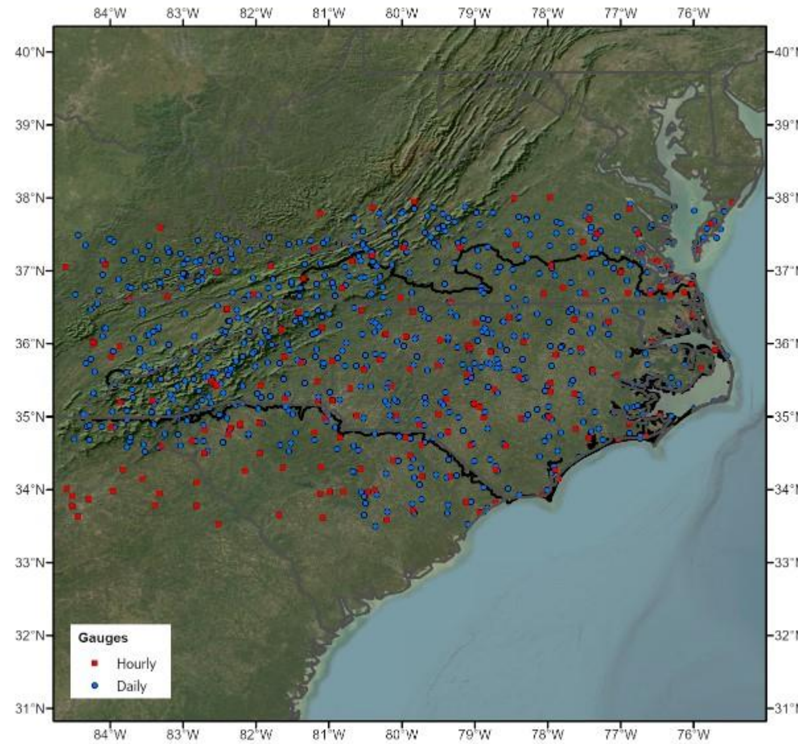
Regional L-moments

- AMS and Homogenous regions
  - Extract 6hr and 24hr AMS
  - Identify homogenous region
    - In this context, homogeneous is taken to mean that probability distributions and their resultant frequency curves for at-site data are identical, except for a site-specific scaling factor, at all sites in a region.
  - 6hr – 184 stations
    - Region 1: 184 stations ~ 3,765 yrs
      - Mean of 20 years
      - Max of 75 years
    - Fixed time adjustment of 1.01
  - 24hr – 630 stations
    - Region 1: 630 stations ~ 36,878 yrs
      - Mean of 59 years
      - Max of 140 years
    - Fixed time adjustment of 1.13



***** NOAA Atlas 14: 51 hourly and 196 daily stations**

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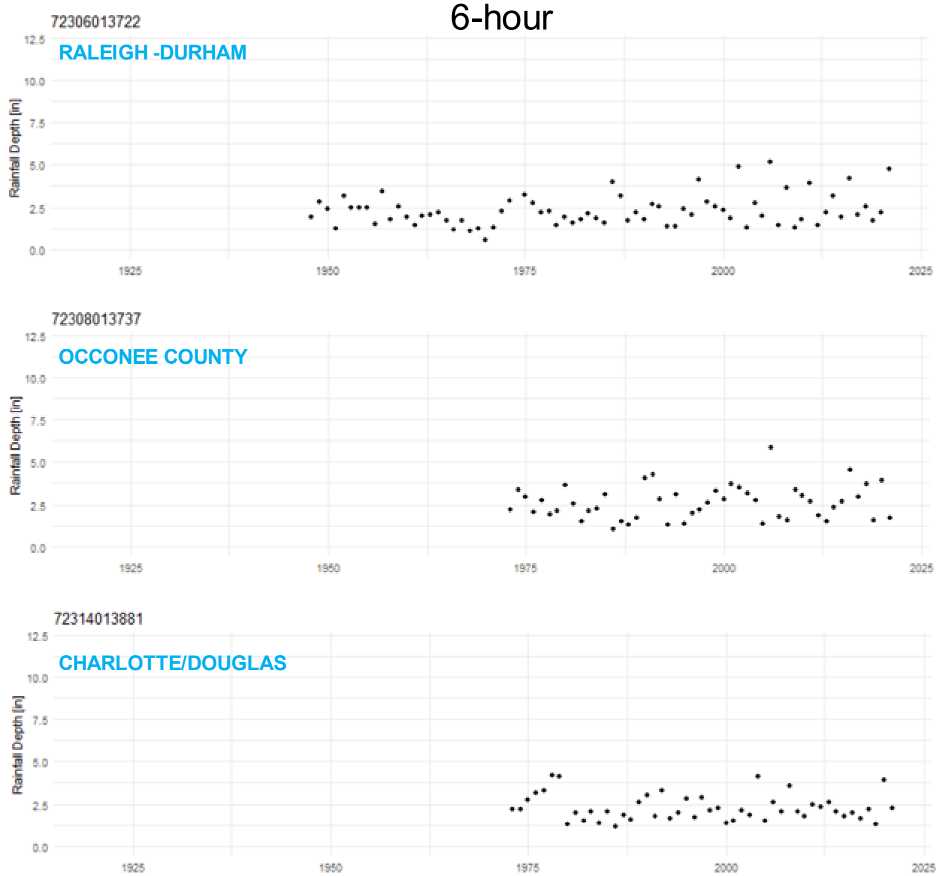
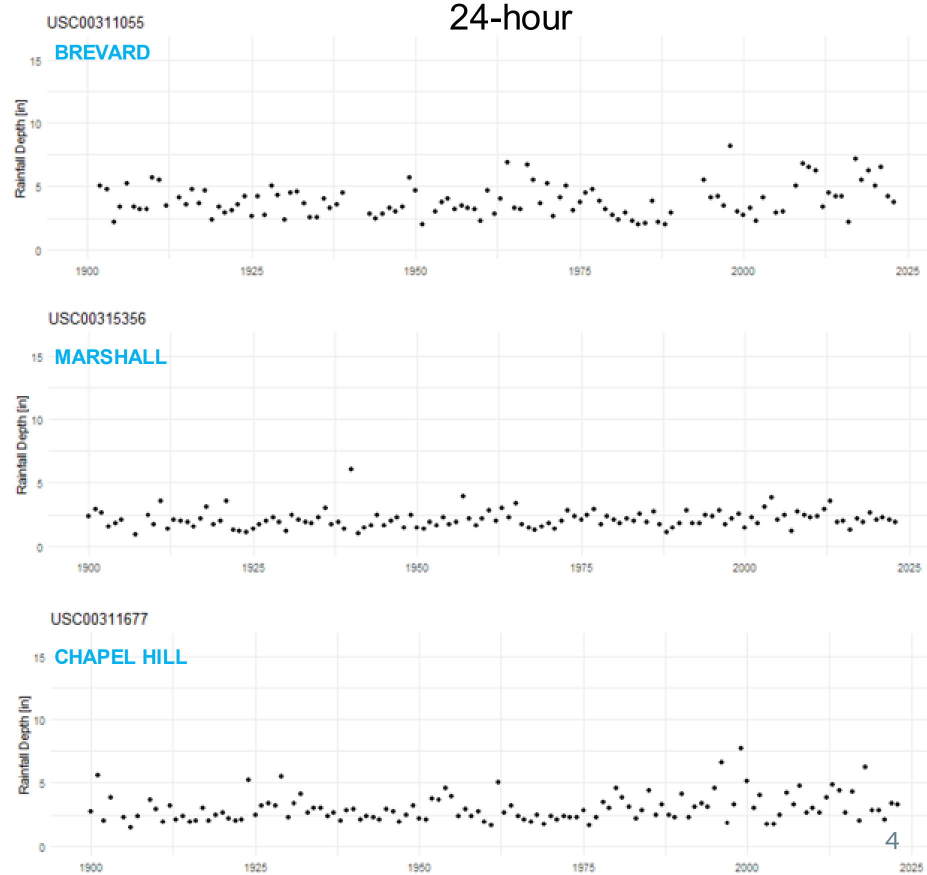
Example Annual Maximum Series

6-hour



24-hour

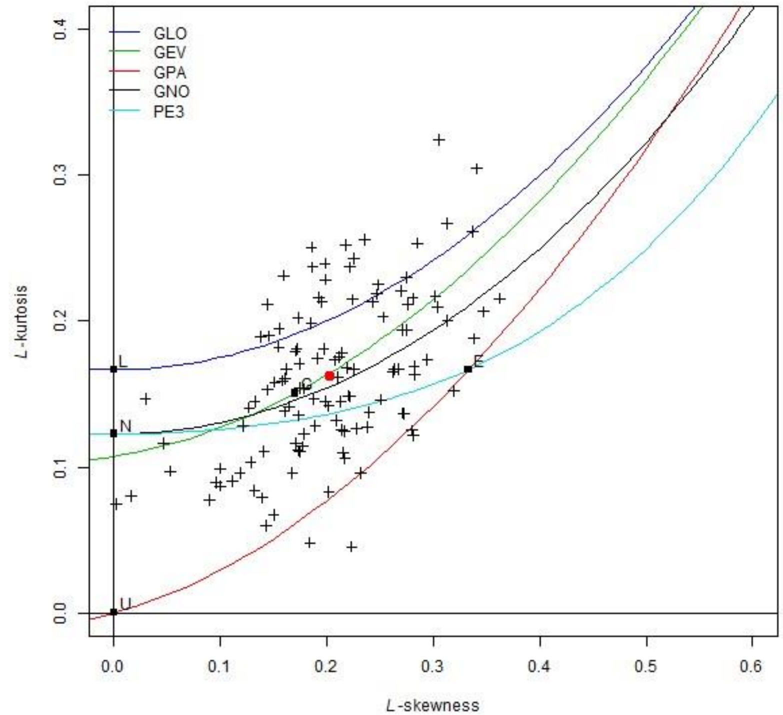


4

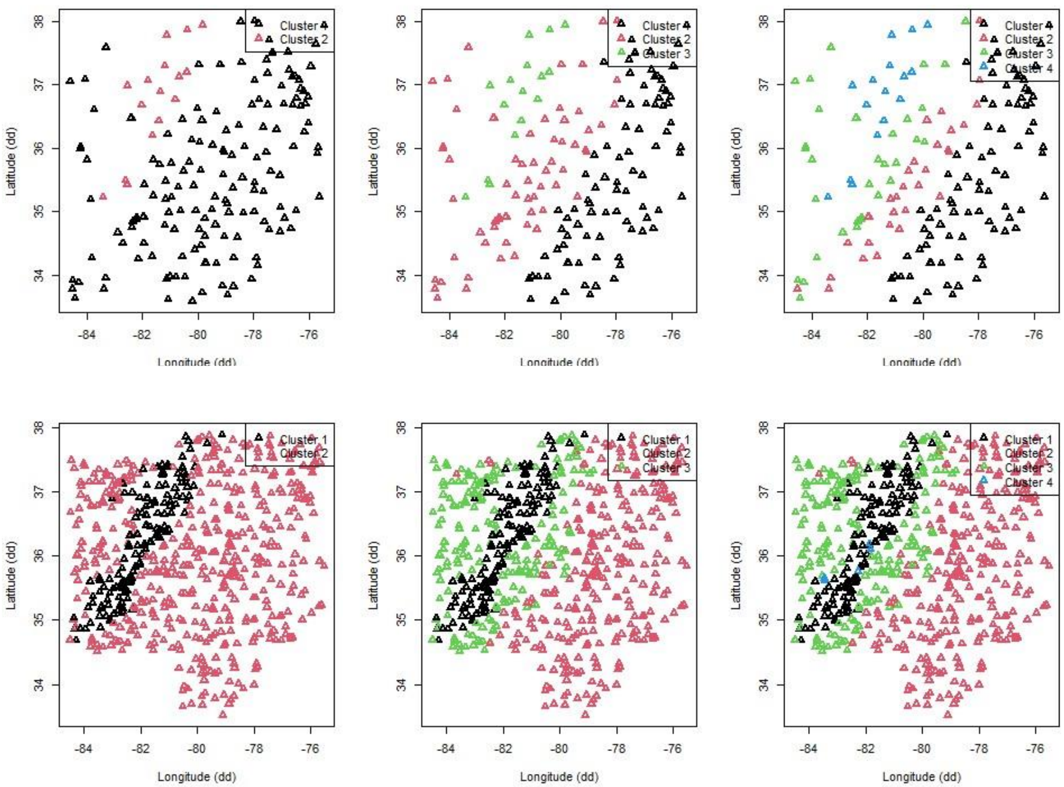
Regional L-moments

- Goodness of fit - Uncertainty
  - Identification of Regional Probability Distribution
  - Goodness-of-fit measures (Hosking and Wallis, 1997) (H1, H2, and D)
  - L-moment Ratio Diagram
    - The regional weighted average L-Skewness ad L-Kurtosis tend to be near the GEV distribution
  - Derivation of Uncertainty bounds
    - Monte-carlo simulation

```
*****  HETEROGENEITY MEASURES  *****
Number of simulations = 1000

Observed     s.d. of group L-CV              =  0.0205
Sim. mean of s.d. of group L-CV              =  0.0198
Sim. s.d. of s.d. of group L-CV              =  0.0016
Heterogeneity measure H[1]                   =  0.44

Observed     s.d. of L-CV / L-skew distance  =  0.0515
Sim. mean of s.d. of L-CV / L-skew distance  =  0.0529
Sim. s.d. of s.d. of L-CV / L-skew distance  =  0.0041
Heterogeneity measure H[2]                   = -0.35

Observed     s.d. of L-skew/L-kurt distance  =  0.0682
Sim. mean of s.d. of L-skew/L-kurt distance  =  0.0671
Sim. s.d. of s.d. of L-skew/L-kurt distance  =  0.0046
Heterogeneity measure H[3]                   =  0.22

*****  GOODNESS-OF-FIT MEASURES  *****
Number of simulations = 1000

Gen. logistic        L-kurtosis =  0.2021    Z value =   7.51
Gen. extreme value   L-kurtosis =  0.1657    Z value =   1.15 *
Gen. normal          L-kurtosis =  0.1561    Z value =  -0.53 *
Pearson type III     L-kurtosis =  0.1368    Z value =  -3.91
Gen. Pareto          L-kurtosis =  0.0805    Z value = -13.74
```



Regional L-moments – Cluster Analysis



Duration	H1	H2	Distribution
6-hour			
Region 1	2.12	2.93	GEV
Region 2	3.05	3.16	GEV, GNO
Region 3	3.06	3.21	GEV,GNO, PE3
24-hour			
Region 1	2.75	0.59	GEV, GNO
Region 2	1.52	1.61	GEV, GNO, PE3
Region 3	2.94	0.08	GEV, GNO

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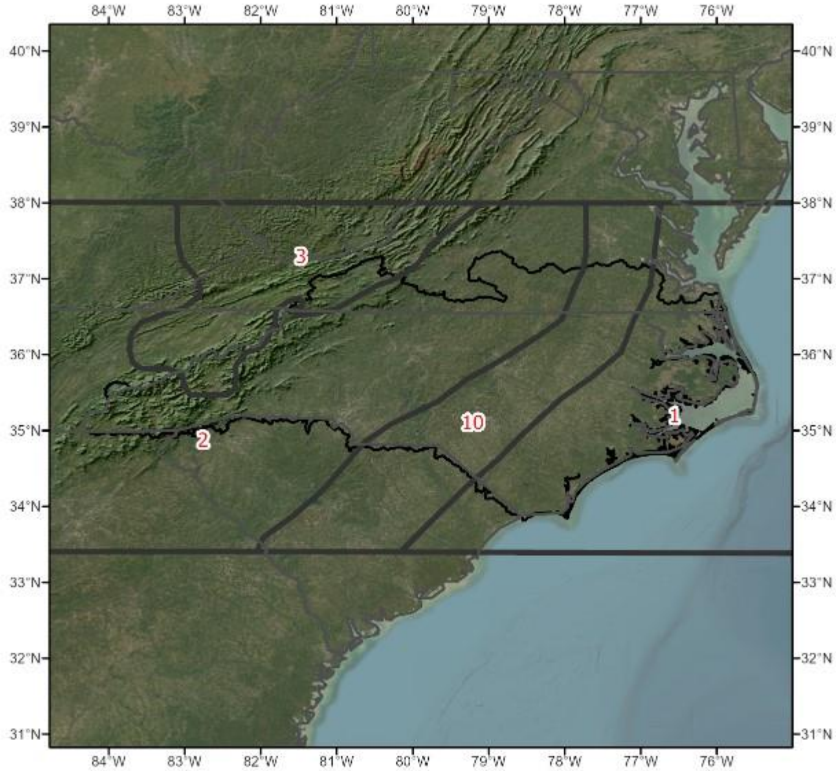
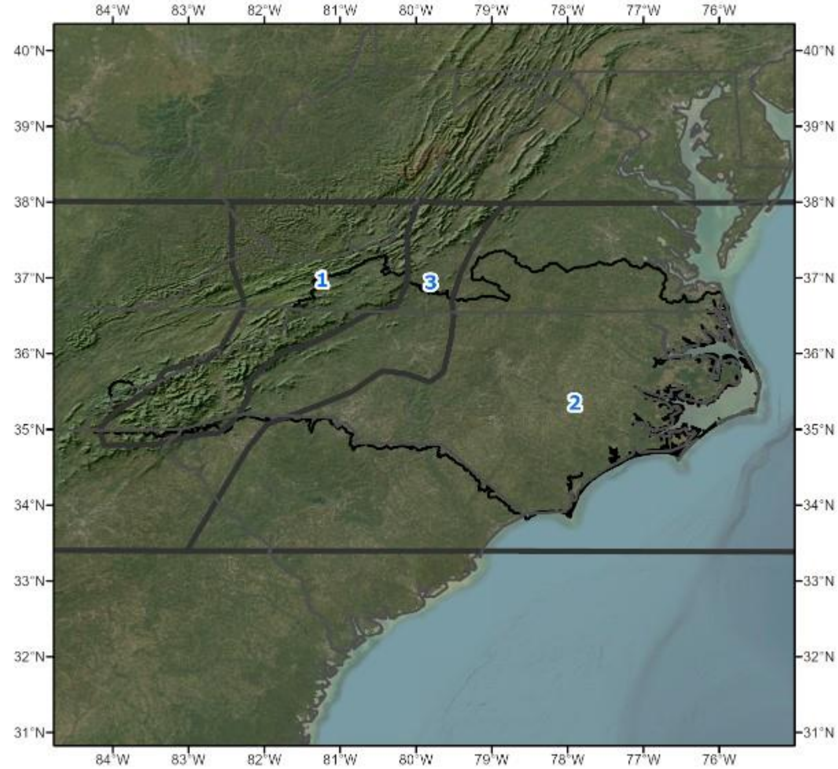
Regional L-moments – Cluster Analysis (Lcv; Lsk)

- 6-hour



- 24-hour



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Regional L-moments – Spatail Mapping

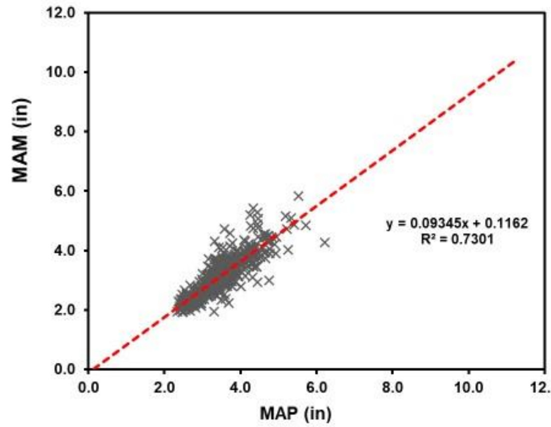
- Spatial Mapping of At-Site Scaling Factor
  - at-site mean or mean annual maximum (MAM) L -moment statistics were spatially mapped
  - explanatory variables and associated predictor equations are used to map at-site MAM using continuous gridded variables

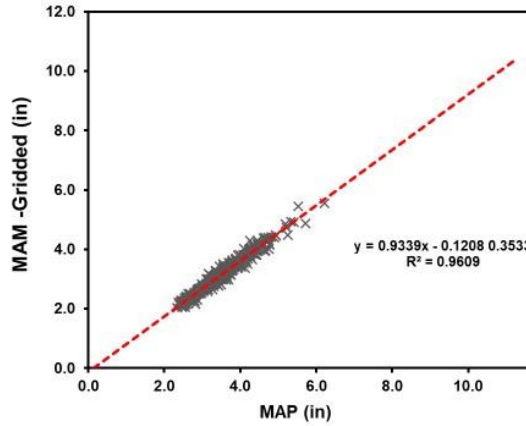
Spatial mapping of at-site MAM involved a three -step process:

1) Determine a predictor equation that describes the regional behavior of the at-site means across the study area.

2) Compute a best-estimate of the at-site mean at a given station using a weighted average of the regionally-predicted at-site mean (step 1 above) and the sample at-site MAM.

3) Adjust the resulting at-site means to account for spatial coherence of the error residuals (observed-predicted values) in a given locality

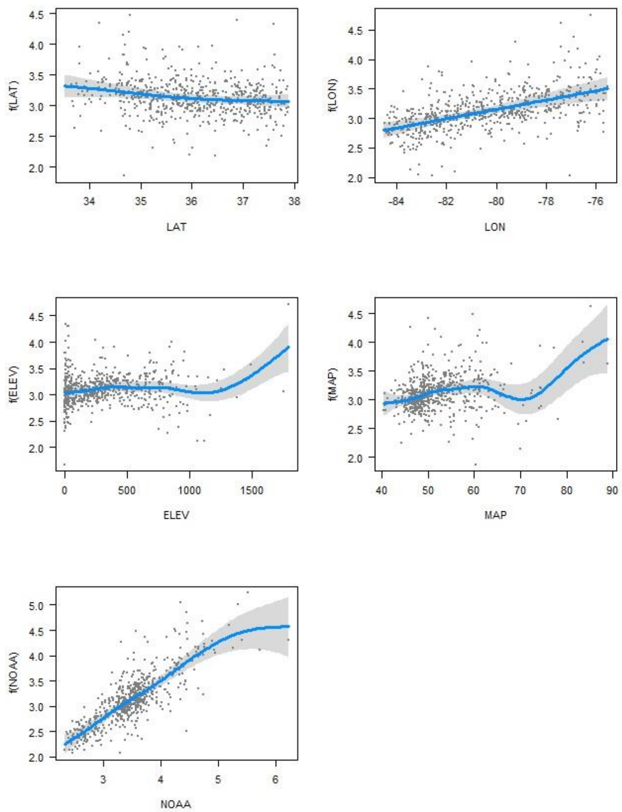




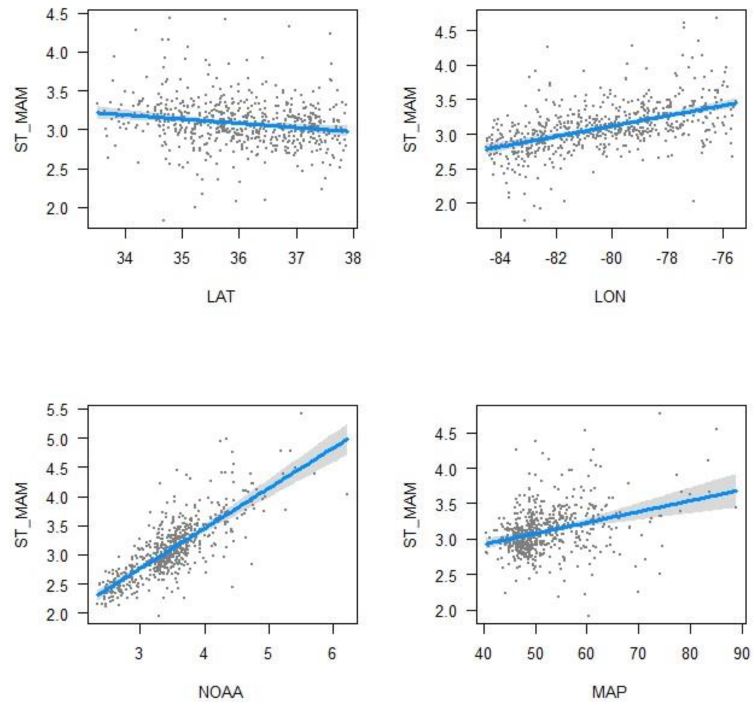
8

Regional L-moments – Spatial Mapping

- Generalized Additive Models (GAM)

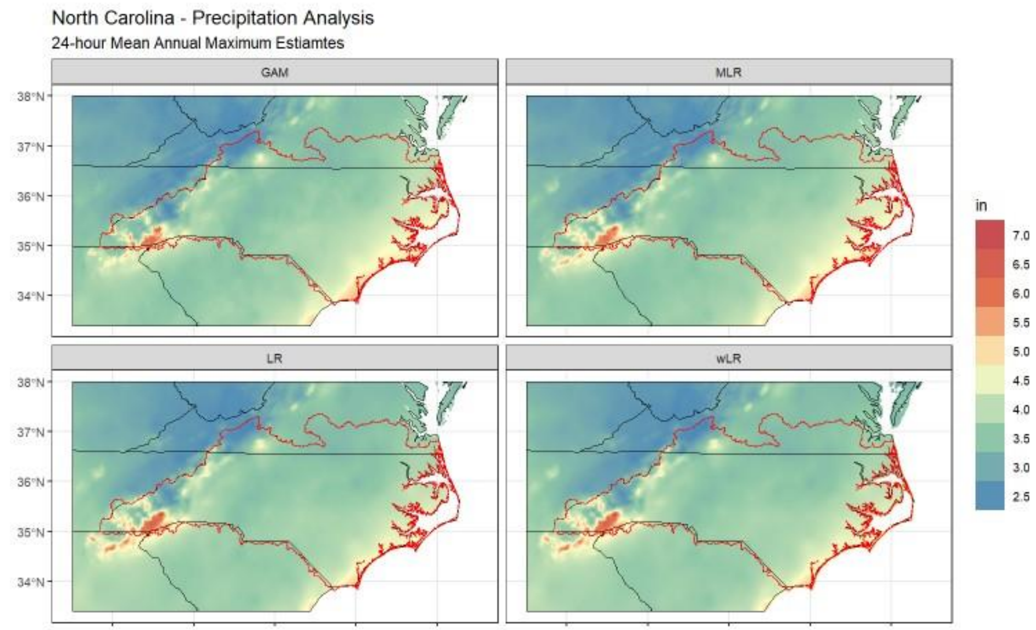


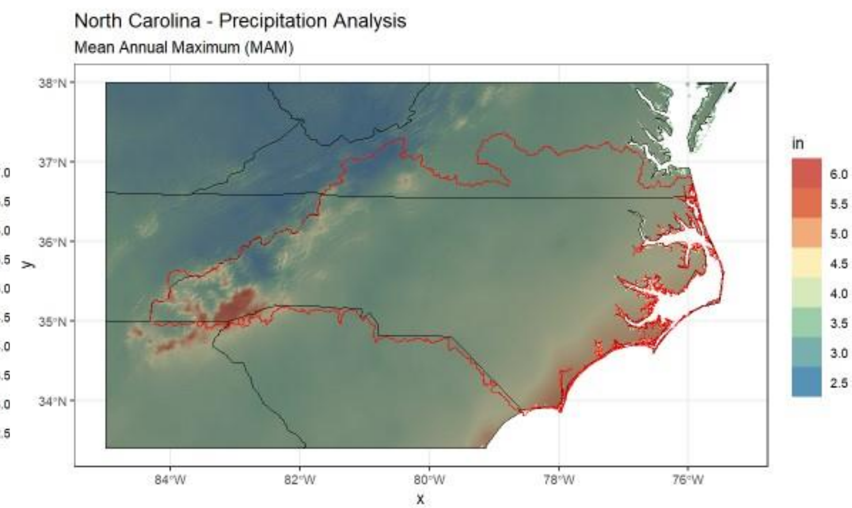
- Multiple Linear Regression (MLR)



Regional L-moments – Spatial Mapping

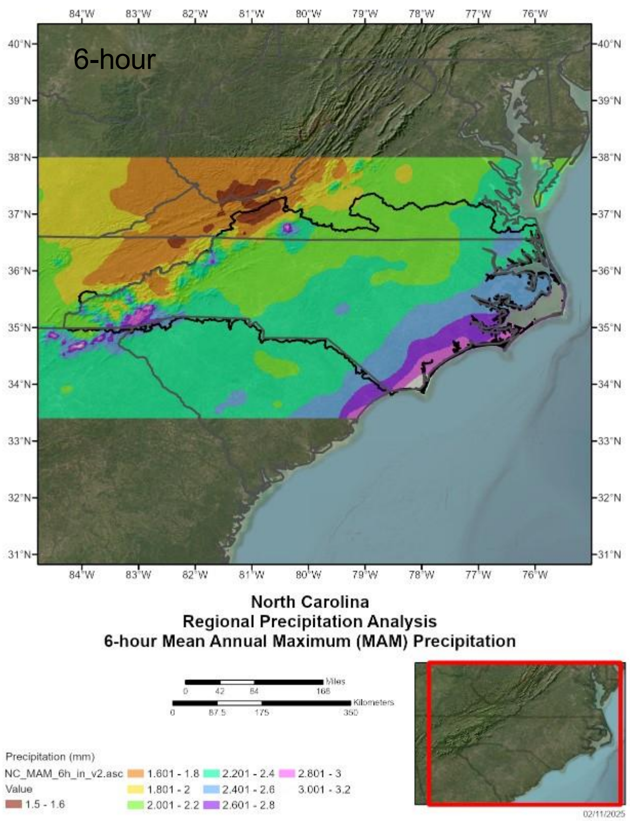
- Generalized Additive Models (GAM)
- Multiple Linear Regression (MLR)
- Linear Regression (LR)
- weighted Linear Regression (wLR)

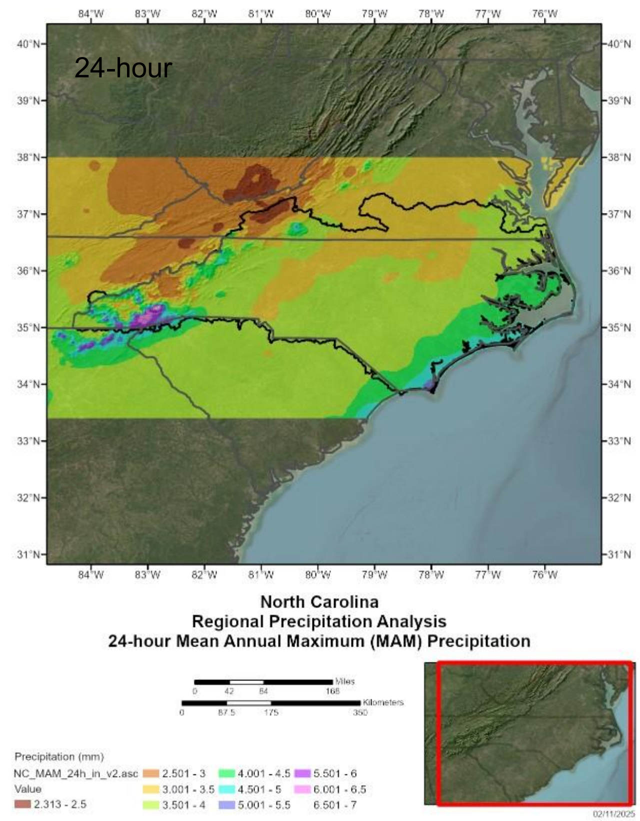




Regional L-moments - (MAM)

- Final At-Site Scaling Factor, MAM





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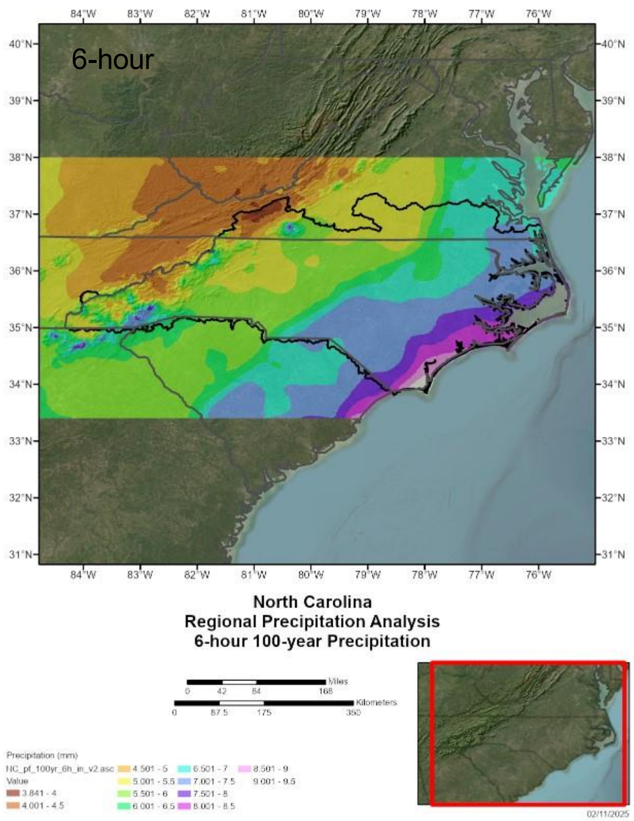
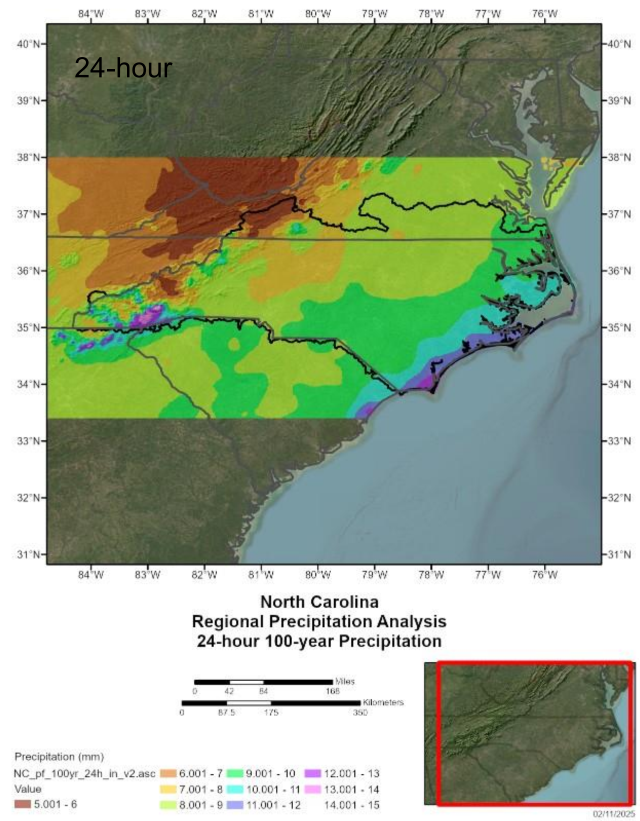
Regional L-moments - (100-year **Point Values**)

- Quantile estimates at-site are estimated by: $Q_i(F) = u_i q(F)$





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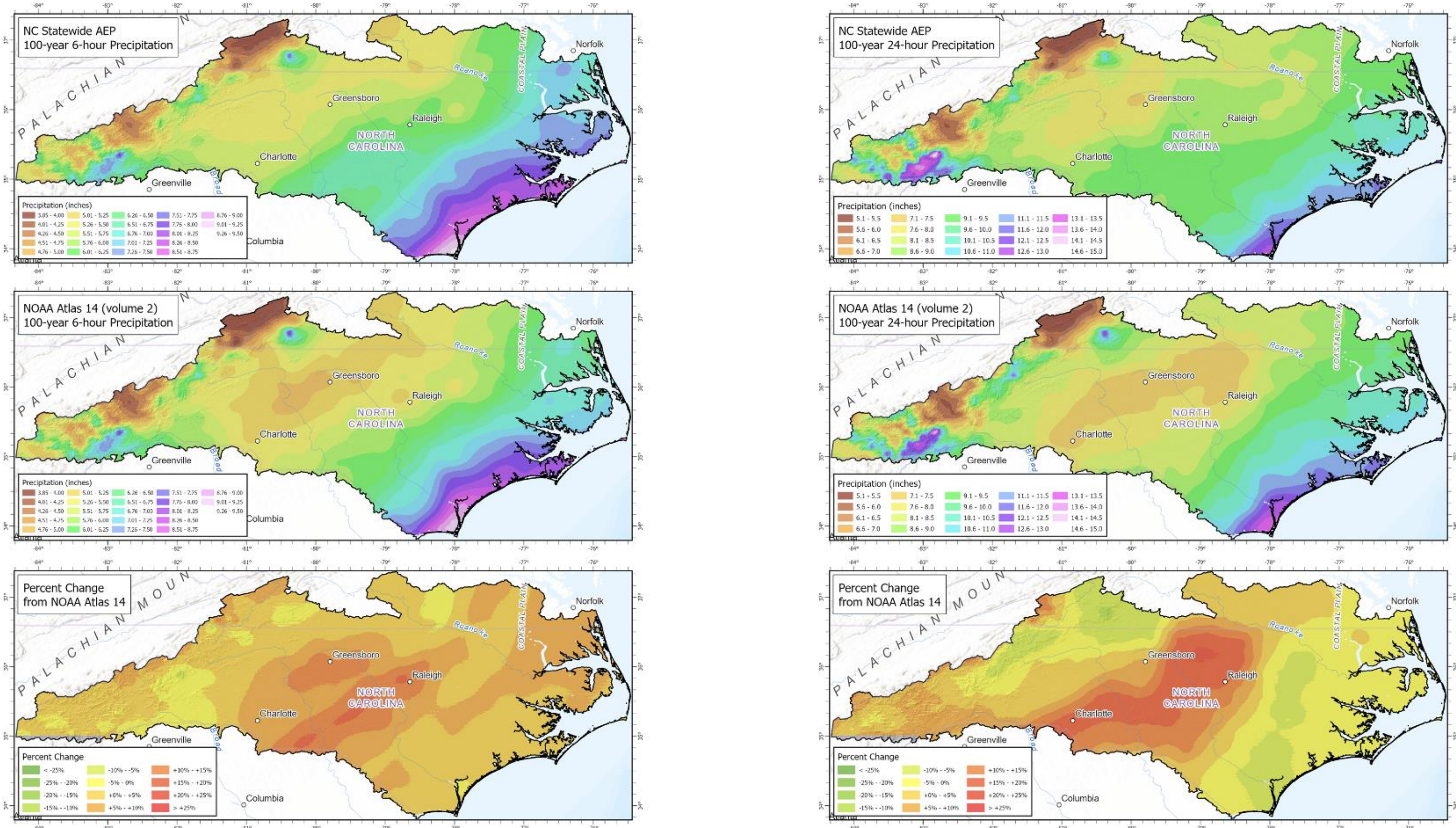
Comparisons Against NOAA Atlas 14



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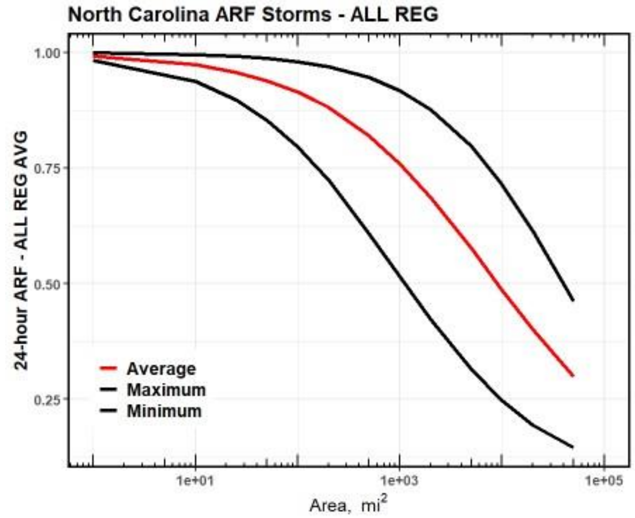
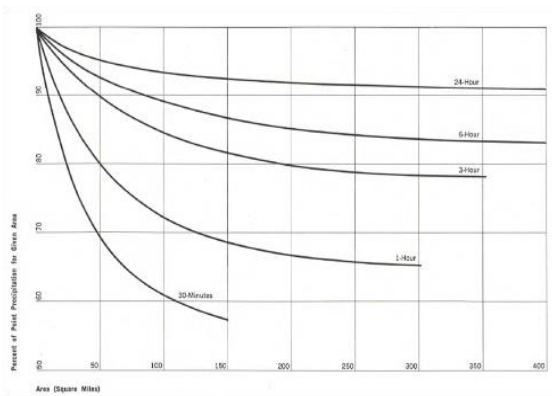
Areal Reduction Factor (ARF)

NOAA defines an ARF as the ratio between area - averaged rainfall to the maximum depth at the storm center

The most common sources for generalized ARFs and depth-area curves in the United States are from the NOAA Atlas 2 and the U.S. Weather Bureau's Technical Paper 29





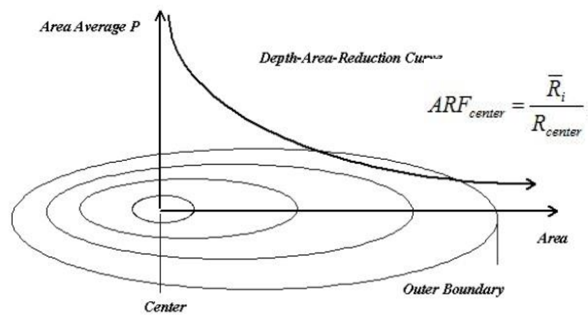


Figure 1 Illustration of Decay of Rainfall Depth from the Storm Center.

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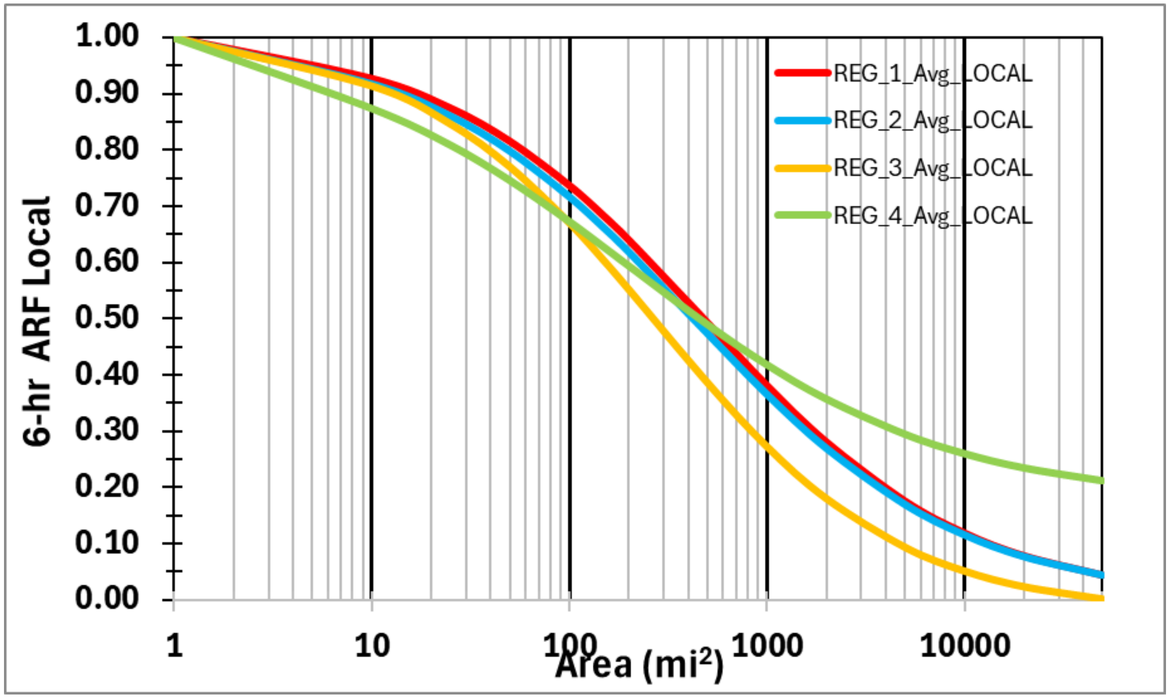
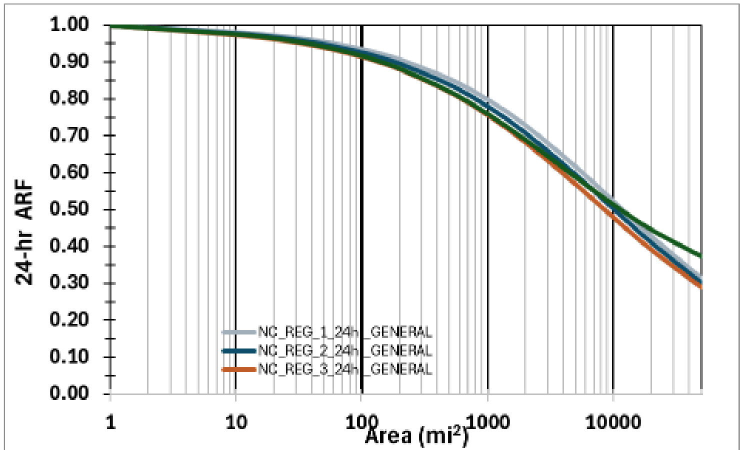
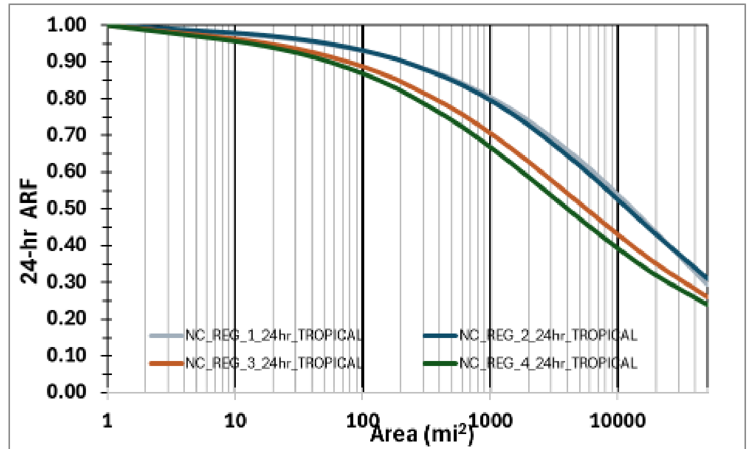
Areal Reduction Factor (ARF)

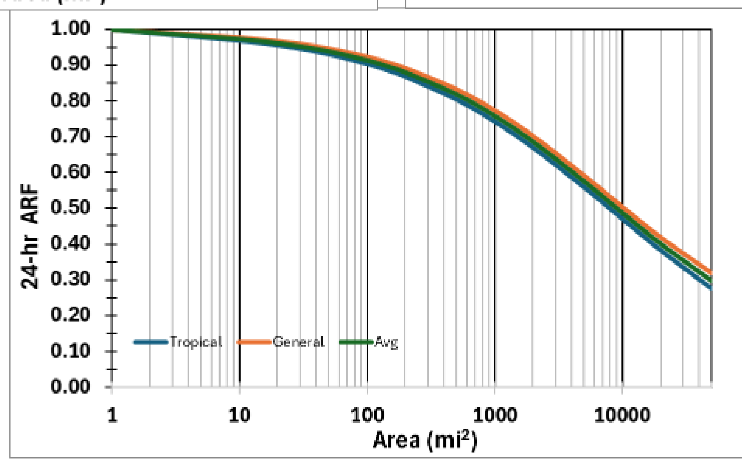
6-hour Local Storms



Areal Reduction Factor (ARF)







24-hour Tropical and General Storms

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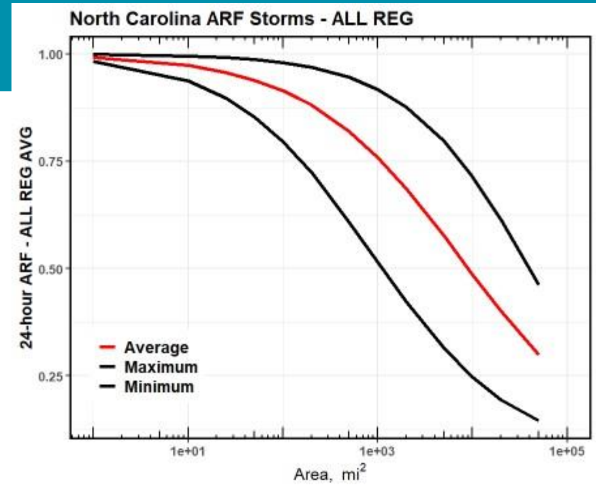
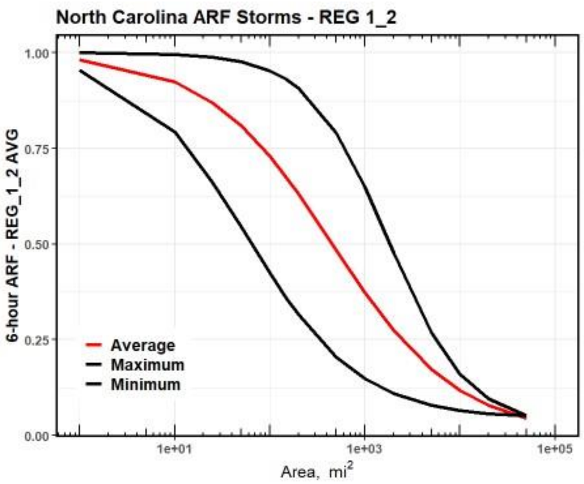
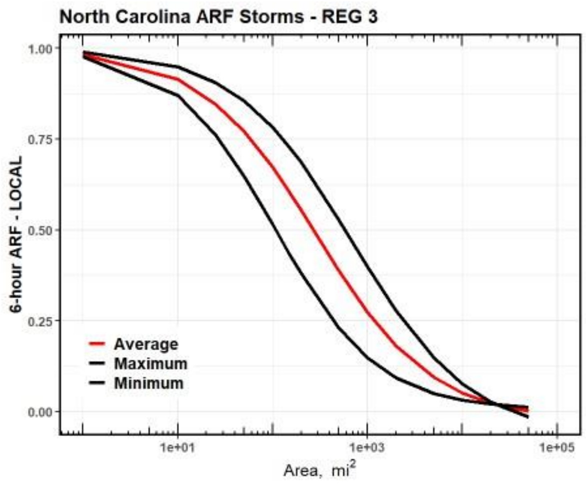
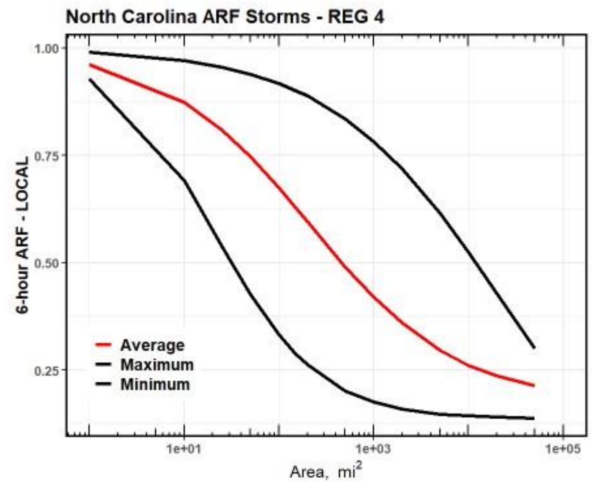
Areal Reduction Factor (ARF)

Test Basin	Transposition Zone	Area (sqmi)	6hr Storm ARF	24hr Storm ARF
CUMBE_052_ArranLakesWestDam	Zone 1	2.4	0.969	0.987
WAYNE_013_Bass_Lake_Dam	Zone 1	5.0	0.950	0.981
CABAR_002_Lake_Fisher_Dam	Zone 2	18.9	0.889	0.963
PERSO_013_Roxboro_Afterbay_Dam	Zone 2	203.1	0.628	0.880
RUTHE_003_Lake_Lure	Zone 3	94.4	0.681	0.917
BUNCO_088_Lake_Julian_DA	Zone 4	4.8	0.912	0.982
MACON024_WataugaVistaDam	Zone 4	0.6	0.971	0.994



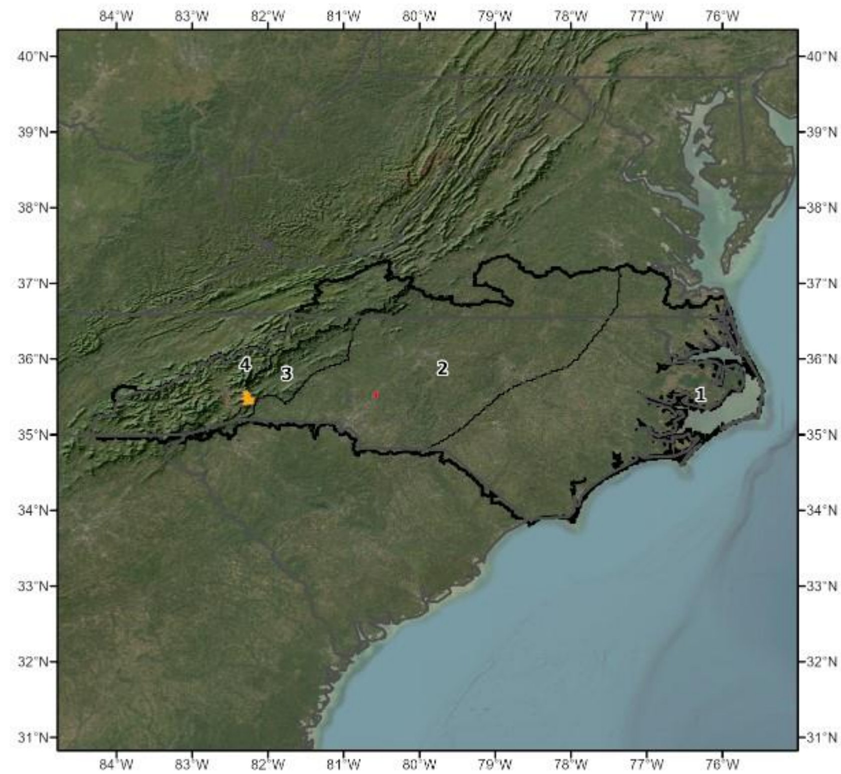






AEP Test Basins

Test Basin	Transposition Zone	Area (sqmi)	6hr Storm ARF	24hr Storm ARF
CUMBE_052_ArranLakesWestDam	Zone 1	2.4	0.969	0.987
WAYNE_013_Bass_Lake_Dam	Zone 1	5.0	0.950	0.981
CABAR_002_Lake_Fisher_Dam	Zone 2	18.9	0.889	0.963
PERSO_013_Roxboro_Afterbay_Dam	Zone 2	203.1	0.628	0.880
RUTHE_003_Lake_Lure	Zone 3	94.4	0.681	0.917
BUNCO_088_Lake_Julian_DA	Zone 4	4.8	0.912	0.982
MACON024_WataugaVistaDam	Zone 4	0.6	0.971	0.994



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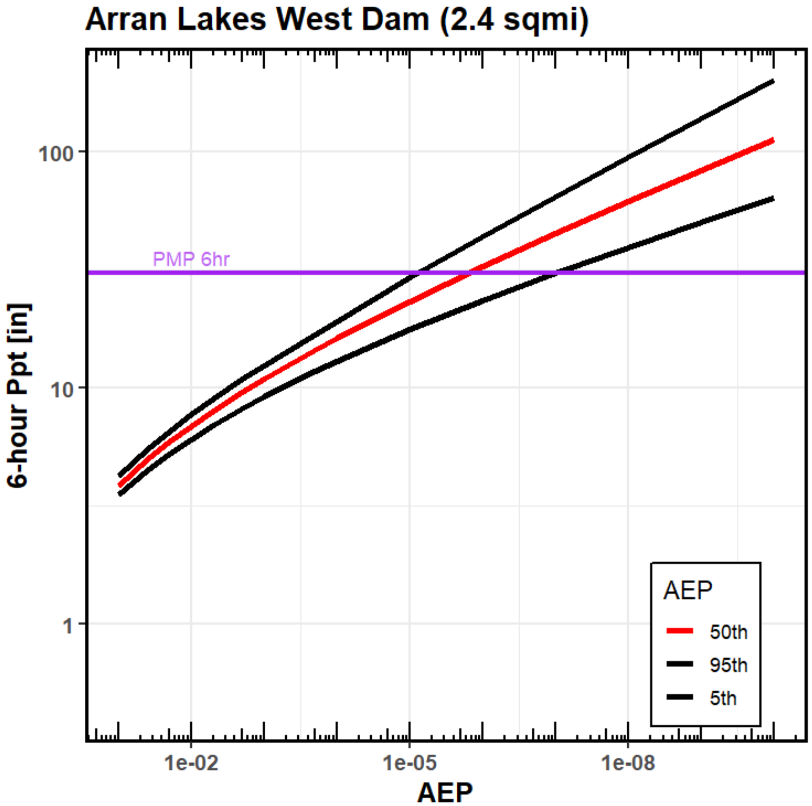
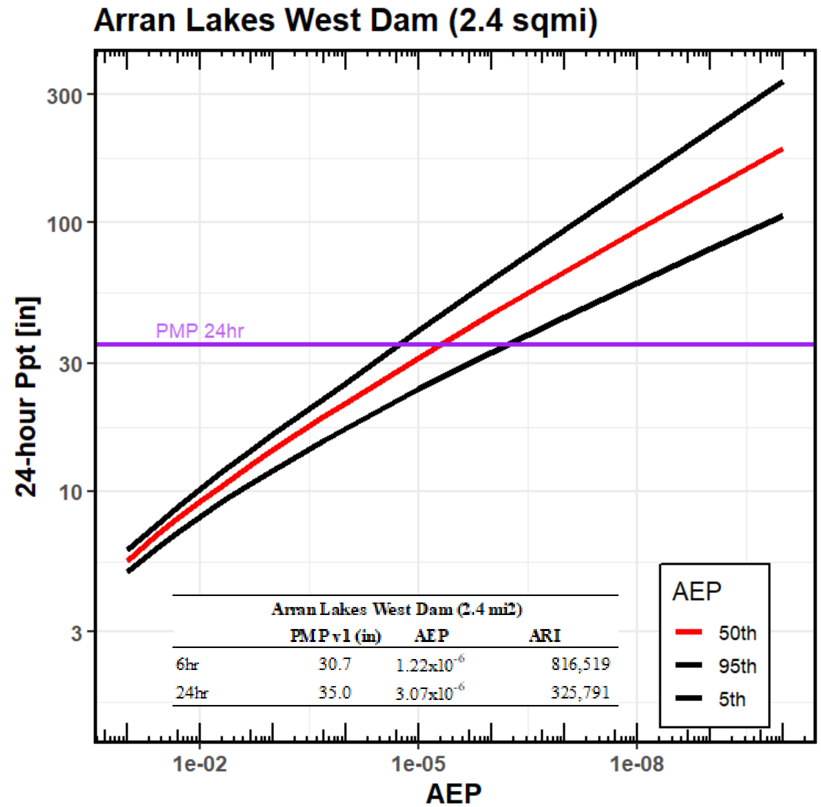
Arran Lakes West Dam AEP Figures





Arran Lakes West Dam (2.4 mi2)			
	PMP v1 (in)	AEP	ARI
6hr	30.7	1.22×10^{-6}	816,519
24hr	35.0	3.07×10^{-6}	325,791

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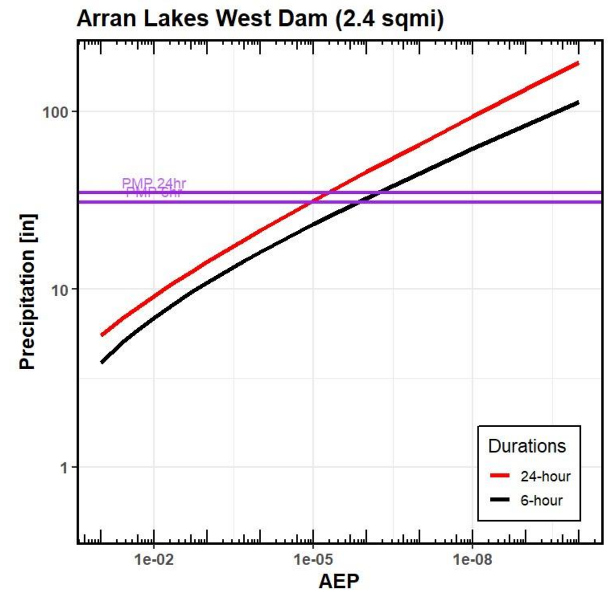
Arran Lakes West Dam AEP Table

Arran Lakes West Dam (2.4 mi^2)		6-hour			24-hour		
ARI	AEP	50%	5%	95%	50%	5%	95%
1	9.9^{-1}	***0.5***	0.4	0.6	***1.7***	1.5	1.9
2	5.0^{-1}	***2.0***	1.8	2.2	***3.4***	3.0	3.7
5	2.0^{-1}	***3.1***	2.8	3.4	***4.6***	4.2	5.1
10	1.0^{-1}	***3.9***	3.5	4.3	***5.5***	5.0	6.1
25	4.0^{-2}	***5.0***	4.5	5.5	***6.8***	6.1	7.5
50	2.0^{-2}	***5.9***	5.3	6.5	***7.9***	7.0	8.8
100	1.0^{-2}	***6.9***	6.1	7.7	***9.2***	8.1	10.2
200	5.0^{-3}	***8.0***	6.9	9.0	***10.5***	9.1	11.8
500	2.0^{-3}	***9.6***	8.2	10.9	***12.5***	10.7	14.2
1,000	1.0^{-3}	***10.9***	9.2	12.5	***14.2***	12.0	16.3
5,000	2.0^{-4}	***14.4***	11.8	16.8	***19.0***	15.5	22.1
10,000	1.0^{-4}	***16.2***	13.0	19.2	***21.4***	17.2	25.3
100,000	1.0^{-5}	***23.2***	17.7	29.3	***31.4***	24.0	39.6
1,000,000	1.0^{-6}	***32.6***	23.5	43.8	***45.6***	32.9	61.2
10,000,000	1.0^{-7}	***45.0***	30.7	64.6	***65.5***	44.6	93.9
100,000,000	1.0^{-8}	***61.6***	39.4	94.8	***93.5***	59.9	143.9
1,000,000,000	1.0^{-9}	***83.6***	50.2	138.6	***133.0***	79.8	220.3
10,000,000,000	1.0^{-10}	***112.9***	63.5	201.7	***188.5***	106.0	336.7

Arran Lakes West Dam (2.4 mi2)			
	PMP v1 (in)	AEP	ARI
6hr	30.7	1.22×10^{-6}	816,519
24hr	35.0	3.07×10^{-6}	325,791



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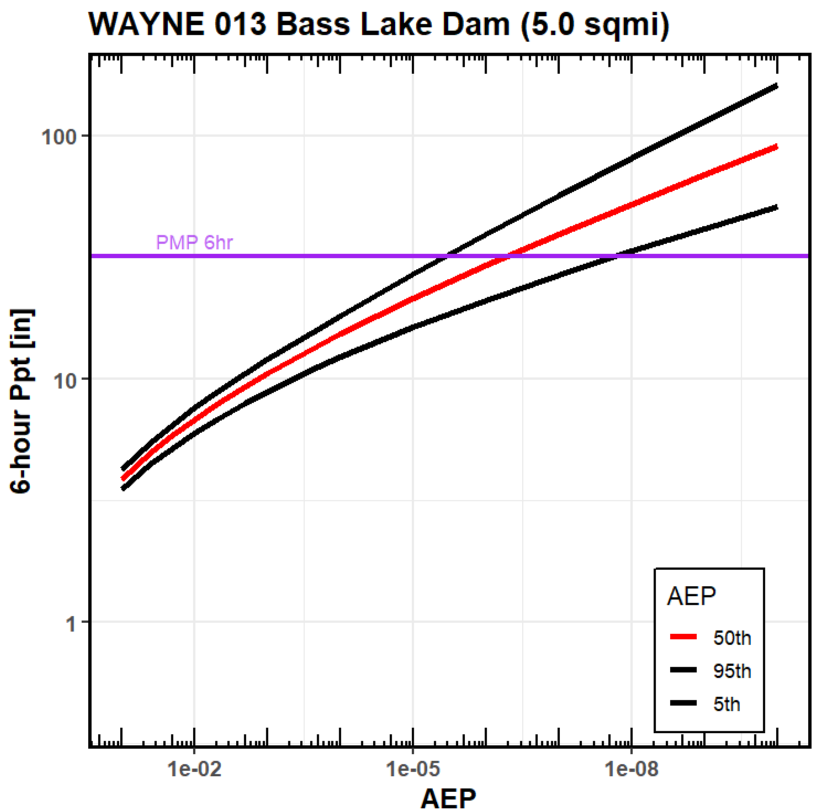
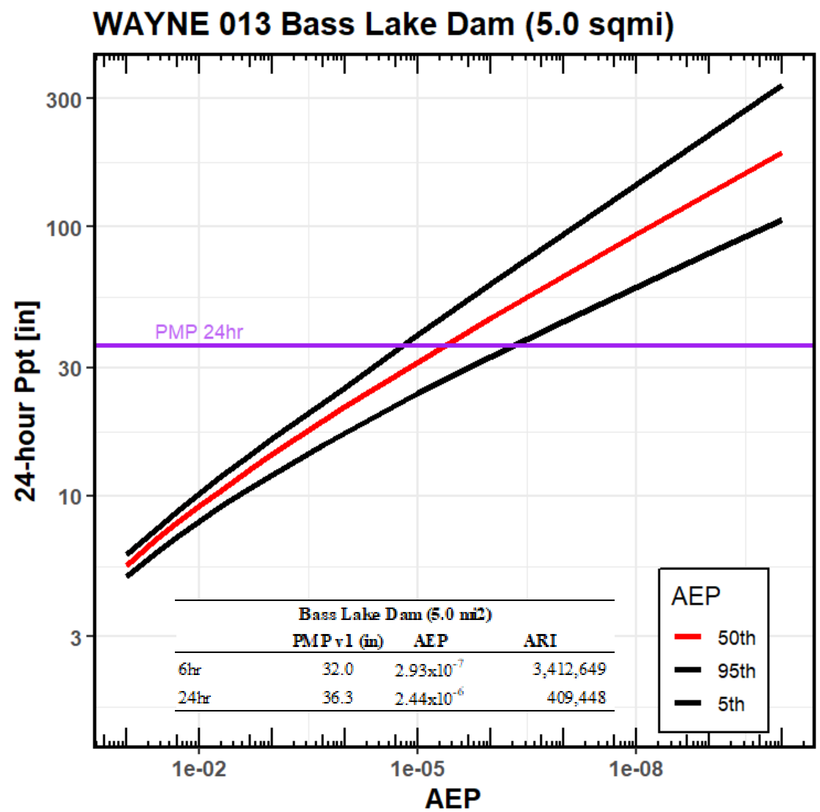
Bass Lake Dam AEP Figures



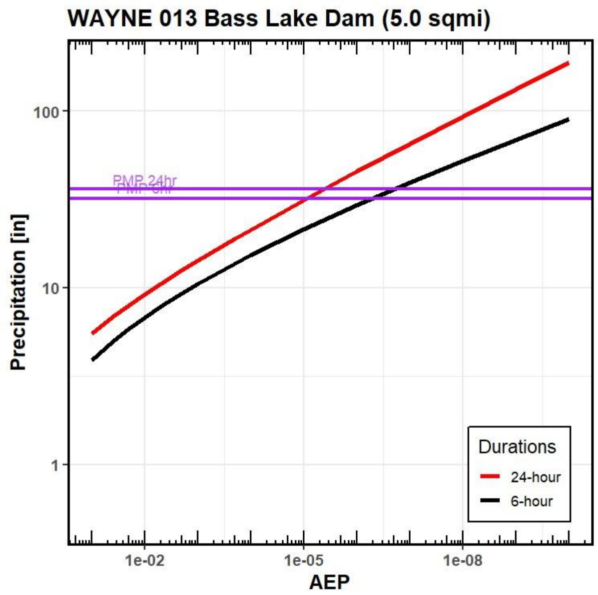


Bass Lake Dam (5.0 mi2)			
	PMP v1 (in)	AEP	ARI
6hr	32.0	2.93×10^{-7}	3,412,649
24hr	36.3	2.44×10^{-6}	409,448

Bass Lake Dam AEP Table

Bass Lake Dam (5.0 mi^2)		6-hour			24-hour		
ARI	AEP	50%	5%	95%	50%	5%	95%
1	9.9^{-1}	***0.5***	0.4	0.5	***1.7***	1.5	1.9
2	5.0^{-1}	***2.0***	1.8	2.2	***3.4***	3.0	3.7
5	2.0^{-1}	***3.1***	2.8	3.4	***4.6***	4.2	5.1
10	1.0^{-1}	***3.9***	3.5	4.3	***5.5***	5.0	6.1
25	4.0^{-2}	***5.0***	4.5	5.4	***6.8***	6.1	7.5
50	2.0^{-2}	***5.9***	5.2	6.5	***7.9***	7.1	8.8
100	1.0^{-2}	***6.8***	6.0	7.6	***9.2***	8.1	10.2
200	5.0^{-3}	***7.8***	6.8	8.8	***10.5***	9.1	11.8
500	2.0^{-3}	***9.3***	8.0	10.6	***12.5***	10.7	14.2
1,000	1.0^{-3}	***10.5***	8.9	12.1	***14.2***	12.0	16.3
5,000	2.0^{-4}	***13.7***	11.2	16.0	***19.0***	15.5	22.1
10,000	1.0^{-4}	***15.3***	12.3	18.1	***21.4***	17.2	25.3
100,000	1.0^{-5}	***21.4***	16.4	27.0	***31.4***	24.0	39.6
1,000,000	1.0^{-6}	***29.3***	21.2	39.4	***45.6***	32.9	61.3
10,000,000	1.0^{-7}	***39.4***	26.8	56.5	***65.5***	44.6	93.9
100,000,000	1.0^{-8}	***52.4***	33.6	80.7	***93.5***	59.9	144.0
1,000,000,000	1.0^{-9}	***69.2***	41.5	114.6	***133.0***	79.9	220.4
10,000,000,000	1.0^{-10}	***90.6***	51.0	161.9	***188.6***	106.1	336.8

Bass Lake Dam (5.0 mi2)	PMP v1 (in)	AEP	ARI
6hr	32.0	2.93×10^{-7}	3,412,649
24hr	36.3	2.44×10^{-6}	409,448



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AEP Test Basins

Test Basin	Transposition Zone	Area (sqmi)	6hr Storm ARF	24hr Storm ARF
CUMBE_052_ArranLakesWestDam	Zone 1	2.4	0.969	0.987
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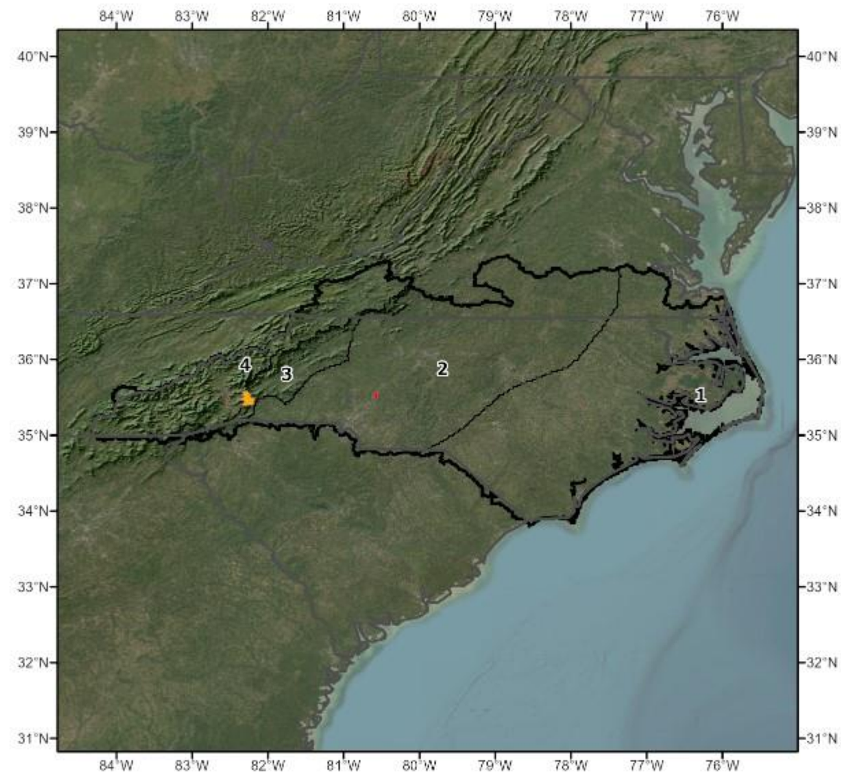

See Example AEP Spreadsheet for remaining test basin results

***** AEP Tool – will perform these calculations**

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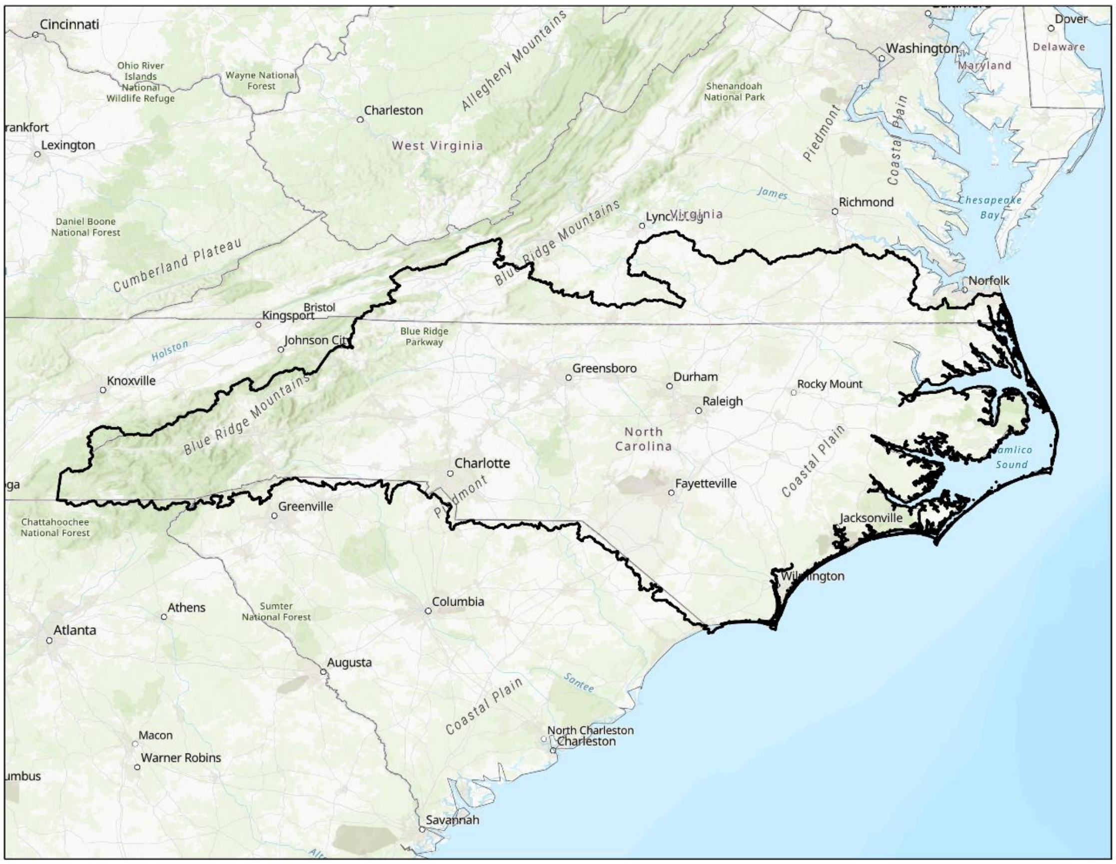
Appendix L
Climate Change Report and Presentation

Climate Change Analysis for North Carolina
Final Report

Prepared for:

North Carolina Dept. of Environmental Quality, Contract # 16-3252966-LB



Prepared by:

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March 2025

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Preparer Signature

Doug Hultstrand, PhD

Reviewer Signature

Bill Kappel

Executive Summary

The potential effects of climate change on meteorological characterization within the study region were assessed. Future climate change projections were downloaded from Regional Downscaled Climate Model (RCM) outputs specifically evaluated for the location. The Global Climate Models (GCMs), also referred to as General Circulation Models, are developed by various governmental, academic, and research agencies around the world in coordination with the Intergovernmental Panel on Climate Change (IPCC). These are utilized to set the boundary conditions and input for the RCMs. The different emissions scenarios that are used to force the GCMs are described by Shared Socioeconomic Pathways (SSPs). SSPs are scenarios of projected socioeconomic global changes and greenhouse gas concentration trajectory that are considered possible in the future.

As part of the IPCC analysis, four pathways were applied for climate modeling: SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 (IPCC, 2021). The various pathways considered different climate futures, depending on the volume of greenhouse gases (GHG) emitted in the years to come. Climate change studies that evaluate future temperature and precipitation projections most often utilize the middle of the road emission scenario (SSP4.5) and the most extreme emission scenario (SSP5-8.5). These provide a bracket of the projections that utilize the most likely outcome (SSP2-4.5) and the most unlikely outcome (SSP5-8.5).

For this study, climate model projections outputs were investigated for the three scenarios: i) historic, ii) SSP2-4.5, and iii) SSP5-8.5. The historical period is based on daily data from 1950 through 2014, and the SSP periods are based on daily data from 2015 through 2100. The NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) dataset, a gridded daily time-series data, which cover the study area, were extracted, aggregated, and applied for the climate change analysis. The climate model projections were used to analyze precipitation trends, precipitation frequency, and maximum precipitation for the 1-day, 3-day, and annual durations for the area covering the study region.

Results of the analysis are presented in Table E.1 through E.4 and represent the results for the four regions covering the North Carolina study regions (Figure E.1). For hydrologic simulation and sensitivity, the ensemble median SSP2-4.5 climate change adjustments and uncertainty values for temperature and precipitation are recommended. The results are based on an evaluation of the rate of change from the current period through 2100. These values can be applied to a given period (i.e., 2050) by linearly adjusting the climate change factors.

Figure E.1: Climate change regions covering the North Carolina PMP study domain.

Table E.1: Climate Change Projections for Region 1 from current climate (1950-2014) through 2100.

Region 1																				
1-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*11*	*13*	*12*	*11*	*12*	*10*	*11*	*10*	*11*	*18*	*18*	*18*	*16*	*16*	*14*	*14*	*14*	*12*	*11*	*16*
Summer 2015-2100	6	7	7	9	9	10	12	13	15	4	5	7	5	4	3	2	0	-1	10	3
Winter 2015-2100	11	13	12	12	13	11	11	10	11	19	19	19	18	17	16	15	13	12	12	16
Summer PF; %																				
Summer 2025-2050	22	25	26	26	24	20	17	15	13	23	27	27	25	23	18	15	9	5	21	19
Summer 2050-2075	25	30	31	28	28	26	24	18	13	23	29	31	35	33	31	26	21	18	25	28
Summer 2075-2100	24	32	32	30	30	26	21	18	15	25	30	35	31	29	27	27	19	13	25	26
Winter PF; %																				
Winter 2025-2050	6	7	7	6	6	6	6	7	6	9	9	9	10	9	9	10	10	11	6	10
Winter 2050-2075	9	9	10	11	13	15	16	17	19	16	15	14	13	12	13	12	12	11	13	13
Winter 2075-2100	13	14	15	16	15	16	18	18	18	28	24	25	23	22	20	20	20	19	16	22

Table E.2: Climate Change Projections for Region 2 from current climate (1950-2014) through 2100.

Region 2																				
1-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*12*	*12*	*13*	*13*	*12*	*11*	*10*	*10*	*11*	*18*	*18*	*17*	*15*	*14*	*12*	*13*	*11*	*10*	*11*	*14*
Summer 2015-2100	7	8	9	11	13	14	13	15	18	4	5	7	10	10	11	11	12	13	12	9
Winter 2015-2100	12	13	13	13	13	13	12	12	11	19	19	17	16	15	14	13	10	8	13	15
Summer PF; %																				
Summer 2025-2050	25	31	32	30	28	26	23	21	18	26	30	29	27	24	21	18	12	7	26	21
Summer 2050-2075	28	32	31	31	29	24	19	13	10	29	35	37	37	37	41	38	34	30	24	35
Summer 2075-2100	28	36	38	39	35	30	26	19	13	30	38	39	38	37	35	41	41	37	29	37
Winter PF; %																				
Winter 2025-2050	4	5	4	4	5	5	6	7	7	8	8	7	5	7	8	6	7	8	5	7
Winter 2050-2075	9	9	10	7	6	4	6	8	13	12	12	12	9	7	5	2	1	0	8	7
Winter 2075-2100	11	13	12	10	10	10	11	11	10	28	25	22	20	17	14	11	8	6	11	17

Table E.3: Climate Change Projections for Region 3 from current climate (1950-2014) through 2100.

Region 3																				
1-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*12*	*12*	*12*	*9*	*8*	*7*	*5*	*2*	*0*	*16*	*16*	*14*	*12*	*10*	*8*	*6*	*2*	*0*	*8*	*9*
Summer 2015-2100	6	8	6	4	5	4	1	0	-1	8	10	8	6	4	-1	-2	-5	-6	4	3
Winter 2015-2100	13	13	13	12	12	11	10	8	8	16	17	17	15	14	13	11	11	11	11	14
Summer PF; %																				
Summer 2025-2050	30	30	28	25	19	11	5	-3	-11	33	35	33	25	16	13	10	0	-8	15	17
Summer 2050-2075	31	34	34	29	23	17	9	-3	-10	33	27	25	24	19	14	7	-7	-16	18	14
Summer 2075-2100	31	33	33	27	21	15	9	0	-8	28	31	30	25	23	18	15	8	-2	18	20
Winter PF; %																				
Winter 2025-2050	5	5	2	1	0	-2	-3	-4	-5	6	5	4	2	1	2	1	-1	-1	0	2
Winter 2050-2075	10	7	6	6	4	4	3	4	4	13	16	16	16	15	15	15	14	14	5	15
Winter 2075-2100	14	13	13	14	14	13	13	13	12	23	22	18	15	12	9	5	1	-1	13	12

Table E.4: Climate Change Projections for Region 4 from current climate (1950-2014) through 2100.

Region 4																				
1-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*11*	*9*	*6*	*3*	*0*	*-3*	*-6*	*-10*	*-14*	*16*	*15*	*12*	*8*	*4*	*2*	*-2*	*-6*	*-7*	*0*	*5*
Summer 2015-2100	6	6	4	0	0	-4	-7	-10	-12	7	9	9	2	1	-4	-5	-3	-4	-2	1
Winter 2015-2100	14	12	11	8	6	5	2	-1	-3	18	18	16	11	8	7	5	2	0	6	9
Summer PF; %																				
Summer 2025-2050	19	19	19	15	8	4	-1	-6	-11	20	25	25	25	16	13	6	-3	-8	7	13
Summer 2050-2075	23	26	21	15	14	12	9	4	-4	17	20	21	27	26	22	15	10	5	13	18
Summer 2075-2100	22	23	21	18	13	12	7	-1	-4	21	23	21	16	11	4	-1	-7	-9	12	9
Winter PF; %																				
Winter 2025-2050	7	4	2	-4	-7	-11	-14	-17	-19	8	6	3	-2	-6	-10	-13	-16	-19	-7	-5
Winter 2050-2075	11	8	6	3	-2	-6	-8	-11	-13	16	13	10	7	4	2	-1	-4	-7	-1	4
Winter 2075-2100	14	11	8	6	3	1	-1	-6	-9	24	16	13	9	4	0	-4	-10	-13	3	4

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Acronyms and Abbreviations

AEP	Annual Exceedance Probability
AMS	Annual Maximum Series
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
AWA	Applied Weather Associates
CDF	Cumulative Distribution Function
EVAP	Evaporation
GCM	Global Climate Model or General Circulation Model
GEV	Generalized Extreme Value distribution
GHCN	Global Historical Climatology Network
GHG	Green House Gas
GLO	Generalized Extreme Value distribution
GNO	Generalized Normal distribution
GPA	Generalized Pareto distribution
IPCC	Intergovernmental Panel on Climate Change
L-Cv	L-moment coefficient of L-variation
L-Kurtosis	L-moment ratio of kurtosis
L-Skewness	L-moment ratio of skewness
MAM	Mean Annual Maximum
MAP	Mean Annual Precipitation
NCDC	National Climate Data Center
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
PE3	Pearson Type III distribution
PF	Precipitation-Frequency
POR	Period of Record
Ppt	Precipitation
Ppt_{adj}	Maximized Precipitation
Ppt_{max}	Largest Thirty Precipitation Events
Ppt_{pmp}	Maximum of Largest Thirty Maximized Precipitation Events
PRISM	Parameter-elevation Regressions on Independent Slopes Model
Press	Surface Pressure
QC	Quality Control
RCP	Representative Concentration Pathway
RGC	Regional Growth Curve
RH	Relative Humidity
SH	Specific Humidity
Srad	Solar Radiation
SSP	Shared Socioeconomic Pathways
Ta	Air Temperature
Td	Dew Point Temperature

1.0 Introduction

Applied Weather Associates (AWA) examined climate model projections to analyze precipitation trends, precipitation frequency, and maximum precipitation for the 1-day, 3-day, and annual durations for the region covering the North Carolina regional study (Figure 1). Three different investigations were completed to evaluate the climate change projections of precipitation through time, each of which provided a different look at the climate change projections. The first method investigated station and climate projection trends using trend analysis methods based on Mann (Mann, 1945) and Hipel and McLeod (2005) utilizing the R-statistical software packages ‘Kendall’ developed by McLeod (2015). The second method was precipitation frequency analysis based on L-moments methods described in Hosking and Wallis (1997) and utilized the R-statistical software packages ‘lmom’ and ‘lmomRFA’ developed by Hosking (Hosking 2015a, and Hosking 2015b). The third method identified the largest precipitation events from the daily climate projections, derived monthly dew point temperature climatologies from the climate model projections and maximized the storm events through storm maximization methods (Rousseau et al., 2014; Kappel et al., 2018; Kappel et al., 2020). In addition, climate change for mean monthly and annual climatologies were derived for precipitation and temperature. It is important to note that the North Carolina Department of the Environment – Dam Safety sponsored a statewide Probable Maximum Precipitation study, AWA completed the Probable Maximum Precipitation (PMP) study in 2024 (Kappel et al., 2024).

Figure 1: Location of the North Carolina study region.

2.0 Climate Change Projection Background

Climate is changing, always has been changing, and always will change as long as the energy received from the sun across the Earth's surface and atmosphere is not distributed evenly. Evaluating climate change projections for a given location is important to reduce risk and ensure infrastructure is designed to safely handle potential future changes. Unfortunately, quantification of the amount and rate of change at any given location for any specific meteorological parameter is not explicitly quantifiable and instead has to be modeled based on our incomplete understanding of the Earth's climate system and future estimates of atmospheric composition. Therefore, model projections that utilize our current understanding of the Earth's climate system and how that climate system responds to greenhouse gases are developed. The climate projections are based on our best quantification of physical understanding of numerous atmospheric parameters and how those affect weather and climate through time and space. However, because our quantification of these parameters are incomplete (and at times inaccurate) and because we currently have a limited understanding of the various interactions and feedbacks, the climate projections represent possible outcomes. None of which can be considered truth, but instead should be treated as "what if" scenarios representing possible outcomes.

To better address these significant limitations, numerous iterations and sensitivity analyses for various atmospheric parameters are performed so that a suite of ensembles are produced to represent a wide range of potential outcomes. From this output, inferences can be made, with more confidence given when ensemble outcomes converge on a common projection.

Another layer of uncertainty within the climate change projection process relates to the assumption applied for future emissions scenarios and how those may affect the climate system. Future emissions scenarios have two major areas of uncertainty. First, our assumption that any given emission scenario will occur following a specific path through time is unknown as there are many internal and external factors that can influence emissions produced through time. Second, our understanding and quantification of how the Earth's climate will respond to any given greenhouse gas emission is limited. Both uncertainties introduce errors into the climate projections.

Finally, the Global Climate Models (GCMs) are computationally intensive and are therefore run at low resolution both in time and space. For regions like the North Carolina region, the resolution of the GCMs is inadequate to capture the spatial variations. To overcome this, projections from GCMs are downscaled using a statistical process into regional downscaled model projections (RCMs). RCMs are downscaled and are what were utilized for this climate change analysis. Given all the limitations and uncertainties noted above, it is still useful to evaluate RCMs to understand the range of potential outcomes that could occur through time over the basin.

2.1 Global Climate Change Models

GCMs produce realizations of the Earth's climate on a generally coarse scale of around 1000km by 1000km. Because the scale is so coarse, a single GCM grid may cover vastly differing landscape (from very mountainous to flat coastal plains for example) with greatly varying potential for floods, droughts, or other extreme events.

2.2 Regional Downscaled Climate Change Models

RCMs and Empirical Statistical Downscaling applied over limited areas cover a much finer resolution. These are therefore able to capture the spatial and temporal variations related to a site-specific region, such as the North Carolina study region. The downscaling methods are driven by GCMs, where the RCM is nested within the overall GCM and utilizes the GCM to set the initial boundary conditions. These are then downscaled using either the statistical methodology or the RCM based on a meteorological model interface. The RCM process can provide projections of future climate conditions on a much smaller scale (e.g., 25km by 25km) supporting more detailed site-specific information allowing for adaptation assessment and planning. An example of different climate model resolutions across the North Carolina region are shown in Figure 2.

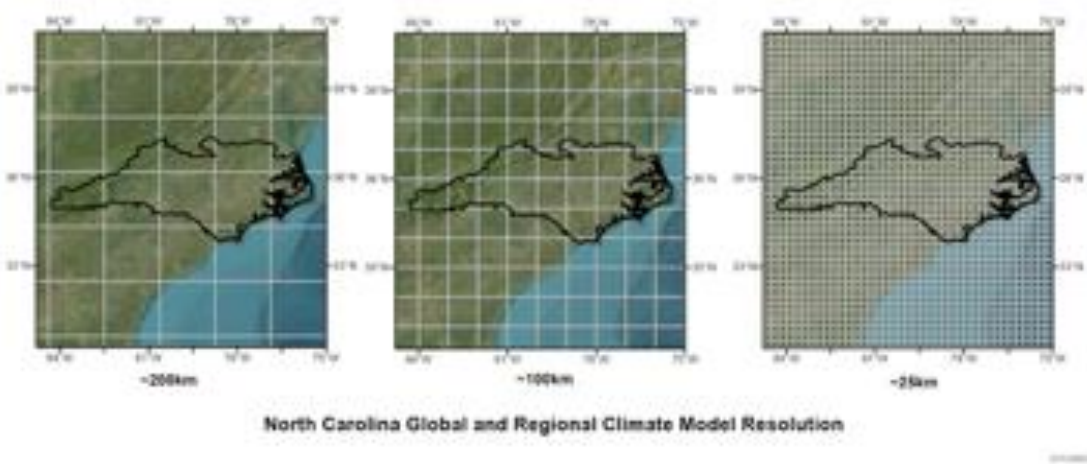


Figure 2: Example of different climate model resolutions across the North Carolina region.

3.0 Climate Change Projection Analysis Methods

The Intergovernmental Panel on Climate Change (IPCC) sixth assessment report (AR6) contains Shared Socioeconomic Pathways (SCPs). SSPs are scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emission scenarios with different climate policies. The SSPs are based on five narratives describing broad socioeconomic trends that could shape future society. These are intended to span the range of plausible futures. They include: a world of sustainability-focused growth and equality (SSP1); a "middle of the road" world where trends broadly follow their historical patterns (SSP2); a fragmented world of "resurgent nationalism" (SSP3); a world of ever-increasing inequality (SSP4); and a world of rapid and unconstrained growth in economic output and energy use (SSP5) (IPCC, 2021). The SSPs investigated; SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5; are labeled after a possible range of greenhouse gas emission scenarios with different climate policies through the year 2100 (Figure 3) (IPCC, 2022). The IPCC AR6 report does not estimate the likelihoods of the climate scenarios (Masson-Delmotte et al., 2021) but Hausfather and Peters (2020) concluded that SSP5-8.5 was highly unlikely, SSP3-7.0 was unlikely, and SSP2-4.5 was likely.

The NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) dataset is comprised of thirty-five global downscaled climate scenarios derived from the GCM runs conducted under the Coupled Model Intercomparison Project Phase 6 (CMIP6) and across two of the four "Tier 1" greenhouse gas emissions scenarios. The CMIP6 GCM runs were developed in support of the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6) (Thrasher et. al, 2021; Thrasher et. al, 2022). The purpose of this dataset is to provide a set of global, high resolution, bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients and the effects of local topography on climate conditions.

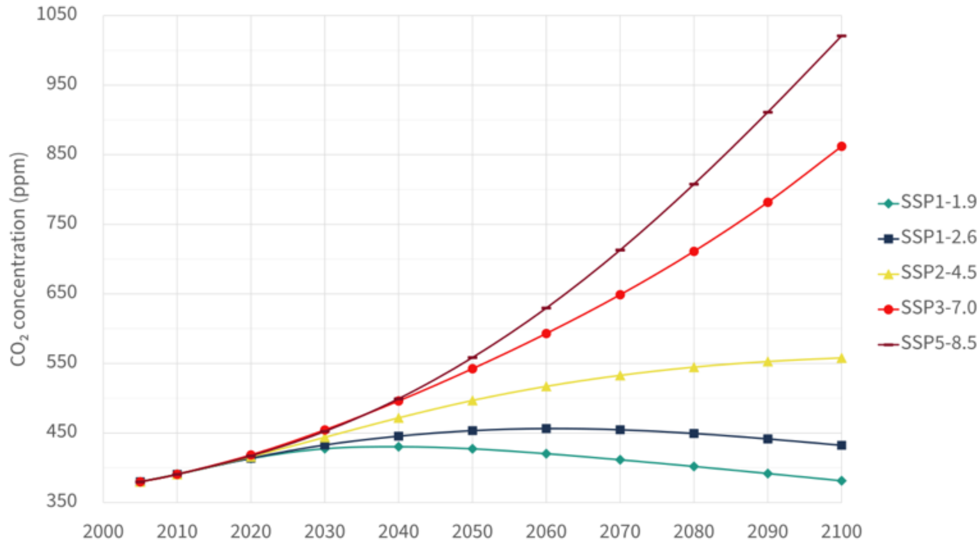


Figure 3: Shared Socioeconomic Pathways (SSP) trajectories. Reproduced from IPCC (2021).

The key climate model parameters used in this analysis were precipitation (Ppt), air temperature (Ta), and dew point temperature (Td). The parameters of relative humidity (RH) and Ta were used to derive the estimates of dew point (Td). The NEX-GDDP-CMIP6 dataset consists of thirty-five models, of these, twenty-six models had the parameters and projections needed for the North Carolina climate change analysis (Figure 4). An example of the modeled daily climate projection parameters of Ppt, Ta, and Td are shown in Figure 5 and the grid resolution covering the covering the study region are shown in Figure 6. The climate projection historical period is based on daily information from 1950 through 2014, and the future periods are based on daily projections from 2015 through 2100.

Model #	MODEL NAME	Relative Humidity (hurs)			Precipitation (pr)			Temperature (tas)		
		HISTORICAL	SSP45	SSP85	HISTORICAL	SSP45	SSP85	HISTORICAL	SSP45	SSP85
1	ACCESS-CM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
2	ACCESS-ESM1-5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
4	CanESM5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
5	CESM2-WACCM	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
6	CESM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
7	CMCC-CM2-SR5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
8	CMCC-ESM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
9	CNRM-CM6-1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
10	CNRM-ESM2-1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
11	EC-Earth3-Veg-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
12	EC-Earth3	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
13	FGOALS-g3	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
14	GFDL-CM4_gr1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
15	GFDL-CM4_gr2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
16	GFDL-ESM4	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
17	GISS-E2-1-G	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
21	INM-CM4-8	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
22	INM-CM5-0	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
23	IPSL-CM6A-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
26	MIROC-ES2L	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
27	MIROC6	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
28	MPI-ESM1-2-HR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
29	MPI-ESM1-2-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
30	MRI-ESM2-0	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
33	NorESM2-MM	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
34	TaiESM1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100

Figure 4: Subset of 26 CMIP6 models, the parameters, and projections used for the climate change analysis.

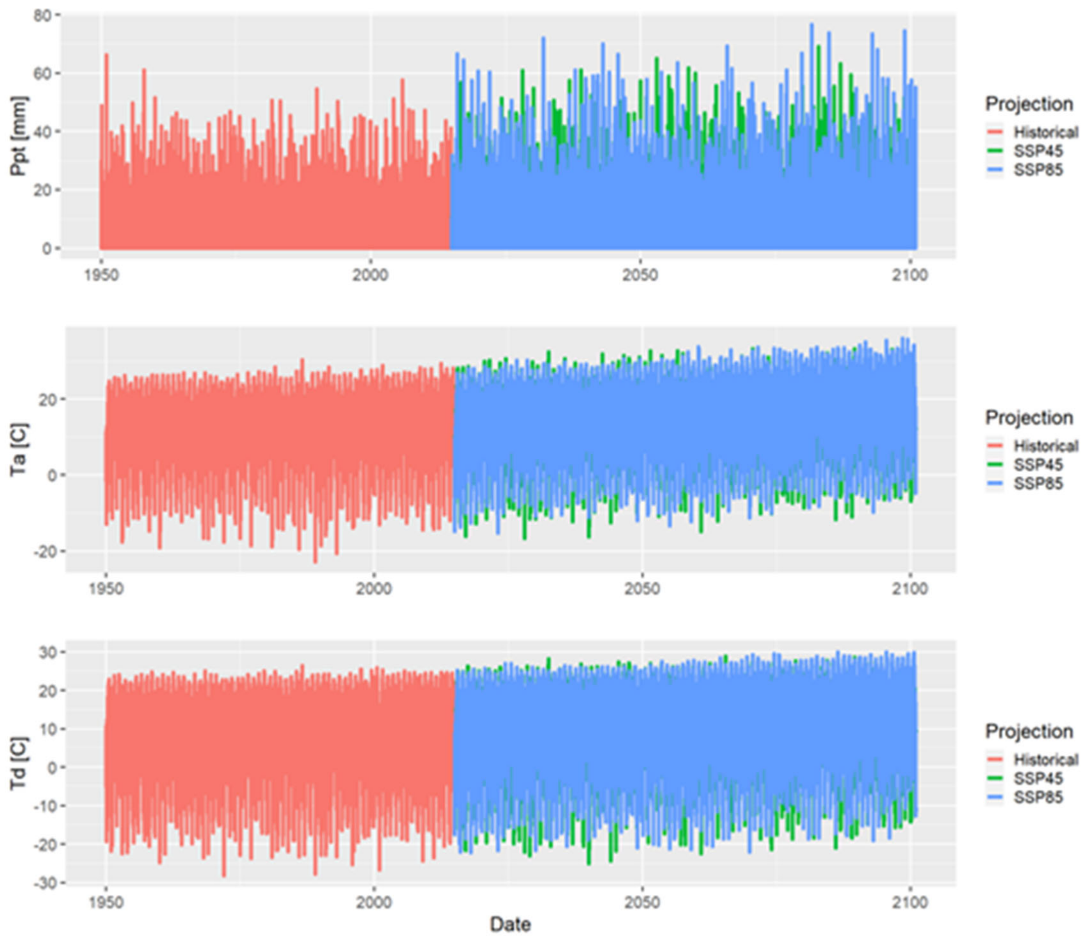


Figure 5: Climate projection parameters of Ppt, Ta, and Td from Model 1 (ACCESS-CM2)

Figure 6: CMIP6 climate model grids covering North Carolina. Orange, yellow, green, and purple regions represent the climate grids extracted for each domain, the grey lines represent the CMIP6 grid resolution.

3.1 Trend Analysis

Mann-Kendall trend analysis (Mann, 1945; Hipel and McLeod, 2005) was performed on several climate stations for 1-day, 3-day, and annual durations. The climate station trend results were used to assess the historic model projections. In addition, Mann-Kendall trend analysis (Mann, 1945; Hipel and McLeod, 2005) was performed on twenty-six climate model projections using the three scenarios (historic, SSP2-4.5, SSP5-8.5) for durations of 1-day, 3-day, and annual. Figure 7 shows an example of the results for Model 1 trend analysis for the historic. Results for Region 1 climate model projection trend analyses are summarized in

Table **1**.

Table 1: Summary of climate projection trend analysis results for Region 1. Trend analyses are evaluated at the 0.05 significant level.

	Precipitation			Temperature
	1-day	**3-day**	**Annual**	**1-day**
Historic	23 – no trend 2 – increase 1 – decrease	25 – no trend 0 – increase 1 – decrease	24 – no trend 2 – increase 0 – decrease	8 – no trend 18 – increase 0 – decrease
SSP2-4.5	18 – no trend 8 – increase 0 – decrease	21 – no trend 5 – increase 0 – decrease	21 – no trend 5 – increase 0 – decrease	2 – no trend 24 – increase 0 – decrease
SSP5-8.5	14 – no trend 12 – increase 0 – decrease	18 – no trend 8 – increase 0 – decrease	11 – no trend 15 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

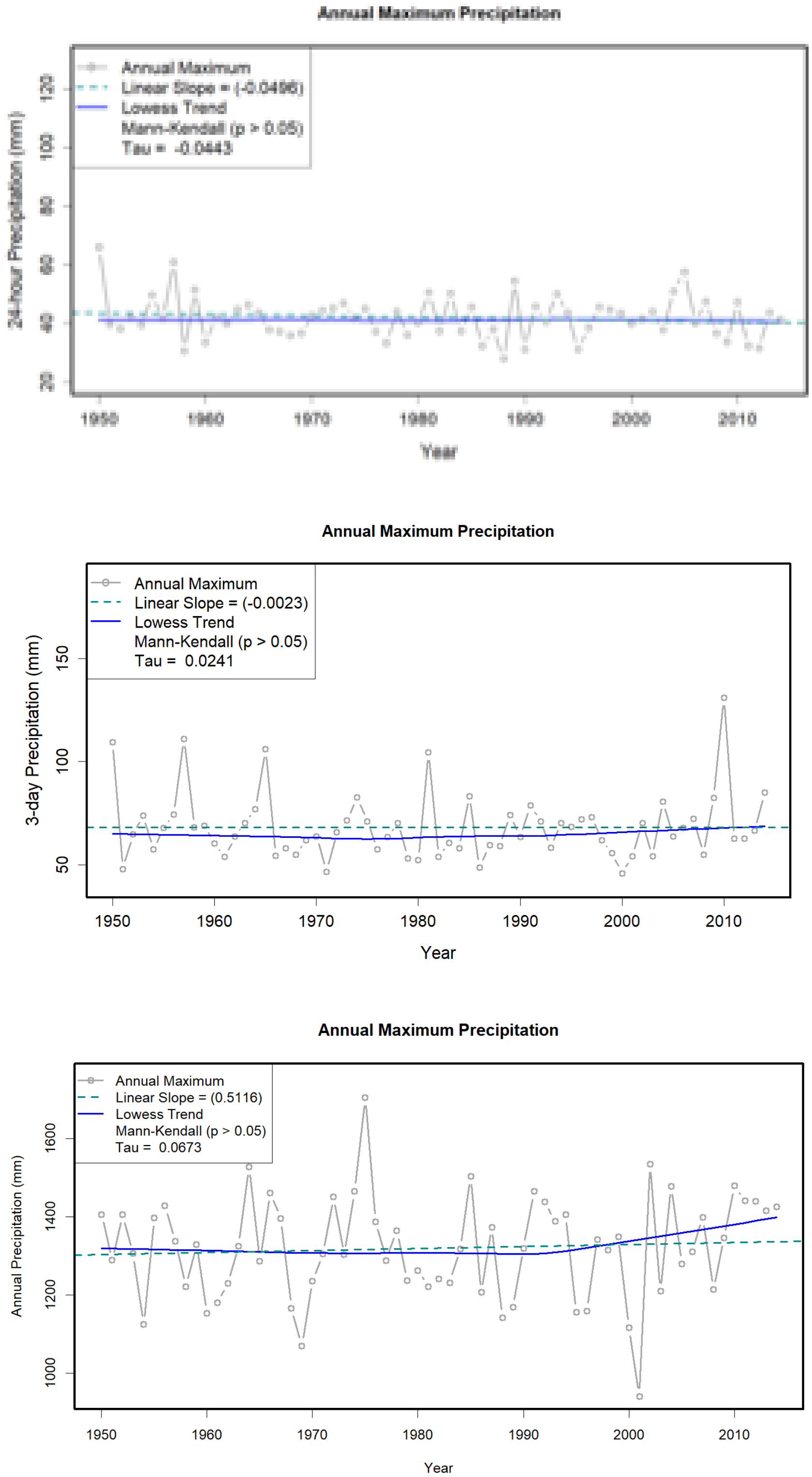


Figure 7: Example results for 1-, 3-, and 365-day trend analysis from Model 1. Blue line is Lowess trend line, dashed line is a linear trend, and Mann-Kendall p-value and Tau statistics are shown.

3.2 Precipitation Frequency Analysis

The precipitation frequency analysis method utilized L-moment statistics instead of product moment statistics, which decrease the uncertainty of rainfall frequency estimates for more rare events and dampens the influence of outlier precipitation amounts from extreme storms (Hosking and Wallis, 1997). Methods to account for non-stationarity in projections were not addressed, the projections were applied assuming stationarity. For the precipitation frequency analysis, AWA utilized the daily climate model projections to perform frequency analysis on the 1-day, 3-day, and annual durations.

AWA evaluates the climate change projections for the entire period available, for CMIP6 that ranges from 2015 through 2100. The changes through time reflect the entire period. However, other evaluation periods can be considered and may change the rate of change through time. For example, one may evaluate the projections through the year 2050 and then do a separate analysis for the years 2050-2100. This may result in slightly different outcomes depending on the climate change projections amount of change through time. For example, some climate change models may show minimal changes for the period 2005 through 2050, then an increasing change from 2051 through 2100. Regardless of the process utilized to evaluate the climate change projections and the increments evaluated, it is recommended that each iteration of the IPCC climate change outputs be evaluated against the previous work to check trends and changes.

AWA identified, extracted, and quality controlled maximum daily precipitation projections for the twenty-six models and three projection scenarios. The Annual Maximum Series (AMS) were then subjected to the frequency analysis methods (Hosking and Wallis, 1997). L-moment statistics were computed for annual maximum data for each projection and duration. Goodness of fit measures were evaluated for five candidate distributions: generalized logistic (GLO), generalized extreme value (GEV), generalized normal (GNO), Pearson type III (PE3), and generalized Pareto (GPA). An L-Moment Ratio Diagram was prepared based on L-Skewness and L-Kurtosis pairs for each duration (Figure 8). The weighted-average L-Skewness and L-Kurtosis pairing were found to be near the GEV distribution for all projections.

The GEV distribution was selected because: i) This is the most common distribution used for precipitation frequency studies (e.g., NOAA Atlas 14, Perica, 2015) ii) the GEV was identified on both the 1-day, 3-day, and Annual goodness-of-fit measures, and iii) using the same distribution ensures a more direct comparison to more rare values of the frequency curve. The GEV is a general mathematical form that incorporates Gumbel's Extreme Value (EV) type I, II and III distributions for maxima. The parameters of the GEV distribution are the ξ (location), α (scale), and k (shape). The Gumbel EV type I distribution is obtained when $k = 0$. For $k > 0$, the distribution has a finite upper bound at $\xi + \alpha / k$ and corresponds to the EV type III distribution for maxima that are bounded above. For $k < 0$, this corresponds to the Gumbel EV type II distribution.

The uncertainty analysis for deriving the frequency curve and uncertainty bounds were conducted as follows. The frequency distributions were randomly permuted, and data were simulated from the selected frequency distribution. The procedure is described in Hosking and Wallis (1997) and Hosking (2015b), except that the permutation of frequency distributions is a later modification, intended to give more realistic sets of simulated data (Hosking, 2015b). From each permutation the sample mean values and estimates of the quantiles of the regional growth curve, for non-exceedance probabilities are saved. From the simulated values, for each quantile specified the relative root mean square error (relative RMSE) is computed as in Hosking and Wallis (1997). The error bounds are sample quantiles of the ratio of the estimated regional growth curve to the true at-site growth curve of the ratio of the estimated to the true quantiles at individual sites (Hosking, 2015b).

In order to separate Summer season and Winter season precipitation events that are controlling of the yearly precipitation regime in the North Carolina region, the 1-day and 3-day annual maximum were also extracted for Summer season (May - October) and for the Winter season (November – April). The summer and winter AMS data were used to perform L-moment frequency analysis methods as described above. Comparisons of percent change were made among model projections for 10-year through 1,000-year recurrence intervals, beyond this the uncertainty in probability distributions estimates is large. Figure 8 shows an example of the results Model 1 1-day precipitation frequency analysis for All season (mixed storm distribution), Summer/Monsoon season, and Winter season for the historic, SSP2-4.5, and SSP5-8.5 projections.

*** 1-Day Precipitation

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	51.6	59.2	62.0	67.7	69.9	-	-	-	-	-	
SSP45	58.0	65.7	68.3	73.1	74.8	12%	11%	10%	8%	7%	10%
SSP85	66.4	76.5	80.0	86.7	89.1	29%	29%	29%	28%	27%	28%

*** 1-Day Summer

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	33.8	47.1	54.1	74.1	84.6	-	-	-	-	-	
SSP45	39.5	56.9	65.9	91.6	105.2	17%	21%	22%	24%	24%	22%
SSP85	38.1	50.8	56.8	72.0	79.2	13%	8%	5%	-3%	-6%	3%

*** 1-Day Winter

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	51.3	59.1	62.1	68.2	70.5	-	-	-	-	-	
SSP45	57.7	66.2	69.2	74.8	76.8	13%	12%	11%	10%	9%	11%
SSP85	66.2	76.9	80.7	88.1	90.7	29%	30%	30%	29%	29%	29%

Figure 8: Example results for 1-day precipitation frequency analysis for climate projection from Model 1.

3.3 Uncertainty

Measurement, modeling, and simulation of many meteorologic components can be highly uncertain, the main reason being the fundamental dynamics of many processes cannot be measured and modeled accurately (Kampf et al., 2020). Most meteorologic processes are not observed in detail, consequently accurate mathematical representation of the variables spatial and temporal processes, model initial boundary layer conditions, and physical processes, cannot be represented accurately. Mantovan and Tondini (2006) have identified sources of water balance uncertainties as: (i) data uncertainty, (ii) model parameter uncertainty, (iii) model structure uncertainty, and (iv) natural uncertainty.

3.3.1 Data Uncertainty

The performance of models is mainly affected by data uncertainty. This uncertainty arises from errors in the observed data, particularly data used for model calibration. The errors may be linked to the quality of the data which depends on the type and conditions of measuring instruments as well as data handling and processing. Precipitation and streamflow are usually the major sources of input and output data that are used to calibrate and evaluate model uncertainty with the spatial and temporal precipitation uncertainty being large.

3.3.2 Model Parameter Uncertainty

Model parameter uncertainty is also known as model specification uncertainty. This relates to the inability to converge to a single best parameter set using available data, which leads to parameter identifiability problems (Beven, 2001; Wagener et al., 2004). The parameters are optimized so that the model results are as good as possible (Beven, 2001; Scharffenberg et al., 2018). Uncertainty then depends on how parameters are optimized (peak flow, volume, residuals) and results are applied (Scharffenberg et al., 2018; Pokorny et al., 2021).

3.3.3 Model Structure Uncertainty

Model structure uncertainty is introduced through simplifications and/or inadequacies in the representation of physical processes in a given model. It also originates from inappropriate assumptions within the modelling procedure, inappropriate mathematical description of these processes (Beven, 2001), and the scale at which processes are represented in the model (Heuvelink, 1998; Blöschl, 1999; Koren et al., 1999). However, no matter how exact the model is calibrated, there always exists discrepancy between model outcome and observed data (Chiang et al., 2007; Beven, 2006).

3.3.4 Natural Uncertainty

Natural uncertainty arises due to the randomness of natural processes (Beven, 2001). This uncertainty can be linked to data uncertainty, whereby the quality and type of data plays a significant role in determining the amount of uncertainty. For example, the spatial and temporal randomness of rainfall can somewhat be represented explicitly when using good rain gauge networks and radar rainfall data (Segond, 2006). In addition, scaling issues, spatial representativity and interpolation methods are typically represented within natural uncertainty (Heuvelink, 1998; Blöschl, 1999).

For this study, the meaning of "within uncertainty" is considered to be within +/-20 percent and was based on several factors. This range is based on AWA's extensive professional experience evaluating each of these factors below and how they relate to the PMP calculations:

- Multiple sources of uncertainty and varying ranges of uncertainty inherent in the PMP development process and inputs
    - Gauge/Observed Precipitation
        - Point measurement 5 to 15% percent for long-term series, and as high as 75% for individual storm events
    - Frequency Analysis
        - NOAA Atlas 14 Volume 1 24-hour 100-year error bounds are approximately +/-18% (Bonin et al., 2011)
    - Climate Projections
        - Projection uncertainty for induvial regional model methods can be quite large 20 to >50% (Lehner et al., 2020)
    - Selection of the storm representative value used in the In-place Maximization Factor calculations
        - Range between 5 and 30%, with an average around 20%

4.0 Results of Analysis

The modeled trends and estimated precipitation frequency results have a large variability that can be attributed to the uncertainty inherent with GCM and RCM projections. The different climate models used for the North Carolina region are subject to significant components of future climate uncertainty in climate models and the uncertainty is manifested by the range of climate futures indicated by the CMIP6 ensemble of projections (McSweeney and Jones, 2016; Masson-Delmotte et al., 2021).

The Region 1 median of the 26 models project an increase in mean annual temperature (2.4 C and 3.3 C) and annual precipitation (9% and 10%). Temperature, in regard to daily maximum (frequency based) and monthly averages show an increase by 2100 for both the SSP2-4.5 and SSP5-8.5 projections (Figure 9 and Figure 10). Numeric values representing the change in temperature are shown in Table and Table under application of results. Monthly climatologies for temperature and precipitation are shown in Figure 10 and Figure 11, numeric values representing the change in temperature and precipitation are shown in Table and Table under application of results.

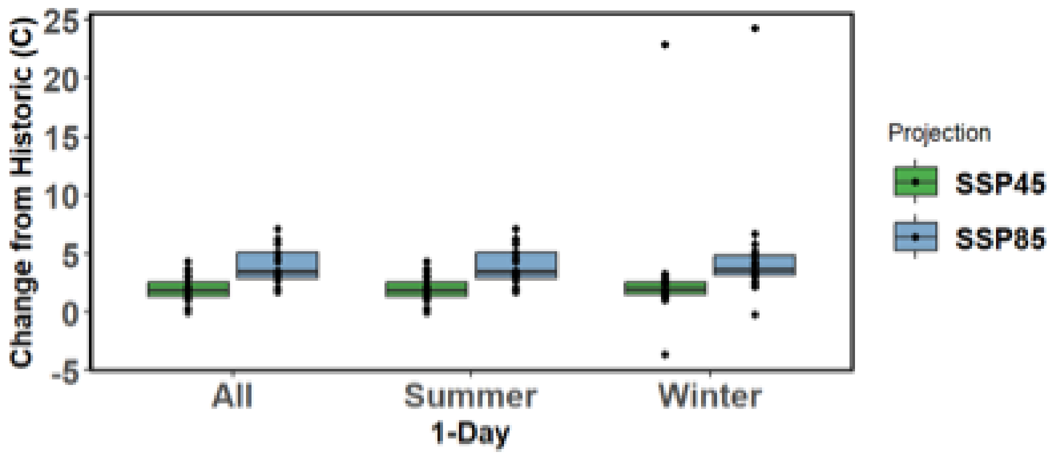


Figure 9: Change in daily maximum temperatures from current climate conditions for Region 1. Results are based on annual maximum frequency analysis.

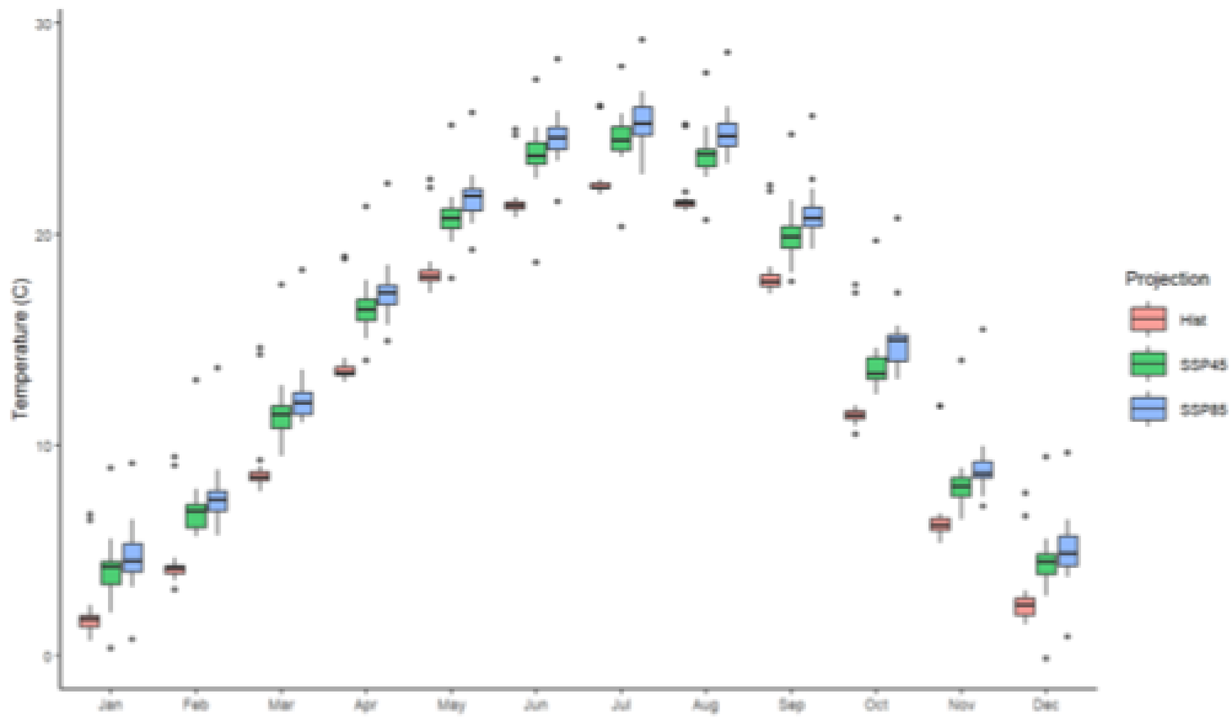


Figure 10: Monthly temperature normal compared to climate change temperature for Region 1. Results are based on daily normal calculations.

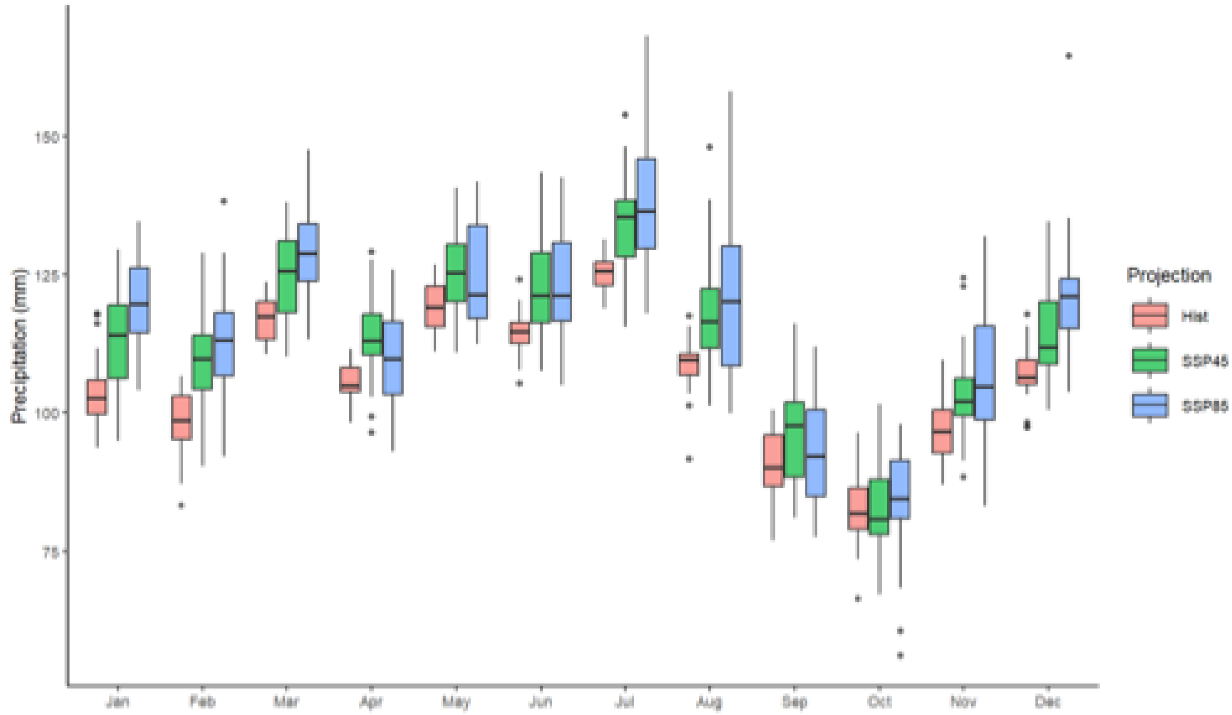


Figure 11: Monthly precipitation normal compared to climate change precipitation for Region 1. Results are based on daily normal calculations.

Precipitation frequency analysis results are summarized for 1-day, 3-day, and annual durations split by All season, Summer season and Winter season (Figure 12). Results indicate a broad range of change with the largest change for 1-day, 3-day, and annual durations, numeric values representing the change in precipitation are shown in Table .

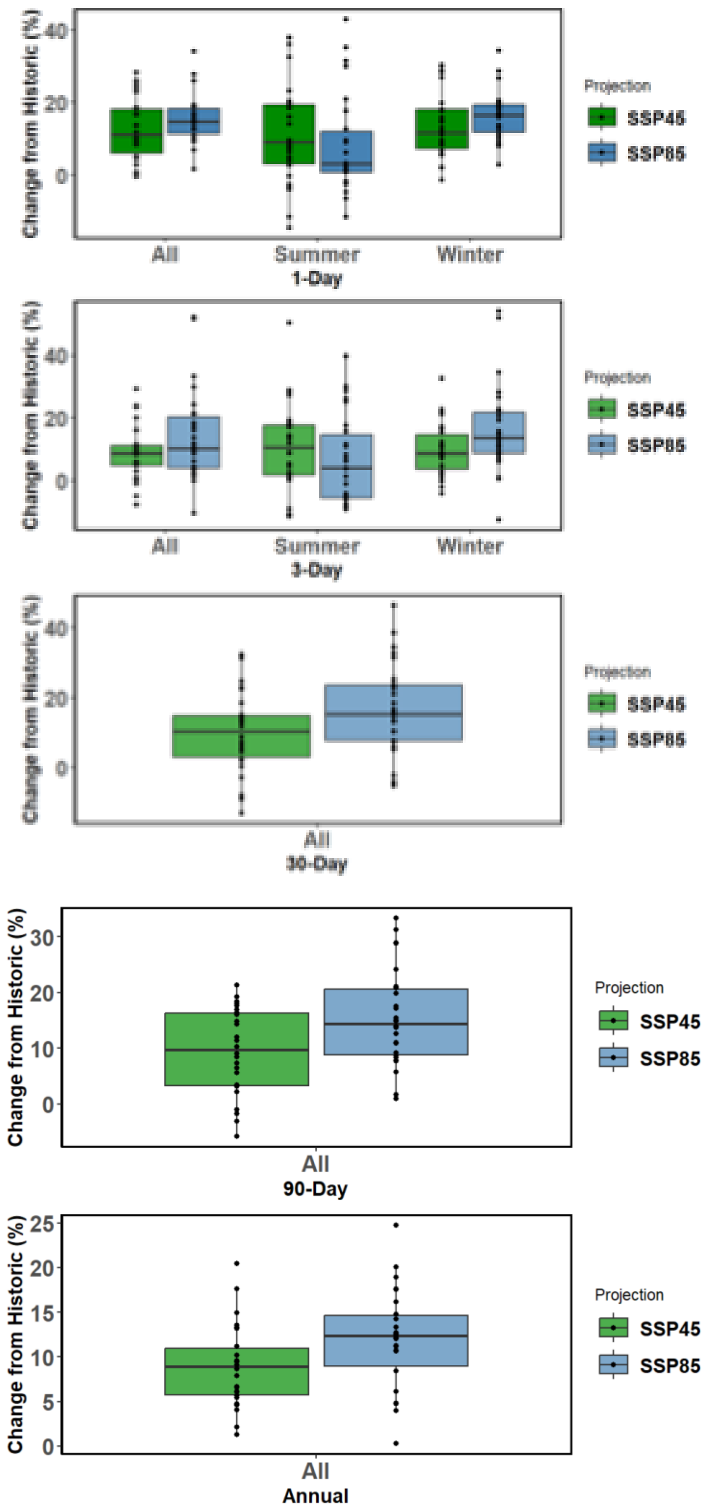


Figure 12: Change in maximum precipitation from current climate conditions for 1-day, 3-day, 30-day, 90-day, and annual durations for Region 1. Results are based on annual maximum frequency analysis. Note, the AMS

frequency approach shows no change in annual precipitation, this is similar compared results based on the mean annual climatology method.

Results indicate no change in any of the precipitation durations beyond the +/-20% range of uncertainty. Temperatures do show an increase in temperature in the future, with similar increases in both the Summer and Winter periods evaluated. The most likely outcome regarding precipitation over the basin in the climate change projections is that the mean annual precipitation and 1-day and 3-day precipitation extremes will stay the same compared to the current climate. This is important because the projections do not show that the PMP depths are expected to change and that the probability depths up to 1000-year recurrence interval are projected to remain within the range of uncertainty already included in the outputs.

This follows expected trends in the region under a warming climate scenario. In this case, more moisture would be available from an overall perspective, and would likely affect some of the precipitation processes, but this would likely be counteracted by other processes that are required to produce precipitation at various timescales and spatial extents (Kappel et al., 2020). This is reflected in **Error! Reference source not found.** where the SSP2-4.5 and SSP5-8.5 emission scenarios. This is likely a reflection of the variance in atmospheric processes that convert moisture in the atmosphere to rainfall on the ground and other factors not fully understood or quantified. These create both positive and negative feedbacks where atmospheric instability at the most extreme levels are lessened in a warming environment because the thermal contrast between airmass is lessened. Therefore, there may be more frequent light rainfall events but less intense (PMP-type) rainfall events. Observational data of the storms which control PMP in the region confirm this as they do not show an increasing trend.

5.0 Application of Results

For hydrologic simulation and sensitivity, AWA recommends the ensemble median SSP2-4.5 climate change adjustments and uncertainty values for temperature and precipitation (Table , Table , Table). These are based on an evaluation of rate of change from the current period through 2100 of each of the projections and taking a median of the outcomes. These values can be applied to a given period (i.e., 2050) by linearly adjusting the climate change factors. Table illustrates how the recommended SSP2-4.5 precipitation climate change adjustments can be scaled the linear from 2100 to 2050. Note that the median change is within the envelopment that is part of the PMP depths.

Table 2: Climate Change Projections from current climate (1950-2005) through 2100 for Region 1.

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**2.0**	**1.8**	1.0	3.3	**3.9**	**3.4**	2.3	5.8
Temperature 1-Day Summer; C	**2.0**	**1.8**	1.0	3.3	**3.9**	**3.4**	2.3	5.8
Temperature 1-Day Winter PF; C	**2.7**	**2.0**	1.3	3.2	**4.5**	**3.6**	2.4	5.5
+ *Precipitation 1-Day PF; %	**12**	**11**	2	25	**15**	**15**	9	23
Precipitation 1-Day Summer PF; %	**11**	**9**	-4	28	**8**	**3**	-4	31
Precipitation 1-Day Winter PF; %	**14**	**12**	2	29	**16**	**17**	9	24
+ *Precipitation 3-Day PF; %	**9**	**9**	0	22	**14**	**10**	2	32
Precipitation 3-Day Summer PF; %	**11**	**10**	-10	28	**6**	**4**	-8	27
Precipitation 3-Day Winter PF; %	**10**	**9**	0	21	**16**	**14**	3	31
Precipitation 30-Day PF; %	**10**	**10**	-6	24	**16**	**15**	2	34
Precipitation 90-Day PF; %	**9**	**10**	-1	18	**15**	**14**	7	29
Precipitation Annual PF; %	**9**	**9**	4	14	**12**	**12**	5	18
Moisture Maximization 1-Day, %	**Potential Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

* Climate Change Projections from 2005 through 2100

\+ Note, SSP8.5 represent the most extreme, unlikely climate projection scenarios

Table 3: Recommended SSP2-4.5 climate change adjustments (%) for 1-day and 3-day precipitation scaled from 2100 to 2050 for Region 1.

	2050	**2100**
1-Day Summer PF; %	4	9
1-Day Winter PF; %	5	12
3-Day Summer PF; %	4	10
3-Day Winter PF; %	4	9
30-Day PF; %	4	10
90-Day PF; %	4	10

Table 4: Monthly temperature (C) for current climate from 2005 through 2100 for Region 1.

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	2.0	1.8	4.0	4.2	4.7	4.5	*2.1*	*2.7*	*2.5*	*2.8*
February	4.4	4.1	6.9	6.8	7.5	7.4	*2.5*	*3.1*	*2.7*	*3.3*
March	8.9	8.5	11.5	11.5	12.2	12.0	*2.6*	*3.3*	*3.0*	*3.6*
April	13.9	13.4	16.5	16.4	17.3	17.2	*2.6*	*3.4*	*3.0*	*3.8*
May	18.3	18.0	20.8	20.8	21.7	21.8	*2.5*	*3.4*	*2.8*	*3.8*
June	21.6	21.4	23.7	23.7	24.6	24.6	*2.1*	*3.0*	*2.4*	*3.2*
July	22.5	22.2	24.5	24.5	25.5	25.3	*2.0*	*2.9*	*2.3*	*3.1*
August	21.7	21.5	23.7	23.8	24.8	24.7	*2.0*	*3.1*	*2.3*	*3.2*
September	18.1	17.8	20.0	19.9	21.0	20.8	*1.9*	*2.9*	*2.1*	*3.0*
October	11.8	11.4	13.7	13.4	14.9	15.0	*1.9*	*3.1*	*2.0*	*3.6*
November	6.6	6.2	8.1	8.0	8.9	8.6	*1.6*	*2.4*	*1.9*	*2.5*
December	2.7	2.4	4.4	4.5	5.0	4.9	*1.7*	*2.3*	*2.1*	*2.5*

Table 5: Monthly precipitation (mm) for current climate from 2005 through 2100 for Region 1.

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	103.7	102.7	113.3	114.1	119.8	119.7	*1.09*	*1.16*	*1.11*	*1.17*
February	98.4	98.5	109.2	109.7	113.1	113.2	*1.11*	*1.15*	*1.11*	*1.15*
March	116.7	117.3	124.7	125.6	128.8	128.9	*1.07*	*1.10*	*1.07*	*1.10*
April	105.7	104.9	114.0	113.0	109.9	109.6	*1.08*	*1.04*	*1.08*	*1.05*
May	119.1	119.0	125.4	125.4	124.9	121.3	*1.05*	*1.05*	*1.05*	*1.02*
June	114.5	114.7	123.1	121.2	123.1	121.2	*1.08*	*1.07*	*1.06*	*1.06*
July	125.1	125.6	134.3	135.5	138.7	136.4	*1.07*	*1.11*	*1.08*	*1.09*
August	108.7	109.6	118.2	116.5	120.7	120.1	*1.09*	*1.11*	*1.06*	*1.10*
September	90.8	90.0	97.2	97.6	93.3	92.1	*1.07*	*1.03*	*1.09*	*1.02*
October	82.0	81.8	82.6	80.7	83.8	84.4	*1.01*	*1.02*	*0.99*	*1.03*
November	96.8	96.7	103.6	102.0	106.7	104.8	*1.07*	*1.10*	*1.06*	*1.08*
December	107.1	106.4	114.7	111.8	121.2	120.9	*1.07*	*1.13*	*1.05*	*1.14*

5.1 Application of Results for Regions 1 through 4

AWA examined climate model projections to analyze precipitation and temperature for four regions covering North Carolina (Figure 6: CMIP6 climate model grids covering North Carolina. . Results discussed in Section 5.0 represent Region 1, the north-central North Carolina location. The results for all four regions are provided in digital spreadsheets as part of this Appendix and shown in Table through **Error! Reference source not found.**.

Table 6: Climate Change Projections for Region 2 from current climate (1950-2014) through 2100.

	SSP45				SSP85			
	Mean	Median	10th	90th	Mean	Median	10th	90th
Temperature 1-Day; C	**1.9**	**1.8**	0.9	3.3	**3.8**	**3.3**	2.1	5.8
Temperature 1-Day Summer; C	**1.9**	**1.8**	0.9	3.3	**3.8**	**3.3**	2.1	5.8
Temperature 1-Day Winter PF; C	**2.7**	**1.9**	1.2	3.1	**4.5**	**3.6**	2.5	5.4
*Precipitation 1-Day PF; %	**12**	**11**	2	21	**14**	**13**	5	23
Precipitation 1-Day Summer PF; %	**11**	**12**	-1	24	**9**	**10**	-2	21
Precipitation 1-Day Winter PF; %	**13**	**12**	3	23	**15**	**15**	6	24
*Precipitation 3-Day PF; %	**8**	**8**	-3	22	**14**	**9**	-1	37
Precipitation 3-Day Summer PF; %	**9**	**9**	-8	24	**6**	**3**	-8	26
Precipitation 3-Day Winter PF; %	**9**	**9**	-3	22	**15**	**12**	1	36
Precipitation 30-Day PF; %	**11**	**12**	-8	25	**17**	**15**	2	28
Precipitation 90-Day PF; %	**10**	**12**	-3	19	**16**	**15**	6	27
Precipitation Annual PF; %	**9**	**9**	4	15	**12**	**12**	6	18
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**Potential Change**				**No Change**			

Table 7: Climate Change Projections for Region 3 from current climate (1950-2014) through 2100.

	SSP45				SSP85			
	Mean	Median	10th	90th	Mean	Median	10th	90th
Temperature 1-Day; C	**1.8**	**1.8**	0.5	3.2	**3.8**	**3.4**	2.3	6.1
Temperature 1-Day Summer; C	**1.8**	**1.8**	0.5	3.2	**3.8**	**3.4**	2.3	6.1
Temperature 1-Day Winter PF; C	**1.8**	**2.1**	1.2	2.7	**3.5**	**3.4**	2.4	5.0
*Precipitation 1-Day PF; %	**8**	**8**	-7	23	**10**	**10**	-4	25
Precipitation 1-Day Summer PF; %	**5**	**5**	-13	28	**6**	**2**	-12	29
Precipitation 1-Day Winter PF; %	**12**	**12**	2	27	**15**	**14**	0	32
*Precipitation 3-Day PF; %	**8**	**7**	-6	22	**11**	**8**	1	30
Precipitation 3-Day Summer PF; %	**1**	**3**	-14	15	**3**	**0**	-13	24
Precipitation 3-Day Winter PF; %	**14**	**11**	-3	34	**17**	**17**	2	31
Precipitation 30-Day PF; %	**11**	**12**	-3	22	**17**	**17**	3	33
Precipitation 90-Day PF; %	**11**	**11**	0	23	**16**	**16**	7	27
Precipitation Annual PF; %	**10**	**10**	4	16	**12**	**12**	6	22
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

Table 8: Climate Change Projections for Region 4 from current climate (1950-2014) through 2100.

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**1.7**	**1.8**	0.7	3.2	**4.7**	**3.0**	2.2	5.6
Temperature 1-Day Summer; C	**1.7**	**1.8**	0.7	3.2	**4.7**	**3.0**	2.2	5.6
Temperature 1-Day Winter PF; C	**1.6**	**1.8**	1.0	2.3	**3.1**	**3.2**	1.8	4.4
*Precipitation 1-Day PF; %	**3**	**0**	-7	14	**6**	**4**	-11	24
Precipitation 1-Day Summer PF; %	**0**	**-1**	-19	20	**2**	**0**	-18	26
Precipitation 1-Day Winter PF; %	**7**	**6**	-5	18	**9**	**8**	-3	21
*Precipitation 3-Day PF; %	**2**	**1**	-6	14	**6**	**6**	-6	17
Precipitation 3-Day Summer PF; %	**-1**	**-1**	-16	15	**3**	**1**	-18	22
Precipitation 3-Day Winter PF; %	**8**	**7**	-6	22	**13**	**13**	-3	28
Precipitation 30-Day PF; %	**6**	**4**	-5	15	**9**	**8**	0	17
Precipitation 90-Day PF; %	**7**	**7**	-3	16	**9**	**9**	1	18
Precipitation Annual PF; %	**8**	**8**	-2	15	**10**	**9**	2	18
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**Potential Change**			

6.0 Conclusions

The North Carolina climate change analysis investigated CMIP6 projections. The projections were evaluated using several statistical methodologies to test for trends in temperature and precipitation, changes in precipitation frequency, and changes in monthly climatologies. The results have large variability that can be attributed to the uncertainties and limitations inherent in climate model projections and the physical representation of meteorological parameters such as precipitation.

The trend and frequency analysis methods provide a robust dataset to test changes in precipitation and temperature. The monthly and annual climatology analysis methods provide projections to test changes in climate normals. More confidence is given to the trend, precipitation frequency, and climatology results as compared to the moisture maximization analysis based on subjective assumptions inherent in the moisture maximization process.

The climate change analysis completed for the North Carolina region was based on twenty-six CMIP6 climate model projections and three climate scenarios (historic, SSP2-4.5, and SSP5-8.5). A summary of the key conclusions from this study are listed below.

TREND ANALYSIS

- Most surface stations show no historic change/trend in precipitation and temperature
- Projections show increase in temperature and dew point temperature
- SSP2-4.5 precipitation – most models show no trend/change at all durations
- SSP5-8.5 precipitation – most models show an increasing trend at all durations

FREQUENCY ANALYSIS

- 1-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for no change in precipitation magnitude by 2100. *** 1-day Summer increase when split by 25-yr period.
- 3-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for no change in precipitation magnitude by 2100. *** 1-day Summer increase when split by 25-yr period.
- 30-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for no change in precipitation magnitude by 2100.
- 90-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for no change in precipitation magnitude by 2100.
- Annual – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for no change in precipitation magnitude by 2100m and both have increase temperature by 2100.

CLIMATOLOGY

- Monthly Climatology – All months show an increase in precipitation (within +/- 20%) and increase in temperature by 2100
- Annual Climatology – increase in annual precipitation (greater +/-20%) and an increase in annual temperature by 2100

References

Allen RG, L.S. Pereira, D. Raes, M. Smith, 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. Irrigation and Drainage Paper No. 56, FAO, Rome

Beven, K.J., 2001. *Rainfall-runoff modelling: The Primer*. John Willey and Sons, Chichester, UK. pp 360.

Beven, K.J., 2006. A manifesto for the equifinality thesis. *Journal of Hydrology*, 320, 18-36.

Blösch, G., 1999. Scaling Issues in Snow Hydrology. *Hydrological Processes*, 13, 2149- 2175.

Bonnin, G.M., Todd, D., Lin, B., Parzybok, T., Yekta, M., and D. Riley, 2006: Precipitation-Frequency Atlas of the United States, NOAA Atlas 14, Volumes 1 and 2, NOAA, National Weather Service, Silver Spring, North Carolina. http://hdsc.nws.noaa.gov/hdsc/pfds/

Cai, W., Santoso, A., Collins, M. *et al.*, 2021: Changing El Niño–Southern Oscillation in a warming climate. *Nat Rev Earth Environ* **2**, 628–644, https://doi.org/10.1038/s43017-021-00199-z

Callahan, C., Chen, C., Rugenstein, M., Bloch-Johnson, J., Yang, S., & Moyer, E. J., 2021: Robust decrease in El Niño/Southern Oscillation amplitude under long-term warming. *Nature Climate Change*, *11*(9), 752–757. https://doi.org/10.1038/s41558-021-01099-2

Chaing, S., Y. Tachikawa, and K. Takara, 2007. Hydrological model performance comparison through uncertainty recognition and quantification. *Hydrological Processes*, 21, 1179-1195.

Hansen, E.M., Fenn, D.D., Schreiner, L.C., Stodt, R.W., and J.F., Miller, 1988: Probable Maximum Precipitation Estimates, United States between the Continental Divide and the 103rd Meridian, *Hydrometeorological Report Number 55A*, National weather Service, National Oceanic and Atmospheric Association, U.S. Dept of Commerce, Silver Spring, MD, 242 pp.

Hausfather, Zeke; Peters, Glen P., 2020. "Emissions – the 'business as usual' story is misleading". Nature. 577 (618–620). doi:10.1038/d41586-020-00177-3. Retrieved 2022-03-28.

Heuvelink, G., 1998. *Error Propagation in Environmental Modelling with GIS*. CRC Press, 150 pp.

Hipel, K.W. and McLeod, A.I., (2005). Time Series Modelling of Water Resources and Environmental Systems. Electronic reprint of our book originally published in 1994. http://www.stats. uwo.ca/faculty/aim/1994Book/.

Hosking, J.R.M, 2015a. L-moments. R package, version 2.5. URL: http://CRAN.R-project.org/package=lmom.

Hosking, J.R.M, 2015b. Regional frequency analysis using L-moments. R package, version 3.0-1. URL: http://CRAN.R-project.org/package=lmomRFA.

Hosking, J.R.M. and J.R. Wallis, 1997, "Regional Frequency Analysis, An Approach Based on L-Moments," Cambridge University Press, 224 pp.

IPCC, 2017. Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) Observed Climate Change Impacts Database, Version 2.01. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4FT8J0X.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y.

Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Kampf, S.K., et al., 2020. The case for an open water balance: Re-envisioning network design and data analysis for a complex, uncertain world. *Water Resources Research*, 56(6), e2019WR026699. https://doi.org/10.1029/2019WR026699

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., McGlone, D., Parzybok, T.W, and E.M. Tomlinson, December 2014: Statewide Probable Maximum Precipitation (PMP) Study for Wyoming.

Kappel, W.D., Hultstrand, D.M., Muhlestein, G.A., Steinhilber, K., McGlone, D., Rodel, J., and B. Lawrence, November 2018: Regional Probable Maximum Precipitation for the States of Colorado and New Mexico. Prepared for the Colorado Division of Water Resources and the New Mexico State Engineers Office.

Kappel, W.D., Hultstrand, D.M., Steinhilber, K., and J.T. Rodel, 2020: Climate Change and PMP: Are These Storms Changing? *Journal of Dam Safety*, Vol. 17, No. 3.

Kappel, W.D, Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, Cheke, D., and Steinhilber, K., June 2023: Statewide Probable Maximum Precipitation for New Jersey. Prepared for the New Jersey Dept. of Environmental Protection Dam Safety.

Kappel, W.D, Hultstrand, D.M., Rodel, J.T., Muhlestein, G.A., Venticinque, M, Cheke, D., and Steinhilber, K., January 2024: Statewide Probable Maximum Precipitation for North Carolina. Prepared for the North Carolina Department of the Environment - Dam Safety.

Koren, V.I., B.D. Finnerty, J.C. Schaake, M.B. Smith, D.J. Seo, and Q. Duan, 1999. Scale dependencies of hydrologic models to spatial variability of precipitation. *Journal of Hydrology*, 217, 285-302.

Lehner, F., Deser, C., Maher, N., Marotzke, J., Fischer, E. M., Brunner, L., Knutti, R., and Hawkins, E., 2020. Partitioning climate projection uncertainty with multiple large ensembles and CMIP5/6, Earth Syst. Dynam., 11, 491–508, https://doi.org/10.5194/esd-11-491-2020

Mann, H.B., 1945: Nonparametric tests against trend, Econometric, 13, 245-259.

Mantovan, P., and E. Tondini, 2006. Hydrological forecasting uncertainty assessment: Incoherences of the GLUE methodology. *Journal of Hydrology*, 330(1-2), 368-381.

Masson-Delmotte, Valérie; Zhai, Panmao; Pirani, Anna; Connors, Sarah L.; Péan, Clotilde; Berger, Sophie; Caud, Nada; Chen, Yang; Goldfarb, Leah; Gomis, Melissa I.; Huang, Mengtian; Leitzell, Katherine; Lonnoy, Elisabeth; Matthews, J. B. Robin; Maycock, Tom K.; Waterfield, Tim; Yelekçi, Ozge; Yu, Rong; Zhou, Baiquan, eds., 2021. "Summary for Policymakers". Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (PDF). IPCC / Cambridge University Press.

McLeod, A.I., 2015. Kendall: Kendall rank correlation and Mann-Kendall trend test. R package, version 2.2. URL: https://cran.r-project.org/web/packages/Kendall/index.html.

McSweeney, C.F., Jones, R.G., 2016. How representative is the spread of climate projections from the 5 CMIP5 GCMs used in ISI-MIP? Climate Services vol 1, 24–29. https://doi.org/10.1016/j.cliser.2016.02.001

Perica, S., Pavlovic, S., Laurent, M.S., Trypaluk, D. Unruh, Martin, D., and O. Wilhite, 2015: *NOAA Atlas 14 Volume 10 version 2, Precipitation-Frequency Atlas of the United States, Northeastern States*, NOAA, National Weather Service, Silver Spring, MD.

Pokorny S. et al., 2021. Cumulative Effects of Uncertainty on Simulated Streamflow in a Hydrologic Modeling Environment. Elementa: Science of the Anthropocene 9(1) 431. https://doi.org/10.1525/elementa.431

Rousseau, A.N., I.M. Klein, D. Freudiger, P. Gagnon, A. Frigon, C. Ratté-Fortin, 2014: Development of a methodology to evaluate probable maximum precipitation (PMP) under changing climate conditions: application to southern Quebec, Canada, *J. Hydrol*., 519 (2014), pp. 3094-3109.

Scharffenberg, B., Bartles, M., Brauer, T., Fleming, M., Karlovits, G. 2018. Hydrologic Modeling System HEC-HMS – User's Manual, Version 4.3. U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center (CEIWR-HEC), Davis, CA, USA.

Segond, M.L., C. Onof, and H.S. Wheater, 2006. Spatial-temporal disaggregation of daily rainfall from a generalized linear model. *Journal of Hydrology*, 331, 674-689.

Thrasher, B., Wang, W., Michaelis, A. Nemani, R., 2021. NEX-GDDP-CMIP6. NASA Center for Climate Simulation, doi:10.7917/OFSG3345.

Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T., Nemani, R., 2022. NASA Global Daily Downscaled Projections, CMIP6. Nature Scientific Data (in review)

US Weather Bureau, 1951, Tables of Precipitable Water and Other Factors for a Saturated Pseudo-adiabatic Atmosphere, *Technical Paper Number 14,* US. Department of Commerce, Washington, DC, 66 pp.

Wagener, T., H.S. Wheather, and H.V. Gupta, 2004. *Rainfall-runoff modelling in gauged and ungauged catchments*. Imperial College Press, London pp 306.

Wengel, C., Lee, S.-S., Stuecker, M. F., Timmermann, A., Chu, J.-E., & Schloesser, F., 2021: Future high-resolution El Niño/Southern Oscillation dynamics. *Nature Climate Change*, *11*(9), 758–765. https://doi.org/10.1038/s41558-021-01132-4

World Meteorological Organization, 2009: Manual for Estimation of Probable Maximum Precipitation, No. 1045, WMO, Geneva, 259 pp.

Yang, Li, Z., Yu, J.-Y., Hu, X., Dong, W., & He, S., 2018: El Nino-Southern Oscillation and its impact in the changing climate. *National Science Review*, *5*(6), 840–857. https://doi.org/10.1093/nsr/nwy046

Yu, Wang, X., Yang, S., Paek, H., & Chen, M., 2017: The Changing El Niño–Southern Oscillation and Associated Climate Extremes. In *Climate Extremes* (pp. 1–38). John Wiley & Sons, Inc. https://doi.org/10.1002/9781119068020.ch1

Climate Results Spreadsheet for All Four Regions

Region 1	SSP45				SSP85			
	Mean	Median	10th	90th	Mean	Median	10th	90th
Temperature 1-Day; C	**2.0**	**1.8**	1.0	3.3	**3.9**	**3.4**	2.3	5.8
Temperature 1-Day Summer; C	**2.0**	**1.8**	1.0	3.3	**3.9**	**3.4**	2.3	5.8
Temperature 1-Day Winter PF; C	**2.7**	**2.0**	1.3	3.2	**4.5**	**3.6**	2.4	5.5
Precipitation 1-Day PF; %	**12**	**11**	2	25	**15**	**15**	9	23
Precipitation 1-Day Summer PF; %	**11**	**9**	-4	28	**8**	**3**	-4	31
Precipitation 1-Day Winter PF; %	**14**	**12**	2	29	**16**	**17**	9	24
Precipitation 3-Day PF; %	**9**	**9**	0	22	**14**	**10**	2	32
Precipitation 3-Day Summer PF; %	**11**	**10**	-10	28	**6**	**4**	-8	27
Precipitation 3-Day Winter PF; %	**10**	**9**	0	21	**16**	**14**	3	31
Precipitation 30-Day PF; %	**10**	**10**	-6	24	**16**	**15**	2	34
Precipitation 90-Day PF; %	**9**	**10**	-1	18	**15**	**14**	7	29
Precipitation Annual PF; %	**9**	**9**	4	14	**12**	**12**	5	18
Moisture Maximization 1-Day, %	**Potential Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

Frequency analysis climate change results for Region 1 from current climate (1950-2014) through 2100.

Region 2	SSP45				SSP85			
	Mean	Median	10th	90th	Mean	Median	10th	90th
Temperature 1-Day; C	**1.9**	**1.8**	0.9	3.3	**3.8**	**3.3**	2.1	5.8
Temperature 1-Day Summer; C	**1.9**	**1.8**	0.9	3.3	**3.8**	**3.3**	2.1	5.8
Temperature 1-Day Winter PF; C	**2.7**	**1.9**	1.2	3.1	**4.5**	**3.6**	2.5	5.4
Precipitation 1-Day PF; %	**12**	**11**	2	21	**14**	**13**	5	23
Precipitation 1-Day Summer PF; %	**11**	**12**	-1	24	**9**	**10**	-2	21
Precipitation 1-Day Winter PF; %	**13**	**12**	3	23	**15**	**15**	6	24
Precipitation 3-Day PF; %	**8**	**8**	-3	22	**14**	**9**	-1	37
Precipitation 3-Day Summer PF; %	**9**	**9**	-8	24	**6**	**3**	-8	26
Precipitation 3-Day Winter PF; %	**9**	**9**	-3	22	**15**	**12**	1	36
Precipitation 30-Day PF; %	**11**	**12**	-8	25	**17**	**15**	2	28
Precipitation 90-Day PF; %	**10**	**12**	-3	19	**16**	**15**	6	27
Precipitation Annual PF; %	**9**	**9**	4	15	**12**	**12**	6	18
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**Potential Change**				**No Change**			

Frequency analysis climate change results for Region 2 from current climate (1950-2014) through 2100.

Region 3	SSP45				SSP85			
	Mean	Median	10th	90th	Mean	Median	10th	90th
Temperature 1-Day; C	**1.8**	**1.8**	0.5	3.2	**3.8**	**3.4**	2.3	6.1
Temperature 1-Day Summer; C	**1.8**	**1.8**	0.5	3.2	**3.8**	**3.4**	2.3	6.1
Temperature 1-Day Winter PF; C	**1.8**	**2.1**	1.2	2.7	**3.5**	**3.4**	2.4	5.0
Precipitation 1-Day PF; %	**8**	**8**	-7	23	**10**	**10**	-4	25
Precipitation 1-Day Summer PF; %	**5**	**5**	-13	28	**6**	**2**	-12	29
Precipitation 1-Day Winter PF; %	**12**	**12**	2	27	**15**	**14**	0	32
Precipitation 3-Day PF; %	**8**	**7**	-6	22	**11**	**8**	1	30
Precipitation 3-Day Summer PF; %	**1**	**3**	-14	15	**3**	**0**	-13	24
Precipitation 3-Day Winter PF; %	**14**	**11**	-3	34	**17**	**17**	2	31
Precipitation 30-Day PF; %	**11**	**12**	-3	22	**17**	**17**	3	33
Precipitation 90-Day PF; %	**11**	**11**	0	23	**16**	**16**	7	27
Precipitation Annual PF; %	**10**	**10**	4	16	**12**	**12**	6	22
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

Frequency analysis climate change results for Region 3 from current climate (1950-2014) through 2100.

Region 4	SSP45				SSP85			
	Mean	Median	10th	90th	Mean	Median	10th	90th
Temperature 1-Day; C	**1.7**	**1.8**	0.7	3.2	**4.7**	**3.0**	2.2	5.6
Temperature 1-Day Summer; C	**1.7**	**1.8**	0.7	3.2	**4.7**	**3.0**	2.2	5.6
Temperature 1-Day Winter PF; C	**1.6**	**1.8**	1.0	2.3	**3.1**	**3.2**	1.8	4.4
Precipitation 1-Day PF; %	**3**	**0**	-7	14	**6**	**4**	-11	24
Precipitation 1-Day Summer PF; %	**0**	**-1**	-19	20	**2**	**0**	-18	26
Precipitation 1-Day Winter PF; %	**7**	**6**	-5	18	**9**	**8**	-3	21
Precipitation 3-Day PF; %	**2**	**1**	-6	14	**6**	**6**	-6	17
Precipitation 3-Day Summer PF; %	**-1**	**-1**	-16	15	**3**	**1**	-18	22
Precipitation 3-Day Winter PF; %	**8**	**7**	-6	22	**13**	**13**	-3	28
Precipitation 30-Day PF; %	**6**	**4**	-5	15	**9**	**8**	0	17
Precipitation 90-Day PF; %	**7**	**7**	-3	16	**9**	**9**	1	18
Precipitation Annual PF; %	**8**	**8**	-2	15	**10**	**9**	2	18
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**Potential Change**			

Frequency analysis climate change results for Region 4 from current climate (1950-2014) through 2100.

All	SSP45				SSP85			
	Mean	Median	10th	90th	Mean	Median	10th	90th
Temperature 1-Day; C	**1.8**	**1.8**	0.5	3.3	**4.0**	**3.3**	2.1	6.1
Temperature 1-Day Summer; C	**1.8**	**1.8**	0.5	3.3	**4.0**	**3.3**	2.1	6.1
Temperature 1-Day Winter PF; C	**2.2**	**2.0**	1.0	3.2	**3.9**	**3.4**	1.8	5.5
Precipitation 1-Day PF; %	**9**	**7**	-7	25	**11**	**10**	-11	25
Precipitation 1-Day Summer PF; %	**7**	**6**	-19	28	**6**	**4**	-18	31
Precipitation 1-Day Winter PF; %	**11**	**10**	-5	29	**14**	**13**	-3	32
Precipitation 3-Day PF; %	**7**	**6**	-6	22	**11**	**8**	-6	37
Precipitation 3-Day Summer PF; %	**5**	**5**	-16	28	**5**	**2**	-18	27
Precipitation 3-Day Winter PF; %	**10**	**9**	-6	34	**15**	**14**	-3	36
Precipitation 30-Day PF; %	**9**	**10**	-8	25	**15**	**14**	0	34
Precipitation 90-Day PF; %	**9**	**10**	-3	23	**14**	**13**	1	29
Precipitation Annual PF; %	**9**	**9**	-2	16	**12**	**11**	2	22
Moisture Maximization 1-Day, %								
Moisture Maximization 3-Day; %								

Frequency analysis climate change results for All Regions from current climate (1950-2014) through 2100.

Region 1		Precipitation					Temperature
		1-day	3-day	30-day	90-day	Annual	1-day
Historic	no trend	25	25	24	24	22	2
	increase	1	1	2	2	4	24
	decrease	0	0	0	0	0	0
SSP45	no trend	19	20	22	19	17	3
	increase	7	6	4	7	9	23
	decrease	0	0	0	0	0	0
SSP85	no trend	10	11	9	7	11	0
	increase	16	15	17	19	15	26
	decrease	0	0	0	0	0	0

North Carolina trend analysis results from current climate (1950-2014) to 2015 through 2100 for Region 1. The numbers represent the climate models that had no trend, a significant increase or decrease trend.

Region 2		Precipitation					Temperature
		1-day	3-day	30-day	90-day	Annual	1-day
Historic	no trend	24	26	24	22	22	3
	increase	2	0	2	4	4	23
	decrease	0	0	0	0	0	0
SSP45	no trend	19	21	20	18	16	3
	increase	7	5	6	8	10	23
	decrease	0	0	0	0	0	0
SSP85	no trend	11	15	11	10	12	0
	increase	15	11	15	16	14	26
	decrease	0	0	0	0	0	0

North Carolina trend analysis results from current climate (1950-2014) to 2015 through 2100 for Region 2. The numbers represent the climate models that had no trend, a significant increase or decrease trend.

Region 3		Precipitation					Temperature
		1-day	3-day	30-day	90-day	Annual	1-day
Historic	no trend	26	24	23	23	22	2
	increase	0	2	3	3	4	24
	decrease	0	0	0	0	0	0
SSP45	no trend	18	19	18	17	12	7
	increase	8	7	8	9	14	19
	decrease	0	0	0	0	0	0
SSP85	no trend	6	12	13	14	12	0
	increase	20	14	13	12	14	26
	decrease	0	0	0	0	0	0

North Carolina trend analysis results from current climate (1950-2014) to 2015 through 2100 for Region 3. The numbers represent the climate models that had no trend, a significant increase or decrease trend.

Region 4		Precipitation					Temperature
		1-day	3-day	30-day	90-day	Annual	1-day
Historic	no trend	21	23	24	25	22	2
	increase	2	1	2	1	4	24
	decrease	3	2	0	0	0	3
SSP45	no trend	20	20	21	20	16	23
	increase	6	5	5	6	8	3
	decrease	0	1	0	0	2	0
SSP85	no trend	14	15	19	19	15	0
	increase	12	11	7	7	11	26
	decrease	0	0	0	0	0	0

North Carolina trend analysis results from current climate (1950-2014) to 2015 through 2100 for Region 4. The numbers represent the climate models that had no trend, a significant increase or decrease trend.

Average		Precipitation					Temperature
		1-day	3-day	30-day	90-day	Annual	1-day
Historic	no trend	96	98	95	94	88	9
	increase	5	4	9	10	16	95
	decrease	3	2	0	0	0	3
SSP45	no trend	76	80	81	74	61	36
	increase	28	23	23	30	41	68
	decrease	0	1	0	0	2	0
SSP85	no trend	41	53	52	50	50	0
	increase	63	51	52	54	54	104
	decrease	0	0	0	0	0	0

North Carolina trend analysis results from current climate (1950-2014) to 2015 through 2100 for All Regions. The numbers represent the climate models that had no trend, a significant increase or decrease trend.

Average as Percent		Precipitation					Temperature
		1-day	3-day	30-day	90-day	Annual	1-day
Historic	no trend	92%	94%	91%	90%	85%	9%
	increase	5%	4%	9%	10%	15%	91%
	decrease	3%	2%	0%	0%	0%	3%
SSP45	no trend	73%	77%	78%	71%	59%	35%
	increase	27%	22%	22%	29%	39%	65%
	decrease	0%	1%	0%	0%	2%	0%
SSP85	no trend	39%	51%	50%	48%	48%	0%
	increase	61%	49%	50%	52%	52%	100%
	decrease	0%	0%	0%	0%	0%	0%

North Carolina trend analysis results from current climate (1950-2014) to 2015 through 2100 for All Regions (average as %). The numbers represent the climate models that had no trend, a significant increase or decrease trend.

Region 1	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	2.0	1.8	4.0	4.2	4.7	4.5	*2.1*	*2.5*	*2.5*	*2.8*
February	4.4	4.1	6.9	6.8	7.5	7.4	*2.5*	*3.1*	*2.7*	*3.3*
March	8.9	8.5	11.5	11.5	12.2	12.0	*2.6*	*3.3*	*3.0*	*3.6*
April	13.9	13.4	16.5	16.4	17.3	17.2	*2.6*	*3.4*	*3.0*	*3.8*
May	18.3	18.0	20.8	20.8	21.7	21.8	*2.5*	*3.4*	*2.8*	*3.8*
June	21.6	21.4	23.7	23.7	24.6	24.6	*2.1*	*3.0*	*2.4*	*3.2*
July	22.5	22.2	24.5	24.5	25.5	25.3	*2.0*	*2.9*	*2.3*	*3.1*
August	21.7	21.5	23.7	23.8	24.8	24.7	*2.0*	*3.1*	*2.3*	*3.2*
September	18.1	17.8	20.0	19.9	21.0	20.8	*1.9*	*2.9*	*2.1*	*3.0*
October	11.8	11.4	13.7	13.4	14.9	15.0	*1.9*	*3.1*	*2.0*	*3.6*
November	6.6	6.2	8.1	8.0	8.9	8.6	*1.6*	*2.4*	*1.9*	*2.5*
December	2.7	2.4	4.4	4.5	5.0	4.9	*1.7*	*2.3*	*2.1*	*2.5*

North Carolina monthly temperature change from current climate (1950-2014) to 2015-2100 for Region 1.

Region 2	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	3.6	3.3	5.7	5.7	6.3	6.1	*2.1*	*2.5*	*2.4*	*2.8*
February	6.1	5.8	8.6	8.4	9.2	9.0	*2.5*	*3.0*	*2.6*	*3.3*
March	10.6	10.2	13.1	13.0	13.8	13.6	*2.5*	*3.2*	*2.8*	*3.4*
April	15.4	15.0	18.0	17.9	18.9	18.7	*2.6*	*3.4*	*2.9*	*3.7*
May	19.8	19.5	22.2	22.2	23.2	23.3	*2.4*	*3.3*	*2.7*	*3.8*
June	23.0	22.8	25.1	25.1	26.0	26.1	*2.1*	*3.0*	*2.4*	*3.3*
July	23.9	23.6	25.9	25.8	26.8	26.7	*2.0*	*3.0*	*2.2*	*3.1*
August	23.1	22.8	25.0	25.1	26.1	25.9	*2.0*	*3.1*	*2.3*	*3.1*
September	19.5	19.1	21.3	21.2	22.4	22.2	*1.8*	*2.9*	*2.1*	*3.1*
October	13.2	12.8	15.2	15.0	16.4	16.2	*1.9*	*3.1*	*2.2*	*3.4*
November	8.0	7.6	9.6	9.6	10.5	10.2	*1.6*	*2.4*	*2.0*	*2.6*
December	4.3	4.0	6.0	6.1	6.6	6.5	*1.7*	*2.3*	*2.2*	*2.5*

North Carolina monthly temperature change from current climate (1950-2014) to 2015-2100 for Region 2.

Region 3	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	4.7	4.3	6.9	6.8	7.5	7.1	*2.1*	*2.4*	*2.5*	*2.8*
February	7.3	6.9	9.8	9.5	10.4	10.2	*2.5*	*3.1*	*2.6*	*3.3*
March	11.9	11.6	14.6	14.6	15.2	15.1	*2.6*	*3.3*	*3.0*	*3.6*
April	17.0	16.6	19.7	19.5	20.5	20.3	*2.7*	*3.5*	*2.9*	*3.7*
May	21.6	21.3	24.0	23.9	24.9	25.0	*2.4*	*3.3*	*2.6*	*3.7*
June	25.0	24.7	27.2	27.3	28.1	28.2	*2.2*	*3.1*	*2.5*	*3.4*
July	26.0	25.8	28.0	28.0	29.0	28.8	*2.0*	*2.9*	*2.2*	*3.0*
August	25.0	24.7	27.0	27.1	28.1	28.0	*1.9*	*3.1*	*2.4*	*3.3*
September	21.2	21.0	23.1	23.0	24.2	23.9	*1.9*	*2.9*	*2.0*	*3.0*
October	14.8	14.4	16.7	16.5	18.0	17.8	*1.9*	*3.1*	*2.1*	*3.4*
November	9.5	9.1	11.1	11.0	11.9	11.7	*1.6*	*2.4*	*1.9*	*2.6*
December	5.5	5.3	7.4	7.3	7.9	7.7	*1.8*	*2.4*	*2.1*	*2.4*

North Carolina monthly temperature change from current climate (1950-2014) to 2015-2100 for Region 3.

Region 4	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	6.6	6.3	8.5	8.5	9.2	8.9	*1.9*	*2.3*	*2.2*	*2.6*
February	8.9	8.6	11.2	11.0	11.8	11.5	*2.3*	*2.9*	*2.4*	*2.9*
March	13.1	12.8	15.5	15.5	16.2	16.3	*2.4*	*3.1*	*2.7*	*3.5*
April	18.0	17.6	20.4	20.4	21.0	20.9	*2.4*	*3.0*	*2.8*	*3.3*
May	22.3	22.1	24.4	24.5	25.2	25.3	*2.1*	*2.9*	*2.4*	*3.2*
June	25.8	25.5	27.8	27.9	28.6	28.6	*2.1*	*2.9*	*2.4*	*3.1*
July	26.9	26.6	28.7	28.8	29.5	29.5	*1.8*	*2.6*	*2.2*	*2.9*
August	25.9	25.7	27.6	27.8	28.7	28.7	*1.7*	*2.7*	*2.1*	*3.0*
September	22.7	22.6	24.3	24.2	25.2	25.3	*1.6*	*2.5*	*1.7*	*2.8*
October	16.7	16.3	18.5	18.2	19.6	19.5	*1.8*	*2.9*	*1.9*	*3.2*
November	11.5	11.2	13.0	13.0	13.9	13.7	*1.5*	*2.4*	*1.9*	*2.5*
December	7.7	7.3	9.2	9.2	9.9	9.7	*1.5*	*2.2*	*1.9*	*2.4*

North Carolina monthly temperature change from current climate (1950-2014) to 2015-2100 for Region 4.

All	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	4.2	3.9	6.3	6.3	6.9	6.7	*2.1*	*2.4*	*2.4*	*2.7*
February	6.7	6.4	9.1	8.9	9.7	9.5	*2.4*	*3.0*	*2.6*	*3.2*
March	11.1	10.8	13.7	13.6	14.4	14.3	*2.6*	*3.2*	*2.9*	*3.5*
April	16.1	15.7	18.7	18.6	19.4	19.3	*2.6*	*3.3*	*2.9*	*3.6*
May	20.5	20.2	22.8	22.8	23.7	23.8	*2.3*	*3.2*	*2.6*	*3.6*
June	23.8	23.6	26.0	26.0	26.8	26.9	*2.1*	*3.0*	*2.4*	*3.3*
July	24.8	24.6	26.8	26.7	27.7	27.6	*1.9*	*2.9*	*2.2*	*3.0*
August	23.9	23.7	25.8	25.9	26.9	26.8	*1.9*	*3.0*	*2.3*	*3.1*
September	20.4	20.1	22.2	22.1	23.2	23.0	*1.8*	*2.8*	*2.0*	*3.0*
October	14.2	13.7	16.0	15.8	17.2	17.1	*1.9*	*3.1*	*2.0*	*3.4*
November	8.9	8.5	10.5	10.4	11.3	11.0	*1.6*	*2.4*	*1.9*	*2.5*
December	5.0	4.7	6.7	6.8	7.3	7.2	*1.7*	*2.3*	*2.1*	*2.5*

North Carolina monthly temperature change from current climate (1950-2014) to 2015-2100 for All Regions (average).

Region 1	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	103.7	102.7	113.3	114.1	119.8	119.7	*1.09*	*1.16*	*1.11*	*1.17*
February	98.4	98.5	109.2	109.7	113.1	113.2	*1.11*	*1.15*	*1.11*	*1.15*
March	116.7	117.3	124.7	125.6	128.8	128.9	*1.07*	*1.10*	*1.07*	*1.10*
April	105.7	104.9	114.0	113.0	109.9	109.6	*1.08*	*1.04*	*1.08*	*1.05*
May	119.1	119.0	125.4	125.4	124.9	121.3	*1.05*	*1.05*	*1.05*	*1.02*
June	114.5	114.7	123.1	121.2	123.1	121.2	*1.08*	*1.07*	*1.06*	*1.06*
July	125.1	125.6	134.3	135.5	138.7	136.4	*1.07*	*1.11*	*1.08*	*1.09*
August	108.7	109.6	118.2	116.5	120.7	120.1	*1.09*	*1.11*	*1.06*	*1.10*
September	90.8	90.0	97.2	97.6	93.3	92.1	*1.07*	*1.03*	*1.09*	*1.02*
October	82.0	81.8	82.6	80.7	83.8	84.4	*1.01*	*1.02*	*0.99*	*1.03*
November	96.8	96.7	103.6	102.0	106.7	104.8	*1.07*	*1.10*	*1.06*	*1.08*
December	107.1	106.4	114.7	111.8	121.2	120.9	*1.07*	*1.13*	*1.05*	*1.14*

North Carolina monthly precipitation (mm) change from current climate (1950-2014) to 2015 through 2100 for Region 1.

Region 2	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	102.1	101.2	109.5	110.3	116.7	115.5	*1.07*	*1.14*	*1.09*	*1.14*
February	96.5	96.1	105.9	106.2	109.2	109.8	*1.10*	*1.13*	*1.11*	*1.14*
March	114.3	114.8	120.7	121.7	124.1	124.4	*1.06*	*1.09*	*1.06*	*1.08*
April	100.5	100.5	109.2	108.7	105.0	105.3	*1.09*	*1.04*	*1.08*	*1.05*
May	116.2	116.5	123.4	123.4	122.5	119.7	*1.06*	*1.05*	*1.06*	*1.03*
June	111.8	112.2	121.8	121.9	120.8	120.1	*1.09*	*1.08*	*1.09*	*1.07*
July	123.2	123.3	132.9	133.7	137.1	134.7	*1.08*	*1.11*	*1.08*	*1.09*
August	110.2	109.8	122.1	119.9	122.9	122.9	*1.11*	*1.12*	*1.09*	*1.12*
September	93.0	93.1	101.2	101.3	97.5	96.2	*1.09*	*1.05*	*1.09*	*1.03*
October	83.1	82.9	84.3	83.0	85.5	85.2	*1.02*	*1.03*	*1.00*	*1.03*
November	92.9	92.5	100.1	98.5	102.2	102.0	*1.08*	*1.10*	*1.06*	*1.10*
December	101.8	101.7	109.5	108.2	115.8	116.3	*1.08*	*1.14*	*1.06*	*1.14*

North Carolina monthly precipitation (mm) change from current climate (1950-2014) to 2015 through 2100 for Region 2.

Region 3	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	87.3	87.6	94.5	96.7	100.7	100.8	*1.08*	*1.15*	*1.10*	*1.15*
February	81.0	82.2	91.2	93.2	93.8	93.1	*1.13*	*1.16*	*1.13*	*1.13*
March	94.9	94.3	101.9	101.0	105.5	106.6	*1.07*	*1.11*	*1.07*	*1.13*
April	82.7	82.9	91.3	91.6	87.9	87.3	*1.10*	*1.06*	*1.11*	*1.05*
May	99.2	98.9	106.6	106.9	106.1	105.1	*1.07*	*1.07*	*1.08*	*1.06*
June	102.9	103.3	111.1	113.0	111.0	111.7	*1.08*	*1.08*	*1.09*	*1.08*
July	119.3	118.6	128.9	129.7	132.5	132.7	*1.08*	*1.11*	*1.09*	*1.12*
August	106.4	106.0	117.5	117.6	119.6	119.6	*1.10*	*1.12*	*1.11*	*1.13*
September	84.6	83.3	89.7	90.0	88.7	87.1	*1.06*	*1.05*	*1.08*	*1.05*
October	74.2	74.1	74.6	74.7	76.6	76.4	*1.01*	*1.03*	*1.01*	*1.03*
November	76.3	77.4	83.0	82.1	84.7	83.4	*1.09*	*1.11*	*1.06*	*1.08*
December	86.5	86.5	93.2	91.7	98.5	99.2	*1.08*	*1.14*	*1.06*	*1.15*

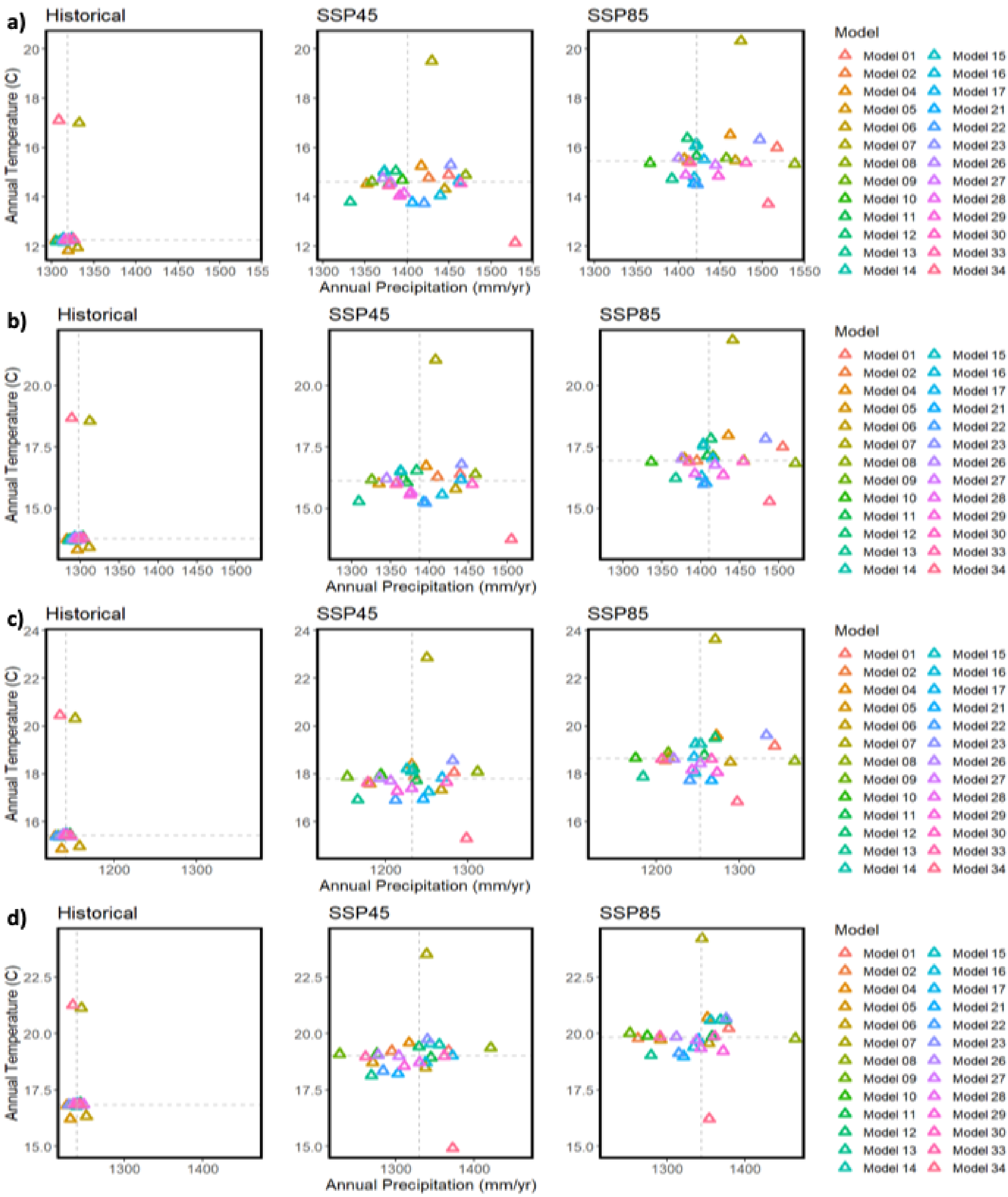
North Carolina monthly precipitation (mm) change from current climate (1950-2014) to 2015 through 2100 for Region 3.

Region 4	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	90.7	91.2	97.7	98.0	101.6	100.4	***1.08***	***1.12***	***1.07***	***1.10***
February	81.2	81.1	89.4	90.5	90.8	92.2	***1.10***	***1.12***	***1.12***	***1.14***
March	91.0	90.8	95.5	94.8	97.4	98.0	***1.05***	***1.07***	***1.04***	***1.08***
April	79.2	80.2	86.5	86.0	82.7	82.6	***1.09***	***1.04***	***1.07***	***1.03***
May	100.3	99.6	108.2	109.8	106.3	105.9	***1.08***	***1.06***	***1.10***	***1.06***
June	116.0	115.4	126.2	126.4	126.2	126.0	***1.09***	***1.09***	***1.10***	***1.09***
July	151.1	150.5	160.9	162.1	160.4	162.5	***1.06***	***1.06***	***1.08***	***1.08***
August	139.7	139.7	150.6	152.1	147.6	146.8	***1.08***	***1.06***	***1.09***	***1.05***
September	102.2	102.5	107.1	108.4	107.6	107.5	***1.05***	***1.05***	***1.06***	***1.05***
October	80.4	79.5	80.7	80.9	81.9	83.4	***1.00***	***1.02***	***1.02***	***1.05***
November	73.9	72.6	78.7	78.4	81.6	80.9	***1.06***	***1.10***	***1.08***	***1.12***
December	89.0	89.4	95.6	94.5	100.3	98.8	***1.07***	***1.13***	***1.06***	***1.11***

North Carolina monthly precipitation (mm) change from current climate (1950-2014) to 2015 through 2100 for Region 4.

All	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	95.9	95.6	103.8	104.8	109.7	109.1	***1.08***	***1.14***	***1.10***	***1.14***
February	89.3	89.5	98.9	99.9	101.7	102.1	***1.11***	***1.14***	***1.12***	***1.14***
March	104.2	104.3	110.7	110.8	113.9	114.5	***1.06***	***1.09***	***1.06***	***1.10***
April	92.0	92.1	100.2	99.8	96.4	96.2	***1.09***	***1.05***	***1.08***	***1.04***
May	108.7	108.5	115.9	116.4	115.0	113.0	***1.07***	***1.06***	***1.07***	***1.04***
June	111.3	111.4	120.5	120.6	120.3	119.7	***1.08***	***1.08***	***1.08***	***1.08***
July	129.7	129.5	139.2	140.2	142.2	141.6	***1.07***	***1.10***	***1.08***	***1.09***
August	116.3	116.3	127.1	126.5	127.7	127.3	***1.09***	***1.10***	***1.09***	***1.10***
September	92.7	92.2	98.8	99.3	96.8	95.7	***1.07***	***1.04***	***1.08***	***1.04***
October	79.9	79.5	80.6	79.8	82.0	82.3	***1.01***	***1.03***	***1.00***	***1.03***
November	85.0	84.8	91.3	90.2	93.8	92.8	***1.07***	***1.10***	***1.06***	***1.09***
December	96.1	96.0	103.3	101.5	108.9	108.8	***1.07***	***1.13***	***1.06***	***1.13***

North Carolina monthly precipitation (mm) change from current climate (1950-2014) to 2015 through 2100 for All Regions (average).



Comparison of mean annual temperature and mean annual precipitation for the three climate projection periods for: (a) Region 1, (b) Region 2, (c) Region 3 and (d) Region 4.

	Temp	Ppt	Delta C	Ppt %
Hist	12.2	1319		
SP45	14.6	1401	2.4	6%
SP85	15.5	1422	3.2	8%

	Temp	Ppt	Delta C	Ppt %
Hist	13.8	1298		
SSP45	16.1	1387	2.4	7%
SSP85	16.9	1411	3.2	9%

	Temp	Ppt	Delta C	Ppt %
Hist	15.4	1142		
SSP45	17.8	1233	2.4	8%
SSP85	18.6	1253	3.2	10%

	Temp	Ppt	Delta C	Ppt %
Hist	16.8	1239		
SSP45	19.0	1330	2.2	7%
SSP85	19.8	1344	3.0	8%

Median annual temperature and precipitation from 3 climate projections

Climate Change Projections for North Carolina

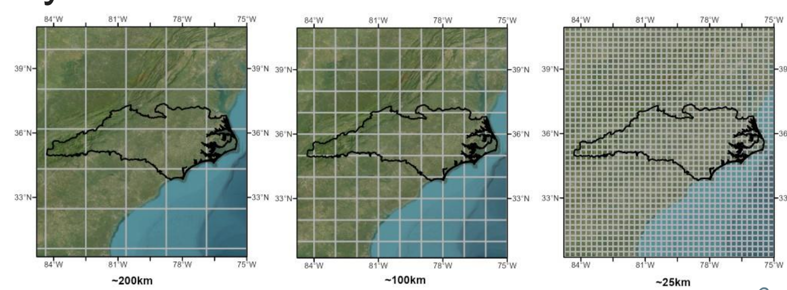
Applied Weather Associates (AWA)

Doug Hultstrand, PhD
Bill Kappel

March 2025

1) Climate Model Background

- Several Global Climate Models, each try to solve atmospheric dynamics to replicate future climate conditions
  - Very coarse resolution in space and time
  - Gross assumptions
  - Many unknowns
- Global Models are downscaled using Regional Climate Models to better replicate local climate/topography
- Two types of downscaling
  - Statistical
  - Dynamic



North Carolina Global and Regional Climate Model Resolution

2

1) Climate Model Background

- Various research groups conduct climate change modeling
  - Share data via CMIP6 group
  - Utilize same requirements to make each model comparable
- Shared Socioeconomic Pathway (SSP)
  - SSP account for unknown future GHG emissions
- SSP scenarios used as boundary conditions for CMIP6 GCMs
  - Commonly use SSP 4.5 and 8.5

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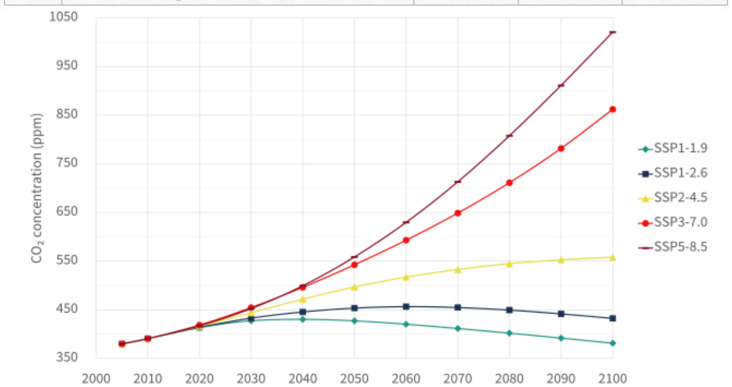
1) Climate Model Projections/Output

- The **SPP 4.5** intermediate GHG emissions: CO2 emissions around current levels until 2050, then falling but not reaching net zero by 2100

- The **SPP 8.5** very high GHG emissions: CO2 emissions triple by 2075

SSP	Scenario	Estimated warming (2041–2060)	Estimated warming (2081–2100)	Very likely range in °C (2081–2100)
SSP1-1.9	very low GHG emissions: CO_2 emissions cut to net zero around 2050	1.6 °C	1.4 °C	1.0 – 1.8
SSP1-2.6	low GHG emissions: CO_2 emissions cut to net zero around 2075	1.7 °C	1.8 °C	1.3 – 2.4
SSP2-4.5	intermediate GHG emissions: CO_2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	2.0 °C	2.7 °C	2.1 – 3.5
SSP3-7.0	high GHG emissions: CO_2 emissions double by 2100	2.1 °C	3.6 °C	2.8 – 4.6
SSP5-8.5	very high GHG emissions: CO_2 emissions triple by 2075	2.4 °C	4.4 °C	3.3 – 5.7



**** SSP45 values are “**likely**” and SSP85 “unlikely”*

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4

1) Climate Model Background

- Each model (global/regional) has issues/unknowns/errors/uncertainty
  - Incorrect replication of atmospheric processes
  - Inability to numerically quantify certain processes
  - Unknown positive/negative feedbacks
  - Inaccurate observational/gridded data
  - Future GHG concentrations
  - Downscaling techniques
  - Natural variability of climate system

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1) Climate Model Background

- No one climate model produces an ideal simulation
- Each represents one of many possible realizations
  - Utilize an **ensemble approach**
  - One model -multiple initial conditions
  - One GHG scenario but multiple models
- Range/distribution of ensemble projections are indicative of uncertainty
- Precipitation, especially extreme precip, shows the greatest range of variability
- Do provide useful projections and "what if" scenarios

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2) "Within Uncertainty" Term

- The meaning of ***"within uncertainty"*** for this analysis
- Multiple sources of uncertainty and varying ranges of uncertainty
  - Gauge/Observed Precipitation
    - Point measurement 5 to 15% percent for long -term series, and as high as 75% for individual storm events
  - Frequency Analysis
    - NOAA 24 -hour 100-year error bounds are approximately +/ -18%
  - Climate Projections
    - Regional Models can be quite large 20 to >50%
  - PMP Storm In-place Maximization Factor
    - Range between 5 and 30%, with an average around 20%
- Consider +/- 20% to be within uncertainty of the analysis results.

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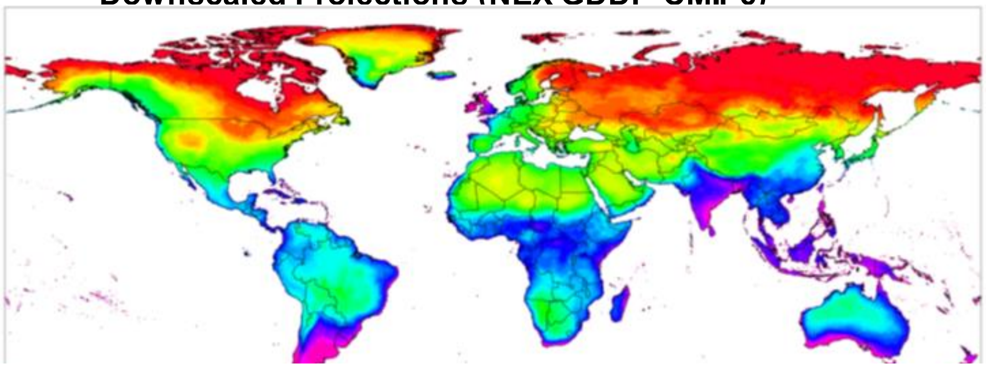
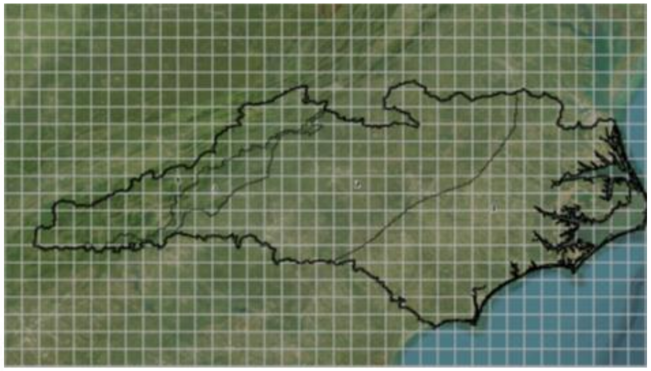
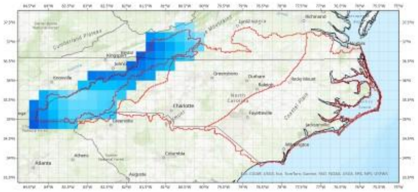
2) Climate Model Projections

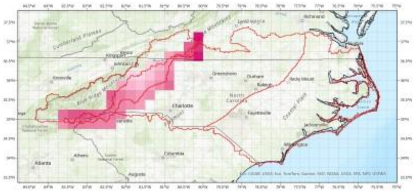
NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)



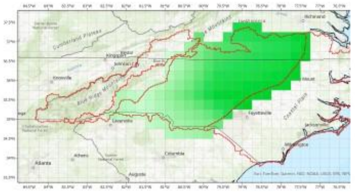




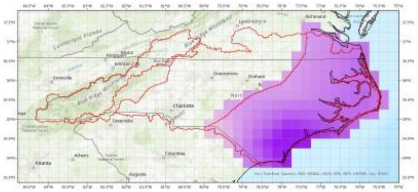
Region 1



Region 2



Region 3



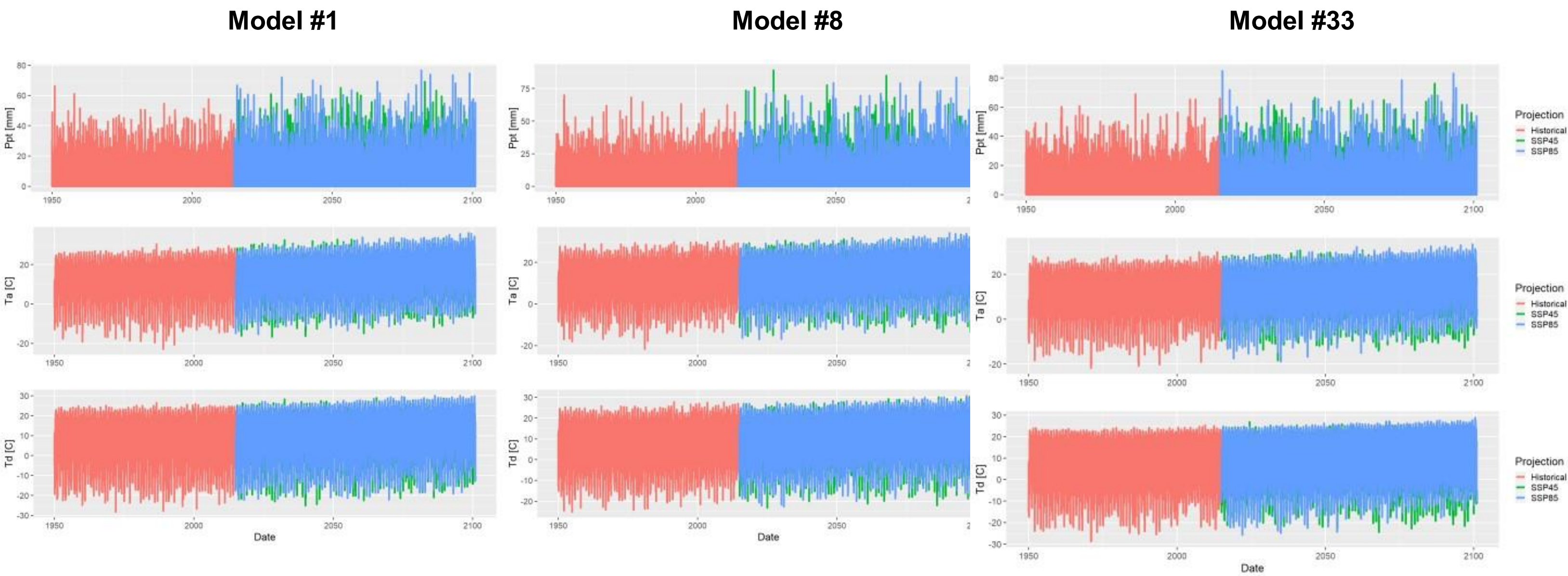
Region 4

2) Climate Model Projections Used

- 26 models on daily time step
  - Temperature (tas)
  - Relative humidity (hurs)
  - Precipitation (pr)

		Relative Humidity (hurs)			Precipitation (pr)			Temperature (tas)		
Model #	MODEL NAME	HISTORICAL	SSP45	SSP85	HISTORICAL	SSP45	SSP85	HISTORICAL	SSP45	SSP85
1	ACCESS-CM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
2	ACCESS-ESM1-5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
4	CanESM5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
5	CESM2-WACCM	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
6	CESM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
7	CMCC-CM2-SR5	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
8	CMCC-ESM2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
9	CNRM-CM6-1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
10	CNRM-ESM2-1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
11	EC-Earth3-Veg-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
12	EC-Earth3	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
13	FGOALS-g3	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
14	GFDL-CM4_gr1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
15	GFDL-CM4_gr2	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
16	GFDL-ESM4	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
17	GISS-E2-1-G	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
21	INM-CM4-8	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
22	INM-CM5-0	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
23	IPSL-CM6A-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
26	MIROC-ES2L	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
27	MIROC6	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
28	MPI-ESM1-2-HR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
29	MPI-ESM1-2-LR	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
30	MRI-ESM2-0	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
33	NorESM2-MM	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100
34	TaiESM1	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100	1950-2014	2015-2100	2015-2100

2) Climate Model Analysis Input (Model 1, 8, 33)



3) Climate Change Analysis Methods

- **1) Trend Analysis** for 1-day, 3-day, and Annual
  - Station Data
  - Model projections (Historic, SSP45, SSP85)
- **2) Monthly and Annual Analysis**
  - Model projections (Historic, SSP45, SSP85)
- **3) Precipitation Frequency Analysis** for 1-day, 3-day, 30-day, 90-day, and Annual
  - Precipitation, Summer Period, and Winter Period
  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes
- **4) Moisture Maximization Analysis** for 1-day and 3-day
  - Derive model projection monthly Td climatologies (Historic, SSP45, SSP85)
  - Quantify changes

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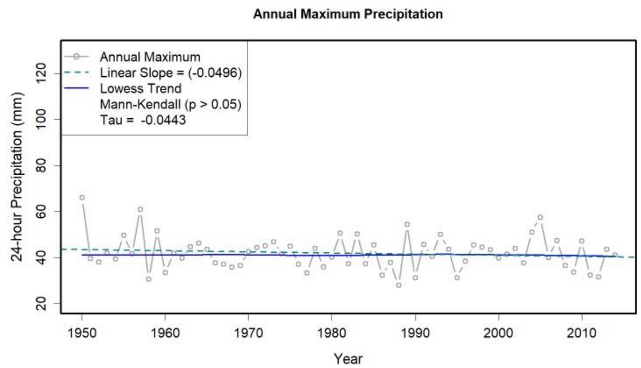
3.1) Model Trend Analysis (1-day Example)

- 1-day AMS Trend Analysis (Mann -Kendall)



- 1) Model 1
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **no trend**
- 2) Model 2
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **increasing trend**
    - SSP85: **no trend**
- 3) Model 4
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **increasing trend**
- 4) Model 5
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **increasing trend**
    - SSP85: **increasing trend**
- 5) Model 6
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **increasing trend**

Completed for 1-day, 3-day, annual, and by season

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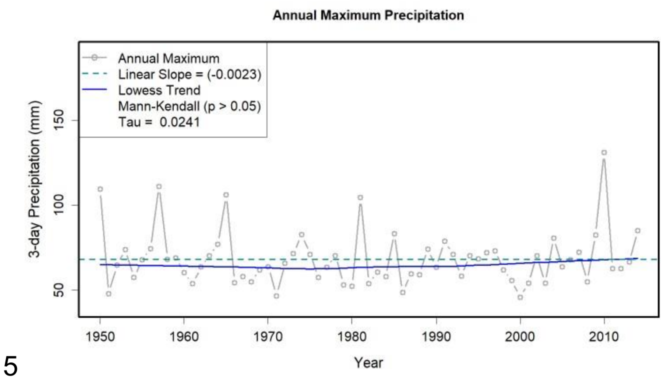
3.1) Model Trend Analysis (3-day Example)

- 3-day AMS Trend Analysis (Mann -Kendall)



- 1) Model 1
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **no trend**
- 2) Model 2
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **increasing trend**
- 3) Model 4
  - trend depends on period investigated
    - Historical: **increasing trend**
    - SSP45: **increasing trend**
    - SSP85: **increasing trend**
- 4) Model 5
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **no trend**
- 5) Model 6
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **increasing trend**
    - SSP85: **increasing trend**

Completed for 1-day, 3-day, annual, and by season

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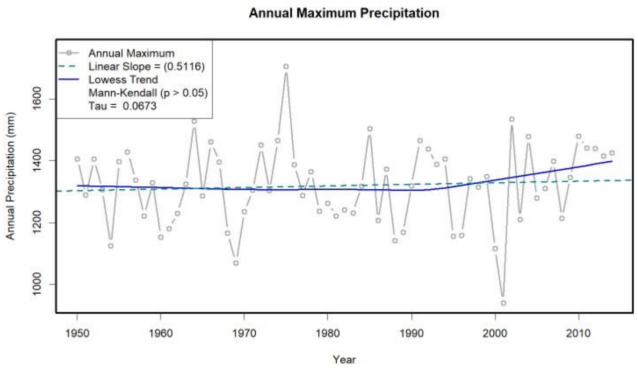
3.1) Model Trend Analysis (365-day Example)

- 365-day AMS Trend Analysis (Mann -Kendall)



- 1) Model 1
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **increasing trend**
- 2) Model 2
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **increasing trend**
    - SSP85: **no trend**
- 3) Model 4
  - trend depends on period investigated
    - Historical: **increasing trend**
    - SSP45: **increasing trend**
    - SSP85: **increasing trend**
- 4) Model 5
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **no trend**
- 5) Model 6
  - trend depends on period investigated
    - Historical: **no trend**
    - SSP45: **no trend**
    - SSP85: **increasing trend**

Completed for 1-day, 3-day, annual, and by season

3.1) Climate Model Trend Results

	Precipitation					Temperature
	1-day	3-day	30-day	90-day	Annual	1-day
Historic	25 – no trend 1 – increase 0 – decrease	25 – no trend 1 – increase 0 – decrease	24 – no trend 2 – increase 0 – decrease	24 – no trend 2 – increase 0 – decrease	22 – no trend 4 – increase 0 – decrease	2 – no trend 24 – increase 0 – decrease
SSP45	19 – no trend 7 – increase 0 – decrease	20 – no trend 6 – increase 0 – decrease	22 – no trend 4 – increase 0 – decrease	19 – no trend 7 – increase 0 – decrease	17 – no trend 9 – increase 0 – decrease	3 – no trend 23 – increase 0 – decrease
SSP85	10 – no trend 16 – increase 0 – decrease	11 – no trend 15 – increase 0 – decrease	9 – no trend 17 – increase 0 – decrease	7 – no trend 19 – increase 0 – decrease	11 – no trend 15 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

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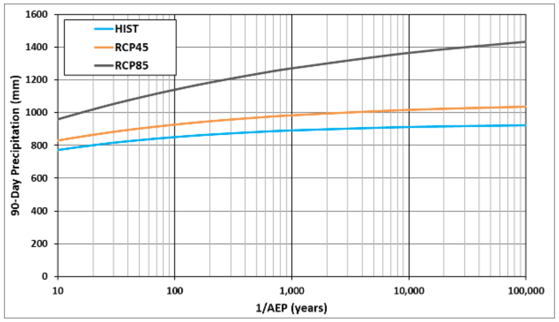
3.2) Frequency Analysis (L-moments)

- 1-day, 3-day, 30-day, 90-day, 365-day L-moment Frequency Analysis (Historic, SSP45, SSP85)
- All Precipitation, Summer Period, Winter Period
  - Identification of Probability Distribution
  - Goodness-of-fit measures
  - L-moment Ratio Diagram
    - The regional weighted average L-Skewness and L-Kurtosis tend to be near the GEV distribution
  - Derivation of Uncertainty bounds
    - Monte-carlo simulation
  - Point Value Annual Exceedance Estimates
  - Compare 2-, 5-, 10-, 25-, 50-, 100-, 200-,500-, 1000-yr



3.2) Frequency Analysis (Model 1)

*** 1-Day Precipitation

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	51.6	59.2	62.0	67.7	69.9	-	-	-	-	-	
SSP45	58.0	65.7	68.3	73.1	74.8	12%	11%	10%	8%	7%	10%
SSP85	66.4	76.5	80.0	86.7	89.1	29%	29%	29%	28%	27%	28%

*** 1-Day Summer

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	33.8	47.1	54.1	74.1	84.6	-	-	-	-	-	
SSP45	39.5	56.9	65.9	91.6	105.2	17%	21%	22%	24%	24%	22%
SSP85	38.1	50.8	56.8	72.0	79.2	13%	8%	5%	-3%	-6%	3%

*** 1-Day Winter

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	51.3	59.1	62.1	68.2	70.5	-	-	-	-	-	
SSP45	57.7	66.2	69.2	74.8	76.8	13%	12%	11%	10%	9%	11%
SSP85	66.2	76.9	80.7	88.1	90.7	29%	30%	30%	29%	29%	29%

*** 3-Day Precipitation

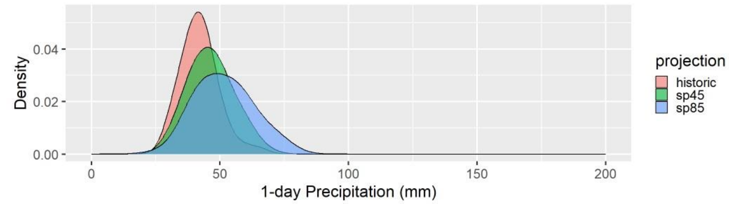
	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	87.6	113.4	126.1	160.6	178.0	-	-	-	-	-	
SSP45	98.7	116.8	123.4	136.9	141.9	13%	3%	-2%	-15%	-20%	-4%
SSP85	109.1	132.2	141.3	161.0	168.9	24%	17%	12%	0%	-5%	10%

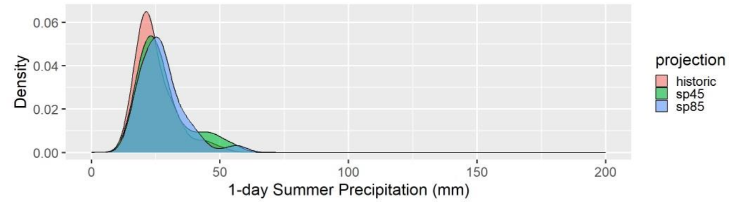
3-Day Summer

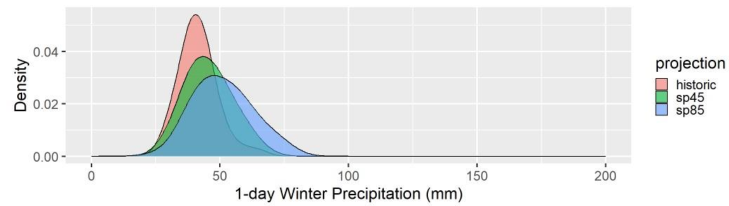
	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	62.4	81.7	91.2	116.9	129.7	-	-	-	-	-	
SSP45	69.5	91.3	102.1	131.6	146.4	11%	12%	12%	13%	13%	12%
SSP85	70.1	88.0	95.9	115.4	124.2	12%	8%	5%	-1%	-4%	4%

3-Day Winter

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	86.3	110.2	121.4	150.0	163.6	-	-	-	-	-	
SSP45	97.1	114.4	120.7	133.1	137.7	12%	4%	-1%	-11%	-16%	-2%
SSP85	108.5	133.8	144.1	166.6	175.8	26%	21%	19%	11%	7%	17%







*** 365-Day

	10yr	50yr	100yr	500yr	1000yr	Pct Change					Average
Historical	1489	1568	1590	1625	1635	-	-	-	-	-	
SSP45	1679	1810	1851	1922	1944	13%	15%	16%	18%	19%	16%
SSP85	1694	1763	1780	1805	1812	14%	12%	12%	11%	11%	12%

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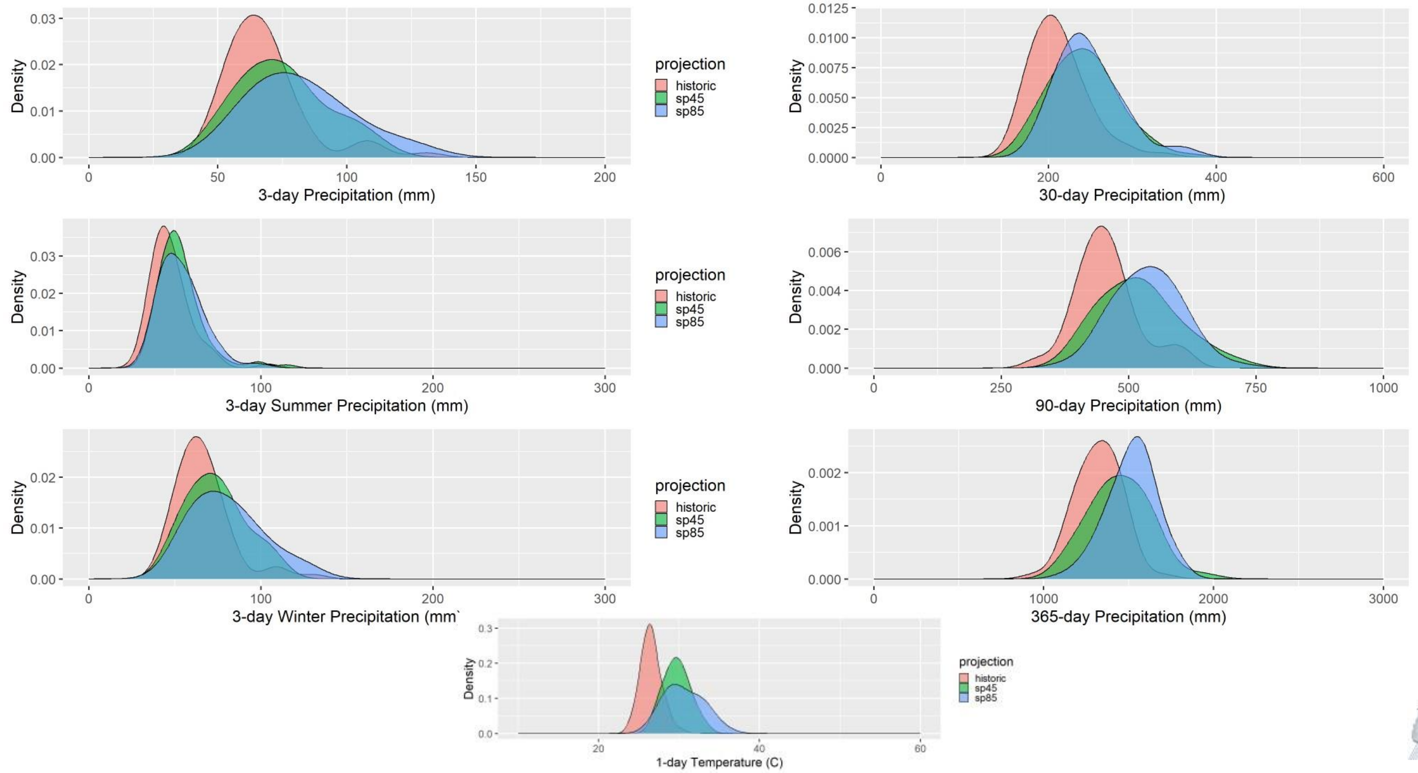
3.2) Frequency Analysis (Model 1)



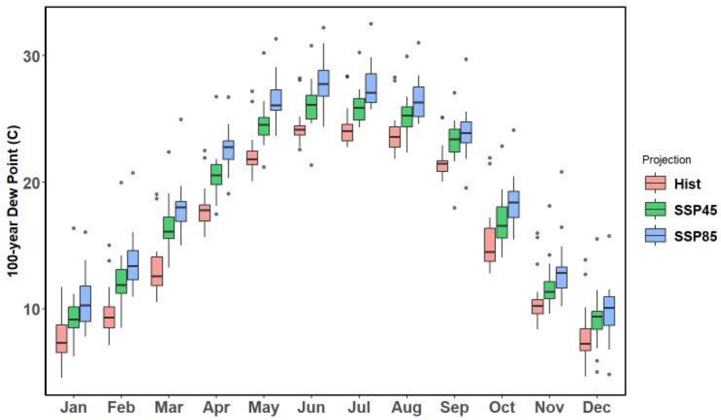
3.3) Moisture Maximization Ratio Analysis

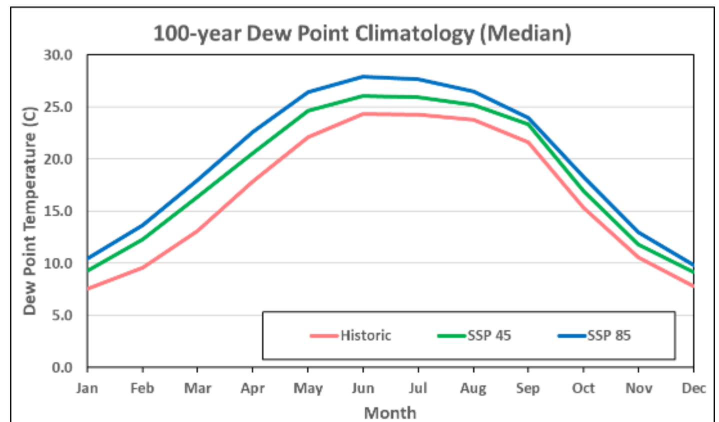
- Estimate 1-day and 3-day $\mathbf{Ppt_{adj}}$ for top 30 1-day and 3-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Derive monthly dew point (td) climatologies (Historic, SSP45, SSP85)
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor
    - (**r = PW_100 / PW_obs**)
  - Estimated $\mathbf{Ppt_{adj}}$ (~PMP) value for each event (**P * r**)

  - Slides split by two topics
    - 3a = Monthly Td analysis
    - 3b = Top 30 rainfall estimation

3.3a) Td Analysis

- Calculate monthly dew point temperature (Td) 100 -year climatology
  - all months have similar shape/seasonality
    - the **SSP 85** has largest range
  - Historic Average – 16.5 C
  - SSP45 Average – 18.5 C
  - SSP85 Average – 19.9 C





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3.3b) 1-Day Ppt_{max} Analysis

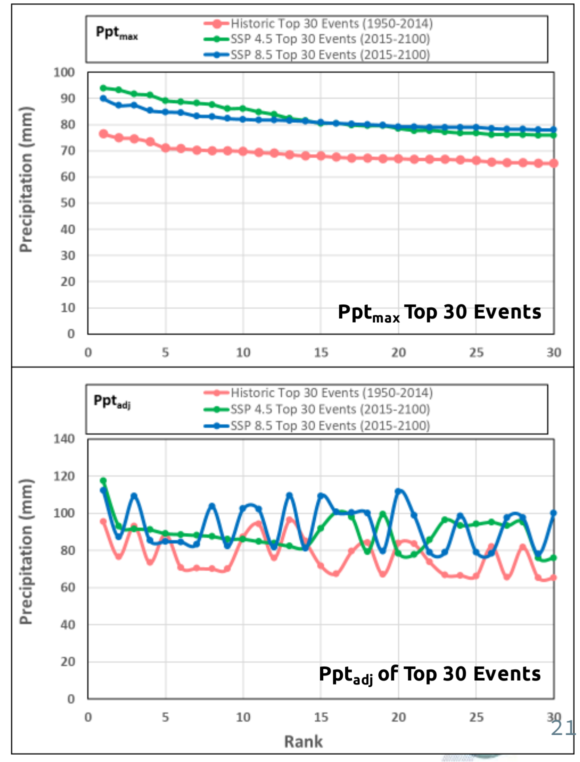
- Estimate **1-day** **Ppt_{adj}** for top 30 1-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor (**r = PW_100 / PW_obs**)
  - Estimated **Ppt_{adj}** value for each event (**P * r)**

1-Day Moisture Maximization

Ppt_{max}	(mm)	Pct Change
Historical	76	-
SSP45	94	23%
SSP85	90	18%

Ppt_{adj}	(mm)	rank	Pct Change
Historical	96	13	-
SSP45	117	1	22%
SSP85	112	1	17%

+++ values represent 1-day not 24-hour



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3.3b) 3-Day Ppt_{max} Analysis

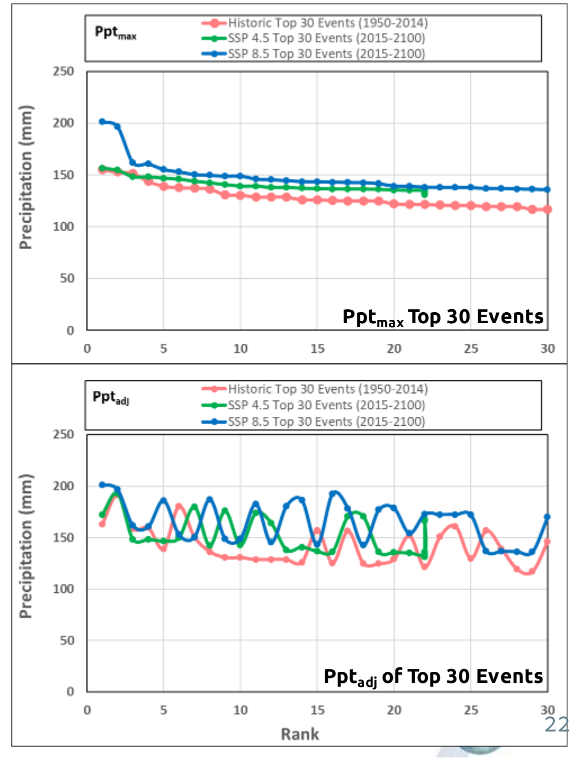
- Estimate **3-day** **Ppt_{adj}** for top 30 3-day precipitation events
  - Extracted top 30 precipitation events (**P**) and associated meteorological data
  - Quantified each storm events precipitable water (**Pobs**)
  - Quantified each storm events climatological maximum precipitable water (**Pw_100**)
  - Calculated each storm events maximization factor (**r = PW_100 / PW_obs**)
  - Estimated **Ppt_{adj}** value for each event (**P * r)**

3-Day Moisture Maximization

Ppt_{max}	(mm)	Pct Change
Historical	155	-
SSP45	156	1%
SSP85	201	30%

Ppt_{adj}	(mm)	rank	Pct Change
Historical	191	2	-
SSP45	193	2	1%
SSP85	201	1	5%

+++ values represent 3-day not 72-hour



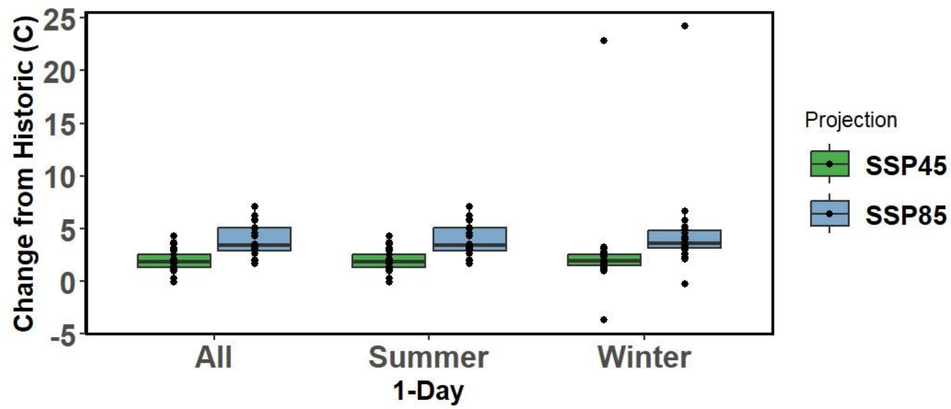
4) Summary Trend Results

	Precipitation					Temperature
	1-day	3-day	30-day	90-day	Annual	1-day
Historic	25 – no trend 1 – increase 0 – decrease	25 – no trend 1 – increase 0 – decrease	24 – no trend 2 – increase 0 – decrease	24 – no trend 2 – increase 0 – decrease	22 – no trend 4 – increase 0 – decrease	2 – no trend 24 – increase 0 – decrease
SSP45	19 – no trend 7 – increase 0 – decrease	20 – no trend 6 – increase 0 – decrease	22 – no trend 4 – increase 0 – decrease	19 – no trend 7 – increase 0 – decrease	17 – no trend 9 – increase 0 – decrease	3 – no trend 23 – increase 0 – decrease
SSP85	10 – no trend 16 – increase 0 – decrease	11 – no trend 15 – increase 0 – decrease	9 – no trend 17 – increase 0 – decrease	7 – no trend 19 – increase 0 – decrease	11 – no trend 15 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

Average as Percent		Precipitation					Temperature
		1-day	3-day	30-day	90-day	Annual	1-day
Historic	no trend	92%	94%	91%	90%	85%	9%
	increase	5%	4%	9%	10%	15%	91%
	decrease	3%	2%	0%	0%	0%	3%
SSP45	no trend	73%	77%	78%	71%	59%	35%
	increase	27%	22%	22%	29%	39%	65%
	decrease	0%	1%	0%	0%	2%	0%
SSP85	no trend	39%	51%	50%	48%	48%	0%
	increase	61%	49%	50%	52%	52%	100%
	decrease	0%	0%	0%	0%	0%	0%

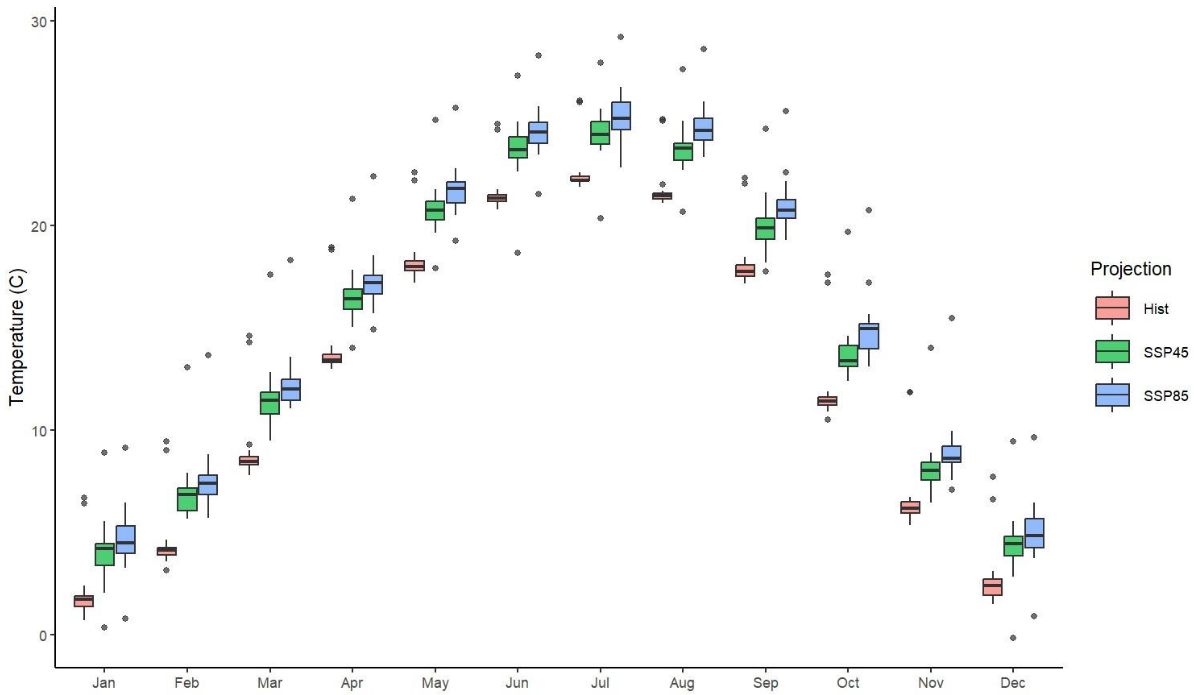
4) Summary Temperature Annual Maximum

- **1-day (SSP 45; SSP 85)**
  - All = 1.8 C; 3.4 C
  - Summer = 1.8 C; 3.4 C
  - Winter = 2.0 C; 3.6 C



*** Frequency based results, 26 RCM
+++ Boxplots based on these data

4) Summary Monthly Temperature



*** Climatology, based on 26 RCM

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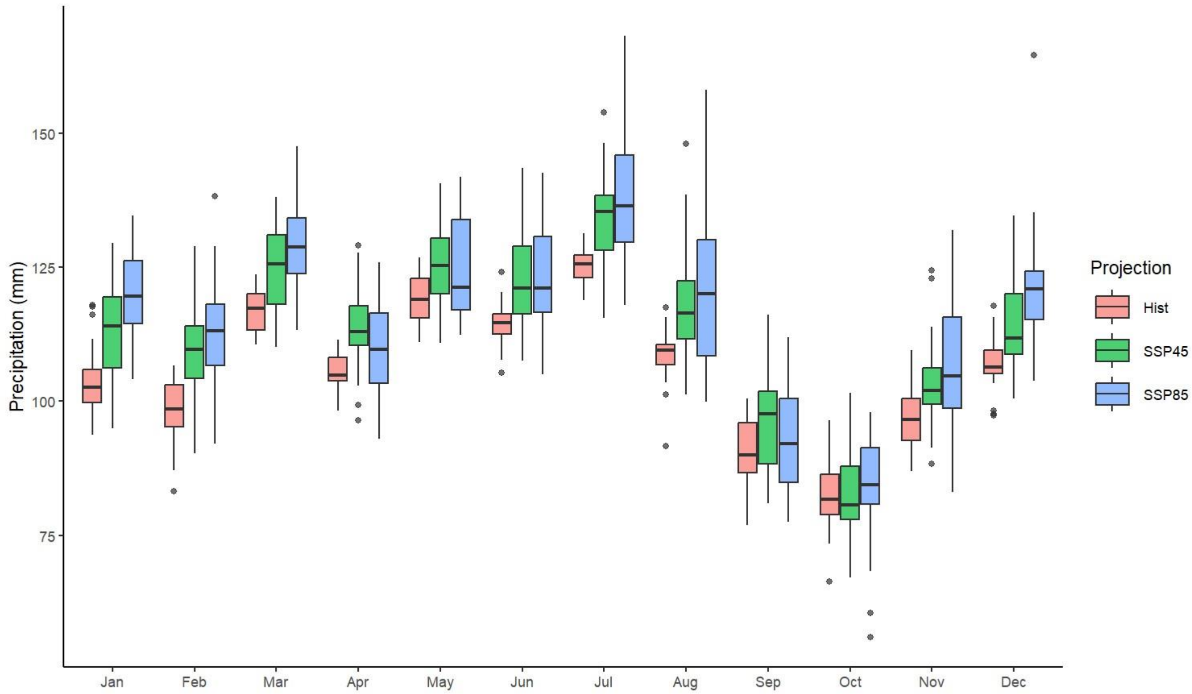
4) Summary Monthly Precipitation



*** Climatology, based on 26 RCM

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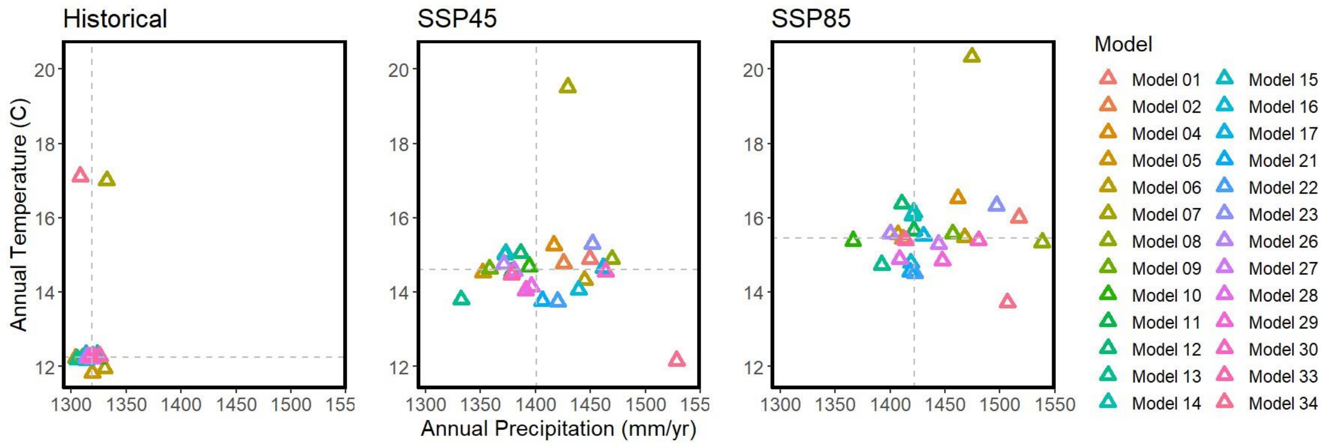
4) Summary Annual Temperature and Precipitation

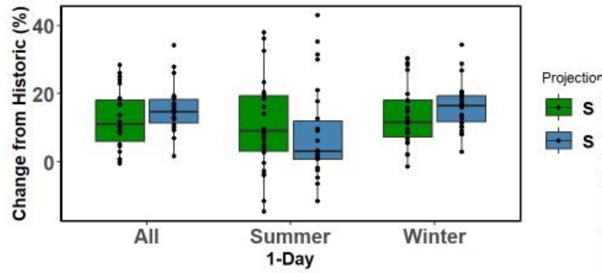
- **Median Annual Climatology (temp, ppt)**
  - Historical = 12.2 C; 1319 mm
  - SSP45 = 14.6 C; 1401 mm (2.4 C; 6%)
  - SSP85 = 15.5 C; 1422 mm (3.2 C; 8%)

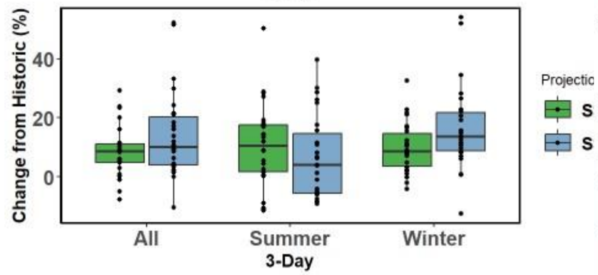


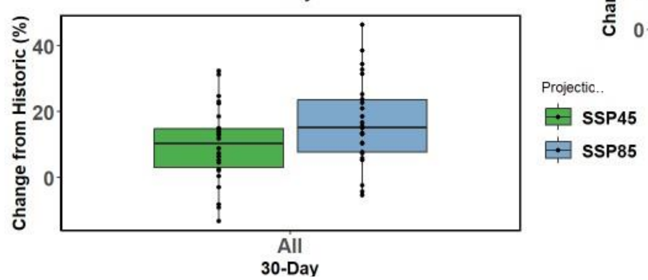
*** Climatology, based on 26 RCM

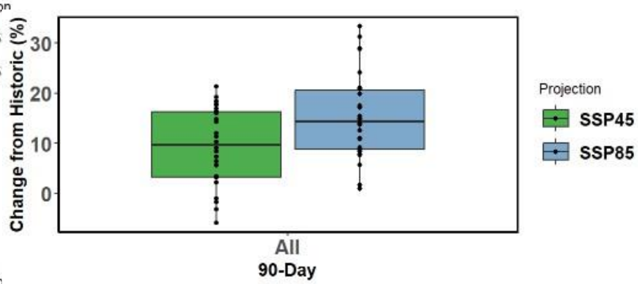
4) Summary Precipitation Frequency

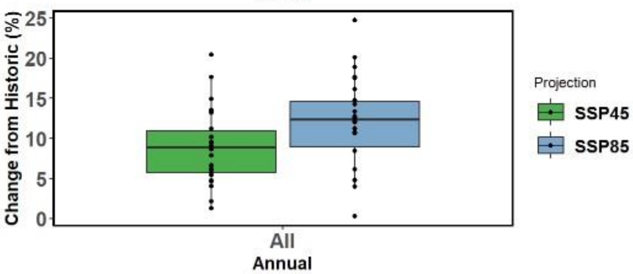
- **1-day (SSP 45; SSP 85)**
  - All = 11%; 15%
  - Summer = 9%; 3%
  - Winter = 12%; 17%
- **3-day**
  - All = 9%; 10%
  - Summer = 10%; 4%
  - Winter = 9%; 14%
- **30-day**
  - All = 10%; 15%
- **90-day**
  - All = 10%; 14%
- **Annual**
  - All = 9%; 12%





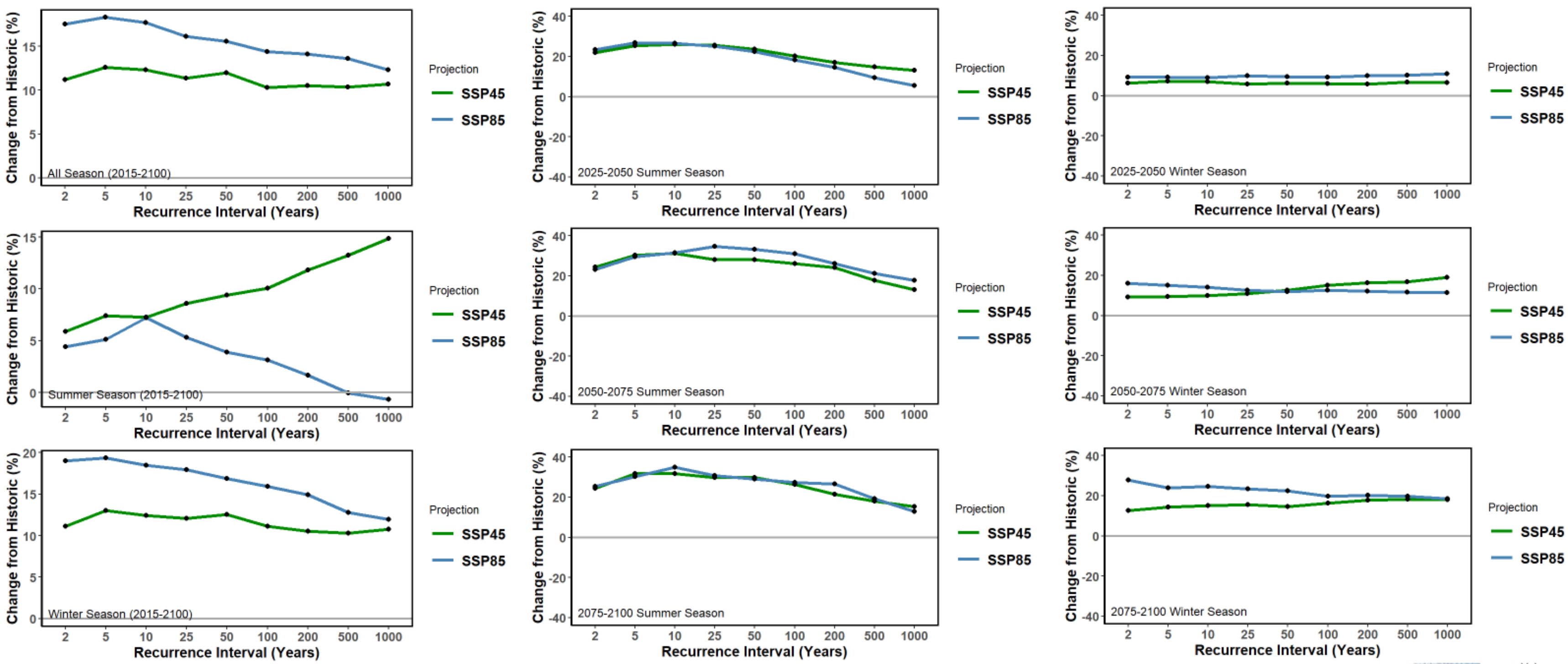






*** Frequency based results, 26 RCM
+++ Boxplots based on these data

1-Day 2015-2100 Three Period Results



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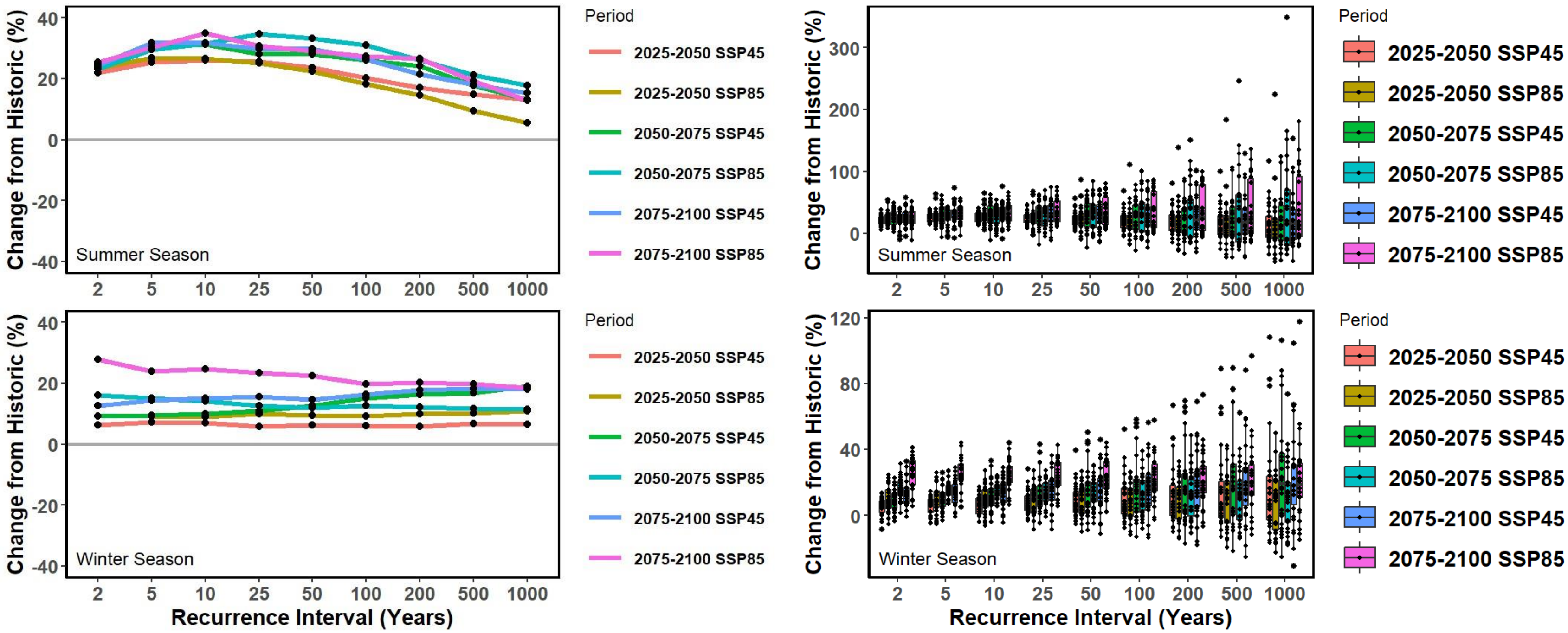
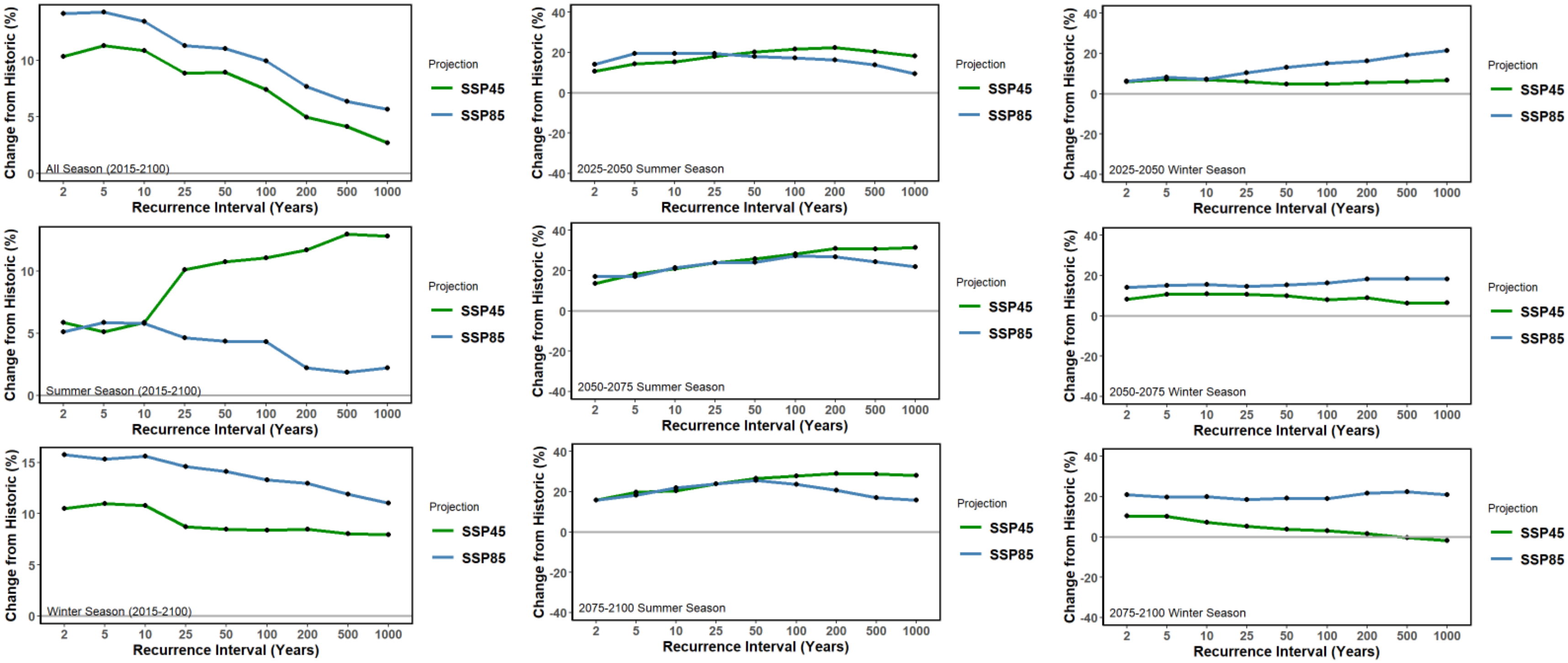
1-day 2015-2100 Three Period Results



3-Day 2015-2100 Three Period Results



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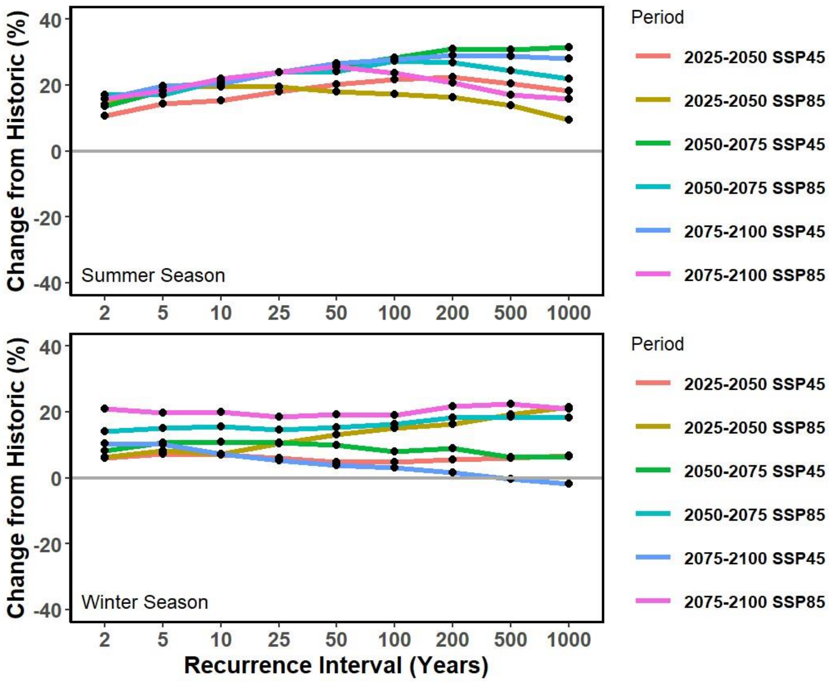
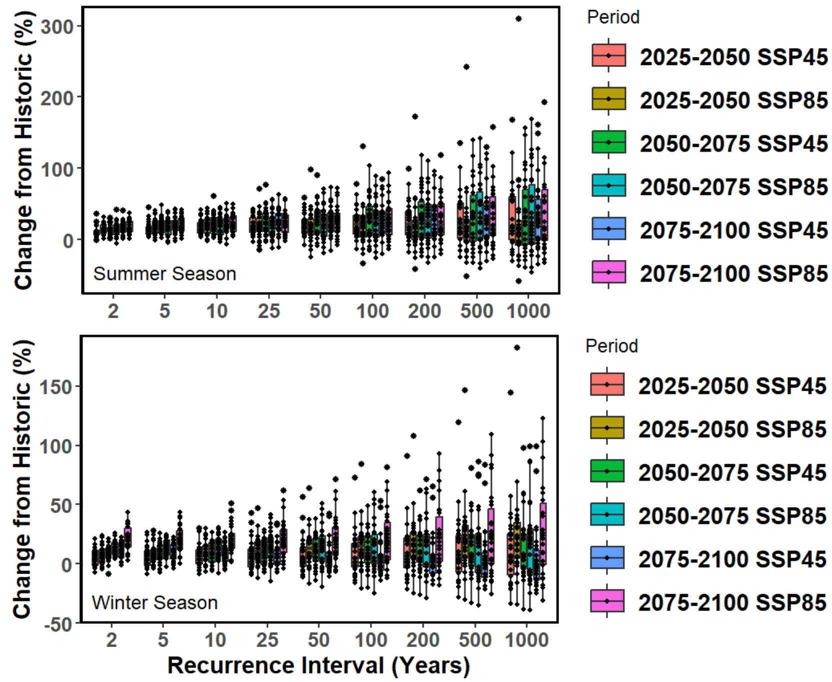
3-day 2015-2100 Three Period Results





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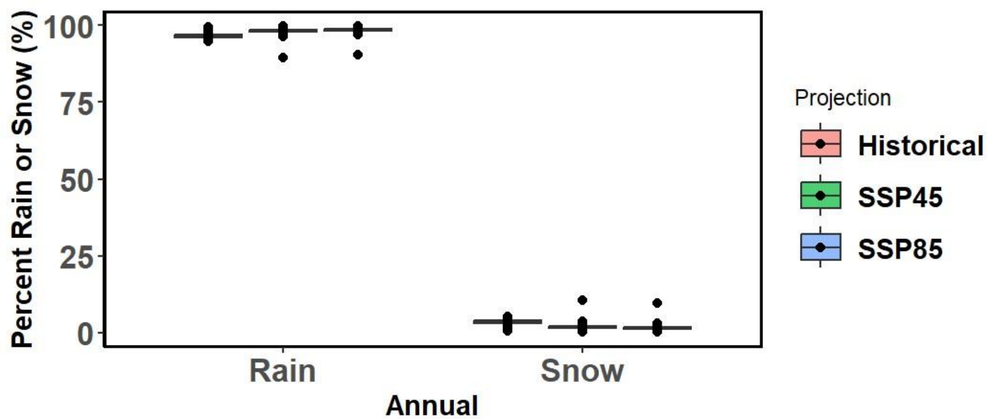
4) Precipitation Type

- **Temperature Threshold 0 -degree Celsius**

	Hist.	SSP45	SSP85
Rain, %	97	98	98
Snow, %	3	2	2



4) Summary Ratio Maximization (PPt_{adj})

- **Dew Point Climatologies**
  - All scenarios produce similar shape/season of monthly 100yr Td values
  - More of scaling adjustment of 2.0 C Historic to SSP 45; 3.5 C for Hist to SSP85

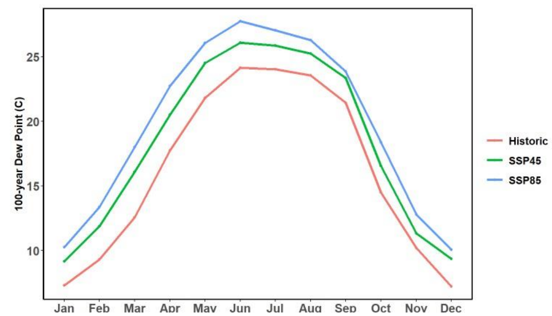
- **1-day (SSP45; SSP85)**
  - All = 22%; 17%
- **3-day**
  - All = 1%; 5%
- **Moisture Max. (SSP45; SSP85)**
  - All = 6%; 10%

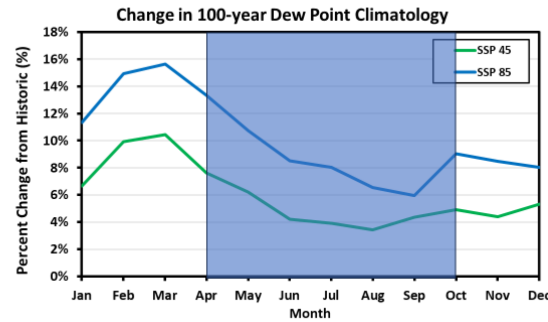
1-Day Moisture Maximization

Ppt_{max}	(mm)	Pct Change	Ppt_{adj}	(mm)	rank	Pct Change
Historical	76	-	Historical	96	13	-
SSP45	94	23%	SSP45	117	1	22%
SSP85	90	18%	SSP85	112	1	17%

3-Day Moisture Maximization

Ppt_{max}	(mm)	Pct Change	Ppt_{adj}	(mm)	rank	Pct Change
Historical	155	-	Historical	191	2	-
SSP45	156	1%	SSP45	193	2	1%
SSP85	201	30%	SSP85	201	1	5%





5) Application of Climate Change Results

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**2.0**	**1.8**	1.0	3.3	**3.9**	**3.4**	2.3	5.8
Temperature 1-Day Summer; C	**2.0**	**1.8**	1.0	3.3	**3.9**	**3.4**	2.3	5.8
Temperature 1-Day Winter PF; C	**2.7**	**2.0**	1.3	3.2	**4.5**	**3.6**	2.4	5.5
+ *Precipitation 1-Day PF; %	**12**	**11**	2	25	**15**	**15**	9	23
Precipitation 1-Day Summer PF; %	**11**	**9**	-4	28	**8**	**3**	-4	31
Precipitation 1-Day Winter PF; %	**14**	**12**	2	29	**16**	**17**	9	24
+ *Precipitation 3-Day PF; %	**9**	**9**	0	22	**14**	**10**	2	32
Precipitation 3-Day Summer PF; %	**11**	**10**	-10	28	**6**	**4**	-8	27
Precipitation 3-Day Winter PF; %	**10**	**9**	0	21	**16**	**14**	3	31
Precipitation 30-Day PF; %	**10**	**10**	-6	24	**16**	**15**	2	34
Precipitation 90-Day PF; %	**9**	**10**	-1	18	**15**	**14**	7	29
Precipitation Annual PF; %	**9**	**9**	4	14	**12**	**12**	5	18
Moisture Maximization 1-Day, %	**Potential Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

Climate Change Projections from 2015 through 2100

+ All season (mixed distribution) analysis

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5) Application of Climate Change Results

1-Day Annual Maximum/Frequency Analysis

1-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*11*	*13*	*12*	*11*	*12*	*10*	*11*	*10*	*11*	*18*	*18*	*18*	*16*	*16*	*14*	*14*	*14*	*12*	*11*	*16*
Summer 2015-2100	6	7	7	9	9	10	12	13	15	4	5	7	5	4	3	2	0	-1	10	3
Winter 2015-2100	11	13	12	12	13	11	11	10	11	19	19	19	18	17	16	15	13	12	12	16
Summer PF; %																				
Summer 2025-2050	22	25	26	26	24	20	17	15	13	23	27	27	25	23	18	15	9	5	21	19
Summer 2050-2075	25	30	31	28	28	26	24	18	13	23	29	31	35	33	31	26	21	18	25	28
Summer 2075-2100	24	32	32	30	30	26	21	18	15	25	30	35	31	29	27	27	19	13	25	26
Winter PF; %																				
Winter 2025-2050	6	7	7	6	6	6	6	7	6	9	9	9	10	9	9	10	10	11	6	10
Winter 2050-2075	9	9	10	11	13	15	16	17	19	16	15	14	13	12	13	12	12	11	13	13
Winter 2075-2100	13	14	15	16	15	16	18	18	18	28	24	25	23	22	20	20	20	19	16	22

Climate Change Projections from 2015 through 2100

+ All season (mixed distribution) analysis

5) Application of Climate Change Results

3-Day Annual Maximum/Frequency Analysis

1-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	**5**	**10**	**25**	**50**	**100**	**200**	**500**	**1000**	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**	**1000**	**SSP45**	**SSP85**
Precipitation; %																				
All Season 2015-2100	*11*	*13*	*12*	*11*	*12*	*10*	*11*	*10*	*11*	*18*	*18*	*18*	*16*	*16*	*14*	*14*	*14*	*12*	*11*	*16*
Summer 2015-2100	6	7	7	9	9	10	12	13	15	4	5	7	5	4	3	2	0	-1	10	3
Winter 2015-2100	11	13	12	12	13	11	11	10	11	19	19	19	18	17	16	15	13	12	12	16
Summer PF; %																				
Summer 2025-2050	22	25	26	26	24	20	17	15	13	23	27	27	25	23	18	15	9	5	21	19
Summer 2050-2075 [+]	25	30	31	28	28	26	24	18	13	23	29	31	35	33	31	26	21	18	25	28
Summer 2075-2100	24	32	32	30	30	26	21	18	15	25	30	35	31	29	27	27	19	13	25	26
Winter PF; %																				
Winter 2025-2050	6	7	7	6	6	6	6	7	6	9	9	9	10	9	9	10	10	11	6	10
Winter 2050-2075	9	9	10	11	13	15	16	17	19	16	15	14	13	12	13	12	12	11	13	13
Winter 2075-2100	13	14	15	16	15	16	18	18	18	28	24	25	23	22	20	20	20	19	16	22

Climate Change Projections from 2015 through 2100

+ All season (mixed distribution) analysis

Application of Climate Change Results

- Results are presented as median values based on model ensemble
- Design Storm and Routing Applications
  - Recommend SSP45 climate scenario as “likely”, SSP85 as “unlikely”
- Results are through 2100 and can be scaled to other periods
  - Example, for 2050 adjustment divide 2100 results in half.

	2050	2100
1-Day Summer PF; %	4	9
1-Day Winter PF; %	5	12
3-Day Summer PF; %	4	10
3-Day Winter PF; %	4	9
30-Day PF; %	4	10
90-Day PF; %	4	10

Climate Change Projections from 2005 through 2100

- Moisture Max/PMP no clear evidence for appropriate scaling adjustment.
  - For sensitivity, recommend applying moisture maximization results or precipitation frequency results or checking deterministic depths via incremental analysis

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5) Application of Climate Change Results

Monthly Temperature (C) Analysis

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**SSP45**	**SSP85**	**SSP45**	**SSP85**
January	2.0	1.8	4.0	4.2	4.7	4.5	***2.1***	***2.7***	***2.5***	***2.8***
February	4.4	4.1	6.9	6.8	7.5	7.4	***2.5***	***3.1***	***2.7***	***3.3***
March	8.9	8.5	11.5	11.5	12.2	12.0	***2.6***	***3.3***	***3.0***	***3.6***
April	13.9	13.4	16.5	16.4	17.3	17.2	***2.6***	***3.4***	***3.0***	***3.8***
May	18.3	18.0	20.8	20.8	21.7	21.8	***2.5***	***3.4***	***2.8***	***3.8***
June	21.6	21.4	23.7	23.7	24.6	24.6	***2.1***	***3.0***	***2.4***	***3.2***
July	22.5	22.2	24.5	24.5	25.5	25.3	***2.0***	***2.9***	***2.3***	***3.1***
August	21.7	21.5	23.7	23.8	24.8	24.7	***2.0***	***3.1***	***2.3***	***3.2***
September	18.1	17.8	20.0	19.9	21.0	20.8	***1.9***	***2.9***	***2.1***	***3.0***
October	11.8	11.4	13.7	13.4	14.9	15.0	***1.9***	***3.1***	***2.0***	***3.6***
November	6.6	6.2	8.1	8.0	8.9	8.6	***1.6***	***2.4***	***1.9***	***2.5***
December	2.7	2.4	4.4	4.5	5.0	4.9	***1.7***	***2.3***	***2.1***	***2.5***

Climate Change Projections from 2015 through 2100

5) Application of Climate Change Results

Monthly Precipitation (mm) Analysis

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	103.7	102.7	113.3	114.1	119.8	119.7	***1.09***	***1.16***	***1.11***	***1.17***
February	98.4	98.5	109.2	109.7	113.1	113.2	***1.11***	***1.15***	***1.11***	***1.15***
March	116.7	117.3	124.7	125.6	128.8	128.9	***1.07***	***1.10***	***1.07***	***1.10***
April	105.7	104.9	114.0	113.0	109.9	109.6	***1.08***	***1.04***	***1.08***	***1.05***
May	119.1	119.0	125.4	125.4	124.9	121.3	***1.05***	***1.05***	***1.05***	***1.02***
June	114.5	114.7	123.1	121.2	123.1	121.2	***1.08***	***1.07***	***1.06***	***1.06***
July	125.1	125.6	134.3	135.5	138.7	136.4	***1.07***	***1.11***	***1.08***	***1.09***
August	108.7	109.6	118.2	116.5	120.7	120.1	***1.09***	***1.11***	***1.06***	***1.10***
September	90.8	90.0	97.2	97.6	93.3	92.1	***1.07***	***1.03***	***1.09***	***1.02***
October	82.0	81.8	82.6	80.7	83.8	84.4	***1.01***	***1.02***	***0.99***	***1.03***
November	96.8	96.7	103.6	102.0	106.7	104.8	***1.07***	***1.10***	***1.06***	***1.08***
December	107.1	106.4	114.7	111.8	121.2	120.9	***1.07***	***1.13***	***1.05***	***1.14***

Climate Change Projections from 2015 through 2100

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Conclusion

TREND

- Projections show **increase** in temperature and dew point temperature
- Historical precipitation – **no change** in precipitation
- SSP45 precipitation –**no change** in precipitation
- SSP85 precipitation – **increase** in precipitation

FREQUENCY

- 1-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100. *** 1-day Summer **increase** when split by 25-yr period.

- 3-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100. *** 1-day Summer **increase** when split by 25-yr period.

- 30-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.

- 90-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.

- Annual – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100m and both have **increase** temperature by 2100

Conclusion

CLIMATOLOGY

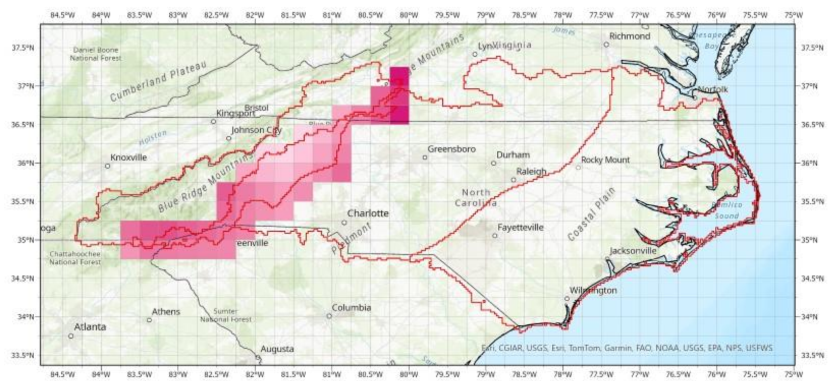
PRECIPITATION and TEMPERATURE

- Monthly Climatology – All months show an **increase** in precipitation (within +/-20%) and **increase** in temperature by 2100
- Annual Climatology – **increase** in annual precipitation (greater +/-20%) and **an increase** in annual temperature by 2100

Region 2 - Climate Change Results

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)

- Total of 35 climate models
- 9 models did not have all data
    - (6) Missing years and/or variables
    - (3) 30-days per month
- Used 26 models on daily time step
    - Temperature
    - Relative humidity
    - Precipitation



Region 2

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Climate Change Analysis Methods

- **1) Trend Analysis** for 1-day, 3-day, and Annual
  - Station Data
  - Model projections (Historic, SSP45, SSP85)
- **2) Monthly and Annual Analysis**
  - Model projections (Historic, SSP45, SSP85)
- **3) Precipitation Frequency Analysis** for 1-day, 3-day, 30-day, 90-day, and Annual
  - Precipitation, Summer Period, and Winter Period
  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes
- **4) Moisture Maximization Analysis** for 1-day and 3-day
  - Derive model projection monthly Td climatologies (Historic, SSP45, SSP85)
  - Quantify changes

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Region 2 - Trend Results

	Precipitation					Temperature
	1-day	3-day	30-day	90-day	Annual	1-day
Historic	24 – no trend 2 – increase 0 – decrease	26 – no trend 0 – increase 0 – decrease	24 – no trend 2 – increase 0 – decrease	22 – no trend 4 – increase 0 – decrease	22 – no trend 4 – increase 0 – decrease	3 – no trend 23 – increase 0 – decrease
SSP45	19 – no trend 7 – increase 0 – decrease	21 – no trend 5 – increase 0 – decrease	20 – no trend 6 – increase 0 – decrease	18 – no trend 8 – increase 0 – decrease	16 – no trend 10 – increase 0 – decrease	3 – no trend 23 – increase 0 – decrease
SSP85	11 – no trend 15 – increase 0 – decrease	15 – no trend 11 – increase 0 – decrease	11 – no trend 15 – increase 0 – decrease	10 – no trend 16 – increase 0 – decrease	12 – no trend 14 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

Region 2 - Climate Change Results

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**1.9**	**1.8**	0.9	3.3	**3.8**	**3.3**	2.1	5.8
Temperature 1-Day Summer; C	**1.9**	**1.8**	0.9	3.3	**3.8**	**3.3**	2.1	5.8
Temperature 1-Day Winter PF; C	**2.7**	**1.9**	1.2	3.1	**4.5**	**3.6**	2.5	5.4
*Precipitation 1-Day PF; %	**12**	**11**	2	21	**14**	**13**	5	23
Precipitation 1-Day Summer PF; %	**11**	**12**	-1	24	**9**	**10**	-2	21
Precipitation 1-Day Winter PF; %	**13**	**12**	3	23	**15**	**15**	6	24
*Precipitation 3-Day PF; %	**8**	**8**	-3	22	**14**	**9**	-1	37
Precipitation 3-Day Summer PF; %	**9**	**9**	-8	24	**6**	**3**	-8	26
Precipitation 3-Day Winter PF; %	**9**	**9**	-3	22	**15**	**12**	1	36
Precipitation 30-Day PF; %	**11**	**12**	-8	25	**17**	**15**	2	28
Precipitation 90-Day PF; %	**10**	**12**	-3	19	**16**	**15**	6	27
Precipitation Annual PF; %	**9**	**9**	4	15	**12**	**12**	6	18
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**Potential Change**				**No Change**			

Climate Change Projections from 2015 through 2100

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Region 2 - Climate Change Results

1-Day Annual Maximum/Frequency Analysis

1-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*12*	*12*	*13*	*13*	*12*	*11*	*10*	*10*	*11*	*18*	*18*	*17*	*15*	*14*	*12*	*13*	*11*	*10*	*11*	*14*
Summer 2015-2100	7	8	9	11	13	14	13	15	18	4	5	7	10	10	11	11	12	13	12	9
Winter 2015-2100	12	13	13	13	13	13	12	12	11	19	19	17	16	15	14	13	10	8	13	15
Summer PF; %																				
Summer 2025-2050	25	31	32	30	28	26	23	21	18	26	30	29	27	24	21	18	12	7	26	21
Summer 2050-2075	28	32	31	31	29	24	19	13	10	29	35	37	37	37	41	38	34	30	24	35
Summer 2075-2100	28	36	38	39	35	30	26	19	13	30	38	39	38	37	35	41	41	37	29	37
Winter PF; %																				
Winter 2025-2050	4	5	4	4	5	5	6	7	7	8	8	7	5	7	8	6	7	8	5	7
Winter 2050-2075	9	9	10	7	6	4	6	8	13	12	12	12	9	7	5	2	1	0	8	7
Winter 2075-2100	11	13	12	10	10	10	11	11	10	28	25	22	20	17	14	11	8	6	11	17

Climate Change Projections from 2015 through 2100
+ All season (mixed distribution) analysis

Region 2 - Climate Change Results

3-Day Annual Maximum/Frequency Analysis

3-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	**5**	**10**	**25**	**50**	**100**	**200**	**500**	**1000**	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**	**1000**	**SSP45**	**SSP85**
Precipitation; %																				
All Season 2015-2100	*10*	*11*	*11*	*9*	*9*	*7*	*5*	*4*	*3*	*14*	*14*	*13*	*11*	*11*	*10*	*8*	*6*	*6*	*8*	*10*
Summer 2015-2100	6	5	6	10	11	11	12	13	13	5	6	6	5	4	4	2	2	2	10	4
Winter 2015-2100	11	11	11	9	9	8	9	8	8	16	15	16	15	14	13	13	12	11	9	14
Summer PF; %																				
Summer 2025-2050	11	14	15	18	20	22	22	20	18	14	20	20	20	18	17	16	14	9	18	16
Summer 2050-2075	14	18	21	24	26	28	31	31	32	17	17	22	24	24	27	27	24	22	25	23
Summer 2075-2100	16	20	21	24	27	28	29	29	28	16	18	22	24	26	24	21	17	16	24	20
Winter PF; %																				
Winter 2025-2050	6	7	7	6	5	5	5	6	7	6	8	7	11	13	15	16	19	22	6	13
Winter 2050-2075	8	11	11	11	10	8	9	6	7	14	15	15	15	15	16	18	19	18	9	16
Winter 2075-2100	11	10	7	5	4	3	2	0	-2	21	20	20	19	19	19	22	22	21	4	20

Climate Change Projections from 2015 through 2100

+ All season (mixed distribution) analysis

Region 2 - Application of Climate Change Results

Monthly Temperature Analysis

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**SSP45**	**SSP85**	**SSP45**	**SSP85**
January	3.6	3.3	5.7	5.7	6.3	6.1	***2.1***	***2.7***	***2.4***	***2.8***
February	6.1	5.8	8.6	8.4	9.2	9.0	***2.5***	***3.0***	***2.6***	***3.3***
March	10.6	10.2	13.1	13.0	13.8	13.6	***2.5***	***3.2***	***2.8***	***3.4***
April	15.4	15.0	18.0	17.9	18.9	18.7	***2.6***	***3.4***	***2.9***	***3.7***
May	19.8	19.5	22.2	22.2	23.2	23.3	***2.4***	***3.3***	***2.7***	***3.8***
June	23.0	22.8	25.1	25.1	26.0	26.1	***2.1***	***3.0***	***2.4***	***3.3***
July	23.9	23.6	25.9	25.8	26.8	26.7	***2.0***	***3.0***	***2.2***	***3.1***
August	23.1	22.8	25.0	25.1	26.1	25.9	***2.0***	***3.1***	***2.3***	***3.1***
September	19.5	19.1	21.3	21.2	22.4	22.2	***1.8***	***2.9***	***2.1***	***3.1***
October	13.2	12.8	15.2	15.0	16.4	16.2	***1.9***	***3.1***	***2.2***	***3.4***
November	8.0	7.6	9.6	9.6	10.5	10.2	***1.6***	***2.4***	***2.0***	***2.6***
December	4.3	4.0	6.0	6.1	6.6	6.5	***1.7***	***2.3***	***2.2***	***2.5***

Climate Change Projections from 2015 through 2100

Region 2 - Application of Climate Change Results

Monthly Precipitation Analysis

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**SSP45**	**SSP85**	**SSP45**	**SSP85**
January	102.1	101.2	109.5	110.3	116.7	115.5	***1.07***	***1.14***	***1.09***	***1.14***
February	96.5	96.1	105.9	106.2	109.2	109.8	***1.10***	***1.13***	***1.11***	***1.14***
March	114.3	114.8	120.7	121.7	124.1	124.4	***1.06***	***1.09***	***1.06***	***1.08***
April	100.5	100.5	109.2	108.7	105.0	105.3	***1.09***	***1.04***	***1.08***	***1.05***
May	116.2	116.5	123.4	123.4	122.5	119.7	***1.06***	***1.05***	***1.06***	***1.03***
June	111.8	112.2	121.8	121.9	120.8	120.1	***1.09***	***1.08***	***1.09***	***1.07***
July	123.2	123.3	132.9	133.7	137.1	134.7	***1.08***	***1.11***	***1.08***	***1.09***
August	110.2	109.8	122.1	119.9	122.9	122.9	***1.11***	***1.12***	***1.09***	***1.12***
September	93.0	93.1	101.2	101.3	97.5	96.2	***1.09***	***1.05***	***1.09***	***1.03***
October	83.1	82.9	84.3	83.0	85.5	85.2	***1.02***	***1.03***	***1.00***	***1.03***
November	92.9	92.5	100.1	98.5	102.2	102.0	***1.08***	***1.10***	***1.06***	***1.10***
December	101.8	101.7	109.5	108.2	115.8	116.3	***1.08***	***1.14***	***1.06***	***1.14***

Climate Change Projections from 2015 through 2100

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Region 2 Conclusion

TREND

- Historical precipitation – **no change** in precipitation
- SSP45 precipitation – **no change** in precipitation
- SSP85 precipitation – split between **no change** and an **increase** in precipitation

FREQUENCY

- 1-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100. *** 1-day Summer **increase** when split by 25-yr period.

- 3-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100. *** 1-day Summer **increase** when split by 25-yr period.

- 30-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.

- 90-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.

- Annual – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100m and both have **increase** temperature by 2100

CLIMATOLOGY

- Monthly Climatology – small increase in precipitation (within +/ -20%) and **increase** in temperature by 2100
- Annual Climatology – **no change** in annual precipitation (within +/ -20%) and **an increase**

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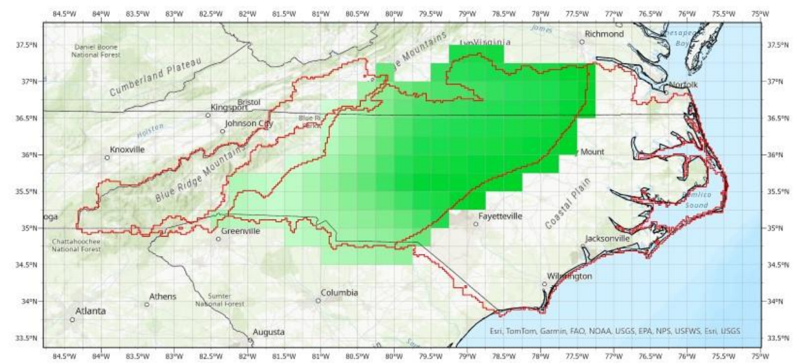
Region 3 - Climate Change Results

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)

- Total of 35 climate models

- 9 models did not have all data
  - (6) Missing years and/or variables
  - (3) 30-days per month

- Used 26 models on daily time step
  - Temperature
  - Relative humidity
  - Precipitation



Region 3

Climate Change Analysis Methods

- **1) Trend Analysis** for 1-day, 3-day, and Annual
  - Station Data
  - Model projections (Historic, SSP45, SSP85)
- **2) Monthly and Annual Analysis**
  - Model projections (Historic, SSP45, SSP85)
- **3) Precipitation Frequency Analysis** for 1-day, 3-day, 30-day, 90-day, and Annual
  - Precipitation, Summer Period, and Winter Period
  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes
- **4) Moisture Maximization Analysis** for 1-day and 3-day
  - Derive model projection monthly Td climatologies (Historic, SSP45, SSP85)
  - Quantify changes

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Region 3 - Trend Results

	Precipitation					Temperature
	1-day	3-day	30-day	90-day	Annual	1-day
Historic	26 – no trend 0 – increase 0 – decrease	24 – no trend 2 – increase 0 – decrease	23 – no trend 3 – increase 0 – decrease	23 – no trend 3 – increase 0 – decrease	22 – no trend 4 – increase 0 – decrease	2 – no trend 24 – increase 0 – decrease
SSP45	18 – no trend 8 – increase 0 – decrease	19 – no trend 7 – increase 0 – decrease	18 – no trend 8 – increase 0 – decrease	17 – no trend 9 – increase 0 – decrease	12 – no trend 14 – increase 0 – decrease	7 – no trend 19 – increase 0 – decrease
SSP85	6 – no trend 20 – increase 0 – decrease	12 – no trend 14 – increase 0 – decrease	13 – no trend 13 – increase 0 – decrease	14 – no trend 12 – increase 0 – decrease	12 – no trend 14 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

Region 3 - Climate Change Results

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**1.8**	**1.8**	0.5	3.2	**3.8**	**3.4**	2.3	6.1
Temperature 1-Day Summer; C	**1.8**	**1.8**	0.5	3.2	**3.8**	**3.4**	2.3	6.1
Temperature 1-Day Winter PF; C	**1.8**	**2.1**	1.2	2.7	**3.5**	**3.4**	2.4	5.0
*Precipitation 1-Day PF; %	**8**	**8**	-7	23	**10**	**10**	-4	25
Precipitation 1-Day Summer PF; %	**5**	**5**	-13	28	**6**	**2**	-12	29
Precipitation 1-Day Winter PF; %	**12**	**12**	2	27	**15**	**14**	0	32
*Precipitation 3-Day PF; %	**8**	**7**	-6	22	**11**	**8**	1	30
Precipitation 3-Day Summer PF; %	**1**	**3**	-14	15	**3**	**0**	-13	24
Precipitation 3-Day Winter PF; %	**14**	**11**	-3	34	**17**	**17**	2	31
Precipitation 30-Day PF; %	**11**	**12**	-3	22	**17**	**17**	3	33
Precipitation 90-Day PF; %	**11**	**11**	0	23	**16**	**16**	7	27
Precipitation Annual PF; %	**10**	**10**	4	16	**12**	**12**	6	22
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**No Change**			

Climate Change Projections from 2015 through 2100

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Region 3 - Climate Change Results

1-Day Annual Maximum/Frequency Analysis

1-Day Duration	**SSP45 Median**									**SSP85 Median**									**Avg**	
	2	**5**	**10**	**25**	**50**	**100**	**200**	**500**	**1000**	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**	**1000**	**SSP45**	**SSP85**
Precipitation; %																				
All Season 2015-2100	*12*	*12*	*12*	*9*	*8*	*7*	*5*	*2*	*0*	*16*	*16*	*14*	*12*	*10*	*8*	*6*	*2*	*0*	*8*	*9*
Summer 2015-2100	6	8	6	4	5	4	1	0	-1	8	10	8	6	4	-1	-2	-5	-6	4	3
Winter 2015-2100	13	13	13	12	12	11	10	8	8	16	17	17	15	14	13	11	11	11	11	14
Summer PF; %																				
Summer 2025-2050	30	30	28	25	19	11	5	-3	-11	33	35	33	25	16	13	10	0	-8	15	17
Summer 2050-2075	31	34	34	29	23	17	9	-3	-10	33	27	25	24	19	14	7	-7	-16	18	14
Summer 2075-2100	31	33	33	27	21	15	9	0	-8	28	31	30	25	23	18	15	8	-2	18	20
Winter PF; %																				
Winter 2025-2050	5	5	2	1	0	-2	-3	-4	-5	6	5	4	2	1	2	1	-1	-1	0	2
Winter 2050-2075	10	7	6	6	4	4	3	4	4	13	16	16	16	15	15	15	14	14	5	15
Winter 2075-2100	14	13	13	14	14	13	13	13	12	23	22	18	15	12	9	5	1	-1	13	12

Climate Change Projections from 2015 through 2100

[+] All season (mixed distribution) analysis

Region 3 - Climate Change Results

3-Day Annual Maximum/Frequency Analysis

3-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*9*	*10*	*10*	*8*	*7*	*6*	*4*	*3*	*2*	*14*	*14*	*12*	*9*	*8*	*6*	*6*	*4*	*3*	*7*	*9*
Summer 2015-2100	5	5	6	2	1	2	-2	-7	-9	8	7	6	5	2	-1	-5	-8	-10	0	0
Winter 2015-2100	11	12	12	12	12	11	10	10	10	16	18	17	17	17	17	17	17	17	11	17
Summer PF; %																				
Summer 2025-2050	15	20	20	15	12	13	11	8	7	22	26	25	20	16	9	3	-5	-11	13	12
Summer 2050-2075	20	21	21	18	17	12	9	8	5	22	24	23	24	23	22	18	12	8	14	20
Summer 2075-2100	19	22	24	21	19	14	11	10	6	22	25	24	19	16	10	5	0	-3	16	13
Winter PF; %																				
Winter 2025-2050	3	-1	0	-1	-2	-3	-4	-5	-7	5	4	3	3	2	1	0	0	0	-2	2
Winter 2050-2075	5	5	6	8	8	14	15	16	17	12	13	12	12	11	11	12	13	14	10	12
Winter 2075-2100	9	7	6	7	6	5	5	4	4	19	15	14	11	14	15	14	14	13	6	14

Climate Change Projections from 2015 through 2100

+ All season (mixed distribution) analysis

Region 3 - Application of Climate Change Results

Monthly Temperature Analysis

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**SSP45**	**SSP85**	**SSP45**	**SSP85**
January	4.7	4.3	6.9	6.8	7.5	7.1	***2.1***	***2.8***	***2.5***	***2.8***
February	7.3	6.9	9.8	9.5	10.4	10.2	***2.5***	***3.1***	***2.6***	***3.3***
March	11.9	11.6	14.6	14.6	15.2	15.1	***2.6***	***3.3***	***3.0***	***3.6***
April	17.0	16.6	19.7	19.5	20.5	20.3	***2.7***	***3.5***	***2.9***	***3.7***
May	21.6	21.3	24.0	23.9	24.9	25.0	***2.4***	***3.3***	***2.6***	***3.7***
June	25.0	24.7	27.2	27.3	28.1	28.2	***2.2***	***3.1***	***2.5***	***3.4***
July	26.0	25.8	28.0	28.0	29.0	28.8	***2.0***	***2.9***	***2.2***	***3.0***
August	25.0	24.7	27.0	27.1	28.1	28.0	***1.9***	***3.1***	***2.4***	***3.3***
September	21.2	21.0	23.1	23.0	24.2	23.9	***1.9***	***2.9***	***2.0***	***3.0***
October	14.8	14.4	16.7	16.5	18.0	17.8	***1.9***	***3.1***	***2.1***	***3.4***
November	9.5	9.1	11.1	11.0	11.9	11.7	***1.6***	***2.4***	***1.9***	***2.6***
December	5.5	5.3	7.4	7.3	7.9	7.7	***1.8***	***2.4***	***2.1***	***2.4***

Climate Change Projections from 2015 through 2100

Region 3 - Application of Climate Change Results

Monthly Precipitation Analysis

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**SSP45**	**SSP85**	**SSP45**	**SSP85**
January	87.3	87.6	94.5	96.7	100.7	100.8	***1.08***	***1.15***	***1.10***	***1.15***
February	81.0	82.2	91.2	93.2	93.8	93.1	***1.13***	***1.16***	***1.13***	***1.13***
March	94.9	94.3	101.9	101.0	105.5	106.6	***1.07***	***1.11***	***1.07***	***1.13***
April	82.7	82.9	91.3	91.6	87.9	87.3	***1.10***	***1.06***	***1.11***	***1.05***
May	99.2	98.9	106.6	106.9	106.1	105.1	***1.07***	***1.07***	***1.08***	***1.06***
June	102.9	103.3	111.1	113.0	111.0	111.7	***1.08***	***1.08***	***1.09***	***1.08***
July	119.3	118.6	128.9	129.7	132.5	132.7	***1.08***	***1.11***	***1.09***	***1.12***
August	106.4	106.0	117.5	117.6	119.6	119.6	***1.10***	***1.12***	***1.11***	***1.13***
September	84.6	83.3	89.7	90.0	88.7	87.1	***1.06***	***1.05***	***1.08***	***1.05***
October	74.2	74.1	74.6	74.7	76.6	76.4	***1.01***	***1.03***	***1.01***	***1.03***
November	76.3	77.4	83.0	82.1	84.7	83.4	***1.09***	***1.11***	***1.06***	***1.08***
December	86.5	86.5	93.2	91.7	98.5	99.2	***1.08***	***1.14***	***1.06***	***1.15***

Climate Change Projections from 2015 through 2100

Region 3 Conclusion

TREND

- Historical precipitation – **no change** in precipitation
- SSP45 precipitation – **no change** in precipitation
- SSP85 precipitation – split between **no change** and an **increase** in precipitation

FREQUENCY

- 1-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.
- 3-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.
- 30-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.
- 90-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.
- Annual – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100m and both have **increase** temperature by 2100

CLIMATOLOGY

- Monthly Climatology – small increase in precipitation (within +/ -20%) and **increase** in temperature by 2100
- Annual Climatology – **no change** in annual precipitation (within +/ -20%) and **an increase**

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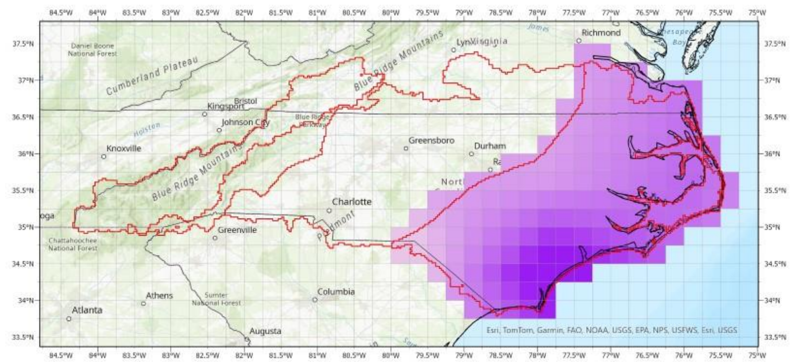
Region 4 - Climate Change Results

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)

- Total of 35 climate models
- 9 models did not have all data
  - (6) Missing years and/or variables
  - (3) 30-days per month
- Used 26 models on daily time step
  - Temperature
  - Relative humidity
  - Precipitation



Region 4

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Climate Change Analysis Methods

- **1) Trend Analysis** for 1-day, 3-day, and Annual
  - Station Data
  - Model projections (Historic, SSP45, SSP85)
- **2) Monthly and Annual Analysis**
  - Model projections (Historic, SSP45, SSP85)
- **3) Precipitation Frequency Analysis** for 1-day, 3-day, 30-day, 90-day, and Annual
  - Precipitation, Summer Period, and Winter Period
  - Model projections (Historic, SSP45, SSP85)
  - Estimate PF for 1-year through 1000-year
  - Quantify changes
- **4) Moisture Maximization Analysis** for 1-day and 3-day
  - Derive model projection monthly Td climatologies (Historic, SSP45, SSP85)
  - Quantify changes

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Region 4 - Trend Results

	Precipitation					Temperature
	1-day	3-day	30-day	90-day	Annual	1-day
Historic	21 – no trend 2 – increase 3 – decrease	23 – no trend 1 – increase 2 – decrease	24 – no trend 2 – increase 0 – decrease	25 – no trend 1 – increase 0 – decrease	22 – no trend 4 – increase 0 – decrease	2 – no trend 24 – increase 0 – decrease
SSP45	20 – no trend 6 – increase 0 – decrease	20 – no trend 5 – increase 1 – decrease	21 – no trend 5 – increase 0 – decrease	20 – no trend 6 – increase 0 – decrease	16 – no trend 8 – increase 2 – decrease	3 – no trend 23 – increase 0 – decrease
SSP85	14 – no trend 12 – increase 0 – decrease	15 – no trend 11 – increase 0 – decrease	19 – no trend 7 – increase 0 – decrease	19 – no trend 7 – increase 0 – decrease	15 – no trend 11 – increase 0 – decrease	0 – no trend 26 – increase 0 – decrease

Region 4 - Climate Change Results

Annual Maximum/Frequency Analysis

	SSP45				SSP85			
	Mean	**Median**	**10th**	**90th**	**Mean**	**Median**	**10th**	**90th**
Temperature 1-Day; C	**1.7**	**1.8**	0.7	3.2	**4.7**	**3.0**	2.2	5.6
Temperature 1-Day Summer; C	**1.7**	**1.8**	0.7	3.2	**4.7**	**3.0**	2.2	5.6
Temperature 1-Day Winter PF; C	**1.6**	**1.8**	1.0	2.3	**3.1**	**3.2**	1.8	4.4
*Precipitation 1-Day PF; %	**3**	**0**	-7	14	**6**	**4**	-11	24
Precipitation 1-Day Summer PF; %	**0**	**-1**	-19	20	**2**	**0**	-18	26
Precipitation 1-Day Winter PF; %	**7**	**6**	-5	18	**9**	**8**	-3	21
*Precipitation 3-Day PF; %	**2**	**1**	-6	14	**6**	**6**	-6	17
Precipitation 3-Day Summer PF; %	**-1**	**-1**	-16	15	**3**	**1**	-18	22
Precipitation 3-Day Winter PF; %	**8**	**7**	-6	22	**13**	**13**	-3	28
Precipitation 30-Day PF; %	**6**	**4**	-5	15	**9**	**8**	0	17
Precipitation 90-Day PF; %	**7**	**7**	-3	16	**9**	**9**	1	18
Precipitation Annual PF; %	**8**	**8**	-2	15	**10**	**9**	2	18
Moisture Maximization 1-Day, %	**No Change**				**No Change**			
Moisture Maximization 3-Day; %	**No Change**				**Potential Change**			

Climate Change Projections from 2015 through 2100

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Region 4 - Climate Change Results

1-Day Annual Maximum/Frequency Analysis

1-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*11*	*9*	*6*	*3*	*0*	*-3*	*-6*	*-10*	*-14*	*16*	*15*	*12*	*8*	*4*	*2*	*-2*	*-6*	*-7*	*0*	*5*
Summer 2015-2100	6	6	4	0	0	-4	-7	-10	-12	7	9	9	2	1	-4	-5	-3	-4	-2	1
Winter 2015-2100	14	12	11	8	6	5	2	-1	-3	18	18	16	11	8	7	5	2	0	6	9
Summer PF; %																				
Summer 2025-2050	19	19	19	15	8	4	-1	-6	-11	20	25	25	25	16	13	6	-3	-8	7	13
Summer 2050-2075	23	26	21	15	14	12	9	4	-4	17	20	21	27	26	22	15	10	5	13	18
Summer 2075-2100	22	23	21	18	13	12	7	-1	-4	21	23	21	16	11	4	-1	-7	-9	12	9
Winter PF; %																				
Winter 2025-2050	7	4	2	-4	-7	-11	-14	-17	-19	8	6	3	-2	-6	-10	-13	-16	-19	-7	-5
Winter 2050-2075	11	8	6	3	-2	-6	-8	-11	-13	16	13	10	7	4	2	-1	-4	-7	-1	4
Winter 2075-2100	14	11	8	6	3	1	-1	-6	-9	24	16	13	9	4	0	-4	-10	-13	3	4

Climate Change Projections from 2015 through 2100

+ All season (mixed distribution) analysis

Region 4 - Climate Change Results

3-Day Annual Maximum/Frequency Analysis

3-Day Duration	SSP45 Median									SSP85 Median									Avg	
	2	5	10	25	50	100	200	500	1000	2	5	10	25	50	100	200	500	1000	SSP45	SSP85
Precipitation; %																				
All Season 2015-2100	*10*	*8*	*5*	*3*	*1*	*-1*	*-3*	*-5*	*-7*	*12*	*12*	*12*	*8*	*7*	*5*	*2*	*-1*	*-2*	*1*	*6*
Summer 2015-2100	6	4	2	0	-1	-2	-5	-9	-13	7	7	6	4	2	1	1	-1	-4	-2	3
Winter 2015-2100	11	11	11	10	8	8	6	3	0	16	15	15	14	14	11	9	9	9	7	12
Summer PF; %																				
Summer 2025-2050	14	13	10	5	5	4	2	2	0	14	14	13	14	10	6	1	-7	-14	6	6
Summer 2050-2075	14	13	9	10	4	-2	-5	-11	-17	13	14	15	20	24	30	34	39	40	2	25
Summer 2075-2100	11	15	13	14	14	14	15	11	9	17	18	15	15	5	3	-3	-11	-16	13	5
Winter PF; %																				
Winter 2025-2050	4	1	-1	-3	-6	-9	-12	-14	-16	3	3	-1	-3	-5	-6	-7	-9	-11	-6	-4
Winter 2050-2075	7	5	3	3	6	4	1	-3	-5	11	8	8	5	3	0	-3	-7	-10	2	2
Winter 2075-2100	8	8	7	8	7	5	3	0	-1	19	14	12	11	8	8	6	-1	-4	5	8

Climate Change Projections from 2015 through 2100

+ All season (mixed distribution) analysis

Region 4 - Application of Climate Change Results

Monthly Temperature Analysis

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	6.6	6.3	8.5	8.5	9.2	8.9	***1.9***	***2.6***	***2.2***	***2.6***
February	8.9	8.6	11.2	11.0	11.8	11.5	***2.3***	***2.9***	***2.4***	***2.9***
March	13.1	12.8	15.5	15.5	16.2	16.3	***2.4***	***3.1***	***2.7***	***3.5***
April	18.0	17.6	20.4	20.4	21.0	20.9	***2.4***	***3.0***	***2.8***	***3.3***
May	22.3	22.1	24.4	24.5	25.2	25.3	***2.1***	***2.9***	***2.4***	***3.2***
June	25.8	25.5	27.8	27.9	28.6	28.6	***2.1***	***2.9***	***2.4***	***3.1***
July	26.9	26.6	28.7	28.8	29.5	29.5	***1.8***	***2.6***	***2.2***	***2.9***
August	25.9	25.7	27.6	27.8	28.7	28.7	***1.7***	***2.7***	***2.1***	***3.0***
September	22.7	22.6	24.3	24.2	25.2	25.3	***1.6***	***2.5***	***1.7***	***2.8***
October	16.7	16.3	18.5	18.2	19.6	19.5	***1.8***	***2.9***	***1.9***	***3.2***
November	11.5	11.2	13.0	13.0	13.9	13.7	***1.5***	***2.4***	***1.9***	***2.5***
December	7.7	7.3	9.2	9.2	9.9	9.7	***1.5***	***2.2***	***1.9***	***2.4***

Climate Change Projections from 2015 through 2100

Region 4 - Application of Climate Change Results

Monthly Precipitation Analysis

	Historical		SSP45		SSP85		Median Delta		Mean Delta	
	Median	Mean	Median	Mean	Median	Mean	SSP45	SSP85	SSP45	SSP85
January	90.7	91.2	97.7	98.0	101.6	100.4	***1.08***	***1.12***	***1.07***	***1.10***
February	81.2	81.1	89.4	90.5	90.8	92.2	***1.10***	***1.12***	***1.12***	***1.14***
March	91.0	90.8	95.5	94.8	97.4	98.0	***1.05***	***1.07***	***1.04***	***1.08***
April	79.2	80.2	86.5	86.0	82.7	82.6	***1.09***	***1.04***	***1.07***	***1.03***
May	100.3	99.6	108.2	109.8	106.3	105.9	***1.08***	***1.06***	***1.10***	***1.06***
June	116.0	115.4	126.2	126.4	126.2	126.0	***1.09***	***1.09***	***1.10***	***1.09***
July	151.1	150.5	160.9	162.1	160.4	162.5	***1.06***	***1.06***	***1.08***	***1.08***
August	139.7	139.7	150.6	152.1	147.6	146.8	***1.08***	***1.06***	***1.09***	***1.05***
September	102.2	102.5	107.1	108.4	107.6	107.5	***1.05***	***1.05***	***1.06***	***1.05***
October	80.4	79.5	80.7	80.9	81.9	83.4	***1.00***	***1.02***	***1.02***	***1.05***
November	73.9	72.6	78.7	78.4	81.6	80.9	***1.06***	***1.10***	***1.08***	***1.12***
December	89.0	89.4	95.6	94.5	100.3	98.8	***1.07***	***1.13***	***1.06***	***1.11***

Climate Change Projections from 2015 through 2100

Region 4 Conclusion

TREND

- Historical precipitation – **no change** in precipitation
- SSP45 precipitation – **no change** in precipitation
- SSP85 precipitation – split between **no change** and an **increase** in precipitation

FREQUENCY

- 1-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.
- 3-day – SSP45 and SSP85 results are within +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100. *** SSP85 Summer 2050 -2075 shows an **increase** when split by 25-yr period.
- 30-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.
- 90-day – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100.
- Annual – SSP45 and SPP85 median results are less than +/- 20% uncertainty which provide more confidence for **no change** in precipitation magnitude by 2100m and both have **increase** temperature by 2100

CLIMATOLOGY

- Monthly Climatology – small increase in precipitation (within +/ -20%) and **increase** in temperature by 2100
- Annual Climatology – **no change** in annual precipitation (within +/ -20%) and **an increase**

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Questions

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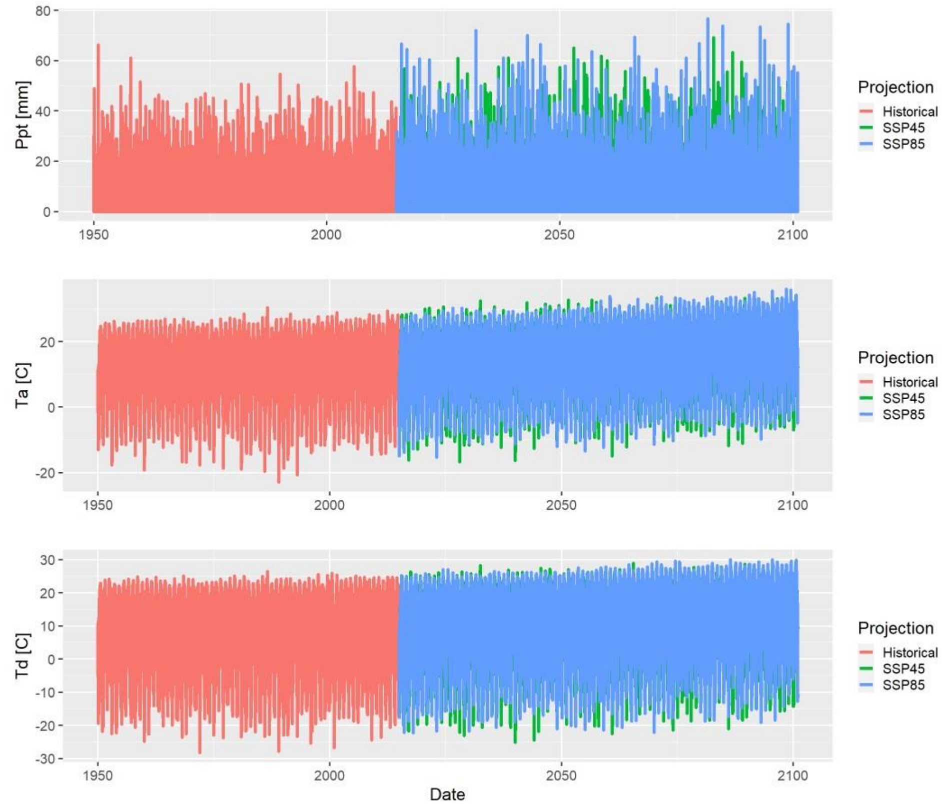

Appendix M
Project Review Board Letter

MEMORANDUM

FREESE AND NICHOLS

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TO: Hadush Hagos, NCDEQ Dam Safety

CC: Bill Kappel, Applied Weather Associates

FROM: Technical Advisory Committee

SUBJECT: Project Review Board Letter – North Carolina PMP Development

DATE: 5/29/2025

Applied Weather Associates (AWA) submitted the final draft report for the Probable Maximum Precipitation Study for North Carolina in late March, incorporating comments from the fourth review meeting that was held on March 3, 2025. Comments on this draft final report were provided by the Technical Advisory Committee (TAC) to NCDEQ Dam Safety by email and AWA incorporated these into a final version of the report. The members of the review committee consisted of both the TAC and additional members of a stakeholder group. The members of each group are listed below.

<u>Technical Advisory Committee (TAC)</u>
John Rutledge, Freese and Nichols
Alex Nice, Gradient
Laura Shearin-Feimster, Schnabel
Sam Ravenel, Withers Ravenel
Matthew Burnette, Weston and Sampson
Corey Davis, NC State Climatologist

<u>Stakeholder Group</u>
Elise Dombeck, FERC
Devan Mahadevan, FERC
Corey Davis -State Climate Office, NCSU
Jared Bowden, State Climate Office, NCSU
Aaron Schwartz, NRCS
Kurt Golembesky, NCDOT, Hydraulics Unit
Jonathan Burgess, FERC
Kathie Dello, NCSU
Aaron Schwarts, NRCS
Kathie Dello, NC State Climatologist
David Watson, Black & Veatch
Shae Hoschek, FERC
Mary Waligora, NRCS
Ross Perry, Withers Ravenel
Seydou Albachir, Black and Veatch
Scarlett Kitts, Black & Veatch
Amy Bergbreitter, FERC

The TAC was requested to review and provide input and comments on each portion of the study and PMP Report development. To facilitate this, the TAC, along with members of the Stakeholder group, met a total of four times to hear presentations by AWA on the progress of the study, reviewed various draft documents and information provided by AWA, and provided feedback and comments on each presentation and document reviewed. The meetings and responses are summarized in the meeting minutes produced for each of the four meetings, copies of which are attached. All action items developed from the various meetings were resolved to the satisfaction of the TAC.

The conclusions of the TAC are that AWA provided a thorough and complete analysis of the PMP that was consistent with currently accepted PMP theories and procedures. We recommend adoption of the findings and results of the PMP study for use in North Carolina.

It should be noted that the TAC acted in an advisory capacity only. Specifically, no calculations were performed by the TAC, nor were detailed reviews of calculations performed by the TAC. We believe that AWA utilized adequate quality assurance and control procedures to provide assurance that the calculations were performed accurately and without any significant errors. As such, the TAC does not make any warranty, express or implied, regarding the use of any information or method shown in the Probable Maximum Precipitation Study for North Carolina report or assume any future liability regarding use of any information or method contained therein.

The TAC appreciates the opportunity to provide these services to the NCDEQ Dam Safety team

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TO: Josh Colley, NCDEQ Dam Safety

CC:

FROM: Technical Advisory Committee

SUBJECT: Summary of Meeting #1 – North Carolina PMP Development

DATE: 10/10/2023

The Kickoff Meeting for the North Carolina PMP Development Study was held in the Green Square building on October 3, 2023 from 9:00 to 5:00 with NCDEQ Dam Safety, Applied Weather Associates, the Technical Advisory Committee and the Stakeholders group. The Agenda for the meeting is attached.

Attendees of the meeting are listed below

North Carolina DEQ Dam Safety (NCDEQ)
Josh Colley
Toby Vinson
Jacob Smith
Hadush Hagos

Applied Weather Associates (AWA)
Bill Kappel
Jake Rodel (virtual)
Doug Hultstrand (virtual)

Technical Advisory Committee (TAC)
John Rutledge, Freese and Nichols
Alex Nice, Gradient
Laura Shearin-Feimster, Schnabel
Sam Ravenel, Withers Ravenel (represented by Wesley Perry)
Matthew Burnette, Geosyntec
Matthew Lauffer NCDOT (represented by Kurt Golembesky)
Kathie Dello, NC State Climatologist (represented by Corey Davis)

Stakeholder Group
Devan Mahadevan, FERC
Jonathan Burgess, FERC (virtual)
Elise Dombeck, FERC (virtual)
Mathhew Henry, FERC (virtual)
Aaron Schwarts, NRCS
Wes Brown, USACE (virtual)

As listed in the agenda, the vast majority of the meeting consisted of a thorough presentation by Bill Kappel of AWA about the work done to date and then planned investigation. Numerous questions were raised and discussed for clarification.

Key points raised during the discussion that would be considered action items to be resolved as the study progresses would include:

1. A concern was raised regarding temporal distributions. AWA, as part of the study will develop a variety of possible temporal distributions for different durations. It was recommended that the NCDEQ adopt a single temporal distribution or group of distributions for their standard minimum design criteria in order to simplify the process. Developing one consistent temporal pattern based on the findings of the study would be needed.
2. It was requested that the study provide a methodology for developing rainfall estimates in subbasins outside the primary storm area for when the critical storm is not the full basin and/or for breach analyses needing rainfall estimates downstream of the dam.
3. Bill requested that members of the TAC provide testing and feedback when the first versions of the new system are available.
4. Bill requested that all study participants provide input on additional storm events that can be investigated for PMP development. This would be especially helpful in the Piedmont-Coastal Plains regions of the state.

The Agenda included three questions for the TAC and NCDEQ - Dam Safety:

1. Are there any watersheds that drain into the region that need to be considered beyond the state boundaries?
2. What durations and area sizes are most critical for NC dam safety needs (e.g. 1hr 1sqmi, 72hr 5,000sqmi)?
3. Are there any storms that are not included on the list that should be considered?

The group discussed each question and agreed that these issues need to be addressed, but did not resolve them at this meeting. These will be added to the action item list. Questions 1 and 2 above have subsequently been resolved through discussions between NCDEQ and AWA as of October 10, 2023. These recommendations will be presented and confirmed at the next meeting.

The following graphic was presented as the schedule for the study. This kickoff meeting is shown as the first meeting in Month 2.

The spreadsheet that will be used moving forward that lists all the action items is also attached.

Task/Month	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Month 14	Month 15
Review Previous															
Storm Search															
Storm adjustments															
PMP															
Temporal															
Report															
GIS PMP Tool															
Meetings															
Optional Task															
Annual Exceedance Probability															
Climate Change															

North Carolina PMP Study Kick Off Meeting

In-Person, October 3, 2023

Green Square Building, Room 1210

217 W Jones St, Raleigh, NC 27603

Please plan to arrive up to 15 minutes early to allow for visitor sign in at reception

Detailed Agenda

Tuesday, October 3

9:00 – 9:30	Welcome/Introductions/Review of Project Goals/Meeting Logistics	NC Dam Safety
9:30 – 10:00	Project Scope/Timeline/Review Process/Benchmarks	NC Dam Safety /AWA
10:00 – 11:30	PMP Background, Task Descriptions, and Examples	Bill Kappel Applied Weather Associates
Lunch 11:30-1:00		
1:00 – 1:30	SPAS storm analysis description	Bill Kappel Applied Weather Associates
1:30 – 2:30	Storm adjustments/Description/ Database Descriptions	Bill Kappel Applied Weather Associates
Break 2:30-3:00		
3:00 –3:30	PMP Analysis example results	Bill Kappel Applied Weather Associates
3:30 –4:30	Hydrologic implemtnation discussions	Review Board/ NC Dam Safety/AWA
4:30 –5:00	Discussions/Questions/Data Needs/Next Steps	Review Board/ NC Dam Safety/AWA

Please feel free to contact Josh Colley at 919-707-9214 or josh.colley@deq.nc.gov or Bill Kappel at 719-964-3395 or billkappel@appliedweatherassociates.com if you have questions about the meeting.

Questions for the Review Board and Dam Safety

1. Are there any storms that are not included on the initial storm list that should be considered?
2. Does the review board concur storm durations less than 72-hrs are most relevant for North Carolina dam safety?

Remote Meeting Teleconference Information

Join on your computer, mobile app or room device

Click here to join the meeting

Meeting ID: 260 835 255 653

Passcode: nvwgQJ

NC DEQ Project No.xxxx
North Carolina Statewide PMP

ATTACHMENT - ACTION ITEM TRACKER

TAC Meeting	ACTION ITEMS			RESPONSE			Status	
	Item No.	Date Opened	Action Item Description	Date Required	Respondent	Response	Status	Date Closed
1	1-1	10/03/23	Provide input for PMP storm list, with focus on local storms	11/03/23	TAC-DEQ		Open	
1	1-2	10/03/23	Determine overall project boundary	10/17/23	AWA-DEQ	Additional area was added to the northern part of the doman to address drainages flowing into the state.	Complete	10/10/23
1	1-3	10/03/23	Determine overall PMP duration	10/05/23	AWA-DEQ	Data are avaialble to 120 hours, in additon going to this duration does not add additional scope. Therefore, AWA will provide PMP depths from 1-hour through 120-hours.	Complete	10/05/23
1	1-4	10/03/23	Consider simplified single temporal distribution of PMF guidelines	10/01/24	NC-DEQ		Open	
1	1-5	10/03/23	Provide guidance on rainfall distribution outside the primary basin	10/01/24	AWA-DEQ		Open	

MEMORANDUM

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TO: Josh Colley, NCDEQ Dam Safety

CC: Bill Kappel, Applied Weather Associates

FROM: Technical Advisory Committee

SUBJECT: Summary of Meeting #2 – North Carolina PMP Development

DATE: 3/22/2024

The Second Meeting for the North Carolina PMP Development Study was held in the Green Square building on March 13, 2024 from 10:00 to 4:00 with NCDEQ Dam Safety, Applied Weather Associates, the Technical Advisory Committee and the Stakeholders group. The Agenda for the meeting is attached. Attendees of the meeting are listed below.

North Carolina DEQ Dam Safety (NCDEQ)
Josh Colley
Jacob Smith
Hadush Hagos

Applied Weather Associates (AWA)
Bill Kappel (virtual)
Jake Rodel (virtual)

Technical Advisory Committee (TAC)
John Rutledge, Freese and Nichols
Alex Nice, Gradient
Laura Shearin-Feimster, Schnabel
Sam Ravenel, Withers Ravenel (virtual)
Matthew Burnette, Weston and Sampson (virtual)
Corey Davis, NC State Climatologist

Stakeholder Group
Jared Bowden, NC State Climatologist
Devan Mahadevan, FERC
David Watson, Black & Veatch
Elise Dombeck, FERC (virtual)
Shae Hoschek, FERC (virtual)
Mary Waligora, NRCS (virtual)
Ross Perry, Withers Ravenel (virtual)
Seydou Albachir, Black and Veatch (virtual)
Scarlett Kitts Black & Veatch (virtual)
Amy Bergbreitter, FERC (virtual)

As listed in the agenda, the vast majority of the meeting consisted of a thorough presentation by Bill Kappel of AWA about the work done to date and the remaining investigation. The SPAS analyses and the first two iterations of some of the draft PMP have been completed and these preliminary results were provided. Numerous questions were raised and discussed for clarification.
Key points raised during the discussion that would be considered action items to be resolved as the study progresses would include:

1. There are a variety of options that would be appropriate for the consideration of rainfall in areas outside the critical basin, generally when doing breach analyses. Factors include the size and nature of the water bodies downstream. The suggestion was made for the TAC to provide examples of how they have handled such situations in the past. These will be compiled for review by AWA and NCDEQ.
2. It was requested of AWA that they provide storm list information, SPAS analysis information, and storm maximization information.

Current List of Action Items:

From Meeting #1

1. Are there any storms that are not included on the list that should be considered? Thirteen new storms were provided that were sufficiently large to be reviewed by AWA. Three of those were run through the full SPAS analysis and included in the full analysis.
2. Are there any watersheds that drain into the region that need to be considered beyond the state boundaries? Include full basins that drain into North Carolina, including some that extend into Virginia.
3. What durations and area sizes are most critical for NC dam safety needs. Include 1 hr to 72hr. There is no limitation on the drainage area being reviewed.
4. Consider simplified single temporal distribution of PMF guidelines. AWA will review and test numerous temporal patterns by storm type. The goal is to limit the number of reasonable patterns based on the historical storms. Maintain distinction between AWA report requirements and state guidance recommendations. Still Open
5. Provide guidance on rainfall distribution outside the primary basin. Still Open.

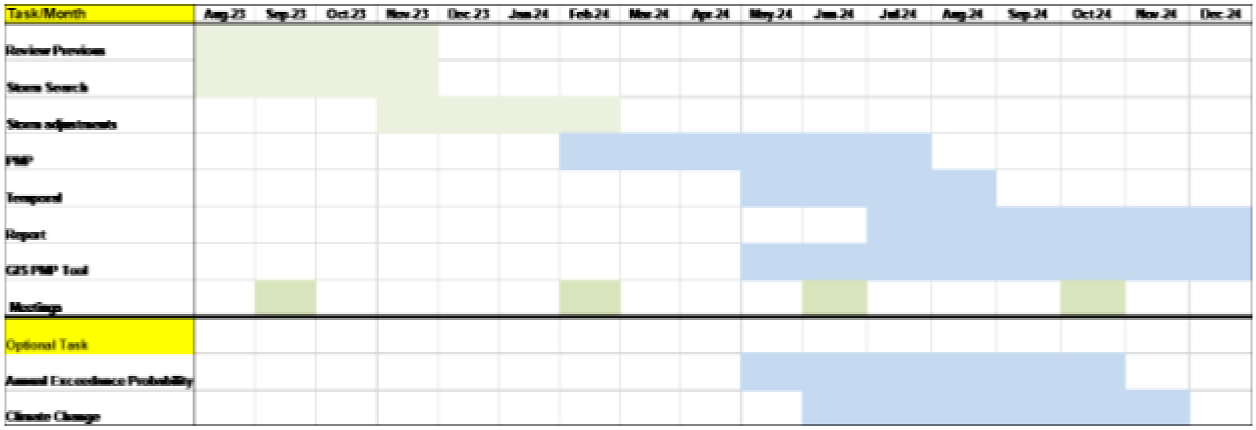
Action items 1 through 3 are considered complete.

From Meeting #2:

1. Request that members of the TAC provide examples of how they have included rainfall in areas downstream of the dam under consideration for breach analyses. This is an extension of Action item 1-5
2. Bill stated that the first draft tool for testing the PMP values will be available a few weeks after receiving input on the draft PMP values, likely about the end of June.

A spreadsheet summary of all action items is attached.

The following updated graphic was presented as the schedule for the study. This meeting is shown as the meeting in February. The next meeting is shown in June.


Task/Month
Aug-23
Sep-23
Oct-23
Nov-23
Dec-23
Jan-24
Feb-24
Mar-24
Apr-24
May-24
Jun-24
Jul-24
Aug-24
Sep-24
Oct-24
Nov-24
Dec-24
Review Previous
Storm Search
Storm adjustments
PMP
Temporal
Report
GIS PMP Tool
Meetings
Optional Task
Annual Exceedance Probability
Climate Change

North Carolina Statewide PMP

Meeting 2- AGENDA

North Carolina Department of Environmental Quality
March 13, 2024

Microsoft Teams meeting

Join on your computer, mobile app or room device

Click here to join the meeting

Meeting ID: 213 064 016 32

Passcode: Ujdis8

Wednesday, March 13, 2024

8:30 – 9:00 am Welcome/Meeting Expectations

9:00 –10:00am Project status-meeting 1 recap/action items (*AWA to lead*)

10:00 – 10:15am Break

10:00 – 12:00pm SSPMP Development status (*AWA to lead*)
- Storm list for PMP Development
- New storms analyzed
- Storm adjustments
- Initial PMP outputs and discussions

12:00 – 1:00pm Lunch/Break

1:00 – 2:00pm SSPMP Development (*AWA to lead*)
- Storm list for PMP Development
- New storms analyzed
- Storm adjustments
- Initial PMP outputs and discussions
- Next Steps

2:00 – 3:00pm Update from NC Dam Safety/Review Board (*NC DEQ to lead)*
- Consultant testing and feedback discussion
- Roll-out communications
- Coordination with other ongoing projects
  - Overtopping studies
  - Screening level risk analysis

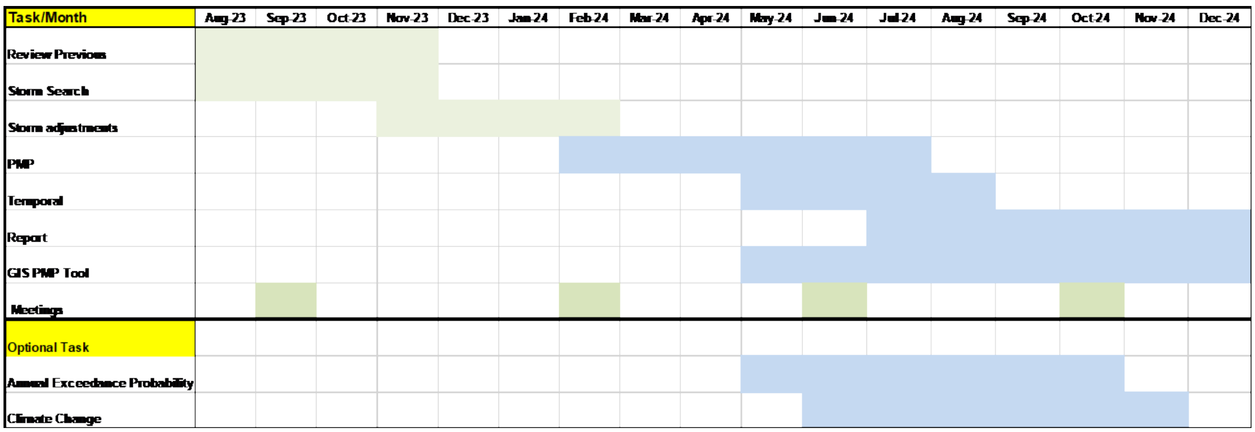
3:00 – 4:00pm Technical Advisory Committee Feedback, Q&A, Next Steps

Key Points from Meeting 1 to be discussed:

1. A concern was raised regarding temporal distributions. AWA, as part of the study will develop a variety of possible temporal distributions for different durations. It was recommended that the NCDEQ adopt a single temporal distribution or group of distributions for their standards to simplify the process. Developing one consistent with the findings of the study would be needed.

2. It was requested that the study provide a methodology for developing rainfall estimates in subbasins outside the primary storm area for when the critical storm is not the full basin and/or for breach analyses needing rainfall estimates downstream of the dam.
3. Bill requested that members of the TAC provide testing and feedback when the first versions of the new system are available.
4. Bill requested that all study participants provide input on additional storm events that can be investigated for PMP development. This would be especially helpful in the Piedmont-Coastal Plains regions of the state.

Study Schedule (light green-completed; blue in progress or upcoming)



Questions/Action items form Meeting 1:

1. Are there any watersheds that drain into the region that need to be considered beyond the state boundaries?
2. What durations and area sizes are most critical for NC dam safety needs (e.g. 1hr 1sqmi, 72hr 5,000sqmi)?
3. Are there any storms that are not included on the list that should be considered?

ATTACHMENT - ACTION ITEM TRACKER

TAC Meeting	ACTION ITEMS			RESPONSE			Status	
	Item No.	Date Opened	Action Item Description	Date Required	Respondent	Response	Status	Date Closed
1	1-1	10/03/23	Provide input for PMP storm list, with focus on local storms	11/03/23	TAC-DEQ	13 storms suggested. 3 were included after review	Complete	03/13/24
1	1-2	10/03/23	Determine overall project boundary	10/17/23	AWA-DEQ	Additional area was added to the northern part of the doman to address drainages flowing into the state from VA.	Complete	10/10/23
1	1-3	10/03/23	Determine overall PMP duration	10/05/23	AWA-DEQ	Data are avaialble to 72 hours, in additon going to this duration does not add additional scope. Therefore, AWA will provide PMP depths from 1-hour through 72 hours.	Complete	10/05/23
1	1-4	10/03/23	Consider simplified single temporal distribution of PMF guidelines	10/01/24	NC-DEQ		Open	
1	1-5	10/03/23	Provide guidance on rainfall distribution outside the primary basin	10/01/24	AWA-DEQ		Open	
2	2-1	03/13/24	Request that members of the TAC provide examples of how they have included rainfall in areas downstream of the dam under consideration for breach analyses	06/01/24	TAC-DEQ		Open	
2	2-2	03/13/24	Release preliminary PMP data for TAC review & testing. Tool released after adjustments from Meeting #3	06/30/24	AWA		Open	

MEMORANDUM

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TO: Hadush Hagos, NCDEQ Dam Safety

CC: Bill Kappel, Applied Weather Associates

FROM: Technical Advisory Committee

SUBJECT: Summary of Meeting #3 – North Carolina PMP Development

DATE: 8/16/2024

The Third Meeting for the North Carolina PMP Development Study was held in the Green Square building on August 7, 2024 from 8:30 to 1:30 with NCDEQ Dam Safety, Applied Weather Associates, the Technical Advisory Committee and the Stakeholders group. The Agenda for the meeting is attached.
Attendees of the meeting are listed below.

North Carolina DEQ Dam Safety (NCDEQ)
Hadush Hagos (virtual)

Applied Weather Associates (AWA)
Bill Kappel (virtual)
Jake Rodel (virtual)

Technical Advisory Committee (TAC)
John Rutledge, Freese and Nichols
Alex Nice, Gradient (virtual)
Laura Shearin-Feimster, Schnabel
Sam Ravenel, Withers Ravenel
Matthew Burnette, Weston and Sampson (virtual)

Stakeholder Group
David Watson, Black & Veatch (virtual)
Elise Dombeck, FERC (virtual)
Shae Hoschek, FERC (virtual)
Mary Waligora, NRCS (virtual)
Ross Perry, Withers Ravenel (virtual)
Seydou Albachir, Black and Veatch (virtual)
Amy Bergbreitter, FERC (virtual)

As listed in the agenda, the vast majority of the meeting consisted of a thorough presentation by Bill Kappel of AWA about the work done to date and the remaining investigation. Bill provided a brief overview describing the work to date, which has been effectively the completion of the development of the PMP values, including all the analysis of different storms and their characteristics, thorough adjustments as needed for the area. Bill described some of the issues related to determining the critical storms, constraints and issues with respect to transposition to the NC area. These details will be covered in the final report. The general conclusion was that there were plenty of storms to analyze with good variability and quality data to develop strong confidence in the results. Bill suggested that it might be helpful to develop some general guidelines on the use of the PMP model to make its use more efficient, such as to ignore local events for large areas. Several questions were raised and discussed for clarification.

AWA provided some example runs using a typical tool from other states, demonstrating both the PMP tool and the AEP tool that is under development for NC. AWA also presented an overview of the Climate Change impact analysis and a summary of the findings from the analysis performed for Maryland, which are expected to be similar to NC.

Hadush Hagos and Laura Shearin presented findings from some initial sample runs using the preliminary data. These are ongoing and feedback will be provided to AWA.

Current List of Outstanding Action Items:

From Meeting #1

4. Consider simplified single temporal distribution of PMF guidelines. AWA will review and test numerous temporal patterns by storm type. The goal is to limit the number of reasonable patterns based on the historical storms. Maintain distinction between AWA report requirements and state guidance recommendations. Still Open
5. Provide guidance on rainfall distribution outside the primary basin. Still Open.

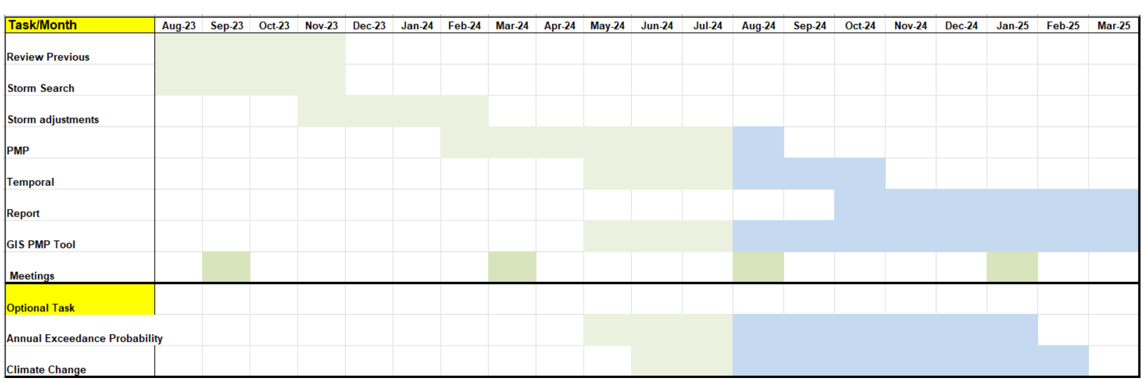
From Meeting #2:

1. Request that members of the TAC provide examples of how they have included rainfall in areas downstream of the dam under consideration for breach analyses. This is an extension of Action item 1-5 from Meeting #1. Some were provided after the meeting by email. This discussion will continue.
2. Bill stated that the first draft tool for testing the PMP values will be available a few weeks after receiving input on the draft PMP values, likely about the end of June.

These items are still ongoing. Action Item #2 will continue with an updated version of the draft tool. No new actions were established from Meeting #3.

A spreadsheet summary of all action items is attached.

The following updated graphic represents the current schedule for the study. The next meeting is shown in January.



MEMORANDUM

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TO: Hadush Hagos, NCDEQ Dam Safety

CC: Bill Kappel, Applied Weather Associates

FROM: Technical Advisory Committee

SUBJECT: Summary of Meeting #4 – North Carolina PMP Development

DATE: 3/3/2025

The Fourth Meeting for the North Carolina PMP Development Study was virtually on March 3, 2025 from 10:30 to 4:30 (EST) with NCDEQ Dam Safety, Applied Weather Associates, the Technical Advisory Committee and the Stakeholders group. The Agenda for the meeting is attached.
Attendees of the meeting, all virtual, are listed below.

North Carolina DEQ Dam Safety (NCDEQ)
Hadush Hagos -Asst Dam Safety Engineer

Applied Weather Associates (AWA)
Bill Kappel
Jake Rodel
Doug Hultstrand

Technical Advisory Committee (TAC)
John Rutledge, Freese and Nichols
Alex Nice, Gradient
Laura Shearin-Feimster, Schnabel
Ross Perry (for Sam Ravenel), Withers Ravenel
Matthew Burnette, Weston and Sampson

Stakeholder Group
Elise Dombeck, FERC
Devan Mahadevan FERC
Corey Davis -State Climate Office, NCSU
Jared Bowden – State Climate Office, NCSU
Aaron Schwartz - NRCS
Kurt Golembesky – NCDOT, Hydraulics Unit

As listed in the attached agenda, the first portion of the meeting consisted of a thorough presentation by Bill Kappel of AWA about the work done to date, including a description of the recently added analysis of Hurricane Helene and Tropical Cyclone Eight on the state. Several questions were raised and discussed for clarification. Hurricane Helene (Sept 24 to 27, 2024) generated extreme rainfall and flooding in Western NC and Tropical Cyclone Eight (Sept 15 to 17, 2024) generated extreme rainfall and flooding in South East NC.

Hadush Hagos presented several examples of PMP calculations for dam sites in NC, focusing on the impact of the changes due to the inclusion of Helene into the database. AWA presented the background on the statistical analyses performed to derive the probability distributions for the PMP values and the overall Annual Exceedance Probability (AEP) development for the state. AWA has developed these outputs for two durations, 6- and 24-hours and recurrence intervals that extend to 10^{-10}. This information will be part of the overall database and tool and provided on the same gridded domain as the PMP depths. Discussions about other durations that could be useful took place and AWA noted these can be derived if needed to support other engineering applications throughout the state.

AWA then presented the results of the climate change assessments across the domain. Several questions were asked about the climate change results and how those compare to other work that has been completed in North Carolina. AWA noted that the projections do not show a change in the PMP depths but instead more frequent events may increase. AWA noted they will include the climate change results and detailed descriptions in the overall report documentation.

Bill presented on the ongoing development of temporal distributions for the PMP indicating that it will be similar to temporal distributions recently developed by AWA for Maryland State as the 95% of the storms used to develop the new PMP for NC and Maryland are the same. For Local Storm, Temporal distributions for 2-hr, 6-hr, 12-hr and 24-hr durations PMPs while for General and Tropical Storms, Temporal distributions for 24-hr, 48-hr and 72-hr durations will be developed.

A presentation for training of the AEP tool will be recorded on March 14. The final PMP and AEP Tools together with user's guideline will be uploaded on NC DEQ Dam Safety website in the near future.

Still missing are the temporal distribution (which is still under development and expected to be complete in coming few weeks) and the AEP Tool, but the development of the PMP data and the tool are complete. AWA will provide the recommended temporal patterns for each storm type by the middle of March for review and testing. The goal of this is to develop a suite of temporal patterns by storm type that can be included in the tool for analysis but limit the amount of patterns that are required to be run based on storm type, basin area size and location.

Current List of Outstanding Action Items:

From Meeting #1

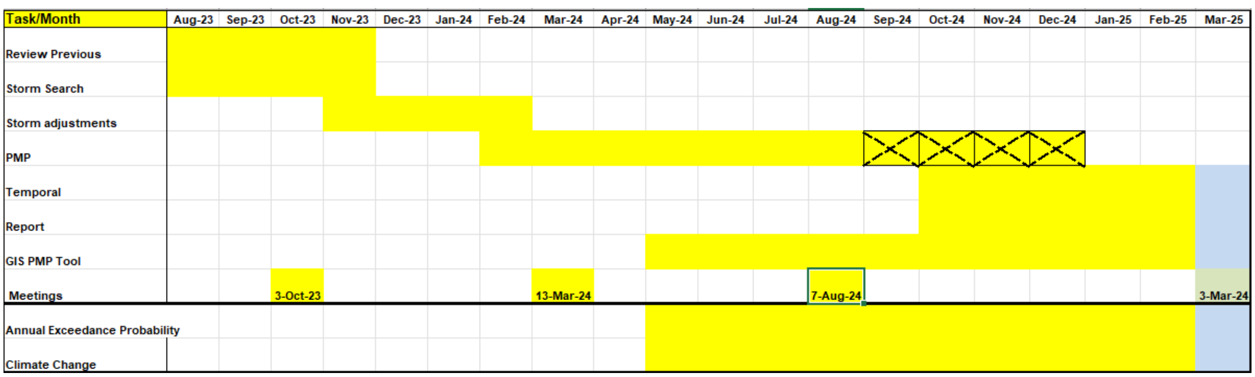
4. Consider simplified single temporal distribution of PMF guidelines. AWA will review and test numerous temporal patterns by storm type. The goal is to limit the number of reasonable patterns based on the historical storms. Maintain distinction between AWA report requirements and state guidance recommendations. AWA will provide some guidance, but final recommendations will be up to the NCDEQ. This action item can be closed.
5. Provide guidance on rainfall distribution outside the primary basin. Still Open. Bill stated that this issue is being reviewed in a separate study for FERC that might be useful in standardizing this process in the future, but not within this study. This action item can be closed.

From Meeting #2:

1. Request that members of the TAC provide examples of how they have included rainfall in areas downstream of the dam under consideration for breach analyses. This is an extension of Action item 1-5 from Meeting #1. Some were provided after the meeting by email. This discussion was provided and used in the reviews. This action item can be closed.
2. Bill stated that the first draft tool for testing the PMP values will be available a few weeks after receiving input on the draft PMP values, likely about the end of June. This was completed and the issue can be closed.

No new actions were established from Meeting #4.

The following updated graphic represents the current schedule for the study and was presented at the meeting.



North Carolina Statewide PMP Development

Meeting 4- AGENDA

North Carolina Department of Environmental Quality
March 3, 2025

Microsoft Teams meeting
Join on your computer, mobile app or room device:

Click here to join the meeting
Meeting ID: 226 984 291 486
Passcode: YC3Zw738

Monday, March 3, 2025 (EST Time)

10:30 – 10:45 am Welcome/Meeting Expectations

10:45 –11:30 am Project status-meeting 3 recap/action items, Amendment #2 (*AWA to lead*)

11:30 – 12:00 pm SSPMP Development status (*AWA to lead*)
Final PMP results incorporating also recent storms.

12:00 – 1:00 pm Break

1:00 – 2:00 pm SSPMP Development status (*AWA to lead*)
Temporal Distribution details/examples.
PMP results and discussions.
Results from New PMP test sites.

2:00 – 2:30 pm Break

2:30 – 3:30 pm SSPMP Development (*AWA to lead*)
AEP analysis details.
Climate change assessment analysis details.

3:30 – 4:00 pm Update from NC Dam Safety/Review Board (*NC DEQ to lead)*
Consultant testing and feedback discussion.
Roll-out communications.
Coordination with other ongoing projects
- Overtopping studies
- Screening level risk analysis

4:00 – 4:30 pm Technical Advisory Committee Feedback, Q&A, Next Steps

Key Points from previous meetings to be discussed:

1. Consider simplified single temporal distribution of PMF guidelines. AWA will review and test numerous temporal patterns by storm type. The goal is to limit the number of reasonable patterns based on the historical storms. Maintain distinction between AWA report requirements and state guidance recommendations.

2. Provide guidance on rainfall distribution outside the primary basin.

3. Request that members of the TAC provide examples of how they have included rainfall in areas downstream of the dam under consideration for breach analyses. This is an extension of Action from previous Meetings. Some were provided after the meeting by email. For example, use of 100-year rainfall/flows downstream was suggested though this needs to be considered case by case. This discussion will continue.

Study Schedule (light green-completed; blue in progress or upcoming)