Barrier islands: naturally-dynamic landforms

NC STATE UNIVERSITY

Dr. Katherine Anarde
Assistant Professor, Coastal Engineering

THE NORTH CAROLINA NATIONAL ESTUARINE RESEARCH'S COASTAL TRAINING PROGRAM PRESENTS:

Living on a Barrier Island – A Workshop for Real Estate Professionals

Barrier islands: naturally-dynamic landforms

Developed barriers: highly-vulnerable landforms

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Living on a Barrier Island – A Workshop for Real Estate Professionals

Agenda for today

- **What are barrier islands and how did they form in North Carolina?**
- **Dynamics on natural vs developed barrier islands**
- **The future of developed barrier islands:**
  - *How are they changing?*
  - *How can we respond?*

Image credit: NOAA

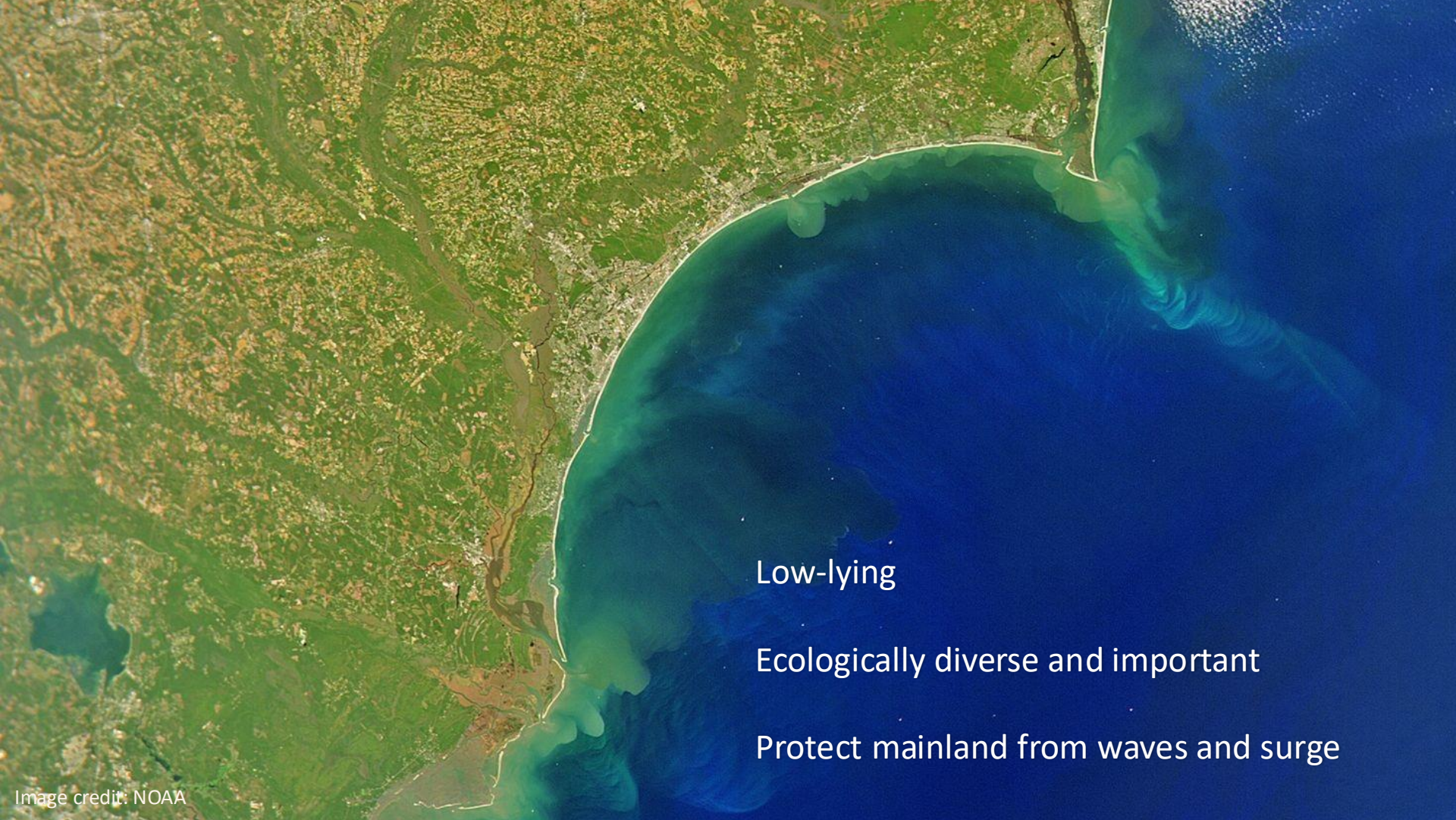


Image credit: NOAA

Long, narrow offshore sand deposits

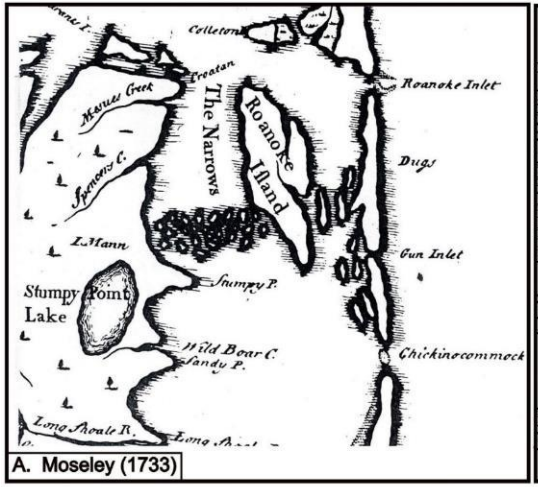
Parallel to the coast

Separated from mainland by a bay/lagoon/sound

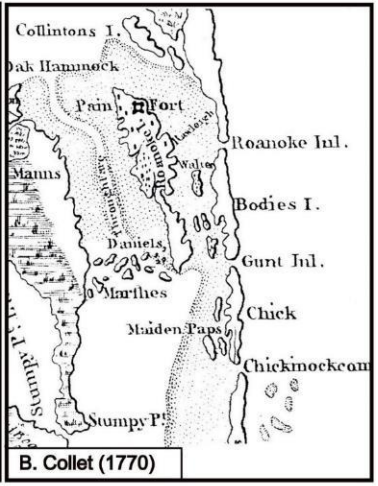
Separated from each other by tidal inlets

Image credit: NOAA

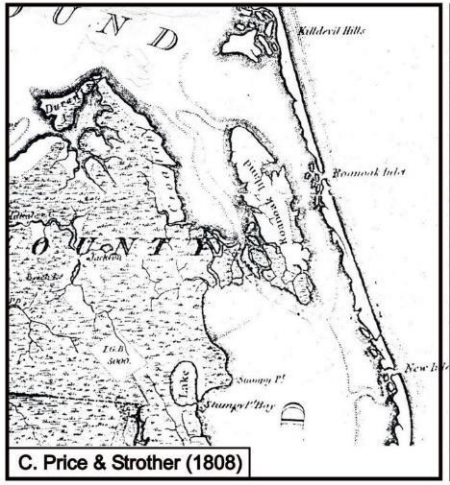
NC barriers have been dynamically changing since they emerged….



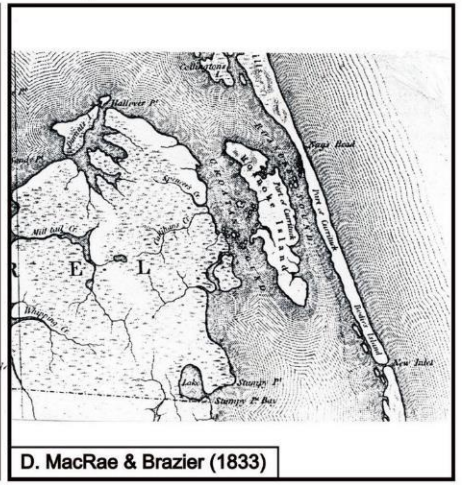
A. Moseley (1733)



B. Collet (1770)

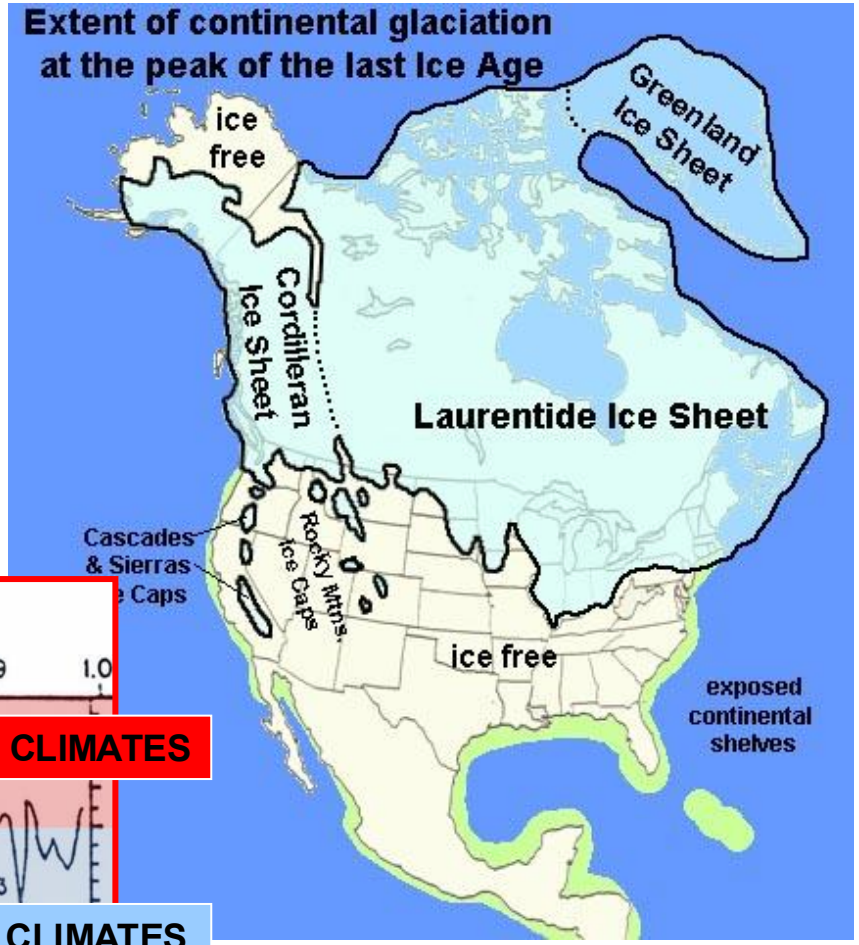


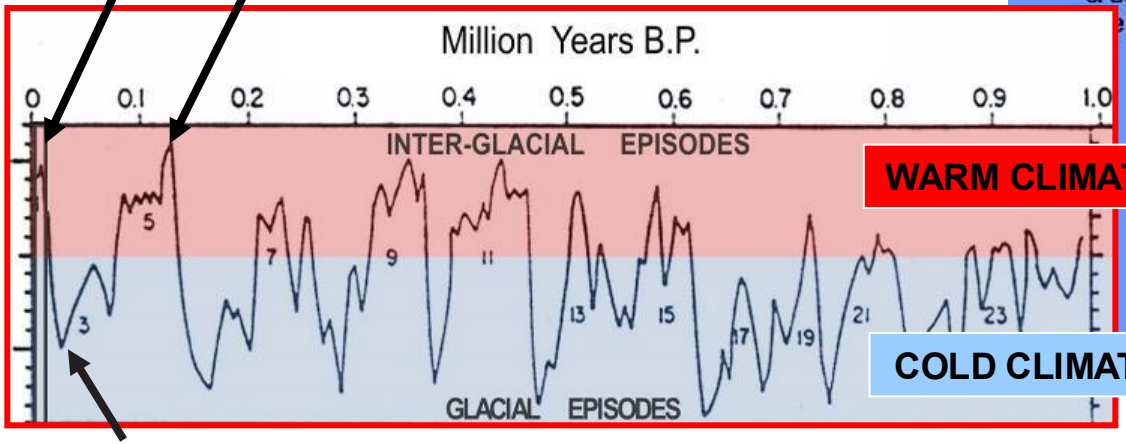
C. Price & Strother (1808)



D. MacRae & Brazier (1833)

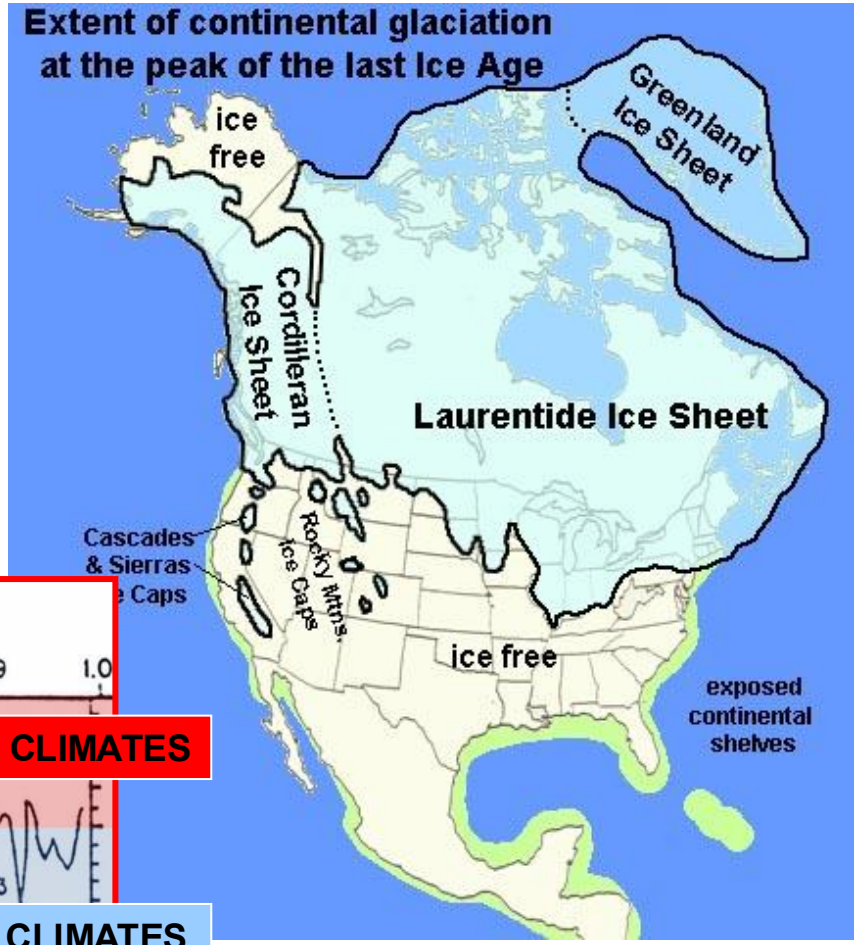
…~12,000 yrs ago, after the last glacial maximum





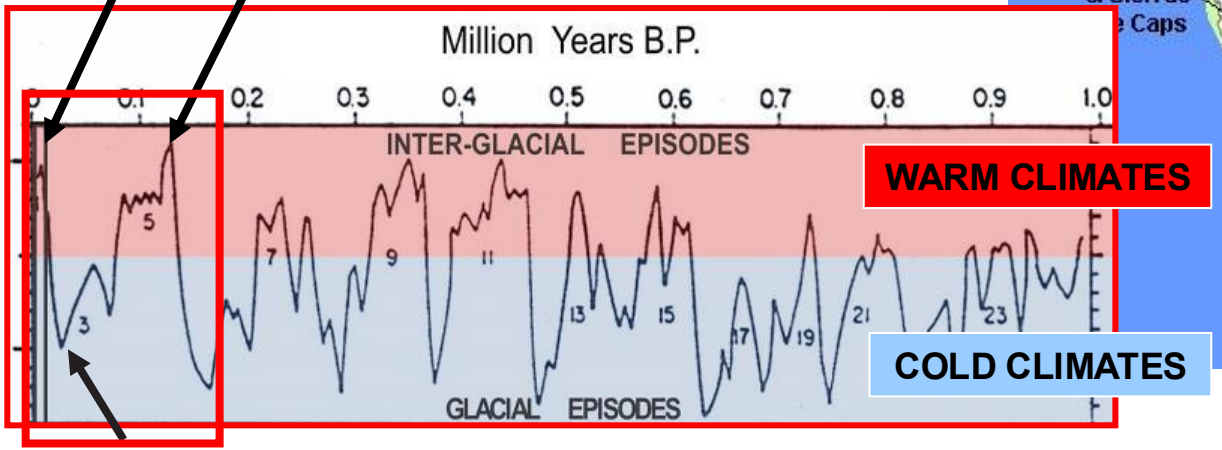
SHACKLETON & OPDYKE (1973)

…~12,000 yrs ago, after the last glacial maximum



TODAY

LAST INTERGLACIAL (~125,000 yrs BP)



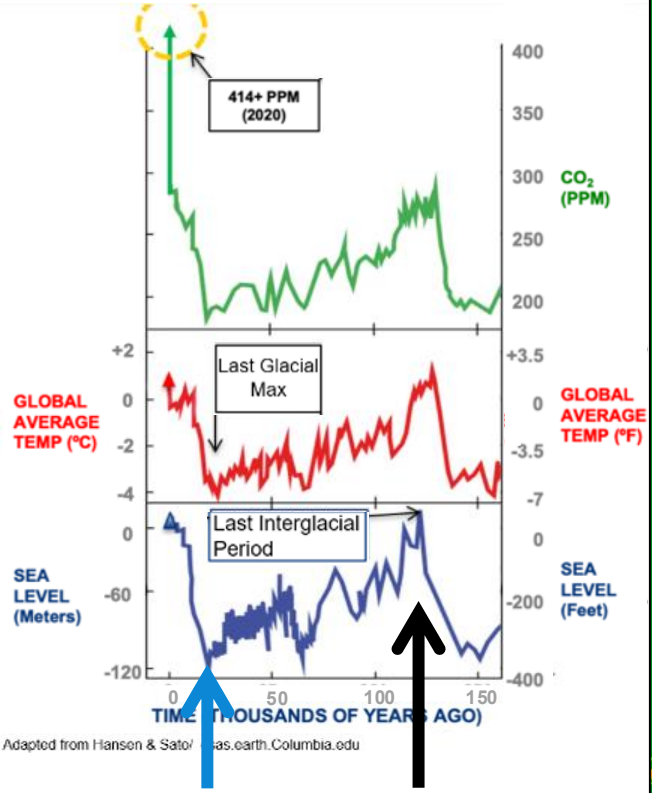
WARM CLIMATES

COLD CLIMATES

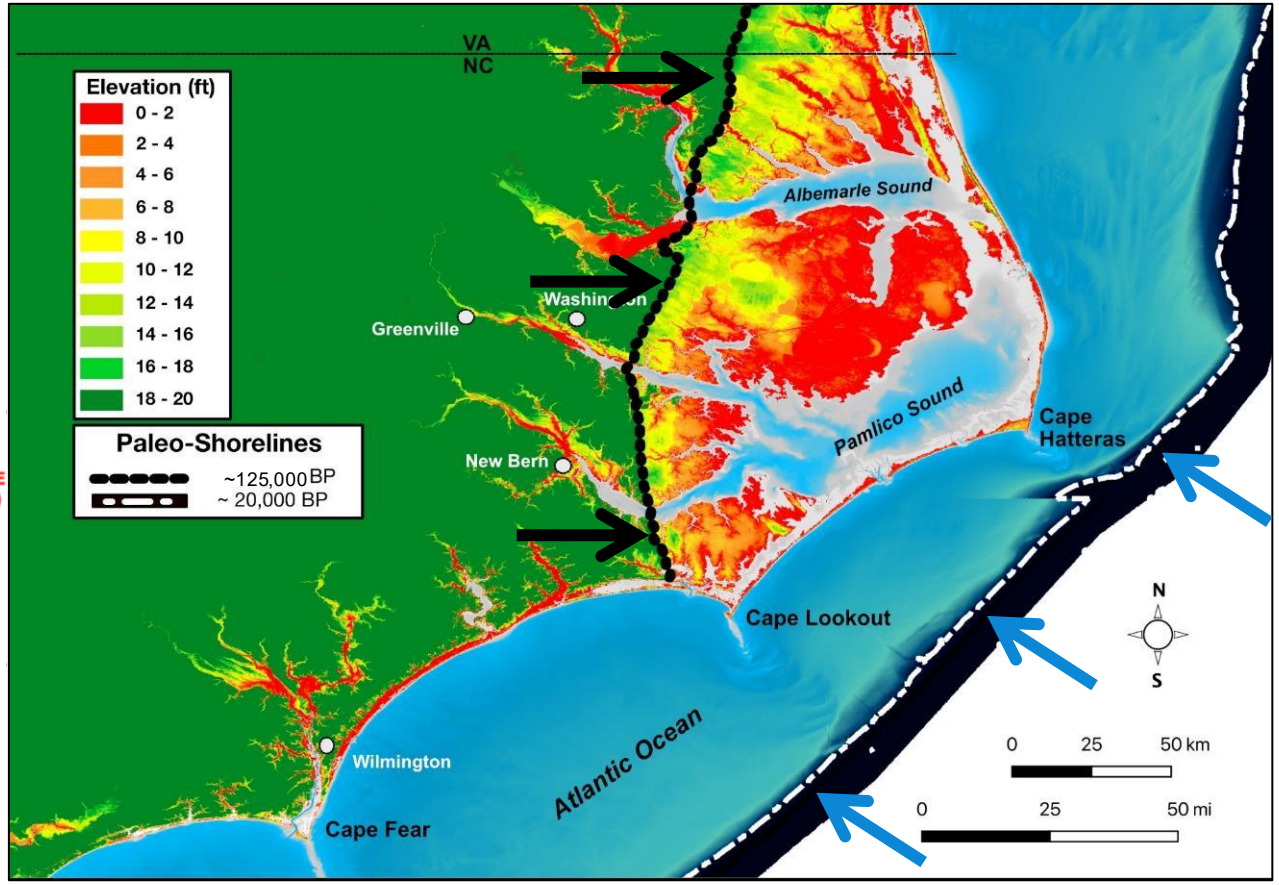
LAST GLACIAL MAXIMUM (~20,000 yrs BP)

SHACKLETON & OPDYKE (1973)

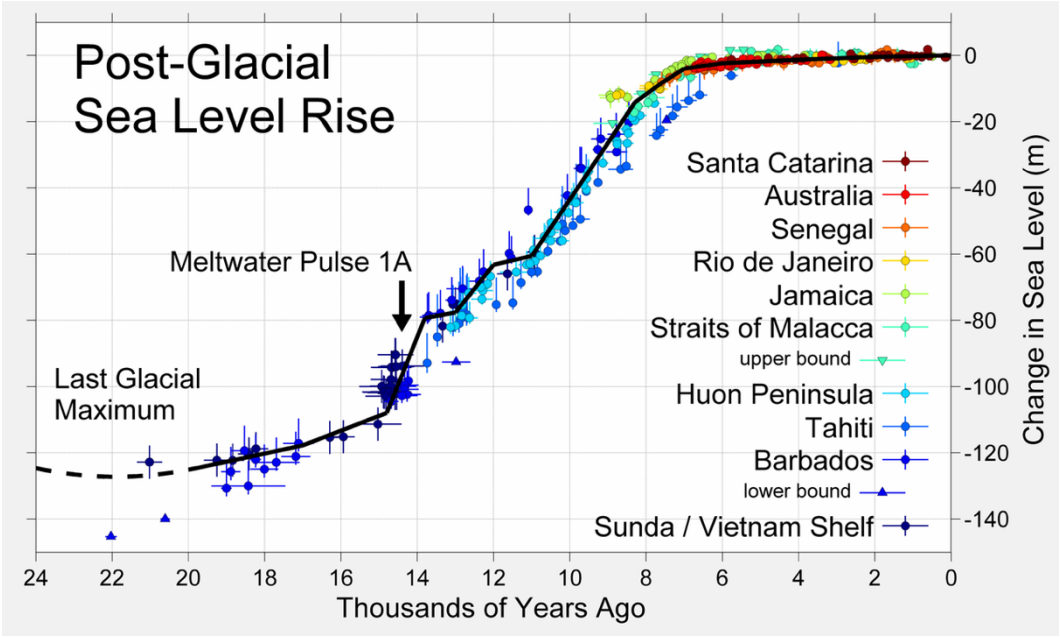
North Carolina's Shorelines of the PAST

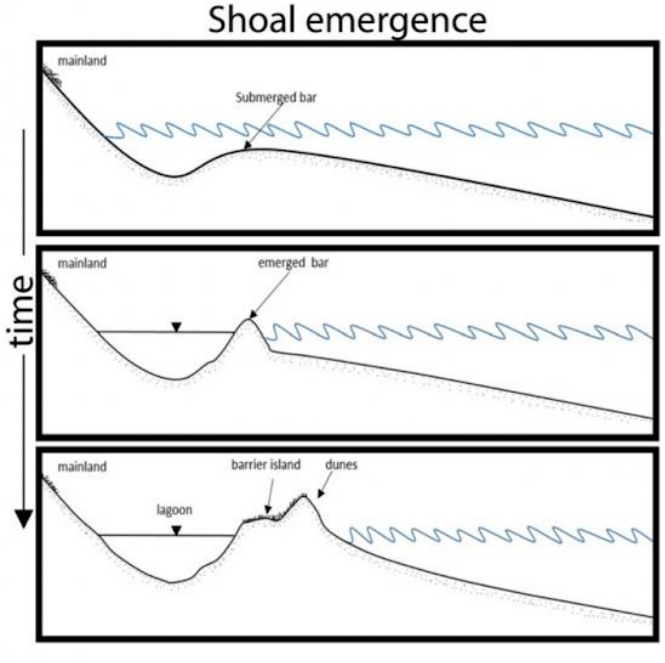


Glacial Interglacial



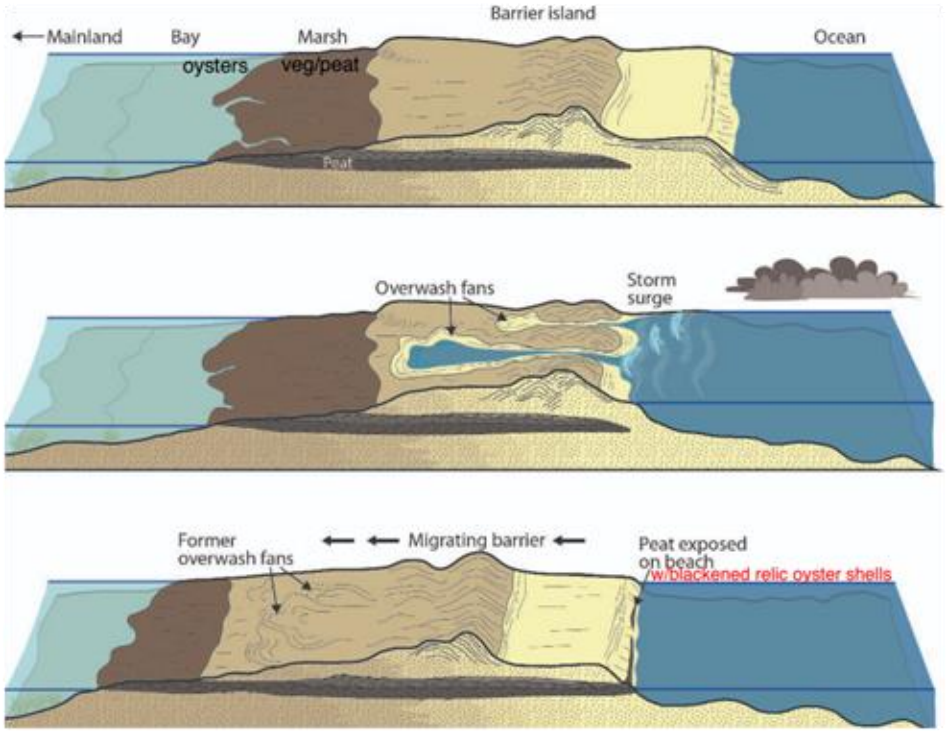
Emergence of barriers when global sea level rise slowed



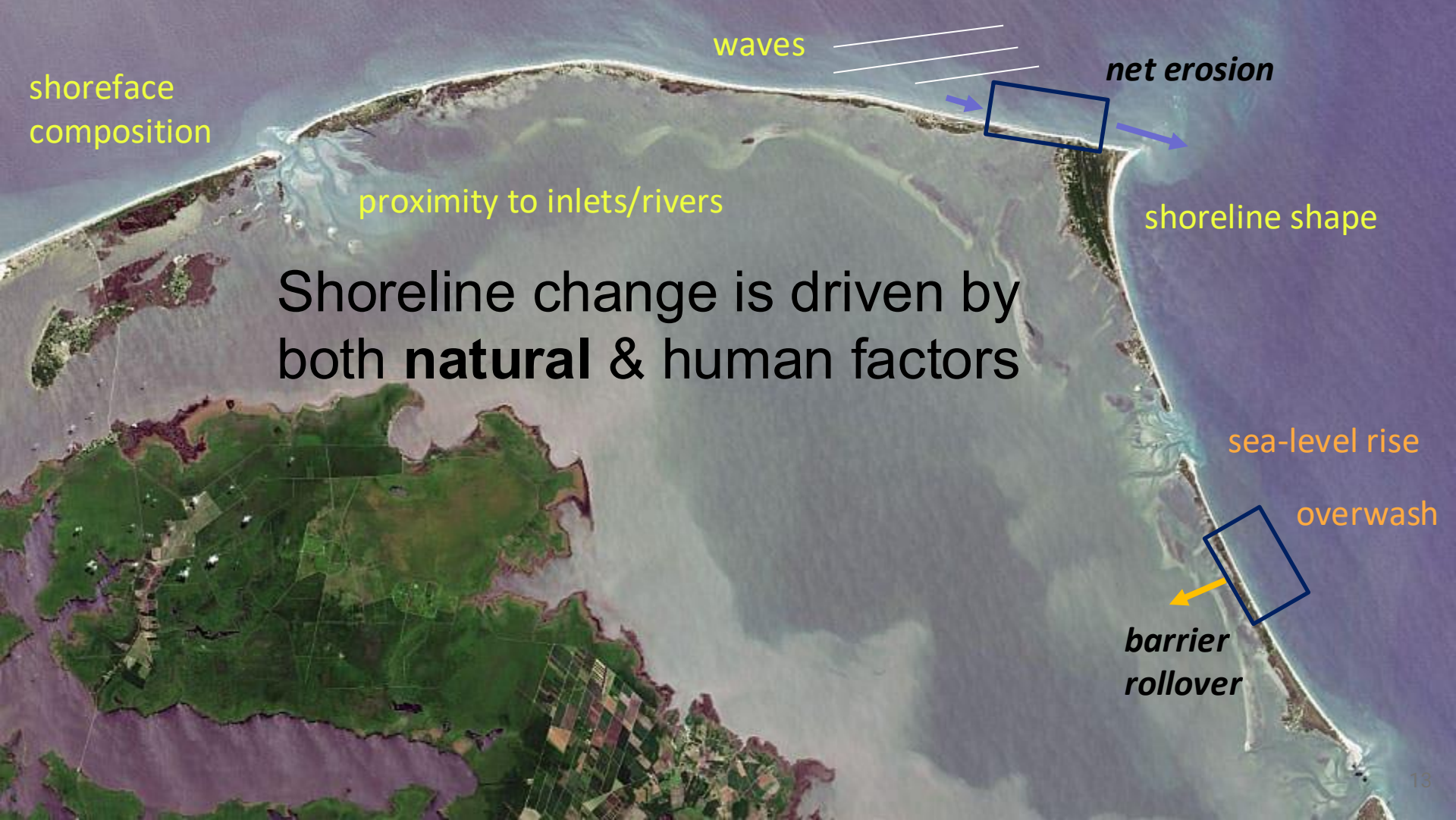


Mariotti 2021

Barrier islands build new land, keep pace with sea-level rise through storm overwash

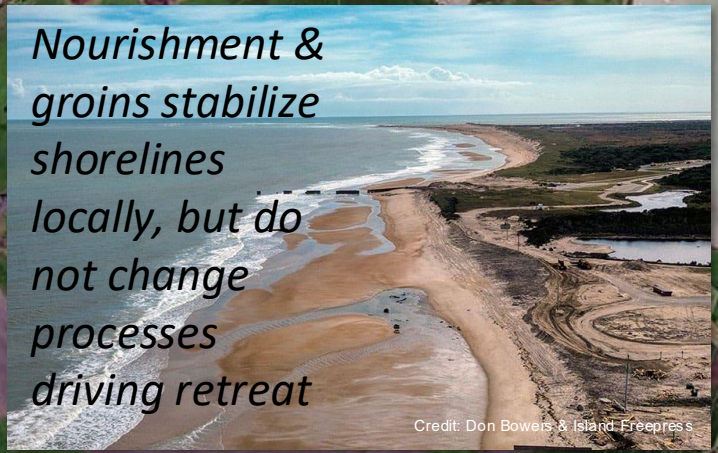


- Once formed, barriers are maintained by **overwash**: landward directed flux of water and sand during storms
- Over decades the barrier island <u>marches landward</u>

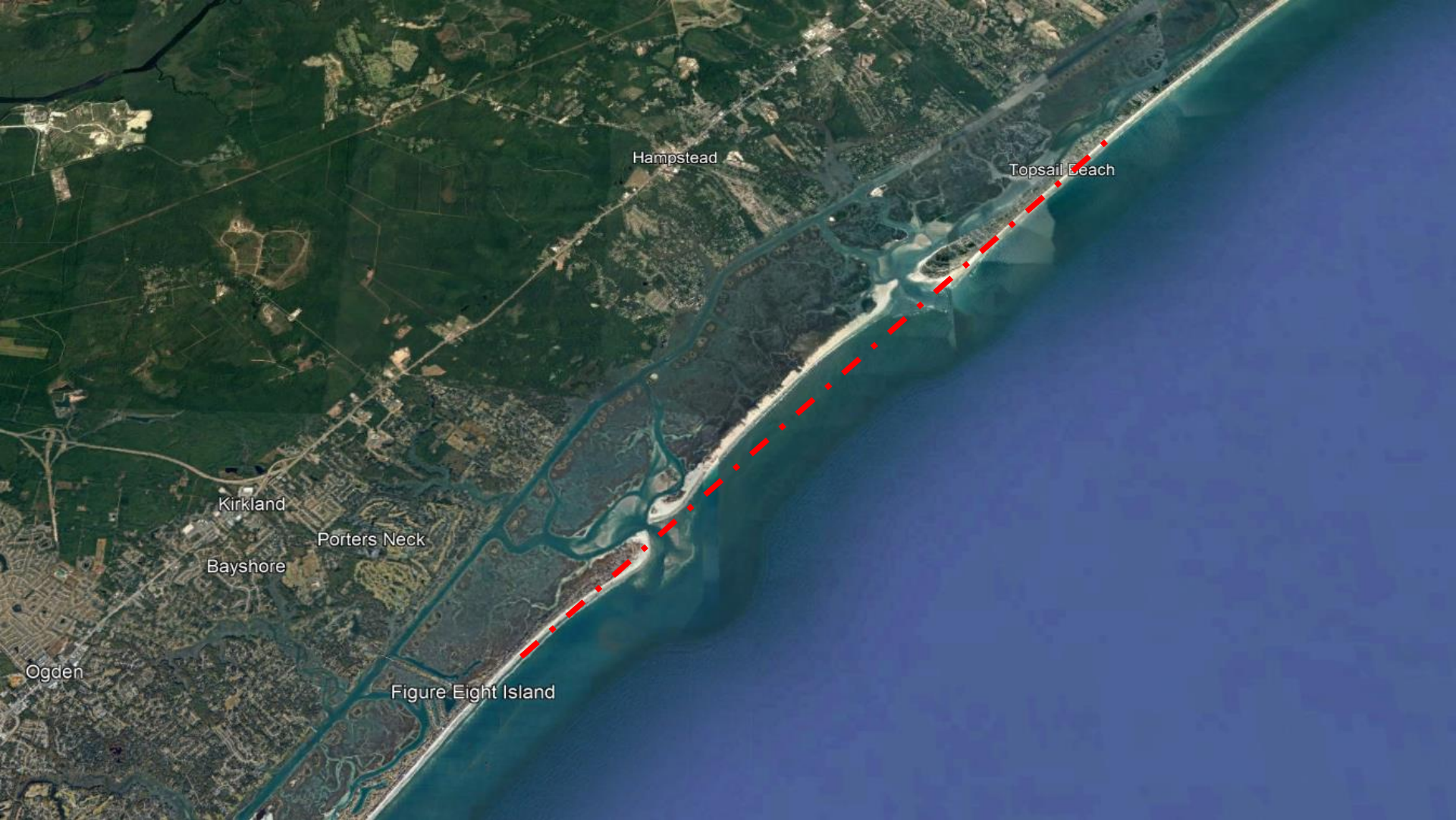

waves
net erosion
shoreface composition
proximity to inlets/rivers
shoreline shape
Shoreline change is driven by both **natural** & human factors
sea-level rise
overwash
barrier rollover

net erosion

Shoreline change is driven by both natural & **human** factors



barrier rollover


Hampstead
Topsail Beach
Kirkland
Porters Neck
Bayshore
Ogden
Figure Eight Island

Shifting inlets

Longshore currents can move sand towards the ends

https://ncseagrant.ncsu.edu/shifting-shorelines-inlet-atlas/

Shifting inlets (and new structures)

Longshore currents can move sand towards the ends


Sand is vanishing on east side of Ocean Isle's $11M erosion fix

09/30/2025 by Trista Talton

A view looking east of Ocean Isle Beach's terminal groin, where sandbags hold off beachfront erosion. Photo: Trista Talton

CoastalReview.org

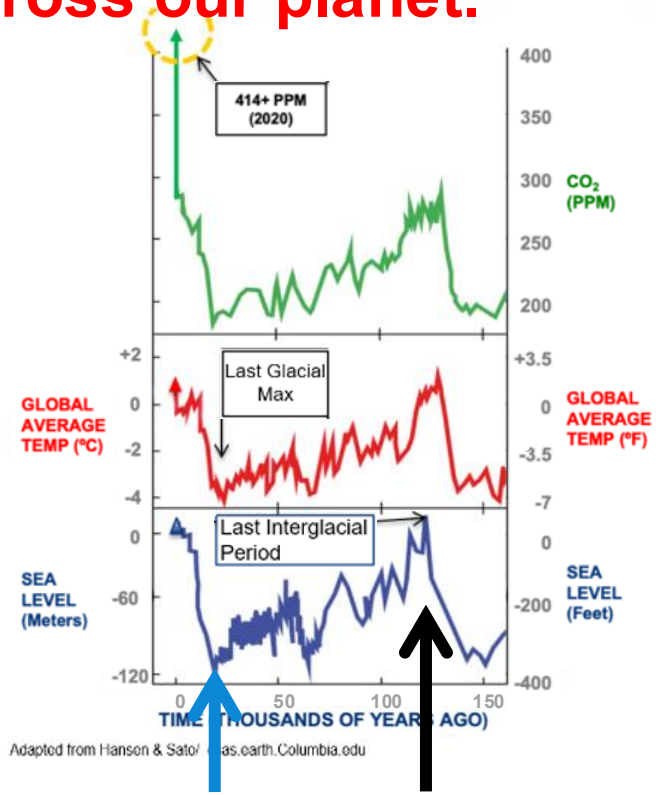
A Daily News Service of the North Carolina Coastal Federation

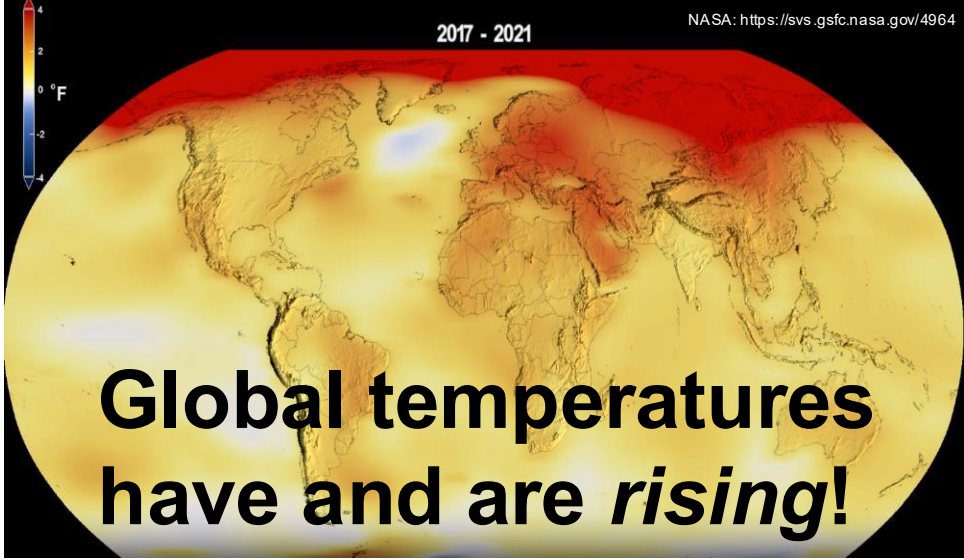
https://ncseagrant.ncsu.edu/shifting-shorelines-inlet-atlas/

What is the future of North Carolina's barriers?

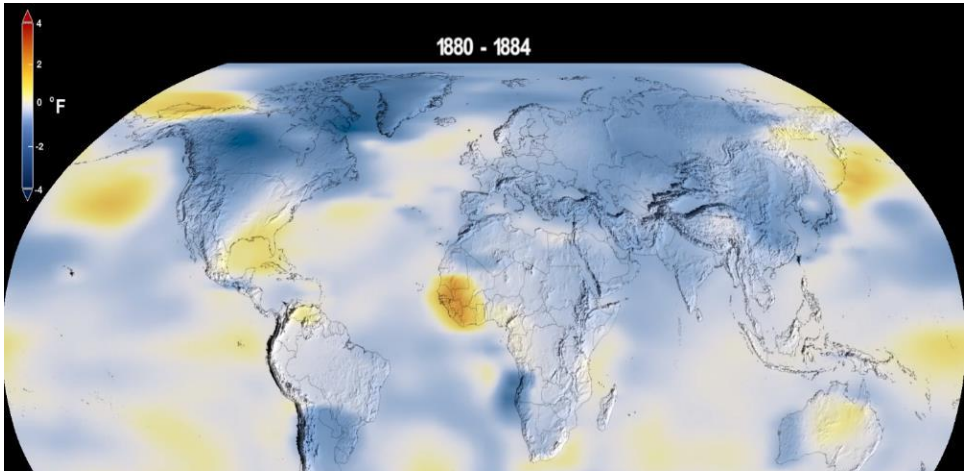
- NC barriers are very low lying
- Dynamic setting
  - Changing river outputs, ocean currents
  - Increasing frequency/intensity storms
  - Sea-level rise
  - Humans: chronic shoreline erosion has caught up with development

Global temperatures are a significant driver of change across our planet.





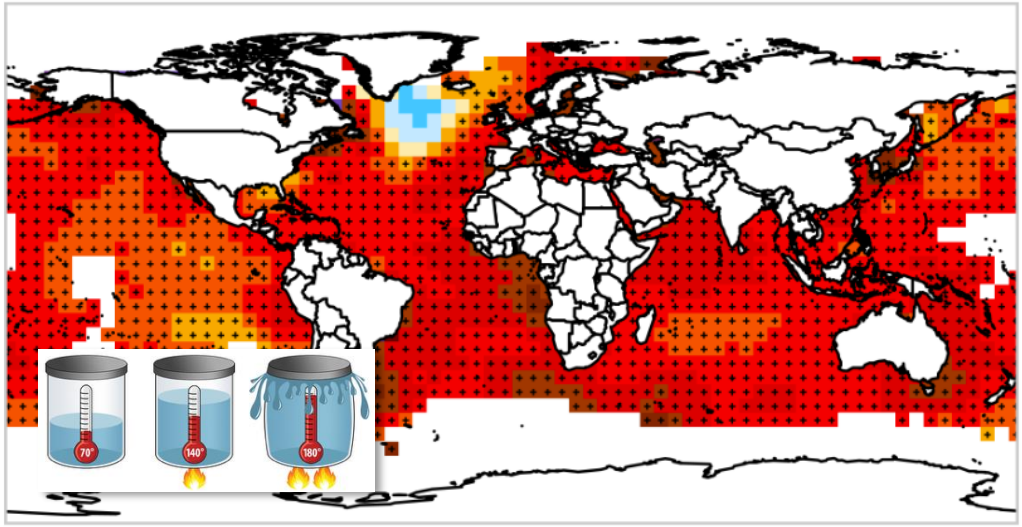
"Normal" temperatures are calculated over the 30-year baseline period 1951-1980



Melting land-based ice

Muir Glacier, Alaska, 1941 and 2004

Rising ocean temperatures



Change in sea surface temperature (°F):

-1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 Insufficient data

+ = statistically significant trend

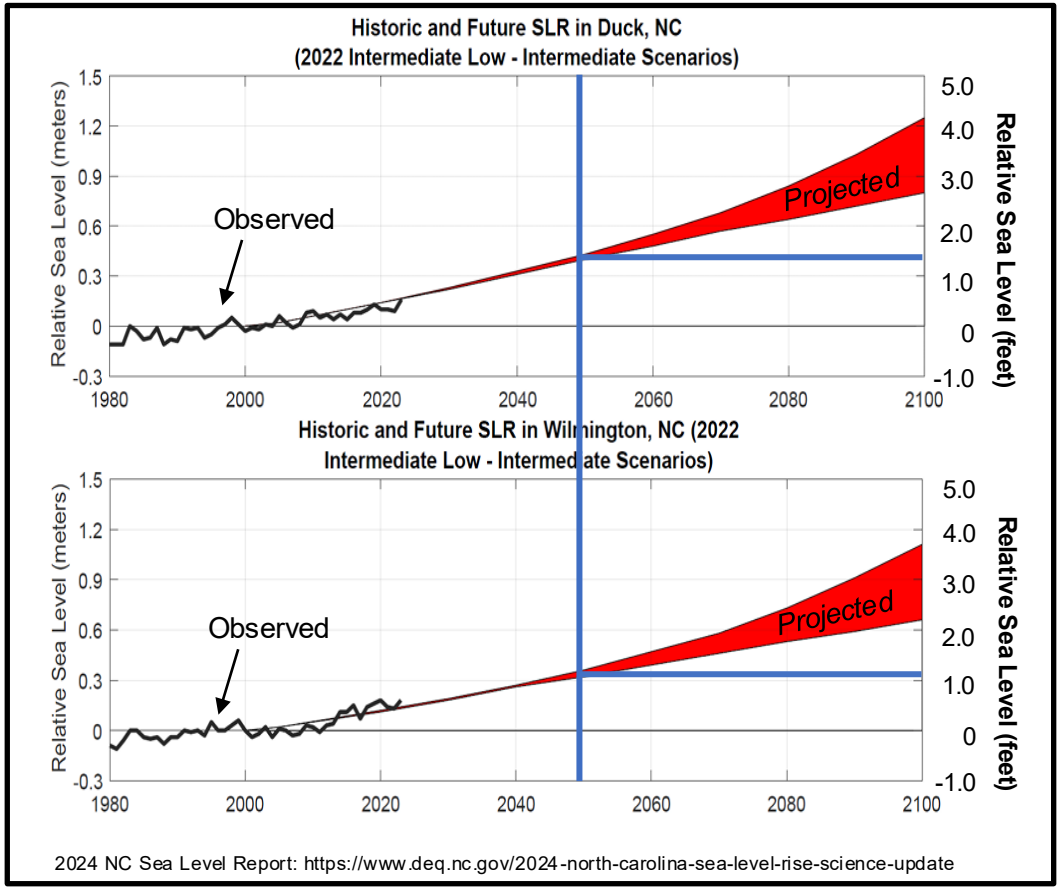
Data source: IPCC, 2013; NOAA, 2021

What does the latest science say about future SLR in NC?

- The report projects **1.0 – 1.4 ft of sea level rise by 2050** (Intermediate-Low & Intermediate Scenarios) **in the Southeast,** relative to 2000.
- Emissions are **on track for a sea level rise of 2 – 4 feet by 2100** (Intermediate-Low – Intermediate Scenarios).
- RSLR in NC varies, with higher rates in the north relative to the south, largely due to differences in vertical land motion.

NORTH CAROLINA
2024 Sea Level Rise
SCIENCE UPDATE

https://earth.gov/sealevel/sea-level-explorer



2024 NC Sea Level Report: https://www.deq.nc.gov/2024-north-carolina-sea-level-rise-science-update

What does the latest science say about future SLR in NC?

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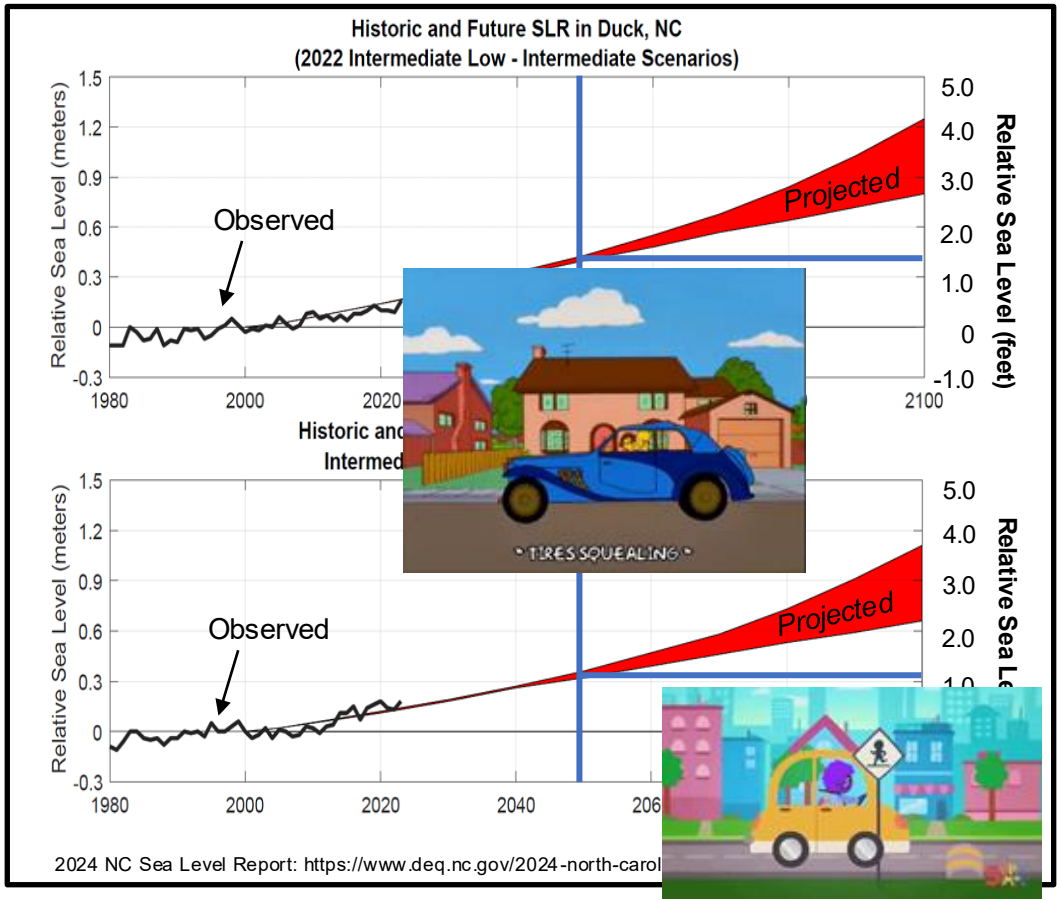
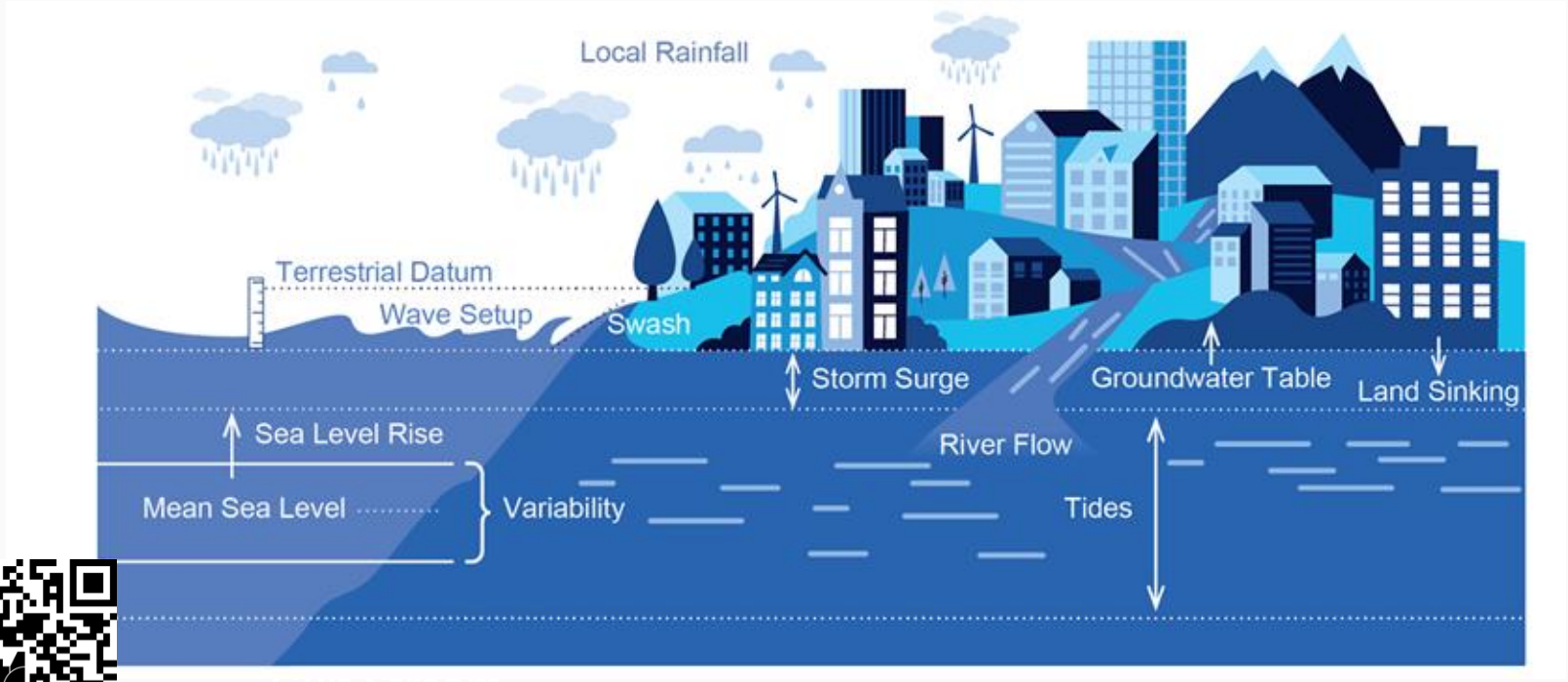
- RSLR in NC varies, with higher rates in the north relative to the south, largely due to differences in vertical land motion.

Best case: future emissions are low or decreasing, and sea level rise is relatively gradual

Worst case: future emissions are high or increasing, and sea level rise occurs relatively quickly

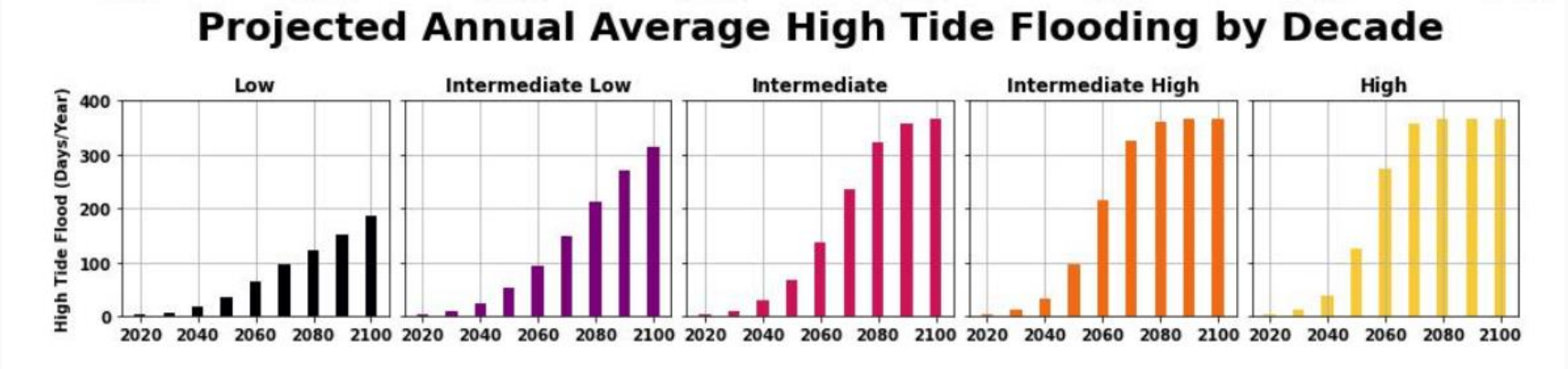


Sea-level rise is increasing flood frequency



Sweet et al., 2022

Tide gauge data are used to estimate flood frequency



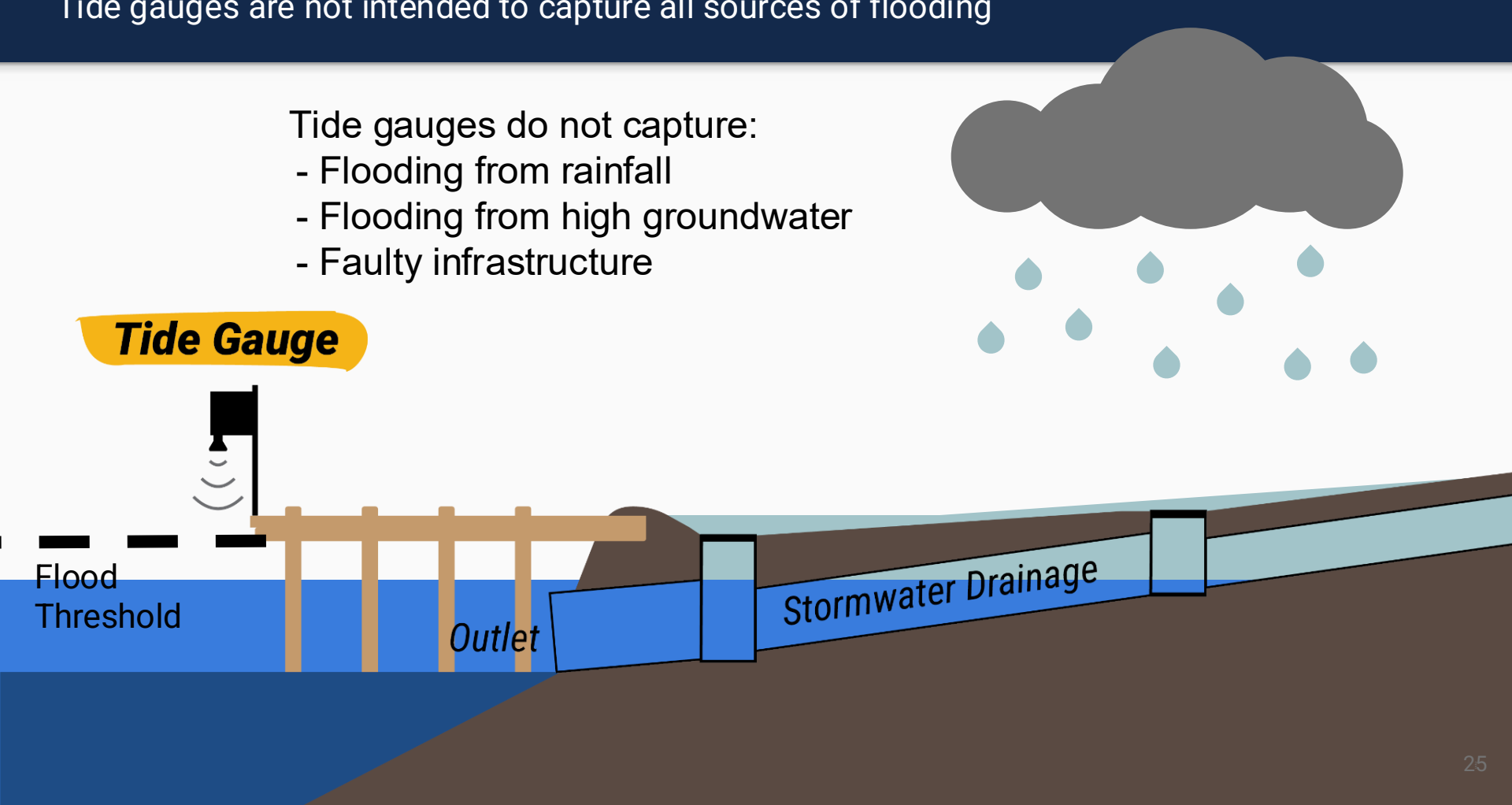
Beaufort, NC

Sweet et al., 2021

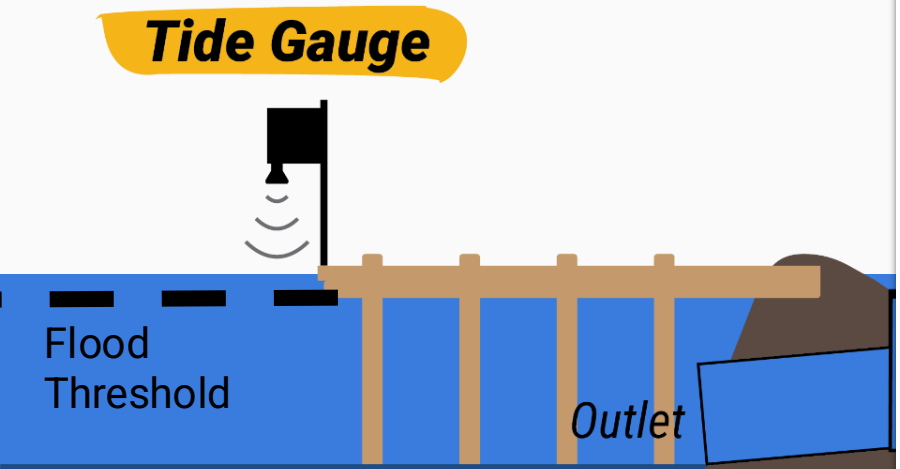
NOAA's high-tide flood thresholds are designed for nationwide consistency, statistical tracking, and "are not intended to supplant local knowledge or existing products concerning flood risk" (Sweet et al., 2018).

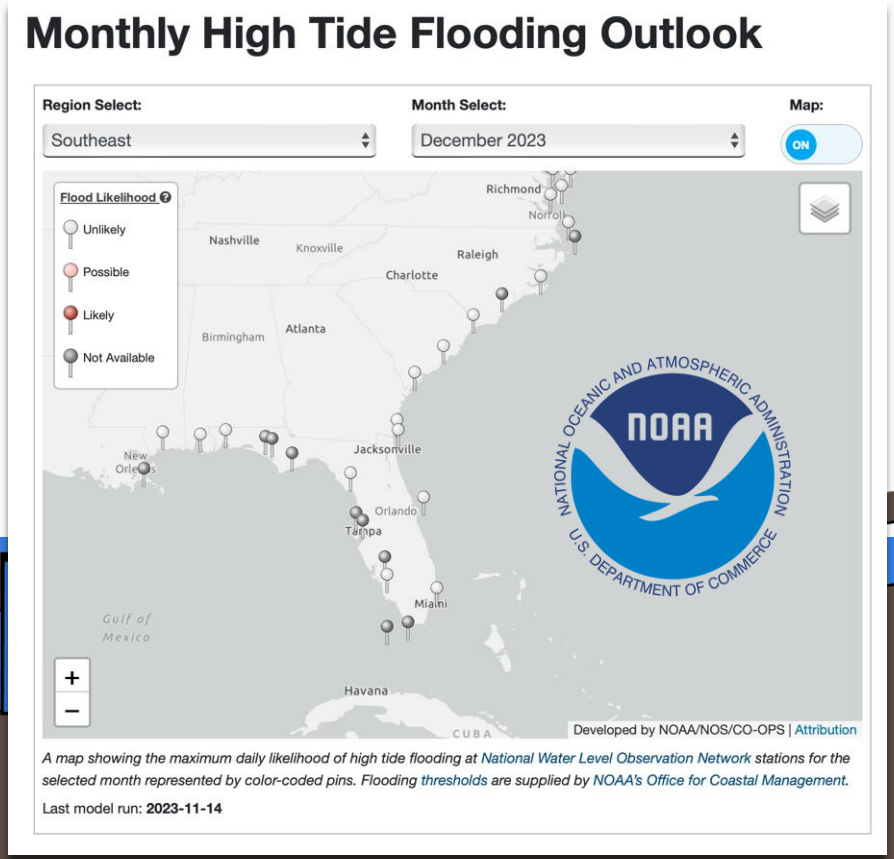
Tide gauges are not intended to capture all sources of flooding

Tide gauges do not capture:
- Flooding from rainfall
- Flooding from high groundwater
- Faulty infrastructure



Tide gauges are sparse - located in more urban, developed areas





A new sensor for measuring multiple causes of flooding

Sunny Day Flooding Sensors

Detected

Outlet

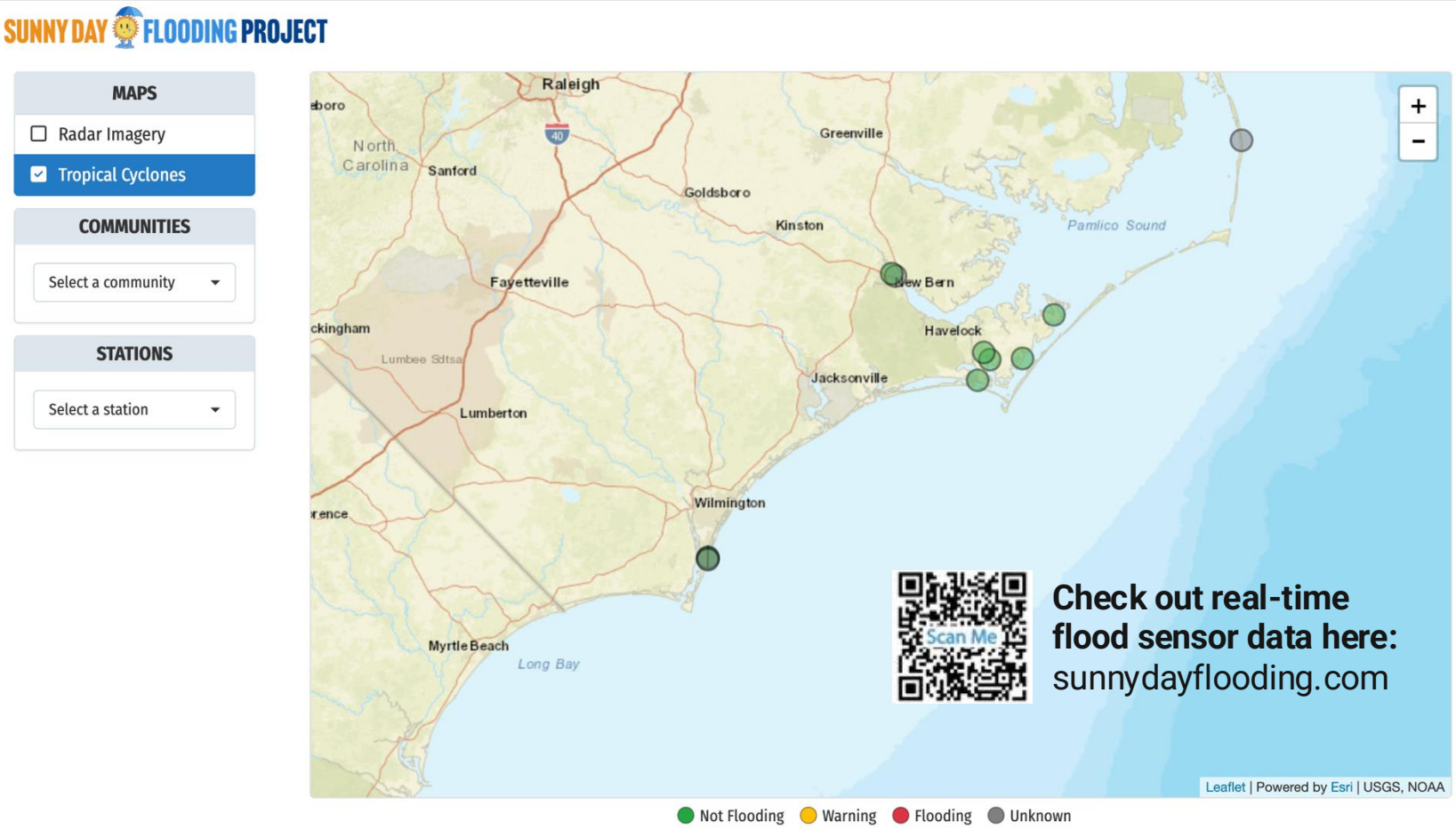
Stormwater Drainage

Deployments in five coastal communities in North Carolina (some since 2021)

Real-time camera

Real-time water levels

Deployments in five coastal communities in North Carolina (some since 2021)



communications earth & environment

Article | Open access | Published: 02 June 2025

Land-based sensors reveal high frequency of coastal flooding

Miyuki Hino, Katherine Anarde, Tessa Fridell, Ryan McCune, Thomas Thelen, Elizabeth Farquhar, Perri Woodard & Anthony Whipple

2023-2024: 65 days
2024-2025: 47 days
2025-2026: 60 days

Nearest tide gauge – Wilmington (Wrightsville Beach):
2023-2024: 3 (23) flood days
2024-2025: 11 (13) flood days
2025-2026: 7 (21) flood days

SUNNY DAY FLOODING PROJECT

communications earth & environment

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Land-based sensors reveal high frequency of coastal flooding

Miyuki Hino, Katherine Anarde, Tessa Fridell, Ryan McCune, Thomas Thelen, Elizabeth Farquhar, Perri Woodard & Anthony Whipple

THE DROWNING SOUTH

ANATOMY OF A FLOOD

The Post installed cameras along the main road of one N.C. town to document the many ways rising seas exacerbate high-tide flooding.

Scroll to continue

2023-2024: 65 days

2024-2025: 47 days

2025-2026: 60 days

Nearest tide gauge – Wilmington (Wrightsville Beach):

2023-2024: 3 (23) flood days

2024-2025: 11 (13) flood days

2025-2026: 7 (21) flood days

SUNNY DAY FLOODING PROJECT

What might sea-level rise look like on Canal Drive? **2022 to 2030**

We expect *this much* SLR **by:**	**2030**	**2040**	**2050**	**2070**	**2100**
3 inches (from 2020)	All cases				

Baseline: 2022 flood + *3 inches* = 2030 flood

What might sea-level rise look like on Canal Drive? **2022 to 2040-2050**

We expect *this much* SLR **by:**	**2030**	**2040**	**2050**	**2070**	**2100**
7 inches (from 2020)		Worst case	Best case		

Baseline: 2022 flood + *7 inches* = 2040 to 2050 flood

What might sea-level rise look like on Canal Drive? **2022 to 2050-2070**

We expect *this much* SLR **by:**	**2030**	**2040**	**2050**	**2070**	**2100**
12 inches (from 2020)			Worst case	Best case	

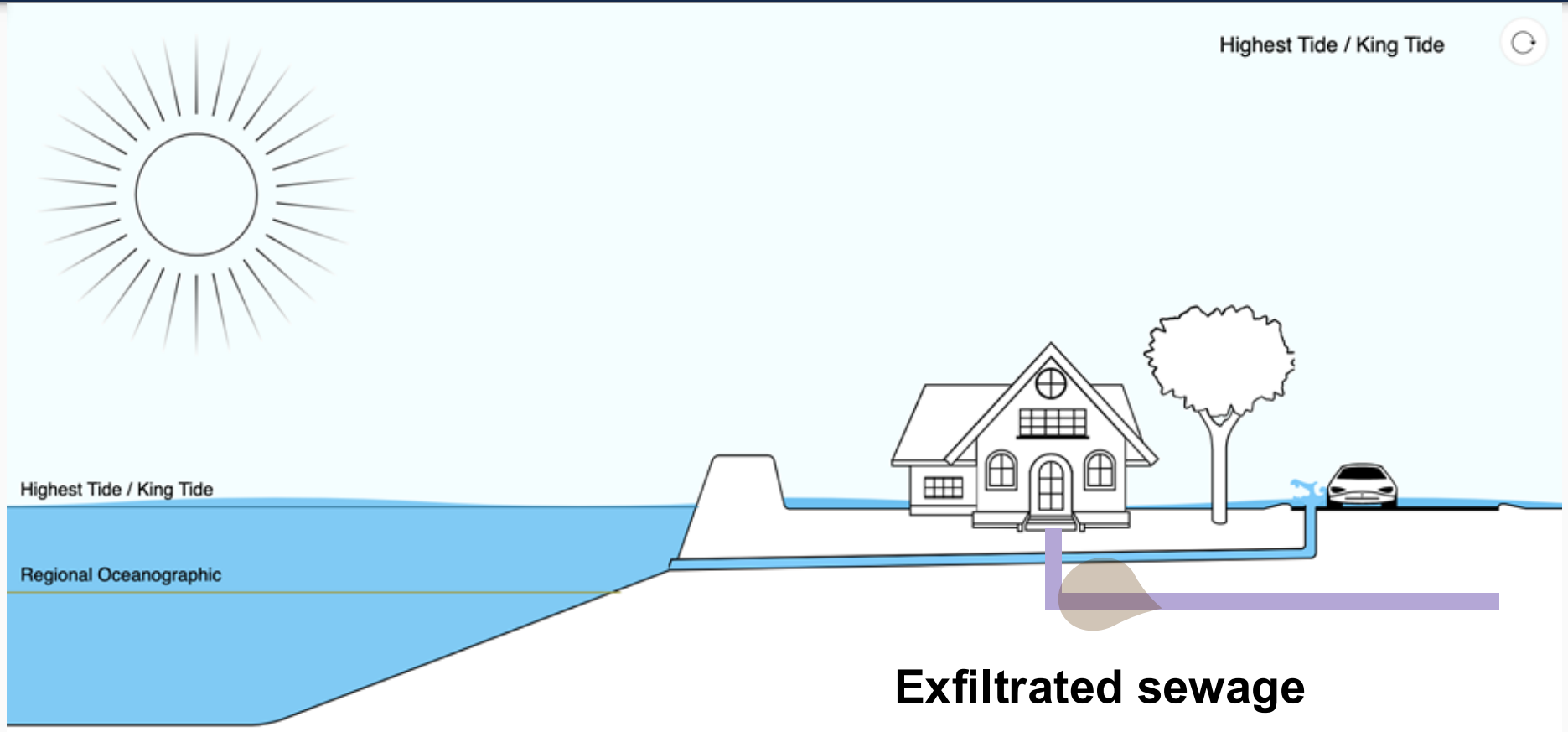
Baseline: 2022 flood + *12 inches* = 2050 to 2070 flood

What might sea-level rise look like on Canal Drive? **2022 to 2070-2100**

We expect *this much* SLR **by:**	**2030**	**2040**	**2050**	**2070**	**2100**
24 inches (from 2020)				Worst case	Best case

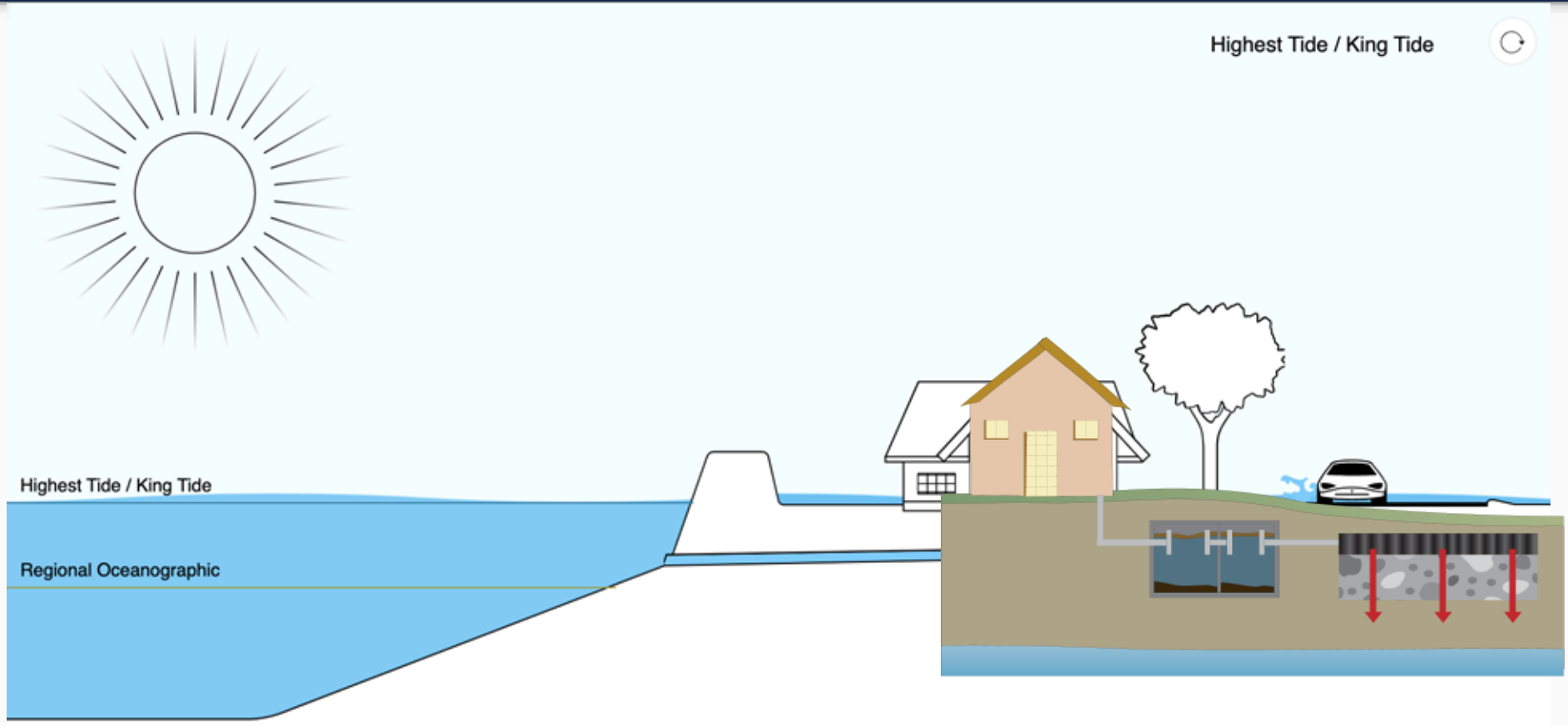
Baseline: 2022 flood *+ 24 inches =* 2070 to 2100 flood

Floodwaters make contact with potential pollutant sources



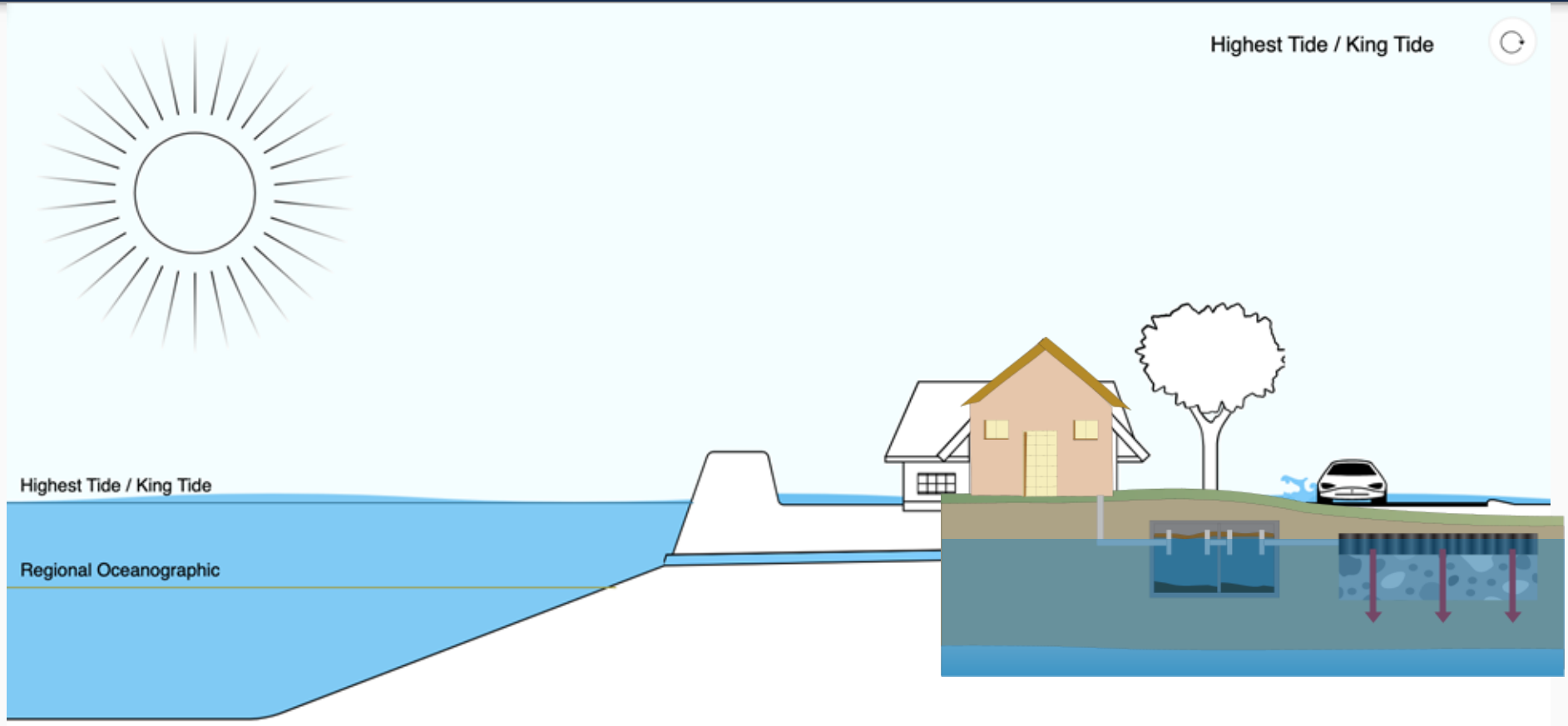
Source: NOAA, Envirosight

Floodwaters make contact with potential pollutant sources



Source: NOAA, Envirosight

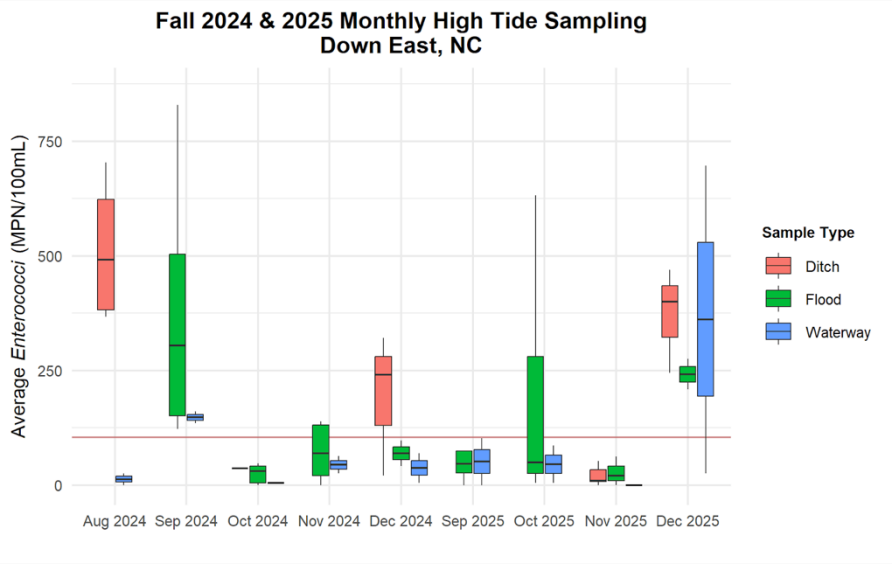
Floodwaters make contact with potential pollutant sources



Source: NOAA, Envirosight

Roadway floodwaters often have high Enterococci concentrations, regardless of flood extent

Rural areas – highly variable



Centralized wastewater – consistently high

10^2 to 10^4 MPN 100 mL^{-1}

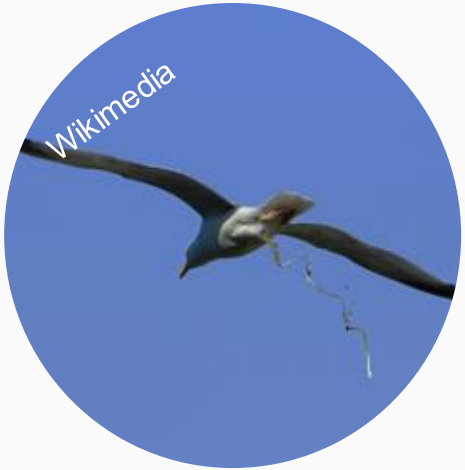
- Led by Nelson & Harris groups (NCSU)
- Measure Enteroccocus spp., a fecal indicator bacteria
- EPA single sample maximum for safe use of recreational waters: 104 MPN 100 mL^{-1}

How are the floodwaters becoming contaminated with feces?

In one community we studied, it would only require approximately…

Sewage: Around 2-75 gallons of sewage per intersection (<1% sewage by volume)

Dog feces: Around 2 recent dog defecations per intersection



Gull feces: Around 5 recent gull defecations per intersection

…to contaminate floods at the observed bacteria concentrations

Carr et al., *In preparation*

What can be done to prevent tidal floodwater contamination?

Research is ongoing, and solutions will vary by community. Sewer infrastructure maintenance, “scoop the poop” campaigns (materials forthcoming via Extension), and bird prevention approaches may be useful mitigation strategies.

At a minimum, reducing floods prevents pedestrian exposure to contaminated floodwaters.

Sea Grant bulletin: Mitigating health impacts from flood exposure

Sea Grant
NORTH CAROLINA

go.ncsu.edu/tidalfloods

Extension fact sheet: Stormwater retrofits for flood prevention

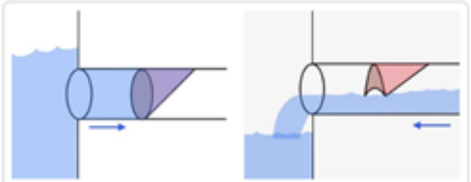


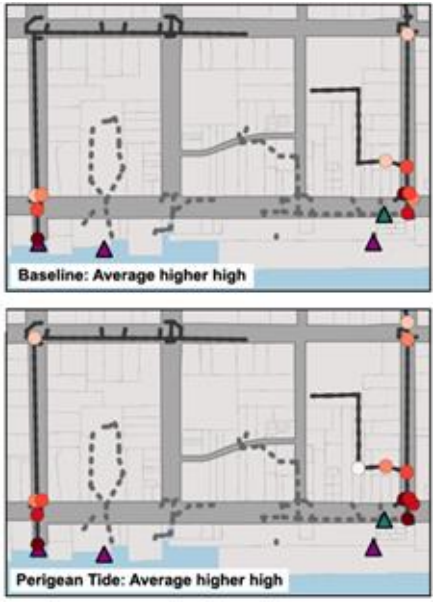
Figure 9. An inline check valve inside of a pipe in closed position (left, at high tide) and open position (right, at low tide, conveying stormwater runoff).

Figure 7. A duckbill check valve at the end of a pipe outfall in closed position (left, at high tide) and open position (right, at low tide, conveying stormwater runoff).

NC STATE EXTENSION

go.ncsu.edu/retrofits

Research article (open access): Floodwater contamination



GeoHealth

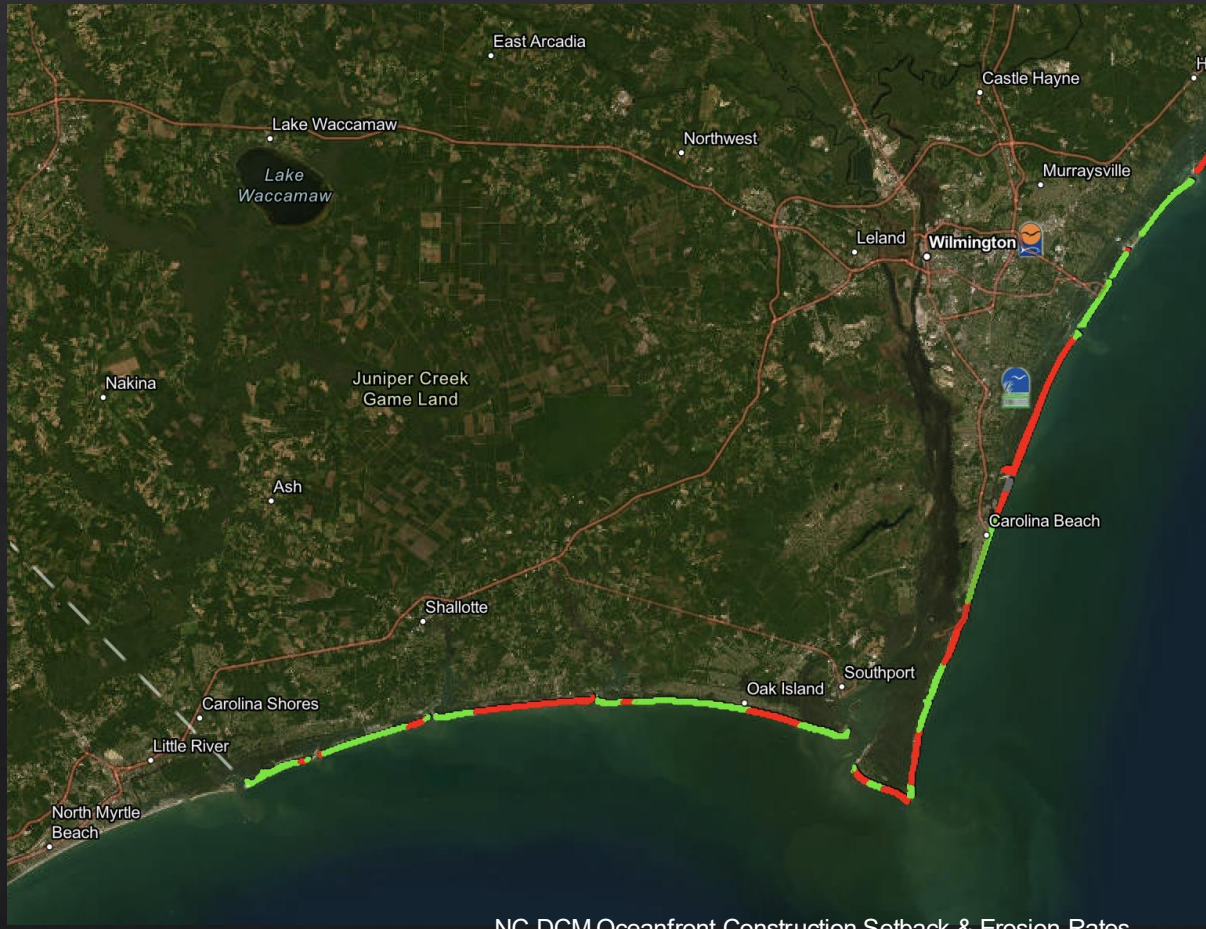
go.ncsu.edu/carr2024

Development on barrier islands is also threatened by landscape change (shoreline & dune erosion + overwash)

Credit: Coastal Observer

Continued and increasing long-term shoreline erosion rates

- The ocean shoreline erodes over time where more sand is lost from the shoreline than supplied.
- Losses related to sea level rise will increase and so background, long-term erosion rates will increase, but this is just one driver of shoreline change!

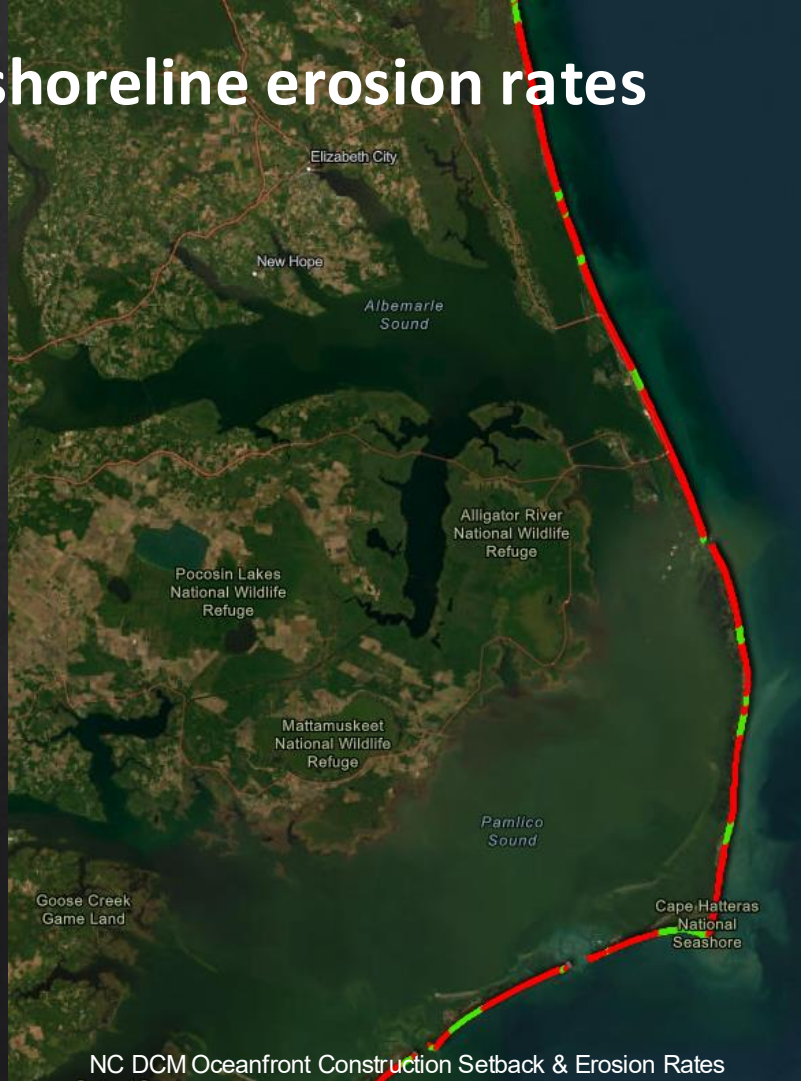


NC DCM Oceanfront Construction Setback & Erosion Rates

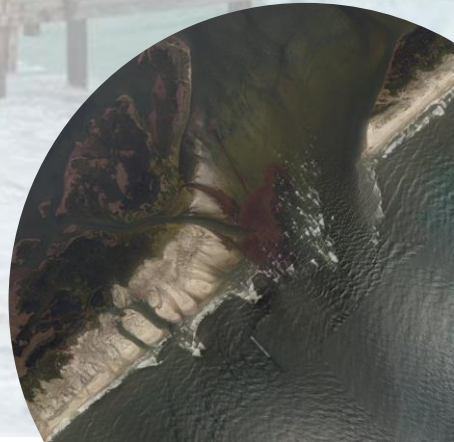
Continued and increasing long-term shoreline erosion rates

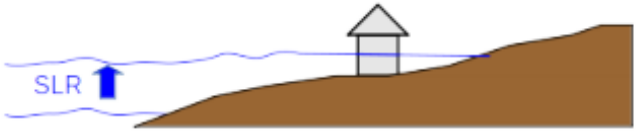
Credit: USGS; Google Maps; Paul Horn/InsideClimate News

S. Nags Head

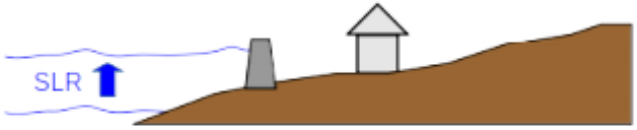


What can we do?

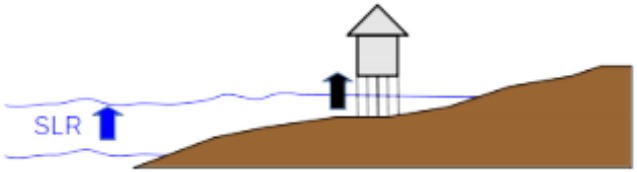




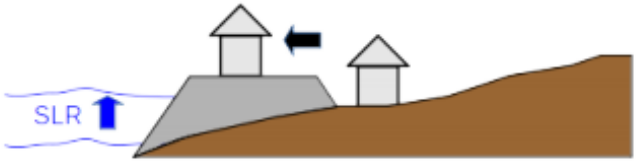
No response



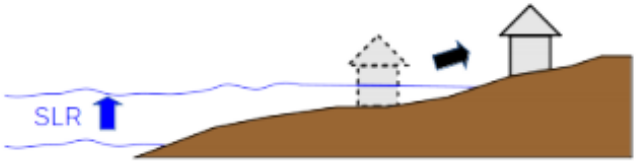
Protect



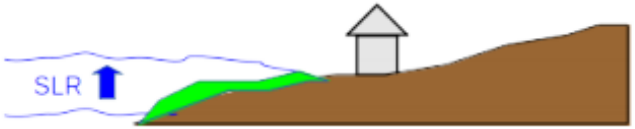
Accommodate



Advance



Deconstruct or Move



Ecosystem-based adaptation

2019 - IPCC SR Ocean and Cryosphere; CH. 4. Sea Level Rise and Implications for Low Lying Islands, Coasts and Communities;

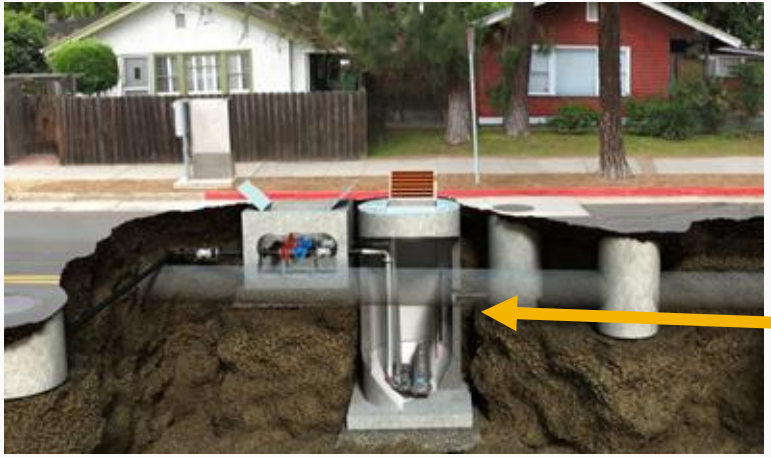
What do we do about the roads? - *Carolina Beach* community workshop series

We engaged *~15 residents* to identify flood resilience **strategies preferred by the community**, and **test how effective** these strategies might be in mitigating flooding now and in the future

Flood resilience strategies selected by participants for modeling

Modeled strategies

- *Minimum bulkhead elevation*
- Pumps
- *Min. bulkhead elevation + pumps*
- Movable flood barrier
- Drainage canal

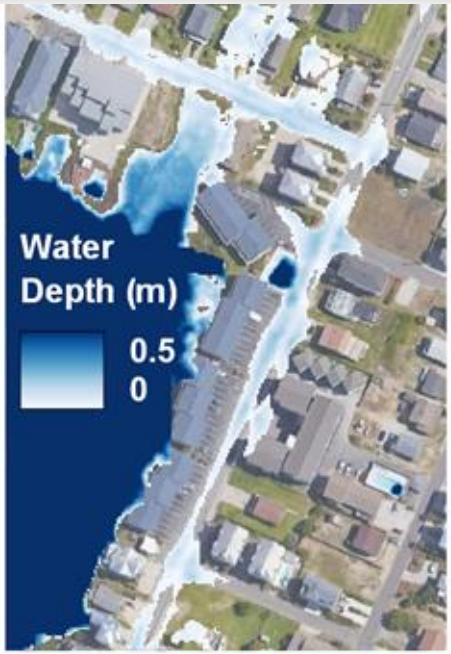


Pump

Bulkhead

(left: Romtect
right: Southern NC Marine)

Higher bulkheads prevent flooding from overtopping at current sea levels

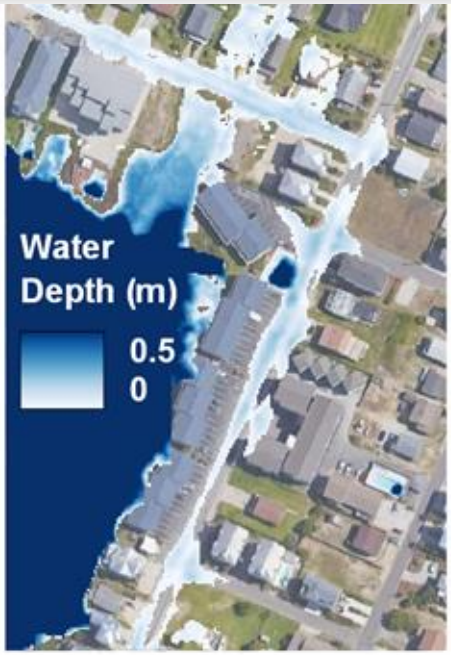


Tides & wind
Present-day sea levels

Tides & wind
Present-day sea levels
Higher bulkheads

Thelen et al., *In preparation*

At 2050 sea levels, flooding originates from north of the Yacht Basin



Tides & wind
Present-day sea levels

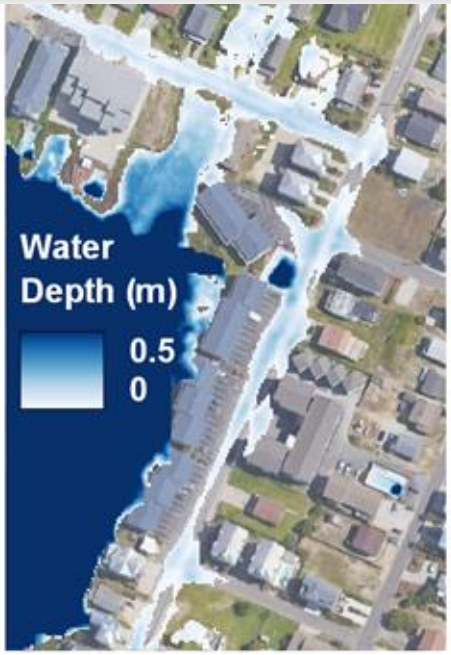
Tides & wind
Present-day sea levels
Higher bulkheads

US Southeast 2020-2050:
10 in SLR (Sweet et al. 2022)

Tides & wind
2050 sea levels
Higher bulkheads

Thelen et al., *In preparation*

Even at *present sea levels*, higher bulkheads do not mitigate compound flooding



Tides & wind
Present-day sea levels

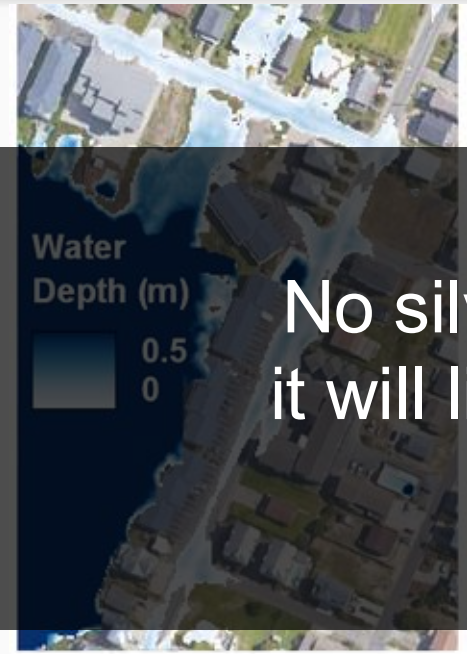
Tides & wind
Present-day sea levels
Higher bulkheads

*Tides, wind, **rain***
Present-day sea levels
Higher bulkheads

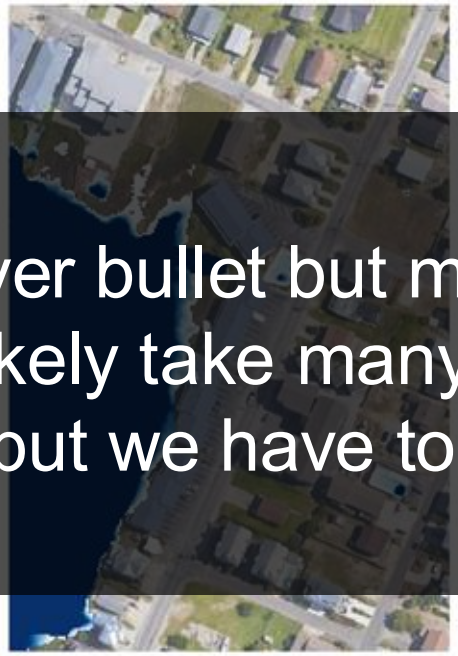
Tides & wind
2050 sea levels
Higher bulkheads

Thelen et al., *In preparation*

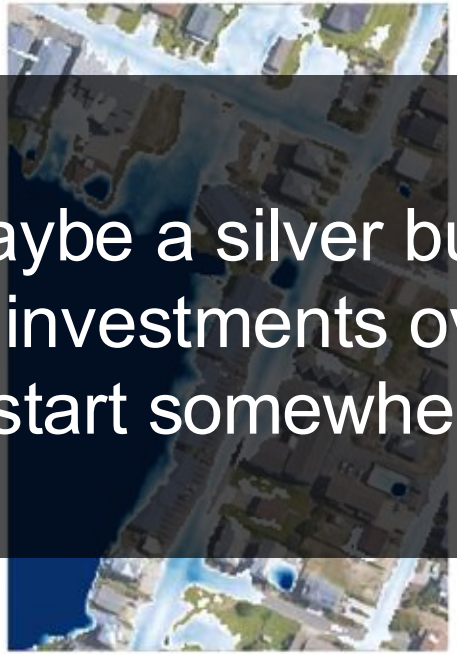
Even at *present sea levels*, higher bulkheads do not mitigate compound flooding



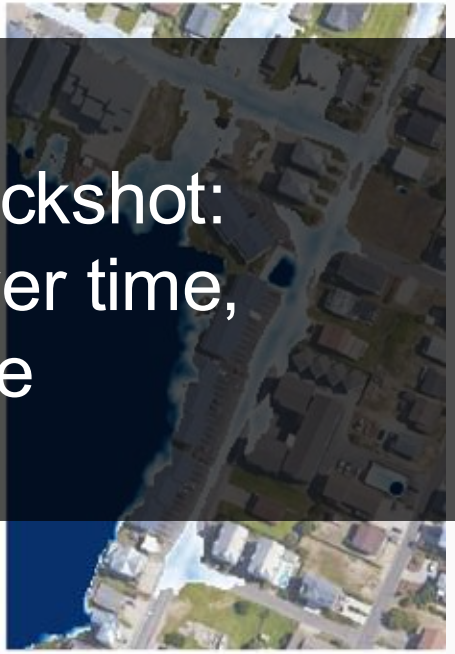
Tides & wind
Present-day sea levels



Tides & wind
Present-day sea levels
Higher bulkheads



*Tides, wind, **rain***
Present-day sea levels
Higher bulkheads



Tides & wind
2050 sea levels
Higher bulkheads

No silver bullet but maybe a silver buckshot:
it will likely take many investments over time,
but we have to start somewhere

Thelen et al., *In preparation*

A survey to understand chronic flooding impacts, responses, and preferred adaptations

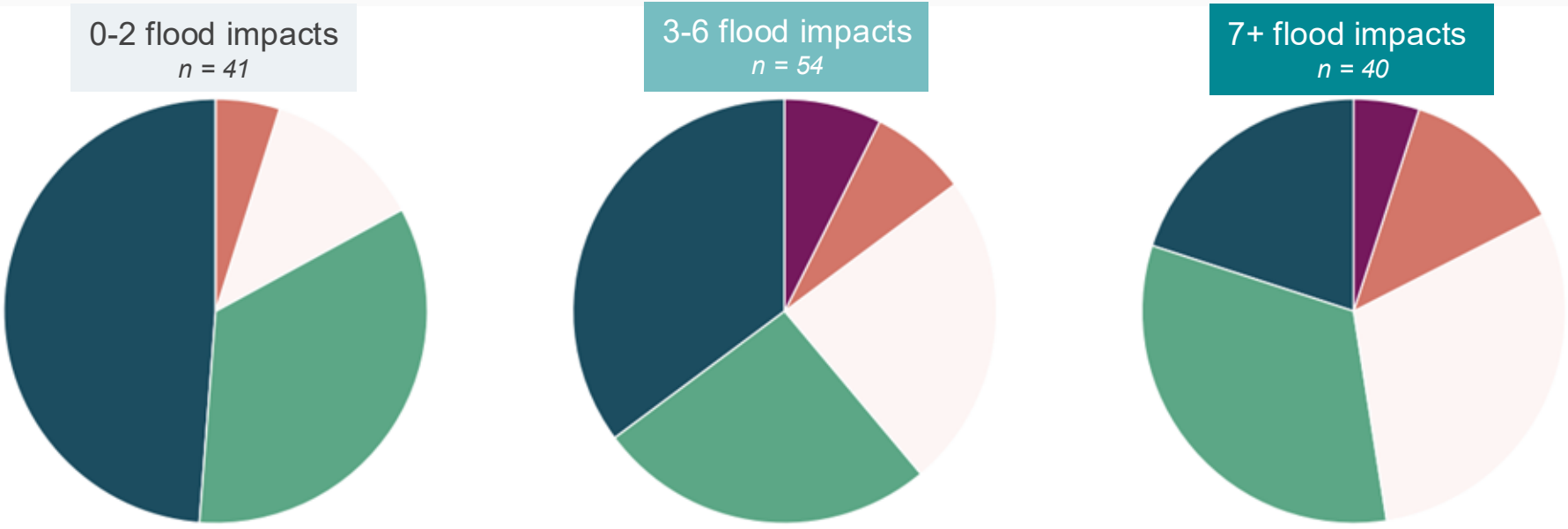
Flooding survey mailer

Survey respondents selected from a list of 15 potential flood impacts

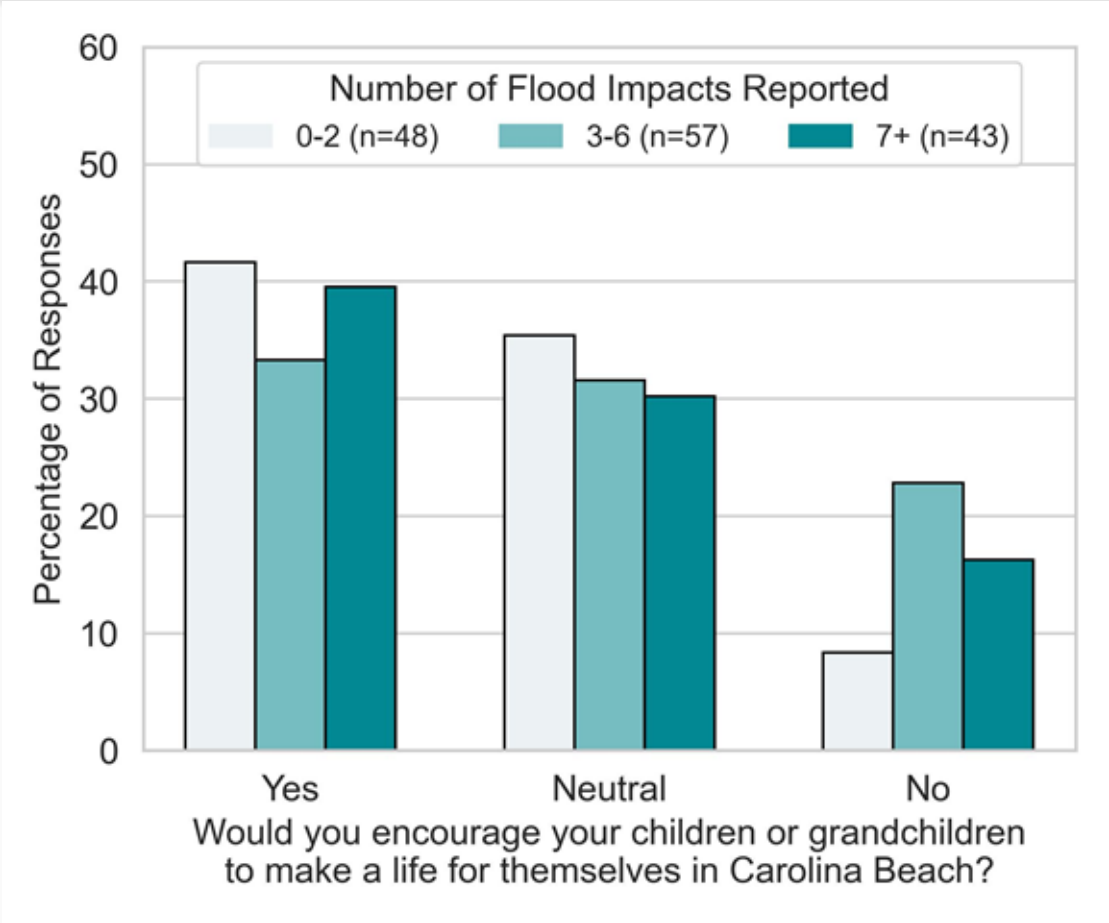
Have you ever experienced any of the following due to flooding outside of hurricanes or tropical storms? You may select multiple options.

- ▢ Difficulty commuting to work or school
- ▢ Difficulty reaching or canceling doctor and other appointments
- ▢ Inability to leave your house
- ▢ School delays and closures
- ▢ Business delays and closures
- ▢ Trash can tipped over or trash collection disrupted
- ▢ Concerns about health and safety due to water quality
- ▢ Damage to personal vehicle
- ▢ Property damage
- ▢ Negative impact on home value
- ▢ Difficulty obtaining homeowner's insurance
- ▢ Neighbors selling homes and moving out
- ▢ Neighbors moving out and renting their homes
- ▢ Complaints from renters
- ▢ Lost rental income

The survey respondents most impacted by flooding are more willing to move



Respondents are positive or neutral about the next generation, more ”No” for 3+ impacts



Takeaways

- Developed barrier islands, and properties on them, are increasingly vulnerable to storm and climate hazards.
- There are emerging sound-side (high tide flooding) and groundwater hazards (septic and water quality issues), which may not make it to flood disclosures, but influence property livability.
- These emerging hazards may also influence whether people stay or go.

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