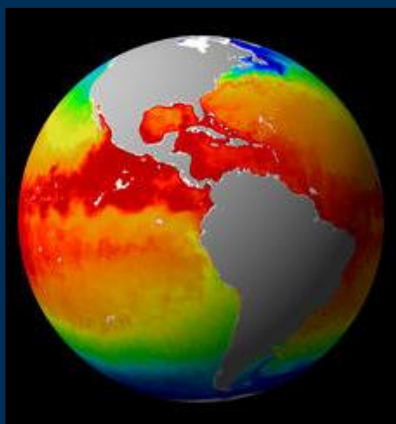
Changing Climate, Changing Coasts

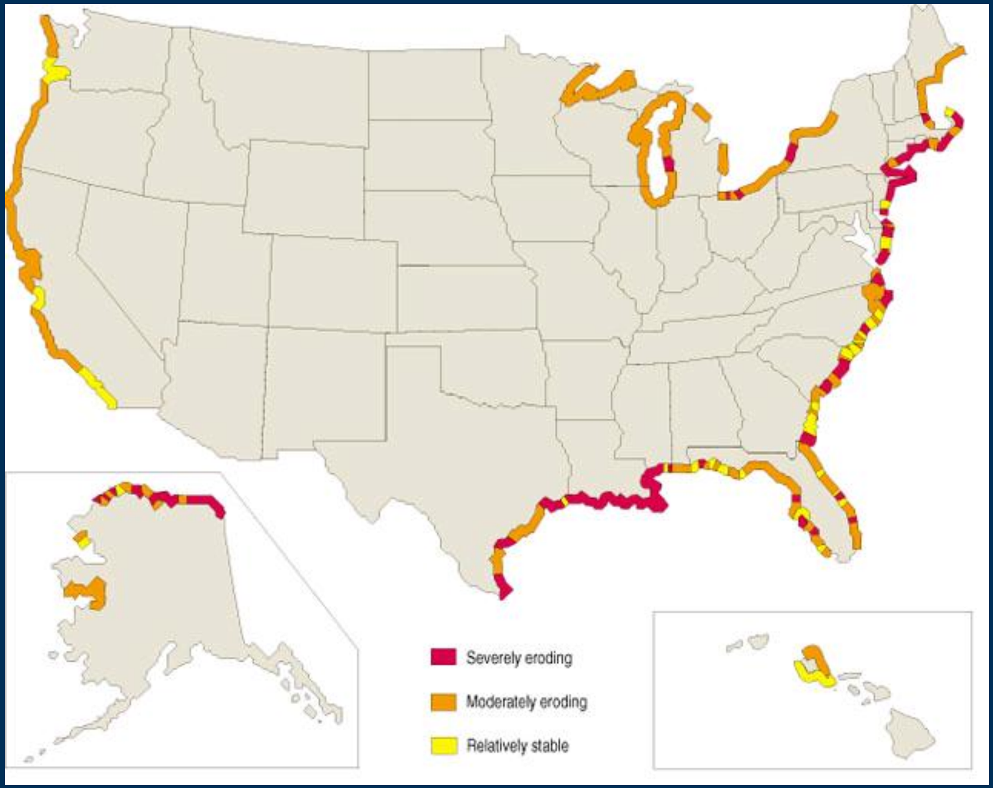


Rob Thieler
U.S. Geological Survey
Woods Hole, MA

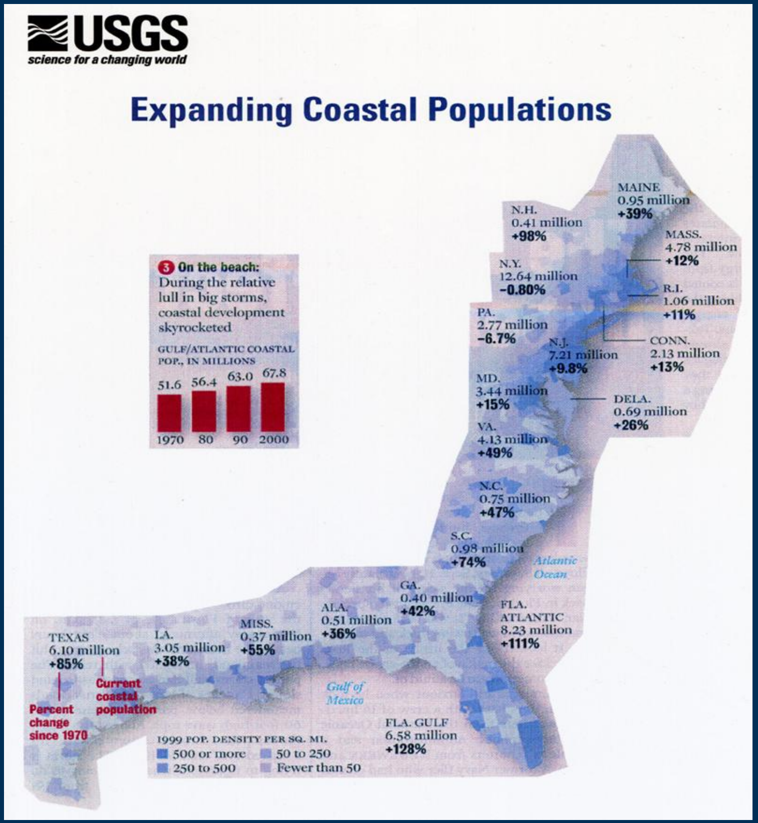
Outline

- Scientific and management dimensions of sea-level change
- Results and implications of recent sea-level rise assessments
- Providing science-based decision support in an uncertain future
- How one town is starting to address the issue

The U.S. Coastal Crisis – Coastal population and development are increasingly vulnerable to coastal hazards



- Erosion affects all 30 coastal states
- 60-80% of coast is eroding
- Erosion caused by diverse, complex processes



- Coastal populations have doubled
- >50% live along coasts
- Infrastructure about $9 trillion

We need better science* to prepare our local responses to climate change, especially in our coastal areas.
(David Carter, Delaware Coastal Management)

*science = better understanding of processes + better situation awareness

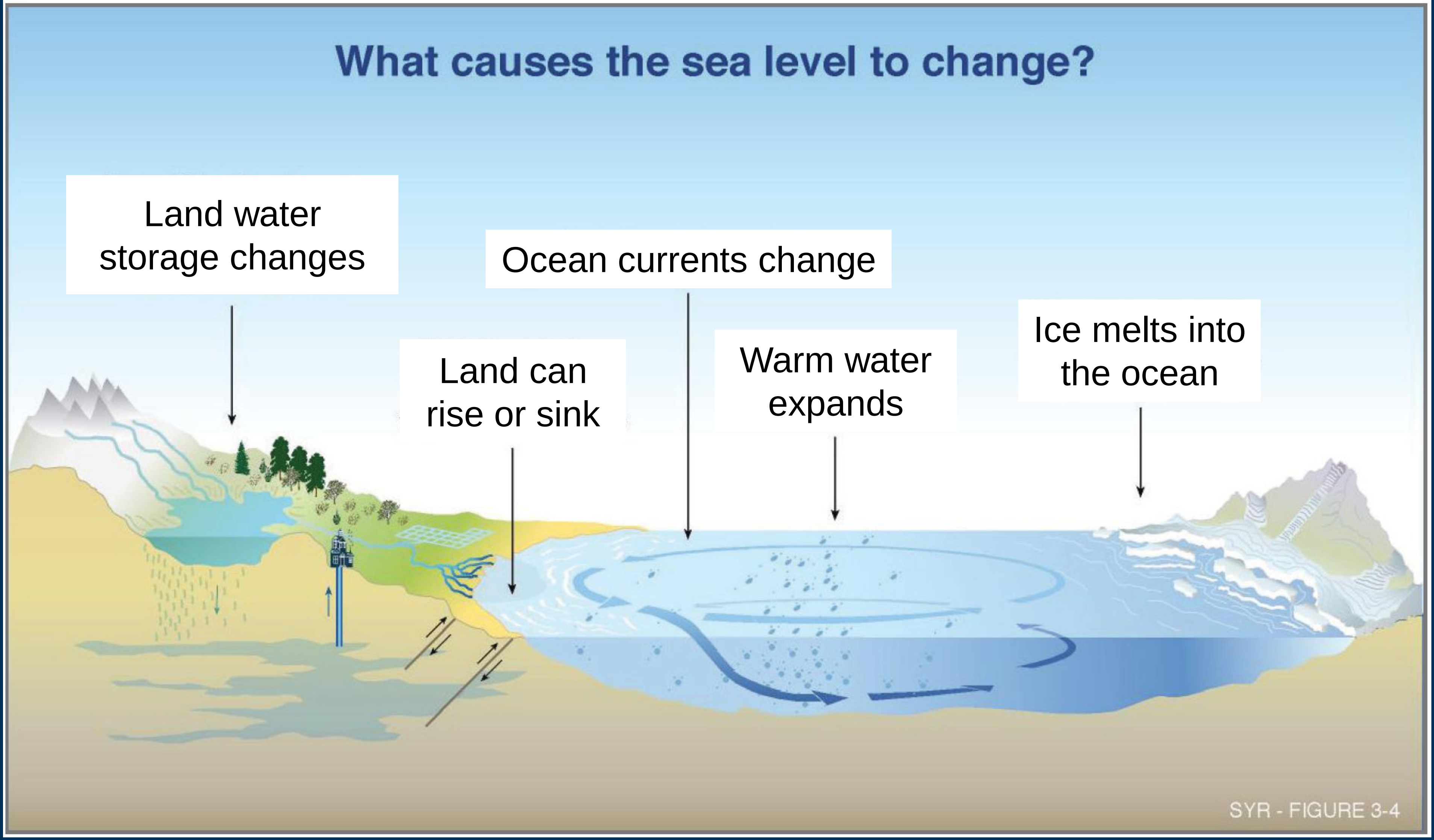
Coastal Flooding in Charleston, SC

(Built environment impacts)

- NOAA NWS Charleston issues shallow coastal flooding advisories for 7 ft tides
- 7 ft tides typically predicted to occur twice a year
- With 1.6 ft of relative sea-level rise, this advisory could be issued 355 times

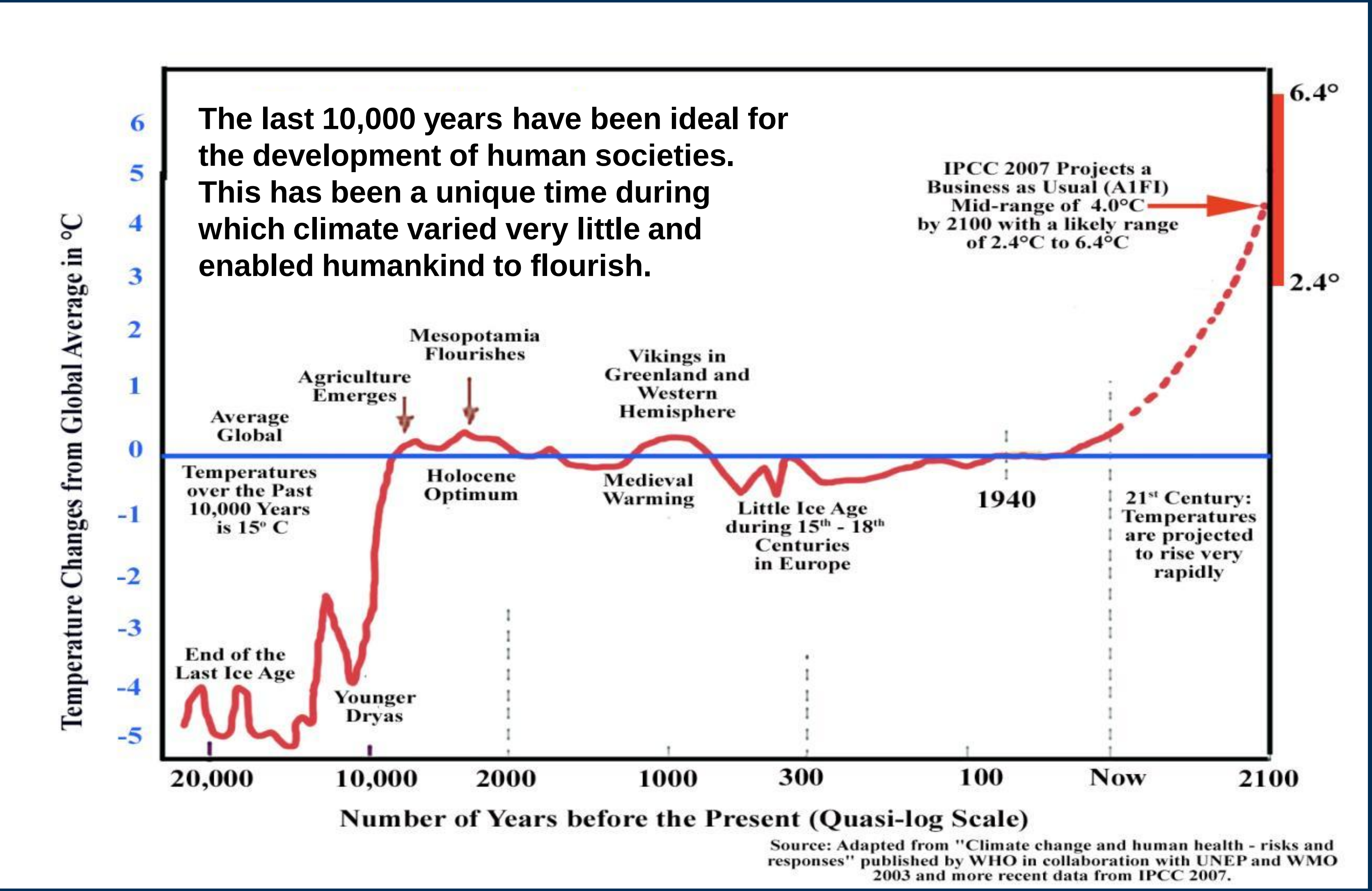
Key Principles Regarding Sea-level Rise

- There is no debate over sea-level rise
  - When the climate warms, oceans increase in volume and land-based ice melts
- Attribution of sea-level rise is largely irrelevant
  - For example, if the world stopped emitting GHGs tomorrow, sea level would continue to rise for several centuries
- The major questions are how much, and how fast?
  - The answers depend in part on our future emission pathways, and the future behavior of large ice sheets

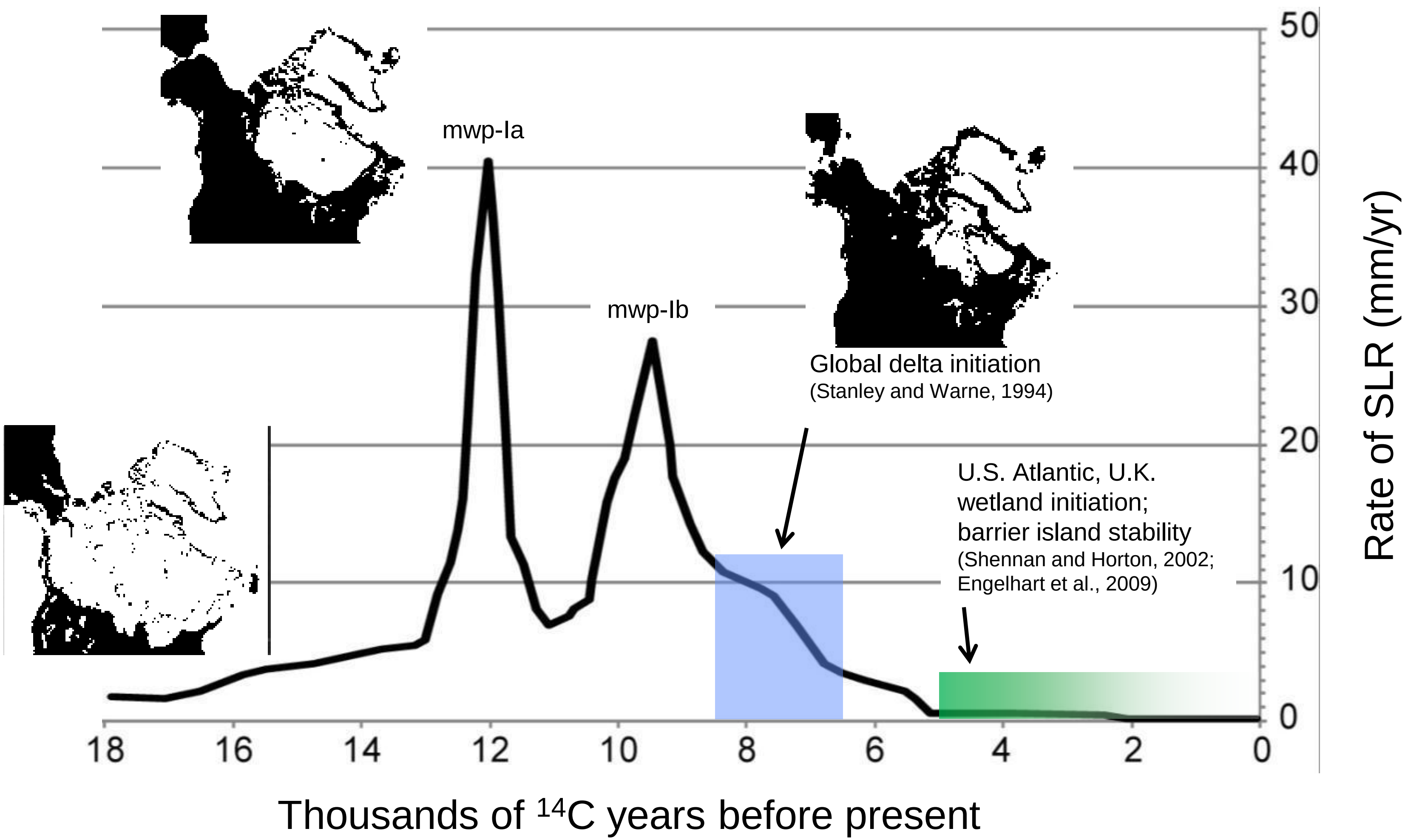

What causes the sea level to change?
Land water storage changes
Ocean currents change
Land can rise or sink
Warm water expands
Ice melts into the ocean
SYR - FIGURE 3-4

(IPCC, 2001)

Past, Current and Projected Global Temperature

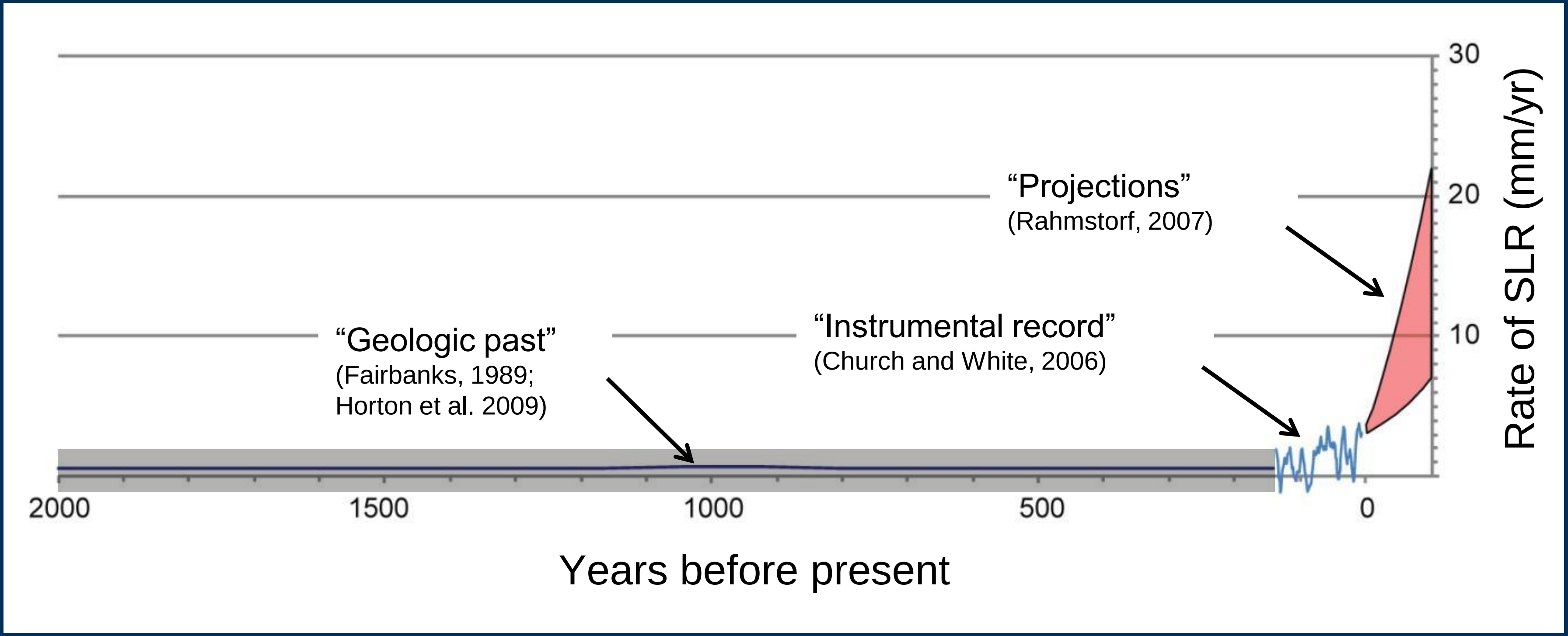


Sea-level rise rates since the Last Glacial Maximum

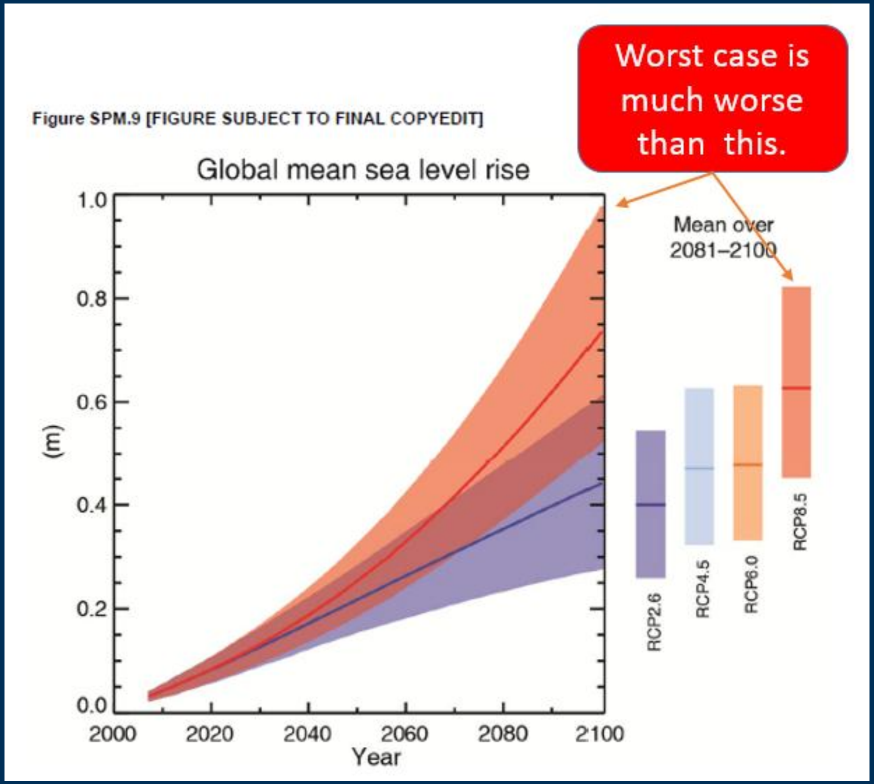


(SLR rate based on Fairbanks, 1989; ice extent from Dyke, 2004)

Past, present, and potential future rates of sea-level rise

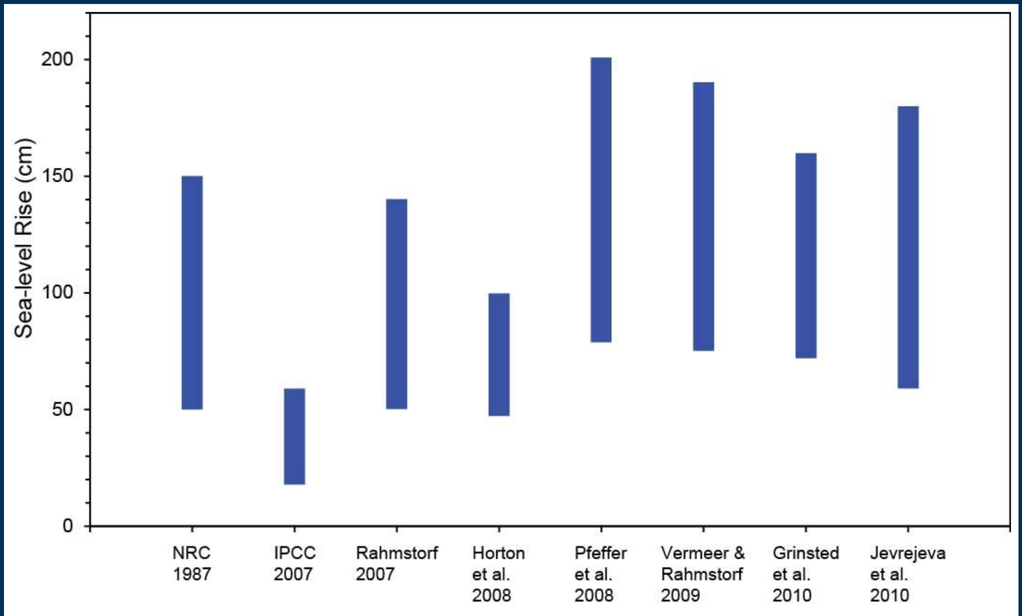


Projected Sea-level Rise



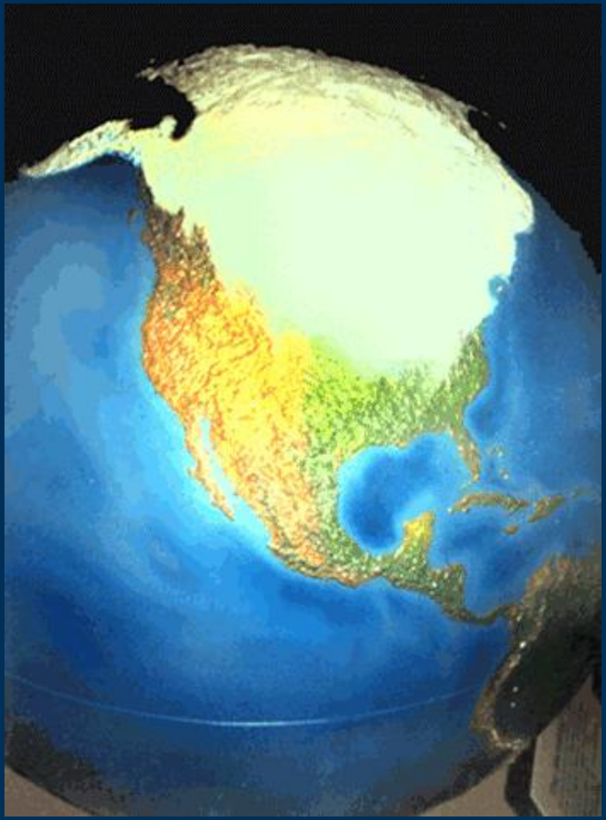
(courtesy Aslak Grinsted; AR5 projections from IPCC, 2013)

Several projections suggest ~60-150+ cm rise is possible over the next century

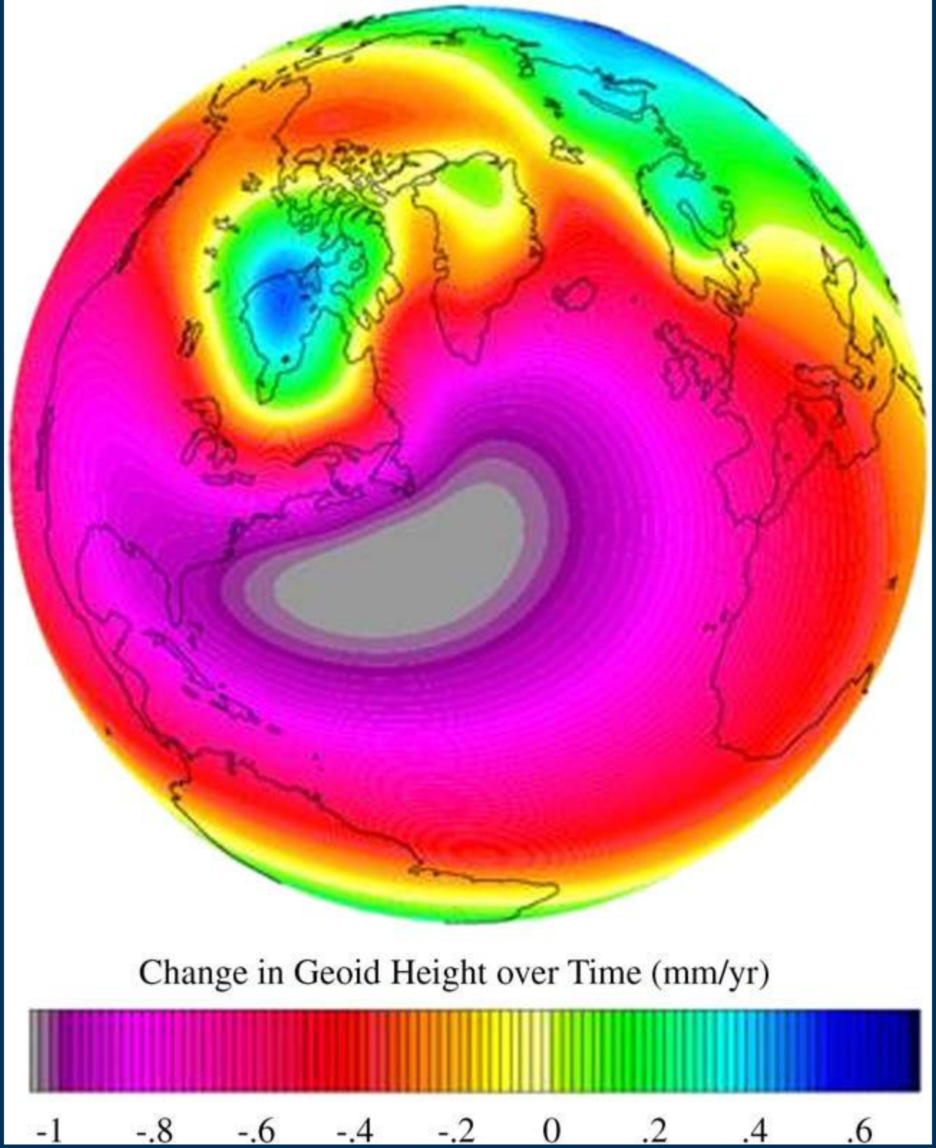


Global variability in SLR

Earth is still undergoing isostatic adjustment from deglaciation



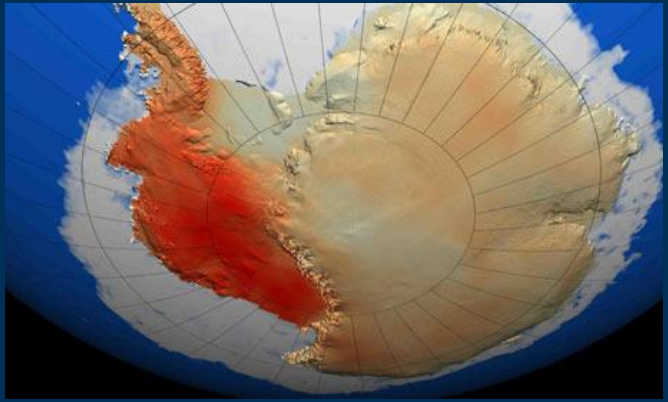
(Illinois Geological Survey)



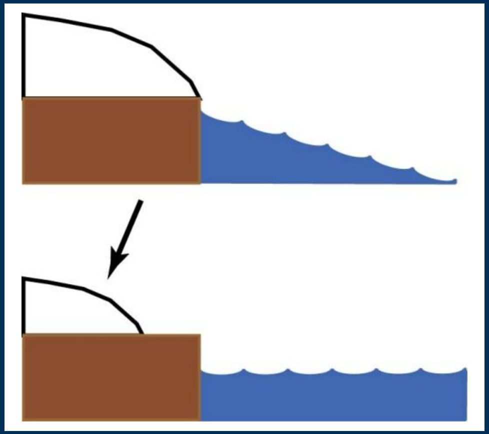
(Horton et al., 2009)

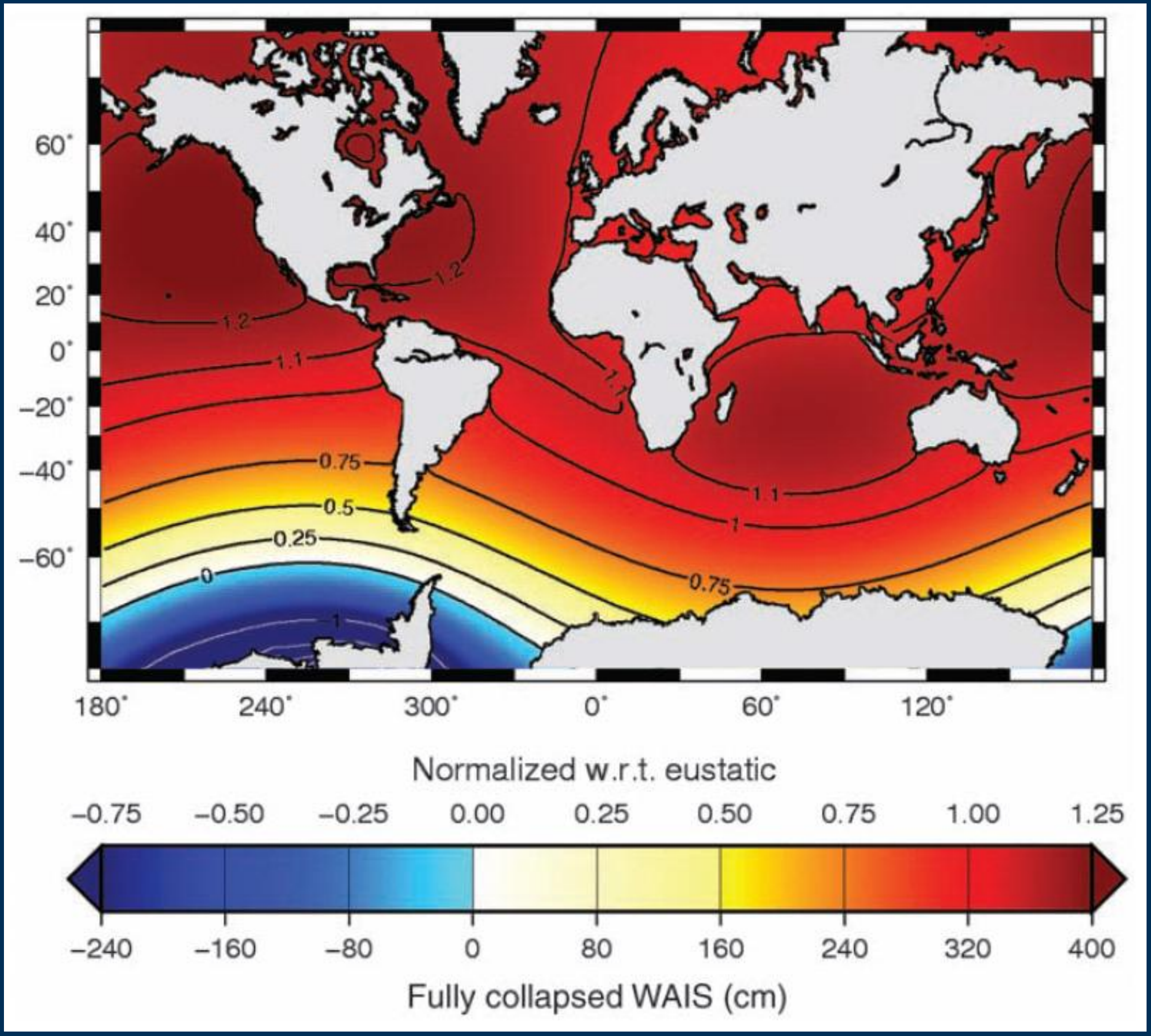
Global variability in SLR

Loss of the West Antarctic Ice Sheet can cause up to 25% more SLR on the U.S. coast.



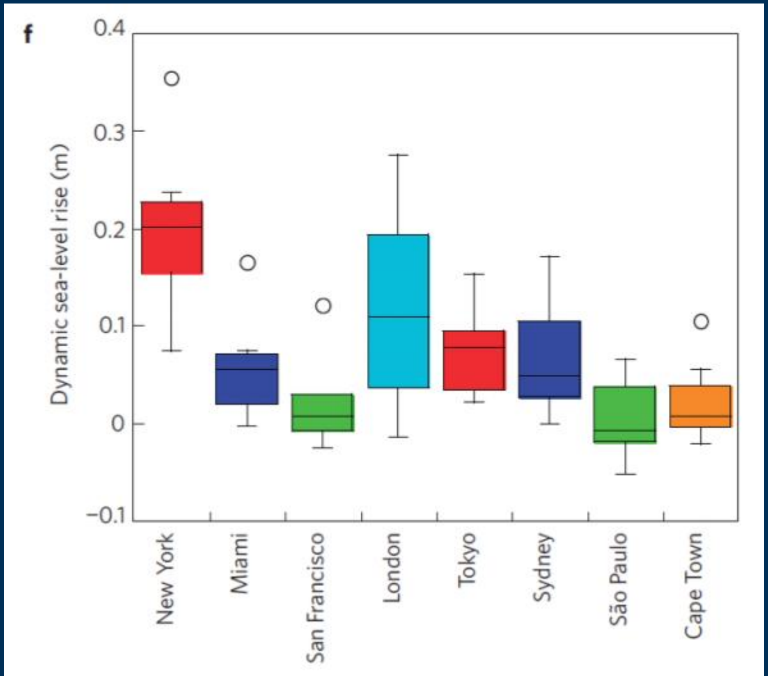
(Eric Steig)



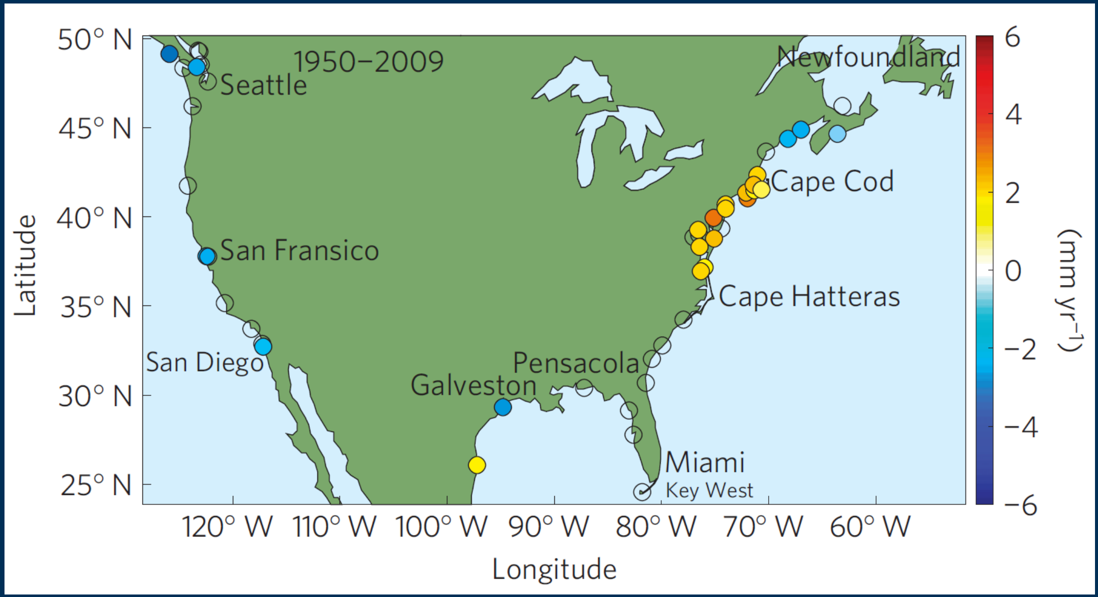


(Bamber et al., 2009)

Regional variability in SLR



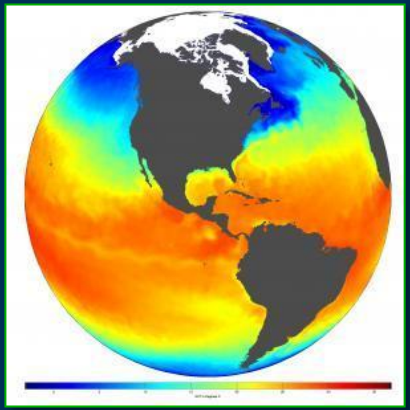
(Yin et al., 2009)



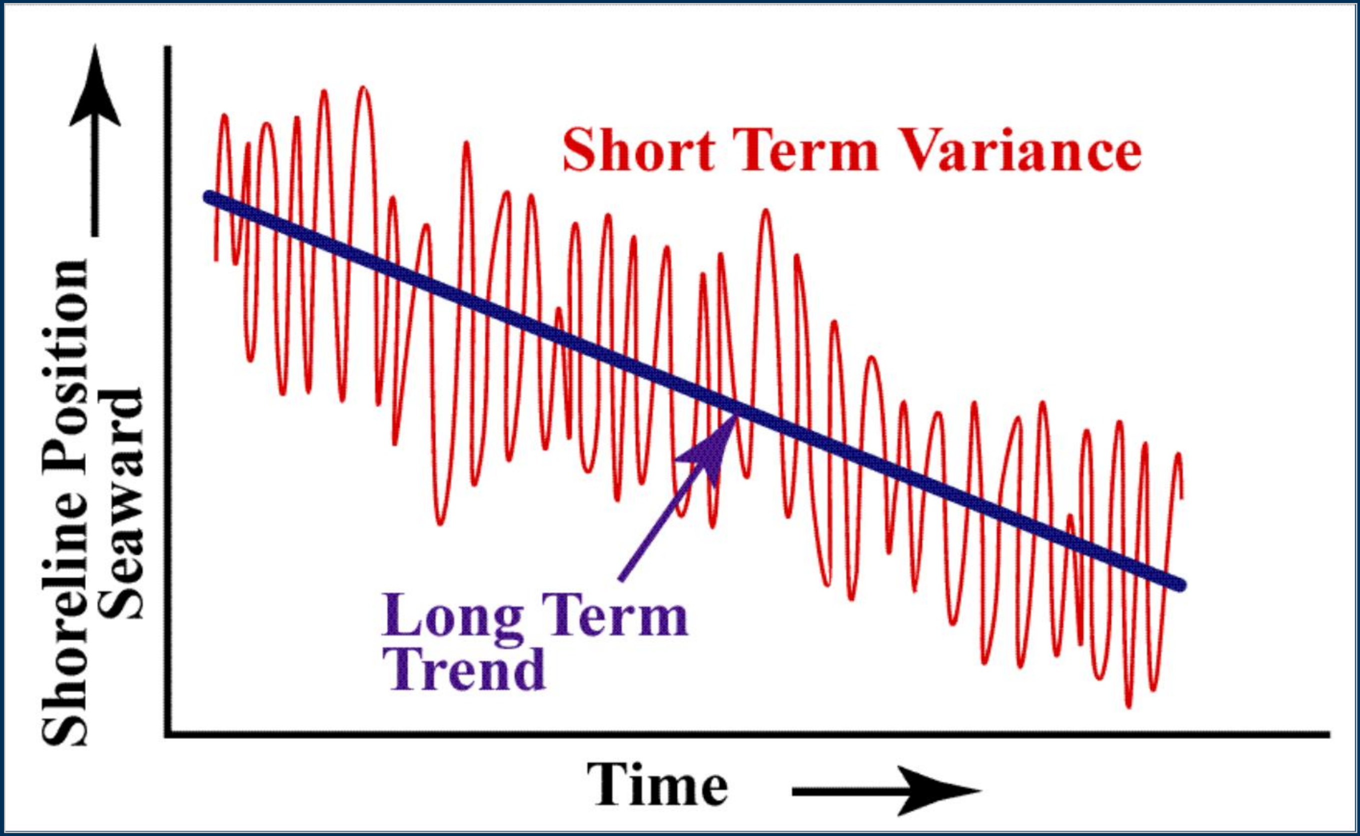
(Sallenger et al., 2012)

Regional changes in circulation and ocean warming can increase sea level by tens of centimeters, for example in the northeastern U.S. (north of Cape Hatteras).

Importance of Spatial Scale



Importance of Temporal Scale



Short-term Variance

(hours to decade)

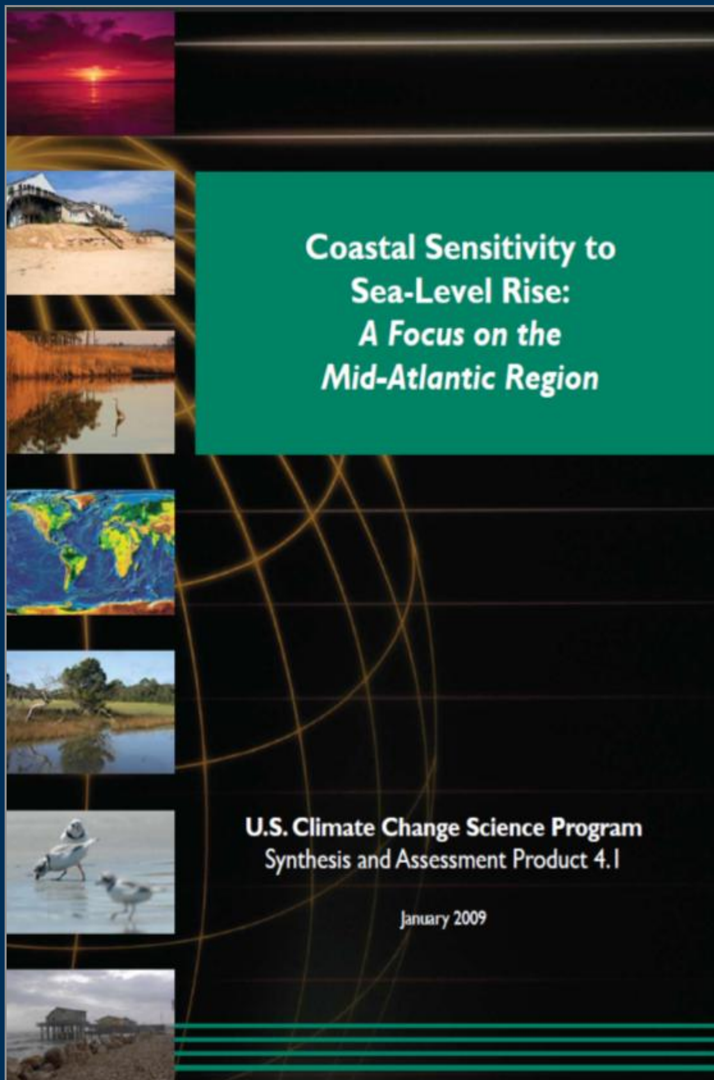
Storm impact/recovery
Annual cycles
El Niño

Long-term Trend

(decades to centuries)

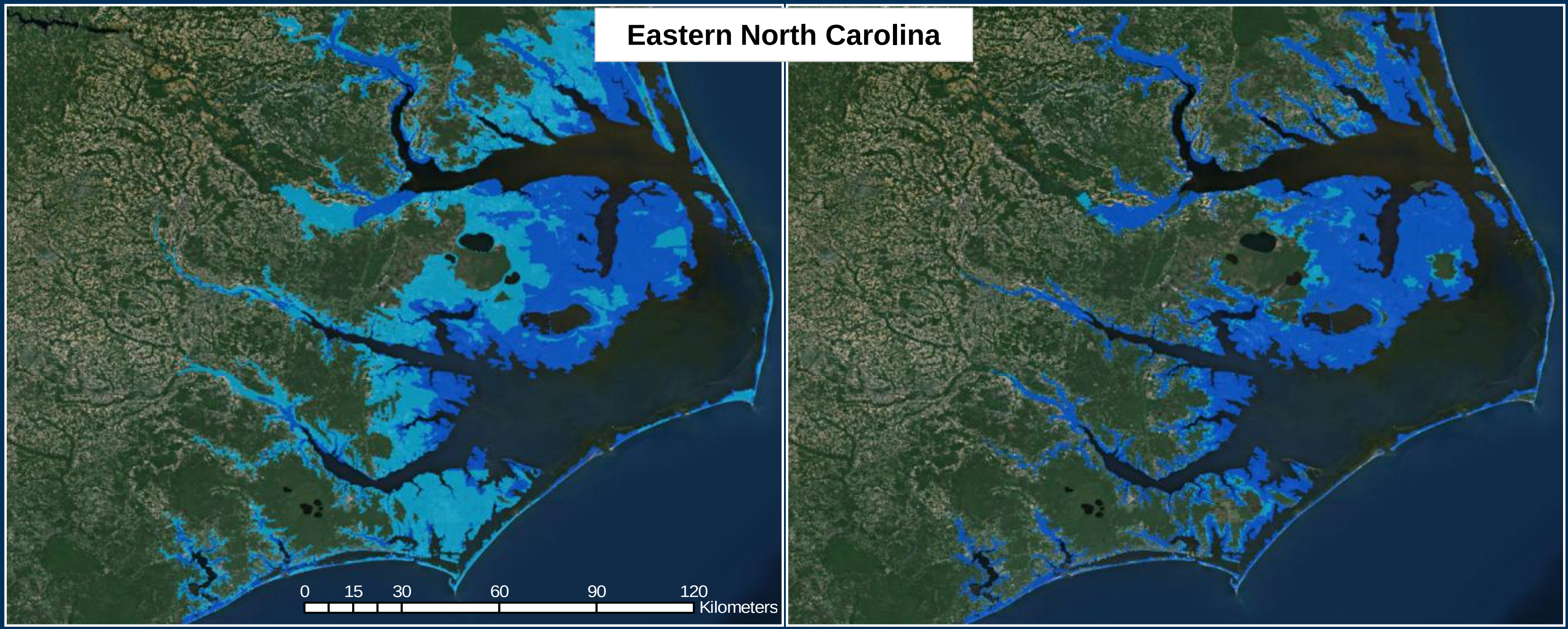
Sediment deficit or surplus
Sea-level rise

Coastal Sensitivity to Sea-Level Rise:
A Focus on the Mid-Atlantic Region



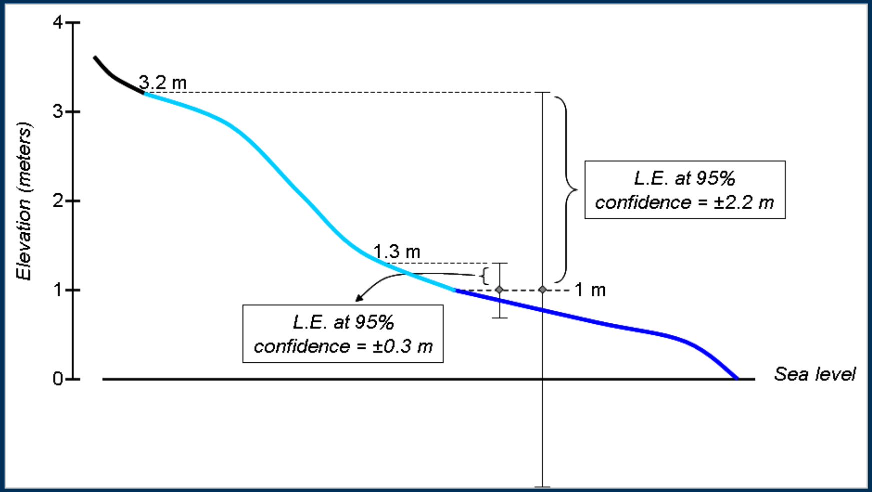
U.S. Climate Change Science Program
Synthesis and Assessment Product 4.1

http://go.usa.gov/Wkwk



Elevation source: 30-m DEM

Elevation source: 3-m lidar data



Dark blue **Land ≤ 1 meter elevation**

Light blue **Area of uncertainty associated with 1 meter elevation**

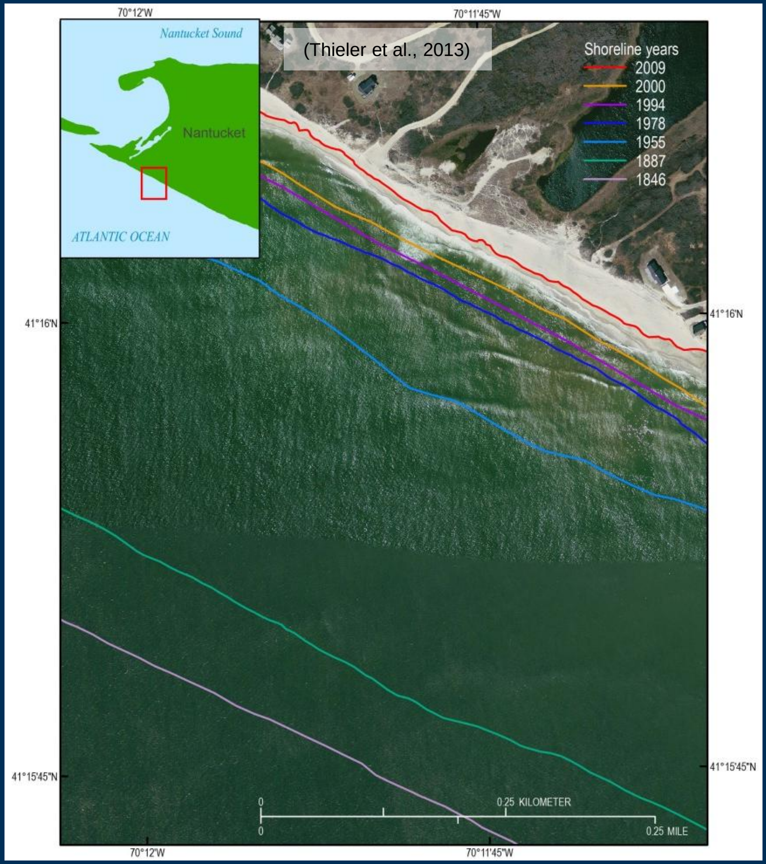
- High quality elevation data reduce uncertainty of potentially inundated areas

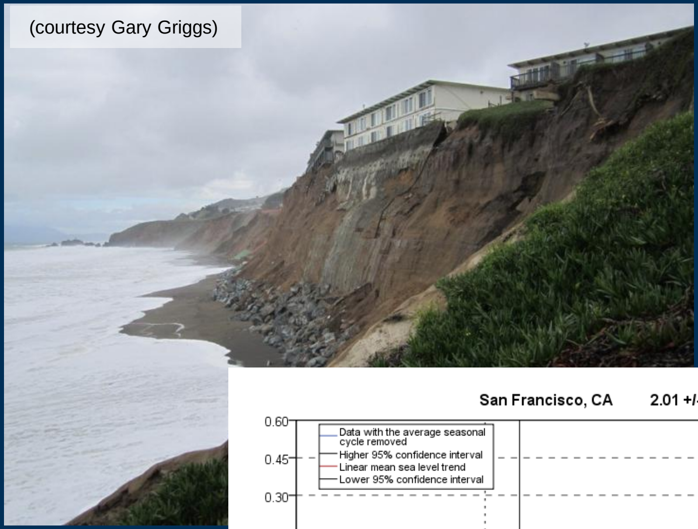
(Gesch et al., 2009)

But… the coast is not like a bathtub

Nantucket, MA

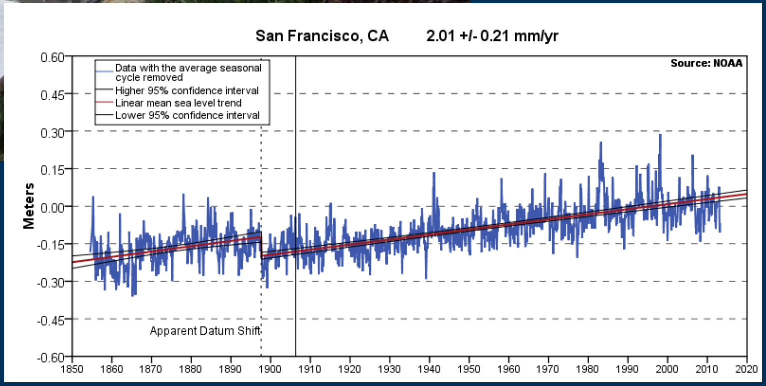
~0.26 m SLR in 100 yr; 500 m shoreline retreat

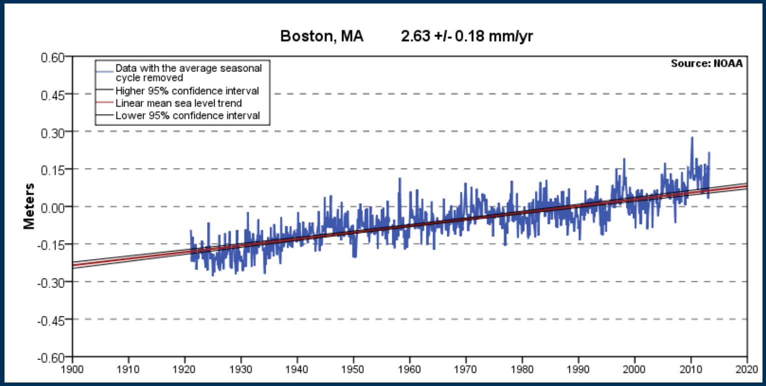




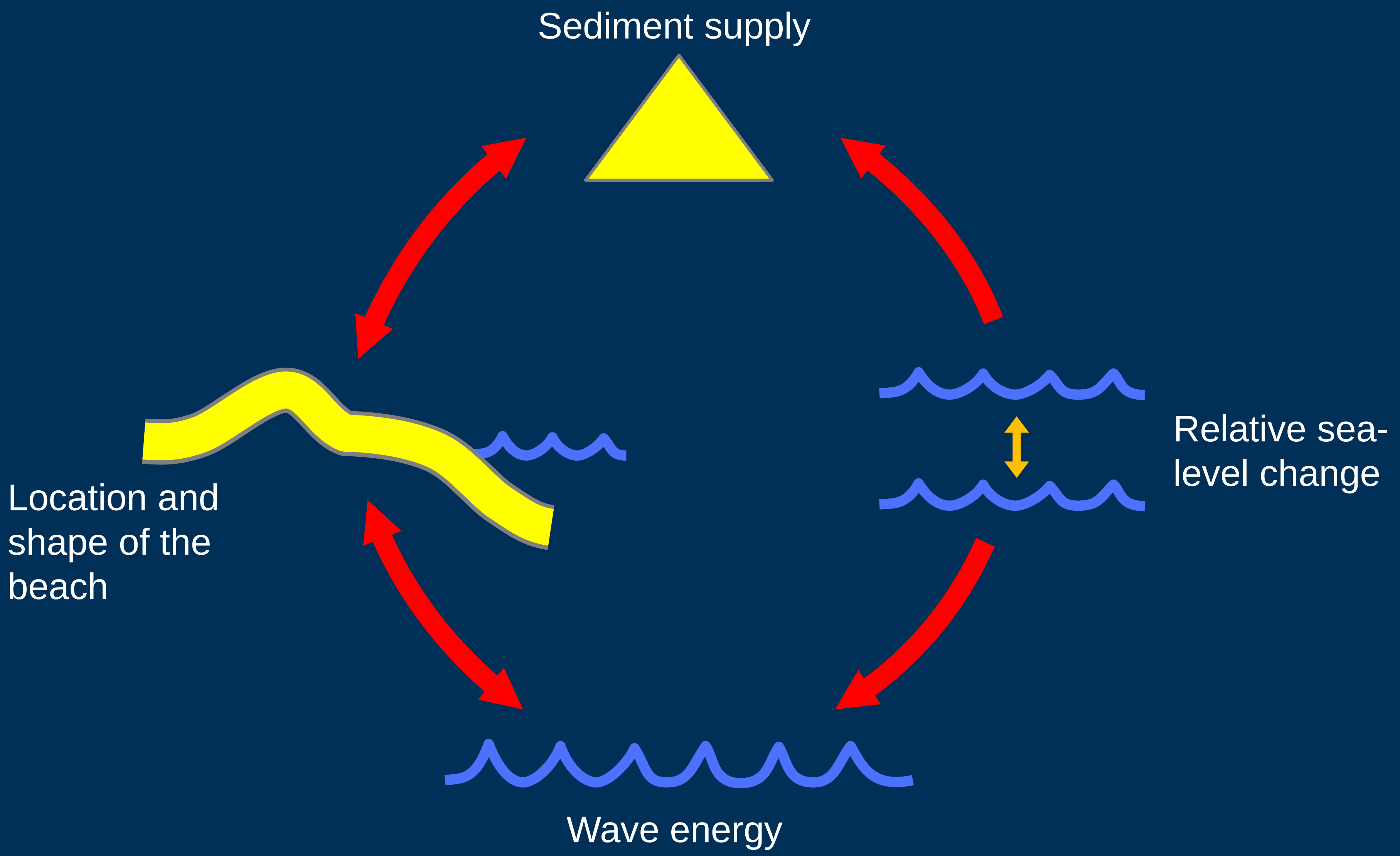
Pacifica, CA

~0.2 m SLR in 100 yr; long-term cliff erosion and retreat



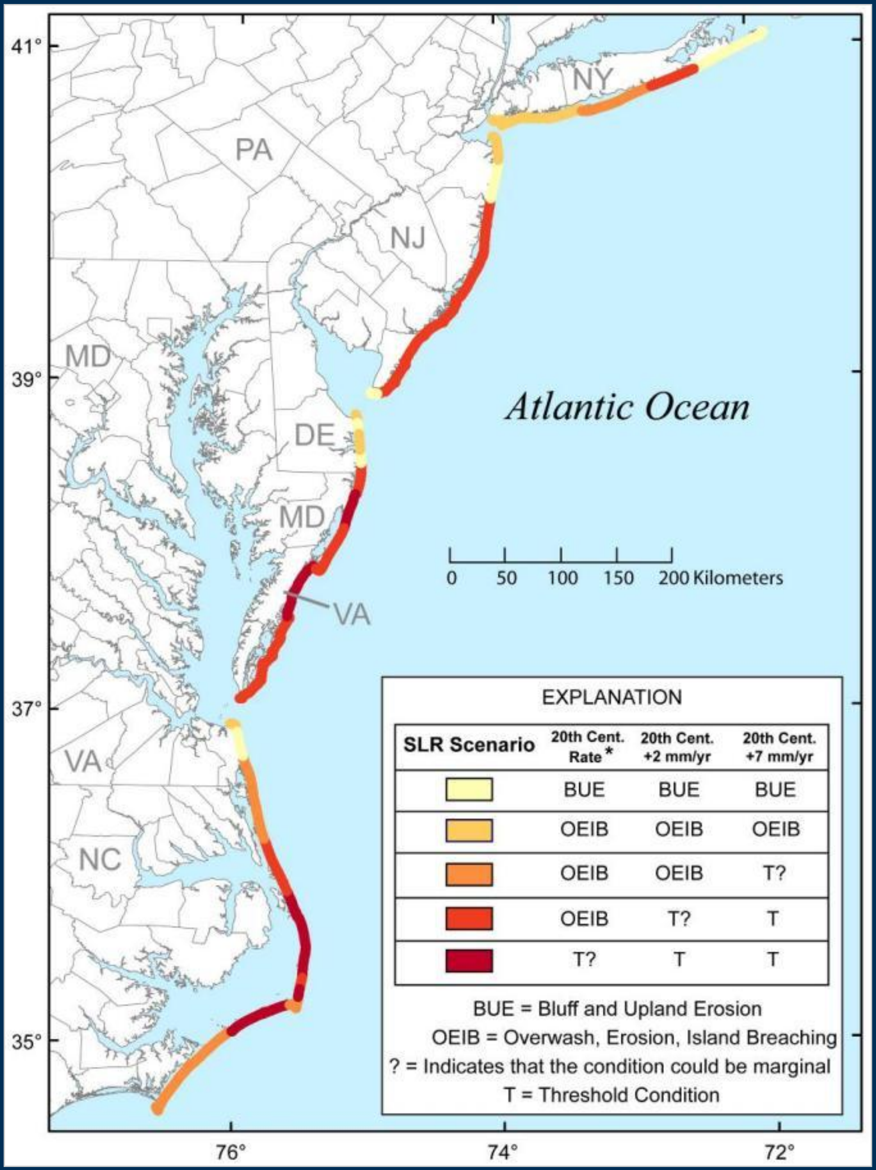


Dynamic Equilibrium of Beaches



(after Pilkey and Thieler, 1992)

Mid-Atlantic Assessment of Potential Dynamic Coastal Responses to Sea-level Rise



(Gutierrez et al., 2009)

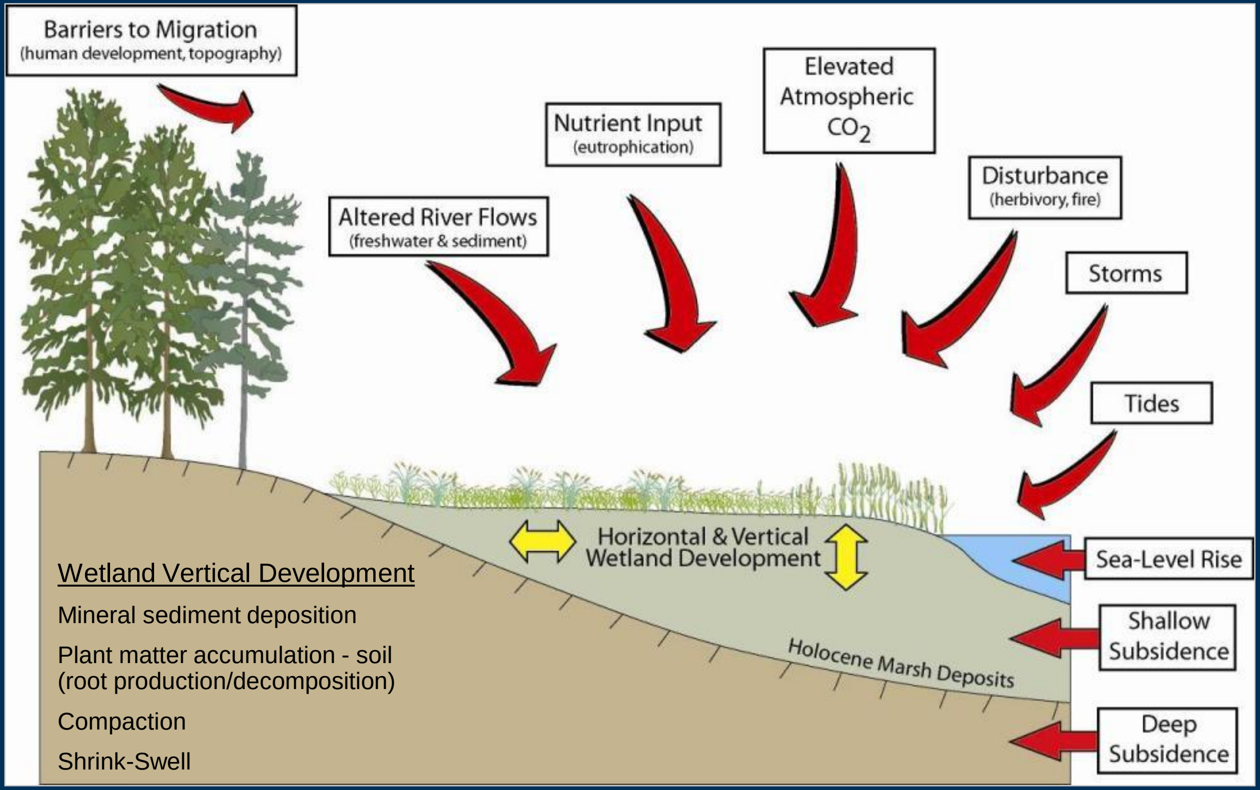
Bluff erosion

Overwash

Island Breaching

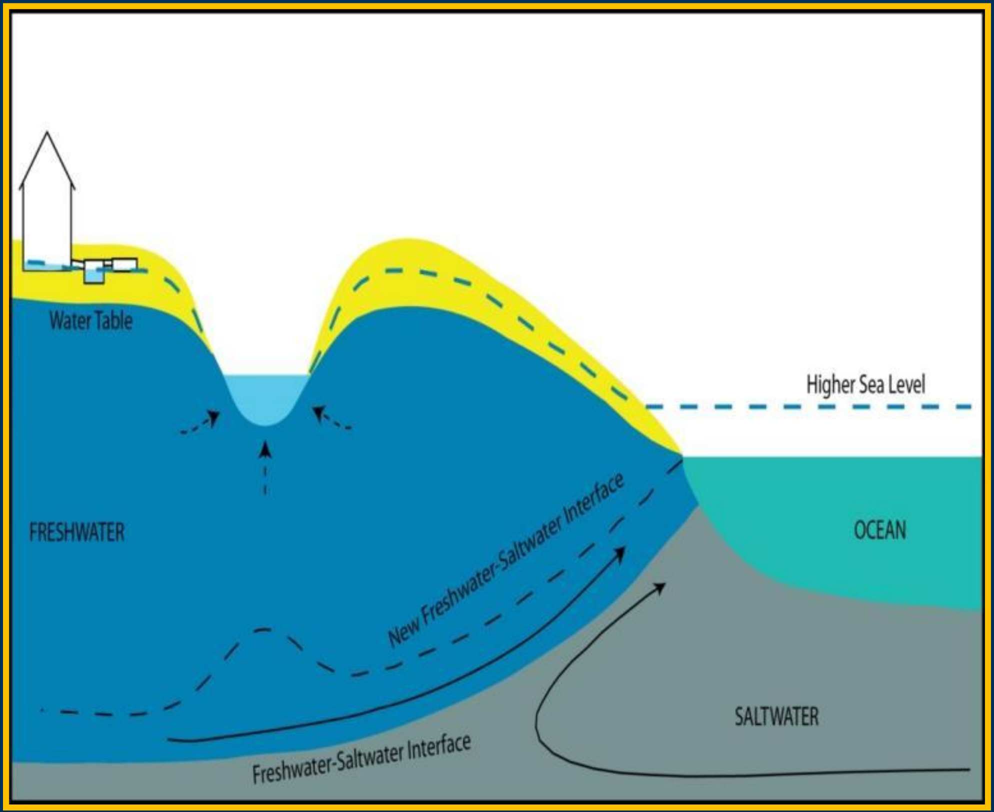
Threshold Crossing

Coastal Wetlands Respond Dynamically to Environmental Change



(Cahoon et al., 2009)

Sea-Level Rise Impacts on Groundwater Systems



(courtesy J.P. Masterson, USGS)

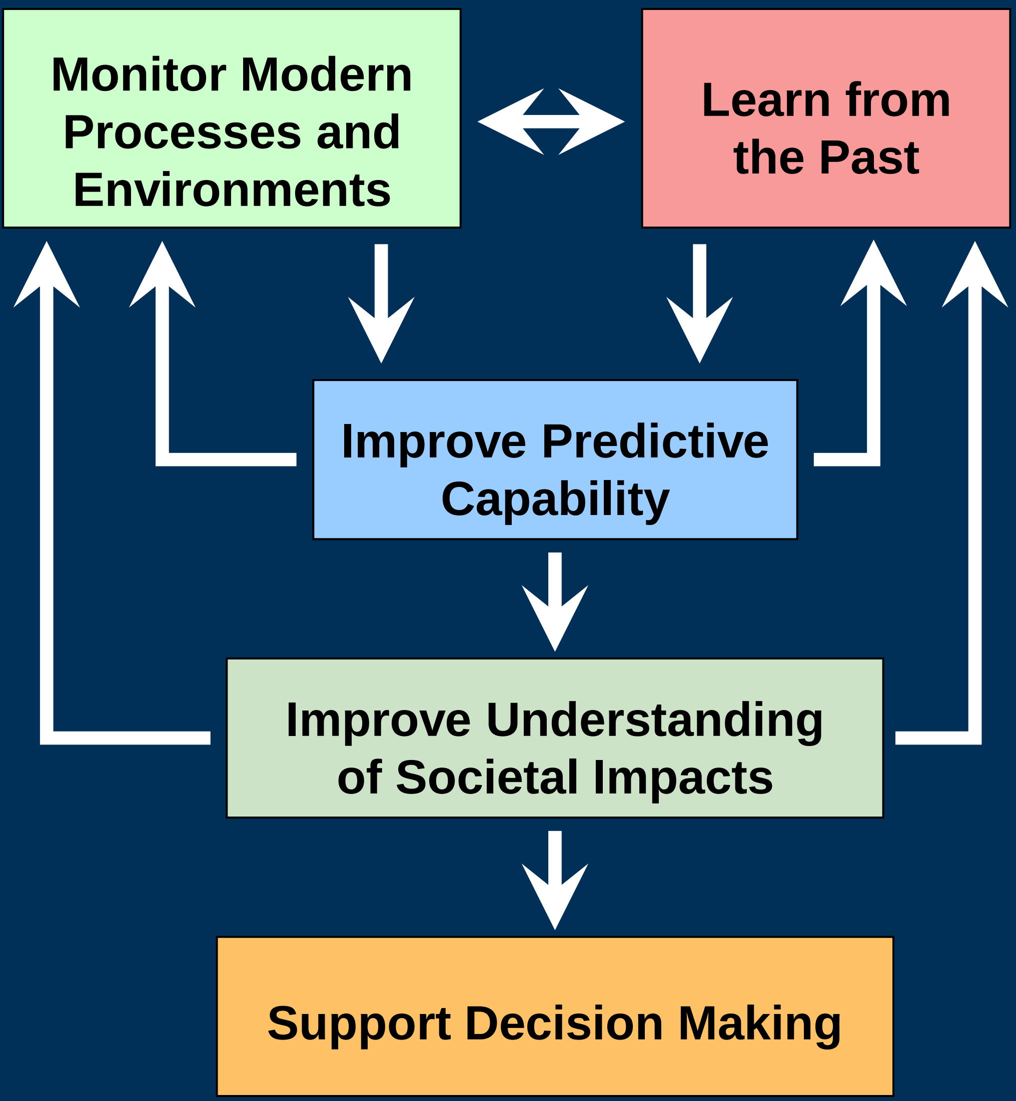
Water quality reduction

Infrastructure failure

Ecosystem change

So, what can happen?

Science strategy to address the challenge of climate change and sea-level rise



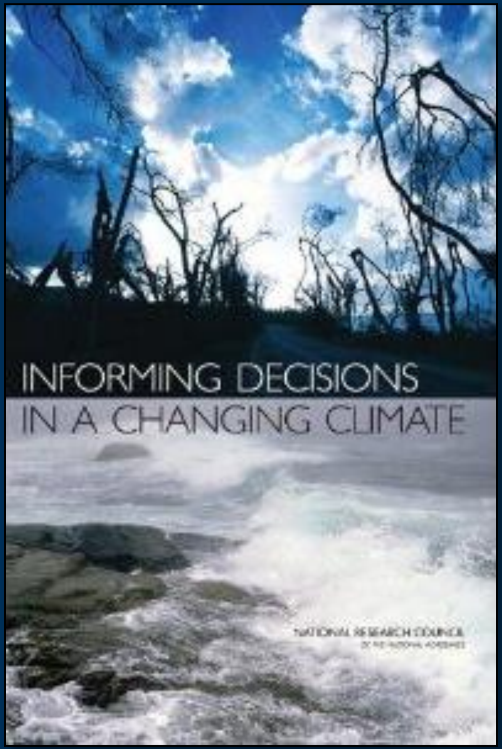
(Thieler et al., 2009)

Informing Decisions in a Changing Climate

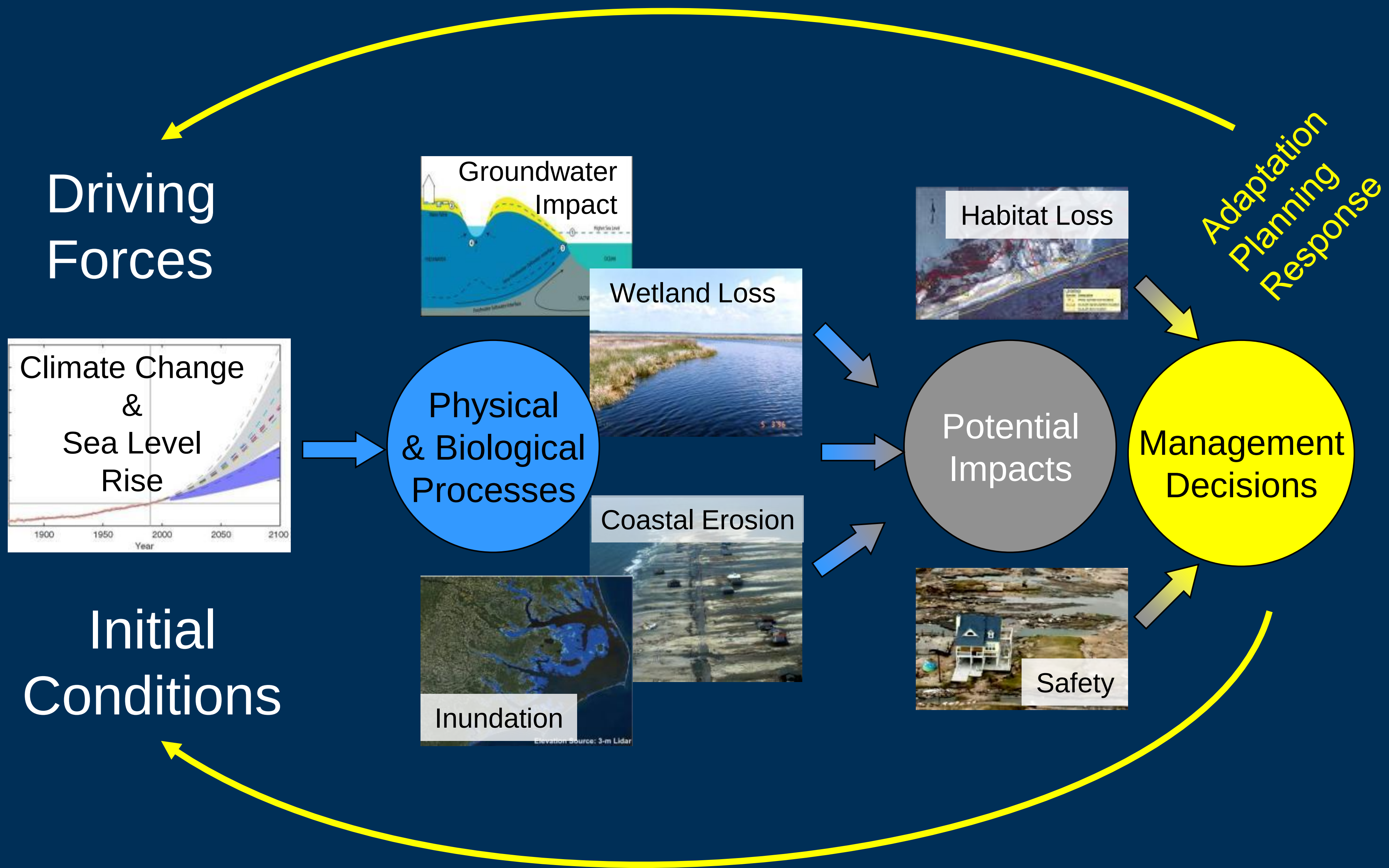
National Research Council (2009)

The end of "Climate Stationarity" requires that organizations and individuals alter their standard practices and decision routines to take climate change into account. Scientific priorities and practices need to change so that the scientific community can provide better support to decision makers in managing emerging climate risks.

- Decision makers must expect to be surprised because of the nature of climate change and the incompleteness of scientific understanding of its consequences.
- An uncertainty management framework should be used because of the inadequacies of predictive capability.



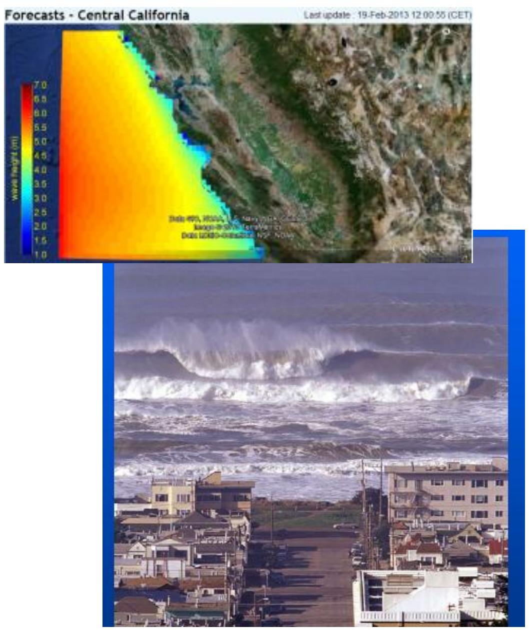
Sea-level rise impacts: A multivariate problem with uncertainties everywhere

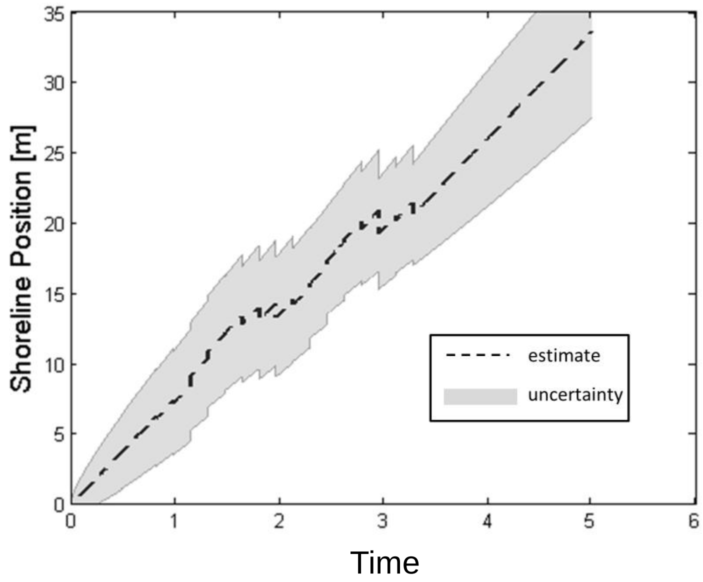


Integration and prediction of coastal change

- Short- and long-term coastal hazard processes (i.e., storms, sea-level rise)
- Uses data and models

storm/wave models + shoreline data = coastal change prediction and prediction uncertainty





Shoreline change near San Francisco using Kalman filter (data assimilation)

(Long and Plant, 2012)

National Assessment of Coastal Change Hazards

Extreme erosion during Hurricane Irene
Rodanthe, NC

Long-term cliff erosion
Pacifica, CA

Goal: Identify, quantify, and model the vulnerability of the U.S. shorelines to coastal change hazards

Ongoing Tasks

- Impacts of severe storms & hurricanes
- Long-term shoreline change
- Coastal vulnerability to sea level rise

USGS

Forecasting Vulnerability to Extreme Erosion during Hurricanes

- Over a decade of research on hurricane-induced coastal change
- Development of models for forecasting future impacts
- Implementation and sharing with stakeholders

USGS

Probabilities of coastal change

What is the likelihood that hurricane induced water levels will exceed the elevation of the base and crest of protective sand dunes?

Collision

Waves/surge higher than base of dune lead to erosion

Overwash

Waves/surge overtop dune crest, moving sand landward

Inundation

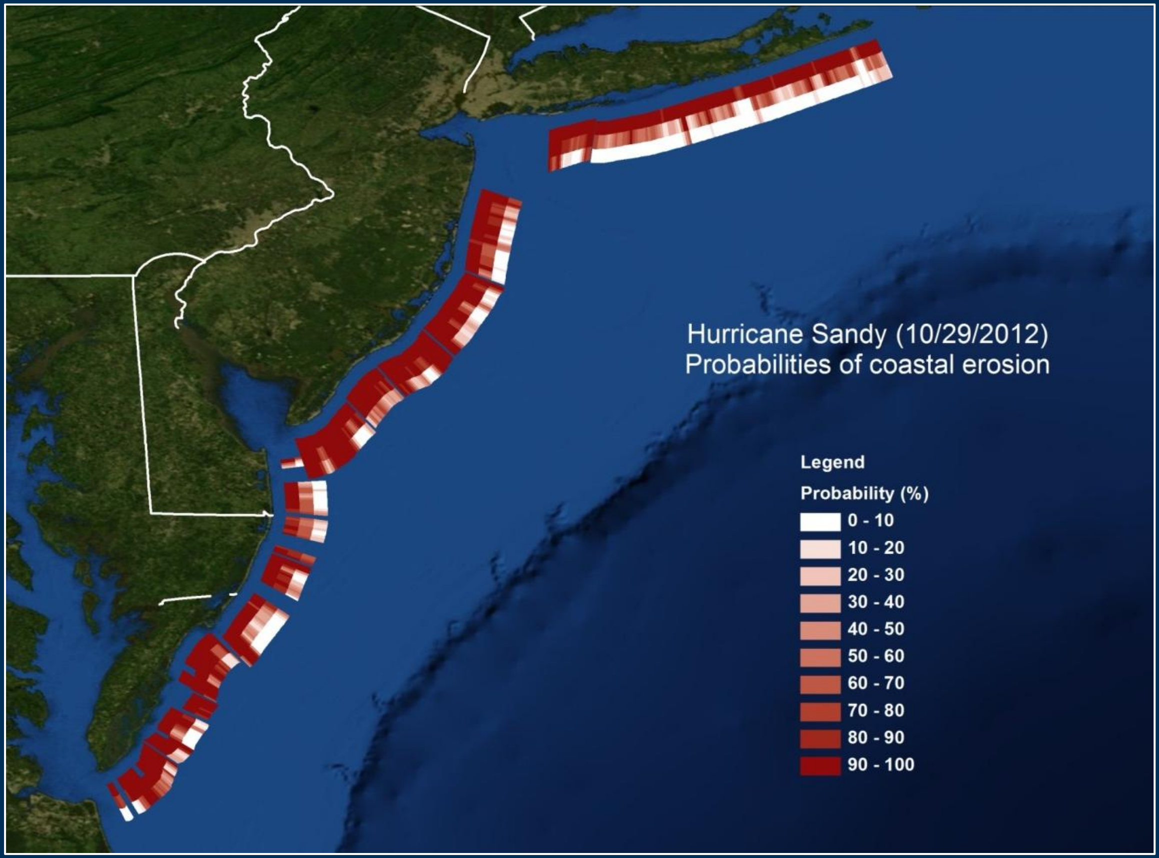
Mean water levels are higher than dune crest, submerging beach system

1) Scenario-based approach for generalized storms
2) Real-time mode for approaching storms

USGS

Real-time forecast of coastal erosion – Hurricane Sandy

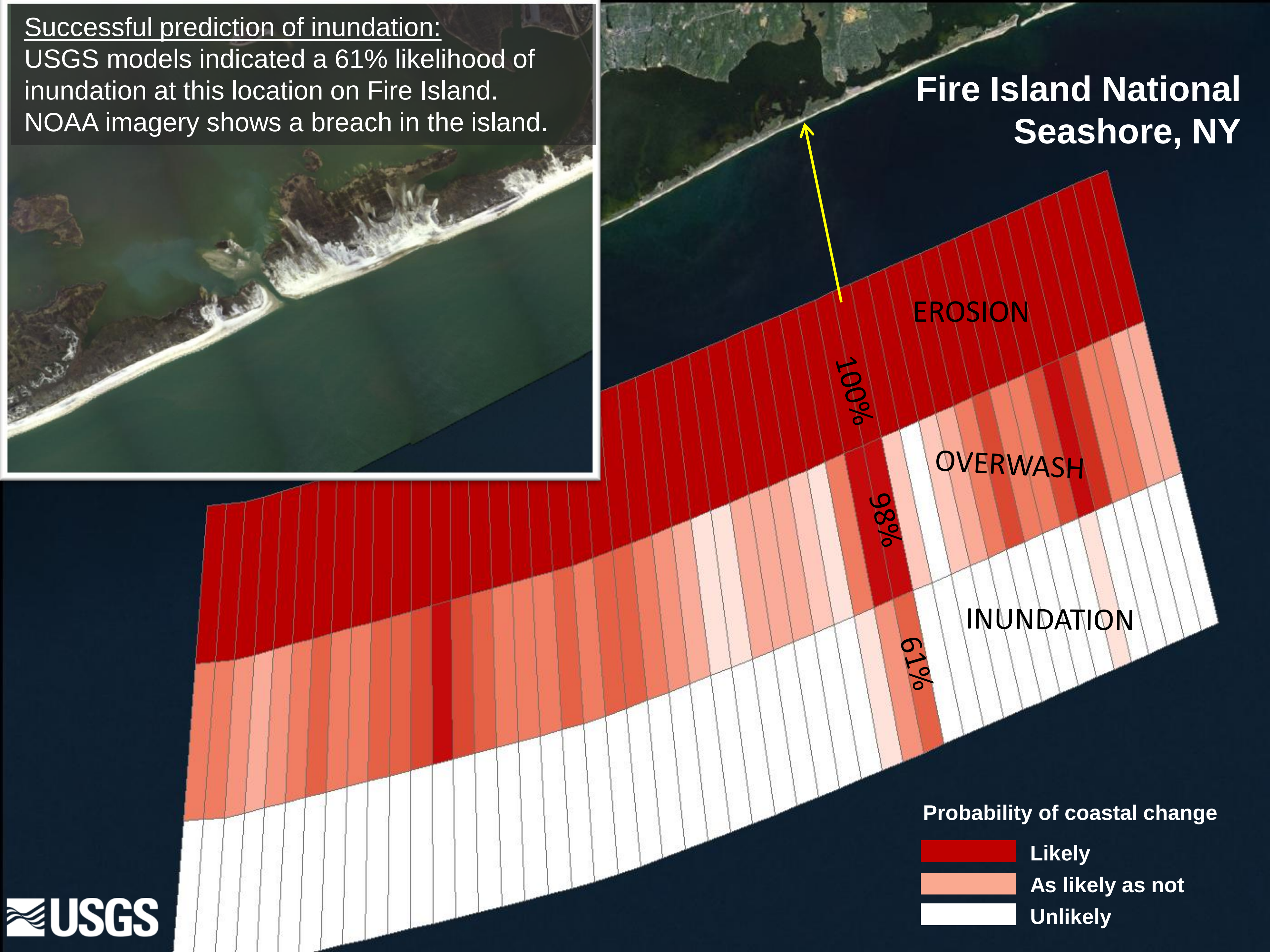
- Inputs:
  - Lidar-based shorelines, dunes (USGS, USACE)
  - Storm surge (NOAA)
  - Wave conditions (NOAA)
  - Wave runup (USGS)
- Output: Probabilities of
  - Dune erosion
  - Overwash
  - Inundation
- Assessments are posted online and updated with current NHC meteorology as the storm approaches landfall.



% of coast very likely to experience coastal change :

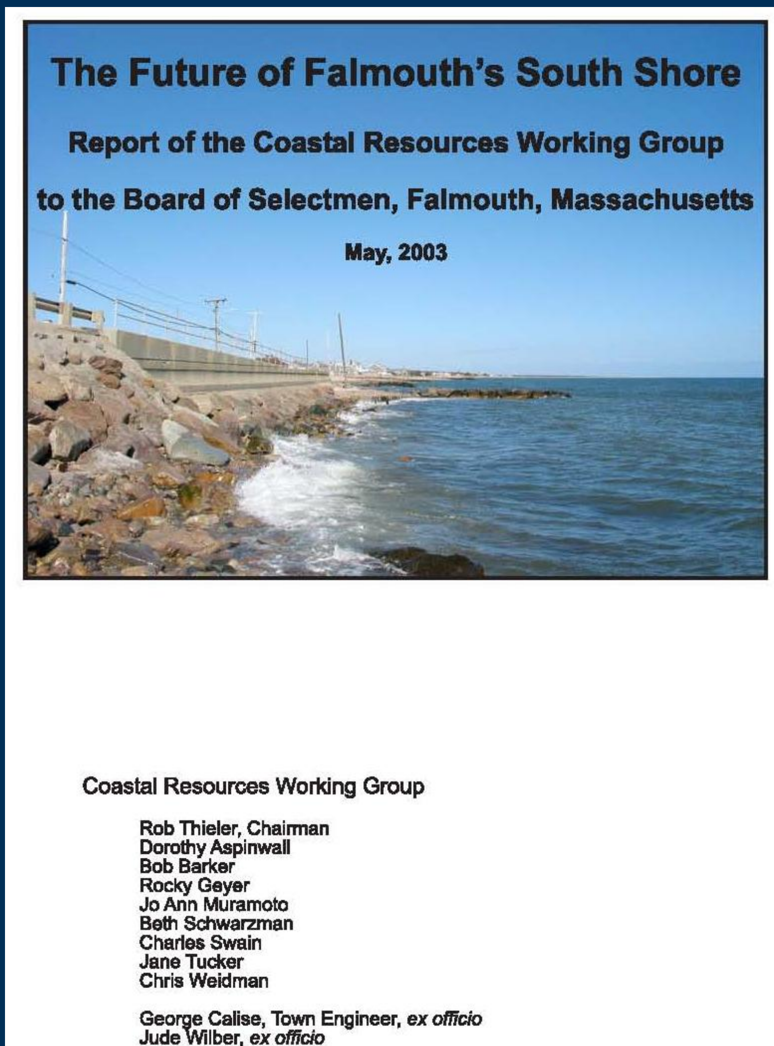
	Dune erosion (inner)	Overwash (middle)	Inundation (outer)
Long Island, NY	93	12	4
New Jersey	98	54	21
Delmarva	91	55	22

USGS


Successful prediction of inundation:
USGS models indicated a 61% likelihood of inundation at this location on Fire Island. NOAA imagery shows a breach in the island.
Fire Island National Seashore, NY
EROSION
OVERWASH
INUNDATION
100%
98%
61%
Probability of coastal change
Likely
As likely as not
Unlikely
USGS

Understanding Where We Are, and Where We Could Go

www.falmouthmass.us/depart.php?depkey=coastal


The Future of Falmouth's South Shore

Report of the Coastal Resources Working Group

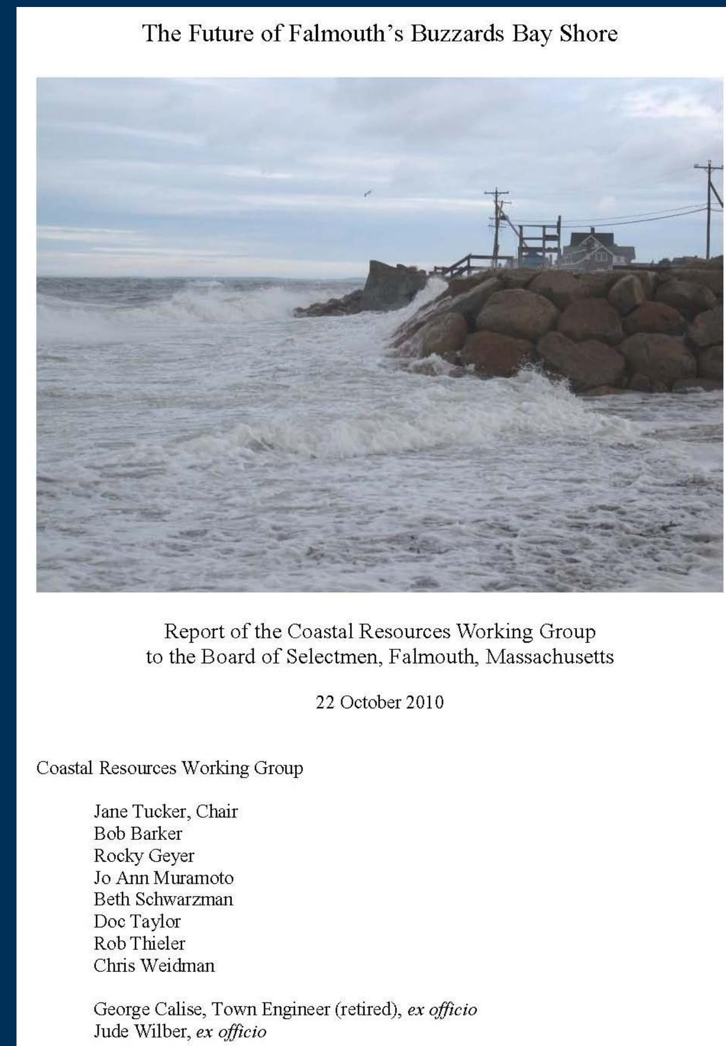
to the Board of Selectmen, Falmouth, Massachusetts

May, 2003

Coastal Resources Working Group

Rob Thieler, Chairman
Dorothy Aspinwall
Bob Barker
Rocky Geyer
Jo Ann Muramoto
Beth Schwarzman
Charles Swain
Jane Tucker
Chris Weidman

George Calise, Town Engineer, *ex officio*
Jude Wilber, *ex officio*


The Future of Falmouth's Buzzards Bay Shore

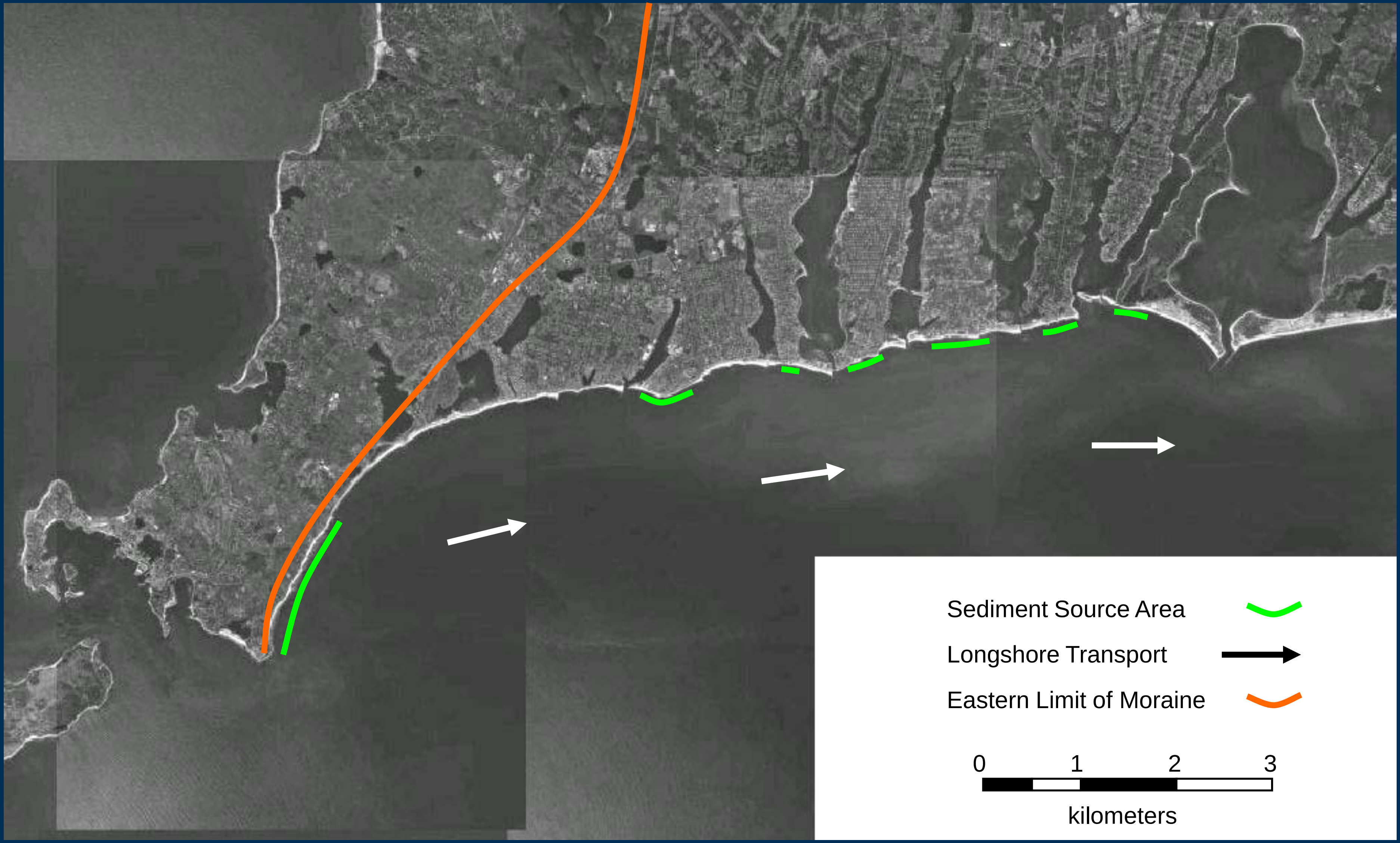
Report of the Coastal Resources Working Group
to the Board of Selectmen, Falmouth, Massachusetts

22 October 2010

Coastal Resources Working Group

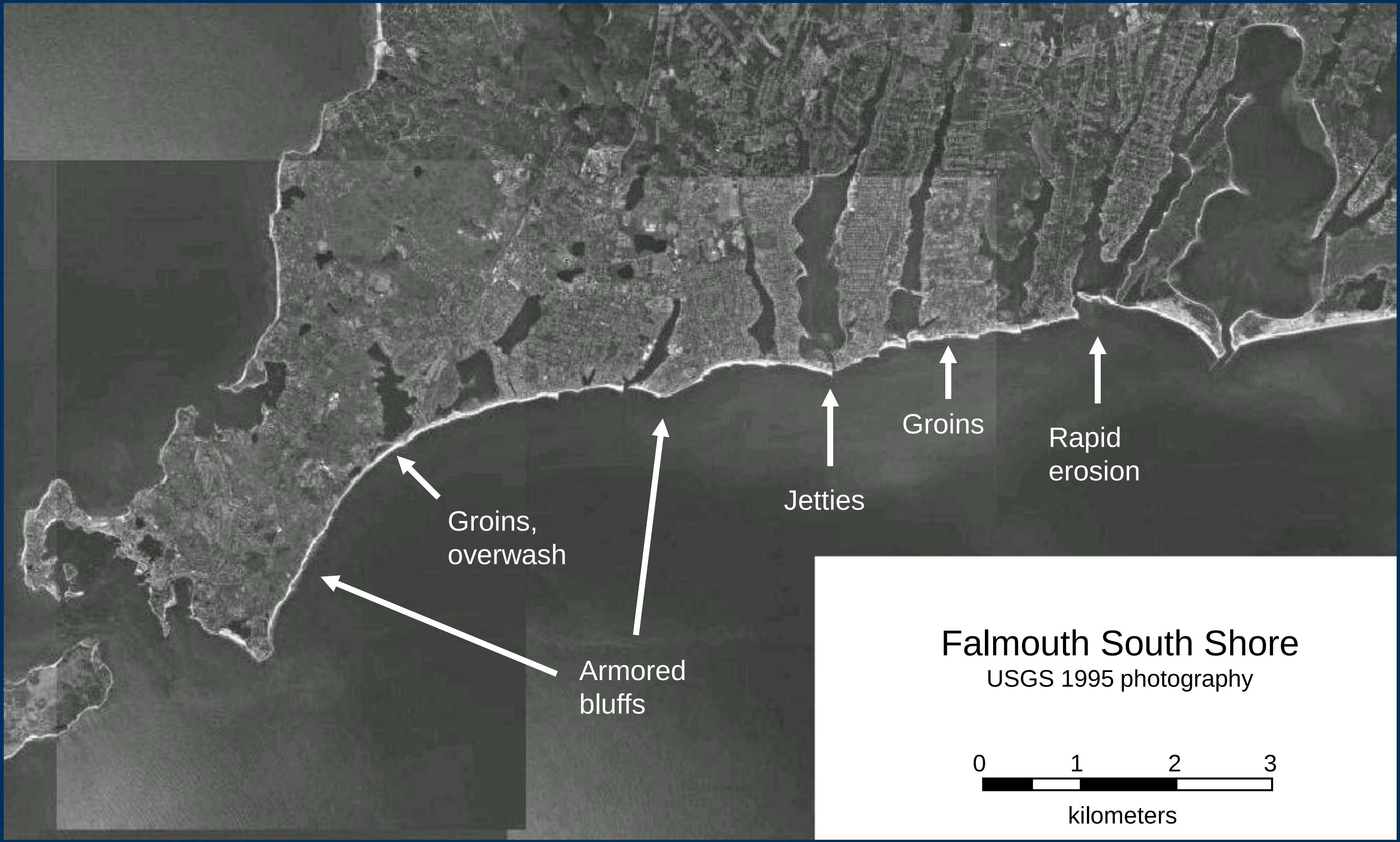
Jane Tucker, Chair
Bob Barker
Rocky Geyer
Jo Ann Muramoto
Beth Schwarzman
Doc Taylor
Rob Thieler
Chris Weidman

George Calise, Town Engineer (retired), *ex officio*
Jude Wilber, *ex officio*



Falmouth South Shore

USGS 1995 photography



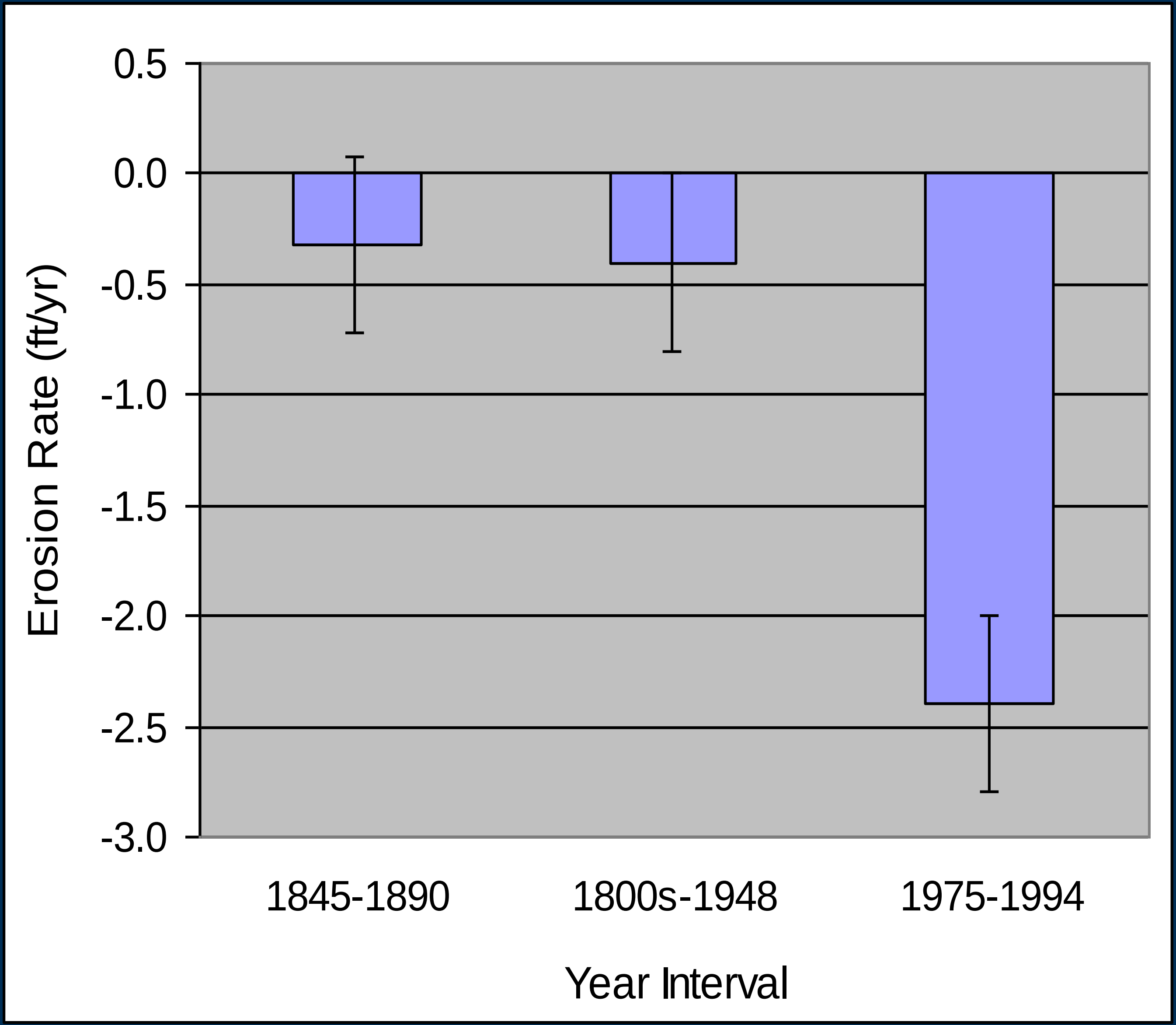
About 50% of south coast parcels are armored. Half are Town parcels. There are 70 groins, 10 jetties, and 94 revetments on the south coast.

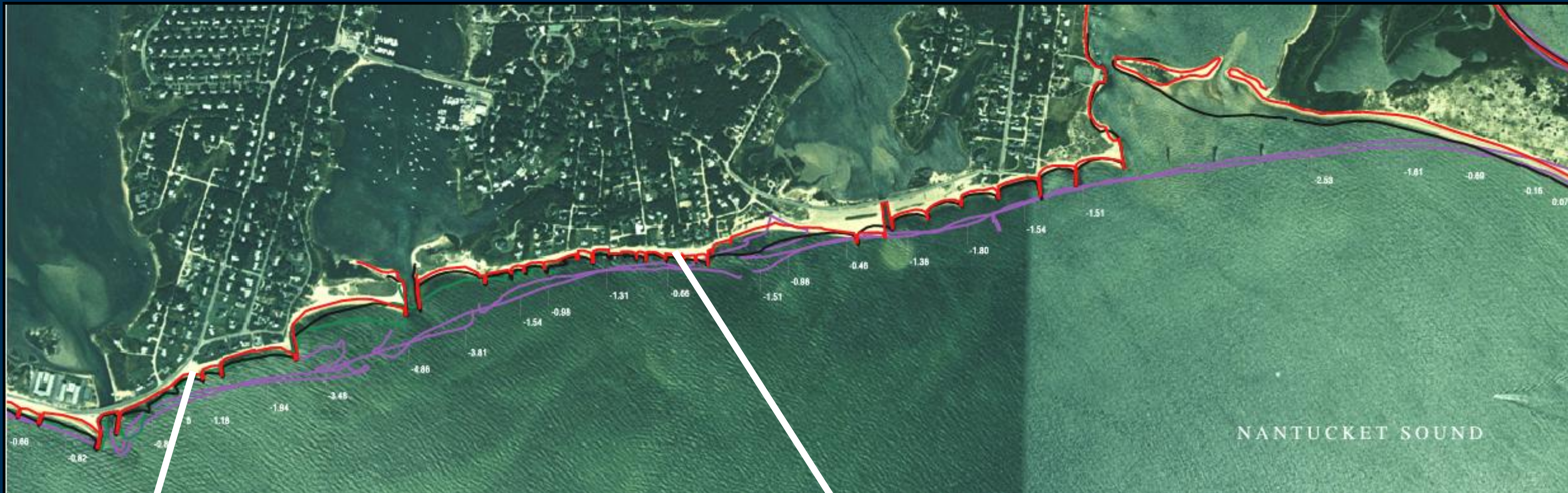
Nobska Point

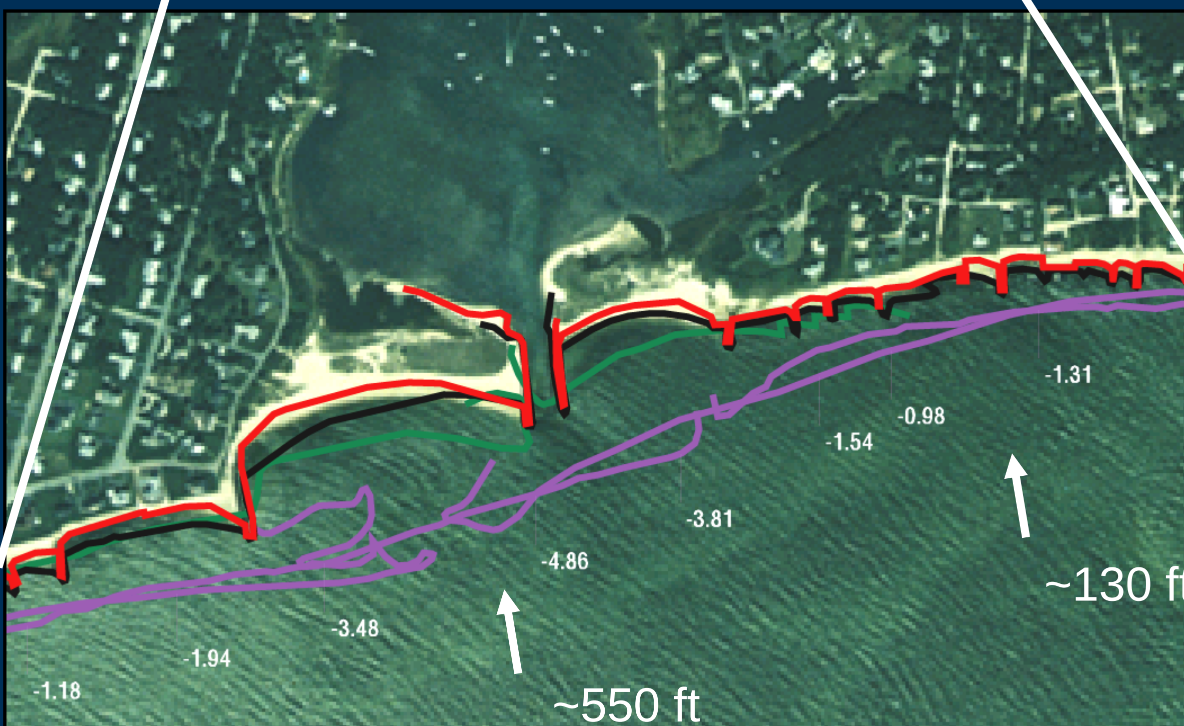
Falmouth Heights, 1897

Falmouth Heights, 2000

Falmouth South Shore Erosion Rates







Green Pond Shoreline Change Since 1845

- Sediment supply decreased
- Uplands armored, beaches narrowed
- Barrier has migrated into the pond

Vision for Falmouth's Coast
(for the next 50-100 years)

- Beaches and dunes wide enough for protection from storms and public access and use.
- Sufficient sand in the coastal system.
- Sustained and enhanced water quality, habitat and fisheries resources.
- A minimum of hard structures (groins, seawalls, etc.).
- Public infrastructure will be relocated from the immediate coast.
- A proactive approach to shoreline management to prevent problems and provide a response protocol when shoreline damage occurs.

Achieving the Vision for Falmouth's Coast

- Acquire coastal land for open space.
- Move or change vulnerable public infrastructure. Plan future infrastructure (e.g., roads, sewers) wisely.
- Conduct beach nourishment experiments at key "source" locations.
- Remove unnecessary, hazardous, or damaging coastal armoring structures.
- Create effective sand management systems.
- Improve regulations to protect coastal systems and beaches.
- Encourage protection of valuable coastal assets such as unarmored bluffs.

Summary

- The coast as we know it today is a product of sea-level rise
- Major changes are coming to the coast, ecosystems, and resources
- Future sea-level rise is a **certain** impact
  - We have already made a commitment to several centuries of rise
- Future sea-level rise is an **uncertain** impact
  - Rates and magnitudes poorly constrained
  - Societal response unknown
- Informed preparation is important