New England Climate Change: Coastal Effects and Vulnerability to Sea-level Rise, Erosion, and Storms

EPA New England Climate Change Forum
University of New Hampshire, Durham, NH
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Potential Climate Change Impacts

- Temperature (local, regional, global)
- Water Cycle (precipitation/evaporation, lake level, and sea-level rise)
- Vegetation (plant cover, including invasive plants, plant pests and pathogens)
- Fish and Wildlife (aquatic, marine, and terrestrial animals, invasive species, range and migration patterns)
- Landscape Modification (fire, flooding, coastal erosion, storms, and coastal processes)

Topics Addressed

- Coastal-change processes, past sea-level change, human effects on climate and the coast, sea-level rise predictions for the near future, and coastal vulnerability to sea-level rise and storms.

- USGS research on sea-level rise effects on ocean coasts

  Coastal Vulnerability Index Assessments

  National Assessment of Coastal Hazards (erosion, storms, SLR)

  Modeling Coastal Landform Response to SLR

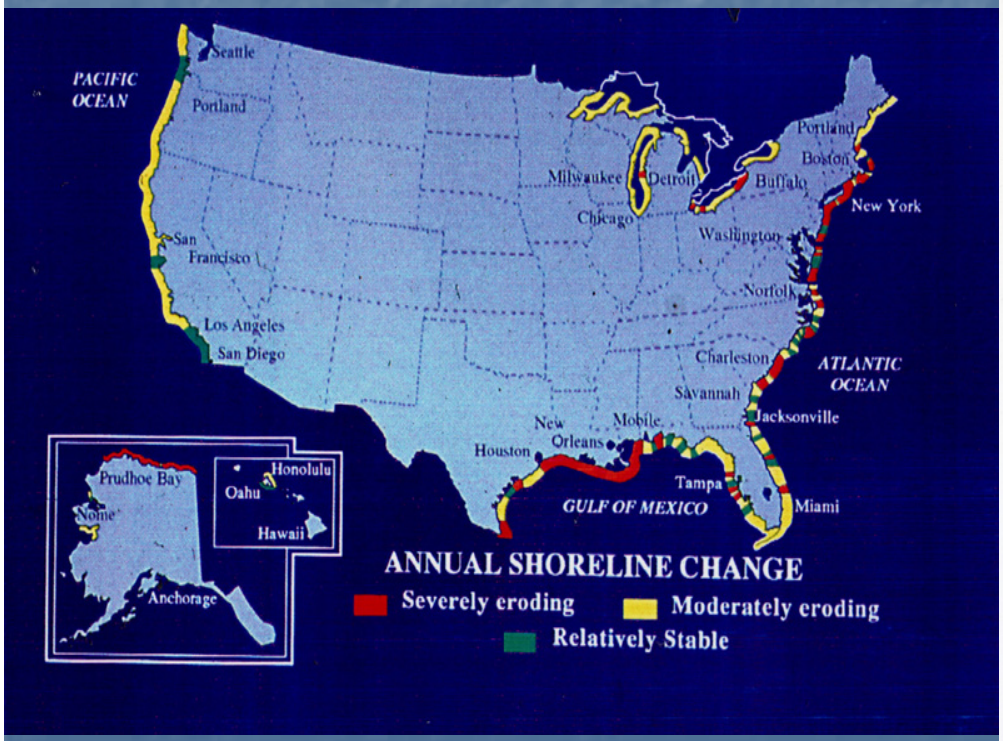
- Climate Change Science Program SAP 4.1 report (EPA, USGS, NOAA):

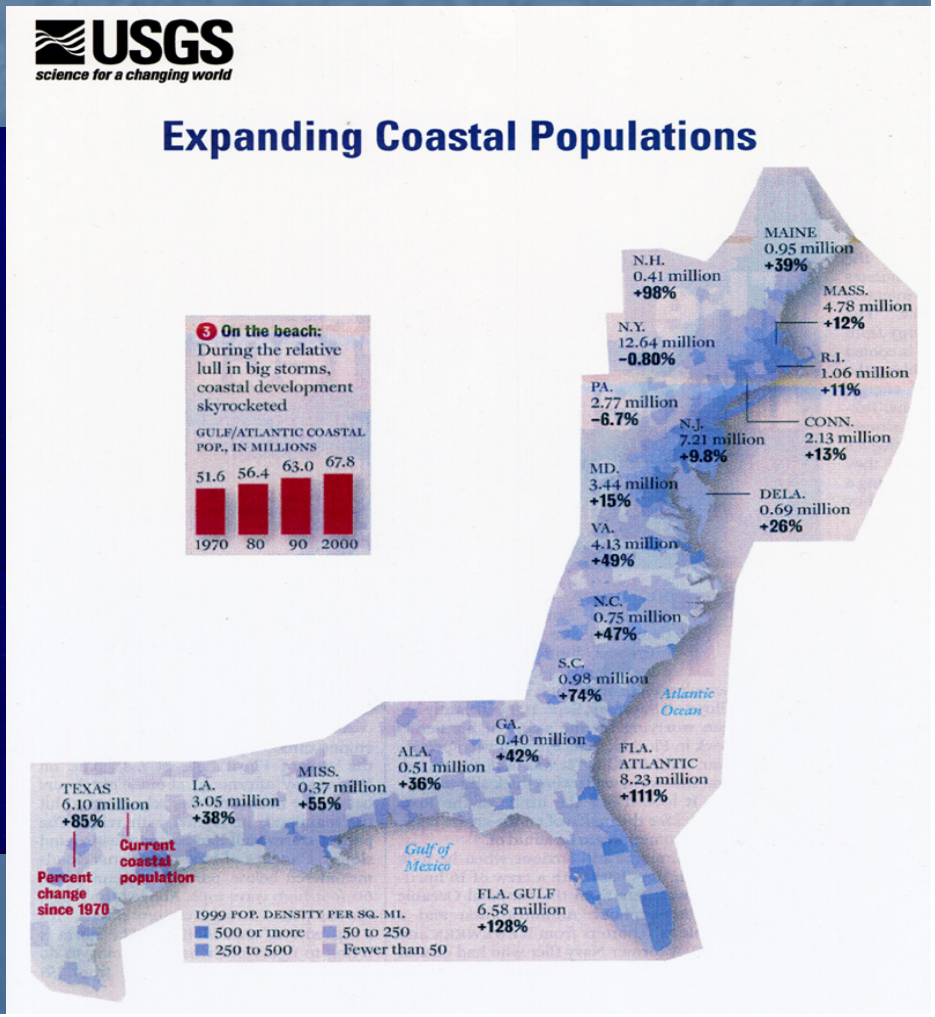
  "Coastal elevations and sensitivity to sea-level rise:
  a focus on the mid-Atlantic region"

Primary Processes Driving Coastal Change

- Geologic framework and character
- Coastal plain geomorphology and slope
- Relative sea-level change
  - global change
  - land subsidence and uplift
- Major storm events
  - tropical storms/ hurricanes
  - extratropical storms
  - northeaster storms
- Routine coastal processes
  - waves, tidal currents and winds
  - cold front storms
- Sediment budgets
  - sediment sources (headlands, cliffs)
  - sediment sinks (washover, inlets)
- Human activities
  - coastal engineering structures, dredging channels, inlets, canals
  - river modifications (dams, levees)
  - fluid (oil-gas-water) extraction
  - climate change (SLR, storms)

America's Coastal Crisis – Coastal population and development are increasingly vulnerable to coastal hazard storms and sea-level rise





Responses to Coastal Erosion and Sea-level Rise

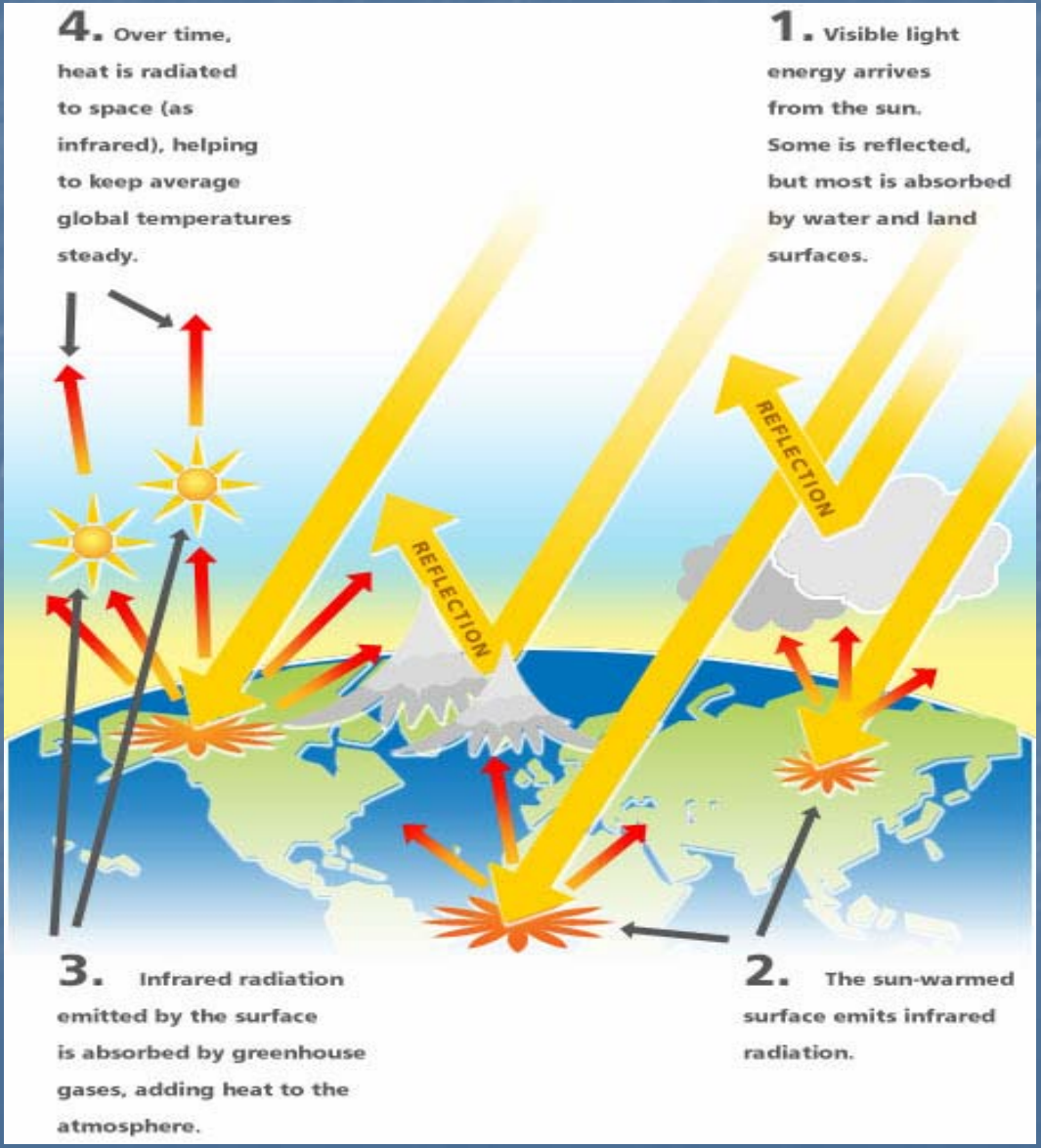
- Status quo – current response to erosion- combination of armoring, nourishment, and relocation (short term, SLR not factored in)
- "Hard engineering" hold the line shoreline protection – groins, breakwaters, seawalls, bulkheads, revetments, levees, dikes, jetties
- "Soft engineering" shoreline protection – beach and dune nourishment, sediment bypassing & back passing, beneficial reuse of sediment, Regional Sediment Management
- Strategic relocation – coastal zone plans, erosion set-backs, economic inducements, undevelopment, open space purchases, conservation easements

Global climate is changing- an observed fact, no longer theory or prediction.....

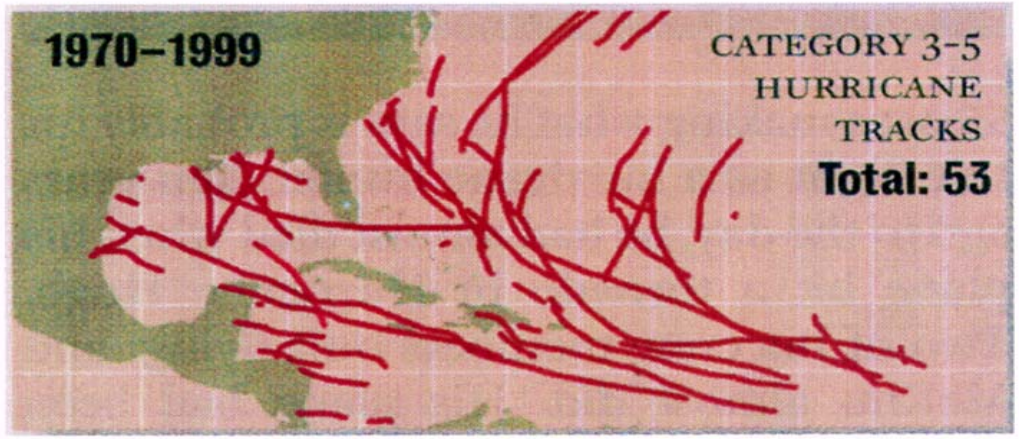
- "Changes consistent with global warming are already underway across the Northeast" (Union of Concerned Scientists, Oct 2006)
- "The scientific evidence is now overwhelming: climate change presents very serious global risks and it demands urgent global response" (Stern Review: The Economics of Climate Change, 2006)
- " Global climate change is due to human activities, current and growing threat to all nations, immediate actions needed on mitigation and adaptation measures" (UN/Sigma XI, Feb. 2007)
- President Bush Participates in Major Economies Meeting on Energy Security and Climate Change (State Dept, 28 Sept 2007)
- "The nature and pace of climate change are grave and pose grave implications for national security" (National Security and the Threat of Climate Change, CNA Corp., 2007)
- "Understanding the climate has improved since IPCC 2001, very high confidence (90%) "unequivocal" that warming is due to human activities, more intense storms, increased sea-level rise. (IPCC, FAR, 2007). NOTE: Conservative, does not fully factor in recent melting of Greenland or W. Antarctica ice sheets
- Arctic region is warming rapidly and ice is melting at faster than predicted rates. Polar bear is listed as threatened by DOI. Other Arctic animals are being considered (May 2008)

What is global warming?

- Build up of greenhouse gases:
  - carbon dioxide
  - methane
  - water vapor
  - forest reduction
- Atmosphere heat blanket enhanced
- Feed backs???

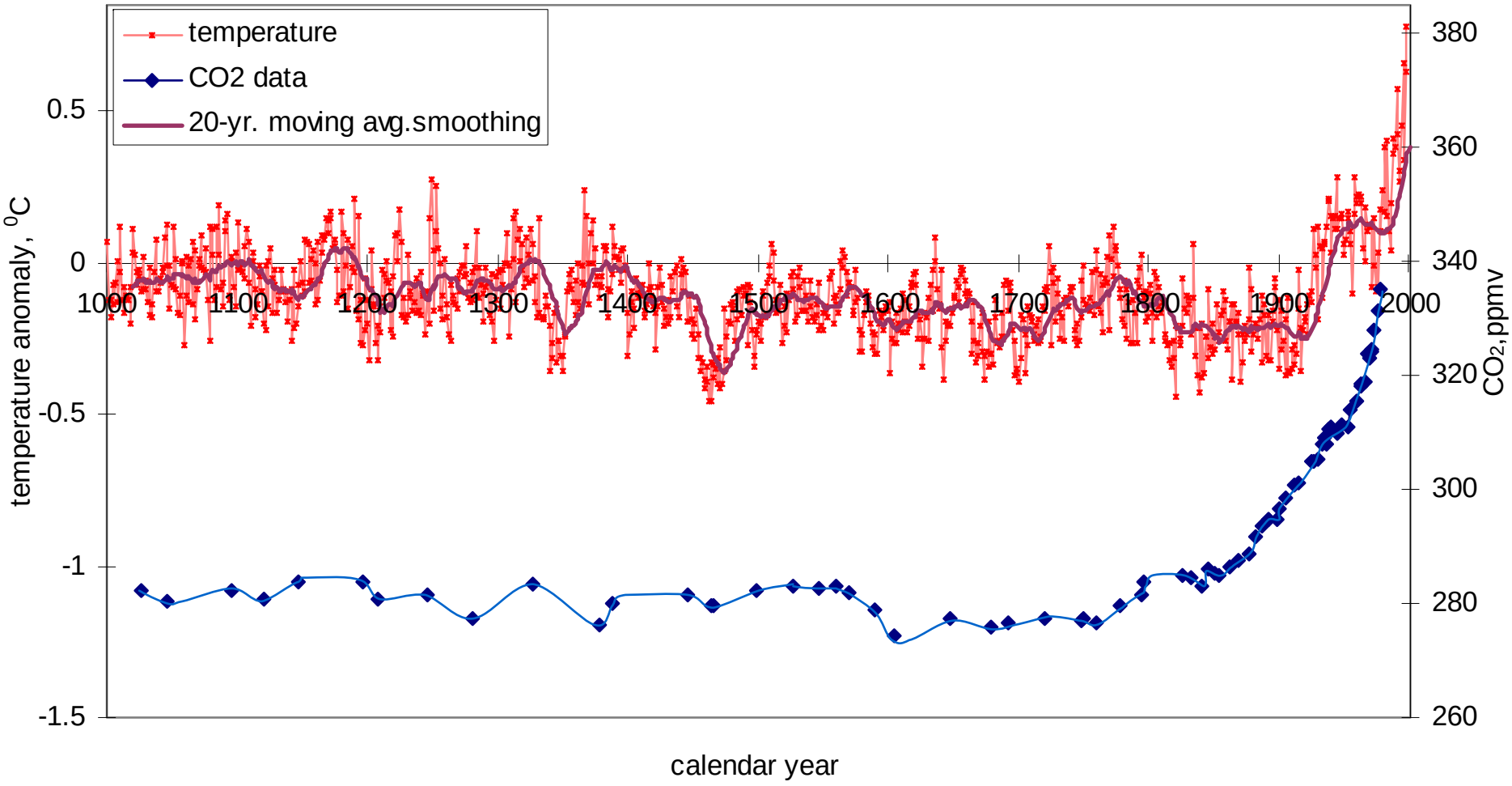


Historic Hurricane Activity

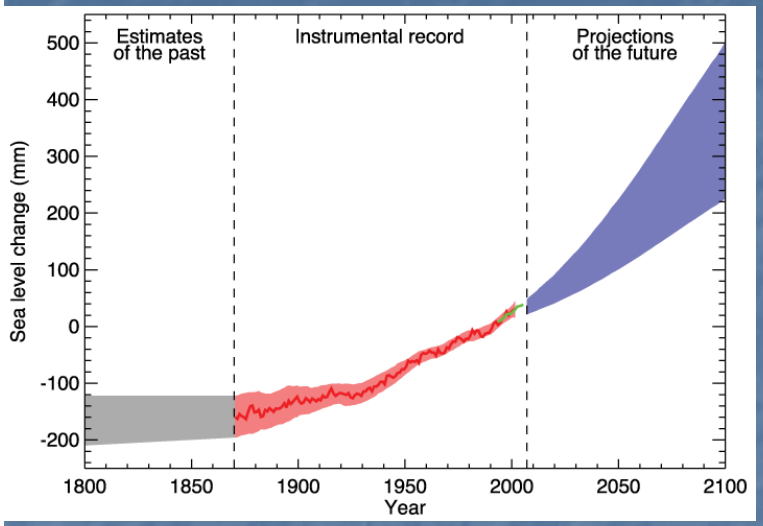


Antarctic ice core record for global temperature and CO2 over the past 1,000 years

Millenial temperature reconstruction (Mann, 1999) compared to the CO_2 data from Taylor and Law domes



Sea-Level Change: Cause and Effect



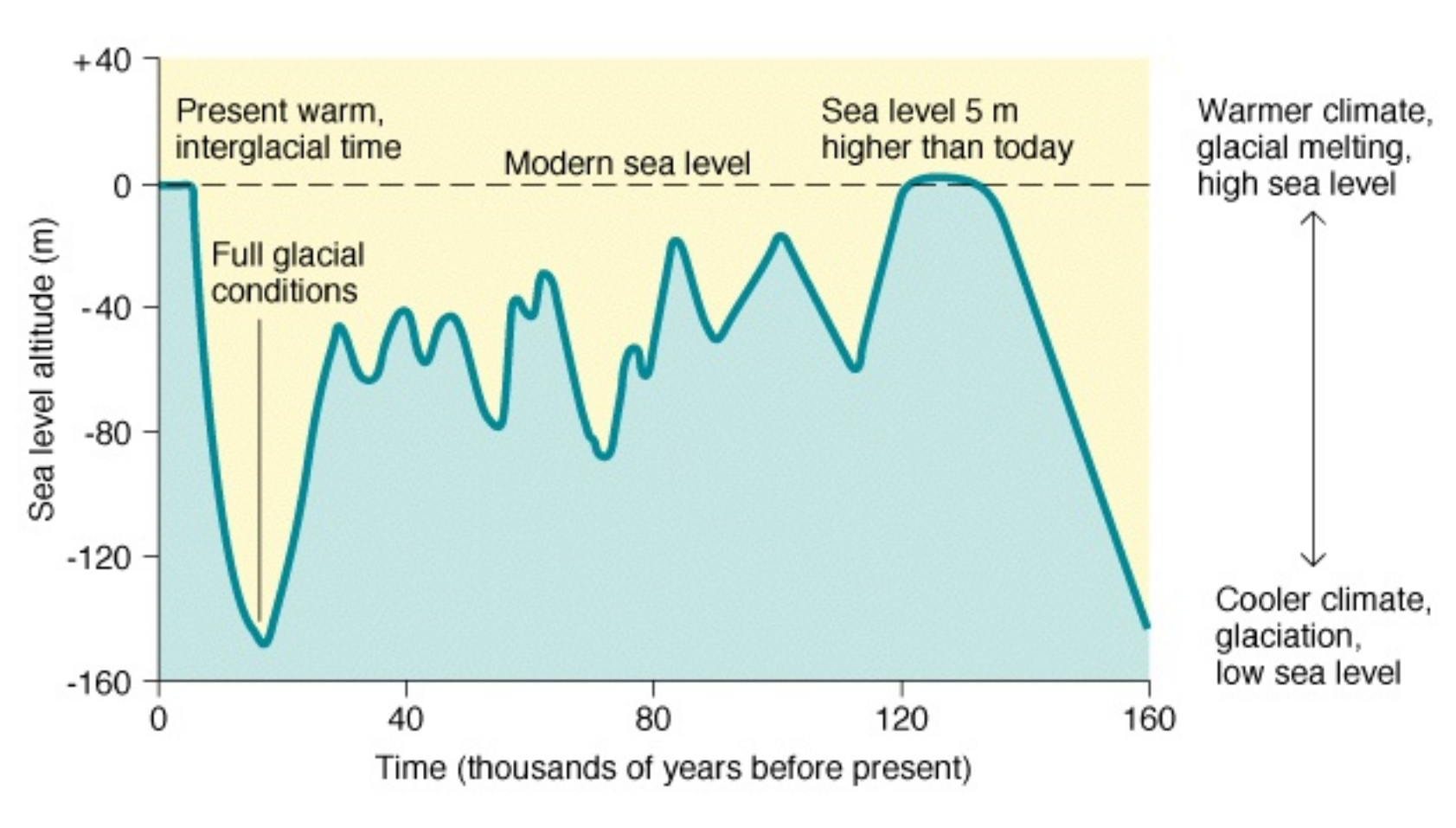
Causes of sea-level change:

- Change in volume of ocean basins (global)
- Melting or accumulation of continental ice (global)
- Thermal expansion (global)
- Subsidence or uplift (local)
- Ocean density and circulation (local)

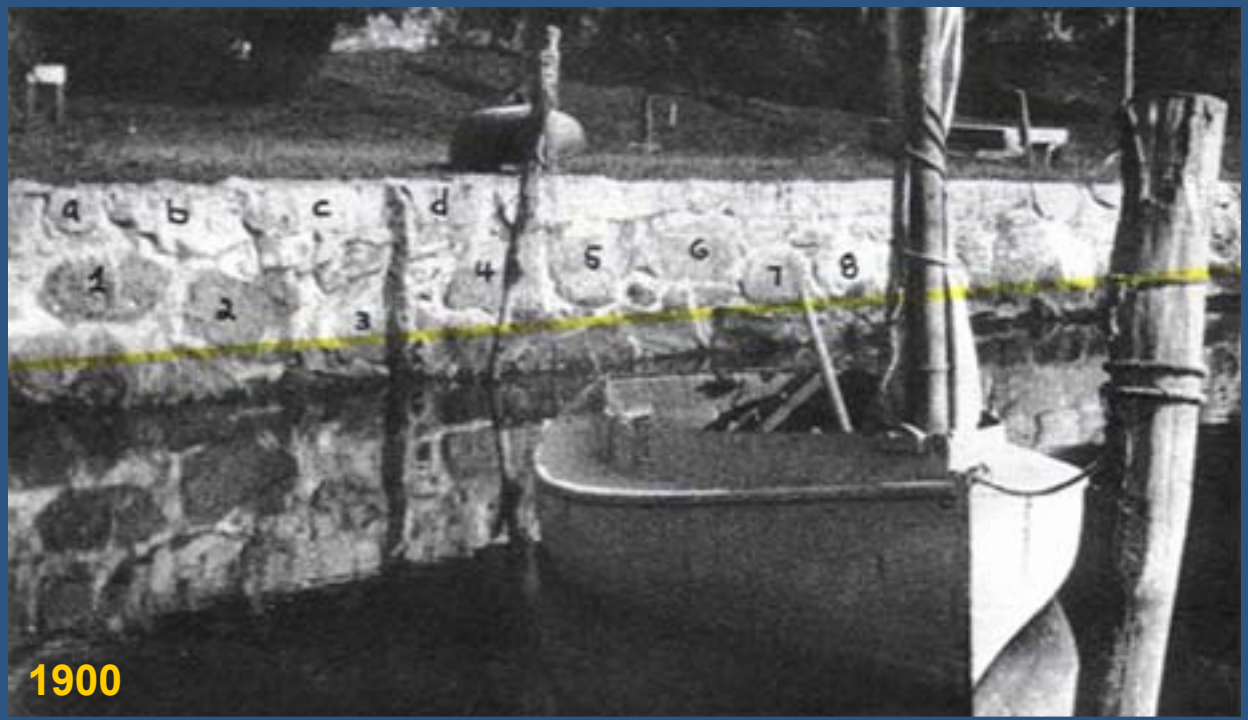
Effects of sea-level rise:

- Shoreline erosion
- Storm-surge flooding
- Saltwater intrusion into groundwater aquifers
- Inundation of wetlands and estuaries
- Risks to people, resources and infrastructure

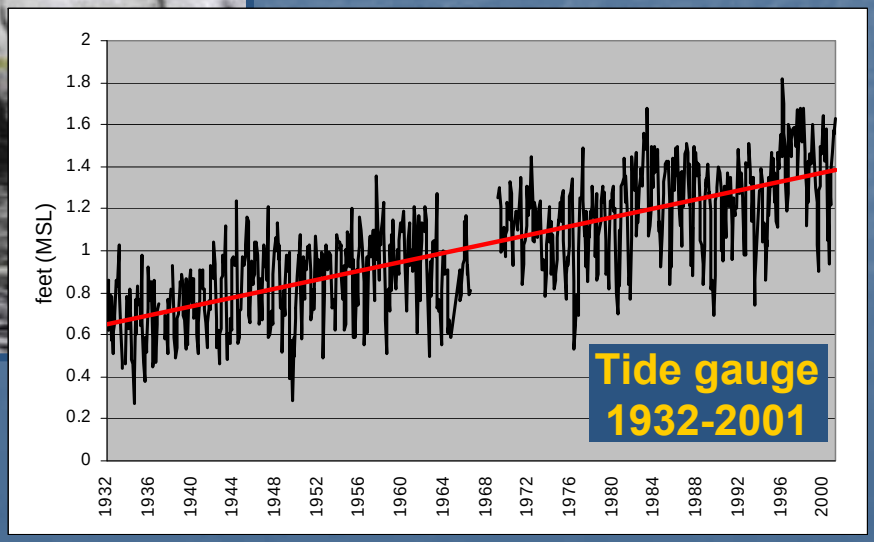
Global sea-level change over the past 160,000 years



(From Merrits et al.)

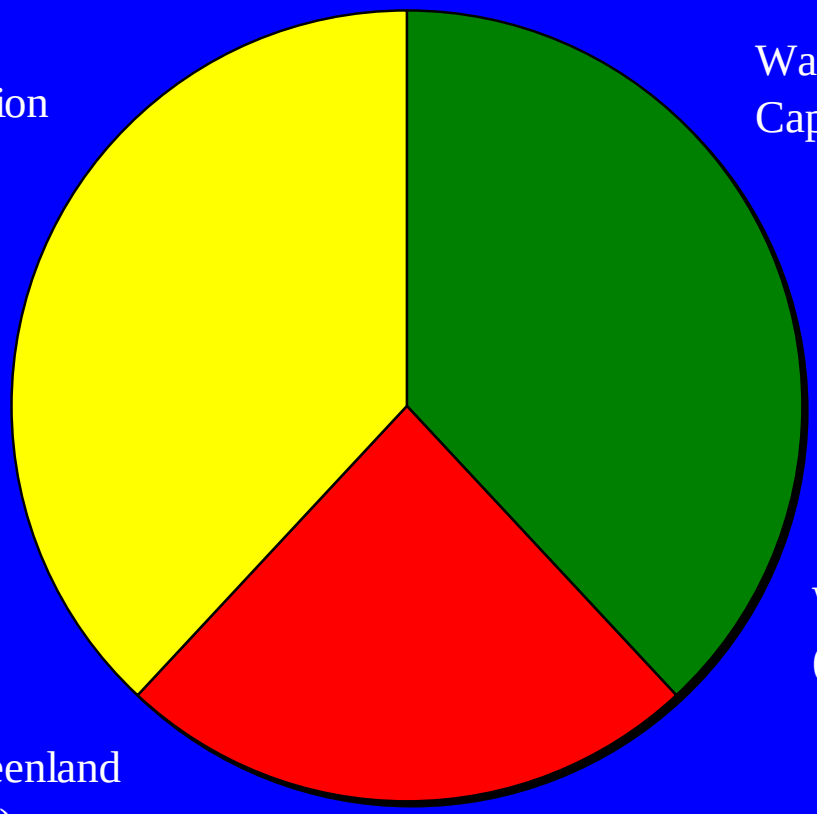


Relative sea-level rise in Woods Hole, MA has been ~30 cm (12 in) over the past century

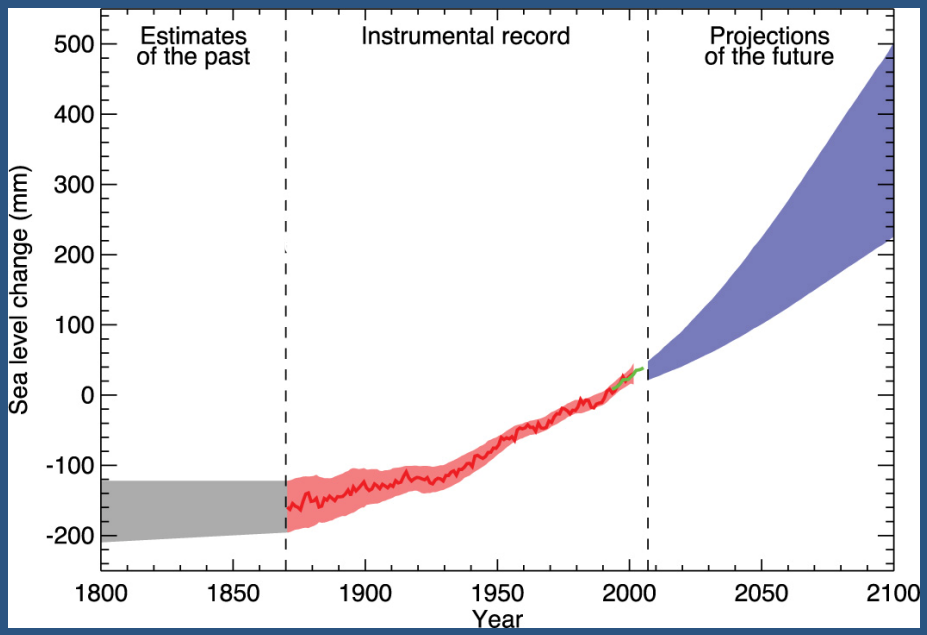


USGS
science for a changing world

Best Estimates of Climate-Related Contributions to Eustatic Sea-level Rise (12 to 15 cm) Over the Last 100 Years



Sea-level Rise Summary



Bindoff et al. (2007)

- Over previous 2000 years, global sea level has been relatively stable. There is evidence, however, of an acceleration since the mid 19th century.

- A growing number of scientists are confident that this can be linked to increase in CO2 and global temperature.

- From 1900- 1999 the of SLR based on long-term tide gauge observations was 1.7 ± 0.5 mm/yr.

- Satellite observations show that rise from 1992- 2008 was 3.4 ± 0.4 mm/yr.

- IPCC (2007) FAR model estimates suggest SLR of 0.18- 0.59 m by 2100.

- A major concern is that this estimate is conservative based on uncertainties of future ice melt from Greenland and West Antarctica

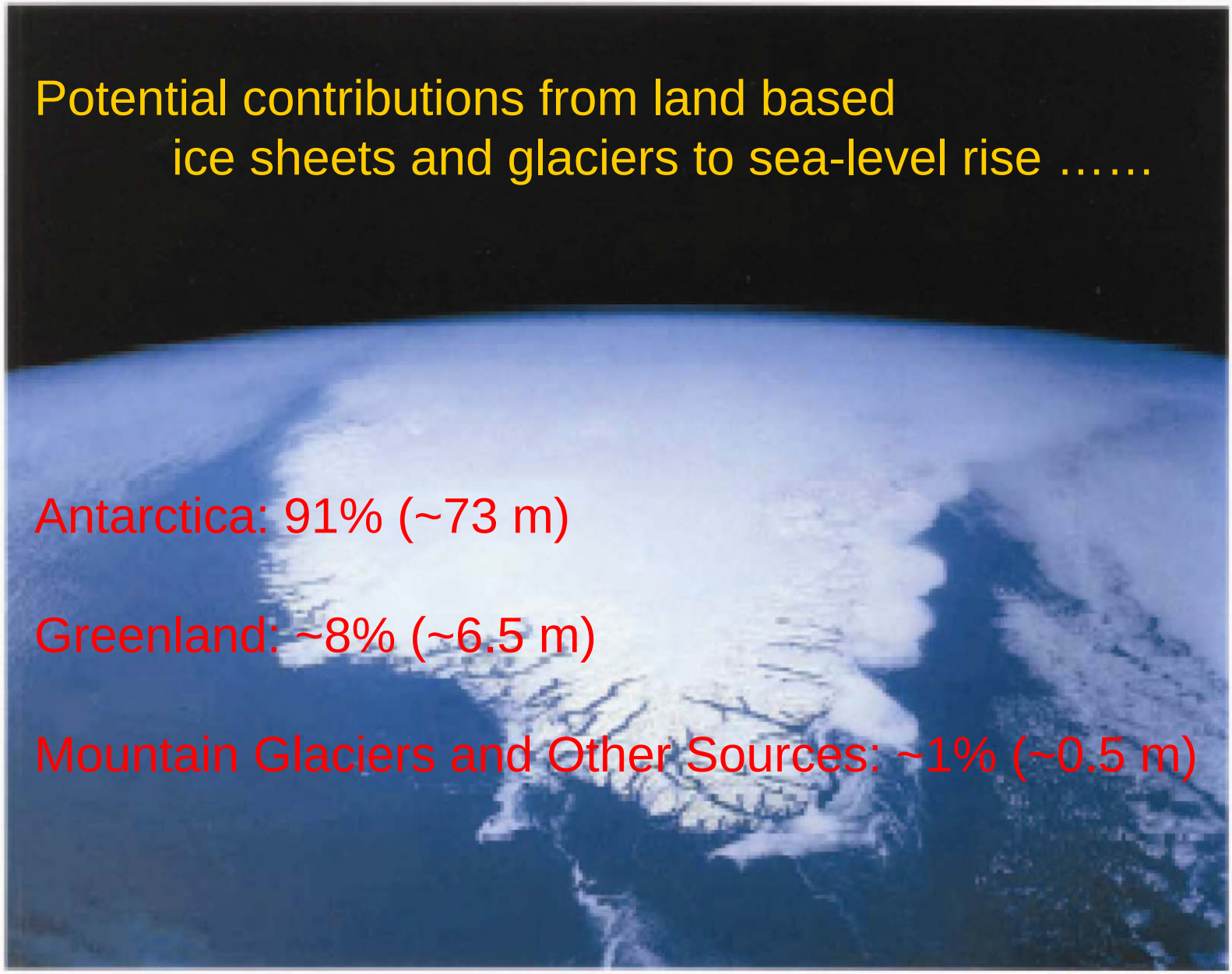
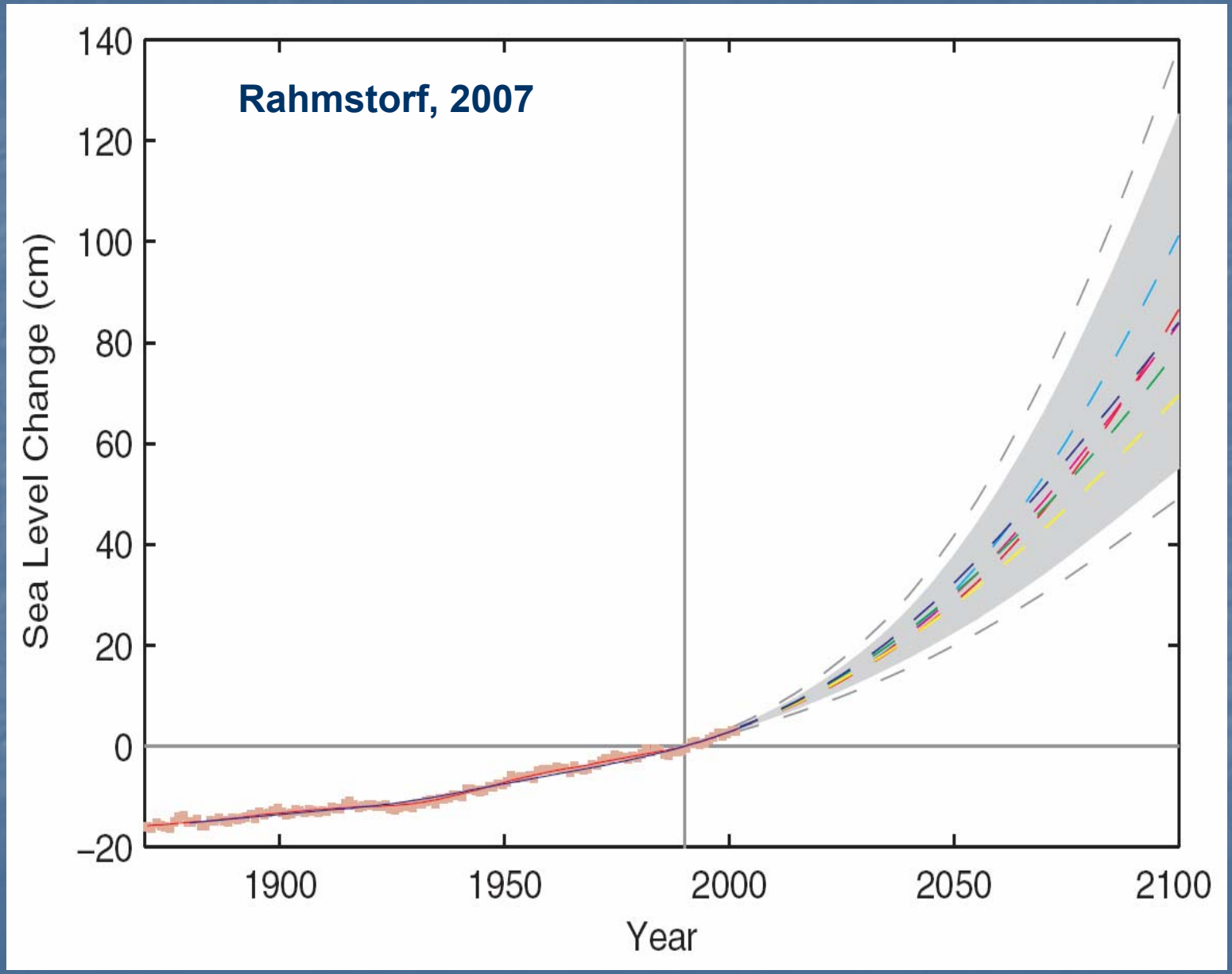


Photo: Williams and Ferrigno, 1995

Past, Current and Projected Sea-level Rise to 2100



IPCC, 2001

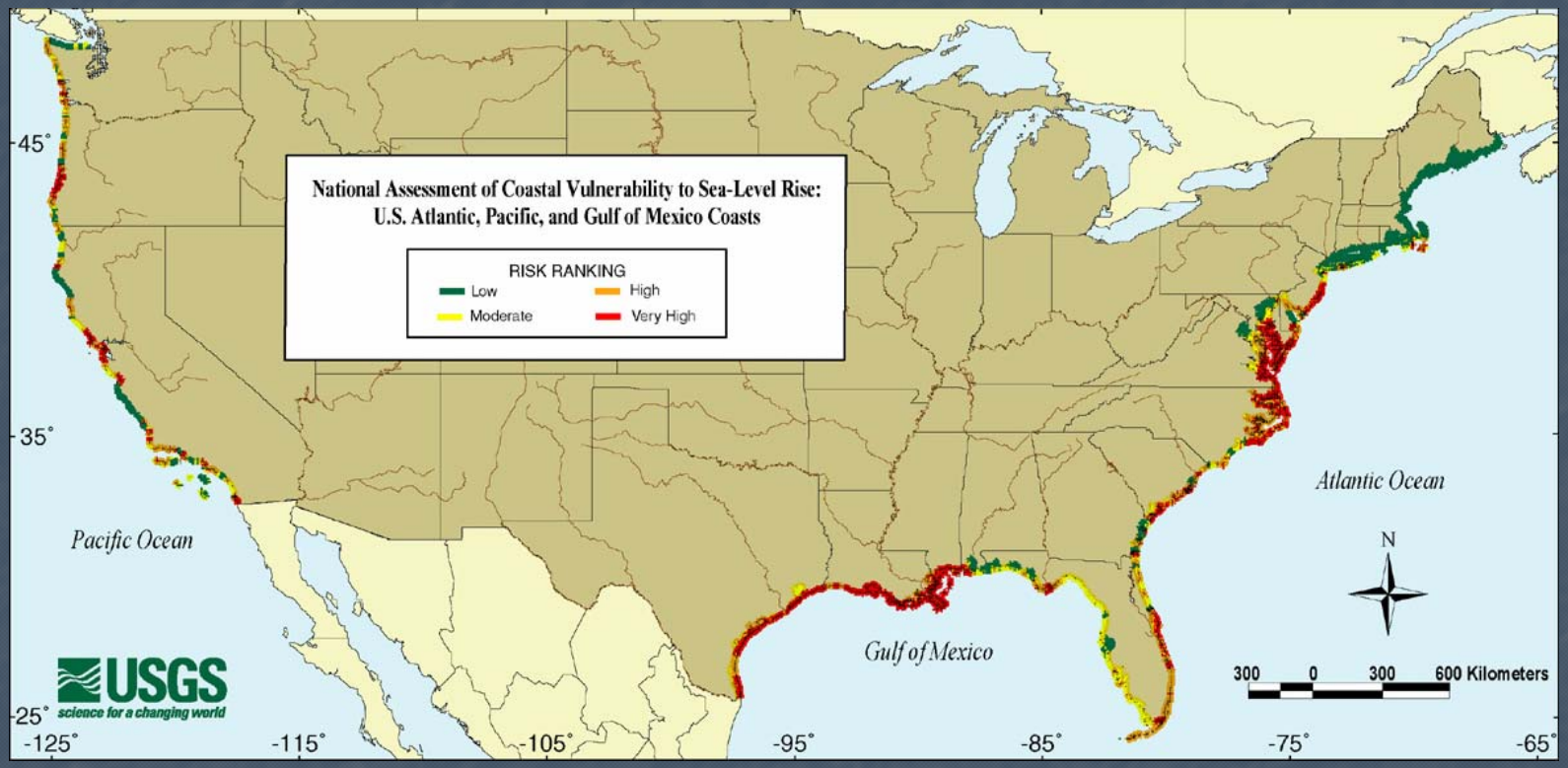
48 cm

IPCC, 2007

National Assessment of Coastal Change Hazards

- ❑ **Long-term change: shoreline & cliffs**
- ❑ **Extreme storms: vulnerability & forecasting**
- ❑ **Sea-level rise: vulnerability**

Coastal Vulnerability Index



National Assessment of Coastal Vulnerability to Sea-Level Rise

E. Robert Thieler, S. Jeffress Williams, Erika Hammar-Klose

http://woodshole.er.usgs.gov/project-pages/nps-cvi/
http://pubs.er.usgs.gov/

Coastal Vulnerability Index Methodology

VARIABLES	SOURCE
GEOMORPHOLOGY	Aerial Photography from MassGIS and USGS http://edcwww.cr.usgs.gov/ http://www.state.ma.us/mgis/
SHORELINE EROSION/ACCRETION (m/yr)	USGS Administrative Report: The Massachusetts Shoreline Change Project: 1800s -1994 (Thieler et al., 2001) http://www.state.ma.us/czm/shorelinechange.htm
COASTAL SLOPE (%)	NGDC Coastal Relief Model Vol 01 12/17/1998 http://www.ngdc.noaa.gov/mgg/
RELATIVE SEA-LEVEL CHANGE (mm/yr)	NOAA Technical Report NOS CO-OPS 36 SEA LEVEL VARIATIONS OF THE UNITED STATES 1854-1999 (Zervas, 2001) http://www.co-ops.nos.noaa.gov/publications/techrpt36doc.pdf
MEAN SIGNIFICANT WAVE HEIGHT (m)	North Atlantic Region WIS Data (Phase II) and NOAA National Data Buoy Center http://bigfoot.wes.army.mil/u003.html http://seaboard.ndbc.noaa.gov/
MEAN TIDE RANGE (m)	NOAA/NOS CO-OPS Historical Water Level Station Index http://www.co-ops.nos.noaa.gov/station_index.shtml?state

VARIABLES	VERY LOW	LOW	MODERATE	HIGH	VERY HIGH
	1	2	3	4	5
GEOMORPHOLOGY	Rocky, cliffed coasts Fjords	Medium cliffs Indented coasts	Low cliffs Glacial drift Alluvial plains	Cobble Beaches Estuary Lagoon	Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mangroves, Coral reefs
SHORELINE EROSION/ACCRETION (m/yr)	> 2.0	1.0 - 2.0	-1.0 - 1.0	-2.0 - -1.0	< -2.0
COASTAL SLOPE (%)	> 1.20 >1.90	1.20 - 0.90 1.90 -1.30	0.90 - 0.60 1.30 - 0.90	0.60 - 0.30 0.90 - 0.60	< 0.30 <0.60
RELATIVE SEA-LEVEL CHANGE (mm/yr)	< 1.8	1.8 - 2.5	2.5 - 3.0	3.0 - 3.4	> 3.4
MEAN WAVE HEIGHT (m)	< 0.55 < 1.10	0.55 - 0.85 1.1 - 2.0	0.85 - 1.05 2.0 -2.25	1.05 - 1.25 2.25 - 2.60	> 1.25 > 2.60
MEAN TIDE RANGE (m)	> 6.0	4.0 - 6.0	2.0 - 4.0	1.0 - 2.0	< 1.0

Utilize existing data for six geological and physical process variables:

a) Geomorphology
b) Historic shoreline change
c) Coastal Slope
d) Relative sea-level rise rate
e) Mean sig. wave height
f) Mean tidal range

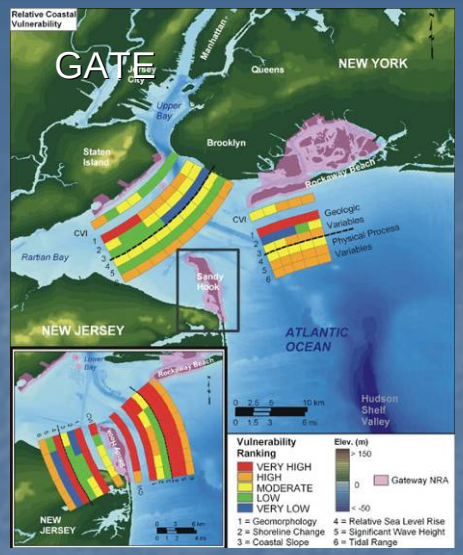
Data are scored using a simple ranking system, so that the variables can be expressed in a quantifiable manner.

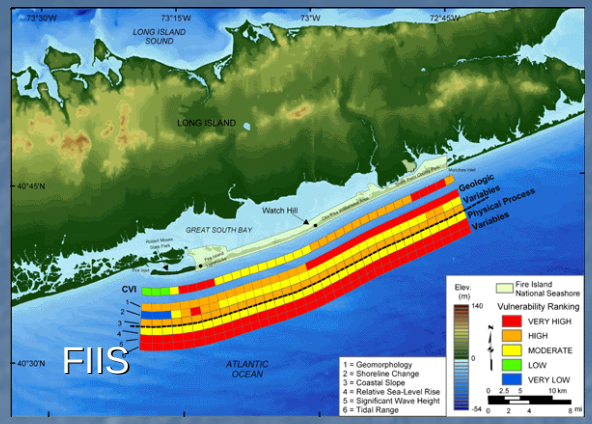
Once the data are complete in a GIS, an equation can be applied to calculate the CVI.

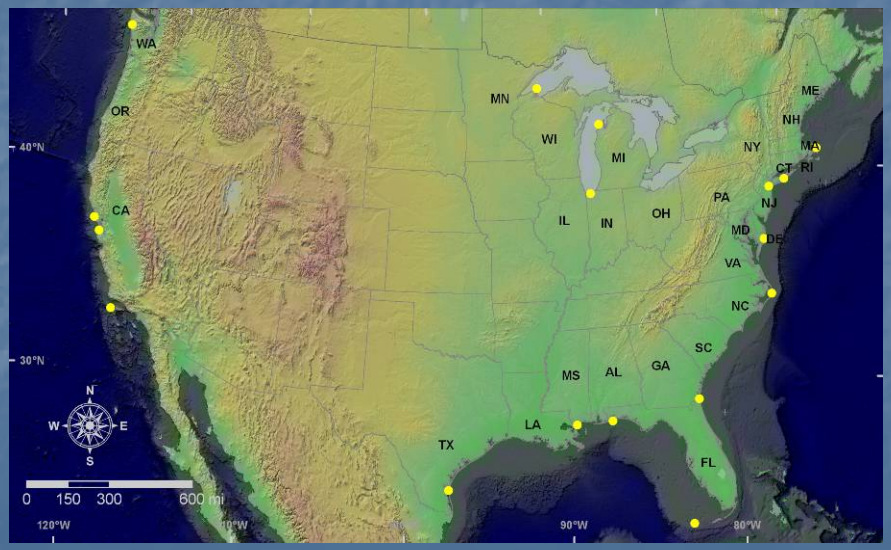
$$CVI = \sqrt{\frac{(a \times b \times c \times d \times e \times f)}{6}}$$

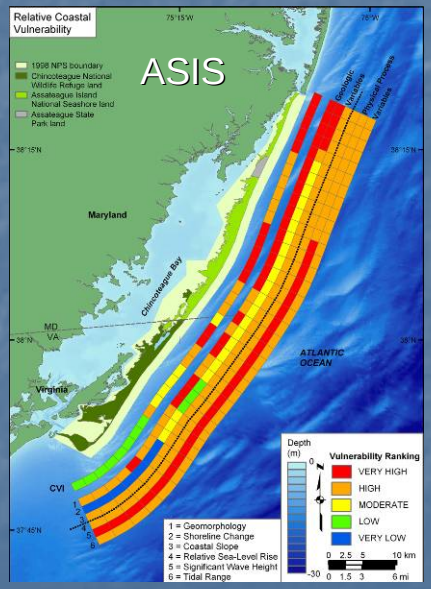
USGS-NPS CVI Project

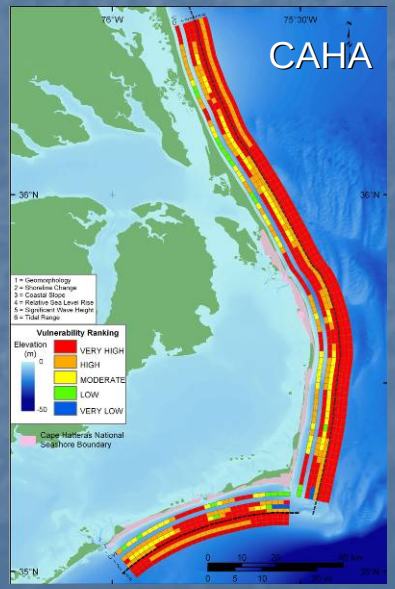
- Applied to 22 NPS units in U.S. and abroad
- Higher-resolution than national study (~1.5 km coastal cell)
- Used by NPS managers and planners





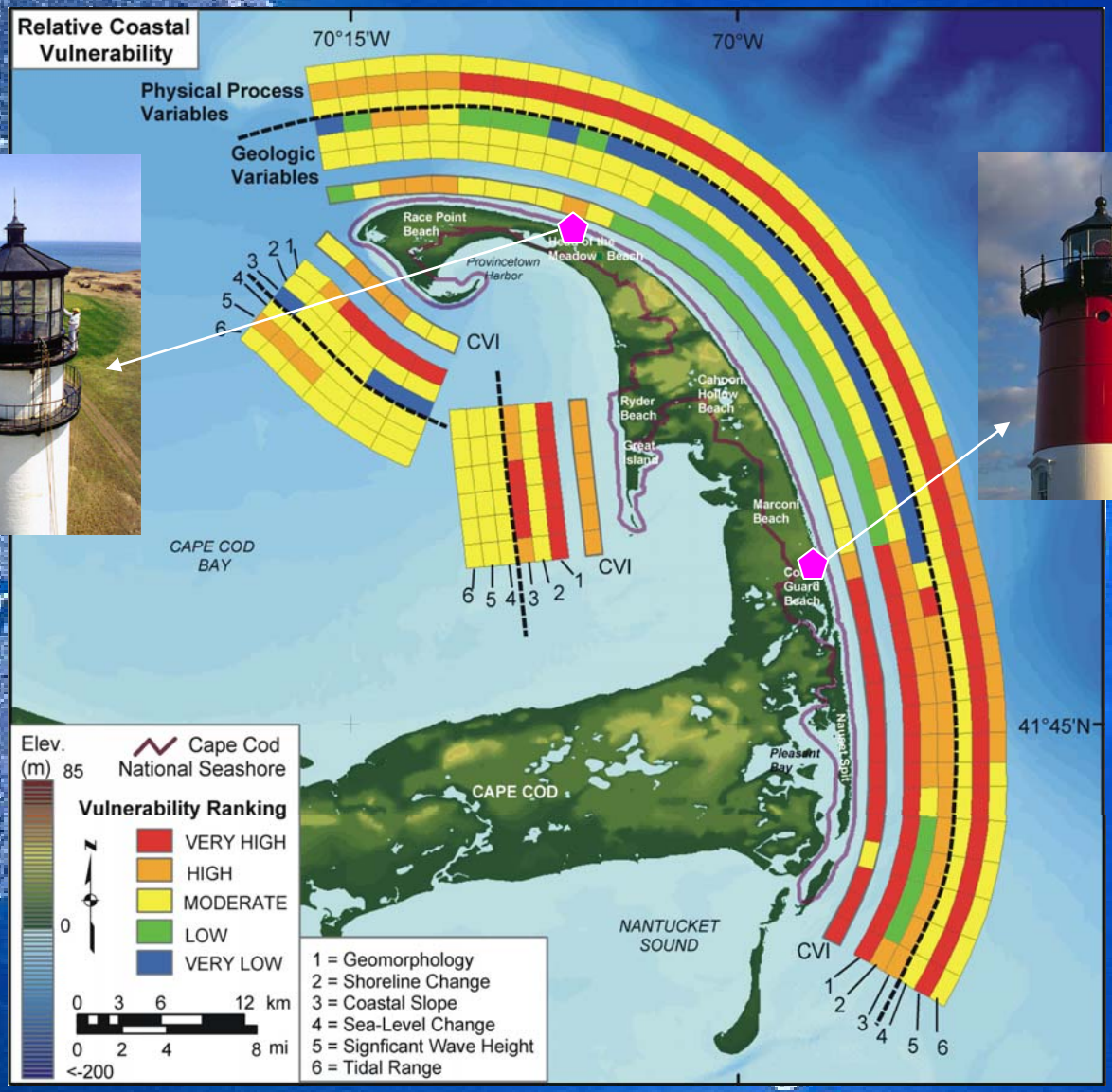






Pendleton et al. (2004- 2007)

CVI Assessment for CACO



1996 location

1996 location

U.S. Climate Change Science Program

Synthesis and Assessment Product 4.1
"Coastal Elevation and Sensitivity to Sea-level Rise: A Focus on the mid-Atlantic Region"
(Leads: EPA, USGS, NOAA)

Topics:

1. Sea-level rise, state-of-the-science, knowledge gaps

2. Factors that influence shoreline change

3. Methods of predicting future shoreline change

4. Science plan for future research on predicting SLR effects

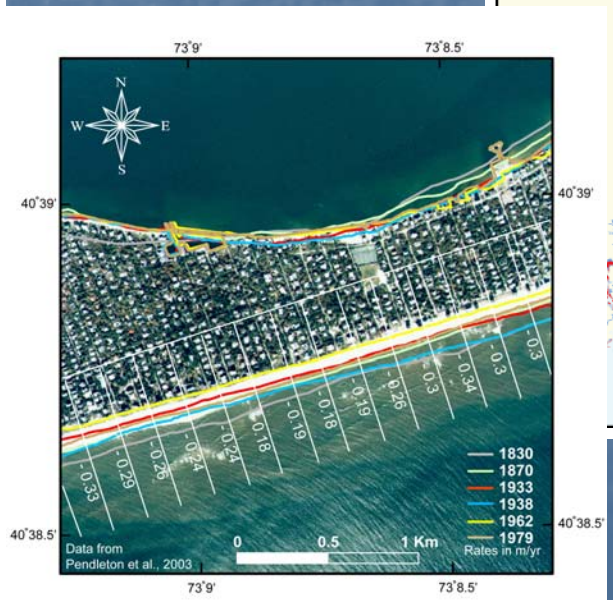
Q-2 Assessing Potential Coastal Changes Due to SLR

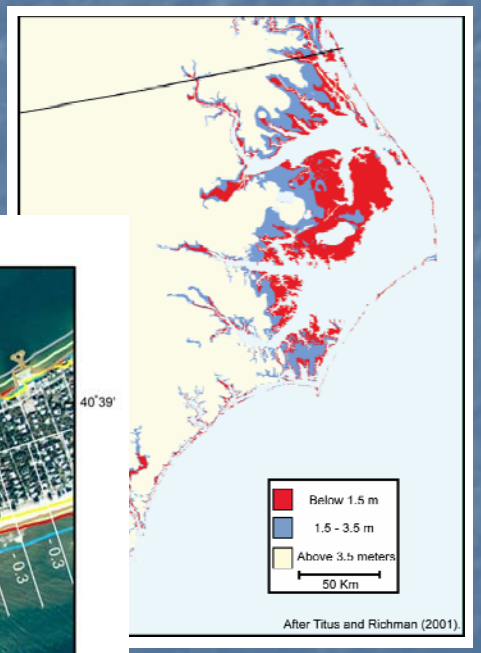
- Focus on ocean coasts, NY to NC
  - Describe present physical setting
  - Current understanding of important physical processes
  - Potential impacts of future SLR (0.3 m, 0.5 m, 1 m, 2 m)
- Review and test models for predicting shoreline/coastal change
  - Erosion-rate extrapolation
  - Bruun Rule
  - Inundation potential
  - Index-ranking based on physical/geological criteria
  - Geometry-based models
- Review guides research plan development

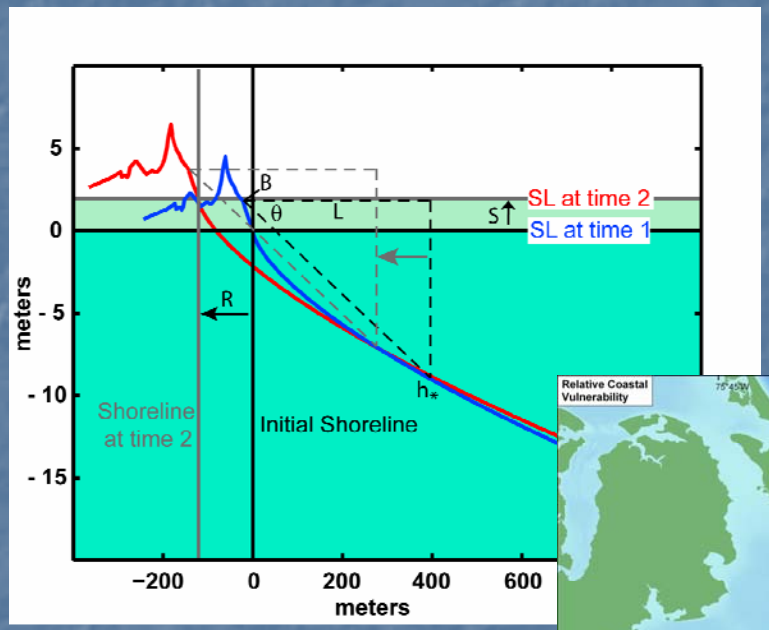
Challenges in predicting coastal change…….

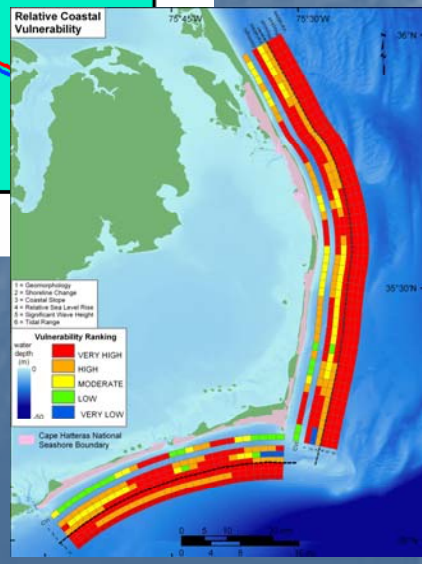
There are a range of techniques that have been developed to model the shoreline response to sea-level rise.

These are debated in scientific community, but no firm consensus on an approach.

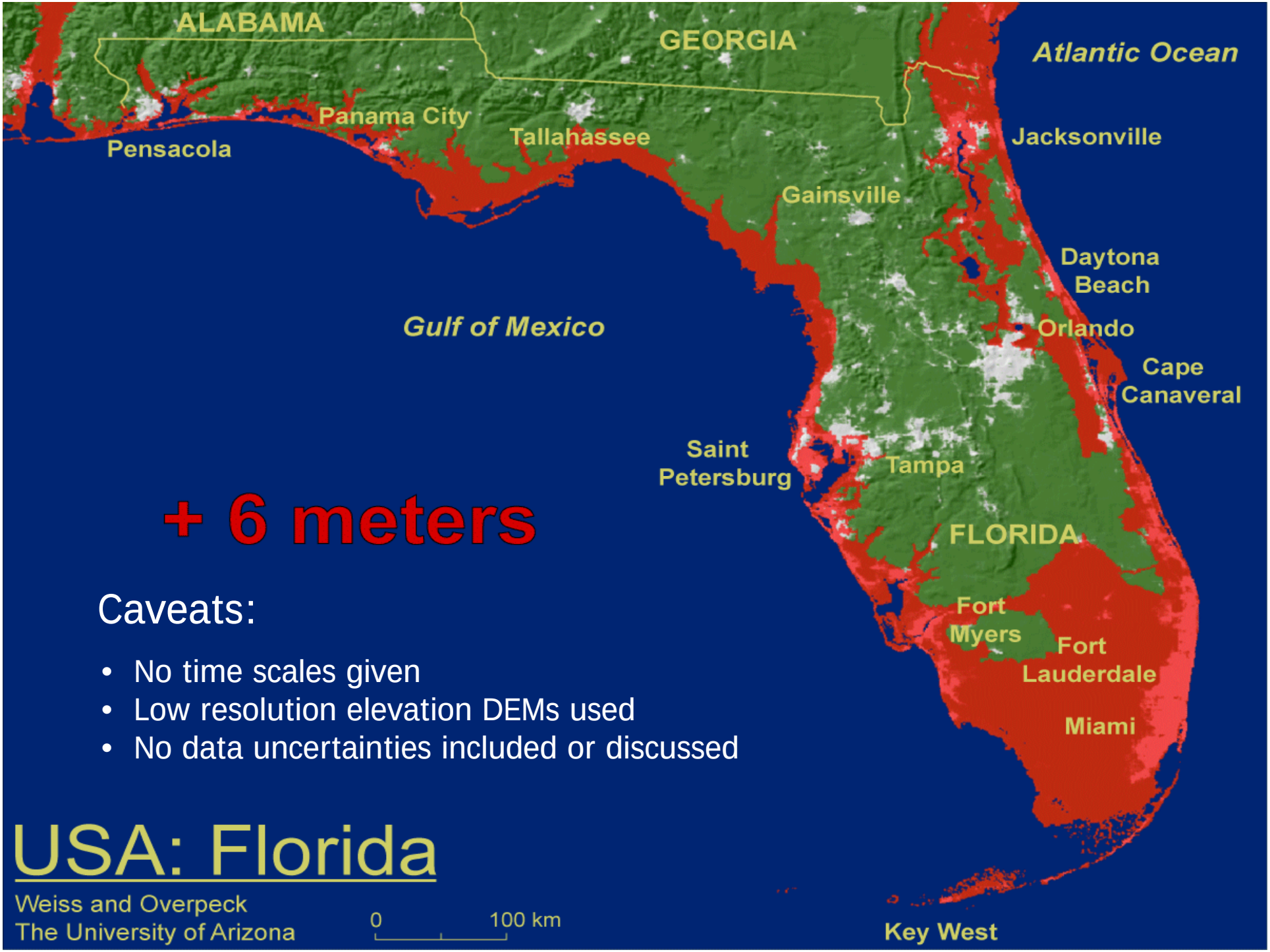








- Erosion rate extrapolation
- Inundation potential
- Bruun Rule
- Coastal Vulnerability Index



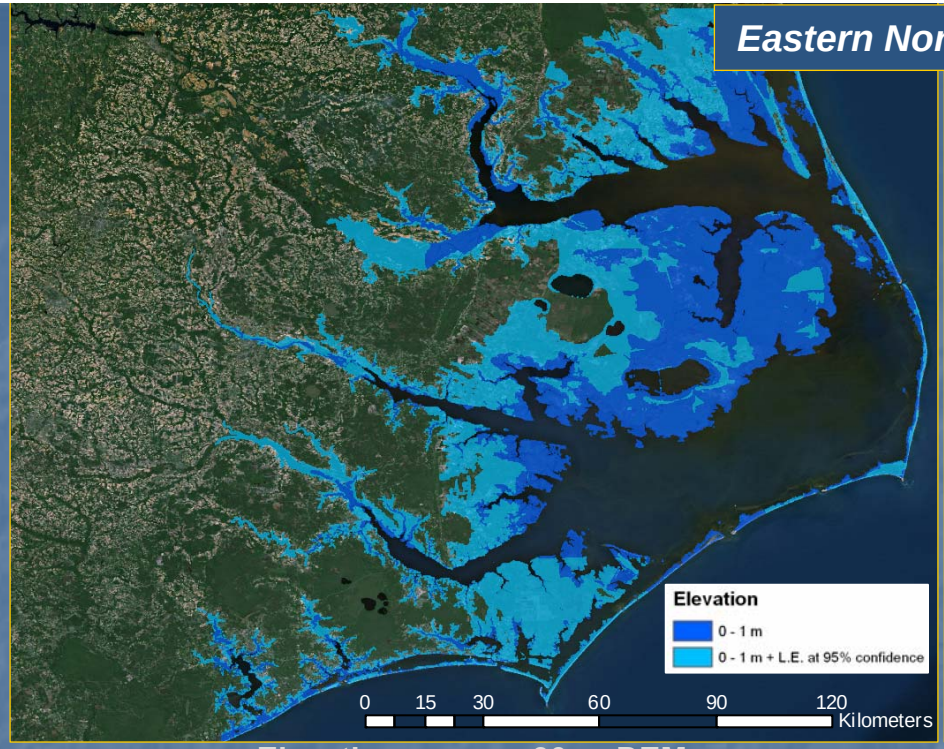
Caveats:

- No time scales given
- Low resolution elevation DEMs used
- No data uncertainties included or discussed

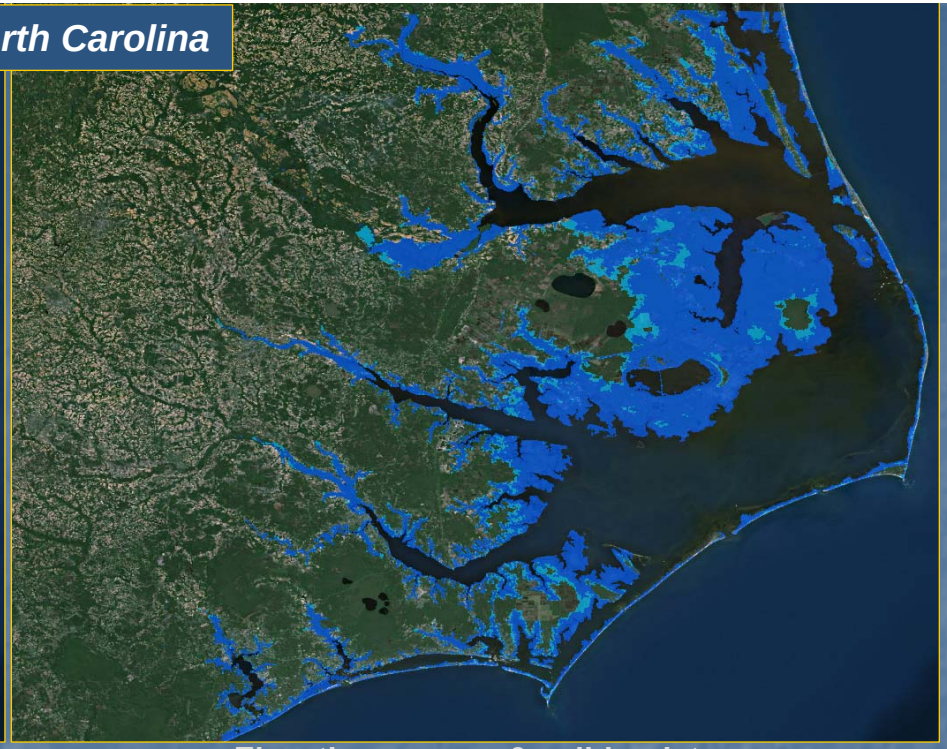
USA: Florida

Weiss and Overpeck
The University of Arizona

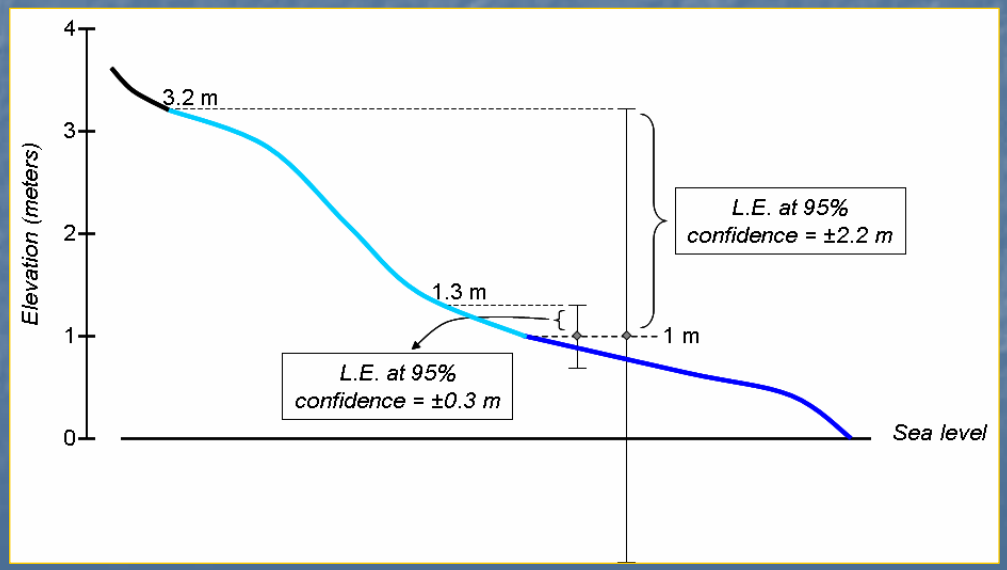
Eastern North Carolina



Elevation source: 30-m DEM



Elevation source: 3-m lidar data



Dark blue: Land ≤ 1 meter in elevation

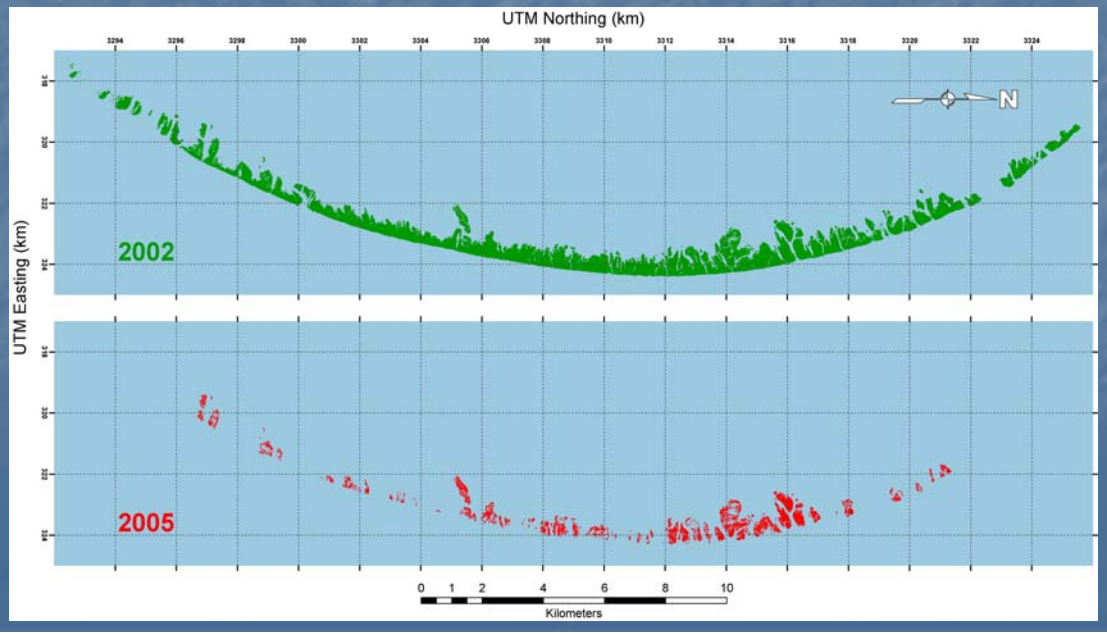
Light blue: Area of uncertainty associated with 1 meter elevation

(Gesch, JCR in press)

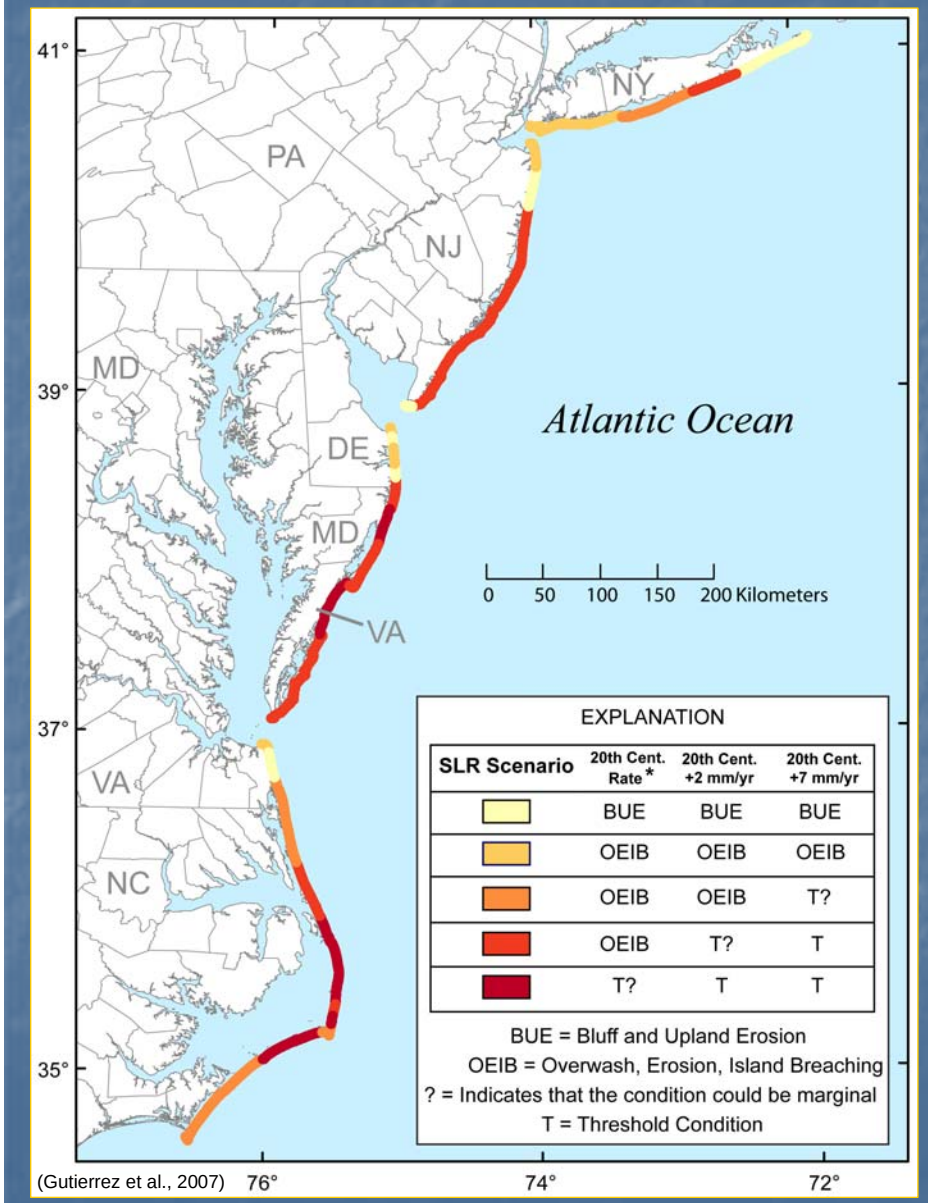
Concern: non-linear behavior, "thresholds" of stability of coastal landforms may be crossed due to SLR, storms

- Increased barrier migration, erosion on ocean and bay side, island narrowing, berm/dune lowering, breaching and island segmentation
- Increasing evidence that SLR from 2000 to 100 yr BP was modest
- Acceleration began at end of 19th century, rates doubled since 1990s
- Consequences may be dire for U.S. barrier islands, spits, and wetlands
- Barriers are ~50% of U.S. coast; ~90% of mid-Atlantic region

Chandeleur Islands extreme coastal change... 85% land loss from Hurricane Katrina; erosion continues, modest recovery to date.....



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



(Gutierrez et al., 2007)

Bluff erosion

Overwash

Island Breaching

Threshold Crossing

Conclusions

- Humans are altering global climate. Climate is becoming more variable, less predictable, warmer. Changes likely: sea-level rise; more flooding; more erosion; uneven rainfall/evaporation patterns.
- Sea-level rise is a primary driver of coastal change and is rising. Future SLR rates and magnitude of erosion and flooding will increase.
- Oceans are warming, SLR is accelerating due to thermal expansion and increased melting of glaciers and ice sheets. Future sea level is likely 0.5- 1m higher by AD 2100 .
- Warming ocean temps are likely to increase hurricane intensity in addition to a natural 25 yr cycle of storm activity. Effects on hurricane frequency are still uncertain.

Solutions

- Mitigation and Adaptation- cut carbon use by adopting new technologies; conservation; improve science and monitoring; reduce uncertainty; more science in coastal planning; reduce global population.

USGS