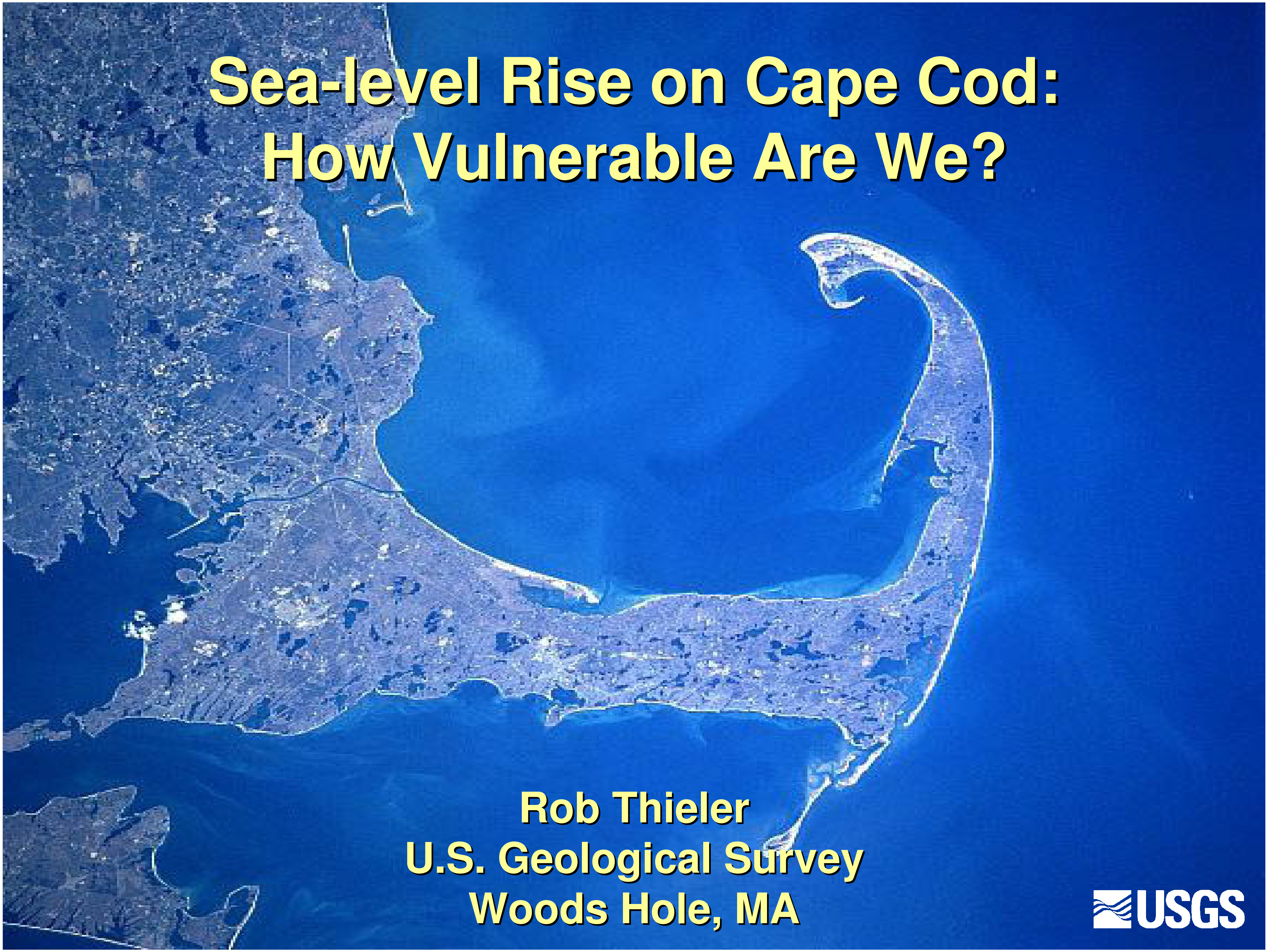
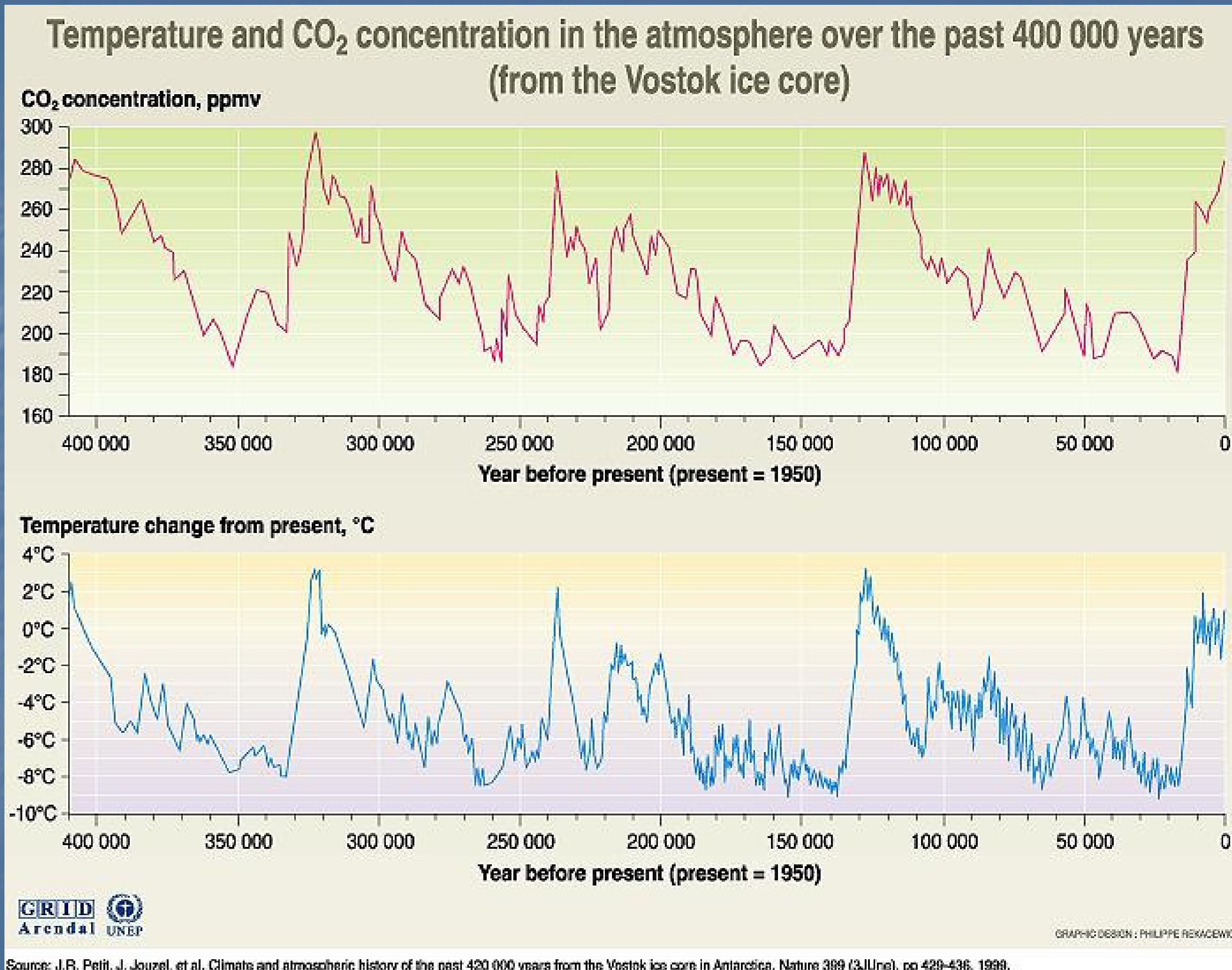
Sea-level Rise on Cape Cod: How Vulnerable Are We?



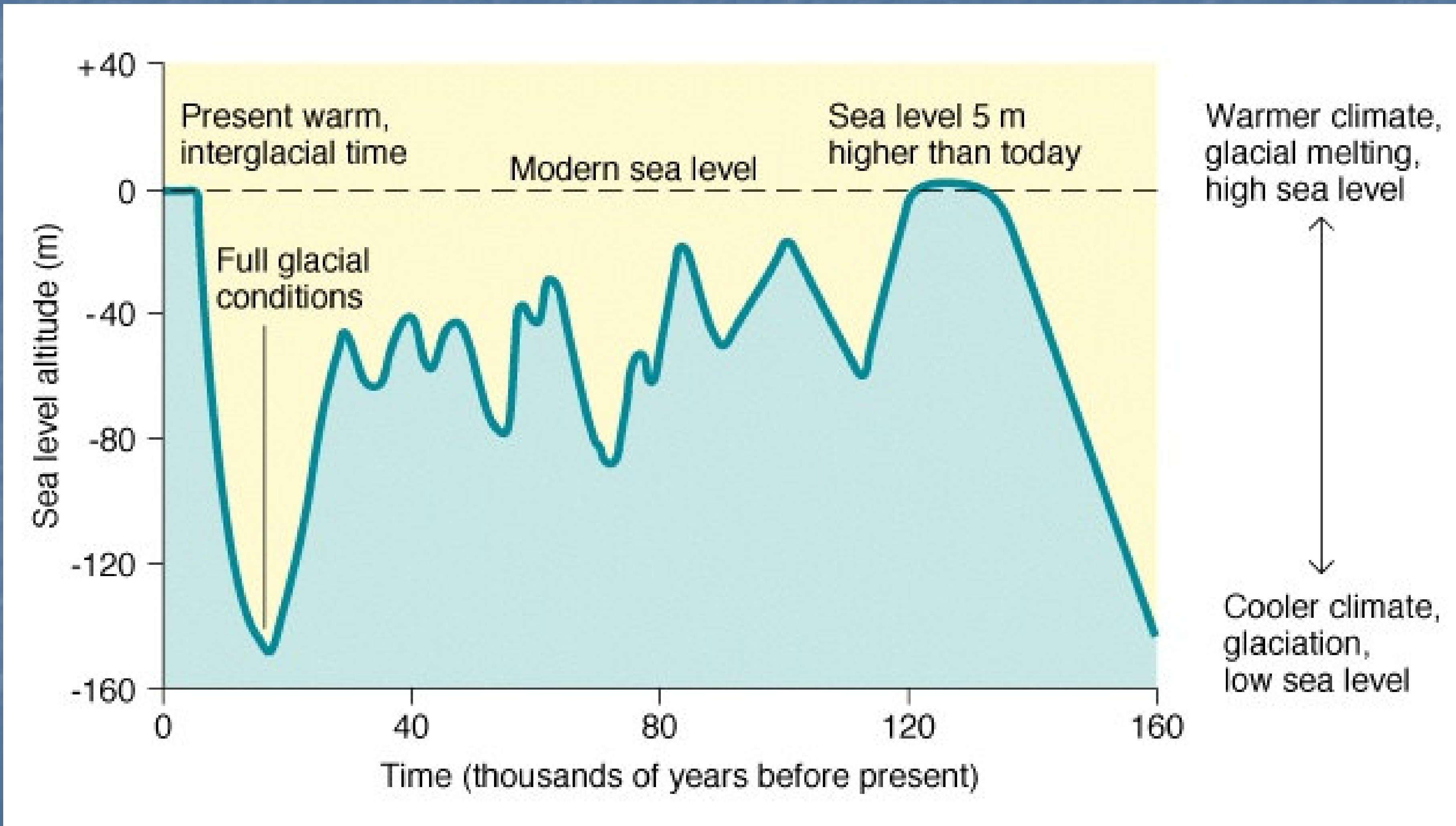
Rob Thieler
U.S. Geological Survey
Woods Hole, MA

Outline

- Sea-level and coastal processes
  - Past sea-level change
  - Predictions for the future
  - Coastal responses
- Assessing coastal vulnerability
  - The U.S., mid-Atlantic, and Cape Cod
  - Cape Cod National Seashore
- Coastal change and potential adaptation in Falmouth


Temperature and CO_2 concentration in the atmosphere over the past 400 000 years
(from the Vostok ice core)
CO_2 concentration, ppmv
300
280
260
240
220
200
180
160
400 000
350 000
300 000
250 000
200 000
150 000
100 000
50 000
0
Year before present (present = 1950)
Temperature change from present, °C
4°C
2°C
0°C
-2°C
-4°C
-6°C
-8°C
-10°C
400 000
350 000
300 000
250 000
200 000
150 000
100 000
50 000
0
Year before present (present = 1950)
GRID Arendal
UNEP
GRAPHIC DESIGN : PHILIPPE REKACEWICZ
Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3JUne), pp 429-436, 1999.

Global Sea-level Change Over the Past 160,000 Years

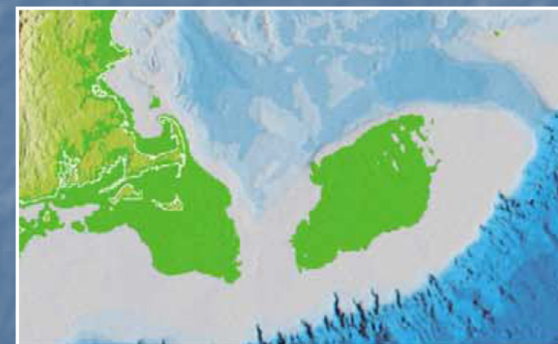


(Merritts et al., 1998)

Sea-level Rise on Cape Cod
12,000 yr BP to Present

12,000 yr BP

11,000 yr BP



10,000 yr BP

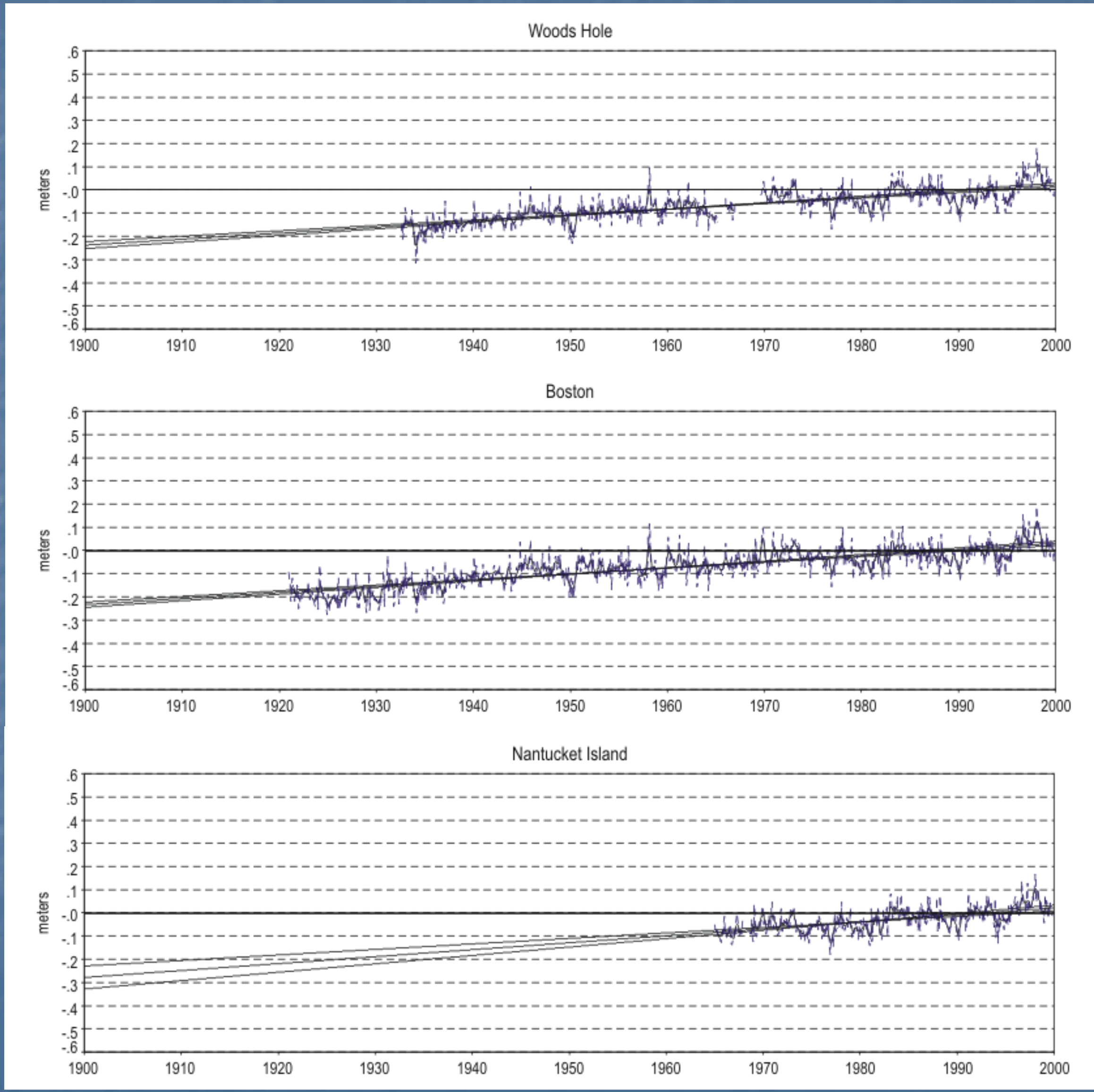
8,000 yr BP

6,000 yr BP

Present

(Shaw et al., 2002)

Regional Sea-level Trends



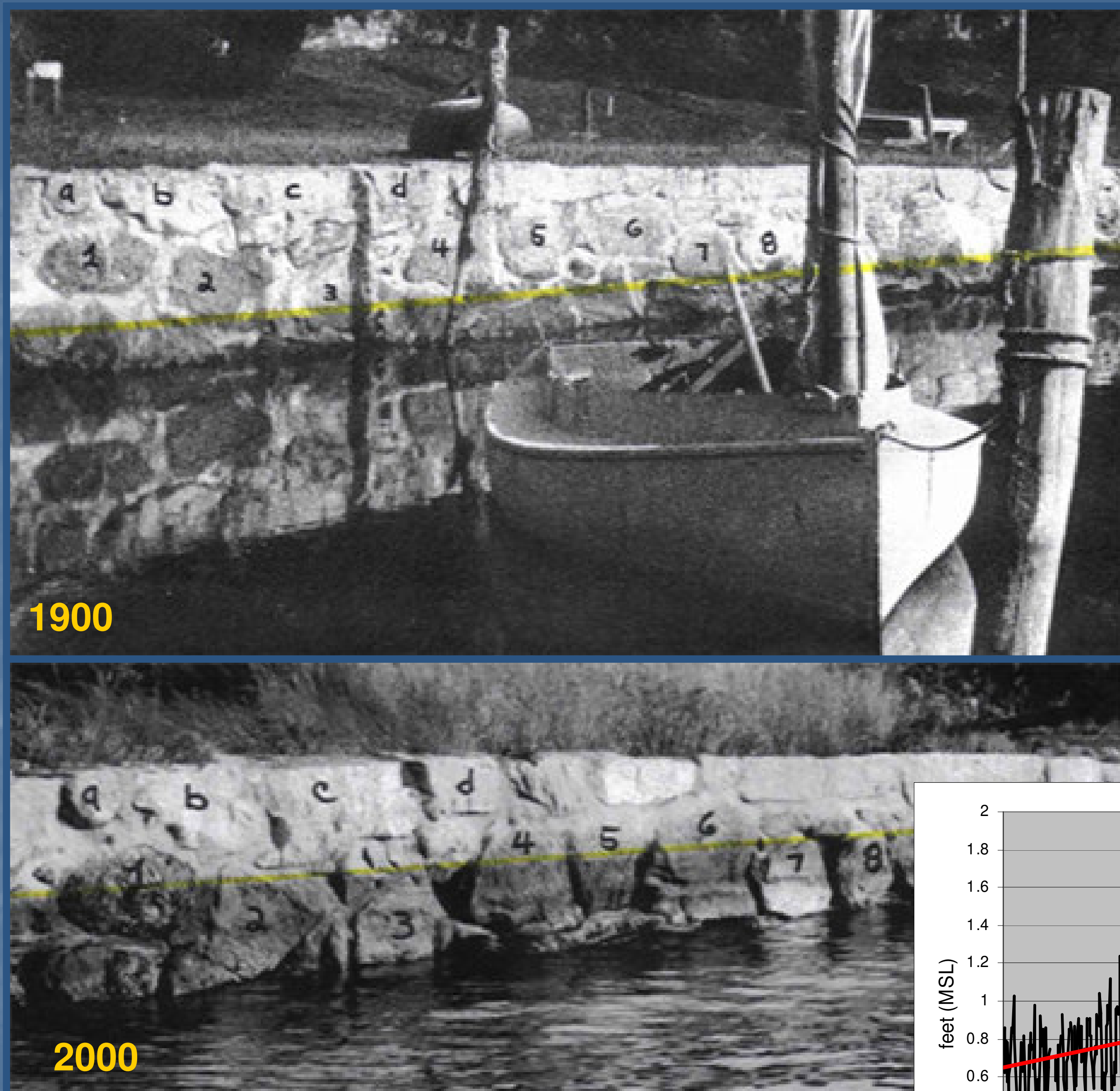
2.59 ± 0.12 mm/yr
(0.85 ft/century)

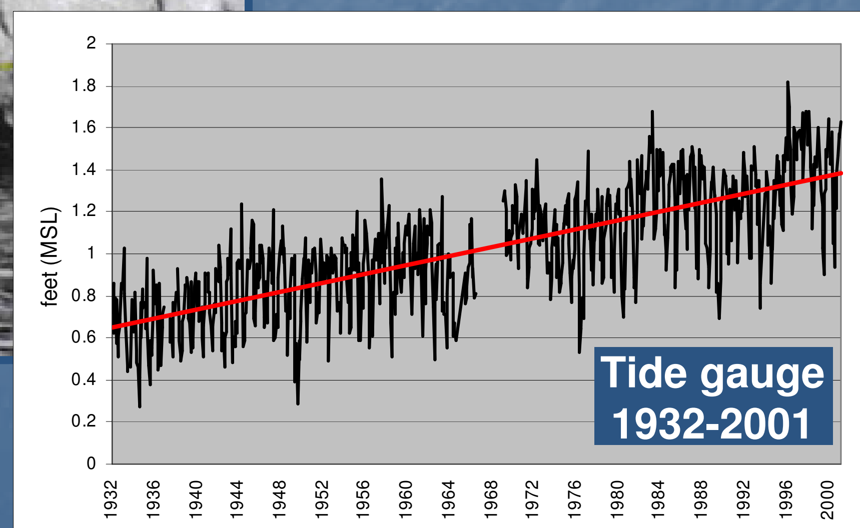
2.65 ± 0.1 mm/yr
(0.87 ft/century)

3.0 ± 0.32 mm/yr
(0.98 ft/century)

(NOAA)

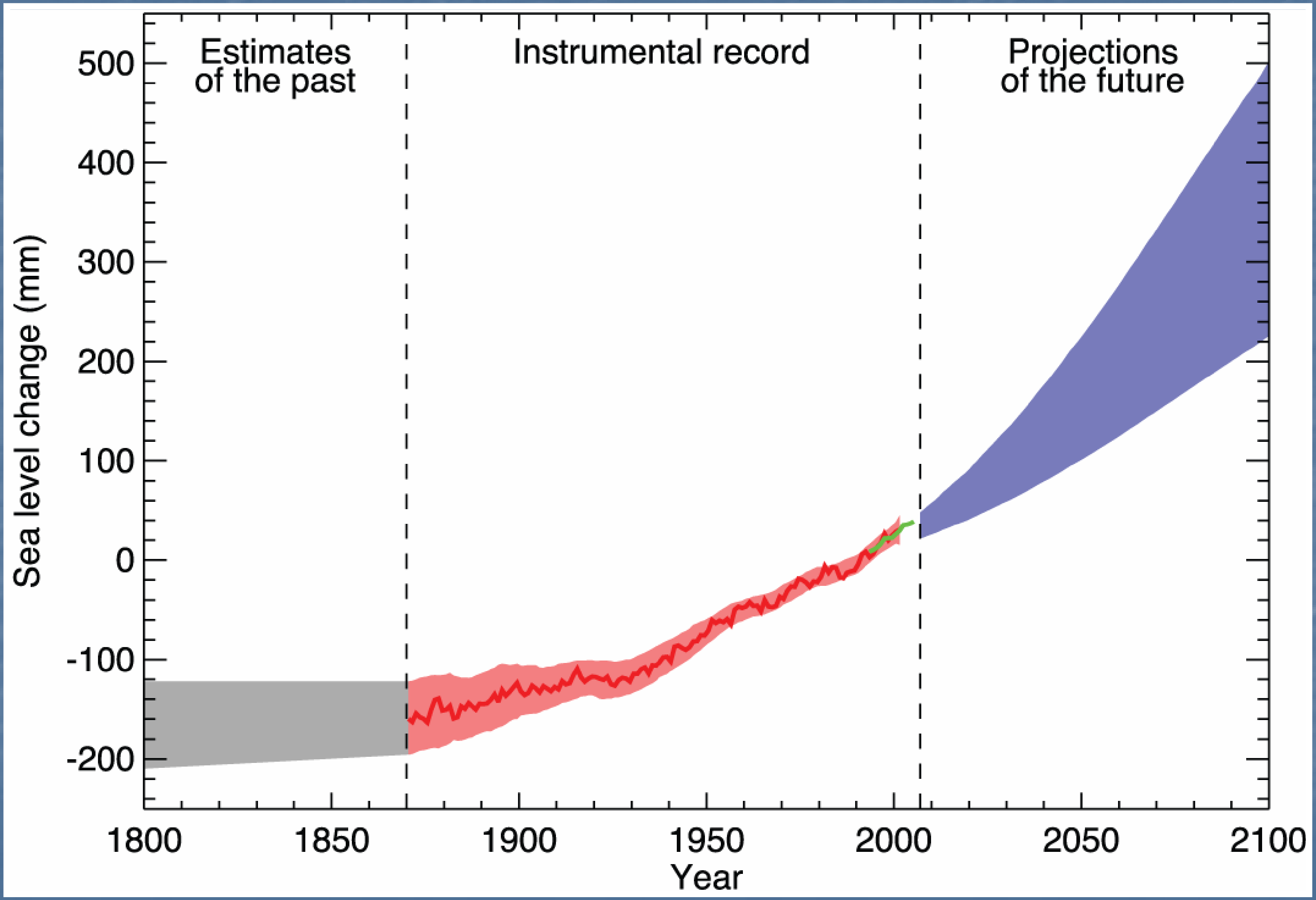
Relative sea-level in Woods Hole has risen ~25-30 cm (10-12 in) over the past 100 years





(2000 photo by R.J. Wilber)

Past, Current and Projected Sea-level Rise

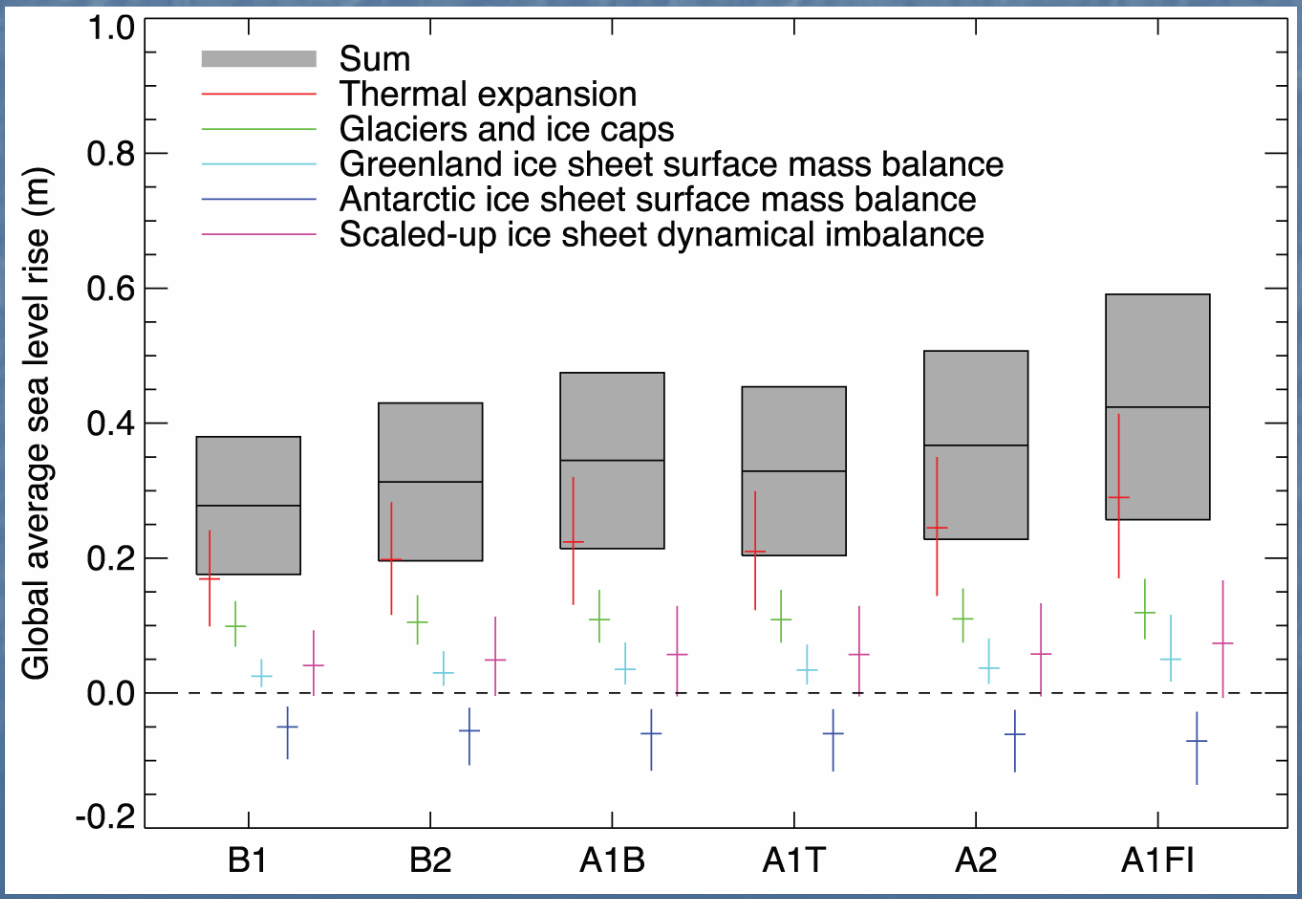


(Bindoff et al., 2007)

Projected Sea-level Rise

- The observed rate of global sea level rise averaged over the 20th century is 0.10 to 0.24 m

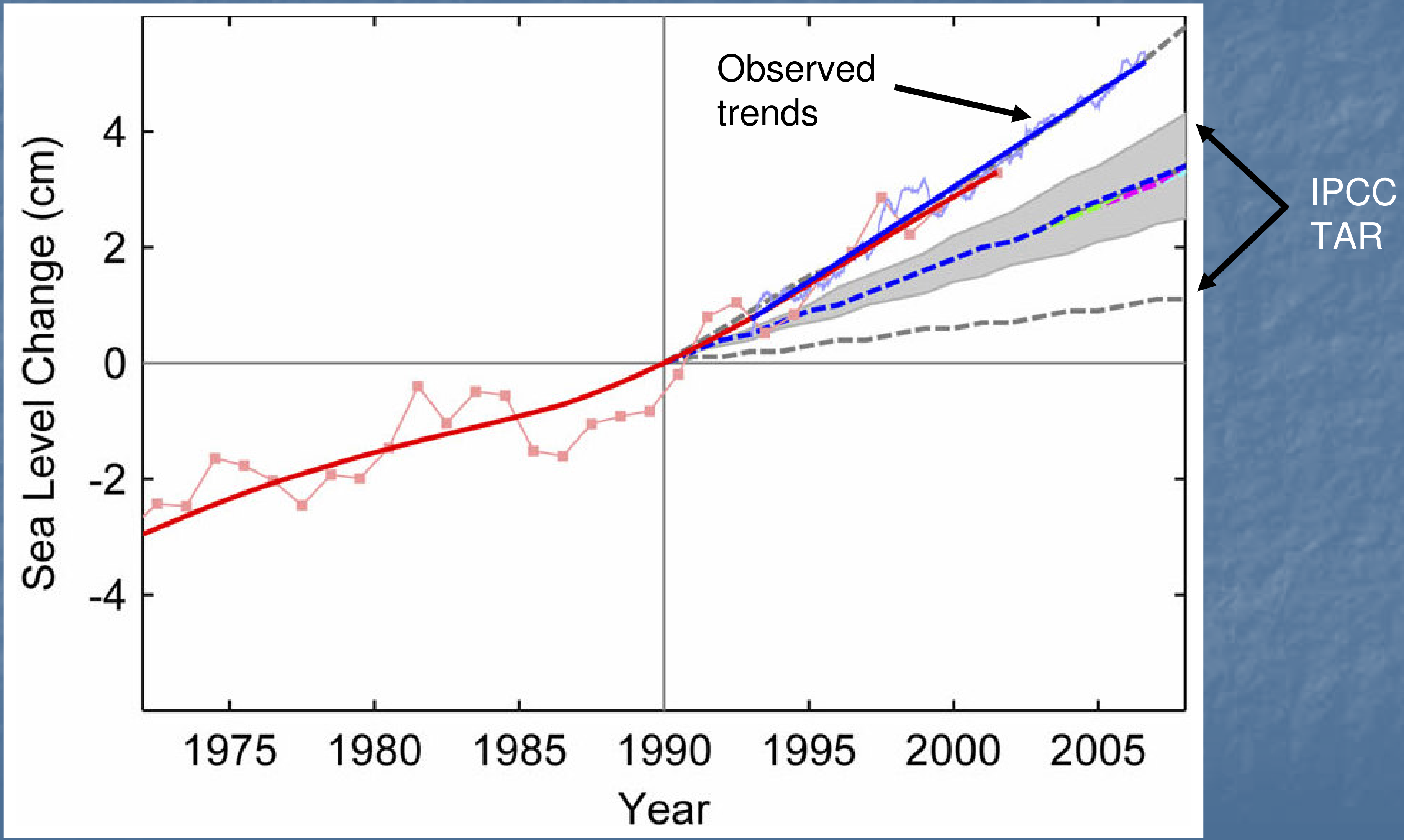
- Sea-level rise is the result of contributions from:
  - Thermal expansion of the oceans
  - Meltwater from ice sheets and glaciers



IPCC projects a rise of 0.18 to 0.59 m by 2100

(Meehl et al., 2007)

Concern: IPCC SLR projections may be too conservative



(Rahmstorf et al., 2007)

Potential contributions from land-based ice sheets and glaciers to sea-level rise …

Antarctica: 91% (~73 m)
Greenland: ~8% (~6.5 m)
Mountain Glaciers, Other Sources: ~1% (~0.5 m)

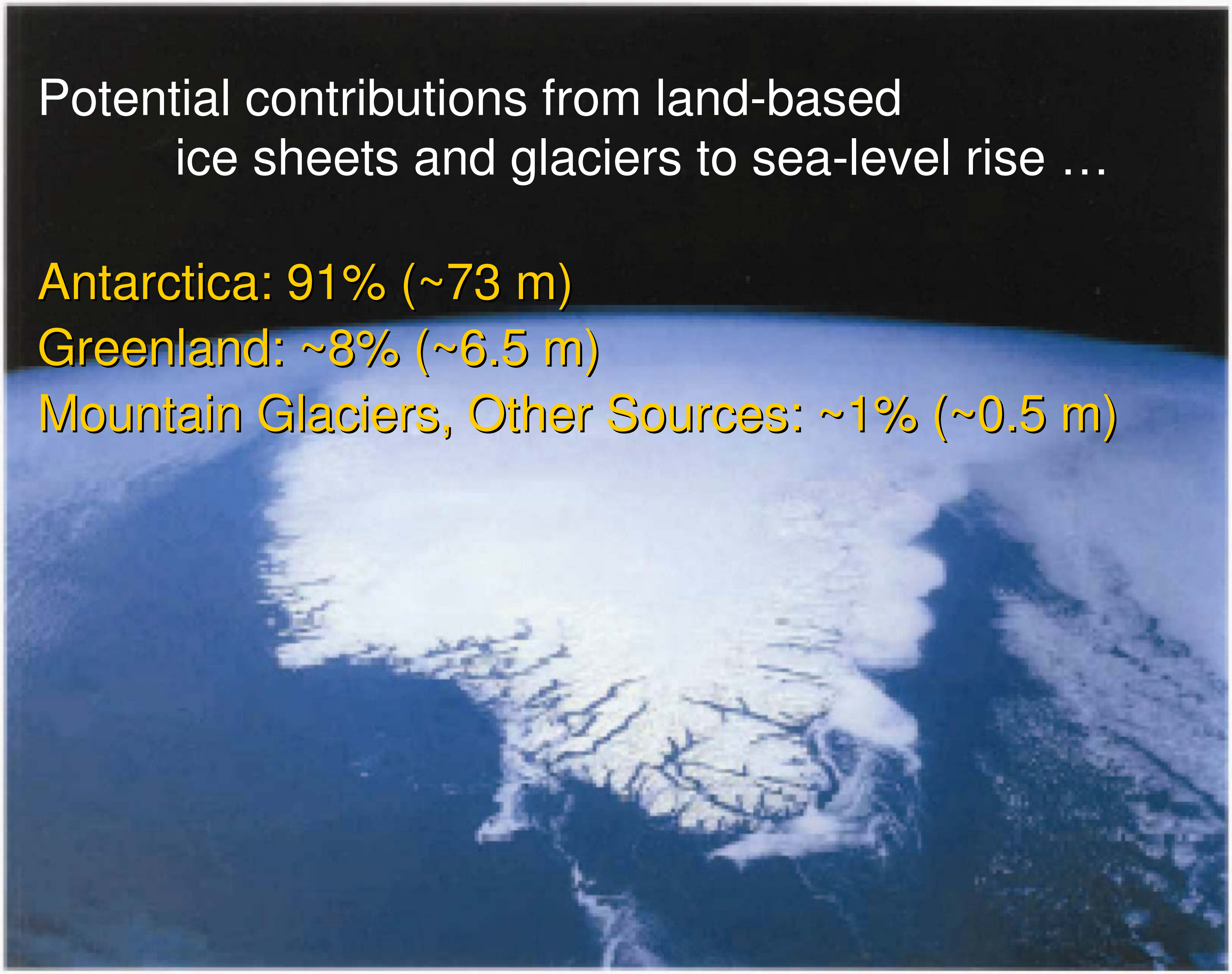
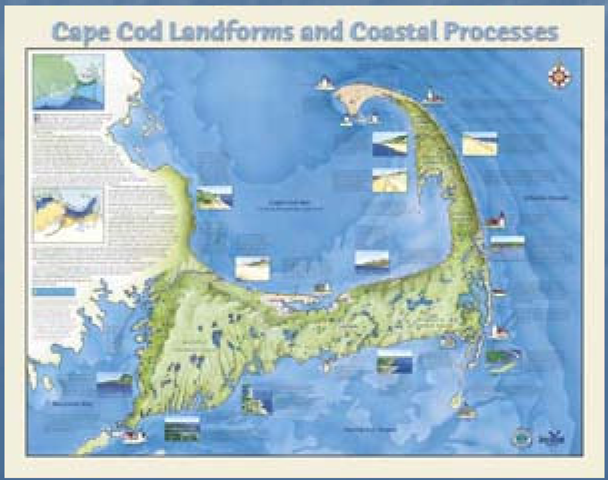


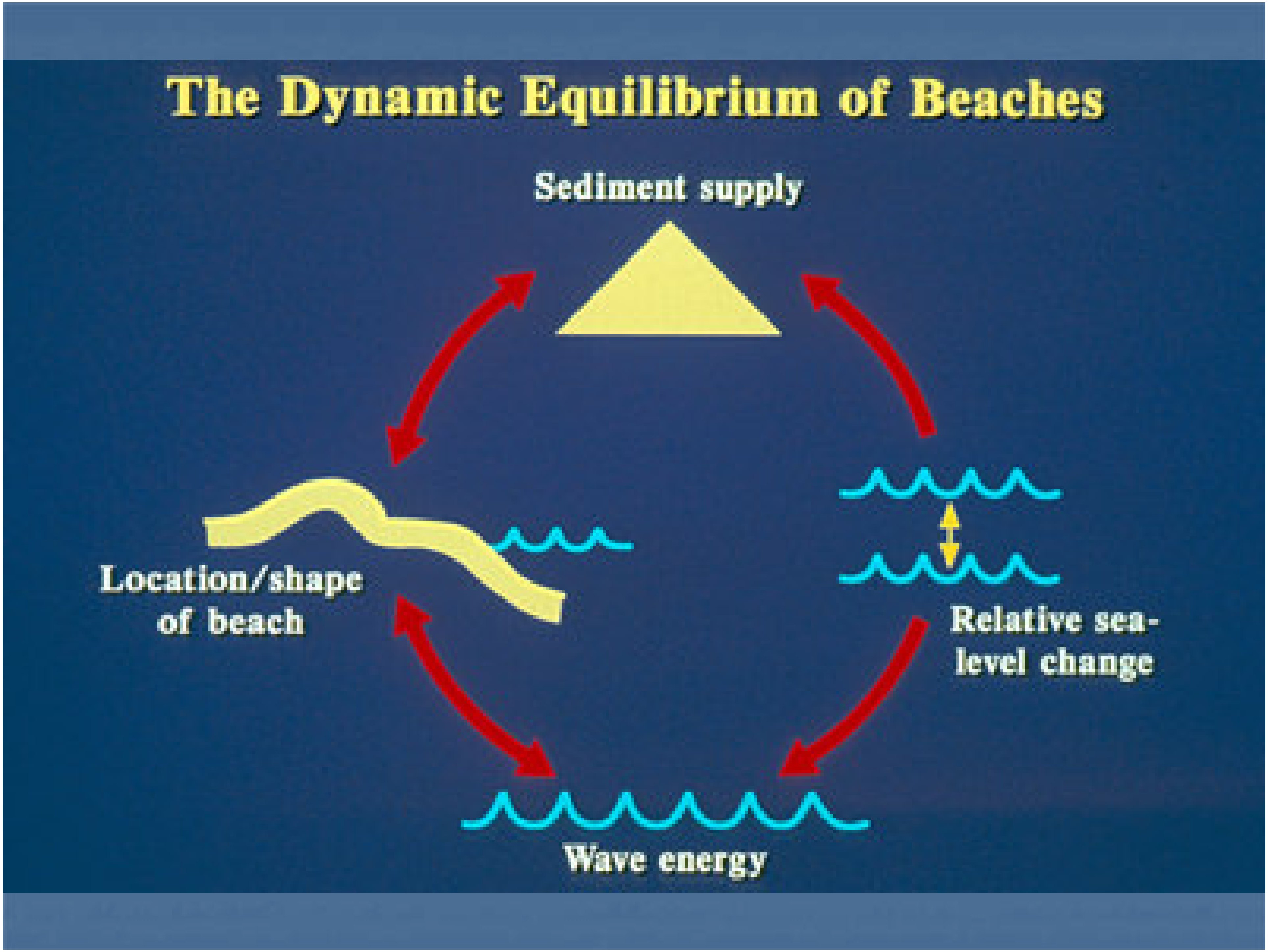
Photo: Williams and Ferrigno, 1995

Primary Processes Driving Coastal Change

- Geologic framework
- Coastal geomorphology and slope
- Relative sea-level change
  - global change
  - land subsidence and uplift
- Major storm events
  - tropical storms, hurricanes
  - Nor'easters



- Everyday coastal processes
  - waves, tidal currents, winds
- Sediment budgets
  - sediment sources (headlands, bluffs)
  - sediment sinks (washover, inlets)
- Human activities
  - coastal development and infrastructure
  - coastal engineering structures
  - dredging channels, inlets, canals,
  - beach nourishment
  - river modification (dams, levees)
  - fluid (oil-gas-water) extraction


The Dynamic Equilibrium of Beaches
Sediment supply
Location/shape of beach
Relative sea-level change
Wave energy


Effects of increased sea-level rise and storminess

- Loss of coastal habitats and resources
- Increased coastal erosion
- Loss of recreation resources (beaches, marshes)
- Salt–water intrusion to water wells, septic systems, farm lands
- Elevated storm-surge flood levels
- Greater, more frequent coastal inundation
- Increased risk to people and urban infrastructure

U.S. Climate Change Science Program

www.climatescience.gov

Synthesis and Assessment Product (SAP) 4.1
"Coastal Elevations and Sensitivity to Sea-Level Rise"
(Leads: EPA, USGS, NOAA)

Topics:

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

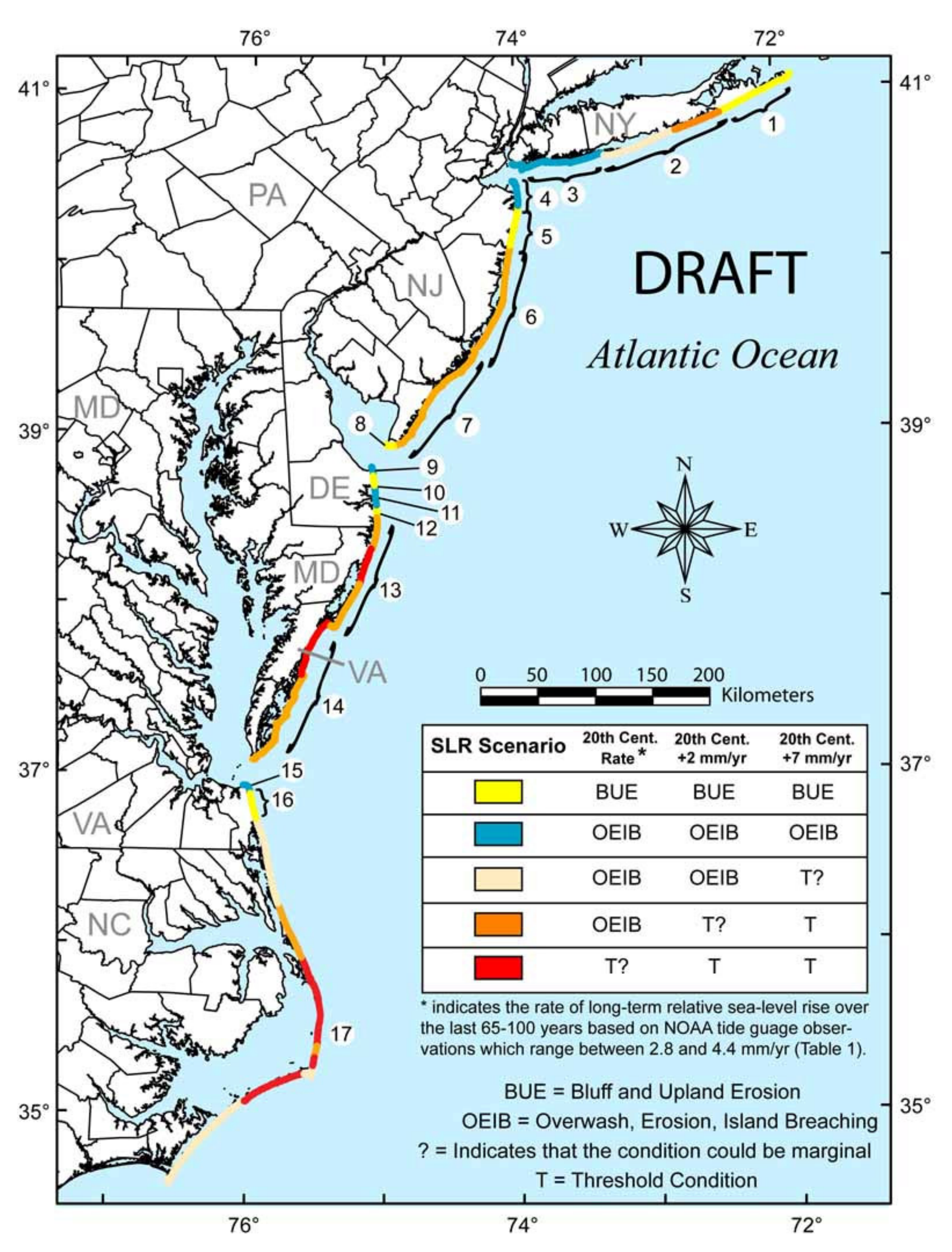
2. Factors that influence shoreline change

3. Methods of predicting future shoreline change

Assessing Potential Coastal Changes

- SAP Question 2 focuses on open-ocean coasts
  - Present shoreline physical setting: NY to NC
  - Current understanding of important geologic factors and oceanographic processes
  - Potential impacts and responses to SLR
- Review and test current models for predicting shoreline and coastal change
  - Shoreline change/erosion rate extrapolation
  - Bruun Rule
  - Inundation of DEM surface
  - Index-ranking based on physical criteria
- Science strategy plan development

CCSP SAP 4.1
Expert Panel
Assessment
for the mid-Atlantic



Mapping Relative Coastal Vulnerability to Future Sea-Level Rise

- Goals
  - Provide initial assessment of SLR vulnerability at national scale
  - Quantitative and reproducible
  - Modeled after others' efforts to do same for U.S. and Canada
  - Similar to Earthquake and Volcano hazards mapping approach
- Products
  - Fact Sheet
  - Open-File Reports ("Preliminary Assessments") for Atlantic, Gulf and Pacific coasts
  - Digital data (via web) of data variables, CVI with ArcExplorer; PDF poster versions of Preliminary Assessments
  - Project web page http://woodshole.er.usgs.gov/project-pages/cvi/

Coastal Vulnerability Index Ranking System

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

Atlantic/Gulf Ranges
Pacific Ranges

USGS

Coastal Vulnerability Index (CVI)

6 variables

A. Regional coastal slope
B. Mean wave height
C. Tide range
D. Shoreline change (m/yr)
E. Geomorphology
F. Sea-level rise (mm/yr)

→

CVI calculation

CVI = √ (A*B*C*D*E*F)/6

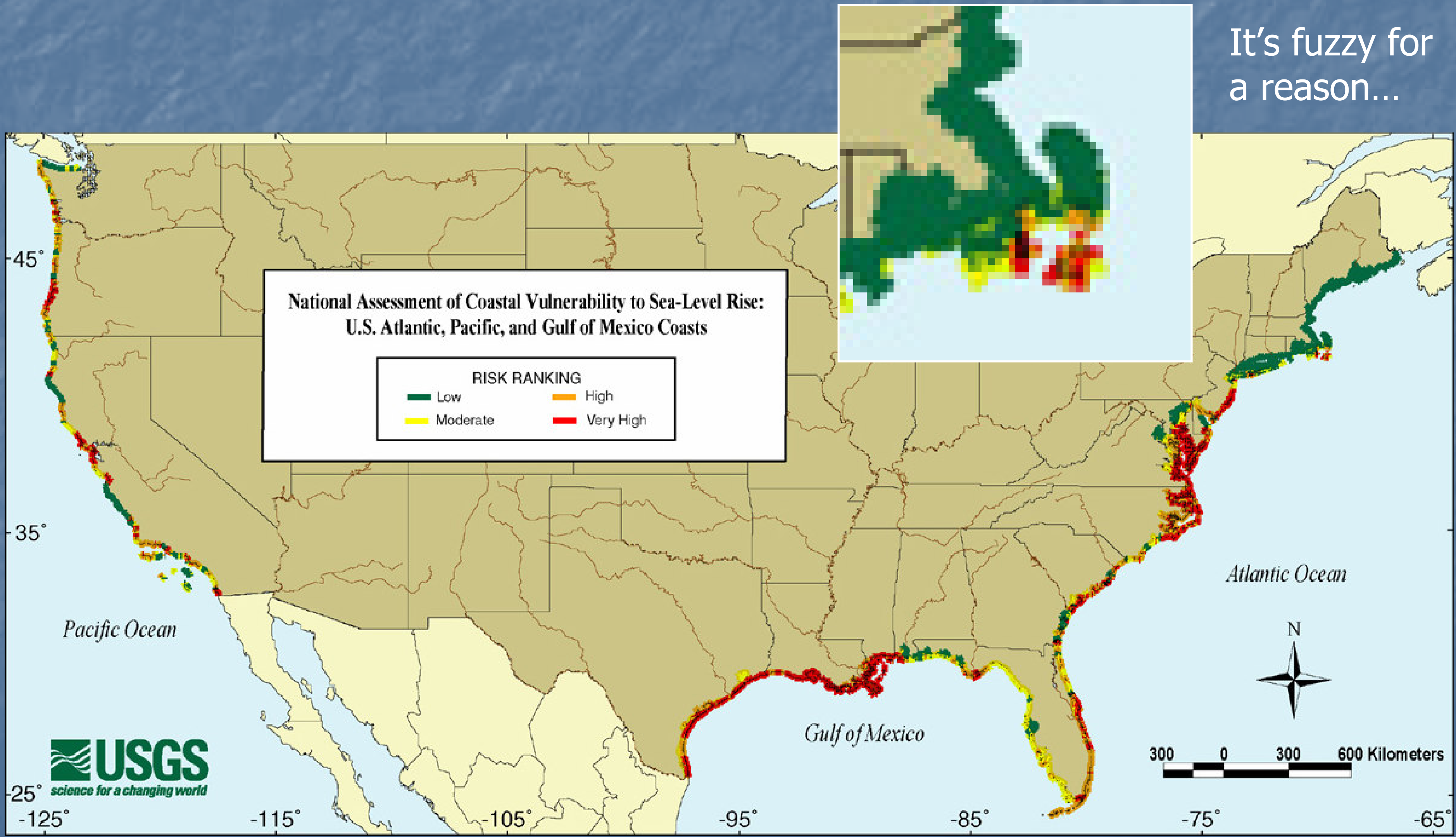
↓

Results

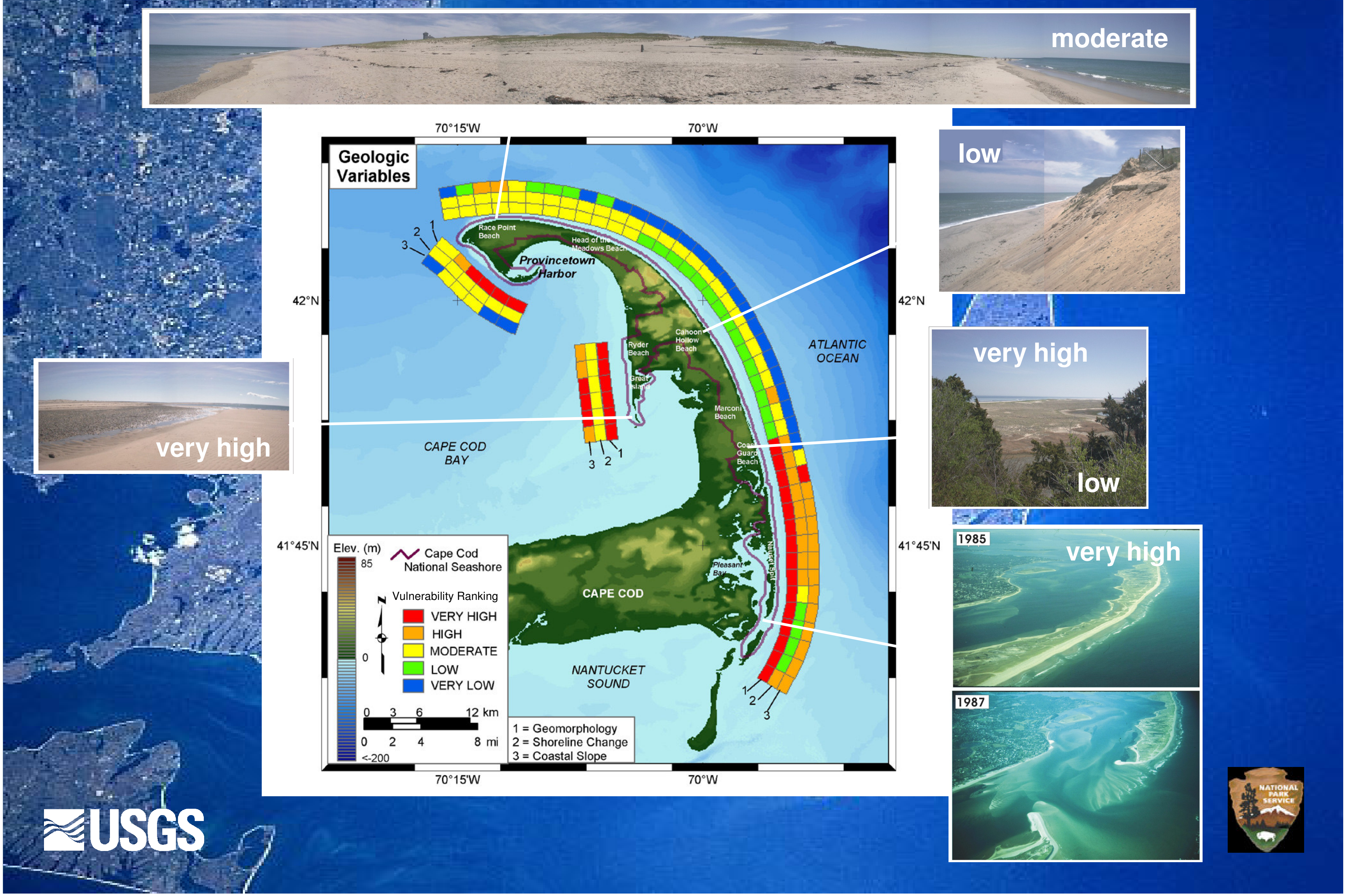
- Yields a numerical value that cannot directly be correlated with a particular physical effect
- Allows a quantitative, yet relative method of comparing areas along the coast
- Highlights regions where the various effects of sea-level rise may be the greatest

Coastal Vulnerability to Sea-level Rise: A Preliminary National Assessment

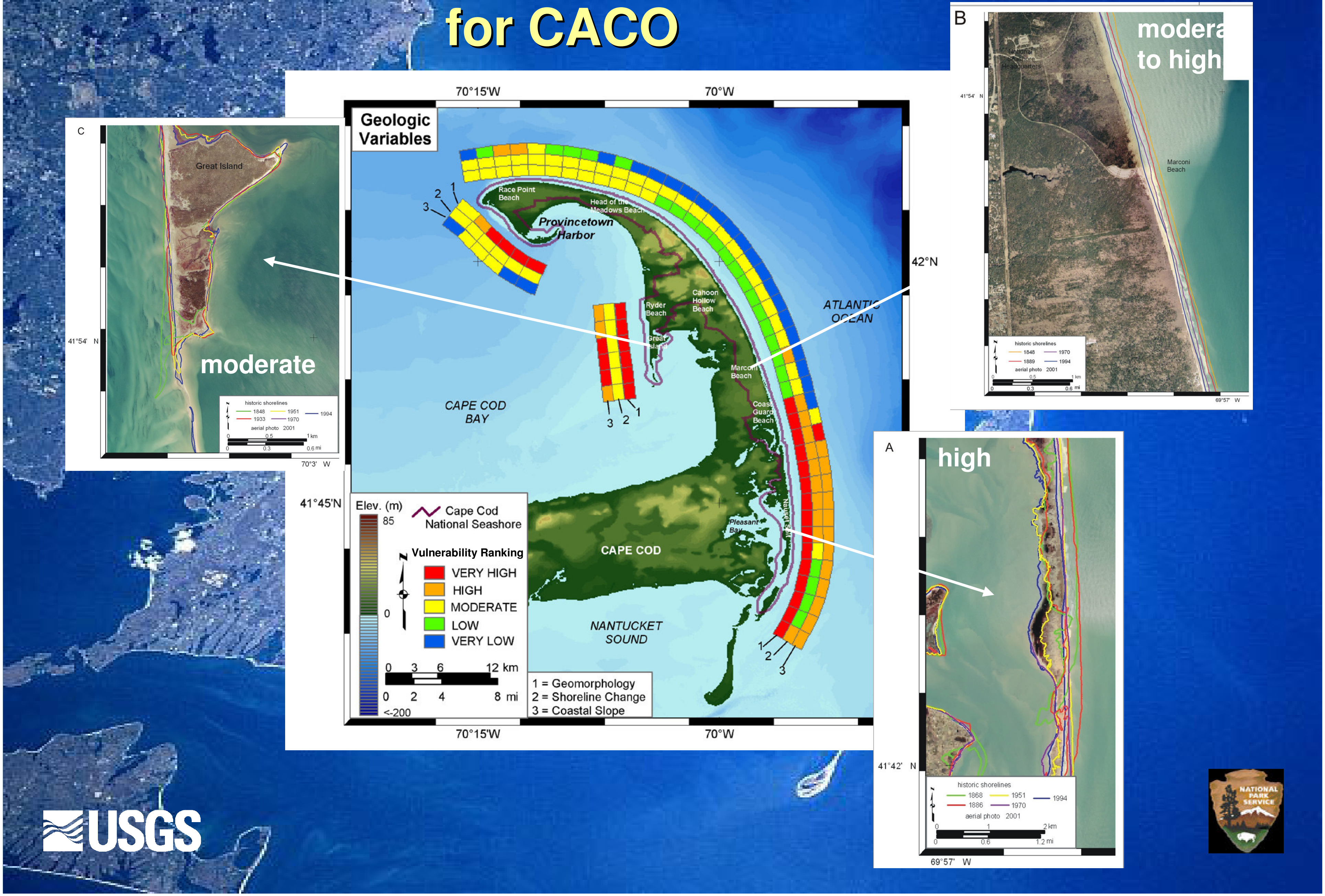
It's fuzzy for a reason…



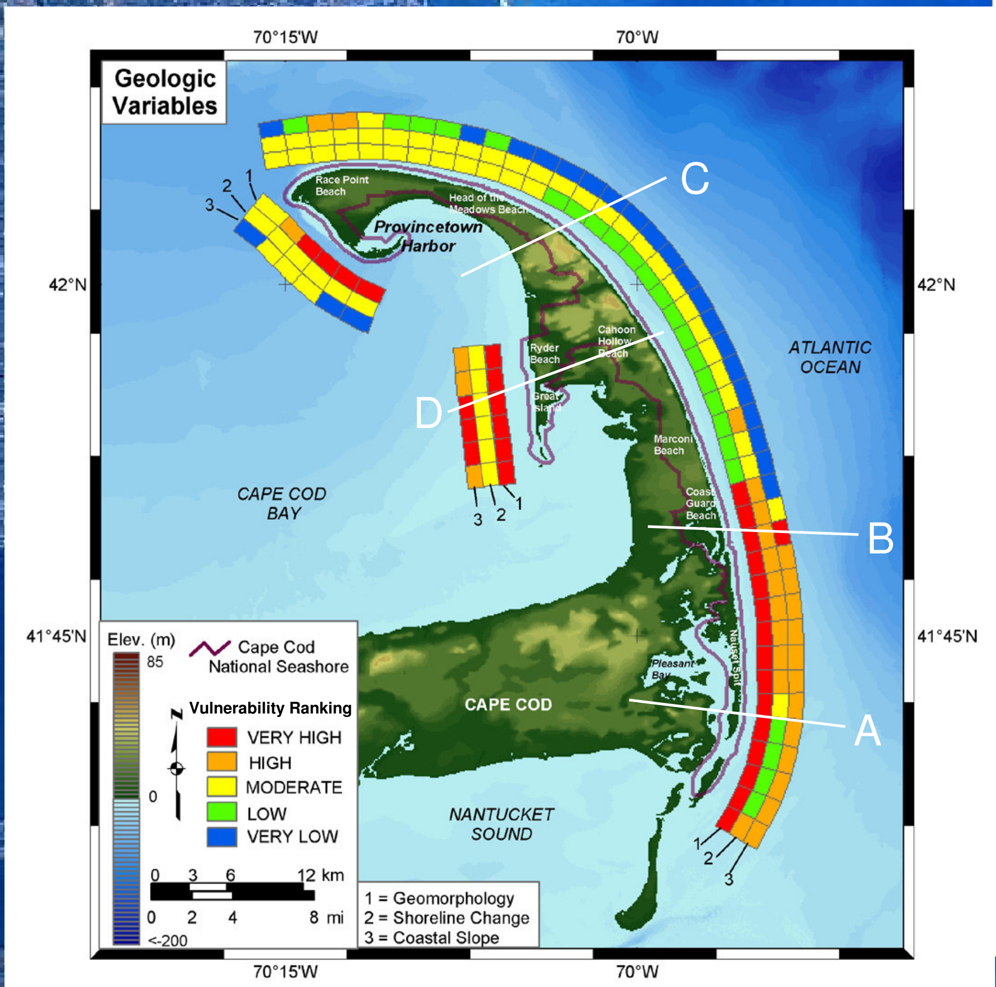
Geomorphologic Vulnerability for CACO

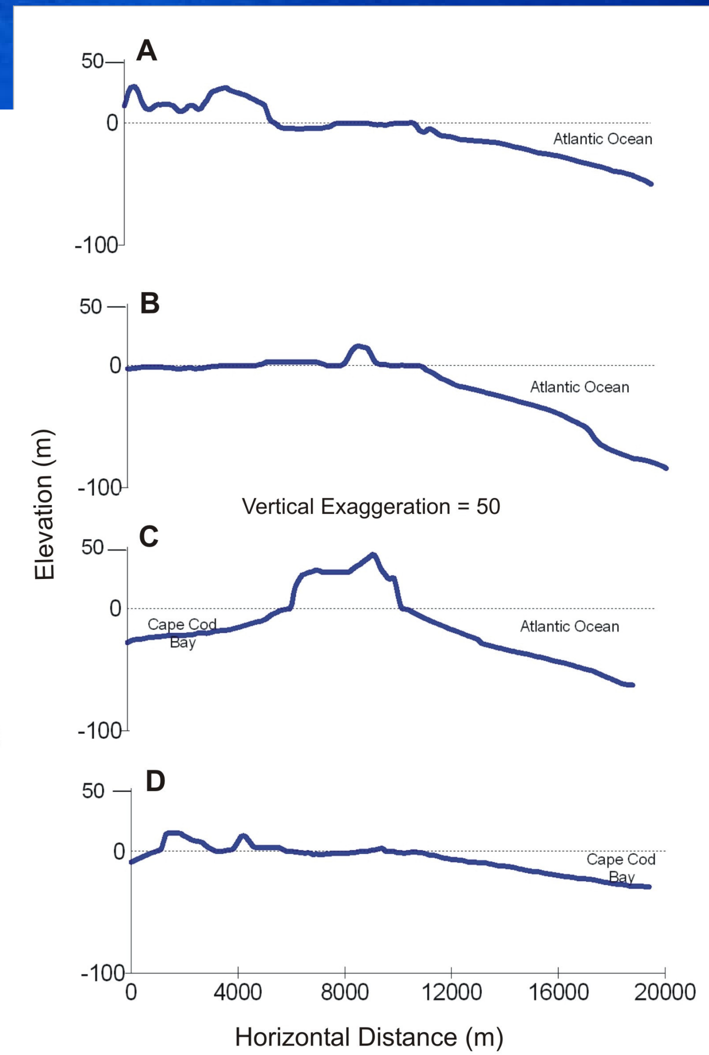


Shoreline Change Vulnerability for CACO

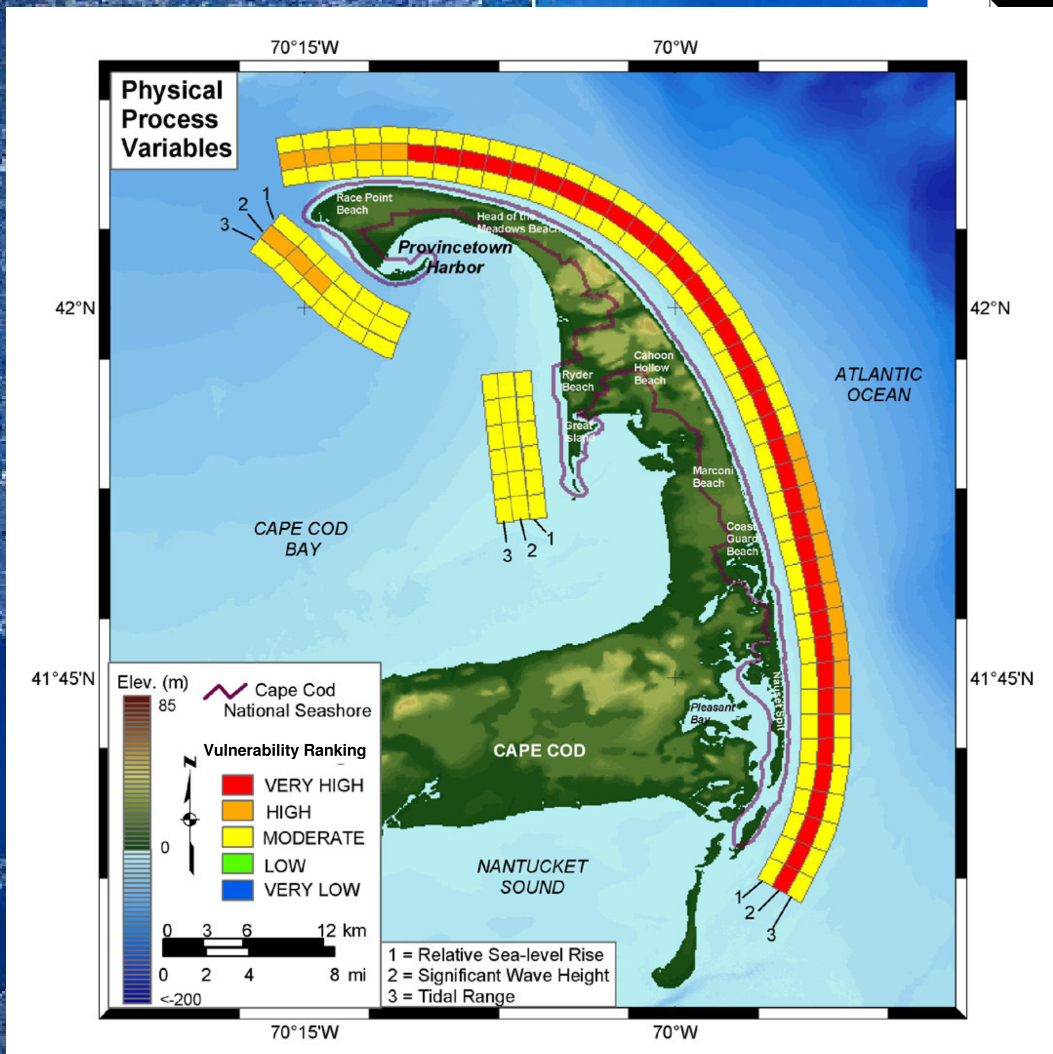


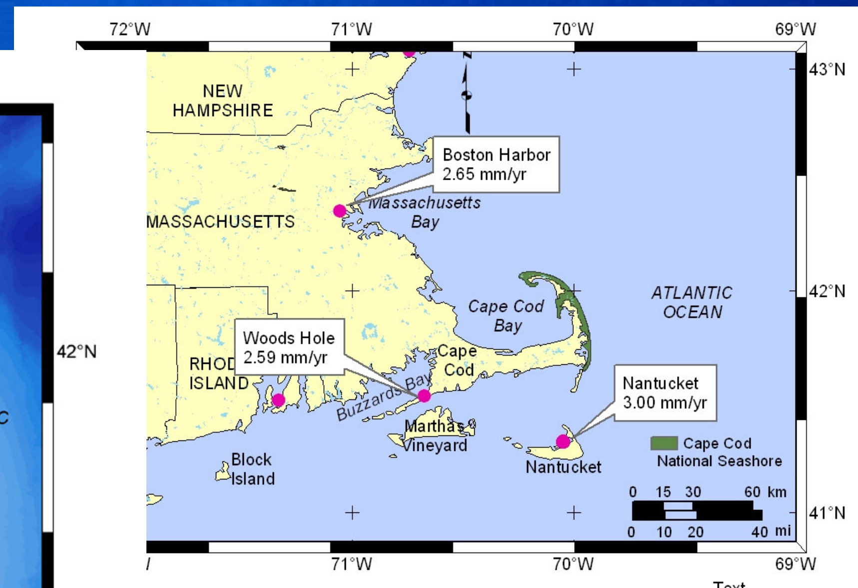
Regional Coastal Slope Vulnerability for CACO



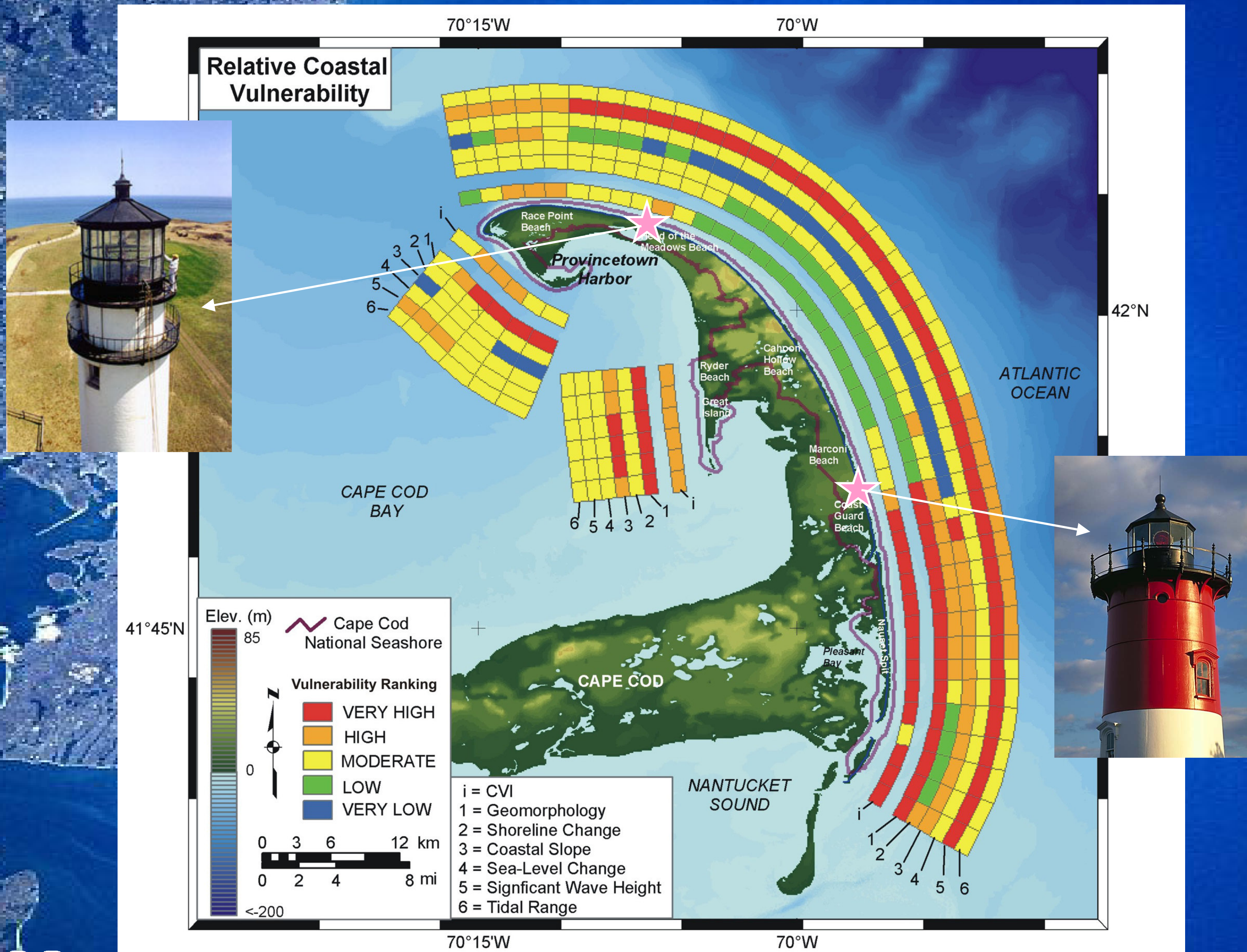


Physical Process Variables on CACO





CVI Assessment for CACO



USGS

Falmouth Coastal Resources Working Group

- Formed in May 2000
- Charged to:
  1) identify key factors that have led to the current condition of the coastal system
  2) explore reasons for the current condition
  3) provide future scenarios of the coastal zone based on an understanding of physical processes and management approaches
  4) conduct community outreach

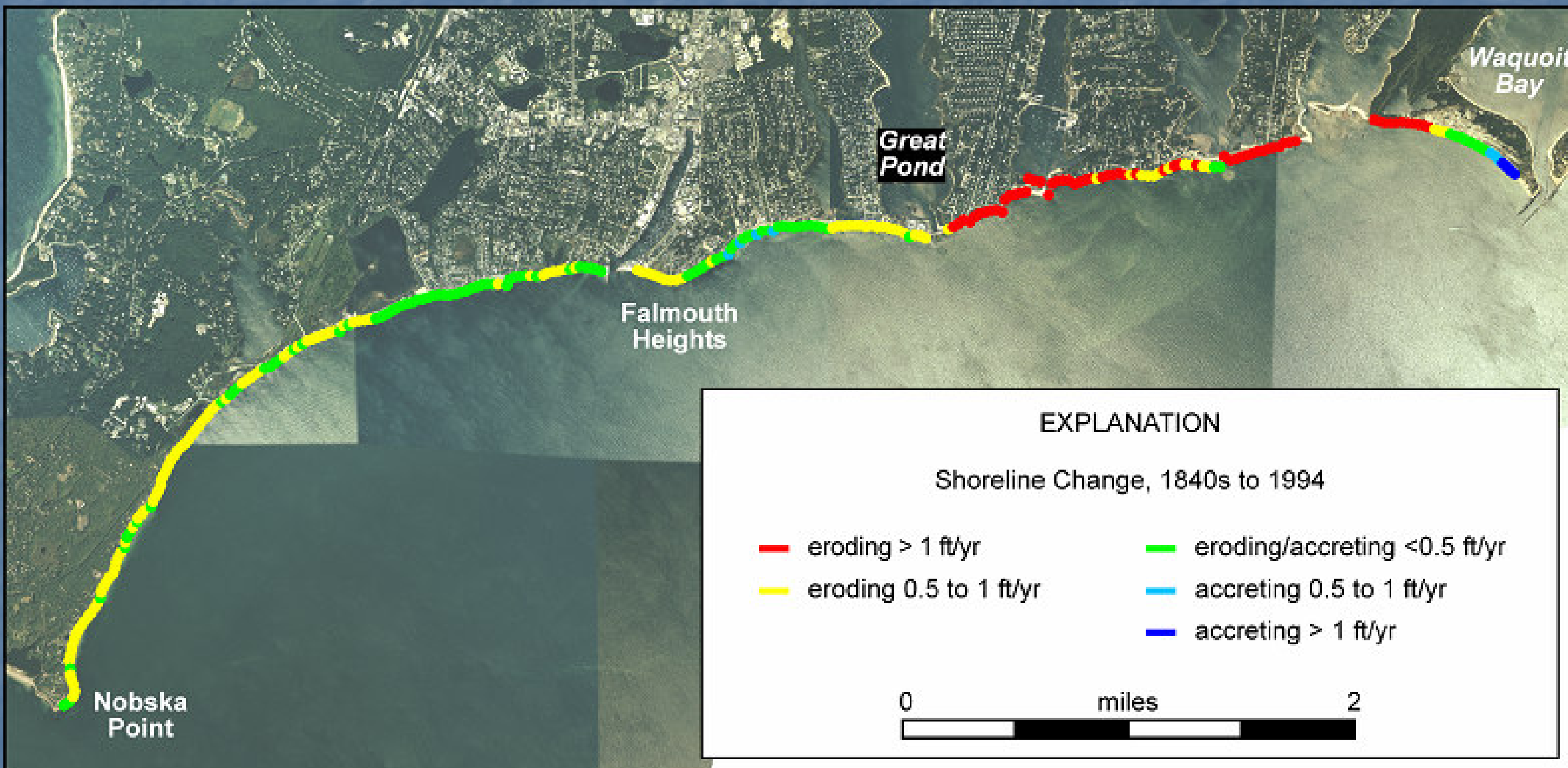
Why we are concerned…

VIEW OF FALMOUTH HEIGHTS FROM THE SOUND.

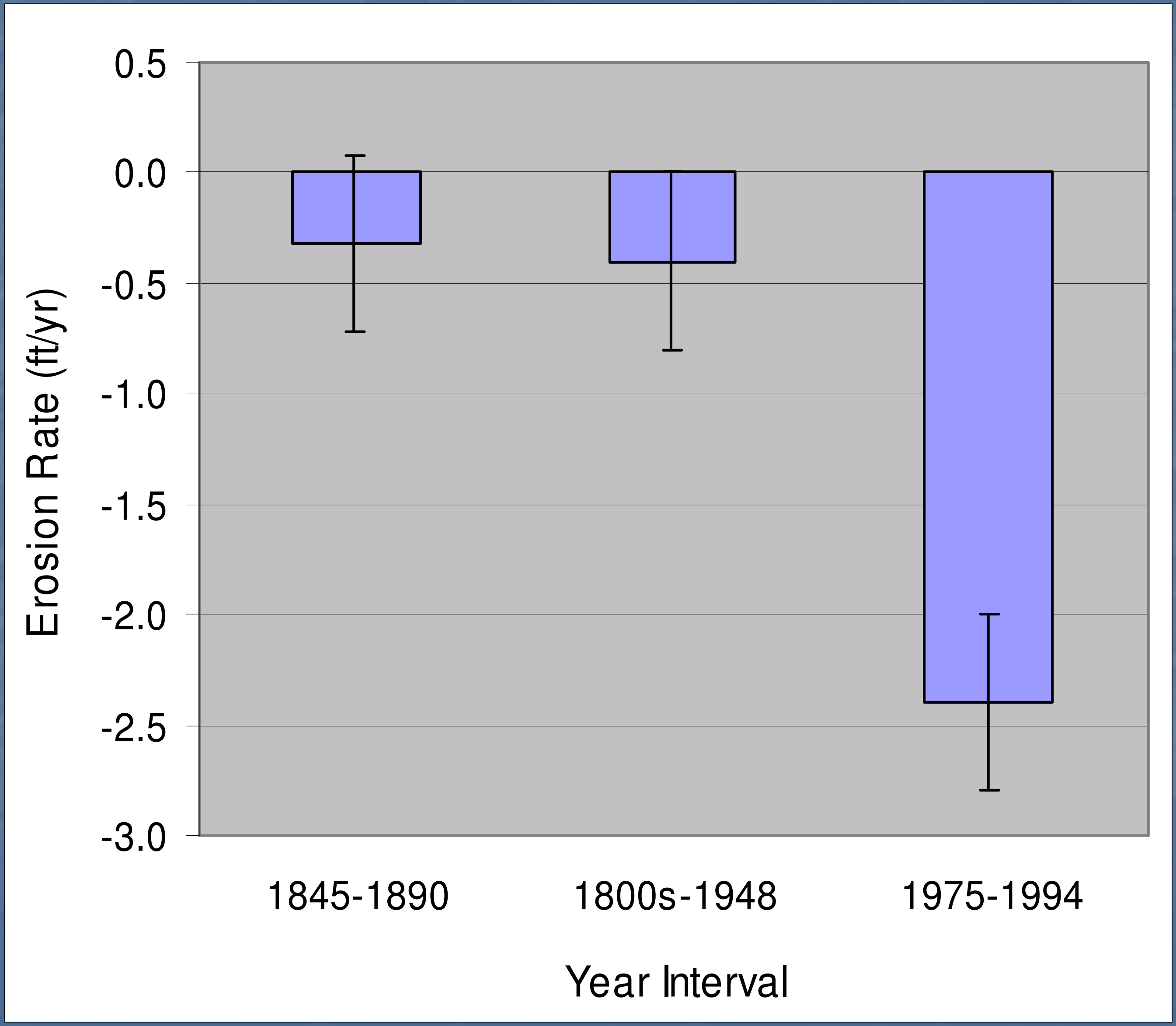
Falmouth Heights, 1897

Falmouth Heights, 2000

Falmouth Shoreline Change
1840s to 1994



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 South Shore
(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.).
- Shoreline armoring structures, where present, will not detract from the aesthetics of and access to the shoreline.
- Public infrastructure will be relocated from the immediate coast.
- A proactive approach to shoreline management will be aimed towards prevention of 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.
- Conduct beach nourishment at key "source" locations.
- Remove unnecessary, hazardous, or damaging coastal armoring structures.
- Create effective sand management systems.
- Develop improved regulations to protect coastal systems and beaches.
- Encourage landowners to obtain conservation easements that protect valuable coastal assets such as unarmored bluffs.

Summary

- Sea-level has been rising (at varying rates) for the past several thousand years
- Sea-level rise is an important component of coastal system evolution
- Current IPCC sea-level rise projections may be optimistic
- Future sea-level rise impacts will occur against a backdrop of significant human presence on the coast
- The vulnerability and resilience of Cape Cod to future sea level rise is a complex function of landform type, ecosystem character, and human interactions with the coast