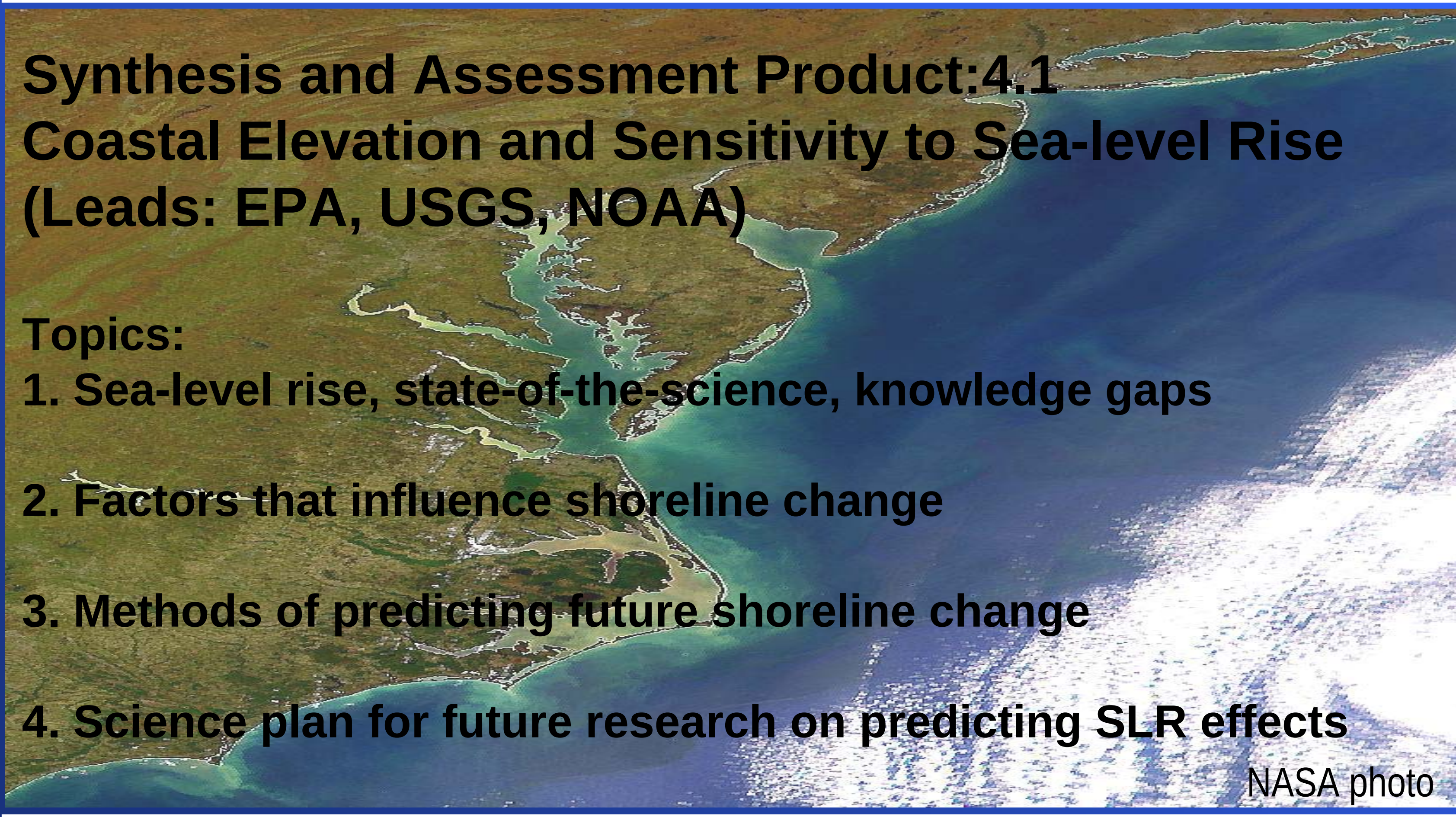
Assessing Coastal Vulnerability and Change-Potential in the Contiguous U.S. and Coastal National Park Units

Pendleton, E.A., Thieler, E.R., Williams, S.J., Hammar-Klose, E.S., and Beavers, R.S.

U.S. Department of the Interior
U.S. Geological Survey

U.S. Climate Change Science Program (CCSP)



Synthesis and Assessment Product:4.1
Coastal Elevation 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

4. Science plan for future research on predicting SLR effects

NASA photo

USGS

Assessing Potential Coastal Changes Due to SLR

- USGS will focus mainly on open-ocean coasts, NY to NC
  - Present physical setting
  - Current understanding of important processes
  - Potential impacts of SLR (25 cm, 50 cm, 100 cm)
- Work will review and test extant models for predicting shoreline/coastal change
- Methodologies to be reviewed:
  - Erosion-rate extrapolation
  - Bruun Rule
  - Inundation
  - Index-ranking based on physical/geological criteria
  - Geometry-based models
- Review will guide research plan development

USGS

Outline

- Motivation
- Methods
- National Coastal Vulnerability Assessment
  - Study area: Contiguous US
  - Updates and new tools
  - Applications and products
- CVI for Coastal National Park Units
  - Study area: coastal national park units
  - Methodology modifications
  - Applications and products

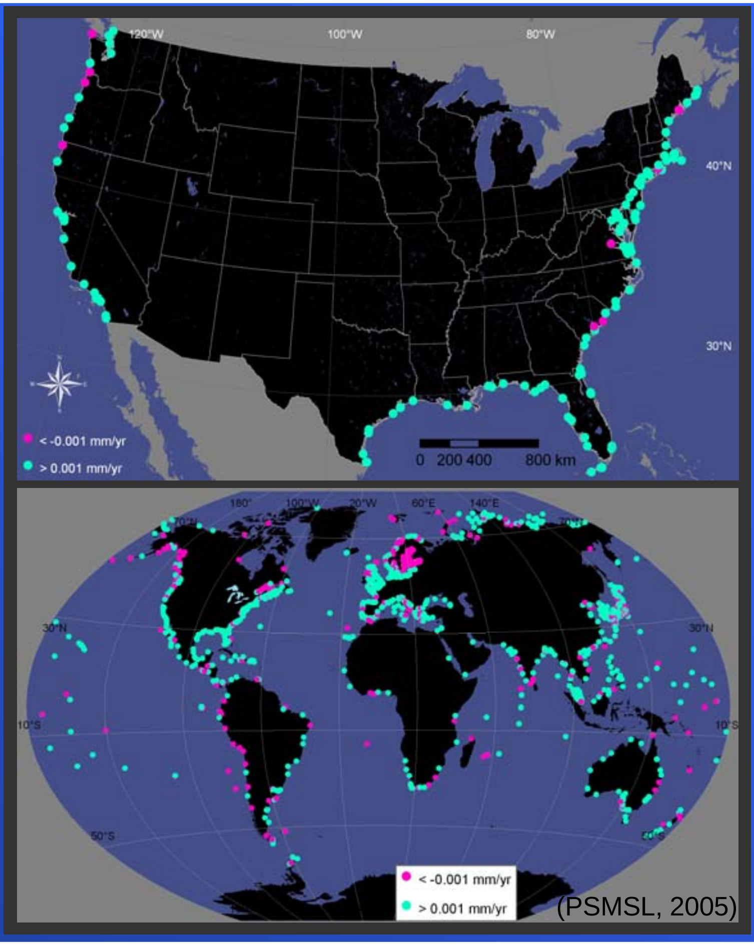
Global and relative sea-level

http://www.pol.ac.uk/psmsl/

Global / eustatic	Relative
• Change in volume of water in oceans	• uplift
• Thermal expansion (steric rise)	• subsidence

	Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	Model-based range excluding future rapid dynamical changes in ice flow
B1 scenario	0.18 – 0.38
A1T scenario	0.20 – 0.45
B2 scenario	0.20 – 0.43
A1B scenario	0.21 – 0.48
A2 scenario	0.23 – 0.51
A1FI scenario	0.26 – 0.59

(IPCC, 2007)



(PSMSL, 2005)

USGS

water level recording stations

Methodology

- (Gornitz and others, 1990 - 1994)
- (Shaw and others, 1998)
- (Thieler and others, 1999 - 2001)

Sources of Data		
Variables	Source	Publisher
Geomorphology	Aerial photography Landform GIS databases	USGS science for a changing world
Shoreline	National Assessment of Shoreline Change	USGS

VARIABLES	VERY LOW 1	LOW 2	MODERATE 3	HIGH 4	VERY HIGH 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

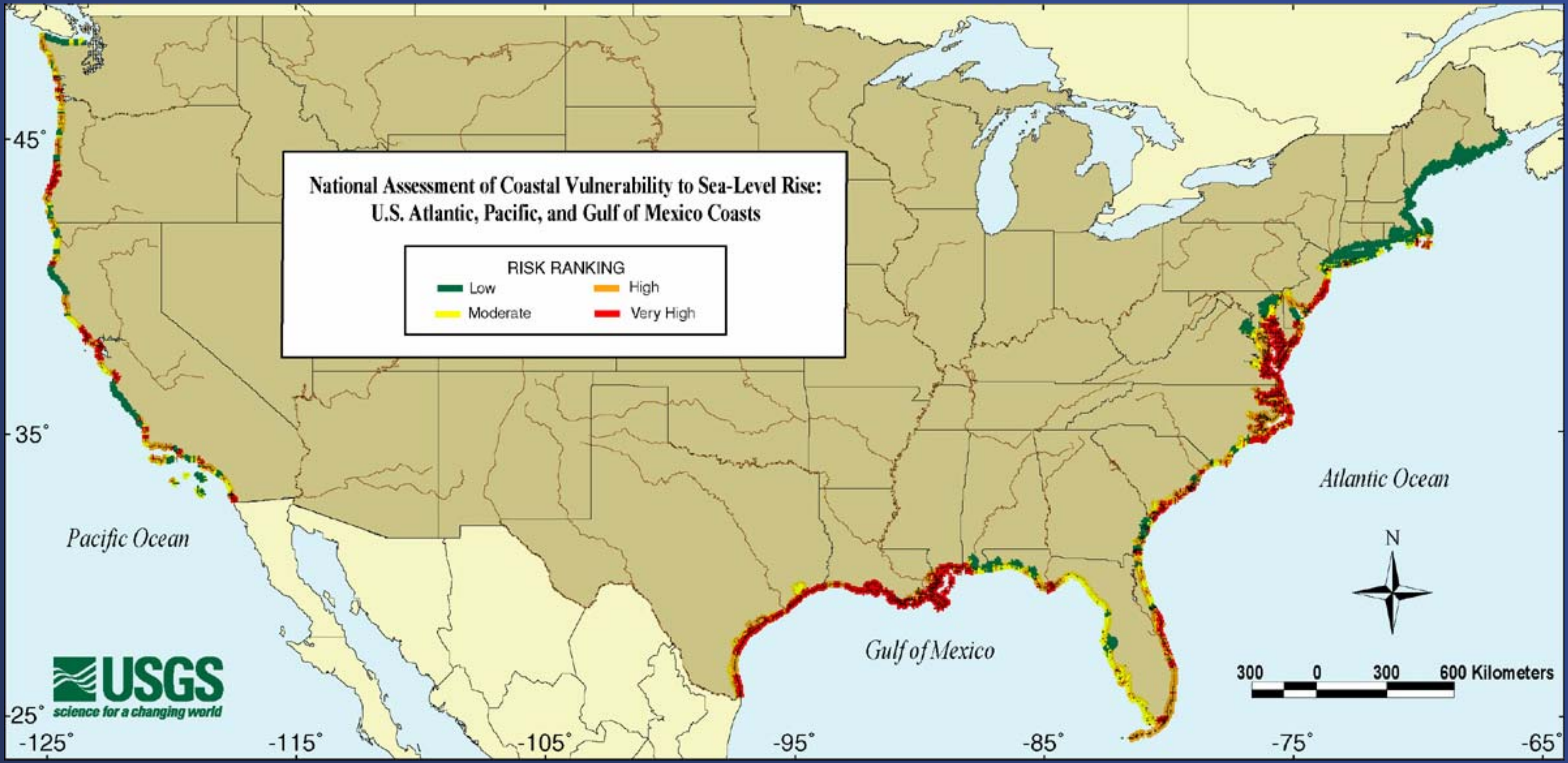
The data are scored using a relatively simple ranking system, so that the variables can be expressed in a quantifiable manner.

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

The National Assessment of Coastal Vulnerability



National Assessment of Coastal Vulnerability to Sea-Level Rise

E. Robert Thieler, Jeff Williams, Erika Hammar-Klose

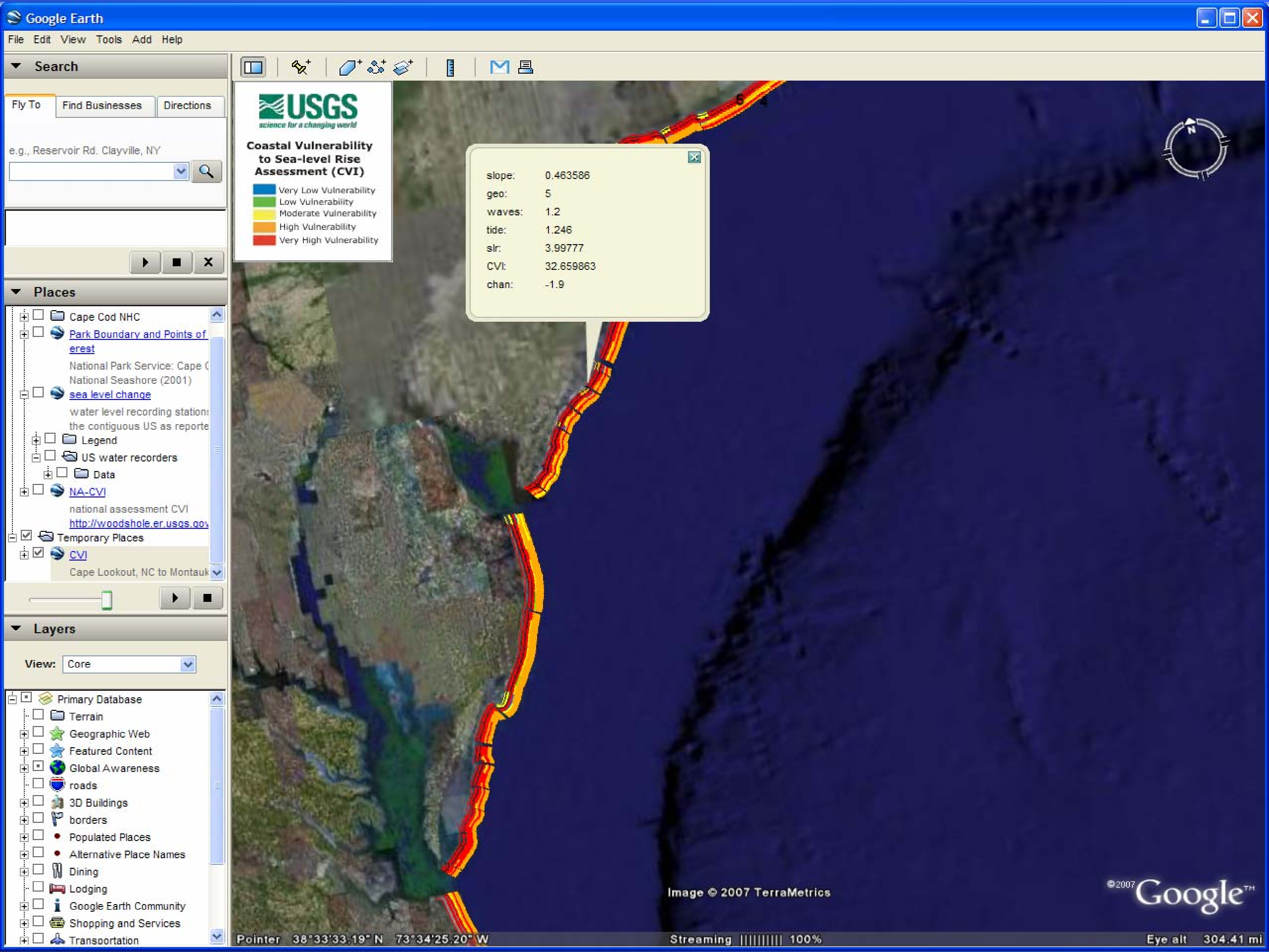
Updates and New Tools

- **Increased shoreline resolution:**
  - **Original scale 1:250,000**
  - **Updated scale 1:80,000**

- **Update CVI variable fields where improvements in data have been made**
  - **Historical shoreline change rate (USGS)**
    - **(http://coastal.er.usgs.gov/national-assessment/)**
  - **Regional coastal slope (NOAA/NGDC ETOPO2→CRM)**
    - **(http://www.ngdc.noaa.gov/mgg/coastal/startcrm.htm)**
  - **Updated Sea-level rise rates**
    - **http://www.co-ops.nos.noaa.gov/publications/techrpt36doc.pdf)**
    - **http://www.pol.ac.uk/psmsl/**

- **Provide CVI data in more accessible formats to the public**
  - **.kmz & .kml for Google Earth™**

USGS


Google Earth
File Edit View Tools Add Help
Search
Fly To
Find Businesses
Directions
e.g., Reservoir Rd. Clayville, NY
Places
Cape Cod NHC
Park Boundary and Points of erest
National Park Service: Cape C
National Seashore (2001)
sea level change
water level recording station
the contiguous US as reporte
Legend
US water recorders
Data
NA-CVI
national assessment CVI
http://woodshole.er.usgs.gov
Temporary Places
CVI
Cape Lookout, NC to Montauk
Layers
View: Core
Primary Database
Terrain
Geographic Web
Featured Content
Global Awareness
roads
3D Buildings
borders
Populated Places
Alternative Place Names
Dining
Lodging
Google Earth Community
Shopping and Services
Transportation
USGS
science for a changing world
Coastal Vulnerability to Sea-level Rise Assessment (CVI)
Very Low Vulnerability
Low Vulnerability
Moderate Vulnerability
High Vulnerability
Very High Vulnerability
slope: 0.463586
geo: 5
waves: 1.2
tide: 1.246
slr: 3.99777
CVI: 32.659863
chan: -1.9
Image © 2007 TerraMetrics
©2007 Google
Pointer 38°33'33.19" N 73°34'25.20" W
Streaming 100%
Eye alt 304.41 mi

National CVI Summary

Applications

- As an indication of where coastal changes may be likely to occur on a National scale as sea level changes
- As a database of coastal information

Products

- Online Open File Report for each Coast: Pacific, Gulf of Mexico, Atlantic
- Shapefiles with metadata for each coast containing all variable information as well as CVI data

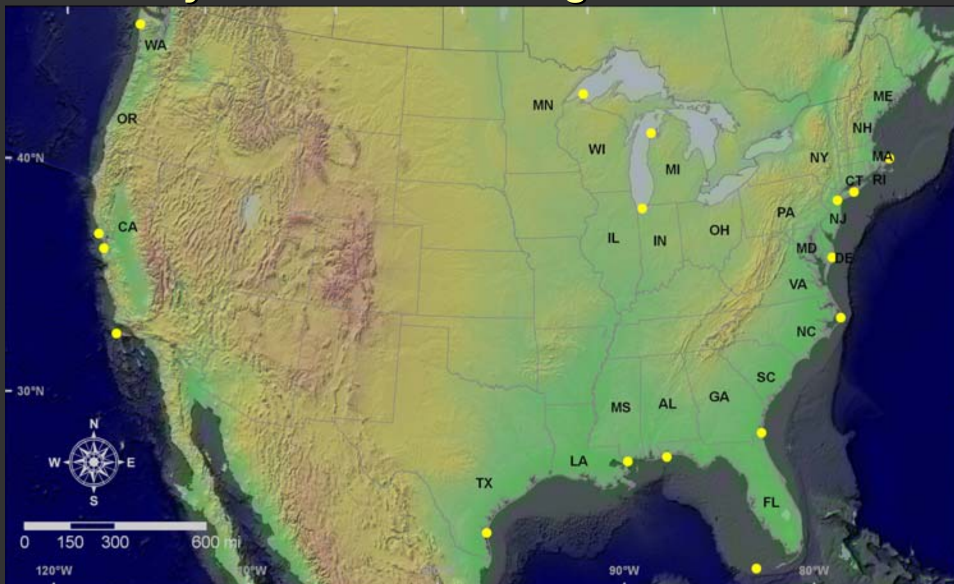
http://woodshole.er.usgs.gov/project-pages/cvi/

http://pubs.er.usgs.gov/

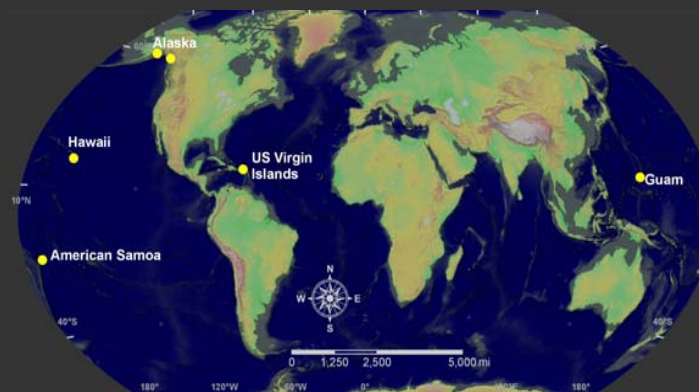
USGS

The NPS CVI project

CVI study sites in the Contiguous U.S.



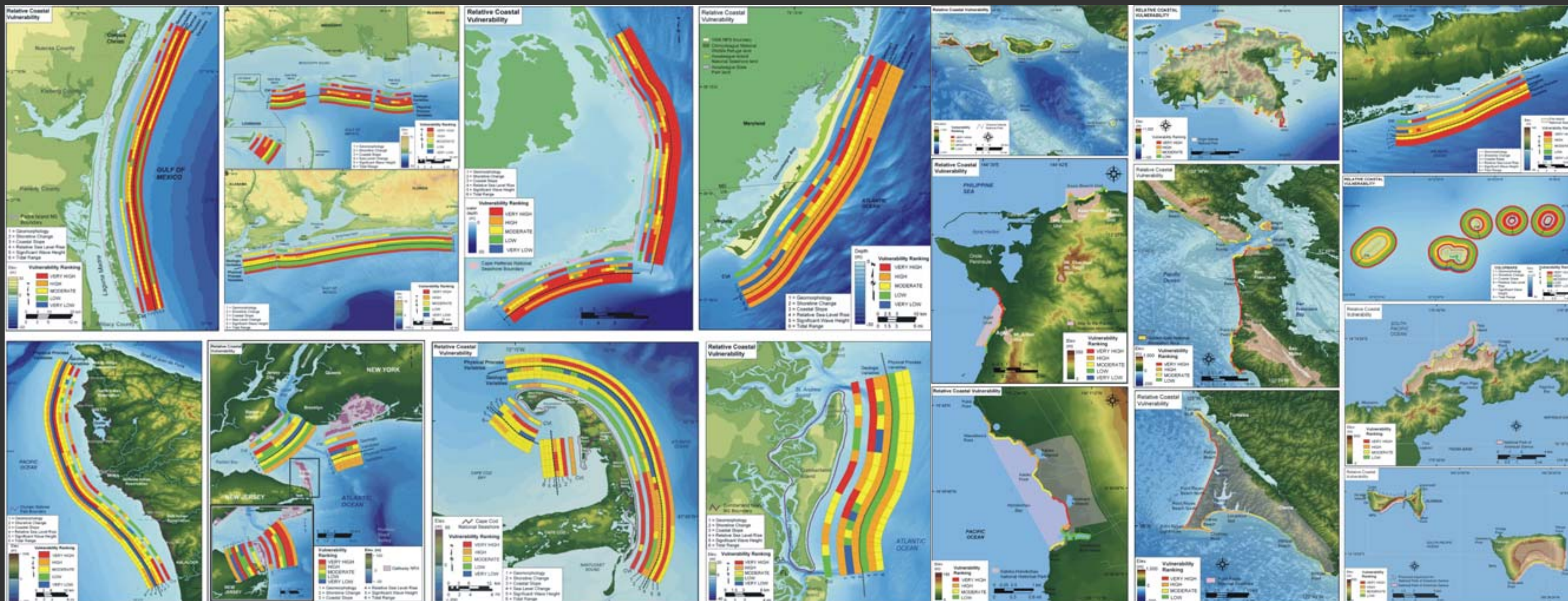
CVI study sites in Hawaii, Alaska, and U.S. Territories



			Sleeping Bear Dunes NL
			Kenai Fjord NP
Cape Cod NS	Cumberland Island NS	Golden Gate NRA	Glacier Bay NPP
Fire Island NS	Assateague Island NS	Point Reyes NS	Kaloko-Honokohau NHP
Gateway NRA	Dry Tortugas NP	Olympic NP	NP of American Samoa
Gulf Islands NS	Padre Island NS	Apostle Islands NL	Virgin Islands NP
Cape Hatteras NS	Channel Islands NP	Indiana Dunes NL	War in the Pacific NHP

USGS

Applying the CVI in NPS Units where relative sea-level is rising



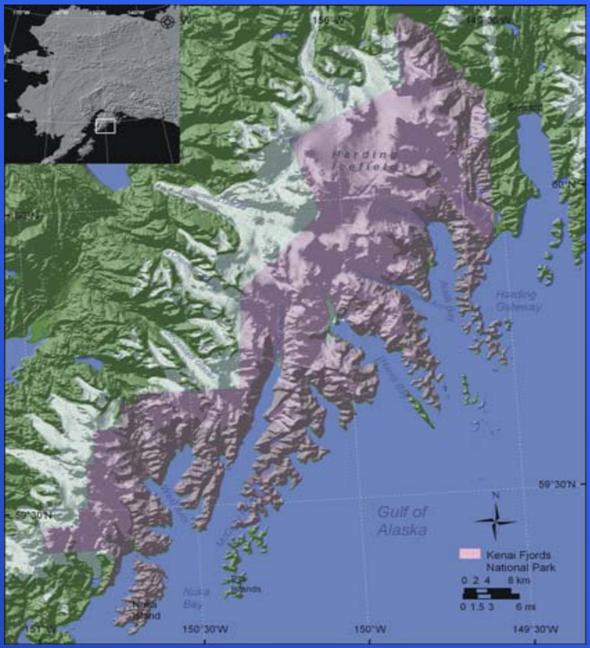
CVI vs. CPI

USGS

What if relative sea-level is falling?

Glacier Bay NPP, AK

Kenai Fjords NP, AK

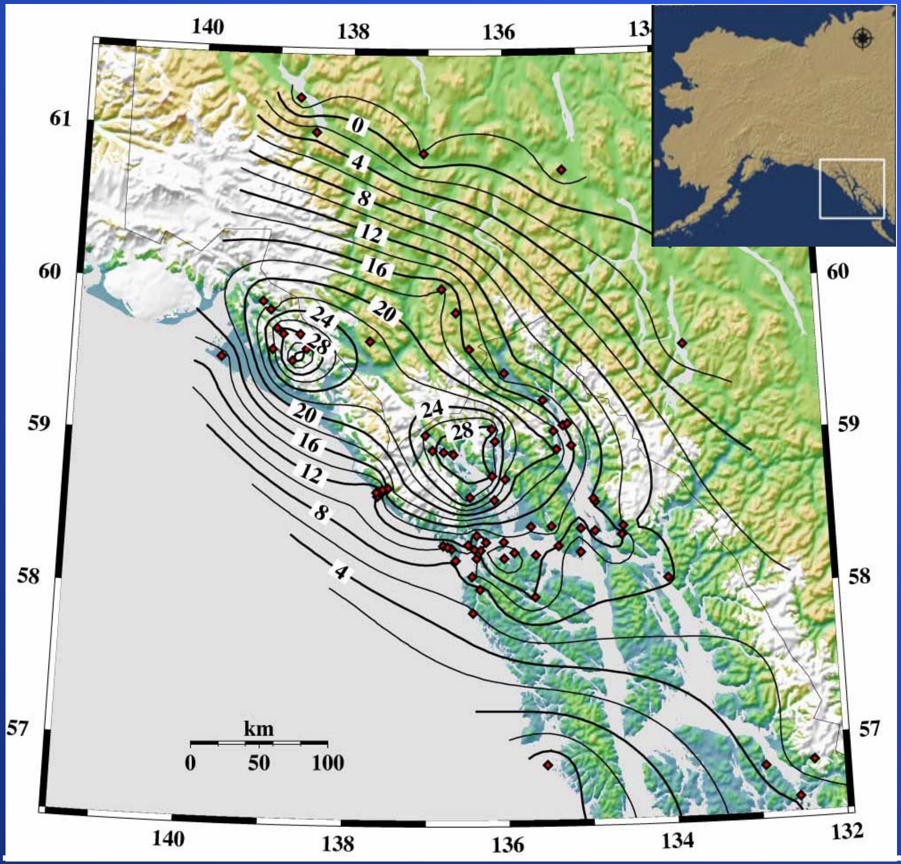


Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

USGS

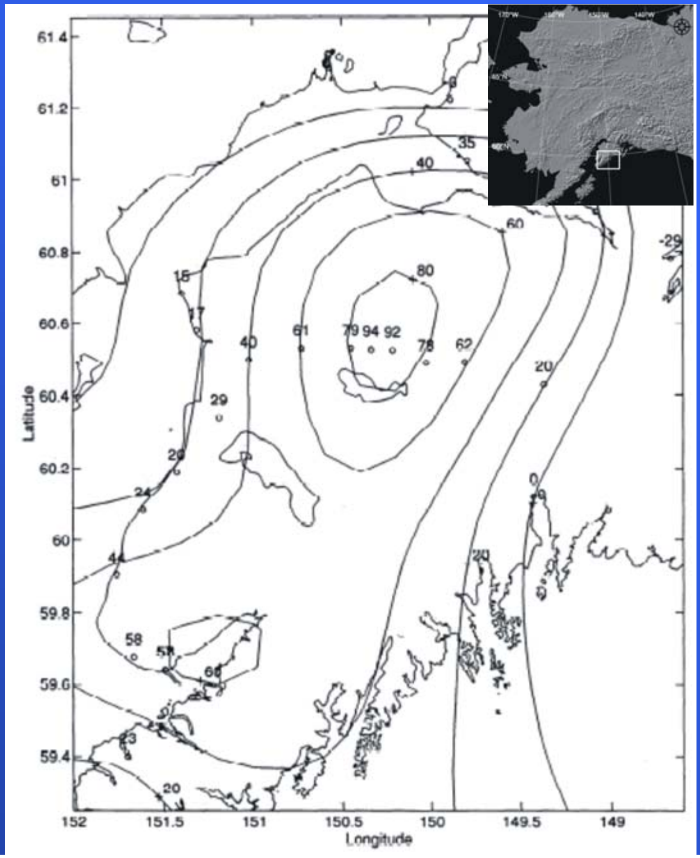
What if relative sea-level is falling?

Glacier Bay NPP, AK



(Larsen and others, 2005)

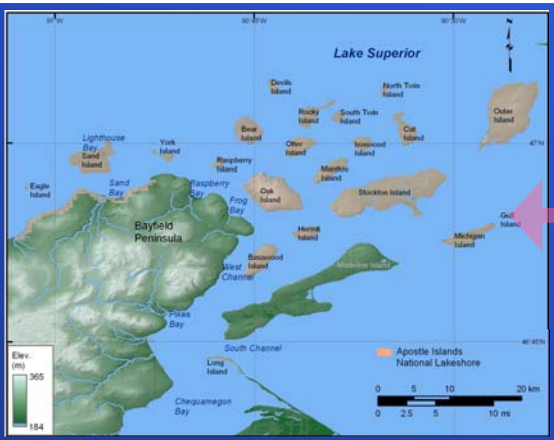
Kenai Fjords NP, AK



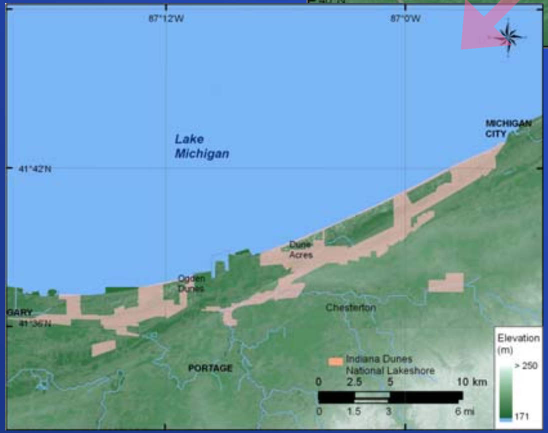
(Cohen and Freymueller, 1997)

USGS

What if water-level change in uncertain?



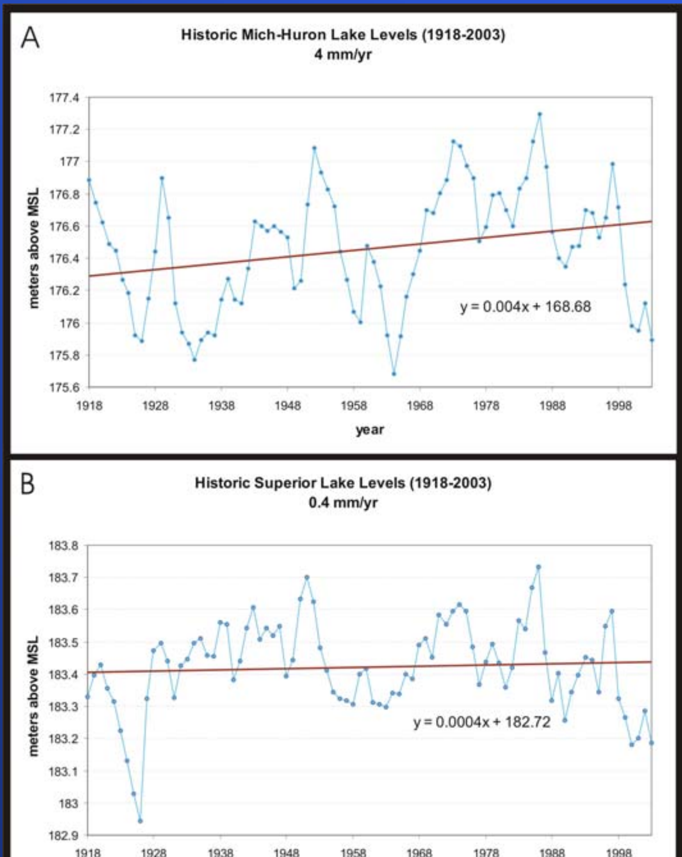
Apostle Islands NL, WI



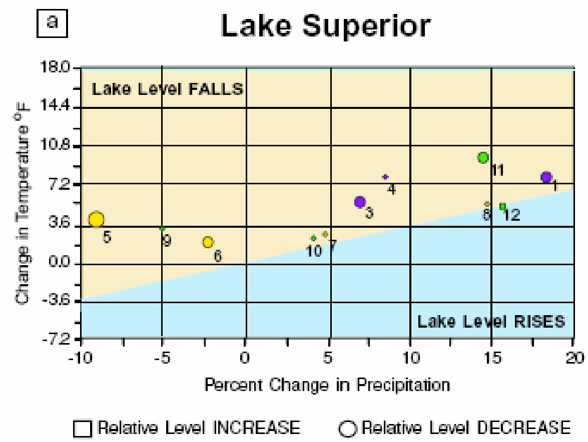
Indiana
Dunes NL, IN

Sleeping Bear
Dunes NL, MI

Historic lake-level trends vs. model predictions for the future

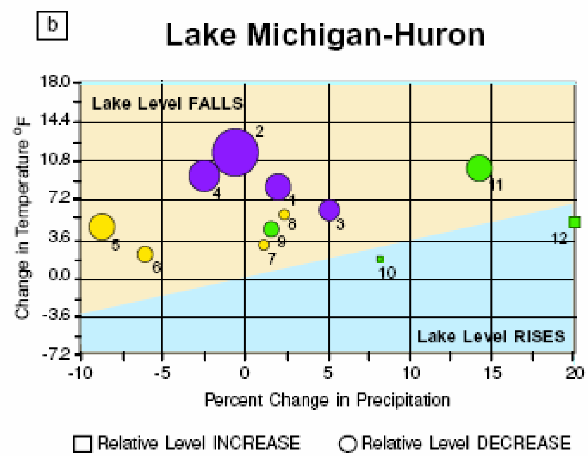


(Great Lakes Environmental Research Laboratory)



	MODEL	PERIOD	TYPE	ΔLEVEL
1	GISS	2XCO$_2$	E	-1.54
2	GFDL	2XCO$_2$	E	failed
3	OSU	2XCO$_2$	E	-1.51
4	CCC1	2XCO$_2$	E	-0.75
5	MOTR2	2020	T	-2.62
6	CCTR2	2020	T	-1.64
7	GFTR2	2020	T	-0.66
8	HCTR2	2020	T	-0.33
9	CGCM1	2030	T	-0.72
10	HadCM2	2030	T	-0.03
11	CGCM1	2090	T	-1.38
12	HadCM2	2090	T	+0.36

E: Equilibrium model
T: Transient model



	MODEL	PERIOD	TYPE	ΔLEVEL
1	GISS	2XCO$_2$	E	-4.30
2	GFDL	2XCO$_2$	E	-8.13
3	OSU	2XCO$_2$	E	-3.25
4	CCC1	2XCO$_2$	E	-5.31
5	MOTR2	2020	T	-4.59
6	CCTR2	2020	T	-2.95
7	GFTR2	2020	T	-1.31
8	HCTR2	2020	T	-1.64
9	CGCM1	2030	T	-2.36
10	HadCM2	2030	T	+0.16
11	CGCM1	2090	T	-4.53
12	HadCM2	2090	T	+0.16

E: Equilibrium model
T: Transient model

(US Global Change Research Program, 2000)

USGS

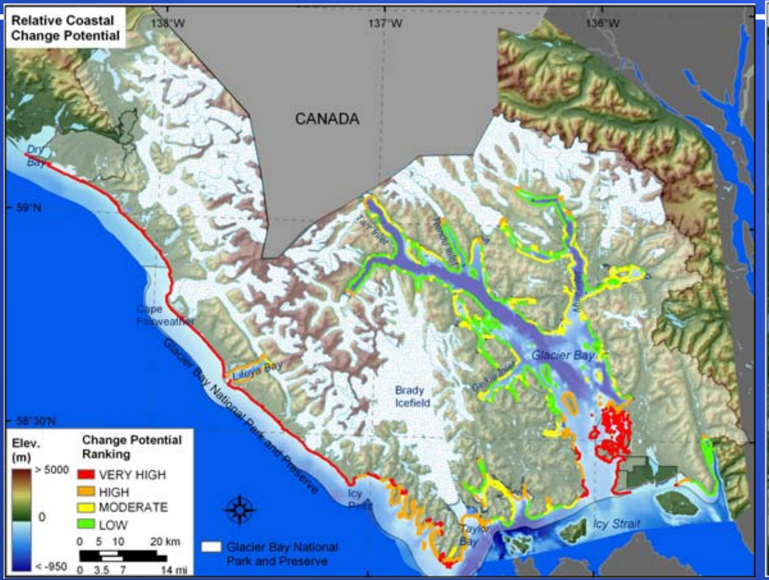
The CPI – Coastal Change-Potential Index

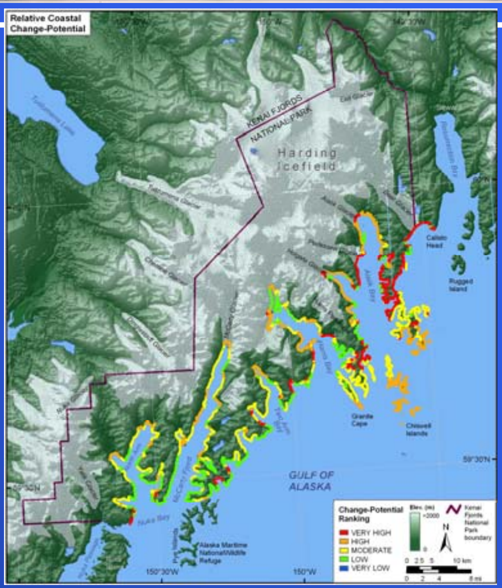
CPI Variables for the Great Lakes

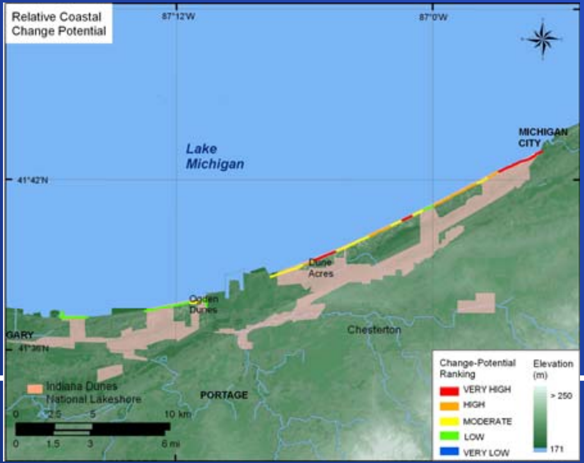
VARIABLES	VERY LOW 1	LOW 2	MODERATE 3	HIGH 4	VERY HIGH 5
GEOMORPHOLOGY	Rocky, cliffed coasts Fjords	Medium cliffs Indented coasts	Low cliffs Glacial drift Alluvial plains	Cobble Beaches Estuary Lagoon	Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mangroves, Coral reefs
Shoreline change (m/yr)	N/A	0 - ± 1	± 1 - ±2	> ± 2	N/A
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
Lake-level change (mm/yr)	0	0.1 –3.0	3.1 – 6.0	6.1 – 9.0	> 9.0
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 Annual Ice Cover (days)	> 135	106 - 135	61 - 105	30 - 60	< 30

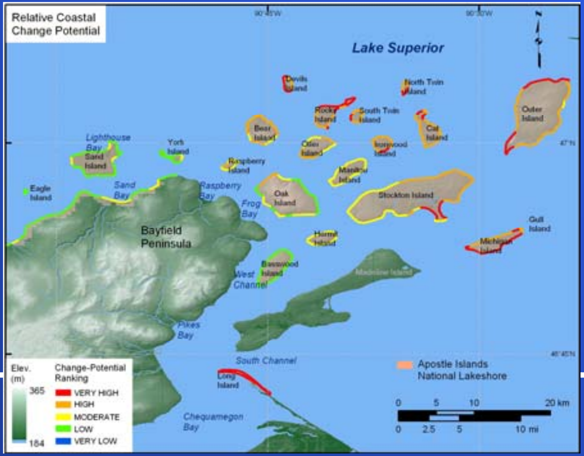
USGS

The CPI Parks









Summary

Conclusions

- As an indication of where physical changes along the shore are likely to occur as sea level changes
- As a planning tool for park managers

Products

- Online Open File Report for each park
- Shapefiles with metadata for each park containing all variable information as well as CVI data
- Photographs from field visits

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

http://pubs.er.usgs.gov/

Limitations

- Scale dependent
- Planning tool for long-term management.
  - Doesn’t account for episodic events/hazards
    - Storms
    - Tsunamis
    - Earthquakes
    - Landslides
    - location specific biologic feedbacks
- Applies best on open ocean coasts where there is variability in factors that determine the CVI
- The CVI cannot be equated with a physical change.

Conclusions

- CVI is a good first step
- Can be applied to almost any coast where assessment data is available
- Provides a visual product that can be used by managers to highlight areas that may be most vulnerable to physical changes as a result of sea or water-level change.

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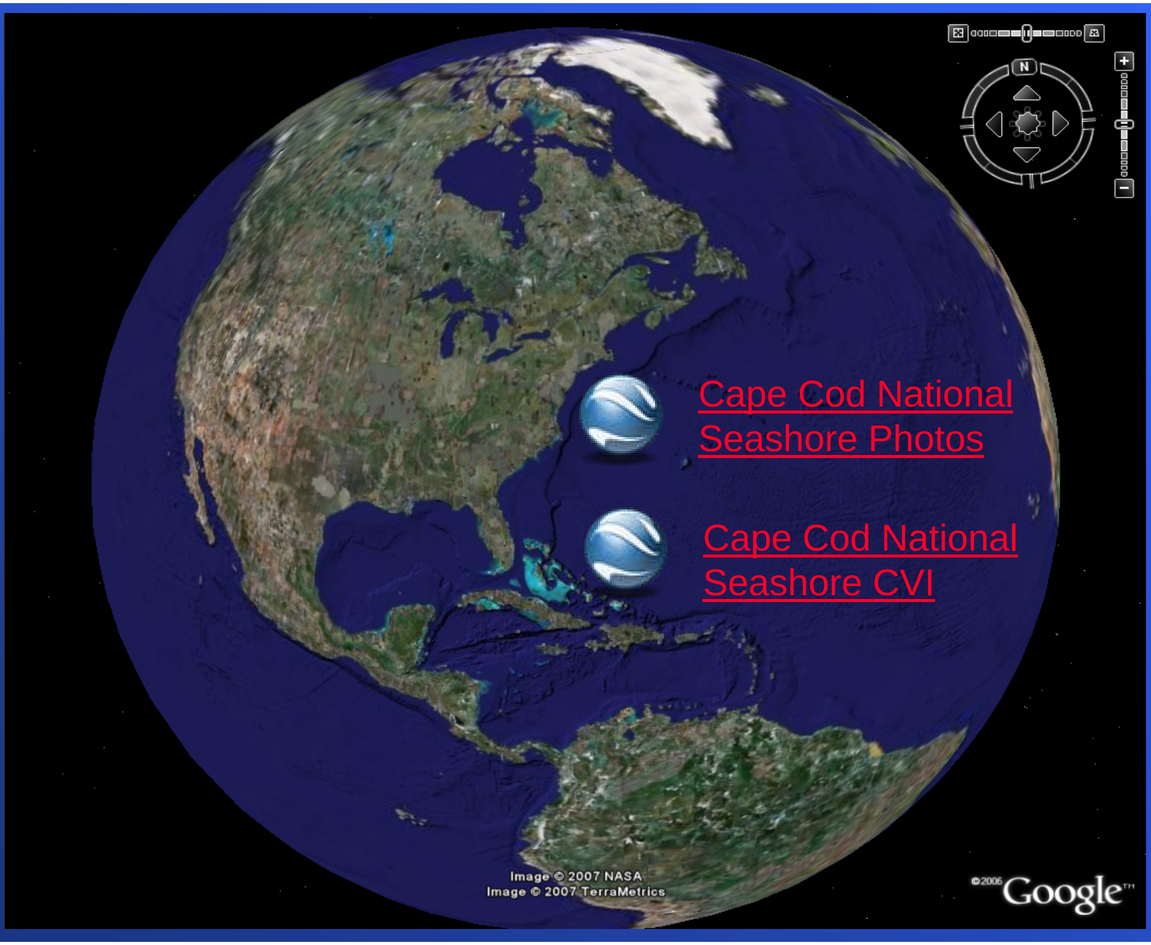
Visualizing Coastal Vulnerability with Google Earth™

Elizabeth A. Pendleton, E. Robert Thieler, S. Jeffress Williams, and Erika S. Hammar-Kose

U.S. Department of the Interior
U.S. Geological Survey

Cape Cod NS Coastal Vulnerability

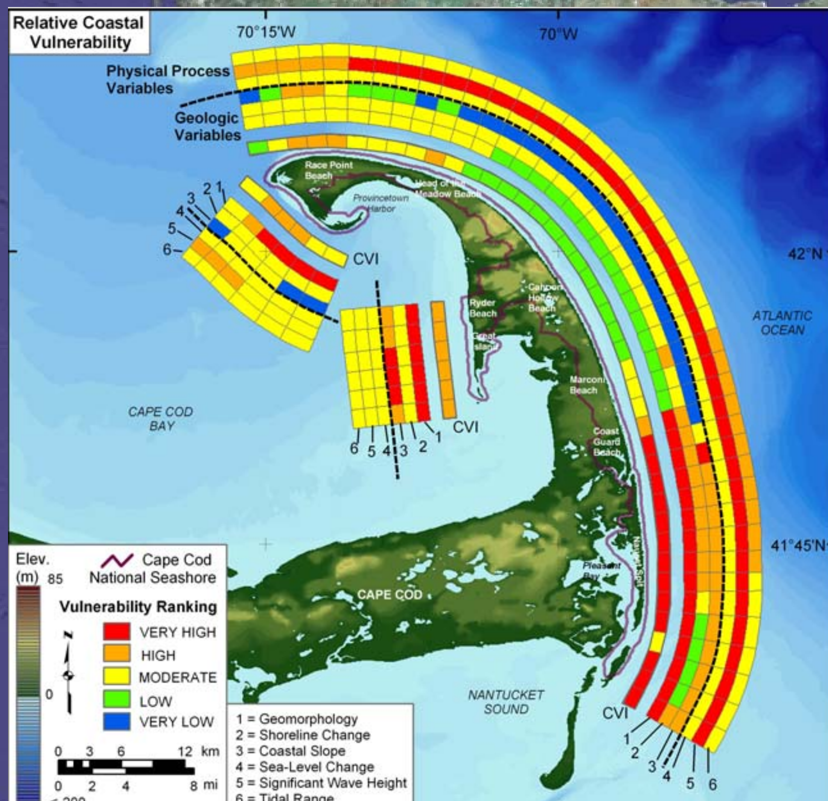


USGS

in Google Earth™

NATIONAL PARK SERVICE

Cape Cod National Seashore



Cape Cod National Seashore Photos

Cape Cod National Seashore CVI

Methodology

- (Gornitz and others, 1990 - 1994)
- (Shaw and others, 1998)
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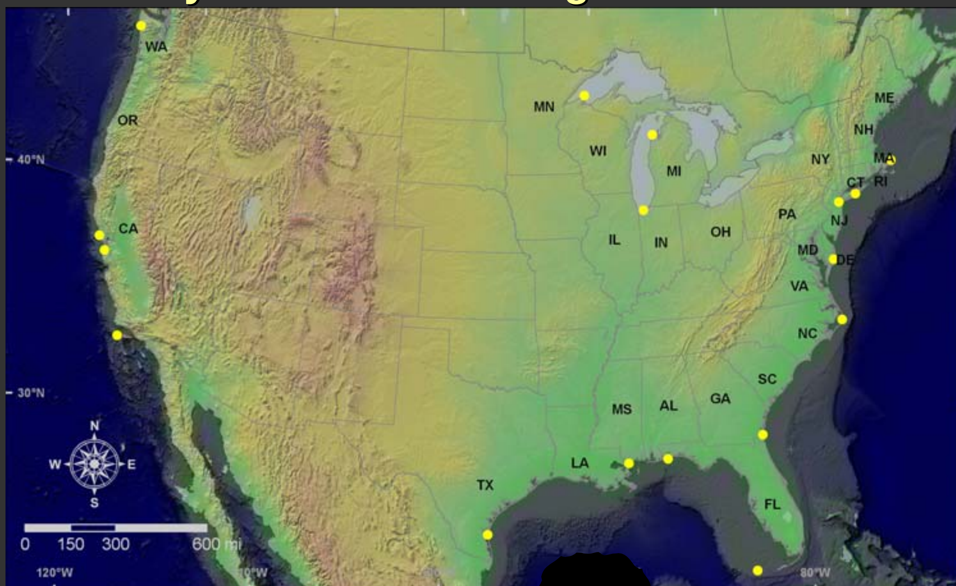
USGS

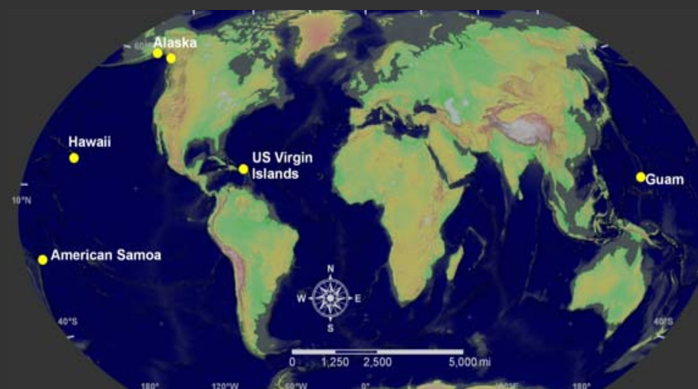
The NPS CVI project

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

CVI study sites in the Contiguous U.S.



CVI study sites in Hawaii, Alaska, and U.S. Territories



Cape Cod NS
Fire Island NS
Gateway NRA
Gulf Islands NS
Cape Hatteras NS

Cumber sland NS
Assateag sland NS
ry To P
Pa
Channe NP

Golden Gate NRA
Point Reyes NS
Olympic NP
Apostle Islands NL
Indiana Dunes NL

Sleeping Bear Dunes NL
Kenai Fjord NP
Glacier Bay NPP
Kaloko-Honokohau NHP
NP of American Samoa
Virgin Islands NP
War in the Pacific NHP

USGS

Cape Cod National Seashore

http://pubs.usgs.gov/of/2002/of02-233/

Available products

- USGS Open File Report
  HTML and printable PDF
- CVI spatial data and metadata
- Field photographs

Future products

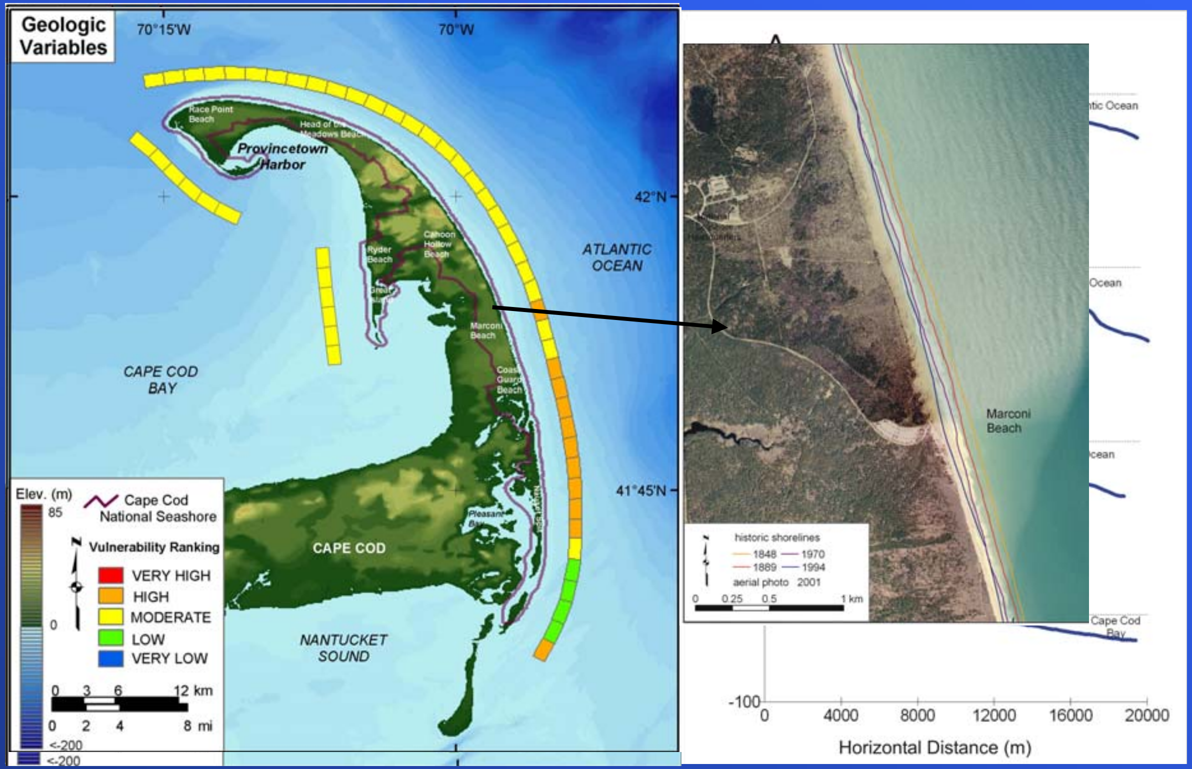
- *.kml and *.kmz for GE

USGS

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

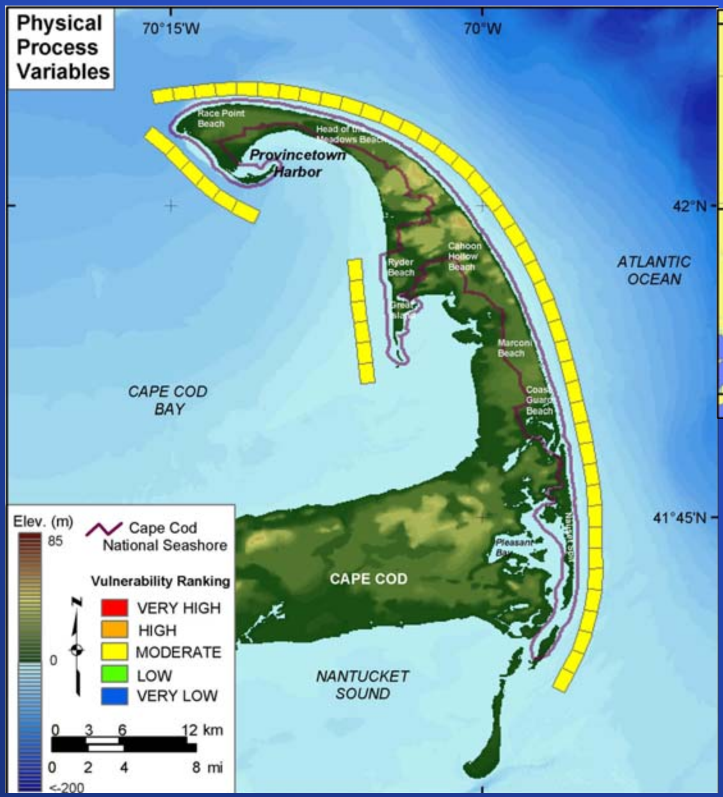
NATIONAL PARK SERVICE

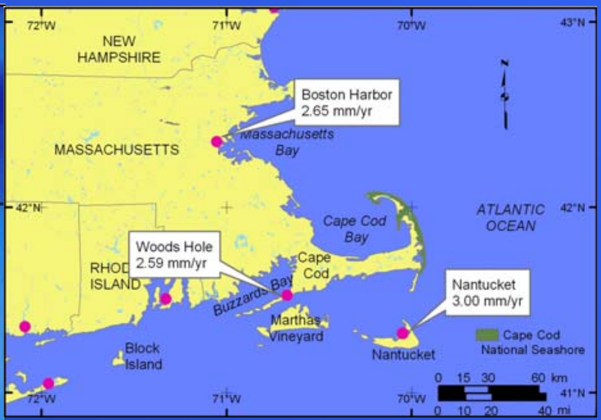
Geology of Cape Cod NS



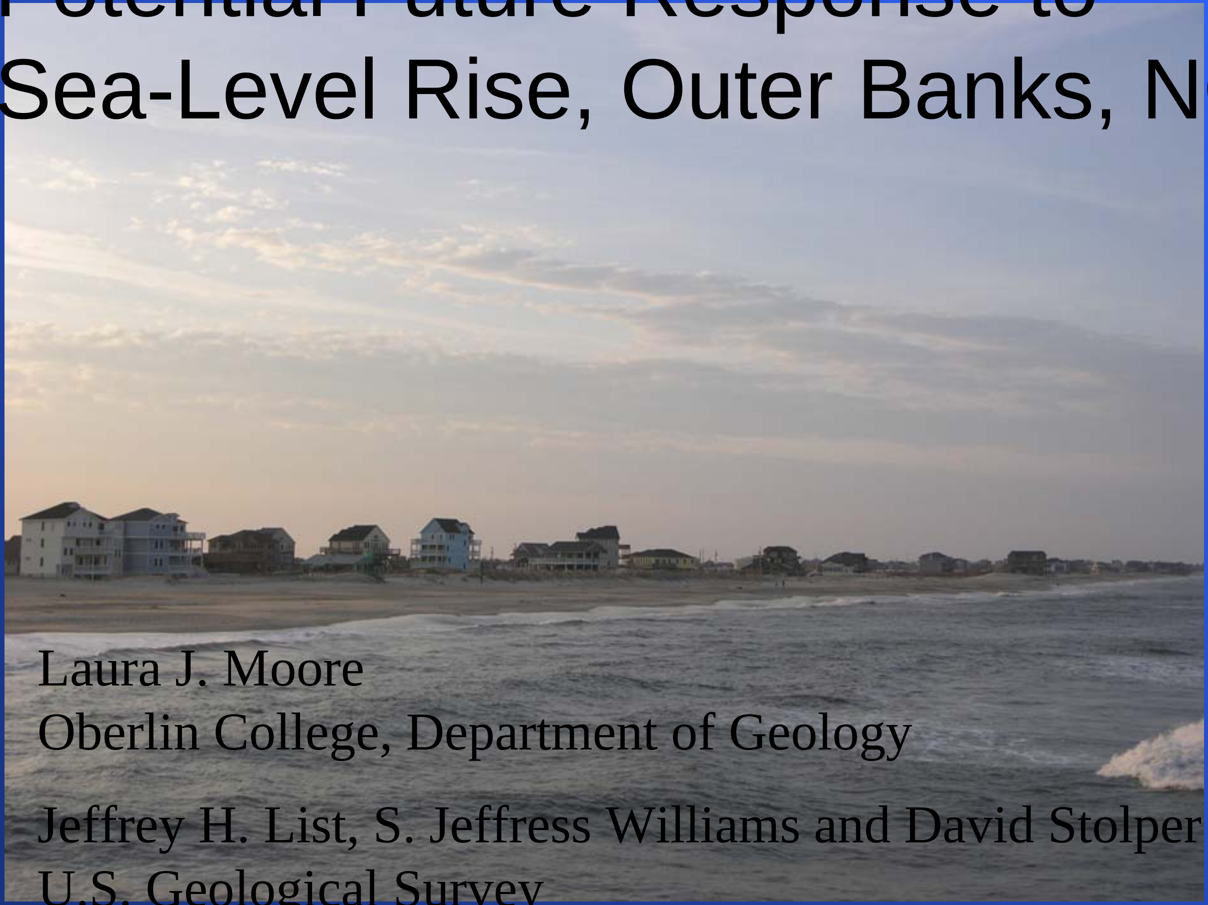
Massachusetts Office of COASTAL ZONE MANAGEMENT

Physical Processes on Cape Cod NS





Modeling Barrier Island Evolution and Potential Future Response to Sea-Level Rise, Outer Banks, NC



Laura J. Moore
Oberlin College, Department of Geology

Jeffrey H. List, S. Jeffress Williams and David Stolper
U.S. Geological Survey

(NASA photo)

Modeling Summary

- For NC barriers, sea-level rise rate is most important in determining migration rates. Sediment supply modifies rates.

- 8500-yr Holocene model simulation with closure depth of -20 m and removal of 4.5 x 10^9 m^3 to shoals reproduces modern barrier/shelf morphology.

- If sea-level rises ~0.9 m by 2100 AD, the NC barriers may migrate up to 3x more rapidly than at present.

- If sea-level rises above IPCC predictions by 2100, reaching 1.4-1.9 m above MSL, the Outer Banks may become vulnerable to system-wide “threshold collapse.”

USGS

USGS North Carolina Coastal Geology Cooperative Study

- USGS/Woods Hole Science Center
- East Carolina University
- North Carolina Geological Survey
- Virginia Institute of Marine Science
- University of Delaware
- University of Pennsylvania
- Other collaborators
  - USGS/WRD
  - USACE
- Other partners
  - NPS, FWS, MMS, ONR, ARO, NSF, EDF, NC DOT, NC Parks

USGS

(NASA photo)

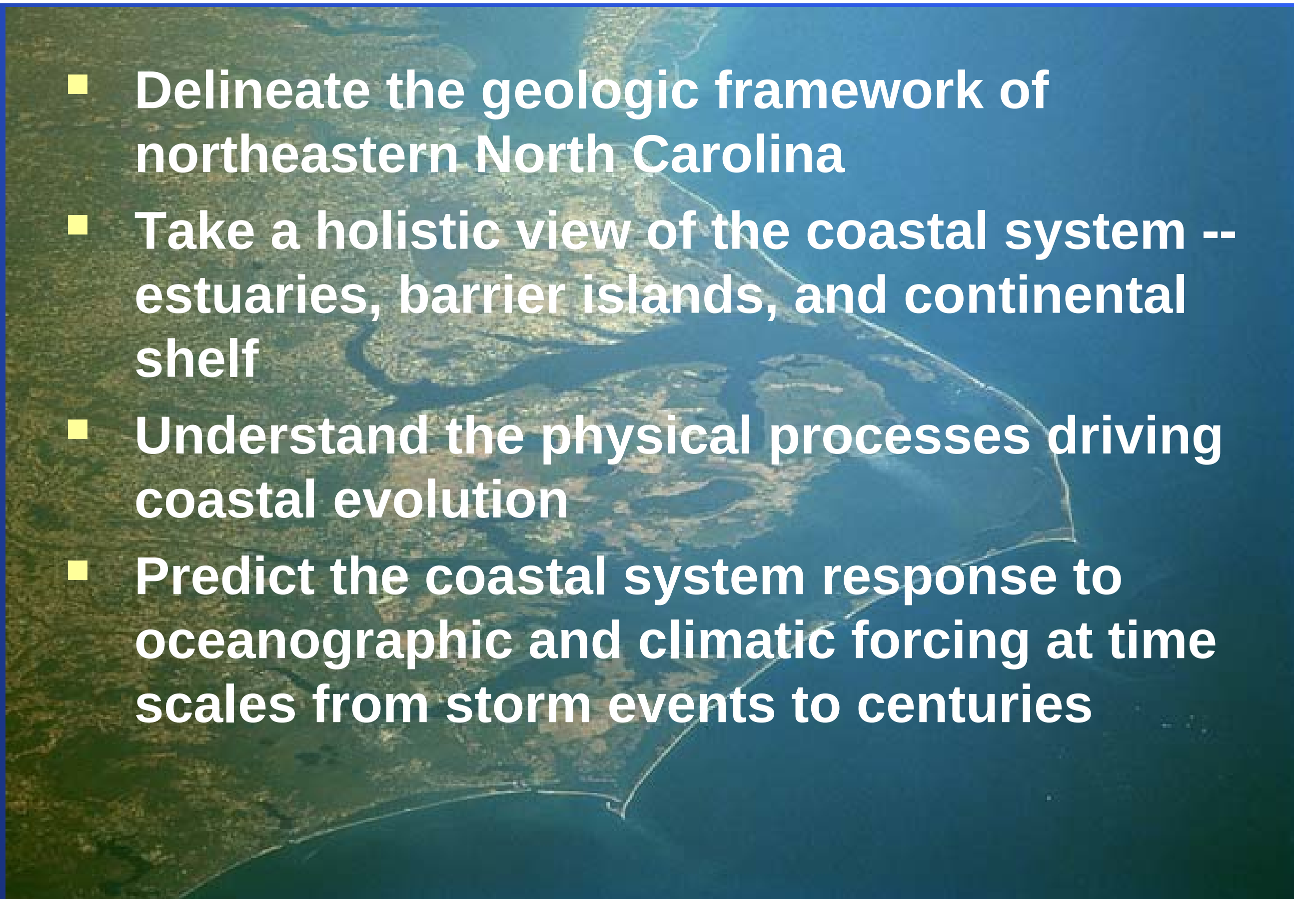
USGS
science for a changing world

Visualizing Coastal Vulnerability at Cape Cod National Seashore with Google Earth™

Elizabeth A. Pendleton, E. Robert Thieler, S. Jeffress Williams, and Erika S. Hammar-Klose

U.S. Department of the Interior
U.S. Geological Survey

Study Objectives



- **Delineate the geologic framework of northeastern North Carolina**
- **Take a holistic view of the coastal system -- estuaries, barrier islands, and continental shelf**
- **Understand the physical processes driving coastal evolution**
- **Predict the coastal system response to oceanographic and climatic forcing at time scales from storm events to centuries**

USGS

(NASA photo)

The Coast of the Future

- Accelerating sea-level rise (>50cm by 2100) and increased storminess due to climate change will increase coastal flooding, erosion, and wetland loss

- Barrier islands, low-lying coasts and port cities will be at greater risk from coastal erosion, more intense storms, storm-surge flooding

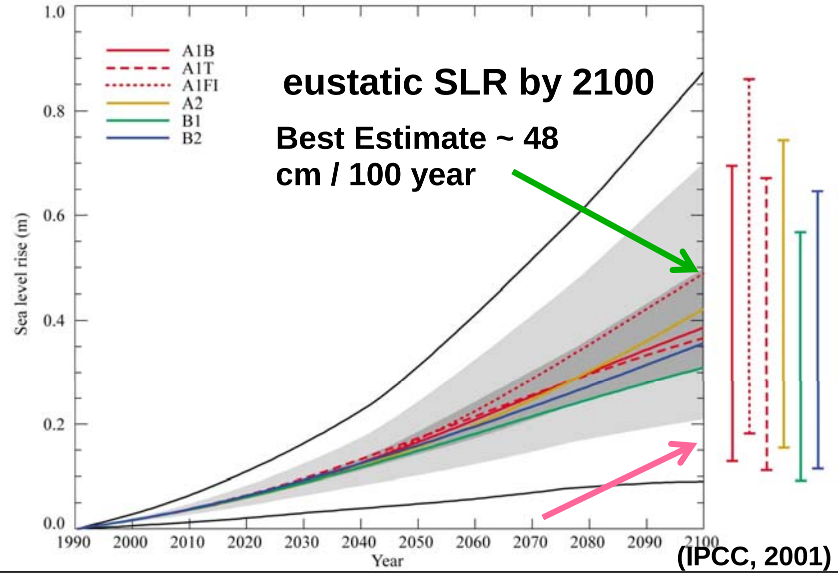
- Ocean salt water will intrude farther into estuaries and coastal aquifers, altering wetland habitats and polluting fresh-water resources

- The Gulf and Atlantic coast will be most vulnerable. Higher-elevation rocky New England and Pacific coast may experience fewer impacts

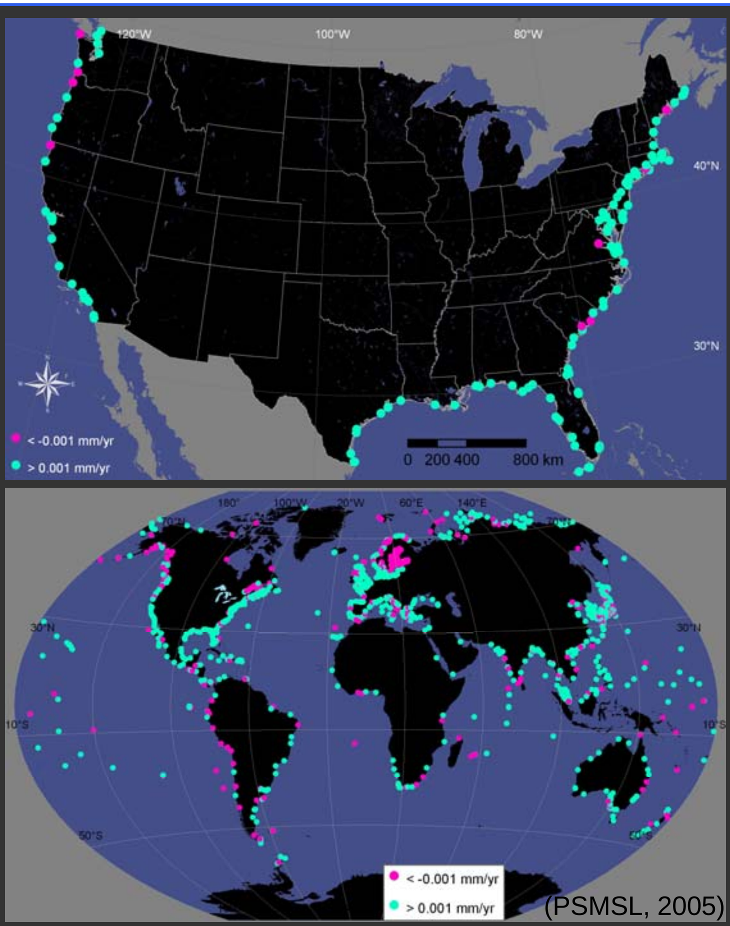
- Use of coastal setbacks, easements, and “soft” engineering can protect shoreline integrity and public resources

Global and relative sea-level

Global / eustatic	Relative
•Change in volume of water in oceans	•uplift
•Thermal expansion (steric rise)	•subsidence



(IPCC, 2001)



(PSMSL, 2005)