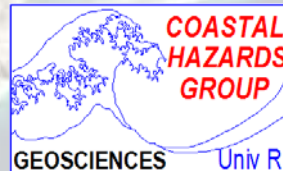


CLIMATE CHANGE, SEA-LEVEL RISE and COASTAL GEOLOGIC HAZARDS

***AWESOME Watershed Science for Educators
27 April 2011***

***Jon C. Boothroyd
Rhode Island State Geologist,
Research Professor Emeritus – Quaternary Geology***

***-----
Rhode Island Geological Survey and Department of Geosciences
College of the Environment and Life Sciences
University of Rhode Island
jon_boothroyd@uri.edu***

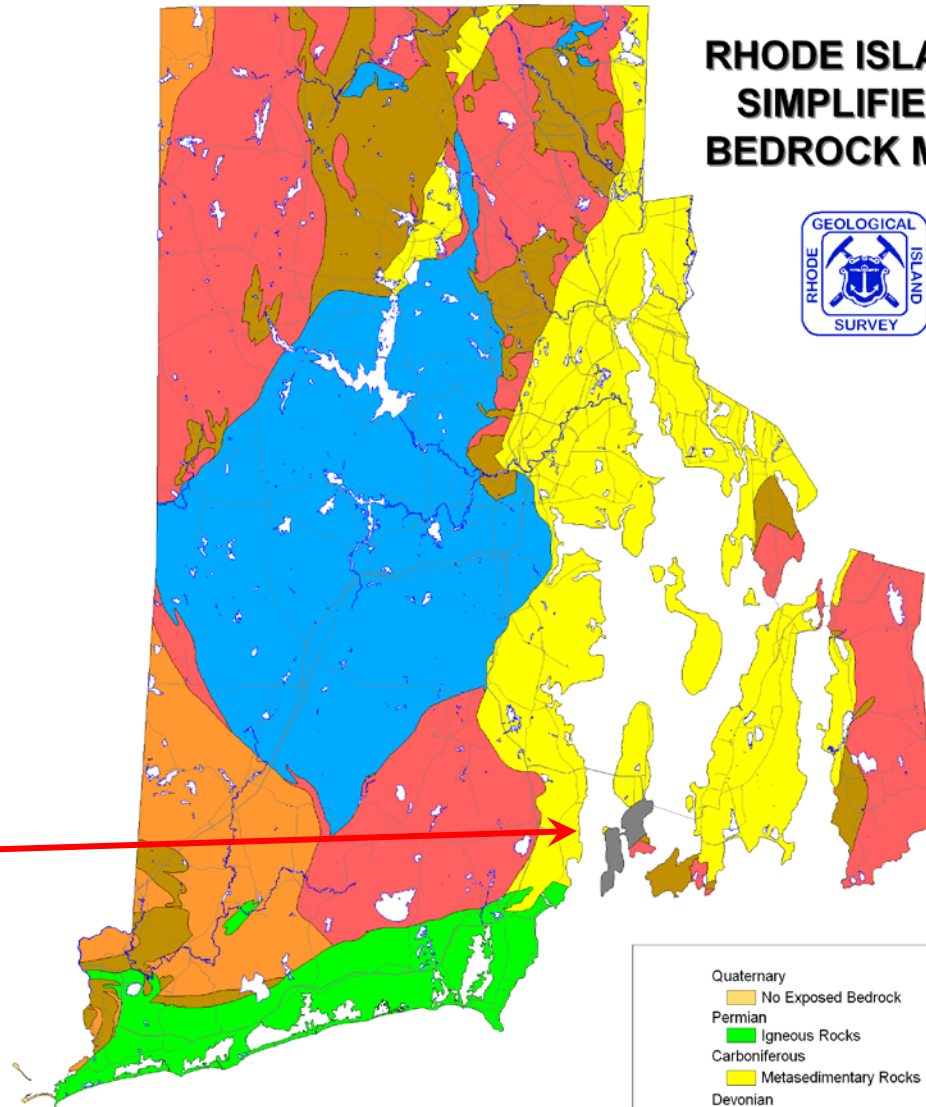
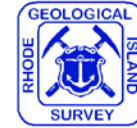


An aerial photograph of a coastal region, likely San Francisco Bay, showing the city of San Francisco on the left and various islands and peninsulas to the right. The water is a deep blue, and the land is a mix of green and brown, indicating urban and natural areas. The text is overlaid on the water in the upper center.

***First,
Some Geological
Background Information***

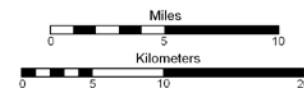
You are
here

RHODE ISLAND SIMPLIFIED BEDROCK MAP

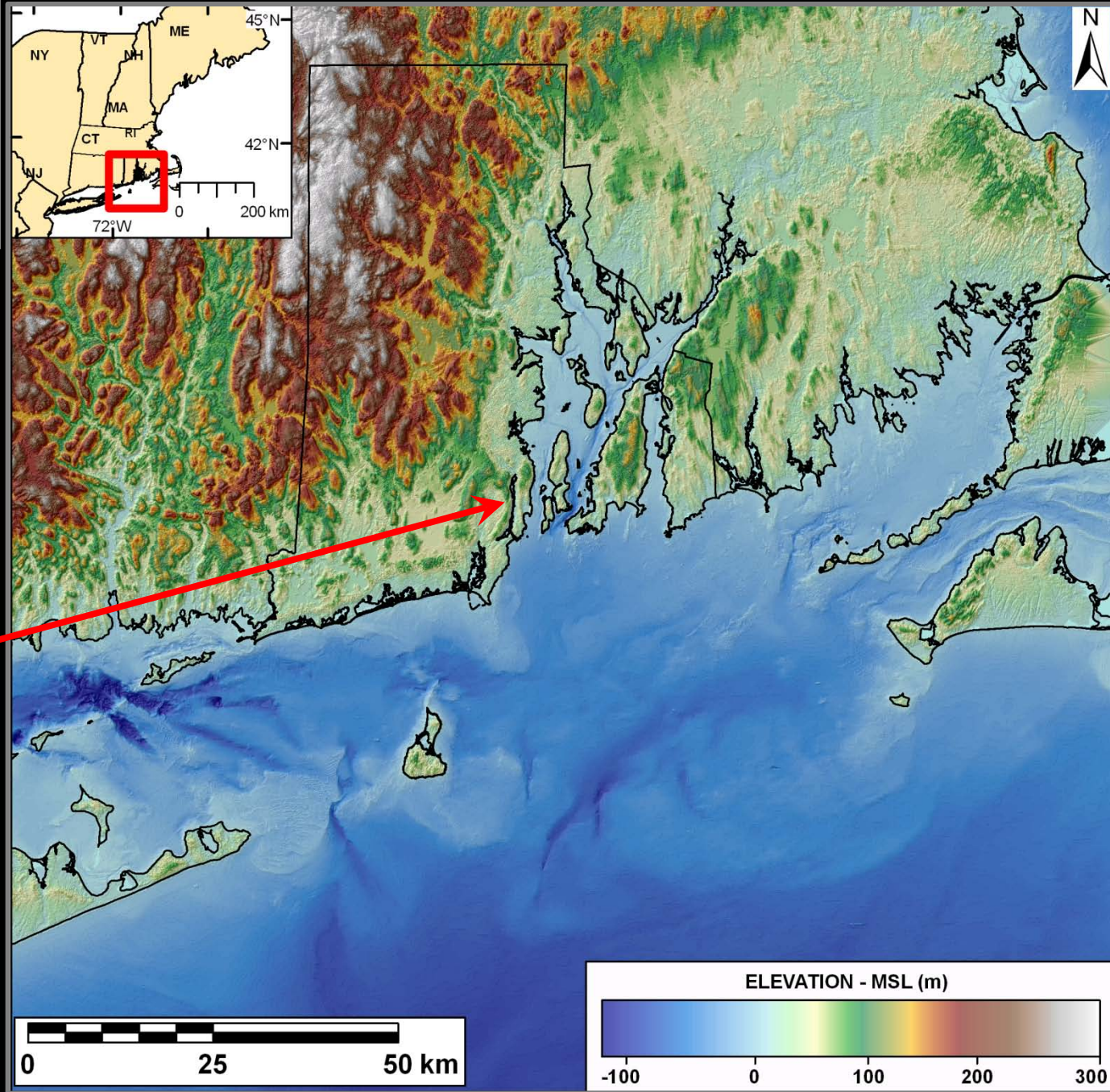


- Quaternary
- No Exposed Bedrock
- Permian
- Igneous Rocks
- Carboniferous
- Metasedimentary Rocks
- Devonian
- Igneous Rocks
- Cambrian
- Metasedimentary Rocks
- PreCambrian
- Igneous Rocks
- Gneissic Rocks
- Metastratified Rocks

Modified from:
Hermes, O.D., Gromet, L.P., and Murray, D.P. (compilers). 1994.
Bedrock geologic map of Rhode Island:
Rhode Island Map Series No. 1,
University of Rhode Island, Kingston.
Scale 1:100,000.



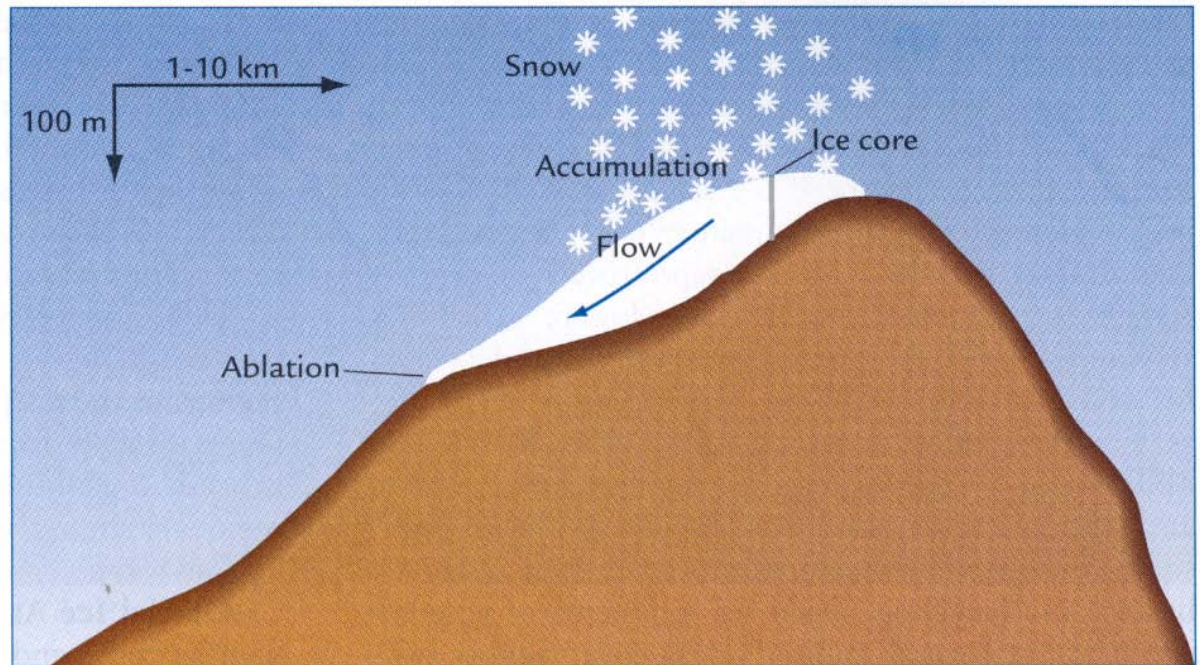
Geomorphology of Southeastern New England



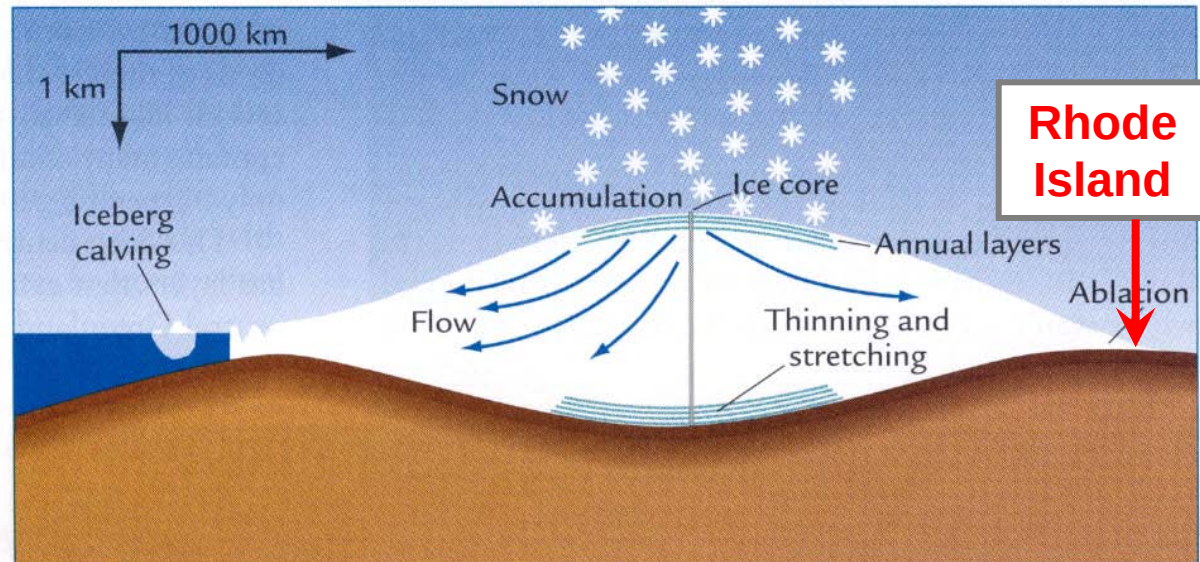
**You are
Here**

Continental Glaciation

W F Ruddiman, 2001

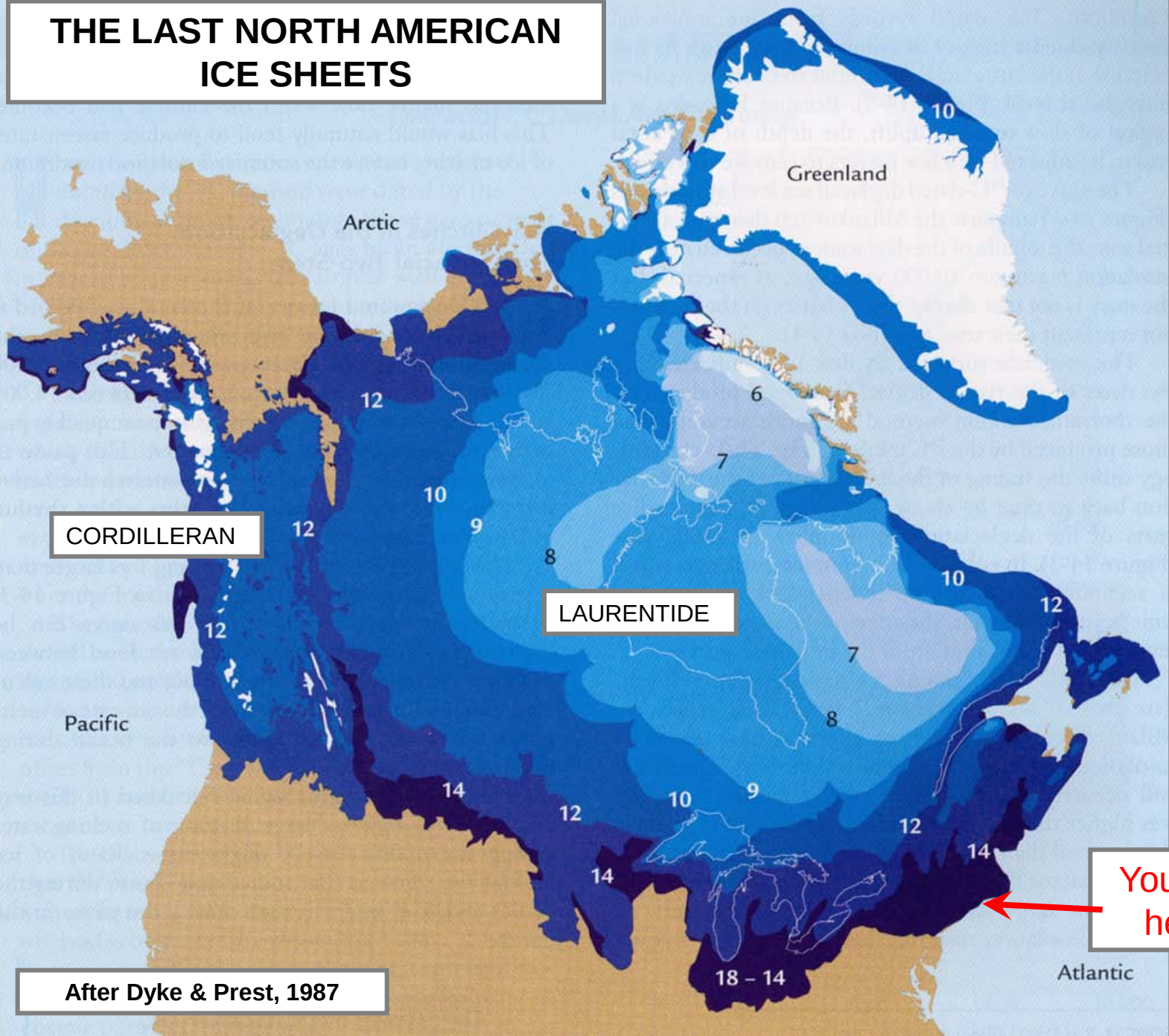


A Mountain glaciers

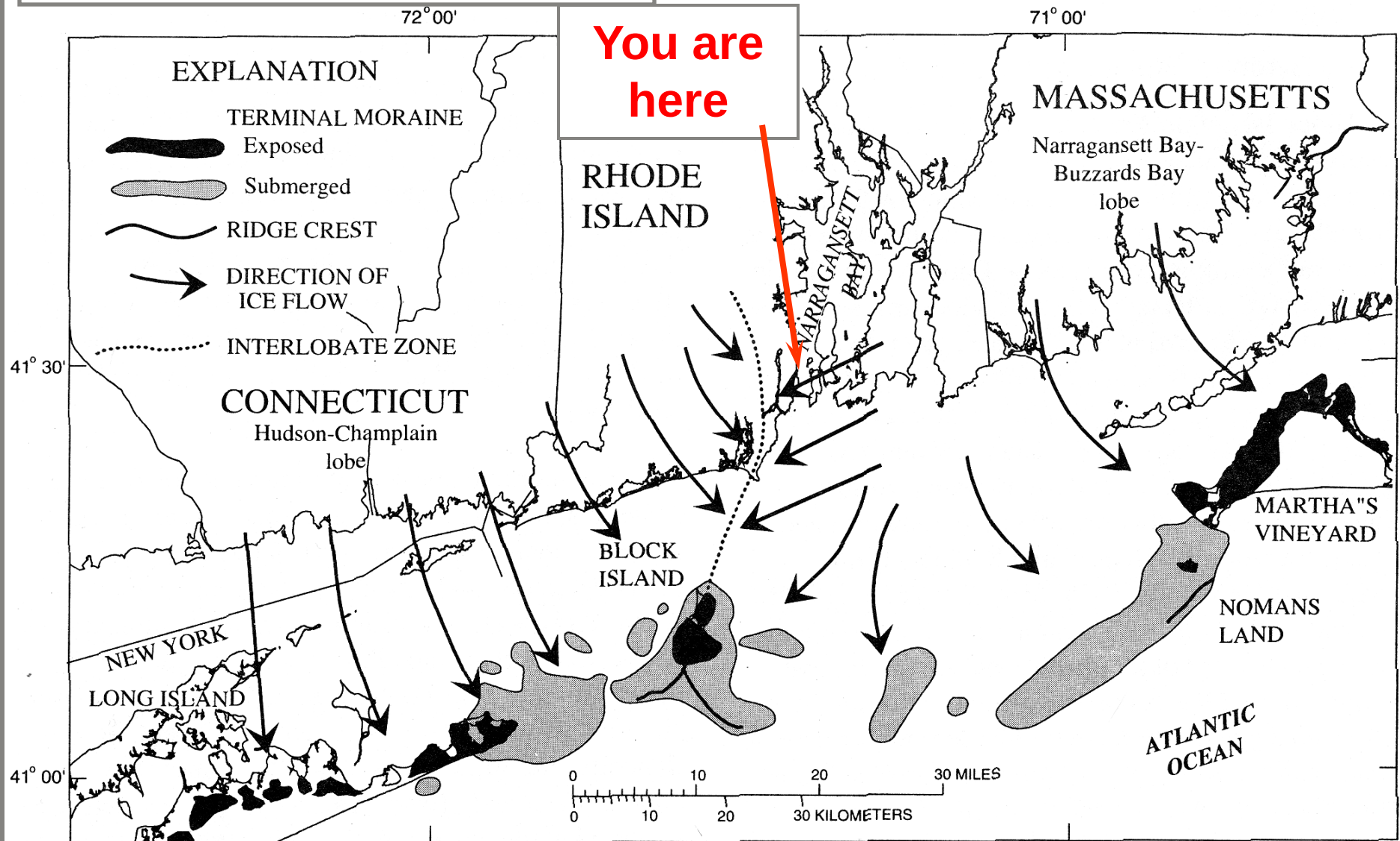


B Continental ice sheets

THE LAST NORTH AMERICAN ICE SHEETS

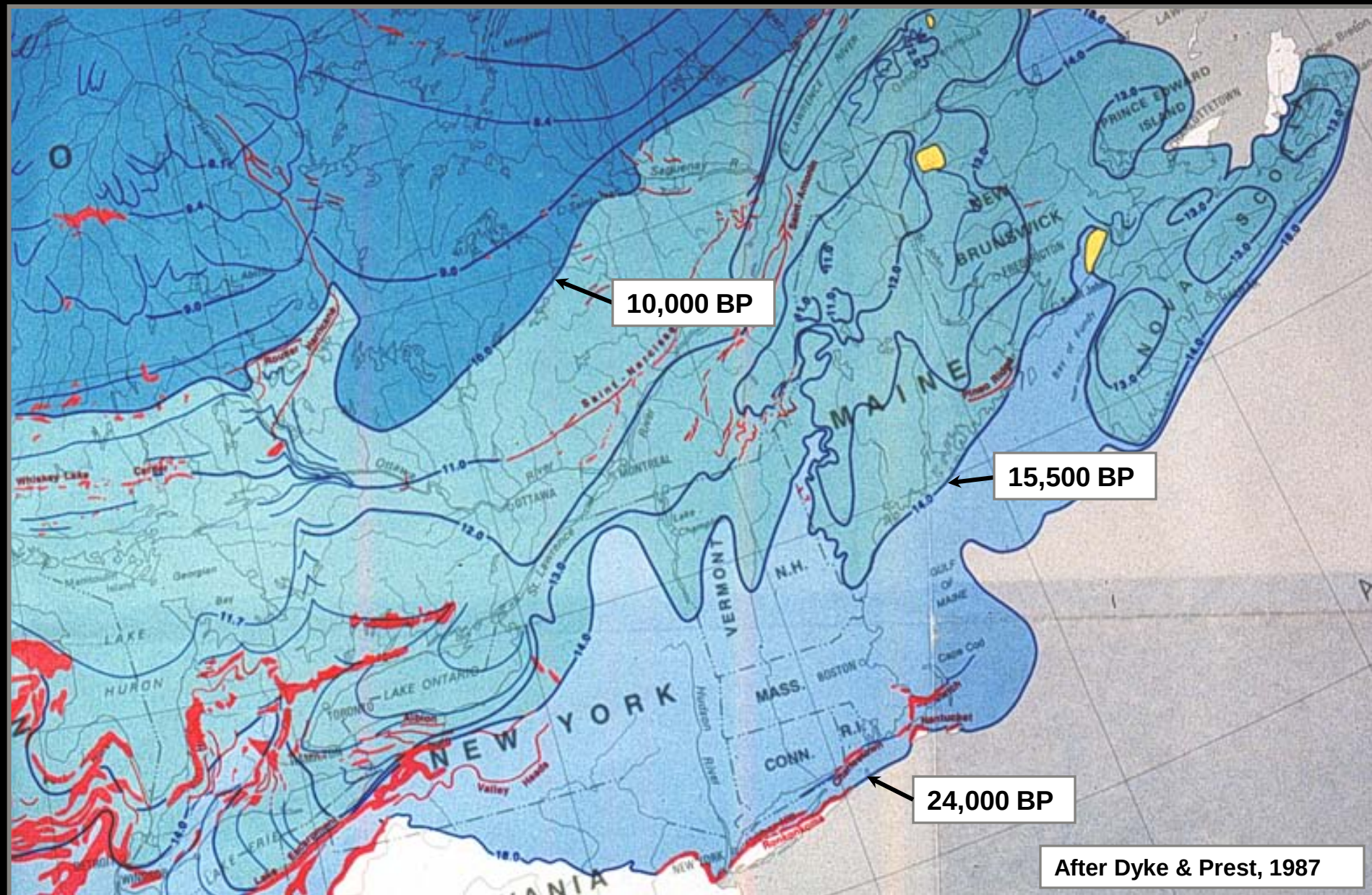


Ice Flow Directions



Base from U.S. Geological Survey, Digital Line Graphs, 1:100,000, 1983

Laurentide Ice Retreat



cal. age
(kyr B.P.)
CALIB 5.01

EXPLANATION:

() - estimates from J. Stone and others (1998)

[] - proposed correlations with Greenland ice core ^{18}O records (Boothroyd and others, 1998)

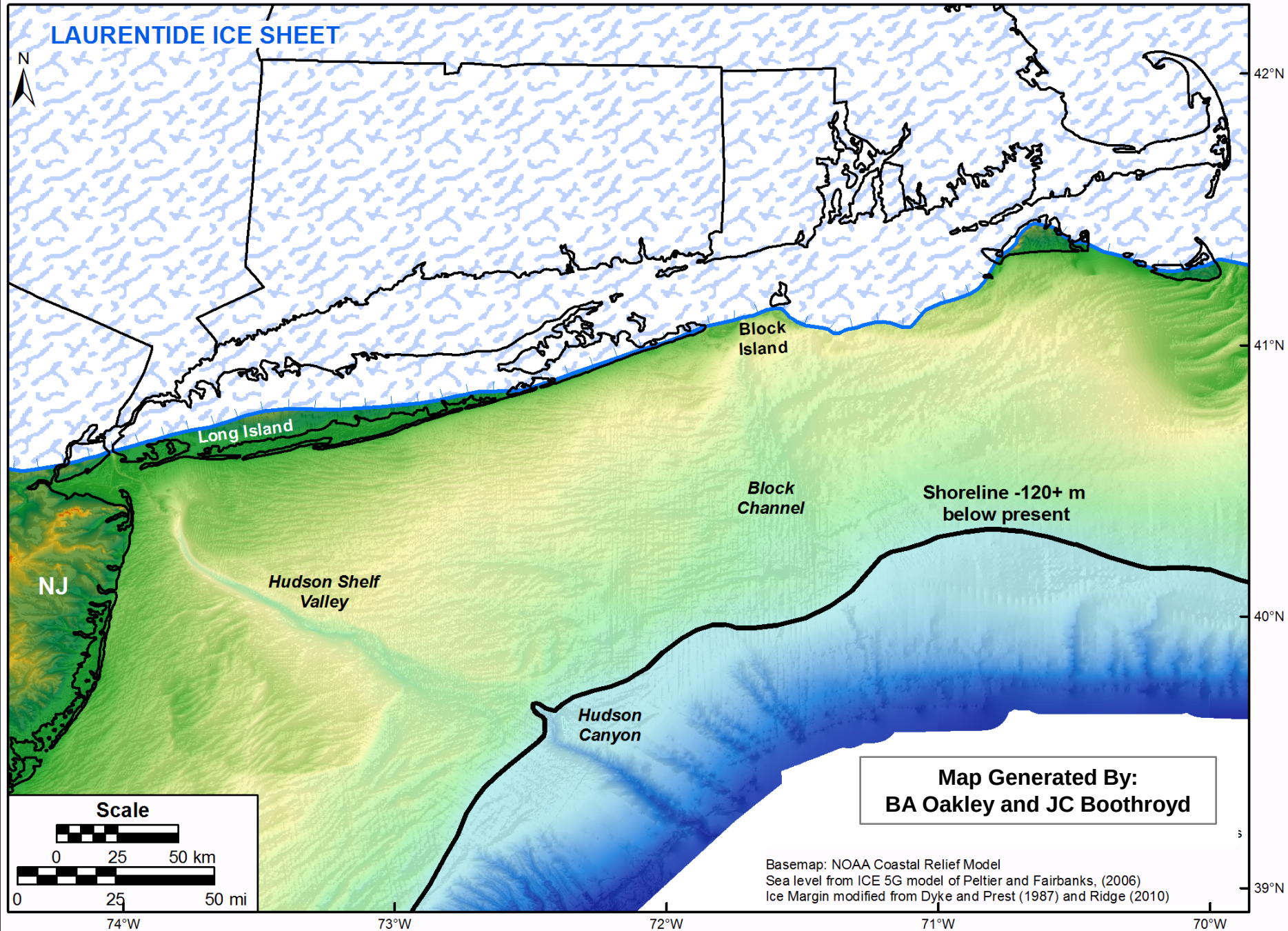
All other ages based on ^{14}C ages and ^{14}C -dated varve and paleomagnetic sequences, or are proposed corrections of lake-bottom, bulk-sediment, and marine ^{14}C ages.

Capitalized ice margin abbreviations are named moraines, readvances (arrows), and lakes. Small abbrev. in Connecticut Valley are local names.

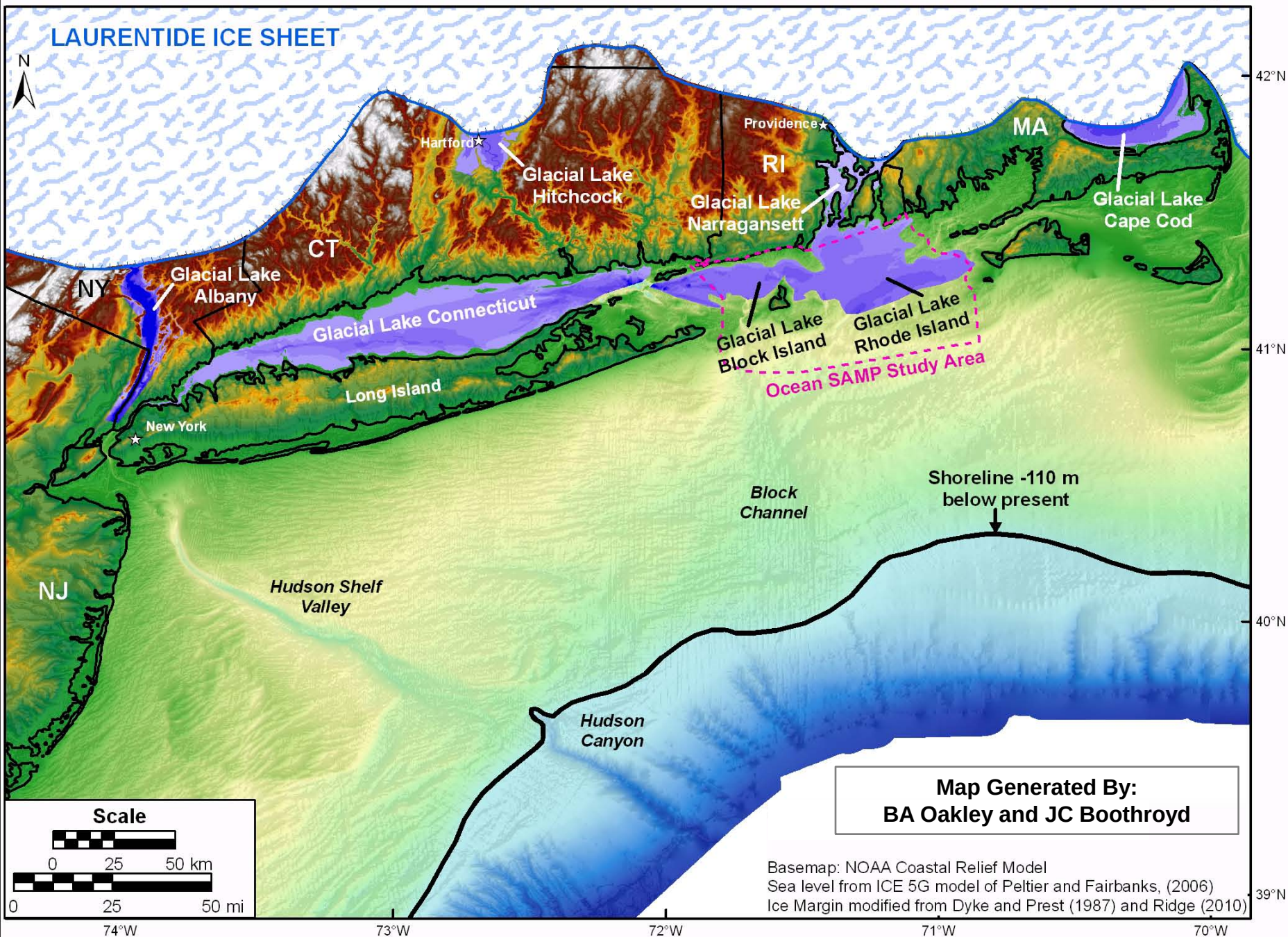
Ridge 2008

Ridge 2008

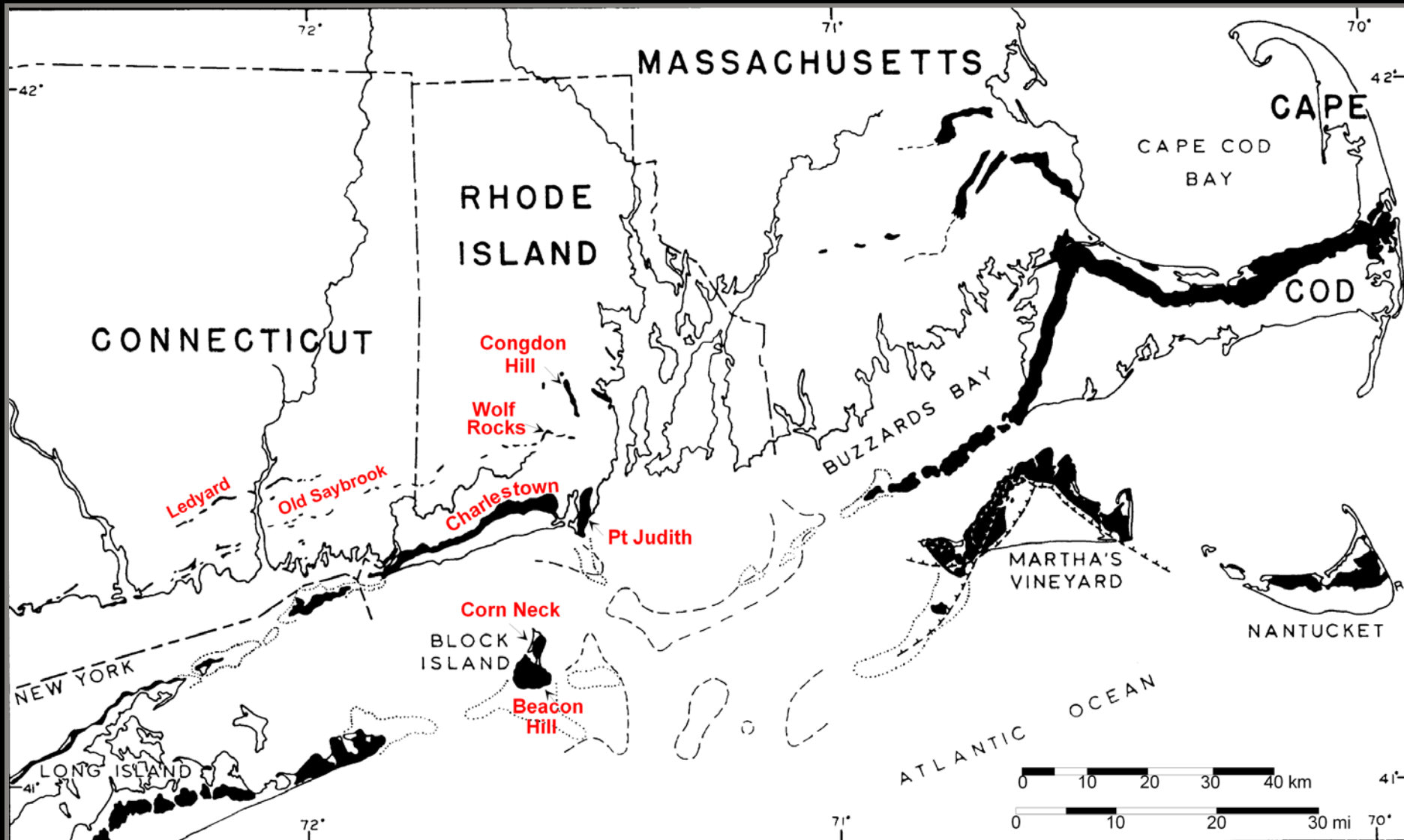
PALEOGEOGRAPHIC MAP OF SOUTHERN NEW ENGLAND - NEW JERSEY CONTINENTAL SHELF ~26,000 yBP



PALEOGEOGRAPHIC MAP OF THE SOUTHERN NEW ENGLAND CONTINENTAL SHELF 18,000 yBP



End Moraines of Southeastern New England



Schafer and Hartshorn, 1965; Goldsmith, 1982; Sirkin, 1982

QUATERNARY DEPOSITS OF RHODE ISLAND

Granitic Till Upland

Thick Stratified Deposits

Narragansett structural basin

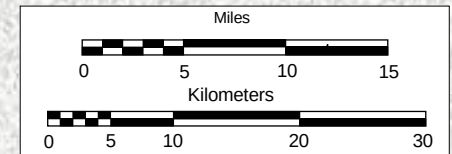
Compact Till Upland

You are here

Block Island
Complex

EXPLANATION

- Stratified Material
- Till
- End Moraine - Till and Stratified Material



Braided River on a Delta Plain

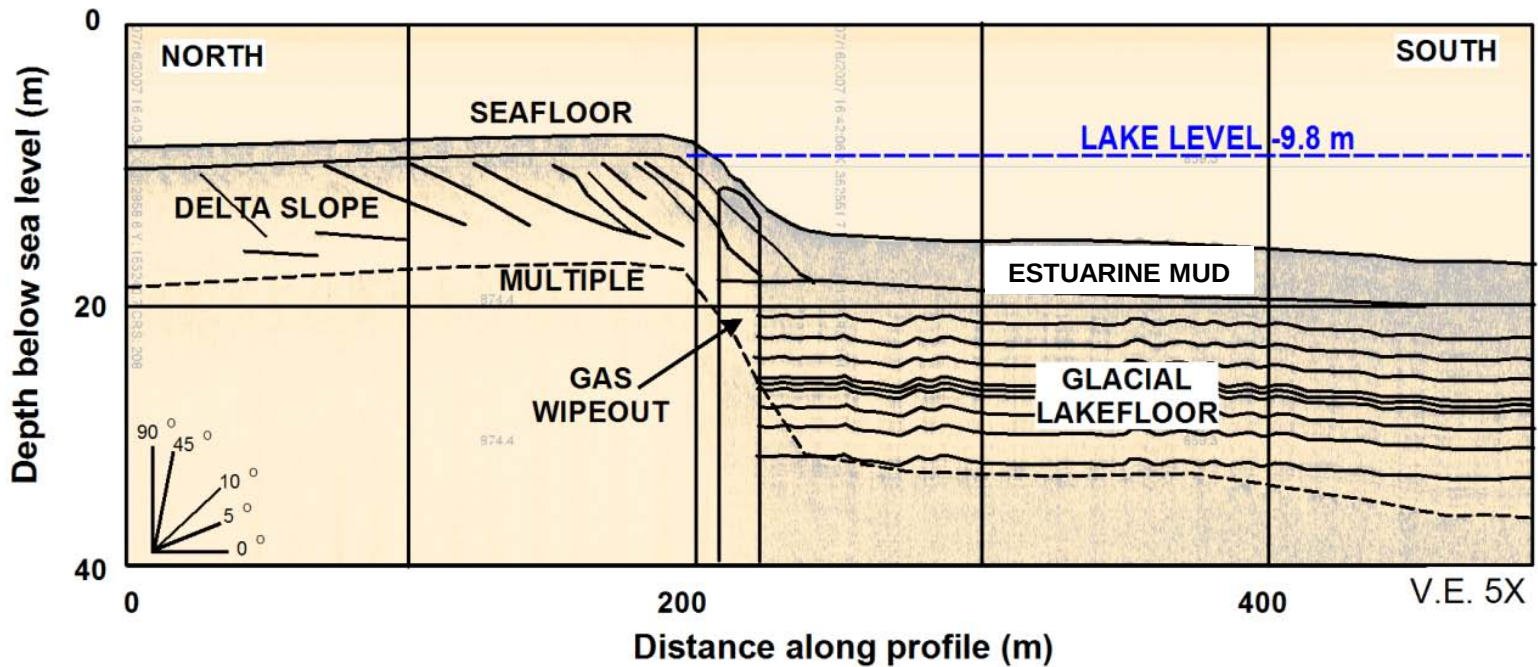
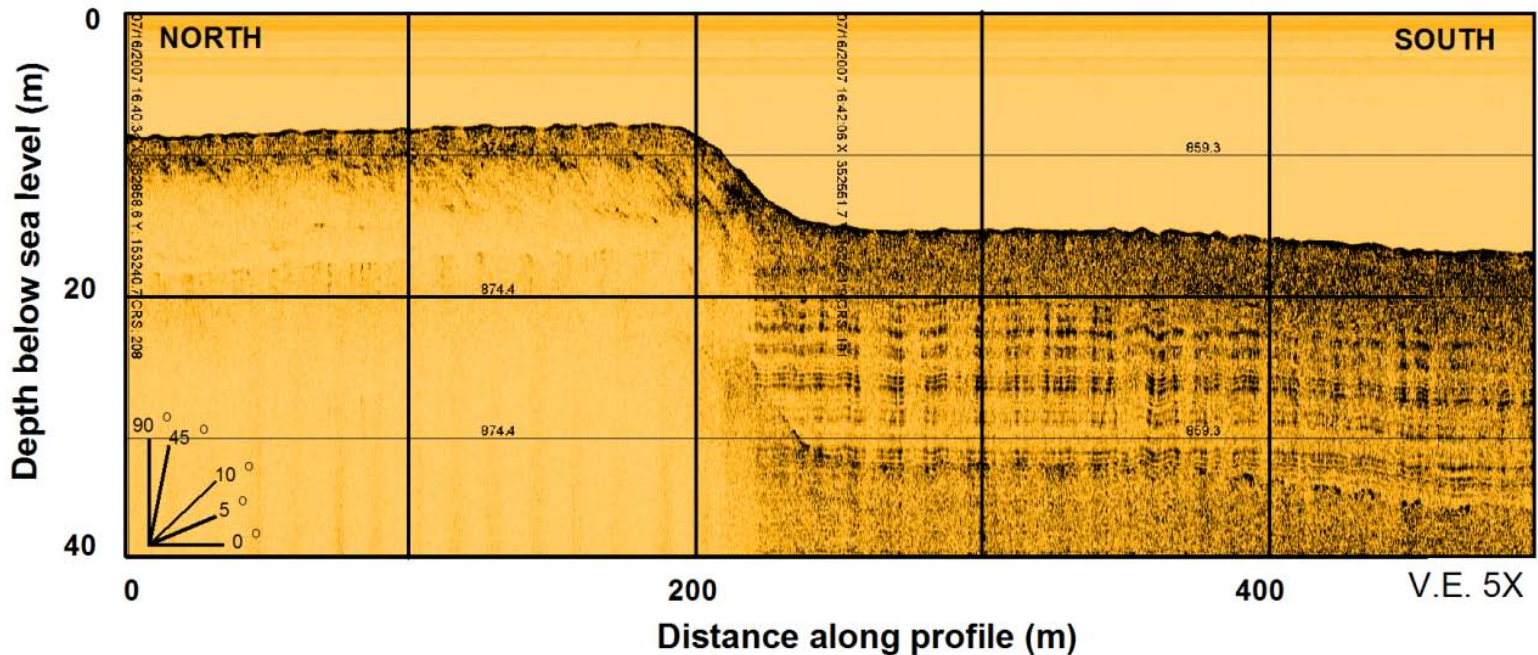


**A GLACIAL
DEPOSITIONAL
ENVIRONMENT**

Facies Deposited in a Glacial Lake Depositional Environment

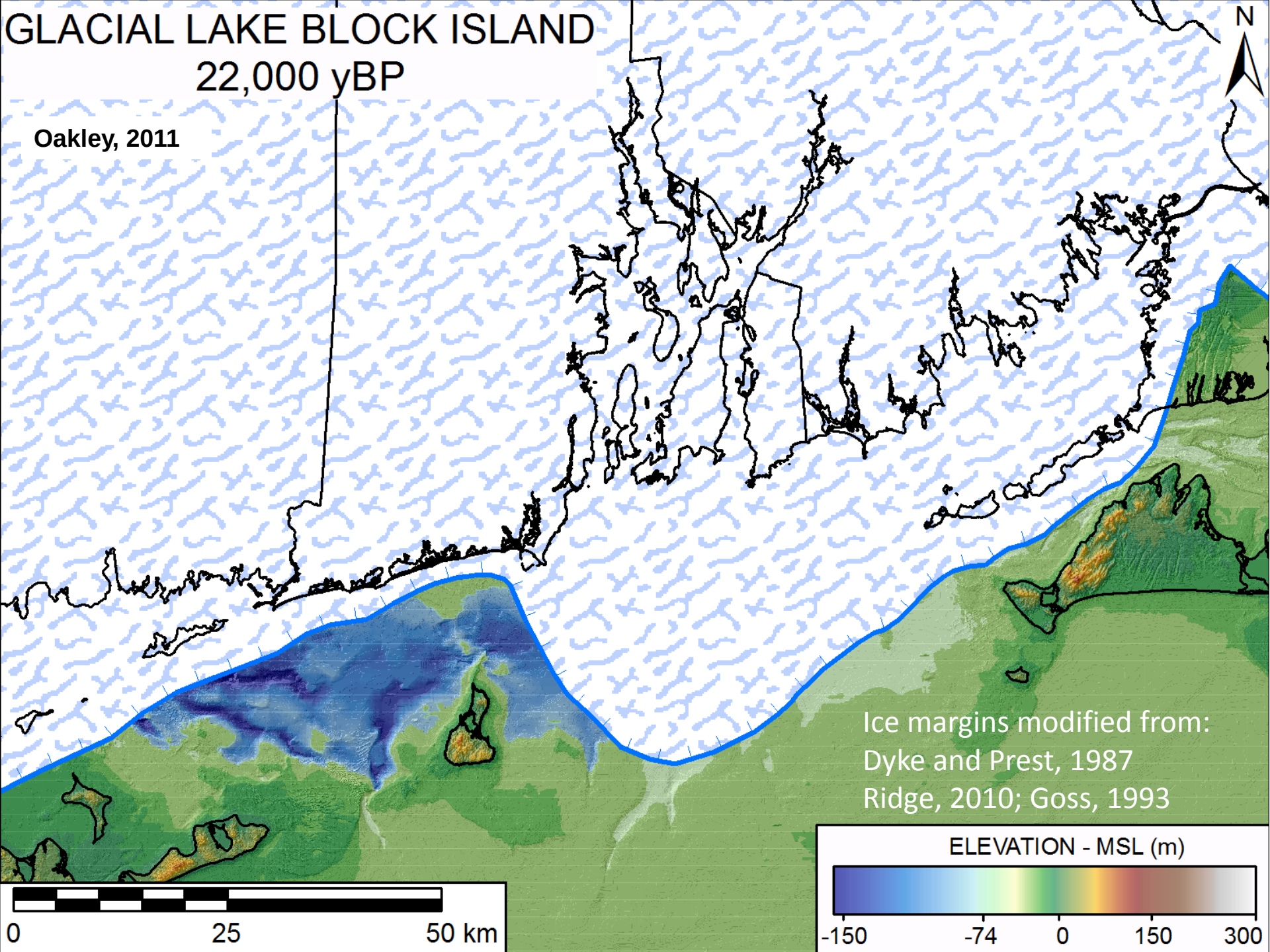


Lower West Passage, Dutch Island Delta



GLACIAL LAKE BLOCK ISLAND 22,000 yBP

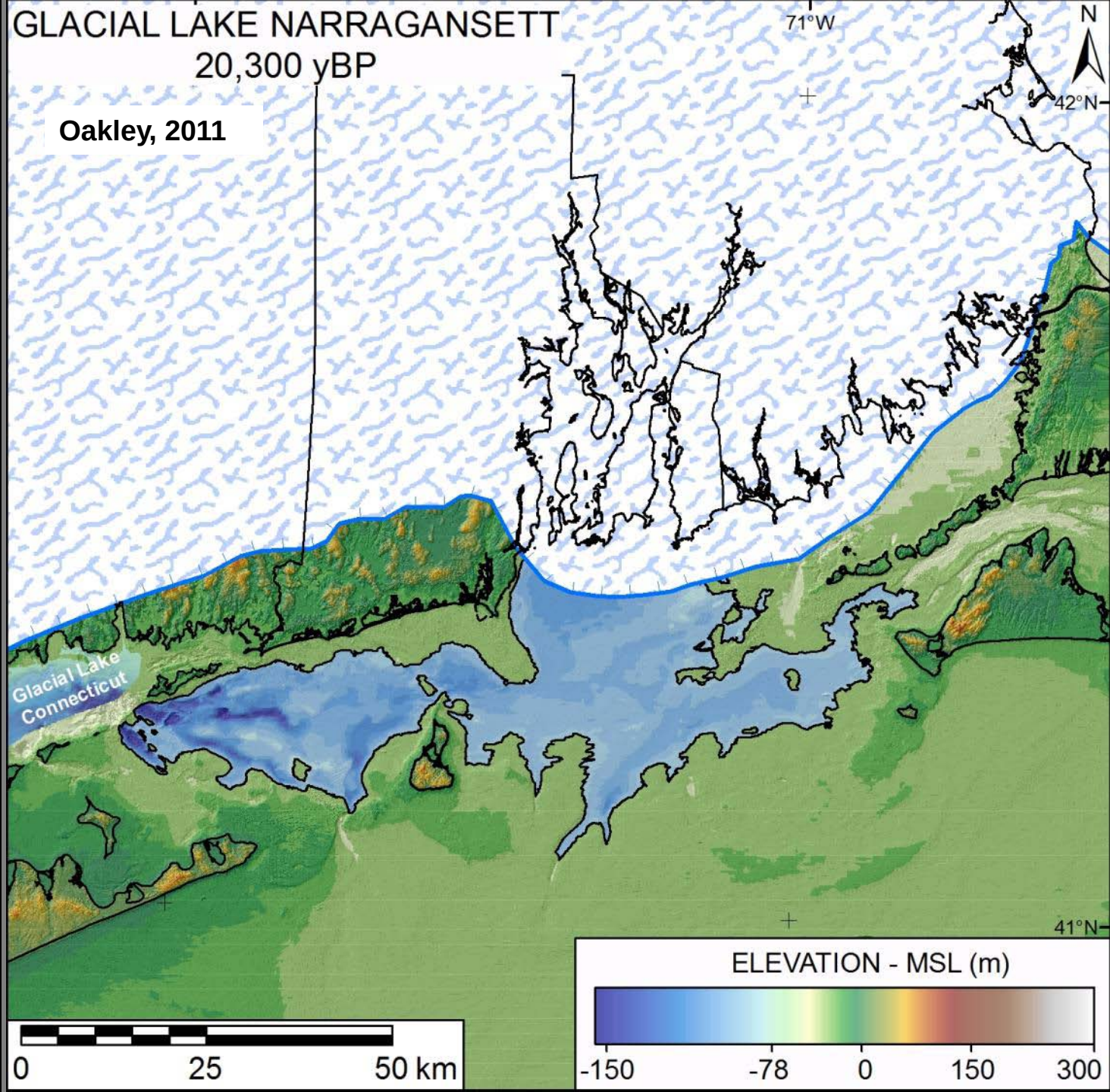
Oakley, 2011



GLACIAL LAKE NARRAGANSETT

20,300 yBP

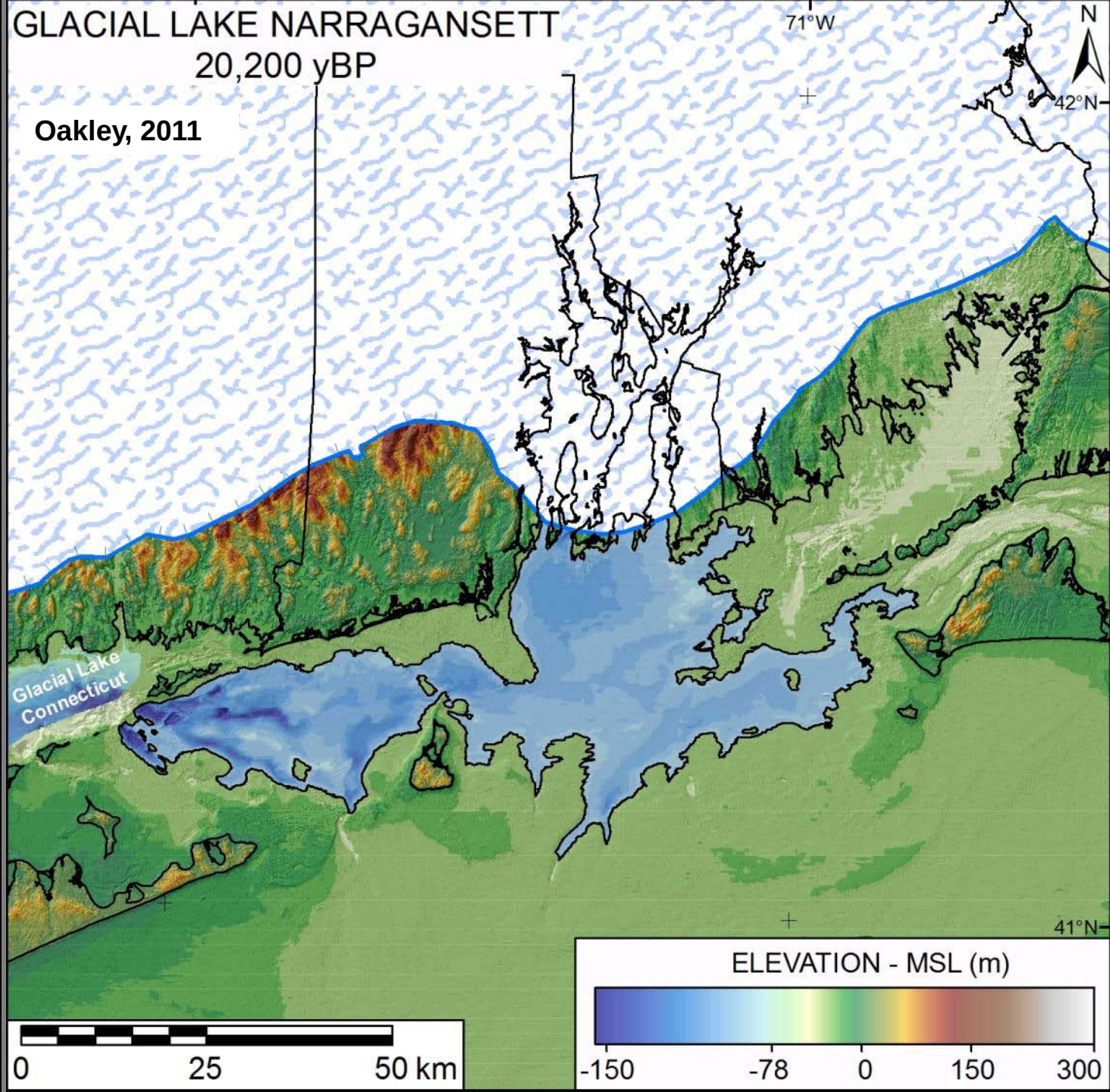
Oakley, 2011



GLACIAL LAKE NARRAGANSETT

20,200 yBP

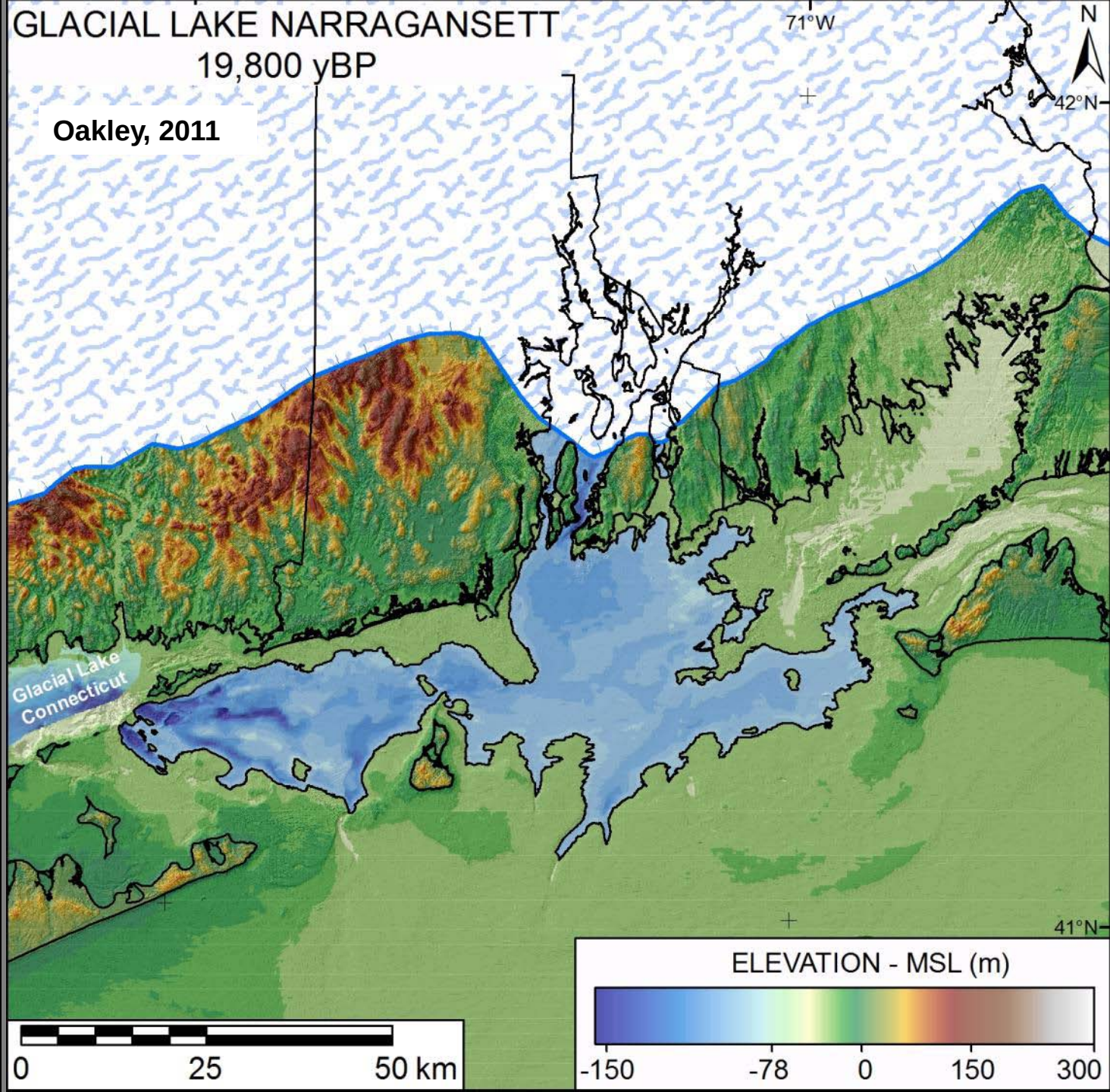
Oakley, 2011



GLACIAL LAKE NARRAGANSETT

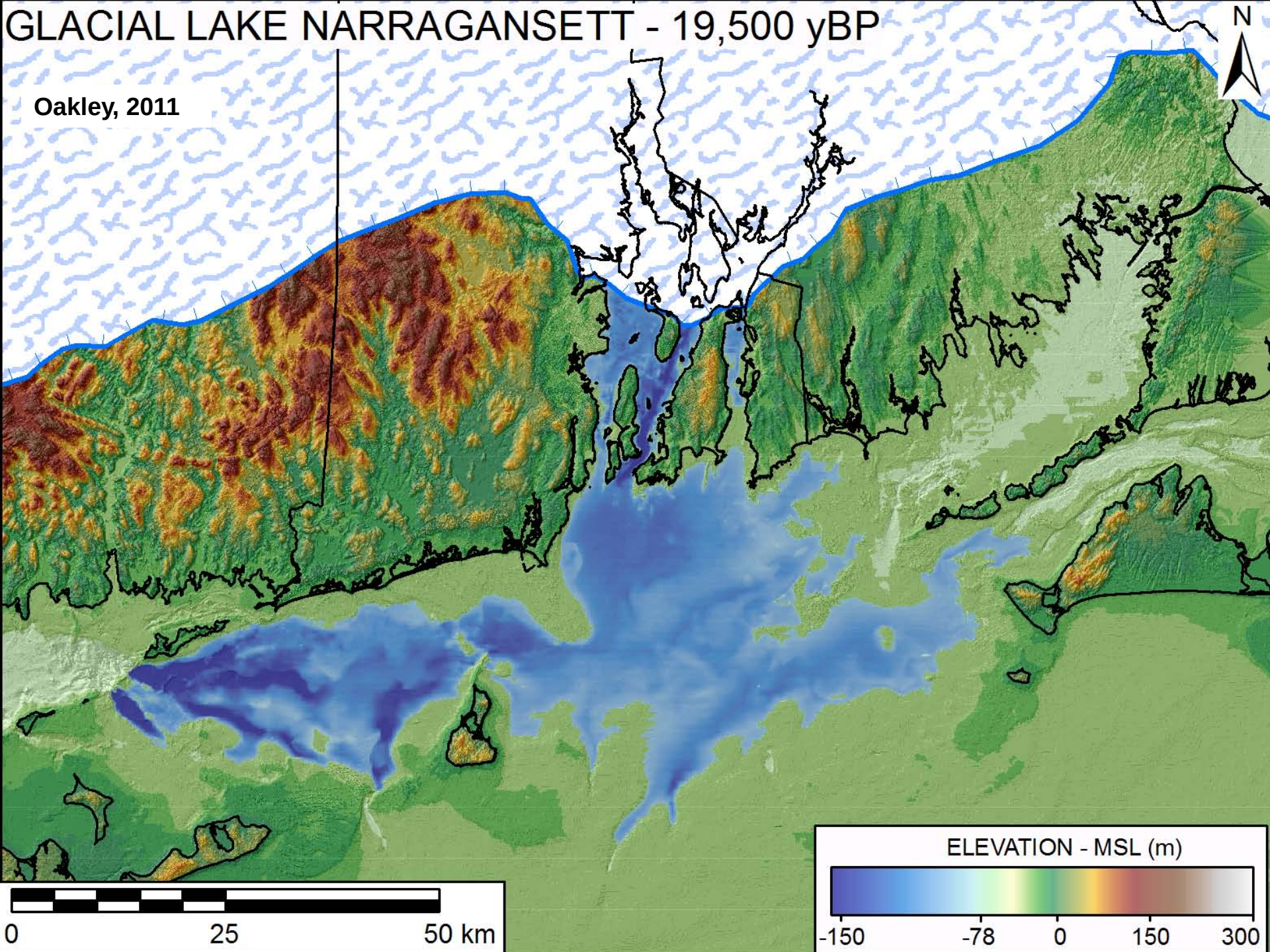
19,800 yBP

Oakley, 2011

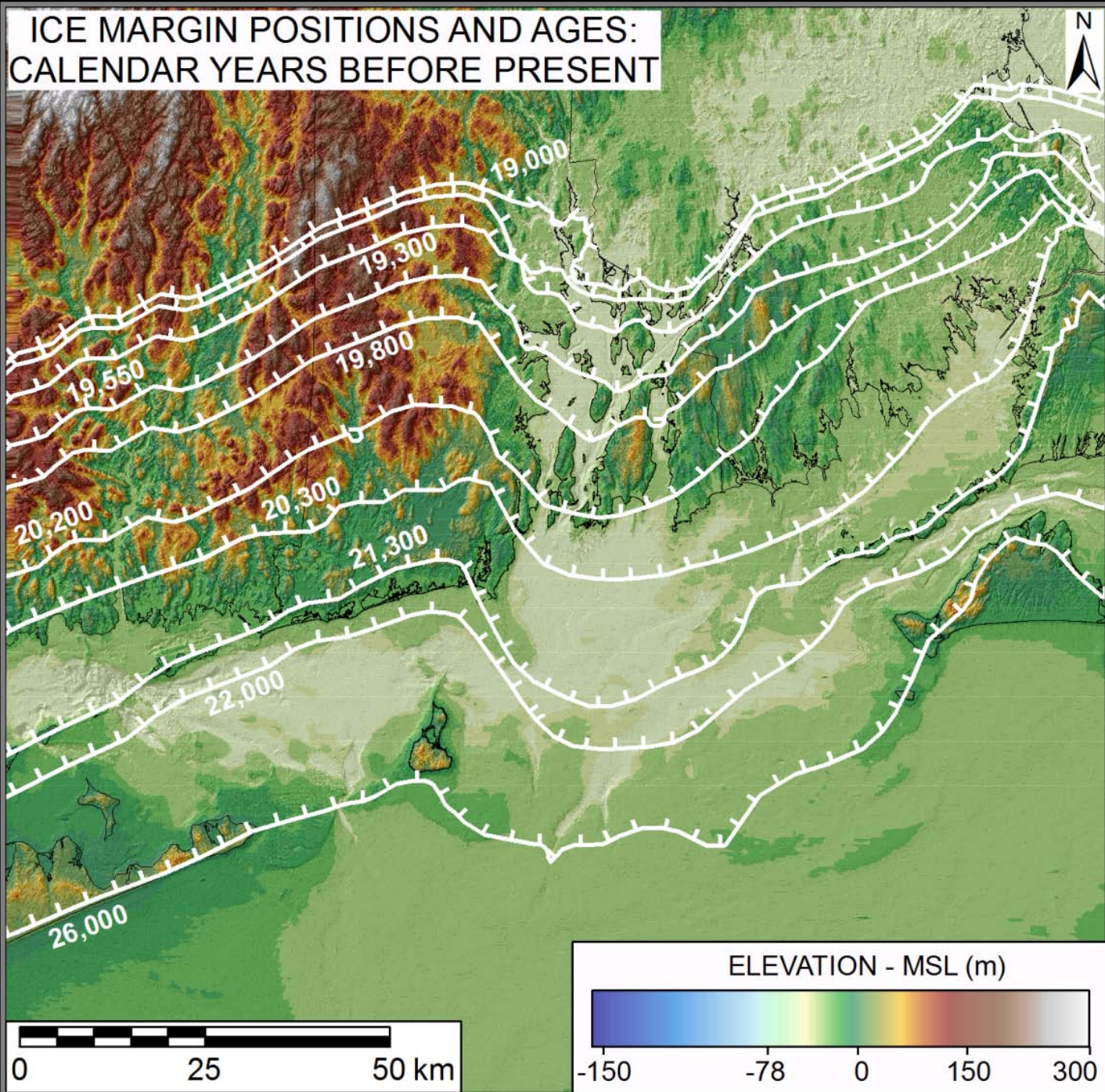


GLACIAL LAKE NARRAGANSETT - 19,500 yBP

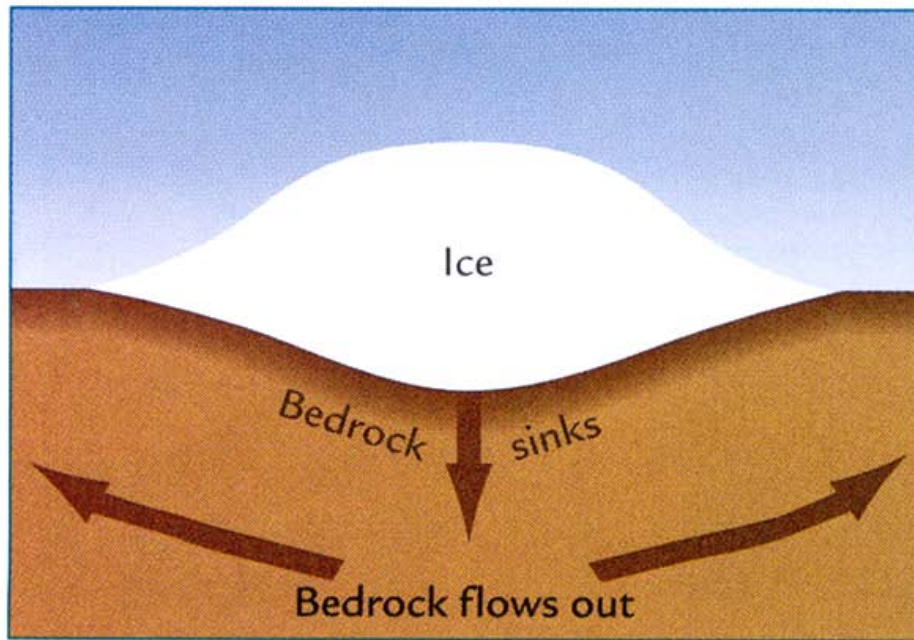
Oakley, 2011



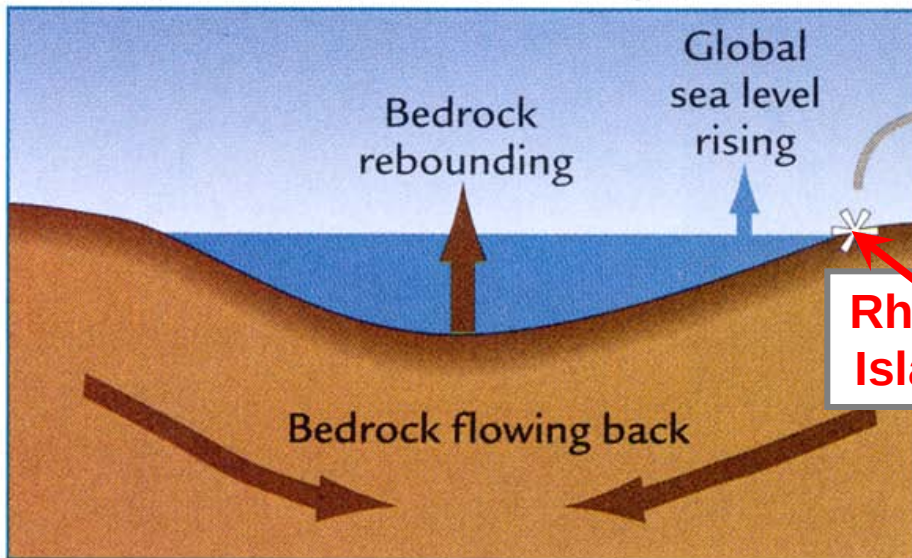
ICE MARGIN POSITIONS AND AGES: CALENDAR YEARS BEFORE PRESENT



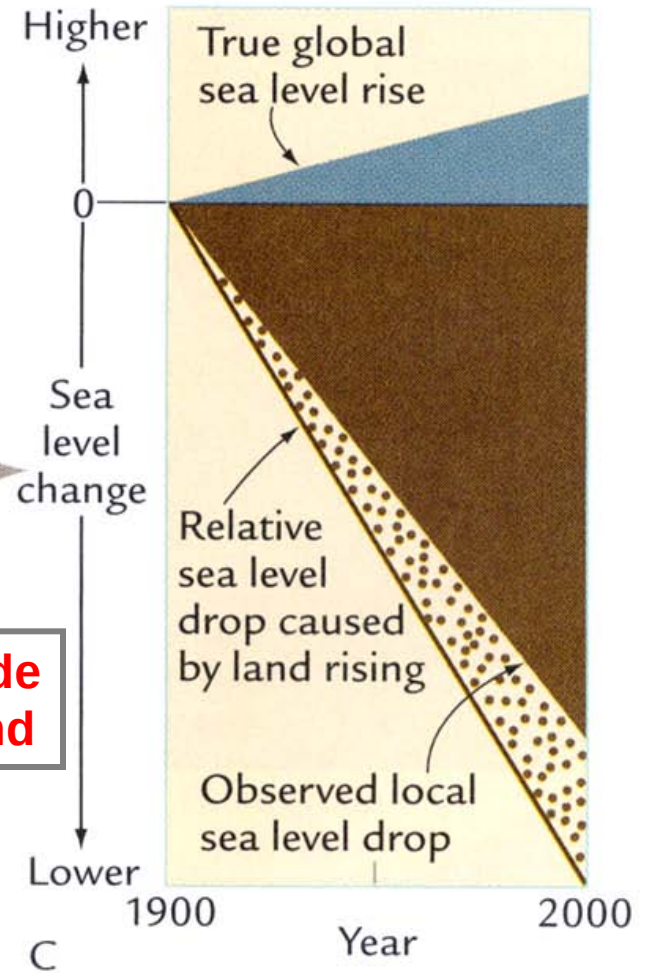
Isostatic Rebound



A Last glaciation (21,000 years ago)

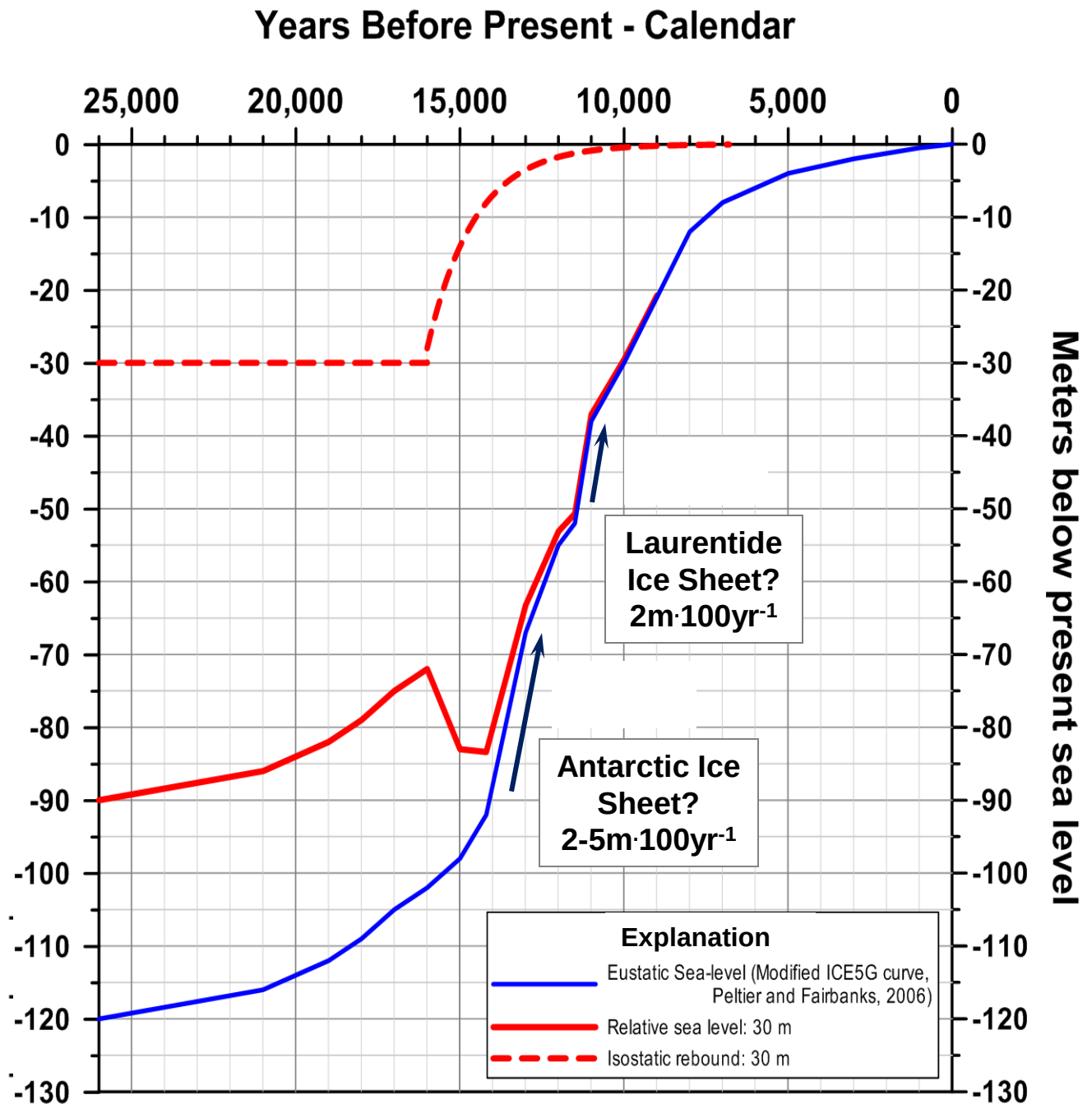


B Today



Eustatic Sea-Level Rise + Isostatic Rebound at Block Island

Oakley and Boothroyd,
in prep 2011



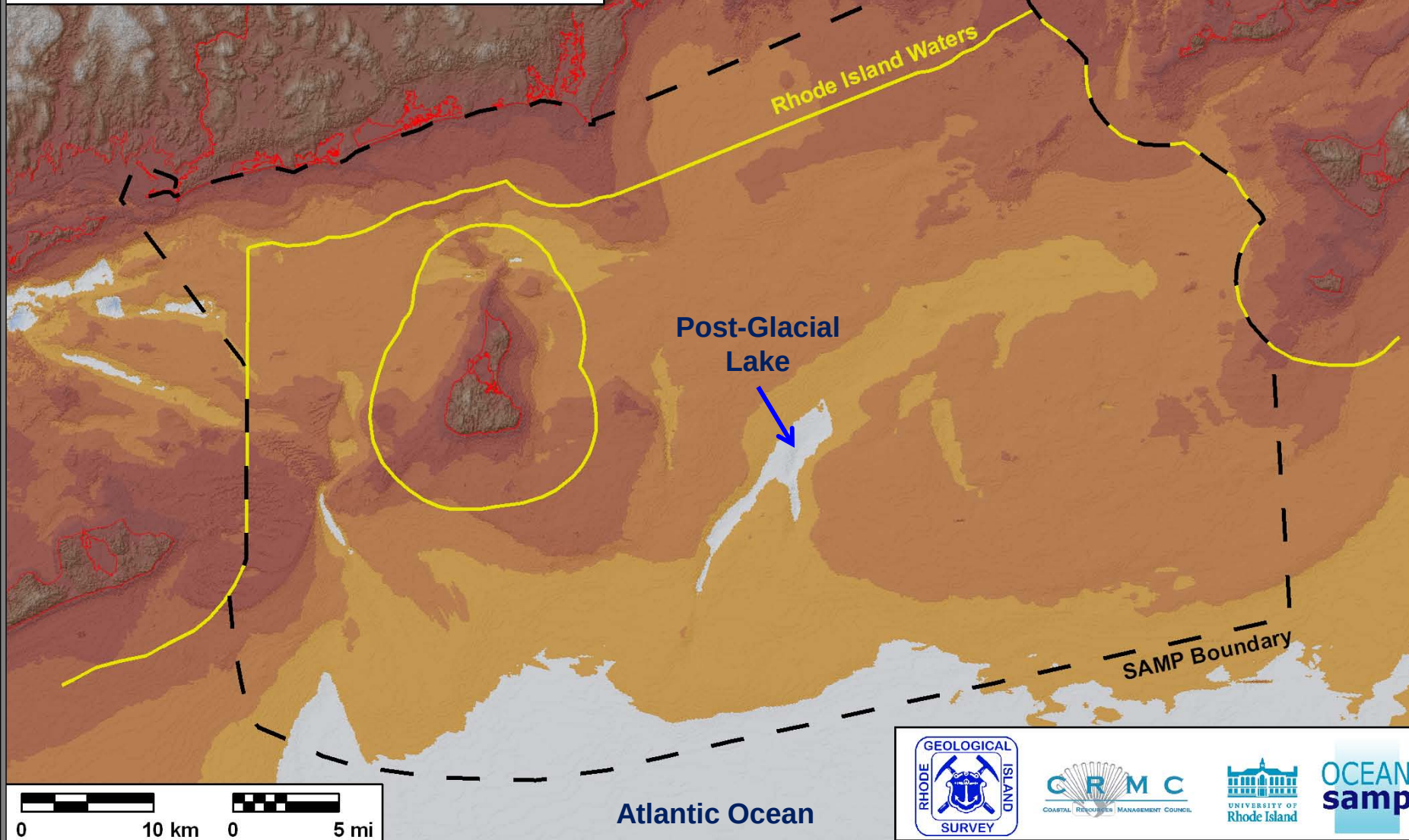
SEA-LEVEL RISE: OSAMP AREA

- 50 m below present
11,500 yBP

Sea level data from Peltier and Fairbanks, 2006

Elevation data from P. Jordan, RI DEM

Map created by B.A. Oakley, URI Geosciences



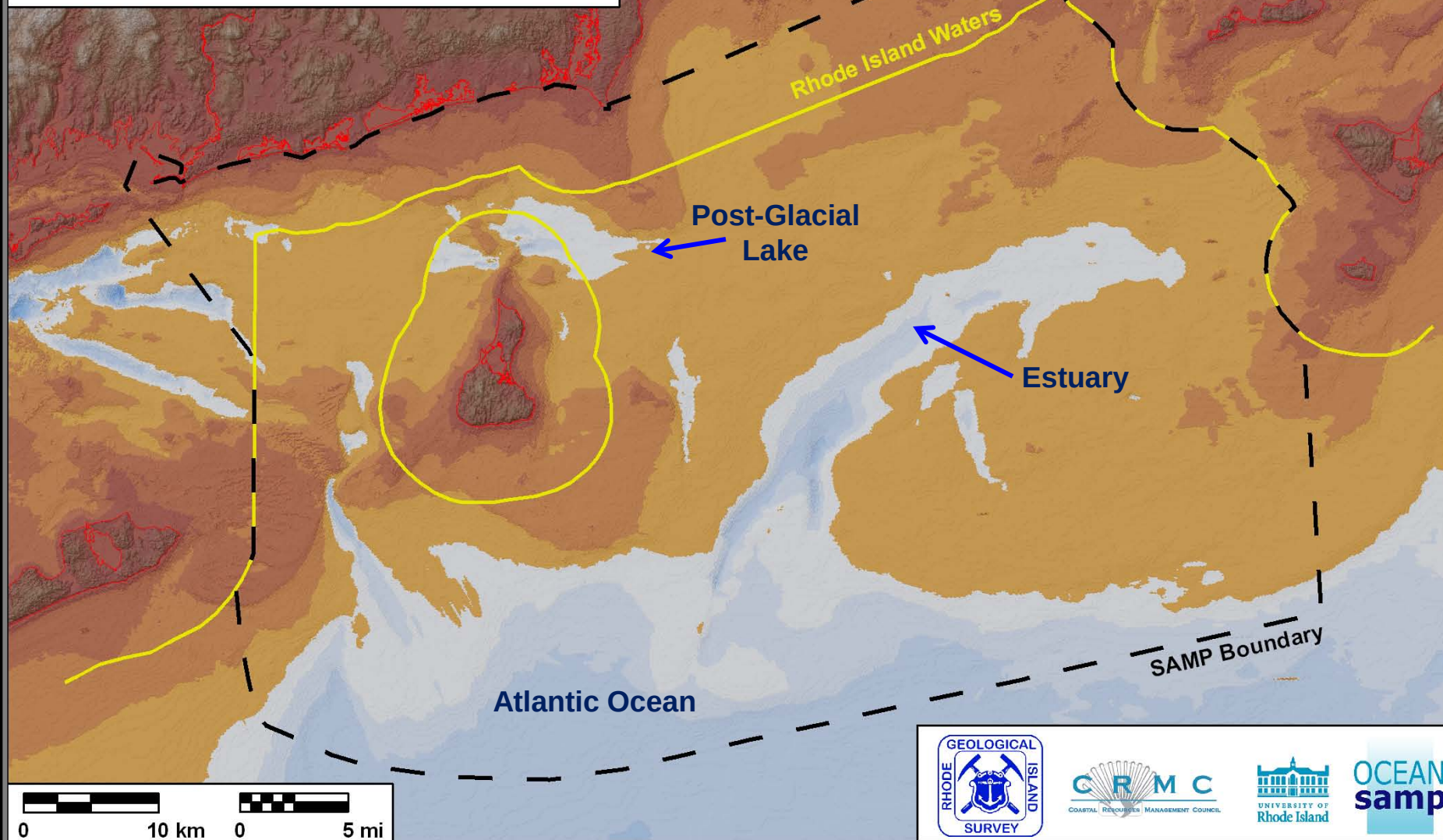
SEA-LEVEL RISE: OSAMP AREA

- 40 m below present
11,000 yBP

Sea level data from Peltier and Fairbanks, 2006

Elevation data from P. Jordan, RI DEM

Map created by B.A. Oakley, URI Geosciences



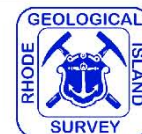
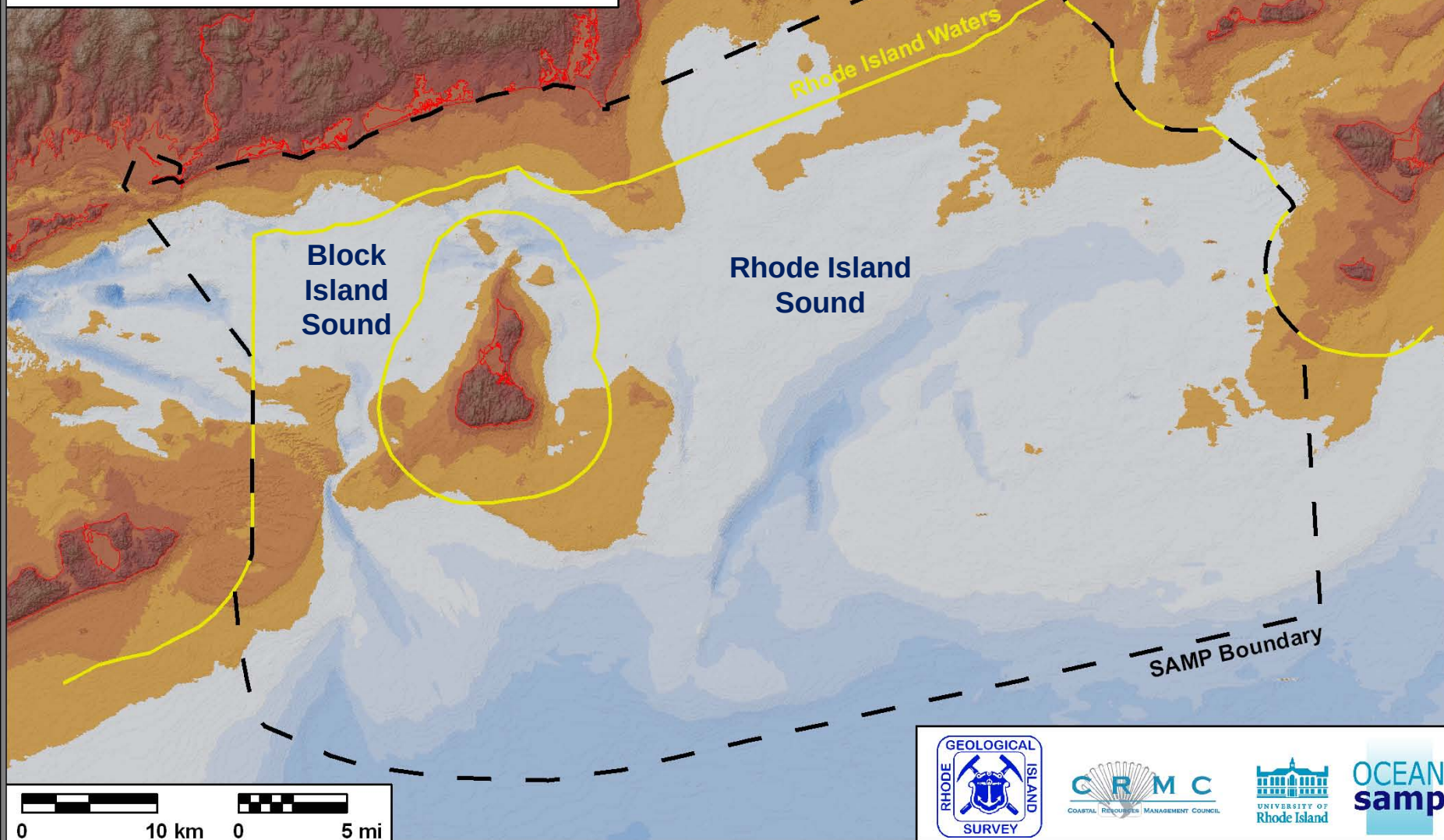
SEA-LEVEL RISE: OSAMP AREA

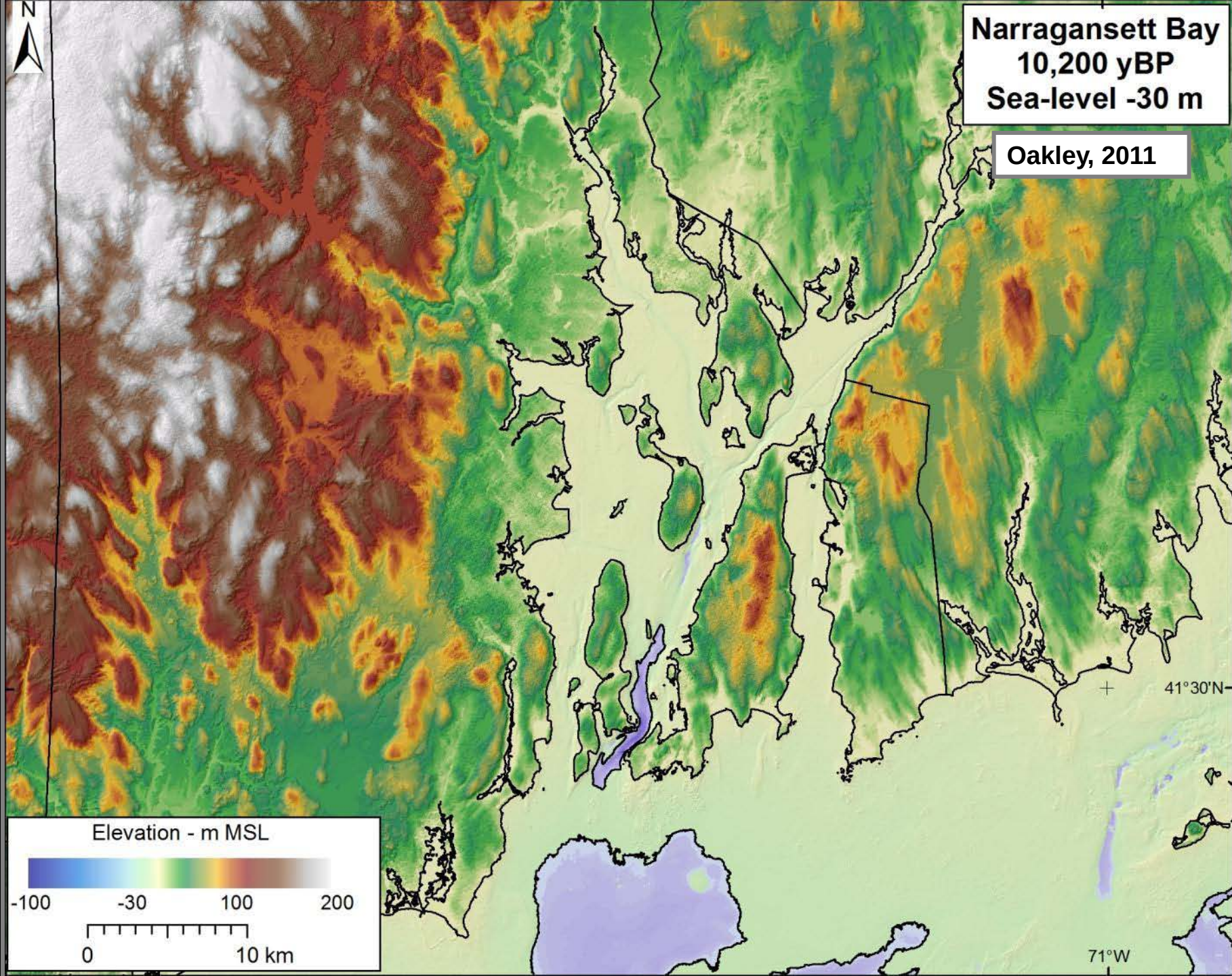
- 30 m below present
10,000 yBP

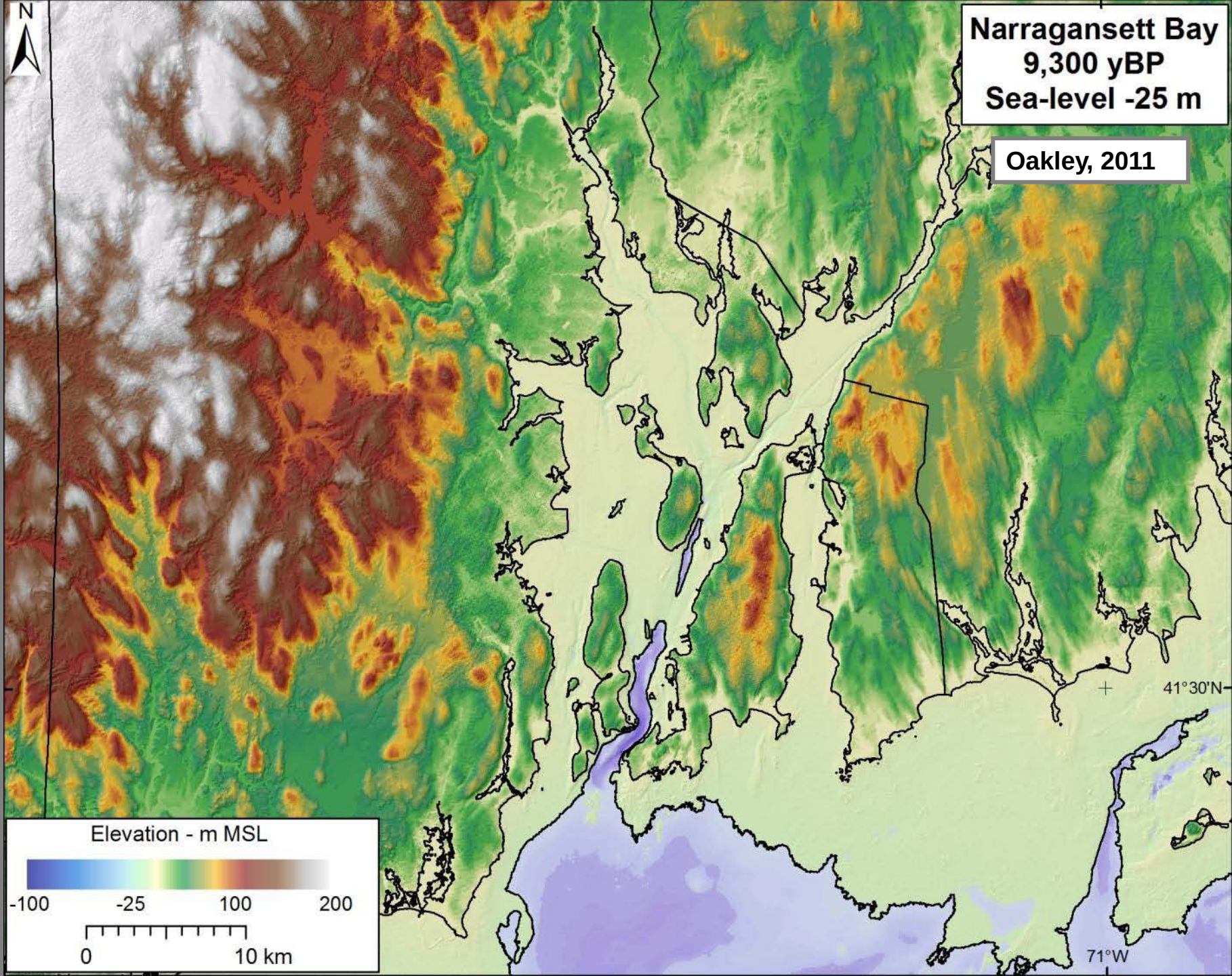
Sea level data from Peltier and Fairbanks, 2006

Elevation data from P. Jordan, RI DEM

Map created by B.A. Oakley, URI Geosciences



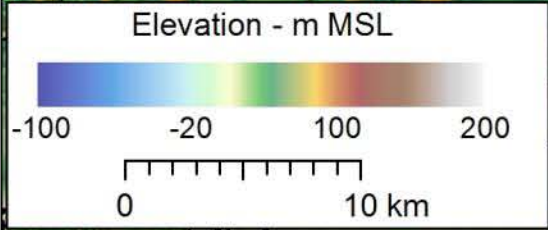
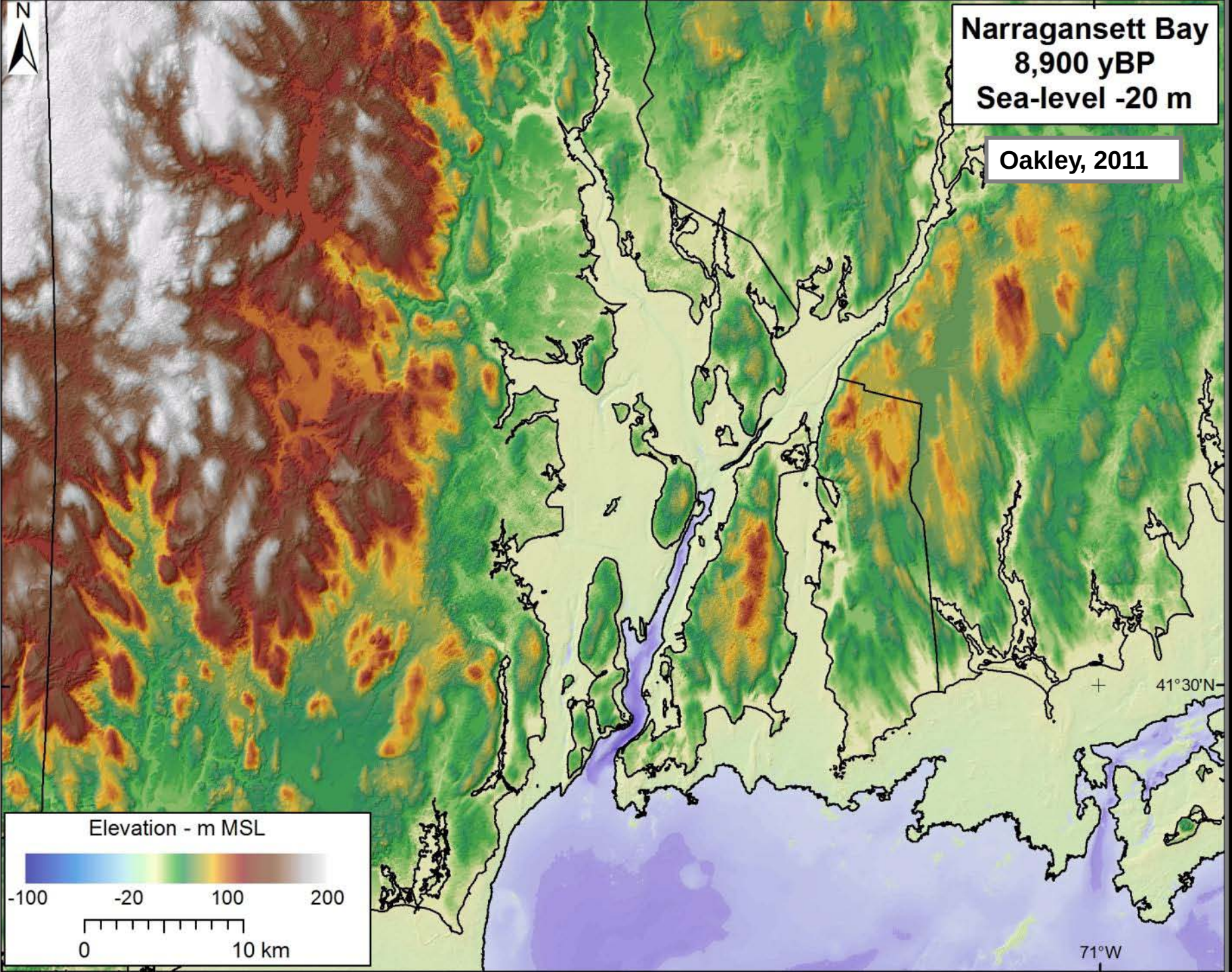


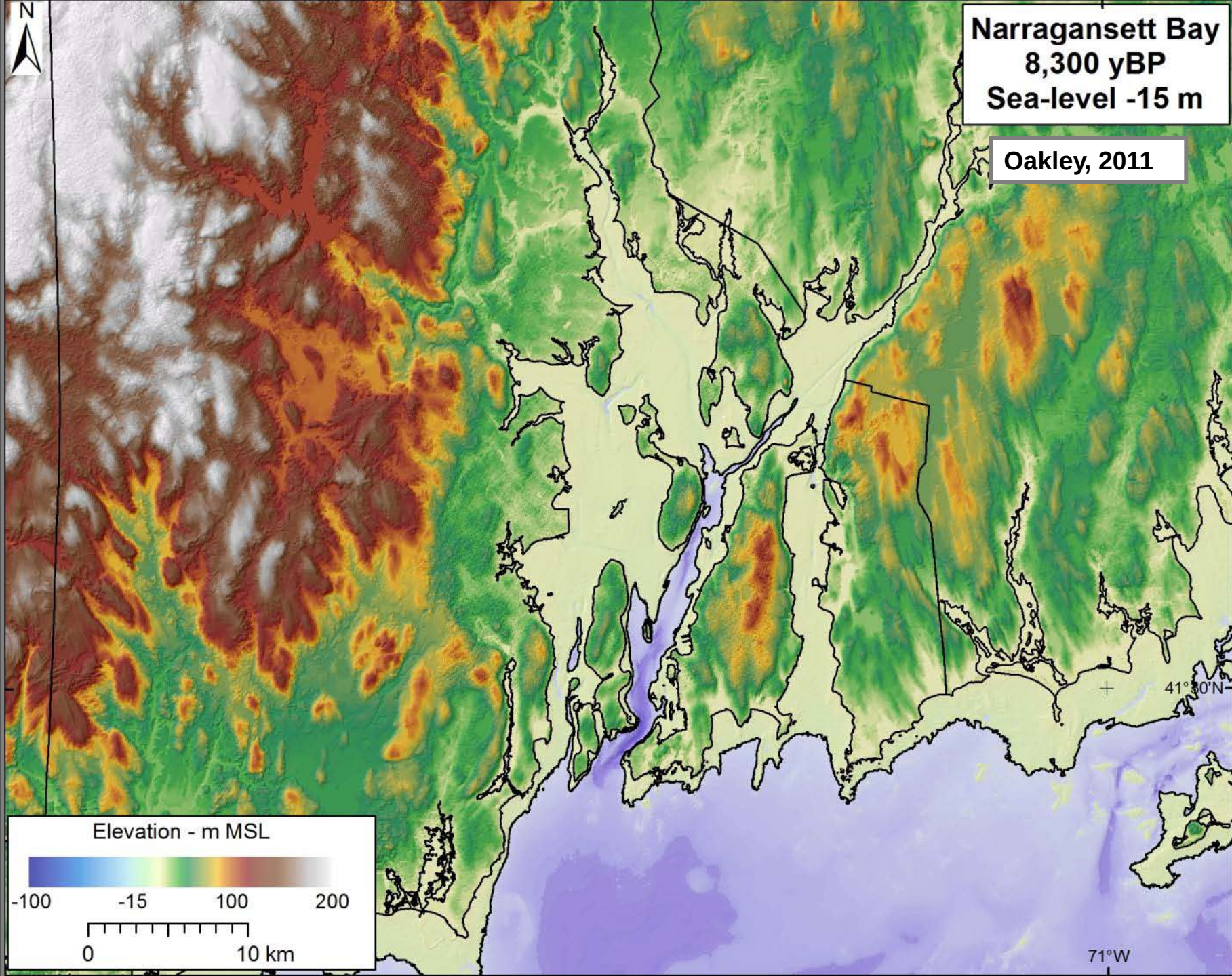




Narragansett Bay
8,900 yBP
Sea-level -20 m

Oakley, 2011

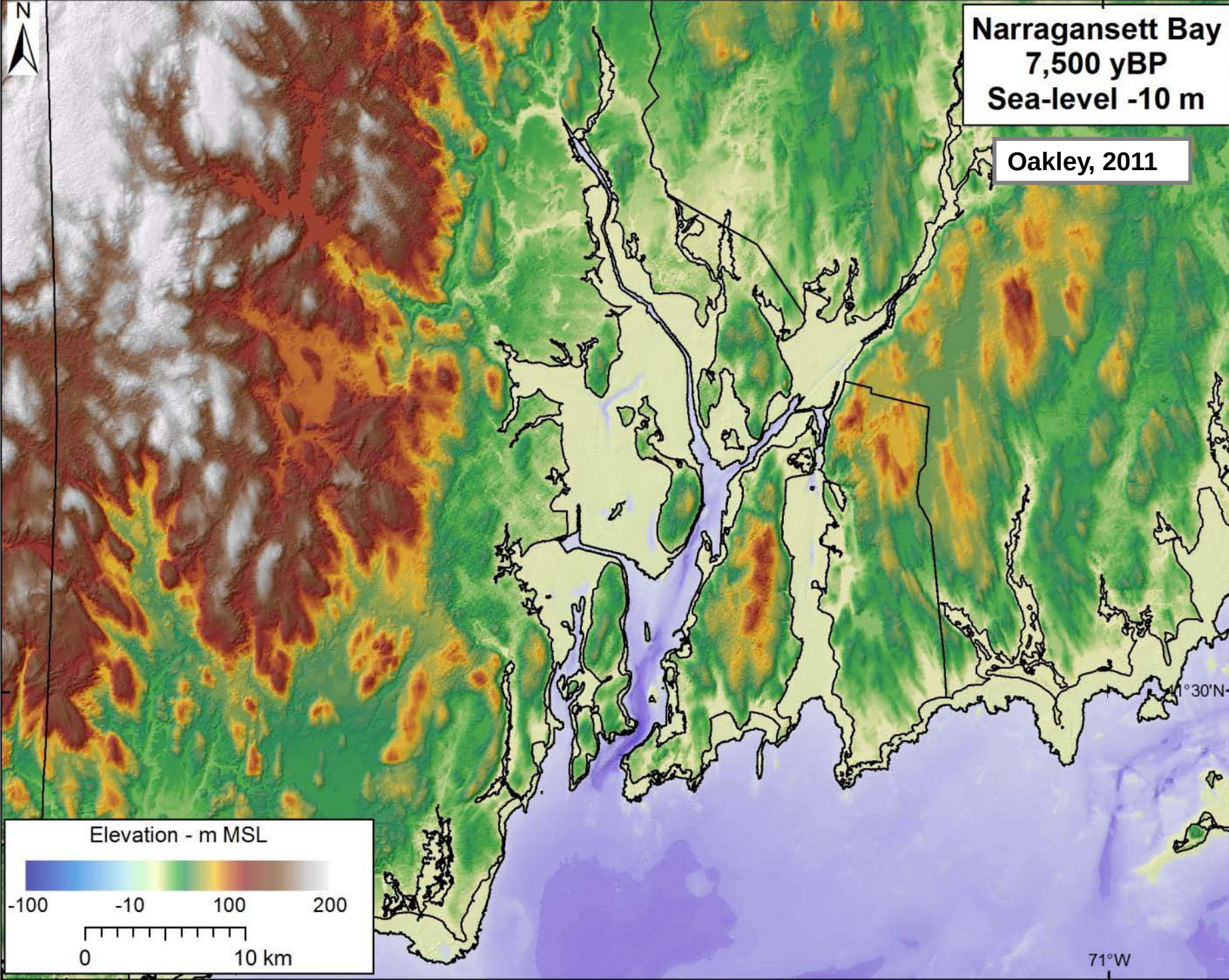




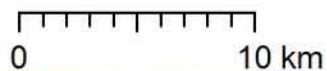


Narragansett Bay
7,500 yBP
Sea-level -10 m

Oakley, 2011



Elevation - m MSL



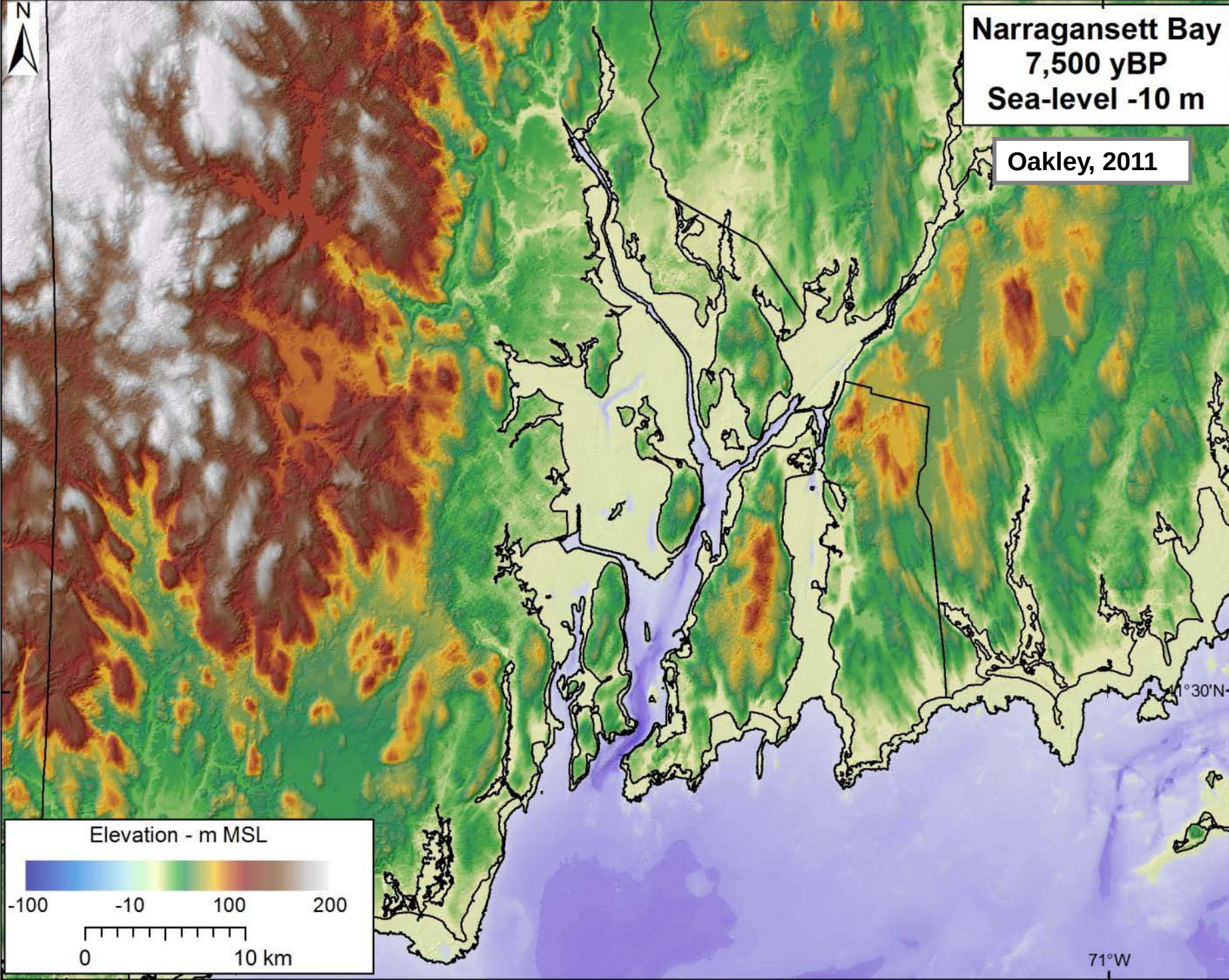
41°30'N

71°W

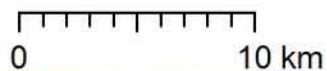


Narragansett Bay
7,500 yBP
Sea-level -10 m

Oakley, 2011

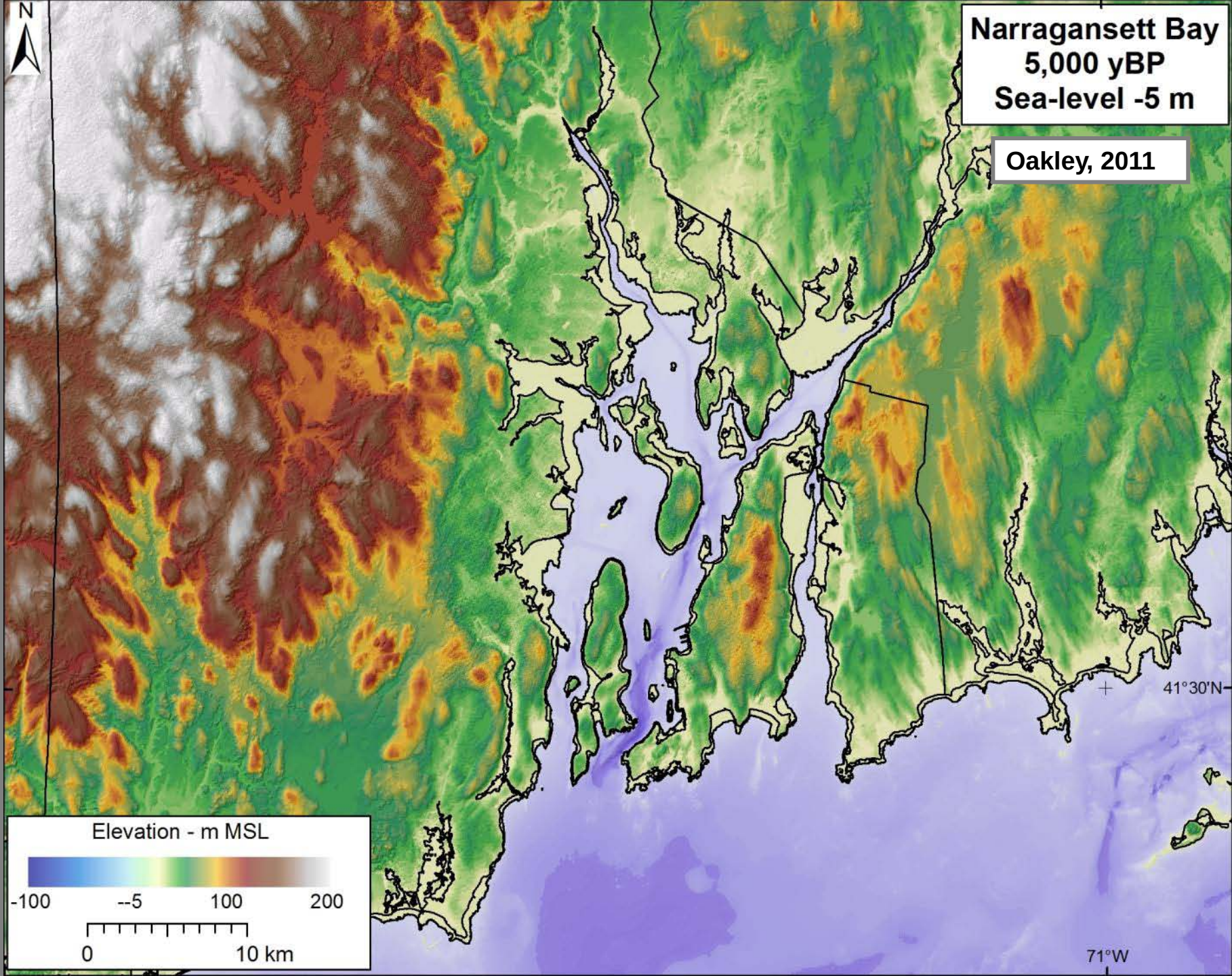


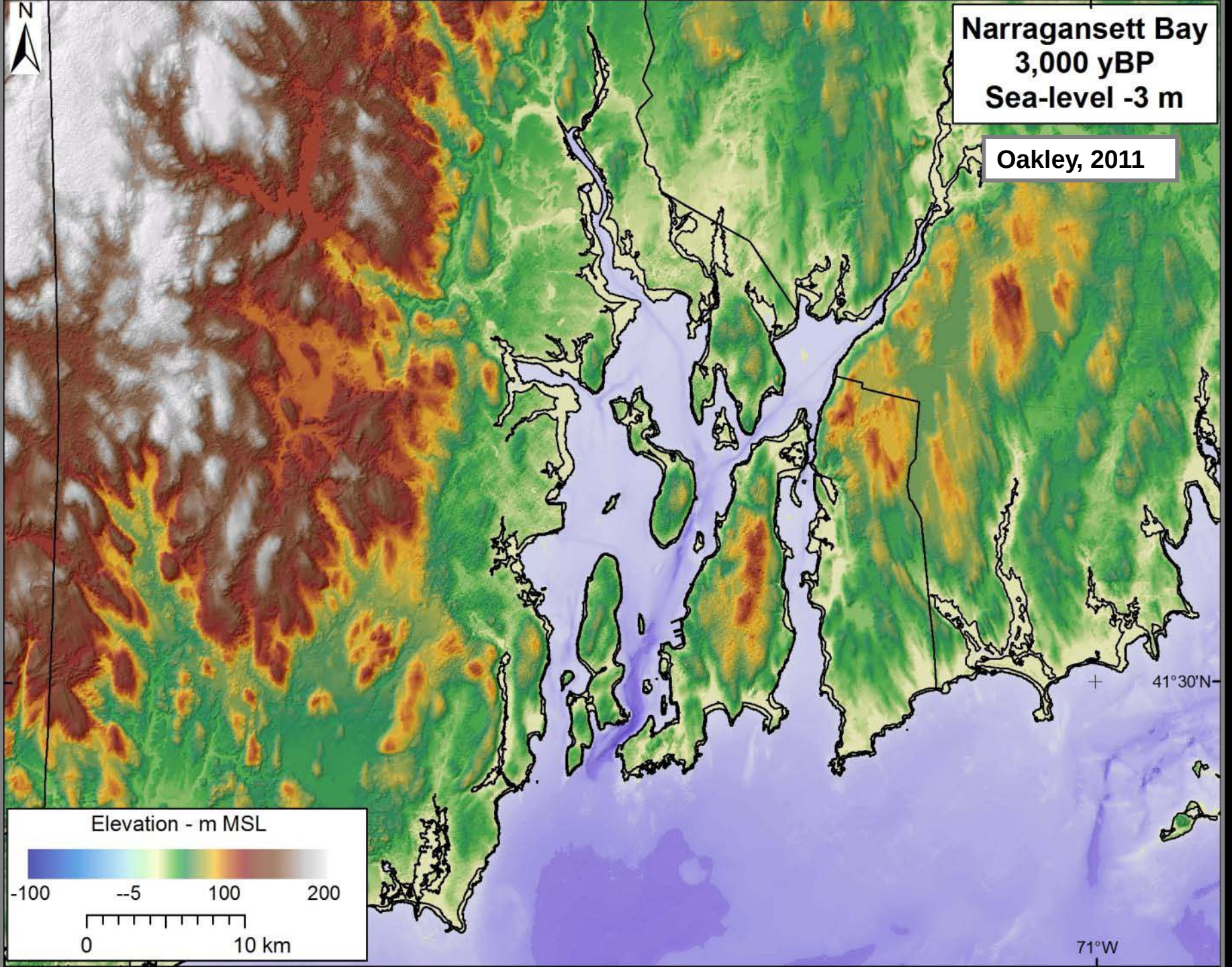
Elevation - m MSL

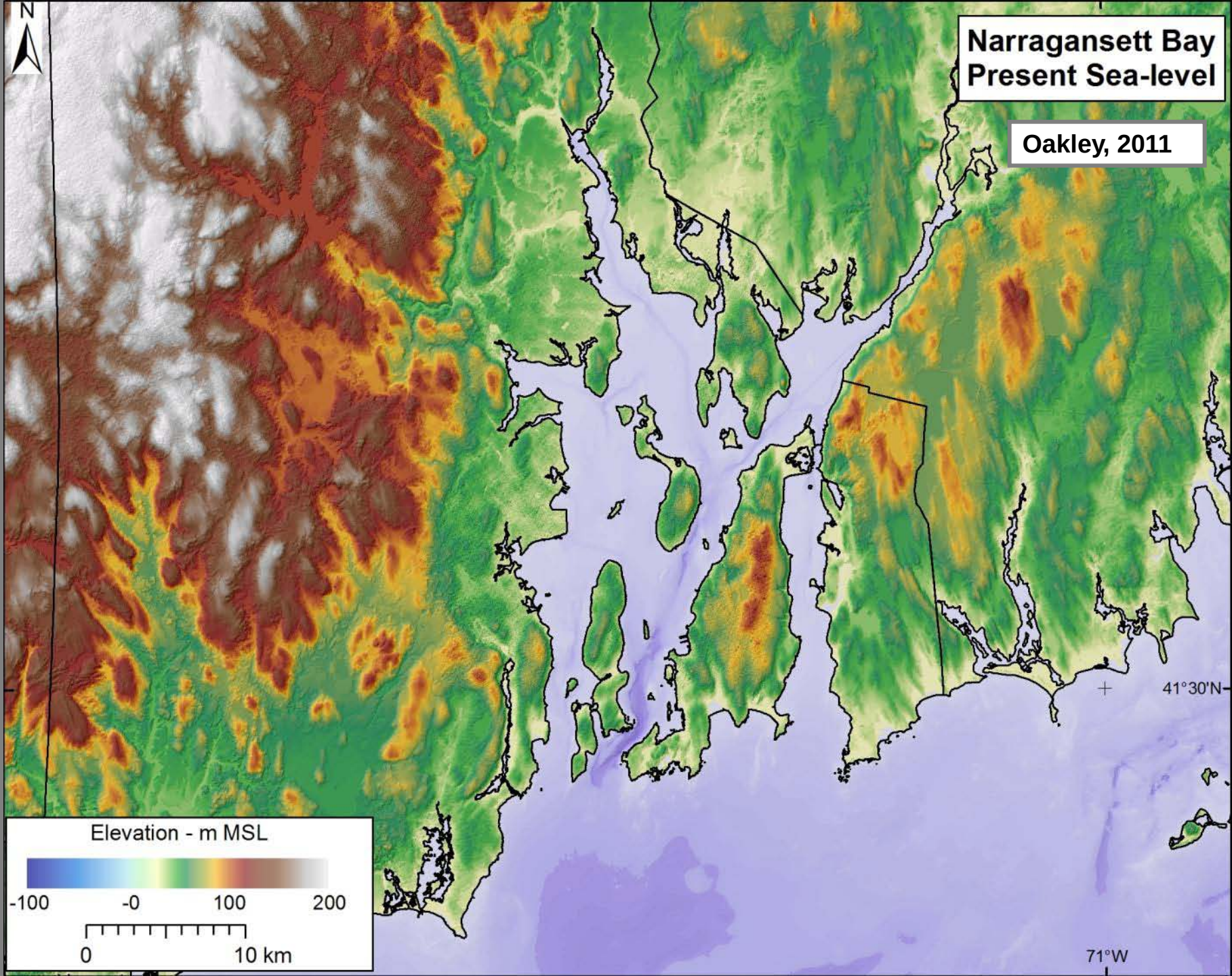


41°30'N

71°W

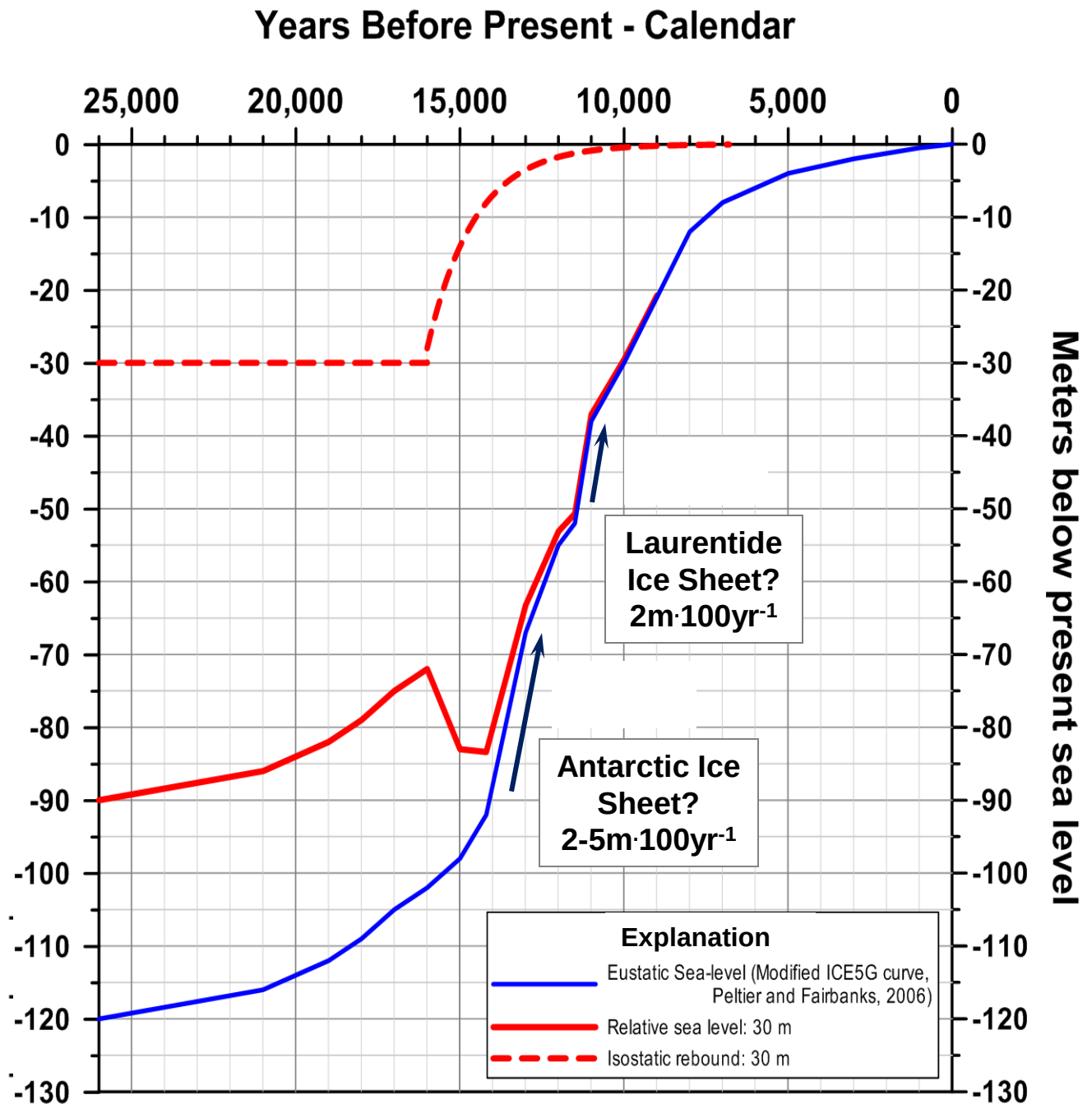






Eustatic Sea-Level Rise + Isostatic Rebound at Block Island

Oakley and Boothroyd,
in prep 2011



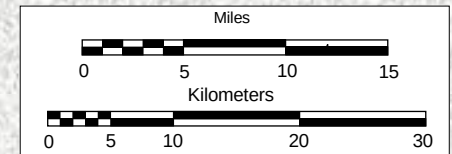
QUATERNARY DEPOSITS OF RHODE ISLAND

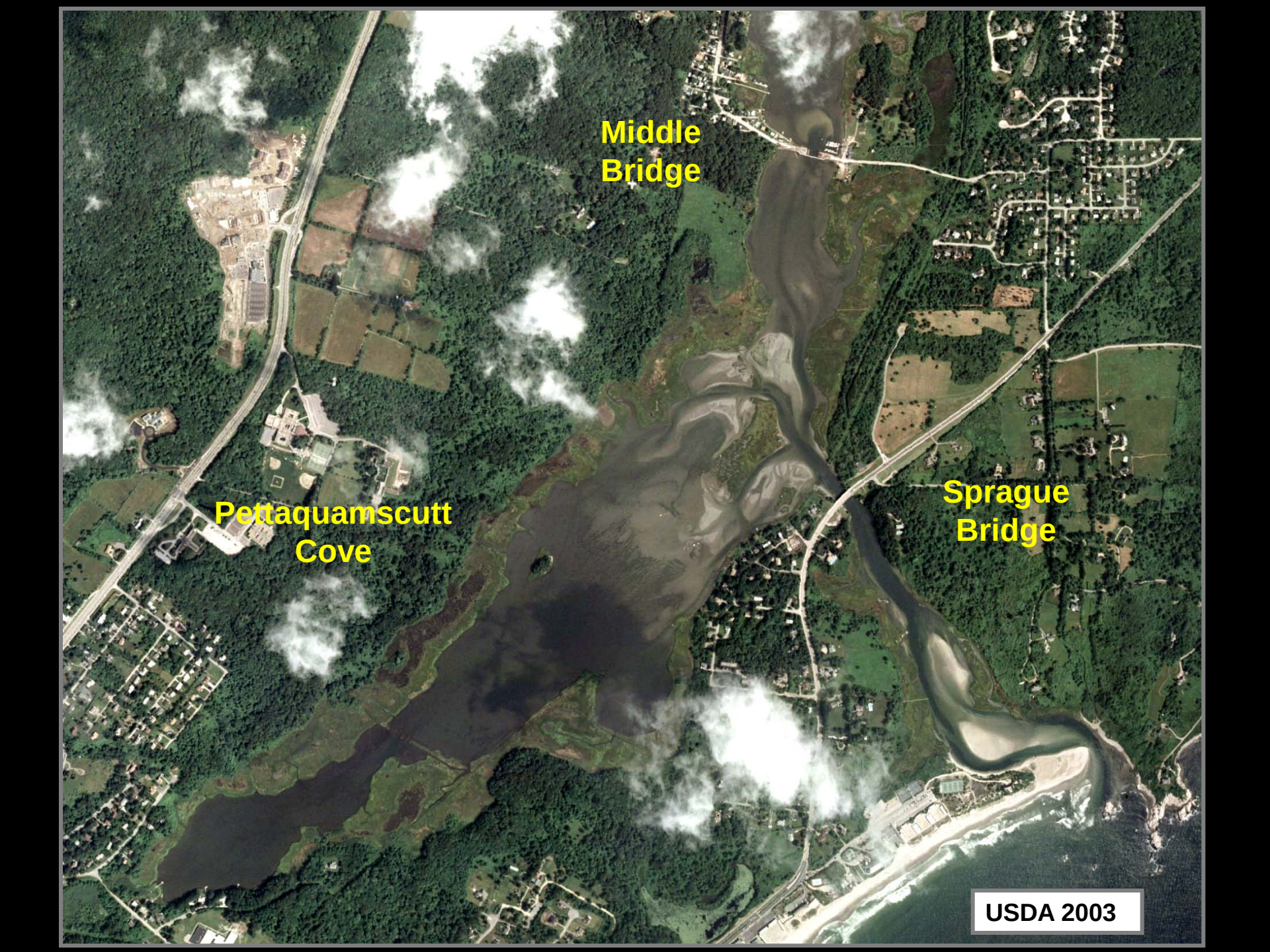
Thick Stratified Deposits

PETTAQUAMSCUTT
RIVER

EXPLANATION

- Stratified Material
- Till
- End Moraine - Till and Stratified Material





**Middle
Bridge**

**Pettaquamscutt
Cove**

**Sprague
Bridge**

USDA 2003

PETTAQUAMSCUTT COVE – Flood-Tidal Delta

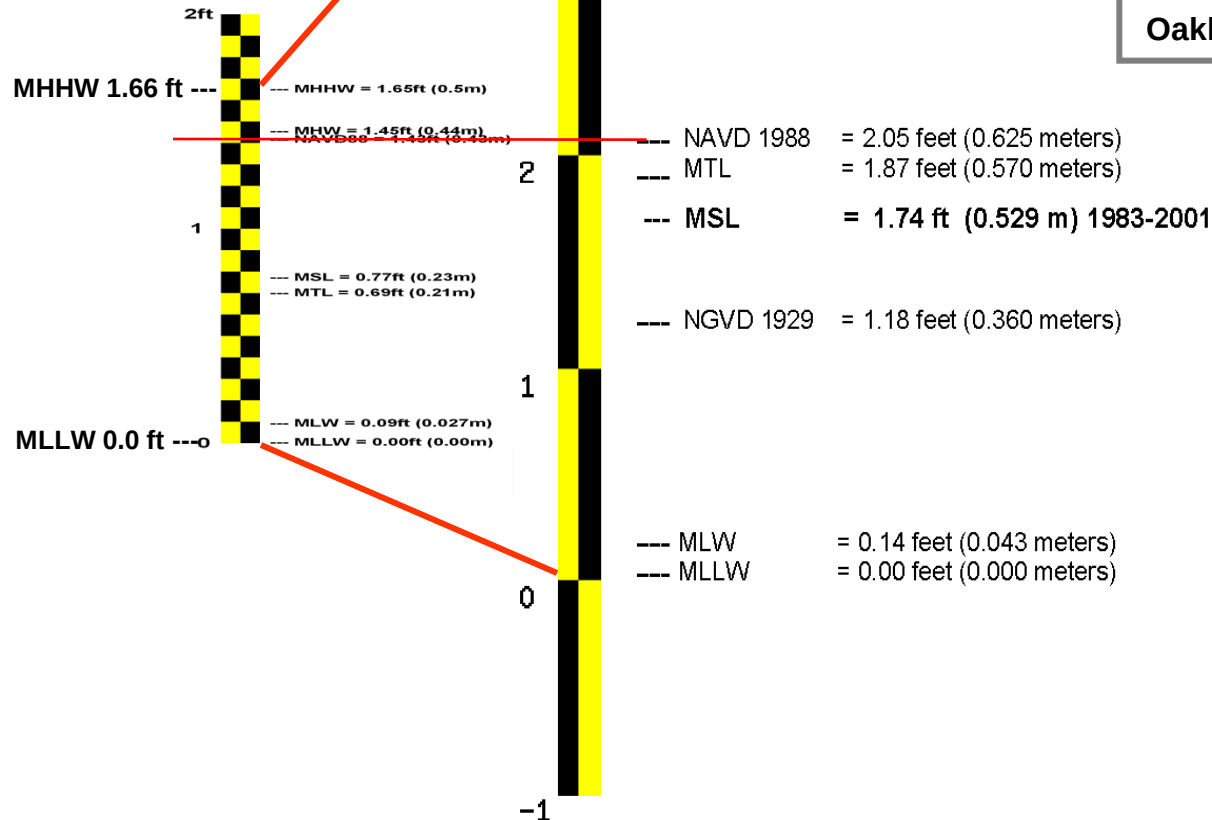


**Benthic
Geologic
Habitats
Middlebridge Area**

15

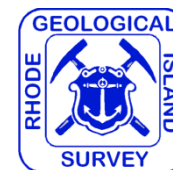
Newport

Narrow River



Narrow River – Newport Tidal Datums

Oakley, Alvarez and Boothroyd, 2008



The NAVD 1988 and NGVD 1929 elevations related to MLLW were computed from Bench Mark, 845 2660 TIDAL 6, at the station.

Displayed tidal datums are MEAN HIGHER HIGH WATER (MHHW), MEAN HIGH WATER (MHW), MEAN TIDE LEVEL (MTL), MEAN LOW WATER (MLW), AND MEAN LOWER LOW WATER (MLLW) referenced on 1983-2001 Epoch.

Newport datum adapted from www.ngs.noaa.gov/cgi-bin/ngs_opsd?PID=LW0493

USDA/NRCS Pontoon boat - R/V Doerner



An aerial photograph of a coastal area, likely a bay or estuary, with various landmasses and water bodies. A semi-transparent blue rectangular overlay covers the central portion of the image, serving as a background for the text.

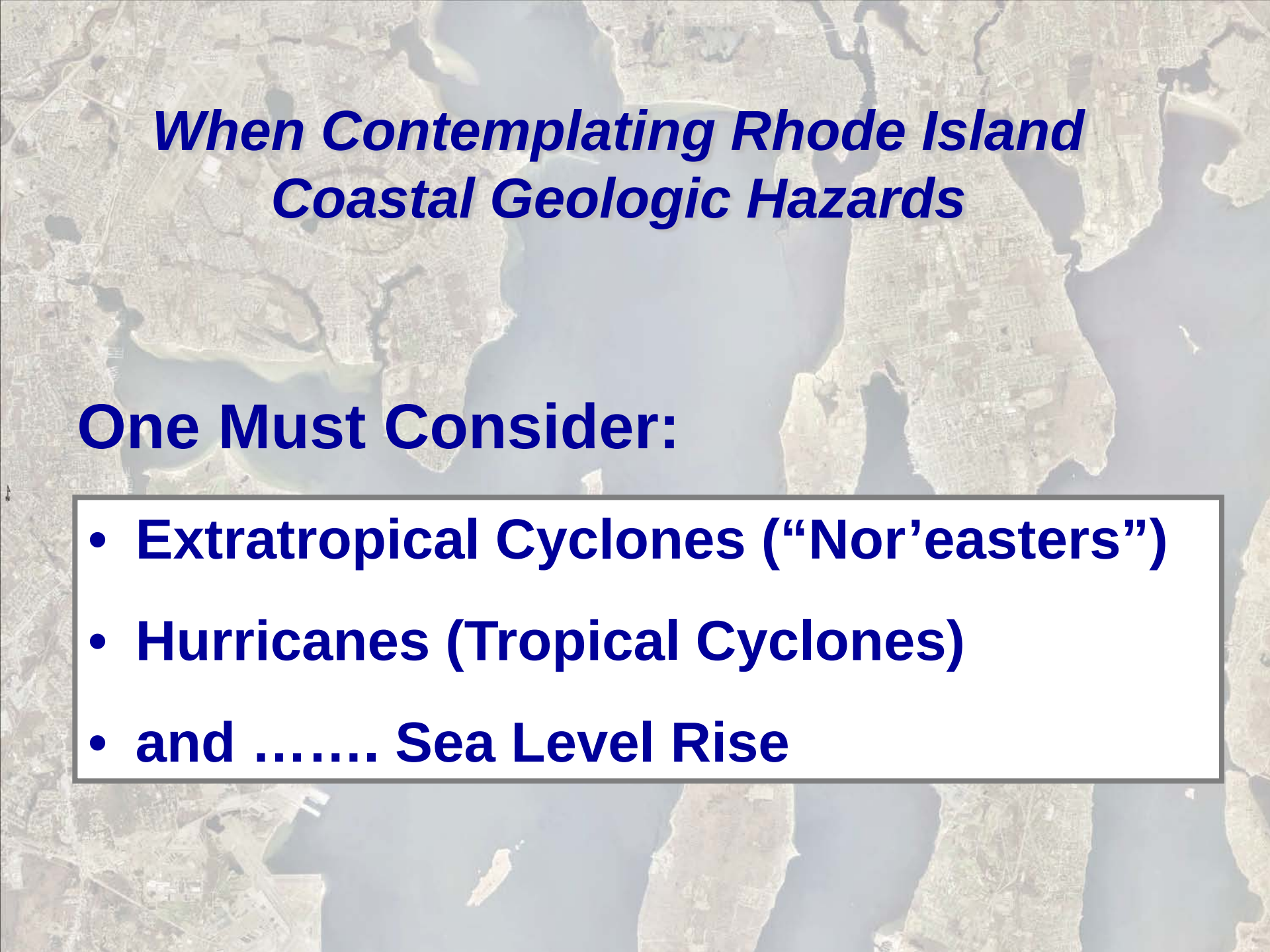
***Now,
We Need to Consider
Coastal Processes Acting Today***

The Sea May Be Rising – But.....

**Narragansett Pier Seawall –
Patriots Day 2007**



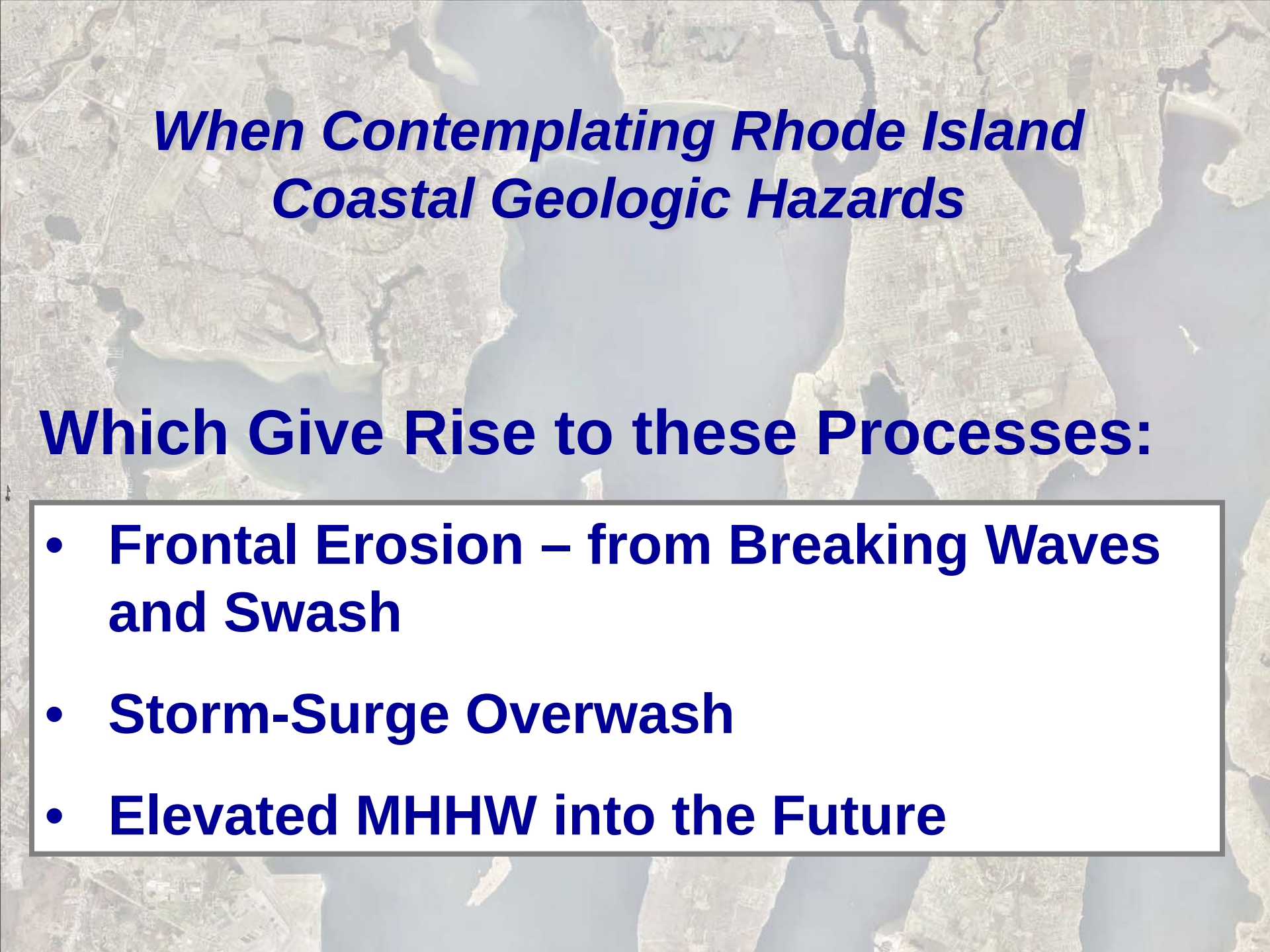
**WPRI.com
16 apr 2007**

An aerial photograph of the Rhode Island coastline, showing the state's irregular shape and surrounding water. The text is overlaid on the map.

When Contemplating Rhode Island Coastal Geologic Hazards

One Must Consider:

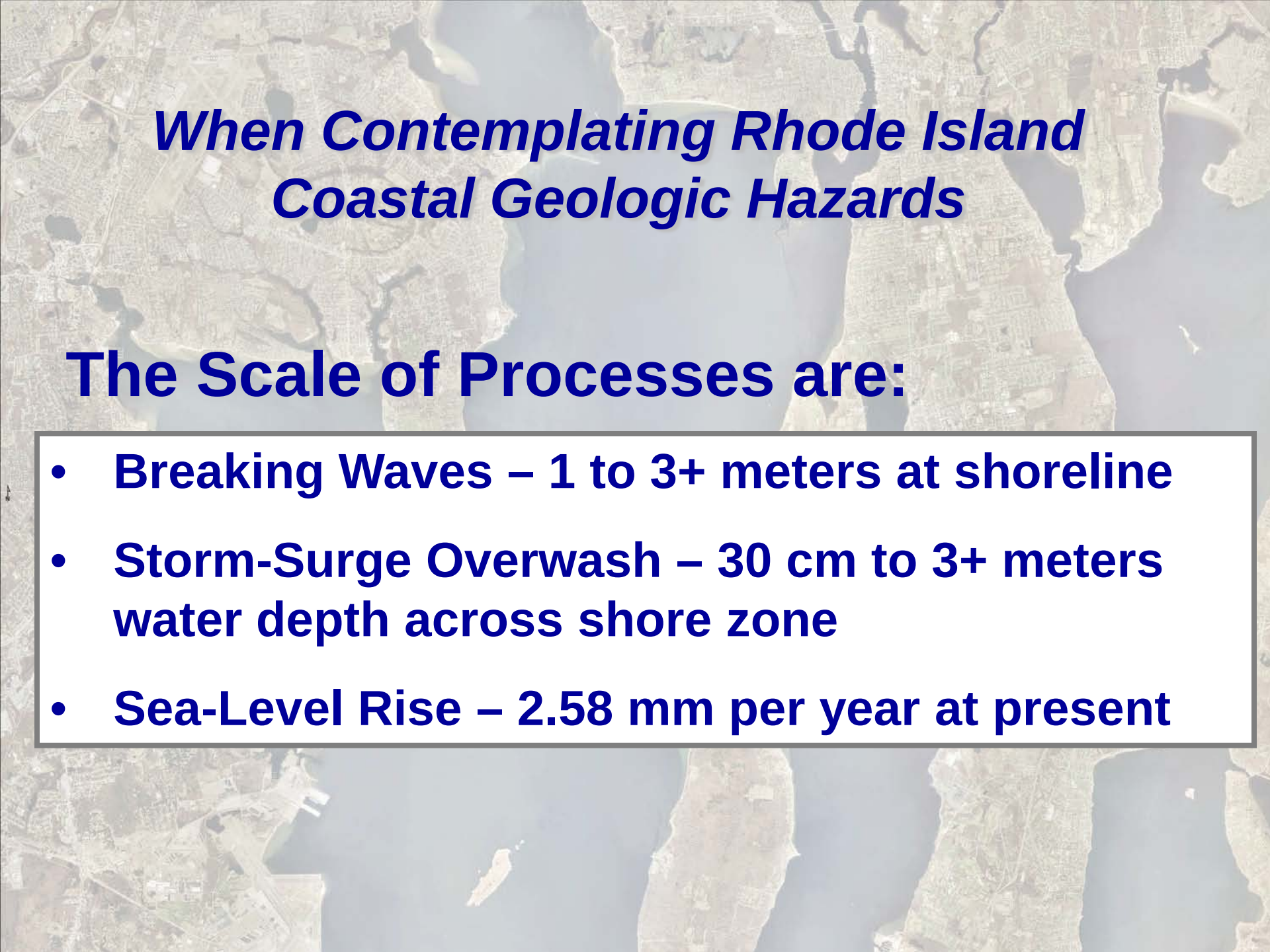
- **Extratropical Cyclones (“Nor’easters”)**
- **Hurricanes (Tropical Cyclones)**
- **and Sea Level Rise**

An aerial photograph of the Rhode Island coastline, showing the state's irregular shape and the surrounding water. The land is a mix of urban areas with grid patterns and more rural, green areas. The water is a deep blue-grey color.

When Contemplating Rhode Island Coastal Geologic Hazards

Which Give Rise to these Processes:

- **Frontal Erosion – from Breaking Waves and Swash**
- **Storm-Surge Overwash**
- **Elevated MHHW into the Future**

An aerial photograph of the Rhode Island coastline, showing the state's irregular shape and surrounding water. The text is overlaid on the map.

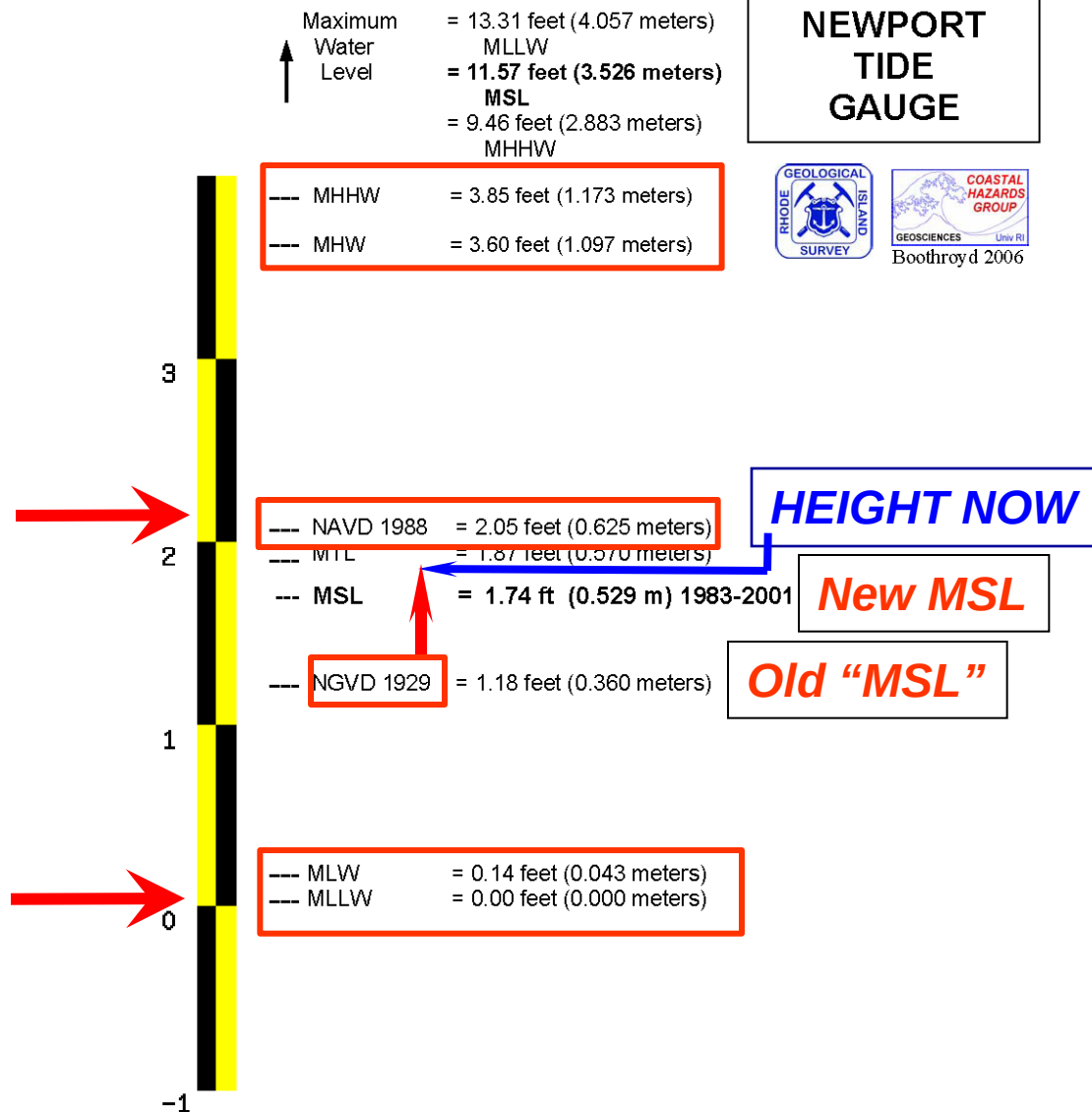
When Contemplating Rhode Island Coastal Geologic Hazards

The Scale of Processes are:

- **Breaking Waves – 1 to 3+ meters at shoreline**
- **Storm-Surge Overwash – 30 cm to 3+ meters water depth across shore zone**
- **Sea-Level Rise – 2.58 mm per year at present**

Tidal Datums Newport

How High
will the
Water Be?



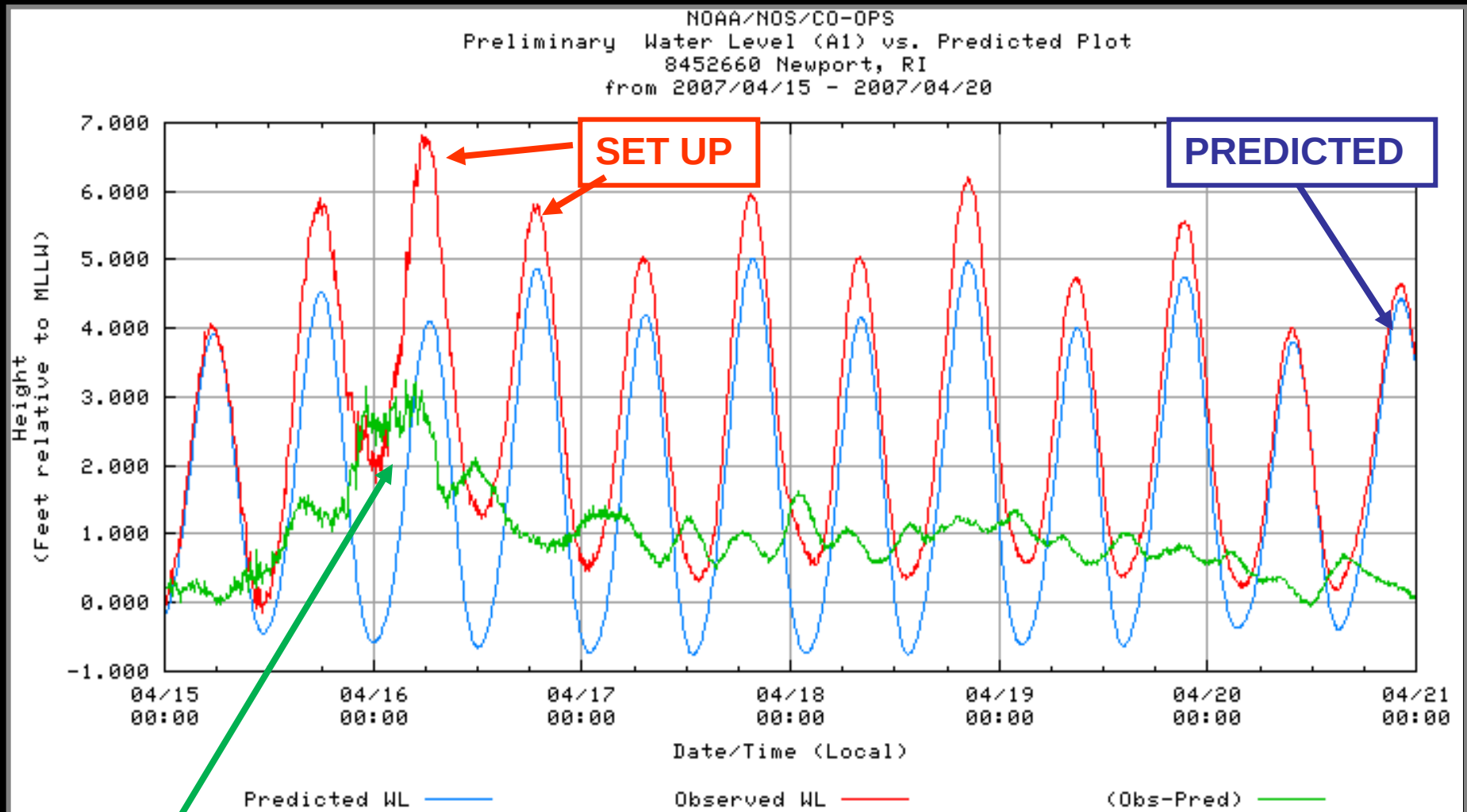
The NAVD 1988 and NGVD 1929 elevations related to MLLW were computed from Bench Mark, 845 2660 TIDAL 6, at the station.

Displayed tidal datums are MEAN HIGHER HIGH WATER (MHHW), MEAN HIGH WATER (MHW), MEAN TIDE LEVEL (MTL), MEAN LOW WATER (MLW), AND MEAN LOWER LOW WATER (MLLW) referenced on 1983-2001 Epoch.

Adapted from:
www.ngs.noaa.gov/newsys/cgi-bin/ngs_opsd.prl?PID=LW0493&EPOCH=1983-2001

Patriots Day Extratropical Storm – April 2007

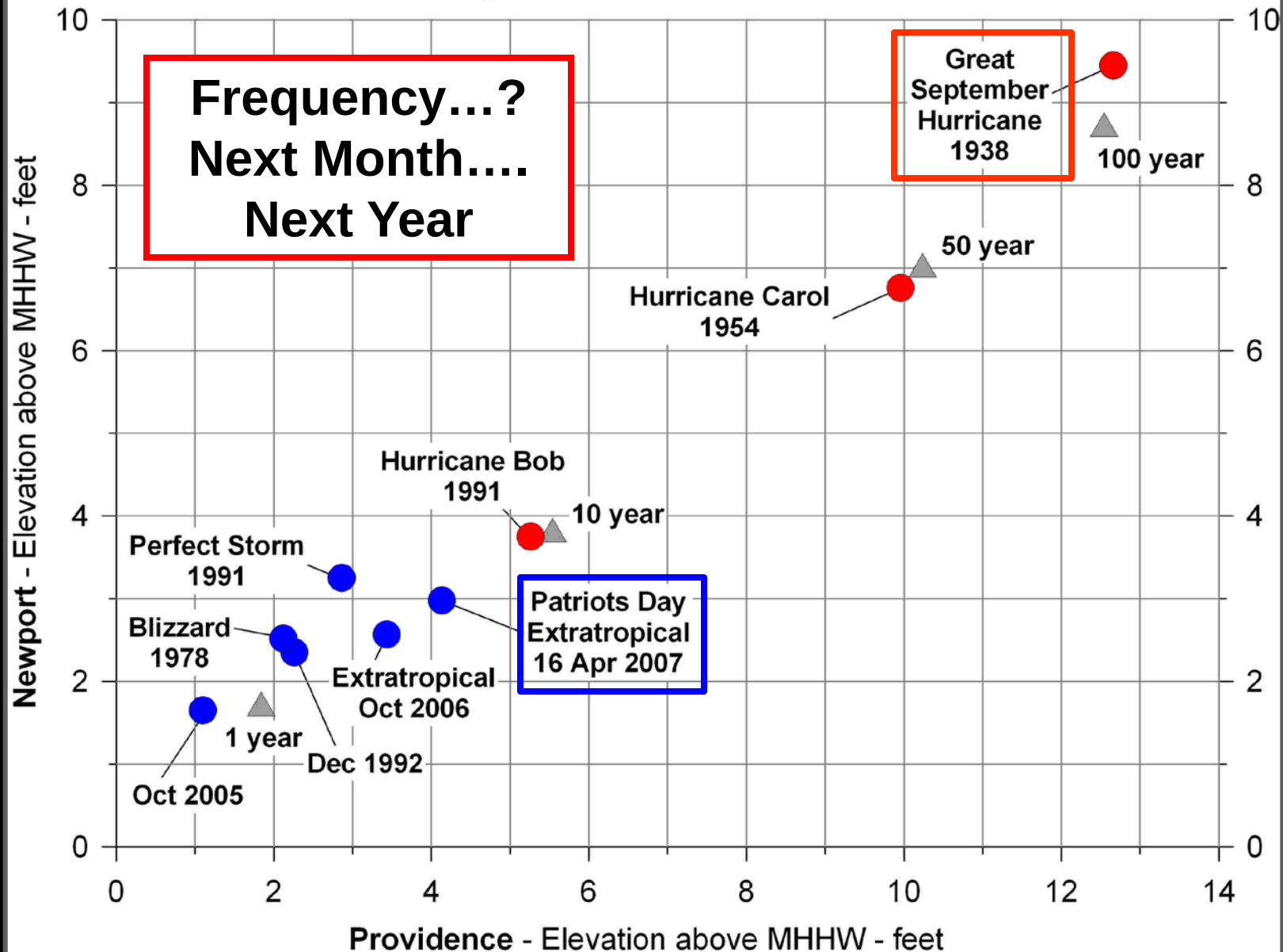
Newport Tide Gauge



[http://tidesandcurrents.noaa.gov/
data_menu.shtml?stn=8452660%20Newport,%20RI&type=Tide+Data](http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=8452660%20Newport,%20RI&type=Tide+Data)

STORM-SURGE ELEVATION

Newport - Providence, RI

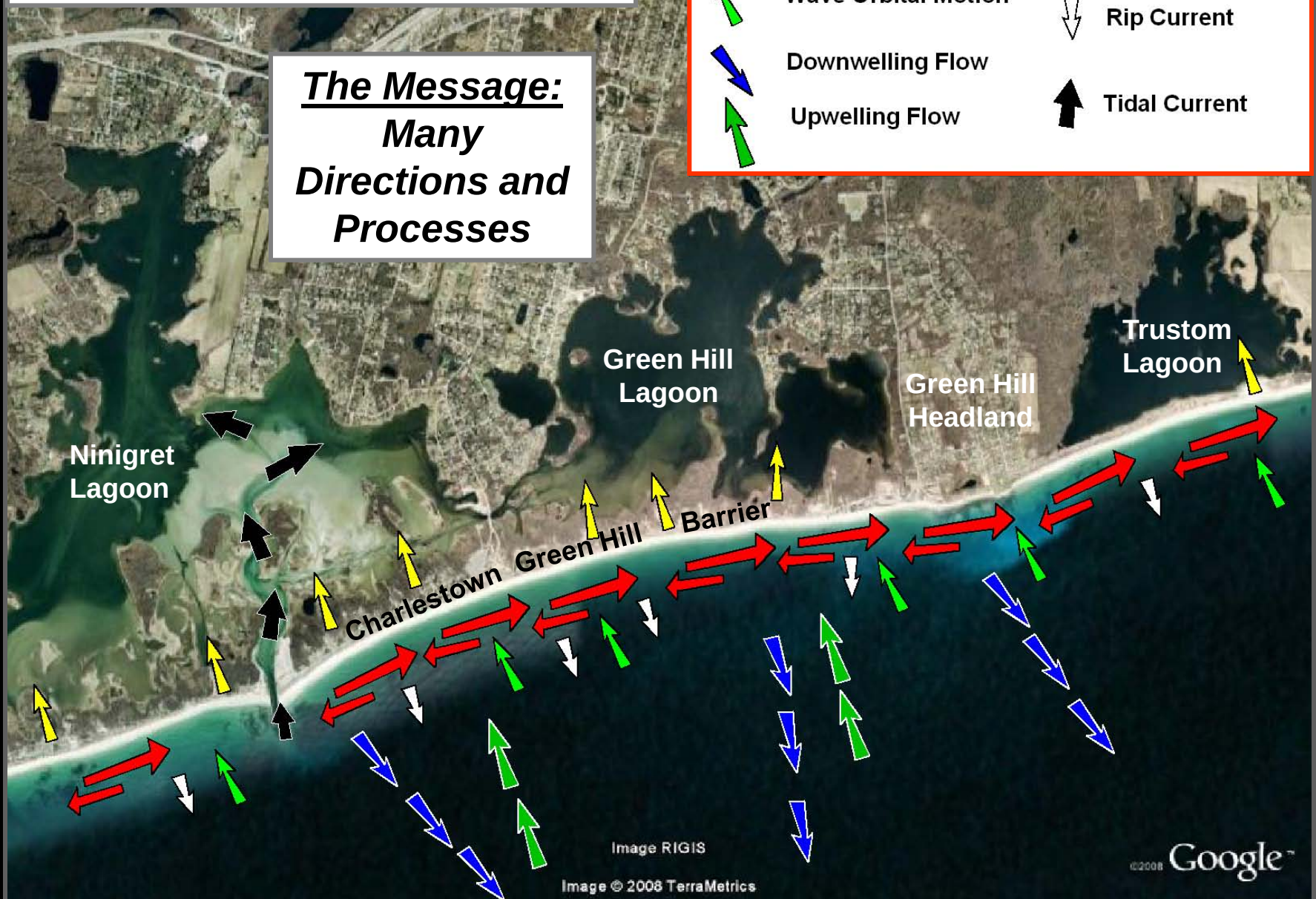
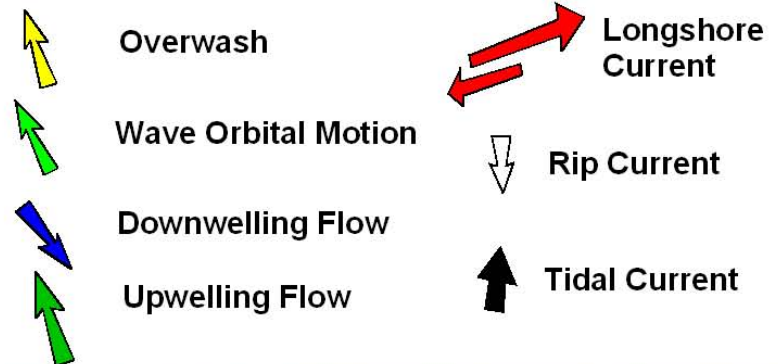


Adapted from
NOAA;
USACE 1988;
Hehre 2007

Sediment Transport Pathways Charlestown – Green Hill Barrier and Headland

The Message:
*Many
Directions and
Processes*

Transporting Mechanism



Charlestown Beach – Blizzard 1978 – No Berm

CHARLESTOWN BEACH
7 February 1978

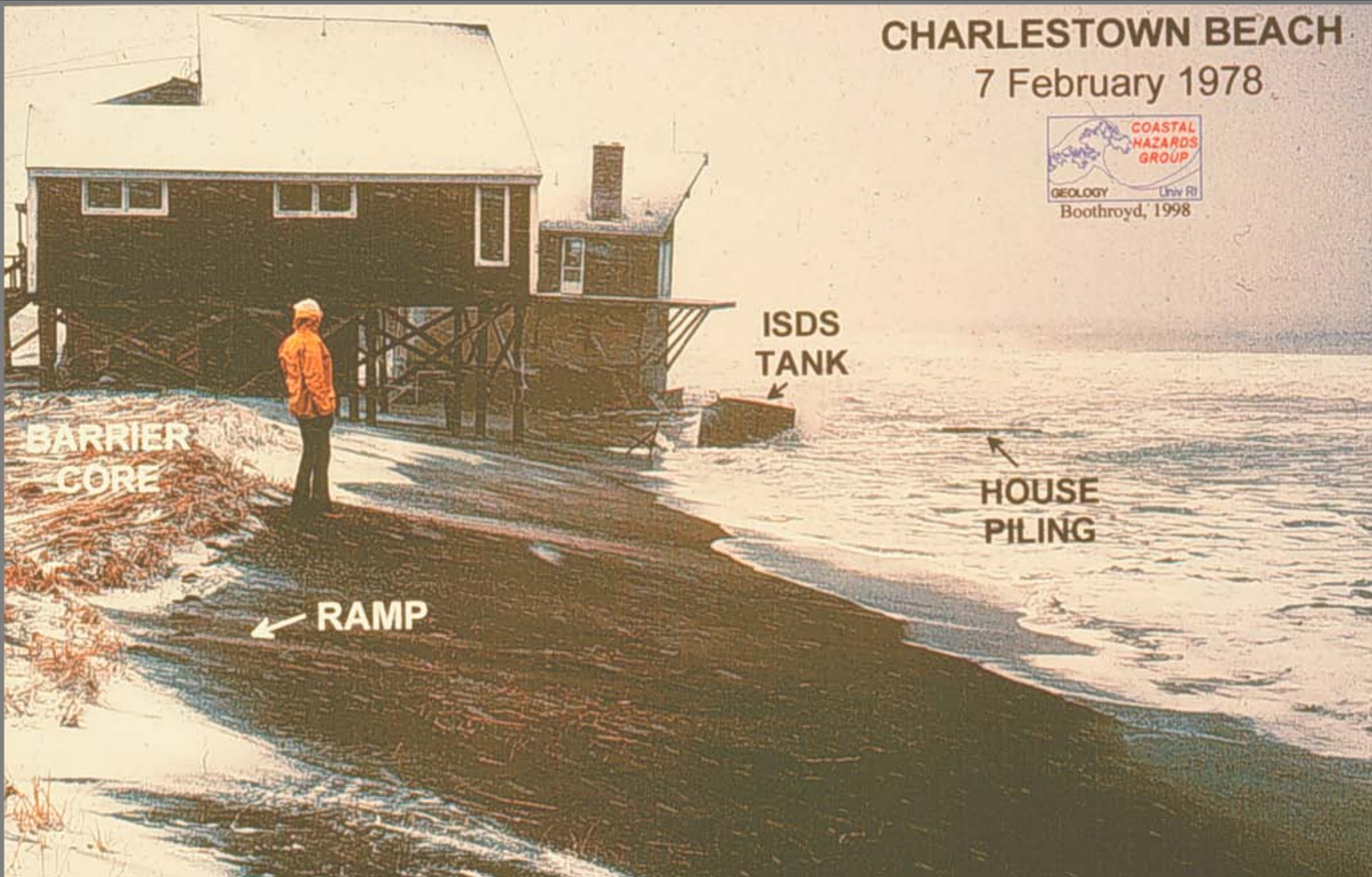


BARRIER
CORE

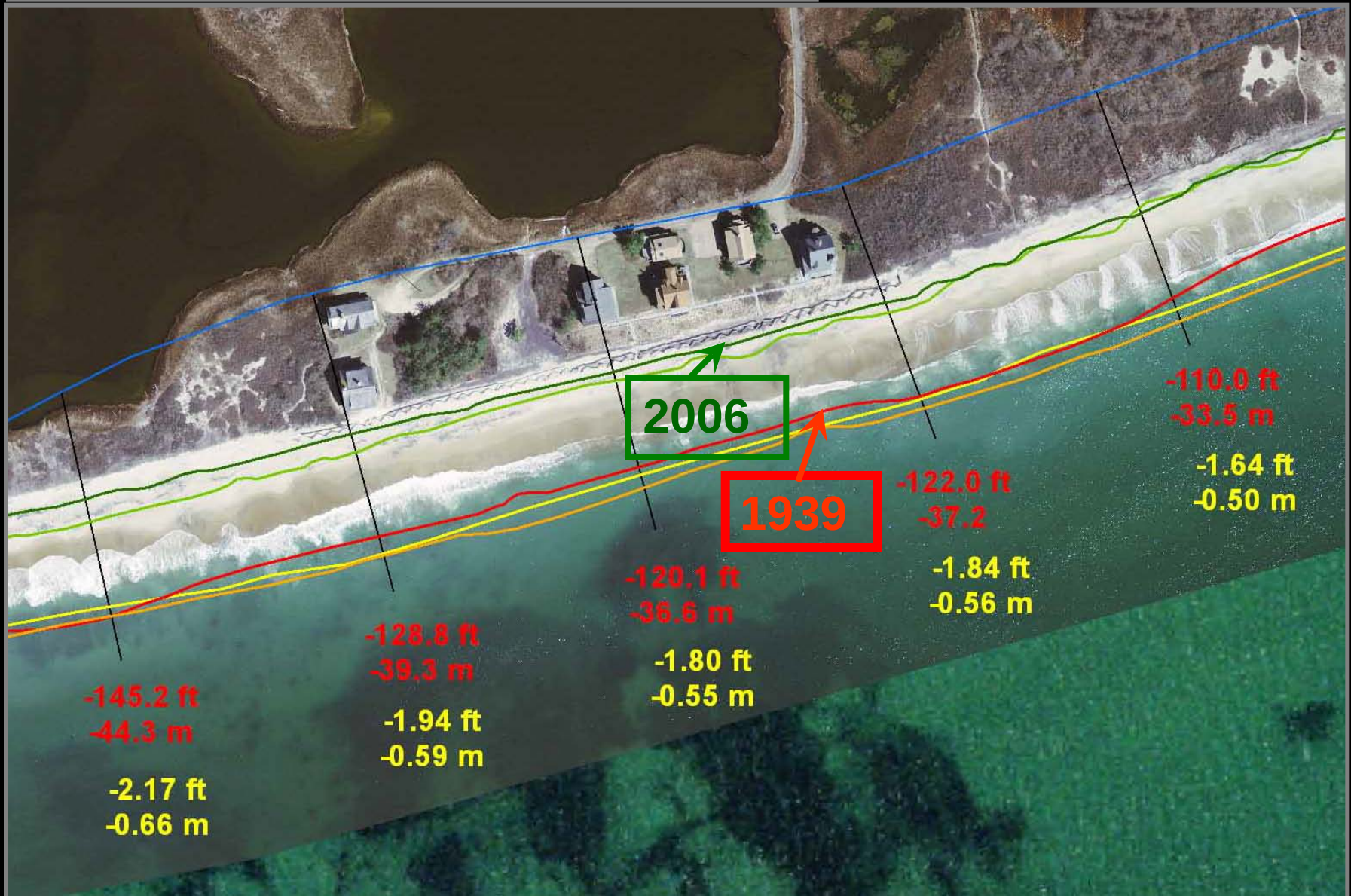
ISDS
TANK

HOUSE
PILING

RAMP



Frontal Erosion 1939-2006 - Browning Cottages



Frontal Erosion - Browning Cottages



FEB 20 2007

BA Oakley

Overwash - Browning Cottages



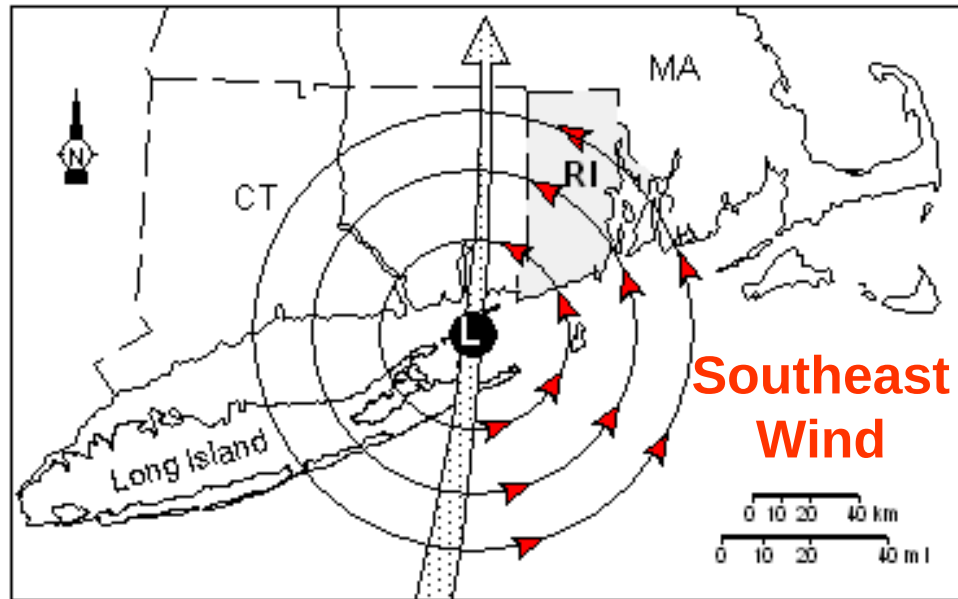
04/16/2007 08:42

RE Hehre

An aerial photograph of a coastal region, likely San Francisco, showing the city's layout, the bay, and surrounding islands. The text "Really Big Storms" is overlaid in the center.

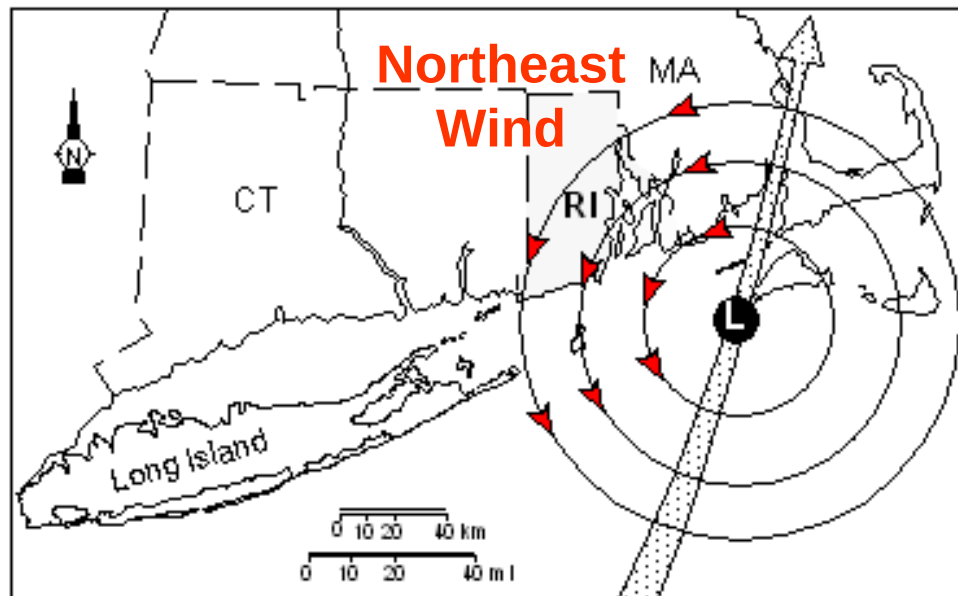
Really Big Storms

HURRICANE and EXTRATROPICAL STORM PATHS and ASSOCIATED WIND PATTERNS



PASSAGE TO THE WEST

- Maximum Onshore Wind
- Severe Storm-Surge Flooding



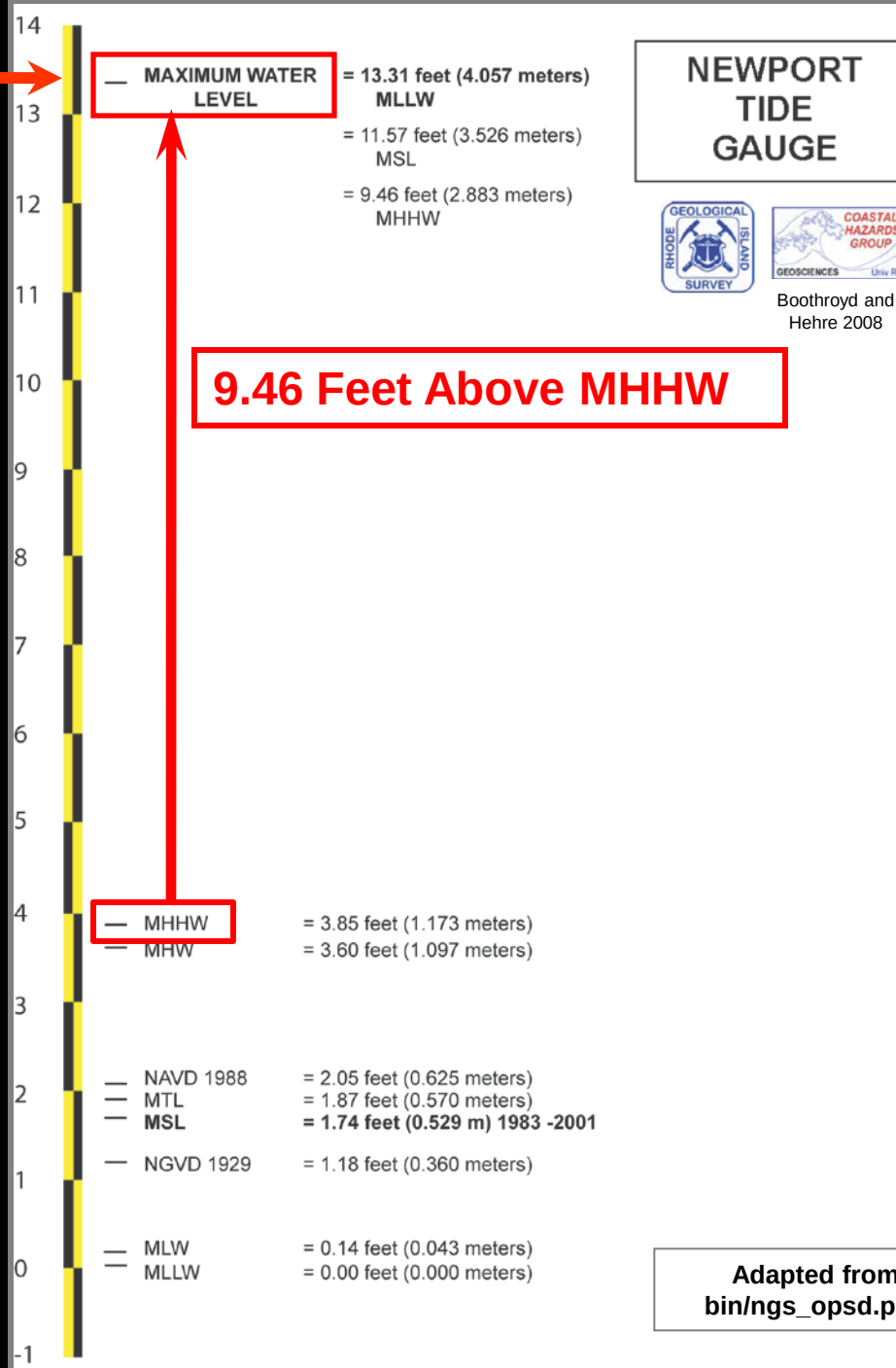
PASSAGE TO THE EAST

- Offshore Wind
- Minimum Storm-Surge Flooding

From Wright and Sullivan, 1982

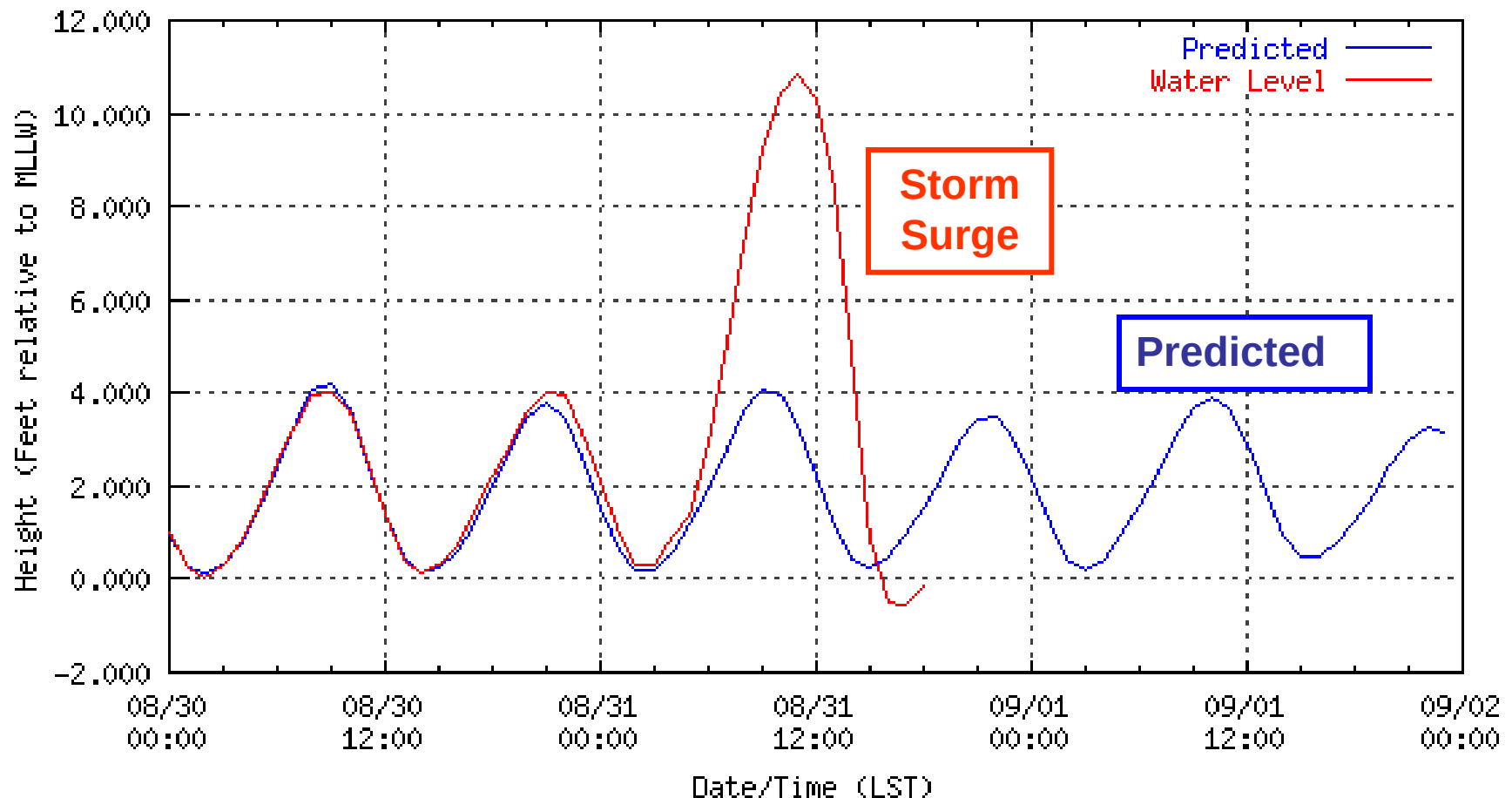
How High
will the
Water Be?

Tidal Heights Newport



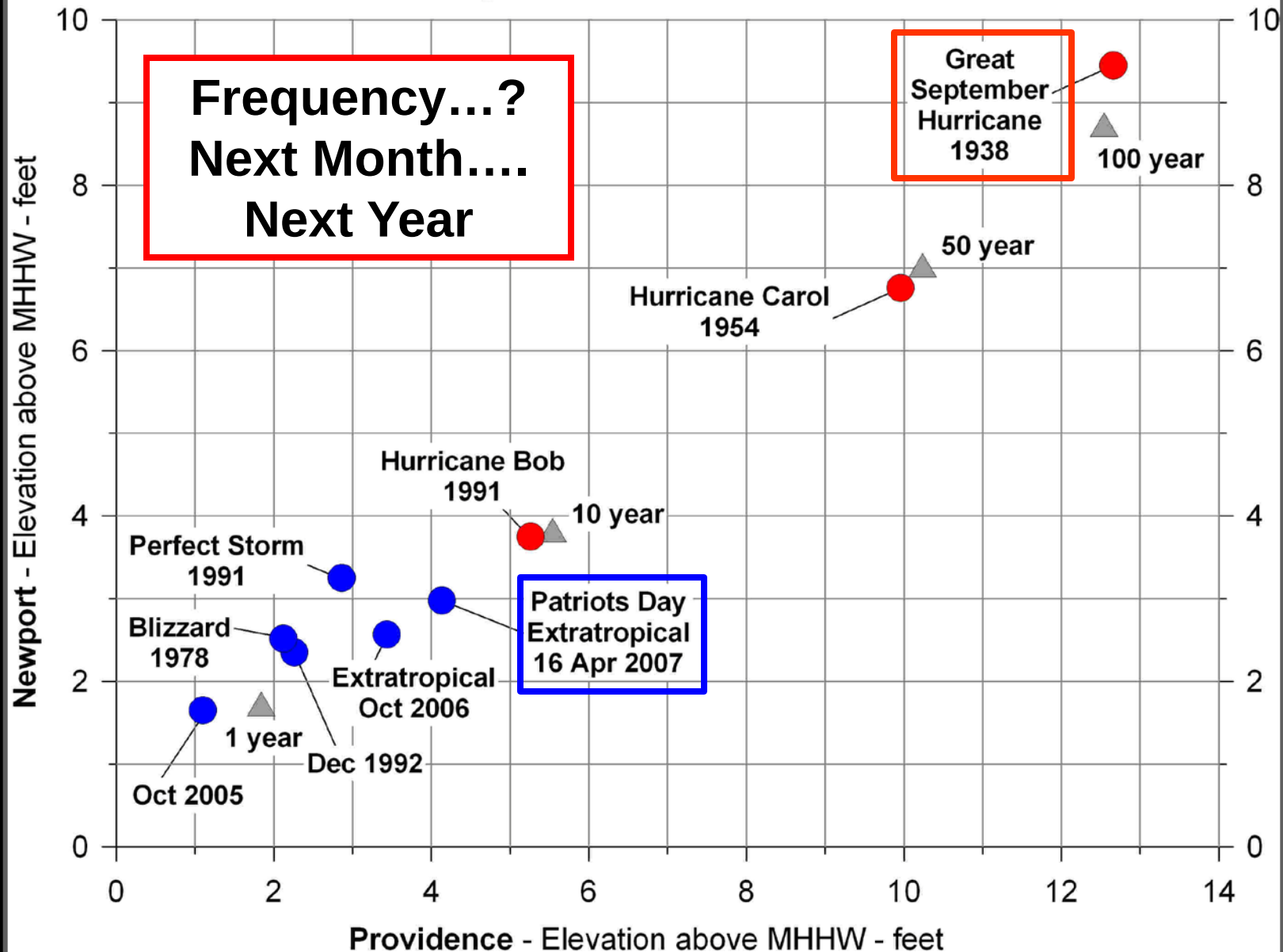
Hurricane Carol - 1954

NOAA/NOS/CO-OPS
Verified Hourly Height Water Level Plot
8452660 NEWPORT, NARRAGANSETT BAY , RI
from 08/30/1954 - 09/01/1954



STORM-SURGE ELEVATION

Newport - Providence, RI



Adapted from
NOAA;
USACE 1988;
Hehre 2007

Charlestown Beach



100 year Storm Surge plus Waves

Overwash

04/17/2007 15:15

RE Hehre

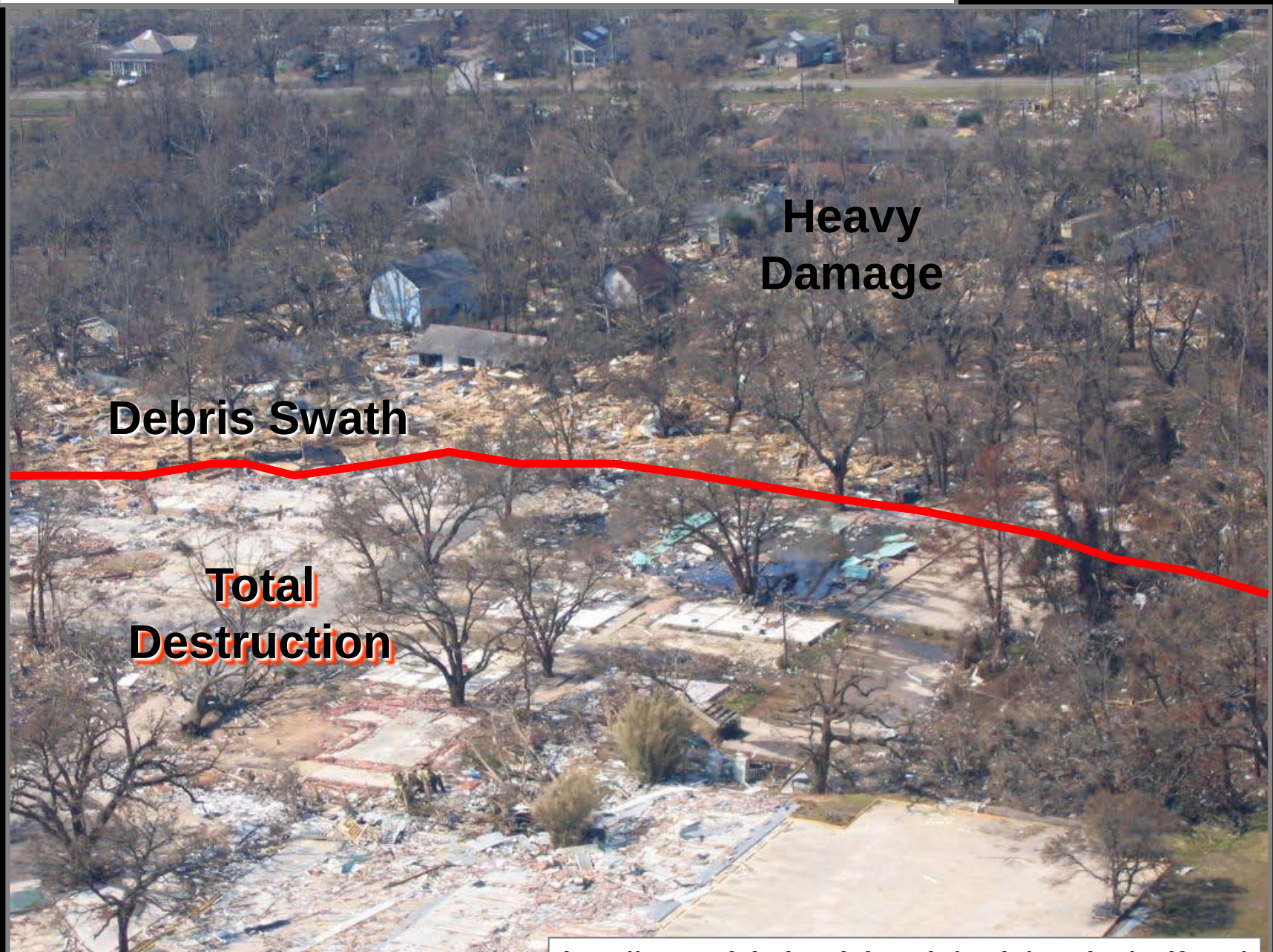
Charlestown Beach – Hurricane Bob 1991 Washover Fan Deposition



**Removal is a Bad Idea
Barriers Naturally Retreat
Landward and Upward**

Aug 1991

Gulfport, MS – Katrina - 2 Sept 2005



**Heavy
Damage**

Debris Swath

**Total
Destruction**

Misquamicut – US 1A – Westerly 1938 Hurricane - Debris Swath



Increased Storm Frequency and Intensity??



2D 3D Road Aerial

25 feet 10 m

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Picometry Bird's Eye © 2010 MDA Geospatial Services Inc

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The Towers – Narragansett Pier – 1938 Hurricane

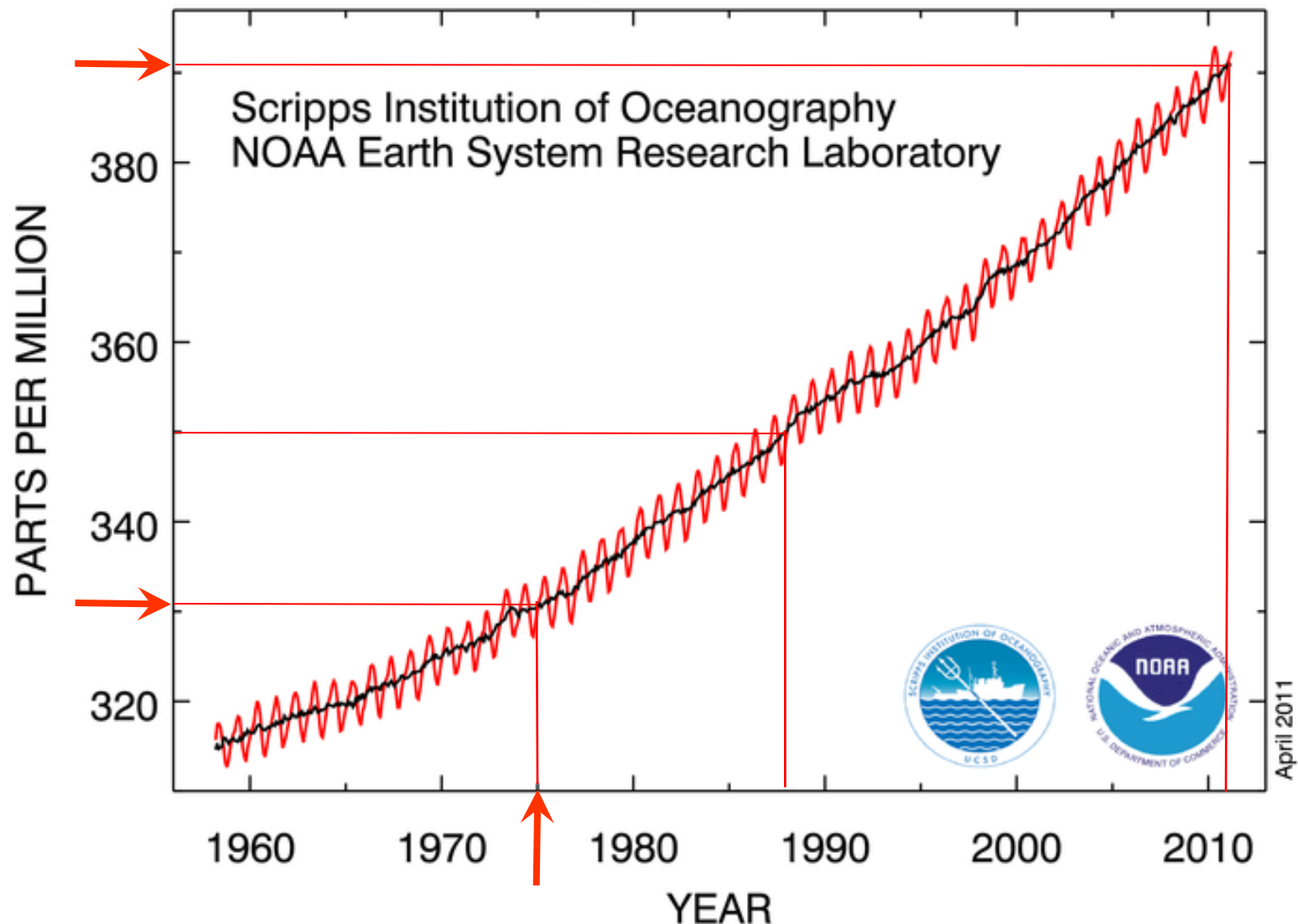


Providence Journal, 1938

An aerial photograph of Rhode Island, showing its coastline, major cities like Providence and Pawtucket, and surrounding water bodies. A semi-transparent blue rectangular area is overlaid on the central part of the state, serving as a background for the text.

***Lastly,
Climate Change
and the
Future Shore Zone
of
Rhode Island***

Atmospheric CO₂ at Mauna Loa Observatory



http://www.esrl.noaa.gov/gmd/ccgg/trends/co2_data_mlo.html

Carbon Dioxide - CO₂ Levels

A Cause for Concern

Now 390+ ppm

Carbon Dioxide Levels Today are Higher than over the Past 650,000 Years

Atmospheric carbon dioxide record data sources: Keeling and Whorf (2004), Petit et al. (1999), IPCC (2001), Ahn et al. (2004).

Industrial CO₂ Levels

Pre-industrial CO₂ Levels

First Moon Landing



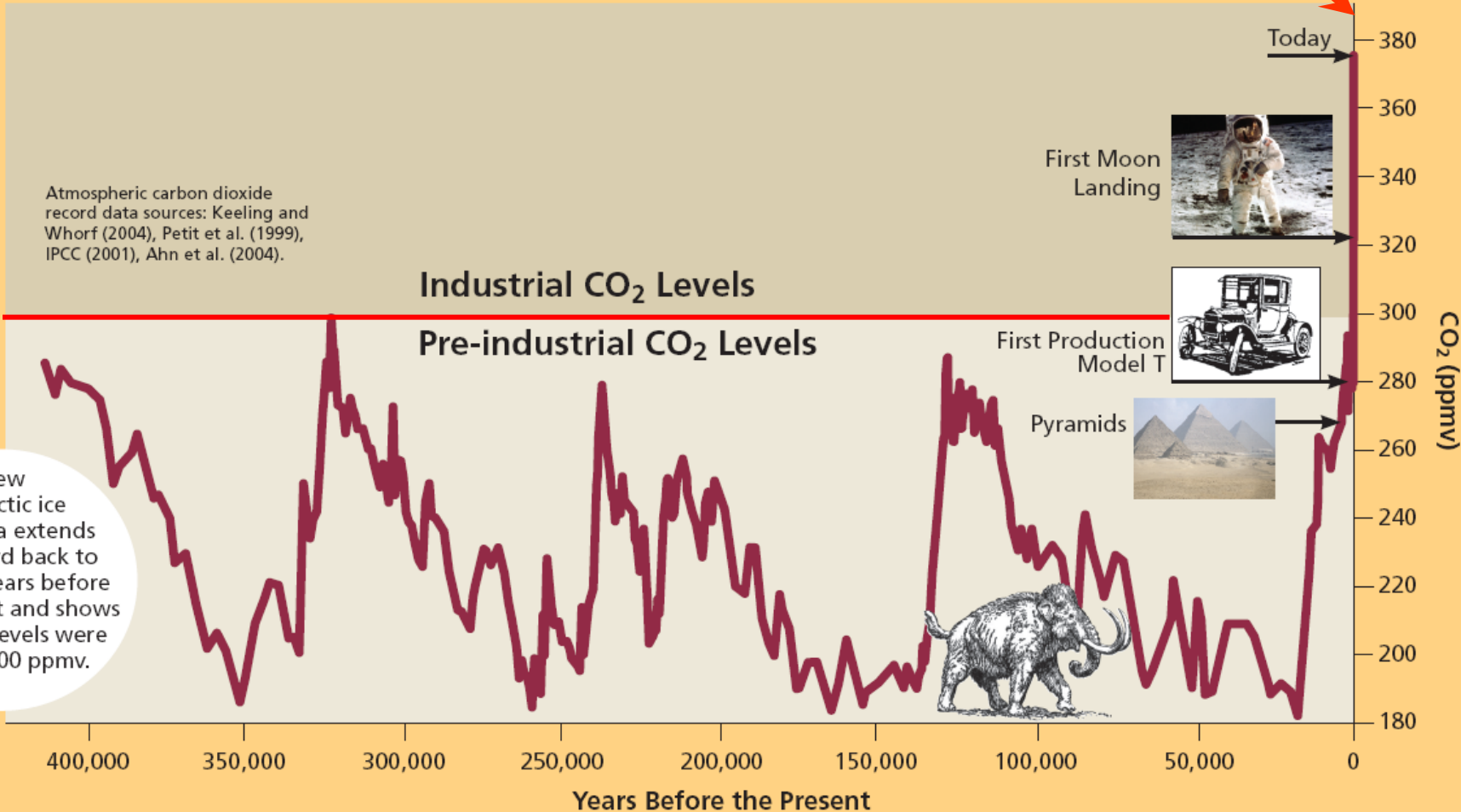
First Production Model T



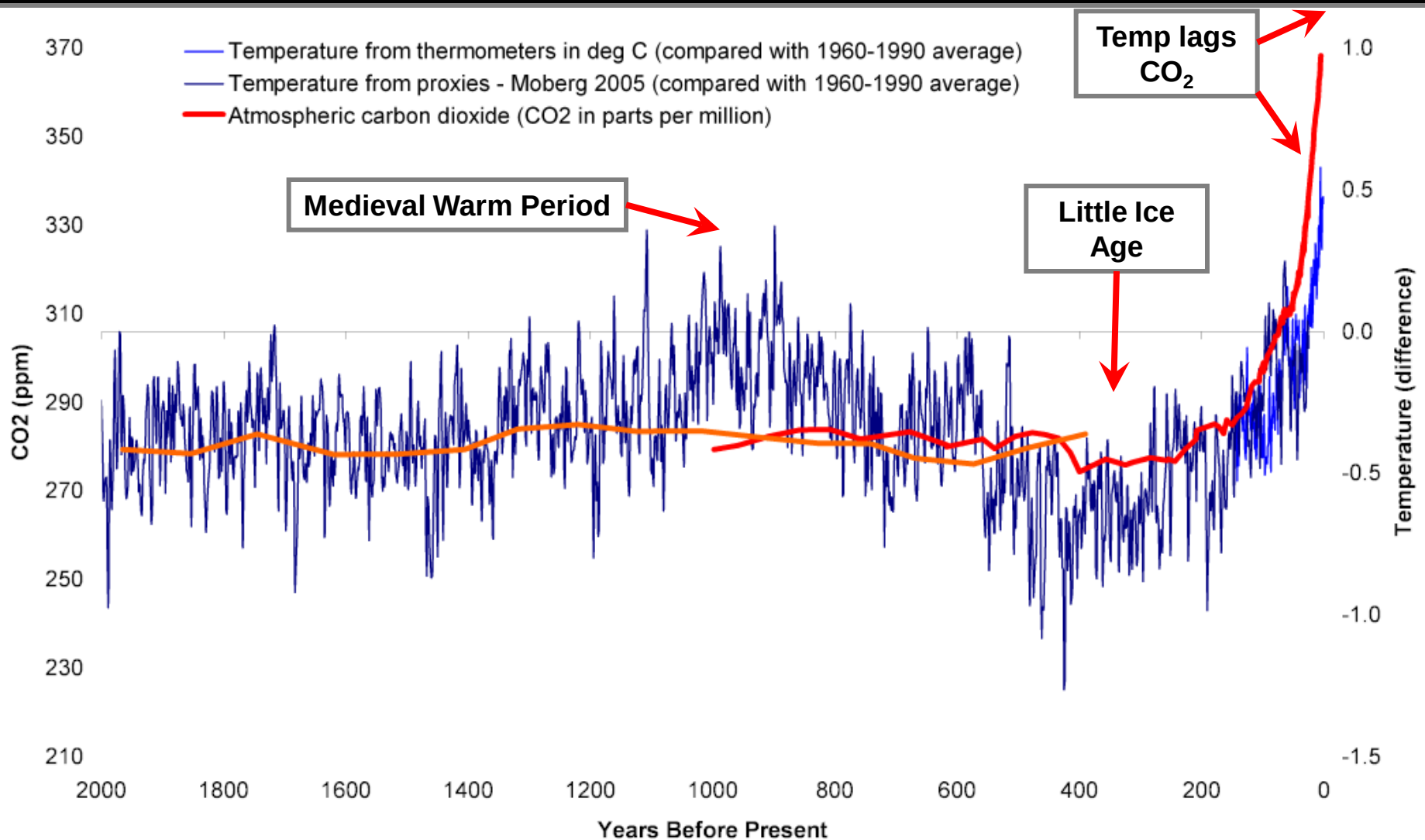
Pyramids



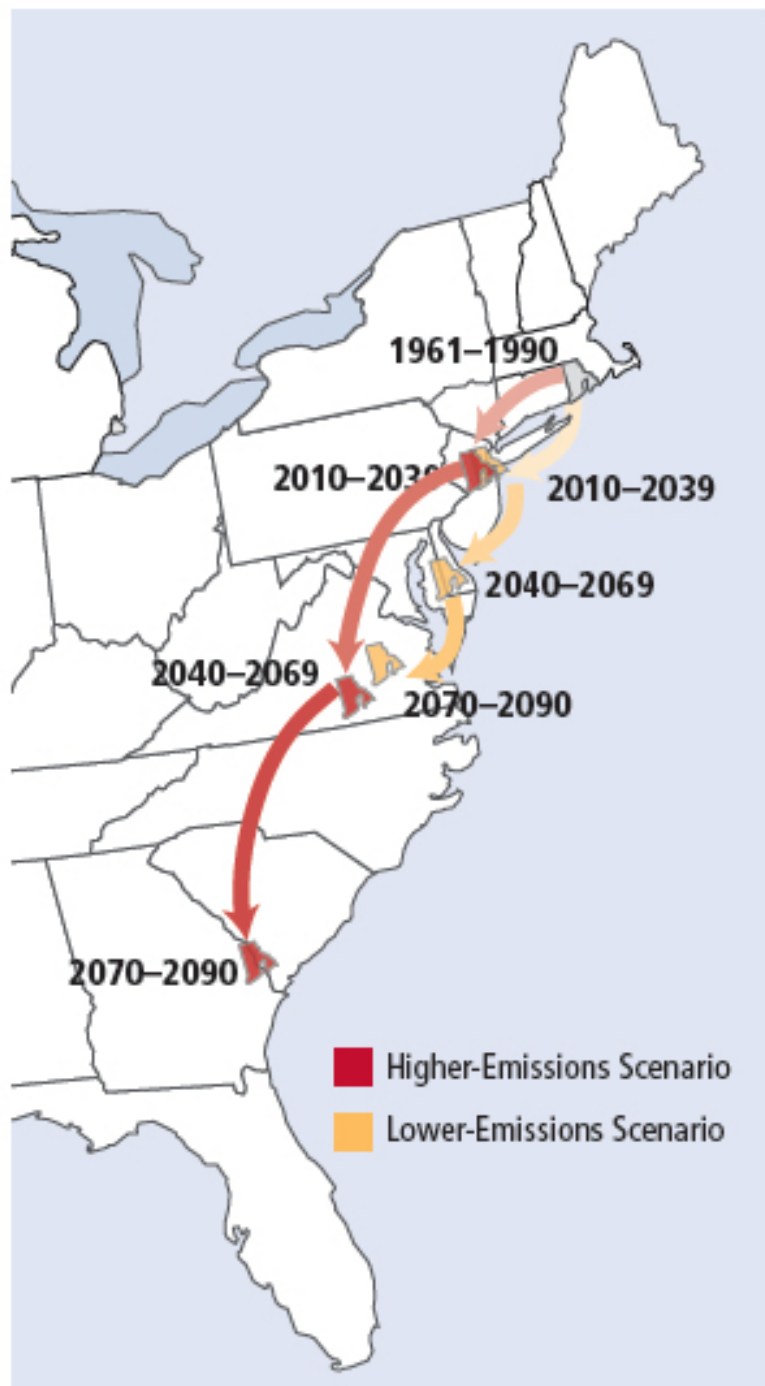
New Antarctic ice core data extends the record back to 650,000 years before the present and shows that CO₂ levels were below 300 ppmv.



THE HOCKEY STICK



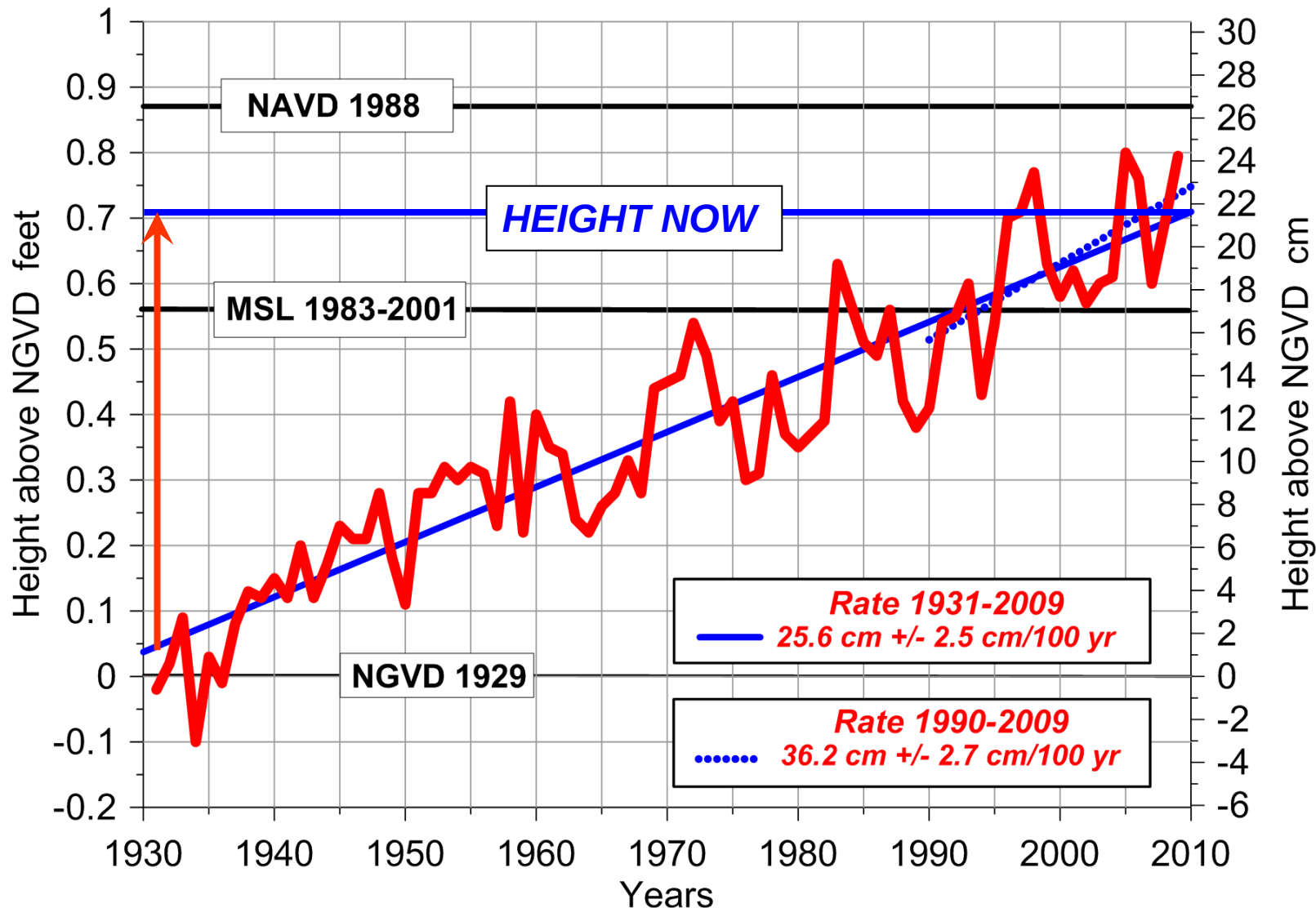
RHODE ISLAND Possible Future Climate



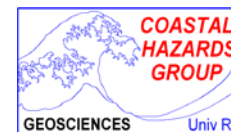
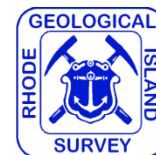
**Confronting Climate Change in the
U.S. Northeast: Climate, Impacts,
and Solutions, NECIA, 2007**

<http://www.northeastclimateimpacts.org/>

HISTORIC SEA-LEVEL RISE - Newport, RI

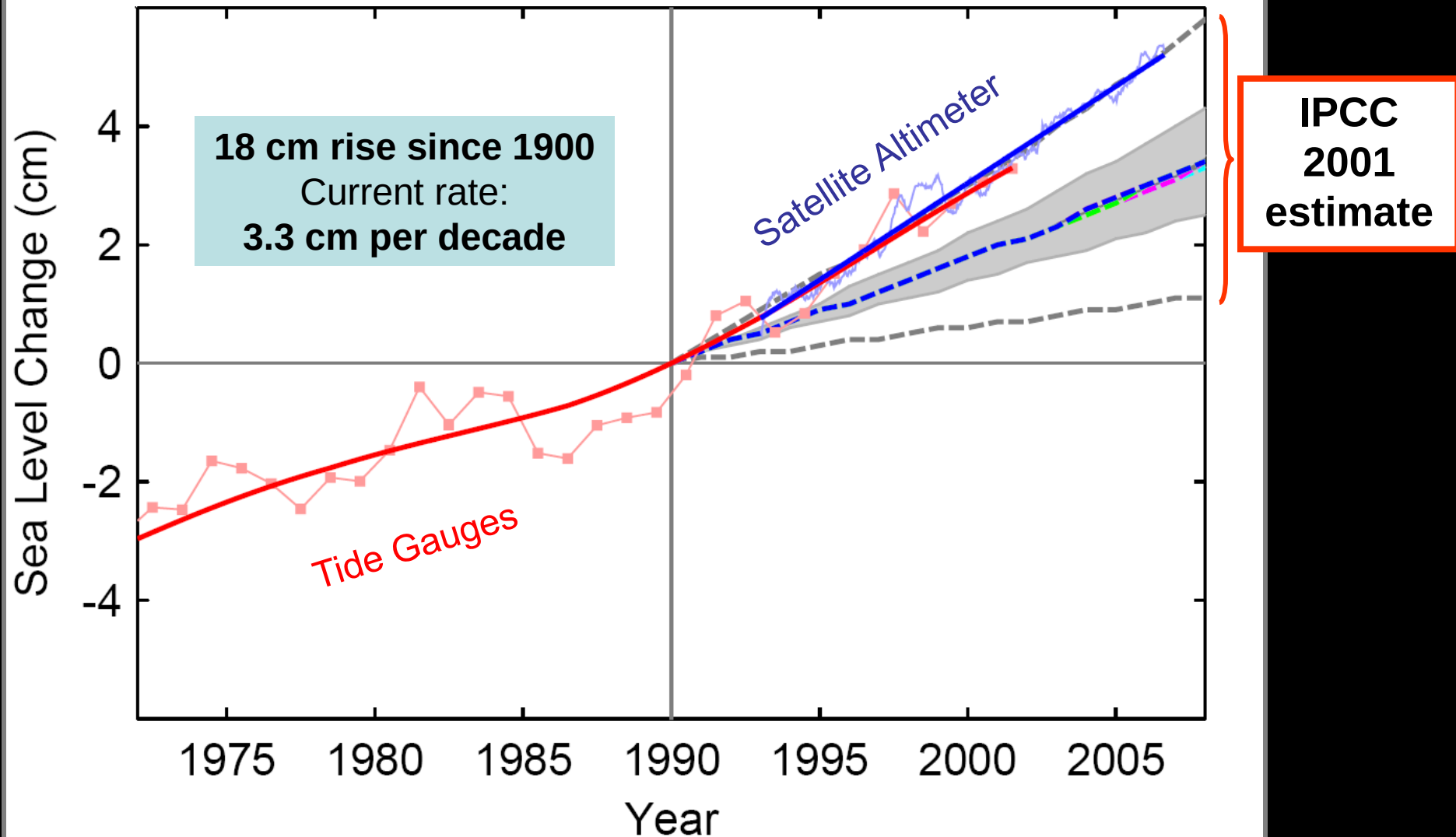


Adapted from:
http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8452660%20Newport,%20RI

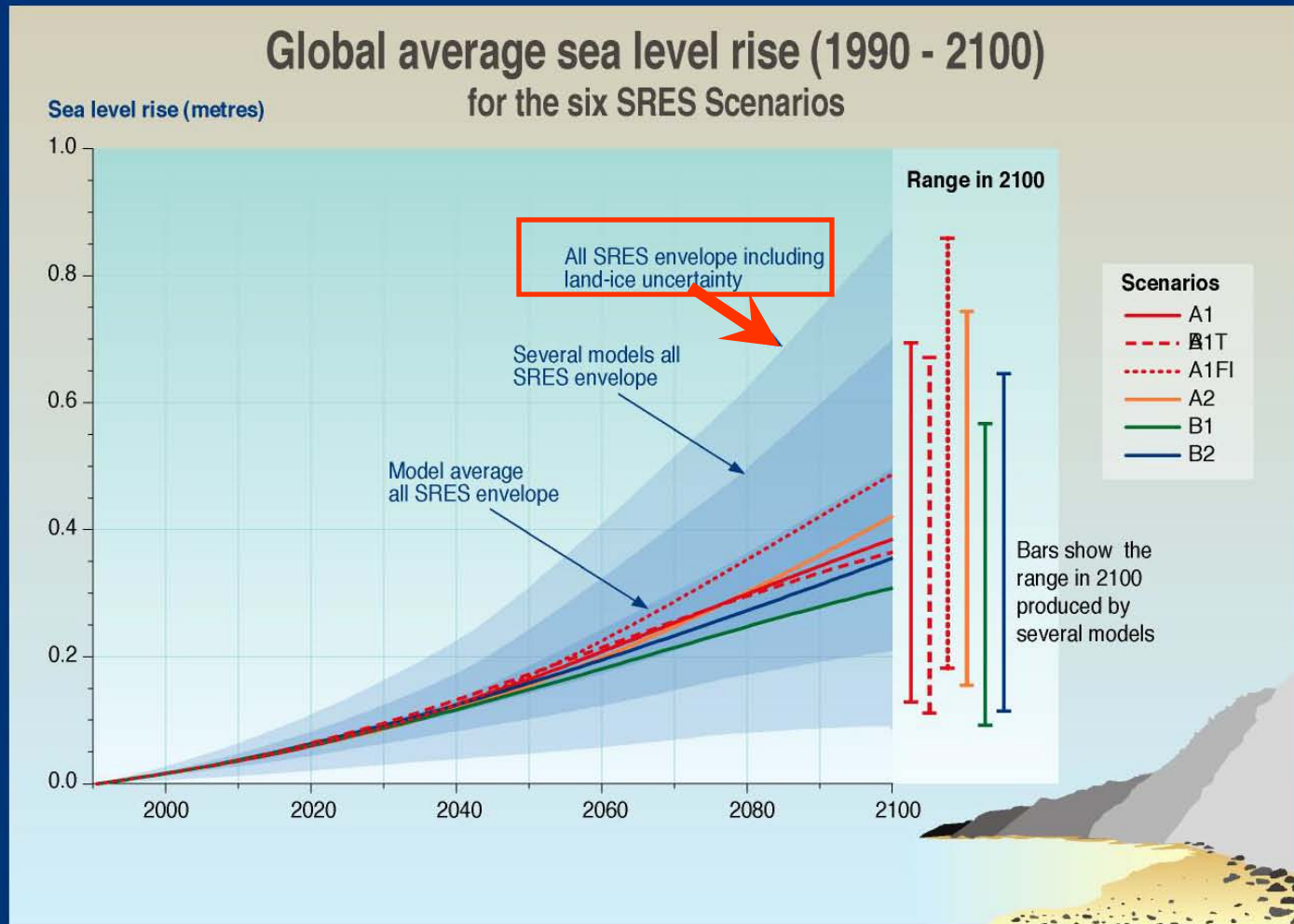


Boothroyd 2011

Observed Global Sea Level Rise ... Accelerating

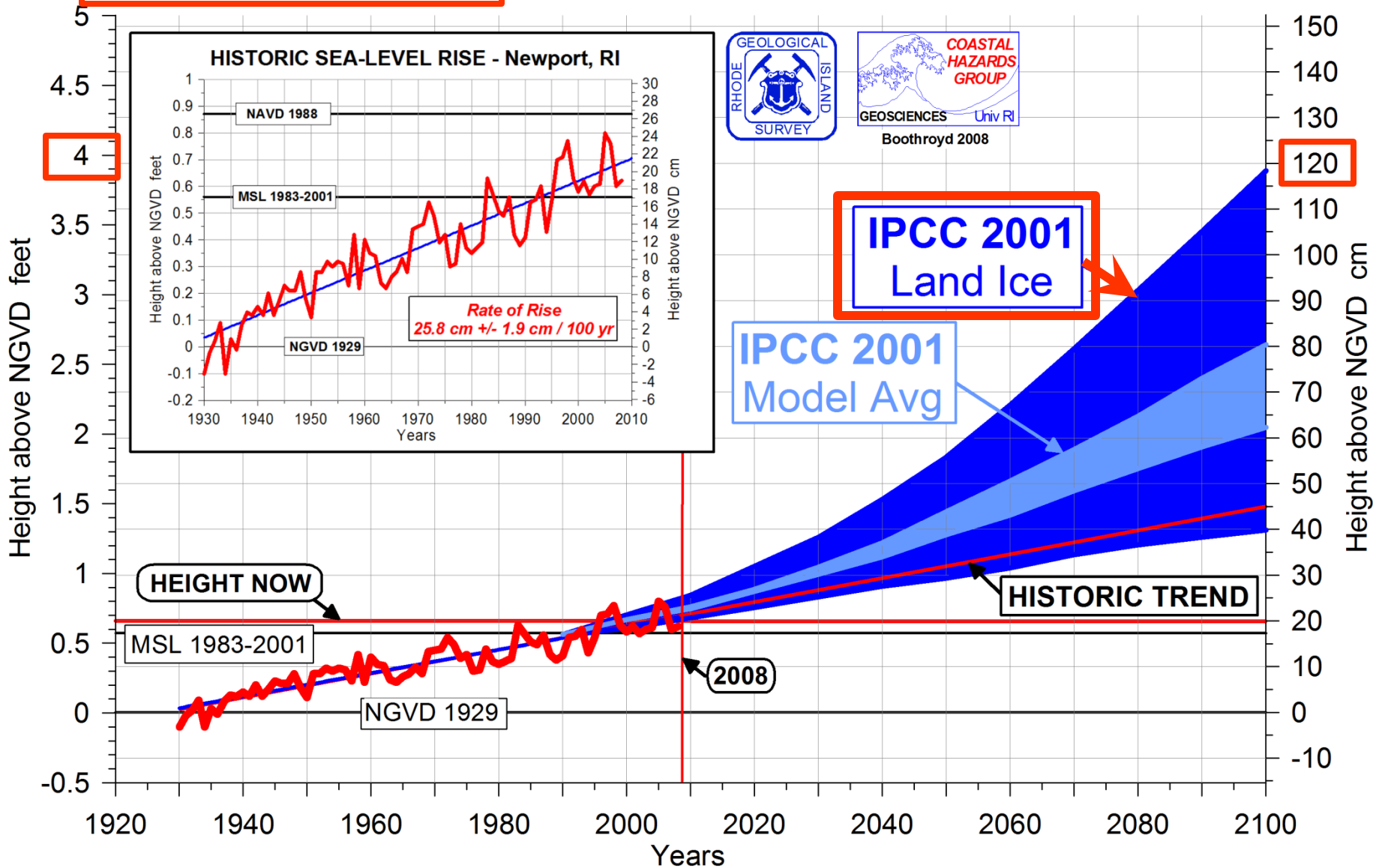


IPCC Scenarios 2001



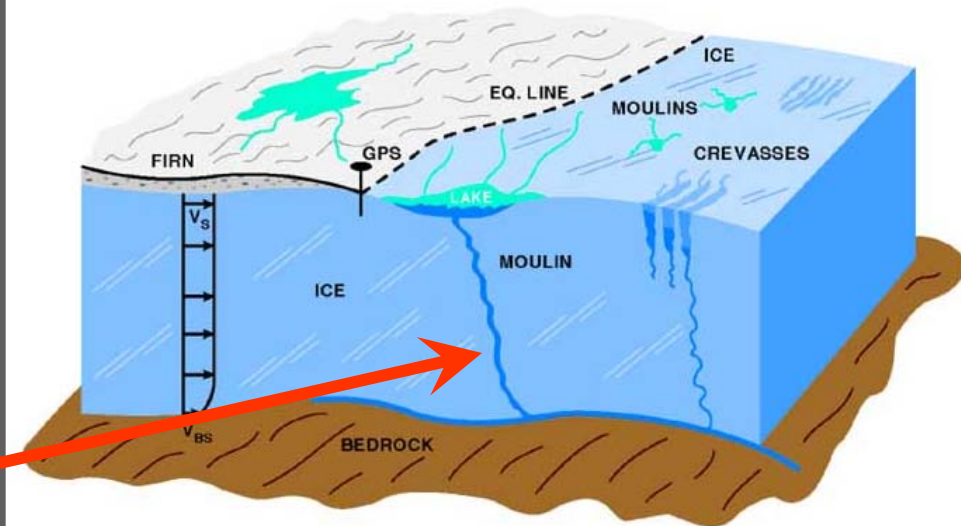
WG1 TS FIGURE 24

ACCELERATED SEA-LEVEL RISE - Newport, RI

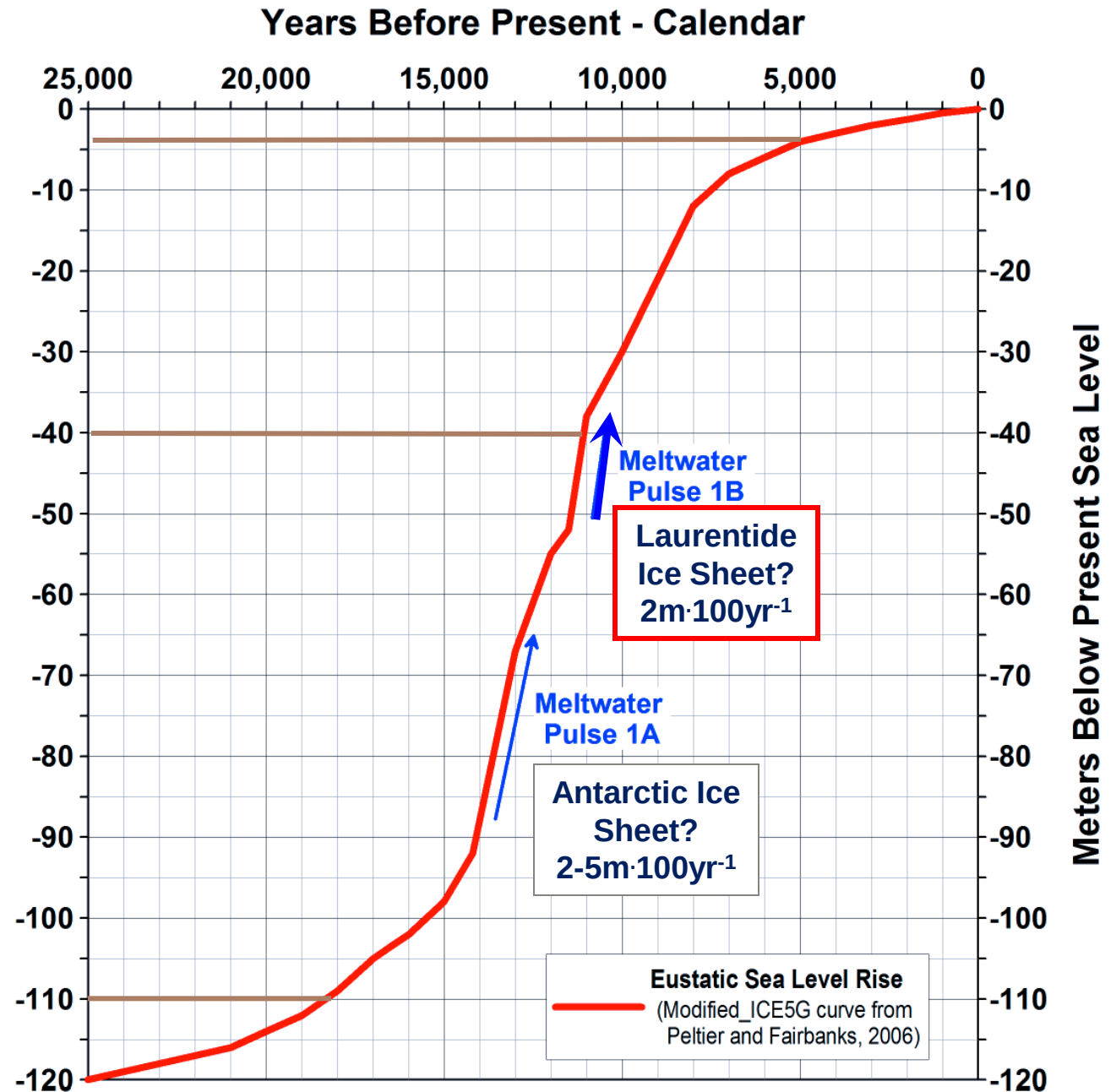


Greenland Outlet Glaciers Change from Polythermal to Warm Based

A Key to Future Sea-Level Rise



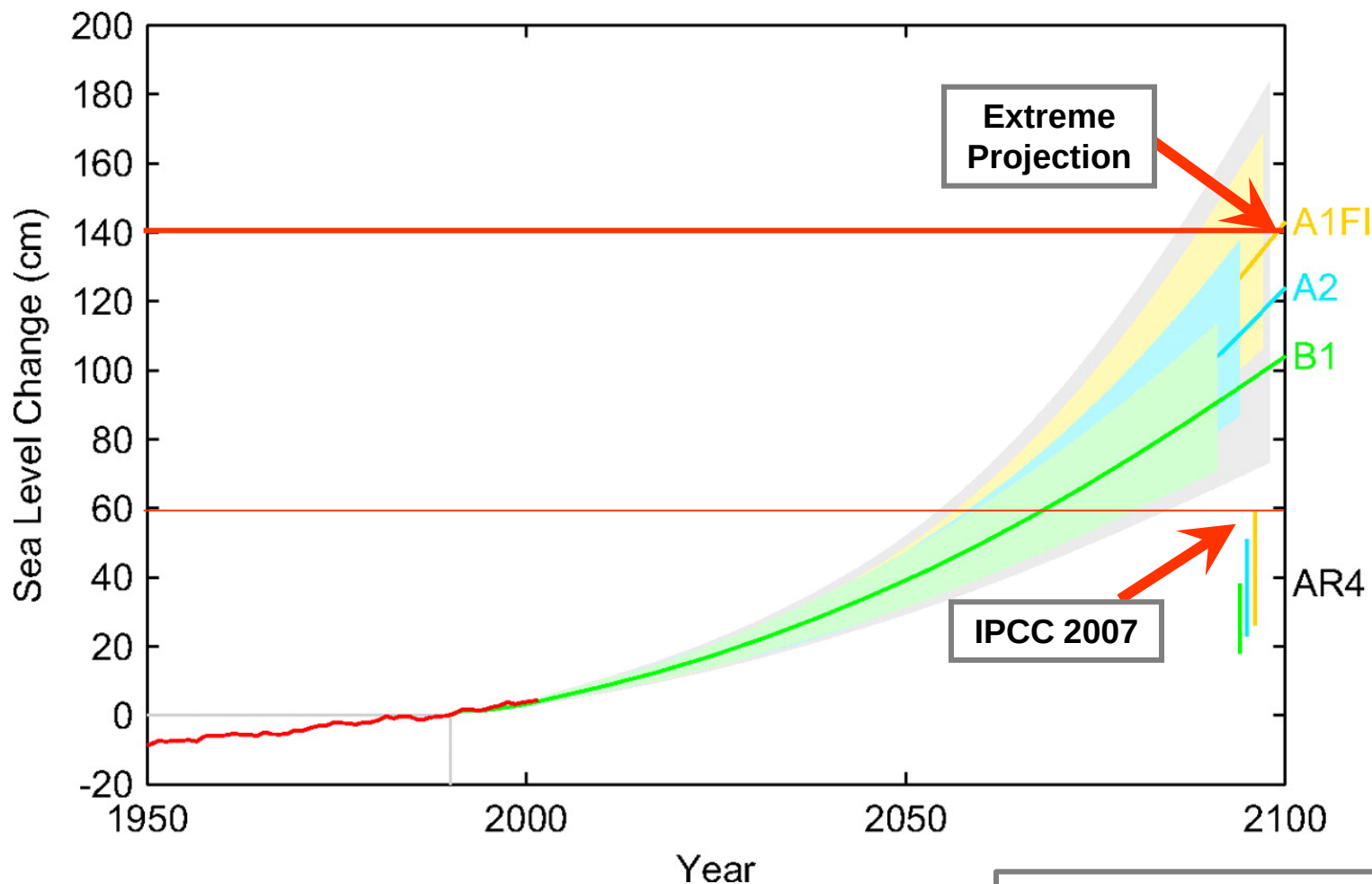
Eustatic Sea-Level Rise



Global Sea Level Linked to Global Temperature

Projection of Sea-Level Rise 1990 - 2100

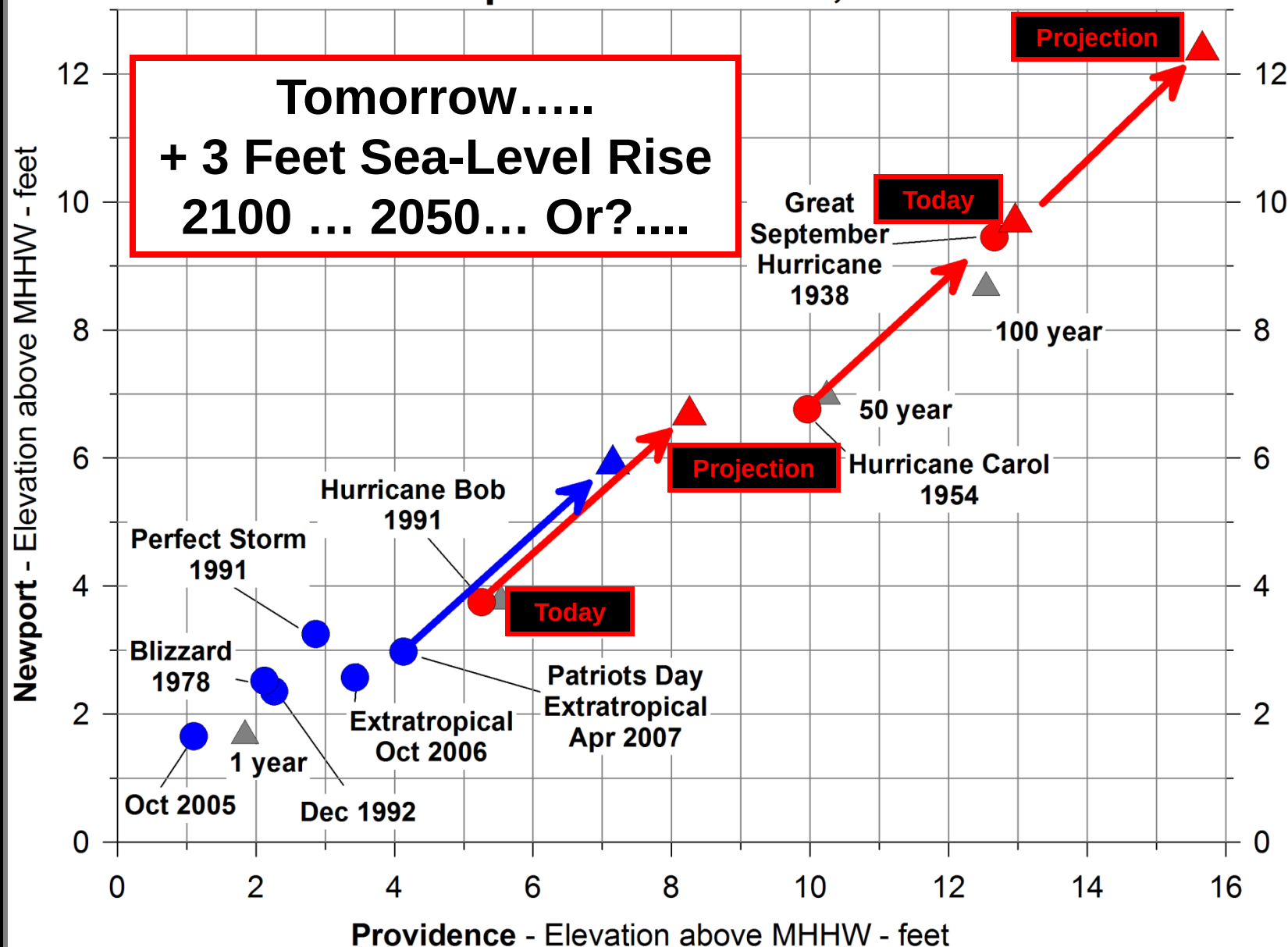
Using IPCC 2007 Temperature Projections



Vermeer and Rahmstorf, 2009,
PNAS, v106, p 21537-21532

PROJECTED STORM-SURGE ELEVATIONS

Newport - Providence, RI



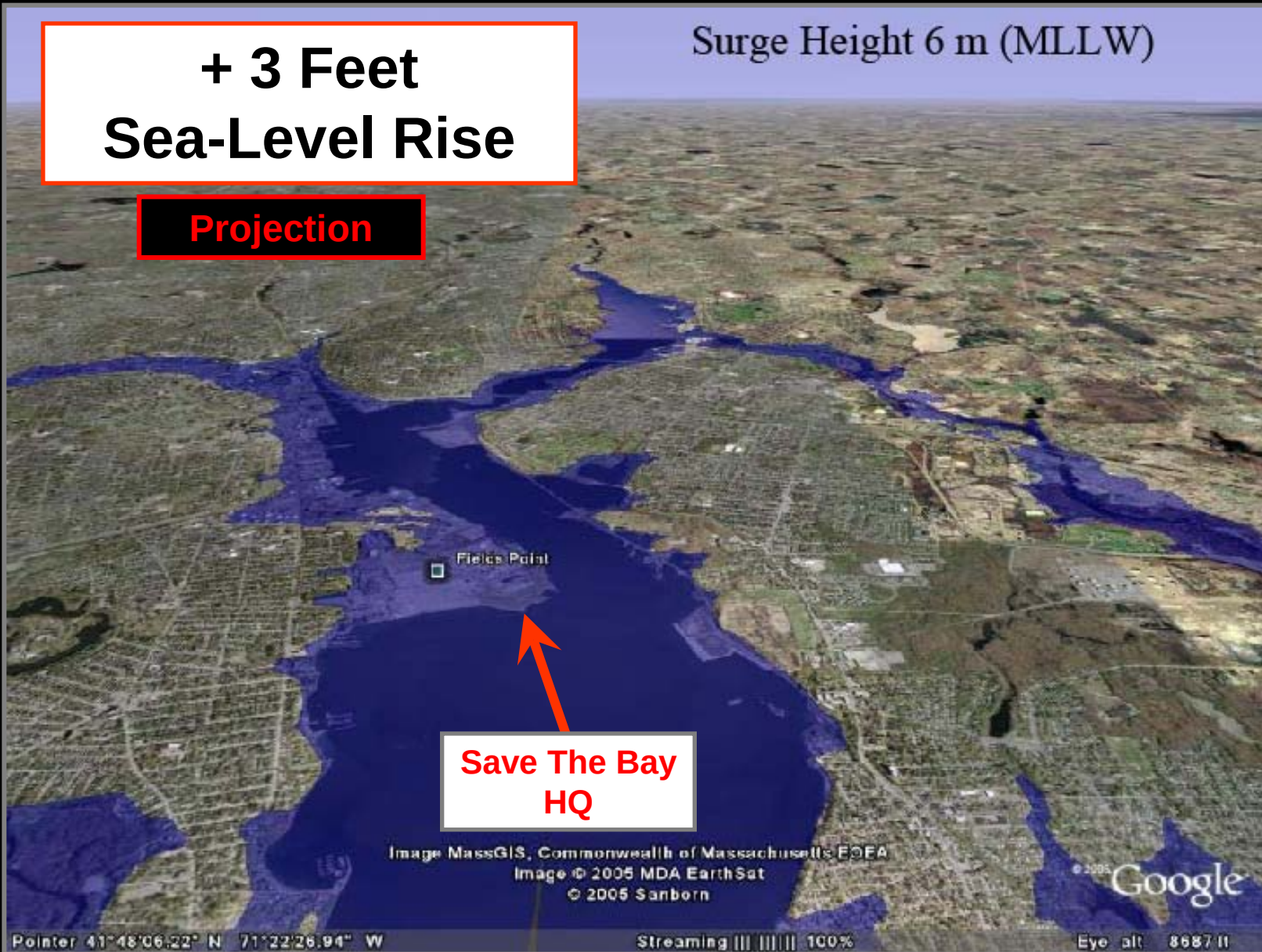
Adapted from
NOAA;
USACE 1988;
Hehre 2007

100-Year Storm-Surge Inundation - Providence

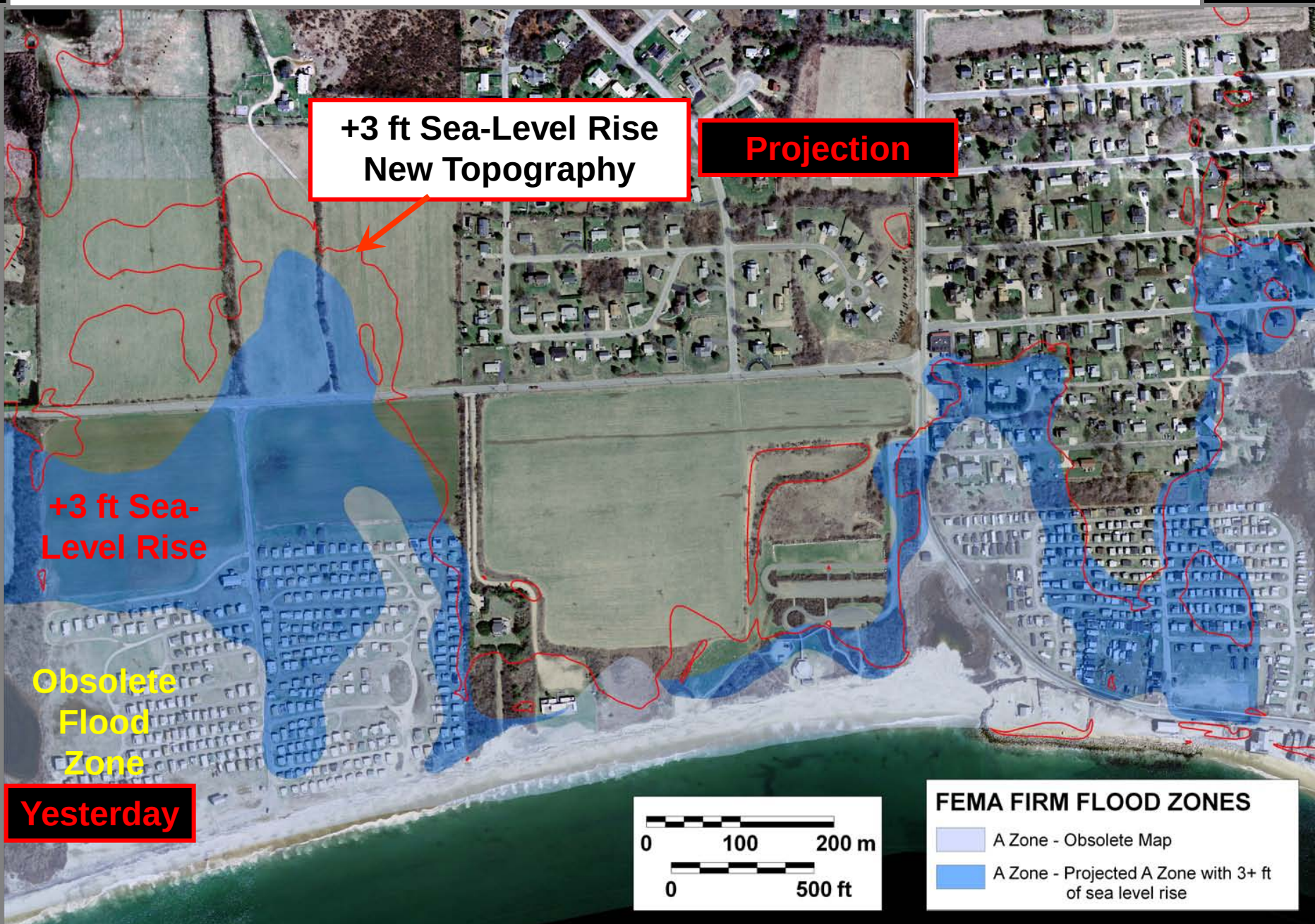
**+ 3 Feet
Sea-Level Rise**

Projection

Surge Height 6 m (MLLW)



100-Year Storm-Surge Inundation - Matunuck



Ninigret Lagoon - 2004

Today

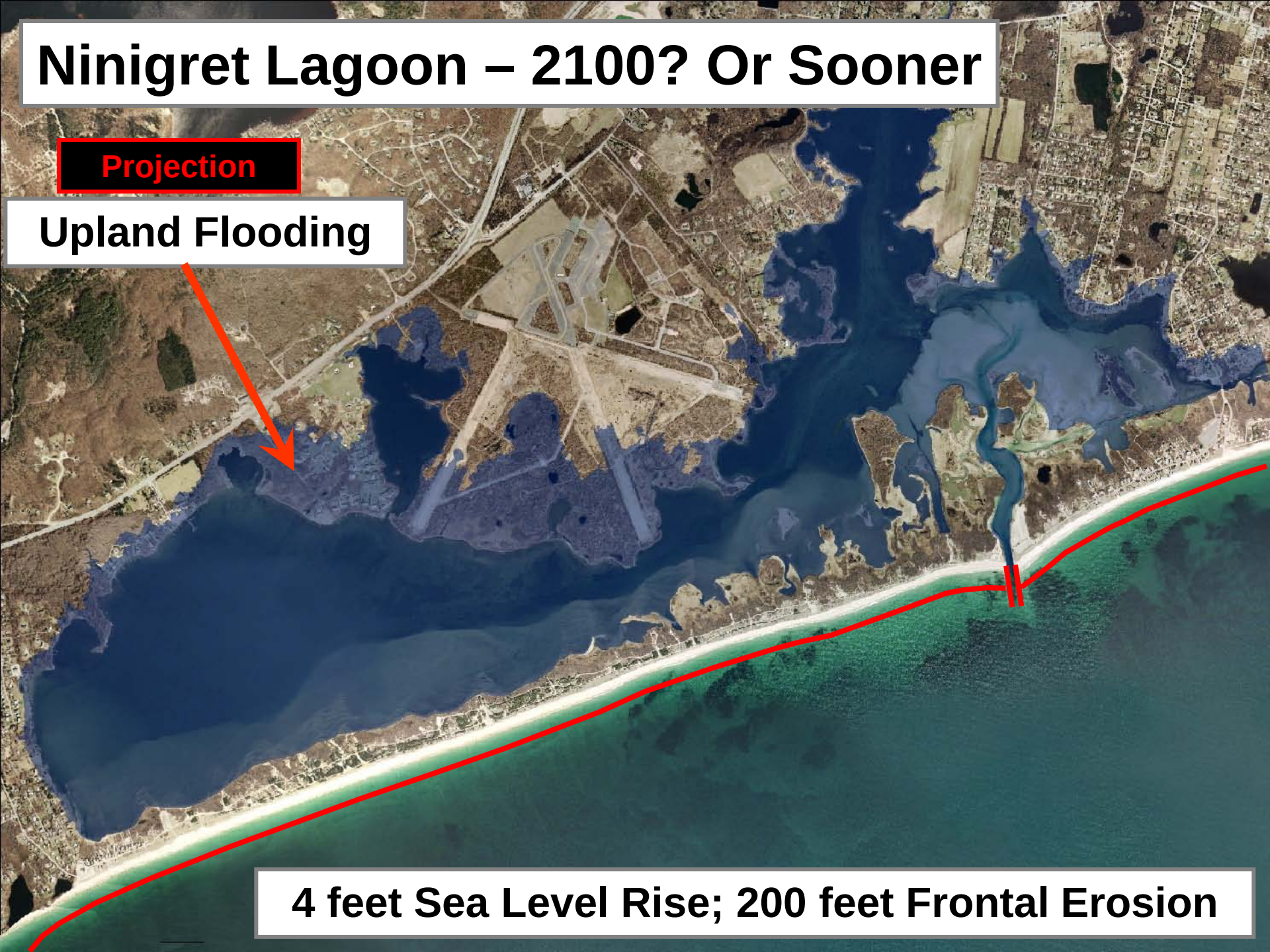


Ninigret Lagoon – 2100? Or Sooner

Projection

Upland Flooding

4 feet Sea Level Rise; 200 feet Frontal Erosion



Wickford Marketplace – In-Place Inundation “The Bathtub Ring”

Today



10 Sept 2010

Teresa Crean

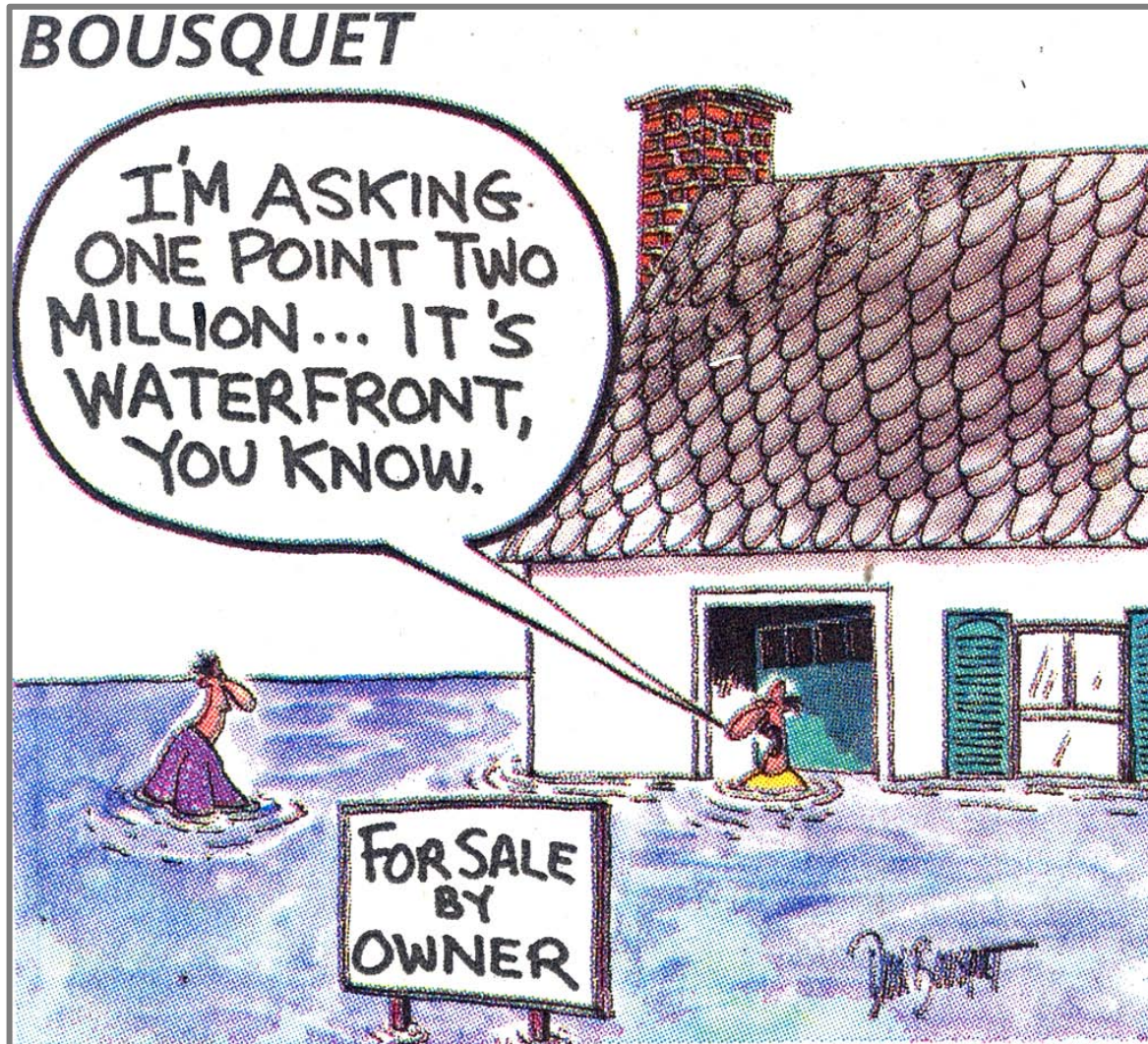
Middlebridge, South Kingstown – A Common View of the Future

Today



OCT 28 2006

Coastal Rhode Island – A Common View of the Future



Today ?

Projection ?

–
Yep

Don
Bousquet,
June 2008

End of Presentation

