Hydrologic Feasibility of Storm Surge Barriers to Protect the Metropolitan New York–New Jersey Region from Coastal Flooding

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HydroQual, Inc.

New York Sea Grant

Eppley Foundation

Marine Sciences Research Center

A tidal wave batters New York City.

New Yorkers flee from an onrushing tidal wave.

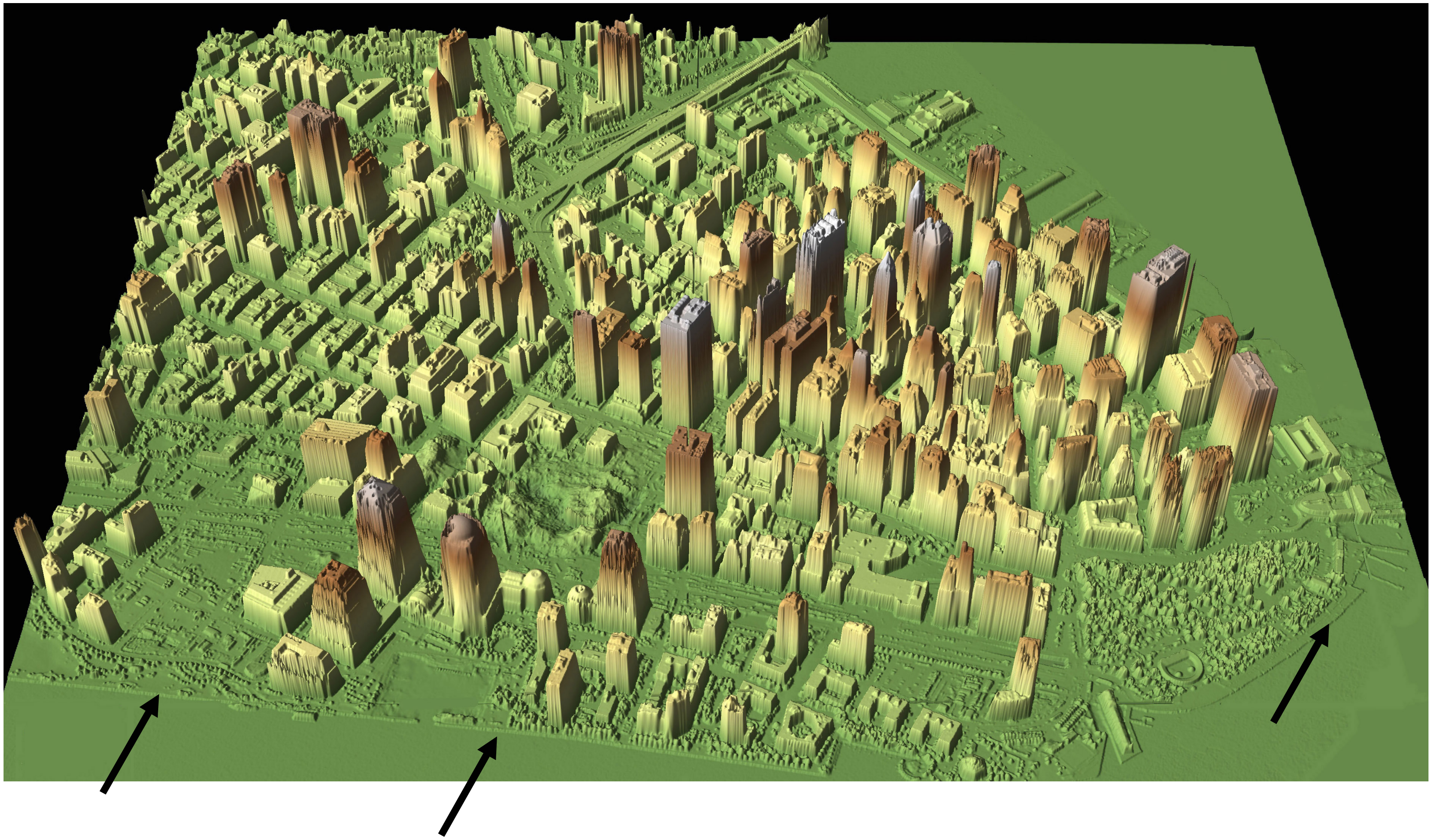
A severe storm in November 1950 caused extensive flooding of La Guardia airport (Bloomfield, 1999)

FDR Drive during the December 1992 nor'easter (Bloomfield, 1999)

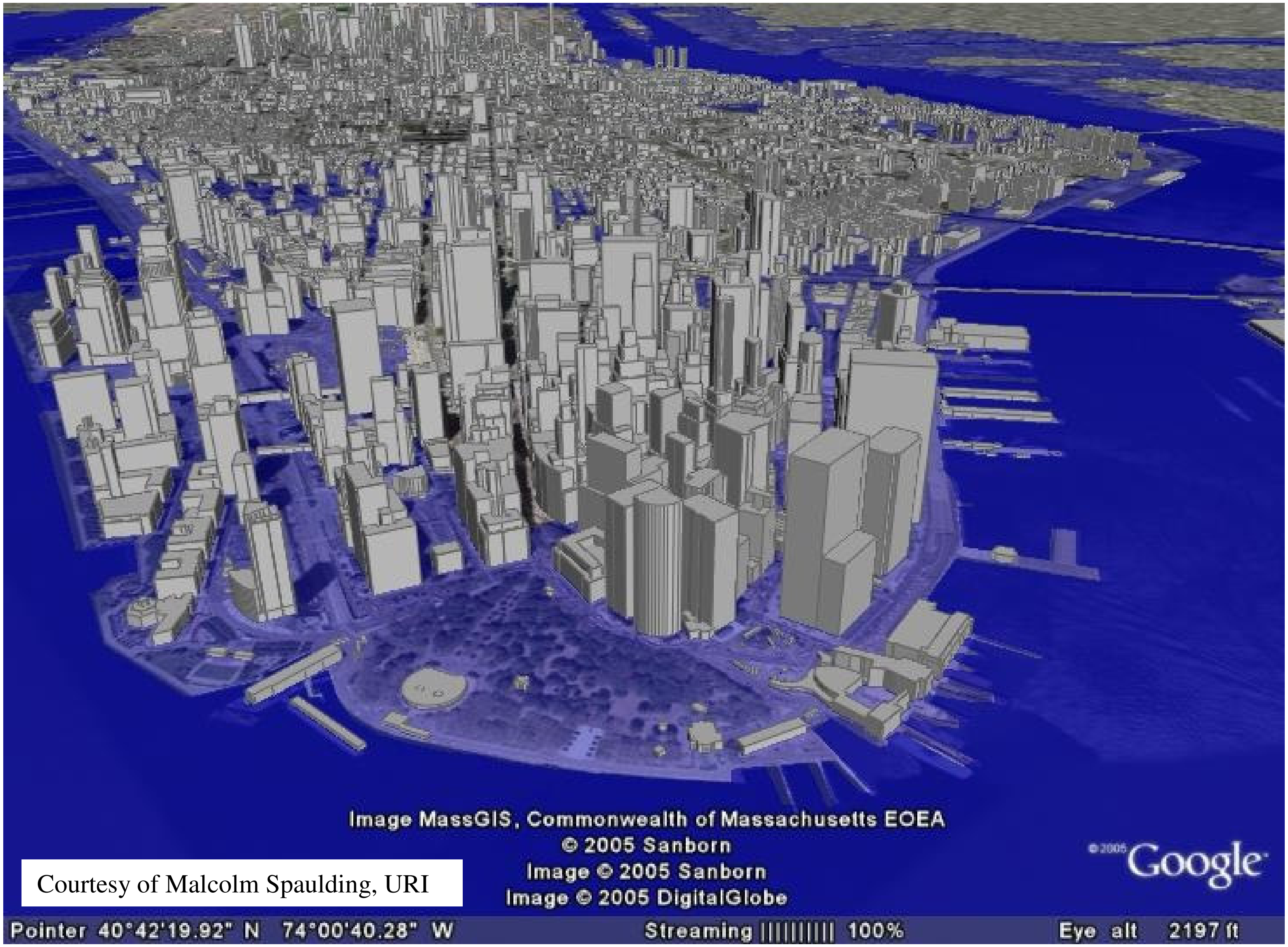
Ref: Bloomfield, J., M. Smith and N. Thompson, 1999. *Hot Nights in the City*. Environmental Defense Fund, New York.

1992 Nor'easter Flooding

Source: Metro New York Hurricane Transportation Study, 1995

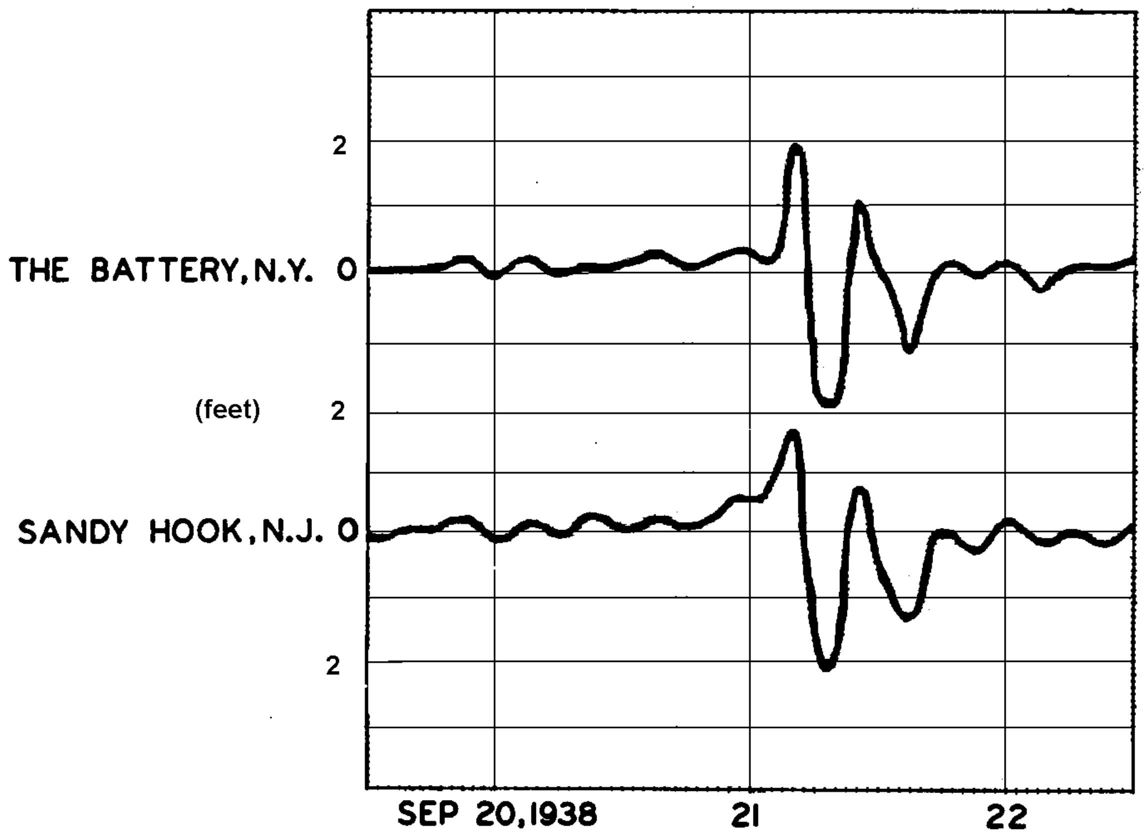


Lidar image of business district of Manhattan showing seawall locations and elevation (arrows). The imager is flying above the Hudson River looking east.



Courtesy of Malcolm Spaulding, URI

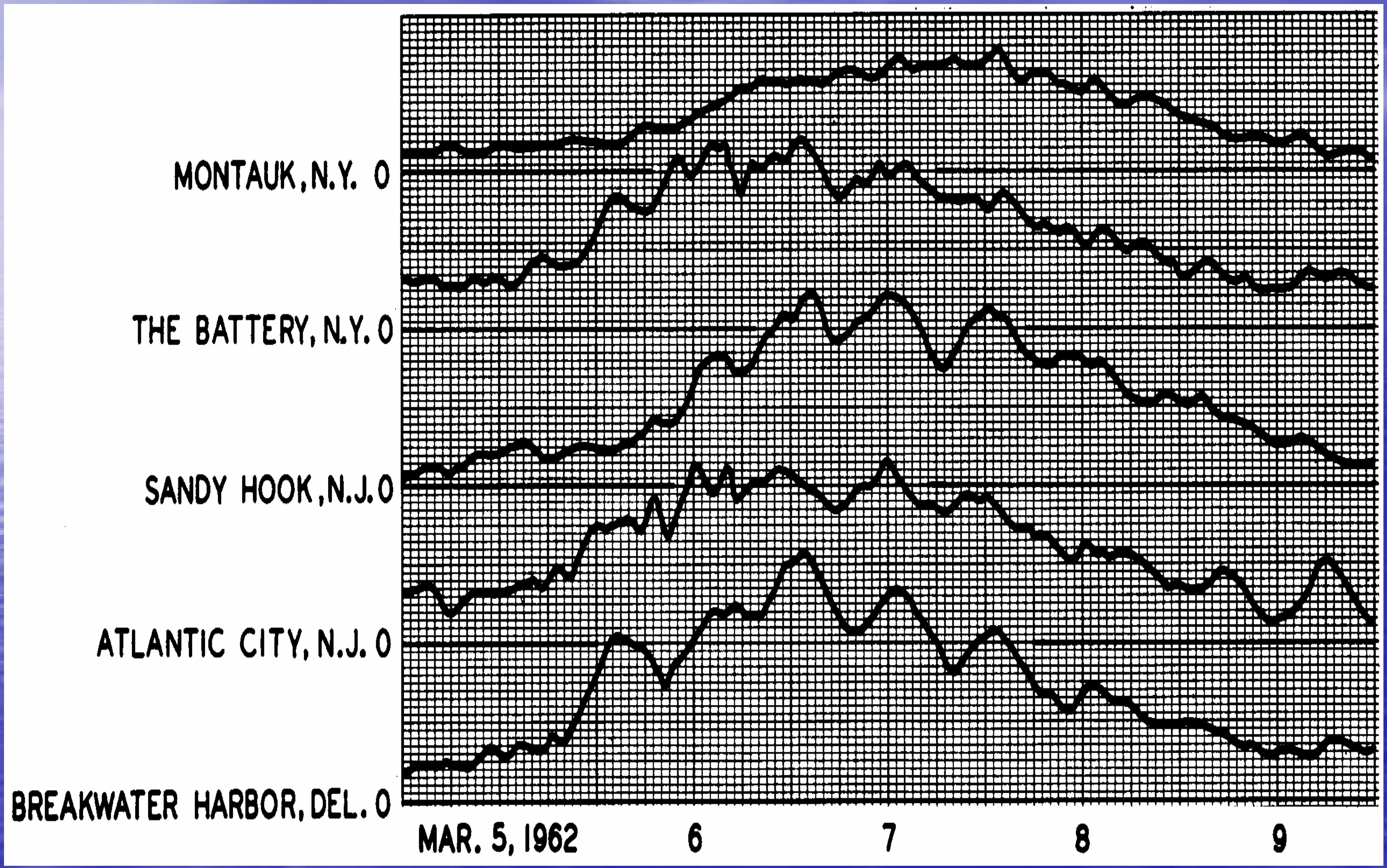
Hurricane Storm Surge



21-22 September 1938 hurricane

Source: N.A. Pore and C.S. Barrientos, Storm Surge, 1976

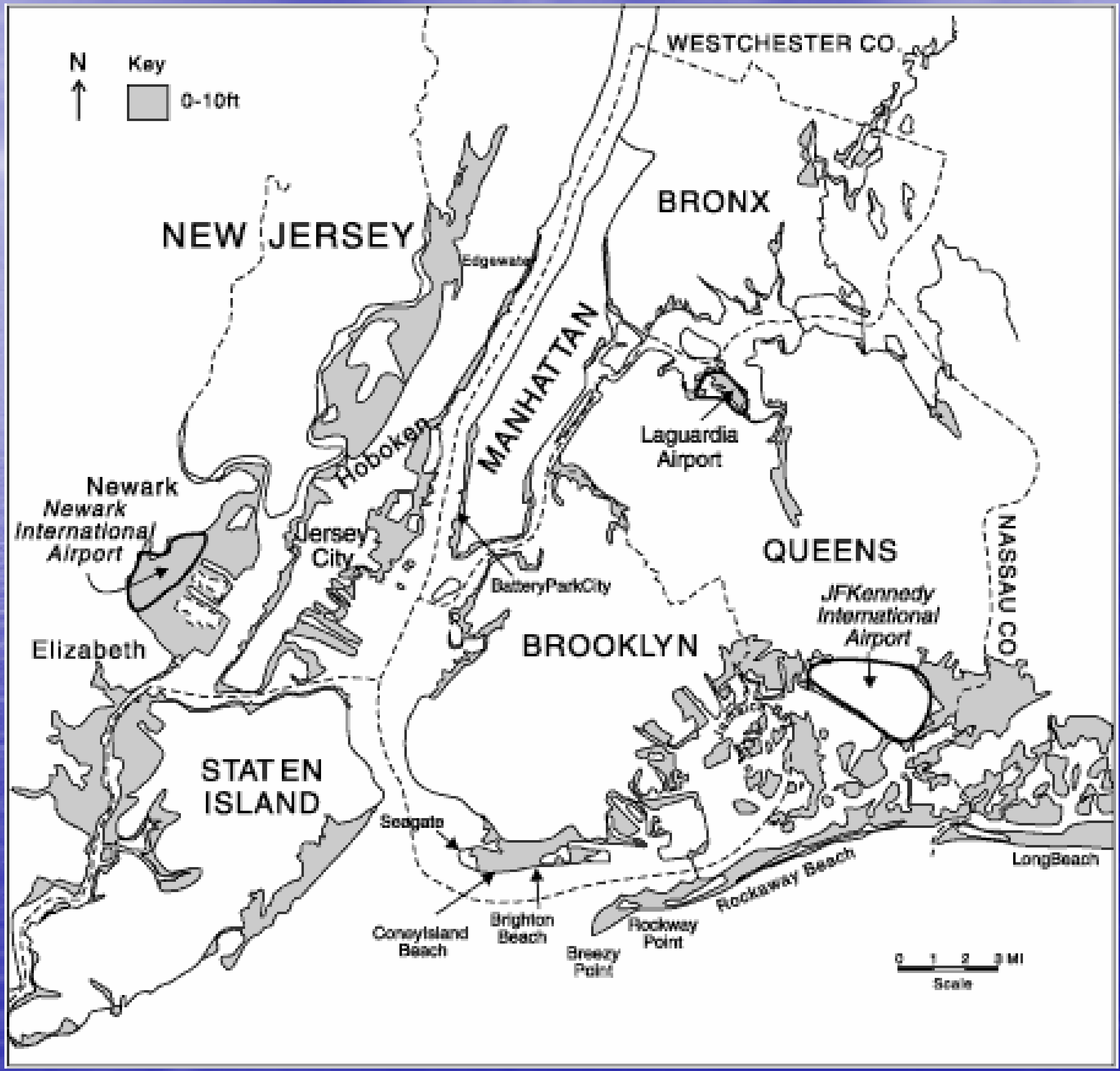
Nor'easter Storm Surge



5-8 March 1962 storm

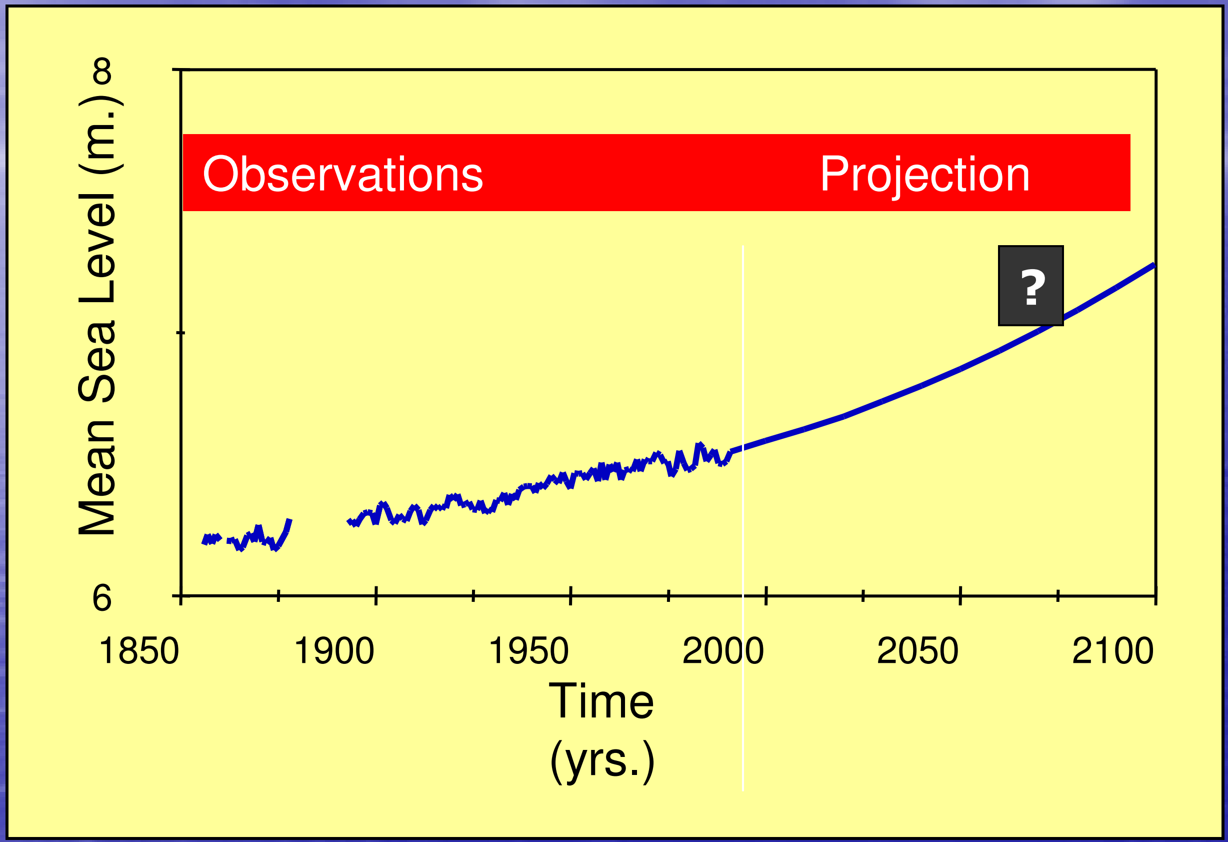
Source: N.A. Pore and C.S Barrientos, Storm Surge, 1976.

100-year Flood Zone



The 100-year flood at present mean sea level (from Gornitz, 2001)

NYC Secular Rise in Sea Level



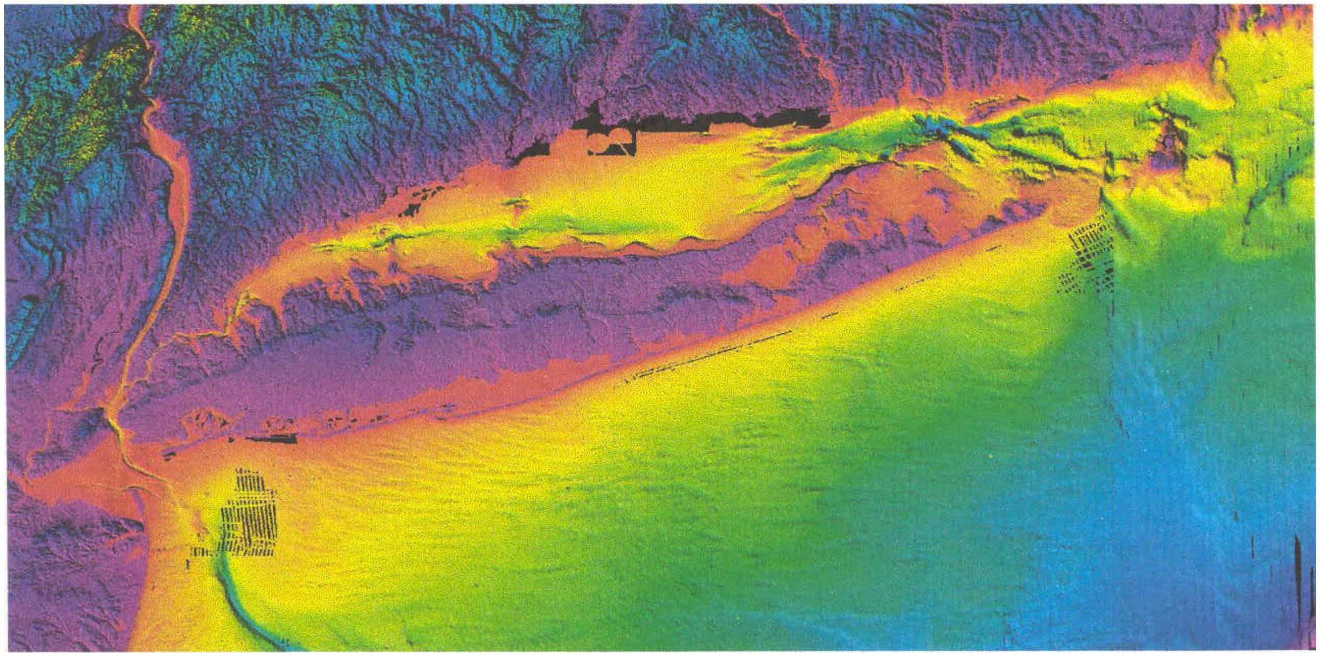
NASA GISS predicts an additional rise of 35 to 47 cm by the year 2050

(courtesy Robert J. Nicholls)

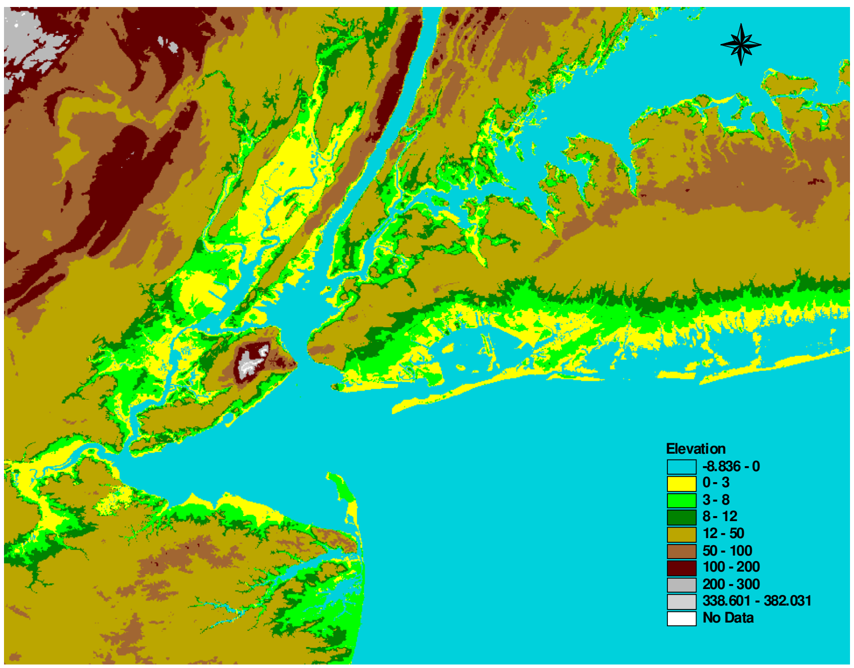
Storm Surge Barriers 101

- **Why** would we need them?
- **Where** would they be located?
- **How** high would they need to be?
- **What** would they look like?
- **How** would they be operated?
- **What** would be the environmental effects?
- **When** will they be needed?

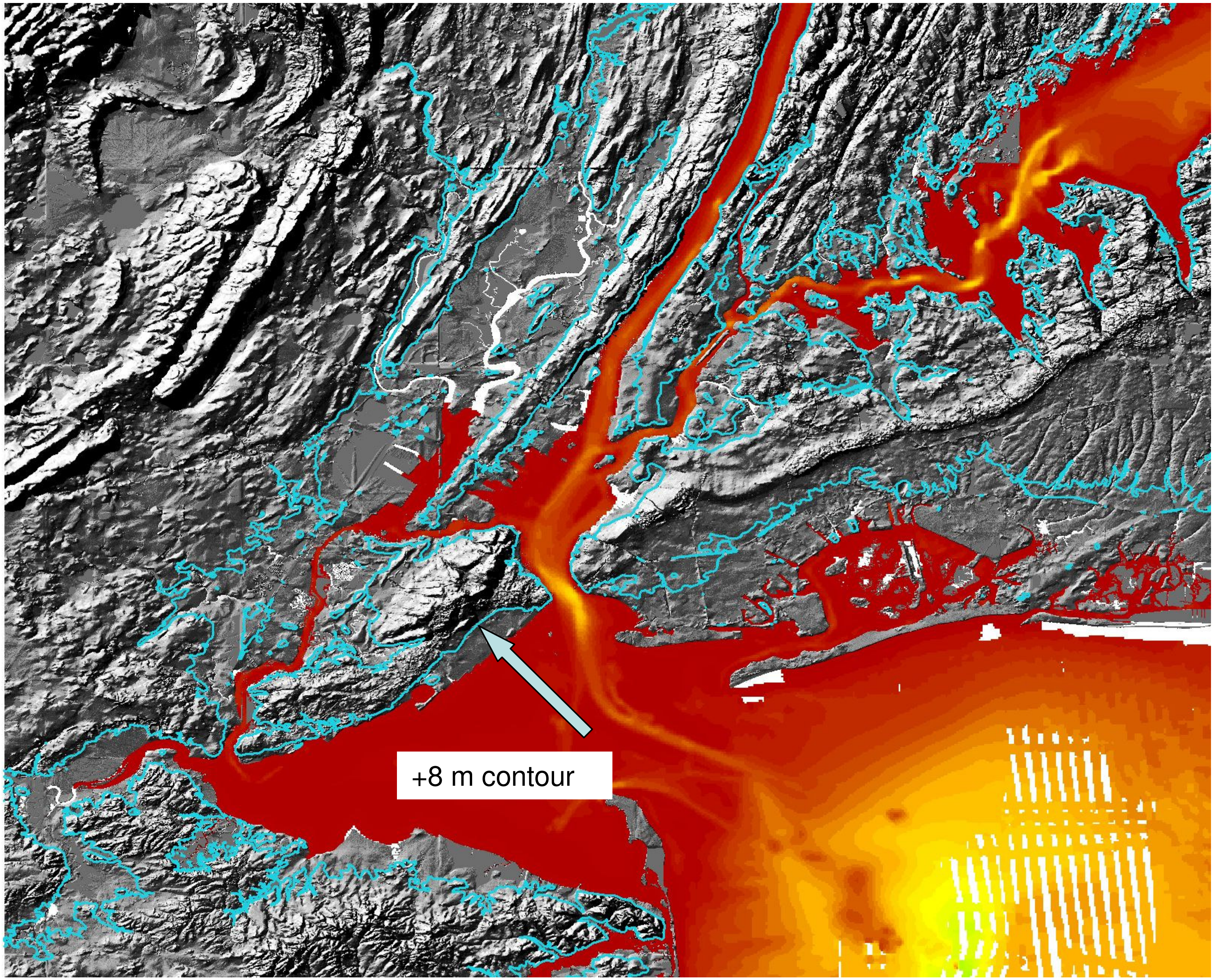
Where located?



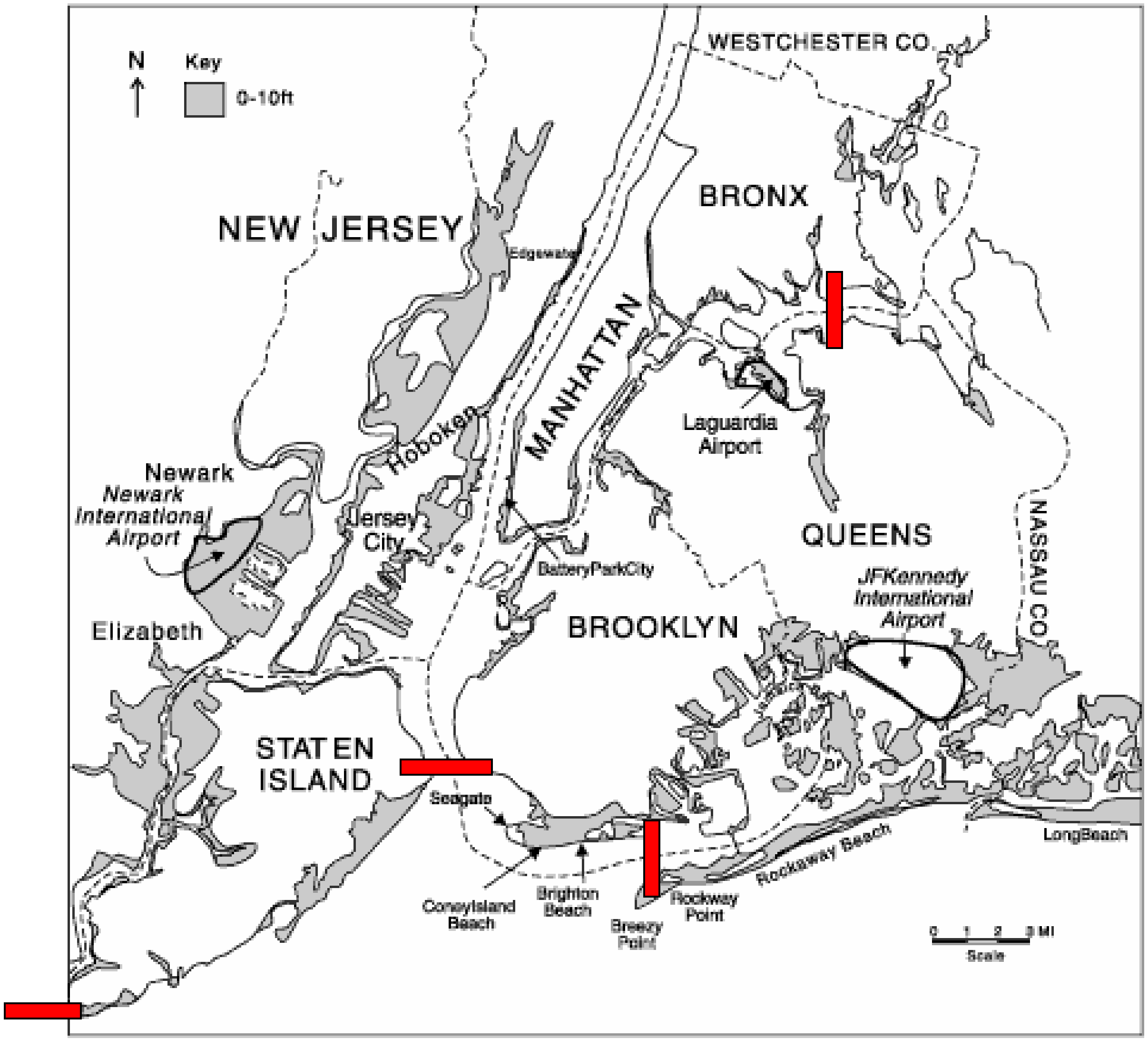
Map of merged high-resolution bathymetric & topographic data for the New York coastal area.



Topographic contour map (m) for the greater Metropolitan region. The dark green-brown color boundary is the 8 m above msl contour.


+8 m contour

Proposed Barrier Locations



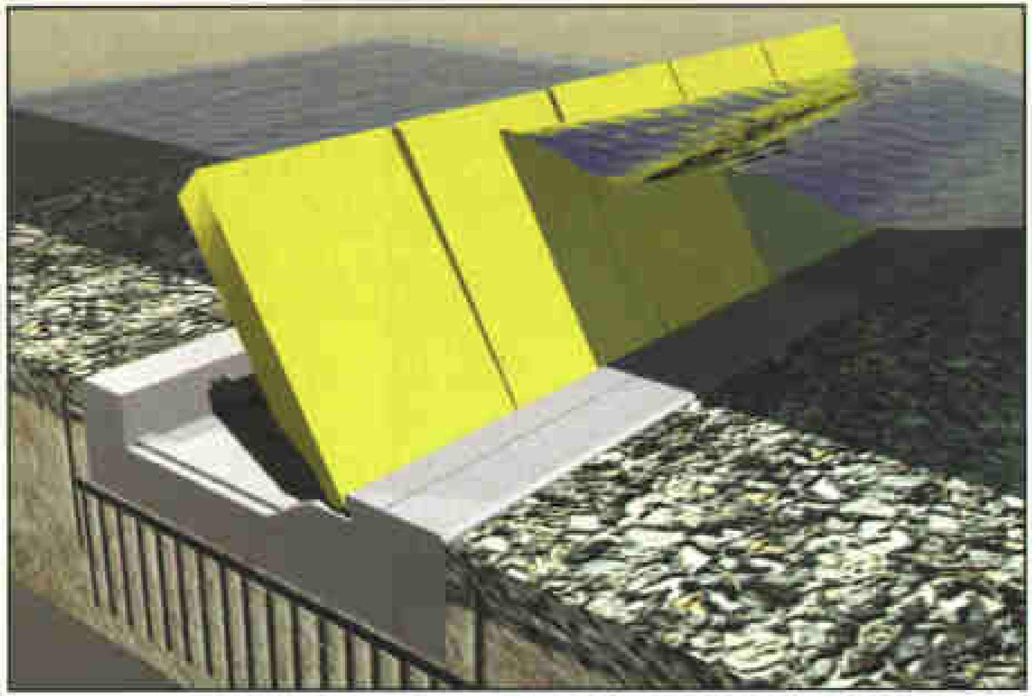
The 100-year flood at present mean sea level (from Gornitz, 2001)

New Bedford MA

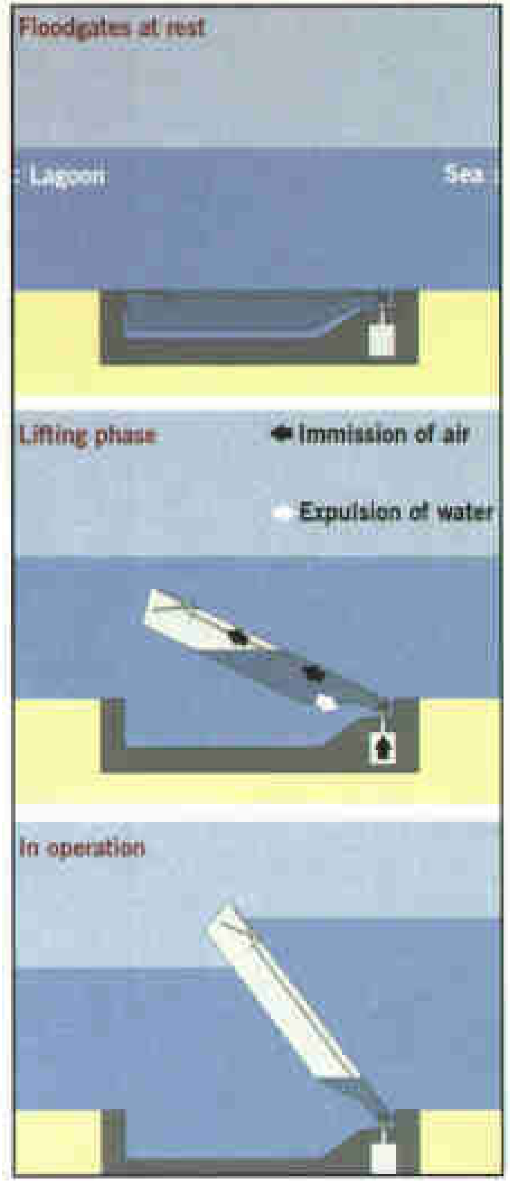
Eastern Scheldt, the Netherlands, 1986

New Waterway, the Netherlands, 1997

Venice Lagoon Design, 2010

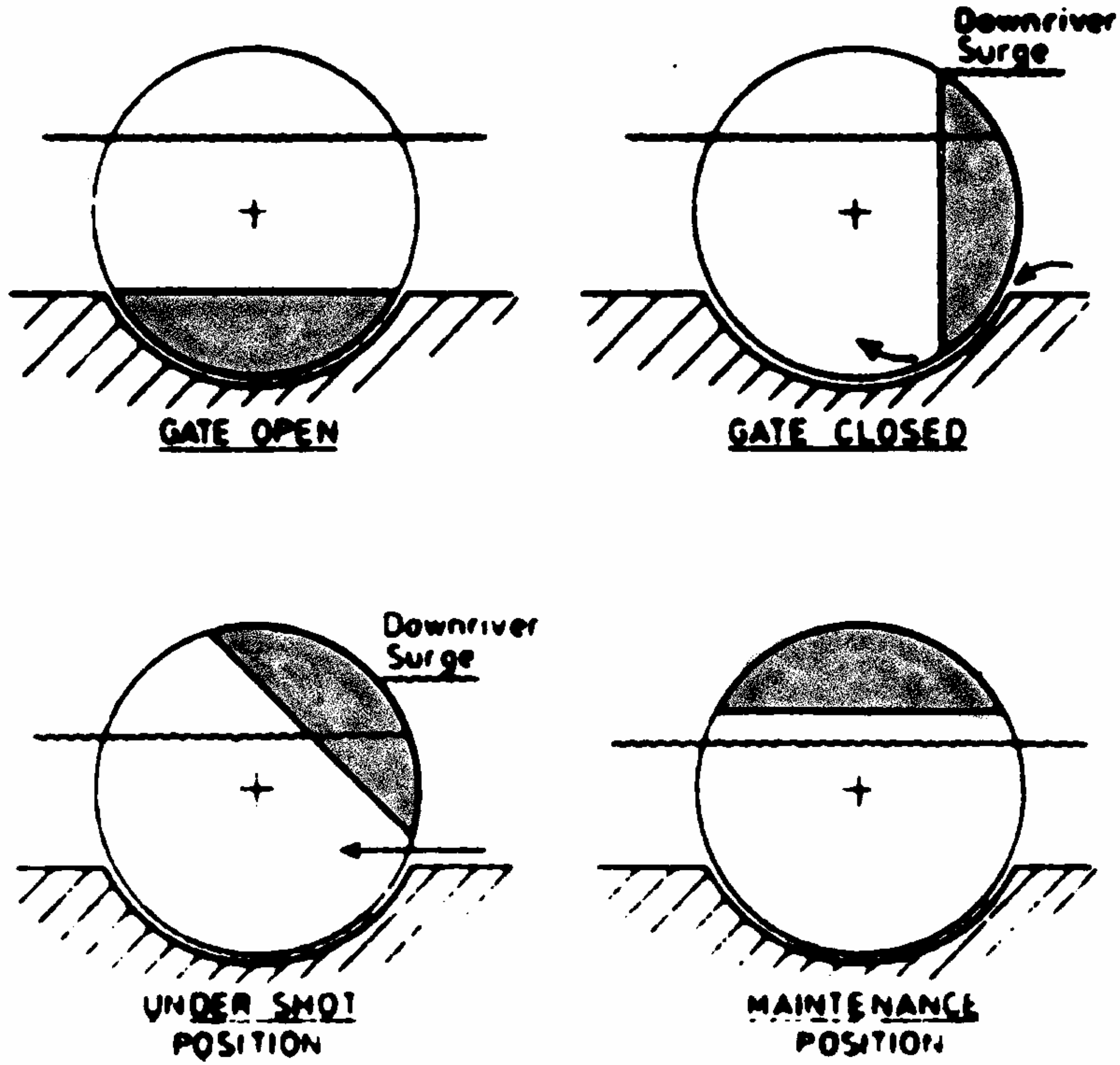


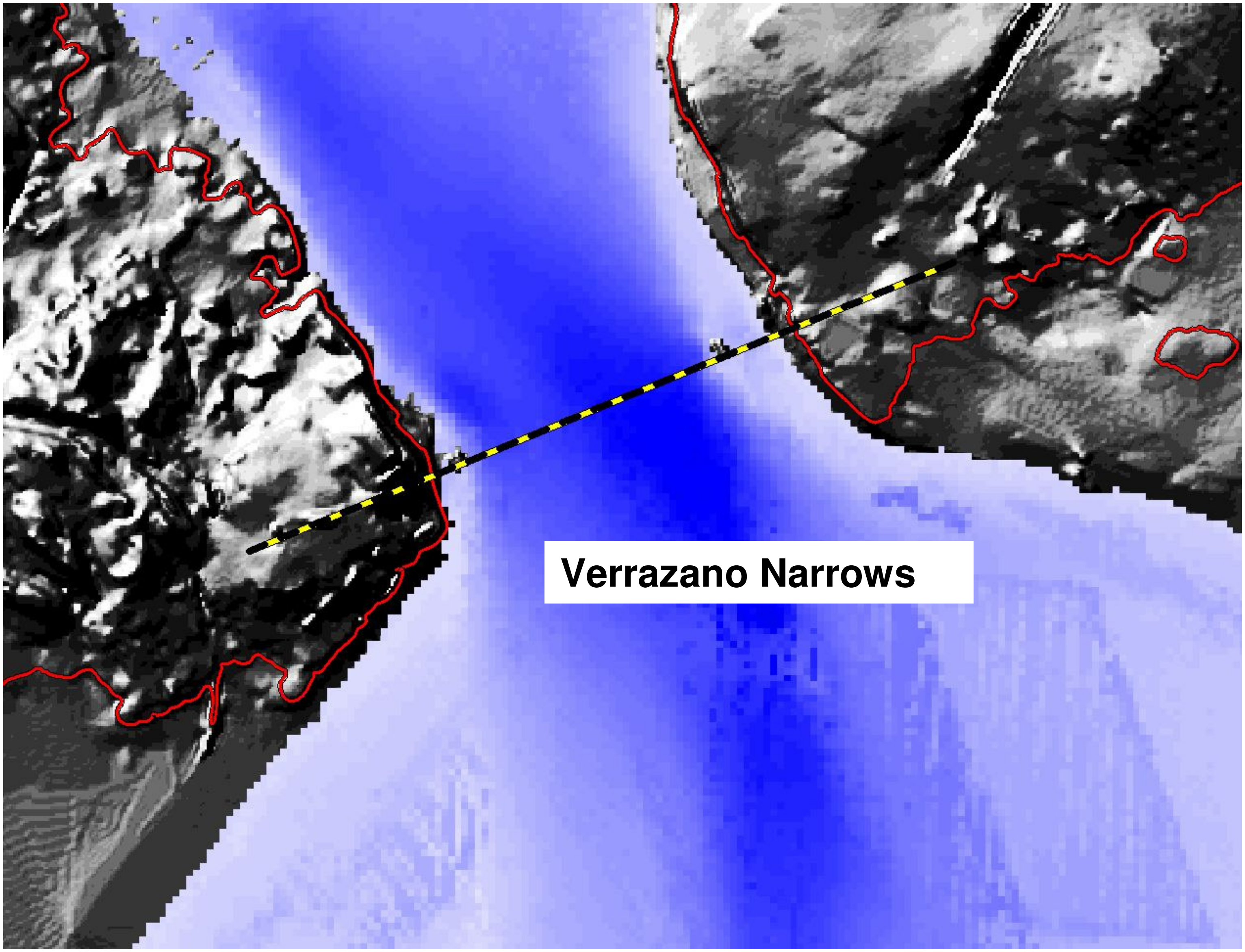
THE GATES *fill with water under normal tidal conditions and rest on the inlet canal bed. When tides reach 100 cm, the gates will be filled with compressed air and rise to isolate the lagoon from the sea.*

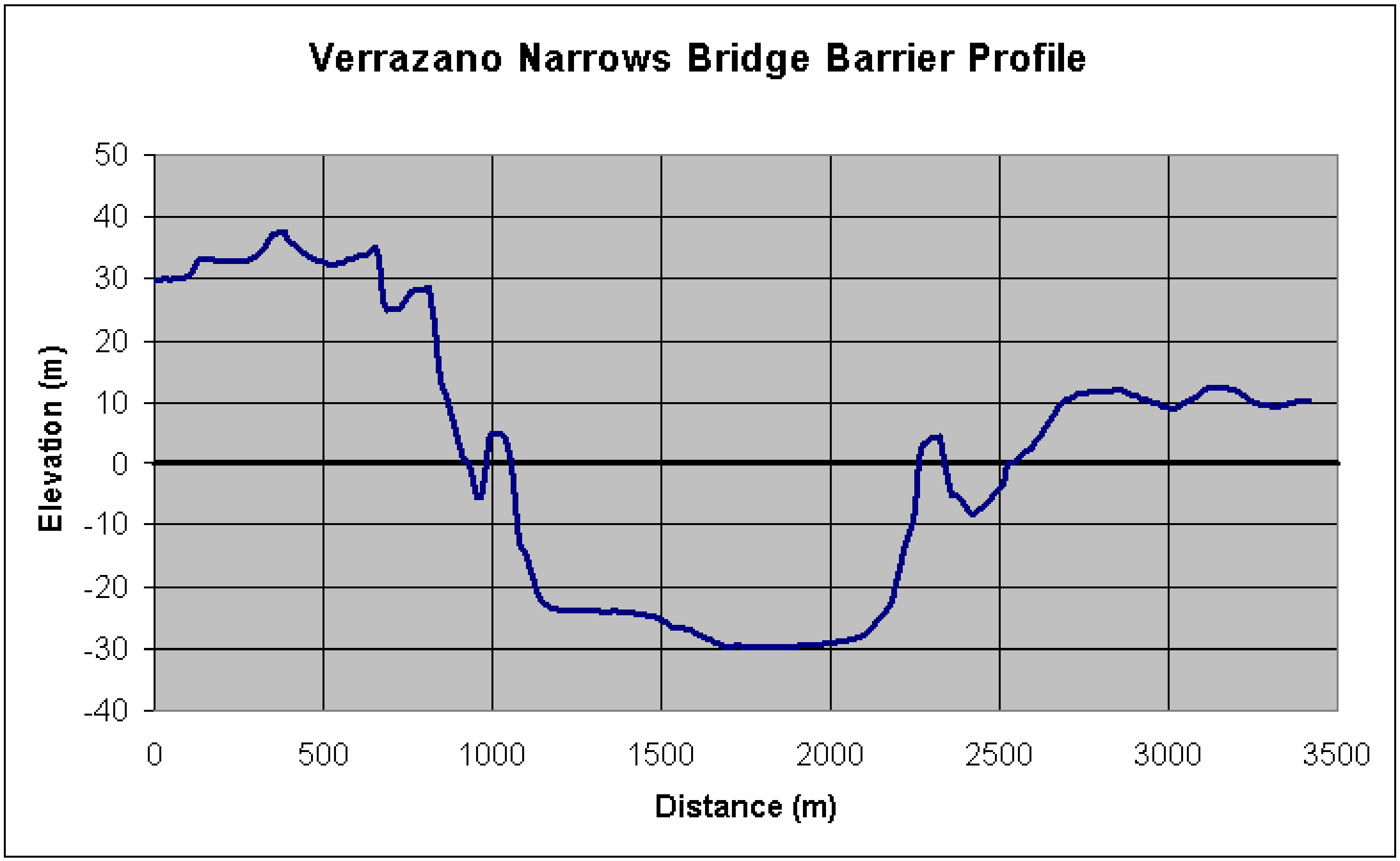


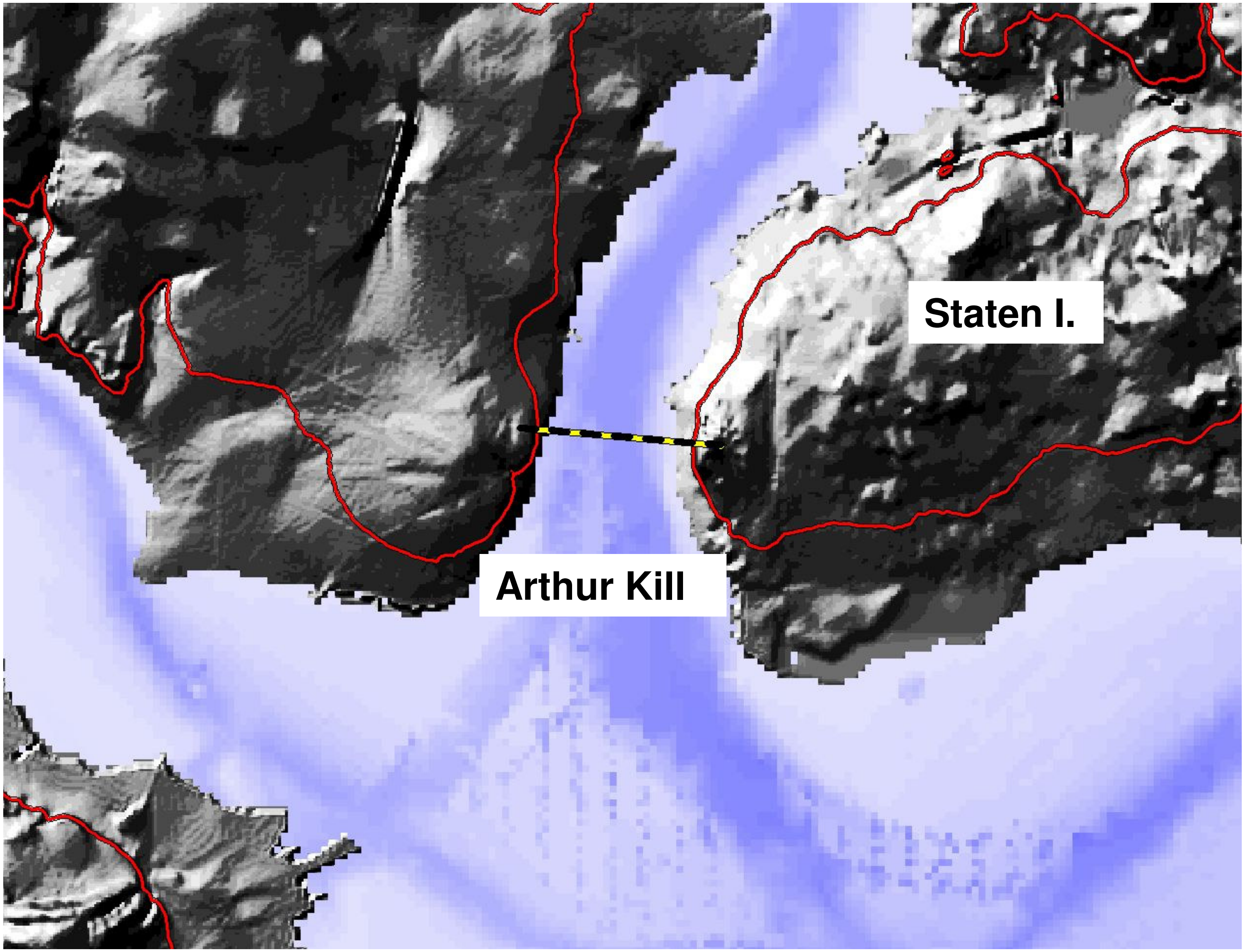
Thames River Tidal Barrier, England, 1982

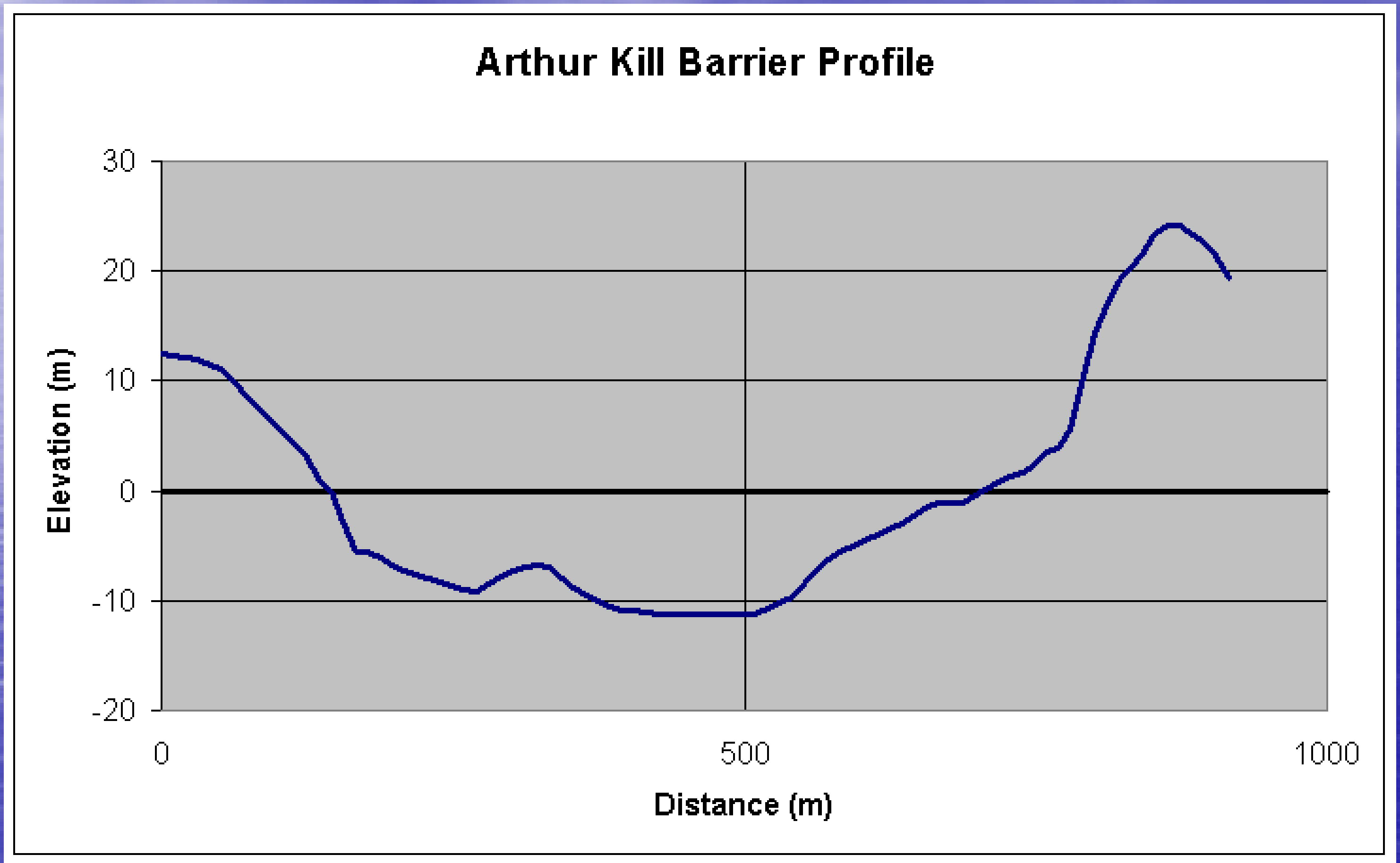
Thames Barrier rotating gates - Operation

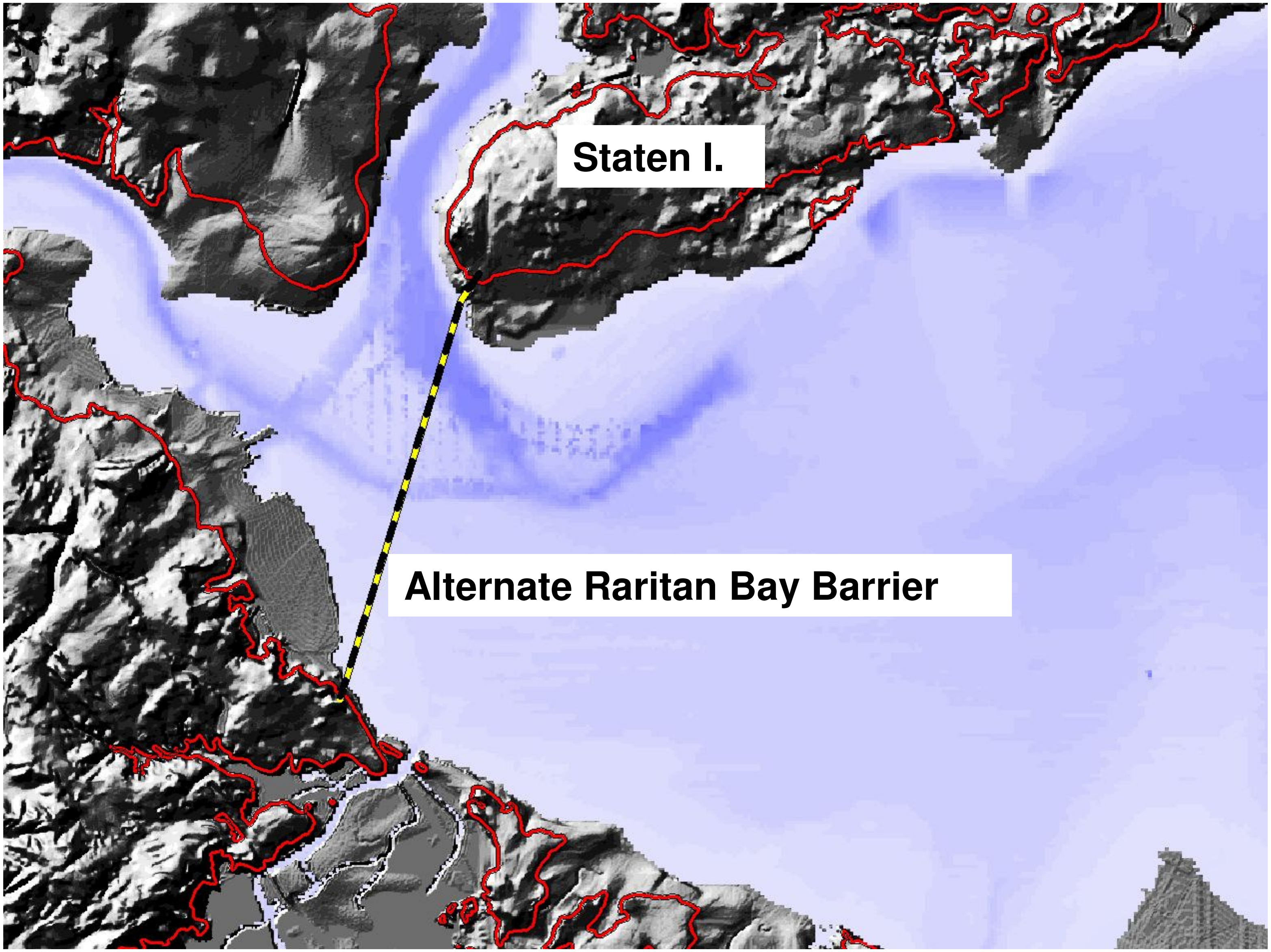



Verrazano Narrows

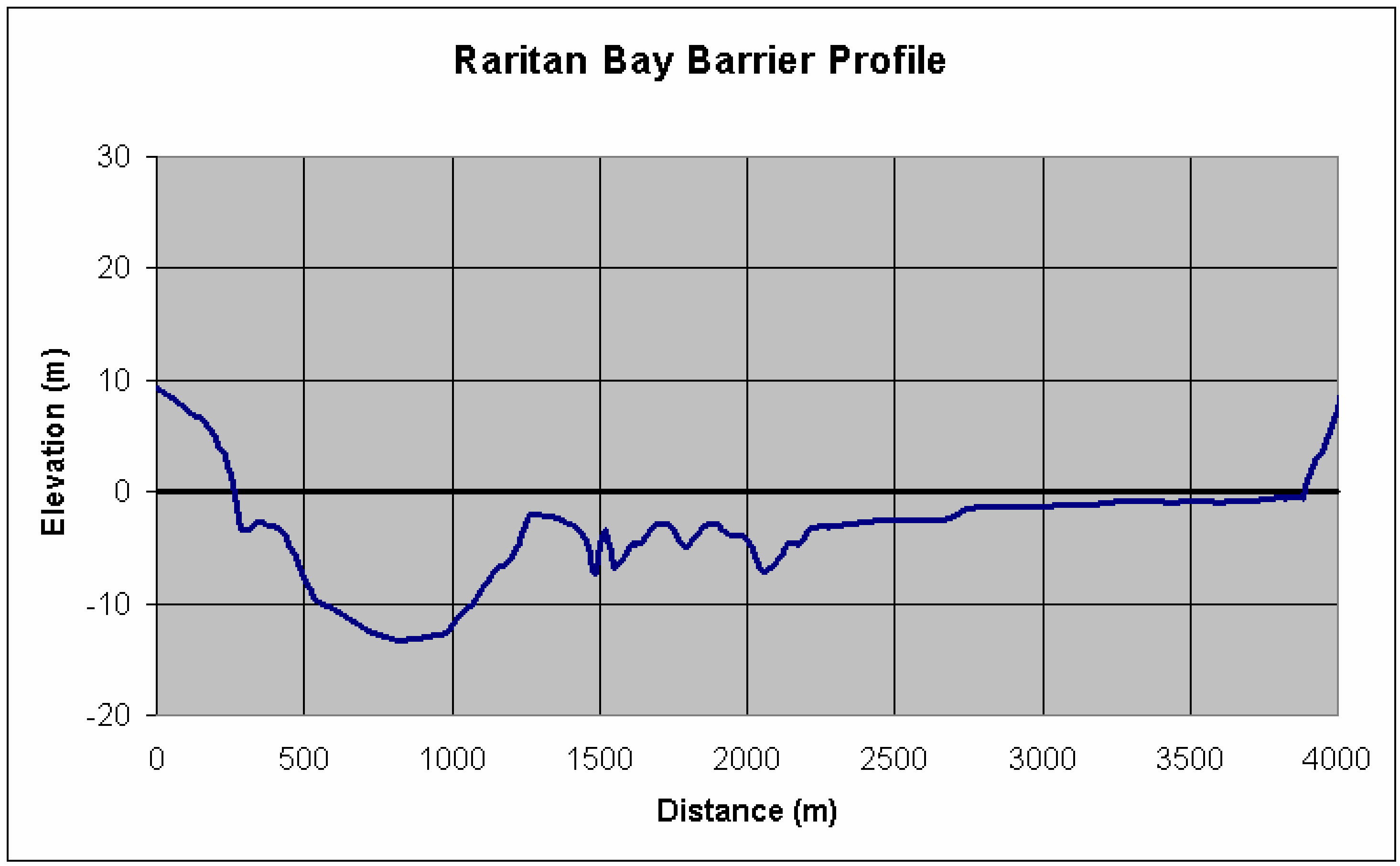

Verrazano Narrows Bridge Barrier Profile
50
40
30
20
10
0
-10
-20
-30
-40
Elevation (m)
0
500
1000
1500
2000
2500
3000
3500
Distance (m)

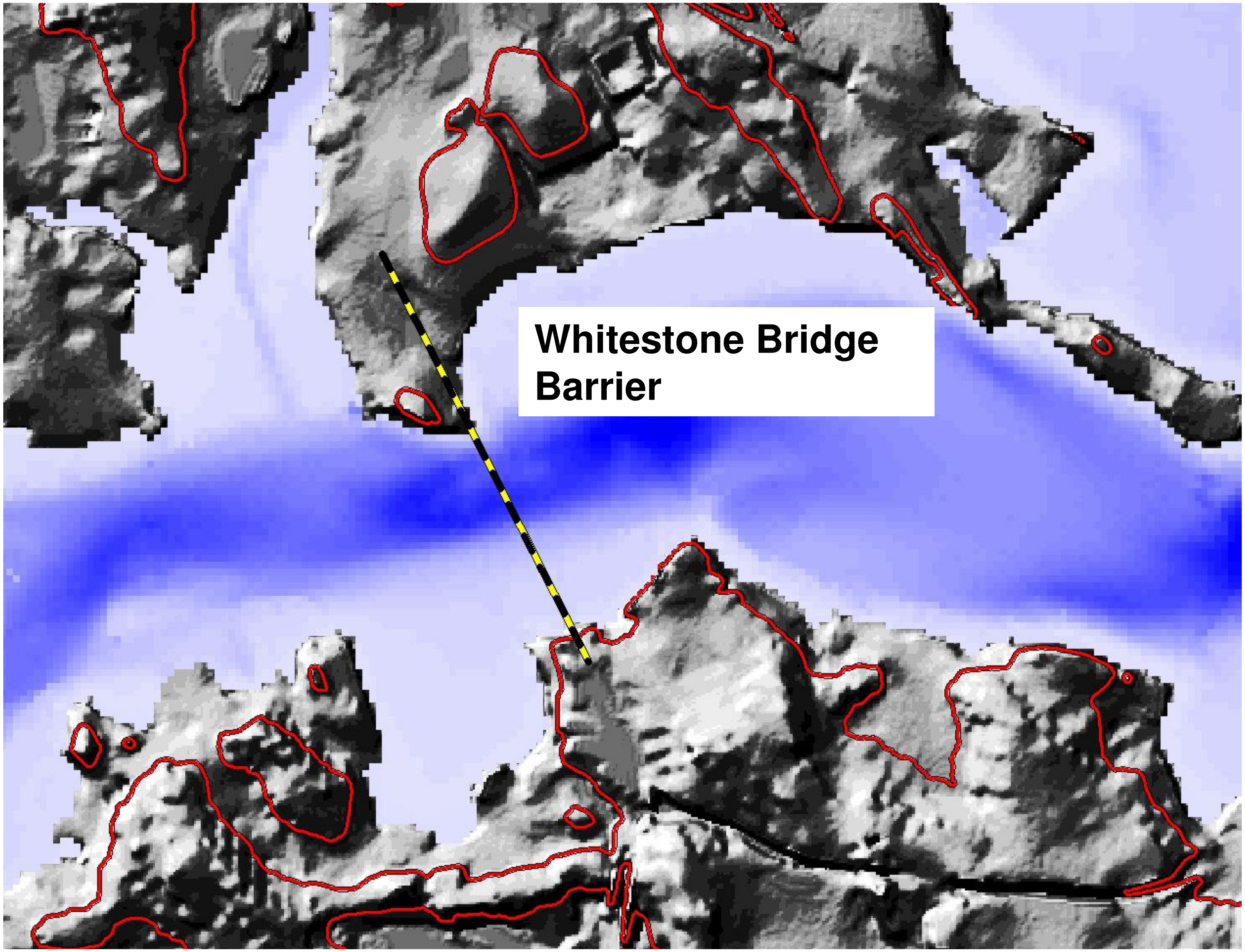

Staten I.
Arthur Kill

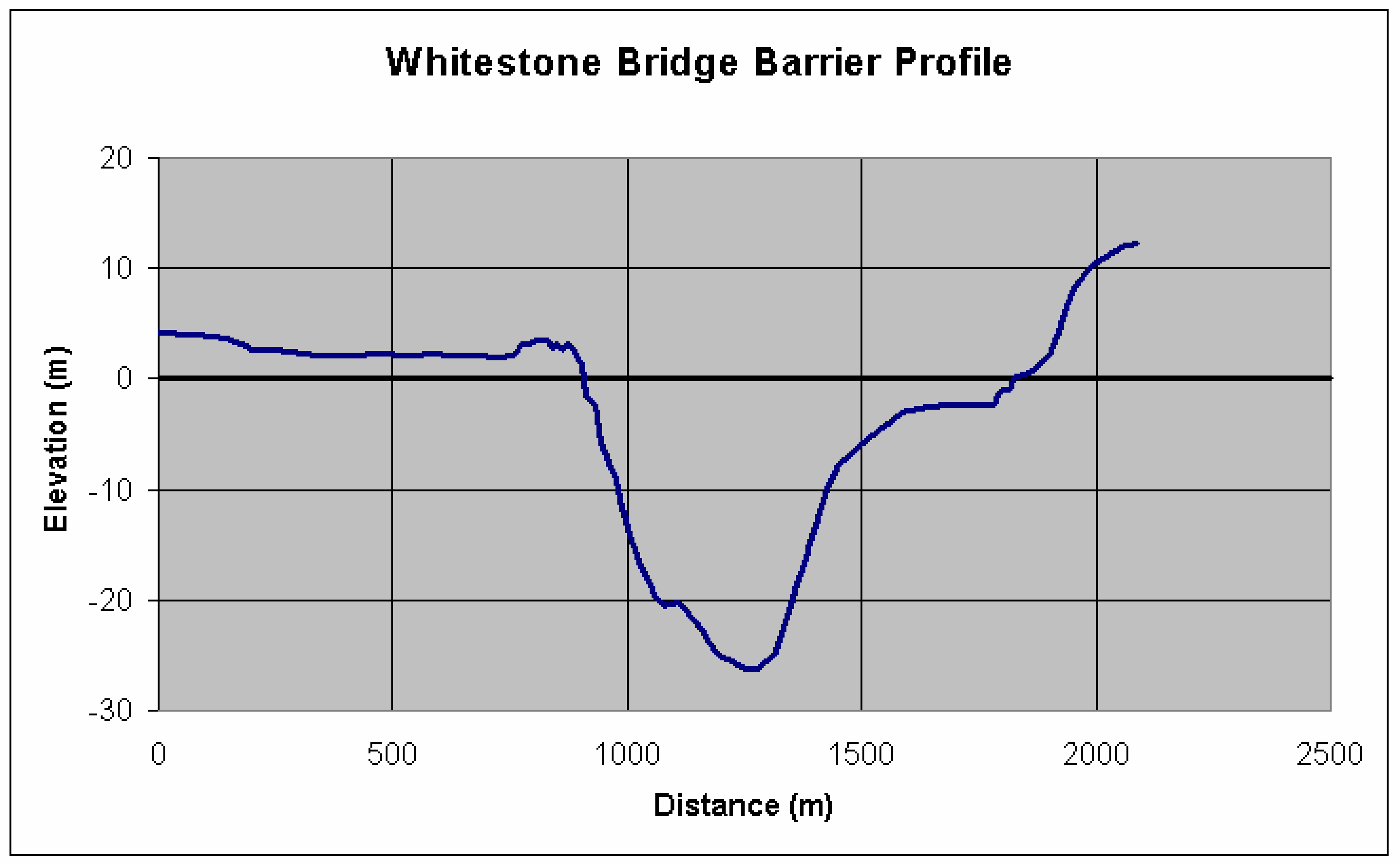

Arthur Kill Barrier Profile
30
20
10
0
-10
-20
0
500
1000
Elevation (m)
Distance (m)



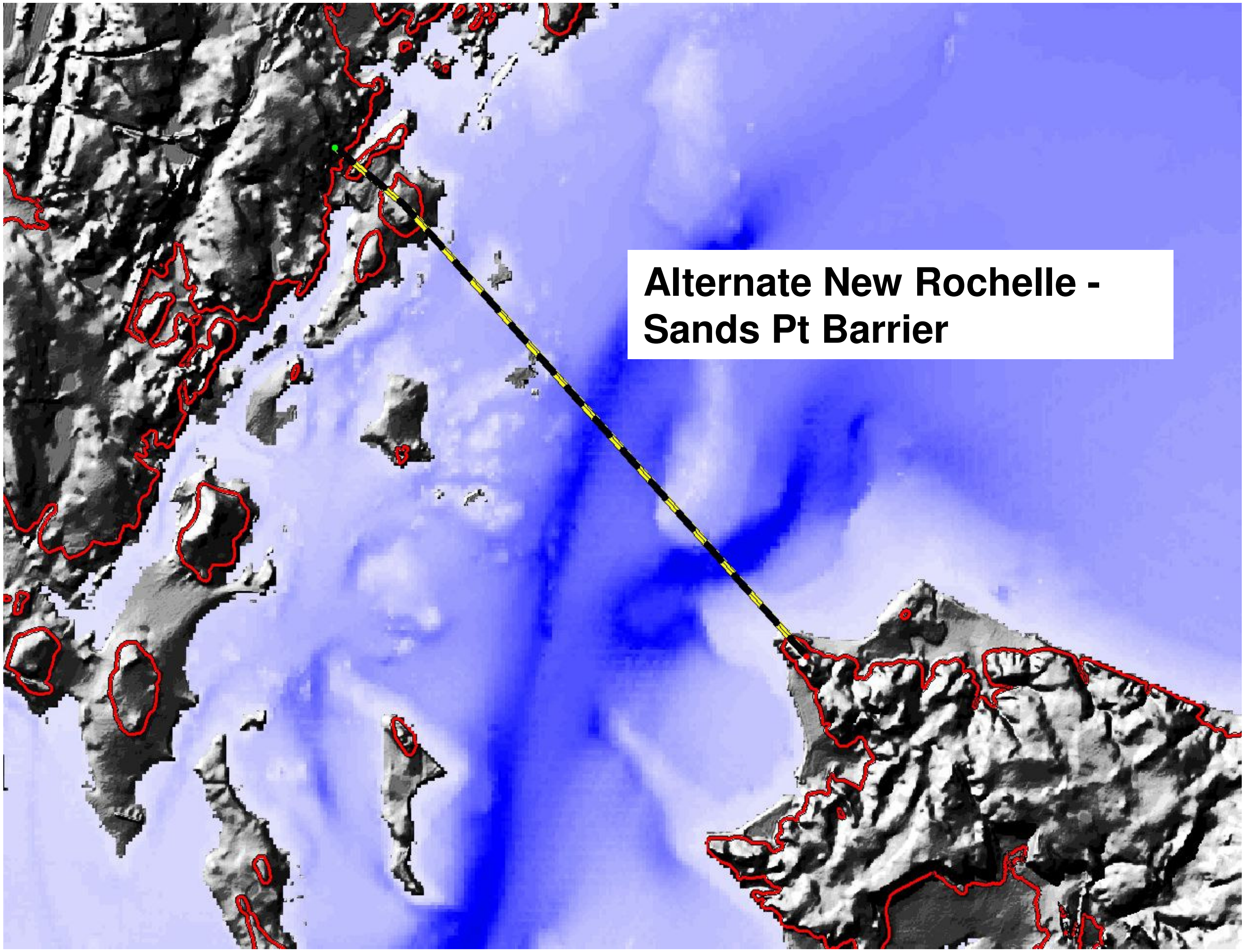
Staten I.
Alternate Raritan Bay Barrier

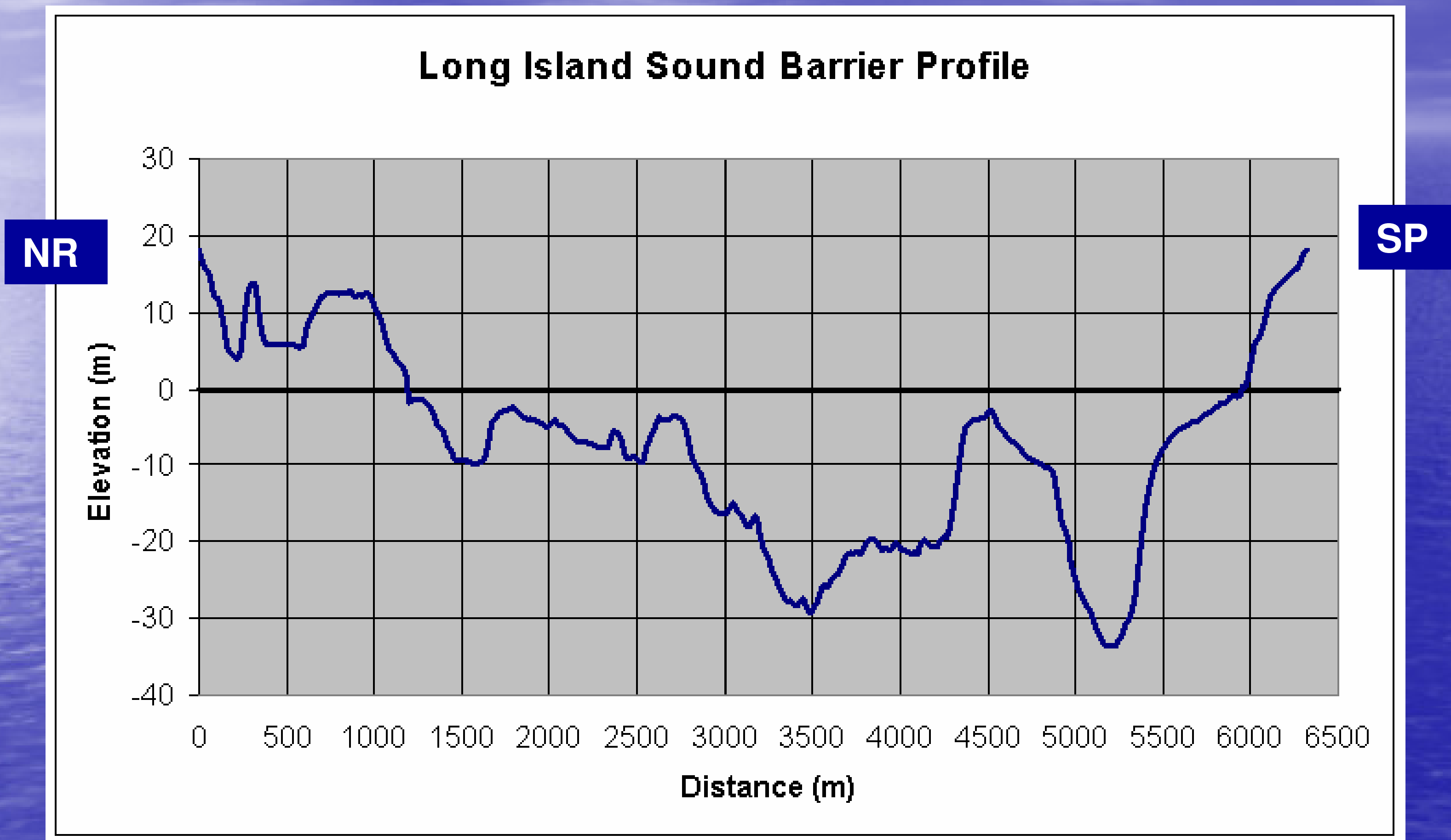

Raritan Bay Barrier Profile
Elevation (m)
30
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (m)


Whitestone Bridge
Barrier



Whitestone Bridge Barrier Profile
20
10
0
-10
-20
-30
Elevation (m)
0
500
1000
1500
2000
2500
Distance (m)


Alternate New Rochelle -
Sands Pt Barrier


Long Island Sound Barrier Profile
NR
SP
Elevation (m)
30
20
10
0
-10
-20
-30
-40
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
Distance (m)

How high?

Top Barrier Elevation Calculation New Bedford Barrier

- Design surge 13.3 ft
- Mean spring high water 2.7
- Significant wave height 9.0
- Top elevation 25.0 ft
- x1.5 =Maximum wave height 13.5
- Structural design 29.5 ft

Design Criterion for New Orleans

- *"The Corps works for Congress, and when the boss says 'design for a Category 3 storm', culturally the Corps is not going to go back and say this is wrong".*

(William F. Marcuson III, former Director of the US Army Corps of Engineers Waterways Experiment Station; President-elect of the American Society of Civil Engineers, NY Times, 21 Sept 2005).

Barrier Height Trade-offs

- Severity of storms
- Probability of severe storms
- Height of storm surge
- Expected rise in sea level
- Incremental cost of higher barrier structure
- Value of area protected
- Economic cost of flood damage averted
- Likely mortality from flooding

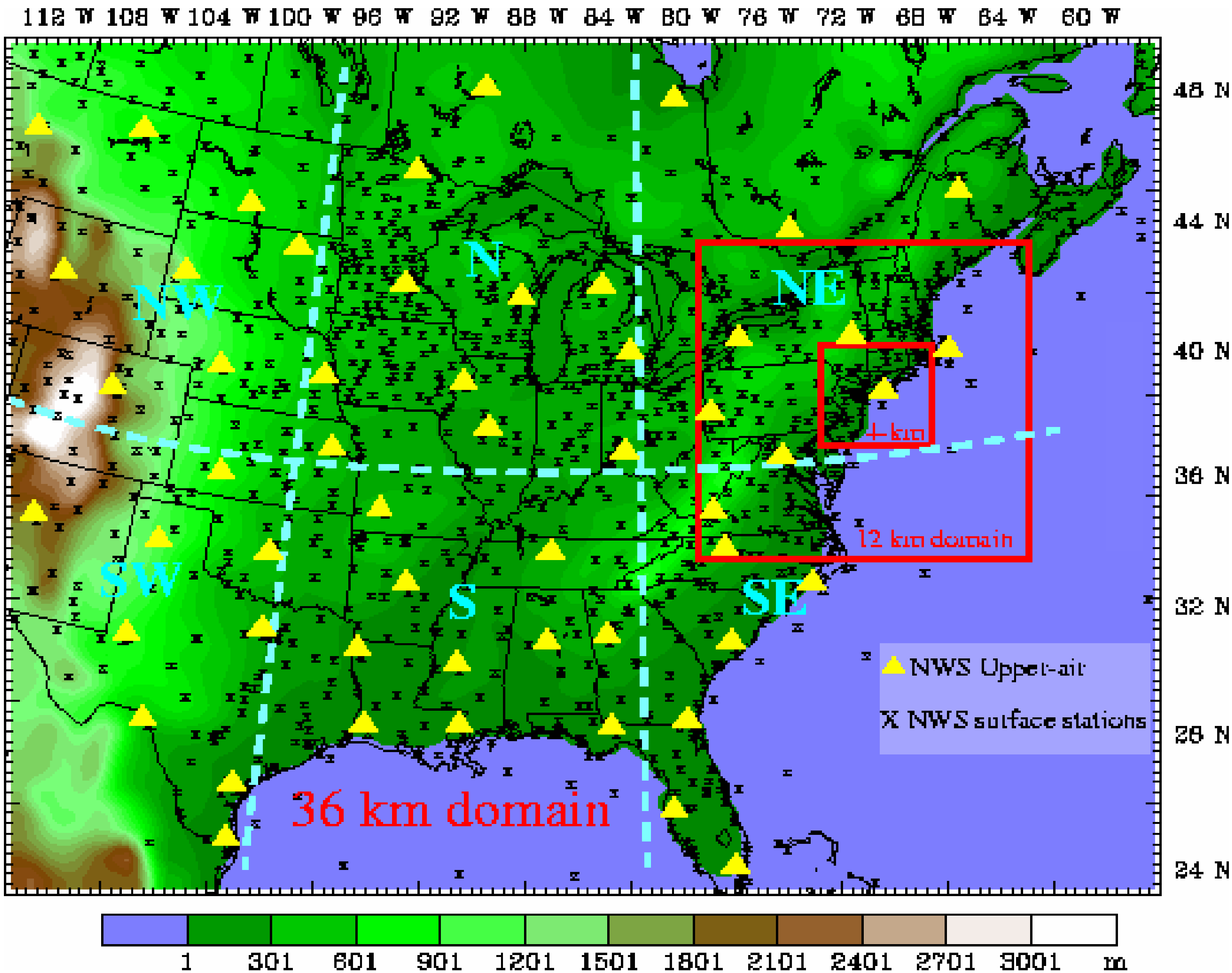
Delays between Inception and Operation

Barrier	Flood	Completed	Delay
New England	1938	1966, 1968	28-30 years
Thames River	1953	1982	29
Holland	1953	1958, 1986, 1997	5, 33, 44
Venice	1966	(2010)	44

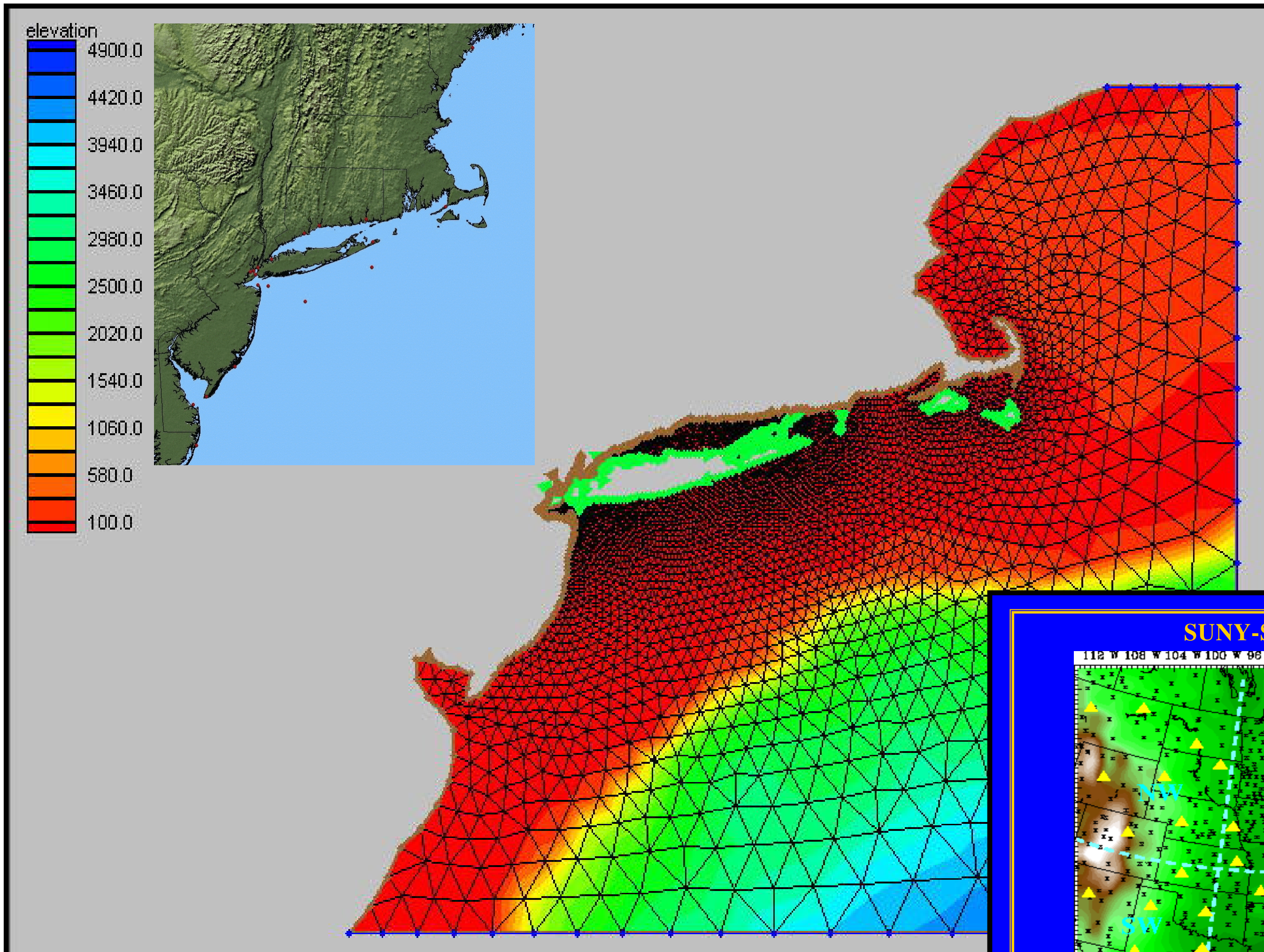
Stony Brook Storm Surge Research Group Modeling Program

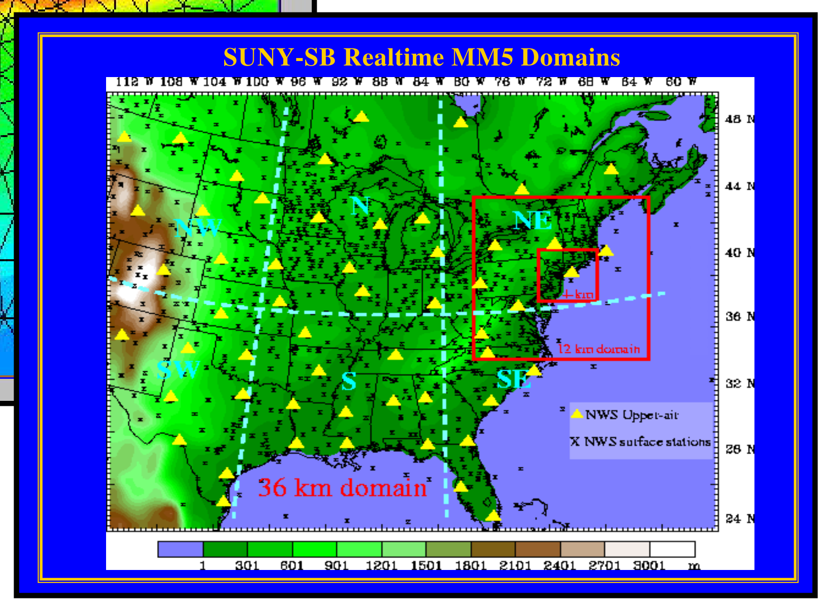
- Based on coupling a mesoscale weather forecasting model (MM5) to an ocean model (ADCIRC) to realistically simulate both weather, tides and storm surge with a 50-hour time horizon.
- Designed to test the efficacy of storm surge barriers.
- Present the surge predictions in real time on the web, with an alert system triggered to go off at critical stages of rising sea level during extreme weather events.
- Future developments will include a wave prediction module to simulate breaking shore waves in critical areas.
- Model is designed to run at present sea level and specified elevated sea level for future scenarios.
- Intent is to have a reliable, accurate prediction system useful to emergency managers at various levels of government.

SUNY-SB Realtime MM5 Domains



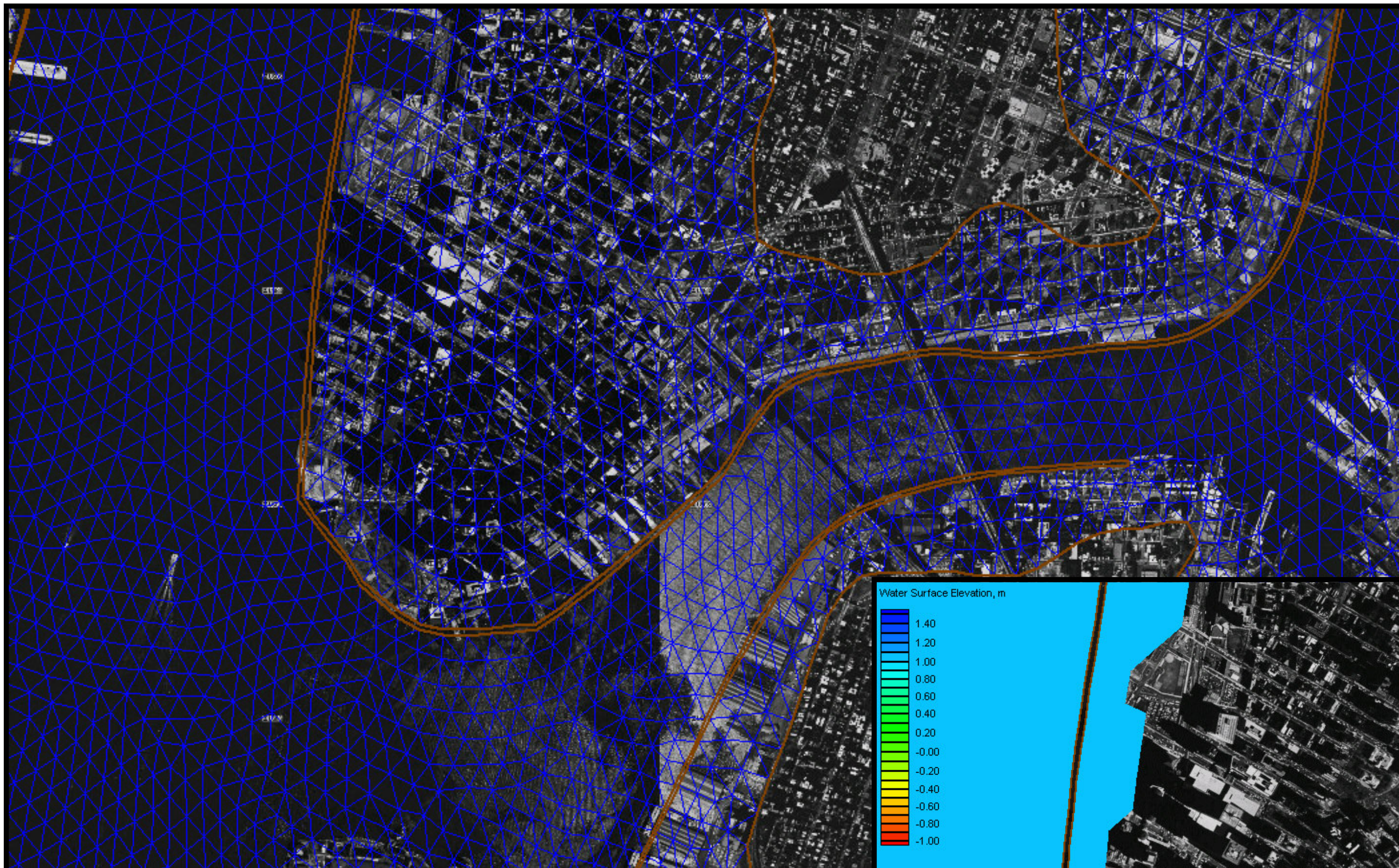
Overview of Modeling System



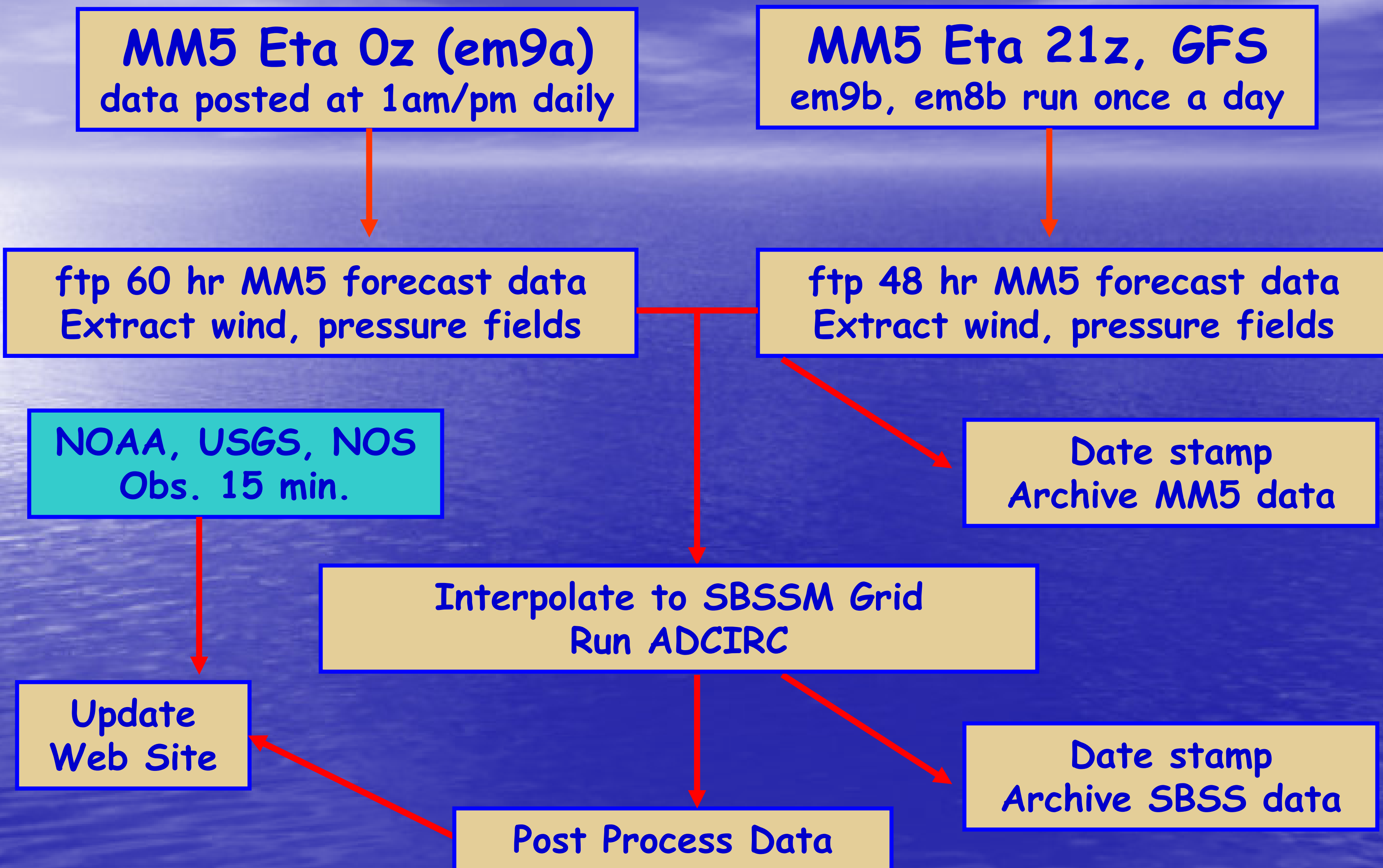


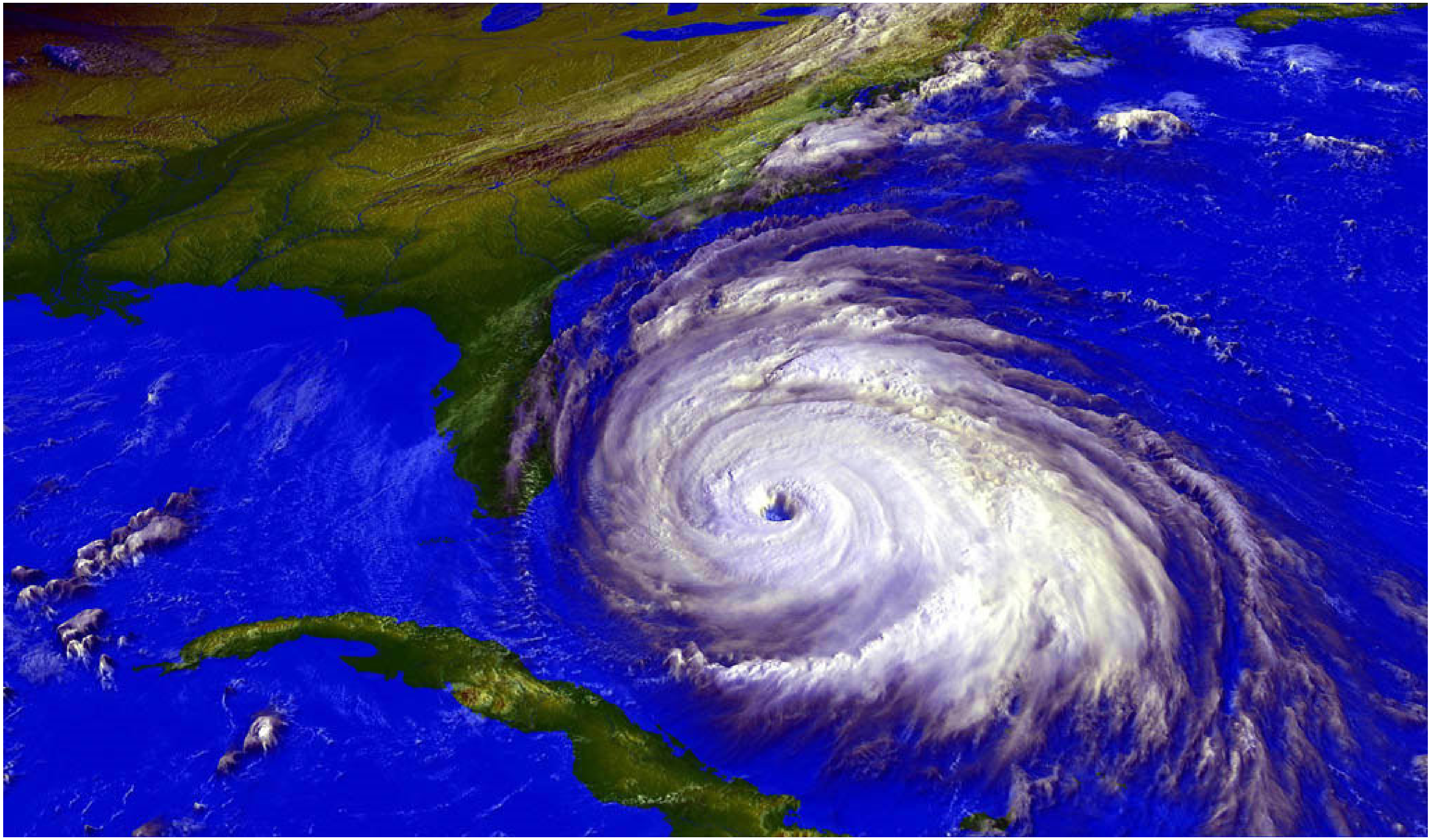
ADCIRC and MM5 model domain.

ADCIRC Model Capability

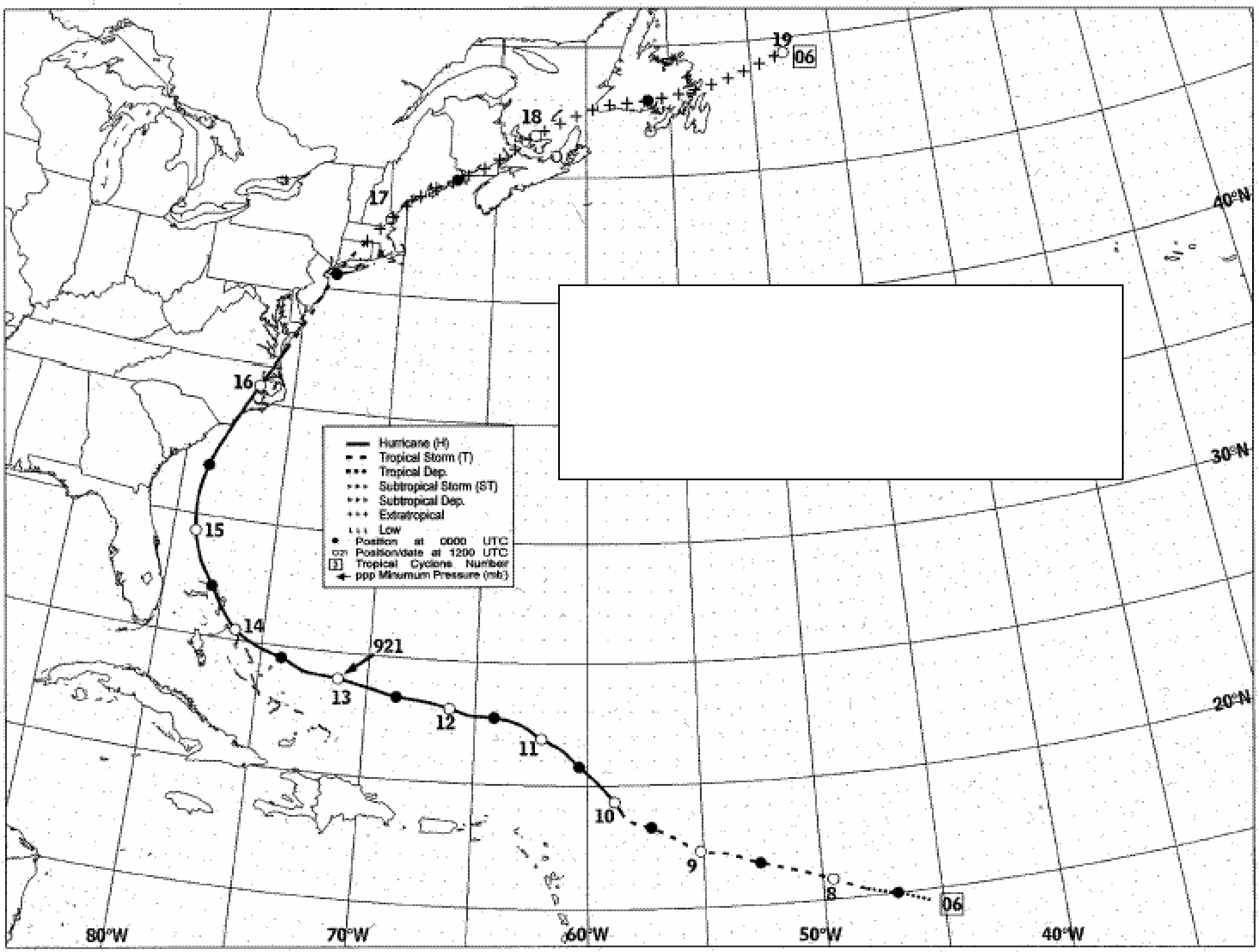


Incorporation of Ensemble Forecasts





Hurricane Floyd: 14 September 1999

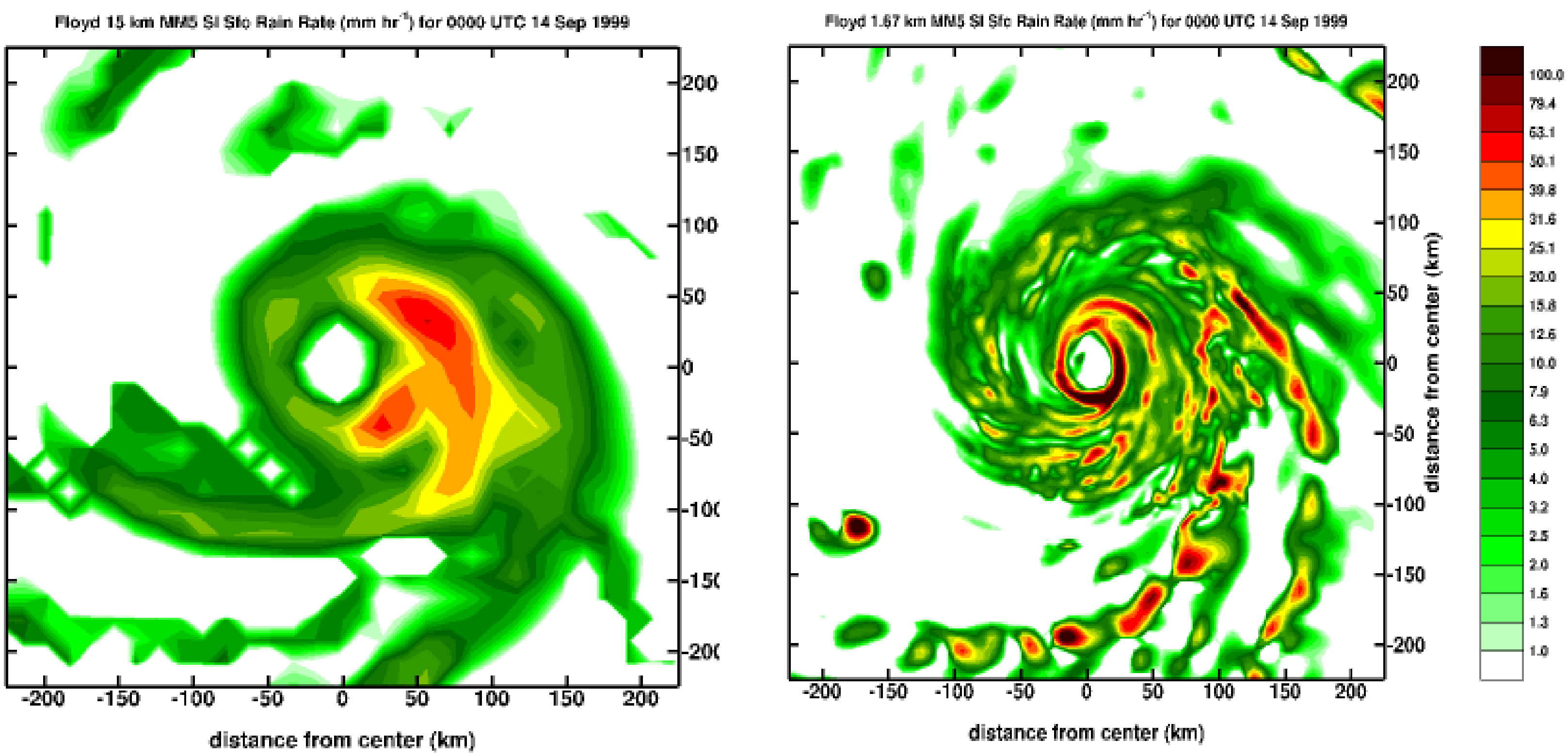


Hurricane (H)
Tropical Storm (T)
Tropical Dep.
Subtropical Storm (ST)
Subtropical Dep.
Extratropical
Low
Position at 0000 UTC
Position/date at 1200 UTC
Tropical Cyclone Number
ppp Minumum Pressure (mb)
921
06
8
9
10
11
12
13
14
15
16
17
18
19
06
80°W
70°W
60°W
50°W
40°W
40°N
30°N
20°N

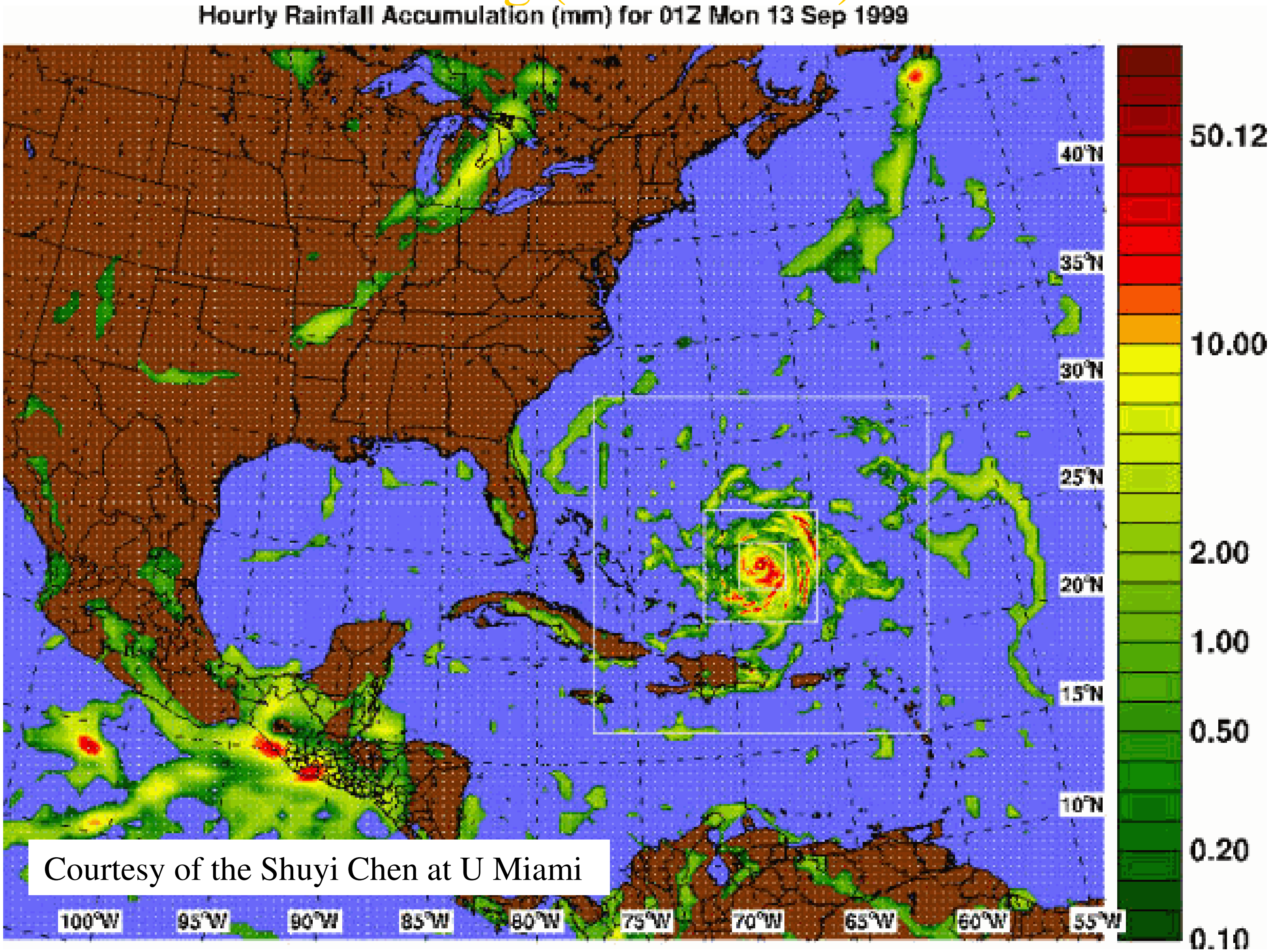
OTHER FORECAST DIFFICULTIES FOR TROPICAL SYSTEMS: Impact of Horizontal Resolution

15-km grid spacing

1.67-km grid spacing

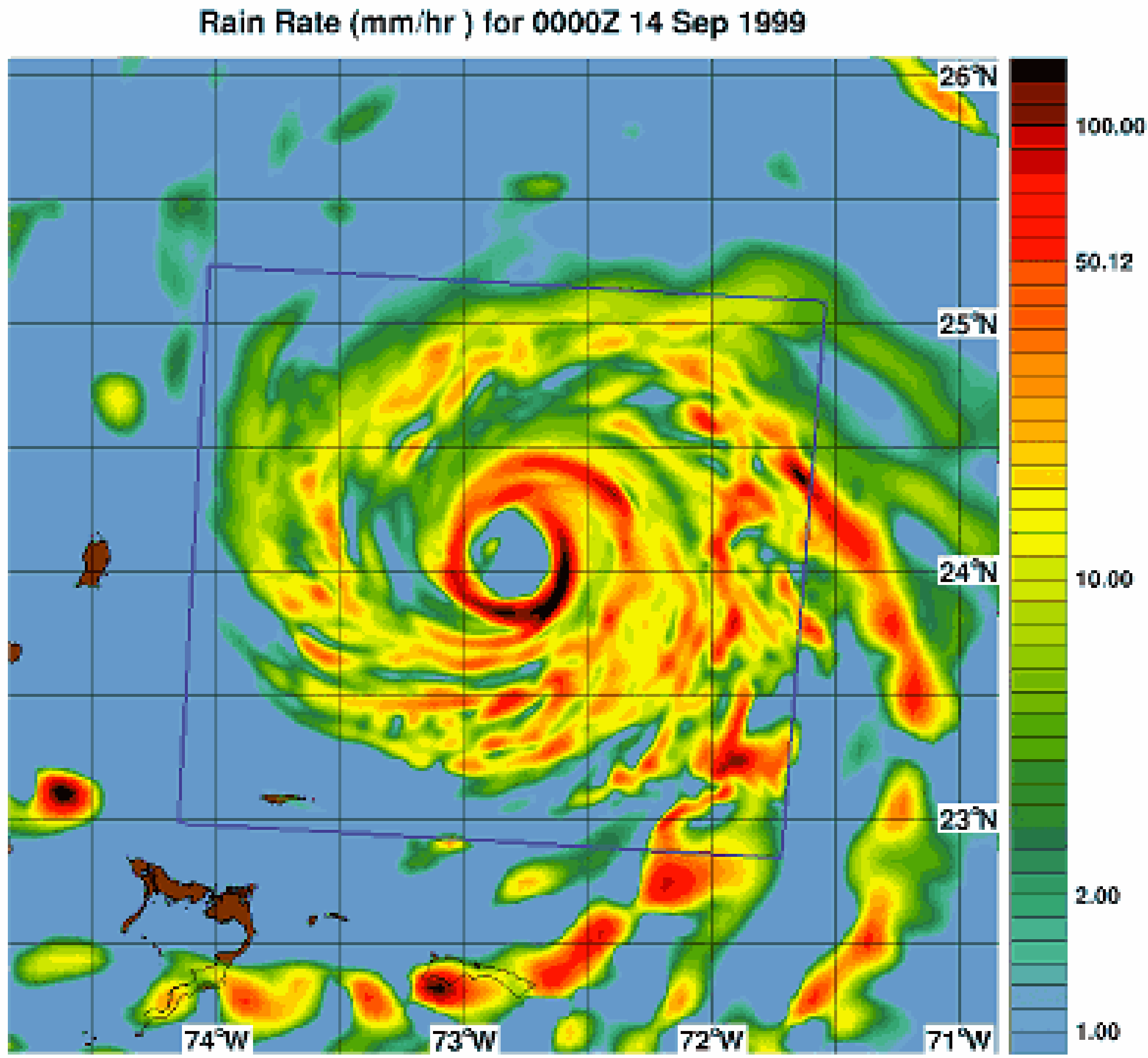


Vortex-following (double nest) MM5 Run



Courtesy of the Shuyi Chen at U Miami

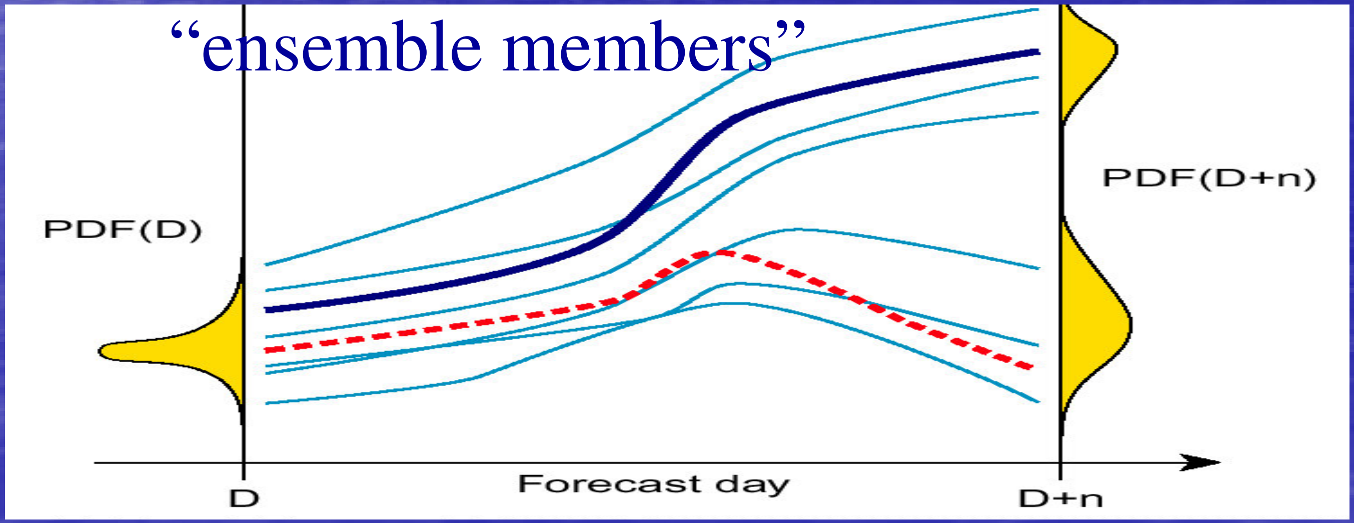
Floyd animation of 4-km moveable nest

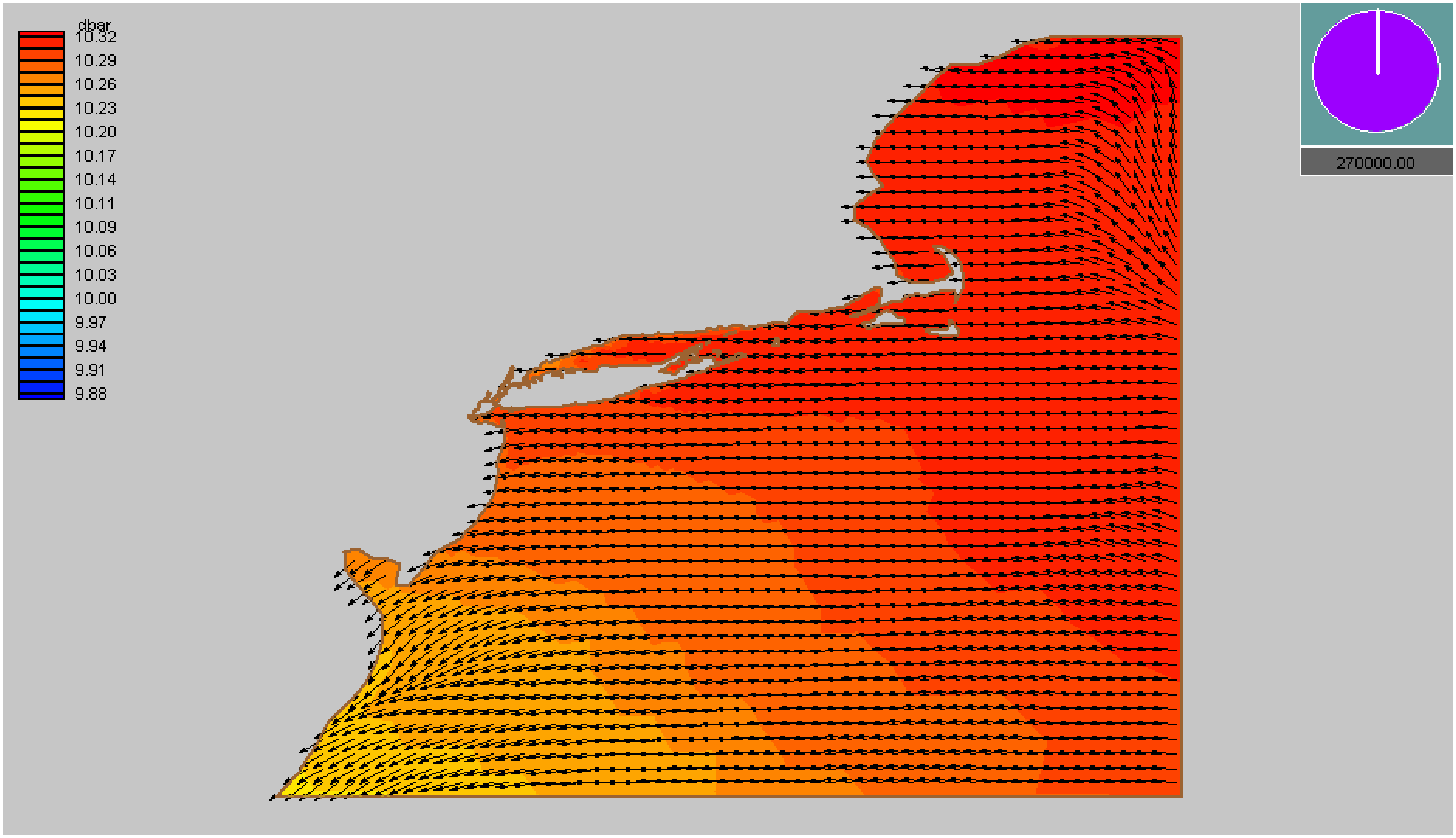


FACT:

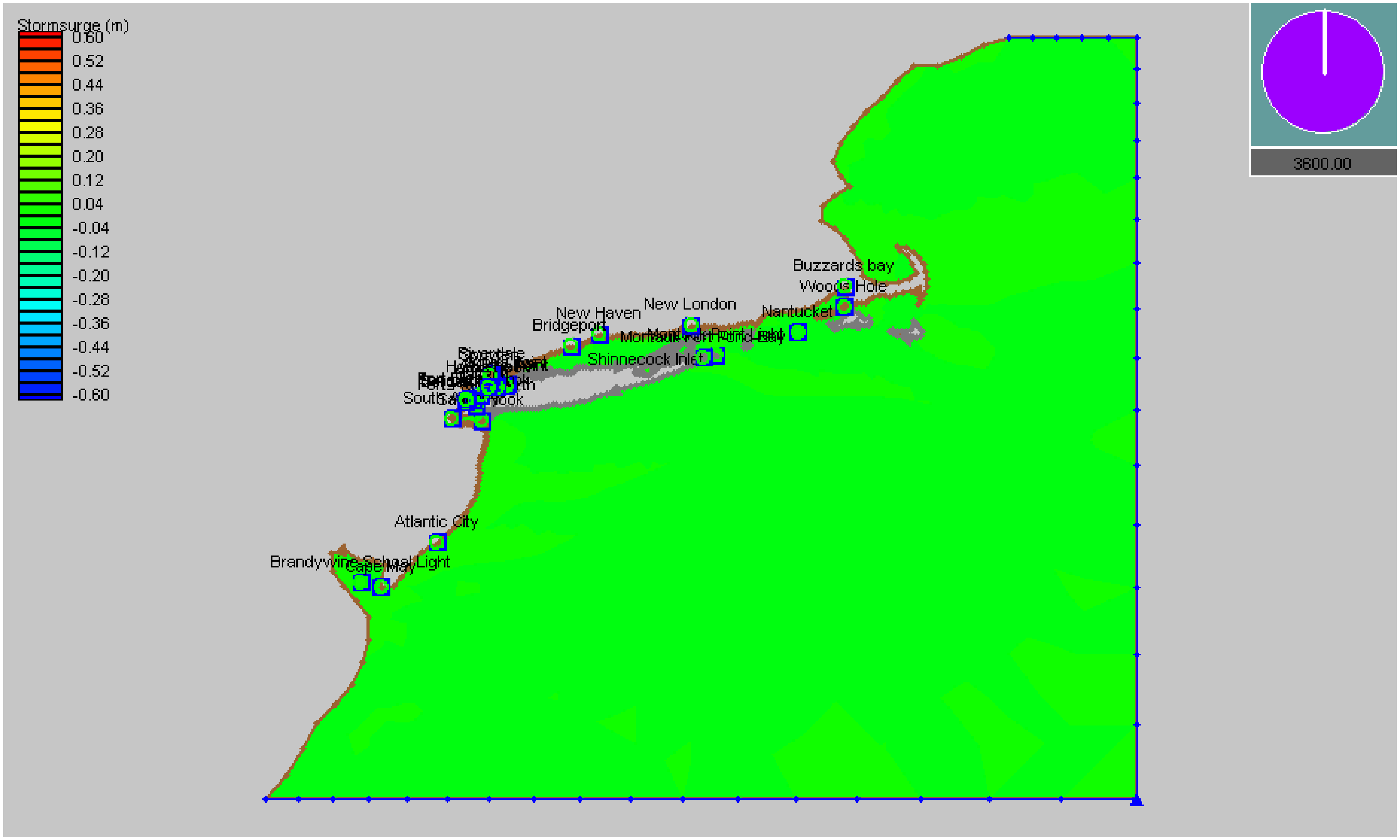
Weather Forecasts Will *ALWAYS* Be Coupled With *Varying* Degrees of Uncertainty ("*Chaos*" *Theory*)!

→ Forecast process is inherently Stochastic (probabilistic) in nature!!

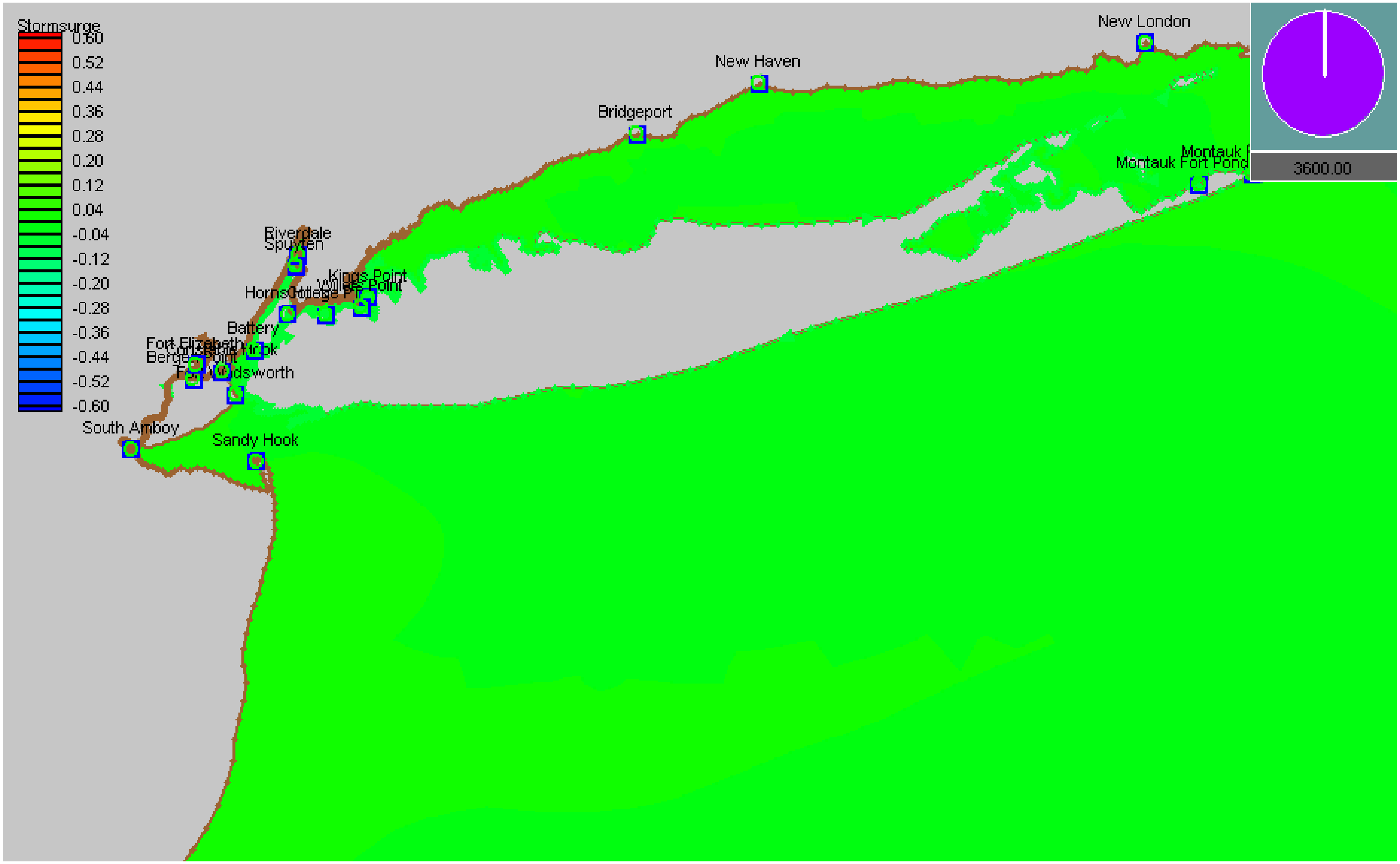


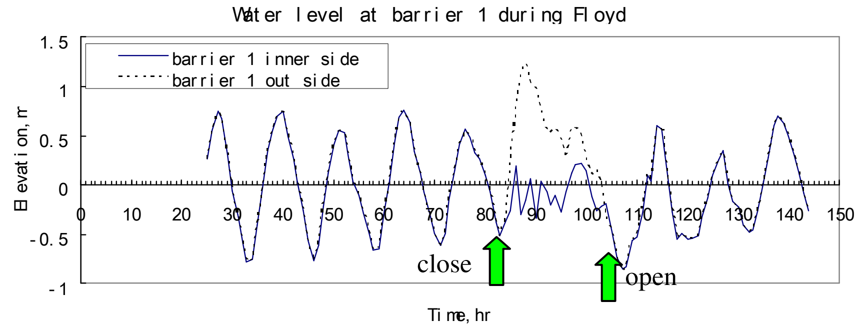


Winds and sea level pressure during Hurricane Floyd (16-19 Sept 1999)

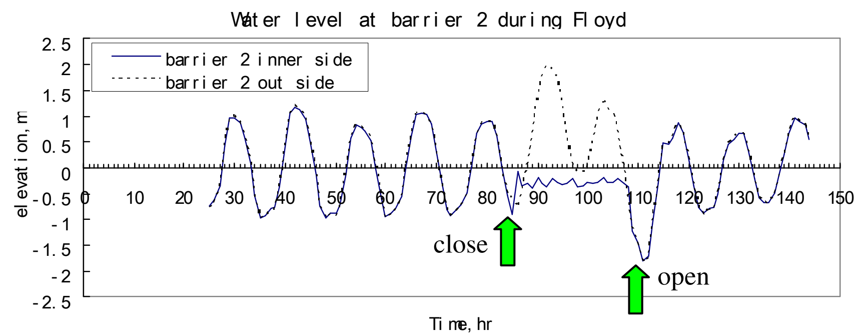

Stormsurge (m)
0.60
0.52
0.44
0.36
0.28
0.20
0.12
0.04
-0.04
-0.12
-0.20
-0.28
-0.36
-0.44
-0.52
-0.60
3600.00
Buzzards bay
Woods Hole
Nantucket
New London
New Haven
Bridgeport
Shinnecock Inlet
Atlantic City
Brandywine Shoal Light
Cape May

Storm surge (m) during Hurricane Floyd 16-19 Sept 1999

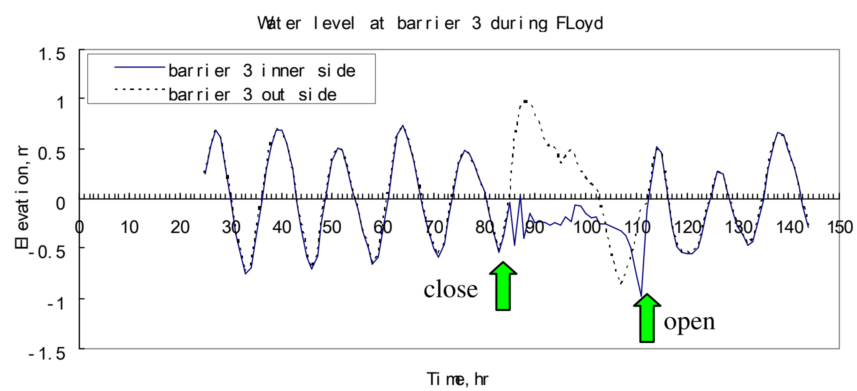




Perth Amboy



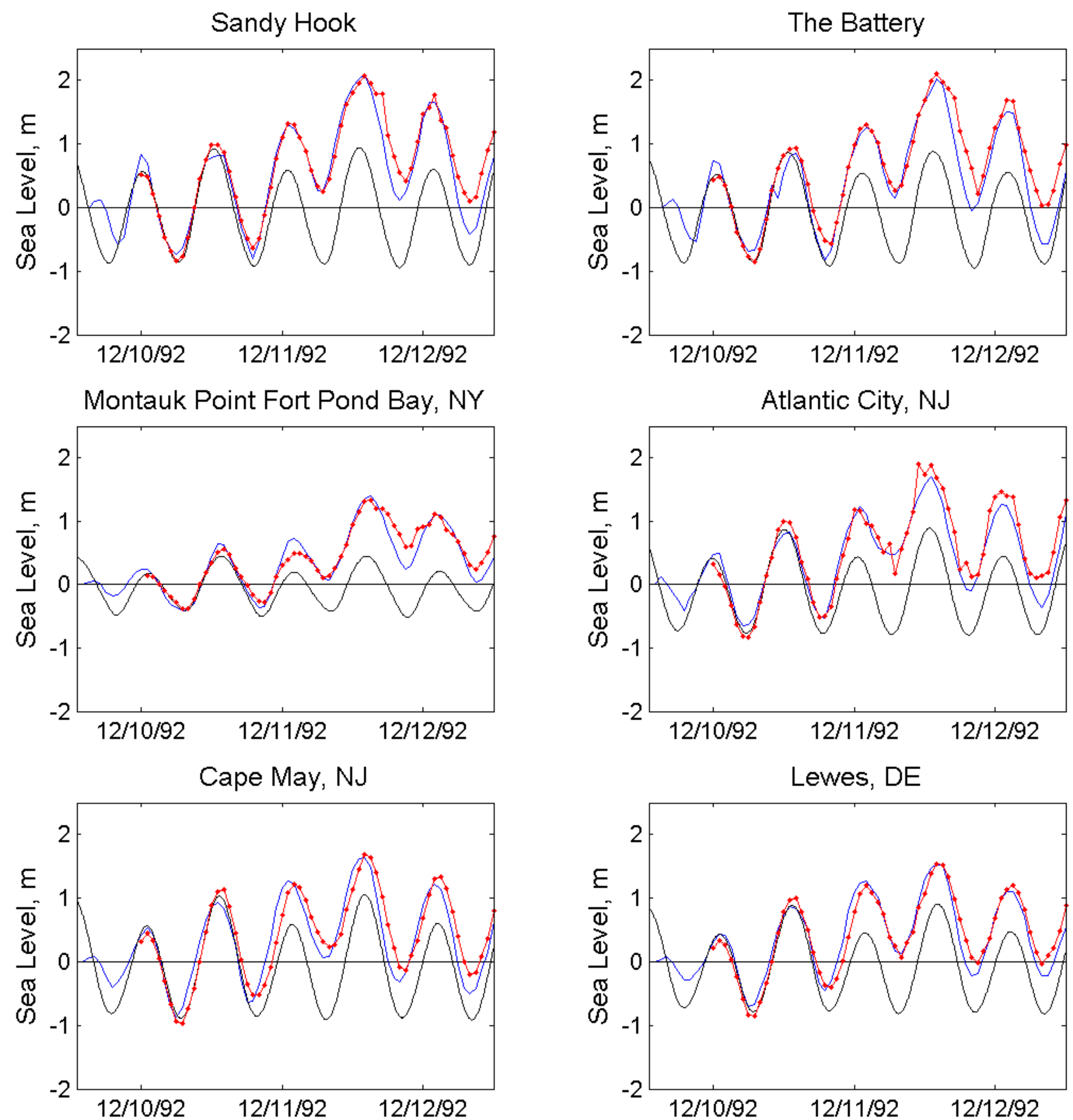
Upper East River



The Narrows

Water levels inside/outside barriers for Floyd simulations.

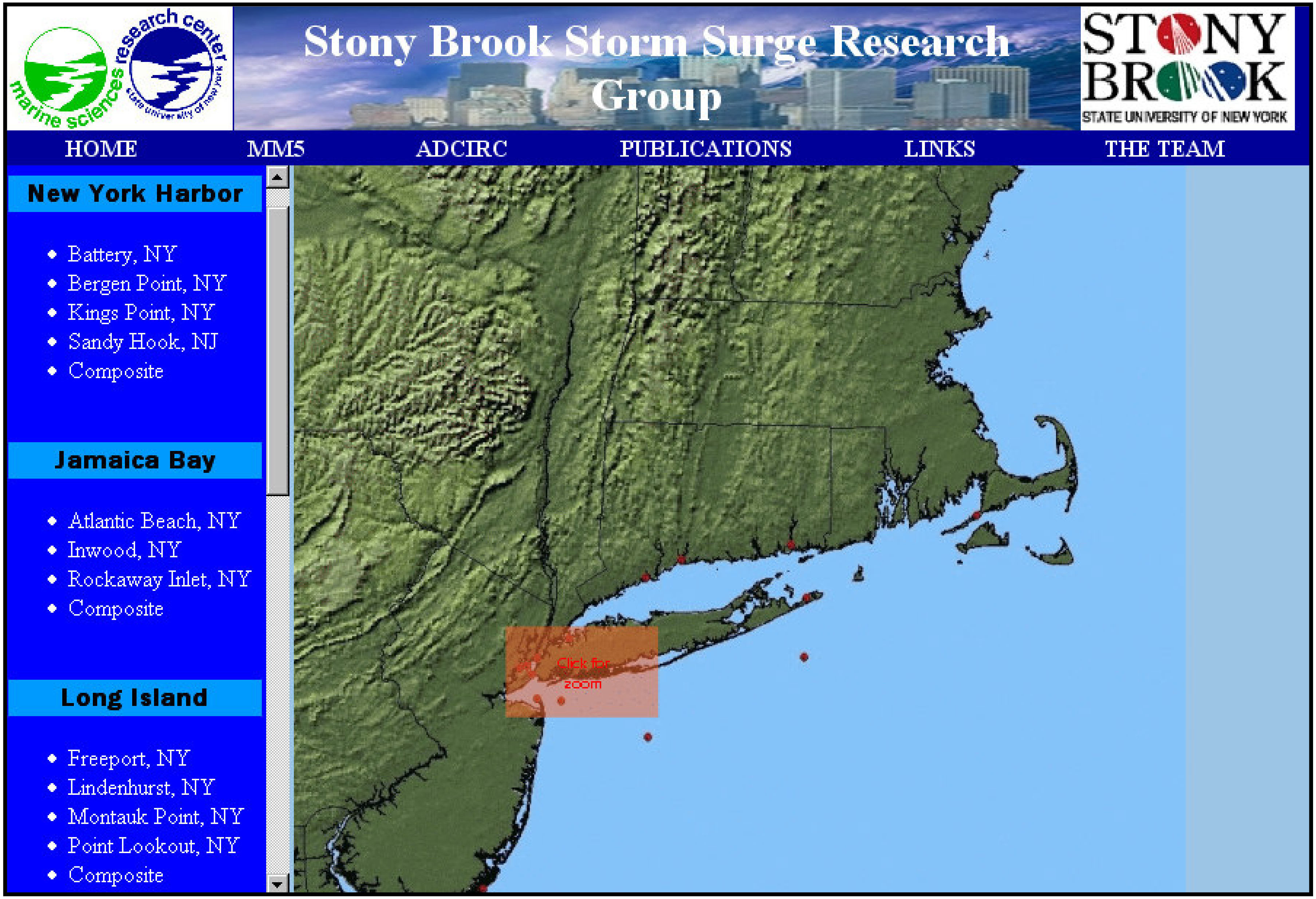
December 2002 nor’easter



Black: Astronomical Tide

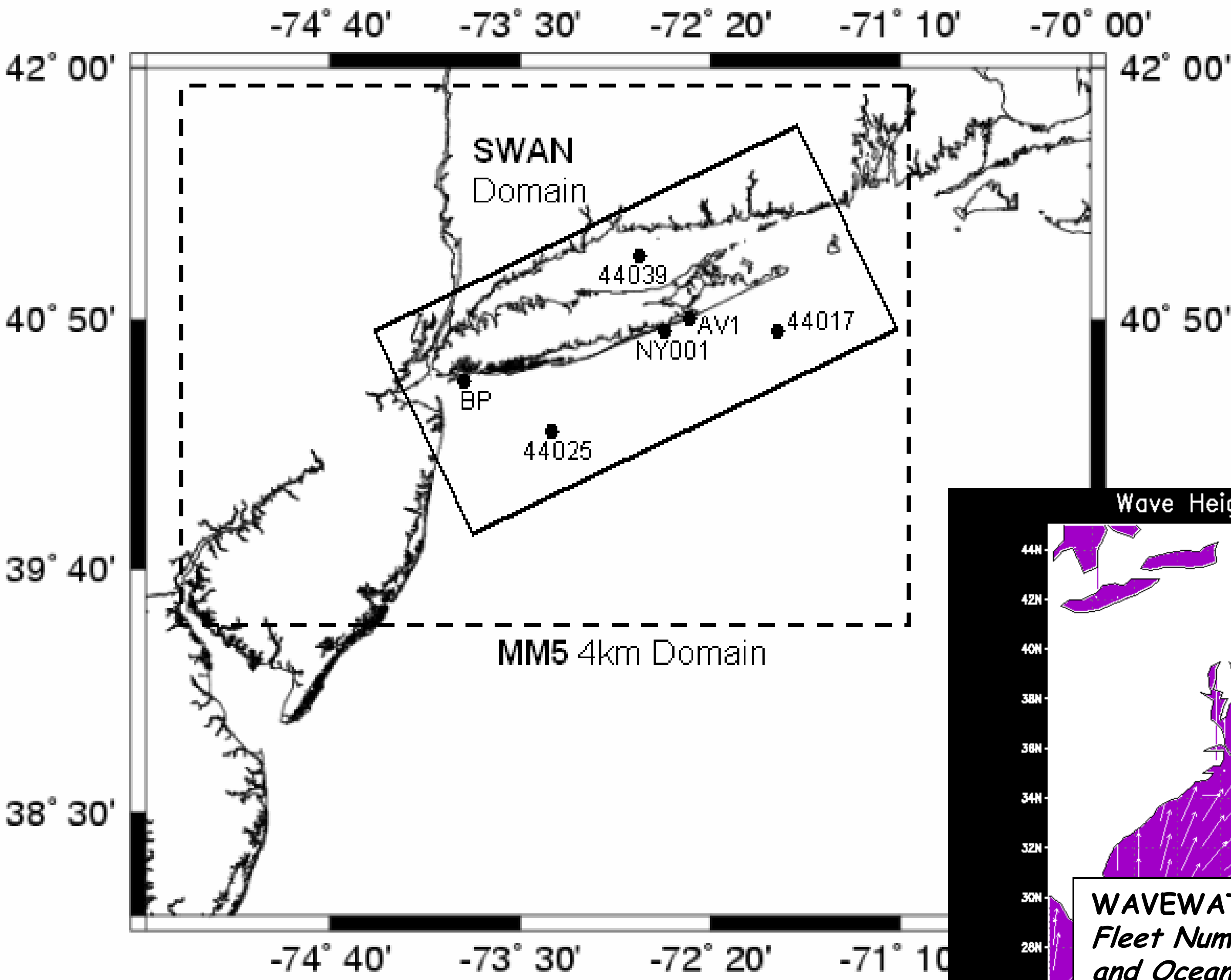
Blue: Model hindcast (48 hr time horizon)

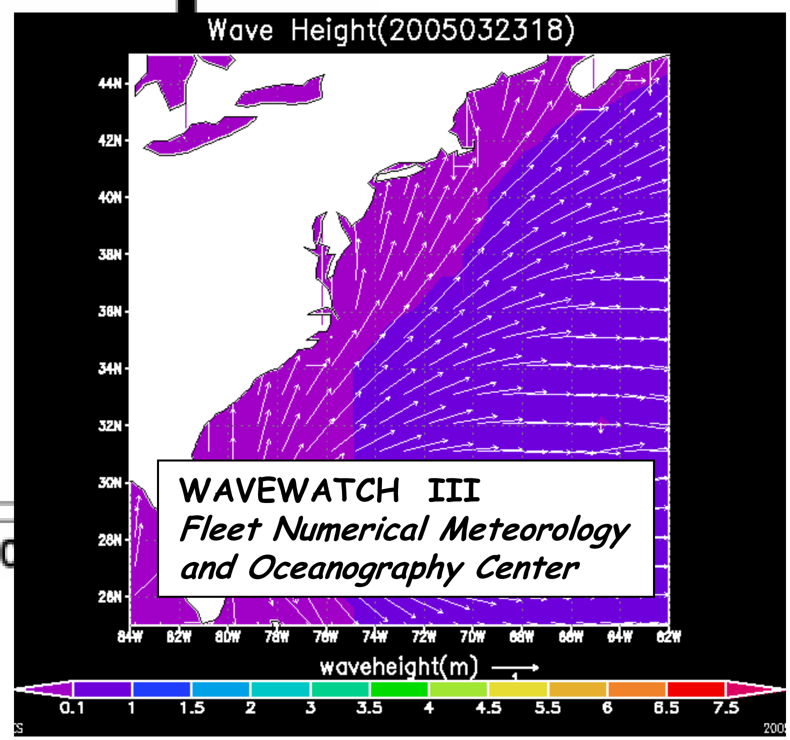
Red: NOAA tidal observations



http://stormy.msrc.sunysb.edu/

South Shore of L.I.





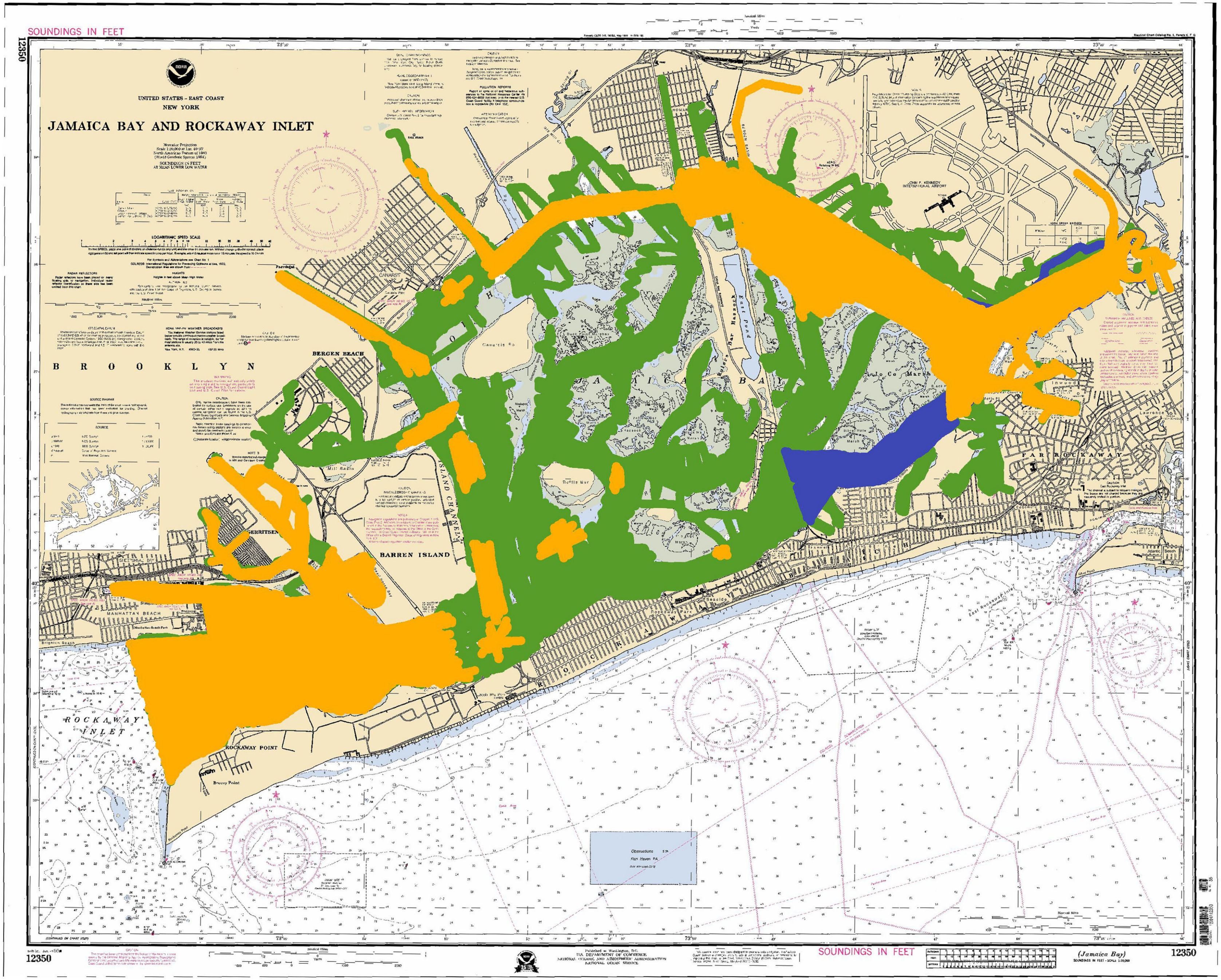


Figure 1. NOS bathymetry data: 1934 (green), 1945 (blue), 1950 (yellow).

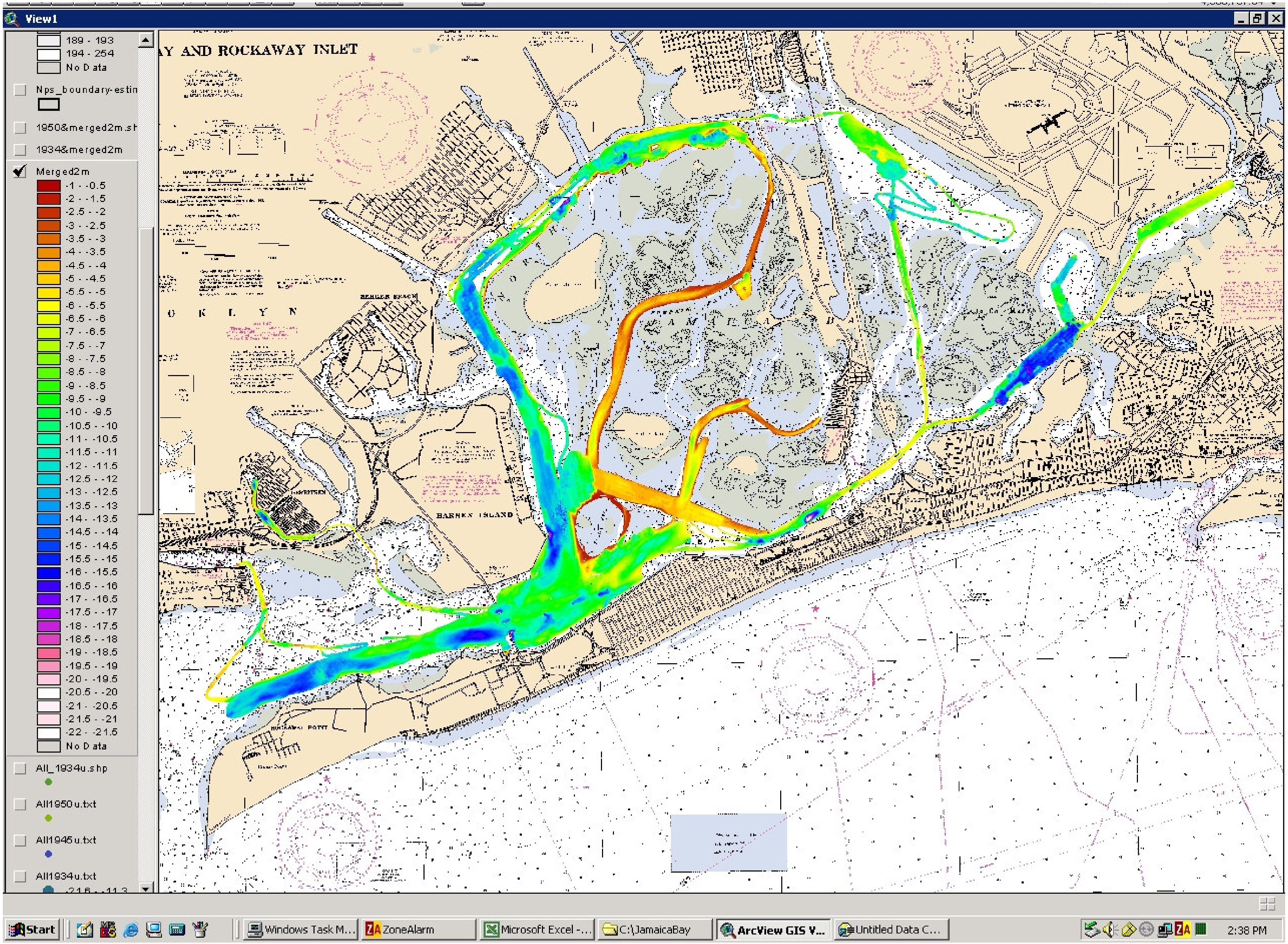


Figure 2. MSRC multi-beam data for 2000 and 2003.

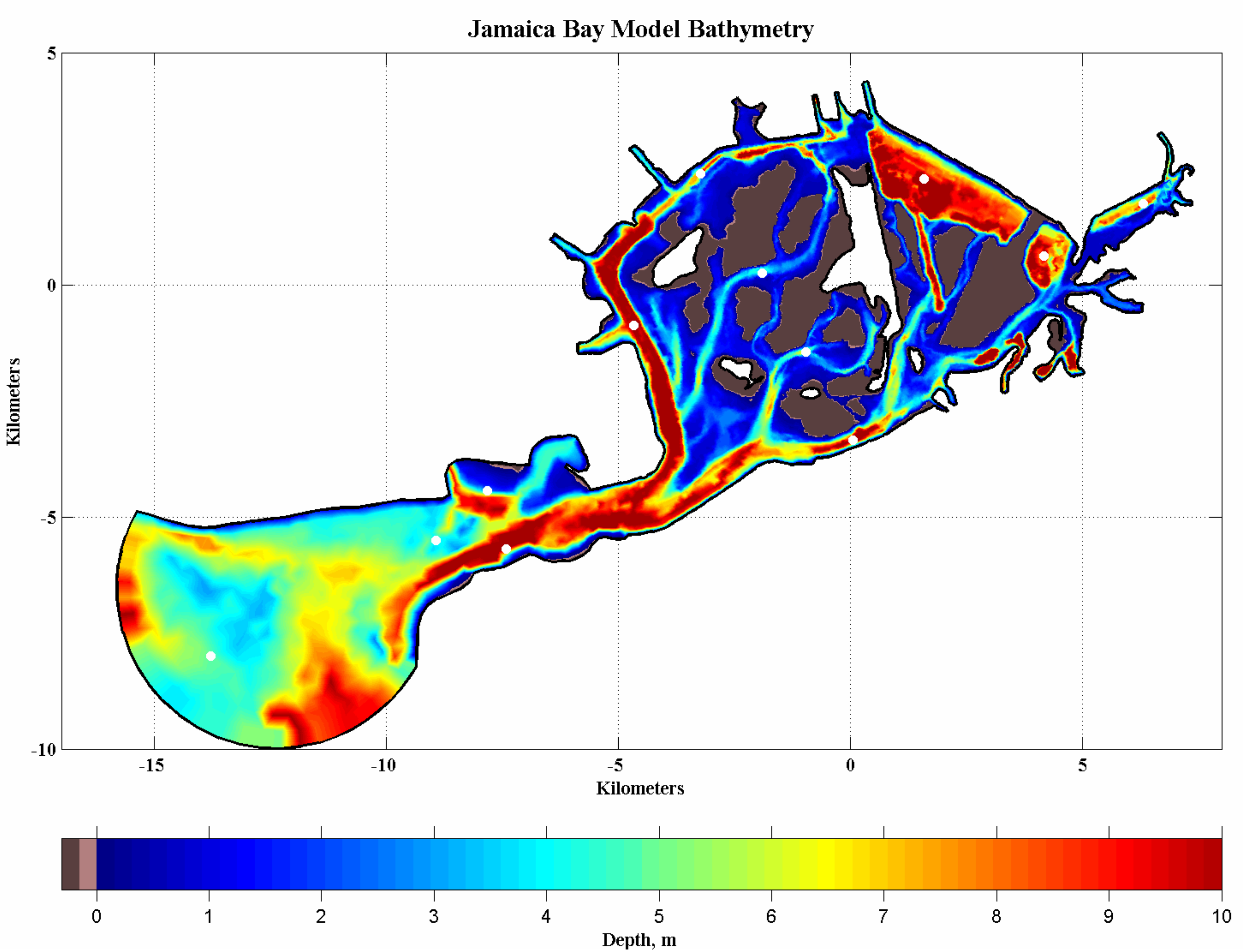
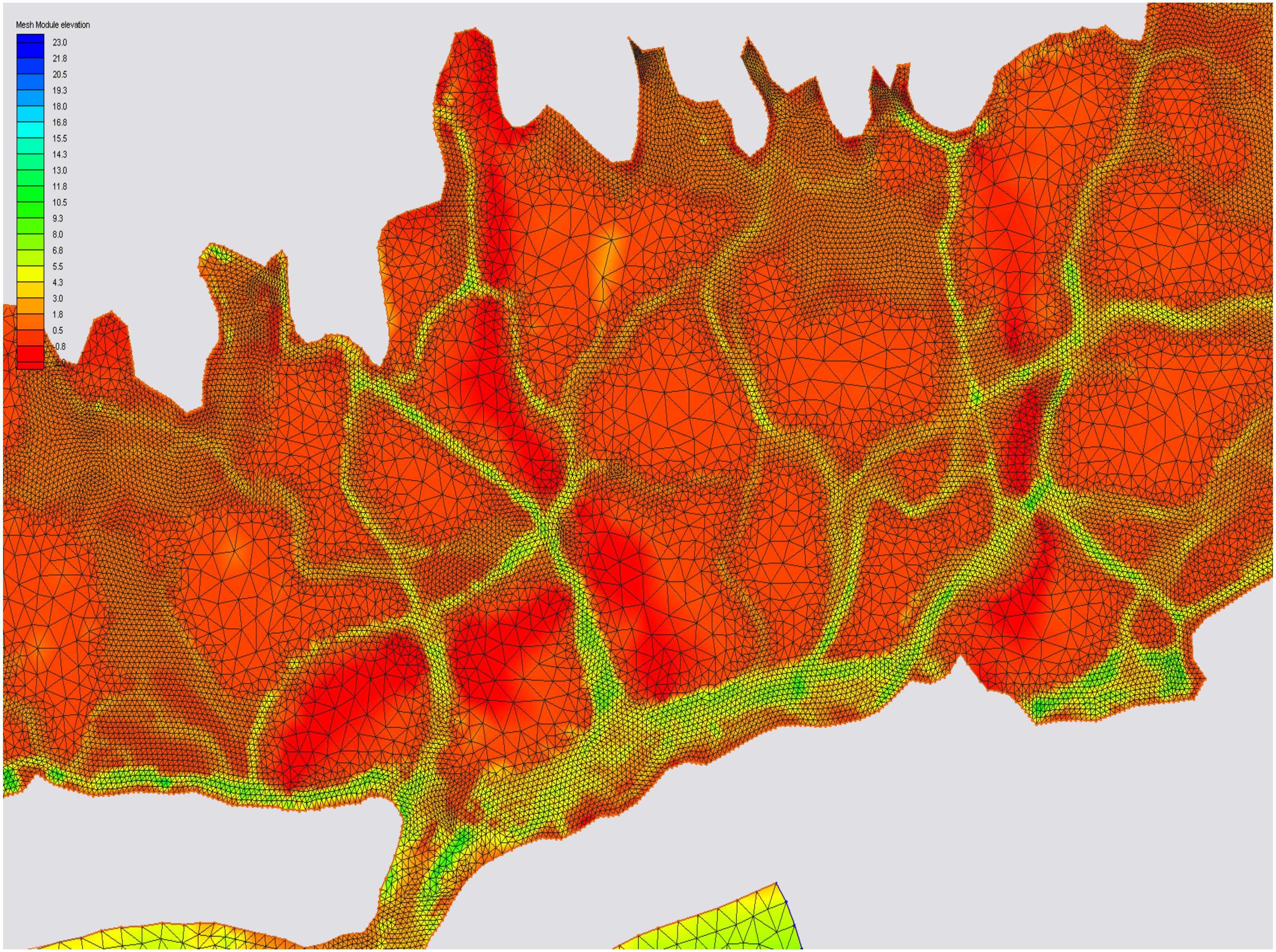
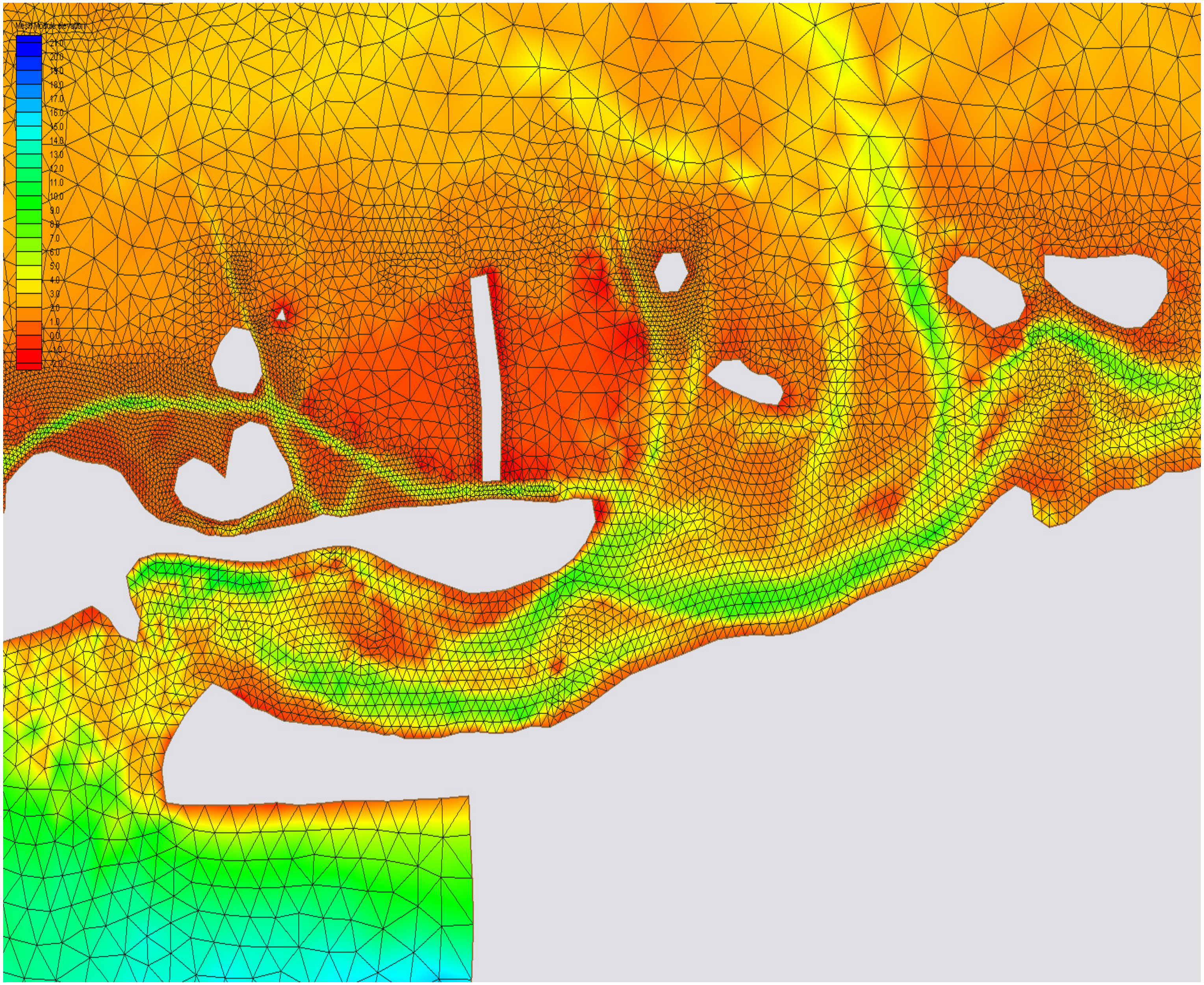


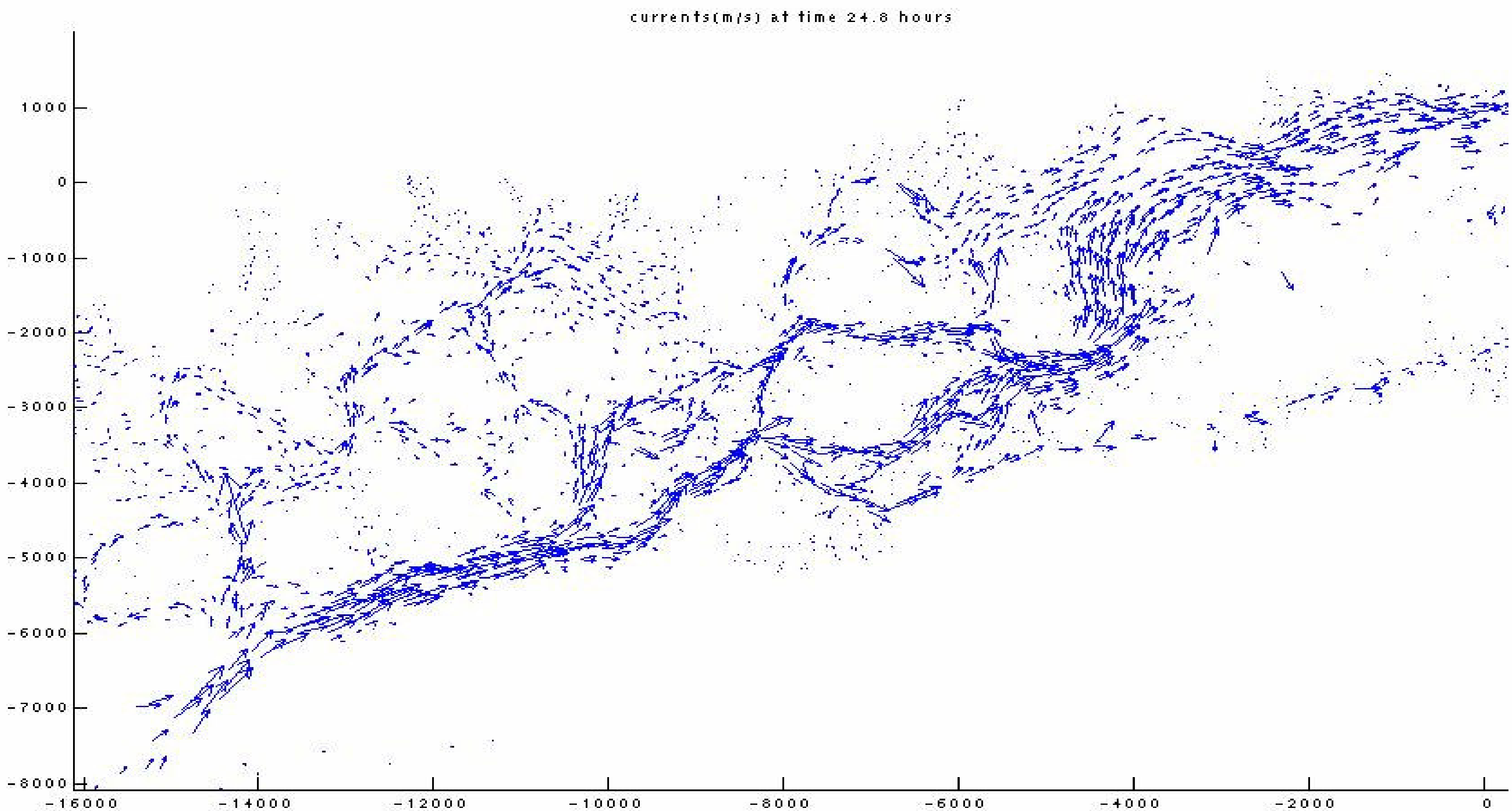
Figure 4. Model domain and model bathymetry.



Unstructured computational grid and interpolated bathymetry in South Oyster Bay



Unstructured computational grid and interpolated bathymetry near Fire Island Inlet



Surface current vectors during flood in South Oyster Bay showing channelization of flow and wetting of marsh areas

Conclusions of Hydrologic Feasibility Research

- Storm surge barriers would work
- All 3, perhaps 4 barriers required
- Rainfall runoff flooding not a problem
- Upper East River location uncertain
- Engineering feasibility studies needed

Design Criteria - Structural

- Suitable geology
- Alternative barrier configurations
  - fail-safe/slow-die
- Static load on piers (multiple cases)
  - height of barrier
  - relative water elevation inside and outside
- Alternative gate configurations
- Dynamic loads on gates when partly open
- Adjacent infrastructure considerations
- Power requirements

Design Criteria - Environmental

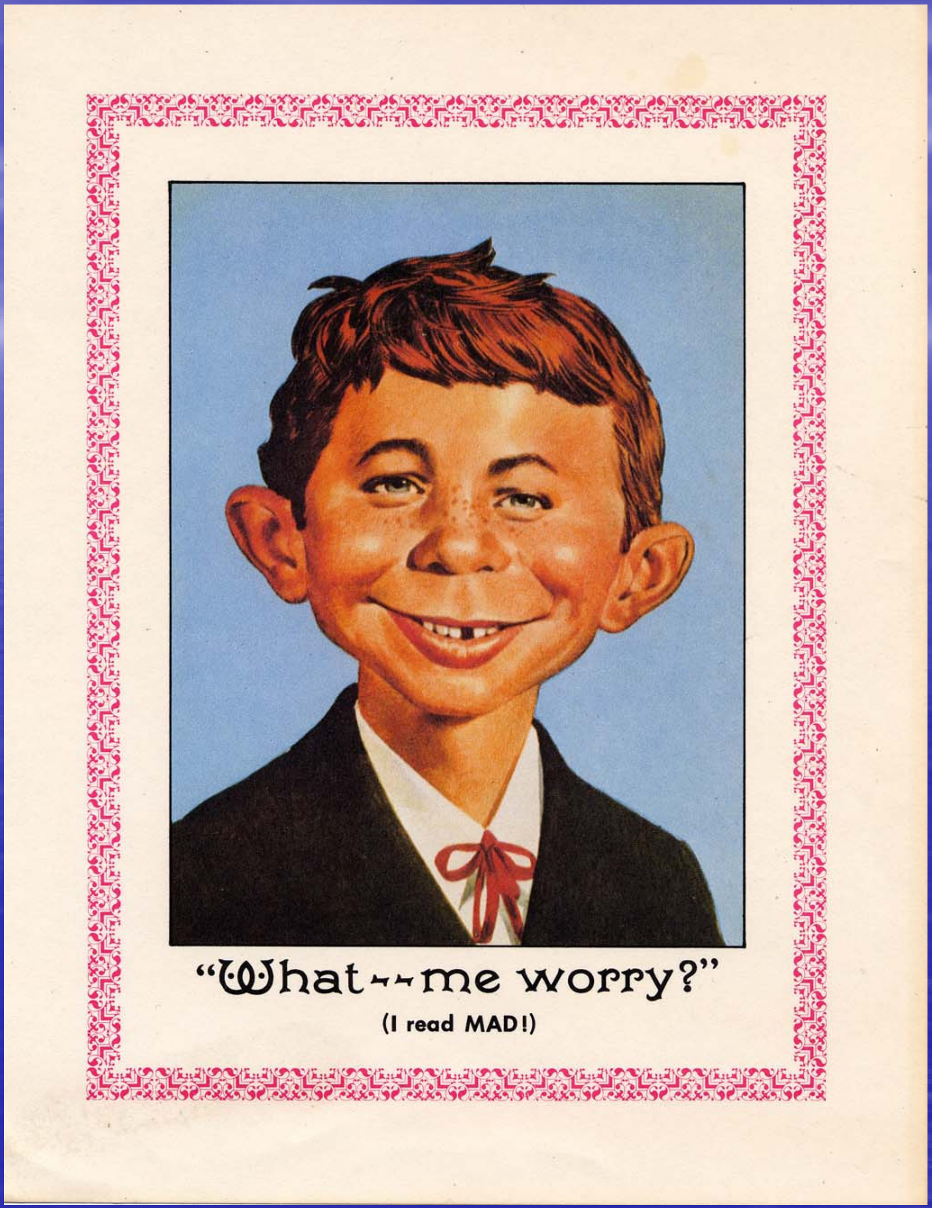
- Effects on harbor flushing (could be improved)
- Effects on water quality
- Effects on sedimentation transport and deposition patterns
- Effects of altered water level on wetlands
- Effects on fish migration through rivers

Conclusions

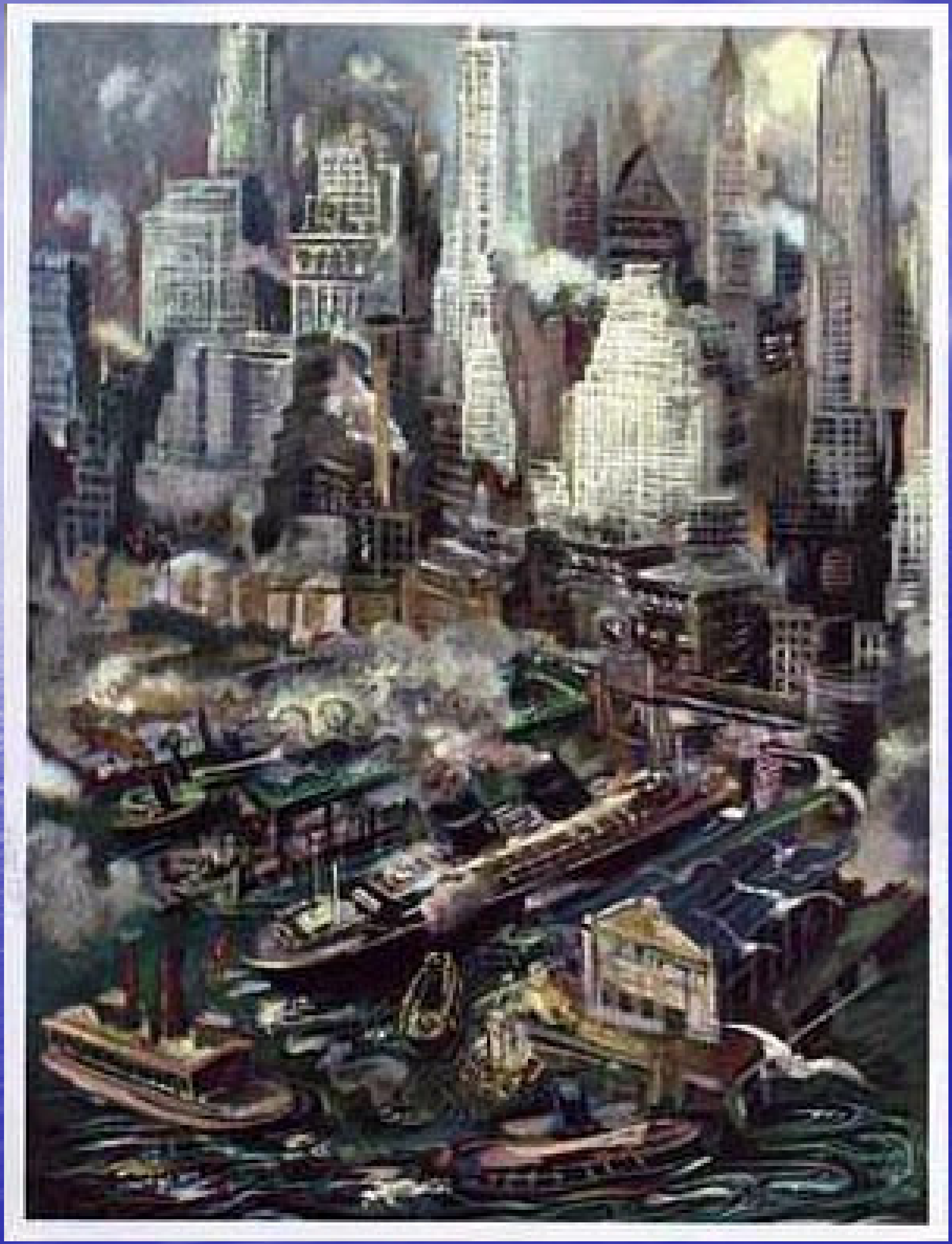
- Great variety of possible barrier configurations
- Main structures must be designed for worst case static and dynamic loads (500 yr storm?)
- Environmental effects cannot be ignored
- Cannot wait for an Act of Congress to move ahead
- Design criteria -- structural and environmental -- need to be defined well beforehand

- **Q.** When do you plan for a flood?
- **A.** Too late?
- So start **NOW**!

Thank you!



This presentation will be posted on http://stormy.msrc.sunysb.edu



The End

Manhattan Harbor
by George Grosz
(1893-1959)