Modelling Storm Surge and Flooding Events

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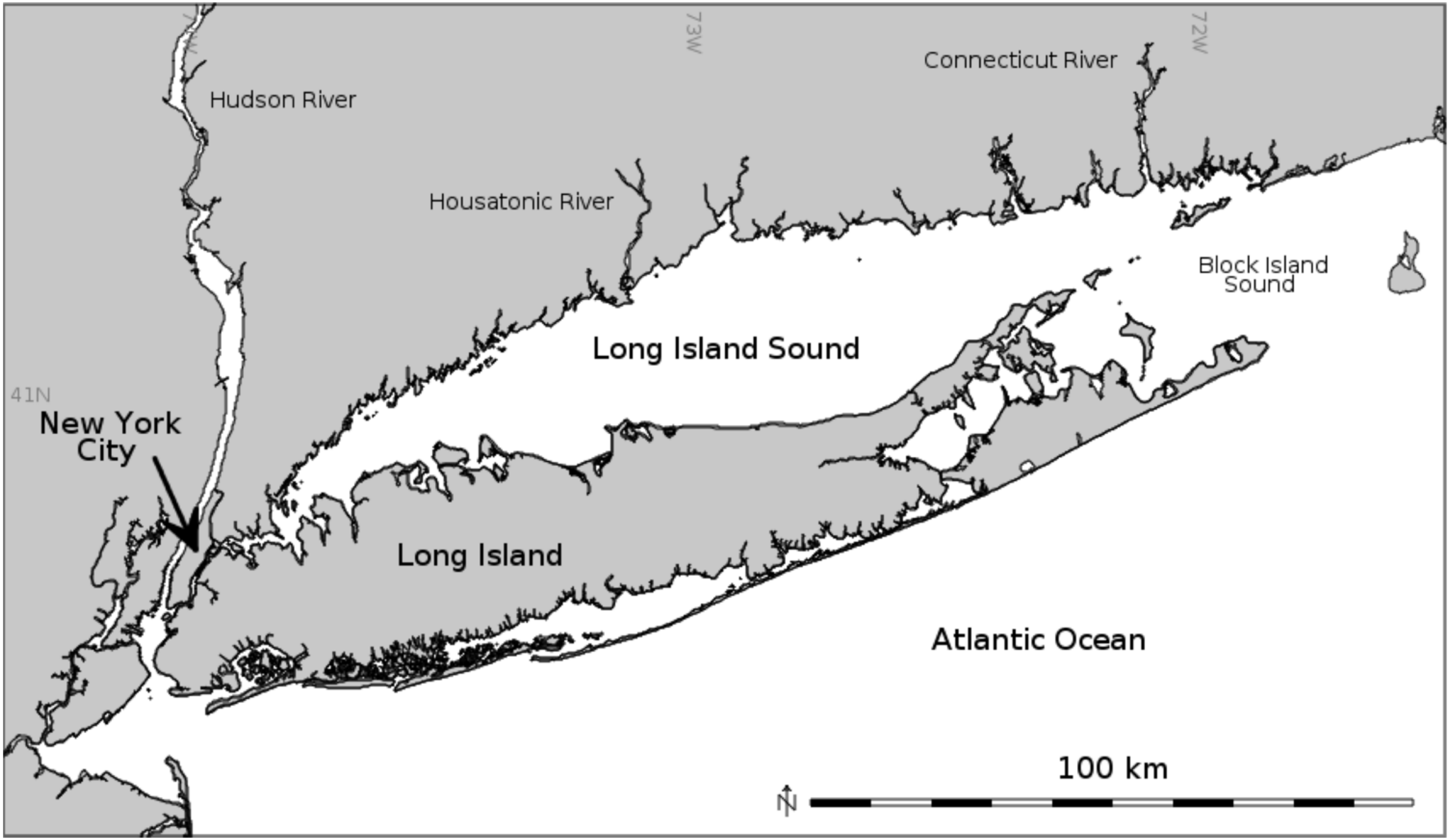
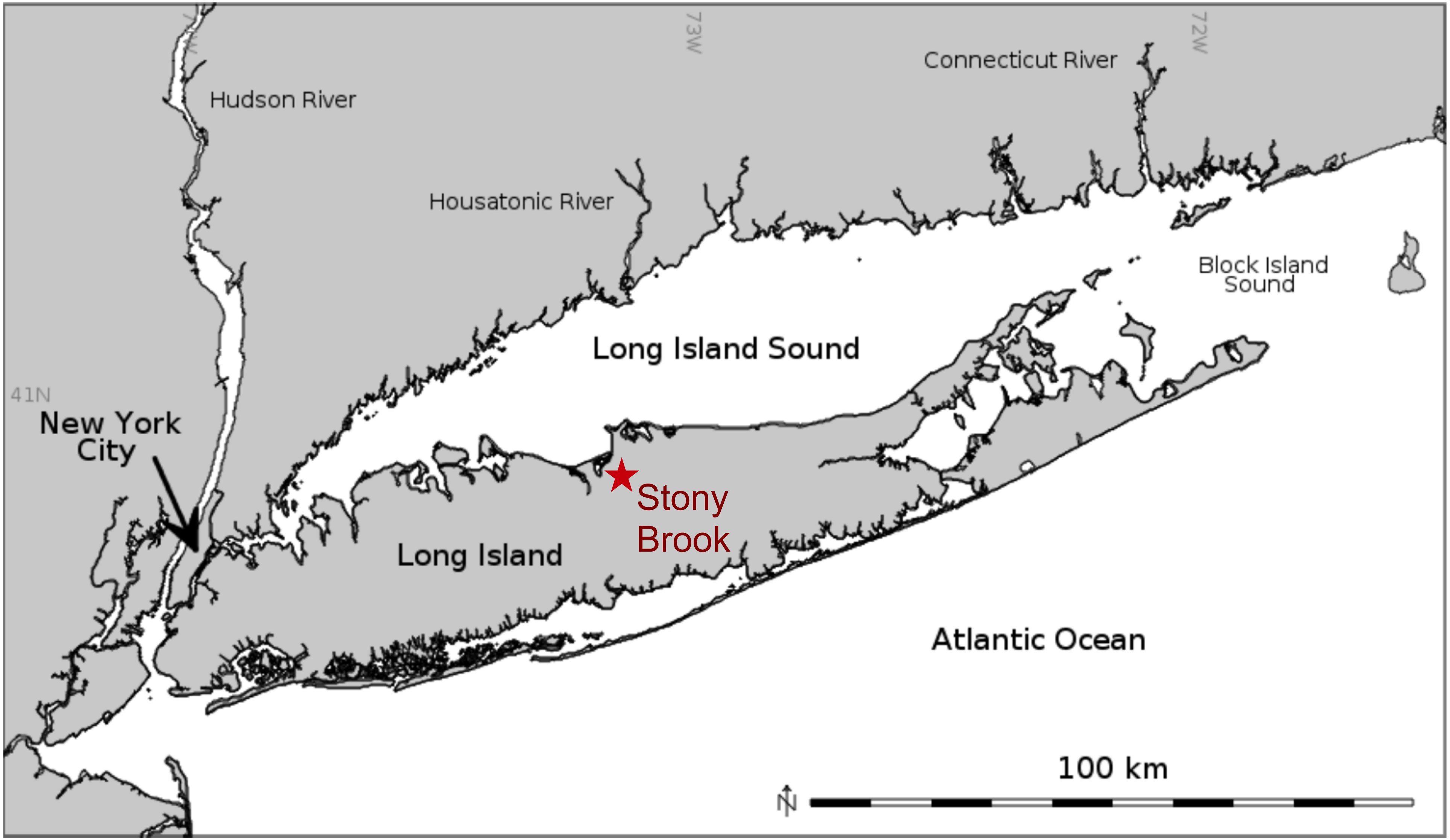

73W
72W
Connecticut River
Hudson River
Housatonic River
Block Island
Sound
Long Island Sound
41N
New York
City
Long Island
Atlantic Ocean
100 km
N

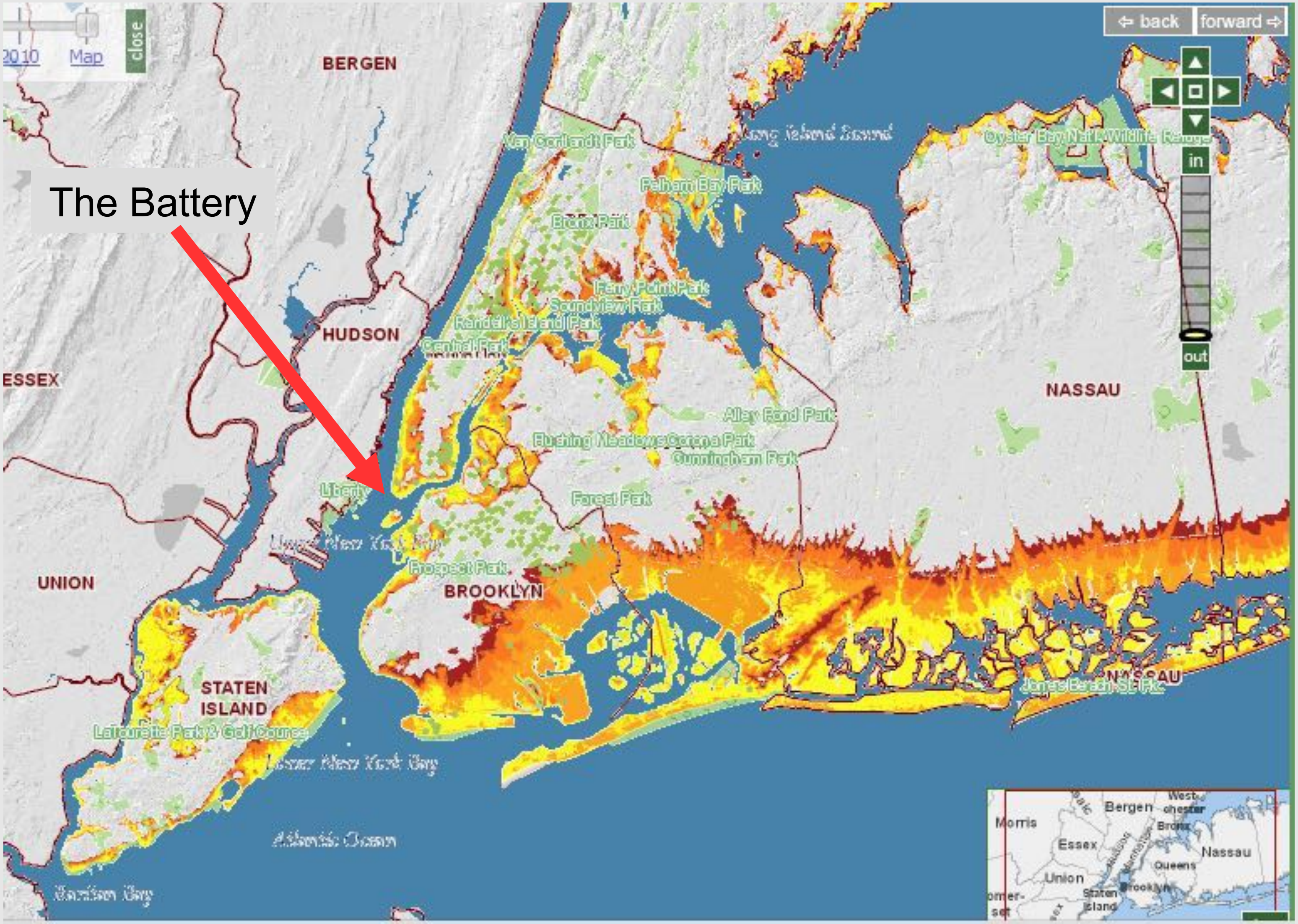


73W
72W
Hudson River
Connecticut River
Housatonic River
Block Island
Sound
Long Island Sound
41N
New York
City
Stony
Brook
Long Island
Atlantic Ocean
100 km
N

- Two hour tidal phase difference between western Long Island Sound and Lower NY Harbor, separated by the East River tidal strait

- Hudson River: mean flow ~600 m^3/sec (heavily seasonal)

- Much of Manhattan, eastern Brooklyn, and metro New Jersey only a few meters above MSL



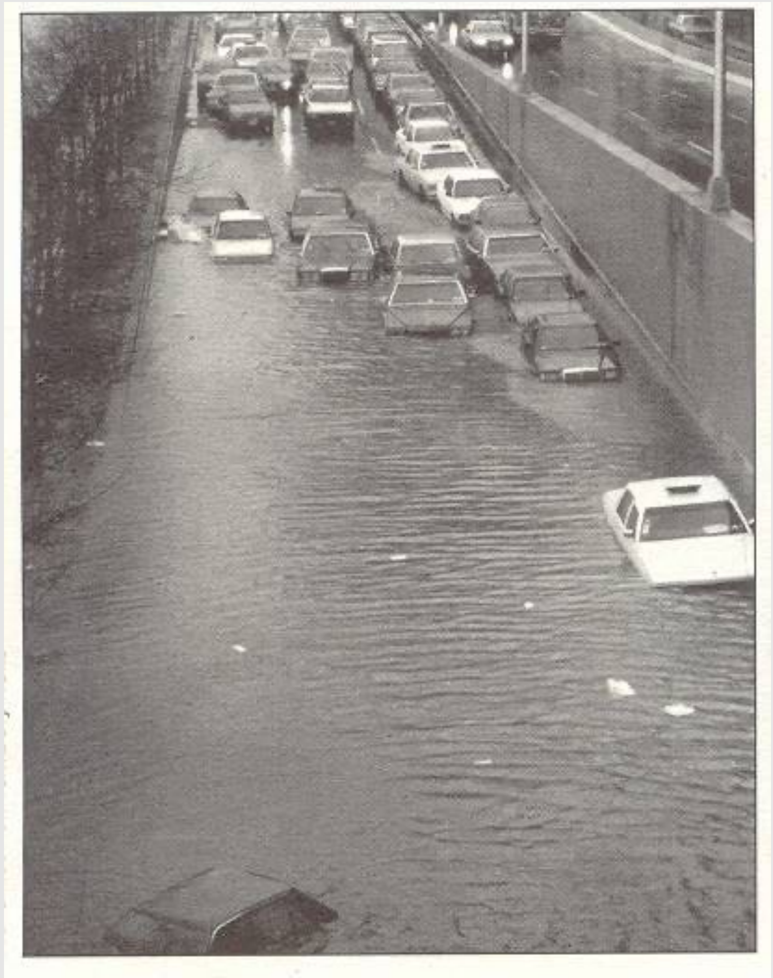
http://www.harborestuary.org/aboutestuary-climatechange-tides.htm

Flood risk map based on SLOSH model for hurricanes category 1-4 for New York City and western Long Island Sound


Coney Island, Brooklyn

The “Long Island Express” hits the south shore of Long Island,
21 September 1938

A severe storm in November 1950 caused extensive flooding of La Guardia airport

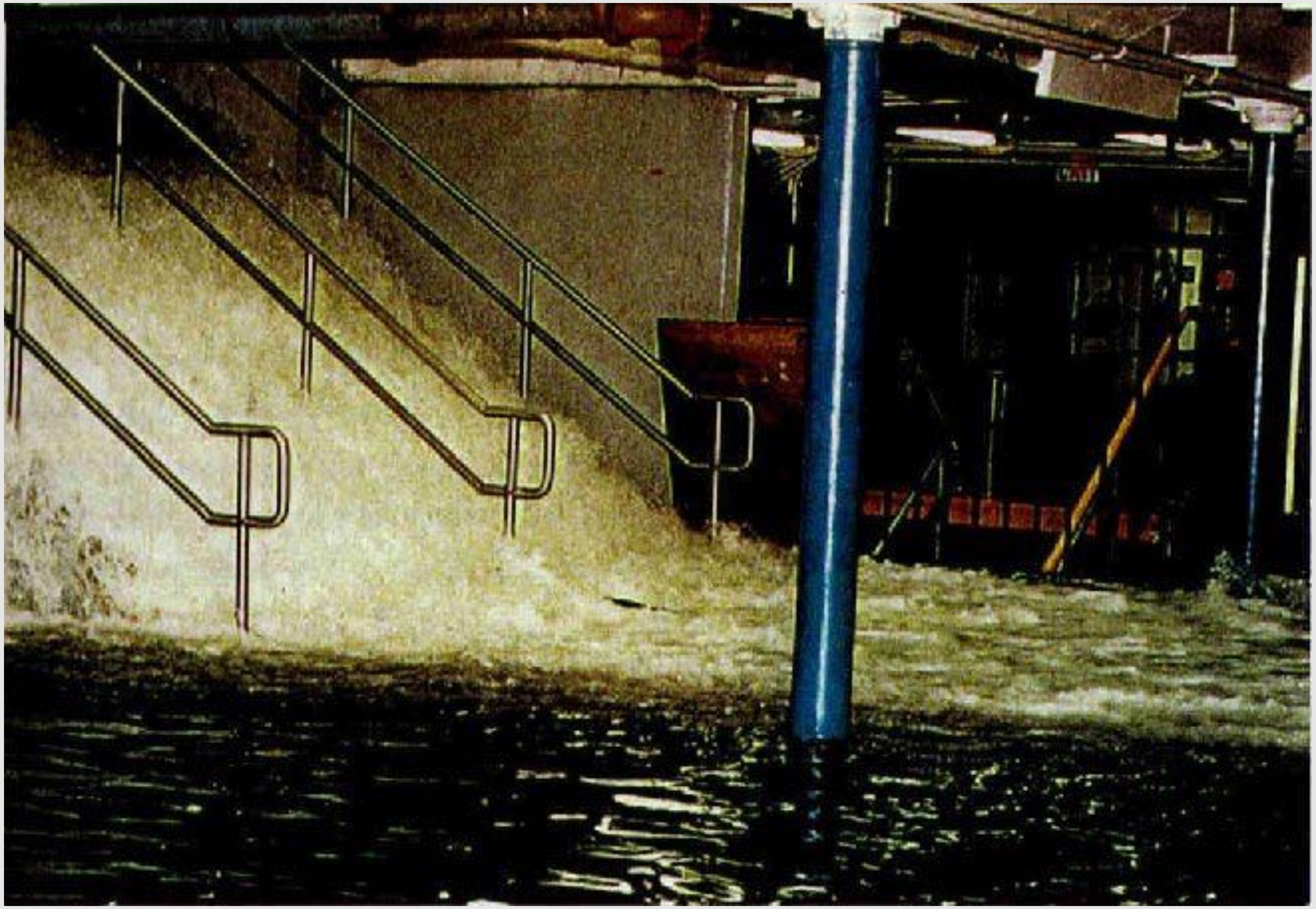


FDR Drive during the December 1992 nor’easter

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

Photo: Daniel Schwen

1992 nor'easter flooding of Hoboken train station with seawater



Source: Metro New York Hurricane Transportation Study, 1995

A major shutdown of the New York City subway and train system resulted

World Trade Center
Memorial

2012: Hurricane Sandy

Entrance to Brooklyn Battery tunnel under New York Harbor

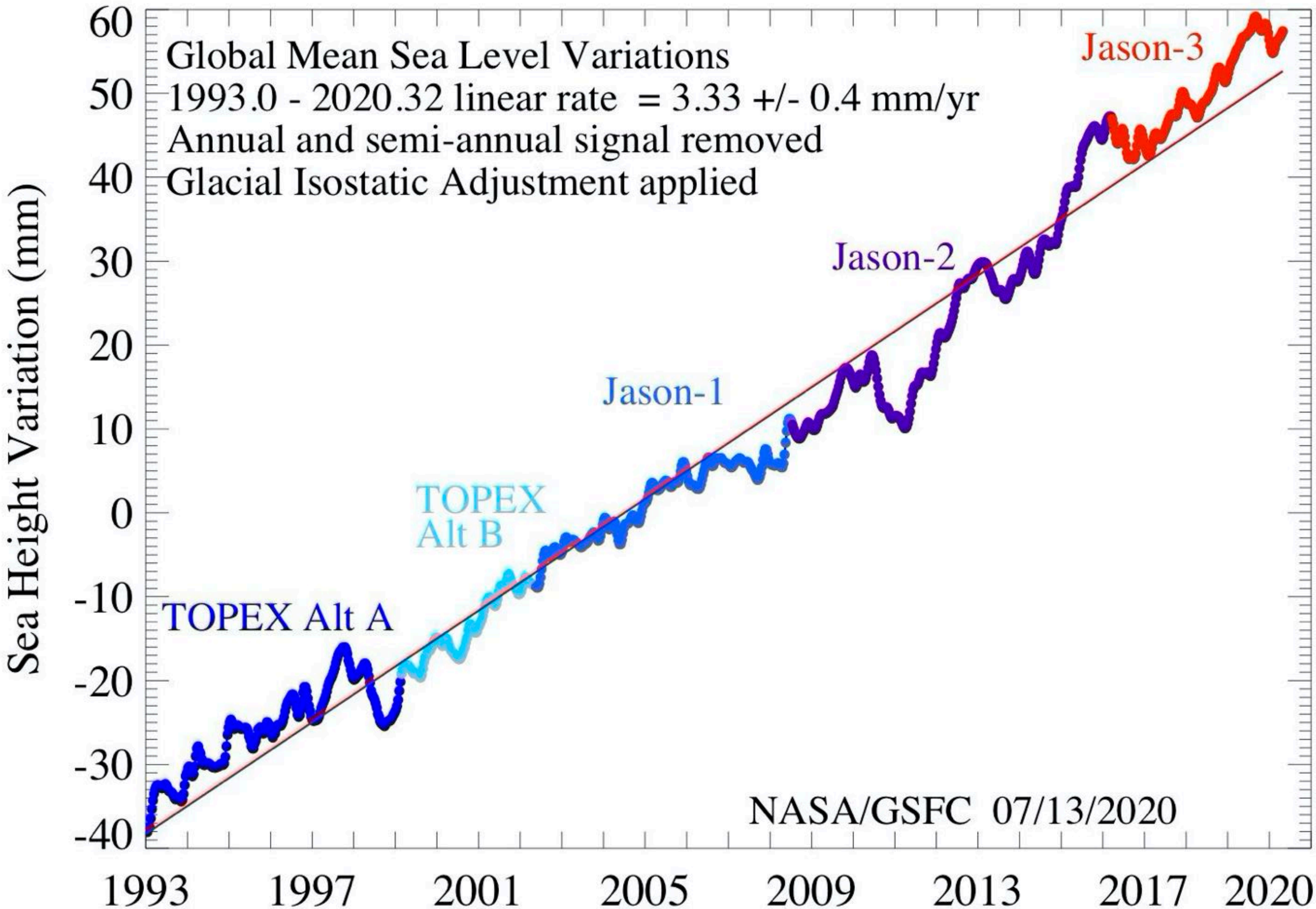
2012: Hurricane Sandy

International Business Times

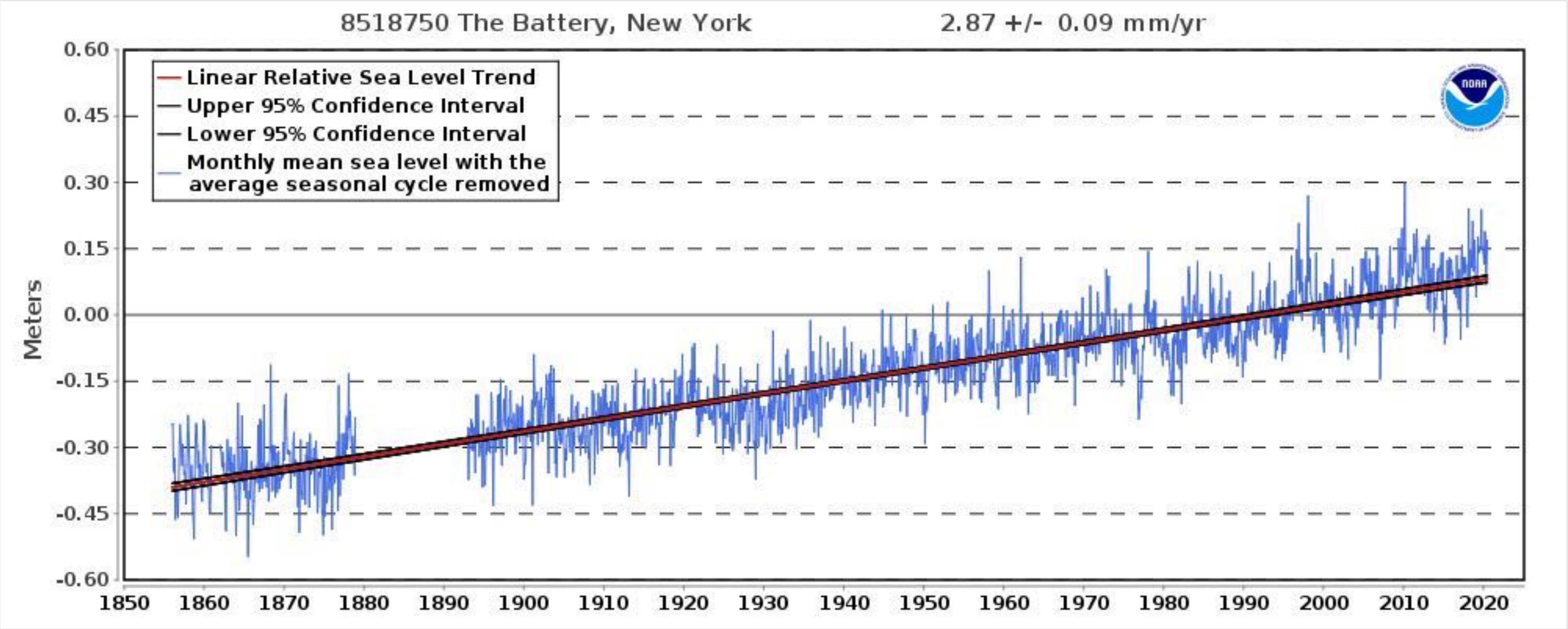
Long Island City subway station, Queens

And if that wasn't enough …

10 cm sea level rise since that ‘92 storm!



164 year tidal record for NY City



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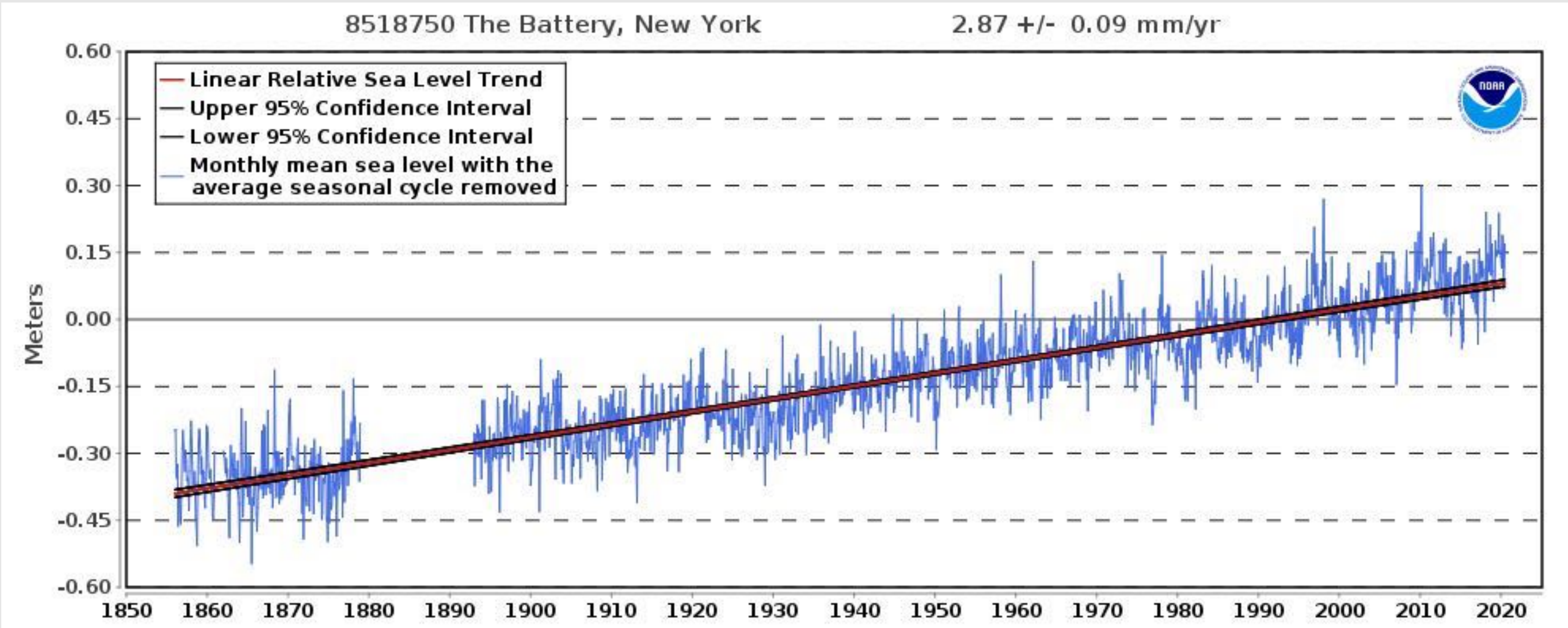
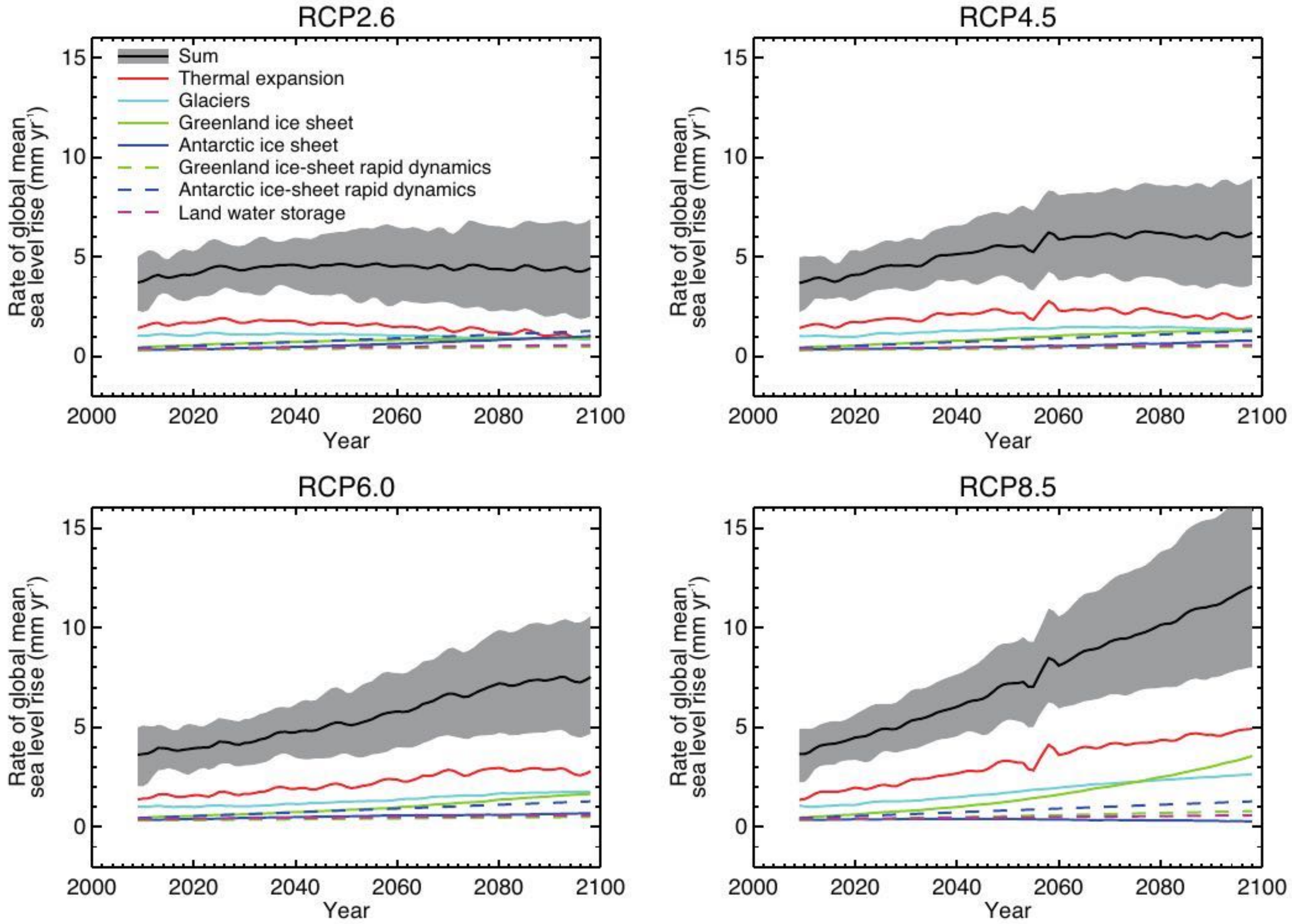


Dunedin 1.4 mm/year trend over last 120 years, but tectonics can move it meters locally

IPCC Fifth Assessment Report (2013)
Chapter 13: Sea Level (rate of) Change



IPCC Fifth Assessment Report (2013)
Chapter 13: Sea Level Change

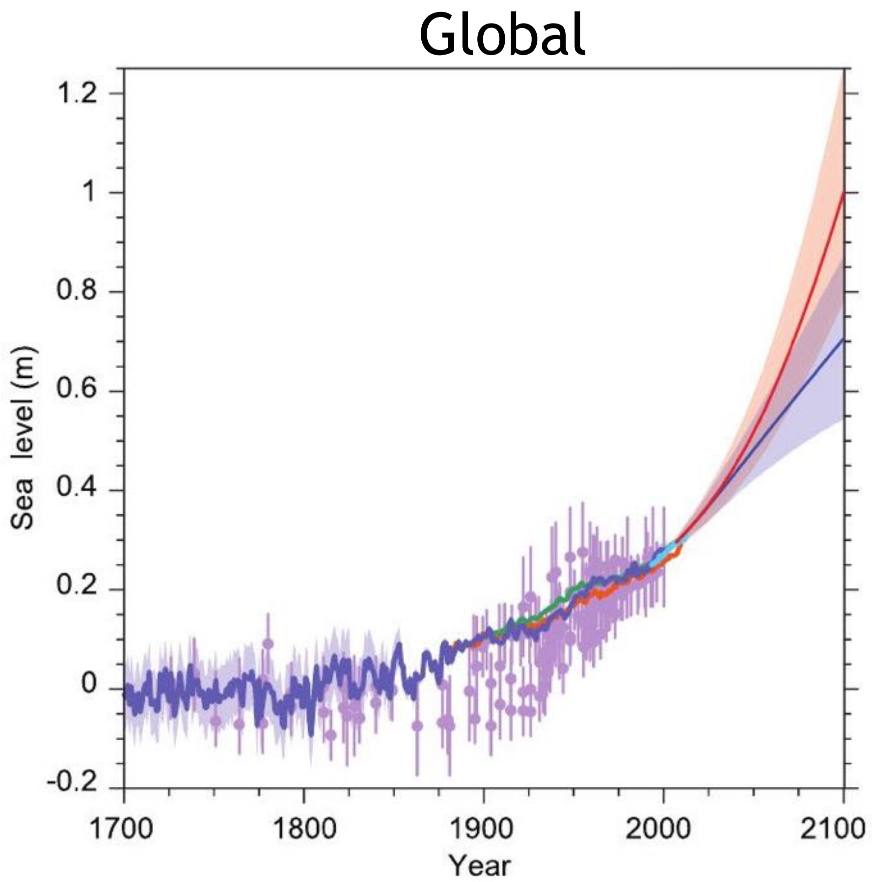
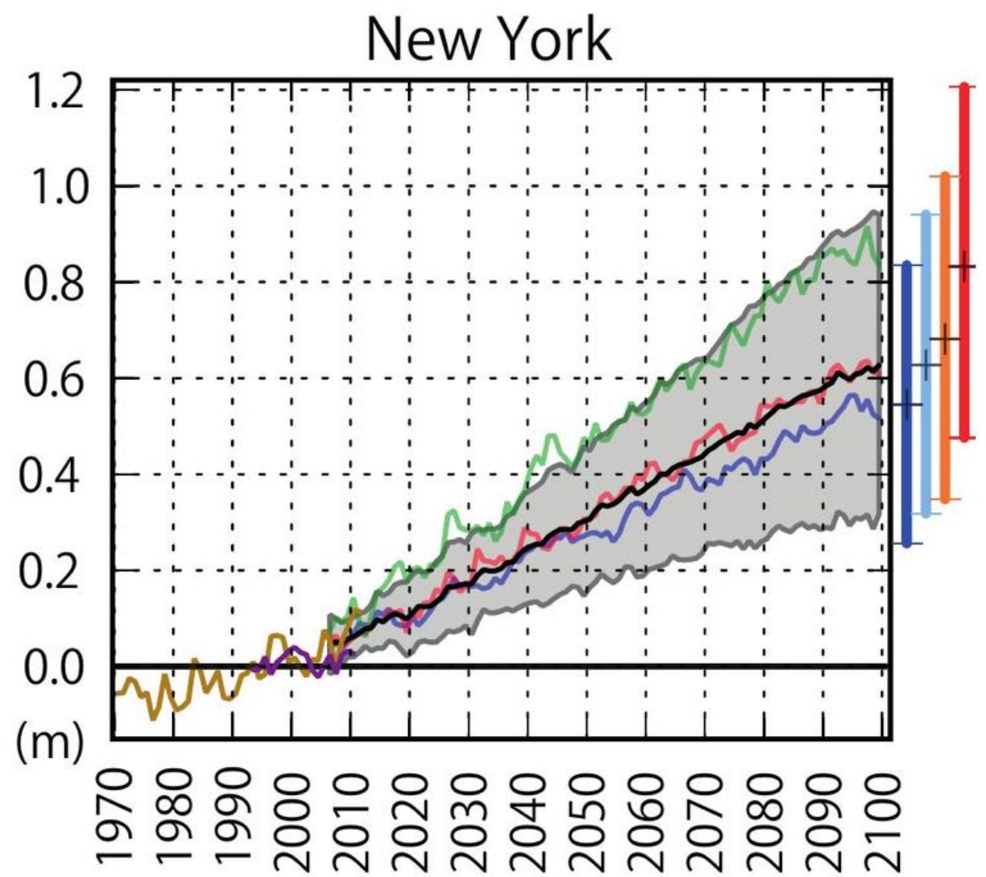


Figure 13.27 | Compilation of paleo sea level data, tide gauge data, altimeter data (from Figure 13.3), and central estimates and *likely* ranges for projections of global mean sea level rise for RCP2.6 (blue) and RCP8.5 (red) scenarios (Section 13.5.1), all relative to pre-industrial values.



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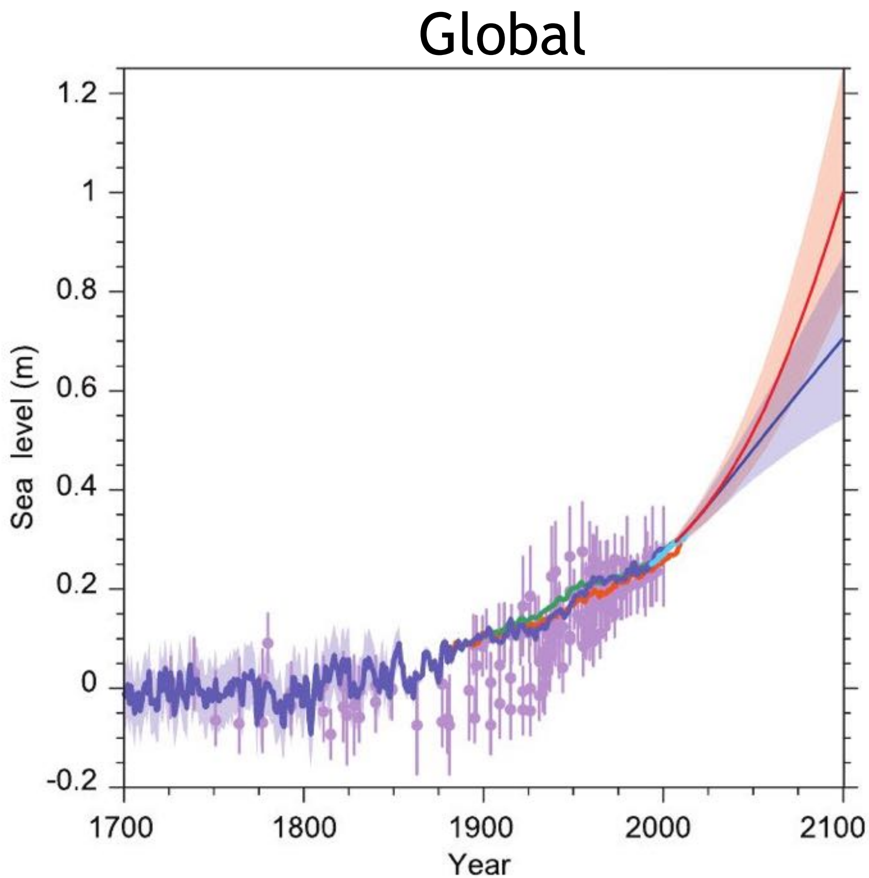
Chapter 13: Sea Level Change



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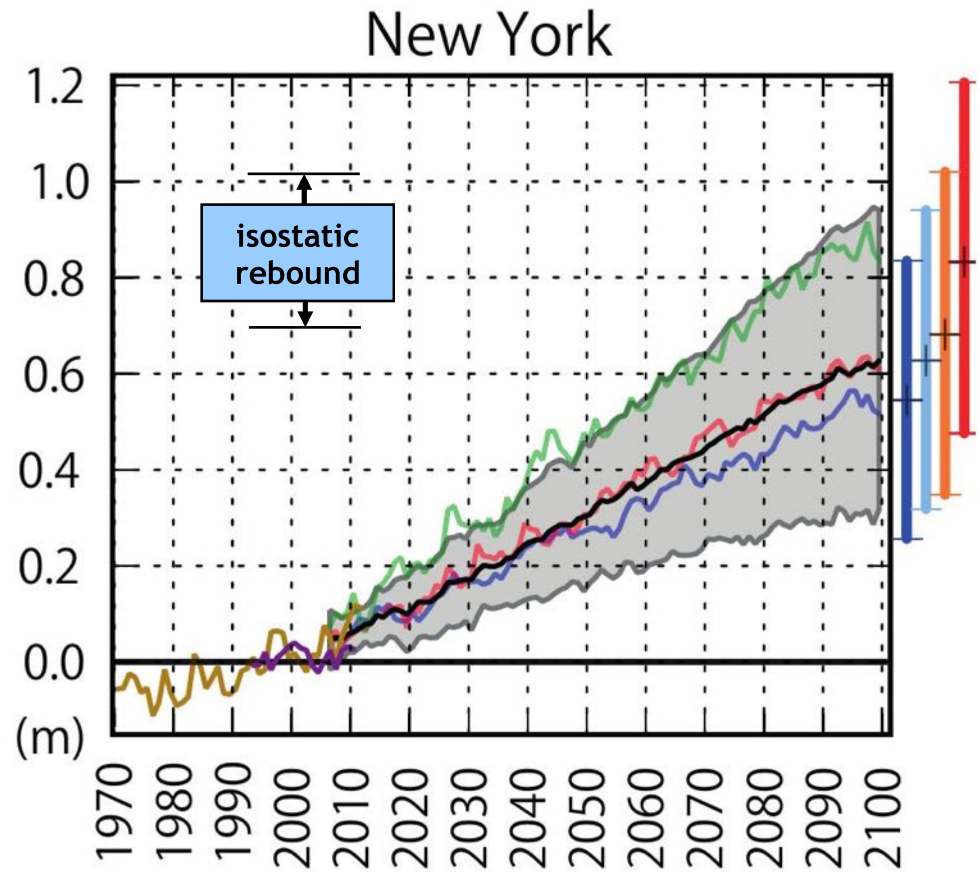
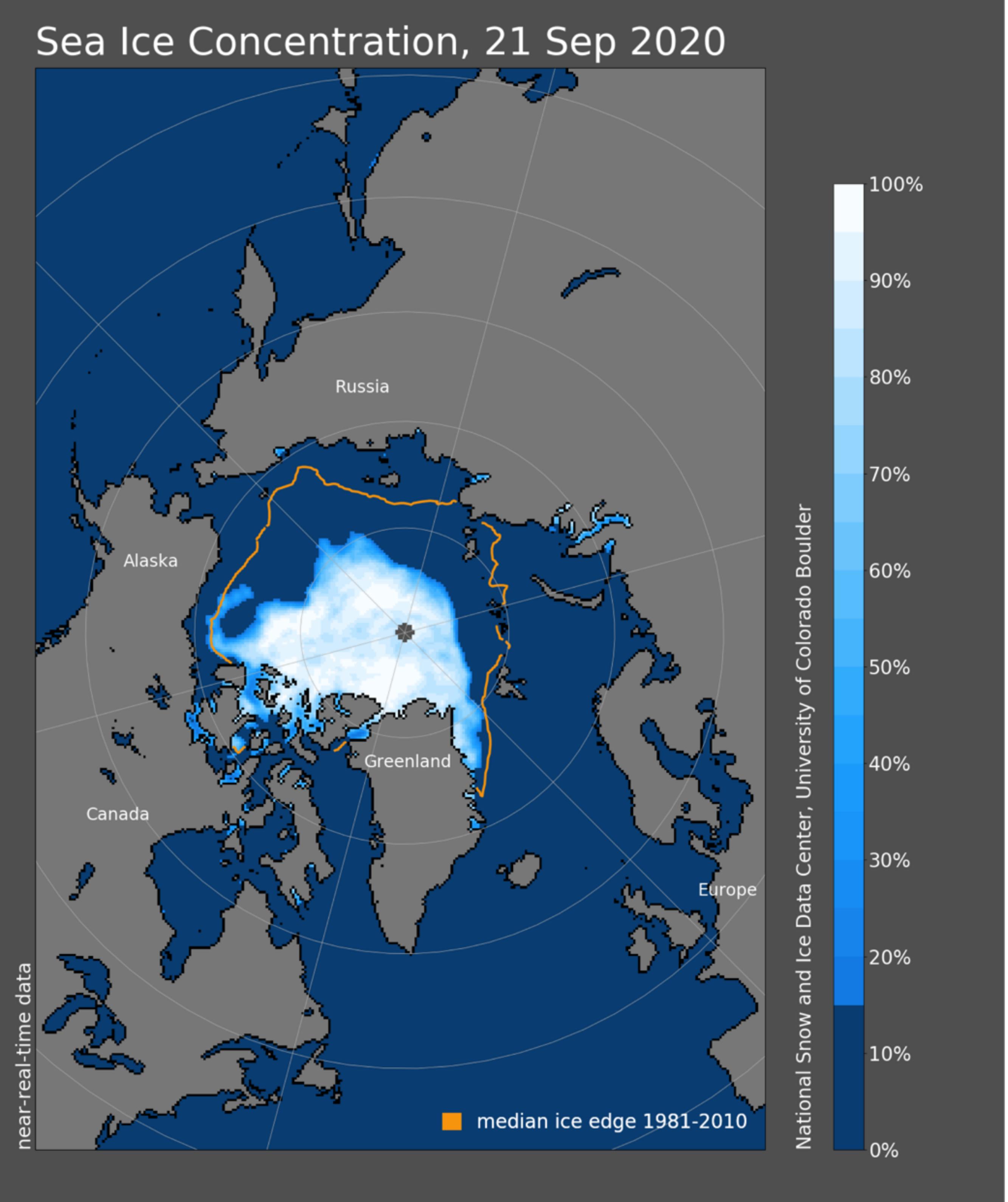
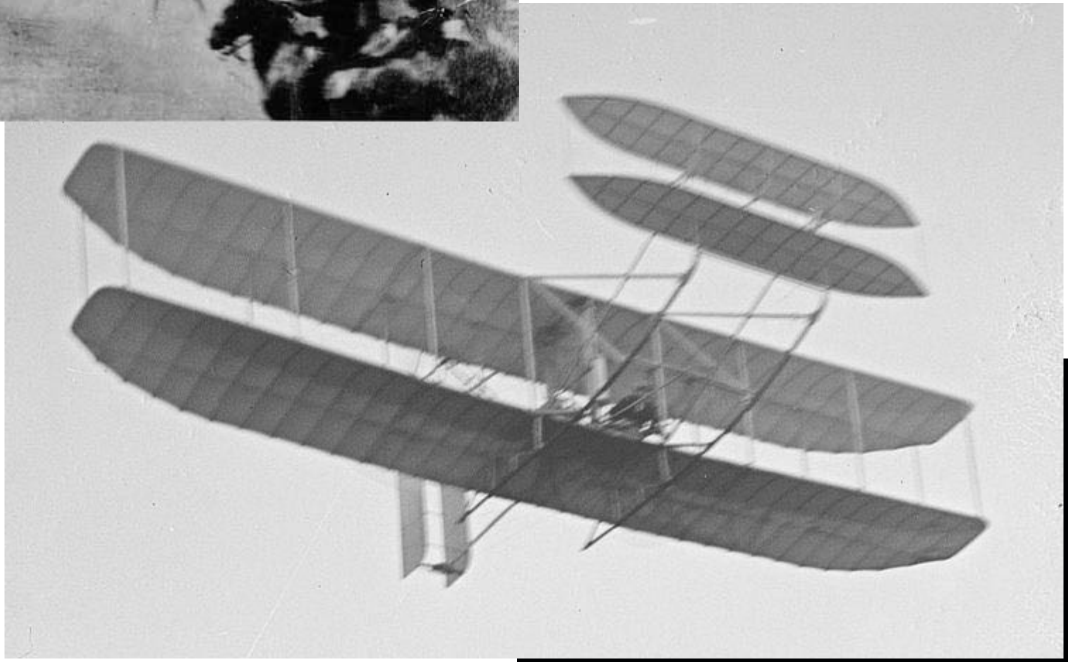


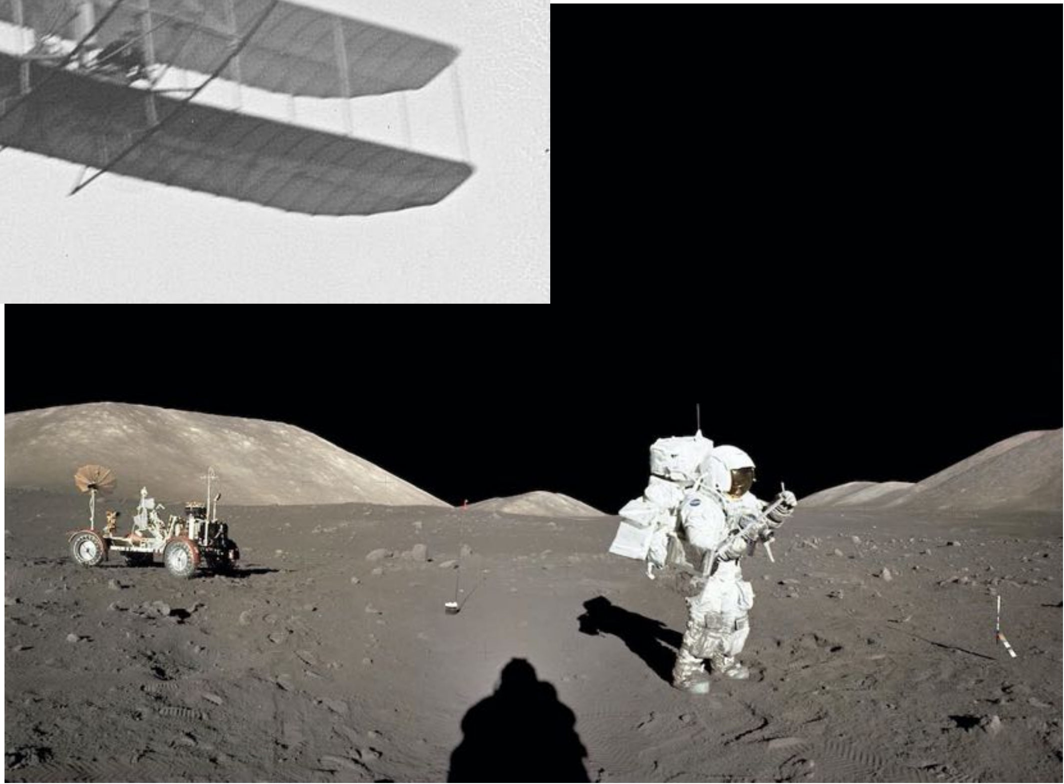


RCP8.5 it is then ...


HERE
COMES THE
SUN

Much progress can be made in 80 years



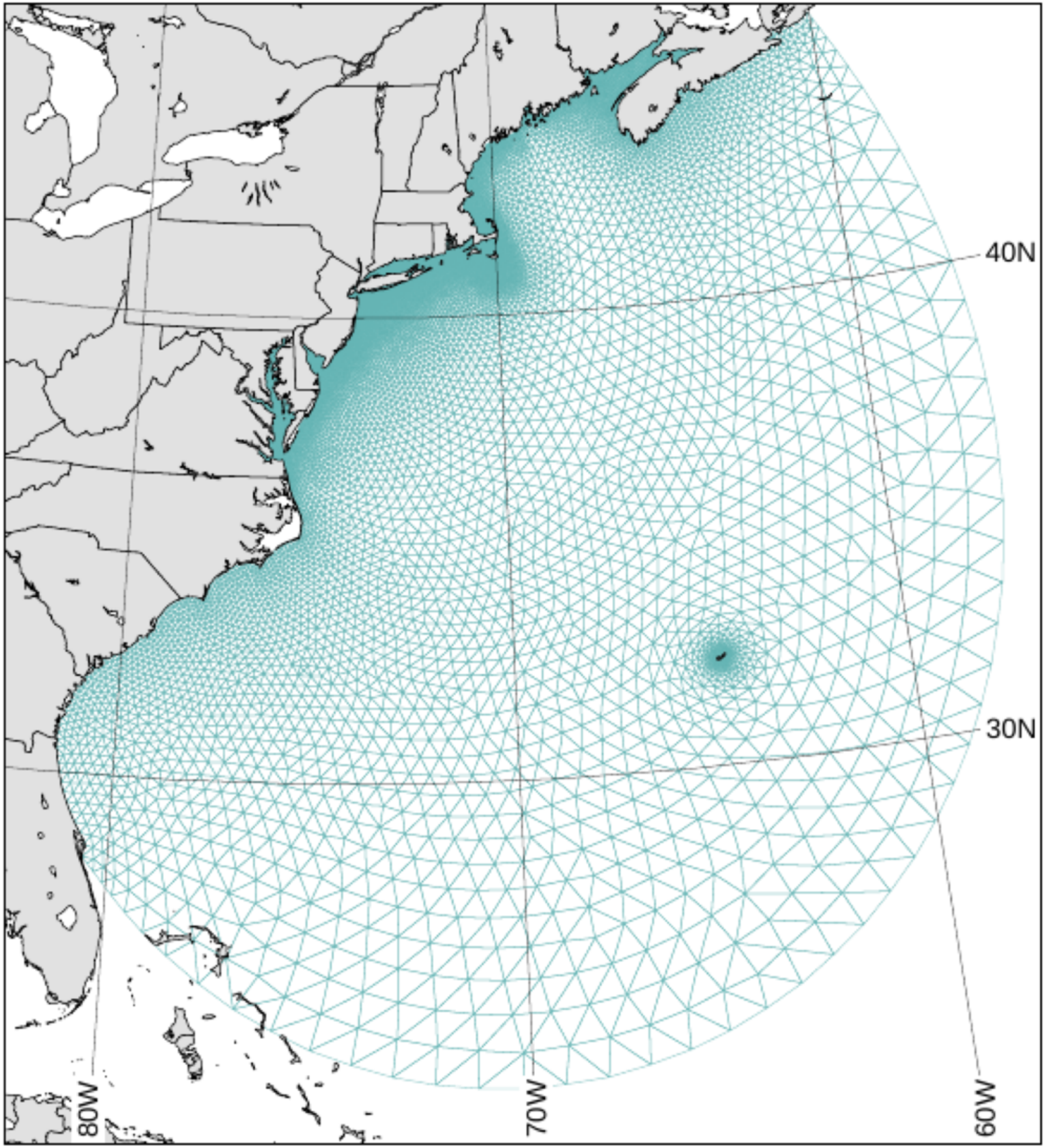


ADCIRC

ADvanced CIRCulation Model

"ADCIRC is a highly developed computer program for solving the equations of motion for a moving fluid on a rotating earth. These equations have been formulated using the traditional hydrostatic pressure and Boussinesq approximations and have been discretized in space using the finite element (FE) method and in time using the finite difference (FD) method."

- Free surface fluid dynamics + tidal harmonics
- 2D, depth-integrated (experimental 3D)
- Written in FORTRAN, coupled with SWAN wave model
- Community developed, open but not FOSS
- Parallelized using MPI, >90% efficiency
- Commonly used as a civil engineering tool



ADCIRC Mesh Grid

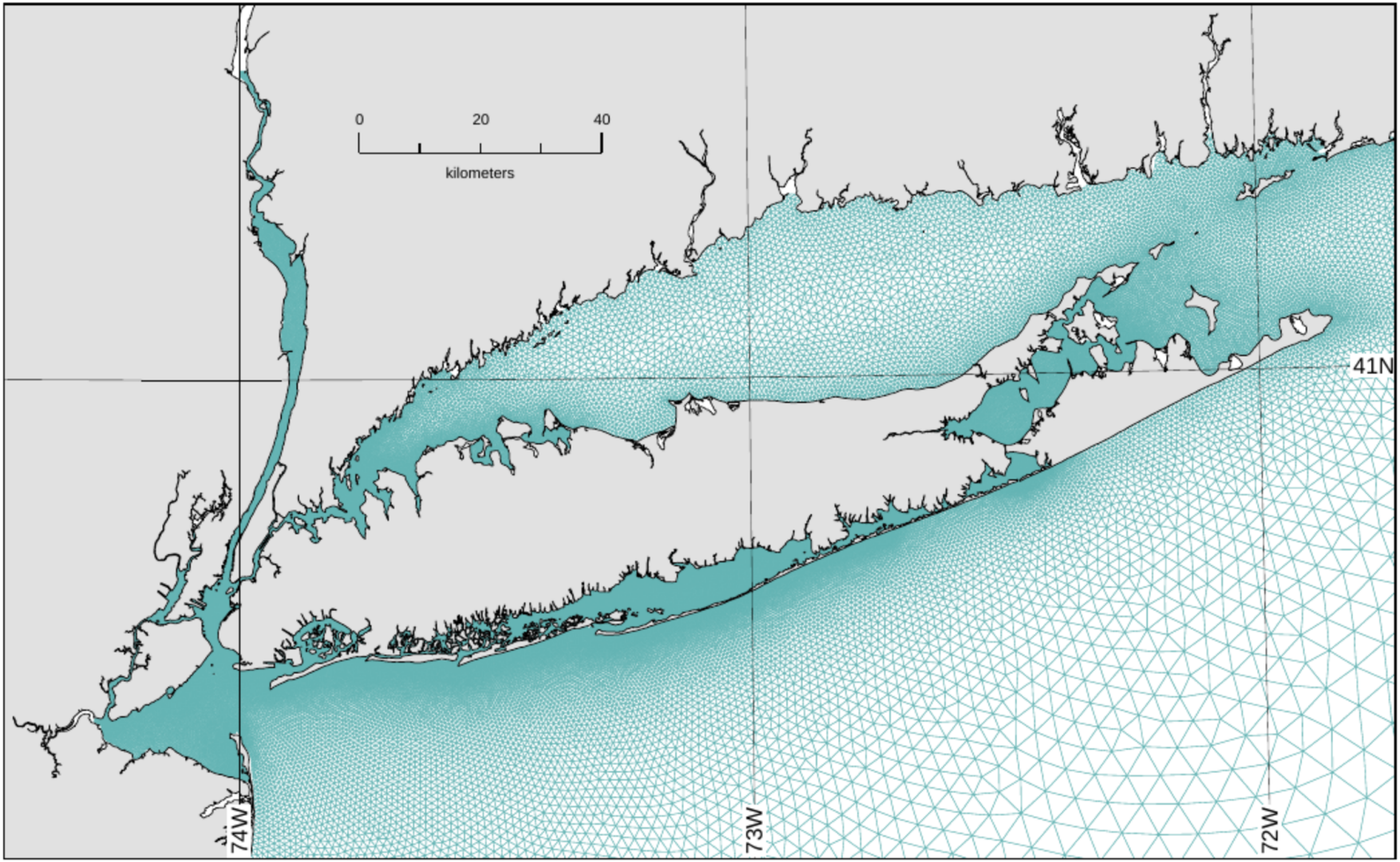
- Extended “Grid 3” mesh, Canada to Florida

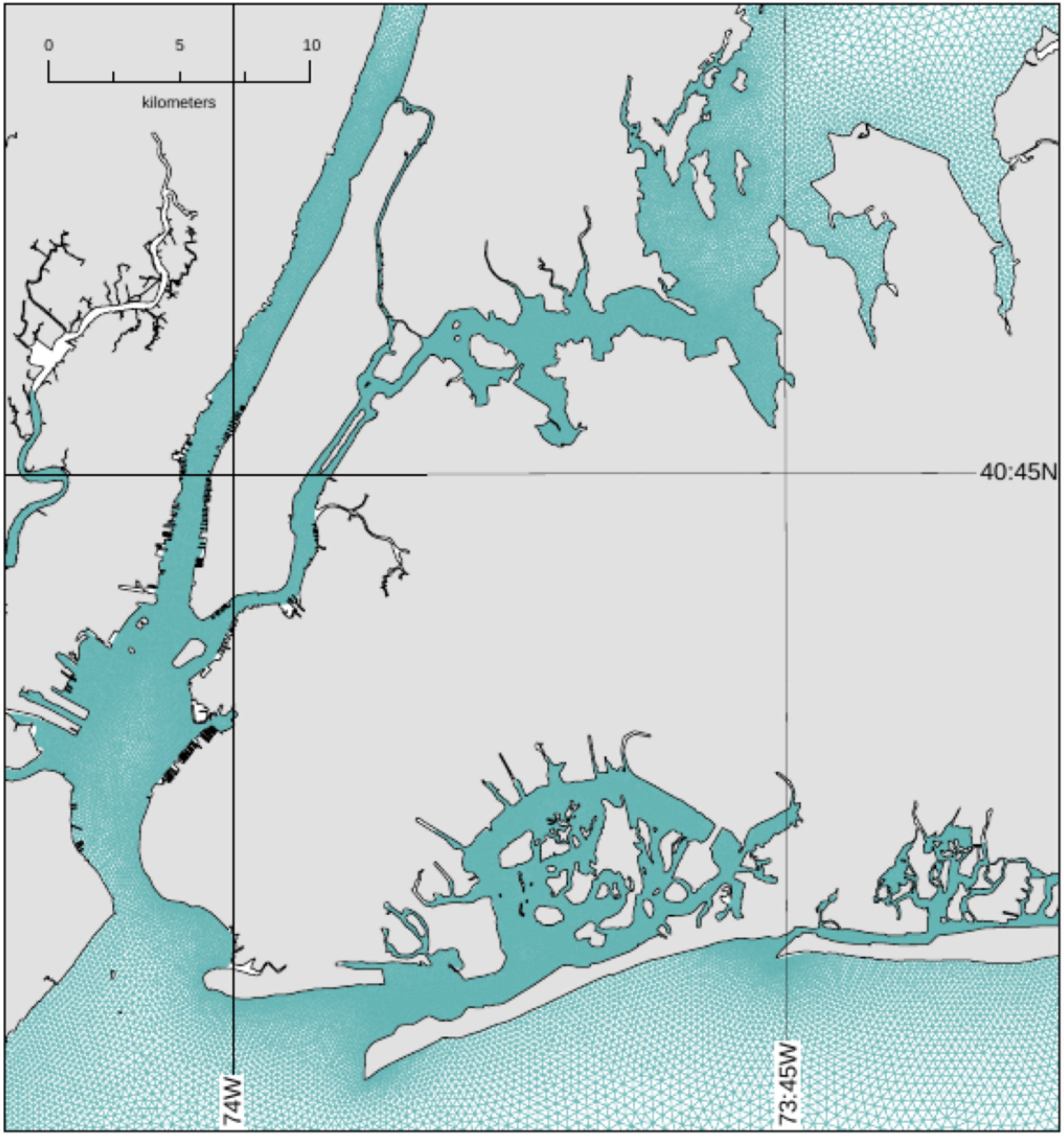
- Approx. 200k nodes for 128 MPI workers

- Triangles scale from 30m to 100km

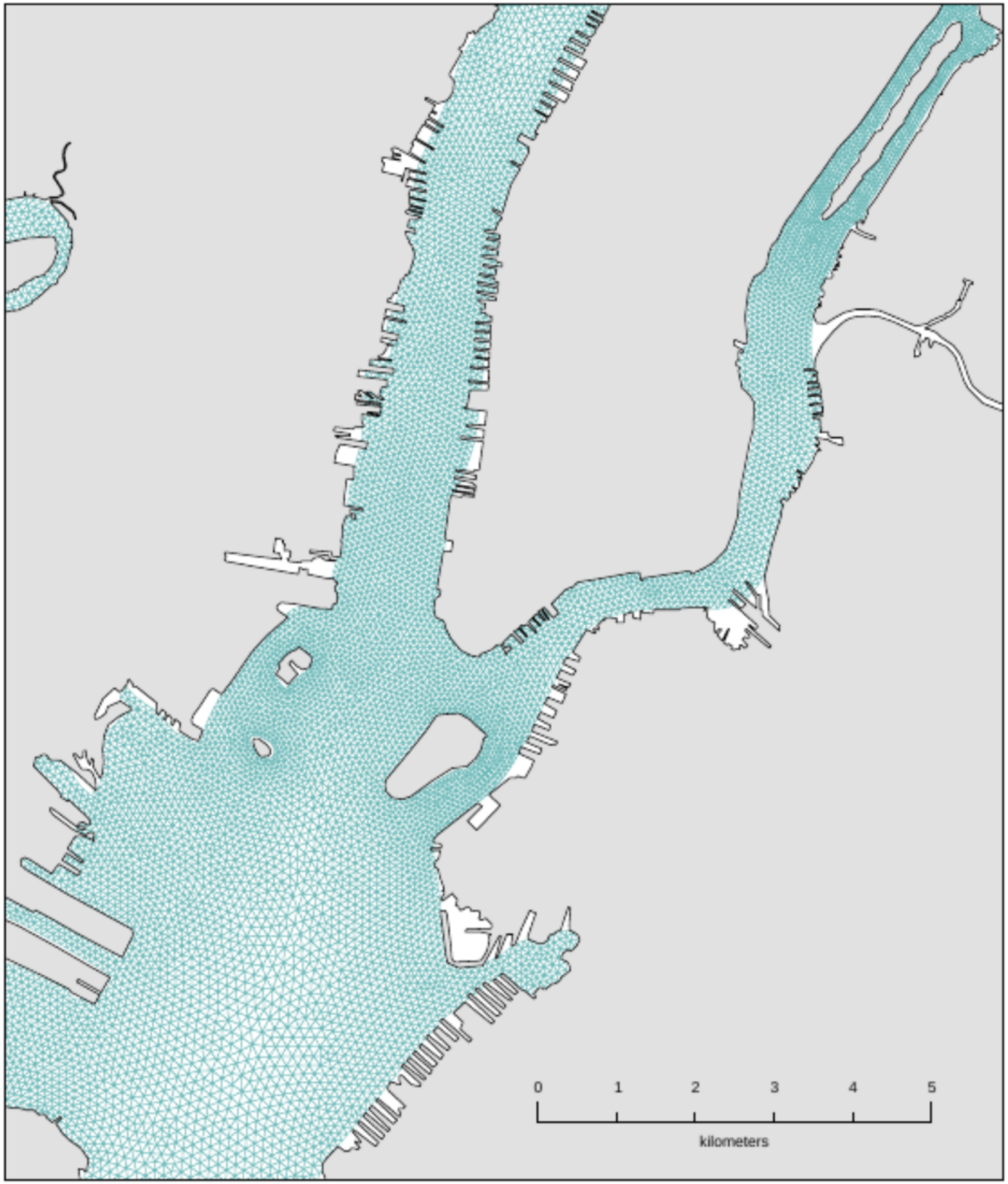
- Higher resolution in shallower waters, areas of high flow rate, and rapid topographic change

Long Island





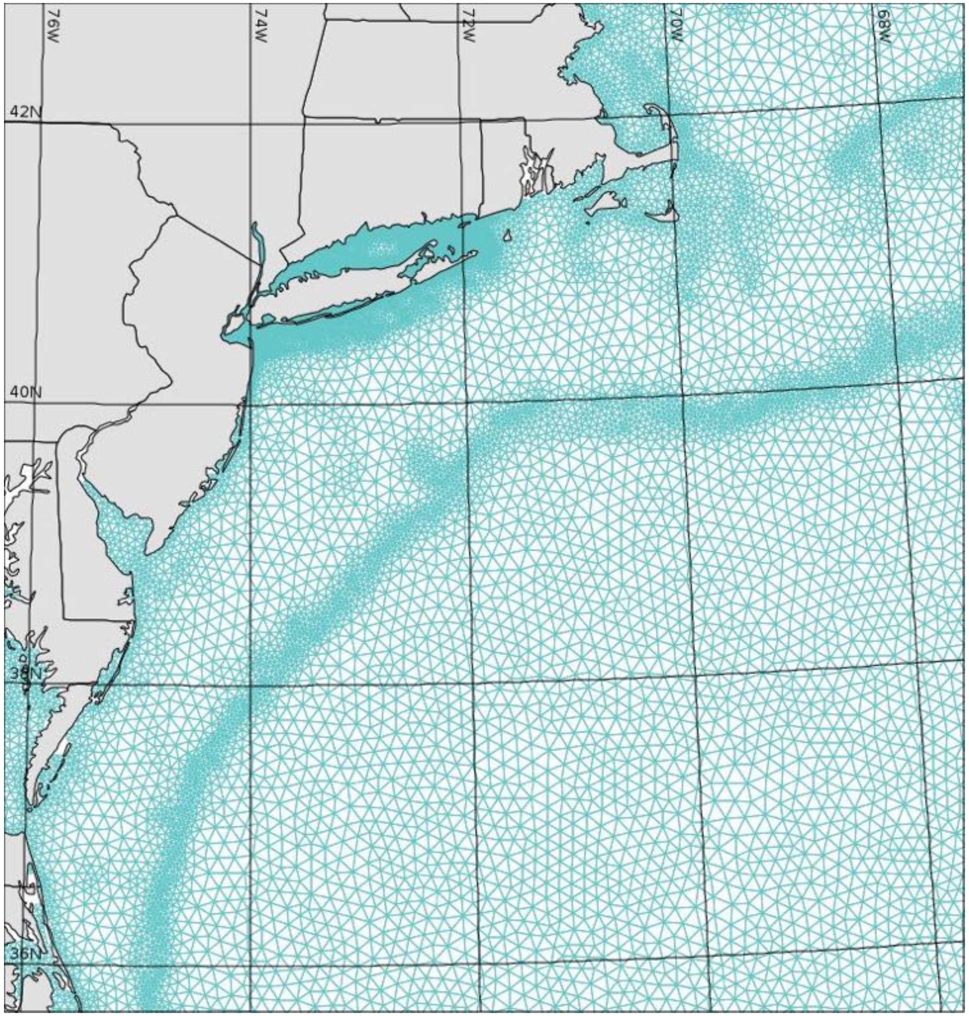
New York City

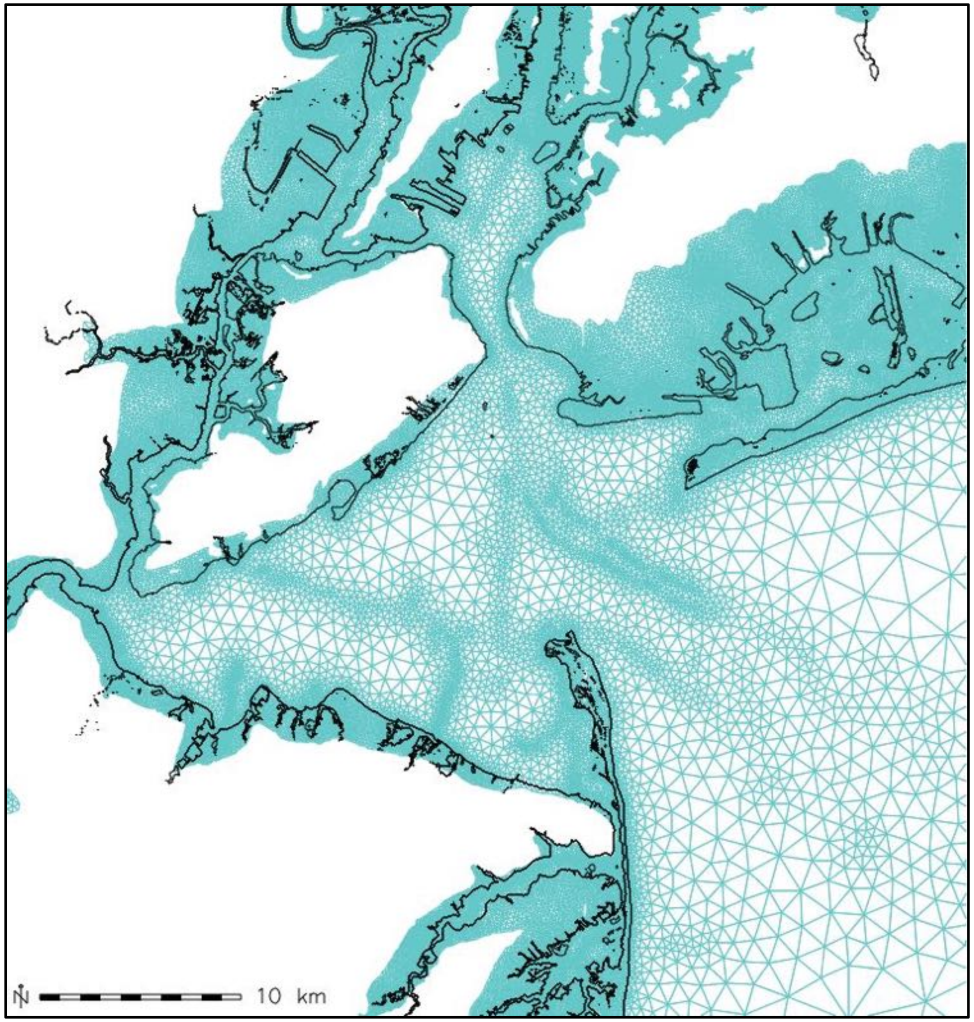


Lower Manhattan and Inner Harbor

OceanMesh2D

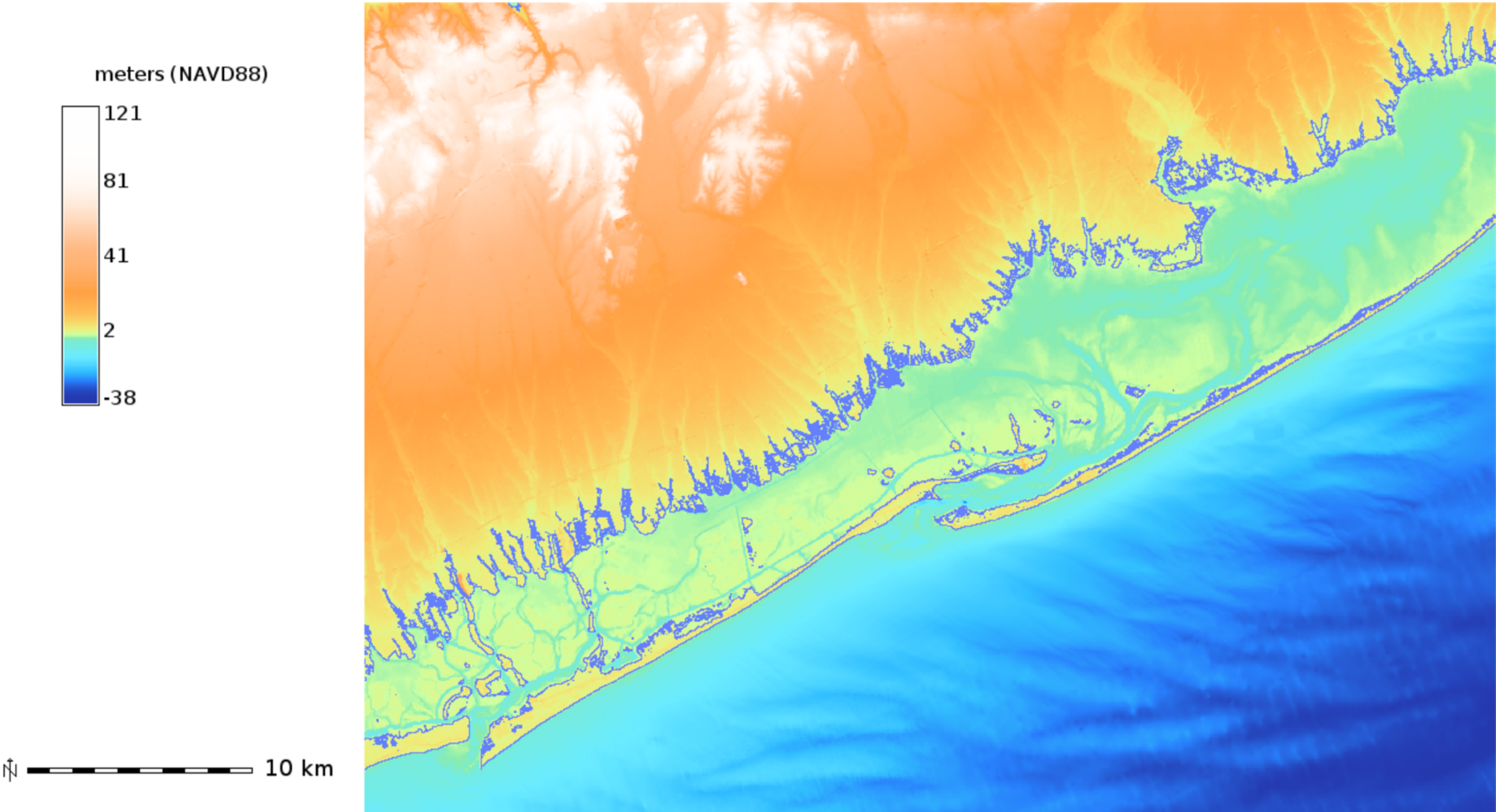
https://github.com/CHLNDDEV/OceanMesh2D



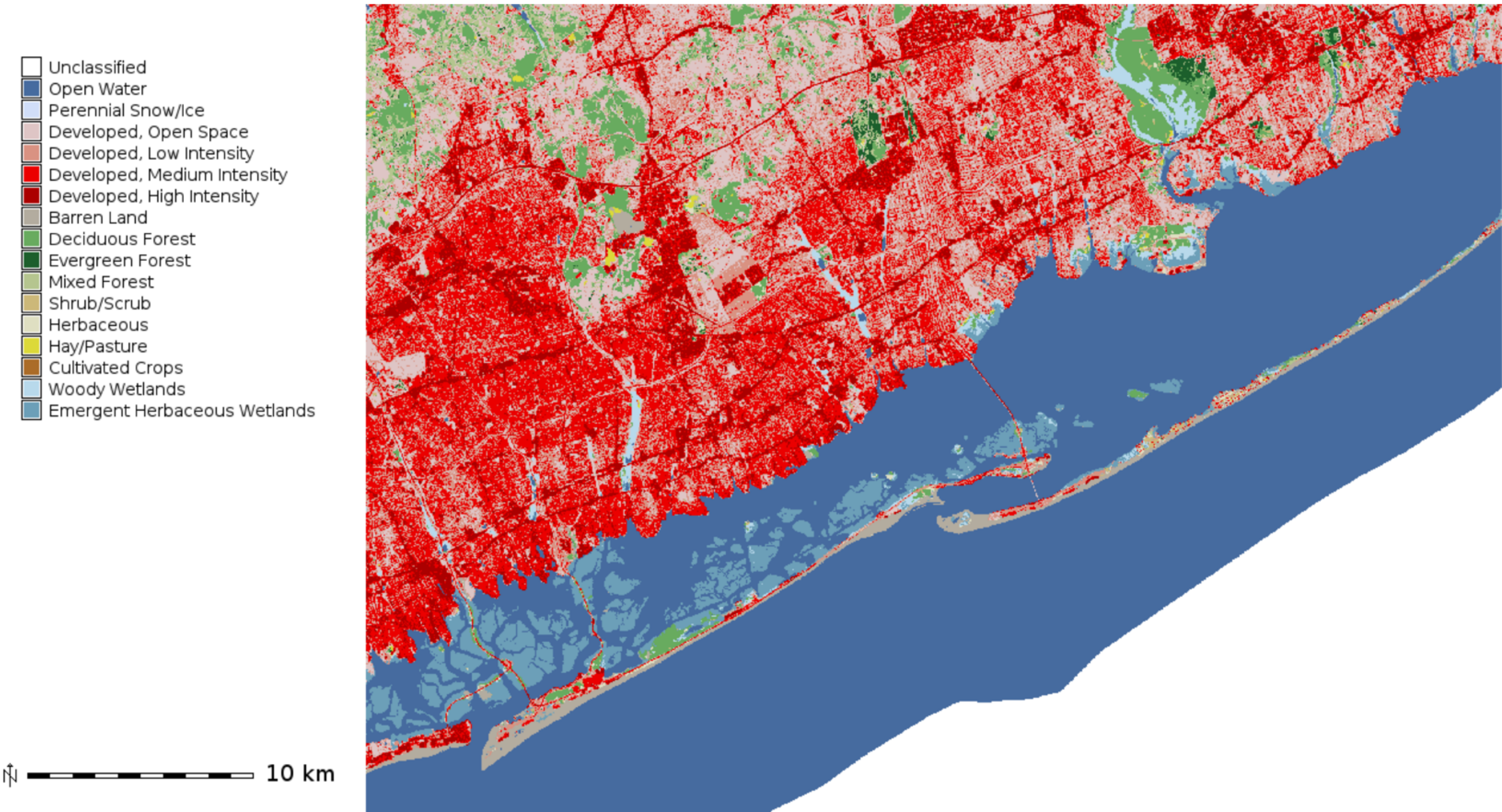


Adapts triangle size for CFL condition and gradient limits

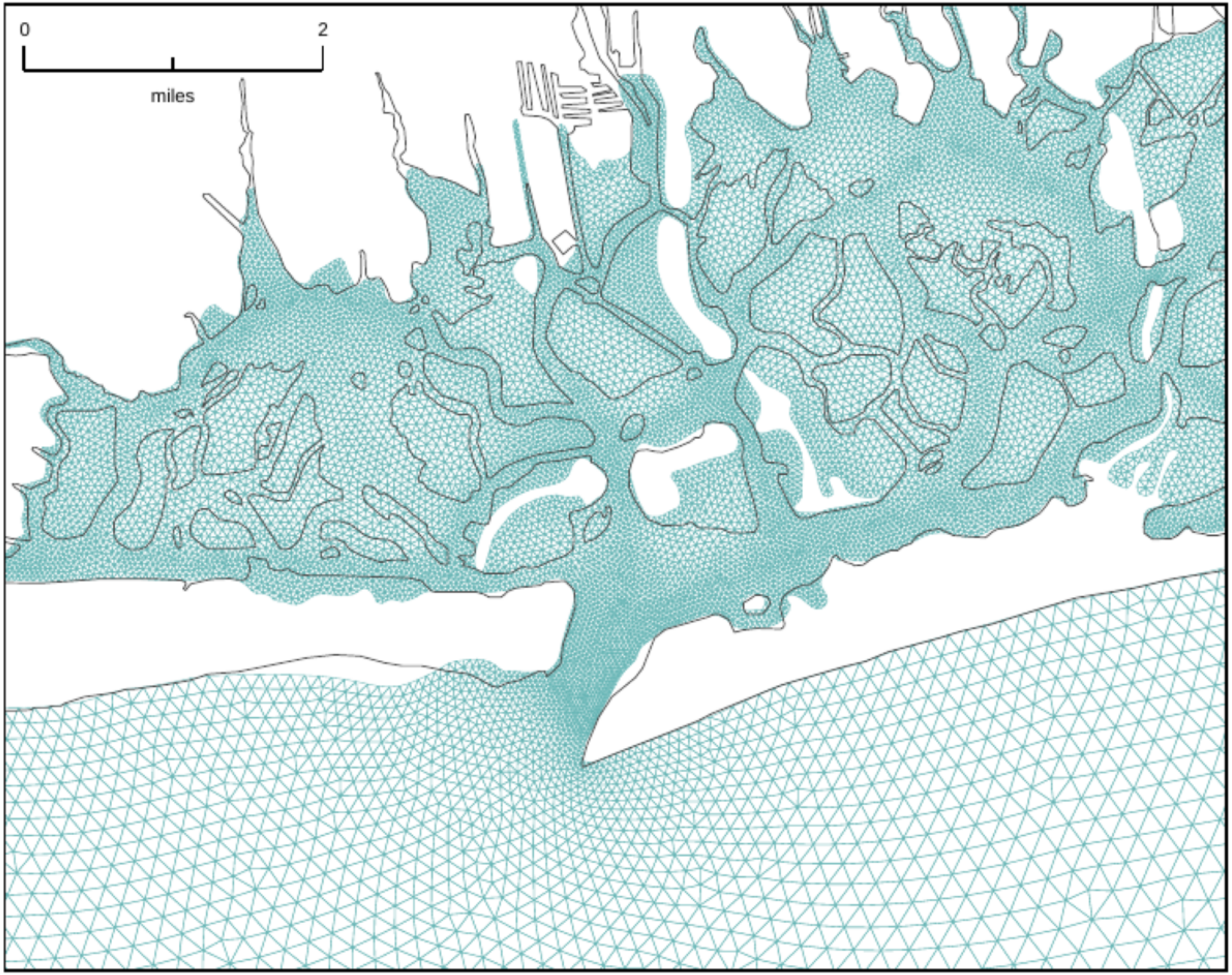
Elevation: Combined LiDAR and bathymetry DEM from FEMA and NOAA, with dredged channels (46,000 x 32,000 raster)



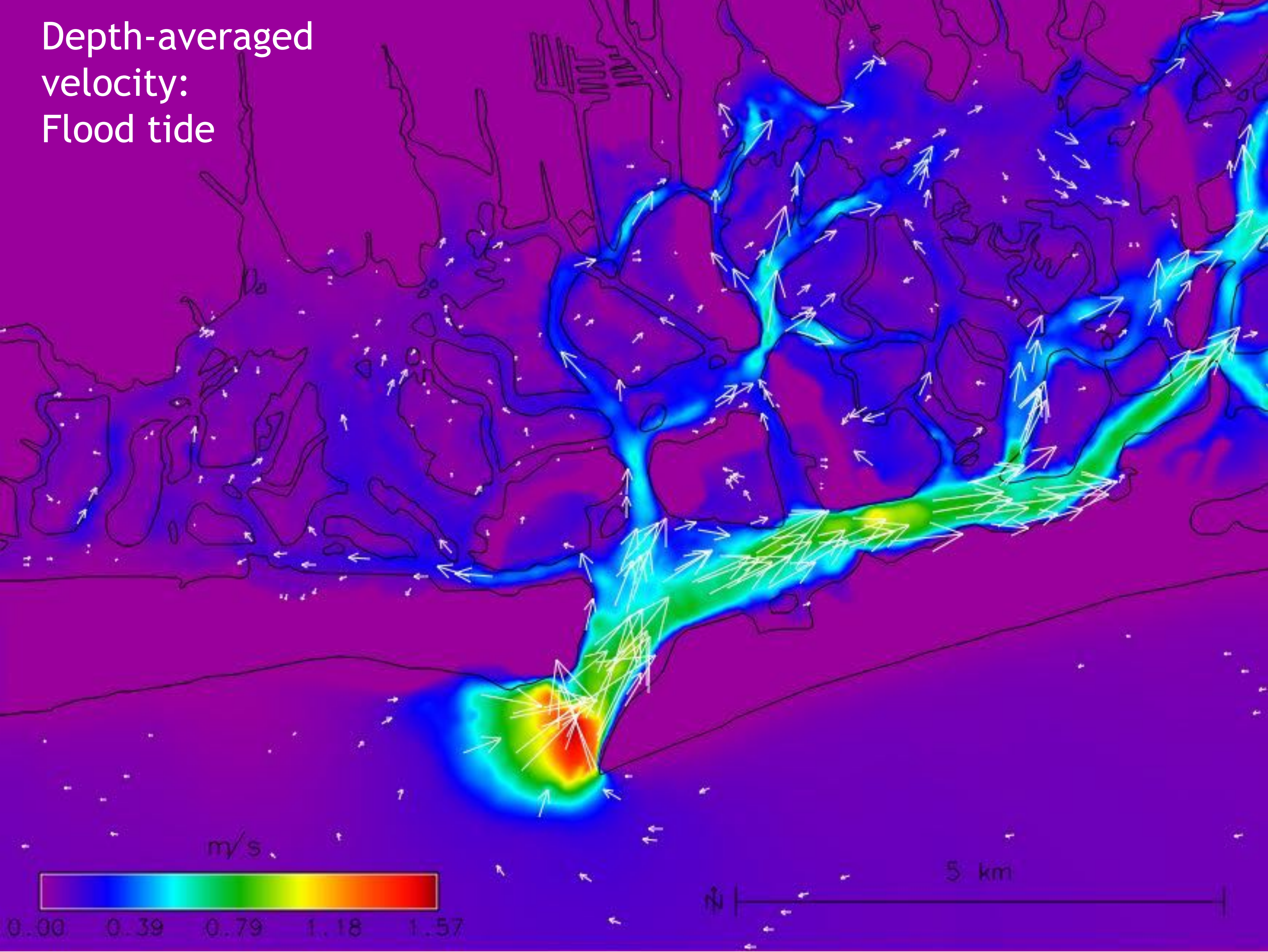
Bottom friction: Manning's *n* value taken from 30m USGS land cover database (85,000 x 96,000 raster)



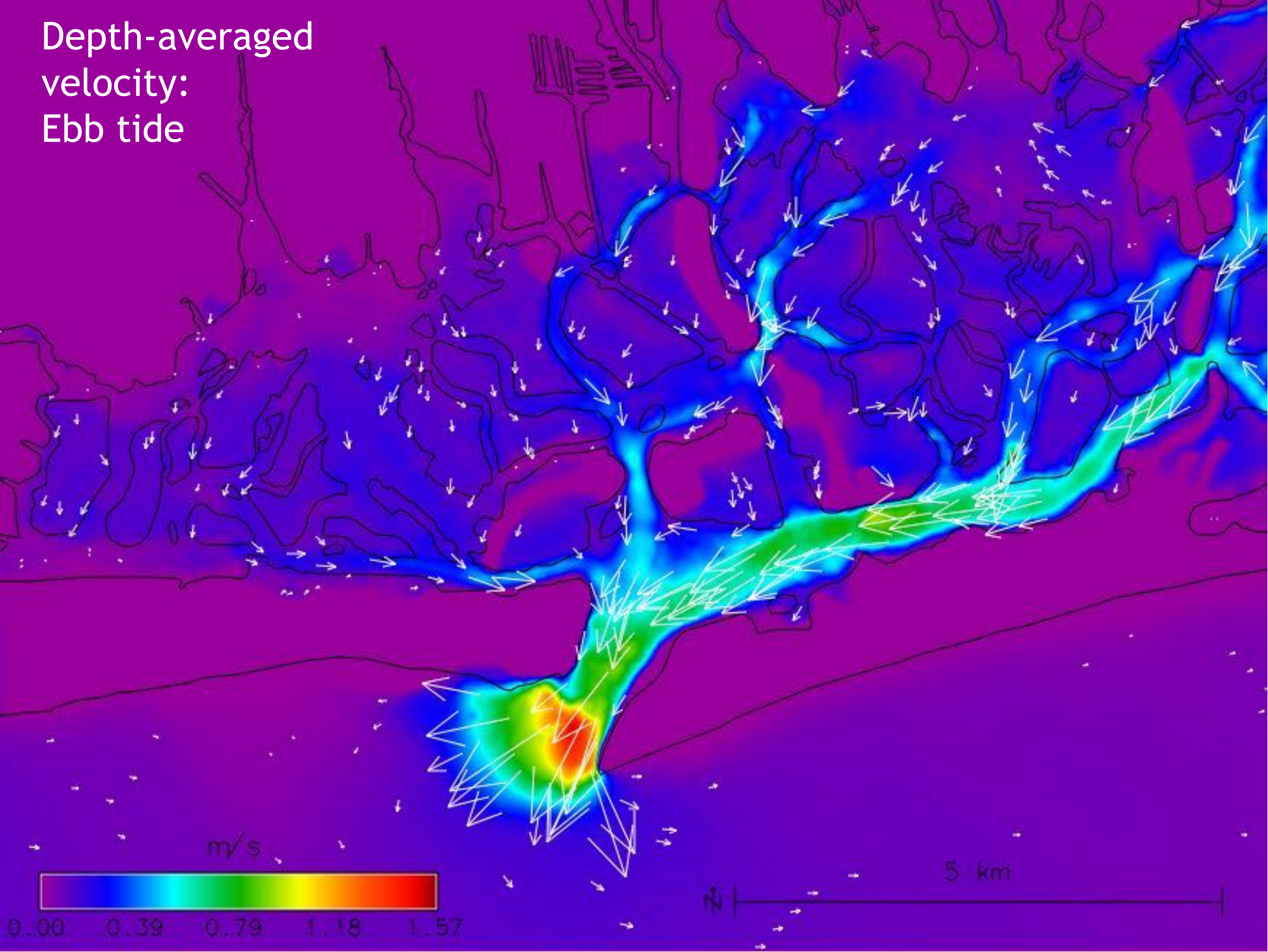
Jones Inlet



Depth-averaged velocity: Flood tide



Depth-averaged velocity: Ebb tide



Daily Model Runs

ADCIRC base line:
- Tides-only (no winds)

Met. Model Ensemble:
- NOAA WRF Hires (x2)
- NOAA WRF RAP & HRRR
- NOAA WRF NMMB NEST
- NOAA WRF NAM long range
- Stony Brook WRF (GFS & NAM)

Daily Model Runs

(What happens when you put too much load on the back-end)

ADCIRC base line:

- Tides-only (no winds)

Met. Model Ensemble:

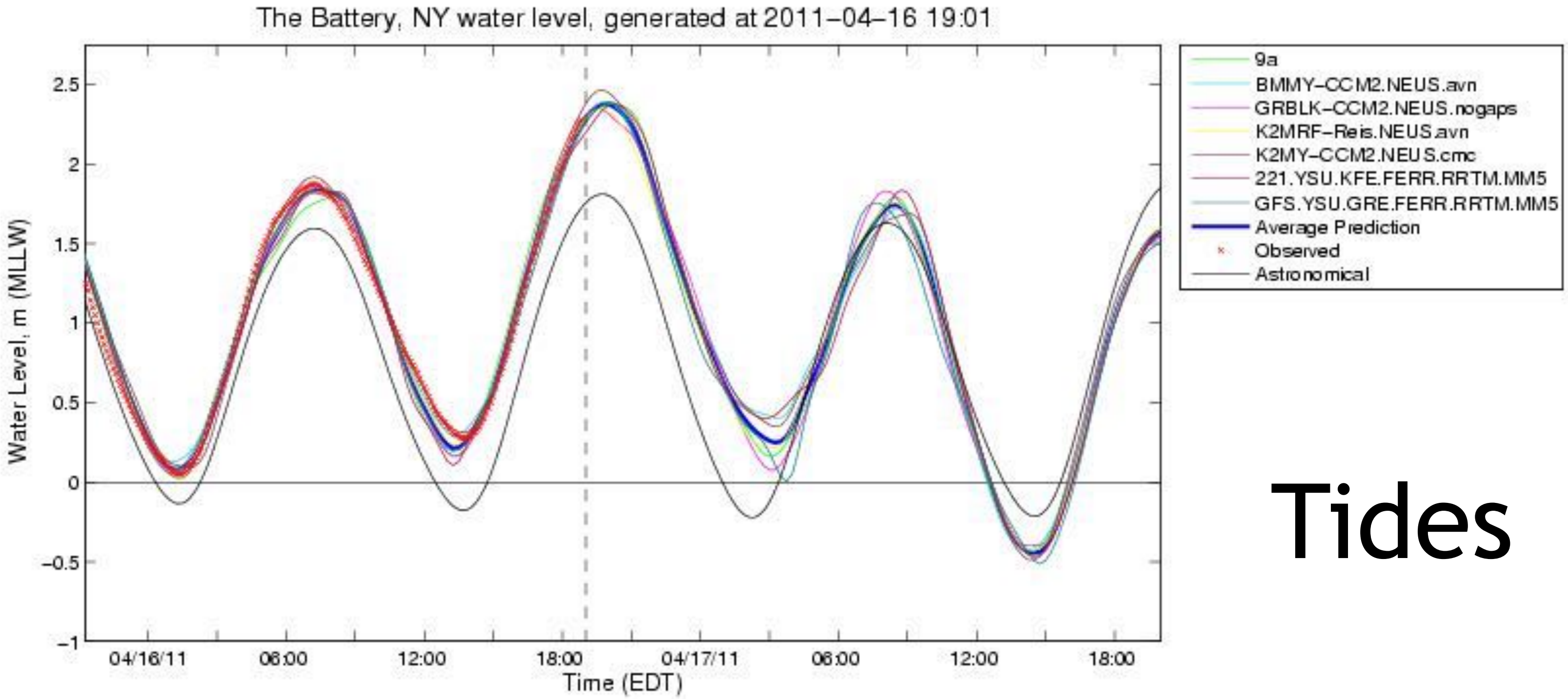
- NOAA WRF Hires (x2)
- NOAA WRF RAP & HRRR
- NOAA WRF NMMB NEST
- NOAA WRF NAM long range
- Stony Brook WRF (GFS & NAM)

Implications of time-sensitive results

- Must process faster than real time
- Must deliver results before next forecast is published
- Requires dedicated cluster nodes to avoid sitting in queue
- Must use stable numerics
- Must cope with missing or corrupted hot-starts
- Must preserve results for archival but not use too much disk space
- Challenge of real-time data assimilation from (noisy) observations

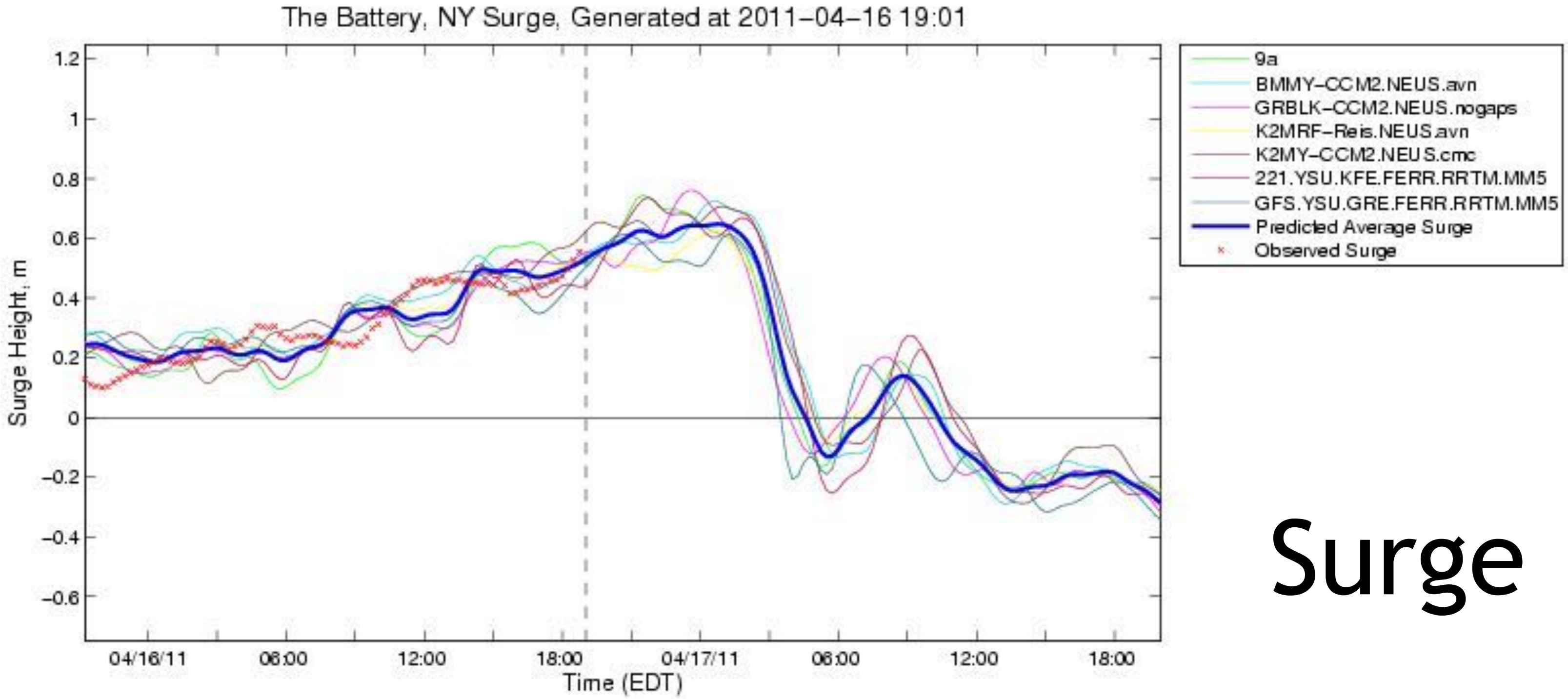
With the luxury of hindcast

- Not sensitive to job completion-time
- Can run on shared super computer cluster queue
- Can use a finer model timestep and mesh resolution
- Can save excessively detailed output files
- Can enable computationally expensive physics, e.g. waves
- Can experiment with synthetic "super storm" variations
- Can experiment with different landfall-time scenarios
- Can experiment with altered coastlines (new channels, Δ sea level)
- Can experiment with different physics and drag coefficients to chase observed real-world answer; sensitivity analysis



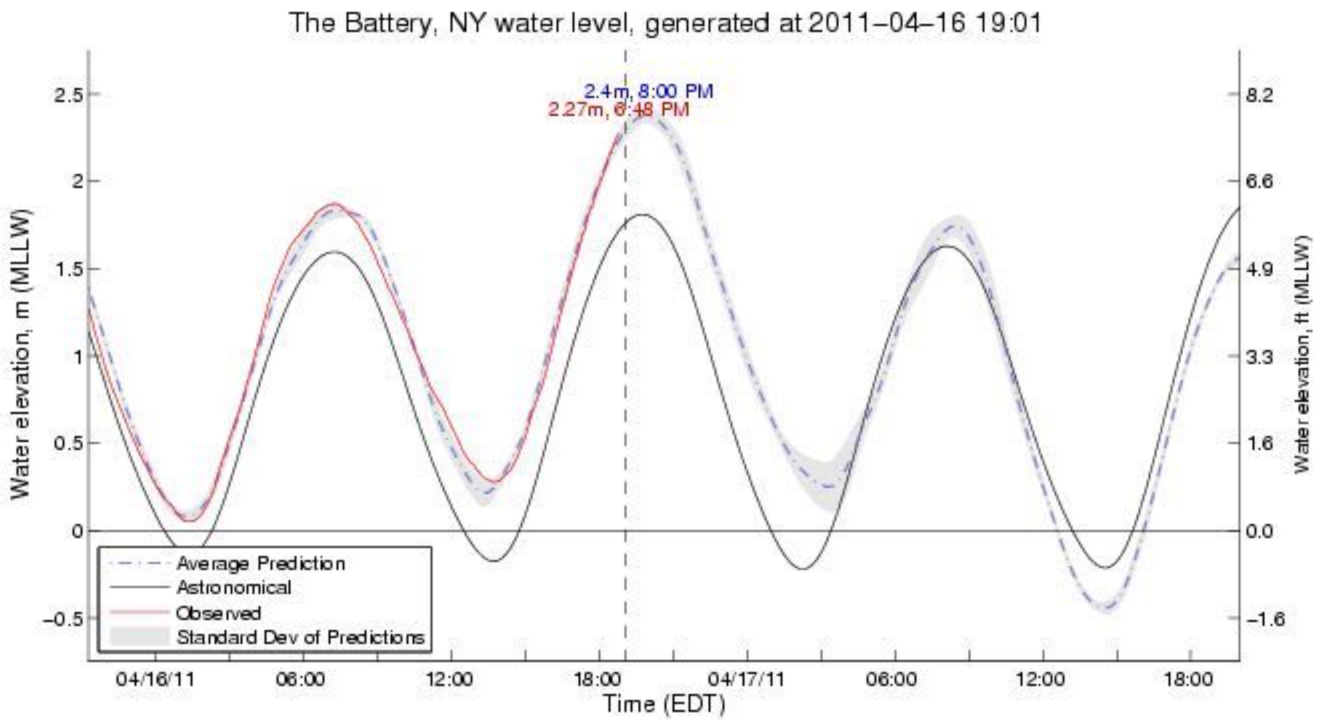
16 April 2011

Tides



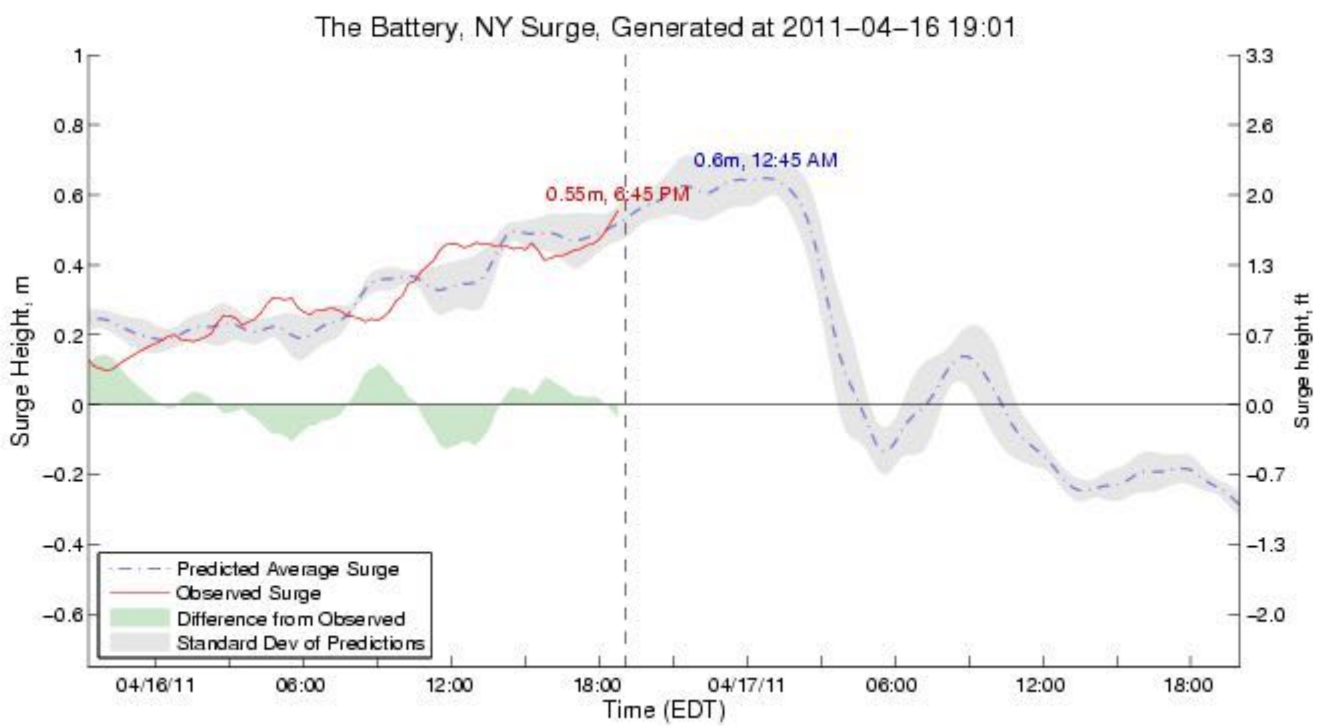
Surge

16 April 2011



Tides

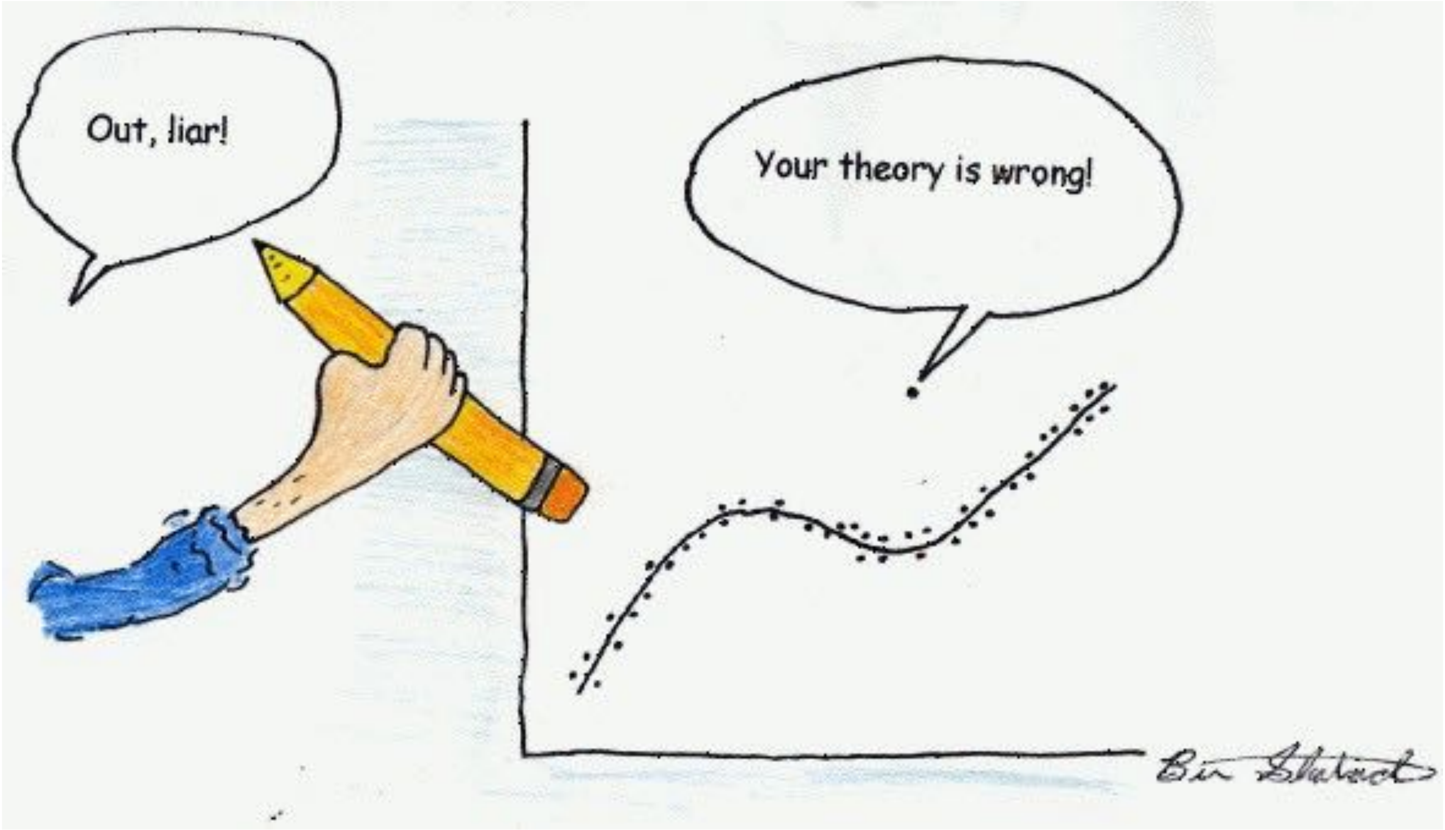
(The water level)



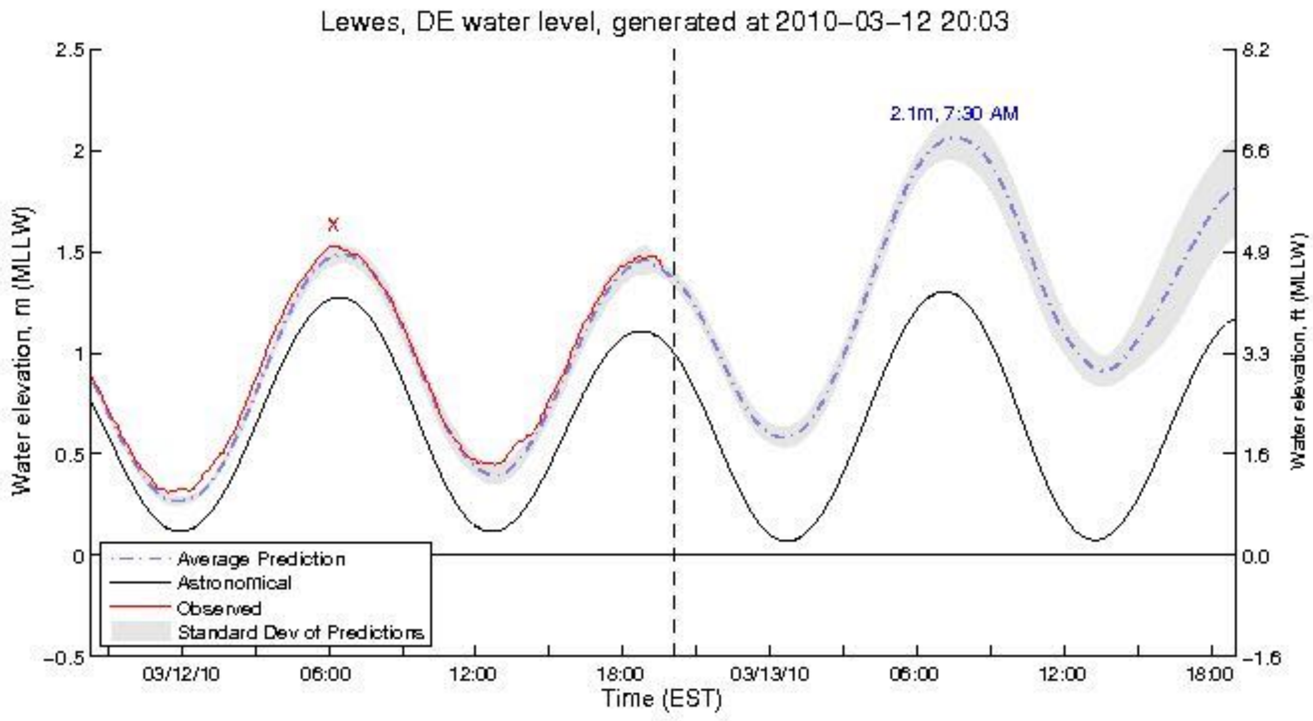
Surge

(The residual)

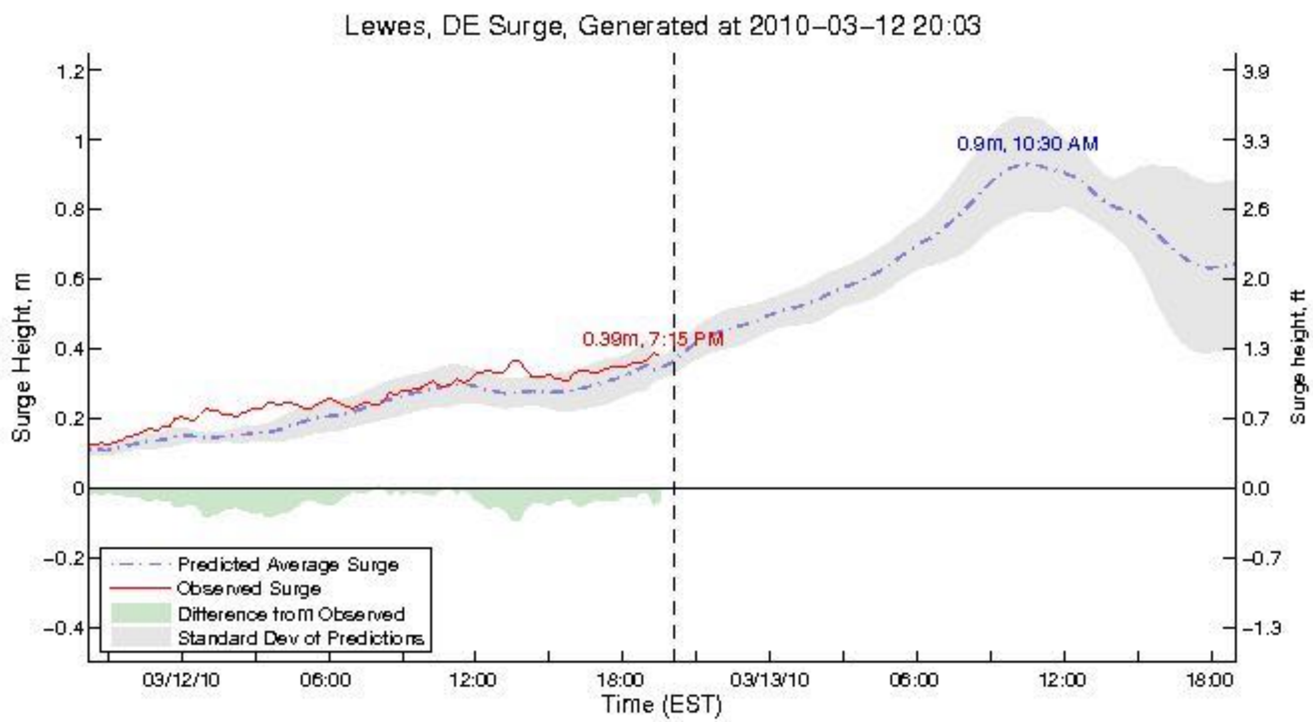
The task: Building a model that successfully predicts outlier events



13 March 2010

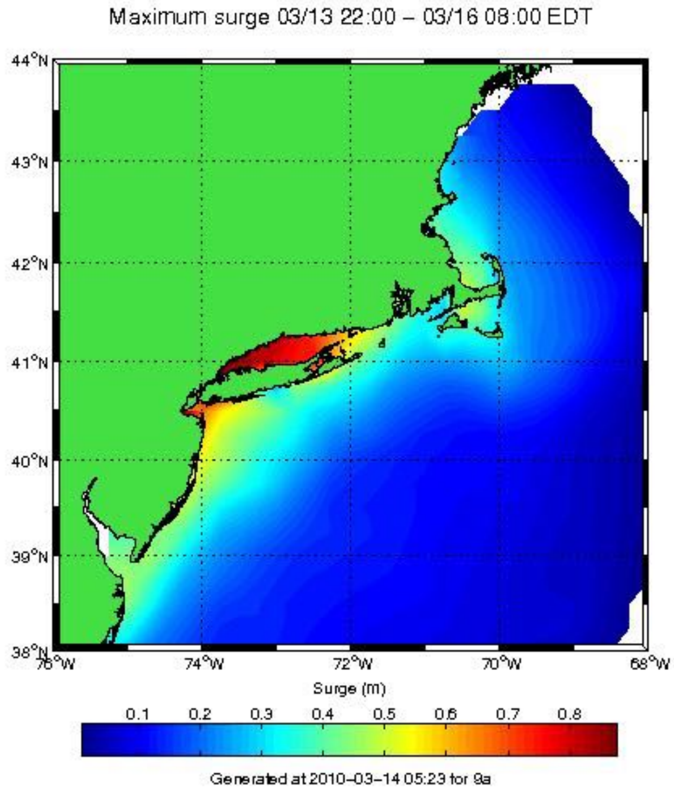


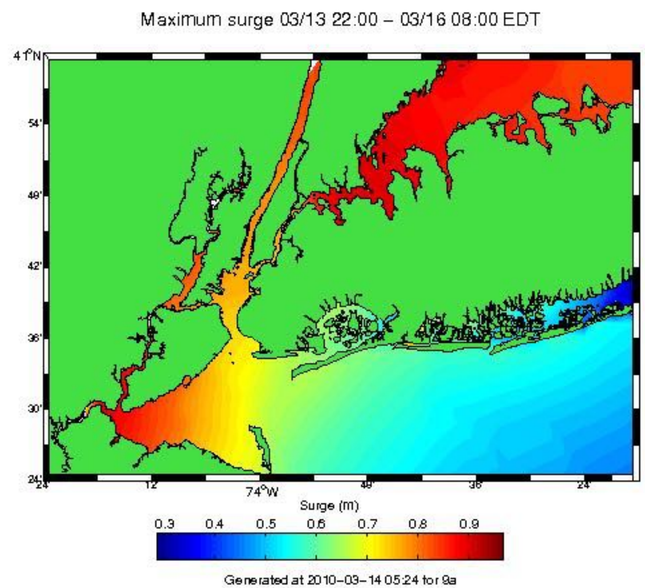
Tides

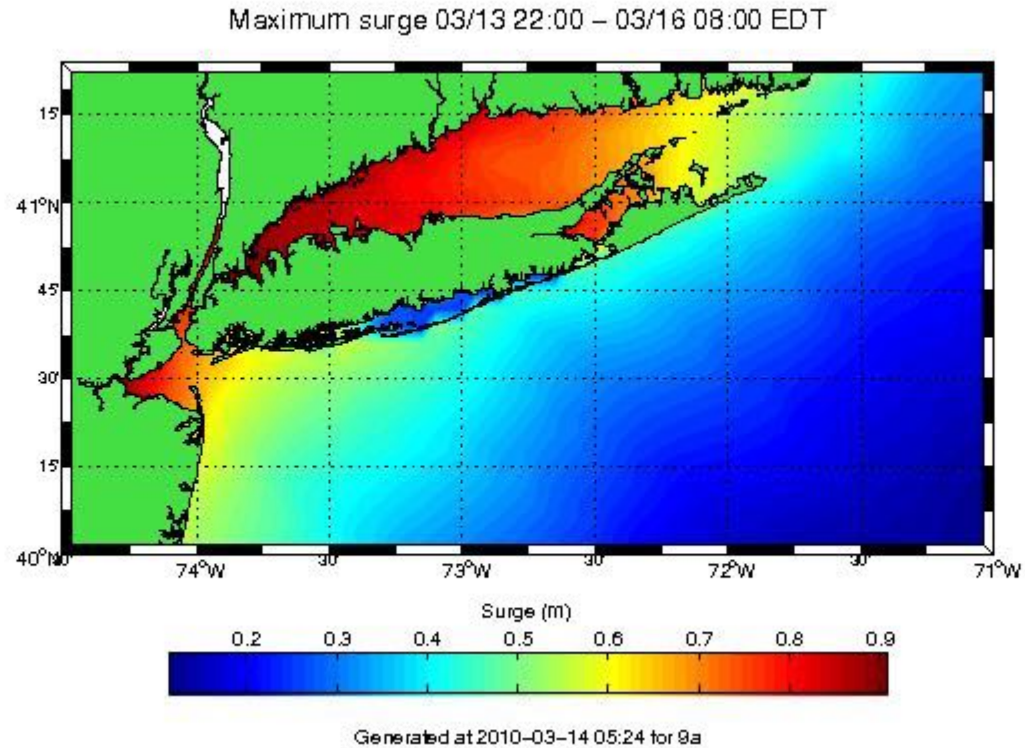


Surge

13 March 2010



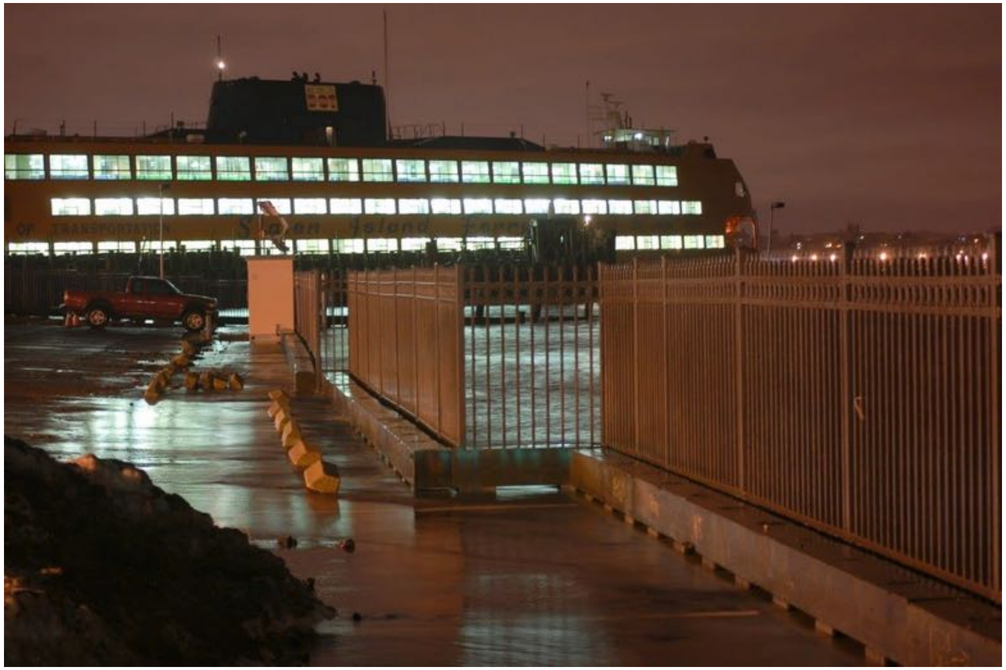


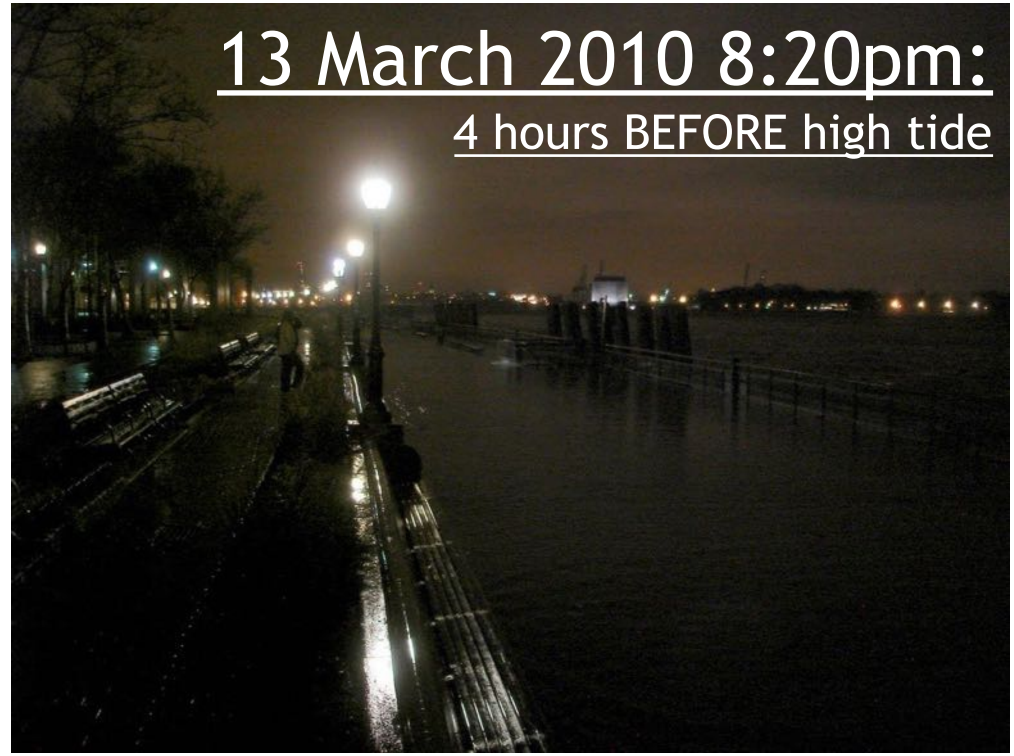


13 March 2010

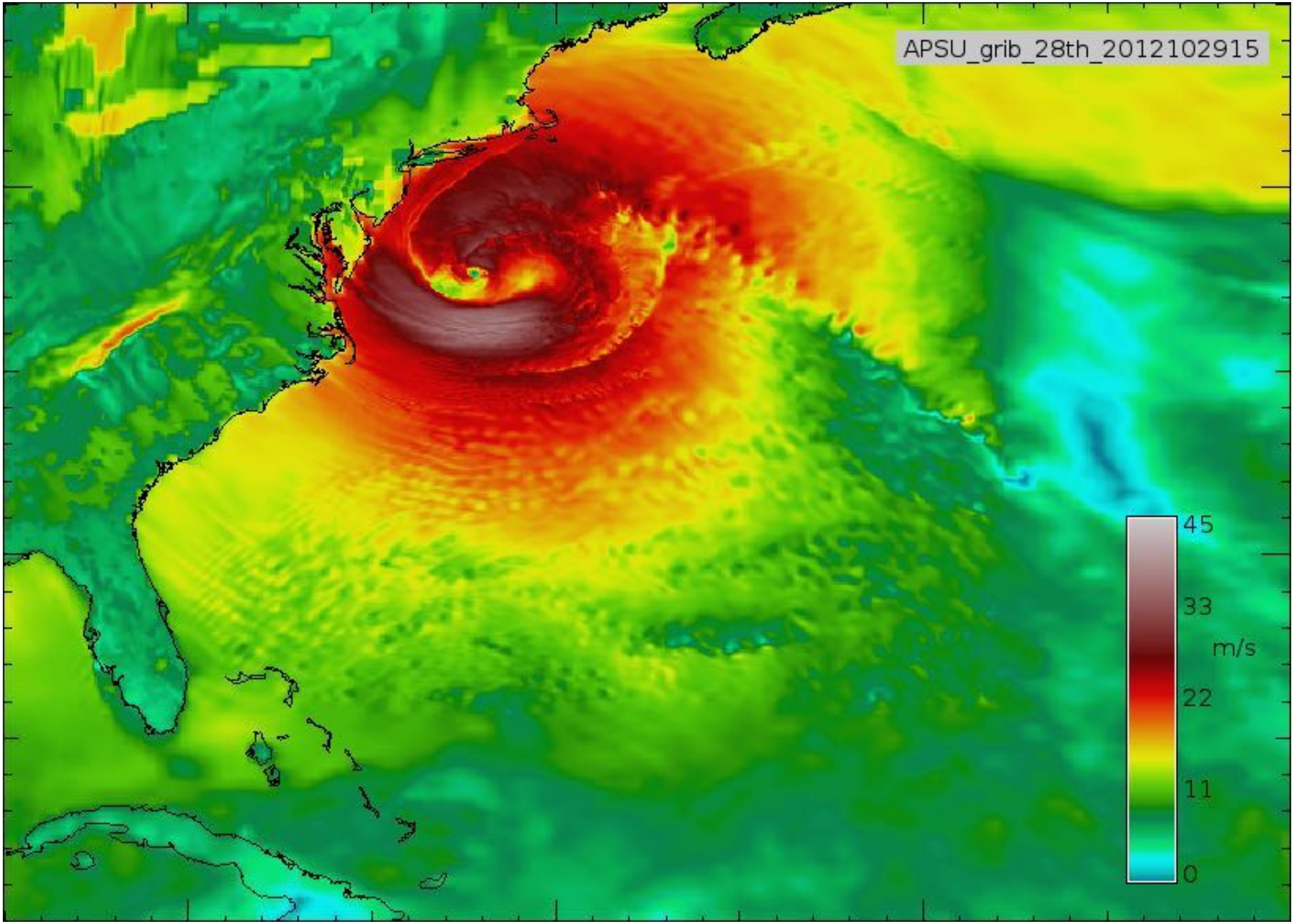
13 March 2010 8:20pm:

4 hours BEFORE high tide

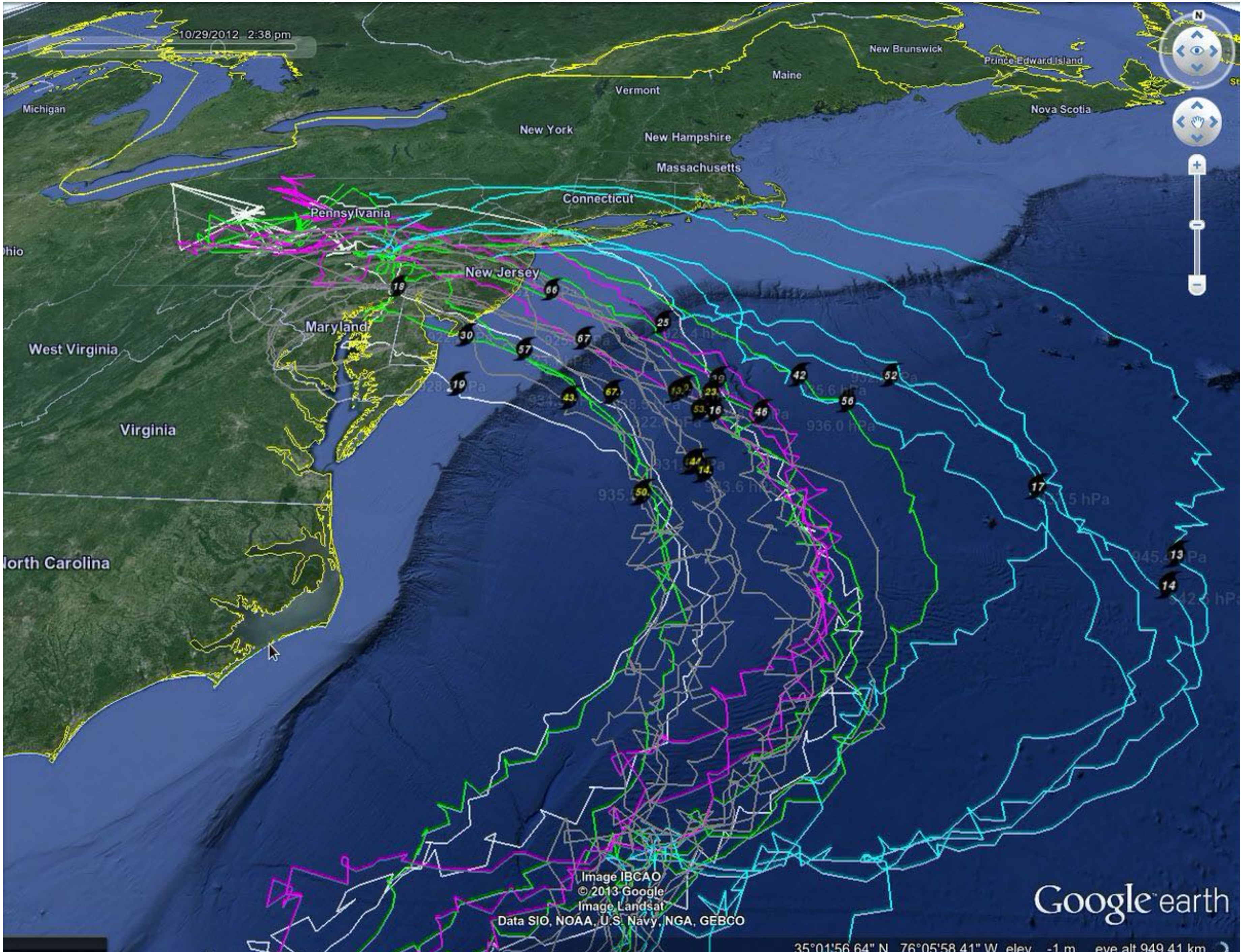




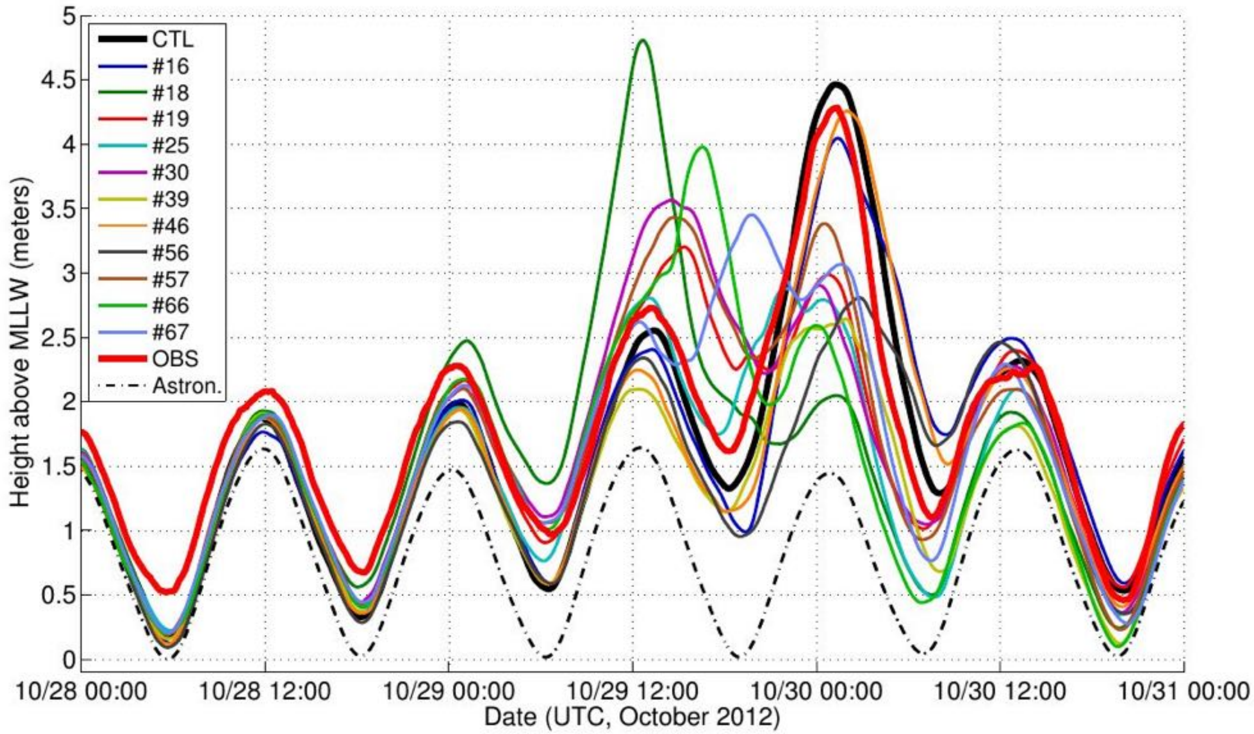
Hurricane Sandy

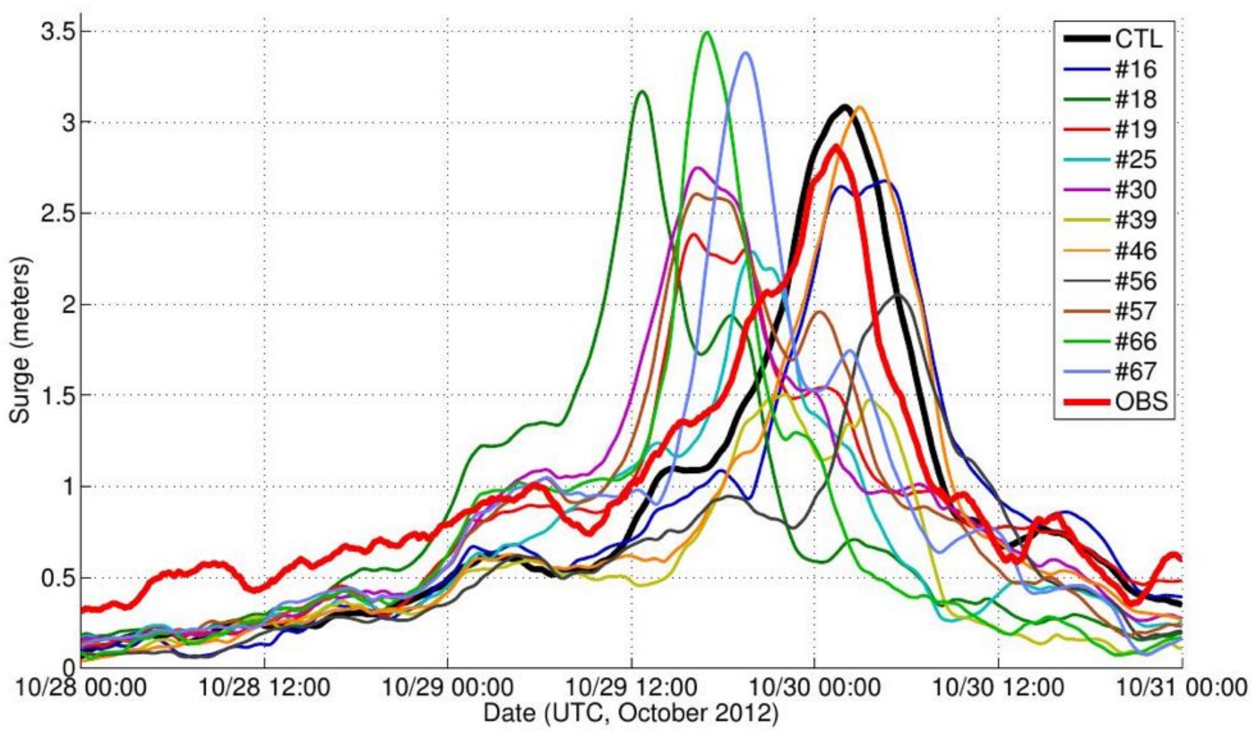


Model runs courtesy of Fuqing Zhang, Penn State U; graphics by Hamish Bowman.



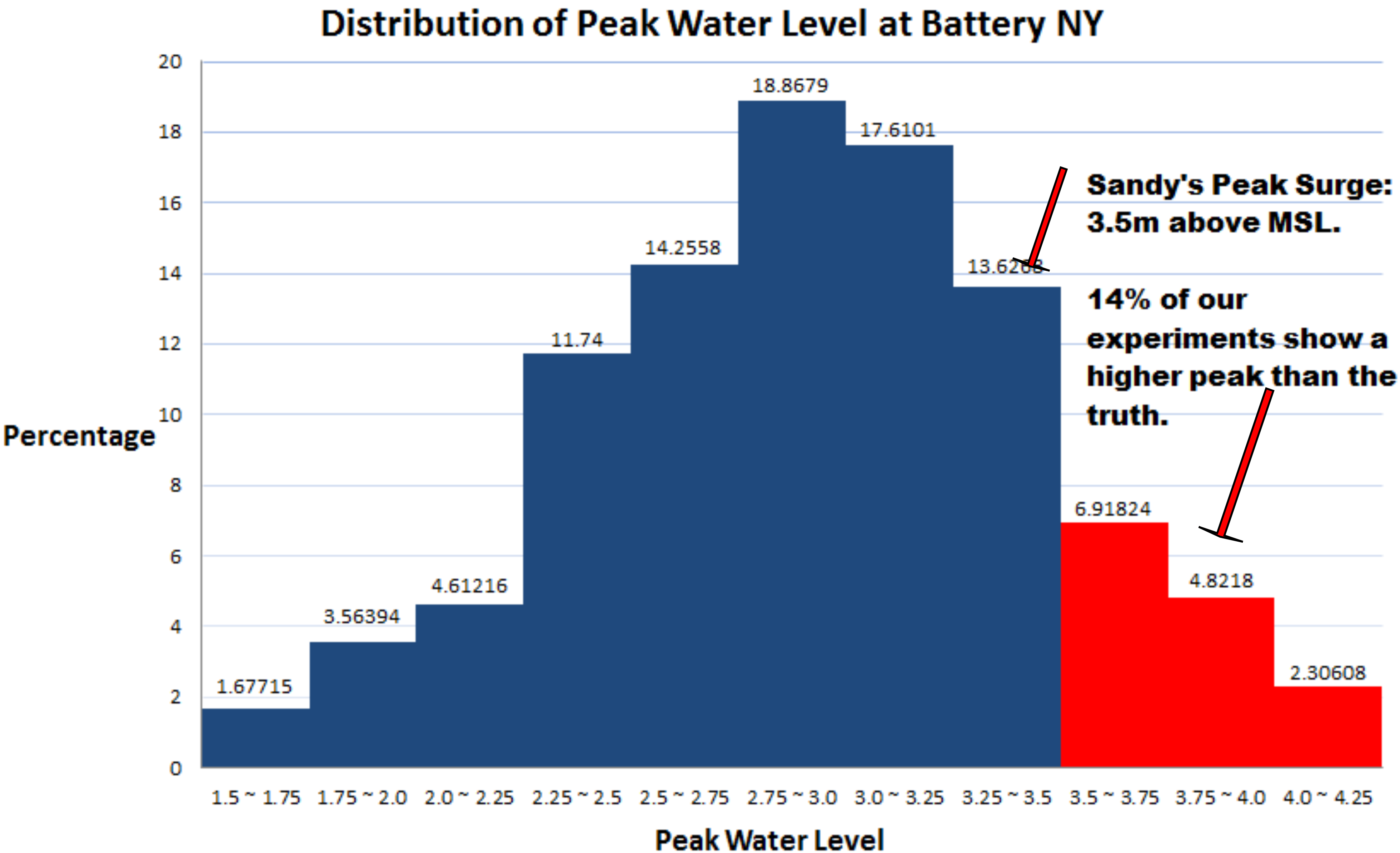
10/29/2012 2:38 pm
New Brunswick
Prince Edward Island
Maine
Vermont
Nova Scotia
Michigan
New York
New Hampshire
Massachusetts
Connecticut
Pennsylvania
Ohio
New Jersey
Maryland
West Virginia
Virginia
North Carolina
Image IBCAO
© 2013 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
35°01'56.64" N 76°05'58.41" W elev -1 m eye alt 949.41 km





Hurricane Sandy at The Battery

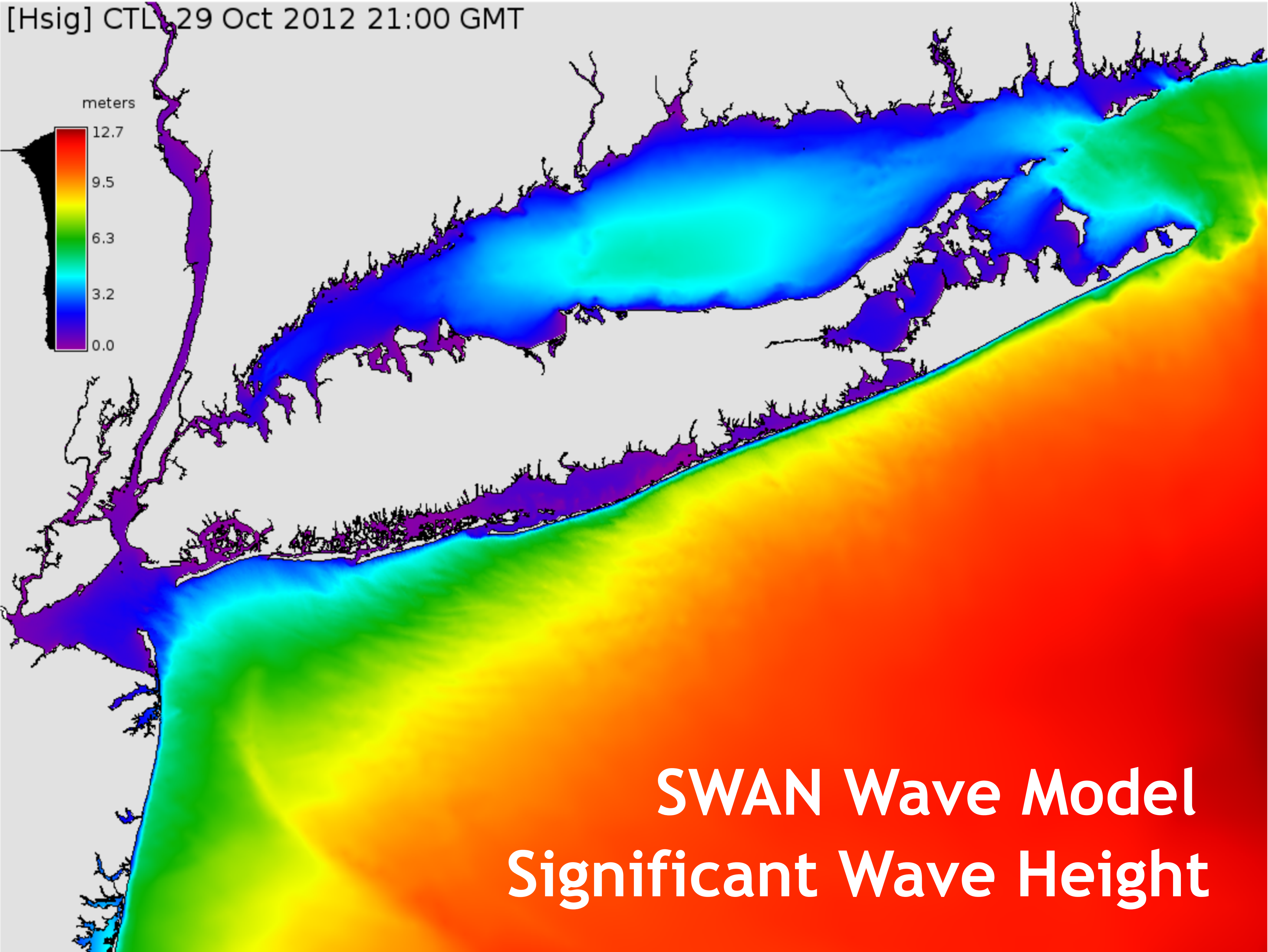
Many competing forecast model results due to slight changes in initial conditions, but how to know which one will be correct?

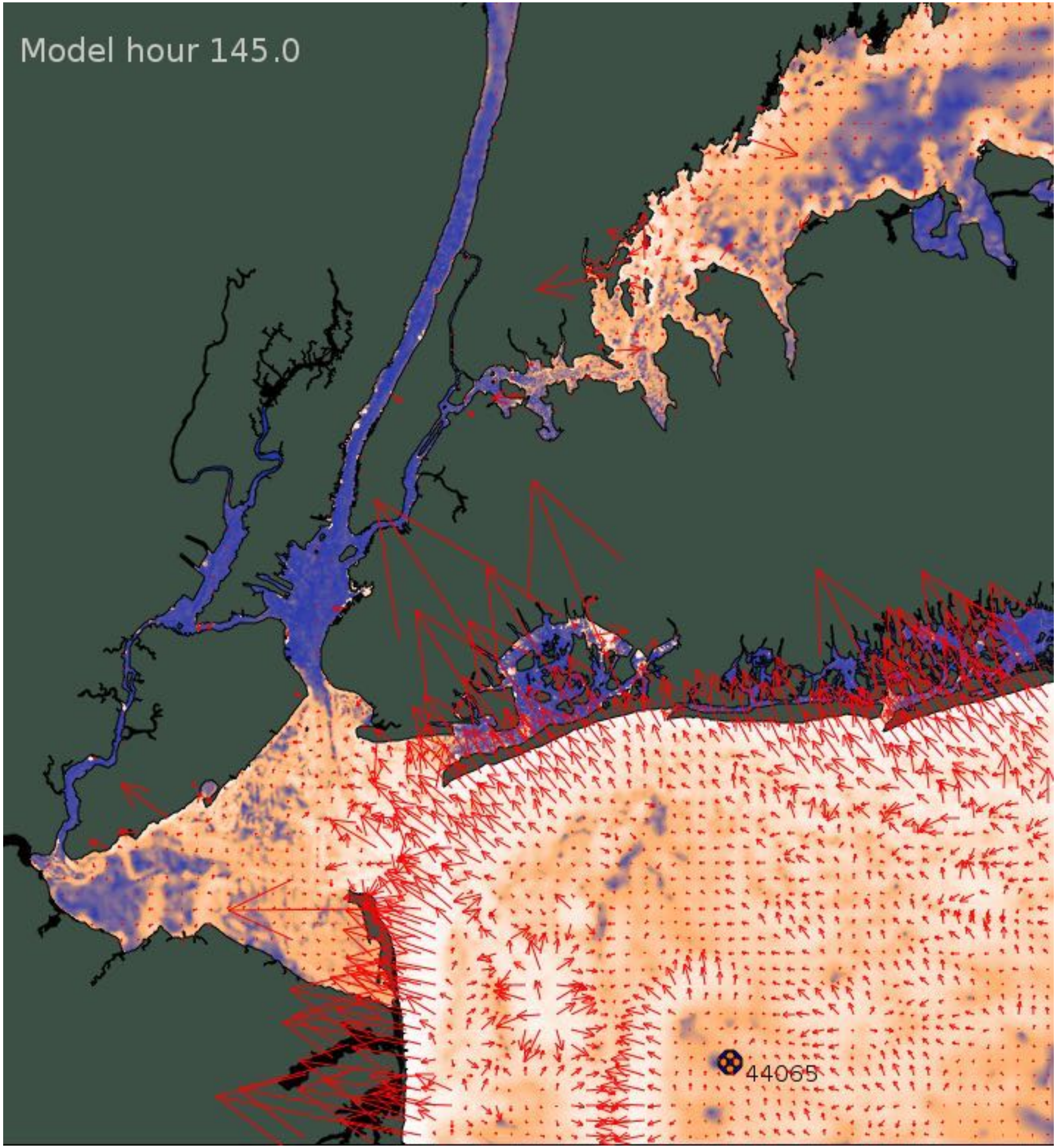


Battery mean = 2.93 m, sigma = +/- 0.53 m,

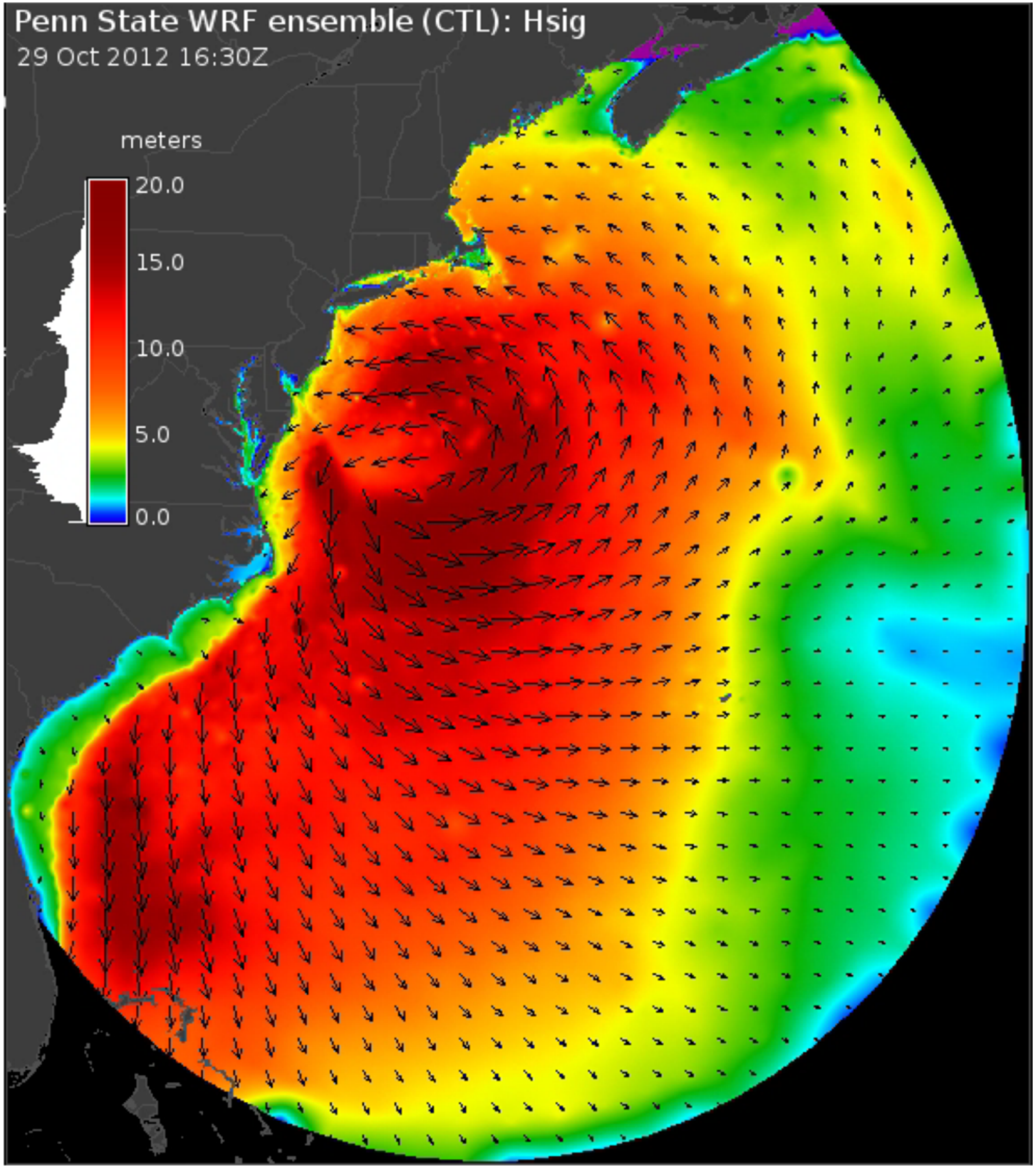
Big storms?

Big storms? Big waves!


[Hsig] CTL 29 Oct 2012 21:00 GMT
meters
12.7
9.5
6.3
3.2
0.0
SWAN Wave Model
Significant Wave Height

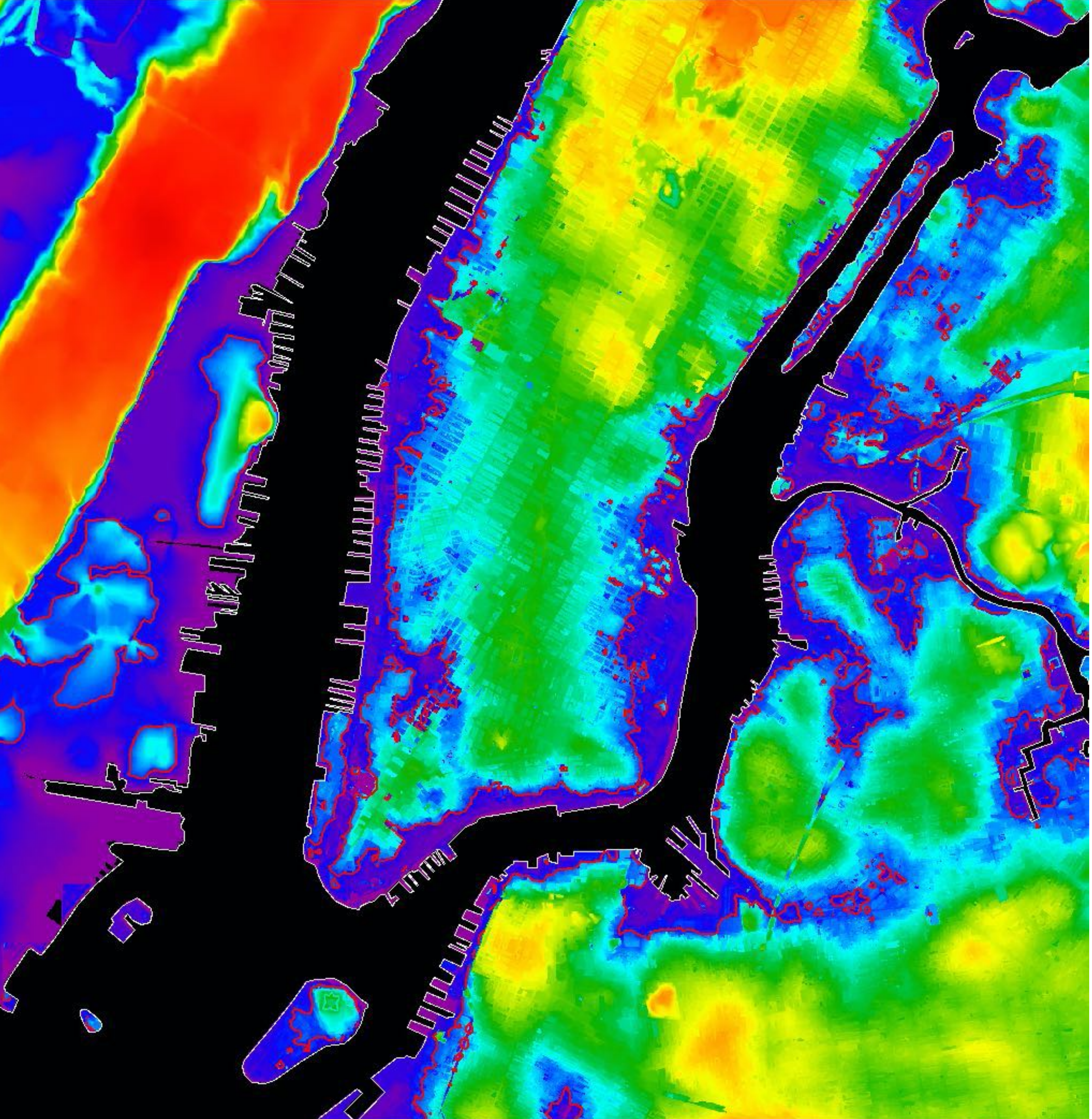


SWAN radiation stress at 2012-10-30 0000Z



SWAN Wave Model
Significant Wave Height

Before the flood *(* a great album)*



- Inland flooding maps using ADCIRC sea level heights intersecting with LiDAR elevations
- Iterative growth approach needed for real-time model runs
- Hindcast runs can use more accurate but less stable wetting and drying over land

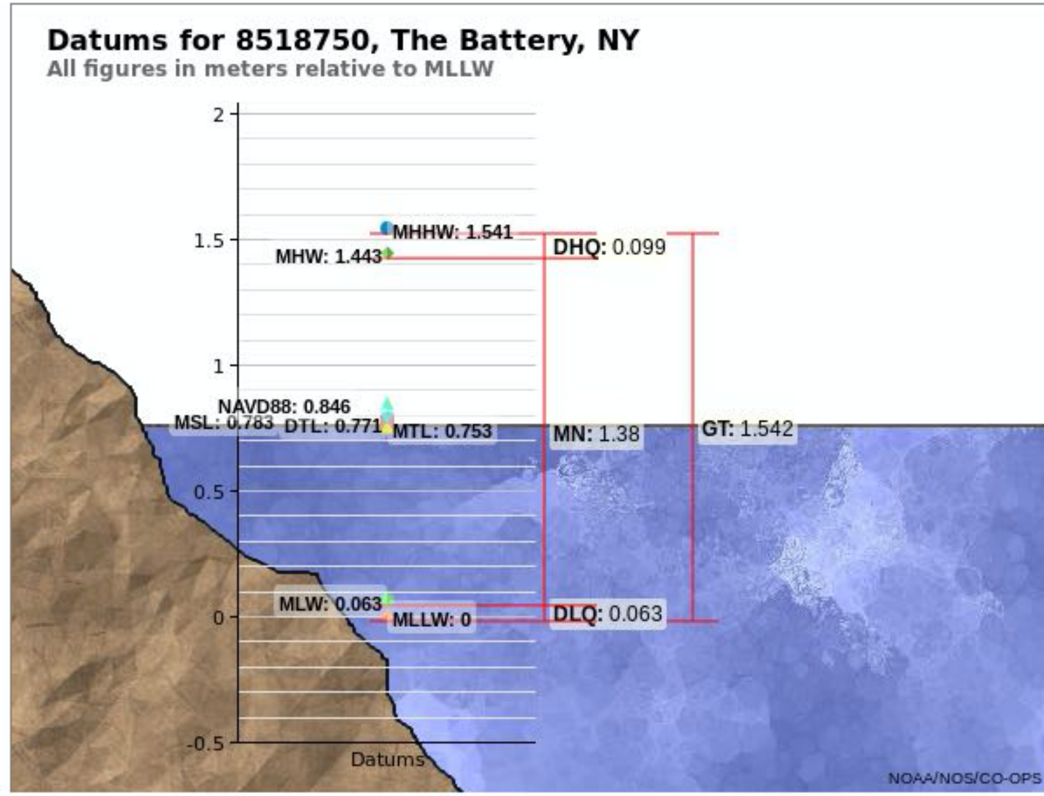
Elevations on Mean Lower Low Water

Station: 8518750, The Battery, NY **T.M.:** 0
Status: Accepted (Nov 19 2012) **Epoch:** 1983-2001
Units: Meters **Datum:** MLLW
Control Station:

Datum	Value	Description
MHHW	1.541	Mean Higher-High Water
MHW	1.443	Mean High Water
MTL	0.753	Mean Tide Level
MSL	0.783	Mean Sea Level
DTL	0.771	Mean Diurnal Tide Level
MLW	0.063	Mean Low Water
MLLW	0.000	Mean Lower-Low Water
NAVD88	0.846	North American Vertical Datum of 1988
STND	-1.002	Station Datum
GT	1.542	Great Diurnal Range
MN	1.380	Mean Range of Tide
DHQ	0.099	Mean Diurnal High Water Inequality
DLQ	0.063	Mean Diurnal Low Water Inequality
HWI	0.840	Greenwich High Water Interval (in hours)
LWI	7.210	Greenwich Low Water Interval (in hours)
Max Tide	4.280	Highest Observed Tide
Max Tide Date & Time	10/30/2012 01:12	Highest Observed Tide Date & Time
Min Tide	-1.307	Lowest Observed Tide
Min Tide Date & Time	02/02/1976 21:30	Lowest Observed Tide Date & Time
HAT	1.935	Highest Astronomical Tide
HAT Date & Time	10/16/1993 13:12	HAT Date and Time
LAT	-0.424	Lowest Astronomical Tide
LAT Date & Time	01/21/1996 20:06	LAT Date and Time

Tidal Datum Analysis Periods

01/01/1983 - 12/31/2001



Showing datums for

8518750 The Battery, NY

Datum

MLLW

Data Units ○ Feet ● Meters

Epoch ● Present (1983-2001) ○ Superseded (1960-1978)

Submit

tidesandcurrents.noaa.gov

Converting between tidal and land datums is non-trivial

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Status: Accepted (Nov 19 2012)
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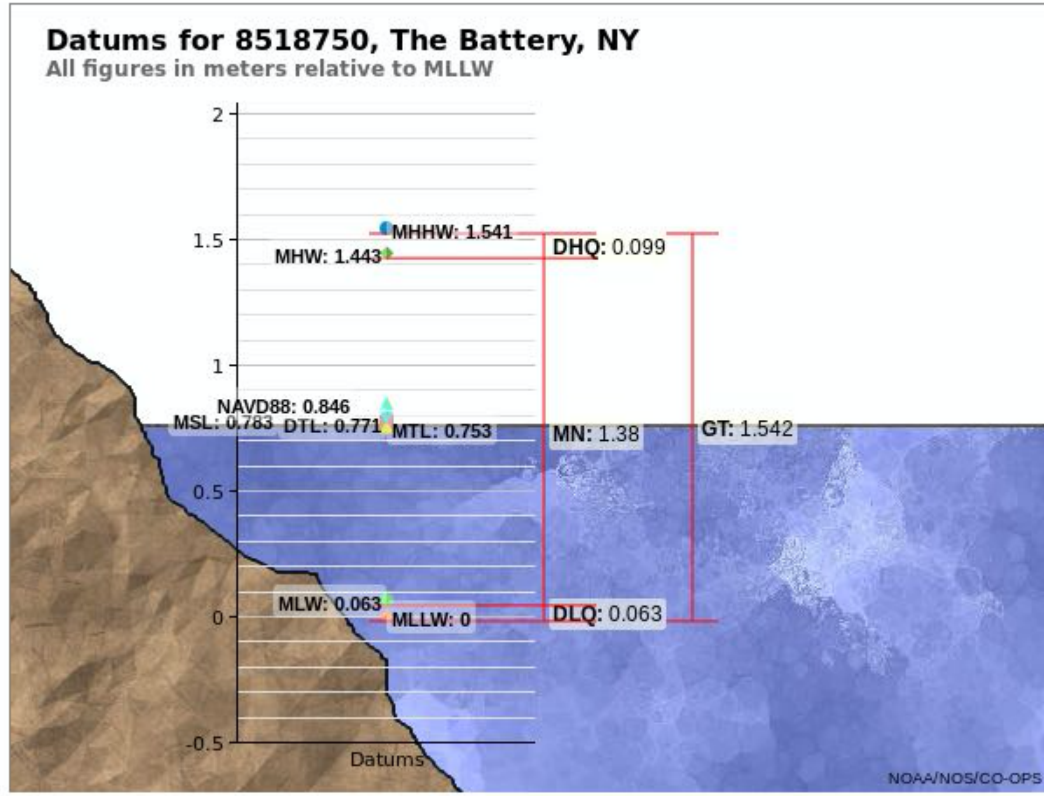
Max Tide Date & Time	10/30/2012 01:12	Highest Observed Tide Date & Time
Min Tide	-1.307	Lowest Observed Tide
Min Tide Date & Time	02/02/1976 21:30	Lowest Observed Tide Date & Time
HAT	1.935	Highest Astronomical Tide
HAT Date & Time	10/16/1993 13:12	HAT Date and Time
LAT	-0.424	Lowest Astronomical Tide
LAT Date & Time	01/21/1996 20:06	LAT Date and Time

Tidal Datum Analysis Periods

01/01/1983 - 12/31/2001



Showing datums for

8518750 The Battery, NY

Datum

MLLW

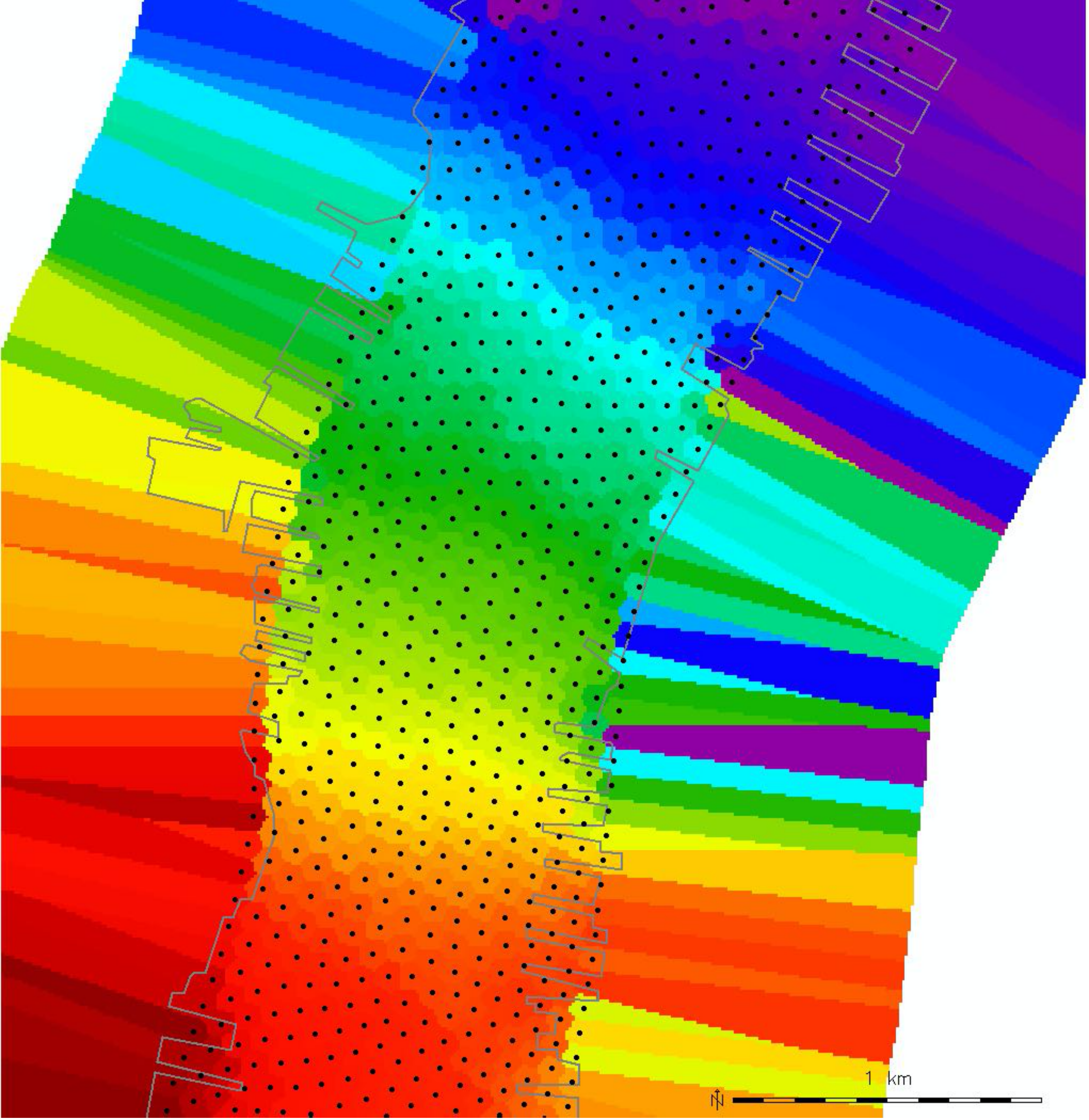
Data Units ( ) Feet (•) Meters

Epoch (•) Present (1983-2001) ( ) Superseded (1960-1978)

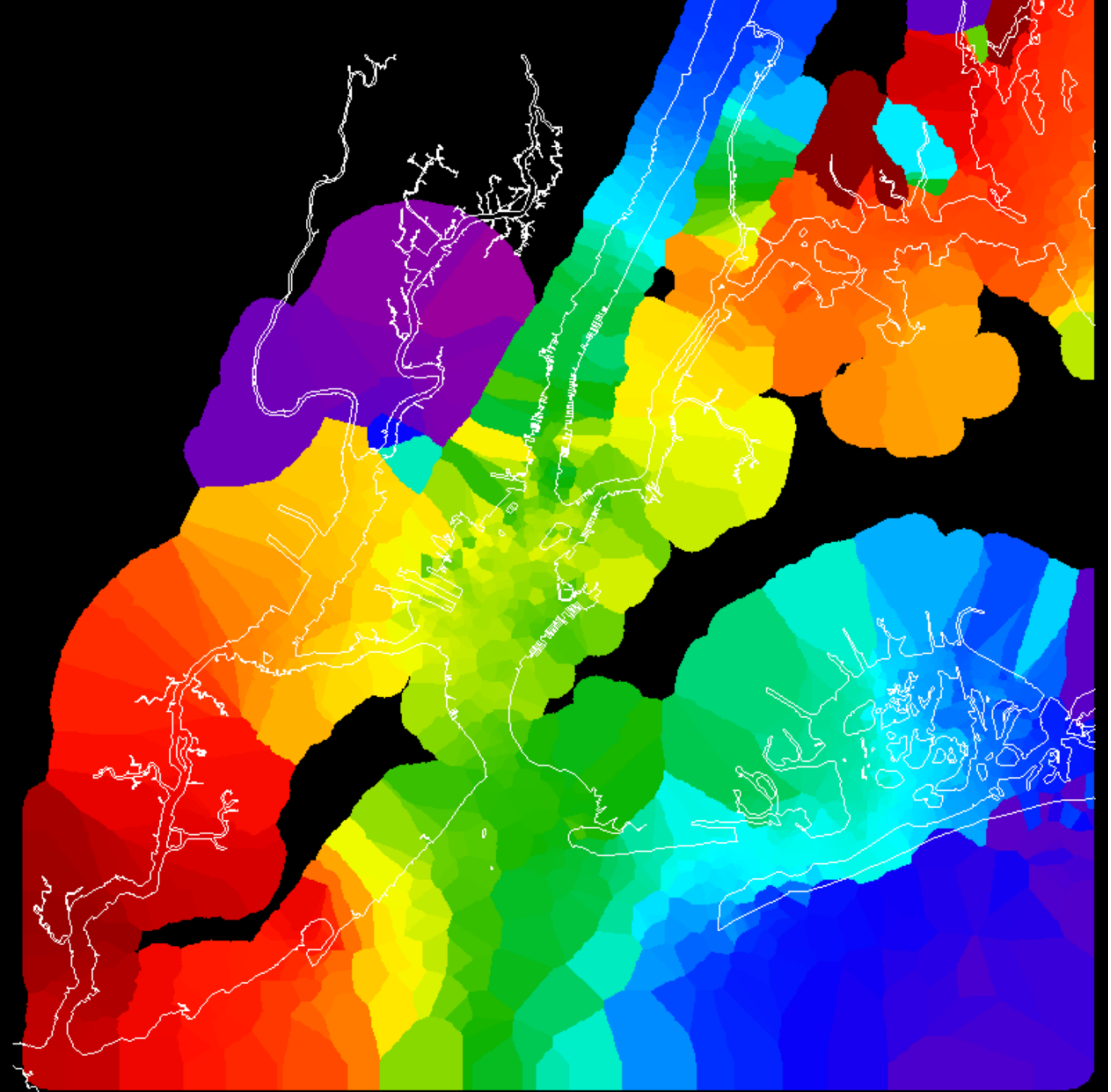
Submit

Converting between tidal and land datums is non-trivial

tidesandcurrents.noaa.gov

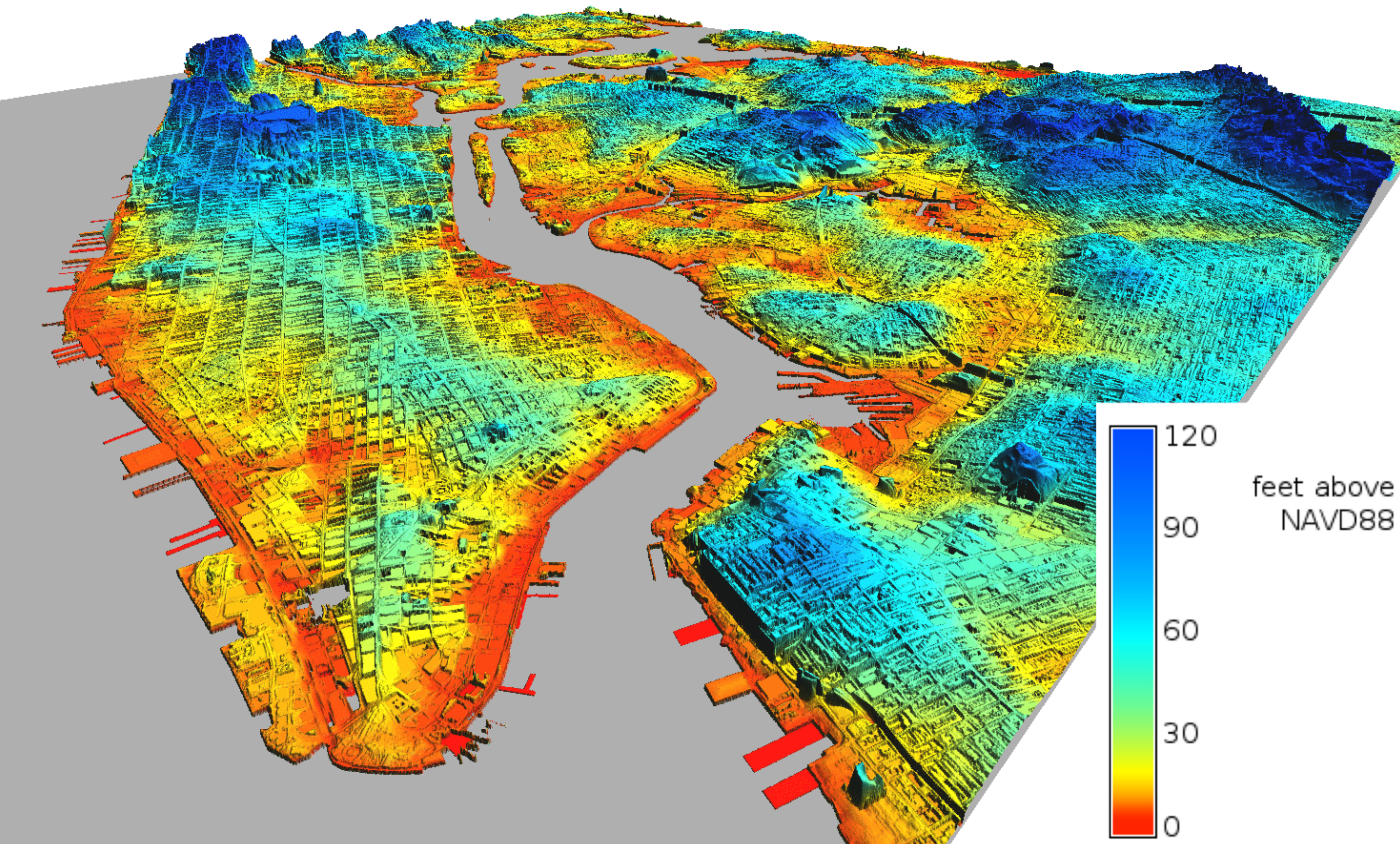


Growing water levels inland in a simple way with GRASS GIS's r.grow module



Growing water levels inland in a simple way with GRASS GIS's r.grow module

If Sandy hit at the following high tide



Operational Summary

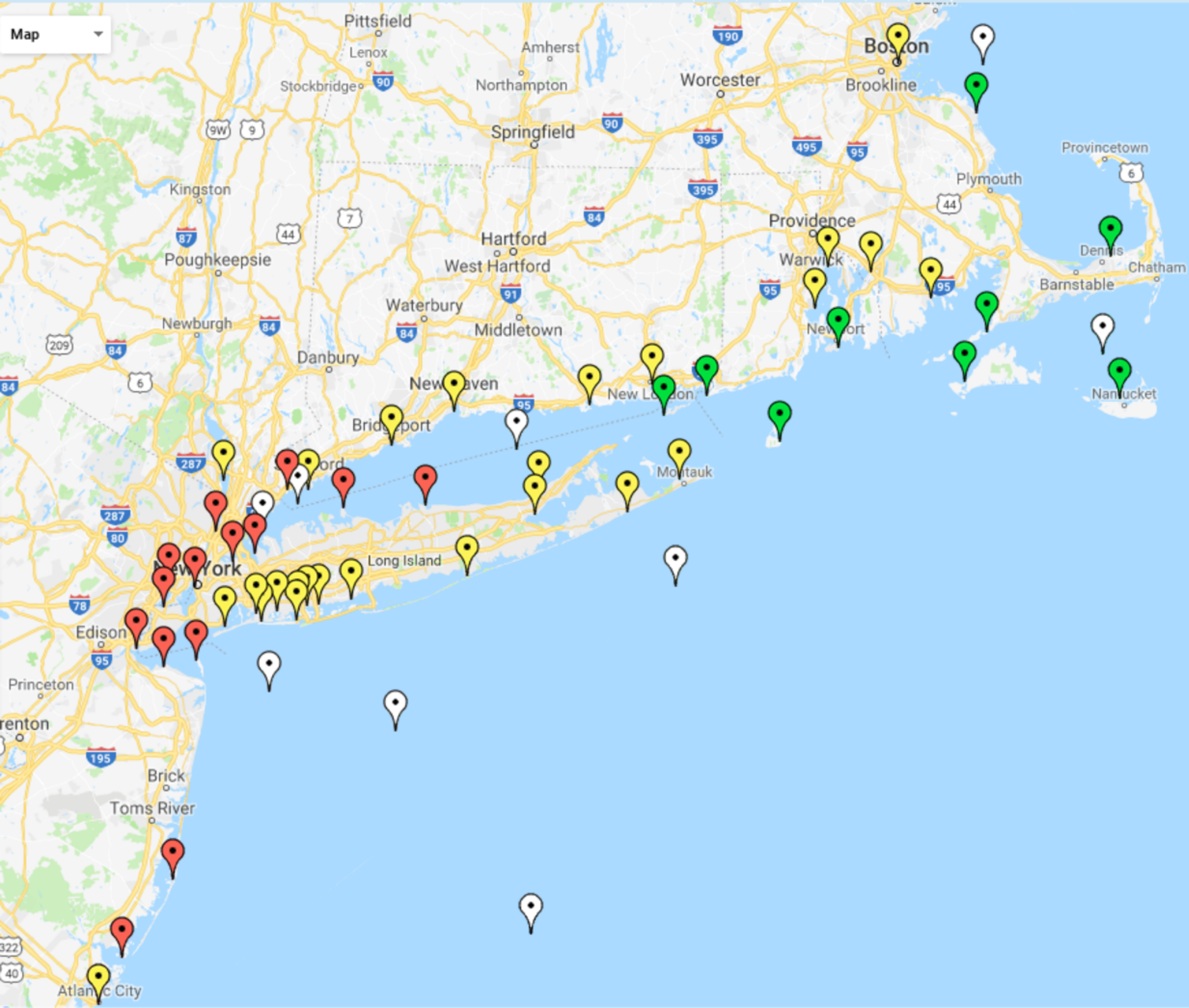
Forecasts of water levels and surge heights at 52 sites from Maine to Delaware including

The Battery, JFK, EWR, and LGA airports

- New York Harbor (8)
- Long Island South Shore (12)
- Long Island Sound (9)
- New England Maritimes (11)
- Boston and North (7)
- New Jersey and South (5)

Running for 12 years at

http://stormy.msrc.sunysb.edu



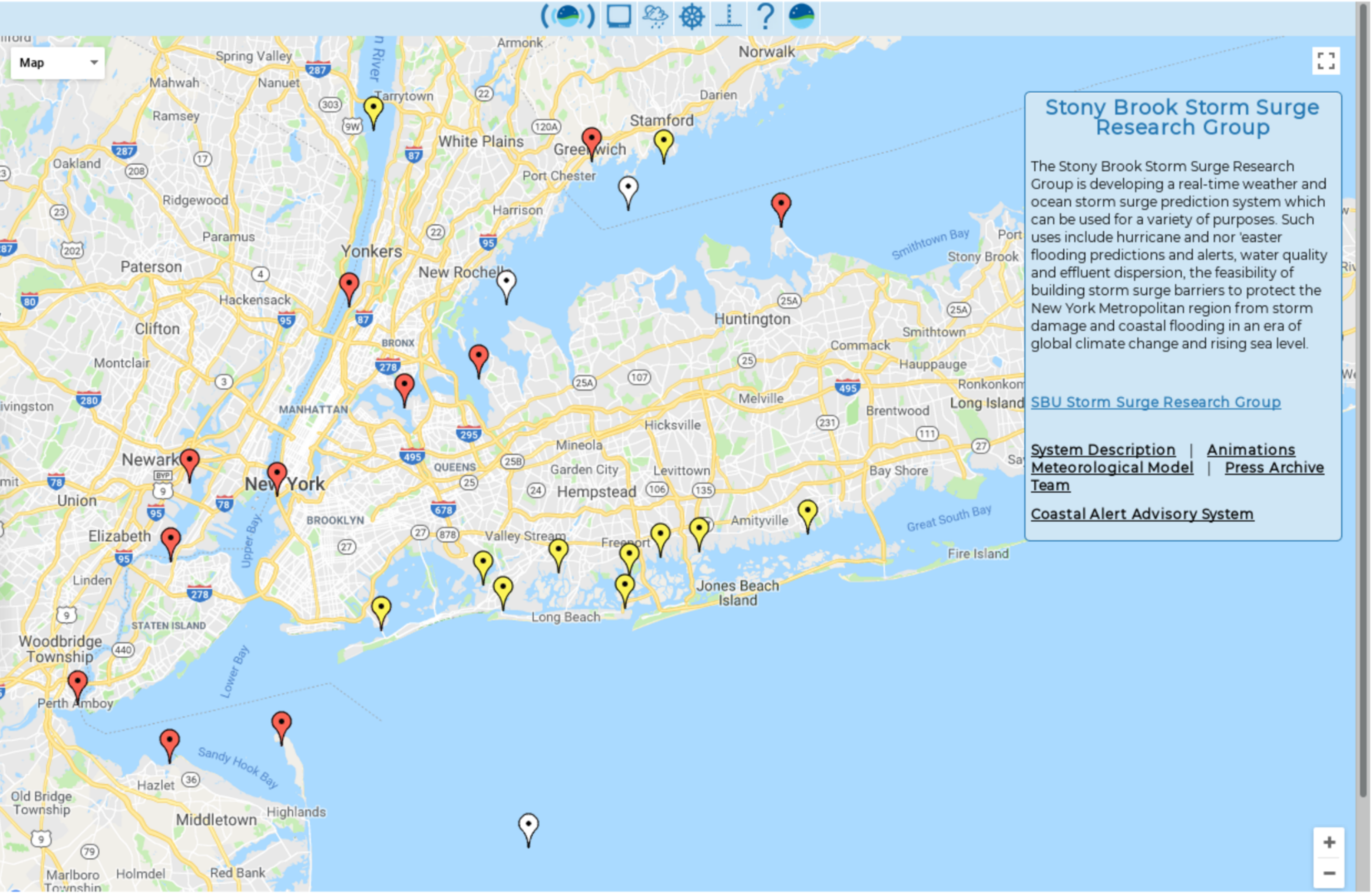
Stony Brook Storm Surge Research Group

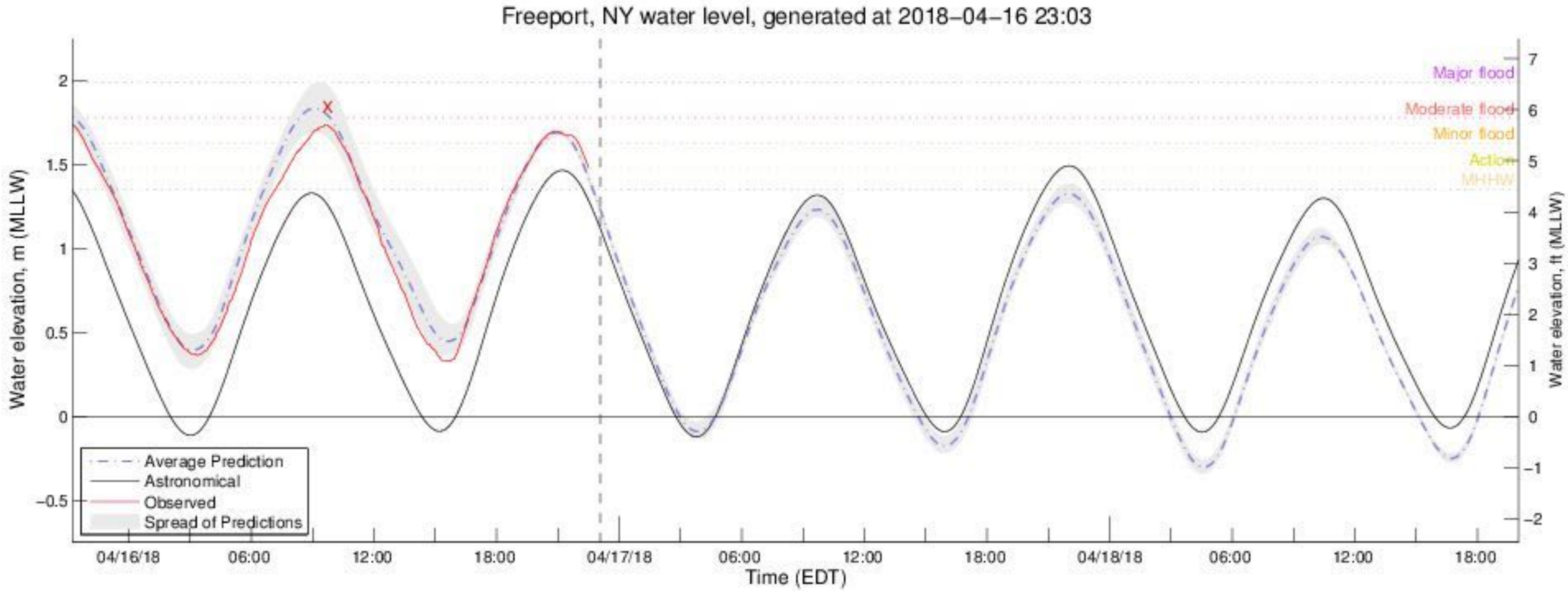
The Stony Brook Storm Surge Research Group is developing a real-time weather and ocean storm surge prediction system which can be used for a variety of purposes. Such uses include hurricane and nor 'easter flooding predictions and alerts, water quality and effluent dispersion, the feasibility of building storm surge barriers to protect the New York Metropolitan region from storm damage and coastal flooding in an era of global climate change and rising sea level.

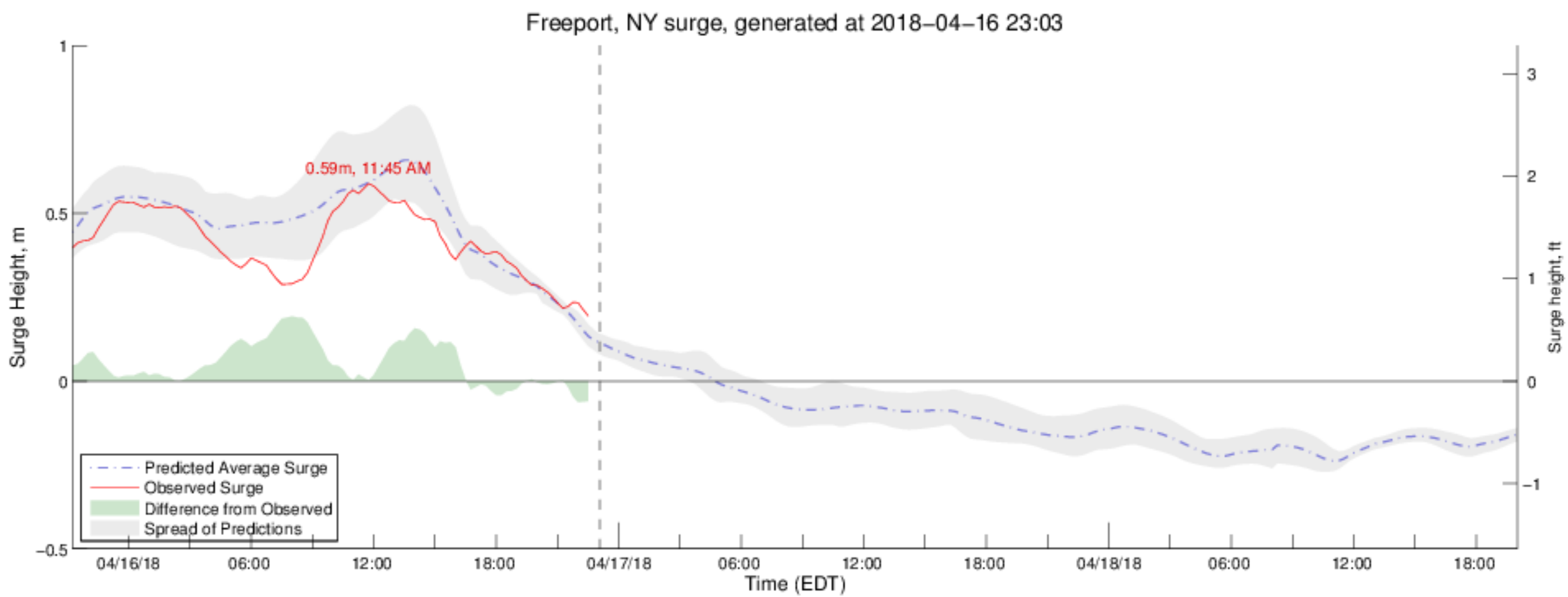
SBU Storm Surge Research Group

System Description | Animations
Meteorological Model | Press Archive
Team

Coastal Alert Advisory System


Map
Stony Brook Storm Surge Research Group
The Stony Brook Storm Surge Research Group is developing a real-time weather and ocean storm surge prediction system which can be used for a variety of purposes. Such uses include hurricane and nor 'easter flooding predictions and alerts, water quality and effluent dispersion, the feasibility of building storm surge barriers to protect the New York Metropolitan region from storm damage and coastal flooding in an era of global climate change and rising sea level.
SBU Storm Surge Research Group
System Description | Animations
Meteorological Model | Press Archive
Team
Coastal Alert Advisory System
Spring Valley
Armonk
Norwalk
Mahwah
Nanuet
Tarrytown
Darien
Ramsey
White Plains
Stamford
Greenwich
Oakland
Port Chester
Ridgewood
Harrison
Paramus
Yonkers
Smithtown Bay
Stony Brook
Paterson
New Rochelle
Hackensack
Huntington
Clifton
BRONX
Smithtown
Commack
Montclair
Hauppauge
MANHATTAN
Melville
Ronkonkoma
Long Island
Brentwood
Hicksville
Mineola
Newark
QUEENS
Garden City
Levittown
New York
Hempstead
Bay Shore
Union
BROOKLYN
Amityville
Elizabeth
Valley Stream
Freeport
Great South Bay
Upper Bay
Linden
Fire Island
Jones Beach Island
Long Beach
STATEN ISLAND
Woodbridge Township
Lower Bay
Perth Amboy
Sandy Hook Bay
Hazlet
Old Bridge Township
Highlands
Middletown
Marlboro Township
Holmdel
Red Bank


Freeport, NY water level, generated at 2018−04−16 23:03
Water elevation, m (MLLW)
Water elevation, ft (MLLW)
Major flood
Moderate flood
Minor flood
Action
MHHW
Average Prediction
Astronomical
Observed
Spread of Predictions
04/16/18
06:00
12:00
18:00
04/17/18
04/18/18
Time (EDT)


Freeport, NY surge, generated at 2018−04−16 23:03
Surge Height, m
Surge height, ft
0.59m, 11:45 AM
Predicted Average Surge
Observed Surge
Difference from Observed
Spread of Predictions
04/16/18
06:00
12:00
18:00
04/17/18
04/18/18
Time (EDT)

Stony Brook Storm Surge Advisory

School of Marine and Atmospheric Sciences, Stony Brook University

Advisory for Bay Park NY

April 17, 2018, 8:37 AM

Bay Park NY is expected to be at 1.24 ft (0.38 meters) above MHHW at Apr 16, 2018 9:15 PM EDT

Advisory for Bergen Point

April 17, 2018, 8:37 AM

Bergen Point is expected to be at 1.18 ft (0.36 meters) above MHHW at Apr 16, 2018 9:15 PM EDT

Advisory for East Dennis MA

April 17, 2018, 8:37 AM

East Dennis MA is expected to be at 1.10 ft (0.34 meters) above MHHW at Apr 19, 2018 2:15 AM EDT

Advisory for Freeport

April 17, 2018, 8:37 AM

Freeport is expected to be at 1.10 ft (0.34 meters) above MHHW at Apr 16, 2018 9:15 PM EDT

Advisory for Inwood

April 17, 2018, 8:37 AM

Inwood is expected to be at 1.41 ft (0.43 meters) above MHHW at Apr 16, 2018 9:15 PM EDT

Advisory for Merrick NY

April 17, 2018, 8:37 AM

Merrick NY is expected to be at 1.07 ft (0.33 meters) above MHHW at Apr 16, 2018 9:30 PM EDT

Advisory for Newark NJ

April 17, 2018, 8:37 AM

Newark NJ is expected to be at 1.01 ft (0.31 meters) above MHHW at Apr 16, 2018 9:15 PM EDT

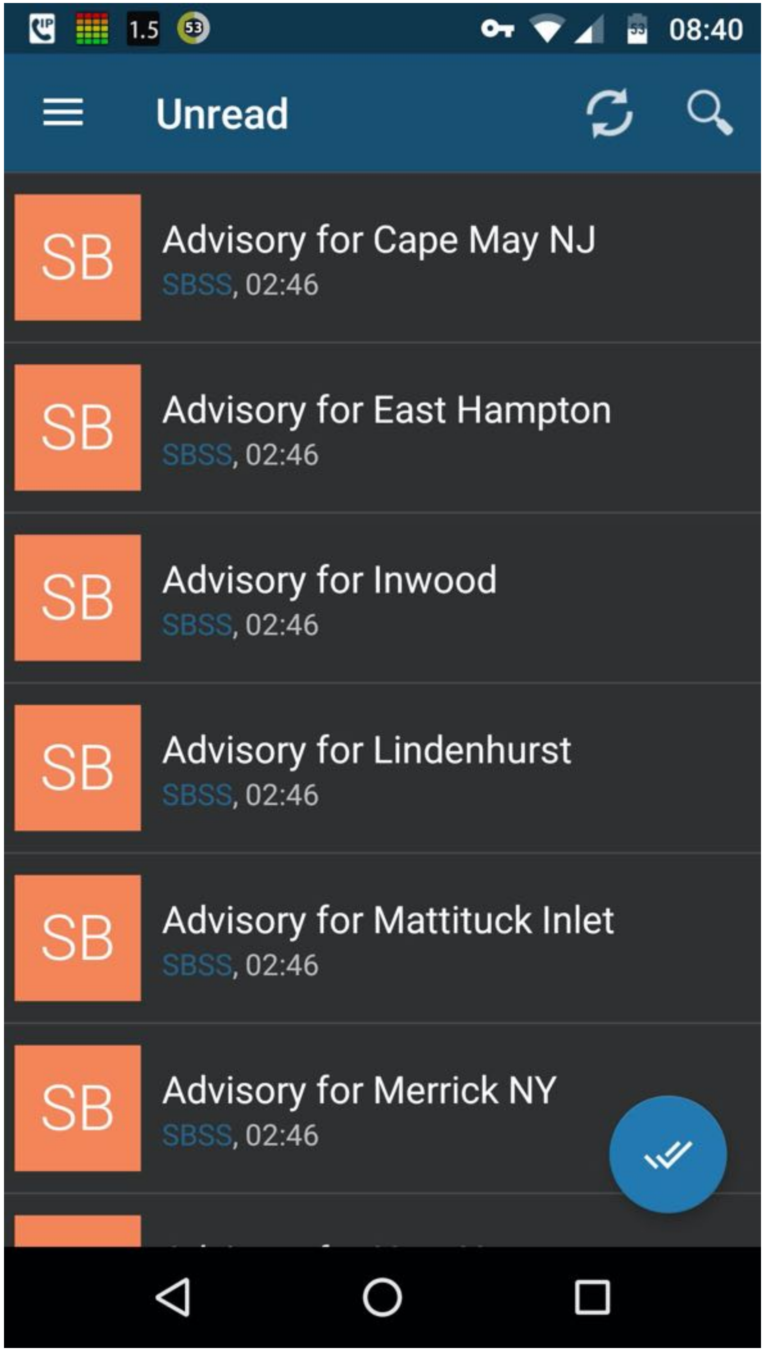
Advisory for Perth Amboy NJ

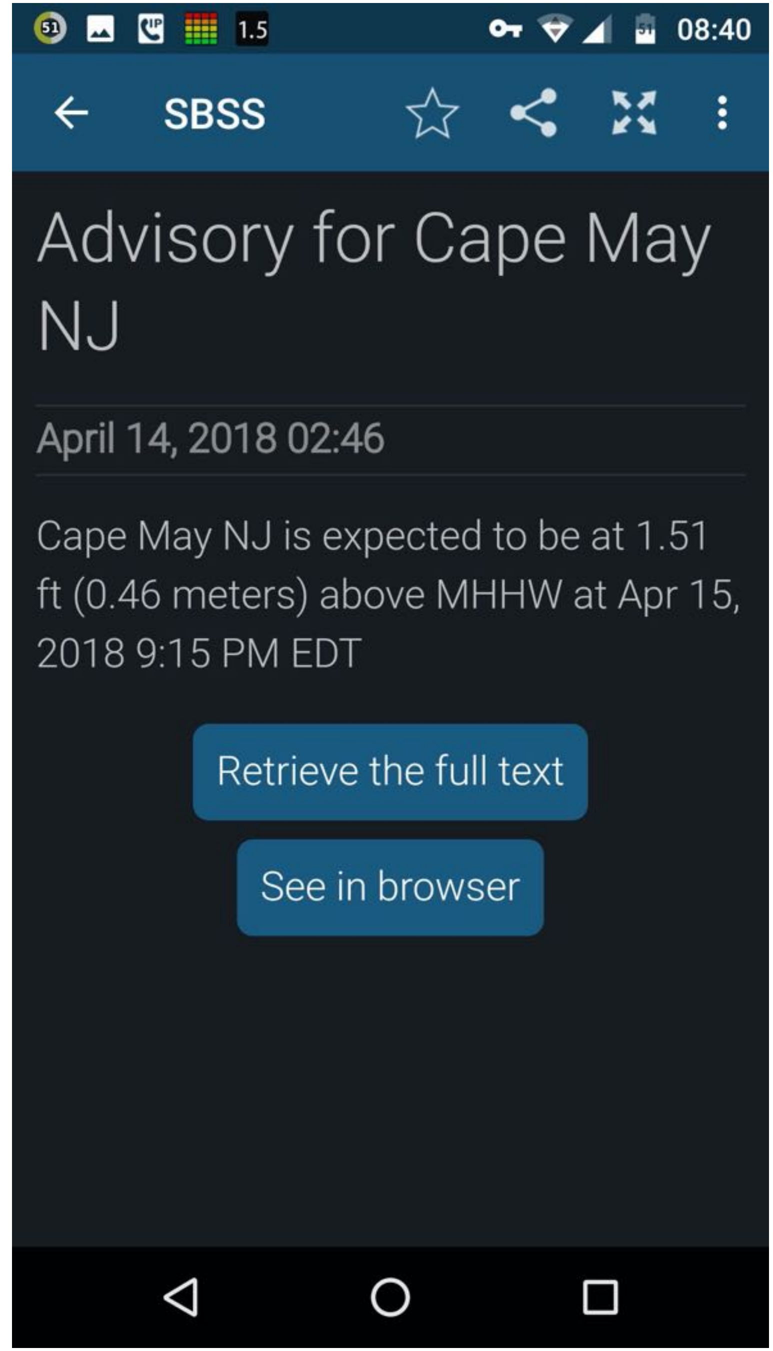
April 17, 2018, 8:37 AM

Perth Amboy NJ is expected to be at 1.09 ft (0.33 meters) above MHHW at Apr 16, 2018 9:15 PM EDT

Advisory for Piermont NY

April 17, 2018, 8:37 AM





Flym news reader app on Android

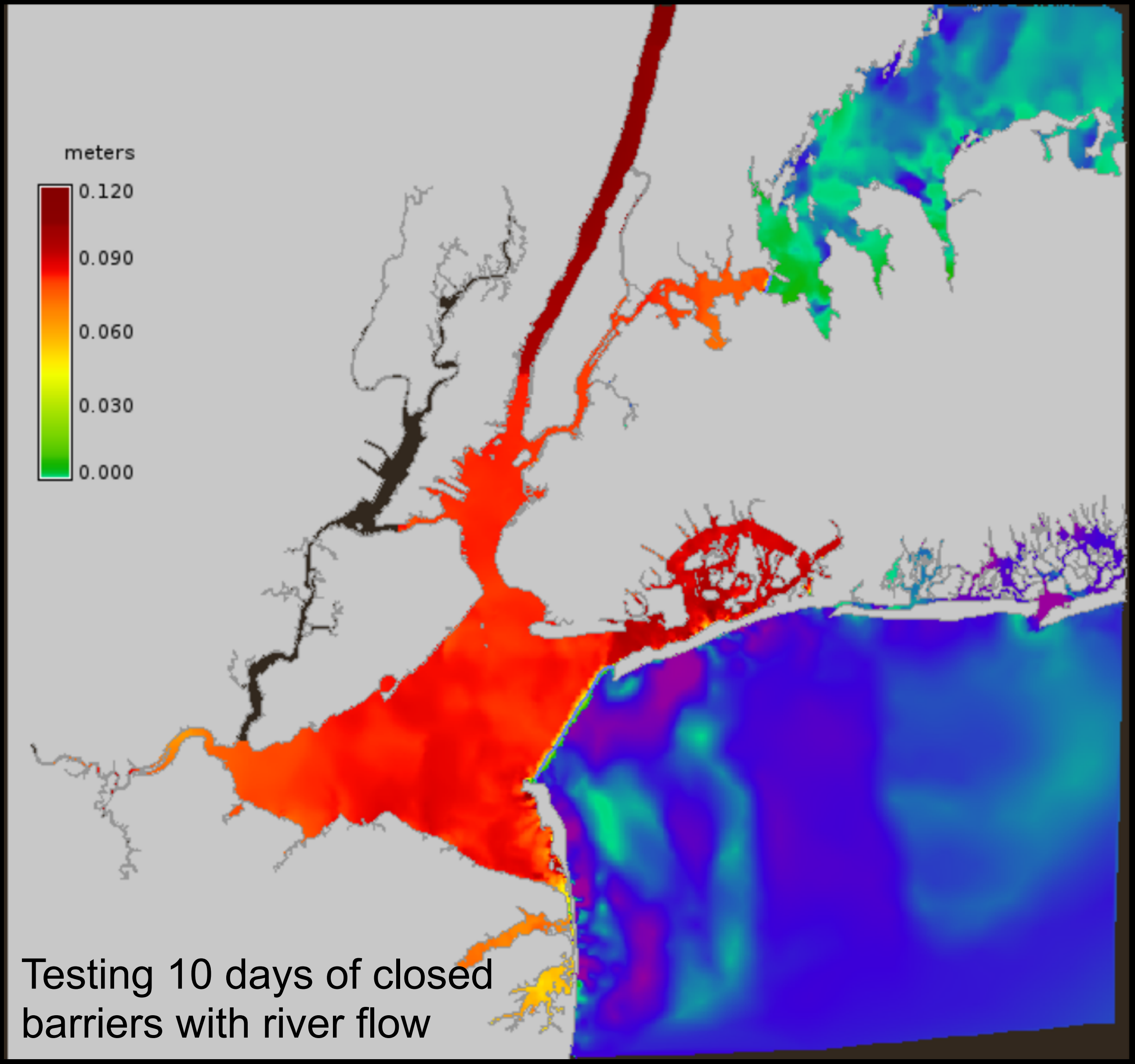
“Everybody always talks about the weather but nobody does anything about it”

Mark Twain or Charles Warner (* they were neighbors) on the weather in New England

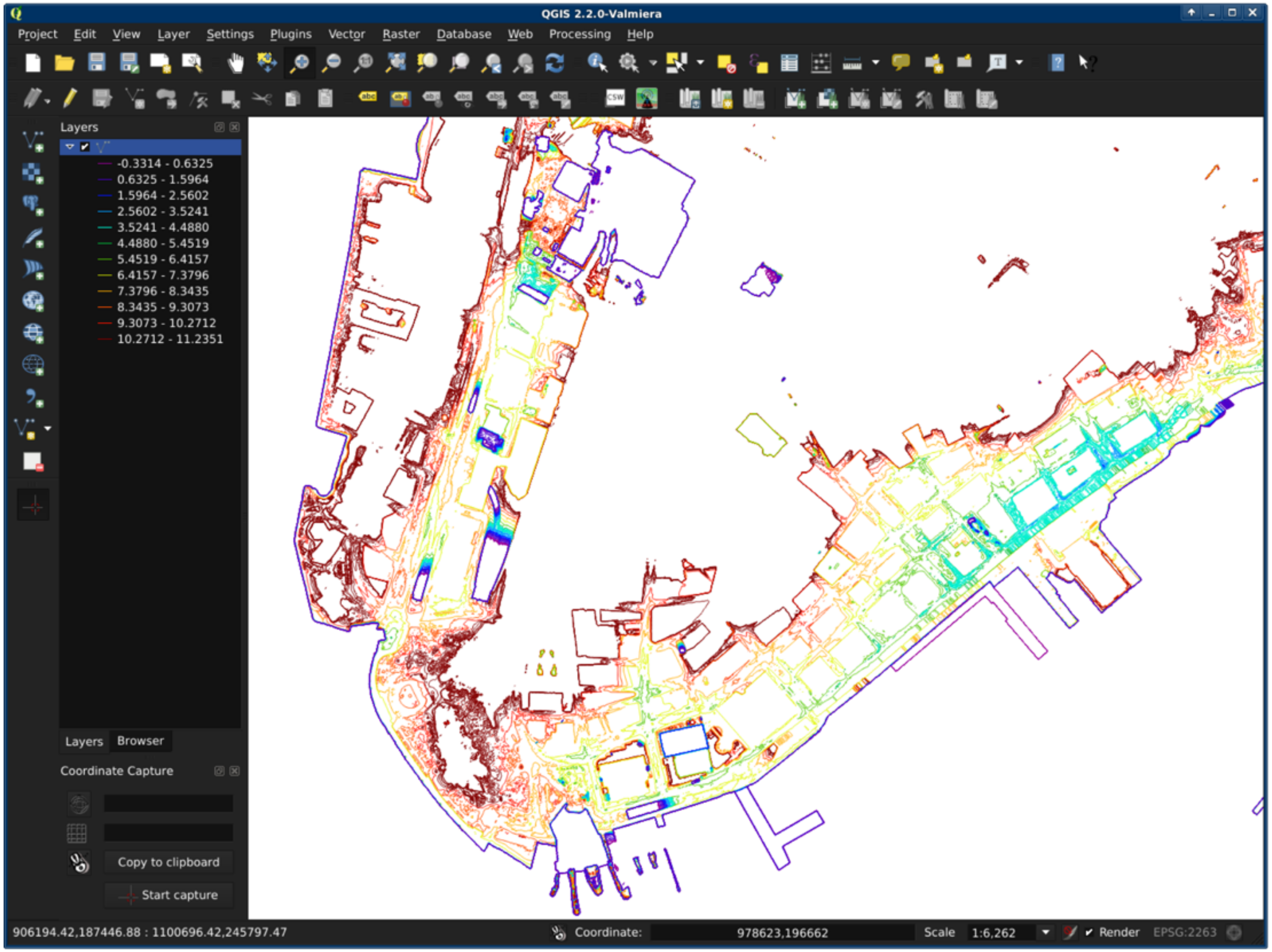
Taintor gates in open position at the St Petersburg storm barrier system

The Thames River Barrier was opened in 1982 and has been used many times to prevent the City of London from flooding

Closable storm barriers experiment, Hurricane Sandy (est. NZ$100 Billion)



Thank You



http://stormy.msrc.sunysb.edu

hamish.bowman@otago.ac.nz

http://stormy.msrc.sunysb.edu

ADCIRC

SWAN

Simulating WAves Nearshore

GRASS

Sea Grant New York

NOAA — National Oceanic and Atmospheric Administration — U.S. Department of Commerce

National Weather Service

USGS — science for a changing world

DEP — New York City Department of Environmental Protection

HydroQual

Stony Brook University

iACS — Institute for Advanced Computational Science

SoMAS — School of Marine and Atmospheric Sciences

Geology — University of Otago New Zealand