

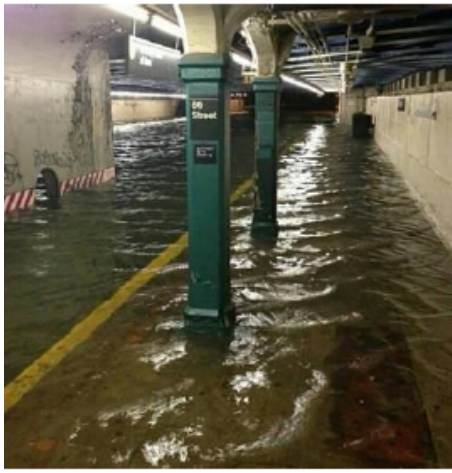

Urban Coastal Flood Risk Assessment: Putting Sandy into Perspective

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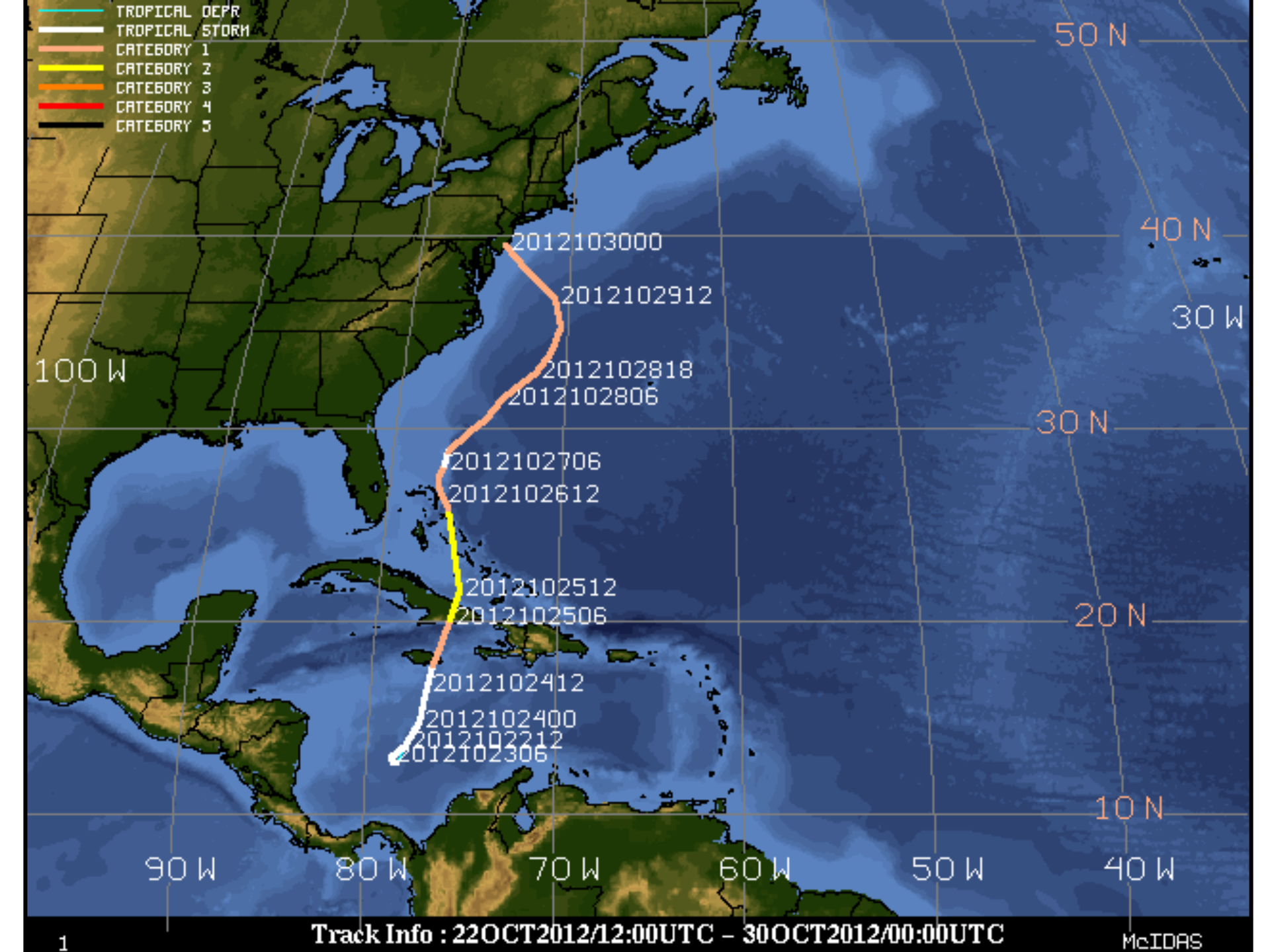
Nickitas Georgas and Alan Blumberg

Davidson Laboratory, Stevens Institute of Technology

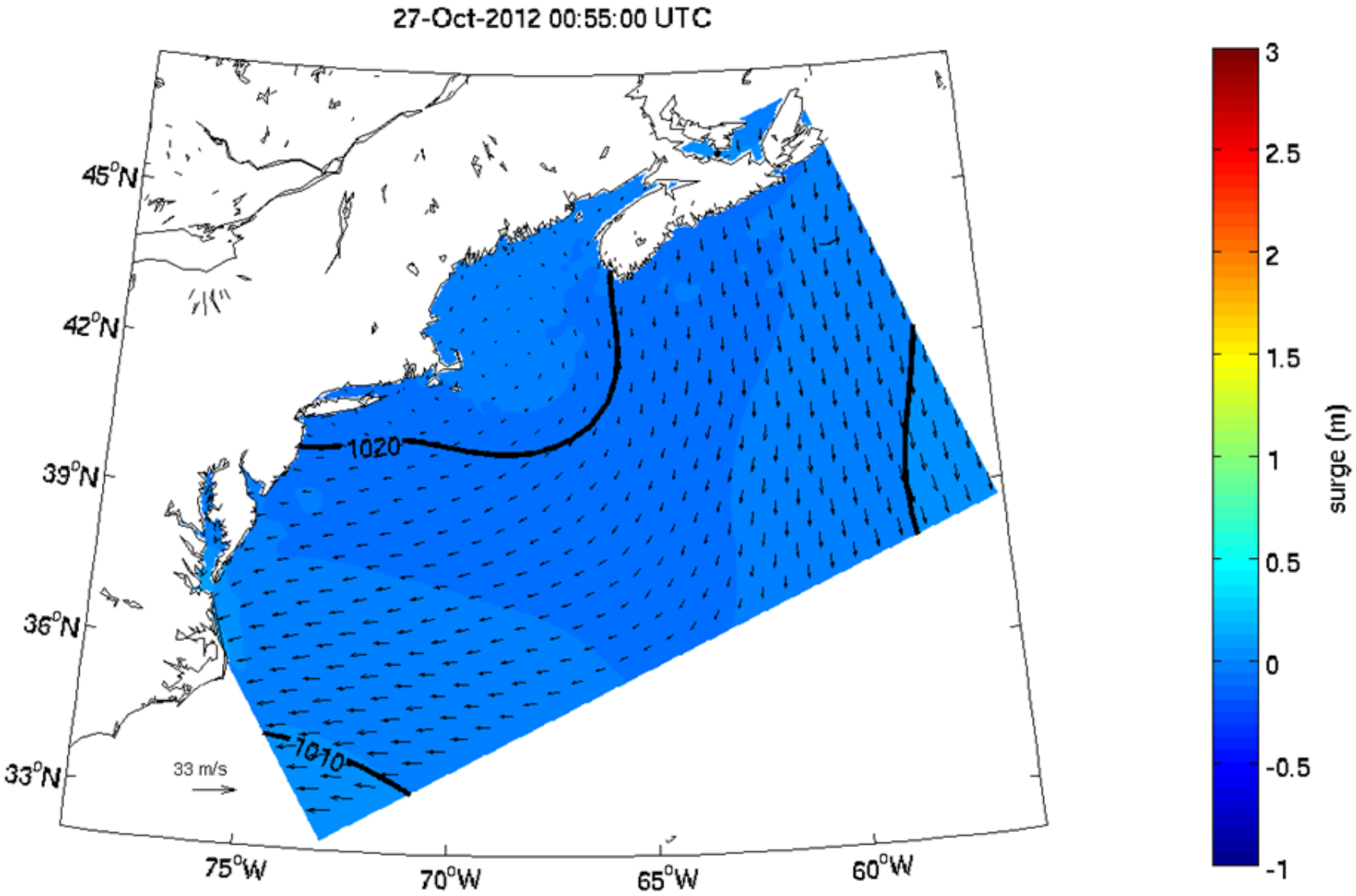
Funding from the NOAA RISA Program (Rosenzweig et al.) project "Consortium for Climate Risk in the Urban Northeast (CCRUN)"

and a NASA project for research supporting the Nat'l Climate Assessment

Thanks also to Paul Muzio and others at the CUNY High Performance Computing Center

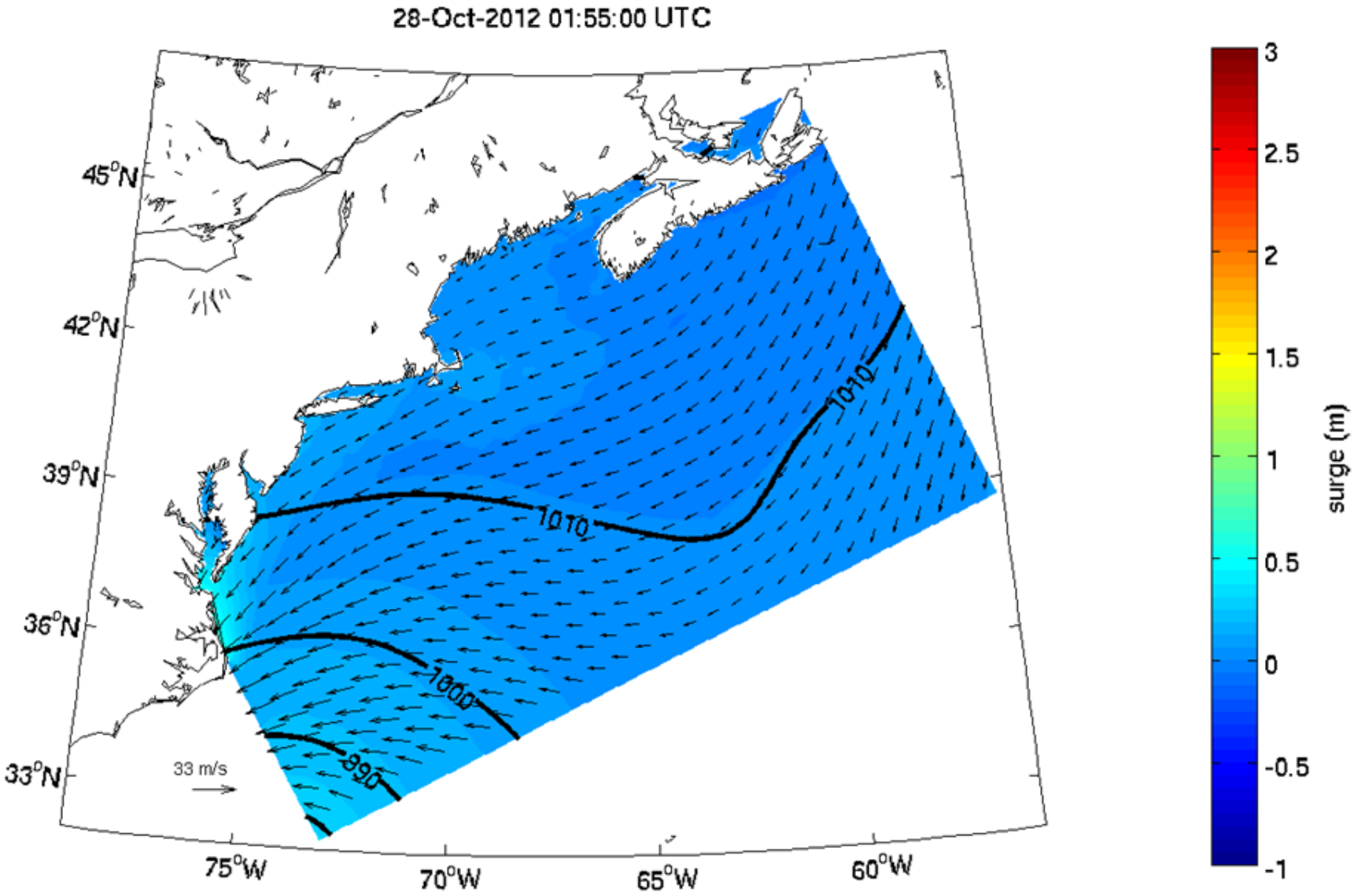

TROPICAL DEPR
TROPICAL STORM
CATEGORY 1
CATEGORY 2
CATEGORY 3
CATEGORY 4
CATEGORY 5
50 N
40 N
30 N
20 N
10 N
100 W
90 W
80 W
70 W
60 W
50 W
40 W
30 W
2012103000
2012102912
2012102818
2012102806
2012102706
2012102612
2012102512
2012102506
2012102412
2012102400
2012102212
2012102306
Track Info : 22OCT2012/12:00UTC – 30OCT2012/00:00UTC
1
McIDAS

Sandy storm surge (in meters), isobars and wind vectors (black)



Ocean Model: sECOM Model domain: Stevens Northwest Atlantic Predictions (SNAP)

Sandy storm surge (in meters), isobars and wind vectors (black)



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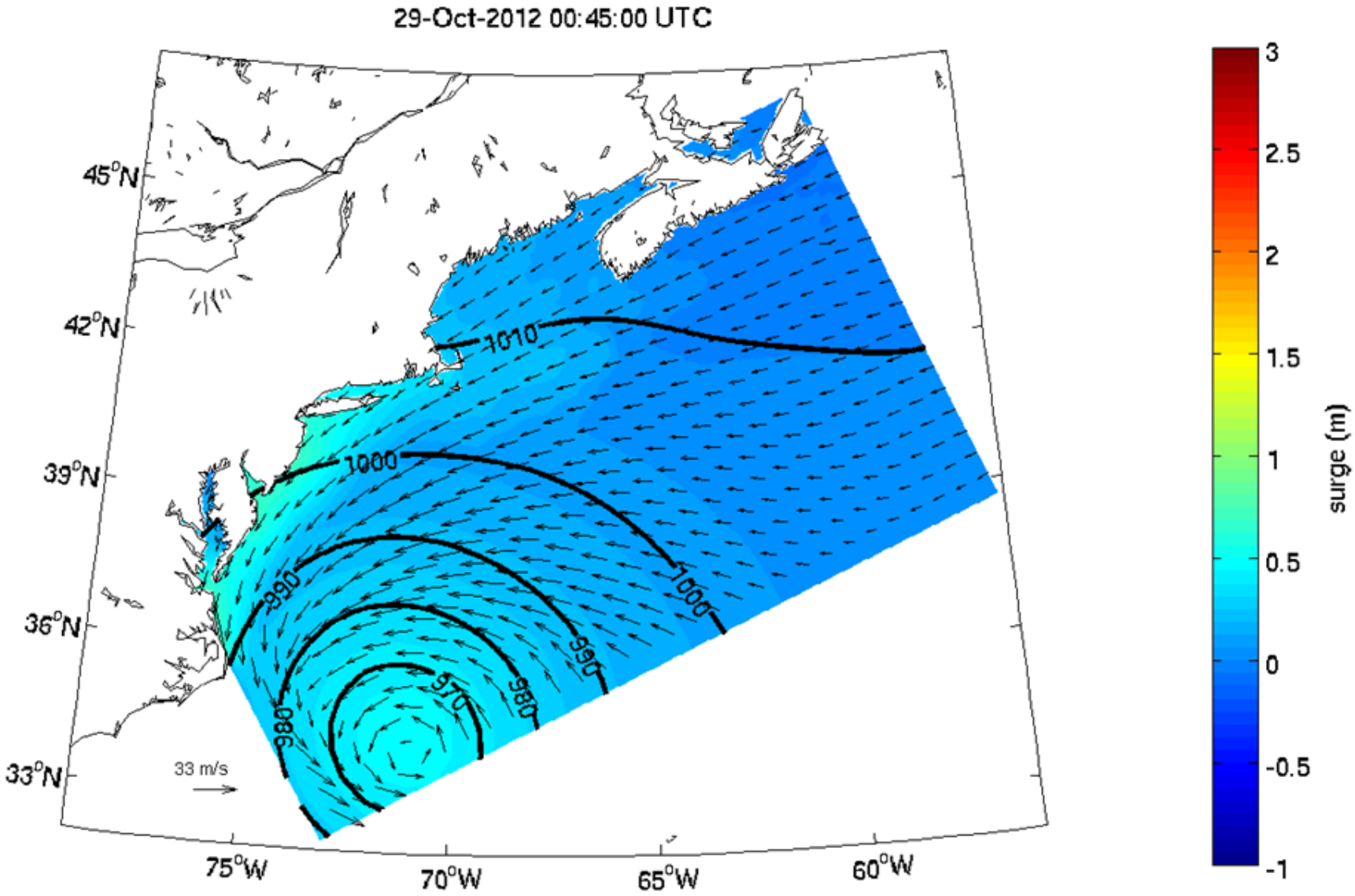

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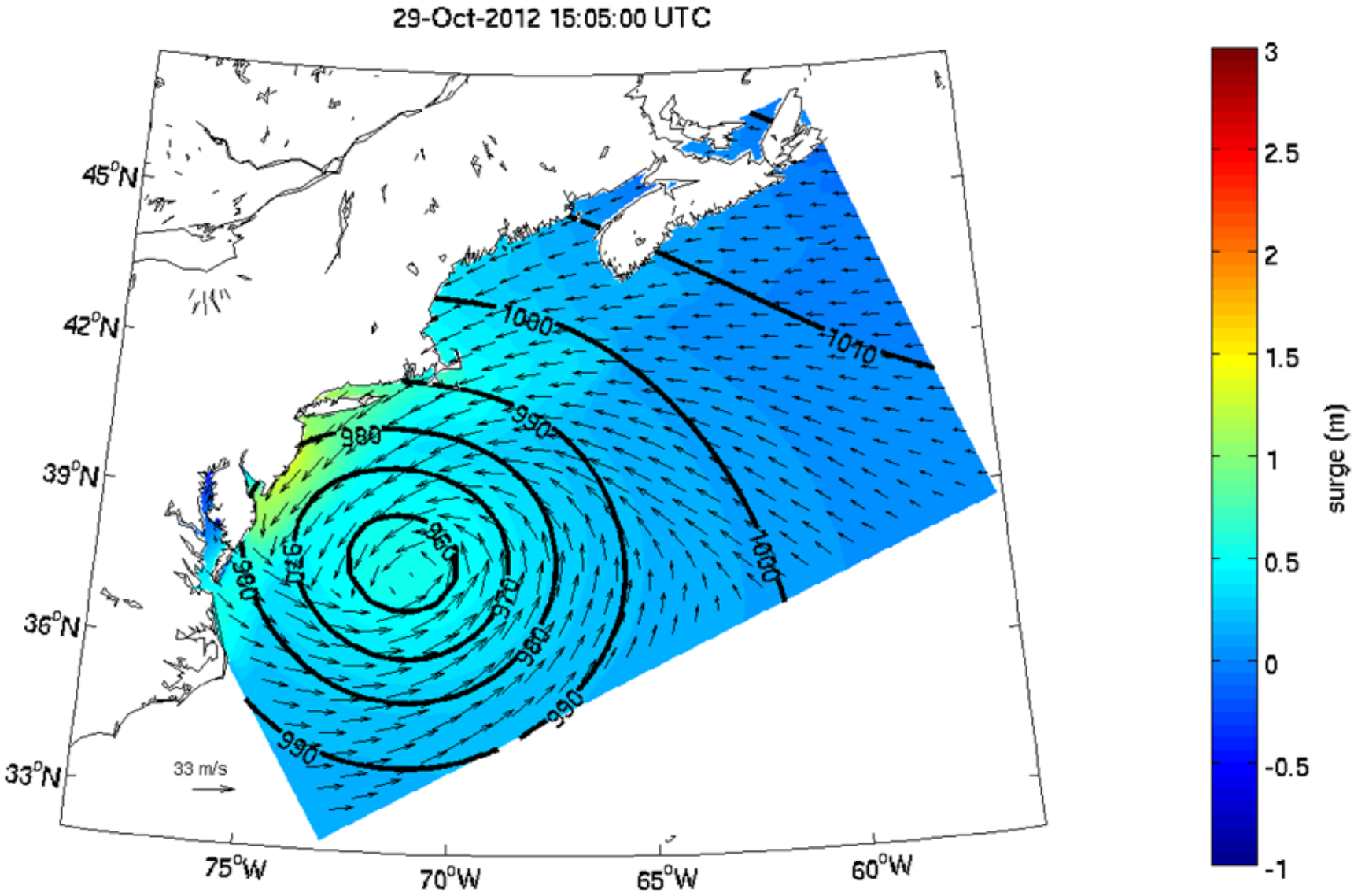

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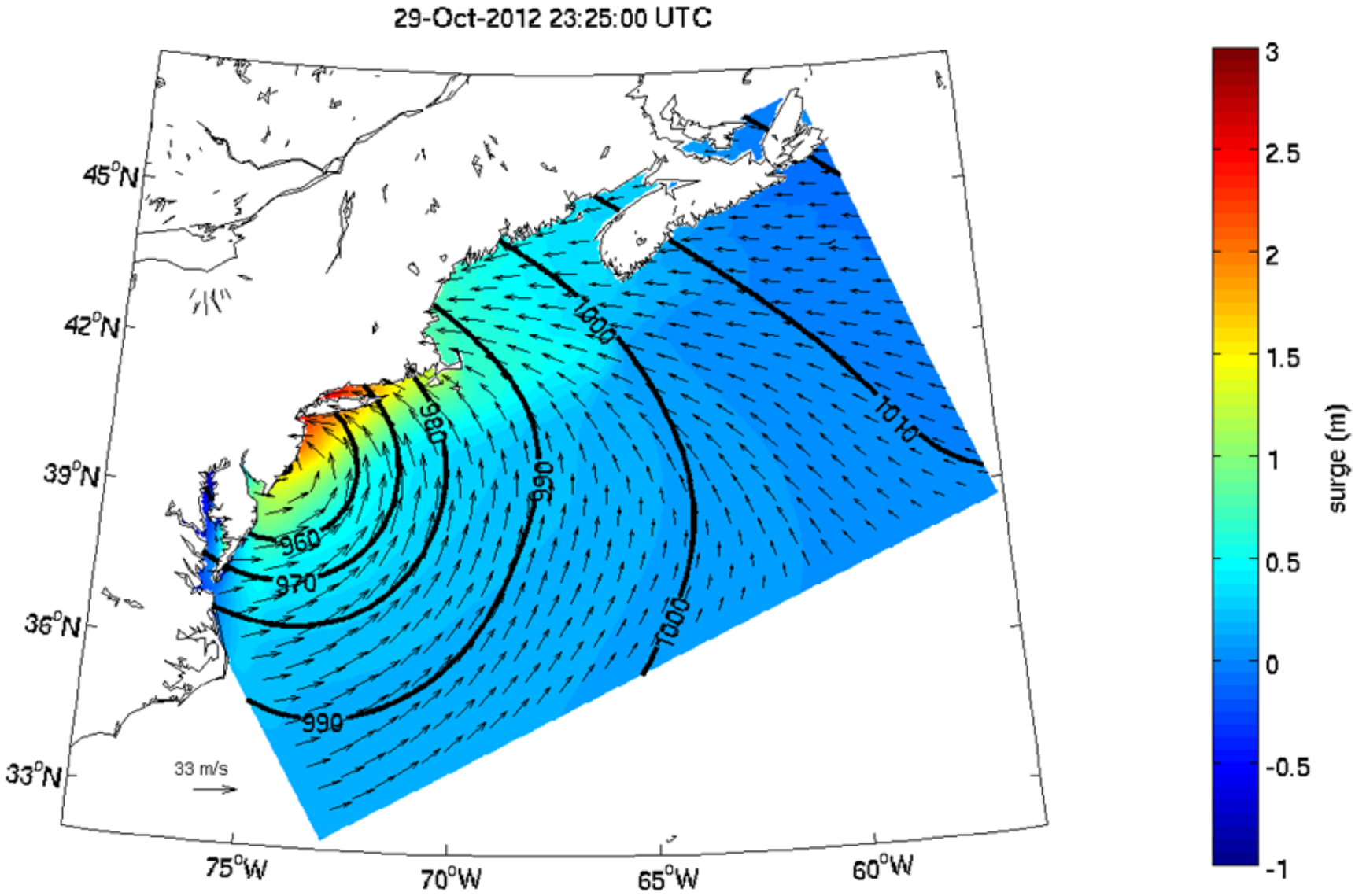
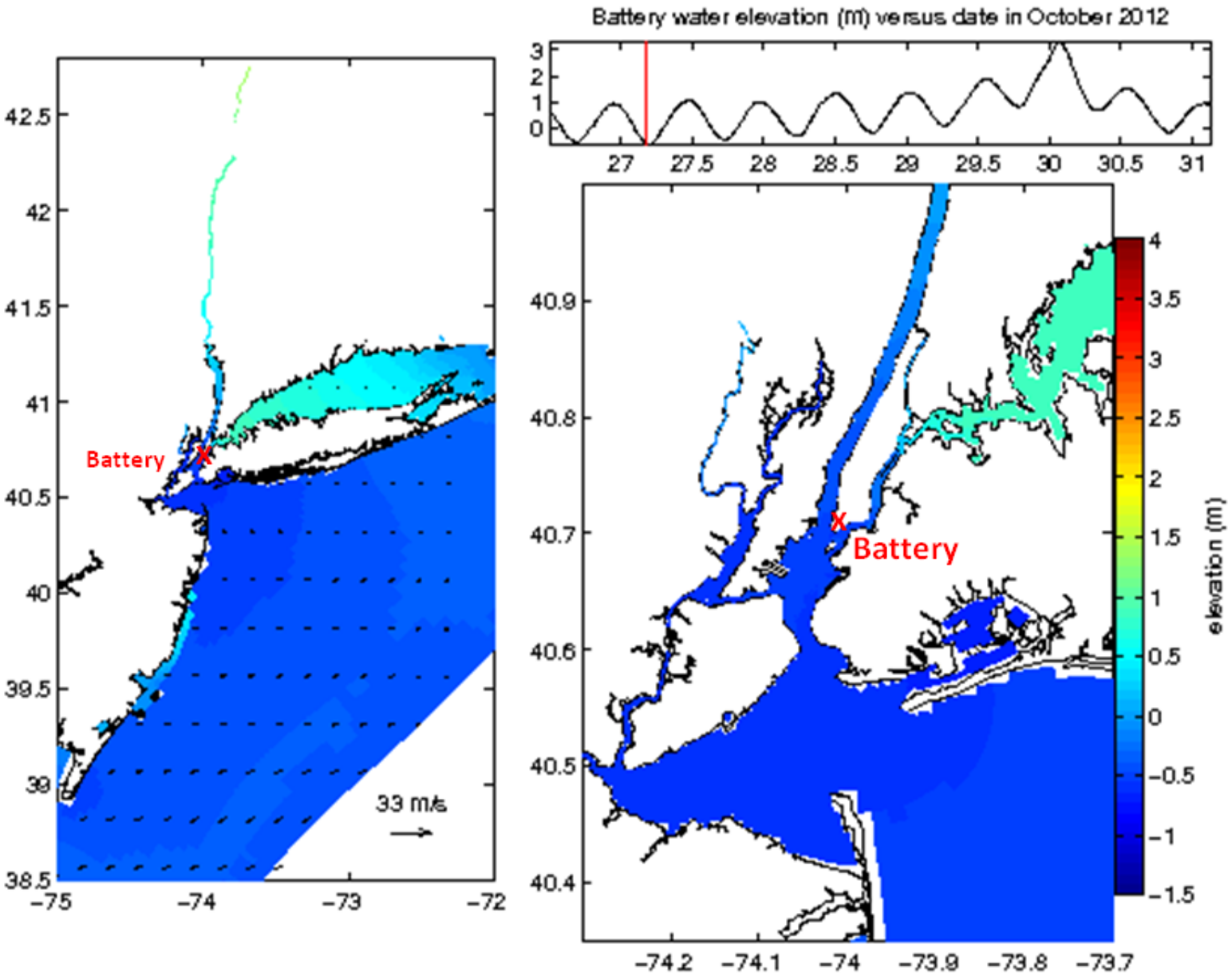


Ocean Model: sECOM Model domain: Stevens Northwest Atlantic Predictions (SNAP)

Sandy Storm Tide (total water elevation)



NYHOPS model grid – NY Harbor Observing & Prediction System (http://Stevens.edu/NYHOPS)

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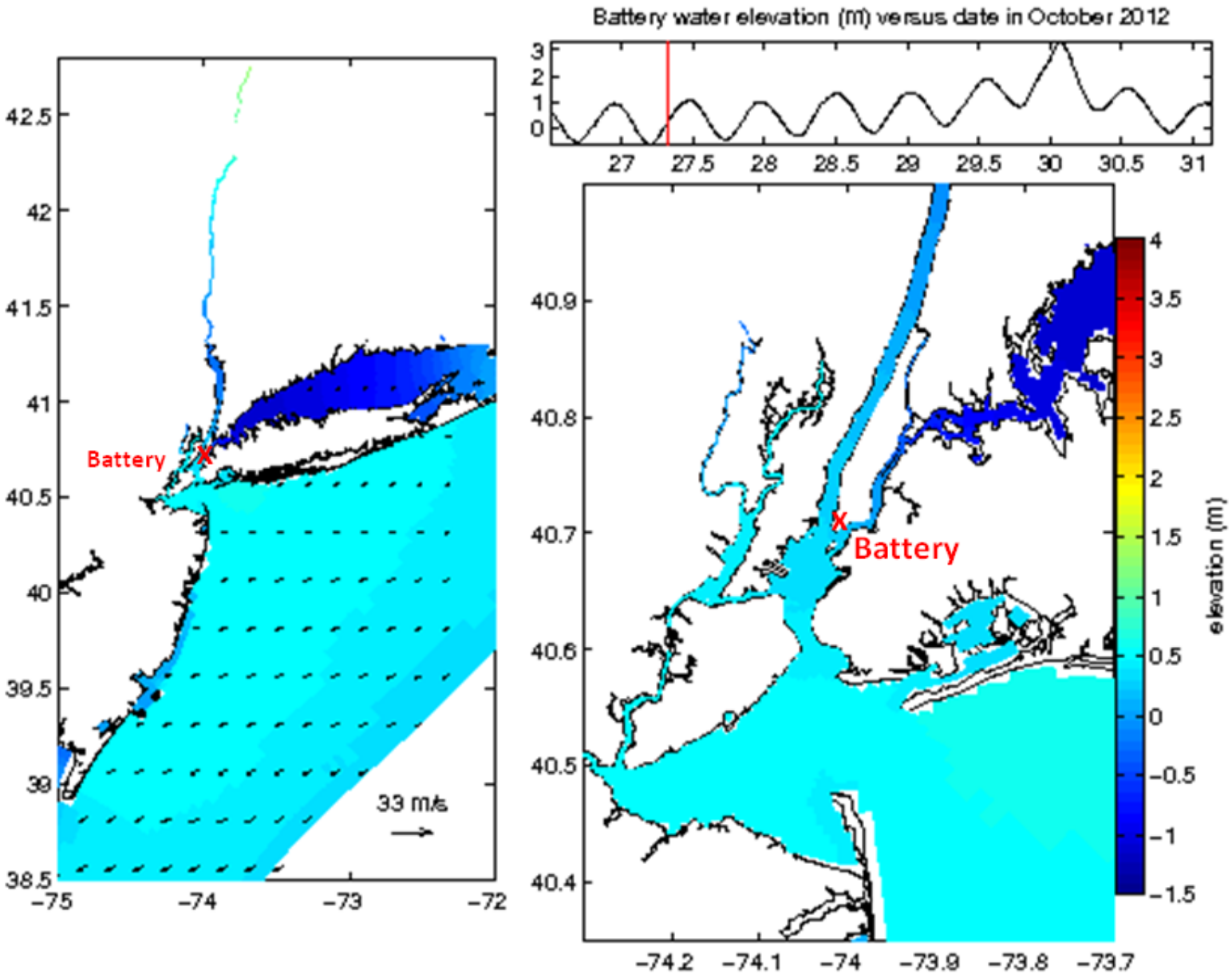

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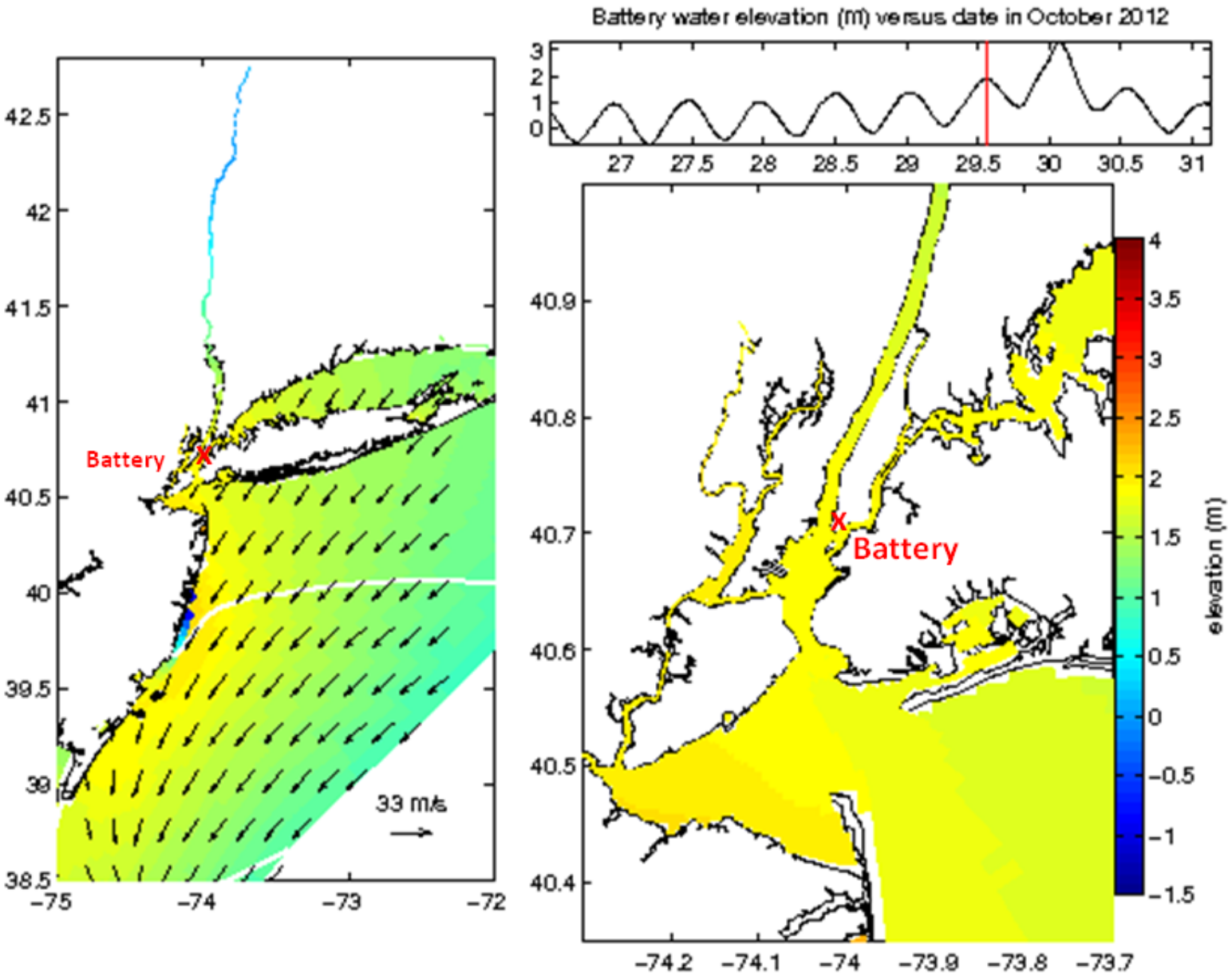

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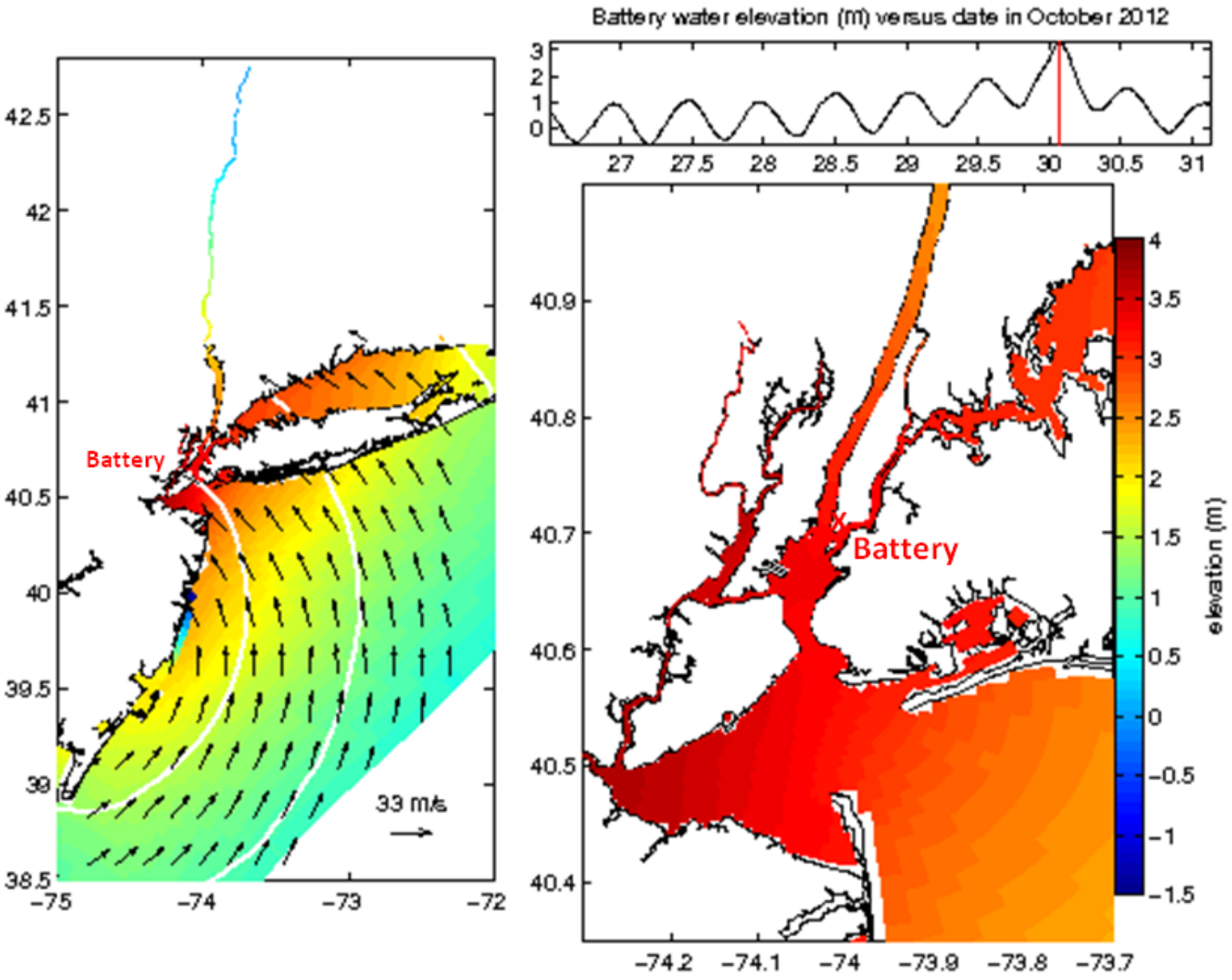


NYHOPS model grid – NY Harbor Observing & Prediction System (http://Stevens.edu/NYHOPS)

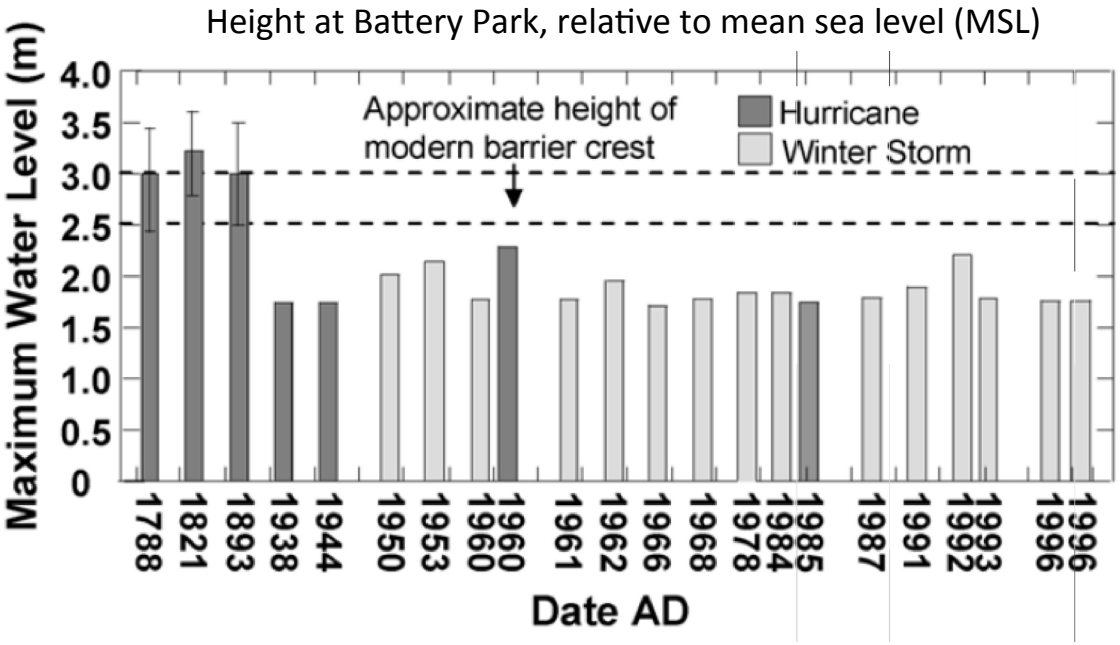
Sandy By the Numbers: Urban Flooding

- Coastal flood elevations in New York Harbor were the highest in all ~300 years of New York City history
- The water elevation at The Battery was 14.06 ft at 9:24pm EDT, with a peak storm surge of 9.4 ft coming close to high tide
- This storm tide is about 5 ft above many of the area's lower sea walls
- It beat the storm tide of Irene by 4.5 ft, the (80 year) tide gauge record of Hurricane Donna (1960) by 4.1 ft, and the estimated all-time (qualitative) record from the Hurricane of 1821 by ~2 ft

What Does History Tell Us?

Historical Extreme Water Levels at NY Harbor

Scileppi and Donnelly, *Geochemistry, Geophysics, Geosystems,* 2007



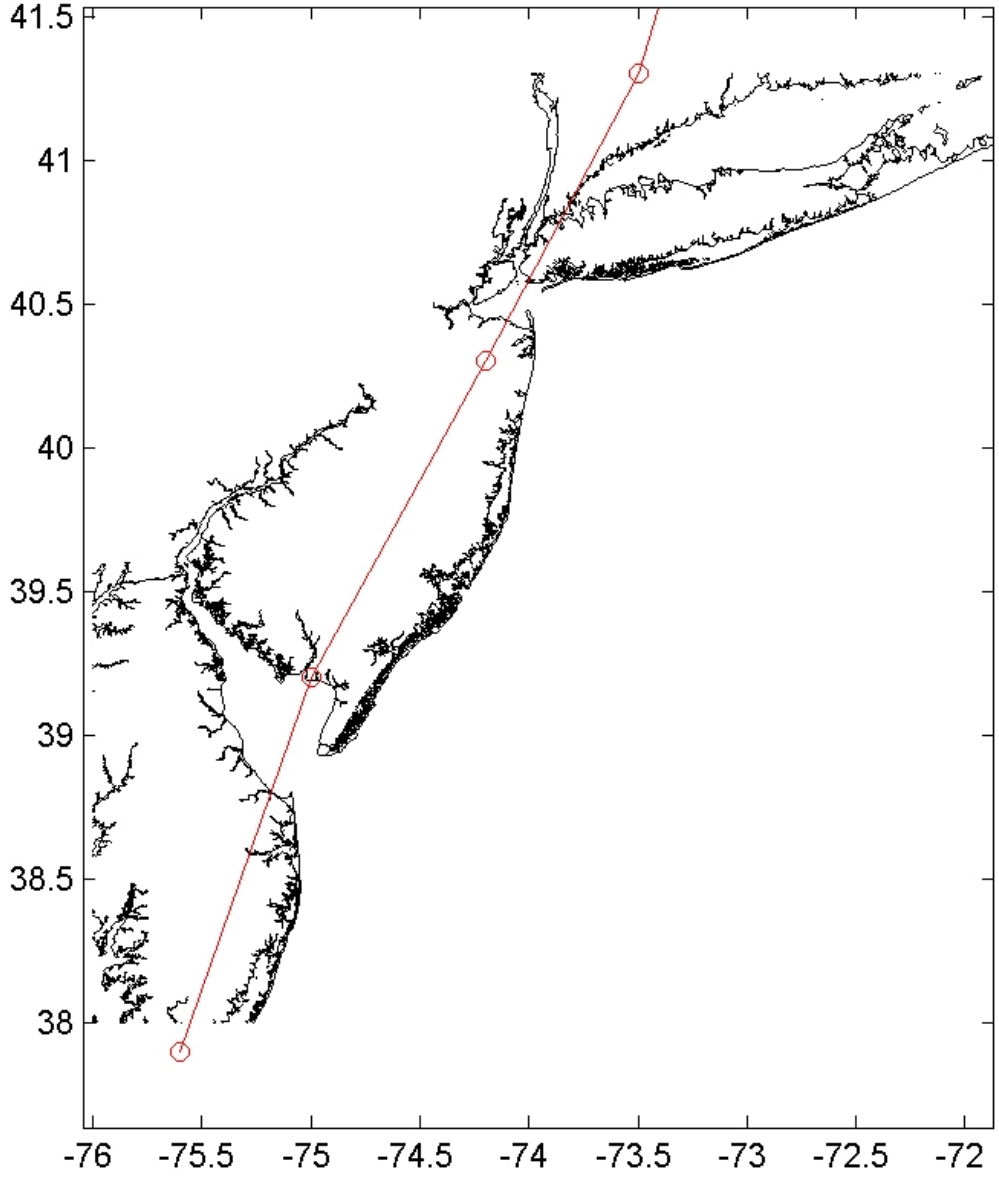
3.46 m MSL for Sandy

2.11 m MSL for Irene

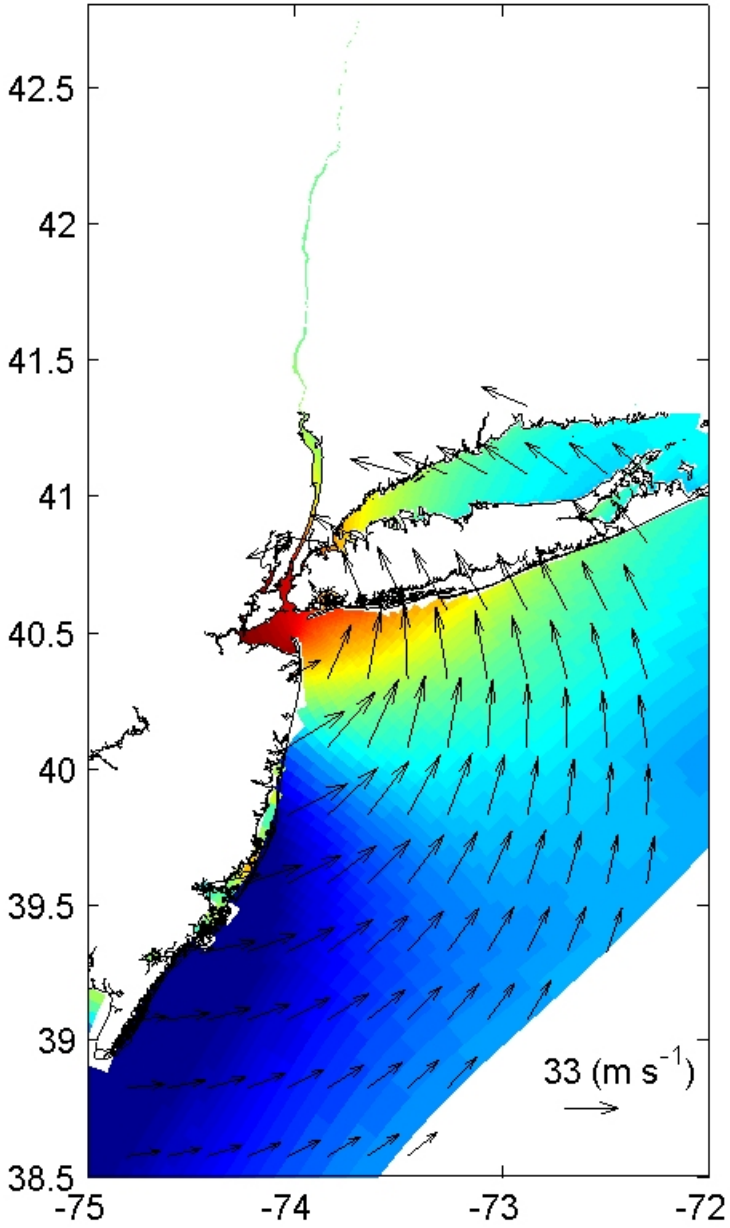
- Prior hurricanes:
  - The city is believed to have been **directly hit** by hurricanes in 1788 (Cat-3?), 1821 (Cat-3?) and 1893 (Cat-1?)

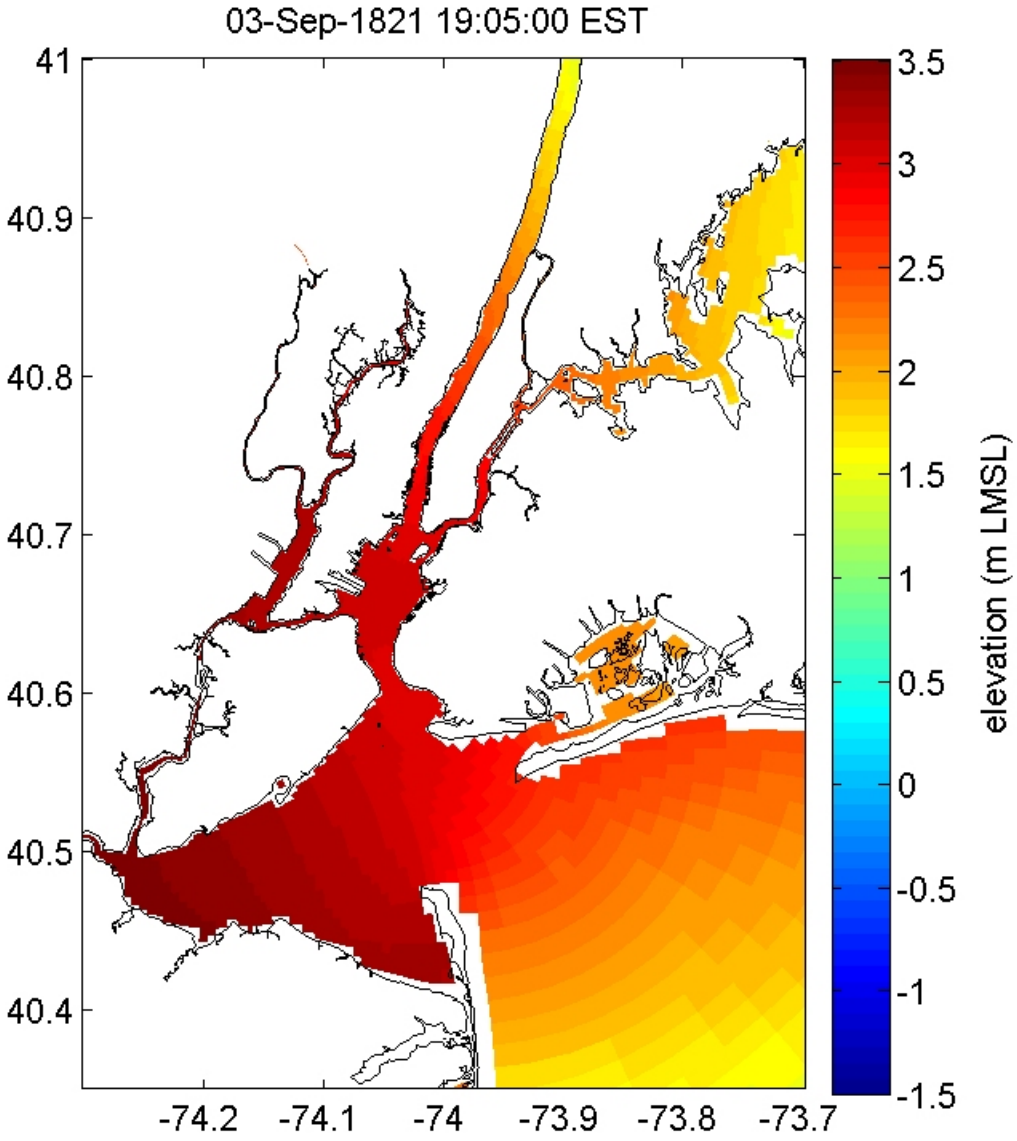
1821 Hurricane: Worse than Sandy?

- Estimated Cat-3 storm at NY Harbor landfall
- Max wind speed: 108 mph (vs 80 for Sandy)
- (don't just prepare for the next Sandy.)



1821 Simulated Wind Vectors and Water Elevation





What Does Model-Based Flood Hazard Assessment Tell Us? (work in progress)

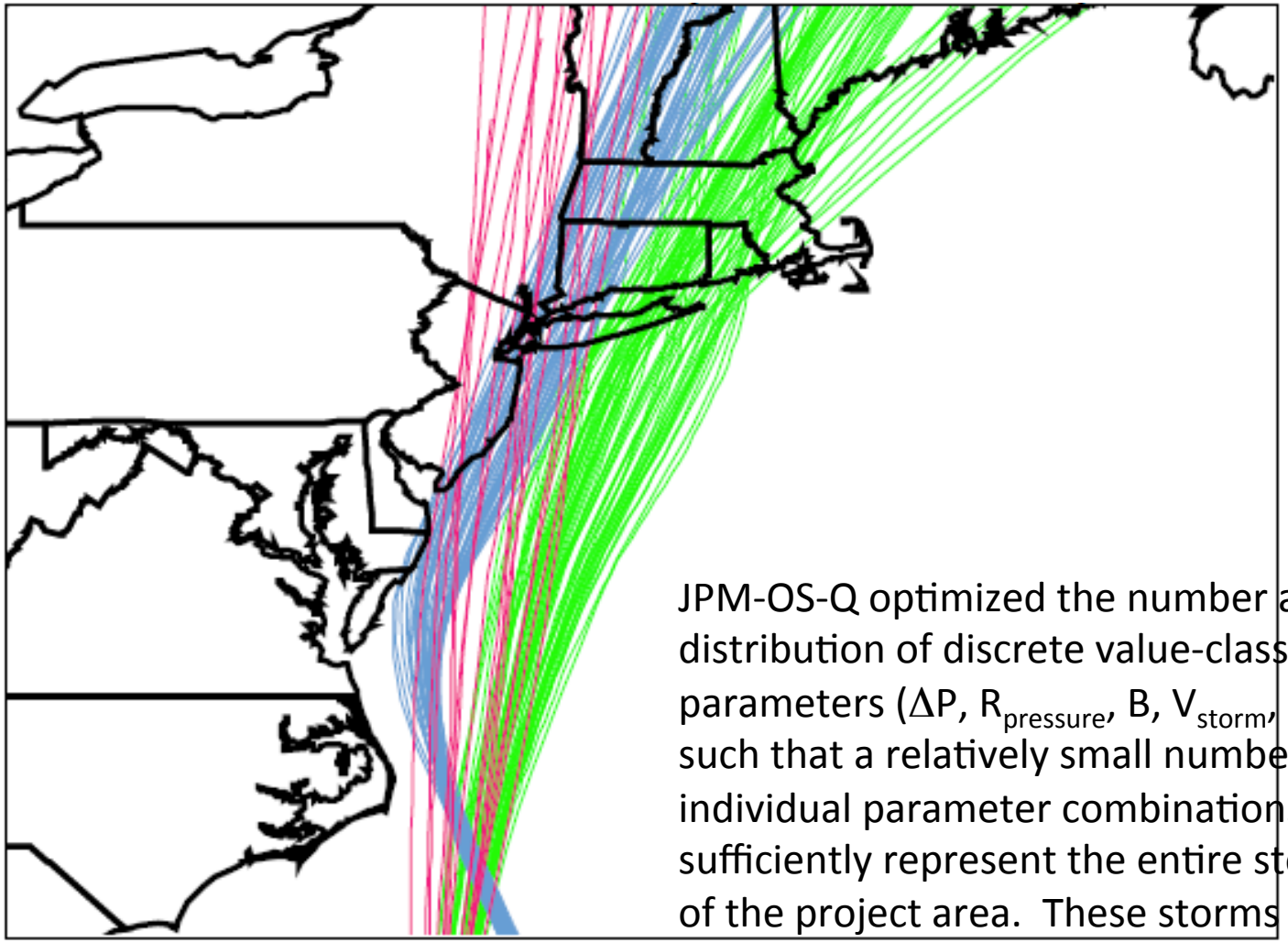
Why Use Computer Models?

- Quantitative historical observations of coastal flooding are limited, but we use all we can get to validate our atmosphere and ocean models, make sure we are not diverging from the real world
- Spatial – tide gauge stations and (recent) high water marks for storms do not cover all areas
- Temporal – the period where we have quantitative measurements of coastal flooding is limited to 90 years
  - cannot accurately estimate a 100- or even 500-year return period event
- Malleable – They also give us opportunities to study adaptation … to modify the system (wall heights, wetlands, surge barriers, etc.)

Hazard Assessments for Coastal Flooding: Tasks

- (finished) Build storm sets that represent the "current climatology"
  - Historic tropical cyclones (TC) AND extra-tropical cyclones
  - Two parametric TC models to simulate O(10000) years of TCs
- (spring 2013): Modeling improvements
  - Build and validate new over-land grids for NYC, Hudson River
  - Improve wave modeling capabilities for more detailed two-way coupling with hydrodynamics (e.g. wave set-up)
- (summer 2013) "Production runs" of flooding, base flood elevations
  - Incorporate sea level rise and any other climate changes (e.g. rain rates)
- (fall 2013) Statistics: Compute probability distributions of storm-maximum water elevation at every grid cell in NYC

FEMA's Synthetic Storm Tracks (Method JPM-OS-Q)



JPM-OS-Q optimized the number and distribution of discrete value-classes of five TC parameters (ΔP, $R_{pressure}$, B, V_{storm}, and $\theta_{landfall}$) such that a relatively small number (35) of individual parameter combinations, can sufficiently represent the entire storm climate of the project area. These storms were repeated with lateral spacing to give a total of 169 storms.

Parametric Statistical-Stochastic TC Model
(Hall/Jewson, 2007; Sobel and Hall, 2013)

- Modeled parameters:
  - (1) intensity (wind speed)
  - (2) size
  - (3) rainfall rate
  - (4) storm track
- Statistical
  - behavior based on statistics of all prior Atlantic TCs, weighted by distance from current location
- Stochastic
  - behavior has a random component

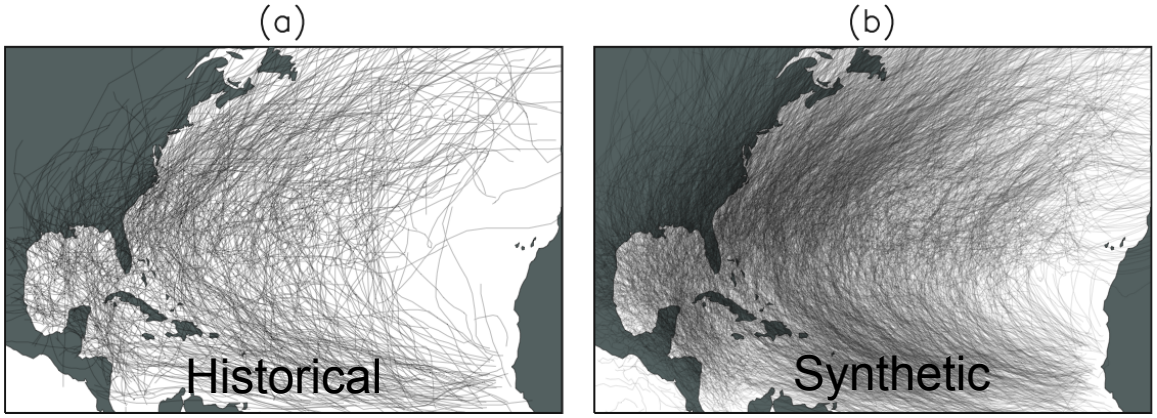


Figure 5: (a) Historical TC tracks from HURDAT 1950-2008; (b) synthetic tracks generated from the stochastic model by simulating the historic period 20 times. Statistical characteristics of the synthetic event set closely match those of the historic set. The much larger synthetic set is used for risk analysis at landfall. Credit: Tim Hall, NASA-GISS.

Stevens ECOM (sECOM) Model Domain for NYHOPS

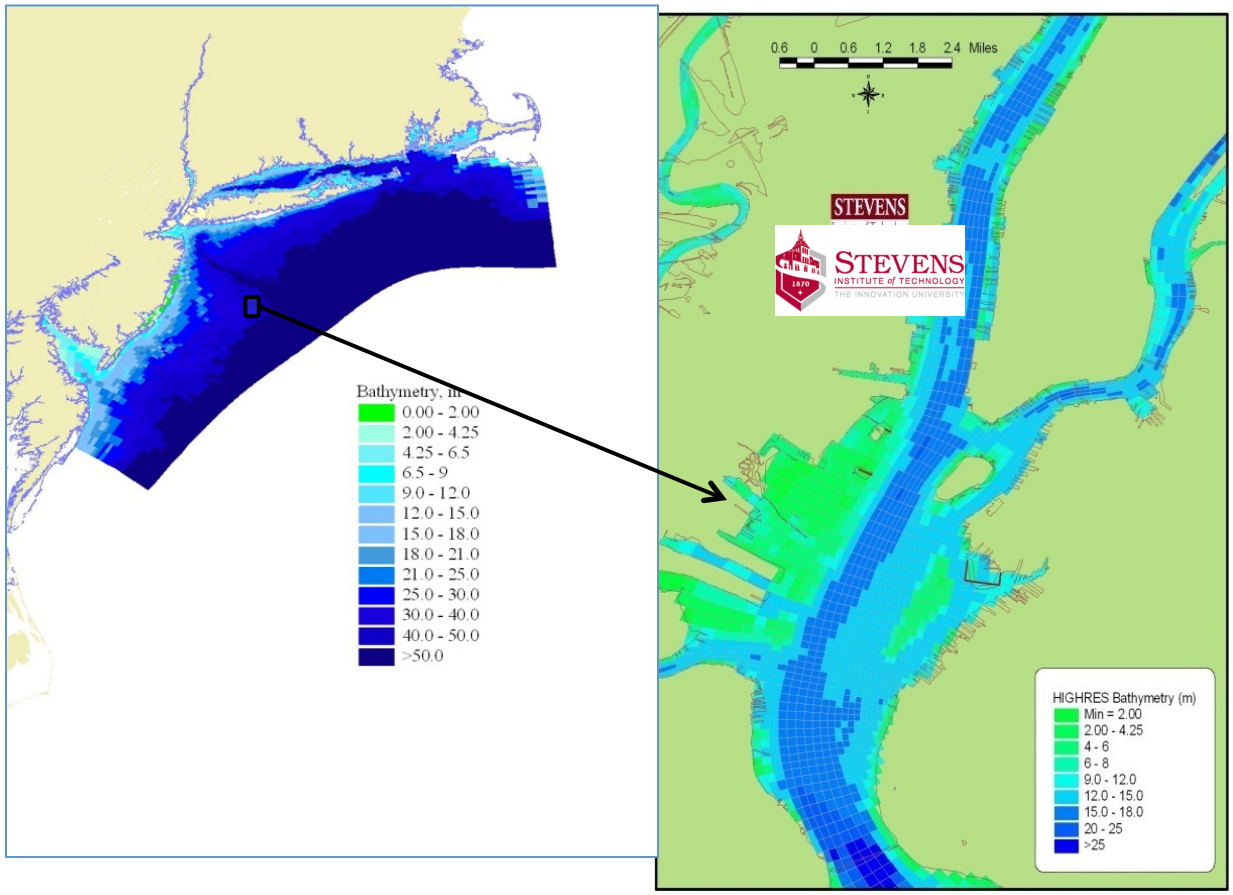
Model: three-dimensional, ~100 m resolution for NYC area, coupled with the GLERL wave model

Atmospheric forcing: NAM WRF 12 km wind, pressure

Freshwater: Gaged major tribs (93), estimated minor tribs (146), WWTP (241)

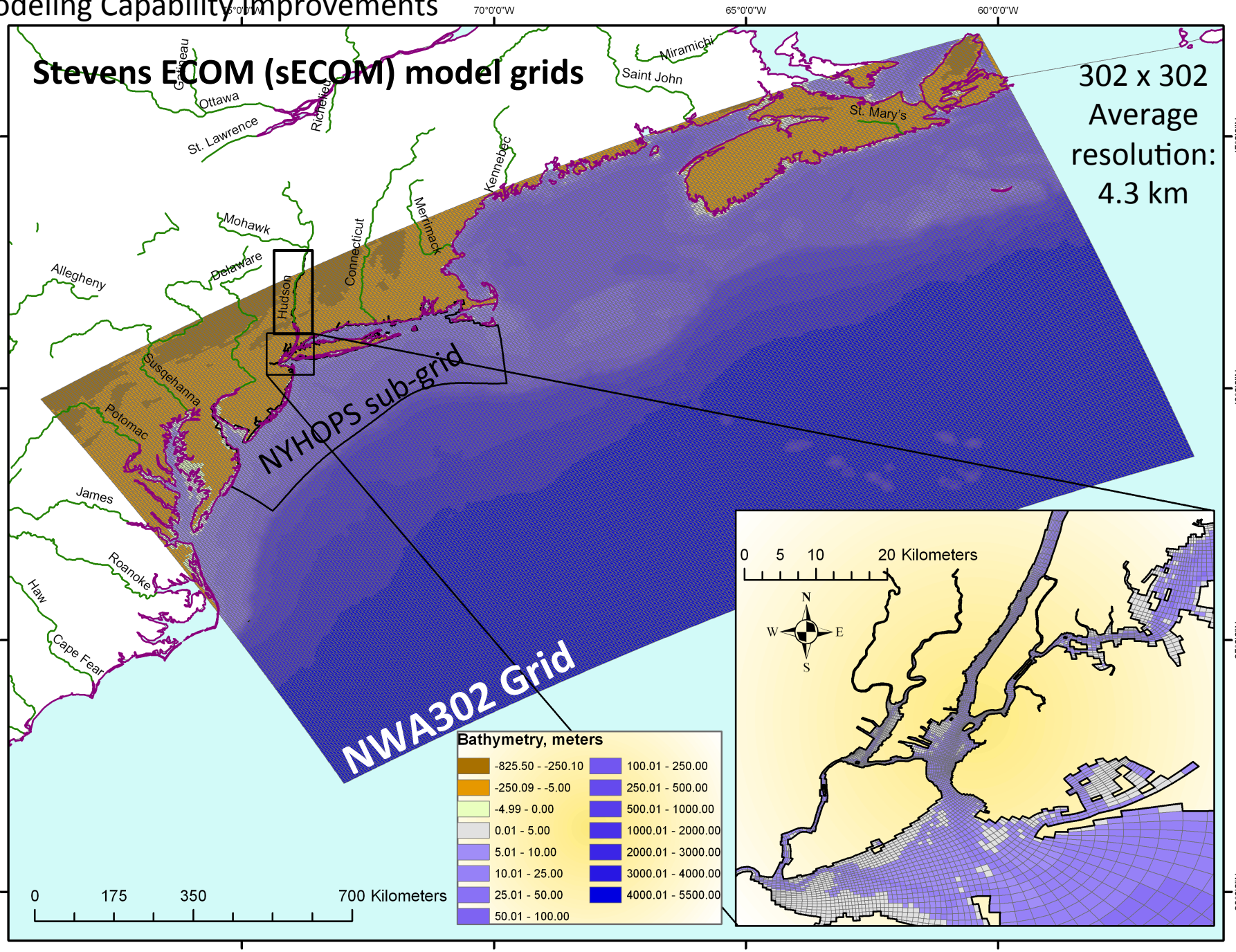
Tides: 9 constituents at open-ocean boundary

Validation: (V1) Blumberg et al, 1999; (V3) Georgas and Blumberg, 2009; Georgas, 2010; and **Orton et al. JGR 2012** for Irene (0.05-0.20 m rms errors)

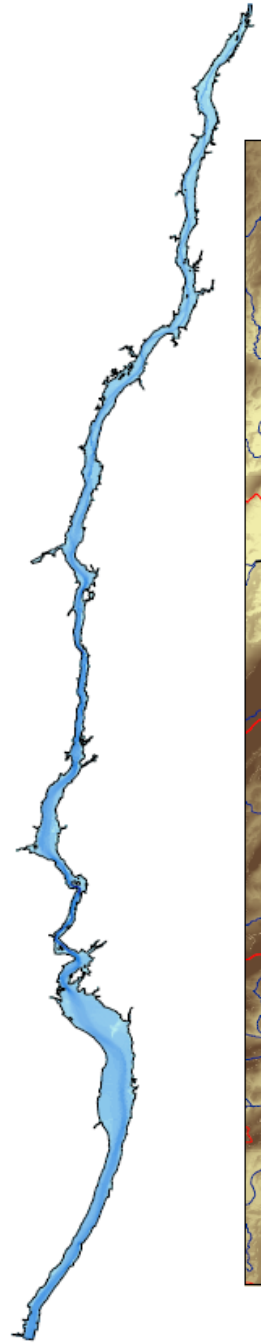


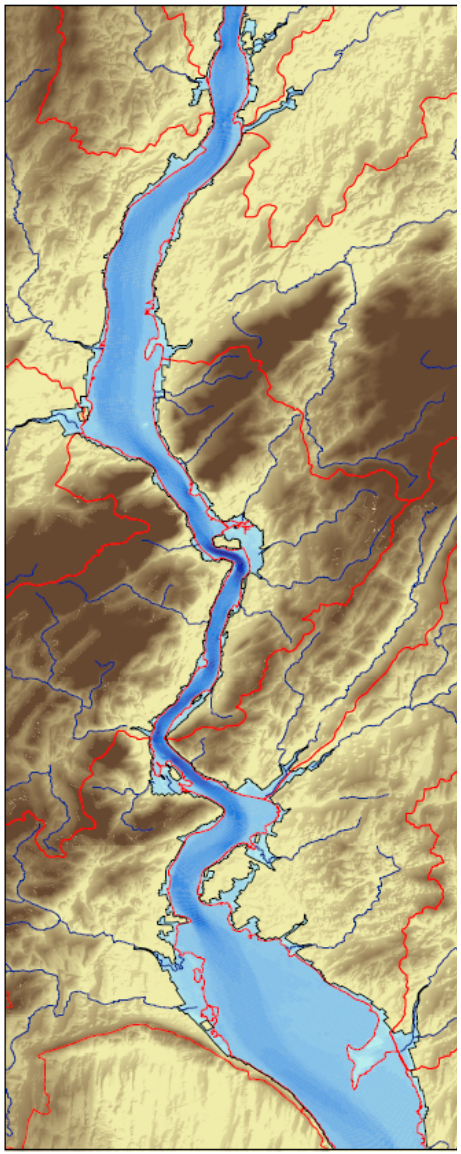
Operational system of observing sensors and forecast models:
http://stevens.edu/nyhops

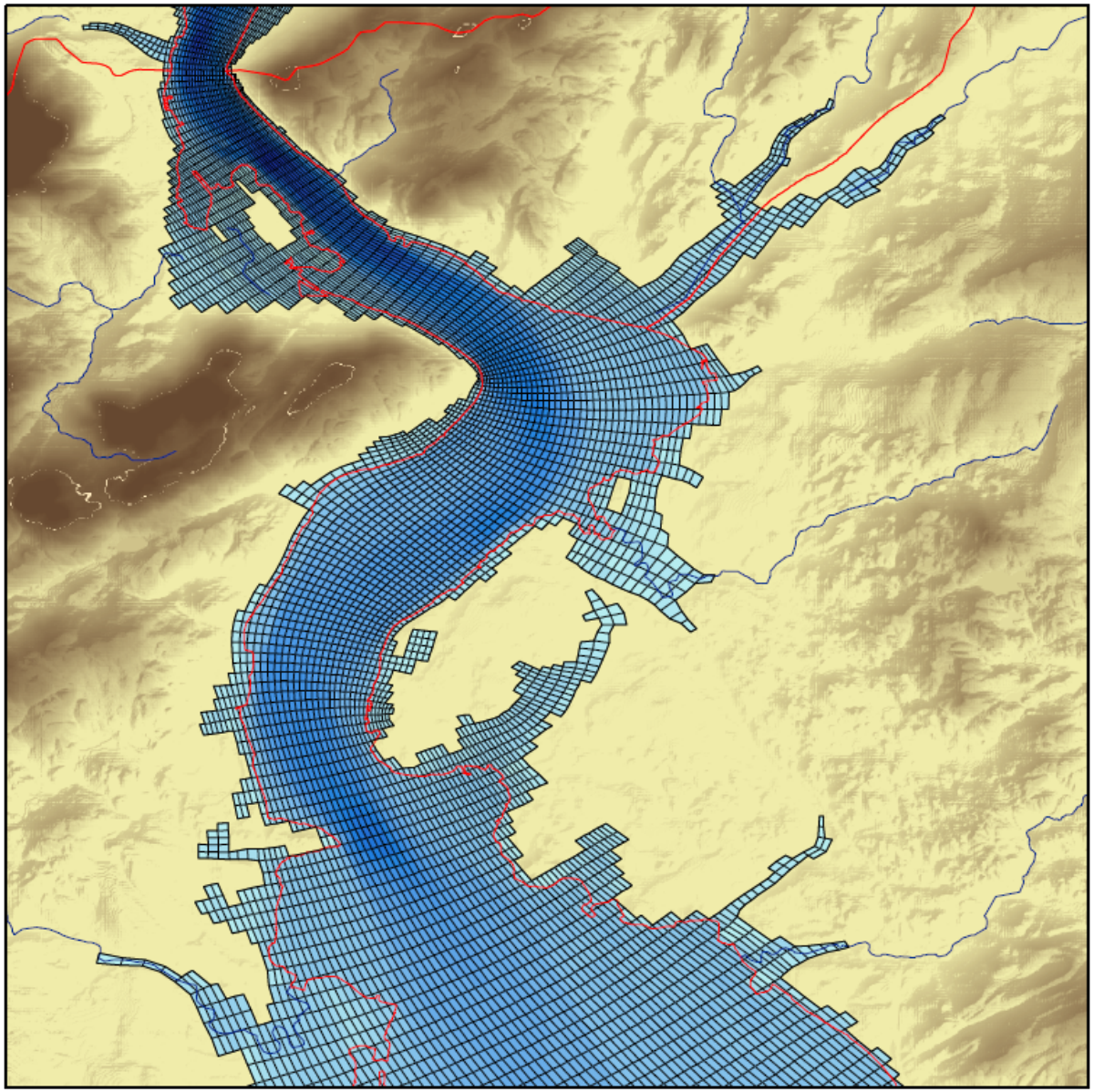
Funding: NJDOT, and many other sources


Stevens ECOM (sECOM) model grids
302 x 302
Average
resolution:
4.3 km
NYHOPS sub-grid
NWA302 Grid
Bathymetry, meters
-825.50 - -250.10
-250.09 - -5.00
-4.99 - 0.00
0.01 - 5.00
5.01 - 10.00
10.01 - 25.00
25.01 - 50.00
50.01 - 100.00
100.01 - 250.00
250.01 - 500.00
500.01 - 1000.00
1000.01 - 2000.00
2000.01 - 3000.00
3000.01 - 4000.00
4000.01 - 5500.00
0 175 350 700 Kilometers
0 5 10 20 Kilometers
N
W E
S
Ottawa
St. Lawrence
Richelieu
Gatineau
Miramichi
Saint John
St. Mary's
Kennebec
Merrimack
Connecticut
Mohawk
Hudson
Delaware
Allegheny
Susquehanna
Potomac
James
Roanoke
Haw
Cape Fear
75°0'0"W
70°0'0"W
65°0'0"W
60°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N

New Hi-Res Hudson River Overland Grid

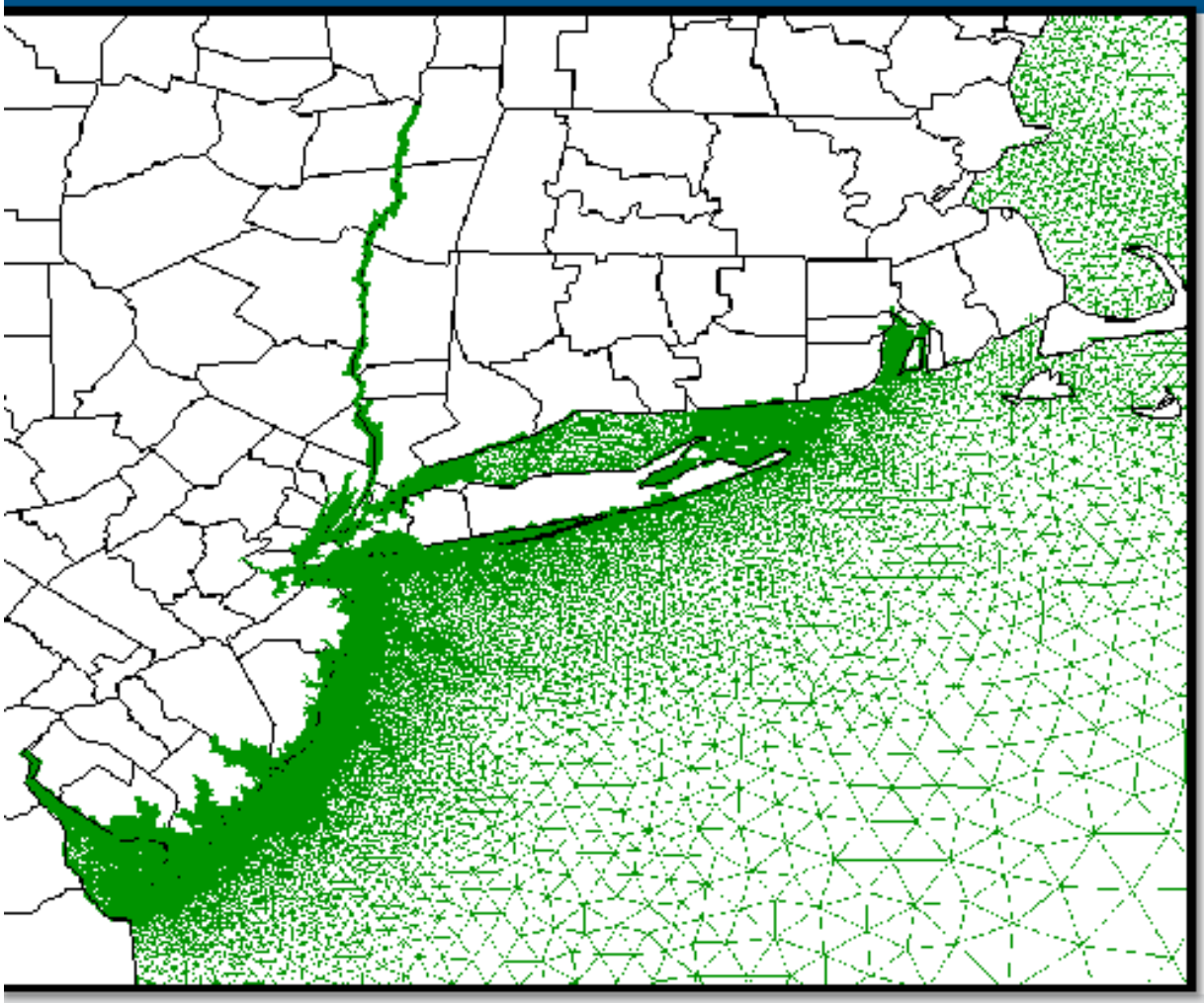




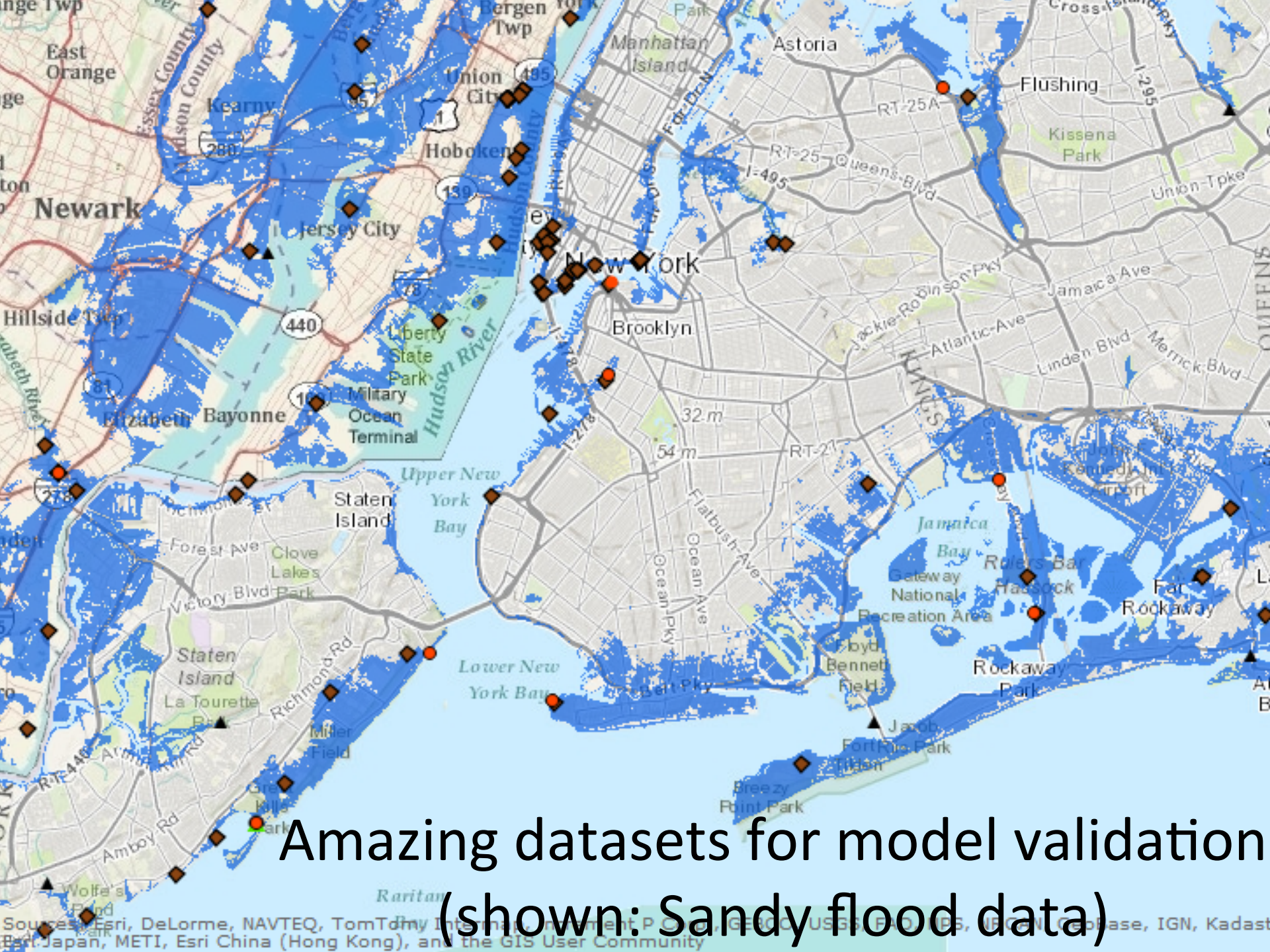


Funding: NYSDEC /Hudson River Sustainable Shorelines

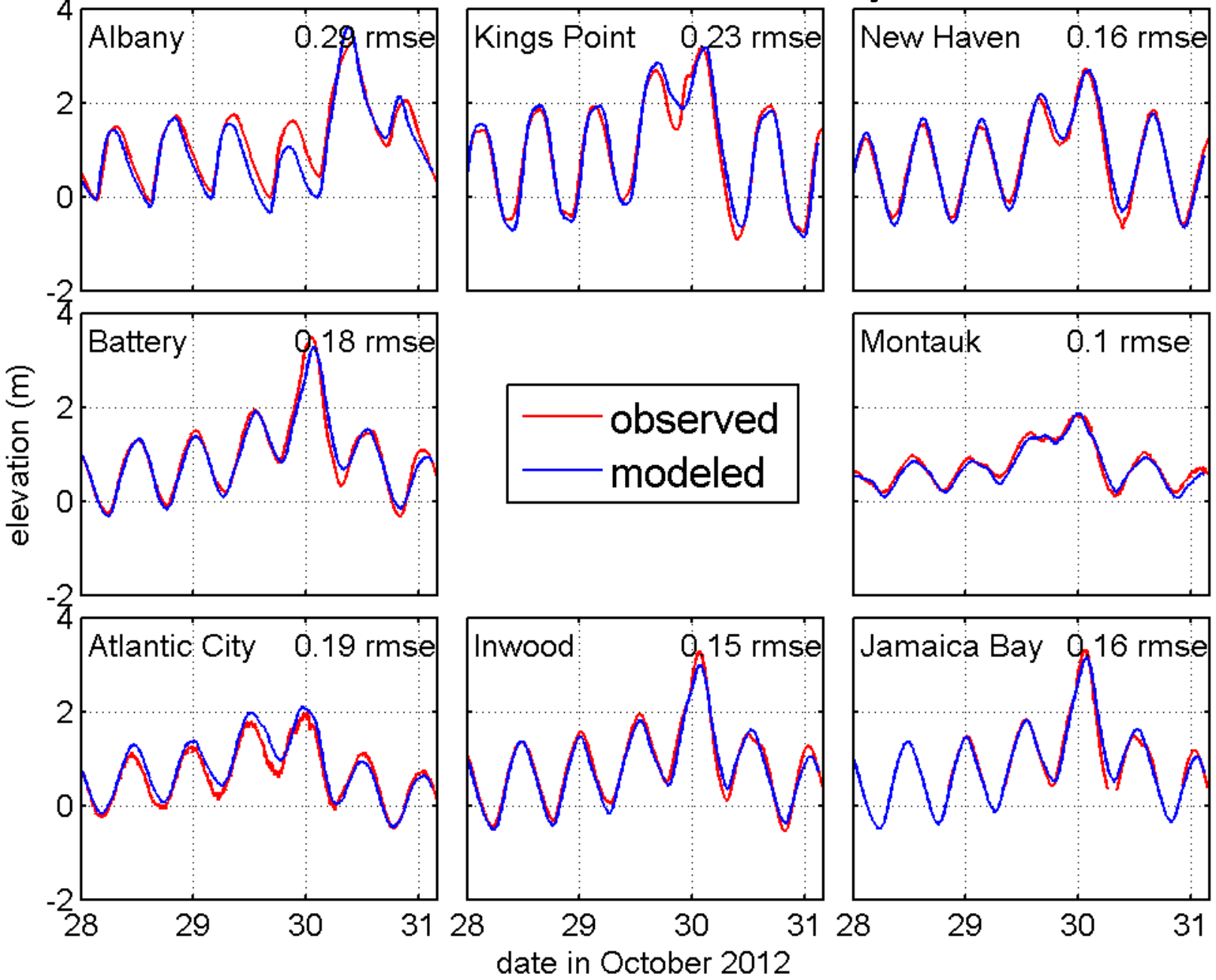
ADCIRC/SWAN Mesh



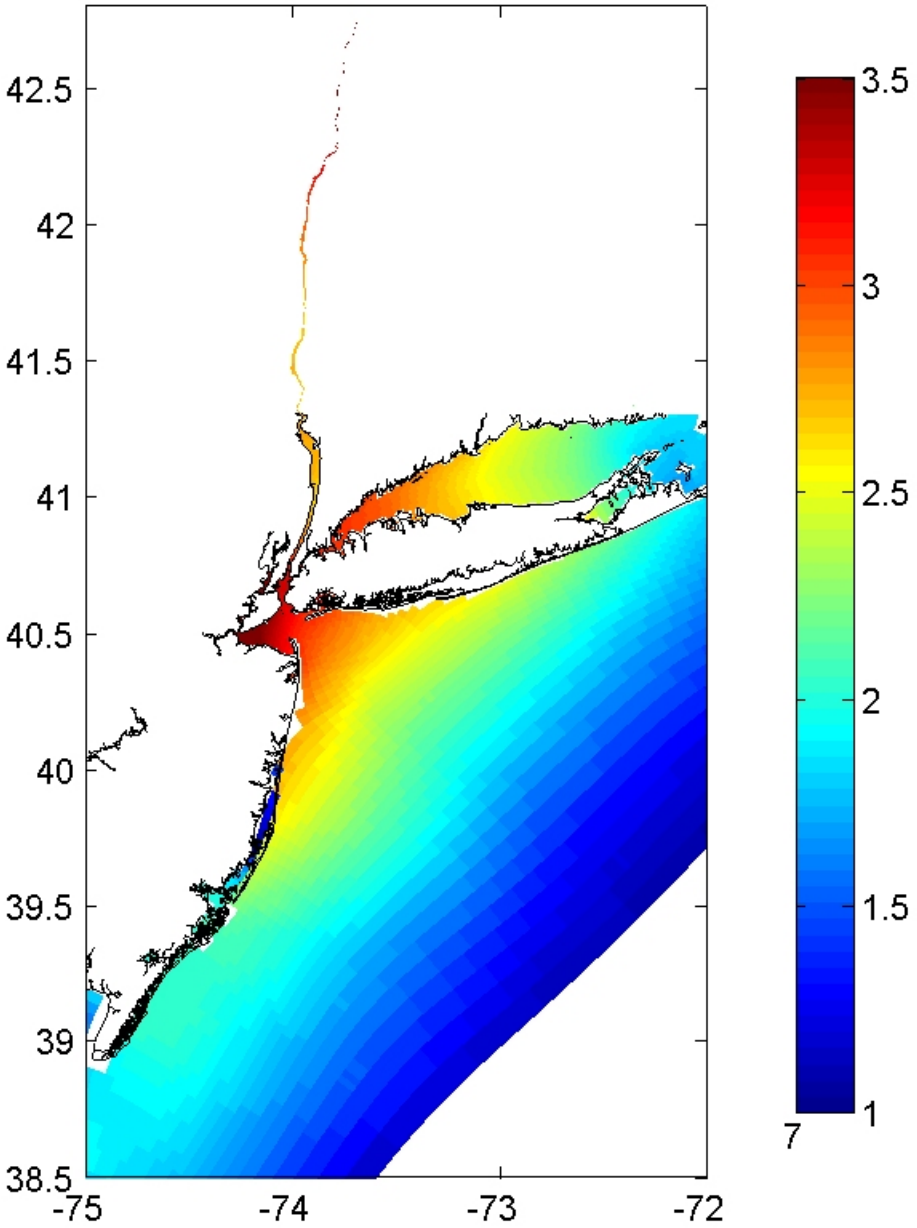
Nodes: 604,790
Elements: 1,188,640
Min mesh size: 70 meters
1 second time step goal

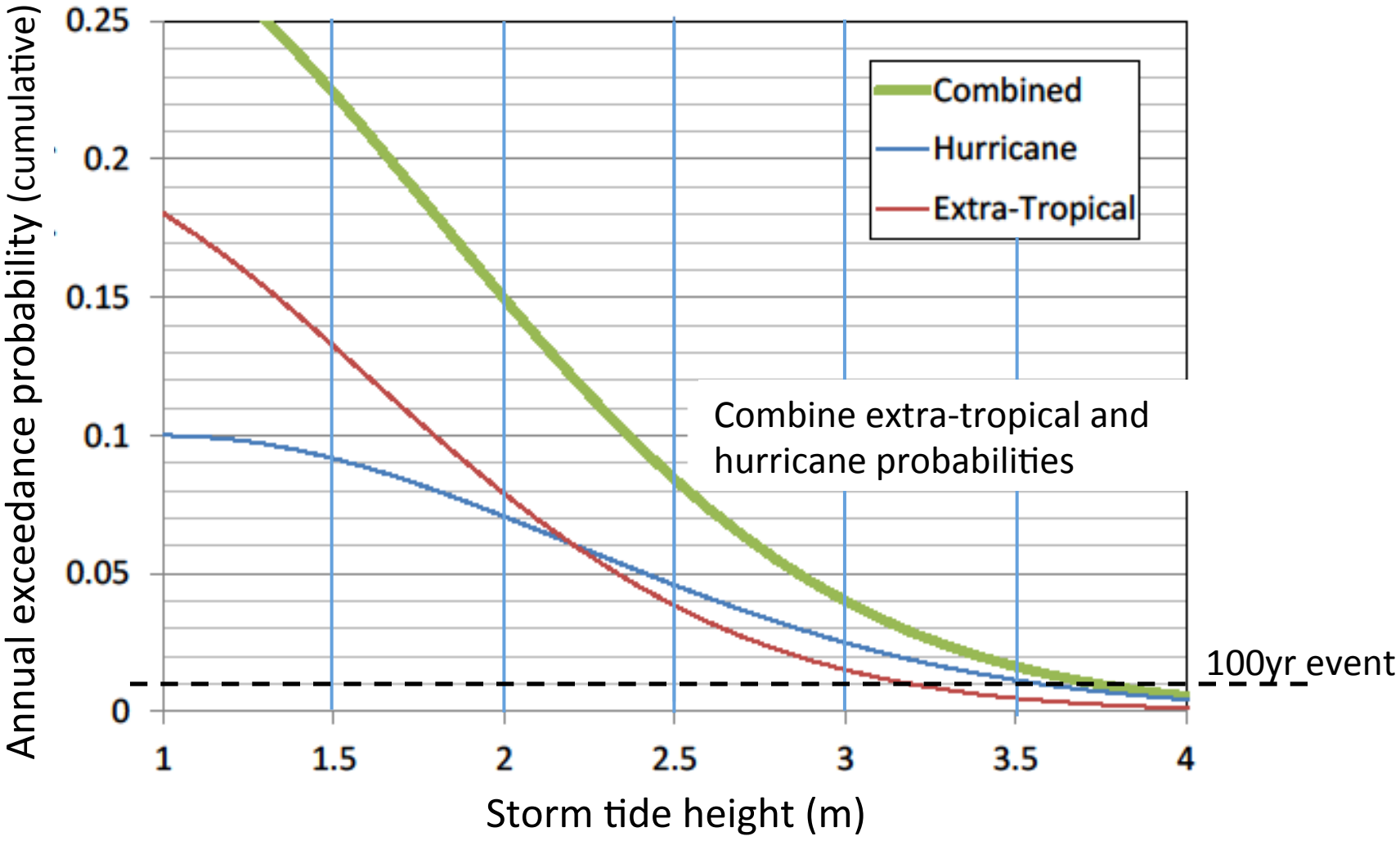

Amazing datasets for model validation
(shown: Sandy flood data)
Newark
Jersey City
New York
Brooklyn
Hoboken
Bayonne
Staten Island
Flushing
Astoria
Manhattan Island
Hudson River
Upper New York Bay
Lower New York Bay
Jamaica Bay
Rockaway Park
Far Rockaway
Gateway National Recreation Area
Liberty State Park
Military Ocean Terminal
Clove Lakes Park
Miller Field
La Tourette Park
Floyd Bennett Field
Fort Tilden
Breezy Point Park
Kissena Park
Union City
Kearny
Hillside Twp
East Orange
Bergen Twp
Elizabeth
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadast
East Japan, METI, Esri China (Hong Kong), and the GIS User Community

Model Validation for Sandy Hindcast



Sandy MEOW: Maximum Envelope of Water




Annual exceedance probability (cumulative)
0.25
0.2
0.15
0.1
0.05
0
1
1.5
2
2.5
3
3.5
4
Storm tide height (m)
Combined
Hurricane
Extra-Tropical
Combine extra-tropical and hurricane probabilities
100yr event

FEMA

Preliminary Conclusions

- Sandy was the highest flood levels on record for many sites in the region
- We're looking deeply into historical information for guidance with our model-based flood hazard assessment work
- We have not quantified the return period in our work yet, but *roughly* a 100- to 400-year event (based on history, no climate change)
  - we've seen a Cat-3 storm before (1821) but it came at low tide
  - we've seen a "left turn" before - Perfect Storm, 1991
- In our new projects, we will quantify and map coastal flood hazards with sea level rise
  - for NYC,
  - the Hudson Valley and
  - (likely; funding permitting) urban Northern New Jersey