Hurricane Wind and Inundation Risk on the US Northeast and New York City

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Philip Orton and Alan Blumberg, Stevens Institute Technology, NJ

Atlantic City, NJ, hours before Sandy landfall

Recent and remaining work

- Statistical/stochastic model to generate large synthetic NA TC event set (*done*).
- Estimate landfall probabilities on NYC-region (*done*).
- Subset of NYC TCs to drive high-resolution hydrodynamic model of surge (*done*).
- Model sensitivity to natural climate states NAO, SOI, AMM (*current*).
- Develop statistical rainfall model (*current*).
- Experiment with parametric wind-field sensitivity (*current*).
- Perform hydrodynamic simulations on synthetic TC subset (*current*).
- Repeat with different SLR scenarios (*remains*).

North American tropical cyclone landfall and SST: a statistical model study

Timothy Hall and Emmi Yonekura, *J. Climate, 2013.*

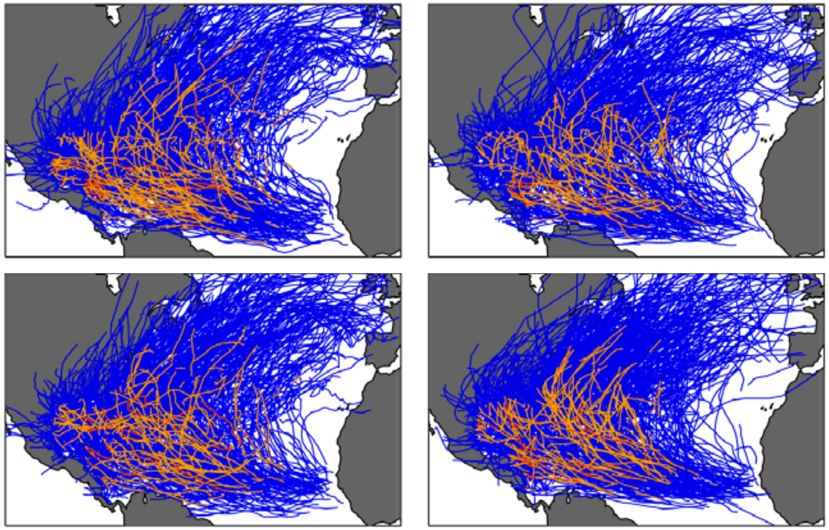
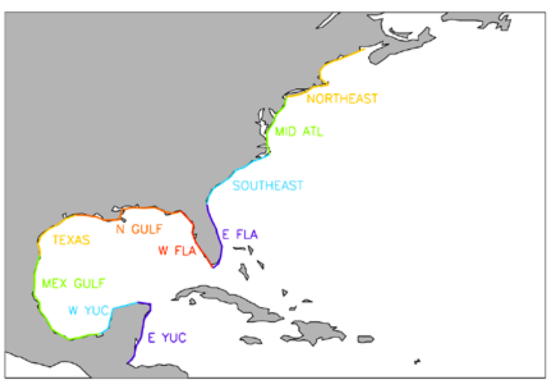


Fig 1: Three stochastic realizations of TCs 1950-2010 (a, b, c) and the historical TCs (d). Named TCs (blue), Cat 3+ (orange), Cat5+ (red)

A stochastic model of North Atlantic tropical cyclones (TCs) is used to examine the relationship between North Atlantic sea-surface temperature (SST) and TC landfall on North America. Millions of synthetic stochastic TCs are derived that have the same statistical properties and SST dependence as the historic TCs 1950-2010. The large synthetic set provides higher precision for regional landfall rates. TCs are generated in each of several fixed SST states, and landfall rate as a function of SST is obtained.

Warm North Atlantic relative to tropical mean linked to greater hurricane landfall on Caribbean and Gulf coasts. No effect on US east coast.



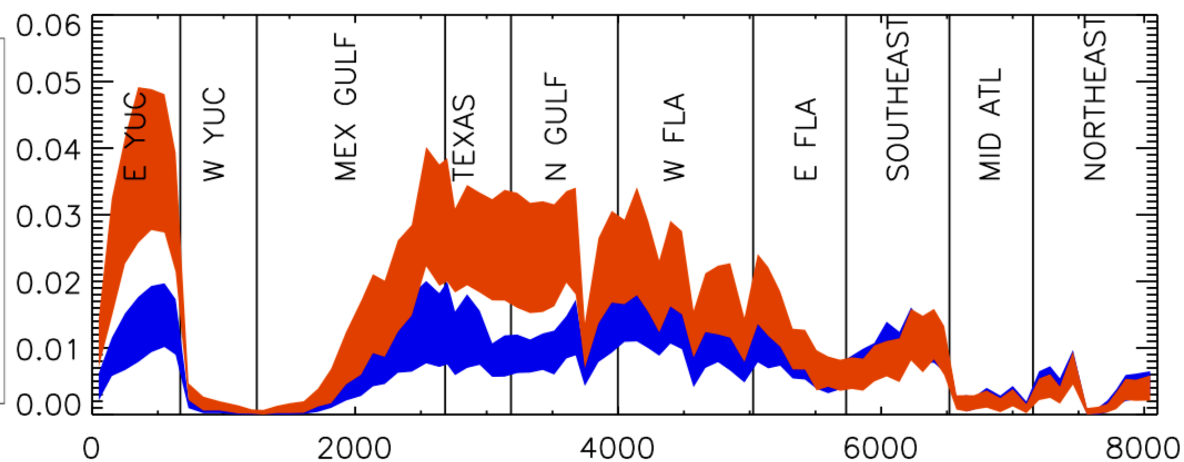
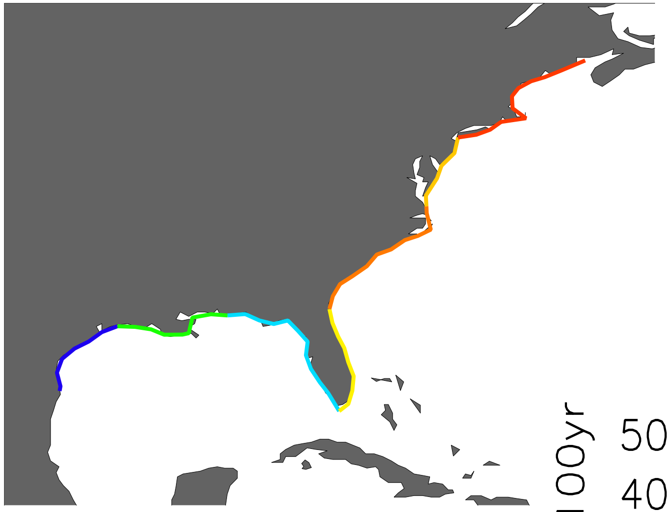
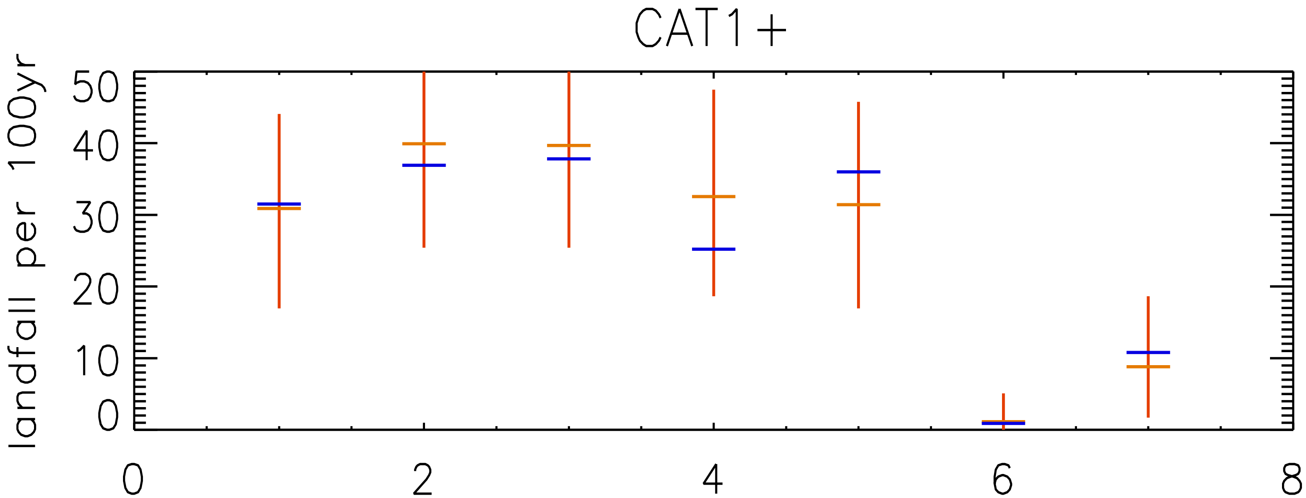


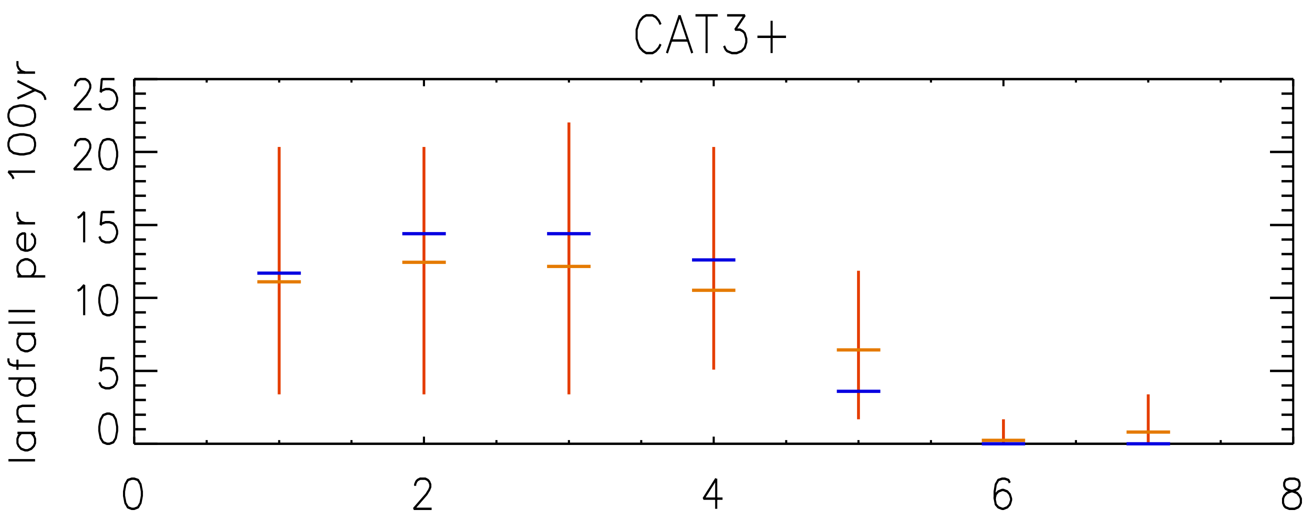
Fig 2: Left: Coastline to compute landfalls and regions as labeled. Right: Annual probability per 100km of a major (Cat 3+) landfall along the coast as labeled. Red high SST (+2σ), blue low STS (-2σ). The spread indicates 95% confidence.



Landfalls from revised model on 7 regions:
Tex, N. Glf, W. Fla, E. Fla, SE, Mid Atl, NE

Red: model mean and inner 95%
Blue: HURDAT 1900-2010.





On the Impact Angle of Hurricane Sandy's New Jersey Landfall

Timothy Hall and Adam Sobel, GRL., 2013 (featured on WNYC, Jan. 2013 and AGU press release.)

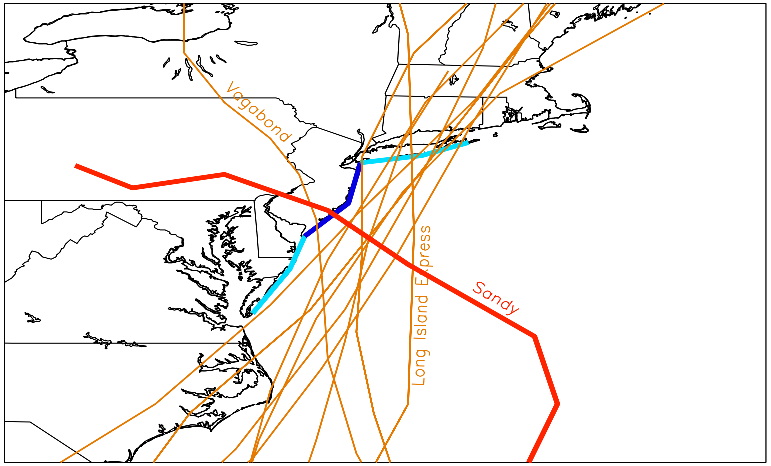


Fig. 1: Track of hurricane Sandy (red) and other historical hurricanes that affected the NYC region.

Hurricane Sandy's near-direct landfall is historically unprecedented on the US NE and contributed to the record surge. Hall and Sobel (GRL, 2013) use a stochastic model of North Atlantic hurricanes under long-term average climate conditions to estimate that a NJ landfall of at least Sandy's intensity at least as close to perpendicular occurs on average every ~700 years (95% confidence range 400 to 1400 years).

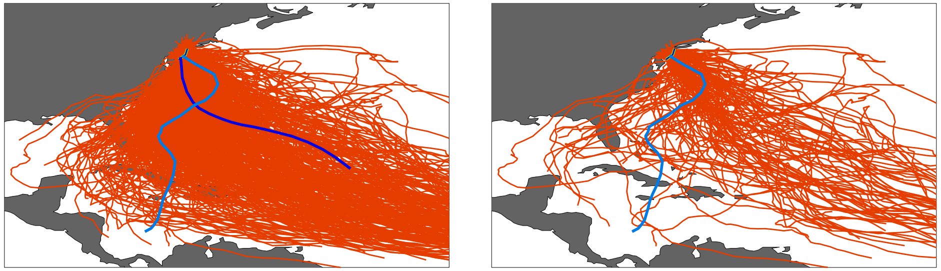


Fig. 2: Hurricanes making NJ landfall from a stochastic simulation (red) and historical (Sandy, light blue). All landfalls (left) and landfalls within 30^{o} from perpendicular (right). The stochastic set is used to estimate rates as a function of impact angle.

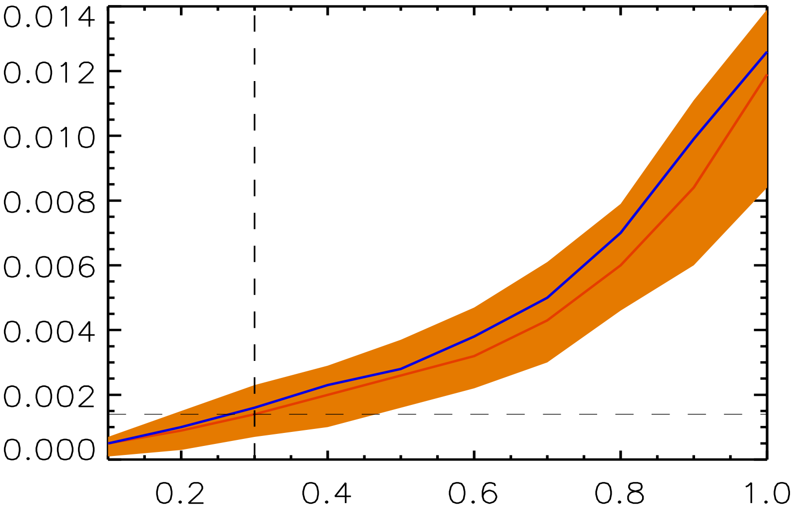
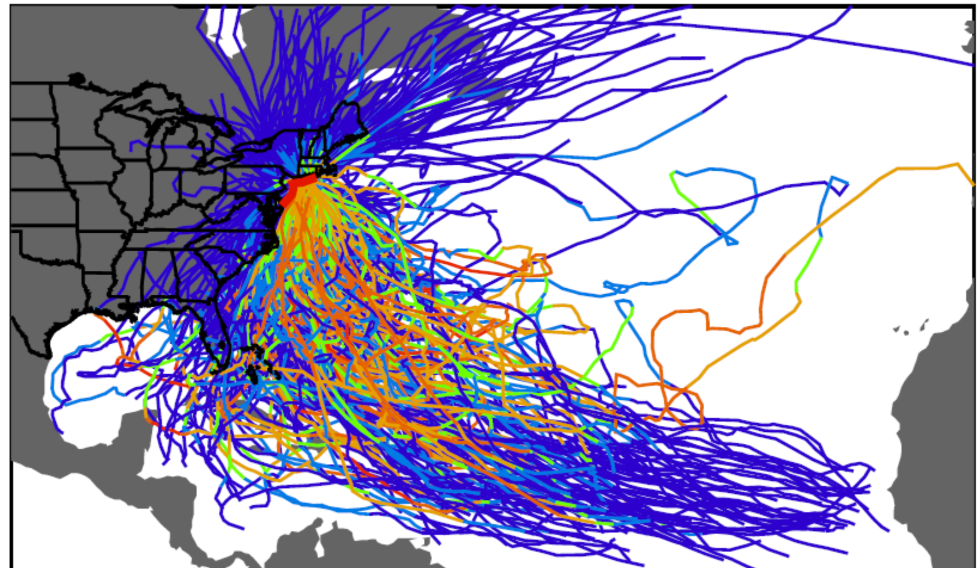


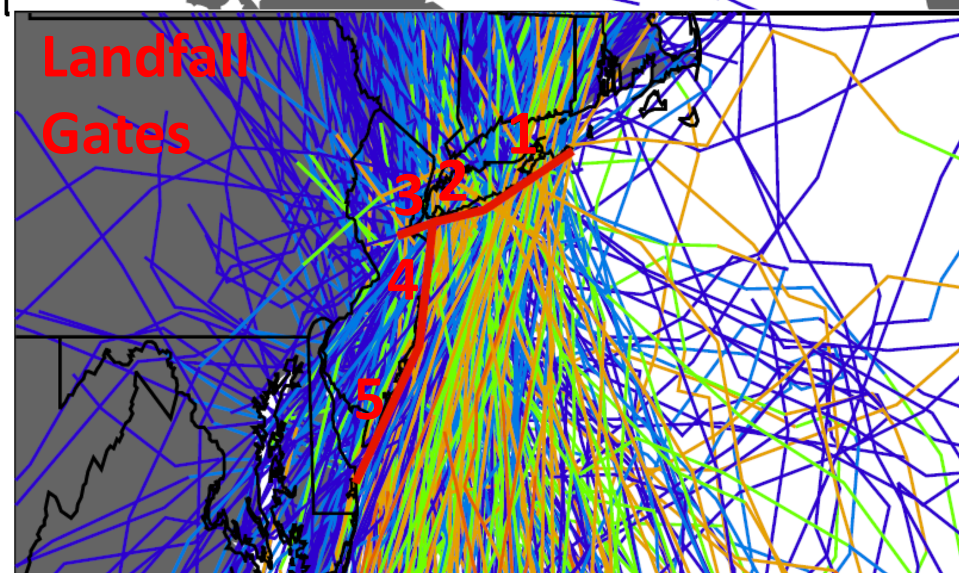
Fig. 3: Annual rate of NJ hurricane landfalls as a function of the the impact angle (red). On the right is the rate for any angle. On the left is the rate for cos(angle) < 0.1. The dashed lines indicate Sandy's impact (17^{o}), with a best-estimate rate of 0.0014/yr, or 714 years.

Use 10^7 years of synthetic NA TCs to drive NYC-area hydrodynamic model to estimate inundation hazard

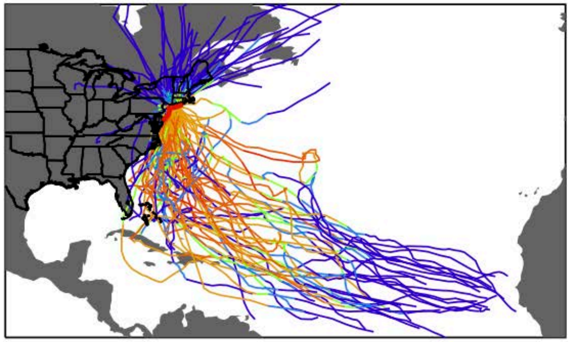
Reduce storm set for surge simulations: frequency analysis of TC model for probabilities in hazard classes; one surge simulation for TC in each hazard class.

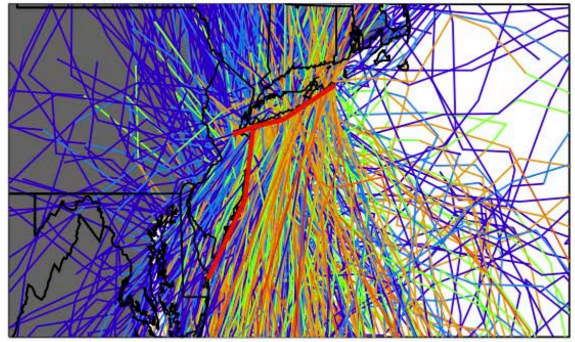
- 5 Landfall Gates
- 3 ‘flavors’ of size
- 3 of intensity
- 3 of landfall angle
- 3 of storm speed
- Total: 405 storms
- Using one random tide, one statistically simulated rainfall (lon,lat,time) per storm





NYC-area CAT3+ landfalls

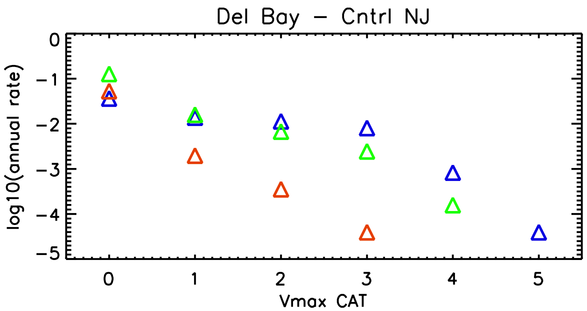


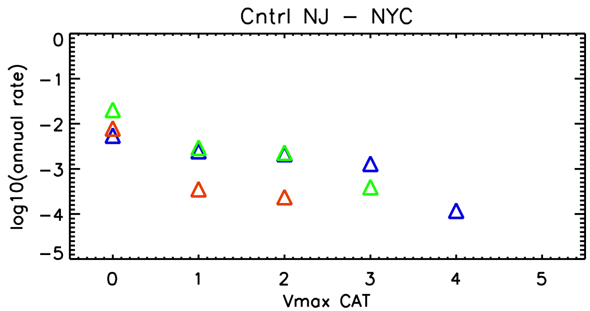


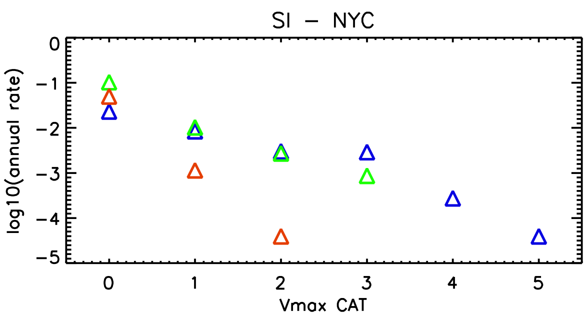
Focus on NYC area:

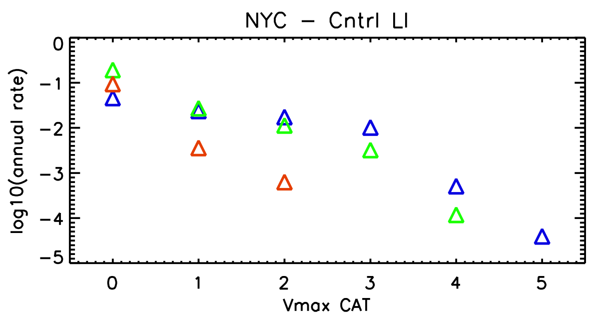
Simulate 10^6 years. Obtain landfall rates for TC categories defined by hazard variables: location, intensity, size, propagation speed, impact angle. Use sample TC from each category to drive expensive hydrodynamic flood model ("Joint Probability Method") to estimate flood rates.

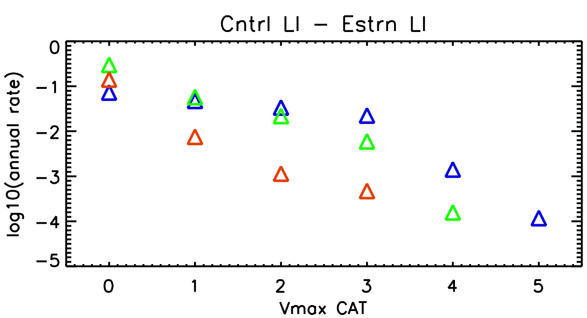
With Philip Orton at Stevens.



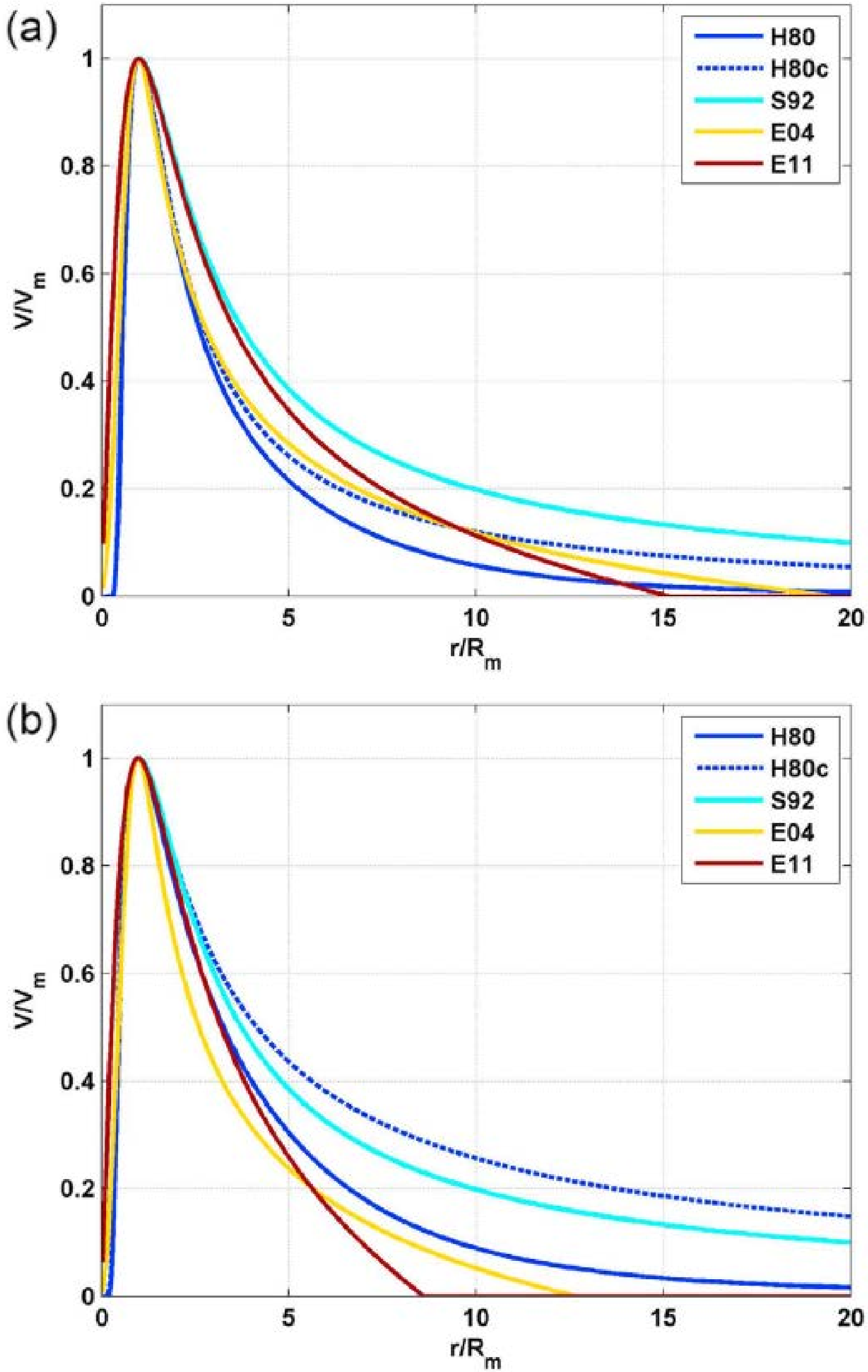








Log annual rates by region, Saffir-Simpson scale, and R_{max} (small, medium, large)



Parametric TC Model Differences

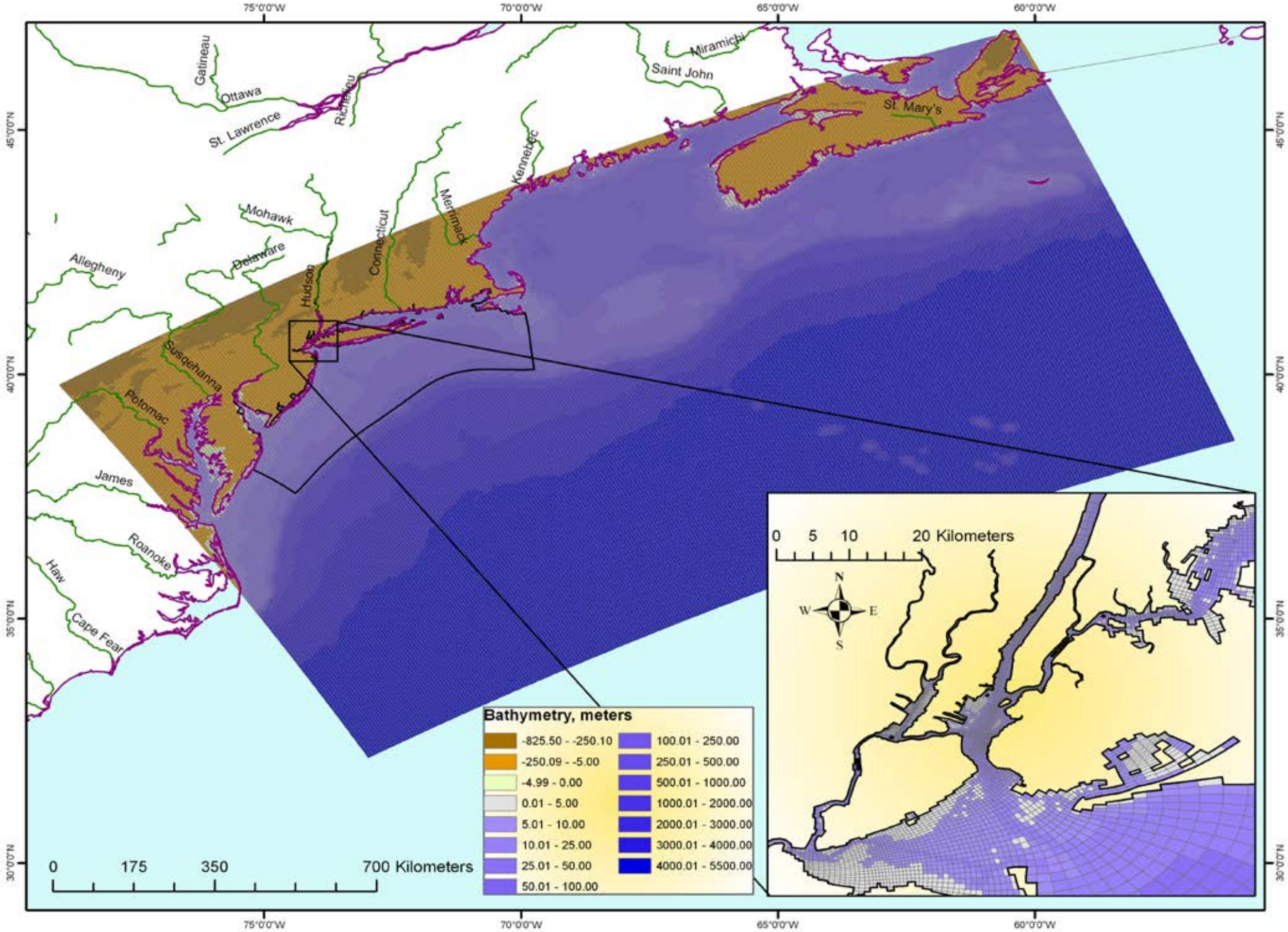
Lin and Chavas, JGR, 2012

Parmetric wind profiles (a) for a relatively intense storm and (b) for a relatively weak storm, making landfall near Tampa.

The storm for Figure 4a has the following parameters: 8 = 28.0, DP = 88.3 mb, V_m = 80.2 m/s, R_m = 20.5 km, and R_o = 400 km.

The storm for Figure 4b has 8 = 28.1, DP = 30.3 mb, V_m = 39.5 m/s, R_m = 31.6 km, and R_o = 400 km.

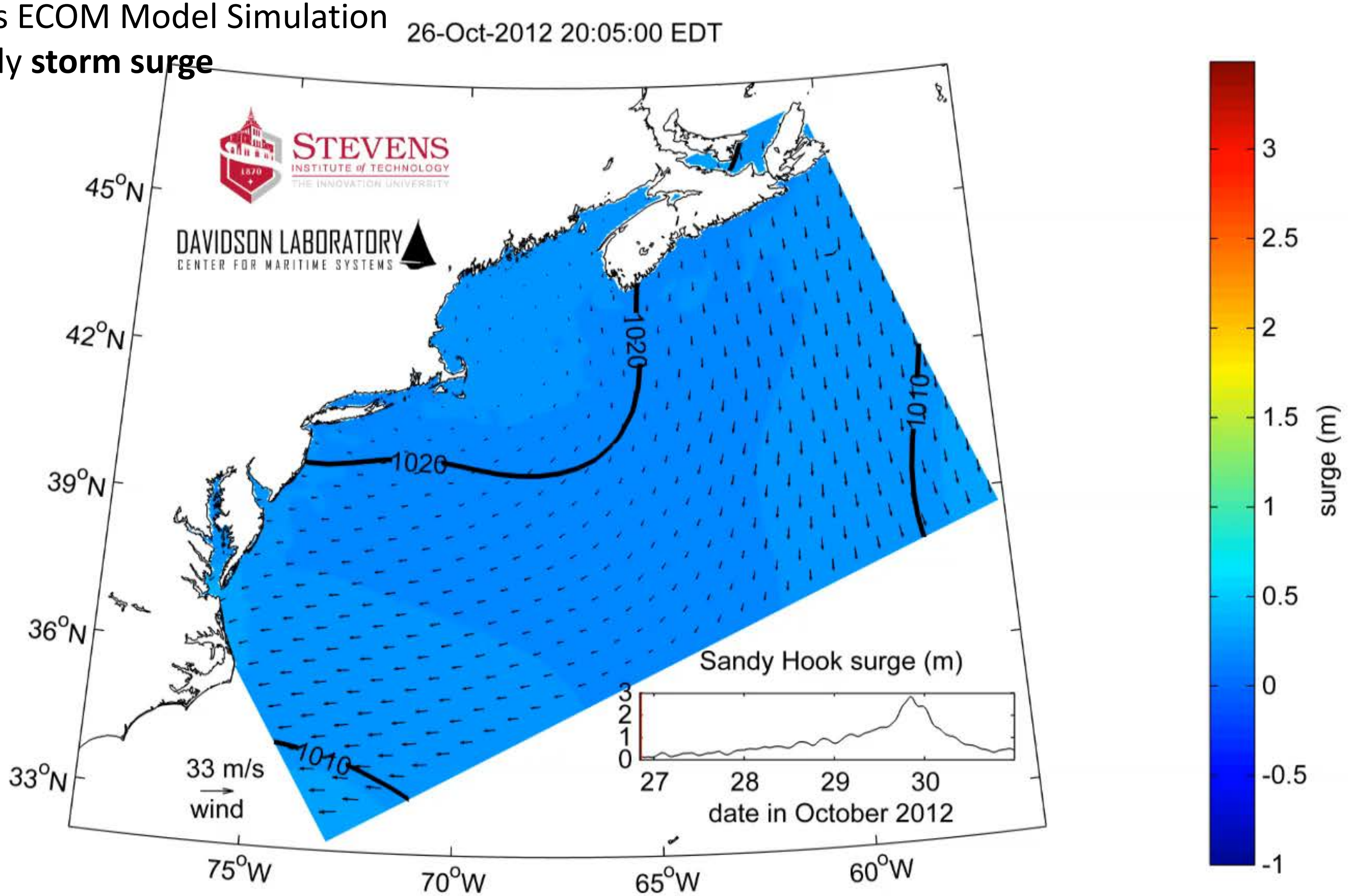
Hydrodynamic modeling: sECOM NY-area high-resolution 3D model



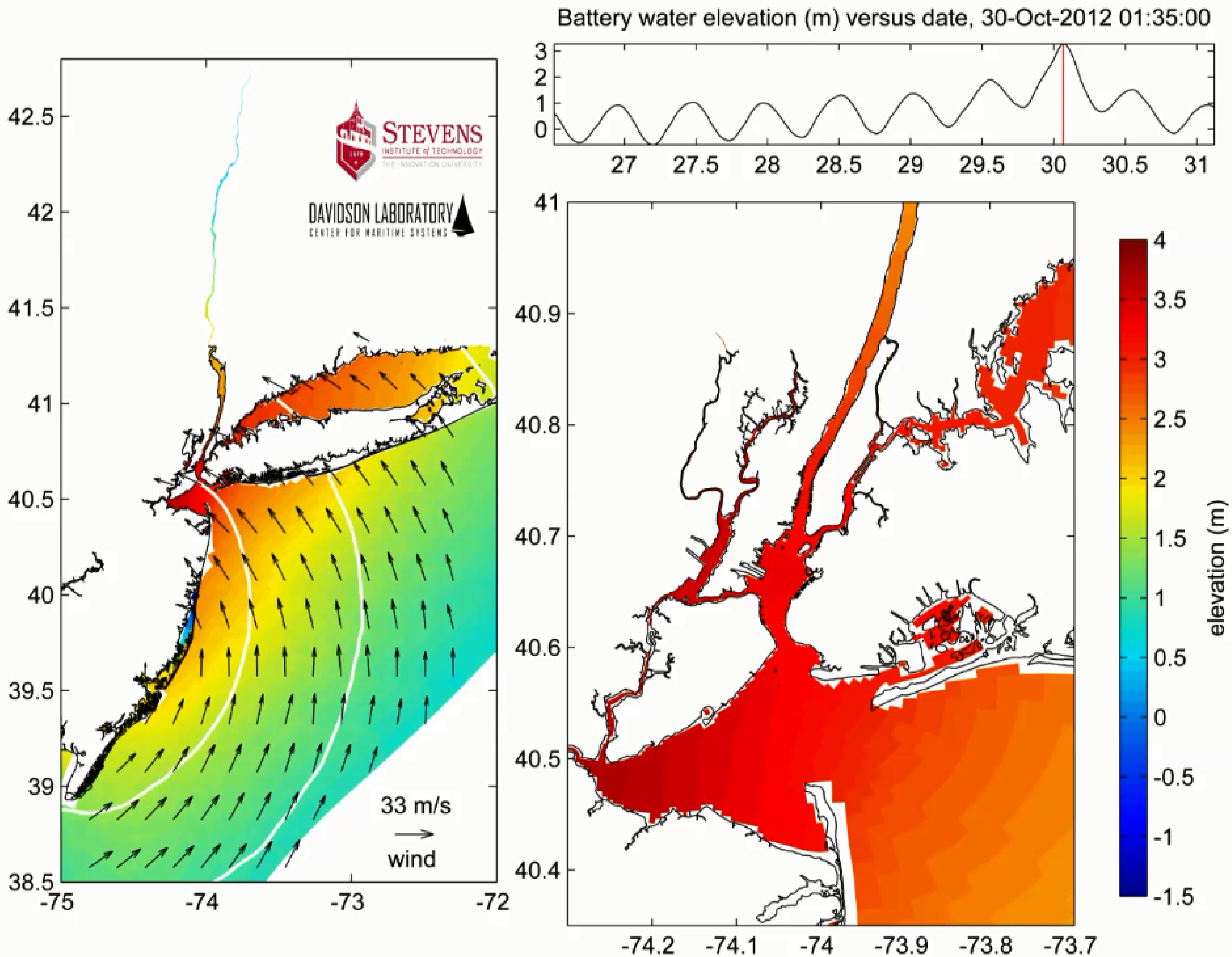
Developed and validated new North West Atlantic grid to improve remote hurricane forcing and new nested Jamaica Bay and Hoboken grids to improve overland flood simulations. Other modeling improvements include improved sECOM model code to better handle wetting and drying of land areas.

Orton et al., 2012, Detailed modeling of recent severe storm tides in estuaries of the New York City region., *J. Geophys. Res.*, 117, doi:10.1029/2012JC008220.

Stevens ECOM Model Simulation of Sandy **storm surge**

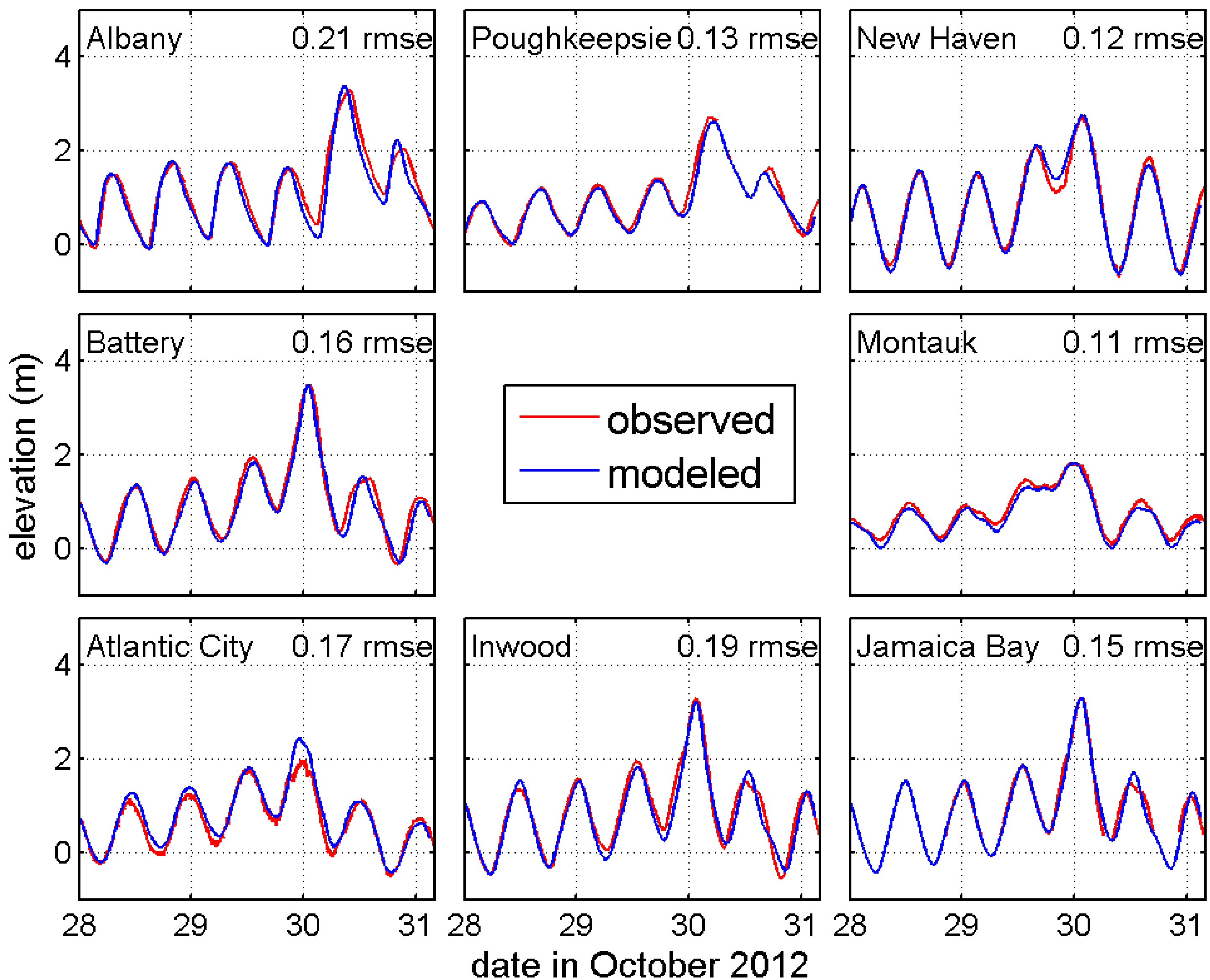


Paper in progress on Sandy surge simulation and experiments (*Geophys. Res. Lett.*)

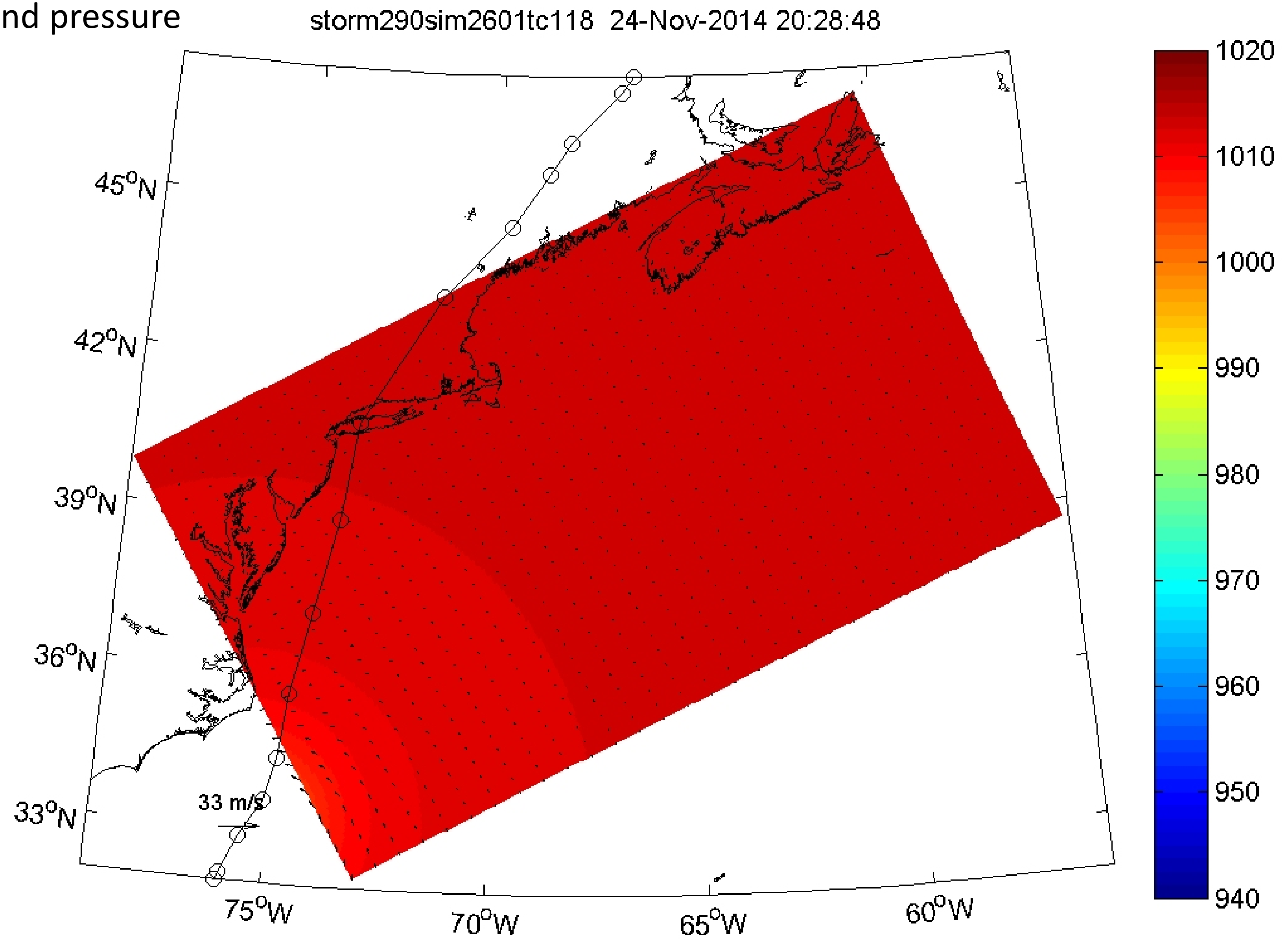


Battery water elevation (m) versus date, 30-Oct-2012 01:35:00
STEVENS
INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY
DAVIDSON LABORATORY
CENTER FOR MARITIME SYSTEMS
33 m/s
wind
elevation (m)

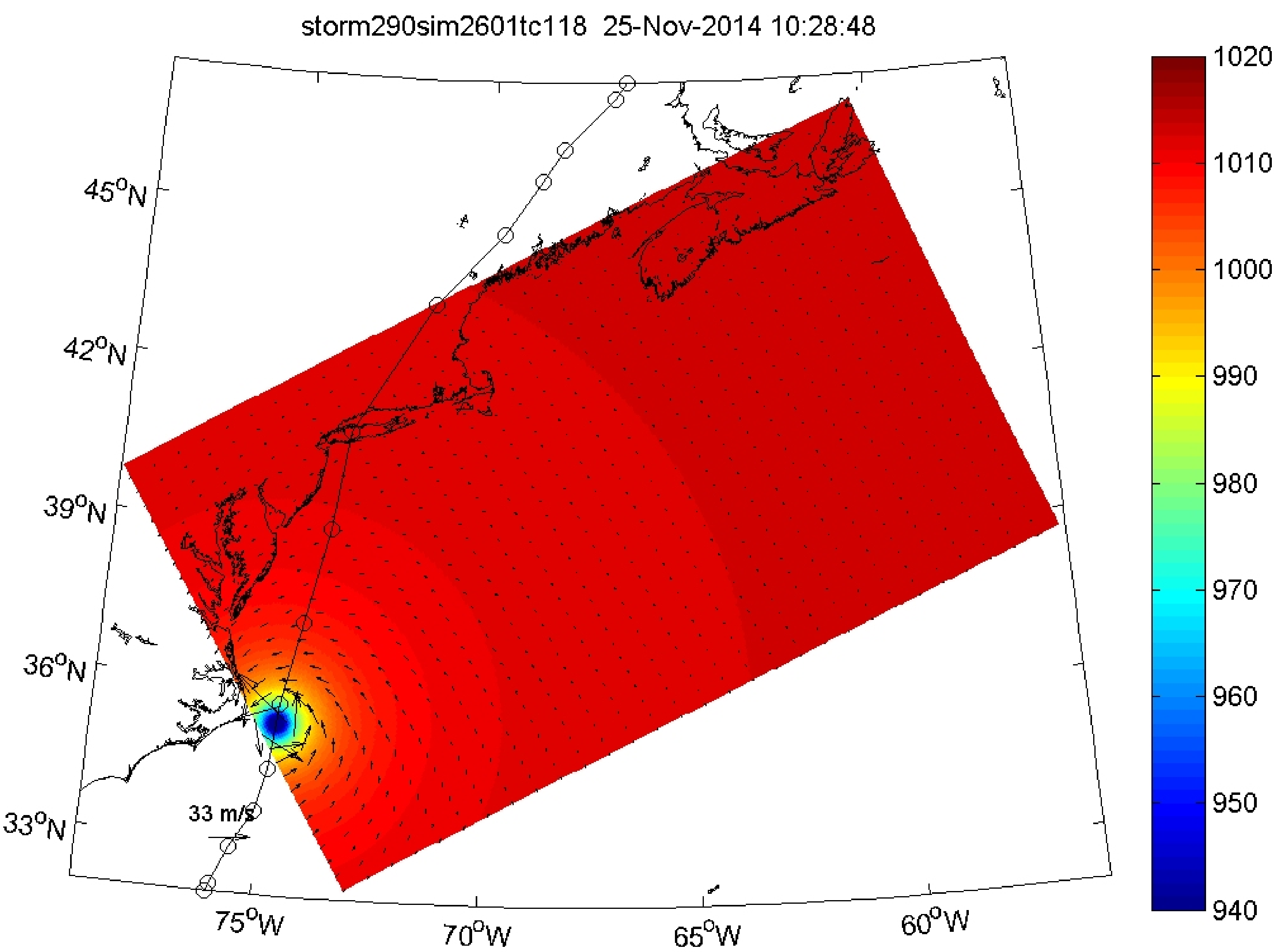
Model Validation for Sandy Hindcast



Holland-model based
wind and pressure



Small fast Cat4 on W. Long Island: 170 year return



storm290sim2601tc118 25-Nov-2014 10:28:48
45°N
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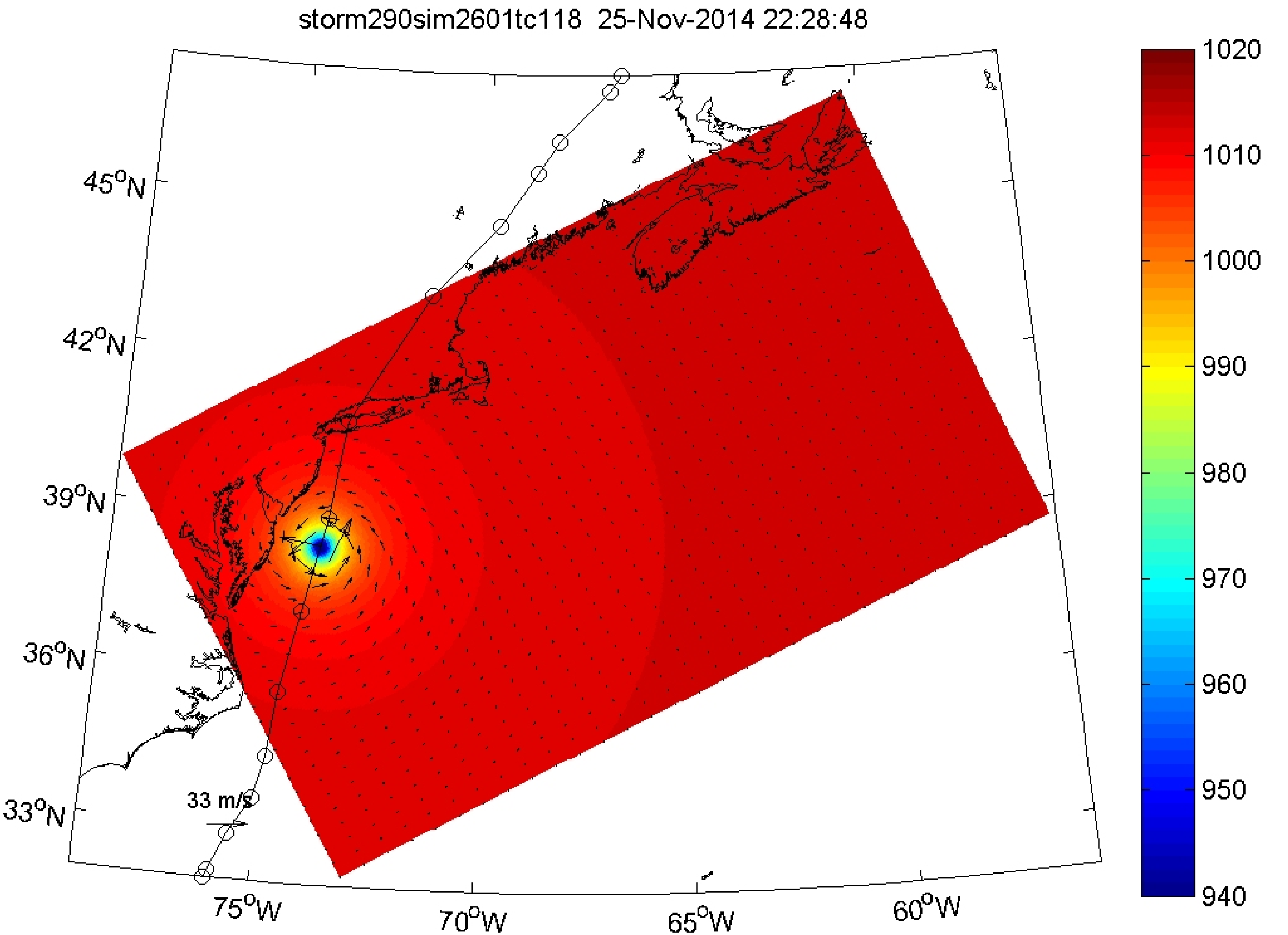
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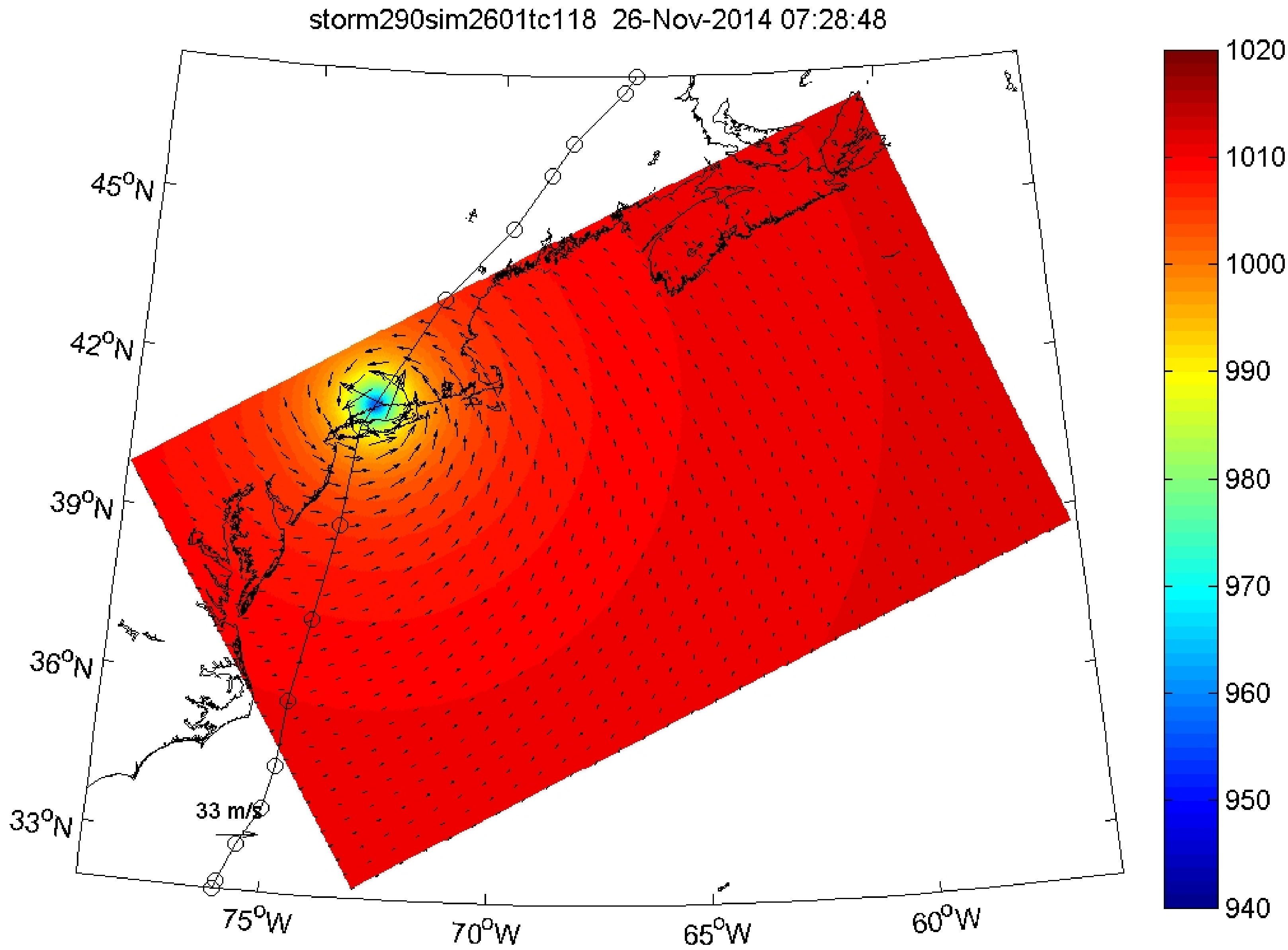

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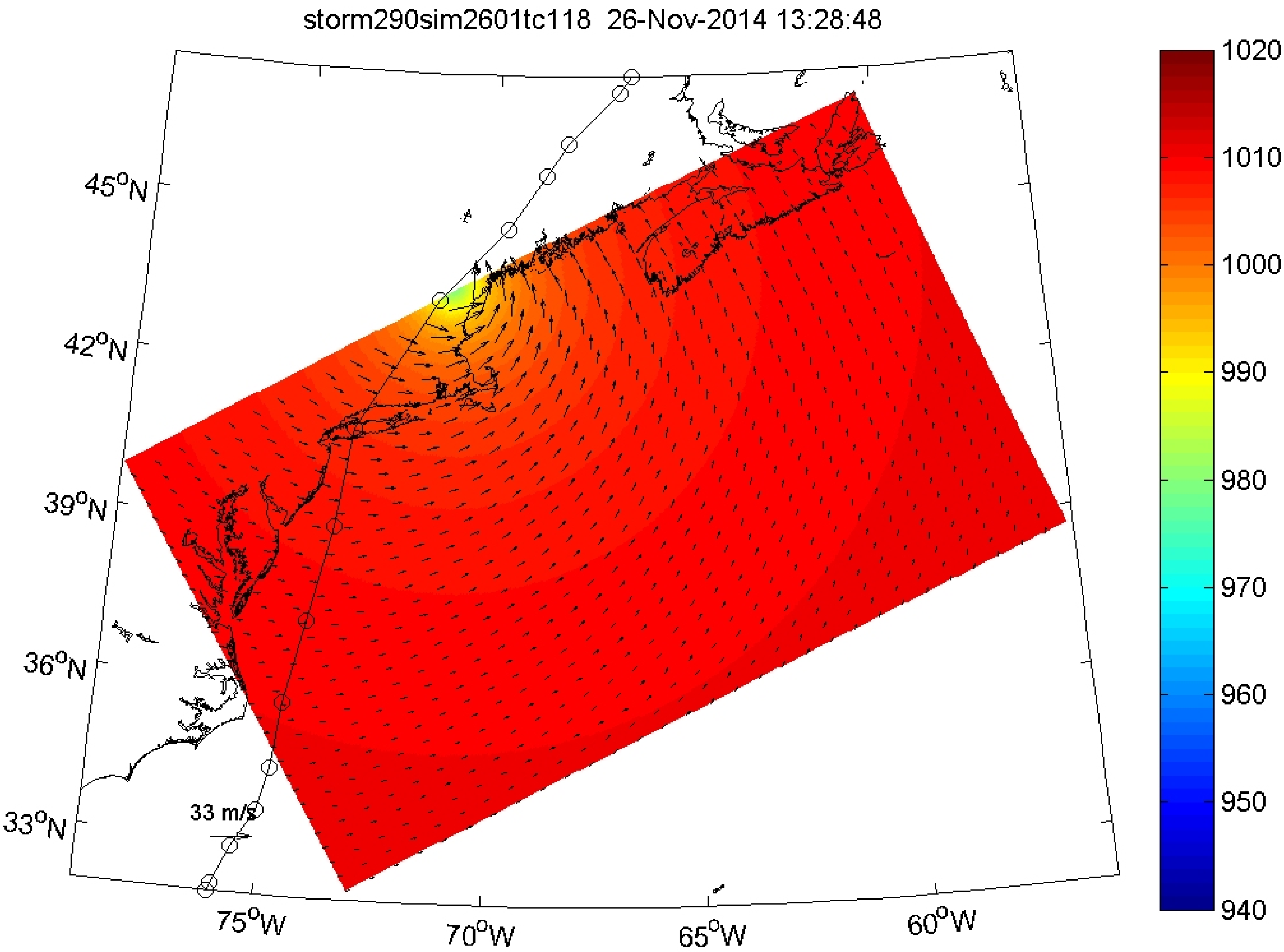

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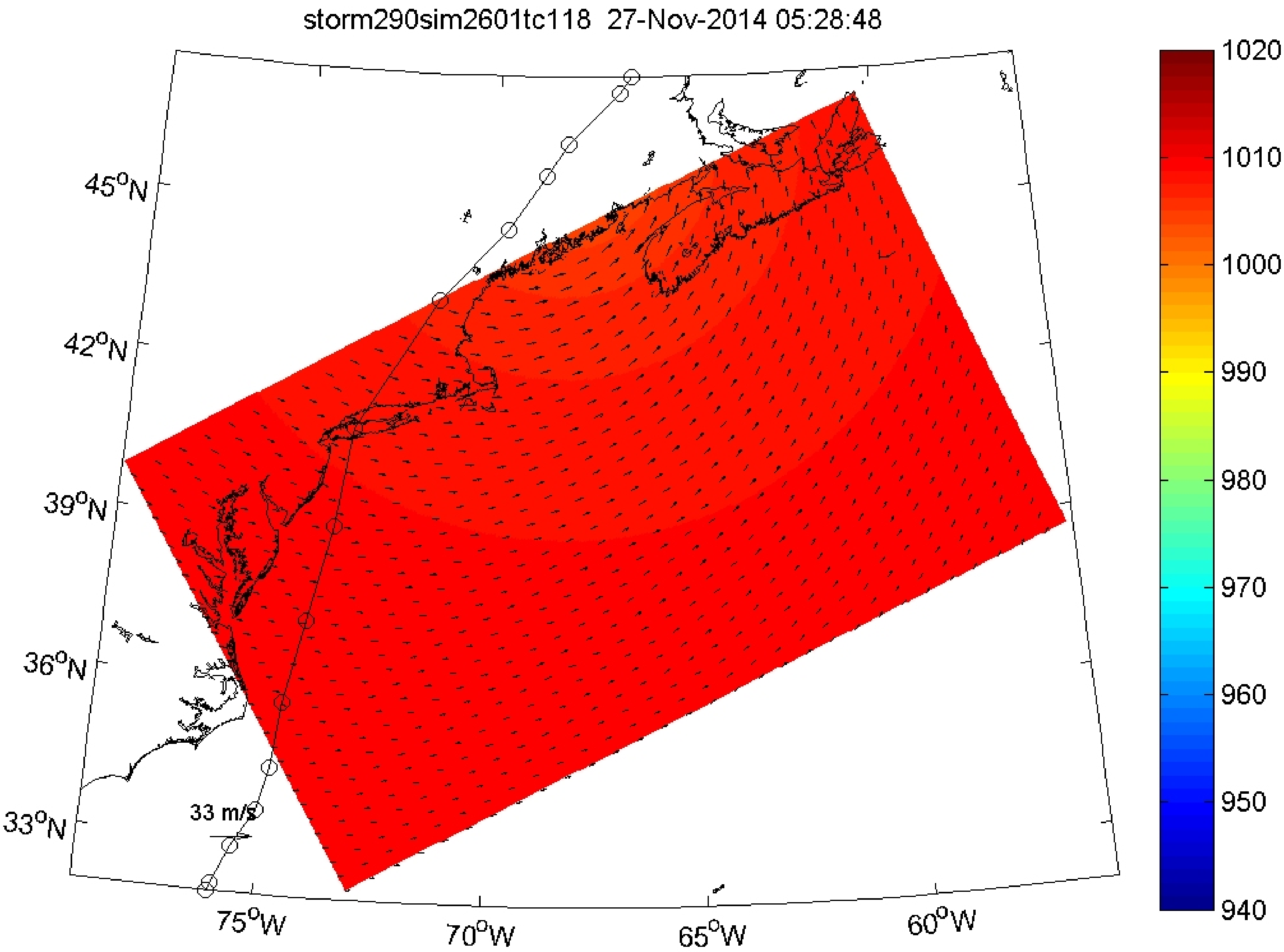

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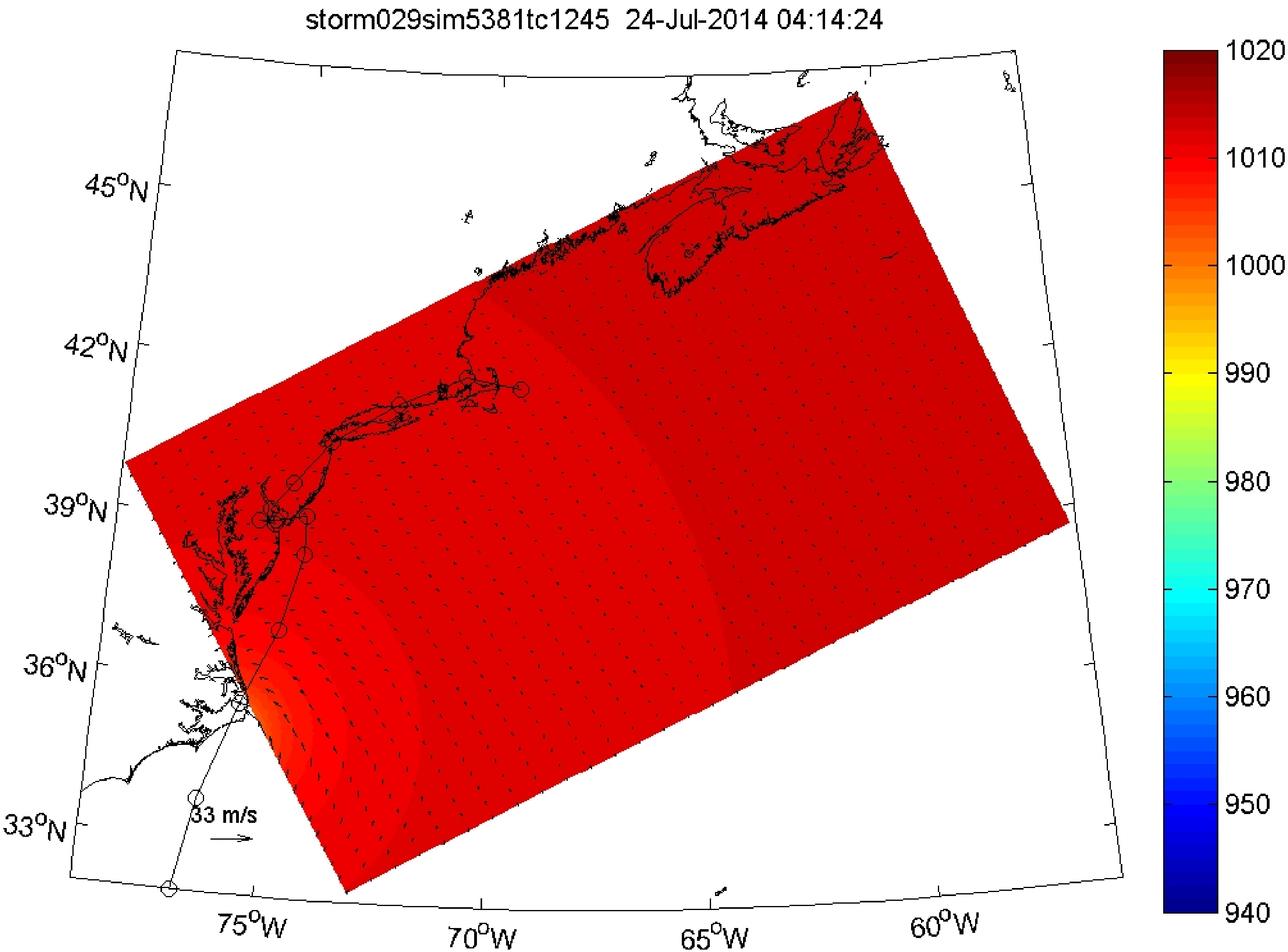
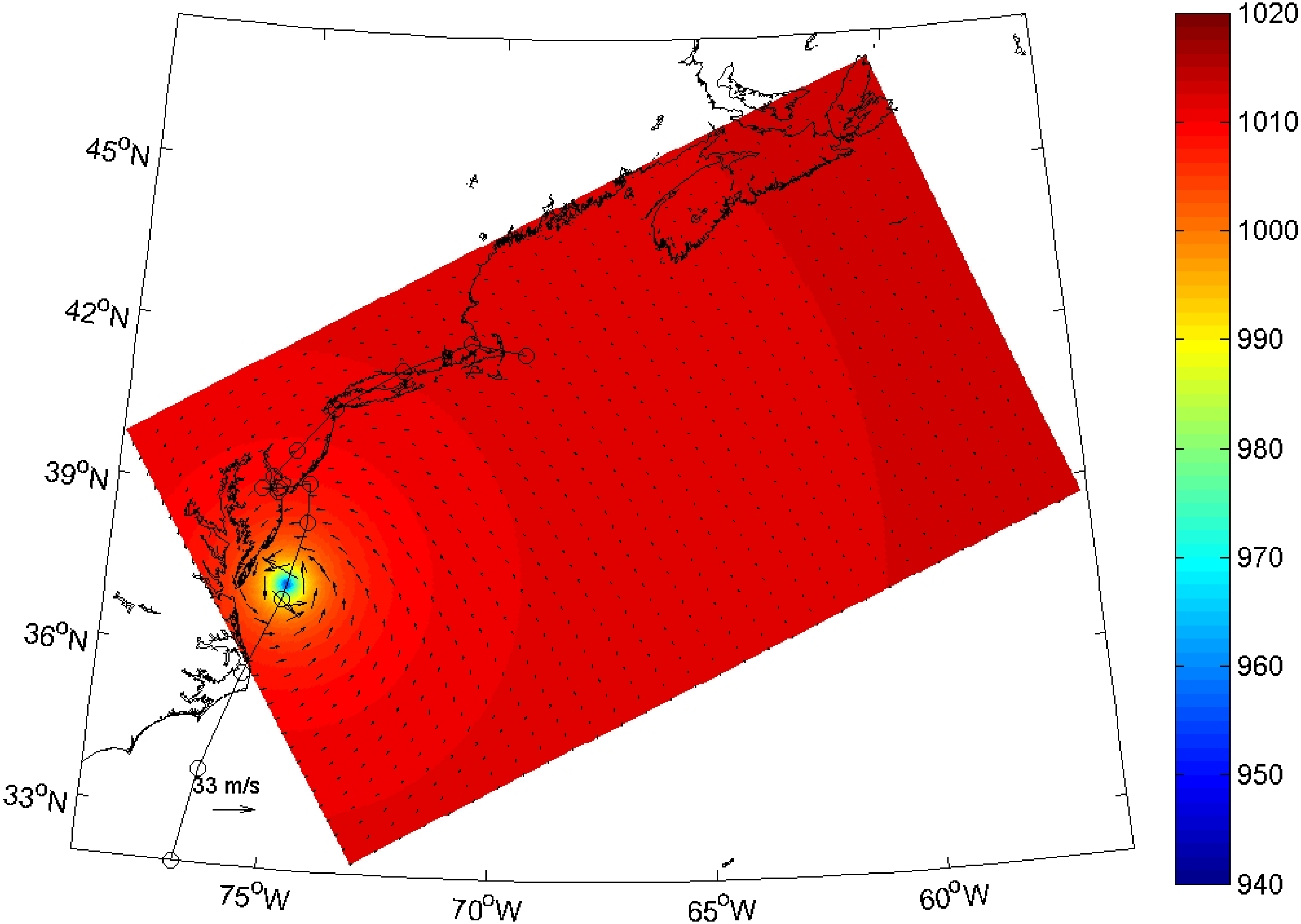


Small, slow Cat1 near perpendicular on S. NJ: 150 year return

storm029sim5381tc1245 24-Jul-2014 13:14:24



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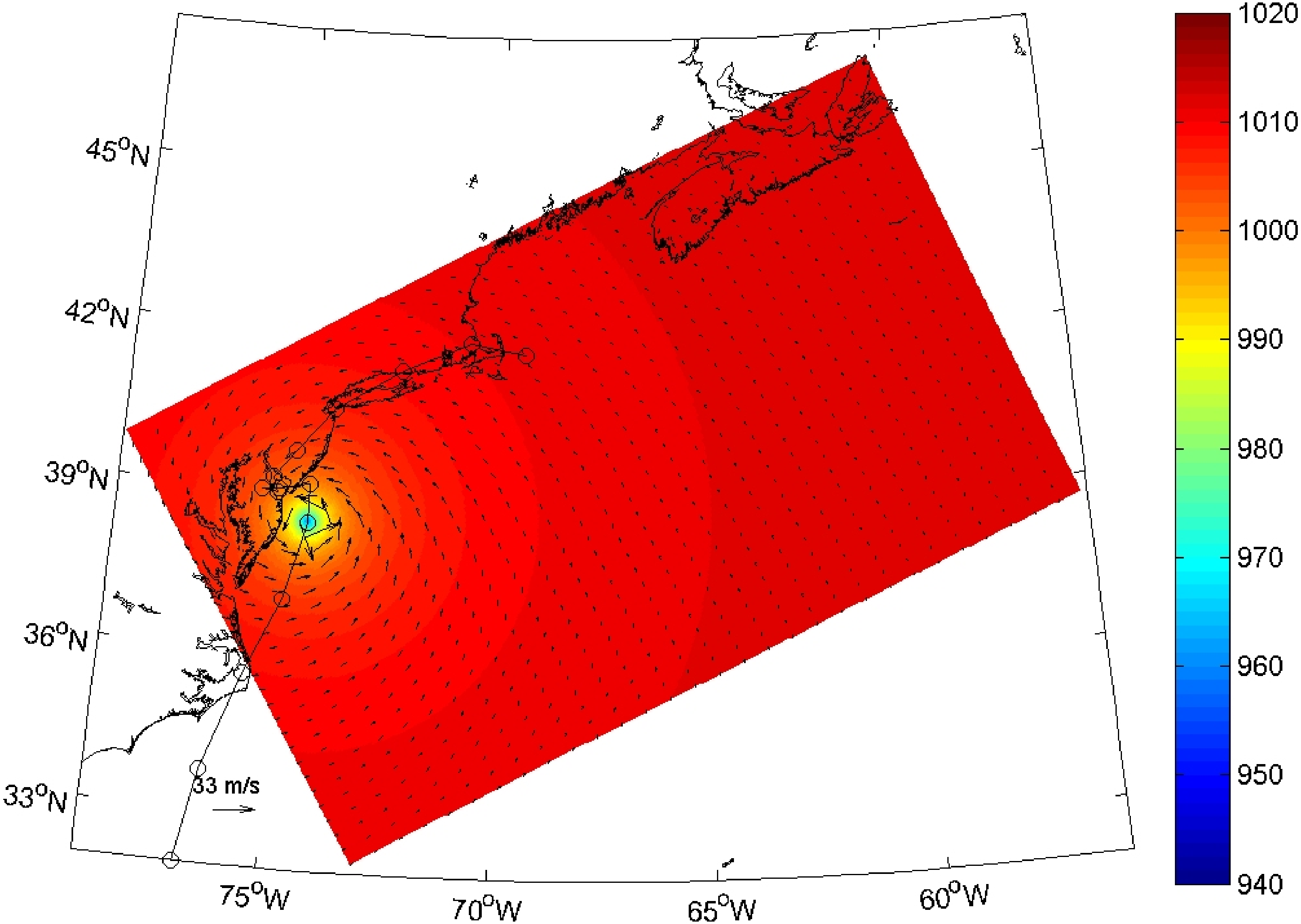

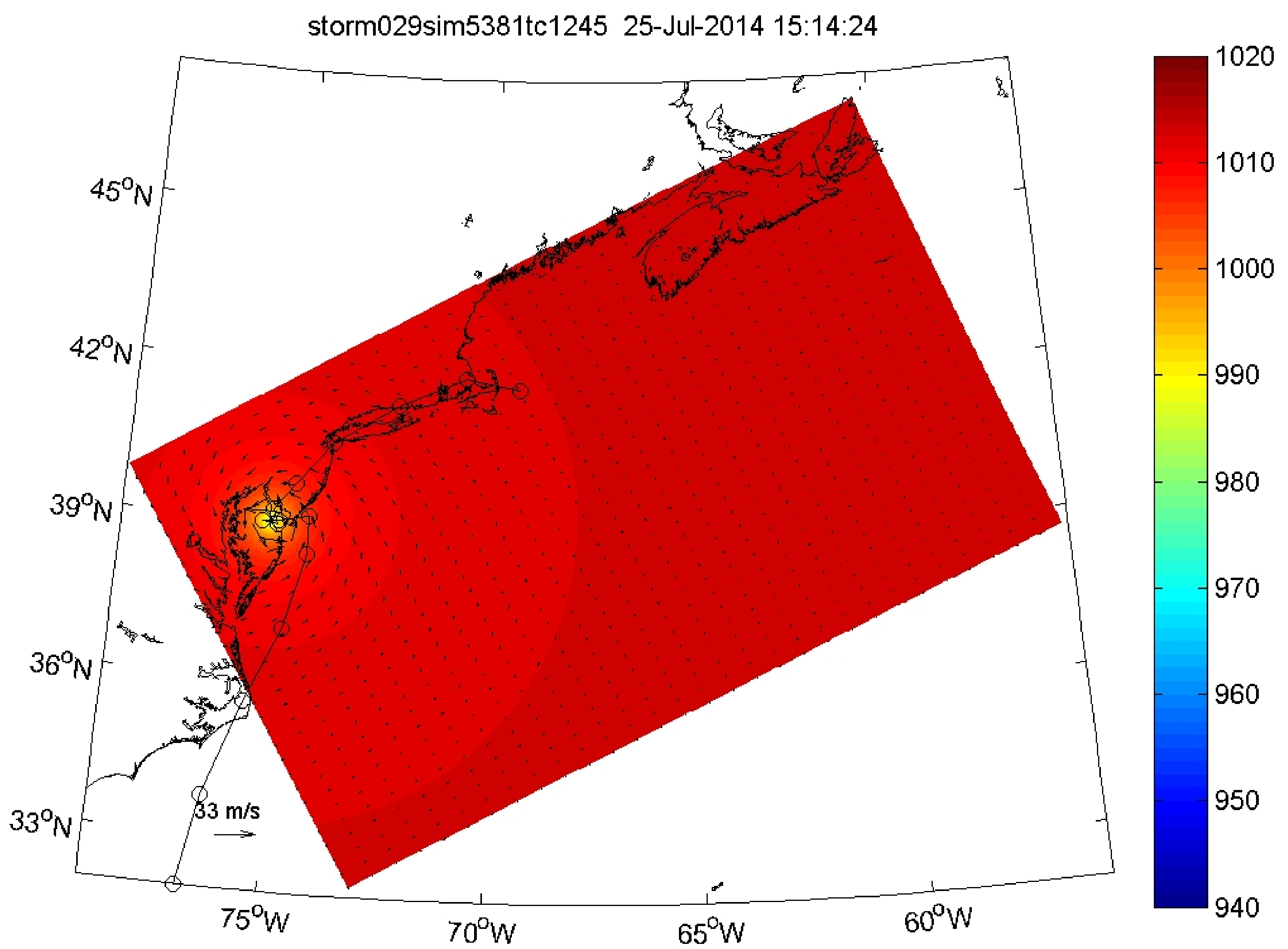

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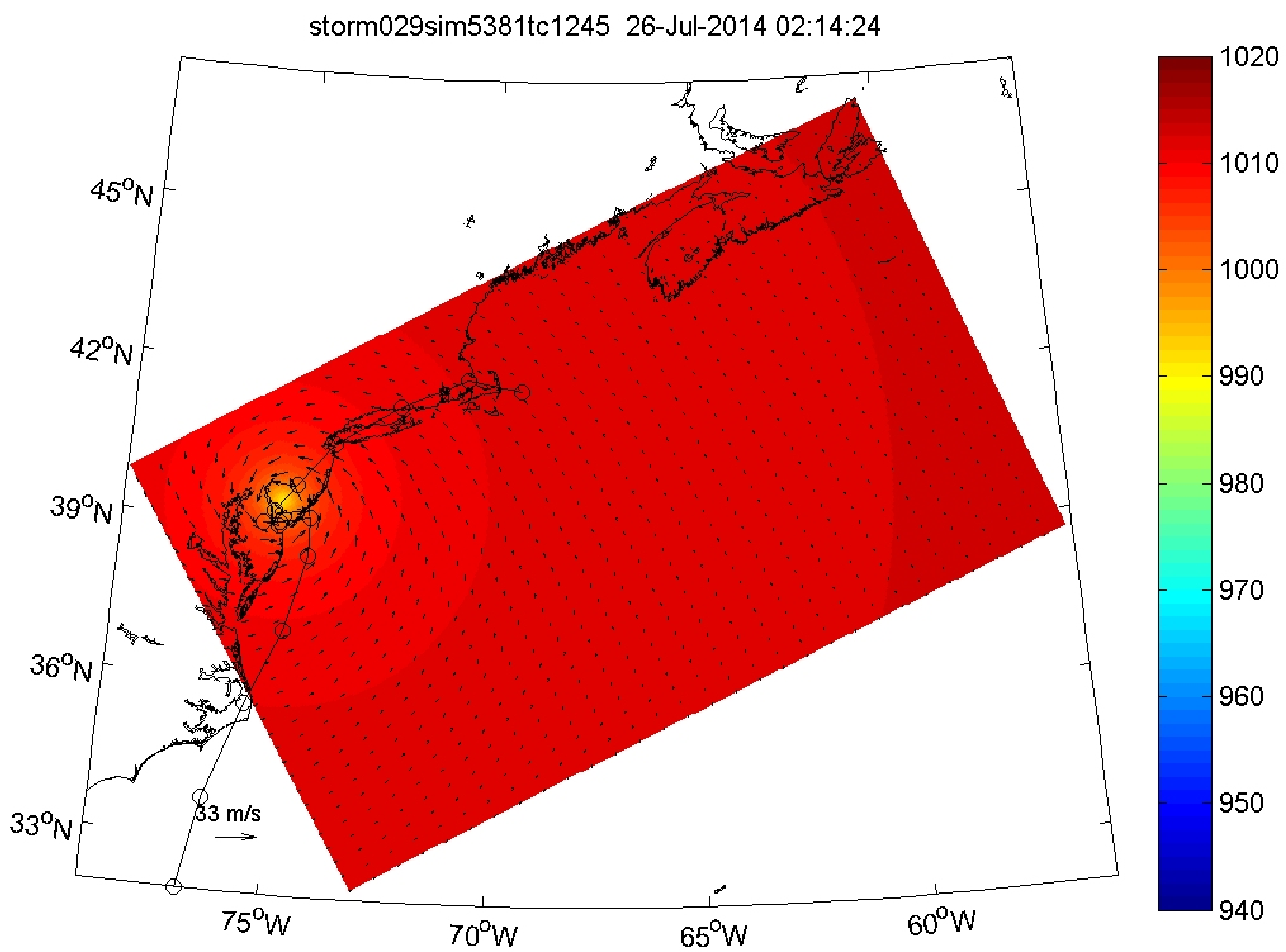

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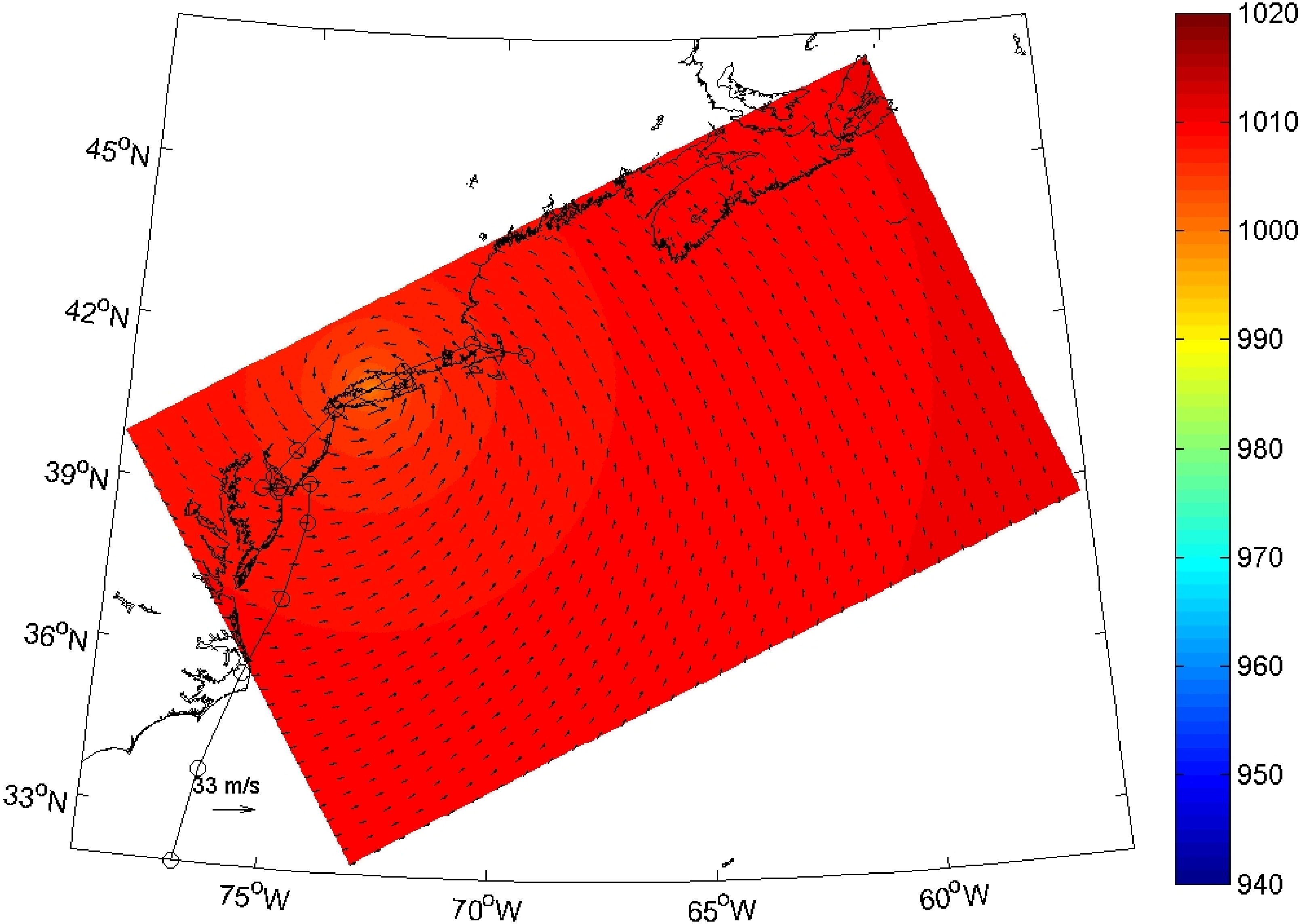
storm029sim5381tc1245 26-Jul-2014 15:14:24



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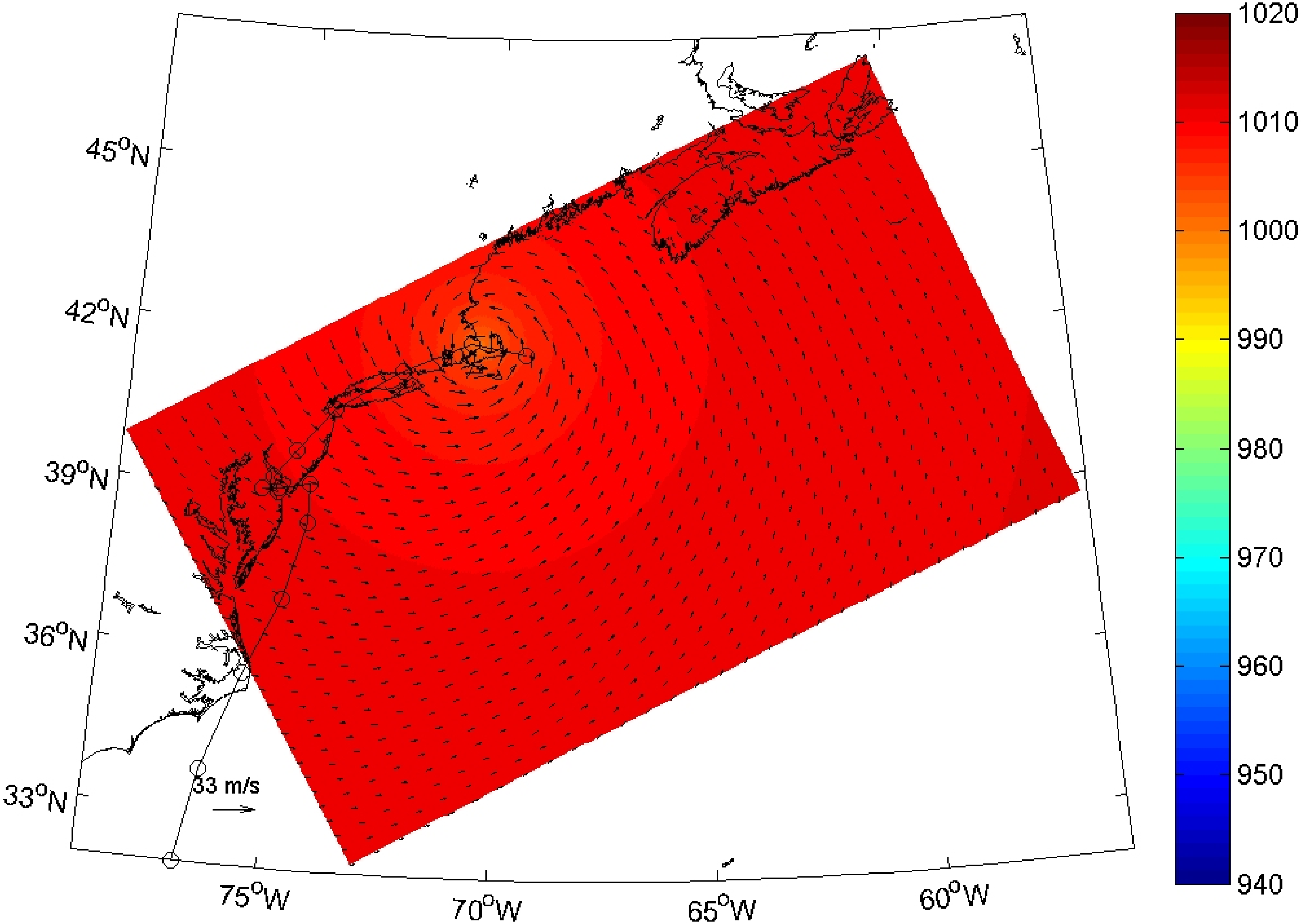

TC Rain-to-Tributary Flow Modeling

- Supervised by Manu Lall, research by student Federico Conticello and professor Francesco Cioffi (U. Rome), with Tim Hall and Philip Orton
- A statistical approach utilizing/testing artificial neural networks (ANN) and k-nearest neighbors (KNN)
- Two submodels are used in sequence.
  - The first submodel translates the attributes of a tropical cyclone to rainfall intensity at selected stations within the watershed of Hudson River
  - The second submodel transforms the rainfall intensities, calculated for the ensemble of the stations, to the streamflows at specific points of the tributaries of the Hudson River
- Calibration and validation of the model is carried out by using, selected tropical cyclone data since 1950, and hourly station rainfall and streamflow recorded for such extreme events.
- Four stream gauges (Troy dam, Mohawk River at Cohoes, Mohawk River diversion at Crescent Dam, Hudson River above lock one nr Waterford), a gauge from a tributary in the lower Hudson River, and over 20 rain gauges are used.

Cioffi, F., Conticello, F.R., Hall, T., Lall, U. and Orton, P.M. A statistical forecast model for Tropical Cyclone Rainfall and flood events for the Hudson River, abstract submitted for the European Geophysical Union annual meeting, identification number EGU2014-3568.

Upcoming work

- Finish statistical rainfall model.
- Perform hydrodynamic simulations on synthetic TC subset.
- Use the simulations to estimate high-water return periods.
- Repeat with different SLR scenarios.

TC Landfall and the North Atlantic Oscillation

with Adam Sobel, Columbia.

NAO is a weather regime mode with an North Atlantic surface pressure dipole. Pressure centers affect steering winds and TC tracks. NAO fluctuates on many timescales. Condition TC model on 1950-2012 daily NAO.