The City University of New York

Statistical Prediction of Storm Surge in the New York Metropolitan Area

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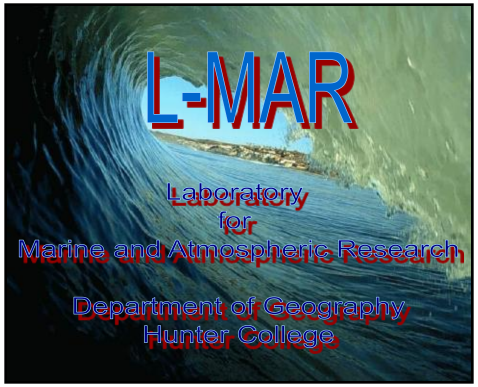
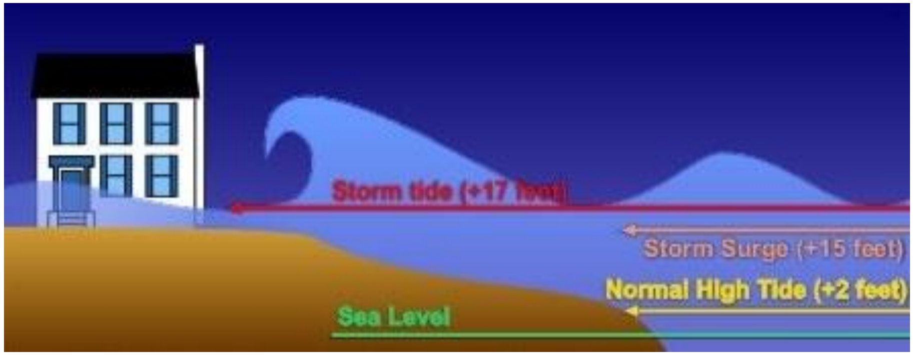


AGU 2010 – Meeting of the Americas

What we are studying:



Storm Surge = observed water level – predicted astronomical tide

Image by NOAA

Tropical and extratropical storms can cause storm surge and flooding.

Coastal impacts of hurricanes have been well studied but extratropical storms have an intrinsic potential for disaster in densely populated places like the New York Metropolitan area. Our research focuses on the storm surge due to extratropical storms that affect the US East Coast area during fall, winter and spring seasons: East Coast Cool-weather Storms (ECCSs). Some Examples:

East Coast Cool-weather Storms (locally called Nor'easters)

More frequent and intense in winter when temperature variations are greatest across the continental US.

Coastal Flooding	(Jan 04 – 5, 1994)	Ice Storm	(Mar 03 – 5, 1994)
High Winds	(Oct 06, 1995)	Flooding	(Oct 19 – 20, 1996)
Heavy Snow	(Feb 14 – 18, 1996)	Heavy Rain	(Oct 08 – 09, 1996)
Extreme Wind Chill	(Jan 25 – 27, 2000)	Freeze	(Oct 16 – 17, 2002)

This past winter The Battery (lower Manhattan) saw high levels of storm surge. So high, in fact, that service was suspended for the Staten Island ferry

This presentation:

Specifically, we want to demonstrate the predictive capability of a statistical relationship between the "storm maximum" storm surge (SSMAX) associated with an ECCS and the storm composite significant wave height at a nearby NDBC buoy.

We are studying this because:

The potential for property damage and loss of life due to storm surge and flooding calls for accurate predictions of high water levels associated with storm conditions.

Still, modeling of storm surge and prediction of coastal flooding remains a problematic issue.

Current dynamical models used to predict storm surge include

- NOAA ET-SURGE – www.nws.noaa.gov/mdl/etsurge/
- ADCIRC, Stony Brooks – http://stormy.msrc.sunysb.edu/
- ECOM, Stevens Institute of Technology – http://hudson.dl.stevens-tech.edu/maritimeforecast/

Our (new) statistical method to estimate storm surge is based on the developments reported by Salmun, H., A. Molod, F. Buonaiuto, K. Wisniewska and K. Clarke (2009): East Coast Cool-weather Storms in the New York Metropolitan Region. *Journal of Applied Meteorology and Climatology*, **48**, 11 2320-2330.

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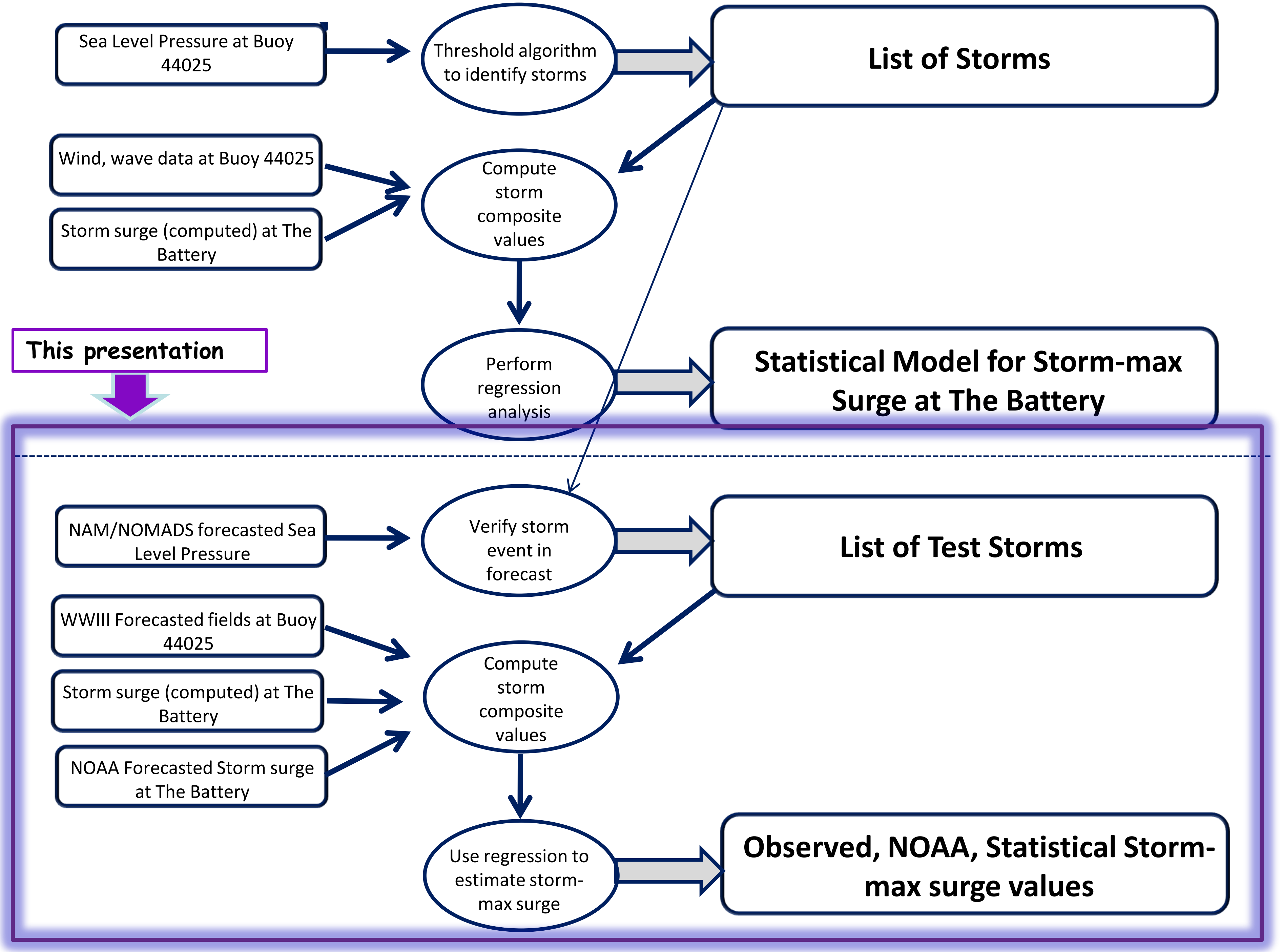

Sea Level Pressure at Buoy 44025
Threshold algorithm to identify storms
List of Storms
Wind, wave data at Buoy 44025
Storm surge (computed) at The Battery
Compute storm composite values
Perform regression analysis
Statistical Model for Storm-max Surge at The Battery
This presentation
NAM/NOMADS forecasted Sea Level Pressure
Verify storm event in forecast
List of Test Storms
WWIII Forecasted fields at Buoy 44025
Storm surge (computed) at The Battery
Compute storm composite values
NOAA Forecasted Storm surge at The Battery
Use regression to estimate storm-max surge
Observed, NOAA, Statistical Storm-max surge values

Forecast Data

Retrospective forecasts (NAM-WRF & NOMADS) of sea level pressure at the location of NDBC Station 44025 for the period Feb 2005 - Dec 2008 - verify storm events on record

Retrospective forecasts of significant wave heights from NOAA's WAVEWATCH III^{TM} were used to compute storm composite significant wave heights at the location of NDBC Station 44025

NOAA ET-SURGE standard forecast of surge values at The Battery

Observed storm surge data calculated from water level data at The Battery for the period 1959 – 2008 obtained from NOAA

Results based on 41 forecasted storms (ECCS ID: 1 – 41)

Locations of The Battery and NDBC station 44025

The statistical forecast model

$$\boxed{SSMAX_{TheBattery} = 0.1961 H_{44025} - 0.0412}$$; (meters)

with RMS error 0.145 m.

SSMAX = "storm maximum" storm surge, is the maximum value of storm surge reached during the storm period

H = storm composite significant wave height, is the average of the 'top third' largest significant wave heights during the storm

Values of SSMAX are obtained from

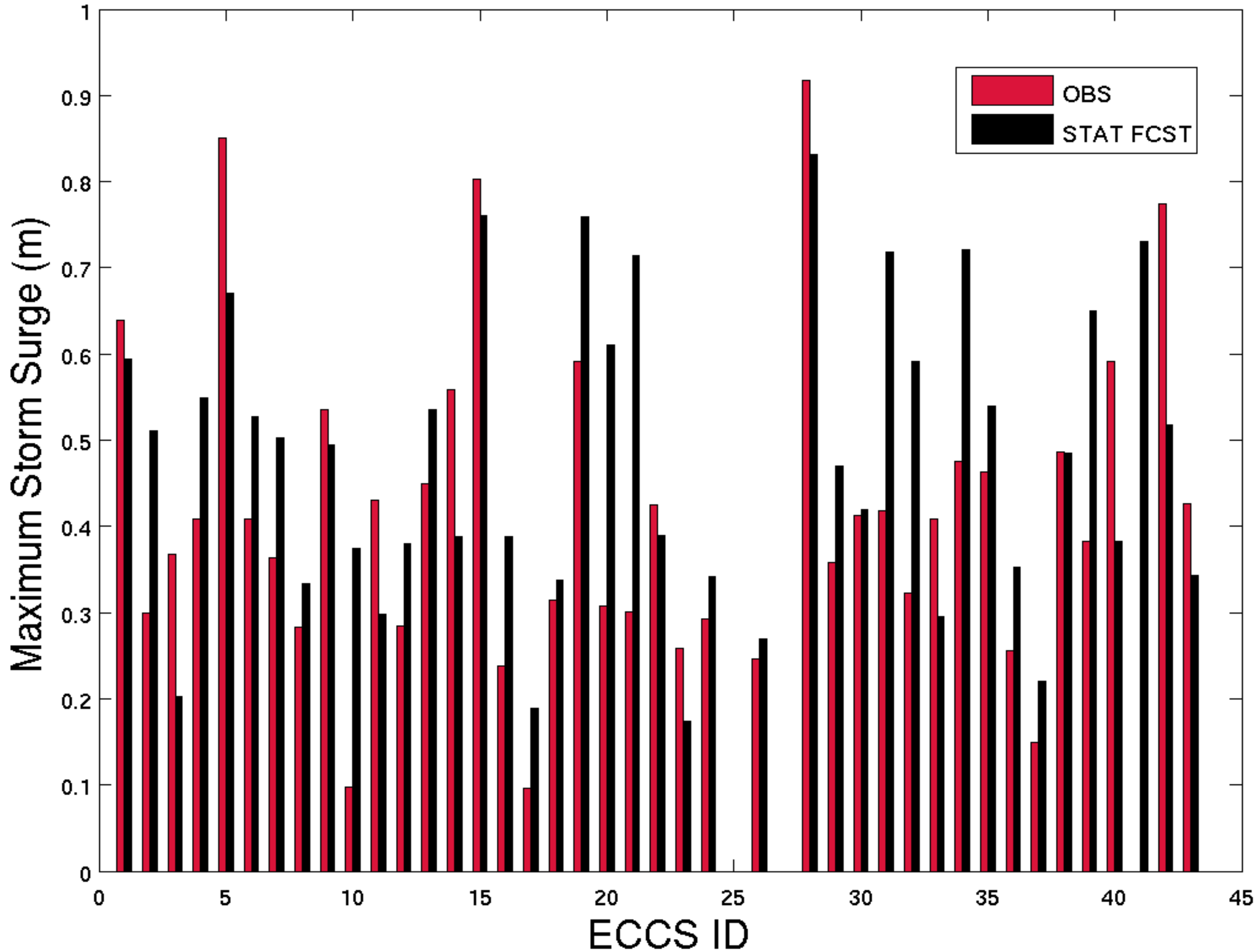
- statistical forecast (STAT FCST)
- NOAA ET-SURGE output (NOAA ET)
- NOAA operational forecast (NOAA ETANOM)
- observations at The Battery (OBS)

and then compared.

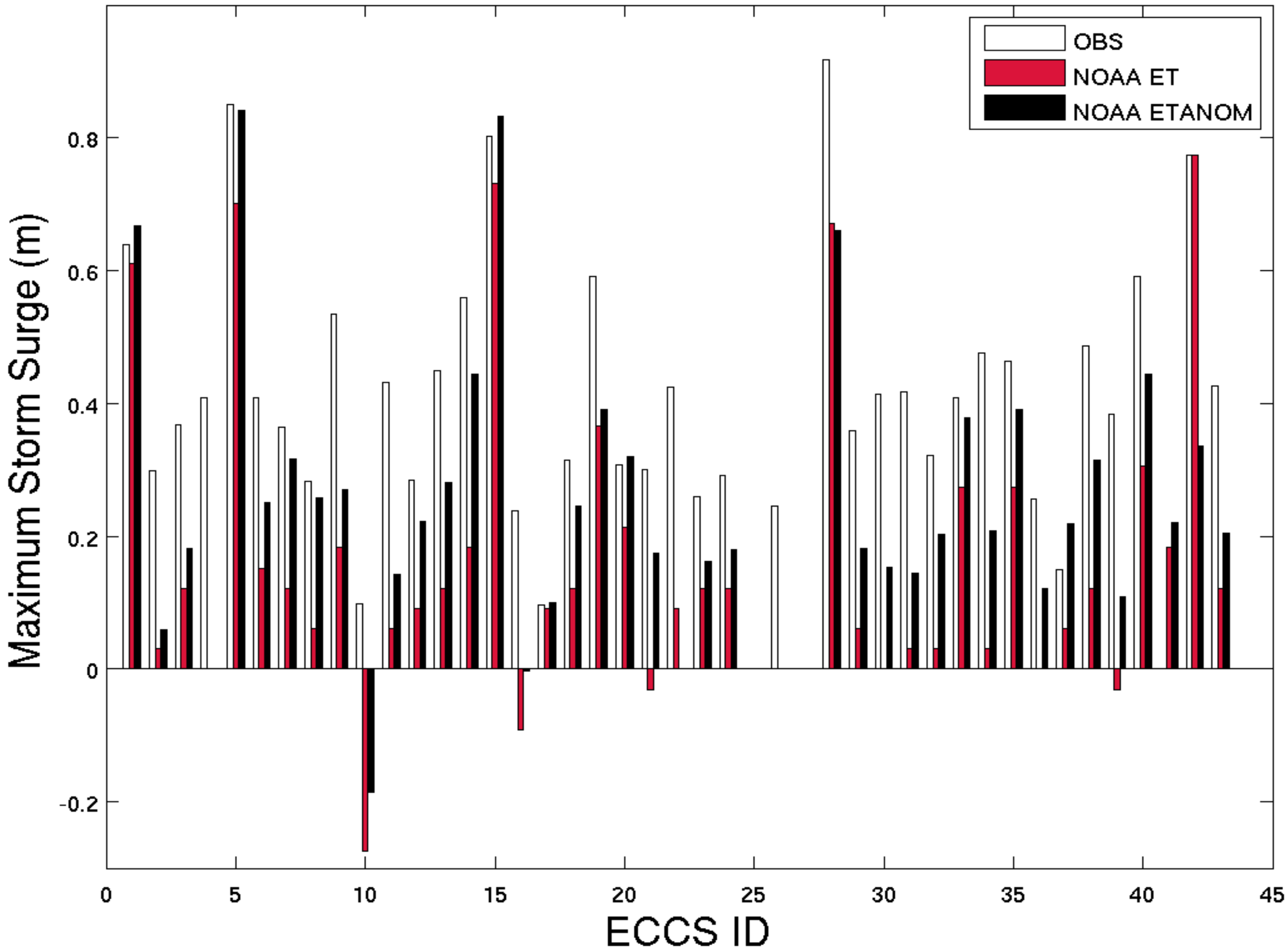
NOAA ET-SURGE predictions are from direct (archived) output from ET-SURGE and from the operational storm surge forecast.

NOAA's operational forecast (NOAA ETANOM) consists of the ET-SURGE output and an error correction (not in archived data), computed as the 5-day running mean of the previous days' errors of ET-SURGE output.

Variability in the anomaly correction is an indication of the variability in the error of ET-SURGE model output (range of anomaly: -0.13 m – 0.28 m)

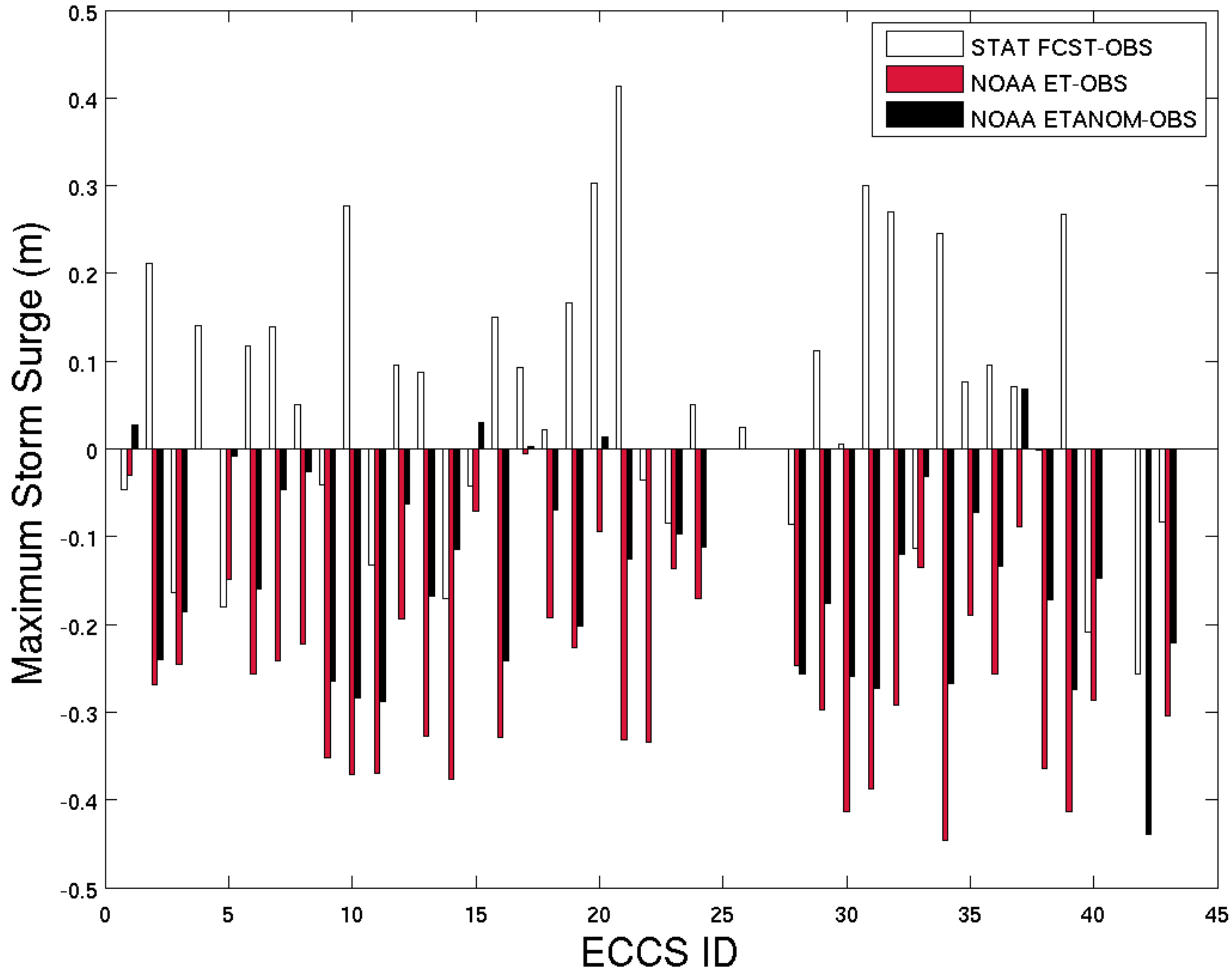


* Values of OBS SSMAX are always positive
* SSMAX estimates using STAT FCST are always positive
* OBS SSMAX range: 0.1 m – 0.92 m
* Range of SSMAX from STAT FCST: 0.17 m – 0.83 m



* SSMAX from ET-SURGE model output can be negative (4 cases)
* SSMAX from ET-SURGE operational fcst negative only once
* Range of SSMAX from ET-SURGE model output: -0.28 m – 0.72 m
* Range of SSMAX from ET-SURGE operational fcst: -0.19 m – 0.84 m

Differences among the different estimates of SSMAX



From statistical analysis for 12-hr lead time:

* error in ET-SURGE SSMAX is greater than the error in STAT FCST SSMAX at > 95% significance level
* error in SSMAX from ET-SURGE operational fcst is statistically indistinguishable from error in STAT FCST of SSMAX

Metrics for the error (differences with OBS) associated with the different estimates of SSMAX, at The Battery, N. Y., for the 12-, 24- and 48-hour lead time forecasts.

Lead Time	Statistic	STAT – OBS	NOAA ET – OBS	NOAA ETANOM – OBS
12-hour	Mean (m)	0.0534	-0.2477	-0.1459
	STD	0.1591	0.1186	0.1151
24-hour	Mean (m)	0.0927	-0.2346	-0.121
	STD	0.1597	0.1266	0.126
48-hour	Mean (m)	0.0418	-0.2713	-0.137
	STD	0.1341	0.1346	0.1474

with respect to OBS:

* STAT FCST tends to slightly underpredict or overpredict on average
    - underpredictions → errors in forecasted significant wave heights
    - overpredictions → failure of the regression relation

* NOAA forecasts, both with and without anomaly, tend to underpredict

In Conclusion:

- we established that the new statistical method for predicting "storm-maximum" storm surge (SSMAX) associated with a particular storm is robust
- we can distinguish between events for which errors in statistical forecast are due to errors in predicted wave heights and those that are due to failure of the statistical model → in two thirds or more of the cases, using predicted values of wave height does not have a negative impact on the statistical estimate of SSMAX
- evaluation of the method for 12-, 24- and 48-hr lead time forecasts are encouraging: the mean error of our prediction is smaller than the mean error of NOAA's ET-SURGE model forecasts with 95% confidence and statistically indistinguishable from NOAA's operational forecast
- the lead time of NOAA's operational forecast is limited to the time span over which the anomaly can be assumed constant – our method does not have this limitation and we propose that it could provide valuable information as an element of operationally issued storm warnings

Details of this work are reported in Salmun, H., A. Molod, K. Wisniewska and F. Buonaiuto (2010): Statistical Prediction of the Storm Surge Associated with Cool Weather Storms at The Battery, New York. *Journal of Applied Meteorology and Climatology*, pending acceptance of revisions.

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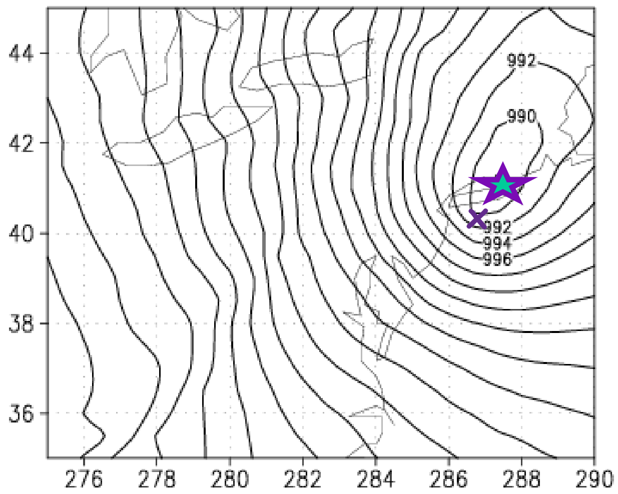

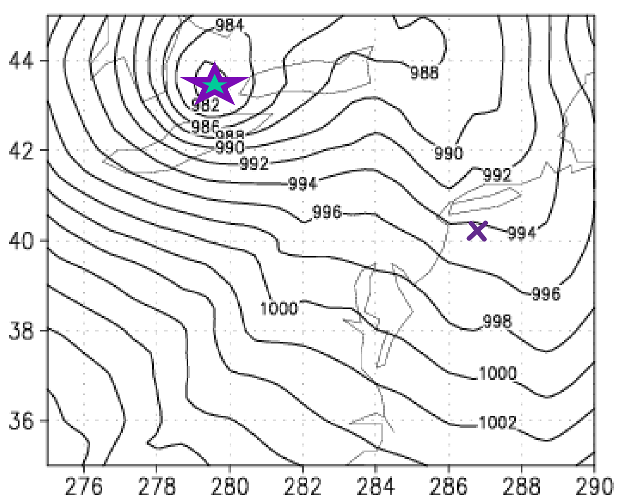

Typical sea level pressure fields from NASA's MERRA re-analysis (~ 0.5° resolution) showing typical patterns of storms for which error in STAT FCST SSMAX are small (top – stronger storms with centers passing directly over area) and those for which errors are large (bottom – weaker storms, centers passing farther away

x approximate location of NDBC station 44025

approximate location of storm's center