Statistical Storm Surge Prediction at the Laboratory for Marine and Atmospheric Research (LMAR), Department of Geography, Hunter College of CUNY.

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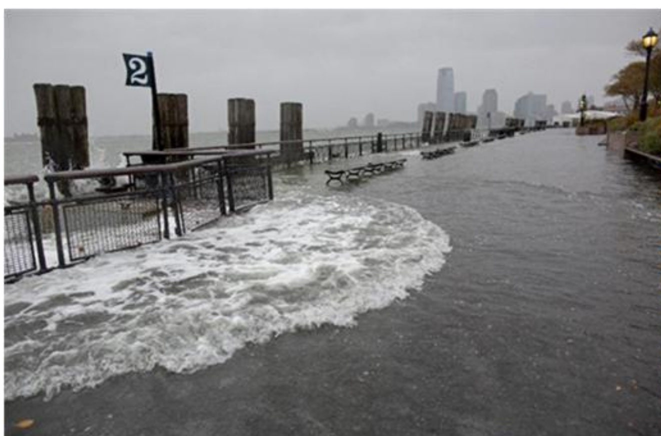
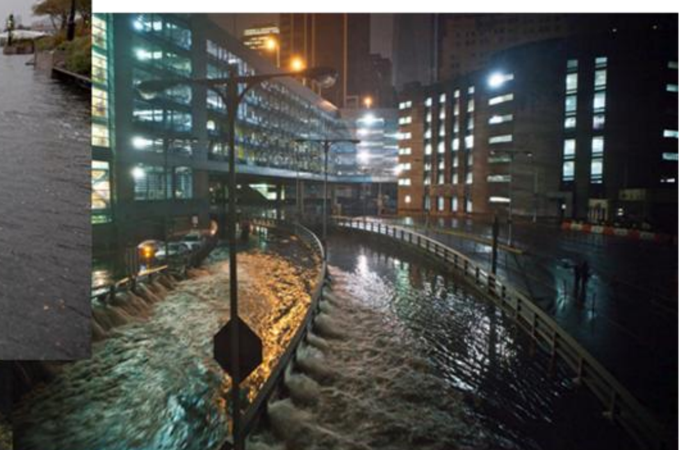
LMAR scientists, along with a colleague from the University of Maryland, have developed a statistical model for prediction of the maximum storm surge that will be reached during a storm event. The model uses sea level pressure forecasts from the North American Mesoscale (NAM) model, and wave height forecasts from WaveWatchIII (WWIII). The LMAR model was used to forecast water level at The Battery, N. Y., during Superstorm Sandy.





New York City on Monday 10/29/2012 – Battery Park, Brooklyn Battery Tunnel, Lower Manhattan around C street.

For details of the LMAR statistical model and its performance in forecasting maximum surge at The Battery, N.Y., see Salmun et al. (2011).

The table below shows the forecasted and observed Maximum Water Level reached during Sandy at The Battery, N.Y. Listed are the deterministic forecasts from LMAR and NOAA, and the assimilation estimate from the Stevens Institute of Technology, Hoboken, N.J. Stony Brook Storm Surge dynamical model forecasts are not yet available. All values are given in reference to Mean Lower Low Water (MLLW), defined as the average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch.

Forecast	**24 hr lead**	**12 hr lead**	**6 hr lead**	**Observed Predictors**	
LMAR	10.45 ft	10.12 ft	11.03 ft	11.16 ft	
NOAA Operational	9.29 ft	10.80 ft			
NOAA+LMAR	9.72 ft	10.29 ft			
Stevens Estimate					10.74 ft
Observed Water Level					13.87 ft

LMAR statistical model forecasts are shown using the NAM and WWIII forecasts at 24 hr, 12 hr and 6 hr lead from 10/29 6 UTC (2:00 AM), which we mark as the beginning of the storm event. Water level from the LMAR statistical model was also computed (after the fact) based on observed wave heights ("Observed Predictors") at a buoy located 34.5 miles from Islip, N. Y.

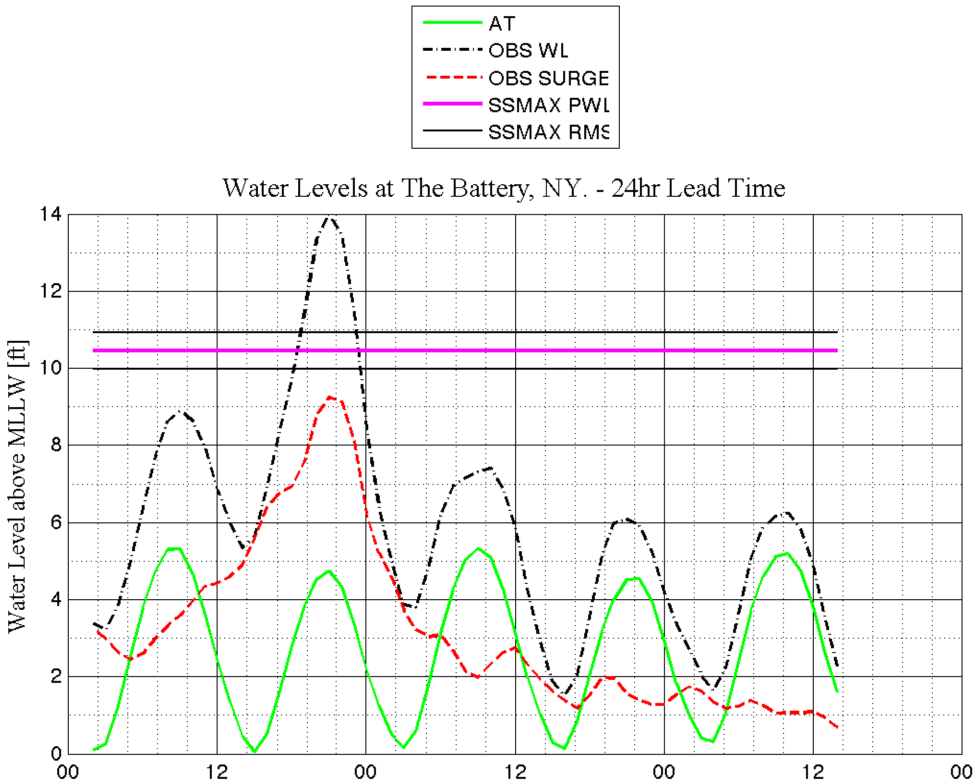
NOAA operational forecasts consist of the dynamical model output, modified by NOAA's bias correction. NOAA+LMAR refers to the NOAA dynamical model modified by a bias correction based on the LMAR statistical forecast.

The probabilistic surge forecasts from the National Hurricane Center predicted a 50% probability of a water level above 10 ft, and a 10-20% probability of a water level above 14 ft.

For reference, a water level of 6.7 ft results in minor flooding and a water level of 8.0 ft results in moderate flooding.

<u>All water level forecasts underestimated water levels by approximately 2 feet or more</u>.

Although the LMAR statistical model predicts “storm maximum storm surge”, a time series of the predicted astronomical tide (AT), the observed water level (OBS WL) and the surge (the residual) at The Battery is shown here to indicate the timing of the maximum water levels. The maximum surge lags behind the tidal maximum by approximately ½ hour. The LMAR statistical forecast with the RMS appears as a constant throughout the duration of the storm.



As stated above, all forecasts and model-based estimates were lower than the observed water level throughout most of the storm event.

Superstorm Sandy was an anomalous event from a synoptic point of view and none of the storm surge prediction models were designed for this combination of a hurricane and an extratropical storm. NOAA's operational forecast model, for instance, was designed with extratropical storms in mind, while the National Hurricane Center's storm surge forecasts were developed for hurricane conditions.

Sandy was an extremely large system, with a diameter on the order of 1000 kilometers; the wind fetch therefore was also anomalously long. Sandy retained its warm-core hurricane structure almost until landfall. The system accelerated suddenly shortly before landfall which affected the meteorological/ocean forecasts that are used to drive storm surge models.

LMAR's statistical model was developed using data for extratropical storm events; specifically, tropical systems were removed from the data that were used to develop the model. To illustrate the differences between the strongest extratropical events (ET composite) that were used to develop the model and Superstorm Sandy, the table below contrasts various storm and waves characteristics.

	min SLP	Hsig	mean WD	max WSpd	max GST	mean WaveD	av. WaveP	max SS@Bat
units	mb	ft	deg > N	mph	mph	deg > N	sec	ft
ET composite (std)	986.84 (7.54)	12.6 (3.4)	202.19 (46.99)	38.3 (5.4)	48.7 (7.4)	153.41 (40.52)	6.12 (0.88)	2.03 (0.9)
Sandy@buoy	958.20	30.41	147.42	55.9	73.8	134.47	7.76	9.25

minSPL = minimum sea level pressure; Hsig = significant wave height; meanWD = average wind direction; maxWSpd = maximum wind speed; maxGST = maximum wind gust; mean WaveD = average wave direction; av. WaveP = average wave period; max SS@Bat = maximum storm surge at The Battery, N.Y.

If events like Superstorm Sandy will become more frequent in a warmer climate, both the dynamical and statistical models will need to be adapted to incorporate these types of events.

For more specific information, please see:

Salmun, H., A. Molod, K. Wisniewska, F. S. Buonaiuto, 2011: Statistical Prediction of the Storm Surge Associated with Cool-Weather Storms at the Battery, New York. *J. Appl. Meteor. Climatol.*, **50**, 273–282. doi: http://dx.doi.org/10.1175/2010JAMC2459.1

NOAA water level observations at The Battery:
http://tidesandcurrents.noaa.gov/quicklook/data/SANDY.html#8518750wl

NOAA Operational Storm Surge Forecasts:
http://www.nws.noaa.gov/mdl/etsurge/

Stevens Institute of Technology Water Level Assimilation:
http://hudson.dl.stevens-tech.edu/SSWS/d/index.shtml?station=N017

Stony Brook Storm Surge
http://stormy.msrc.sunysb.edu/

National Hurricane Center Surge Forecasts:
http://www.nws.noaa.gov/mdl/psurge/archive.php?S=Sandy2012adv28&Ty=gt9&Th=9&Z=y36