Salmun, H: A proposal submitted to PSC-CUNY program on October 15, 2009.

Statistical prediction of storm surge associated with East Coast Cool-weather Storms at The Battery, New York.

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PROJECT DESCRIPTION

1. Introduction

Problem Statement

The main goal of the proposed research project is to evaluate the performance of a statistical method to predict the storm surge related to forecasted east coast wintertime storms. The PI and colleagues developed and published a method that uses data from National Data Buoy Center (NDBC) stations in the New York metropolitan area to identify East Coast Cool-weather Storms (ECCSs), characterize their climatology and assess their impact on the coastal environment by computing 'storm average' values of storm surge data. The particular result of interest to the present proposal is that a regression analysis demonstrated that the best storm surge predictor at a given location (e.g., The Battery, NY) is based on measurements of significant wave height at a nearby buoy (e.g., NDBC station 44025, off Fire Island, LI). Following the methodology described by the authors, and focusing on NDBC station 440025 and The Battery, the present work will use time series of forecasted surface pressure to identify ECCSs and time series of forecasted significant wave heights along with the statistical model to compute a forecasted storm surge. The statistical forecast will be evaluated against observed surge at the Battery and against surge predictions produced by dynamical models. Because of the record of available surface pressure, wave height and surge forecast products, the test period will be March 2005 – December 2008. The research question posed in this study is: can this type of statistical prediction of storm surge provide additional useful information about future surge?

The proposed research is an element of a research program that seeks to understand and assess the surface-atmosphere exchange of mass and energy on local, regional and global scales in the context of a changing climate. The Principal Investigator's work (partially supported by PSC-CUNY Awards # 66304-00 35, 67865-00 36, 68640-00 37 and 69725-00 38) focused extensively on the land-atmosphere interface, and the work proposed here is the continuation of the more recent research on the coastal ocean-atmosphere interface that began with partial funding from PSC-CUNY Award # 61533-00 39.

Context

East coast winter storm systems can bring high winds, heavy rain, flooding, ice storms, blizzards, heavy snow and extreme wind chills to the New York coastal regions. These storms systems are also primarily responsible for the erosion of the barrier beaches, and for the general westward transport of sediment throughout the littoral system that extends from Montauk Point to New York Harbor. The heavy surf during such events has destroyed numerous piers, seawalls, marinas, roads, boats and shorefront homes. Coastal flooding associated with these storm systems has compromised transportation infrastructure. For example, the December 1992 storm resulted in over $230 million in disaster assistance (DeGaetano et al., 2002) and temporarily flooded subway routes between New York City and Hoboken, NJ.

The eustatic sea level rise expected in the future climate (Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4), 2007), which enhances the storms' ability to erode the beaches, along with the continued development on the shorefront is expected to increase the negative impacts of these extratropical storms on these densely populated regions. For example, Jiang and Perrie (2007) used IPCC climate change simulation results and found that with a warming climate Nor'easters show an increase in radius and a marginal tendency to become stronger and propagate faster. The destructive impact of these storms makes it critical to assess the potential behavior of U.S. east coast winter storms in a changing climate.

Significance to the Academic Discipline

This work is important to researchers involved with the study of the regional impacts, particularly on urban regions, of climate and of climate change. The results of this study have the potential to aid in the prediction of storm impacts based on climate change simulations using different IPCC scenarios. Rising sea level will aggravate storm surges along the New York City metro region coast, causing more flooding and increasing the frequency of these floods. The results are also of interest to researchers concerned with the potential impacts of extratropical storms on coastal morphology as well as those who engineer mitigation strategies.

2. Background

A study on the ability to identify seasonal east coast winter storms and storm surge activity using a set of global and local atmospheric and oceanic indicators (atmospheric circulation and sea surface temperatures) was presented by DeGaetano (2008). That work follows the general approach of using statistical methods for predicting seasonal winter storm activity but extended previous works by focusing on a subset of storms that are likely to produce coastal flooding and erosion impacts on New York's Long Island area. He finds that in terms of storm surge potential, forecasts of strong winter storms activity are more skillful than direct forecasts of the number of extreme surge events, but that forecasts of active strong storm seasons and low surge activity show high false alarm ratios. The main issue related to this finding is one of spatial scale. The spatial resolution of the NCEP reanalysis data that was used to identify the storms in the study is 2.5 by 2.5 degrees of latitude and longitude, corresponding roughly to an area of 40,000 km^2. This spatial resolution does not affect the ability to anticipate regional seasonal storm activity but it provides a serious disadvantage in assessing that the localized impact of any particular storm event on a specific location.

The work by Salmun et al. (2009) addresses some of the disadvantages of the existing methods to identify and characterize ECCSs. They assessed the behavior of ECCS systems in the New York metropolitan area using meteorological data from ocean buoys to define and classify the storms and describe their climatology. In addition, they computed climatological means of the impact of the storms on water levels and beaches, and found a correspondence between storm surge and the storm intensity as characterized at the near-shore buoys only. Their method has a local focus, uses meteorological conditions to assess the storms, and provides a highly localized independent assessment of storm impacts. This method therefore has the potential to be used to predict the impact of forecasted ECCSs.

The proposed research builds on the results of the work by Salmun et al. (2009). The method presented by these authors uses surface pressure and surface temperatures data from National

Data Buoy Center (NDBC) stations in New York region to identify and classify East Coast Cool-weather Storms (ECCSs). The storms were identified using hourly mean surface pressure data from two NDBC stations located 33 Nautical miles south of Islip, NY (record begins in 1991), in a depth of 36.2 m and at 200 Nautical Miles from East of Cape May, NJ (record begins in 1977), in a depth of 3182 m. The storm events were verified using US Daily Weather Maps from NOAA. To assess the local impact of the ECCSs on the New York metropolitan region, storm composites of storm surge were computed. A multiple regression analysis was used to estimate the maximum storm surge during a given storm based on combinations of the individual storm composites of various fields measured at the NDBC Stations. The fields used as part of the regression were the minimum pressure, pressure tendency, wind speed, wind gustiness, wave height, and storm duration. The regression analysis at both NDBC Stations demonstrated that the most significant predictor of the maximum storm surge for each storm is the storm composite significant wave height. An F-test on the sum of the squares of the error revealed that the surge estimated with wave height alone is statistically the same as the surge estimated using all the predictors. The regression equation constructed to calculate maximum surge at The Battery using the storm maximum significant wave height measured at NDBC station 44025 is

$$ESS_{44025} = 0.2055 H_{44025} - 0.0851 \qquad \text{with an RMS error of 0.167 m}$$

Statistical results such as this one above are good indicators of relations between physical processes but to understand the complexity of the connections between atmospheric variables, coast configuration, oceanic variables and storm surge requires the use of comprehensive hydrodynamic models. Well-established water level and storm surge forecasts for the New York Metropolitan Region are generated with the aid of ocean circulation models, which are forced by the output from atmospheric circulation models. These efforts are designed for research and are used for guidance purposes by the local NWS forecast offices when issuing estimates and warnings. The most commonly used models for predictions of water level, continuous surge and storm surge are provided by the Extratropical (ET) Water Level Forecast of NOAA, the Storm Surge Research Group at the Stony Brook University and the Storm Surge Warning System of the Urban Ocean Observatory at the Center for Marine Systems, Stevens Institute of Technology. Complete and detailed descriptions of these models can be found at http://www.nws.noaa.gov/mdl/etsurge/, http://stormy.msrc.sunysb.edu/ and http://hudson.dl.stevens-tech.edu/maritimeforecast/, respectively.

Despite significant progress in the area of storm and storm surge predictions, storm surge modeling and prediction of costal flooding in the New York – Long Island region remains a problematic issue for the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service (NWS). The NWS's flood warnings due to extratropical storms issued to costal residents during the 2002-2006 period had a false-alarm rate of 85% (Colle et al., 2009). Improvements of existing methods as well as new developments in storm surge prediction become even more of an urgent matter as the development of costal areas and the regional sea level continue to rise.

3. Project Design

The statistical model summarized in the previous section indicates that the storm composite significant wave height measured at the local NDBC Station's buoy (44025) is a good predictor, in a climatological sense, of storm composite surge at The Battery. Based on this result, it is expected that the statistical model would also work in forecast mode. This expectation is further predicated on the fact that the forecasted wave heights are anywhere near accurate. To investigate this expectation, following the methodology described by Salmun et al. (2009), the present work will use time series of forecasted surface pressure to identify ECCSs and time series of forecasted significant wave heights for the forecasted storms' duration as input to the statistical model to compute a forecasted storm surge. The statistical forecast will then be evaluated against observations and dynamically predicted surge. The research question that we pose is: can this type of statistical prediction of storm surge provide additional useful information about future surge?

Forecast of surface pressure produced by North American Mesoscale (NAM-WRF) weather forecast model will be obtained from NOAA's National Operational Model Archive and Distribution System (NOMADS). This network of data servers provides both real-time and retrospective climate and weather model output data available at http://nomads.ncdc.noaa.gov/. Surface pressure values at the NDBC station 44025 (40.25N 73.17W) will be extracted from weather forecast model output using the software Grid Analysis and Display System (GrADS) for interpolation within a one by one degree grid box that includes the location of the station. We plan to use a long enough period of forecasted fields as to be able to obtain an ensemble of approximately 50 winter storms, and recent enough in time to preserve quality in forecast archived data. Our preliminary research determined that because of the record of available surface pressure, wave height and surge forecast products, the test period will be March 2005 – December 2008.

Forecasts of significant wave heights to be used in this study will be obtained form NOAA's WAVEWATCH III™ operational wave model, which outputs data corresponding to locations of the National Data Buoy Center's (NDBC) and World Meteorological Organization's (WMO) data buoys. All archived data are stored as retrospective forecast driven by NCEP reanalysis and can be obtained from the Marine Modeling and Analysis Branch server ftp://polar.ncep.noaa.gov/pub/history/waves. Point data output at all NDCB stations are available for the period 2005 to the present.

Measurements of water level and tidal mean water level obtained from the NOAA National Ocean Survey (NOS) water level gauges at The Battery will be used to validate the statistical estimates of storm surge. Storm surge is defined as the difference between the astronomical tide level and the observed water levels at the gauge. Our next step is then to compare the statistical estimates with NOAA Extratropical Water Level forecast. NOAA's extratropical surge forecast is produced by dynamic storm surge model based on the depth-integrated shallow water equations and forced by surface winds and pressures generated by NWS's Aviation (AVN) model. The ET surge model incorporates the bathymetric and topographic data from the Sea, Lake and Overland Surge from Hurricanes (SLOSH) model that is used by National Weather Service (NWS) and by the National Hurricane Center (NHC) to estimate storm surge heights and winds resulting from hurricanes. Archived forecast data for surge at The Battery produced by the ET surge model have been made available to the present project by Arthur Taylor from NOAA.

The differences between the statistical storm surge estimates and the observed surge at The Battery will be compared to the difference between surge values predicted by NOAA

Extratropical Water Level Forecast and the water gauge observations will be subjected to standard variance analysis.

The results of this work will constitute the basis for a peer-reviewed publication, which along with the research itself will strengthen the foundation of a research proposal (external funding) to continue and to extend the studies of the impact of extratropical storms on the New York region.

Research Tasks Summary and Schedule

- Compile all data described above.
- Determine the appropriate time step for the forecast to be used (e.g., 1-day, 2-day forecasts).
- Apply our technique to the sea level pressure data from the forecast to identify storms and to determine storm start and end date.
- On the basis of the statistical relation between storm surge and significant wave height of Salmun et al. (2009), assess the expected value of storm surge for these storms.
- Compare these ‘predicted’ storm surge values with the historical storm surge data at The Battery and to the NOAA ET forecast.
- Compute the appropriate statistics to assess the performance of the statistical ‘prediction’.

These tasks will be accomplished over the period of two academic terms approximately. This work will be conducted by the PI with the partial assistance of a student. The research will be carried out at the Laboratory for Marine and Atmospheric Research (L-MAR) of Hunter. It is expected that this research will contribute to an Honors thesis for the student.

4. Bibliography

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