Real-Time Forecasting System of Winds, Waves and Surge in Tropical Cyclones

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LONG-TERM GOAL

The long-term goal of this partnership is to establish an operational forecasting system of the wind field and resulting waves and surge impacting the coastline during the approach and landfall of tropical cyclones. The results of this forecasting system would provide real-time information to the National Hurricane Center during the tropical cyclone season in the Atlantic for establishing improved advisories for the general public and federal agencies including military and civil emergency response teams.

SCIENTIFIC OBJECTIVES

1) To describe and define the functions and interfaces of the tropical cyclone forecasting system.
2) To determine the required data sources and data flow for initializing the models and providing boundary conditions.
3) To design a powerful, high-speed computing system with flexible architecture for optimal real-time model computations.
4) To define output products necessary to enhance the guidance skills of the Tropical Cyclone Forecast/Advisory product.
5) To test the model infra-structure that would lead toward better forecast information for landfall hurricane wind, wave, and surge conditions. Several historical storms will be used to assess model infra-structure.
6) To develop the interface that couples high-resolution cyclone wind fields to the selected wind model.
7) To develop a system that couples storm surge and spectral wave models driven by winds specified in 6).
8) Test entire system via a proof-of-concepts approach with data from several historical hurricanes.
9) Test system in semi-operational mode during several hurricane seasons and begin transition to fully operational mode.

APPROACH

The estimation of tropical cyclone-generated waves and surge in the coastal waters and nearshore zone is of critical importance to the timely placement of warnings to the public and evacuation of coastal residents in the event that a storm makes landfall. The model predictions of waves and storm surge in coastal waters are functionally related and both depend on the fidelity of the atmospheric forcing.

The actual time and location of land-fall is still difficult to predict, even with significant improvements in skill by the global model. Therefore, we chose to forecast the winds, waves and storm surge not only along the official track prediction by the National Hurricane Center (NHC), but also along all alternate tracks. The results will allow us to provide a risk factor of the expected conditions for a given region and time period. This probability will allow emergency managers to weigh the relative risk of evacuating one area over another.

Another critical component is the highly efficient performance of the numerical models. The WAM-4 model uses most of the time to execute and with recent advances in computational capabilities and the assistance of IBM we have significantly reduced the execution runtime. Our current capabilities exceed those at typical national and international weather centers.

WORK COMPLETED

This project has just ended its second year. In YR-3 we will commence testing a prototype forecast system in a semi-operational phase with the intent to provide sample output to the NHC during the hurricane season. This output will be provided on a contingency basis subject to evaluation and assessment. The timeliness and value of the deterministic and probabilistic output products would be evaluated during the upcoming hurricane season.

The major tasks that have been completed are:

- Completed implementation of WAM-4 on IBM p690 “Regatta” and made considerable enhancements and accelerations of the code
- Implementation and testing of ADCIRC surge model completed
- Establishment of high resolution common bathymetry grid and common land mask as well as wave model grids at 10 and 20 km resolution and an Atlantic/GOM finite element (FE) grid for storm surge
- Special very high resolution FE grids for selected cities started
- Selected historical storms for testing and data preparation in progress
- Alternate track simulations (18 tracks) for Georges completed
- Reference simulation of Floyd complete
- Development of proto-type wave forecast system for NHC this summer continuing
- Simple risk analysis scheme for ensemble statistics in test mode

RESULTS

Windfield Modeling:
The wind field generation process consists of two major components: WindScript and WindGen. The WindGen program inputs wind field “snapshots” from either the HRD HWIND analysis or from OWI’s tropical boundary layer model (TC96). Current work has concentrated on times when the HWIND analyses were available. These snapshots can be incorporated at arbitrary times and on arbitrary grid spacings. A moving features time interpolation routine is used to preserve the system’s circulation and prevent smearing of the interpolated wind fields. These snapshots are then blended into a background wind field using OWI’s IOKA objective analysis routine. Each snapshot can be repositioned in space to reflect a particular input track and intensity modification according to the official forecast to a particular forecast model. Tracks for multiple systems within a basin are fully

supported. Since centers of a track forecast may differ radically from any background wind field a search algorithm is applied to remove wind centers from the background wind field before blending is applied. WindGen currently outputs a wind and pressure field at the specified time interval on the working grid for use in the wave and hydro-dynamical models.

We have continued to develop our model strategy and skills using historical datasets of interesting hurricanes and tropical storms. The historical storms include Georges, Floyd, Hugo, Opal, Andrew and Bonnie. However, hurricane Isabel in early September 2003 provided an excellent environment to test both the data ingestion/decoding scripts as well as the WindGen program in a near real time application. Winds were generated on reduced lat/long grid at 0.2-degree resolution to match WAM model restricted domain (for run time). Some test runs of alternate tracks were made (we currently get AVN, ETA, NGM, NGX, BAMD, A98E, LBAR and BAMM in real time) but not uploaded. For example, Figure 1 shows the maximum wave height conditions along the path of Hurricane Isabel as predicted by WAM-4. The graph clearly delineates the intensity of Isabel north of the Caribbean Islands where waves in excess of 15 m and more covered a large area. Large waves accompanied Isabel all the way until landfall at Cape Hatteras. The fact that the was a breach on Hatteras is testimony of Isabel's strength and wave impact.

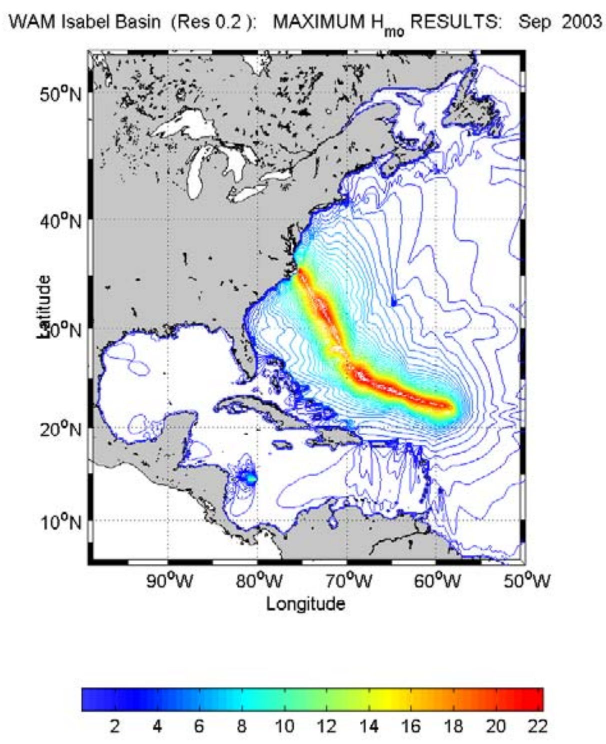

Figure 1: Maximum wave heights along Isabel's path generated by WAM-4.

Storm Surge Modeling:
A tidal data set was established and verified for the entire Western North Atlantic Tidal (WNAT) model domain. The open ocean boundary of the WNAT model domain coincides with the 60° W meridian, and lies predominantly in the deep ocean. The coastal boundaries are composed of the South, Central, and North American coastlines. Because of its great size (8.347x106 km2) 333,701

computational nodes are employed to construct a two-dimensional finite element mesh. The mesh resolves the deep ocean at approximately 45 kilometers with the highest resolution reserved for coastal, island and shelf break regions on the order of 500 meters to two kilometers. The final data set is compared to NOS station data and shown to be within 10 degrees phase and 10% amplitude at nearly all of more than 100 tidal stations. A test case involving tides, storm surge and freshwater flows was performed using a wind field hindcast for Hurricane Hugo.

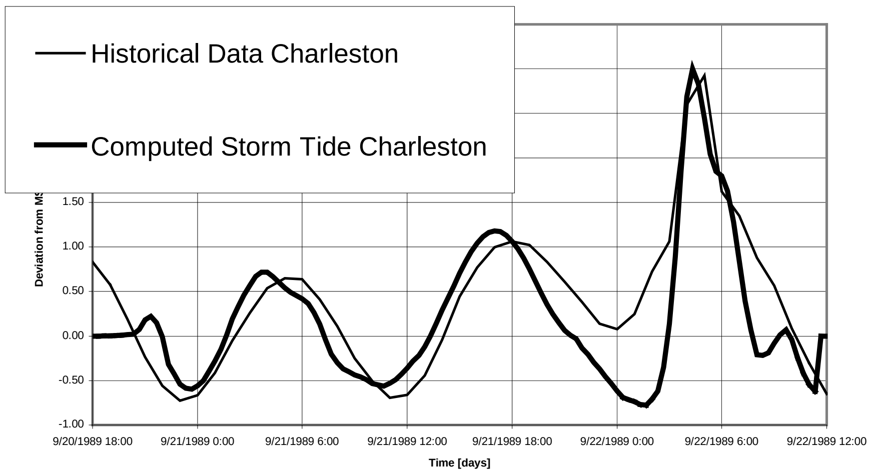

Figure 2: Storm tide resulting from Hurricane Hugo at Charleston, SC.

For a wide range of wind-wave conditions our model predictions show that the wave-induced sea-level elevation rise is approximately 10% of the deep-water wave height. This result is nearly independent of the shelf topography. Hurricanes can produce waves on the order of 5 to 25 m high and may contribute approximately 0.5 to 2.5 meters of surge at the coast. The surge produced by the wind setup, however, is a strong function of the shelf slope and the speed at which the eye of the storm moves. A weakly non-linear analysis shows that the coastal setup is nearly proportional to the depth of the water column. Consequently, the same 50 m/s wind may produce anywhere between 1 and 5 meters of surge depending on whether it arrives on a narrow or broad shelf. Broad shallow shelves are at much greater risk for increased coastal flooding. The proportion of surge that is caused by the wind and waves is therefore a strong function of the shelf topography. For storms on a shallow shelf, wave setup may only contribute 10% to the overall sea level rise, whereas on a steep shelf, the wave induced setup may contribute 50% or more. Hence, including wave setup can be important to making accurate predictions of storm surge. During hindcasts of Hurricane Georges, that made landfall near Gulfport, Mississippi in 1998, we found that including wave-induced surge increased the model skill by approximately 35%. Figure 3 shows surge predictions compared to the NOAA tide gauge data located in Waveland, Mississippi during landfall of Georges. The model was run with (a) wave stress only, (b) wind stress only, and (c) combined wind and wave forcing. Note that the combined forcing is slightly higher than a simple linear combination of the two separate effects at this location. The black curve shows the tide gauge data. Tides were not included in these surge simulations, but can be added separately because, to a good approximation, tides superposition linearly with the storm surge.

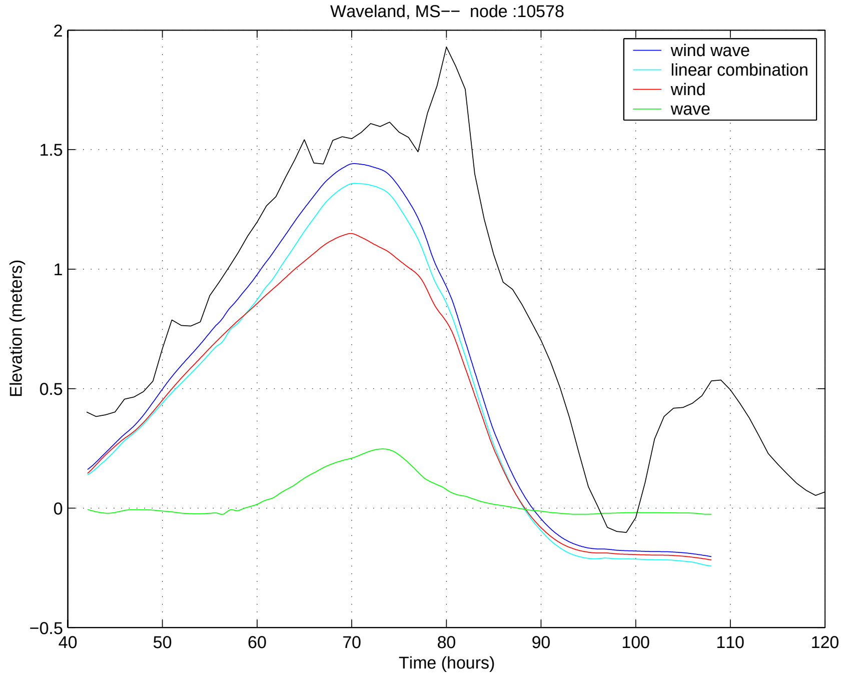

Figure 3: Storm surge comparison from Hurricane Georges in Waveland, Mississippi. NOAA tide gauge observations in black. Model predictions for various combinations of wind and wave effects in color.

IMPACT/APPLICATION

An improved forecast of the coastal environment under hurricane conditions has potential benefit for society in several areas. A primary benefit is the early warning and evacuation of population and mobile assets from threatened coastal areas. The expected results of the real-time forecasting system for winds, waves and surge in tropical cyclones promise to provide timely critical information to the National Hurricane Center for better advisories and warnings to local, state and federal emergency agencies and the general public. The challenge of crisis managers and emergency planners is to relocate an ever-increasing coastal population from the path of destructive tropical cyclones.

TRANSITIONS

None yet.

RELATED PROJECTS

Modeling the wave field in shallow water and coastal regions is one of the primary objectives of the Shoaling Waves Experiment (SHOWEX). From the experimental phase we expect to find improved source term definitions for waves in shallow water which we would implement for the real-time forecasting system. Several Florida municipalities and state agencies expressed an interest of our storm surge modeling capability.