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

Hans C. Graber, Mark A. Donelan and Michael G. Brown
RSMAS - Applied Marine Physics, University of Miami
4600 Rickenbacker Causeway, Miami, FL 33149-1098,
USA phone: (305) 411-4935, fax: (305) 411-4701, email: hgraber@rsmas.miami.edu

Donald N. Slinn
Civil and Coastal Engineering Department,
University of Florida Gainesville, FL 32611-6590
phone: (352) 392-1436 x1431, email: slinn@coastal.ufl.edu

Scott C. Hagen
Civil & Environmental Engineering, University of Central Florida
P.O. Box 162450, Orlando, FL 32816-2450
phone: (407) 823-3903, fax: (407) 823-3315, email: shagen@mail.ucf.edu

Donald R. Thompson
The Johns Hopkins University, Applied Physics Laboratory
11100 Johns Hopkins Road, Laurel, MD 20723-6099
phone: (240) 228-4559, fax: (240) 228-5548, email: donald.thompson@jhuapl.edu

Robert E. Jensen
USAEWES, Coastal and Hydraulics Laboratory, Research Division,
3909 Halls Ferry Road, Vicksburg, MS 39180-6199 USA
phone: (601) 634-2101 fax: (601) 634-4314 email: jensen@madmax.wes.army.mil

Peter G. Black and Mark D. Powell
NOAA/AOML, Hurricane Research Division
4301 Rickenbacker Causeway, Miami, FL 33149 USA
phone: (305) 361-4320 fax: (305) 361-4402 email: black@aoml.noaa.gov

John L. Guiney
DOC/NOAA/NWS-Eastern Region, Eastern Region Headquarters
630 Johnson Avenue, Bohemia, NY 11716 USA
phone: (631) 221-0121, fax: (631) 221-0167, E-mail: John.Guiney@noaa.gov

Vincent J. Cardone, and Andrew T. Cox
Oceanweather, Inc. 5 River Road, Suite 1, Cos Cob, CT 06807 USA
phone: (203) 661-3091 fax: (203) 661-6089 email: vcardone@oceanweather.com

Award #: N00014-02-1-0150
http://hurricanewaves.org

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2006		**00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Real-Time Forecasting System of Winds, Waves and Surge in Tropical Cyclones	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **RSMAS - Applied Marine Physics, University of Miami,4600 Rickenbacker Causeway,Miami,FL,33149-1098**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

LONG-TERM GOALS

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.

OBJECTIVES

1) To define output products necessary to enhance the guidance skills of the Tropical Cyclone Forecast/Advisory product.

2) 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.

3) To develop the interface that couples high-resolution cyclone wind fields to the selected wind model.

4) To develop a system that couples storm surge and spectral wave models driven by winds specified in 6).

5) Test entire system via a proof-of-concepts approach with data from several historical hurricanes.

6) Test system in semi-operational mode during several hurricane seasons and begin transition to fully operational mode.

APPROACH

So far the 2005 hurricane season was one of the best “real tests” of the forecasting model system for winds, waves and surge. With unprecedented active storm season of 26 named storms, the 2005 season provided a major challenge to the forecast system with having multiple storms present in all basins as well as little downtime between storms. Several major hurricanes such as Katrina, Rita and Wilma tested the system with extreme high winds, waves and surge. As always the system was spun up on June 1, 2006 and is running uninterrupted in real time when a storm is present and provides graphical output accessible through a website in an operational mode. During this last year the focus of the project was to make final improvements to the wind, wave and surge models and in particular the graphical output, strengthening of the interfaces and the links to access of external data sources. H*Wind snapshots from NOAA/AOML were produced on a three-hourly cycle instead at synoptic times for more timely initialization of the wind fields. We were also operating fully within the six-hourly advisory cycle of the National Hurricane Center (NHC) and made results available to NHC for evaluation purposes via our web interface. This year we include runs for the ensemble of alternate tracks which will be used to provide risk factors of exposure to winds, waves and surge.

WORK COMPLETED

1. Completed the extremely active 2005 hurricane season in fully automated, "operational" mode. Even the last tropical storm ZETA in January 2006 was forecasted. The new 2006 season was started on June 1.

2. The WINDGEN system continued to perform excellent during this extremely active hurricane season with many super-type hurricanes. The system is ready for operational use and we have tested a higher resolution grid covering the entire area at 10 km and 15 minute intervals.

3. Wave and surge models have been coupled to include the effect of momentum input (radiation stress) from breaking waves on sea-level rise in coastal regions.

4. Numerous improvements have been made to the WAM model, in particular the wave growth algorithm has been modified to correctly simulate wave generation in extreme wind forcing conditions.

5. Tidal dynamics are fully integrated into the surge predictions.

6. Surge model is fully integrated into forecast system to run in real-time.

7. We have added all alternate track forecasts deemed of importance to the NHC (currently about dozen) to the computational cycle. Current limitations to include more tracks for ensemble predictions are insufficient computer resources.

8. We have completed several improvements to graphical formats and posting to website (http://hurricanewaves.org

RESULTS

Wind Field Generation Program:

The WINDGEN program is in its third iteration and has been successfully applied during the 2005 hurricane season and is currently running for 2006. All required real time acquisitions of track, H*WIND snapshots, background fields from NCEP and alternate track information required by the WIND GENeration program (WINDGEN) are automatically accessed and retrieved. In addition, wind/wave validation data from NDBC (National Data Buoy Center) and water level/tide data from NOS (National Ocean Service) are being ingested in real time. All scripts have been running throughout the hurricane season and are robust and stable and keep performing well. The WINDGEN program can input either H*WIND analysis or perform its own wind field generation using the TC96 tropical boundary model. The program also provides wind/pressure output for numerous alternate track models for use by the modelers. Numerous upgrades were made to the WINDGEN software during the 2004/2005 period. Native ADCIRC output is now built into the model. This integration not only saves time during the forecast run, but also makes use of WINDGEN's space interpolation routines to better describe the stress and pressure inputs on the ADCIRC grid. The surge modelers can easily apply updates to the ADCIRC output as new grids/domains are tested and brought online into the operational system. As a result of post-analysis work done on Hurricane Ivan 2004, the blending of the H*WIND/TC96 into the GFS background field has been adjusted. This results in wind fields that better blend into the synoptic flow. Additional work on the WINDGEN code involved the handling of bad/erroneous winds data and better failover if bad data is encountered. The latest version of

WINDGEN is run operationally on GERONIMO at 0.2 degree and SATANTA at 0.1 degree currently for post-storm analyses. Figure 1 shows an example of the wind field product available from the NOPP project and the exposure winds from the ensemble tracks for Miami Beach, Florida.

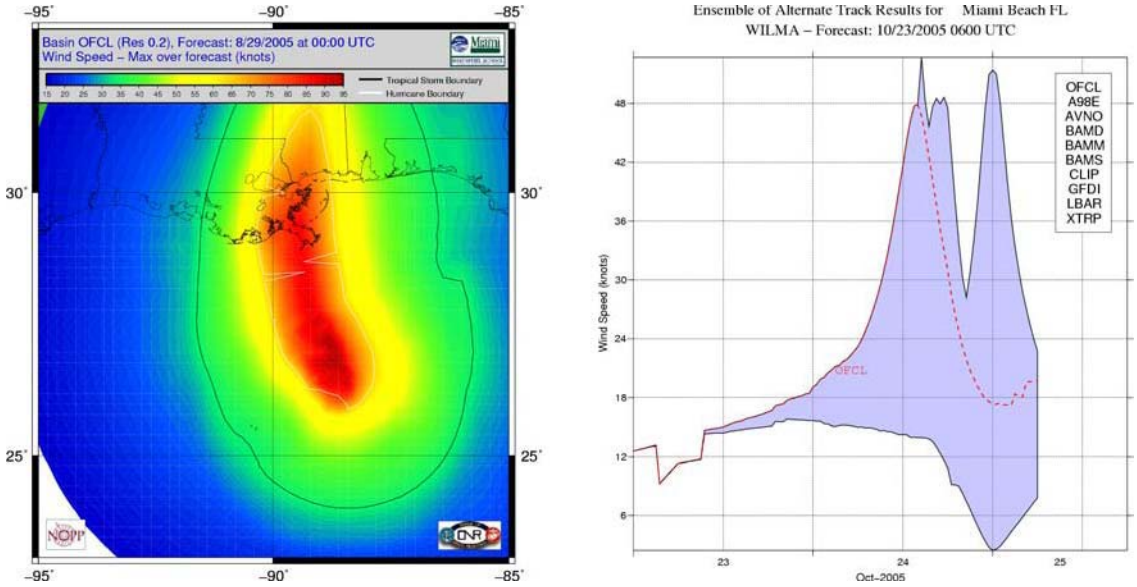

Figure 1: Left: Zoomed in graphics of maximum wind speeds over five day forecast period associated with Hurricane Katrina near landfall. The black boundary shows the extent of tropical force winds while the white line shows the region of hurricane force winds. Right: Forecasted exposure winds for Miami Beach, Florida before landfall of Hurricane Wilma derived from an ensemble of alternate tracks (listed inside box). The red dashed line shows expected wind speeds for the official forecast track.

Wave Modeling:

A fully tested and automated, operational wave forecasting system based on WAM Cycle 4.5-V2 for Hurricanes at Landfall was put in place for the 2004 Hurricane season. The 2005 Hurricane season demonstrated how robust and stable WAM performed and the quality of the wave forecasts. This was made possible by significant improvements internal to the model which led to revisions to source term specification that constrained wave growth consistent with recent behavior of the drag coefficient as the surface condition goes from aerodynamically smooth (characterized by a drop in the drag coefficient with increasing wind) to aerodynamically rough (drag coefficient increasing with wind speed), multi-grid nesting, ice coverage implementation and more importantly depth limited breaking. In addition the model has been optimized for scalable computational platforms reducing the operational constraints by a factor of 20. These improvements, and three years of critical evaluation for the 2003 through the 2005 hurricane season by the NOPP project that included many historical tropical storm simulations produced a wave model with unprecedented performance characteristics. The latter implementation and execution provided insights into improvements in the source terms reducing significant errors in the core of tropical systems by 30-percent. Figure 2 shows two examples of wave height predictions for the super active 2005 Hurricane season. These products are typically generated and available on the NOPP project website.

Surge Modeling:

We have now fully integrated the ADCIRC (Advanced Circulation Model for Coasts, Shelves and Estuaries) with the WAM Cycle-4.5 model to improve predictive skill for storm surge during tropical cyclones. In addition to the standard ADCIRC implementation, we are also running a parallel version (PADCIRC) to achieve more efficient processing for the alternate track ensemble. Both ARCIRC

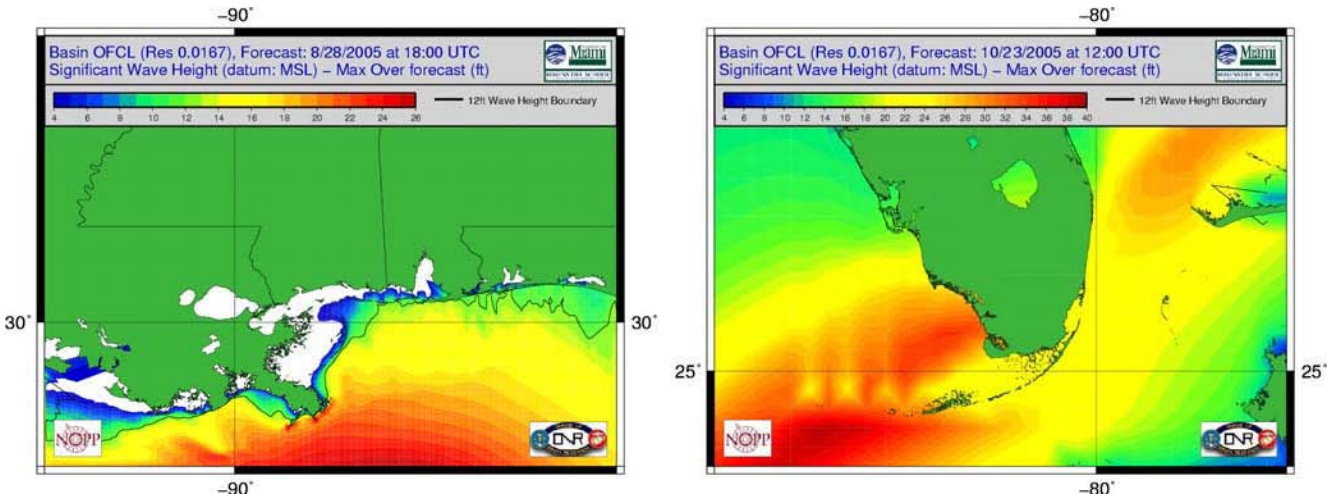

Figure 2: Left: Zoomed in wave height predictions of Hurricane Katrina near landfall over a five day forecast cycle commencing on August 28, 2005 at 18:00 UTC. Maximum wave height conditions exceeded 25 ft offshore the Mississippi Delta. Right: Zoomed in wave height predictions of Hurricane Wilma shortly before landfall for a five day forecast cycle commencing on October 23, 2005 at 12:00 UTC. Maximum wave height conditions reached nearly 40 ft in the Florida Straits.

versions have been optimized and include the effects of wave through the radiation stress provided by the WAM model. Additional improvements were made by establishing an operational mesh with a minimal number of computational points (47,860, hereto referred as the 48K mesh) that produces highly accurate astronomical tide simulation results. Spatial resolution of the mesh ranges from a node spacing of approximately 160 km in the Atlantic Ocean to roughly 6 km element sizes along the coastal boundaries. This mesh can be employed in astronomic and meteorological tidal simulations with a time step of 30 seconds, permitting a five day forecast to be completed on the NOPP IBM computing system in less than 10 minutes. Figure 3 shows two examples of the maximum predicted storm surge over a 5-day forecast cycle for Hurricanes Katrina and Wilma. The forecasted conditions were pretty close to the observed water level changes during these storms.

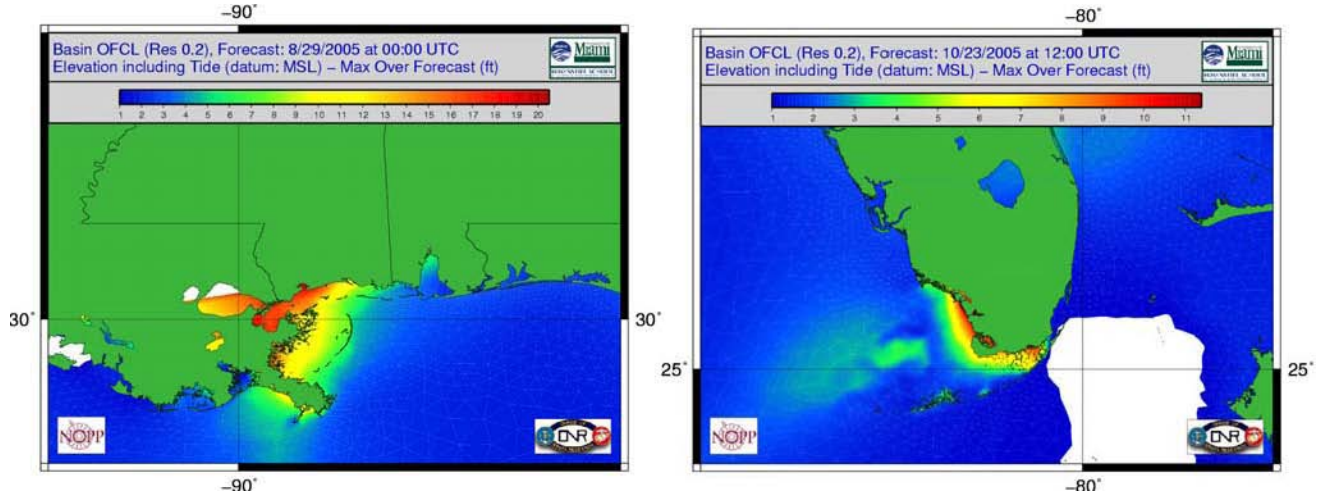

Figure 3: Maximum storm surge levels for Hurricanes Katrina (left) and Wilma (right) over a five day forecast cycle along the official track as provided by the National Hurricane Center.

IMPACT/APPLICATIONS

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 storm surge modeling can also be extended to include tsunami prediction and warning capabilities.

National Security

Improved forecasting of several days in advance will help emergency planners and FEMA as well as DHS to prepare adequately for approaching tropical cyclones.

Economic Development

This forecast system could also be used to determine which coastal regions are extremely vulnerable to the impact of tropical cyclones especially caused by flooding and wave damage. New risk and exposure maps for flooding can readily be generated with the added benefit of risk factors, i.e. not all *storm may lead to flooding.*

Quality of Life

Understanding better the risk to potential damage will allow the public and communities to make decisions on where to live and how to manage coastal and ecological resources.

Science Education and Communication

Assessment of operational models will identify shortcomings in the science and physics of models used for weather prediction as well as the need for the right data at critical locations and times.

TRANSITIONS

National Security

The NOPP system will be implemented for the New Orleans District of the US Army Corps to provide warning messages for wind and surge in the event when flooding conditions may arise and the three gates along Lake Pontchartrain need to be closed.

RELATED PROJECTS

This NOPP project began to partner with SCOOP whose primary goal is to provide high-resolution storm surge predictions during severe weather phenomena such as tropical and extra-tropical storms in coastal regions along the US East coast and Gulf of Mexico. To achieve this goal SCOOP will utilize the NOPP's coupled model forecast system. Two studies started that target specific coastal and inland regions. First, a study with the NWS Southeast River Forecast Center to produce real-time tides and storm tide hydrographs for the Waccamaw River region in South Carolina. In addition, NOAA, through the NWS Office for Hydrologic Development has funded a three-year. A collaborative effort between UCF and UF led to a pilot study for the Florida Department of Transportation (FDOT), which will examine the effects that inlet shapes, as well as coupled short and long wave models have on nearshore storm tide hydrographs that are then employed in bridge scour studies.

PUBLICATIONS

Dietsche, D., "Storm Tide Simulations for Hurricane Hugo (1989): on the Significance of Including Inland Flooding Areas," A UCF Masters Thesis, Orlando, FL, Summer 2004.

Dietsche, D., and S.C. Hagen, "Influence of Inland Flooding Areas on Near-Shore Storm Tide Hydrographs," Journal of Waterways, Port, Coastal, and Ocean Engineering, In Preparation.

Donelan, M.D., B.K. Haus, N. Reul, W.J. Plant, M. Stiassnie, H.C. Graber, O.B. Brown, E.S. Saltzman, 2004: On the limiting aerodynamic roughness of the ocean in very strong winds. Geophys. Res. Letters., 31:18, L8306, doi: 10.1029/2004GL019460.

Graber, H.C., V.J. Cardone, R. E. Jensen, D.N. Slinn, S.C. Hagen, A.T. Cox, M.D. Powell, and C. Grassl, 2006: Coastal Forecasts and Storm Surge Predictions for Tropical Cyclones. A Timely Partnership Program. Oceanography, 19(1), 130-141.

Graber, H.C., D. Slinn, S.C. Hagen, R.E. Jensen, V.J. Cardone and A. Cox, "Forecasting of Storm Generated Surge in Hurricane Isabel," 58th Interdep. Hurricane Conf., March 1-5, 2004, Charleston, South Carolina.

Hagen, S.C., D. Dietsche, and Y. Funakoshi, "Storm Tide Hindcasts for Hurricane Hugo: Into an Estuarine and Riverine System," Sixth Int. Conf. on Hydro-Sci. –Engin., Brisbane, Australia, May 30 – June 4, 2004.

Hagen, S.C., H.C. Graber, V.J. Cardone and A. Cox, "A Computationally Efficient Hindcast of Storm Tides from Hurricane Hugo," 58th Interdep. Hurricane Conf., March 1-5, 2004, Charleston, South Carolina.

Hagen, S.C., A. Zundel, and Y. Funakoshi, “An LTEA-Based Mesh for Tidal Modeling in the Western North Atlantic,” Int. J. Num. Meth. in Fluids, In Preparation.

Weaver, R.J. and Slinn, D.N., Effect of Wave Forces on Storm Surge, Submitted to Coastal Engineering, June 2004.

Weaver, R.J., 2004, Effect of Wave Forces on Storm Surge, Masters Thesis, University of Florida Department of Civil and Coastal Engineering.

Zundel, A. and S.C. Hagen, “An Optimal, Automatically-Generated Mesh for 2-D Flows in a Large-Scale Domain,” J. Comp. & Inform. Sci. Engineer., In Preparation.