Meteorological Aspects of the Gulf of Mexico Hurricanes

by

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ABSTRACT

The 2004 and 2005 Atlantic and Gulf of Mexico hurricane seasons were unprecedented in the length of the seasons, the number of named storms and landfalls, and the amount of damage.

A tropical storm becomes a hurricane when winds reach 74 mph (64 kt). There are on average six Atlantic hurricanes each year; over a three-year period, approximately five hurricanes strike the United States coastline from Texas to Maine. When hurricanes move onto land, the heavy rain, strong winds and heavy waves can damage buildings, trees and transportation systems.

According to FEMA, hurricanes account for seven of the top ten most costly disasters in U.S. history. The State of Florida was struck by four major hurricanes in 2004 with losses totaling \$42B (Meade and Abbot, 2003). This was considerably more than the losses resulting from Hurricane Andrew in 1992, which had been the standard for single hurricane losses in the U.S. The 2005 season included 27 named storms and 15 hurricanes, 6 of which struck the U.S.² The losses due to Hurricanes Katrina, Rita and Wilma in 2005 are still being determined, but early estimates place losses from Hurricane Katrina upwards of \$200B. This dwarfs the losses due to any disaster in the U.S. and approaches a significant percentage of the U.S. Gross Domestic Product.

Recent storms demonstrated how hurricanes can affect the entire U.S. and its economy, from energy, to raw materials, to food supplies. The impacts of hurricanes are the dependent on response immediately prior to storm landfall and on the years and decades of decisions and development preceding the storm impact. Better forecasts, better warnings and better preparedness plans in the days and hours before a storm makes landfall are needed, as are better development policies, long-term mitigation strategies and long-term assessments of risk and vulnerability.

KEYWORDS: hurricane winds, hurricane damage

1.0 INTRODUCTION

When hurricanes enter the Gulf of Mexico from the Atlantic Ocean or develop in situ in the Gulf, they have no where to go but make landfall, if not in the United States, then in Mexico, Central America, and/or the Caribbean Islands.

When the steering winds of these storms are light, there is very little skill in predicting their track. These slow moving storms are often the most destructive from wind damage and especially from flooding. For any hurricane in the Gulf, there is very little skill in predicting the intensity of the storm at landfall, its rate of weakening after

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landfall, or its potential for spawning tornadoes. Tornadoes in hurricanes or tropical storms after landfall tend to be of the weaker variety (F0 to F2), but they can locally significantly add to wind damage.

Added to wind and freshwater flooding damage is the storm surge and shallow water wave damage on the coast. The U.S. National Oceanic and Atmospheric Administration (NOAA) runs an operational storm surge model (Sea, Lake, and Overland Surges from Hurricanes or SLOSH) (http://www.nhc.noaa.gov/HAW2/english/su rge/slosh.shtml) (Jelesnianski, 1992) which provides a reasonable forecast for relatively simple coastlines, but does not do well in complex coastlines, such as with small bays and estuaries with complex bathymetry, and does not include the additional effects of fresh water flooding in estuaries nor the effects of shallow water waves. Currently, there is work being done to incorporate shallow wave into the next generation NOAA operational air-sea-land-coupled hurricane prediction model (hurricane weather and research forecast, or HWRF, model) (Surgi and Evans, 2003)

2.0 CONDITIONS LEADING TO THE ACTIVE 2005 GULF OF MEXICO HURRICANE SEASON

The seasonal conditions were primed for an active Gulf hurricane season (Fig. 1). The "loop current", a prevalent feature in the Gulf during the warm season, was considerably larger and warmer than normal. Also, a persistent tropical circulation was set up that helped steer the Atlantic hurricanes northwestward into the Gulf. The number of Atlantic hurricanes was above normal due to the unusually warm tropical Atlantic sea surface temperatures and weak wind shear at least partially due to a weak La Niño.

3.0 CURRENT U.S. HURRICANE WIND FORECASTING CAPABILITIES

Two years ago, the U.S. National Weather Service (NWS)/Tropical Prediction Center officially began extending its hurricane forecasts (more accurately described as "outlooks") to five days. The motivation to do so emerged from a requirement of the U.S. Navy who needed long lead times to move their ships in port out of harm's way. These longer lead times necessitated describing the uncertainty of hurricane track forecasts

3.1 Hurricane Track

A skillful forecast of hurricane track at landfall is essential. If the track forecast is not correct, the wind, rain, storm surge, and shallow wave forecasts will also not be correct. Through strategic U.S. investment in research on hurricane forecast model development through the U.S. Weather Research Program and through improvements in operational global model predictions of steering currents in the tropical Atlantic and Gulf of Mexico, significant improvements have been realized in hurricane track forecasts within the past decade (Fig. 2).

The global model (NWS Global Forecast System, or GFS) improvements in the tropics has mainly been realized by improved satellite measurements of moisture in the tropics, which has, in turn, greatly improved precipitation and wind forecasts. The NWS hurricane model, currently the Geophysical Fluid Dynamics Laboratory's (GFDL's) model, which is embedded in the GFS was updated to by compatible with the improved GFS dynamics.

As seen in Figure 3, coupling the hurricane model with an ocean wave model also improves the track. The fully coupled GFDL model will be run operationally in the 2006 hurricane season.

3.2 Hurricane Intensity

Of most direct importance to hurricane winds is improving the hurricane intensity forecasts at landfall. There is currently little skill for any lead time in predicting hurricane intensity. Coupling hurricane models with an ocean model (Falkovich and Ginis, 2005; Bender and Ginis, 2000), as has been done with the GFDL operational hurricane forecast model, has provided an improvement in skill (Fig. 4).

The fully coupled GFDL model, with a deep ocean wave model and an improved Gulf of Mexico loop current model, which will be operational in the 2006 hurricane season, holds promise of significant improvement in intensity forecast skill (Fig. 5). However, missing is knowledge of hurricane inner core processes and detailed knowledge of the small-scale interactions between a hurricane and its immediate environment which are also critical to changes in intensity.

4.0 CURRENT HURRICANE SURFACE WIND MEASUREMENT CAPABILITIES

The measurement of surface winds within a hurricane is extremely challenging, whether over land or over water.

Over water, the most accurate, but not necessarily the most reliable or representative winds are observed by anemometers on buoys. However, in high winds, these observations are plagued by the damping effects of breaking waves and sea spray, let alone the extreme oscillations of the buoy. In addition, due to their maintenance costs, ocean buoys in the Gulf that measure winds are quite sparse.

Also over water, GPS dropsondes from aircraft (Uhlhorn and Black, 2003) are now observing winds close to the ocean surface without the previous need to extrapolate winds to the surface. In addition, the airborne Stepped Frequency Microwave Radar (SFMR) has been used for many but recently is being vears. used operationally. It remotely senses the ocean surface foam and can be calibrated for surface wind speed and direction and corrected for interference from rain (Uhlhorn and Black, 2003).

The GPS dropsondes and the SFMR have revealed that the surface winds over the ocean in strong hurricanes are higher than previously determined by models using estimated drag coefficients at high winds (French et al., 2006). The sea-surface drag coefficients appear to be nearly constant with wind speed rather than increase at high winds as older parameterizations have indicated. These new drag coefficients are now being used in the GFDL operational model and contribute to improved track and intensity forecasts (Moon et al., 2006).

Sea surface wind observations are derived from Quickscat (NASA) and Windsat (Navy) which are passive microwave sensors that are not affected by clouds, but do have some interference in heavy rain conditions. However, the spatial resolution of these observations is not particularly high – 12.5 km for Quickscat and about 60 km for Windsat. These instruments sense the capillary surface waves and the sea-surface foam to derive wind speeds and directions.

Along the coast and inland, the bulk of the surface wind observations come from Automated Surface Observing System (ASOS) operated at airports by the Federal Aviation Administration and the NOAA. In terms of the instrumentation itself, these are high quality measurements, but they are subject to power outages and lost data, which often happens in hurricanes and other severe storms. There also is a question about exposure. Some sites are subject to wind blockage in certain directions. The spatial coverage of these systems is rather sparse.

A new source of near surface wind measurements over land and to some distance over water are from Doppler radars. The largest source of such data are the WSR-88D (or NEXRAD) operational radars. Although the coverage is excellent, the spatial resolution is poor for structural engineering applications and, because the winds are usually derived from single Doppler velocity-azimuth data (VAD), except where radar ranges overlap, the observations only provide one wind dimension and can be many 10s of meters above the surface, increasing with distance from the radar. Although much more robust with respect to power sources than ASOS, they do lose power and, more importantly, can lose data communication at which point the data is usually not recoverable.

A more experimental, but potentially very rich data set comes from the mobile, deployable Doppler radars such as the SMART or Doppler on Wheels (DOW) radars (Biggerstaff et al., 2006; Knupp et al, 2005) and portable towers with in situ wind instruments (Masters et al., 2004; Masters et al., 2003; Howard et al., 2003). These systems have been deployed for the past several years by U.S. universities in collaboration with NOAA, along the Gulf and Atlantic Coasts at critical times and locations relative to forecasted hurricane landfalls. They are very robust with respect to winds measurements with their own power sources and designed for the very high surface winds expected at landfall in the more powerful hurricanes. The radars are KU band radars with less than one kilometer resolution. Figure 6 shows a Doppler display that clearly reveals small scale streaks representing the wind gusts. The disadvantages of these systems are that they are not operational and therefore are not continuously available, the systems are few in number, and their funding source is not secure.

5.0 SOME CURRENT HURRICANE WIND PRODUCTS

NOAA's Tropical Prediction Center/National Hurricane Center has offered the hurricane track "cone of uncertainty" (Fig. 7) operational products, introduced about three years ago, that provide probabilistic hurricane track information. Although these products do not directly forecast surface winds, they do indirectly provide information on the possible location and timing of hurricane force winds. These cones are derived from ensembles of hurricane models from operational centers and experimental models from U.S. universities.

Tested during the 2005 hurricane season and to become operational during the 2006 season are the surface wind probabilities, an example of which is shown in Figure 8. These contours are derived by using similar ensemble forecasts and provide 34 Kt (tropical storm wind), 50 Kt, and 64 Kt (hurricane force wind) thresholds. A corresponding text product provides information on the probable timing of these thresholds at selected coastal communities.

A wind product that has been used experimentally for several years is the NOAA-developed HWIND surface wind analysis that uses data buovs. dropwindsonde, SFMR, and Quikscat data over the ocean and ASOS, any available in situ wind data, and Doppler radar derived winds over land (Powell et al., 1996; Powell et al., 1998). An example of this product is shown in Figure 9. Among other users, it is used by insurance companies and FEMA for damage estimation.

6.0 FUTURE SURFACE WIND OBSERVING SYSTEMS IN HURRICANES

An effort is emerging in the U.S., led by NOAA and called the Integrated Surface Observing System (ISOS) initiative, to nationally integrate surface observing systems and provide data quality control. Although, if successful, this effort will provide more reliable and more easily available wind data, among other parameters, it will not necessarily provide higher time and spatially resolved wind observations, nor will the instrumentation be more resilient to the extreme conditions in hurricanes.

Although there is some delay, the SFMR will be installed on the Air Force C-130

reconnaissance aircraft to provide a much richer source of ocean surface wind measurements.

In the "hoped for" category, but not yet definitely planned due to the lack of a funding source, is the deployment of more buoys that will have sea surface wind and even wind profiles from wind profiling radars in the Gulf and off of the Gulf coast.

There are also discussions for the deployment of unmanned aerial systems provide more continuous (UAS) to monitoring of the development, track, and intensity changes in hurricanes while over the ocean and to provide a richer data set for assimilation into numerical models. Finally, using nanotechnology, a system of Global Environmental Micro Sensors (GEMS) is being developed. These would be very small Lagrangian balloons with micro sensors that could be deployed by the 100s into developing tropical system and follow it through all of its stages.

7.0 THE FUTURE OF OPERATIONAL HURRICANE MODELING

The National Weather Service's new Hurricane Weather Research and Forecasting (HWRF) community model will be operational for the first time during the 2007 hurricane season. It is essentially based on the GFDL hurricane model and, like the GFDL model, will be fully coupled to an ocean model and ocean wave model. It will initially have a four kilometer resolution and will be in a moving grid nested in the operational GFS model.

In the next few years, HWRF will be coupled with an improved land surface model that will include coastal wetlands and even ground water from previous flooding. In addition, coupling with a shallow wave model will also be added. Finally, if operational computer capabilities allow, the resolution of HWRF will be increased.

8.0 CONCLUDING REMARKS

When tropical depressions, tropical storms, or hurricanes form within or move into the Gulf of Mexico, forecasters become concerned. Very often, during hurricane season, the Gulf waters are warm with relatively deep warm mixed layers and the winds are light. These are the ingredients for the development of major hurricanes. Two ingredients that sometimes foil this development are entrainment of drier air into the storm or wind shear, often due to the weak southern edge of a mid-latitude trough. Since these subtle changes are very difficult for models to predict, it is a challenge to forecast both the direction of the track and the intensity changes. At the same time, forecasters know that a storm in the Gulf must make landfall somewhere in some form

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Figure 1: Favorable tropical steering currents for Gulf of Mexico hurricanes during the 2005 hurricane season.



Figure 2: NOAA National Weather Service operational forecast skill of hurricane tracks



Figure 3: Forecasted tracks from Katrina: Actual track (black); GFDL hurricane model without ocean coupling (red); GFDL model with ocean coupling (green); GFDL model with ocean and wave coupling and other improved physics (blue).



Figure 4: Improvement in hurricane intensity prediction with a fully ocean coupled hurricane model.



Figure 5: Improvement in hurricane intensity forecast with inclusion of more accurate depiction of the Gulf of Mexico loop current in an ocean coupled hurricane model.



Figure 6: Doppler on Wheels (DOW) Doppler wind display during Hurricane Rita showing role vortices representing gustiness in the near surface winds.



Figure 7. Example of the U.S. National Weather Service, National Hurricane Center's "cone of uncertainty" hurricane product.



Figure 8. Example of the new U.S. National Weather Service, National Hurricane Center's 120-hr cumulative surface wind speed forecast probability product.



Figure 9. Example of HWIND surface wind swath from Hurricane Katrina. Contours are in miles per hour.