Improving the GFDL/URI Coupled Hurricane-Ocean Model for Transition to Operations

Final Report

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Summary

This is final report for this program. We have successfully accomplished all the project objectives, which are:

- To improve the ocean component of the GFDL/URI coupled model in the Atlantic basin and implement the ocean coupling into the operational GFDL model in the East Pacific.
- To develop, evaluate and transition to operations at NCEP a new high resolution version of the GFDL/URI coupled model.
- To test and implement operationally new air-sea flux parameterizations in the GFDL coupled model.
- To develop and test the GFDL/URI hurricane-wave-ocean model.

The major accomplishment during the last six months of this project is the transfer to operations at NCEP a new high-resolution version of the GFDL/URI coupled hurricane-ocean forecast system in the Atlantic and Eastern Pacific basins. The primary development of the high-resolution model was done by the URI group and the final testing and tuning was done in collaboration with the GFDL hurricane group. The 2005 operational GFDL model also includes a new bulk parameterization of the air-sea momentum flux developed by the URI group under this JHT funding and an improved initialization packages developed by the GFDL group.

Our group has completed the development of a new coupled hurricane-wave-ocean model by implementing the URI coupled wave-wind model (CWW) into the GFDL/URI coupled hurricane-ocean model. The new model was transition to NCEP for further testing and evaluation. Its operational implementation is planned for the 2006 hurricane season.

Tasks Completed

Here we summarize the main tasks completed over the last six months of this project.

a. Transition of the high resolution GFDL/URI hurricane model to operations

In the 2005 semi-annual report we described in some details the configuration and test results based on 130 cases selected in collaboration with Richard Pasch of TPC of the high resolution version of the GFDL/URI hurricane. The test results indicated significant reduction in the track and intensity forecast errors at 3-5 days. The new coupled model was transitioned to operations at NCEP in May of 2005. The intensity forecasts skill through mid August in the very busy 2005 season is roughly comparable to the statistical intensity prediction models (SHIPS and DECAY SHIPS). More details about the GFDL/URI model performance and preliminary statistics in 2005 can be found in the JHT final report submitted by the GFDL hurricane group.

b. The *new bulk air-sea momentum flux parameterization*

Here we summarize the new bulk momentum flux parameterization implemented operationally in the 2005 GFDL/URI coupled model. It is based on a coupled wave-wind model (CWW) developed by our group [*Moon et al.* 2004 a,b,c]. In the CWW model, the surface wave directional frequency spectrum near the spectral peak is calculated using the WAVEWATCH III [*Tolman*, 2002] model and the high frequency part of the spectrum is parameterized using the theoretical model of *Hara and Belcher* [2002]. The complete wave spectrum is then introduced to the wave boundary layer model of *Hara and Belcher* [2004] to estimate the surface roughness length for different wind and wave conditions. The main result of the CWW model is that the neutral drag coefficient levels off at high wind speeds, consistent with the recent results of field observations, laboratory experiments, and theoretical studies at high winds [*Powell et al.,* 2003; *Alamaro et al.,* 2002; *Donelan et al.,* 2004; *Emanuel,* 2003].

From numerical simulations of hurricanes in Atlantic Ocean during 1998-2003 using the CWW model we derived a new bulk parameterization of the surface roughness length (z_0) at wind speed W > 12.5 m/s [*Moon et al*., 2004c]. A scatter plot of CWW model-calculated z_0 against wind speed is shown in Fig. 1a from which the following empirical relationship between z_0 and W was established using a linear regression function (see Fig. 1a, blue line):

$$z_0 = (0.085W - 0.58)\times 10^{-3}, \qquad W > 12.5\ m/s\,. \tag{1}$$

The neutral drag coefficient C_d as a function of W is then obtained by introducing (1) into the following expression:

$$C_d = \kappa^2 \left(\ln \frac{10}{z_0} \right)^{-2}. \tag{2}$$

Fig. 1b compares *Cd* calculated using (1) – (2) with the bulk parameterization used in the old operational GFDL hurricane model, and the results from *Wu* [1982], *Large and Pond* [1981], *Donelan et al.* [2004], and *Powell et al*. [2003]. For $W \le 12.5$ m/s, the new C_d is identical to that in the old GFDL model. For $W > 12.5$ m/s, the new C_d levels off between 2.0 and 3.0. At a 60 m/s wind speed, the new C_d is only half of the value used in the old GFDL model. It should be noted that at high winds the boundary layer close to the surface is nearly neutral since $\ln z/z_0 >> f_m(z/L)$, where f_m is the universal function and

L is the Monin-Obukhov length. At low winds, however, the stability effect may be important.

We implemented the new Cd formulation into the GFDL hurricane model and carefully tested it before operational implementation in 2005. Fig. 2 shows the impact of the new momentum flux parameterization on the predictions of the minimum sea level pressure (SLP) and the 10 m maximum wind speed (MWS) for eleven forecasts of Hurricane Isabel (2003), Ivan (2004), Frances (2004), Jeanne (2004) and Charley (2004). As seen in Fig. 2, the new *Cd* parameterization leads to an increase of the MWS at very high winds while the minimum SLP is not significantly affected. As a result, the well known negative biases in the GFDL model predictions of the MWS for very strong hurricanes are significantly reduced. It is illustrated in Fig. 3 by comparing the pressure-wind relationship in the old and the new GFDL models with observations.

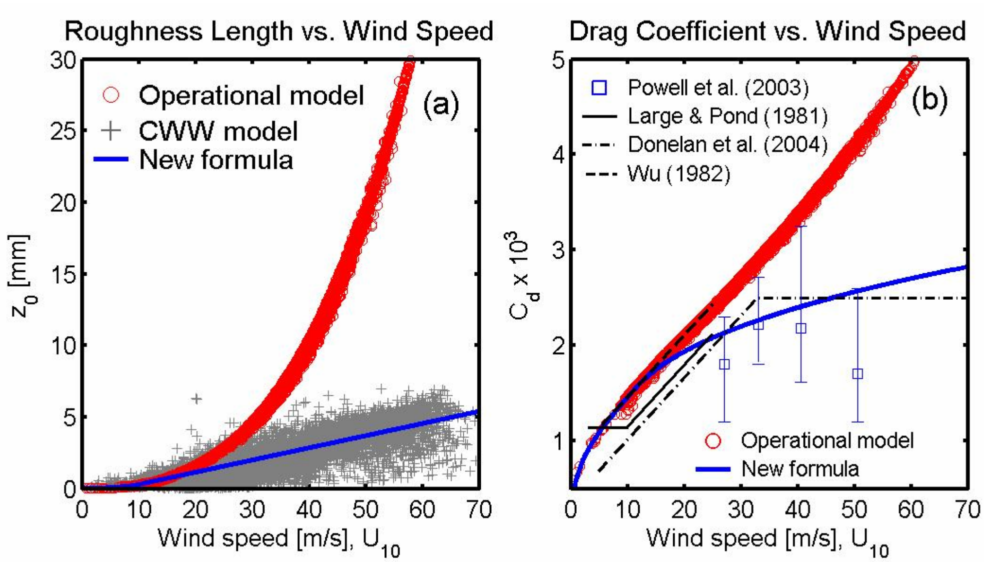


Fig. 1. Roughness length (a) and drag coefficient (b) vs. wind speed at 10 m. The thick blue line is the new formula based on (1) and (2); red circles and gray plus symbols are from the results of a hurricane Ivan experiment (initial time: 00Z 12 Sep. 2004) using the 2004 operational GFDL model and the CWW model, respectively; black solid line, according to Large and Pond [1981]; dashed dot line, according to Donelan et al. [2004]; squares, averaged values over four layers from data of Powell et al. [2003].

c. Development of the coupled GFDL hurricane-wave-ocean model

We have completed the development of the new coupled GFDL model which now consists of three atmosphere, wave and ocean models coupled together: the GFDL hurricane model, the Princeton Ocean Model (POM) and the EMC WAVEWATCH III model with the URI wave boundary layer model. Some details of the model configuration, size and resolution were presented in our 2005 semi-annual report.

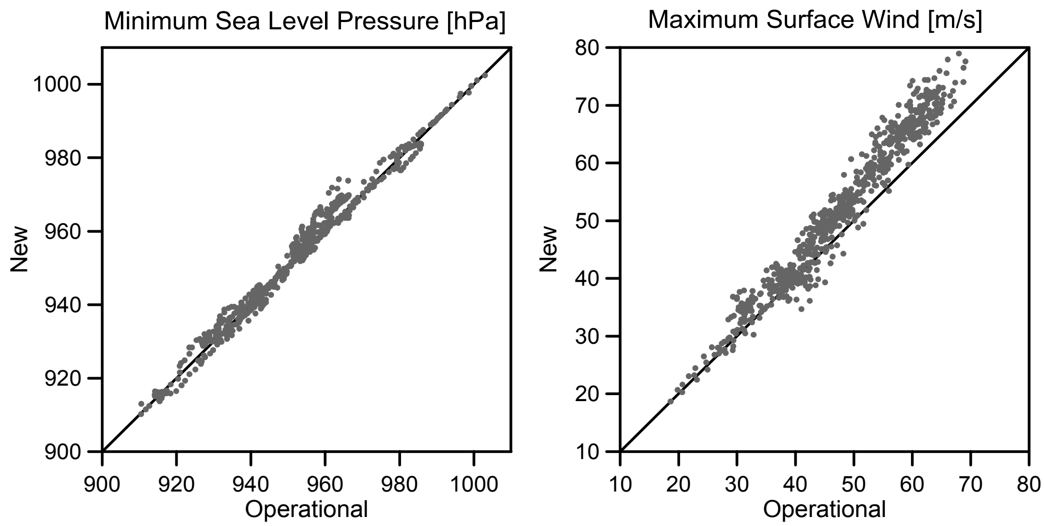


Fig. 2. Comparisons between the old (2004 operational) and the 2005 GFDL model (with the new flux parameterization) forecasts of the minimum sea level pressure (left panel) and maximum surface wind (right panel) in 11 forecasts of Hurricane Isabel (2003), Ivan (2004), Frances (2004), Charley (2004), and Jeanne (2004).

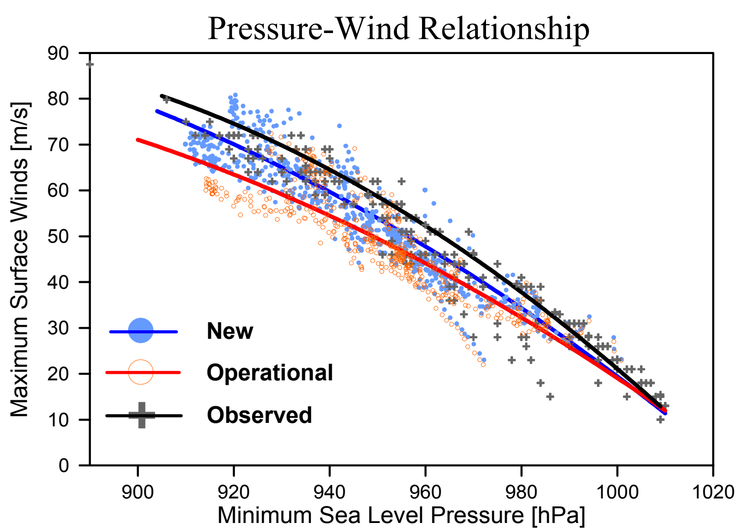
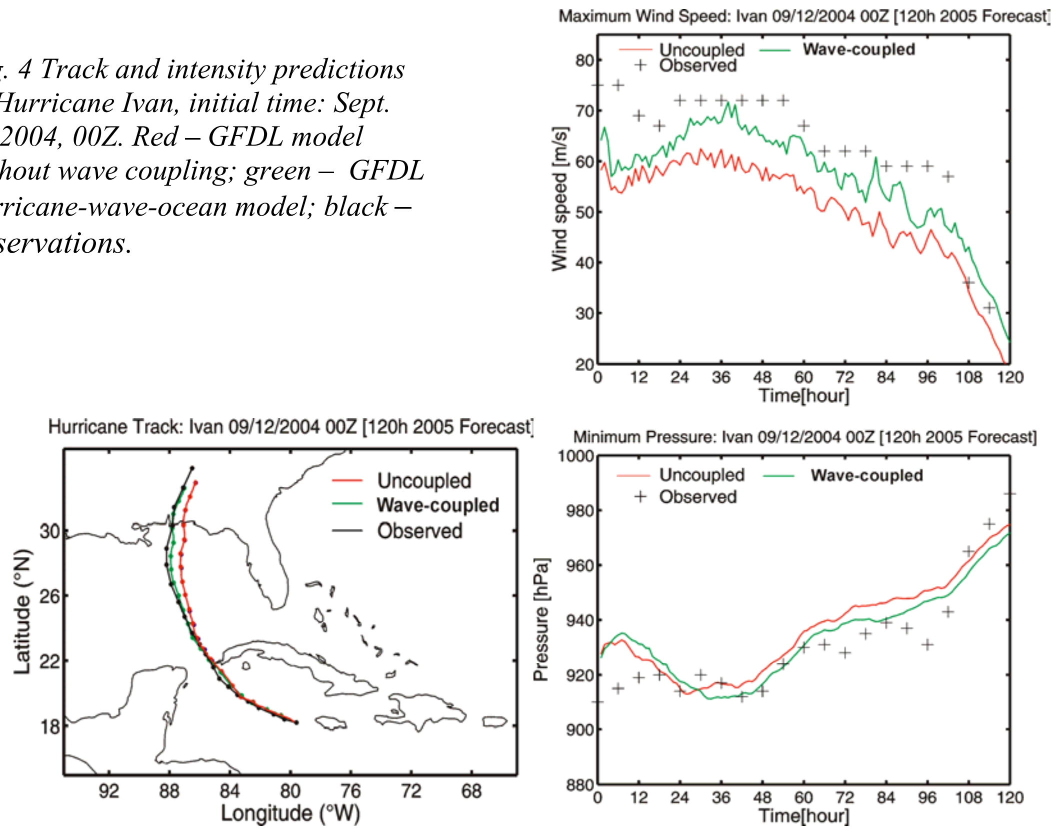


Fig. 3. Comparison of the pressure-wind relationship in observation (black), the new, 2005 (blue) and old (red, 2004 operational) GFDL models for 11 forecasts of Hurricane Isabel (2003), Ivan (2004), Frances (2004), Charley (2004), and Jeanne (2004). Lines represent the best polynomial fits (2^{nd} order) for each group.

During the last few months of this project we transferred the new GFDL hurricane-wave-ocean coupled model to the NCEP super computer and presently carry out test runs. The model continues to show improvements in the track and intensity predictions. Fig. 4 illustrates the model performance in one forecast of Hurricane Ivan (2004), initial time September 12, 00Z. Both track and intensity predictions are improved in this case due to the improved air-sea fluxes, which now explicitly include the effect of surface waves (Fig. 5) in the calculations of the drag and heat exchange coefficients (Fig 6).

Fig. 4 Track and intensity predictions of Hurricane Ivan, initial time: Sept. 12 2004, 00Z. Red – GFDL model without wave coupling; green – GFDL hurricane-wave-ocean model; black – observations.



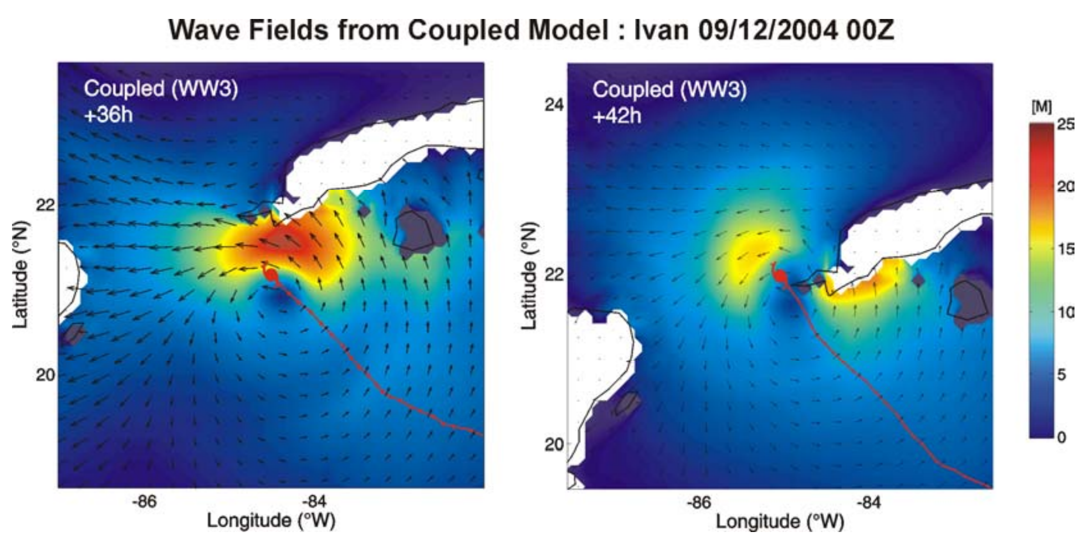


Fig.5 Significant wave heights and directions (arrows) in a GFDL coupled-wave-ocean model forecast of Hurricane Ivan, initial time Sept. 12 2004, 00Z. The snapshots are shown before, t=36 hrs, and after, t=42 hrs, the hurricane crossed Cuba.

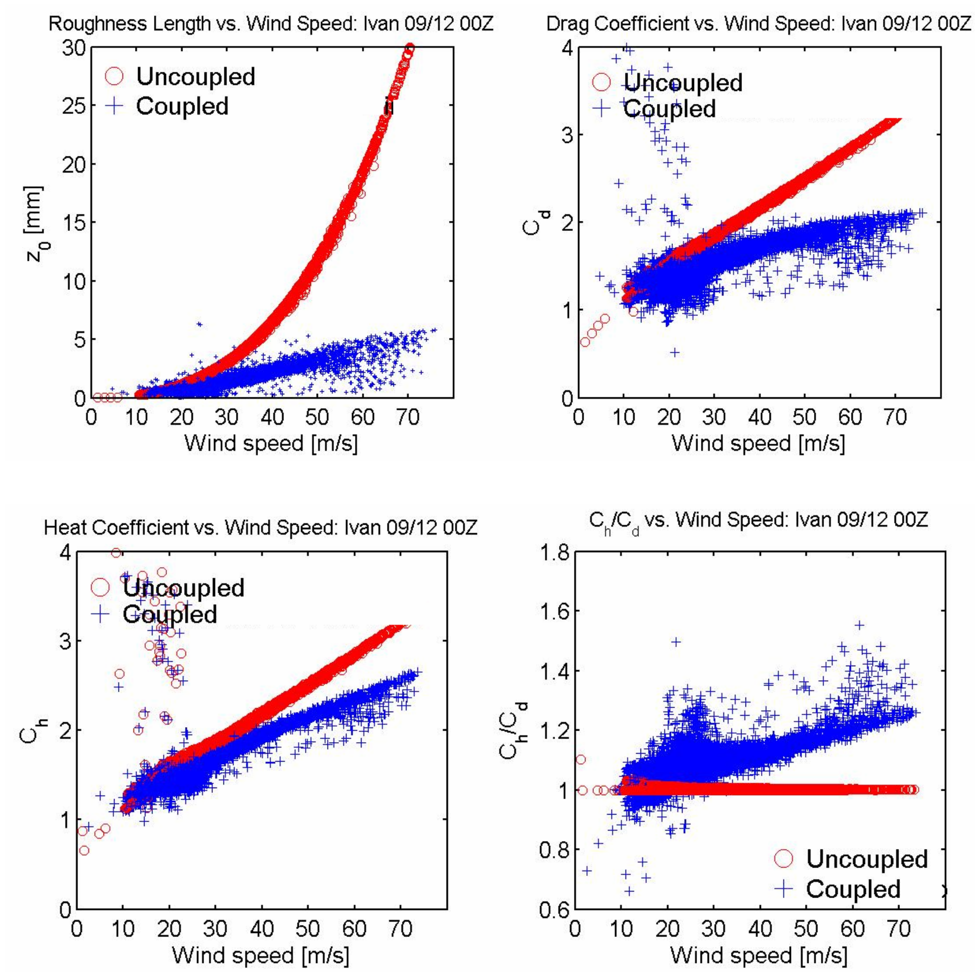


Fig. 6. The roughness length, Z_0, drag coefficient,t Cd, heat exchange coefficient, Ch and Cd/Ch versus 10 m wind speed from a forecast of Hurricane Ivan, initial time Sept. 12 2004, 00Z (blue dots) by the new GFDL coupled hurricane-wave-ocean model. The same parameters, but in the GFDL model without wave coupling are shown in red.

More testing will be done during the 2005 hurricane season. The results will be carefully evaluated in close collaboration with GFDL and NCEP scientists, particularly Morris Bender and Naomi Surgi. Operational implementation of this model is planned for the 2006 hurricane season if the results continue to be positive.

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