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

Semi-Annual Progress Report

Isaac Ginis
Graduate School of Oceanography
University of Rhode Island

February 6, 2004

1 Introduction

This is the first semi-annual report for this program. During this time period, significant progress has been made toward our overall project objectives, which are to:

- To improve the ocean component of the GFDL/URI coupled model in the Atlantic basin and implement the ocean coupling into the GFDL model used for operational forecasting in the East Pacific

- To evaluate and transition to operations a new high resolution version of the GFDL/URI coupled model

- To test and implement operationally new air-sea flux parameterizations in the coupled model

We have finished development and testing of explicit initialization of the location and structure of the Gulf Stream and Loop Current in the GFDL/URI coupled model. It is planned to be implemented into operations in 2004. Coupling of the GFDL model with 1-D ocean model in the Eastern Pacific has been implemented and initial testing has begun. The high-resolution version of the GFDL hurricane has implemented at NCEP computers and is presently being tested for hurricanes in the 2003 season. Sensitivity studies were conducted to evaluate the sensitivity of the GFDL model hurricane predictions to various surface flux parameterizations.

We now briefly elaborate on the present status of the project, including personnel and recent results.

2 Personnel, Logistics and Facilities

There are three scientists committed to this project: Isaac Ginis and Biju Thomas at URI and Alexandr Falkovich at NCEP. We work in close collaboration with Morris Bender and Tim Marchok at GFDL and NCEP scientists. The majority of the model development is done on the URI Silicon Graphics (SGI) ORIGIN 2000, 10-processor computer. The more computer-intensive numerical simulations and testing of the operational version of the GFDL/URI coupled model are performed on the GFDL and NCEP supercomputers.

3 Tasks Completed and Work in Progress

a. Improving the ocean model initialization in the Atlantic

We have developed a new data ocean assimilation and initialization procedure to improve simulation of the Gulf Stream (GS) and Loop Current (LC) in the GFDL/URI operational coupled hurricane prediction system. This procedure is based on feature modeling and involves cross-frontal "sharpening" of the background temperature and salinity fields according to data obtained in specialized field experiments in the GS. We are presently testing it for past hurricanes in the Atlantic basin using the data for the 2002 and 2003 hurricane seasons. Fig. 1 shows an example of the surface ocean currents after ocean model initialization during a forecast of Hurricane Isidore initiated at 12 UTC, September 19, 2002. The developed methodology allows initializing the LC and GS with any given paths in the GFDL/URI hurricane model. In order to take advantage of this technology satellite-retrieved sea surface height (SSH) data available at the time of a hurricane forecast can be used in future.

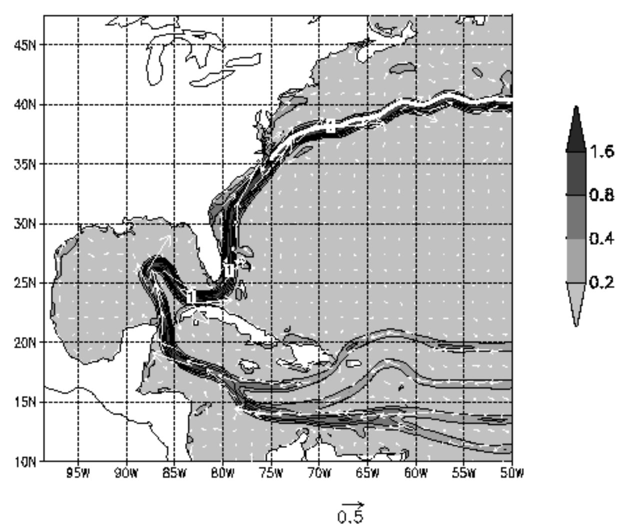

Fig. 1 Surface current after ocean model initialization during Hurricane Isidore forecast (initial time: 12Z, September 19, 2002). White line indicates the GS North Wall in September.

b. Implementation of ocean coupling in the East Pacific

We have developed a 1-D ocean model for its coupling with the GFDL hurricane model in the Eastern Pacific. The 1-D model was derived from the 3-D Princeton Ocean Model

(POM) used in the GFDL/URI coupled model in the Atlantic. It was first tested in the Atlantic basin for simulations of the ocean response to hurricanes and results were compared with similar simulations using the POM. For the Eastern Pacific, the ocean model is configured on a 40 x 40 degree relocatable grid with a horizontal resolution of 1/6 degree and 16 levels in vertical. The center of the grid coincides with the center of the GFDL hurricane model's outer mesh which is determined at the beginning of each forecast. The monthly Levitus climatology is used to specify initial temperature and salinity fields.

We have recently coupled the 1-D ocean model with the GFDL hurricane model and started to test the new coupled system. Fig. 2 shows an example of the coupled model forecast of Hurricane Ignacio initiated at 1200 UTC Aug 24.

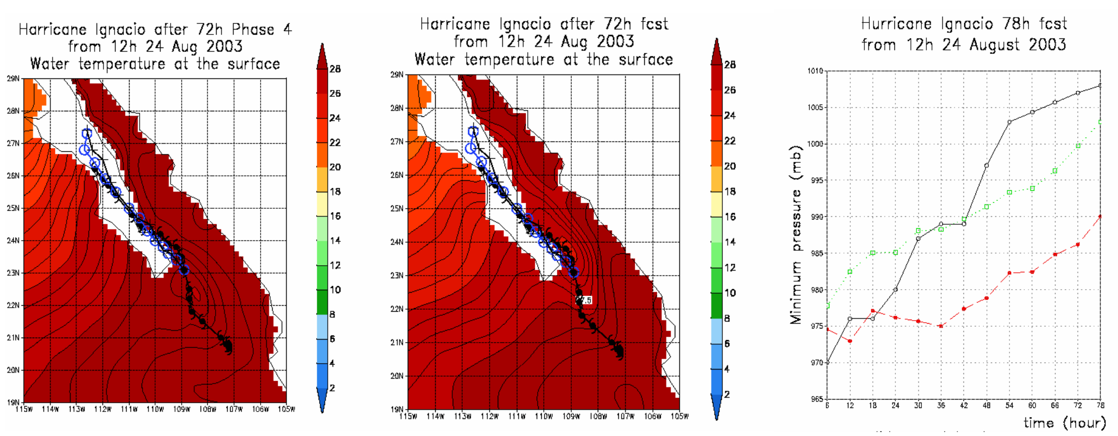

Fig. 2 The GFDL/URI coupled model forecast of Hurricane Ignacio initiated at 1200 UTC, Aug 2003: Sea surface temperature in the operational, uncoupled model (left panel), coupled model (middle panel) and central pressure forecast (right panel; red – operational uncoupled model, green - coupled model, black – observations).

c. Investigation of the momentum flux under hurricane conditions

In strong winds, typical under hurricane conditions, momentum exchange at the sea surface should be described by a sea-state-dependent drag coefficient. However, presently the GFDL hurricane model, as most atmospheric models do, utilizes the bulk parameterization, i.e., the boundary layer parameterization based on the Monin-Obukhov similarity theory with the behavior of the drag coefficient ($C_d = u_*^2/U_{10}^2$) based on extrapolations from field measurements in much weaker winds. These extrapolations describe an increase in C_d with wind speed. Recent theoretical, laboratory and observational studies suggest that the C_d levels off or even decrease as the wind speed increases above hurricane force.

Using a Coupled Wave-Wind CWW) model developed in our group recently (Moon et al. 2003) we began investigating the effects of waves on the momentum fluxes in high wind conditions. The CWW model was applied for constant winds from 10 m/s to 50 m/s. We found for growing seas with winds less than 30 m/s, Cd increases with wind speed, consistent with earlier studies. For winds higher than 30 m/s, however, the CWW model produces a different trend, that is, very young waves yield less drag and Cd levels-off and even decreases. This is because the wave-induced stress due to very young waves makes a small contribution to the total wind stress in extremely high wind conditions. The upper and lower bounds of C_d in our experiments are shown in Fig. 3. Our results are consistent with the recent observations of Powell et al. (2003).

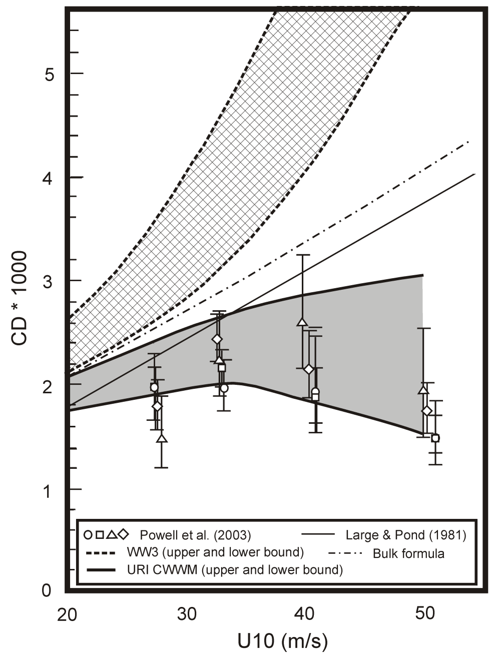

Figure 3. Comparison of drag coefficient (C_d) between various observation-based values, formulas, and model outputs as a function of U_{10}. Symbols represent observations from GPS sonde wind profiles (Powell et al. 2003) above hurricane forces. Vertical bars represent 95% confidence limits. Solid line is an extrapolation of the Large and Pond (1981) formula. Dash-dot line is the Bulk formula used in GFDL model. Shaded and hatched areas represent ranges between upper and lower bound of C_d obtained by the URI coupled wave-wind model and internal estimation of NCEP WAVEWATCH model for hurricane Bonnie in 1988, respectively. Both observations and URI model results show leveling–off of the drag coefficient as the wind speed increases.

d. Sensitivity of GFDL hurricane intensity prediction to momentum flux parameterization

We started experiments with the GFDL/URI coupled hurricane-ocean model to investigate sensitivity of the hurricane intensity to the momentum flux parameterization at the sea surface. The air-sea exchange in the operational GFDL/URI model is parameterized using the Monin-Obukhov similarity theory as described in Kurihara and Tuleya (1974). Shown in Fig. 4 is a set of idealized experiments in which an idealized hurricane is embedded into a 5 m/s easterly flow. In the control run model physics is the same as in the operational GFDL/URI model. In another run, the roughness length, z_0, is set constant (capped) for wind speeds > 35 m/s (this is consistent with the results from our CWW model). The capping of z_0 at high wind speed leads to a substantial increase of maximum surface wind (Fig. 3a) and a reduction of wind stress and heat flux (Fig. 4b & 4c). The changes of the wind speed extend through the boundary layer (Fig. 4d). Therefore, we may conclude that the GFDL/URI model intensity predictions measured by the surface winds could be significantly affected by improved parameterization of the air-sea exchange at high wind speeds.

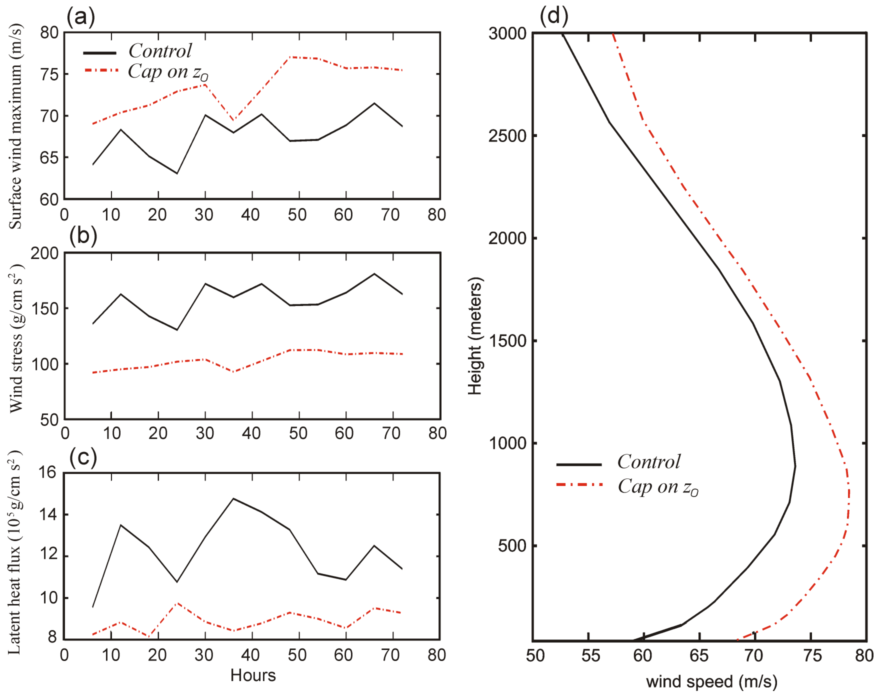

Fig. 4. Evolution with time of (a) surface wind speed, (b) wind stress, and (c) latent heat flux, and (d) vertical wind profiles at 24 hours, averaged around the maximum wind point, obtained by two idealized sensitivity simulations using the GFDL/URI hurricane model. The "Control" run uses the exchange coefficients for heat and momentum fluxes as in the operational version of the model which are based on parameterization described in Kurihara and Tuleya (1974). The "Cap on z_0" run uses the same coefficients, but z_0 is kept constant at wind speeds of above 35 m/s.

References

Moon I.-J., I. Ginis, T. Hara, 2003. The effect of waves on air-sea momentum exchange: Behavior of drag coefficient under tropical cyclones, *J. of Atmos. Sci.,* under review.

Kurihara, Y. and R.E. Tuleya, 1974. Structure of a tropical cyclone developed in a three-dimensional numerical simulation model. *J. of Atoms. Sci.,* **31***,* 893-905.

Powell, Mark D., P. J. Vickery, and T. A. Reinhold, 2003. Reduced drag coefficient for high wind speeds in tropical cyclones. *Nature*, **422**, 279-283.