COUPLED TROPICAL CYCLONE-OCEAN MODELING FOR TRANSITION TO OPERATIONAL PREDICTIVE CAPABILITIES

Isaac Ginis and Lewis M. Rothstein
Graduate School of Oceanography
University of Rhode Island, Narragansett, RI 02882
Phone: 401-874-6484 Fax: 401-874-6728
`email:ig@cone.gso.uri.edu` `http://seip.gso.uri.edu/`

Award Number: N000149610758

LONG-TERM GOALS

Our long term fundamental goals are I) to better understand the interaction between the ocean and tropical cyclones using numerical simulation models, and II) to investigate the operational capability of coupled tropical cyclone-ocean models in predicting the ocean response and tropical cyclone movement and intensity.

OBJECTIVES

Our primary objectives for the past year have been:

- Development of a coupled hurricane-ocean experimental prediction system for the North Atlantic;
- Improved ocean model initialization and data assimilation techniques for forecast modeling;
- Development of a movable grid multi-nested ocean model.

APPROACH

Our tools for this work are high-resolution ocean and tropical cyclone models used in either coupled or uncoupled configurations. We currently employ two ocean models and one tropical cyclone model.

The first ocean model we use is the Princeton Ocean Model (POM) (Blumberg and Mellor 1987). We have used the POM for the Atlantic region and we plan to continue to use it for this area for the near future. The POM is a three-dimensional, free-surface primitive equation model. This model is widely distributed to the academic community and used by the Navy in various applications.

Our newly developed movable nested grid ocean model (Ginis et al. 1997, Rowley and Ginis 1997) is the second ocean model. The major feature of the model is its multiply-nested, movable mesh configuration, which is capable of depicting the ocean response with high resolution underneath the tropical cyclone.

We employ one of the premier tropical cyclone forecast systems, the GFDL model (Kurihara et al. 1997), which was adopted as the official operational hurricane prediction model at the National Weather Service starting with the 1995 hurricane season. This model (as the GFDN) is also run operationally for the western Pacific at Fleet Numerical (FNMOC) in support of the Joint Typhoon Warning Center (JTWC).

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **Coupled Tropical Cyclone-ocean Modeling for Transition to Operational Predictive Capabilities**	5a. CONTRACT NUMBER 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) **University of Rhode Island,Graduate School of Oceanography,Narragansett,RI,02882**	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)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

The major tasks we completed this year relate directly to our primary objectives:

- We successfully completed the conversion of the research-oriented coupled hurricane-ocean model of Bender et al. (1993) to a real-case, coupled hurricane-ocean experimental hindcast model for the Gulf of Mexico and western Atlantic, by coupling the GFDL hurricane model with a high-resolution version of the Princeton Ocean Model. Comparisons of coupled and uncoupled model hindcast results were produced for several storms in the Gulf of Mexico and western North Atlantic.

- Under our current ONR funding, the mesh movement algorithm of the GFDL hurricane model was implemented in the new nested grid primitive equation ocean model developed by Ginis, et al. (1997). **The result is the first ocean GCM with fixed *or* moving telescopically nested meshes**. A suite of idealized simulations has been performed to rigorously test the mesh movement algorithm. The test experiments have demonstrated that the model with moving grids performs extremely well, even in challenging situations such as mesh movement over existing mesoscale fronts and rings.

- A numerical procedure has been developed to assimilate subsurface temperature and velocity data together with the stream position to initialize the realistic mean structure of the Gulf Stream (GS) in the Princeton Ocean Model (POM). The procedure takes advantage of the temporal and spatial stability of the GS cross-stream structure, utilizing a limited number of observed cross-sections in stream coordinates, and a satellite AVHRR-derived GS path. In particular, conservation of the cross-stream potential vorticity (PV) pattern along the GS path is assumed. Assimilation of the PV instead of temperature and velocity measurements provides a more dynamically consistent transition between the reproduced Gulf Stream system and the surrounding climatological fields.

RESULTS

1 Development of a coupled hurricane-ocean experimental prediction system for the North Atlantic

We completed the conversion of the coupled hurricane-ocean model of Bender et al. (1993) to a real-case, coupled hurricane-ocean experimental hindcast model. In the coupled system, the POM was enhanced with fine resolution of $1/6^{\circ}$ for the entire computational domain. The version of the GFDL hurricane model used for this study is identical to the one run operationally by the National Weather Service, with the addition of the ocean coupling. Experiments were run with and without ocean coupling for two cases of Hurricane Opal (1995) and one case of Hurricane Gilbert (1988) in the Gulf of Mexico, and for two cases of Hurricanes Felix (1995) and Fran (1996) in the western Atlantic. **For the first time, a coupled hurricane-ocean model has been applied in simulations of real-case hurricanes**, albeit in a hindcast mode. In each of the seven hindcasts, inclusion of the ocean coupling led to a substantial improvement in the prediction of storm intensity as measured by the storm's minimum sea-level pressure. In the case of Hurricane Opal, for example, the uncoupled model runs predicted drops in the minimum sea-level pressure to 927 and 931 hPa by 1200 UTC Oct. 3, where in the coupled model hindcasts the minimum sea-level pressures were 960 hPa and 973 hPa, respectively (Fig. 1). These results clearly demonstrate the importance of including the effect of ocean coupling for reliable intensity predictions with the GFDL/GFDN forecast system, and probably for dynamical models in general.

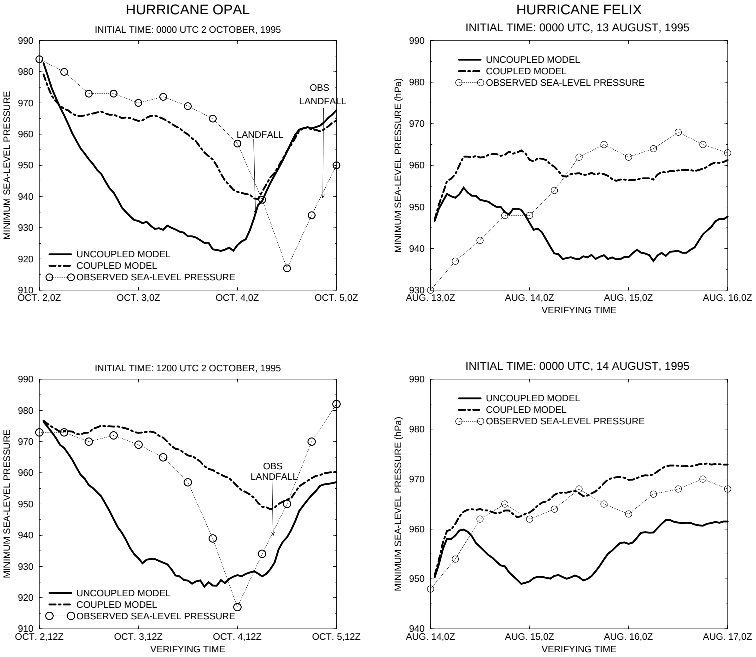

Figure 1: Time series of minimum sea-level pressure for the uncoupled (solid line) and coupled experiments (dot-dashed line) compared to observed values (thin dotted line, circles indicate values every 6 hours) for the two hindcasts of Hurricane Opal (left panels) and Hurricane Felix (right panels). In each case the forecast of the intensity change was greatly improved with the ocean coupling.

2 Design of a movable nested-mesh primitive equation model

Under our current ONR funding, the mesh movement algorithm of the GFDL hurricane model was implemented in our nested grid ocean model. In order to test the mesh movement in a realistic setting, we simulated the ocean response to Typhoon Roy (1988) in the western North Pacific. We initialized the model using the January fields from a six-year spinup of the single grid model with 1° resolution in the zonal direction, and a stretched grid in the meridional, with spacing 1/3° on the equator increasing poleward. The spinup was forced by the monthly averaged wind stress and surface heat flux fields. The Typhoon Roy simulation was configured with three meshes, of uniform 1°, 1/3°, and 1/6° resolutions. The inner meshes were centered at the position of the typhoon at 0000 UTC 8 January, and the integration used the typhoon's observed strength and track to produce the wind forcing for a 7-day integration. Fig. 2 shows the model-calculated SST for the area near the storm track, together with the track and the locations of the nested meshes.

3 Model initialization and data assimilation

Coupled hurricane-ocean forecasts require realistic initialization and assimilation of **mesoscale** features of the pre-storm oceanic fields such as warm and cold eddies, currents and their meanders. These features cannot be derived from climatological background fields, and have to be constructed and embedded into the climatology. Our study has focused on a more realistic initialization of the Gulf Stream system. We developed a new data assimilation technique that utilizes the data collected during the SYNOP field experiment (Johns et al. 1995), and the AVHRR-derived GS path. The procedure includes the following steps: a mean Gulf Stream potential vorticity (PV) structure is constructed in stream coordinates using the SYNOP velocity and temperature profiles. The GS PV is then blended with the

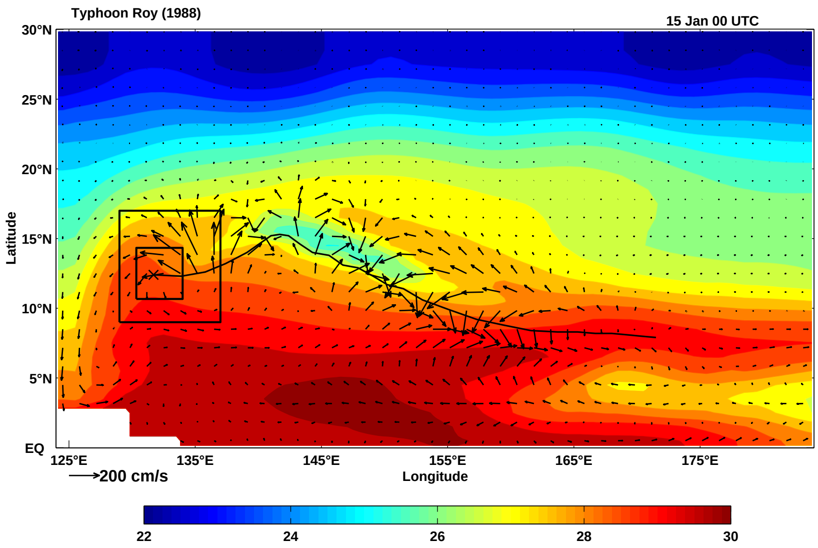

Figure 2: Simulation of the ocean response to Typhoon Roy (1988) using the movable mesh model, initialized with January fields from a six-year spinup. Vectors of the surface velocity are superimposed on the SST (°C), with the typhoon track and the position of the nested grids at 0000 UTC Jan 15 for a portion of the model domain.

GDEM climatological PV field, assuming conservation of PV along the GS path. Using the QG approximation, the corresponding stream function is calculated numerically by solving a 3-D Poisson equation. The new density and temperature fields are then computed and utilized during the diagnostic spinup of the velocity field. The structure of the front and the barotropic recirculations is well-maintained during integration. An example of the great improvement in the Gulf Stream temperature and velocity structure is demonstrated in Fig. 3.

IMPACT/APPLICATIONS

The results of this study indicate that the present tropical cyclone forecast system at FNMOC utilizing NOGAPS and GFDN is deficient in its inadequate description of the evolution of the subsurface ocean, and that including ocean coupling will greatly improve tropical cyclone intensity forecasting and therefore provide a better numerical guidance product for the JTWC. Improved modeling of tropical cyclones may also lead to significantly better extended range weather forecasts.

The new movable grid ocean model makes it feasible to combine realistic global or basin-scale ocean simulations with mesoscale forecasts for selected regions. The nested grid model may be coupled with the Naval operational regional atmospheric prediction system (NORAPS) and may also be utilized as the ocean component of the coupled ocean atmosphere mesoscale prediction system (COAMPS) which is being developed at the Naval Research Laboratory, Marine Meteorology Division, Monterey, CA.

TRANSITIONS

It is expected that the results of this project will be used by the Navy for operational purposes. On completion, the coupled tropical cyclone-ocean system will be operational at FNMOC.

It is also hoped that the nested-grid ocean model developed during this project will add to the utility of COAMPS as it transitions to operational use over the next few years.

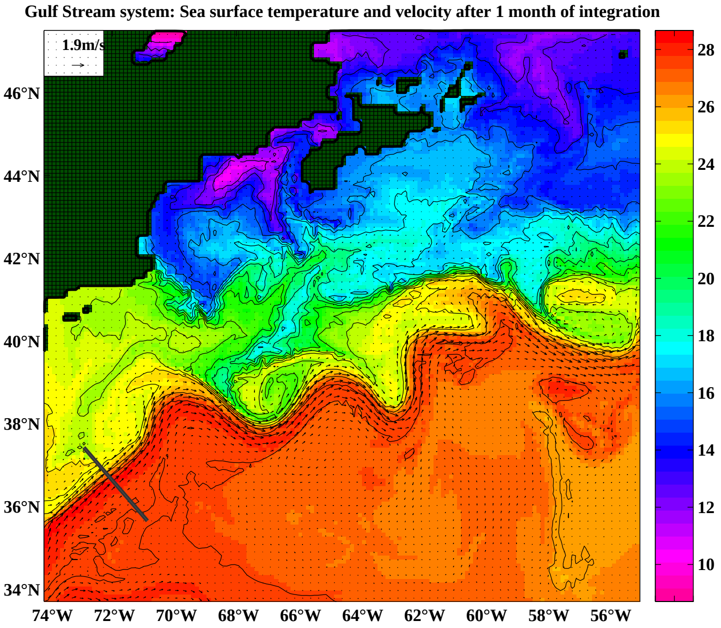

Figure 3: The surface temperature (°C) and velocity (m/s) fields after one month of integration using the new initialization technique.

RELATED PROJECTS

This research is closely related to other research projects funded by ONR that study tropical cyclones and the ocean response to tropical cyclone forcing (Professor Russ Elsberry at Naval Postgraduate School, Dr. Mark Lander at University of Guam, and Dr. Lynn Shay at University of Miami). Prof. Elsberry and his group and Dr. Lander are collecting data and conducting empirical analyses of tropical cyclones in the western Pacific. Dr. Shay is involved in collecting and analyzing observations of the currents and thermohaline structure in the upper ocean induced by hurricanes. We are also working in close collaboration with atmospheric scientists in developing and testing coupled tropical cyclone-ocean models: Dr. Kurihara and his group at the NOAA Geophysical Fluid Dynamics Laboratory; and Prof. Khain and his group at the Hebrew University of Jerusalem. Implementation and testing of the coupled hurricane-ocean system at FNMOC will be conducted in collaboration with Dr. Mary Alice Rennick.

REFERENCES

Bender, M. A., I. Ginis, and Y. Kurihara. 1993. Numerical simulations of the tropical cyclone-ocean interaction with a high-resolution coupled model. *J. Geophys. Res.*, **98**, 23,245–23,263.

Blumberg, A.F. and G.L. Mellor, 1987: A description of a three-dimensional coastal ocean circulation model. In: *Three-dimensional Coastal Ocean Models*, Vol.4, edited by N. Heaps, 208 pp, American Geophysical Union, Washington, D.C.

Ginis, I., R.A. Richardson, and L.M. Rothstein, 1997: Design of a multiply-nested primitive equation ocean model. *Mon. Wea. Rev.* In Press.

Kurihara, Y., M.A. Bender, R.E. Tuleya, and R.J. Ross. 1995: Improvements in the GFDL hurricane prediction system, *Mon. Wea. Rev.*, 123, 2791-2801

Rowley C.D., and Ginis I., 1997: Implementing a mesh movement algorithm into a multiply-nested grid primitive equation ocean model. To be submitted to *Mon. Wea. Rev.*

More information is available at `http://seip.gso.uri.edu/`.