# The Impacts of an Active Ocean Boundary Condition on Tropical Cyclone Evolution Using a Coupled Atmosphere-Ocean Model

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## 1. Introduction

In response to the need to improve the understanding of tropical cyclones (TC), especially in the wake of recent events such as Charley (2004) and Katrina (2005), much effort has been invested towards improving the Numerical Weather Prediction (NWP) model's ability to forecast the track, intensity, and structure of TCs. Presently, NWP models are employed by both the operational meteorological centers and research institutions where scientists are attempting to understand the factors which modulate the tendencies in a respective TC's track, structure, and intensity. The National Hurricane Center (NHC), in Miami, FL, reports that considerable improvements in track forecast skill has been attained, partly as a result of the evolution of NWP. However, there remains considerably less skill when attempting to forecast a TC's intensity.

One of the suggested hypotheses to explain the inability of NWP to improve intensity forecasts is that many models *ignore* the evolution of the ocean sea-surface temperature (SST) during the TC passage. As a result, the air-sea interactions and resultant fluxes, which are linked to the upwelling and cooling of the SST, are not resolved, and can subsequently have unrealistic impacts on the structure and intensity for the TC (Price, 1981; Brooks, 1983; Bender and Ginis, 2000; Shay et al., 2000; Chan et al., 2001). In this discussion, we illustrate the current stages in the development of a coupled atmosphere-ocean model which will be used to better understand and address the deficiencies related to forecasting TC intensity – particularly as the pertain to air-sea interactions. In the following section, we provide a brief description of the coupled-modeling system, which is followed by the results of a simple twin-experiment for TC Bertha (2008). Finally, we conclude with the future work regarding this subject.

## 2. Model Configuration and Initial Experiments

The atmospheric model in the coupled-model system is the **W**eather **R**esearch and **F**orecasting (WRF) **A**dvanced **R**esearch **W**RF (ARW) (Skamarock et al., 2005). The ocean model for the coupled-model system is the **HY**brid **C**oordinate **O**cean **M**odel (HYCOM) (Bleck, 2002; Chassignet et al., 2003; Halliwell, 2004). The equatorial resolution for the HYCOM grid is 1/12° and is a sub-region of the NAVO[2]/NRL[3] global HYCOM (Wallcraft et al., 2005). The WRF-ARW grid is defined using a Mercator projection with a grid-length resolution of approximately 8.81-km. The WRF-ARW grid resolution is chosen so as to co-locate the HYCOM and WRF-ARW grids as closely as possible. The initial and boundary conditions are obtained from the NAVO/NRL Global HYCOM analysis grids and the NCEP[4] 1.0° FNL analysis. The HYCOM model grid has X×Y×Z dimension 1063×545×32 while the WRF-ARW grid dimension is 1083×565×35.

The coupling procedure is as follows: (1) The atmosphere model (WRF-ARW) integrates from $t$=0 to $t$=$dt$ – where $dt$ is the coupling interval, to calculate all the atmospheric forcing variables that are required to force the ocean model (HYCOM). (2) The WRF-ARW forcing variables for 10-meter wind ($U$), zonal- and meridional wind stress ($\tau_x$ and $\tau_y$), 2-meter temperature ($T_2$) and specific humidity ($q_2$), precipitation rate ($\dot{R}$), and the net downward (into the ocean) long- and short-wave radiation fluxes ($Q_{LW}$ and $Q_{SW}$, respectively) are calculated and interpolated to the ocean model grid. (3) HYCOM integrates from $t$=0 to $t$=$dt$ and calculates a sea-surface temperature (SST) grid defined by the prescribed WRF-ARW forcing. (4) The HYCOM SST is interpolated to the WRF-ARW grid and updated within the boundary condition file. This coupling cycle repeats at the interval of $dt$ and continues for the duration of the forecast.

Fig. 1 illustrates the 72-hour forecast (initialized 00Z 11 July) latent-heat flux (LHF) swath for TC Bertha (2008). The un-coupled model simulation is one in which the SST is held fixed for the duration of the forecast, while the coupled forecast is one in the which the atmosphere and ocean interact along each hour. The coupling interval is chosen to illustrate the differences between the un-coupled and coupled model simulations. The differences in the LHF values, namely the lower maximum values for the coupled-model, suggest that the air-sea interactions act to modulate the intensity of the TC. Fig. 2 illustrates the log-scale normalized minimum sea-level pressure (MSLP) time-series for the respective TC Bertha (2008) simulations and the best-track re-analysis (BTRA). It is clear that the air-sea interactions, which are afforded by the coupled-model, have a dramatic impact on the intensity of the TC and that the intensity modulations, relative to the BTRA, are better represented.

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## 3. Ongoing and Future Developments

The configuration described within this document produces near real-time forecasts for the atmospheric and oceanic variables currently believed to enable forecaster's to understand the genesis and life-cycle aspects, as well as the synoptic-scale interactions for TCs. The forecasts produced by the respective atmosphere (WRF-ARW[5]) and ocean (HYCOM[6]) models can be viewed online.

These preliminary results, illustrating the impacts upon TC vortex, suggest that the coupled-model is performing satisfactorily. However, as with all NWP problems, the quality of the model solution is highly sensitive to the initial conditions provided to the model. It is worth noting that the initial conditions for the atmospheric model (ie. the TC vortex structure) are considerably different in terms of both the structure and intensity relative to the available observations. Though the intensity modulations for the coupled-model simulation and the BTRA are similar, the MSLP intensities calculated by the coupled-model indicate a considerably weaker TC than those contained in the BTRA. This suggests, that in order to fully understand and realize both the temporal and spatial scales of the air-sea interaction dynamics, an improved initial state pertaining to the vortex structure, intensity, and position is desired. The implementation of a vortex specification scheme, akin to the GFDL[7] method (Kurihara et al., 1995), as well as the incorporation of a wave-model parameterization within the coupled-model system are the next features to be included. The vortex initialization will use observed 2-D surface wind analyses, while the wave-model will include wind-stress parameterizations which have been derived from observations collected within high-wind speed events. The uses of both an improved initial vortex state and parameterizations derived within TC-type environments will lead to further improvements in the model's representation of the sea-state as well as a better representation of the enthalpy exchanges associated with the sea-spray and moisture fluxes from the ocean into the atmospheric boundary-layer.

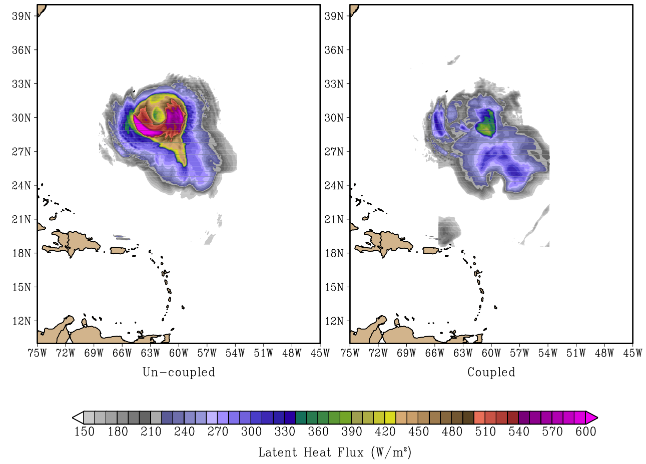

Fig. 1: Latent-heat flux swaths for TC Bertha (2008), initialized 00Z 11 July, for an un-coupled (left) and coupled (right) model simulation.

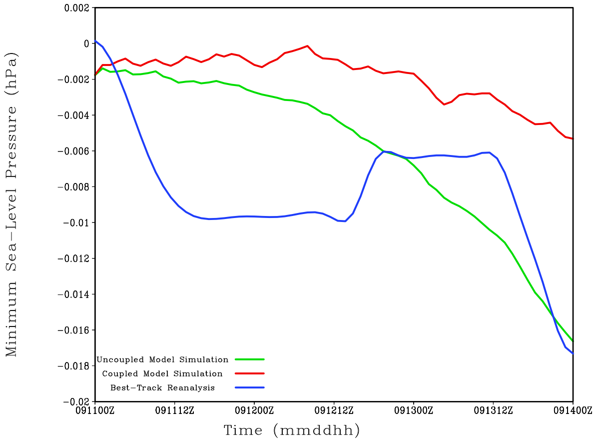

Fig. 2: Normalized and log-scaled MSLP time-series for the un-coupled (green) and coupled(red) model simulations, as well as the BTRA (blue) for TC Bertha (2008). Time-series spans from 00Z 11 July thru 00Z 14 July.

## 4. References

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[5] `http://www.coaps.fsu.edu/~hwinter/wrfarwtc`

[6] `http://www.coaps.fsu.edu/~hwinter/hycomtc`

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