NCEP HWRF-HYCOM-WW3 Forecast System

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1. Introduction

Development of a 3-way coupling HWRF-HYCOM-WW3 modeling system has been completed at EMC/NCEP/NWS/NOAA. This new system (Fig. 1) adds WW3 (WAVEWATCHIII) to the existing 2-way coupled HWRF-HYCOM system (Kim et al. 2014), to better represent complex air-sea interaction processes. Interactions with the wave model in the system include: i) generation of lengths that depend on wave age, which in turn modify drag coefficients and wind stress; and, ii) the capability to simulate wave-current interactions and enhance KPP turbulent mixing with instabilities associated with these interactions (Langmuir mixing). HYCOM receives wave-induced Coriolis-Stokes forcing in the form of Stokes drift that later interacts with oceanic currents at upper ocean depths, and HYCOM generates a Langmuir number based on Langmuir mixing. The specific role of the Langmuir number (La) in HYCOM is to modify turbulent velocity scales. HYCOM v3 has four options for calculating La (see Table 1) based on suggestions published by McWilliams and Sullivan (2001), Smyth et al. (2002), Harcourt and D'Asaro (2008), and Takaya et al. (2010).

The 3-way coupled system uses a default setting wherein at each coupling step WW3 sends a set of surface mean Stokes drift (*Us,Vs*) and wave-number (k) averaged over total 25 wave lengths to HYCOM. In turn, HYCOM projects these mean values to sub-surface depths, using an exponential function (e^{kz}) where z represents ocean depths.

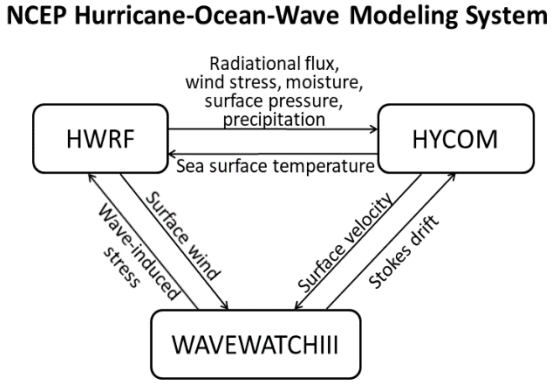

Figure 1. Schematic representation of NCEP 3-way coupled modeling system.

Table 1. List of experiments:

#	Reference
HW31	McWilliams and Sullivans (2001). Spill Sci. Tech. Bull., 6
HW32	Smyth et al. (2002). Ocean Dynamics, 52
HW33	McWilliams and Sullivans (2001). Spill Sci Technology Bull., 6; Harcourt and D'Asaro (2008). J. Phys. Oceanogr.,38
HW34	Takaya et al (2010), J. Geophys. Res., 115
HW35	Takaya et al (2010), J. Geophys. Res., 115; and Breivik et al. (2014); $k=k_m/3$ (k_m=mean surface wavenumber)

2. Model configurations

HWRF is a triply-nested domain, solving a Non-hydrostatic Mesoscale Model (NMM) dynamic core in the earth-rotated Arakawa E-staggered grid at a horizontal resolution of 1.5/4.5/13/5-km and 75 hybrid-pressure-sigma levels. The set of physics, radiation effects, vertical diffusion and the land surface model employed are discussed in more detail in https://dtcenter.org/HurrWRF/users/docs/users_guide/HWRF_v3.7a_UG.pdf. Initial and boundary conditions (ICs/BCs) are provided from the grib2 products of the EMC new global model FV3GFS (v15). As part

of the initialization, HWRF uses data assimilation based on GSI (Gridpoint Statistical Interpolation) hybrid ensemble 3D-Var data assimilation (DA). HYCOM solves 3D free-surface, primitive equations on a staggered Arakawa C-grid at a resolution of 1/12-degree and 41 pressure-z hybrid levels. Sub-grid physics are represented by the KPP mixing scheme. ICs and BCs for HYCOM are a subset of the Global Real-Time Operational Forecast System. WW3 is a spectrum model that simulates surface waves at a resolution of 25 in frequency from 1.1 Hz and 24 in the direction from true north. BCs for the solution are obtained from previous cycle's global wave multi_1 run, while ICs utilize a restart file from current cycle's global wave multi_1 run.

We have performed sensitivity experiments for different La options (as shown in Table 1), including an experiment with a reduction in wavenumber by a factor of 3 (e.g., Breivik et al. 2014). The experiments focus on Hurricane Michael (14L) from 2018 in the North Atlantic basin. Each experiment produces 22 cycles of 5.25-day simulations in total, to cover the entire lifecycle of the storm. Except for the first cycle, each model component, except WW3, uses a warm start using 6-hour coupled forecasts from the previous cycle. When Tail Doppler Radar observations are available, HWRF initialization also uses a hybrid self-cycled DA method based on a 40-member HWRF ensemble, in place of the GSI ensemble. This self-cycled DA was performed for a total of 6 cycles that extend from October 7 12Z to October 8 18Z. This paper presents an introduction to the 3-way coupling forecast system, and briefly reports on preliminary results of this sensitivity study.

3. Results and discussion

Fig. 2 shows comparisons of verified track and intensity forecasts for the five experiments, also including 2-way coupling runs with the 2018 operational HWRF (forced by GSMGFS; HWRF in Fig. 2), FV3GFS forced HWRF-POM (S219) and HWRF-HYCOM (Y219). For track forecasts, HW34 and HW35 show the smallest errors for all lead times, and Y219 simulates the worst track (Fig. 2A). The worst intensity forecast is found with S219, having the maximum AME of 32.6 kt at 66-hr forecast (Fig. 2B). It appears that HW33 predicts smallest intensity error, and all the 3-way coupled runs improve on the AME from the 2-way coupled experiment. As for intensity bias (Fig. 2C-2D), all simulations have a negative bias. However, S219 shows the worst forecast, having the largest negative bias for Vmax and the largest positive bias for Pmin. The second worst run is with Y219. Different representations of Langmuir mixing result in different Vmax bias errors as large as O(10 kt). However, their bias for Pmin is either positive for the HW32 setup or negative for the HW33 configuration. The rest of the experiments vary in between these two.

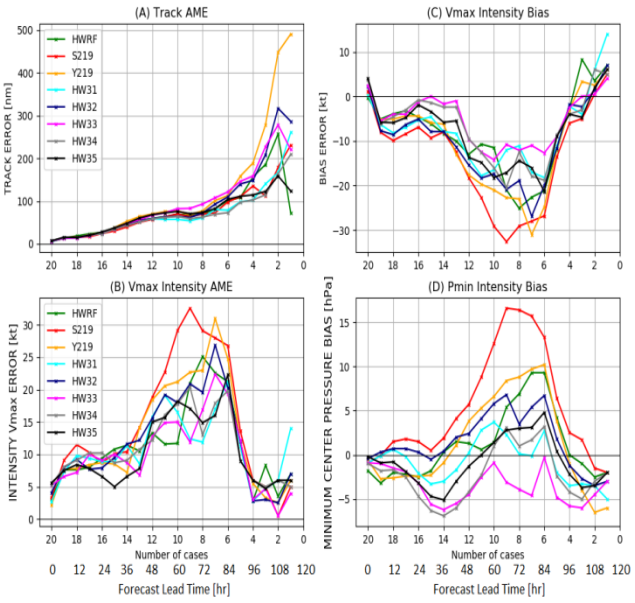

Figure 2. Absolute mean error (A-B), and bias (C-D) comparisons: HWRF is the 2018 operational coupled HWRF-POM (Princeton Ocean Model) forced by GSM (Global Spectrum Model)GFS, S219 is HWRF-POM forced by FV3GFS, and Y219 is HWRF-HYCOM forced by FV3GFS.

Preliminary results suggest that the 3-way coupling evidently improves both track and intensity forecasts over 2-way coupling. However, a more extensive analysis with a larger sample of storms is required to reach a robust conclusion. Overall, it is encouraging that an adjustment of the 3-way coupling system can improve hurricane forecasts.