JHT year-1 mid-year progress report:
Improving Predictability of the Atlantic Warm Pool in Ocean Model for Assistance to Operational Hurricane Forecast

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1. Introduction

This report is a summary of research conducted by the project personnel during the last 6 months period (August 1, 2009 - January 31, 2010). The rationale for the current project is the recent scientific finding that the Atlantic warm pool (AWP) — a large body of warm water comprised of the Gulf of Mexico, the Caribbean Sea, and the western tropical North Atlantic — may add a value to improving the simulation of Atlantic tropical cyclone (TC) in operational hurricane forecast models. In particular, recent studies using both observations and models have shown that a large AWP reduces the vertical wind shear and increases the convective available potential energy over the main development region, and thus facilitates the formation and development of Atlantic TCs (Wang et al. 2006; Wang et al., 2008a, 2008b). Therefore, our ultimate goal is to improve the forecast of the formation and intensification of Atlantic hurricanes in NCEP/EMC operational model, by improving the simulations of the AWP in that model during the hurricane season of June to November.

2. Achievements

We have setup a low-resolution ($1^o \times 1^o$) HYCOM for the Atlantic domain between 20^oS and 70^oN using RTOFS-Atlantic as the basic platform. At this stage, we are mainly working with this low-resolution stand-alone HYCOM to facilitate implementation, testing and verification of various model schemes and codes. So far, we have (1) successfully implemented and tested the atmospheric mixed layer model of Seager et al. (1995), (2) evaluated the surface flux bias in Global Forecast System (GFS), (3) performed low-resolution HYCOM experiments using the GFS forcing and other two surface flux datasets, and (4) performed a preliminary heat budget analysis to diagnose potential sources of AWP bias in the low-resolution HYCOM forced by the GFS air-sea flux. Our major findings are that (1) the shortwave radiative heat flux of the GFS dataset may not be realistic adding too much heat into the AWP, and (2) the low-resolution HYCOM tends to create a cold bias in the AWP region. A brief summary of our achievements is provided here.

2.1 Implantation of atmospheric mixed layer (AML) model

In ocean-only models, such as HYCOM, the model ocean is always forced by the prescribed atmospheric conditions. Thus, in a strict sense, ocean–only models are useful only over the regions where ocean is predominantly forced by the atmosphere. Typically, flux forms of atmospheric forcing, such as short and long wave radiative heat fluxes, precipitation rate and wind stress, are directly used to force the ocean model. For latent and sensible heat fluxes, however, bulk equations are typically used to compute them interactively using wind speed, air humidity and air temperature at 10m (or 2m) along with the model SST. The main reason for not using the observed turbulent heat flux is that any bias in surface heat flux or in ocean model leads to local accumulation or depletion of oceanic heat, resulting in an unrealistic simulation of the upper ocean heat content. Therefore, using bulk formula is equivalent to damping the model SST toward observation. The main point is that it is certainly improper to evaluate an ocean model's performance if the SST in that model is damped toward observation.

An effective way to allow an ocean-only model to have realistic heat and freshwater exchanges at the air-sea interface is to couple the ocean model with an atmospheric mixed layer model (AML) of Seager et al. (1995). The AML solves advection-diffusion equations for air temperature and humidity in the planetary boundary layer (PBL). The air temperature and humidity above the PBL and the wind vector in the PBL are needed and they can be provided from, in the case of RTOF-Atlantic, the Global Forecast System (GFS). The benefit of coupling the AML to RTOFS-Atlantic is to allow physically more realistic thermal interactions at the air-sea interface, thus to minimize thermodynamic inconsistency at the air-sea interface for HWRF-HYCOM. So far, we have successfully implemented and tested the AML model of Seager et al. (1995) in the low-resolution HYCOM.

2.2. Evaluation of surface flux bias in Global Forecast System (GFS)

Earlier studies have demonstrated that HYCOM may have some limitations in simulating the thermodynamics of the AWP and thus requires some modifications and optimizations of model schemes and codes (Lee et al. 2005, 2007). Among others, the largest model uncertainty originates from the surface heat flux bias, since the magnitude of surface net heat flux into the AWP varies by as much as 100 W/m^2 among various observational surface flux products and model-based reanalysis products typically used in regional simulations (Enfield and Lee 2005, Lee et al. 2005). Therefore, since the operational RTOFS-Atlantic is driven by the 3-hour forecast Global Forecast System (GFS), our first task is to evaluate the air-sea flux variables from the 3-hour forecast GFS, which are available for only 2009 in NOAA national operational model archive and distribution system (http://www.nomads.noaa.gov). A preliminary analysis of the 2009 GFS dataset suggests that the GFS surface net heat flux into the AWP is too large. In comparison to the Coordinated Ocean Research Experiments version-2 (CORE2) surface flux product (Large and Yeager 2008), an observation-based biased corrected surface flux product, the GFS adds up to 50 W/m^2 of extra heat flux into the AWP. Further analysis suggests that the GFS surface heat flux bias largely comes from the shortwave radiative heat flux component (see section 2.4 for more details). Further analysis is required to verify this finding and to implement an effective surface flux bias correction scheme.

2.3 Low-resolution HYCOM experiments

In order to force the low-resolution HYCOM with the GFS air-sea flux, we need a longer time series air-sea flux dataset. Therefore, we construct a pseudo-GFS dataset for 1949-2009 periods by combining the GFS for 2009 and NCEP reanalysis-1 (NCEP1) for 1949-2009. First, for each air-sea flux variable, we compute the difference between GFS and NCEP1 in 2009. For each air-sea flux variable, the difference in each month of 2009 is added to the NCEP1 for the entire period of 1949-2009 to construct a pseudo-GFS dataset. The main assumption here is that the difference in each air-sea flux variable between the GFS and NCEP1 in 2009 repeats in all other years. Note that this process does not modify the GFS air-sea flux in 2009. Along with the pseudo-GFS and NCEP1, we construct a bias-corrected NCEP1 dataset for 1949-2009 periods by combining the CORE2 for 1971-2000 and NCEP1 for 1949-2009. In this case, for each air-sea flux variable, the NCEP1 climatology for 1971-2000 is simply replaced with the CORE2 climatology then the NCEP1 air-sea flux anomaly is added to the CORE2 climatology. The low-resolution HYCOM is forced with the three air-sea flux datasets, namely pseudo-GFS, NCEP1 and bias-corrected NCEP1 for 1949-2009 periods.

2.4 Preliminary heat budget analysis in the AWP region

Figure 1 shows the observed and simulated AWP SST during June-July-August (JJA) and September-October-November (SON) in 2009. The black solid line represents 27.5^{o}C isotherm in 2008 to be compared with the colored AWP region of 2009. It is clear from this figure that the simulated AWP in the case of HYCOM_GFS is too warm suggesting that the GFS surface heat flux adds too much heat into the AWP (This issue is further investigated later in this section). On the other hand, when the low-resolution HYCOM is forced with NCEP1 and bias corrected NCEP1, the simulated AWP is too cold. Note that the color scale used is in the range of 25.5 - 28.5^{o}C for the HYCOM simulations under NCEP1 and bias corrected NCEP1, because in those cases, there is no AWP of its SST higher than 28.5^{o}C. The black solid line in these cases represents 25.5^{o}C isotherm in 2008. If we treat the bias corrected NCEP1 surface flux dataset as the truth, what this means is that the oceanic processes in the low-resolution HYCOM, such as vertical turbulent mixing and advection, tend to create a large cold bias in the AWP region. Further studies are needed to validate these findings.

Figure 2 shows the upper ocean heat budget (upper 40m) for 2009 averaged in the AWP region (100^{o}W-40^{o}W; 5^{o}N-30^{o}N). The heat budget terms include vertical mixing at 40m (vrtmix), vertical advection at 40m (vrtadv) surface net heat flux (surflx), heat storage rate (storag), numerical vertical mixing (hybmix), horizontal diffusion (hrzdif), and horizontal advection (hrzadv). See Lee et al. (2007) for the head budget equation. This figure clearly shows that the surface net heat flux is the main driving force for the onset and decay of the AWP whereas the oceanic mixing and advection terms plays a secondary role and tend to cool down the AWP in boreal summer and fall months (Lee et al. 2007). Consistent with Figure 1, the surface net heat flux in HYCOM_GFS is much larger than the other two cases.

Figure 3 shows the 2009 surface flux components from the three low-resolution HYCOM experiments, and those from the three surface flux datasets (i.e., pseudo-GFS, NCEP1 and bias corrected NCEP1). Note that the low-resolution HYCOM recalculates the surface latent and sensible heat fluxes using the AML model of Seager et al. (1995). Thus, the HYCOM-derived heat flux is different from the original surface heat flux dataset used to force the HYCOM. The latent heat flux in the original GFS dataset shows a reasonable range of values when it is compared with the bias corrected NCEP1 dataset (Figure 3c). However, as mentioned in section 2.2, it is clear from Figure 3b that the original GFS dataset adds up to 50 W/m^2 of extra shortwave radiative heat flux into the AWP region in comparison to the bias corrected NCEP1 dataset. Further analysis is required to verify this finding and to implement an effective surface flux bias correction scheme.

3. References

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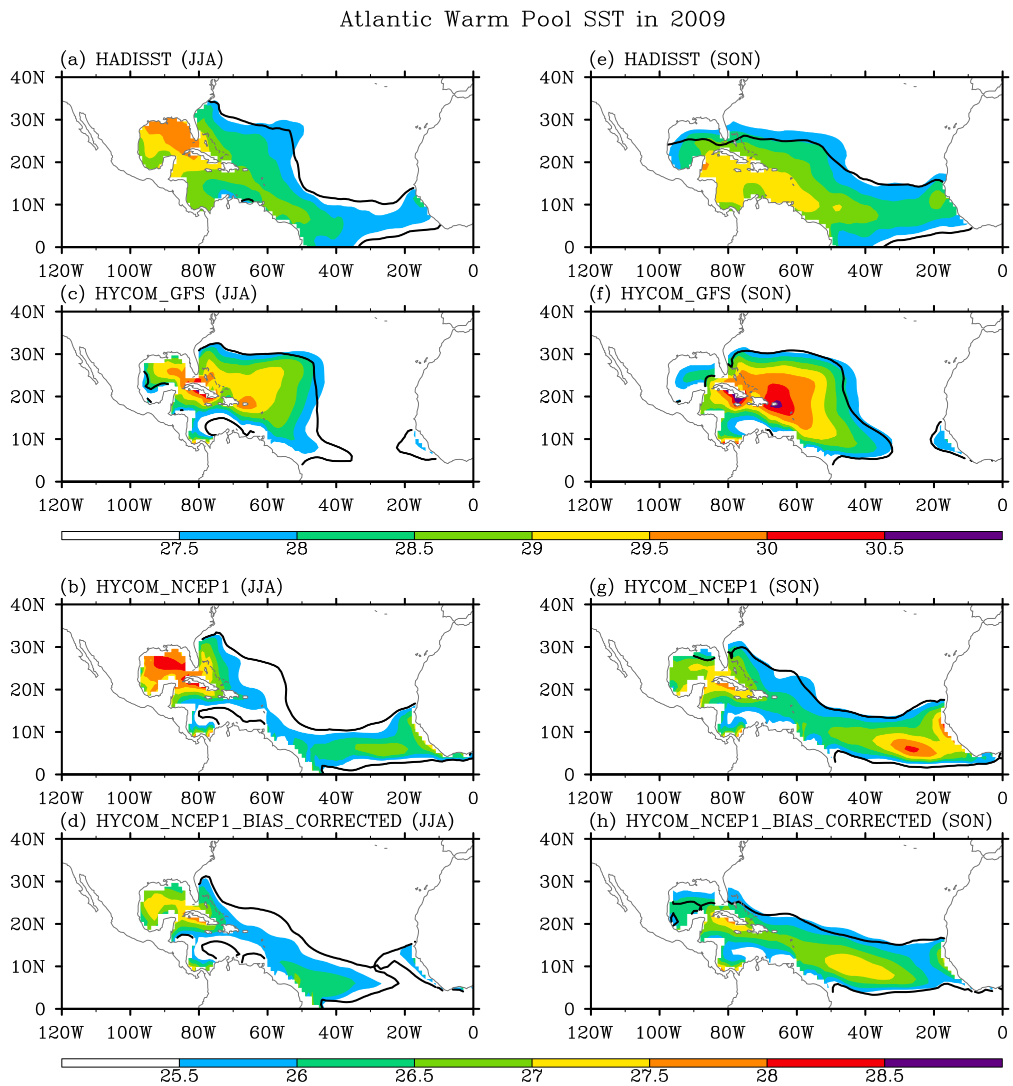

Figure 1. Observed and simulated AWP SST during June-July-August (JJA) and September-October-November (SON) in 2009. The black solid line in (a), (c), (e) and (f) represents 27.5°C isotherm in 2008 to be compared with the colored AWP region of 2009, whereas the black solid line in (b), (d), (g) and (h) represents 25.5°C isotherm in 2008.

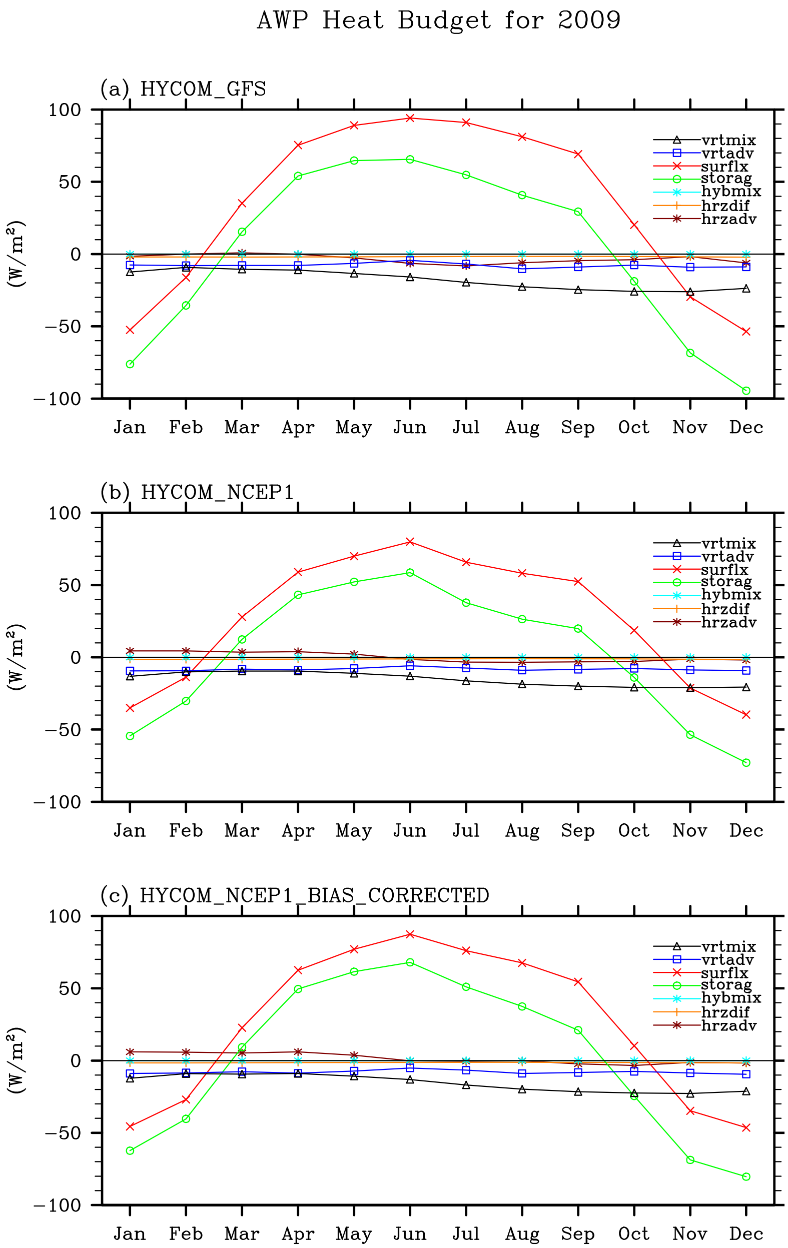

Figure 2. Simulated upper ocean heat budget (upper 40m) for 2009 averaged in the AWP region (100°W-40°W; 5°N-30°N). The heat budget terms include vertical mixing at 40m (vrtmix), vertical advection at 40m (vrtadv) surface net heat flux (surflx), heat storage rate (storag), numerical vertical mixing (hybmix), horizontal diffusion (hrzdif), and horizontal advection (hrzadv). See Lee et al. (2007) for the head budget equation.

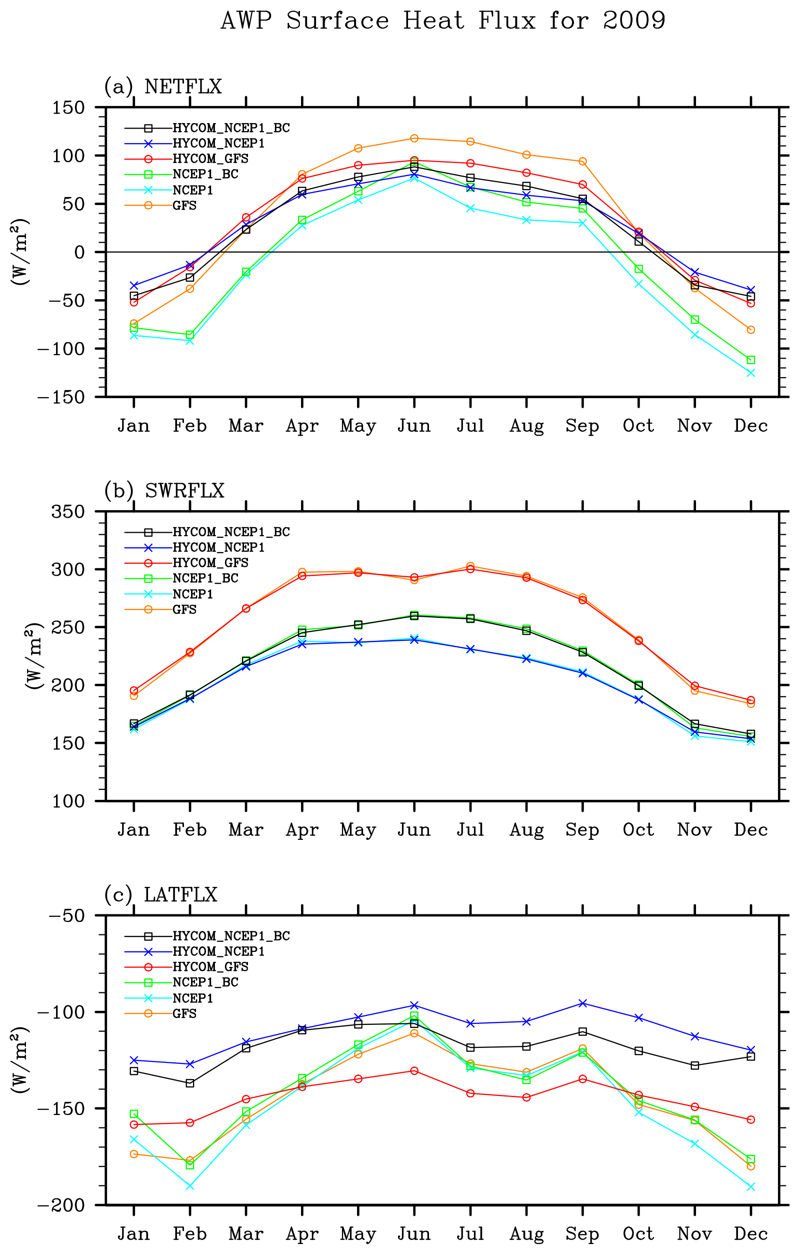

Figure 3. (a) Net surface heat flux, (b) shortwave radiative heat flux and (c) latent heat flux in 2009 averaged in the AWP region (100°W-40°W; 5°N-30°N) from the three low-resolution HYCOM experiments, and those from the three surface flux datasets (i.e., pseudo-GFS, NCEP1 and bias corrected NCEP1).