Findings from temporal nudging experiments of sea surface temperature

Hae-Cheol Kim[1,*], Carlos Lozano[2], Dan Iredell[1], Hyun-Sook Kim[1], Avichal Mehra[2], Liyan Liu[1]
[1] IMSG at NWS/NCEP/EMC, [2] NWS/NCEP/EMC
Email: Hae-Cheol.Kim@noaa.gov

The ocean states represented in the ocean model component in a coupled atmosphere-ocean hurricane forecast system are required to maintain an accurate representation of the upper ocean and major mesoscale features, in particular, during the hurricane season along the hurricane paths. In support of this requirement this study examines some aspects of data assimilation in a regional ocean model for the Western North Atlantic (HAT11W) to be used as an ocean component of an operational coupled atmosphere-ocean hurricane forecast system, the Hurricane Weather Research Forecast-Hybrid Coordinate Ocean Model (HWRF-HYCOM). Specifically, a series of numerical experiments are conducted for the period that covers normal and hurricane-intensity conditions during Hurricane Isaac (Aug. 21 – Sep 1, 2012) which was a destructive hurricane that came ashore in the U.S. state of Louisiana during August 2012. Various nudging scales of sea surface temperature (SST) are examined to explore the appropriate temporal range of nudging SST in a regionally nested domain (HAT11W). These SST fields are from the Global Real-Time Ocean Forecast System (RTOFS-Global [1]; http://polar.ncep.noaa.gov/global/) which is an operational ocean weather forecast system at the National Centers for Environmental Prediction (NCEP), National Weather Service (NWS).

HAT11W is nested as a sub-domain within RTOFS-Global with its boundary conditions defined from the outer global domain. The numerical ocean modeling component is the eddy-resolving 1/12^{o} HYbrid Coordinate Ocean Model (HYCOM) with horizontal recti-linear coordinate. Vertical coordinates employ 32 layers, following isopycnals in the deep sea, z-levels in the surface and a terrain-following σ-coordinate near coastal areas [2]. K-Profile Parameterization (KPP) [3] is used as a vertical mixing scheme. RTOFS-global is re-initialized every day from an analysis prepared by the Naval Oceanographic Office (NAVOCEANO) using a multivariate optimal interpolation (MVOI) scheme [4] for assimilating observations collected from various platforms. In this study, we focus on the simplest configuration in which we can isolate the effects of the global model fields with atmospheric forcings from NCEP's Global Data Analysis System (GDAS) and Global Forecast System (GFS), in order to understand the pure effect of driving the SST fields of the model at the surface with an SST analysis based on observations. The analysis employed in this study ingests SST observations derived from the Advanced Very High Resolution Radiometer (AVHRR).

The updated SST field is based on a two-dimensional variational (2DVAR) analysis [5]. Time interpolated SST analysis fields are included in the temperature tendency of the surface layer by nudging with a relaxation time scale (rlxsst). The additional heat flux added to the surface is distributed by vertical mixing, horizontal advection and eddy diffusivity with the main physical process distributing the additional heat flux being vertical turbulence. The intent of nudging at the surface is to gently steer the mixed layer (ML) temperature toward observations.

A comparison of ML averaged temperature between the free (Expt000) and a strong nudging case (Expt007) is done for Sep. 3, 2012, 00Z, after 50 days of initialization (Fig.1). Compared to the free run, the distribution of ML averaged temperature is noticeably different in the assimilated fields. For example, temperature patterns in the Gulf of Mexico tend to be warmer offshore but colder in the coastal areas in data assimilative mode. Overall, this tendency is true for the Caribbean region as well. Cold water mass along the South American coast (Venezuela to Brazil) presented in Expt000 disappeared in Expt007. In addition, warm/cold patches of Expt000 have been diffused in Expt007 when SST observations are assimilated, which is as anticipated.

Some of our findings are highlighted in Figure 2. A nudging scale (rlxsst) of 1 day (the black line in Fig. 2) yields the minimum root mean square error (RMSE) of innovation, but it injects large negative heat fluxes (approximately -1.38 KWm^{-2} for ΔT=1 °C) onto the surface leading to rapid entrainment (artificial negative buoyancy), which is not expected in this region. This can be avoided by limiting the change in heat flux (>-1KWm^{-2}). In our experiments, the implicit KPP algorithm converges with four iterations under both normal/abnormal conditions away from hurricane footprint with/without SST nudging. Without limiting the size of assimilated fluxes we find that the nudging scale of 6 days is the optimum time scale for SST nudging in the upper ocean in our region of study. For general circulation patterns, after 50-day simulations RTOFS-Global and those experiments with appropriate nudging scales were similar. This suggests that six day forecasts will give reasonable results in the absence of strong dynamical events.

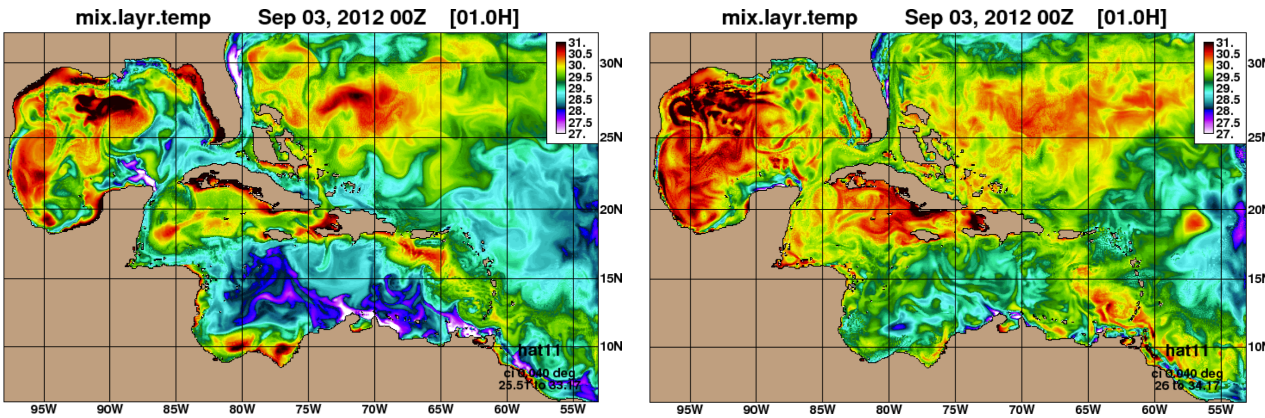

Fig. 1. Mixed layer (ML) averaged temperature fields for the same day are compared for Expt000 (left) and Expt007 (right).

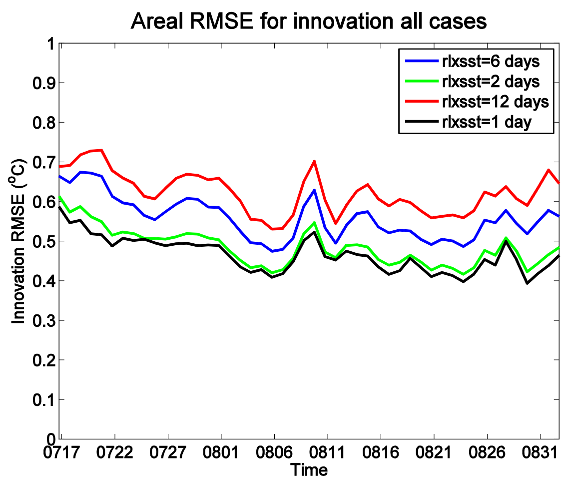

Fig. 2. Time evolution of RMSE for innovation for different settings of relaxation scale.

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