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Recipient Name: University of Rhode Island
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Reporting Period: 09/01/2013 - 02/28/2014
Final Report: No
Report Due Date: 03/30/2014

Work Accomplishments:

1. Tasks scheduled for Year 1

a) Transition the 1/18° benchmark GFDL/N, perhaps with physics changes, to operations.
b) Transition open MP software in 1/18° GFDL/N, for improved efficiency, to operations.
c) Begin testing the radiation package with an increased number of vertical levels.
d) Continue to test the upgraded Ferrier microphysics in preparation for operations.
e) Transition the meso-SAS convective scheme to operations, pending positive results.
f) Transition GFDL/MPIPOM-TC to operations in the Atlantic, pending positive results.
g) Set up the worldwide MPIPOM-TC domains in GFDN and conduct initial testing.
h) Select the optimal set of air-sea interface physics packages and transition the hurricane-wave-ocean coupled system to operations in the Atlantic, pending positive results.

2. Tasks accomplished this period

a) *Transition the 1/18° GFDL with physics upgrades to operations.*

Through JHT funding, major upgrades have been finalized at the National Centers for Environmental Prediction (NCEP) for operational implementation of the new high-resolution version of the GFDL hurricane model. The inner nest resolution has increased from 9 to 6 km, which is the highest resolution possible for a hydrostatic model. The surface exchange coefficients (C_h and C_d) have been reformulated consistent with some of the recent referred studies (Figure 1) (Edson et al. 2013; Andreas 2011; Soloviev et al. 2014). In addition, the ocean currents are now taken into account in the surface stress computation. The new model is fully coupled in both the Atlantic and Eastern Pacific with the new MPIPOM-TC (Yablonsky et al. 2014; see section b).

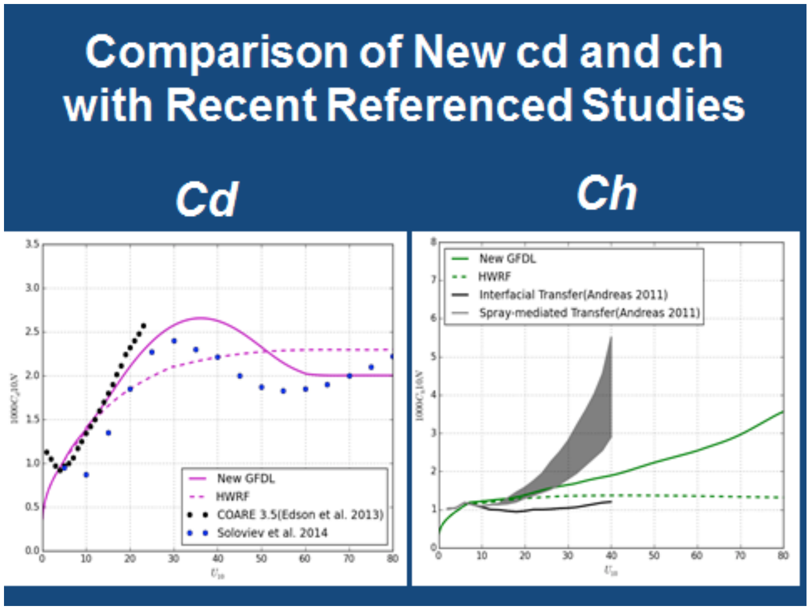

***Figure 1**. Plot of the new C_d (left, purple line) compared to the version operational in both GFDL and HWRF (purple dashed line), compared to estimates from observational data (black dots) and a recent theoretical study (blue dots). Also shown (right) is the formulation of the new C_h (solid green) compared to the version operational currently in HWRF (green dashed) and theoretical studies by Andreas (2011).*

Additional model upgrades include modification of the Planetary Boundary Layer (PBL) and surface layer using the critical Richardson number, advection of the individual microphysics species, and improved targeting of the storm maximum wind and storm radius in the vortex initialization. Advection of the rime factor was also evaluated but not included because impact was minimal. Finally vortex specification (bogussing) was removed during the model initialization for weak storms with maximum surface winds of 40 knots or less.

The new model configuration has been extensively tested for most of the storms during the 2008 and 2010-2012 Atlantic seasons, as well as the 2011-2013 Eastern Pacific seasons. Results indicated significantly reduced intensity errors, particularly in the Atlantic basin (Figure 2). For the Atlantic, the reduction of wind intensity errors averaged nearly 15% at days 3-5 and about 6% at the shorter forecast lead times. For the Eastern Pacific, improvements averaged about 5 to 8%. Another measure of improved model performance is the percent of storms that had overall improved intensity guidance compared to the current version. As seen in Figure 3, compared to the current operational model, over 80% of the Atlantic storms had better intensity guidance for the 3-5 day forecast lead times, and about 60% of the storms had improved guidance at the earlier forecast times.

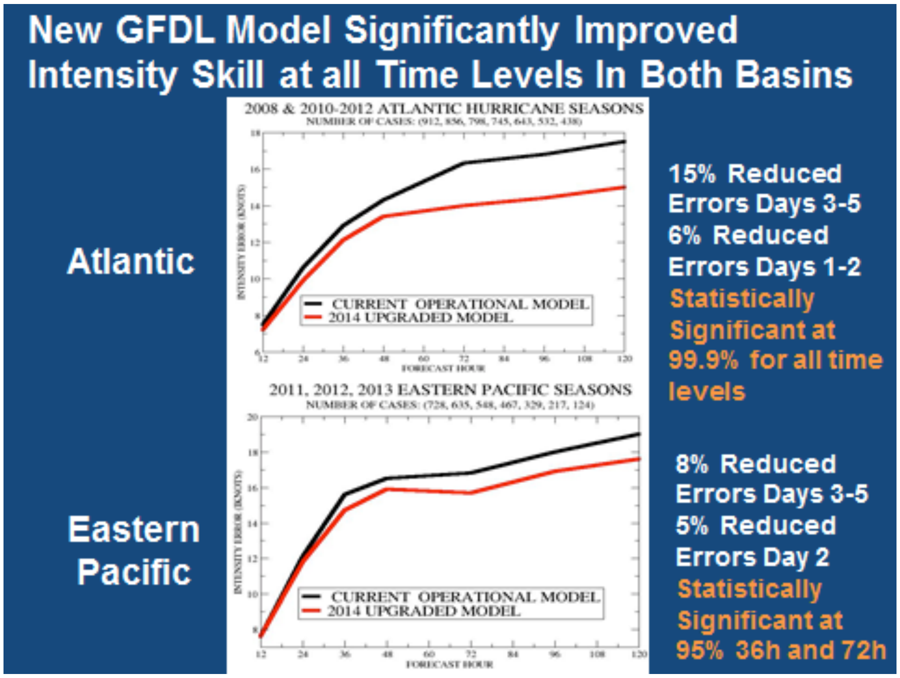

Figure 2. *Average intensity errors for the Atlantic (top) and Eastern Pacific (bottom) for all forecast time periods for the selected storms used in the evaluation of the new model (red line), compared to the version currently used in operations at NCEP (black line).*

The biggest impact on intensity was a large reduction in the over-intensification of weaker storms (Figure 4), greatly reducing the model's positive bias for these non-intensifying systems. This should enable the model reliability to be significantly improved once the upgraded model becomes operational.

Finally, in regards to track errors, the model demonstrated about a 5-6% reduction in the Atlantic and neutral impact in the Eastern Pacific (Figure 5). However, the improvement was statistically significant in the Atlantic at all forecast lead times except day 5.

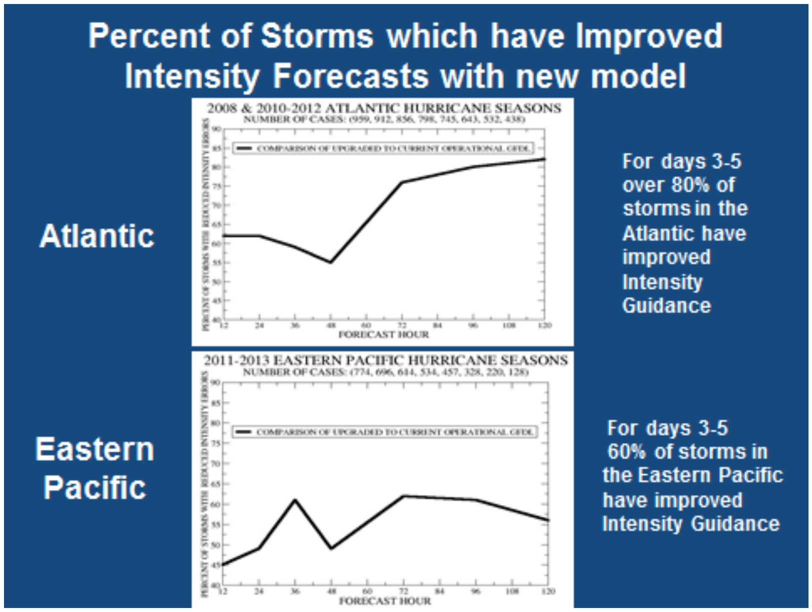

Figure 3. *Percent of storms with improved intensity guidence as a function of forecast lead times for the selected storms used in the model evaluation for both the Atlantic (top) and Eastern Pacific (bottom).*

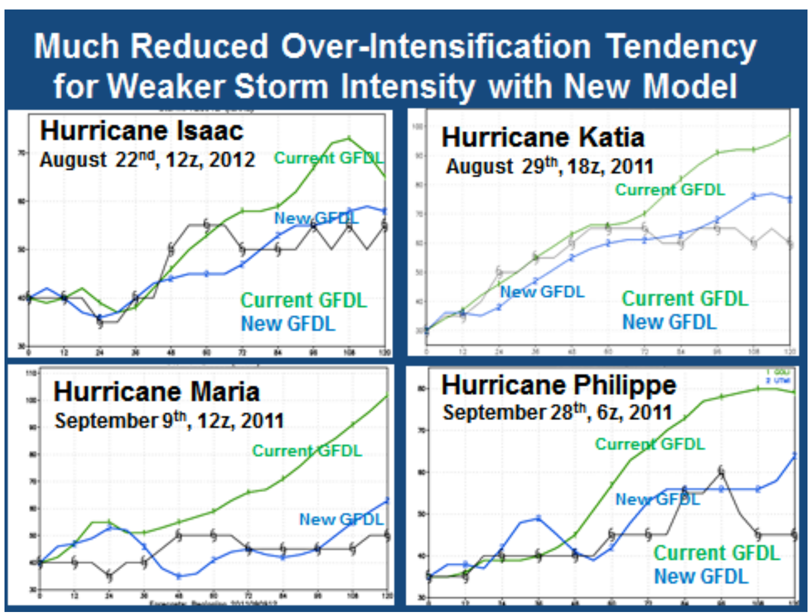

Figure 4. *Time series of forecasted maximum surface winds with the new upgraded GFDL model (blue) compared to the current operational model (green) for the forecast of four Atlantic storms.*

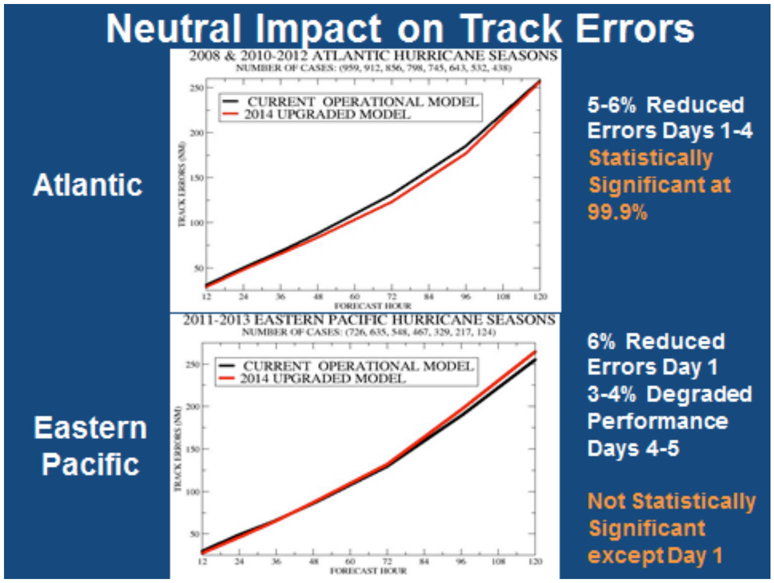

Figure 5. *Average track errors for the Atlantic (top) and Eastern Pacific (bottom) at all lead times for the selected storms used in the evaluation of the new model (red line), compared to the version currently used in operations at NCEP (black line).*

b) Transition GFDL/MPIPOM-TC to operations in the Atlantic

URI's new MPIPOM-TC ocean model with ~1/12° grid spacing has now been successfully transitioned to the GFDL model (as a replacement for POM-TC with ~1/6° grid spacing) for 2014 operations in the Atlantic. This upgrade also replaced the two overlapping POM-TC ocean domains in the Western and Eastern Atlantic with a new, expanded transatlantic domain to prevent loss of ocean coupling for storms that move quickly from west to east or east to west in the central Atlantic (Figure 6). Indeed, retrospective GFDL/MPIPOM-TC tests of Hurricanes Igor (2010) and Katia (2011), for example, show a positive impact by preventing loss of ocean coupling using GFDL/MPIPOM-TC's new transatlantic domains (not shown).

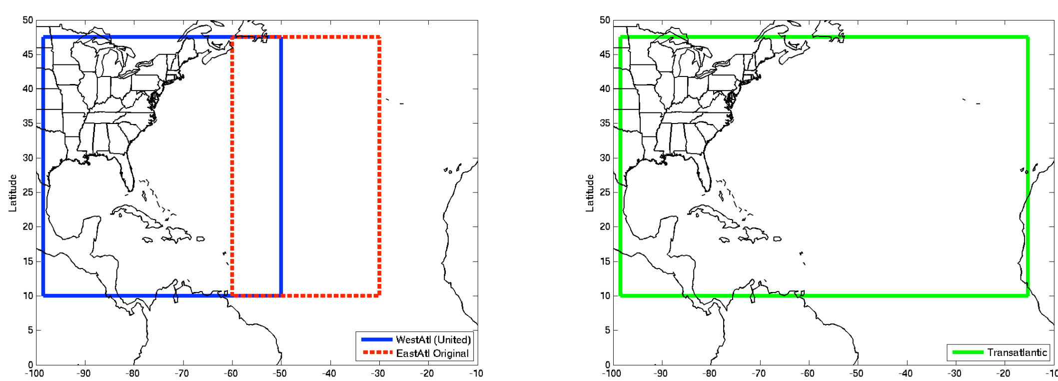

Figure 6. *POM-TC's overlapping Western and Eastern Atlantic domains (left) and MPIPOM-TC's expanded transatlantic domain (right).*

Overall, MPIPOM-TC's impact on the GFDL forecasts were positive, but some cases still pose challenges in terms of accurately predicting the SST response to hurricane forcing. One example is the 2011082300 cycle of Hurricane Irene (Figure 7). While the track forecast was quite good, the intensity forecast was over predicted, at least part of which may have been attributable to the under predicted SST cooling, relative to remotely-sensed TMI SST observations. A major collaborative effort to evaluate and improve MPIPOM-TC (and other ocean components of coupled hurricane models) is underway.

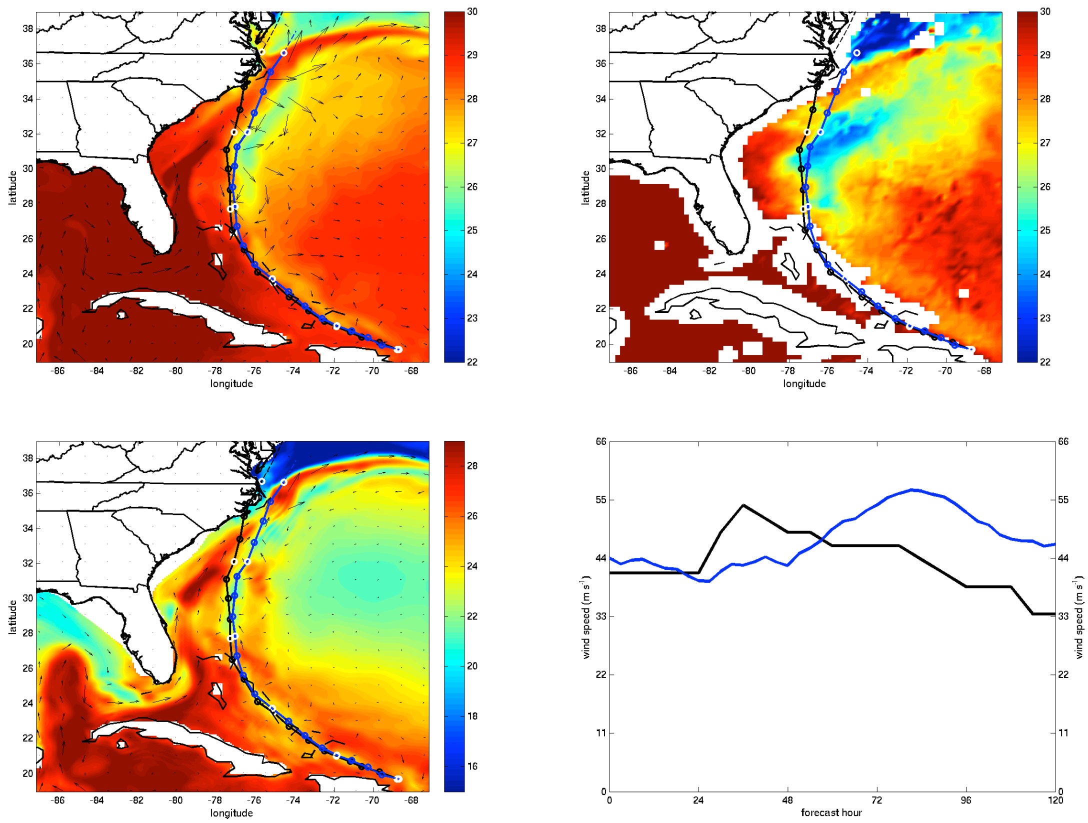

Figure 7. *GFDL/MPIPOM-TC forecast of Hurricane Irene, initialized 2011082300: 120-h model SST with model track (blue; white circles every 24 h) and best track (black) (upper-left); 8/26-8/28 TMI SST (upper-right); 120-h model 77.5-m ocean temperature (lower-left); maximum wind from model (blue) and observed (black) (lower-right).*

c) Development of MPIPOM-TC domains in all worldwide ocean basins

One of the goals of this project is to incorporate URI's new MPIPOM-TC ocean model with ~1/12° grid spacing and flexible initialization options into the GFDL and GFDN models worldwide. Towards this end, the following seven MPIPOM-TC ocean domains have now been developed: Transatlantic (to be operational in GFDL in 2014), East Pacific (to be operational in GFDL in 2014), West Pacific, North Indian, South Indian, South West Pacific, and South East Pacific (all seven of which are proposed for the operational GFDN during the next upgrade cycle). Figure 8 shows the geographical locations of the seven MPIPOM-TC ocean domains.

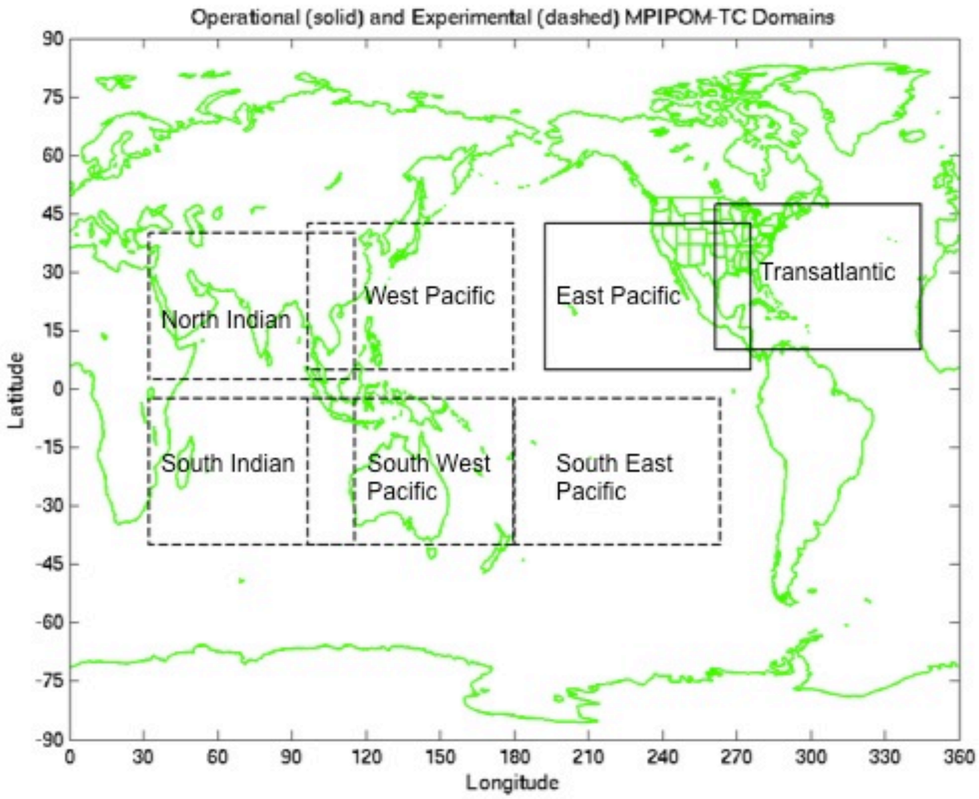

Figure 8. *MPIPOM-TC ocean domains for the GFDL and GFDN coupled models.*

The seven ocean domains are all the same size and resolution, with 869 longitudinal grid points that span 83.2° of longitude and 449 latitudinal grid points that span 37.5° of latitude. Keeping all of the ocean domains the same size and changing only the location of the domain from basin to basin simplifies the code management and the air-sea coupling.

The MPIPOM-TC ocean domains can be initialized from a variety of ocean initial conditions by simply utilizing a given "prep" module that has been developed for this purpose. All ocean initial conditions have the ability to assimilate the daily GFS or NAVGEM SST into the upper ocean mixed layer. For the 2014 operational GFDL model, MPIPOM-TC is initialized with the feature-based prep module in the Transatlantic domain (fbtr) and the GDEMv3 monthly climatology prep module in the East Pacific domain (g3ep); both of these initializations are set to assimilate the GFS SST, as in the POM-TC initialization for the operational GFDL model prior to 2014. For the next operational GFDN model upgrade, the proposed MPIPOM-TC initialization is the feature-based prep module in the Transatlantic domain (fbtr) and the NCODA prep modules in all of the other ocean domains (naep, nawp, nani, nasi, nasw, and nase), when the NAVGEM SST is assimilated into fbtr but SST assimilation is not required for the other ocean domains because NAVGEM SST is derived from the NCODA SST.

A new effort is underway to test the GFDL model worldwide, which is the equivalent of replacing NAVGEM with GFS as the atmospheric initial condition in the GFDN model. As part of this effort, both GDEMv3 and NCODA ocean initial conditions, with and without GFS SST assimilation, will be tested in each ocean basin to determine the impact of the ocean initial condition on the worldwide GFDL forecasts. In addition, MPIPOM-TC prep modules are under development to initialize the model with various configurations of the Global HYCOM ocean model; this effort is primarily funded by HFIP in conjunction with MPIPOM-TC's implementation in the HWRF coupled model.

Figures 9 and 10 show MPIPOM-TC's ocean response to Supertyphoon Bolaven (West Pacific) and Cyclone Phailin (North Indian), respectively, using forcing from observed winds derived from the NHC message file (i.e. TC vitals) and two different ocean initial condition options. The SST cold wakes produced by these tropical cyclones are evident, but the details of the cold wakes depend on the pre-storm SST initial condition and the subsurface ocean initial condition.

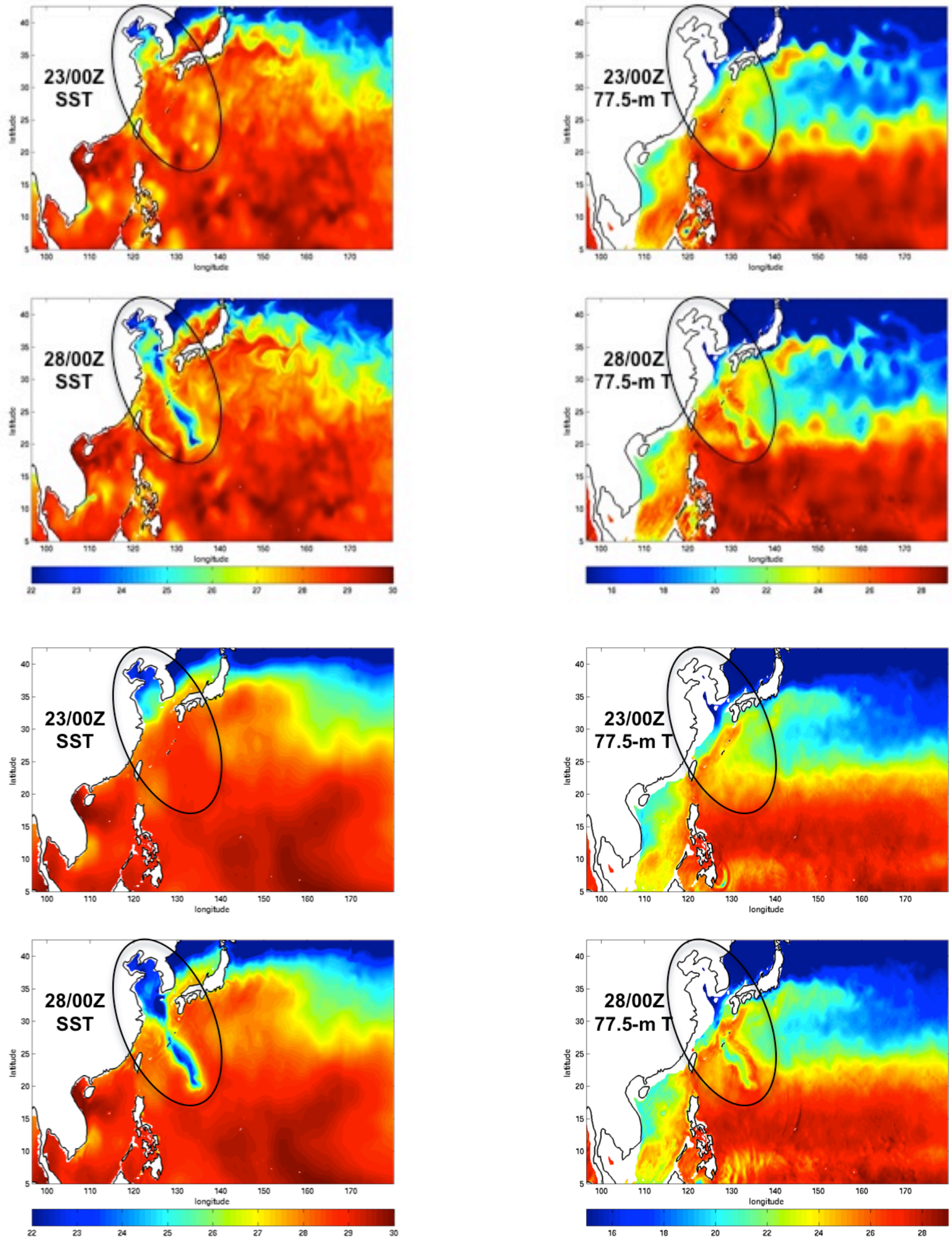

Figure 9. *MPIPOM-TC's ocean response to West Pacific Supertyphoon Bolaven's observed wind forcing from 20120823 at 00Z to 20120828 at 00Z using the NCODA (first four panels) or GDEMv3 + GFS SST (last four panels) initial condition: SST at 23/00Z (1st and 3rd rows, left); 77.5-m T at 23/00Z (1st and 3rd rows, right); SST at 28/00Z (2nd and 4th rows, left); 77.5-m T at 28/00Z (2nd and 4th rows, right).*

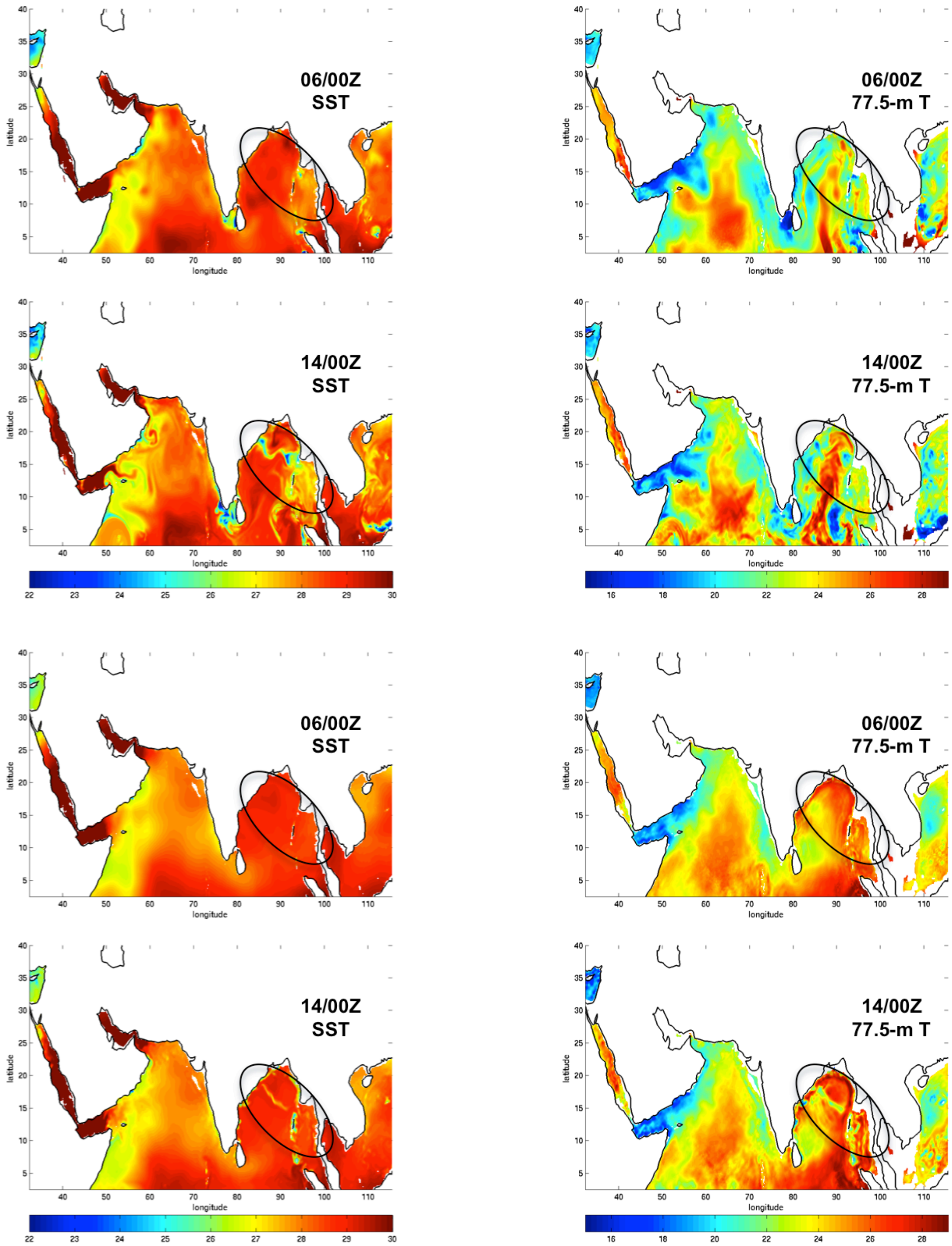

***Figure 10**. MPIPOM-TC's ocean response to North Indian Cyclone Phailin's observed wind forcing from 20131006 at 00Z to 20131014 at 00Z using the NCODA (first four panels) or GDEMv3 + GFS SST (last four panels) initial condition: SST at 06/00Z (1st and 3rd rows, left); 77.5-m T at 06/00Z (1st and 3rd rows, right); SST at 14/00Z (2nd and 4th rows, left); 77.5-m T at 14/00Z (2nd and 4th rows, right).*

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