Numerical sensitivity study on the rapid intensification of tropical cyclone Megi (2010)

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I. Introduction

Rapid intensification (RI) of tropical cyclones has been a major challenge in the research and forecasting community. In this work, we intend to understand the physical processes that may induce rapid deepening on a tropical cyclone (TC) by examining the sensitivity of the simulated TC Megi (2010) to Planetary Boundary Layer (PBL) schemes and model's horizontal resolution.

II. Methodology

The intensification of Super Typhoon Megi (2010) is simulated as it enters the Philippine Area of Responsibility using the JMA Non-hydrostatic Model (Saito et al., 2007). Numerical experiments are conducted comparing the effects of the PBL parameterizations (Mellor-Yamada Level 3 (MY3) vs Deardorff scheme) and model's resolutions (8, 6, 4, 2-km with MY3 scheme). Data from JRA and JMASST are used as initial boundary conditions for the mother domain.

III. Sensitivity to PBL Schemes

Turbulent mixing in the planetary boundary layer plays a key role in the response of tropical cyclone to surface forcings. It is the mechanism for energy transport, mass and momentum fluxes in the PBL which is vital to the intensification or weakening of TCs. Figure 1 shows the intensity hindcasts from the PBL experiment: MY3 versus Deardorff closure model. From these graphs, one can see a stronger typhoon with the Deardorff PBL scheme gaining a maximum intensity of 21.4 hPa deeper than in the MY3 case. It is interesting to note the good fit of the two cases during the early stage of intensification (first 36 hours of integration: $\mathbf{t_0}$) but suddenly diverged as they approach their maximum intensities at $\mathbf{t_1}$.

Figure 2 shows the azimuthally averaged vertical profile of the simulated wind speed within the boundary layer at the onset of RI (t=36). The weaker wind speed in the Deardorff experiment corresponds to a weaker vertical momentum transport relative to those in the MY3 case (see Figure 3). In particular, the first case show a decreased in absolute angular momentum (AAM) at the lower PBL, eyewall and r >150. Here, we define AAM of axisymmetric TC as:

$$AAM = r\bar{v}_t + \frac{fr^2}{2} \, , \quad (2)$$

where r, ρ and f refer to the distance from the TC center, density and Coriolis constant, respectively, (Sawada and Iwasaki, 2010). Note that AAM is dissipated primarily via surface friction and the energy loss due to this retarding flow is also reduced as a result of the smaller calculated vertical momentum flux in the Deardorff scheme.

Figure 4 illustrates significant variations on the effect of the Deardorff scheme on the distribution of mass stream function (MSF) along the radial and vertical structure of TC Megi. MSF describes the radial and vertical flow of the TC (Sawada and Iwasaki, 2010):

$$\Psi\,(r,z) = -r\int_0^z \bar{\rho}\;\bar{v}_r\,dz = \int_0^r \bar{\rho}\bar{w}\;r\,dr\,, \quad (3)$$

It is shown that during the early development of TC Megi, the Deardorff scheme simulated a weaker secondary circulation in the lower and upper boundary layer with positive values on the middle boundary layer. This corresponds to a reduction in the energy conversion rate by the scheme.

The resulting stronger TC with the Deardorff scheme indicates a positive impact of the reduction of energy loss in inducing rapid intensification despite a decreased in the energy conversion within the system.

IV. Sensitivity to Model's Resolution

With the increasing capability of high-performance computational system and advanced modeling techniques, simulations of weather phenomena such as tropical cyclones have been geared towards Cloud-resolving model. However, it is not clear how well high-resolution models simulate tropical cyclone in the real world. Here, we compare the 2-km resolution from other cases with 4 and 6 km grid size initiated from an 8-km parent domain and using the same model's physics.

As expected the 2-km case generated the most intense and rapid typhoon. The results show a common trend of intensification in terms of pressure drop for all cases except the early deepening and intensity oscillation in the 2-km case (see Figure 5).

REFERENCES:

Saito, K., et al, 2007: The operational JMA nonhydrostatic mesoscale model. *Mon. Wea. Rev.*, **134,** 1266–129810.

Sawada, M., and T. Iwasaki, 2010: Impacts of evaporation from raindrops on tropical cyclones. Part I: Evolution and axisymmetric structure. *J. Atmos. Sci.*, **67,** 71–83.

Tuleya, R. E., and Kurihara Y., 1975: The energy and angular momentum budgets of a three-dimensional tropical cyclone model. *Journal of the Atmospheric Sciences*, **32(2)**, 287-301.

FIGURES:

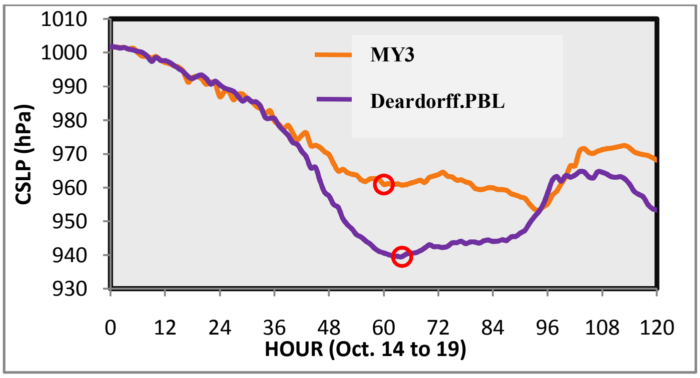

FIG 1. Comparison of the simulated central sea level pressure (CSLP) of different PBL schemes: where t_0 refers to initial time of rapid intensification (t=36) and O refers to the first peak (t_1).

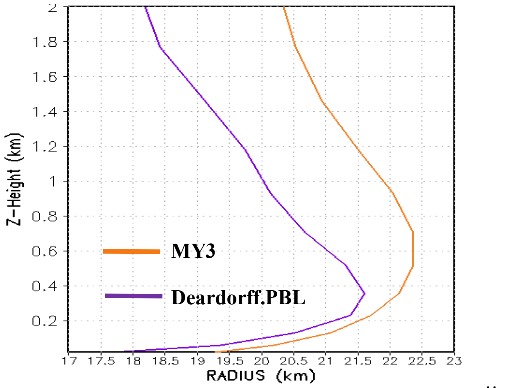

FIG 2. Vertical profile of azimuthally and radially (within 200 km from the center) averaged wind speed.

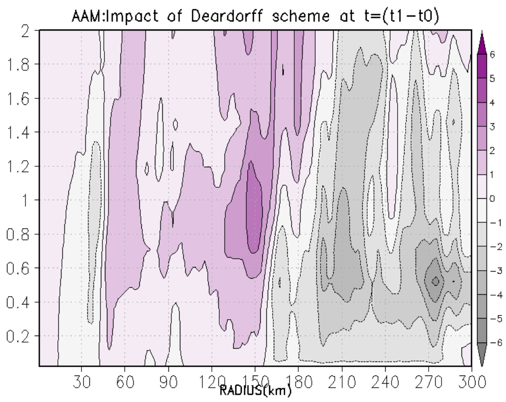

FIG 3. Vertical profile of azimuthally averaged AAM at $t=t_1-t_0$:Deardorff minus MY3

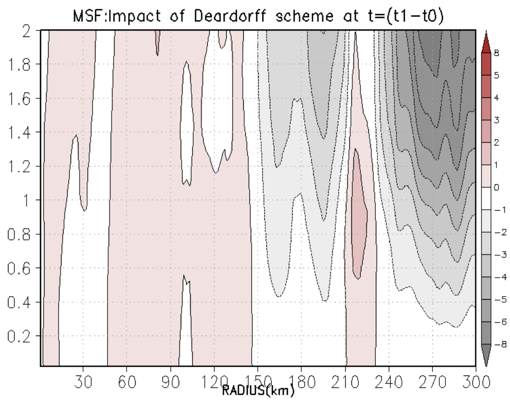

FIG 4. Vertical profile of azimuthally averaged MSF at $t=t_1-t_0$: Deardorff minus MY3

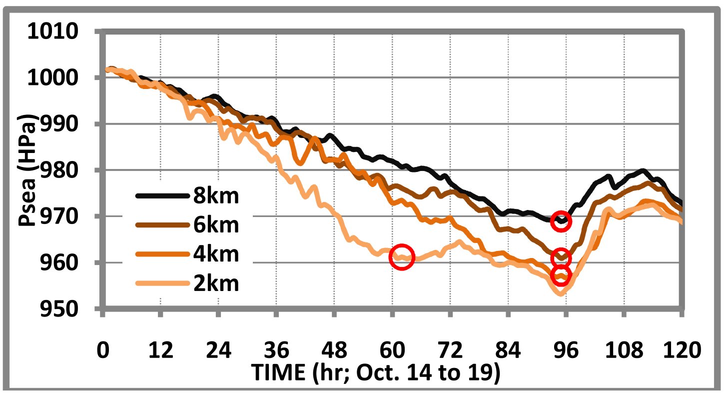

FIG 5. Comparison of the simulated CSLPs with different horizontal resolutions.
O refers to the first peak.