11C.2 Simulating Hurricane Pre-Landfall and Post-Landfall Intensity Changes

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1. Introduction

With continual upgrade of data assimilation techniques and physics packages, numerical prediction of tropical cyclone (TC) intensity has been undergoing improvements in recent years. Recent research using sophisticated assimilation techniques (e.g. 4DVAR, EnKF) also provide promising results.

The dependence of simulated TC intensity on horizontal resolution has been known for a long time, because the grid must resolve the strong gradients near the eyewall. However, there is no consensus on how small the horizontal grid size should be for TC simulation. Recent study suggests that a 1 km horizontal resolution is necessary (Chen et al. 2007).

The dependence of simulated TC on the vertical grid is less obvious. Unlike the horizontal grid problem where one would expect more intense TCs for higher resolution, recent results (Kimball and Dougherty 2006) suggest that higher vertical resolution in the planetary boundary layer may result in less intense TCs, possibly due to the surface fluxes parameterization. Overall, the vertical grid that one should adopt for TC simulations is even less known.

The objective of this study is to address the effect of the horizontal and vertical grid on the simulated TC intensity of hurricane Katrina.

2. Methodology

Version 2 of the Advanced Research Weather Research and Forecasting Model (WRF-ARW) is used in this study. The numerical experiments can be categorized into three groups (Table 1). Storm following grid of 27-9-3 km horizontal resolution and 27 vertical layers is used for the first group of experiments. The YSU uses the Yonsei University boundary layer parameterization. All the other experiments in the first group use a slightly different set of physics parameterization. For example, the MYJ uses different boundary layer/surface fluxes parameterizations.

The second group is based on the YSU and MYJ experiments, with the addition of an even finer grid of either 1 km or 600 m to test the sensitivity to horizontal resolution; The third group is also based on the YSU and MYJ, with 4 layers at the bottom (L4) or the outflow levels (H4) removed. The use of both the YSU and MYJ in these groups would enable us to better identify those differences that results from a grid change.

Here we use the minimum sea level pressure (MSLP) as the measure of TC intensity. The prediction is further stratified into pre-landfall and post-landfall cases, from 00Z Aug 28 to 12Z Aug 29, and 12Z Aug 29 to 00Z Aug 31, respectively.

3. Physics Parameterizations

Both the pre-landfall and post-landfall experiments suggest that the boundary layer/surface fluxes parameterizations are the most and perhaps the only important physics parameterization in determining the TC intensity (results not shown). The MYJ gives a much more intense TC during pre-landfall intensification/maintenance, but the post-landfall decay is also faster. Apparently it is due

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to the larger surface exchanges in MYJ.

Note that the rapid deepening of Katrina during the 12 hours between 00 and 12Z of Aug 28 and also the weakening just prior to landfall can not be simulate. Recent research employed additional datasets and techniques to reduce spin-up problems. These are beyond the scope of the current study.

4. Horizontal Grid

a. Pre-Landfall

For either the YSU or MYJ group, the differences in simulated intensity at the end of the simulation is not large (Fig. 1). However, the intensity in the first 18 hours can be as large as ~20 hPa between the YSU-3km and YSU-600m simulations. This would either suggests that smaller horizontal grid size is required for vortex spin-up. This can be resolved by better assimilation of data; another possibility is that the 600m grid is indeed necessary to predict the intensification.

Unexpected results are also noted when the 600m domain is reduced in size, from 301x301 grid points to 271x271 grid points. The change appears so slight that a large difference would not be anticipated. However, both the YSU and MYJ experiments show a weakened TC of ~10 hPa (Fig. 1). Therefore, care must be taken to ensure that the coverage of the fine grid does not affect the results.

b. Post-Landfall

The intensity between YSU and YSU-1km (MYJ and MYJ-1km) is negligibly small after about t = 12 h (Fig. 2). One may conclude that a fine grid is not necessary for TC decay. A plausible explanation is that the weakening of winds occur at all scales, and does not depend on convection, which occurs in a small scale.

5. Vertical Grid

a. Pre-Landfall

When four layers at the bottom are removed, both the YSU and MYJ groups intensify at a slower rate, leading to less intense TCs at t=36 h (Fig. 3).

One possibility for a difference in simulated TC intensity is that the surface fluxes are different when the model surface level is changed. Another is that the boundary layer transport of near-surface heat and moisture is enhanced. However, the difference in surface fluxes between the YSU and YSU-L4 (also for MYJ) in the first 12 hours do not seem to be the reason for the subsequent intensity differences.

Another possibility is related to the thermodynamic structure. One may argue that the equivalent potential temperature (θ_e) is highest at the surface, and therefore the surface level of L0 has higher θ_e than that of L4. According to the conceptual model of conserved θ_e in deep convection, one would then conclude that the upper-level temperature anomaly in the L0 case could be higher. Similarly, the CAPE for L0 is higher than that of L4.

Yet another possibility is the dynamic structure at the near-surface. Even if the surface fluxes are the same between L0 and L4, the direction of surface friction must be different. As can be expected from the classical Ekman spiral, the surface friction in L0 would point more away from the TC center than that in L4.

In order to verify these hypotheses, the θ_e and inflow-outflow structures in the YSU and YSU-L4 (MYJ and MYJ-L4) are studied. During early hours (t=3 to 6 h) when the YSU and YSU-L4 has similar intensity, one could find that the extent of the inflow is different, with the YSU case penetrating to inner radius. To further compare the simulated TCs in L0 and L4, times where the YSU and YSU-L4 have similar MSLP are chosen. Although the MSLP is similar, the radius of maximum wind, which is related to the extent of the inflow, is small in the YSU case. Similar analyses between the MYJ and MYJ-L4 also reveal that the radius of maximum wind is smaller in MYJ.

The larger radius of maximum wind in L4 may also be explained by classic theory. The radius of maximum wind would be large if the lost in angular momentum of the inflow is large. The lost in angular momentum, in turn, depends on the retardation of the tangential flow, or the friction in the tangential direction. Because the frictional force in L4 has a strong tangential component relative to L0, the radius of maximum wind would be larger.

Reduction of outflow levels gives contrasting results. While YSU-H4 is much weaker than the YSU after 18 h, the MYJ-H4 is not weaker than the MYJ (Fig. 4). Although the results are not consistent, it might reflect the fact that the intensity (MSLP) of TCs is very sensitive to the upper level warm core.

b. Post-Landfall

For either the YSU or MYJ group, although the L4 variants are slightly more intense as for pre-landfall, the differences in simulated intensity at the end of the simulation is not large (Fig. 5).

Similar to pre-landfall, the intensity of YSU-H4 (MYJ-H4) seems to be slightly more intense than YSU (MYJ) during early hours (Fig. 6). In contrast to pre-landfall, however, the differences become negligibly small as time proceeds.

6. Summary

Simulated pre-landfall intensity of Katrina is found to depend on both the boundary layer and surface fluxes parameterizations as well as the grid. Here a possible reason for a reduction in intensity for a reduced grid is proposed. This differs from a previous work using the Blackadar boundary layer/surface fluxes parameterizations.

On the other hand, similar to other methods (e.g. decay-SHIPS), the post-landfall decay would be more predictable in numerical simulations because the physics involved are much simpler. Specifically, latent heat flux parameterization that is crucial in pre-landfall would become unimportant. Both the horizontal and vertical grid may not be important in post-landfall simulation.

Acknowledgments

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References

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Code:	**LW**	**SW**	**CUM**	**MIC**	**PBL**	**SFC**	**LSM**	**Hor.**	**Vert.**
YSU	RRTM	Dudhia	AS	Ferrier	YSU	MO	Therm. Diff.	3 km	27
MYJ					MYJ	MO(Janjic)			
RAD	NIL	NIL							
CUM			KF						
MIC				Lin					
SOIL							Noah		
YSU-1km								1km	
YSU-600m								600m	
YSU-L4									23
YSU-H4									23

Table 1. The physics parameterizations and grid (1^{st} row) used in the numerical experiments (1^{st} column). LW, SW, CUM, MIC, PBL, SFC, LSM, HOR, VER stand for long-wave radiation, short-wave radiation, cumulus, microphysics, planetary boundary layer, surface layer, land-surface, horizontal resolution, and vertical levels, respectively. All the experiments use a slightly different combination from either the YSU or MYJ experiments.

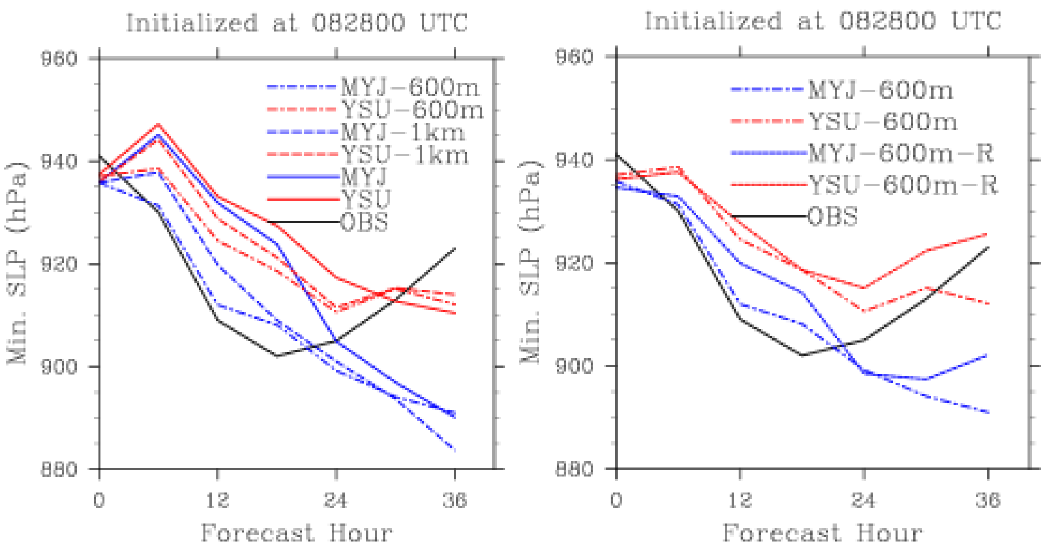

Fig. 1. (Left) Simulated pre-landfall intensity for horizontal resolutions of 3 km, 1 km, and 600 m. The black curve is the data from the NHC best track. (Right) Consideration of a smaller 600 m grid.

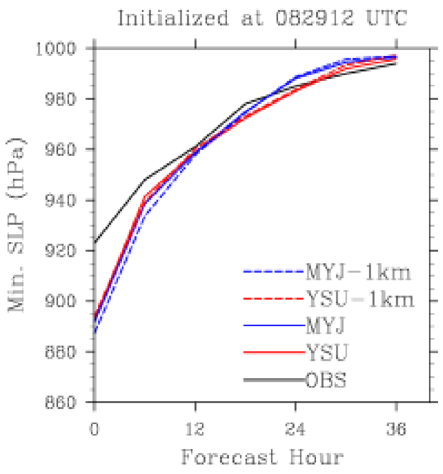

Fig. 2. Simulated post-landfall intensity for different horizontal resolution.

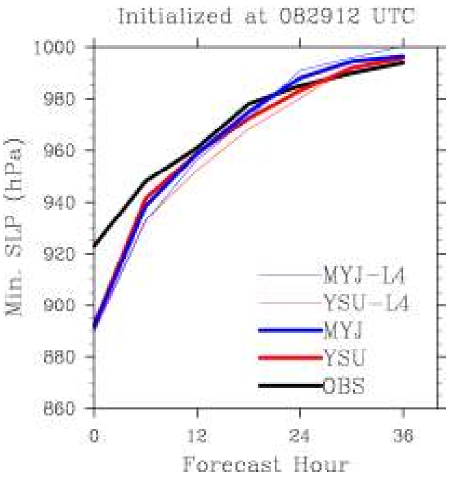

Fig. 5. Simulated post-landfall intensity for reduced lower levels.

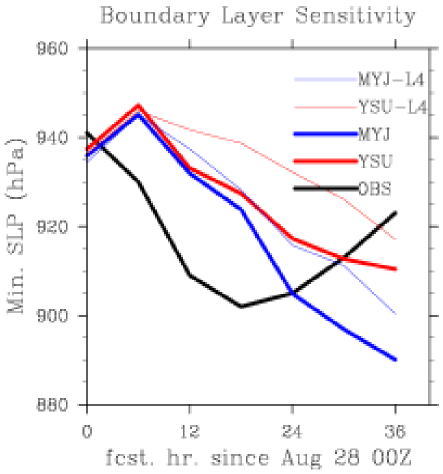

Fig. 3. Simulated pre-landfall intensity for reduced lower levels.

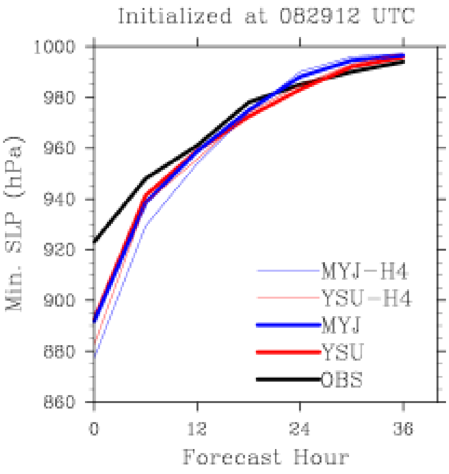

Fig. 6. Simulated post-landfall intensity for reduced outflow levels.

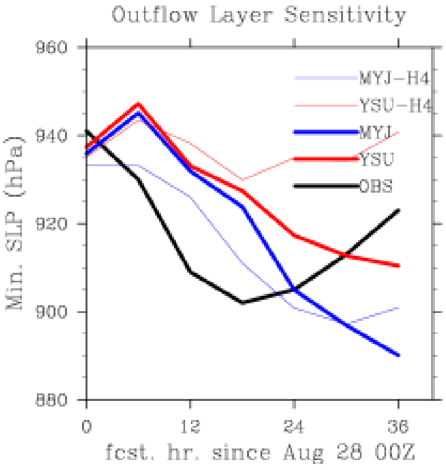

Fig. 4. Simulated pre-landfall intensity for reduced outflow levels.