Sensitive experiments of different vertical levels in NWP model on tropical cyclone*

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ABSTRACT

Based on the new generation numerical prediction model ARW(Advance Research WRF), a sensitivity experiment of different vertical levels is made on the tropical cyclone, Krosa. The sensitivity of changing vertical levels is analysed. The result shows that the change of vertical levels of the numerical model has obvious impact on modeling effect of the tropical cyclone. Increasing the model vertical levels at the large vertical shear section of the vertical profile is beneficial to enhance the model performance on tropical cyclone modeling.

1． introduction

Tropical cyclones are one of the most devastating and deadliest meteorological phenomena. Strong winds, torrential rainfall and worst of all, the associated storm surges are the three major elements of the tropical cyclone disaster. The accurate prediction of tropical cyclones is of great importance.

During the last two decades, there have been considerable improvements in the prediction of tropical cyclones by numerical models. The model horizontal resolution is an important issue in present day numerical weather prediction, particularly in tropical cyclone prediction. Delineation of fine structure of the large-scale phenomenon by numerical model is very important for accurate prediction of intensity and movement of the cyclone. A regional model can capture the fine structure of the cyclones, if the model resolution is increased sufficiently. The topographic features and sub-grid scale physical processes are better represented with increase in horizontal resolution of the model. Further, all physical parameterizations in a numerical model are sensitive to model horizontal resolution. In his study on monsoon prediction at different resolutions with a global spectral model Krishnamurti (1990) found that the higher resolution models simulate more realistic precipitation. Giorgi and Marinucci (1996) in their sensitivity experiment found that the model simulated precipitation amount is sensitive to grid spacing. Zhongbo Yu et al (1999) studied the impact of model horizontal resolution in simulation of precipitation associated with two storms over Susquehanna River Basin. Version 1 of MM5 model with horizontal resolution of 36 km, 12 km, 4 km was used in the study. The range of cumulative precipitation and precipitation rate at each time step is found to increase as the model grid spacing decreases.

However, the adequacy of vertical resolution in the current NWP models has recently been questioned, and some studies have indicated that increasing horizontal resolution alone does not always guarantee a better solution. Lindzen and Fox-Rabinovitz(1989) derived a consistency criterion between horizontal and vertical resolution for quasi-geostrophic flows. They suggest vertical and horizontal resolutions should be proportional to each other, and finer vertical resolution should be used for the tropics. They pointed out that a fine horizontal resolution, without considering an appropriate vertical resolution, would lead to the production of ‘noisy’ fields and may degrade the overall accuracy of the solution. They argued that the current NWP models, despite their inconsistent horizontal and vertical resolutions, could still produce reasonable results because of the use of too strong smoothing and damping.

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Based on a two-dimensional hydrostatic primitive equation model, Pecnick and Keyser(1989) concluded that increasing both the horizontal and vertical resolutions results in better frontal structures; and inconsistent horizontal and vertical resolutions tend to generate spurious wavelike features superposed on the frontal zone.

Using high resolution mesoscale model MM5 with the finest grid size 6km, Zhang et al(2003) examined the sensitivity of the explicit simulation of the Hurricane Andrew(1992) to varying vertical resolutions in terms of its intensity and inner-core structures. Their results showed that the use of higher vertical resolution, a thin surface layer, and smaller time-step sizes, alone with higher horizontal resolution, is desirable to model more realistically the intensity and inner-core structures and evolution of tropical storms as well as the other convectively driven weather systems.

This paper is a case study of Hurricane Krosa to show the effect of varying vertical resolutions. The next section describes the model and experiment design. The weather background of Krosa is described in section 3. The result analyzing is detailed in section 4. The last section summarizes the conclusion.

2． model and experiment design

The Advance Research WRF (hereafter referred to ARW) model, which is a fully compressible nonhydrostatic model of National Center for Atmospheric Research(NCAR), is used.. The horizontal resolution is 15km in lambert projection. ARW user the terrain following hydrostatic pressure vertical coordinate:

$$\sigma = (p_h - p_{ht}) / \mu \quad where \quad \mu = p_{hs} - p_{ht} \tag{1.1}$$

where p_h is the hydrostatic component of the pressure, and p_{hs} and p_{ht} (=50hpa) refer to values along the surface and top boundaries, respectively. The domain has the (x,y) dimensions of 281 ×241 with grid size of 15km. The domain center locates at (130E, 20N). Physics options include the Mellor-Yamada-Janjic Eta boundary layer shceme, the Monin-Obukhov (Janjic Eta) surface layer scheme, the Kain-Fritsch Cumulus Scheme, and the Lin cloud microphysics. Initial and boundary conditions are obtained from the T213-typhoon model in NMC/CMA. The simulation is started at 00UTC 7 Oct. 2007, runs for 72h.

In the simulation of Hurricane Andrew(1992), Zhang et al(2003) used 47 uneven vertical σ levels with higher resolution in the PBL as the control run. the 47 σ levels are placed with the values of 1.000, 0.995, 0.990, 0.985, 0.980, 0.970, 0.960, 0.945, 0.930, 0.910, 0.890, 0.855, 0.820, 0.785, 0.750, 0.715, 0.680, 0.645, 0.610, 0.575, 0.540, 0.505, 0.470, 0.440, 0.410, 0.380, 0.350, 0.325, 0.300, 0.275, 0.250, 0.230, 0.210, 0.190, 0.170, 0.155, 0.140, 0.125, 0.110, 0.095, 0.080, 0.065, 0.050, 0.035 , 0.020, 0.010, 0.000, which given 46 uneven half- levels(EXP. CRL46). Several sensitivity experiments are designed to study the effects of varying vertical resolutions on the simulated hurricane intensity and inner-core structure (see Fig.1). The EXP. HRL69 has 70 σ levels which 23 vertical layers are evenly added to CTL46. The EXP. HRL23 has 24 σ levels, the CTL46 vertical resolution is halved evenly. In this simulation of Hurricane Krosa(2007), we use the EXP. in hang et al(2003) as the control, and adopt the EXP. 69 and EXP. 23 as two sensitivity experiments. In addition, another two sensitivity experiments are conducted to examine the effects of varying vertical resolutions in different portions of the troposphere on the hurricane intensity base on the vertical wind shear profile of Hurricane Krosa (2007) of HRL69 averaged between 200km and 800km radius (see Fig.2). It is obvious that there are two large absolute value areas in the average vertical wind shear profile: one is about above σ=0.3, another is roughly below σ=0.8. So Experiment HLT.37 use the intensive vertical layers (with interval=0.1) below σ=0.89, and keep the same resolution as Exp. LRL23 above σ=0.68, and there is a slow changing range between σ=0.68 to σ=0.89. Experiment HUT37 use the intensive vertical layers above σ=0.13, and keep the same resolution as Exp. LRL23 below σ=0.35, and the range between σ=0.13 to σ=0.35 is a slow changing buffer(see Fig.1).

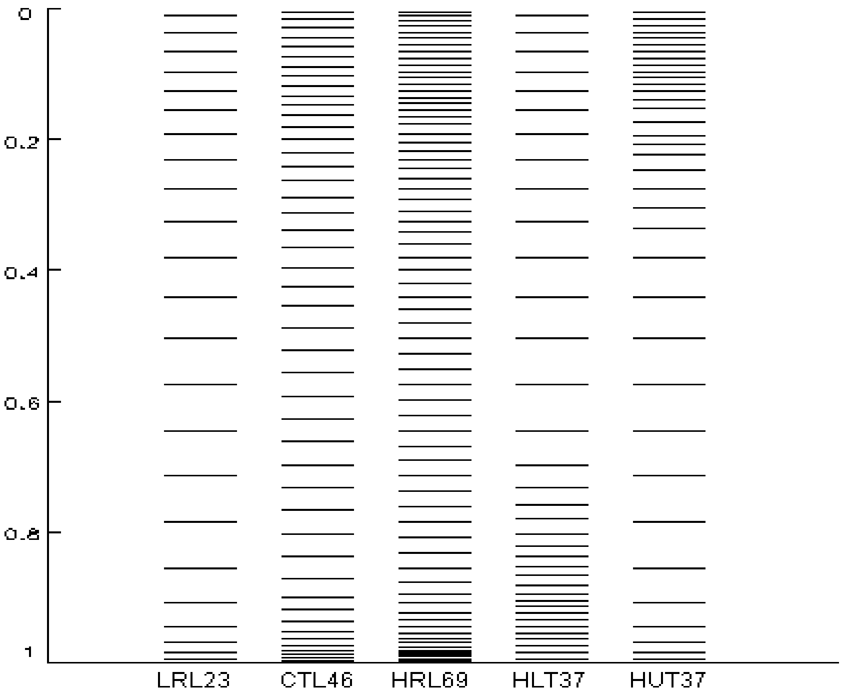

Fig.1. Vertical distribution of half-σ levels for each sensitivity experiments.

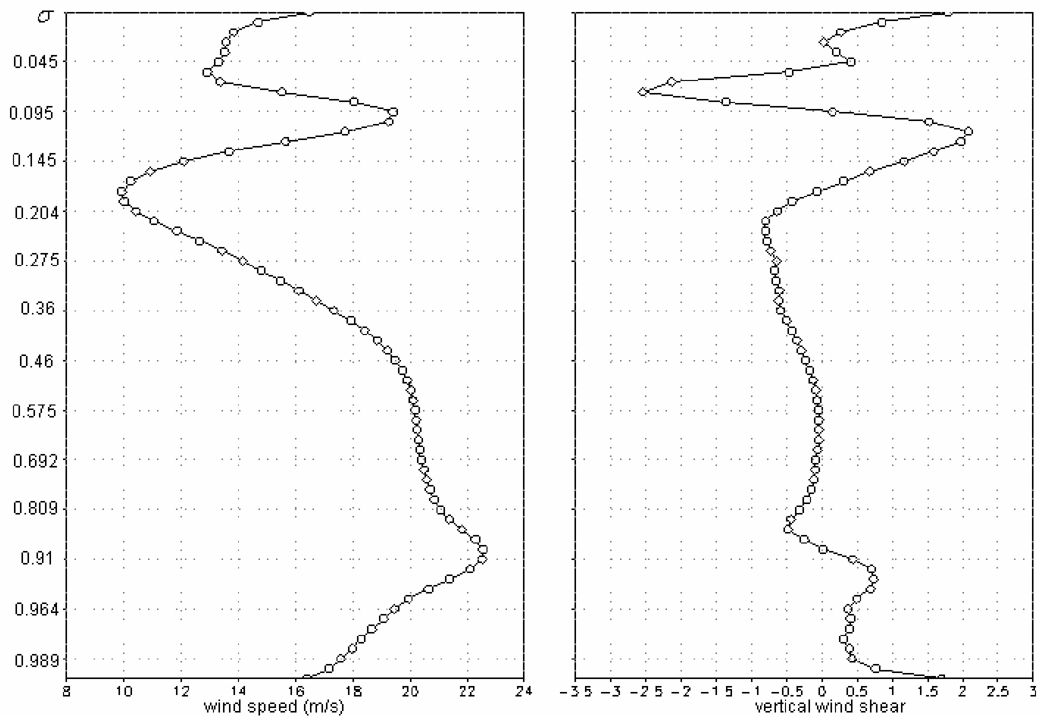

Fig. 2 The vertical wind speed and vertical wind shear of Hurricane Krosa (2007) of Exp. HRL69 averaged between 200km and 800km radius

3. Case select

Hurricane Krosa was formed in east of Philippines at 00:00 UTC 02 Oct. 2007, and it was classified as Tropical storm at 12:00 UTC 02 October. It reached Typhoon strength at 18:00 UTC 02 October. Krosa intensified to super Typhoon with a minimum sea level pressure of 925 hpa on 05 October, and with a maximum surface wind of 63.2 m/s observed at Yonaguni Island on 06 October. Krosa made twice land fall over the north of TaiWan island on 6 October. Then, it moved into the Taiwan strait, and weaken by the surface friction of Taiwan and the low sea surface temperature. At 07:00 UTC 07 October, it landed again over the margin area between Zhejiang province and Fujian Province.

4. Results

The simulation result shows that the simulated tracks of Hurricane Krosa exhibit little sensitivity to the vertical resolution, although their differences between observation growth with the time of integration increasing.

Fig.3 is the time series of the simulated minimum central pressure for all sensitivity experiments. It shows the time series of central pressure of Exp. CTL46 is the lowest, while the time series central pressure of the Exp. LRL23 and Exp HRL69 are all above that of Exp. HRL69. This is quite different from the result of Zhang et al (2003) which the series line is between the lines of Exp. LRL23 and Exp. HRL69. It indicates that the resolution of Exp. CTL46 may be the most suitable for the horizontal resolution 15km.

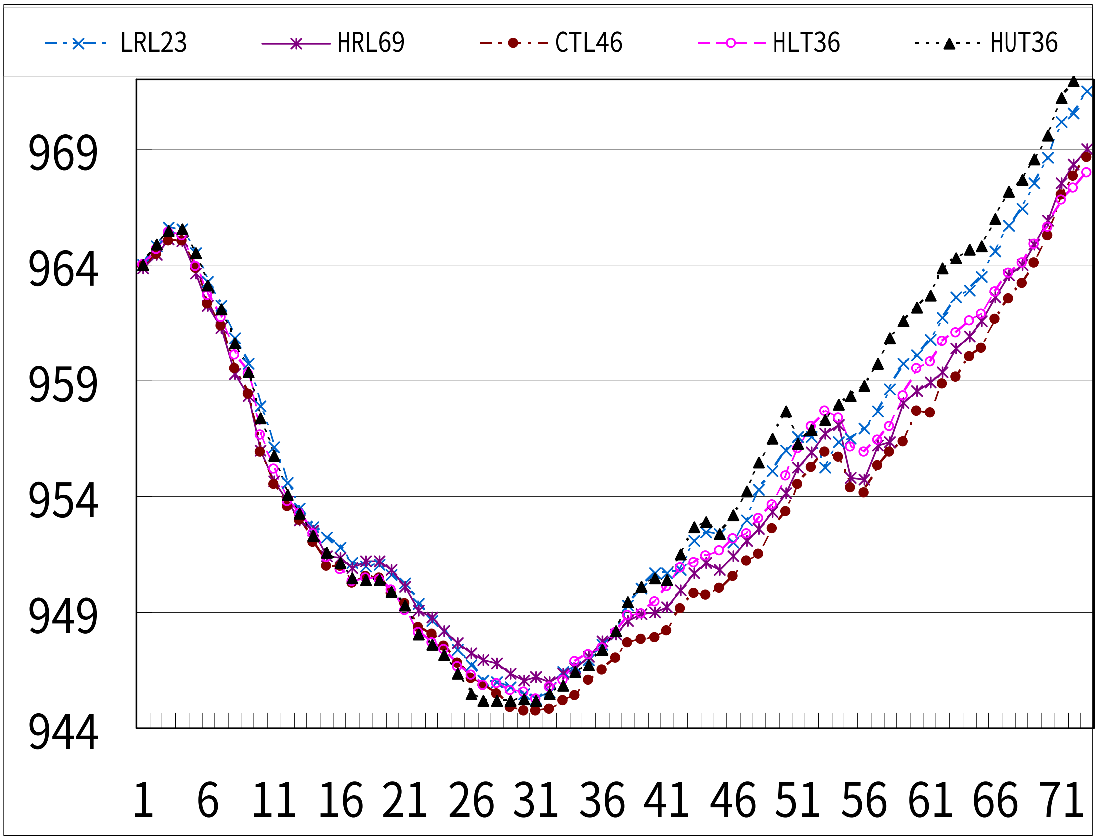

Fig. 3 Time series(72h) of the minimum surface pressure form all sensitivity experiments

We also investigate the impact of increasing the lower-level(Exp. HLT36) and upper-level(EXP. HUT36) vertical resolution. The result of Exp. HLT36 shows that the intensity time series line similar to that Exp. CTL46 before the hurricane reaches its maximum intensity, while it similar to that of Exp. HRL69 after the hurricane reaches its maximum intensity. The increasing the upper-level vertical resolution(Exp. HUT37) produces the strongest typhoon from 18-28 h integration, but the difference is very slight Exp. HUT37 and Exp. CTL46 and Exp. HLT37. Then intensity of Exp. HUT37 decreases quickly, and becomes the weakest typhoon during the latest 38-h integration. The results generally agree the conclusion of Zhang et al(2003) that (i) increasing the vertical resolution in the lower troposphere is more efficient than that in the upper levels in deepening a hurricane, and (ii) different partitionings of a given number vertical layers could have different impacts on the deepening rates during the different stages of hurricane development.

The time series of simulated maximum surface winds are given in Fig.4. During the intensity deepening stage of the fist 32h integration, the use of the thickest surface layer in Exp. LRL23 produces the greatest maximum surface wind, whereas the thinnest surface layer in HRL69 has the weakest maximum surface wind. However, in the weakening stage of the latest 54h integration, the time series of maximum surface winds of Exp. LRL23 is below that of Exp. HRL69, while that of Exp. CTL46 is on the top.

The simulated radar reflectivity from the 32-h integrations shows different inner-core structures of clouds and precipitation among the various experiments(see Fig.5). Increasing the vertical resolution form 23 to 69 layers has less notable impact on the eyewall convection, except that the shape of eyewall convection is the most regular which is consistent with the simulated intensity changes. The shape of eyewall convection of Exp. HUT36 is close to that of Exp. LRL23, while Exp. HLT46 is near to the Exp. HRL69.

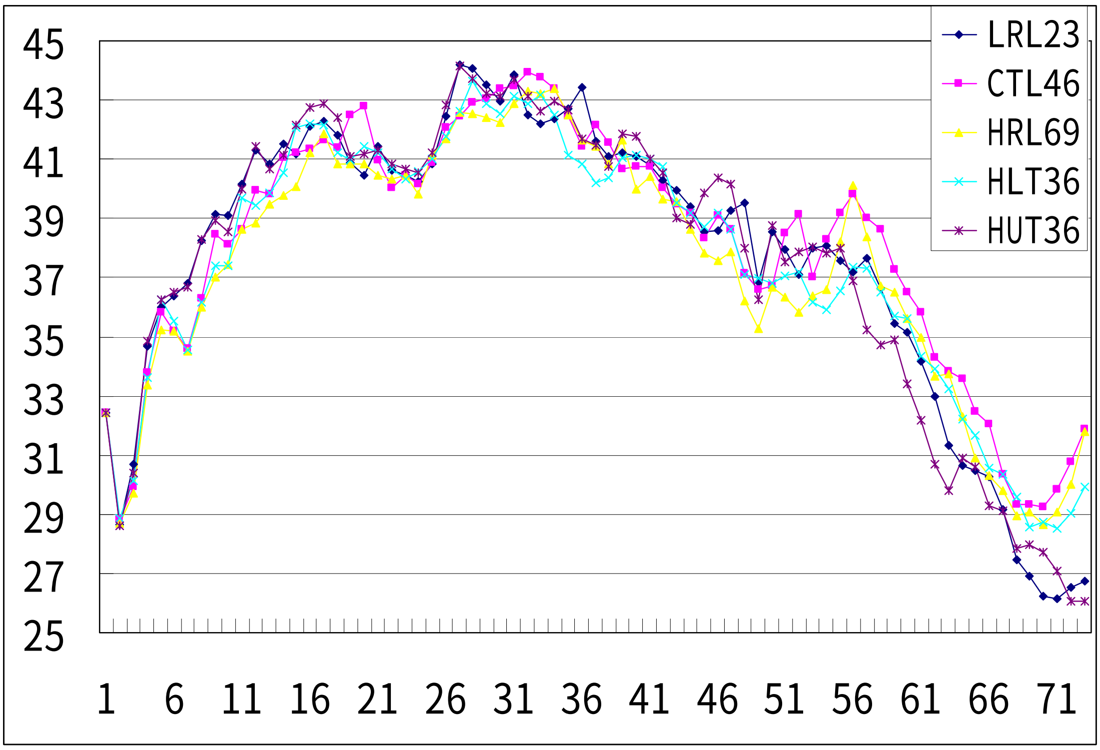

Fig. 4 Time series(72h) of the maximum surface winds form all sensitivity experiments

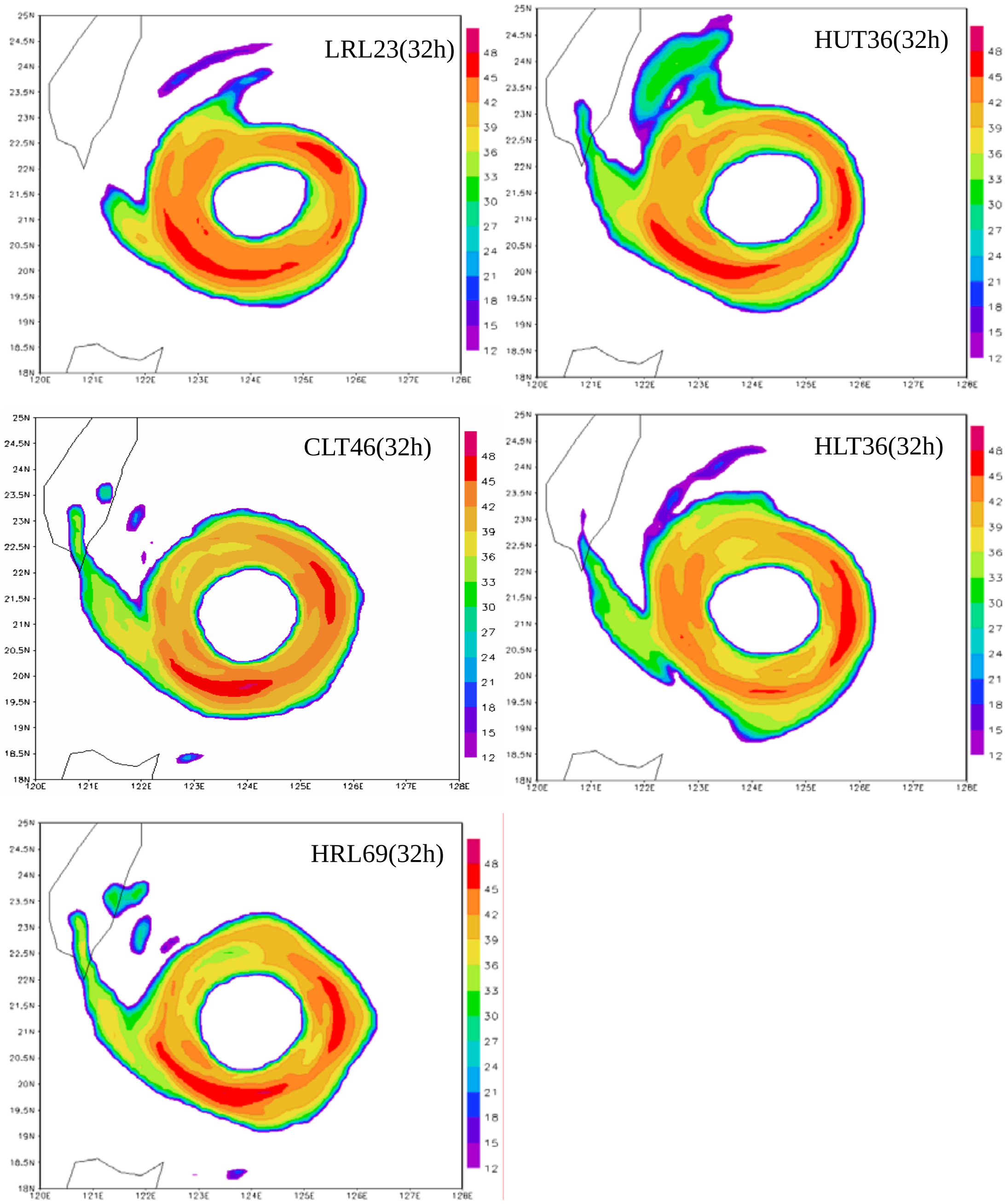

Fig. 5. Horizontal distribution of radar reflectivity, taken at about σ =0.785(near 800hpa), form the 32-h integrations of all sensitivity experiments.

5． conclusion

In this study, several 72h numerical integrations are performed to study the sensitivity of the simulated Hurricane Krosa (2007) to various vertical resolutions using the Advanced Research WRF model with horizontal resolution of 15km. The vertical resolution varies from 23 to 69 layers, with changing layer thicknesses in the lower and upper portions of the troposphere where the absolute average vertical wind shear is large relatively.

Detailed analyses of the sensitivity experiments show that changing vertical resolutions has little impact on the hurricane track. However, the hurricane intensity is very sensitive to the vertical resolution. The conclusion generally agrees with that of Zhang et al (2003). However, there are some differences: the vertical resolution is higher, but the model performance is not better. The horizontal resolution should be consistent with vertical resolution. For Example, for grid size 15km, about 46 layers in vertical direction may be more suitable for simulate Hurricane Krosa.

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