10D.3 SENSITIVITY OF TROPICAL CYCLONE INTENSIFICATION AND INTENSITY TO CLOUD MICROPHYSICS PARAMETERIZATION

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1. Introduction

Although it has been long known that cloud microphysics can have a significant impact on the simulations of precipitation, there have been few studies so far that have investigated the effect of cloud microphysics on tropical cyclones. In the most advanced simulation of tropical cyclones by numerical models, the use of explicit cloud microphysics becomes more and more attractive with cumulus parameterization bypassed at very high resolutions. The objective of this study is to investigate the sensitivity of the simulated tropical cyclone, especially its intensification, intensity and structure to the cloud microphysics parameterizations using the triply nested movable mesh tropical cyclone model (TCM3) developed by Wang (1999, 2001, 2002). An attempt will be made at understanding the physical processes that contribute to the sensitivities. Details of the numerical model used in this study can be found in Wang (1999; 2001, 2002).

2. Experimental design

Six numerical experiments are conducted to test the effects of variations in cloud microphysics parameterization on the intensification, structure, and intensity of the model tropical cyclone. The control experiment (CTRL) is identical to the control experiment discussed in Wang (2001) except for the use of the new version of TCM3 described in Wang (2002). In the experiment WMRN, only warm-rain processes are retained in the cloud microphysics parameterization. In HAIL, the intercept parameters for hail are used instead of those used for graupel in CTRL. The experiment NMLT is identical to CTRL except that the atmospheric cooling associated with evaporation of rain and melting of snow and graupel are excluded (but sublimation of snow and graupel and evaporation of cloud water are still retained). The experiment NEVP is identical to WMRN except that the evaporation of rain is excluded. In DSHT, we include the effect of dissipative heating in the control experiment to see whether it can offset the effect of downdrafts on the intensification and intensity of the simulated tropical cyclone. The changes in cloud microphysics parameterization in all the experiments are imposed from the start of model time integration. The initial conditions are the same as those for the control experiment given in Wang (2001) except that the initial vortex has a maximum tangential wind of 20 m s^{-1} at a radius of 80 km at the surface.

3. The numerical results

The tropical cyclone in the control experiment (CTRL) intensified, after an initial adjustment of about 24 h, to its maximum intensity after about 5 days and then evolved gradually with a lifetime low-level maximum wind speed of 73 m s^{-1} (Fig. 1a) and a minimum central sea surface pressure of 909 hPa (Fig. 1b). Note that the final intensity of the storm in CTRL is weaker than (about 20 hPa higher in the central sea surface pressure) the maximum potential intensity (MPI) calculated from the algorithm of Holland (1997), as shown by the horizontal line in Fig. 1b. Removing the ice-phase processes but retaining the warm rain processes in the model cloud microphysics parameterization in WMRN provides a first-order assessment of the usefulness of simple, rain-only parameterizations on estimating tropical cyclone intensity. We see from Fig. 1 that the result is to substantially increase the cyclone intensification rate and the final intensity beyond that in the control experiment by about 10 hPa deeper in central sea surface pressure. In this case, the cyclone reached its mature stage after about 4 days, one day earlier than that in CTRL. This increased intensification rate and final intensity results mainly from the reduced downdrafts, which cool and dry the inflow boundary layer.

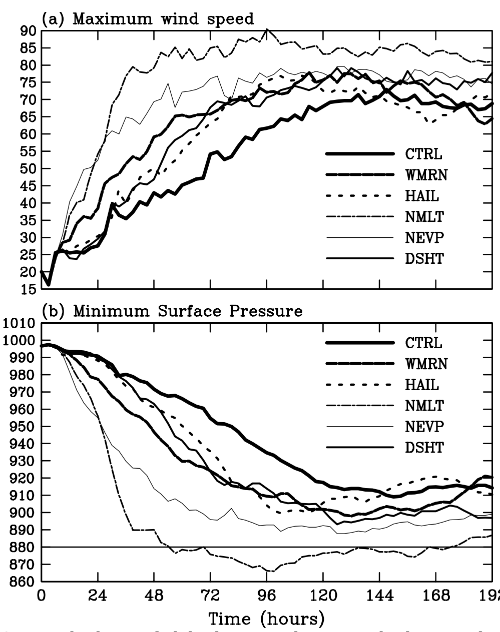

Fig. 2. Evolution of (a) the maximum wind speed at the lowest model level (about 20 m from the sea surface) and (b) the minimum central sea surface pressure in the 6 experiments. The horizontal line shows the maximum potential intensity (MPI) at the given sea surface temperature and the environmental sounding used as the initial conditions in all the numerical experiments calculated by the method of Holland (1997).

Since the downdrafts mainly occur in the stratiform cloud region outside the eyewall (Wang 2001), any process that alters the extent of stratiform clouds in the near core environment may change the intensification rate and intensity of the model tropical cyclone. The effect can be tested by using the parameters of hail instead of graupel in the cloud microphysics parameterization in HAIL. Both the intensification rate and the maximum intensity in HAIL were increased compared with those in CTRL (Fig. 1). This occurs because the reduced downdrafts and less spiral rainbands in HAIL and in CTRL, especially in the first 5 days (Fig. 2).

Two extreme cases (experiments NEVP and NMLT) were designed to evaluate the effect of downdrafts on both the intensification and intensity of the simulated tropical cyclone. In the experiment NEVP, evaporation of rain in the warm-rain only cloud microphysics scheme (WMRN) was removed. This almost removed the downdrafts in the simulated tropical cyclone (Fig. 2), thus both the intensification and final intensity of the storm were increased greatly (Fig. 1). As in NEVP, the capacity to induce downdrafts in NMLT was also greatly reduced (Fig. 2) and the intensification rate and final intensity of the tropical cyclone increased dramatically (Fig. 1). In this case, the tropical cyclone reached its mature stage in less than two days with an extremely rapid intensification. An interesting feature is that the storm in this case reached its final intensity even stronger than the MPI determined by the thermodynamic approach (Holland 1997) by about 12 hPa. This extra intensity increase in NMLT compared with that in NEVP could be a result of the extra latent heat of fusion in NMLT.

Dissipative heating, which is an important process for tropical cyclones, can offset the effect of downdrafts to some extent, and thus increases the intensification rate and final intensity compared with the control experiment, as seen in DSHT shown in Fig. 1. An interesting result is that both the intensification rate and the final intensity in the experiments WMRN and DSHT are similar to each other. It is unknown whether this result is physically robust or was obtained just by chance.

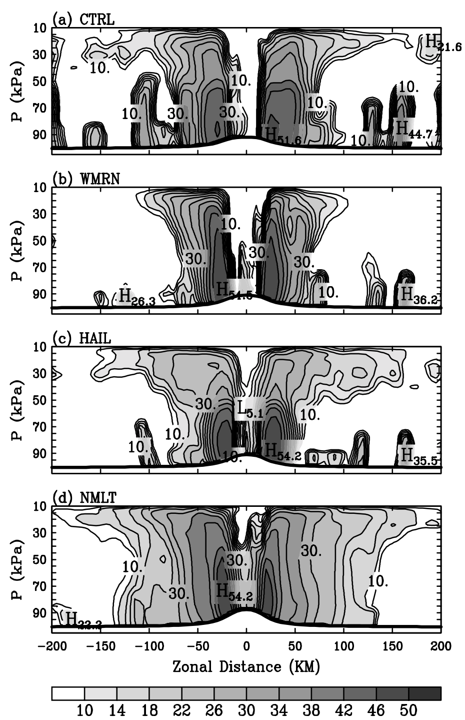

Fig. 2. Zonal-vertical cross-sections of model estimated radar reflectivity through the storm center in the experiments (a) CTRL at 144 h, (b) WMRN at 120 h, (c) HAIL at 108 h, and (d) NMLT at 96h.

Fig. 2 gives the model estimated radar reflectivity in four different experiments. In CTRL (Fig. 2a), sharp vertical gradients in radar reflectivity occurred near the freezing level at about 500 hPa in the eyewall with an eye free of reflectivity and some high reflectivity associated with the rainbands outside the eyewall (Fig. 2a). Stratiform clouds extended outward above the eyewall in the upper troposphere. In the warm rain-only experiment (WMRN), the high reflectivity in the eyewall penetrated into the upper troposphere with little stratiform clouds outside the eyewall (Fig. 2b). Replacing the graupel by hail in the cloud microphysics parameterization in HAIL produced high reflectivity below the freezing level in the eyewall and stronger stratiform clouds in the mid-upper troposphere (Fig. 2c) due to the higher concentration of cloud ice and snow than that in CTRL. In NMLT, in addition to the high radar reflectivity in the deep eyewall, there is a large area with stratiform precipitation with relatively weak reflectivity (Fig. 2d), which is quite different from that in CTRL (Fig.2a).

4. Conclusions

In this study an initial evaluation of the sensitivity of simulated tropical cyclone structure, intensification, and intensity to the choice and details of cloud microphysics parameterizations has been carried out using the tropical cyclone model TCM3. We found that these all are sensitive to the cloud microphysics parameterizations in the model. Such sensitivity stems from the differences in the simulated stratiform clouds and the associated downdrafts outside the eyewall by various cloud microphysics parameterizations. The melting of snow and graupel in the stratiform clouds is a major process in initiation of spiral rainbands outside the eyewall by producing strong downdrafts. Spiral rainbands, once they are initiated, affect the structure, intensification and final intensity of a tropical cyclone through three major processes. (1) Strong downdrafts can be generated in the spiral rainbands and thus reduce euqivalent potential temperature in the inflow boundary layer. (2) Updrafts in the spiral rainbands may partially reduce the updrafts in the eyewall and suppress the eyewall convection. (3) Condensational heating in the spiral rainbands reduces radial temperature gradient between the eye and the near core environment and thus reduces radial gradient of surface pressure, and thus the tangential wind and intensity of the model tropical cyclone. However, this last effect is secondary in our simulated tropical cyclone. A complete discussion of the results can be found in Wang (2002).

References

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