9B.5 The effect of mid-level moistening on tropical cyclogenesis

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1. INTRODUCTION

A high resolution nonhydrostatic cloud model is used to investigate the importance of mid-level moistening on the cyclogenesis process. A recent study by Motgomery et al. (2006) demonstrated cyclogenesis from an initial mid-level vortex, a frequent by product of mesoscale convective systems during summertime conditions over tropical oceans. This previous study and the present one uses the Jordan (1958) mean Atlantic hurricane season sounding. For the majority of experiments conducted by Montgomery et al (2006) the low-to-mid troposphere ($z<6$ km) was moistened slightly near the center of the vortex. Without this initial moistening the simulation did not undergo cyclogenesis within the 72 h simulation period. For the simulations that underwent cyclogenesis there was clearly considerable mid-level moistening prior to rapid strengthening. In this study, we compare a simulation without any moisture modification of the Jordan sounding to one that has increased moisture extending to mid-levels. Our goal is to examine the importance of mid-level moistening on the rate of tropical cyclogenesis and also to examine the thermodynamic processes and structural changes of the system that lead up to the point at which rapid strengthening occurs.

2. MODEL

This study uses the Regional Atmospheric Modeling System (RAMS) developed at Colorado State University (Cotton et al. 2003), with a similar configuration and parameters as used by Montgomery et al. (2006). Three grids are used with horizontal grid increments of 12, 3 and 1 km, with (x, y, z) dimensions of 200 by 200 by 31, 202 by 202 by 31, and 302 by 302 by 31, respectively. Each nested grid is centered within the next coarsest grid. The vertical grid increment is 300 m at the surface and gradually stretched with height to the top of the model domain at 22 km.

The initial vortex dimensions are the same as used by Montgomery et al. (2006). The maximum tangential winds are at 4 km above the ocean surface at a radius of 75 km. The maximum tangential winds were increased from 6.5 ms^{-1} to 8.5 ms^{-1} from the previous study. This is similar to values found recently for a tropical mesoscale convective vortex (Reasor et al. 2005). Without this wind speed increase the drier simulation that uses the unmodified Jordan sounding does not undergo cyclogenesis during the five day simulation period.

For the moist simulation the relative humidity was increased to 90% at the center of the vortex below 8 km. A bell shaped curve was used in the horizontal so that the relative humidity decreased with radius to 45 % at 100 km from the initial vortex center, or to the environmental value if that was reached first. For comparison the unmodified Jordan sounding has relative humidity of 74% at the surface and 52% at 4 km above the surface.

3. RESULTS

Figure 1 shows the minimum surface pressure versus time for the two simulations. The dry case shows a gradual increase in pressure during the first three days, which is due to radiative cooling.

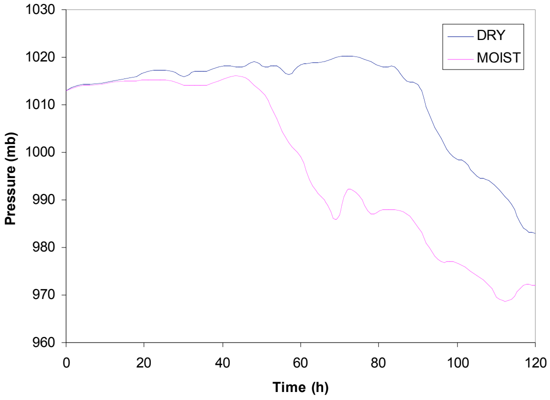
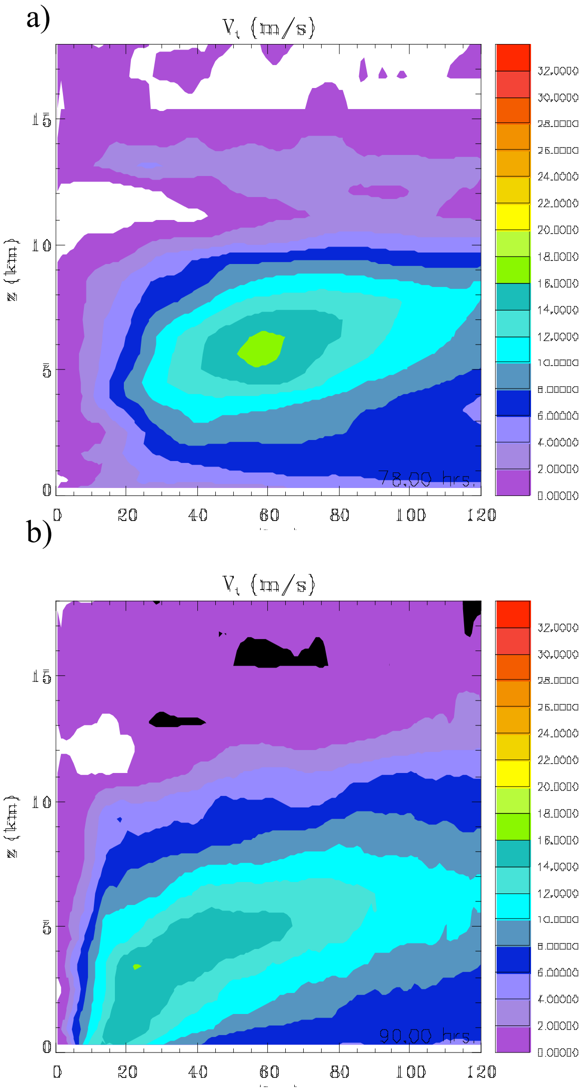


Figure 1.The minimum pressure versus time for the dry and moist simulations.

At t=90 h the system starts to develop rapidly with a pressure fall of 16 mb occurring within the next 12 h. For the moist case, the minimum pressure starts to decrease much sooner at t=50 h, with a fall of 19 mb within the next 12 h. Clearly, moistening of the vortex core has had a very significant effect on the rate of genesis. Examination of the dry case revealed that the relative humidity reached average values of approximately 90% at mid-levels in the center of the vortex, prior to rapid development.

Figure 2 shows the time evolution of the mean tangential wind speed between t=78 and 102 h for the dry case. At t=78 h, prior to cyclogenesis there has been a considerable increase in wind speeds at 6 km above the surface and at a radius of 60 km. The wind speed maximum is 16 ms^{-1}. During the next 24 hours the wind speed maximum appears to descend and its radius contracts to 25 km. The moist case showed similar behavior between t=40 and 64 h.



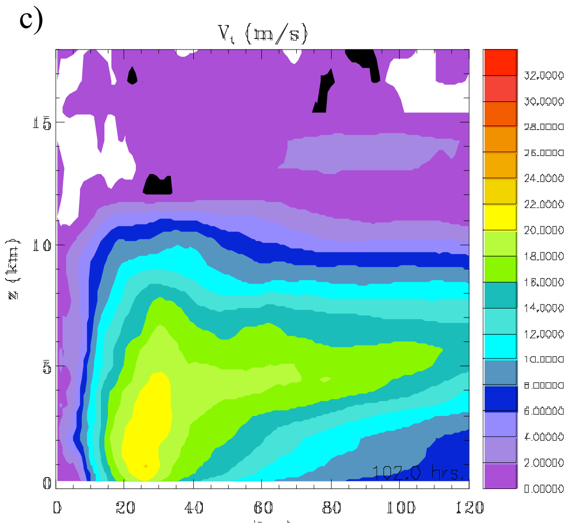


Figure 2. Tangential wind speeds for the dry case at 12 hour intervals: (a) 78 (b) 90 and (c) 102 hours.

Both simulations show the early development of deep cumulonimbus towers that possess intense cyclonic vorticity in their cores. The cyclogenesis process in these high resolution 1 km horizontal grid increment simulations proceeds in a similar manner to the 2 km and 3 km grid increment simulations discussed by Montgomery et al. (2006). The transition to a tropical depression for the dry case takes approximately four days. The pathway to this stage is by a series of intense convective pulses that consume CAPE, followed by periods of regeneration of CAPE. Fig 3 shows fields of CAPE during the cyclogenesis stage for the dry case. At t=84 h there are relatively large values of CAPE near the center of the vortex, although at the very center values are depressed. Shortly after this time there is a surge in convective activity that builds outward consuming the CAPE. By t=96 h there has been a considerable reduction of CAPE after which it starts to increase again. By t=108 h there is a resurgence in convective activity and CAPE starts to be consumed again working out from the center.

The mid-levels of the vortex core gradually moisten prior to cyclogenesis due to venting of moist near surface air aloft by the "vortical" hot towers. Even though the moist case was initialized with 90% saturated air in the core, it is interesting that the minimum pressure did not start to fall rapidly until the mid-level circulation

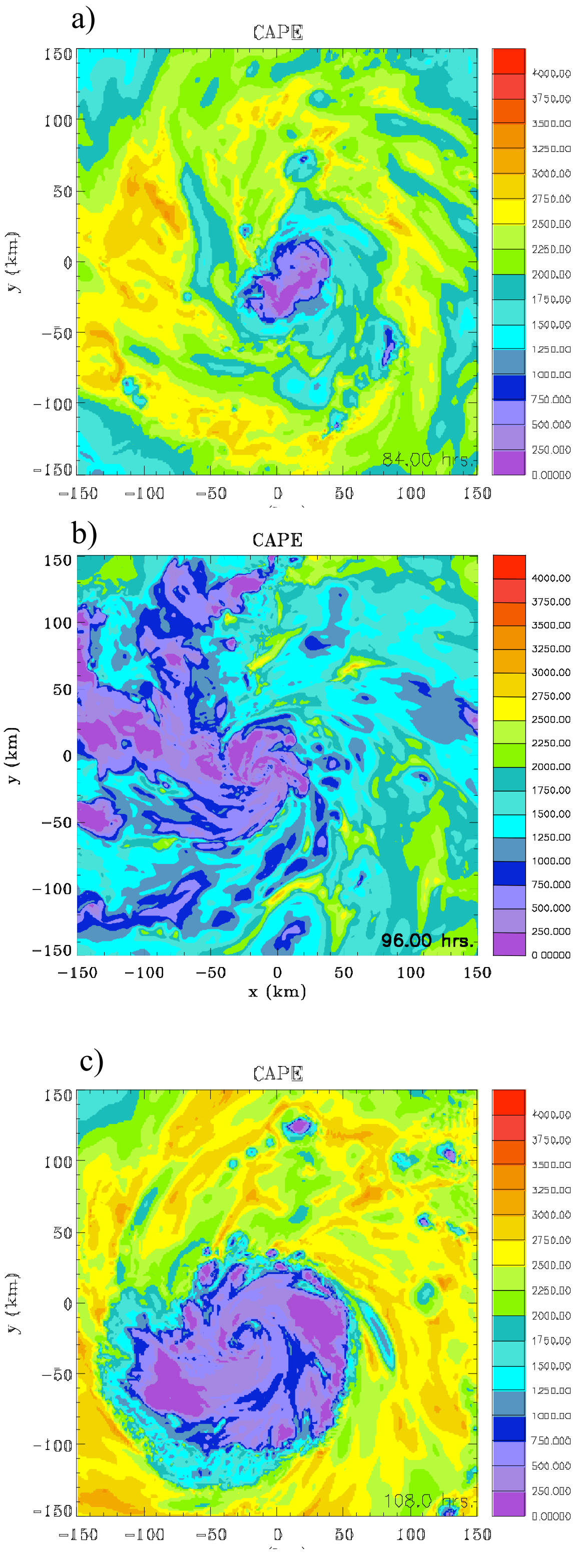


Figure 3. Fields of CAPE at (a) 84 (b) 96 and (c) 108 hours, for the dry case.

strengthened considerably. For both cases there was deep convection near the center of the vortex core during the period that the surface pressure minimum started to fall rapidly.

Similarly to the dry case, the moist case also showed surges in convective activity. An additional simulation was conducted for the moist case with only grids 1 and 2 activated and some diagnostic quantities were calculated. This simulation with a fine grid increment of 3 km showed similar results as the 1km grid simulation. Fig. 4 shows the total mass of liquid and ice in grid 2. Large pulses are evident that illustrate the surges in convective activity as CAPE is consumed.

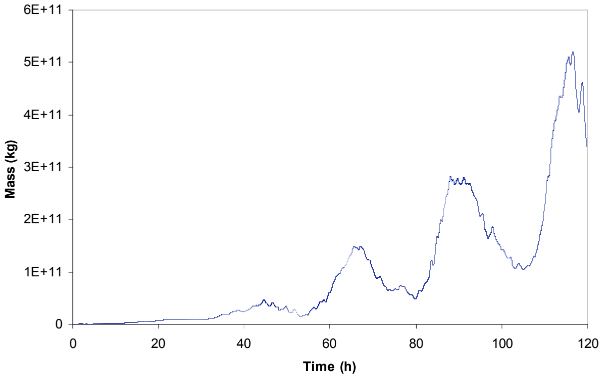


Figure 4. The total mass of liquid and ice in the grid 2 domain.

These large surges of convective activity occur at approximately every 24h, so they are likely to be related to the diurnal cycle of solar radiation. The total latent heating rate calculated following the procedure outlined in Nicholls and Pielke (2000) for grid 2, is shown in Fig. 5. The variations in the total latent heating rate are extremely large for this simulation.

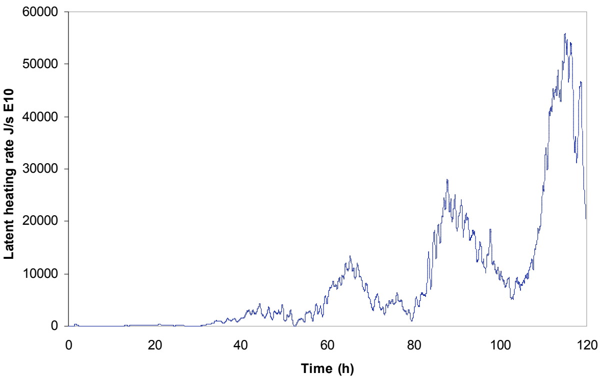


Figure 5. The total latent heating rate in the grid 2 domain.

4. CONCLUSIONS

The dry simulation using the unmodified Jordan sounding took approximately four days before undergoing genesis. Prior to genesis the mid-levels moistened considerably reaching near saturated values in the vortex core. The moist case simulation underwent a transition to a tropical depression much sooner, a little over two days. For both cases the mid-level circulation strengthened considerably before cyclogenesis. Preliminary analysis suggests that this may be mainly due to strong convective updrafts aloft forcing mid-level inflow rather than because of stratiform ascent. Also, during genesis both systems developed strong convective cells near the center of the vortex. Mid-level moistening is likely to favor convection within the vortex core since there is less entrainment of dry air into the updrafts and also because boundary layer modification by cool dry downdrafts is reduced.

There were interesting surges in convective activity in these idealized simulations that appear to show a strong diurnal cycle. It is possible that in nature external forcing of developing systems might significantly modify this behavior. We must also be open to the possibility that model results are sensitive to the details of the interaction between radiation and microphysics. For instance, the amount of ice that develops at upper levels depends on the parameters controlling the fall speed of ice particles. Variations in these parameters might have a significant feedback on the absorption and scattering of radiation, and on the dynamics of the system. Future research will investigate these model sensitivities to determine how robust these results are. It is interesting to speculate, as these results suggest, that a considerable amount of the variability in convective activity in the early stage of a tropical cyclones life cycle may be a result of internal dynamic and thermodynamic processes.

Acknowledgments

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