13C.7 A MODELING AND OBSERVATIONAL STUDY OF THE IMPACTS OF MICROPHYSICAL PROCESSES ON THE EVOLUTION OF HURRICANE ERIN 2001

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1. INTRODUCTION[·]

Quantitative precipitation forecasts (QPFs) require knowledge of synoptic, mesoscale, and microscale processes, and their adequate representation in models. To improve QPFs for hurricanes, an improved understanding of phenomena occurring over various spatial and temporal scales is required. Previous studies (Willoughby et al. 1984; Lord and Lord 1988; Rogers et al. 2004) have shown that microphysical processes affect the evolution of hurricanes at larger scales.

In this study, fine resolution simulations of Hurricane Erin 2001 are conducted using the Penn State University/National Center for Atmospheric Research mesoscale model (MM5) version 3.5 to investigate the roles of microphysical and boundary layer processes in Erin's structure and evolution, and their effects on horizontal and vertical distributions of hydrometeors. Comparisons against observations of Erin made during the Convection and Moisture Experiment4 (CAMEX4) represent a critical component of the work. Our findings on the roles of microphysical processes must be interpreted in context of other uncertainties affecting simulations of hurricanes.

2. MODEL SIMULATIONS

Simulations describe a 4-day period from 0000 UTC on 7 Sept. 2001 to 0000 UTC on 11 Sept. 2001, when the minimum central pressure of Erin dropped from 1012 mbar to 968 mbar (1800 UTC, 9 Sept. 2001) and then rose to 970 mbar. The coarse model domain consists of 112 by 112 grid points in the horizontal direction with a grid spacing of 54 km. Higher resolution was used in three finer grids of 18, 6, and 2 km, with two-way nesting between domains except for the course domain. The finer resolution domains were used only when the cyclone started to intensify, with the 6 km domain initialized at 1200 UTC on 9 Sept. and the 2 km domain initialized at 0000 UTC on 10 Sept.

There are 36 uneven terrain-following σ levels in the vertical, with 20 mbar being the pressure at the model top. The innermost domain was moved 3 to 4 times, depending upon the simulation, to keep the eye of the hurricane close to the center of the domain, and the convective parameterization scheme was turned off in the inner domain. Global analyses fields, including temperature, humidity, geopotential height, and winds, from the National Center for Environmental Prediction (NCEP) global analyses on 1^o by 1^o grids were used for the initial and boundary conditions.

Simulations were conducted to determine how different boundary layer and microphysical processes impacted hurricane evolution. Additional studies investigated the sensitivity to graupel fall speed (slow, medium, and fast) and to the use of a new iterative condensation scheme (McFarquhar et al. 2004) that limits unphysical increases of equivalent potential temperature, Θe, associated with many existing schemes in MM5.

3. MODEL RESULTS

Figure 1 shows the effect of the choice of microphysics scheme on the prediction of minimum central pressure, P_{min} and maximum tangential velocity, U_{max} for simulations using the Burk-Thompson boundary scheme. A similar figure (not shown), generated using the Eta scheme, shows a different microphysics scheme producing the lowest P_{min} and highest U_{max},. There is no clear trend for how the complexity of the microphysical scheme relates to the intensity of the hurricane produced. When varying coefficients describing graupel fall speeds, similar variations in P_{min} (6 mbar) and U_{max} ($5\ m\ s^{-1}$) between simulations (not shown) are seen as in Fig. 1. This shows that choices in descriptive microphysical parameters definitely feed back on hurricane evolution. Simulations with varying boundary layer schemes show larger variations in P_{min} (20 mbar) and U_{max} ($10\ m\ s^{-1}$), suggesting that even though latent heat release gives the energy for storm maintenance, surface exchange processes are more important for ultimately determining its strength. Braun and Tao (2000) previously investigated how such processes modified hurricane development.

Simulations are also conducted with a new iterative condensation scheme. The development of this scheme was motivated by Bryan and Fritsch (2000), who determined that unphysically high values of Θe were predicted in models for rapidly growing updrafts because of the way in which condensation is treated in many models. Simulations with the new scheme give higher P_{min} of 8 mbar and lower U_{max} of $5\ m\ s^{-1}$, showing the representation of condensation is critical for determining hurricane strength. Further, unlike microphysical schemes that showed no systematic impacts on hurricane intensity, the use of this scheme always reduces the intensity.

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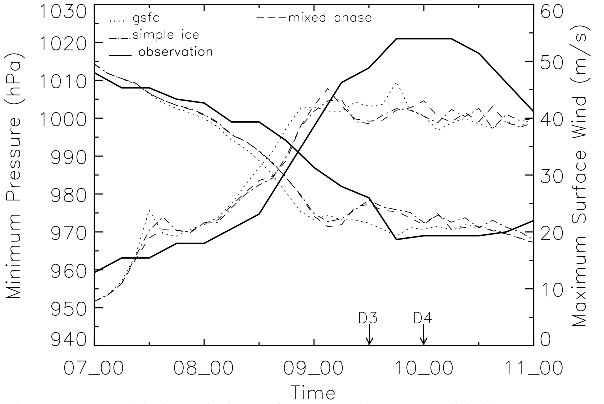

Figure 1: Modeled evolution of P_{min} and U_{max}. Solid lines represent observations, different line types correspond to varying microphysical parameterization schemes as indicated in legend; all simulations use Burk-Thompson boundary layer scheme. D3 and D4 indicate time at which 6 km grid and 2 km grid are activated respectively.

4. COMPARISON AGAINST OBSERVATIONS

During CAMEX4, the National Oceanic and Atmospheric Administration (NOAA) P-3 and the National Aeronautics and Space Administration (NASA) ER-2 and DC-8 aircraft obtained comprehensive observations of wind, temperature, and moisture characteristics on 10 September 2001. The observations were made when Erin was post-mature and beginning to rapidly decay, with maximum wind speeds dropping by 13 m s^{-1} during the P-3 flight. Nevertheless, the observations represent a great opportunity for comparing observed and simulated hurricane characteristics.

Regardless of the microphysics or boundary layer scheme, the maximum modeled reflectivity (Z) values are always larger than those measured by the P-3 radar and ER-2 Doppler radar (EDOP). Comparing simulations, the main differences are not in the total amount of precipitation, but rather in the way they are distributed within the hurricane. Simulations with the new condensation scheme, limiting unphysical increases in Θe, however, consistently produced substantially fewer occurrences of high rain rates and high Z than all other simulations, better matching patterns in the observed data.

Direct comparison between measured and modeled graupel mixing ratio is not possible because in-situ observations of graupel do not exist. But, brightness temperatures measured by the Advanced Microwave Precipitation Radiometer suggest large amounts of graupel are not required to explain observations because scattering effects at 37.1 and 85.5 GHz are substantially less than those effects associated with squall lines, where large concentrations of graupel exist. The lack of graupel scattering is also consistent with the relatively weak Z seen above the melting layer in the EDOP data.

Direct comparison of observed and modeled updraft characteristics is not possible because the EDOP measured Doppler velocity is a combination of air motion and reflectivity-weighted particle fall speed. However, an equivalent Doppler velocity can be computed from the modeled hydrometeor fields and air motions. Regardless of the microphysical, boundary layer, or graupel fall speed used, model-produced updrafts are typically greater than equivalent values measured by EDOP. However, for simulations limiting the artificial increase of Θ_e, the updraft magnitudes are reduced and are more consistent with observations. This shows the importance of a proper representation of condensation for accurate model simulations.

Thermodynamic profiles obtained in the hurricane eye from dropsondes are compared against simulated thermodynamic profiles to improve our understanding of eye thermodynamics. Better agreement between observed and simulated Θ_e are obtained in the eye near the surface for the new condensation scheme; model overestimates of Θ_e found in other simulations are not present. However, the substantial dry layer observed between 800 and 300 mbar and modeled in other simulations, does not exist in the eye wall for the simulations with the new convective scheme. Implications of this finding for mixing processes between the eye and the surrounding environment will be discussed.

5. SUMMARY

Physical processes governing the maintenance of hurricanes are investigated using MM5 simulations of Hurricane Erin and observations collected during CAMEX4. Surface fluxes are shown to be more important than microphysics processes in determining hurricane strength. An appropriate representation of condensation is also necessary to accurately determine the distribution of precipitation, and of updrafts and downdrafts. Because our studies suggest that the way microphysical processes distribute latent heat affects hurricane characteristics, ongoing studies are attempting to quantify and better understand these microphysical processes.

6. ACKNOWLEDGMENTS

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