HIGH-RESOLUTION MM5 SIMULATIONS OF HURRICANE ERIN 2001: ROLE OF MICROPHYSICAL PROCESSES

Henian Zhang[1], Greg M. McFarquhar[1*],
Gerald Heymsfield[2], Robbie Hood[3], Jimy Dudhia[4], Jeffrey B. Halverson[2], and Frank Marks Jr.[5]

[1]Dept. of Atmospheric Sciences, University of Illinois, Urbana, Illinois
[2]NASA Goddard Space Flight Center, Greenbelt, Maryland
[3]NASA Marshall Space Flight Center, Huntsville, Alabama
[4]National Center for Atmospheric Research (NCAR), Boulder, Colorado
[5]NOAA Hurricane Research Division, Miami, Florida

1. Introduction

To improve our understanding of the microphysical parameterization schemes on the development of tropical cyclones and achieve better quantitative precipitation forecasts (QPFs), simulations of Hurricane Erin 2001, conducted using the Pennsylvania State University/National Center for Atmospheric Research mesoscale modeling system (MM5) version 3.5 with various microphysics schemes, have been analyzed by McFarquhar et al. (2005). This presentation will summarize the findings of that paper. In particular, impacts of varying coefficients that describe the fall velocities of graupel particles on updraft and downdraft strength are described. A new iterative condensation scheme, developed to limit the artificial increase of equivalent potential temperature θ_e that occurs during the adjustment step of many condensation schemes is also tested.

2. Model Simulations

MM5 simulations of Hurricane Erin cover a 4-day period from 0000 UTC 7 September to 0000 UTC 11 September. During this period, Erin evolved from a tropical depression into a category 3 hurricane reaching a minimum central pressure of 968 hPa at 1800 UTC 9 September, and then weakened into a category 1 hurricane at 0000 UTC 11 September.

The National Center for Environmental Prediction (NCEP) global analyses on 1^o by 1^o grid every 6 hours are used as the initial and lateral boundary conditions. There are four nested domains with horizontal resolutions of 54 km, 18 km, 6 km and 2 km. The 6 km domain is initialized at 1200 UTC 9 September. The 2 km domain is initialized at 0000 UTC 10 September and is moved to keep the eye within the center of the domain. In the vertical, 36 σ levels are unevenly distributed between the surface and 20 hPa.

Three groups of sensitivity tests have been performed. A detailed list of these simulations can be found in Table 1. The Betts-Miller convective scheme and the Burk Thompson planetary boundary layer (PBL) scheme are used for all simulations. The Betts-Miller convective scheme is turned off for the inner 2 km domain.

3. Results

a. Sensitivity to microphysics scheme

The predicted tracks of Erin vary by at most 57 km for the simulations described in Table 1. But all simulated tracks are

*Corresponding author address: Greg M. McFarquhar, University of Illinois, Dept. of Atmospheric Science, 105 S. Gregory St., Urbana, IL, 61801
E-mail: mcfarq@atmos.uiuc.edu

Table 1. Summary of different series of simulations performed.

Experiment Name	Simulations Performed
Sensitivity to microphysics scheme	1. Simple ice 2. Reisner mixed phase 3. Goddard (control simulation)
Sensitivity to graupel fall velocity (V_g)	1. (a, b) = (351.2 $cm^{.63}$ s^{-1}, .37) 2. (a, b) = (199.9 $cm^{.75}$ s^{-1}, .25) 3. (a, b) = (700.1 $cm^{.25}$ s^{-1}, .75)
Test of a new iterative condensation scheme using the Reisner mixed phase microphysics	1. Original condensation scheme 2. New condensation scheme (McFarquhar et al., 2005)

consistently west of the observed track. Simulations with different microphysical parameterizations show fewer variations in the storm intensity compared with simulations using different planetary boundary layer schemes (figure not shown). As shown in Figure 1, the control simulation with the Goddard microphysics scheme intensifies relatively quicker than the simulations with other microphysics schemes. The minimum sea level pressure P_{min} of the control simulation averaged over the last 18 hours differs by only 5 hPa from observations. However, differences up to 15 m s^{-1} from observed surface winds are noted and the control simulation does not represent the decline in winds seen in the last 18 hours.

To evaluate the simulated hydrometeor mass contents, the modeled radar reflectivity Z was compared against Z measured by the NASA ER-2 Doppler radar (EDOP) during the Fourth Convection and Moisture Experiment (CAMEX-4). As shown in Figure 2, all schemes overestimated the occurrence of higher Z at the five altitudes. The Advanced Microwave Precipitation Radiometer (AMPR) onboard the ER-2 measured brightness temperatures Tb over Hurricane Erin at 10.7, 19.35, 37.1 and 85.5 GHz channels during the CAMEX-4. A comparison of the Tb calculated from the hydrometeor fields predicted by the control simulation using the Kummerow Radiative Transfer Model (RTM) against Tb observed by the AMPR has been made. The normalized frequency of occurrence for Tb at these four channels from AMPR observation and model simulation are shown in Figure 3. The comparison at 10.7 and 19.35 GHz shows that the simulation overpredicted the frequency of heavy rain and underestimated that of light rain, which is consistent with the previous finding from the comparison of simulated and observed Z. The comparison at 37.1 and 85.5 GHz suggests the model overpredicted the amount of graupel. The simulated graupel mass contents are found to be 10 times larger than those found in other hurricanes (McFarquhar and Black 2004).

A comparison against vertical velocity statistics analyzed from 7 Atlantic hurricanes (Black et al. 1996) shows that the updrafts predicted by the control simulations in the eyewall at higher altitudes were greatly larger than those observed from other hurricanes. Black et al. (1996) showed that 5% of updrafts in the eyewall above 9 km are stronger than 5 m s^{-1}, whereas the control simulation produced more than 30% of updrafts stronger than 5 m s^{-1}.

b. Sensitivity to graupel fall speeds

The role of graupel is a key focus due to the importance of graupel conversion processes on storm thermodynamics. McFarquhar and Black (2004) identified a range of a/b coefficients, where $V_g=aD^b$, that applies to graupel. D is the diameter of a

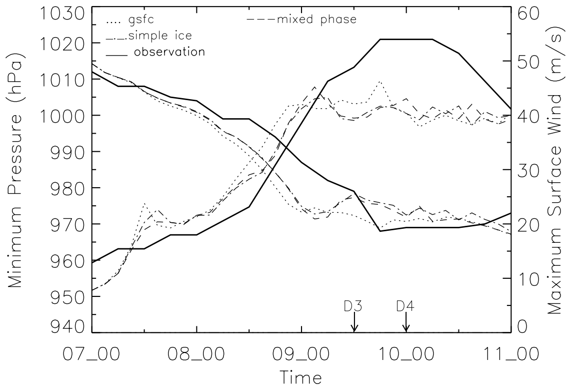

Fig.1 Temporal evolution of simulated and observed minimum sea level pressure (P_{min}) and maximum wind (U_{max}) of Hurricane Erin between 0000 UTC 7 September 2001 and 0000 UTC 11 September 2001. Solid lines represent observations. Different line types correspond to simulations conducted with varying microphysical parameterization schemes as indicated in legend. D3 and D4 indicate time at which 6 km grid and 2 km grid are activated respectively. (McFarquhar et al., 2005)

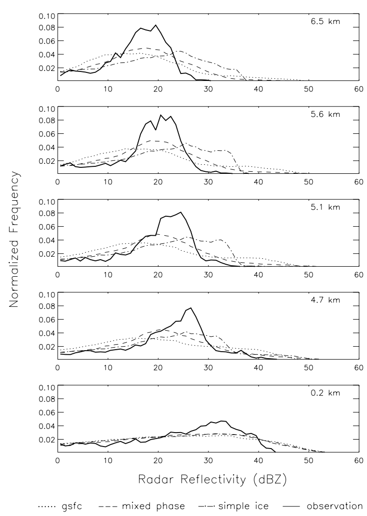

Fig. 2 Histograms of Z derived from the EDOP (solid line) and from modeled fields at 5 altitudes for simulations using different microphysical parameterization schemes as indicated in legend. Z histograms are computed from the last 18 hours of simulation. The observations correspond to data collected during all 3 ER-2 sorties over Erin. (McFarquhar et al., 2005)

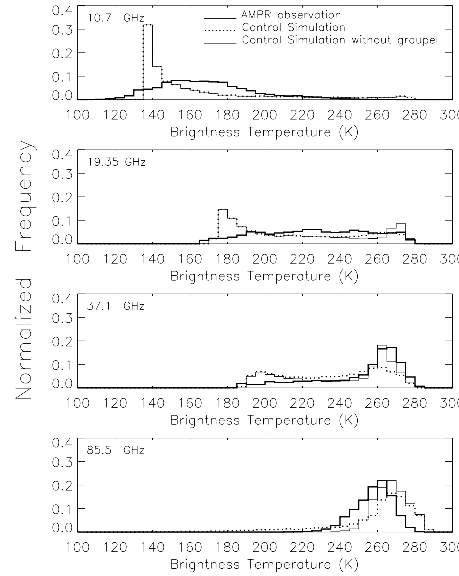

Fig. 3 Histograms of observed and computed brightness temperature at the 4 operating frequencies of AMPR. Points corresponding to modeled and observed eye location have been removed from T_b sample. (McFarquhar et al., 2005)

graupel particle. From their Fig. 3 and as shown in Table 1, coefficients corresponding to faster and slower falling graupel are used in simulations. Simulations with faster V_g consistently produced lower P_{min} and stronger maximum wind (U_{max}). Differences of 7 hPa in P_{min} and 5 m s^{-1} in U_{max} between simulations are noted when averaged over the last 18 hours. The simulation with slower V_g tends to produce weaker updrafts and higher graupel mixing ratios.

c. Application of a new iterative condensation scheme

A new iterative condensation scheme (McFarquhar et al. 2005), which limits the unphysical increase of θ_e associated with many existing condensation schemes, has been tested. The development of this scheme was motivated by Bryan and Fritsch (2000). By comparing observed and model-derived temperature and dew point temperature profiles in the eye, the new scheme was found to limit the artificial increase in temperature and water vapor content in the eye. For averages over the last 18 hours of Erin's simulations, higher P_{min} of 8 hPa and lower U_{max} of 5 m s^{-1} are realized with the new condensation scheme. Occurrence of Z greater than 50 dBZ and occurrence of updrafts greater than 5 m s^{-1} have been reduced.

4. Conclusions

Simulations of Hurricane Erin 2001 were conducted with MM5 to examine the roles of microphysical, thermodynamic, and boundary layer processes on hydrometeor distributions and on the structure and evolution of Erin. Statistical comparisons of modeled fields with observations collected during CAMEX-4 and in other hurricanes are used to assess the importance of physical processes acting within Erin. Because of the complexity of interactions between different processes, it is impossible to categorically state the sensitivity to any single process or parameterization scheme. Nevertheless the following conclusions can be made:

1) The choice of microphysical parameterization scheme and of coefficients to describe graupel fall velocities have similar impacts on the simulated intensity of Erin.

2) Variations between microphysics, boundary layer, convection or V_g schemes are not large enough to explain discrepancies between modeled and observed Z and graupel mass content. The MM5 overestimates the amount of graupel and produces larger area of heavy rain compared to observations.

3) The use of an iterative condensation scheme developed to limit the artificial increase of θ_e associated with some condensation schemes produced a weaker storm and reduced the occurrence of updrafts stronger than 5 m s^{-1} and of Z above 50 dBZ.

4. REFERENCES

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