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Sensitivity of Hurricane Charley Simulations to Changes in the WRF Model

Matthew J. Rosier, Douglas K. Miller*

National Environmental Modeling and Analysis Center
University of North Carolina – Asheville,
Asheville, North Carolina

1. Introduction

This study focuses on numerical simulations of Hurricane Charley (2004) performed to investigate the role that explicit and implicit moisture parameterization play in governing the track, intensity, and rainfall distribution of Charley during and around its landfall on the central Gulf Coast of Florida. The three dimensional, fully nonlinear, nonhydrostatic Weather Research and Forecasting (WRF) model, version 2.0, was used to simulate the tropical cyclone over a 24-hour time period.

The main purpose of this research is to document the effect of varying microphysics and convection parameterizations on simulations of a land-falling tropical cyclone at both coarse and fine horizontal model resolutions. Included in this objective is the comparison of simulated features with the observed track, intensity, and precipitation data.

2. Model Description and Details

The version of WRF used in this research has been documented in a variety of applications, including tropical cyclone simulations. The 24-hour simulation utilized in this research uses two domains, a coarser domain with a 25 km grid length and a finer domain with a 10 km grid length. These domains are not nested and both cover roughly the same horizontal area. The coarse domain size is 68 x 56 grid points while the fine domain is 144 x 144 grid points. Both domains have 31 vertical levels. The initial fields are obtained from National Centers for Environmental Prediction (NCEP) analyses taken from the Eta model. The NCEP Eta model is also used for lateral boundary conditions. The simulations begin at 1200 UTC 13 August 2004, which is 7-8 hours before Charley's landfall, and end at 1200 UTC 14 August 2004 when Charley is at a position off the coast of the GA/FL border.

Precipitation processes on the grid scale are represented using three different explicit moisture schemes. The first scheme includes predictive equations for cloud water, cloud vapor, cloud ice, rain, snow, and graupel (Lin et. al 1983). The second scheme does not include a predictive equation for graupel and is based upon the NCEP class-5 scheme. The third scheme is the scheme used in the operational NCEP Eta model (Ferrier 1994). To represent deep, moist convection in the model, two varying convective parameterizations are employed, Kain-Fritsch and Betts-Miller-Janjic.

3. Observed characteristics of Hurricane Charley

The origin of Charley can be traced to a tropical wave that emerged from western Africa on August 4, becoming a tropical depression by 1200 UTC 9 August. Late on 9 August, the depression moved into the Caribbean Sea. A strong, deep-layered high pressure center to the north of the depression induced a swift west-northwestward motion at 20-24 kt. Given the low vertical shear and well-established upper-level outflow, the depression strengthened into a tropical storm early on 10 August. Relatively steady strengthening continued as the storm moved into the central Caribbean Sea and Charley reached hurricane status by 1800 UTC 11 August as it approached Jamaica. By early on 13 August, Charley had strengthened to 105 kt just before hitting western Cuba.

By the time of our simulation initialization, Charley had come under the influence of an unseasonably strong mid-tropospheric trough,

Corresponding author address: Douglas K. Miller, National Environmental Modeling & Analysis Center, Rhodes Hall CPO #2345, UNCA, One University Heights, Asheville, North Carolina 28804-8511
E-mail: dmiller@unca.edu

extending from the east-central United States into the eastern Gulf of Mexico (Figure 1). In response to the steering flow on the southeast side of this trough, Charley turned north-northeastward and accelerated toward the southwest coast of Florida. At this time Charley also underwent a rapid period of intensification. By 1400 UTC 13 August, the maximum winds had increased to 110 kt and just three hours later, Charley's maximum winds reached Category 4 strength (125 kt). Due to a decrease in the eye diameter, these extreme winds were confined to an area of only 6 nm within the center. Moving north-northeastward at 18 kt, Charley made landfall on the southwest coast of Florida near Cayo Costa around 1945 13 August with maximum sustained winds near 130 kt. Charley's eye passed over Punta Gorda at 2045 UTC and continued north-northeastward across the central Florida peninsula. The center passed near Kissimmee and Orlando around 0130 UTC 14 August, with a decreased intensity of 75 kt. Charley was still a hurricane, with maximum sustained winds of 65-70 kt when the center moved off the northeast coast of Florida near Daytona Beach around 0330 UTC 14 August.

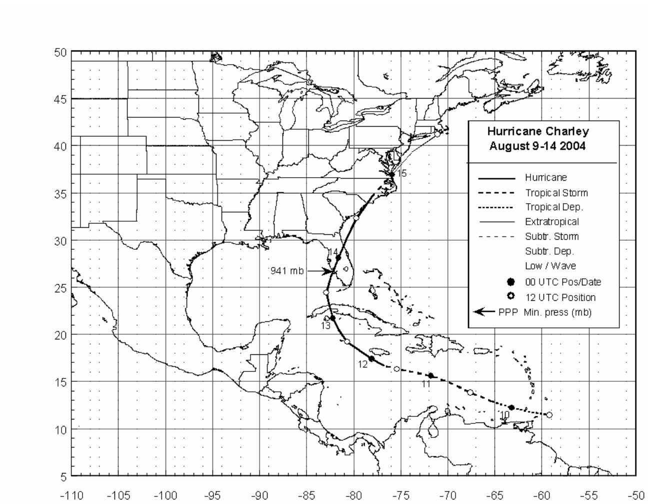


Figure 1 - Best track positions for Hurricane Charley, 9-14 August 2004. Courtesy National Hurricane Center (NHC).

After moving back over the waters of the Atlantic, Charley slightly re-strengthened as it accelerated northeastward toward the coast of South Carolina. This re-intensification proved to be temporary and Charley came ashore again near Cape Romain, SC at 1400 UTC 14 August as a weak hurricane with maximum sustained winds of 70 kt.

4. Results

Simulation results suggest that the highest variability in rainfall and storm intensity are a result of changes in the convective (implicit moisture) parameterization, rather than changes in the explicit moisture parameterization, and the convective parameterization is highly sensitive to changes in grid resolution.

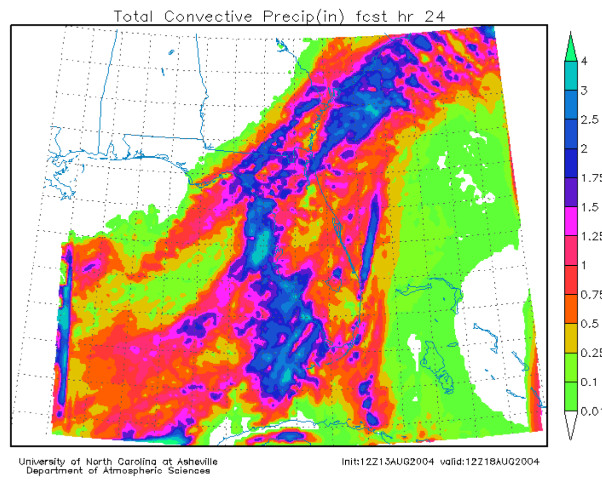
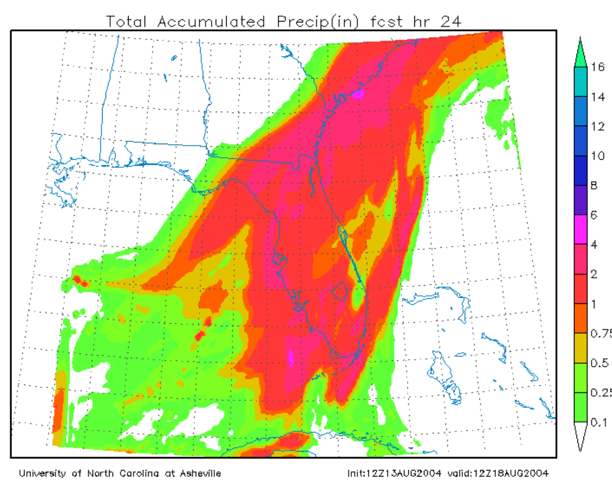


Figure 2 – Top: 24-hour total convective precipitation using Kain-Fritsch CPS (top) and Betts-Miller-Janjic CPS (bottom) at 10 km horizontal resolution.



Although the physical justification for use of convective parameterization is generally only valid at a particular range of model grid resolutions (Molinari and Dudek 1992), often no lower than 20 km, several studies have found that adequate simulation of precipitation may require the use of such parameterizations at grid spacings as fine as 5-10 km (Molinari and

Dudek 1992). In this particular research, it is evident that the Kain-Fritsch parameterization responds noticeably to an increase in the model resolution, whereas the Betts-Miller-Janjic parameterization produces nearly identical precipitation output regardless of a 25 km or 10 km model grid resolution.

The Kain-Fritsch appears to be the most accurate CPS choice when simulating precipitation intensity and precipitation distribution in Hurricane Charley (Figure 2). Not only does the Kain-Fritsch capture the general distribution of precipitation at 25 km, but at 10 km the Kain-Fritsch CPS accurately and realistically represents the banding nature of tropical cyclone precipitation, whereas the Betts-Miller-Janjic scheme does not respond to the increased resolution and fails to capture both the banding structure of the precipitation as well as the overall rainfall distribution, especially across central Florida.

In examining the total accumulated precipitation over the 24-hour duration of the simulation, the simulation using the Kain-Fritsch CPS was nearest to radar derived estimates during a similar period (Figure 3). Both the 25 km and 10 km runs capture the swath of 2-4" totals across central Florida, with the 10 km run is better able to resolve the banding structure of the precipitation. While the Betts-Miller-Janjic CPS did not capture the banding nature of the precipitation, it was fairly accurate in predicting the general precipitation totals over the 24-hour period of the simulation.

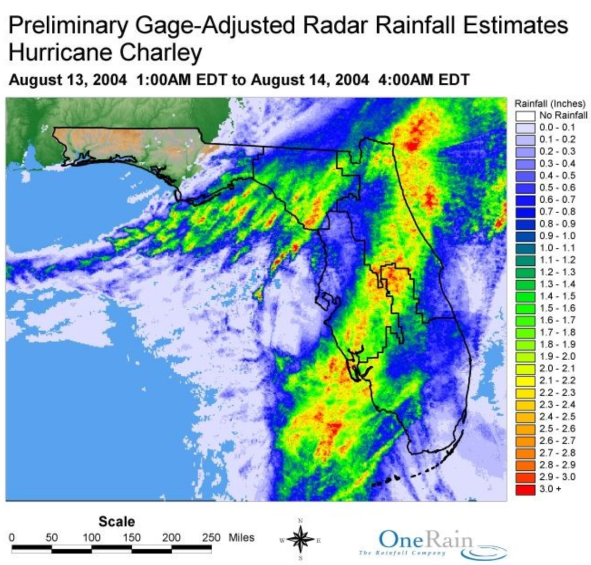


Figure 3 - 27-hour radar estimated rainfall from 0500 UTC August 13 to 0800 UTC August 14, roughly corresponding with the period of our model simulation. Courtesy OneRain, Inc.

5. Conclusions

Overall, the WRF simulations of Hurricane Charley, though of varying accuracy, provided successful and useful in many regards. The high-resolution numerical model reproduced the storm track and evolution of the precipitation features reasonably well. Although the simulated storm was weaker than observed, model biases are common in numerical simulations of tropical cyclones and reflect the limitations of the model initialization and parameterization of surface fluxes, ocean feedback, and microphysics.

Results from the sensitivity simulations generally show that 1) tropical cyclone intensity and precipitation features are largely responsive to changes in the cumulus parameterization, 2) the use of smaller computational time steps at coarser resolution results in a weaker cyclone, 3) there is a strong sensitivity of precipitation to the horizontal resolution and the 10 km runs capture the banding structure of the precipitation that the 25 km runs fail to resolve, and 4) the explicit moisture scheme makes a more significant contribution to precipitation amounts over land.

Future research regarding Hurricane Charley at landfall may benefit from modifications in the convective parameterizations and experimentation with various methods of model initialization.

6. References

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