# 3C.2 INTENSITY CHANGE AND EYEWALL REPLACEMENT IN HURRICANE FLOYD (1999)

Joseph E. Tenerelli* and Shuyi S. Chen
RSMAS, University of Miami, Miami, FL

## 1. Introduction

Over the last a few decades hurricane track forecasts have improved significantly, whereas relatively little progress made in hurricane intensity forecasts. The lack of skill in the intensity forecasting may be attributed to insufficient spatial resolution to resolve the hurricane inner-core structure and inadequate representation of physical processes in hurricane prediction models. Though axisymmetric models can resolve the inner-core of the hurricane vortex, they cannot explicitly treat the effects of asymmetries on hurricane intensity. It is observed that hurricane intensity changes are often associated with eyewall contraction and replacement. However, the mechanisms responsible for the development of secondary wind maxima and eyewall replacement processes are not well understood. Willoughby et al. (1982) speculate that eyewalls (or convective rings) may have their origin in symmetric instability, precipitation-induced downdrafts, and eddy momentum flux convergence associated with radially propagating waves.

Here we examine simulations of Hurricane Floyd (1999) using a nonhydrostatic full physics model that explicitly resolves the dynamics and microphysics near the vortex center through use of a 1.67 km mesh that follows the vortex. Focusing on the concentric eyewall structure, we examine the evolution of the horizontal structure of the storm's wind and precipitation fields in relation to the evolution of its intensity.

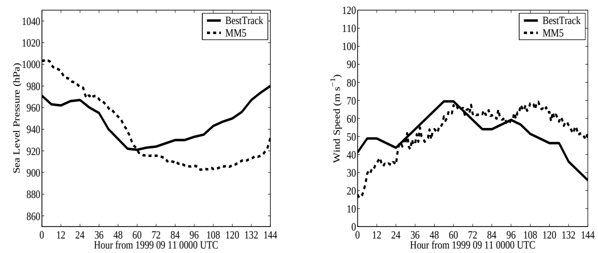
## 2. Methodology

In this study we employ the PSU/NCAR non-hydrostatic atmospheric mesoscale model (MM5V3) to simulate Hurricane Floyd. We initialize the model at 0000 UTC 11 September 1999 with the NCEP AVN model initial fields on a 1.25$^o$x1.25$^o$ mesh. Instead of using global SST analysis from NCEP, we use the 9-km AVHRR Pathfinder SST data in a manner described in Tenerelli and Chen (2001). Lateral boundary conditions are obtained from 12-hourly NCEP analysis fields.

Four levels of nesting are used, with grid spacings of 45 km on the (fixed) coarsest mesh and 1.67 km on the finest mesh. There are 28 vertical levels in the model, with 9 levels below 900 hPa at the initial time.

We use both an explicit moisture scheme and a slightly modified Kain-Fritsch cumulus parameterization on the 45 and 15 km meshes, and the explicit moisture scheme only on the 5 and 1.67 km meshes. The Blackadar PBL scheme is used on all meshes, but we include the modification of Pagowski and Moore (2001) in which we introduce different roughness scales for temperature ($z_t$) and moisture ($z_q$). In the original formulation of the Blackadar scheme, the roughness scales for temperature and moisture are identical to that for momentum ($z_0$), and this is inappropriate since the physics governing momentum transfer at the surface are different from that governing temperature and moisture.

*Corresponding author address: Joseph E. Tenerelli, MPO, RSMAS, University of Miami, Miami, FL, 33149. email: joe@orca.rsmas.miami.edu




(a) Minimum sea level pressure

(b) Maximum surface wind speed

FIG. 1: Observed and simulated (a) minimum sea level pressure (hPa) and (b) maximum surface wind speed (m s$^{-1}$) of Hurricane Floyd.

## 3. Results

Hurricane Floyd (1999) developed from a tropical depression on 10 September 1999 and became an intense category 4 hurricane prior to making landfall in the Bahamas, where it recurved and eventually made landfall in North Carolina on 16 September.

Fig. 1 shows the minimum pressure and maximum surface wind speed for the simulation. Peak intensity (in terms of both minimum sea level pressure and maximum wind speed) in the simulation is reached 0800 UTC 15 September (104 hours into the simulation), at which time the model storm begins a slow weakening phase.

Hurricane Floyd underwent an eyewall replacement cycle beginning on 13 September. At 0000 UTC 14 September, concentric eyewalls existed, with the inner eyewall roughly at a radius of 30 km and the outer eyewall at a radius of about 70 km. By 0000 UTC 15 September the inner eyewall had disappeared and had been replaced by the outer eyewall, which by this time had contracted to a radius of about 40 km. The storm reached peak intensity at 1200 UTC 13 September (roughly coincident with the start of the development of the outer eyewall), and began a weakening phase after this time.

The model-simulated hurricane exhibits a similar evolution. The radius of maximum wind from 60 to 96 hours into the simulation is roughly 30 km, which is in good agreement with the observed radius of maximum wind before the eyewall replacement cycle. By the time

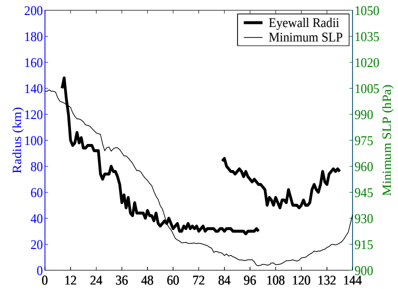
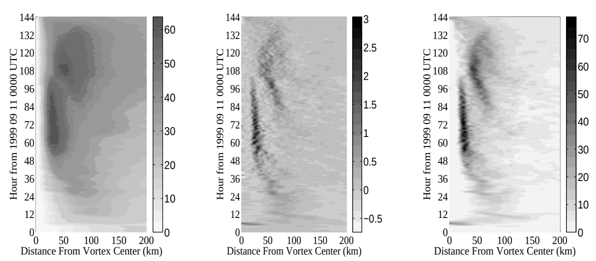



FIG. 2: Time evolution of the radius of maximum wind and minimum pressure for the simulation.

of peak intensity, however, a secondary maximum in the tangential wind had formed, as shown in Fig. 2. This secondary peak (Fig. 3a) is associated with a peak in symmetric vertical velocity (Fig. 3b) and symmetric rain rate (Fig. 3c). As the simulation proceeds this outer maximum contracts, and by 108 hours into the simulation the inner eyewall has disappeared, leaving only the outer eyewall, which by this time has contracted to radius of about 50 km.




(a) Tangential wind speed

(b) Vertical velocity

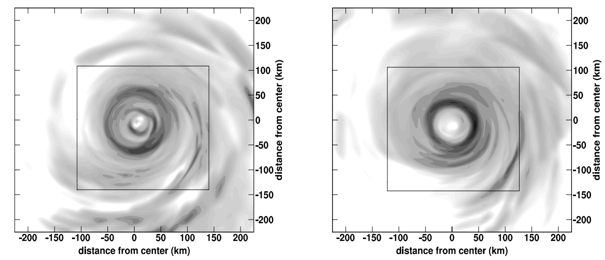
(c) Rain rate

FIG. 3: Time-radius cross sections of azimuthally averaged (a) tangential wind at 3 km, (b) vertical velocity at 3 km (m s$^{-1}$), and (c) surface rain rate (mm hr$^{-1}$).

This eyewall replacement cycle is evident in the surface rain rate fields. Fig. 4a shows two symmetric peaks in rain rate at 0000 UTC 15 September; one at around 30 km radius and the other at 70 km radius. These peaks correspond to the locations of the peaks in tangential wind speed at that time. By 1200 UTC 15 September this well-defined, symmetric ring of precipitation has contracted inward and weakened substantially, and and outer ring of high rain rate has formed and contracted to just beyond 50 km radius (Fig. 4b). By this time the storm had begun a weakening phase, consistent with observations of both Floyd (1999) and previous storms (Willoughby et al., 1982).

## 4. Conclusions

The 6-day long simulation with a 1.67 km vortex following mesh allows the model to capture the inner-core dynamics of the hurricane with sufficient realism that the model is able to reproduce the observed eyewall replacement cycle. Consistent with previous observational work, the development and subsequent contraction of the outer eyewall coincides with the end of a rapid deepening phase. We are conducting a number of numerical experiments designed to reveal the mechanisms responsible for the development of eyewalls and eyewall replacement cycles and their relationship to storm intensity change.




(a) 0000 UTC 15 Sept. 1999

(b) 1200 UTC 15 Sept. 1999

FIG. 4: Hourly rain rate (mm hr$^{-1}$) from MM5 simulation (a) before and (b) after the eyewall replacement cycle. Darker shading indicates higher rain rate.

## 5. Acknowledgements

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