PARAMETERIZATION IMPACTS ON A SIMULATION OF HURRICANE OPAL (1995)

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1. Introduction

Landfalling hurricanes are known to bring with them many hazards to the public as they approach land. Most notably are storm surge, high winds, flooding rains, and tornadoes. In particular, observational studies of landfalling hurricanes have recognized the commonality of favorable shear and buoyancy for severe thunderstorms in the right-front quadrant of an advancing cyclone (Bogner, 2000; McCaul, 1991; Novlan, 1974). Hurricane modeling research studies to date have not focused on the detailed structure of the associated convective rainbands due in large part to computational constraints, although individual convective element behavior in an idealized hurricane environment has been studied (McCaul, 1996, 2001). It is now possible to study these storms and their potential for producing tornadoes using high resolution hurricane simulations using models such as MM5.

The authors are carrying out such simulations for Hurricane Opal, continuing the work of Ramamurthy et al. (1999). As part of this effort, high resolution MM5 simulations of Hurricane Opal are used to study the impact of various microphysical and boundary layer parameterizations using 10 km horizontal resolution. Others have shown that the tropical convective behavior can be highly sensitive to parameterizations of the microphysics (Liu, 1997) as well as of the PBL (Braun, 2000). A limited set of tests were conducted to determine the coupling which for this case most reasonably matched observations.

The storm track was strongly influenced by the use of explicit verses parameterized microphysics on a 10 km horizontal grid, and was modestly influenced by the choice of PBL scheme. Variations in storm intensification appeared to be closely linked to the storm track relative to the warm core ring in the Gulf of Mexico. This warm core likely played a key role in Opal's rapid intensification (Shay, 1999). Grid resolution finer than 10 km was not found to significantly influence the storm track nor the minimum central pressure (MCP) reached. Employing grid analysis nudging during the first 24 hours was crucial to correcting initial storm track errors that were likely induced by a significant wind/mass field inconsistency in the NCEP analyses used in the initialization.

2. Methodology

Multi-day numerical simulations were conducted using the Penn State/NCAR Mesoscale Model Version 5 Release 3-4. A multi-scale two-way nesting was employed with grid resolutions of 90, 30, 10, and 3.3 km (future runs will also include a 1.1 km grid nest). The vertical domain extends from the surface to 50 mb with 35 vertical levels. All simulations were performed on the NCSA SGI Origin 2000 using 16 processors.

The Burk-Thompson and Blackadar boundary layer parameterizations were tested, as were the use of explicit microphysics (Goddard Mixed Phase) on the 10 km grid. Nudging with the Blackadar scheme was also investigated along with fixed verses varying SSTs during the simulation. Convective parameterization was handled by the Betts-Miller scheme. The simulation was initialized on 00 UTC October 2, 1995 using the 2.5° NCEP Global Analyses. Opal was at tropical storm strength at this time, and soon after rapidly intensified to a Category 4 hurricane by 12 UTC on 04 October. The storm then weakened to a marginal Category 3 by landfall at 22 UTC on 04 October.

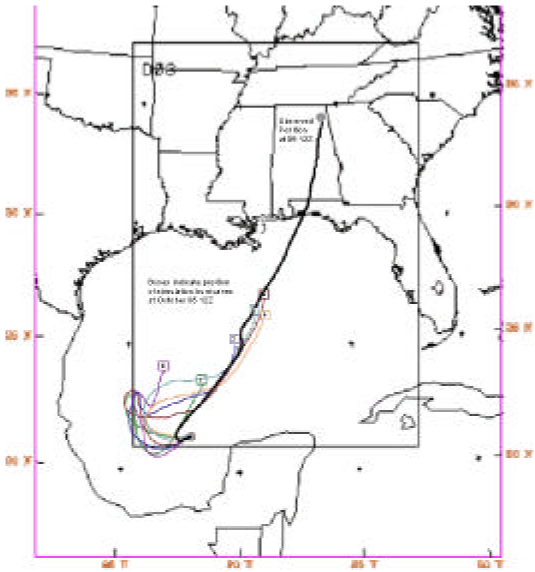

Fig. 1: Storm tracks from some of the tests conducted. Heavy line: Opal best track. 1) BT,EM,VS; 2) BT,BM,VS; 3) BL,BM,VS; 4) BL,BM,VS,N; 5) BL,EM,VS,N; 6) BL,BM,FS,N
Where BT-Burk Thompson, BL-Blackadar, VS-varying SST, FS-fixed SST, N-grid nudging employed.

3. **Results**

The NCEP data set used for initial and boundary conditions contained a severe mass/wind field misalignment at the initialization time in the tropical vortex region. The adjustment process is suspected of causing problems with the early movement and intensification in all simulations. These simulations showed a strong westward jog during the first six hours. Further, the vortex centers travel along the boundary of the third grid which may also have adversely effected early storm movement. Tracks from the simulations are shown in Figure 1.

A number of studies have investigated the appropriateness of cumulus parameterization verses solely employing explicit microphysics in the 10 km grid resolution. Simulations testing both for this case found consistent track errors with the explicit scheme. Intensities were considerably weaker and storm tracks were closely aligned along the grid three domain boundary.

The primary driving factor that appeared to govern the minimum central pressure (MCP) was

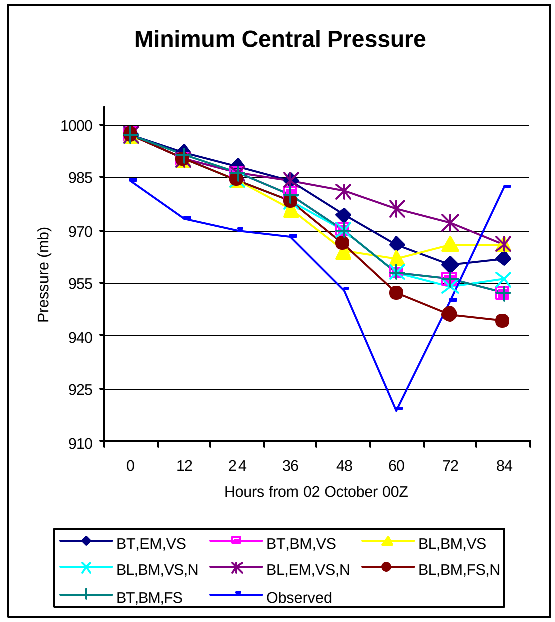

Fig. 2: Minimum central pressure on the 30 km grid vs. hours into simulation and observed values for Hurricane Opal.

the passage of the hurricane eye over the warm SST core (region with SSTs greater than 29.5° C) in the central Gulf of Mexico. A summary of test results are shown in Figure 2. Tracks errors consistently failed to move across the warmest surface waters and hence lacked significant deepening. Some simulations did cross back over the warm water core yet failed to deepen as much as storms which moved further north. This suggests an additional role by the trough interaction in further intensification as found by Krishnamurti (1997) and Bosart (1999). None of the simulations approached the rate of deepening observed.

Grid nudging was needed to ensure the eye tracked over the warm core, so without the ability to nudge the Burk-Thompson PBL cases, no direct comparison could be made. However, given the sensitivities shown by Braun and Tao (2000) in their simulations of Hurricane Bob (1991), the Burk-Thompson might have been the preferred scheme to implement. They found that the surface flux characteristics of the Burk-Thompson PBL scheme was most favorable for the development of strong hurricanes. However, Liu et al. (1997, 99) showed the suitability of the Blackadar scheme in developing a significant hurricane in their in depth series on Hurricane Andrew (1992).

The model generated very little precipitation near the hurricane center during the early stages of all simulations. Considerable variability was observed in the rainwater fields for the simulations beyond 24 hours. Most notably was the shift from west to east relative to the eye of the dominant precipitation core when nudging was applied during the formative stages.

A new feature with the current release of MM5 is the ability to allow SSTs to vary over the course of a simulation. For the hurricane modeling scenario, this poses a problem when the storm motion lags the observed behavior. This places the simulation in the 'wake' of the hurricane, resulting in cooler waters along the hurricane's track. While fixing the SST field is unrealistic, it is more acceptable where the ocean mixed layer depth is large, as it was with Opal (Shay 1999).

4. Conclusions

Movement of the simulated hurricane eventually lined up with the observed storm track. The best simulation coupled the Blackadar PBL scheme with Betts-Miller CP scheme with a fixed SST and grid nudging employed for 24 hours on the outer grid. While finer grid resolutions than 10 km did not result in greater intensity, the storm structure, including the development of rainbands, was greatly enhanced with the use of higher resolution simulations.

Potential boundary condition problems plagued the usage explicit microphysics in the 10 km resolution domain. The lack of nudging facilities with the Burk-Thompson PBL scheme prevented achieving a reasonable track with tests imploring it. Storm intensity was strongly linked to the duration of passage over the SST warm core. Substantial variability was noted in the convective nature of the hurricane with regards to grid resolution. All of the simulations lagged the observed hurricane in forward progress.

5. Future Work

The larger hurricane environment has been well simulated recently by works such as those by Liu and Zhang (1997, 1999). The tropical cyclone storm scale environment has been explored by McCaul (1996, 2001), which successfully simulated supercell structures. However, the influence of the mesoscale structure of the hurricane is absent from the storm-scale simulations of McCaul, and the storm scale is not resolved in the studies of Liu and Zhang (1997, 1999).

The authors are pursuing an investigation of the environment and behavior of the discrete convective elements generated and associated with hurricanes (Fig. 3). Storms exhibiting supercell like structure are commonly observed within the rainbands of landfalling hurricanes. The convective clouds generated within the high resolution simulations will be studied, to determine their characteristics and whether their environment is favorable for the development of supercell type storms, particularly in the right front quadrant. Results will then be compared with observational studies such as those by McCaul (1991) and Novlan and Gray (1974) through bulk parameter comparisons and extracted soundings. Further, the characteristics of resolved convective elements on the finer grid resolutions will be compared with the behavior of observed convection near landfall and mini-supercells.

Previous efforts by Ramamurthy et al. (1999) provided a significant framework for current and future studies. These early high resolutions runs of Hurricane Opal were conducted using MM5 V2.12 and provided encouraging results for planned explorations. Examples of the simulation quality are shown in a volume rendering visualization (Fig. 4).

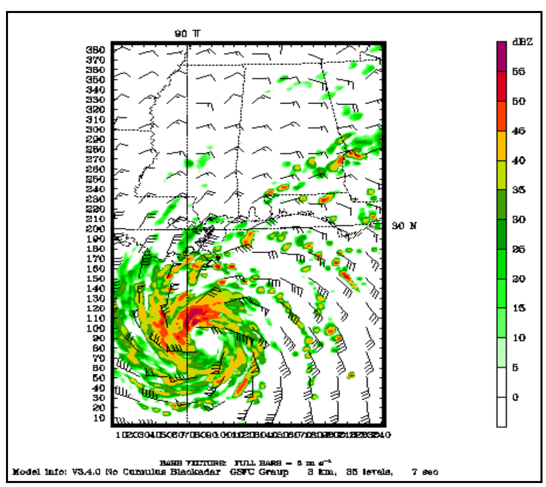

Fig. 3: Simulated reflectivity of Hurricane Opal showing rainband features and cellular type convection with 3.3 Km horizontal resolution.

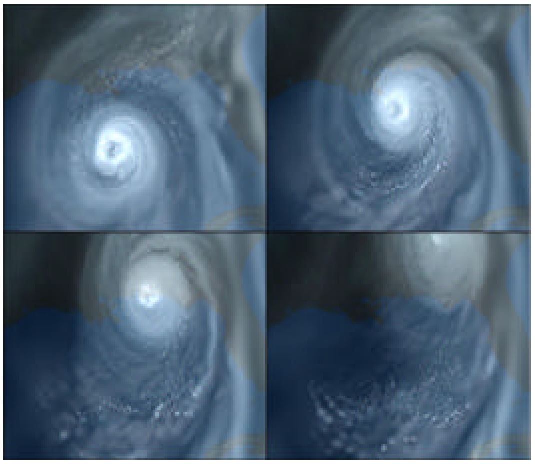

Fig. 4 Four frames from an animation using 5 grids with the innermost grid having 1.1 km horizontal resolution. This was the first 5 grid simulation completed last year using MM5 Version 2.12 (current simulations are being done with Version 3.4). Animations can be found at: **http://woodall.ncsa.uiuc.edu/dbock/projects/Opal/**

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