HURRICANE SIMULATIONS USING A VORTEX-FOLLOWING NESTED GRID IN MM5 AND WRF

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1. INTRODUCTION

To resolve the structure of a hurricane's inner core, which is crucial for hurricane intensity forecasts, and to allow for a 5-day or longer forecast, a vortex-following nested grid with a high-resolution terrain and landuse refinement was developed at the University of Miami (UM) (Tenerelli and Chen 2001, Chen and Tenerelli 2005). It has been used successfully in a number of hurricanes including Hurricanes Bonnie (1998), Georges (1998), Floyd (1999), Lili (2002), Fabian and Isabel (2003). It allows for an unlimited number of nested grids to achieve the desirable resolution at 1-2 km. A significant amount of collaborative effort between UM and NCAR has been set forth to adapt the UM vortex-following nested grid in WRF. A clear advantage of using this vortex-following grid is that the hurricane will always be centered in the highest resolution and in all moving nests. A first step is to conduct extensive tests and evaluation of the moving nest simulations of hurricanes in WRF and compare the existing MM5 results as well as observations. In particular, comparing and validating the model simulated hurricane tracks, storm structure and intensity, and especially the atmospheric surface properties with observations.

2. MODEL SIMULATIONS AND DATA

The cases we are using for our model comparisons are Hurricane Frances, Ivan and Jeanne (2004). These three storms are of significant interest as they all made landfall in Florida as category 2 (Frances and Ivan) and category 3 (Jeanne) hurricanes. Both Frances and Ivan, category 4 and 5 hurricanes respectively, unexpectedly weakened before the U.S. landfall.

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The simulations are 5 day forecasts near or during the landfalls for each hurricane. We use two nested domains with 12 and 4 km grid resolutions, with the inner domain following the center of the vortex (Chen and Tenerelli 2005). Except for Hurricane Jeanne, where we used only one domain with a 15 km grid resolution. All domains have 30 sigma levels with 11 of them in the planetary boundary layer (PBL). The model initial and lateral boundary conditions are from the 1° x 1° NCEP global analysis fields including sea surface temperature (SST). Identical model configurations, including domain sizes, resolution, initial and lateral boundary conditions are used in MM5 and WRF to make accurate comparisons.

For observational comparisons we analyzed the lower fuselage radar reflectivity from the two NOAA WP-3D aircrafts, rain rates from the Tropical Rainfall Measuring Mission's (TRMM) microwave imager (TMI) and precipitation radar (PR), and the HWIND, a surface wind speed estimation using the flight-level and GPS dropwindsonde data, from the NOAA/Hurricane Research Division. The storm tracks and minimum sea-level pressure (SLP) are from the National Hurricane Center's best track data.

3. PRELIMINARY RESULTS

All of the simulated storms display excellent track forecasts compared with the best track from the National Hurricane Center (NHC) (Fig. 1). At this time, the WRF simulations for Frances and Ivan are not yet complete; therefore, those simulations will not be included in the results. The MM5 track forecasts for Frances and Ivan and the overall motion and speed compare well with the best track. The MM5 and WRF simulations for Hurricane Jeanne are nearly perfect, both the MM5 and WRF simulations capture the entire looping motion north of Hispaniola, and steer the storm towards the east coast of Florida.

The intensity of the simulations is also very adequate compared with the best track. The

MM5 simulation for Frances is slightly stronger prior to the landfall, for Ivan it is slightly weaker for much of the 5 days, and for Jeanne the intensity is about on target. The WRF intensity for Hurricane Jeanne matches extremely well with the best track. In fact, the WRF model correctly indicates the intensification 24-48 hours before the landfall, which the MM5 does not capture.

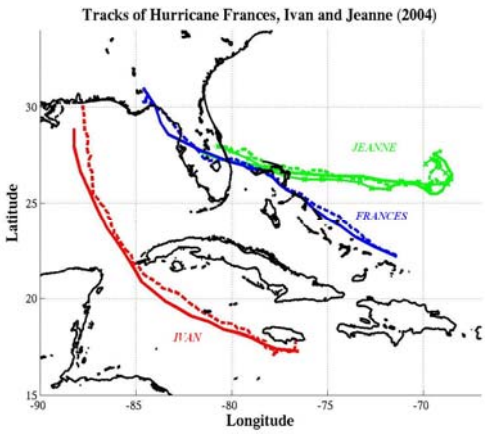

Fig. 1: Observed (solid) and MM5 simulated (dashed) tracks for Hurricane Frances, Ivan, and Jeanne (2004). The WRF simulated track for Jeanne is indicated by the solid green line with x markings every six hours.

Fig 2a shows the HWIND analysis for Hurricane Frances at 1300 UTC September 4th, which is about 18 hours prior to the Florida landfall. Fig 2b shows the MM5 surface wind speed at the same time. At this time, the storm developed a strong asymmetry in the northern quadrants. The MM5 depicted this asymmetry very well; however, the simulated wind speeds are 10 knots stronger than the HWIND analysis. Several hours before the landfall, Frances became nearly symmetric, until falling apart over Florida. The MM5 simulation captures this wind speed structure evolution in Hurricane Frances. The simulations for Ivan and Jeanne also compared well with HWIND. Ivan was nearly symmetric when it was a category 5 storm on September 12th, but as it began to rapidly weaken to a category 2 prior to making landfall on the U.S. Gulf coast it had a developed a strong asymmetry in the northeast quadrant. Jeanne was a small weak somewhat symmetric hurricane when it was in the looping motion, but as the ridge steered it westward the storm significantly grew in size and intensity while remaining mostly symmetric.

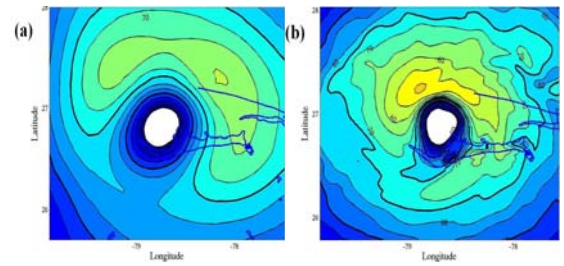

Fig. 2: (a) HWIND and (b) MM5 simulated surface wind speed analysis of Hurricane Frances at 1300 UTC September 4th.

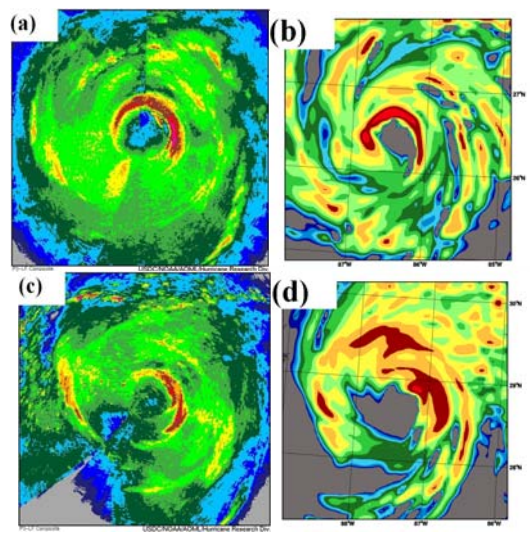

Fig 3: (a and c) NOAA 42 composite reflectivity and (b and d) MM5 reflectivity at 2300 UTC September 14th and 2200 UTC September 15th, respectively.

Fig 3 displays radar and model comparisons with the NOAA 42 aircraft and the MM5 simulation for Hurricane Ivan. Ivan went through oscillations of intensity between a category 4 and 5, mostly due to the eyewall replacement cycles that are evident from the airborne radar on September 12th. On the 13th and 14th, the outer eyewall contracted into one strong eyewall. Fig 3a and b shows Ivan with strong reflectivity values in most of the eyewall, especially the northern portion. However, about 24 hours later, significant structural changes occurred (this is about 6-12 hours prior to the rapid weakening phase). The storm developed a rainfall asymmetry to the north/northeast quadrants. The MM5 simulation forecasted this

process very well as Ivan approached the Gulf coast.

4. SUMMARY

The vortex-following moving nested grid with high-resolution terrain/landuse refinement developed at UM is implanted and working correctly in WRF. The simulations for hurricanes Frances, Ivan and Jeanne display clear similarities with observations. More elaborate comparisons will be made and presented at the conference with the WRF simulations of Frances and Ivan, with a focus on surface properties comparisons between the simulations (landuse, surface fluxes, wind speed, rainfall, etc.)

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5. REFERENCES

Chen, S. S., and J. E. Tenerelli, 2005: Simulation of hurricane lifecycle and inner-core structure using a vortex-following mesh refinement: Sensitivity to model grid resolution. *Mon. Wea. Rev.*, submitted.

Grell, G.A., J. Dudhia, and D.R.Stauffer,1995: A description of the fifth generation Penn State/NCAR Mesoscale Model (MM5). NCAR Tech. Note NCAR/TN 398+STR, 138pp.

Jarvinen B.R., C.J. Neumann, and M.A.S. Davis, 1984: A tropical cyclone data tape for the North Atlantic basin, 1886-1983: Contents, limitations and uses. NOAA Tech. Memo. NWS NHC-22, 21pp.

Marks F.D., R.A. Houze and J. Gamache, 1992: Dual-aircraft investigation of the inner core of Hurricane Norbert. Part I: Kinematic structure. *J. Atmos. Sci*. **49**, 919-942.

Tenerelli, J.E., and S. S. Chen, 2001: High-resolution simulation of Hurricane Floyd (1999) using MM5 with a vortex-following mesh refinement. Preprints, 14th Conference on Numerical Weather Prediction, 30 July – 2 August 2001.Ft. Lauderdale, FL. AMS.