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Front Cover: WSR-88D depiction of Tropical Storm Beryl as it moved northward across the Florida panhandle during the early morning hours of 16 August 1994 (top left and top right), and radar depiction of tornadic supercells (from the remnants of Beryl) near Columbia, South Carolina during the afternoon hours of 16 August 1994 (bottom left and bottom right). Tropical Storm Beryl produced 37 tornadoes as it moved up the Atlantic coast from 16 to 17 August. Tornadoes resulted in more than 50 injuries, and caused property damage in excess to 10 million dollars.

Refer to page 651, paper P3.21, entitled "Tropical Storm Beryl: A WSR-88D Radar Overview," by J. Korotky, NOAA/NWS, Tallahassee, FL, et al.

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NUMERICAL SIMULATION OF HURRICANE ANDREW - RAPID INTENSIFICATION

Joseph L. Eastman
Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

1. Introduction

In this work, a simulation of Hurricane Andrew is presented. Andrew slammed into the southeast Florida coast in August of 1992 and did billions of dollars of damage (Mayfield et al., 1994). While its path was well predicted, its rapid strengthening into a major hurricane was not (Dept. of Commerce, 1993). The Regional Atmospheric Modeling System (RAMS; Pielke et al., 1992; Nicholls et al., 1993), was used to simulate the movement and intensification of Andrew. Currently, no numerical models provide direct intensity forecasts. RAMS includes the explicitly resolved convection, and variable initialization with nudging at the boundaries. The convection is resolved by employing 2-way interactive nesting, with a horizontal grid interval of 5 km on the finest mesh. This mesh moved along with the storm center, so that areas of deep convection were always resolved by the finest grid. A total of 3 grids were employed during the integration. The coarsest grid was 74 by 47 points in the horizontal directions with a grid increment of 80 km. Nested inside the coarse mesh was a movable grid with 20 km increments and a total of 74 by 74 horizontal grid points, and inside this mesh was the fine grid with 71 by 71 horizontal grid points. In all grids the vertical increment was stretched from 100 m at the surface to 1500 m at the top, encompassing a total vertical distance of 26 km. The model was run in a nonhydrostatic compressible mode and used parameterizations of radiation, liquid and ice phase microphysics, surface layer fluxes, and subgrid scale turbulence. Previous models with similar capabilities (Tripoli, 1992) have been used to model tropical cyclones, but their initialization of environmental thermodynamic and dynamic variables was idealized, while this simulation takes environmental variability into account.

2. Initialization

The model was integrated for 72 hours, starting at 12 GMT on 21 August 1992. In order to properly incorporate the environmental conditions present during this period the RAMS isentropic objective analysis program was used to interpolate observed NMC gridded pressure data, upper air rawinsonde data, and surface observations taken within the modeling domain onto the RAMS defined grid. The outer 5 points of the coarse grid served as boundary points for the solution using a nudging technique (Davies, 1976). In this sense the solution represents a simulation rather than a true prediction, although for other RAMS studies, predictive forecast model output has been used for the boundary conditions (Cotton et al., 1994). In any case, for these Andrew simulations, the interior was at least 1000 km from the boundary points and any influence from the boundary points is minimal in the sense they do not directly impact the solutions.

The sea surface temperature, was set to a constant of 28.5 C for this simulation. Initial conditions also included a vortex in gradient wind balance which was introduced at the location of the storm derived from best track data taken at 12 GMT on 21 August 1992. The maximum winds of the vortex were 20 m s^{-1} and located 50 km from the center. The minimum surface pressure was 12 mb below the surrounding environment.

3. Results

Figure 1 provides a summary of the observed and modeled path following the storm center. The time is indicated at six hour intervals along the tracks (date and time in UTC). Also, at each six hour interval the minimum sea-level pressure and maximum sustained winds are shown. The model data is represented by circles, observations by squares. For the first 30 hours shown there was a slow strengthening in both the model storm and observation. The maximum winds increased to roughly 41 m s^{-1} and the pressure dropped roughly 6mb. During the first twelve hours the vortex was in an environment characterized by strong easterly winds at low levels and southerly winds aloft, which agrees well with observations taken at this time. Both the model and observations indicated no well-defined eye.

The period from 22 August at 18 GMT to 23 August at 18 GMT saw the numerical and observed hurricane undergo rapid intensification (RI), at which time Andrew reached a Category 4 on the Saffir/Simpson Hurricane Scale (Simpson, 1974). The pronounced drop in pressure and increase in maximum sustained winds during this period is evident in Figure 1. At the end of this time the difference between the tracks is less than one degree in the north-south direction and slightly greater than one degree in the east-west direction. Although the model hurricane lags the observed sea level pressure by about 7 mb at each time interval, the drops between successive measurements are fairly close. The factors responsible for such rapid intensification is an active area of research for both forecasters and theoreticians.

Figure 1: Perspective view from the southeast shown at 66 hours simulation time. The shaded isosurface is condensate mixing ratio set to 1.9 kg kg^{-1}. Only the 20 km/5 km grids are shown, with the grid boundaries outlined.

Inspection of the observed and model fields show the development of a tropical upper tropospheric trough (TUTT) to the northwest of the hurricane. It has been emphasized by Gray (1979), Challa and Pfeffer (1981), Chen and Gray (1984), Holland and Merrill (1984), and Molinari and Vollaro (1989a,b), that upper tropospheric influences are important in hurricane development. Merrill (1988a,b) and DeMaria et al. (1993) emphasize the importance of TUTTS and mid-latitude troughs in forcing shear over a tropical cyclone. Recently, it has been shown that the National Weather Service operational aviation (AVN) model tends to wash out TUTTS, leading to difficulties in forecasting (Fitzpatrick et al., 1994). This paper does not attempt to quantify upper tropospheric disturbances as a primary forcing mechanism, but point out that the upper level disturbance is simulated. The model-derived shear, calculated as the difference in 850 and 200 mb winds, within a 350 km radius of the center, shows a difference of 10 m s^{-1} just before the onset of RI. It is common for forecasters to use this threshold as a indicator of possible ensuing intensification. The intergovernmental discussions, prepared by the National Hurricane Center during Andrew's advance towards the southeast Florida coast, indicate that the shear was beginning to decrease slightly before the onset of RI. In the model the shear begins decreasing roughly nine hours before RI. At the end of the RI phase, the model-derived shear goes up slightly and the difference stays at a value around 10 m s^{-1}. Further work will attempt to discern the primary mechanism responsible for the RI phase.

The next 36 hours of integration showed further strengthening, with peak wind speeds greater than 70 m s^{-1}. Shown in Figure 2 is a three-dimensional rendering of the modeled cyclone. The grey-scaled field represents an isosurface of total condensate mixing ratio, set to 10^{-4} kg kg^{-1}, taken 60 hours into the simulation. A banded structure can be seen, with several bands extending outside the finest mesh. An eye is also evident with a diameter of 60 km at this time. It should be noted that the observations and the model show eye development at nearly the same time, 22 August at 12 GMT.

By 24 August at 0 GMT the model solution begins to diverge from the observations as it tracks towards the northwest, while the observations showed the cyclone stayed on a westerly track. The simulated hurricane's landfall lagged the observed landfall by about 12 hours. This is still fairly good agreement considering the model has been integrated for more than 3 days of simulation time.

The numerical model results compared favorably for the 3 days simulated by RAMS. Features such as minimum central pressure, maximum wind speeds, and track are well represented by the model. In addition, the RAMS model correctly simulated the period of rapid intensification that Andrew underwent. The model and the observations showed a upper level trough located to the northwest of the cyclone as well as a decrease in the wind shear. Investigation into their impact on intensification is ongoing. Given the advent of parallel computer processing (Cotton et al., 1994) it is not inconceivable that RAMS could be applied in a forecast mode, using the nested grid model (NGM) or other models to force the boundary conditions.

4. ACKNOWLEDGMENTS

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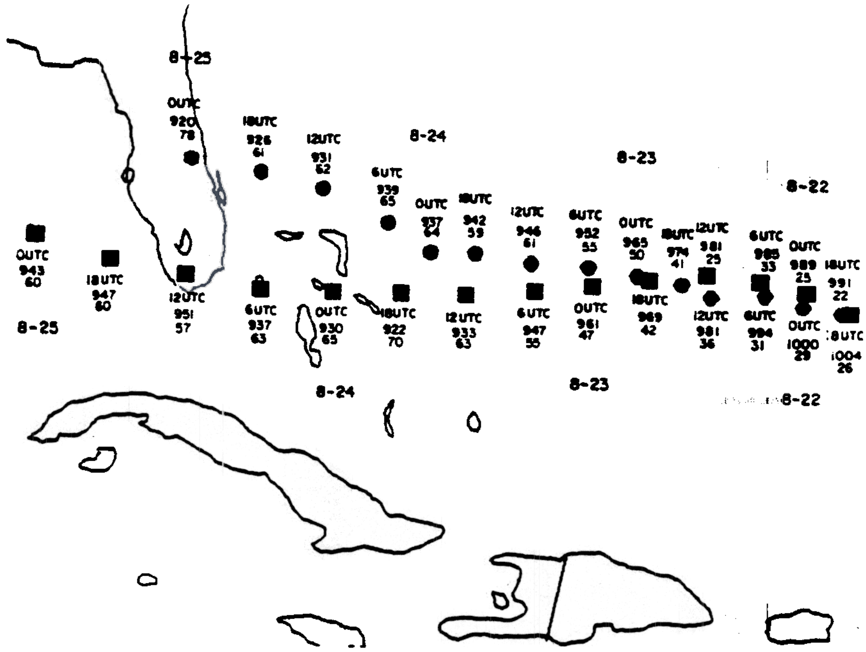

Figure 2: Model track is indicated by circles, observations by squares. Listed above and below the symbols are time (UTC), minimum central pressure (mb), and maximum sustained winds (m s^{-1}), for the model and observations, respectively. The dashed lines above and below the symbols indicate the date for the model and observations, respectively.

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