VORTEX-FOLLOWING MESH REFINEMENT FOR SIMULATING HURRICANES WITH MM5

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1. Introduction

It has long been recognized that grid resolution can have a significant impact on the simulation of hurricanes. Rosenthal (1970) investigated the effect of horizontal grid spacing and lateral diffusion on solutions to the axisymmetric primitive equations and found that the hurricane vortex in a simulation with 10 km radial grid spacing was slightly stronger and exhibited more realistic spatial structure than the vortex in a simulation with 20 km grid spacing. He also demonstrated that this sensitivity was at least partially attributable to the numerical dissipation associated with the discretization of the advective terms in governing equations.

More recently, advances in computing power have made possible three-dimensional simulations of hurricanes. GFDL has developed a three-dimensional primitive equation model that incorporates a mesh refinement scheme in which the fine meshes automatically follow the hurricane vortex (Kurihara et al., 1998). Vortex-following mesh refinement was introduced in the early 1970's (Harrison and Elsberry, 1972; Harrison, 1973) and has since been employed in mesoscale models (Skamarock and Klemp, 1993) in a more general form in which the local truncation error estimates are used to determine where the numerical mesh should be refined (Berger and Colella, 1989). In the case of the GFDL model, fine meshes are moved such that they are centered on the vortex center. Over open water, the vortex center is defined as the centroid of the negative deviation of surface pressure from some reference pressure. Presently the finest mesh has a grid spacing of $1/6^o$.

Recently, a nonhydrostatic version of MM5 has been used to simulate hurricanes with success (Liu et al., 1999; Zhu et al., 2000), but the lack of a vortex-following mesh refinement scheme in the available versions of the MM5 have made high-resolution ($<$ 5 km grid spacing) integrations for periods greater than a few hours impractical. In this paper we introduce a vortex-following mesh refinement scheme into MM5V3 in order to facilitate relatively long ($>$ 4 days) high-resolution simulations.

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2. Methodology

Here we present results from a test of the scheme on Hurricane Floyd (1999). Floyd became an intense category 4 hurricane prior to making landfall in the Bahamas, where it recurved and eventually made landfall in North Carolina. We initialize the model at 0000 UTC 11 September 1999 with the initial fields from the NCEP MRF on a 1.25^ox1.25^o mesh and the NCEP global SST analysis. We use successive 12-hourly initial NCEP model fields for the lateral boundary conditions. The (fixed) coarsest mesh has a grid spacing of 45 km, and the refinement ratio is fixed at 3. There are 28 vertical levels in the model, with 9 levels below 900 mb at the initial time. On both the 45 and 15 km meshes we use an explicit precipitation scheme and a slightly modified Kain-Fritsch cumulus parameterization. The Blackadar PBL scheme is used on all meshes.

We performed four simulations in which we successively added finer meshes. In the control run we employed only the 45 km mesh. In the successive three runs we introduced a 15 km, a 5 km, and finally a 1.67 km mesh in order to determine the effects of increased resolution on the structure of the storm. Each hour during the simulation the vortex center was determined by locating the minimum geopotential height of the 500 mb total pressure surface. The 15 km mesh was moved based on the location of the vortex on the 15 km mesh, while moves for all finer meshes were based on the locations of the vortex in the parent meshes.

3. Results

Fig. 1 shows the observed storm track along with the storm tracks from the four model simulations. The track is generally insensitive to the model resolution. However, the intensity of the modeled storm is sensitive to resolution. Fig. 2 shows the observed and simulated maximum surface wind speed. The 45 km and 15 km simulations produce surface winds that are substantially weaker than observed. By contrast, the 5 km and 1.67 km simulations produce winds in close agreement with observed winds. Fig. 3 shows that the radius of maximum azimuthally averaged surface wind decreases sharply as we introduce finer meshes. For the 45 km simulation the radius of maximum wind exceeds 100 km, while for the 1.67 and 5 km simulations the radius of maximum wind is below 25 km. Aircraft flight-level data (not shown) suggest that the actual radius of maximum wind near the storm's peak varied between 30 and 50 km.

4. Conclusions

In this paper we present results from simulations of Hurricane Floyd using a version of MM5V3 that incorporates a vortex-following mesh refinement scheme. Consistent with past studies using axisymmetric models, we found that as

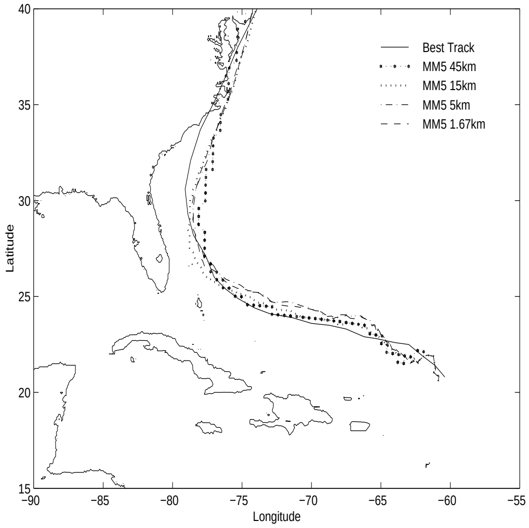

FIG. 1: Hurricane Floyd tracks. Best Track (solid); MM5 45 km (heavy-dot); MM5 15 km (light-dot); MM5 5 km (dash-dot); MM5 1.67 km (dash).

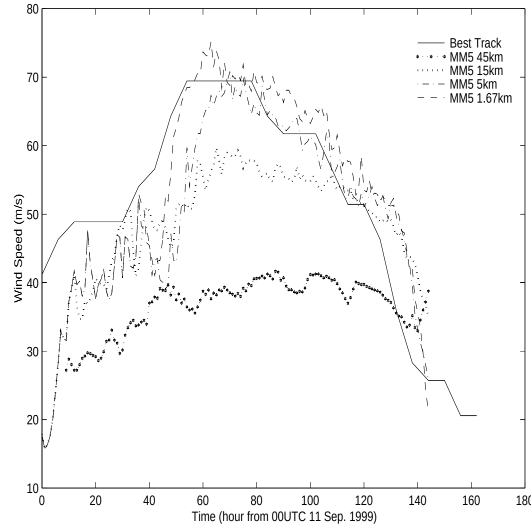

FIG. 2: Hurricane Floyd maximum surface wind speeds. Best Track (solid); MM5 45 km (heavy-dot); MM5 15 km (light-dot); MM5 5 km (dash-dot); MM5 1.67 km (dash).

we refined the mesh around the vortex the simulated vortex strengthened. Although the gross features of Floyd could be simulated with coarse (> 15 km) resolution grids, we found that the intensity and spatial structure of the storm improved as we introduced finer meshes. We are presently examining the influence of the limited size of the fine meshes by performing a series of simulations in which we systematically increase the sizes of the finer meshes.

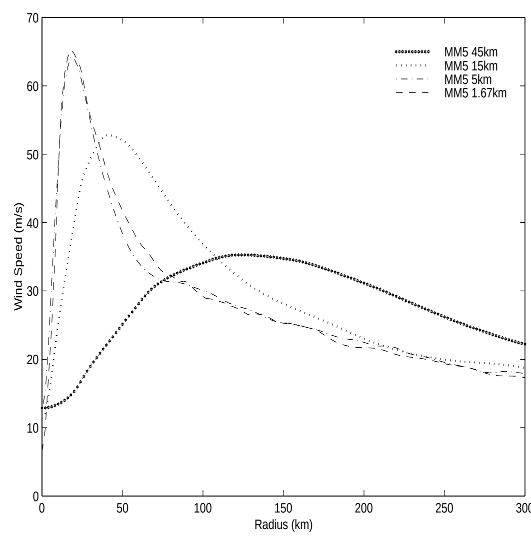

FIG. 3: Radial profiles of azimuthally averaged 10 m wind speed in the four Hurricane Floyd simulations (at roughly the time of peak intensity). 45 km (heavy-dot); 15 km (light-dot); 5 km (dash-dot); 1.67 km (dash).

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