9D.2
INITIALIZATION OF A HURRICANE VORTEX BASED ON SINGLE-DOPPLER RADAR OBSERVATIONS

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1. INTRODUCTION[1]

An initialization scheme for tropical cyclones (TC) has been developed and used to initialize hurricane Danny which occurred in July, 1997. The TC initialization scheme is designed to be used with high resolution mesoscale models such as MM5/WRF. The initialization scheme utilizes the vorticity method to accurately determine the hurricane vortex dynamic structure based on the single Doppler radar wind fields retrieved from the ground-based velocity track display (GBVTD) technique. The GBVTD technique (Lee et al. 1999) retrieves the reliable rotational wind and vorticity of a tropical cyclone from single Doppler radar data. The vorticity method (Sawyer 1949) infers vertical motions dynamically from the vorticity variations in space and in time based on the vorticity equation. The large-scale vorticity method based on the quasi-geostrophic (Q-G) vorticity equation has been successfully used to infer the large-scale divergence fields (e.g., Sardeshmukh and Hoskin 1987; Lee and Browning 1994; Lee et al. 1995). In this study, the mesoscale vorticity method including the tilting term is used to derive hurricane Danny's divergent wind/vertical velocity from the high temporal and spatial vorticity variations retrieved by GBVTD. A four-dimensional data assimilation system (FDDA) based on Newtonian relaxation/nudging is used to generate the dynamically consistent datasets for unobserved fields such as temperature and moisture fields.

2. NUMERICAL METHODS

Numerical methods used to derive the initial field for a tropical cyclone include the vorticity method, GBVTD technique, and FDDA. These methods are described in detail by Sawyer (1949) and Lee et al. (1995) for the vorticity method, Lee et al. (1999) for GBVTD, and Anthes (1974) and Stauffer and Seaman (1990) for FDDA. Following is a brief summary of these methods.

2.1 The Vorticity Method

The variation of vorticity in time and space can be used to derive the vertical velocity through the vorticity equation. The dimensionless vorticity equation can be written in terms of the parameter $\varepsilon = 10^{-1}$ as follows:

$$[\frac{\partial\zeta}{\partial t} + V_h \cdot \nabla_h(\zeta + f) + \varepsilon^n w \frac{\partial\zeta}{\partial z}] =$$

$$-(f + \varepsilon^n\zeta)\,\nabla_h \cdot V_h - \varepsilon^n \vec{k} \cdot \nabla_h w \times \frac{\partial V_h}{\partial z}$$

$$-\varepsilon^{3-2n}\frac{1}{\rho_s^2}\vec{k} \cdot \nabla_h p \times \nabla_h \rho \ , \qquad (1)$$

where

$$n = \begin{cases} 1 & \text{for } L \sim 10^6 \ \text{m} \\ 0 & \text{for } L \sim 10^5 \ \text{m} \end{cases} .$$

The horizontal and vertical components of wind are $V_h = (u, v)$ and w; the vorticity ζ is defined as $\zeta \equiv \partial v/\partial x$ - $\partial u/\partial y$, and f is the Coriolis parameter. The horizontal gradient operator is defined as $\nabla_h = (\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, 0)$. In addition, p and ρ denote pressure and density, respectively.

The vorticity equation, valid for the large-scale and mesoscale motion, is obtained by retaining $O(1)$ terms with $n = 1$ or $n = 0$, respectively. Because $\varepsilon^{3-2n} \ll 1$ for both the large scale and mesoscale, the solenoidal term is negligible to a first approximation in both scales. The vorticity equation with $n = 1$, i.e., the quasi-geostrophic (Q-G) vorticity equation, has been used by Sawyer (1949) to derive the large-scale vertical velocity. More recently, Lee and Browning (1994) and Lee et al., (1995) derived

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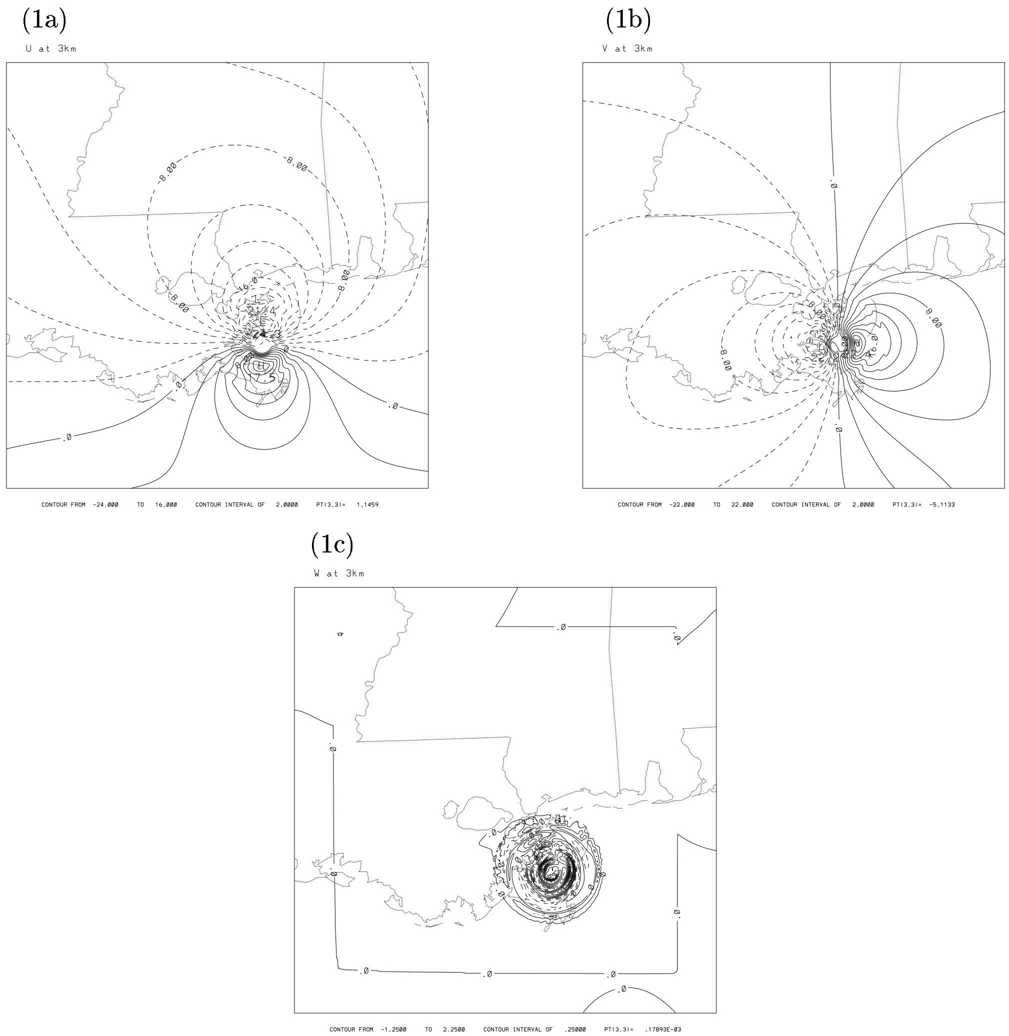

Figure 1: The derived zonal wind (1a), meridional wind (1b), and the vertical velocity (1c) fields at 3-km AGL. The vertical velocity field in ms^{-1} with positive (negative) sign for upward (downward) motions.

the large-scale divergence using the Q-G vorticity equation in conjunction with wind profiler hourly data. In this study, the mesoscale vorticity equation with $n = 0$ is used in conjunction with the high temporal 6-min, 1-km spatial resolution data derived from a single Doppler radar.

2.2 The GBVTD Method

The GBVTD technique (Lee et al. 1999) retrieves tropical cyclone circulation from single-Doppler radar data. It retrieves the rotation part of the tropical cyclone circulation while the asymmetric inflow/outflow part of the circulation is aliased into the rotation part. As a result, the vorticity field is more reliable than the divergence field, which is estimated from the GBVTD-derived wind field. Since the GBVTD-derived 6-min vorticity fields are rather reliable, they can be used with the vorticity method to derive the vertical velocity, and thus, the divergent part of winds.

2.3 FDDA

FDDA provides a flexible way to insert the observations and/or analysis data into a high resolution mesoscale model in a way that the time dependent governing equations provide time as well as spatial continuity and dynamic/physical coupling among various fields. FDDA based on Newtonian relaxation has been shown to be an effective way for dynamical initialization (Stauffer and Seaman 1990). The Fifth Generation Penn State/NCAR mesoscale model (MM5) FDDA with nudging terms is used to gradually nudge the model predicted kinematic wind fields toward the balanced kinematic wind fields obtained by the vorticity method based on GBVTD radar data. The purpose of FDDA in this study is to generate the dynamically consistent temperature and cloud fields as well as kinematic fields below 1 km where no radar observations are available.

3. NUMERICAL RESULTS

Hurricane Danny (1997) approached the data-rich Alabama coast area on 18 July 1997. For this case study, the GBVTD technique has been applied to the Slidell (KLIX) single-Doppler data to derive high temporal resolution of horizontal wind fields. The spatial resolution of the wind data is 1 km in the horizontal and vertical from a minimum height of 1 km above the ground level (AGL) to a maximum height of 10 km AGL. The GBVTD-derived wind fields are used for the computations of the vorticity fields at 04, 09, and 15 min of 1400 UTC, 18 July 1997. The 1-km radar derived wind and vorticity fields are smoothly inserted into large-scale background fields specified based on the Eta model output. These high temporal and spatial wind/vorticity fields are used to derive the vertical velocity using the vorticity method. Figure 1 shows the smooth and balanced horizontal and vertical wind fields at 3 km derived from the initialization. The derived wind fields clearly show the inner structure of Hurricane Danny. The derived wind fields show a much closer agreement with radar observed echoes than the wind fields derived from Eta grid data (not shown). These balanced kinematic wind fields including vertical velocity are interpolated to MM5 FDDA with the horizontal resolution of 1 km to generate a complete balanced initial field including moisture for hurricane predictions. Results from FDDA are under investigated and will be shown in the oral presentation at the conference. Comparisons of the vertical velocity and radar echoes will also be shown in the presentation.

4. DISCUSSION

We have developed a tropical storm initialization scheme that utilizes the vorticity method to accurately determine the hurricane vortex dynamic structure based on the single Doppler radar wind fields retrieved from the ground-based velocity track display (GBVTD) technique. The GBVTD technique retrieves the reliable rotational wind and vorticity of a tropical cyclone from single Doppler radar data. Based on the momentum conservation, the vorticity method derives the hurricane divergent wind/vertical velocity from the high temporal and spatial vorticity variations retrieved by GBVTD. The divergent wind field inferred dynamically and the rotational wind observed from single Doppler radar data are combined to form the total balanced wind field, including the vertical velocity in a hurricane vortex. Finally FDDA is used to generate the unobserved balanced fields including temperature and moisture. A balanced tropical cyclone derived from the vorticity method based on GBVTD-derived winds from a single-Doppler radar can be used to initialize high resolution mesoscale models such as MM5/WRF to improve storm track and intensity forecast of tropical cyclones.

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