P4R.4 CHARACTERIZING TORNADOES IN MULTIPLE-DOPPLER RADAR DATA USING A LOW-ORDER MODEL

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1. INTRODUCTION

Several methods have been used to fit low-order models of velocity fields to radial velocity data from a single Doppler radar. The Velocity-Azimuth Display (VAD; Lhermite and Atlas 1962) and Volume Velocity Processing (VVP; Waldteufel and Corbin 1979) techniques use spatially-linear wind models, and are often successful as long as the conditions for their validity are approximately met. A relatively new class of low-order wind models is being used to analyze hurricanes and tornadoes: the Velocity Track Display (VTD, Lee et al. 1994), Extended Velocity Track Display (EVTD; Roux and Marks 1996) and the Ground-Based Velocity Track Display (GBVTD, Lee at al. 1999, Lee and Marks 2000). These methods seek to obtain the key axisymmetric and low-order asymmetric components of the tangential wind from a harmonic analysis of radial velocity data from a single Doppler radar.

A new multiple-Doppler radar analysis technique is being developed for the objective detection and characterization of tornadoes. Observed radial wind data is fit to an analytical low-order model of a tornado in order to retrieve key characteristics of the wind field, particularly the location, movement and strength of the tornado. This technique is being designed for use within the network of densely-spaced, adaptively scanning radars envisioned by the CASA (Collaborative Adaptive Sensing of the Atmosphere) Engineering Research Center (McLaughlin et al. 2005).

2. LOW-ORDER MODEL

The tornado model is a combination of four idealized flow fields: a uniform flow, linear shear flow, linear divergence flow, and modified combined Rankine vortex (representing the tornado). The latter three fields are allowed to translate with different speeds and directions. The model is described using 19 parameters, including vortex center, translation, and radius, as well as maxima and decay exponents for the tangential and radial wind components. Model winds are projected in the direction of the radar(s) to obtain the model radial wind.

3. OPTIMIZATION

A cost-functional *J* accounts for the discrepancy between model and observed radial wind:

$$J \equiv \sum_{n=1}^{N} \int_{A_n} [v_{r_n}^{obs} - \hat{r}_n \cdot (u\hat{i} + v\hat{j})]^2 \, dA_n$$

where $v_{r_n}^{obs}$ is the radial wind data from the n'th radar, $\hat{r}_n$ is the unit vector at an analysis point associated with the n'th radar, *u* and *v* are the Cartesian velocity components in the low-order model, and A_n is the four-dimensional domain of integration for each radar. *J* is evaluated over both space and time so that observations can be used at the time they were acquired, thus bypassing the need for time interpolation, moving reference frames or other ad-hoc procedures. Since the model radial wind is calculated from a set of nonlinear equations in the unknown parameters, *J* generally cannot be minimized by linear minimization methods. Instead, the Fletcher-Reeves conjugate-gradient algorithm is used to minimize *J* and so determine the low-order model parameters (Fletcher and Reeves 1964).

4. SCANNING STRATEGY

The two emulated radars are located at adjacent corners of a 10 km square domain. Our test observation set is analytically derived from the low-order model. A 200 m diameter tornado with maximum tangential wind of 50 m/s and maximum radial wind of 10 m/s is simulated near the center of the domain, with translational speed of about 15 m/s. Wind decay exponents in the vortex field are set to one.

The optimal radar scanning strategy for minimizing *J* is being investigated. For the test case, we have found there to be sufficient spatial-scale separation between the broadscale and vortex wind fields to allow for the two flows to be optimized independently. This method has been far more successful in determining the model flow parameters than optimizing both flows simultaneously. Our current general strategy is to 1) optimize the broadscale parameters by scanning outside of the region potentially affected by the vortex flow, 2) estimate the vortex center by scanning over many sub-regions within the domain where the vortex is potentially located, 3) simultaneously minimize all vortex parameters by scanning around the vortex center

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determined in the previous step, then (4) iterate some or all of the above steps until J is satisfactorily minimized.

5. FUTURE WORK

The model will be tested against an ARPS (Advanced Regional Predicting System) dataset of a tornado (Figure 1), as well as real radar observations. Level I data (power spectra) will be used to address the degradation of azimuthal resolution with distance from the radar. The threat of multiple solutions will also be assessed.

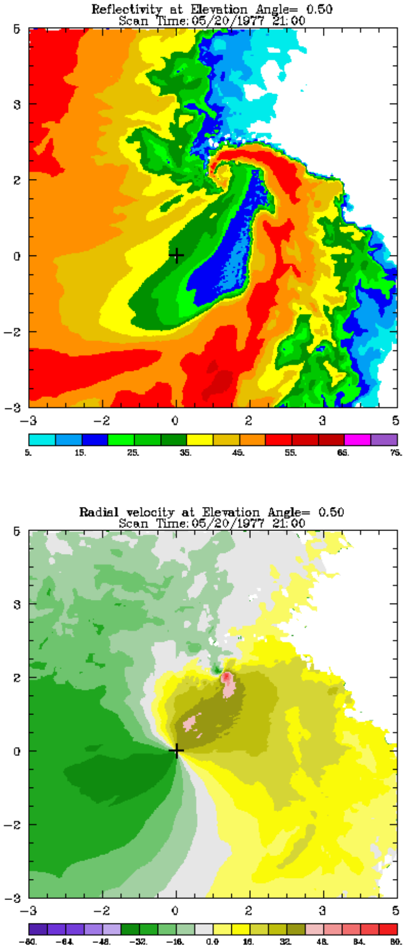

Fig. 1. Emulated radar observation of reflectivity (top panel) and radial velocity (bottom panel) of model simulated tornado to be fit to low-order model. The radar location is marked by a cross.

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