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THE 12 MAY 2004 HARPER, KS TORNADO: ANALYSIS OF DOW RADAR OBSERVATIONS OF THE LOW LEVEL WIND FIELD

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1. Introduction

The near surface wind field of a tornado is a complex interaction of three regions of flow: the swirling boundary layer, the vertically-erupting corner region and the core flow. These regions of low level vortex flow are directly responsible for damage sustained at the surface, yet they are the least understood. Mobile Doppler radars have been very successful in providing high-resolution, near-surface observations of tornadoes. Much of the data obtained, however, is single-Doppler; thus in order to retrieve kinematic and dynamic properties of the 3D wind field, some simplifying assumptions need to be made *a priori* about the nature of the flow.

The initial quantities that need to be extracted from single-radar observations are the radial (u) and tangential (v) wind components. Once retrieved, the vertical velocity and the perturbation pressure can be derived from the continuity equation and the horizontal momentum equations, respectively. Dowell et al. (2005) derived an axisymmetric vortex model to retrieve the azimuthally-averaged (wavenumber 0) u and v velocity components. It is this model that will be used in the analysis of the Harper, KS tornado.

2. Data and Methodology

2.1 *Overview of the data*

The X-band Doppler on Wheels (DOW, Wurman et al. 1997) collected data on several tornadoes that occurred in Harper County, KS on 12 May 2004. A few structures sustained varying degrees of damage throughout the event; consequently the tornadoes received F-scale ratings between F-0 and F-4. An initial analysis period between 01:39:33 and 01:42:20 UTC was chosen due to the proximity of the radar to the tornado and the strengthening of the tornado.

During this time, the DOW sampled the tornado at a range of approximately 1.5--3 km, corresponding to lowest beam (0.3º) heights between 9 and 15 m AGL. Gate spacing varied between 12.5 m, in earlier observations, to 25 m in later observations. The use of a staggered pulse repetition frequency increased the Nyquist velocity to ±128 m/s, eliminating the need to unfold the velocities. Only data from heights around or below 100 m, usually from the lowest 4-7 elevation scans, were used in the analysis of the wind field. Ground clutter was subjectively removed from the data using the NCAR SOLOII software (Oye, 1995). Although the lowest elevation scans were often severely contaminated by ground clutter/beam blockage in the vicinity of the tornado, they were not excluded from the analysis.

2.2 *Retrievals*

The axisymmetric model is a superposition of divergent and rotational flows. Included in the model is the background flow (i.e., the tornado motion), which is determined *a priori* by tracking the movement of the center of circulation through several volume scans. By minimizing the following function in a least squares sense around an annulus surrounding the tornado center, the radial (u) and tangential (v) winds were retrieved:

$$J = \sum_i [D_i - u\cos(\alpha_i - \theta_i) - v\sin(\alpha_i - \theta_i) \\ - C\cos(\beta - \theta_i)]^2 \qquad (1)$$

where D is the observed Doppler velocity, α is the angle of the observation with respect to the tornado center, θ is the angle of the observation with respect to the radar, C is the translation speed of the tornado, β is the translational angle of the tornado with respect to the tornado center, and i refers to the index of the observation along the annulus (Figure 1). Since axisymmetry is assumed, the divergence can be calculated from the radial wind component.

Implicit in the formulation of (1), is the assumption that the radar is only sampling the horizontal wind field (i.e., the vertical velocity is

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negligible). When applied to low elevation angles, as in the current study, this is a reasonable assumption. It should be noted, however, that the implementation of the axisymmetric model is sensitive to the location of the tornado center. Currently a more robust, center-finding algorithm is being developed.

Before applying the model, an extra step was taken to interpolate the data to a Cartesian grid using NCAR's SPRINT software package. A grid spacing of 32 m was chosen to accommodate the varied azimuthal and range resolutions.

3. Preliminary Results

The tornado rapidly intensified throughout the brief analysis period as manifested by an increase in the retrieved tangential winds (Figure 2). During the first volume scan, the circulation was rather broad, with a radius of maximum winds around 200 m. Retrieved tangential winds were correspondingly low; on the order of 40 m/s. By the next volume scan the radius of maximum winds had decreased and the tangential winds had increased at all levels. The tornado continued to intensify into the third volume scan where the peak axisymmetric tangential wind speed of 64 m/s occurred at an elevation of approximately 65 m AGL (Figure 3).

The largest retrieved velocities were slightly elevated, not observed to occur within the lowest elevation scan. Thus data from the lowest elevations (~ 15 m AGL) may be within the viscous boundary layer. The observation of the largest velocities occurring at ~ 50 m AGL is consistent with limited, previous low level observations (Wurman and Alexander, 2005). It is also possible, though, that the intensification was not temporally resolved or that beam blockage obscured the data at the lowest level.

4. Future Work

The results presented thus far have demonstrated the feasibility of using an axisymmetric vortex model to retrieve the horizontal velocity components. Therefore the next step will be to retrieve the vertical velocity, by integration of the continuity equation, and the perturbation pressure, following the pressure retrieval approach of Gal-Chen (1978) and Hane and Scott (1978). We will apply these methods to our preliminary analysis period as well as over a more comprehensive time interval. Additionally, we plan to apply this procedure to other cases, as they become available, with the possibility of relating the near-surface wind characteristics to structural and tree damage sustained during these events.

The high-resolution DOW radar observations and subsequent retrievals provide needed data to incorporate into the LES modeling of tornadoes. We will be adapting the NCAR LES model (Moeng, 1984) to study tornadic flow. Additionally, we plan to incorporate DOW radar data to constrain and/or parameterize the model with the objective that the assimilation of radar data at the tornadic scale will lead to a more complete understanding of the complex interactions of the low level flow.

5. References

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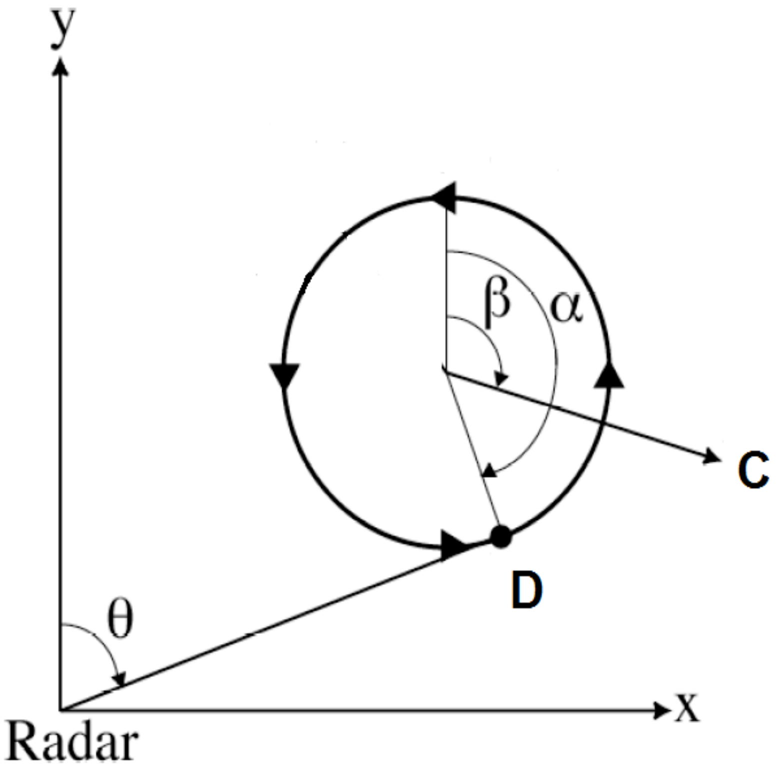


Figure 1: Illustration of the geometry used in the axisymmetric vortex model. Symbols are the same as in the text. Adapted from Wurman and Alexander (2005b).

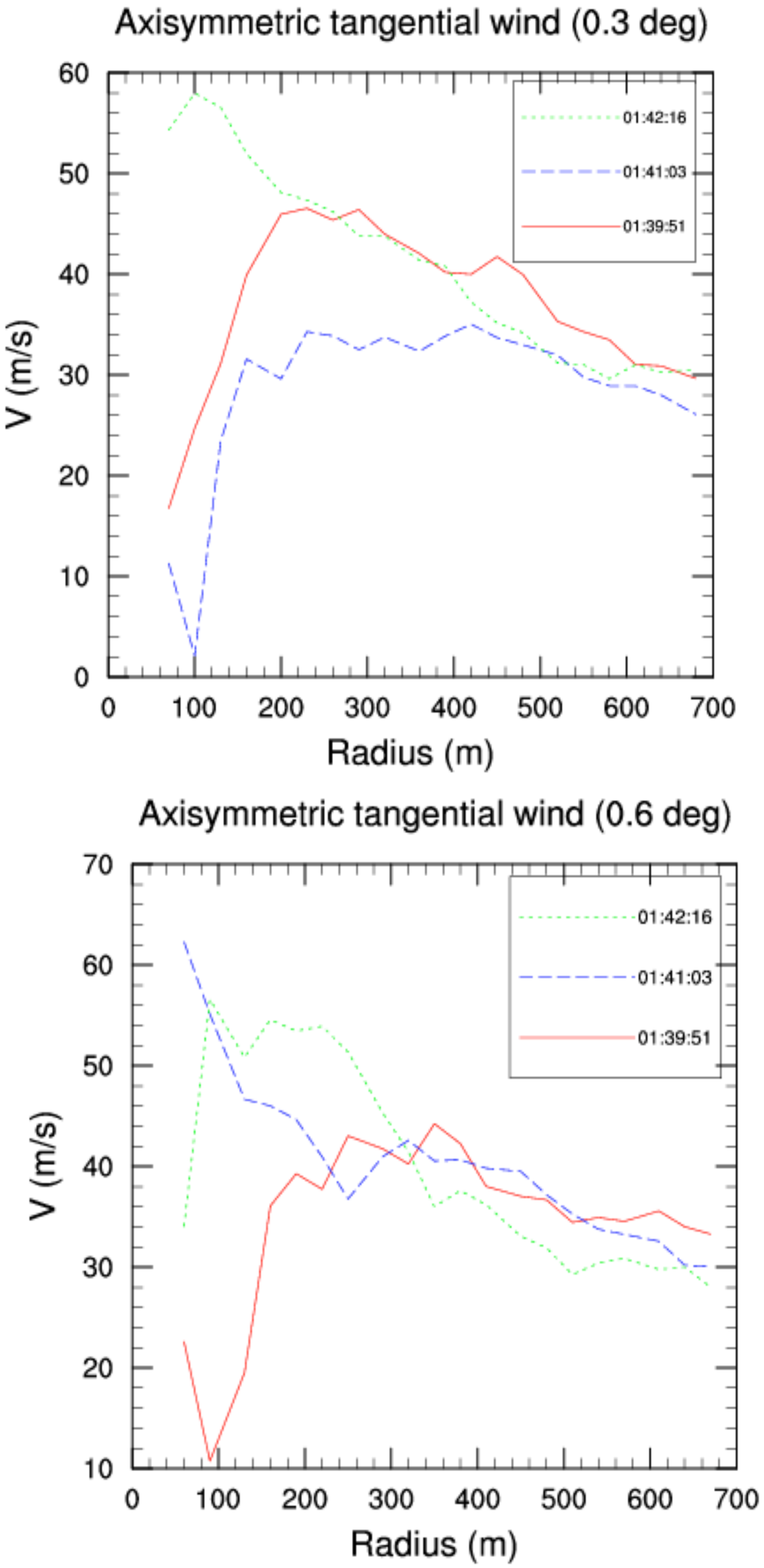


Figure 1: Axisymmetric tangential velocity as a function of time for 5 different elevations.

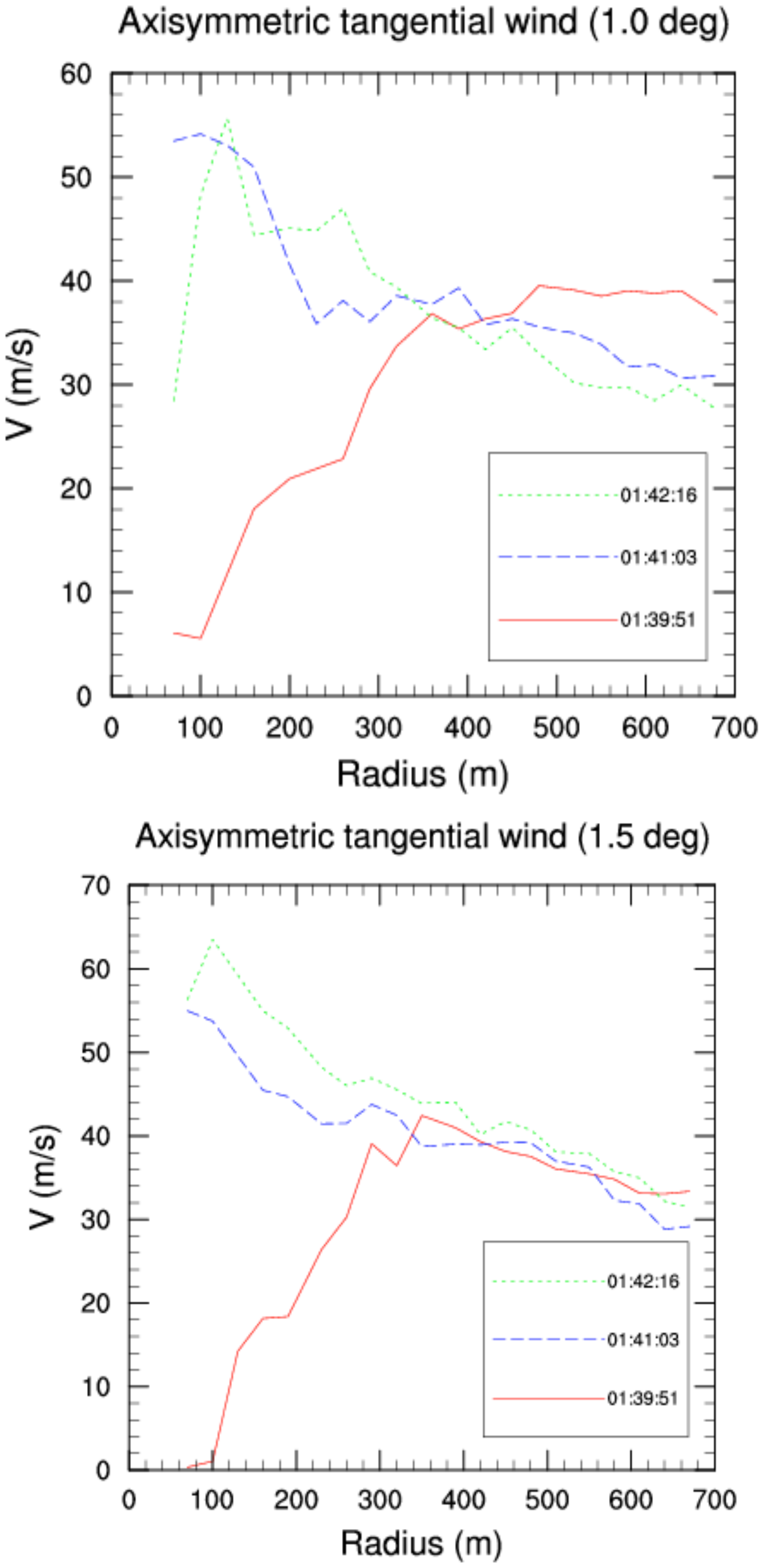
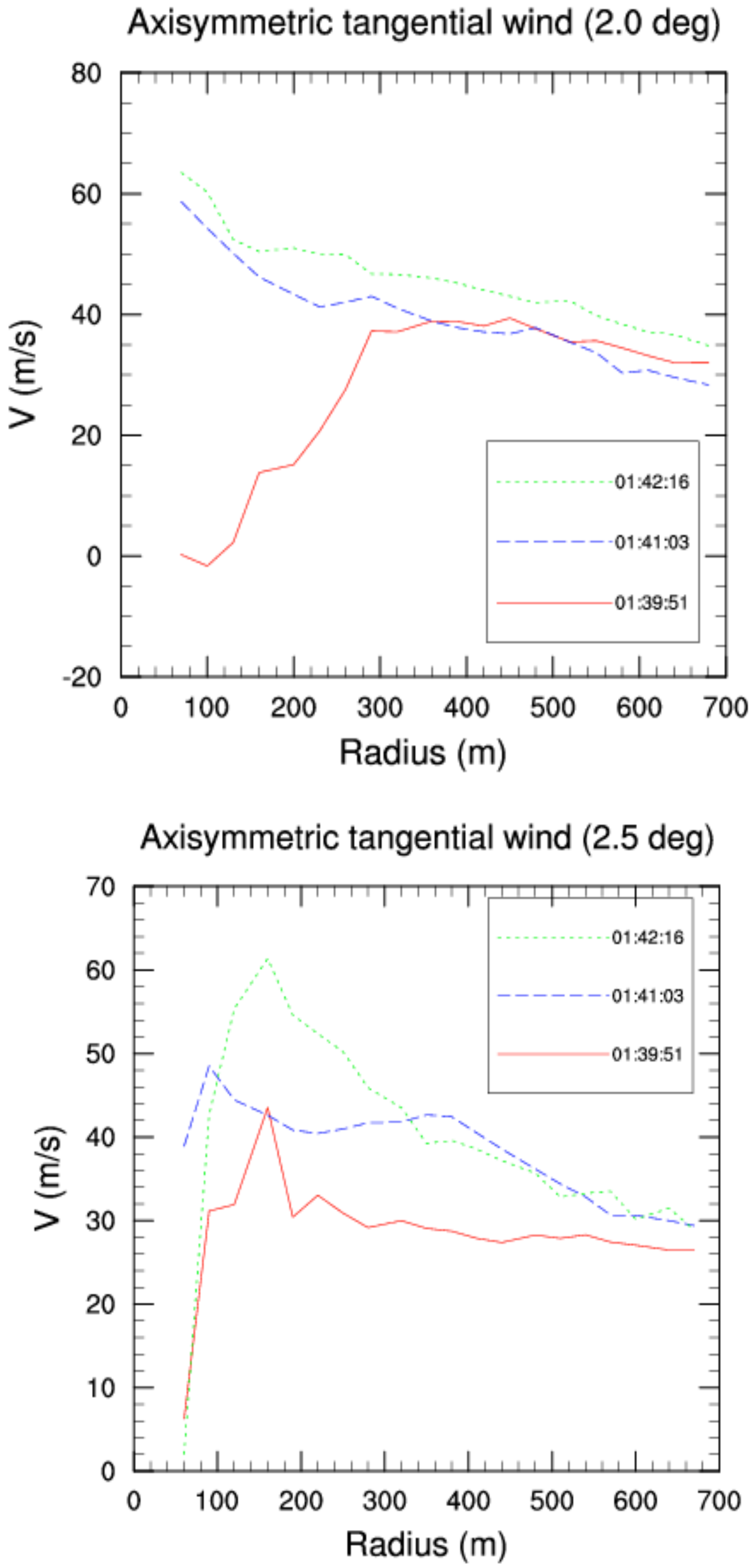


Figure 1: (continued)



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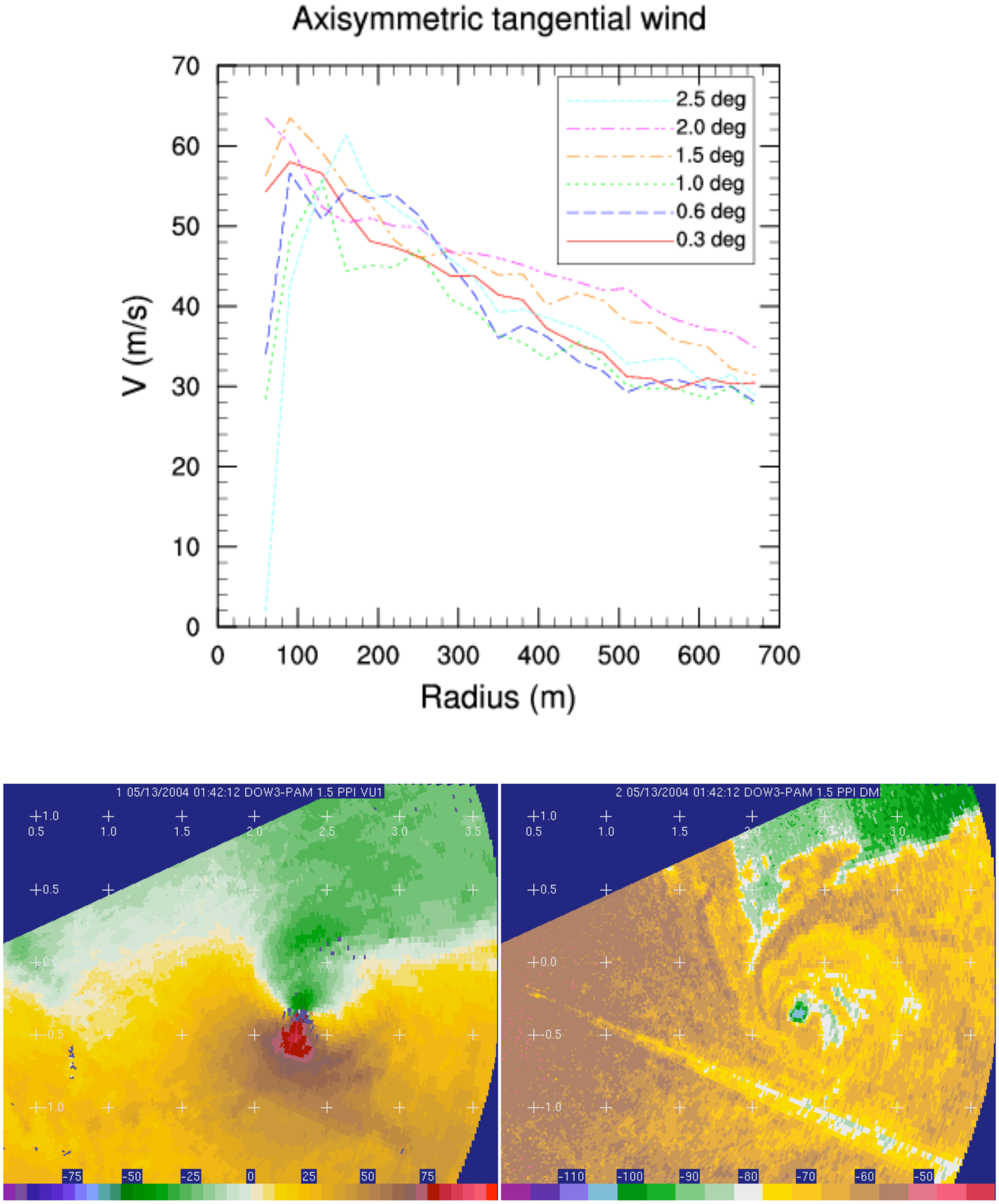

Figure 2: (a) Axisymmetric tangential wind as a function of elevation angle between 01:41:58--01:42:16, when the tornado was most intense; (b) Corresponding velocity (VU1) and received power (DM) for 1.5º beam at 01:42:12. Tick marks are every 0.5 km.