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Near-Surface Thunderstorm Outflow Characteristics Observed by the TTUKa Mobile Doppler Radars

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Introduction

Severe convective outflow events are of interest to the wind engineering community as they are the dominant extreme wind type for much of the inland midlatitudes. However, building design codes (ACSE 7-05) do not currently incorporate turbulence and velocity characteristics unique to thunderstorm outflow (Letchford et al. 2002), in part because of the limited availability of full-scale observations of extreme convective outflows to be used as the basis for wind tunnel and wall jet experiments (Orwig and Schroeder 2007, Holmes et al. 2008). The difficulty in obtaining research-grade wind observations in extreme convective outflow events from fixed-site anemometers coupled with the growing fleet of mobile Doppler radars suggests that the ability to remotely sense the turbulence characteristics of convective outflow would benefit the wind engineering community.

This study will assess the ability of the two Texas Tech University Ka-band (TTUKa) mobile Doppler radars (Weiss et al. 2009) to remotely sense the turbulence intensity, defined as the ratio of the standard deviation of the wind to the mean wind ($I_u = \sigma_u / \mu$), in two convective outflow events:

- The passage of a nonsevere mesoscale convective system over the Texas Tech Wind Science and Engineering Field Site on 15 June 2012 (Gunter and Schroeder 2012) will be used to assess the representativeness of TTUKa-derived turbulence intensities by comparing them to UVW anemometry installed on a 200 m instrumented tower located near the 90° beam crossing angle of the TTUKa radars.

- TTUKa-derived turbulence intensities will then be calculated for multiple internal rear-flank downdraft (RFD) momentum surges occurring within the 18 May 2010 Dumas, Texas supercell observed by the second Verification of the Origin of Rotation in Tornadoes Experiment (VORTEX2)

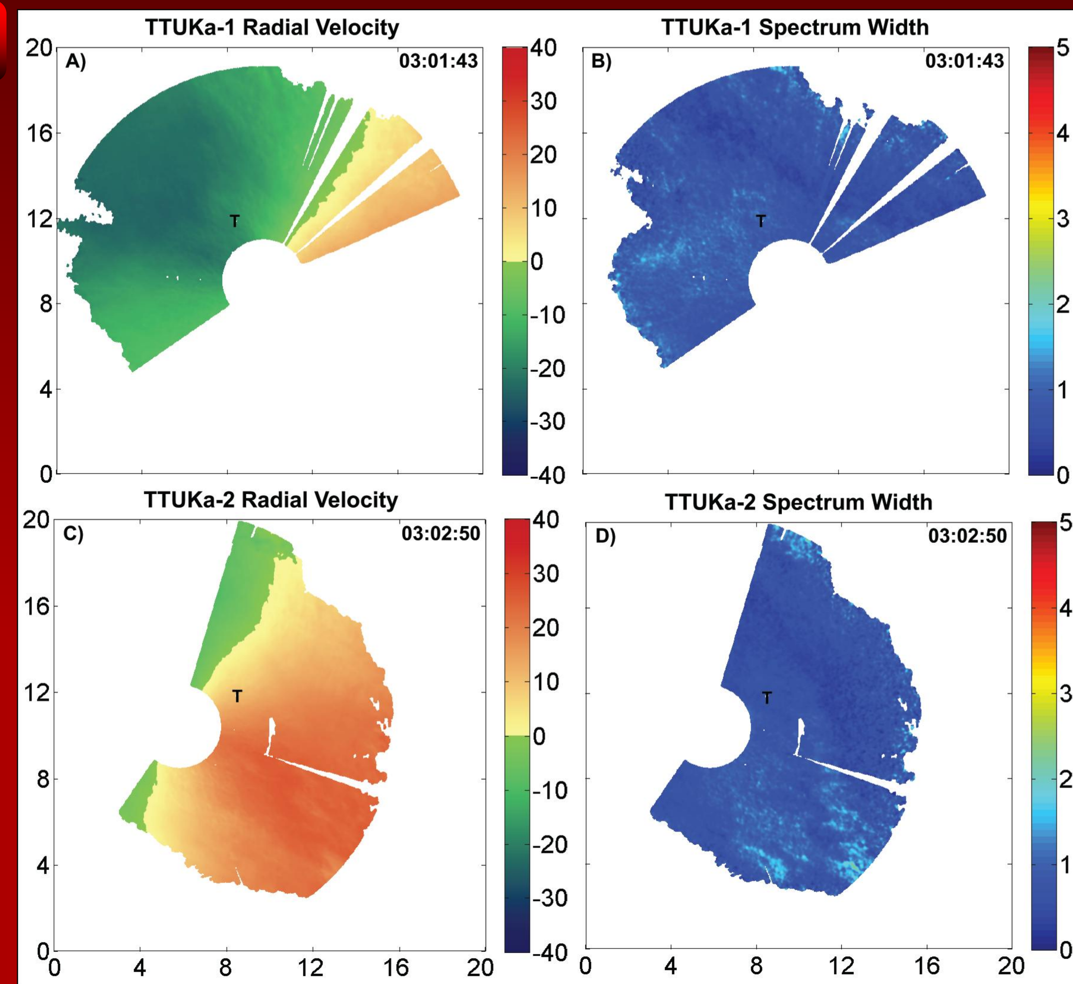

Figure 1. Objectively analyzed TTUKa radial velocity (m s^{-1}) (A, C) and spectrum width (m s^{-1}) (B, D) 1.0° elevation angle PPIs from 15 June 2012. Bold "T" represents location of the 200m instrumented tower.

Methodology

As Doppler radar returns include the volumetric mean radial velocity of each scatterer in each volume and the variance of the radial velocity for each volume given by the spectral width, they provide the necessary information to compute turbulence intensity (Fig. 1). Turbulence intensity is typically calculated for the longitudinal and lateral standard deviation of the wind divided by the mean wind speed over a given period. For TTUKa data, the two dimensional dual-Doppler synthesis of the wind speed is utilized as the mean and the square root of the turbulent component of TTUKa-1 and TTUKa-2 radial spectrum width is used in place of the lateral and longitudinal components of the standard deviation of the wind. The spectrum width moment of Doppler radar returns is impacted by several phenomena besides the turbulent variation of the radial wind within each gate (Istok and Doviak 1986):

$$\sigma_v^2 = \sigma_s^2 + \sigma_a^2 + \sigma_d^2 + \sigma_o^2 + \sigma_t^2$$

where σ_v represents the returned spectrum width and the terms on the right-hand side of the equation represent contributions by the wind shear, antenna rotation, differences in hydrometeor fall speed, changes in hydrometeor orientation and turbulence to the total spectrum width. The low elevation angles and relatively slow antenna rotation rate utilized by the TTUKa radars for the deployments considered herein allow the components of antenna rotation and hydrometeor fall speed and orientation to be neglected and the turbulent contribution to spectrum width can be retrieved by subtracting an estimation of the wind shear contribution from the total. The horizontal wind shear across each grid space is estimated using finite differencing across the objectively analyzed sweep, vertical wind shear is estimated using a linearly interpolated mean profile of 200 m tower data for the 15 June case and neglected for the 18 May case.

TTUKa data are subjectively edited to remove regions of aliasing, ground clutter and incoherency prior to objective analysis, which is performed as in Majcen et al. 2008. Regions where the center-beam height difference of the 1° elevation angle scans on 15 June exceeds 25 m are removed from the analysis (Fig. 2) and data collected on 18 May were at a 0° elevation angle. UVW anemometer data from the 74 m level of the 200 m instrumented tower were used for comparison with TTUKa turbulence intensities. UVW data were averaged using a 20 s moving average and variance from the mean was separated into radial TTUKa-1 and TTUKa-2 components.

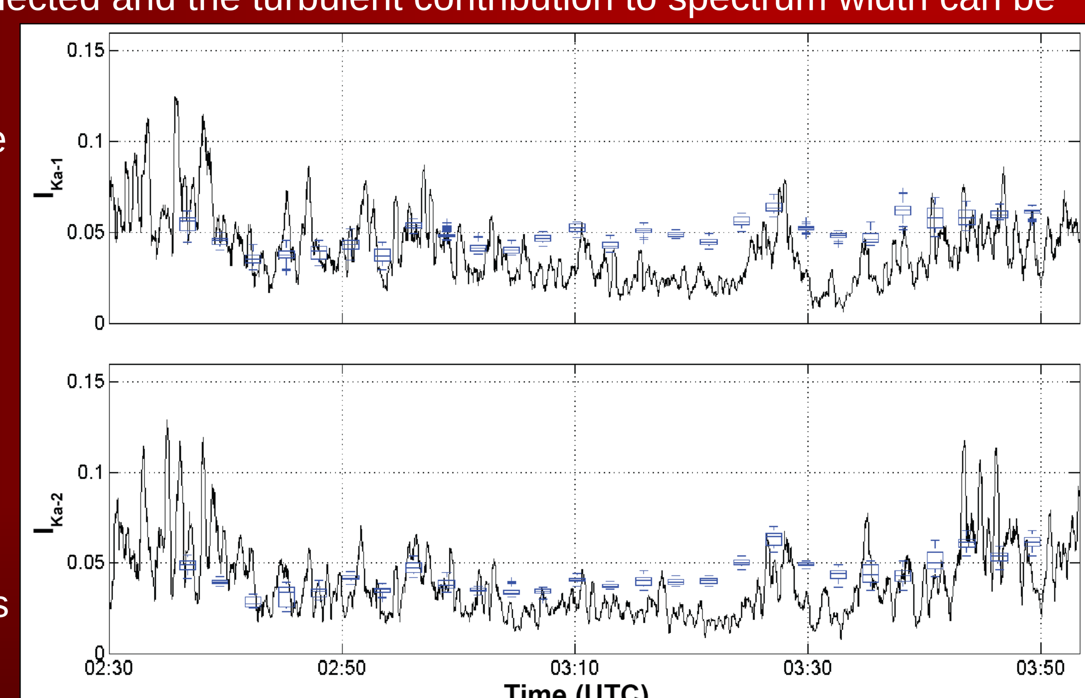

Figure 3. (top) Time series of 74 m tower UVW turbulence intensity of the TTUKa-1 radial component of the wind with box and whisker plots of TTUKa-1 derived turbulence intensities within a 150 x 400 m rectangle upstream of the tower (Fig. 2a). (bottom) As in the top panel but for the TTUKa-2 radial component of the wind.

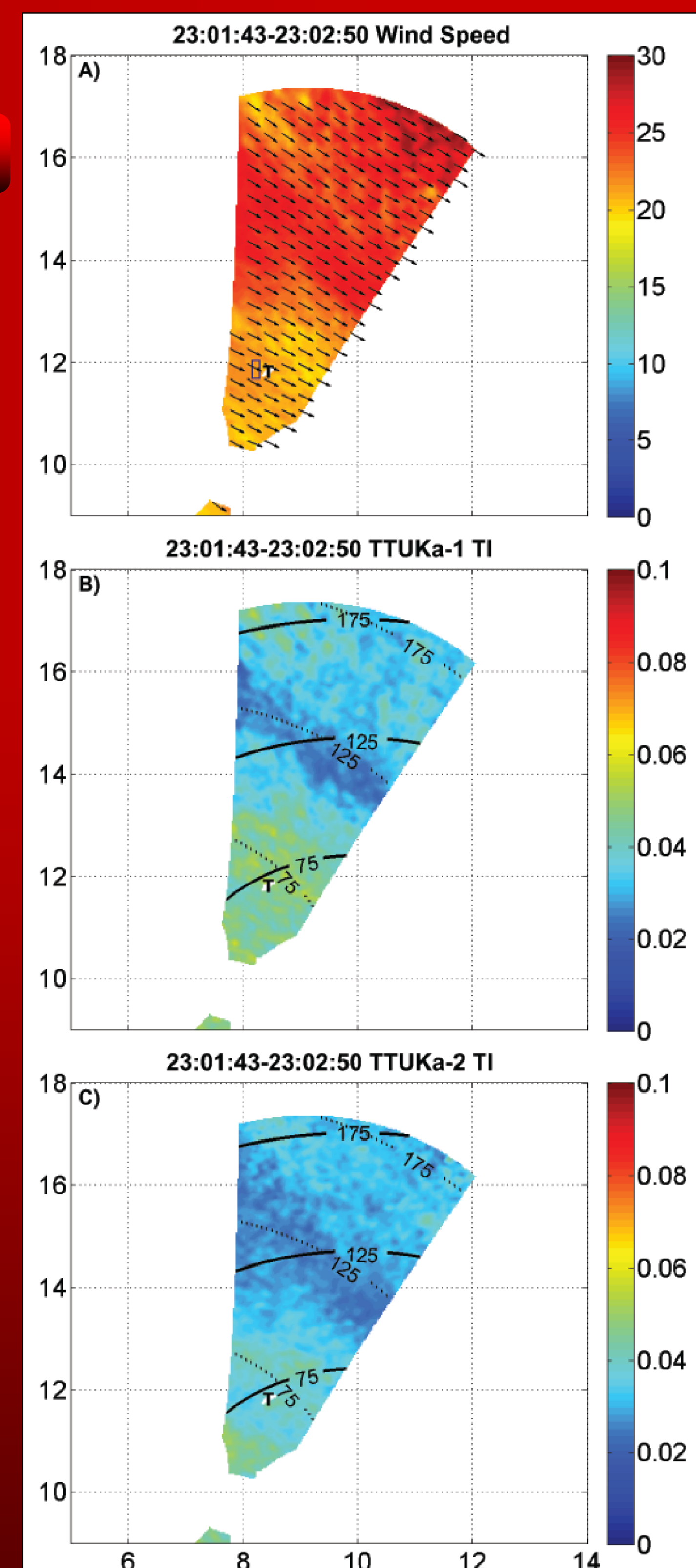

Figure 2. (A) Dual-Doppler synthesis of radial velocity scans in Fig. 1, (B) TTUKa-1 derived turbulence intensities and (C) TTUKa-2 derived turbulence intensities. Thin rectangle, solid(dashed) contours and "T" denote region used for 200m tower comparison in Fig. 3, center beam height of TTUKa-1(TTUKa-2) and location of 200m instrumented tower.

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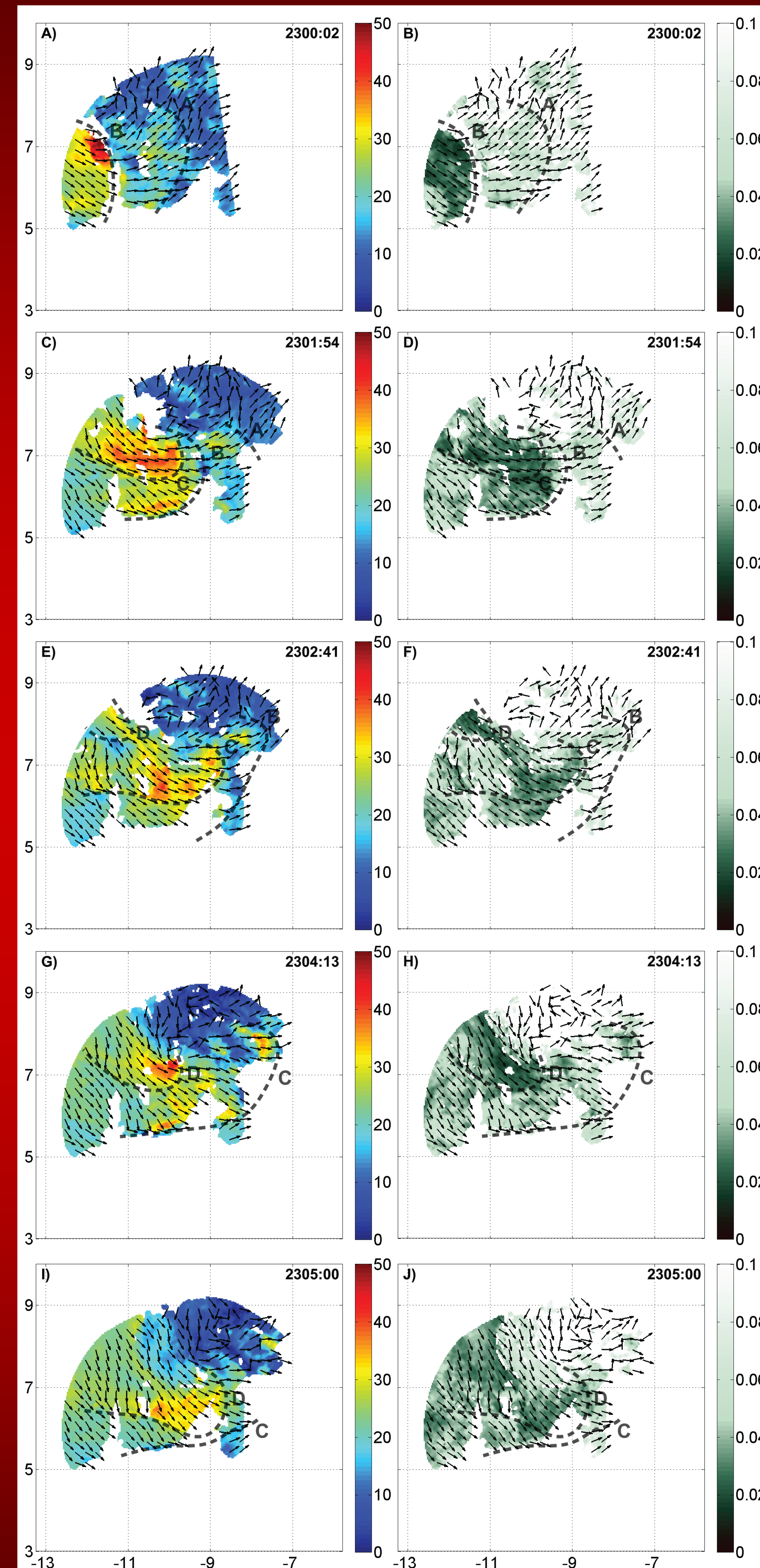

Figure 4. (A, C, E, G, I) TTUKa dual-Doppler syntheses of the 18 May 2010 Dumas, TX supercell. (B, D, F, H, J) Corresponding TTUKa-2 derived turbulence intensities. Dashed lines indicate subjectively analyzed position of internal RFD surge gust fronts.

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Figure 5. Photograph looking north towards the Dumas supercell taken during the TTUKa dual-Doppler deployment from a location south of TTUKa-2 by the Lyndon State College and National Center for Atmospheric Research photogrammetry team A. Estimated position of internal RFD surge gust fronts are labeled with dashed lines and "V" denotes a wall cloud associated with a brief, intense circulation north of the apex of surge D.

Results and Limitations

TTUKa radial velocities and dual-Doppler syntheses of the 15 June case show a relatively consistent northwest wind which increases with height and exhibits low spectrum widths and turbulence intensities (Figs 1, 2), which agrees with data collected by the 200 m instrumented tower (Fig. 3) and previous results collected in thunderstorm outflow (Orwig and Schroeder 2007, Holmes et al. 2008). Comparison of the 74 m UVW turbulence intensities and the TTUKa-derived turbulence intensities in a 150 x 400 m rectangle upstream of the 200 m tower generally agree well (Fig. 3). However, it is apparent that TTUKa-derived turbulence intensities show less variation throughout the time period than UVW turbulence intensities. This likely arises due to the objective analysis of spectrum width utilized in the calculation of TTUKa turbulence intensities, which will smooth spectrum width values and result in less variation than what the raw spectrum width values would produce. Additionally, the lack of synchronous PPI scans for this case will limit the ability of the dual-Doppler syntheses to capture transient variations in the wind and result in a smoother turbulence intensity profile.

In the 18 May case, the TTUKa-derived turbulence intensities are considered to assess the evolution of four internal RFD surges across the dual-Doppler domain (Figs. 4, 5). The turbulence intensities within the RFD surges are typically very low, less than 0.06, which is far below what is expected in synoptic-scale wind events (ASCE 7-05) and below values calculated from anemometer data in prior thunderstorm cases (Holmes et al. 2008). This may be attributed to the sampling of RFD surge winds near the time they first impact the surface. It can be seen that turbulence intensities are at a minimum when RFD surges are first captured by the dual-Doppler synthesis and increase with time as the surge wraps cyclonically around the near-surface circulation. This increase in turbulence intensity with time is due to both deceleration of the mean wind speed and an increase in spectrum width, which is consistent with the mechanical generation of turbulent eddies as air parcels within the RFD surges interact with the surface. Additionally, radar specific issues such as turbulent eddies larger than the TTUKa resolution bin and artificially low spectrum widths due to hydrometeors being imperfect tracers (Brewster and Zrnic 1986) may induce a low bias in TTUKa-derived turbulence intensities.

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