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 (ASCE 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 (Dray 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 availability of mobile Doppler radars (Weiss et al. 2009) 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 ($\sigma_v/v$), in two convective outflow events:

1. 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 UWV anemometry installed on a 200 m instrumented tower located near the 90° beam crossing angle of the TTUKas.
2. 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 Turbulent Experiment (VORTEX2).

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 ($I_v$). Turbulence intensity is typically calculated for the longitudinal and lateral components of the wind, but the vector component of the wind is used in this analysis. The spectral width is obtained from the Doppler radar 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 $TTUKa$ and $TTUKa$ radial spectral width is used in place of the lateral and longitudinal components of the wind. The variance of Doppler velocity at each grid space is estimated using finite differences by the object analysis software. The variance of Doppler velocity at each grid space is estimated using finite differences by the object analysis software.

$$\sigma_v^2 = \sigma_v^2 + \sigma_o^2 + \sigma_I^2 = \sigma_v^2$$

where $\sigma_v$ represents the returned spectrum width and the terms on the right-hand side of the equation represent contributions

1. by the wind shear, antenna rotation, differences in hydrometeor fall speed, and orientation to be neglected and the turbulent contribution to spectrum width can be removed by subtracting the wind shear contribution from the total. The horizontal wind shear across each grid space is estimated using finite differences by the object analysis software. Vertical wind shear is estimated using a linearly interpolated mean velocity of 200 m instrumented tower data for the 15 June case and for the 18 May case.

TTUKa data are subjectively edited to remove regions of aliasing, ground clutter and incompleteness prior to objective analysis, which is performed as in Majcen et al. (2008). Regions where the center beam height difference of the 1st elevation angle scans exceed 15 m are removed from the analysis (Fig. 2) and data collected by 18 May were at a 1° elevation angle. UWV anemometer data from the 74 m level of the 200 m instrumented tower were used for comparison with TTUKa turbulence intensities.

UWV data were averaged using a 20 m moving standard deviation of the mean profiles from the divided 400 m instrumented tower into radial TTUKa and TTUKa-2 components.

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 (Dray and Schroeder 2007, Holmes et al. 2008). Comparison of the 74 m UWV turbulence intensities and the TTUKa-derived turbulence intensities in a 150 x 400 m rectangle upstream of the 200 m tower generally agrees well (Fig. 3). However, it is apparent that TTUKa-derived turbulence intensities show less variation throughout the time period than UWV turbulence intensities. This likely results due to the objective analysis of spectrum width utilized in the calculation of 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 Dumas area (Figs. 4, 5). The turbulence intensities within the RFD surges are typically very low, less than 0.15, which is very low due to the lack of expectations 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 syntheses and increase with time as the surge wraps cyclonically around the near-surface circulation. This increase in turbulence intensity is due to both deceleration of the mean wind speed and an increase in spectrum width, which is consistent with the mechanical generation of turbulence, which is a major effect within the RFD surges as they impact the surface. Additionally, radar specific issues such as turbulent eddies larger than the TTUKa resolution bin and artificially low 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.