7B.2 A Review of Texas Tech Ka-band Operations During VORTEX2

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1. INTRODUCTION

Texas Tech University brought two Ka-band (TTUKa) radars to the field for the 2010 phase of the Verification of the Origin of Rotation in Tornadoes Experiment 2 (VORTEX2; Wurman et al. 2010). The high transmit frequency of these systems (35 GHz) permits a fine angular half-power beamwidth (0.49 deg) and, therefore, the resolution of fine cross-beam scales of motion. Further, the limited diffraction of the beam allows for the collection of data very near the surface with minimal influence from ground targets.

A number of VORTEX2 objectives will be satisfied with data from the TTUKa radars. For example, intricacies of tornado cyclone structure are well resolved by these systems, allowing the determination of high wavenumber / multiple-vortex structure in the horizontal. Similar scales of variance can also be retrieved in the vertical, such as that related to the corner flow region, the shallow boundary layer portion of the tornado core where sharp horizontal gradients in vertical perturbation pressure gradient are thought to exert significant influence on the maintenance, structure and, perhaps, genesis of tornadoes (Lewellen et al. 2000; Lewellen and Lewellen 2007).

The TTUKa radars have been instrumental in identifying areas of storm-scale horizontal vorticity along pre-existing and storm-generated boundaries (e.g., the rear-flank gust front). The evolution of these boundaries relative to tornado formation and dissipation is under investigation.

2. THE TTUKA RADARS

The build of TTUKa-1 was completed in March 2009, just ahead of a pilot study conducted during the 2009 VORTEX2 field phase (Fig. 1). TTUKa-2 was completed in the winter of 2010, and was available for VORTEX2-2010.

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The specifications of the TTUKa radars are provided in Table 1.

TABLE 1 – Selected specifications of the TTUKa mobile Doppler radar systems for VORTEX2 (asterisks indicate specs that have been improved upon since VORTEX2)

Transmitter Frequency:	34,860 MHz (λ=8.6 mm)
Transmit Power:	200 W peak, 100 W average
Transmitter Type:	TWTA
Duty Cycle:	up to 50%
Antenna Gain:	50 dB
Antenna Type:	Cassegrain feed, epoxy reflector
Antenna Beamwidth:	0.49 deg *
Polarization:	Linear, horizontal
Waveguide:	WR-28, pressurized
PRF:	Variable, up to 20 KHz
Gate Spacing:	15 m *
Receiver:	MDS: -118 dBm
IF Frequency:	60 MHz
Pedestal:	Orbit AL-4016
DSP:	Sigmet RVP-8 *
Vehicle:	Chevy C5500 Crewcab
Moments:	Reflectivity, radial velocity, spectrum width

A non-linear FM pulse compression technique is utilized that allows for the use of a long pulse (therefore, improved return power density from targets) without sacrificing radial resolution. The results from the 2009 pilot study indicate that the pulse compression filters were incorrectly tuned, such that data were effectively smeared in the radial direction. The filters were corrected for the 2010 field phase

Each TTUKa radar was staffed with a crew of three members (driver, navigator and operator) during VORTEX2. An onboard hydraulic leveling system ensured that all PPI(RHI) scans were horizon-parallel(normal).

3. VORTEX2 OVERVIEW

In total, there were approximately 150 deployments of the TTUKa radars in VORTEX2. A list of these deployments with brief descriptions of the data collection is included in Table 2. Descriptions of select cases follow below. Other cases are described in more detail in Skinner et al. 2011 (7B.1, this conference) and Metzger et al. 2011 (7B.4, this conference).

a. 5 June 2009 (Lagrange, WY)

TTUKa-1 was in position for the collection of PPI and RHI sweeps on the only significant tornado of VORTEX2-2009. The terrain was distributed such that the radar had to take a position at considerable range from the tornado (approximately 10-15 km), well outside the optimal range of ~2 km, a tradeoff of the linear resolution of the beam and the data eclipse generated by the pulse compression technique. From this location, the radar had a largely unobstructed view of the tornado; the line-of-sight extended to approximately 70 m AGL (Fig. 2).

The RHI presentation of the Lagrange tornado reveals two separate scales of confluent flow relative to the tornado cyclone (Fig. 3a). The deepest of the layers extends over the lowest 125 m of the RHI plane (to approximately ~200 m AGL), featuring measured confluence on the scale of 10^{-1} s^{-1}. A shallower embedded layer of confluence (order 10^{0} s^{-1}) is observed extending from the lowest radial to approximately 120 m AGL. This two-tiered presentation is similar in form to that revealed by large-eddy simulations of tornadoes (Fig. 3b). As previously mentioned, the pulse compression filters excessively averaged data in the along-radial direction in 2009, suggesting that the gradients were somewhat stronger than pictured.

b. 13 June 2010 (Booker, TX)

The most robust TTUKa sample of a tornado in VORTEX2-2010 occurred on 13 June 2010 to the northeast of the town of Booker, TX. The tornado was rated EF0, but was distinct enough to allow for a series of three RHI scans to either side and through the core of the vortex (Figs. 4,5). For these scans, the RHI plane remained stationary as the tornado translated through.

All RHI sweeps indicate a northeastward lean and contraction of the weak-echo region with height (Fig. 5), similar to that observed in other cases (e.g., Bluestein et al. 2004). An elevated inflow jet is also depicted clearly for the three slices. This jet demonstrates a clear increase in magnitude near the position of the weak echo region at approximately 1300 m AGL. Given the local increase of reflectivity concurrent with this region, it is possible that the plane of the RHI briefly crosses to the outbound side of the vortex at this location.

Areas of horizontal vorticity are also apparent on RHIs taken near the core of the Booker tornado. Though it is again possible that areas to the inbound/outbound side of the vortex are sampled in the RHI plane (e.g., due to the tilt and translation of the vortex over the period of the sweep), the sharpness of the vertical gradients in radial velocity lends credence to the presence of rather compact (diameter ~ 200 m) circulations normal to the tornado vortex. The position and sense of the horizontal vorticity on the forward edge is similar to that which one might expect from a traditional secondary circulation (as Lewellen et al. 2000 describe, a circulation that would owe its existence to radial gradients in vertical vorticity and would be responsible for advecting angular momentum radially inwards towards the core). On the back side of the vortex, other areas of horizontal vorticity are present, but appear to be too lofted (i.e., inward radial motion well above the boundary layer) or of the wrong sign (i.e., horizontal vorticity vector is opposite the tangential flow) to be consistent with the traditional model of a secondary circulation.

A detailed discussion of the horizontal structure of the Booker, TX tornado is given by Metzger et al. (2011).

c. 12 May 2010 (SW Oklahoma)

On 12 May 2010, TTUKa-1 gathered RHI cross sections of a supercell rear-flank gust front (RFGF) near Willow, OK (Fig. 6a). Though the precipitation from an adjacent updraft attenuated the presentation of the region behind (west of) the RFGF, the RFGF fineline shows clearly as a region of significant shear (Fig. 6b). Numerous inflections are noted along the fineline, consistent with the presence of horizontal vorticity. A few of these areas of vorticity (at and above 2 km AGL) amplify through time in a manner consistent with Kelvin-Helmholtz instability and ascend along the RFGF. During this time, the fineline of the RFGF propagates discretely, particularly above the 2 km AGL altitude where the rollup vortices are noted.

4. ACKNOWLEDGEMENTS

The authors wish to acknowledge the members of the TTUKa crews that participated in VORTEX2 for their dedication and hard work. This research is supported by the National Science Foundation under grant AGS-0964088.

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TABLE 2 – A list of TTUKa deployments from VORTEX2-2010. Higher priority cases are in red.

Date	*Event Description*
5/10/10	*Single Doppler of hook echo (Seminole, OK)*
5/11/10	*Dual Doppler of elevated supercell (Woodward, OK)*
5/12/10	*RHIs of KHI waves along RFGF, single Doppler of tornado (Clinton, OK)*
5/14/10	*Single Doppler of two tornadoes, RHIs of severe outflow (Midland, TX)*
5/17/10	*Single Doppler of weak low-level mesocyclone (Artesia, NM)*
5/18/10	*Dual-Doppler of pre-tornadic low-level mesocyclone, single Doppler of tornado (Dumas/Stinnett, TX)*
5/19/10	*Dual-Doppler of decaying mesocyclone, single Doppler of tornado, intense RFD circulations (Royal, OK)*
5/23/10	*Single Doppler of hook echo (western KS)*
5/24/10	*Single Doppler of moderate low-level mesocyclone (western NE)*
5/25/10	*RHI/PPI of possible DRC, Single Doppler of three tornadoes, RHIs of KHI waves (Tribune, KS)*
5/26/10	*Dual-Doppler of persistent low-level mesocyclone (Byers, CO)*
5/29/10	*Dual-Doppler of CI on fineline (eastern NE)*
6/5/10	*Dual RHIs of gust front passage (central IA)*
6/6/10	*Single Doppler scans of low-level meso, coordinated RHI/PPI through severe outflow (Ogallala, NE)*
6/7/10	*2-3 tornadoes scanned in transit, single (stationary) Doppler of intense surface circulation (Scottsbluff, NE)*
6/10/10	*Single Doppler of occluded tornado (Agate, CO)*
6/11/10	*Single Doppler of two tornadoes, multiple-vortex structure (Agate, CO)*
6/12/10	*Single Doppler of hook echo (TX Panhandle)*
6/13/10	*Single Doppler of entire lifecycle of tornado, RHIs (Booker, TX)*
6/14/10	*Single Doppler of weak meso, gustnadoes (Tahoka, TX)*

Figure 1 – Photograph of the TTUKa-1 radar sampling a mature supercell thunderstorm near Greensburg, KS on 9 June 2009.

Figure 2 – Google Earth image profiling the terrain between the TTUKa-1 radar and the Lagrange, WY tornado on 5 June 2009.

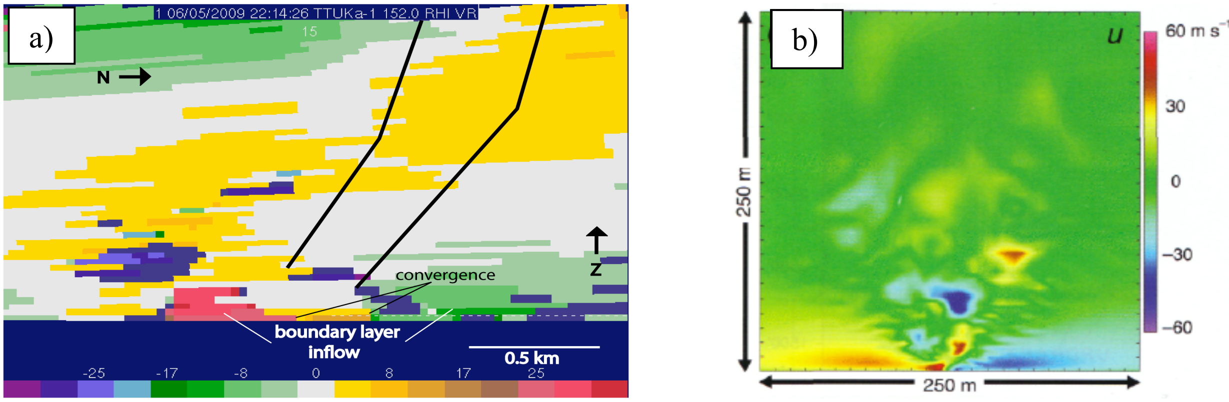

Figure 3 – a) TTUKa-1 RHI profile of radial velocity (colored, m s^{-1}, scale at bottom) from the Lagrange, WY tornado, and b) the vertical profile of u-component wind velocity (colored, m s^{-1}, scale to right) from a tornado-scale LES (adapted from Markowski and Richardson (2010); image courtesy Dave Lewellen). Base of the RHI in a) is 70 m AGL.

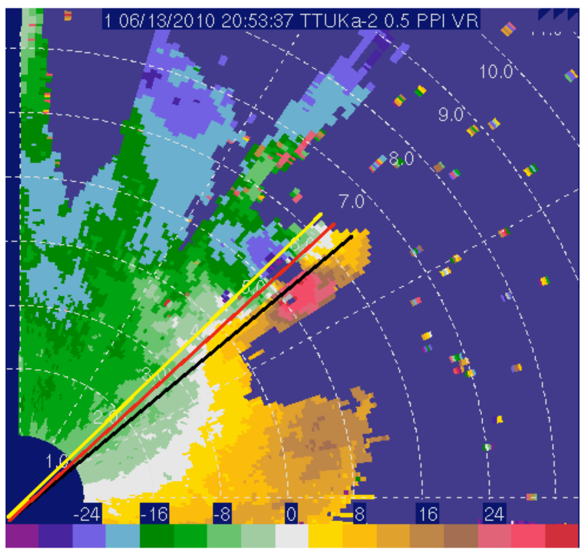

Figure 4 – PPI of radial velocity from the Booker, TX tornado on 13 June 2010. The colored lines represent the plane of RHI cross section for the inbound, outbound and center portions of the tornado vortex.

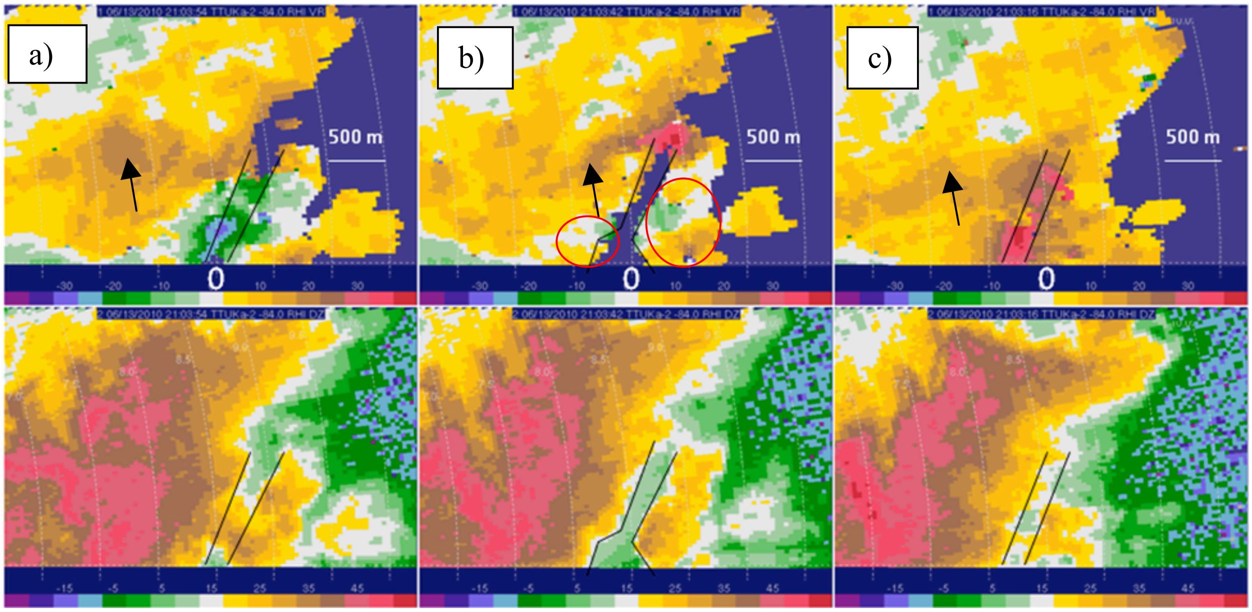

Figure 5 – RHI profiles of (top) radial velocity (colored, m s^{-1}, scale at bottom) and (bottom) reflectivity (colored, dBZ, scale at bottom) for the a) inbound, b) core and c) outbound sections of the Booker, TX tornado on 13 June 2010. Black line segments denote the weak echo region of the vortex (common to top and bottom panels). Arrows point to the elevated jet feature discussed in the text. Red ovals denote regions of horizontal vorticity referred to in the text.

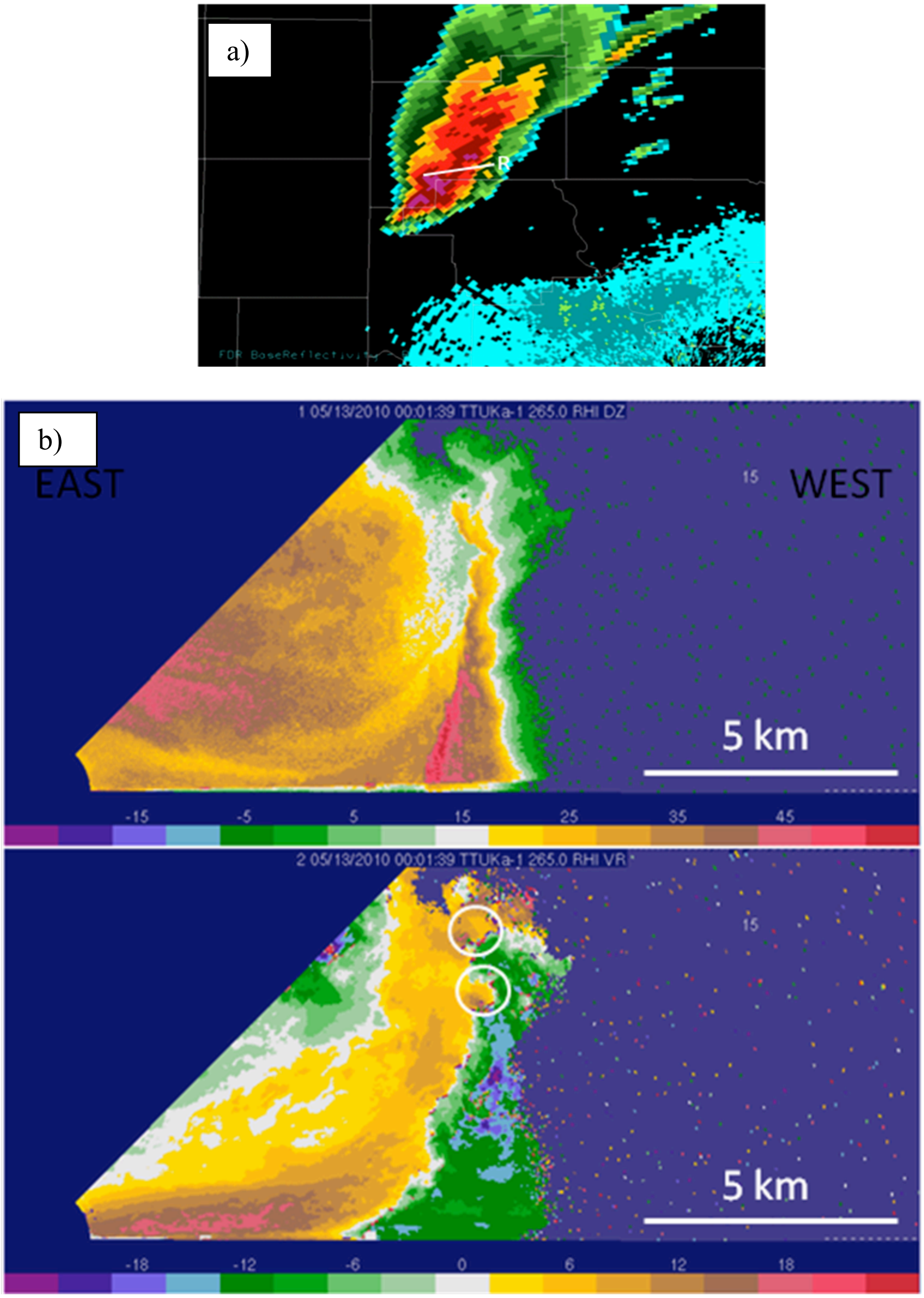

Figure 6 – a) WSR-88D reflectivity PPI (0.5 deg) from KFDR (Frederick, OK) at 0000 UTC 13 May 2010, and b) RHI of (top) reflectivity (dBZ) and (bottom) radial velocity (m s^{-1}) from TTUKa-1 at 0001 UTC 13 May 2010. In a) "R" denotes the position of TTUKa-1 and the white line denotes the plane of the RHI in b). In b), the white ovals identify the regions of horizontal vorticity referred to in the text. Note that the view in b) is to the south (east is to the right, west is to the left).