11B.2 THE TTUKA MOBILE DOPPLER RADAR: COORDINATED RADAR AND IN SITU MEASUREMENTS OF SUPERCELL THUNDERSTORMS DURING PROJECT VORTEX2

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1. INTRODUCTION

In 2006, the Texas Tech Vice President of Research awarded a Research Development Grant for the development of two Ka-band mobile Doppler radars. These systems, hereafter referred to as the TTUKa radars, were developed with an emphasis on sensitivity and resolution, such that it is possible to map a wide spectrum of atmospheric phenomena in four dimensions.

Detailed below are the specifications of the TTUKa radar system and preliminary results from field testing before and during the 2009 field phase of the Verification of the Origin of Rotation in Tornadoes Experiment 2 (VORTEX2).

2. TTUKa RADAR CHARACTERISTICS

The TTUKa radars are the first research grade platforms in the radar community to utilize a non-linear frequency modulation pulse compression technique at 35 GHz. Primary specifications follow (TABLE 1):

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

TABLE 1 – Selected specifications of the TTUKa mobile Doppler radar systems

The TTUKa design employs an extended-pulse non-linear frequency modulation in order to suppress typical artifact range side lobes (Keeler et al. 1999) generated from the compression and from filters on the receive chain. This technique achieves enhanced range resolution, consistent with that of a short pulse, but with the increased receiver sensitivity of a long pulse transmission, yielding more accurate velocity estimates with a shorter number of pulses compared to conventional radar systems.

Operation of the TTUKa requires a three-man crew consisting of a driver, navigator and operator. A hydraulic leveling system is included to ensure that azimuth scans are parallel to the horizon. Hot-start park-to-level data acquisition elapsed times of < 60 s were common in 2009 field deployments. Four separate scanning strategies have been developed and employed for VORTEX2, including PPI, RHI and VAD modes.

The first of the two TTUKa radars (FIG. 1) was completed in March 2009, and was field tested for the first time in the VORTEX2 project (section 3). The second radar is midway through construction as of September 2009 and will be completed in the late fall of 2009.

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

3. FIELD DEPLOYMENTS

One TTUKa was integrated into the 2009 VORTEX2 operations plan [available at

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Date	Location	Event	Deployments	Description
5/26/2009	Sunset/Forestberg, TX	Left-moving supercell	2	Attenuation estimation experiment within hail core Data on anti-cyclonic circulation obtained VAD of inflow environment
5/29/2009	Rose, NE	Dissipating supercell	2	RHI scans of inflow, mid-level vortices
5/31/2009	Randolph, IA	Multicell storm	2	PPI scans
6/1/2009	Hebron, NE	Multicell cluster	2	PPI and RHI scans of outflow, gustnadoes
6/4/2009	Southeastern WY	Supercell storm	4	PPI scans of shallow circulations along gust front
6/5/2009	**Lagrange, WY**	**Tornadic supercell**	**5**	**PPI and RHI scans of tornado vortex** **Coordinated RFD sample with in-situ probes**
6/6/2009	Sutherland, NE	Supercell/bow transition	1	PPI scans of supercell transitioning to outflow-dominant stage
6/7/2009	Northwest MO	Supercell storm	3	PPI and RHI scans of non-tornadic supercell PPI scans of gustnadoes and anticylonic rotation along rear flank
6/9/2009	Greensburg, KS	Supercell storm	4	PPI scans of near-mesocyclone
6/10/2009	Hugoton, KS	Multicell storm	3	RHI scans of leading edge of gust front
6/11/2009	LaJunta, CO	Supercell storm	1	PPI scans of anticylonic rotation along rear flank
6/13/2009	Panhandle, TX	Supercell storm	3	PPI and RHI scans of target storm

TABLE 2 – TTUKa deployments during the 2009 field phase of VORTEX2

http://www.vortex2.org/home] for tornado-scale operations. As the TTUKa radars are platforms emphasizing both resolution (0.49 deg beamwidth) and sensitivity (MDS -118 dBm), they well complement other mobile radars involved in the project, particularly in their ability to make velocity measurements deep into the tornado cyclone, within the radius of maximum wind, a volume typically void of substantial scatterer concentration (Dowell et al. 2005).

There were 32 TTUKa deployments during the 2009 field phase of VORTEX2 (TABLE 2). Most of these deployments featured PPI and RHI scans of target supercell thunderstorms.

Only one tornado was officially intercepted by VORTEX2, that being the event of 5 June 2009 near Lagrange, WY. Due to an intervening mesa between the closest highway and the tornado, the TTUKa had to assume a position approximately 10-15 km in range from the tornado, well outside the most effective range of ~2 km, considering the linear resolution of beam and the data eclipse (out to 1.5 km range) generated by the pulse compression method. (Pulse compression can be switched off if the target moves within 1.5 km range.) Nonetheless, the TTUKa successfully mapped the reflectivity and velocity of the tornado.

The tornado clearly is depicted with spiraling rings of reflectivity and a sharp gradient in radial velocity (FIG. 2). StickNet probes (Weiss and Schroeder 2008) deployed at this time reveal a clear discontinuity in wind direction (with weak wind velocity) east of the tornado owing to the presence of the rear-flank downdraft, which is confirmed with the radial velocity depiction from TTUKa. Even though a tremendous amount of precipitation surrounds the tornado (FIG. 3), the attenuation of the signal is not significant enough to prohibit the retrieval of wind velocity through the expanse of the tornado.

In the RHI presentation (FIG. 3), the shallow (~200 m deep) inflow layer to the Lagrange tornado becomes clear. Another area of convergence is evident in a shallower (~50 m deep) layer coincident with the base of the weak echo region of the tornado. Further analysis is planned to ascertain if the true corner flow region was sampled.

On 1 June 2009, the TTUKa captured strong outflow winds surging in advance of a severe multicell cluster over southeastern Nebraska. A number of gustnadoes were observed visually along the leading gust front, and were consistent with vertical vorticity maxima identified on radar (FIG. 4). Similar inflections in boundaries were noted in other VORTEX2 cases.

Opportunities were also available to sample clear-air boundaries in the pre-convective environment. On 13 June 2009, for instance, a westward-moving boundary was identified that represented the leading edge of increased water vapor mixing ratio (FIG. 5).

4. OBJECTIVES IN VORTEX2

Many tornado-scale VORTEX2 research objectives will be served by the TTUKa radar, particularly in collaboration with other mobile Doppler radars. One goal is the characterization of high-wavenumber horizontal structure of the tornado vortex including sub-vortices. The ability to retrieve wind velocity deep within the tornado cyclone will permit estimations of swirl ratio (e.g., Lee and Wurman 2005) and its relation to vortex breakdown.

As evidenced by the RHIs of the Lagrange, WY tornado (FIG. 3), objectives will be satisfied related to the vertical structure of the tornado vortex, including the characteristics of the shallow boundary-layer inflow and corner flow regions. Secondary circulations normal to the vortex (e.g., Bluestein et al. 2004) will also be investigated.

Similar to the vorticity maxima resolved along a gust front on 1 June 2009 (FIG. 4), the TTUKa radar will be used to monitor pre-existing vertical vorticity maxima along the rear-flank gust front. Such vortices have been suggested to be potentially relevant to the vorticity of the incipient tornado.

5. FUTURE PROJECTS

Proposals are pending to support the TTUKa radars in the 2010 field phase of VORTEX2. Beyond VORTEX2, it is anticipated that the TTUKa radars will be able to contribute to a number of observational thrusts. The clear-air sensitivity demonstrated by these platforms will be beneficial for studies of general boundary-layer flow, dryline evolution and motion, wind turbine inflow and wake investigation, and thunderstorm outflow characterization. The platforms will also be utilized to document the mesoscale structure of landfalling hurricanes.

5. ACKNOWLEDGEMENTS

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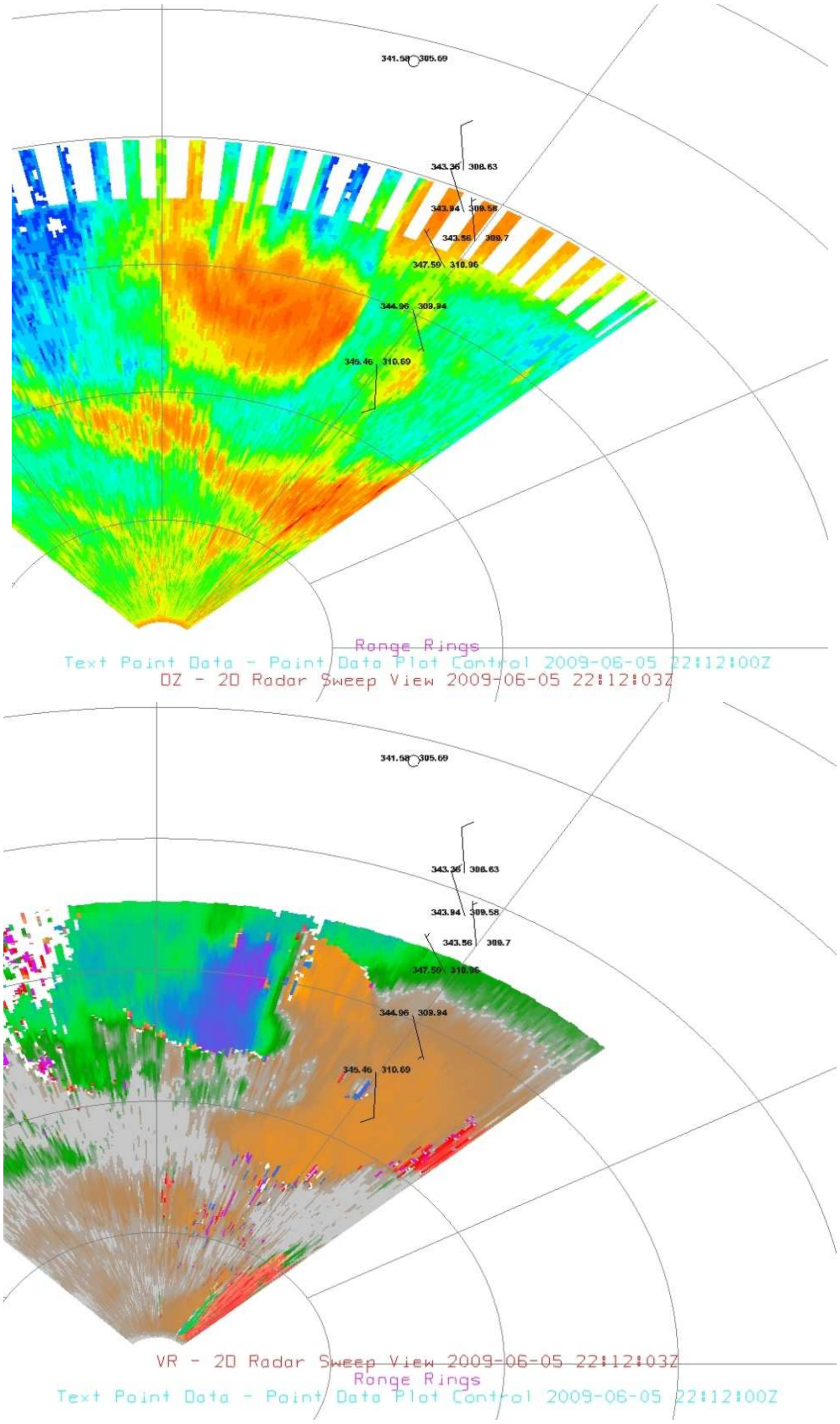

FIGURE 2 – (top) Base reflectivity and (bottom) radial velocity at 0.25 deg elevation for a TTUKa radar sweep of the Lagrange, WY tornado (2212 UTC 5 June 2009). In the velocity images, cool (warm) colors indicate motion towards (away from) the radar. Data from StickNet probes are overlaid.

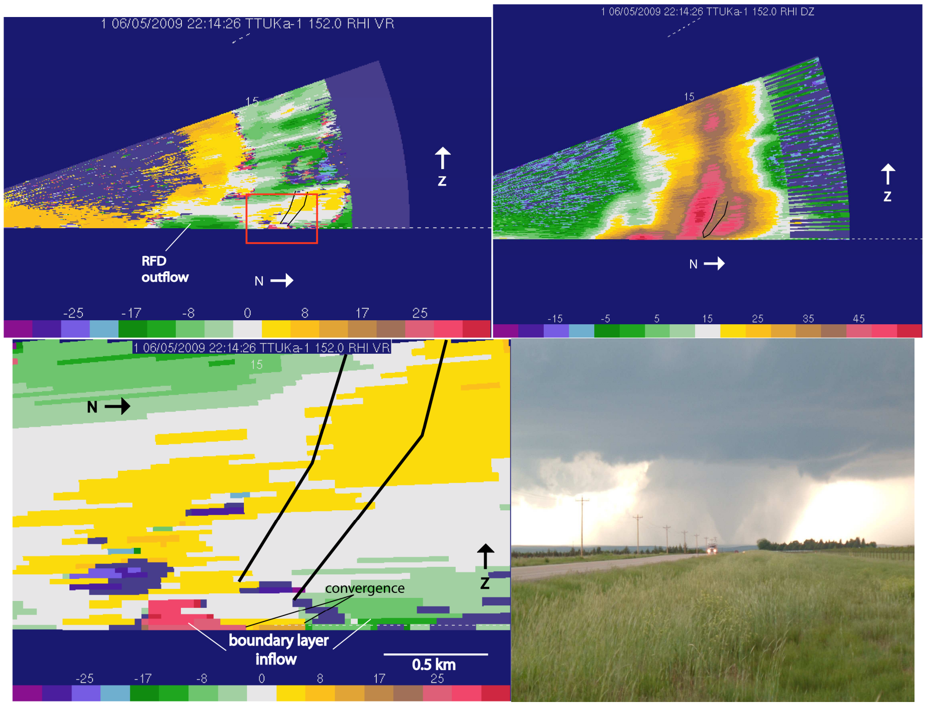

FIGURE 3 – (top left) PPI 0.3° elevation radial velocity ($m\ s^{-1}$) and (top right) reflectivity (dBZ), RHI (bottom left) radial velocity ($m\ s^{-1}$) and (bottom right) a photograph of a tornado near Lagrange, WY on 5 June 2009 at 2215 UTC. In the photograph, the TTUKa was observing the tornado from the left. The black trace in the RHIs represents the reflectivity minimum of the tornado core, and the red box denotes the domain for the zoomed image at the bottom left.

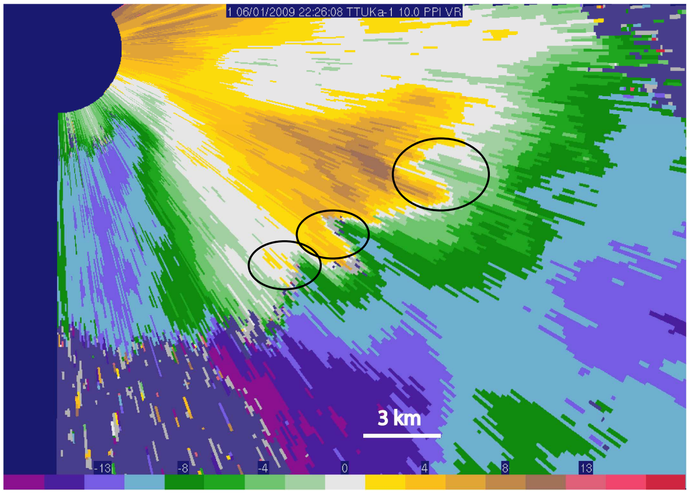

FIGURE 4 – PPI radial velocity ($m\ s^{-1}$) of a surging outflow boundary on 1 June 2009 near Hebron, NE. Vorticity maxima (visually identified as gustnadoes) resolved by the TTUKa are circled.

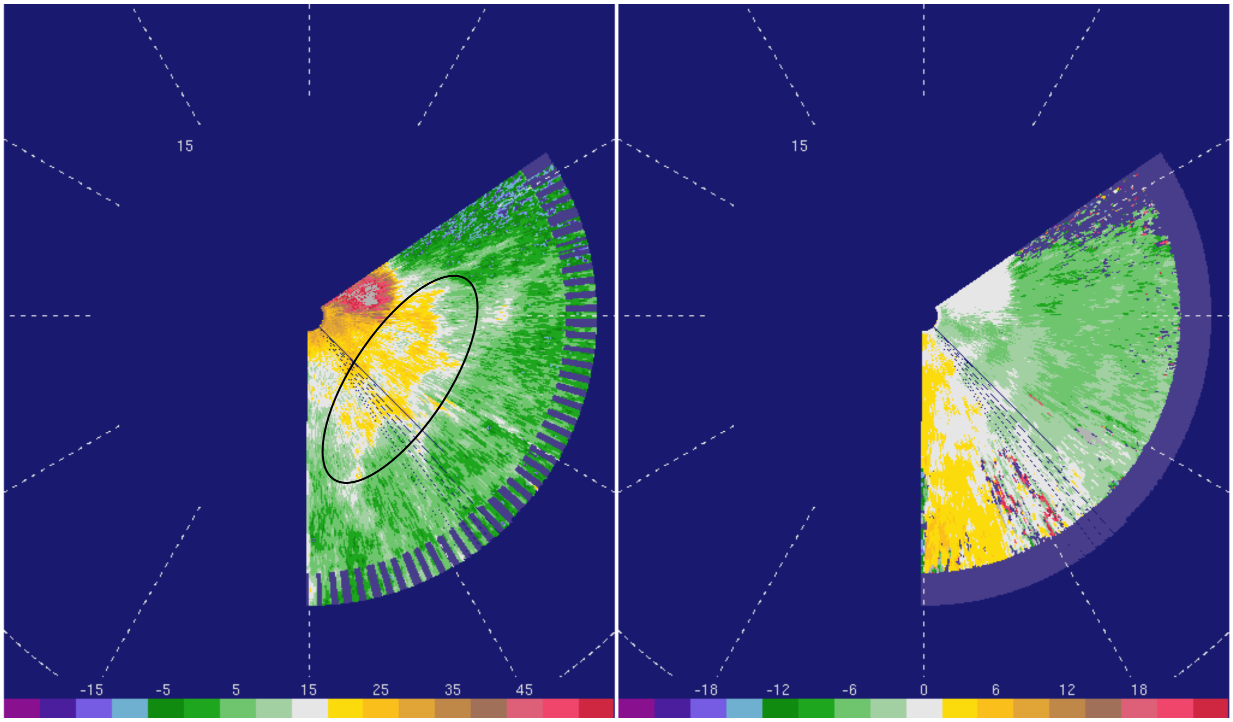

FIGURE 5 – (left) PPI reflectivity (dBZ) and (right) radial velocity (m s^{-1}) of clear-air boundaries in the pre-convective environment on 13 June 2009 in the northern Texas Panhandle. The boundary is identified with an oval in the reflectivity pane.