5B.1 OBSERVATIONS OF TORNADOGENESIS USING A MOBILE, PHASED-ARRAY, DOPPLER RADAR

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1. INTRODUCTION

Tornadoes and many severe convective storms evolve on very short time scales (~ 10 s), owing to very high horizontal wind speeds and vertical velocities. This paper documents the formation of a tornado in the U. S. using a mobile, rapidly scanning, Doppler radar. This radar, the MWR-05XP (Meteorological Weather Radar, 2005, X-band, Phased Array), electronically scans in elevation and azimuth over limited sectors, and mechanically in azimuth at high speed. While the radar scans electronically in elevation, the attitude of its beam is held nearly fixed in space because it electronically back scans in azimuth at the same rate as it mechanically scans. Back scanning in azimuth is accomplished by frequency hopping, while scanning in elevation is accomplished by changing the phase delay.

Transmitted frequency	9.3 – 10 GHz (X band)
Maximum power (peak)	≥ 15 kW
Beamwidth (half power)	1.8^0 (azimuth), 2^0 (elevation)
Maximum PRF	10 kHz
Pulse duration/range resolution	1 ms / 150 m
Sensitivity	~ -15 dBZ@10 km (minimum)
Range sampling interval	75 m
Mechanical azimuth scanning rate	180^0 s^{-1} (maximum)
Electronic azimuth back-scanning	6 – 8^0 swath (varies with elevation angle)
Electronic elevation scan capability	-18^0 to +55^0 with respect to the horizon

Table 1. Characteristics of the MWR-05XP.

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The most important characteristics of the MWR-05XP are given in Table 1. Other rapidly scanning radars in operation now include the NWRT PAR S-band, fixed-site radar in Norman, OK (Zrnic et al. 2007) and the Rapid-DOW X-band mobile radar at CSWR in Boulder, CO (http://www.cswr.org/docs/radar-conf-rapid-2001-0327.pdf).

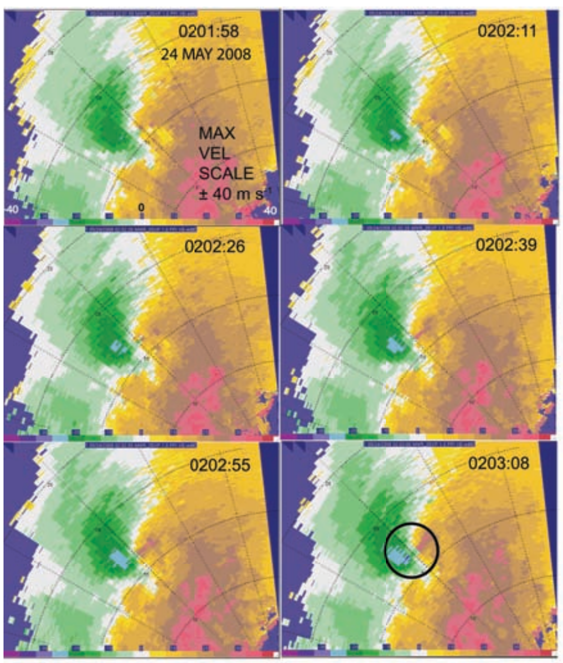
The MWR-05XP was first used in spring 2007. In 2008 frequency hopping had not yet been implemented, so the mechanical scanning rate was slowed down to minimize beam smearing. In 2009, frequency hopping was implemented so that beam smearing was eliminated and more independent samples were available.

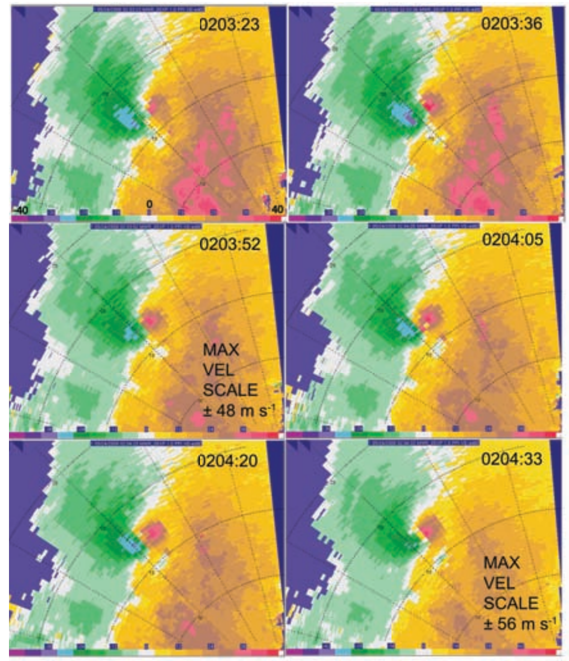
Two modes of data collection are used. The stepped frequency spiral (STF-SP) volume scan sequence is similar to that of the WSR-88D and is used for surveillance. The stepped frequency elevation (STF-E) volumetric sector-scan sequence is used for more focused probing. In 2008 only, when frequency hopping was not available, sector elevation (SE) scans were taken.

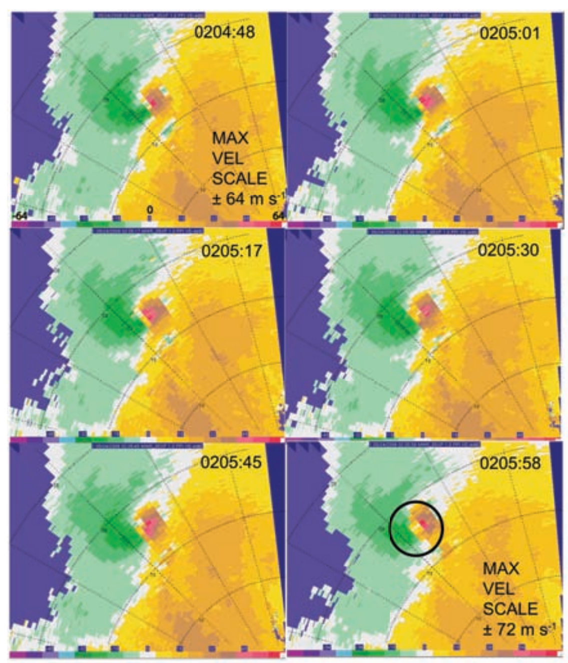
In 2008, SE volume scans were available with a maximum range of 60 km and updated every 10.8 s up to 20^o elevation angle. In 2009, STF-E scans with a maximum range of 30 km were updated every 10 s up to 55^0 elevation angle. Data were collected for other values of maximum elevation angle and maximum range at similar update times. In general, typical update times of ~ 15 s were available for sector scans in 2008 and ~ 6 – 7 s in 2009.

In 2008 data were collected in several tornadic storms. Tornadogenesis on 1 May and 10 May was captured, but for the former the tornado was at relatively long range (> 20 km) and for the latter, attenuation was severe because the radar was located just upstream from the parent supercell. The focus of this paper is on a cyclonic tornado and companion anticyclonic vortex that formed in an HP supercell in Kansas on 23 May. Data slightly oversampled in the vertical were collected when the tornado formed at range as close as ~ 16 km, from near the surface to 20^0 elevation angle (~6.5 km AGL). The update time for the volume scans was ~ 13 s over a ~ 50 min period, from ~ 15 min prior to tornadogenesis to well after the tornado had dissipated.

2. PRELIMINARY DISCUSSION OF DATA







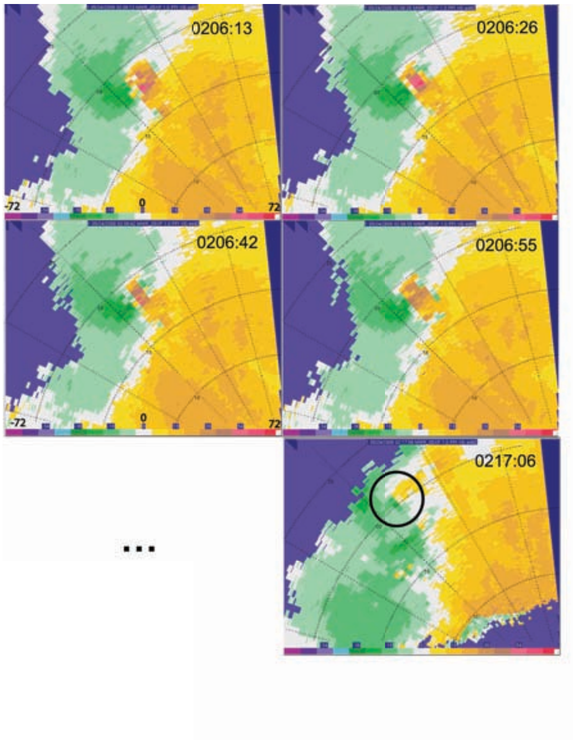


Fig. 1. The life cycle of a supercell tornado in Kansas, as documented by the MWR-05XP. Doppler velocity (m s^{-1}) at 1^0 elevation angle on 23 May 2008 (24 May UTC). The maximum Doppler wind speeds associated with the vortex signature (sometimes highlighted by a circle) that marks the tornado weaken steadily after 0206:55 and data are not shown until 0217:06, when the maximum wind speeds are much weaker (ellipsis denotes panels that are not shown for the sake of brevity). The color scale for Doppler velocity (m s^{-1}) is changed while the isodop maximum exceeds the maximum allowed by the color scheme; when this is done, the new range is indicated at the lower-right hand side of the panel. Range markers shown every 5 km.

Fig. 1 depicts the entire life cycle of a cyclonically rotating tornado at low elevation angle, ~ 300 m AGL. Also seen in this storm and in another tornadic storm on the same day are nearby, intense, anticyclonic vortices, both of whose life cycles were captured (one is shown in Fig. 2). Analyses of these features are ongoing; some preliminary results will be shown at the conference by French et al. (2009; this conference, 5B.6). [More details on the radar are found in PopStefanija et al. (2009, this conference, P5.9) and on both the radar and the data in Bluestein et al. (2010).] Owing to the strong attenuation by precipitation in the high-precipitation (HP) supercell parent storms, analyses of the cyclonic vortices are not possible at the highest elevation angles. For the anticyclonic vortices, there is less attenuation, so analyses of these vortices are possible up to higher altitudes.

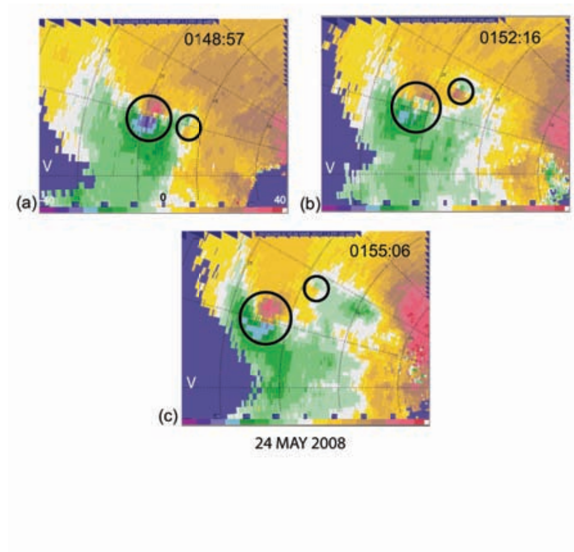


Fig. 2. The behavior of a cyclonic tornado and a neighboring, intense, anticyclonic vortex in Kansas, as documented by the MWR-05XP on 23 May 2008 (24 May in UTC time). Doppler velocity (m s^{-1}) at 1^0 elevation angle at (a) 0148:57, (b) 0152:16, and (c) 0155:06. Cyclonic vortex signatures indicated by large circles; anticyclonic vortex signatures indicated by smaller circles. For brevity, only three representative images are shown; data are available as in Fig. 1, every 13 s. Range markers shown every 5 km. Maximum Doppler velocities are ± 40 m s^{-1}.

It is seen from the data shown in Figs. 1 and 2 show that there is excellent temporal continuity in the locations of the cyclonic and anticyclonic vortex signatures associated with the tornado and anticyclonic vortex at low levels.

In 2009, during VORTEX-2 (Verification of the Origins of Rotation in Tornadoes Experiment-2) in the Plains of the U. S., an excellent dataset was collected depicting the entire life cycle of a tornadic storm at close range (Figs. 3 and 4). Owing to the addition of frequency hopping in 2009, the update time was cut down to ~ 7 s for each volume scan (up to 20^0). Some of these data will be shown at the conference.

Fig. 3. Photograph of a tornado being probed by the MWR-05XP in southeastern Wyoming during VORTEX-2 at 2218:46 UTC on 5 June 2009. Courtesy of Chad Baldi (ProSensing, Inc.).

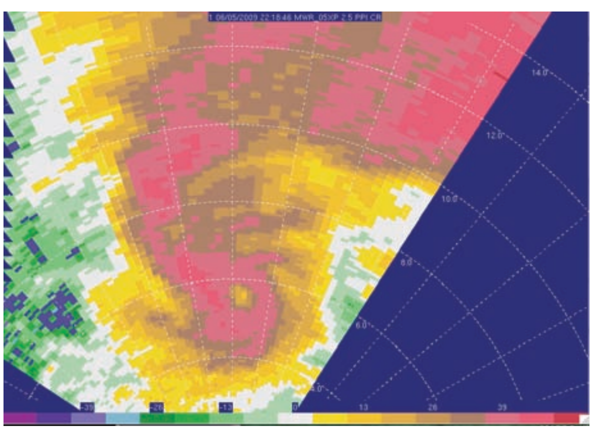


Fig. 4. Unedited radar reflectivity (dBZ) from the MWR-05XP at 2.5^0 elevation angle, of the parent supercell for the tornado seen in Fig. 3. Range markings shown every 2 km. Tornado was located at the weak-echo hole seen at 5.5 km range.

3. FUTURE WORK

The MWR-05XP will be used in spring 2010 during year 2 of VORTEX-2. Several improved capabilities will have been added. It will be possible to change scanning parameters without temporarily stopping data collection. Different PRFs will be implemented on alternate scans to make unfolding aliased Doppler velocity data easier. A pulsed, 2 μm Doppler lidar having 150 m range resolution was added during the summer of 2009 to provide clear-air data collection. It is anticipated that a non-scanning W-band radar will also be added to the facility.

One issue that must be addressed is what scan parameters should be selected. There is a tradeoff between the highest elevation angle scanned and the volumetric update time. Currently, we typically scan up to 20^o elevation angle. When a convective storm is relatively far away we can scan to its top. When it gets within close range, we must scan to higher elevation angle to scan to the same altitude, but the update time increases. Our philosophy has been to scan to the top of the storm when there is no tornado, but to scan only to midlevels when a tornado is imminent or is occurring to provide for as rapid updates as possible at low altitudes. Our choice of scanning parameters in the future will be based on our experiences in 2008 and 2009 and what is necessary to track tornadogenesis and/or provide data adequate for assimilation into nonhydrostatic cloud models.

4. ACKNOWLEDGMENTS

Chad Baldi (ProSensing) led the data collection and field operations. Bethany Seeger (ProSensing) did much of the data processing. Jana Houser (OU) contributed to the field efforts. Jeff Snyder (OU) and Mark Laufensweiler (OU) provided computer-related assistance. Paul Buczynski (NPS) also contributed to the project. This work was supported in part by NSF grant ATM-0637148 to OU and contracts to ProSensing from the Navy SBIR program at the Office of Naval Research.

5. REFERENCES

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