Observation of Tornadoes Using a Compact Polarimetric X-Band Weather Radar

Toshiaki Takaki[1] , Takuo Kashiwa[1] , Masahiro Minowa[1] , Hirotaka Nakajima[1] , Koji Sassa[2] , V. Chandrasekar[3] ,
1. FURUNO ELECTRIC CO., LTD., 2. Kochi University, 3. Colorado State University

1.Introduction

On 30 April 2019, an EF-1 tornado occurred in Denton, Texas. According to Public Information Statement issued by NWS Dallas/Fort Worth (Fig. 3), the tornado touched down at midnight shortly before 00:00Z, in Denton and ran for several minutes on the ground. Tree damages at several locations showed that the tornado intensity was EF-1, and its wind speed was on the order of 85-90 mph. The radar XUNT (X-band in University of North Texas), a compact Polarimetric X-band Doppler weather radar, has been operated in the CASA Network in Texas (Fig 1). This radar observed and resolved the tornado near ground and NWS mentioned that it gave them confidence to issue the tornado warning. The present study aims to clarify the characteristics of the tornado vortex and of its parent cloud.

"XUNT" radar in Denton, Texas.

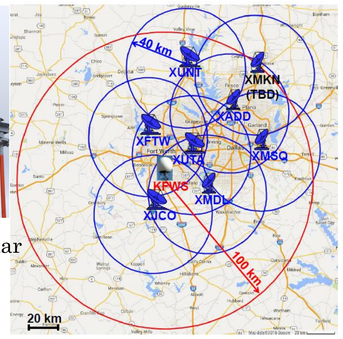

Fig 1 : The network of the DFW polarimetric X-band radars (40 km range rings in blue). The letter symbols, such as "XUNT", correspond to the name of various radars.

2. The case of tornado

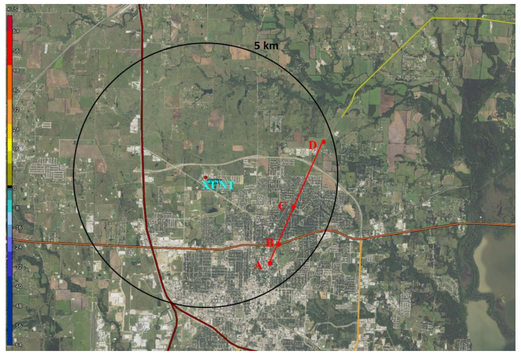

Fig 2 : The tornado path. The symbols A-D indicate the points along the path according to the NWS statements. The position of the radar site is also indicated as "XUNT".

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Rating:                 EF1
Estimated Peak Wind:    90 mph
Path Length /statute/:  2.89 miles
Path Width /maximum/:   250.0 yards
Fatalities:             0
Injuries:               0

Start Date:             04/30/2019
Start Time:             06:52 PM CDT
Start Location:         1 NNE Denton / Denton County / TX
Start Lat/Lon:          33.2261 / -97.1252

End Date:               04/30/2019
End Time:               07:01 PM CDT
End Location:           4 NNE Denton / Denton County / TX
End Lat/Lon:            33.2643 / -97.1053
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Fig 3 : Public Information Statement issued by NWS Dallas/Fort Worth, TX.

Table 1: Comparison of the NWS statements and the result of the radar XUNT.

	Survey summary (NWS)	Estimated time (NWS)	ΔVrad (XUNT) m/s	Vortex diameter (XUNT) m	Convergence (XUNT) $10^{-3}s^{-1}$	Vortex altitude (XUNT) m
A	This tornado formed on the east side of the Texas Woman's University (TWU) campus.	04/30 23:52Z	21	330	63	140
B	Moving northeastward, the tornado uprooted several large trees along the edge of the TWU golf course before crossing University Drive.	23:53Z	23	560	41	140
C	The track continued northeastward through heavily wooded neighborhoods in northeast Denton, snapping or uprooting numerous trees.	23:56Z	50	720	69	120
D	This tornado crossed Loop 288 and caused some minor tree damage before dissipating near the intersection of Sherman Drive (FM 428) and Hartlee Fields Road.	05/01 00:01Z	29	780	37	210

The NWS statement and the data observed by the radar XUNT are compared in Table 1. The four points (A-D) are defined along the tornado path on the ground in Fig 2. The maximum value of velocity difference (ΔVrad) are observed at the point C where the NWS reported the most severe damage.

3. Results of analysis

The temporal changes of ΔVrad and vortex diameter are shown in Fig 4.
The temporal change of convergence is also shown in Fig 5.
The maximum convergence is observed at 23:55Z before the tornado reaches the point C as shown in Fig 5. At the same time, the maximum value of ΔVrad, about 50 m/s, and the diameter shrinks to 400 m in Fig 4.
The maximum velocity is consistent with the NWS statement in Fig 3.

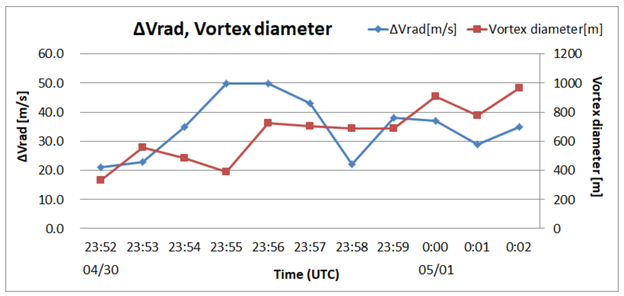

Fig 4 : Temporal change of the ΔVrad and vortex diameter of the tornado vortex.

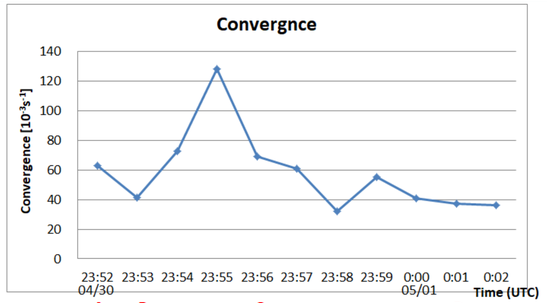

Fig 5 : Temporal change of the convergence of the tornado vortex.

4. Comparison of radar echoes

The reflectivity, Doppler velocity and correlation coefficient, ρhv, observed by the radar XUNT at 23:56Z when the tornado located at the point C are shown in Fig 6. The observation altitude is approximately 120 m. Therefore, the observation information shows not that for a funnel cloud but directly the tornado vortex and/or debris signal due to the tornado. The debris ball can be seen clearly as the high value of reflectivity and the low value of correlation coefficient in Fig 6. The location of the tornado estimated by the radar observation well matches with the point C along the tornado path.

The NEXRAD radar data in Fort Worth (KFWS) is compared with that of XUNT/CASA. There are no distinctive signs of a tornado on the NEXRAD radar data as described in Fig 7.

According to the radar data in KFWS, the echo top is approximately 15 km and is quite deep convection, but neither meso cyclone nor hook echo is observed. This fact implies that the parent cloud of the tornado is non-supercell type.

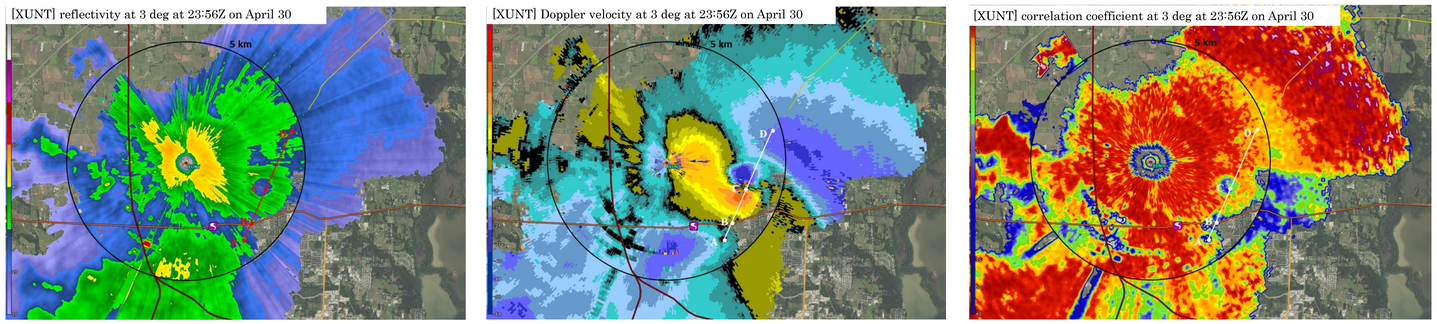

Fig 6 (above) : The PPI images of reflectivity, Doppler velocity and correlation coefficient at 3 deg. in elevation angle at 23:56Z observed by the radar XUNT.

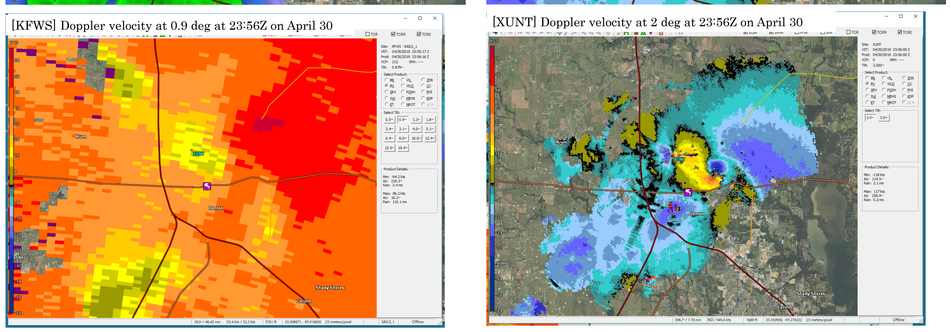

Fig 7 (left) : The PPI images of Doppler velocity are compared between KFWS of NEXRAD and XUNT of CASA.

5. Analysis by Rankine vortex model

To examine the velocity structure of the tornado, Doppler velocity field is compared with that of conceptual models (Fig 8).
The tangential velocity Vt of the modified Rankine vortex is;

$$V_t = V_0 \frac{R}{R_0} \quad \text{for} \quad R \le R_0,$$

$$V_t = V_0 \left(\frac{R_0}{R}\right)^{\alpha} \quad \text{for} \quad R > R_0,$$

where R is the distance from the center of the vortex and V_0 is the peak tangential velocity at $R=R_0$, and the alpha is a constant. Doppler velocity at 23:55Z and Rankine vortex model are compared in Fig 8. As can be seen in Fig 8, R_0 is 220 m and V_0 is 26 m/s approximately. Here the distance where the tangential velocity is 17 m/s (half the lower limit of EF-1) is defined as R_{17}. R_{17} is 600 m approximately. The model curve is better fitted in case of (b) α=0.66 than in case of (a) α=1.

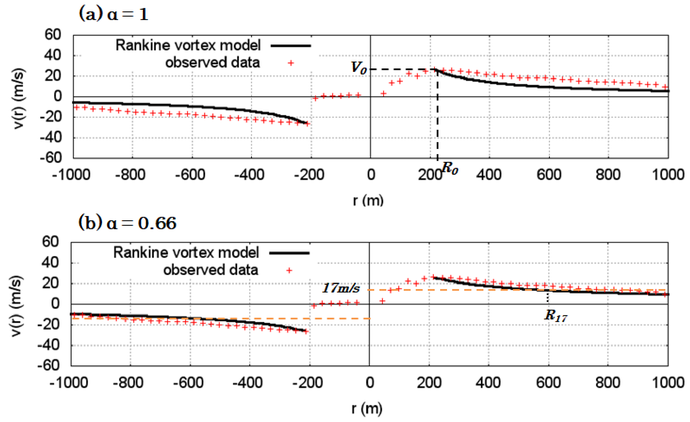

Fig 8 : Azimuthal profile of observed Doppler velocity (red dots) and Rankine vortex model ($R > R_0$, black line) through the core of the tornado at 3 deg at 23:55Z. The constant α is 1.0 in above profile (a), and is 0.66 in below one (b).

6. Conclusions

The results of radar analysis on this tornado were consistent with the NWS statement. Moreover, the radar has resolved the tornado path accurately every minute. This is the reasonable evidence that our radar is a great tool for detecting and tracking tornadoes even for non-supercell tornadoes whose parent clouds don't have mesocyclones, and then quickening the warning process of NWS.

7. Acknowledgements

All the radar images were analyzed and created by GR2Analyst 2.80 developed by Gibson Ridge Software, LLC.