Observations of hail cores of tornadic thunderstorms with three polarimetric radars

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Goals:

- Adjacent WSR-88D radars operate at different frequencies. Observe hail cores with various radars to study frequency dependences of differential reflectivity (ZDR) and the correlation coefficient (CC = ρhv).
- Study attenuation of X band radiation in tornadic thunderstorms.
- Study the utility of the Slant Differential Ratio (SDR) in tornadic thunderstorms.

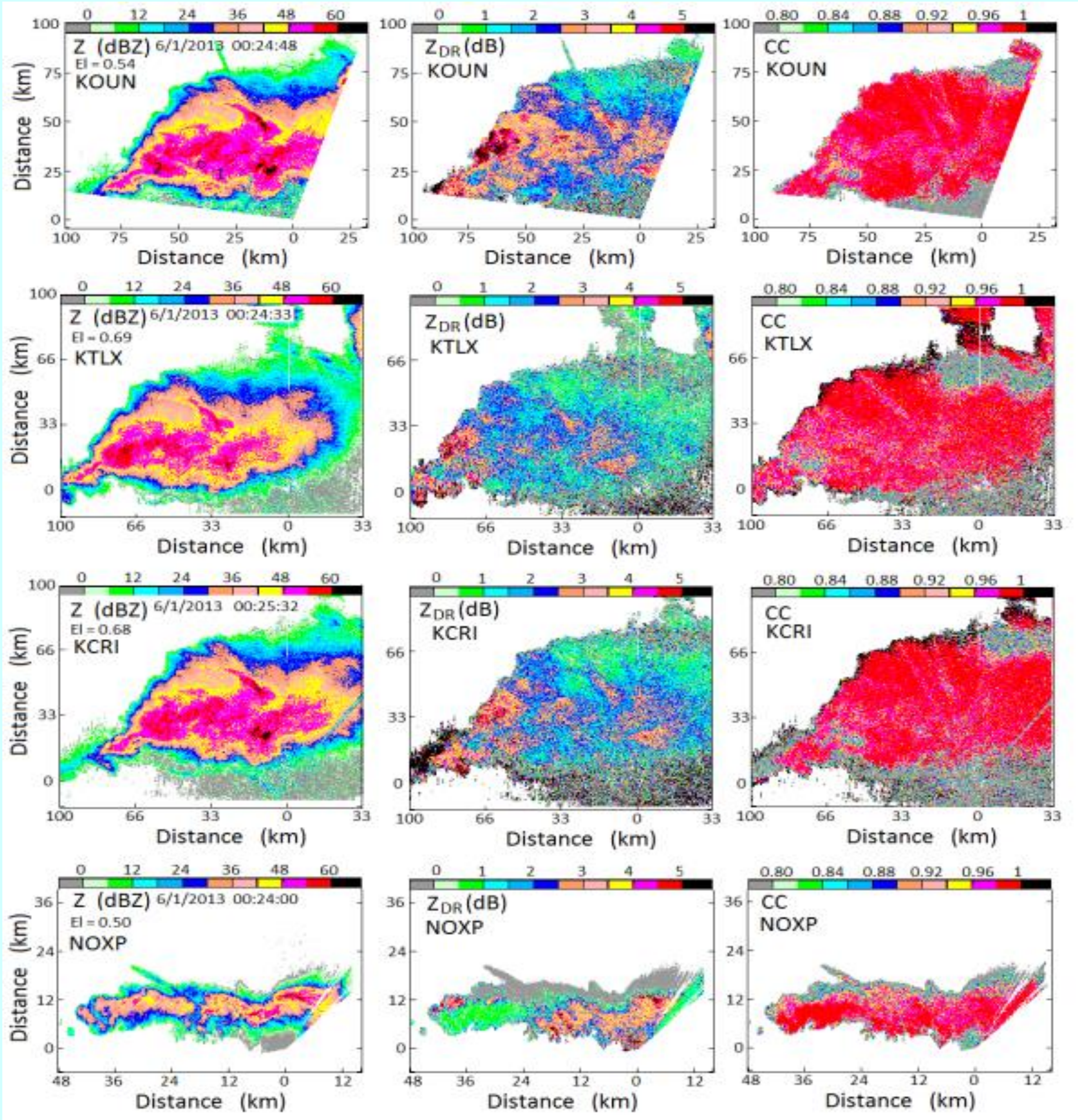
Radar Systems

Radar	Frequency, MHz
KOUN	S band, 2705
KTLX	S band, 2910
KCRI	S band, 2995
NOXP	X band, 9410

Fig. 1. The data have been collected with three polarimetric S band WSR-88Ds and the mobile X band dual-polarization NOXP.

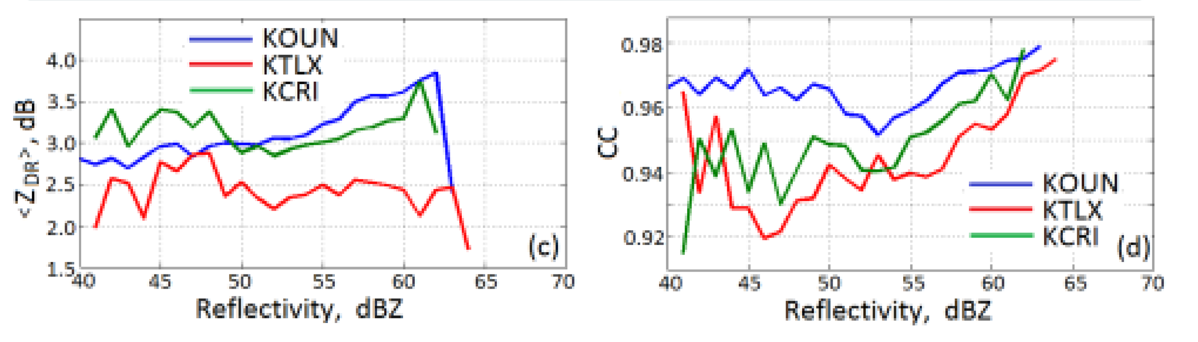
Fig. 2. A giant hailstone picked up by J. Coleman in City of El Reno, OK, 31 May, 2013 at 00:25 UTC.

Fig. 3. (below) . Area '1' of high reflectivity is close to the EF3 tornado (see also images of the Doppler velocities in the right top figure in this poster). The area of giant hail is shown with the circle.

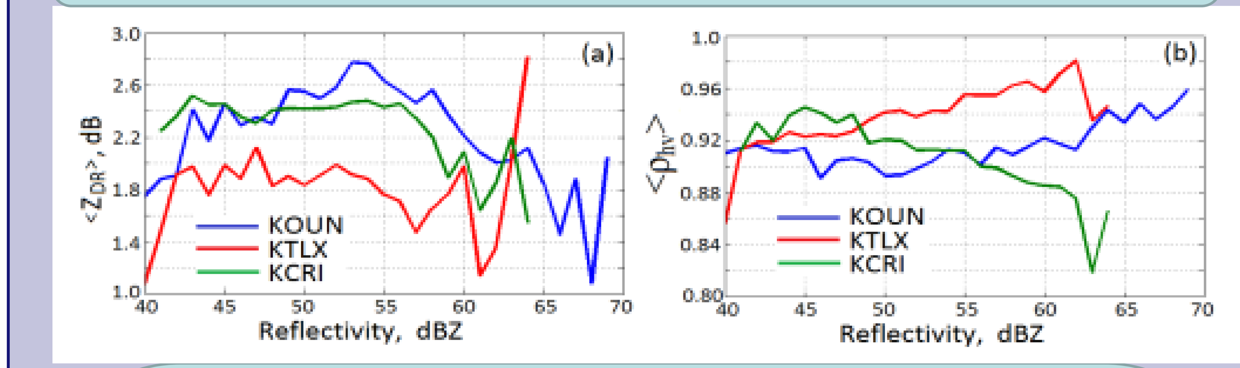


The mean ZDR and CC in the areas of giant hail as functions of reflectivity Z

Tornado event 31 May 2013 (Fig. 4)



Tornado event 19 May 2013 (Fig. 5)

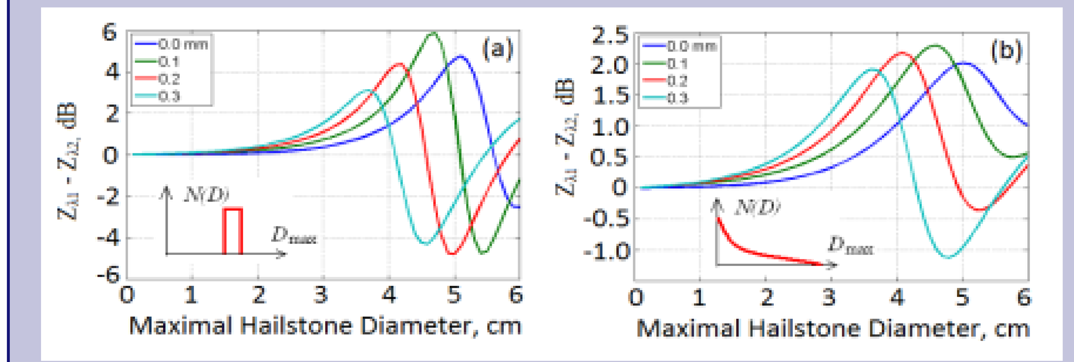


Results of observations

1. X band radiation experienced severe attenuation so that NOXP was unable to observe hail cores in the tornadic thunderstorms (Fig. 3, bottom –left).
2. The maximal reflectivity in the hail cores at longer wave-length of S band is frequently higher than at shorter wavelengths (e.g., Fig. 5 above).
3. Differences in ZDR from the three WSR-88Ds reached 1 dB in the hail cores that cannot be attributed to radar miscalibration.
4. The measured CC are different in the hail cores (Figs. 4 and 5).

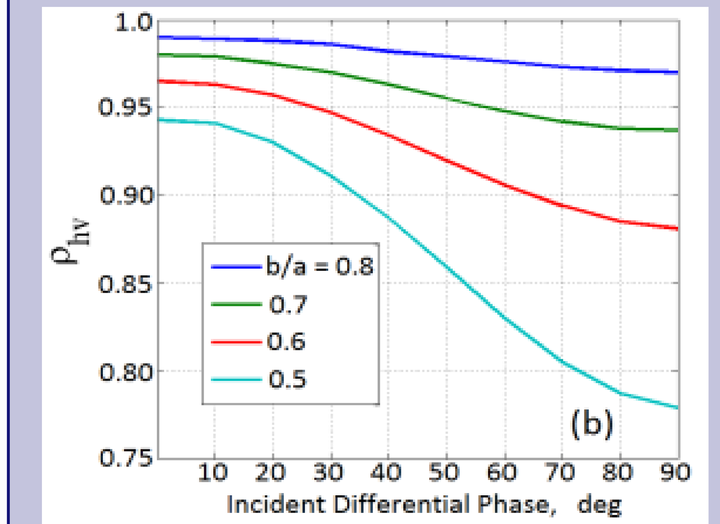
Trying to explain the observed features

Results of calculations using the T-matrix method



N(D) is the size distribution of hailstones

Fig. 6. (left): Calculated Reflectivity difference Z(KOUN) – Z(KCRI) as a function of the maximal hail size and water film in mm. N(D) is shown in the insert. (right): Same as in the left panel but for the exponential N(D). Z(KOUN) can be larger than Z(KCRI



In the polarimetric configuration of the WSR-88Ds (simultaneous transmission), the transmitted waves at horizontal and vertical polarization are shifted by the differential phase in transmit, which is the incident differential phase (IDP) for hail cores.

Fig. 7. The correlation coefficient as a function of the incident differential phase for different hailstone axis ratios (width/ length=b/a). Note a strong dependence of CC on the IDP

SDR parameter in tornadic thunderstorms

The WSR-88Ds employ a polarimetric configuration with Simultaneous Transmission And Reception (STAR) of horizontally and vertically polarized waves.

SDR is a parameter calculated from Zdr in power units and ρhv (CC) as,

$$SDR = \frac{Z_{dr} + 1 - 2Z_{dr}^{1/2}\rho_{hv}}{Z_{dr} + 1 + 2Z_{dr}^{1/2}\rho_{hv}}$$

In areas with hydrometeors, SDR is in an interval from -30 dB (almost spherical droplets) to -15 dB. (highly non spherical ice crystals)

If SDR > -15 dB, the scatterers are extremely non spherical , e.g., insects in the atmosphere (see the black areas in the lower right corners of the SDR panels).

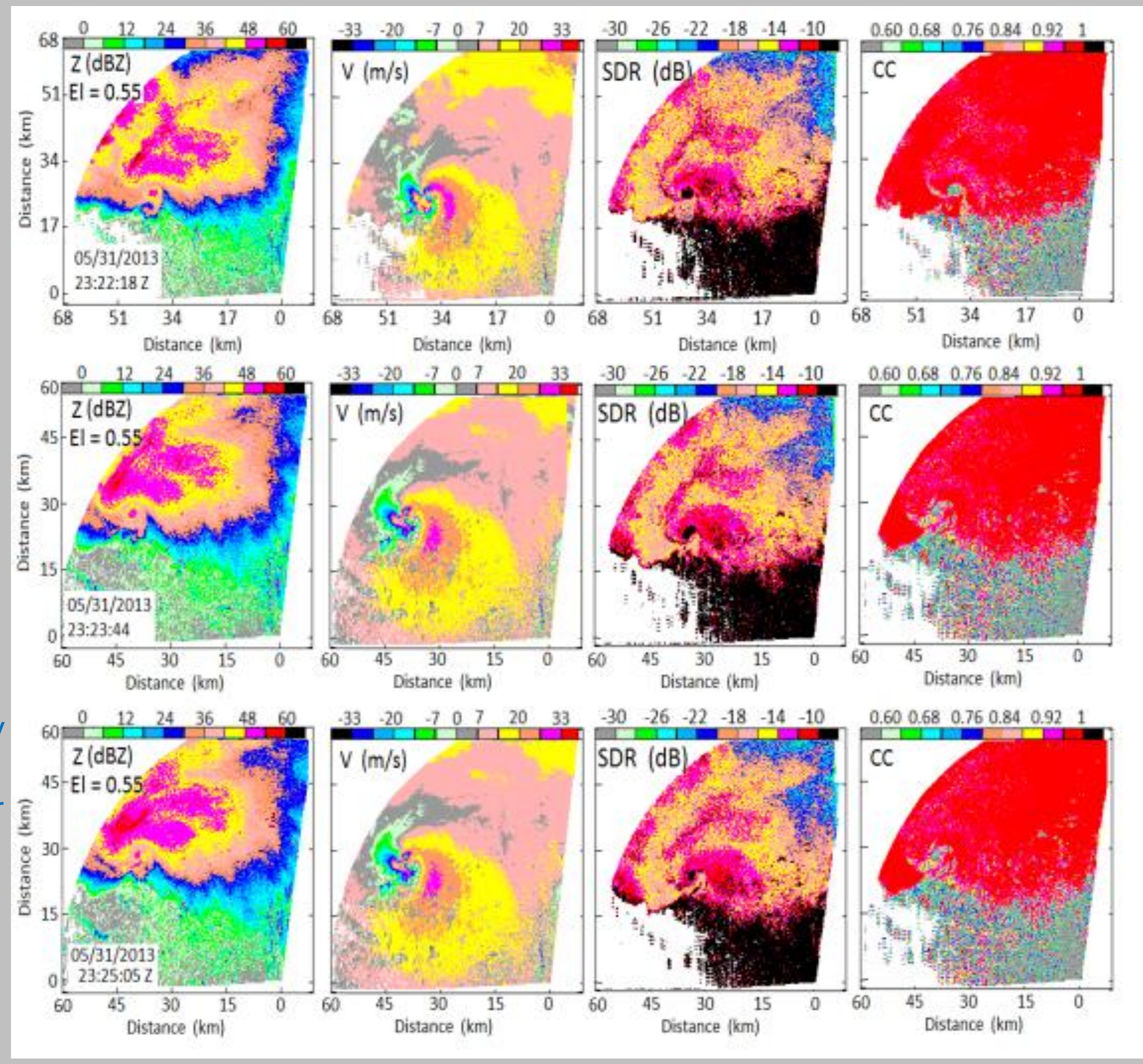
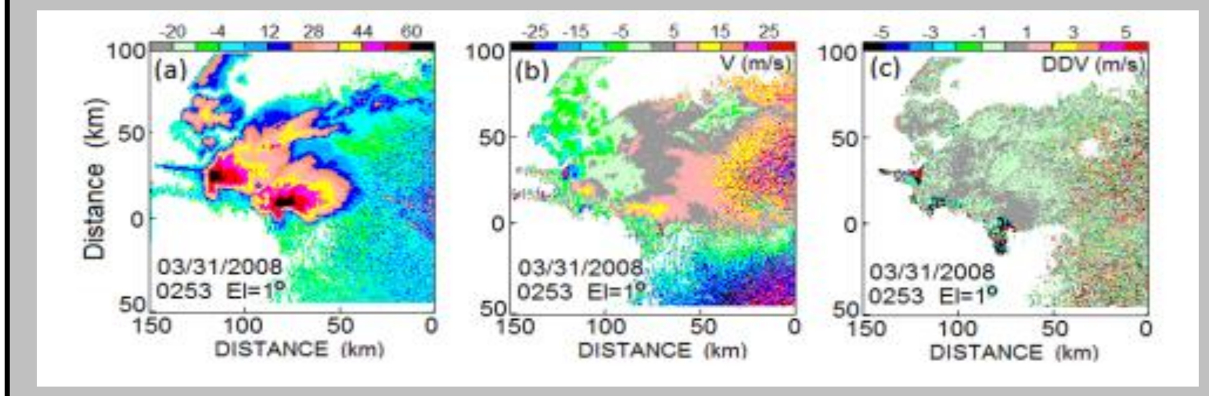


Fig. 8. Areas of SDR > -15 dB in weather echoes indicate the presence of highly non spherical scatterers. See patches of high SDR in the tornado area.

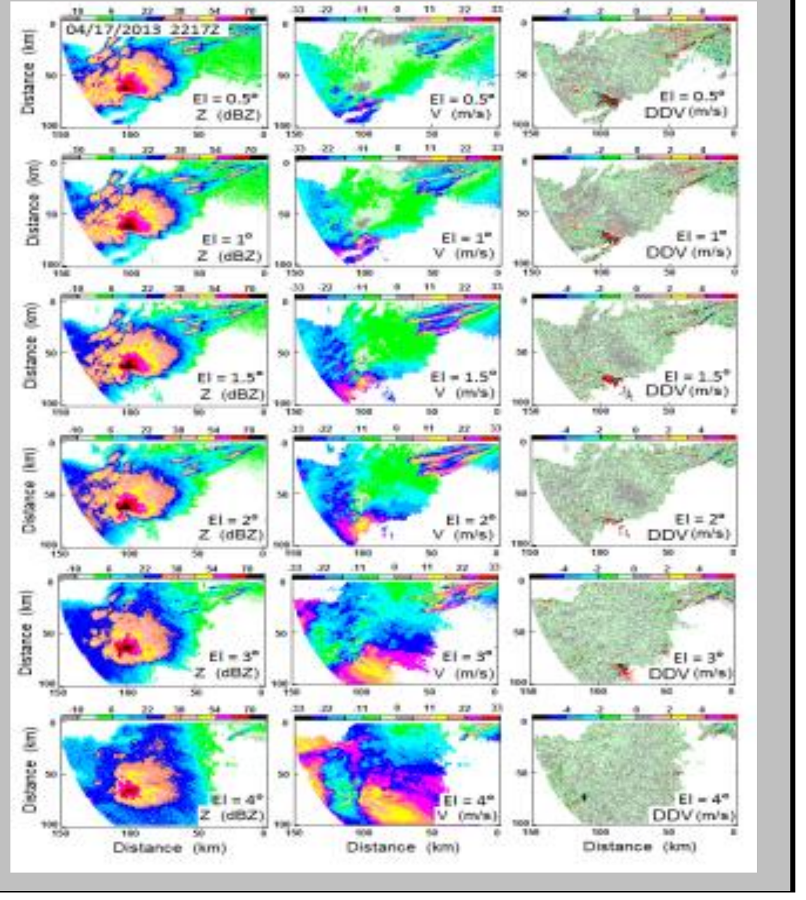
Differential Doppler velocity as an indicator of inflow areas

Tornado event 31 May 2008 (Fig. 9)



Differential Doppler Velocity (DDV) is the difference between the Doppler velocities measured at horizontal (Vh) and vertical (Vv) polarizations: DDV = Vh – Vv.
In clouds and precipitation |DDV| < 0.5 m/s. Areas of large DDVs contain ingested insects. Such areas are seen in the right panel of Fig . 9 and the right column in Fig. 10. The inflow area is observed up to heights of 4 km in Fig. 10.

Fig. 10
17 April



CONCLUSIONS:

- There are frequency dependences of Z, ZDR, and CC in hail cores so that various WSR-88Ds operating at different frequencies can measure different values in the same hail area. (Figs. 4 ,5, and 6)
- The measured differential phase and CC strongly depend upon the system differential phase in transmit. This phase can be different in various WSR-88Ds therefore measured CC can be different. (Fig. 7)
- SDR can be used to estimate non-sphericity of scatterers. Typical SDR values in rain are about -20 dB. SDR in tornado balls can reach -10 dB indicating the presence of highly non-spherical scatterers. (Fig. 8)
- Differential Doppler velocity (DDV) can be used to identify areas of inflow. Our observations show that inflow areas can reach 4 km in height. (Fig. 10)
- X band radiation experiences severe attenuation in hail thunderstorms. In the 2013 tornado thunderstorms in Oklahoma, X band radiation did not reach the hail cores at all (e.g., Fig. 3)