

HAIL SPIKE IMPACTS ON DOPPLER RADIAL VELOCITY DATA DURING SEVERAL RECENT LOWER OHIO VALLEY CONVECTIVE EVENTS

CHRIS SMALLCOMB

National Weather Service, Weather Forecast Office
Louisville, Kentucky

1. INTRODUCTION

The mid-level three body scatter spike (TBSS) Doppler radar signature generally is a 10-30 km long region of artifact echo aligned radially downrange from a highly reflective (>60 dBZ) echo core. Caused by non-Rayleigh radar microwave scattering or Mie scattering (Zrnić 1987), the TBSS (commonly called a hail spike) is widely used by operational NWS forecasters as a sufficient but not necessary indication of very large hail within a severe thunderstorm.

Established research (Lemon 1998, Wilson and Reum 1988) and training material (NWS 2004) describe the radial velocity signature associated with the TBSS as generally weak inbound coupled with high (noisy) spectrum width values, due in part to the combination of horizontal and vertical air motions along the path of the radar return, moderated by the influence of ground targets. As such, the radial velocity data associated with the TBSS are nearly always meaningless.

During recent severe convective events in the Lower Ohio River Valley, several examples of the TBSS exhibiting high inbound radial velocity signatures have been noted. In at least one case, the signature resulted in false mesocyclone and tornado vortex signature algorithm alerts from the Louisville/Fort Knox, Kentucky WSR-88D (KLVX).

The cases presented in Section 2 demonstrate that the TBSS can contaminate velocity data, thereby making storm interrogation and the warning decision process more complicated. In the discussion (Section 3), it is emphasized that forecasters need to be cautious in analyzing the placement of these features within the overall storm structure before making a warning decision, particularly when weighing whether a tornado is imminent.

2. CASES FROM THE 2006 SPRING SEASON

Two cases from the 2006 spring convective season are presented which illustrate hail spike contamination of velocity data (Figure 1). Both of these cases were selected due to the pronounced impact on warning operations.

2.1 Clark County, Indiana: 7 April 2006

A number of left-moving supercell thunderstorms formed in the Lower Ohio River Valley region the afternoon of 7 April 2006. One particular storm reached peak intensity between 1930 and 1950 UTC as it moved across Floyd and Clark Counties in far southern Indiana, adjacent to the Louisville metropolitan area. This storm produced estimated 2.5 inch (6.35 cm) diameter hail in Georgetown, Indiana (Floyd County) at 1931 UTC and near Henryville, Indiana (central Clark County) at 1942 UTC. The latter resulted in numerous reports of car and home windows smashed, due in part to the storm crossing Interstate 65, a major north-south artery between the Midwest and South.

This storm exhibited classic TBSS signatures aloft well before the 1942 UTC large hail report, including the 1938 UTC volume scans from the KLVX radar. Figure 2 shows a pronounced hail spike signature in the reflectivity emanating northeastward from the storm core, and Figure 3 indicates high spectrum width (SW) values associated with this hail spike, especially close to the storm. Previous research (Wilson and Reum 1988) has shown that TBSS sig-

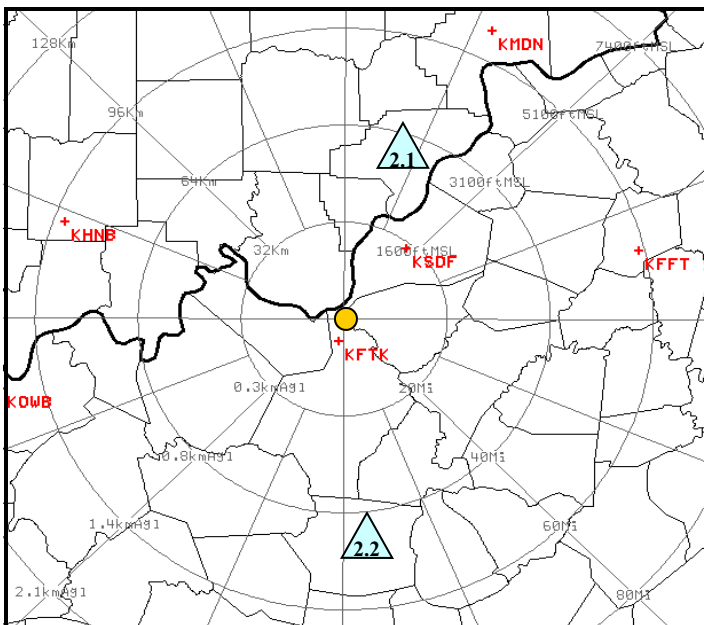


Figure 1. Locations of the two cases in this paper, identified by their subsection numbers. The gray radar range rings indicate the distance and altitude of the 0.5 degree beam from the KLVX radar (yellow dot).

Contact Information:

National Weather Service
6201 Theiler Lane, Louisville, KY 40229
502.969.8842 (<http://weather.gov/louisville>)
chris.smallcomb@noaa.gov

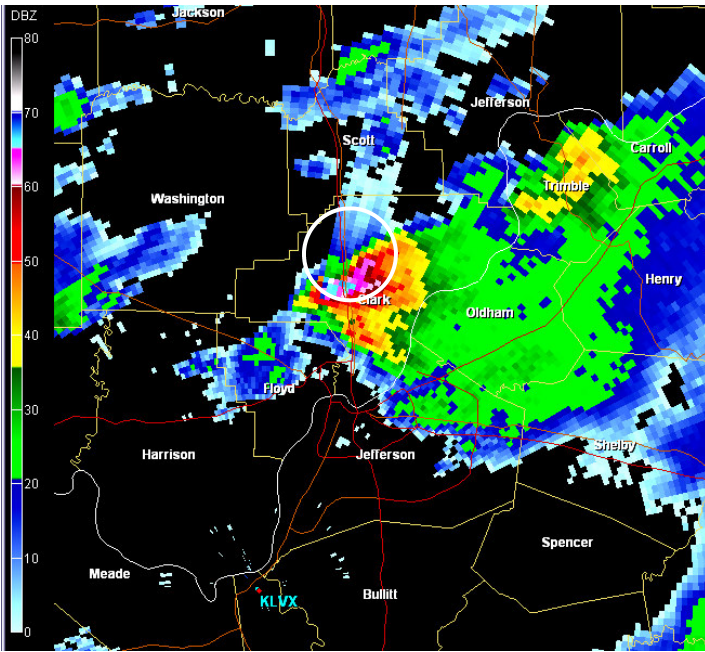


Figure 2. 3.0 degree base reflectivity scan from the KLVX radar at 1938 UTC on 7 April 2006. The beam altitude at the center of the white circle is approximately 3,346 m (10,980 ft) AGL at a distance from the radar site of 61 km (33 nm). In this and all successive figures: Counties outlined in tan, county names and state borders white, Interstates red, and highways brown. The radar site is noted by the light-blue "KLVX" and the color scale for the data is shown on the left-hand side of the image. GRLevel2 Analyst Edition software was used to produce images.

natures are associated with high values of spectrum width (SW). During this same period, velocity data exhibited high inbound values associated with the TBSS (Figures 4 and 5 within the white circle). The peak inbound base velocity was -42.7 knots (-22 m sec⁻¹) in Figure 4, with the maximum inbound storm relative motion at -68 knots (-35 m sec⁻¹) in Figure 5. Clearly in this case, the presence of the TBSS impacted the velocity data, as has been documented in past research on the phenomena. The pro-

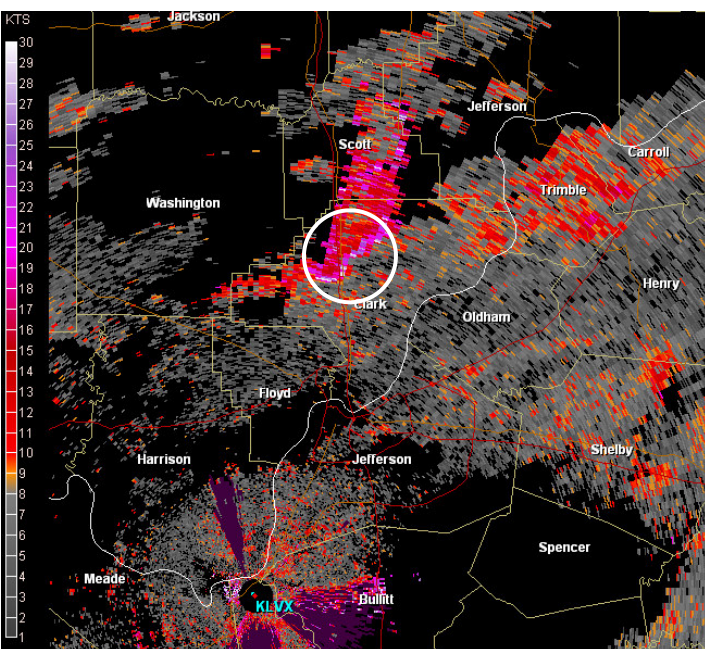


Figure 3. 3.0 degree spectrum width image from the KLVX radar at 1938 UTC on 7 April 2006.

nounced cyclonic circulation evident in the velocity data on the poleward side of the Clark County storm, through a fairly deep layer including the 0.5 through 3.0 degree elevation slices, helped trigger the WSR-88D mesocyclone (MD) and tornado vortex signature (TVS) alerts for this area of the storm in the 1938 UTC scan. The TVS attributes are displayed in Table 1, and the location shown in Figure 4, although the location is displaced from the strongest inbound velocities at this altitude.

During this high-stress warning environment with other storms occurring simultaneously in the area, forecasters took this information and upgraded an ongoing severe thunderstorm warning to a tornado warning. A report of a tornado touchdown in proximity to the storm at 1951 UTC seemed to confirm the forecasters' suspicions that a real circulation had developed. However, it was learned that this tornado sighting was likely in fact the heavy rain/hail core of the storm, as no tornado damage was found in a subsequent survey. Recurrent obstacles to efficient warning operations are false funnel cloud or tornado reports, especially from untrained people and particularly at night or around twilight.

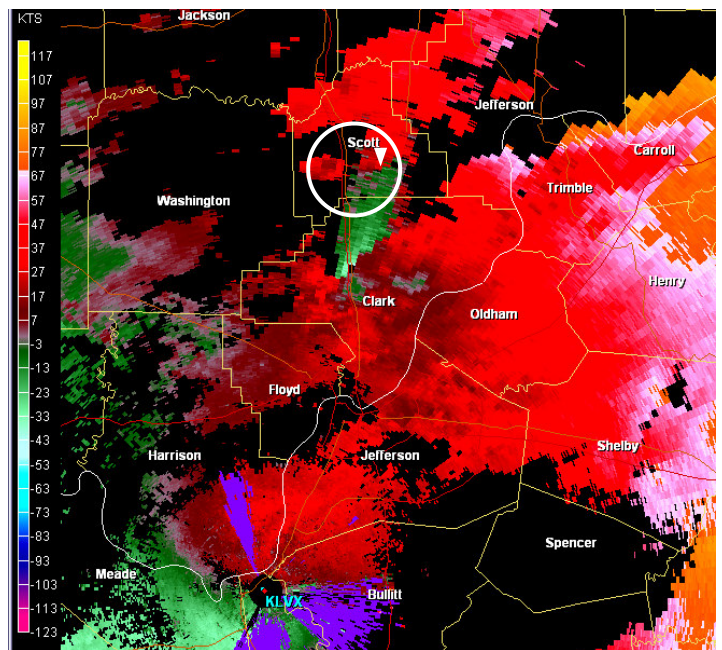


Figure 4. 3.0 degree base velocity scan from the KLVX radar at 1938 UTC on 7 April 2006. Green (red) colors denote inbound (outbound) velocities. Purple areas in this and other velocity figures indicate range folding. The location of the TVS algorithm alert is noted by the upside-down white triangle.

Table 1. NEXRAD TVS Attributes for Clark Co. Storm at 1938 UTC	
Latitude/Longitude	38.52° / -85.70°
Base	< 2,300 ft (701 m) AGL
Depth	> 19,000 feet (5,791 m)
Average Velocity Difference	47 knots (24 m sec ⁻¹)
Low-Level Velocity Difference	26 knots (13 m sec ⁻¹)
Maximum Velocity Difference	115 knots (58 m sec ⁻¹)

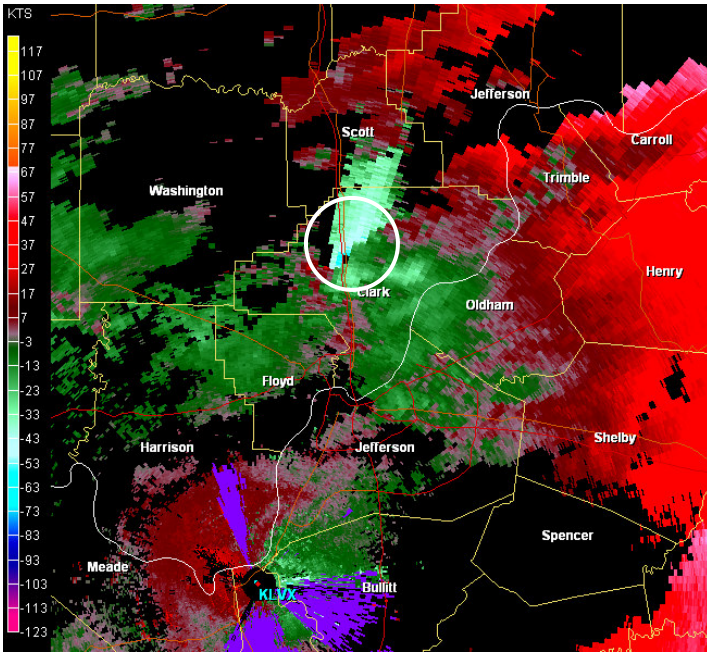


Figure 5. 3.0 degree storm relative velocity scan from the KLVX radar at 1938 UTC on 7 April 2006. Storm motion was estimated to be from 230° at 30 knots (15.2 m sec^{-1})

A further discussion of the ramifications of contaminated velocity data in this and the subsequent case will be done in Section 3.

2.2 Hart County, Kentucky: 2 April 2006

Less than one week prior to the 7 April event, another widespread episode of severe weather affected much of the eastern U.S. from North Carolina to Iowa. Supercell thunderstorms producing large hail impacted areas in cen-

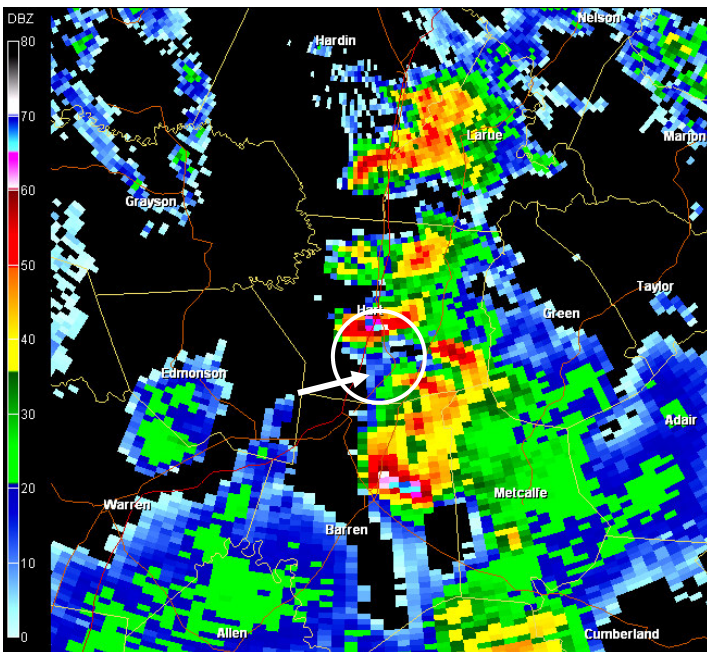


Figure 6. Base reflectivity at the 2.3 degree elevation slice from the KLVX radar at 2059 UTC on 2 April 2006. The beam altitude at the center of the white circle is approximately 3,657 m (12,000 ft) AGL at a distance from the radar site of 83 km (45 nm). White arrow points out TBSS reflectivity signature.

tral Kentucky during the afternoon hours, including a small cell that moved across central Hart County (Figure 6), producing 1 inch (2.5 cm) diameter hail 7 miles east of Mundefordville in the east-central part of the county. The TBSS signature with this storm was largely obscured with significant radar returns up- and down-radial. It can just barely be seen at the tip of the white arrow in Figure 6. The TBSS at this time is at the center of the white circle in Figure 6, and in subsequent Figures 7-9.

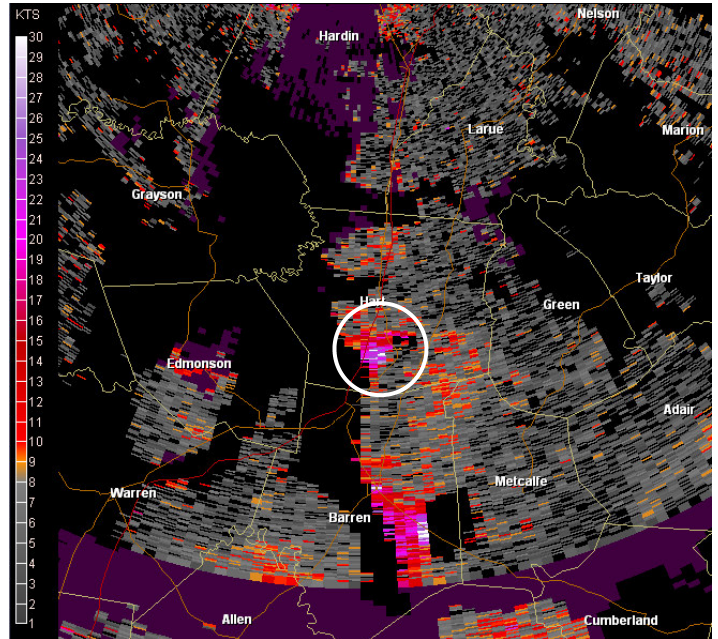


Figure 7. 2.3 degree spectrum width image from the KLVX radar at 2059 UTC on 2 April 2006.

However, an examination of reflectivity imagery prior to 2059 UTC (when the storm is more isolated from other cells) reveals the presence of a subtle TBSS signature, as does the spectrum width data at 2059 UTC (Figure 7). The base velocity and storm relative motion data at 2059 UTC (Figures 8 and 9, respectively) depict another example of high inbound velocities within the TBSS. In Figure 8, the maximum inbound base velocity was -64.1 knots (-33 m sec^{-1}), and the peak inbound storm relative motion in Figure 9 was -55.4 knots (-28.5 m sec^{-1}). This storm was moving toward the radar, compared to the Clark County cell which was moving away; therefore, the base velocities associated with the Hart County storm are nearly all inbound. No WSR-88D algorithm alerts occurred with this apparent cyclonic circulation in the storm relative motion data, likely due to the broader nature of the circulation depicted. However, an ongoing severe thunderstorm warning was upgraded to a tornado warning at 2104 UTC based on the appearance of a developing mesocyclone aloft, albeit broad, and due to unsubstantiated reports of funnel clouds associated with the storm.

3. DISCUSSION & RECOMMENDATIONS

These two cases present situations where the TBSS

ened the threat that afternoon mentioning this was a "PARTICULARLY DANGEROUS SITUATION" and "RAPID DEVELOPMENT OF SEVERE THUNDERSTORMS OVER LOWER OH AND TN VALLEYS BY EARLY AFTERNOON. TORNADIC SUPERCELLS ARE EXPECTED."

On 2 April 2006, a northwest-southeast oriented warm front was draped across central Kentucky, a feature which can contribute to enhanced storm relative helicity for storms that develop in the vicinity of the warm front, which the Hart County storm (Section 2.2) did. The 20 UTC Day One Convective Outlook from the SPC mentioned the environment near and southwest of the warm front, including portions of the Lower Ohio River Valley was, "SUPPORTIVE OF SUPERCELLS CAPABLE OF LARGE DESTRUCTIVE HAIL...DAMAGING WINDS AND A FEW TORNADOES".

Even in these environments which were favorable for mesocyclone and/or tornado formation, an analysis of the apparent circulation's location relative to the rest of the storm cell, and consideration of the accepted conceptual models for mesocyclone development within supercells, may have given forecasters clues that suggested these cyclonic circulations were not real. The specific goal of the conference paper is simply to ensure that operational forecasters are aware that the TBSS can, but not always, extensively contaminate radial velocity data.

In the Clark County event (Section 2.1) on 7 April, the TBSS was very apparent and had been for a number of volume scans prior to the 1938 UTC scan shown in Figures 2-5. The spectrum width values were high within the TBSS signature (Figure 3), in excess of 17 knots (8.75 m sec^{-1}) in most bins, consistent with established research. The strong inbound velocities depicted in Figures 4 and 5 are located just outside the far northern periphery of the storm. So even though it gives the appearance of an elongated but strong cyclonic circulation, it would have to be treated as suspect due to its positioning relative to the storm. The TVS algorithm alert mentioned earlier (Table 1) was likely due to this contaminated data not only at the 3.0 degree elevation but in lower level slices as well. Examination of the cell at the same altitude from a different perspective via the Indianapolis WSR-88D radar (Figure 10) revealed a cleaner velocity image with lower spectrum width values. An apparent mesoanticyclone is detected in the mid-levels of the thunderstorm, an attribute of storms moving to the left of the mean flow (Nielsen-Gammon and Read 1995), which this was. This typically is associated with supercells producing very large hail, not tornadoes.

The Hart County event (Section 2.2) was more subtle in nature, as the TBSS was obscured by down-radial convection over far southern Hart County and Barren County (Figure 6). The Barren County storm produced a second TBSS signature visible in reflectivity and SW data (Figure 7), but a much less apparent inbound velocity signature (Figures 8 and 9). The SW product clearly indicates the presence of a potential TBSS associated with the Hart County storm, with values exceeding 17 knots (8.75 m sec^{-1}). The highest inbound velocities associated with the

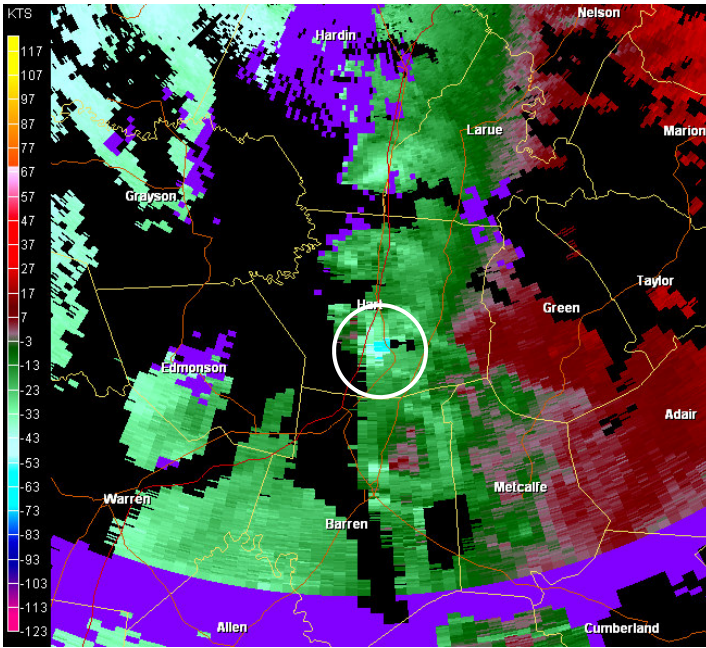


Figure 8. Base velocity on the 2.3 degree elevation slice from the KLVX radar at 2059 UTC on 2 April 2006.

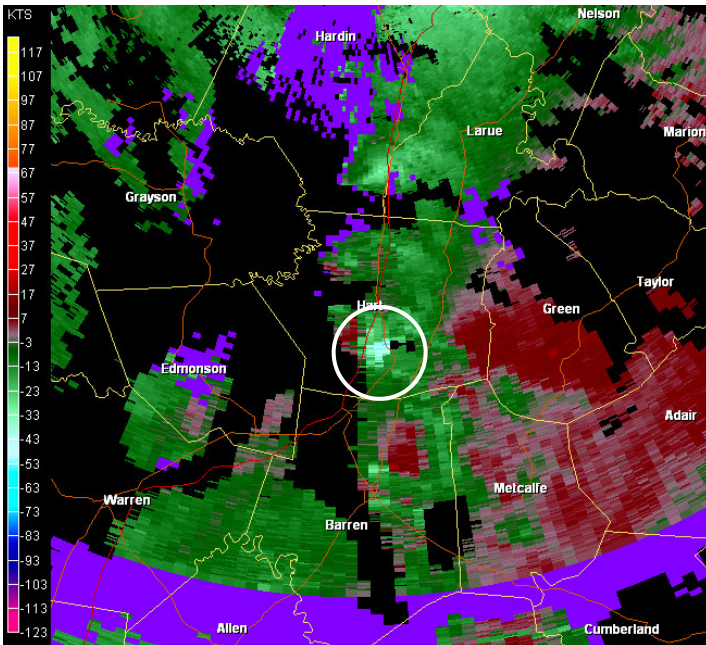


Figure 9. 2.3 degree storm relative velocity scan from the KLVX radar at 2059 UTC on 2 April 2006. Storm motion was estimated to be from 250° at 30 knots (15.2 m sec^{-1})

significantly contaminated radial velocity data within two severe thunderstorms, complicating the process of storm interrogation during fast-paced and high-stress severe weather situations.

Synoptic environments in both events were ones of at least modest tornado potential, likely heightening forecasters' anticipation of supercell/mesocyclone signatures on radar.

The 7 April 2006 environment was more conducive to tornadoes, with a tornado watch from the NWS Storm Prediction Center (SPC) in effect at the time the Clark County storm (Section 2.1) occurred. This watch height-

Hart County TBSS were well outside (south) of the storm core if one compares the reflectivity and base velocity images (Figures 6 and 8, respectively). Therefore, any apparent circulation this generates in the base velocity or storm relative motion data would need to be treated as suspect.

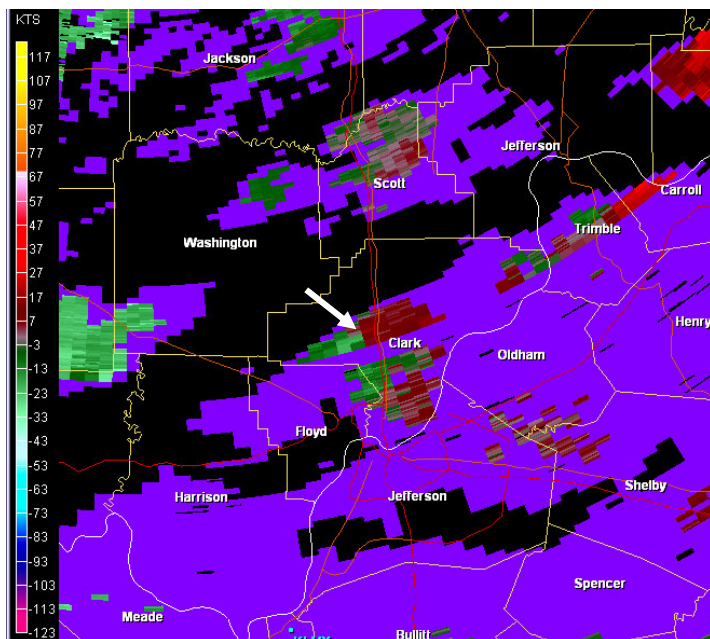


Figure 10. 0.9 degree base velocity scan from the Indianapolis, Indiana (KIND) WSR-88D radar at 1937 UTC on 7 April 2006. The beam altitude at the white arrowhead is approximately 3,490 m (11,450 ft) AGL at a distance at a distance from the radar site of 145 km (78 nm). The radar is located off the image to the top-left.

The following are suggested points for operational meteorologists which could help identify potentially contaminated velocity data associated with TBSS signatures during episodes of severe convection with large hail:

- First and foremost consider placement of any velocity signatures relative to the storm reflectivity structure before making a warning decision. Basically ask the question, "Does this make sense given the conceptual models that I know?"
- Though not widely used in operations, spectrum width (SW) data can be a valuable tool in identifying TBSS in radar data. By making use of the SW product, forecasters would be able to identify potential TBSS signatures, especially those that are masked by down-radial precipitation such as in the Hart County example.
- If TBSS velocity contamination is suspected, make use of data from surrounding WSR-88D radar sites which, given their different angles and perspectives relative to the storm cell in question, may provide cleaner velocity data.

Future work in this topic includes identifying additional cases where a TBSS significantly contaminates velocity data. Anyone with knowledge of such a case is invited to contact the author. One key question that remains is why

some TBSS exhibit this behavior, while the majority produce the more typical weak inbound radial velocity signatures. Whether this is due to environmental factors, radar orientation, or another cause is uncertain at this time.

4. ACKNOWLEDGEMENTS

The author would like to thank John Gordon, Meteorologist-in-Charge at NWS Louisville, and the forecasters at NWS Louisville for giving the author inspiration and motivation to examine this topic.

Ted Funk, Science and Operations Officer at NWS Louisville, Joe Ammerman and Angela Lese, forecasters at NWS Louisville, and Karen Smallcomb, my wife, provided beneficial feedback by reviewing the abstract.

5. REFERENCES

- Lemon, Leslie R., 1998: The Radar "Three-Body Scatter Spike": An Operational Large-Hail Signature. *Weather and Forecasting*, **13**, 327-340
- National Weather Service (NWS), Advanced Warning Operations Course, 2004: Three Body Scatter Spike (TBSS). <http://www.wdtb.noaa.gov/courses/awoc/ICSvr3/>
- Nielsen-Gammon, John W., and W. L. Read, 1995: Detection and Interpretation of Left-Moving Severe Thunderstorms Using the WSR-88D: A Case Study. *Weather and Forecasting*, **10**, 127-140
- Wilson, James W., and D. Reum, 1988: The Flare Echo: Reflectivity and Velocity Signature. *J. Atmos. and Oceanic Technol.*, **5**, 197-205
- Zrnić, D. S., 1987: Three-body scattering produces precipitation signatures of special diagnostic value. *Radio Sci.*, **22**, 76-86