P7.1 THUNDERSTORM TYPES ASSOCIATED WITH THE “BROKEN-S” RADAR SIGNATURE

Richard H. Grumm[*]
NOAA/National Weather Service
State College, PA
and Matthew Glazewski
The Pennsylvania State University

1. INTRODUCTION

The “broken-S signature” was identified by McAvoy et al. (2000, hereafter MJM) as a radar signature associated several tornadoes in South Carolina. They identified the phenomena primarily as a cool season structure occurring with low-topped mesoscale convective systems (MCS). They also noted that these signatures are similar in appearance to a line echo wave patterns (LEWP; Nolan 1959). Figure 1 shows an example of a cool season “broken-S signature” associated with an F0 tornado over southwestern Pennsylvania at 1328 UTC 8 November 1996.

Observations of thunderstorms and weak tornado events in Pennsylvania have revealed many “broken-S signatures”. These events were initially identified as splits or fractures in the line of thunderstorms. Many of these fractures clearly exhibit the same signature as the broken-S. The “broken-S” terminology appears to apply to many previously identified echoes, including the boomerang echo. The boomerang echo often develops from a single storm as the mesocyclone takes on the shape of a boomerang. Typically, the northern mesocyclone with the boomerang is cyclonically rotating. Often, these features split forming to distinct echoes. This fracture, or break in the line appears to be a favored location for the development of weak (F0/F1) tornadoes. Similar fractures or breaks have also been observed with rotating supercell thunderstorms. In contrast to the findings of MJM (2000), radar observations have revealed apparent fractures or “broken-S signatures” in both the warm and cold seasons in central Pennsylvania.

This study will focus on the importance of and conditions associated with “broken-S signatures” on radar. The results suggest a wide range of thunderstorms lines can produce this apparent signature. The focus here is on rotating storms and multi-cellular lines, which can produce the broken-S signature. The synoptic scale setting associated with these radar signatures is also presented.

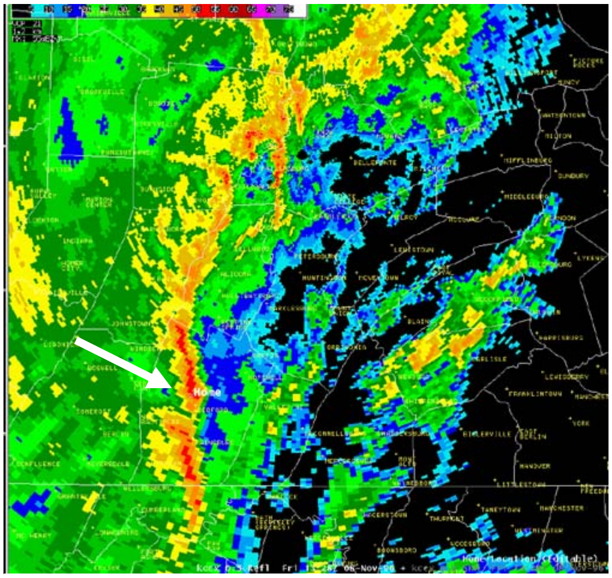

Figure 1.Central Pennsylvania (KCCX) WSR-88D 0.5 degree elevation angle showing reflectivity data valid at 1328 UTC 8 November 1996. White arrow shows the split in the line and the approximate location of an F0 tornado.

2. METHODS

Preliminary cases were obtained using the NOAA's Storm Prediction Center (SPC) severe weather database and available data from the Central Pennsylvania (KCCX) Weather Surveillance Radar (WSR-88D). The large-scale conditions were assessed using NOAA’s National Centers for Environmental Predictions (NCEP) reanalysis data displayed using the Grid Analysis and Display System (GrADS). Climatic anomalies are as described by Grumm and Hart 2001.

Initial cases were selected with some a prior knowledge of the outcome. This method quickly revealed over 10 different severe weather events in which 1 or more “broken-S signatures” were observed. The location of tornadoes was extracted from the severe weather database and

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[*] *Corresponding author address*: Richard H. Grumm, 227 West Beaver Ave, State College, PA 16803; email:richard.grumm@noaa.gov

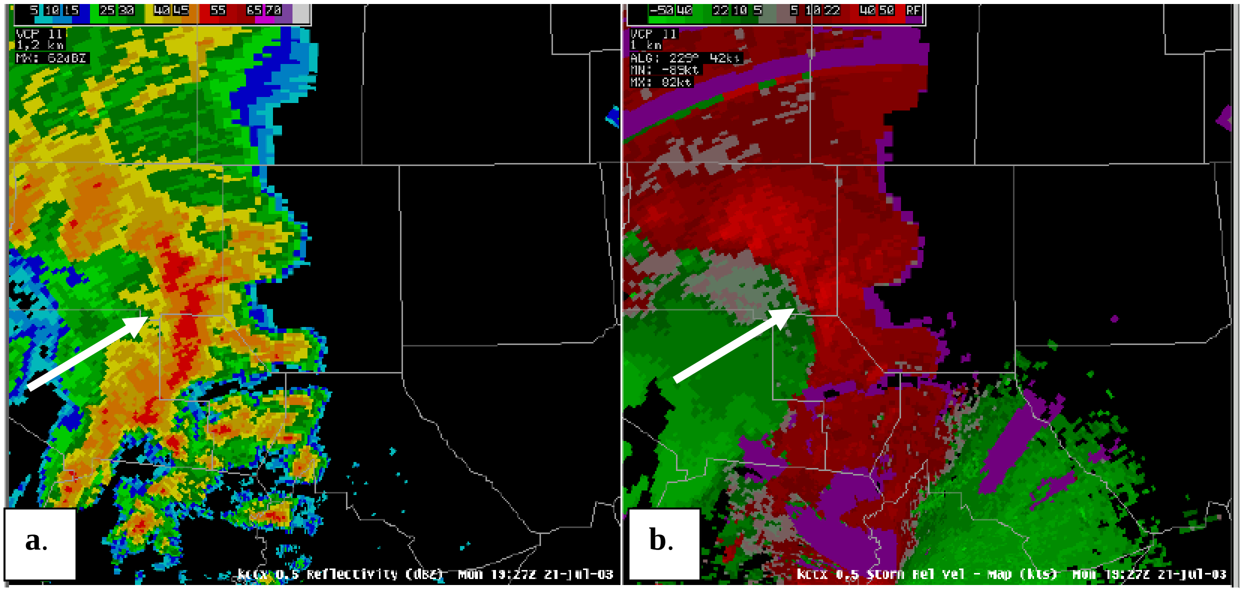

Figure 2. KCCX 0.5 degree radar data valid at 1927 UTC 21 July 2003 showing a) base reflectivity and b) storm relative velocity. Storm motion was 229 degrees at 42 kts. White arrow denotes the split in the line.

plotted on the radar imagery to show where the tornado was observed relative to the radar signatures closest to the tornado touchdown time.

The date of each severe weather event that produced 1 or more broken-S signatures on radar were used to identify the large-scale conditions associated. This facilitated classifying the events using radar characteristics and the large-scale patterns. The two examples presented in the results show two distinct event types identified to date. The first case shows a broken-S with rotating storms and the second case shows a broken-S associated with a multi-cellular line of storms.

The SPC storm data also allowed for production of statistics on the number of severe weather reports for each event. Radar data allowed the events to be classified based on the characteristics of the echoes on radar. The larger severe weather events in central Pennsylvania, associated with 30-50 individual severe weather reports, are typically associated with lines of thunderstorms (LEWPs). These lines appear to favor the presence of the “broken-S signature". The less common supercell events also had the ability to produce the “broken-S” signature.
NCEP re-analysis data was used to examine the large scale conditions associated with some of the larger severe weather events. Key parameters included the mean sea-level pressure and anomalies, 850 hPa winds, and anomalies, 0-1.5km shear (derived from 850 hPa and 10m winds), 0-3km shear (700 hPa and 10m winds), and instability. For simplicity, the totals-totals index was used to depict instability. Anomalies are shown as standard deviations from the 30-year means, referred to as standardized anomalies (SDs).

3. RESULTS

3.1 21 July 2003 rotating storm event

The base reflectivity and storm relative velocity data (SRM) at valid at 1927 UTC 21 July 2003 are shown in Figure 2. At the fracture in the reflectivity data (white arrow in Figure 2), a strong mesocyclone developed. As this feature moved to the northeast, it produced a tornado. This tornado blew down portions of the Kinzua viaduct in northwestern Pennsylvania. There were 5 other (not shown) fractures or “broken-S signatures” over central Pennsylvania on 21 July. Two of tornadoes were associated with “broken-S” signatures on radar.

The large-scale pattern over the eastern United States is shown in Figure 3. A deep low-level cyclone, -3 to -4 SDs below normal, (Fig. 3a) moved into the Great Lakes on 21 July 2003. A low-level equivalent potential temperature ridge was present in the warm sector ahead of the 250 hPa jet (Fig. 3b). The U-wind in the upper-

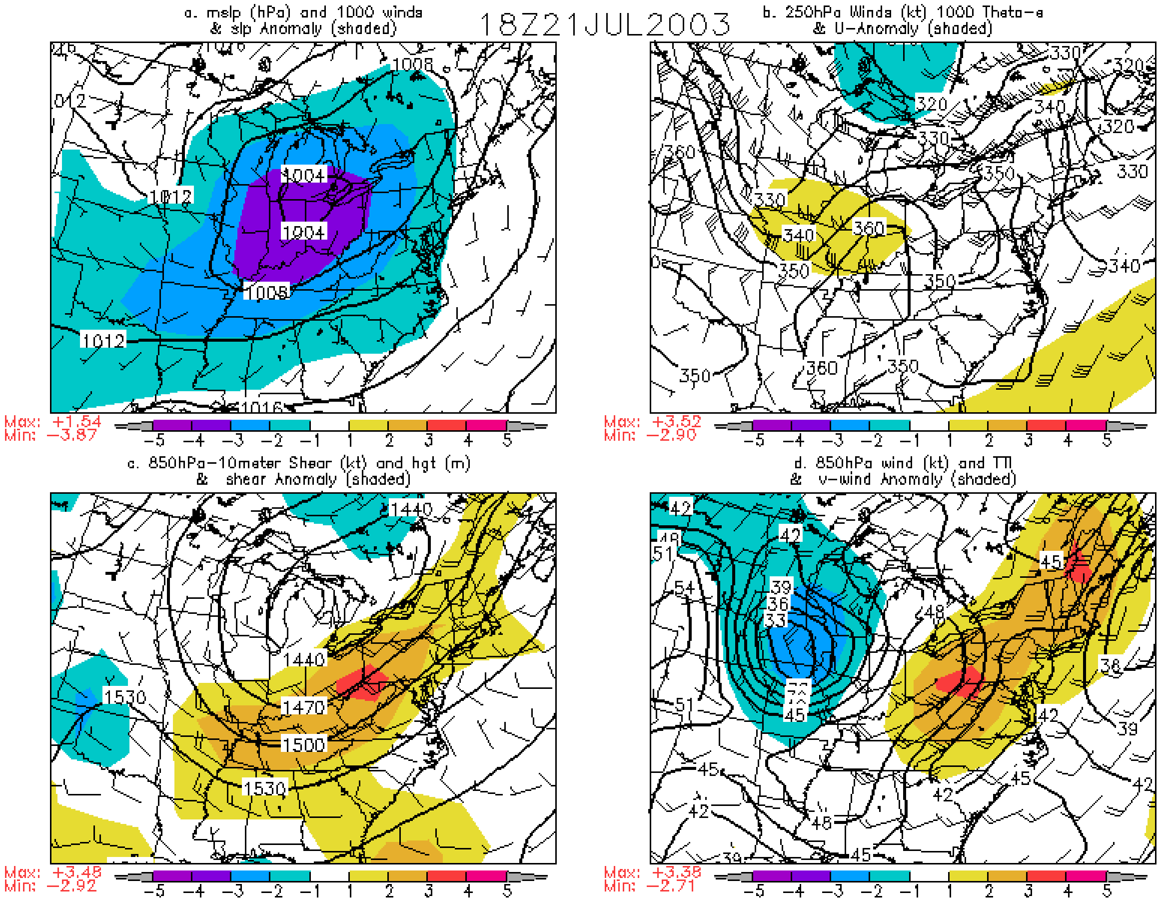

Figure 3. Reanalysis data valid at 1800 UTC 21 July 2003 showing a) mean-sea level pressure (hPa) 1000 hPa winds (kts) and standardized pressure anomalies, b) 250 hPa winds (kts), 1000 hPa equivalent potential temperature (K), and u-wind anomalies, c) 850 hPa to 10 meters above the surface shear vectors and shear anomalies, and 850 hPa height, and d) 850 hPa winds, V-wind anomalies and totals totals-totals index . Isobars are every 4 hPa, equivalent potential temperatures are every 5K, heights every 30 m, and totals-totals are every 3 degrees. Anomalies (shaded) are in standard deviations from normal.

level jet was slightly above normal. Strong shear in the layer from 10 meters to 850 hPa (about 1.5km layer) was present over the region (Fig. 3c). The shear anomaly was closely aligned with the above normal (+2 to +3SDs) 850 hPa southerly jet (Fig. 3d). The totals-totals index shows there was instability over the region of interest.

3.2 8 November 1996 multi-cellular event

This cold season event shared many of the large-scale characteristics described by MJM. In this event, a multi-cellular line of thunderstorms moved across Pennsylvania on 8 November 1996. It contained 5 “broken-S signatures” associated with weak tornadoes. The radar image associated with Bedford, PA tornado is shown in Figure 1. This event and similar broken-S signatures in these multi-cellular events were often associated with strong inflow, such as a rear-inflow jet, into the line of thunderstorms. The SRM data (not shown) revealed a mini-bow echo like structure along the segment of the line where the “broken-S signature” appeared.

The large-scale pattern for this event is shown in Figure 4. The southwesterly winds dominated from near the surface to 250 hPa. Note the southerly and south-southeasterly winds ahead of the frontal trough (Fig. 4a). The 850 hPa southerly winds were 2-3 SDs above normal over Pennsylvania. The 850 hPa wind anomalies were comparable in size to those observed on 21 July 2003 though the magnitude of the winds was greater in the November case. The instability, strong shear, and strong low-level jet were closely aligned during this event which may have favored upright convection so late in the year.

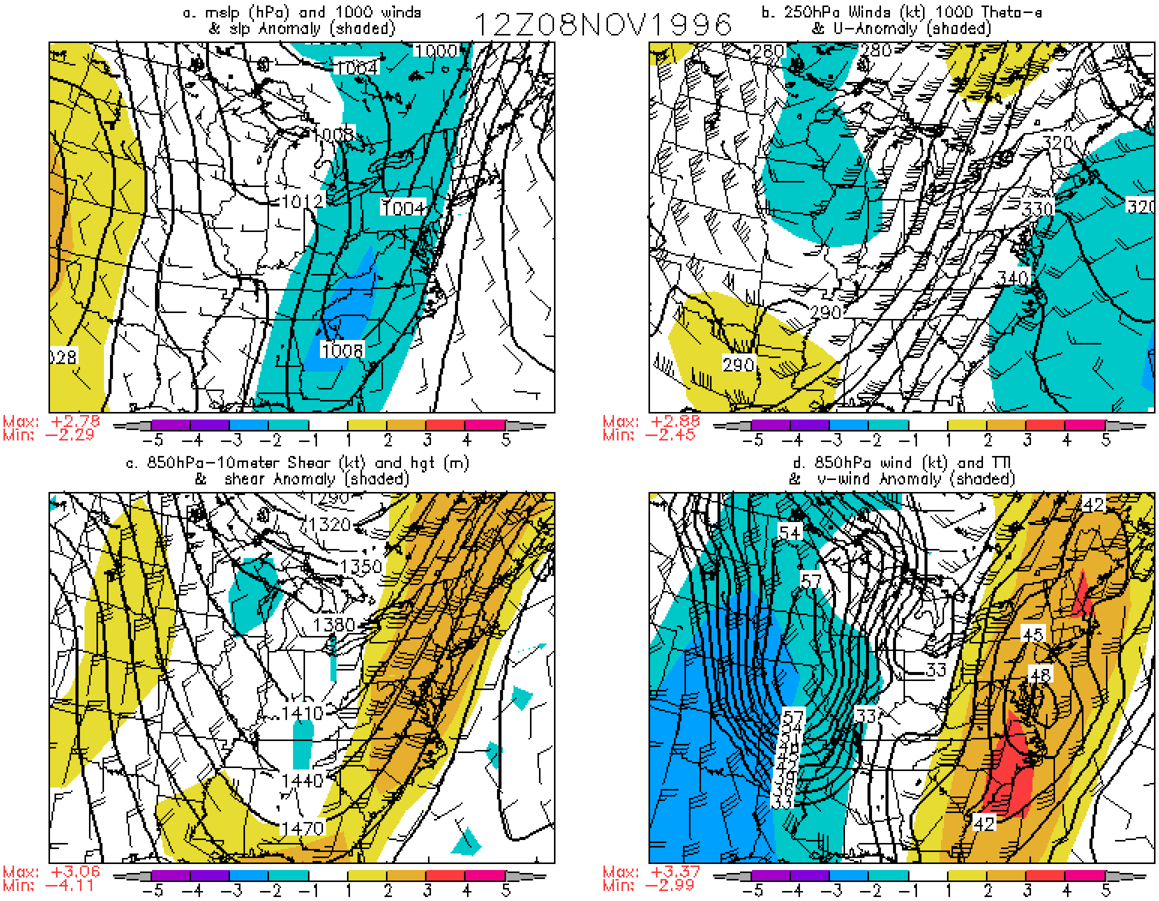

Figure 4. As in Figure 3 except valid at 1200 UTC 08 November 1996.

4. CONCLUSIONS

The results suggest that the broken-S may be a useful reflectivity signature to focus the radar operator's attention to a storm worthy of further investigation. The storm relative velocity (SRM) data suggest that two different storm types can produce the broken-S signature. The storm types shown here included a line of rotating storms (21 July 2003) and multi-cellular line of storms (8 November 1996).

The large-scale conditions revealed the presence of strong shear in surface to 1.5km layer and a strong southerly jet in both cases. Though displaced to the south, the event of 21 February 1997 (not shown) described by MJM shared many of the anomalies shown in Figure 4. The lower-topped multi-cellular events in the cold season appear to develop in more unidirectional shear environments.

With rotating storms, the development of a strong rear-flank downdraft may explain the tendency of "broken-S signatures" to occur within lines of rotating storms. The mechanisms in the multi-cellular lines that produce this signature are readily as apparent. Further study on the effects of terrain may help explain why fractures occur with relative frequency in multi-cellular lines of thunderstorms over Pennsylvania and the mountains of the eastern United States.

5. REFERENCES

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