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HIGH-PRECIPITATION SUPERCELLS: A CONCEPTUAL MODEL AND DOCUMENTATION

Alan R. Moller
NOAA/NWSFO, Fort Worth, TX

Charles A. Doswell, III
NOAA/ERL/NSSL, Norman, OK

Ron Przybylinski
NOAA/NWSFO, Indianapolis, IN

1. INTRODUCTION

Supercell thunderstorms are defined as those storms with persistent spatial and temporal correlation of intense updraft and vorticity centers, resulting in a mesocyclone (Klemp, 1987). The supercell portion of the convective storm spectrum includes a variety of visually distinct forms: Low-precipitation supercells (LP - Bluestein and Parks, 1983); Classic supercells; and the High-precipitation supercell (HP - Moller and Doswell, 1988 and Doswell et. al., 1990). The primary characteristic of HP supercells is that considerable precipitation (perhaps including hail) is observed on the trailing side of the mesocyclone (and perhaps on the leading side as well).

Several previous studies apparently have dealt with HP supercells. Weaver and Nelson (1982) described two severe thunderstorms, each of which contained strong mesocyclones and multiple BWERS. Their data suggest that each storm exhibited both supercell and multicell traits. Nelson (1987) examined an extremely severe hailstorm and elaborated on the supercell-multicell "hybrid" concept from the Weaver and Nelson paper. The storm was characterized by a large, persistent bounded weak-echo region (BWER), which contained 2 or 3 concurrent updrafts. He concluded that such a storm is important because of its hybrid traits and its production of large and unusually widespread damaging hail.

From operational experience, we have found that HP supercells frequently produce devastating hailfalls across large areas, similar to Nelson's storm. Furthermore, HP storms often produce extreme and prolonged downburst events and serious flash flooding (the copious hail and rainfall being another reason for the "High-Precipitation" label). An example of an HP storm that produced extreme hail, wind, and flash flood events is the Dallas-Fort Worth Metroplex storm of 8 May 1981. This event caused a record amount of dollar damage for a severe thunderstorm without a major tornado (Moller, 1982). Strong and violent tornadoes seemingly are not as common with HP storms as with "classic" supercells, although notable exceptions have occurred (e.g. Drumwright, OK - 6/8/74; Laurel, MS - 1/19/88; and Barneveld, WI, 6/7/84).

Our experiences also have made clear the need to communicate knowledge of HP supercells to severe weather forecasters and severe storm spotters. Radar operators and meteorologists have had considerable trouble in identifying the front-flank mesocyclones and broad hook echo structures of HP storms. Similarly, spotters have had difficulties in discerning the precipitation-enshrouded wall clouds and tornadoes.

2. DATA

Over 50 examples of HP supercells have been found in the 1973 to 1990 period, across all portions of the United States east of the Rocky Mountains. Archived National Weather Service and National Severe Storm Laboratory radar films, NWS radiosonde data, 3-hourly National Meteorological Center-analyzed surface charts, and NOAA's Storm Data are being used to develop conceptual models of HP storms and patterns of their associated severe weather events, and to understand better the background environments which produce HP storms. Concerning the latter, we want to test the following hypotheses: (1) HP supercells most often develop in environments characterized by considerable thermodynamic instability but only weak to moderate helicity, and (2) HP storms almost always form or intensify near and move along pre-existing thermal boundaries.

3. CONCEPTUAL MODELS OF HP SUPERCELLS

Rotating storms present a wide-ranging array of radar reflectivity patterns and visual structures. Previous studies point to pendant and hook echoes (Stout and Huff, 1953), line-echo wave patterns (LEWPS - Nolan, 1959), bow echoes (Fujita, 1978 and Przybylinski and Gery, 1983), and derechos (Johns and Hirt, 1987) as possible indicators of individual storm and/or storm complex rotation. Obviously, circulations over a range of scales are involved in producing these radar-observed configurations, complicating the tasks of both understanding the interrelations of these different signatures and creating rotating storm (including HP supercell) prototypes.

A detailed look at radar reflectivity data has helped us to understand better the nature of isolated HP storms and the role of HP supercells in organized storm complexes such as derechos, LEWP's, and bow echoes. For example, some supercells follow a life cycle similar to LP supercell-classic supercell-HP supercell (LP-C-HP), whereas a more common transition is C-HP. Further, it is quite common for HP storms to evolve into bow echo (BE) storms with rotating comma heads (HP-BE life cycle). Forbes (1981) analyzed radar reflectivity data of the 3 April 1974 tornado outbreak and called storms which apparently went through such a transition "LEWP" storms, one of three "distinctive" tornadic storm PPI echo structures which he observed.

An alternative life cycle to HP-BE is for the front-flank mesocyclone of the HP storm to continue moving northeastward relative to the radar reflectivity pattern with time, never assuming a BE shape.

These different life cycles are presented in Fig. 1. The C-HP transition (2 through 4) may culminate in a BE (2-8a) or, alternatively, the 2-7b life cycle. Note that in 7b a new mesocyclone is in the formative stages on the storm's upshear flank. Cyclic mesocyclone development occasionally occurs with either of the life cycles, with storm evolution repeating the 2-8a or 2-7b sequences. It is interesting to compare and contrast cyclic HP life-cycles to that of the cyclic classic supercell (Burgess, et. al., 1982).

Most importantly, we stress that Fig. 1 portrays composite life cycles for HP storms. Other life cycles and events are possible within the supercell continuum. Severe weather forecasters must be aware of the variations of rotating storm reflectivity patterns. It is critical to understand that a storm with a persistent "inflow notch" (WER) or kidney-bean shape on the east flank may be an HP supercell. Larger than normal storm size, persistently high reflectivity levels and gradients adjacent to the notch, mid-level overhang (often with a BWER within the overhang), and top displacement to above the WER will confirm HP supercell structure. Similarly, tilt sequences should be done when bow echo shapes or any of the other echo mass appearances in Fig. 1 are observed.

Forecasters should be alert for a rapid HP-BE transition (2-8a). Echo distortion due to intrusion of the rear-inflow jet (and resultant upshear weak-echo channel, Przybylinski and Gery, 1983) could mean an increase in violent downburst potential. The mesocyclone may weaken at this time, or it may move to the northeast side of the reflectivity echo. If the latter occurs, tornado production may continue with the rotating comma head storm.

Several derechos, and a number of smaller complexes not reaching minimum derecho criteria, have been found to contain clusters of HP supercell storms. The derecho HP supercell events often are spectacular, producing widespread and very severe events. These cases are being analyzed. However, preliminary results show that HP derechos are often of the "progressive" type (Johns and Hirt, 1987). The HP storms become supercells near the derecho's bow echo position, and later shift to the north side of the bow as the HP storm undergoes an HP-BE transition. These derechos will have the appearance of storm-scale HP supercells and bow echoes embedded within a derecho-scale bow echo. Strong tornadoes, large hail, downbursts, and

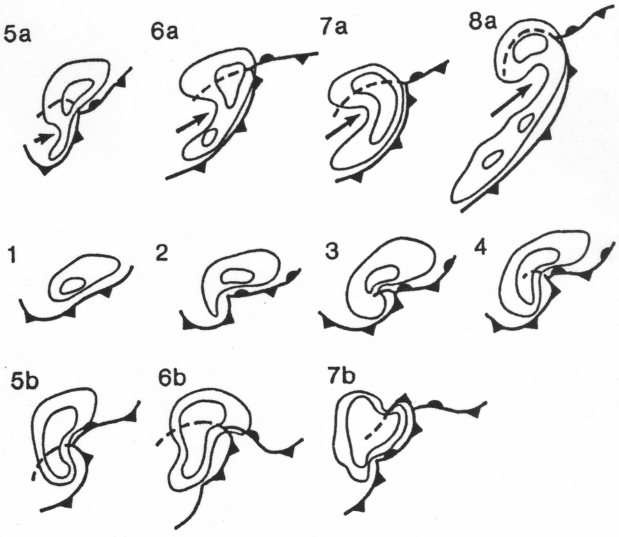

Figure 1. Two composite life cycles (1-8a and 1-7b) that have been identified with High Precipitation Supercells. Two radar reflectivity contours and gust front positions are shown. Dark arrow in 5a-8a indicates location of rear-inflow jet.

some flash flooding occur in the HP stage, with severe weather in the BE stage typically including continuing downbursts, flash flooding, moderate-size hail and a few weak tornadoes (if any).

4. HP SUPERCELL ENVIRONMENTS

We have begun recently to ascertain the nature of the synoptic and mesoscale environments associated with HP supercells. A number of HP storms occur in close proximity to so-called classic supercells, and as mentioned, some HP storms evolve from classic supercells. It is not clear whether local changes in vertical wind shear, stability, or other factors are involved with either the C-HP evolution or the coexistence of classic and HP supercells.

There are more situations, however, when HP storms occur without classic supercells, with the HP storms clearly being the dominant convection of the day. Most of the events that have been examined are characterized by: (1) significant instabilities but helicity which is only marginal for supercells and (2) the HP storm travelling along a pre-existing thermal boundary (usually an old outflow boundary or stationary front, similar to the findings of Maddox, et. al., 1980), possibly benefiting from locally-backed surface winds and/or solenoidally-produced horizontal vorticity effects to enhance mesocyclone development.

Early results show that significant low-level warm advection across the thermal boundary may play a major role in the development of mesoscale vertical motions on HP supercell days. In several of the HP events, a short wave trough was associated with initial convection, which in turn laid down a boundary. HP storms then occurred <u>behind</u> the mid-level disturbance as low-level jet-induced warm advection combined with a very unstable atmosphere to initiate further convection. In other cases, the warm advection was assisted by a secondary short wave trough.

5. CASE I - AN ISOLATED HP SUPERCELL

The 16 May 1989 HP supercell caused over $10 million hail damage in Amarillo (hail to softball size), along with downburst and flash flood damage. Several significant tornadoes, partially embedded in rain, developed in open country 5 miles southwest of Amarillo.

The 1200 UTC Amarillo (AMA) sounding (Fig. 2) showed an unstable, weakly-capped environment, with only a moderately impressive hodograph (good turning of the shear vectors, but a pronounced mid-level wind speed minimum). Storm-relative helicity in the lowest 3 km., using a storm motion from 240 deg. at 11 m/s, was about 170 m^2s^{-2} (Davies-Jones, et. al., 1990). The storm occurred in the late afternoon and evening, unfortunately tainting the 17 May 1989 0000 UTC AMA sounding (not shown). Nevertheless, we think it is significant that an acceleration of mid-level winds occurred from 1200 UTC to 0000 UTC.

A mid-level, long wave trough across the southwest U.S. ejected a short wave trough across northeast New Mexico and the Texas Panhandle early on the 16th, resulting in a band of thunderstorms moving across the area. By early afternoon the short wave disturbance was exiting the area, with the early convection leaving a southwest-northeast oriented boundary across the Panhandle just north and west of AMA (Fig. 3). During the afternoon, a warm front intersected the outflow boundary southwest of AMA, with a dry line further to the south. Gusty southerly flow resulted in strong warm advection into the Panhandle, also evident on the 1200 UTC 850 mb chart (not shown).

Objectively analyzed, surface-based lifted indices reached -6 to -8 in the AMA area by 2100 UTC. The warm advection and moisture convergence initiated two storms near the warm front-outflow boundary intersection. These two HP supercells moved along the boundary, the first (storm A, Fig. 3) producing large hail and tornadoes west of AMA in the mid-afternoon, with our subject storm, storm B, producing additional severe weather several hours later. A composite of storm A and storm B's radar reflectivities over time is presented in Fig. 4. Although storm A had weakened after its tornadic phase, note the WER on the east flank at 2134 and 2300 UTC.

Figure 4 shows storm B's transition to HP supercell from 2134 to 2300 GMT and the HP-BE transition from 2300 to 0104 GMT. Tornadoes and the largest hail occurred mainly during the HP stage, with smaller hail and flash flooding predominating as the mesocyclone weakened. From our personal storm chase observations, we conclude that considerable downburst activity occurred throughout storm B's life, but was only reported when the storm was in the urban AMA area.

Although other thunderstorms formed in the unstable air east of the outflow boundary, the two HP storms were the only afternoon/evening cells in the Panhandle to produce tornadoes and supercell radar characteristics. As would be expected, spotters had a very difficult time viewing and reporting the tornadoes.

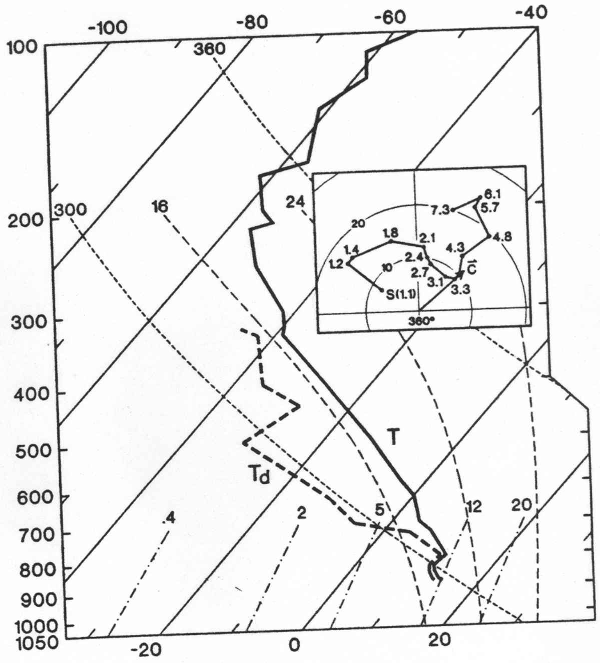

Figure 2. Plotted sounding data and hodograph for Amarillo, TX (AMA), 1200 UTC, 16 May 1990.

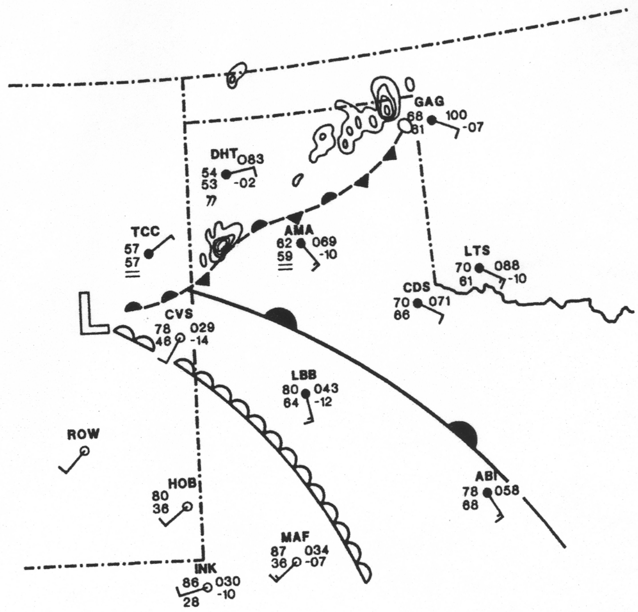

Figure 3. Surface analysis and radar echoes, 1800 UTC, 16 May 1989. Dry line is indicated by solid line with clear semi-circles, warm front by standard symbology, and thunderstorm outflow boundary by dashed line with cold, warm, and stationary front symbology. HP storm "A" is west of AMA.

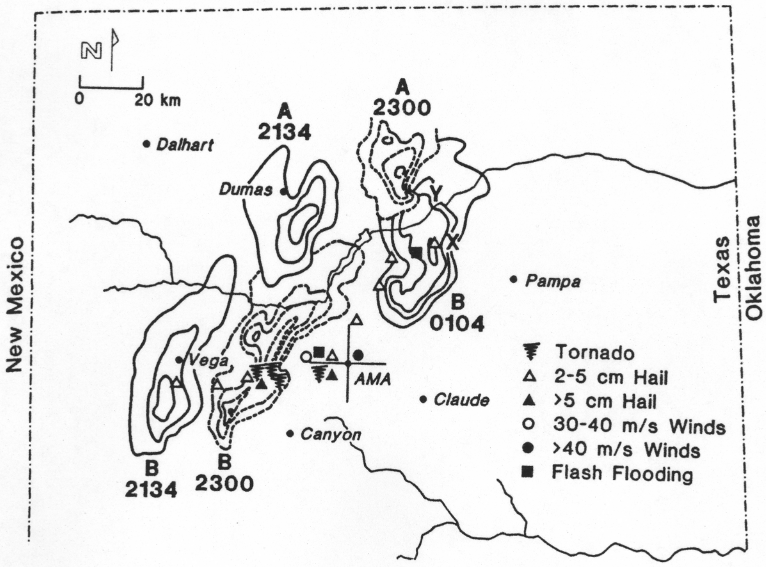

Figure 4.

Severe weather events and selective radar reflectivites (solid and dashed lines -- NWS VIP levels 2, 3, 5, and 6) for the 16 May 1989 HP supercells. HP storm A is shown at 2134 and 2300 UTC. HP storm B is shown at 2134, 2300, and 0104 UTC. "X" denotes storm B's top location at 0104. "Y" indicates the 0104 UTC position of the weakening mesocyclone which produced the radar hook echo and tornadoes in storm B at 2300 UTC.

6. CASE II - A DERECHO WITH HP SUPERCELLS

The 25 May 1976 event produced extreme downburst and hail damage along an approximate 750 km path across Northwest and North Texas. Eleven rural North Texas Counties each reported at least $2 million damage. Measured downburst winds reached 110 mph (before the anemometer was destroyed) at an electrical-generating plant at Lake Graham. Baseball-size hail accompanied these winds, causing over $6 million damage alone in the small town of Graham, TX. Flash flooding caused extensive damage at several locations, and several damaging tornadoes occurred near Waco, TX.

The derecho developed beneath or immediately east of a mid-level ridge, in association with a mid- and upper-level jet streak that was moving across Northwest Texas. Low-level warm advection again played a critical role, as the derecho moved southeast along a pre-existing warm front (Fig. 5). This pattern closely fits that of many classic derechos (Johns and Hirt, 1987) and can best be described as a northwest flow event.

A 1200 UTC sounding and hodograph for Stephenville, TX (SEP) indicated a strong lifted index (for morning) of -7 (Fig. 6). The hodograph favored supercell storms, although once again wind speeds were not overly impressive in the mid levels. The storm-relative helicity in the lowest 3 km using a storm motion from 305 deg. at 10 m/s, was about 310 m^2s^{-2}.

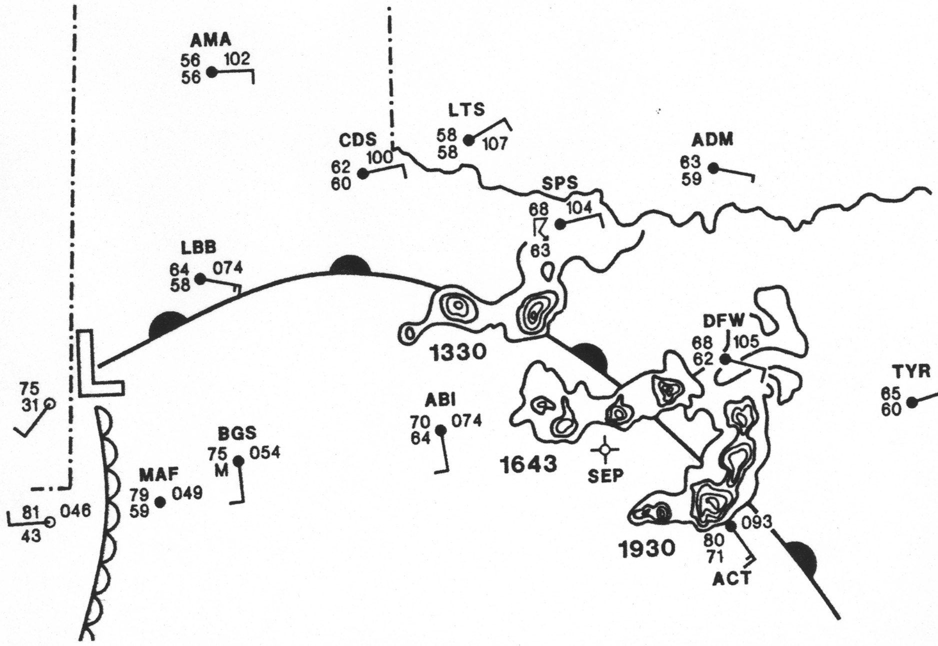

Figure 5. Surface analysis, 1500 UTC, and radar reflectivities (solid lines -- NWS VIP levels 2-6) for the derecho at 1330, 1643, and 1930 UTC, 25 May 1976.

The derecho developed north of the front, producing a number of golfball hail reports near AMA. As the complex moved into the frontal zone, severe weather intensified (Fig. 7). During this phase, high-precipitation supercells developed close to the derecho's bow position, exhibiting either southeast-flank WER's, and/or high reflectivity (VIP 5 and 6) hooks, similar to the 1981 DFW Metroplex storm (Moller, 1982). At least four HP storms could be discerned from the 1976 SEP radar film, with the last three of these (storms B, C, and D) shown through their severe stages in Figure 7. Note the differential motion of the storms relative to that of the derecho bow position. Apparently more rightward derecho bow propagation is the reason that the BE segment of an individual storm's life cycle occurs on the north side of the derecho.

Figure 8 is a more detailed view of radar reflectivities near the time of peak derecho intensity. Storm D (HP stage) was producing an F3 tornado in the vicinity of the VIP 5 hook at this time. The same storm cell unleashed a barrage of baseball to softball hail that stripped vegetation over an approximate 32 by 7 km section of Bosque County. Storms B and C had weakened as they undertook the HP-BE transition, but still were producing hail, damaging downbursts, and very heavy rainfall at 1930 GMT.

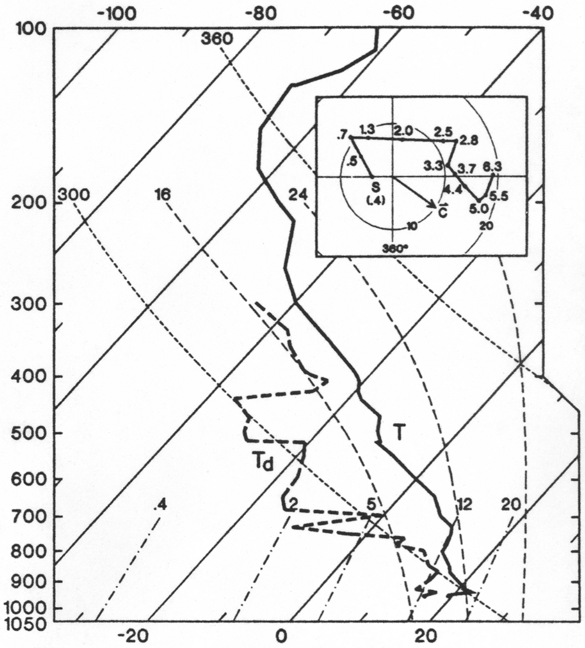

Figure 6. Plotted sounding data and hodograph for Stephenville, TX (SEP), 1200 UTC, 25 May 1976.

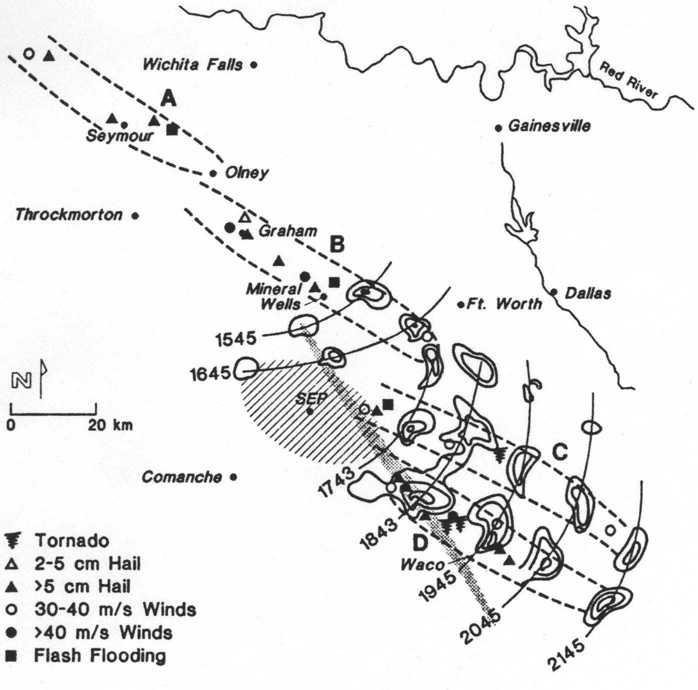

Figure 7. Time history of selective radar reflectivities (solid lines -- NWS VIP levels 4, 5, and 6) for HP storms B, C, and D in the 25 May 1976 derecho. Severe weather swaths (dashed lines) are shown for storms A, B, C, and D. Severe weather events are indicated by the legend. Shaded line denotes the track of the derecho's bow echo, and diagonal lines cover SEP's ground clutter area.

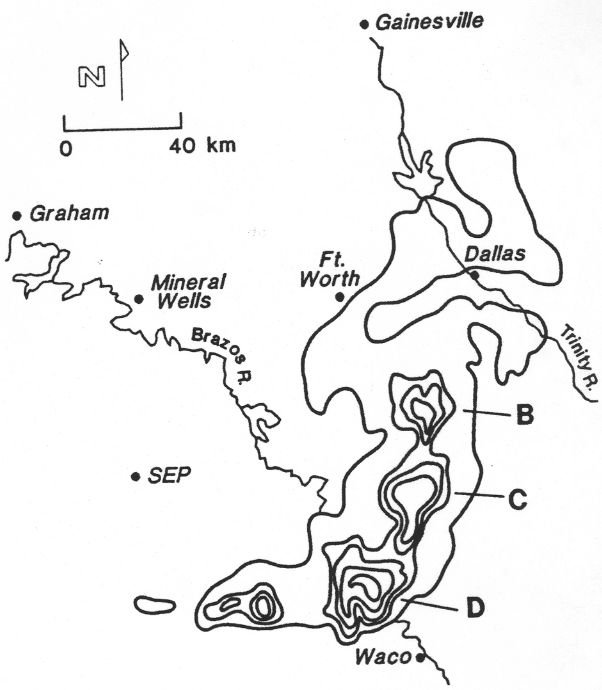

Figure 8. Radar reflectivities (solid lines -- NWS VIP levels 2-6) of the 25 May 1976 derecho at 1930 UTC. An F3 tornado and damaging winds were occurring in storm D's hook echo, while storm C (BE stage -- see text) was producing a possible tornado or damaging winds at this time.

7. DISCUSSION

An important member of the supercell thunderstorm spectrum is the High-Precipitation (HP) supercell. The HP storm is characterized by considerable precipitation (including hail) on the trailing (and possibly) leading side of the mesocyclone. Radar reflectivity patterns of HP storms indicate either a broad, high-reflectivity (VIP 5 or 6) pendant or hook echo, or a notched appearance (radar WER) on the east side of an unusually large and intense storm cell. In the latter case, the HP storm has a front-flank mesocyclone, in contrast to the right-rear flank mesocyclone typically observed with classic supercells. These contrasting traits make the HP storm hard to recognize for severe storm spotters and radar operators, who have been trained to recognize the structures of classic supercells.

Heavy-precipitation supercells occur singly or in derecho-like complexes, usually traveling along pre-existing thermal boundaries. It is possible that the HP storm spins-up its mesocyclone either from solenoidal effects of the thermal contrast along the boundary, and/or from increased vertical wind shear from the backed and increased low-level winds.

Extreme severe weather frequently occurs with HP storms, spanning the full range of hail, downburst, flash flood, and tornado events. Hail and downburst swaths can be unusually long and wide, causing widespread severe damage. This is particularly true when HP storms occur in derechos. The threat of flash flooding is substantial enough that forecasters should consider issuing combined flash flood and severe thunderstorm warnings (or flash flood and tornado warnings) after having detected HP supercells. Strong and violent tornadoes do occur with HP storms, but less commonly than with the classic type of supercell.

Finally, limited Doppler data has been available with past HP storms (Weaver and Nelson, 1981; and Huffman, 1989) indicating that HP storms tend to have large, weak to moderate intensity mesocyclones and a series of large, concurrent updrafts typically seen with multicell storms. It has been suggested that the close spacing of these updrafts within the large BWER may be the reason that such large areas are affected by giant hail with HP (or, alternatively, hybrid) supercells (Nelson, 1987). Further Doppler studies are needed to verify this, as well as to investigate why only a few HP storms produce strong and violent tornadoes.

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8. REFERENCES

Bluestein, H. B., and C. Parks, 1983: A Synoptic and Photographic Climatology of Low-Precipitation Thunderstorms in the Southern Plains. Mon. Wea. Rev. 111, 2034-2046.

Burgess, D. W., V. T. Wood, and R. A. Brown, 1982: Mesocyclone Evolution Statistics. Preprints, 12th Conf. Severe Local Storms, San Antonio, Texas, Amer. Meteor. Soc., 422-424.

Davies-Jones, R., D. W. Burgess, and M. Foster, 1990: Test of Helicity as a Tornado Forecast Parameter. Preprints, 16th Conf. Severe Local Storms Kananaskis Park, Alberta Amer Meteor. Soc. (elsewhere in this volume)

Doswell, C. A., A. R. Moller, and R. W. Przybylinski 1990: A Unified Set of Conceptual Models for Variations on the Supercell Theme. Preprints, 16th Conf. Severe Local Storms, Kananaskis Park, Canada, Amer. Meteor. Soc. (elsewhere in this volume)

Huffman, Lloyd, 1989: Private Communication.

Forbes, G. S., 1981: On the Reliability of Hook Echoes as Tornado Indicators. Mon. Wea. Rev. 109, 1457-1466.

Fujita, T. T., 1978: Manual of Downburst Identification for Project Nimrod. SMRP Res. Paper 156, Univ. of Chicago, 42 pp.

Johns, R. H., and W. D. Hirt, 1987: Derechoes: Widespread Convectively Induced Windstorms. Weather and Forecasting, 2, 32-49.

Klemp, J. B., 1987: Dynamics of Tornadic Thunderstorms. Ann. Rev. Fluid Mech. 19, 1-33.

Maddox, R. A., L. R. Hoxit, and C. F. Chappel, 1980: A Study of Tornadic Thunderstorm Interactions with Thermal Boundaries. Mon. Wea. Rev., 108, 322-336.

Moller, A. R., 1982: A Record Severe Thunderstorm Event. Preprints, 9th Conf. Wea Fcstg. and Anal., Seattle, Washington, Amer. Meteor. Soc.

Moller, A. R., and C. A. Doswell, 1988: A Proposed Advanced Storm Spotters' Training Program. Preprints, 15th Conf. Severe Local Storms. Baltimore, Maryland, Amer. Meteor. Soc. 173-177.

Nelson, S. P., 1987: The Hybrid Multicell-Supercell Storm-an Efficient Hail Producer. Part II: General Characteristics and Implications for Hail Growth. J. Atmos Sci., 44, 2060-2073.

Nolan, R. H., 1959: A Radar Pattern Associated With Tornadoes. Bull. Amer. Meteor. Soc. 40, 277-279.

Przybylinski, R. W., and W. J. Gery, 1983: The Reliability of the Bow Echo as an Important Severe Weather Producer. Preprints, 13th Conf. Severe Local Storms. Tulsa, Oklahoma, Amer. Meteor. Soc.

Stout, G. E., and F. A. Huff, 1953: Radar Records an Illinois Tornado. Bull. Amer. Meteor. Soc., 34, 281-284.

Weaver, J. F., and S. P. Nelson, 1982: Multiscale Aspects of Thunderstorm Gust Fronts and Their Effects on Subsequent Storm Development. Mon. Wea. Rev., 110, 707-718.