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SYNOPTIC AND MESOSCALE ANALYSIS OF THE 9 AUGUST 2000 APPALACHIAN-CROSSING DERECHOS

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1. INTRODUCTION

Widespread convectively-induced windstorms meeting specific criteria for areal coverage of wind damage reports and chronological progression of those reports have been defined as “derechos” originally by Hinrichs (1888), and about a century later refined by Johns and Hirt (1987). Climatological analysis of derechos by Johns and Hirt (1987) suggest these events are most common in the upper Mississippi Valley and Ohio Valley in the summer months. Occasionally, derechos will continue eastward through the Appalachians, but the gradient in frequency drops off significantly from the Appalachian mountains eastward (see Johns and Hirt, 1987 Figure 2). Forecasters in the Blacksburg, Virginia National Weather Service Forecast Office have indeed observed a distinct tendency for organized severe convection moving eastward out of the Ohio Valley through West Virginia to weaken rapidly as it encounters the more stable air over the higher elevations in western Virginia and western North Carolina, especially during the evening and overnight hours as daytime heating is lost. Exceptions to this occur most often during the afternoon hours, and with more isolated severe convection such as supercells.

On 9 August 2000, not only did one derecho-producing line of convection sweep through the Appalachians of northern Virginia during the mid afternoon hours (very similar to the 5 July 1980 event documented by Johns and Hirt, 1987), but a second derecho, which had developed in the Ohio Valley behind the first one in the early evening hours, managed to cross the mountains of southern Virginia and North Carolina during the overnight hours (reaching into the piedmonts of North and South Carolina after midnight). Figures 1 and 2 show the areas affected by the damage and severe wind reports (by county) from derecho #1 and derecho #2 respectively. The two derechos combined to produce a total of several million dollars worth of damage, one death, and at least 15 injuries.

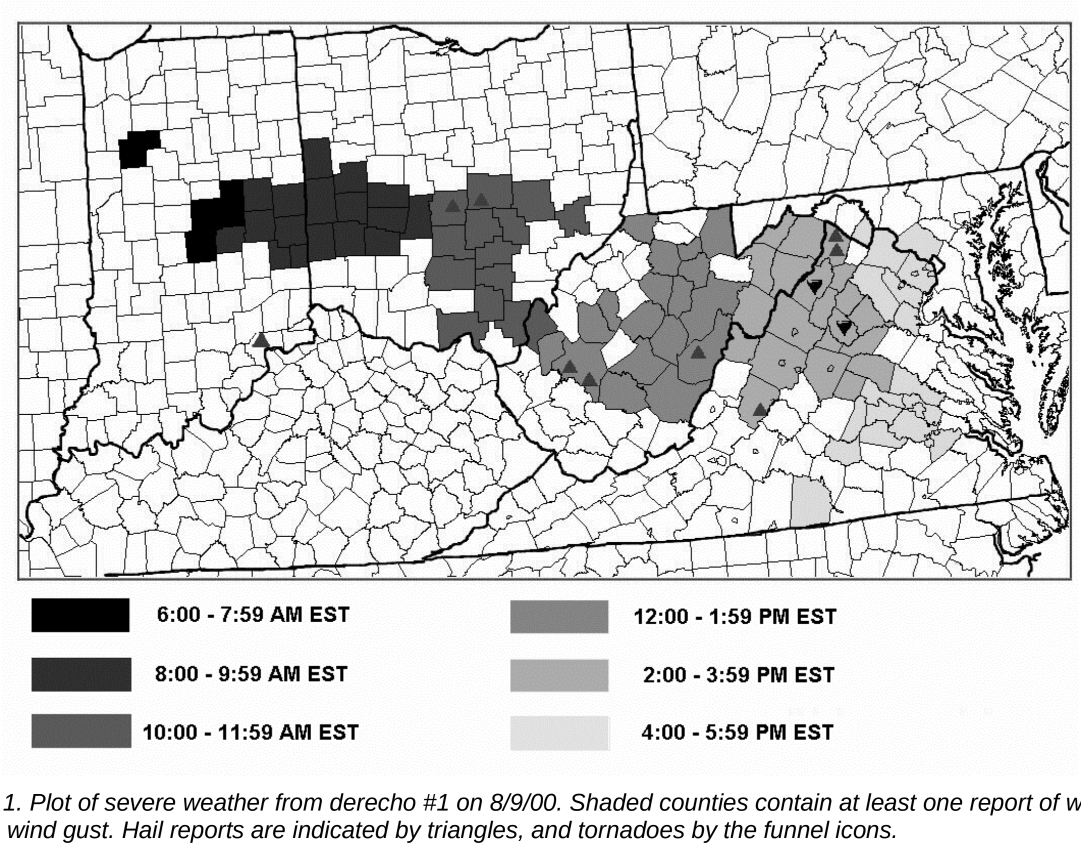


Figure 1. Plot of severe weather from derecho #1 on 8/9/00. Shaded counties contain at least one report of wind damage or severe wind gust. Hail reports are indicated by triangles, and tornadoes by the funnel icons.

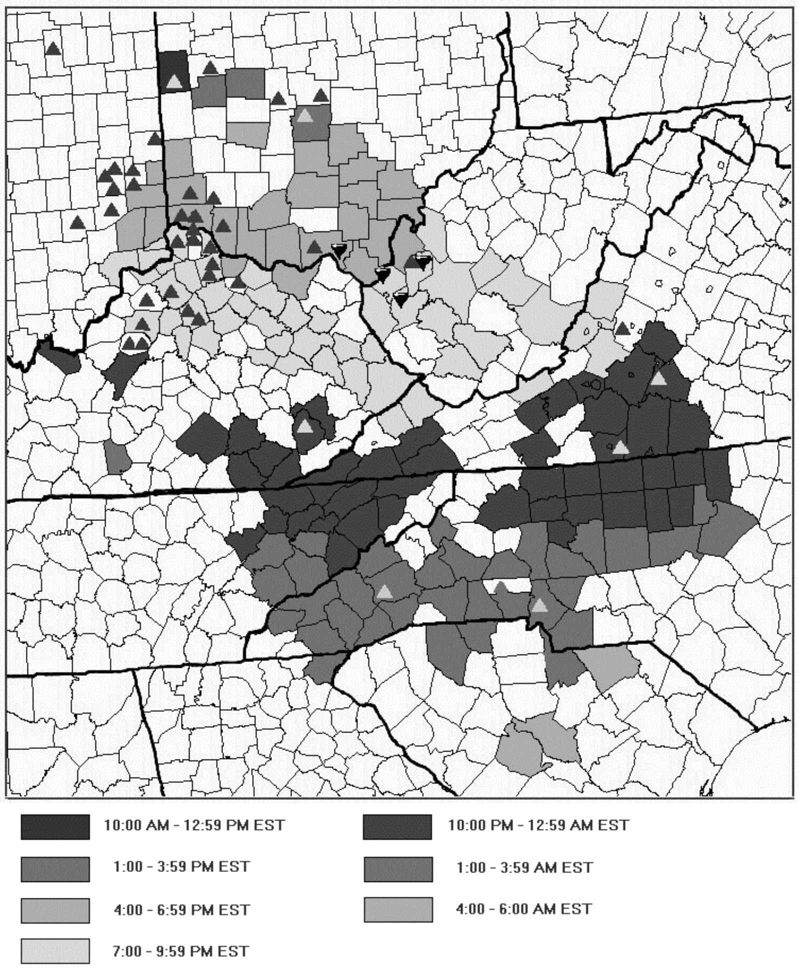


Figure 2. As in Fig. 1, but for derecho #2.

This paper documents the evolution of the relatively uncommon Appalachian-crossing pair of derechos, including the synoptic setting in which the convective systems developed, the role an outflow boundary may have played in the evolution and associated severe whether of the second system, and briefly compares and contrasts a couple of previous events to determine what factors may be important to sustaining severe organized convection as it moves through the Appalachians.

2. ENVIRONMENT AND CONVECTIVE EVOLUTION OF DERECHO #1

Convection began in Iowa in the middle of the night, but became better organized in a line soon after daybreak on 9 August 2000 near the central Illinois/Indiana border. This developing convection was out ahead of a slow moving surface cold front, and on the northern edge of a surface moist tongue (Figure 3 shows the surface frontal positions and 70^0 F isodrosotherm at 1200 UTC), where convective available potential energy (CAPE) was over 3000 J kg^{-1}. The convection was embedded in northwest flow at mid levels (15-20 ms^{-1} at 500 mb), with a thermal trough immediately to the west. The convective line quickly evolved into a bow echo and elongated as it moved southeastward through Indiana and into southern Ohio during the morning hours, and then into West Virginia by the early afternoon. An 1800 UTC sounding at Blacksburg, VA (RNK), located in the Appalachians at an elevation of 600 m, showed abundant low-level moisture and instability in the mountains during the early afternoon (Figure 4). Therefore, the bow echo was able to progress southeastward through the Appalachians, as it continued to elongate into more of a narrow squall line, and eventually crossed through Virginia (except for the far southwestern part), and into northeast North Carolina by the evening.

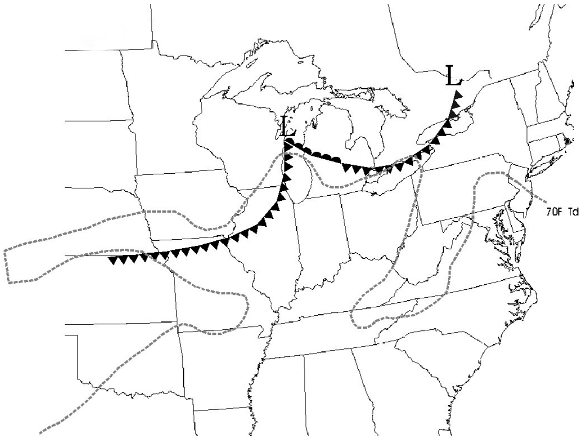
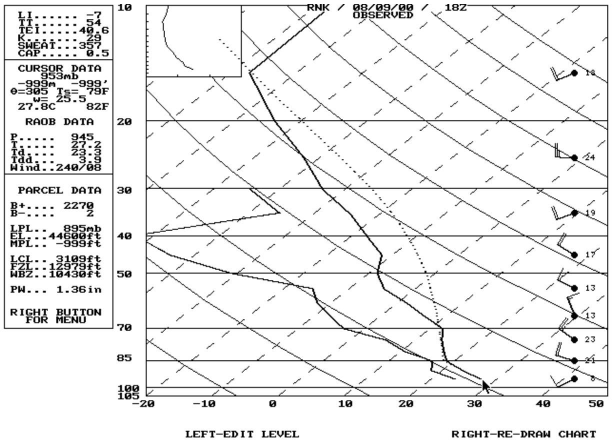


Figure 3. 9 August 2000, 1200 UTC surface frontal analysis. 70 ^{0} F isodrosotherm is dashed contour.


LI....... -7
TT....... 54
TEI.....40.6
K........ 29
SWEAT...357
CAP..... 0.5

CURSOR DATA
953mb
-999m -999'
θ=305 Ts= 79F
w= 25.5
27.8C 82F

RAOB DATA
P..... 945
T..... 27.2
Td.... 23.3
Tdd... 3.9
Wind..240/08

PARCEL DATA
B+.... 2270
B-.... 2
LPL.. 895mb
EL...44600ft
MPL.. -999ft
LCL.. 3109ft
FZL..12979ft
WBZ..10430ft
PW... 1.36in

RIGHT BUTTON FOR MENU

Figure 4. 9 August 2000, 1800 UTC skew-T plot from Blacksburg. CAPE is indicated in the table at left by the B+. Winds speeds are plotted in knots.

Figure 5 shows the progression of the evolving bow echo/squall line in 3-hr increments, as characterized by the trace of the 40 dBZ contour at the lowest elevation slice from a mosaic image of WSR-88D radars. The system produced primarily wind damage along its path, with isolated severe hail reports, and two weak tornadoes (F0 and F1) near the eastern edge of the mountains in northern Virginia. The major axis of reported severe thunderstorm winds was over 750 km in length, from central Indiana to eastern Virginia, which covered a 12 hour period. Furthermore, the system produced periodic straight line wind damage equivalent to F1 strength on the Fujita scale, therefore allowing it to meet all the derecho criteria defined by Johns and Hirt (1983 and 1987). It also met their definition of the warm season “progressive” derecho; the average length of the convective line was about 200 km and was aligned parallel to the mean wind, and averaged a speed of about 20 ms^{-1}, which was well above the mean wind (as was observed in a majority of progressive derechos studied by Johns and Hirt 1987).

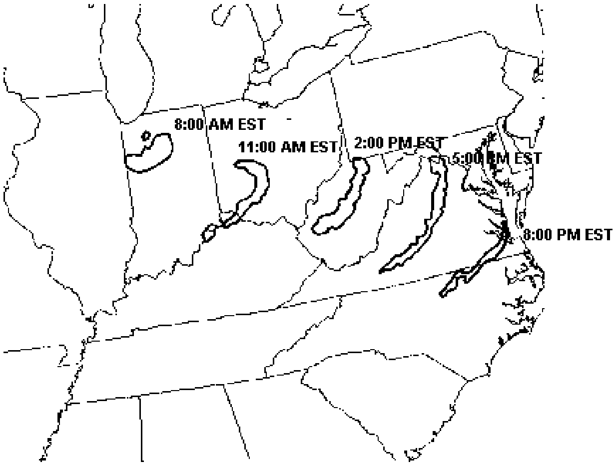


Figure 5. Trace of 40 dBZ contour in three-hour increments for convective system responsible for derecho #1. Local times are plotted.

3. ENVIRONMENT AND CONVECTIVE EVOLUTION OF DERECHO #2

In addition to the widespread wind damage, the first convective system also left a wake of relatively stable air. Combined with steady moisture pooling along and south of the Ohio River, this resulted in a significant surface equivalent potential temperature (theta-E) gradient along the southern edge of the first system’s track by 2100 UTC (Figure 6). Scattered convection began forming again in the early afternoon at the northeast edge of the surface moisture pool (dew points were near 80^{0}F over southern Indiana and Illinois), and on the north side of the theta-E gradient, and began to organize and move south-southeastward toward the warm sector during the late afternoon. The line produced numerous wind damage and large hail reports. As the leading edge of the convection crossed the Ohio River near the Ohio/Kentucky/West Virginia state borders, it developed an inflection point within a line echo wave pattern (LEWP) structure at about 0000 UTC. This appeared to be the location where the convective line intersected the outflow boundary from the previous system, and was also where the first of four tornadoes occurred (see Figure 2). This inflection point moved east initially, and was closely associated with the location of the next three tornadoes, then turned more southeast into southern West Virginia (note the orientation of the theta-E gradient a few hours earlier in Figure 6.

By 0000 UTC, an axis of high CAPE and low-level moisture convergence extended into southwestern Virginia (not shown) along the apparent outflow boundary from the first system. Figure 7 shows the unusually high instability still evident in the evening 0000 UTC RNK sounding, perhaps largely due to enhanced moisture pooling along the old boundary. In addition, data from a new Global

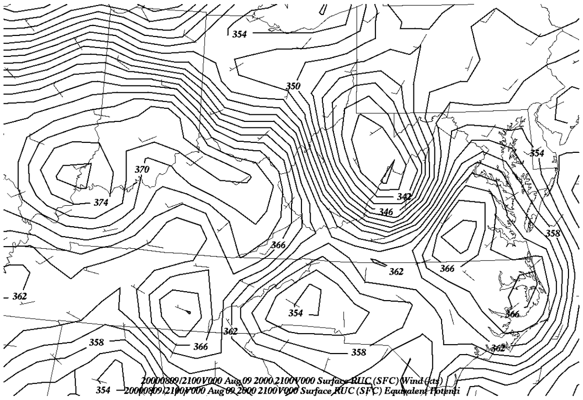


Figure 6. 9 August 2000, 2100 UTC surface objective analysis of theta-E in degrees K (contour interval is 2 K), as well as surface wind flags.

Positioning System (GPS) sensor installed at Blacksburg to measure integrated precipitable water (IPW) at 30 minute intervals (see Keighton et al 2001) revealed that while the IPW had briefly trended down after the passage of the first convective line just to the north of the sensor, within about two hours it rebounded again and eventually peaked higher than it had before, coincident with the passage of the second convective line (figure to be shown at the conference). After 0000 UTC, the eastern portion of the line continued moving south-southeastward through southern West Virginia, the mountains of southwest Virginia, and eventually into the Piedmont portions of Virginia and North Carolina by midnight, more or less paralleling the old outflow boundary. Meanwhile, the western half of the line was moving a little more slowly toward the south, and eventually south-southwestward into Kentucky, and later Tennessee, toward the region of greatest surface dew points.

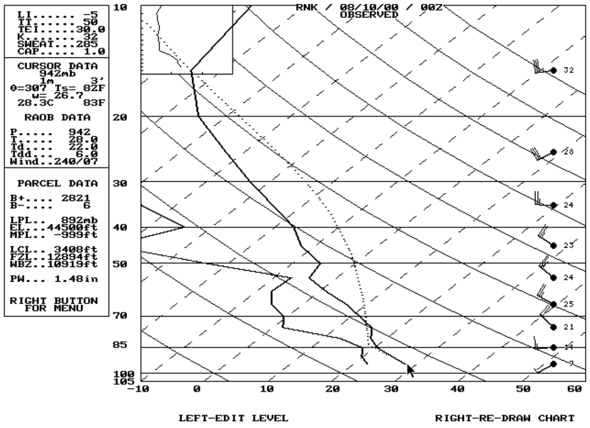


Figure 7. As in Figure 4, but for 0000 UTC 10 August 2000.

Figure 8 shows the radar evolution of this second convective system at 3-hr intervals (similar to Figure 5). This system produced over 200 reports of wind damage, 40 large hail reports, and four tornadoes over a 16 hr period. The average speed of movement was noticeably slower compared to the first system (around 12 ms^{-1} - still slightly above the mean wind). The collection of wind damage reports attributed to this second convective system also meets the Johns and Hirt derecho criteria, and while this line was oriented somewhere between perpendicular and parallel to the mean wind and had a slower propagation, it still comes much closer to meeting the "progressive" category of derecho than the "serial" category.

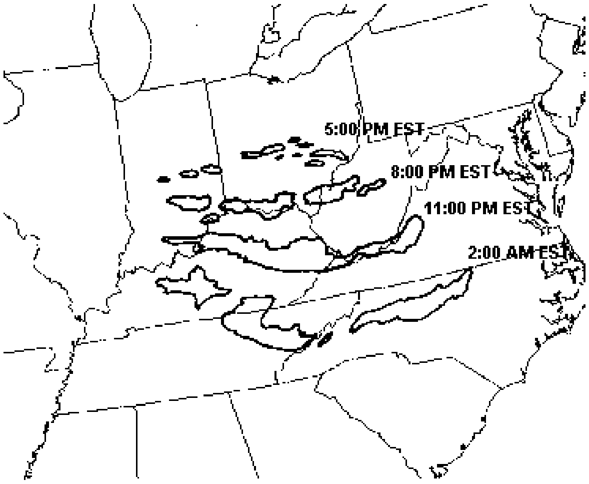


Figure 8. As in Figure 5, but for derecho #2.

Both the propagation toward the greater instability to the southwest, as well as the influence of the building ridge to the west (turning the mean wind more northerly), likely played roles in the western portion of the line turning toward the right of the original track. In addition, Skamarock, Weisman, and Klemp (1994) concluded from numerical simulations that for long-lived squall lines the Coriolis parameter affects the rightward propagation of the anticyclonic portion of the line (as well as the enhancement of the cyclonic circulation at the opposite end of the line), leading to significant asymmetry after several hours. Even the first convective line exhibited this rightward turn late in its evolution as it moved into eastern Virginia and North Carolina (see Figure 5). In most long-lived convective lines, it is possible that a combination of factors are responsible for this particular observation, and that certainly appears to be the case here.

4. COMPARISONS WITH OTHER RECENT EVENTS

Forecasting whether or not severe organized convection will reach and cross the Appalachian chain has always been a challenge on both the local and national scales. We offer some brief preliminary comparisons based on three other events, although many more cases need to be collected in order to establish more definitive results.

On 10 July 2000, under a similar synoptic regime, both at the surface and 500 mb, an east-west oriented line of severe convection formed over southern Ohio and central West Virginia, and moved toward the southeast. Surface dew points in the Appalachians were 5-6^0 C lower than on 9 August 2000, which resulted in near-zero CAPE at Blacksburg during the afternoon. Therefore, the eastern portion of the line quickly dissipating as it entered the western slopes of the Appalachians, while the western portion propagated into high surface dew point air in eastern Kentucky.

On 26-28 June 1998, a series of mainly nocturnal bow echoes developed in eastern Ohio, and moved southeast through West Virginia, again, under similar synoptic conditions as 9 August 2000. None of the severe convection survived past the western edge of the Appalachian chain. While relatively high surface dew points lead to instability similar to 9 August 2000, it appeared that the depth of the moisture was limited, possibly reducing updraft potential due to mixing and resulting in lower precipitable water values to below the monthly average for June/July at Blacksburg (sounding not shown).

Finally, on 2 June 1998, isolated severe convection in the form of one long-lived supercell developed during the late morning in central Indiana, and moved in a gently right-turning path through central West Virginia, southwest Virginia, and into central North Carolina by the evening hours, producing severe wind damage, hail, and a few tornadoes in West Virginia, all along its path. There is obviously a difference in the character of convection in this case, which formed in strong, deep vertical wind shear as well as high instability. The squall line and bow echo events previously discussed all were observed in environments with only moderate vertical wind shear in the lowest few kilometers, and very weak shear above that. An 1800 UTC sounding launched at Blacksburg just a few hours before the supercell passed directly overhead (not shown) indicated relatively low CAPE (under 1000 J kg^{-1}), but very strong vertical wind shear through the depth of the storm. This event also occurred during the afternoon rather than after dark.

5. SUMMARY AND FURTHER STUDY

Analysis of the structure, evolution, and associated severe weather of the two Appalachian-crossing convective systems on 9 August 2000 shows they qualify as derechos according to the Johns and Hirt 1987 definition. Climatology suggests Appalachian-crossing derechos are relatively rare, and two in one day are undoubtedly very uncommon. It appears likely that the success of the second system in overcoming the typical Appalachian hurdle was related to the outflow boundary and enhanced low-level moisture pooling from the first system. This is consistent with findings of Johns et al (1990) where long-lived derechos were supported by moisture pooling along a pre-existing thermal boundary (usually synoptic scale in nature however). This outflow boundary may have also played a role in producing a series of tornadoes earlier in the second derecho evolution as it crossed the Ohio River into West Virginia. Preliminary comparison with a few other similar events suggests that for organized systems to remain severe through the Appalachians, high surface dew points and corresponding high instability must be present through the higher elevations. Perhaps continued moderate low-level wind shear is also important in maintaining active updrafts (Weisman 1993), but more study of this aspect is needed. For more isolated severe convection (i.e., supercells), strong, deep vertical wind shear may be more important to sustaining the convection through the mountains. Finally, perhaps the depth of the moisture and the integrated precipitable water may also be important, and the new GPS IPW measurements at Blacksburg will help to identify mesoscale changes in this parameter.

Future work involves collecting more cases to validate these preliminary results and to establish better climatology of Appalachian-crossing derechos, and to identify more subtle differences in environmental parameters, including considering downdraft available potential energy (DAPE), theta-E lapse rates, low-level hodograph characteristics and IPW trends.

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