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AN EXAMINATION OF TWO ATYPICAL SEVERE WEATHER EPISODES IN THE NORTHERN PLAINS: THE ROLE OF JET-“FRONT” INTERACTION

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1. INTRODUCTION

A large part of the mission of the National Weather Service (NWS) is to protect life and property through its array of forecast services (NWS 2004). In no segment of NWS operations is this more poignant than in short-fused convective warning services. In recent years, there has been considerable focus on improving warning services through not only advances in technology, but the merits of training. An example of such an area is assessment of the importance of near-storm environment on storm evolution. Rasmussen and Blanchard (1998) and Edwards and Thompson (2000), among many others, have applied results of field, climatological, and modeling studies to reveal that diagnoses of the initiation, mode, and evolution of a convective event depend on correct diagnoses (and implicitly prognoses) of dynamic and thermodynamic parameters.

Over the 2000 and 2001 convective seasons, five severe weather events affecting the Sioux Falls NWS area of responsibility of southeast South Dakota, southwest Minnesota, northeast Nebraska and northwest Iowa were found to be associated with prefrontal surface troughs. A cursory examination revealed several common characteristics; 1) each was tornadic, during a period which is somewhat atypical from a climatological perspective, 2) proximity of a strong upper-level potential vorticity (PV) anomaly, and 3) severe convection focused along a surface prefrontal trough, which underwent significant intensification prior to convective initiation. In this paper, a subset analysis of two severe weather episodes is presented. The conceptual model of jet-front interaction is proposed as a mechanism for this intensification. It is demonstrated that this conceptual model can be effectively applied to modify operational model prognostication to improve convective forecasts.

2. CASE 1 REVIEW: 17 AUGUST 2001

Figure 1a depicts the pre-storm environment across the region, roughly 6 hours prior to significant convective activity. A prefrontal surface trough extended through eastern South Dakota, with winds shifting roughly 90 degrees across the boundary. Surface dewpoint from 14-16^{o} C characterized the low levels air mass, even well southward through the central plains. The region was initially cloud free, which allowed for a maximum insolation component through the early afternoon.

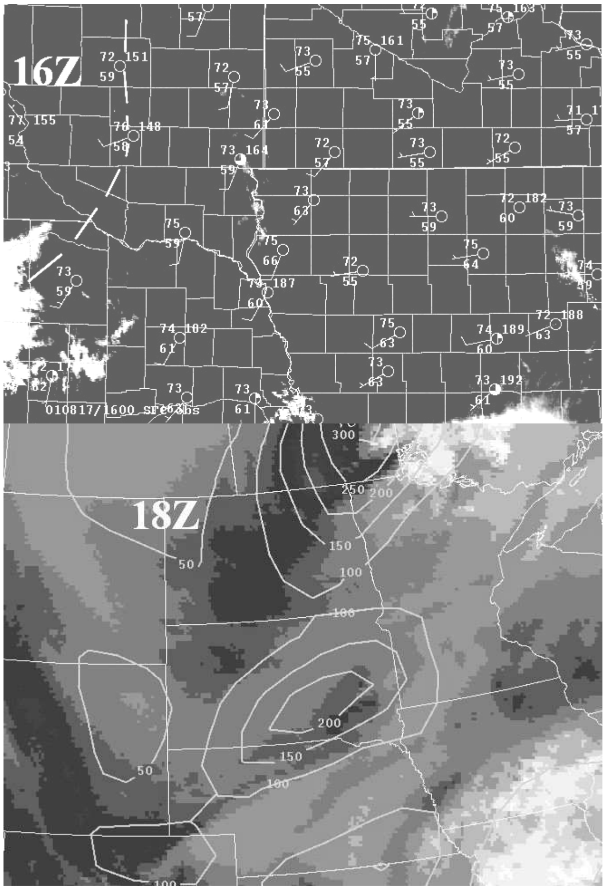

Figure 1. a) Visible satellite image from 1600 UTC 17 August 2001, with surface observations. Location of prefrontal trough indicated by dashed line. b) GOES Channel 3 water vapor image at 1800 UTC 17 August 2001. Solid line overlay are contours of Rapid Update Cycle (RUC) 0 h analysis of 300-400 hPa potential vorticity in 100*PVU (1 PVU = 10^{-6} m^{2} K kg^{-1} s^{-1}).

By 1800 UTC (not shown), the surface trough had advanced eastward with a slight increase in convergence. Dewpoint near the boundary has nudged upward, with some initial cumulus development. At upper levels, 300-400 hPa PV defined location of a strong trough of low pressure (Fig. 1b) across eastern North Dakota associated with the main cold front, and a secondary trough in eastern South Dakota. Strong differential thermal advection in the 850-500 hPa layer from 1800-2100 UTC was increasing the potential instability over the location of the prefrontal trough.

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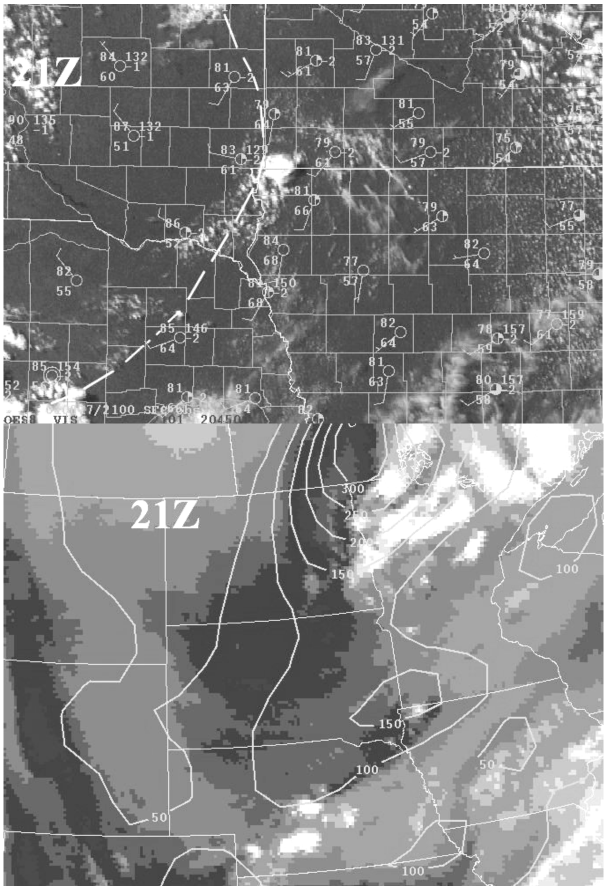

Figure 2. Same as in Figure 1, except for 2100 UTC.

Through 2100 UTC, the PV anomaly (Fig. 2) continued to close in on the location of the prefrontal trough. In response, winds continued to back ahead of the prefrontal trough, and strengthen following the trough to result in increased convergence. A temporal sequence of images displayed in Fig. 3 documents progression of the upper level PV anomaly and the response of the low level observed frontogenesis. To additionally capture the effects of moisture, equivalent potential temperature was used in calculations in place of potential temperature.

Severe hail was first reported with the cell at 2115 UTC (Fig 4). Ninety minutes later, an F2 tornado impacted the town of Jackson, Nebraska with significant damage and injuries, one of eight observed tornadoes that afternoon and early evening. A total of 31 county warnings were issued during the event by NWS Sioux Falls.

3. CASE 2 REVIEW: 30 APRIL 2001

By late morning of 30 April 2001, a weak surface boundary (not shown) had become stationary from southwest Minnesota across northwest Iowa, to eastern Nebraska. There was very little difference in air mass and only a 90 degrees shift in wind direction across the boundary. Accordingly, low-level wind fields were weak in proximity to the trough, at or less than 5 m s-1, broadly and weakly convergent across the boundary. Visible satellite imagery revealed no evidence of surface-based response to this convergence. At 1800 UTC, water vapor (GOES Channel 3) satellite imagery and RUC 300-400 hPa PV analyses (Fig. 5) indicated a strong upper-level trough upstream across the western Dakotas. Mid-level convective activity had initiated across eastern South Dakota away from the low-level boundary, an indication of the strength of the lift

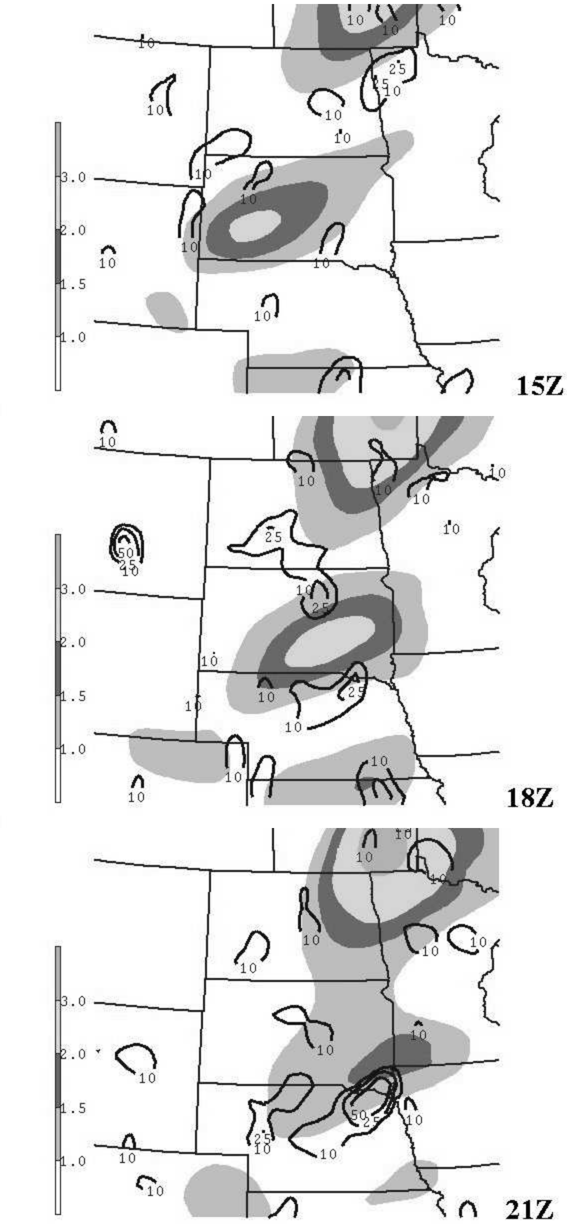

Figure 3. 0 h RUC analysis fields of PV (shaded, PVU) and observed 2D “moist” surface frontogenesis [K (100 km) $^{-1}$ (3h)$^{-1}$] at 1500 UTC, 1800 UTC, and 2100 UTC 17 August 2001.

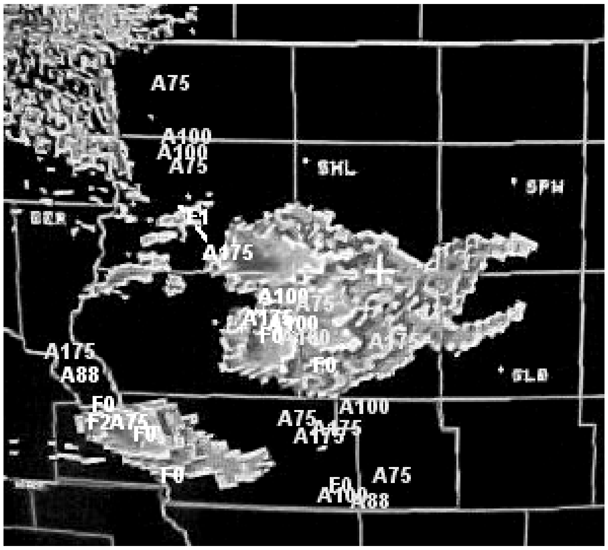

Figure 4. 2250 UTC WSR 88-D reflectivity image from NWS Sioux Falls with overlay of severe weather reports from entire event. A100 and F0 denote 1 inch hail and an F0 rated tornado, respectively. Brighter reports are within a 20 minute window either side of the image time. The Jackson, NE tornado (rated F2) is near the lower right hand corner.

induced by the approaching upper level wave. Through 2000 UTC, there was a gradual strengthening and scale collapse of the 950 hPa convergence fields across northwest Iowa as the upper level PV anomaly shifted toward the location of the surface trough. Despite continuation of only a minor contrast in air mass across the boundary, low-level winds had trended more southerly on the "warm" side of the boundary, and more northerly on the "cool" side. However, the increased convergence of moisture generated slightly higher dewpoint in proximity to the boundary. Cumuliform development was noted where surface-based convective available potential energy (SBCAPE) had climbed to near 1000 J kg^{-1}, which yielded a few showers by 2032 UTC across northwest Iowa along the surface trough.

The upper-level PV anomaly continued to trek to the east with the strong PV gradient situated over the surface boundary by 2200 UTC. Increased lift and release of instability occurred with cumulonimbi development across northeast Nebraska and northwest Iowa. Perhaps most remarkable for this event is the significant westward backing since 1800 UTC of the surface trough location, and marked backing of low-level winds. The convergence at 950 hPa continued to exhibit scale contraction and increase in magnitude along the trough axis, which had become the primary focus for convective development. The 0-6 km shear of 20 m s^{-1} and SBCAPE of 1000-1500 J kg^{-1} were well within expected ranges for organized convection, including supercells. At 2215 UTC, the first report of severe weather (golf ball size hail) was received east of Sheldon, IA (KSHL). Over the next three and a half hours, over 30 reports of severe weather occurred, including three tornadoes. The most significant tornado was on the ground for nearly 10 minutes near Salix, IA, south of Sioux City, IA (KSUX). A detailed examination of this event is available online at www.crh.noaa.gov/fsd/soo/svr0430/april30.htm.

4. JET-"FRONT" INTERACTION

Uccellini and Johnson (1979) and Shapiro (1982) suggested that a coupling of an upper-level thermally indirect circulation and the thermally direct low-level frontal circulation would be a mechanism to invoke a deeper production of ascent. Korner and Martin (2000) and Morgan (1999) quantified the relative influence of the upper PV anomaly on the low level frontal zone through piecewise PV inversion. A crucial element in these diagnostics was the penetration depth of the upper PV anomaly, dependent on the intervening static stability between features. In the two cases discussed here, a well-defined upper level PV anomaly approached the location of a preexisting surface prefrontal trough, with destabilizing conditions in the layer between. As a result, the trough underwent a marked scale contraction and subsequent intensification to the point of taking on near-frontal characteristics. The surface trough became the primary focus for convective development, denoting the favored zone for deepest ascent. Stronger convergence of moisture, as well as enhanced deep-layer shear can be attributed to backed low-level winds ahead of the quasi-frontal zone, which acted to increase instability and potential for organized storms, respectively.

It is of interest to note that while upper level features were adequately simulated in operational models, the low-level fields lacked sufficient frontogenetic impact. A weaker and less convergent prefrontal trough was produced in each case, causing precipitation to be incorrectly focused in time and space. A comparison of short-term model forecasts of "moist" frontogenesis with observed values from the 17 August 2001 case (Fig. 6) shows much stronger frontogenesis in reality. Dynamic and thermodynamic parameters computed from weaker model parameters yielded a diminished threat for organized severe convection. A conceptual model, such as jet-front interaction in the presence of such destabilized conditions, can be applied to modify model output parameters, and glean a more precise operational forecast.

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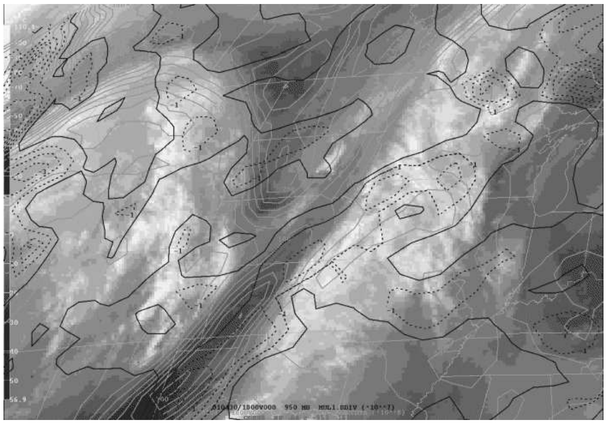

Figure 5. 1800 UTC 30 April 2001 GOES channel 3 satellite image. Light solid lines are PV (PVU*100). Dark solid lines are 950 hPa moisture convergence (1*10^{-7} s^{-1})

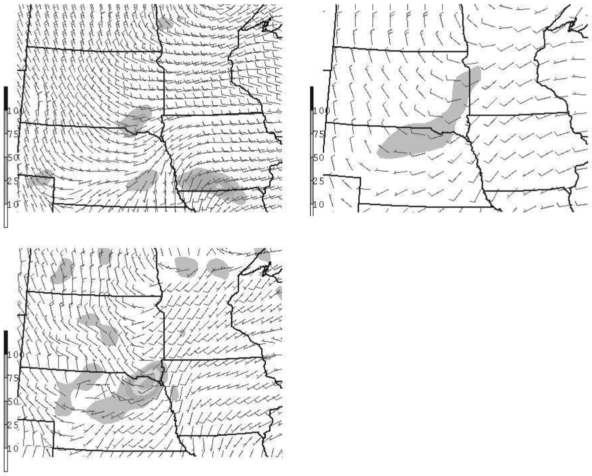

Figure 6. Comparison of "moist" frontogenesis [K (100 km)-1 (3 h) -1] at 2100 UTC. Upper left is ETA 950 hPa 09h forecast. Upper right is RUC 950 hPa 03h forecast. Lower left is observed surface frontogenesis.