A Synoptic Overview of the 9 June 2003 Central Plains Tornado Outbreak

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1. Introduction

The Storm Prediction Center (SPC) received over 200 severe weather reports as a result of severe thunderstorms that erupted in the Central Plains during the afternoon and evening of 9 June 2003 (Fig. 1). Observed tornadoes were confined to South Dakota, Nebraska, and Kansas, however, hail and wind damage were observed along an arcing line from South Dakota through southwest Texas (Fig. 1). Nineteen tornado occurrences are indicated in the National Climatic Data Center Storm Events Database (NCDC; 2004) including four in South Dakota, thirteen in Nebraska, and two in Kansas. The most destructive tornado was approximately 0.8 km (half mile) wide at its maximum extent and produced F3 damage on the Fujita Scale near O'Neill, Nebraska. A separate storm produced a large damaging tornado near Comstock, NE which was nearly 0.5 km (one-third mile) wide and rated F1 on the Fujita Scale. Large hail accompanying the storms was over 10 cm (4 in.) in diameter in the towns of St. Libory, NE and Comstock, NE.

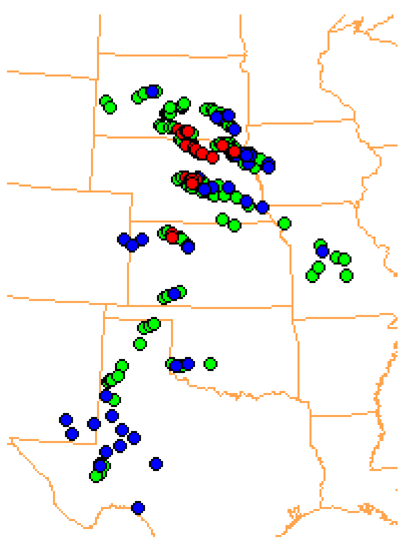
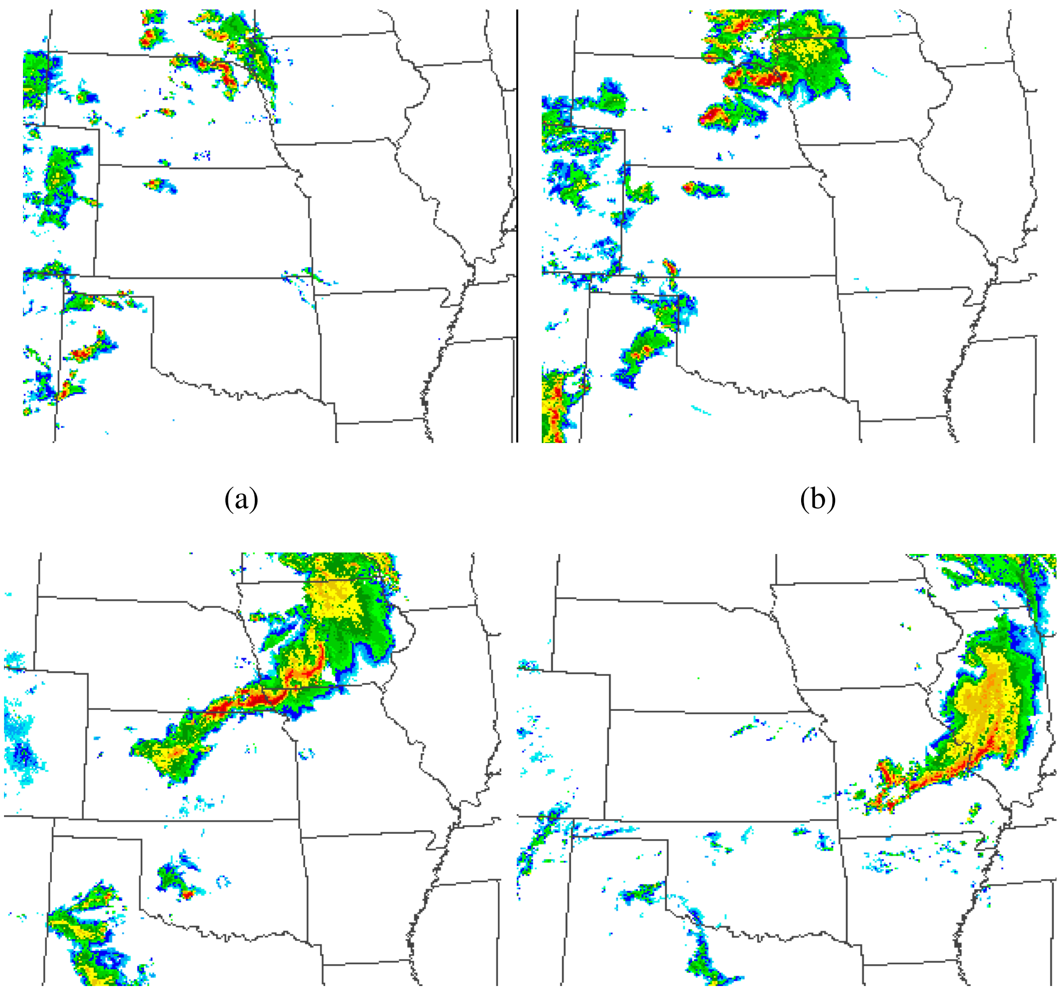


FIG 1. Preliminary severe weather reports on 09 June 2003 in the central United States (from SPC).

As the evening progressed, storm cells that formed in central Nebraska merged with the storms in northeast Nebraska and storms propagating out of northern Kansas forming a linear mesoscale convective system (MCS; Fig. 2c). The MCS propagated to the southeast during the evening hours and brought heavy rain, high wind, and hail to western Iowa and southeast Nebraska. The MCS continued to propagate to the southeast through the overnight hours and by 1200 UTC the next morning was located along a line from central Illinois stretching southwest through much of central Missouri (Fig. 2d).

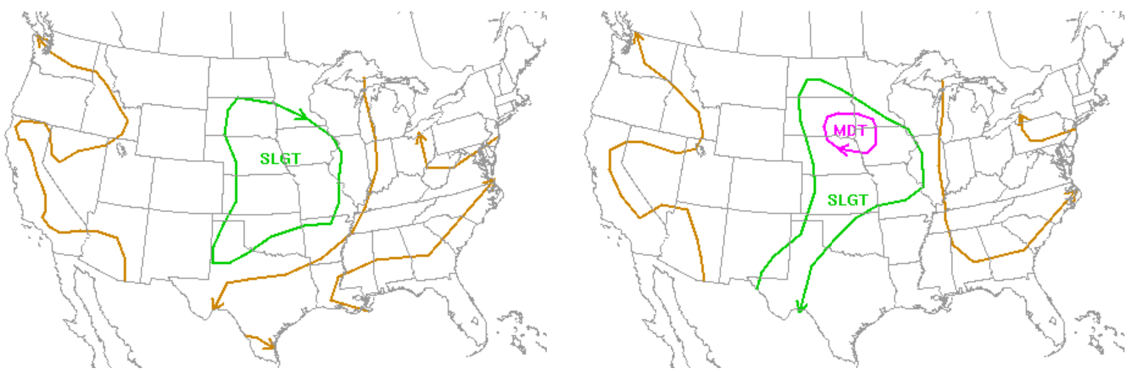


(a) (b)

(c) (d)

FIG 2. Radar reflectivity for (a) 2300 UTC 9 June 2003, (b) 0132 UTC 10 June 2003, (c) 0603 UTC 10 June 2003, and (d) 1204 UTC 10 June 2003 (from SPC).

The ingredients which came together to produce severe storms on 9 June 2003 were relatively well advertised by forecast models (not shown). The severe threat for this day, particularly for northeast Nebraska and southeastern South Dakota was also relatively well forecasted by the SPC. The 0600 UTC SPC Day 1 Convective Outlook suggested a slight risk for severe thunderstorms for a large portion of the Plains region (Fig 3a). The majority of severe weather incidents (Fig. 1) did occur in this area. At 1630 UTC the slight risk region remained over nearly the same area, however, northeast Nebraska, northwest Iowa, southeast South Dakota, and extreme southwest Minnesota were elevated to a moderate risk (Fig 3b). The majority of tornadoes touched down in or near the moderate risk area.



(a) (b)

FIG 3. SPC Day 1 Convective Outlook valid at (a) 1200 UTC, 09 June 2003 and (b) 1630 UTC, 9 June 2003 (from SPC).

The tornado outbreak of 9 June 2003 was one of many such events to occur in the spring and early summer of 2003. Significant events such as the 4-11 May 2003 tornado outbreak, the 22 June 2003 record hail stone in Aurora, NE, and the 24 June 2003 record breaking daily number of tornadoes in South Dakota have overshadowed the 9 June 2003 event. The synoptic set-up for the 9 June 2003 tornado event was not necessarily unique.

The event is interesting to examine given tornadic thunderstorms developed near the warm front boundary and along the dryline boundary at about the same time. This paper will discuss surface and upper-air synoptic conditions prior to convective initiation.

2. Upper Air Observations

A review of the 1200 UTC upper air charts on 9 June 2003 (Fig. 4-7) indicated several notable features. The 250 hPa flow (Fig. 4) was characterized by an amplified trough in the Great Lakes region which extended well into the southeastern United States. A less amplified trough was evident in the northern Rocky Mountain region. Maximum wind speeds at this level exceeded 45 ms^{-1} (1 ms^{-1} = 2 knots) ahead of the eastern trough with approximately a 35 ms^{-1} wind maximum measured in the Northern Plains.

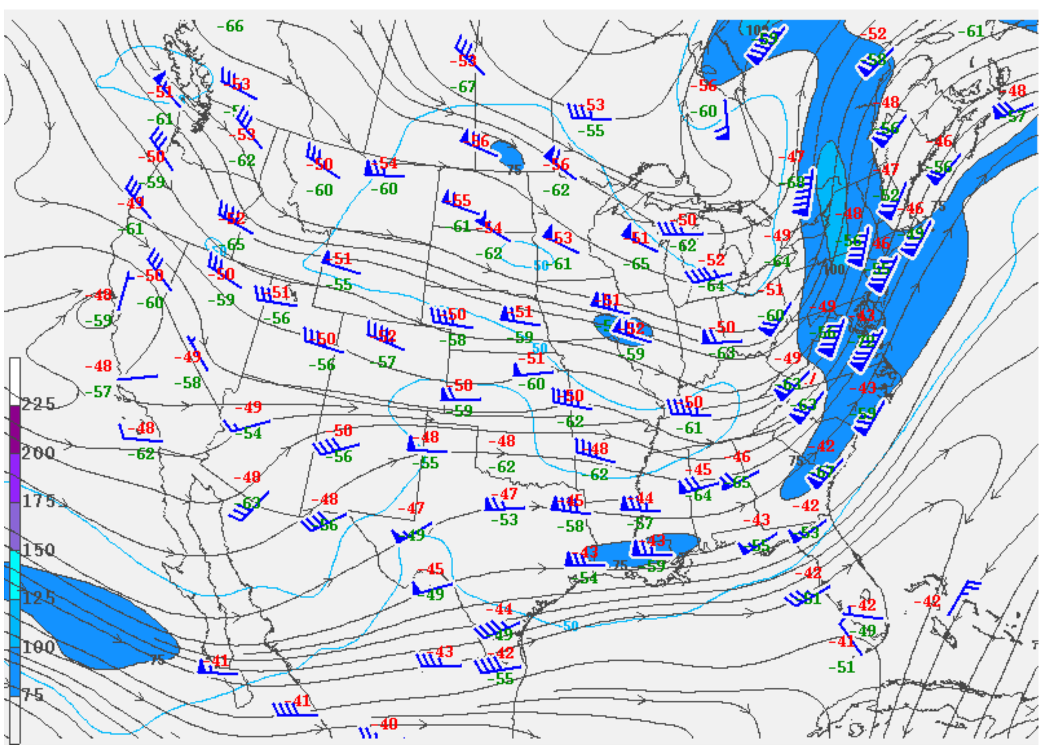


FIG 4. 250 hPa analysis for 1200 UTC, 09 June 2003. Grey lines indicate streamlines. Blue shaded areas are isotachs in knots (1 knot = 0.5 ms^{-1}; from SPC)

Both the eastern trough and western trough were easily detected on the 1200 UTC 500 hPa chart (Fig. 5). The general flow was from the west/northwest to the west of the eastern trough. Measured wind speeds were less than 15 ms^{-1} between the West Coast and Mississippi River Valley. Temperatures at 500 hPa were relatively cool. The Omaha, NE (OAX) and North Platte, NE (LBF) soundings both indicated 500 hPa temperatures of -15°C. The 500 hPa temperature over Pierre, SD was -16°C.

The 1200 UTC 700 hPa analysis (Fig. 6) indicated two closed height contours about low height center associated with the trough in the Great Lakes region. The shortwave trough in the northern Montana was well defined with an area of ridging just ahead of it in eastern Montana and western North Dakota. Winds at 700 hPa were relatively weak, at between five and ten meters per second. Temperatures were 1°C at OAX and 6°C at LBF. A west wind normal to the 700 hPa isotherms indicated warm air advection at the level across Nebraska and the Dakotas. Weak cold air advection was observed in northern Montana. Deep moisture at 700 hPa was limited to eastern Oklahoma, northeast Texas, and western portions of Arkansas and Louisiana. The dewpoint at 700 hPa for both OAX and LBF was -1°C.

The Great Lakes system contained three closed height contours on the 1200 UTC 850 hPa analysis (Fig. 7). A ridge extended across the Mississippi River valley and lower Missouri River valley and a trough was located in the High Plains region. The low height center was near Glasgow, MT (GGW). Winds at 850 hPa in the High Plains were from the southwest, averaging 10 ms^{-1}. The peak wind was located at Amarillo, TX (AMA) where 18 ms^{-1} wind speed was observed. Temperatures at 850 hPa were 12°C at OAX and 20°C at LBF. Weak warm air advection was occurring throughout the Dakotas and eastern Plains region while cold air advection was occurring in Montana. Significant moisture advection was occurring throughout the southern Plains. Dewpoint temperatures at 850 hPa ranged from 4°C at OAX, 9°C at LBF, 11° at Dodge City, KS (DDC), and 15°C at AMA.

By 0000 UTC, the 250 hPa trough that was initially over the northern Rocky Mountains at 1200 UTC (Fig. 4) had entered western North Dakota (Fig. 8). Winds at 250 hPa had changed little with the notable exception of increased winds at the base of the trough in western South Dakota and Nebraska. The wind speed increased over LBF from 20 ms^{-1} at 1200 UTC (Fig. 4) to 30 ms^{-1} at 0000 UTC (Fig. 8). Diffluent 250 hPa flow was indicated in eastern South Dakota and Nebraska (Fig. 8), over the area of greatest concentration of severe weather reports (Fig. 1). Northwesterly flow existed over LBF and OAX while westerly flow existed over Rapid City, SD (UNR), Aberdeen, SD (ABR), and Minneapolis, MN (MPX).

The 500 hPa western trough had entered the Dakotas by 0000 UTC (Fig. 9). Wind direction across the Northern Plains had shifted from the northwest at 1200 UTC (Fig. 5) to the west/southwest and had uniformly increased in speed by 5 ms^{-1}. The 500 hPa temperature increased by 3°C at LBF and ABR, and 1°C at OAX in response to height rises and zonal flow in the wake of the Great Lakes trough. Similar changes occurred between 1200 UTC and 0000 UTC at the 700 hPa level (Fig. 6 and 10). Initial northwest flow at OAX had shifted to the southwest. Temperatures at ABR, LBF, and OAX at 700 hPa increased by 2°C, 4°C, and 6°C respectively.

A comparison of the 1200 UTC and 0000 UTC 850 hPa charts (Fig. 7 and 11) revealed marked changes. The closed low height center had propagated from eastern

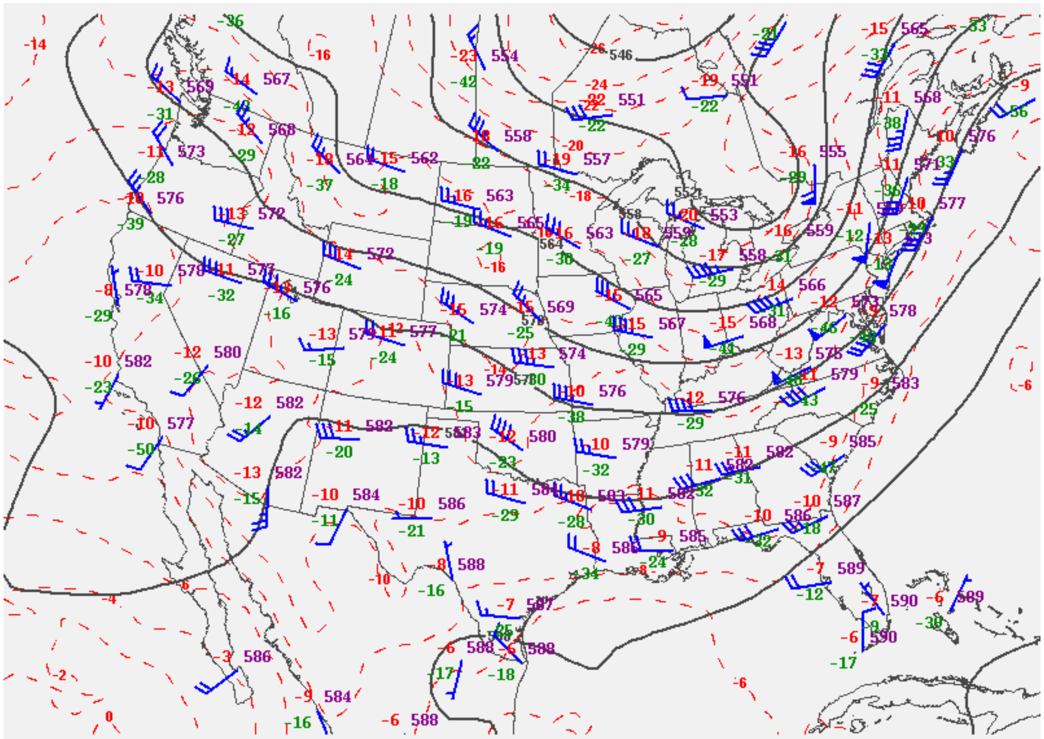


FIG 5. 500 hPa analysis for 1200 UTC, 09 June 2003. Grey lines indicate height contours in decameters. Dashed red lines are isotherms (from SPC).

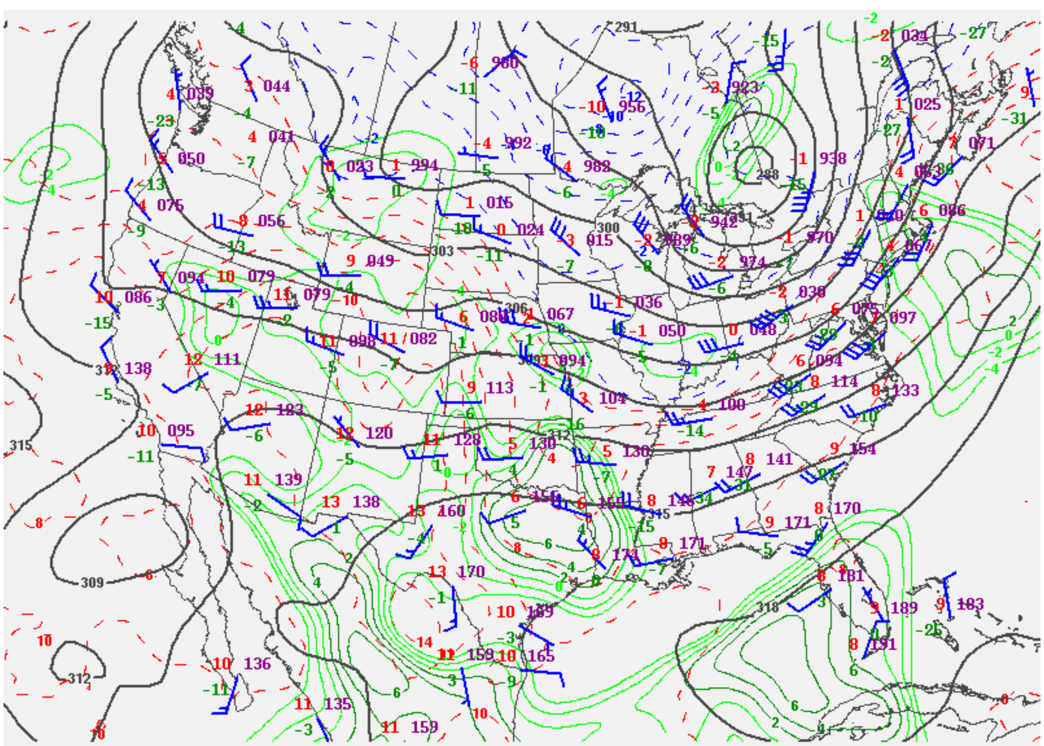


FIG 6. 700 hPa analysis for 1200 UTC, 09 June 2003. Grey lines indicate height contours in decameters. Dashed red lines are isotherms and solid green lines are isodrosotherms (from SPC).

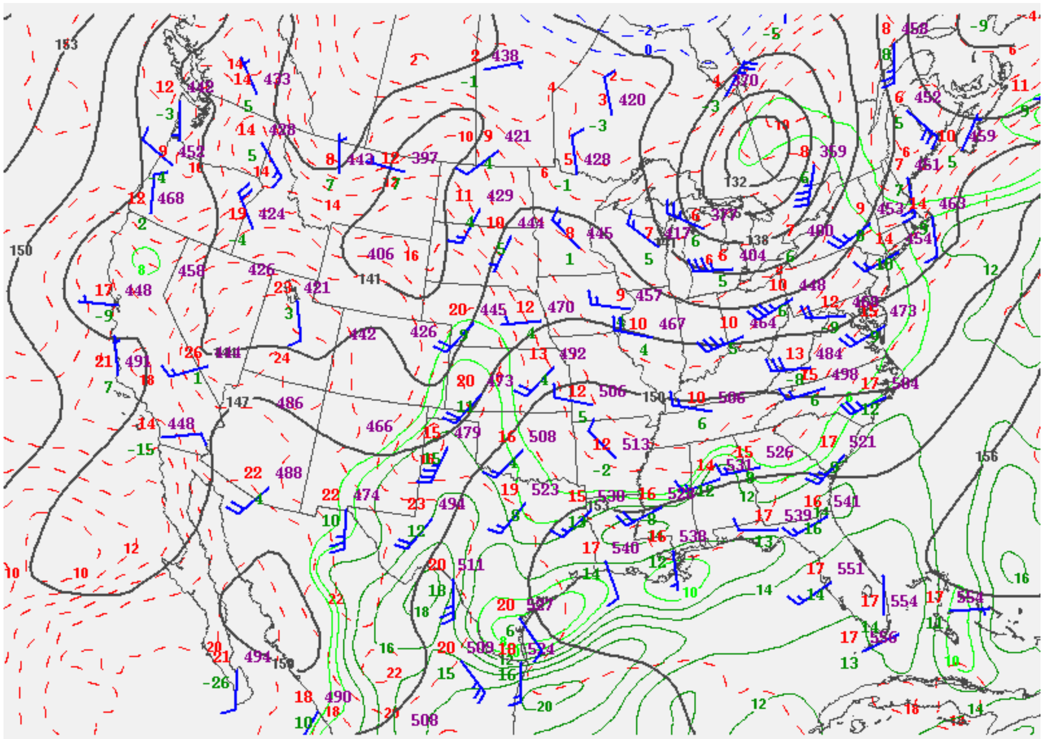


FIG 7. 850 hPa analysis for 1200 UTC, 09 June 2003. Grey lines indicate height contours in decameters. Dashed red lines are isotherms and solid green lines are isodrosotherms (from SPC).

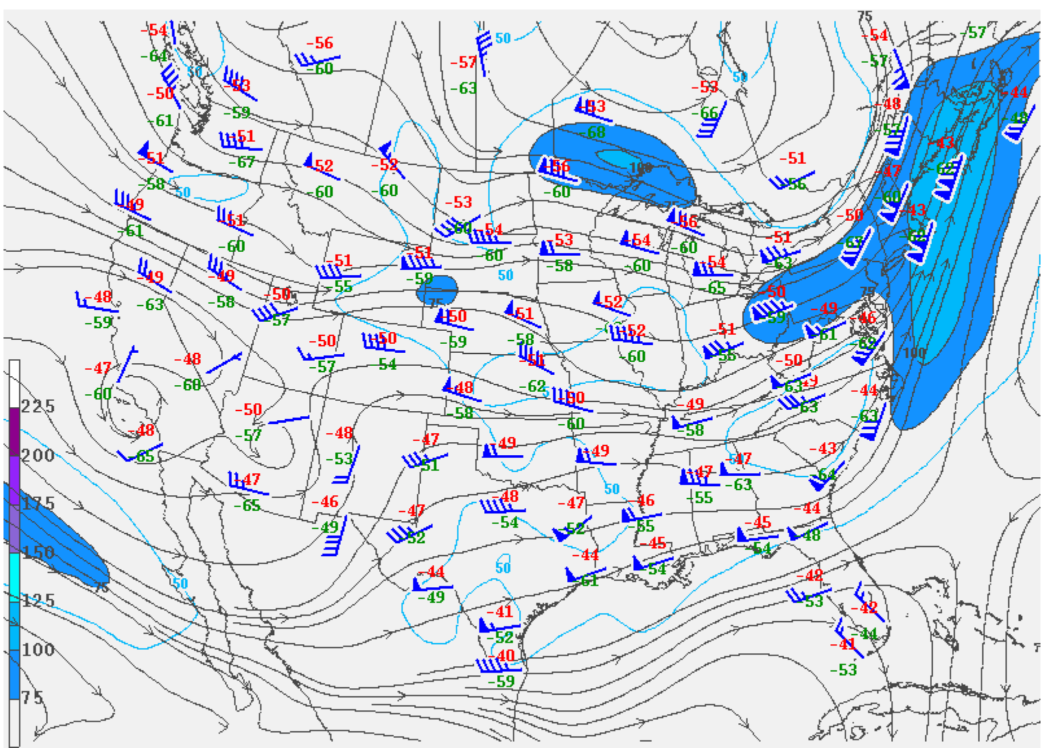


FIG 8. 250 hPa analysis for 0000 UTC, 10 June 2003. Grey lines indicate streamlines. Blue shaded areas are isotachs in knots (1 knot = 0.5 ms^{-1}; from SPC).

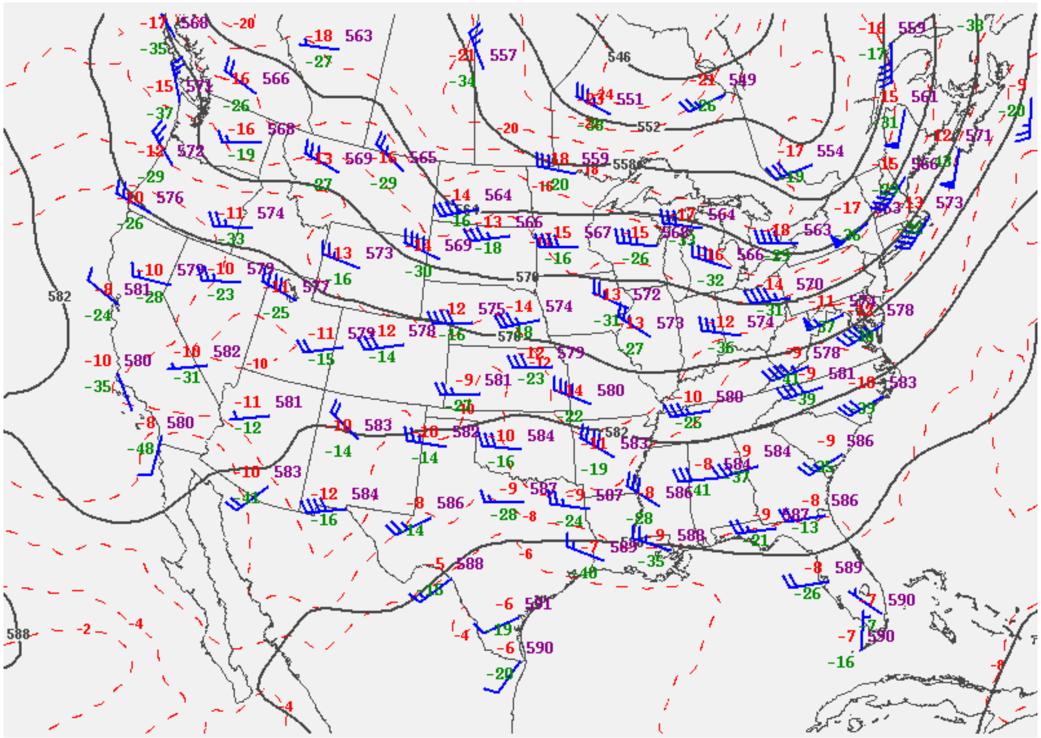


FIG 9. 500 hPa analysis for 0000 UTC, 10 June 2003. Grey lines indicate height contours in decameters. Dashed red lines are isotherms (from SPC).

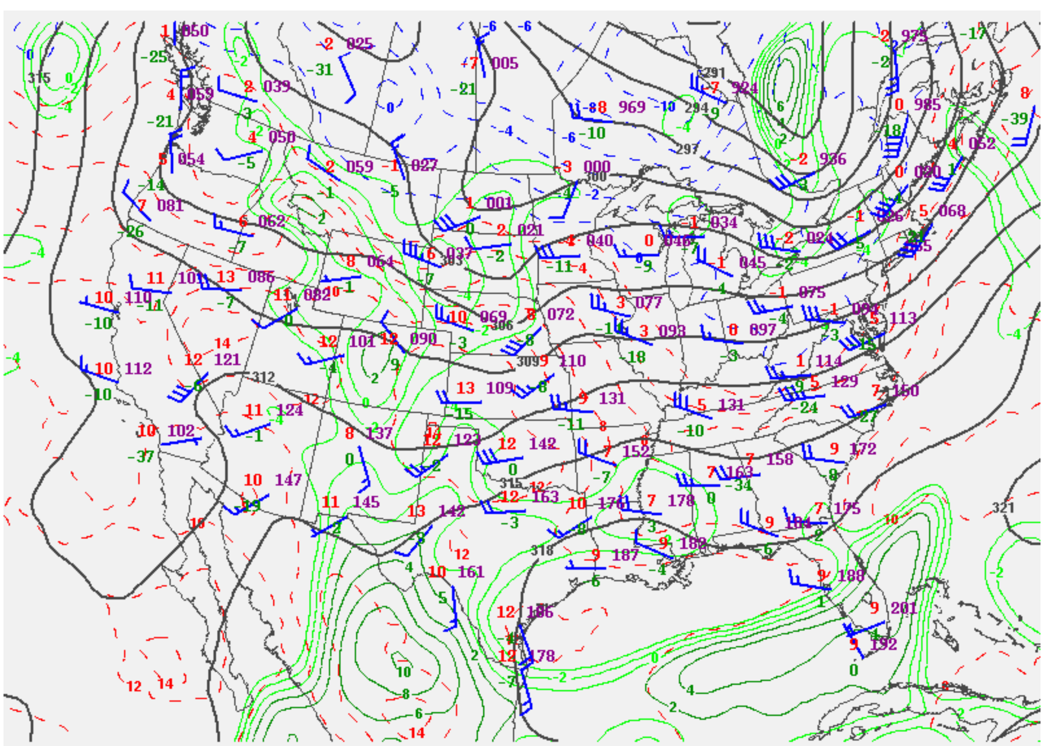


FIG 10. 700 hPa analysis for 0000 UTC, 10 June 2003. Grey lines indicate height contours in decameters. Dashed red lines are isotherms and solid green lines are isodrosotherms (from SPC).

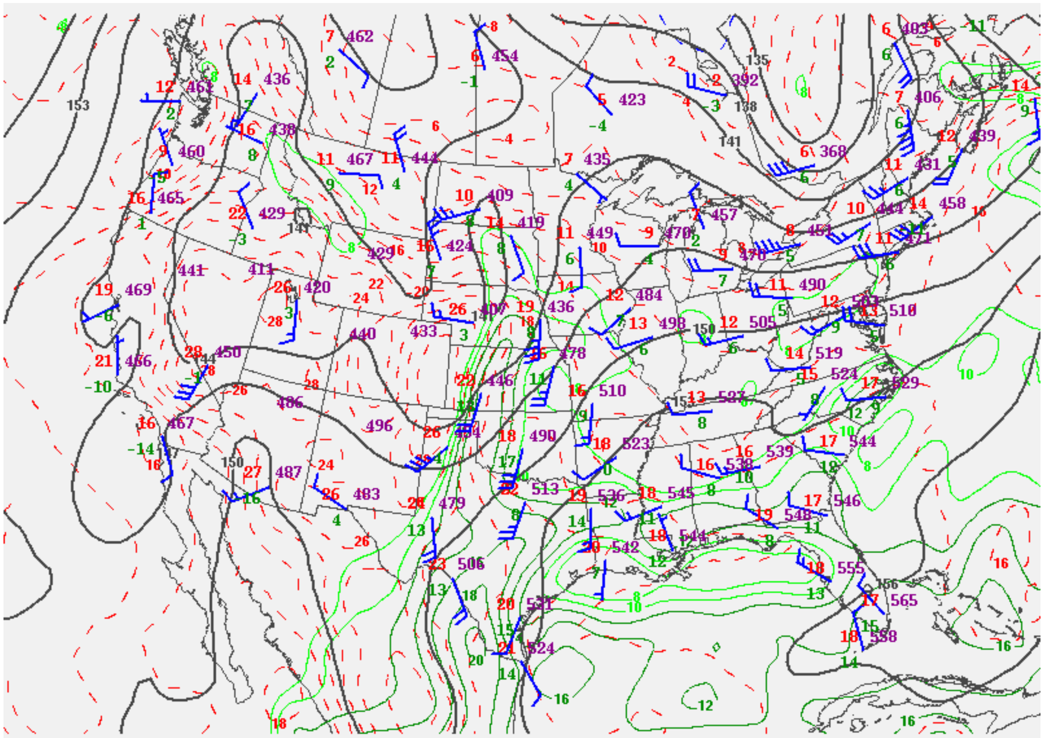


FIG 11. 850 hPa analysis for 0000 UTC, 10 June 2003. Grey lines indicate height contours in decameters. Dashed red lines are isotherms and solid green lines are isodrosotherms (from SPC)

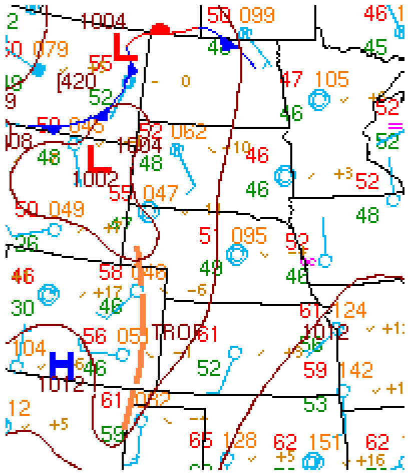
Montana into central South Dakota forcing the wind field to back to the south/southeast at ABR and south at OAX. A strengthened low level jet allowed heat and moisture to surge northward. The wind speed increased from less than 3 ms^{-1} at OAX at 1200 UTC to 17 ms^{-1} at 0000 UTC. Thermal and moisture advection (theta-e advection) allowed the temperature at OAX to surge 7°C and dewpoint to increase by 4°C within twelve hours.

3. Surface Observations

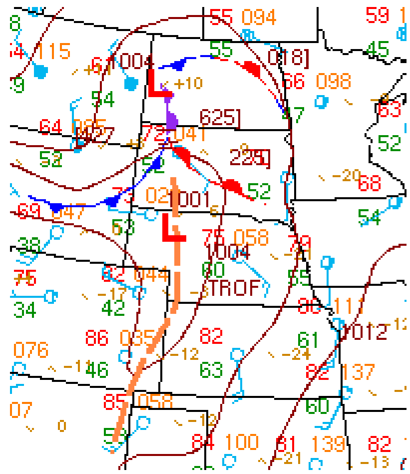
Surface analysis for 1200 UTC (Fig. 12a) indicted a 1004 hPa low pressure center in northeast Montana and associated cold front trending to the southwest. A secondary 1002 hPa low pressure center was located in northeastern Wyoming. Surface winds were generally light across South Dakota and Nebraska. A general temperature and moisture gradient existed from north to south with surface temperatures of 8-11°C (46-52°F) and dewpoint temperature around 9°C (48°F) across South Dakota and Nebraska. To the south, across Oklahoma and Texas, surface temperature and dewpoint observations were approximately 10°C higher.

By 1500 UTC (not shown) surface dewpoint temperatures had increased several degrees across South Dakota and Nebraska. Surface wind speeds had also increased in the Central Plains ahead of a dryline located in the High Plains. The surface low pressure system previously located in eastern Montana had propagated into western North Dakota. At 1800 UTC (Fig. 12b), the western North Dakota low pressure center was beginning to occlude. A poorly defined warm front was analyzed in a northwest to southeast orientation across South Dakota. Surface wind speeds in central Nebraska had increased to 7 ms^{-1}. Dewpoint temperatures across central Kansas and Nebraska had reached or exceeded 15°C (≈ 60°F) ahead of the dryline located in western Nebraska and extending south along the Kansas and Colorado border.

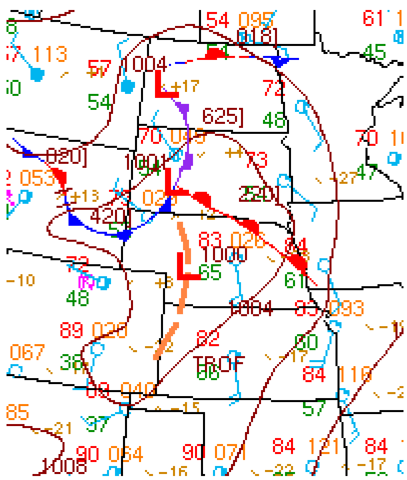
By 2100 UTC (Fig. 12c), the surface warm front became more clearly defined, extending from the secondary 1001 hPa surface low pressure center located just east of the Black Hills region of South Dakota and extended southeastward across northeast Nebraska. The temperature and dewpoint contrast was about 6°C (10°F) between eastern South Dakota and the warm sector in central Nebraska. Between 1800 UTC and 2100 UTC (Fig. 12b and 12c) the dryline was nearly stationary. Within the next 90 minutes, severe thunderstorms developed along the warm frontal and dryline boundaries. By 0000z (Fig. 12d), the surface low had deepened to 996 hPa and the dryline had advanced eastward.



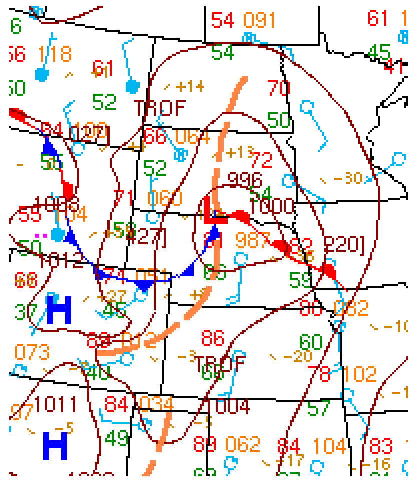
(a)



(b)



(c)



(d)

FIG 12. Hydrometeorological Prediction Center (HPC) surface analysis for (a) 1200 UTC, 09 June 2003, (b) 1800 UTC, 09 June 2003, (c) 2100 UTC, 09 June 2003, and (d) 0000 UTC, 10 June 2003. Brown contours are isobars (from SPC).

4. Discussion

The upper-air flow rapidly changed from a unidirectional regime at 1200 UTC to a highly sheared regime at 0000 UTC. Backed surface flow, in response to a deepening surface low, further enhanced shear profiles. The area impacted by tornadoes and large hail was located between the LBF, ARR, and OAX 0000 UTC upper-air soundings. Output from the RUC model indicated 0000 UTC bulk layer 0-6 km shear on the order of

25 ms^{-1} in northeast Nebraska which falls within the highest 25-percentile of tornado cases studied by Rasmussen and Blanchard (1998), where proximity soundings were used. The observed 0000 UTC OAX (Fig. 13) sounding indicated 23 ms^{-1} of 0-6 km bulk layer shear, confirming the model output. Model indicated effective storm relative helicity (0-3 km storm relative helicity above any surface stable layer; Davies-Jones et al. 1990) values in excess of 300 m^2s^{-2} over areas along the warm front in northeast Nebraska, southeast South Dakota, northwest Iowa, and extreme southwest Minnesota (Fig. 14a). A small area effective storm relative helicity exceeding 500 m^2s^{-2},a statistical outlier in the Rasmussen and Blanchard (1998) study, was embedded within the larger area and located just ahead of the surface warm front.

Advection of steep lapse rates at the mid-levels of the atmosphere (Fig. 14b) in conjunction with strong surface theta-e advection combined to form a very unstable atmosphere. The nearest upper-air observing station to the area of tornado reports along the warm front was OAX. The 0000 UTC OAX sounding (Fig. 13) indicated approximately 600 J/kg of surface based convective available potential energy (SBCAPE) and a surface parcel lifted index of -4. The OAX sounding was not indicative of the near storm environment however, as the surface dew point temperature at OAX was nearly 5°C cooler than areas in central and northeast Nebraska. Simply increasing the surface dewpoint in the OAX sounding to the values present to the west would have more than doubled the SBCAPE and provided a surface parcel lifted index of approximately -10.

5. Summary

Rapid evolution of the upper-air and surface pattern between 1200 UTC and 0000 UTC created an unstable and highly sheared air mass Strong moisture transport near the surface combined with steep lapse rates in the mid-levels of the atmosphere created an environment for buoyant parcels. Readjustment of the upper-level wind flow, a deepening surface low pressure circulation, and surface boundaries combined to allow for a highly sheared profile. Focused lift along surface boundaries allowed for convective initiation. Instability and shear provided a favorable environment for the thunderstorms to rapidly evolve into supercells and generate tornadoes.

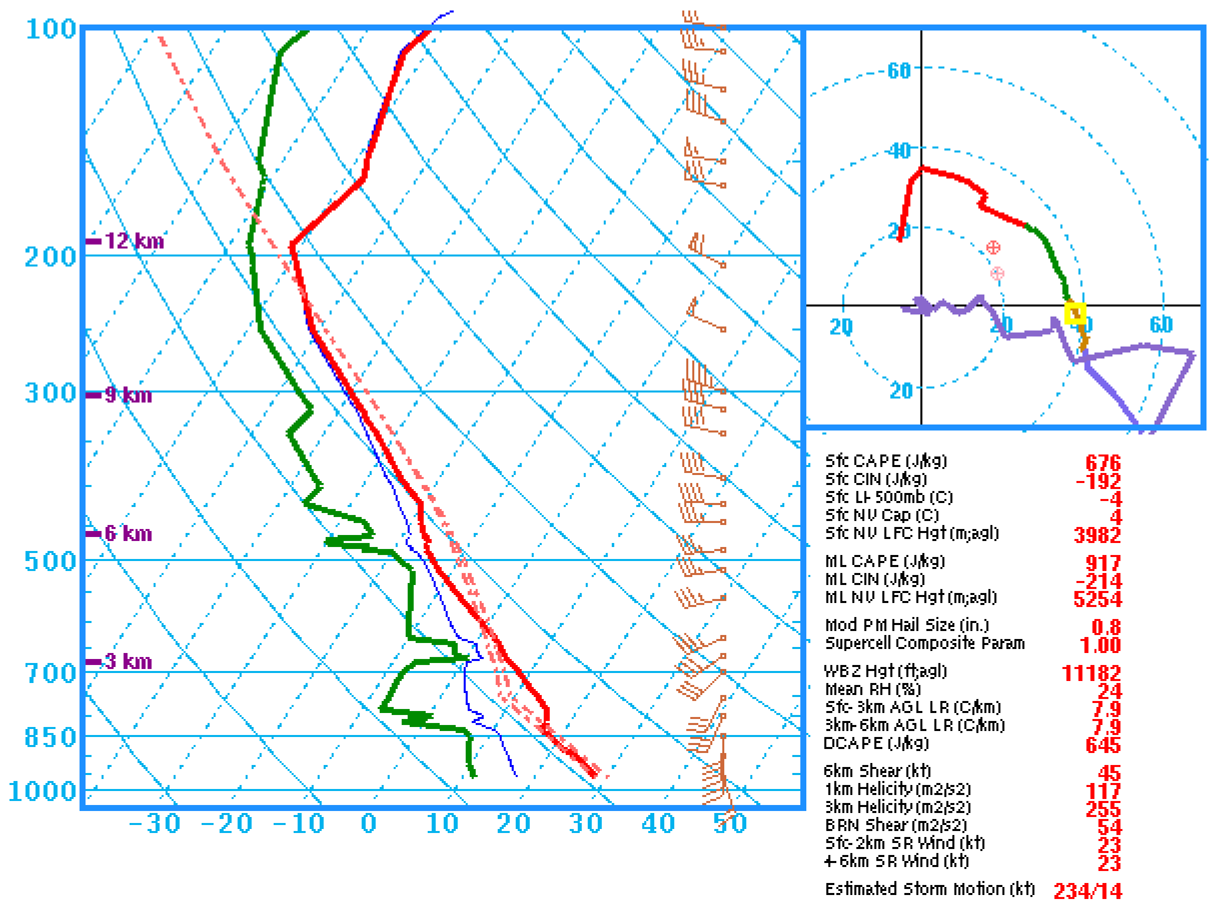
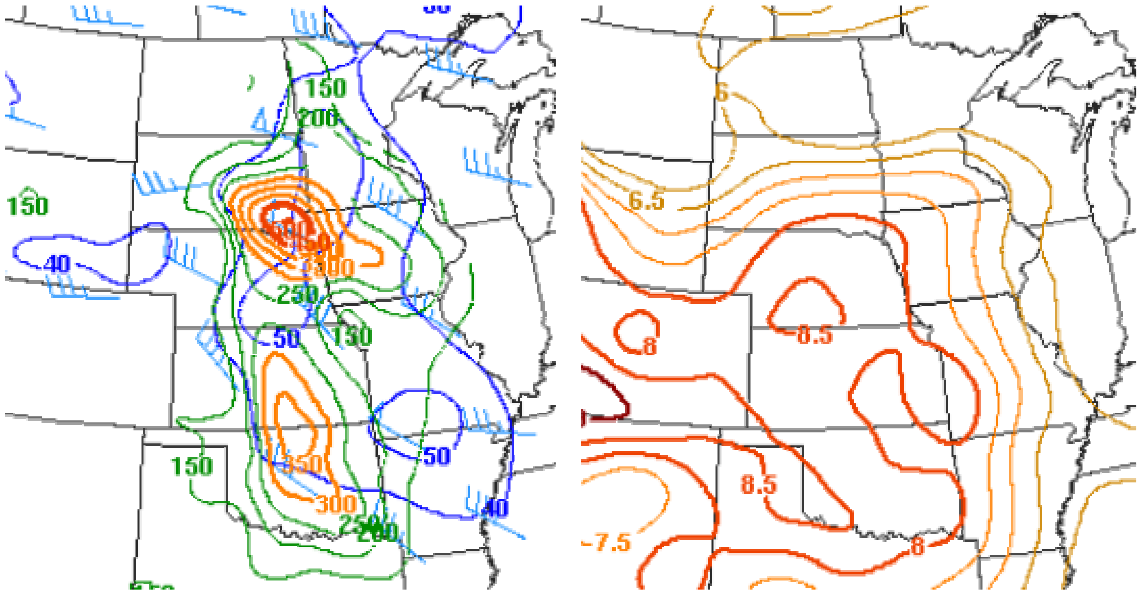


FIG. 13. Observed 0000 UTC 10 June 2003 sounding for OAX. Stability and shear parameters indicated at lower right (from SPC).



(a) (b)

FIG 14. RUC model output for 0000 UTC for (a) bulk layer 0-6 km shear indicated in blue (knots, 1 knot = 0.5 ms^{-1}) and effective storm relative helicity (m^2s^{-2}) from SPC) and (b) 700 hPa to 500 hPa lapse rates (from SPC).

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