The Southern Minnesota Tornadoes of 29 March 1998: A Ten Year Anniversary Perspective

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1. INTRODUCTION

During the afternoon and evening hours of 29 March 1998, a long-lived supercell produced 13 tornadoes while moving across southern Minnesota. The tornadoes included one rated F4 on the Fujita Scale with a path length of 67 miles, another rated a strong F3 with an 18 mile path length, and a third tornado rated F2 with a 17 mile long path. These three tornadoes devastated the towns of Comfrey, St. Peter, and Le Center, and the rural Lake Hanska area, and resulted in 2 fatalities, numerous injuries and several millions of dollars in damage.

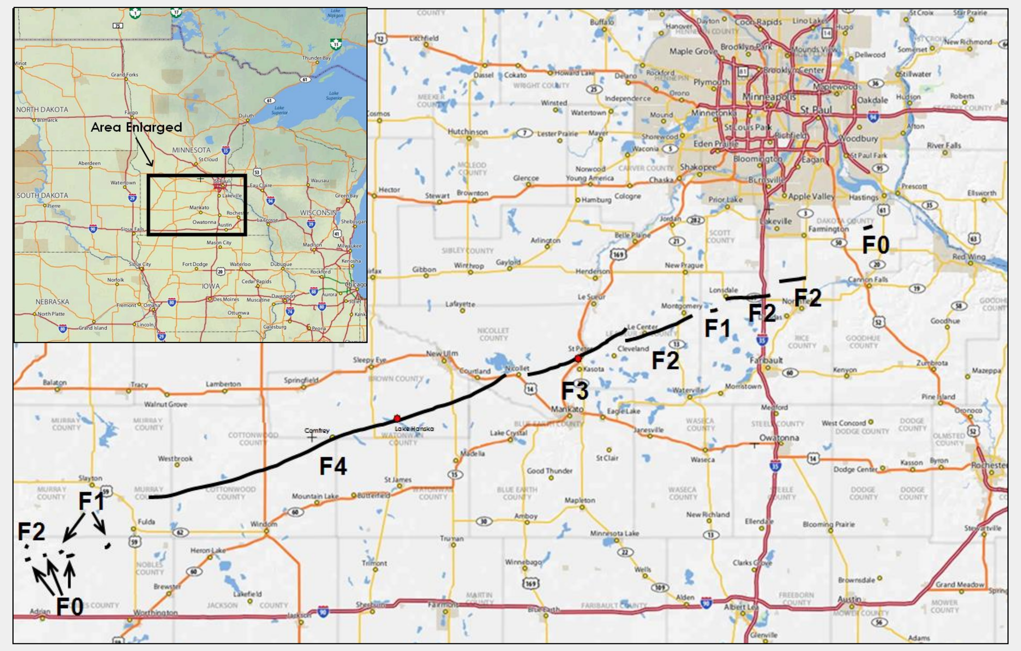

Figure 1. Map of southern Minnesota showing the damage paths of the 13 tornadoes on 29 March 1998 and associated Fujita Scale rating (the Enhanced Fujita Scale was not implemented until 2007). The area enlarged is indicated by the black rectangle on the small inset map. Locations of tornado fatalities are denoted by the small 8-pointed red stars near Lake Hanska and St. Peter.

The 10 year anniversary of this event in 2008 provided a unique opportunity to look back on this event from scientific, operational and impacts-based perspectives, and to examine these three aspects of the event within the context of our current understanding of significantly tornadic supercell storms. During the winter of 2007-2008, a comprehensive historical post-mortem of the 29 March 1998 event was undertaken by three National Weather Service Offices in the Northern Plains, and included meteorologists that currently serve at the Twin Cities/Chanhassen, MN WFO, and several other meteorologists who worked the event 10 years ago in 1998, but who have since moved on to jobs at other National Weather Service offices.

The post-mortem included 1) a comprehensive study of the climatological significance of this early season event, 2) the overall synoptic and mesoscale meteorological environments, 3) a detailed analysis of radar and satellite data, 4) a local modeling study, and 5) collection and examination of personal accounts of the tornadoes from survivors, local media, emergency managers and NWS staff who worked the event in an attempt to understand how information exchange has improved during the past decade. The historical post-mortem is summarized on this poster, with some thoughts on how this type of historical post-mortem can be leveraged to improve current and futures services.

2. CLIMATOLOGICAL SIGNIFICANCE

While an event of this magnitude across southern Minnesota is certainly exceptionally rare so early in the convective season, its occurrence is not unprecedented. There was a similar event on 5 April 1929 that affected east-central Minnesota and northwest Wisconsin, when 5 significant tornadoes occurred, including 3 rated F4, 1 rated F3 and 1 rated F2 on the Fujita Scale, in locations from what is now the Minneapolis-St. Paul metro area northeastward to the south shore of Lake Superior. The 1929 event occurred only 7 days closer to the climatological peak tornado occurrence in the Minnesota/Wisconsin area (see image at left).

In addition, it should be noted that there have been several other early-season high-end tornado events that have involved similar synoptic set ups in other parts of the United States: 1) 18 March 1925 - the "Tri-State" tornado that affected Missouri, Illinois, and Indiana, 2) 9 April 1947 - in the Texas Panhandle and northwest Oklahoma (the Woodward, Oklahoma tornado) and 3) 28 March 1984 - the "Carolinas" tornado outbreak. While these events do not carry the same climatological significance for their respective geographic regions, each event was the result of one primary cyclic tornadic supercell, moving along a warm front, and in each case, snow fell on the tornado damage paths within 72-84 hours of tornado occurrence.

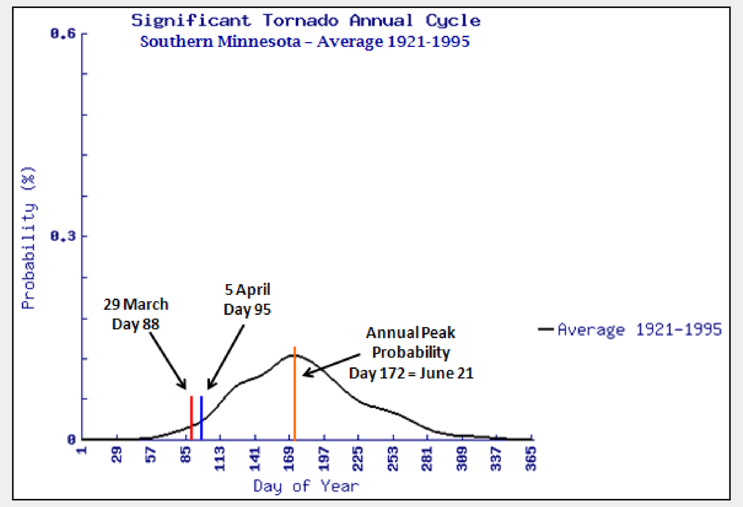

Figure 2. Significant tornado annual cycle for southern Minnesota (black line) for the time period 1921-1995. Source: National Severe Storms Laboratory Hazards page: http://www.nssl.noaa.gov/hazard/hazardmap.html

3. SYNOPTIC SET-UP

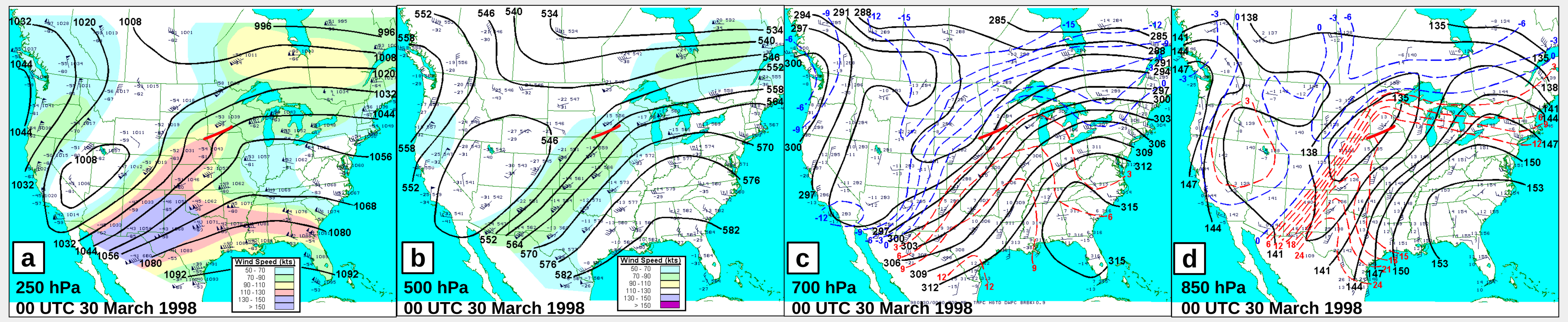

Figure 3. Upper air analysis maps from a) 250 hPa, b) 500 hPa, c) 700 hPa, and d) 850 hPa, at 0000 UTC 30 March 1998 (6 PM CST 29 March 1998) as the tornado event was in progress across southern Minnesota. Height contours on all maps are denoted by the black lines. Isotachs are indicated by the shading and associated color tables on the 250 mb and 500 mb maps, respectively. On the 700 mb and 850 mb maps, isotherms are denoted by the red and blue dashed lines, with temperature contours above freezing depicted in red and temperature contours at or below freezing depicted in blue. At mid and upper levels, southern Minnesota was underneath the nose of a strong speed max that had developed to the east of the main upper level trough axis from Wyoming to southern California. A weakly-coupled upper level jet structure is also evident. At 700 mb, a low-amplitude eastward moving disturbance is located over South Dakota and Nebraska and at 850 mb, an intense thermal gradient denotes a strong frontal zone across central and southern Minnesota, with the region at the nose of a thermal ridge and 40+ knot low level jet.

4. MESOSCALE ENVIRONMENT AND SURFACE OBSERVATIONS

Despite being a very early season event, the meso-scale meteorological environment was quite characteristic of what could be considered a more "typical" warm season environment supportive of tornadic supercells: Deep-layer bulk wind shear (0-6 km) values were 50-60 kt, CAPE values were 1500-2000 j/kg, low level bulk wind shear (0-1 km) values were 25-30 kt, and surface temperature-dewpoint spreads were less than 10 degrees Fahrenheit, resulting in low lifting condensation levels (LCLs) around 700 m agl (~2100 ft) and levels of free convection (LFCs), around 1600 m agl (~5000 ft) along and south of the surface warm front. Given the discrete nature of the convective mode, it should nor be too surprising that one supercell rooted in the near-surface layer along the warm front became a cyclic and significant tornado producer.

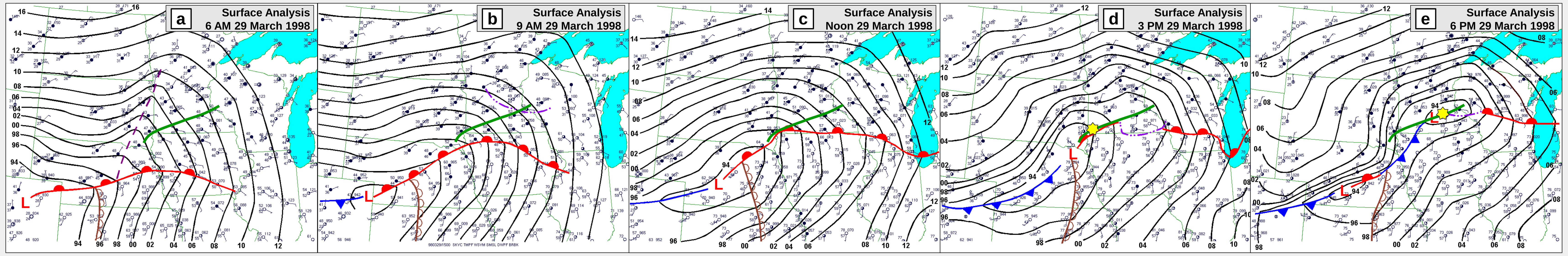

Figure 4. Surface analyses from a) 1200 UTC (600 PM CST), b) 1500 UTC (900 AM CST), c) 1800 UTC (Noon CST), and d) 2100 UTC (300 PM CST) 29 March 1998, and e) 0000 UTC 30 March 1998 (600 PM CST 29 March 1998). Surface pressure contours are denoted by the solid black lines. A surface warm front moved slowly northward into southern Minnesota during the day, and the intense frontal zone along and north of the warm front became the focus for severe thunderstorm development. The first severe storms to develop were elevated to the north of the surface warm front, and the outflow boundary from these storms is evident as a break in the continuity of the surface warm front near the Iowa/Minnesota border at 2100 UTC (300 PM CST). The path of the cyclic tornadic supercell responsible for the 13 tornadoes is denoted by the bold dark green line in very close proximity to the surface warm front. The yellow star annotated on the green line on the 2100 UTC (300 PM CST) (d), and 0000 UTC (600 PM CST) (e), maps is the location of the tornadic supercell at those respective times.

5. RADAR DATA

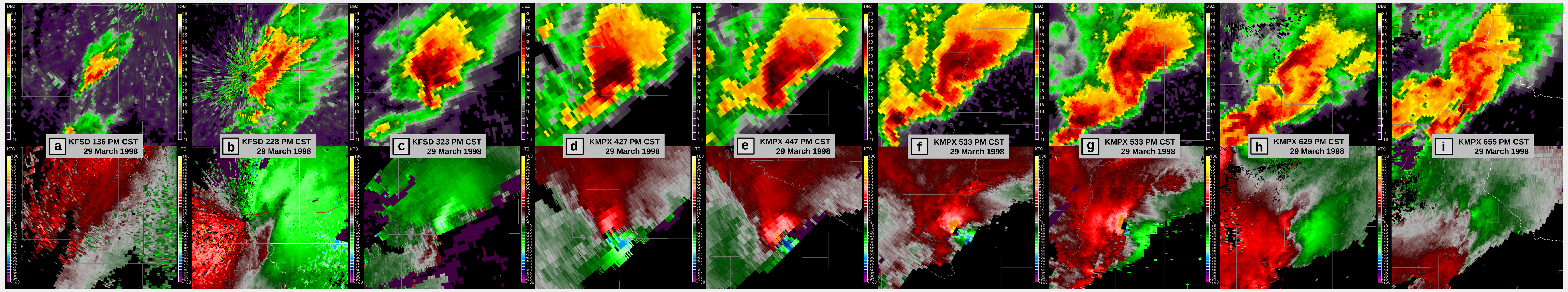

Figure 5. WSR-88D 0.5 degree reflectivity imagery (top) and 0.5 degree storm-relative velocity imagery (bottom) from Sioux Falls, SD (KFSD) at a) 1936 UTC (136 PM CST), b) 2028 UTC (228 PM CST), and c) 2123 UTC (323 PM CST), and Twin Cities/Chanhassen (KMPX) at d) 2227 UTC (427 PM CST), e) 2247 UTC (447 PM CST), f) 2333 UTC (533 PM CST), g) 2353 UTC (553 PM CST), h) 0029 UTC (629 PM CST) and i) 0055 UTC (655 PM CST), showing most of the 7 hour evolution of the southern Minnesota tornadic supercell during the afternoon and evening hours of 29 March 1998. First echo observed on the KFSD radar was shortly after 1900 UTC (100 PM CST) (a). The storm dissipated about 45 minutes after the last images in this sequence (i) over western Wisconsin shortly before 0200 UTC 30 March 1998 (800 PM CST 29 March 1998). Some times of interest include: 1) 2123 UTC (323 PM CST) (c); first short-lived F2 tornado in northwest Nobles County. 2) 2227 UTC (427 PM CST) (d): tornado hits the city of Comfrey. 3) 2247 UTC (447 PM CST) (e): long tracked F4 tornado near peak intensity in the Lake Hanska vicinity, an elderly man sustained fatal injuries near this location. 4) 2333 UTC (533 PM CST) (f): second long track F3 tornado near peak intensity just west of the city of St. Peter (rotational velocity difference in excess of 176 knots in radar velocity data). A second fatality occurred near this location. 5) 2353 UTC (553 PM CST) (g): third long-tracked F2 tornado affects the city of Le Center. 6) 0029 UTC (629 PM CST) (h): Storm losing supercell characteristics, but intense/tight low-level rotation persists in radar velocity data and the last F2 tornado nears dissipation. 7) 0055 UTC (655 PM CST) (i): supercell produces its last of 13 tornadoes just southwest of the city of Hastings.

6. LOCAL MODELING

In an effort to gain additional insight into the near-storm environmental conditions during the event, a simulation was done using the WRF-ARW using North American Regional Reanalysis (NARR) data to provide initial/boundary conditions, and allowed for a closer analysis of the thermodynamic and kinematic environment over southern Minnesota at temporal and spatial scales that was not possible in 1998. The simulation not only provided a more complete picture of how mesoscale conditions evolved throughout the event, but also provides a glimpse at how high resolution simulations (and potentially ensembles) can potentially provide similar information in near real time in 2008 and beyond. The simulation consisted of three domains, nesting from 27 km to 9 km to 3 km. Evaluation of the output on the 27 km grid showed that the large scale conditions were accurately simulated, based on comparisons with the basic mass fields at 850 hPa, 700 hPa, 500 hPa, and 250 hPa (see **Figure 3,** at left). Surface conditions were also accurately simulated, based on comparisons of sea-level pressure, 10 m winds, temperature, and dewpoint (see **Figure 4**, above). Given the accurate simulation of larger scale conditions, there was a fair degree of confidence in higher resolution information on the 9 km and 3 km grids. An evaluation of several near storm environmental parameters commonly used to assess the potential for supercell tornadogenesis indicated atmospheric conditions were highly favorable for the development of tornadoes across southern Minnesota during the mid-late afternoon hours.

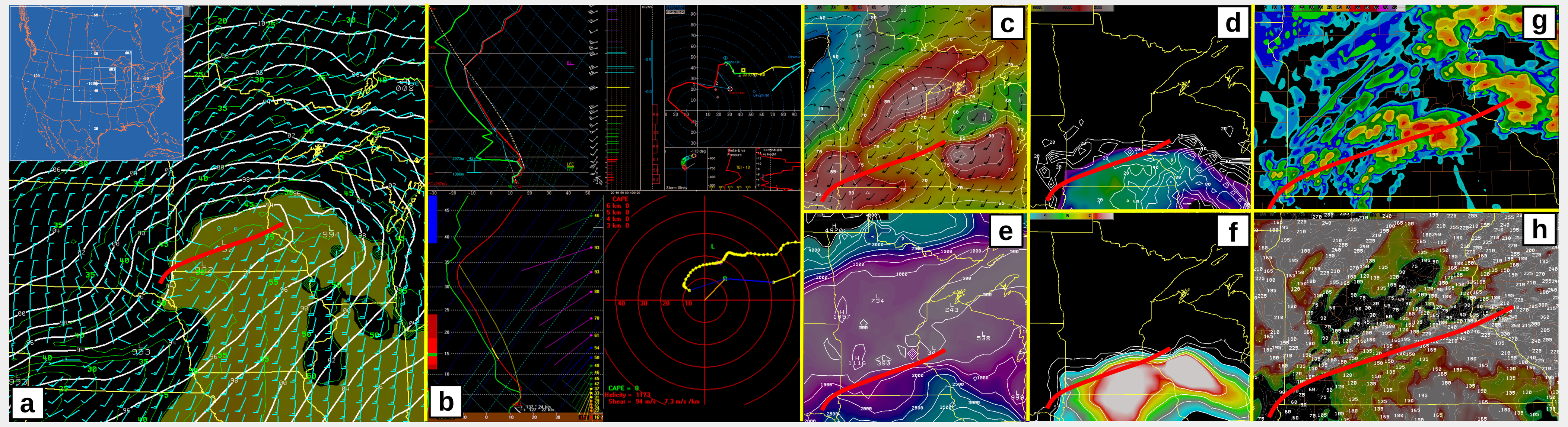

Figure 6. a) 12-hour forecast (27 km resolution) valid 0000 UTC, sea-level pressure (white contours), 10 m wind (cyan barbs), dewpoint (shaded), inset illustrates model domains. Compares well with the analysis valid at the same time in figure 4; b) KMPX observed 1800 UTC skew-t and hodograph (top), and forecast 1800 UTC KMPX skew-t and hodograph (bottom). Forecast thermodynamic and kinematic profiles closely match observation; c) Forecast (27 km) valid 2300 UTC 0-6 km bulk shear (shaded) and 0-1 km bulk shear (black barbs). Deep layer shear in excess of 70 kt present, and low-level shear of around 30 kt exisits; d) Forecast (27 km) valid 2300 UTC MLCAPE (shaded) and MLCIN (white contours). MLCAPE of 1500-2000 JKg^{-1} present, with MLCIN of 0-20 JKg^{-1}; e) Forecast (27 km) valid 2300 UTC MLLCL (shaded and white contours). MLLCL ~1000 m agl; f) Forecast (27 km) valid 2300 UTC Significant Tornado Parameter (shaded and white contours). Sharp STP gradient along warm front with STP values in excess of 4 in the warm sector; g) Forecast (3 km) valid 2100 UTC composite reflectivity (shaded). Overall character and mode captured reasonably well; h) Forecast (3 km) valid 2200 UTC 0-1 km SRH (shaded and white contours). Localized ribbon of higher values (in excess of 200 s^{-1} present near warm front); Red line on all images depicts approximate observed track of the tornadic supercell.