

Synoptic and Mesoscale Analysis of the Forcing Mechanisms Behind the 11 August 1999 Salt Lake City Tornado

ADAM VARBLE

Department of Atmospheric and Oceanic Sciences, University of Wisconsin-Madison, Madison, Wisconsin

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ABSTRACT

On August 11, 1999, a climatologically rare tornado touched down in downtown Salt Lake City and move northeastward between 1841Z and 1855Z before it dissipated just northeast of the city. During 10 of the 14 minutes that the tornado was on the ground, it was classified as a F2 with winds between 113 and 157 miles per hour. The tornado caused one death, over 80 injuries, and over \$170 million in damage. Synoptic lift due to an upper level trough and jet and vertically differential temperature advection destabilized the troposphere. By 18Z over the Salt Lake Basin, lifted indices had dropped to around -4°C , CAPE ranged between 1000 and 2000 J kg^{-1} , and 850-400 mb shear was about 35 knots. A convergence zone caused by a combination of orography, the Great Salt Lake lake breeze, and a pressure trough provided the low level lifting mechanism needed to initiate free convection. The tornado was not classical in that it was non-descending. It formed along the convergent boundary just south of the lake near downtown Salt Lake City where the boundary had become distorted by the mesocyclone circulation, causing an enhanced region of cyclonic vorticity to form along the boundary in Salt Lake City. When the updraft became superimposed over this region of vorticity, it stretched the vorticity vertically producing a non-descending tornado.

Introduction

Around midday on August 11, 1999, a climatologically rare F2 tornado, having winds between 113 and 157 miles per hour, developed just west of downtown Salt Lake City, Utah. As a F2, the tornado stayed on the ground from 12:45 PM to 12:55 PM MDT (1845Z to 1855Z). From F0 to F2 status, it stayed on the ground for approximately 14 minutes while traveling approximately four and one quarter miles uphill. The change in elevation was 1095 feet, starting at 4,225 feet and ending at 5,320 feet. A tornado warning was never issued for Salt Lake City because tornadic signatures were very difficult to pick up on the elevated radar well to the north of the city. Analysis of observations as well as

model data indicates that this was a non-descending tornado that formed along a surface boundary manipulated by the mesocyclone circulation. Overall, the tornado caused one death, over 80 injuries, and \$170 million in damage.

This tornado was one of only seven that were observed at F2 or greater strength in Utah from 1950-1999 (Dunn and Vasiloff, 2001). Utah has one of the lowest incidences of tornadoes in the entire nation, reporting only 121 tornadoes and 22 waterspouts from 1950 to 2005. The actual number of incidences is thought to be much higher, however, as much of the state is scarcely populated. This is shown in the fact that the number of tornadoes reported has increased as the population of the state has increased. The tornado formed on August 11, 1999, was a result of several

factors. Severe weather parameters were high due to synoptic conditions that had destabilized the atmosphere. Low to mid level moisture was also relatively high due to rainfall on the previous day (Dunn and Vasiloff, 2001). A mesoscale convergent boundary provided the essential low level mechanism that helped low level air reach free convection. A coupling of mesoscale circulations caused by the lake and supercells led to an enhanced region of vorticity that produced the tornado.

Data

Several sources of information are used to analyze this event between 12Z and 19Z on August 11, 1999. RUC model gridded model data is used in conjunction with surface observations, atmospheric soundings, GOES satellite data, and NEXRAD radar data. TDWR radar data is also examined. The surface observations are taken from MesoWest, managed by the University of Utah. The model data is important for examining synoptic vertical motion forcings as well as positioning of varying air masses. Surface observations show mesoscale vertical motion and rotational forcings. Severe weather potential is analyzed through the atmospheric soundings. Lastly, severe weather signatures are examined in both satellite and radar data.

Synoptic Overview

The synoptic picture on August 11, 1999 was dominated by a significant upper level negatively tilted trough axis over eastern Oregon and central Nevada. The synoptic lift associated with this trough and the jet positioned on the eastern side of the trough played a role in forcing the initiation of convection.

Vertically differing temperature advection also played a role in destabilizing the atmosphere at mid levels. To show the progression of these features, the conditions at 12Z and 18Z are analyzed. Thunderstorms were initiated around 1740Z and passed through the Salt Lake City area about an hour later.

A. 12Z Conditions

At 12Z on August 11, 1999, there was a prominent upper level trough situated over the western United States with a ridge to the east over the eastern portion of the Rocky Mountains and the Great Plains (Figure 1(a)). There was a jet streak located just to the east of the trough at 250 mb that focuses upper level divergence downstream of the trough toward the left exit region of the jet (Figure 1(a)). Although the maximum wind speed in the jet remained below 100 knots, it was compact and situated directly over western Utah at this time frame. In addition to acting as a vertical motion forcing mechanism, this jet provided significant shear and a north-south aligned baroclinic zone at mid levels. The baroclinic zone was important in aiding cold air advection at mid levels.

The trough was also visible at 500 mb in Figure 1(b) although the geopotential height contours exhibited wiggles that were likely due to the interaction of the mean flow with the mountainous terrain. Because of interaction with the terrain and because the lowest geopotential heights were cut off in the trough, the vorticity field was not balled up in a characteristic manner at the base of the trough. At this time frame, the absolute vorticity took on an elliptical shape with maxima over

eastern Oregon and southern Nevada (Figure 1(b)). The vorticity advection by the 300 mb to 700 mb thermal wind is plotted in Figure 1(b). The primary feature to note is the U-shaped area of positive vorticity advection over northern Utah, northeastern Nevada, and south-central Utah (Figure 1(b)).

Positive vorticity advection by the thermal wind is occurring over northern Utah, but it is not enough to induce precipitation. Between 12Z and 18Z, this synoptic lift helps cool mid levels along with the vertically differential temperature advection.

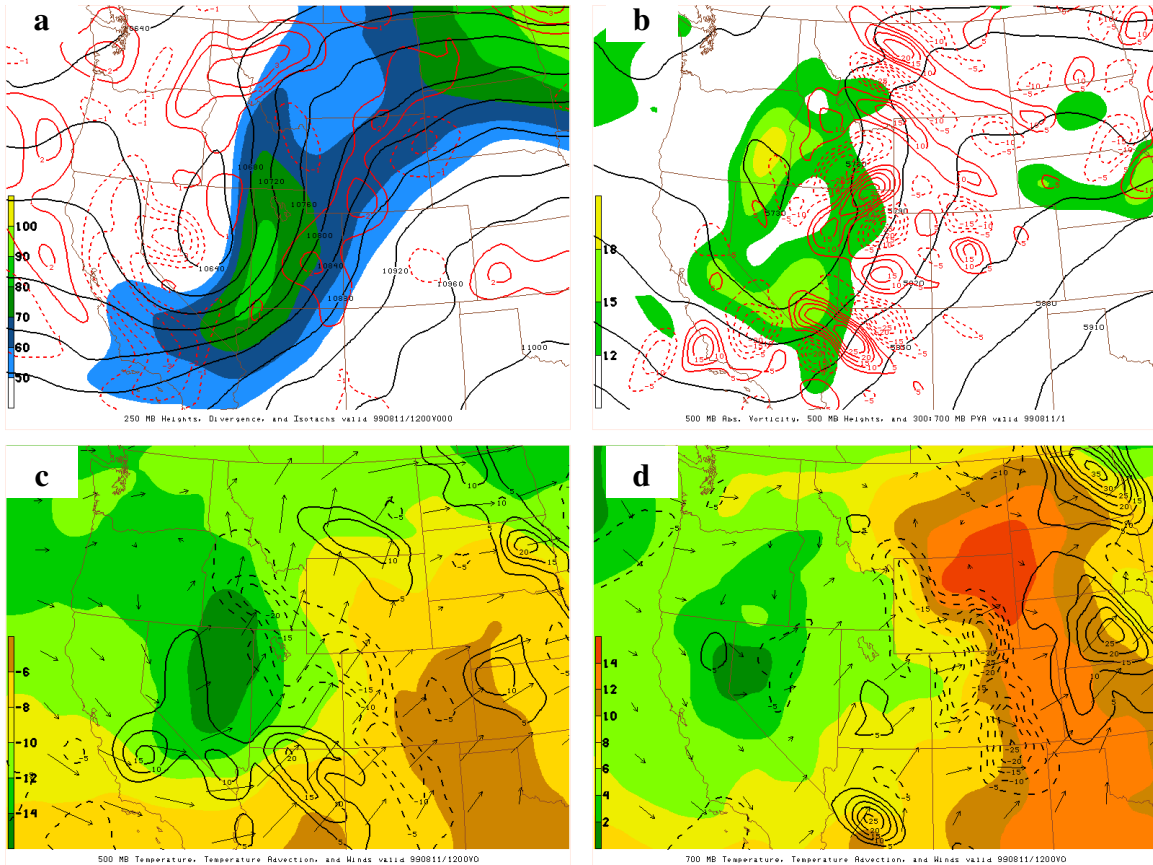


Figure 1: 12Z 11 August 1999 synoptic conditions from the RUC zero hour forecast: (a) 250 mb geopotential heights (black contours), isotachs (color filled), divergence (solid red contours), and convergence (dashed red contours); (b) 500 mb geopotential heights (black contours), absolute vorticity (color filled), positive vorticity advection by the thermal wind (solid red contours), and negative vorticity advection by the thermal wind (dashed red contours); (c) 500 mb temperature (color filled), wind vectors, positive temperature advection (solid black contours), and negative temperature advection (dashed black contours); (d) 700 mb temperature (color filled), wind vectors, positive temperature advection (solid black contours), and negative temperature advection (dashed black contours).

To get strong thunderstorms, the atmosphere needs to be destabilized at mid levels to increase CAPE. This was accomplished over northern Utah through significant cold air advection at mid levels and slight warm air advection

below the strong cold air advection. The 500 mb temperature and wind vector fields are plotted in Figure 1(c) with temperature advection contoured. At 12Z, there was strong cold air advection over all of northern Utah associated with

the eastward movement of the upper level trough. At 700 mb, the cold air was further to the west with the strongest

baroclinic zone to the east. This allowed warm air advection to occur over Utah, shown in Figure 1(d).

B. 18Z Conditions

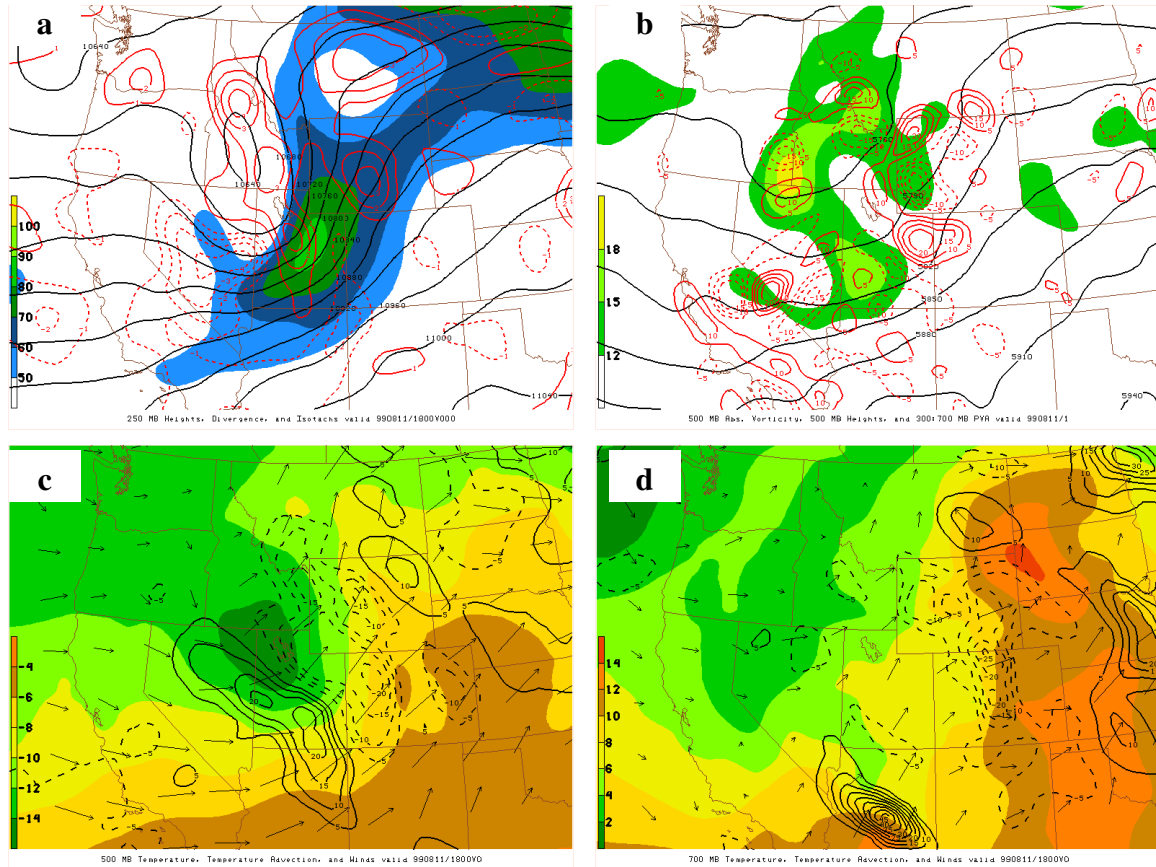


Figure 2: 18Z 11 August 1999 synoptic conditions from the RUC zero hour forecast: (a) 250 mb geopotential heights (black contours), isotachs (color filled), divergence (solid red contours), and convergence (dashed red contours); (b) 500 mb geopotential heights (black contours), absolute vorticity (color filled), positive vorticity advection by the thermal wind (solid red contours), and negative vorticity advection by the thermal wind (dashed red contours); (c) 500 mb temperature (color filled), wind vectors, positive temperature advection (solid black contours), and negative temperature advection (dashed black contours); (d) 700 mb temperature (color filled), wind vectors, positive temperature advection (solid black contours), and negative temperature advection (dashed black contours).

By 18Z on August 11, 1999, the upper level trough had migrated to the east and was centered over Idaho and western Utah (Figure 2(a)). The 250 mb jet streak also moved slightly eastward, and significant divergence was occurring over central and northern Utah, shown in figure 2(a). To the south of the Great

Salt Lake, this divergence was coupled with significant vertical shear due to the jet. The absolute vorticity field at 500 mb no longer had an elliptical shape, but had taken on a U-shape with the maximum vorticity over the intersection of Oregon, Idaho, and Nevada (Figure 2(b)). Two areas of positive vorticity

extended southeastward from this max, one over western Wyoming and one over western Utah. The positive vorticity over western Utah was aiding positive vorticity advection by the 300 mb to 700 mb thermal wind over northeastern Utah, shown in Figure 2(b). This positive vorticity advection by the thermal wind combined with the divergence associated with the upper level trough and jet streak was providing significant synoptic lift over northern Utah during this time frame.

In addition to the synoptic lift, the atmosphere was continuing to be destabilized at mid levels due to differential temperature advection. The coldest air at 500 mb associated with the upper level trough had just about centered itself over northern Utah at this time frame, shown in Figure 2(c). At 700 mb, the air over northern Utah had warmed slightly. The cold air was still far to the west and winds were southerly at the surface as opposed to southwesterly at upper levels. This differential temperature advection that occurred between 12Z and 18Z increased the lapse rate at mid levels and destabilized the atmosphere there.

Mesoscale Analysis

The synoptic scale pattern over the western United States provided a destabilized middle troposphere with upward vertical motion over northern Utah. It was a mesoscale convergence zone just south of the Great Salt Lake that provided the low level lifting mechanism that spawned the thunderstorms. RUC data shows the presence of this convergent zone, and there are several mechanisms that may have contributed to the presence of this zone. In addition, RUC data also shows unusually high moisture and low temperatures for this time of year in Salt Lake City. Combined with severe weather parameters, there was clearly enough support for the development of severe weather given an initial forcing mechanism. Lastly, satellite and radar data clearly show signatures of strong thunderstorms with the presence of a mesocyclone and possible tornado. A tornado did in fact develop along the convergence boundary and its track and picture are shown in figure 3(a) and 3(b).

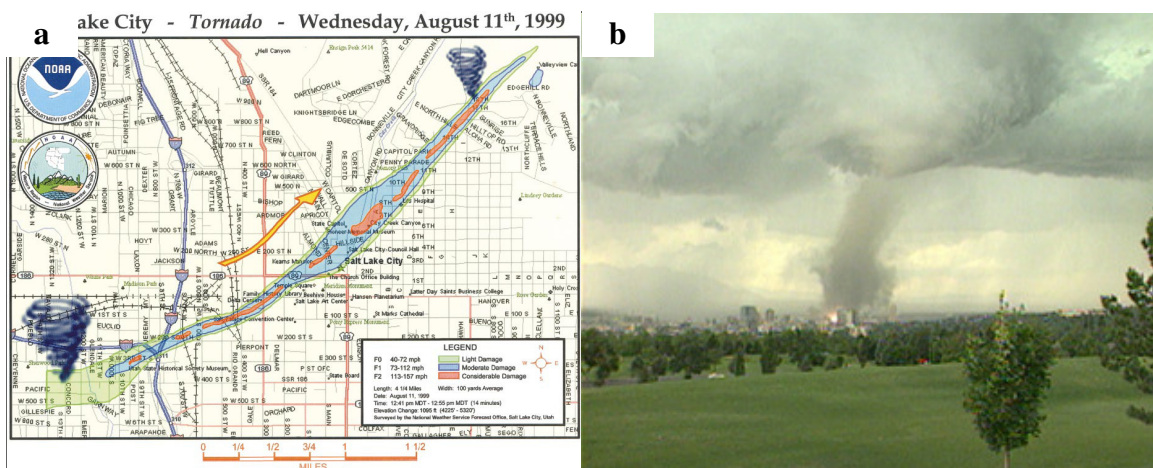


Figure 3: (a) National Weather Service estimated track and strength of the tornado based upon damage assessments and (b) a photograph of the tornado as it passes through downtown Salt Lake City (National Weather Service).

A. Convergence Zone

The most important factor to initiating severe weather was the low level lifting mechanism. Southerly flow throughout the day had brought warm and drier air into the Great Salt Lake area by 18Z, shown in figure 4(a) and (b). The intrusion of this drier air at the surface meant that the lifted condensation level was heightened during the day. This air, although drier than at 12Z, was still relatively moist for a summer day in the intermountain western United States. At 18Z, a strip of moisture convergence at 850 mb aligned

northwest to southeast was moving toward the Great Salt Lake. It is important to note that 850 mb approximates the surface of the basin in which Salt Lake City is situated. 700 mb approximates the level of the mountain tops of the ranges to the east, the Wasatch Mountains, and west, the Oquirrh Mountains, of the basin. The moisture convergence was likely not large enough to lift the surface air to the LCL, but over the Oquirrh Mountains and the Great Salt Lake, the temperature was likely much closer to the dewpoint. In these regions, the lifting would not have had to be as great.

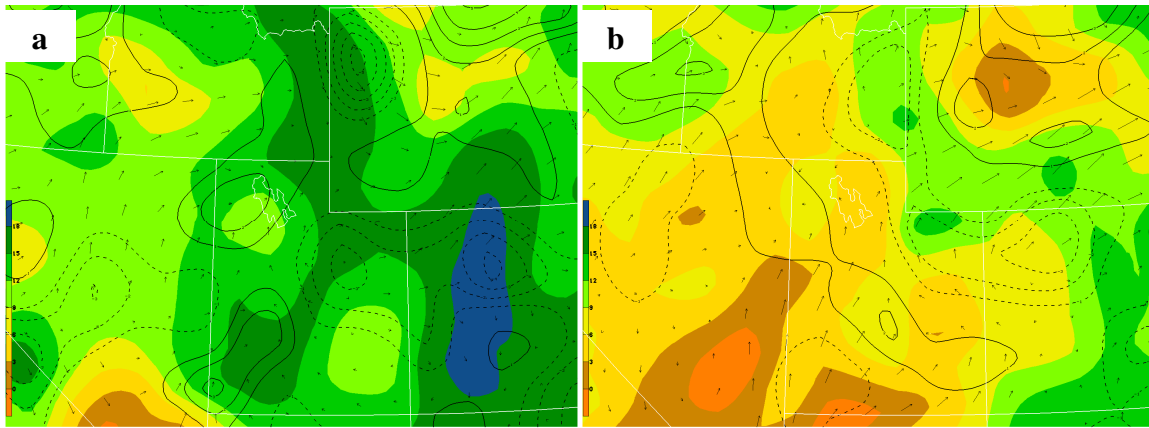


Figure 4: RUC model zero hour forecast of 850 mb dewpoint temperature and moisture convergence for (a) 12Z 11 August 1999 and (b) 18Z 11 August 1999.

The convergent zone is much more obvious in the ten meter height above ground level streamline analysis at 18Z in Figure 5. There is a pressure trough that extends from a low pressure center in central Wyoming southwestward into northwestern Utah. This trough produces a stretching deformation zone in this region that is visible in Figure 5. In addition to this confluent zone, the complex orography of the intermountain western United States and the lake breeze circulation associated with the Great Salt Lake aid in the production of converging air flow

around the Great Salt Lake. During the daytime, the basin heats along with the slopes of the surrounding mountain ranges. This induces a thermal upslope circulation leading to a chimney effect at the top of the mountain range ridgelines, where air is forced upward. The initiation of convection along the Oquirrh Mountains may have been partially caused by this process.

In addition to orographic effects on producing low level convergence, the lake breeze caused by the thermal contrast between the Great Salt Lake and the surrounding land was observed on

August 11, 1999. The lake breeze system is very common during the summer in Salt Lake City. The University of Utah operates a large surface observational array system called MesoWest that regularly picks up the lake breeze front. At 18Z, this network showed that the lake breeze had progressed slightly southward of the lake with winds out of the north behind the lake breeze front. South of the front,

winds were out of the south throughout the basin. One thunderstorm cell formed along this boundary north of the Oquirrh Mountains in addition to the cell that formed over the Oquirrh Mountains. The convergent zone along this lake breeze front was very important in producing the thunderstorm that caused a tornado in Salt Lake City. This convergent zone is further discussed in section E.

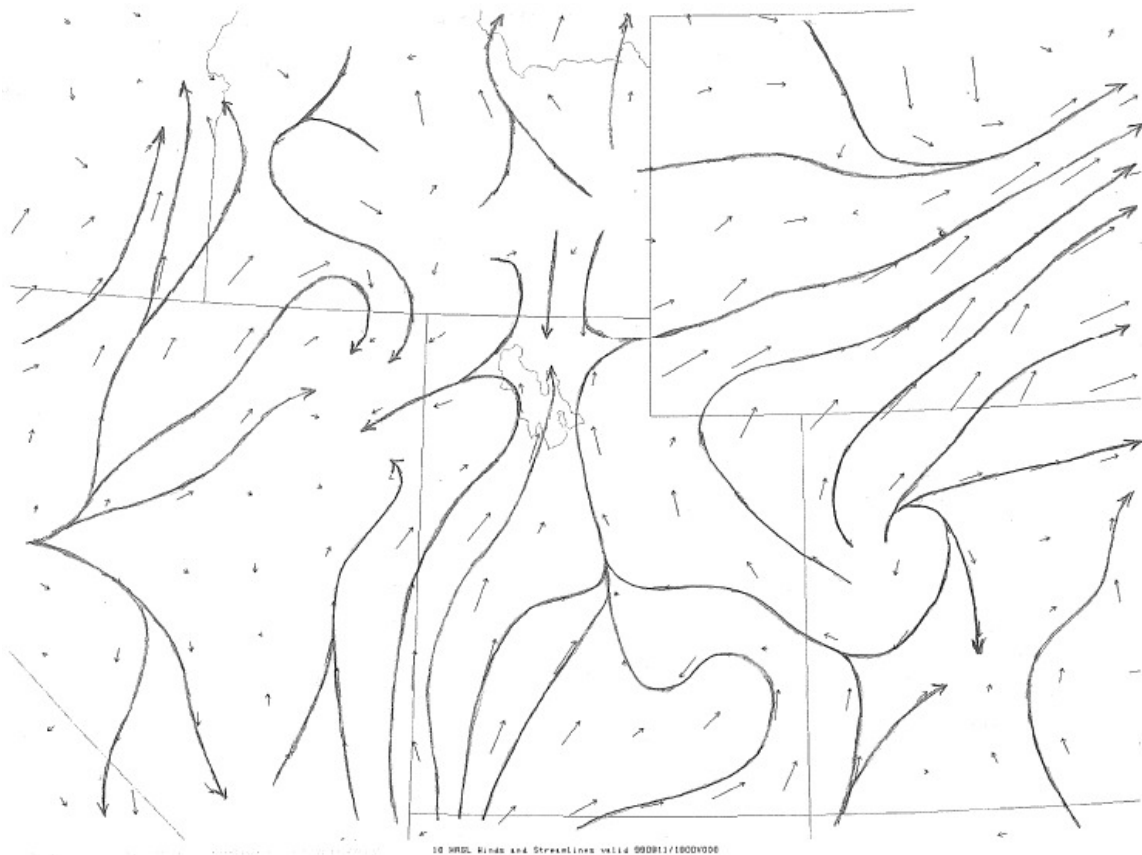


Figure 5: 10 meters above ground level wind vectors and streamlines valid at 18Z 11 August 1999.

B. Atmospheric Soundings

A cross section, shown in Figure 6, taken from Boise, Idaho to Salt Lake City, Utah to Grand Junction, Colorado at 18Z on August 11, 1999 shows the convection around the Salt Lake City area as equivalent potential temperature contours go from the surface all the way

to the tropopause around 300 mb. The jet streak to the east of the convection causes significant vertical shear in the vicinity of the thunderstorms, also noted in the soundings in figure 7. The left exit region of the jet causes divergence aloft, which helps the thunderstorm

outflow and allows the thunderstorms to live and strengthen.

The RUC model derived soundings in Figure 7 show that the atmosphere was very moist for this time of year at low to mid levels at 12Z. Six hours later, the air at the surface and at mid levels was drier, but a layer of

relatively moist air remained around 700 mb. Despite the increase in dryness, the air was still more moist than usual.

Some of the residual moisture may have been a result of rain that had fallen the previous day in the Salt Lake City area (Dunn and Vasiloff, 2001).

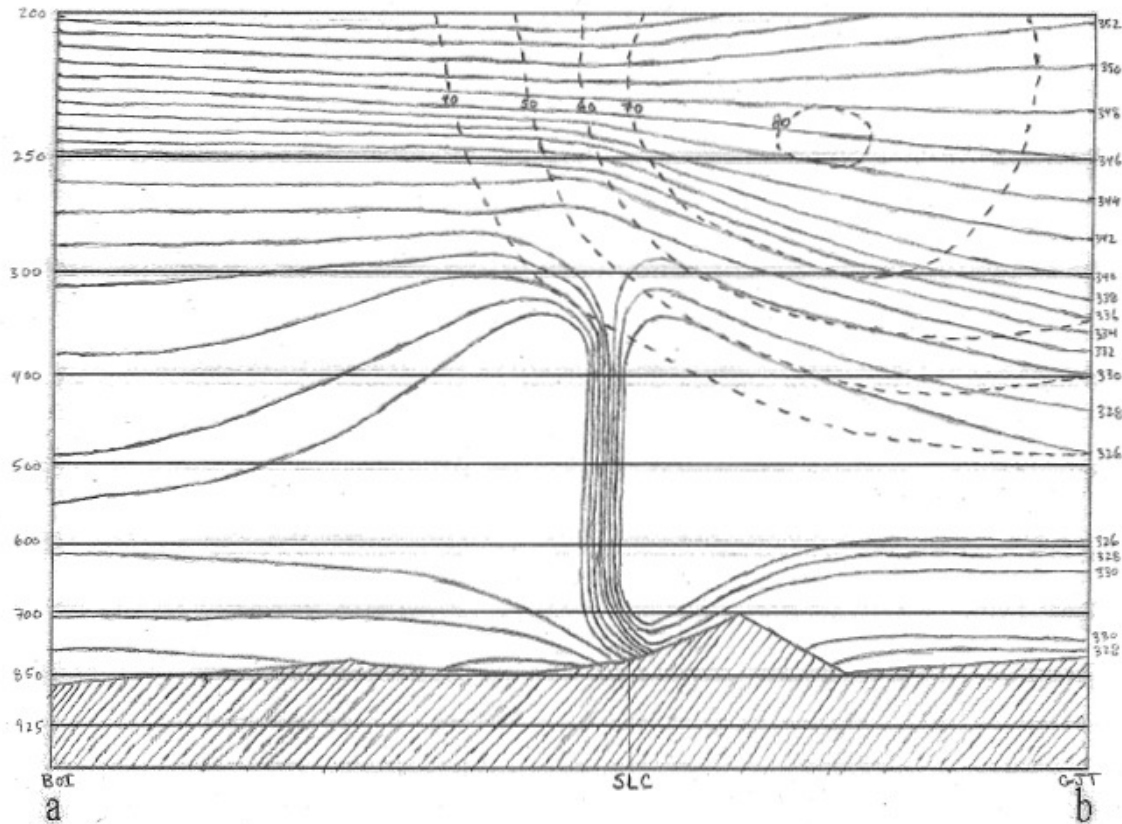


Figure 6: Cross section of equivalent potential temperature (solid contours every 2 K) and isotachs (dashed contours every 10 knots greater than or equal to 40 knots) from Boise, Idaho (left) through Salt Lake City, Utah to Grand Junction, Colorado (right) valid at 18Z 11 August 1999.

The LCL and LFC became heightened between 12Z and 18Z, but synoptic and mesoscale forcing mechanisms not present at 12Z were coming together at 18Z in an environment that was still favorable for convective development because of the conditionally unstable lapse rates at mid levels. Comparison of these soundings shows that the temperature at 700 mb had slightly increased due to warm air

advection and the temperature at 500 mb had decreased due to cold air advection. The veering of winds in the lower troposphere and backing of winds in the upper troposphere in Figure 7(a) shows this differential advection well. Temperatures at 500 mb cooled by about three degrees Celsius during this six hour period, which made the lifted index more favorable for thunderstorm development. Despite the decrease in

moisture, the CAPE remained at high enough levels for convective development due to differential temperature advection. The wind

vectors also showed moderate shear that balanced the CAPE in leading to supercell formation.

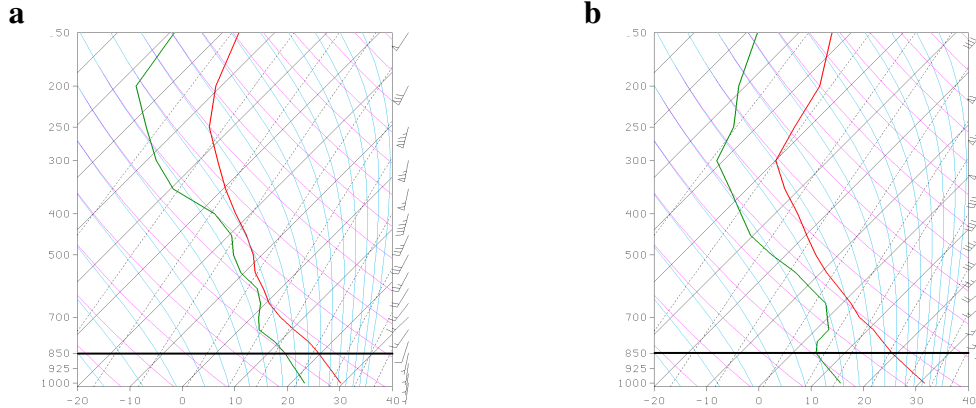


Figure 7: RUC model zero hour forecast derived soundings for Salt Lake City valid at (a) 12Z and (b) 18Z 11 August 1999. Temperature is contoured in red, dewpoint is contoured in green, and the black line shows the approximate level of the surface.

C. Severe Weather Parameters and Surface Observations

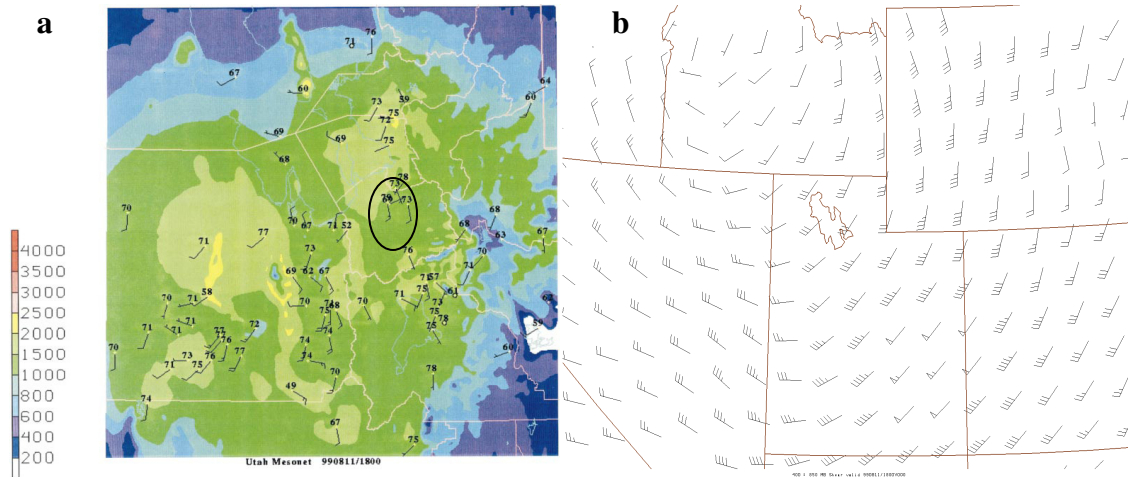


Figure 8: (a) Surface wind vectors and temperature from MesoWest overlaid with ADAS derived CAPE in the Salt Lake City area at 18Z 11 August 1999. The Salt Lake City metropolitan area is circled in black. (b) 850 mb to 400 mb shear vectors valid 18Z 11 August 1999.

Numerical values are attributed to CAPE and vertical shear in Figure 8. CAPE in Figure 8(a) is derived from the Utah Advanced Regional Prediction System Data Analysis System (ADAS), a mesoscale regional model ran at the University of Utah. The ADAS plot shows CAPE values ranging from 1000

to 2000 J kg^{-1} throughout the basin surrounding Salt Lake City. The magnitude of the vector vertical shear between 850 mb and 400 mb is also significant, as shown in Figure 8(b). These levels are used in the intermountain West instead of the 0-6 km shear measure commonly used east

of the Rocky Mountains. RUC data shows 35 knot shear between these two levels. Surface observations provided by MesoWest in Figure 8(a) show winds predominantly out of the south in the basin south of the Great Salt Lake with a few measurements just south of the

Great Salt Lake shoreline having winds out of the north. This is the lake breeze front discussed earlier. The Salt Lake City area is circled in black. Just southwest of the circled area is the location of the Oquirrh Mountains where thunderstorms initiated.

D. Satellite Analysis

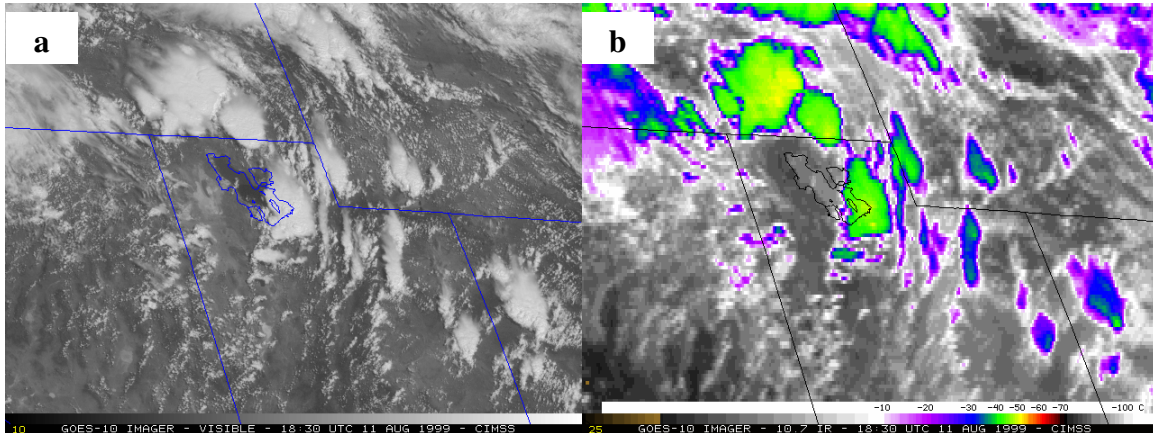


Figure 9: GOES-10 West images valid at 1830Z 11 August 1999 centered over northern Utah. The visible channel is shown in (a) and the 10.7 μm infrared channel is shown in (b) (CIMMS).

Figure 9(a) shows a visible image of the thunderstorms at 1830Z just before they hit Salt Lake City. Within the sheared off anvil, the strong updrafts of the storms are represented by overshooting cloud tops. The 10.7 μm infrared image shows these cloud tops have a brightness temperature of between -45°C and -50°C . The model derived sounding in figure 7(b) shows that the approximate temperature of the tropopause at 18Z was -40°C , which is the approximate brightness temperature of the sheared off anvil. Brightness temperature is not equivalent to temperature, but it can often be used as an estimate. In this case, the overshooting tops appear significantly cooler than the surrounding environment represented in the sounding. This provides evidence that the updraft within these supercells was strong. Satellite

derived lifted indices produced by CIMSS showed increasing destabilization between 12Z and 18Z over northern Utah with lifted indices reaching around -4°C by 18Z. Satellite derived CAPE was also over 1000 J kg^{-1} at 18Z, and total precipitable water was estimated at 20 mm over the Great Salt Lake region, enough to support heavy precipitation.

E. Radar Signatures

Much of the analysis up to this point has been focused on the factors leading to thunderstorm development, but has not focused on specific characteristics of the supercells themselves. One of the best ways to analyze thunderstorm structure and determine the severity of a thunderstorm cell is through radar data. The National

Weather Service operational NEXRAD radar is located at Promontory Point on a peninsula that sticks out into the Great Salt Lake and carries the site ID KMTX. One of the major problems with the radar site is that it is positioned 6,460 feet above sea level, which is over 2,000 feet higher than Salt Lake City. Being approximately 41 miles from Salt Lake

City, this means that the lowest level that the radar sensed at the location of the tornado was about 4300 feet above the surface (Dunn and Vasiloff, 2001). This radar is useful for analyzing the evolution of the supercells and the convergence zone just south of the Great Salt Lake, but is not useful for analyzing the tornado.

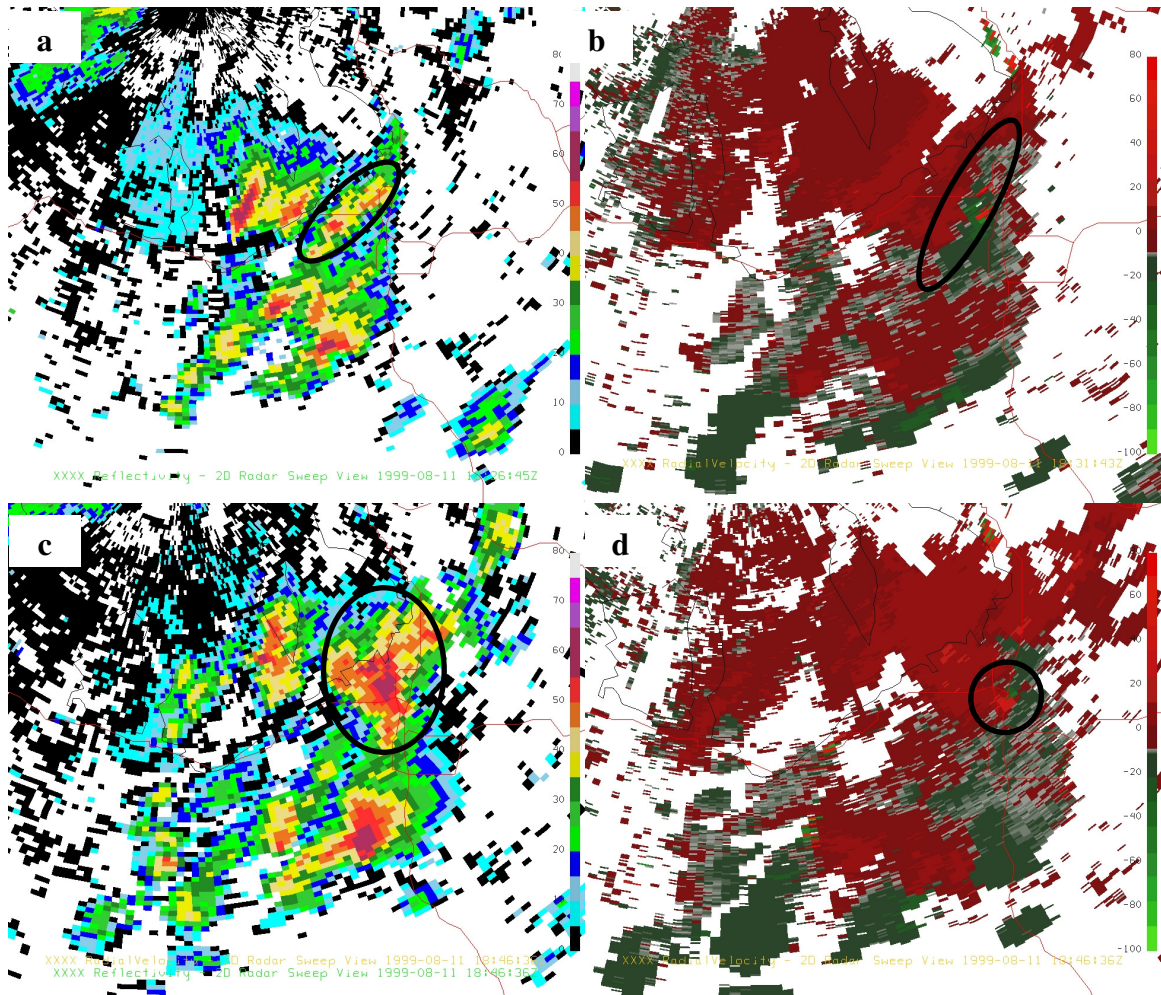


Figure 10: KSMTX NEXRAD radar data showing the progression of the thunderstorms through base reflectivity and base radial velocity: (a) 1826Z base reflectivity, (b) 1831Z base radial velocity, (c) 1846Z base reflectivity, and (d) 1846Z base radial velocity.

A Terminal Doppler Weather Radar (TDWR) is located about 12 miles north of Salt Lake City and is much more useful in analyzing the tornado. This radar uses a wavelength and beam width that are half that of the WSR-88D KMTX radar. It

also scans at more elevation angles due to the decreased beam width. The lowest elevation angle of this radar scanned about 500 feet above the surface at the location of the tornado (Dunn and Vasiloff, 2001) with much greater resolution than the

KMTX radar. Data from both radar sites is used in analysis of the evolution of the supercell, the convergent boundary south

of the Great Salt Lake, and the development of the tornado.

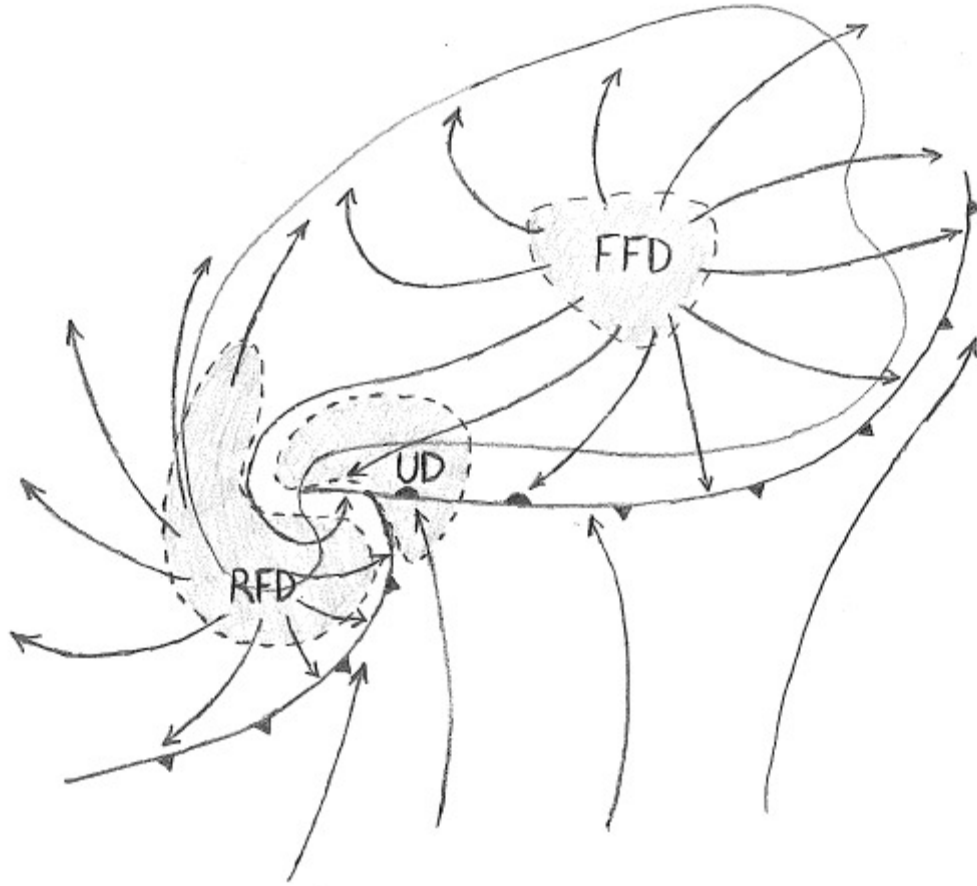


Figure 11: Top-down conceptual model of a supercell thunderstorm, showing its updraft (UD), forward flank downdraft (FFD), and rear flank downdraft (RFD) as represented by Lemon and Doswell (1979).

Data from the KMTX radar site is shown in Figure 10. Figure 10(a) shows the beginning stages of the cell that will eventually produce the tornado, circled in black. It starts out as a linear reflectivity feature that is aligned along the convergent boundary shown in Figure 10(b). Prior to the formation of this cell, there were two other supercells that had formed. One cell is shown to the west of the circled cell and one cell is shown to the south of the circled cell in Figure 10(a). These two thunderstorms were the first to initiate around 1740Z in the vicinity of the

Oquirrh Mountains. The outflow boundaries from these two thunderstorms may have interacted with each other and the lake breeze convergent boundary to initiate the thunderstorm circled in Figure 10(a) at 1826Z. The supercell to the south continued to strengthen and went on to produce one and a half inch hail in the southwest suburbs of Salt Lake City.

The circled supercell strengthened quickly and by 1846Z (Figure 10(c)), the F2 tornado was already on the ground and moving northeastward with the thunderstorm. The supercell does not

exhibit the classic comma reflectivity shape associated with a tornadic supercell, but this is partially a result of the poor resolution of the WSR-88D radar. The rotation of the mesocyclone is visible in the radial velocity image in Figure 10(d). The red colors represent velocities radially away from the radar and the green colors represent velocities radially toward the radar. The couplet of bright red and green circled in Figure 10(d) represent the cyclonic rotation associated with the supercell. Although the base reflectivity and radial velocity are shown in Figure 10, it is important to remember that this data represents the structure of the thunderstorm approximately 4,300 feet above the surface. Because the WSR-88D radar at Promontory Point could not pick up the tornado vortex signature, a tornado warning was never issued for Salt Lake City. If operational forecasters would

have had access to the TDWR radar data, they would have clearly seen the presence of a tornado signature in both the reflectivity and radial velocity data.

A top-down conceptual model of a supercell is shown in Figure 11. The mesoscale fronts produced by the forward flank downdraft and rear flank downdraft became coupled with the lake breeze front in the supercell over Salt Lake City. The supercell distorted the convergent zone along this front as shown in the figure. A region of enhanced cyclonic vorticity was produced at the intersection of these two fronts. When the updraft became superimposed with this region as depicted in Figure 11, the vorticity was stretched vertically, which acted to tighten and strengthen the rotation at low levels. This led to the production of a F0 non-descending tornado that quickly strengthened to F2 status.

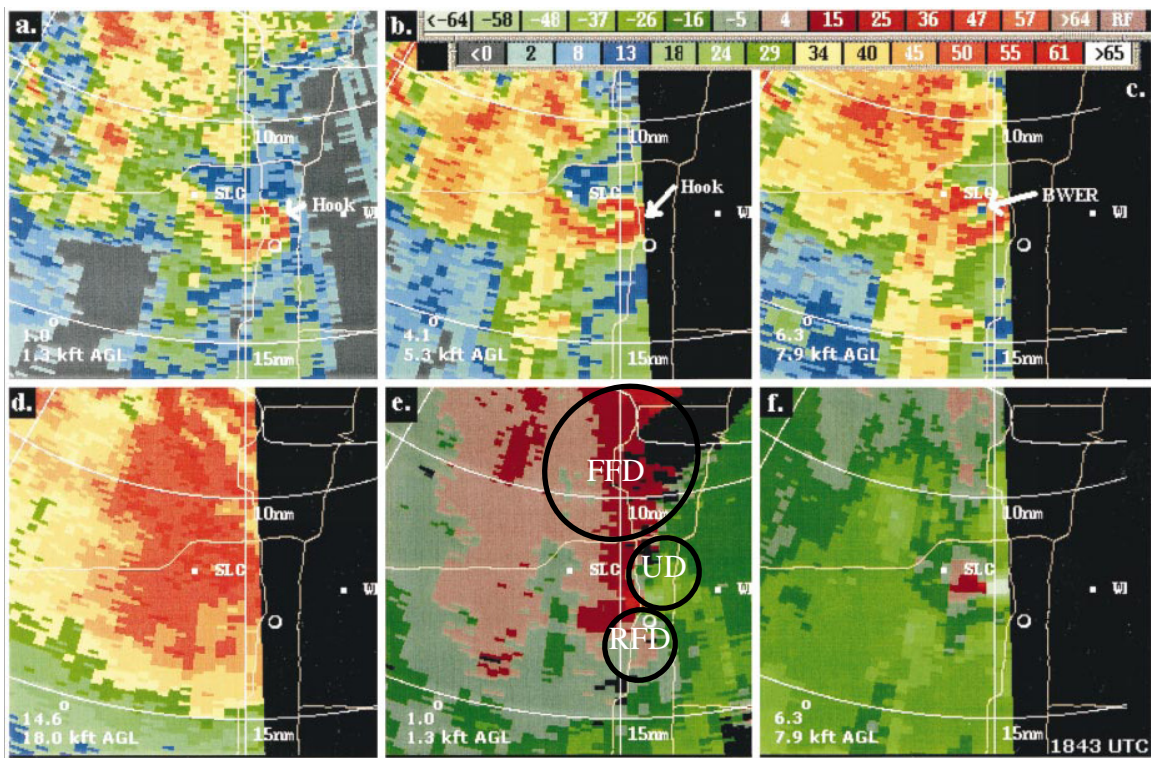


Figure 12: TDWR radar reflectivity and radial velocity data at 1843Z 11 August 1999: (a) 1.0° reflectivity, (b) 4.1° reflectivity, (c) 6.3° reflectivity, (d) 14.6° reflectivity, (e) 1.0° velocity, and (f) 6.3° velocity. Hook echo is identified in (a) and (b), and bounded weak echo region (BWER) is identified in (c) (Dunn and Vasiloff, 2001).

The presence of the tornado at 1843Z was clearly visible in the TDWR radar data shown in Figure 12. A characteristic hook echo can be seen in 12(a) and 12(b) at elevation angles of 1.0° and 4.1° . Figure 12(b) is at an elevation that the KMTX radar viewed the thunderstorm at, but the hook echo was not present in the KMTX data because of poor resolution. Figure 12(c) shows that the cyclonic circulation is still clearly visible at 7,900 feet above the surface, but is represented as a bounded weak echo region (BWER) instead of a hook echo. At 18,000 feet in figure 12(d), the bounded weak echo region is no longer visible. The radial velocity couplet is clearly visible at 7,900 feet height as well, shown in Figure 12(f). At this height, the rotation of the tornado is essentially separated from the downdraft region of the storm further to the north. At lower elevation angles such as the 1.0° angle, the cyclonic circulation of the mesocyclone overshadows the individual tornadic circulation. Nevertheless, Figure 12(e) shows the distortion of the convergent boundary into the shape shown in Figure 11, with a RFD, FFD, UD, and associated frontal boundaries. The peak gate to gate shear is in the vicinity of the tornado.

Conclusion

On August 11, 1999, a combination of several synoptic and mesoscale mechanisms lead to the development of several supercells and a tornado in Salt Lake City, Utah. Synoptically, an upper level trough caused upward vertical motion over northern Utah through positive vorticity advection by the thermal wind and

divergence downstream of the trough axis. A jet streak to the east of the trough further caused upper level divergence in its left exit region over northern Utah. Vertically differential temperature advection acted to destabilize mid levels between 12Z and 18Z. This destabilization countered the decrease in moisture at low levels. At 18Z, CAPE values over Salt Lake City were between 1000 and 2000 J kg^{-1} , 850 mb to 400 mb shear was 35 knots, and lifted indices were around -4°C .

A mesoscale convergence zone picked up in MesoWest surface observations and radar data provided the boundary that the tornadic supercell formed on. The initial convection was initiated in the vicinity of the Oquirrh Mountains possibly due to a combination of moisture convergence and a thermal upslope circulation. A thunderstorm also formed on the south end of the Great Salt Lake in the vicinity of the lake breeze front, behind which winds were out of the north in opposition to the southerly flow over the rest of the Salt Lake Valley. The outflow boundaries from the two initial cells may have coupled with the convergent boundary caused by the lake breeze circulation near Salt Lake City causing the initiation of the tornadic supercell. The supercell circulation enhanced and warped the sea breeze circulation making a small region of high cyclonic vorticity near the surface. When the updraft of the supercell became superimposed with this region of high cyclonic vorticity, it vertically stretched the vorticity which scaled down the rotation to produce a non-descending tornado. The tornado quickly strengthened to F2 status as the rotation tightened. The tornado moved

northeastward with the supercell for 14 minutes rising over 1,000 feet in elevation until the supercell updraft was cut off leading to the quick deterioration of the supercell and the tornado.

Acknowledgements

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the National Weather Service in Salt Lake City, Utah provided statistics about this tornado as well as others in Utah. Lastly, Professor Greg Tripoli and teaching assistant Holly Hassenzahl provided the education and guidance necessary to perform this analysis.

References

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