The Siren Tornado: Destruction in Northern Wisconsin

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Abstract

The Siren tornado is a somewhat classic case of the formation of a classic case supercell thunderstorm while also carrying some non-classical ideas of formation. A low level jet brings moisture into the affected area, with ambient directional and speed wind shear already located in the area. With daytime heating destabilizing an area with an already healthy mid-level elevated mixed layer, the setup for a severe thunderstorm outbreak was present, only requiring a force to break the boundary layer inversion cap. This forcing was a shortwave pressure trough located in the low to mid-levels of the atmosphere. A theory of tornadogenesis via local lake-induced dynamics is presented. What results is an F3 tornado, killing 2 and injuring over a dozen. The storm is classical in nature, demonstrating the capability of Doppler Radar to detect supercell characteristics, such as velocity coupling and hook echoes. It is because of these features that forecasters were able to protect the village of Siren, WI, from more deaths and injuries.

Introduction

While many atmospheric scientists focus most of their tornado research on the central Plains of the United States, tornadoes occur in many other places of the county. 49 of the 50 states average at least 1 tornado per year; however every state has experienced at least one in history. On the northern edge of "tornado alley," the state of Wisconsin has had its share of destructive tornadoes. Two (original Fujita scale) F5 tornadoes have occurred in the state, and numerous other F3 and F4 storms have affected the state. One such F3 tornado affected the northern portion of the state during the early hours of 19th June 2001. Hardest hit was the village of Siren, WI, a community of about 1000 (988 in the 2000 census). According to the National Weather Service Weather Forecasting Office (WFO) in Duluth, WI, "The most extensive damage was in a 6 block wide area in Siren, where numerous homes were leveled. There was also extensive structural damage to many buildings. The average width of the tornado was 1/8 to 1/4 mile, with the widest width being about a half mile. Preliminary indications are that the path length of the tornado was about 27 miles. Two people died as a direct result of the tornado, with another person killed indirectly after the tornado. In all, there were 16 injuries as a result of the tornado." The question remains, what was the cause of this storm, and how was it so strong?

The Siren tornado was forced by a multitude of synoptic and mesoscale forcings. A warm frontal passage placed the city in the "triple point" of a growing surface cyclone, and the storms were triggered by an approaching shortwave and the surface cyclone. This forcing was aided by a low level jet which advected moisture into the region behind the warm front throughout the day. Perhaps also aiding

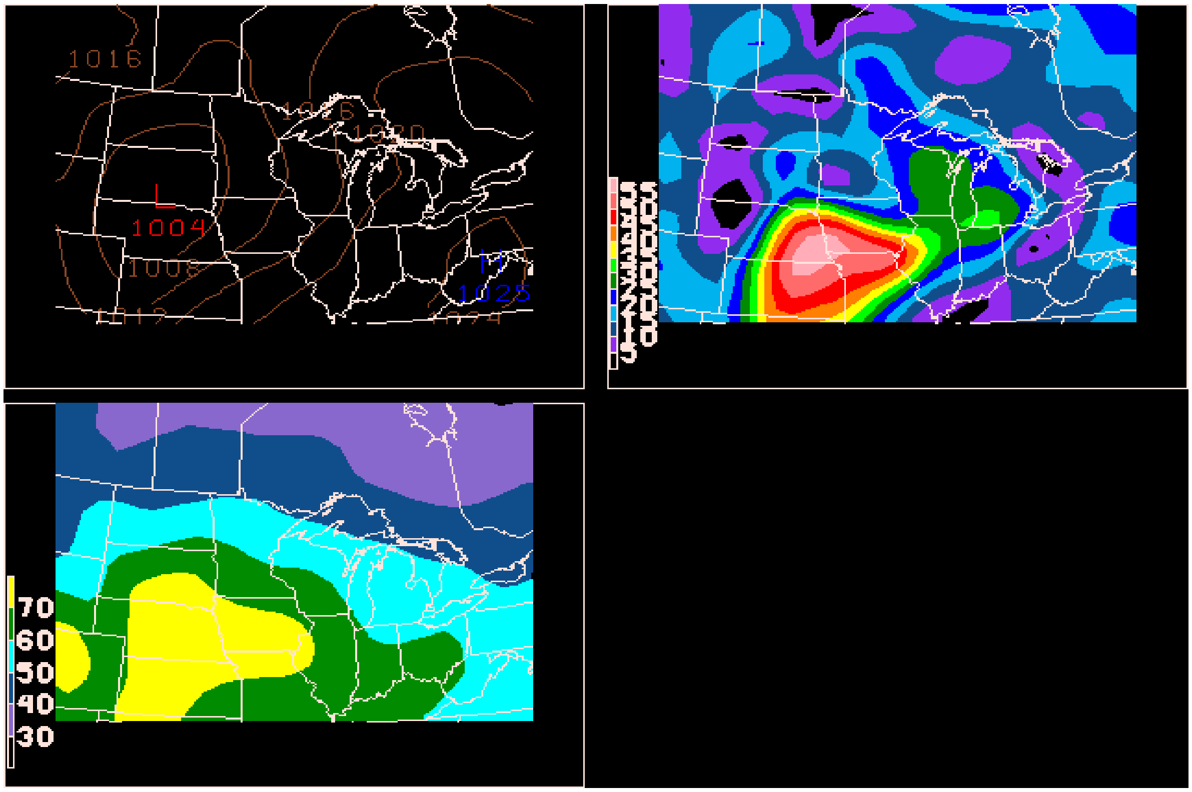

Figure 1 – A 3 panel plot for 12z on 18th June 2001 Eta model run. The upper left panel (a) is surface observations with high and low pressure centers and their central pressures noted, isobars every 4 millibars, upper right (b) is 900mb winds every 5 knots, and lower left (c) shows 850mb dewpoints every 10 degrees F starting at 30 degrees F. The low level jet produced warm moist air out ahead of the surface cyclone, which continued throughout the day.

aided by a low level jet which advected moisture into the region behind the warm front throughout the day. Perhaps also aiding supercell formation is a dew point and temperature contrast caused by Lake Superior. Also important to the system is the presence of an elevated mixed layer, which adds to the instability of the atmosphere. All of these features work in unison to create destruction for the village of Siren on this fateful night.

Data/Methods

First, to get a grip on the overall synoptic pattern of the system, Unisys Weather synoptic maps were used. These graphics provided an initial view into the dynamics of the cyclone which produced the tornado, such as the center of low pressure and location of the warm and cold fronts. Surface features are provided that are author-created. Also used during the study is the ETA analysis and model run from the 18 June 2001 at 12z. This is used to create maps showing upper dynamics such as the low level jet, and low-to-mid-level height fields. Wind barb maps are created using GEMPAK and GARP. No data was available for the ETA model analysis on 19 June 2001 at 0z. Soundings are attained from the University of Wyoming sounding website and are from the Minneapolis (MPX) sounding site. Radar and satellite data and pictures are compliments of CIMSS.

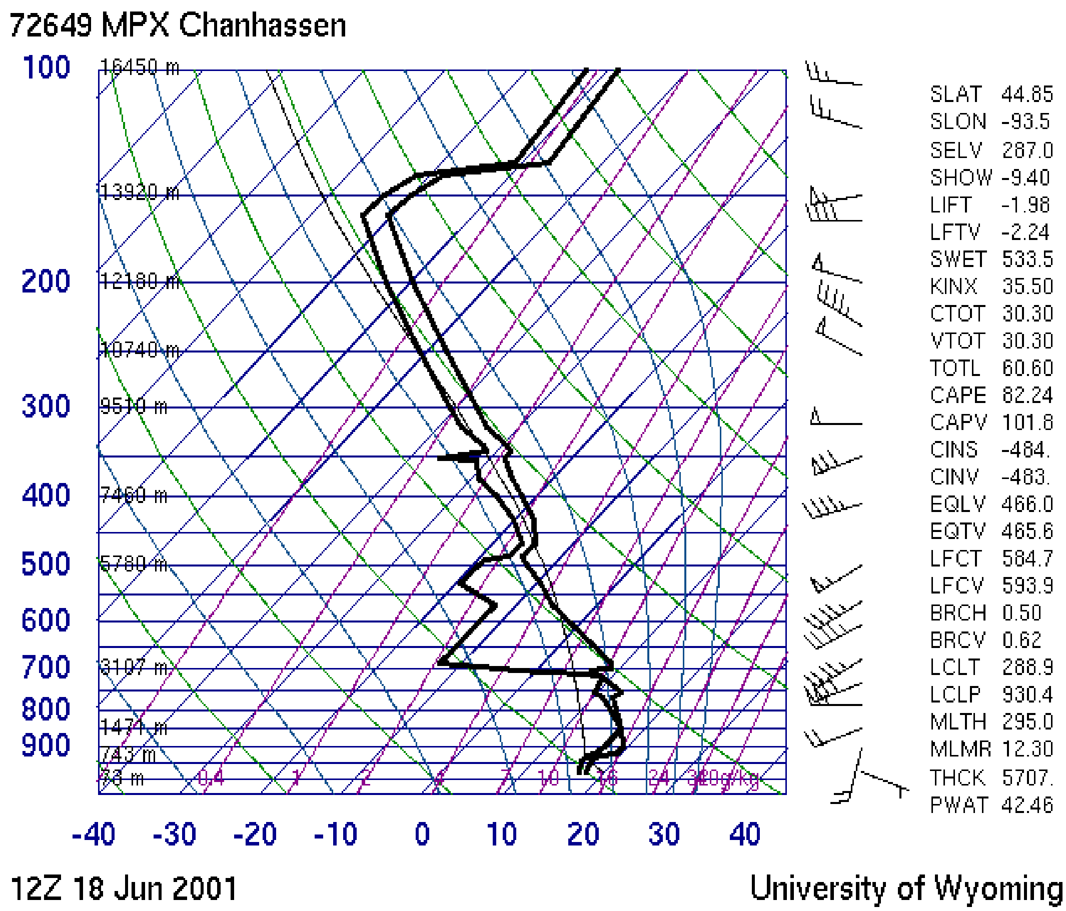

Figure 2 – The Minneapolis (MPX) sounding for 12z for 18th June 2001. Note the large inversion near the surface. Elements will become oriented correctly for a severe weather outbreak later in the day.

Synoptic and Mesoscale Overview: Morning - Building Blocks

The morning before the tornado began similar to other severe weather outbreak days. At 12z, a surface low with a central pressure of 1004mb located where the Missouri River forms the border between Nebraska and South Dakota was making its way east-northeast towards the region (Figure 1a, upper right). The pressure trough extending east from the center of the low's center is the warm front, which is located south of Siren, positioned across the Minneapolis-St. Paul metro area (MPX) towards the city of Eau Claire, WI (EAU). The cold front extends from the center of the low to the south-southwest, towards the southwest border region of Kansas and Nebraska. Cyclonic flow forced by the low would force air from the south into the region, where dew points were already in the high 50 to low 60 degrees F. Looking at 900mb winds, one can see a large maximum to the southwest of the affected region, with speeds in excess of 55 knots (Figure 1b, upper right). This jet maximum will move towards the affected region through the day, bringing more and more southerly air into the area. In association with this southerly air there is a copious amount of gulf moisture. This

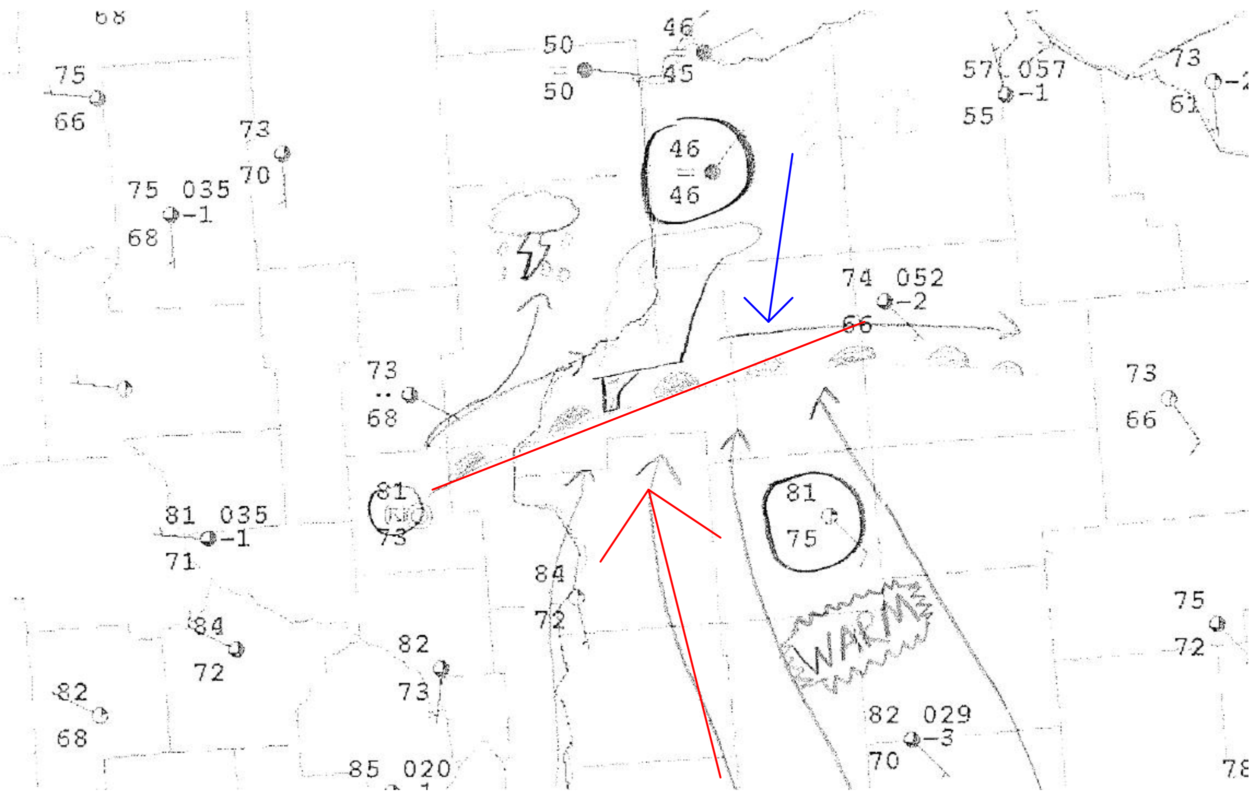

Figure 3 – Surface Observations at 0z on the 19th June 2001 and Conceptual Model for the Siren Supercell system. The red line oriented diagonally is the warm frontal position. Flow from the south behind the front is denoted by the red arrow, while flow off of the lake is denoted by the blue arrow. The black arrow is the track of the 2 cell, with the left mover being a lesser storm and the right mover being associated with the tornado, denoted by the funnel cloud. Computer graphics are meant to enhance hand-drawn features. Note the tremendous dew point and temperature range between the two circled stations. This convergence of lake flow and warm air enhances the cold front. Local helicity associated with the warm front is thought to have been a factor in tornadogenesis.

moisture will act as one of the catalysts for the severe weather that will be forced late in the day. One can see this moisture on the next panel, the 850mb dew points in degrees F (Figure 1c, lower left), with readings at or above 60 in west central Wisconsin. Another factor in tornadogenesis is wind shear, which at this point in the day is present. 1000mb level winds are coming from the southeast, while 850mb winds are out of the southwest. This shear certainly promotes tornado formation. One of the best proxies for tornado shear, helicity, was not available for this project, but will be theorized upon later. Surprisingly, this shear will actually grow smaller throughout the day, but location of the warm front will come into play.

Since the location of the warm front is near the sounding station of MPX, the 12z sounding from this location will show the inherent instability that is already

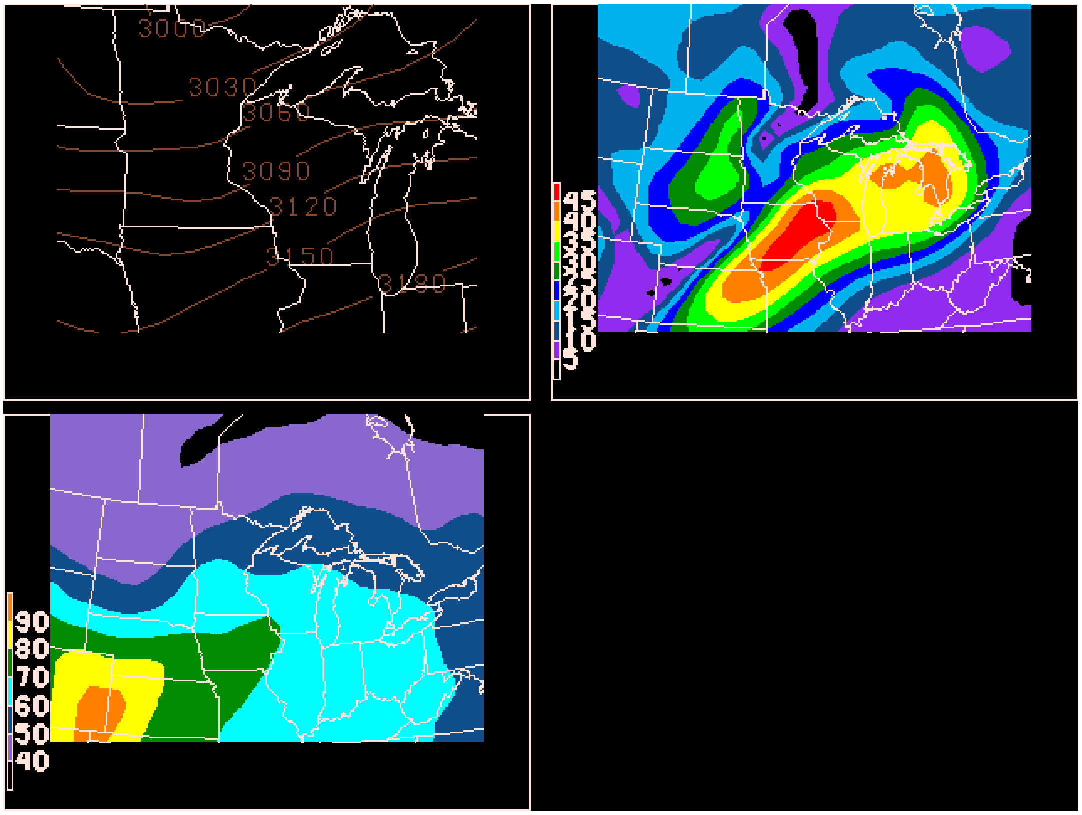

Figure 4 – 3 panel plot showing 12 hour forecast from Eta model 12z run. The Eta initialization for the time period was unavailable. Upper left (a) is 700mb heights, Upper right (b) same as 1(b), Lower right (c) is same as 1(c). While the dewpoint forecast was low, the low level jet forecast was reasonable. Warm air continued to flood the region thorugh the day, resulting in surface temperatures in the high 80s to low 90s F. The trigger for the supercell is the shortwave located in eastern Minnesota in panel (a).

present in the airmass (Figure 2). At this point, the vertical profile for severe weather is hardly impressive. A large temperature inversion is present near the surface. This would certainly hinder convection, but will weaken near the surface and will become oriented at the correct level with daytime heating. The low level moisture, however, is high. This is good for severe weather initiation and, thanks to the previously mentioned low level jet stream, the moisture content in the low level will grow throughout the day. A mid-level elevated mixed layer is present from around 700mb to about 500mb, which a piece of the classic "loaded gun" sounding. While not conducive to a severe weather outbreak at this point, the ingredients are present if oriented correctly.

Each severe weather index contains certain data about what severe weather parameters are present or not present. First, the Total Totals index takes into account the 850mb temperature, the 850mb dewpoint, and the temperature at 500mb. The total totals in this sounding is 60.60. This is tremendously high value, with values in the mid-50s being high enough for a severe weather outbreak. The Lifted Index (LI) for the sounding is near -2, too high for severe weather. The SWEAT index (**S**evere

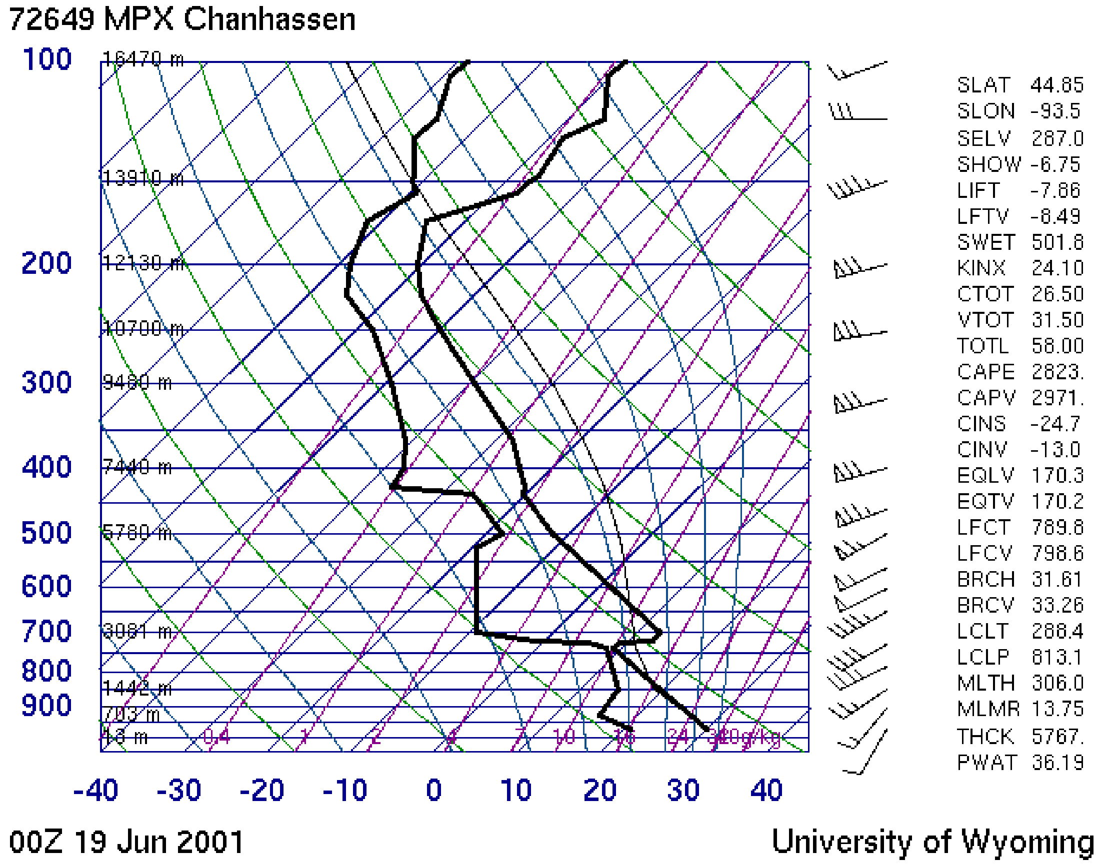

Figure 5 – Same as for Figure 2, but at 0z 19th. Note the strong inversion cap at the top of the boundary layer, but wind shear is somewhat lacking far away from the warm from. N impressive elevated mixed layer remains.

<u>WEA</u>ther **<u>T</u>**hreat) is quite high this early in the day, with a value of 533.5. This is largely due in part to the high values of low level wind shear in the region. There is tremendous veering of the winds from the surface to 800mb, as seen earlier in the regional maps as well as on the sounding. CAPE (Convective Available Potential Energy) is low, as multiple temperature inversions prevent CAPE formation of the sounding. Severe weather spawns the easiest with a combination of all parameters coming together, and CAPE must become higher for severe storms to occur. In this case, higher CAPE values indeed occur, along with destabilization of the area due to daytime heating as well as increased moisture.

Evening – Synoptic and Mesoscale Overview

As the day progressed, the elements finally came together for a healthy severe weather outbreak. Looking first at the surface observations at 0z on the 19th, the effects of daytime heating are easily seen (Figure 3). Observations in northwestern Wisconsin show dew points in the low to mid 70 degrees F. Interestingly, there is a tremendous dew point gradient between two stations in northwestern Wisconsin, with a 20 degree drop in about 20-30 miles. This is somewhat likely to have had an effect on the storms, and will be analyzed with the

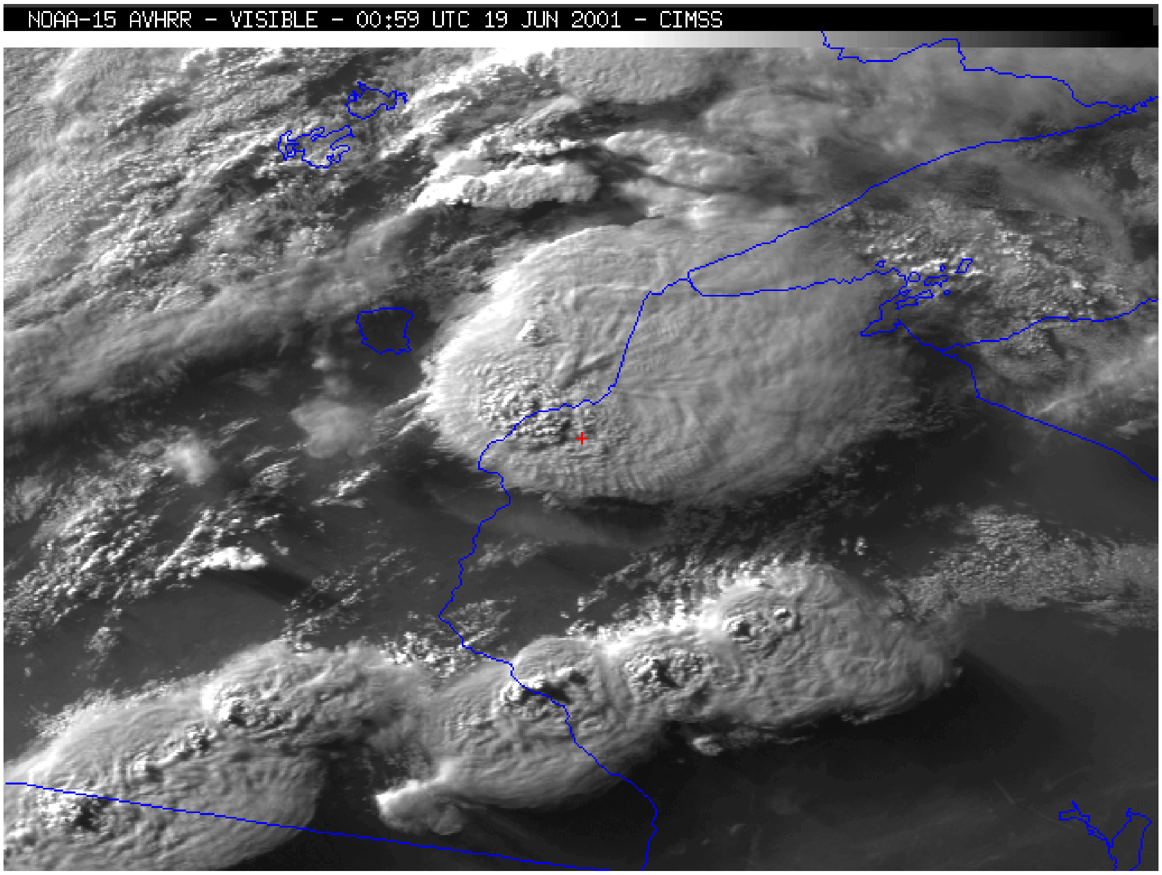

Figure 6 – Visible Satellite Image from the NOAA-15 AVHRR at 0059z on the 19th. The red dot signifies the village of Siren. Note the overshooting tops associated with the supercell in the north and the hail producing storms in the south.

radar section. Looking at the 4-panel plot for upper air dynamics for 0z, the first panel shows the 700mb heights for the time (Figure 4a). The problem with the following dynamics is that the ETA initialization for the time period was unavailable, and the 12z forecast from the previous model run was used. Obviously, forecasts are not as reliable as initializations, but the forecasts are, for the most part, correct. The warm front previously mentioned had moved to the north of the Siren area, allowing warm air into the region. A shortwave trough is present at 700mb, which acts at the initiator for the cell. The low level jet is present and continues from the morning, and continues to bring high moisture values into the region (Figure 4b). Looking at the dew points for the 12hr forecast from 12z, the values were only projected to reach the low to mid 60s (Figure 4c). Obviously, viewing the 0z surface observations, this is not the case. But, the model did suggest that moisture would continue to flux into the area, prompting the Storm Predicition Center in Norman, Oklahoma to issue a moderate risk of severe thunderstorms in the area on this day. Synoptically speaking, many features were in place for a severe weather outbreak – a shortwave trough intercepting warm,

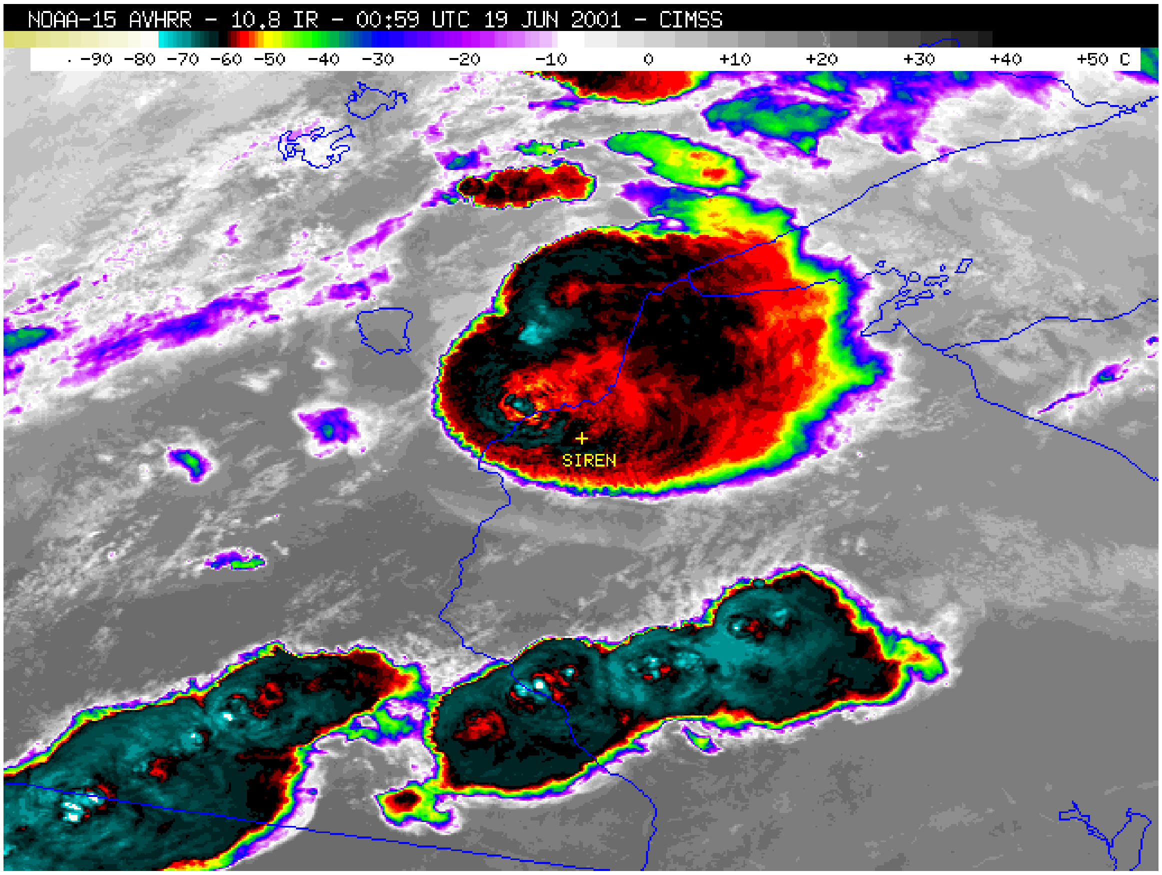

Figure 7 – NOAA-15 AVHRR 10.8 micron IR channel with color table enhancement. An "enhanced-V" feature is prominent on the supercell. The clouds on the southern storms seem anomalously cold to the author.

moist surface air. Wind shear continues, but not as strong as in the morning. But what of the mesoscale dynamics, such as upper level dry layers, as well as wind shear?

The 0z sounding for the 19th at MPX shows that the final parts of the outbreak scenario were in place (Figure 5). A tremendous elevated mixed layer formed from just above the boundary layer inversion to about 500mb. The station missed the full brunt of the low level jet, but areas to the northeast were not so lucky, where low level moisture values are higher. The inversion cap on the boundary layer is healthy, but will eventually be broken by the shortwave. CAPE is quite high at 2823 J/kg. The Bulk Richardson Number is also within tornadic range at 31.61. The Total Totals value is 58, still well within severe limits. Surprising is the lack of strong veering winds. This can be attributed to the sounding station being far south from the warm front. Closer to the front, wind shear is observed to be much stronger in direction and speed, and this is likely why the storm in northern Wisconsin was tornadic while the west central Wisconsin storms were only hail producers.

The storm begins in east central Minnesota, first affecting Pine County before moving into Burnett County, Wisconsin. What

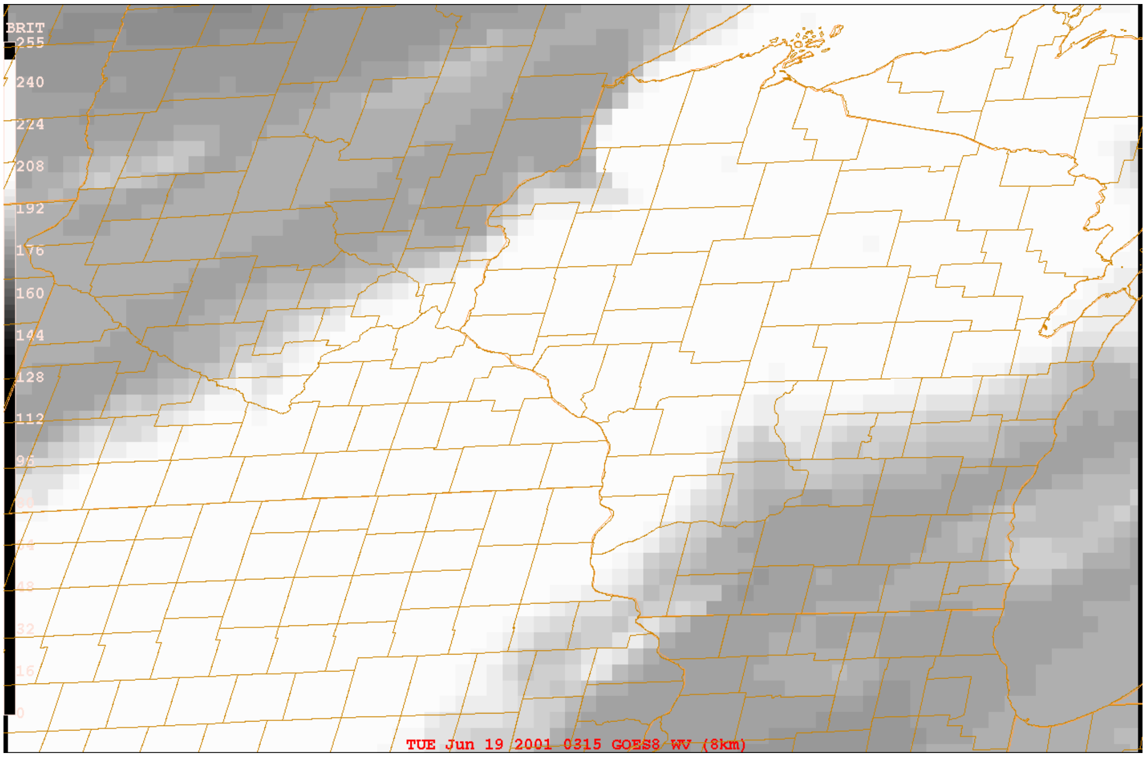

Figure 8 – 6.5 micron water vapor image from the GOES-8 satellite at 315z on the 19th. This is the closest available water vapor image for the system after initiation. Note the large cloud water contents in association with the storm.

follows is a tremendous amount of destruction.

The Storm - Satellite Analysis

There was not only one major storm that evening, as the Eau Claire area received copious amounts of large hail. There was also a small storm that split from the supercell that will also be analyzed. First, looking at the visible satellite, the supercell producing the system can be easily seen (Figure 6). Taken from 115z on the 19th, the photo is focused on the affected area. A few cells are visible in the area, including a line over Eau Claire stretching back towards Faribault, MN (FBL). producing cell is located near where the St. Croix River becomes the Minnesota/Wisconsin border in Burnett County, WI. Plainly visible are the overshooting tops associated with the storm. Overshooting tops are caused by the updraft penetrating the tropopause and placing cloud matter into the stratosphere. These phenomena are associated with only mighty updrafts, as an intense amount of force is needed to push cloud matter past the extremely stable tropopause. This cloud feature shows just how strong the Siren supercell is.

Looking at the infrared satellite, a similar picture can be seen. Taken just a few minutes earlier at 059z on the 19th, the overshooting tops can be discerned by the cold, circular feature surrounded by warmer temperatures (Figure 7). The stratosphere is warmer than the troposphere, so a cold feature entering a warmer layer

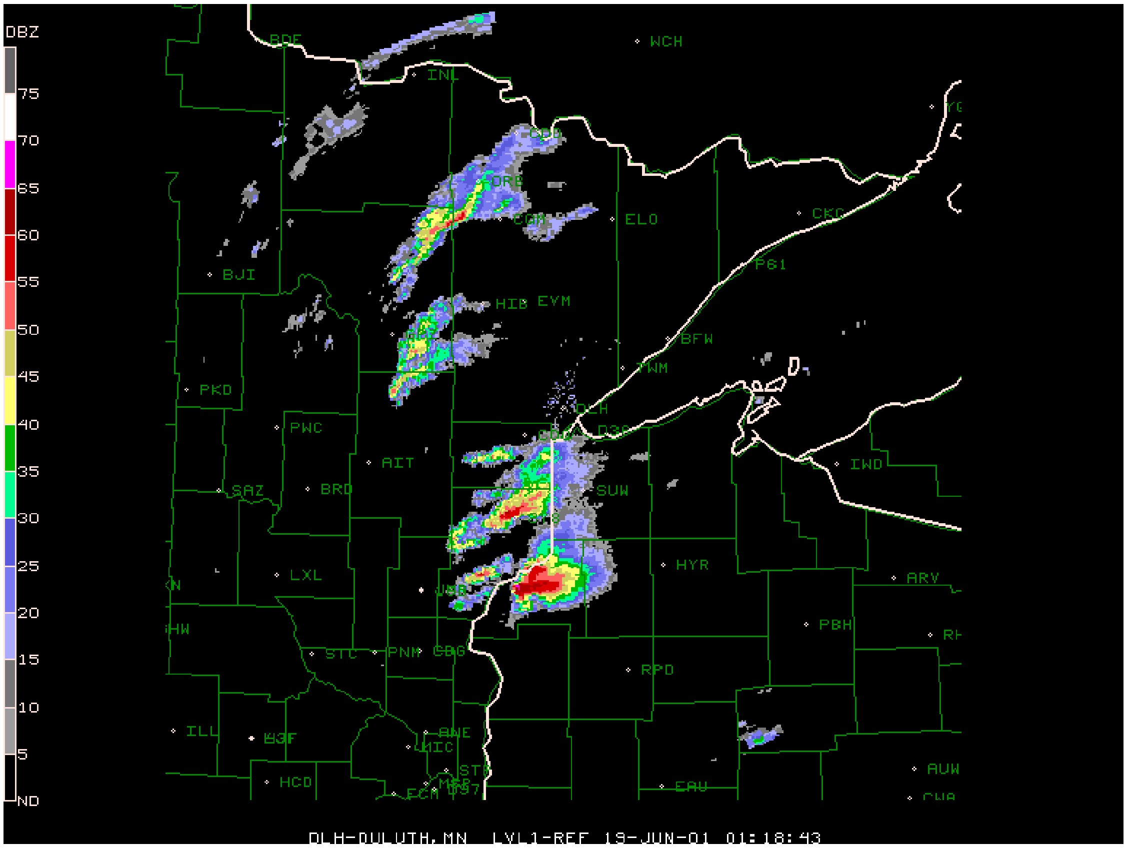

Figure 9 – Doppler radar base reflectivity image from DLH for 118z on the 19th. 3 prominent cells are featured. The supercell is located in Burnett County, WI, about to affect the village of Siren. To its immediate west is likely a small thunderstorm forming on the flaking line of the supercell, while the storm to the northwest of the supercell is a left-mover associated with the right mover, the actual supercell. Note the prominent hook echo associated with the right-moving supercell, signifying the mesocyclone.

makes sense. Also shown in this frame is a feature known as the "enhanced-V." The enhanced-V is seen only from a color-enhanced IR picture. The feature is created from an overshooting top. Winds in the troposphere must go around the penetrating overshooting top of the thunderstorm. This causes the warmer air of the stratosphere to flow around the colder air of the troposphere, causing the V shape. Again, only the strongest of thunderstorms will have the enhanced V. The storms to the south in the west central portions of Wisconsin into Minnesota do not have this feature, but are anomalous. These clouds are seen by the satellite as much colder than the top of the supercell, which does not equate. The supercell dynamics makes sense, but the Eau Claire storms do not. An answer evades the author at this time. The water vapor image for this time period was unavailable, but later images from 3z on the 19th show large plumes of moisture associated with the chain of storms that eventually affect the eastern portions of Wisconsin later on the 19th. (Figure 8) Moisture plumes are always associated with thunderstorms, and the more moisture visible on the water vapor

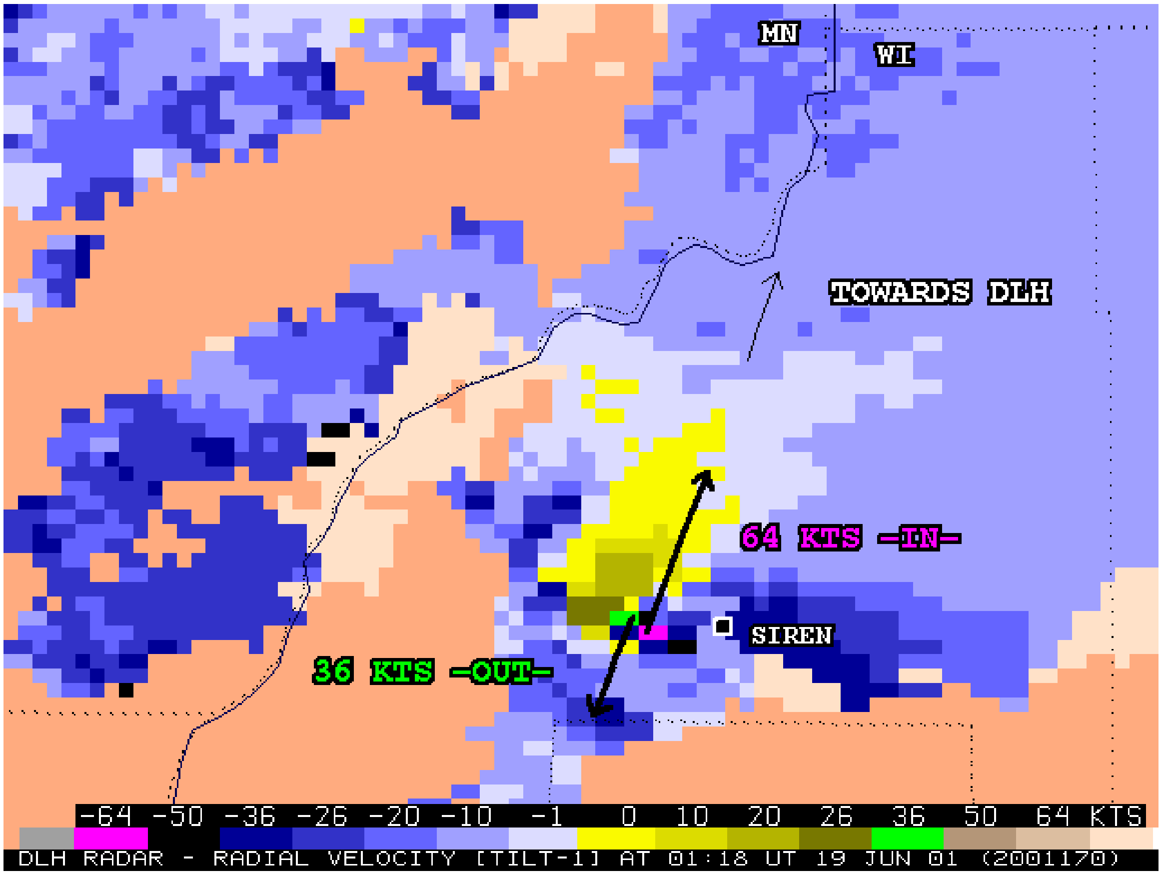

Figure 10 – DLH base velocity image for 118z on the 19th. Veolcities away from and toward the radar site are noted and arrowed. Velocity coupling such as this denotes the location of the mesocyclone which could produce a tornado. In this case, a tornado did occur.

channel, the stronger the storm is. Unfortunately, the water vapor imagery available was of 8km resolution, and for a supercell producing a tornado less than a kilometer wide, this is a grainy and poor resolution grid.

The Storm - Radar Analysis

The base reflectivity radar frame presented is from DLH at 118z on the 19th (Figure 9). The supercell has just crossed from Pine County, Minnesota into Burnett County, Wisconsin. Including the supercell, there are two other discrete cells. First, a much smaller cell left in southern Pine County, as well as another in northern Pine County. These other storms were indiscernible from the supercell on the satellite images due to the large cloud mass produced by the larger storm. The cell in northern Pine County may have had a high top, but the only storm that produces a tornado is the Burnett County storm. This storm was the “left mover” in this case, and fizzles out before causing any problems. The southern Pine County storm is mostly likely a small thunderstorm that forms on the flanking line of the supercell’s gust front. As previously noted, the storm stuck Siren at 820pm CDT, or 120z. This is the closest radar sweep of the storm as it bears down on the village.

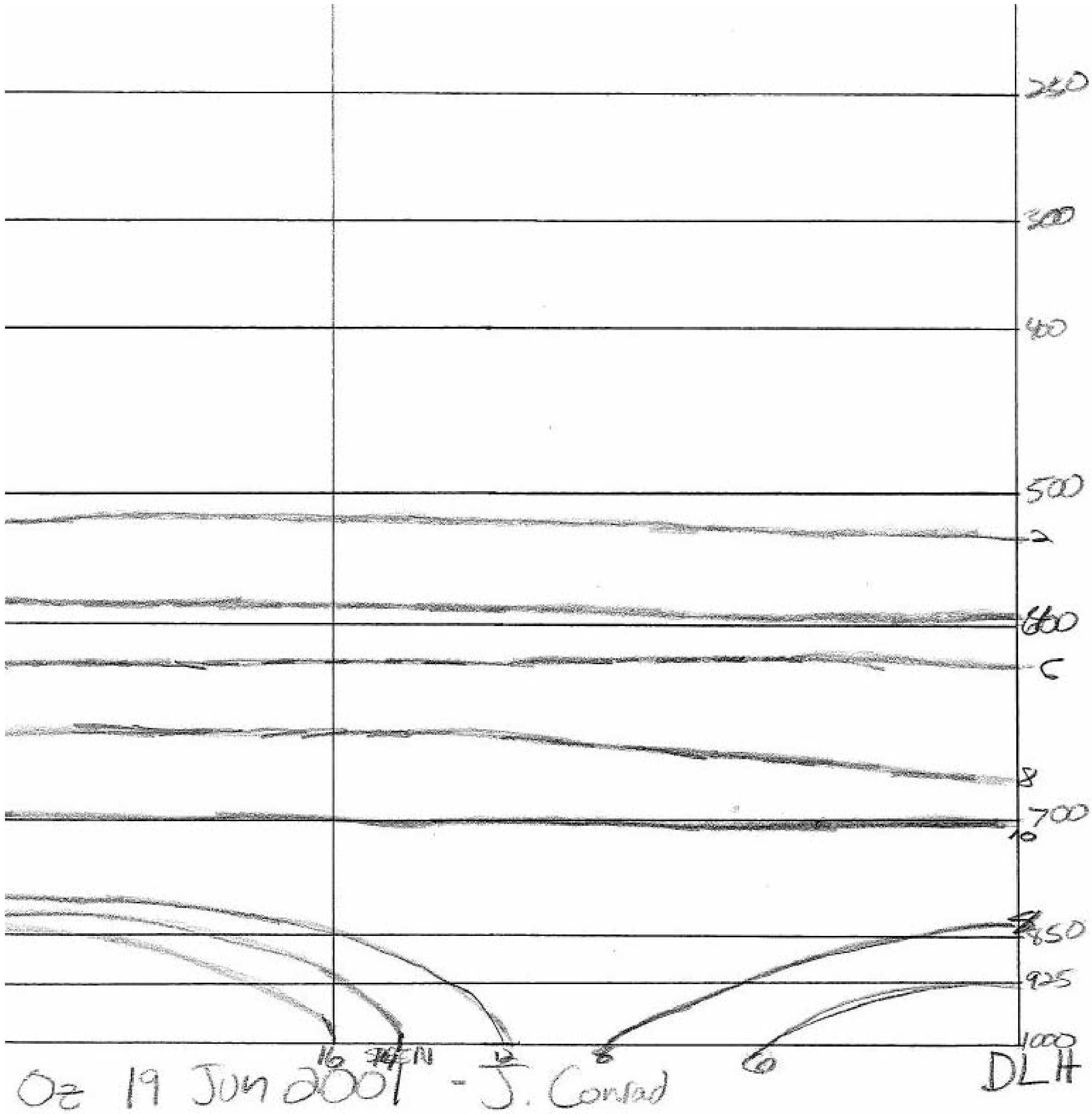

Figure 11 – Cross Section from Minneapolis to Duluth at 0z, denoting mixing ratio. The warm, moist tongue is moving north, but the lake induced cool air is awaiting in the north. The supercell will move in the direction out of the page, along the mixing ratio valley.

Most important in this image is the hook echo on the southwest edge of this storm. A hook echo shows the location of a supercell mesocyclone and is represented by reflectivity echoes wrapping around an area of low reflectivity. A hook echo is a classic example of a location of a tornado, with the funnel most likely occurring at the edge of the hook. Without the aid of local storm spotters, this is one of the best ways for National Weather Service meteorologists to issue tornado warnings. In this case, the hook echo is placed correctly, as the village of Siren is located in the south central portion of Burnett County. A loop of images show the propagation of the storm is to the east around 25mph.

The storm radial velocity image for this time gives a similar notion. (Figure 10) The mesocyclone is located just to the west of Siren, designated by a distinct velocity coupling. Velocity coupling, also known as gate-to-gate shear, is another way to designate the location of a tornado. Being as tornadoes usually rotate cyclonically, and this storm is located to the south of the radar, the eastern edge of the cyclone would have velocity towards the radar site, with the western side having velocities away from the site. Indeed, this supercell has this characteristic. As noted in the figure, the velocity toward the site is near 64 knots, while velocity one gate to the northwest is 36 knots away. Sometimes referred to as a Tornado Vortex Signature (TVS), gate to gate shear helps forecasters determine the location of the tornado.

Using the radar data in this storm was absolutely critical. This storm had a strong TVS for several minutes prior to the tornado affecting Siren. The DLH office networked with local authorities to determine if the TVS was a real case of a tornado and not just a false alarm. The office wrote in a report on their website, "The National Weather Service issued a tornado warning well ahead of time, with **35 minutes** of lead time before it first touched down, and **50 minutes** of lead time before it moved through Siren, WI." Lead times for the public are absolutely critical in tornado situation, allowing people to shelter and possibly save their lives.

The storm tracked east from its origin, seemingly across the boundary of the warm front and lake-induced temperature and dew point boundary. Higher values of helicity are known to form along the north side of a warm front, and this temperature boundary may act to strengthen the warm front (refer back to figure 3). It seems rather conspicuous to the author that the storm followed right across this boundary. Was this plausibly higher region of helicity present in this local area of more unstable airmass, causing the tornado? It certainly seems possible but cannot be proven without added data. This hypothesis also carries some leverage as the storms to the south in the Eau Claire region did not produce tornadoes. While shear was similar in the two regions, the Siren storm was the only tornado producer. This case is plausible surface convergence along this line, with the ambient wind shear being enough to produce a tornado. There also seems to be a region of tight mixing ration gradient the storm follows, as seen on the provided cross section (figure 11). It is quite difficult to prove without helicity data. But, the storm reports tell the story: the region had enough helicity locally to produce tornadoes (Figure 12).

Conclusion

The Siren tornado is a classic-style supercell that forms and is possibly strengthened by local lake dynamics. Through the day, normal synoptic and mesoscale forcings such as the low level jet and low level shortwave cause storms to fire, but the only storm to become tornadic

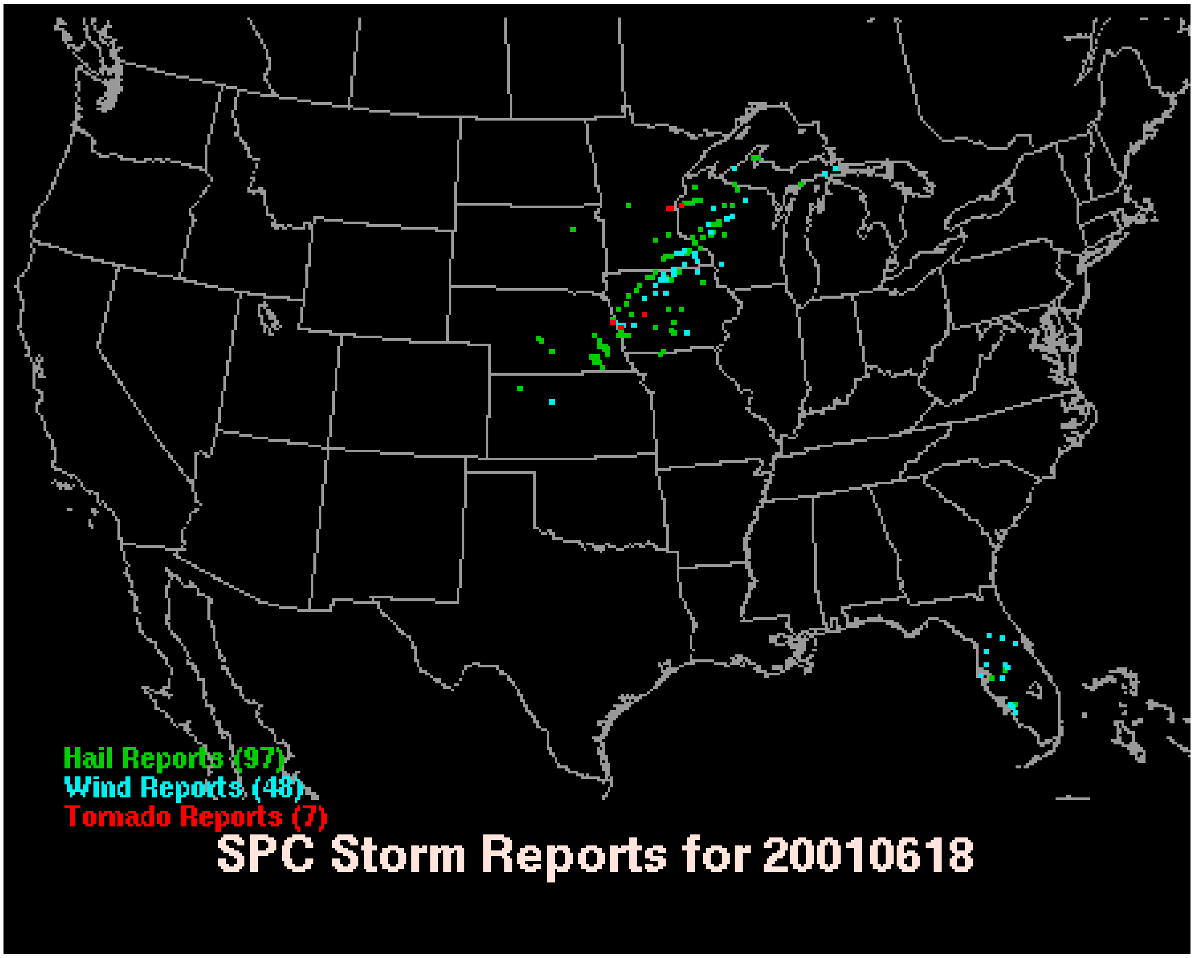

Figure 12 – SPC storm reports from the 18th into the 19th. Note how only tornadoes were produced by the northern Wisconsin storms, but not by the west central Wisconsin storms. Locally enhanced frontal helicity may be the culprit in this case.

affects the village of Siren, possibly enhanced by warm frontal helicity enhancement. This theory cannot be proven without helicity values, but is a sound theory. Further investigation into this case, as well as Lake Superior induced dynamics is a worthy investment in the future.

Resources and Acknowledgements

Radar and Satellite frames compliments of CIMSS.

Information and quotes compliments of the National Weather Service Office in Duluth, MN (www.crh.noaa.gov/dlh)

Many thanks to all of the AOS deparment faculty and teaching assistants for the hard work and dedication have taught me everything that I know. I'm not perfect, but I sure have learned a lot!