The Oakfield Tornado of 18 July 1996

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ABSTRACT

The Oakfield, Wisconsin tornado of 18 July 1996 is examined using datasets provided by GARP, GOES-8 infrared satellite imagery and WSR-88D radar data. The analysis provides an insightful description of the meteorological setting and evolution that led to the severe weather on this day. Strong thunderstorms and a tornado were spawned by a loaded gun sounding which was indicative of warm dry air over moist air near the surface. The storms strength can also be attributed to the convergence of winds along a cold front and a sharp temperature gradient which extended throughout Wisconsin. Convergence and the position of the upper level jet created conditions for the capping inversion to be broken causing a release in conditional instability. This case also displays how a Miller Diagram, a conceptual model as well as other data sets can be used together to provide a valuable and precise overview of a rapidly evolving meteorological event.

I. Introduction

On 18 July 1996, Oakfield, Wisconsin, in the northeastern portion of the state, was affected by an F5 tornado. In addition to the tornado, strong thunderstorms produced heavy rains, lightning and gusty winds in the region. The original report from the National Weather Service categorized the tornado to be either an F3 or F4, with winds varying in strength between 158 and 260 miles per hour. However, after an inspection of the damage from the tornado in the Oakfield area, the tornado was issued the status of an F5 which was indicative of winds stronger than 260 miles per hour. The strength and assigned status of the tornado bring to attention the significance of this storm. F5 tornadoes are very rare and only tend to occur every other year in the United States. It is expected that converging winds along the cold front and a significant temperature gradient were the primary reasons for the development of this powerful storm. The tornado was responsible for over $40 million in damage as 47 of 320 homes were destroyed. 56 additional homes and businesses sustained significant damage. The tornado demolished the Friday Canning Company and caused empty cans to be sprawled up to 50 miles from the business. Additionally, the tornado also affected agriculture as crops, livestock and farm equipment were destroyed. Despite the severity of the tornado, there were no reported deaths and only 17 injuries from the incident. A tornado watch was issued well in advance of the tornado occurrence. The tornado remained in existence for over 20 minutes and traveled nearly 20 miles before dissipating. The tornado developed in Fond du Lac County and moved southeastward across Wisconsin till it reached Oakfield at 0015 UTC (Achtor et al.).

II. Data

The severe weather event over Wisconsin on 18 July 1996 are examined using WSR-88D radar data, GOES-8 visible satellite imagery, ETA model analysis and

surface data in GARP, as well as soundings from the University of Wyoming. The combined use of these data sets provides an insightful description of the meteorological setting and evolution that led to the Oakfield tornado.

III. Morning Synoptic Situation

At 1200 UTC on 18 July 1996, a low pressure system was centered over northern Minnesota with a warm front extending off to the east through central Wisconsin and Michigan. A cold front associated with this system extends from northern Minnesota to the southern Plains. Anti-cyclonic rotation associated with high pressure over the Southeast is advecting Gulf moisture towards the Midwest. More significantly perhaps was the moisture provided by the corn due to evapotranspiration. This moisture is providing humid conditions with high dew points. Cooler and drier air is present to the west of the cold front. Analysis of the 1200 UTC sounding at Minneapolis (Figure 1) reveals a capping inversion that would result in convective initiation later in the day.

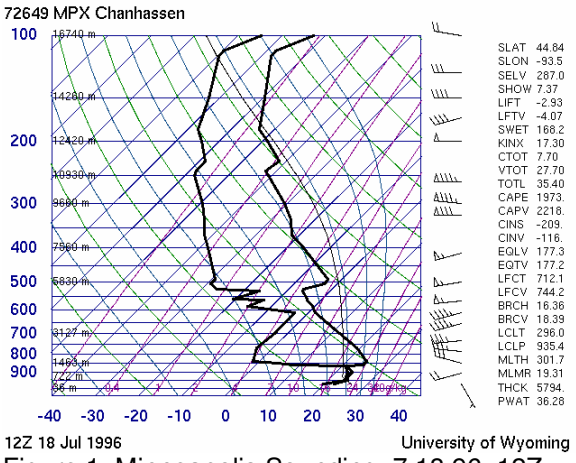

Figure 1: Minneapolis Sounding, 7.18.96, 12Z

This is a typical loaded gun sounding (University). A temperature inversion exists near 850-mb; the cap is represented by the warm layer above it, wherein the parcel would be cooler than the surrounding air and thus would accelerate upward. Also at this time, the environment between 850 and 550-mb was conditionally unstable and was indicative of an elevated well mixed boundary layer. Relatively weak wind shear exists at levels above 850-mb. The most significant shear occurs below 850-mb where the winds shift from the southeast to the west-southwest. The convective available potential energy (CAPE) is nearly 2000 which designates a good condition for the formation of a supercell. Also, the lifted index is in a range where severe thunderstorms are possible.

A relatively strong mid-level jet extended through the Dakotas and Minnesota at the 500-mb level. Diverging winds at the 500-mb level suggest that the surface air is being lifted upwards due to convergence at the surface associated with a cold front. Divergence and a strong jet continues to be the case at the 250-mb level. The most significant divergence was present in the northern portion of the state at 12Z. The divergence acts to bring surface moisture upwards and aid in breaking the inversion.

IV. Afternoon and Evening Synoptic Situation

As the day progressed, there was little change in the strength of the low pressure system which shifted towards the southeast and was now present over northeastern Wisconsin.

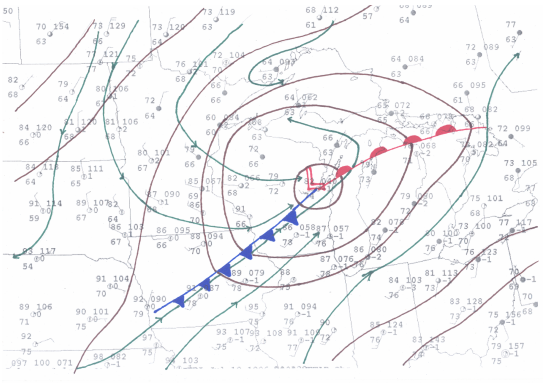

Figure 2: Surface Oservations, Sea Level Pressure (mb), Streamlines, 7.19.96, 00Z

The high pressure system located in the Southeast slightly moved to the east while weakening by 3-mb The anti-cyclonic flow around the high continued to feed moisture into the Midwest. Figure 2 exhibits the surface observations, pressure contours as well as the frontal structure and streamlines. The low pressure system is centered over northeastern Wisconsin and a warm front extends off to the east-northeast. A cold front extends from northeastern Wisconsin to southwestern Iowa. Also notable is that the surface winds to the south of the cold front are generally from the south-southeast. The orientation of the flow at the surface, as shown by the streamlines, reiterates that moisture is being advected from the Gulf through the cornbelt towards the Midwest. Streamlines also indicate that cooler Canadian air is being advected into the Midwest and is converging with the warm sector. A large temperature gradient is associated with the frontal structure extending through the Midwest. Figure 3 shows the temperature gradient at 850-mb across the Midwest.

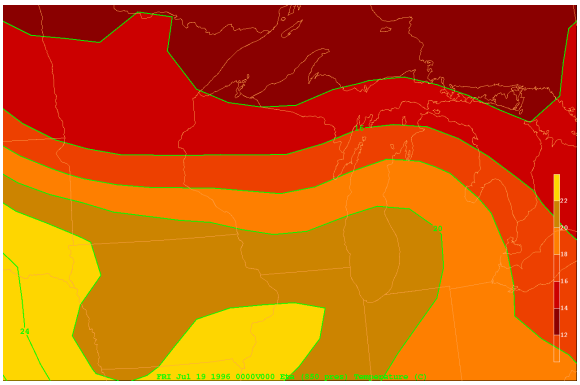

Figure 3: 850-mb temperature ℃, 7.19.96, 00Z

The temperatures are in Celsius and are contoured every 2 degrees. The image demonstrates that the temperatures in Wisconsin vary between 12 and 24°C. In Fahrenheit this is a temperature contrast from the lower 50s to the mid 70s. The collision of these air masses along the cold front are aiding in the production of the powerful storms that took place. Figure 4 shows the vertical motion that is associated with these converging air masses. Notice that the most significant vertical motion was confined to levels below 300-mb in the north central portion of the state. However, the southern portion of the state is seeing more vertical motion than prior in the day which will aid in breaking the cap.

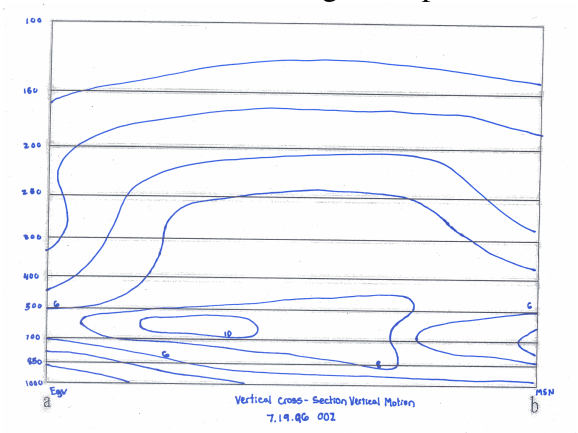

Figure 4: Vertical Cross Section of Negative Omega, 7.19.96, 00Z

At 00Z on July 19 1996, the Miller Diagram shown in Figure 5 gives a good representation of the synoptic situation

occurring throughout the atmosphere.

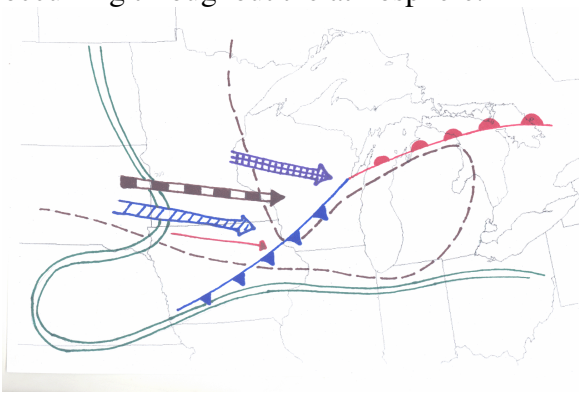

Figure 5: Miller Diagram, 7.19.96, 00Z

The general direction of the flow between 850 and 300-mb is out of the west-northwest. There is also a moisture tongue at the 850-mb level which is denoted in green. Also notice that a dry tongue is present at 700-mb and is shown as a dashed brown line. The areas where the moist and dry tongues overlap are the areas of interest as they provide suitable conditions severe weather. Compared to the 1200 UTC analysis, the 500-mb jet maximum (Figure 6) shifted from the Dakota's and Minnesota to Wisconsin and Minnesota. The streamlines associated with this jet are diffluent over Wisconsin and Illinois and are providing the appropriate dynamical conditions for surface parcels to rise in the atmosphere. Meanwhile, at 250-mb, the core of the jet stream (Figure 6) was now located directly over Wisconsin.

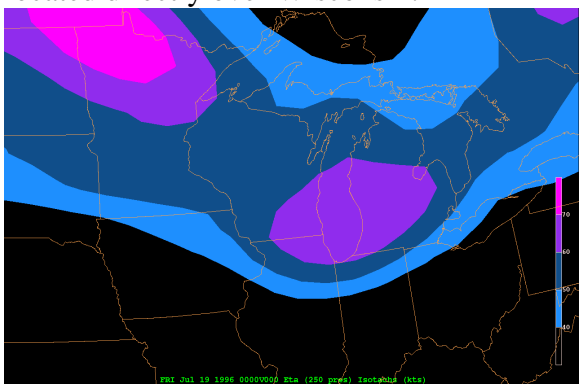

Figure 6: 250-mb jet with winds in kts, 7.19.96, 00Z

While the divergence was more impressive at 1200 UTC, there is still enough divergence to provide lift for surface air parcels.

Supercell thunderstorms were present across east central and northeastern Wisconsin throughout the afternoon of 18 July. The cap had been broken in the afternoon which created a release of conditional instability. However the situation was different across southwestern Wisconsin where the cap remained firm along the cold front. The inversion, shown in the Davenport sounding at 00Z in Figure 7, inhibited the formation of thunderstorms in southern Wisconsin.

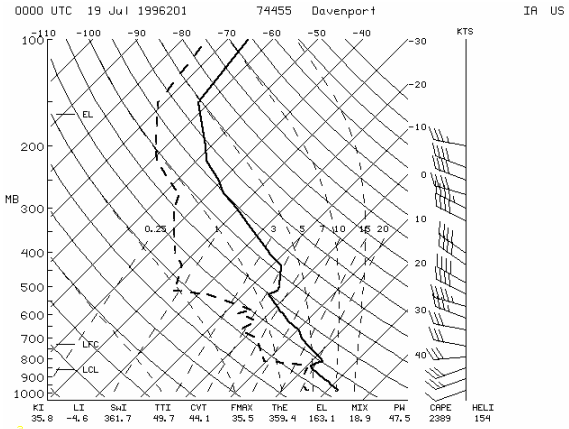

Figure 7: Davenport, IA Sounding 7.19.96, 00Z

Also notable in Figure 7 is the amount of CAPE which is 2389. Therefore at 00Z the CAPE is stronger at Davenport than it was at Minneapolis at 12Z. The lifted index was also higher indicating an increasing chance for the formation of severe thunderstorms. The helicity was measured to be 154 which represents a moderate amount of shear that is conducive for supercell formation. The available energy and the dry conditions aloft and the moist conditions below created the conditions for explosive thunderstorm development (Achtor et al.).

V. Mesoscale Analysis

Near surface moisture played a role in the convection that occurred on 18 July 1996. Figure 8, a zero hour forecast for 00Z on 19 July, shows that the high dew points (filled contours) were located over Wisconsin and Michigan while the highest relative humidity values in the Midwest were present in both central and southern Wisconsin.

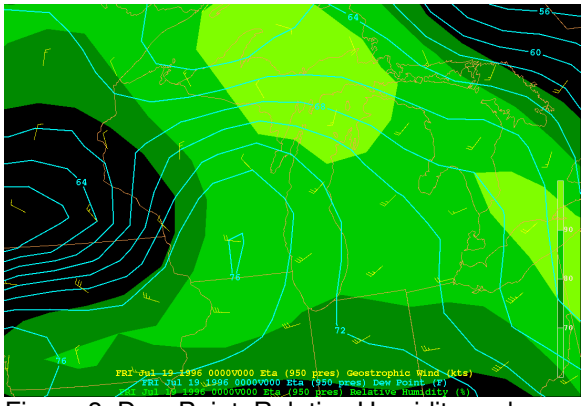

Figure 8: Dew Point, Relative Humidity and Winds at 950-mb, 7.19.96, 00Z

The dew point in Oakfield is roughly 70°F and has cooled off as dew points in Oakfield earlier in the afternoon were as high as 78°F. The dew point decreased in Oakfield due to its proximity to the cold front. By 00Z the cold front was passing through the Oakfield area. Temperatures remained fairly constant despite the position of the cold front. The temperatures in the Oakfield area remained in the upper 80s. The clashing of temperatures across the region created convergence at the surface and divergence at upper levels. This reason as well as the position of the jet was enough to break the cap and cause a release of conditional instability (achtor et al.). The cap was broken earlier in northern Wisconsin due to high dew points and more vertical motion. The timing of the breaking of the cap is an important phenomena of this storm, as it was necessary for the cap to be broken at a time with a large amount of available energy.

According to the base reflectivity radar scan at 2100 UTC, strong storms began to develop in north central Wisconsin. This was likely because the cap had already been broken at this point in northern and central Wisconsin. Numerous reports of tornadoes, large hail, and damaging winds were reported along this path of intense thunderstorms as they moved from eastern Minnesota to east central Wisconsin. Meanwhile only light rain began to develop across southern Wisconsin as the cap had not yet been broken and there had not been a release of unstable air. By 2300 UTC a supercell had formed just west of the southern tip of Lake Winnebago. This supercell continued to increase in magnitude in a southeasterly direction. By 00Z a hook echo was apparent in the base reflectivity radar scan. Figure 9 shows the base reflectivity scan with the hook echo denoted by a circle.

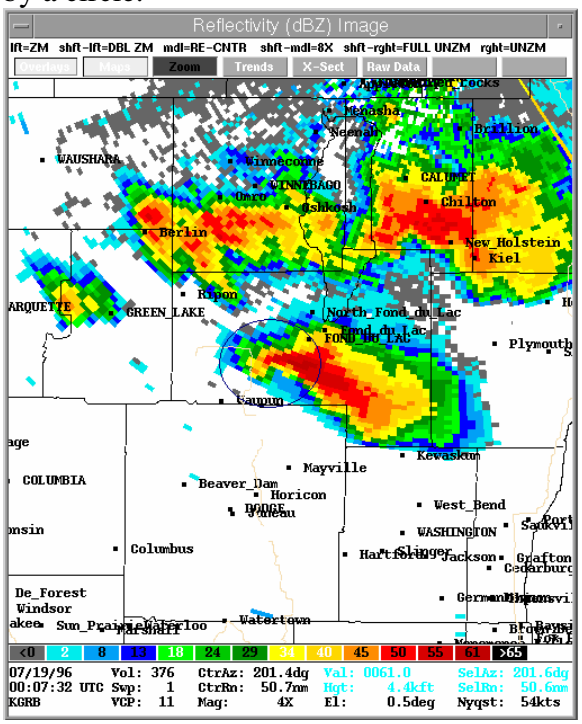

Figure 9: Base Reflectivity Radar Image, 7.19.96, 0007 UTC

Hook echoes are typically the region where strong tornadoes develop in supercells. The doppler velocity image in Figure 10 further

emphasizes the presence of a tornado. Tornadoes are indicative of wind velocities which change over a short period of time. This change in velocities can be interpreted from a doppler velocity image which displays a sharp contrast of colors in areas where the wind velocities significantly change.

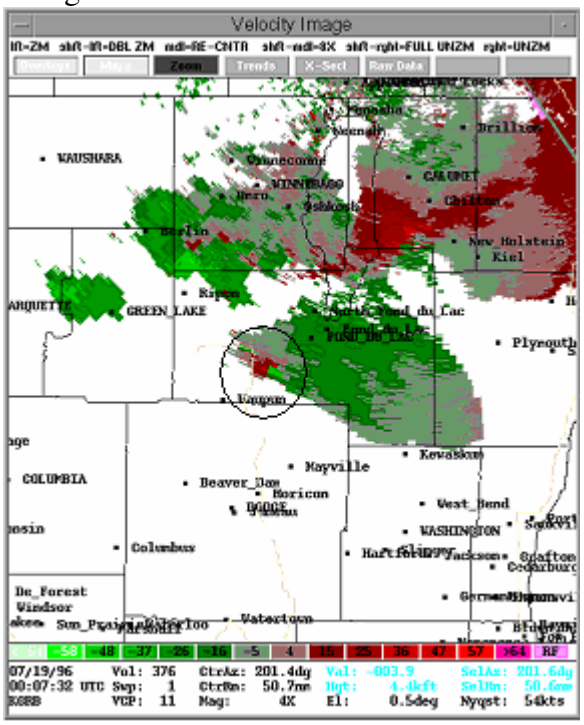

Figure 10: Doppler Velocity, 7.19.96, 0007 UTC

From Figure 10, there is a region denoted by a circle in which the colors change from green to red. From the scale it can be inferred that over a short distance the winds shift from 50 knots to 30 knots in the opposite direction, a strong signature of rotation. This region is consistent with the location of the hook echo as shown in Figure. These features exist in Oakfield which is located between Fon du lac and Wapun.

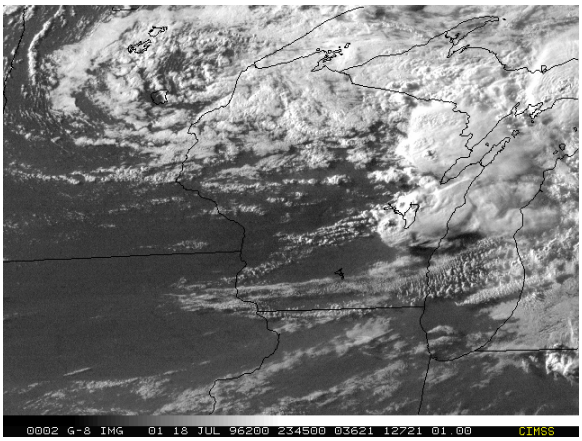

Figure 11: Visible Satellite Imagery, 7.18.96, 2345 UTC

Satellite imagery in the Oakfield case is useful for identifying features the cold front as well as overshooting tops. The cold front is evident from the GOES-8 visible satellite image at 2345 UTC (Figure 11). The cold front is representative of a thin band of clouds which extends from northeastern Wisconsin to southwestern Wisconsin. Also overshooting tops are present in northeastern Wisconsin. (Achtor). The flow around the overshooting top is also displayed in the conceptual model for a supercell in Figure 12.

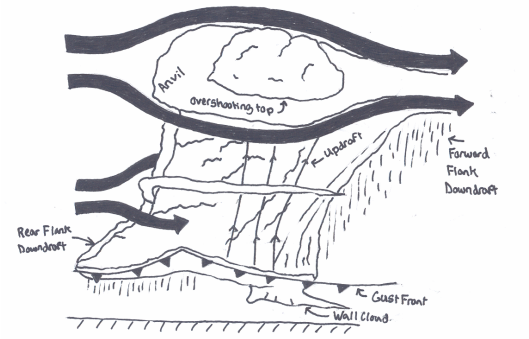

Figure 12: Conceptual Model of a supercell

The conceptual model shows the main ingredients of a supercell which includes an updraft, downdraft, rear flank downdraft and a forward flank downdraft. An anvil, overshooting top, gust front and a wall cloud are also significant elements of a supercell. The downdraft is responsible for areas of

precipitation. In this model both the forward and rear flank downdraft are creating precipitation. Some of the precipitation can be heavy and often in the form of hail. The rear flank downdraft and the updraft are apparent by the kink in the gust front. This model applies to the Oakfield case because it contained many of the elements associated with this model.

VI. Conclusion.

The Oakfield tornado of 18 July 1996 developed from a combination of synoptic and mesoscale meteorological phenomena. The synoptic setup revealed that 00Z a cold front extended from northeastern Wisconsin to southwestern Illinois. Associated with this cold front were converging winds and a temperature gradient. Winds to the north of the cold front advected cool Canadian air into Wisconsin while south-southeast winds transported Gulf moisture and moisture from corn into the Midwest. Convergence at the surface and divergence aloft created significant upward vertical motion that was necessary for the existence of the storm. Also, the inversion which separated moist air below from warm dry air above, created conditions which would give way to a significant amount of conditional instability when the cap would be broken. Eventually the cap was broken by upward vertical motion from surface convergence and the position of the upper level jet. A significant amount of energy was then released and spawned the supercell which produced the F5 tornado which destroyed the town of Oakfield, Wisconsin. Radar imagery supported the existence of the tornado as a hook echo was present in both the base reflectivity scan and the Doppler velocity image. Meanwhile, satellite imagery was useful in this case for detecting the overshooting tops associated with the supercell. These ingredients together made up the common elements of a supercell which was displayed by the conceptual model in Figure. The Oakfield tornado was consistent with this model.

References

Achtor, T., et al. The Oakfield Wisconsin Case Study. http://cimss.ssec.wisc.edu/oakfield/cs1.htm

University of Wyoming. http://www.aos.wisc.edu/weather/index.html