In Like a Lion:

The March 8th, 2000 Tornado

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Abstract

The tornado that struck Milwaukee, WI on March 8, 2000 was the earliest on record. Unlike most tornadoes, this particular tornado was not associated with a supercell or any form of a mesocyclone. The author argues that a lake breeze circulation created a misocyclone in the region, which was elongated vertically by a rapidly deepening convective thunderstorm in the region, producing the tornado.

I. Introduction

March has always been a month of transition for Wisconsin weather. Today's rain will give way to tomorrow's blizzard; today's mild temperatures will plunge to a wind chill advisory. Hence, even the 77-degree highs that occurred in Milwaukee on March 7-8 were unusual but not extraordinary. Such is the nature of Wisconsin weather.

What are not expected in March are severe thunderstorms, much less tornadic activity. According to the National Severe Storms Laboratory, Southern Wisconsin has only a one percent chance of suffering a severe thunderstorm on a given day by *late April*, and only a .25 percent chance of a tornado in the same period. The ingredients are rarely in place for significant convective activity (except, perhaps for thundersnow), considering temperatures typically peak around 40 degrees and dewpoints only occasionally break the freezing point.

March 8, 2000 was not your typical dreary March day. Insolation coupled with strong warm air advection boosted temperatures to a record 77 degrees Fahrenheit. Imbedded in the warm flow was unusually moist air from the Gulf of Mexico, bringing dewpoints to near 60 degrees and destabilizing the atmosphere. Additionally, several synoptic features in the area aided ascent.

Nor was the tornado that touched down around 6 pm local time your typical tornado. According to the NWS, it was the earliest recorded tornado in Milwaukee's recorded history, which stretches back to 1840. Fueled by perhaps as little as a lake breeze or a preceding storm's out flow, this F1 tornado had a path 75 yards wide and 2.5 miles long. Several persons were injured, and many buildings suffered structural damage. In total, the tornado caused 4.6 million dollars in damage.

Considering the storm was so exceptional and unusual, some may question the usefulness in analyzing its genesis. There are two critical reasons to come to a basic understanding as to how this storm developed. First, the tornado was largely a surprise event, and even an unexpected weak tornado can wreak havoc. Even though such a situation may never occur again in a forecaster's lifetime, it is important to stay vigilant of even the most unusual situations. Secondly, the recent IPCC report on global climate change has suggested that Wisconsin winters may become much milder in the future. In fact, IPCC reports indicate that it is likely Wisconsin winters will bear a closer resemblance in the future to the winters that Arkansas experiences in the present. Although it is ludicrous to assign mesoscale features to global climate change patterns, it is reasonable to expect that warmer winters may allow for earlier severe weather seasons.

This case study will contend that several unique mesoscale features contributed to this storm. Initially, a dryline through south central

Wisconsin and north central Illinois most likely played a significant role in the early development of this storm. Later, as the convective thunderstorm approached lakeshore, a lake breeze near the surface likely created the vorticity necessary to produce a misocyclone and the tornado.

II. Data Sources

Data collection for this event was exceedingly difficult. Radar, satellite, and radiosonde data each had several errors or data missing that hampered proper investigation of this event. Though none of the problems proved fatal, it is worth noting each issue.

In a terrible irony, the Milwaukee/Sullivan radar station was down during the entire event. In its place, data from Chicago/Romeoville was used. However, distance issues with this data make this selection not ideal. This storm developed and moved on the fringes of Romeoville's radial velocity range, a critical tool in the analysis of tornadic events. As will be shown, outflow from a previous thunderstorm and/or a lake breeze probably contributed to the development, but the lack of radial velocity data in the region makes each possibility more conjectural than demonstrable. Additionally, the distance also prohibits the radar from getting any returns within the boundary layer, another serious impediment to proper analysis.

Satellite data also suffered from unavailable data. Between 23:45z on March 8 and 00:45z on March 9, there is neither visible nor IR data available. Typically, this would be a minor issue, but this is *exactly* when the tornado is touching down. However, the satellite after this time shifted to rapid scan operation, which allowed for analysis of the later stages of the tornado.

Radiosonde data also was rendered less meaningful by missing data. For whatever reason, the key sounding (00z on March 9) from Green Bay provided no wind data above 675 millibars, precluding the creation of a hodograph or having a true measurement of shear. Though data can be extrapolated from upper air reanalysis, it is unfortunate that the radiosonde could not provide hard evidence.

Fortunately, much of the data was quite useable. As previously mentioned, Level II radar data, provided by the NCDC, from Romeoville, IL was used, and ingested using IDV. Satellite data (used for reference, not in the final form) was from GOES-East, primarily using the longwave IR and WV bands, provided by the NCDC's CLASS data service. Model data from the NAM 00z run on March 8th was used to provide context and further analysis. Finally, radiosonde data from the University of Wyoming, coupled with North American Regional Reanalysis from Plymouth State allowed for additional investigation.

III. Synoptic Overview

Such an unusual storm requires very unusual conditions. Although conditions would generally only be considered merely adequate for strong thunderstorms during warmer months, their very presence was highly anomalous for the late winter/early spring. In many regards, this storm was the product of a violent clash between two sharply different air parcels.

The most readily apparent synoptic feature of this day was the extremely warm air being pumped into the region from the Mississippi Delta region. As the streamlines in Figure 1 indicate, the parcels were moving meridionally directly into Southeastern Wisconsin. A strong, 994 mb surface low not only was pulling air from the Mississippi region but also drawing cold, dry air from the Canadian Arctic, as seen in the upper left portion of Figure 2.

Another stark feature of this synoptic situation was the juxtaposition of highly unstable air with much more stable air behind it, as seen in the lower right panel of Figure 2. In the Milwaukee vicinity, lifted indices approached -4, whilst in Iowa lifted indices were well above zero. This particular feature will play an important role in the development of this storm.

Upper level support for these storms was good, though not excellent, as the upper right panel of Figure 2 shows. A jet streak from the Mexican border extending into Central Illinois was positioned to provide at least some left front quadrant ascent, though it likely was neither a help nor hindrance to the storms development. The jet extended far enough into the region to provide some speed shear. However, comparison of the 850 mb and 300 mb maps shows their directions to be largely the same, detrimental to the development of supercells.

Several other synoptic conditions suggested that Southeastern Wisconsin would be ground zero for the development of strong thunderstorms. The four-panel plot of Figure 3 shows that largely independent factors were priming the environment for a storm break out. In the upper left hand corner, positive vorticity advection is strongly represented in the NE Illinois/SE Wisconsin region. This suggests large-scale upward vertical motion in the vicinity.

Bolstering this claim is the strong Q-vector convergence in the region, shown in the upper right hand corner, showing that ageostrophic conditions were also in place for a storm outbreak, perhaps caused by the aforementioned jet streak. It also seems that this highly localized upward vertical motion was pooling moisture from around its area, creating strong moisture convergence (lower left corner) in the region. In addition, convective temperatures in the region of ~26 degrees Celsius suggest that the conditions were just below surface-based convection.

Many of these conditions manifested themselves within the sounding taken at Green Bay, WI at the same time (Figure 4). Green Bay was selected since it is nominally in the same flow as Milwaukee, as depicted in the streamlines of Figure 1. Unfortunately, technical difficulties inhibited winds from being detected at the higher levels. However, as we will see, upper level winds do not play a significant role in this storm. Instead, notice the substantial moisture throughout the column of air.

IV. Mesoscale Analysis

A. Dryline

One of the more unusual features of this case was the development of a dryline throughout Central Wisconsin and Central Illinois. Typically, a dryline is associated with an elevated mixed layer leaving a mountain plateau. Certainly, the terrain near Wisconsin is insufficient to create such a mesoscale feature. Hence, another explanation must account for the dry line development.

Figure 5 shows the evolution of the dryline from 12z on March 8 to 00z on March 9. A notable feature of this dryline is its absence in the early morning and midday hours. In a ‘typical’ dryline, the dryline persists throughout the day and moves eastward as the diurnal heating eats through the inversion layer. The dryline of this particular system only begins to form in earnest around 20z, only a few hours before the storms develop in Central IL. Between 20z and 00z, it does begin to push off to the east, though it is likely being advected by the flow.

The cause of this dryline is most likely a result of the region of high moisture convergence in the Northern Illinois/Southern Wisconsin region, analogous to the Gulf of Mexico moisture that pervades to the east of the West Texas dryline. However, unlike many of the drylines that occur in the Desert Southwest, the well-mixed layer in this region was likely the result of convective overturning at the surface. As the sounding taken in Davenport, IA at 00z on March 9 (Figure 6) shows, much of the momentum in the mid-levels of the atmosphere had been transferred to the surface, resulting in very strong winds. As this development moved off to the east, it forced vertical ascent in the region, as the dry air, backed by the strong winds behind the dryline, undercut the warm, moist air. The sharp contrast of the dryline is illustrated in Figure 7.

B. Influence of Lake Breeze

Though it is easy to see how instability in the atmosphere and a surface boundary as a dryline can trigger convection, much difficulty lies in determining the exact mechanism by which the tornado formed. In fact, the official National Weather Service narrative on this storm system suggests that either a preceding storm outflow boundary or a lake breeze influenced the tornadogenesis that we see in this region. However, radar returns suggest (see Section III.C) that no outflow boundary existed near the storm that produced the tornado. Additionally, surface observations just before tornadogenesis (Figure 8) suggest that the Milwaukee-Racine-Kenosha corridor was under the influence of a lake breeze, as their temperatures are lower than the surrounding temperatures, especially in Racine County.

The lake breeze-tornadogenesis tornado scenario posited in this case study is often called a “landspout.” First defined by Bluestein (1985), a landspout is a tornado that is not the result of a mesocyclone, and is often short-lived and relatively weak. *Prima facie*, this case is an excellent example of such an event. However, more extensive work by Wakimoto and Wilson (1989) suggested that more concrete conditions are required for the development of these landspouts. Thus, this paper will analyze if this case fit the idealized structure of a non-supercell tornado.

The work of Wakimoto and Wilson (1989) suggests that “landspouts” are the result of low-level convergence vortices. As these zones of convergence come under the influence of updraft regions, they are rapidly stretched vertically. This creates short-lived tornadoes that reach an intensity of no more than F2 or F3 status. Frequently, these circulations occur off the Rocky Mountains in Eastern Colorado, where the intersection of northwesterly flow out of the mountains intersects with southeasterly flow.

One of the unique challenges of these storms is that they often appear on radar only 20 km from the radar site. Thus, it is important that forecasters have an understanding of the conditions that cause these storms, even if they are unable to detect them from radar. Especially in our case, where radar data was available only from 100 km away (at the very bound of radial velocity data), a conceptual understanding is critical to the analysis of these types of events.

Caruso and Davies (2005) in an internal National Weather Service paper shed significant light on the operational aspects of detecting these storms. Much like Wakimoto and Wilson, Caruso and Davies stress the importance of low-level convergence and vorticity fields. Typically, these fields develop *misocyclones*, which are low-level vorticity structures that are extremely small in nature, between a few meters and tens of kilometers. In addition, the region must be conducive to significant rapid development of updrafts; hence their must be limited convective inhibition (CINH) and relatively high values of convective available potential energy (CAPE). It is also critical that very steep lapse rates occur at lower levels, implying that the CAPE is very close to the surface. Lastly, the atmosphere must not have significant shear, which would favor the development of mesocyclones over non-mesocyclone tornadoes.

C. Set up of Lake Breeze Influences

Without the proper thermodynamic support for rapid tornadogenesis, any misocyclone development along a boundary would be rendered ineffectual. To analyze the vertical structure near this time, the Lincoln, IL sounding (Figure 9) seems most reasonable, since it is nominally ahead of the dry line. Many of the features critical to the development of a non-mesocyclone tornado are prevalent in this Skew-T. CAPE values (corrected for virtual temperature, at the suggestion of Caruso and Davies) approach 1000 J/kg. Though this is not particularly powerful, it should be noted that the Boone-Kenosha-Racine-Milwaukee corridor was a region of intense moisture convergence and warmer surface temperatures than Lincoln, IL. We can expect larger CAPE values in the vicinity of these storms. In addition, low-level lapse rates are approaching the dry adiabatic rate, to promote rapid updrafts. This particular Skew-T also has relatively low CINH values, which would be lower near greater moisture and surface heating. Finally, wind shear is practically non-existent, with Bulk Richardson numbers hovering around eight, grossly insufficient for the development of supercells. The vertical structure was well suited for the development of a non-supercell tornado.

Unfortunately, it is exceedingly difficult to "prove" that a lake breeze exists in the region. However, several clues indicate that a lake breeze is certainly having an impact in the Milwaukee area. Both temperatures (Figure 8) and the wind barbs beneath the streamline analysis (Figure 1) imply that a definite breeze is blowing of the lake. Merely from a qualitative standpoint, such strong surface heating on land coupled with a cold Lake Michigan surface temperature (typically around the upper 30's according to the NWS) strongly supports the development of a lake breeze. Combining the various aspects of this case into a cohesive 'roadmap,' Figure 10 shows the fortuitous set up. Without serendipitous positioning of key factors, it is unlikely that this tornado would have ever seen the light of day.

D. Radar Manifestation of Storm Development

For the casual observer, the radar development of this storm is a remarkable sight. Though perhaps not as large or powerful as mesocyclone based tornadoes, such a surprise event maintains a certain *je ne sais quoi*. It stands as a testament to the unpredictability of the atmosphere. For forecasters on duty, both at Milwaukee/Sullivan and the Storm Prediction Center, the confluence of events on this day likely hearkened back to the days of minimal lead warning time and a reliance on storm spotters for the issuance of tornado warnings, a most unenviable position.

The radar development of this storm (Figure 11 a-c) is, without risk of hyperbole, explosive. This is exactly the sort of updraft necessary to stretch a misocyclone into vortex. Within 11 minutes (from 23:07z to 23:18z), the maximum radar returns jump nearly 30 dBz, into the low 70's from around 40 dBz. Just 18 minutes later (23:35z), the storm develops a hook echo on its rear flank. All of this occurs as the storm moves closer to the lakeshore, reaching the outer extent of the lake breeze boundary and the likely location of the misocyclone.

Much of the literature on this topic attests that it is very difficult, if not impossible, to detect these storms on Doppler radar, particularly using radial velocity. However, a time sequence of radial velocity images from the same time as the base reflectivity (Figure 12 a-c) shows a similarly rapid development of a tornado vortex signature. One inconsistent feature in this radar scan is the large section of velocities directed towards the radar in 12b. This might lead one to believe that outflow boundaries are more likely to be playing a role in the development of this tornado. However, inspection of the reflectivites in the same region (the Walworth-Racine-Kenosha county border region) shows that the reflectivites are similarly disorganized. It is likely that the misocyclone was being rapidly integrated into the convective system, and that this particular radar scan caught the maximum extent of the misocyclone (about 10-15 km).

V. Discussion

The peculiar circumstances of March 8, 2000 resulted in equally unusual weather. A surface dryline, during winter, touched off what seemed to be largely insignificant convection in Northeast Illinois. However, a misocyclone generated by a lake breeze was rapidly incorporated by one particular storm with a strong updraft, the perfect recipe for the development of a non-supercell tornado.

The National Weather Service, the National Severe Storms Laboratory, and the Storm Prediction Center are all very concerned about the high degree of unpredictability of non-supercell tornadoes. A survey of their websites reveals specific instructions to forecasters on the detection of these storms, and admonishes them to not rely too heavily on NEXRAD data and trust professional storm spotters. In particular, they share a concern that the once underpopulated regions of the country (namely, Eastern Colorado) that typically have these sorts of events are becoming more populous, creating a dangerous situation of unpredictable tornadoes and an unsuspecting populace.

Fortunately, increased population will bring enhanced incentive to study these unusual storms and provide for greater observation and analysis of their events. As this case study has shown, greater spatial resolution (such as the MESONET in Oklahoma) would likely allow for more accurate identification of these small-scale patterns. At any rate, the events of March 8, 2000 served to enhance the myth and lore of Wisconsin winters.

VI. Acknowledgements

The author thanks Holly Hassenzahl for providing much of the data incorporated into this paper, and Professor Greg Tripoli for many of the concepts included herein. Additionally, the author thanks Prof. Bennartz, Ackerman, and Mr. Mark Kulie for their excellent radar meteorology course, which allowed for easy identification of key features. The author also thanks the University of Wyoming for the upper air data, Plymouth State University for surface observations and model reanalysis, and the NCDC for radar data.

VII. References

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Caruso, James M. and Davies, Jonathan M., 2005: Tornadoes in Nonmesocyclone Environments with Pre-existing Vertical Vorticity along Convergence Boundaries. *Electronic Journal of Operational Meteorology*, 1 June 2005.

Wakimoto, R. M., and J. W. Wilson, 1989: Non-supercell tornadoes. *Mon. Wea. Rev.*, **117**, 1113-1140.

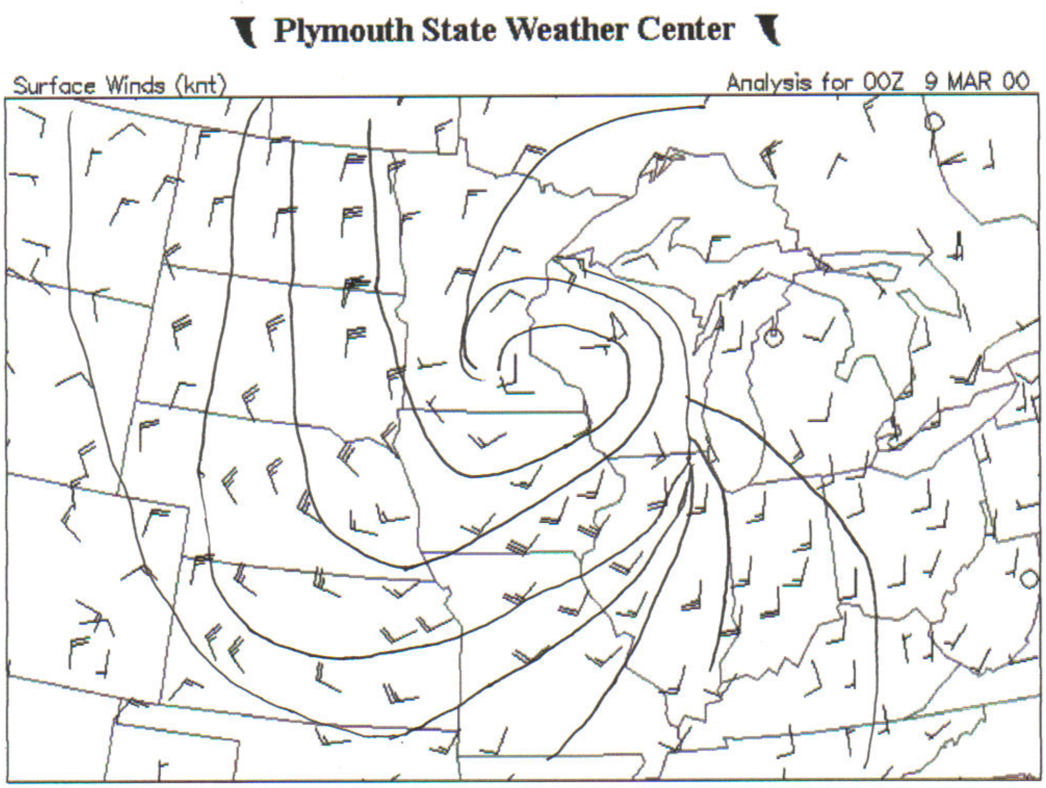


Figure 1. Surface Streamlines at 00z March 9, 2000. From Plymouth State.

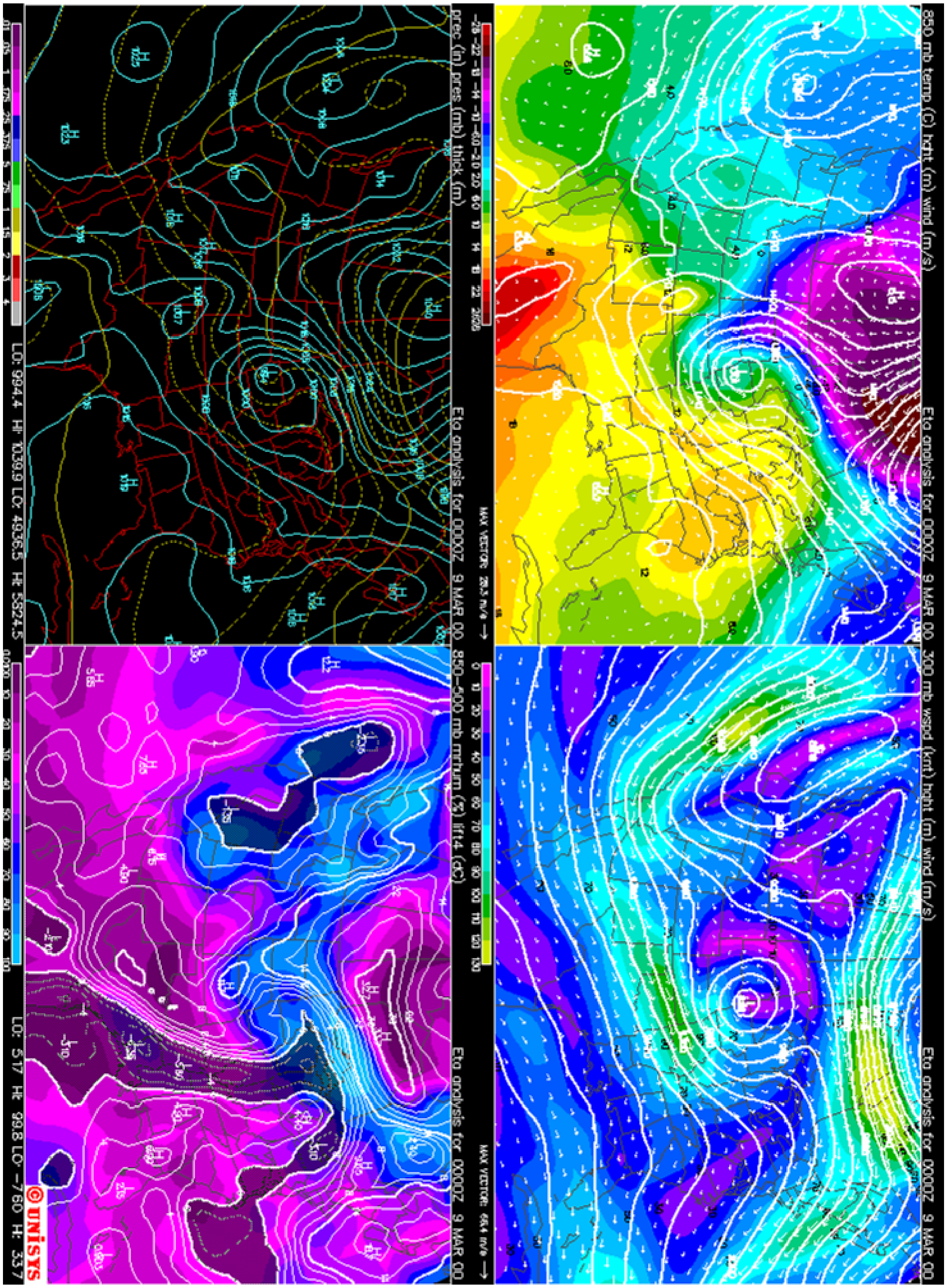


Figure 2. Four panel plot, as described in the text, of synoptic conditions on March 9, 2000 at 00z. From UNISYS Weather.

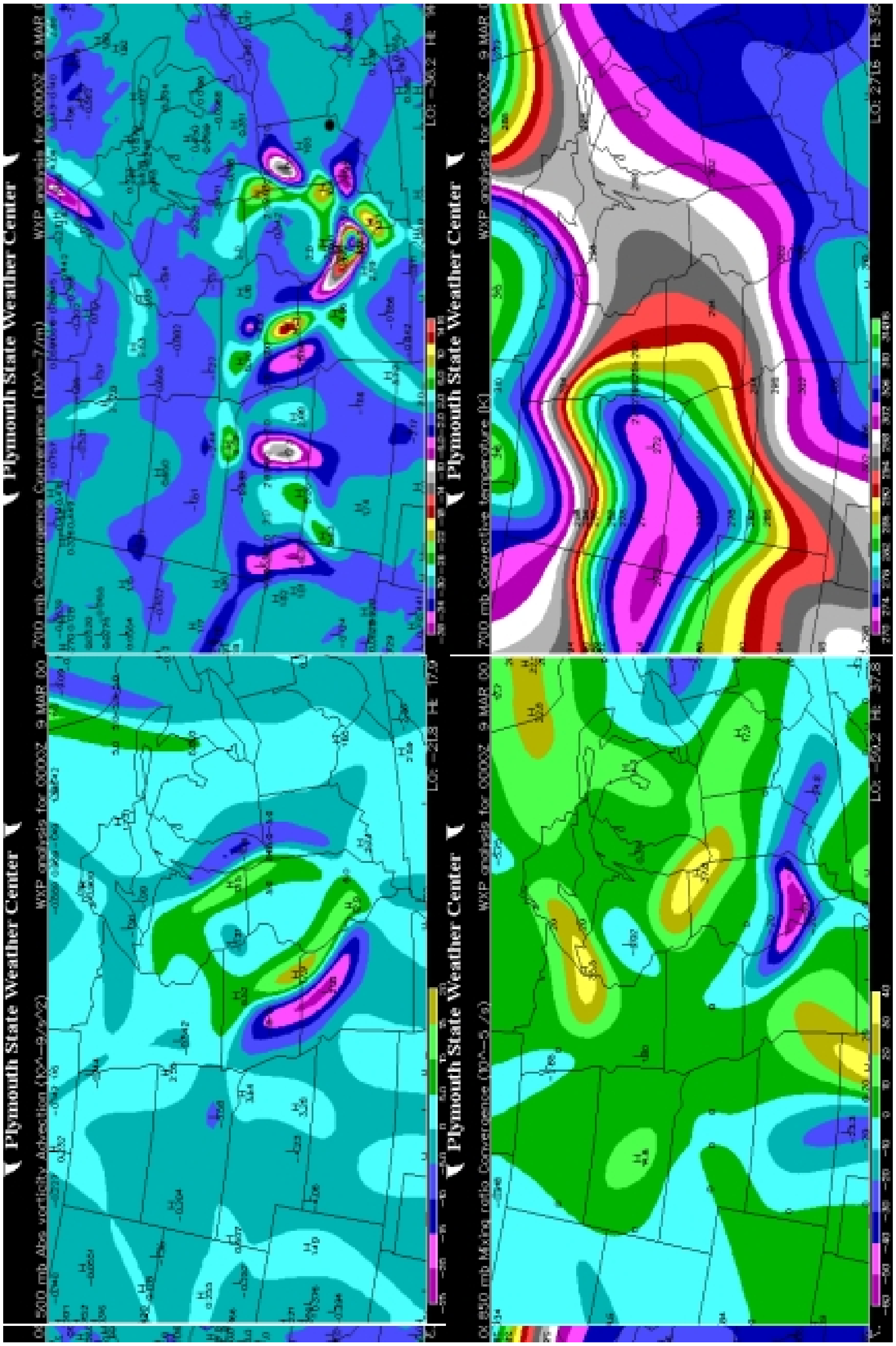


Figure 3. Four panel plot, as described in the text, of derived synoptic measures on March 9, 2000 at 00z. From Plymouth State University.

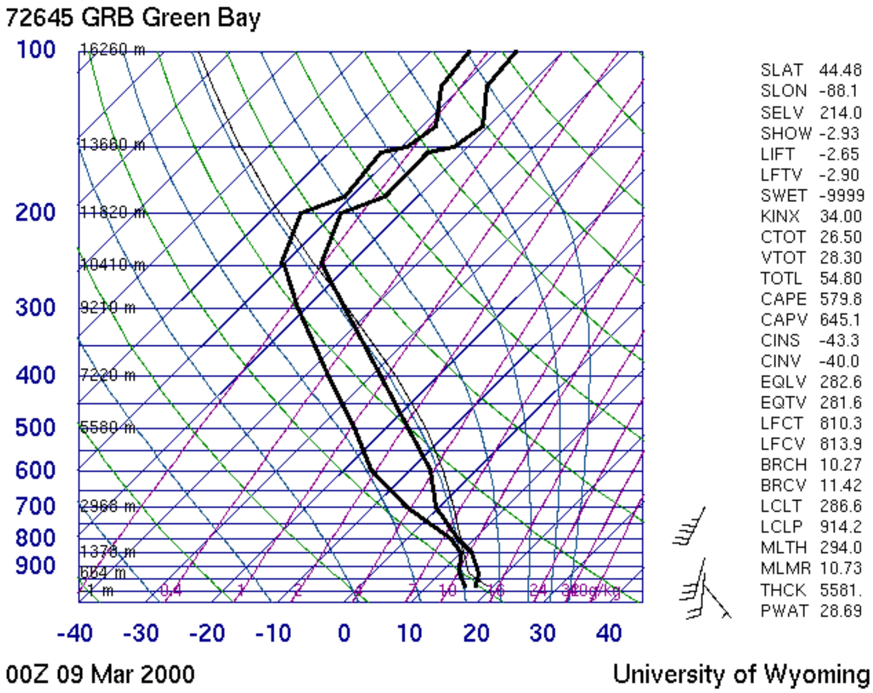


Figure 4. GRB Sounding at 00z 9 March 2000. From UWYO.

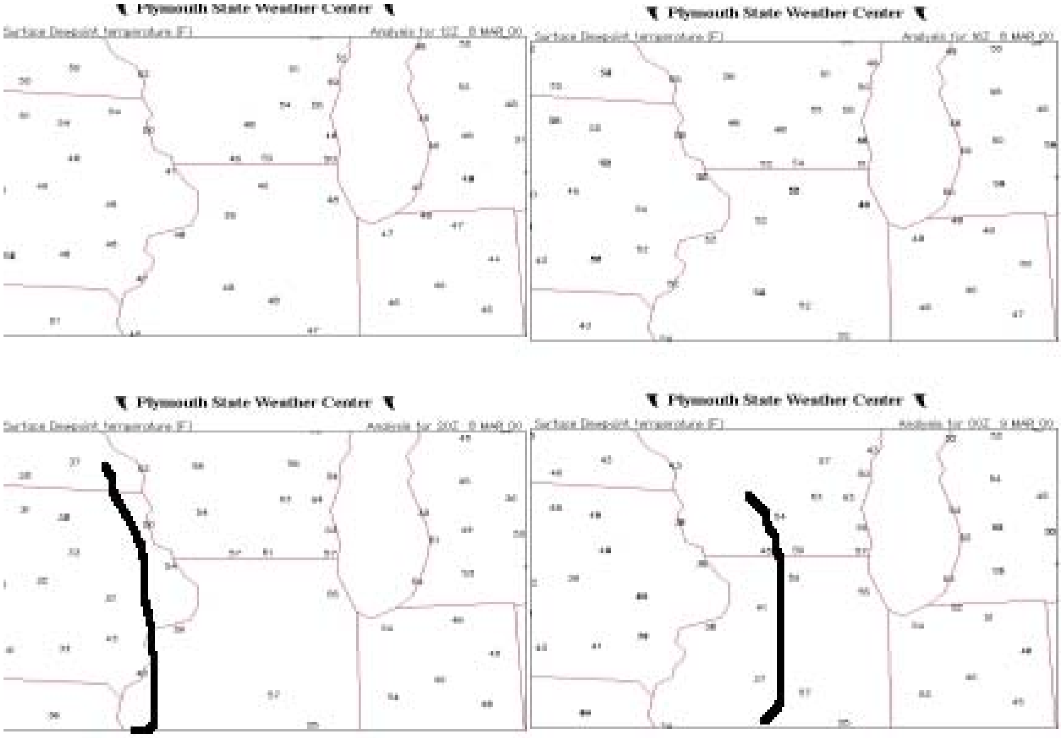
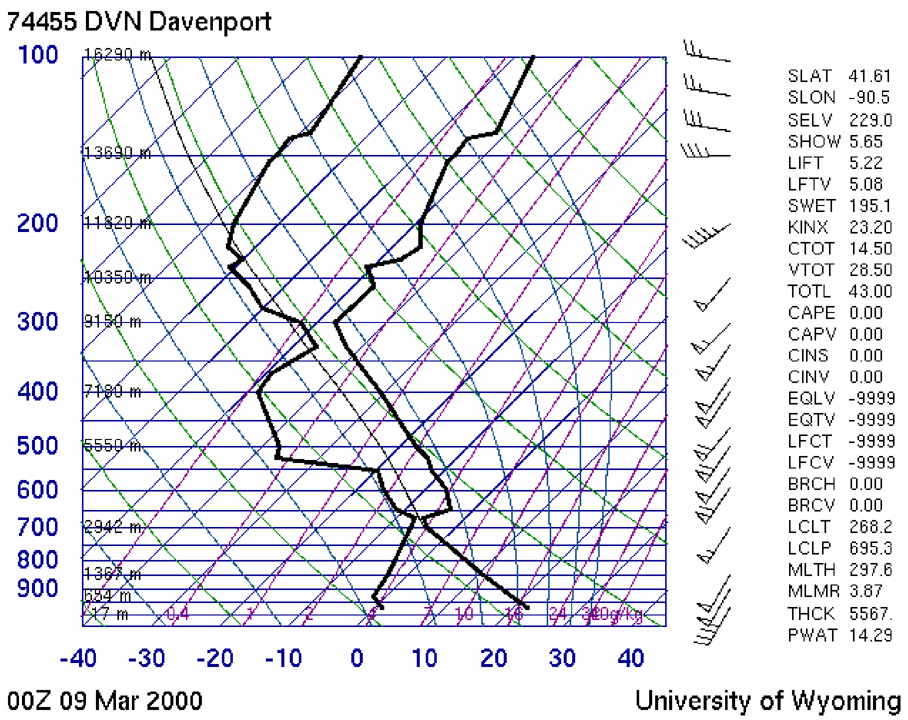


Figure 5. Development and Progression of Dryline. From Plymouth State.



SLAT	41.61
SLON	-90.5
SELV	229.0
SHOW	5.65
LIFT	5.22
LFTV	5.08
SWET	195.1
KINX	23.20
CTOT	14.50
VTOT	28.50
TOTL	43.00
CAPE	0.00
CAPV	0.00
CINS	0.00
CINV	0.00
EQLV	-9999
EQTV	-9999
LFCT	-9999
LFCV	-9999
BRCH	0.00
BRCV	0.00
LCLT	268.2
LCLP	695.3
MLTH	297.6
MLMR	3.87
THCK	5567.
PWAT	14.29

Figure 6. GRB Sounding at 00z 9 March 2000. From UWYO.

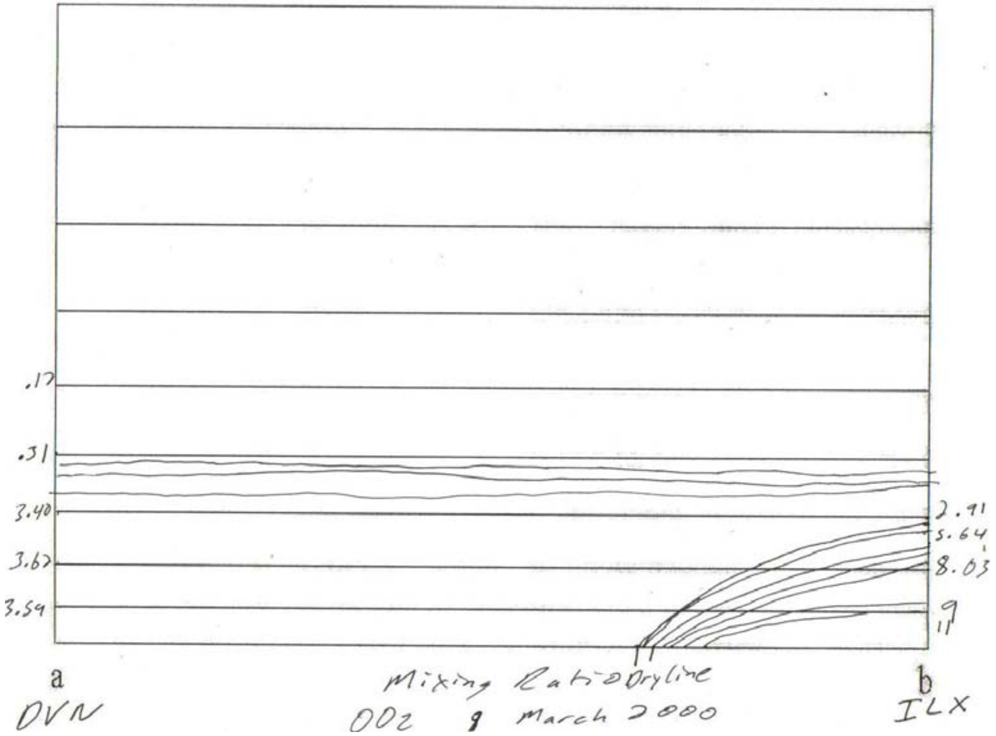


Figure 7. Davenport to Lincoln Cross Section of Mixing Ratio (each line is 1 g/kg).

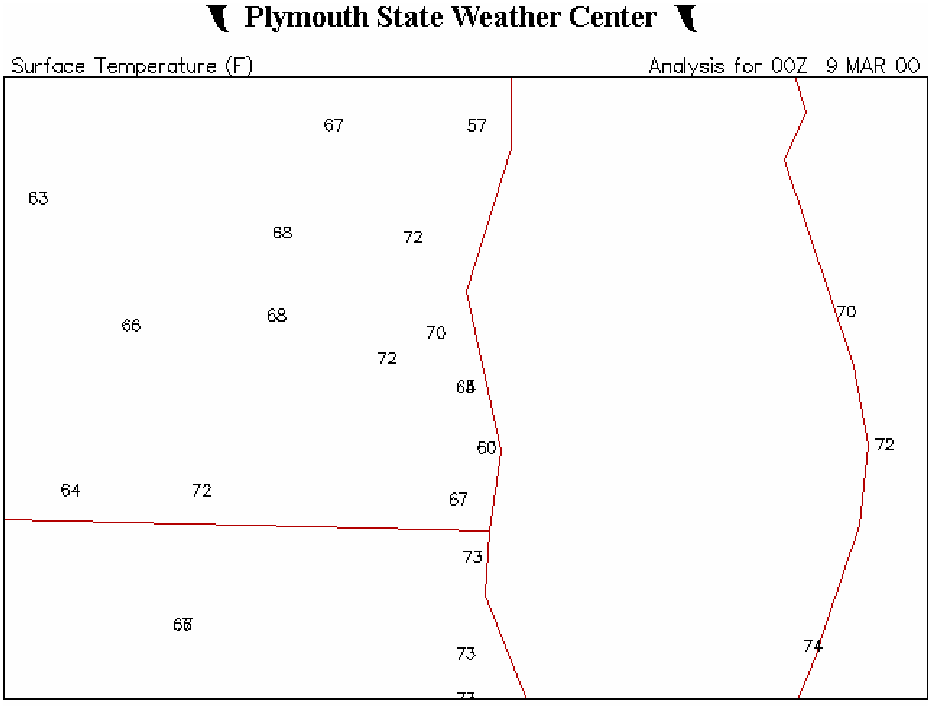


Figure 8. 00z Surface Temperatures. Notice the sharp contrast between Waukegan and Racine.

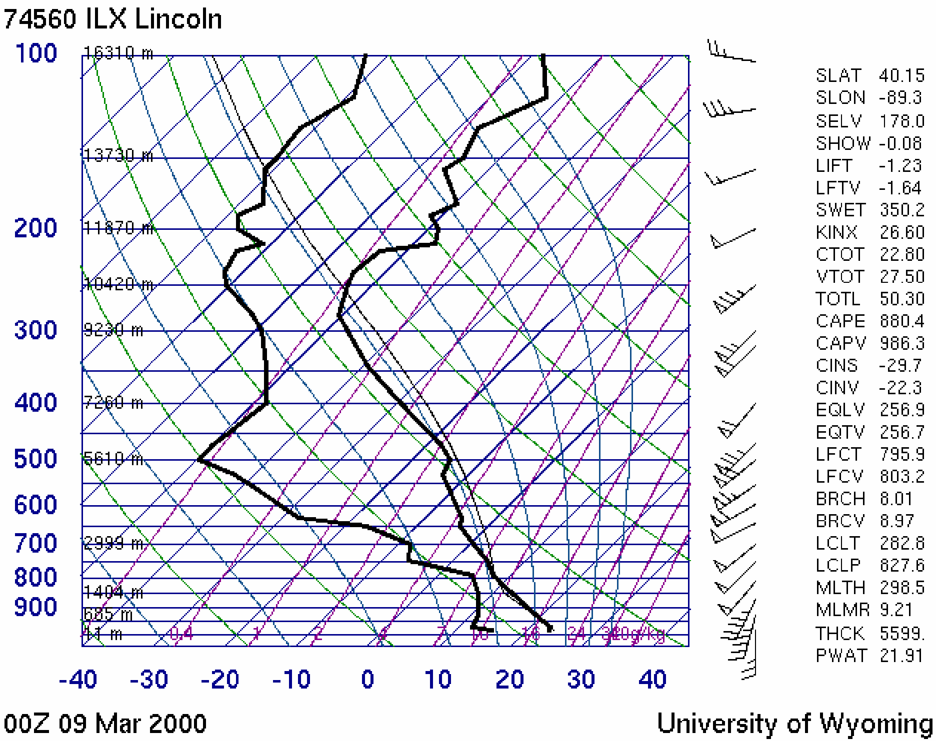


Figure 9. ILX Sounding at 00z 9 March 2000. From UWYO.

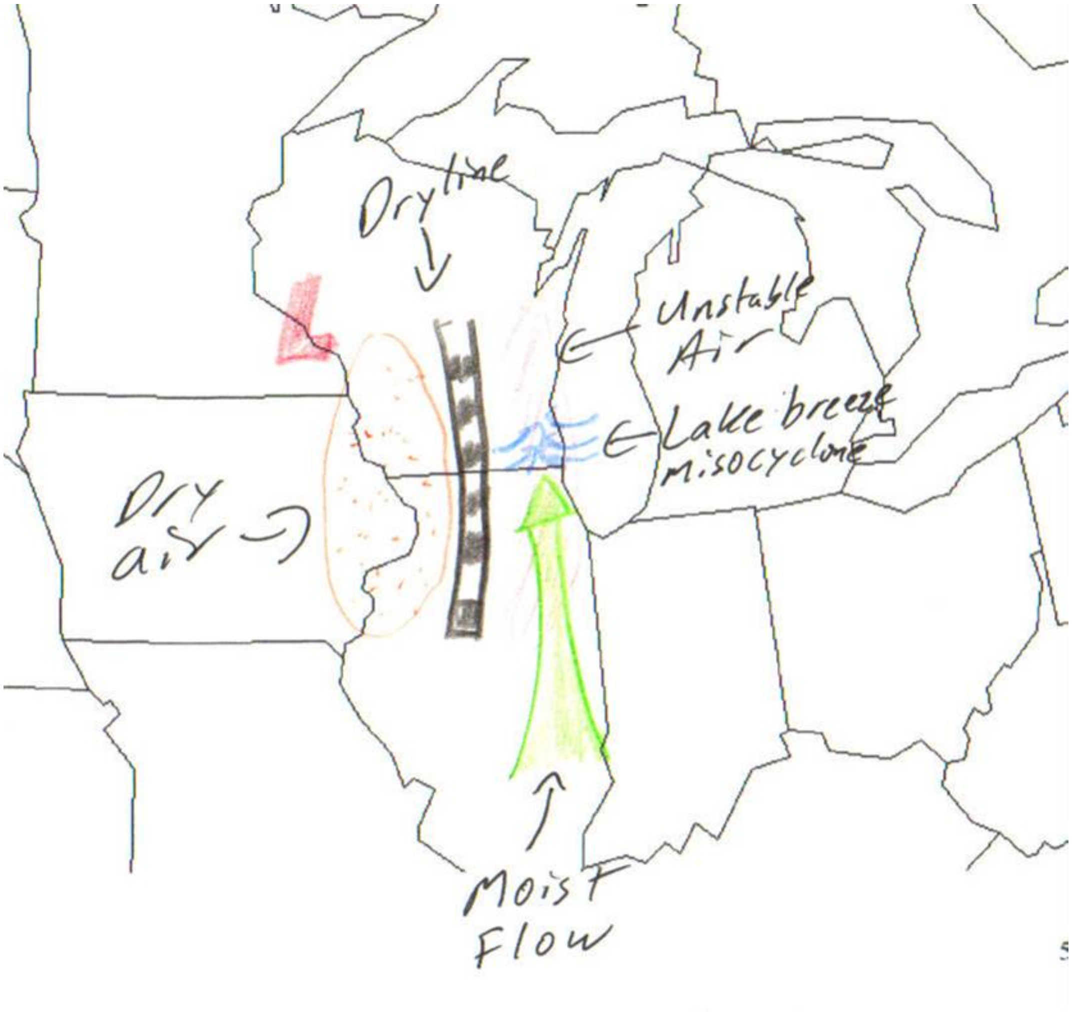


Figure 10. Schematic of the development of the non-supercell tornado.

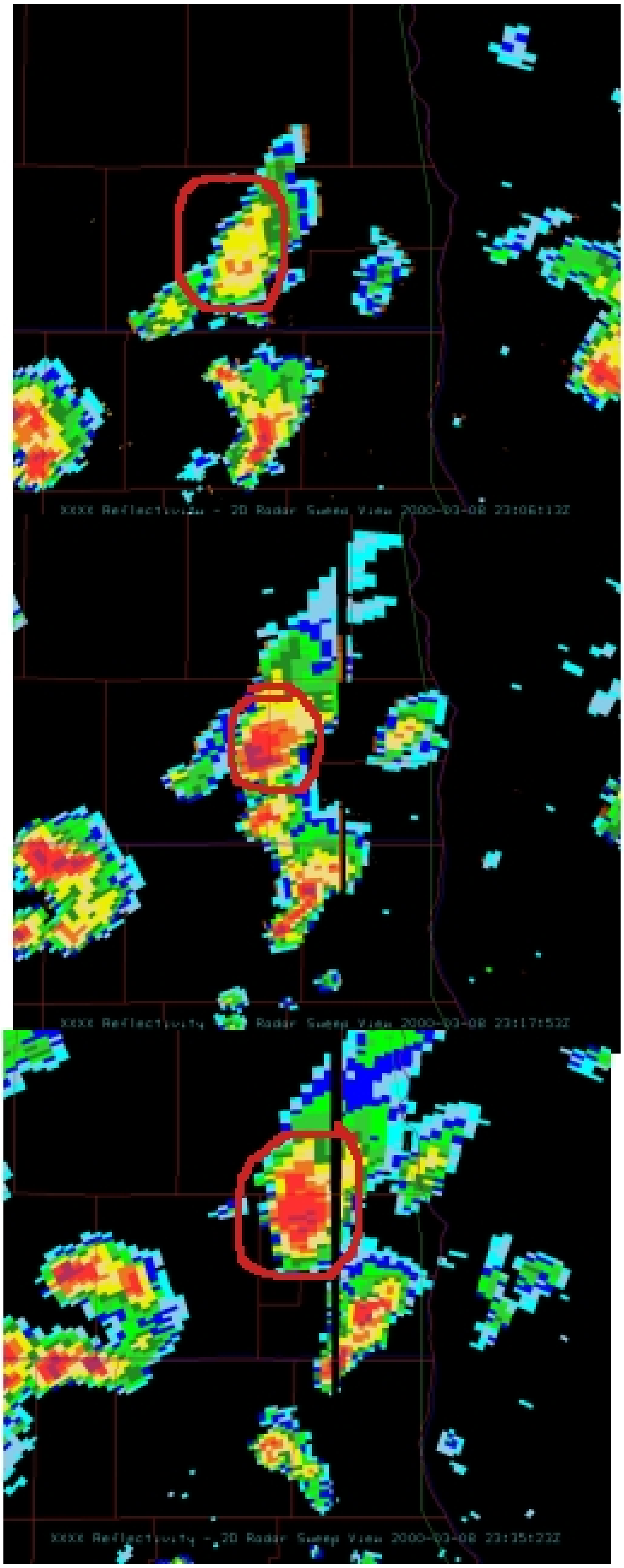


Figure 11 a-c. Radar reflectivity (1.5 degrees) of tornado.

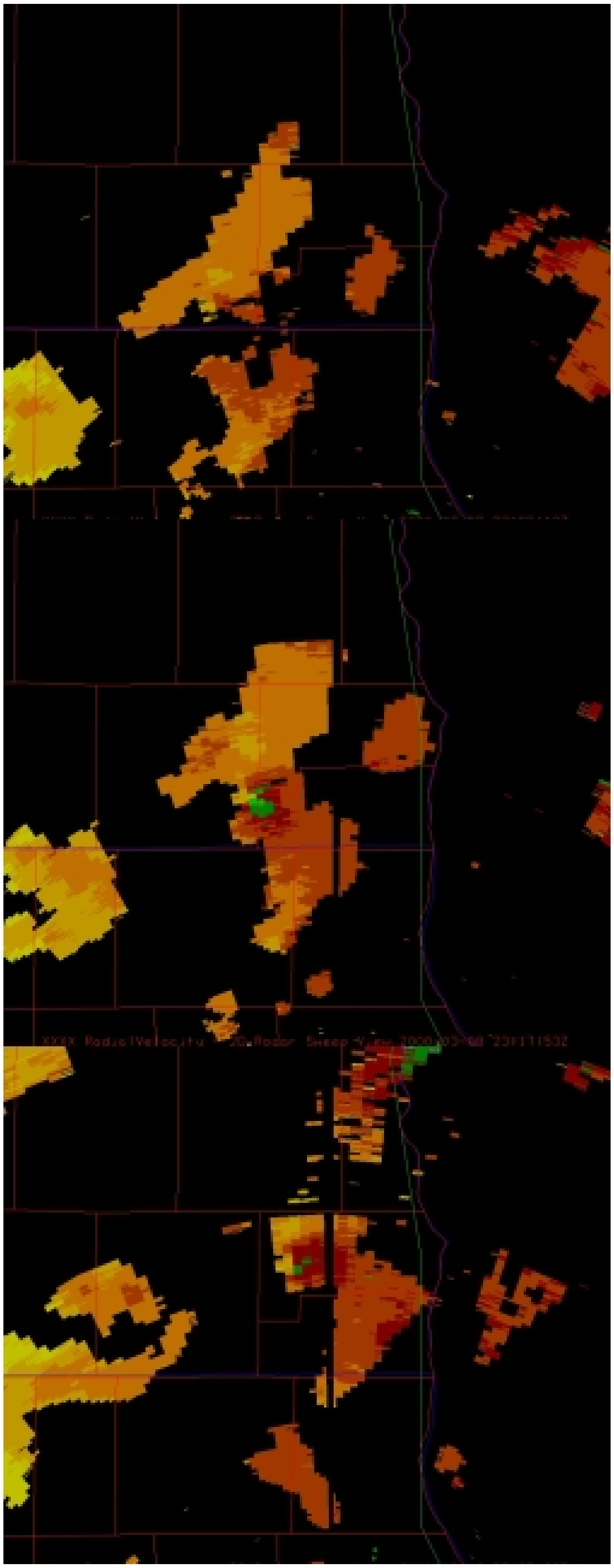


Figure 12 a-c. Radial velocity reflectivity (1.5 degrees) of tornado.