National Weather Service

Gaylord Michigan

The WFO Gaylord Science Corner

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Frontogenesis Explained

When a meteorologist forecasts tomorrow's weather, one of the most important elements they will try to predict is vertical motion within the atmosphere. This is critical since upward vertical motion results in cooling, moistening, and better chances for precipitation. Downward vertical motion, on the other hand, results in warming, drying, and lower chances for precipitation.

One very important constraint in the atmosphere that impacts vertical motion is referred to as "thermal wind balance". Thermal wind balance defines the relationship between mass and momentum in the atmosphere, and essentially requires strong horizontal temperature gradients (mass) to be located in areas of high vertical wind shear (momentum). When this balance between the horizontal temperature gradient and vertical wind shear is lost (a very common condition in the atmosphere) the atmosphere makes adjustments in an effort to re-establish balance. These adjustments, and the corresponding areas of upward and downward vertical motions, give us weather. Forecasters observe this attempt by the atmosphere to maintain balance every day; noting that jet structures aloft (high vertical wind shear) are frequently located near low and mid tropospheric frontal boundaries (strong horizontal temperature gradients). Not coincidentally, this is also where the weather is frequently most active.

One way meteorologists quantify, track, and

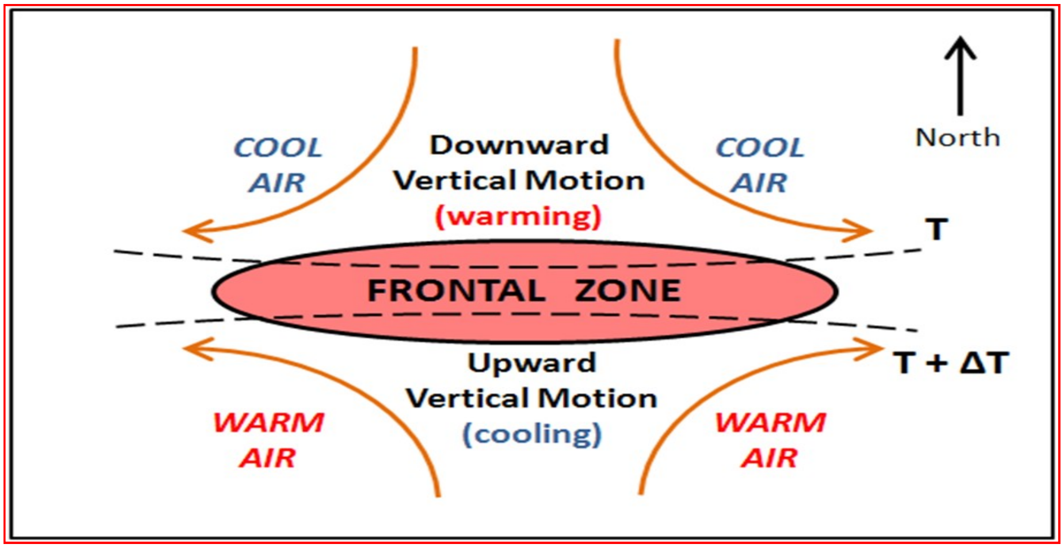

Figure 1. A top-down or plan view showing frontogenesis. Confluent winds (shown in orange) are causing the temperature gradient (dashed lines) to tighten within the frontal zone. Enhanced upward vertical motion occurs on the warm (south) side of the frontal zone, with enhanced downward vertical motion on the cool (north) side.

predict vertical motion associated with departures from thermal wind balance is through frontogenesis. **Frontogenesis is defined as an intensification of a temperature gradient at the surface or aloft.** Areas of active frontogenesis are typically referred to as “frontal zones”, and are often the result of horizontal changes in the wind (i.e., patterns of confluent or diffluent flow).

When frontogenesis occurs, a thermally direct circulation is produced. In other words, air ascends and cools on the warm side of the frontal zone, while air descends and warms on the cool side of the frontal zone (see Figure 1 on previous page). As Figure 2 shows, frontal zones generally slope upward toward cold air. Thus, the vertical component of the circulation will be sloped with height toward cold air. The horizontal components of the frontogenetic circulation consist of an acceleration of air parcels from cold-to-warm air in low levels and from warm-to-cold air at upper levels. These atmospheric adjustments act to weaken the thermal gradient that frontogenesis initially strengthened. In other words, the atmosphere attempts to maintain thermal wind balance by cooling the warm side and warming the cool side of the frontal zone.

Frontogenesis occurs throughout the year, and often results in mesoscale bands of heavy precipitation just to the south (or warm side) of the frontogenesis maximum. During the cool season, locally intense snowfall often accompanies frontogenesis. Snowfall rates of 1-3 inches per hour are not uncommon.

In Area Forecast Discussions (AFDs), meteorologists commonly abbreviate frontogenesis with “FGEN”. So, the next time you see FGEN in an AFD, you’ll know that the horizontal temperature gradient is intensifying, thermal wind balance is being disrupted, and forecasters are trying to anticipate how the resulting atmospheric adjustments may impact clouds and precipitation.

Bruce Smith
Science and Operations Officer

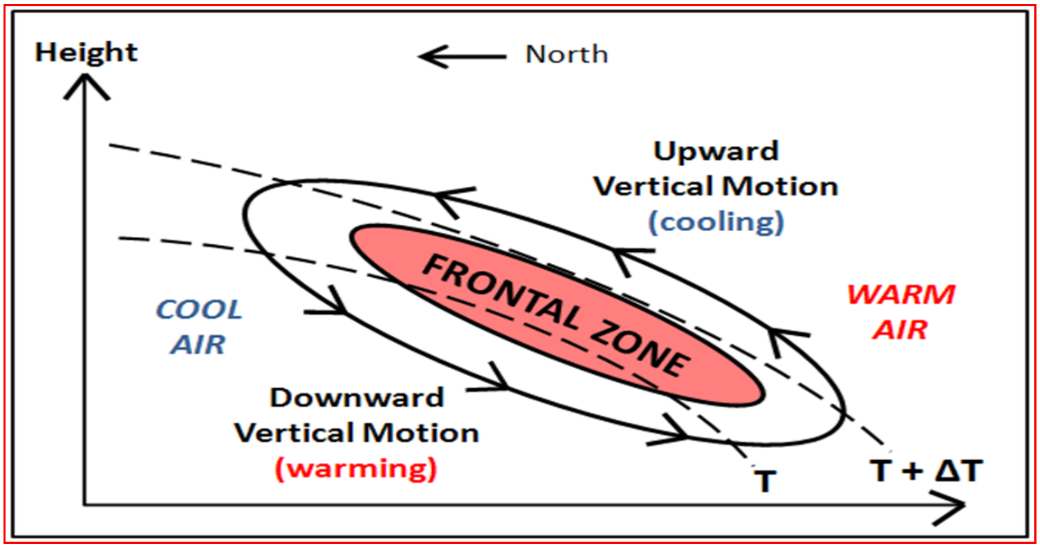

Figure 2. A vertical cross section showing active frontogenesis within a frontal zone. Enhanced upward vertical motion occurs on the warm (right-hand) side of the frontal zone, with enhanced downward vertical motion on the cool (left-hand) side. Dashed lines depict potential temperature.

Frontogenesis results in the development of a thermally direct circulation, where air ascends on the warm side of a developing thermal gradient, and sinks on the cold side.

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Questions? Comments?
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Frontogenesis At Work: A Look at an Enhanced Snowfall Event

After taking a look at the science behind frontogenesis, now let's focus on an example from this past winter season. Specifically, we will review an event from 21 November 2007. In this event, a sloped band of frontogenesis generated an enhanced band of heavy snow from southwest Wisconsin into northern Lake Huron. This band of snow impacted northern Lower Michigan between the Straits of Mackinac and M-72.

The event was characterized by an elongated area of surface low pressure across the Ohio Valley (Figure 1). The *surface* front was located over the Ohio Valley, and was associated with mainly light precipitation across the southern Great Lakes. However, the Green Bay radar (Figure 2) reveals an enhanced band of snowfall from southeast Wisconsin to Northern Michigan, producing snowfall rates of 1 to 2 inches per hour.

So, what was behind these significant snowfall rates so far removed from the surface low and front?

The answer is Frontogenesis. As described in "Frontogenesis Explained", it is important to remember that frontal zones typically slope upward toward colder air. Figure 3 shows winds and temperatures at 650mb, or about 11,000 feet above the ground. As you can see in the figure, the confluent nature of the winds is acting to tighten the horizontal temperature gradient (i.e., frontogenesis). Along the axis of confluent flow is where the frontal zone aloft is located. Just on the warm or south side of this frontal zone is where the enhanced band of precipitation developed.

Although the frontal boundary at the surface was in the Ohio Valley, the frontal boundary aloft at 650mb was over northern Michigan. Figure 4 shows a cross section through the frontal zone. If you look closely on Figure 4, you can see a maximum area of frontogenesis aloft approximately over Northern Lake Michigan (near 650mb). This corresponds roughly to the enhanced mesoscale band of snow observed on the Green Bay radar.

In review, this case illustrates the importance of using a three dimensional approach when forecasting the weather. The most important features are not always

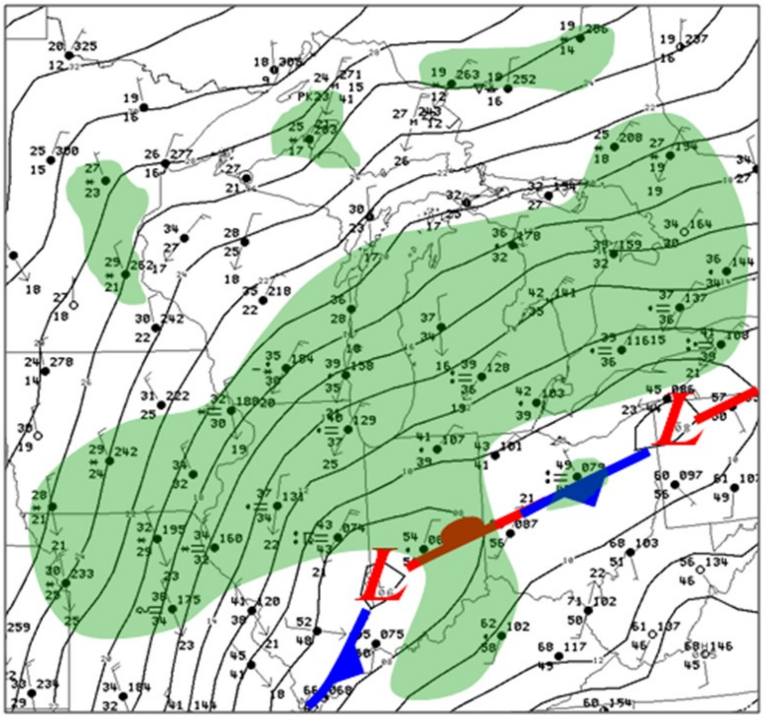

Figure 1. Surface pressure and frontal analysis valid 700 pm on 21 November 2007. The shaded green areas represent ongoing precipitation.

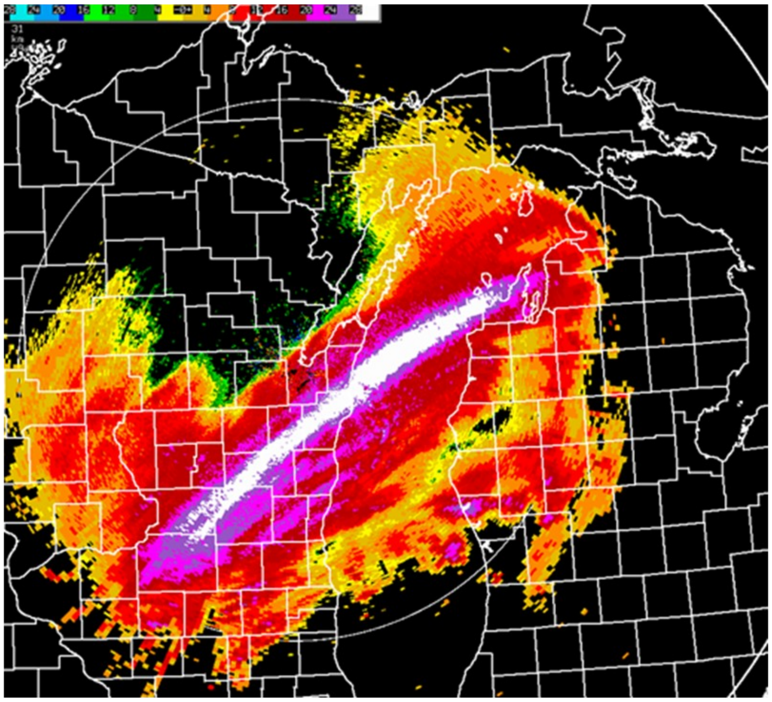

Figure 2. Green Bay (KGRB) radar valid 700 pm 21 November 2007. Purple and white shades represent an enhanced mesoscale band of snowfall generated by frontogenesis aloft. Snowfall rates of 1 to 2 inches per hour were common beneath this snow band.

located at the surface. Frontogenesis often occurs on a sloped frontal zone and can lead to enhanced precipitation a considerable distance away from the surface front. In this event, enhanced frontogenesis at 650mb generated by confluent winds tightening the temperature gradient led to an enhanced band of snowfall. This band of snowfall eventually led to 3 to 6 inches of snow falling across portions of northern Michigan during the evening hours November 21.

Kevin Sullivan

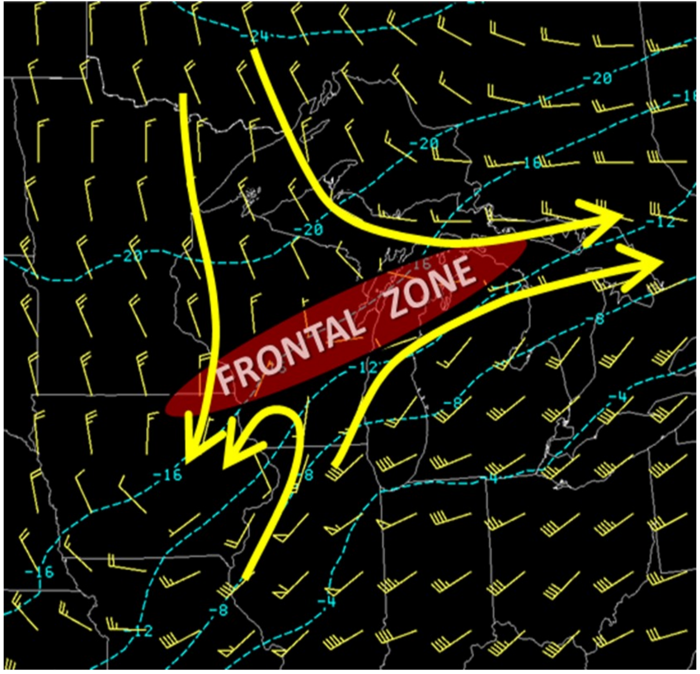

Figure 3. NAM model forecast winds and temperatures at 650mb, valid at 700 pm 21 November 2007. The confluent winds act to tighten the temperature gradient within the frontal zone.

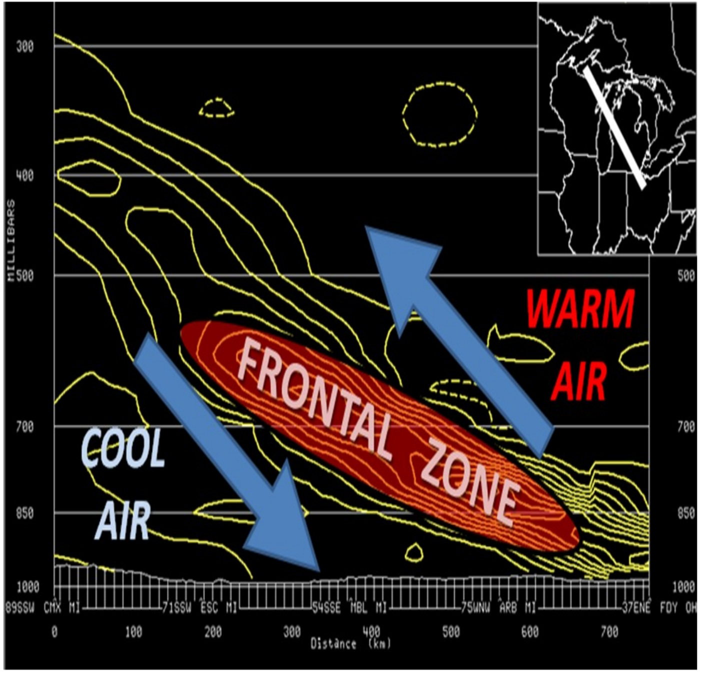

Figure 4. Cross section of 2-D Frontogenesis (yellow contours) valid 700 pm 21 November 2007. Left side of the image is near Ironwood, MI and the right side of the image is near Toledo, OH. Note the frontal zone sloping with height toward cold air. Enhanced upward vertical motion occurs on the warm side of the frontal zone.

BLIZZARD!

Two Storms in Two Weeks Hit Northern Michigan Hard

Two blizzard events within two weeks of each other during the end of January and early February resulted in some major impacts across northern Michigan...the first occurring during the period of 29-30 January, and the other on 10 February. Both events were preceded by unseasonably mild temperatures, with rain on the front end transitioning to lake effect/enhanced snowfall in the wake of a strong cold frontal passage. Although the snowfall amounts were not particularly heavy in either event, the combination of falling and blowing snow and subsequent blizzard conditions snarled traffic, closed roads, and shut down area schools for multiple days following these winter storms.

St. Ignace News

We'll be taking a look at these two events primarily from a wind perspective, since it is the wind component that sets blizzards apart from "other" winter storms. But first, let's review some of the factors that drive strong wind events.

Pressure Gradient Force

Horizontal pressure differences are what creates the wind, as air parcels are pushed around from areas of higher pressure toward areas of lower pressure. How strongly these parcels are pushed (the strength of the wind) is dependent on the magnitude of the pressure change between two points. This change in pressure between two points divided by the distance between the points determines the pressure gradient. The tighter the pressure gradient, or the greater the pressure difference over a given distance, the stronger the winds will be. Strong low pressure centers typically have stronger winds blowing around them due to the tight pressure gradient surrounding the system.

Vertical Momentum Transport

High wind events are typically aided by the mixing of stronger winds aloft down to the surface. There are several factors that assist in this process. One is low static stability within the boundary layer. The closer the lapse rate is to dry adiabatic, the more easily higher momentum aloft can be mixed down to the surface. Another is strong isentropic downslope flow within the lowest layers of the atmosphere, often manifesting itself as strong cold advection in the wake of a cold front. Parcels being "driven" down a sloped isentropic surface is an effective method of bringing higher momentum into the boundary layer.

Isallobaric Wind

The isallobaric wind can be thought of as a component of the ageostrophic acceleration due to local changes in pressure. Isallobars are lines of constant pressure tendency (usually expressed in units of millibars/3 hours). As with the pressure gradient force, air parcels will be accelerated from higher pressure tendency toward lower pressure tendency, and the magnitude of the acceleration is governed by the change in pressure tendency over a given distance (or the gradient of pressure tendency). Systems that are quick moving and/or deepening quickly tend to have significant pressure rise/fall "couplets", or centers of maximum and minimum pressure tendency, associated with them. Ageostrophic accelerations associated with these couplets can contribute to the strong winds associated with a weather system.

Let's take a look at how these three factors contributed to the strong winds associated with the two blizzard events.

29-30 January Event

The synoptic set up prior to the event was dominated by a strong temperature gradient across the upper Midwest and Great Lakes region (figure 1). During the evening of the 29th, temperatures across northern Michigan were in the upper 30s and 40s, while across North Dakota and Minnesota temperatures were in the teens below zero. Meteorologists both amateur and professional alike, know that the transition from a very mild regime to a very cold one can result in violent weather, and this was no exception. At 00z 30 January, the cold front was poised just west of the lower Peninsula, with a frontal wave over southern Lake Michigan. A negatively tilted mid level short wave trough (figure 2) was lifting northeast out of the middle Mississippi valley, which interacted with the frontal wave and resulted in rapid deepening of the system as it lifted northeast across the state and into northeast Ontario by the morning of the 30th (12mb deepening in 12 hours). Widespread rain showers occurred in the warm air ahead of the front, which quickly turned to snow as the cold front passed around midnight (figure 3). By 12z on the 30th, temperatures had dropped into the single digits above zero across northern Michigan (figure 4).

The strongest winds with this event set in several hours after passage of the cold front. Figure 5 shows 3 hour pressure tendency at 08z 30 January. Note the strong pressure rise/fall couplet extending from lower Michigan northeast to Georgian Bay, and the strong isallobaric gradient in place. The acceleration is oriented perpendicular to the gradient from high to low pressure tendency; in this case from the west and southwest. This is in the same basic direction as the surface wind flow, so the acceleration is adding to the surface wind velocity.

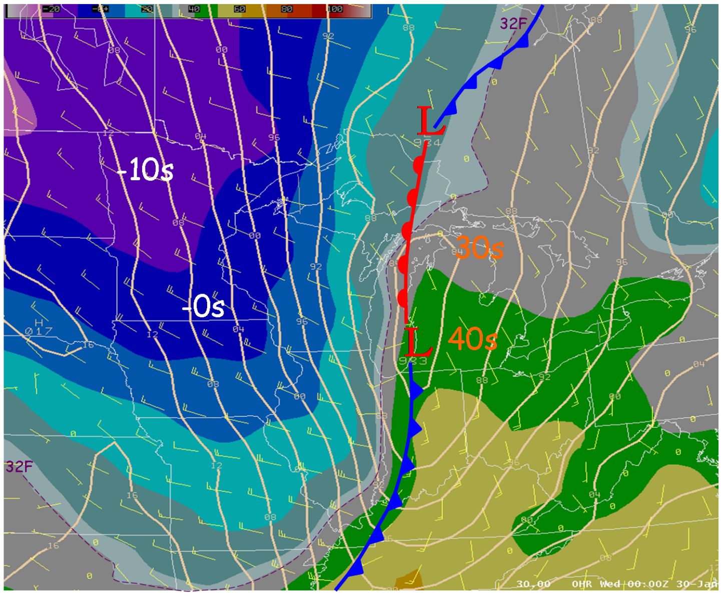

Figure 1. Mean sea level pressure (tan contours), surface wind barbs (yellow) and surface temperature (image) at 00z 30 January 2008. Dashed purple line marks the surface 32F isotherm. Temperature bands are every 10 degrees, except for the narrow white band, which depicts temperatures between 30-32F.

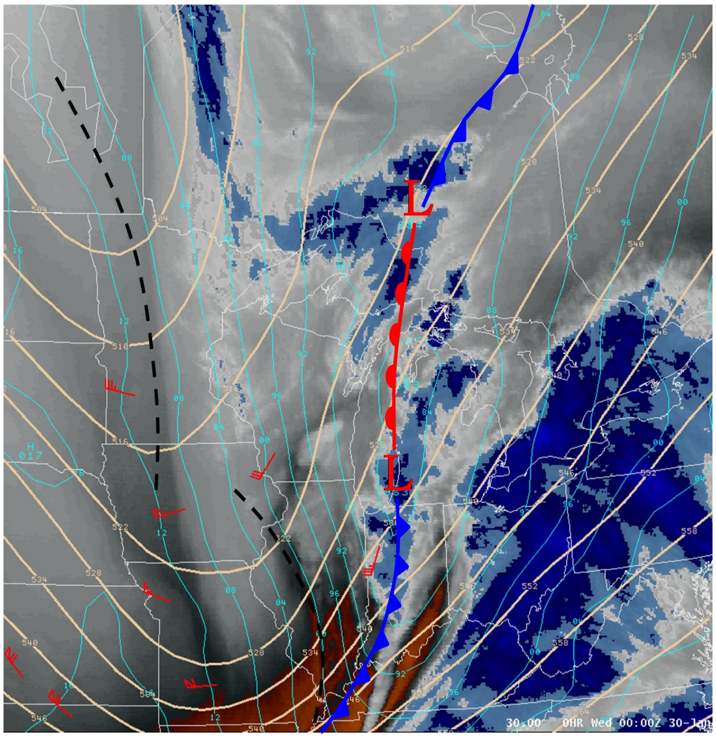

Figure 2. Water vapor image from 00z 30 January. Overlaid are 500mb heights (tan contours) and surface pressure (thin blue contours). Dashed lines mark 500mb short wave troughs, red wind barbs are winds at the 500mb level from the National Profiler Network.

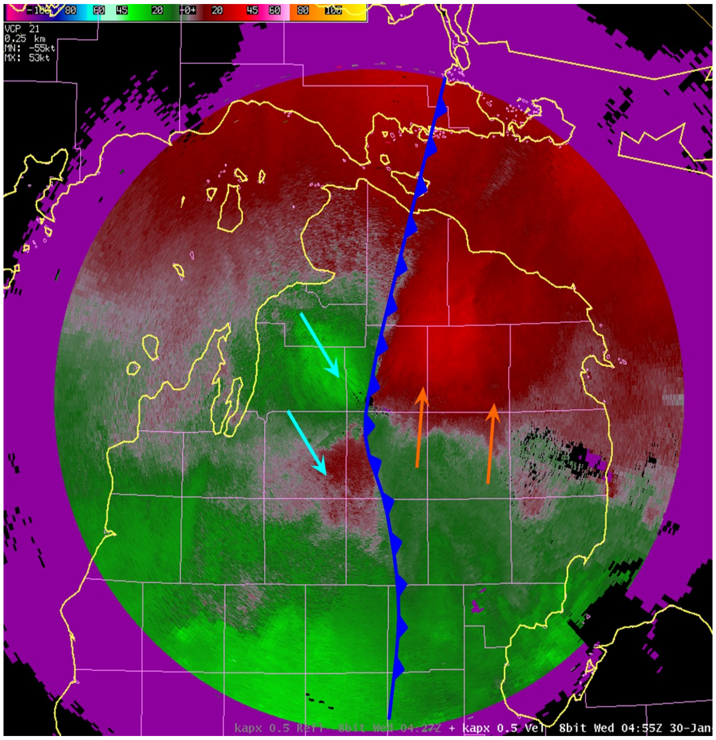

Figure 3. 0.5 degree base velocity product from the KAPX WSR-88D at 0457z 30 January...at the time the cold front was passing the radar. Wind flow as indicated by the radar shown by arrows; strong inbound velocities (brighter green) noted to the west and northwest of the radar (black dot) indicate winds just off the surface of 40kts.

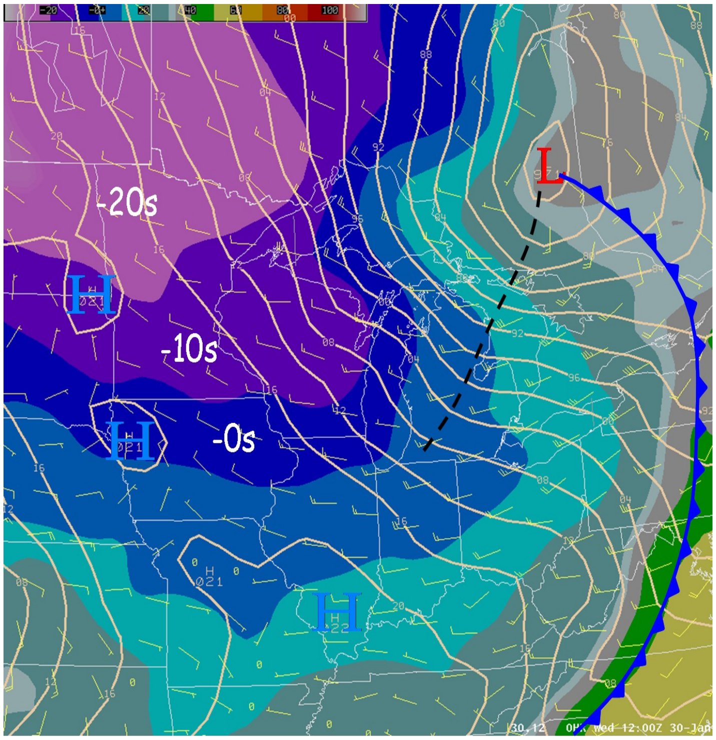

Figure 4. Same as figure 1, except at 12z 30 January 2008. Surface temperatures across Lower Michigan have dropped into the single digits above zero by this time.

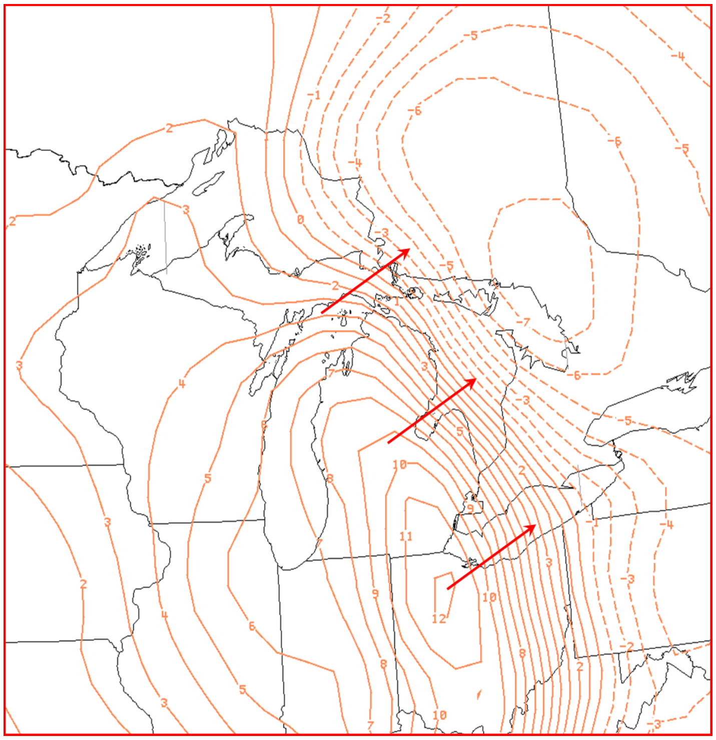

Figure 5. Three hour pressure tendency (isallobars in orange contours, units are millibars/3h) at 08z 30 January 2008. Red arrows depict direction of ageostrophic acceleration implied by the isallobaric gradient. Maximum pressure rise over northwest Ohio was 12mb/3h...minimum pressure fall over Georgian Bay was 7mb/3h.

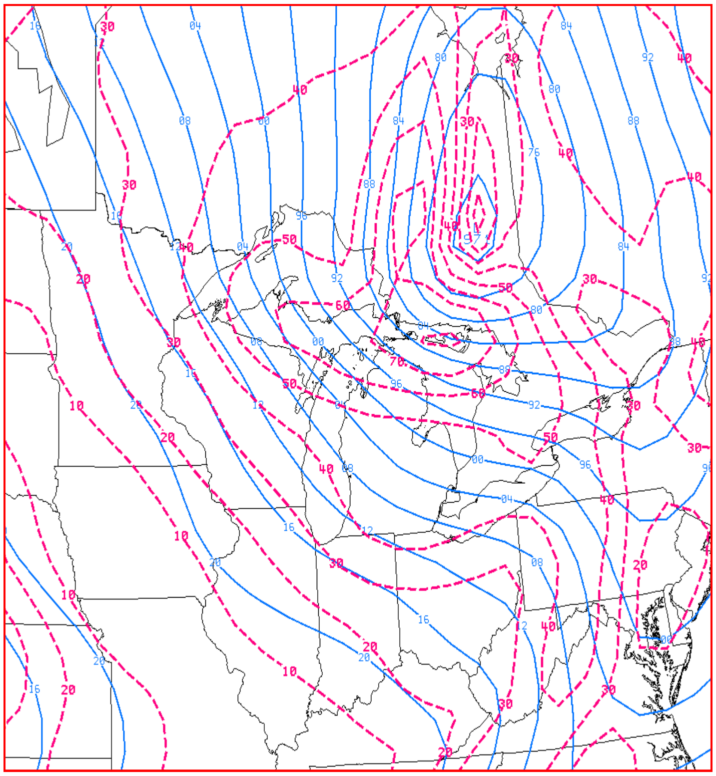

Figure 7. NAM-WRF model 00h analysis of surface pressure (blue contours) and pressure gradient magnitude (dashed purple contours, units of microbars/km) from 12z 30 January 2008. Values across eastern Upper Michigan range from 70-80 microbars/km.

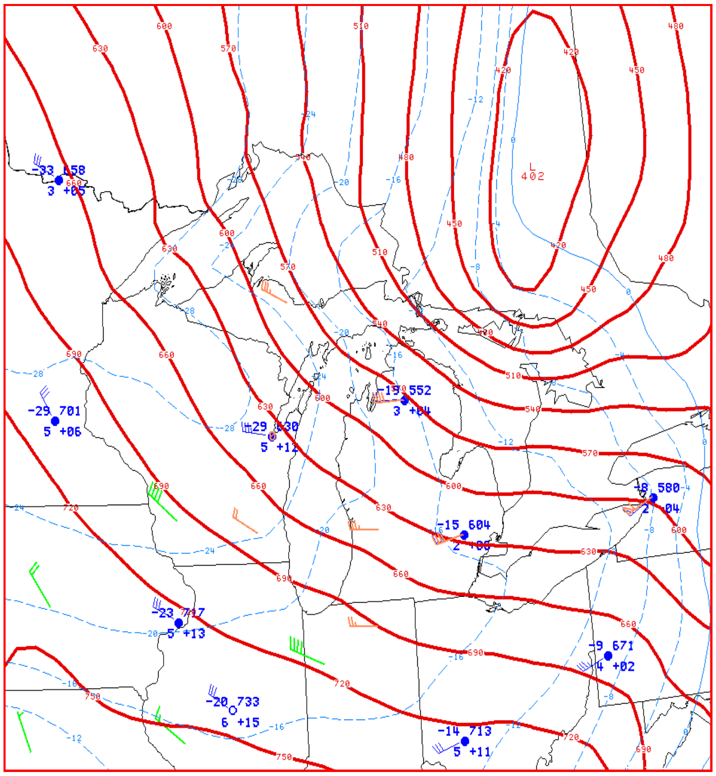

Figure 8. 925mb analysis from 12z 30 January. Red contours are heights, dashed contours are isotherms every 4C. Green wind barbs are 925mb winds from the National Profiler Network...orange wind barbs are derived from WSR-88D VAD Wind Profiles.

Highest winds with this event occurred across eastern Upper and the tip of the mitt counties of northern Lower Michigan. Sault Ste. Marie, Ontario recorded a wind gust of 65kts (75mph) around 500 am on the 30th, while across the St. Mary's River Sault Ste. Marie, Michigan gusted to 53kts (61mph). Mackinac Island recorded a gust of 43kts (49mph), while the anemometer up on Presque Isle Lighthouse between Rogers City and Alpena saw a wind gust of 62kts (71mph). Taking a look at a map depicting the magnitude of the pressure gradient (figure 7), we see the strongest gradient lying right across eastern Upper Michigan and the Straits of Mackinac, right where the strong winds were recorded (although some contribution to the extreme gusts noted in the Sault region could be attributed to winds funneling into the entrance to the St. Mary's River).

Figure 8 shows the analysis from the 925mb pressure level (about 2000 feet ASL) at 12z on 30 January, showing strong cold advection and implied isentropic subsidence occurring across the western Great Lakes region. Winds at this level range from 30-40kts, and this momentum is being mixed down to the surface in the form of strong wind gusts.

Heaviest snowfall from this event was 6 to 8 inches across northwest Lower Michigan from around Waters to Petoskey, which was the bulls-eye of the most persistent lake effect snowfall during the daytime hours of the 30th. But the biggest impact was the wind driven snow, with visibilities being reduced to near zero at times across eastern Upper and parts of northwest Lower Michigan, including the tip of the mitt counties. Parts of US-2 had to be closed west of St. Ignace due to the poor travel conditions. The rain during the previous evening and the subsequent "flash freeze" that occurred during the early morning hours of the 30th as temperatures plummeted, left a coating of ice on roadways that only added to the travel headaches. School closings were widespread on the 30th, and some remained closed the following day as well due to significant drifting.

10 February Event

Similar to its' 30 January counterpart, the 10 February winter storm was also the result of a transition from relatively mild weather to bitter cold temperatures, although in this case the subsequent surface low was not as strong, nor were winds as extreme as they were for the January case.

Low pressure initially over northern Lake Michigan on the morning of the 9th (figure 9) lifted north and deepened a little as it crossed Lake Superior. An initial cold front crossed the state during the afternoon of the 9th, but the main push of cold air (temperatures in the teens and 20s below zero) was behind a secondary cold front which reached western portions of the Upper Peninsula and Wisconsin by the evening of the 9th (figure 10). Aloft, short wave energy was digging southeast into the western Great Lakes and deepening (figure 11). The arrival of the mid level dynamics resulted in further deepening of the surface low as it pulled away from Lake Superior, which increased the winds and pulled the coldest air into northern Michigan during the early morning hours of the 10th (figure 12). Several waves of snow swept across northern Michigan on the 9th, but with passage of the cold front west-northwest flow lake effect snow bands set up off Lakes Superior and Michigan. The combination of falling and blowing snow resulted in many areas across eastern Upper and northwest Lower Michigan reporting visibilities at or below one quarter mile during the daylight hours of the 10th. US-2 west of St. Ignace was closed again during the height of the event, as well as portions of I-75 in Chippewa county and south of Gaylord as well (the latter due to traffic accidents).

Looking again at the factors the drove the strong winds, figure 13 shows the 3 hour pressure tendency chart from 08z on the 10th. Again there is a west-to-east oriented acceleration due to the isallobaric gradient, although in this case it is quite a bit weaker than the 30 January event (maximum pressure rise around 4mb/3h). This is likely a consequence of the surface low being displaced farther away from the region during the period of greatest strengthening, and the deepening of the low was not as great as it was in the previous event.

The magnitude of the pressure gradient (not shown) was only about half as strong in this event as compared to the 30 January event, but the degree of momentum mixing was similar as strong cold advection at the 925mb level (figure 14) helped mix 30-35kt winds to the surface. Wind gusts from this event generally ranged from 30-40mph, though there were some gusts approaching 50mph across eastern Upper Michigan. Also note on the 925mb map the impacts of the warmer Great Lakes on the low level temperature field, with a pronounced thermal ridge over Lake Superior. It is not uncommon during these events to have the coldest air do an "end run" around the southern end of Lake Michigan. This type of pattern can set up an area of strong convergence over southwest Lower Michigan, and subsequently develop strong lake snow bands off southern Lake Michigan (often referred to as "I-94" bands given the penchant for these bands to set up in the vicinity of the interstate).

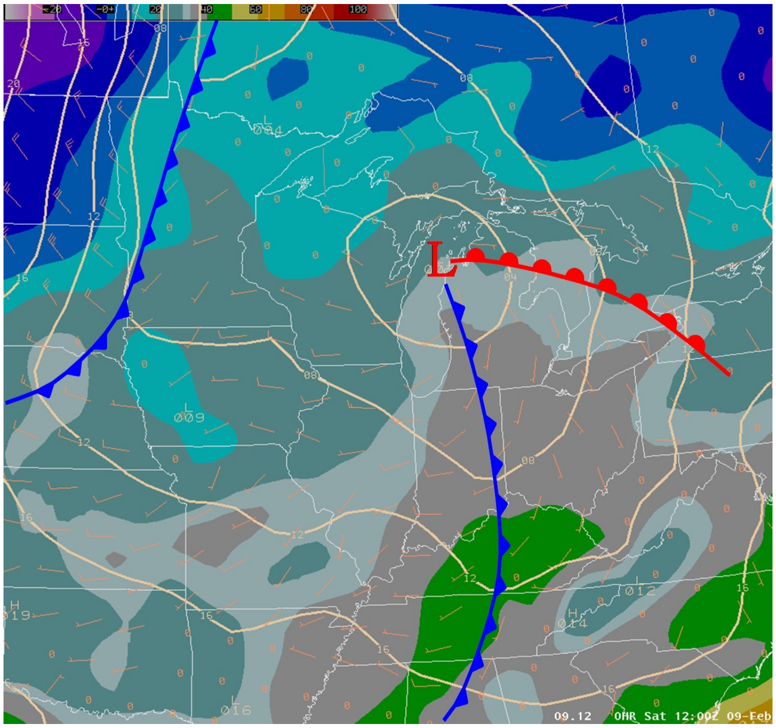

Figure 9. Mean sea level pressure (tan contours), objectively analyzed surface wind barbs (orange) and surface temperature (image) at 12z 9 February 2008. Temperature bands every 10 degrees, except white band representing temperatures between 30-32F.

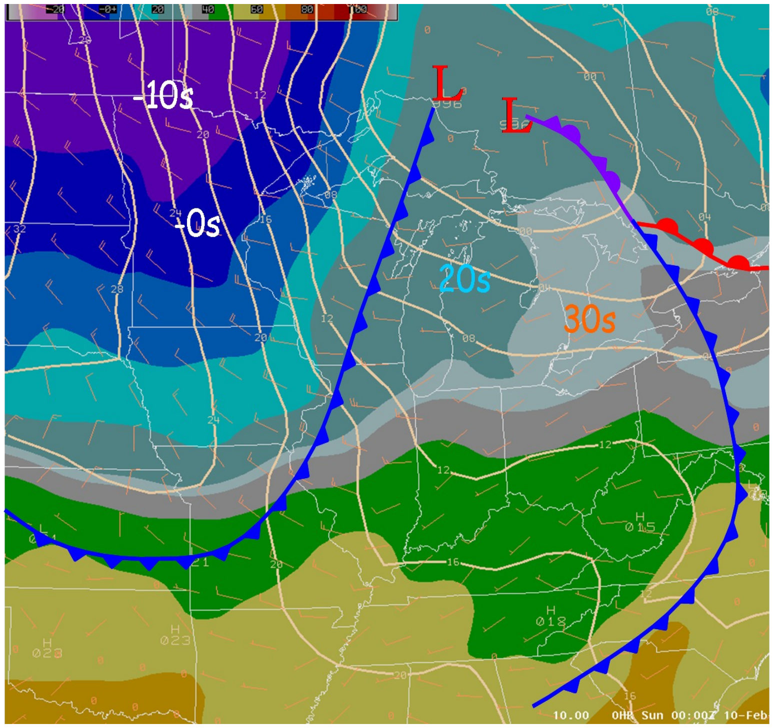

Figure 10. Same as figure 9, except at 00z 10 February 2008. Temperatures initially dropped into the 20s behind the lead cold front...with the coldest air poised just upstream.

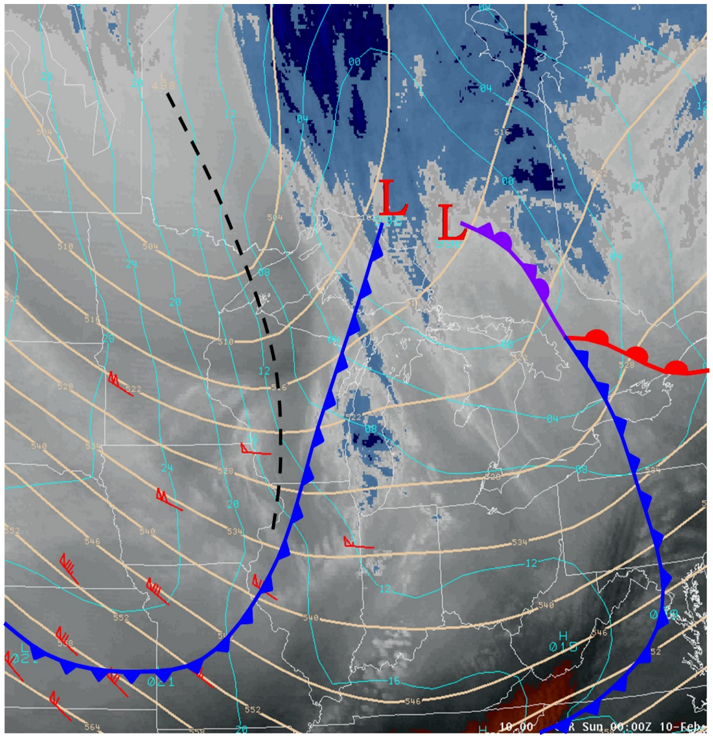

Figure 11. Water vapor image from 00z 10 February. Overlaid are 500mb heights (tan contours) and surface pressure (thin blue contours). Dashed line marks the 500mb short wave trough, red wind barbs are winds at the 500mb level from the National Profiler Network.

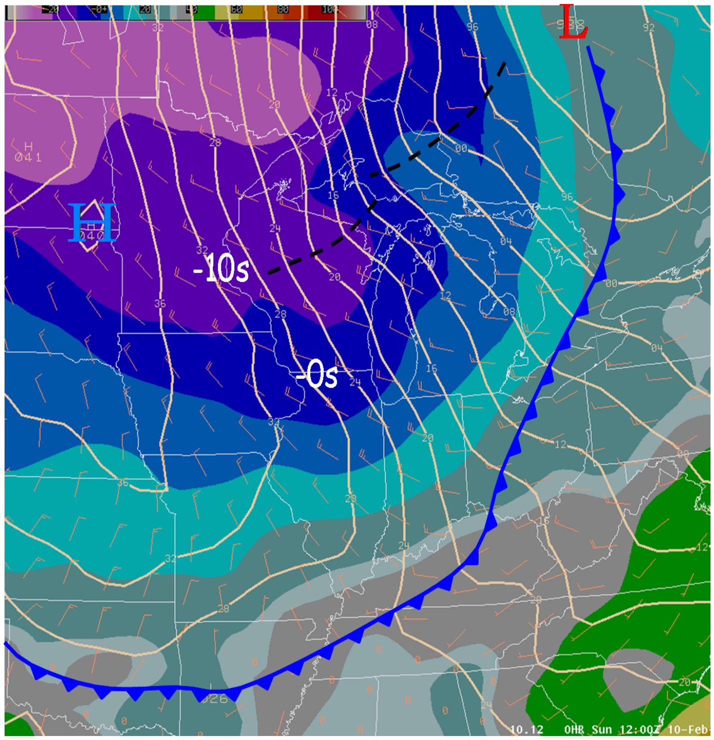

Figure 12. Mean sea level pressure (tan contours), objectively analyzed surface wind barbs (orange) and surface temperature (image) at 12z 10 February 2008.

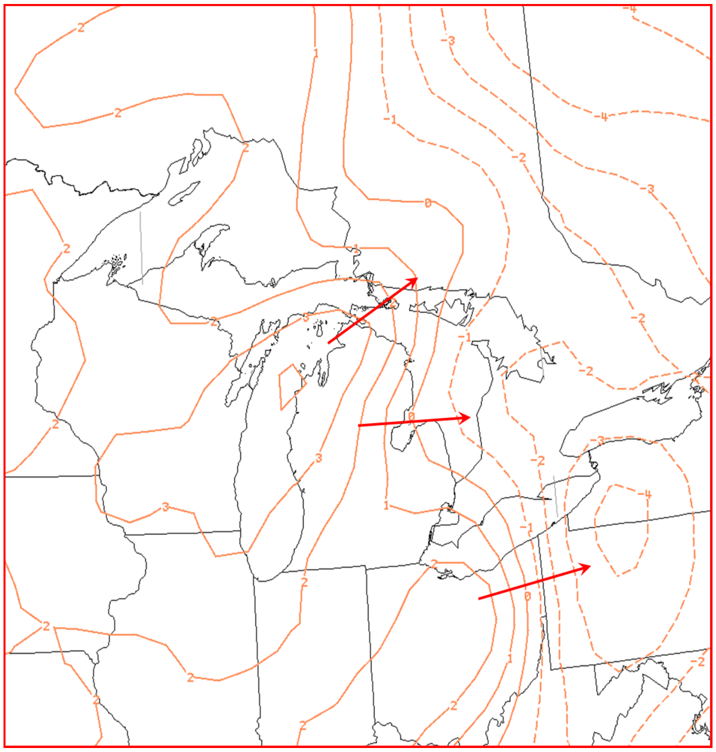

Figure 13. Pressure tendency (isallobars in orange contours, units are millibars/3h) at 08z 10 February 2008. Red arrows depict direction of ageostrophic acceleration implied by the isallobaric gradient.

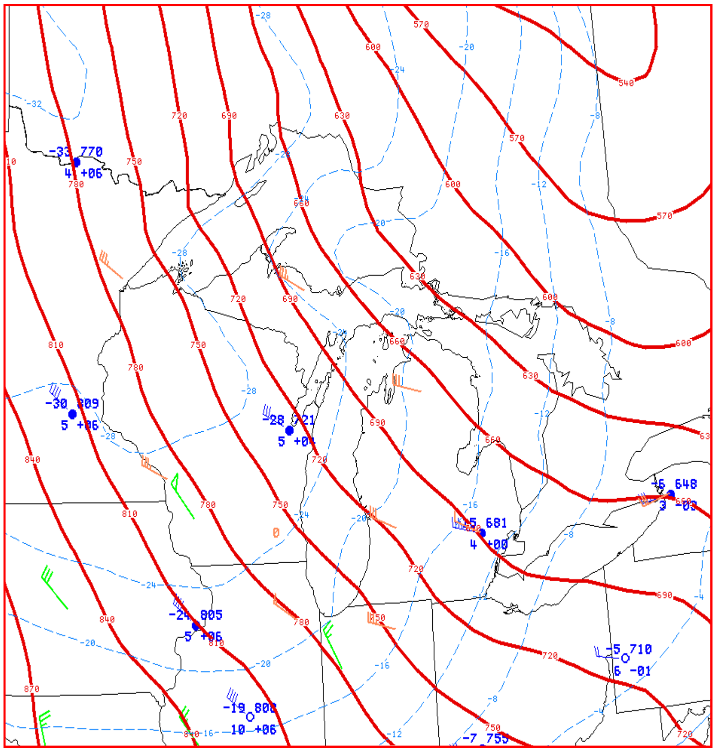

Figure 14. 925mb analysis from 12z 10 February. Red contours are heights, dashed contours are isotherms every 4C. Green wind barbs are 925mb winds from the National Profiler Network...orange wind barbs are derived from WSR-88D VAD Wind Profiles.

Summary

In this article, we looked at how the combination of a strong pressure gradient, downward mixing of higher momentum aloft, and accelerations due to pressure changes contributed to high winds and blizzard conditions during two winter storms in late January and early February. It is interesting to see how both of these events were transitions from relatively mild conditions (for the season) to bitterly cold temperatures. One can also look back at another northern Michigan blizzard event from 9-10 March 2002 to see a similar set up; warm temperatures (50s...and thunderstorms!) on the morning of the 9th, with a rapid onset of blizzard conditions during the afternoon as very cold air swept into northern Michigan.

John Boris

Convective Season Primer

Evaluating Summertime Instability

Almost all summertime severe weather is associated with deep, moist convection (in other words, thunderstorms). To achieve deep convection, there are three necessary ingredients: moisture, lift, and instability. Meteorologists typically evaluate dew point temperatures from the surface to about 700mb when assessing moisture. Lift is often provided from a low level trough, front, mid level short wave, and/or an upper level jet streak. When it comes to instability, several quantitative measures can be assessed. Two of the most common include Lifted Index (LI) and Convective Available Potential Energy (CAPE). A Skew-T diagram comparing LI and CAPE is shown in Figure 1 (next page).

Lifted Index (LI) is defined as the algebraic difference between an air parcel and the environmental temperature at 500mb, when a representative air parcel is lifted from the surface to 500mb. Lower (more negative) values of LI promote greater instability.

Convective Available Potential Energy (CAPE) is defined as the vertically integrated positive buoyancy of an adiabatically rising air parcel. Whereas LI assesses instability at a single level (500mb), CAPE essentially integrates instability through the entire convective depth. Higher values of CAPE promote greater convective vertical motions. CAPE is calculated using the following equation:

$$CAPE = g \int_{Z_{LFC}}^{Z_{EL}} \left(\frac{T_{vp} - T_{ve}}{T_{ve}} \right) dz$$

where T_{vp} is the virtual temperature of the lifted parcel, T_{ve} is the virtual temperature of the environment, Z_{EL} is the height of the equilibrium level, Z_{LFC} is the level of free convection, and g is gravity. CAPE is measured in units of J/kg.

Each measure of instability has its own strengths and weaknesses, and no single index can be thought to provide a complete characterization of the state of atmosphere. For example, LI is a single level stability index and is susceptible to unrepresentative values of instability if the temperature at 500mb is unrepresentative of the environment above or below, such as might occur if a mid level inversion or stable layer is present. In contrast to LI, CAPE is a vertically integrated index and measures the cumulative buoyant energy in the convective layer. As a result, it tends to be a more robust measure than LI, and in recent years has become increasingly preferred over LI.

One shortcoming of both LI and CAPE is that entrainment (mixing) with the environment is not considered. Another potential weakness of CAPE and LI is the fact that it’s computed value can vary significantly depending on the choice of lifted parcel. As a result, when considering CAPE, meteorologists will commonly reference either Surface Based CAPE (SBCAPE) or Mixed Layer CAPE (MLCAPE). As the name implies, SBCAPE is calculated using the actual surface temperature and dew point. MLCAPE, on the other hand, is calculated using a mean mixing ratio and potential temperature in the lowest 50 or 100mb of the atmosphere. MLCAPE better accounts for mixing processes in the lower troposphere and is generally preferred when assessing convective potential.

Forecasting summertime convection can be extremely challenging. Subtle variations in moisture, lift, and instability can make substantial differences in the timing, location, and severity of the resulting thunderstorms. When evaluating surface based instability, MLCAPE is the parameter most frequently referenced by operational meteorologists. It more accurately accounts for mean thermodynamic conditions within the boundary layer, and also captures buoyancy through the entire convection depth – rather than at a single level.

Bruce Smith

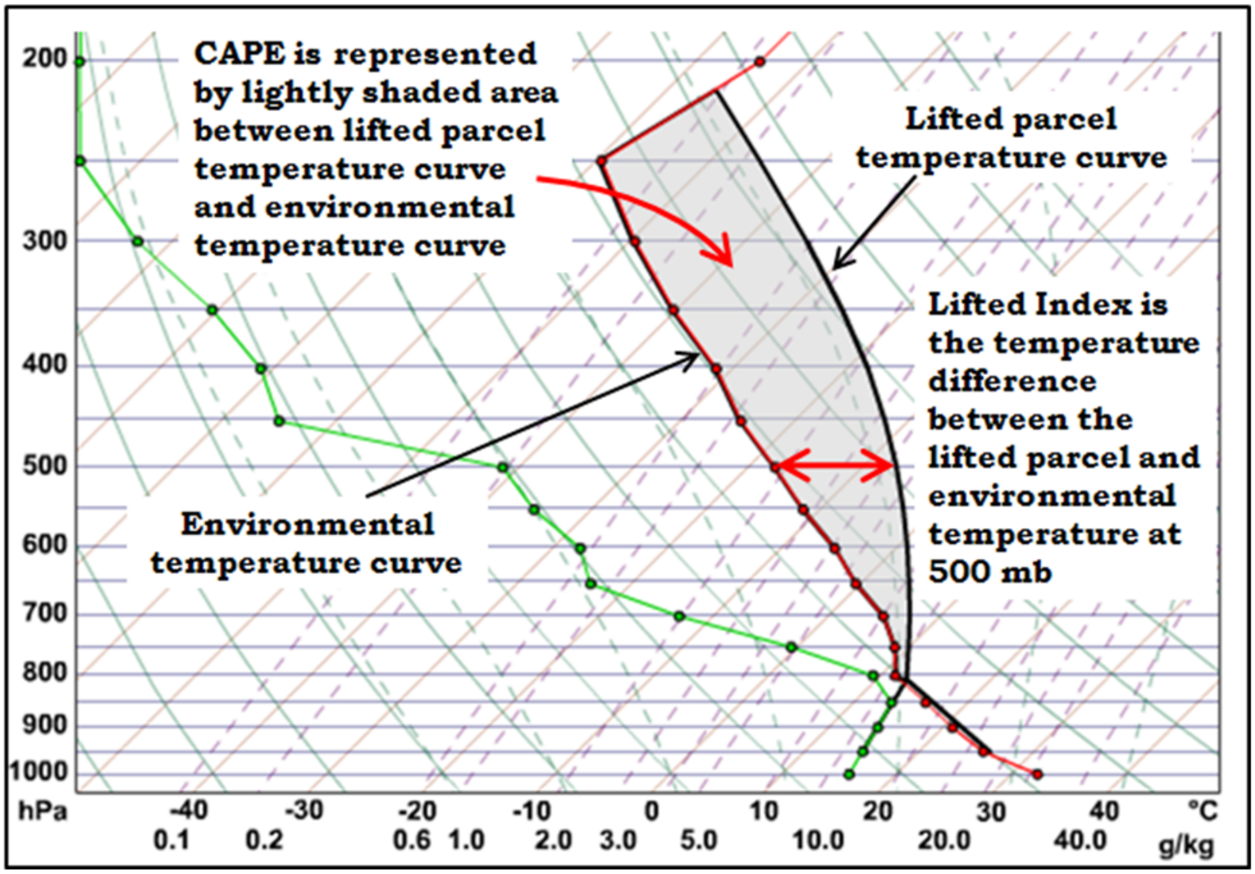

Figure 1. Skew-T diagram showing environmental temperature (red) and environmental dew point temperature (green). CAPE is represented by light gray shaded area. Lifted Index is represented by temperature difference (°C) between lifted parcel (black line) and environmental temperature at 500mb.

SBCAPE versus MLCAPE—An Example of the Difference

As mentioned in the article “Evaluating Summertime Instability”, it was mentioned that 100mb mixed layer CAPE, or MLCAPE, was preferred over purely surface based CAPE (SBCAPE) in evaluating instability in the boundary layer. Parcel theory in evaluating instability assumes that a parcel does not mix with the surrounding environment, sort of like a bubble. However, this is not exactly true in the real atmosphere. Calculating CAPE using the mean temperature and dew point in the lowest 100mb, and assigning those values to a surface based parcel and then lifting, accounts for mixing of a parcel’s properties with that of the surrounding environment. Research has shown (Craven, et al. 2002) that convective cloud base heights are more accurately predicted lifting a “mean” parcel rather than using a parcel’s actual temperature and dew point.

A good example of the dangers in using purely surface based CAPE to evaluate instability occurred in west Texas on 13 May 2008. Figure 1 shows a map of SBCAPE at 14z, indicating over 3000 J/kg of SBCAPE over west Texas (Midland, TX is marked with an “X”). Figure 2 is a map of 100mb MLCAPE at the same time, which shows no CAPE over the same area that had 3000+ J/kg SBCAPE. The reason for the difference can be found in the 12z upper air sounding from Midland (MAF). The surface dew point at observation time is 63F, but the moist layer is very shallow (less than 40mb). While the high surface dew point implies potentially a large amount of instability, the shallow moist layer would likely not support thunderstorm development, and will mix out quickly during the morning as heating continues and drier air is mixed to the surface (a good example of how the dryline “mixes” eastward with time as shallow surface based moist layers are eliminated).

John Boris

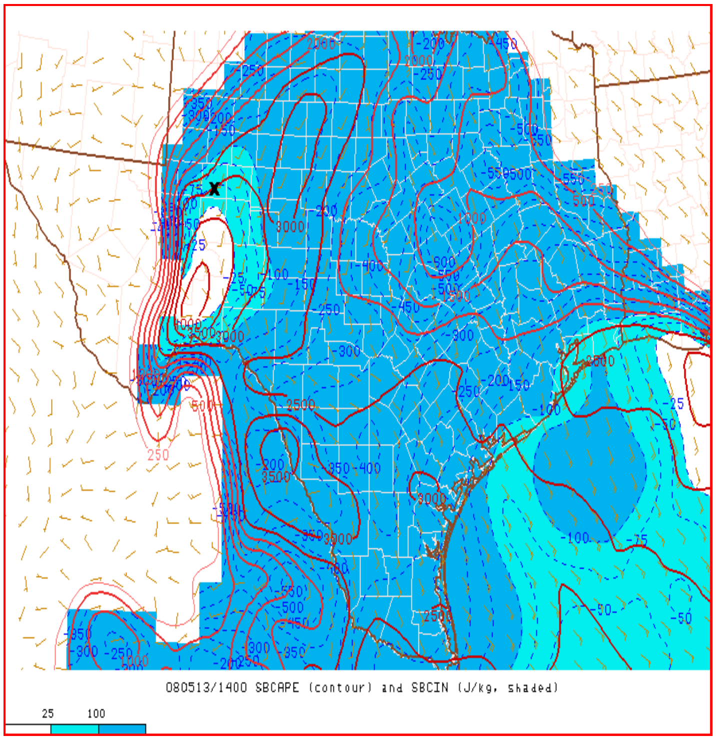

Figure 1. Map of SBCAPE at 14z 13 May 2008 (from SPC Mesoanalysis Page). Convective inhibition is show by the shading and dashed blue contours. Midland, TX (MAF) is marked with an “X”.

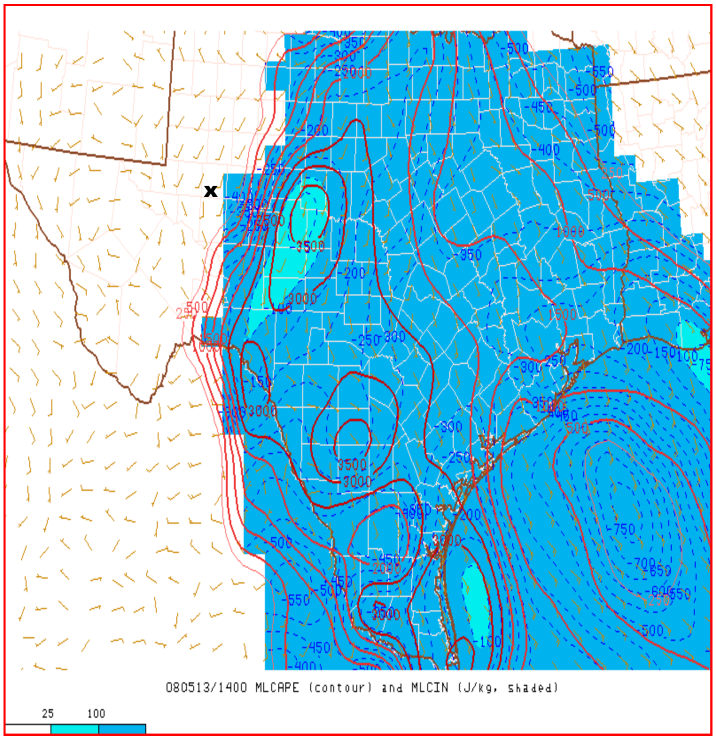

Figure 2. Map of MLCAPE at 14z 13 May 2008 (from SPC Mesoanalysis Page). Convective inhibition is show by the shading and dashed blue contours. Midland, TX (MAF) is marked with an “X”.

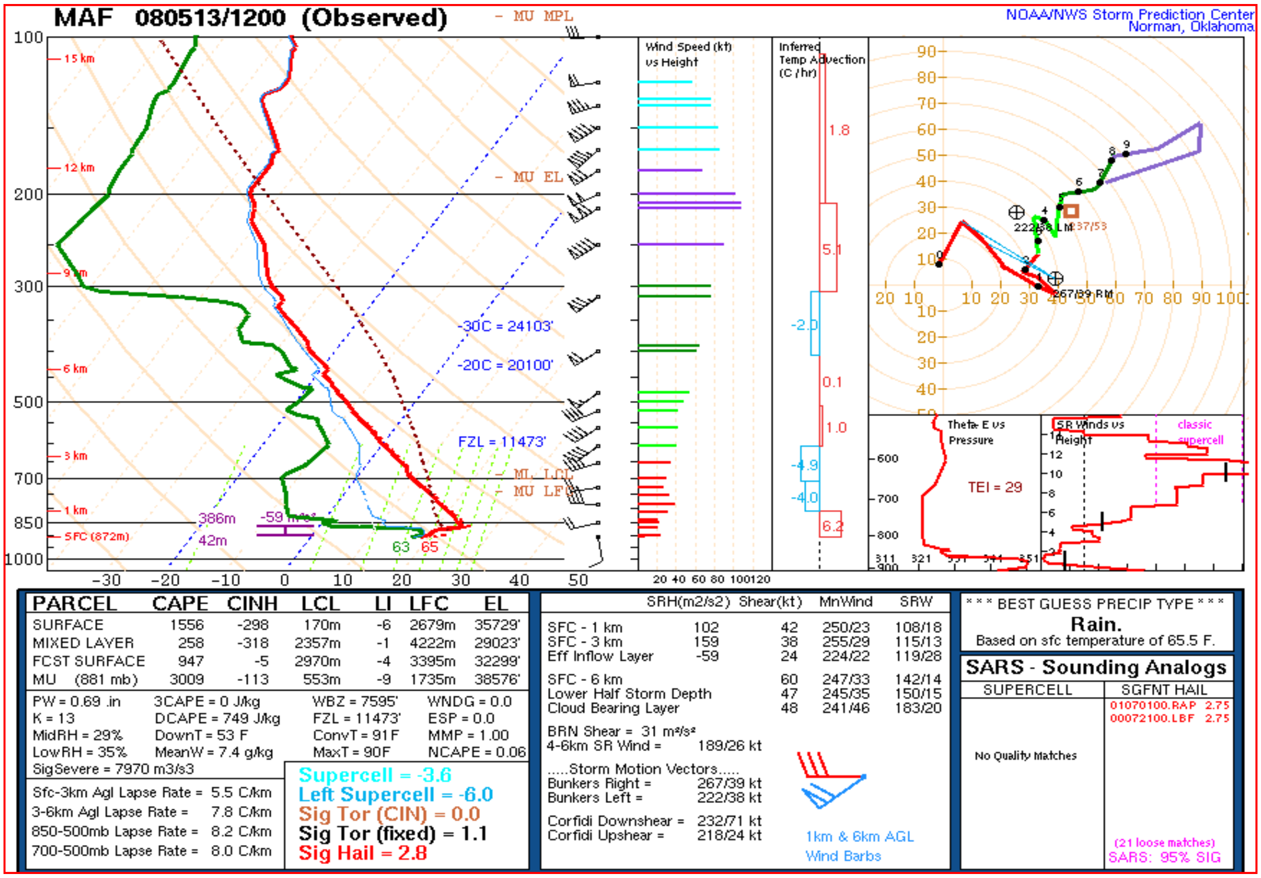

Figure 3. Midland, TX sounding from 12z 13 May 2008. Note the shallow surface based moist layer (green trace in skew T-log P diagram).

Fire Weather

Red Flag Warning Event of 16 April

Introduction

Atmospheric conditions favoring extreme fire behavior developed quickly during the afternoon of 16 April. The Fire Management Officer (FMO) from the Huron-Manistee National Forest requested a Red Flag warning due to the extreme dryness and high winds. Red Flag Warnings are issued when the following three criteria are met: 1) Temperatures at or above 75 degrees, 2) Relative humidity values below 25 percent, 3) Sustained winds or frequent gusts above 15mph. The relative humidity fell in many instances below 20%. The winds at US Forest Service RAWS observing sites were sustained between 10-15mph, however with frequent gusts of 20-25mph. ASOS observing sites recorded sustained winds of 15-20mph with frequent gusts of 30-35mph, and occasional gusts 40-45mph. The big surprise, however, were temperatures. Forecasted highs were expected in the 65-70F range. However, the mixed layer was deeper than expected and temperatures rose to 70-75F, with several locations making it past 75F. Pellston was the warm spot at 79F. The set up and the reason for the spiking temperatures will be discussed.

Setup

Surface: This case was not a typical fire weather set up for the region. Typically, we are set up by a Hudson Bay high with a 500mb ridge over the western Great Lakes. In this case, this may have been more typical of a pattern referred to as, "the break down of the upper level ridge." This would be as an upper level ridge breaks down, allowing warm dry air to move into the region. The surface high in this case moved through the Great Lakes and into the Mid-Atlantic states, pre-warming the region with southwest flow (figure 1). Temperatures overnight didn't cool as much with the southwest flow, with lows mainly in the upper 40s.

To the west, a surface low located over the northern Plains helped reinforce the southwest flow. Typically, once a surface high moves into the Mid-Atlantic, the low level flow would originate in the Gulf of Mexico, the main source for moisture into the Great Lakes region. However, looking at the isobars around this high on 16 April, isobars that are in the Gulf focus into south Texas, while the flow into the Great Lakes originated from the southwestern states, an area of extremely dry air.

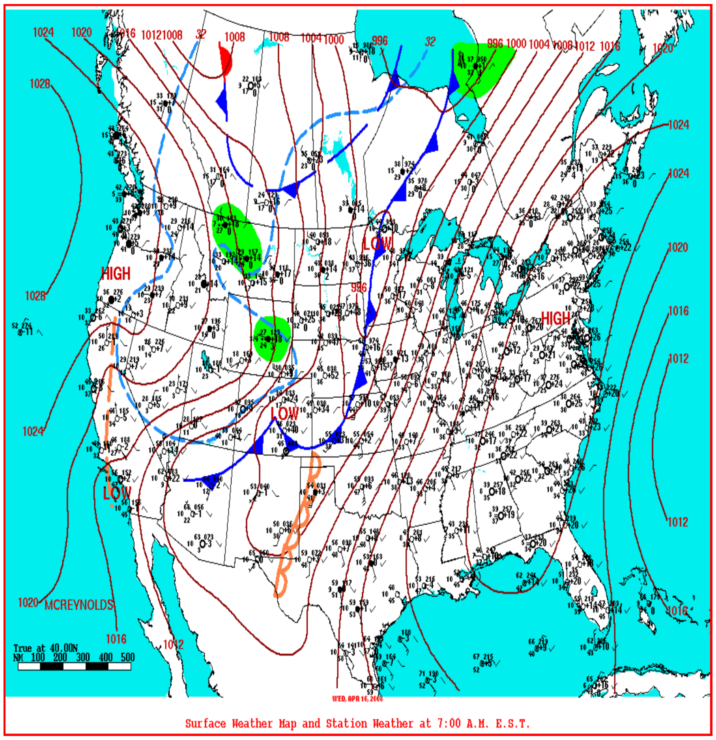

Figure 1. Surface Analysis from 12z 16 April 2008

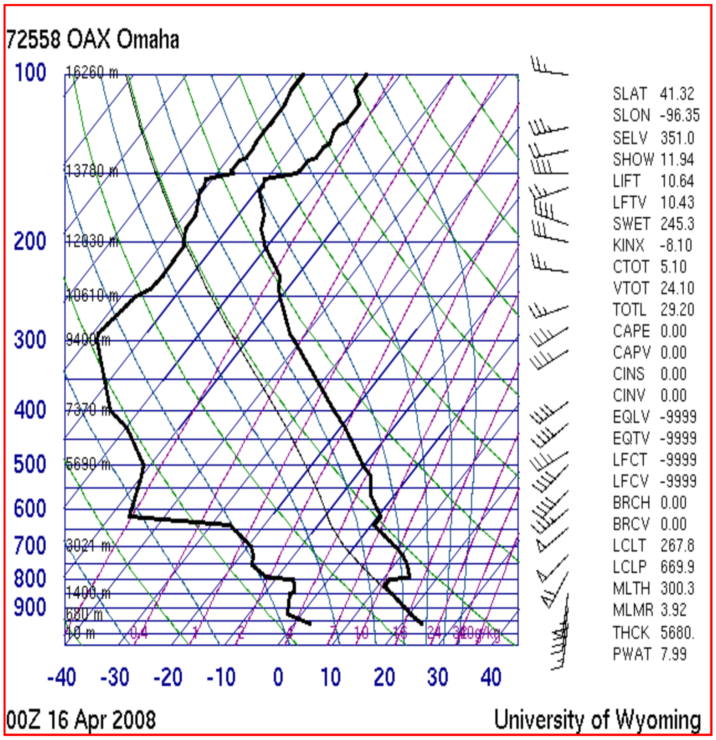

Figure 2. Upper air sounding from Omaha, NE on 00z 16 April.

Upper Air Pattern: At 500mb, the pattern was that of a trough in the west over the Rocky Mountains and a ridge that was building in the upper Mississippi Valley. This ridge continued to build to the east so that by 16 April, the 500mb jet stream was north of the western Great Lakes. This would allow for above normal temperatures to get into the western Great Lakes. Temperatures at 850mb at 12z on the 16th over the region were 10C, with temperatures as warm as 14C upstream of the region. When fully mixed, parcels at 850mb with a temperature of 10C would warm to around 76F when brought dry adiabatically to the surface. Parcels at 850mb with a temperature of 14C brought to the surface dry adiabatically would warm to a temperature of around 83F (28C). The question was whether there would be enough sunshine and subsequent mixing to help realize these maximum temperatures.

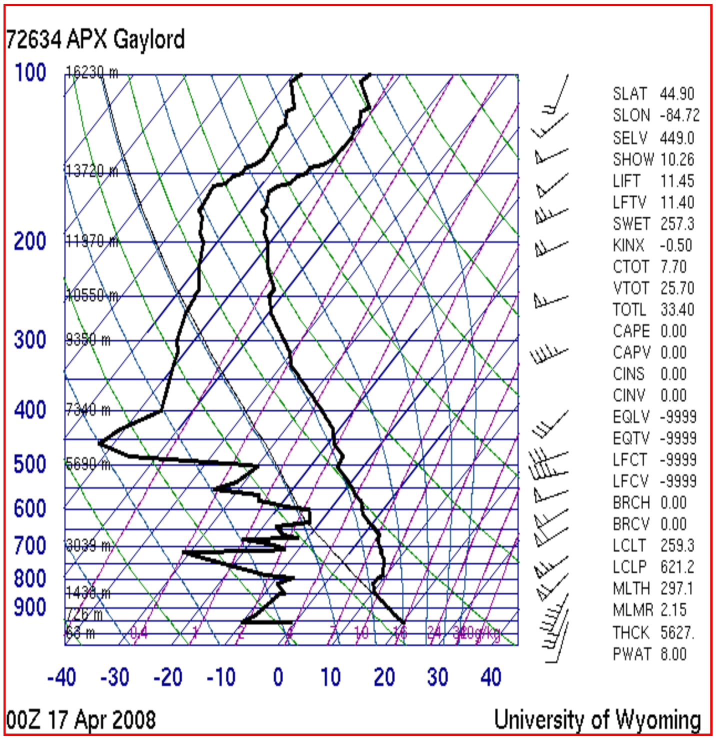

Figure 3. Upper air sounding from Gaylord, MI from 00z 17 April 2008.

The Event

Forecasts from the previous day, as well as those on the morning of 16 April, expected high temperatures in the 65-70F degree range, as an inversion around 900mb was expected to prevent deep mixing. High temperature forecasts from Model Output Statistics (MOS) guidance from both the NAM and GFS models anticipated afternoon highs in the upper 60s. Normal mid April highs for the region are in the lower to middle 50s. So the expectation was that high temperatures much above 70 degrees on the afternoon of 16 April would be a low probability event.

As the morning wore on, temperatures rose at the expected rate, but the relative humidity fell below 25 percent by 1000 am. By 1100 am, winds had increased to 12 to 16mph sustained at the 20 foot level, with frequent gusts to 25 mph. Around 1130 am, the FMO of the Huron-Manistee National Forest requested that the forest be put under a Red Flag Warning. This is an option that fire weather customers have for conditions that may impact fire danger, although weather parameters may not actually reach formal Red Flag criteria. With temperatures rising on schedule, it was still anticipated that temperatures would top out around 70 degrees.

However, by 200 pm Bellaire became the first station to hit 75 degrees. Then within the next couple of hours, many locations on the west side of the state had warmed into the mid 70s. In the end, three out of the five fire weather forecast zones covered by the Gaylord office met all three Red Flag conditions (temperature, relative humidity, wind).

Analysis

Looking upstream of the region on 15 April, while there was an area of middle to upper 70s that had occurred the previous day, there was no clear analog for forecasting high temperatures for the 16th from a surface pressure, temperature, or 1000-850mb thickness standpoint. Figure 2 shows an upper air sounding from Omaha, NE (OAX) at 00z on 16 April. This sounding bore a very close resemblance to the Gaylord, MI sounding from 00z 17 April (figure 3). In this case, both 00z soundings showed that the winds at the top of the mixed layer had reached over 50 knots, and both had mixed to around 5500ft AGL, which is above the 850mb level. Once the mixing depth got to this level, temperatures began to rise rapidly late in the day.

At the surface, the strong winds were out of the southeast, which becomes a downslope wind on the west side of the state. It is believed that the strong winds and the downslope, adiabatic warming helped to contribute to a deeper mixed layer in northwest lower Michigan. Circumstantially, this evidence is found from the only places where the temperatures went into the middle to upper 70s, which were many of the stations along or near the Lake Michigan shoreline.

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