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In Review

A Look Back at Winter 2008-09

We thought it would be fun to look back at what many northern Michiganders probably thought was a “good old-fashioned” northern Michigan winter. Indeed, when looking at the overall numbers, one could argue as such, with below normal temperatures and above normal snowfall for the winter. However, as often is the case with “averages”, these values do not represent the extremes experienced this past winter. Upon closer inspection, cold and exceptionally snowy conditions dominated the first half of the winter, with the second half more seasonable and less snowy. Interestingly, the less snow was at least partially tied to the cold early winter season, which led to abundant Great Lakes ice cover (Figure 1). This resulted in significantly less intense lake effect snow, which accounts for a substantial portion of northern Michigan winter snowfall. This trend tied nicely with the re-development of La Nina conditions in the equatorial Pacific Ocean (colder than normal water temperatures west of South America, see Figures 2 and 3).

Following are month by month summaries for the past winter, tables summarizing various temperature and precipitation statistics, and records set during this past winter. Although meteorological winter is classified as December through February, we have included summaries for November and March since, as northern Michigan residents can attest, winter around these parts **does not** follow traditional guidelines.

November

A Tranquil Beginning, A Wintry Finish

The month started on a nice enough note, as warm high pressure settled over the northern Lakes region, bringing unseasonably warm conditions for much of the first week of the month. Several high temperature records were broken on the 5th and 6th. As is expected during November, the warm weather did not last, as a quick change in the configuration of the upper level wind pattern during mid month featured a rather persistent Great Lakes trough axis, which is a classic La Nina signature (see Figure 4). This trough continued unabated through the end of November, allowing several southward



Figure 1. High resolution satellite imagery showing extensive Lake Superior and northern Lakes Michigan and Huron ice cover; a common feature this past mid-to-late winter season.

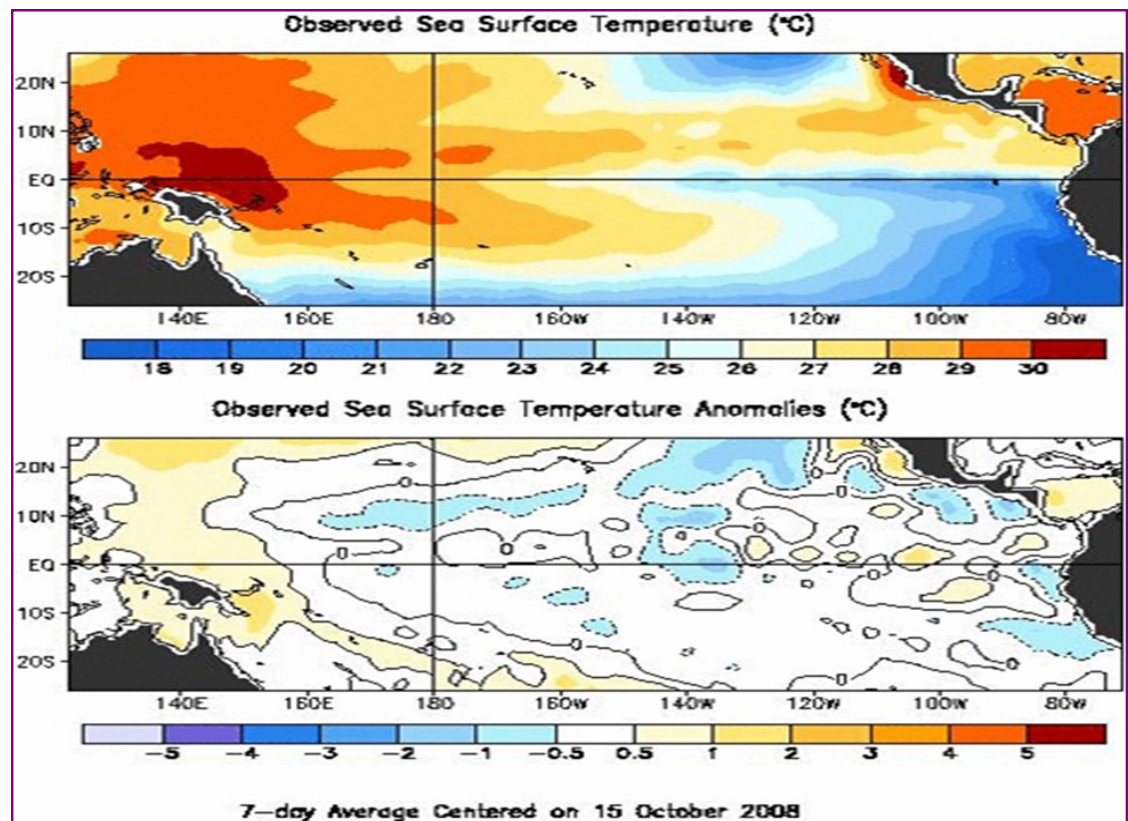


Figure 2. Developing La Nina conditions in October 2008. Note the cold equatorial water extending westward from the South American coast toward the International Date Line (180 degrees longitude).

travelling rounds of cold arctic air to impact northern Michigan, setting up a rather chilly and snowy second half of November. However, the month ended about normal in the temperature department, as the cold second half of the month was mostly offset by the warmth during the first week of November, as well as warmer than normal overnight lows owing to the extensive amount of cloud cover observed.

with the sustained cold, much of what fell remained on the ground, leading to nearly unprecedented snow depths for so early in the season. A solid foot or more of snow depth was common over northwest Lower and eastern Upper Michigan by month's end.

December One "Wild and Crazy" Month

As for precipitation, while the month's precipitation ended below normal for most locations, this does not reflect the very active second half of the month as much of the precipitation fell as lake effect snow, which often has a low water content. Nearly all locations across northern Michigan did report above average snowfall, a combination of both snowfall associated with larger scale weather systems, as well as lake effect snow. Per usual, the heaviest snow was found across the typical snowbelts of both peninsulas, with several locations totaling two feet or more during the month. In addition,

Borrowing a line from a famous Steve Martin *Saturday Night Live* skit from many years ago, December was about as "wild and crazy" as can be seen around these parts, with record snows and remarkably persistent cold air (with just a few significant exceptions) across the northern Great Lakes. The exceptionally snowy end to November simply did not stop, continuing right through the entire month of December. By the time all was said and done, much of northern Michigan experienced record to near record monthly snowfall totals, and exceptional snow depths for so early in the season. However,

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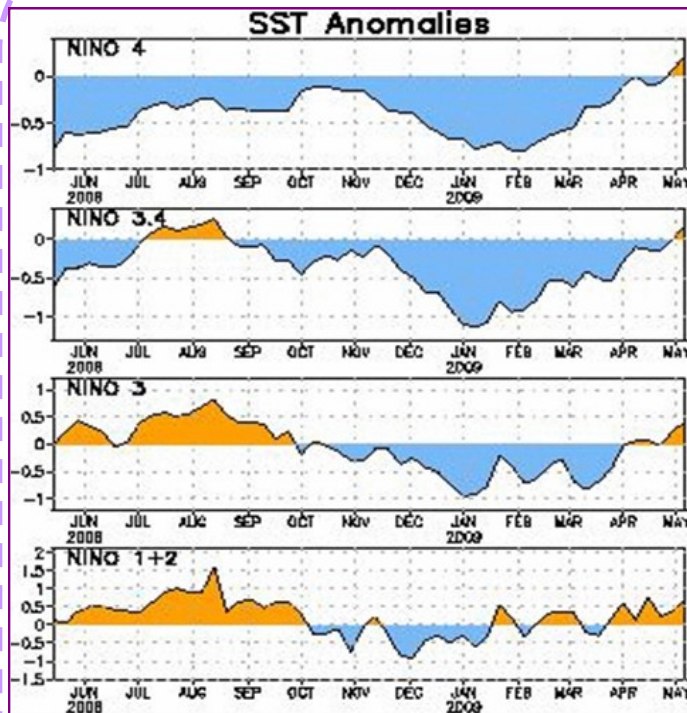


Figure 3. Graphs of sea surface temperature (SST) anomalies across the eastern equatorial Pacific Ocean from May 2008-April 2009. Note the cooling conditions in the Nino 3.4 and Nino 4 regions through February 2009, before warming during the spring.

two brief but rather significant warm-ups (or better yet, meltdowns), one on the 14th-15th, and another on the 26th-27th, prevented snow depths from reaching phenomenal values by month's end. Some locations by the dawn of 2009 had already received in excess of 100 inches of snow for the still early winter season.

So why the active pattern? It was a combination of a few things, namely plenty of "system" snow, and a vigorous start to our lake effect season. Actually, the overall pattern was very similar to the winter of 2007-08, with two notable exceptions: 1) the storm track this winter was shifted further north, often placing much of northern Michigan in the heavy snow producing northwest quadrant of passing low pressure systems. Last winter's storm track was often across the northern Ohio Valley, keeping the heaviest snows across far southern sections of our area and points south and west. 2) As a result of the further north storm track, cold air and lingering moisture often co-existed in harmony, leading to phenomenal lake effect snow events after the system snow had exited. Add it all up, and you get prodigious snow amounts for many. The exception was across eastern Upper Michigan, though even here the snowfall was above normal.

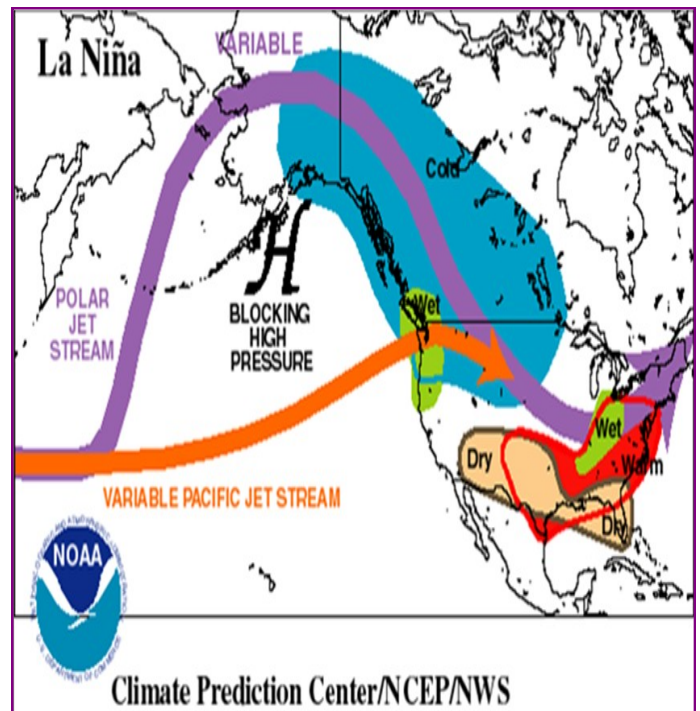


Figure 4. Classic La Niña driven winter time upper level pattern over North America. Notice the Great Lakes centered trough axis...allowing cold Canadian and arctic air to drop south into the region.

January

Persistent Cold, Albeit Quieter than December

Easily the biggest story for January was the remarkably persistent cold (even by frigid January standards), with the vast majority of days through the month averaging below normal, including several nights featuring well below zero temperatures. In fact, the main northern Lower Michigan climatological sites (Alpena, Houghton Lake, Traverse City) each experienced one of their top ten coldest Januaries on record. Ironically, no record lows were set for the month. The culprit behind the repeated cold intrusions was the maintenance of the deep Great Lakes trough axis that had set up earlier in the winter. Such a pattern is also typically a dry one, except for the favored lake effect snowbelts. But even still, with the exception of Alpena, below normal snowfall and much below normal total precipitation occurred over much of northern Michigan.

There are several reasons behind the below normal snowfall despite the persistently cold weather. One is that the cold weather led to rapidly developing Great Lakes ice cover (see Figure 1), which significantly reduced the fetch of open water

and resulted in less available moisture for heavy snow showers. This was an especially key player later in the month, when much of northern Lake Michigan from Beaver Island and points north was ice covered. Secondly, the very cold air often supported the development of very small snowflakes. These are famous for reducing visibilities, but struggle to accumulate efficiently as the snow becomes more “dense”. The one exception to the snow “drought” was at Alpena, where north to northeast wind flow lake enhancement was common, leading to one of the more snowier Januarys on record.

February

A month of variation

After a persistently cold January which featured consistently below normal temperatures, February showed much more volatility as changing upper air patterns brought fluctuating temperatures to northern Michigan. A cool start and finish to the month was more than offset by a week of exceptional warmth during the mid month period, enough so that temperatures actually averaged slightly above normal for the month.

Increasingly frozen Great Lakes, and maintenance of northwest flow out of the moisture starved Canadian tundra, kept the dry conditions observed through the month of January going through the first week or so of February. The weather pattern kicked it up a notch during the rest of the month as Gulf moisture became entrained in systems lifting out of the southern plains. As a result of the active mid and late month period, both total precipitation and snowfall averaged above normal across northern Michigan.

March

A fairly seasonable month

March failed to come in like a lion, and in fact the first several days were very quiet, but chilly. A period of warmer weather was right on the heels of the cold start, persisting from the end of the first week through the early part of the second week of the month. However, with the warmer weather came another round of snow on the 8th, where some parts of northern Lower Michigan picked up more than a foot of heavy, wet snow.

We did see some extremes around the middle of March, with a cold shot of air on the 10th, then much milder weather arriving by St. Patrick’s Day. The remainder of the month was very quiet with only one significant storm passing across the area on the 29th. Despite seeing some temperature extremes during March, these extremes acted to cancel each other out, establishing overall mean temperatures fairly close to normal for the month.

Notable Weather Events of This Past Winter

— **9/10 November 2008:** First significant lake effect snows of the season targets the traditional snowbelt regions of northwest Lower Michigan and northern Chippewa county. Heaviest snowfall was confined to interior elevated regions of northern Lower Michigan, with snow totals of 6 to 9 inches.

— **4/5 December 2008:** Lake effect snow targeted the traditional snowbelts, with one particularly intense snow band producing heavy snowfall rates across parts of Otsego and Antrim counties during the evening of the 4th. Up to 5 inches of snow fell in one hour out of this band over western Otsego county.

— **6 December 2008:** Another intense lake effect snow band developed, this one targeting parts of Mackinac county as cold southwest winds blew up the long axis of Lake Michigan, dumping 14 inches of snow in Epoufette in Mackinac County. By afternoon, the passage of an intense arctic front produced near blizzard conditions across northern Lower Michigan as heavy snow showers and gusty northwest winds developed.

— **15 December 2008:** Another arctic front brought an end to a period of above freezing temperatures, dropping temperatures 20 to 30 degrees in just 7 hours, and pushing afternoon temperatures down into the single digits and teens.

— **21/22 December 2008:** The official start of winter came in with more snow. A combination of system and lake effect snow pounded Manistee and Wexford counties, producing 23 inches of snow near Wellston, and 16 inches in Meauwataka.

— **26-28 December 2008:** A big post-Christmas meltdown as a strong storm passed west of the state, allowing very warm air to spread north. Temperatures warmed well into the 40s and 50s, combined with plentiful rainfall, helped erase a significant amount of the northern Michigan snowpack, with several locations losing more than a foot of snow. Winter came back with a vengeance on the 28th, as a strong cold front pushed temperatures down, accompanied by 50-60mph wind gusts.

— **13-20 January 2009:** An air mass directly from the North Pole paid an extended visit to northern Michigan, with high temperatures during this period struggling to reach even the teens. Overnight lows dipping below –20F were common.

— **6-11 February 2009:** A significant change in the upper level jet stream pattern across North America brought almost a week long “heat wave” to the northern Great Lakes. The warm temperatures peaked on the 7th and 10th, when many record highs were broken with temperatures reaching the 40s and 50s.

— **21/22 February 2009:** Another strong upper level disturbance brought a combination of system and lake enhanced snowfall to the region. Snowfall totals of 16 inches were reported in Cadillac, with 12 inches falling in McKinley in Oscoda County, and 11 inches in Onkama in Manistee County.

— **8 March 2009:** A quick hitting winter storm brought a whopping 15 inches of snow to parts of Leelanau county in just a matter of hours during the evening.

Stats, stats...and more stats

Winter Temperatures:

Departures from Normal

	SSM	HTL	APN	TVC	GLR	ALL
DEC MAX	-2.9	-3.8	-3.3	-2.9	-4.6	-3.5
DEC MEAN	-3.1	-3.6	-3.8	-2.9	-4.0	-3.5
DEC MIN	-3.3	-3.2	-4.5	-2.9	-3.5	-3.5
JAN MAX	-3.1	-5.9	-4.6	-5.0	-6.8	-5.1
JAN MEAN	-3.3	-7.4	-5.9	-5.2	-7.3	-5.8
JAN MIN	-3.6	-9.0	-7.1	-5.4	-7.8	-6.6
FEB MAX	+1.3	+0.9	+2.4	+2.0	-0.4	+1.2
FEB MEAN	+2.4	+0.7	+1.5	+1.6	-0.3	+1.2
FEB MIN	+3.6	+0.5	+0.7	+1.3	-0.2	+1.2
WINTER MAX	-1.6	-2.9	-1.8	-2.0	-3.9	-2.5
WINTER MEAN	-1.3	-3.4	-2.7	-2.2	-3.9	-2.7
WINTER MIN	-1.1	-3.9	-3.6	-2.3	-3.8	-3.0

- WITH AN AVERAGE WINTER TEMPERATURE OF 16.1 AT GAYLORD...THIS WAS THE 6TH COLDEST WINTER SEASON ON RECORD SINCE 1893.
- WITH AN AVERAGE WINTER TEMPERATURE OF 17.5 AT ALPENA...THIS TIED FOR THE 8TH COLDEST WINTER SEASON ON RECORD SINCE 1916.
- WITH AN AVERAGE WINTER TEMPERATURE OF 17.0 AT HOUGHTON LAKE...THIS WAS THE 9TH COLDEST WINTER SEASON ON RECORD SINCE 1913.
- THE WARMEST REPORTED TEMPERATURE ACROSS NORTHERN MICHIGAN DURING THE WINTER SEASON WAS 60 DEGREES...RECORDED 5 MILES SOUTHWEST OF STANDISH DURING THE AFTERNOON OF FEBRUARY 10TH.
- THE COLDEST REPORTED TEMPERATURE ACROSS NORTHERN MICHIGAN DURING THE WINTER SEASON WAS -28 DEGREES...RECORDED AT PELLSTON ON THE MORNING OF FEBRUARY 4TH.

Winter Precipitation:

	SSM	HTL	APN	TVC	GLR
DEC PRECIPITATION	4.53	4.60	3.85	6.39	4.55
DEC DEPARTURE	+1.62	+2.85	+2.02	+3.73	+1.35
JAN PRECIPITATION	1.29	1.12	1.39	1.79	1.16
JAN DEPARTURE	-1.35	-0.49	-0.37	-1.19	-1.89
FEB PRECIPITATION	1.81	2.46	2.69	2.75	2.19
FEB DEPARTURE	+0.27	+1.26	+1.39	+0.96	+0.09
TOTAL PRECIPITATION(IN)	7.63	8.18	7.93	10.93	7.90
DEPARTURE FROM NORMAL	+0.54	+3.62	+3.04	+3.50	-0.45

- WITH 8.18 INCHES OF PRECIPITATION AT HOUGHTON LAKE DURING WINTER...THIS WAS THE WETTEST WINTER SEASON ON RECORD SINCE 1913 (OLD RECORD OF 7.40 INCHES IN 1952-1953).
- WITH 10.93 INCHES OF PRECIPITATION AT TRAVERSE CITY DURING WINTER...THIS WAS THE 3RD WETTEST WINTER ON RECORD SINCE 1896.
- WITH 7.93 INCHES OF PRECIPITATION AT ALPENA DURING WINTER...THIS WAS THE 7TH WETTEST WINTER ON RECORD SINCE 1916.

Winter Snowfall:

	SSM	HTL	APN	TVC	GLR
DEC SNOWFALL	46.7	45.8	48.1	47.9	57.1
DEC DEPARTURE	+10.4	+29.9	+28.5	+23.3	+22.2
JAN SNOWFALL	21.7	16.4	30.0	27.9	31.7
JAN DEPARTURE	-13.3	-1.9	+8.2	-2.3	-7.1
FEB SNOWFALL	19.5	13.2	22.6	21.7	21.1
FEB DEPARTURE	0.0	+0.9	+6.1	+2.8	-3.0
TOTAL SNOWFALL	87.9	75.4	100.7	97.5	109.9
DEPARTURE FROM NORMAL	-2.9	+28.9	+42.8	+23.8	+12.1

- WITH 75.4 INCHES OF SNOWFALL AT HOUGHTON LAKE DURING WINTER...THIS WAS THE SNOWIEST WINTER SEASON ON RECORD SINCE 1913 (OLD RECORD OF 74.2 INCHES IN 1970-1971).
- WITH 100.7 INCHES OF SNOWFALL AT ALPENA DURING WINTER...THIS WAS THE 2ND SNOWIEST WINTER SEASON ON RECORD SINCE 1916 (RECORD OF 114.5 INCHES IN 1970-1971).
- WITH 97.5 INCHES OF SNOW AT TRAVERSE CITY DURING WINTER...THIS WAS THE 3RD SNOWIEST WINTER SEASON ON RECORD SINCE 1896.
- THE GREATEST 24 HOUR SNOWFALL TOTAL FOR THE WINTER SEASON WAS 17 INCHES... REPORTED AT BOTH TROUT LAKE (ON DECEMBER 1ST) AND WELLSTON (ON DECEMBER 21ST).

Records

- RECORD HIGH TEMPERATURE OF 68 DEGREES WAS SET AT SAULT STE MARIE NOVEMBER 5TH. THIS BROKE THE OLD RECORD OF 65 DEGREES SET IN 1978.
- RECORD HIGH TEMPERATURE OF 71 DEGREES WAS SET AT TRAVERSE CITY NOVEMBER 5TH. THIS BROKE THE OLD RECORD OF 70 DEGREES SET IN 1975.
- RECORD HIGH TEMPERATURE OF 64 DEGREES WAS SET AT SAULT STE MARIE NOVEMBER 6TH. THIS BROKE THE OLD RECORD OF 58 DEGREES SET IN 2001.
- RECORD HIGH TEMPERATURE OF 69 DEGREES WAS SET AT HOUGHTON LAKE NOVEMBER 6TH. THIS TIED THE OLD RECORD OF 69 DEGREES SET IN 1975.
- RECORD SNOWFALL OF 3.3 INCHES WAS SET AT HOUGHTON LAKE NOVEMBER 17TH. THIS BROKE THE OLD RECORD OF 1.0 INCHES SET IN 2005.
- RECORD SNOWFALL OF 8.0 INCHES WAS SET AT SAULT STE MARIE NOVEMBER 19TH. THIS BROKE THE OLD RECORD OF 3.9 INCHES SET IN 1978.
- RECORD LOW TEMPERATURE OF 2 DEGREES BELOW ZERO WAS SET AT GAYLORD NOVEMBER 21ST. THIS BROKE THE OLD RECORD OF 1 DEGREE SET IN 1987.
- RECORD SNOWFALL OF 3.0 INCHES WAS SET AT HOUGHTON LAKE NOVEMBER 21ST. THIS BROKE THE OLD RECORD OF 1.8 INCHES SET IN 1995.
- RECORD PRECIPITATION AMOUNT (MELTED FROZEN PRECIPITATION AND RAIN) OF 0.55 INCHES WAS SET AT ALPENA NOVEMBER 24TH. THIS BROKE THE OLD RECORD OF 0.49 INCHES SET IN 1959.
- RECORD SNOWFALL OF 2.0 INCHES WAS SET AT HOUGHTON LAKE NOVEMBER 30TH. THIS BROKE THE OLD RECORD OF 1.5 INCHES SET IN 1983.
- DECEMBER 9TH - ALPENA RECORD PRECIP OF 0.52 INCHES
- DECEMBER 9TH - ALPENA RECORD SNOWFALL OF 8.0 INCHES
- DECEMBER 9TH - HOUGHTON LAKE RECORD PRECIP OF 0.65 INCHES
- DECEMBER 9TH - HOUGHTON LAKE RECORD SNOWFALL OF 8.4 INCHES
- DECEMBER 19TH - ALPENA RECORD SNOWFALL OF 5.4 INCHES
- DECEMBER 19TH - HOUGHTON LAKE RECORD SNOWFALL OF 5.7 INCHES
- DECEMBER 21ST - ALPENA RECORD PRECIP OF 0.48 INCHES



More Records

- DECEMBER 27TH - HOUGHTON LAKE RECORD HIGH OF 50 DEGREES
- DECEMBER 27TH - SAULT SAINTE MARIE RECORD HIGH OF 44 DEGREES
- DECEMBER 27TH - SAULT SAINTE MARIE RECORD PRECIP OF 0.64 INCHES
- DECEMBER 27TH - TRAVERSE CITY RECORD HIGH OF 53 DEGREES
- DECEMBER 27TH - GAYLORD RECORD HIGH OF 49 DEGREES
- DECEMBER 27TH - GAYLORD RECORD PRECIP OF 0.87 INCHES
- RECORD SNOWFALL OF 6.6 INCHES WAS SET AT HOUGHTON LAKE JANUARY 17TH. THIS BROKE THE OLD RECORD OF 4.2 INCHES SET IN 1992.
- RECORD SNOWFALL OF 6.2 INCHES WAS SET AT ALPENA JANUARY 18TH. THIS BROKE THE OLD RECORD OF 6.1 INCHES...SET IN 1960.
- RECORD LOW TEMPERATURE OF 17 DEGREES BELOW ZERO WAS SET AT GAYLORD ON FEBRUARY 5TH. THIS BROKE THE OLD RECORD OF 16 DEGREES BELOW ZERO SET IN 1995.
- RECORD HIGH TEMPERATURE OF 51 DEGREES WAS SET AT ALPENA FEBRUARY 7TH. THIS BROKE THE OLD RECORD OF 49 SET IN 1925.
- RECORD HIGH TEMPERATURE OF 50 DEGREES WAS SET AT TRAVERSE CITY FEBRUARY 7TH. THIS TIED THE OLD RECORD OF 50 DEGREES LAST SET IN 1925.
- RECORD HIGH TEMPERATURE OF 45 DEGREES WAS SET AT GAYLORD FEBRUARY 7TH. THIS BROKE THE OLD RECORD OF 44 DEGREES FROM 1990.
- RECORD HIGH TEMPERATURE FOR FEBRUARY 10TH OF 46 DEGREES WAS SET AT SAULT STE MARIE. THIS BROKE THE OLD RECORD OF 43 SET IN 1966.
- RECORD HIGH TEMPERATURE OF 54 DEGREES WAS SET AT HOUGHTON LAKE FEBRUARY 10TH. THIS ECLIPSED THE OLD RECORD OF 49 DEGREES SET BACK IN 1998.
- RECORD HIGH TEMPERATURE OF 55 DEGREES WAS SET IN ALPENA FEBRUARY 10TH. THIS WIPED OUT THE OLD RECORD OF 50 DEGREES SET BACK IN 1966.
- RECORD HIGH TEMPERATURE OF 57 DEGREES WAS SET AT TRAVERSE CITY FEBRUARY 10TH. THIS SHATTERED THE LONG STANDING RECORD OF 50 DEGREES SET WAY BACK IN 1903.
- RECORD HIGH TEMPERATURE OF 54 DEGREES WAS SET AT GAYLORD FEBRUARY 10TH. THIS SMASHED THE OLD RECORD OF 49 DEGREES SET BACK IN 1984.
- RECORD SNOWFALL OF 6.3 INCHES WAS SET AT HOUGHTON LAKE FEBRUARY 21ST. THIS BROKE THE OLD RECORD OF 5.9 INCHES SET IN 1976.
- RECORD SNOWFALL OF 6.1 INCHES WAS SET IN ALPENA FEBRUARY 21ST. THIS BROKE THE OLD RECORD OF 5.2 INCHES SET IN 1993.
- RECORD DAILY MAXIMUM PRECIPITATION AMOUNT OF 0.57 INCHES WAS SET AT HOUGHTON LAKE MI ON FEBRUARY 26TH. THIS BROKE THE OLD RECORD OF 0.54 INCHES SET WAY BACK IN 1946.
- RECORD DAILY PRECIPITATION OF 0.56 INCH WAS TIED AT HOUGHTON LAKE ON MARCH 29TH. THE RECORD WAS ORIGINALLY SET IN 1988.
- RECORD SNOWFALL OF 2.9 INCHES WAS SET AT HOUGHTON LAKE ON MARCH 8TH. THE OLD RECORD WAS 1.2 INCHES SET IN 1982.
- RECORD DAILY PRECIPITATION OF 0.77 INCH WAS SET AT ALPENA ON MARCH 29TH. THE RECORD WAS ORIGINALLY SET IN 1944.

Mike Boguth

Grand Traverse Bay Heavy Snow Event: 8 March 2009

During the evening hours of March 8th, a swath of precipitation associated with a compact but potent short wave trough/mid level circulation spread across northern Michigan. Although precipitation initially fell as a mix of rain, sleet, and snow...it quickly changed over to all snow and became quite heavy around the Grand Traverse Bay region and across the tip of the mitt counties of northern Lower Michigan. Snowfall rates in excess of two inches per hour occurred across parts of northwest Lower, and all told over a foot of snow fell over portions of Charlevoix, Grand Traverse (specifically across the Old Mission Peninsula) and Leelanau counties, with a maximum of 15 inches around Leland and Lake Leelanau.

This event was characterized by strong frontogenesis around the north and northwest portions of a mid level circulation that was in the process of closing off as it crossed the western Great Lakes on the evening of the 8th. Figures 2 through 4 show the progression of the surface response to this developing mid level low. Starting out as a 1003mb low over northwest Missouri at 12Z on 8 March (Figure 2)...the low deepened by about 8mb in a 12 hour period by the time it reached southern Lake Michigan at late afternoon (Figure 3). The surface low then crossed

southern Lower Michigan (Figure 4) and into southern Ontario by the early morning hours of 9 March.

Figure 5 shows a series of upper air analyses valid at 00Z on 9 March, as the event was getting cranked up. A strong short wave which was located over Nebraska and Kansas during the morning hours of the 8th, had lifted quickly northeast and deepened by the evening, resulting in a closed circulation up through 500mb over southern Lake Michigan. Notice the "col" regions on the 500mb and 700mb analyses in figure 5, indicative of a well defined deformation zone around the northern and western flanks of the circulation. Deformation zones interacting with favorably oriented thermal gradients can lead to frontogenesis and the resultant secondary thermal circulations that can greatly enhance vertical motions on a small scale. Strong upper level divergence was noted ahead of the wave at 250mb, the red ageostrophic wind vectors spreading out from a common center over northern Lower Michigan. Strong low level warm advection was evident at 850mb...with a tight temperature gradient interacting with strong winds around the low pressure center (such as the 50kt 850mb wind over southeast Lower Michigan per the White

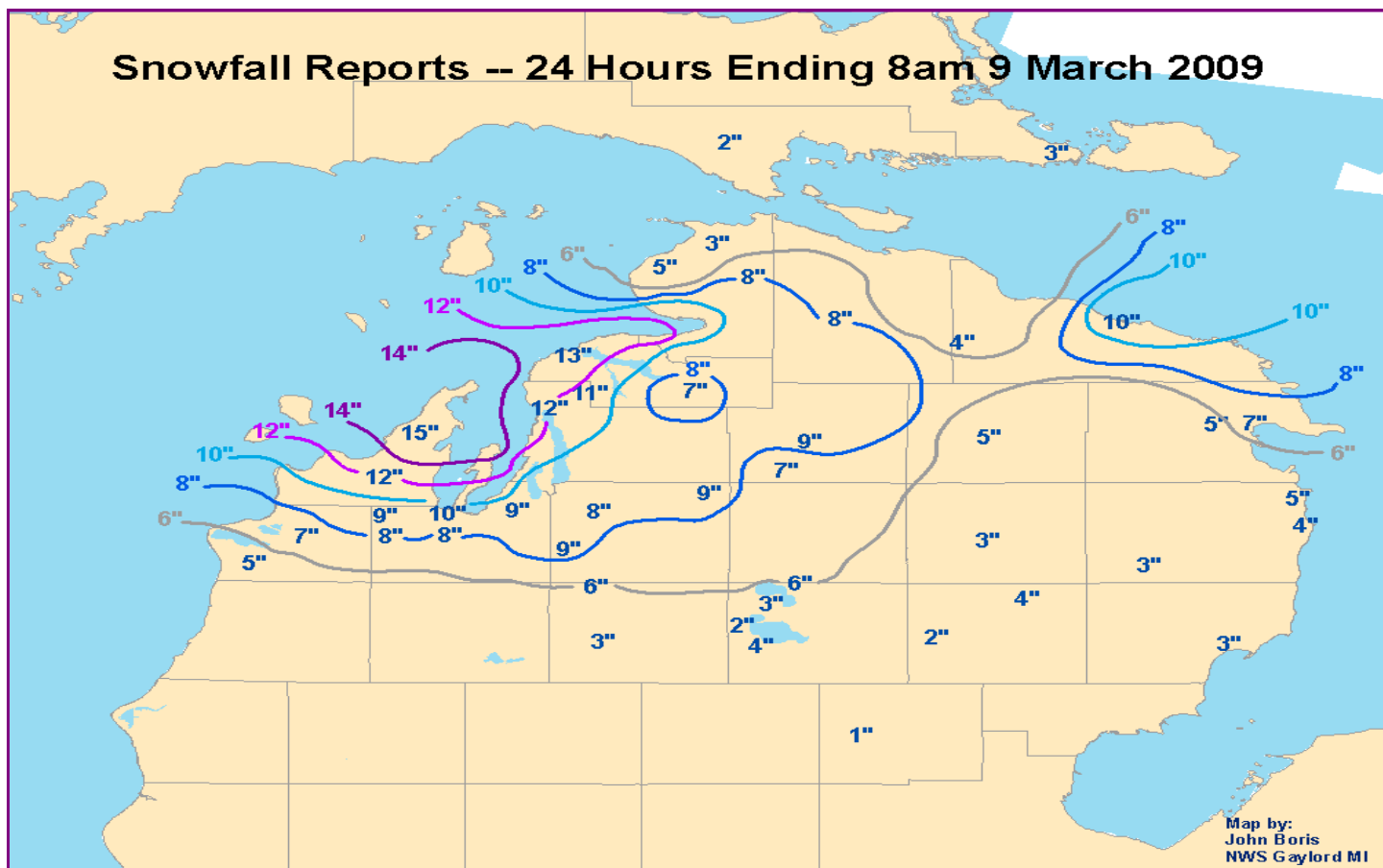
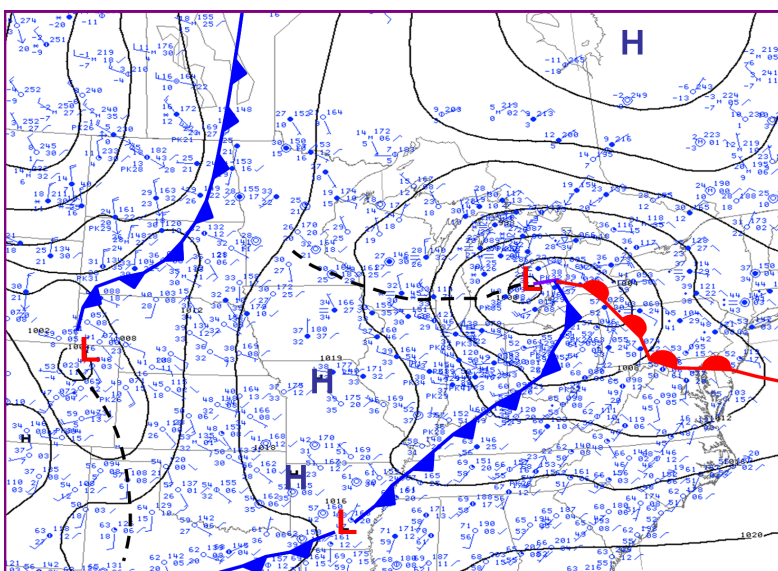
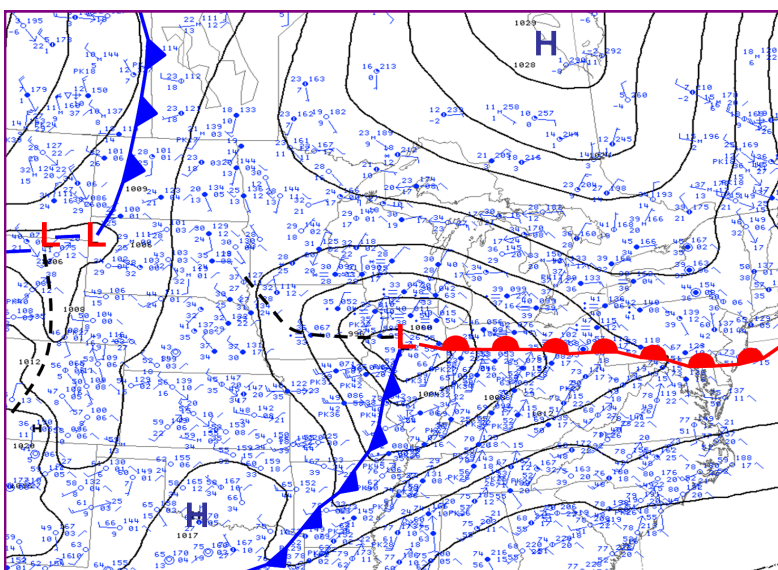
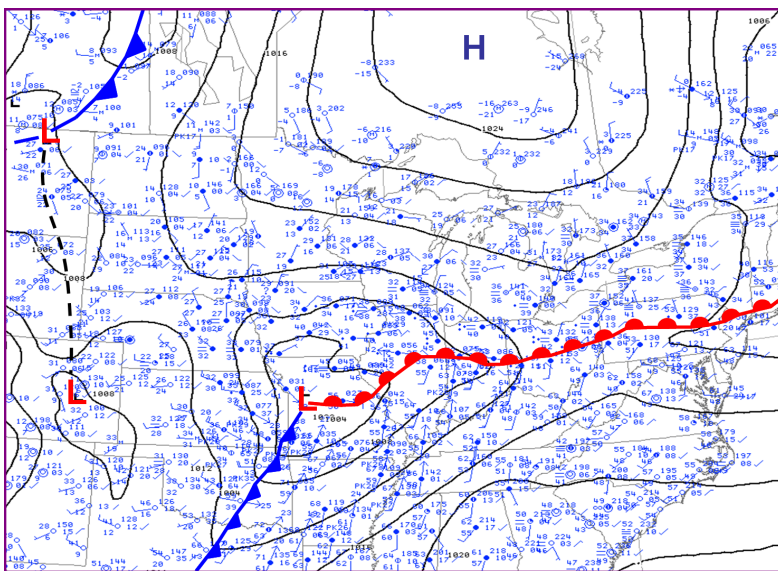


Figure 1. Northern Michigan 24 hour snowfall totals ending 12Z 9 March 2009.



Figures 2 through 4. Surface maps valid at 12Z 8 March (top, figure 2), 18Z 8 March (middle, figure 3), and 03Z 9 March 2009 (bottom, figure 4).

Lake, MI (DTX) upper air observation). Note the strong contrast in temperature between the two upper air sounding locations across the Lower Peninsula at 850mb, from +8C at DTX to -4C at the Gaylord RAOB site (APX). Low level moisture was also getting pulled into the circulation, with 850mb dew points ≥ 8 C advecting northward into the Lower Peninsula.

Figures 6 through 11 show the radar depiction of this event, as viewed from the NWS Gaylord (KAPX) WSR-88D. Figure 6 was taken at 2:47pm on the afternoon of the 8th, which shows the arrival of precipitation into western Lower Michigan. This initial surge of precipitation was comprised of mostly rain and drizzle, with surface temperatures in the mid 30s to lower 40s at the time. At 4:00pm, precipitation was beginning to transition over to a mix of rain, snow, and sleet. Some of the higher radar returns noted around Traverse City and Cadillac on the 2103Z radar image (figure 7) were likely due to “bright banding”, with highly reflective partially melted snowflakes and graupel producing strong radar returns.

Precipitation continued to spread into northern Lower Michigan toward sunset, and by this time was transitioning to all snow. By 5:00pm, moderate to heavy snow was falling at Frankfort, Traverse City, and Bellaire, with thundersnow reported at Houghton Lake. Snowfall rates of 1 to 2 inches per hour were already occurring across areas adjacent to Grand Traverse Bay. By 7:30pm (0030Z radar image, figure 10), heavy snow had spread northward across the Leelanau and Old Mission peninsulas and into Charlevoix and Petoskey, as well as farther east along the M-32 corridor through Gaylord and Alpena. The band of heavy snow then continued to pivot across northwest Lower Michigan, shifting from a west-east to southwest-northeast orientation but still focusing heavy snow on areas from Leelanau County northeast toward Little Traverse Bay (0227Z radar image). Heavy snowfall rates began to diminish during the late evening hours, with snow tapering off after midnight on the 9th, though not after dumping more than a foot of snow around Grand Traverse Bay and Little Traverse Bay.

Figures 11 through 14 examine the role that frontogenetic processes played in this heavy snow event (for a more in-depth discussion on the topic of frontogenesis, see [Volume 1, Issue 2](#) of the WFO Gaylord Science Corner). In figure 11, frontogenetic forcing in the 600-500mb layer is depicted, with the frontogenesis maximum (positive f-gen) extending in an arc from northern Lake Huron, across the Upper Peninsula, and down into Lake Michigan. The response to this area of frontogenesis is depicted in the right portion of figure 11, which represents F-vector divergence in the same 600-500mb layer. Where F-vectors converge is an area of forcing for upward motion (with F-vector divergence implying forcing for downward motion), and will be found on the “warm”

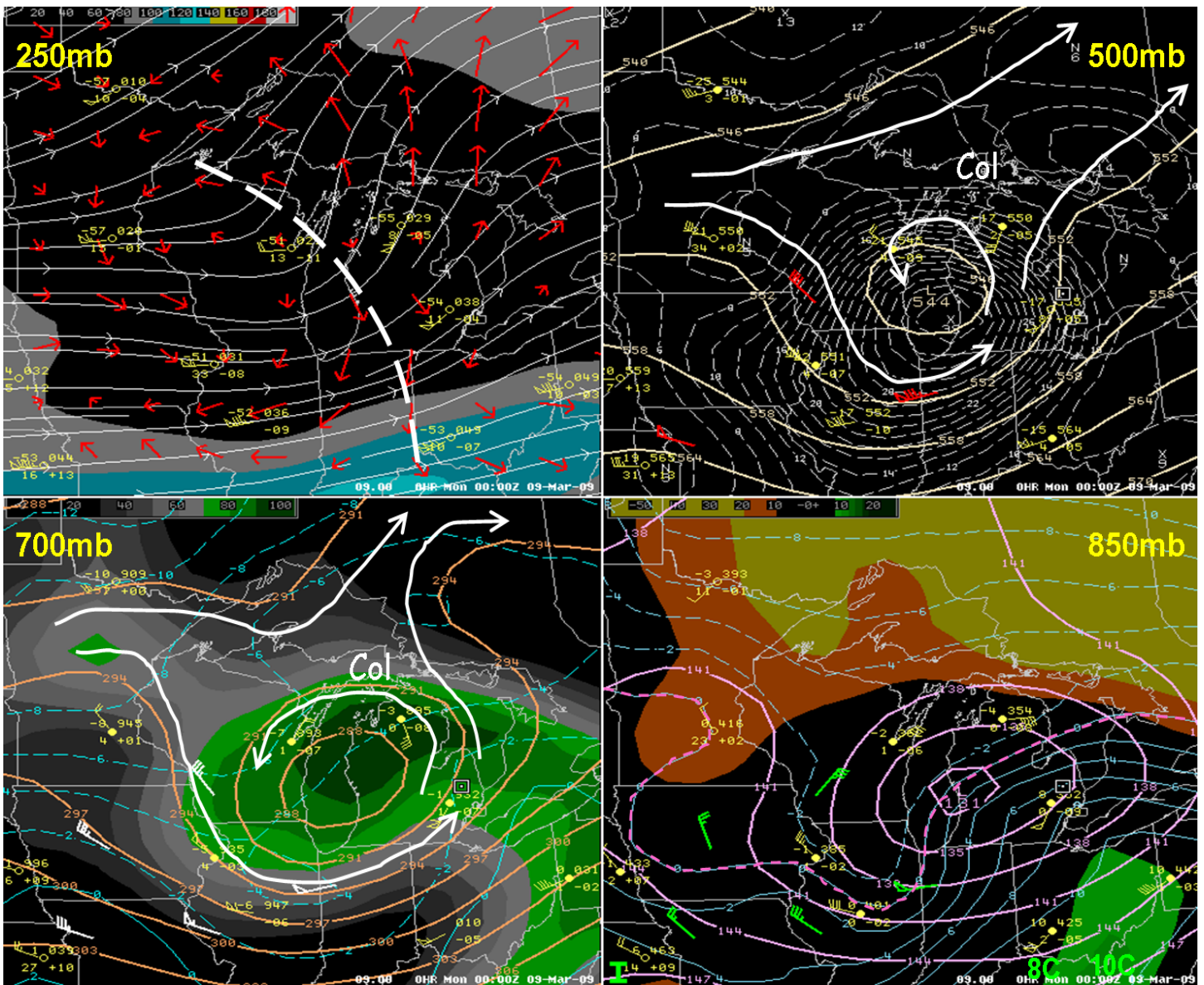
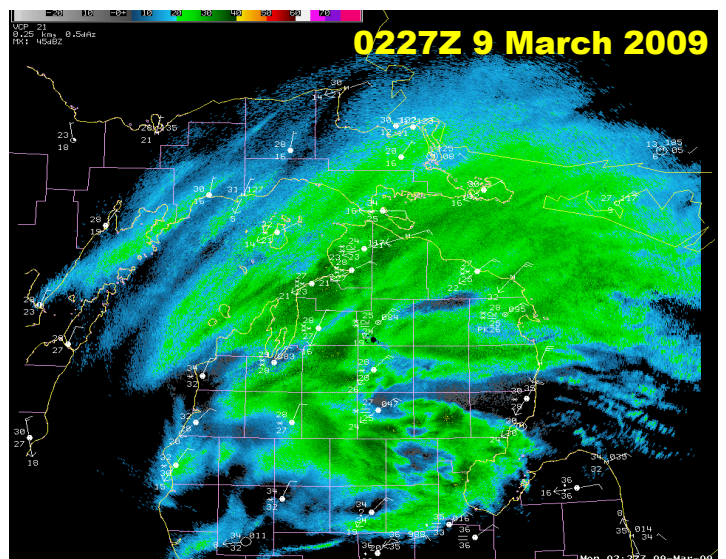
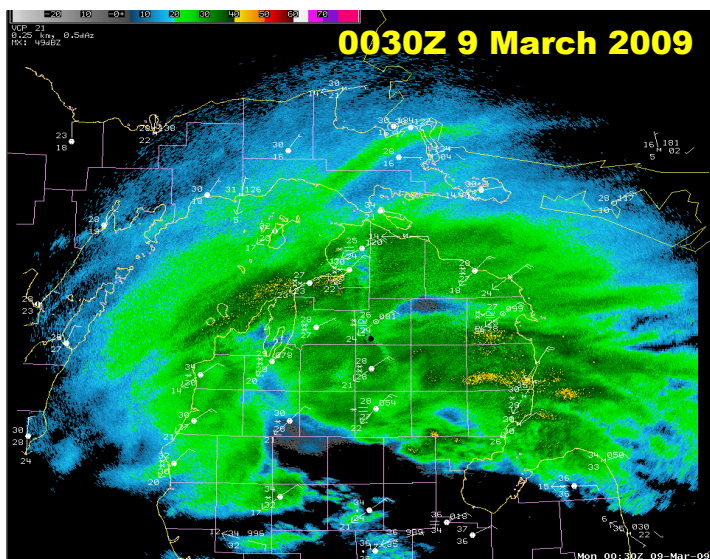
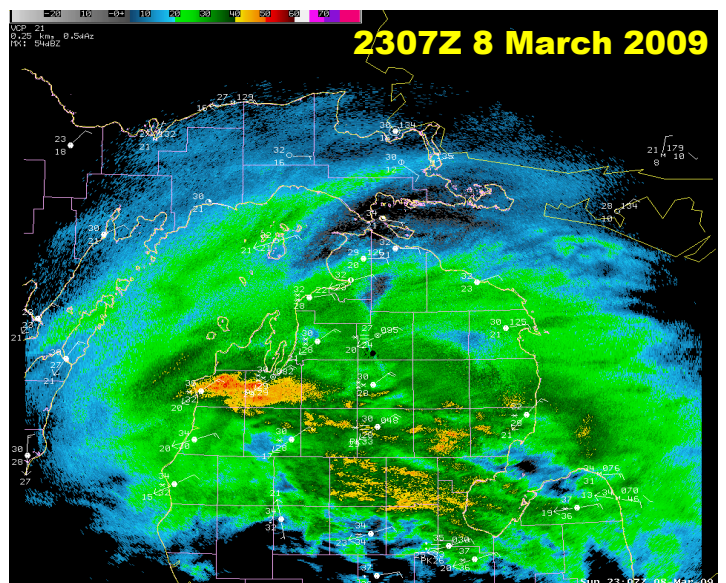
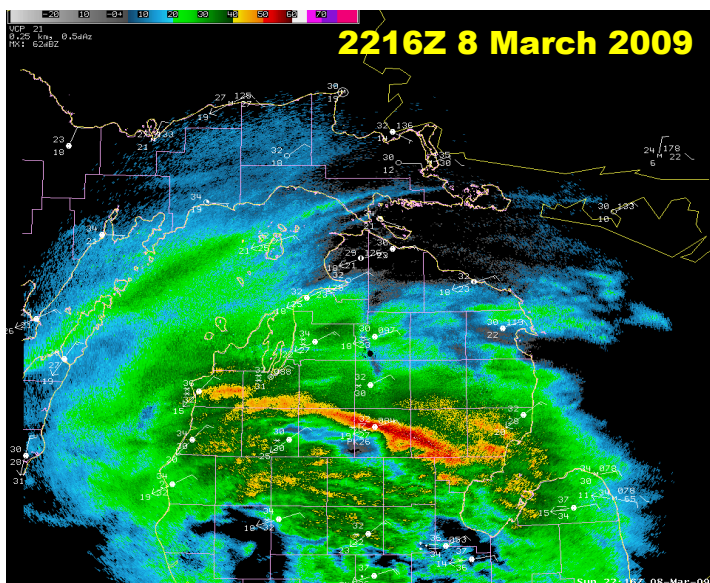
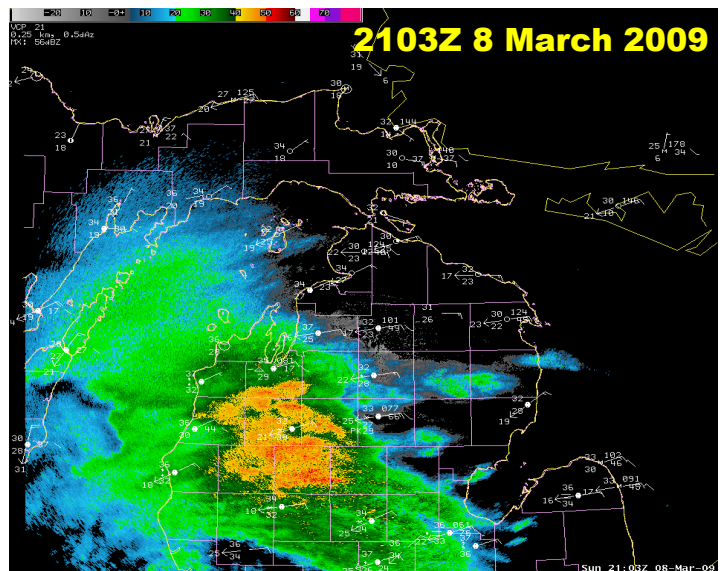
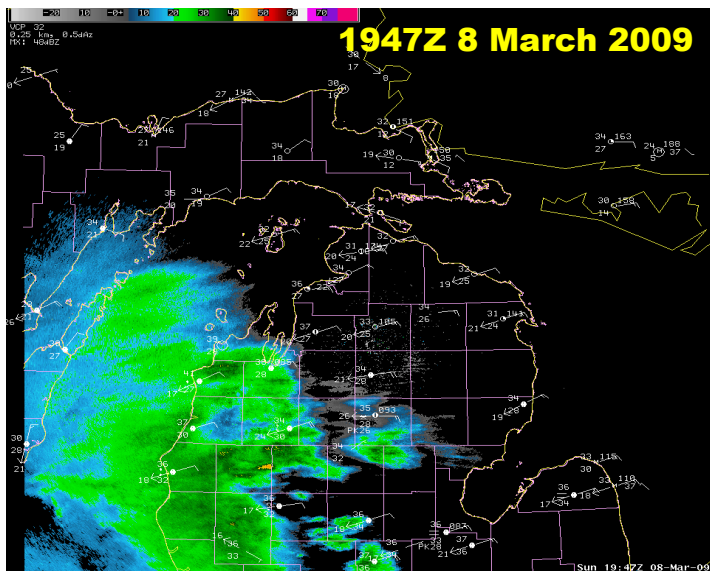


Figure 5. Four panel of upper air analyses valid 00Z 9 March 2009, during the middle of the event. Top left: 250mb isotachs >80kt (shaded every 20kt), streamlines, and 300-250mb ageostrophic wind vectors (red). Top right: 500mb heights (solid) and geostrophic vorticity (dashed contours). White streamlines denote col region at 500mb. Bottom left: 700mb heights (orange contours), isotherms (cyan contours), and relative humidity (>70% shaded green, dark green shading >90%). White streamlines denote col region at 700mb. Bottom right: 850mb heights (solid purple), isotherms (blue contours, 0C isotherm shown dashed) and dew point temperature (>8C shaded green, <-10C shaded orange, <-20C yellow).

side of a frontogenesis maximum. Thus, the response to a frontogenesis maximum is not co-located with it, but is displaced to the warm side of the maximum where the upward branch of the thermally direct circulation forced by the tightening thermal gradient is located. In this case, the forcing for upward motion from frontogenesis at this level is located right across the tip of the mitt counties, extending southwest across the Grand Traverse Bay region and Leelanau County, right where the heaviest snowfall was setting up.

We can look at the frontogenetic forcing from a vertical perspective, as well as assess instability by looking at cross sections taken perpendicular to the heaviest snow band. The cross sections shown on page 13 (figures 12 and 13) are taken along the white line shown in figure 11, essentially running northwest-southeast through the area of heaviest snowfall. Figure 12 show frontogenesis values through the depth of the troposphere along the cross section, along with contours of equivalent potential temperature. Note the rather shallow nature of the slope of the baroclinic zone, not uncommon with warm frontal type features though given the strength of the thermal gradient at 850mb one might expect a little more slope to the frontal zone. Thus, much of the frontogenesis was occurring at and below 700mb across the Lower Peninsula, although frontogenesis was occurring farther aloft



Figures 6 through 11. KAPX WSR-88D reflectivity images and METAR surface observations valid at 1947Z 8 March (figure 6), 2103Z 8 March (figure 7), 2216Z 8 March (figure 8), 2307Z 8 March (figure 9), 0030Z 9 March (figure 10), and 0227Z 9 March (figure 11).

across the Upper Peninsula and northern portions of Lake Michigan. Above the maximum in low level frontogenesis is a strong area of frontolysis, which is significant in that, while often overlooked, also contributes to vertical motion through thermally *indirect* circulations (cold air rising, warm air sinking). Notice in figure 11 the maximum 600-500mb frontogenesis adjacent to the maximum in frontolysis...this can also be seen in the cross sections as well. Recall the upward motion response to frontogenesis will be on the “warm” side of the f-gen maximum (in this case to the south)...the upward motion response to frontolysis, given the thermally indirect circulation it drives, is opposite that of frontogenesis and will be found on the cool side of the frontolysis maximum (in the case to the north). Thus, it is likely that the upward branches of the frontogenetic/frontolytic thermally induced circulations were working in tandem to force strong upward motion. In figure 13, we can see that the maximum in model upward motion is located to the north of the maximum in frontolysis, and south of the maximum in frontogenesis. Also note this is occurring above 700mb, the significance of which will be discussed next.

Given reports of thundersnow and the high intensity snowfall, convective elements clearly played a role in the magnitude of this snow event. Figure 14 shows the sounding from the 00Z 9 March Gaylord (APX) upper air observation. There is a deep, stable layer from 875mb up to 600mb, but above that lapse rates become moist adiabatic. We can visualize this in the cross sections as well; figure 12 shows a strong vertical gradient in theta-e below about 650mb, implying strong stability, but above which lies a deep layer extending to the tropopause where the rate of increase of theta-e with height drops off substantially, indicative of a layer of weaker stability. Figure 13 shows values of saturated geostrophic equivalent potential vorticity, negative values of which highlight layers of instability (either from an “upright” or “slantwise” perspective) Without getting into a detailed discussion of conditional instability versus conditional slantwise instability (or CSI), the main thing to note from figure 13 is the strong upward motion coinciding with a layer of weak stability above 600mb (where the frontogenesis/frontolysis couplet is likely playing a role). In this case, given the stronger baroclinicity in the lower layers and the steeper lapse rates noted in the APX sounding, upright convection likely played a dominant role in this event. Figure 15 shows a cross section of geostrophic momentum and potential temperature, showing the strong vertical shear in the low levels associated with the frontal zone (shallow slope and strong vertical gradient of momentum), but the vertical shear weakens aloft, which does not favor slantwise instability.

Also note in figure 13 the juxtaposition of strong upward vertical motion, weak stability, and the -15°C isotherm, which happens to be the temperature at which dendritic snowflake growth is maximized. Production of large dendritic snowflakes is enhanced by strong vertical motion and saturated conditions coinciding with temperatures favorable for dendrite growth (from -12°C to -18°C). In addition, the APX sounding shows a deep layer of temperatures warmer than -10°C , which also promotes snowflake growth by aggregation, or clumping of snowflakes together to form larger flakes (and lower snow-to-liquid snow ratios, leading to a “wet”, heavy snow). So it appears that an environment supporting efficient snowflake growth also contributed to the impressive snowfall rates during this event.

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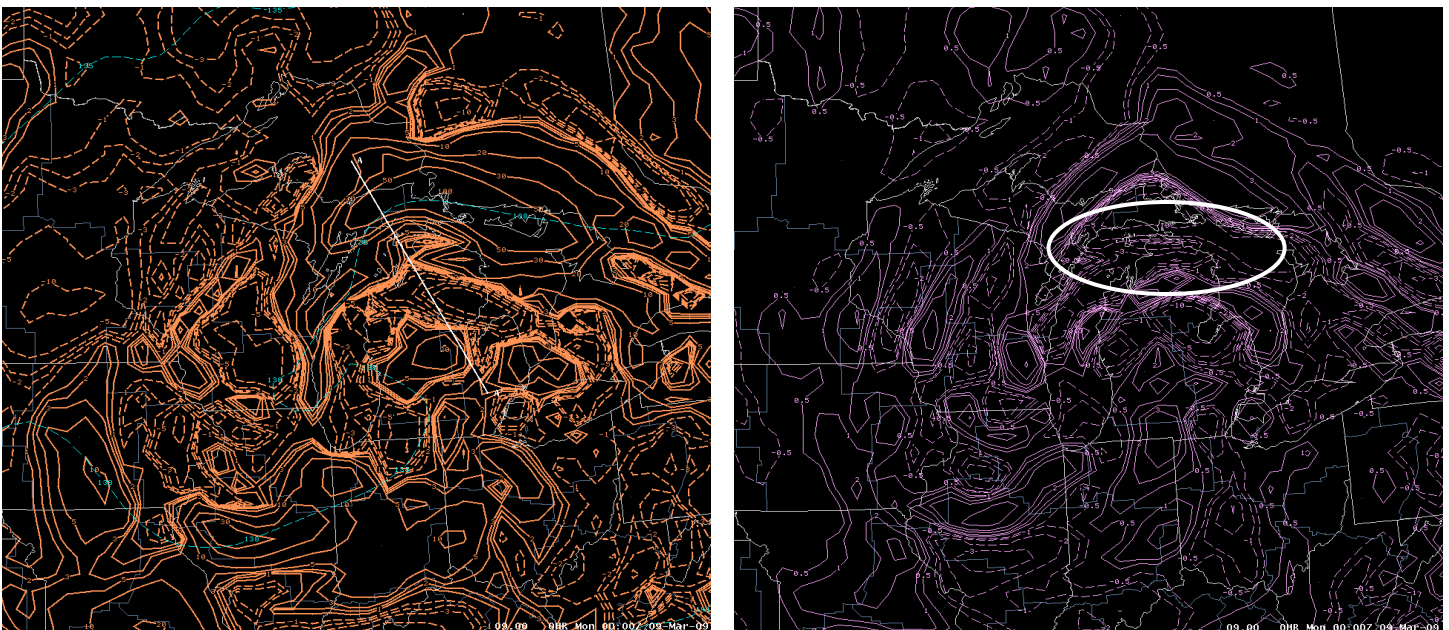


Figure 11. Left: 600-500mb frontogenesis (orange contours, solid positive contours indicate frontogenesis, dashed negative contours indicate frontolysis) and 600-500mb thickness (dashed cyan contours), valid at 00z 9 March. White line marks location of cross sections. Right: 600-500mb F-vector divergence (negative dashed contours indicate convergence). White oval denotes F-vector convergence.

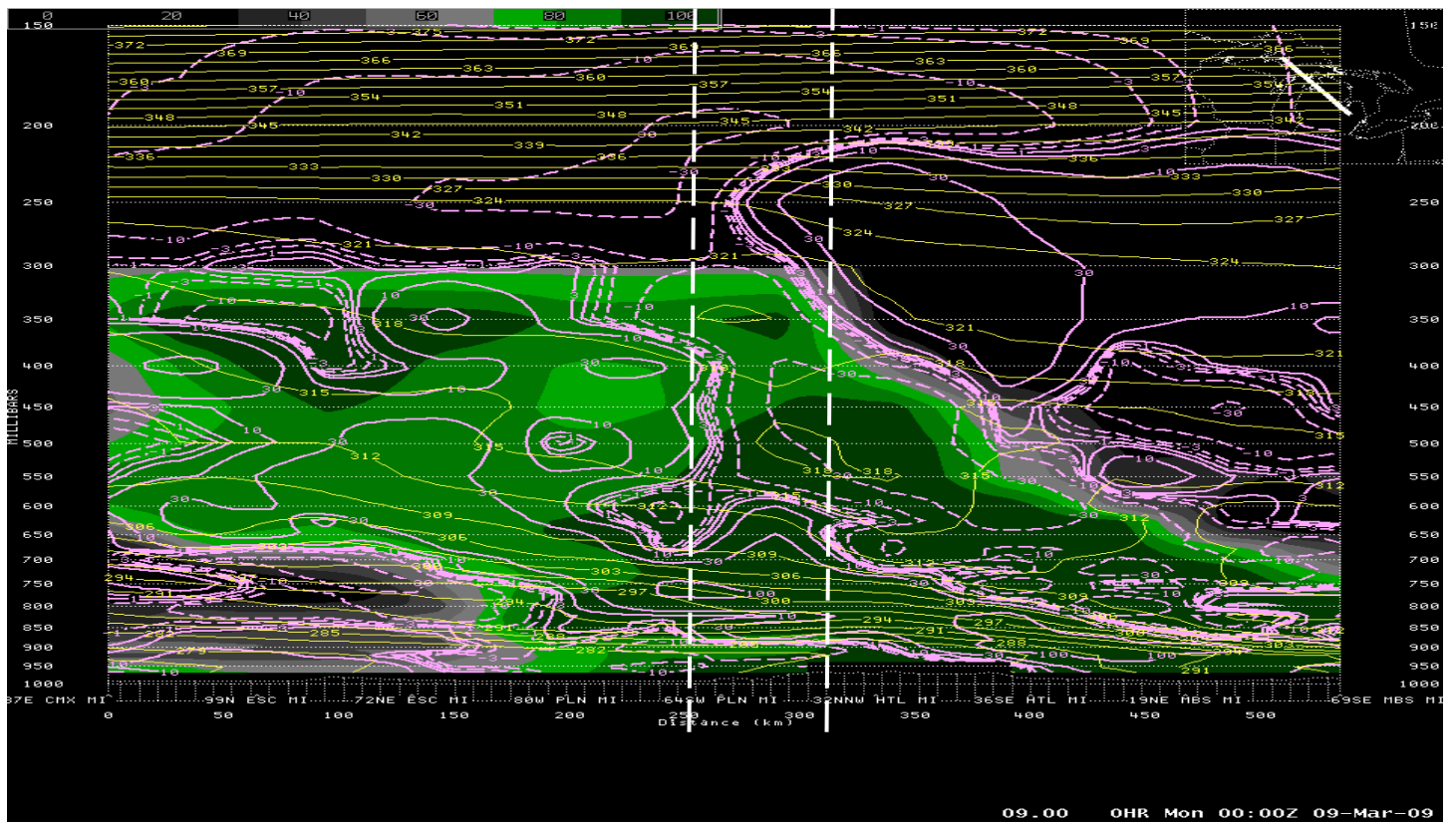


Figure 12. Vertical cross section from the NAM-WRF model, valid 00Z 9 March 2009, taken along white line in figure 11. Yellow contours are equivalent potential temperature (θ -e), purple contours are frontogenesis. Background image represents relative humidity (green shading $RH > 70\%$, dark green shading $RH > 90\%$). Dashed white lines indicate area of heaviest snowfall at valid time of cross section.

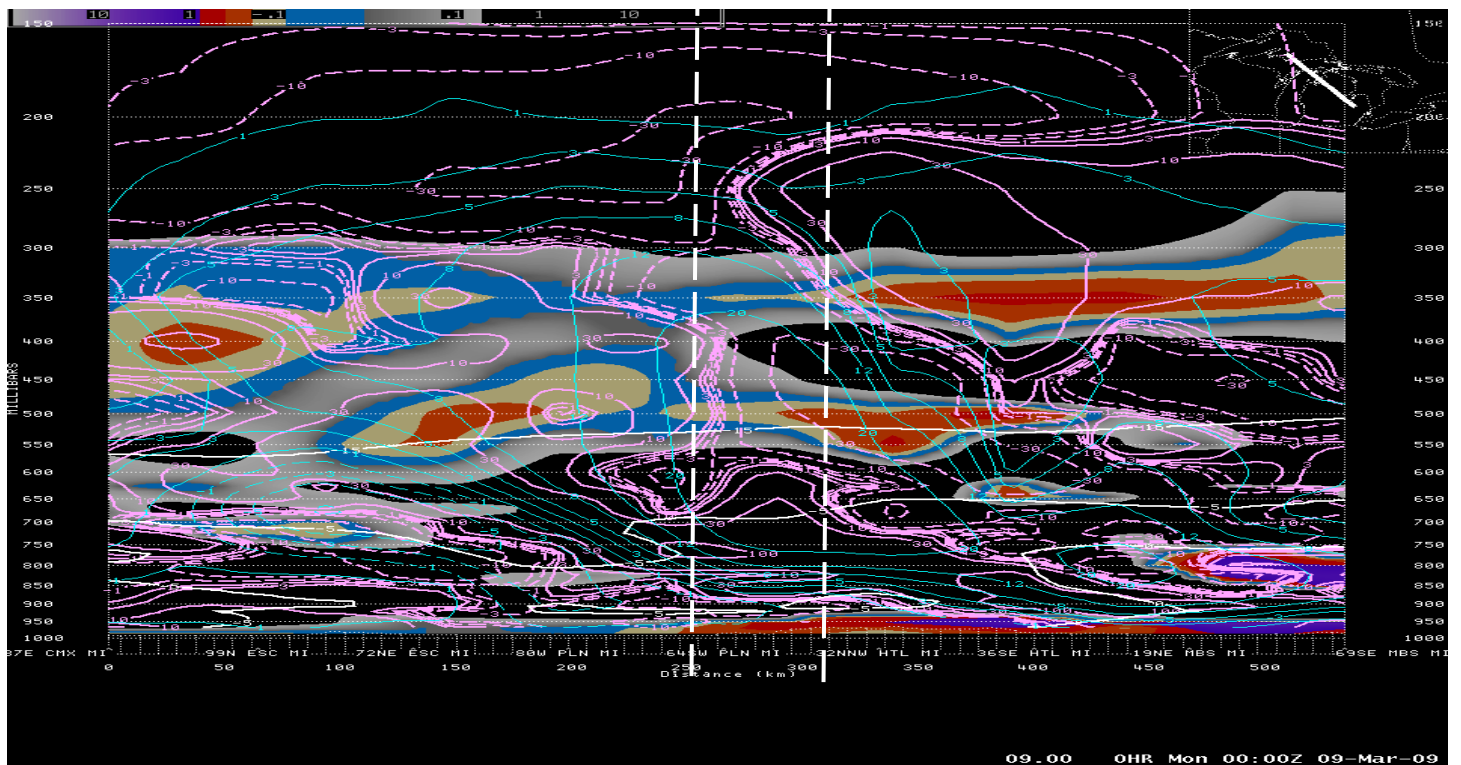


Figure 13. Same cross section as in figure 12. Purple contours are frontogenesis, thin cyan contours are model omega (units $-\mu\text{bars/second}$, so positive values represent upward motion). Solid white contours are the 0C, -5C, and -15C isotherms. Background image represents saturated geostrophic equivalent potential vorticity $< 0.25 \text{ PVU}$ (gray shading represents values from 0-0.25 PVU). Dashed white lines same as in figure 12.

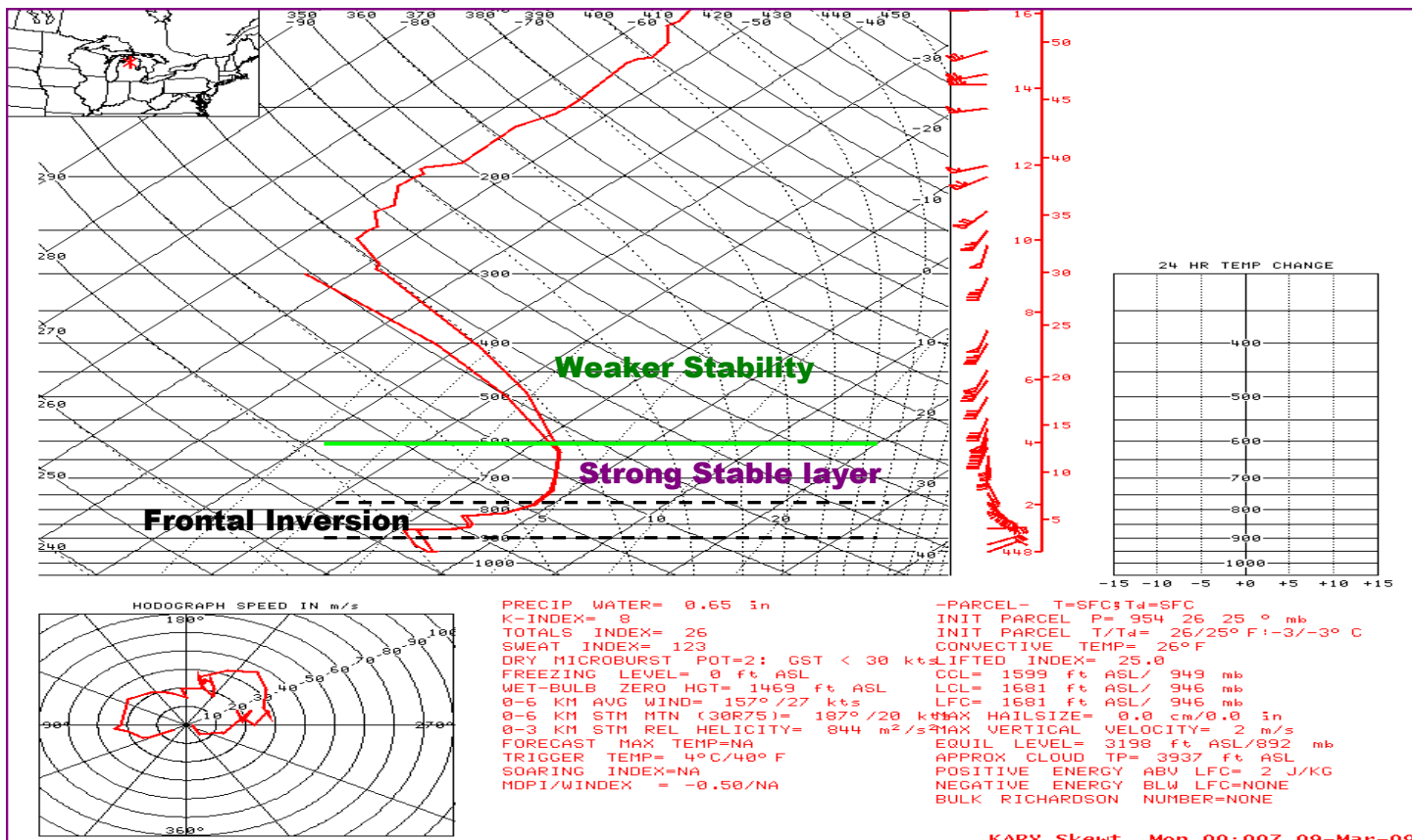


Figure 14. Gaylord MI upper air sounding, valid 00Z 9 March 2009.

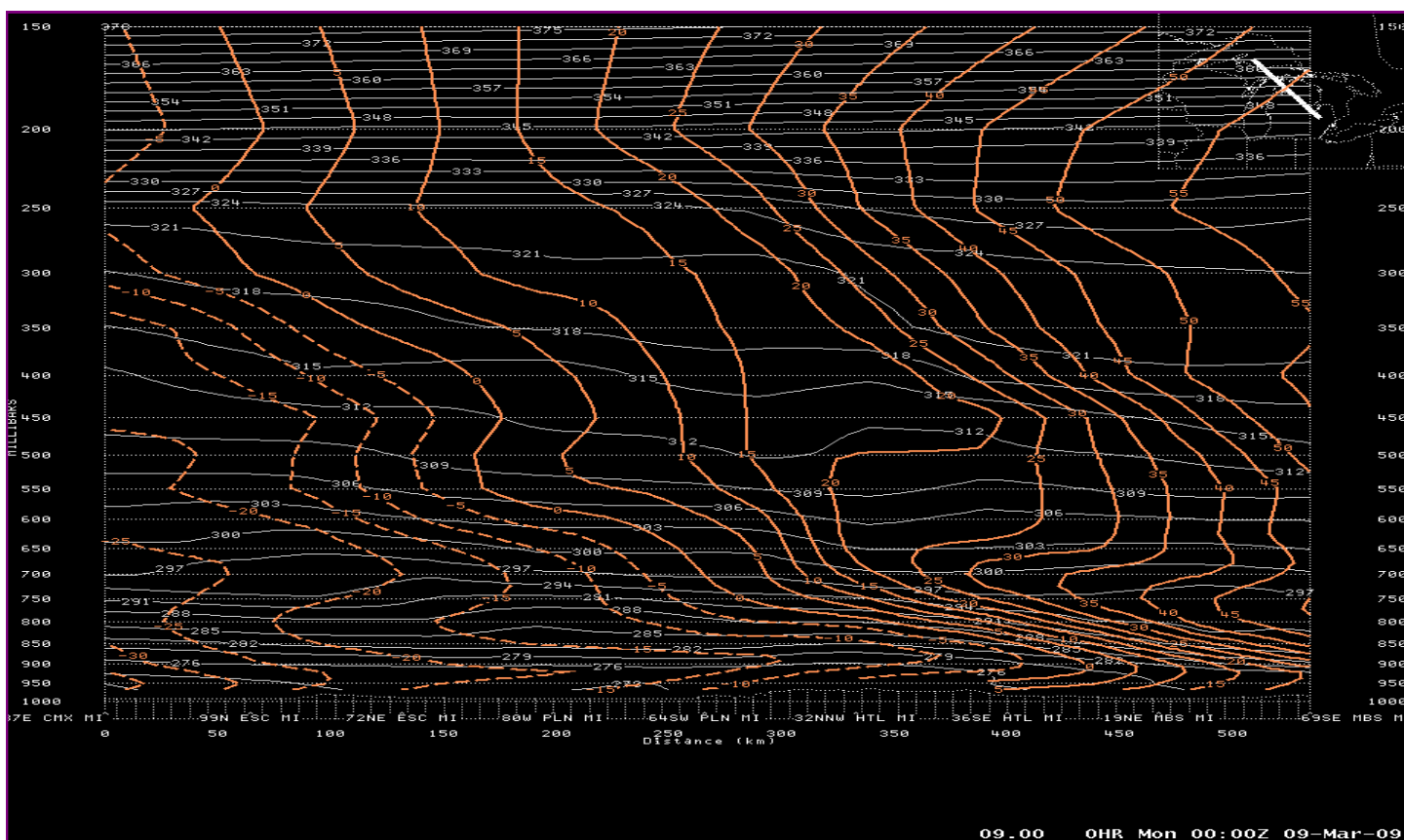


Figure 15. Same cross section as in figures 12 and 13. Geostrophic momentum (orange contours) and potential temperature (gray contours).