National Weather Service

Gaylord, Michigan

The WFO Gaylord Science Corner

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Ten Years Later

A Look Back at the Otsego County Windstorm of 26 September 1998

Shortly after one o'clock on the afternoon of 26 September 1998, a supercell thunderstorm swept quickly across Otsego county along and north of the M-32 corridor. This storm produced a swath of downburst induced wind damage in and around the Gaylord area. Sustained winds of 60 to 80mph occurred over a five minute period, with estimated gusts in excess of 100mph to the north of the city. The storm also produced hailstones up to two inches in diameter. Thousands of trees were blown down across the county, and property damage totalled over $12 million. Fifteen persons were injured by flying and falling debris.

The National Weather Service did some retrospective work on this storm as part of the ten year commemoration of this devastating event for the Gaylord community. This article will reflect on those efforts as we take a look back at what happened that warm, late September Saturday afternoon.

Photos courtesy of the *Gaylord Herald Times*

The Storm

The severe thunderstorm that impacted the Gaylord area was part of four rounds of severe weather to impact northern Lower Michigan that late September weekend. The first occurrence of severe storms occurred around and shortly after daybreak on the 26th, as several clusters of thunderstorms rolled across areas along the M-55 corridor.

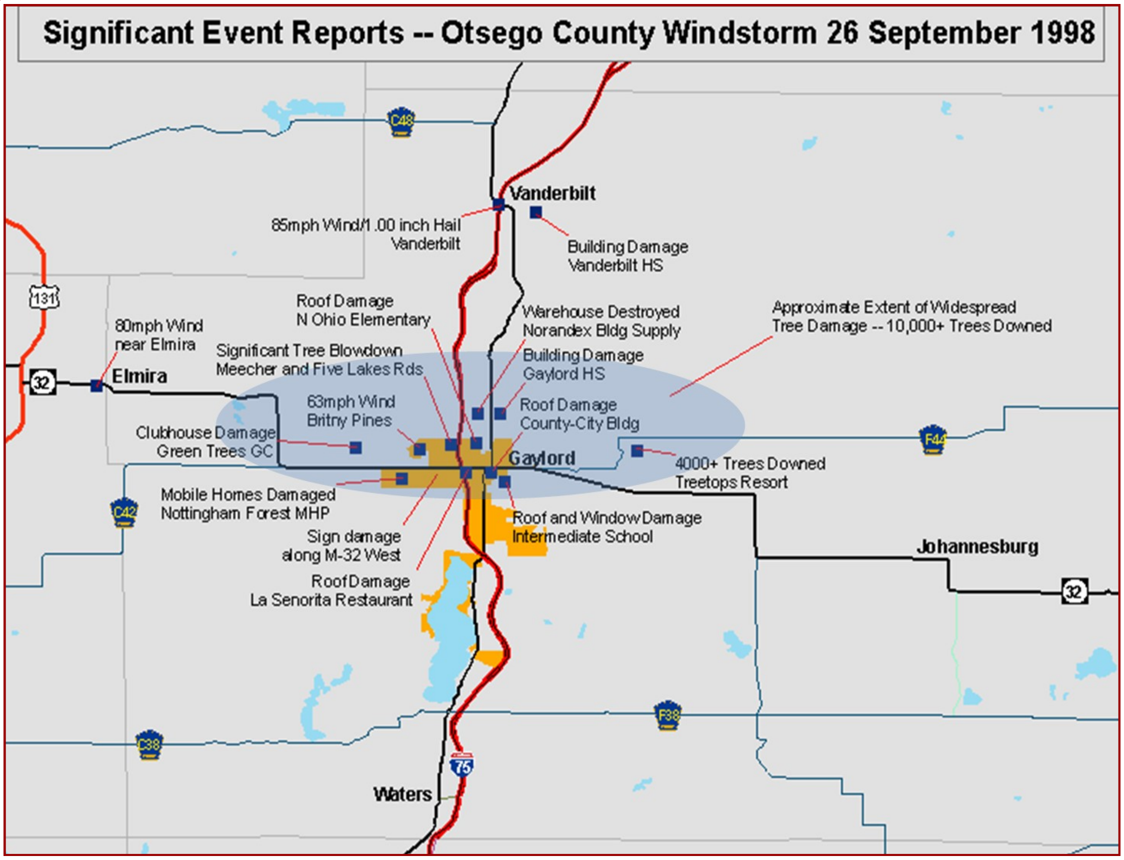

Figure 1. Significant event reports from Otsego County — 26 September 1998.

Large hailstones, some up to three and a half inches in diameter, pounded portions of Manistee, Gladwin, and Arenac counties. Two apple orchards were badly damaged by the hail near Bear Lake in Manistee County, with over 15,000 bushels of apples destroyed. Once this line of storms moved out into Lake Huron, the remainder of the morning was relatively quiet across northern Michigan...mainly overcast and humid. A warm front lifting northward across northern Lower Michigan brought temperatures and dew points into the 70s up to the M-72 corridor by midday. Within this increasingly warm and humid air mass, new thunderstorms began to develop over northern Lake Michigan shortly after noon, and moved quickly onshore into Charlevoix and Antrim counties. Within this cluster of new cells, one storm in particular became better organized and began to take on supercellular characteristics with the development of a mid level mesocyclone (figure 1). This rotation, combined with a descending rear inflow jet, led to the development of severe wind gusts. Wind damage was reported in East Jordan and Boyne Falls, followed by an estimated 80mph wind gust near Elmira along the Antrim/Otsego county line around 1:00pm. Figure 2 shows a closer look at the radar reflectivity depiction from the 0.5 degree elevation slice off the KAPX WSR-88D. This image shows the bowing line segment along the forward flank of the organizing supercell associated with the storm's outflow surge approaching northwest Otsego county.

Moving into Otsego County: After producing the damaging wind gusts near Elmira, the storm accelerated eastward into Otsego county, moving at speeds near 65mph. Figure 3 shows the reflectivity and storm relative velocity

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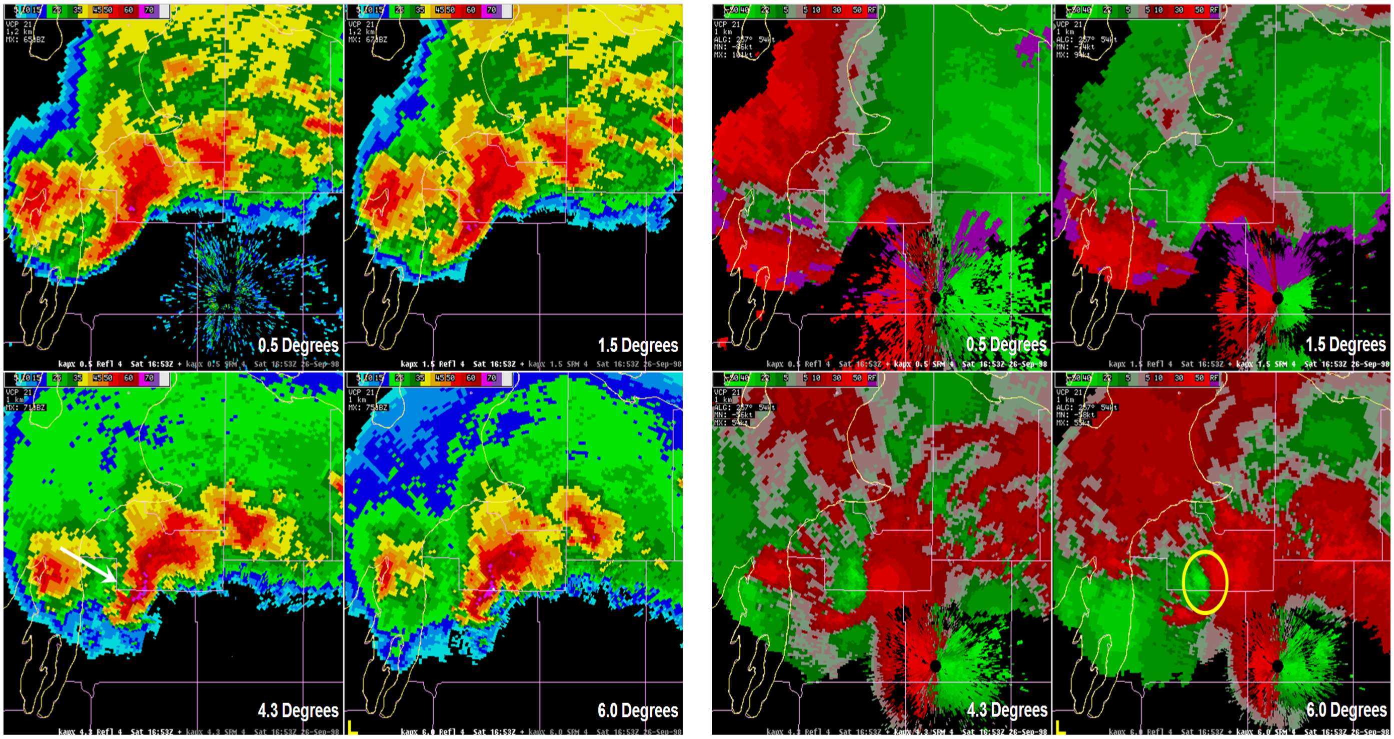


Figure 1. Four panel reflectivity (left) and corresponding storm relative velocity (right) images from the KAPX WSR-88D at 12:53pm EDT 26 September 1998. Radar data was taken from the 0.5, 1.5, 4.3, and 6.0 degree elevation angles. At left, reflectivity data shows a developing bowing configuration, with a weak echo channel depicted by the white arrow on the 4.3 degree elevation slice associated with a descending rear inflow jet. At right, the developing mesocyclone is denoted by the yellow circle in the 6.0 degree elevation slice. Convergence signatures are also evident along the leading edge of the storm's outflow.

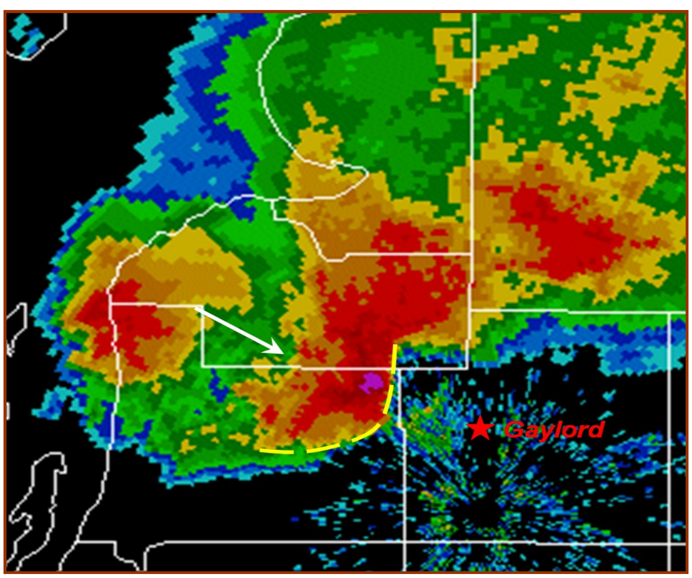
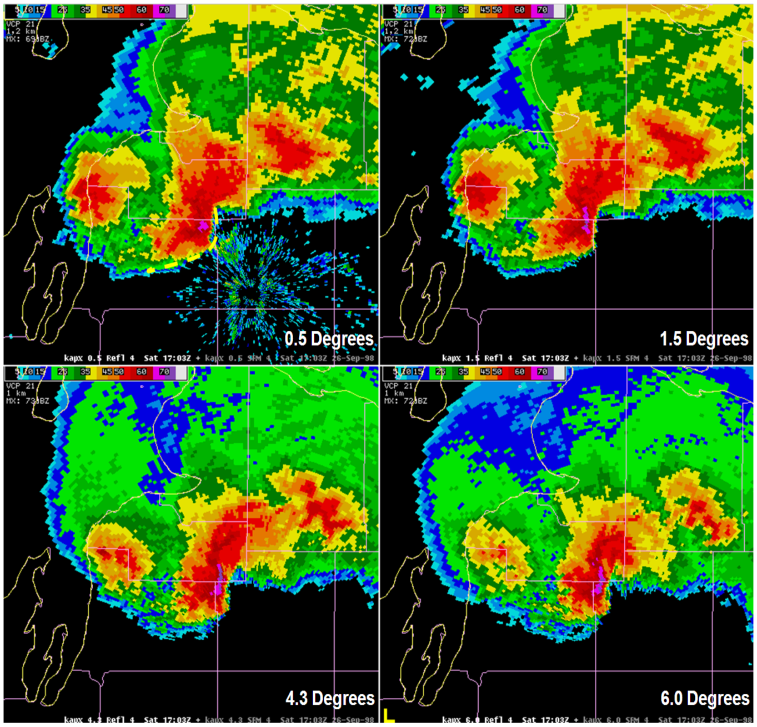


Figure 2. 0.5 degree elevation reflectivity from the KAPX WSR-88D at 12:58pm EDT 26 September 1998. Bowing echo indicated by dashed yellow line, with the weak echo channel now evident in the lowest levels of the storm denoted by the white arrow.

characteristics of the supercell at 1:03pm, about 10 minutes before the storm reached Gaylord proper. It is surmised that, in addition to the outflow associated with the forward flank downdraft, a rear flank downdraft began to develop along with the appearance of a reflectivity appendage or "hook" echo. The rear flank downdraft enhanced the outflow already occurring with the storm, and is the portion of the storm that swept across the city of Gaylord (figure 4). This downdraft surge likely contained the core of the strongest winds that produced a swath of damage extending from the Glen Meadows development and the adjacent Green Trees Golf Course west of downtown, east through the Five Lakes neighborhood, then across I-75 where significant damage occurred to buildings and homes along and north of M-32.

A five minute period of sustained winds from 60 to 80mph occurred in Gaylord as the storm arrived, with estimated gusts around 100mph across the aforementioned more heavily damaged areas. After hitting Gaylord, the storm



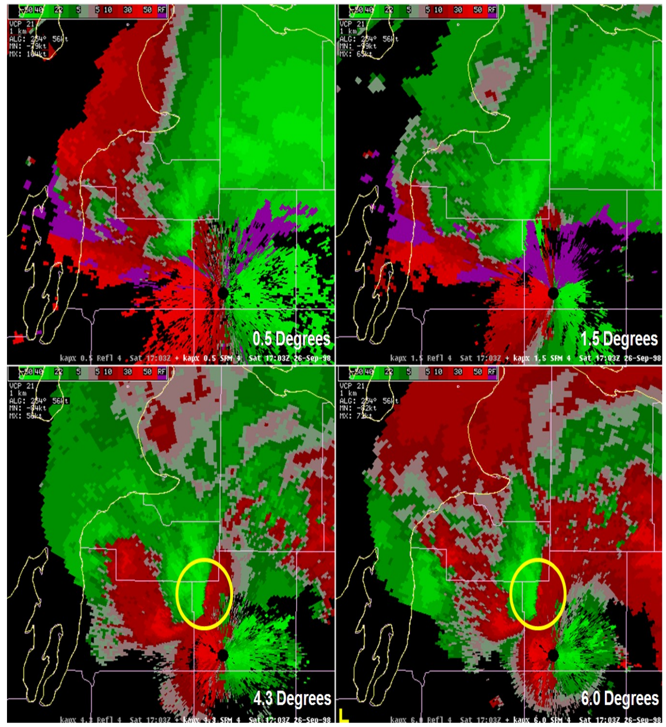


Figure 3. Same as figure 1, valid at 1:03pm EDT 26 September 1998. Cyclonic rotation noted by yellow circle on the 4.3 and 6.0 degree elevation storm relative velocity panels. Bowed out outflow boundary denoted by yellow dashed line in 0.5 degree reflectivity panel.

continued to race east, knocking down thousands of trees around the Treetops Sylvan resort. By 1:30pm, the storm had already moved out of Otsego county, producing continued wind damage across Montmorency, Presque Isle, and Alpena counties before moving out onto Lake Huron around 2:30pm.

Although the kinematic environment across northern Lower Michigan was supportive of rotating updrafts in its own right (see figure 6 for a hodograph analysis), the development of supercellular characteristics within the storm that impacted Gaylord was likely aided by external processes resembling those associated with quasi-linear convective systems (QLCS). Mesocyclone development within QLCS events involves either isolated cells or a line of storms interacting with a low level boundary that acts as a source of enhanced horizontal vorticity due to buoyancy differences between the warm and cool sides of the boundary. This horizontal vorticity is ingested into the storm's inflow region, supporting the development of updraft rotation. QLCS events are prolific damaging wind producing systems, as was the case with this event.

Figure 5 shows two reflectivity images as the storm approached Otsego county. As the severe cell is initially moving onshore into western portions of Charlevoix and Antrim counties, the northern end of the storm is interacting with an east-west oriented boundary associated with an area of precipitation moving across the tip of the mitt counties. This boundary lies right along the eventual track of the storm, with the associated enhanced vorticity being ingested right into the storm's updraft as the cell propagates along the boundary (note intersection of boundary and inflow notch in figure 5). This collocation of updraft and horizontal vorticity (high helicity) allows this spin to get pulled into the updraft and stretched vertically, which increases the rate of rotation. This rotation can enhance development of a rear inflow jet, which also occurred in this case. Additional information on QLCS event research conducted at the St. Louis NWS office can be found here: http://www.crh.noaa.gov/lsx/?n=qlcslatest

The Aftermath

Property damage for this event totalled over $12 million, with 47 homes destroyed and over 770 homes damaged by the winds. Two businesses were destroyed, and over 70 businesses damaged. Seven public buildings were damaged, and an estimated 10,000+ trees were toppled. Fifteen persons were injured, but fortunately there were no fatalities. After the storm, Governor John Engler visited the area, and issued a disaster declaration. National Guard troops were dispatched to assist clean-up efforts,

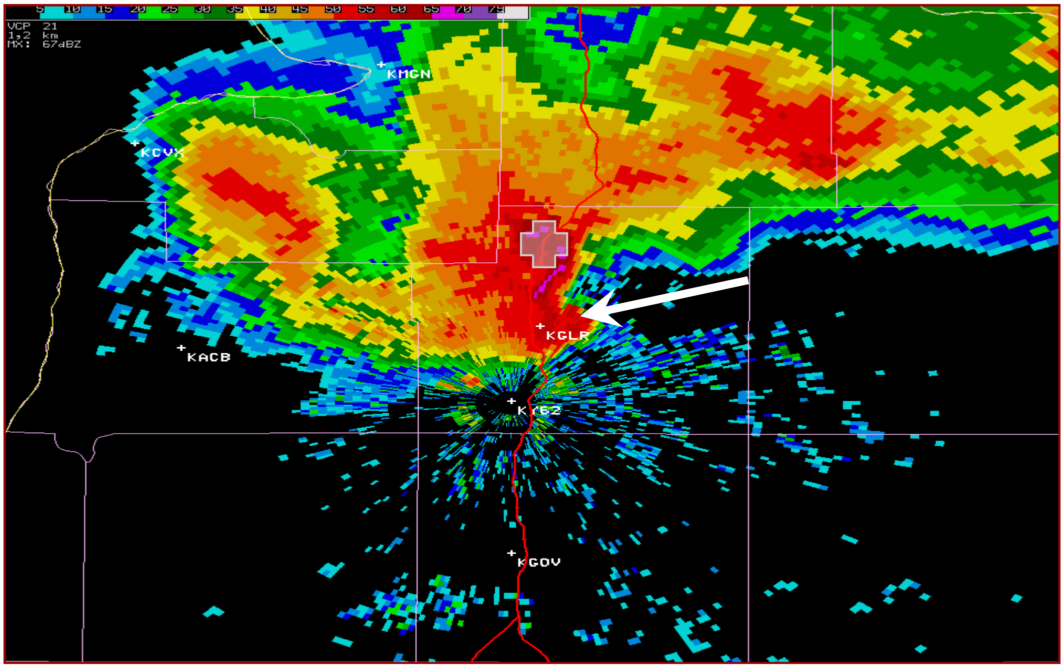


Figure 4. Supercell thunderstorm impacting Gaylord (denoted on the map by KGLR) — 1:15pm EDT 26 September 1998. Rear flank downdraft and appendage echo on southern flank of the storm denoted by the arrow. At this time, wind damage and large hail were also occurring in Vanderbilt, marked by the "+" on the map. This latter area was impacted by what remained of the original bow echo associated with the forward flank downdraft.

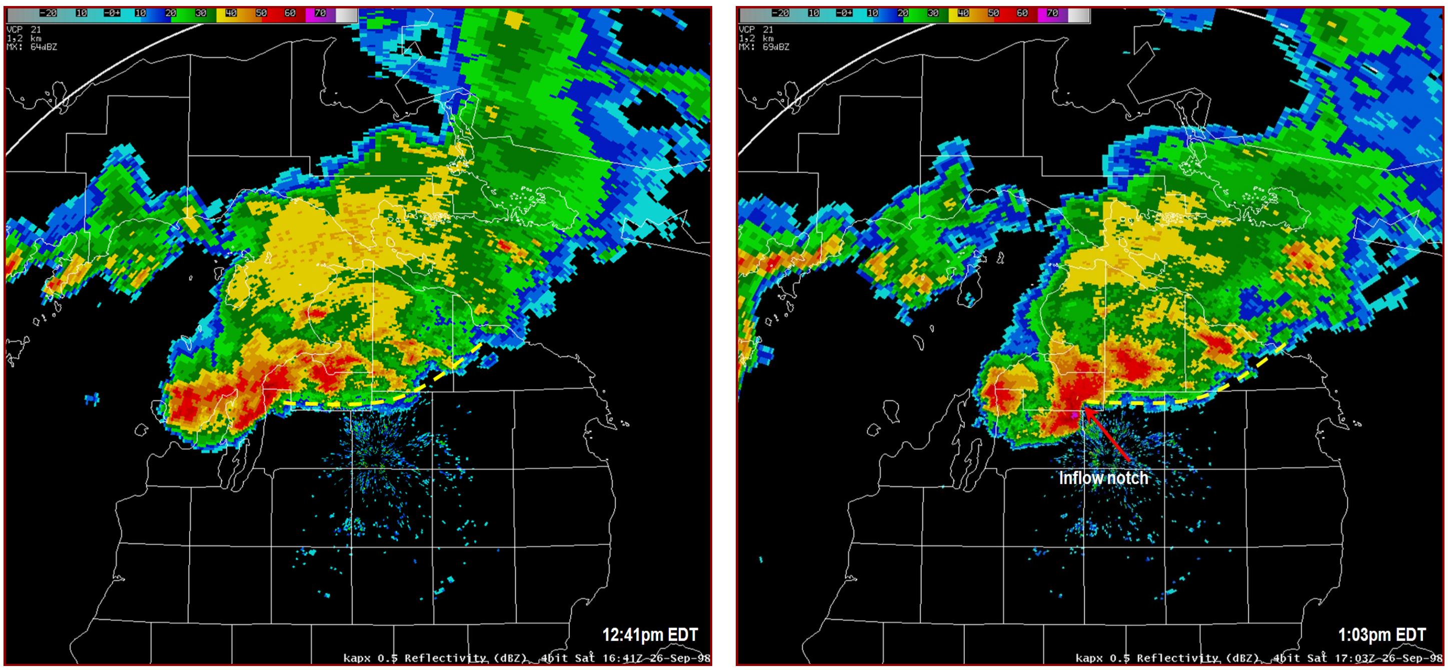
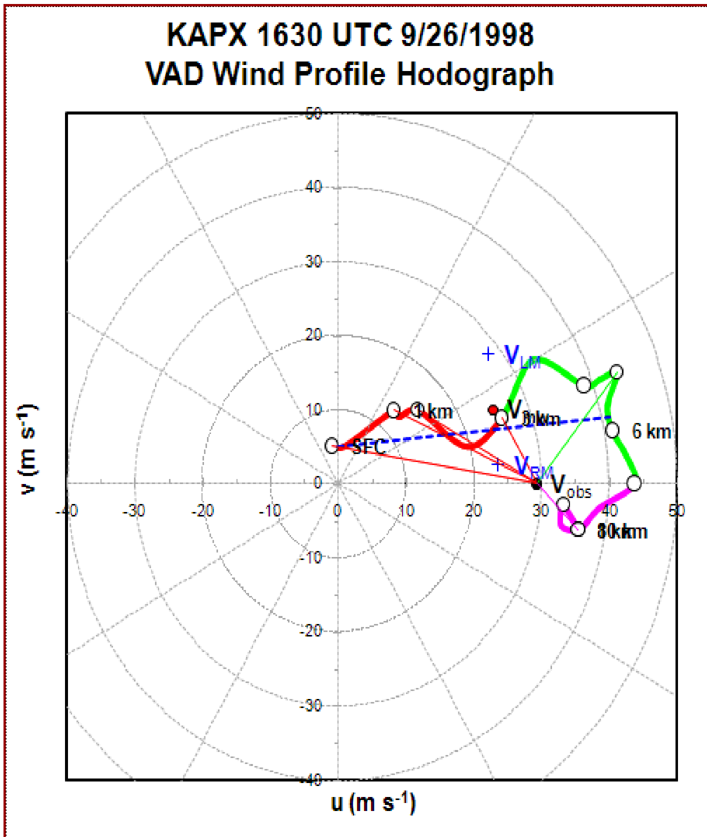


Figure 5. 0.5 degree reflectivity images valid at 12:41pm (left) and 1:03pm (right). Yellow dashed line indicates leading edge of cooler outflow associated with the precipitation across the Straits region. The boundary and its enhanced low level vorticity is intersecting the northern end of the storm that eventually impacts Otsego county. In the right image, a well defined inflow notch has developed (denoted by the red arrow). Low level vorticity is being ingested right into the updraft, which is supporting/enhancing the mesocyclone within the developing supercell.

particularly with the extensive tree damage. The most widespread damage occurred in a roughly 2 mile wide by 12 mile long area parallel to and north of M-32, extending approximately from Elmira, through the city of Gaylord, then east out towards Treetops resort. One concentrated area of damage occurred around and to the north of Gaylord. Many signs and billboards were damaged, and several gas pumps were tipped over. The La Senorita restaurant along M-32 had a large portion of its roof torn off. A large cinder block warehouse at the Norandex Building Supply Company north of Gaylord was largely destroyed. As the walls of the warehouse collapsed, the metal roof and steel trusses were torn off and blown over 300 yards into the Gaylord High School building, causing extensive damage. Many light posts in the school parking lot were toppled over or badly bent. Damage also



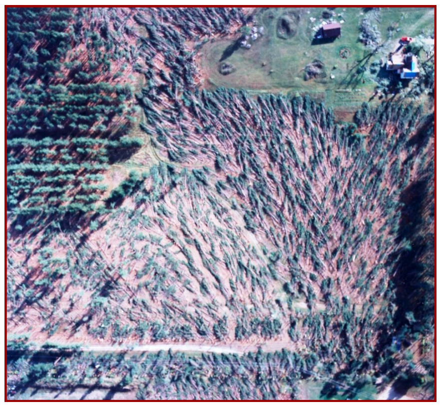
	Wind Data Entry		CAPE	BRN	EHI	VGP
Surface	170	10	500	2	0.6	0.26
0.5 km AGL	190	10	1000	4	1.1	0.37
1 km AGL	220	25	1500	7	1.7	0.45
1.5 km AGL	225	25	2000	9	2.3	0.53
2 km AGL	230	30	2500	11	2.9	0.59
2.5 km AGL	255	38	3000	13	3.4	0.64
3 km AGL	250	50	3500	15	4.0	0.69
3.5 km AGL	240	65	4500	20	5.1	0.79
4 km AGL	250	75	Torns -->	(5<BRN<50)	(EHI > 2.5)	(VGP > 0.3)
4.5 km AGL	250	80		BRN>50; HP		
5 km AGL	250	85				
5.5 km AGL	255	80	<--- Dir/Spd (1) or u/v (2) =			1
6 km AGL	260	80	<--- Knots (1) or m/s (2) =			1
6.5 km AGL	265	83				
7 km AGL	270	85	Deviation from MW?			7.5
7.5 km AGL	275	75	Mean Wind Depth?			6
8 km AGL	280	70	(3, 4, 6, 8, or 10 km)			
8.5 km AGL	280	65				
9 km AGL	275	65	Elevated Depth?			sfc
9.5 km AGL	280	70	(sfc, 0.5, 1.0, 1.5, or 2 km)			
10 km AGL	280	70				
				Direction	Speed (kts)	
	Observed Motion =			270	57	
	MA Error RMover ($m\ s^{-1}$) =			6.3		

								Positive	Negative	
0-1km SRH (V_{obs})=	183	$m^2 s^{-2}$	0-8km Bulk Shear=	38	$m\ s^{-1}$	> 25-30 $m\ s^{-1}$ for > 4-h supercells				
0-3km SRH (V_{obs})=	267	$m^2 s^{-2}$	0-6km Total Shear=	60	$m\ s^{-1}$	> 20-25 $m\ s^{-1}$ for supercells	<---	22.3	-37.9	$m\ s^{-1}$
0-1km SRH (V_{RM})=	132	$m^2 s^{-2}$	0-6km Bulk Shear=	42	$m\ s^{-1}$	> 10-15 $m\ s^{-1}$ for supercells				
0-3km SRH (V_{RM})=	183	$m^2 s^{-2}$	0-3km Total Shear=	30	$m\ s^{-1}$	> 13-15 $m\ s^{-1}$ for sustained bows	<---	9.7	-19.9	$m\ s^{-1}$
0-1km Bulk Shear=	10	$m\ s^{-1}$	0-3km Bulk Shear=	25	$m\ s^{-1}$	> 8-10 $m\ s^{-1}$ for sustained bows				
			BRN Shear=	226	$m^2 s^{-2}$	> 30-40 and < 100-120 for low-level mesos				
0-3km SRH (V_{LM})=	-197	$m^2 s^{-2}$	0-1km SRF (V_{obs})=	27.4	$m\ s^{-1}$	> 10 for significant rotation				
1-3km SRH (V_{LM})=	-185	$m^2 s^{-2}$	0-3km SRF (V_{obs})=	20.5	$m\ s^{-1}$	> 10 for significant rotation				
1-3km SRH < -40 for significant mesoanticyclones			5-km SRF (V_{obs})=	19.0	$m\ s^{-1}$	> 8 for tornadic supercells				
© Matthew J. Bunkers, NWS Rapid City, SD (UNR)			8-km SRF (V_{obs})=	8.8	$m\ s^{-1}$	< 14 for HP, 14-24 for CL, > 24 for LP				
Last Updated -- 3/13/2008			7-10km SRF (V_{obs})=	8.3	$m\ s^{-1}$	< 14 for HP, 14-24 for CL, > 24 for LP				

Figure 6. Hodograph analysis based off the VAD wind profile from the KAPX WSR-88D, valid at 12:30pm EDT 26 September 1998, about 45 minutes prior to the storm impacting Gaylord. The red trace on the hodograph represents shear vectors from the surface to 3km AGL, the green trace shows shear vectors from 3 to 7km AGL, and the magenta trace shows wind vectors from 7 to 10km AGL. The storm motion used was from 270 degrees at 57kt (denoted on the hodograph by $\mathbf{V_{obs}}$). The mean 0-6km wind is marked by the red dot. The points marked $\mathbf{V_{LM}}$ and $\mathbf{V_{RM}}$ represent forecast motion of left and right moving supercells based on the Bunkers Internal Dynamics method. Thin red lines indicate storm relative flow vectors from 0-3km. Much of the directional shear was confined to the lowest 2km of the hodograph, though substantial speed shear is evident to around 5km AGL. Deep layer shear values were supportive of supercell development (e.g., 0-6km bulk shear values over 80kt), with rotation potential also enhanced by strong low level storm relative inflow. Note that speed of the storm was faster than what the Bunkers method would forecast for a right moving (i.e., cyclonically rotating) supercell. This was likely due to the rapid eastward surge of the outflow boundary, resulting in a large propagation component to storm motion (due to new updraft development along the leading edge of the outflow). This fast storm motion contributed to the strong low level storm relative inflow, which also inflated low level storm relative helicity values. (Hodograph analysis spreadsheet courtesy of Matthew Bunkers, Science and Operations Officer, NWS Rapid City, SD).

occurred at North Ohio Elementary School, which lost about two-thirds of its gymnasium roof, and at Gaylord Intermediate School, where the roof was damaged, windows shattered, and the press box at the athletic field was pushed over onto the bleachers. Gaylord schools were closed for three days following the storm while repairs were made.

John Boris



Storm damage photos courtesy of the *Gaylord Herald Times*

Forecast Thought Process Behind the 8 June 2008 West Branch Severe Wind Event

Thunderstorm initiation , propagation, and intensity is often tied to mesoscale phenomena, including forced ascent along congealed cold pool boundaries from pre-existing thunderstorm complexes (Mesoscale Convective Systems (MCS's)), instability magnitude, and location of axes of high instability in relation to the thunderstorm complex. Pre-existing thunderstorms also impact future storm evolution by disrupting low level moisture, and altering instability as a result of remnant cloud shields. To further complicate matters, high resolution deterministic model guidance often struggles with the placement and subsequent effects of these phenomena, placing too much emphasis on convective initiation along large scale forcing mechanisms while not accounting for the cumulative disruptive effects of pre-existing storms. Thus, forecasters must rely on pattern recognition skills and detailed analysis of in situ storm environments for subsequent thunderstorm initiation, movement, and intensity characteristics.

A thunderstorm event from 8 June 2008 presented many of these challenges to forecasters at NWS Gaylord. An approaching unseasonably strong Rocky Mountain shortwave and attendant cold front, further supported by focused upper level jet dynamics, interacted with an antecedent conditionally unstable air mass, just as an overnight MCS impacted the southern Great Lakes and mid Mississippi Valley. This article will focus on this Great Lakes thunderstorm event, centering specifically on a convectively driven high impact damaging wind event that occurred at West Branch during the mid afternoon hours of 8 June.

Environmental Conditions

As figure 1 indicates, conditions were very supportive for western Great Lakes convective initiation during the early morning hours of 8 June. An impressive low level moisture feed in broad southwest flow was overlain by excellent upper level jet dynamics via a strong difluent region within the right entrance region of 120kt 250mb jet streak pivoting northeast into Ontario. Forced ascent was further supported by impressive inferred low level mass convergence maxima on nose of 60kt low level jet moving into southwest Missouri. As anticipated, squall line initiation rapidly took place during the early morning hours over south central Wisconsin where low level mass convergence and upper level divergence were best juxtaposed (figure 2). The rapidly advancing convective complex took on classic squall line properties with a well defined bookend vortex on its northern end as it advanced into Lake Michigan. Of particular interest, note in figure 3 is the mid level jet core of 65kts advancing in behind the line, as observed from the Milwaukee/Sullivan (KMKE) WSR-88D. This feature would be of particular interest as it crossed northern Michigan during the early afternoon hours.

Examining kinematic profiles using high resolution Rapid Update Cycle (RUC) analyses as the squall line moved into Michigan, notice the 65kt 500mb jet core (initially captured by the KMKE WSR-88D) pivoting northeast into north central Michigan, with a corresponding 0 to 6km bulk shear magnitude increase to greater than 60kts (figure 4). From a kinematic viewpoint, these values are more than sufficient to support a high end wind event as the upstream squall line propagates into the area.

Although kinematics were supportive, the amount of instability was potentially the greatest uncertainty to severe weather possibilities, owing specifically to the remnant MCS cloud shield and possible disruption of northward advancing low level moisture. However, as an early morning visible satellite imagery illustrates (figure 5), the anvil cloud shield associated with a decaying lower lakes MCS dissipated much earlier than anticipated, allowing a several hour period of at least partly cloudy skies over central and northeast Lower Michigan, before upstream clouds overspread the area. Also note the uninterrupted northward advancing moisture surge, with observation sites throughout central and southern Michigan indicating dew points well into the upper 60s. Although there is no specific West Branch observation, dew points in the mid to upper 60s can easily be inferred. Local Analysis and Prediction System (LAPS) data showed a subsequent rapid increase in surface based CAPE, with values approaching 800J/kg in this region during the late morning hours. Although these values of SBCAPE typically represent "marginal" instability values, coupled with the

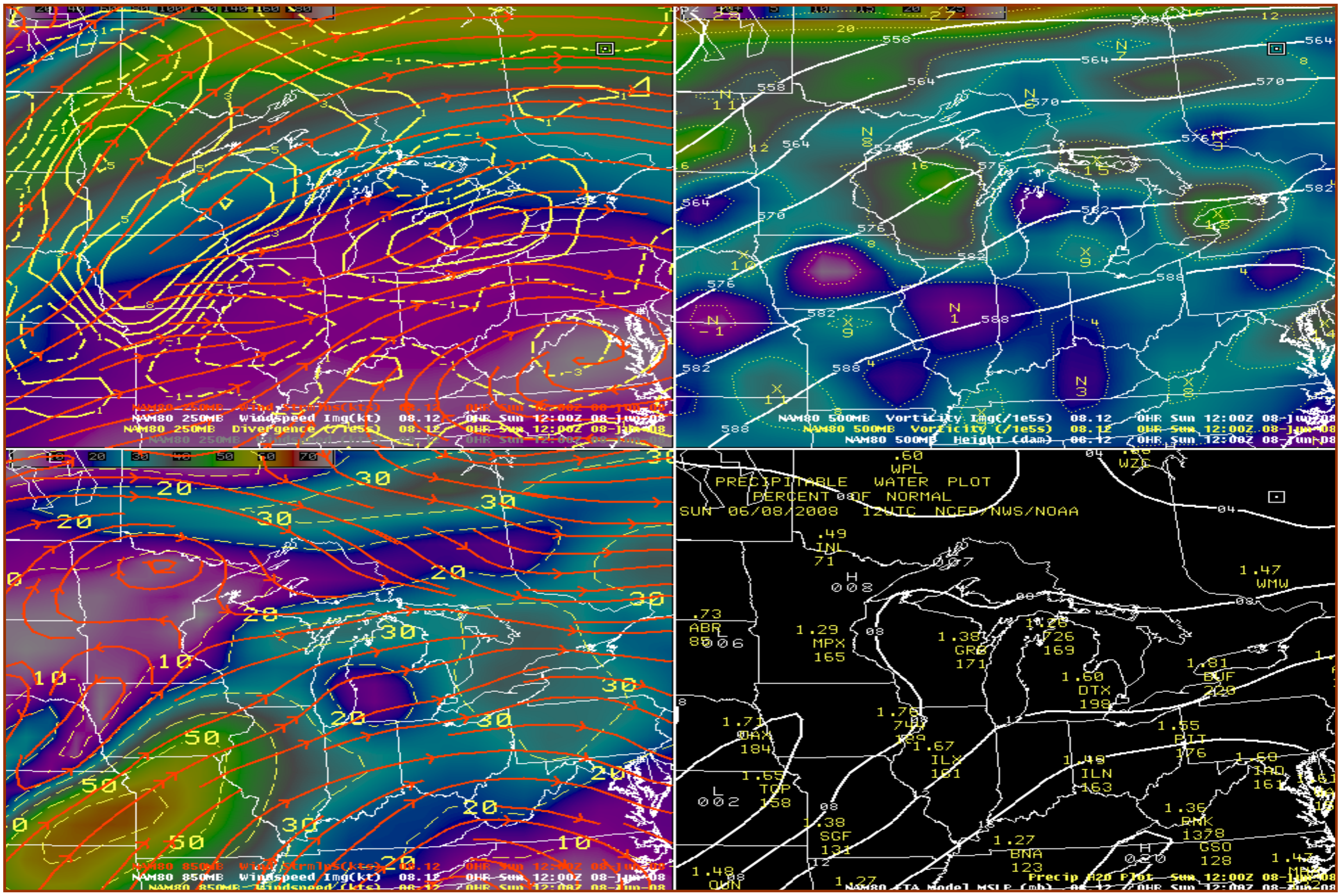


Figure 1. Four panel overview of environmental conditions, valid 12z 8 June 2008. Top left: 250mb isotachs (shaded...green/yellow shading indicates maximum wind core), streamline, and divergence (solid contours represent positive values). Top right: 500mb heights (white) and absolute vorticity (shaded). Bottom left: 850mb isotachs (shading and yellow dashed contours) and streamlines. Bottom right: Sea level pressure field and observed precipitable water values.

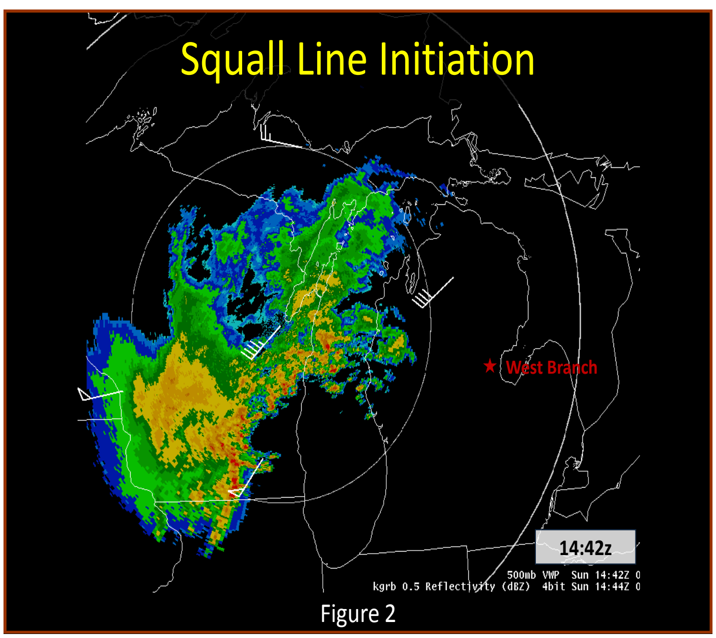


Figure 2. Radar composite valid 1442z 8 June 2008. Wind barbs represent 500mb winds from WSR-88D velocity profiles.

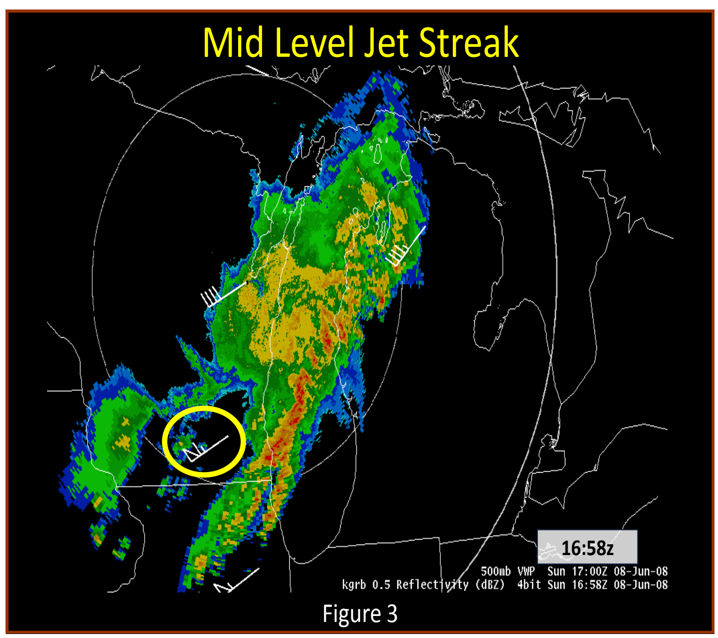


Figure 3. Same as figure 2, valid 1658z 8 June 2008. The 65kt wind observed by the KMKE WSR-88D is shown by the yellow circle.

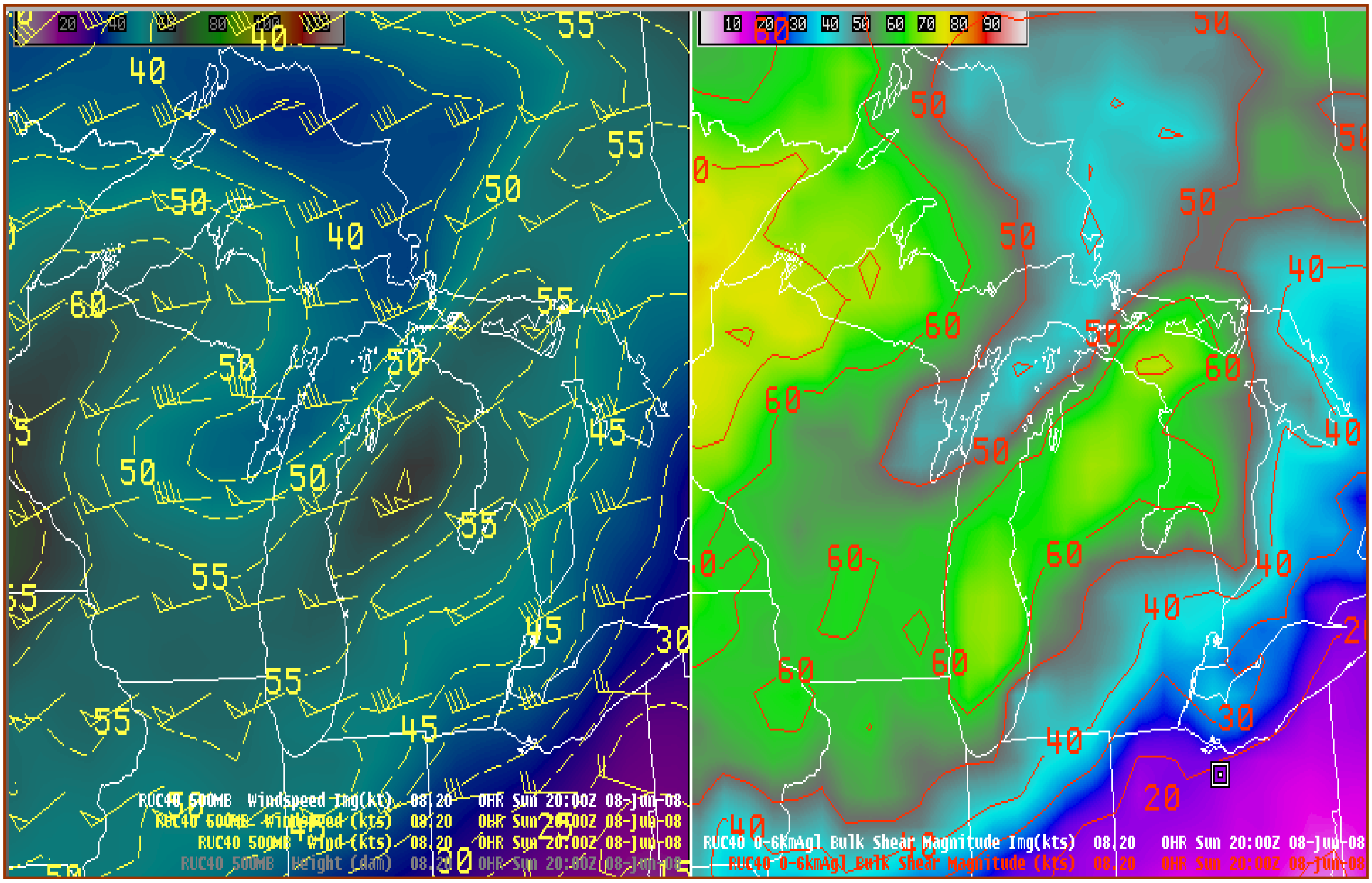


Figure 4. Left: 500mb wind barbs and isotachs, valid 20z 8 June 2008. Right: 0-6km Bulk Shear magnitude in knots, valid 20z 8 June 2008.

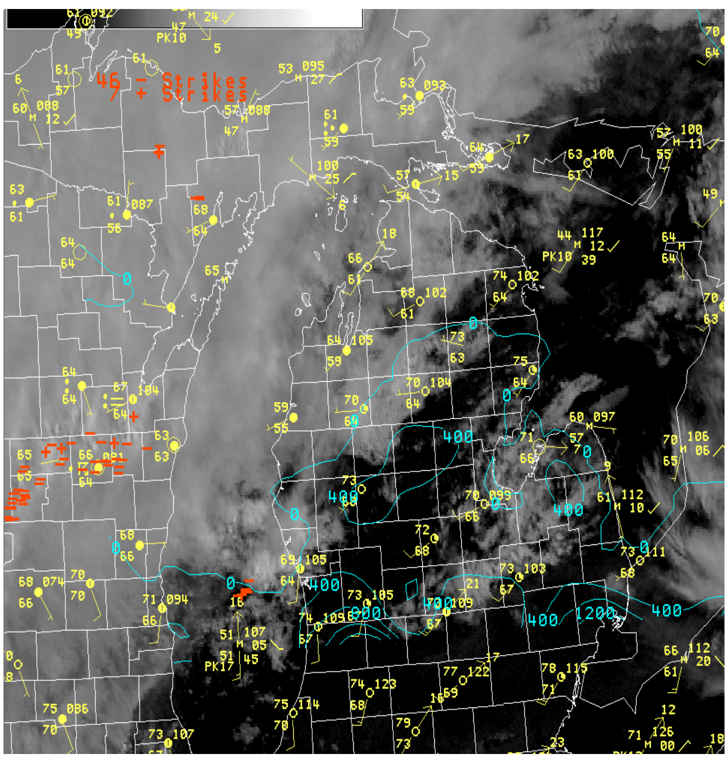
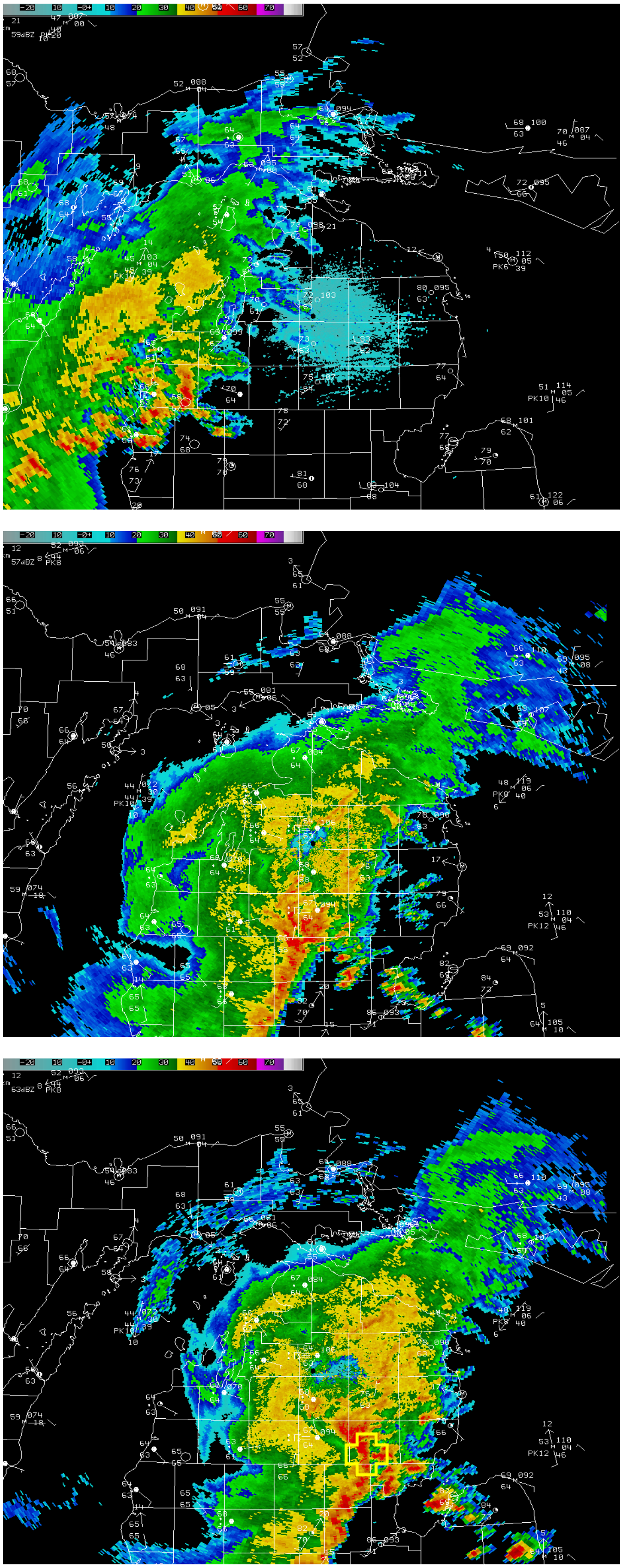


Figure 5. Visible satellite image, surface observations, and LAPS surface based CAPE analysis, valid 13z 8 June 2008.

approaching strong kinematic profiles, substantially increased the severe weather concern for the West Branch area.

Event Synopsis

The rather initially disorganized northern extent of the convective complex rapidly intensified as it approached the instability axis near Houghton Lake (figure 6 top and middle), once again assuming classic squall line characteristics. Of particular interest is the focused bowing of the mid-line segment (bottom figure 6) just prior to the line entering West Branch, with a distinct reduction in reflectivity directly behind the bowing segment. This fits the conceptual Rear Inflow Jet (RIJ) model illustrated in figure 7, which shows the RIJ driven by horizontal buoyancy gradients in the rear flank of the convective complex as the front to rear inflow into the system the system creates upper level negative vorticity, while the cold pool at the surface creates low level positive vorticity. Coupled together, these focus a rear to front flow into the leading line segment, supplying cool and relatively dry air into the convective line, allowing evaporative cooling to further



strengthen downdraft potential, often causing damaging winds at the surface as the downdraft is accelerated.

Forecasters often look for these distinct features which may signify the onset of destructive surface winds owing to RIJ dynamics: 1) a Mid Altitude Radial Convergence (MARC) signature (figure 7), indicating enhanced mid level convergence as the RIJ impinges upon the updraft induced front-to-rear flow within the convective towers; 2) a focused, rapidly advancing bowing segment within the squall line as enhanced outflow increases cold pool dynamics; and 3) a distinct reduction in low level reflectivity directly behind this bowing segment as drying associated with the RIJ reduces precipitation intensity.

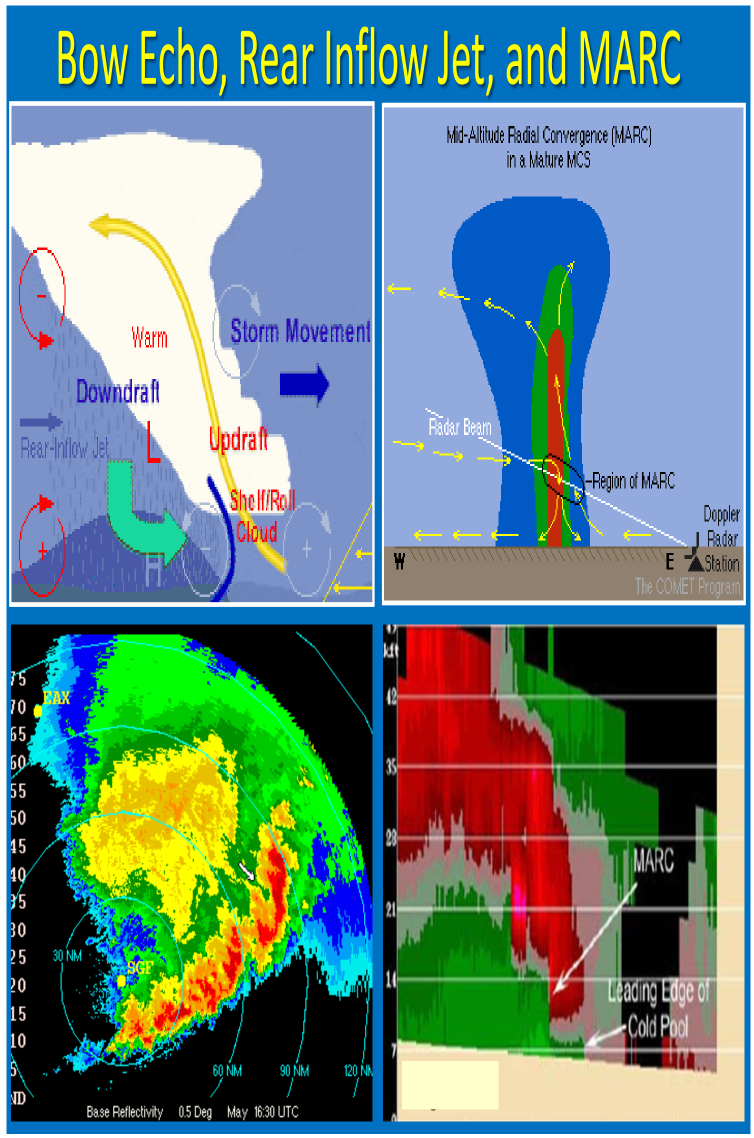


Figure 6. KAPX WSR-88D 0.5 degree elevation reflectivity, valid at 1613z (top), 1850z (middle) and 1923z (bottom). Location of West Branch is marked with a "+" in the bottom image.

Figure 7. Conceptual model of the Rear Inflow Jet and associated Mid Altitude Radial Convergence (MARC) signature, courtesy of the COMET program.

Clearly evident in figure 8 (at right) are these rear inflow jet signatures, with a reduction in base reflectivity behind a focused bowing line segment just prior to the line advancing into the West Branch area. Also notice the weak convergent coupling per the 4.0 degree Storm Relative Motion (SRM) slice, with magnitudes of 15 to 20 knots at approximately 18kft. While this value is rather low for a RIJ MARC signature, distance and azimuth (50 miles south-southeast) of the radar is probably leading to insufficient sampling, with actual convergence magnitudes much higher in this region.

The apex of this bowing segment went through West Branch proper at 3:21pm, bringing with it winds estimated at 60mph, which caused extensive residential, building, and tree damage. Using the RIJ conceptual model for situational awareness and decision making processes, radar warning meteorologists placed Ogemaw County, including West Branch, under a severe thunderstorm warning at 3:06pm, giving the residents of Ogemaw County and West Branch 15 minutes of valuable lead time.

Mike Boguth

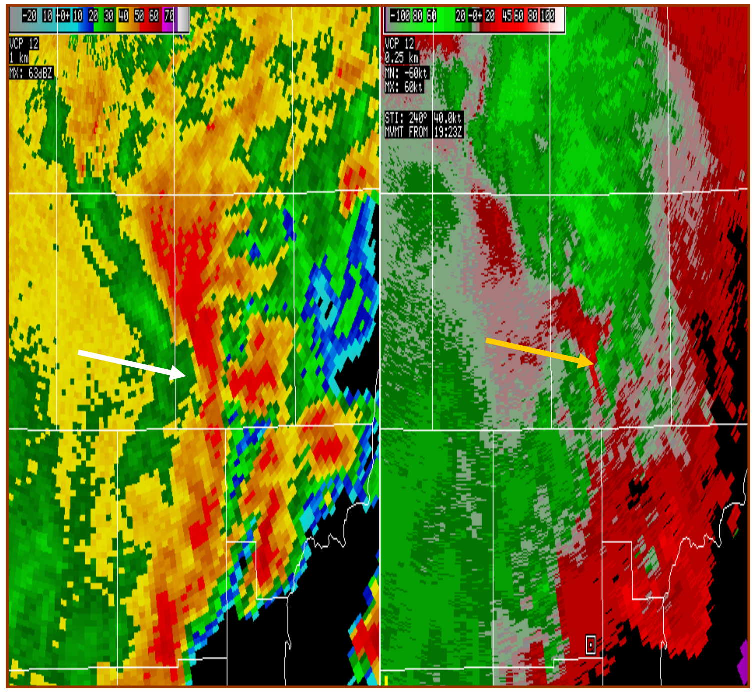


Figure 8. KAPX WSR-88D 0.5 degree reflectivity (left) and 4.0 degree Storm Relative Motion (right), valid 1923z. White arrow denotes reflectivity notch associated with rear inflow jet, yellow arrow depicts convergence couplet in mid levels associated with a MARC signature.

Winter Weather Research

Precipitation Type Issues During Early Season Lake Effect Events

Michigan residents are very familiar with the phenomenon known as Lake Effect Snow (LES). LES is common during the fall and winter when cold air traverses the relatively warm and unfrozen waters of the Great Lakes. The cold air, typically originating from the north or west, is warmed and moistened by the underlying warm water. The result is instability, rising air, and eventually the development of clouds and precipitation.

Forecasting LES requires the consideration of many factors. A few of these factors include: air temperature, water temperature, instability, wind direction, wind speed, antecedent moisture, inversion height, cloud microphysics, and large-scale ascent.

Many times, early season lake effect events are even more challenging due to the impact of very warm water temperatures on precipitation type. When an incoming cold air mass passes across +10°C to +20°C water temperatures (common from late September through early November) an above freezing layer of air frequently develops immediately downwind of the lakes. If this layer is sufficiently deep, the snow can completely melt before reaching the ground (in other words, lake effect rain falls rather than lake effect snow).

To further complicate this situation, the nearly 1000 foot rise in elevation from Lake Michigan to the interior of north central Lower Michigan is often sufficient to overcome the above freezing layer, causing the lake effect rain to change back to lake effect snow. The net result may be accumulating snow over interior areas such as Mancelona, Gaylord, and Grayling, with just rain at Frankfort, Traverse City, and Petoskey.

To help meteorologists with this forecast challenge, two forecast "nomograms" (or charts) have been developed (shown below). These charts were developed using observed weather from the Lake Michigan shoreline and from the interior of north central Lower Michigan, where rain, snow, or mixed rain and snow were occurring. The precipitation type was then plotted versus lake temperature and 850mb temperature. In general, warmer lake and/or 850mb temperatures tend to favor rain or mixed rain and snow. As the charts indicate, however, the thresholds for precipitation type were different for lakeshore and inland areas.

These charts represent only a small part of what meteorologists consider when making a lake effect rain or snow forecast. However, even when used as 'general guidance' forecasters have found the charts to be a valuable tool.

Bruce Smith

Science and Operations Officer