National Weather Service

Gaylord, Michigan

The WFO Gaylord Science Corner

Volume 1, Issue 3 21 July 2008

Inside this issue:

Special Edition

The Manistee-Ludington Flash Flood of 12-13 June 2008

This special edition of the WFO Gaylord Science Corner will take a look at the recent Manistee and Ludington flash flood event which occurred on 12-13 June 2008.

On the evening of 12 June, a line of thunderstorms moved northeast out of southern Wisconsin and took a bead on northwest and west central portions of Lower Michigan. Several rounds of thunderstorms impacted areas around Manistee, Wexford, Missaukee, Mason, and Lake counties over a six hour period, from approximately 0130Z 13 June through 0730Z 13 June (930pm 12 June-330am 13 June EDT). The first round of thunderstorms arrived around 930pm EDT on the 12th, and packed severe wind gusts, with estimated gusts to 80mph in Manistee causing widespread damage to trees and buildings. Part of the roof of a convenience store was torn off near Freesoil in Mason county. In addition, a weak tornado touched down about 8 miles east of Manistee around 945pm. Later that evening, another round of storms produced some damaging wind gusts and large hail (up to golf ball sized) across Wexford county.

But the biggest problem came after midnight as thunderstorms producing heavy rainfall continued to train across the same five county area. Several weather spotters phoned in reports of 4-6 inches of rain in about a six hour period, with rainfall estimates from the WFO Gaylord WSR-88D indicating over 8 inches of rain over southern portions of Manistee, Wexford, and Missaukee counties, and northern portions of Mason and Lake counties. The result was widespread flash flooding with many roads washed out, including portions of U.S. 31 between Manistee and Ludington, as well as flooded homes. Flooding lasted for several days along the Manistee, Pine, and Pere Marquette Rivers, as runoff from the heavy rainfall made its way toward Lake Michigan. Several record crests were set at river gages within the Manistee River basin. Water levels on Lake Cadillac also rose dramatically, flooding nearby roads and parks in Cadillac. Total storm damages in Manistee county alone reportedly exceeded $7 million, and flood damage across Mason county totalled at least $5 million.

Ludington Daily News

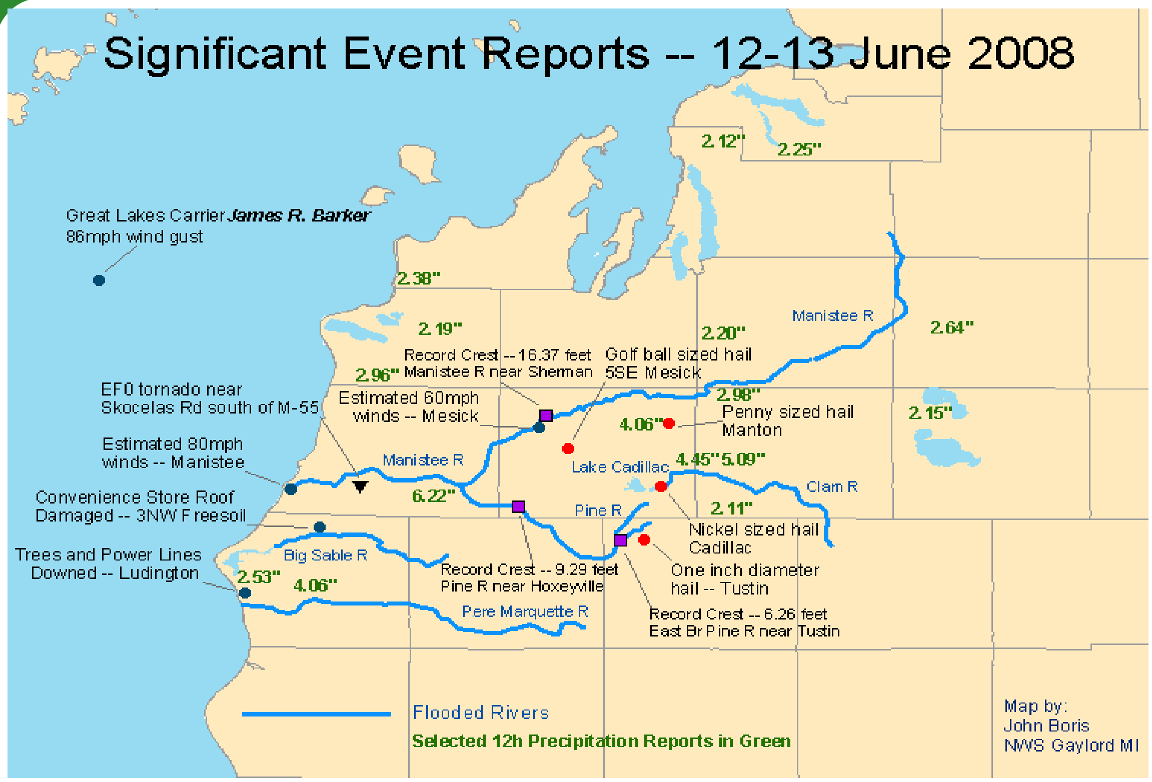


Figure 1. Significant event reports from 12-13 June 2008.

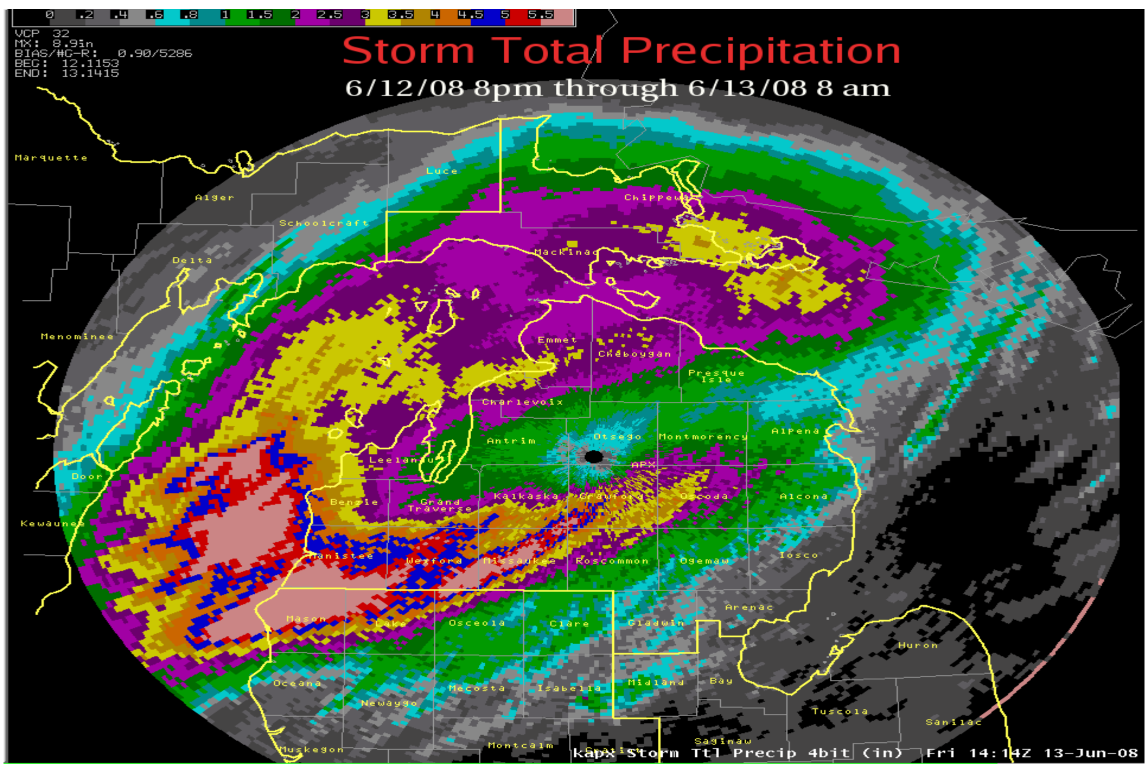


Figure 2. Radar estimated rainfall from the KAPX WSR-88D. Yellow shading is greater than 3 inches, red shading above 5 inches. Rainfall estimates exceeded 6 inches across southern portions of Manistee, Wexford, and Missaukee counties, as well as northern portions of Mason and Lake counties.

The WFO Gaylord Science Corner

Volume 1, Issue 3 (July 2008)

Editors:
John Boris
Bruce Smith

Questions? Comments?

E-mail us at:
w-apx.webmaster@noaa.gov

Use "Science newsletter" in the subject line.

Review of the Maddox Synoptic Flash Flood Archetype

We'll examine this event a little more closely using the Maddox Synoptic Type Flash Flood conceptual model as our guide, illustrating similarities between the model and this event. First, a quick review:

In their 1979 paper titled "Synoptic and Meso-α aspects of Flash Flood Events", Maddox et al., developed several conceptual models of typical flash flood events, one of which they called the "Synoptic" type (Figure 1). This type of flash flood event was most common during the spring and fall months, and was associated with a strong mid level trough moving slowly to the east and northeast. The associated surface cold front also moves slowly or can stall, with the heaviest rainfall typically falling in the warm air ahead of the surface front along the axis of a low level jet. Typical moisture values associated with Synoptic-type events include surface dew points in the 60s, 850mb dew points at and above 12C, and precipitable water values greater than 1.50 inches.

Vertical wind profiles will typically show some veering associated with the deep layer warm advection ahead of the mid level trough axis, though typically wind direction will vary less than 40 degrees from the surface to 500mb. Winds aloft usually run parallel to the low level baroclinic zone, which is important component to these types of events from a storm propagation standpoint, which will be discussed on the next page. Moisture convergence is strong ahead of the low level jet, with storms repeatedly developing on the south and southwestern edge of earlier storms, then moving northeast. This "training" effect is a component of many flash flood events, as storms dump heavy rain across the same areas over and over until the forcing and/or instability diminishes.

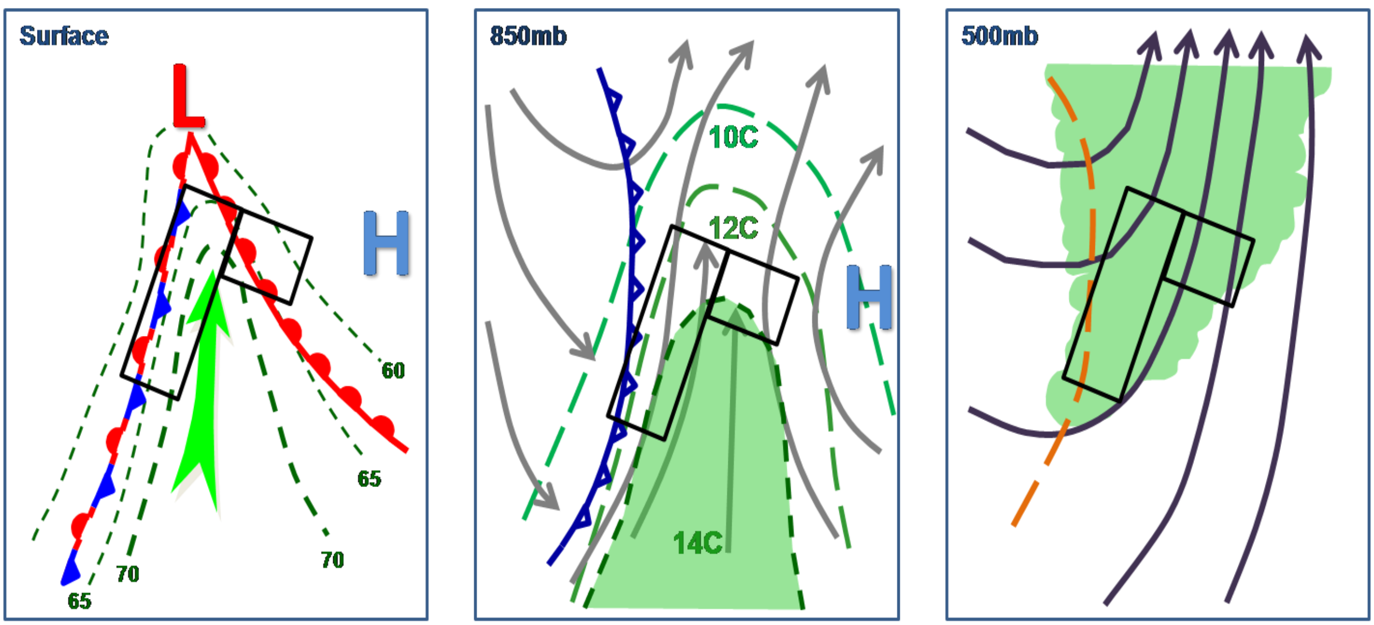


Figure 1. Maddox Synoptic-Type flash flood conceptual model, showing common features associated with these types of events. Black parallelograms show typical flash flood areas with respect to the synoptic features.

Left: Surface fronts and isodrosotherms every 5F. Green arrow indicates position of low level jet.

Center: 850mb streamlines and isodrosotherms every 2C. Shaded area represents dew points ≥ 14C.

Right: 500mb streamlines and short wave trough axis. Green shading represents dew point depressions < 6C.

Storm Propagation

An important component to heavy rainfall events is storm propagation, which impacts the overall movement of an organized area of thunderstorms.

If we consider a typical organized multicell thunderstorm, we will find that the movement of the storm is governed by two factors. One is advection, which is more or less simply how the thunderstorm cloud is carried by the winds aloft. This advective component is usually attributed to the mean wind through the depth of the cloud layer. The other factor has to do with where new convective cells are forming with respect to the overall thunderstorm. The location of new updraft development can result in an overall storm movement that can deviate substantially from what would be expected just from looking at the mean cloud layer wind. This contribution to storm motion is called propagation, and is illustrated in figure 2. The vector representing the advection component to storm motion is often approximated operationally by the 850-300mb mean wind. The propagation component can be assumed to be a vector that is opposite (anti-parallel) of the low level inflow to the storm (pointing in the direction of the strongest low level convergence where new convection tends to develop.

The left example in figure 2 is one where new cell development results in a storm motion that is slower and more displaced from the mean wind direction. This is typical of thunderstorms where new cells are developing along the trailing flank of the storm. In this particular case, while individual cells are moving northeast, new convection is developing on the southwest flank of the storm, thus the actual storm movement is slower than that implied by the mean wind, and also displaced to the right of the mean wind. The right example in figure 2 shows how the propagation component can lead to a storm motion that is closer to or even faster than the mean wind. This occurs when new cells are developing on the forward flank of the storm, such as the case with a mature squall line.

It should be evident from these examples that a slow or nearly stationary storm motion can arise in one of two ways. Either the advective (mean wind) component is small, or that the propagation component is nearly offsetting the cell motion due to the cloud layer mean flow. This results in new convection developing along the upwind flank of the storm, which allows storm cells to move repeatedly across the same area and result in significant rainfall accumulations.

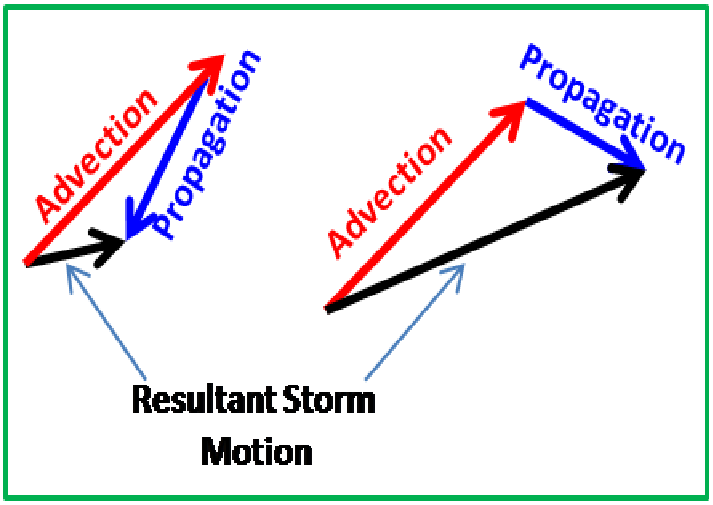


Figure 2. Storm motion vectors (black arrows) represented as the vector difference between the advection component (red arrows) and propagation component (blue arrows).

The Event

Let's put this together and see how all of these factors contributed to this flooding event. Figure 3 shows five day mean 500mb height and anomaly maps centered on 13 June 2008. Anomalous mean troughing (125-150m below the climatological mean) was situated over central Canada and the adjacent High Plains states. The top left panel of figure 4 shows 500mb heights and 250mb isotachs (shaded >80kt). The eastern portion of a strong short wave trough is evident moving into the upper Midwest, with a strong jet streak (>120kt) moving into northwest Ontario. Note the right entrance region of this jet streak is focused on eastern Wisconsin and northern Illinois, a quadrant of the jet favorable for divergence and subsequent upward vertical motion. So one of the characteristics of a synoptic-type flash flood event, associated with a strong and slow moving mid level trough, was present in this case. Looking at the 850mb level (bottom left panel in figure 4), we find a low level jet in excess of 40 knots impinging upon eastern Wisconsin and western Lower Michigan, drawing low level moisture northward with 850mb dew points in the 12-16C range.

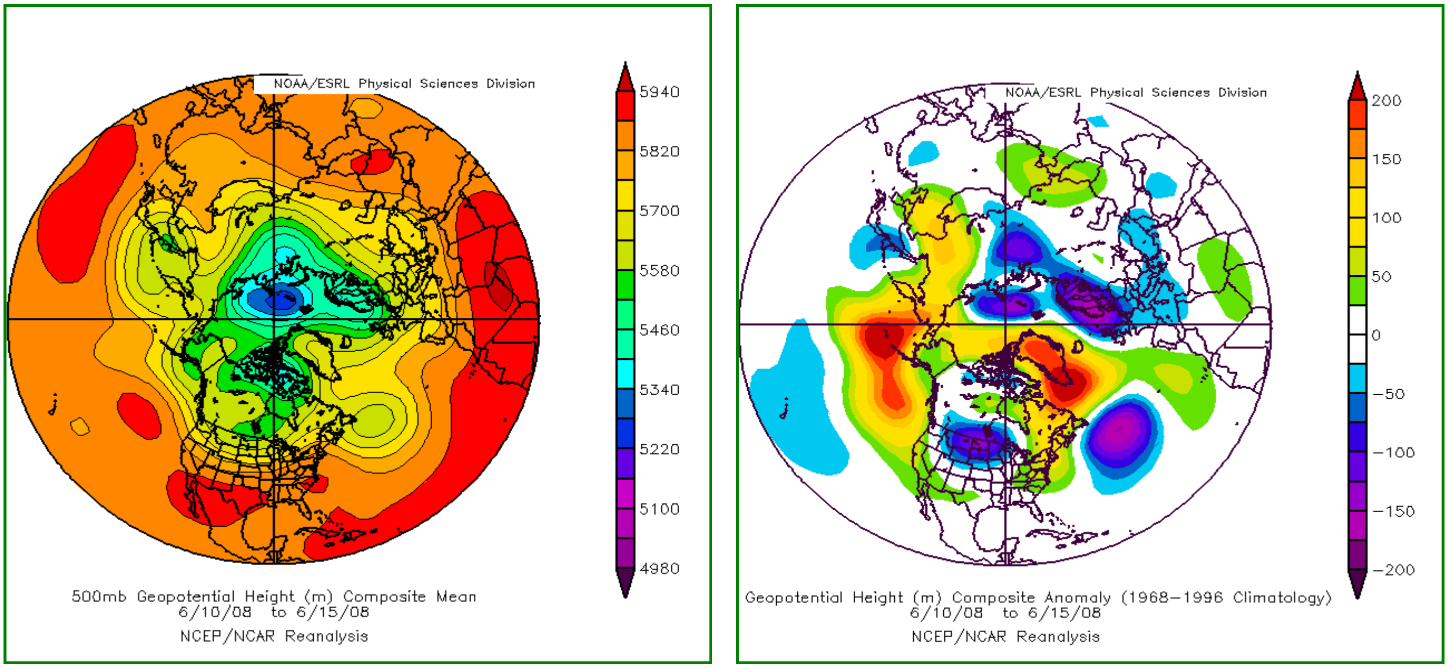


Figure 3. Left: Five day mean 500mb height pattern. Right: Five day mean 500mb height anomaly. Maps are centered on 13 June 2008.

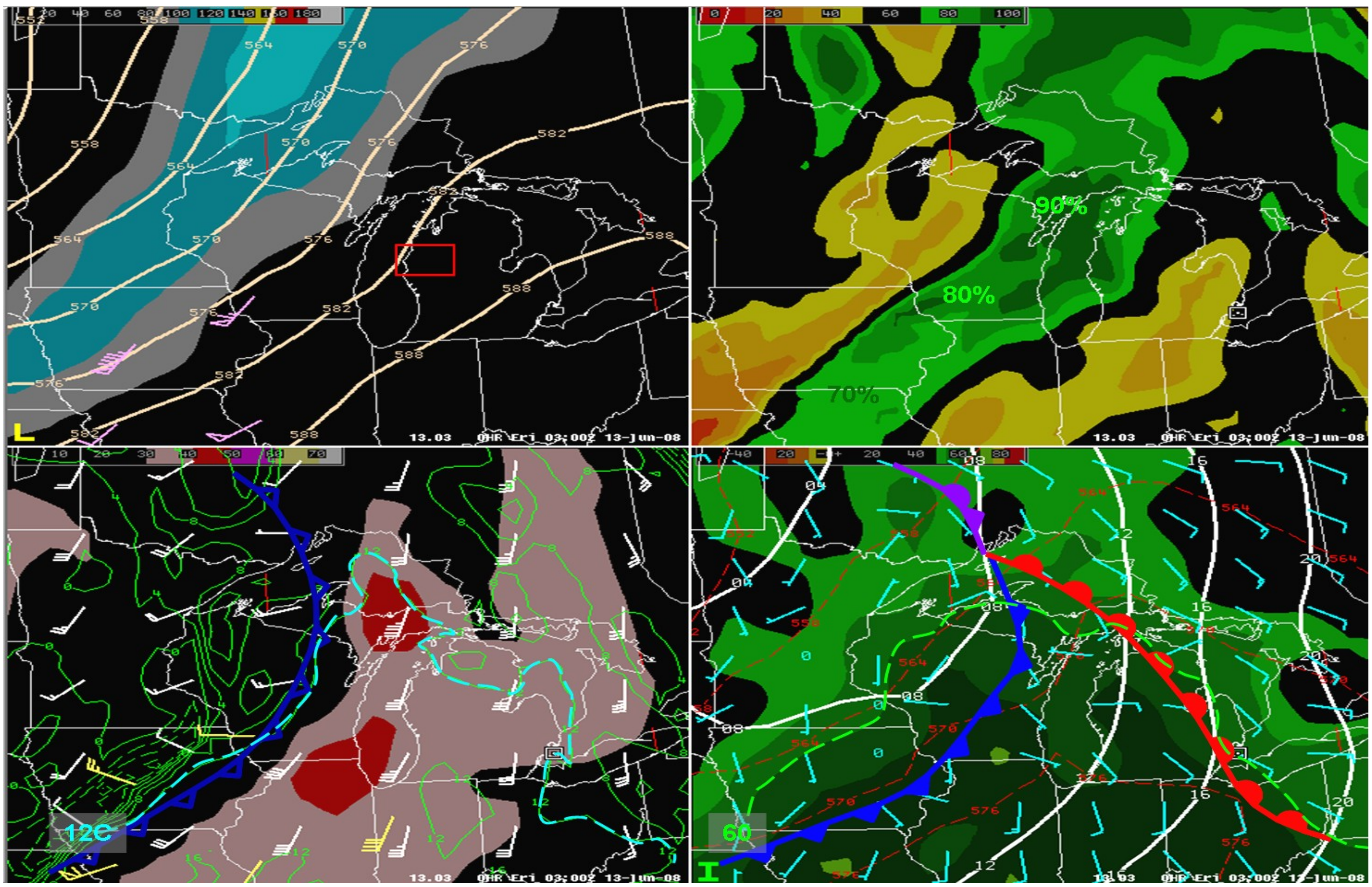


Figure 4. Four panel RUC 00h forecast of synoptic fields valid 03Z 13 June 2008. Top Left: 500mb heights/250mb isotachs (>80kt every 20kt). Red rectangle indicates heavy rain area. Top Right: 850-500mb mean relative humidity (green shading >70%). Bottom Left: 850mb winds, isotachs (>30kt every 10kt) and dew points. Dashed light blue contour represents 12C isodrosotherm. Bottom Right: Surface pressure, surface wind, 1000-500mb thickness (dashed red), and surface dew point (green shading >50F every 5F). Dashed green line indicates 60F isodrosotherm.

At the surface (bottom right panel, figure 4), we find the area of concern within the warm sector of an occluding cyclone associated with the strong upper level wave, with surface dew points above 60F. From a low level perspective, we can see similarities between this event and the synoptic flash flood conceptual model; the area of heaviest rains just downstream of a low level jet (an area of favorable moisture convergence) and just on the upwind edge of the best low level moisture. Another favorable aspect of this event was the deep layer moisture in place, which combined with high freezing levels (above 14,000 feet), can result in higher precipitation efficiency. Deep layers of high relative humidity reduce the amount of dry air entrainment within a thunderstorm, and thus reduces evaporation of rain drops. High freezing levels promote deep layers of cloud at temperatures above freezing, which in turn promotes rain drop growth by collision and coalescence, also known as the “warm rain” process. This process can lead to a rain drop population that contains large numbers of small rain drops. Rain clouds with larger populations of smaller rain drops and broad drop size distributions (drops of many different sizes, such as clouds associated with tropical systems) often have higher rainfall rates. An example of this can be seen in figure 5, which shows rain drop size distributions taken from two summertime rainfall events in Iowa. These events had similar rainfall amounts, but different mean intensities. Note the storm with the higher rainfall rate contained a larger number of small drops, particularly of drops less than 2mm diameter. Figure 6 shows the precipitable water analysis from 00Z on 13 June; note the long axis of precipitable water values greater than 1.50 inches from Oklahoma into central Upper Michigan, with the 1.95 inch value at Davenport, IA being 200 percent of normal. Mean precipitable water values associated with the synoptic flash flood conceptual model were around 1.50 inches, and from an operational perspective, precipitable water values exceeding 150 percent of their climatological value raise a “red flag” regarding the potential for heavy precipitation.

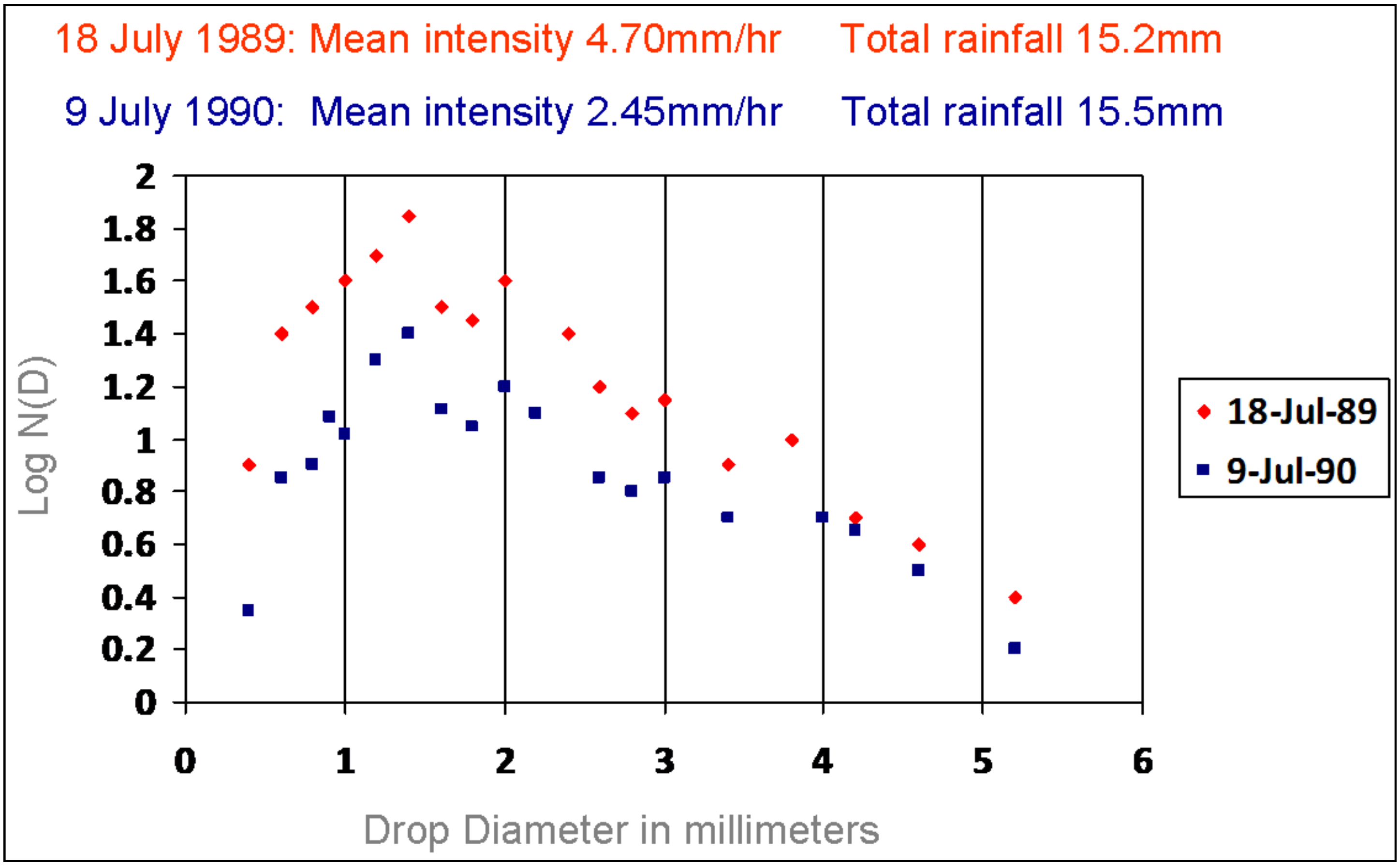


Figure 5. Mean one-minute rain drop size distributions associated with two Iowa rainfall events (18 July 1989 and 9 July 1990), as measured by a rain drop disdrometer. Drop size in millimeters is plotted on the X-axis, and the log of the mean number of drops per each size category is plotted on the Y-axis (this is done to allow the data to be plotted on a linear scale).

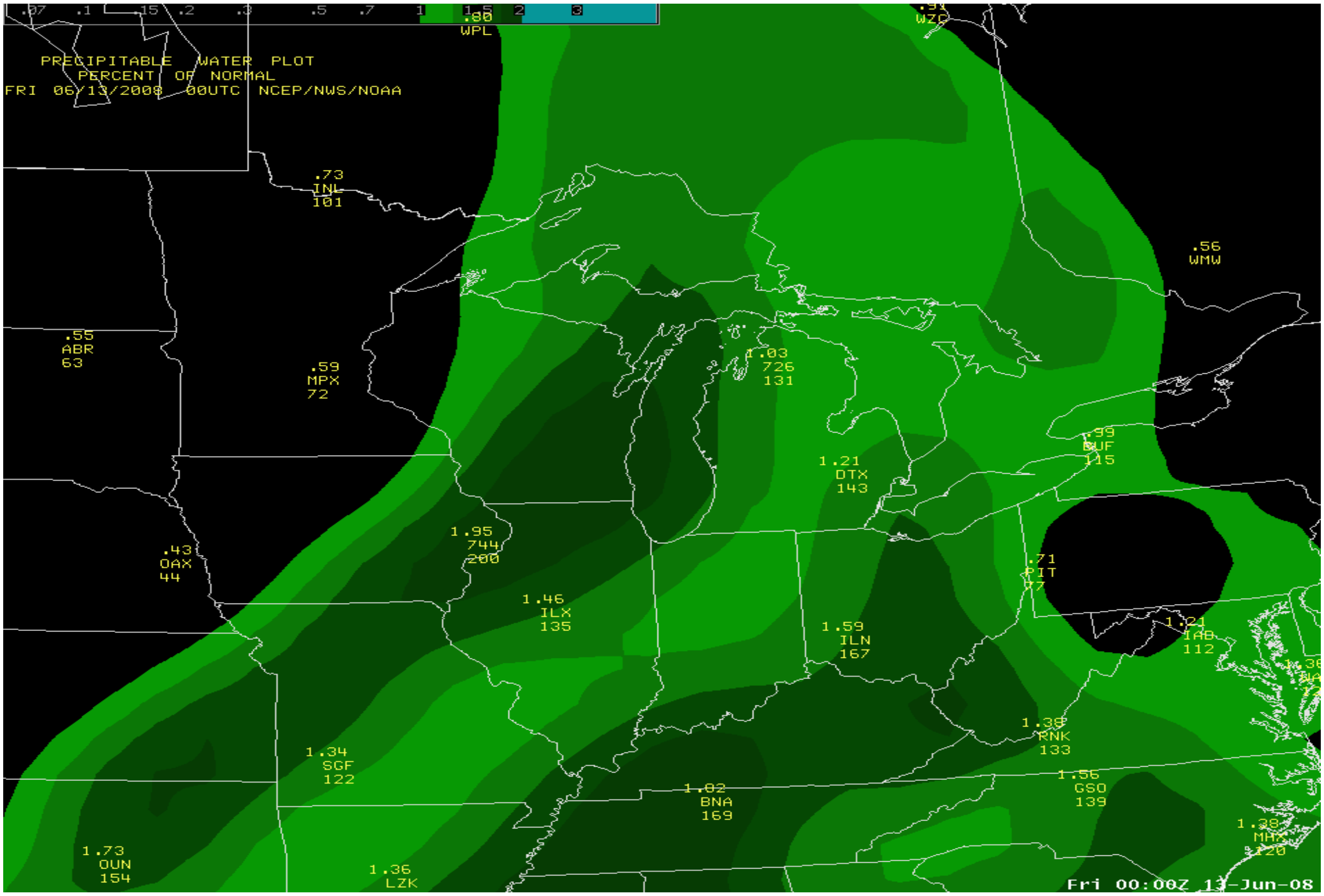


Figure 6. Precipitable water analysis valid 00Z 13 June 2008. Green shading represents values greater than 1 inch, with each darker band representing an additional 0.25 inch. The 1.95 inch precipitable water value at Davenport, IA (station 744) is 200 percent of normal for mid June.

Figure 7 shows the upper air sounding taken at Davenport at 00Z on 13 June. The green dashed line shows the ascent profile of a parcel lifted form 900mb. Although the surface layer is capped, there is a significant amount of elevated instability...with a parcel lifted from 900mb resulting in CAPE values above 3000 J/kg. This shows the tremendous amount of instability available ahead of the approaching cold front for thunderstorm development.

The last piece of the puzzle deals with thunderstorm movement and propagation. Figure 8 shows an overview of various kinematic fields from 03Z 13 June. The first thing to notice is the deep layer southwest flow. This allows thunderstorm cells to move in a northeast direction. The mean 850-300mb wind (taken as a proxy of the cloud bearing layer wind) is pretty fast in this event (45-50kt), this allowed for a strong advection component to storm motion, and is typically not associated with heavy rain events. But as well shall see, where new storms develop is the key to

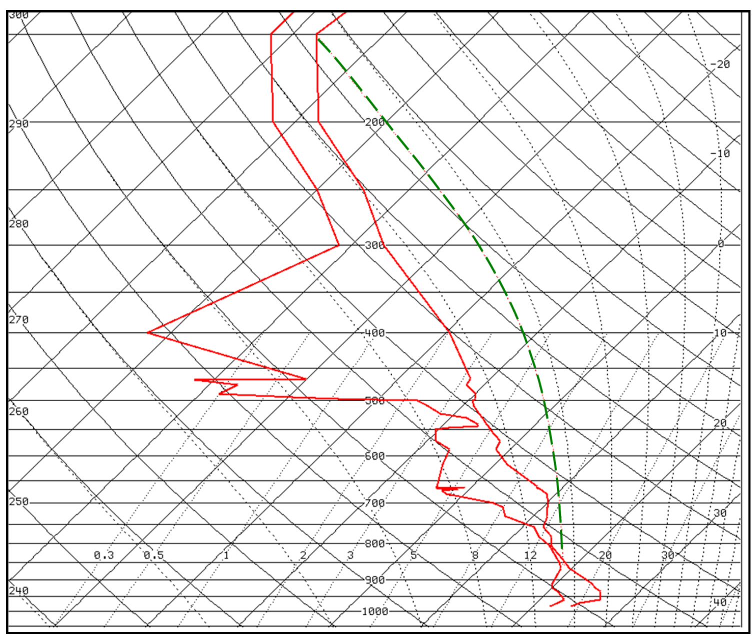


Figure 7. Upper air sounding from Davenport, IA — 00Z 13 June 2008. Green dashed line represents moist adiabatic ascent of a parcel lifted from 900mb.

flash flood events. In this case, new cells continued to develop to the southwest of previous storms, which were then pushed to the northeast by the steering flow...and across the same areas over and over.

We can estimate the resultant motion of thunderstorm cells within organized thunderstorm clusters (mesoscale convective systems) through the use of Corfidi vectors. There are two methods of calculating Corfidi vectors, depending on whether the convective system in question is quasi-stationary or back building, or one that is of the forward propagating variety. For this event, we can use the original formulation of the Corfidi vector, since we are essentially dealing with a slow moving/back building event. The bottom right panel of figure 8 shows an example of Corfidi vectors valid at 03Z on 13 June. These vectors are calculated by taking the mean 850-300mb wind (the blue barbs in the lower right panel of figure 8) and subtracting from that the low level jet (taken as the 850mb wind velocity). Note over western Lower Michigan that despite the strong cloud layer flow, the forecast storm cell movement is much slower (small vector, since vector length is related to its' magnitude) and deflected to the right of the mean wind. This is due to the propagation component mostly offsetting the strong 850-300mb mean winds. Compare that to the Corfidi vectors in western Wisconsin, which are much stronger and are directed just about parallel to the mean wind. This is because the propagation component across western Wisconsin is much weaker than farther east (weaker 850mb flow), thus the stronger cloud layer mean wind has a much bigger impact on storm motion. The possibility of repeated training of thunderstorm cells would be unlikely in that type of kinematic environment.

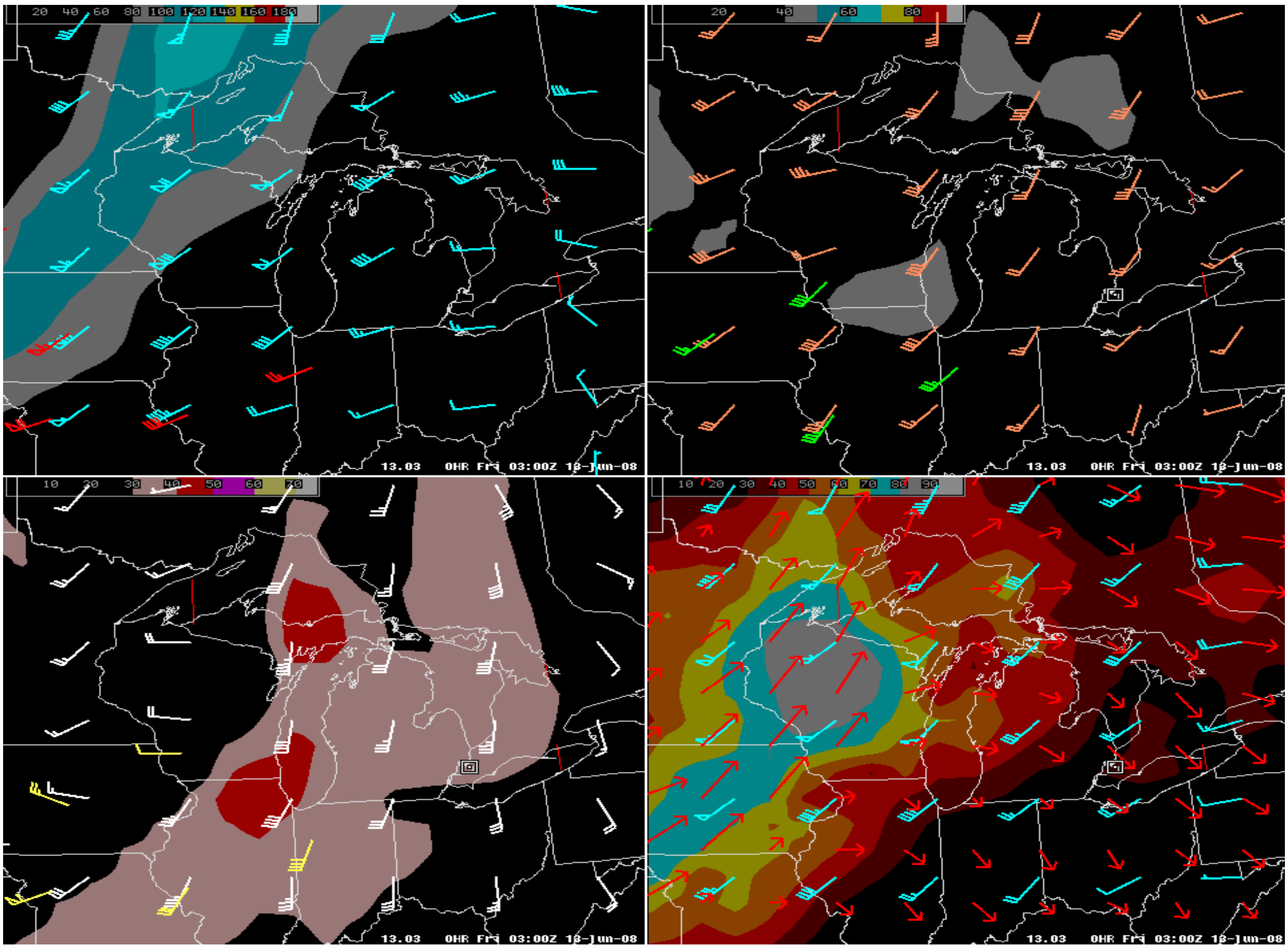


Figure 8. Overview of kinematic fields at 03Z 13 June 2008. Top Left: 500mb wind barbs (red barbs from profiler network) and 250mb isotachs (>80kt every 20kt). Top Right:: 700mb wind barbs (green barbs from profiler network) and isotachs (40-50kt gray shade). Bottom Left: 850mb wind barbs (yellow barbs from profiler network) and isotachs (>30kt every 10kt). Bottom Right: Mean 850-300mb wind (cyan barbs), 0-6km bulk shear values (>30kt shaded every 10kt...yellow shading >60kt), and Corfidi vectors (red arrows...calculated using original vector method).

The initial convection with this event developed from northeast Iowa into southern Wisconsin during the afternoon of the 12th (Figure 9a). As thunderstorms advanced into northwest Lower Michigan during the evening hours, notice how new thunderstorm cells (dark gray to white shades) continue to develop across eastern Wisconsin throughout the evening hours, as denoted by the white circles in figures 9b, 9c, and 9d. These thunderstorms were tracking to the east-northeast, and across the same areas around Manistee, Ludington, and Cadillac. By midnight on the 13th, there is a nearly continuous line of thunderstorms extending from northeast Michigan down into Oklahoma. The red arrow in figure 9d denotes the last of the convection that would impact northwest and west central Lower Michigan during the early morning hours of the 13th, moving east-northeast out of Iowa.

Radar imagery of the event more clearly shows the several waves of thunderstorms that swept across the region. Figure 10 shows five separate clusters of thunderstorms that moved across the flooded areas over a period of about seven hours. The initial severe thunderstorms moved into Manistee and Mason counties around 925pm on the 12th. Subsequent redevelopment of storms over eastern Wisconsin brought four additional rounds of convection to those same areas and adjacent counties, which resulted in heavy rainfall accumulations. Figure 11 shows a series of three hour precipitation estimates from the KAPX WSR-88D, ending at 03Z, 06Z and 09Z. Although some of the radar estimates likely have some hail contamination, the broad swaths of heavier rainfall impacting the same areas in the M-55 and U.S. 10 corridors are evident, especially in the estimates ending at 06Z and 09Z. The area around Big Sable Point and Hamlin Lake in Mason county were among the hardest hit locations, with 2-3 inch rain amounts occurring in each of the three hour accumulation windows, before the rain finally let up in intensity after 08Z.

Figure 12 shows an example of the hydrologic response to the intense rainfall. The USGS streamgaging station on the Pine River near Hoxeyville in southeast Wexford county was right in the axis of the heaviest precipitation. A three foot rise in water levels occurred within the first 12 hours of the rainfall event, which pushed the river quickly out of its banks. After falling about one foot during the latter portions of 13 June, another surge of runoff arrived from upstream, resulting in a more than two foot jump in river levels within about a 12 hour period, and a new record crest of 9.29 feet (the old record was 7.45 feet set on 13 April 2001).

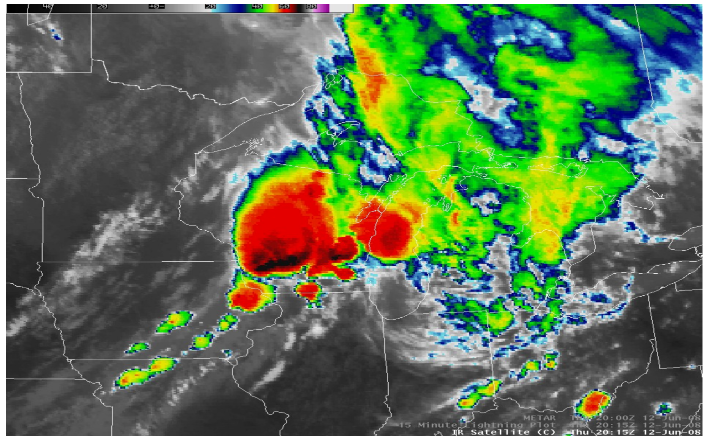


Figure 9a. IR imagery valid 2015Z 12 June 2008.

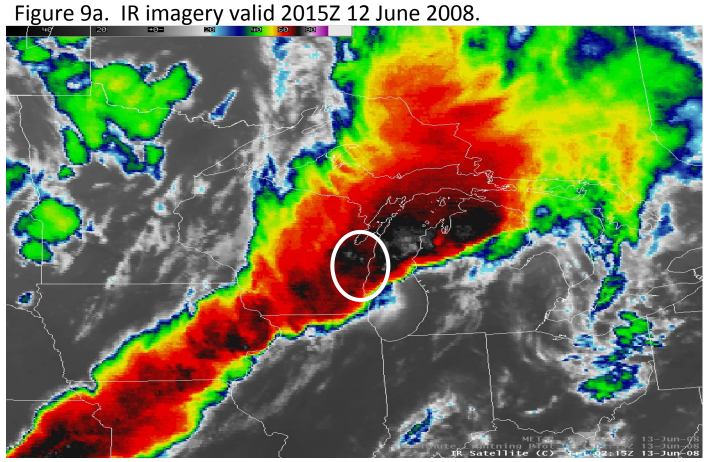


Figure 9b. IR imagery valid 0215Z 13 June 2008.

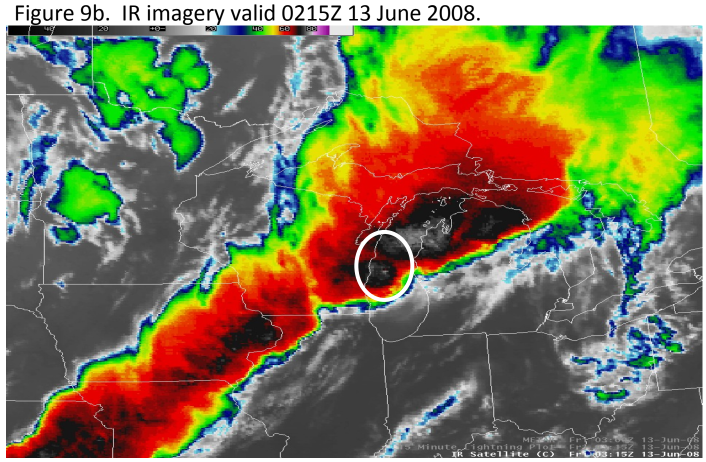


Figure 9c. IR imagery valid 0315Z 13 June 2008.

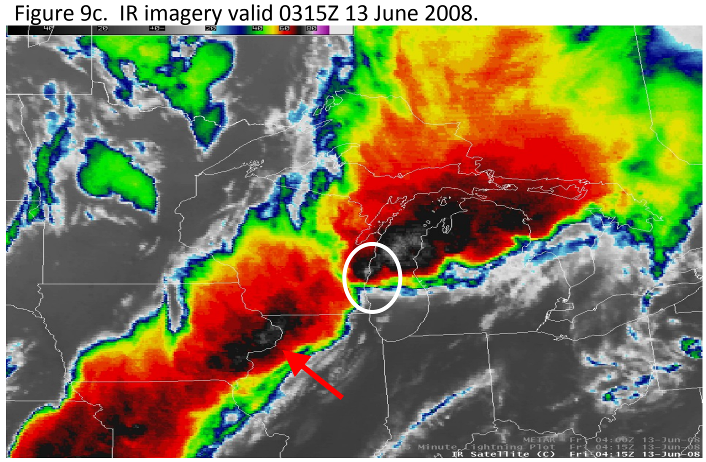
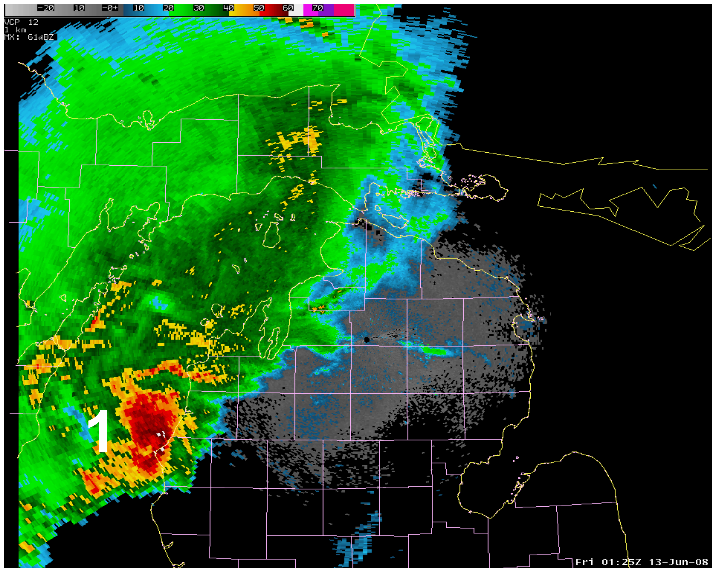
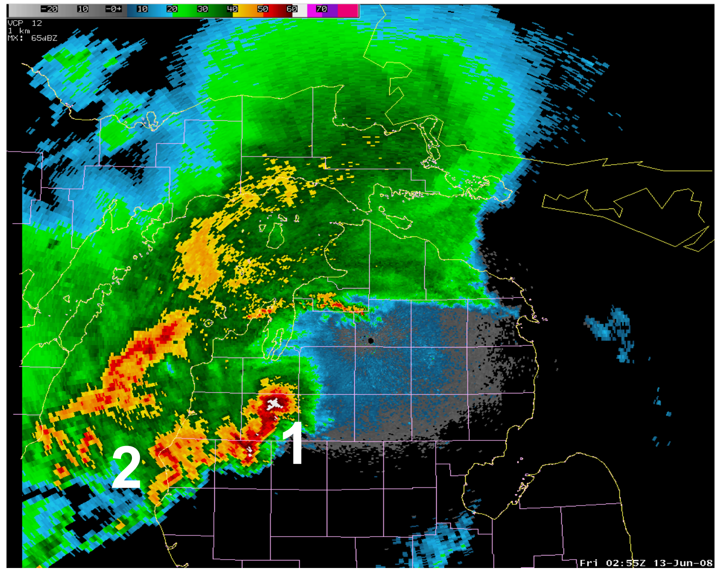


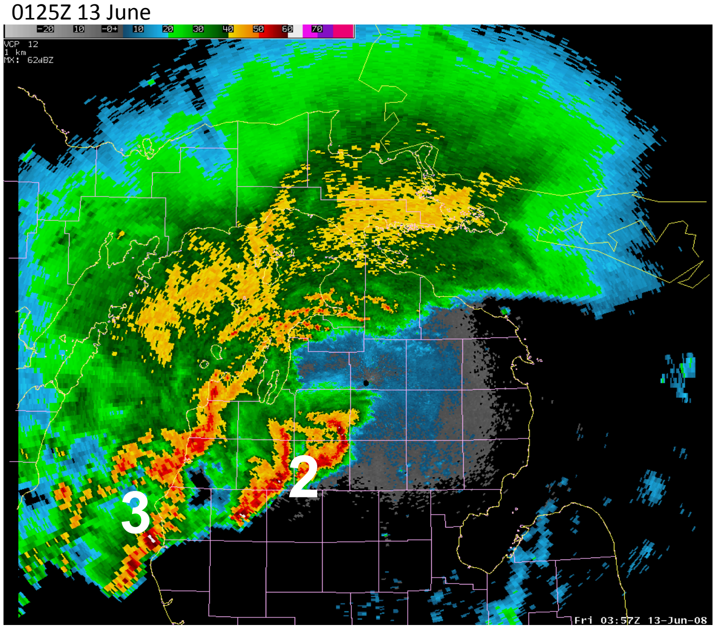
Figure 9d. IR imagery valid 0415Z 13 June 2008.



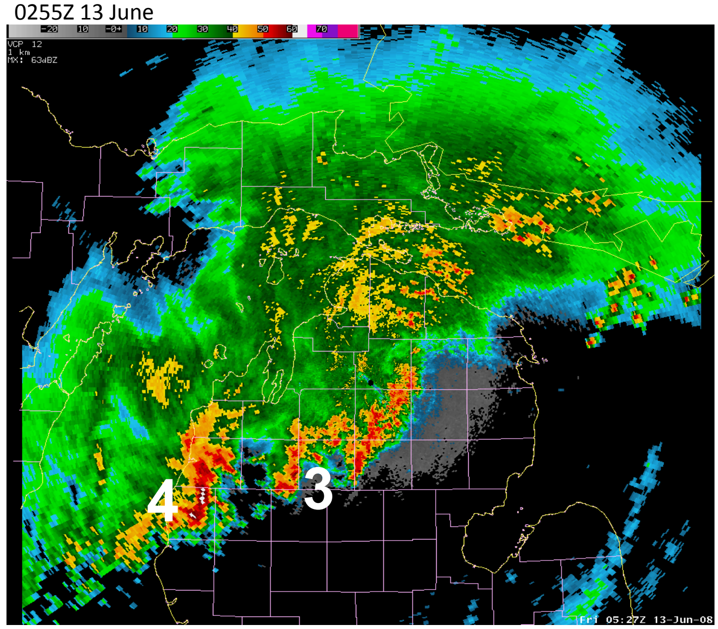
0125Z 13 June



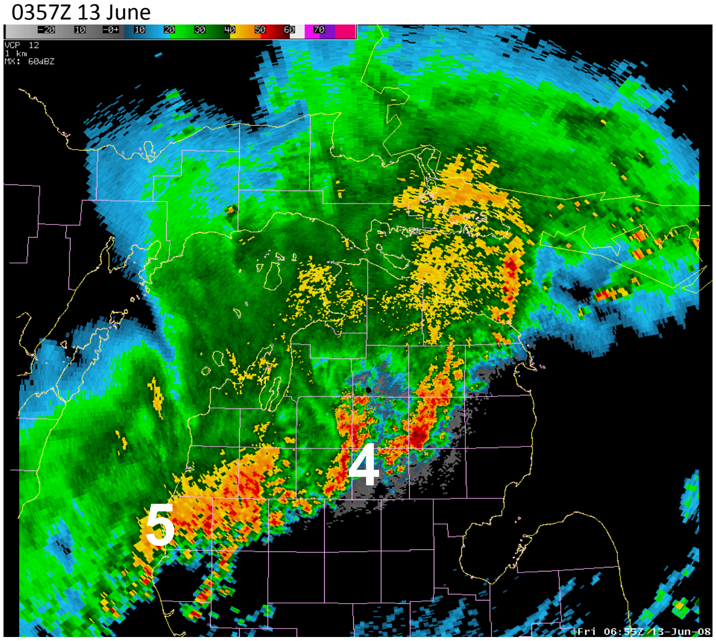
0255Z 13 June



0357Z 13 June

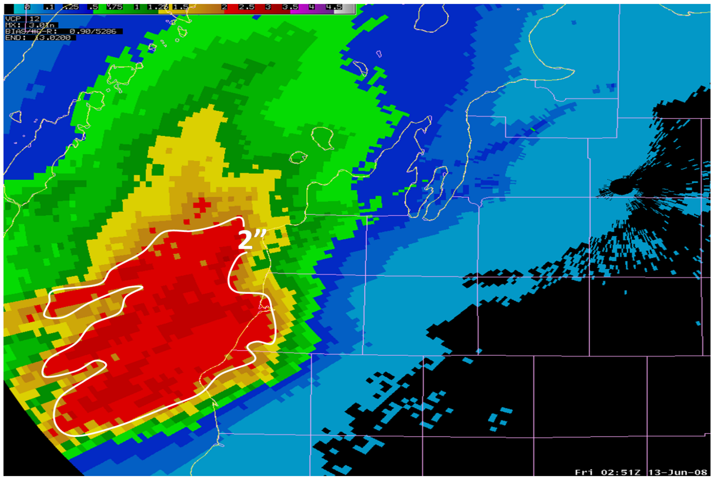


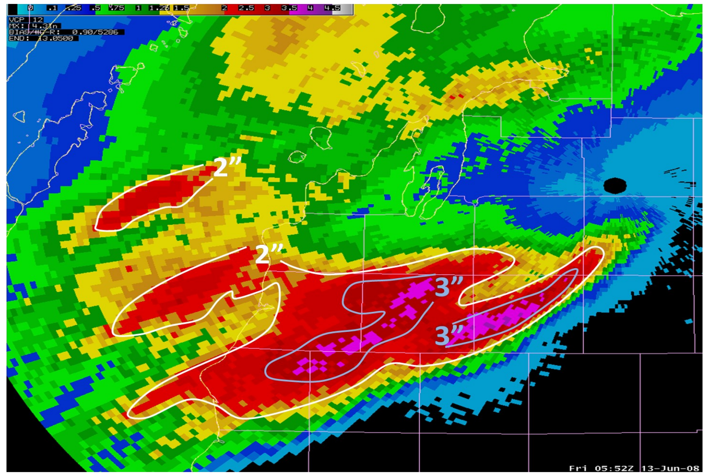
0527Z 13 June



0655Z 13 June

Figure 10: Five snapshots of 0.5 degree reflectivity from the KAPX WSR-88D radar from 0125Z through 0655Z on 13 June 2008. The numbers in each image correspond to each separate "cluster" of thunderstorms that impacted northwest and west central Lower Michigan. Note some of the small bowing segments within some of the storm clusters, indicative of strong winds associated with thunderstorm downdrafts.





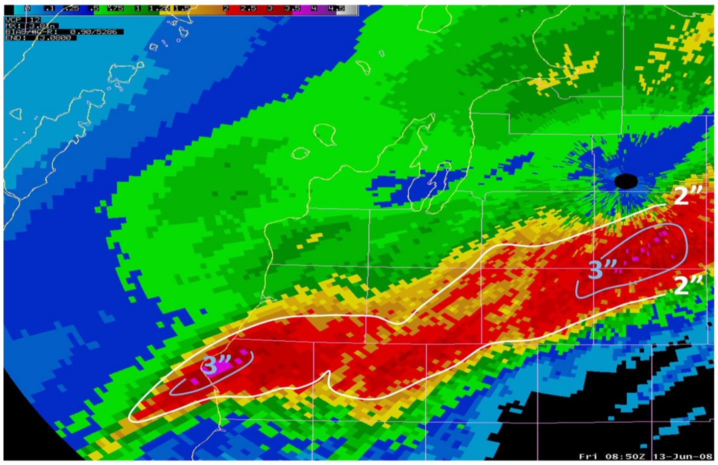


Figure 11: Three hour precipitation estimates from the KAPX WSR-88D, ending at 03Z (top left), 06Z (top right) and 09Z (bottom left) 13 June 2008. Red shading represents rain amounts from 2.00-3.50 inches...purple shading indicates 3.50-4.00 inches of rainfall. The first estimate reflects the initial heavy convection moving onshore, while the 06Z and 09Z estimates show the swath of heavier rains targeting central and southern portions of Manistee, Wexford, and Missaukee counties, and northern portions of Mason and Lake Counties.

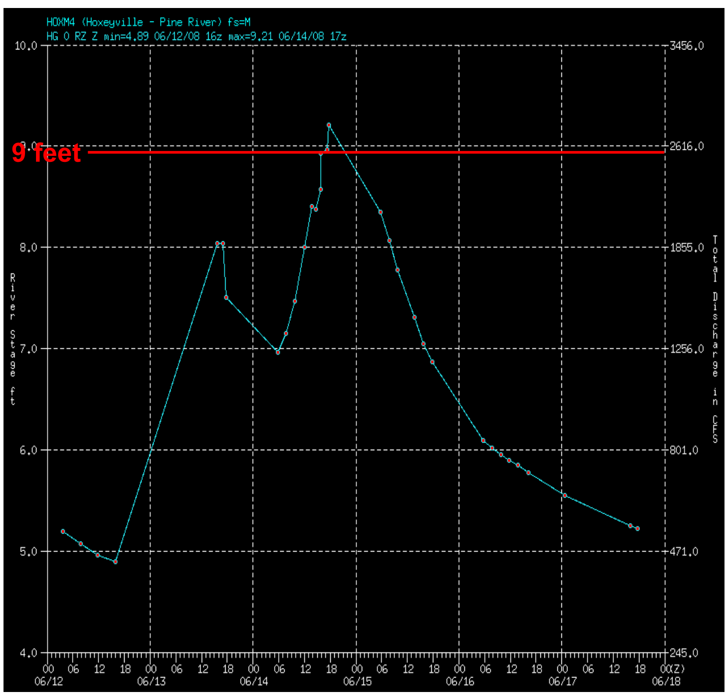


Figure 12: Observed hydrograph for the USGS Streamgaging Station on the Pine River near Hoxeyville in southeast Wexford County (HOXM4). Graph runs from 00Z on 12 June to 00Z and 18 June 2008. The peak crest was 9.29 feet on 14 June. Red line shows 9 foot stage.

Historical Significance

Precipitation frequency analyses for Michigan were created in the early 1960s, and while efforts are underway to update these maps, it is likely that these original estimates are underdone (perhaps by as much as 20 percent). But there is still value in looking at this type of analysis to put an event into historical perspective. For six hour rainfall accumulations, the 100 year return period is around 3.75 inches for west central Lower Michigan. Although 200 year return period amounts are not available for Michigan, amounts between 4.50 and 5 inches in six hours is a reasonable estimate. In this event, with six hour rainfall totals possibly exceeding 8 inches, clearly we are dealing with a very rare event for Lower Michigan, likely exceeding the 200 year return period even if available rainfall frequency analyses are 25 percent too low.

And a last word about dealing with return periods (such as 100 year floods): return period is simply another way of stating the probability an event will occur in a given year. For a given 100 year event magnitude, there is a 1% probability of that event being exceeded in any one year. It does not mean that an event like this won’t be seen for another 100 years; it means that, over a long time period, the average time span between events of that magnitude is 100 years.

John Boris