6.6 The 49th Parallel Severe Rainstorm - An example of elevated thunderstorms and their impact, June 8 to 11, 2002

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1. Introduction

Severe flooding and record-high river flows and lake levels occurred from a series of Mesoscale Convective Systems (MCS) that moved through southern portions of Northwestern Ontario, southeastern Manitoba and northern Minnesota (MOM area) from the evening of 8 June 2002 through the early morning hours of 11 June 2002. A west to east quasi-stationary surface frontal boundary from North Dakota across northern Minnesota and Wisconsin provided the focus for a series of elevated thunderstorms. The highest rainfall rates occurred on 9 and 10 June associated with intense thunderstorms that were continuously generating and moving across the area from the Roseau River to just southwest of Upsala, Ontario. This phenomena referred to as “training of thunderstorm cells” or “train echoes”, resulted in a swath having rainfall accumulations in the 200-400 mm range (Figure 1).

The one-day rainfall totals from this event greatly exceed the previous record one-day rainfalls for the only two Canadian climatological stations near the rainfall maxima having a period

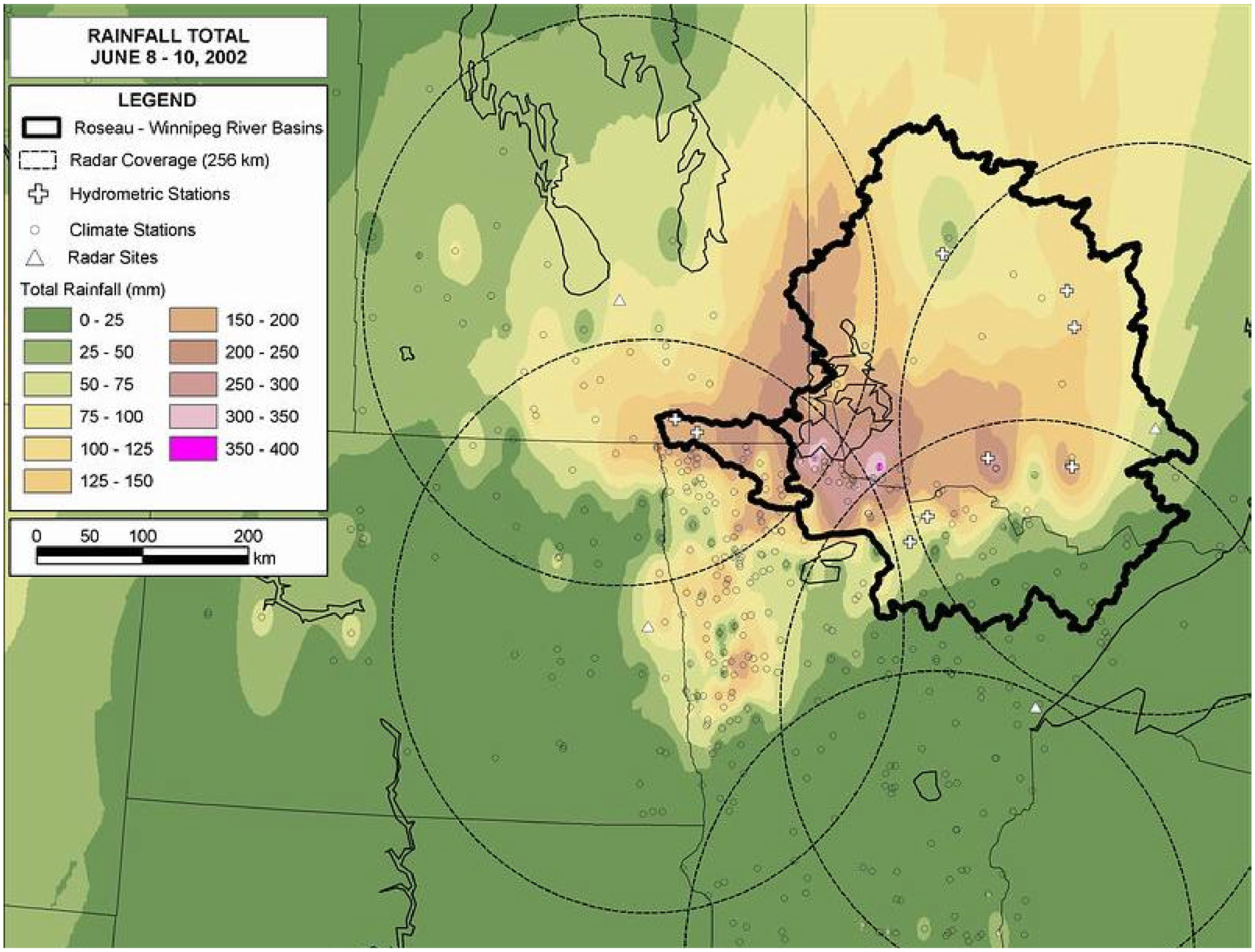

Figure 1. 8-11 June 2002 rainfall amounts.

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of record of at least 20 years. The three-day (8-11 June 2002) totals for Atikokan and Mine Centre are 194.0 mm and 293.2 mm respectively. The new record one-day rainfall for this event greatly exceeds the previous record one-day rainfall at nearby Meteorological Service of Canada (MSC) climatological stations. In particular, Fort Frances, ON and Kenora Airport, ON (both long-record climatological stations) have one-day record rainfalls of only 127.8 mm (31 July 1987) and 128.3 mm (29 July 1970) respectively compared to the 176.4 mm of rain that was reported at Atikokan automatic station on June 10, 2002. The total rainfall for this event appears to more than double the total amount associated with other major storms in the area.

2. Meteorological Characteristics

2.1 Characteristics of heavy rainfall events

"The heaviest precipitation occurs where the rainfall rate is the highest for the longest time" (Doswell et al. 1996). This very simple and obvious statement does not accurately reflect the complexity of the phenomena. Examining and predicting high rainfall events requires detailed analyses of a variety of features on a variety of scales, in both time and space. The meteorological conditions favourable for producing heavy rainfall are often benign in the synoptic scale but with interaction of mesoscale forcing can produce significant precipitation amounts. Heideman and Fritsch (1988) noted that convective rain processes are important in heavy rainfall events. In the cases they studied, they found that 80 percent of the total significant precipitation area (>12.7 mm in 24 hr) is predominantly due to convective precipitation.

Certain synoptic patterns are known to be favourable for producing heavy rainfall events. One type of event identified by Maddox (1979) is the Frontal-type flash flood (see Figure 2). In these situations, there is a stationary or very slow moving frontal boundary (usually oriented west to east) that helps to focus the heavy rainstorms. Warm moist air is advected in a southerly flow in the low levels. The air is forced to rise over the frontal boundary generating elevated thunderstorms on the cold side of the stationary frontal boundary. The resulting storm motion is nearly parallel to the frontal system. This ensures the persistence of the quasi-stationary mechanism since the storms do not move across and destroy the frontal boundary (Chappell, 1986).

Another type of event identified by Maddox is the Mesohigh-type flash flood (Figure 3). In these events, a nearly stationary thunderstorm outflow boundary generated by previous convection acts as the mechanism to trigger and focus the heavy rains. Chappell identified a quasistationary MCS pattern that is a combination of both the Maddox frontal and mesohigh types. In these Combination Frontal-Mesohigh events (Figure 4), a very slow moving warm front is oriented west to east similar to Maddox's Frontal type, but the instability is not released until the warm air is lifted over the frontal surface for some distance. Elevated thunderstorms develop well to the cold side of the front, forming a cold pool from their combined downdrafts and rain cooled air.

This colder outflow air continues to re-enforce the front keeping it quasistationary and maintaining the lift. The outflow boundary acts as a focus for further thunderstorm activity, usually resulting in a regenerative MCS (Fritsch and Forbes, 2001) and "training" convective cells.

A major challenge associated with predicting heavy rainfall is not just forecasting the occurrence of the rain but also the quantitative precipitation forecast (QPF). Total precipitation (P) at a point is simply the average rainfall rate (R_{avg}) multiplied by the duration (D) of the rainfall ($P = R_{avg}D$) (Doswell et. al, 1996). The rainfall rate can and often is quite variable over the length of an event, while the duration of an event can be as short as an hour or as long as several days.

The rainfall rate in a thunderstorm is dependent on three factors, namely the precipitation efficiency of its environment, the magnitude of vertical velocity and mixing ratio (or specific humidity). For most thunderstorms, the vertical velocity and specific humidity are functions of the environment. Vertical velocity is a function of the CAPE and the low-level moisture plays a major role in determining the CAPE. The mixing ratio is a function of the low-level moisture. Thus low level moisture availability (or the mixing ratio of the air mass) is important in thunderstorm development and in precipitation amounts.

Rainfall duration is also critical to heavy rainfall events. Storm motion and cell propagation are both important in determining rainfall duration at any given point. Long duration rainfall is associated with systems that have slow motion or cell training. When cell motion is normal to storm motion of the line then this system will not produce long-lasting precipitation at any point, whereas when cell motion is parallel to the motion of the line, the line will take longer to pass a given point resulting in more rainfall. In the extreme cases, training of cells results from new cells repeatedly forming and moving over the same point. The size of the system also plays a role in determining the duration, since a bigger area of precipitation will take longer to pass over any given point.

Vertical wind shear in the environment is important to convective storm development and movement. The environmental shear will affect storm strength and cell motion. Slow moving MCS are often associated with weak vertical wind shear through the deep tropospheric layer (Maddox, 1979). Convective cell movement is related to the mean wind. Cells will tend to move with the mean flow. However, there is often a propagation component that is equal in magnitude and opposite in sign to the low-level jet (Corfidi, et al., 1996). This propagation vector when combined with mean storm motion can determine the speed and direction of the storm, thus determining the duration of the rainfall at any given point.

The synoptic circulation pattern is important in conditioning the environment for the occurrence of convection and thus precipitation. But it is the mesoscale processes that can cause an otherwise benign system to develop convective cells that produce heavy rainfall at a given point. Most significant heavy rain events are the result of complex and complimentary scale interaction that produce the high impact weather event.

2.2 Summary of Meteorological Conditions surrounding the heavy rainfall of 8-11 June 2002

The large-scale synoptic circulation pattern, associated with the heavy rainfall over the MOM area, had an upper low and trough over the western North America with a weak upper ridge over the central continent. The 250 hPa analysis at 1200 UTC 10 June 2002 (Figure 5) shows that the main jet stream came around the base of the trough in California then northward through the high plains into southern Saskatchewan and curving eastward north of the Great Lakes. The upper flow was very divergent over the Manitoba-Ontario-Minnesota area.

A persistent southerly flow in the low levels was bringing warm very moist air from the south into the northern U.S. and increasing the moisture in the low and mid levels. The moisture from the Gulf of Mexico was gradually working its way northward toward the 49th parallel. The low-level jet as indicated by the 850 hPa wind field (Figure 6) intensified at night and provided the moisture required to keep the storm system going. There was strong low level convergence over northern Minnesota and North Dakota along the frontal boundary, a surface low in Wyoming, and an area of high pressure feeding cooler arctic air southward out of Ontario (Figure 7). This pattern persisted for about three days before it finally broke down.

The atmosphere over the MOM area was quite unstable and the low-level moisture was deep, reaching to the 700 hPa (about 3000 m) level over northern Minnesota. This moisture was used by the storms to provide the energy required to create the intense thunderstorm complex that persisted along the international border. The rawinsonde data from International Falls, Minnesota at 0000 UTC 10 June 2002 (Figure 8) indicated that the air mass was very moist and stable in the low levels (below 700 hPa), but quite unstable aloft. Instability parameters all indicated a very favourable air mass for intense severe thunderstorms. Lifted Index was below -4 C and CAPE values were 2500 to 3500 J kg^{-1}.

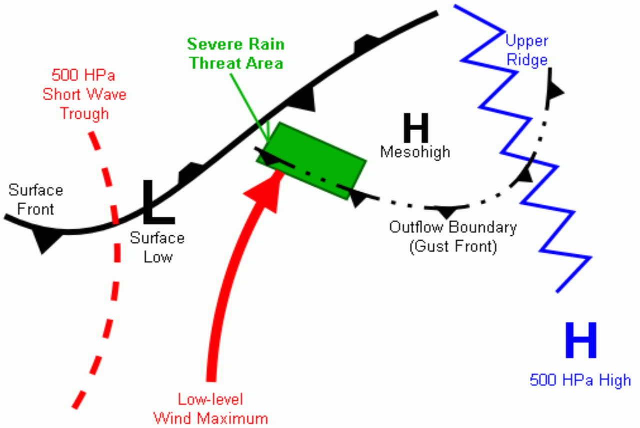

Figure 2. Conceptual model of the Frontal flash flood circulation pattern. Adapted from Maddox et al. (1979).

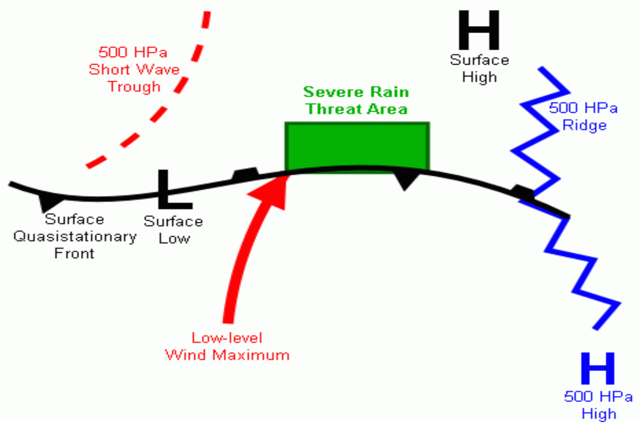

Figure 3. Conceptual model of the Mesohigh flash flood circulation pattern. Adapted from Maddox et al. (1979).

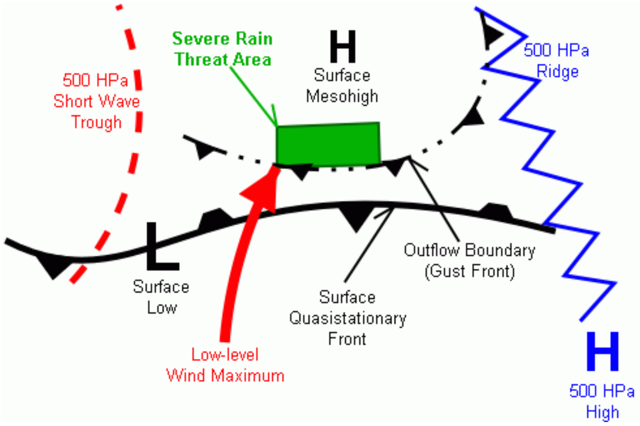

Figure 4. Conceptual model of the Combination Frontal-Mesohigh flash flood circulation pattern. Adapted from Chappell (1986).

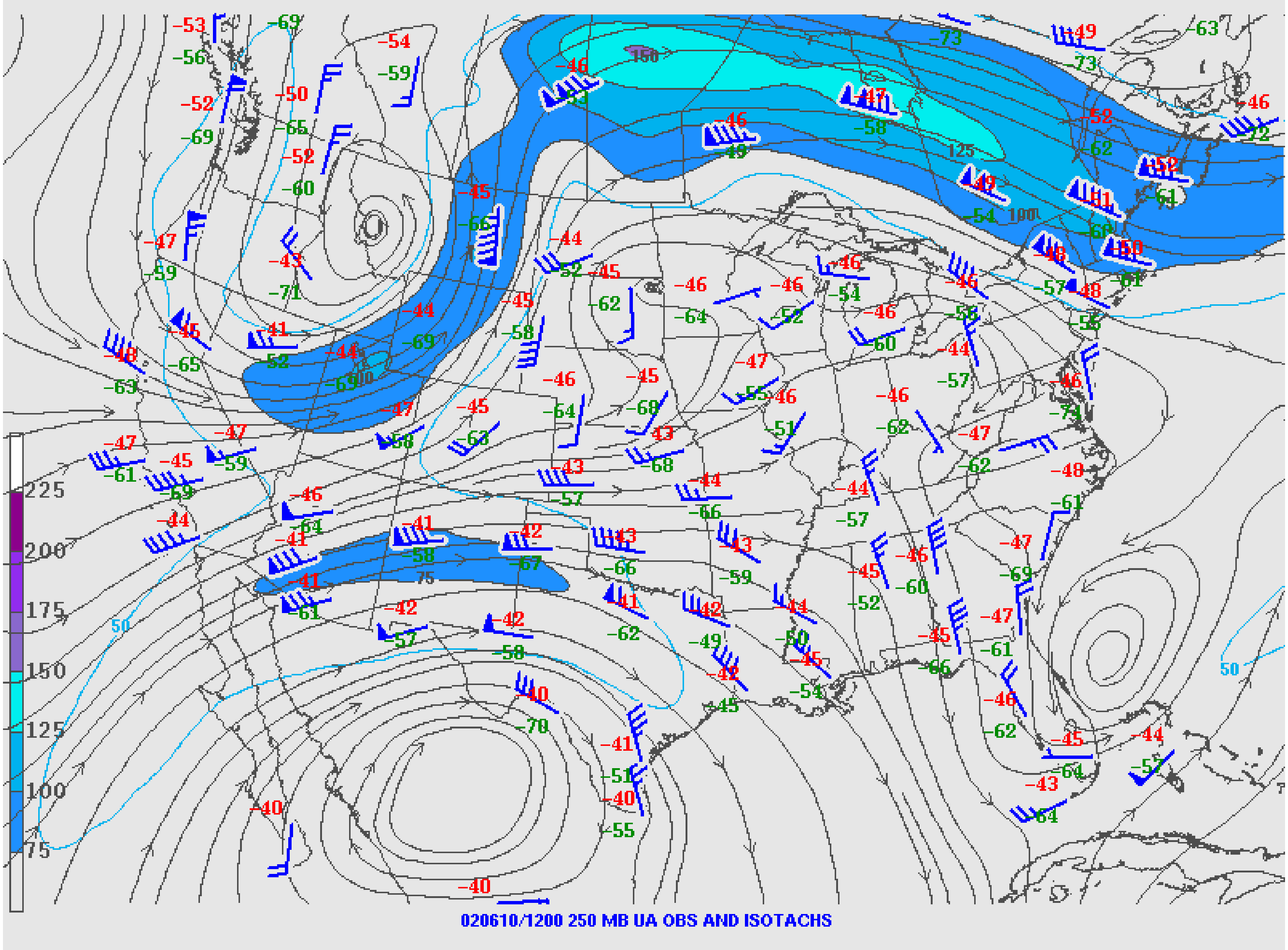

Figure 5. 250 hPa analysis valid at 1200 UTC 10 June 2002.

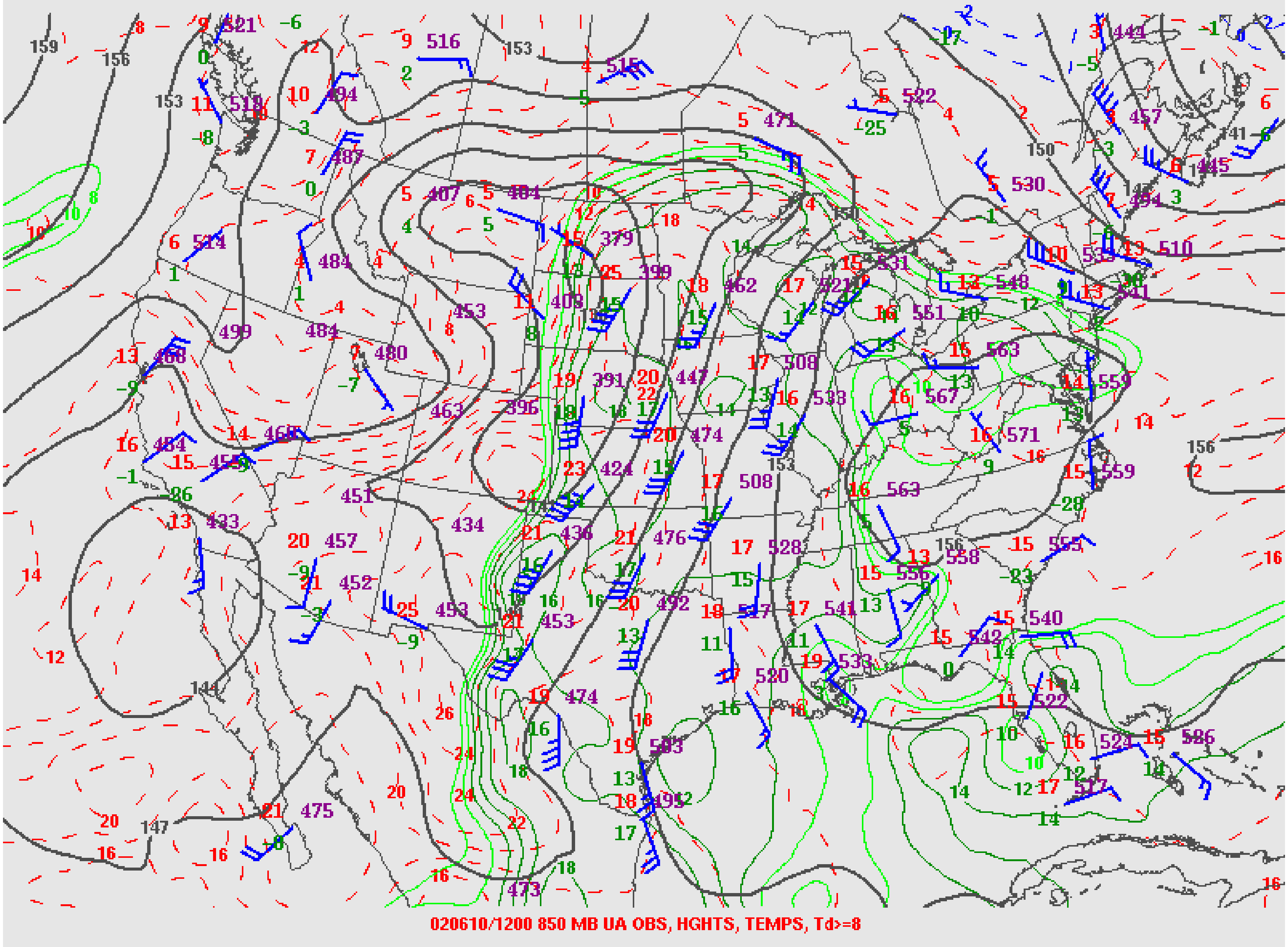

Figure 6. 850 hPa analysis valid at 1200 UTC 10 June 2002.

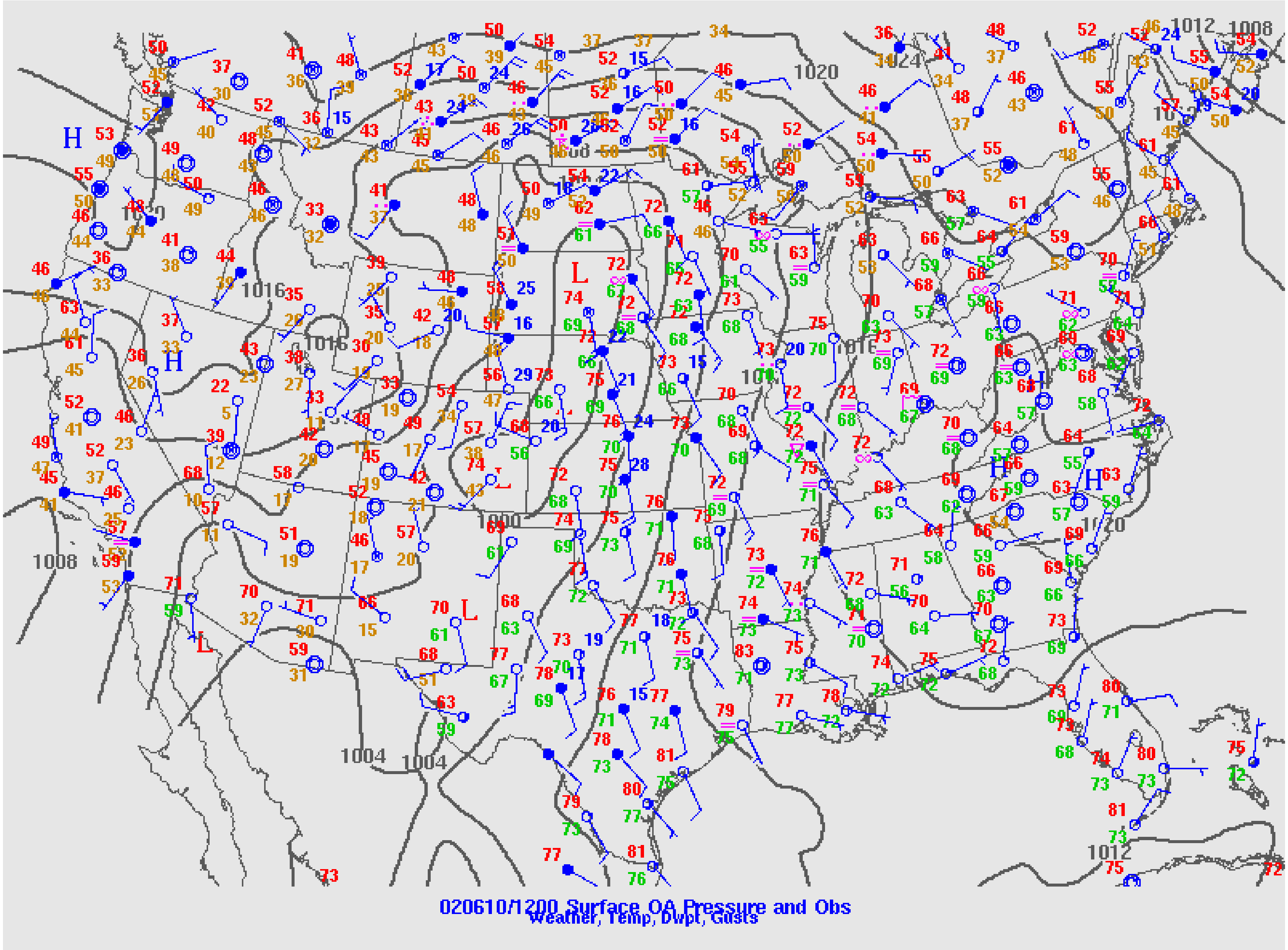

Figure 7. Surface analysis valid at 1200 UTC 10 June 2002.

3. Rainfall Analysis

3.1 Data Sources

Rain gauge data from 464 observing sites in Ontario, Manitoba, Saskatchewan, Alberta, North Dakota and Minnesota are used to spatially analyze the total precipitation in the Lake of the Woods-Atikokan corridor (the axis of maximum precipitation in Ontario) and upstream. A small number of key supplementary surface observations close to the area of heaviest rain are added to the data set.

The volunteer and cooperative climate observations used in the study are typically made once a day in the early morning, though some observers also make evening observations. The early morning rainfall observation includes rain from the previous 24 hours. Data from three climate days (June 8-10) is required here owing to the prolonged nature of this event.

Radar images from the MSC and U.S. Doppler radar networks provide areal rainfall estimates and verify storm tracks. Images from the GOES and NOAA polar orbiting satellites confirm the intense nature of the thunderstorms. Satellite-based rainfall amount and rain rate estimates from the Satellite Services Division (SSD) of the U.S. National Weather Service (NWS) are compared to data from other sources and provide crude areal estimates of precipitation outside of optimum radar range, between rain gauges. Lightning data from the North American Lightning Detection Network (NALDN) were used as a proxy for the tracks of the heaviest precipitation, especially over gaps in the radar network.

3.2 Historical Significance of Event

Two MSC climate stations received record one-day rainfall totals: Mine Centre, ON (172.0 mm on June 9, 2002) and Atikokan, ON (176.4 mm on June 10, 2002). The previous one-day rainfall records for June for those two stations were 120.8 mm (on June 2, 1990) and 55.4 mm (on June 10, 1970), respectively. The previous record annual one-day rainfall for the two stations were 120.8 mm (on June 2, 1990) and 96.6 mm (on September 19, 1985), respectively. These new records were nearly double the previous one-day rainfall record for these two sites.

Negligible precipitation was recorded the days before and after the dates of the previous records, so the total associated with the previous record one-day rainfall may be viewed as storm total as well. The storm total for this event, 293.2 mm at Mine Centre and 194.0 mm at Atikokan, far exceeds the storm totals from the previous one-day record setting storms.

The new record one-day rainfall amount at Mine Centre (172.0 mm) and Atikokan (176.4 mm) greatly exceeded the record one-day rainfall at two nearby MSC climate stations that have long periods of record. Fort Francis, ON, which has records dating back to 1892, has a one-day record rainfall of 127.8 mm (July 31, 1987). Kenora, ON, which started keeping records back in 1939, has a one-day rainfall record of 128.3 mm (July 29, 1970). Again, at both of these stations, less than 3 mm of rain was recorded on the days surrounding these record totals, thus it is assumed that these amounts would be event totals (or storm totals) as well.

The highest one-day rainfall total for any station in Northwestern Ontario was 156.2 mm, set on July 12, 1999 at Barwick. In 2002, Barwick reported over 200 mm in two days with 110.8 mm on June 9 and 90.4 mm on June 10. Table 1 shows the one-day rainfall totals for all three days at some MSC stations in Northwestern Ontario.

The three-day rainfall totals for this event seem to have far exceeded any previous event based on record one-day rainfall totals. The amounts of 200-400 mm are extreme for this area of the country. Unfortunately storm-totals that include multiple day events are not easily extracted from the archive.

Two non-MSC observing sites, just north of Highway 11 between Rainy River and Fort Francis, Ontario, reported three-day totals of 401 mm and 375 mm,

Station Name	June 8	June 9	June 10	Total
Atikokan	0.0	17.6	176.4	194.0
Atikokan (Climate)	Trace	25.0	93.0	118.0
Barwick	10.0	110.8	90.4	211.2
Dryden “A”	0.0	61.6	51.5	113.1
Dryden Automatic	0.0	71.5	35.9	107.4
Emo	N/A	N/A	N/A	208
Fort Francis	14.0	118.4	81.0	213.4
Kenora	0.0	61.0	39.8	100.8
Mine Centre	8.4	172.0	112.8	293.2
Rainy River	33.0	87.5	124.0	244.5
Stratton	24.6	101.4	96.8	222.8
Thunder Bay	0.0	1.0	9.0 (8.5 on the 11th)	10.0 (18.5)

Table 1. Rainfall Total June 8 – 10, 2002

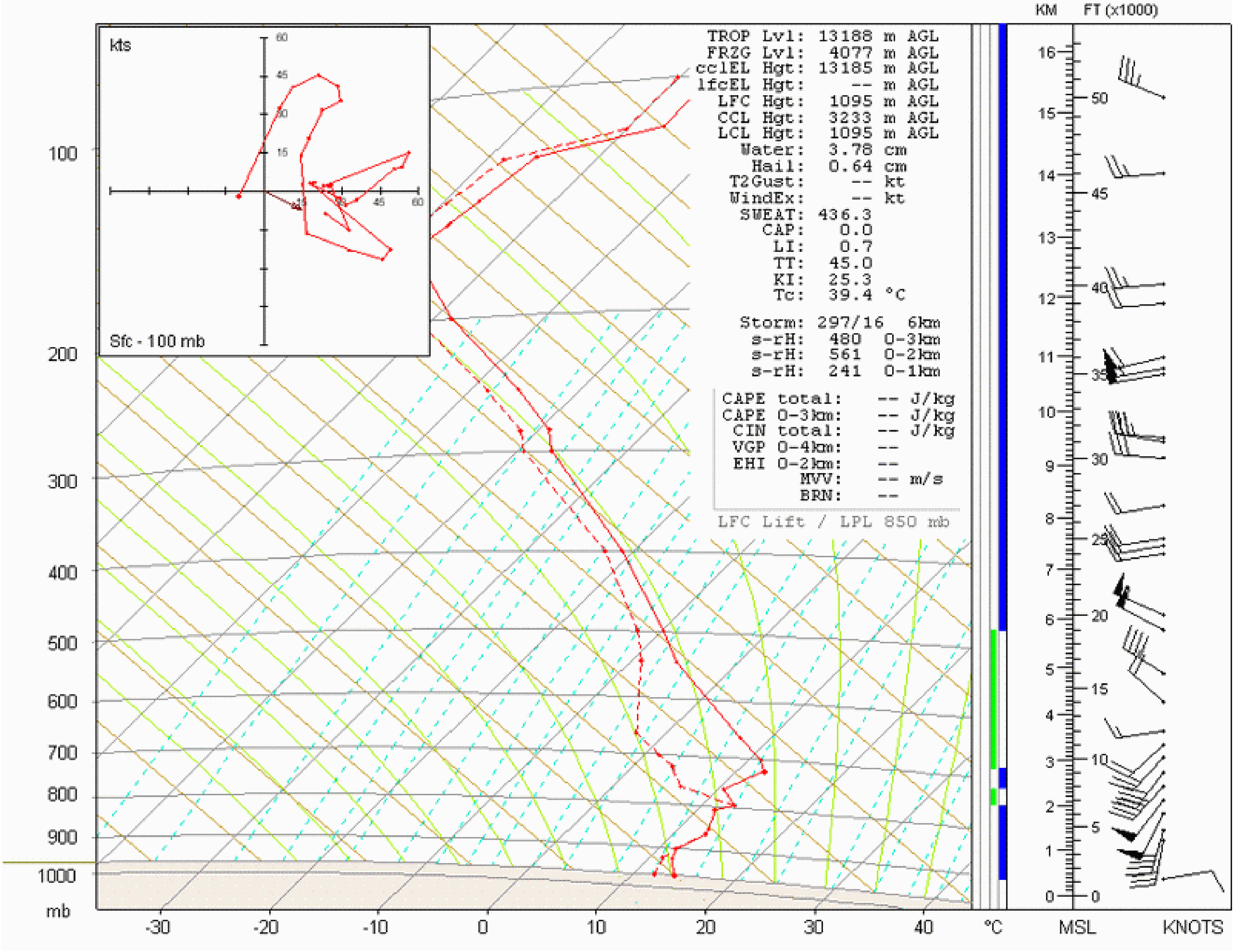

Figure 8. Rawinsonde analysis from International Falls, MN valid at 0000 UTC 10 June 2002.

respectively. Two climate stations in Minnesota, just south of Lake of the Woods, reported comparable three-day totals of 370 mm and 325 mm. extreme for this area of the country. Unfortunately storm-totals that include multiple day events are not easily extracted from the archive.

Two non-MSC observing sites, just north of Highway 11 between Rainy River and Fort Francis, Ontario, reported three-day totals of 401 mm and 375 mm, respectively. Two climate stations in Minnesota, just south of Lake of the Woods, reported comparable three-day totals of 370 mm and 325 mm.

4 Impact of Flooding

As of 15 August 2002, claims for damages totaled $7.5 million in Northwestern Ontario. Major highways in the region were closed for a week or more. Highway 11 was closed near Lavallee and a temporary bridge crossing over the Seine River had to be installed to reinstate traffic between Kenora and Thunder Bay.

The Canadian National (CN) rail line between Winnipeg and Thunder Bay was washed out in approximately thirty places, one of the washouts measuring almost a kilometer in length. The railway was most severely impacted east of Kenora.

In Manitoba, flooding forced over 200 people out of their homes mainly from the towns of Sprague, Marchand and Piney as well as the regional municipality of Piney. In Sprague, businesses were also closed. $6.7 million was paid in Disaster Relief.

On the U.S. side, the town of Roseau was severely impacted by the flooding, affecting most residences and the business district. Early estimates of damages total $120 million U.S (Minnesota Public Radio 17/06/02).

5. Discussion

A quasi-stationary frontal system that was situated in a west to east orientation across the Dakota's and northern Minnesota from 8-11 June 2002 was the focus for a series of severe rainstorms. Warm and very moist air with its source in the Gulf of Mexico was forced upward over the front by a strong and persistent low-level jet. A series of regenerative MCSs containing elevated thunderstorms developed to the west of the Roseau River and Winnipeg River watersheds. New cells repeatedly developed and moved across the same parts of southern Manitoba, northwestern Ontario, and northwestern Minnesota resulting in storm total rainfalls of 200 - 401 mm. The highest rates of fall occurred during the evening of 9 June and early morning of 10 June due to training of the individual thunderstorm cells. The storm established new records for 24-hour rainfall at Mine Centre, ON and Atikokan, ON that greatly exceeded the previous records. Figure 33 shows some estimated return periods for peak flows resulting from this storm.

The large-scale circulation pattern that produced the severe rains shifted toward the east over the next several days and as a result, heavy thunderstorms also occurred across parts of the Ohio valley and Great Lakes later in the week. The upper pattern eventually broken down and the upper low over western North America moved eastward. However, these heavy rains set the stage for more potential flooding the days and weeks to follow.

Over the summer of 2002, estimated damages directly related to flooding totaled $31 million in Ontario, over $7 million in Manitoba and an estimated $120 million U.S. in the Minnesota town of Roseau alone.

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