

The Derecho of 4-5 July 1999 in Southern Quebec

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1- Introduction

During the night of July 5, 1999, violent thunderstorms woke people from their sleep. The lightning made it as bright as day, and strong gusting had people fearing for their homes. A derecho was moving at 100 km/h across southern Quebec, from the Temiscamingue region to the Eastern Townships, causing one death and considerable destruction as it passed.

This report begins with a description of the meteorological structure of a derecho, and the dynamic and thermodynamic factors which are conducive to derecho formation. The next section describes the synoptic situation on July 4, 1999, in order to explain the genesis of the derecho and why it held steady at the mature stage on July 4-5. The last section gives an example of the radar structure of this derecho, followed by a portrait of the damage sustained that night.

2- General description of a derecho

A derecho is any rapidly moving extratropical convective system that produces downbursts causing significant and widespread damage (Fujita & Wakimoto 1981). It lasts several hours (sometimes more than 10) and as a result it covers a very long distance, occasionally over 1000 km (Hirt & Johns 1987). A derecho follows a straight line path—whence its name, which means ‘straight ahead’ in Spanish.

Derechos may have some of the features of a mesoscale convective system (MCS) as well as some of the features of a squall line. The best way of distinguishing them from these other two types of storm system is to look at the radar structure. Radar images show a squall line perpendicular to the mean wind between 5000 feet and the tropopause, and moving more rapidly than this mean wind (Hirt & Johns 1987). A crest in the precipitation wave is found at the north end of the squall line. There is also a bow echo on the squall line, extending in the direction of the mean upper wind, and behind which severe weather is observed.

Strong dynamic and thermodynamic activity is conducive to derecho formation, and the resulting instability must continue if the system is to be maintained. Hirt & Johns (1987) and Duke & Rogash (1992) point out that there must be high potential instability (CAPE) and high conditional instability, arising from abundant moisture at low levels and cold, dry air at mid levels. Winds at mid levels must be over 40 knots. Between the time when the formation originates, and the time it reaches maturity, the level of free convection approaches the surface. Strong wind shear at low levels (under 2 km) gives rise to a strong storm-relative flow which penetrates the cloud at this level, due mainly to the directional component of the shear. At mid levels (4-6 km), the shear must become weaker and lose this directional component so that the storm-relative flow penetrating the cloud can also become weaker. This storm-relative wind pattern, along with heat advection, concentrates the cold air at mid levels, this being necessary for the

maintenance of the derecho formation. It is the high hydrostatic energy levels (buoyancy) which partly explain why the speed of propagation of the derecho exceeds the mean wind speed (Lilly 1979).

Dry air intrusion into the storm cloud at mid levels causes cooling by evaporation. The weak wind shear at this level attenuates mixing of the cooled air with the ambient air, and the cooled air accelerates downward as a result of hydrostatic balance. When these winds reach the surface, they contribute to strong gusting. The other contributing factors are the downward transport of the high momentum of the mid-tropospheric winds, and the entrainment of air caused by falling precipitation (Duke & Rogash 1992). The strongest gusts, or more rarely tornados, thus occur just behind the centre of the bow echo.

While the synoptic conditions and radar structure described above are the same for all derechos, there are nevertheless two types—warm-season and cold-season.

In late spring and in summer, derechos form either along a 500mb short-wave trough or else along, or to the east of, a relatively flat 500mb long-wave ridge. The winds are westerly or westnorthwesterly. The derecho forms along, or sometimes on the cold side of, a quasi-stationary frontal zone which usually has an east-west orientation, and it is associated with an area of convergence along the frontal zone, where there is significant warm-air advection. Surface and low-level moisture concentrates in a pool along, and to the south of, the convergence area, and the moisture maximum is found near the centre of the derecho trajectory (Hirt & Johns 1987). The derecho moves along the 850 and 700mb thermal gradient just north of the thermal ridge (Duke & Rogash 1992). Higher up, the 250mb jet stream has a weak anticyclonic curvature and may be over 400 km north of the zone of derecho formation. The derecho tends to develop at the right entrance of this jet stream, near an area of diffluence aloft (Hirt & Johns 1987).

Cold-season derechos occur in late winter and in spring. There is a well-defined long-wave trough at 500 mb, while at the surface there is a moving cold front. In the warm sector, low-level moisture does not form in a pool, but takes the form of a moisture ridge extending northward. The derecho moves across the 850 and 700 mb thermal gradient (which is highly baroclinic) toward the warmer air of the thermal ridge. The mid-level dry air is found upwind of the zone of derecho formation. The high level jet stream has the same cyclonic curvature that is observed at 500 mb. The derecho develops at the right entrance of the jet stream, but near an area of weak diffluence aloft (Duke & Rogash 1992).

Table 1 in the Appendix sets out the shared features of the two types of derecho, while Table 2 (based on Duke & Rogash 1992) sets out the differences.

3- The synoptic situation

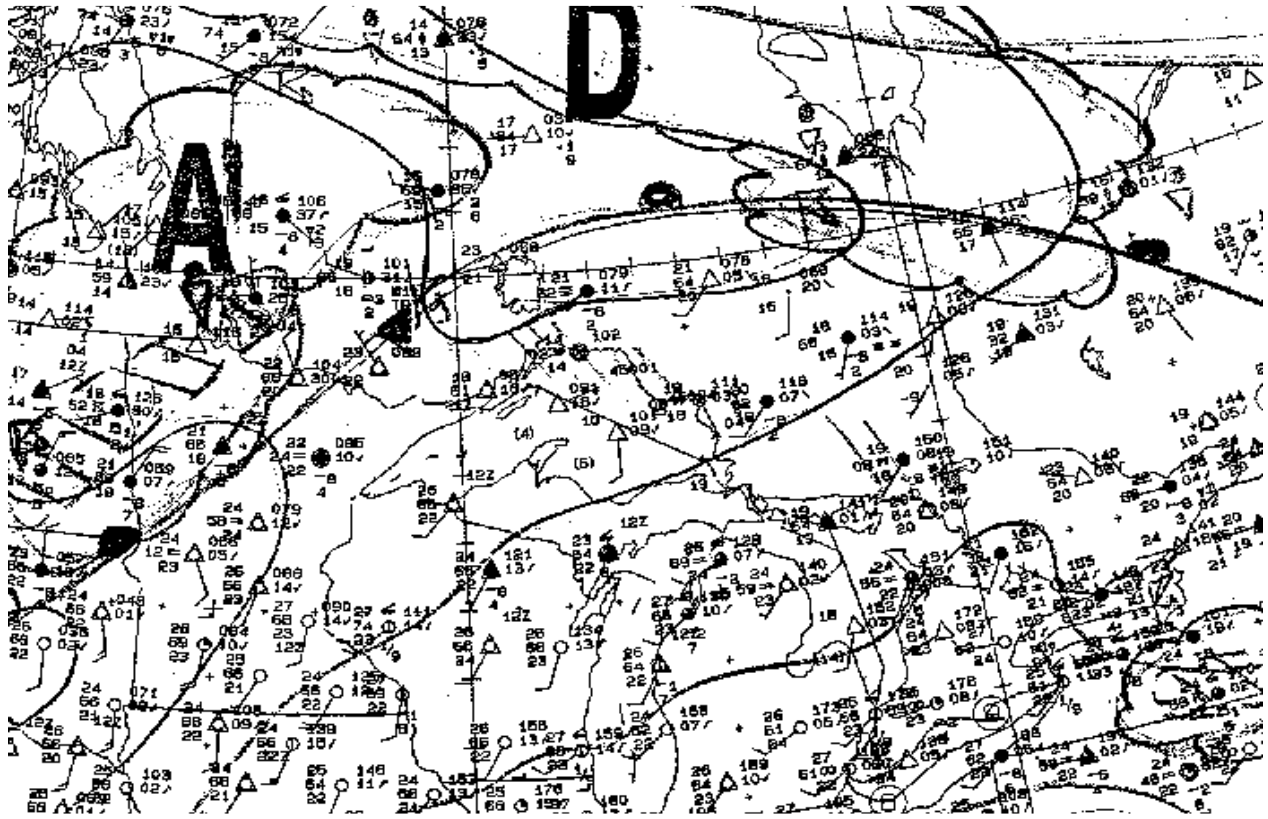


Figure 1- 12Z surface analysis, 4 July 1999

During the day of July 4, 1999, a quasi-stationary frontal trough extended from north of Geraldton to Matagami and New Brunswick (Figure 1). A storm system, apparently an MCS, was moving slowly along the Ontario-Minnesota border and remained in the cold sector of the frontal structure. It would take almost 8 hours for the system to reach Lake Superior. In the warm sector, surface winds were generally southwesterly about 10 knots, and over Ontario and Wisconsin the surface moisture was increasingly concentrated in a pool within which the dewpoints had risen to 24 degrees.

At 500 mb (Figure 2), Central Ontario and all of southern Quebec were under a flat long-wave ridge with winds of 40-50 knots. Pickle Lake reported a dewpoint depression of 25 degrees near the thunderstorms. At 700 mb (Figure 3), the air was dry near and downwind of the storm system, with a dewpoint depression of 17-21 degrees reported by International Falls and Pickle Lake. At 850 mb (Figure 4) near Lake Huron, both a moisture maximum and warm-air advection were observed. The high-level jet stream (Figure 5) was moving with a slight anticyclonic curvature from the far north of

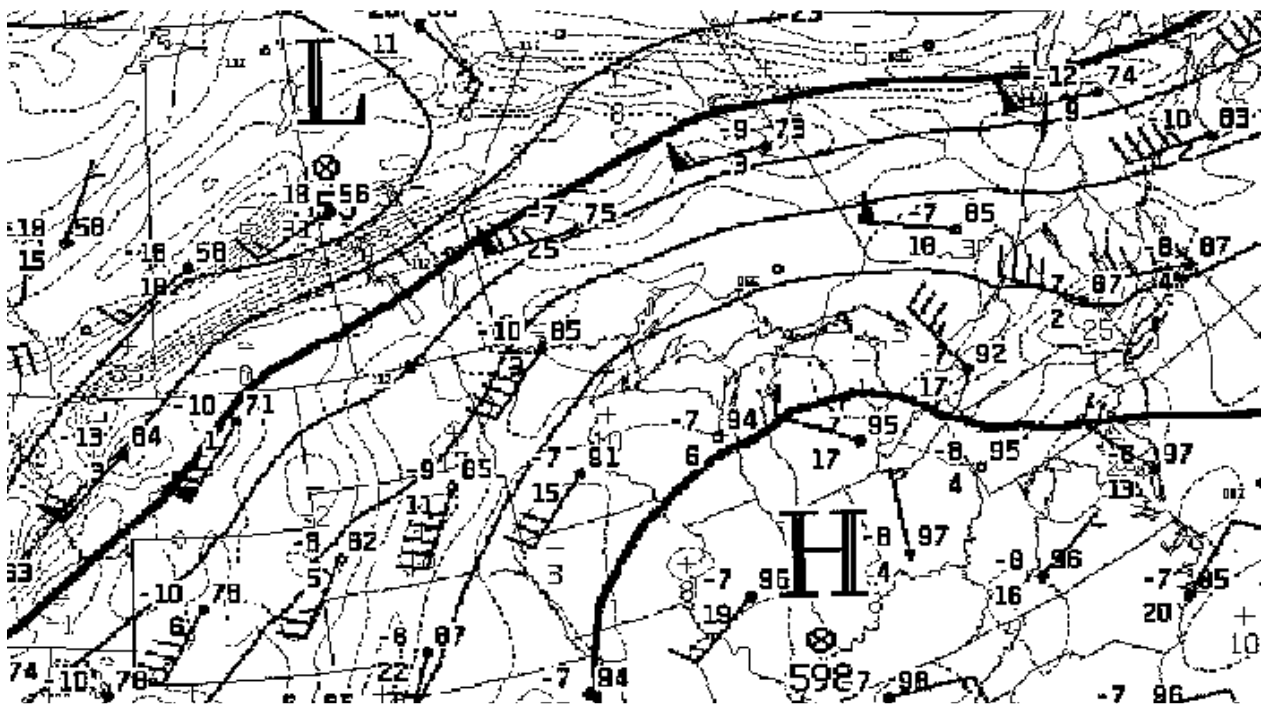
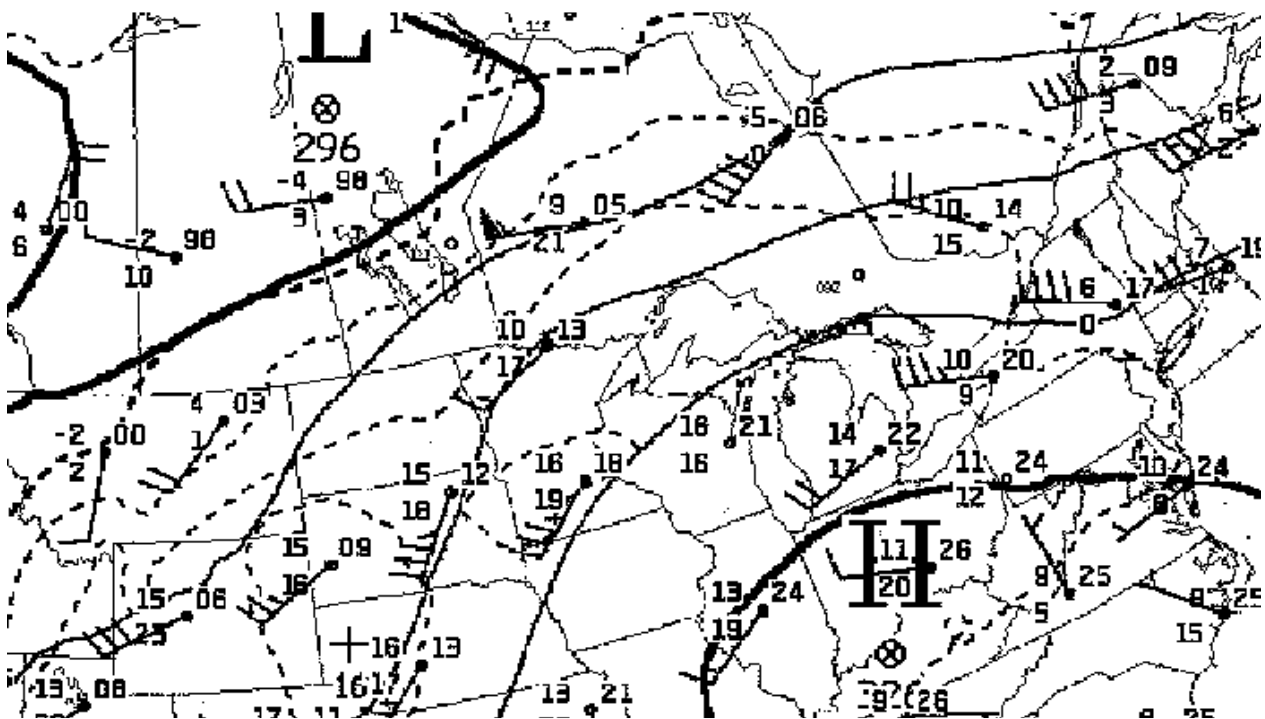


Figure 2 - 12Z 500mb analysis, 4 July 1999

Figure 3 - 12Z 700mb analysis, 4 July 1999



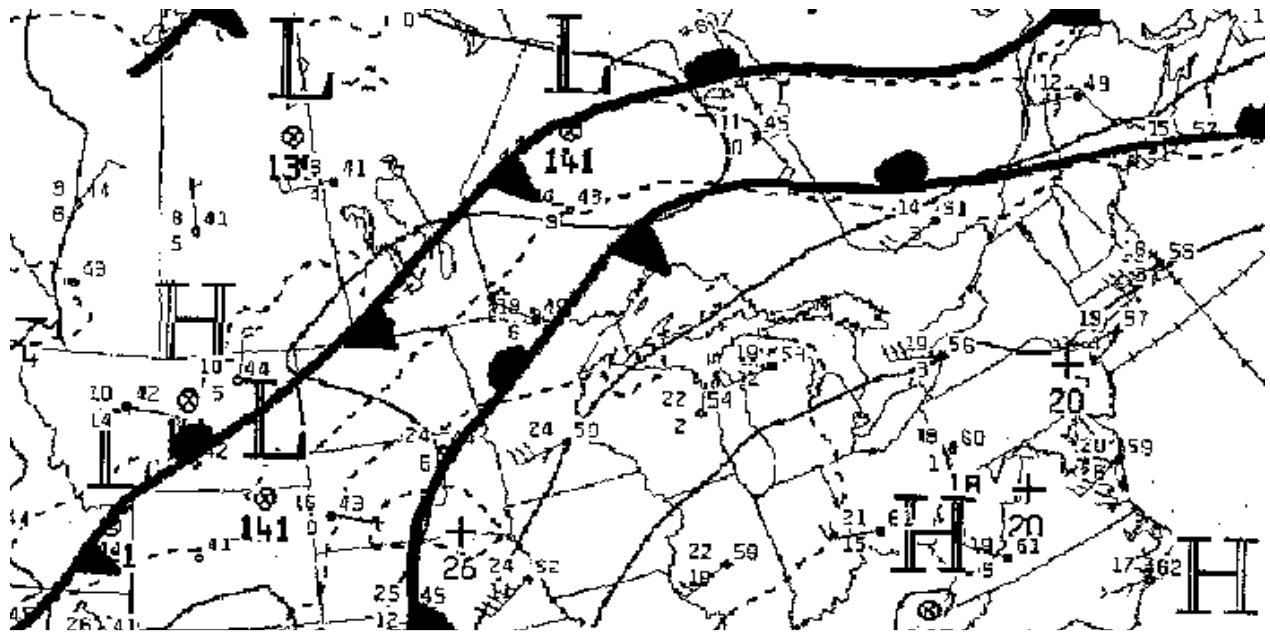


Figure 4 - 12Z 850mb analysis, 4 July 1999

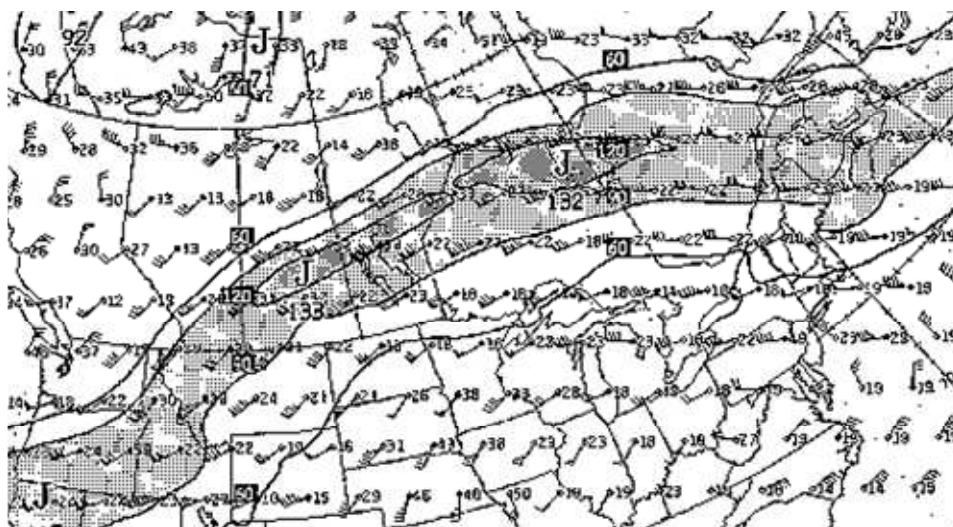


Figure 5 - Winds forecast for 00H in 12Z GEM output, 4 July 1999

Ontario toward central Quebec. The jet stream core was moving east, and the area of interest continued to be at its right entrance. Analysis of the winds aloft suggests that the mean winds between 5000 feet and the tropopause were about 35 knots.

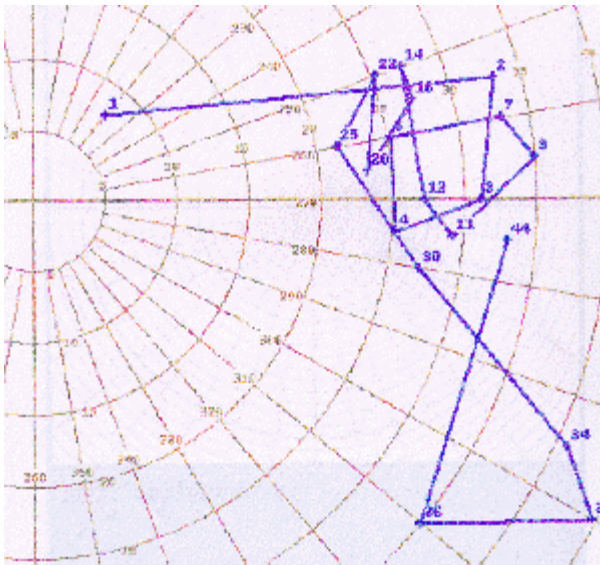


Figure 6 - 12Z tephigram and hodograph for Gaylor, Wisconsin, 4 July 1999

On the morning of July 4, the tephigram for Gaylor (Figure 6) showed very high instability, Gaylor being located near the pool of moisture and near the area where favourable conditions were present aloft. Despite the negative energy caused by capping, analysis of the indices (with no change in the initial parameters) does suggest severe weather. The buoyant energy of 2563 J/kg exceeded the 2400 J/kg required for derecho formation. Once capping had been eliminated by diurnal warming, and more particularly by warm-air advection at low levels, there was a high potential for severe thunderstorms, with the level of free convection around 750 mb. Once these changes had occurred, the equivalent potential temperature at the surface exceeded the 360 K which indicates a derecho. High values for SSI (123), shear (9.6×10^{-3}), $\Delta\theta_e$ (28°C), EHI (1.93), precipitable water (36mm), and Lifted Index (-6) indicate the potential for severe thunderstorm formation. The wind shear pattern on the Gaylor hodograph (Figure 6) also suggests a potential for derecho formation: high shear under 2 km (6,000 feet), partly directional, and weak shear between 4 and 6 km (12,000 and 18,000 feet) with no directional component.

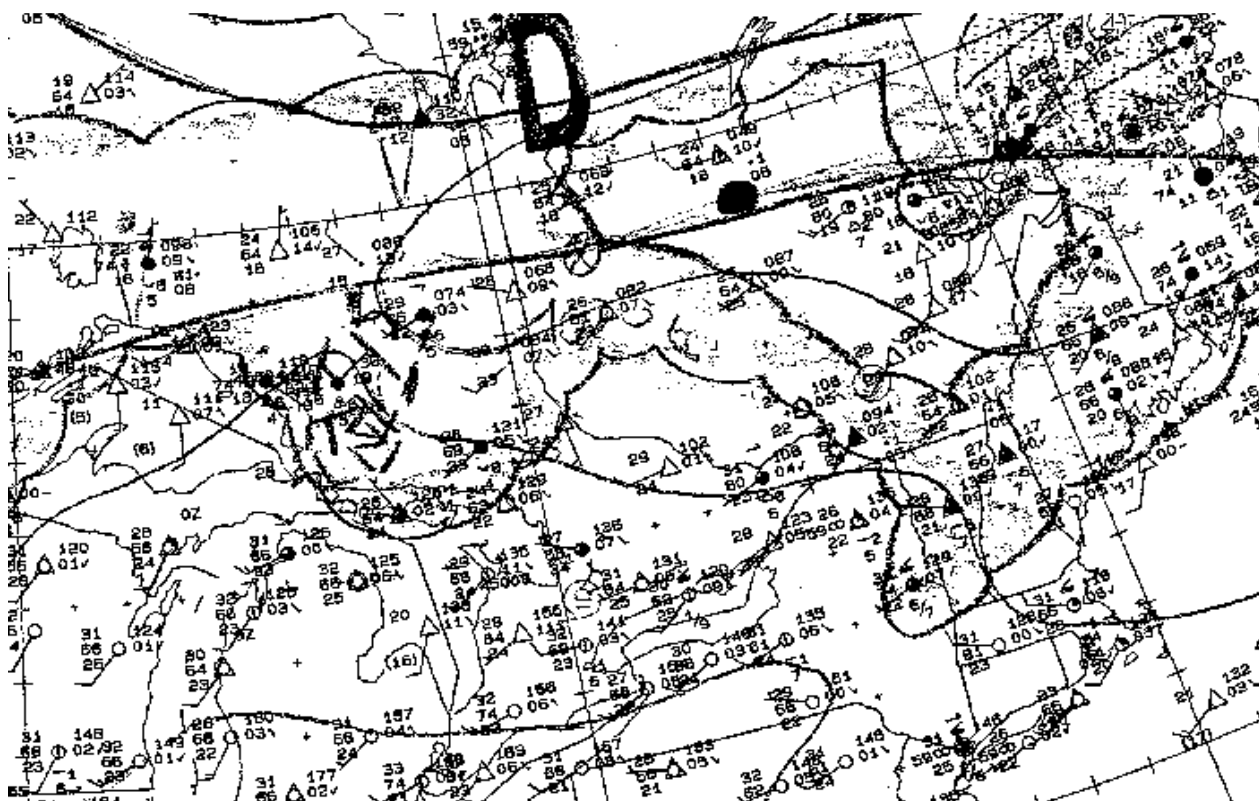


Figure 7 - 00Z surface analysis, 5 July 1999

Late in the day, once the storm system was in the warm sector, it accelerated toward Quebec, reaching a speed of almost 100 km/h. It would take about 6 hours to cross the province, from the Temiscamingue region to the Eastern Townships. The frontal zone was virtually stationary (Figure 7) and the winds over southern Quebec continued to be southwesterly at about 10 knots. A barometric trough extended south from the frontal zone and became associated with the storm system. The pool of moisture became increasingly well defined as it slid over southern Quebec ahead of the storm. The dewpoints held at 23-25 degrees even when night fell.

The flat long-wave ridge continued to hold at 500 mb over southern Quebec (Figure 8) and the winds were at 50 knots. The storm system, associated with a short-wave trough crossing the sector, was advancing at a speed greater than the mean winds between 5000 feet and the tropopause (WNW 40 kt). In the evening, dry air continued to be present aloft downwind from the storm system: Maniwaki reported a dewpoint depression of 23 degrees at 700 mb (Figure 9). Observations continued to show a moisture maximum and a warm advection maximum in the warm sector at 850 mb (Figure 10), but now it was over southern Quebec and the adjacent area east of Lake Ontario. Southern Quebec was now at the right entrance to the 250mb jet stream (Figure 11), which was flowing from James Bay to the Gulf of St Lawrence, still with a weak anticyclonic curvature.

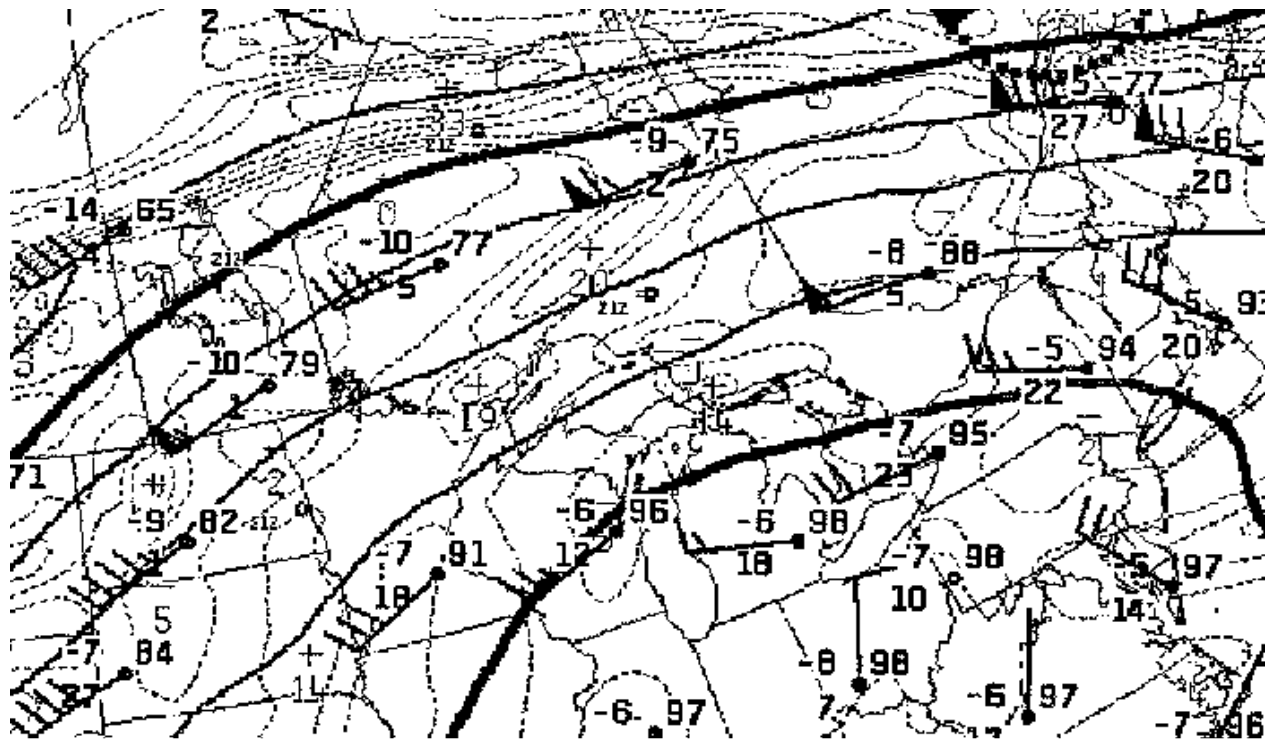


Figure 7 - 00Z 500mb analysis, 5 July 1999

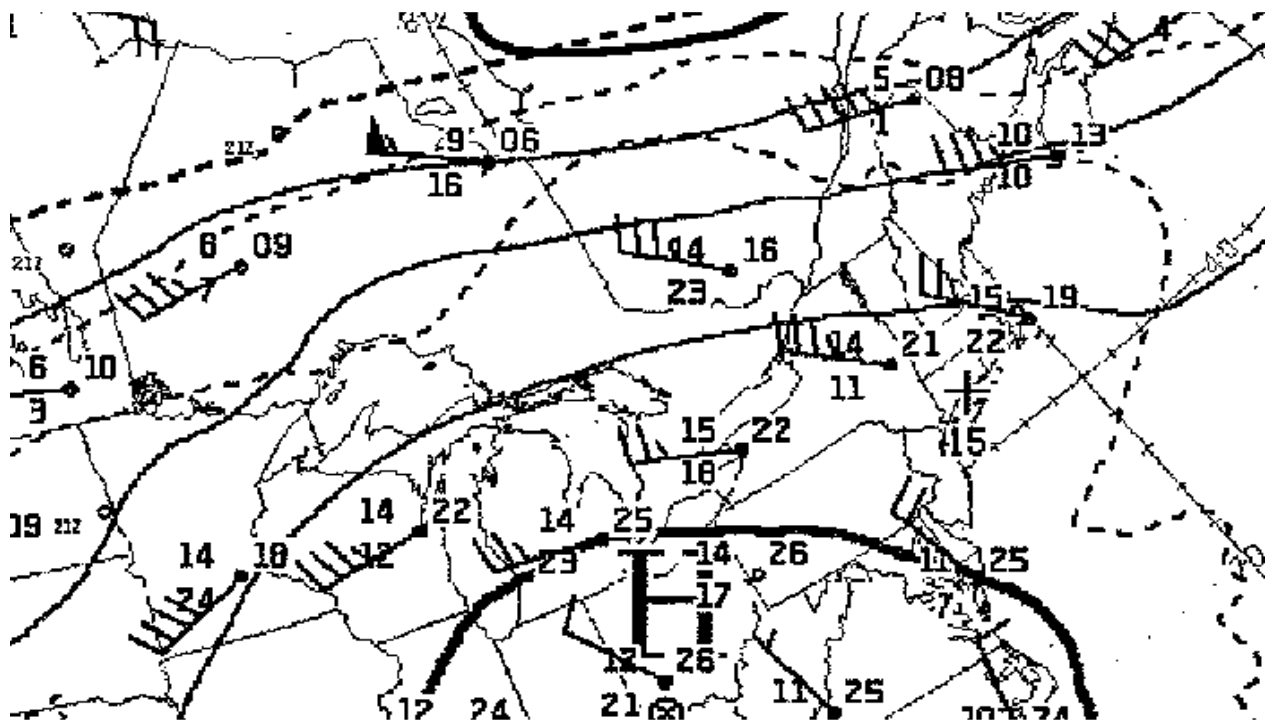


Figure 8 - 00Z 700mb analysis, 5 July 1999

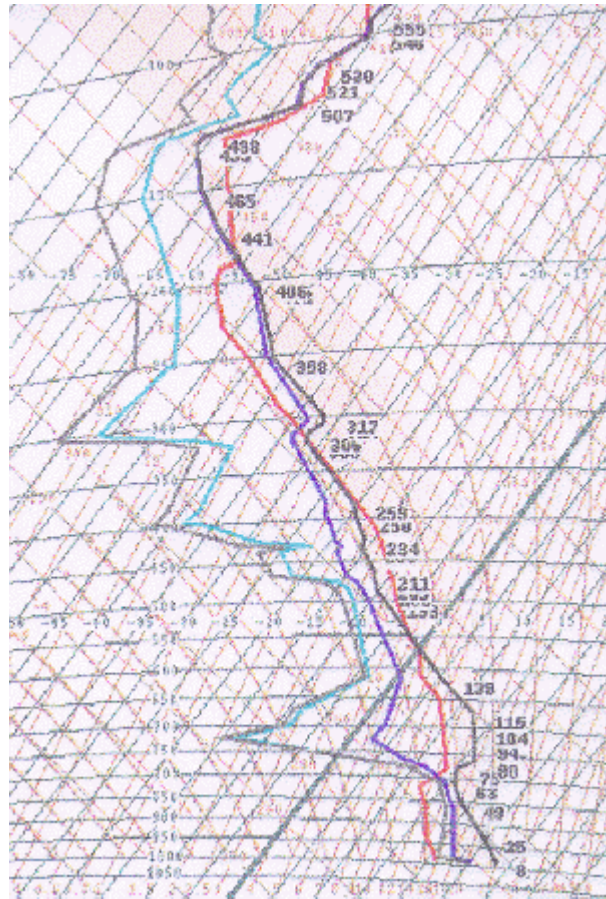


Figure 11 - 00Z tephigram and hodograph for Maniwaki, 5 July 1999

The tephigram for Maniwaki (Figure 12) provides a good picture of the conditions prevailing over southern Quebec just before the derecho passed. If surface conditions held through the night, severe thunderstorm development could be expected once there was no longer any capping aloft and the negative energy near the surface had been eliminated. The level of free convection had been approaching the surface over the course of the day, moving from 750mb at Gaylor in the morning to nearly 900 mb in the evening. The buoyant energy available was very high (3533 J/kg), as was the surface equivalent potential temperature (370 K). The severe weather indices remained conducive to severe thunderstorm formation; indeed some of the values had increased: SSI 160, shear 2.3×10^{-1} , $\partial\theta_e$ 32°C, EHI 2.7, precipitable water 43mm, and Lifted Index -9. The hodograph for Maniwaki (Figure 12) continued to show a favourable shearing pattern, this time with a better defined directional input under 2 km (6000 feet).

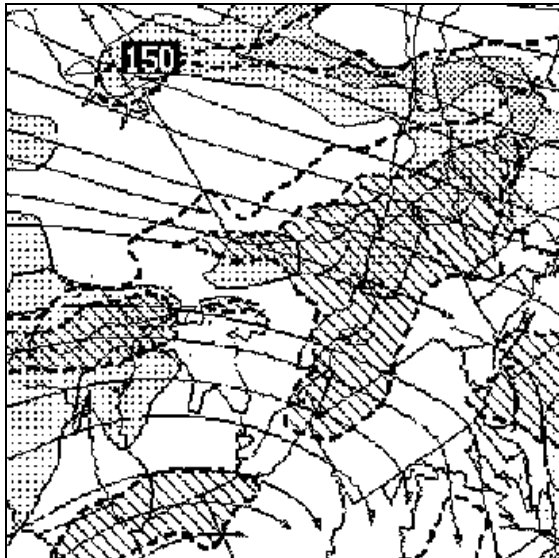
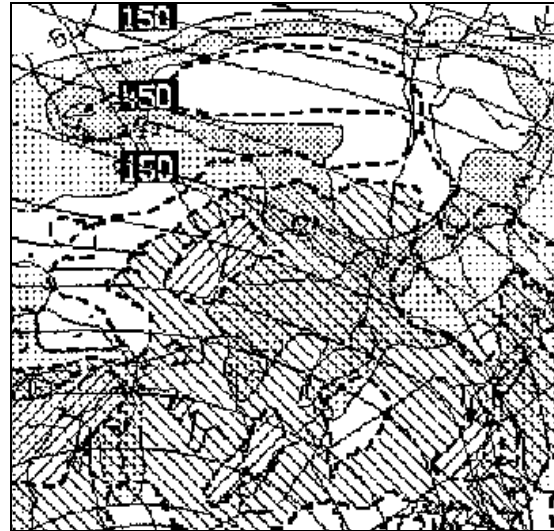
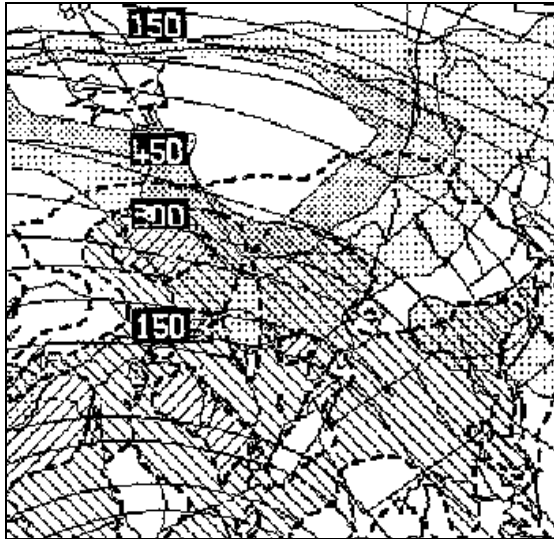


Figure 12 - Relative helicity forecast for 06H, 12H and 18H in 12Z GEM output, 4 July 1999

The 12Z Global Environmental Multiscale model outputs for relative helicity on the morning of July 4 (Figure 13) indicate a zone of high helicity ($400 \text{ m}^2/\text{s}^2$ and over) crossing southern Quebec in the afternoon and evening. They also show a well-defined zone with high SSI (over 120) affecting the whole of southern Quebec for the evening and at least part of the night (the outputs only cover the period until 06Z July 5). The other severe weather parameters, shown on their respective outputs, are nevertheless favourable to severe storm development. Between 00Z and 12Z on July 5, a 500mb short-wave trough crossed southern Quebec. There were also two low-level jet streams, one moving along the frontal zone from southern James Bay to Quebec City, the other moving eastward from eastern Ontario. During this same period, precipitable water values were over 50 mm in southern Quebec. The forecast chart of Figure 14 shows all the factors conducive to convection over southern Quebec around 00Z on July 5.

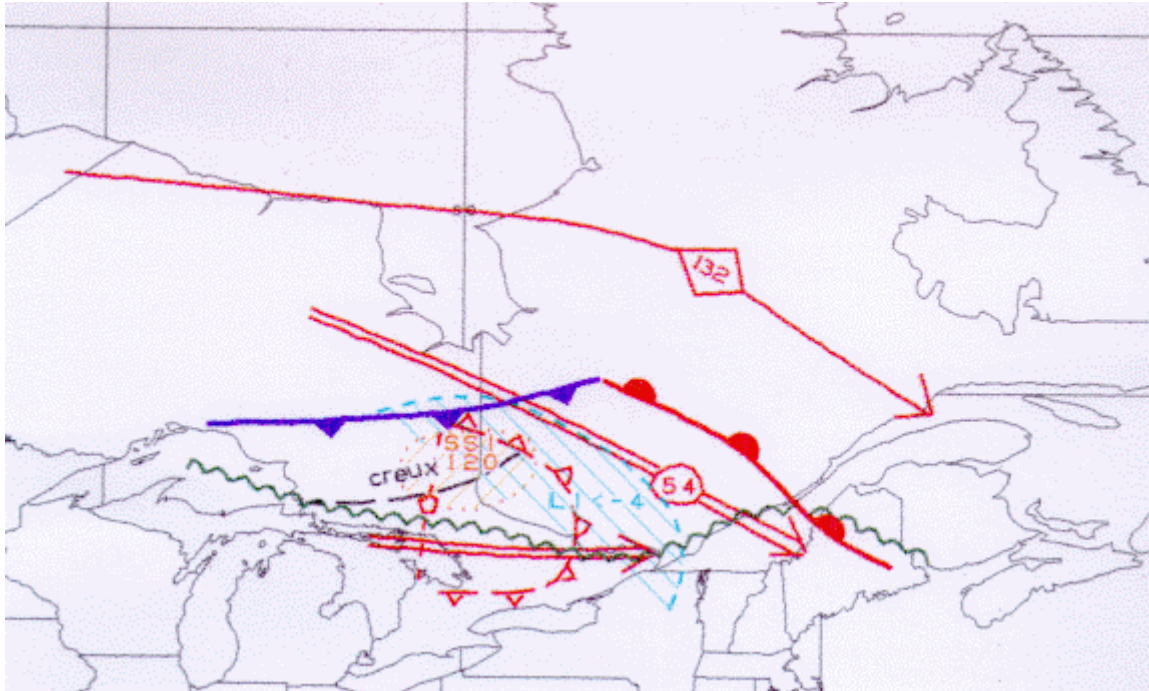
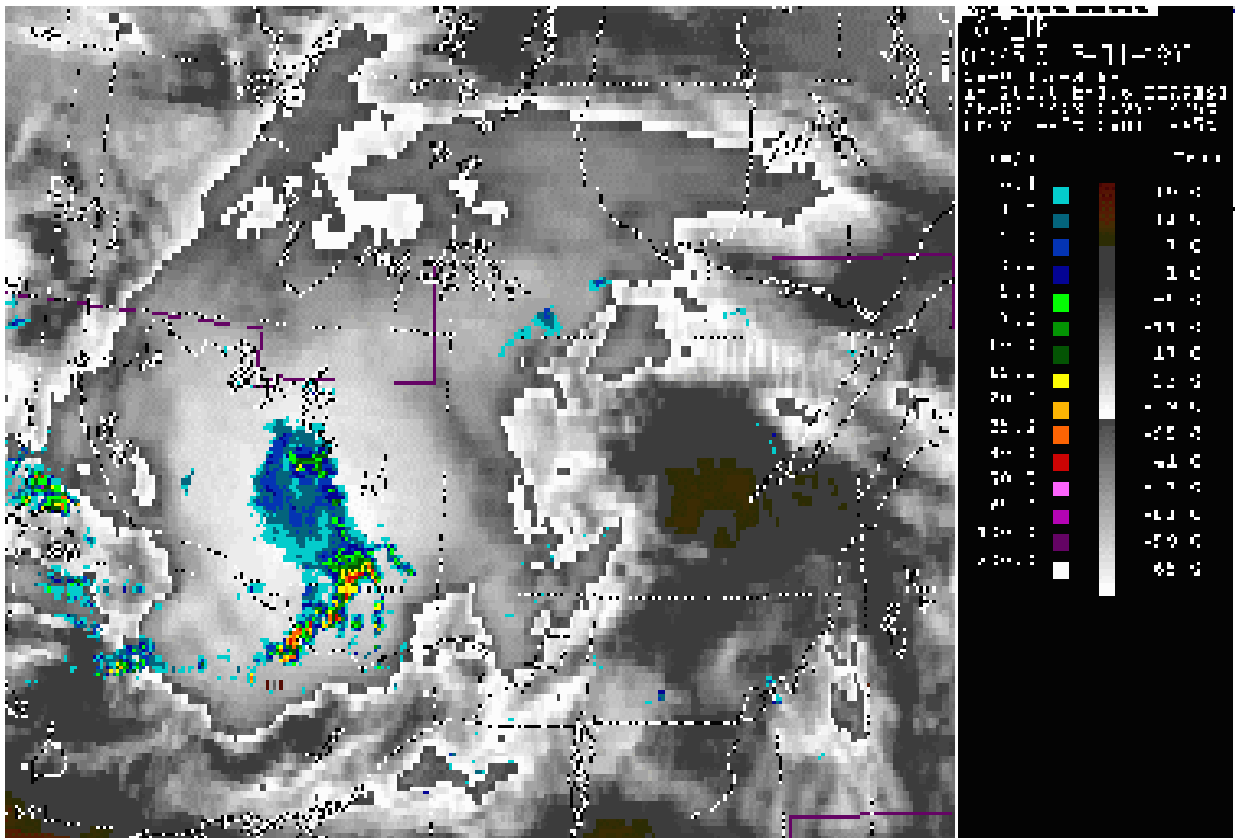
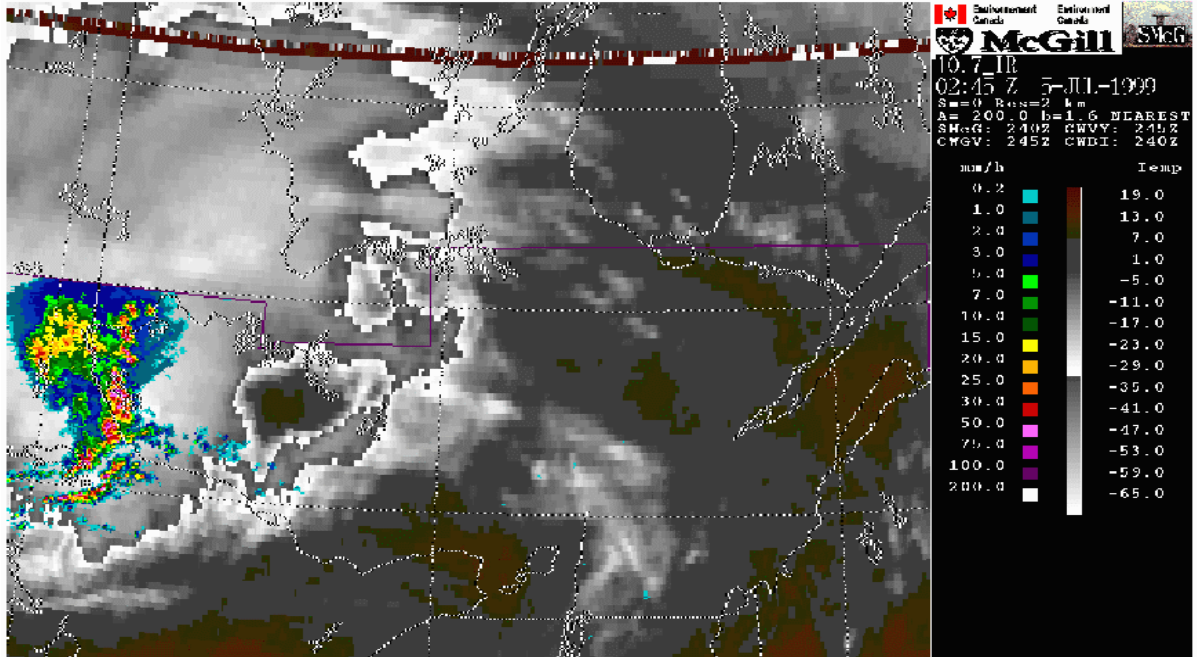


Figure 13 - 00Z composite map of convective weather, 5 July 1999

To summarize, analysis of the tephigrams and weather parameters indicated that there would be well organized thunderstorms during the evening and overnight in southern Quebec. Surface conditions remained favourable even when night fell. It was then a matter of recognizing the derecho pattern based on the synoptic situation aloft and the way the storm system developed.

4- Description of the events

When the storm system entered Quebec, it was already a derecho and had caused some damage in Ontario. Around 10:30 pm on July 4, it reached the Temiscamingue region, moving at about 100 km/h. Its trajectory included Mont-Laurier, the Outaouais region, the Laurentians and Greater Montreal as it crossed Quebec discharging up to 6000 lightning strokes an hour. It reached the Eastern Townships around 3:30 am on July 5, and then left the province a short while later, heading toward Maine. Figure 15 features the composite satellite and radar images of the event. At all times, the radar structure held steady: a squall line perpendicular to the WNW direction of the mean winds between 5000 feet and the tropopause, its strength indicated by numerous overhangs on the radar. Also seen on the radar was a crest in the precipitation wave over central Quebec, north of the squall line.



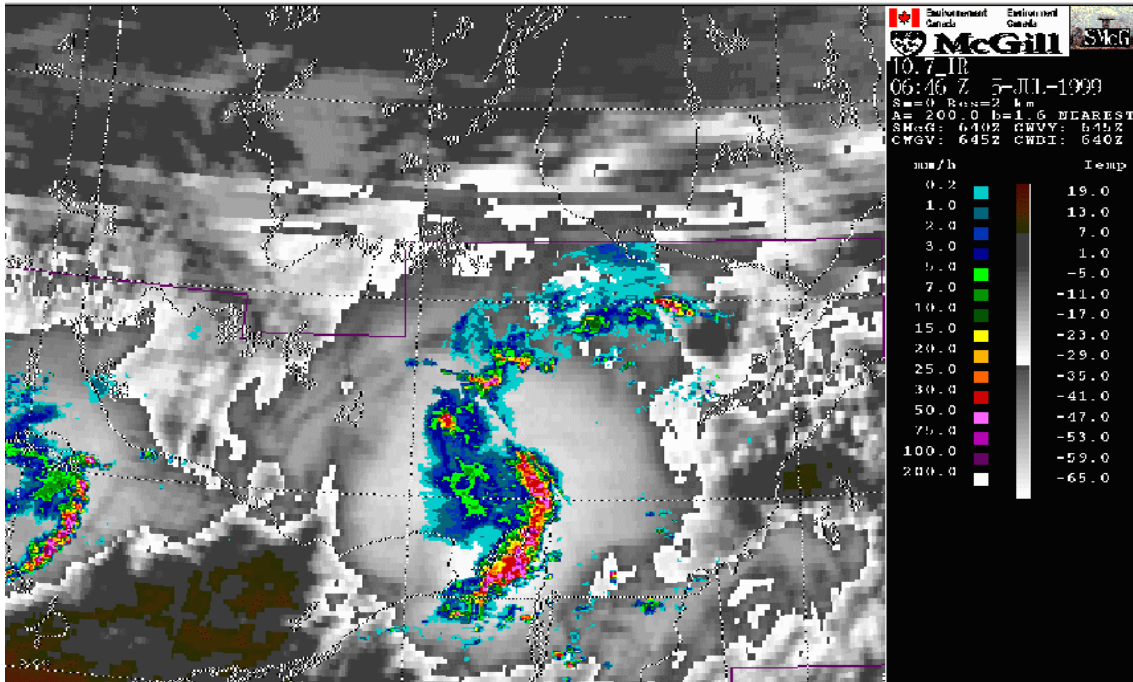
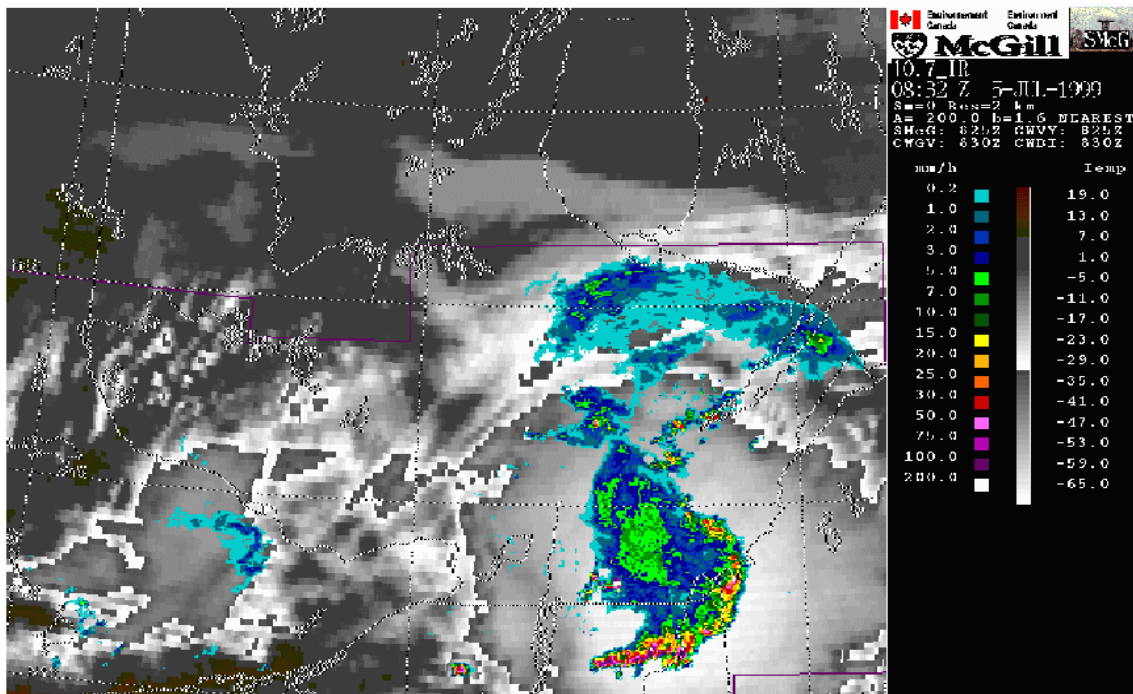


Figure 14 -Composite satellite and radar images, 5 July 1999 at 0245Z, 0445Z, 0646Z and 0832Z



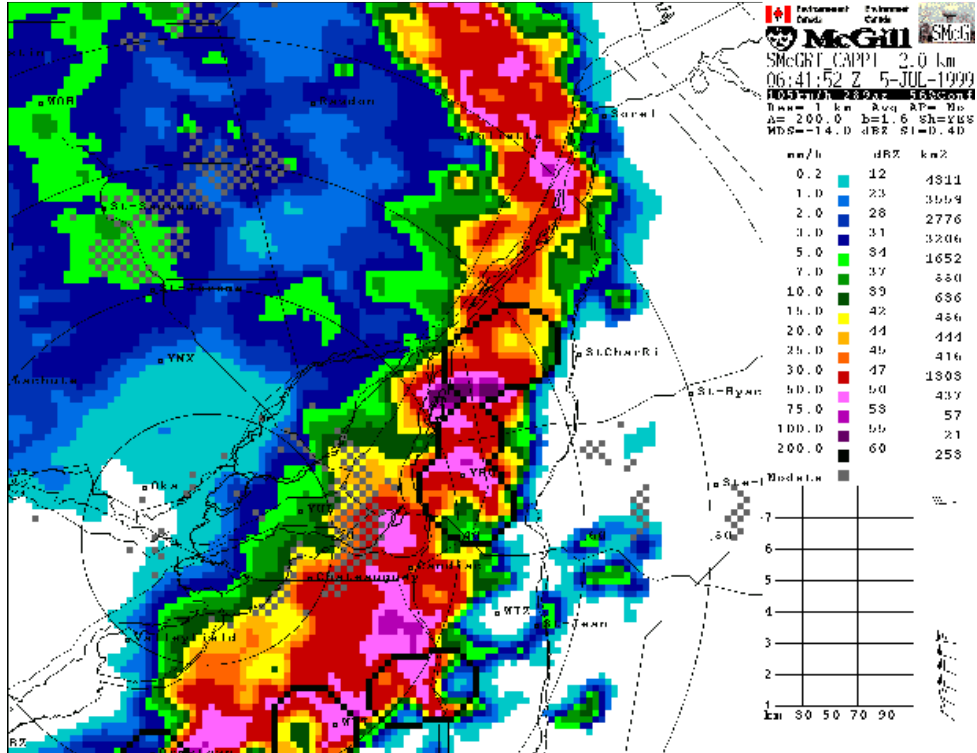


Figure 15 - 2km CAPPI from McGill, 5 July 1999 at 0641Z

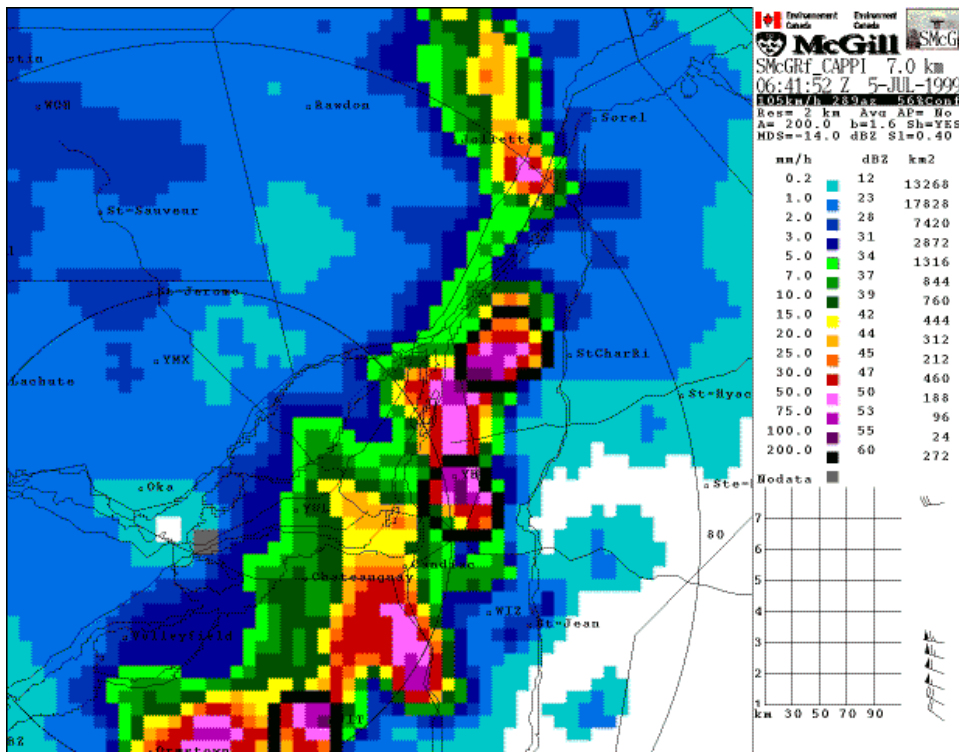


Figure 16 - 7km CAPPI from McGill, 5 July 1999 at 0641Z

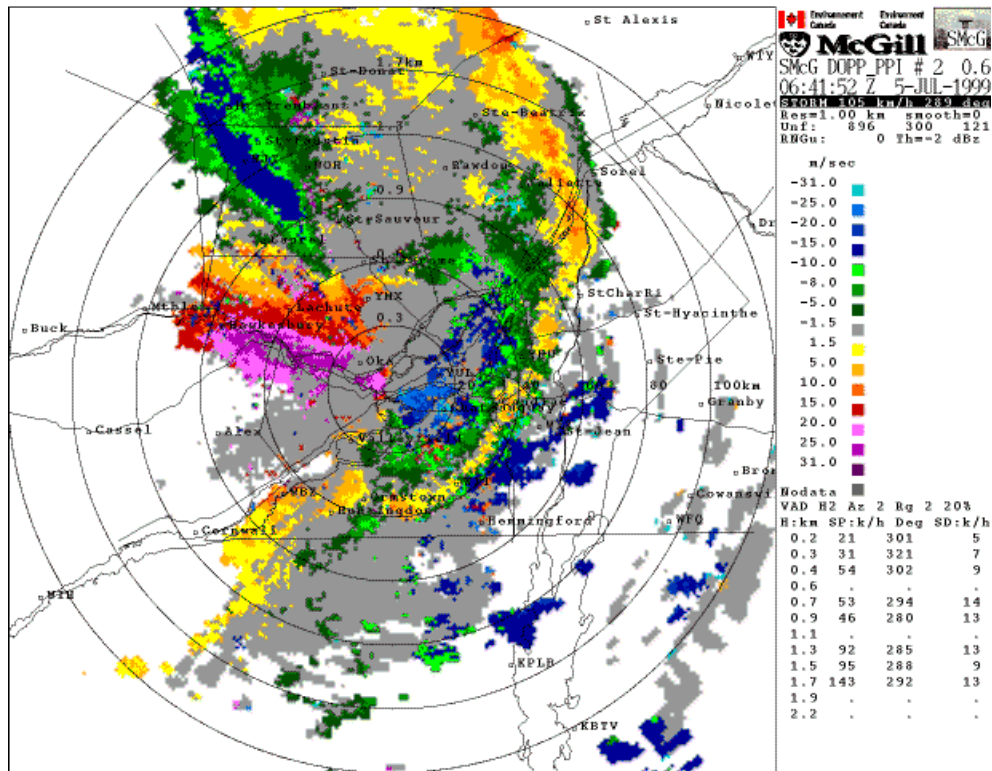


Figure 18 - Apparent winds on 0.6km Doppler PPI, 5 July 1999 at 0641Z

The 2km CAPPis (Figure 16) and 7km CAPPis (Figure 17) from the McGill radar show the situation at 2:41 am on July 5, when the derecho passed over St-Hubert station. From Sorel to the US border, the squall line had a number of bow echoes pointing in the direction of the mean winds aloft, which indicates downbursts. There is one bow right near St-Hubert. Looking at the Doppler radar data for the storm-relative winds (the radial velocity of the precipitation particles less the radial component of the propagation of the storm system), we see on the PPI image 0.6 km from the McGill radar (Figure 18) that under the squall line there is a zone of divergence as a result of downbursting to the surface of the cooled air aloft. And indeed the temperature at St-Hubert dropped from 28 to 21°C as the derecho passed. Figure 18 also shows low-level convergence between the gust front and the storm-relative flow downwind from the squall line. This convergence created an updraft of the ambient moist air, which fed the storms and maintained the derecho.

On the vertical cross-section (Figure 19), which extends from northern Laval toward the Chambly basin, St-Hubert station is 20 km from point A (northern Laval). Between 10 and 20 km from point A, lower reflectivities can be seen between the 1km and 3km levels—evidence of drying caused by downbursting toward the surface. Winds observed at that time at St-Hubert were northwesterly gusting to 46 knots. Looking at the

Doppler vertical cross-section (Figure 20), which extends along a radial line

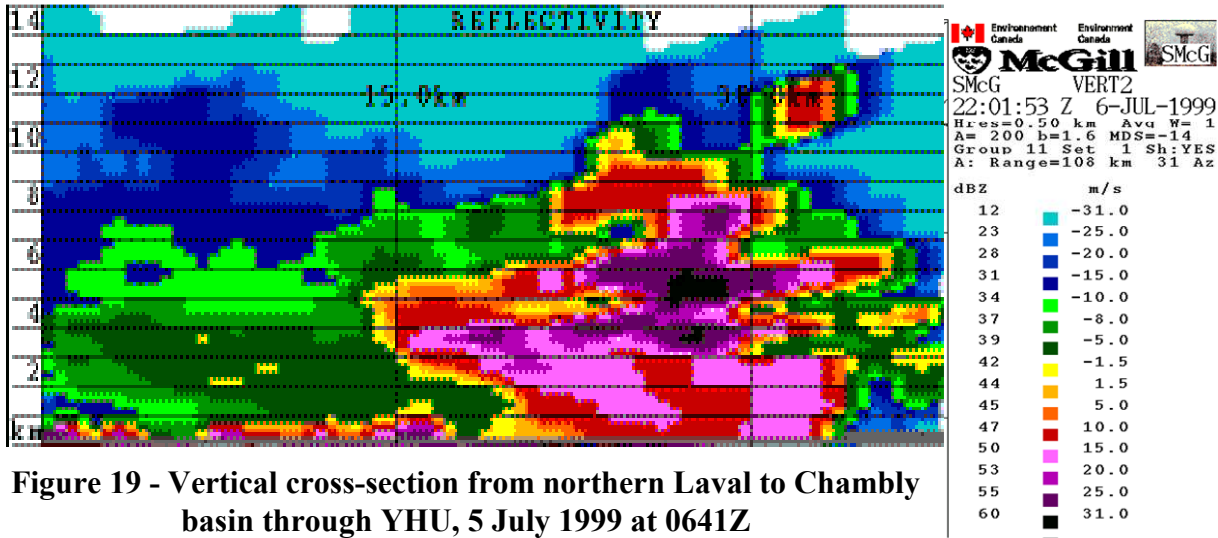


Figure 19 - Vertical cross-section from northern Laval to Chambly basin through YHU, 5 July 1999 at 0641Z

perpendicular to the squall line (with point A closest to the radar), the vector total of the downbursts along the radial, behind the line of storms, is a very considerable 40 m/s near the ground. This matches the drying indicated on Figure 19. The Doppler cross-section shows strong vertical shearing under 2 km, then weak vertical shearing between 4 and 6 km. This pattern indicates the presence of a derecho, despite the fact that such a cross-section cannot show the directional component of the shear at low levels.

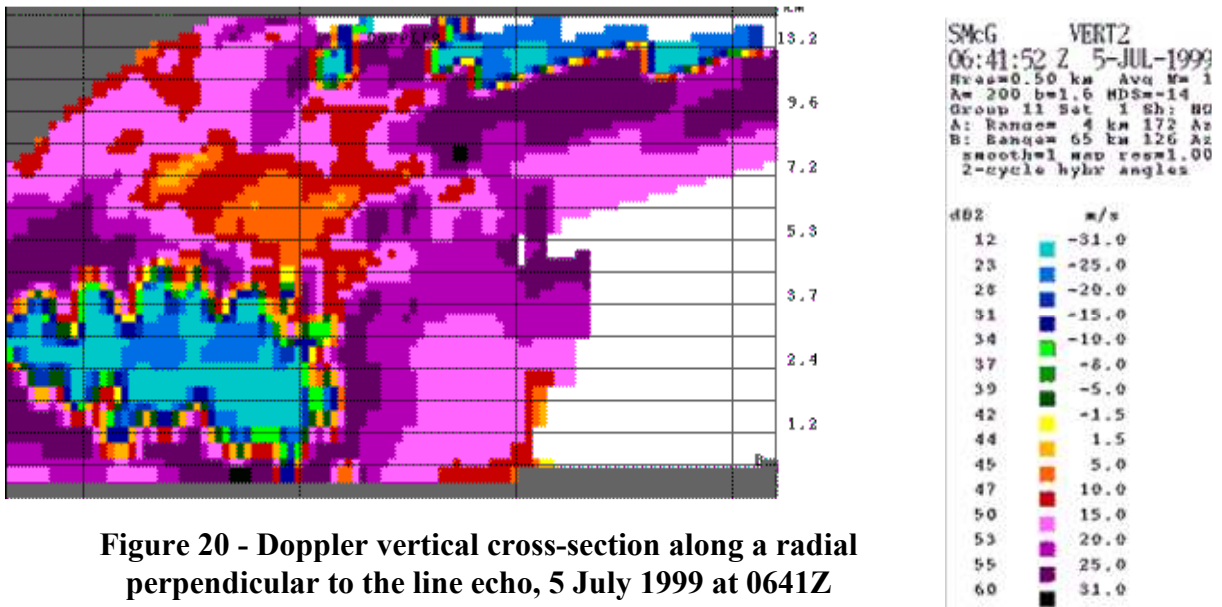


Figure 20 - Doppler vertical cross-section along a radial perpendicular to the line echo, 5 July 1999 at 0641Z

Most of the damage associated with this derecho (roofs torn off, power lines down, mature trees uprooted or damaged, farm buildings damaged, boats overturned) may be attributed to strong gusting of 90-120 km/h. One young camper died when a tree fell on him. Falling trees also crushed cars and houses, and a few tree farms were destroyed. The heavy rain caused some basement flooding as well as infiltration of water around the edges of closed windows. Lightning damaged numerous trees and even started a few fires.

Appendix 2 gives a partial summary of incidents and damages based on reports from Environment Canada, volunteer observers, the media and reconnaissance trips. Everywhere uprooted trees and other debris were found east of their point of origin, as a result of the strong west to northwesterly gusts. The alignments were perfect-- no rotation or disorder in the way the debris lay on the ground. Also included in the Appendix are a few photos taken in the Eastern Townships (a region which seems to have been particularly affected) on the afternoon after the derecho passed.

The first weather watch was issued for the Abitibi and Temiscamingue regions at 6:46 pm on July 4, three hours before the derecho arrived in Quebec. The first alert, for Abitibi, came about an hour before severe thunderstorms in the Quebec/Ontario border region. Because the storm system was moving with unusual speed, it was a race against the clock to get out weather watches and alerts in each region. The watches were issued between one and two hours before the derecho arrived, while the alerts came 15 to 45 minutes ahead of time.

5- Summary

The main consequence of the derecho of July 4-5, 1999 in southern Quebec was a large number of uprooted trees and damaged roofs. The radar structure remained unchanged along the entire length of the trajectory: a squall line perpendicular to the WNW direction of the mean winds aloft, with an echo ridge at its northern tip. The strength of the thunderstorms is reflected in the squall line's numerous overhangs and bows, as seen on the CAPPIs, and also in the profile of the storm-relative winds, seen on the McGill Doppler radar.

High potential instability (CAPE) along with high conditional instability resulting from abundant moisture at low levels and dry, cold air at mid levels are conducive to derecho formation. Another required condition is strong wind shear at low levels (under 2 km), including a significant directional component, and weak wind shear at mid levels (between 4 and 6 km). This pattern, along with ambient heat advection, helps concentrate cold air at mid levels. As long as all these conditions are present, the derecho structure will be maintained. Derechos can last several hours, and they move more rapidly than the mean winds aloft. The trajectory can be very lengthy indeed—over 1000 km.

There are two types of derecho: warm-season and cold-season. In a warm-season derecho such as the one that occurred on July 4-5, development is along, or to the east of,

a relatively flat 500mb long-wave ridge. The derecho tends to be situated at the right entrance of an upper jet stream having a slight anticyclonic curvature. At the surface, there is a quasi-stationary frontal zone oriented in an east-west direction and accompanied by a zone of convergence. Near this zone of convergence, surface and low-level moisture concentrates in a pool. The derecho moves along the 850 and 700 mb thermal gradient just north of the thermal ridge.

It is a challenge for a meteorologists to predict a derecho because there are problem in analysing the acceleration of the storm system and the continuance of the convection factors after night falls. Also, derechos are so rare in Quebec that meteorologists are tempted to think they are just dealing with a squall line. More needs to be known about the conditions of derecho development, so that weather watches and alerts can be issued earlier.

6- Bibliography

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Lilly, D.K. 1979, «The Dynamical Structure and Evolution of Thunderstorms and Squall Lines», *Ann. Rev. Earth Planet. Sci.*, 7, p.117-161.

APPENDIX 1

Table 1 – Summary of derecho features

	DERECHOS OF BOTH TYPES
Movement	<ul style="list-style-type: none"> - rapidly in a straight line; - faster than the mean winds between 5000 feet and the tropopause; - long life-span, possibly over 10 hours; - lengthy trajectory, possibly over 1000 km.
Radar structure	<ul style="list-style-type: none"> - squall line perpendicular to mean wind between 5000 feet and the tropopause; - hook parallel to the mean wind between 5000 feet and the tropopause; - dry air intrusion behind hook; - echo ridge north of storm system.
Dynamics	<ul style="list-style-type: none"> - strong directional wind shear, becoming unidirectional as the derecho develops; - winds of at least 40 kt at 500 mb; - zone of diffluence at 500 and 250mb near the area where the derecho is developing; - development at right entrance to upper jet stream.
Thermodynamics	<ul style="list-style-type: none"> - abundant moisture at surface and at low levels; - warm advection at surface and at low levels; - cold, dry air aloft; - high potential instability (CAPE of 2400 J/kg or more); - level of free convection descends toward ground as time passes; - severe weather indices have high values.

Table 2 – Features of warm-season and cold-season derechos

	WARM SEASON	COLD SEASON
Frontal structure	east-west orientation quasi-stationary genesis along front or in cold sector near zone of convergence	moving cold front genesis in warm sector near zone of convergence
Propagation	along thermal gradient north of the thermal ridge	across thermal gradient toward the warm air of the thermal ridge
Surface winds	weak; southerly to southwesterly	weak, southerly
Surface moisture	concentrated in a pool	concentrated in a ridge
Surface theta-e	> 360 K throughout the event	340 K at first, then dropping
850 mb moisture	concentrated in a pool max values reached along the track	concentrated in a ridge max values at start of track
Warm advection at 850 and 700 mb	maximum in genesis area	maximum east of genesis area
Dewpoint depression at 700 mb	14C downwind of and near genesis area	> 10C upwind of genesis area
Synoptic situation at 500 mb	flat long-wave ridge	strong long-wave trough
Dewpoint depression at 500 mb	22C near genesis area	10C near genesis area
Upper jet stream	slightly anticyclonic well to the north of the genesis area	cyclonic

APPENDIX 2

A- Partial summary of incidents and damages reported to the Montreal Weather and Environmental Services Office

Temiscamingue region: gusts of 95-105 km/h around 10:30 pm, July 4 1999

- Angliers: gusts of 105 km/h;
- Temiscaming: gusts of 100 km/h ;
- power lines affected.

Haute-Gatineau, Mont-Laurier, Laurentides regions: from 1 to 2 am, July 5 1999

- fire at house in Déléage near Maniwaki;
- farm buildings damaged in Aumond, near Maniwaki;
- numerous trees uprooted in Maniwaki area, Mt-Tremblant park, Brébeuf, Lake Nominique and Val-Morin;
- death of a young camper when a pine tree fell, at Val-des-Lacs near St-Jovite;
- light injuries sustained by a woman when a tree fell on her car at Val-des-Lacs;
- power lines affected.

Montreal and surrounding region: 90-120 km/h gusts from 2 to 3 am, July 5 1999

- Carillon, near Lachute gusts of 120 km/h;
- Dorval: gusts of 95 km/h;
- Montérégie: gusts of 85 to 95 km/h;
- numerous trees uprooted;
- roof damage and cars affected by falling trees in Montreal and suburbs, Vaudreuil-Soulanges, and the Richelieu Valley;
- roofs damaged by wind in Montreal and suburbs, Vaudreuil-Soulanges, the Richelieu Valley and St-Hyacinthe;
- farm buildings affected in Vaudreuil-Soulanges and Beloeil;
- one house and one car on fire in Dollard-des-Ormeaux;
- some fifteen boats overturned in Pointe-Claire;
- commercial building fire in Longueuil;
- windows affected in upper storeys of hotel, and roofs damaged, in St-Hyacinthe;
- power lines affected.

Eastern Townships: gusts of 90 to 115 km/h between 3 and 4 am, July 5 1999

- Frelighsburg: gusts of 92 km/h;
- Lennoxville: gusts of 105 km/h;
- Sherbrooke: gusts of 114 km/h;
- basements flooded and water infiltration around edges of closed windows in Sherbrooke and near Magog;
- numerous trees uprooted;
- numerous roofs and cars damaged by falling trees, especially in Sherbrooke;
- numerous roofs and chimneys damaged by wind, especially in Sherbrooke;
- brick wall collapses and back third of roof ripped off St. Andrew Church in Sherbrooke due to wind;
- some farm buildings damaged by wind in Johnville and Martinville;
- a few tree farms, one with 2000-3000 trees, destroyed in Johnville and Sawyerville;
- power lines serving 80% of Hydro-Sherbrooke customers affected.

B – Photographs taken in the Eastern Townships on the afternoon of July 5, 1999 after the passage of the derecho



Photo 1 – West side of St. Andrew church, located at the top of a hill in downtown herbrooke



Photo 2 – East side of St. Andrew church, with remains of brick wall downwind



Photo 3 – Farm building and silo damaged by gusts near Johnville (facing southeast)



Photo 4 – West part of farm building hit by gusts near Martinville



Photo 5 – One of the 200-year-old trees uprooted in the old north town, Sherbrooke (facing south)



Photo 6 – Small pine forest destroyed in Sawyerville (facing south)