Report on the tornado at Aylmer, Thursday, August 4, 1994

Technical Note
Environment Canada
Quebec Region

October 21, 1994

The Aylmer Tornado

1. INTRODUCTION

On the afternoon of Thursday, August 4, 1994, a series of tornadoes struck southwestern Quebec and eastern Ontario. Over five tornadoes were confirmed. The first struck the Carp, Ontario area, before moving on to Aylmer, Quebec; there was a second at St Pascal, Ontario, a third at Alexandria, Ontario, a fourth at Laurel, Quebec, and finally, a fifth at Rawdon, Quebec.

In eastern Ontario, other areas sustained less serious damage. Houses were damaged and trees uprooted or broken in the municipalities of Franktown and Calabogie. Judging by the description of damage by Environment Canada staff at the Ottawa Weather Office, the damage could have been caused by a tornado, but the lack of information and eyewitnesses means that it cannot be confirmed.

In Quebec, the municipalities of Saint-Ambroise de Kildare, Morin-Heights, Maskinongé, Saint-Joseph-de-Maskinongé and Drummondville all suffered damage from the severe weather. As in Ontario, the lack of information and eyewitnesses makes it impossible to draw any definite conclusions about the nature of the phenomena that occurred in these areas.

In this report we will concentrate on the case of Aylmer, which suffered the most serious damage by far. First of all, we will describe the damage as reported by the Quebec Department of Public Security, the media and Environment Canada authorities who went to the site. We will then describe and analyse the weather conditions on the day in question. We will examine the development of the weather situation, to see what role the use of conventional and Doppler radar played in determining the potential for severe weather. The work of Environment Canada meteorologists will also be evaluated, on the basis of the scientific knowledge available to date. The report will close with recommendations aimed at enabling us to provide the best possible advance notice through weather warning services.

2. DESCRIPTION OF DAMAGE

The tornado, with a strength of F2 to F3 (winds of 180 to 330 km/hr), struck Aylmer at about 3:00 pm EDT. According to the Department of Public Security, it left traces along a **west-south-west** to **east-north-east** path about 8 km long and 100 to 300 metres wide. The tornado caused damage to private property of nearly $5,000,000 – over 284 properties were damaged, 33 of them heavily, while 10 were totally destroyed. This amount does not include damage to public facilities and municipal infrastructures.

Four people suffered minor injuries, and 250 families had to be evacuated.

3. METEOROLOGICAL CHARACTERISTICS

3.1 Surface analyses and satellite photos

On the morning of August 4, 1994, a low of 100,8 kPa near Georgian Bay (Figure 1) had already brought cloud over most of Ontario and Quebec (Figure 2). The sky was generally overcast over the National Capital Region, and veiled over the Montreal region. A warm front extended from the low toward Ottawa and Montreal. Near this front and to the south, the air was humid and unstable. Satellite photos and lightning detectors already showed thunderstorms near Lake Huron and Georgian Bay. To the northeast of this front and the low, a showery zone covered southern Temiscamingue and Pontiac.

The low continued to shift eastward and reached the Ottawa Valley in the early afternoon, with the associated warm front near the Montreal area (Figure 3). Satellite photos showed strong thunderstorm cells over Lake Erie and Lake Ontario, while other cells were beginning to show up over the Ottawa valley (Figure 4). The temperatures to the south of this system varied from 24°C in Ottawa to 29°C in northern New York state, with dewpoint temperatures of 19° to 21°; evidence of a very humid air mass. The precipitation zone extended as far as Lake Saint-Jean and remained to the north of the Saint Lawrence Valley.

By about 5:00 pm EDT, the low was near Mirabel, with its warm front toward the Beauce region (Figure 5). Moderate to heavy rain was falling throughout southern Quebec. In the warm sector, satellite photos showed many thunderstorms striking eastern Ontario and southwestern Quebec (Figure 6).

4. ANALYSIS AND DIAGNOSIS

There were a number of factors present on the morning of August 4 likely to engender severe weather. The intensity and orientation of upper-air winds were favourable to the development of severe thunderstorms. The air was humid and unstable. The thermodynamic severe weather indexes showed a strong probability of severe weather for this day. The Summer **Severe Index** (SSI), for example, stood at 118, meaning that severe weather was very probable. Another index, the **Energy-Helicity Index** (EHI), reached 2.29; pointing to probable tornadoes.

Note that the EHI is calculated based on hypothetical thunderstorm movements, namely a speed equivalent to 70% of the average wind in the lower atmosphere and a direction of 30° to the right of this average wind. Any change in lower-level winds will change the SSI. We will see later how the use of Doppler radar allows us to correct these two indexes and obtain a more accurate evaluation of atmospheric conditions.

5. CHRONOLOGY OF EVENTS

Following this analysis and diagnosis, a zone of potentially severe weather was defined (Figure 7). A severe weather watch was issued at 10:56 am EDT for the Ottawa/Hull/Cornwall (including Aylmer), Montreal, Trois Rivières/Drummondville, and Eastern Townships/Beauce regions. The risk of a heavy thunderstorm was mentioned in the updated public forecast at 11:30 am EDT for these regions.

At 2:10 pm EDT, the Carp radar showed strong thunderstorms 30 km northwest of the radar site and another thunderstorm zone of the same intensity near Papineauville (Figure 8). Five minutes later (2:15 pm EDT), the Montreal radar picked up these same two thunderstorms, but the one near Papineauville was more intense and seemed potentially severe (Figure 9). This storm was heading toward the Laurentians. Fifteen minutes later (2:30 pm EDT), a severe weather warning was issued for the Laurentians region.

At 2:30 pm EDT, the 40 decibels chart produced by the Carp radar (Figure 10) showed that the thunderstorm heading toward the Laurentians was still strong, but that the one to the northwest of the radar site had weakened and was no longer visible on the radar.

At 2:50 pm EDT, the Montreal radar showed an extremely severe thunderstorm over the southern Laurentians (Figures 11 and 12). Five minutes earlier, this Doppler radar had indicated rotation in this storm (Figure 13), which is often a warning of severe weather. Other storm cells were also present, including those to the west of Aylmer (Figure 14), but none of them met the criteria for severe weather used by the Montreal radar (Appendix 1). The Carp radar also showed a severe storm cell over the southwestern Laurentians (Figures 15 and 16), but the thunderstorms headed toward Aylmer disappeared in the radar silent zone. A few minutes later (2:52 pm EDT), the severe weather warning was updated for the Laurentians region with a mention of a possible tornado.

At 3:00 pm EDT, the Montreal radar showed three large storm cells: one near Laurel (west of Saint-Sauveur), another between Buckingham and Papineauville and a third, the weakest of the three, near Aylmer (Figure 17). A number of products generated by the Carp radar were not available at this time and up to 3:40 pm EDT, because Environment Canada's computer systems were overloaded.

At 3:35 pm EDT, the Environment Canada weather office in Ottawa contacted the Quebec Weather Centre to report that five houses had been damaged at Aylmer at about 3:15 pm EDT. Furthermore, The Ottawa office took the initiative (between 3:20 pm and 3:30 pm EDT) to send a local severe weather warning on Weatheradio and on Automatic Telephone Answering Devices (ATAD). A few minutes later (3:42 pm EDT), the severe weather warning was updated to add the Ottawa/Hull region with the mention of a possible tornado.

At 5:00 pm EDT, the Ottawa office called the Quebec Weather Centre again to report that an eyewitness had seen a funnel-shaped cloud at Aylmer, thereby confirming the presence of a tornado.

6. DISCUSSION

6.1 The Montreal and Carp radar stations

Radar (from RAdio Detection And Ranging) is an instrument that consists essentially of a transmitter, a receiver and a data processing system. The transmitter sends out electromagnetic waves that are reflected by particles such as water droplets and ice crystals, captured by the receiver and decoded by the data processing system. The results are expressed mainly in terms of reflectivity and speed. Reflectivity indicates the intensity of precipitation, while speed shows the movement of this precipitation and the surrounding wind. A radar is considered a conventional type if it detects only reflectivity, and a Doppler type if it also shows the movement of precipitation and surrounding wind.

The Aylmer area is covered by both the Carp radar station, located to the west of Ottawa, and the Montreal radar station, at Sainte-Anne-de-Bellevue on the western tip of Montreal Island.

The Montreal radar is a Doppler model. In addition to generating reflectivity data within a 240-km radius, it produces wind fields for up to 120 km around the site. Its resolution varies from one square kilometre within this 120 km radius to four square kilometres between 120 and 240 kilometres. It indicates the intensity of echoes and their distribution in space (reflectivity) and estimates the wind speed (Doppler). The station's conventional radar coverage extends over much of southern Quebec and eastern Ontario, taking in the National Capital Region. Its Doppler coverage is more limited, and does not extend to the Ottawa/Hull region.

The radar's products are generated by a software program called RDP (Radar Data Processor). This program allows the operator to see different fields, such as echoes at 1.5, 3.0, 5.0 and 7.0 km above the earth, cloud tops, the wind field, etc. In addition, it allows severe weather specialists to generate a variety of products on request, such as a vertical cross-section of a thunderstorm and point forecasts. This very versatile program is a powerful tool, allowing forecasters to properly understand the nature of the phenomena observed. The Quebec Weather Centre developed two severe weather criteria based on data from this radar (Appendix 1), after many years of observations and experiments.

The Carp radar is a conventional (non-Doppler) version, with coverage of 240 km. It generates five products, fewer than the Montreal station: intensities at 1.5 km, a map of cloud tops, a map of maximum reflectivity above 4.0 km and a 40 dBz chart above 5.5 km. Although these fields are very useful for detecting thunderstorms, they do not offer as much detail as those from a Doppler radar such as the one in Montreal. The criteria for severe weather rely on reflectivity fields such as echoes at 3 and 7 kilometres with overhang, the gust field produced by RDP and the internal structure of the cell. The detection of air rotation (mesocyclones) by Doppler radar is another criteria. Since these products were not available from the Carp radar station, it was more difficult to diagnose the severity of the storm.

The Carp station is located some 20 kilometres west of Ottawa. Since weather systems generally move from west to east, they pass by the station only a few minutes before reaching Ottawa-Hull. However, every radar has what is called a silent zone covering a radius of about 10 kilometres around the site; in which the radar is "blind" – technically unable to obtain data. Consequently, any disturbance from the west, including severe storms, becomes "invisible" for a few minutes when it enters this zone, disappearing and then reappearing over the Ottawa-Hull area. Moreover, severe storms may form or disappear within minutes. This lack of data just upstream of an area with high population density can prove very problematical in such situations.

6.2 Interpretation of radar data

6.2.1 Conventional data

The thunderstorm that struck Aylmer did not resemble a traditional thunderstorm supercell in a number of ways. Whereas the cloud tops of severe storms normally reach above the tropopause (inversion at the top of the troposphere), the top of the Aylmer tornado remained below this level, never exceeding 12 km (40,000 feet) (Figure 18). According to meteorologists' reports, the structure of this storm as seen on the radars corresponded to a vigorous, but not severe, thunderstorm. There was no slope in the intensities, and although the core of the cell was in the upper air, at 5 km, it was much weaker (75 mm/hr rather than 300 mm/hr) than those of other major storm cells.

6.2.2 Doppler data

Although Aylmer is not in the Doppler coverage zone of the McGill radar, we will see how the use of Doppler data enables meteorologists to better diagnose atmospheric conditions.

The severe weather indexes calculated on the morning of August 4, for the area encompassing southwestern Quebec and eastern Ontario, were based on critical temperature values of 26° to 27°C and a dewpoint of 20° to 21°C. The maximum low-level winds were from the southwest at 35 knots. The software program that calculated the speed and direction of the thunderstorms gave speeds of close to 26 knots, with directions varying from 270° to 280°.

Nevertheless, weather conditions during the afternoon were not as predicted. The temperature at the Ottawa International Airport did not rise above 24°, and the dewpoint was 20°. The Doppler radar in Montreal (Figure 19) indicated much stronger low-level winds from the **southwest**, reaching 58 knots (108 km/hr). These data allowed the forecasters to change the low-level wind field. In addition, the conventional echoes showed storm cells moving from the southwest at about 35 knots. These new data altered the severe weather indexes.

Since the temperature at Ottawa was not at the critical value, forecasters could have decided that there were no severe weather conditions, and ended the severe weather watch. However, the wind, shear and propagation conditions from the Montreal Doppler radar showed an atmospheric structure different from the one analysed that morning. The upper-air winds were fairly similar in the warm sector of the system, so the meteorologists considered these data the best estimate of the situation over the entire region at the time, including Ottawa. The severe weather indexes showed a decrease in the hydrostatic energy, but an increase in the shear terms as compared with the Maniwaki sounding. Consequently, the severe weather watch was maintained.

7. CONCLUSION

A number of factors favourable to severe weather were present on August 4, 1994. At least five tornadoes caused millions of dollars in damage in several municipalities. The Aylmer tornado, in particular, was the most devastating both in terms of severity and costs.

Environment Canada had its team of meteorologists and radar specialists to cope with the situation. The work was carried out professionally, in keeping with established standards and practices. The analysis and diagnosis of the weather situation were clear and accurate, and as a result a severe weather watch was issued in the morning, four hours before the tornado actually struck. The Environment Canada team followed the situation very closely, and was able to issue weather warnings with up to 45 minutes advance notice in the case of the tornado at Laurel. This follow-up was possible thanks to the Doppler radar in Montreal.

There was no severe weather warning in effect when the tornado struck Aylmer. The Montreal radar's resolution is four times weaker at this distance, and so the intensity of the echoes detected by it over the city did not justify a severe weather warning. In addition:

1- The echoes detected by the Carp radar were useful in that they showed the cell approaching the city, but were not very helpful in determining the severity of the storm in this specific case, because of the limitations of the current display system.

2- The storm passed through the radar's silent zone, becoming "invisible" in the minutes just before the tornado struck.

3- Finally, there was an interruption in the transmission of several radar images at the Carp station during the event, because of overloading of the computer systems at the Quebec Weather Centre.

A number of US and Canadian studies have discussed thunderstorms that produce tornadoes despite being of only average intensity. According to these studies, such thunderstorms are very difficult to detect operationally, for they generally resemble common thunderstorms. The clue may lie in the intensity of low-level wind shear. Research must continue to improve detection techniques and radar criteria.

We would like to offer a few recommendations that would help make substantial improvements in the detection and severe weather warnings for this part of the Ottawa Valley.

8. RECOMMENDATIONS

8.1 Access to radar data

It is important to ensure that the existing computer systems can support overloads during busy periods.

8.2 Carp radar station image processing system

Had the Carp station had a more sophisticated system for image processing, called the RDP (Radar Data Processor), it would have been possible to obtain a better diagnosis of the situation. The Department plans to install such a system by 1995.

8.3 Installing a Doppler radar at the Carp station

Converting the radar to a Doppler version would improve its detection efficiency, lead to more accurate forecasts of the severity of events, and give more advance warning of severe weather.

8.4 Relocating the Carp radar station

When the radar is converted to a Doppler version, it would be a good time to rethink the location of the Carp radar station, in order to maximize its coverage and avoid "blind spots" in the corridor where severe weather often occurs.

8.5 Advances in science

Research must continue in order to better understand the behaviour and structure of this type of storm, as well as the way it forms. Efforts should probably concentrate on the influence of low-level wind shear in the development of tornadoes.

8.6 Improving detection techniques

We need to develop radar techniques capable of detecting this type of storm and improve pattern recognition methods.

-END-

GLOSSARY

Radar echoes

Conventional type: detects precipitation rates and echo intensity.

Doppler type: detects movement of particles in the air.

EHI: Energy-Helicity Index. A meteorological index including hydrostatic energy and helicity.

Interpretation:

if EHI > 1, F2-F3 tornado possible
if EHI > 5, F4-F5 tornado possible

SSI: Summer Severe Index, a meteorological index including hydrostatic energy and shear (one of the best indicators of severe weather).

Interpretation:

if SSI > = 100	severe weather
if 95 < = SSI < 100	severe weather probable
if SSI < 95	no severe weather

Tornado: A column of air rotating at terrific speed.

Categories (Fujita scale):

F0:	winds from 90 to 120 km/hr
F1:	winds from 120 to 180 km/hr
F2:	winds from 180 to 250 km/hr
F3:	winds from 250 to 330 km/hr
F4:	winds from 330 to 420 km/hr
F5:	winds from 420 to 510 km/hr

APPENDIX 1

RADAR CRITERIA DEVELOPED BY THE QUEBEC WEATHER CENTRE

1. Echoes at 7 km with intensity greater than or equal to 47 decibels (dBz) (or 30 mm/hr) (Figure 20, point A).

2. Overhang indicating a difference of at least 30 dBz between the 7 and 3 km levels (Figure 20, point A).

3. Presence of a mesocyclone (rotating air) on the Doppler radar (Figure 21, point A).

4. Presence of a slope in the echoes (visible in a vertical cross-section) (Figure 22, line A).

5. Gusts of at least 26 m/s (51 knots or 94 km/hr) (Figure 23, point A).

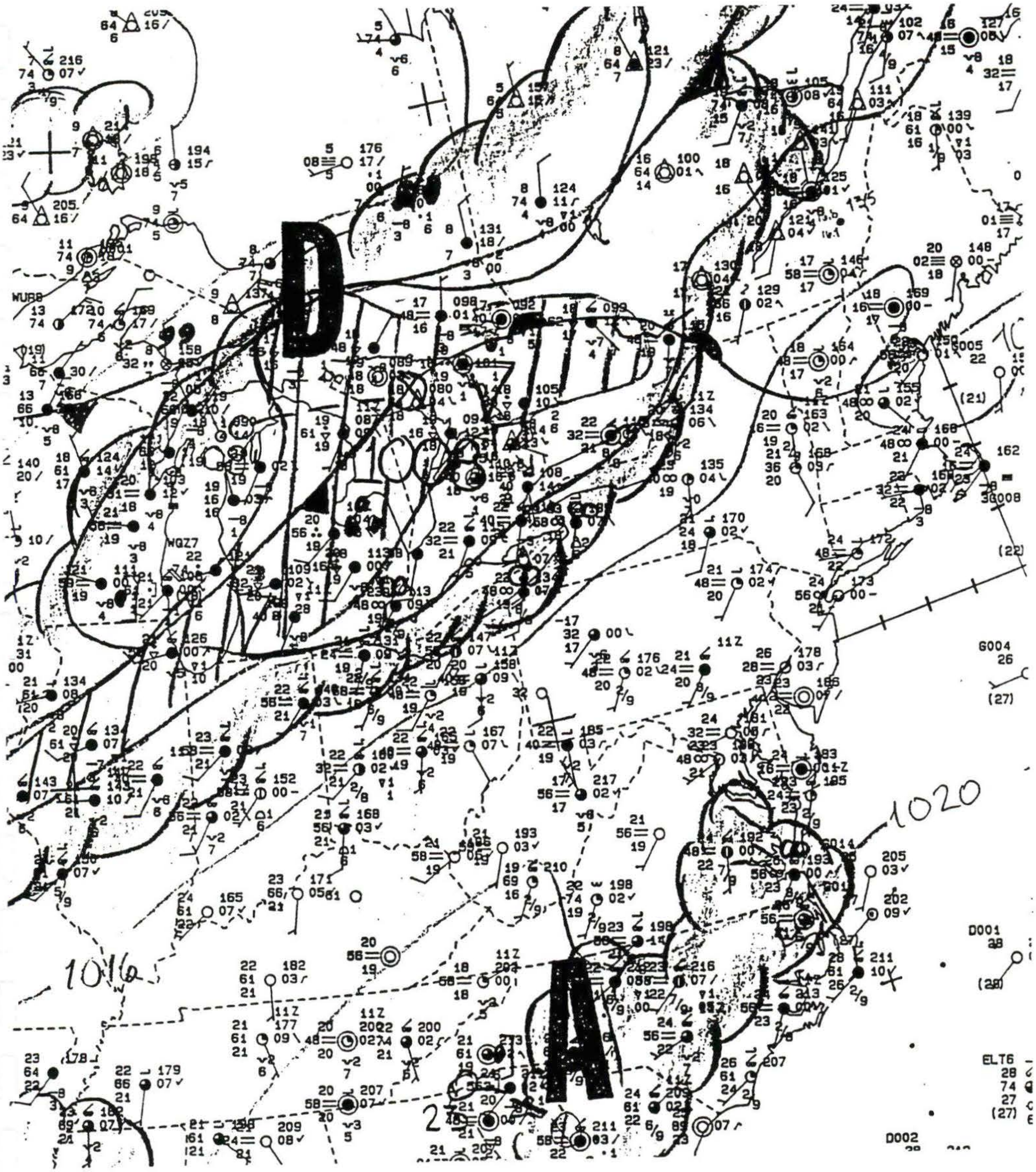

Figure 1. Surface analysis valid at 8:00 A.M. EDT (12:00 GMT)

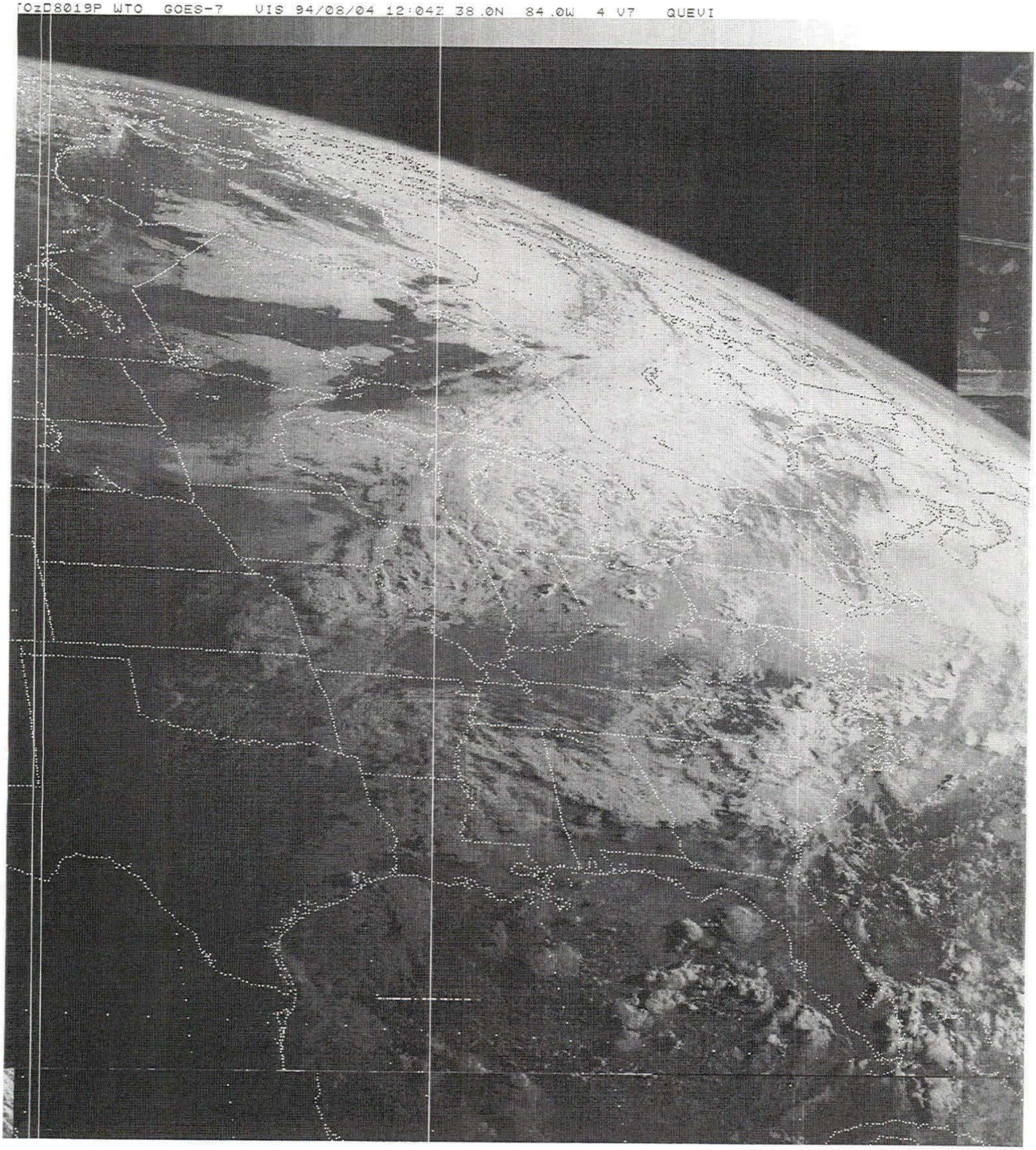

Figure 2. Satellite picture valid at 8:00 A.M. EDT (12:00 GMT).

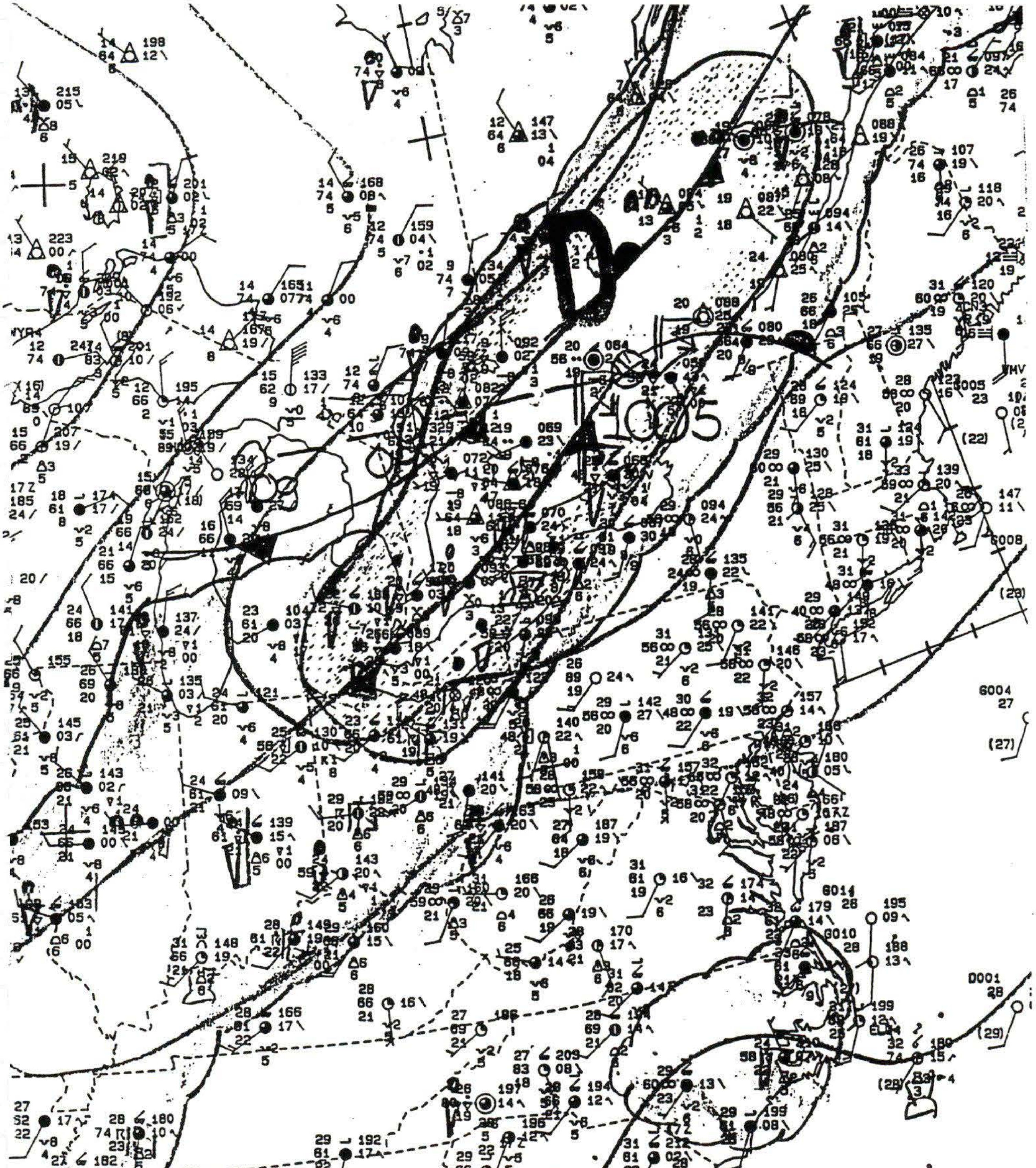

Figure 3. Surface analysis valid at 2:00 P.M. EDT (18:00 GMT).

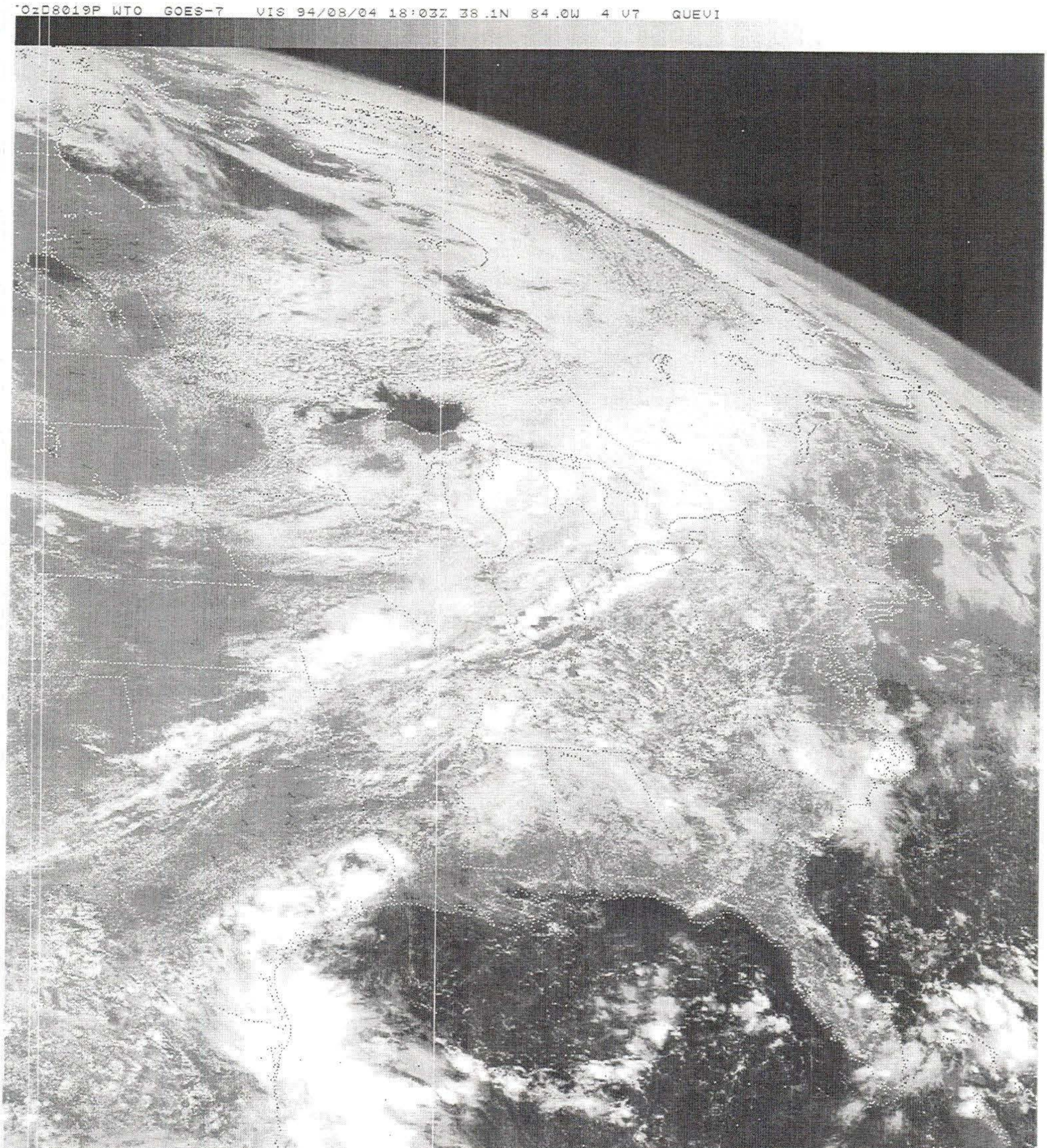

Figure 4. Satellite picture valid at 2:00 P.M. EDT (18:00 GMT).

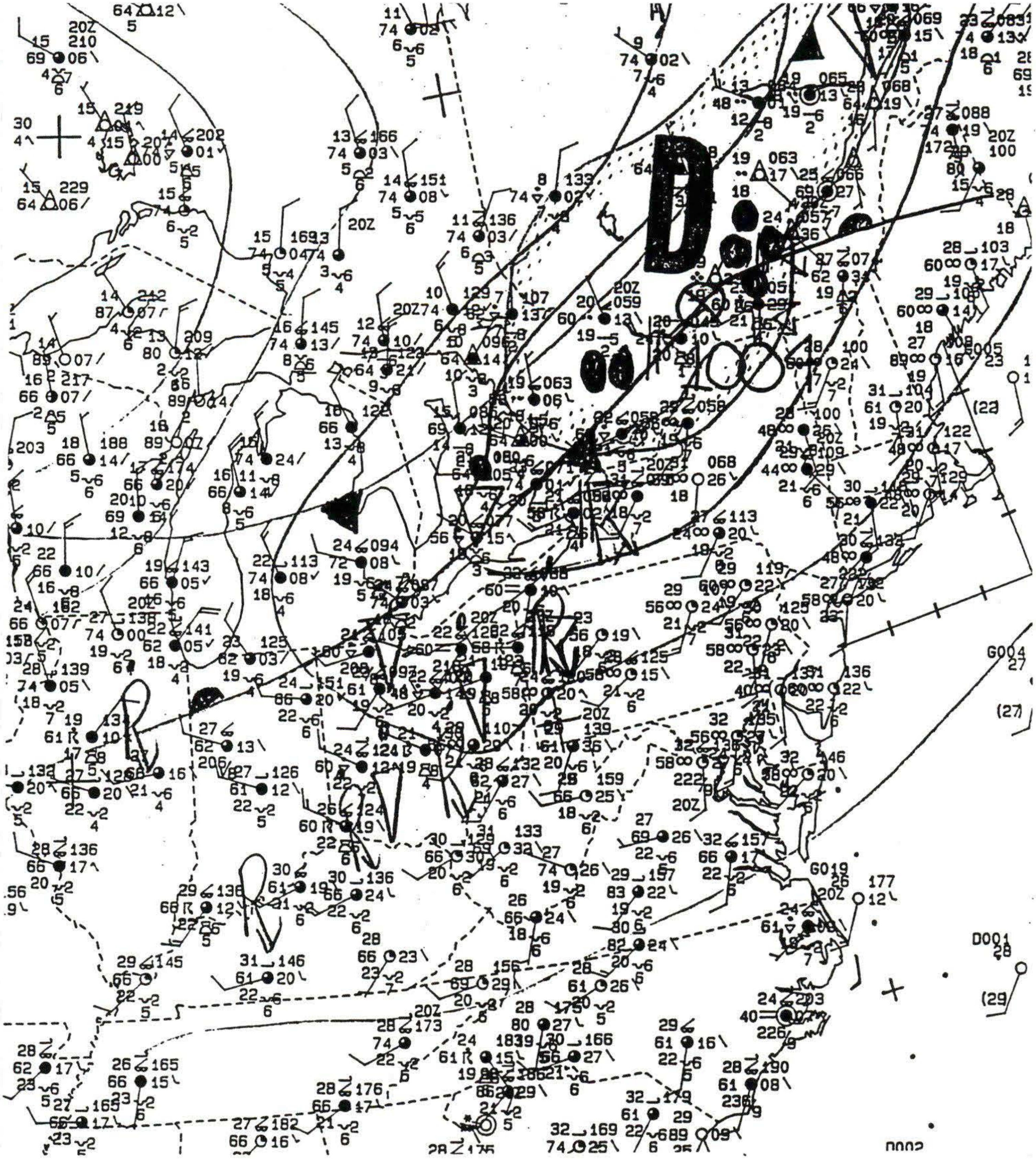

Figure 5. Surface analysis valid at 5:00 P.M. EDT (21:00 GMT).

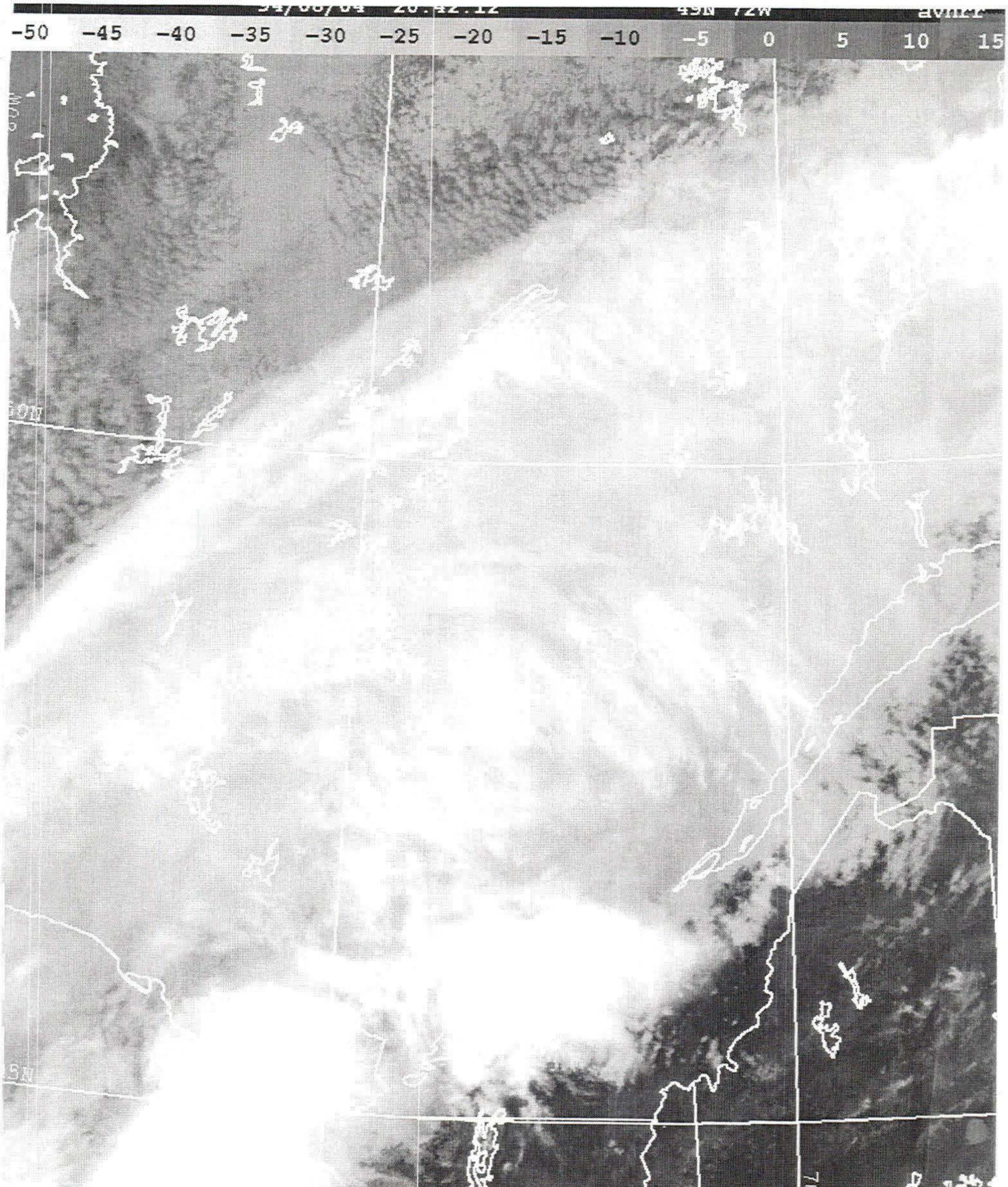

Figure 6. Satellite picture valid at 4:42 P.M. EDT (20:42 GMT).

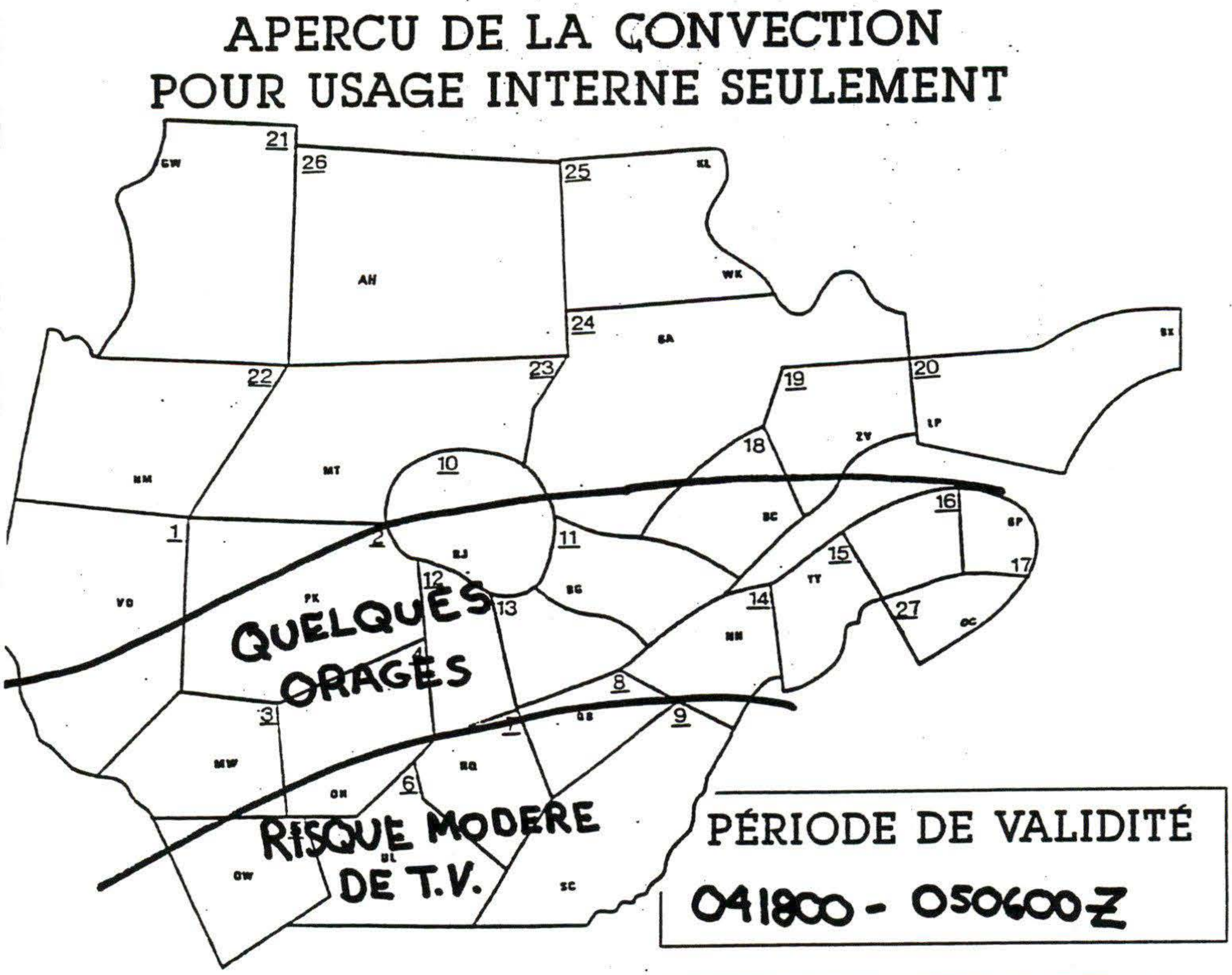

Figure 7. Area for potential severe weather from August 4, 2:00 P.M. to August 5, 2:00 A.M..

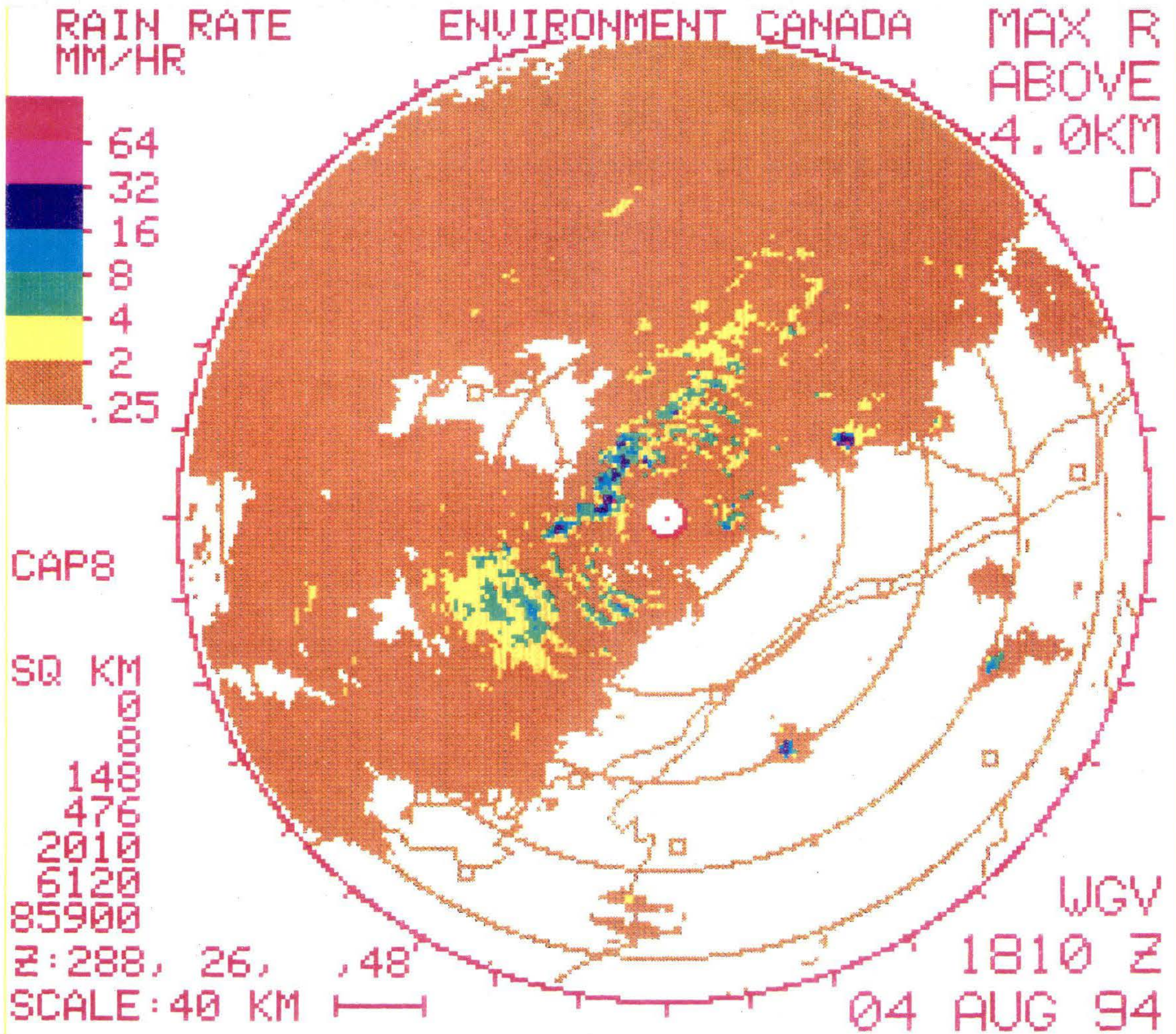

Figure 8. Maximum reflectivity above 4 km valid at 2:10 P.M. (18:10 GMT). Carp Radar.

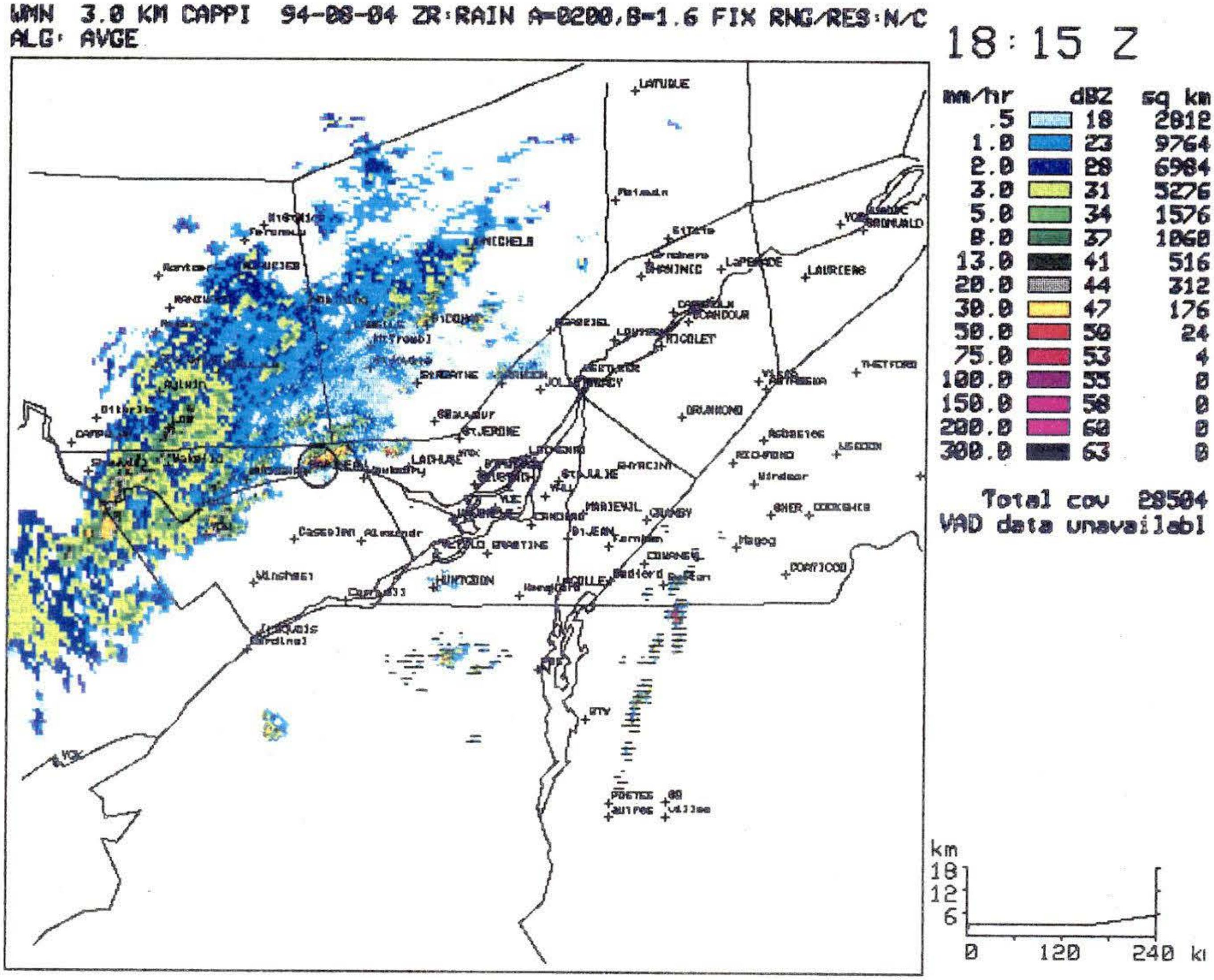

Figure 9. Reflectivity at 3 km with overhang near Papineauville valid at 2:15 P.M. (18:15 GMT). Montreal Radar.

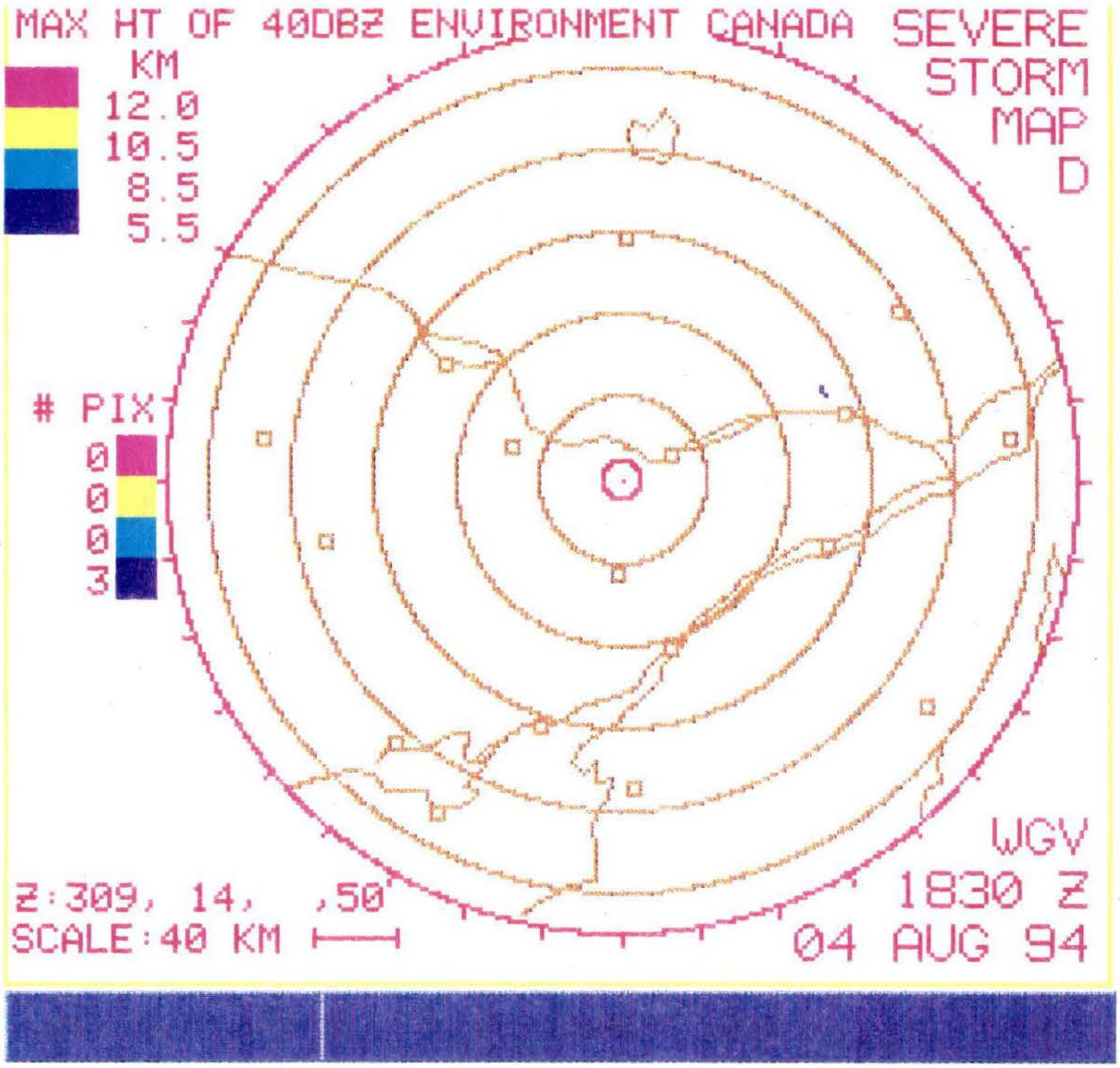

Figure 10. Maximum height of 40 dBz valid at 2:30 P.M. (18:30 GMT). Carp Radar.

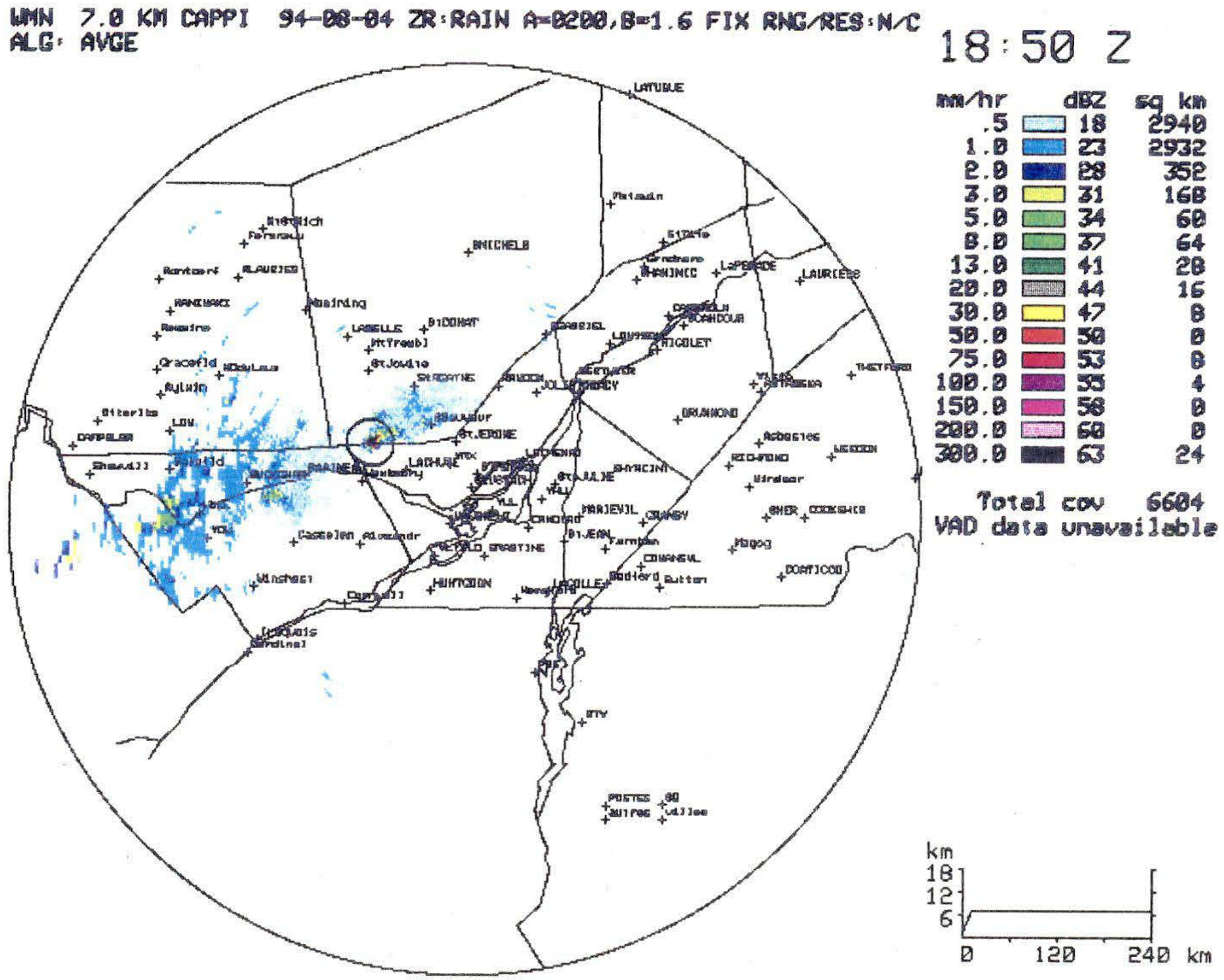

Figure 11. Reflectivity at 7 km with overhang valid at 2:50 P.M.
(18:50 GMT). Montreal Radar.

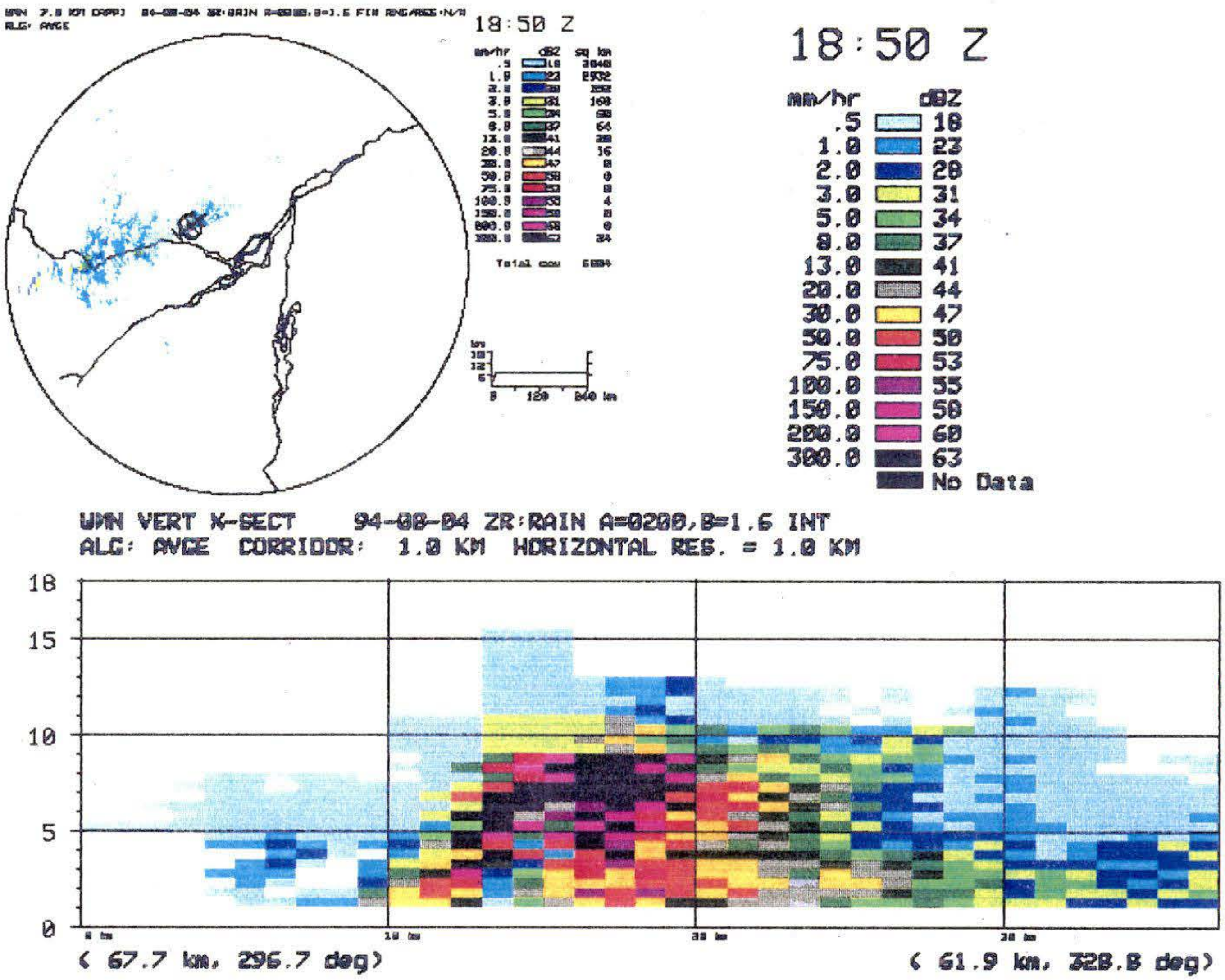

Figure 12. Vertical cross section of the storm over the southern part of the Laurentides region valid at 2:50 P.M. (18:50 GMT). Montreal radar.

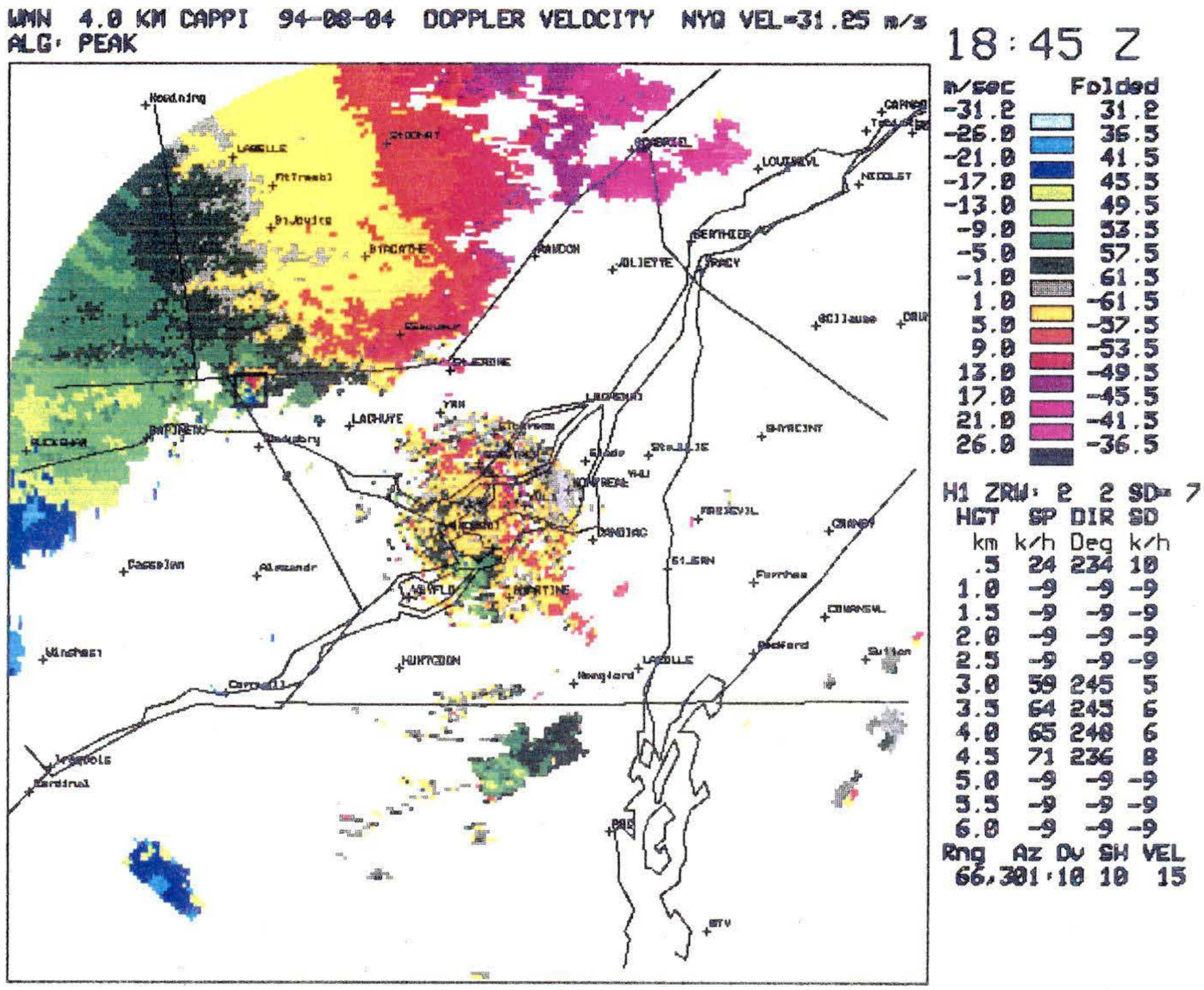

Figure 13. Doppler velocity with detected rotation (square box)
valid at 2:45 P.M. (18:45 GMT). Montreal radar.

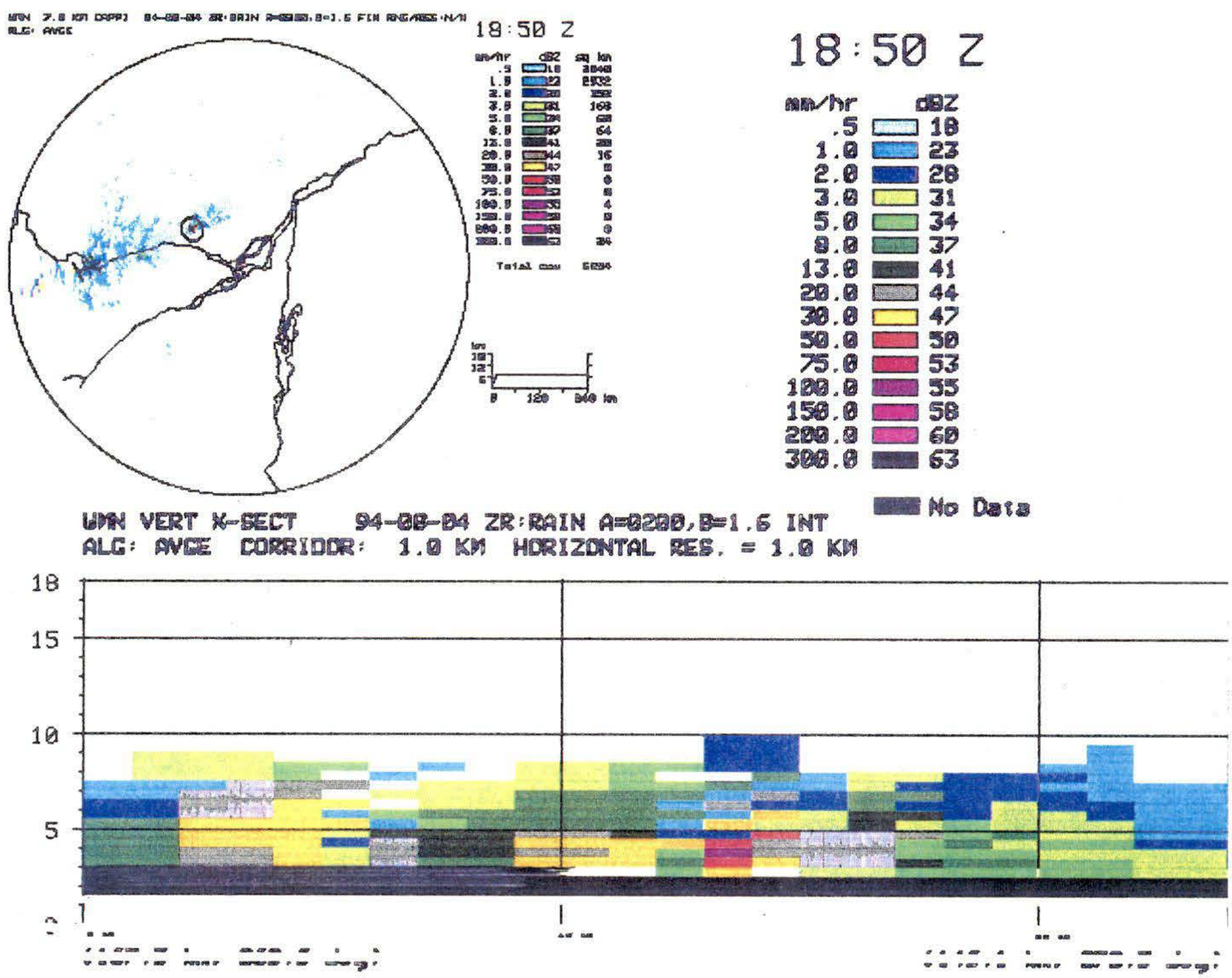

Figure 14. Vertical cross section of the storm near Aylmer valid at 2:50 P.M. (18:50 GMT). Montreal radar.

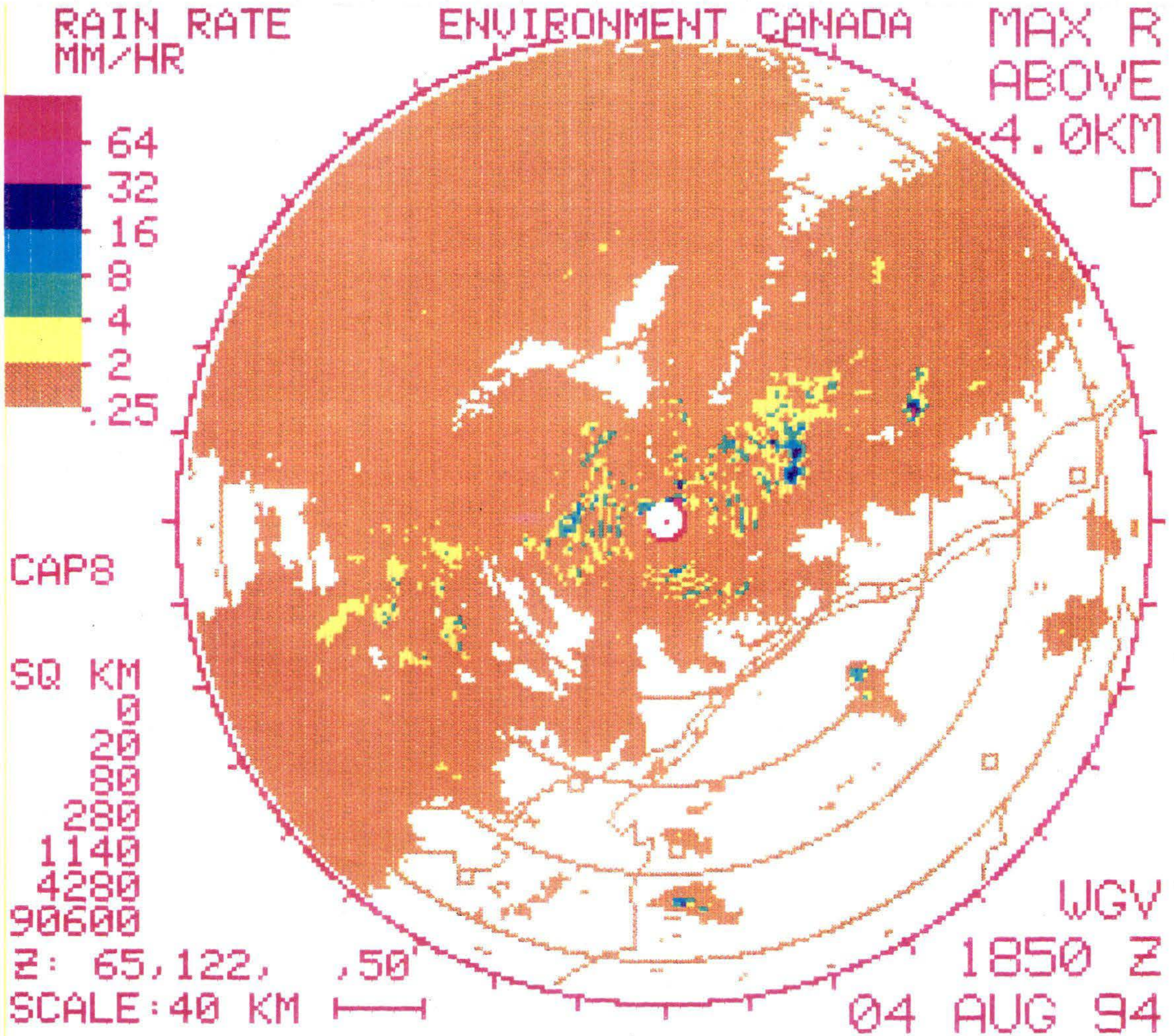

Figure 15. Maximum reflectivity above 4 km valid at 2:50 P.M. (18:50 GMT). Carp Radar.

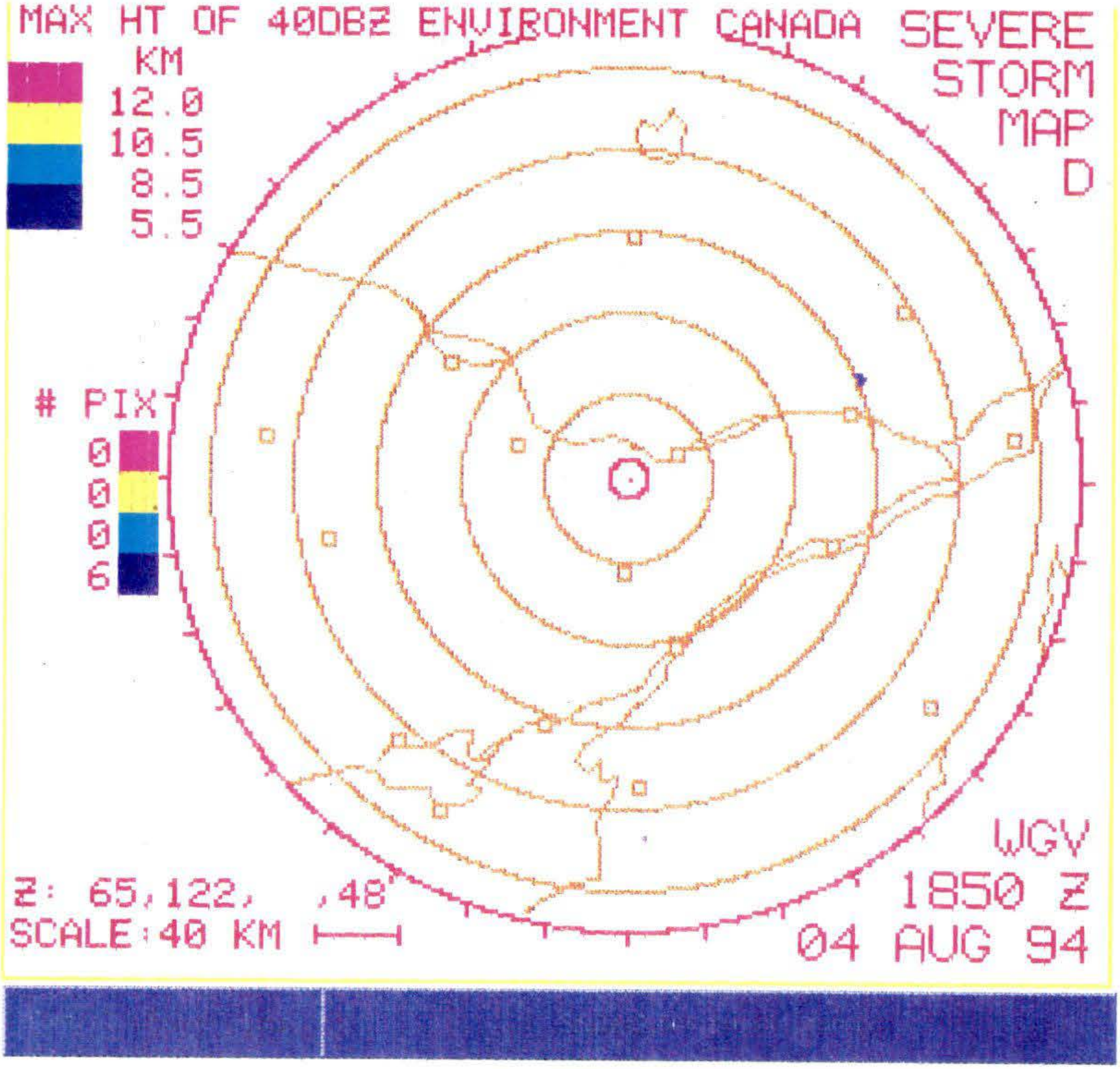

Figure 16. Maximum height of 40 dBz valid at 2:50 P.M. (18:50 GMT). Carp Radar.

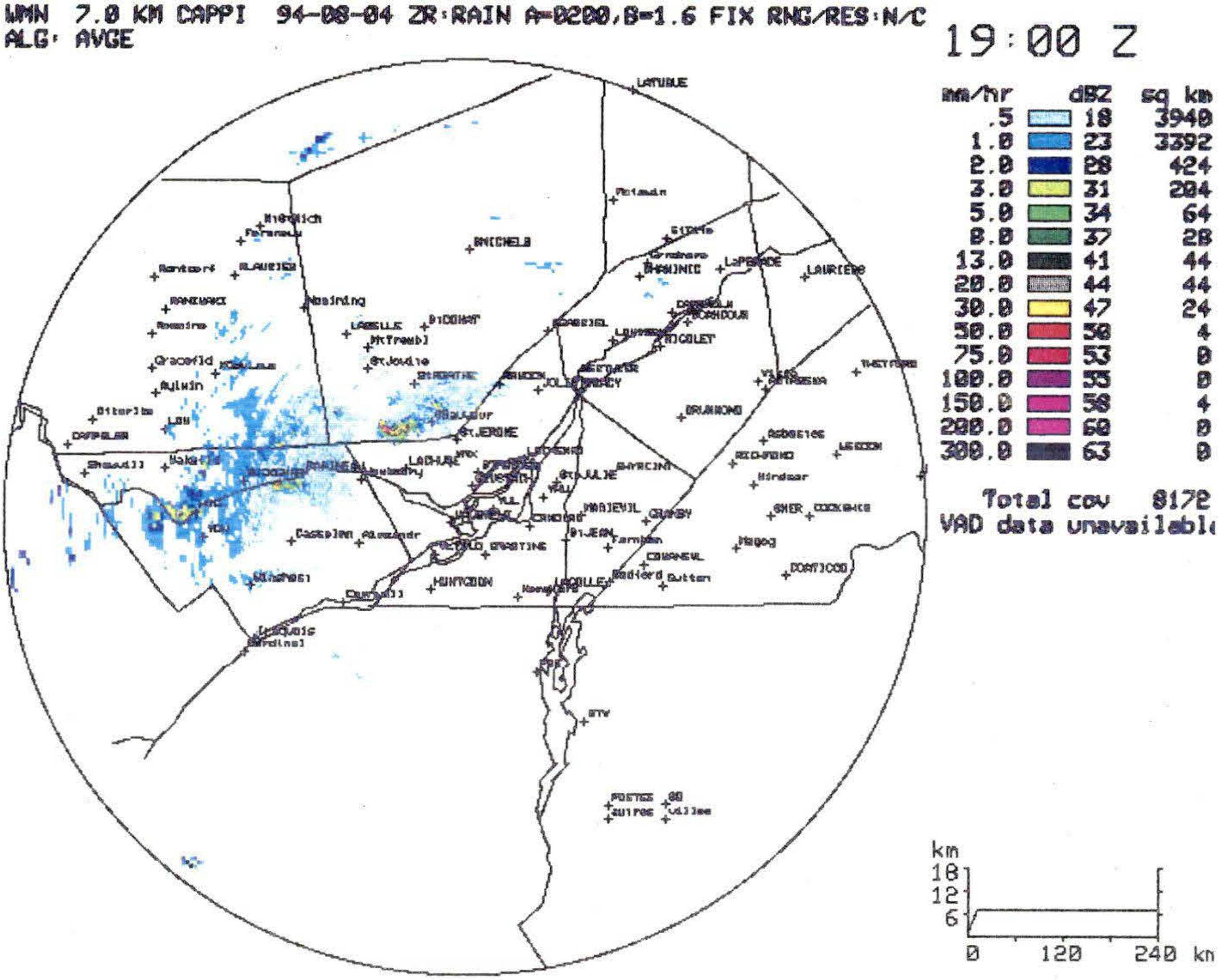

Figure 17. Reflectivity at 7 km valid at 3:00 P.M. (19:00 GMT).
Montreal Radar.

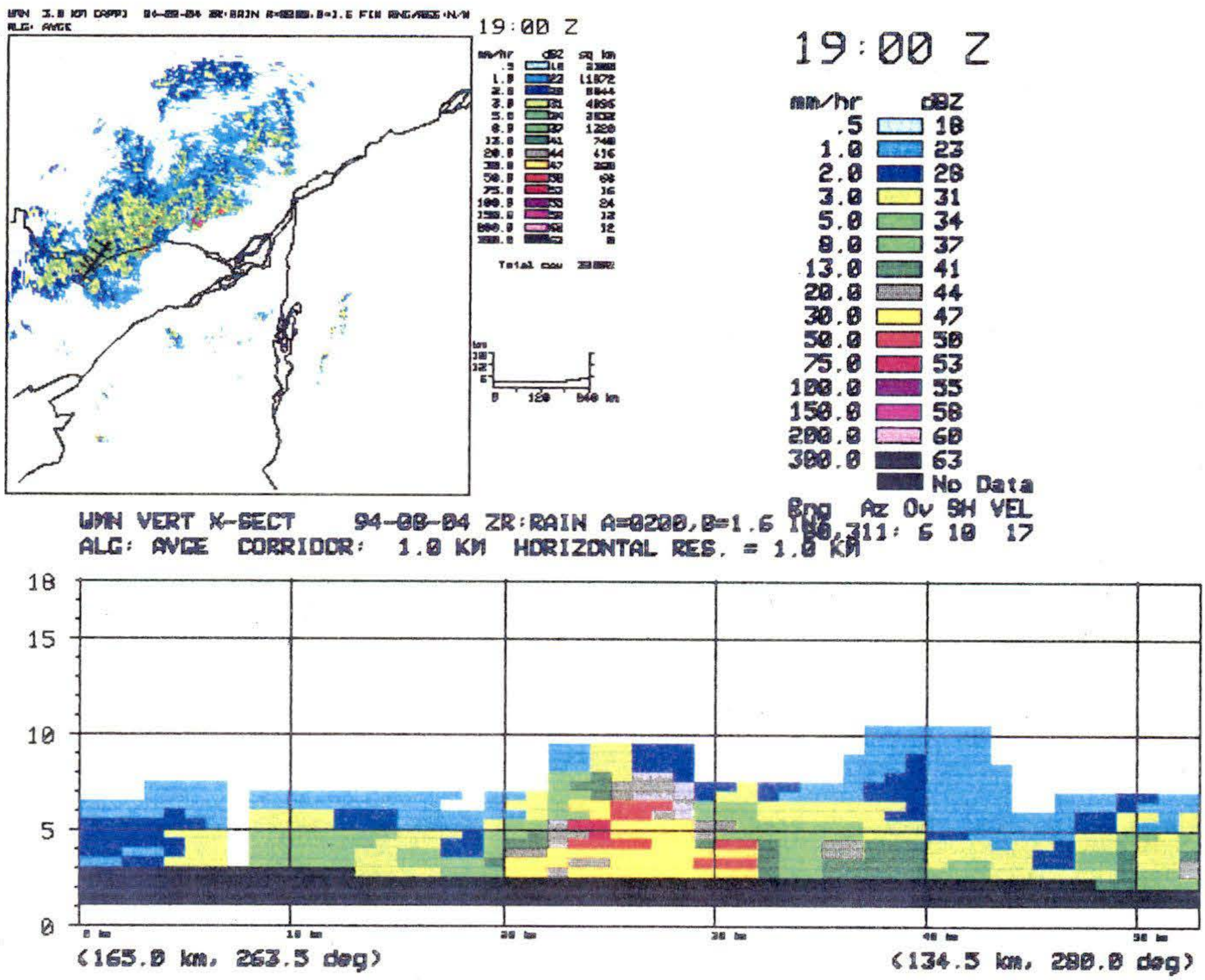

Figure 18. Vertical cross section of the storm near Aylmer valid at 3:00 P.M. (19:00 GMT). Montreal radar.

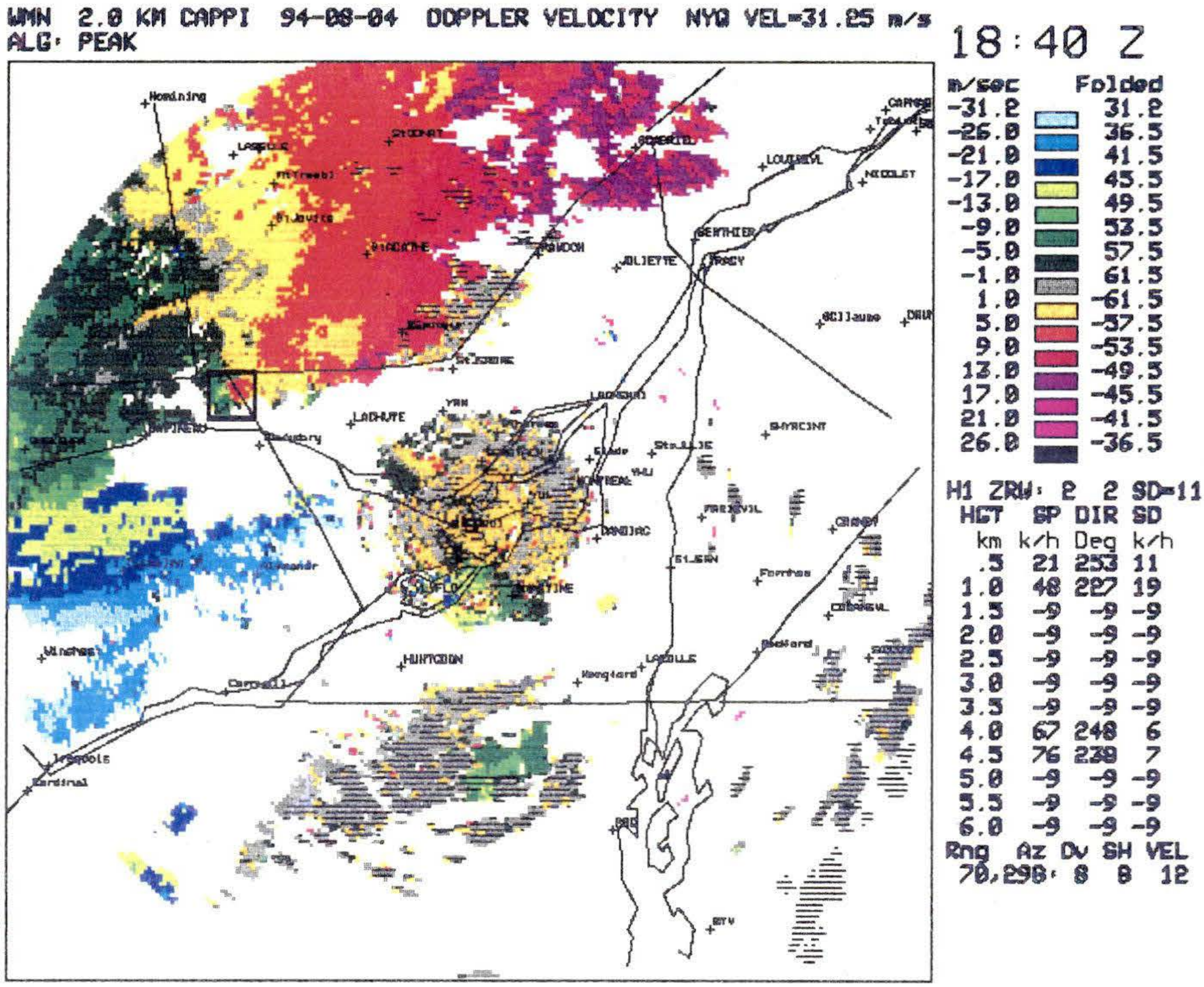

Figure 19. Doppler velocity reaching 30 m/s (light-blue area) valid at 2:40 P.M. (18:40 GMT). Montreal radar.

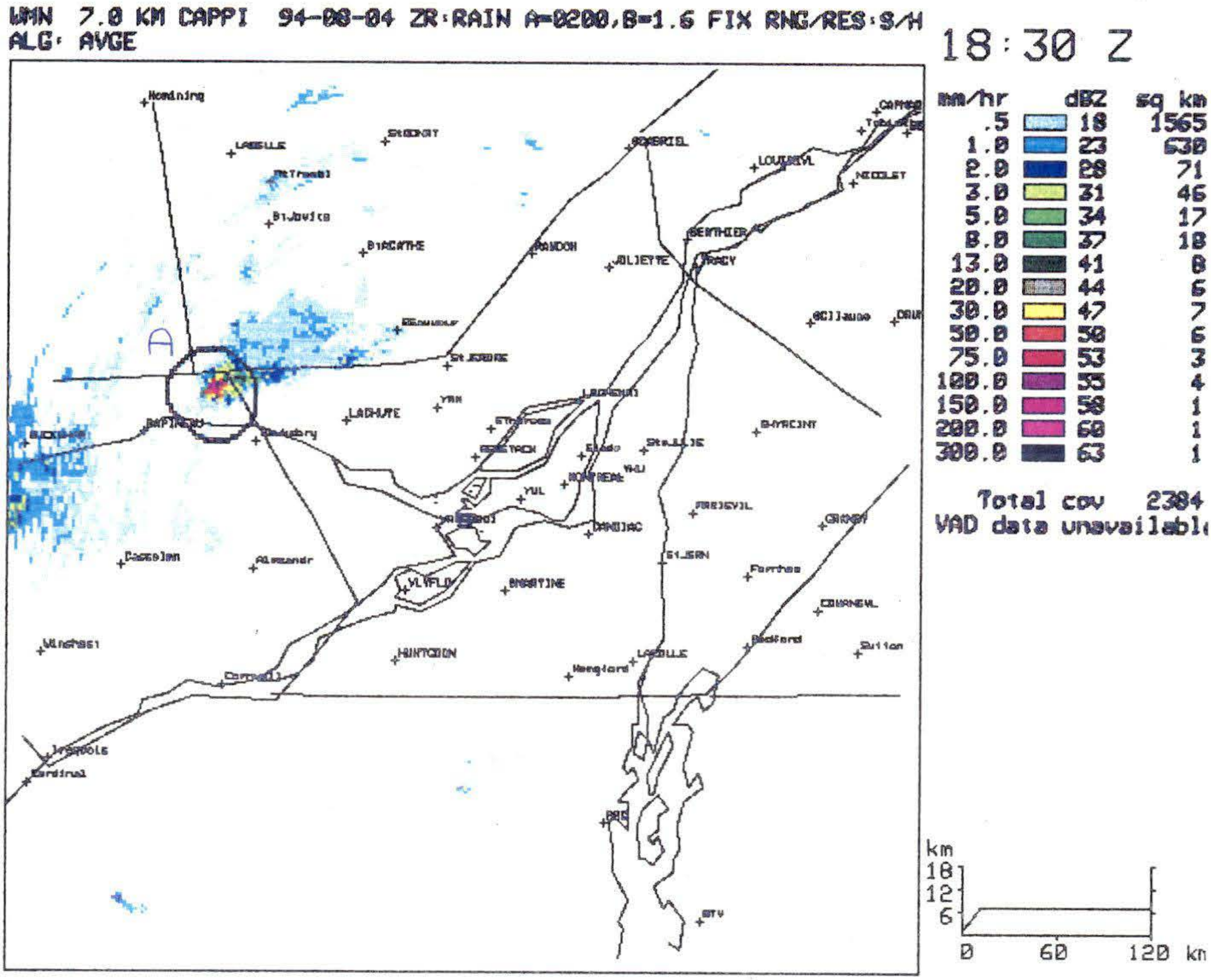

Figure 20. Overhang (A) North-West of Hawkesbury.
Montreal Radar.

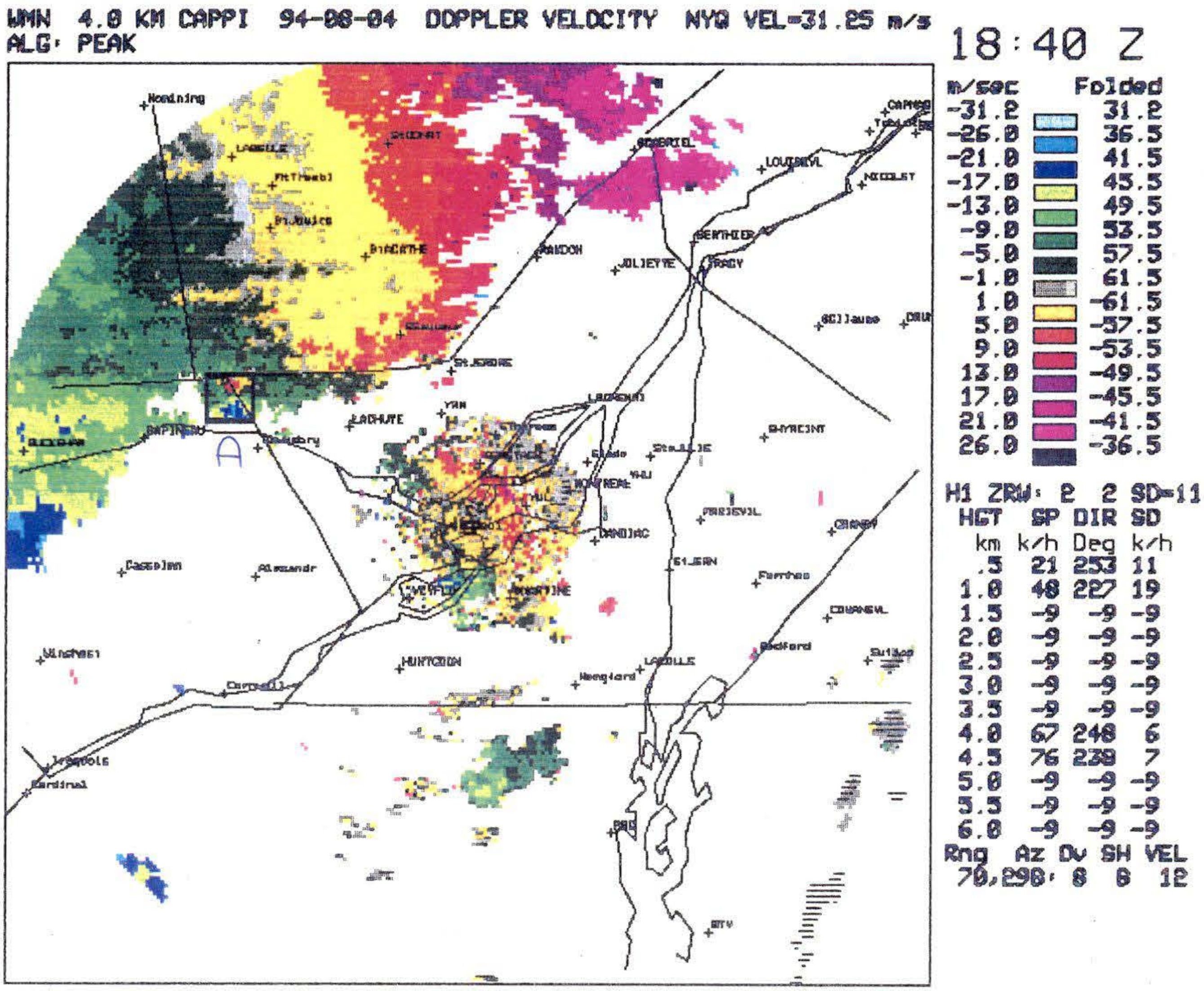

Figure 21. Meso-cyclone (A) North-West of Hawkesbury.
Montreal Radar.

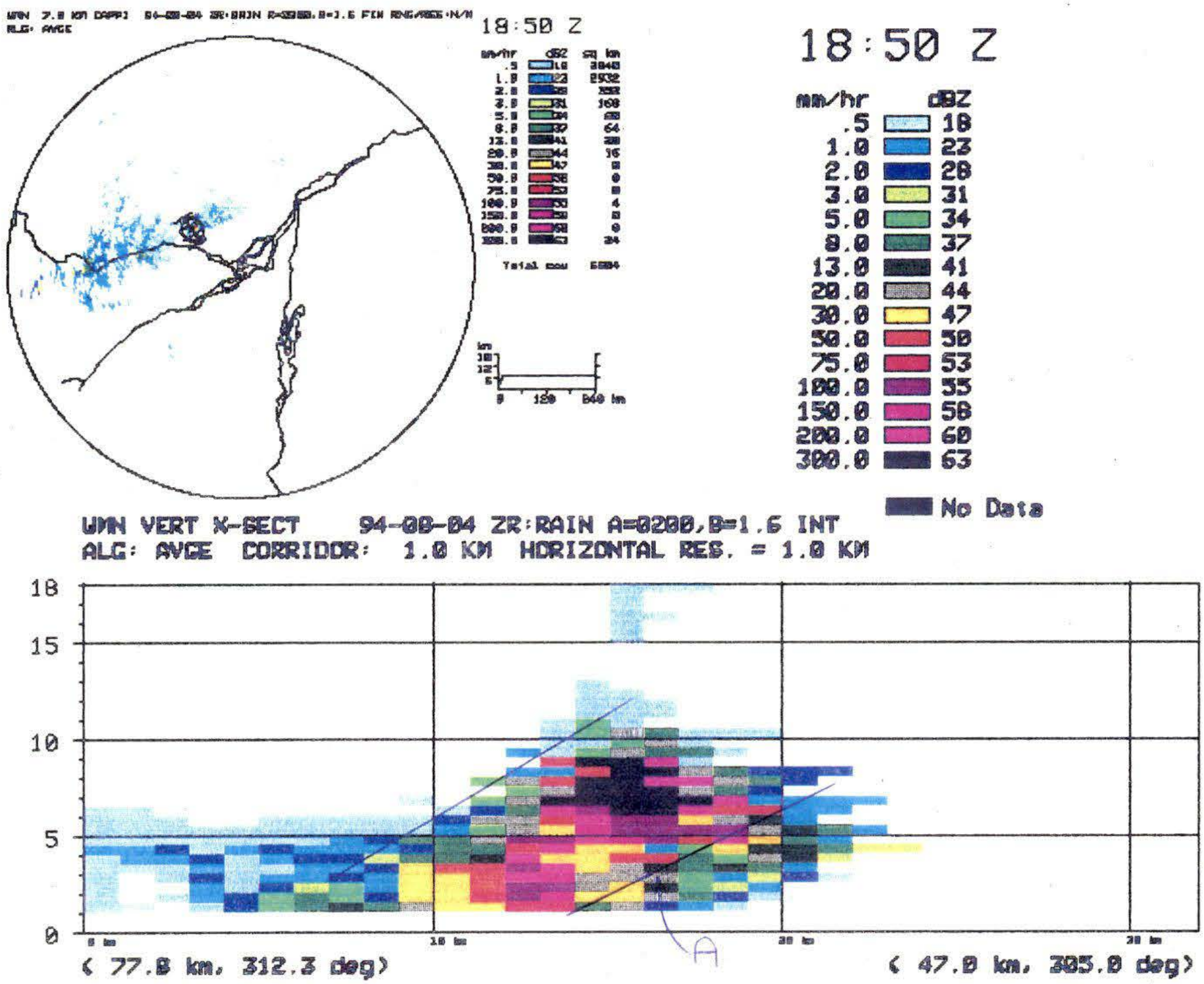

Figure 22. Slope (line A) in the storm. Montreal Radar.

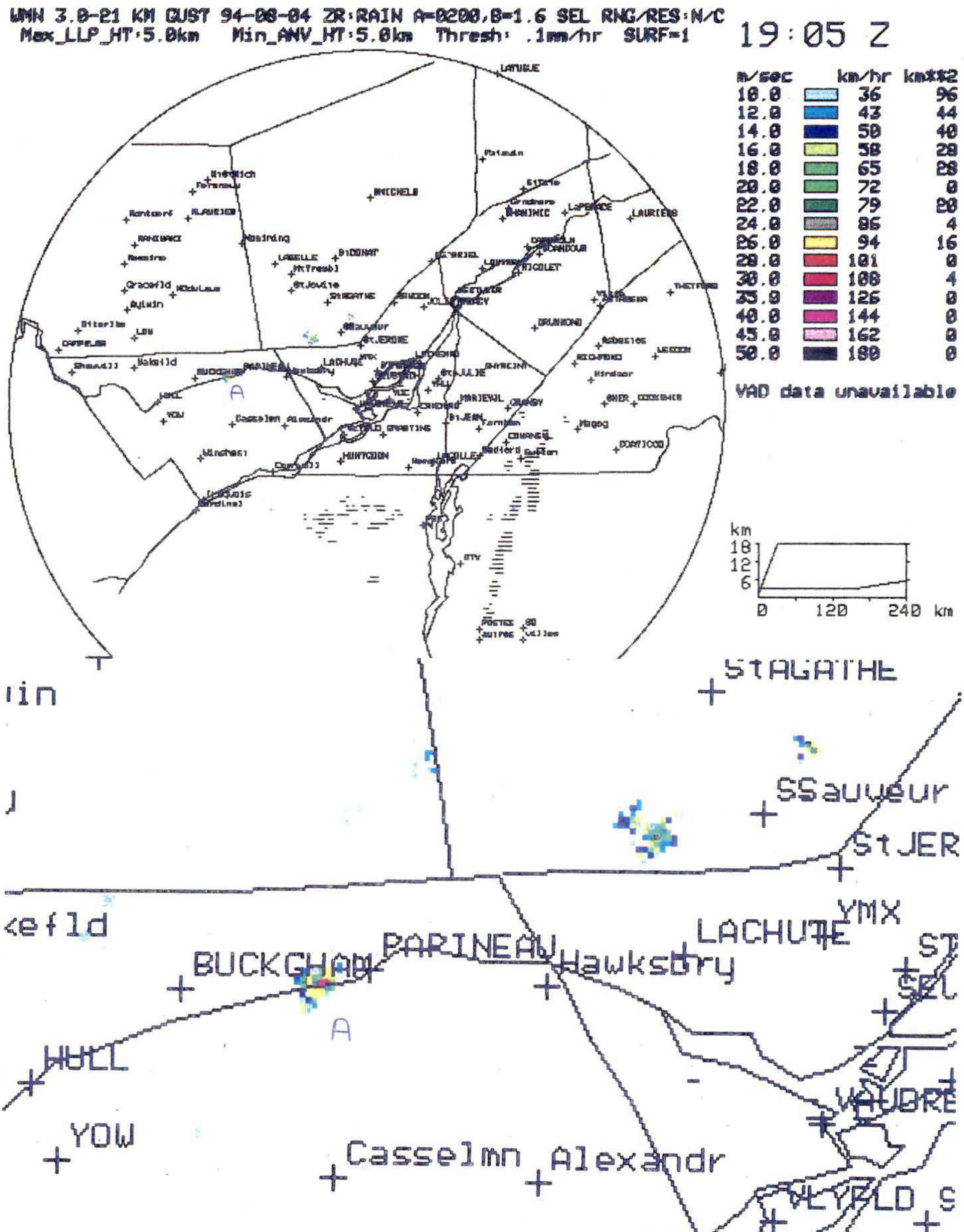

Figure 23. Gusts reaching 106 km/h (A). Montreal Radar.