Confirmed Tornado
Etobicoke, Ontario
September 17, 1988

Date- Local: Saturday, September 17th, 1988.
UTC: Saturday, September 17th, 1988.
Time-Local: 17:30
UTC: 21:30
Location: Etobicoke
Region: York - Durham
Classification: Confirmed Tornado
Category: A
Casualties: None
Track Length: ~400m
Width: None Available
Motion: ~270°
Damage Estimate: ~ $75 000
F-Scale Rating: F0
Code: IB
Damage Survey: yes
Spotter Reports: a few
Other Documents:

Logged event citing brief tornado with minor damage.
Newspaper articles detailing damage.
The 17 September 1988 Weak Tornado Event report.

Tornado F-Scale Assessment

Marci Vanhoucke
Tornado Data Production Assistant, Environment Canada
June 30, 2005.

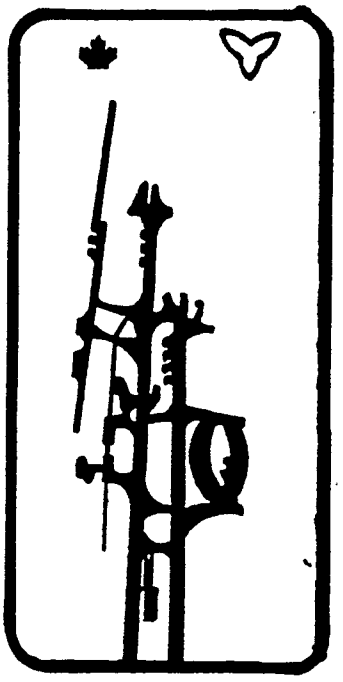
Classification: Confirmed Tornado
Date: Saturday, September 17th, 1988.
Location: Etobicoke, York – Durham

Assessment: F0
F-Code: IB
Explanation of Assessment: The damage report has pictures of minimal damage done to a factory roof. Due to this minimal damage, this tornado is rated an F0.

CLASSIFICATION: Severe Thunderstorm
SOURCE/WATCHER ID:
EVENT TIME (UTC): 21-30 **EVENT DAY:** 17.0 **MONTH:** 9.0 **YEAR:** 1988.0 **EVENT DURATION (HR):** 0.0 **(MIN):** 0.0
DAY OF THE WEEK:
EVENT LOCALE: Etobicoke
ASOCTD PUBLIC RGN: Toronto
DETAILED DESCRIPTION: Tornado, minor damage.

INITIAL ASSESSMENT: YES
SPL WX STATEMENT IN EFFECT ?: UKN **STATEMENT LEAD TIME (HR):** **(MIN):**
WATCH IN EFFECT ?: UKN **WATCH LEAD TIME (HR):** **(MIN):**
WARNING IN EFFECT ?: UKN **WARNING LEAD TIME (HR):** **(MIN):**
TORNADO: YES F?
WINDSPEED:
RAINFALL: MM **RAIN DURATION:**
HAIL DIAMETER: MM **HAIL DESCRIPTION:**
EVENT DESCRIPTION: Tornado
Mesoscale ?: **Synoptic ?:** **Big Event ?:**
Statement Est Hit/Miss:
Watch Est Hit/Miss:
Warning Est Hit/Miss:
Separate Event (30km/30min): YES
Vetted by:
Vetted date:

RECEIVED JUN 2 9 1989



ONTARIO REGION TECHNICAL NOTES

ORTN-89-2

THE 17 SEPTEMBER 1988 WEAK TORNADIC STORM IN METRO TORONTO

BY

Richard Hogue
Paul Joe
Tom Nichols

June 1989

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Atmospheric Environment Service • Service de l'environnement atmosphérique

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THE 17 SEPTEMBER 1988 WEAK TORNADIC STORM IN METRO TORONTO

Richard Hogue[1]
Paul Joe[2]
Tom Nichols[2]

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REFERENCES

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[1]Meteorologist, Ontario Weather Center

[2]King City Weather Radar Research Station

1. INTRODUCTION

During the late afternoon of Saturday 17 September 1988, a weak tornado briefly touched down in the Etobicoke area, just northeast of Toronto's Pearson International Airport.

During that day, the development of localized convective activity occured in southern Ontario. Following a few morning thunderstorms in the Georgian Bay area, widely scattered showers formed in the late afternoon. At 2030Z, two cells developed rapidly into small thunderstorms with tops briefly reaching the 8-10 km range. One of them spawned a very weak tornado. Due to their very short life span and limited spacial and vertical extent the duty forecasters dissmissed these cells as sources of severe weather. However, the analysis of the Doppler radial velocity data by the mesocyclone detection algorithm identified the potential for severe storms nearly one hour before the event. The use of this information would have significantly altered the nowcasting of this situation. This marginal event was therefore rather unusual because the reflectivity structure of the storm did not provide any classical indication of severity.

This Technical Note will examine the following aspects of the event. First, a synoptic and mesoscale analysis will examine the conditions under which the tornado developed. Second, a detailed analysis of the King City radar data will be presented. Third, the damage investigation will be briefly discussed. Finally, we will discuss the isolated nature of the event, our ability to forecast it along with the use of the Doppler radar information in such situations.

2. SYNOPTIC AND MESOSCALE DISCUSSION

2.1 Surface analysis

Between 00Z and 12Z, 88/09/17 a moderately active warm front moved through Southern Ontario triggering scattered thunderstorms. By 12Z, the front was just southwest of a line from Sault Ste-Marie to Trenton (figure 1). Along with the front, a weak meso-low was analysed just west of Sault Ste-Marie with a cold front extending westwards. In the morning, a deck of strato-cumulus dominated most of Southern Ontario. A few thunderstorms developed in the southern Lake Michigan area but they quickly dissipated. Also, a few thunderstorms were reported over the northern Lake Huron area and eastwards. The airmass which affected most of Southern Ontario during the day was characterized by dew points in the high teens (18-20 degrees).

Around 18Z west of the Toronto area the strato-cumulus cloud became broken to scattered; over areas east of London, cumulus clouds developed in bands oriented southwest to northeast. One hour later isolated towering cumulus (TCu) developed along these bands.

At 20Z a TCu developed northeast of Guelph and quickly intensified to a cumulo-nimbus (Cb) reaching its peak intensity just northeast of Brampton. The same complex redeveloped rapidly at 2120Z and triggered a weak tornado just northeast of the Toronto International Airport, in the Etobicoke area.

In order to try to relate the storm activity with the surface observations a 1mb surface pressure analysis is presented in figure 2 and 3 along with wind, temperature and dew point observations. A 1 to 2 mb presure fall tendency in three hours was observed for most stations in Southern Ontario during the afternoon. Between 18Z and 23Z, the pressure and wind fields suggest that a meso-low with an associated weak wind shift trough line crossed Southern Ontario. Most stations registered a

wind shift from south to southwest [1].

By 21Z, bands of TCu oriented southwest to northeast were present and a thunderstorm had developed west of Toronto. This activity is corelated with the wind shift line shown in figures 2 and 3. One of the reporting stations where the wind shift was the most clearly observed was the King City automatic station where it occurred around 2040Z. By 23Z the trough had weakened and was difficult to analyse due to the lack of observations.

In summary, based on the surface observations, we are able to detect features in the pressure and wind fields which are related in time and space with the thunderstorm activity. We will now examine the upper air information.

2.2 500 mb analysis

Figure 4 presents the 500 mb height and vorticity field analysis at 12Z, 88/09/17 and 00Z, 88/09/18 respectively. Also the dotted line indicates the vorticity trough along with its interpolated 18Z position. Figure 4a shows a sharp vorticity trough, embedded in a moderate height trough, which was associated with the few thunderstorms that occured overnight in the southern Lake Michigan area. The interpolated 18Z position correlates very well with the afternoon Cb development. By 20Z the vorticity trough was lying over Toronto. It moved eastwards at approximately 25 knots during the day and was lying east of Trenton by 00Z.

2.3 850 mb analysis

Figure 5 shows the 850 mb height and temperature fields at 12Z and 00Z respectively. The weak warm air advection is the dominant feature here along with the tongue of warm air which is oriented in the same direction as the wind field. Note that the temperature field over southern Ontario was only slightly modified between 12Z and 00Z suggesting that thermal advection in the low levels was not significant on that day. In fact, part of the warm air was directly injected in the convective development in the afternoon. Consistent with the upper air pattern, the height trough crosses Southern Ontario during the day. Although much weaker, this evolution is reflected on the surface pressure field (fig.2).

2.4 Tephigram analysis

Figure 6a shows the 12Z tephigram for Flint, a representative sounding corresponding to the pre-storm environment. The warm air at 850 mb is clearly visible and is acting as a lid at that time. Over that level, the air is unstable. A surface temperature of 24 degrees and dew point temperature of 19 degrees (conditions which prevailed after 18Z in Southern Ontario) would break that inversion possibly giving way to Cb's up to 11km (35 thousand feet). Note the 30 knot low level jet between 2 and 3 thousand feet on the hodograph.

The 00Z tephigram over Flint (fig. 6b) confirms the breaking of the inversion. Note also the much drier air above 750 mb. Similar comments apply to the 00Z Buffalo tephigram (fig. 6c) on which we can see the upper level cooling (destabilization) that occurred between 12Z and 00Z with the passage of the upper trough.

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[1]Valuable observation data from Kitchener (YKF) was not received near the time of the event as the site closed at 18Z, according to its weekend schedule. Also, the Mount Forest (WLS) wind observation is in brackets (on fig. 2 and 3) because its wind data are often unreliable.

2.5 Severe weather assessment

Figure 7 shows some elements of the severe weather composite chart. A low-level moisture axis was present during the day pushing into southwestern Ontario with associated surface dew point temperatures of 19 degrees. A 85 knot westerly high-level jet dominated the area throughout the period. At 12Z, a well defined low-level jet estimated at 35 to 40 knots entered southwestern Ontario from the west then curved northeastwards under the upper jet. A similar set-up was observed at 00Z. Note that the Doppler radar measured a slightly stronger low-level jet intensity. The radial velocity field detected local wind speeds of up to 24 m/s (48 knots) between 20 and 22Z associated with the convective cells. Also, the position of the line of convection is corelated with that of the low-level jet axis.

The sharp vorticity trough, the moderately unstable air, the low-level moisture feed and the relative position of the low and high level jets were all elements somewhat conducive to the development of severe weather. The strong PVA suggests good upper level divergence along with potential strong upward vertical motion.

The 12Z Flint sounding modified by a surface temperature of 24 degrees and dew point of 19 degrees is sufficent to release a buoyant energy of approximately 1700 J/kg. Also the average wind shear between the surface and 4 km was $9x10^{-3}$/sec for both the Flint 12Z and Buffalo 00Z hodograph. Rasmussen et al(1983) have suggested prerequisite low level wind shear conditions and available energy requirements for the formation of tornadoes. In this case, the combination of both values places the environment in a marginal potential tornado development area. Also, when compared to a study by Vigneux et al. (1987), the values of wind shear and potential buoyant energy in this case correspond to a marginal potential for severe weather with a Storm Severity Index (SSI) value of 105 (SSI value of 100 differentiates between severe and non-severe storms, SSI>120 indicates a good probability of tornado occurence).

3. RADAR ANALYSIS

This section describes the King City radar observations of the tornadic storm. In general, there were only a few isolated small cells visible on radar for much of the day. Although some of the cells may have been thunderstorms, none of them appeared very severe. The cells formed on a southwest to northeast line suggesting a larger scale feature. In addition, there were very few cloud to ground lightning strikes observed from the complex (only three strikes were registered).

3.1 Reflectivity data

Around 20Z a southwest to northeast line of TCu developed northeast of Guelph. One of the cells quickly developed into a Cb and reached a peak intensity at 2030Z just northwest of Brampton. Figure 8a shows the reflectivity field at an elevation of 0.6 degrees. Reflectivities of up to 50dBZ were reported with that cell. From 2020Z to 2030Z, the storm echo tops increased from 4-6km in height to 8-10km indicating a very rapid growth.

The precursor cells moved east to northeast prior to 2030Z then veered to the right (east southeast) after 2040Z. This motion is often associated with the movement of severe convective storms. However, the area of 8-10km echo tops moved southeastwards through the whole period with the mid-tropospheric flow indicating directional shear of the winds. This is confirmed by the 00Z Buffalo hodograph (fig. 6c) which clearly shows the wind shear from the surface up to 4km.

A cell developed rapidly around 2120Z northwest of Toronto and triggered a weak tornado just northeast of Pearson International Airport. Figure 8b shows the reflectivity field at 2120Z for an elevation of 0.6 degree. Note the southwest to northeast organization of the cells. Prior to 2120Z, these transverse lines formed and moved eastward at different speeds allowing the lines to merge. A close examination of the reflectivity fields showed that the cells were organized in bands stretching in a perpendicular direction to the lines.

The rapid growth and decay of the area greater than 64mm/hr on the MAX R image around 2030Z and again at 2130Z indicates clearly a rapid storm evolution. The rain rates at the 1.5km CAPPI level were generally fairly low, occasionally reaching 64mm/hr for a short period of time. The maximum reflectivity observed with the complex was 56dBZ at 3km in height. For most of the life of the storm, the echo tops were not very high (the maximum observed was 8-10km) and at no time did the 40dBZ intensities exceed the 5.5km threshold of the Severe Storm chart. The storms were isolated and very small in areal extent but some relatively high reflectivities (> 50dBZ or > 64mm/hr) and hence strong reflectivity gradients were occasionally reported (sharp gradients are often reported with severe weather).

An apparent hook or comma shaped echo (suggesting weak echo regions with high updraft speeds and rotation with the thunderstorms) may be visible (for example at 2040Z on the MAX R chart). However, this may be a pattern that results as two cells merge.

3.2 Radial velocity data

An important clue related to the development of a possible severe storm was available from the analysis of the Doppler radial velocity data. In real time, the mesocyclone algorithm identified a mesocyclone in the appropriate storm complex beginning at 2030Z and continuing through to 2120Z. Mesocyclones are indicated by colored circles superimposed on the reflectivity data as seen on figure 8a and 8b. In the United States, mesocyclones have been found to be associated with tornadoes 50% of the time and with severe weather 90% of the time (JDOP, 1979). The initial measurement at 2030Z was for an azimuthal shear of 18m/s/km and this was accompanied by angular momentum values in excess of 100km m/s. These values meet the preliminary criteria for a "tornadic" mesocyclone (mesocyclone shear parameters [2] exceeds 10m/s/km and angular momentum parameter exceeds 100 km m/s).

Qualitatively, the signature of a mesocyclone was clearly identifiable from the radial velocity field as well. Figures 8c and 8d show the radial velocity field at 2120Z for the two lowest elevations. Although dificult to see on this reproduction, the mesocyclone couplet (indicated by the black arrow) is very well corelated with the cell that was responsible for the formation of the tornado. The rotation signature was probably better defined in this case than any other case studied so far at King City. This is especially true at 2120Z and 2130Z. Also at these times, the storm motion was perpendicular to the radar beam so that the radial velocity data was not contaminated by the radial component of the storm motion.

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[2]The azimuthal shear is in this case the maximum radial velocity gradient between two consecutive radials within the mesocyclone. The "angular momentum" is a quantity which is actually proportional to the angular momentum (r x m x V, where r is the distance from the centre of rotation, m is the mass and V is the rotational velocity) within the feature since the mass of the air is not in the equation and a factor 2 has been dropped. This quantity is an indicator of mesocyclone development (Joe(1988), Joe et al.(1988)).

The mesocyclone algorithm was reapplied on the data using lower detection treshold values. In this exercise, the algorithm identified the tornadic storm even earlier in its evolution. At 20Z, the storm was in its early growth phase; before strong vertical development, before high reflectivities and before it veered to the right. The algorithm continued to identify mesocyclones for the next 90 minutes up to 2130Z. The "tornadic" mesocyclone category was still only surpassed at the same two time steps (2030Z and 2040Z).

It should also be noted that initially the algorithm identified mesocyclones in each of two separate storms. The two storms eventually merged and as this was occuring the algorithm merged two mesocyclones and identified one although two distinct signatures were visible on the radial velocity fields.

Quantitatively, the shear values were relatively high, generally greater than 10m/s/km but the angular momentum values were quite low, generally less than 100km m/s. These thresholds were selected to identify tornadic mesocyclones based on the limited tornadic cases in Southern Ontario. Therefore, it should be noted that these are guidelines and are not statistically defendable. This case exceeded these thresholds only briefly and therefore can be considered to represent a weak mesocyclone that was tornadic.

4. DAMAGE INVESTIGATION [3]

An investigation of the damaged site was done Monday morning 19 September 1988. Following telephone interviews and news reports one specific damage site was located in the Belfield Road and Kipling Ave. an area just northeast of the Pearson International Airport. An industrial building located on Belfield Rd just west of Kipling Ave. suffered damage to its roof. Large areas of roof were folded back with some pieces completely torn off. An empty tractor trailer parked near the industrial building was rolled to his side. Across Kipling Ave., two large sections of windows were broken on an Ontario Ministry building. Adjacent buildings were not damaged.

Close to a dozen reports of funnel cloud sightings were collected. Most reports agreed on the time and location of the funnel cloud. It occured in the Belfield Rd. and Kipling Ave. area between 17:30 and 17:40 EDT (2130-2140Z). Most of the eyewitnesses had a clear view of the funnel cloud which briefly touched down two or three times during approximately a five minute period. No thunder was reported and only cloud-to-cloud lighting was briefly observed across the western edge of the cloud. A photograph of the funnel was taken by one of the witnesses.

The damage assessment indicates that the event could be classified as a F0 tornado on the Fujita scale. Winds of the order of 90 to 115 km/h were likely through the path of the tornado.

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[3]For the detailed investigation report see Hogue(1989).

5. DISCUSSION AND CONCLUSION

On Saturday 17 September 1988, a weak tornado briefly touched down around 17:30 EDT just northeast of Toronto's Pearson International Airport, in the Kipling Av. and Belfield Rd. area.

The on-site investigation along with interviews of witnesses suggest that the event be classified as an F0 tornado on the Fujita scale.

The detailed radar analysis supports the occurence of the tornado. A mesocyclone meeting minimum criteria was positively and unambiguously identified using Doppler radar both from the mesocyclone detection algorithm product and from the radial velocity products. The mesocyclone was weak, only briefly exceeded the existing preliminary threshold guidelines for identifying a severe storm threat area. The mesocyclone was detected more than one hour before the tornado touched down.

Also, in hindsight, possible clues as to the severity of the storm were identified using conventional radar data: rapid storm development along with occasionally strong reflectivity gradients and veering motion of the storm from the east-northeast to the east-southeast. ambiguous!

The synoptic and mesoscale dynamics analysis support, do not preclude, the development of severe storms. The sharp vorticity trough, the moderately unstable air, the moisture feed and the relative position of the low and high level jets were all elements somewhat conducive to the development of severe weather.

Some questions remain as to the very isolated nature of the thunderstorm cells that developed that afternoon. The triggering of the isolated strong cells after 20Z is reasonably explained by the breaking of the 850 mb warm air lid as the surface temperatures and dew points reached 24 degrees and 19 degrees respectively. But why more thunderstorm cells didn't develop under these conditions remains unclear. A possible explanation lies in the examination of the evolution of the reflectivity field and the surface analysis. As pointed out in the previous sections, around 20Z a southwest to northeast line of TCu developed northeast of Guelph. The position of the line is correlated with the position of the weak surface pressure trough (fig. 2 and 3). A weak windshift line was also noticeable with that trough (however the lack of surface observations prevents a rigourous identification of that windshift line). In addition, the position of the line follows approximately that of the low-level jet. These elements tend to indicate that low-level convergence might have been the principal contributing factor supporting the cells. The short life span of the cells was therefore mainly due to the localized nature in time and space of the surface convergence, the position of the low-level jet and the sharpness and narrowness of the vorticity trough.

It is important to discuss our ability to forecast this isolated marginal severe weather event. In this case, the morning severe weather assessment was very reasonable in calling for isolated Cb activity east of the vorticity trough. But due to their very short life span and limited vertical and spacial extent, the cells were dismissed as sources of severe weather by the duty forecasters. The relatively short lifetime, the very localized nature of the cell which became severe, and the lack of deep vertical development made this case a difficult one to forecast. However, the detailed use of Doppler radar might have aided in the nowcasting of the situation. The mesocyclone detection algorithm identified the mesocyclone more than one hour before the tornado touched down. But, in real time, when the CAPPI radar picture does not show significant severe weather potential, as in this case, the forecasters have a tendency not to look at the Doppler information. Therefore, this

suggests that our system should somehow signal automatically to the forecasters any information leading to potential severe weather (i.e. detection of mesocyclones). In the past, conventional reflectivity images were examined before the more complex Doppler information which has been a reasonable approach. This case indicates that tornadoes can exist in weak reflectivity storms and that the Doppler should perhaps be examined concurrently.

Also, even if the forecasters would have been fully aware of the identification of the mesocyclone and considering the assessment of a marginal severe weather situation, the decision to issue or not issue watches and/or warnings would not have been obvious based on previous experiences.

In a broader climatological perspective, one might ask how often this type of marginal severe weather event occurs and remains unobserved. In this case, interest in the event was strongly increased by the fact that it occured in Metro Toronto where the funnel was seen by quite a few people and also that a picture was taken of the funnel cloud. This was a classic case of "expect the unexpected".

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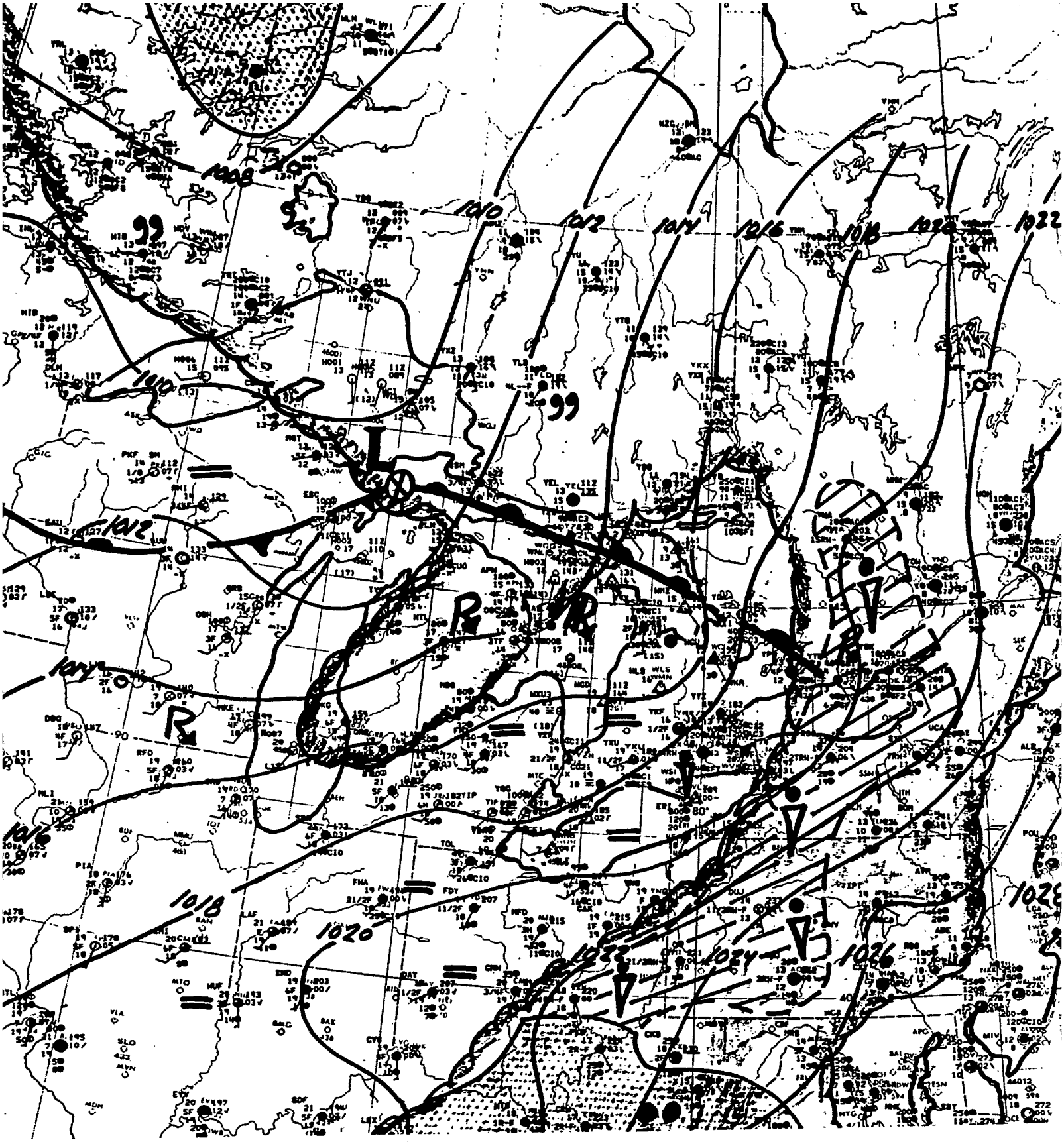
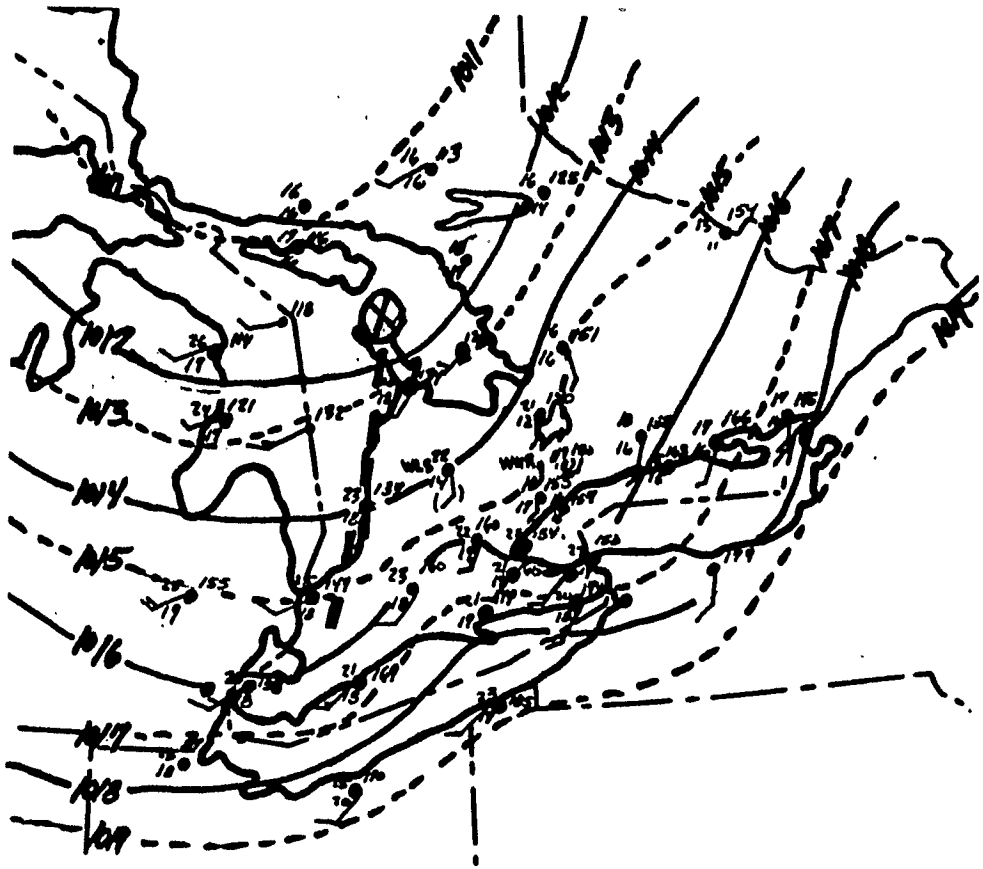
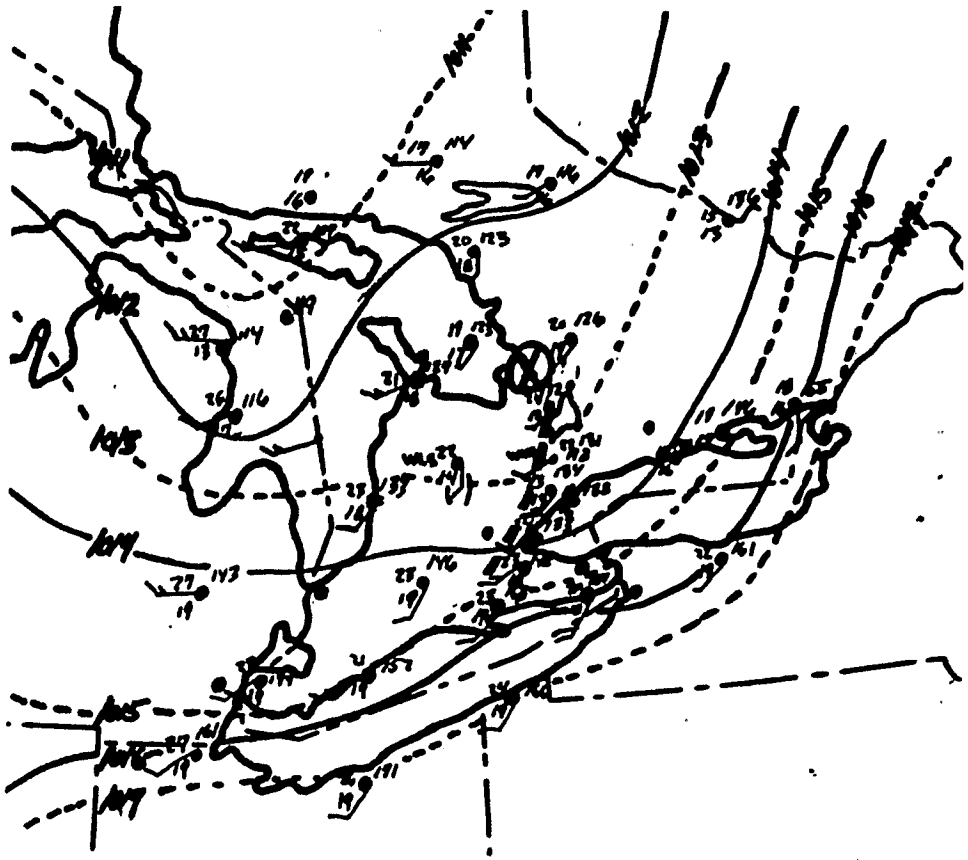


Figure 1. 12Z Surface analysis, 17 Sept. 1988

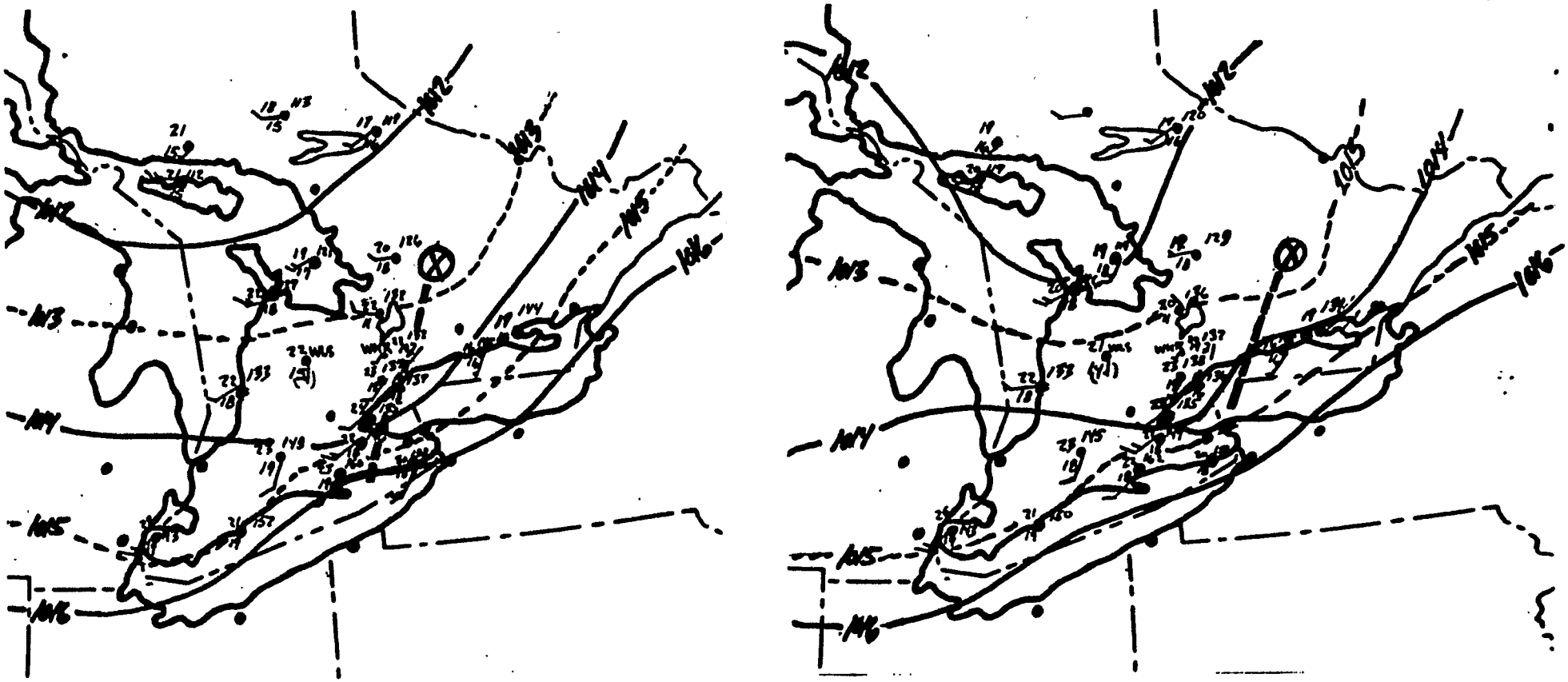


18Z, 17 Sept. 1988



21Z, 17 Sept 1988

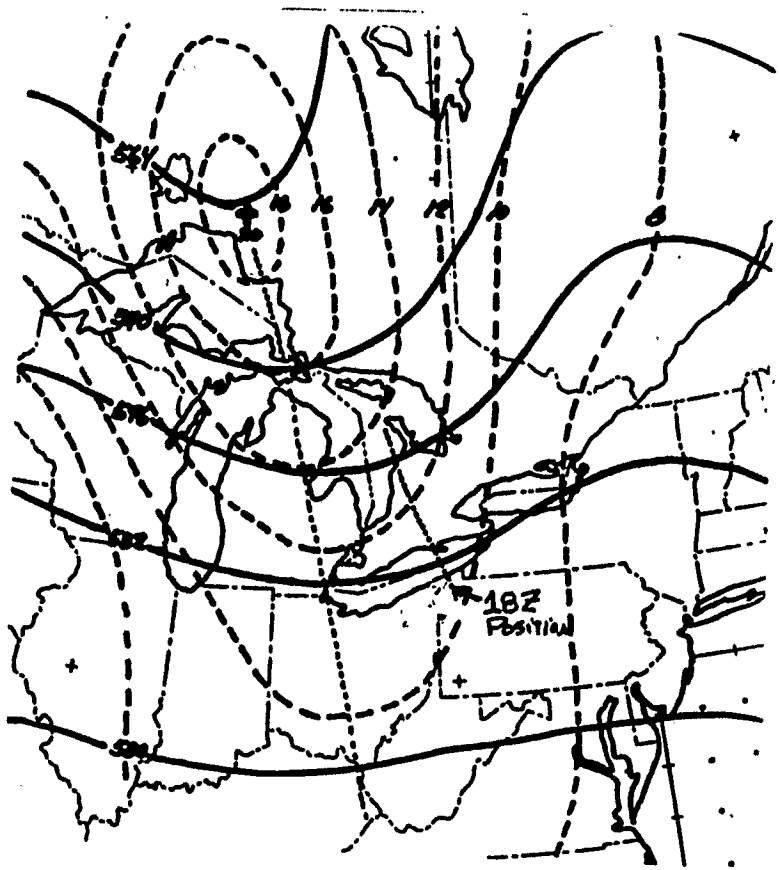
Figure 2. 1 mb surface analysis



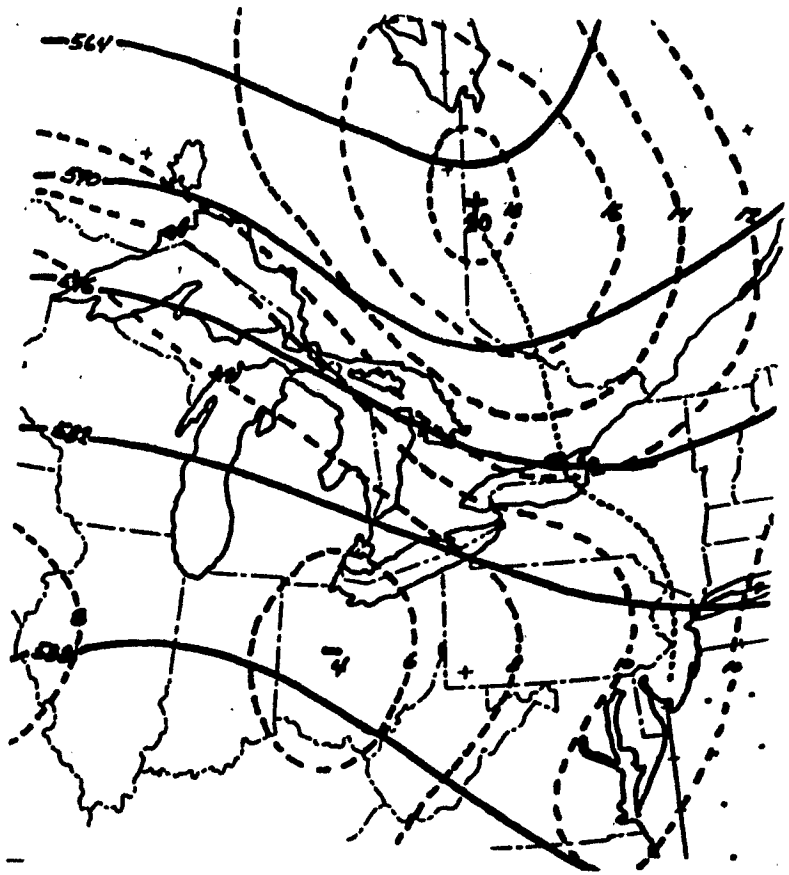
22Z, 17 Sept. 1988

23Z, 17 Sept. 1988

Figure 3. 1 mb surface analysis

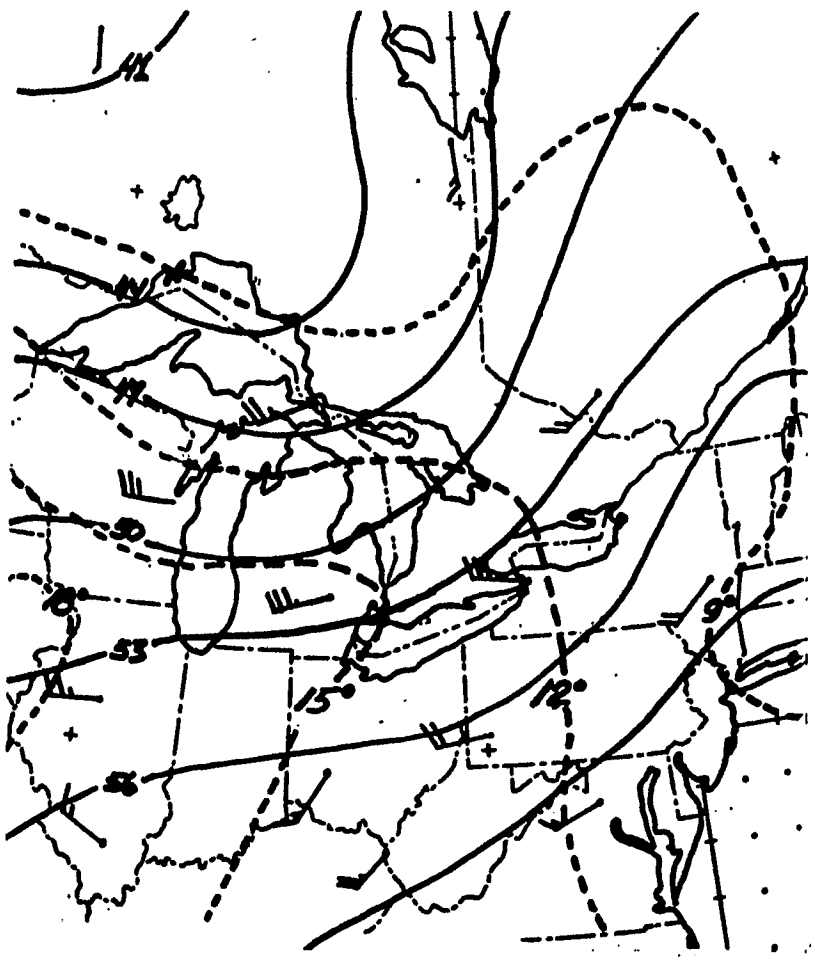


12Z, 17 Sept. 1988

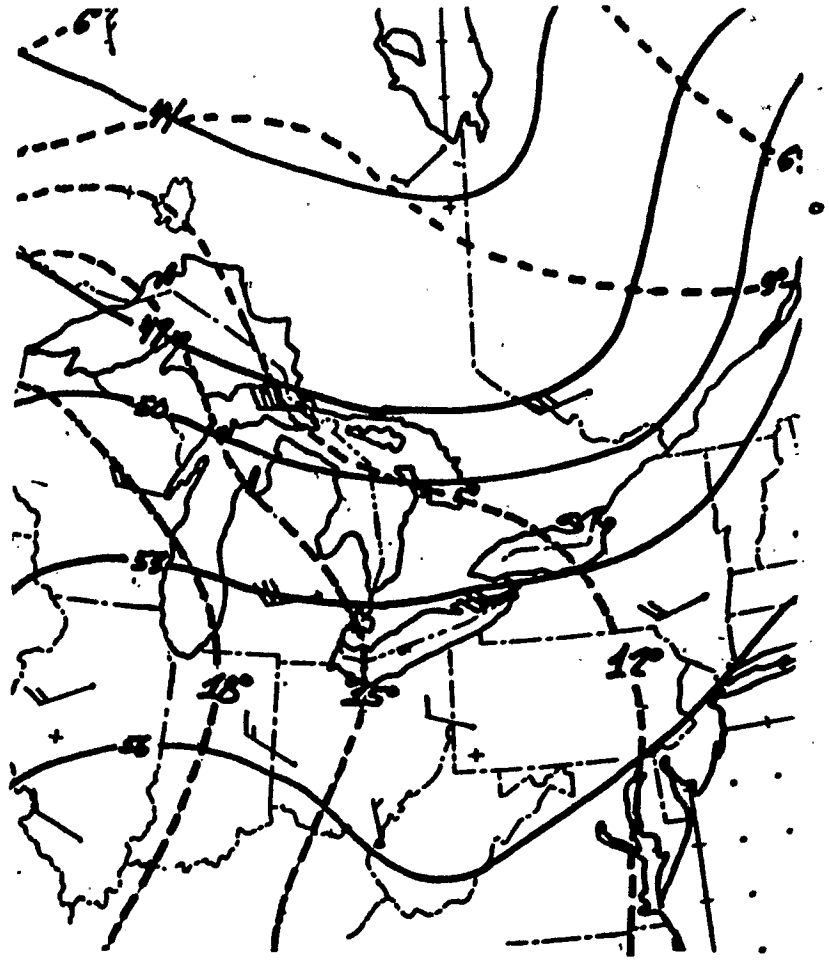


00Z, 18 Sept 1988

Figure 4. 500 mb height and vorticity fields

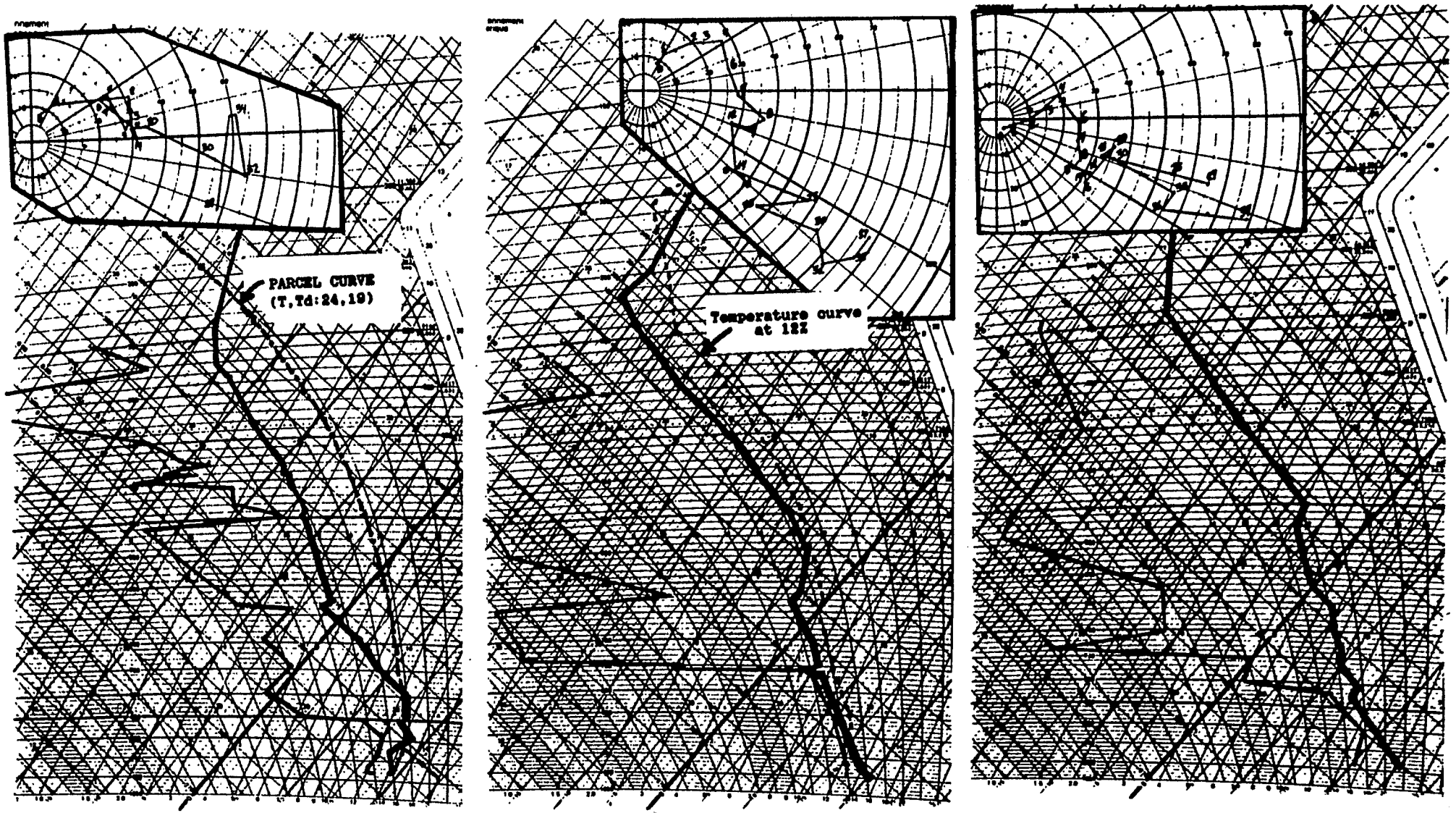


12Z, 17 Sept. 1988



00Z, 18 Sept 1988

Figure 5. 850 mb height and temperature fields

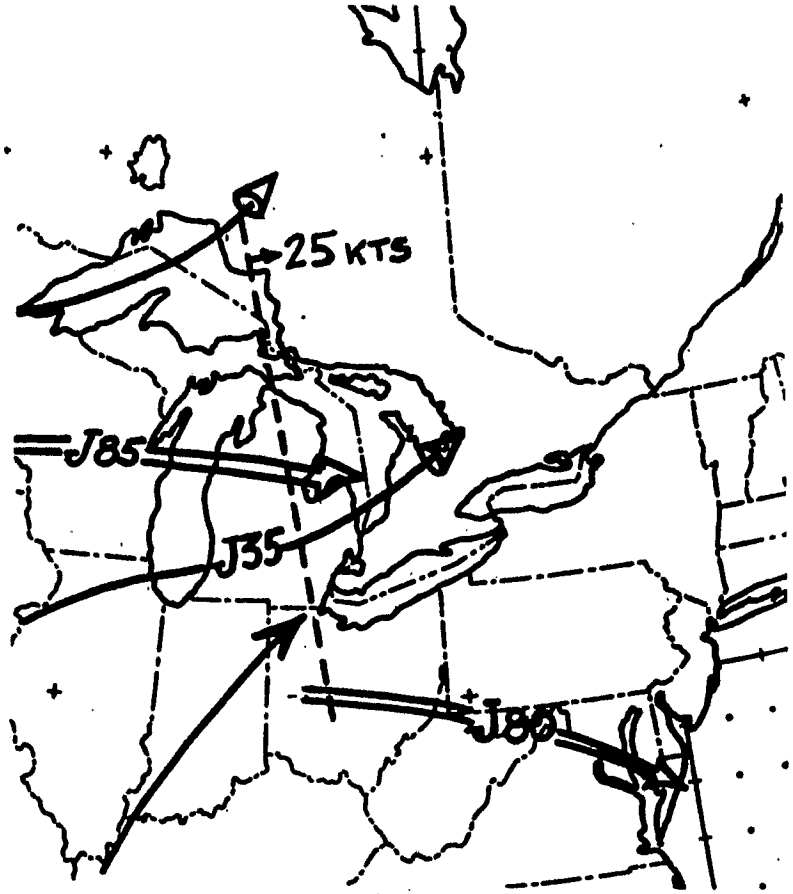


a) 12Z Flint, 17 Sept. 1988

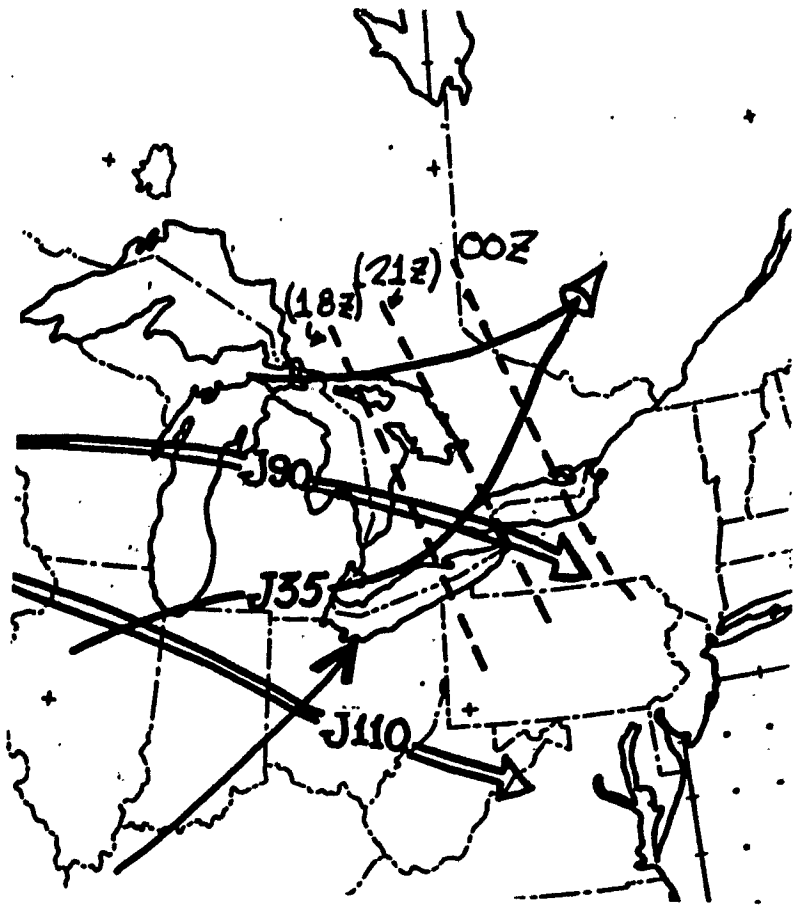
b) 00Z Flint, 18 Sept. 1988

c) 00Z Buffalo, 18 Sept. 1988

Figure 6. Tephigrams and hodographs



12Z, 17 Sept. 1988



00Z, 18 Sept 1988

Figure 7. Severe Weather composite chart: high level jet(⟹), low level jet(⊖), moisture axis(⟶) and 500 mb vorticity trough(- - -).

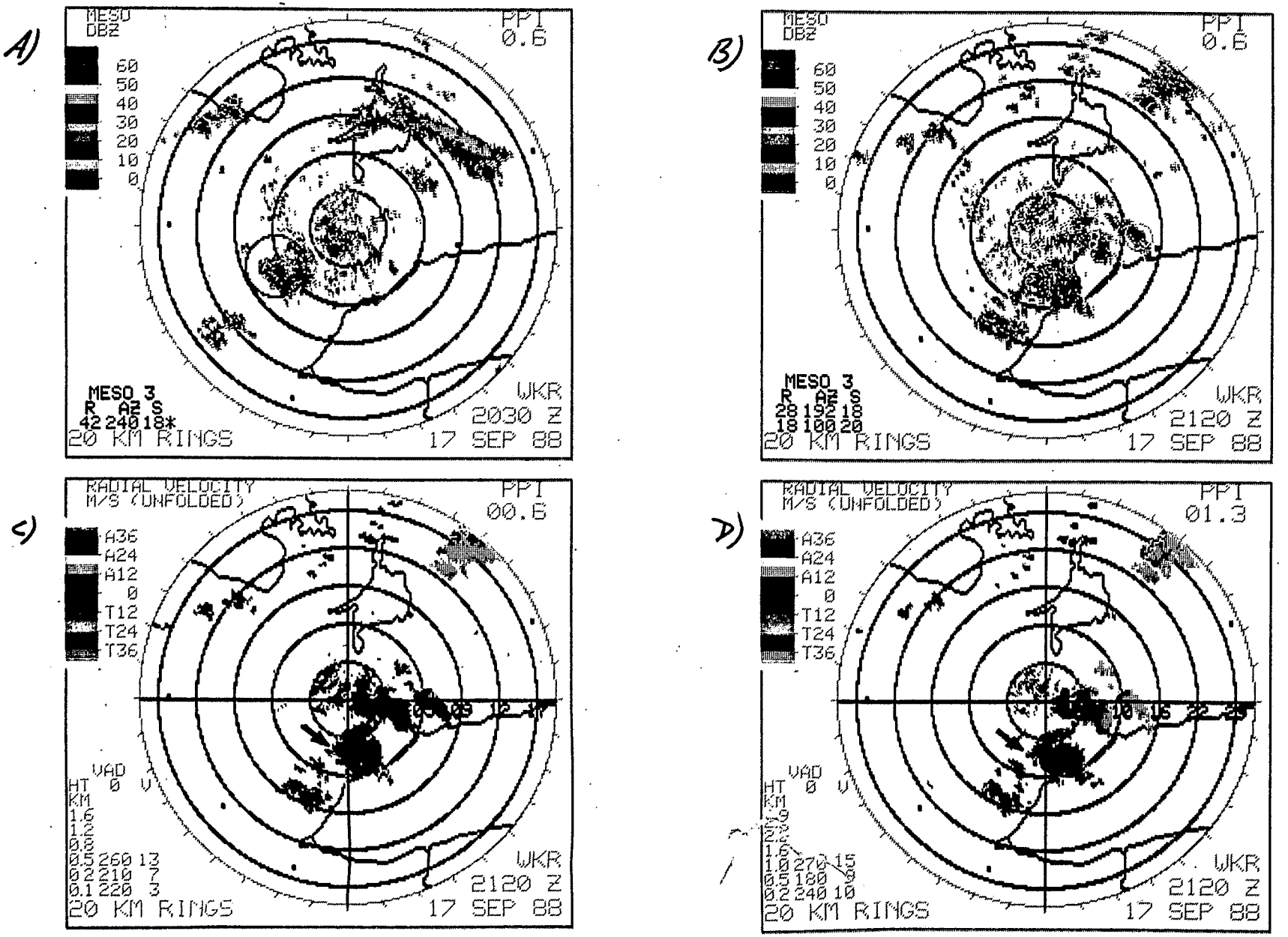


Figure 8. Radar images; reflectivity 0.6° PPI at 2030Z (a) and 2120Z (b), radial velocity at 2120Z for 0.6° (c) and 1.3° (d). The black arrow points in the direction of the mesocyclone.

THE 17 SEPTEMBER 1988 WEAK TORNADO EVENT

Richard Hogue
Paul Joe
Tom Nichols

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- 3.2 Funnel sightings and severe weather reports
- 3.3 Intensity assessment and classification

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- 4.2 Radial velocity data

5. DISCUSSION AND CONCLUSION

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ANNEX 1. Severe weather reports

1. INTRODUCTION

During the late afternoon of Saturday 17 September 1988, a weak tornado briefly touched down just northeast of Toronto's Pearson International Airport, in the Etobicoke area.

During that day, the development of extremely localized convective activity occured in Southern Ontario. Following a few morning thunderstorms in the Georgian Bay area, only one or two thunderstorms formed in the late afternoon unexpectedly generating a very weak tornado. This event was therefore a rather unusual one which is studied in detail in this report.

This Technical Note will examine the event through three distinct aspects. First, a synoptic and mesoscale analysis will provide the discussion on the conditions in which the tornado developed. Second, the results of the damage investigation will be discussed. Finally, a detailed analysis of the King City radar data will be presented.

2. SYNOPTIC AND MESOSCALE DISCUSSION

2.1 Surface analysis

Between Friday night (00Z, 88/09/17) and Saturday morning (12Z, 88/09/17) a moderately active warm front moved through Southern Ontario triggering scattered thunderstorm activity. By 12Z, the front had moved to lie just southwest of a line from Sudbury to Trenton as depicted in figure 1. The overnight activity had significantly increased the moisture content in the low levels and thick strato-cumulus dominated most of Southern Ontario in the morning. A few thunderstorms developed in the southern Lake Michigan area but they quickly dissipated early in the morning. Also, a few thunderstorms were reported in the morning over the Georgian Bay area and eastwards.

The airmass which affected most of Southern Ontario during the day was characterized with dew points in the high teens (18-20 degrees). Another front which is seen on the southernmost part of the 12Z map was associated with dew points higher than 20 degrees. This front slowly progressed northeastward and reached eastern Iowa 24 hours later (12Z, 88/09/18).

By 18Z in the vicinity and west of the Toronto area the cloud became broken to scattered extending between 3 and 5 thousand feet. Around 18Z, over areas east of London, cumulus clouds developed in bands oriented southwest to northeast. One hour later isolated towering cumulus (TCu) developed along these bands.

At 20Z a larger TCu developed northeast of Guelph. It quickly intensified to a Cb and reached its peak intensity just northeast of Brampton. Later the cell redeveloped rapidly around 2120Z and triggered a weak tornado just northeast of the Toronto International Airport, in the Etobicoke area. The detailed radar analysis is presented in section 4.

Figure 2 and 3 present a detailed 1 mb pressure field analysis along with wind, temperature and dew point observations. A 1 to 2 mb presure fall tendency in three hours was observed for most stations in Southern Ontario during the afternoon. The 18Z pressure field shows a weak broad troughing over Lake Huron and an associated gradual wind shift from the south to the west.

We will examine all other data in the following sections. However, based on the surface observations, we will relate here the development of the stronger convective activity to the pressure patterns and the wind field. By 21Z the trough over western Lake Huron is still present. However note the weak trough extending from Georgian Bay to the south-southeast. At that time a thunderstorm had developed west of Toronto and isolated TCu activity was present to the east. The associated wind shift is difficult to highlight but a weak veering of the winds can be detected between 18Z and 21Z. King City automatic station was the only one to clearly show a wind shift. It occurred around 2040Z. By 23Z only the trough extending from Georgian Bay to the Niagara Peninsula is present.

Footnote[The Mount Forest (WLS) wind observation is in brackets because it has a history of unreliability. Also, valuable observation data from Kitchener (YKF) was not received near the time of the event as the site closed at 18Z, according to its weekend schedule.***

In summary, based on the surface observations, we are able to detect elements in the pressure and wind fields which are related in time and space with the thunderstorm activity. We will now examine the upper air information.

2.2 500 mb analysis

Figure 4 and 5 present the 500 mb height and vorticity fields analysis at 12Z (88/09/17) and 00Z (88/09/18) respectively. Also the vorticity trough is indicated along with its interpolated 18Z position. Figure 4 shows, embedded in a moderate pressure trough, a sharp vorticity trough which was associated with the few thunderstorms that occured overnight in the southern Lake Michigan area. The interpolated 18Z position correlates very well with the afternoon Cb development. By 20Z the vorticity trough was lying over Toronto. It moved eastwards at approximately 25 knots during the day and was lying east of Trenton by 00Z.

2.3 850 mb analysis

Figure 6 and 7 show the 850 mb pressure and temperature fields at 12Z and 00Z respectively. The warm air advection is the dominant feature here along with the tongue of warm air which gradually moved southward during the day across Southern Ontario. Consistent with the upper air pattern, the pressure trough crosses Southern Ontario during the day. Although much weaker, this evolution is reflected on the surface pressure field (fig. 2 and 3).

2.4 Tephigram analysis

Figure 8 shows the 12Z tephigram over Flint, a representative sounding corresponding to the pre-storm environment. The warm air at 850 mb is clearly visible and is acting as a lid at that time. Over that level, the air is moderately unstable. A surface temperature of 24 degrees and dew point temperature of 19 degrees (conditions which prevailed after 18Z in Southern Ontario) would break that inversion possibly giving way to Cb's up to 30 to 35 thousand feet. On the upper left corner, note the 30 knot low level jet between 2 and 3 thousand feet.

The 00Z tephigram over Flint (fig. 9) confirms the breaking of the inversion. Note also the much drier air above 750 mb. Similar comments apply to the 00Z Buffalo tephigram (fig. 10). Note the destabilization that occurred between 12Z and 00Z with the passage of the upper trough.

2.5 Severe weather assessment

Figure 11 shows some elements of the severe weather composite chart. A low-level moisture axis was present during the day entering through Southwestern Ontario with associated surface dew point temperatures of 19 degrees. A 100 knot high-level jet dominated the area throughout the period. At 12Z a well defined low-level jet of 35 to 40 knots entered Southwestern Ontario then curved northeastwards under the upper jet. A similar set-up was observed at 00Z. Note that the Doppler radar measured a slightly stronger low-level jet intensity. The radial velocity field detected local wind speeds of up to 24 m/s (48 knots) between 20 and 22Z associated with the convective cells.

The sharp vorticity trough, the moderately unstable air, the moisture feed and the relative position of the low and high level jets were all elements somewhat conducive to the development of severe weather. The strong PVA suggests good upper level divergence along with potential strong upward vertical velocity.

The 12Z Flint sounding modified by a surface temperature of 24 degrees and dew point of 19 degrees is sufficent to release a buoyant energy of approximately 1700 J/kg. Also the average wind shear between the surface and 4 km was 9x10-3/sec for both the Flint 12Z and Buffalo 00Z hodograph. Rasmussen et al(1983) have suggested prerequisite low level wind shear conditions and available energy requirements for the formation of tornadoes. In this case, the combination of both values places the environment in a marginal potential tornado development area. Also, when compared to a study by Vigneux et al(1987), the values of wind shear and potential buoyant energy in this case correspond to a marginal potential of severe weather.

3. DAMAGE INVESTIGATION

3.1 Description of damage path

An investigation of the damaged site was done Monday morning 19 September 1988. Following telephone interviews and news reports one specific damage site was located in the Belfield Road and Kipling Ave. an area just northeast of the Pearson International Airport as can be seen on figure 12. Unfortunately, since the event occured two days before (Saturday, 17 September

1988), most of the debris on the ground had been cleaned up. However, it was possible to see damage in two specific locations that we will describe here using figure 13.

3.1.1 Damage to an industrial building at 40 to 60 Belfield Rd.

As described on figure 13, an industrial building located between 40 and 60 Belfield Rd (mainly occupied by Consumer's Distributing's head office) suffered some damage to its roof at the extreme northern end of the building. Three large areas of roof were folded back with some pieces completely torn off. The roofing material was a typical solid industrial roof type topped by a thin gravel layer. The flashing appeared to be solidly attached and well covered the top of the brick wall to the roof. Each one of the three damaged areas of the roof were folded back in the southeast direction. In the process, some plexiglass windows in the shape of bubbles that were fastened to the ceiling, were torn off of the roof. According to the building manager, Mr. Mike Fruchtman, the damage is evaluated at $150 000.

Picture #1 shows a view from the roof looking north-northeast (the position and direction where the photographs were taken are indicated on figure 13). We can clearly see the area of the roof that was folded back to the south-southeast. Also, in the foreground, a bubble shaped plexiglass window was popped out of its place. In the background, some of those windows were left intact. Looking west, picture #2 shows also parts of the roof folded to the southeast. Picture #3, looking north, shows the plexiglass windows popped out. Notice on the right side of the picture, the wrinkle on the rooftop material. Finally, picture #4 shows the brick and flashing torn off of the roof on the western side of the building.

In the back of the building, an empty tractor trailer from Fairway Cartage Company was rolled onto its side. It was 28 feet long, weighted approximately 2100 kg and was oriented in an north-south direction. Surprisingly, a dozen similar trailers were also parked in the same area but they were left intact.

As mentioned earlier, most of the debris had already been cleaned up, but we were able to notice that a piece of flashing (2' X 8') had landed on the hydro wires. It was torn off the roof of the building and tossed some 200 metres to the east and landed at least at approximately 60 metres off the ground.

Picture #5 shows a piece of flashing wrapped around on of the legs of a tractor trailor located at the back of the building. The piece of flashing caught in the hydro wires is shown in picture #6.

3.1.2 Damage to an Ontario Ministry's building

As indicated on figure 13, a mechanical maintenance building of the Ontario Ministry of Transportation and Communication was slightly damaged. Two large sections of windows were destroyed at the back the building. Picture #7 shows the western portion of the damaged area. On the left of the photograph notice the type of windows that were destroyed.

3.2 Funnel cloud sightings and severe weather reports

Close to a dozen reports of funnel cloud sightings were collected. Most of them are detailed in annex 1. The location of each sightings in indicated on figure 12. All reports tend to agree on the time and location of the funnel cloud. It occured in the Belfield road and Kipling ave. area between 17:30 and 17:40 EDT (2130-2140 Z)

Most of the eyewitnesses had a clear view of the funnel cloud which briefly touched down two or three times during approximately a five minute period. The funnel was hanging down from a cloud which was at the trailing edge of a bigger and much darker one. Localized heavy showers were reported prior to the passage of the funnel associated with the darker cumulo-nimbus located to the east of the funnel. Surprisingly, no thunder was reported and only cloud-to-cloud lighting was briefly observed across the western edge of the cloud.

Picture #8 shows a photograph looking southwards taken by Mrs. Johanne Miller from the 12th floor of her apartment located near Kipling and Albion Rd. (figure 12). A small cone hanging down from the parent cloud is clearly visible on the photograph. Also, note the milky appearance of the area where the funnel reaches the ground which suggest a funnel tilted to the west at an 15 degree angle from the vertical. Mrs. Miller mentionned that the picture was overexposed and that the scene was much darker than what it appears to be. Also of importance, she added that before and after the time when this picture was taken the funnel was much darker and clearly visible for one or two minutes. Although difficult to distinguish on this copy, notice the slightly darker shades on the left of the picture (to the east) suggesting the presence of the thicker darker cloud under the cumulo-nimbus.

A close examination of the picture suggests that the funnel cloud also touched down earlier along Belfield Rd. between highway 27 and Martin Grove Rd.. This is confirmed by Mrs. Miller's comments. However, no damage was apparent in that area.

3.3 Intensity assessment and classification

Following the on-site investigation, the lack of clues make it very difficult to assess if the wind damaging event was tornadic or not. However interviews with witnessess along with a photograph of the funnel cloud made it clear that a weak tornado did in fact hit the Kipling Av. and Belfield Rd. area at approximately 17:30 EDT, 17 September 1988.

The damage assessment indicates that the event could be classified as a F0 tornado on the Fujita scale. Winds of the order of 90 to 115 km/h were likely through the path of the tornado (figure 14). However, over the Consumers Distributing's warehouse, damage on the roof possibly suggests stronger winds up to 140 km/h briefly touching down on the roof.

4. RADAR ANALYSIS

This section describes the King City radar observations of the tornadic storm. In general, there were only a few isolated small cells visible on radar for much of the day. Although some of the cells were thunderstorms, none of them appeared very severe. The cells formed on a southwest to northeast line suggestive of a larger scale feature.

4.1 Reflectivity data

At 20Z a line of TCu developed northeast of Guelph. One of the cells quickly developed into a Cb and reached a peak intensity at 2030Z just northwest of Brampton. Figure 14 shows the reflectivity field for that time at an elevation of 0.6 degree. Reflectivities of up to 50dBZ were reported with that cell. From 2020Z to 2030Z, the storm echo tops increased from 4-6km in height to 8-10km indicating a very rapid growth.

The precursor cells were moving east to northeast prior to 2030Z then veered to the right (east southeast) after 2040Z. This motion is often associated with the movement of tornadic storms. However, the area of 8-10km echo tops moved southeastwards through the whole period with the mid-tropospheric flow. This is confirmed by the 00Z Buffalo hodograph (fig. 10) which clearly shows the wind shear between the surface up to 4 km.

Later on, a cell redeveloped rapidly around 2120Z northwest of Toronto and triggered a weak tornado just northeast of Pearson International Airport. Figure 15 shows the reflectivity field at 2120Z for an elevation of 0.6 degrees. Note the southwest to northeast organization of the cells. Prior to 2120Z, these transverse lines formed and moved eastward at different speeds allowing the lines to merge.

The rapid growth and decay of the > 64mm/hr area on the MAX_R image around 2030Z and 2130Z indicates clearly a rapid storm development. The rainrates at the 1.5km CAPPI level were generally fairly low, occasionally reaching 64mm/hr for a short period of time. The maximum reflectivity observed with the complex was 56dBZ at 3km. For most of the life of the storm, the echo tops were not very high (the maximum observed was 8-10km) and at no observed time did the 40dBZ intensities exceed the 5.5km threshold of the Severe Storm chart. Also, the storms were isolated and very small in areal extent but some relatively high reflectivities (> 50dBZ or > 64mm/hr) and hence strong reflectivity gradients were occasionally reported (sharp gradients are often reported with severe weather).

An apparent hook or comma shaped echo (suggesting weak echo regions with high updraft speeds and rotation with the thunderstorms) may be visible (for example at 2040Z on the MAX R chart). However, this may be a pattern that results as two cells merge.

In addition, there were very few cloud to ground lightning strikes observed from the complex (only three strikes were registered).

4.2 Radial velocity data

An important clue as to the development of a possible severe storm was available from the analysis of the radial velocity data. In real time, the mesocyclone algorithm identified a mesocyclone with the appropriate storm complex beginning at 2030Z and continuing through to 2120Z. Mesocyclones are indicated by small colored circles superimposed on the reflectivity data as seen on figure 14. In the United States, mesocyclones have been found to be associated with tornadoes 50% of the time and with severe weather 90% of the time (JDOP 1979). The initial measurement at 2030Z was for an azimuthal shear of 18m/s/km and this was accompanied by angular momentum values in excess of 100kmm/s. These values fall within the preliminary criterea to identify a "tornadic" mesocyclone which are defined when the mesocyclone shear parameters exceeds 10m/s/km and angular

momentum parameter exceeds 100 kmm/s (*).

(*)..**footnote..[The azimuthal shear is in this case the maximum radial velocity gradient between two consecutive radials within the mesocyclone. The "angular momentum" is a quantity which is actually proportional to the angular momentum (r x m x V, where r is the distance from the centre of rotation, m is the mass and V is the rotational velocity) within the feature since the mass of the air is not in the equation and a factor 2 has been dropped. This quantity is an indicator of mesocyclone development. (Joe(1988), Joe et al.(1988))]***

Qualitatively, the signature of a mesocyclone was clearly identifiable from the radial velocity field as well. The rotation signature was probably better defined in this case than any other case studied so far. This is especially true at 2120Z and 2130Z. Figure 16 shows the radial velocity field at 2120Z for an elevation of 0.6 degrees. The arrow points in the direction of mesocyclone responsible for the formation of the tornado.

The mesocyclone detection algorithm was replayed on the data using the treshold values set somewhat lower. In this exercise the algorithm identified the tornadic storm very early in its evolution at 20Z. At that time, the storm was in its early growth phase; before strong vertical development, before high reflectivities and before it veered to the right. The algorithm continued to identify mesocyclones for the next 90 minutes up to 2130Z. The "tornadic" mesocyclone category was still only surpassed at the same two time steps (2030Z and 2040Z). It should also be noted that initially the algorithm identified mesocyclones in each of two seperate storms. The two storms eventually merged and as this was occuring the algorithm merged two mesocyclones and identified one although two distinct signatures were visible on the radial velocity fields.

Quantitatively, the shear values were relatively high, generally greater than 10m/s/km but the angular momentum values were quite low, generally less than 100kmm/s. These thresholds were selected to identify tornadic mesocyclones based on the limited tornadic cases in Southern Ontario. Therefore, it should be noted that these are guidelines and are not statistically defensible. This case exceeded these thresholds only briefly and therefore can be considered to represent a weak mesocyclone that was tornadic.

5. DISCUSSION AND CONCLUSION

On Saturday 17 September 1988, a weak tornado briefly touched down around 17:30 EDT just northeast of Toronto's Pearson International Airport, in the Kipling Av. and Belfield Rd. area.

The on-site investigation along with interviews of witnesses suggest that the event be classified as an F0 tornado on the Fujita scale.

The radar analysis confirms the presence of the tornado. A tornadic mesocyclone was positively and unambiguously identified using Doppler radar both from the mesocyclone detection algorithm product and from the radial velocity products. The mesocyclone was weak and only briefly exceeded the preliminary guidelines for a tornadic mesocyclone.

Also, in hindsight, possible clues as to the severity of the storm were identified using conventional radar data: rapid storm development along with occasionally strong reflectivity gradients and veering motion of the storm from the east-northeast to the east-southeast.

The synoptic and mesoscale analysis support, marginally however, the development of severe storms. The sharp vorticity trough, the moderately unstable air, the moisture feed and the relative position of the low and high level jets were all elements somewhat conducive to the development of severe weather.

However some questions remain as to the very isolated nature of the thunderstorm cells that developed that afternoon. The triggering of the isolated strong cells after 20Z is reasonably explained by the breaking of the 850 mb warm air lid as the surface temperatures and dew points reached 24 degrees and 19 degrees respectively. But why more thunderstorm cells didn't develop under these conditions remains somewhat unexplained. The answer probably lies in the fact that each element was marginally supporting the development of severe thunderstorm cells and these elements were at their strongest at a specific time. The sharpness and narrowness of the vorticity trough along with the weak surface convergence (section 2.1) are some of these factors. (...more to come here....)

On another level, it is important to discuss the forecastibility of such isolated marginal severe weather events. The relatively short lifetime, the very localized nature of the cell which became severe, and the lack of deep vertical development made this case a difficult one to forecast. However,

the use of radar and specifically Doppler radar might have aided in the nowcasting of the situation.

In this case, the existance of the strong cells remained unoticed by the forecasters on duty. However, the mesocyclone detection algorithm identified the mesocyclone more than one hour before the tornado touched down. This suggests that efficient means of indicating the potential of severe weather through automatic radar data assessment are needed in real time.

In a broader perspective, the decision to issue or not issue watches and/or warnings based on a assessment of marginal severe weather is certainly not obvious.

Also, climatologically, one might ask how often this type of marginal severe weather event occurs and remains unobserved.

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ANNEX 1. SEVERE WEATHER REPORTS

The witness's account of the event is detailed in this section. The location of each sighting is given by their corresponding number on figure 13.

A-1 Joanne Miller, 2435 Kipling Ave., near Albion, #1204 (742-8111)

From her balcony, located at the 12th floor and looking southwards, she and her family had a clear view of the funnel cloud. It dipped down to the surface during one or two minutes in two occasions between 17:30 and 17:40. Reacting quickly, she grabbed her camera and took a picture of the funnel (picture #8). She mentioned that the funnel was very dark and much more visible than on the photograph.

A-2 Ed Pasquale, Suscana Corp., (896-4444)

Mr. Pasquale, who is a ATR pilot and sounded very knowledgable about the weather, was driving south on highway 400 between Finch and Sheppard where he saw a distinct funnel at a 45 degree angle to his right (southwest). The funnel was hanging from a cloud west of a much darker one. The funnel extended down at a 15 degree angle from the vertical. Later he drove into a "very heavy shower". He evaluated the time of the event at approximately 17:30.

A-3 Ken Newton, 50 Lockaby, (241-3457)

From his appartement located in the Jane and Weston rd. area Mr. Newton was looking in the northwest direction. He saw the funnel cloud just to the west of a heavy downpour. He mentioned that the bottom of the cone shaped cloud was going up-and-down. He didn't seem too sure about the time of the event but thought it occurred around 17:00.

A-4 Janet Davis, Eglington and Weston Rd. area, (763-6853)

Looking northwestward from her balcony Mrs. Davis and her family had a clear view of the funnel for about 5 minutes. She mentioned that the funnel was touching down most of the time. She added that she saw a very brief flash that "could have been lightning". She evaluated the time of the event at around 17:30.

A-5 Mrs. Doyle, 8 Gracey blvd., Weston

From her second floor apartment, in the Kipling Ave. and The Westway area, she saw a blue and black cloud to the north. At the west end of the cloud she noticed a swirl which was quickly moving east and from which a funnel formed. The funnel dipped down three times and the last time it appeared to have touched down. She estimated the time of the event at 17:40.

A-6 Unknown name, (535-5400)

This person was driving westward on Eglington Ave. in the vicinity of Islington Ave. when he saw a narrow funnel to the north which was moving eastwards. He explained that "the funnel went down, then moved up and got thicker".

A-7 Charla Goodison, Newmarket (895-5818), wife of Barry Goodison who works for Hydromet.

Mrs. Goodison was on her way to the airport when she witnessed the tornado while driving through the Kipling ave. and highway 409 area. She observed the debris flying upwards and distinguished pieces of glass flying up in the air. She estimates the time of the event at 17:35.

A-8 Cheryl McNaughton, 50 Belfield Rd. (675-3622)

Mrs. McNaughton was inside the large building which had the roof damaged by the tornado. Looking northwards through a window that was overlooking the roof she was able to witness the passage of the tornado. She saw debris flying all over the place mainly bricks and pieces of wood. She also noticed a very loud noise that sounded "much larger that the one an aircraft would make".

A-9 Dave Murdoch, OAESC, (973-8771)

Mr. Murdoch was south of Georgetown, 3/4 miles north of Trafalgar Rd. where he made a series of observations between 16:30 and 18:00. He noticed at first a cumulo-nimbus embedded in strato-cumulus cloud based between 25 and 40 hundred feet. A series of buildups passed by with anvils on top which were developing rapidly as the clouds moved southeast. He was under the edge and mentioned that it "was dark as hell". He felt a few spinkles, didn't notice any roll cloud nor heard thunder but he saw cloud-to-cloud lightning briefly.

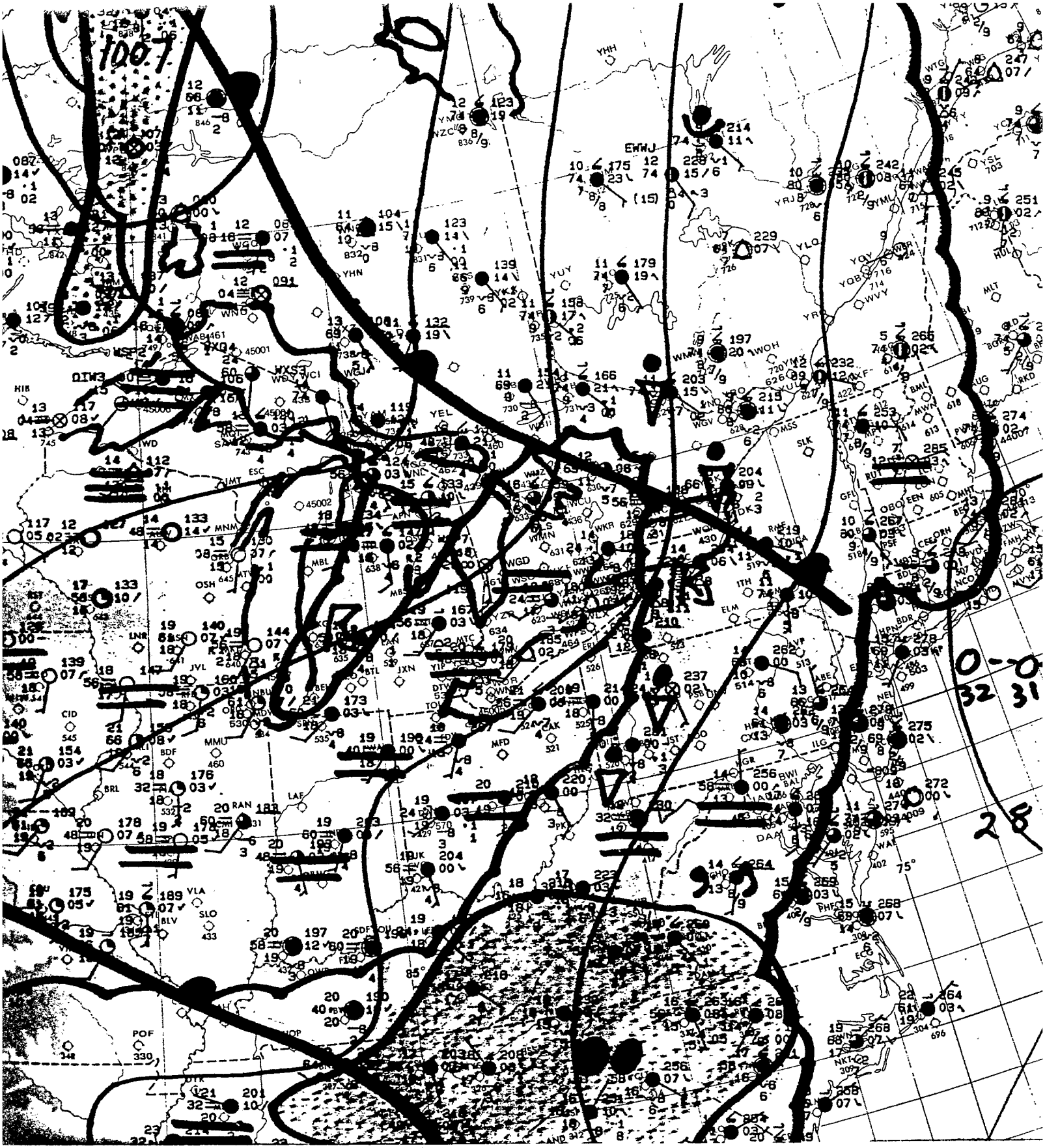


Figure 1. 12Z Surface analysis, 17 Sept. 1988

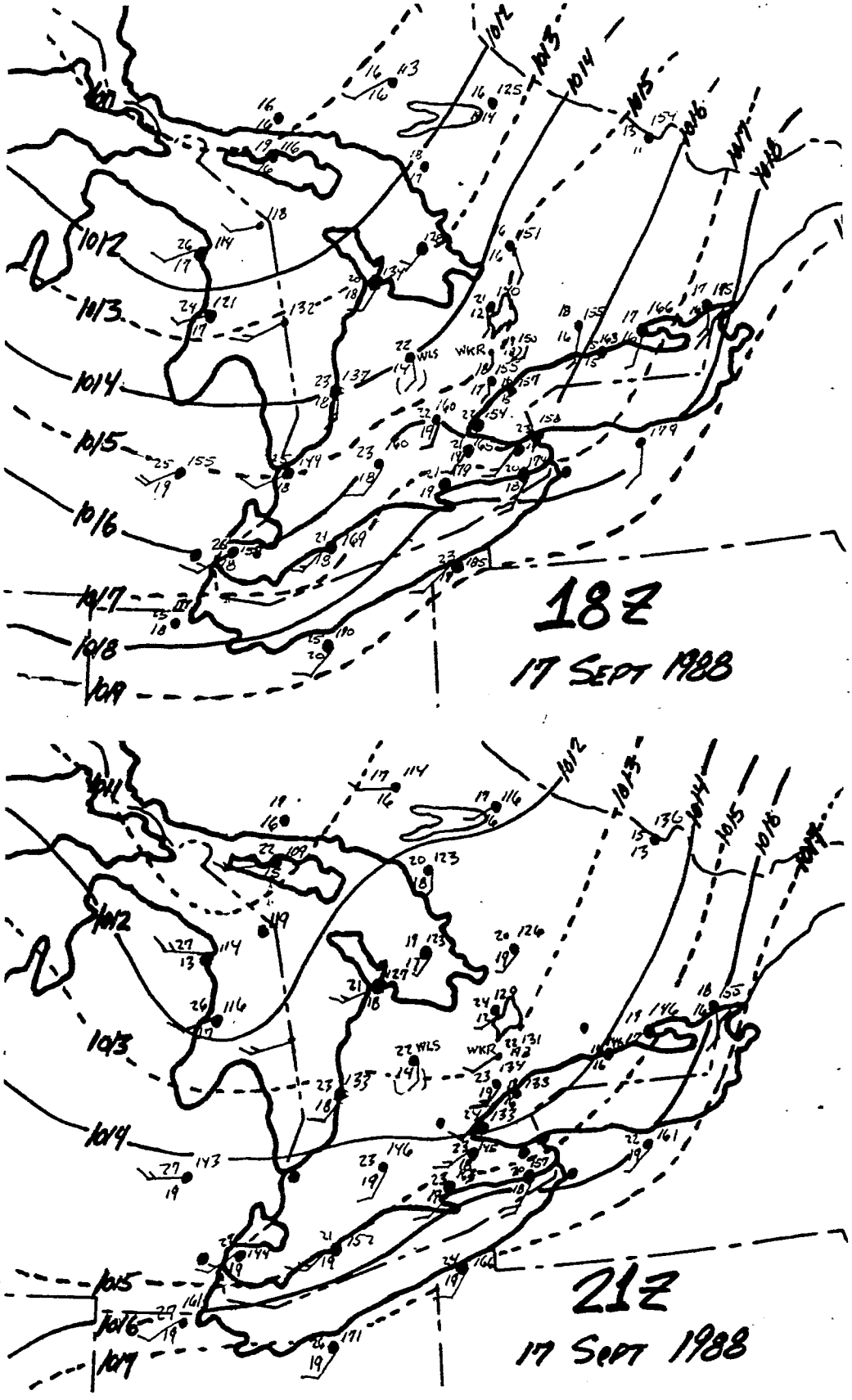


Figure 2. Surface analysis at 18Z and 21Z, 17 Sept. 1988

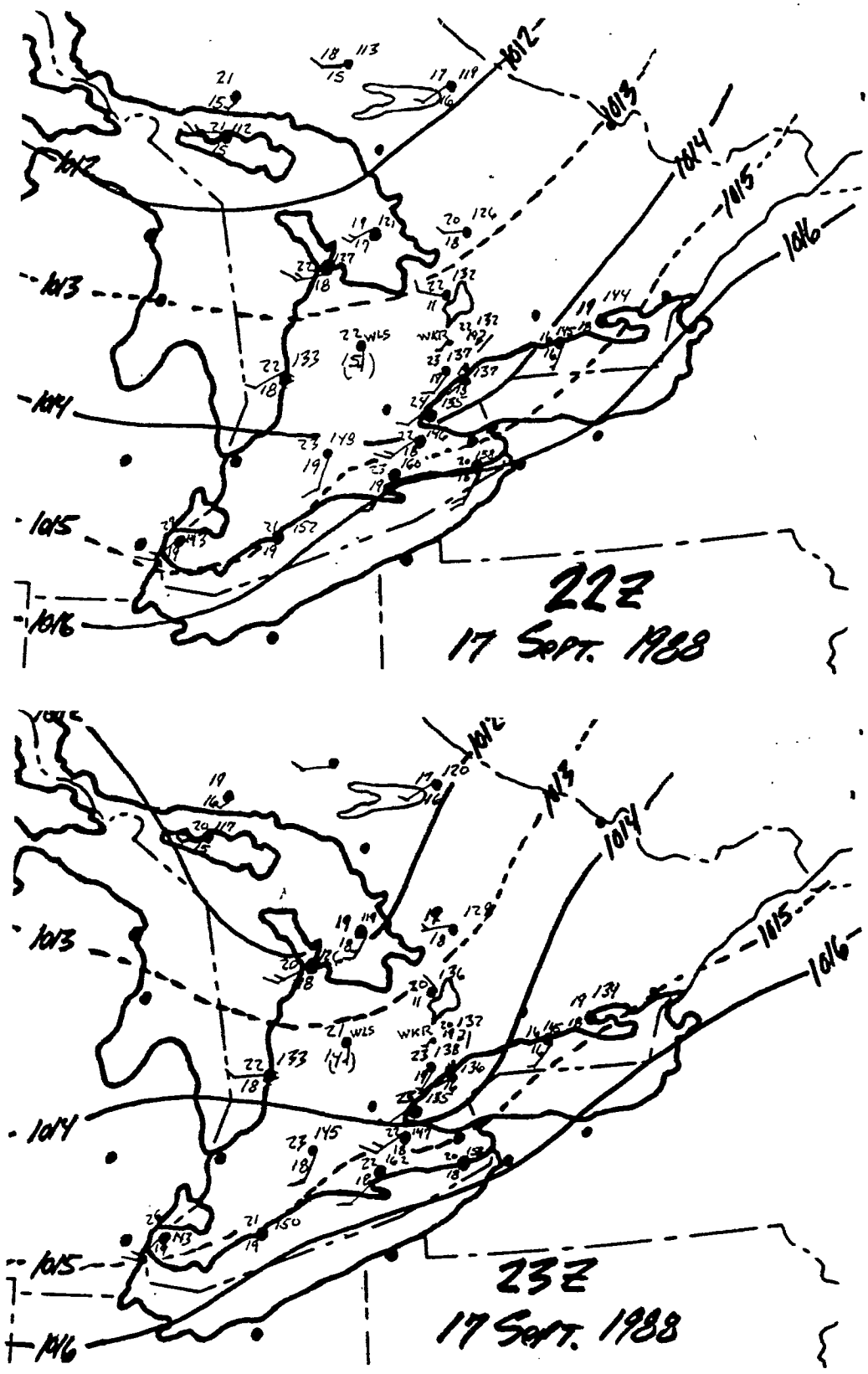


Figure 3. Surface analysis at 22Z and 23Z, 17 Sept. 1988

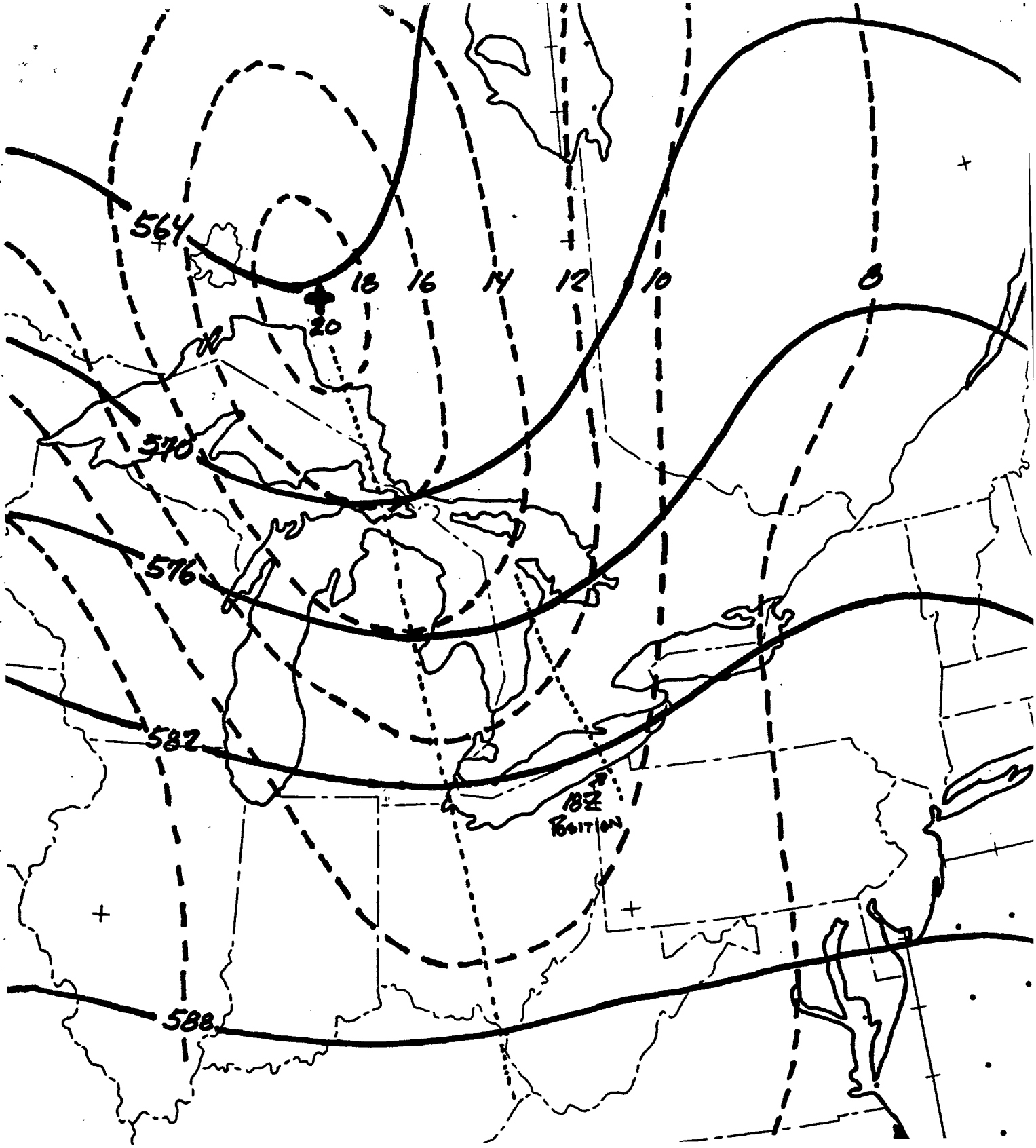


Figure 4. 500 mb height and vorticity fields at 12Z, 17 Sept.

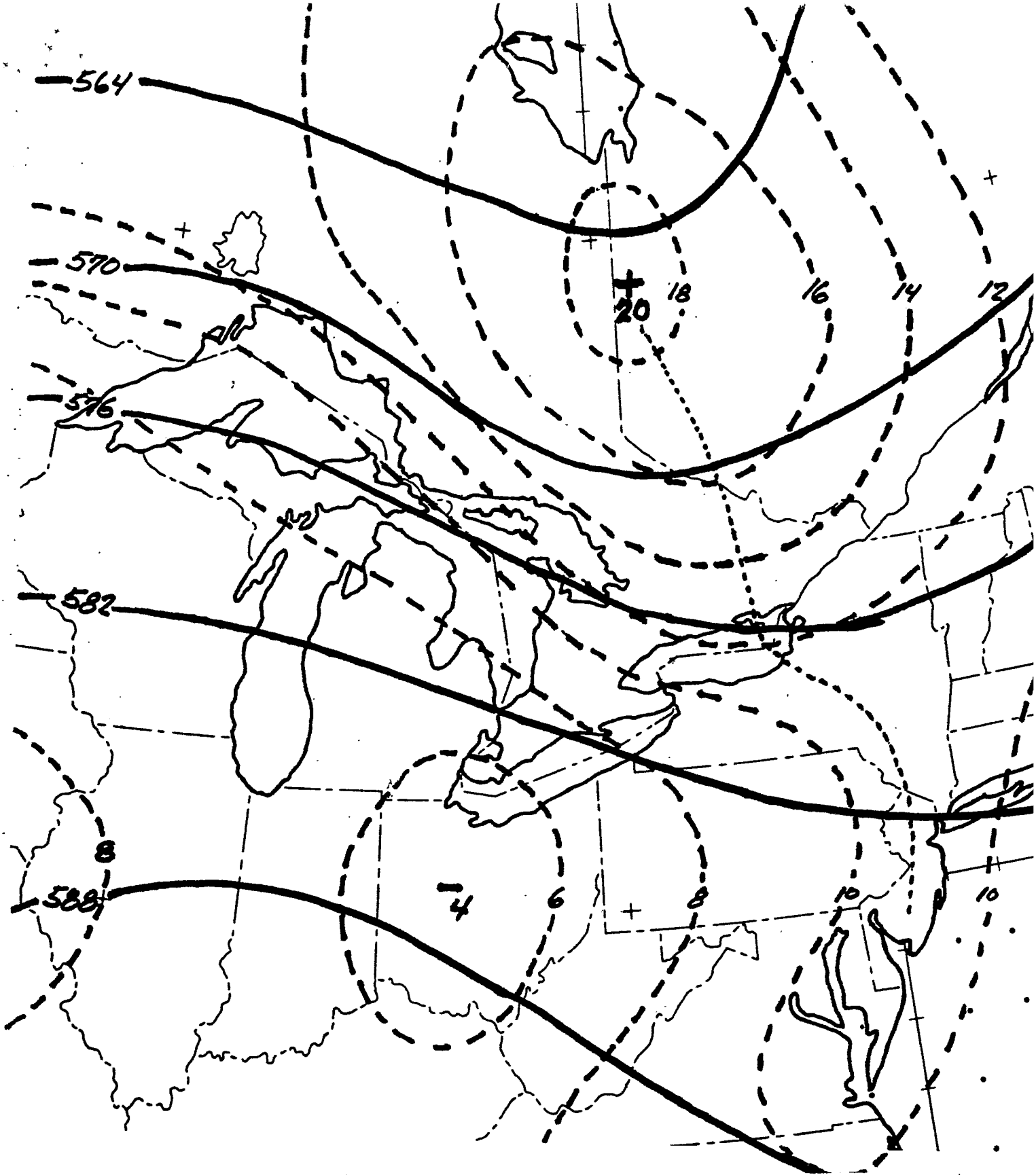


Figure 5. 500 mb height and vorticity fields at 00Z, 18 Sept.

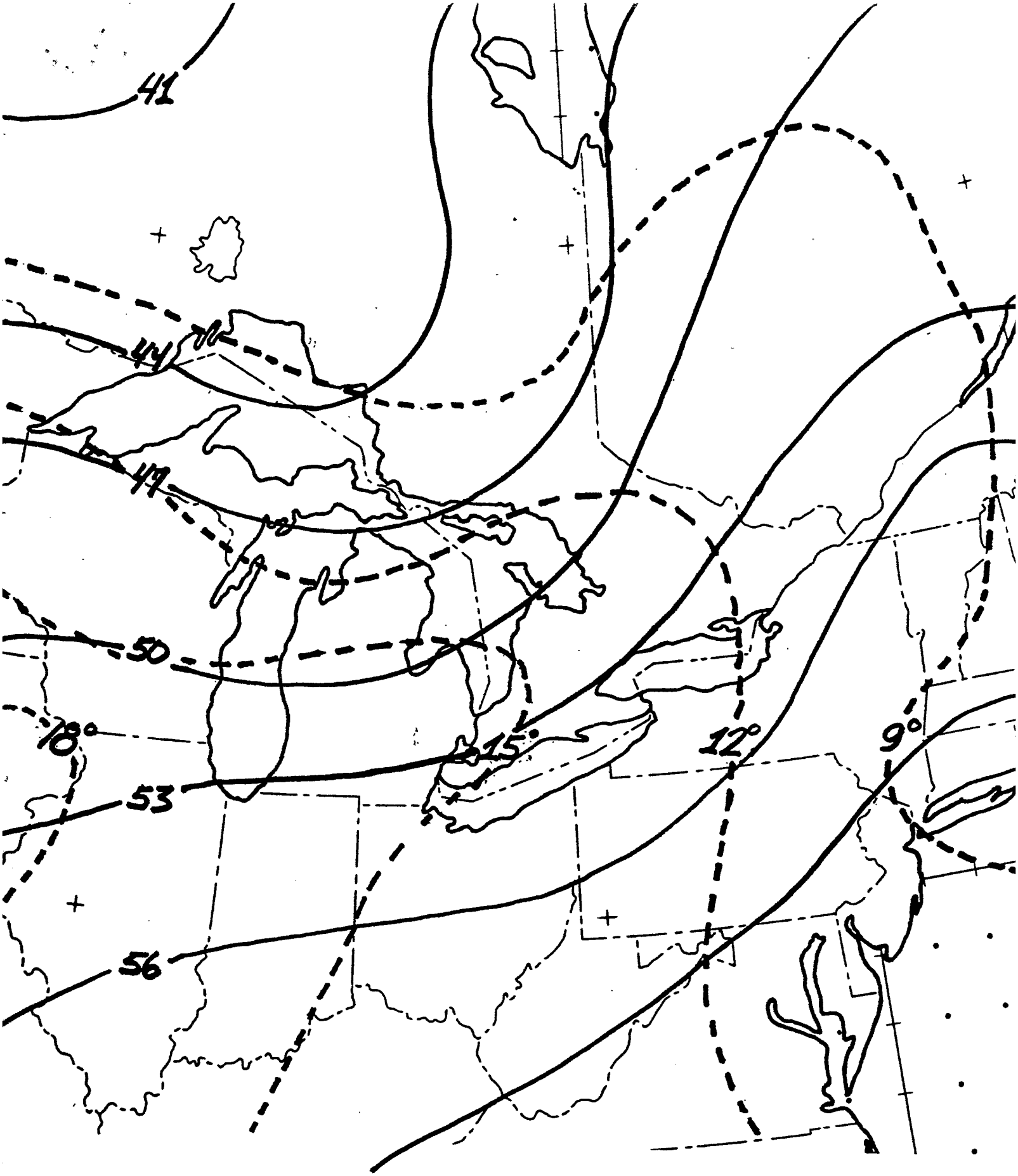


Figure 6. 850 mb height and temperature fields at 12Z, 17 Sept.

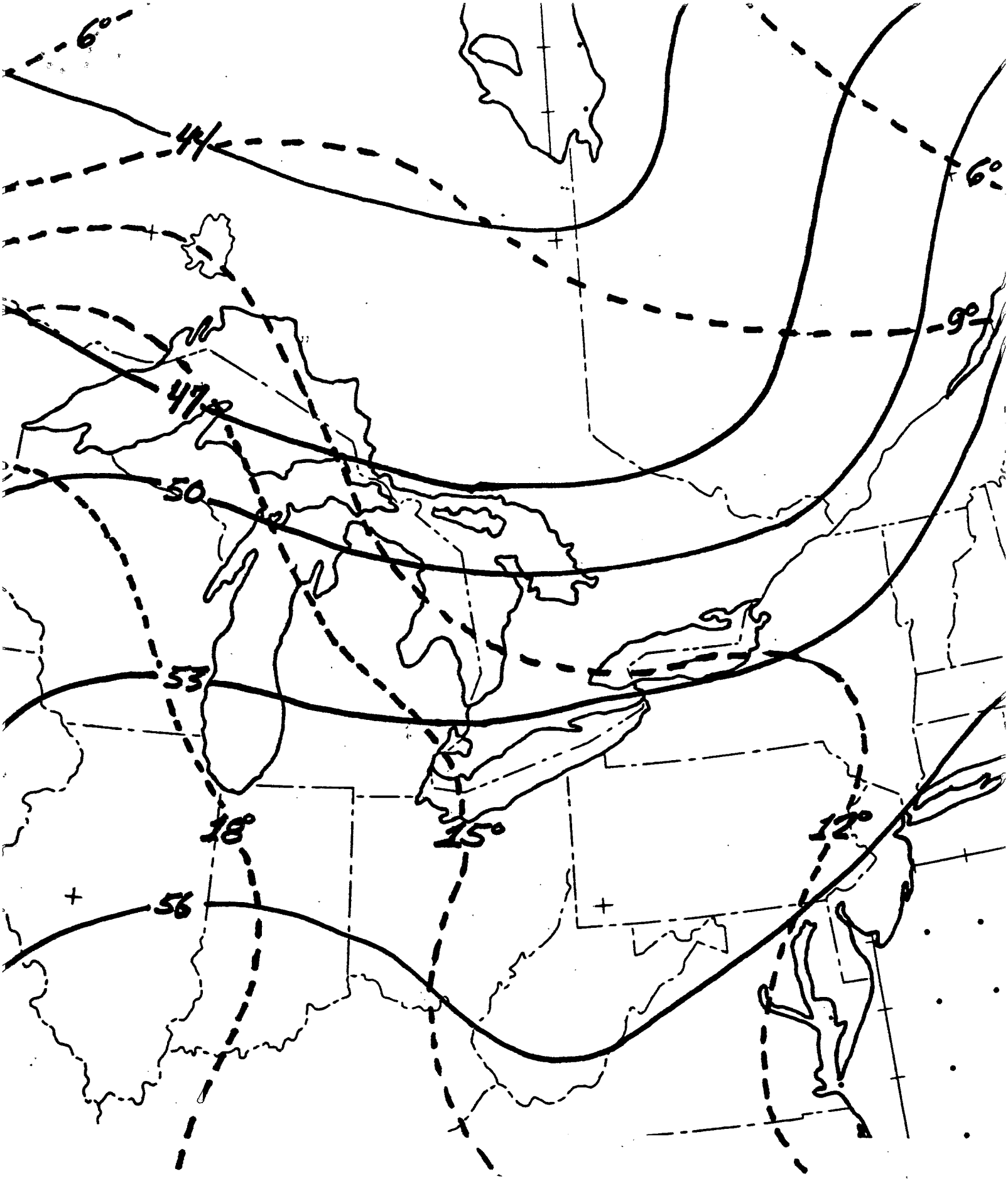


Figure 7. 850 mb height and temperature fields at 00Z, 18 Sept.

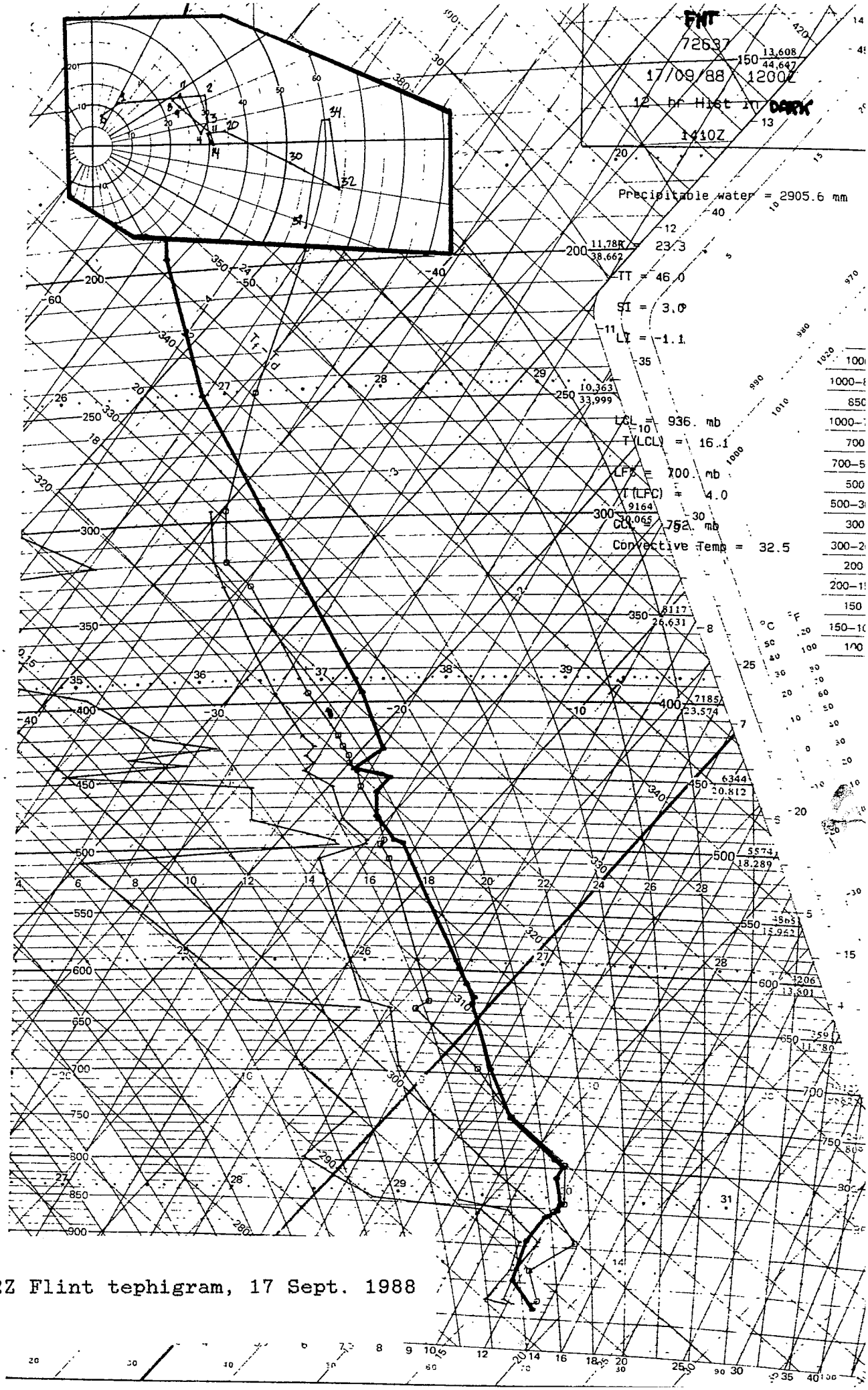


Figure 8. 12Z Flint tephigram, 17 Sept. 1988

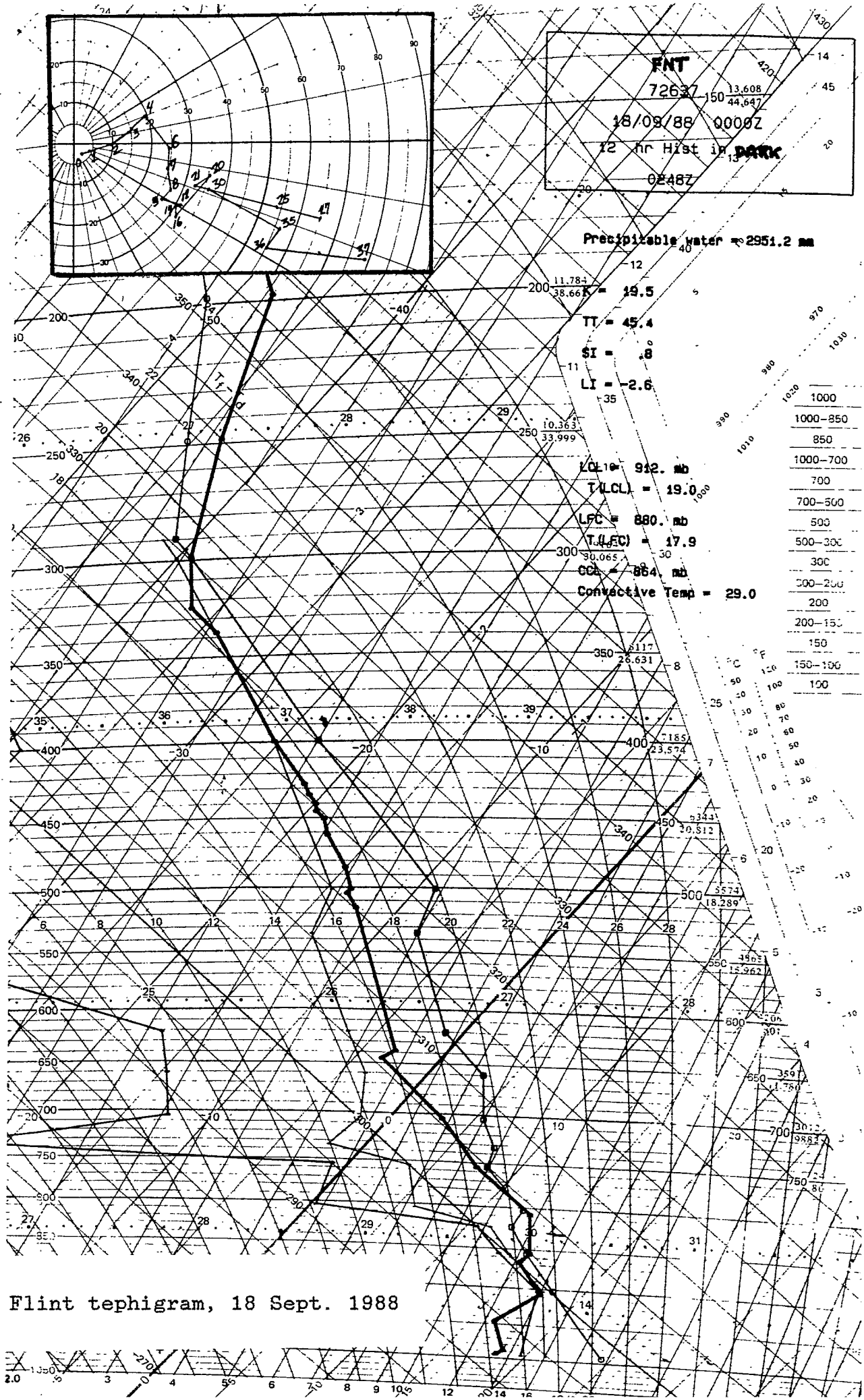


Figure 9. 00Z Flint tephigram, 18 Sept. 1988

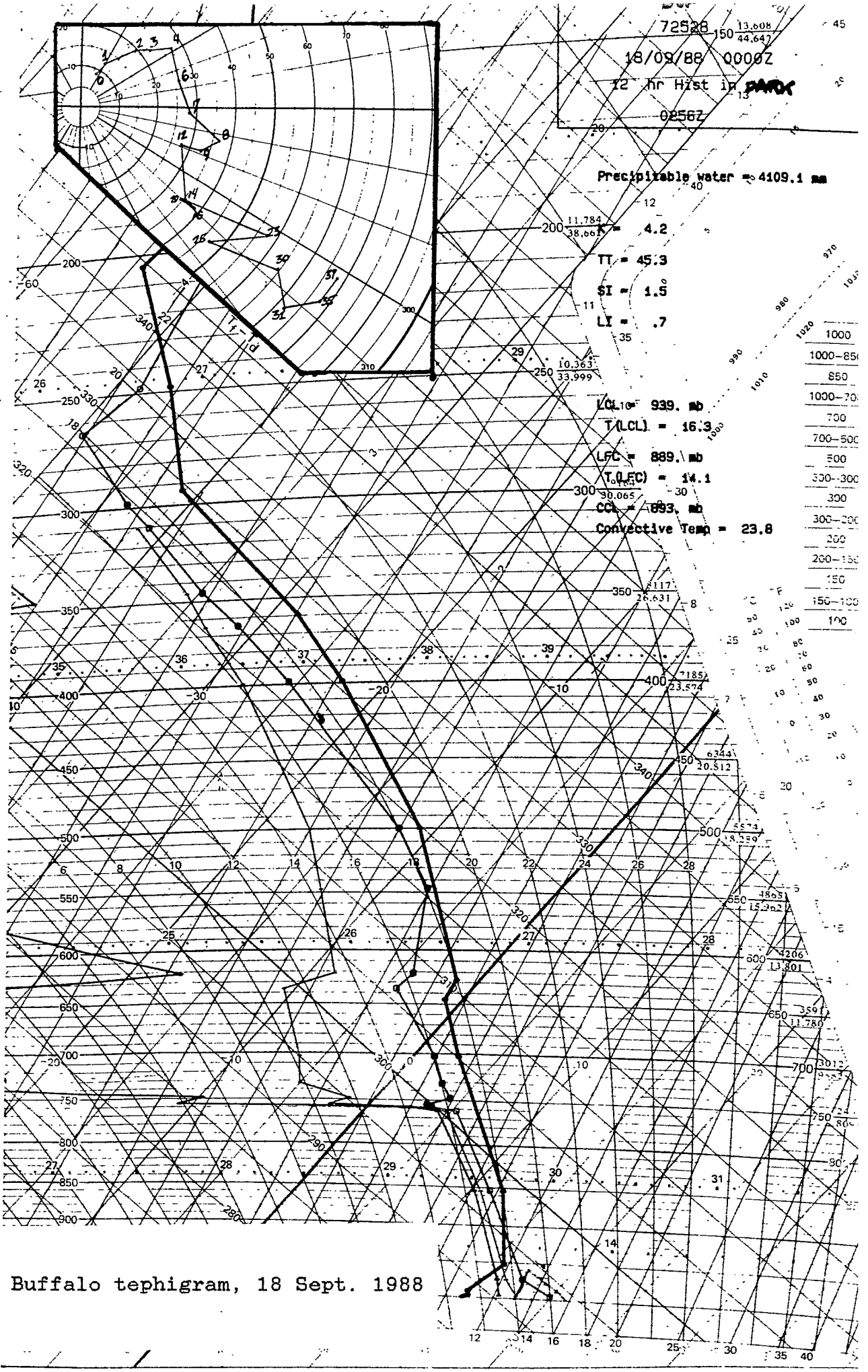
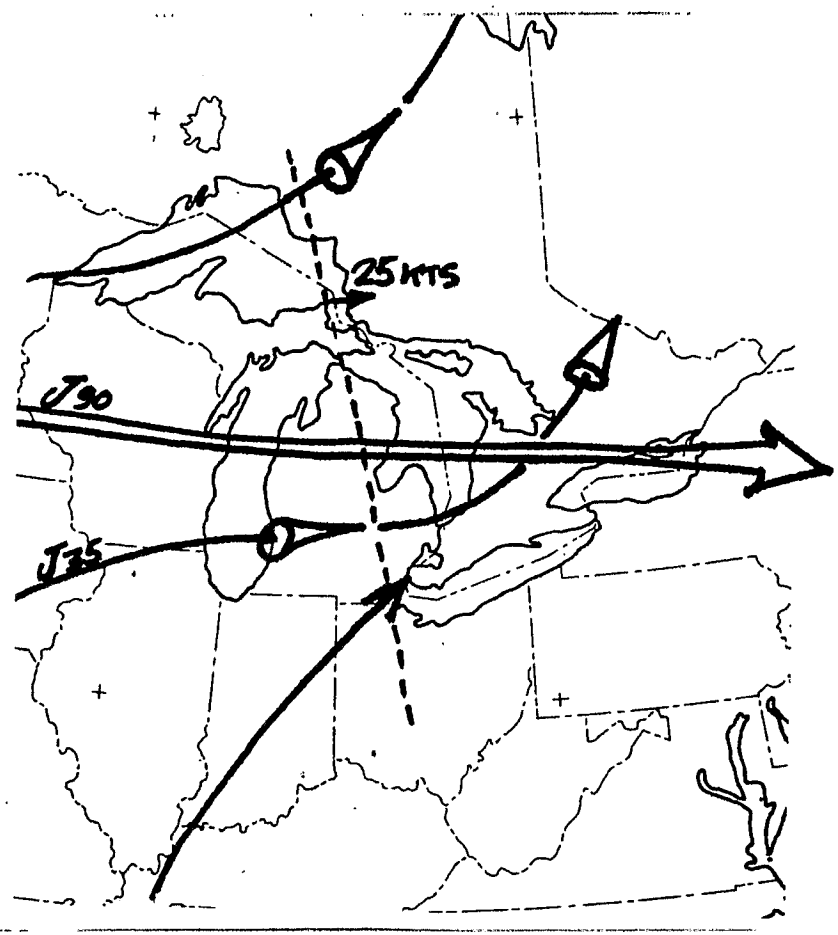
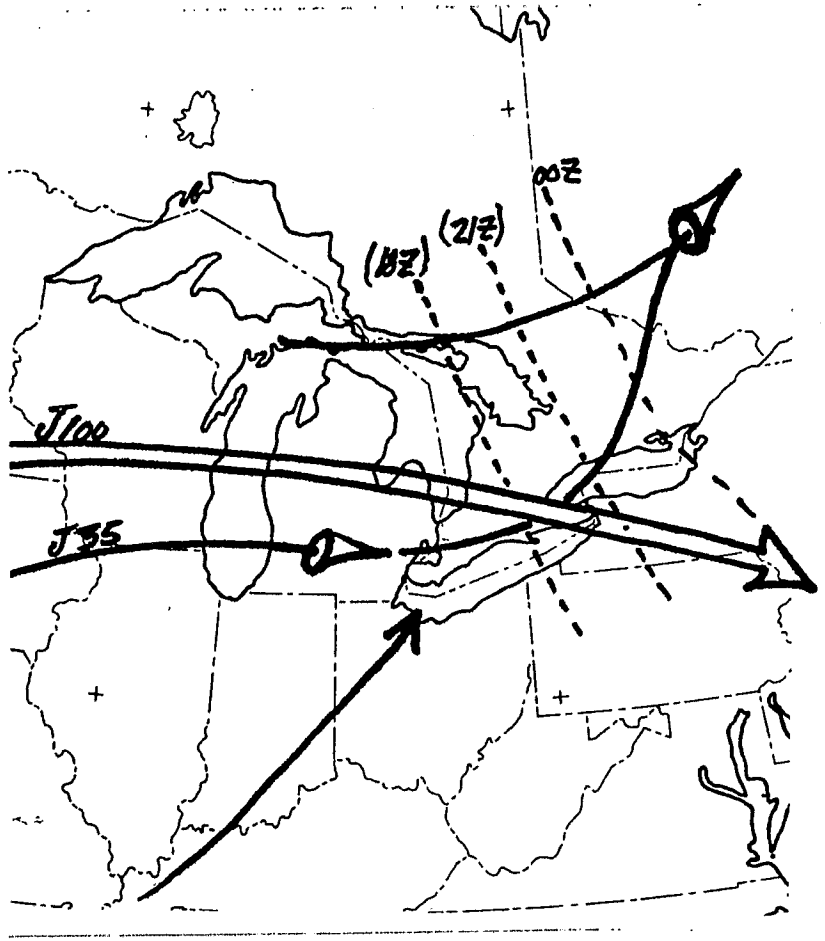


Figure 10. 00Z Buffalo tephigram, 18 Sept. 1988



12Z, 17 Sept. 1988



00Z, 18 Sept. 1988

Figure 11. Sever Weather composite chart: high level jet( ), low level jet( ), moisture axis( ) and 500 mb vorticity trough( ).

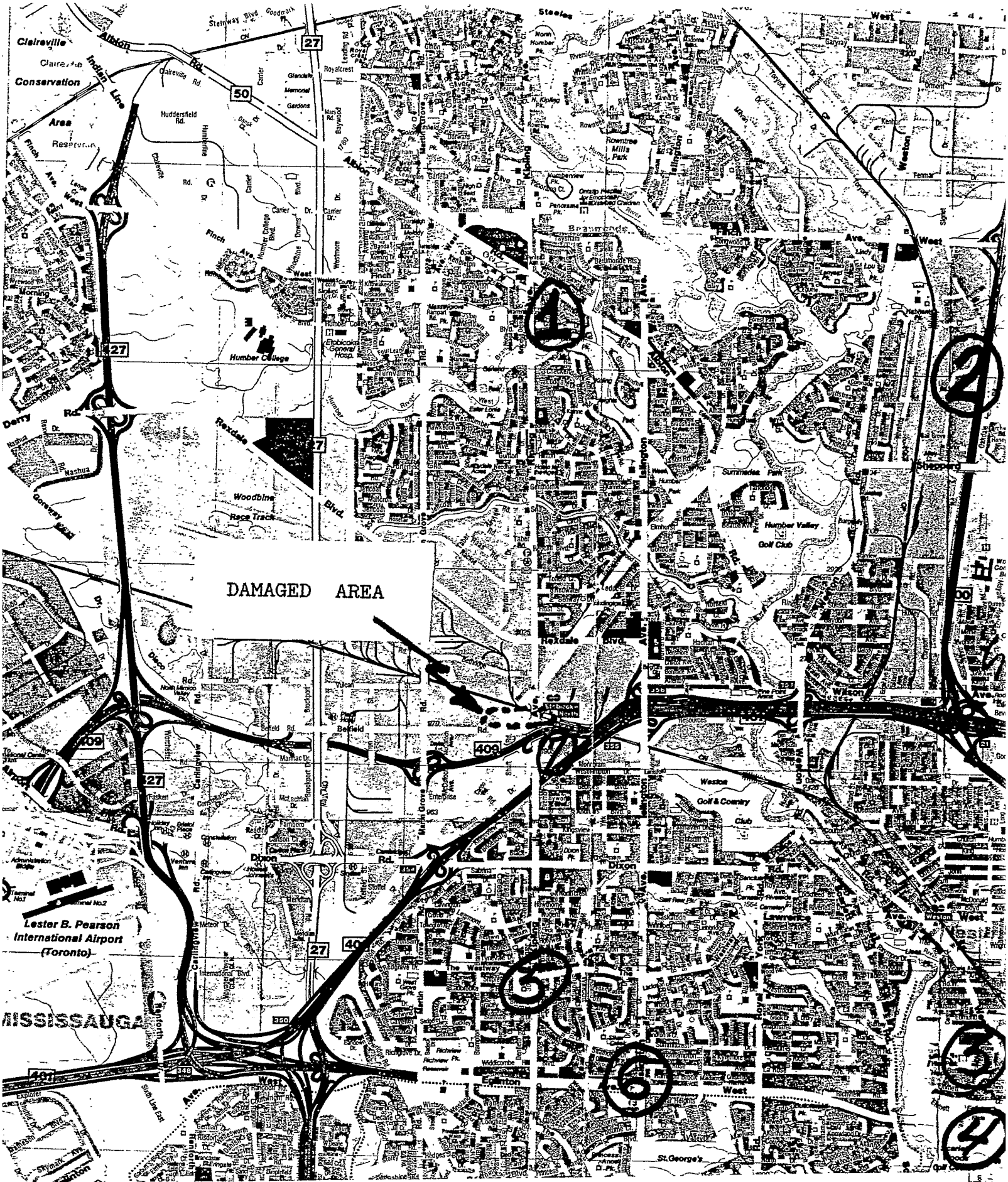


Figure 12. Map of the vicinity of the damaged area. The numbers indicate location of weather reports (Annex 1)

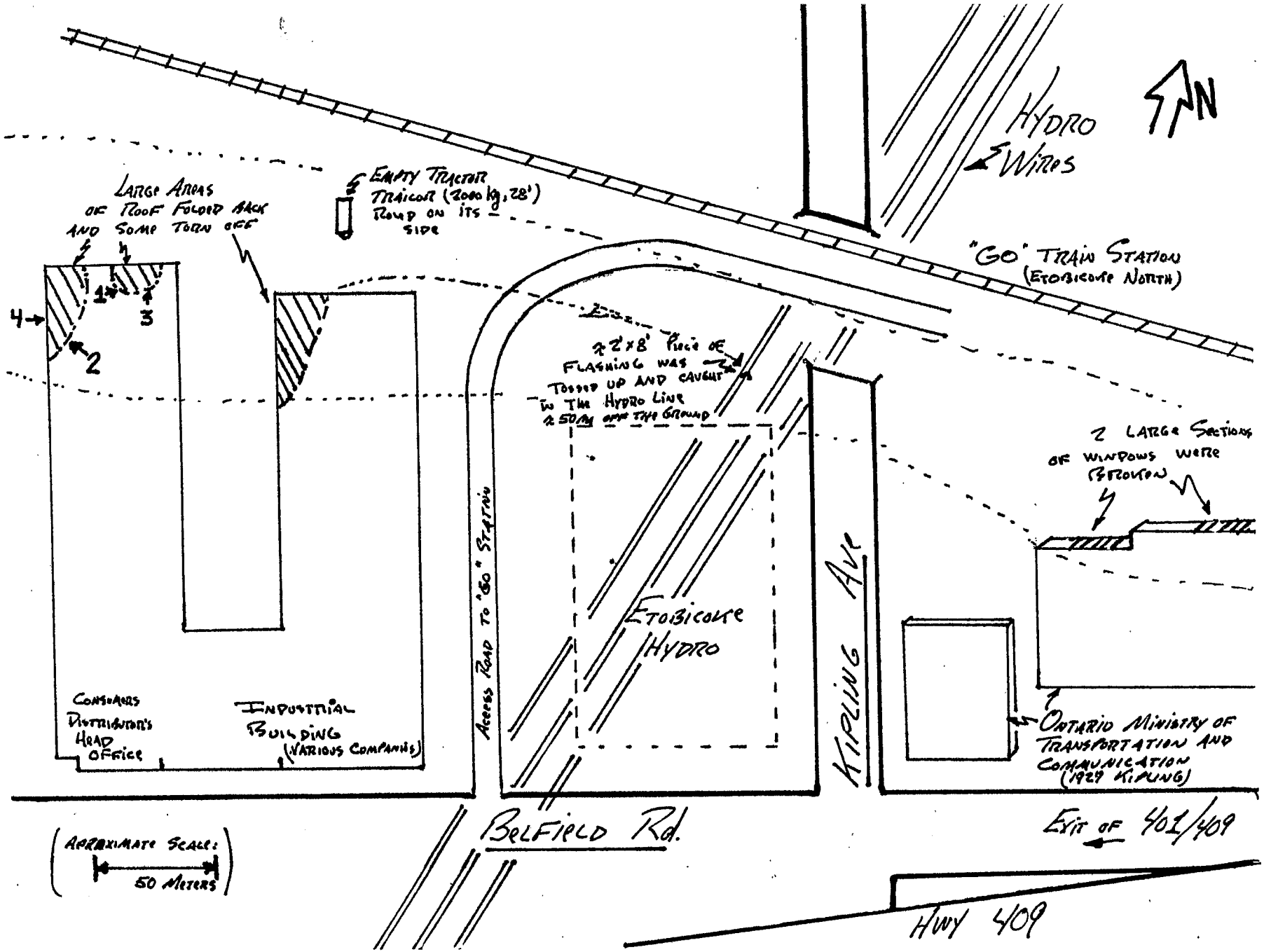
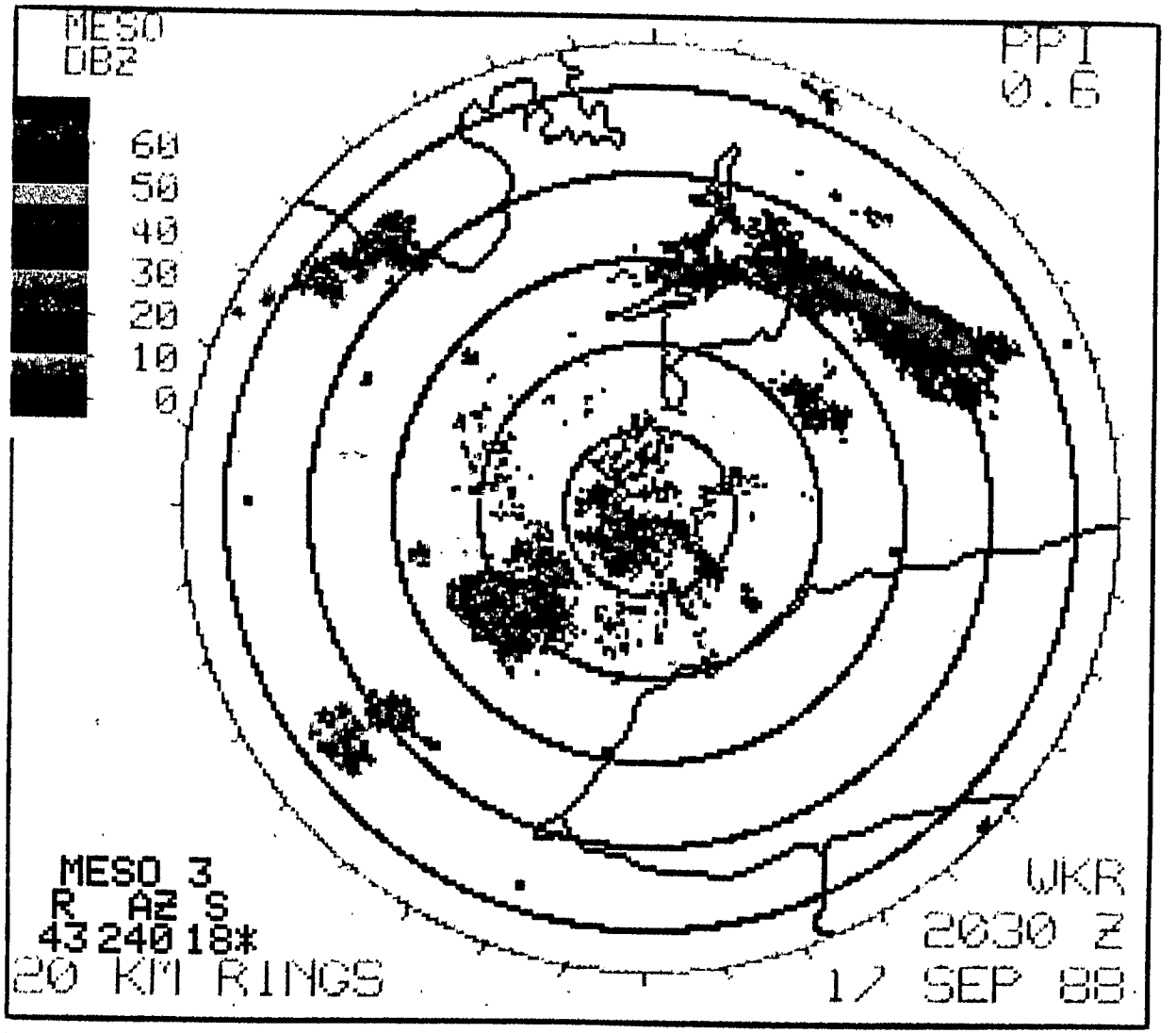


Figure 13. Detailed map of the damaged area



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Figure 14. 2030Z Reflectivity field at 0.6 degree elevation

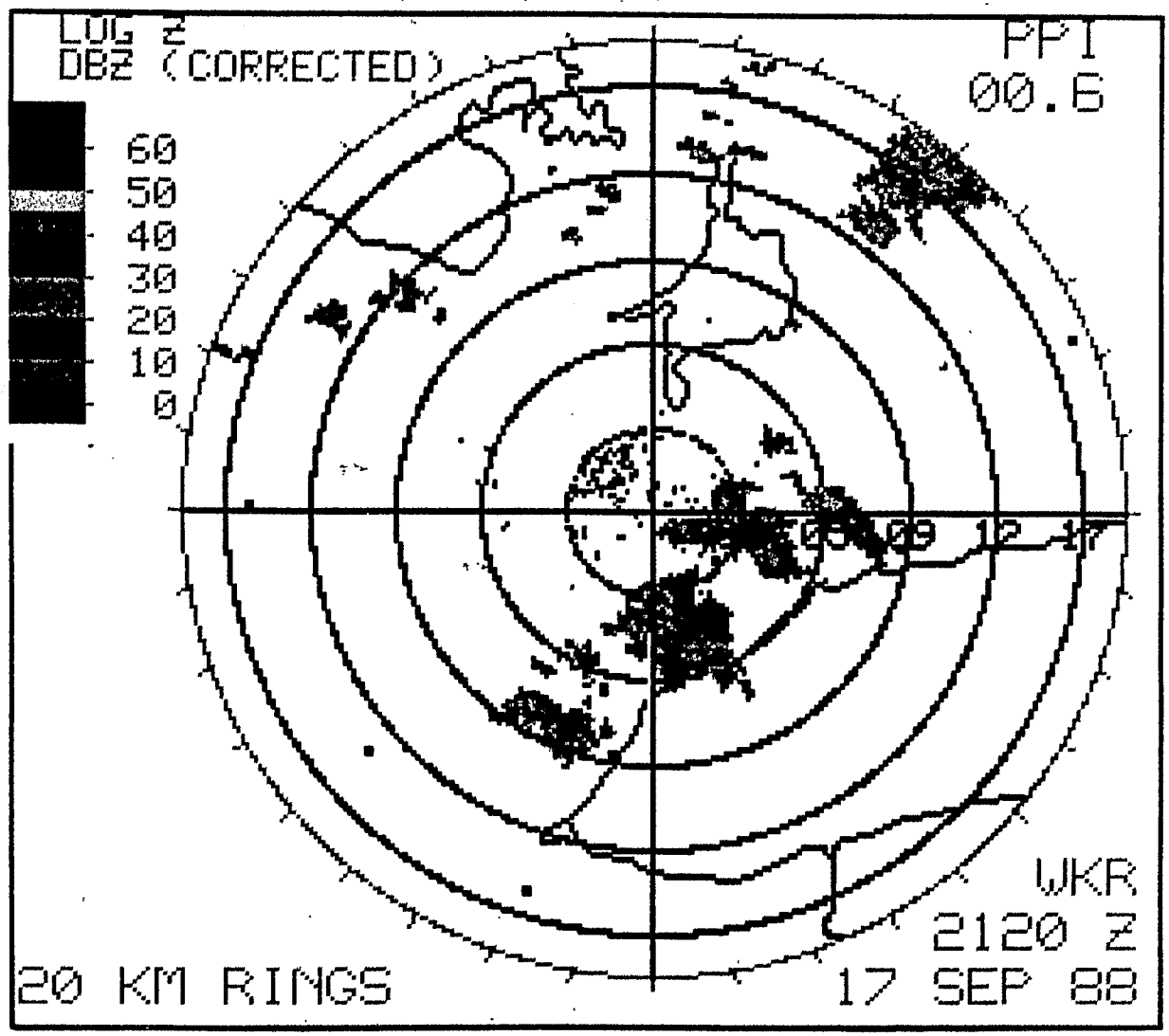


Figure 15. 2120Z Reflectivity field at 0.6 degree elevation

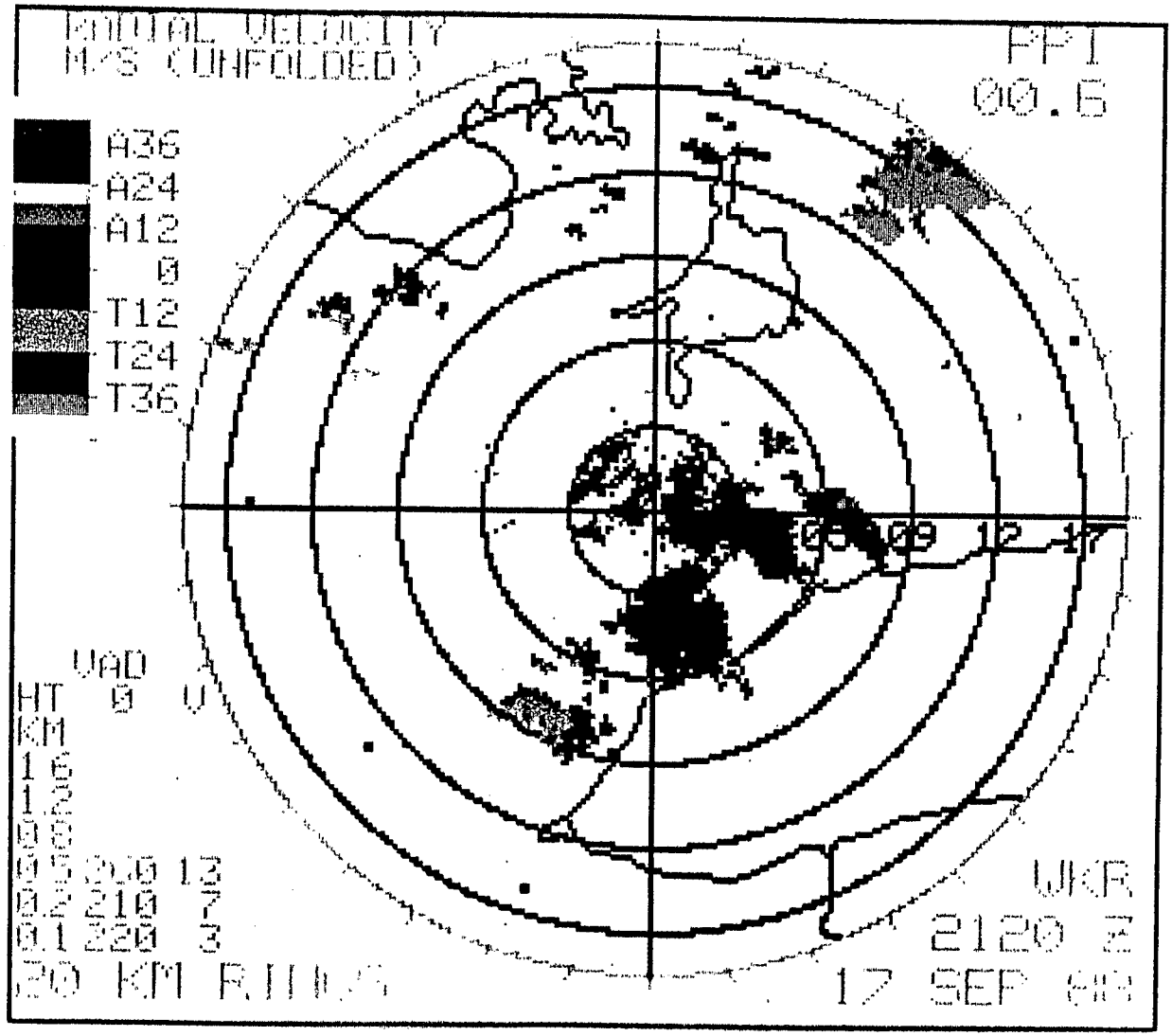
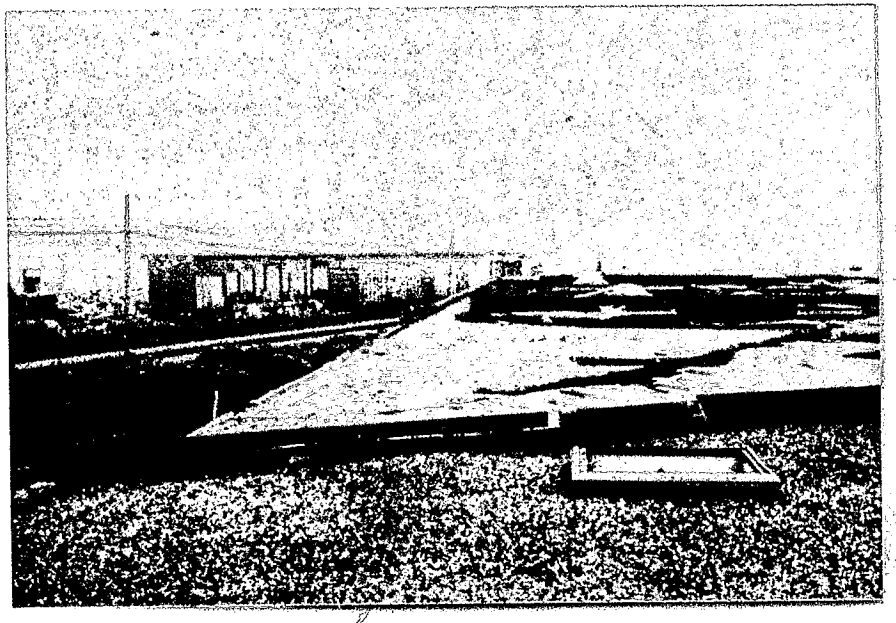
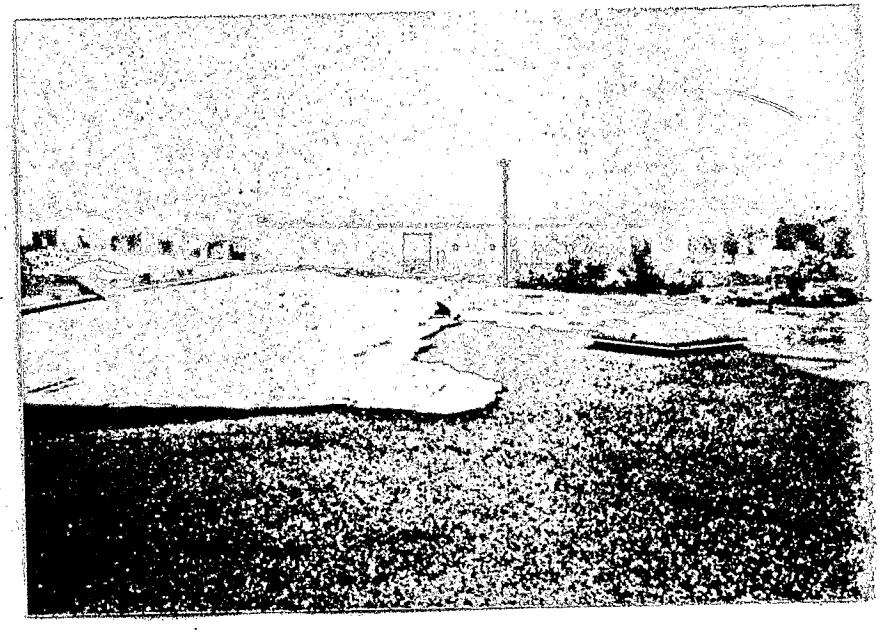


Figure 16. 2120Z Radial velocity field at 0.6 degree elevation

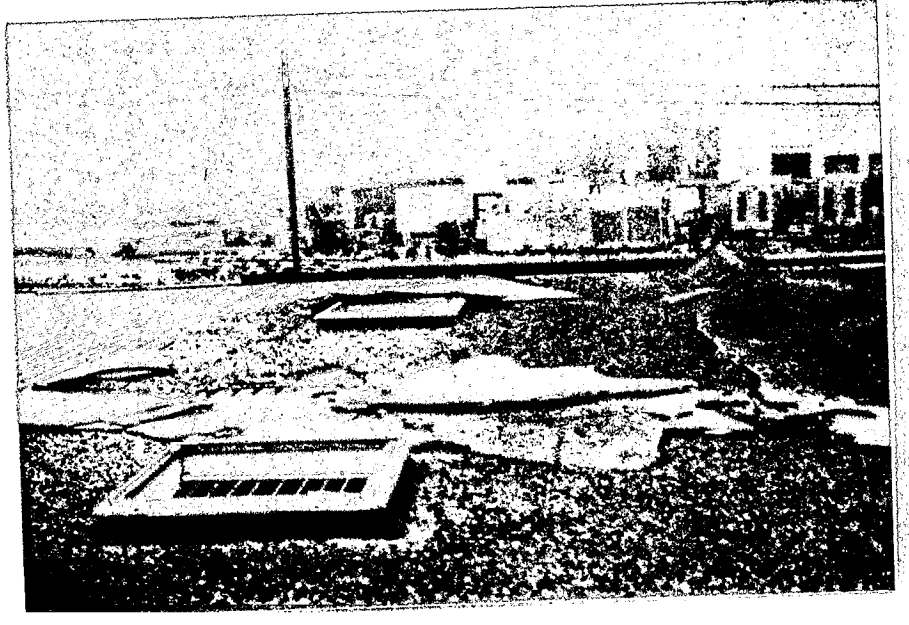


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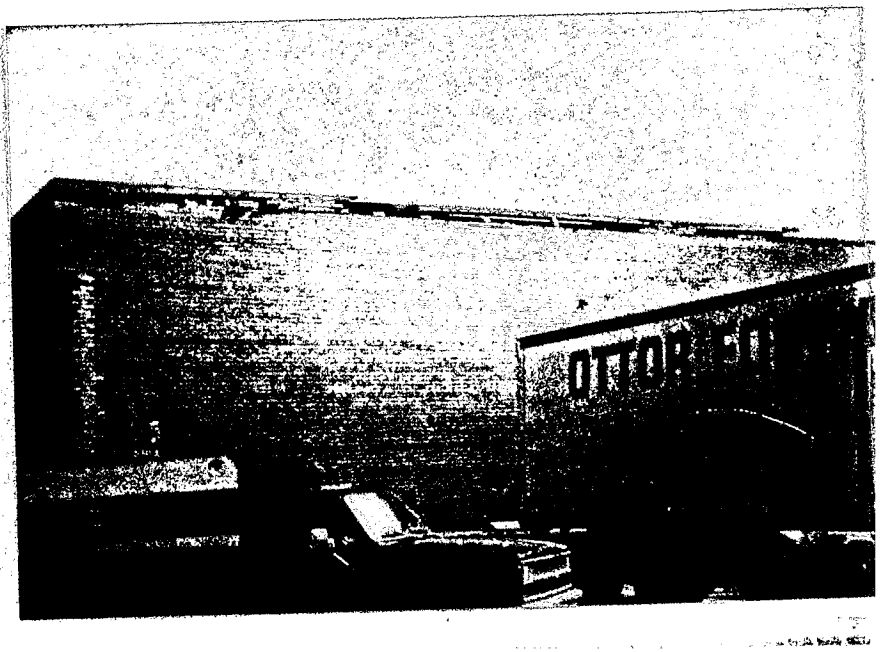


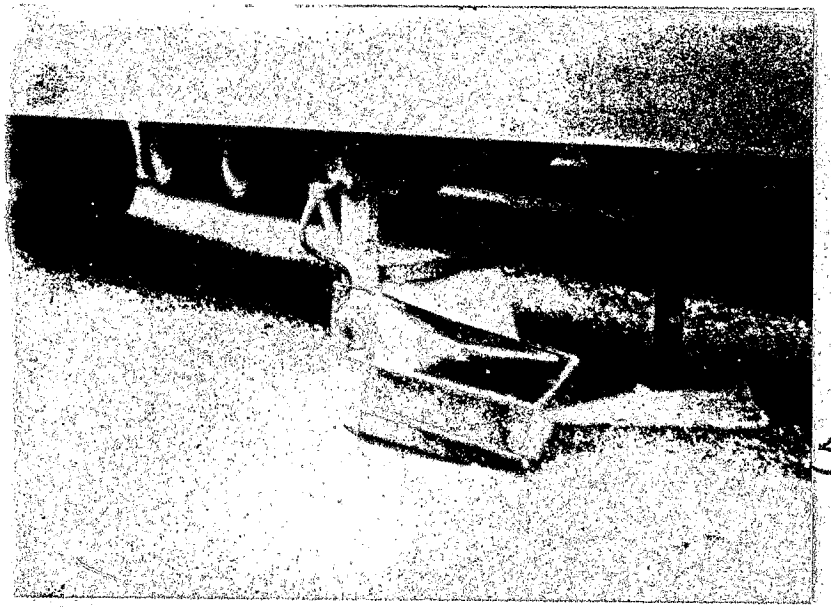
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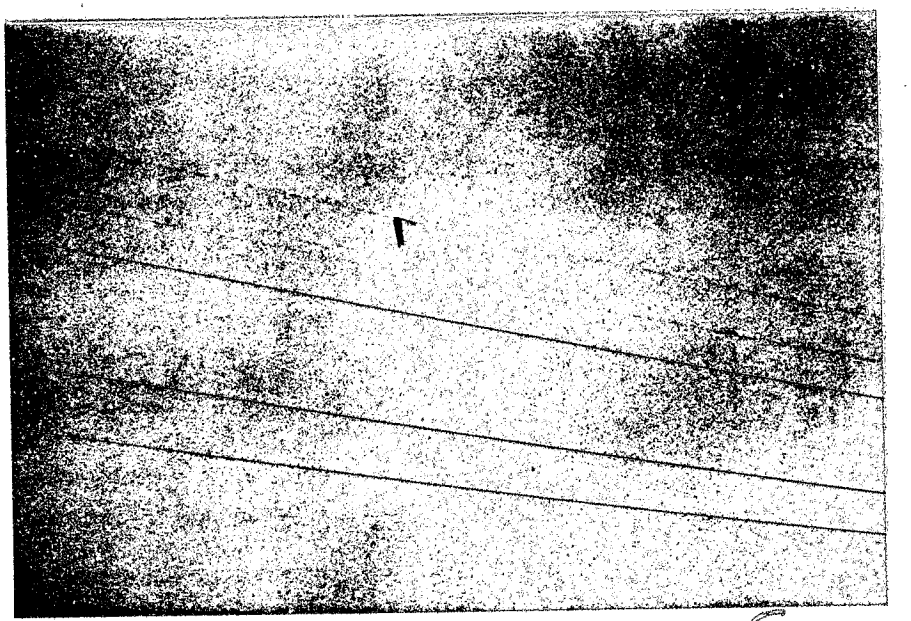


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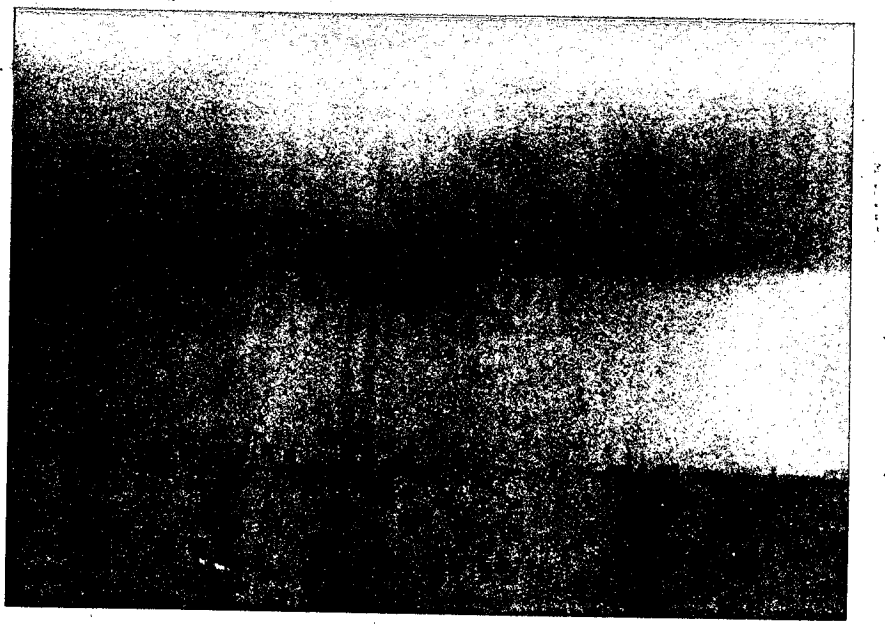


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Weather office checks report of small tornado hitting Metro; [FIN Edition]

Toronto Star. Toronto, Ont.: Sep 19, 1988. pg. A.27

Full Text (104 words)

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Environment Canada's Toronto weather office says it will investigate reports that a small tornado touched down in northwest Metro Saturday night.

No one was injured when a thunderstorm moved through the area about 6 p.m., but high winds damaged buildings along Belfield Rd. between Kipling Ave. and Martin Grove Rd.

Metro police said they have no reports of a funnel cloud in the area.

A weather office spokesman told The Star the service has no information which could confirm that a tornado of any size passed through the Metro area Saturday night.

The spokesman said its investigation was prompted by a televison news report.

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Section: *NEWS*
ISSN/ISBN: 03190781
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Wind storm confirmed as weak tornado; [FIN Edition]

Toronto Star. Toronto, Ont.: Sep 20, 1988. pg. A.6

Full Text (548 words)

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A small tornado hit the Rexdale area in northwest Toronto over the weekend and caused minor damage to some buildings, Environment Canada confirmed yesterday.

The Toronto weather office issued a statement yesterday confirming that a "class zero" tornado had touched down in the Kipling Ave.-Highway 401 area about 6 p.m. Saturday.

Tornados are ranked on a scale from zero to five, with five being the most severe. A class zero tornado usually has winds from 90 to 110 kilometres an hour (56 to 68 m.p.h.) and damages the outside of buildings, bends or uproots trees and knocks down fences.

The statement said a funnel cloud was preceded by several rainstorms, one of which spawned the tornado.

$15,000 in tropical fish

die in Scarbrough fire

Thousands of expensive tropical fish died when fire destroyed the North American Fish Breeder store on Kingston Rd. near Midland Ave. in Scarborough yesterday.

Owner Bob Bostanci hoped to have some of his stock moved to another aquarium by nightfall, but expected to salvage only about 3,000 from his inventory of 20,000. He estimated his loss at $15,000.

Rain may swell creeks

police tell parents, kids

Forecasts of heavy rainstorms have prompted Metro police to advise parents to warn their children to stay away from ponds, rivers and waterways today and tomorrow.

Heavy rainfall is expected to swell bodies of water, such as streams and ditches, in and around the Metro area.

Toronto seeks means

to let homeless vote

Thousands of homeless in Metro are being disenfranchised because they can't get on municipal rolls to vote in the November election without a residential address, Toronto Councillor Roger Hollander complained yesterday.

City council asked staff to report on what community facilities could be used as an address for the homeless for voting purposes.

City hall square gets

six mobile food carts

Space will be provided on Toronto's Nathan Phillips Square for six mobile food vendors, city council decided yesterday. East-end Councillor Tom Jakobek opposed the move, saying the square is already too cluttered. But Mayor Art Eggleton said vending carts add color to downtown.

Robber gets 8 years

for series of holdups

A 24-year-old man has been sentenced to eight years in prison for holding up several banks.

Kevin Gyugyei pleaded guilty in Toronto District Court to nine counts of robbery, one of attempted robbery and attempting to obstruct justice by giving police a false name, prosecutor John Hanbidge reported yesterday.

Street in west end

named for Mandela

A new street in Toronto's west end is to be named after Nelson Mandela, imprisoned leader of blacks fighting apartheid in South Africa.

City council yesterday accepted Councillor Joe Pantalone's suggestion that the Mandela name be given to a street in the Massey-Ferguson development in the Wellington St.-Strachan Ave. area.

Alderman seeks help

to pay court costs

Toronto Alderman Dale Martin has promised to reveal within six weeks the names of people or organizations helping him pay a $20,000 legal bill.

Martin lost a court bid to halt plans for the $400 million World Trade Centre development on Toronto's waterfront and was ordered to pay the legal costs of the city and the developers. Martin said yesterday he has launched a campaign for the money and will release the names of donors as soon as possible.

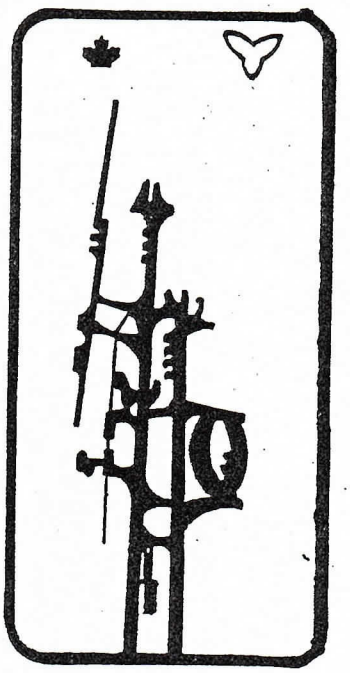
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People: Mandela, Nelson, Martin, Dale
Section: *NEWS*
ISSN/ISBN: 03190781
Text Word Count 548
Document URL:

- weak tornado occurs during rapid growth stage of low-topped, low-reflectivity storm
- suggests a convergence line at sfc was involved
- no mention of lake breeze, looks like LBs weren't occurring but LBs a la King might have had an influence

Sept. 23/96

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ONTARIO REGION TECHNICAL NOTES

ORTN-89-2

THE 17 SEPTEMBER 1988 WEAK TORNADIC STORM IN METRO TORONTO

BY

Richard Hogue
Paul Joe
Tom Nichols

June 1989

Environment Canada • Environnement Canada
Atmospheric Environment Service • Service de l'environnement atmosphérique

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Canada

THE 17 SEPTEMBER 1988 WEAK TORNADIC STORM IN METRO TORONTO

Richard Hogue[1]
Paul Joe[2]
Tom Nichols[2]

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5. DISCUSSION AND CONCLUSION

REFERENCES

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[1]Meteorologist, Ontario Weather Center

[2]King City Weather Radar Research Station

1. INTRODUCTION

During the late afternoon of Saturday 17 September 1988, a weak tornado briefly touched down in the Etobicoke area, just northeast of Toronto's Pearson International Airport.

During that day, the development of localized convective activity occured in southern Ontario. Following a few morning thunderstorms in the Georgian Bay area, widely scattered showers formed in the late afternoon. At 2030Z, two cells developed rapidly into small thunderstorms with tops briefly reaching the 8-10 km range. One of them spawned a very weak tornado. Due to their very short life span and limited spacial and vertical extent the duty forecasters dissmissed these cells as sources of severe weather. However, the analysis of the Doppler radial velocity data by the mesocyclone detection algorithm identified the potential for severe storms nearly one hour before the event. The use of this information would have significantly altered the nowcasting of this situation. This marginal event was therefore rather unusual because the reflectivity structure of the storm did not provide any classical indication of severity.

This Technical Note will examine the following aspects of the event. First, a synoptic and mesoscale analysis will examine the conditions under which the tornado developed. Second, a detailed analysis of the King City radar data will be presented. Third, the damage investigation will be briefly discussed. Finally, we will discuss the isolated nature of the event, our ability to forecast it along with the use of the Doppler radar information in such situations.

2. SYNOPTIC AND MESOSCALE DISCUSSION

2.1 Surface analysis

Between 00Z and 12Z, 88/09/17 a moderately active warm front moved through Southern Ontario triggering scattered thunderstorms. By 12Z, the front was just southwest of a line from Sault Ste-Marie to Trenton (figure 1). Along with the front, a weak meso-low was analysed just west of Sault Ste-Marie with a cold front extending westwards. In the morning, a deck of strato-cumulus dominated most of Southern Ontario. A few thunderstorms developed in the southern Lake Michigan area but they quickly dissipated. Also, a few thunderstorms were reported over the northern Lake Huron area and eastwards. The airmass which affected most of Southern Ontario during the day was characterized by dew points in the high teens (18-20 degrees).

Around 18Z west of the Toronto area the strato-cumulus cloud became broken to scattered; over areas east of London, cumulus clouds developed in bands oriented southwest to northeast. One hour later isolated towering cumulus (TCu) developed along these bands.

At 20Z a TCu developed northeast of Guelph and quickly intensified to a cumulo-nimbus (Cb) reaching its peak intensity just northeast of Brampton. The same complex redeveloped rapidly at 2120Z and triggered a weak tornado just northeast of the Toronto International Airport, in the Etobicoke area.

In order to try to relate the storm activity with the surface observations a 1mb surface pressure analysis is presented in figure 2 and 3 along with wind, temperature and dew point observations. A 1 to 2 mb presure fall tendency in three hours was observed for most stations in Southern Ontario during the afternoon. Between 18Z and 23Z, the pressure and wind fields suggest that a meso-low with an associated weak wind shift trough line crossed Southern Ontario. Most stations registered a

wind shift from south to southwest [1].

By 21Z, bands of TCu oriented southwest to northeast were present and a thunderstorm had developed west of Toronto. This activity is corelated with the wind shift line shown in figures 2 and 3. One of the reporting stations where the wind shift was the most clearly observed was the King City automatic station where it occurred around 2040Z. By 23Z the trough had weakened and was difficult to analyse due to the lack of observations.

In summary, based on the surface observations, we are able to detect features in the pressure and wind fields which are related in time and space with the thunderstorm activity. We will now examine the upper air information.

2.2 500 mb analysis

Figure 4 presents the 500 mb height and vorticity field analysis at 12Z, 88/09/17 and 00Z, 88/09/18 respectively. Also the dotted line indicates the vorticity trough along with its interpolated 18Z position. Figure 4a shows a sharp vorticity trough, embedded in a moderate height trough, which was associated with the few thunderstorms that occured overnight in the southern Lake Michigan area. The interpolated 18Z position correlates very well with the afternoon Cb development. By 20Z the vorticity trough was lying over Toronto. It moved eastwards at approximately 25 knots during the day and was lying east of Trenton by 00Z.

2.3 850 mb analysis

Figure 5 shows the 850 mb height and temperature fields at 12Z and 00Z respectively. The weak warm air advection is the dominant feature here along with the tongue of warm air which is oriented in the same direction as the wind field. Note that the temperature field over southern Ontario was only slightly modified between 12Z and 00Z suggesting that thermal advection in the low levels was not significant on that day. In fact, part of the warm air was directly injected in the convective development in the afternoon. Consistent with the upper air pattern, the height trough crosses Southern Ontario during the day. Although much weaker, this evolution is reflected on the surface pressure field (fig.2).

2.4 Tephigram analysis

Figure 6a shows the 12Z tephigram for Flint, a representative sounding corresponding to the pre-storm environment. The warm air at 850 mb is clearly visible and is acting as a lid at that time. Over that level, the air is unstable. A surface temperature of 24 degrees and dew point temperature of 19 degrees (conditions which prevailed after 18Z in Southern Ontario) would break that inversion possibly giving way to Cb's up to 11km (35 thousand feet). Note the 30 knot low level jet between 2 and 3 thousand feet on the hodograph.

The 00Z tephigram over Flint (fig. 6b) confirms the breaking of the inversion. Note also the much drier air above 750 mb. Similar comments apply to the 00Z Buffalo tephigram (fig. 6c) on which we can see the upper level cooling (destabilization) that occurred between 12Z and 00Z with the passage of the upper trough.

---

[1]Valuable observation data from Kitchener (YKF) was not received near the time of the event as the site closed at 18Z, according to its weekend schedule. Also, the Mount Forest (WLS) wind observation is in brackets (on fig. 2 and 3) because its wind data are often unreliable.

2.5 Severe weather assessment

Figure 7 shows some elements of the severe weather composite chart. A low-level moisture axis was present during the day pushing into southwestern Ontario with associated surface dew point temperatures of 19 degrees. A 85 knot westerly high-level jet dominated the area throughout the period. At 12Z, a well defined low-level jet estimated at 35 to 40 knots entered southwestern Ontario from the west then curved northeastwards under the upper jet. A similar set-up was observed at 00Z. Note that the Doppler radar measured a slightly stronger low-level jet intensity. The radial velocity field detected local wind speeds of up to 24 m/s (48 knots) between 20 and 22Z associated with the convective cells. Also, the position of the line of convection is corelated with that of the low-level jet axis.

The sharp vorticity trough, the moderately unstable air, the low-level moisture feed and the relative position of the low and high level jets were all elements somewhat conducive to the development of severe weather. The strong PVA suggests good upper level divergence along with potential strong upward vertical motion.

The 12Z Flint sounding modified by a surface temperature of 24 degrees and dew point of 19 degrees is sufficent to release a buoyant energy of approximately 1700 J/kg. Also the average wind shear between the surface and 4 km was $9x10^{-3}$/sec for both the Flint 12Z and Buffalo 00Z hodograph. Rasmussen et al(1983) have suggested prerequisite low level wind shear conditions and available energy requirements for the formation of tornadoes. In this case, the combination of both values places the environment in a marginal potential tornado development area. Also, when compared to a study by Vigneux et al. (1987), the values of wind shear and potential buoyant energy in this case correspond to a marginal potential for severe weather with a Storm Severity Index (SSI) value of 105 (SSI value of 100 differentiates between severe and non-severe storms, SSI>120 indicates a good probability of tornado occurence).

3. RADAR ANALYSIS

This section describes the King City radar observations of the tornadic storm. In general, there were only a few isolated small cells visible on radar for much of the day. Although some of the cells may have been thunderstorms, none of them appeared very severe. The cells formed on a southwest to northeast line suggesting a larger scale feature. In addition, there were very few cloud to ground lightning strikes observed from the complex (only three strikes were registered).

3.1 Reflectivity data

Around 20Z a southwest to northeast line of TCu developed northeast of Guelph. One of the cells quickly developed into a Cb and reached a peak intensity at 2030Z just northwest of Brampton. Figure 8a shows the reflectivity field at an elevation of 0.6 degrees. Reflectivities of up to 50dBZ were reported with that cell. From 2020Z to 2030Z, the storm echo tops increased from 4-6km in height to 8-10km indicating a very rapid growth.

The precursor cells moved east to northeast prior to 2030Z then veered to the right (east southeast) after 2040Z. This motion is often associated with the movement of severe convective storms. However, the area of 8-10km echo tops moved southeastwards through the whole period with the mid-tropospheric flow indicating directional shear of the winds. This is confirmed by the 00Z Buffalo hodograph (fig. 6c) which clearly shows the wind shear from the surface up to 4km.

A cell developed rapidly around 2120Z northwest of Toronto and triggered a weak tornado just northeast of Pearson International Airport. Figure 8b shows the reflectivity field at 2120Z for an elevation of 0.6 degree. Note the southwest to northeast organization of the cells. Prior to 2120Z, these transverse lines formed and moved eastward at different speeds allowing the lines to merge. A close examination of the reflectivity fields showed that the cells were organized in bands stretching in a perpendicular direction to the lines.

The rapid growth and decay of the area greater than 64mm/hr on the MAX R image around 2030Z and again at 2130Z indicates clearly a rapid storm evolution. The rain rates at the 1.5km CAPPI level were generally fairly low, occasionally reaching 64mm/hr for a short period of time. The maximum reflectivity observed with the complex was 56dBZ at 3km in height. For most of the life of the storm, the echo tops were not very high (the maximum observed was 8-10km) and at no time did the 40dBZ intensities exceed the 5.5km threshold of the Severe Storm chart. The storms were isolated and very small in areal extent but some relatively high reflectivities (> 50dBZ or > 64mm/hr) and hence strong reflectivity gradients were occasionally reported (sharp gradients are often reported with severe weather).

An apparent hook or comma shaped echo (suggesting weak echo regions with high updraft speeds and rotation with the thunderstorms) may be visible (for example at 2040Z on the MAX R chart). However, this may be a pattern that results as two cells merge.

3.2 Radial velocity data

An important clue related to the development of a possible severe storm was available from the analysis of the Doppler radial velocity data. In real time, the mesocyclone algorithm identified a mesocyclone in the appropriate storm complex beginning at 2030Z and continuing through to 2120Z. Mesocyclones are indicated by colored circles superimposed on the reflectivity data as seen on figure 8a and 8b. In the United States, mesocyclones have been found to be associated with tornadoes 50% of the time and with severe weather 90% of the time (JDOP, 1979). The initial measurement at 2030Z was for an azimuthal shear of 18m/s/km and this was accompanied by angular momentum values in excess of 100km m/s. These values meet the preliminary criteria for a "tornadic" mesocyclone (mesocyclone shear parameters [2] exceeds 10m/s/km and angular momentum parameter exceeds 100 km m/s).

Qualitatively, the signature of a mesocyclone was clearly identifiable from the radial velocity field as well. Figures 8c and 8d show the radial velocity field at 2120Z for the two lowest elevations. Although dificult to see on this reproduction, the mesocyclone couplet (indicated by the black arrow) is very well corelated with the cell that was responsible for the formation of the tornado. The rotation signature was probably better defined in this case than any other case studied so far at King City. This is especially true at 2120Z and 2130Z. Also at these times, the storm motion was perpendicular to the radar beam so that the radial velocity data was not contaminated by the radial component of the storm motion.

---

[2]The azimuthal shear is in this case the maximum radial velocity gradient between two consecutive radials within the mesocyclone. The "angular momentum" is a quantity which is actually proportional to the angular momentum (r x m x V, where r is the distance from the centre of rotation, m is the mass and V is the rotational velocity) within the feature since the mass of the air is not in the equation and a factor 2 has been dropped. This quantity is an indicator of mesocyclone development (Joe(1988), Joe et al.(1988)).

The mesocyclone algorithm was reapplied on the data using lower detection treshold values. In this exercise, the algorithm identified the tornadic storm even earlier in its evolution. At 20Z, the storm was in its early growth phase; before strong vertical development, before high reflectivities and before it veered to the right. The algorithm continued to identify mesocyclones for the next 90 minutes up to 2130Z. The "tornadic" mesocyclone category was still only surpassed at the same two time steps (2030Z and 2040Z).

It should also be noted that initially the algorithm identified mesocyclones in each of two separate storms. The two storms eventually merged and as this was occuring the algorithm merged two mesocyclones and identified one although two distinct signatures were visible on the radial velocity fields.

Quantitatively, the shear values were relatively high, generally greater than 10m/s/km but the angular momentum values were quite low, generally less than 100km m/s. These thresholds were selected to identify tornadic mesocyclones based on the limited tornadic cases in Southern Ontario. Therefore, it should be noted that these are guidelines and are not statistically defendable. This case exceeded these thresholds only briefly and therefore can be considered to represent a weak mesocyclone that was tornadic.

4. DAMAGE INVESTIGATION [3]

An investigation of the damaged site was done Monday morning 19 September 1988. Following telephone interviews and news reports one specific damage site was located in the Belfield Road and Kipling Ave. an area just northeast of the Pearson International Airport. An industrial building located on Belfield Rd just west of Kipling Ave. suffered damage to its roof. Large areas of roof were folded back with some pieces completely torn off. An empty tractor trailer parked near the industrial building was rolled to his side. Across Kipling Ave., two large sections of windows were broken on an Ontario Ministry building. Adjacent buildings were not damaged.

Close to a dozen reports of funnel cloud sightings were collected. Most reports agreed on the time and location of the funnel cloud. It occured in the Belfield Rd. and Kipling Ave. area between 17:30 and 17:40 EDT (2130-2140Z). Most of the eyewitnesses had a clear view of the funnel cloud which briefly touched down two or three times during approximately a five minute period. No thunder was reported and only cloud-to-cloud lighting was briefly observed across the western edge of the cloud. A photograph of the funnel was taken by one of the witnesses.

The damage assessment indicates that the event could be classified as a F0 tornado on the Fujita scale. Winds of the order of 90 to 115 km/h were likely through the path of the tornado.

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[3]For the detailed investigation report see Hogue(1989).

5. DISCUSSION AND CONCLUSION

On Saturday 17 September 1988, a weak tornado briefly touched down around 17:30 EDT just northeast of Toronto's Pearson International Airport, in the Kipling Av. and Belfield Rd. area.

The on-site investigation along with interviews of witnesses suggest that the event be classified as an F0 tornado on the Fujita scale.

The detailed radar analysis supports the occurence of the tornado. A mesocyclone meeting minimum criteria was positively and unambiguously identified using Doppler radar both from the mesocyclone detection algorithm product and from the radial velocity products. The mesocyclone was weak, only briefly exceeded the existing preliminary threshold guidelines for identifying a severe storm threat area. The mesocyclone was detected more than one hour before the tornado touched down.

Also, in hindsight, possible clues as to the severity of the storm were identified using conventional radar data: rapid storm development along with occasionally strong reflectivity gradients and veering motion of the storm from the east-northeast to the east-southeast.

The synoptic and mesoscale dynamics analysis support, do not preclude, the development of severe storms. The sharp vorticity trough, the moderately unstable air, the moisture feed and the relative position of the low and high level jets were all elements somewhat conducive to the development of severe weather.

Some questions remain as to the very isolated nature of the thunderstorm cells that developed that afternoon. The triggering of the isolated strong cells after 20Z is reasonably explained by the breaking of the 850 mb warm air lid as the surface temperatures and dew points reached 24 degrees and 19 degrees respectively. But why more thunderstorm cells didn't develop under these conditions remains unclear. A possible explanation lies in the examination of the evolution of the reflectivity field and the surface analysis. As pointed out in the previous sections, around 20Z a southwest to northeast line of TCu developed northeast of Guelph. The position of the line is correlated with the position of the weak surface pressure trough (fig. 2 and 3). A weak windshift line was also noticeable with that trough (however the lack of surface observations prevents a rigourous identification of that windshift line). In addition, the position of the line follows approximately that of the low-level jet. These elements tend to indicate that low-level convergence might have been the principal contributing factor supporting the cells. The short life span of the cells was therefore mainly due to the localized nature in time and space of the surface convergence, the position of the low-level jet and the sharpness and narrowness of the vorticity trough.

It is important to discuss our ability to forecast this isolated marginal severe weather event. In this case, the morning severe weather assessment was very reasonable in calling for isolated Cb activity east of the vorticity trough. But due to their very short life span and limited vertical and spacial extent, the cells were dismissed as sources of severe weather by the duty forecasters. The relatively short lifetime, the very localized nature of the cell which became severe, and the lack of deep vertical development made this case a difficult one to forecast. However, the detailed use of Doppler radar might have aided in the nowcasting of the situation. The mesocyclone detection algorithm identified the mesocyclone more than one hour before the tornado touched down. But, in real time, when the CAPPI radar picture does not show significant severe weather potential, as in this case, the forecasters have a tendency not to look at the Doppler information. Therefore, this

suggests that our system should somehow signal automatically to the forecasters any information leading to potential severe weather (i.e. detection of mesocyclones). In the past, conventional reflectivity images were examined before the more complex Doppler information which has been a reasonable approach. This case indicates that tornadoes can exist in weak reflectivity storms and that the Doppler should perhaps be examined concurrently.

Also, even if the forecasters would have been fully aware of the identification of the mesocyclone and considering the assessment of a marginal severe weather situation, the decision to issue or not issue watches and/or warnings would not have been obvious based on previous experiences.

In a broader climatological perspective, one might ask how often this type of marginal severe weather event occurs and remains unobserved. In this case, interest in the event was strongly increased by the fact that it occured in Metro Toronto where the funnel was seen by quite a few people and also that a picture was taken of the funnel cloud. This was a classic case of "expect the unexpected".

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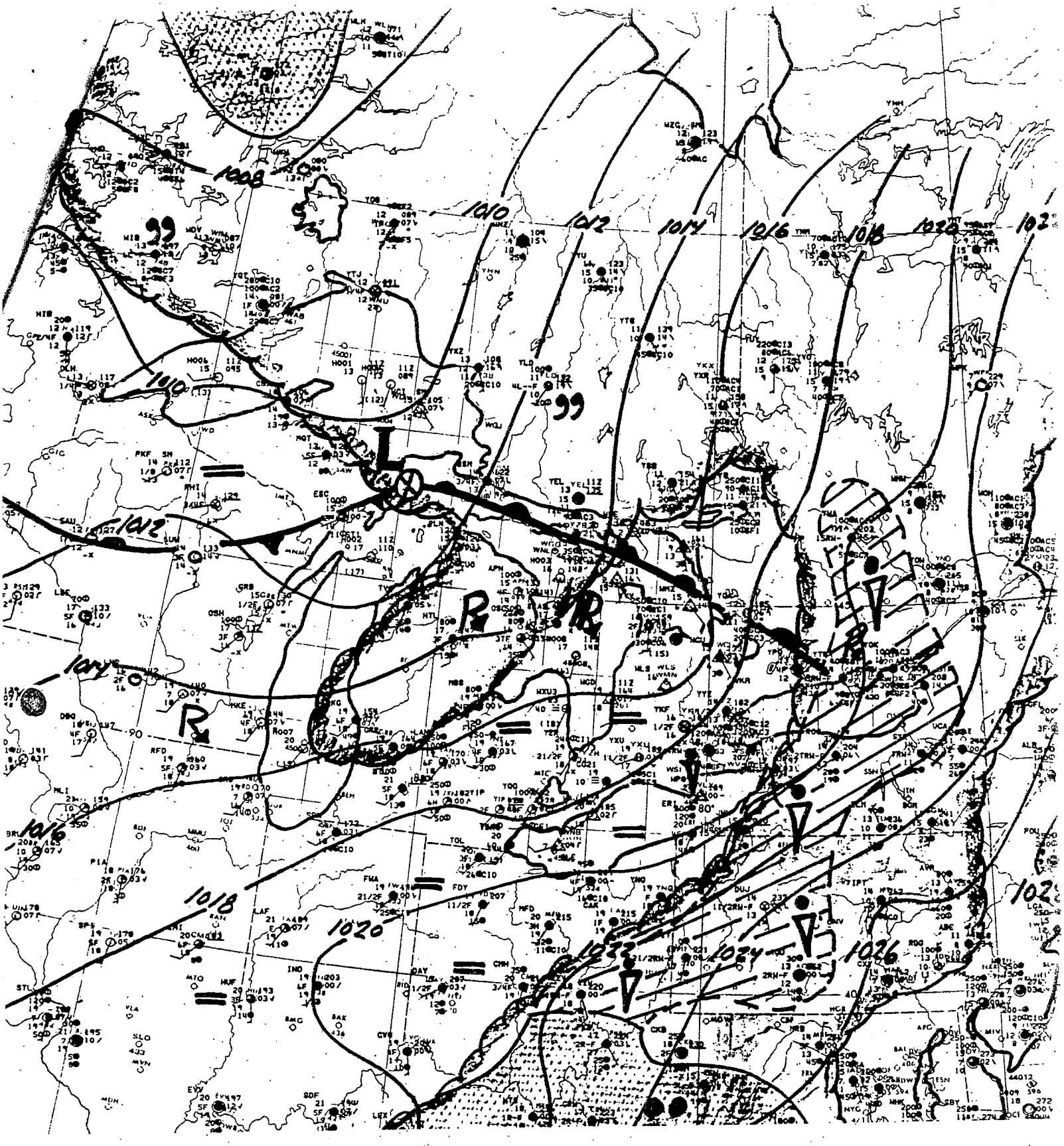
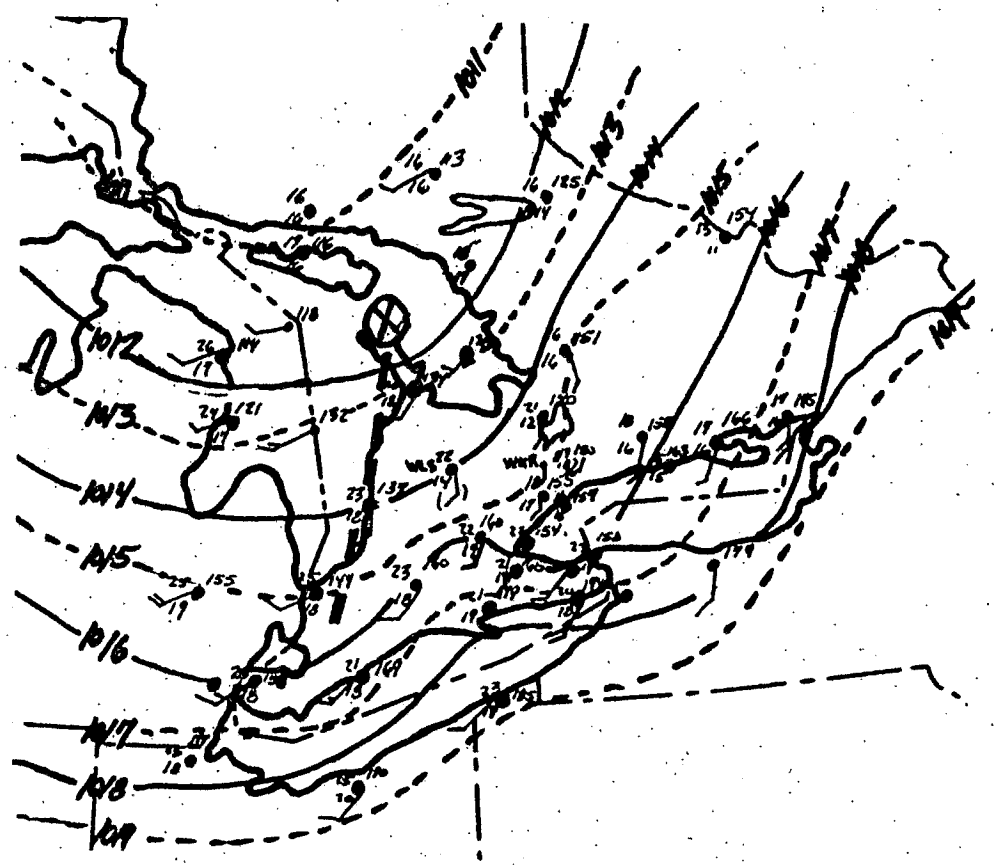
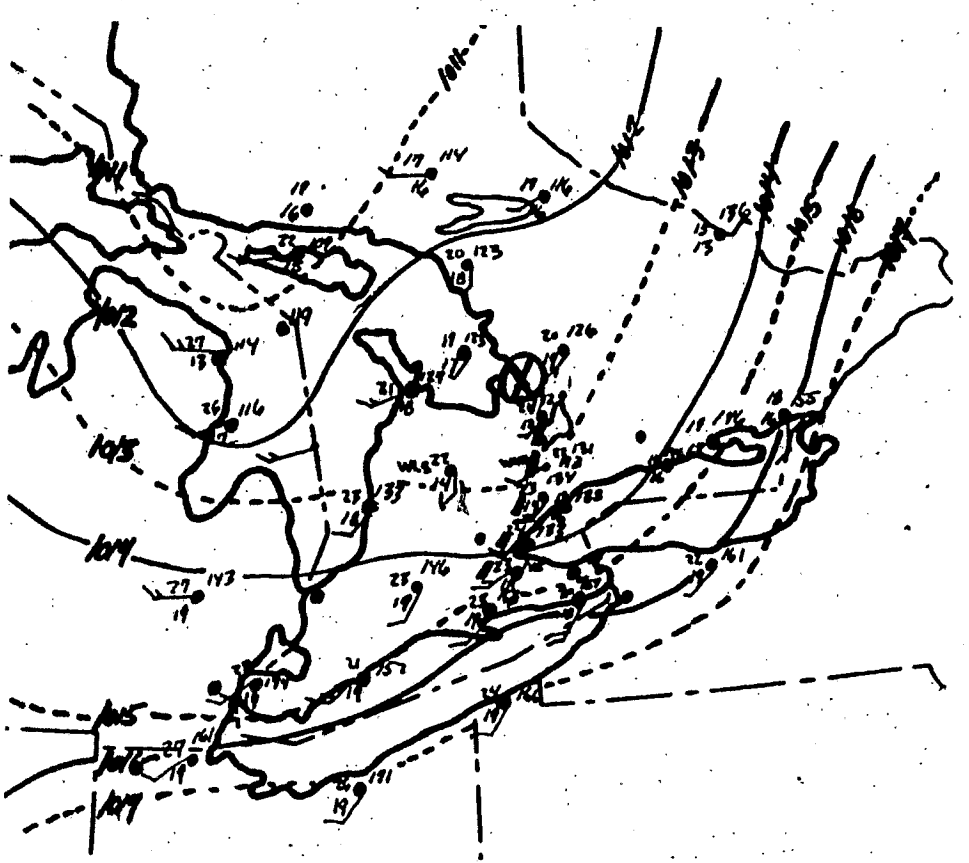


Figure 1. 12Z Surface analysis, 17 Sept. 1988

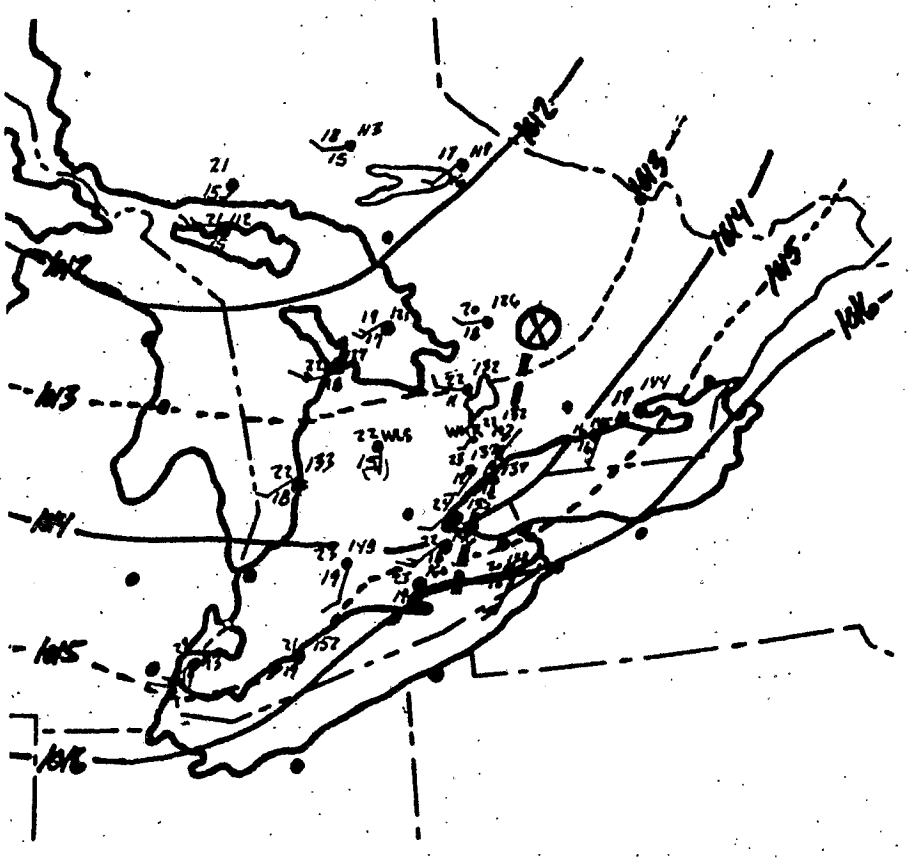


18Z, 17 Sept. 1988

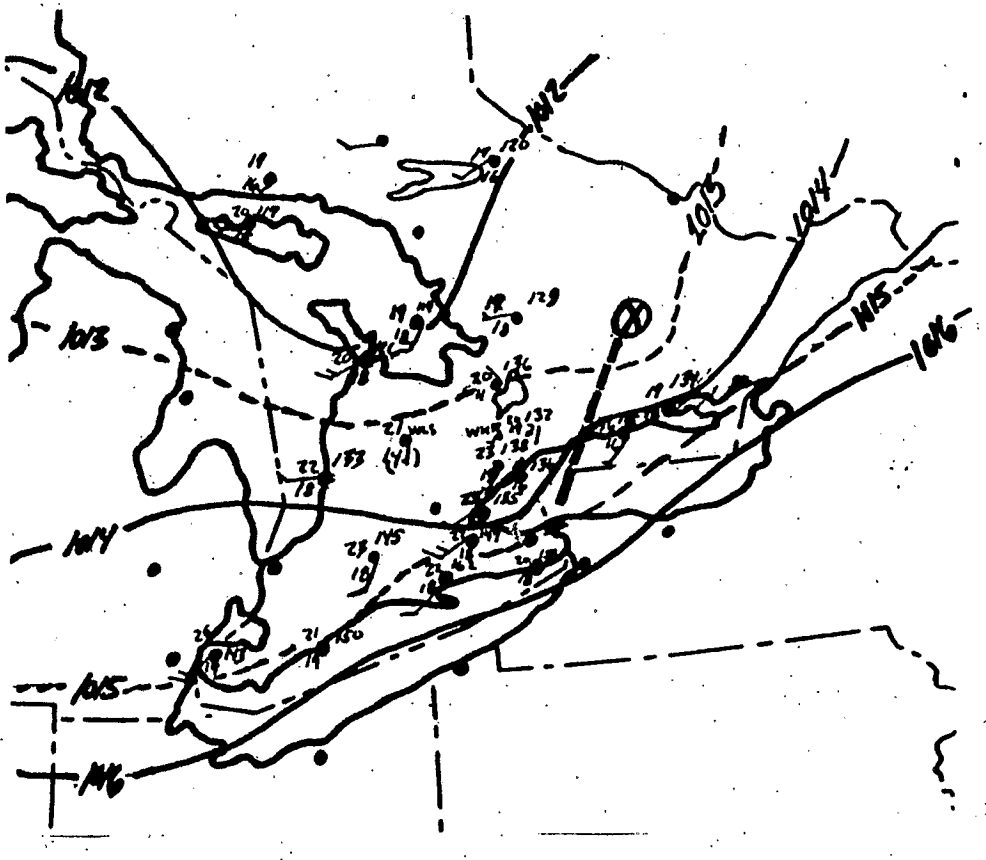


21Z, 17 Sept 1988

Figure 2. 1 mb surface analysis

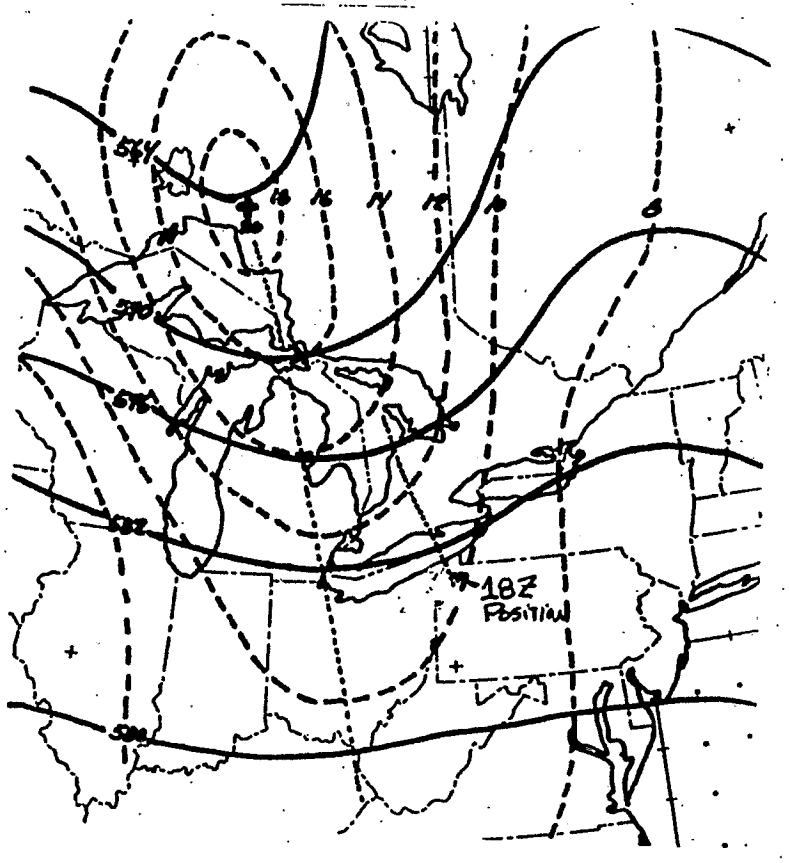


22Z, 17 Sept. 1988

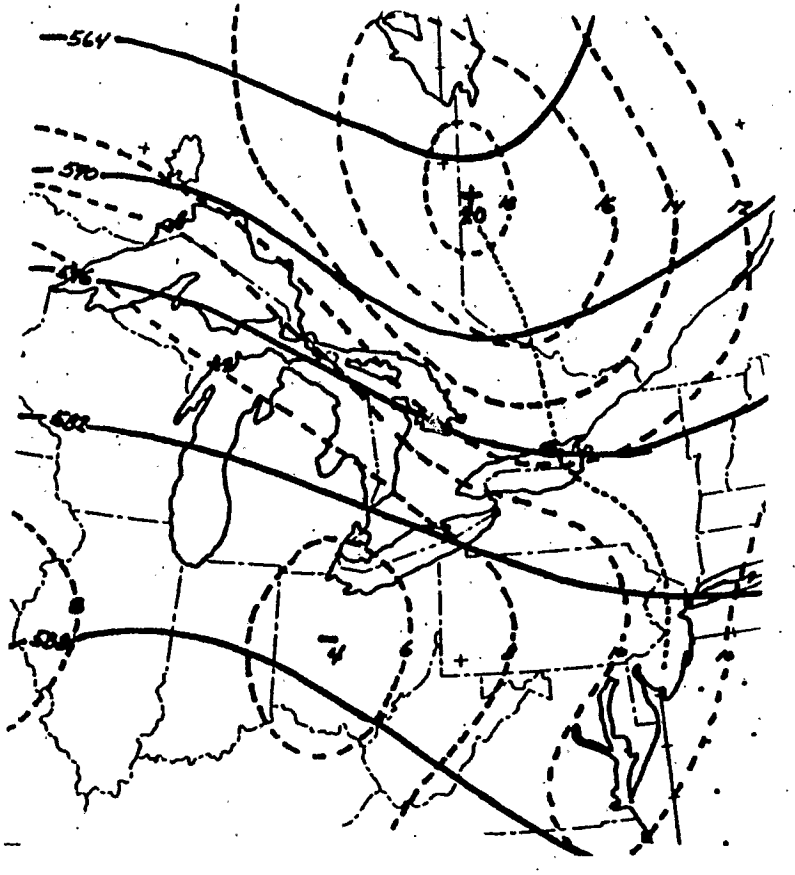


23Z, 17 Sept. 1988

Figure 3. 1 mb surface analysis

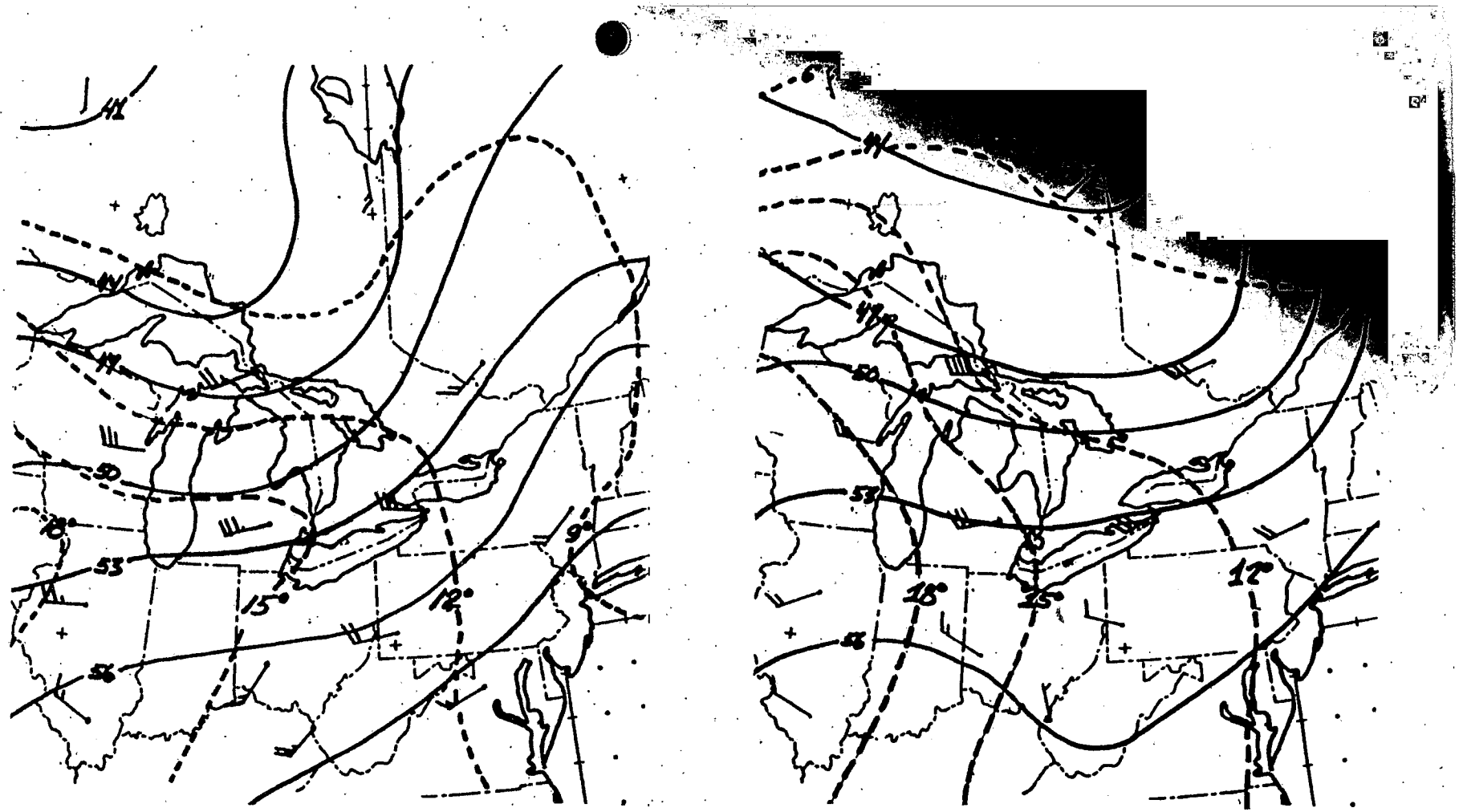


12Z, 17 Sept. 1988



00Z, 18 Sept 1988

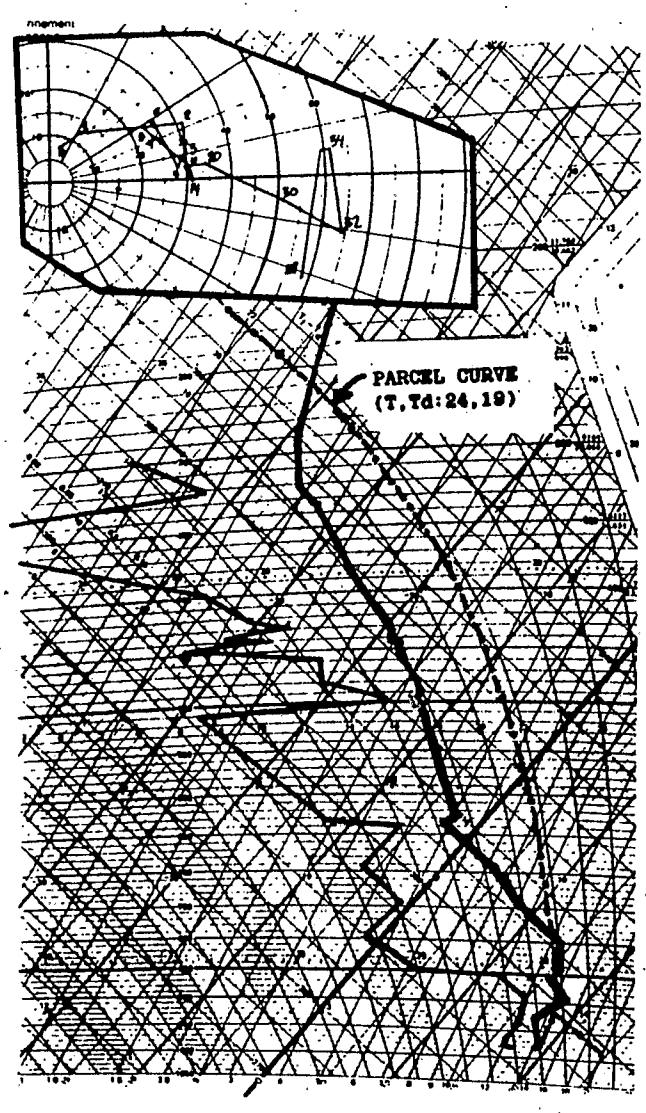
Figure 4. 500 mb height and vorticity fields



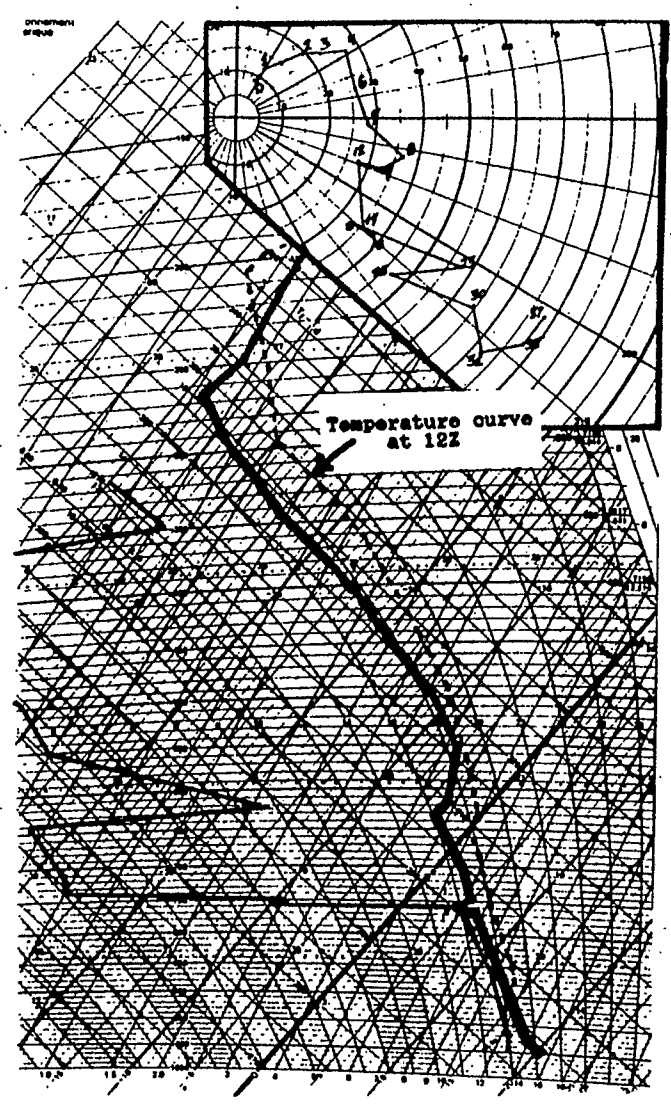
12Z, 17 Sept. 1988

00Z, 18 Sept 1988

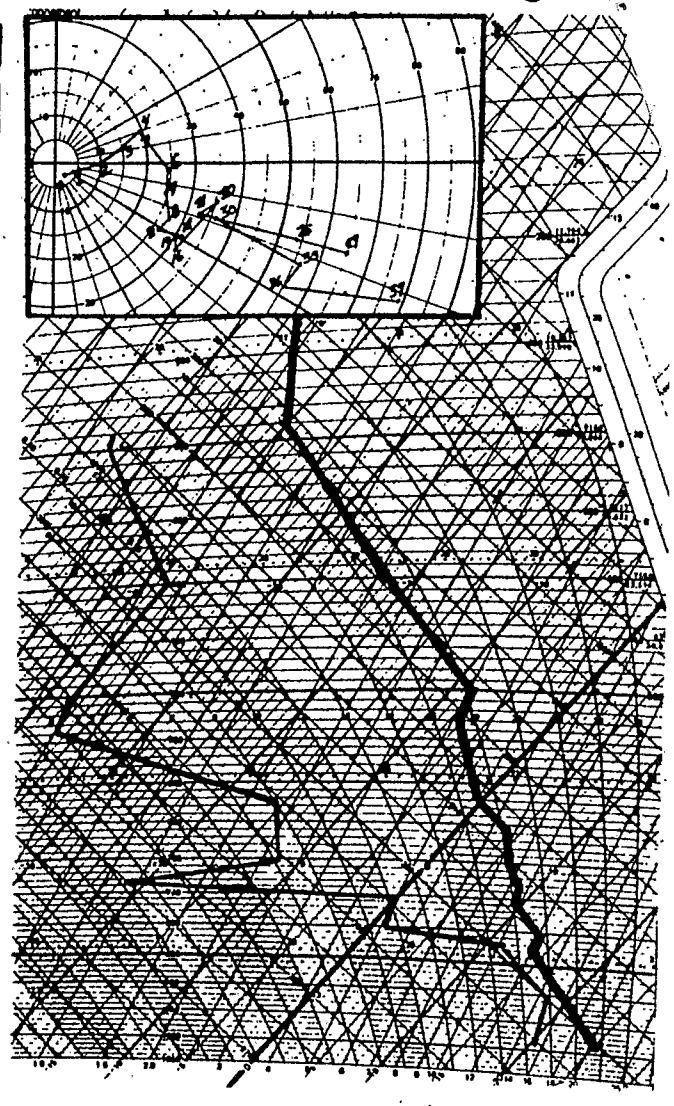
Figure 5. 850 mb height and temperature fields



a) 12Z Flint, 17 Sept. 1988

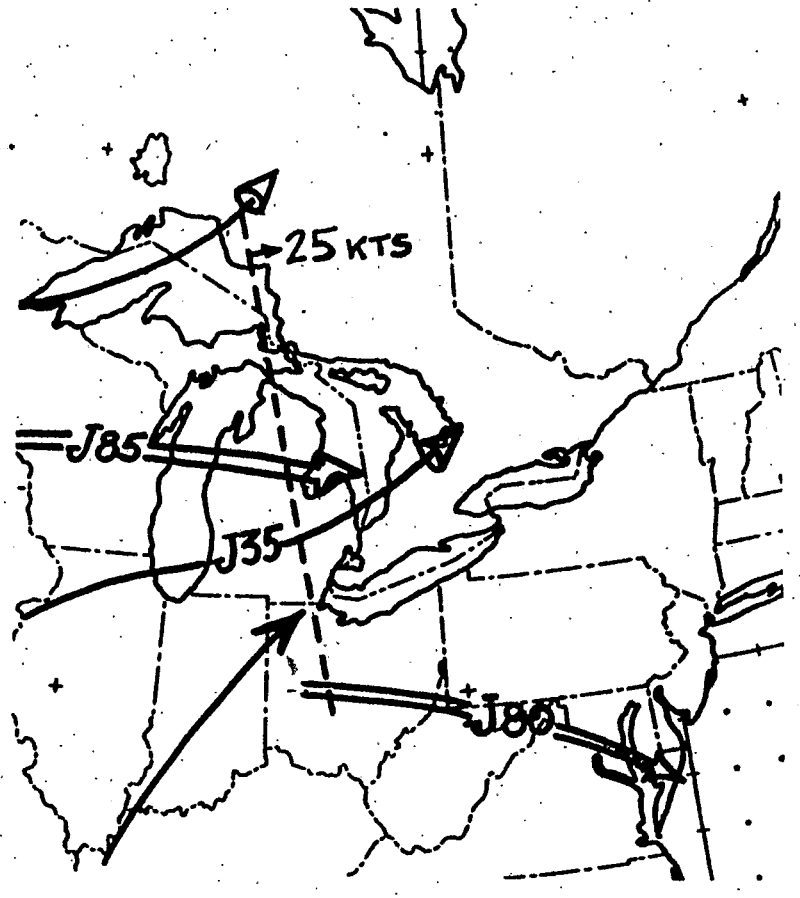


b) 00Z Flint, 18 Sept. 1988

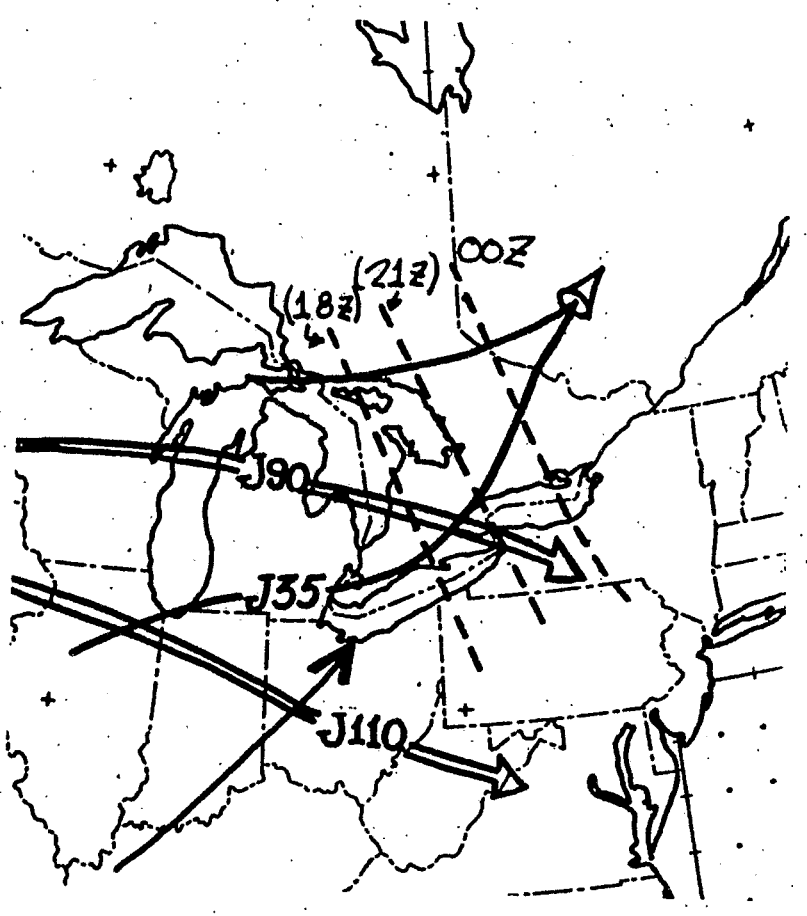


c) 00Z Buffalo, 18 Sept. 1988

Figure 6. Tephigrams and hodographs



12Z, 17 Sept. 1988



00Z, 18 Sept 1988

Figure 7. Severe Weather composite chart: high level jet(⟹), low level jet(⊸), moisture axis(⟶) and 500 mb vorticity trough(- - -).

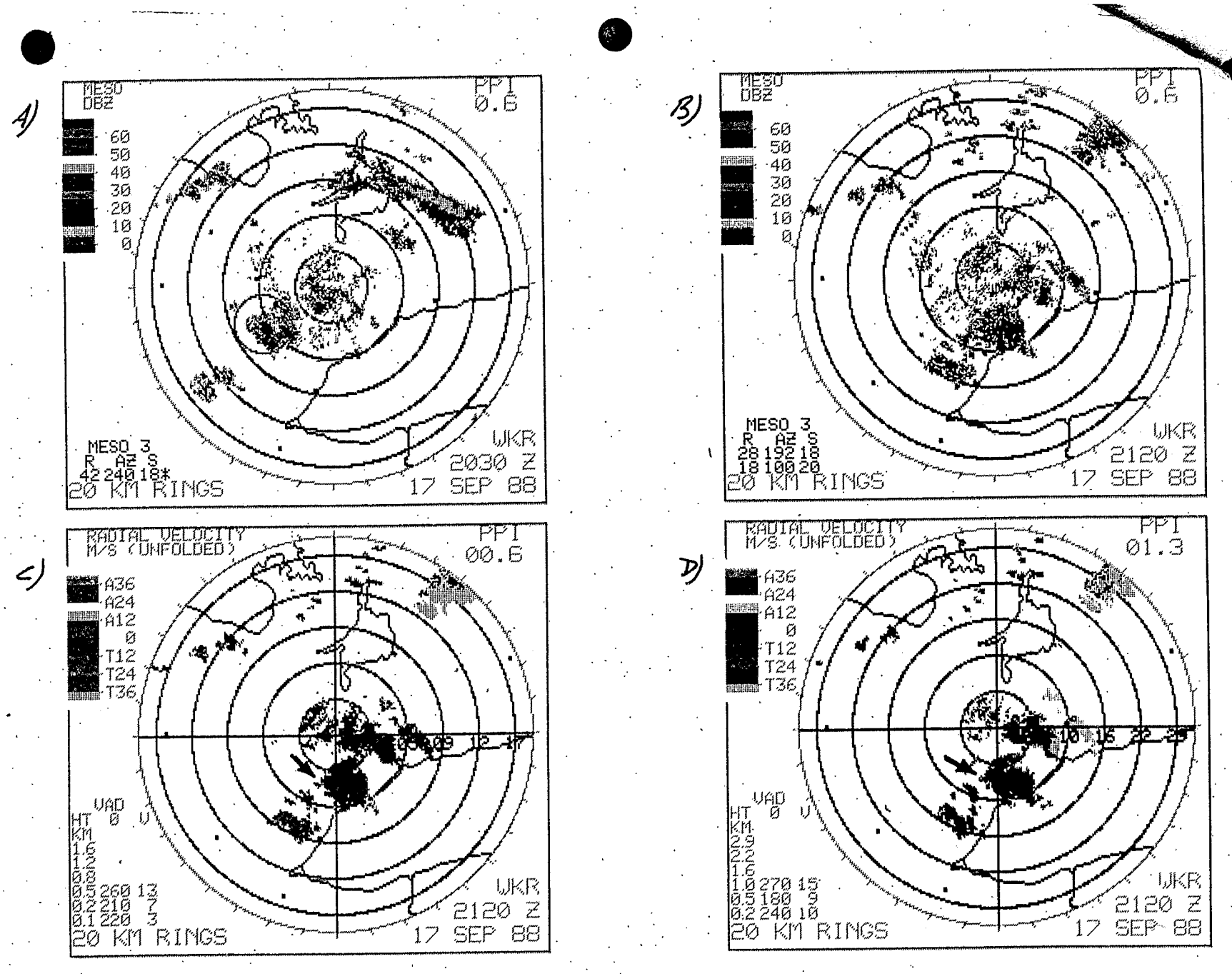


Figure 8. Radar images; reflectivity 0.6° PPI at 2030Z (a) and 2120Z (b), radial velocity at 2120Z for 0.6° (c) and 1.3° (d). The black arrow points in the direction of the mesocyclone.