EASTERN REGION TECHNICAL ATTACHMENT
NO. 93-9A
SEPTEMBER 1993

AN ANALYSIS OF A LAKE-ENHANCED RAIN EVENT OFF LAKE ERIE

Robert R. Mundschenk
National Weather Service Forecast Office
Buffalo, New York

1. INTRODUCTION

On September 26, 1991 a lake-enhanced rain event, driven by both synoptic and meso-scale processes, occurred over Buffalo, New York. The precipitation was significantly greater than that indicated by the Nested Grid Model (NGM) and the Limited Area Fine Mesh (LFM) model. This event was unusual for several reasons. While most documented cases of lake-effect precipitation have occurred as snow, this lake-enhanced rain event was convectively active with approximately 70 cloud to ground lightning strikes, and contrary to most lake-effect events, nearly all of the rainfall was pre-frontal.

This study compares two successive model runs with analyses to determine the accuracy of the synoptic scale pattern predicted by the NGM. Based on an accurate prediction of the synoptic scale pattern, similarities, especially in the meso-scale, between this event and the more traditionally known "lake-effect" events are discussed. Results of this study suggest that, even though model guidance may not reliably indicate the potential for lake-enhanced precipitation, certain meteorological variables, similar to those applied to lake-effect snow events, can alert forecasters to the potential for significant lake-enhanced rain events.

Until now, there has been very little written about lake-enhanced rain events. Most studies of this nature pertain to the more traditional lake-effect snow events that occur during the late fall and winter seasons (Hill 1971, Niziol 1987). The purpose of this study was twofold: first, to determine if the model correctly predicted the synoptic pattern, and second, to determine if mesoscale processes, such as those observed during lake-effect precipitation events, were evident.

During the early morning hours of September 26, 1991 a cold front, which was approaching western New York, helped initiate rainfall over the region. Precipitation observed at Buffalo was substantially greater than predicted by the NGM. Between 0000 UTC and 1800 UTC, 1.25" of rain was observed at Buffalo, whereas the previous two model runs, 1200 UTC on September 25 and 0000 UTC on September 26, were forecasting 0.0" and 0.04", respectively.

In this study, an overview of the synoptic and mesoscale pattern is presented, whereby the important features that helped influence the event are identified. Meteorological similarities that are present during lake-effect snow events and this particular event are also depicted.

2. SYNOPTIC OVERVIEW

Between September 25-27 1991, a cold front associated with a fairly deep low pressure system tracked across southern Ontario from just north of Lake Superior northeast across Quebec (Figure 1). The surface low was east of James Bay by September 27, and it was a closed system up to 700 mb.

The synoptic situation was reviewed by comparing the 12 and 24 hour forecasts from the 1200 UTC September 25 NGM run against the 0000 and 1200 UTC September 26 analyses at the surface, 850, 700, and 500 mb level. The 0000 UTC September 26 NGM run was also compared against the 1200 UTC September 26 analyses. In general, the forecasts from both model runs were in close agreement with the September 26 analyses.

The NGM FOUS T1, T3, and T5 temperatures were also compared to the 0000 and 1200 UTC September 26 soundings at Buffalo. The midpoint of each layer was the height used for comparison with the actual soundings. For the most part the temperature differences were within one degree centigrade.

Figures 2 and 3 show the 0000 and 1200 UTC NGM analyses, respectively, for September 26. The 500 mb analysis for 0000 UTC reveals a short wave with its attendant vorticity maximum near Grand Rapids, MI. Positive vorticity advection (PVA) was evident across Lake Erie and western New York through the overnight period. At 1200 UTC, the NGM was still showing PVA associated with this same short wave across western New York. Also identified during the 0000 and 1200 UTC analysis periods was evidence of cold air advection aloft, a factor which helped destabilize the atmosphere. The combination of this cold air advection aloft and embedded short waves rotating through the 500 mb trough resulted in synoptic-scale forcing across eastern Lake Erie and western New York up to the time of frontal passage (≈1500 UTC). By 0000 UTC September 27 a subsidence inversion was present at 700 mb and winds within the lower levels were northwesterly.

Although considerable agreement was found between the NGM forecasts and the analysis, major differences, however, were evident when the NGM FOUS precipitation forecasts were compared with the observed precipitation (Figure 4). For this event, forecast precipitation amounts were 0" and .04" for the 1200 UTC September 25 and the 0000 UTC September 26 runs, respectively. Observed precipitation totals at most locations across western and central New York were fairly close to NGM predictions. Buffalo and the lake zone area were the only locations where the precipitation totals were substantially greater than those predicted by the model.

3. MESOSCALE

Since the NGM depicted the synoptic situation accurately and the precipitation amounts were reasonable except for Buffalo, the next step was to examine the mesoscale. Beginning around 0000 UTC showers were scattered across central Lake Erie and adjacent Southern Ontario. These showers were in advance of the cold front that was located just west of Lansing, MI. At 0137 UTC, the first pre-frontal showers were observed at Buffalo (Table 1). The showers were light and intermittent until 0442 UTC. Between 0442 and 1504 UTC, showers and thunderstorms (some heavy) were observed at Buffalo for all but two hours. Precipitation fell across all of Western New York during this same time period but not with the same intensity or duration as was observed in Buffalo. As the cold front crossed the Buffalo region around 1500 UTC, the winds shifted to the west and the precipitation ended.

The precipitation that occurred with this event was mainly prefrontal, whereas lake effect events generally occur well after cold frontal passage when a deep layer of arctic air is established (Hill 1971). With Buffalo located at the eastern end of Lake Erie, lake effect precipitation is a common occurrence through fall and winter. Wiggin (1950) outlined the general synoptic pattern necessary for lake-effect snowstorms, while Niziol (1987) listed some of the important meteorological variables necessary for lake-effect snows.

For lake-effect precipitation, one of the most critical forecast parameters is the temperature difference between the lake and the 850 mb level. Holroyd (1971) stated that nearly all lake storms producing precipitation occurred when the 850 mb temperature was more than 13°C colder than the lake surface. The 850 mb temperatures at 0000 and 1200 UTC on September 26 were 4.8°C and 3.6°C, respectively. With the lake at 19.4°C, the temperature differences of 14.6°C and 15.8°C met this criteria. The temperature difference was large enough throughout this period to support lake-enhanced rain if other meteorological factors were also present.

The 0000 and 1200 UTC soundings for September 26 do not indicate a low level inversion that would inhibit lake-effect precipitation (Figure 5). The 0000 UTC sounding showed, for the most part, a conditionally unstable environmental lapse rate to 690 mb. This would help to support convective cloud growth given the presence of adequate upward vertical motion.

The wind direction from the soundings are also used to verify the location of lake-effect precipitation bands. Forecasters at Buffalo use the 850 mb winds for this purpose. At 0000 UTC, the 850 mb winds were from 235°. The persistent precipitation band during the early part of the event was oriented over the Niagara Peninsula of southern Ontario and Niagara Falls, with Buffalo on the southern edge. By 1200 UTC the 850 mb winds were from 250°, and the precipitation band had gradually moved south. At 1200 UTC this band was generally oriented over Buffalo and continued its southeast progression throughout the morning. The 850 mb wind direction and the observed precipitation band agree with the locator table (Table 2) used at Buffalo for lake-effect precipitation and as described by Kolker (1978).

The 0000 UTC sounding showed little directional wind shear from the boundary layer through 500 mb. At 0000 UTC the winds varied from 230° to 250°. This would support an organized lake-effect precipitation band. However, the 1200 UTC sounding exhibited significant directional wind shear, particularly within the lowest four thousand feet. During this period, an active convective environment was present over Buffalo.

An interesting feature is observed when comparing Buffalo's 1200 UTC sounding to Pittsburgh's 1200 UTC and Flint's 0000 UTC soundings. The temperature profiles are all similar except Buffalo's precipitable water value is greater. This suggests that the airmass likely gained additional moisture as it crossed Lake Erie (Figure 6). This is predominantly due to the fetch over the lake, which is another important variable when considering lake-effect precipitation. A greater fetch results in air parcels remaining over the lake for a longer period of time. Thus allowing for further moistening of the airmass. At 0000 and 1200 UTC, the 850 mb fetch was 80 and 225 miles, respectively, both long enough to support lake-effect precipitation as stated by Dockus (1985).

From this discussion it is apparent that a number of meteorological variables considered important for the production of lake-effect precipitation were present during this event. The surface wind field, radar profiles, lightning detection charts, and satellite imagery, will now be used to show what occurred over Lake Erie and the Buffalo area.

The wind field over Lake Erie from 0300-1200 UTC revealed a wind convergence zone along the long axis of the lake. Winds along the south shore of the lake had a southerly component, while winds across the lake were westerly. Overlaying the precipitation field on the wind field indicated that the wind convergence area and the precipitation band were aligned (Figure 7). Peace and Sykes (1966) discussed the occurrence of wind convergence associated with lake-effect snowstorms.

The lightning data, which were obtained from the National Lightning Detection Network (Orville et al. 1983; Orville 1991), identified strikes that were aligned with the precipitation band (Figure 8). Seventy cloud to ground flashes were associated with this event. Satellite imagery during the event depicted the lake-enhanced clouds over Lake Erie (Figure 9). The 0500 and 0900 UTC imagery on September 26 showed a band of clouds at the eastern end of the lake. The cloud band had a higher top than the general cloud shield and was oriented along the long axis of the lake. This enhanced cloud band correlates well with the location of the convergence zone, precipitation band, and the lightning strikes. This alignment of lake-enhanced clouds is frequently observed during lake snow events that occur during the winter season, and satellite imagery is one of the best tools to locate these features (Holroyd 1971).

As outlined in Moore and Orville (1990), lake induced thunderstorms occur mainly during the early part of the lake-effect season (September-December), and are depicted primarily as intense, single band storms. From a sample of four fall/winter seasons, Moore and Orville concluded that lake induced lightning producing storms were infrequent, and typically produced only a few cloud to ground flashes per event. Only one event in this study produced more than 70 flashes.

4. CONCLUSION

The NGM model runs of 1200 UTC September 25 and 0000 UTC September 26 accurately predicted the synoptic pattern for September 26, 1991. The surface and upper air forecasts, and the FOUS temperature profile all verified well against the analyses. The FRH precipitation forecasts were reasonable for all locations except Buffalo, which was affected by a local lake-enhanced precipitation event.

This event on September 26 contained the necessary synoptic and mesoscale conditions conducive to producing lake-enhanced precipitation. Cold air advection aloft, which helped destabilize the atmosphere, and positive vorticity advection associated with embedded short waves were evident as this system moved across eastern Lake Erie and western New York. The coupling of these features with the associated mesoscale features, and influenced by the Great Lakes, produced this convective lake-enhanced rain event.

This event was unusual because most of the precipitation was prefrontal. The air mass prior to frontal passage was conditionally unstable and cold enough to support lake-effect precipitation. During the period, the 850 mb winds became aligned with the long axis of Lake Erie. A long fetch increased the amount of moisture available for convection and produced a strong mesoscale convergence zone along this axis. This combination produced most of the lake-enhanced rain before the cold front crossed the area. After frontal passage, a subsidence inversion developed and the winds shifted to the northwest, reducing the fetch, and shearing the convective band off Lake Erie. Forecasters should be aware that significant lake-induced events could occur prior to frontal passage when conditions similar to those described above are evident.

5. ACKNOWLEDGMENTS

The author would like to thank the forecast staffs at WSFO's Albany, Buffalo and Cleveland for the data which they supplied, and their helpful suggestions.

REFERENCES

Dockus, D.A., 1985: Lake effect snow forecasting in the computer age. *National Weather Digest*, 10-4, 5-19.

Hill, J.D., 1971: Snow squalls in the lee of Lake Erie and Lake Ontario. *NOAA Technical Memoramdum*, NWS ER-43. NOAA/NWS, Garden City, NY., 20 pp.

Holroyd, E.W.,III, 1971: Lake effect cloud bands as seen from weather satellites. *Journal of Atmospheric Sciences*, 28, 1165-1170.

Kolker, B., 1978: Current forecast procedures for lake effect snows in western New York especially related to 1976-1977 and 1977-1978 winters. Procedings of the 1978 Annual Meeting, *Eastern Snow Conference*, Hanover, NH, 17-35.

Moore, P.K., and R.E. Orville, 1990: Lightning characteristics in lake-effect thunderstorms. *Monthly Weather Review*, 118, 1767-1782.

Niziol, T.A., 1987: Operational forecasting of lake effect snowfall in western and central New York. *Weather and Forecasting*, 1, 310-321.

Orville, R.E., 1991: Lightning ground density in the contiguous United States. *Monthly Weather Review*, 119, 573-577.

Orville, R.E., R.E. Henderson, and L.F. Bosart, 1983: An east coast lightning detection network. *Bulletin of the American Meteorological Society*, 64, 1029-1037.

Peace, R.L., and R.B. Sykes, Jr., 1966: Mesoscale study of a lake effect snowstorm. *Monthly Weather Review*, 94, 495-507.

Wiggin, B.L., 1950: Great snows of the Great Lakes. *Weatherwise*, 3, 123-126.

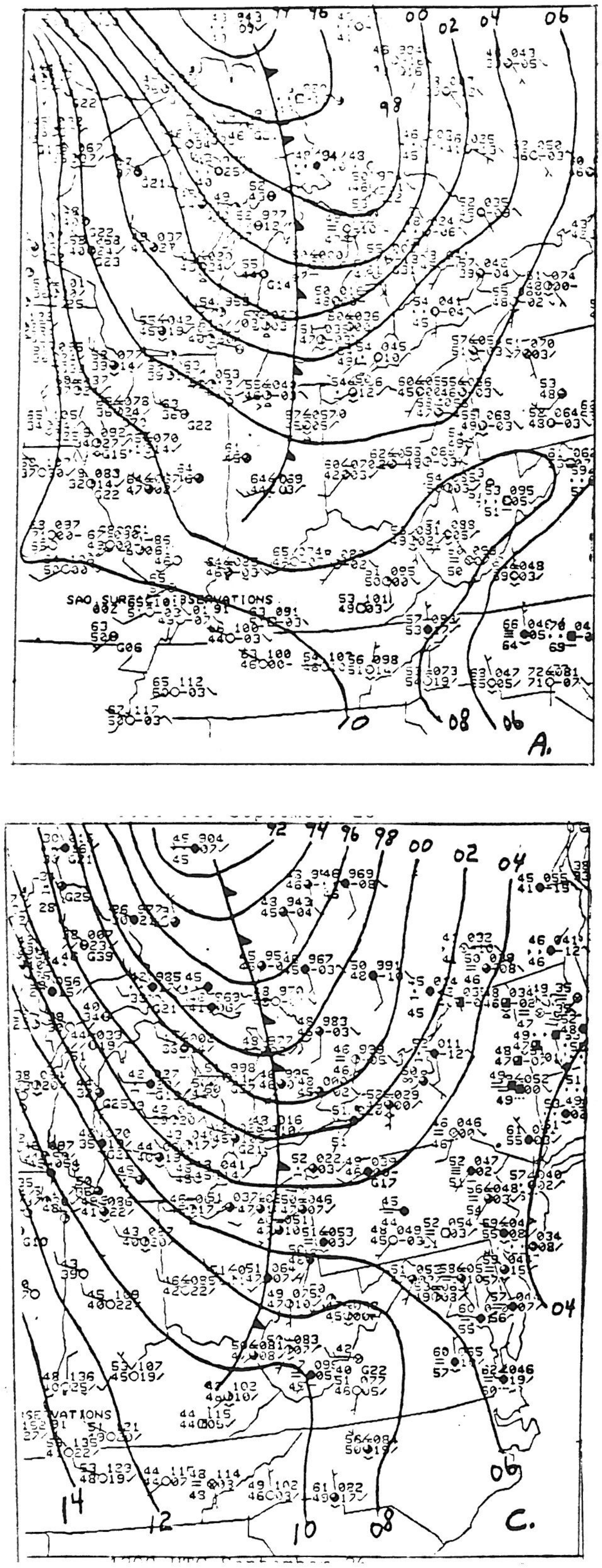


Figure 1. Surface analyses for September 26, 1991. (a) 0000 UTC (b) 0600 UTC (c) 1200 UTC (d) 1500 UTC. Contours every 2 mb.

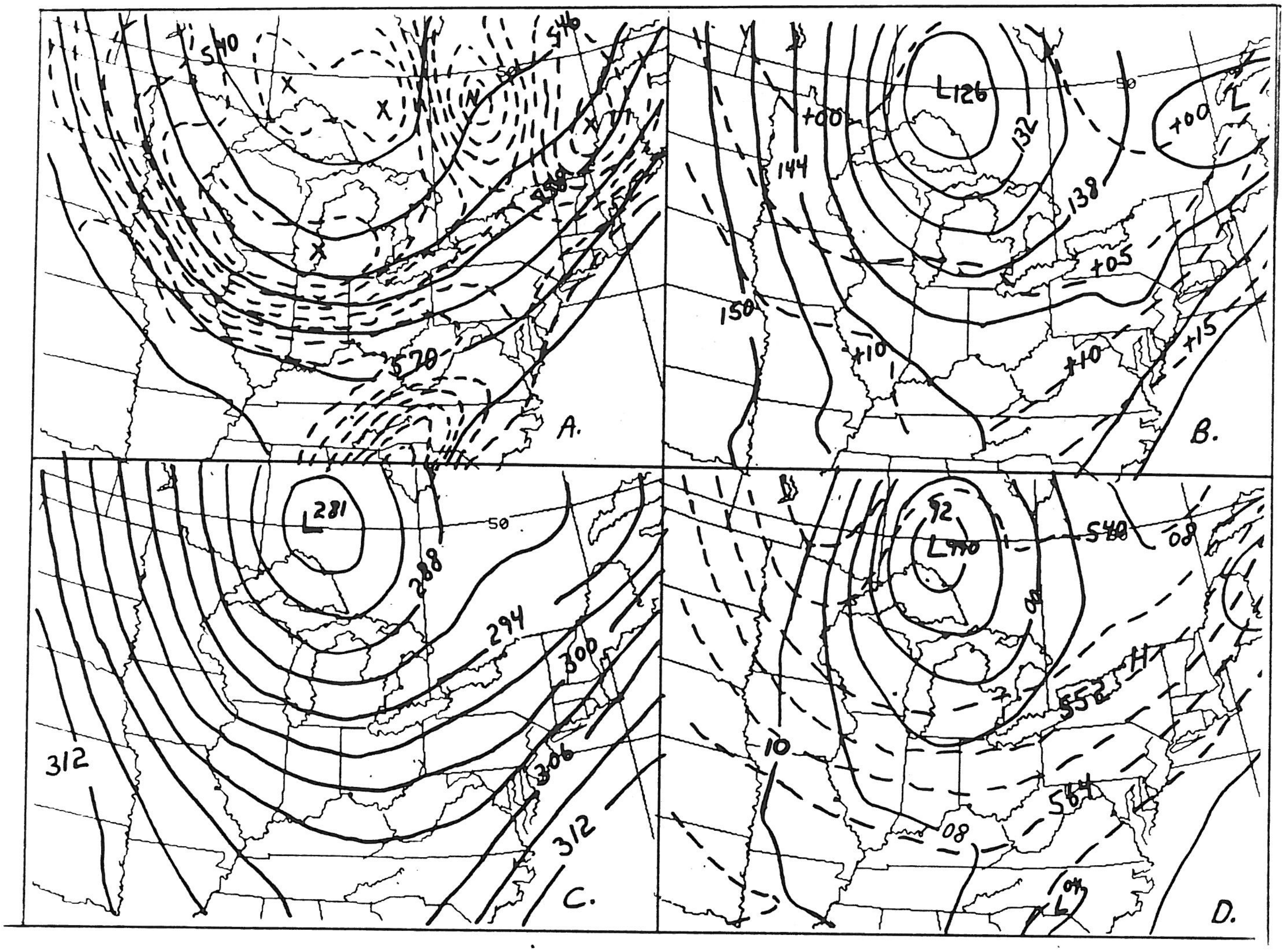


Figure 2. NGM analyses from 0000 UTC on September 26, 1991. (a) 500 mb heights (solid) and vorticity (dashed). (b) 850 mb heights (solid) and temperature (dashed). (c) 700 mb heights. (d) Surface pressure (solid) and thickness (dashed).

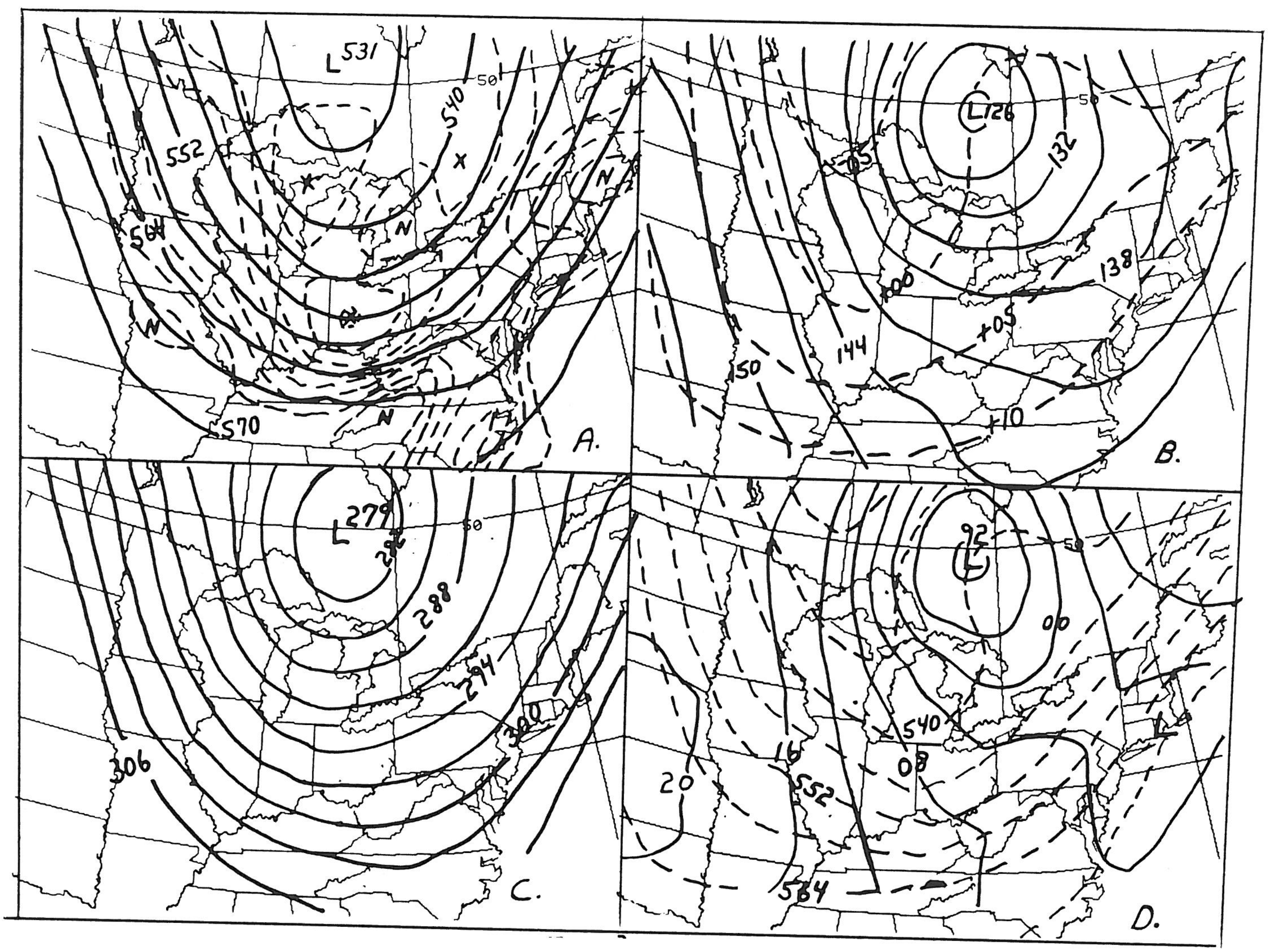
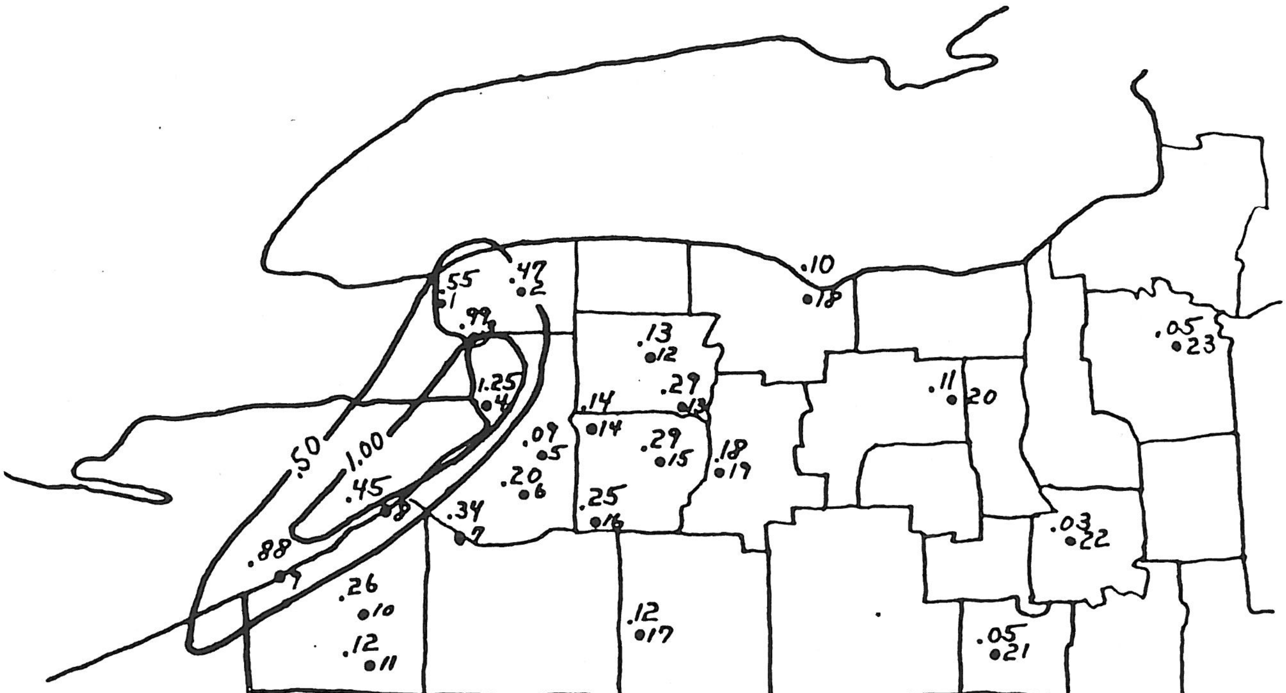


Figure 3. Same as Figure 2 except analysis from the 1200 UTC NGM run on September 26, 1991.



LOCATION

1-Lewiston
2-Lockport
3-North Tonawanda
4-Buffalo
5-Wales
6-Colden
7-Gowanda
8-Silver Creek
9-Westfield
10-Sinclairville
11-Jamestown
12-Batavia
13-Pavilion
14-Bennington
15-Warsaw
16-Arcade
17-Friendship
18-Rochester
19-Mt. Morris
20-Geneva
21-Elmira
22-Ithaca
23-Syracuse

Figure 4. Precipitation observed during the rain event.

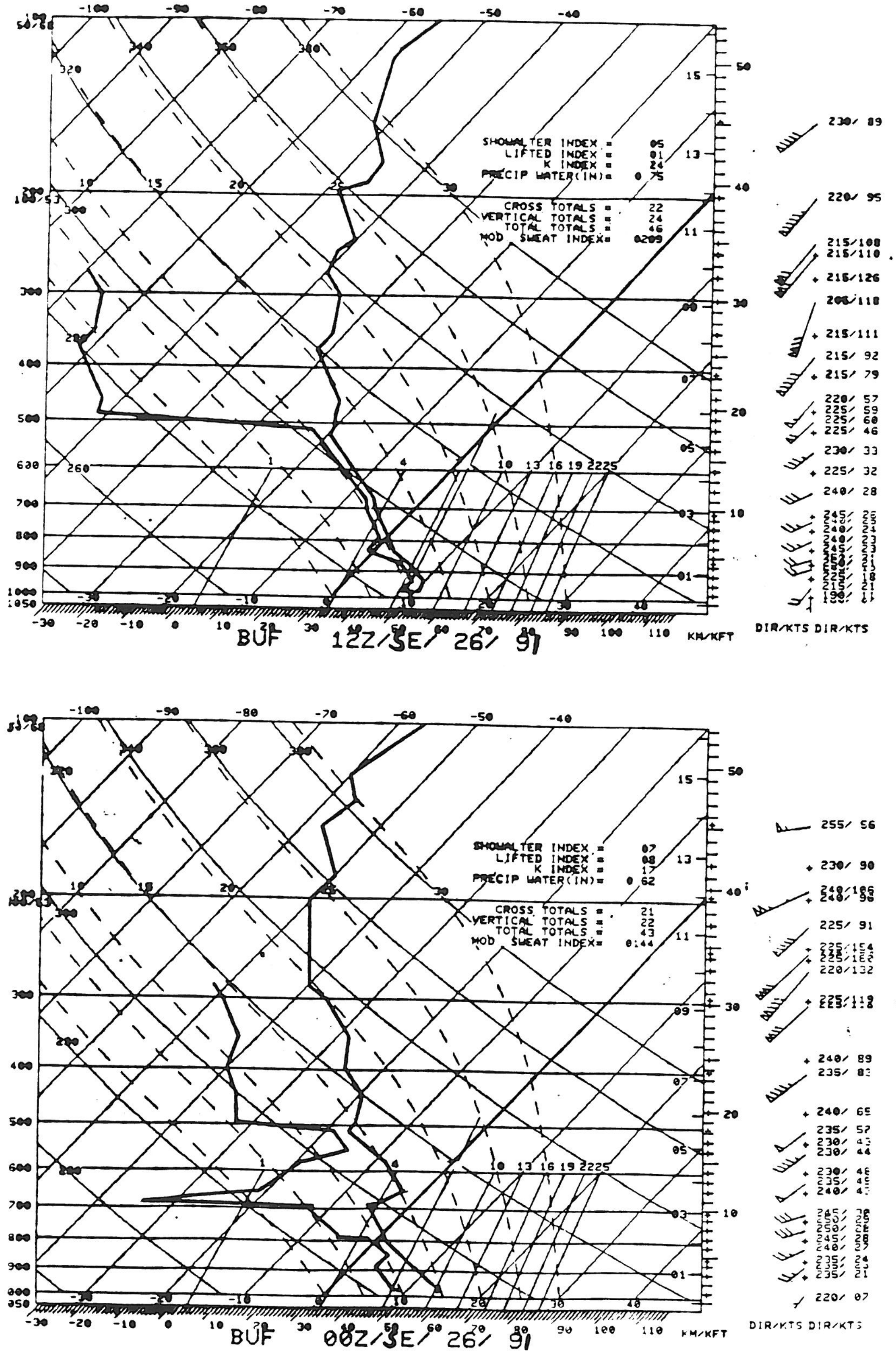


Figure 5. Soundings for Buffalo at 0000 UTC (bottom) and 1200 UTC (top) for September 26, 1991 showing temperature (°C), dewpoint (°C), wind direction and speed (kts).

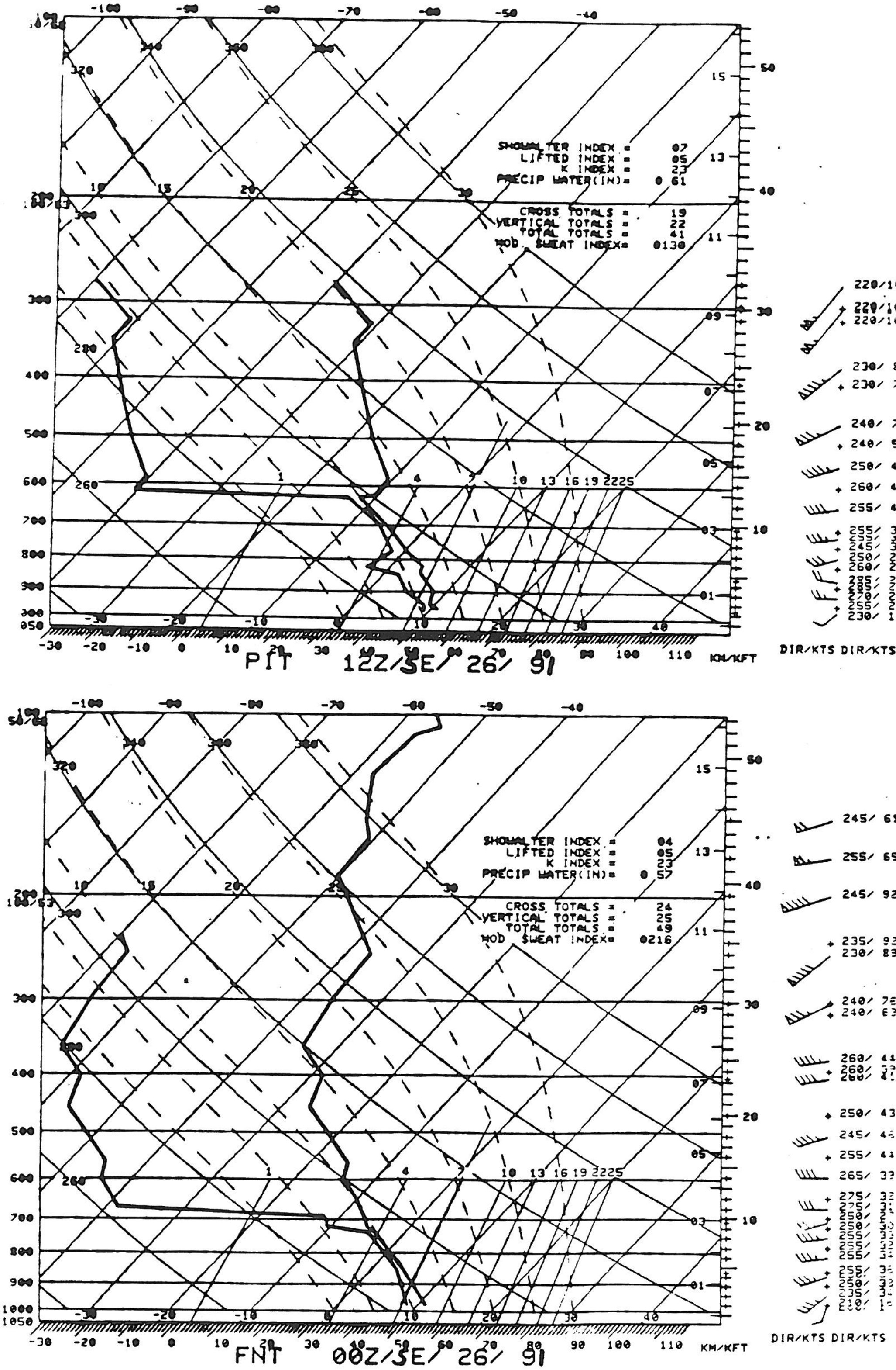


Figure 6. September 26, 1991 soundings for (top) Pittsburgh at 1200 UTC, and (bottom) Flint at 0000 UTC. Plot shows temperature (°C), dewpoint (°C), wind direction and speed (kts).

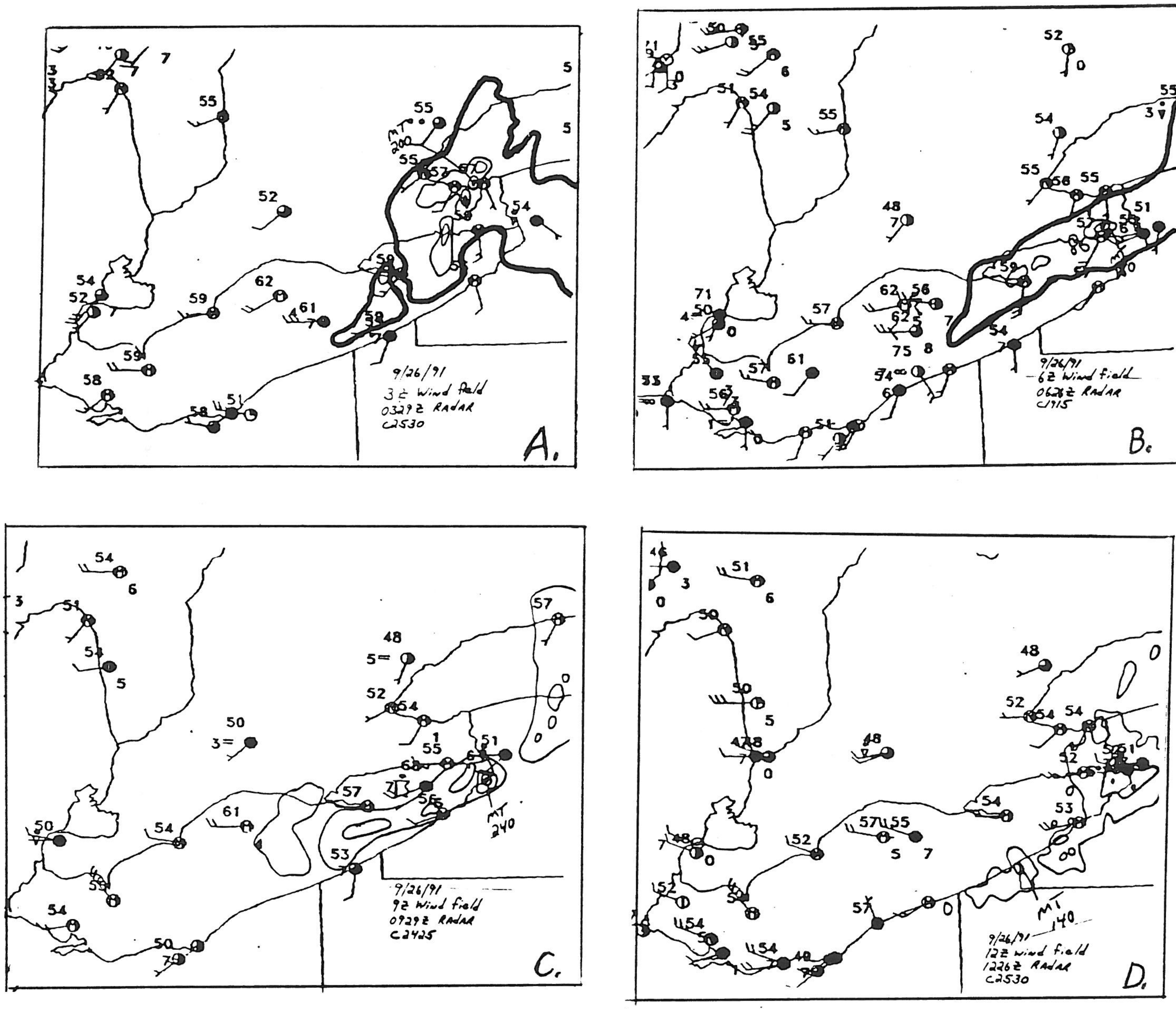


Figure 7. Wind and precipitation field (from local WSR-57 network radar) composite showing VIP levels and maximum tops at (a) 0300 UTC (0329 radar image), (b) 0600 UTC (0626 radar image), (c) 0900 UTC (0929 radar image), and (d) 1200 UTC (1226 radar image).

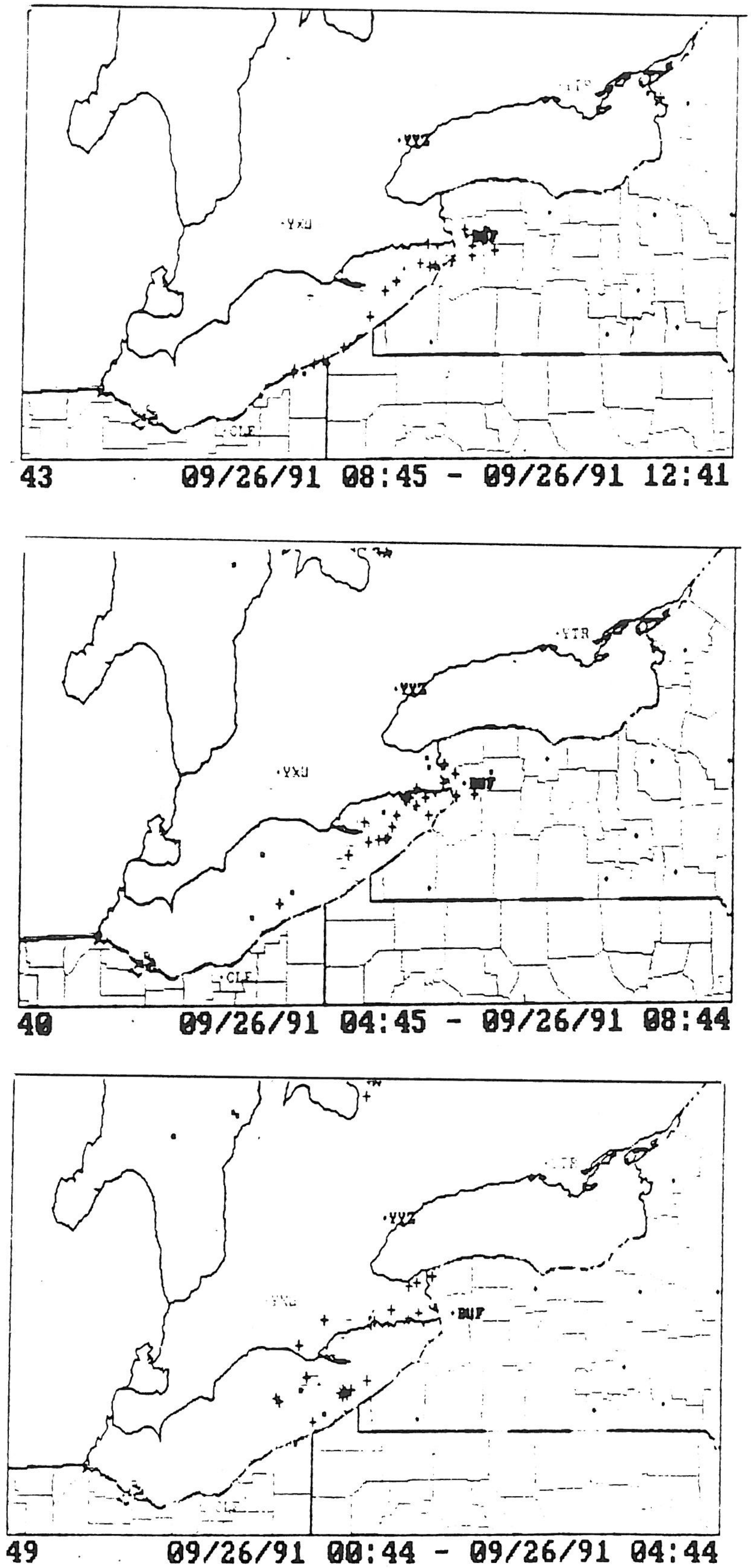


Figure 8. Lightning detection chart.

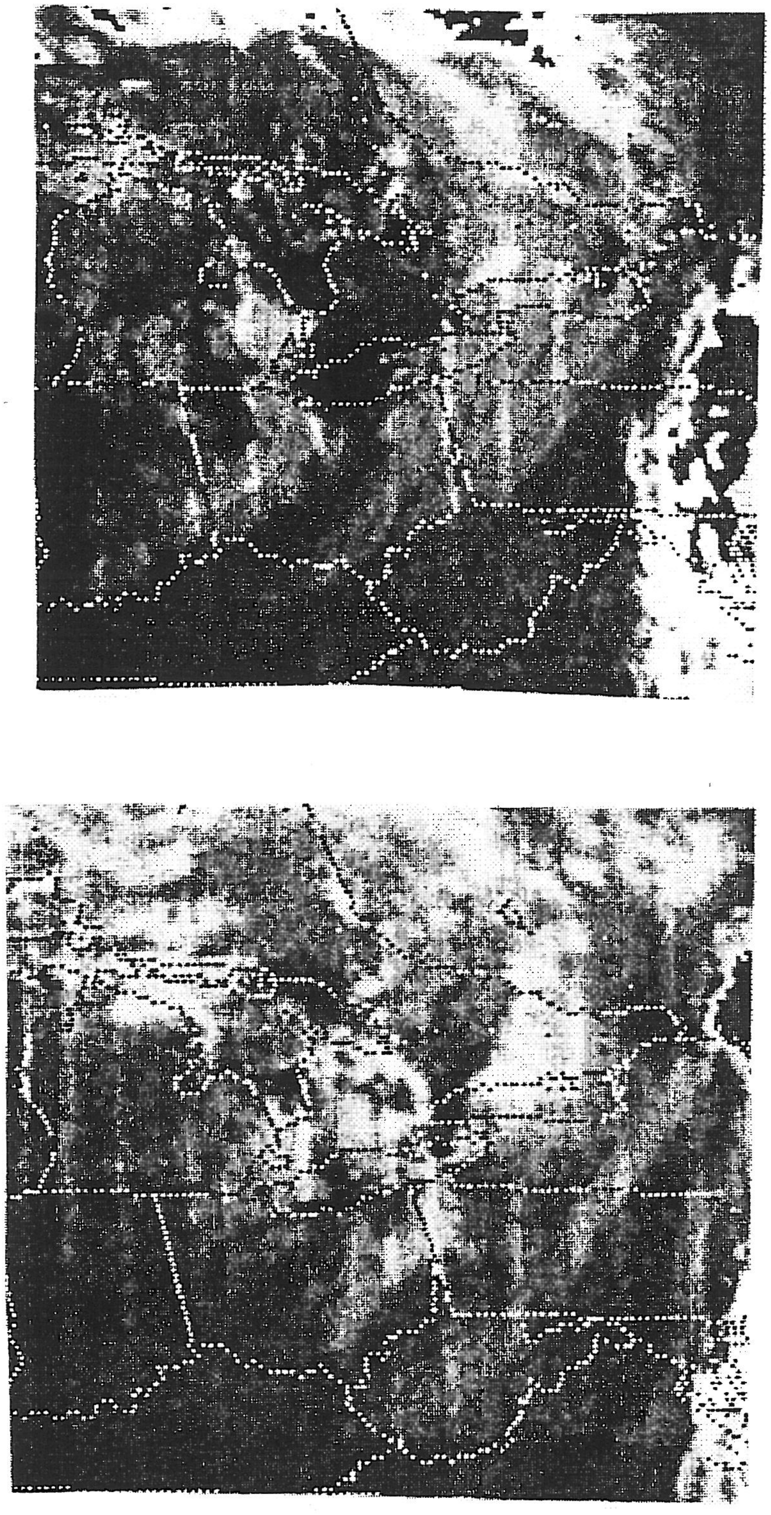


Figure 9. Satellite imagery for September 26, 1991 at 0500 UTC (top), and 0900 UTC (bottom).

Table 1. Select surface observations at Buffalo from 2350 UTC on September 25, 1991 through 1750 UTC on September 26, 1991.

2350 UTC	55	48	060
0250 UTC	54	50	051
0442 UCT			RW+ OCNLY RW-
0552 UCT	51	51	039
0658 UTC			RW+ OCNLY RW-
0814 UTC			RW- OCNLY LTGIC
0851 UTC	51	49	021
0908 UTC			RW-
1123 UTC			RW- OCNL LTGICCA
1151 UTC	51	51	020
1213 UTC			RW- OCNL LTGICCG
1450 UTC	51	50	023
1750 UTC	59	43	024 G31 FEW MDT CU

Table 2. Locator table for Lake Erie showing 850 mb wind direction and expected structure and location of the lake effect precipitation.

LOCATOR TABLE: WESTERN/CENTRAL NEW YORK

LAKE ERIE WIND DIR. (850mb)	FETCH (km)	STRUCTURE AND LOCATION
230	120	Single band..Niagara and Orleans counties. Also portions of the Niagara Peninsula.
240	260	Single band..southern Niagara..Orleans counties Northern Erie including North Buffalo suburbs.
250	390	Single band..metro Buffalo and airport ..Genesee county. Western Monroe county and Rochester with winds > 30 mph. Affects greatest population.
255/260	320	Single band..hugs south shore..South Buffalo including southern and eastern suburbs. Most of Genesee and northern Wyoming county.
260/270	215	Single band..southern Erie and Wyoming county. Parts of Genesee valley with >30 mph winds. Take orographic lifting into account.
280/310	110	Multiple bands..Chautauqua and Cattaraugus counties. Allegany with > 30 mph winds. Take orographic lifting into account. Streamers off Lake Huron possible even with Erie frozen.