NWS-CR-TA-90-36

CRH SSD
OCTOBER 1990

# CENTRAL REGION TECHNICAL ATTACHMENT 90-36

# SHORE-PARALLEL SNOW BANDS OVER NORTHWEST INDIANA AND SOUTHWEST LOWER MICHIGAN DURING A MAJOR ARCTIC OUTBREAK

Mark P. DeLisi and Ron W. Przybylinski
National Weather Service Forecast Office
Indianapolis, Indiana

## 1. Introduction

Lake effect snows that form over the Great Lakes occur when cold Arctic air moves over the relatively warm water of the lakes. These types of snow storms, which occur during the late fall and winter, are often characterized by (1) wind-parallel cloud streets, or (2) shore-parallel snow bands (Mecikalski et al., 1989; McVehil and Peace, 1965). Wind-parallel cloud streets occur when strong northwesterly winds advect cold air across the Great Lakes. The surface pressure gradients are often steep. In contrast, according to Mecikalski et al. (1989), shore-parallel snow bands generally occur under tranquil large scale settings where surface pressure gradients are relaxed.

During the nine day period from December 15 through 23, 1989, three shore-parallel lake snow events occurred across the southern part of Lake Michigan and generated varying amounts of snow over extreme southwest lower Michigan and/or extreme northwest Indiana. Synoptic scale short waves and their associated dynamics were not responsible for any of the three events (December 15 to 16, December 19, and December 22 to 23). In each of the three cases there was no detectable positive differential vorticity advection at 500 mb, the 700 mb short wave was east of the site of concern, there was no 850 mb or surface low pressure area west of the site, and there was no significant wrap around moisture.

Radar data, both recorded on 16 mm film at WSO South Bend (SBN) during each event and viewed via dial-up at WSFO Indianapolis, confirmed that snowfall in all three cases was from shore-parallel snow bands rather than wind-parallel cloud streets. Figure 1 shows a sequence of radar reflectivity data from SBN of the December 15 shore-parallel snow band over southwest lower Michigan and extreme north central Indiana.

This study focuses on the subsynoptic and mesoscale environments of these three shore-parallel heavy snowfall events. It will test the decision tree of Mecikalski et al. (1989), pertaining to shore-parallel snow band development using these events. Additionally, it will show that strong localized low level warm air advection and a thermally induced convergence area played a significant role in making the December 15 to 16 case stand out from the other two cases.

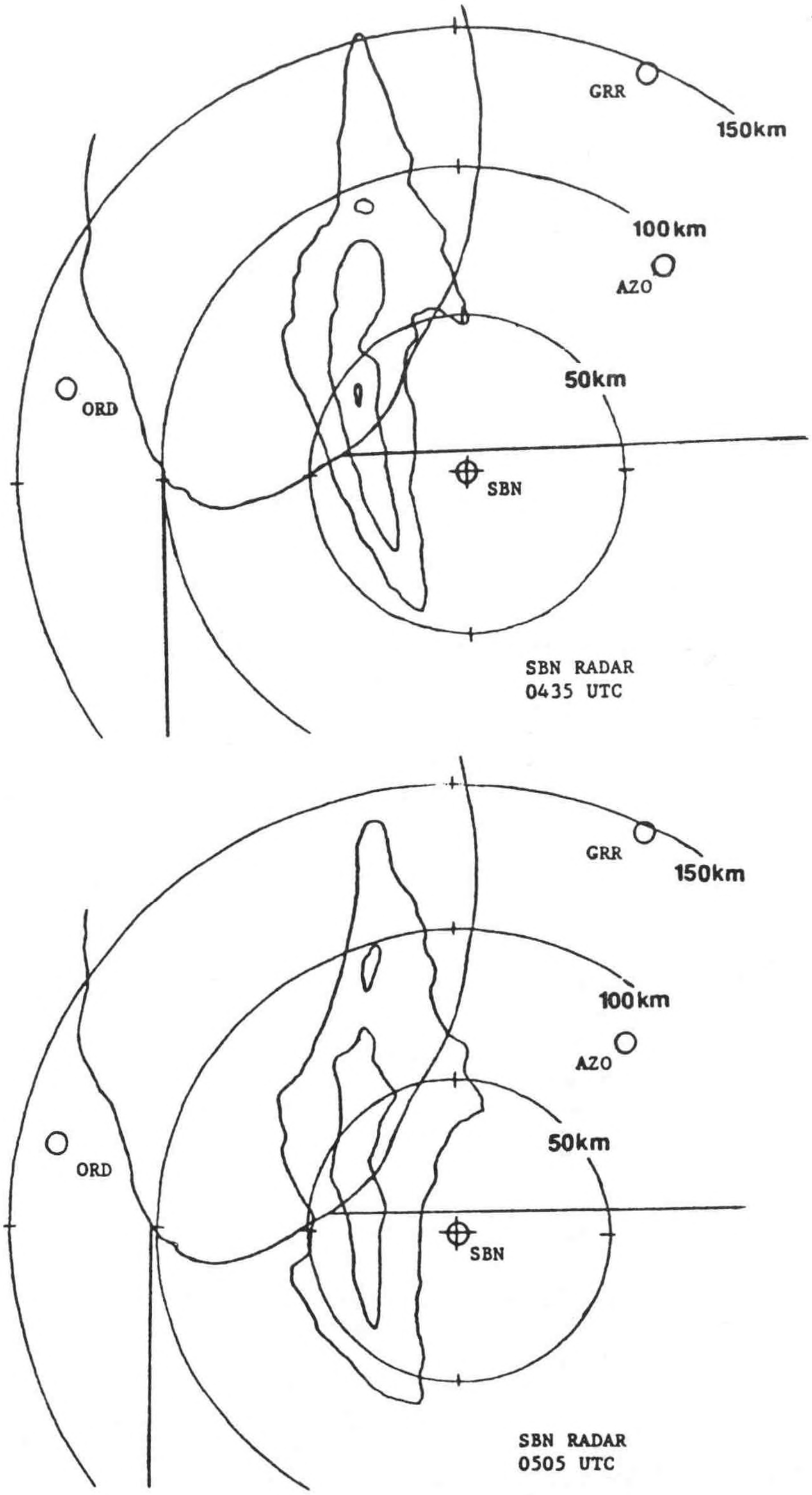


Fig. 1. Radar analysis of shore-parallel snow band viewed from SBN radar at 0435 UTC and 0505 UTC, 16 December, 1989. Reflectivity contours are 18, 30, and 41 dBZ.

## 2. Prerequisite Conditions from Initial Studies

A study by Passarelli and Braham (1981) showed the importance of a shallow winter land breeze in the formation of shore-parallel snow bands when it developed in opposition to a weak synoptic scale flow with an onshore component. An additional study by Schoenberger (1986) showed that strong radiational cooling over interior lower Michigan resulted in the formation of strong temperature gradients and a land breeze cold front along the eastern shore of Lake Michigan. The strong temperature gradients forced a "land breeze front," along with a localized convergence zone, to develop. This resulted in the formation of shore-parallel snow bands along the eastern shore of Lake Michigan.

Mecikalski et al. (1989) concluded that shore-parallel snow bands developed when (1) the lake surface/land temperature difference is greater than or equal to 10°C, (2) the lake surface/850 mb temperature difference is greater than or equal to 13°C, and (3) the flow over Lake Michigan is weakly onshore (surface winds usually less than or equal to 10 knots) due to a relaxed synoptic scale pressure gradient. Such a gradient occurs when an Arctic high pressure system settles near Lake Superior or when low pressure moves northeast from the Ohio River Valley. Mecikalski et al. (1989) note an alternate pressure related condition, namely a tighter east/west pressure gradient, as long as the gradient results in a northerly flow over Lake Michigan that is confluent.

## 3. December 1989 Cases

### a. Temperature

On December 15, 1989, an outbreak of frigid Arctic air overran the Great Lakes and northern Ohio Valley regions. From December 15 through December 24, maximum temperatures reached the teens (°F) at best and nighttime temperatures dropped below 0°F. This outbreak established the temperature conditions necessary for the development of shore-parallel snow bands as far south as the southern tip of Lake Michigan throughout virtually the entire period.

As previously stated, there were three occasions of shore-parallel snow bands during the period of interest. The first event (Case 1) occurred from 2200 UTC on December 15 to 1100 UTC on December 16, 1989 with the heaviest snow falling from around 2300 to 0800 UTC. The second event (Case 2) occurred between 1400 and 2000 UTC on December 19 with the heaviest snow falling from around 1500 to 1900 UTC. The third event (Case 3) began around 1600 UTC on December 22 and ended near 1500 UTC on December 23 with heaviest snow falling from around 2000 to 0800 UTC.

Figures 2 through 4 show temperatures at 850 mb during or near the time of the three events. Given a lake surface temperature between 0 and 1°C, an 850 mb temperature of -13°C would satisfy one of the temperature conditions from Mecikalski et al. (1989). Temperatures from all three events were below that prerequisite.

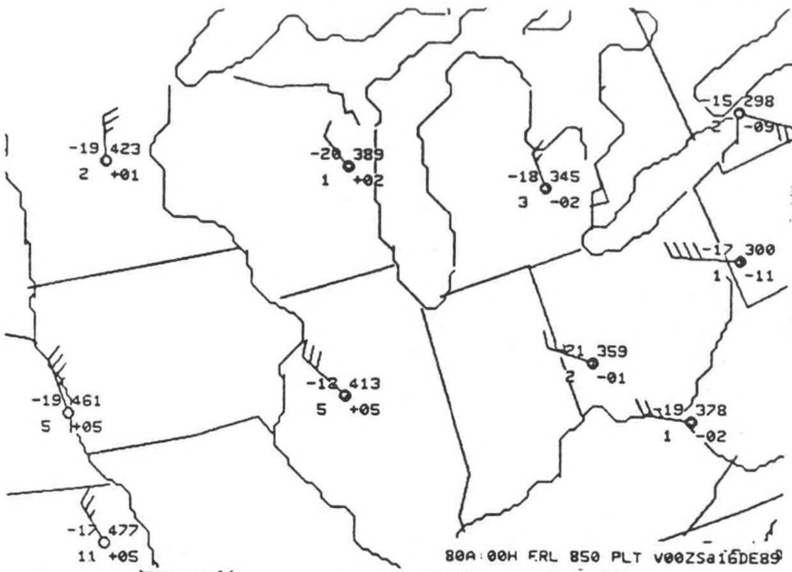


Fig. 2. NMC 850mb Plot 0000 UTC 16 December 1989 (Case 1)

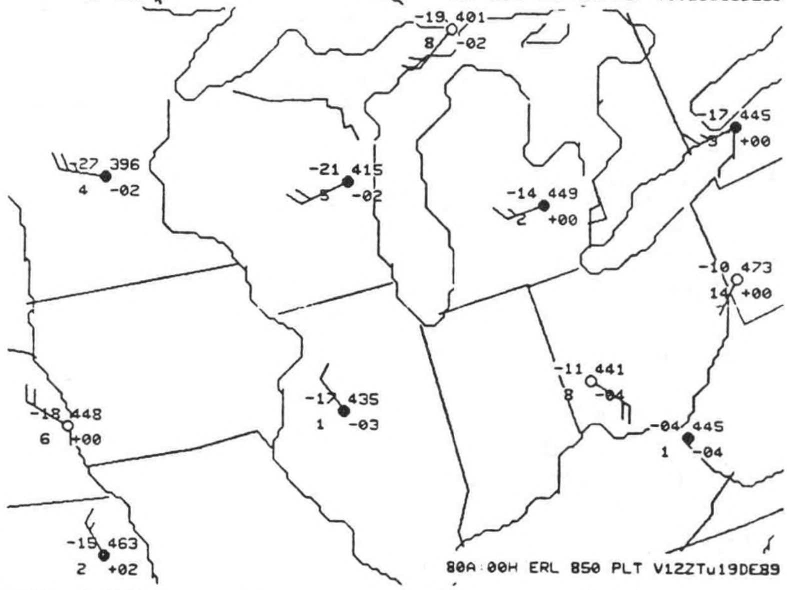


Fig. 3. Same as Fig. 2 except at 1200 UTC 19 December 1989

(Case 2)

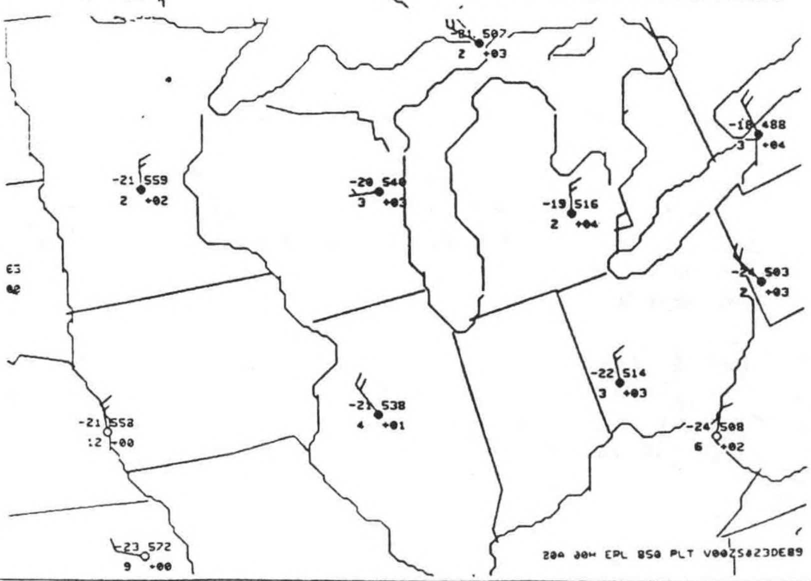

Fig. 4. Same as Fig. 2 except at 0000 UTC 23 December 1989 (Case 3)

Figures 5 through 10 are surface plots during the three events. Surface temperatures of 15°F or below would satisfy the surface temperature condition. The figures show that surface temperature conditions were met throughout the region during Cases 1 and 3, and were met mainly west of the lake during Case 2.

b. Winds and Pressure Pattern

Figures 5 and 6 show that the winds from Case 1 marginally met the conditions from Mecikalski et al. (1989). Surface winds west of Lake Michigan generally were greater than ten knots throughout much of the period, and winds south of Lake Michigan were above ten knots at the beginning of the period. Winds at Milwaukee and Muskegon show that confluence over southern Lake Michigan increased throughout the period.

Figure 7 shows that winds from Case 2 met the prerequisite conditions well, as they were light and confluent. Figures 8 through 10 show that winds from Case 3 also met the prerequisite conditions well, as they were light throughout the event and became increasingly confluent with time.

Figure 11 is the NGM initial surface pressure panel with 1000 to 500 mb thickness superimposed for 0000 UTC on December 16. Heavy snow already was falling in extreme northwest Indiana. It is apparent from the panel that the pressure gradient was not relaxed at this time. A low pressure system was moving northeast from central Pennsylvania, and high pressure had dropped well into the central Great Plains to produce a fairly tight pressure gradient. Remember that wind speeds west of Lake Michigan were in excess of ten knots throughout much of Case 1, and wind speeds south of the lake were in excess of ten knots at the beginning of the event. Some confluence can be inferred from Figure 11 mainly over northern Lake Michigan. Figure 5, the surface plot from December 15 at 23Z, only one hour before the time of Figure 11, shows that confluence was only just beginning between Muskegon and Milwaukee as the Muskegon wind has a little less westerly component than the Milwaukee wind.

However, Figure 5 also indicates some confluence at the southern tip of Lake Michigan associated with cyclonic flow. Winds along the western bank have a northerly component, while winds along the eastern bank have a southerly component. This "thermal trough" was induced by the temperature contrast between the lake and the unusually cold ambient air. Because it was so cold throughout the period of this study, this phenomenon should have been persistent. Indeed, the trough in the wind field and associated directional confluence at the southern tip of the lake can be found in each of the surface plots (Figures 5 through 10) from each of the events. Confluence is, however, most pronounced in Figure 5 because of greater wind velocities.

Figure 12 is an NGM six hour prognosis of the surface pressure field with a 1000 to 500 mb thickness prognosis superimposed. It was chosen since its valid time, 1800 UTC on December 19, falls in the middle of the time of Case 2. It shows a pressure gradient that is more relaxed than that of Case 1, and as mentioned previously, wind speeds from Case 2 were light as defined by

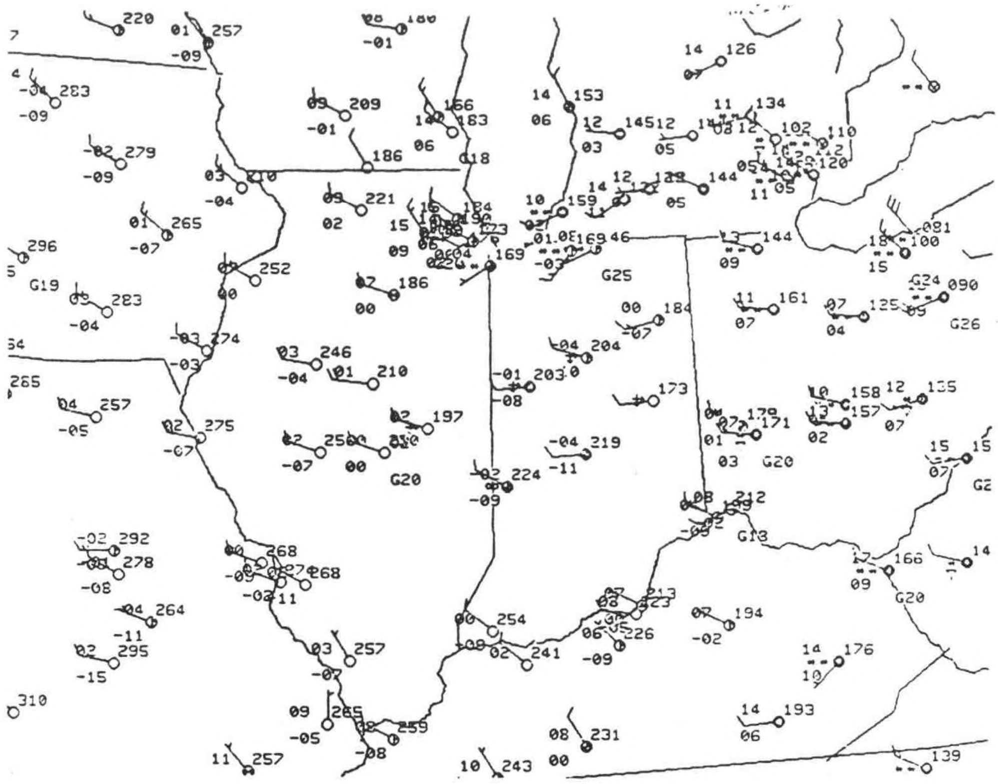

Fig. 5. Surface Plot 23 UTC 15 December 1989 (Case 1)

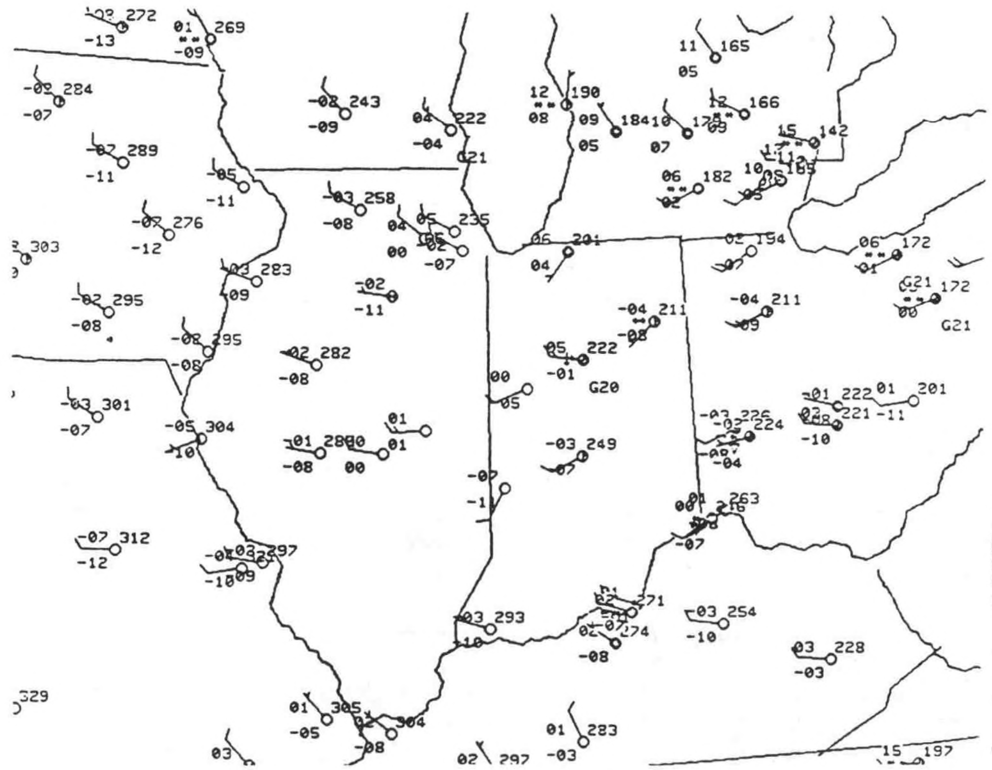

Fig. 6. Surface Plot 05 UTC 16 December 1989 (Case 1)

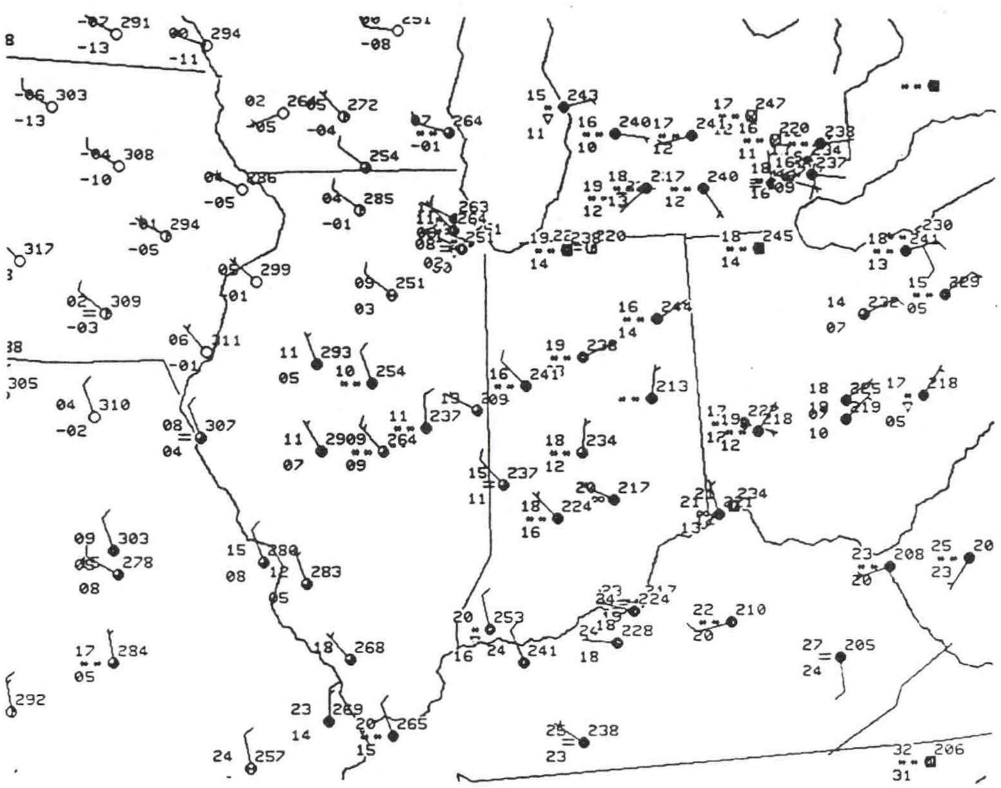

Fig. 7. Surface Plot 16 UTC 19 December 1989 (Case 2)

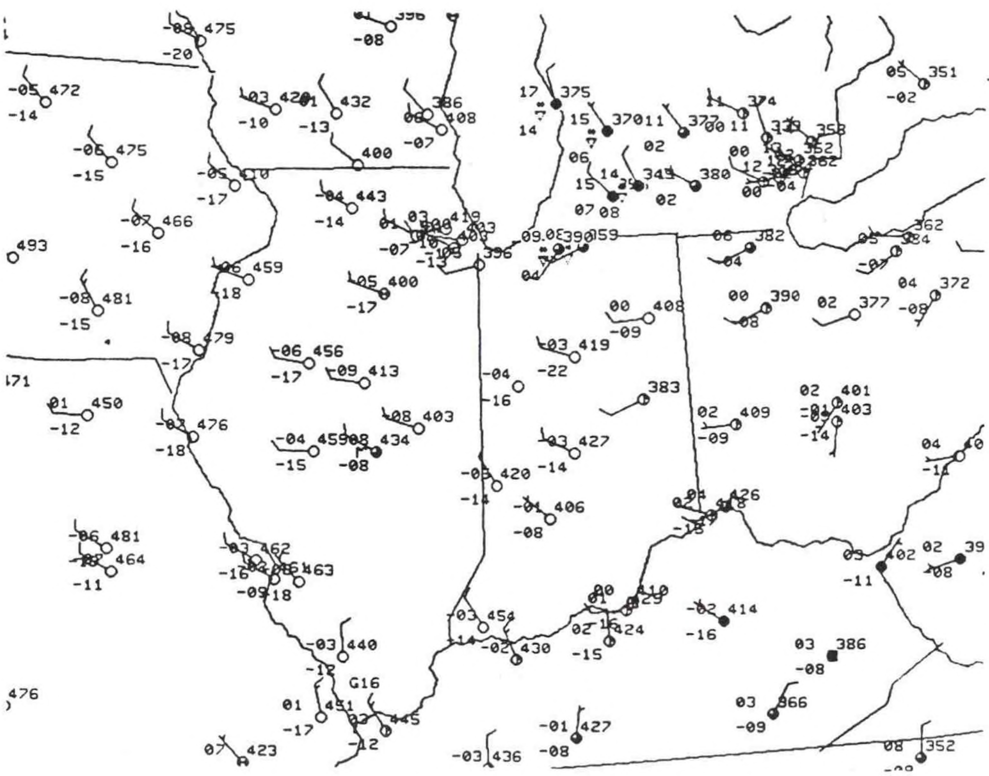

Fig. 8. Surface Plot 20 UTC 22 December 1989 (Case 3)

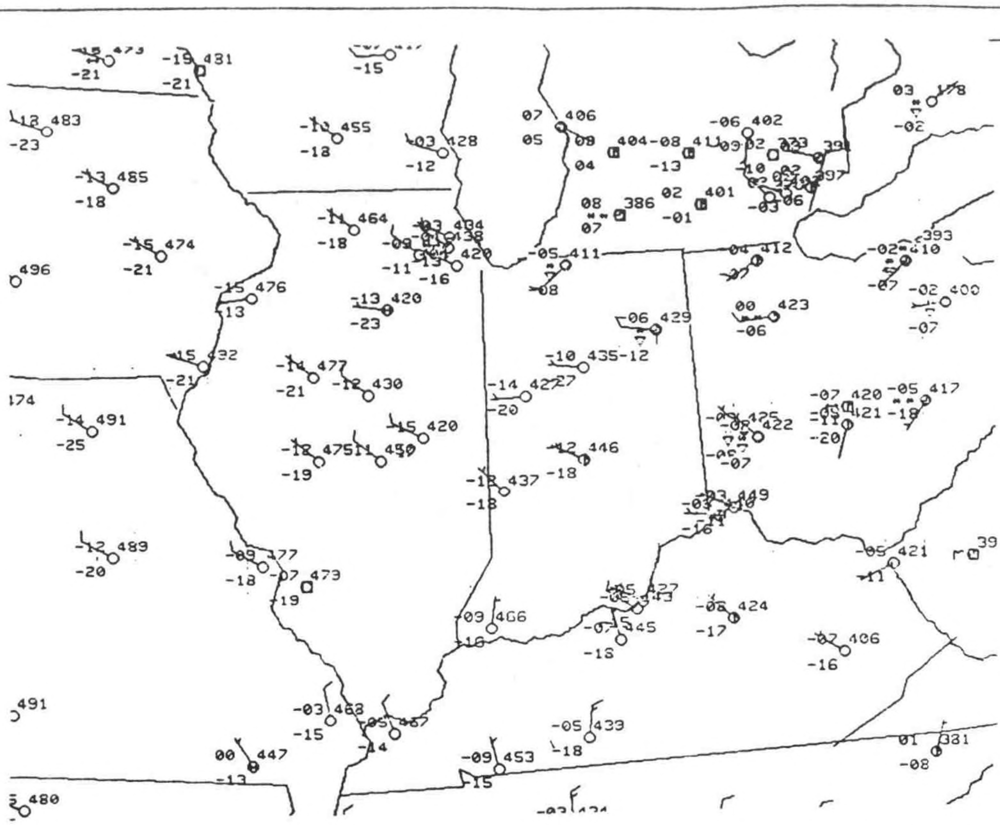

Fig. 9. Surface Plot 03 UTC 23 December 1989 (Case 3)

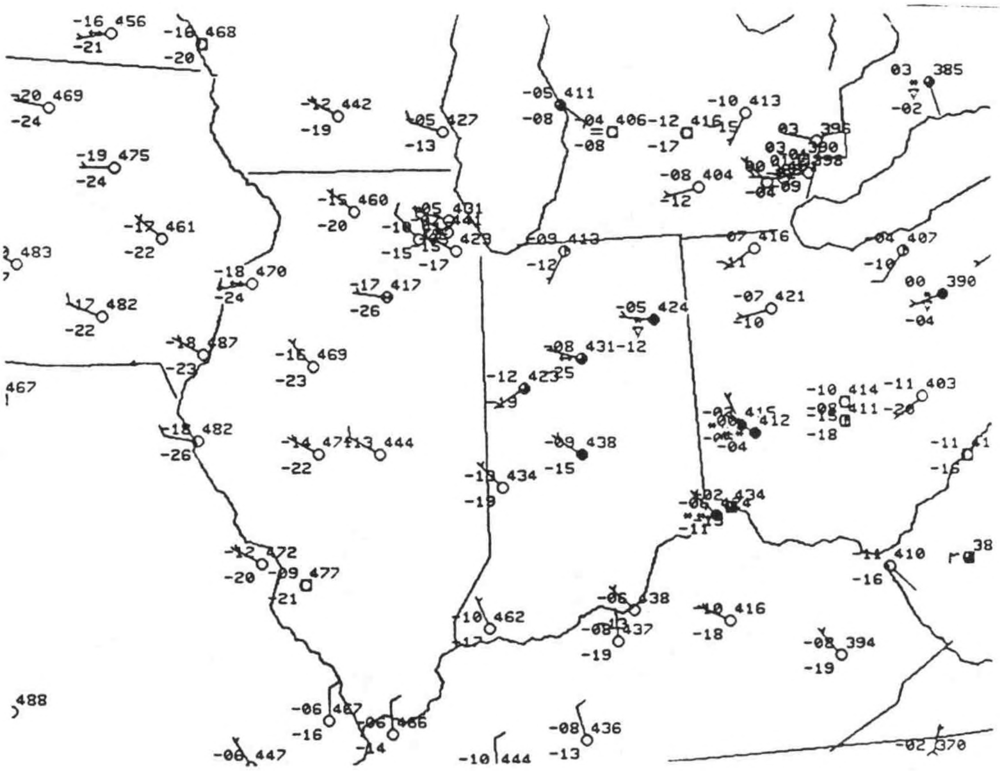

Fig. 10. Surface Plot 08 UTC 23 December 1989 (Case 3)

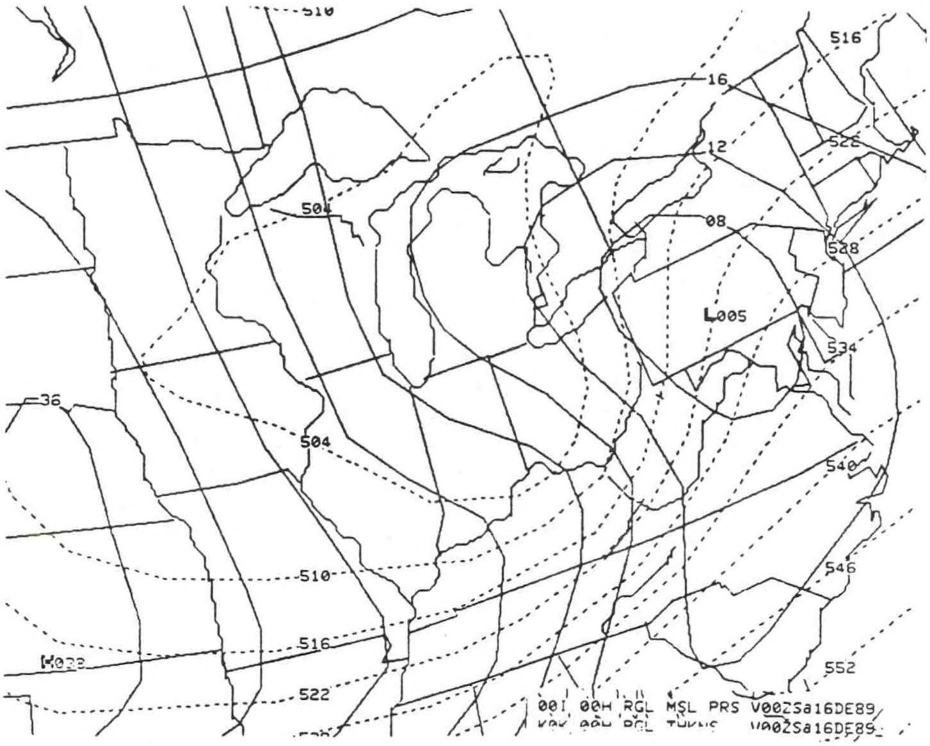


Fig. 11. NGM 00h MSL pressure/1000-500 mb thickness valid 0000 UTC 16 December 1989 (Case 1)

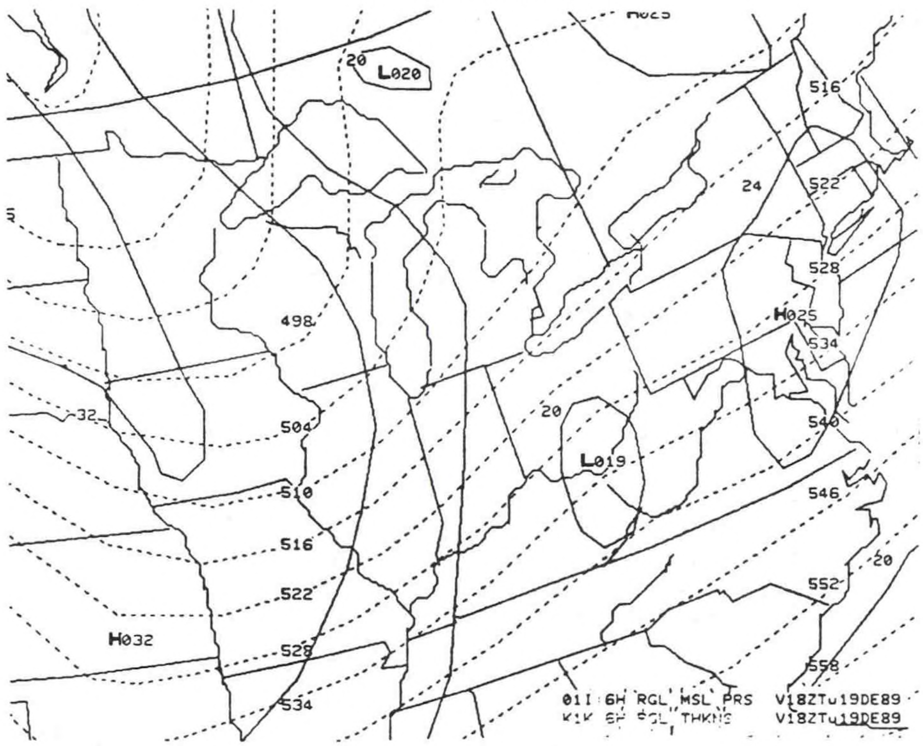


Fig. 12. NGM 06h MSL pressure/1000-500 mb thickness prog valid 1800 UTC 19 December 1989 (Case 2)

Mecikalski et al. (1989). A weak low was north of Lake Michigan, while another weak low was along a cold front in southern Ohio. High pressure was dropping into the eastern Great Plains, and surface flow was anticyclonic in contrast to Case 1.

Note in Figure 7 that there is a modicum of directional confluence at the southern tip of the lake, as indicated by the southwest wind at Kalamazoo, but that it is weaker than it was in Case 1 because the larger scale pressure gradient and the subsequent winds are weaker.

Figure 13 is the NGM initial surface pressure panel with 1000 to 500 mb thickness superimposed for 0000 UTC on December 23. One can see that the pressure gradient over Lake Michigan is about as relaxed as it was in Case 2 (Figure 12). Low pressure had moved into the Canadian Maritimes, and high pressure had dropped into the central Great Plains. This pressure pattern is most similar to those described by Mecikalski et al. (1989) as a prerequisite to the development of shore-parallel snow bands. Figures 8 through 10 show the directional confluence again. It is stronger than in Case 2, but not as strong as in Case 1, as wind speeds are weaker than in Case 1.

Based on the prerequisite conditions previously outlined, it would be expected that Case 3 would be the strongest case of shore-parallel band snowfall of the three, and either Case 1 or Case 2 would be the weakest. In addition to the other factors in its favor, the pressure pattern from Case 3 was similar to one of the ideal patterns from Mecikalski et al. (1989). Temperatures on the eastern side of Lake Michigan were a few degrees F warmer than optimum through much of Case 2. During Case 1, winds were stronger than what is considered optimum on the west and south sides of the lake.

In fact, Case 2 was the weakest and most transient of the three, lasting only about six hours and dropping about six to ten inches of snow from near Laporte to Michigan City. Also, Case 3 was the most persistent, as 12 to 16 inches of snow fell over 23 hours, although the bulk of the snow fell over a 12 hour period. However, Case 1, which lasted 13 hours, resulted in 24 to 30 inches of snow in an area from just east of Laporte to just west of South Bend. The bulk of that snow fell over a nine hour period.

One reason for the magnitude of the snowfall from Case 1, at least during its initial stages, was the thermally induced confluence at the southern tip of Lake Michigan. Assuming this confluence to be a factor in the formation of the shore-parallel snow bands of Case 1, it would mean that shore-parallel bands can develop in conditions not previously believed to be conducive to them. The confluence was stronger than in Cases 2 and 3 because the pressure gradient and resultant wind speeds were greater. Under less extreme temperature conditions, such pressure gradients and wind velocities are usually associated with transient wind-parallel cloud streets.

4. Warm Air Advection

Figures 14 and 15 are identical to Figures 5 and 6, the surface plots from Case 1, except that they are analyzed for isobars and isotherms. Note in Figure 14 (2300 UTC on December 15) a mesoscale thermal ridge from north central

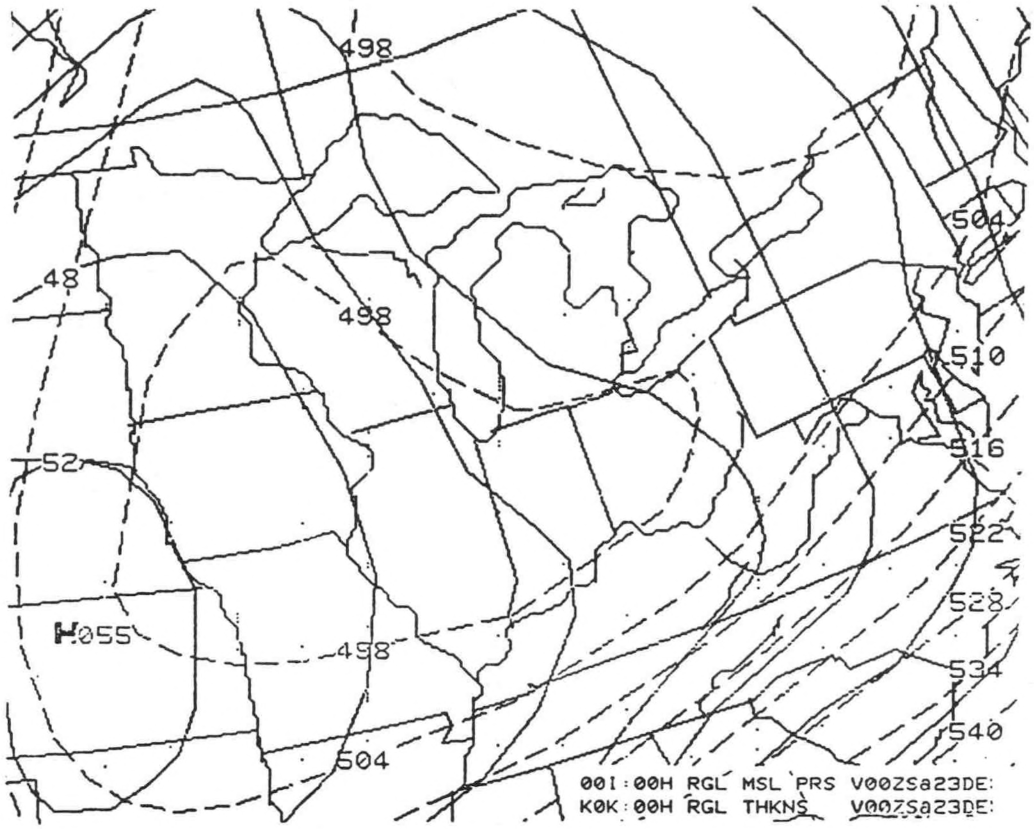


Fig. 13. Same as Fig. 11 except at 0000 UTC 23 December 1989 (Case 3)

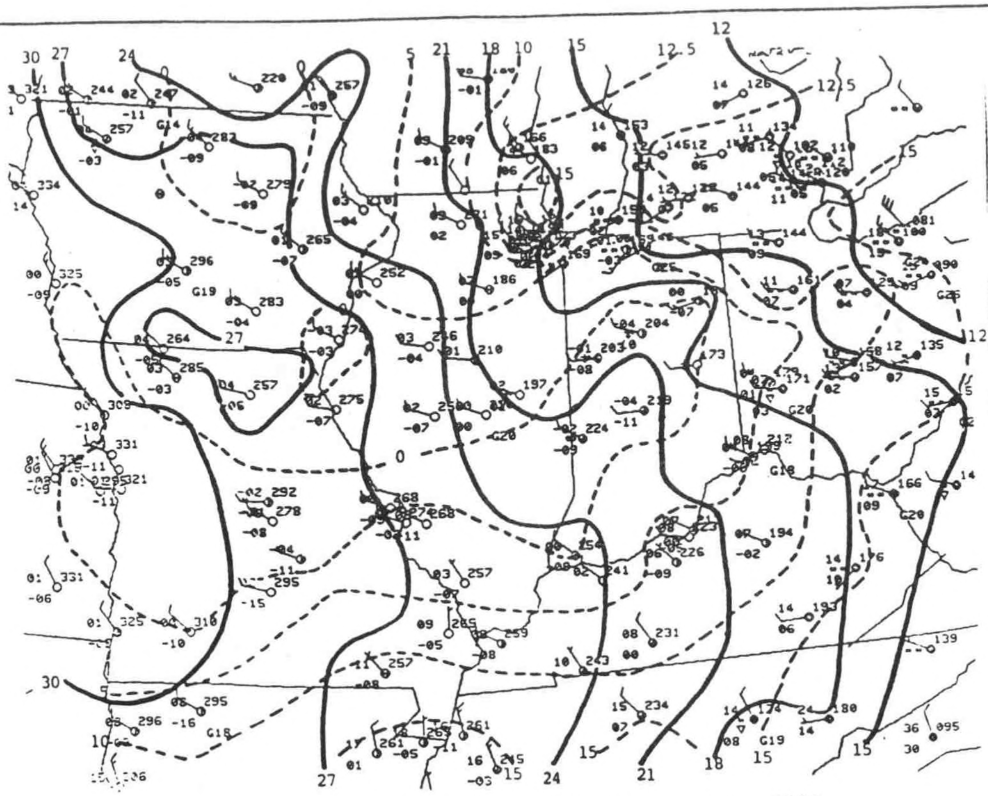

Fig. 14. Surface analysis at 2300 UTC 15 December 1989. Isobars are solid lines (mb), isotherms are dashed lines (deg F) (Case 1)

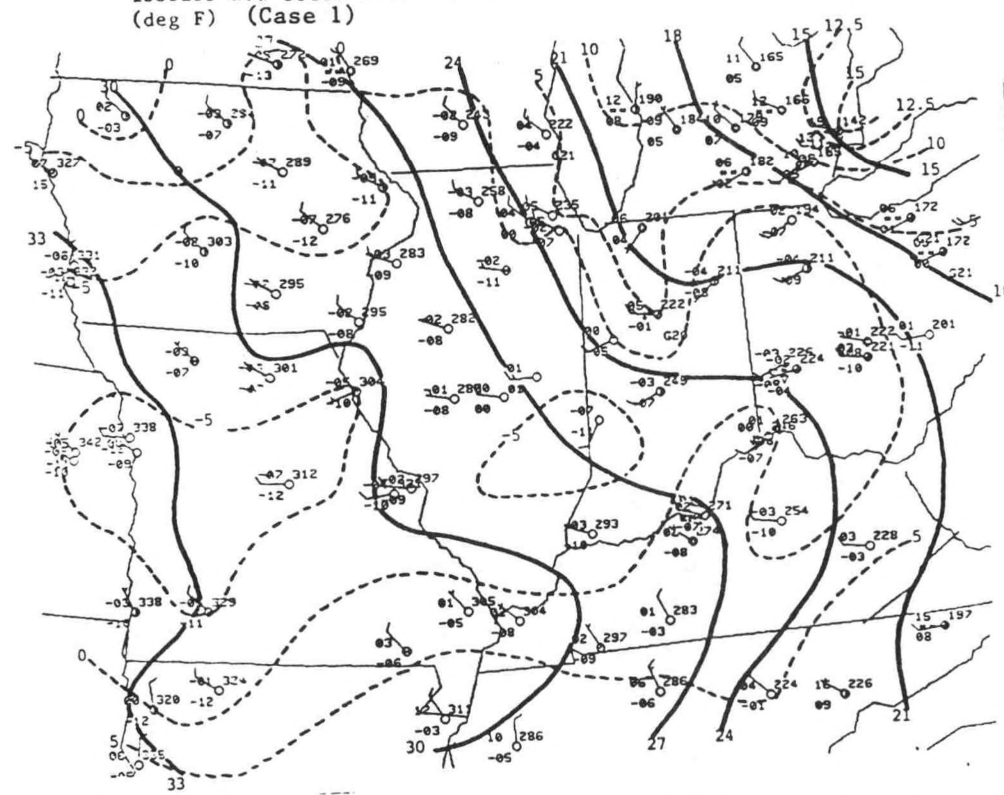

Fig. 15. Same as Fig. 14 except at 0500 UTC 16 December 1989 (Case 1)

Illinois through west central lower Michigan. The thermal ridge appears to be unrelated to the lake induced trough so common during the nine day period. As evidence of this, note that the temperature 25 miles west of the southern tip of the lake was 15°F (a local maximum) with a decidedly offshore wind from the northwest. There is also a hint of a pressure trough to the west of the lake, although it is difficult to see a related and coherent wind shift.

The thermal ridge runs through the snow band from near Muskegon to between Chicago and Milwaukee at 2300 UTC. It is in position to feed energy to the existing shore-parallel bands.

By 0500 UTC on December 16 (Figure 15), the thermal ridge is from extreme western Lake Michigan through north central Indiana. It has moved over the southern part of the snow band area. A broader mesoscale trough from central lower Michigan through north central Indiana with a coherent wind shift is apparent as well. During the six hours between the times of Figures 14 and 15, the temperature at South Bend rose 5°F, and the temperature at Grissom Air Force Base, about 60 miles south of South Bend, rose 9°F. Keep in mind this happened during an overnight period.

Figures 16 through 20 are ADAP plots generated at WSO Fort Wayne showing potential temperature advection over the region from near Lake Michigan to the Ohio Valley. Figure 16 through 18 pertain to Case 1. Figure 16 shows an axis of very strong warm air advection from southern Lake Michigan through east central Illinois moving into the southern extent of the newly developed shore-parallel snow band over extreme southwest lower Michigan and extreme north central Indiana. The time was 2300 UTC on December 15, and heavy snow was just beginning over northwest Indiana. Figure 17 shows that warm advection was weaker but still considerable at 0300 UTC. Heavy snow had been falling for about four hours. By 0700 UTC, warm air advection had shifted eastward and ended over northwest Indiana (Figure 18). Heavy snow tapered off one hour later. The thermal ridge by this time had moved southeast of the snow band area.

Without running a surface analysis, the ADAP potential temperature advection plots gave the information necessary to determine that additional energy was feeding the shore-parallel snow bands. Earlier studies would have noted that confluence at the beginning of the event was weak and the wind speeds were rather high, but as stated previously directional convergence over southern Lake Michigan was stronger. Still, shore-parallel bands in such an environment could well have been weak and transient. In fact, explosive development occurred in conjunction with the warm air advection. Within a few hours, the flow over southern Lake Michigan was noticeably confluent given the winds at Muskegon and Milwaukee (Figure 6).

Figures 19 and 20, the ADAP temperature advection plots from Cases 2 and 3, are included for comparison. Note that during both Case 2 and Case 3, the ADAP plots indicated cold air advection over the area where heavy snow fell. Figures 8 through 10 show that overnight temperatures during Case 3, as would be expected normally, fell.

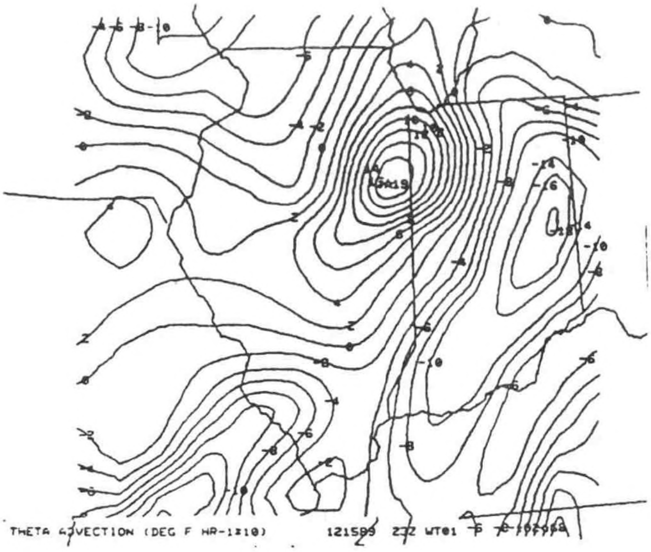


Fig. 16. Surface objective analysis field. Theta advection at 2300 UTC 15 December 1989. Units Deg F hr -1x10. (Case 1)

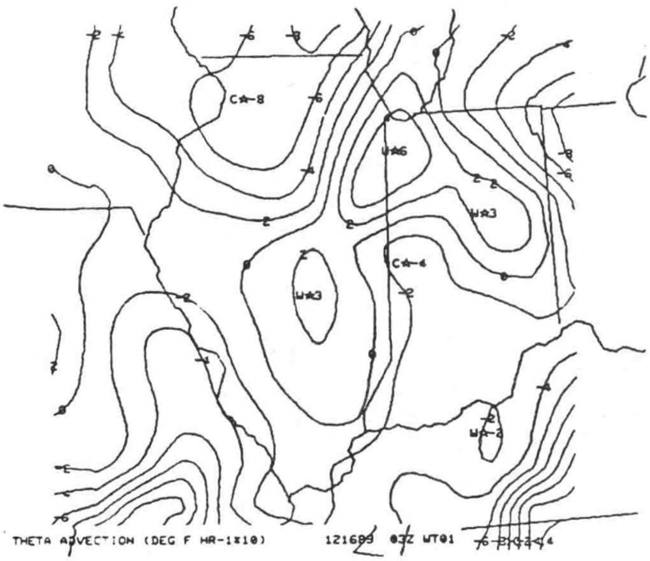


Fig. 17. Same as Fig. 16 except at 0300 UTC 16 December 1989. (Case 1)

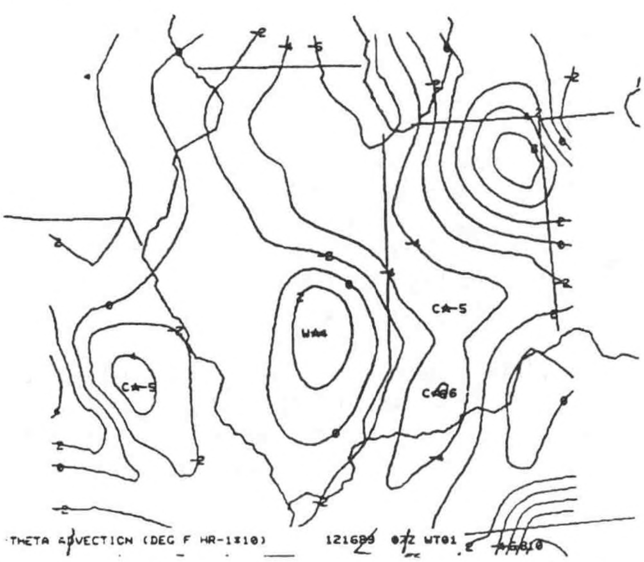


Fig. 18. Same as Fig. 16 except at 0700 UTC 16 December 1989 (Case 1)

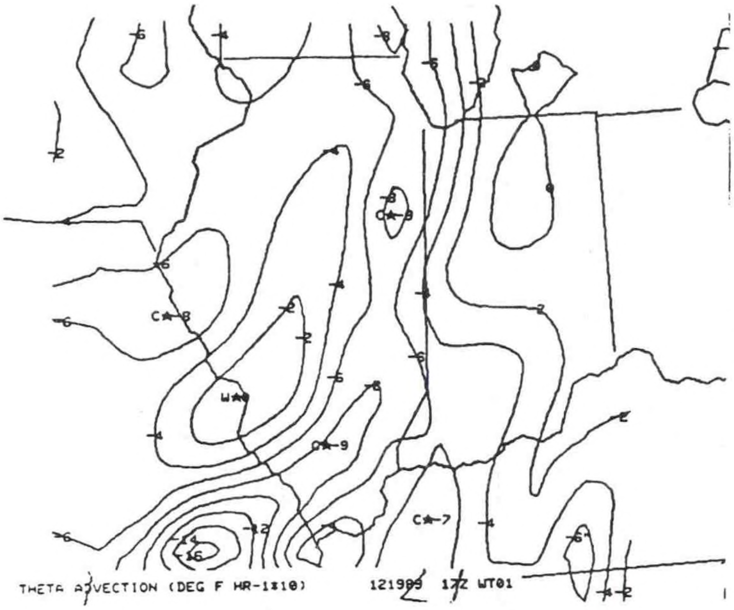


Fig. 19. Same as Fig. 16 except at 1700 UTC 19 December 1989 (Case 2)

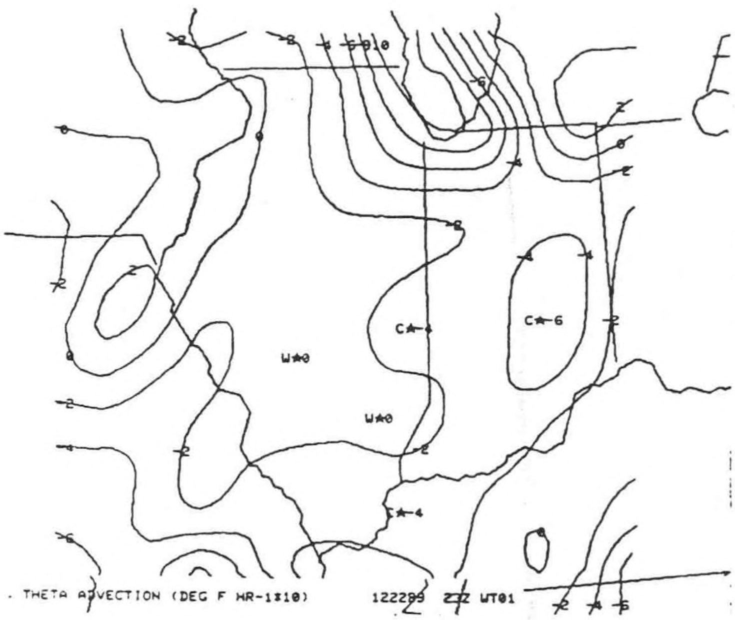


Fig. 20. Same as Fig. 16 except at 2300 UTC 22 December 1989 (Case 3)

## 5. Conclusions

An outbreak of frigid temperatures over the Great Lakes and Ohio Valley regions will establish the temperature conditions necessary for shore-parallel snow bands to affect northwest Indiana.

Case 3 fit the prerequisites from Mecikalski et al. (1989) best. The pressure gradient and resultant surface wind velocities during Case 1 were not what previous studies have considered optimal. During Case 2, the surface temperature pattern became less than optimal. For Case 2, shore-parallel snow bands dissipated after only a few hours. In the matter of Case 1, development of shore-parallel bands occurred where one might have thought wind parallel streets would occur. The indication from this study is that the unusually cold temperatures, combined with the relatively warm water of the lake, induced directional confluence over southern Lake Michigan and helped produce a stationary shore-parallel band. This study also suggests that low level warm air advection was a factor in making Case 1 a greater snow producer than Case 3.

It bears repeating that, during the period of this study, temperatures were unusually cold for the southern Great Lakes region. During the period of Case 1, temperatures were so cold that about six to eight hours of warm air advection were not enough to destroy the temperature conditions necessary for shore-parallel bands to develop or continue. Had ambient conditions been warmer, this would not have been the case.

Without running a surface analysis, one could have deduced from the ADAP potential temperature charts the existence of the thermal ridge, or at very least one could have deduced the ridge's pertinent effect. By themselves, the ADAP plots showed that additional energy was feeding into existing snow bands and, perhaps, that intensification of the snow event was about to occur.

Moreover, ambient temperatures were so cold that a thermally induced confluent area formed over southern Lake Michigan. This confluent area was more of a factor in Case 1 than in the other cases precisely because the pressure gradient was stronger than what had been considered optimal for the development of shore-parallel snow bands. Had ambient conditions been warmer, the confluent zone would not have existed to the extent it did.

## 6. Acknowledgements

Thanks to Larry Mowery and his staff, WSO South Bend, for their help with the radar data and with information pertaining to the events discussed in this paper.

## 7. References

McVehil, G. E., and R. L. Peace, 1965: Some Studies of Lake Effect Snowfall from Lake Erie. Proceedings, Eighth Conf. on Great Lakes Research, Publ. 13, Great Lakes Research Division, Univ. of Michigan, Ann Arbor, MI, 262-272.

Mecikalski, J. R., J. B. Elsner, and R. G. Bann, 1989: Some Aspects of Forecasting Lake Effect Snowfall in Eastern Wisconsin. Preprints, Twelfth Conf. on Weather Analysis and Forecasting (Monterey, CA), Amer. Meteor. Soc., Boston, MA, 364-367.

Passarelli, R. E., Jr., and R. R. Braham, Jr., 1981: The Role of the Winter Land Breeze in the Formation of Great Lake Snow Storms. Bull. Amer. Meteor. Soc., 62, 482-491.

Schoenberger, L. M., 1986: Mesoscale Features of the Michigan Land Breeze Using PAM II Temperature Data. Weather and Forecasting, 1, 127-135.