DETERMINING USEFUL FORECASTING PARAMETERS FOR LAKE-EFFECT SNOW EVENTS ON THE WEST SIDE OF LAKE MICHIGAN

Bradley M. Hegyi
National Weather Center Research Experiences for Undergraduates
University of Oklahoma, Norman, Oklahoma
Purdue University, West Lafayette, Indiana

Dr. Kevin Kloesel
Associate Dean, College of Atmospheric and Geographic Sciences
National Weather Center
University of Oklahoma, Norman, Oklahoma

ABSTRACT

Many of the techniques that have been developed for lake-effect snow forecasting have been designed for regions where lake-effect snow is common, such as western Michigan and upstate New York. In this paper forecasting parameters developed by the NWS forecast offices in Buffalo and Detroit are applied to lake-effect snow cases on the west side of Lake Michigan to see if the parameters accurately depict conditions that are favorable for lake-effect snow development. North American Mesoscale (NAM) and Rapid Update Cycle (RUC) model data at two points near Chicago and Milwaukee are used in the evaluation. Northeast and north-northeast 850 mb and 925 mb winds are found to be common to lake-effect snow events in this region. In addition, the minimum -13°C temperature difference between 850 mb and the lake surface is present during most of the lake-effect snow cases. Low directional wind shear between the surface and 850 mb is also present, but is not an absolute requirement for lake-effect snow to occur in this region.

1. Introduction

Although the cities of Chicago and Milwaukee sit adjacent to the west coast of Lake Michigan, lake-effect snow does not contribute much to the annual snowfall amounts for the two cities. For instance, the city of Milwaukee receives about 47.3 inches of snow per year, while Muskegon, MI, located almost due east of Milwaukee on the other side of Lake Michigan, receives 96.1 inches of snow per year (Comparative Climatic Publication 2007). Most of the studies that have looked at forecasting techniques for lake-effect snow have focused on cases in the more favored regions such as western Michigan. No previous study has looked into the prediction of the rare lake-effect snow events on the west side of Lake Michigan.

The following paper will attempt to apply lake-effect snow forecasting parameters developed by the NWS forecasting offices in Buffalo and Detroit to lake-effect snow cases on the west side of Lake Michigan from the winter of 2003-2004 to the winter of 2007-2008. The forecasting parameters will be tested on these cases using model data from points near Chicago and Milwaukee.

2. Background

One of the techniques developed by the NWS forecasting office in Buffalo, NY to forecast lake-effect snow is shown in Figure 1 found in the appendix. The forecasting scheme relies on comparing certain values derived from current conditions to threshold values that when exceeded, signal that the conditions are favorable for lake-effect snow development. These threshold values are called forecasting parameters. Some of the threshold values are approximations that have a physical significance. The -13°C 850 mb-lake surface temperature difference approximates the dry adiabatic lapse rate in the 850 mb-surface layer (Niziol et al. 1995).

The favorable wind directions represent fetches of the wind over the lake that travel at least 100 miles over the surface of the lake, the minimum distance that is typically needed for lake-effect snow (Dockus 1985). Others, such as directional wind shear, derive from patterns recognized by forecasters in observations of many lake-effect snow events.

3. Data and Methodology

Details about the lake-effect snow events of January 9 and 10, 2004 and January 26 and 27, 2005 were found in case studies produced by the NWS Sullivan/Milwaukee, WI forecasting office. Blogs and reports from local meteorologists in the area, especially those by Tom Skilling in Chicago, helped find information about the rest of the dates. The duration of each event was found by looking at radar images from both the Milwaukee (MKX) and Chicago (LOT) radars. The duration of each event was defined as the time lake-effect snow bands can be seen either within the range of MKX or LOT. Snow bands found exclusively in northwest Indiana, as seen in LOT radar images, were not counted among the list of lake-effect snow cases. All seven cases are summarized in Table 1 found in the appendix.

Once each case was identified, vertical data for each lake-effect snow case was required. This study did not use sounding data primarily due to its spatial and temporal limitations. Green Bay, Wisconsin is the nearest sounding location to the Chicago/Milwaukee area, approximately 100 miles north of Milwaukee. The site is located near the coast of Lake Michigan, but the Door Peninsula, located east of the site, modifies any lake influence on air masses moving west over Lake Michigan. Since Milwaukee and Chicago lie directly on the coast of Lake Michigan, the Green Bay site would not accurately represent the conditions found at Chicago and Milwaukee. In addition, the data from soundings are also spread too far apart in time to fully represent each lake-effect snow case. Sounding data is normally available every twelve hours. Several of the lake-effect snow cases listed in table 1 lasted less than 24 hours. These cases could only be described by two soundings at the most. To mitigate these limitations, all data in this study comes from model representations of the conditions. Model data contains two distinct advantages. First, using model data allows for data to be collected for every three hours of the event, instead of every twelve hours. Second, the data can be taken at points near both Chicago and Milwaukee. Zero and three hour forecasts from the North American Mesoscale (NAM) and Rapid Update Cycle (RUC) model are used to characterize the conditions in each lake-effect snow case. Model data is taken from two points, one near Chicago at (41.9°N, 87.7°W) and one near Milwaukee at (43.0°N, 87.9°W). The model data is pulled from the NOAA National Operational Model Archive and Distribution System (NOMADS) and NOAA Live Access Server (LAS) websites. NAM data is used for five of the seven cases: 3/8/2008, 12/5/2007, 1/26-1/27/2005, 1/22-1/23/2005, and 1/9-1/10/2004. RUC data is used for the other two cases, 2/14/2007 and 2/8/2006, due to the lack of NAM model data available for those two dates. Four sets of variables are analyzed in this study: 850 mb and 925 mb temperature, 850 mb, 925 mb, and surface wind direction, 850 mb and 925 mb vertical velocity, and 850 mb relative humidity.

4. Results

All figures discussed in the results are found in the appendix.

Figure 2 shows the maximum 850 mb relative humidity (RH) values for each case of lake-effect snow. The categories listed on the graph are taken from a paper written by Michael Evans, a forecaster at the NWS forecasting office in Detroit, Michigan in 1996. The paper looked at a number of lake-effect snow cases in western Michigan. The categories are based off of trends seen in 31 distinct lake-effect snowfall events before April 1995. Snowfall amounts were taken at 11 locations in this study. If two or more stations with the highest snowfall amounts reported snowfalls within the light or heavy category, then the event was classified as such (Evans 1997).

In Figure 3, the differences between the lake surface temperature and the 850 mb temperature are shown. Lake surface temperatures were taken from NOAA's

National Ocean Service station at Calumet, IL (Station Number: 9087044). If lake surface temperatures were not available, then the temperature was assumed to be 0°C. X values represent the number of hours after the start of the snowfall in each case. For example, if an event started at 12 UTC, the difference value at 15 UTC would be plotted with an x value equal to 3. The Buffalo criterion line is based off of a -13 degree Celsius difference threshold used on the flow chart presented in Figure 1.

Table 2, found in the appendix, lists the 12 total cases where the temperature difference was above the -13 degrees Celsius. 925 mb vertical velocities that correspond to each occurrence listed in the table are included. The one occurrence listed in the table where lake surface temperature data was available is bolded.

Figure 4a and 4b show a plot of all 850 and 925 mb wind direction values. The range of wind values marked by the dotted lines contains 90% of the data points that occur within the first 24 hours of all events. Positive y values represent wind direction values east of due north (e.g. +40 = 40°); negative values represent wind direction values west of due north (e.g. -40= 360-40 = 320°). The graphs use the same x values as Figure 3.

The final two graphs, Figure 5a and Figure 5b, present directional wind shear values between the surface and 850 mb. The wind shear values are the difference between the degree value of the wind direction at 850 mb and the degree value of the wind direction at the surface. Both graphs incorporate the same x values as seen in the previous graphs. The Buffalo criterion dotted line comes from the flow chart presented in figure 1 and represents the maximum shear value where lake-effect snow development is favored (Niziol 1987). All data points from the 1/9-1/10/2004 lake-effect snow case are removed in Figure 5b.

5. Discussion

5.1 *850 mb Relative Humidity*

In Figure 2, 12 of the 14 maximum 850 mb relative humidity (RH) values are above the 80% threshold for heavy snow. Only values from Chicago on 1/9/-1/10/2004 and 1/26-1/27/2005 are less than 80%. Looking back at Table 1, only 7 of the 14 snowfall amounts listed would be classified as “heavy”, including one of the two snowfalls that had a maximum 850 mb RH value of less than 80%. The heavy snow classification fails for 2/8/2006, where 0.5 and 0.3 inches of snowfall were reported in Chicago and Milwaukee, respectively. Despite the failure of Evans’s categories to correctly classify some of the cases of lake-effect snow, not enough snowfall data was looked at to definitively call them inapplicable to western Lake Michigan lake-effect snow events. In this study, snowfall was only taken at two points, not 11 points as in the Evans study. There is no way to tell if greater amounts of snow fell outside of Chicago or Milwaukee.

5.2 *850 mb-lake surface temperature difference*

The graph and table concerning 850 mb-lake surface temperature differences are more conclusive. Only one of the points where lake surface temperature data is available lies above the Buffalo criterion line (Figure 3). This result suggests that the Buffalo criterion line signifies favorable lake-effect snow conditions if the water temperature is known. The only caveat to this conclusion is that mid-lake surface temperatures, which would be more representative of the lake temperature across the entire lake surface, were not available. Most likely, the mid-lake temperatures would be slightly less than the average of 4.7°C at the Calumet, IL coastal station. If mid-lake temperatures were considered, the points on figure 3 would shift upward. However, this consideration would not significantly change the number of points that lie above the Buffalo criterion line. 88% of the points are positioned at least 2 degrees below the -13°C difference line. A decrease as large as 2°C of the lake surface temperature used in the calculation of the differences would not shift a significant number of points above the Buffalo criterion difference
of -13°C. Thus, the conclusion that the Buffalo criterion signifies favorable lake-effect snow conditions would not be seriously compromised by the use of mid-lake surface temperatures.

For the cases where the temperature of the lake surface is not known, the 0°C approximation of the lake surface temperature seems to be inadequate. As mentioned earlier, the average temperature of the lake at the Calumet, IL station was 4.7°C. Even if mid-lake temperatures were taken into consideration, lake surface temperatures would most likely be a few degrees above freezing, given the fact that Lake Michigan has only completely frozen over only once in the past 30 winters (NOAA Great Lakes Ice Atlas). An assumption that the lake temperature is 2°C would shift the points where no lake temperature is available down 2°C. This would move all but one of the 12 points above
above the Buffalo criterion threshold downward to positions below the threshold. Even with the 0°C estimate, 94 of the 106 points, about 89% of the points, fall below the -13°C difference line. Clearly the Buffalo criterion line signifies favorable lake-effect snow conditions in most cases where lake-effect snow is occurring. However, it is not known if this is a definite rule-of-thumb, since cases where lake-effect snow did not occur were not considered.

An interesting pattern arises from looking more closely at the three-hour periods where the temperature difference was above -13°C, regardless of whether the assumption for lake surface temperature was used or not. In all 12 cases, upward-directed vertical velocities at 925 mb were present. However, only one of these points includes a calculation with actual lake temperature data. More points above the Buffalo criterion with actual lake temperature data are needed to validate this connection between the 850 mb-lake surface temperature difference and 925 mb vertical velocity.

5.3 *850 and 925 mb Wind Direction*

90% of the 850-mb wind direction data within the first 24 hours after the initiation of the lake-effect snow event fall within a range of about 350 degrees to 35 degrees (Figure 4a). Similarly, 90% of the data points with the first 24 hours after initiation fall within a range of 355 degrees to 70 degrees (Figure 4b). The resulting small ranges suggest that northeast winds at both levels are present in most cases of lake-effect snow around Chicago and Milwaukee. In addition, it implies indirectly that directional shear is small within the layers that contain lake-effect snow convection, since the difference in the ranges is small. Again, both of these results would be more conclusive if tested against cases where lake-effect snow did not occur.

5.4 *850 mb-Surface Directional Shear*

13 points lie above the 60 degree threshold from Buffalo in Figure 5a. Further analysis of the points above the threshold reveals that most of these outliers are from one lake effect snow case: 1/9-1/10/2004. Removing the data points from this case reduces the number of points above the 60 degree line from 13 to 3 and increases the percent of points below the line from 88% to 97%. The fact that one case contains many instances of directional shear values above 60 degrees means that the cutoff is not a strict separation between lake-effect snow occurring and lake-effect snow absolutely not occurring. 850 mb-surface directional shear values below 60 degrees are common in lake-effect snow events, but the 60 degree threshold is not an absolute requirement.

6. Conclusion

The efforts to connect relative humidity values to snowfall amounts in each of the lake-effect snow cases did not yield anything conclusive. The snowfall categories established by Evans do not definitively describe the seven lake-effect snow cases analyzed in this study. One lake-effect snow case where a half an inch of snow fell in Chicago would be counted among the heavy snow events, according to the categories proposed by Evans. A greater number of locations with snowfall measurements for each case would help more clearly determine if the categories are applicable.

Looking at the 850 mb-lake temperature differences gave more clues about the conditions favorable for lake-effect snow, despite the lack of null cases analyzed in this study. All but one of the data points where lake surface temperature data were available was found below the -13°C threshold. Even if cooler mid-lake temperatures were used instead of coastal water temperature values, most (89%) of the data points would still lie below the threshold. Even with the poor 0°C approximation for lake surface temperature, 89% of all times during the lake-effect snow cases on the west side of Lake Michigan in the last 5 winters exhibit the minimum -13°C 850mb-lake temperature difference. In addition, upward motion at 925 mb is present in all cases where the difference between the 850 mb temperature and lake surface temperature is greater than -13°C. However changing the 0°C approximation would reduce the number of times this relationship would be seen in all of the lake-effect snow cases in this study.

The final two forecasting parameters, 850 mb/ 925 mb wind direction and 850 mb-surface directional wind shear, confirmed that a range of values was common to almost all of the lake-effect snow cases for each parameter. For the first 24 hours of each snowfall event, the wind direction at 850 mb and 925 mb is found in a relatively narrow range. 90% of the 850 mb wind direction values fall between 350 and 35 degrees; 90% of the 925 mb wind direction values fall between 355 and 70 degrees. At both levels, northeast or north-northeasterly winds are most common to the lake-effect events. In addition, 850 mb-surface directional shear values of less than 60 degrees are common to almost all of the lake-effect snow events. 89% of the values of directional shear are below 60 degrees. However, lake-effect snow is possible with larger values, as seen in the lake-effect snow event of 1/9-1/10/2004. The exceptions, as in the case of directional shear, show that these forecast parameters are only guides to the conditions favorable for lake-effect snow development. If a forecasting parameter threshold is met, it does not mean that lake-effect snow will absolutely occur, but that conditions are favorable for lake-effect snow development on the west coast of Lake Michigan.

7. Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. ATM-0648566. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. A special thanks goes out to Daphne LaDue for organizing activities that enriched the research experience over the summer.

8. References

Comparative Climatic Data Publication, 2007. National Climatic Data Center. 46-54.

Dockus, D.A., 1985: Lake-effect snow forecasting in the computer age. *Nat. Wea. Dig.* **10**. 5-19.

Documented Extreme Weather Events: Southeast and South Central Wisconsin. National Weather Service Forecasting Office: Milwaukee/Sullivan, WI. 11 Jun 2008. < http://www.crh.noaa.gov/mkx/?n=documented_storms>.

Evans, Michael, 1997: A study on the relationship between synoptic-scale forecasts of vertical motion and snow amounts across southwest Lower Michigan in lake effect snow environments. NWS Central Region Applied Research Paper. **17-11.**

Niziol, Thomas A., 1987: Operational forecasting of lake effect snowfall in western and central New York. *Wea. Forecasting*. **2**. 310-321.

Niziol, Thomas A., Snyder, Warren R., Waldstreicher, Jeff S., 1995: Winter weather forecasting throughout the eastern United States. Part IV: Lake effect snow. *Wea. Forecasting*. **10**. 61-77.

NOAA Great Lakes Ice Atlas: Original Ice Charts (1973-2002). Great Lakes Environmental Research Laboratory. 19 Jun 2008. <http://www.glerl.noaa.gov/data/ice/atlas/ice_charts/index.html>

Appendix A: Tables and Figures

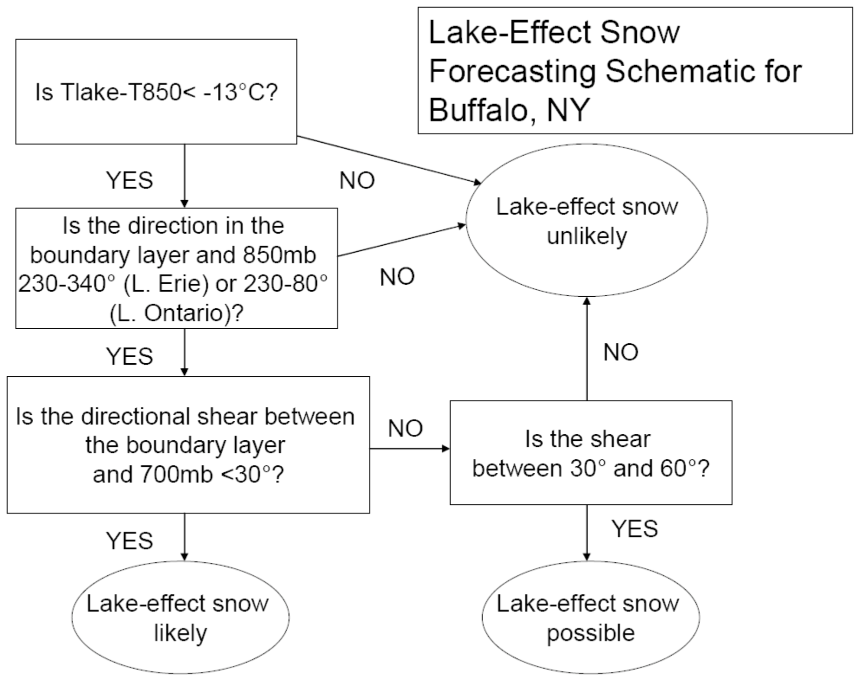

Figure 1. Forecasting scheme from the Buffalo NWS forecasting office. Forecasting parameters are found within the boxes in the flow chart.

Start Date	End Date	Start Time	End Time	Duration	Snowfall Amounts (in.)••	
					Chicago (ORD)	**Milwaukee**
3/8/2008	3/8/2008	4:00Z	19:00Z	13h	0.3	3.9
12/5/2007	12/5/2007	12:00Z	21:00Z	9h	2.1	3.6
2/14/2007	2/14/2007	2:30Z	20:00Z	17h 30min	1.4	1.4
2/8/2006	2/9/2006	14:30Z	5:00Z	14h 30min	0.5	0.3
1/26/2005	1/27/2005	15:00Z	22:00Z	31h	3.1	3.8
1/22/2005	1/23/2005	14:30Z	17:30Z	27h	6.4	4.8
1/9/2004	1/10/2004	0:00Z	6:00Z	30h	0.7	5.4

••- For Milwaukee on 2/14,2/8, and 1/22, snowfall amounts are estimated by using the average snowfall rate times the liquid precip. during times of lake-effect snow.

Table 1. All cases in the past five winters (2003-2004 through 2007-2008) of lake-effect snow the Chicago and Milwaukee area. The total snowfall in most of these cases is less than six inches.

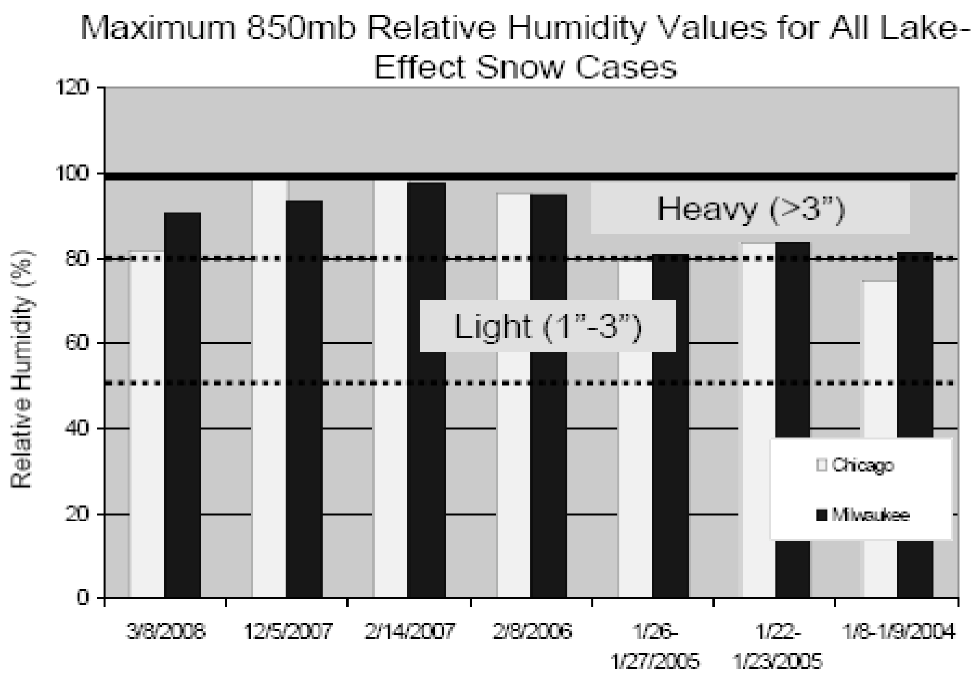

Figure 2. Graph comparing maximum RH values to the categories described by Evans. Most of the cases have RH values within the heavy snowfall category (>3" in 24 hours).

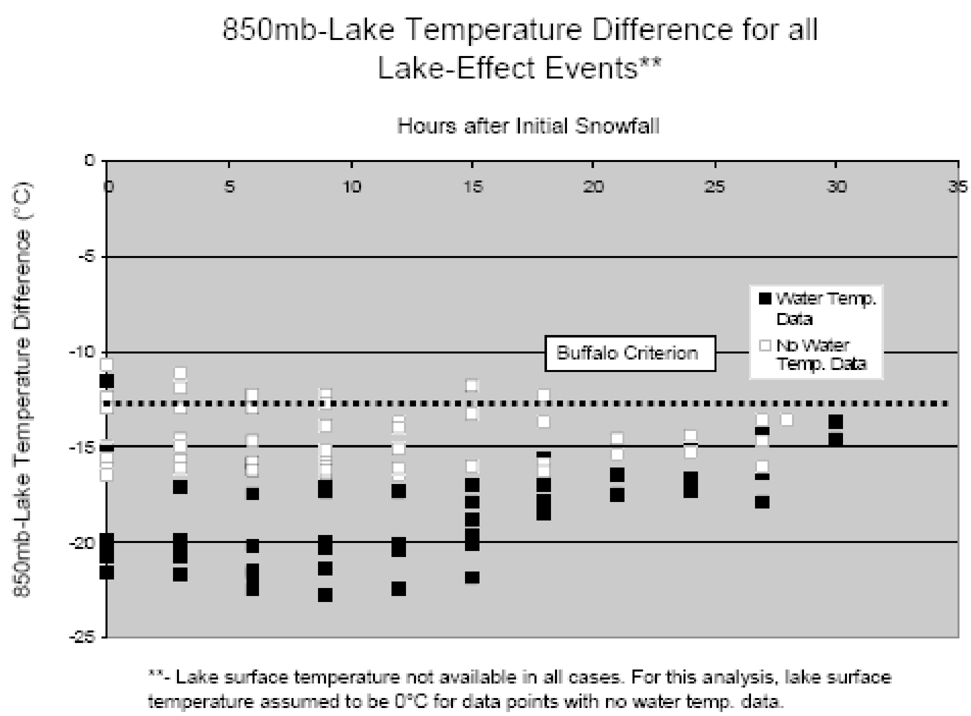

Figure 3. 850 mb-lake surface temperature differences for all lake-effect snow cases. All of the points that include water temperature data lie below the Buffalo criterion line.

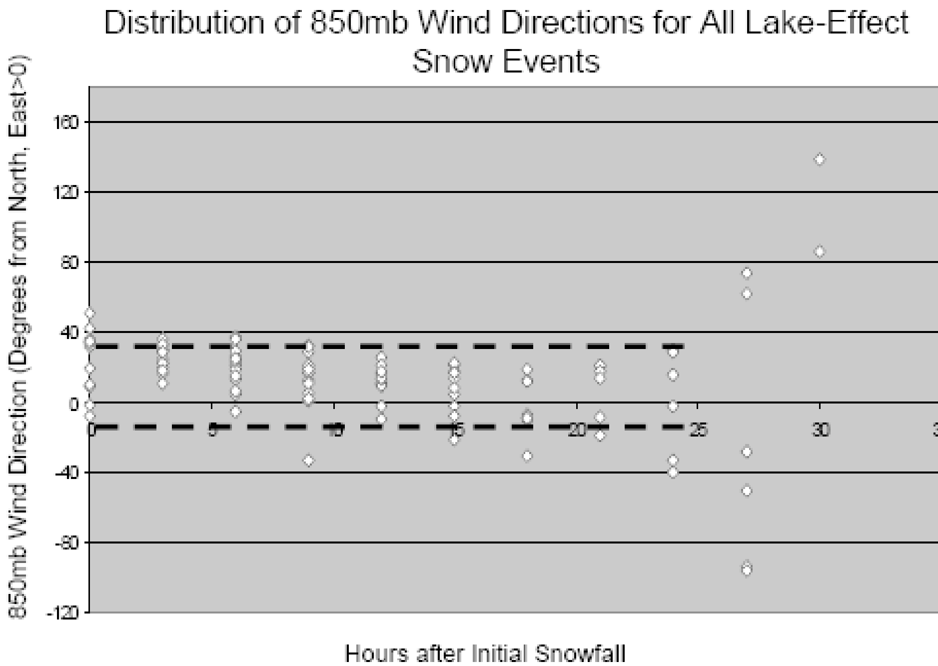

Figure 4a. 850 mb wind direction values for all lake-effect snow cases. For the first 24 hours of each event, the wind direction tends to fall in a narrow range, from 350 degrees to about 35 degrees.

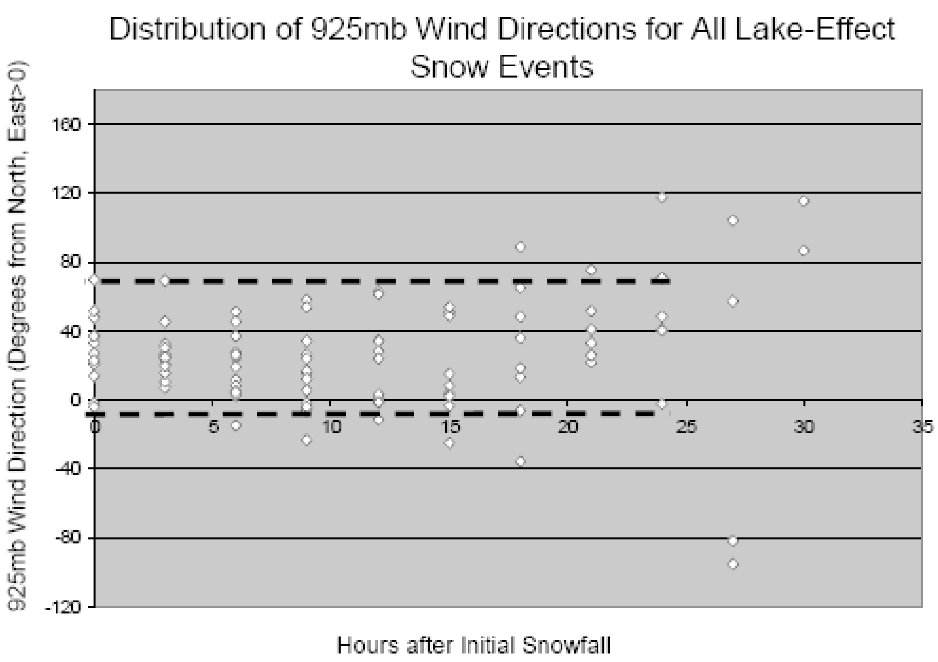

Figure 4b. 925 mb wind direction values for all lake-effect snow cases. The points again fall in a tight range for the first 24 hours after the initial snowfall. The range, a little larger than the range in Figure 4a extends from 355 degrees to about 70 degrees.

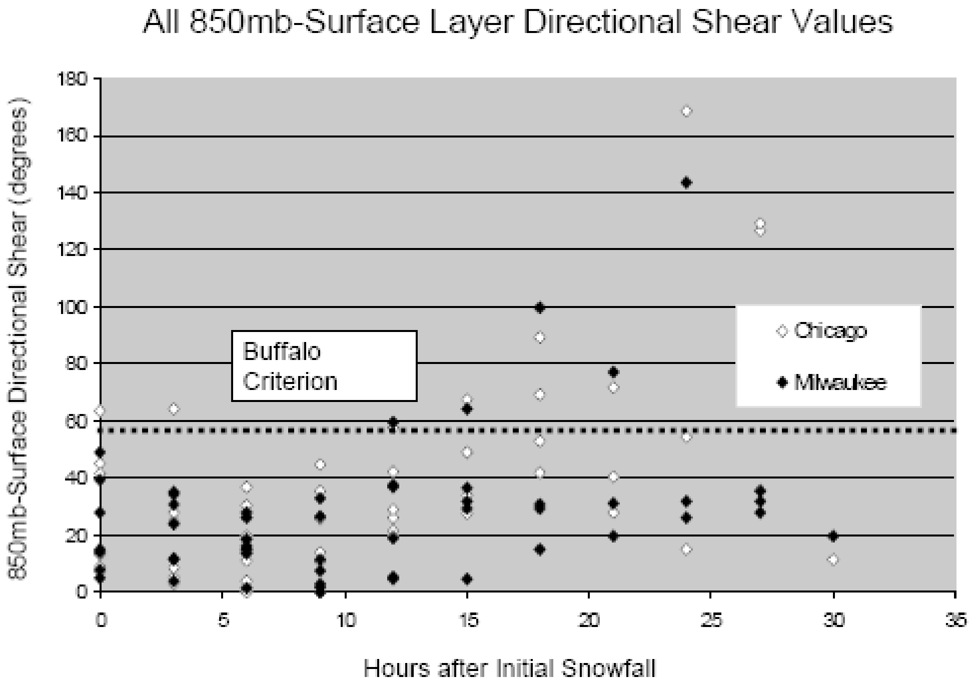

Figure 5a. 850 mb-surface directional wind shear values for all lake-effect snow cases. Most data points fall below the 60 degree threshold established by Buffalo, but there are several exceptions.

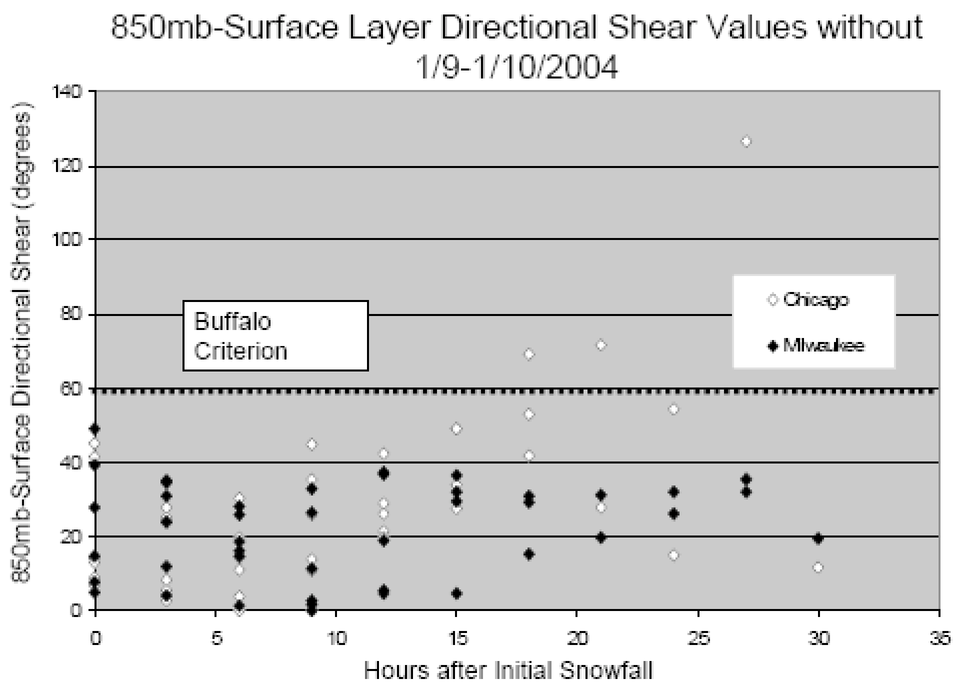

Figure 5b. 850 mb-surface directional shear values for all cases except 1/9-1/10/2004. Taking out this one case removes most of the outliers above the Buffalo criterion line at 60 degrees.

		850mb temperature (degrees Celsius)		925mb Vertical Velocity (Pa s^{-1})	
Date	Time	Chicago	Milwaukee	Chicago	Milwaukee
12/5/2007	12Z	-10.7	-11.8	-0.257	-0.329
	15Z	-11.9	-12.3	-0.623	-0.266
	18Z	-12.3		-0.417	
	21Z	-12.3		-0.155	
1/26/2005	**15Z**	**-11.6**		**-0.161**	
1/9/2004	0Z	-12.4		-0.26	
	3Z	-11.1	-13	-0.222	-0.133
	6Z	-12.3	-12.7	-0.0288	-0.0436

Table 2. All cases of 850 mb-lake surface temperature differences greater than -13°C with corresponding 925 mb vertical velocity values. Upward motion is present in all cases of 850mb- lake surface temperature differences greater than -13°C.