# 5.2 Observations of the Diurnal Evolution of Lake-Effect Precipitation Occurrence

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## 1. BACKGROUND

Lake-effect snow storms are important components of the climate of the U.S. Upper Midwest, resulting in some locations near the Great Lakes receiving double the average wintertime snowfall of locations several 10s of km inland (e.g., Scott and Huff 1996, Braham and Dungey 1984). The economic and societal impacts of these storms depend critically on the timing of their occurrence relative to activities of the 35 million people living in the Great Lakes basin (GLERL 2002). This study utilizes hourly precipitation data collected in the snow belt regions of Lakes Superior and Michigan to determine the typical diurnal behavior of lake-effect precipitation occurrence.

While much is known about the causes of lake-effect precipitation, little research has been reported in the scientific literature on the diurnal evolution of such storms. Passarelli and Braham (1981), for example, speculated that snowfall rates in Lake Michigan lake-effect storms would be expected to be greater in the early morning hours due to climatically larger lake-air temperature differences at that time. Ruhf and Cutrim (2003) found such a morning peak in total wintertime precipitation at a site 55 km east of Lake Michigan and suggested that lake-effect processes were largely responsible. Alternatively, Miner and Fritsch (1997), using radar observations, found that autumn lake-effect rain near Lake Erie was more frequent and intense during the afternoon hours. These authors hypothesized that destabilization of the air upstream of the lake through afternoon radiational heating may have played a role in allowing for more rapid over-lake precipitation development.

The current study seeks to determine the typical diurnal evolution of precipitation rate in approximately 200 lake-effect events over a five-year time period identified by Kristovich and Steve (1995). Hourly precipitation observations at several sites are utilized to examine the spatial variability in the diurnal trends and surface weather observations at several sites are used to quantify some meteorological factors which may affect lake-effect diurnal variations.

## 2. DATA AND METHODOLOGY

In order to differentiate the diurnal evolution of lake-effect precipitation from that due to other processes (such as cyclones), it is important to independently identify cases when lake-effect storms occurred. For this study, we utilize the dataset developed by Kristovich and Steve (1995). They used five years (1988 to 1993) of visible satellite imagery to identify dates with distinctive cloud patterns indicative of widespread or banded lake-effect events. These data were then used to determine the spatial variation in the frequency of different types of lake-effect events.

Hourly precipitation data were collected by the NOAA Cooperative Observation Network (National Climatic Data Center TD 3240). Seven sites with hourly precipitation data were chosen to determine the diurnal evolution of lake effect precipitation for the cases identified by Kristovich and Steve (Figure 1). Precipitation observations were obtained using Universal Weighing Bucket gauges at Marquette, Grand Rapids, and Muskegon, MI, and Milwaukee, WI, and the Fischer-Porter recording rain gauges elsewhere (Nolan Doesken, personal communication, 2003). Six of these sites were near the lake-effect snow belt region east and south of Lake Michigan and one site was located in the snow belt region south of Lake Superior. For comparison of precipitation distributions upwind and downwind of Lake Michigan, an additional site was chosen west of Lake Michigan. These stations were all within 50 km of the lake shore and had hourly precipitation data available with fewer than 20 percent of the values missing.

Finally, in order to obtain insight on the mechanisms responsible for the diurnal evolution of lake-effect precipitation, factors thought to be important to lake-effect storm formation were examined. In particular, the diurnal variation of surface sensible and latent heat fluxes were estimated using surface observations from several sites near Lake Michigan (Muskegon and Traverse City, MI, and Milwaukee, WI) and corresponding lake surface temperature observations from United States Coast Guard installations 14C, 15C, and 17C.

## 3. RESULTS

Figure 1 shows the frequency of precipitation occurrence for each hour observed at sites near Lakes Michigan and Superior during lake-effect events from 1988-1993. Each column represents the number of lake-effect events that reported a measurable amount of precipitation during that hour. For reference, 50 cases (highest value on the ordinate) represent 22% and 25% of lake-effect cases over Lakes Superior and Michigan, respectively. Red frequency diagrams represent observations taken by weighing bucket gauges (0.25

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mm minimum reported value) and blue diagrams represent observations taken by Fischer-Porter gauges (2.5 mm minimum reported value).

It was found that precipitation observed on lake-effect days had a distinct diurnal pattern at all locations. Maxima precipitation frequencies tended to occur in the early morning hours and minima precipitation frequencies tended to occur during the mid-afternoon and early evening. However, the difference between the maxima and minima varied greatly from station to station, likely due in part to differences in gauges used for observing precipitation. The lower resolution of the Fischer-Porter gauges may make it difficult to adequately observe the light lake-effect precipitation. IN addition, diurnal variations may be best sampled in regions that generally receive the most frequent and intense lake-effect snow, south of Lake Superior and in southwestern Lower Michigan (e.g., Eichenlaub 1979).

Comparison of diurnal variations in precipitation occurrence for lake-effect (Fig. 1) and non-lake-effect cases (not shown) reveals that the diurnal pattern observed is likely due to the lakes. There was no systematic diurnal variation in precipitation occurrence on non-lake-effect cases.

It should be noted that because precipitation amounts observed during each hour tended to be very small (most often at the minimum measurable amount), plots of the diurnal variation of precipitation amount have a nearly identical appearance.

## 4. FACTORS INFLUENCING LAKE-EFFECT OCCURRENCE

In order to gain insight on the possible reasons for the diurnal pattern of lake-effect precipitation, factors thought to be important to lake-effect occurrence were examined. Possible large-scale factors which may influence the development of lake-effect precipitation include the passage of fronts, cyclones, and troughs through the region. Local factors found to be important to lake-effect formation by Kristovich and Laird (1998) include surface heat and moisture fluxes and atmospheric stability.

Since cold frontal, trough, or cyclone passages usually precede the development of lake-effect snow storms, the diurnal distribution of the timing of such events were examined. Three-hourly surface charts from the National Climatic Data Center (NCDC) for the period of interest were utilized for this study. Surface boundaries that were associated with cold air advection were noted as they crossed the mid-point of Lake Michigan. It was found that the times of crossing of these boundaries did not have a significant diurnal variation, and were thus unlikely to play an important role in the observed diurnal patterns of lake-effect precipitation.

The diurnal pattern of lake-air sensible and latent heat fluxes, often cited as a major factor in lake-effect development and intensity (e.g., Kristovich and Laird 1998, Niziol et al. 1995), was examined to determine its possible role in the diurnal variation of lake-effect precipitation. Hourly surface observations of air temperature, humidity, and wind speed were combined with daily-mean lake surface temperatures to estimate variations in surface flux rates, using methods outlined in Kristovich and Laird (1998). It should be noted that lack of over-lake atmospheric data may result in local differences between calculated fluxes and actual over-lake fluxes. Nevertheless, the diurnal variation in fluxes should be well captured.

It was found that the diurnal variation in surface sensible heat fluxes closely mirrored that of lake-effect snowfall occurrence. Sensible heat fluxes tended to be greater in the morning hours than in the afternoon hours, due to greater differences in lake-air temperature and humidity (not shown). Surface winds were stronger in the afternoon hours, which would tend to increase surface fluxes. However, this effect was offset by the larger decrease in lake-air temperature difference. On the other hand, latent heat flux diurnal variations were found to be considerably smaller in magnitude.

Another factor found to be important by several studies (e.g., Kristovich and Laird 1998, Agee and Hart 1990, Chang and Braham 1991) is upwind atmospheric stability. Since sounding data are only available twice per day, it was not possible to detail variations in low-level atmospheric stability upwind of Lakes Superior and Michigan. However, it would be anticipated that upwind stability is greater in the morning hours than in the afternoon hours. If this was the dominant factor in lake-effect precipitation development in this region, precipitation frequencies would be expected to peak in the afternoon, contrary to these observations.

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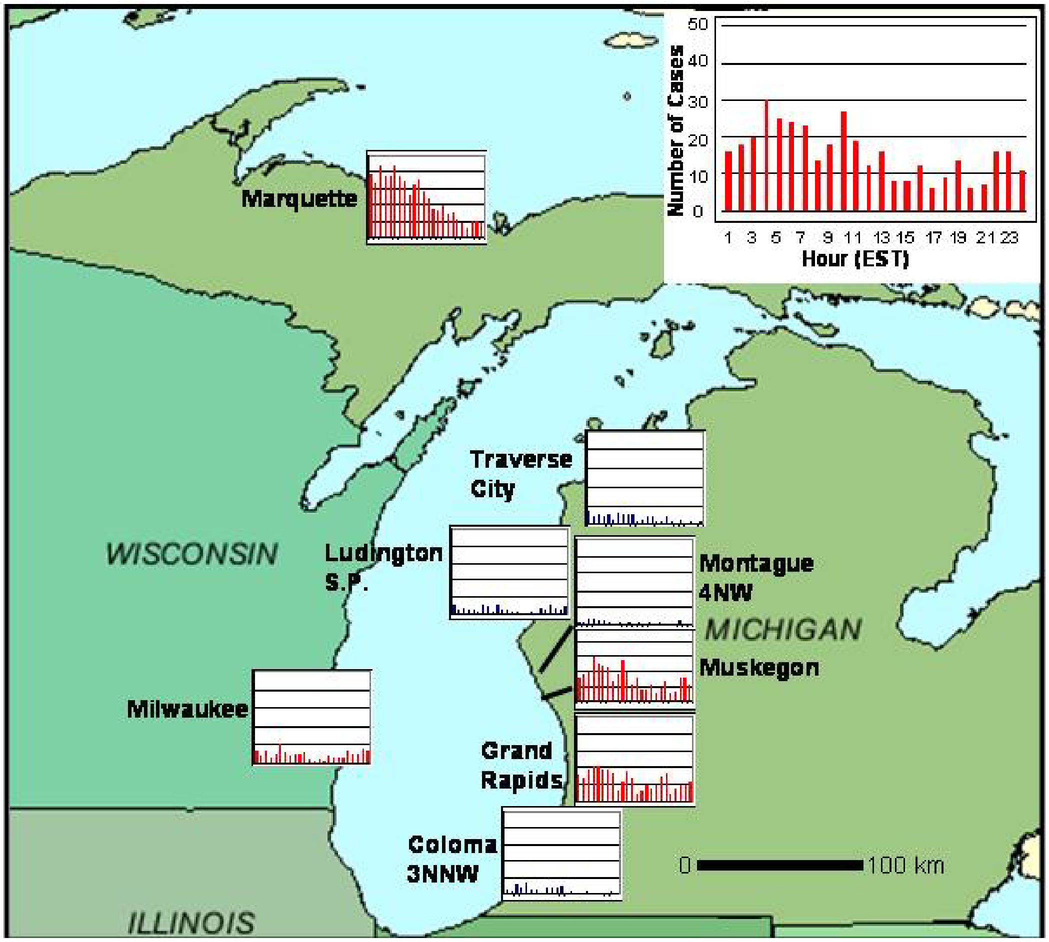

**Figure 1.** The frequency of precipitation by hour on lake effect days from October through March during the years 1988 through 1993 at several Great Lakes stations. The hour of the day in Eastern Standard Time is along the abscissa and the number of occurrences measurable precipitation during that hour is along the ordinate. Axis scales for all plots are shown in the sample in the upper-right corner. Red frequency diagrams represent observations taken by weighing bucket gauges (0.25 mm minimum reported value) and blue diagrams represent observations taken by Fischer-Porter gauges (2.5 mm minimum reported value).Note that there were 221 lake-effect days over Lake Superior, and 199 lake-effect days over Lake Michigan (Kristovich and Steve 1995).