Does Lake-Effect Snow Extend to the Mountains of West Virginia?

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ABSTRACT

Some popular texts, ski resorts, and NWS forecasters claim that the Great Lakes make significant contributions to the 450 cm annual snowfall of the West Virginia mountains. These 1200-1450 m ridges are 400 km south of the lakes. Thirty-eight snow events of 15 cm or more at Snowshoe (1454 m) were identified that were not caused by synoptic-scale precipitation processes. During these events, wind flow was from the north or northwest and snow also fell in the snowbelt adjacent to Lake Erie, leading to the conclusion that moisture for these events is partly of Great Lakes origin and extracted by orographic processes. Lake-effect snowfall contributed 25% to 30% of the total snowfall at Snowshoe, with the greatest contributions (41%) in December and March.

INTRODUCTION

The Great Lakes of central North America contribute much water vapor and heat to cold air masses passing over the lakes in autumn and winter. The addition of energy and water vapor leads to frequent and occasionally heavy snow downwind of the lakes. This 'lake-effect' snow creates 'snowbelts' east and southeast of the lakes. Average annual snowfall exceeds 250 cm in the snowbelts and reaches 600 cm in the snowiest locations of northern Michigan and New York.

The snowbelts are traditionally depicted as being adjacent to the south and east shores of the lakes and extending 60 to 100 km inland from the lakes (Eichenlaub, 1970; 1979; Schmidlin, 1989) (Fig. 1). Their inland borders are not distinct but are located where lake-effect snow contributes little to

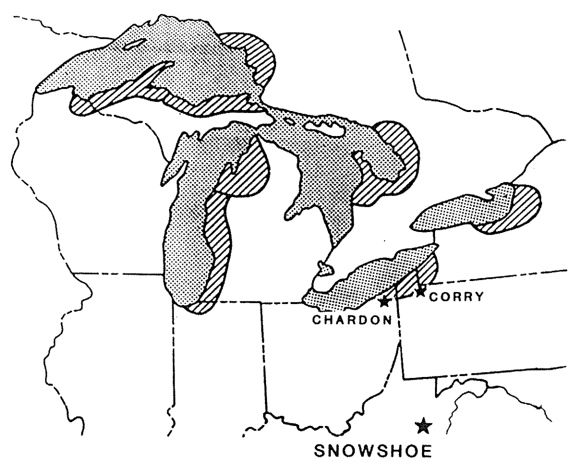

Figure 1. The snowbelts of the Great Lakes (Eichenlaub, 1979) and the location of Snowshoe, West Virginia (star).

the total annual snowfall. Orographic uplift enhances the snowfall within the snowbelts, even with the modest relief of 200 m in western Michigan (Hjelmfelt, 1992). Hill (cited by Niziol, 1987) reported mean annual snowfall increased 25-50 cm/ 100 m elevation in the snowbelt of western New York. The mountains of the central Appalachians in West Virginia are SW-NE oriented ridges with crest elevations of 900 m to 1400 m. Heavy snowfall has been known in these regions since the turn-of-the-century, although most weather stations are in valleys at elevations of 500 to 1000 m. Brooks (1915) reported an 11-year average of 280 cm at Pickens and assigned the cause to forced ascent of moist west winds from the Ohio Valley. Recent records from high valleys (800 m to 1000 m) give a mean annual snowfall of 410 cm at Pickens, 366 cm at Kumbrabow State Forest, and 330 cm at Canaan Valley (Schmidlin, 1992). The only ridge-top station was Snowshoe at 1454 m where the mean was 448 cm.

Large average snowfall in the mountains of West Virginia would be expected simply from their elevation and the moist climate of eastern North America. Hendrick and Heath (1978) showed increases in winter precipitation between 300 m and 1300 m in Vermont were associated with cold cyclonic flow from the northwest in the day or two following passage of a strong storm center. They noted that precipitation in this pattern required some external effect such as surface heating, lake enhancement, or orographic lifting, and attributed the snowfall increase in Vermont to orographic uplift. Johnson (1987) and Kocin and Uccellini (1990) attributed a portion of the heavy snow in the West Virginia mountains to lake-effect as does promotional material from West Virginia ski resorts, although evidence is not provided in any of these materials. The NWS Forecast Office at Charleston considers moisture input to northwest air flows from the Great Lakes to play a minor role in mountain snows. Their forecast protocol for the mountains does not incorporate lake-effect, although some forecasters use the term 'lake-effect' for mountain snowfall during northwest flows (communication with Ken Batty, NWS Charleston). The question addressed in this research is whether the large snowfall at these high elevations is simply an orographic effect on synoptic-scale precipitation events or whether there is a contribution from the Great Lakes in the form of lake-effect snow. If lake-

If lake- effect snow occurs in mountains of W. Virginia, we assume that its source is primarily Lake Erie and Lake Huron and its occurrence will be correlated with snowfall in the Lake Erie snowbelt of Ohio and Pennsylvania. Lake-effect snow in the central Appalachians could also have origins from Lake Michigan but we assume that is minor. Significant lake-effect snowfall does not occur more than 100 km from Lake Erie in eastern Ohio or western Pennsylvania, where elevations are generally under 300 m, or at elevations under 300 m in West Virginia. However, lake-effect clouds extend several hundred kilometers inland from the lakes (Dewey, 1978), so the much higher elevations (over 1000 m) of West Virginia may cause additional snowfall through orographic enhancement far downwind from the lakes (Figure 2). In essence, we are asking "do the mountains of West Virginia extract snowfall from north-northwest airflows that was not extracted over the lower terrain between the lakes and West Virginia?"

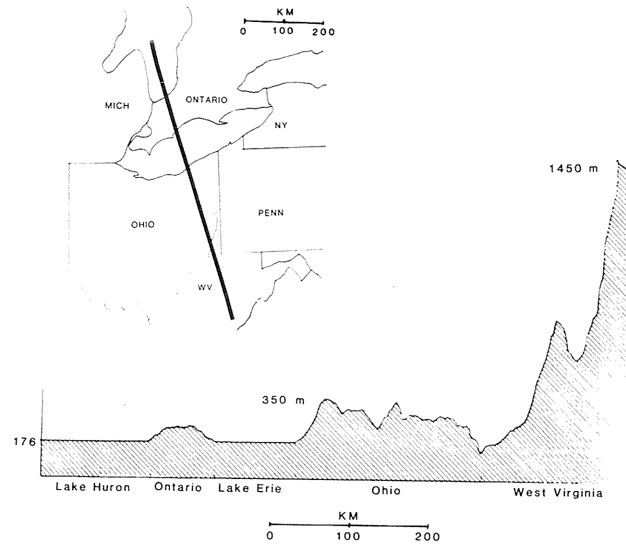

Figure 2. An north-south elevation transect from central Lake Huron to the West Virginia mountains.

METHODS

Daily snowfall data from Snowshoe, West Virginia, were examined for the period 1976-1988. Snowshoe, on a ridge at 1454 m elevation, is the highest weather station in the central Appalachians and is 400 km southeast of Lake Erie (Figure 1). Mean January temperature is -7.8°C and mean annual precipitation is 143 cm (56.2 in).

Snow events with possible lake-effect origins at Snowshoe were identified. A 'snow event' was defined to occur when 15 cm or more of new snow fell in one day and included snowfall on all adjacent days with at least 2.5 cm each day. Snow events were then eliminated from that list if over 0.25 cm of rain or over 2.5 cm of snow fell at nearby Clarksburg (290 m), west of the Appalachians, or at Romney (200 m), east of the Appalachians. The snow events at Snowshoe on days with significant rain or snow at Clarksburg or Romney were assumed to be from large-scale synoptic systems rather than lake-effect, since we assume that lake-effect snow would not occur at low elevations in West Virginia, such as Clarksburg and Romney. The remaining snow events were then tested for possible lake-effect origins. The relationships between snowfall during possible lake-effect snow events at Snowshoe and snowfall during the same periods in the Lake Erie snowbelt were examined through correlation. To obtain a representative snowfall for the Lake Erie snowbelt, snowfall totals at Corry, PA, and Chardon, OH, (average snowfall 350 cm and 269 cm, respectively) were averaged during snow events at

Snowshoe. The locations of pressure centers and fronts on the daily weather maps were noted for each event, as was the general air flow into West Virginia. A flow diagram of the methods is shown in Figure 3.

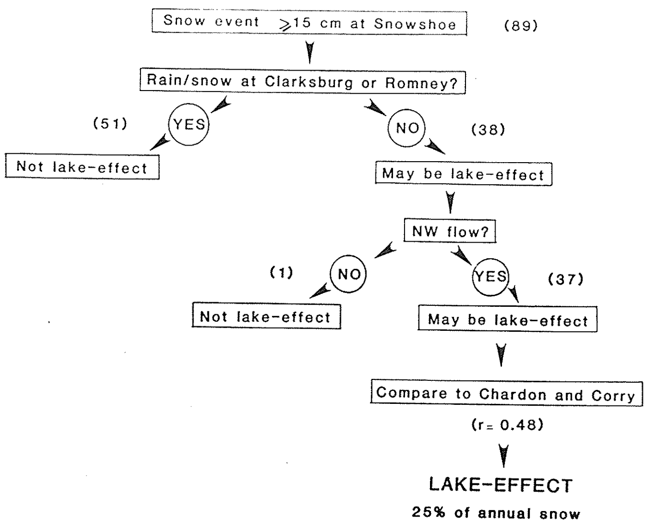

Figure 3. Research method flow diagram with the number of snow events on each path shown in parentheses.

RESULTS AND DISCUSSION

A total of 89 snow events with 15 cm or more snow in one day were identified at Snowshoe during 1976-88. These typically lasted two or three days (with >2.5 cm/day) and were as long as eight days. Over half of these snow events were eliminated as possible 'lake-effect' events because they were part of synoptic-scale storms that spread precipitation throughout the central Appalachians, as indicated by significant concurrent rain or snow at Romney or Clarksburg. This elimination process left 38 snow events that were 'potential lake-effect' snow events at Snowshoe (Figure 3). Average snowfall during these 38 events was 36.5 cm at Snowshoe and the greatest was 147 cm during 17-21 March 1981.

The snowfall at Snowshoe during these 38 potential lake-effect events was about 25% of the total snowfall during 1976-88. This is a conservative estimate of the total potential lake-effect snowfall since only snow events with over 15 cm in one day were considered. The contribution of these events to the total snowfall at Snowshoe was greatest during December (41%) and March (41%) and lowest in February (16%) and January (24%). This seasonal pattern with a minimum during mid-winter and maxima early and late in winter may be a result of more Great Lakes ice cover during January and February or from stronger winds early and late in winter which can carry moisture farther inland, as suggested by Strommen and Harman (1978) for Michigan.

Correlation between snowfall during snow events at Snowshoe and snowfall during the same periods in the Lake Erie snowbelt was 0.48. Snowfall over 2.5 cm occurred at one of the two stations examined in the Lake Erie snowbelt during 37 of the 38 snow events at Snowshoe with an average snowfall of 18 cm during these events in the Lake Erie snowbelt. Thus, potential lake-effect snow events in the West Virginia mountains are nearly always associated with snowfall in the Lake Erie snowbelt and correlation of amounts is significant ($p < 0.05$).

Prevailing wind direction during the 38 potential lake-effect snow events at Snowshoe was from the northwest or north-northwest. This is similar to the wind direction during lake-effect snow in Michigan (Eichenlaub, 1970). It is in contrast to the many studies of lake-effect snow to the lee of Lakes Erie and Ontario in New York that show the importance of southwest or west winds along the long axes of those lakes (Niziol, 1987, for example). The typical synoptic situation for lake-effect snow in the mountains of West Virginia had low pressure over New England, the Atlantic provinces, or adjacent Atlantic waters. A high was ridged from the western lakes or northern Plains southward to the western Gulf of Mexico coast. The resulting flow is from the north or northwest across the central Great Lakes into West Virginia.

While it is not possible from this work to determine with certainty that a significant portion of the snowfall in the central Appalachians is of Great Lakes origin, the evidence is in favor of that conclusion. There were 38 potential lake-effect snow events in 12 years at Snowshoe, West Virginia, with over 15 cm snow in one day. No significant rain or snow fell at nearby valley stations during these events, winds were from the north or northwest, and snowfall occurred upwind from West Virginia in the Lake Erie snowbelt. Significant snowfall did not occur at Snowshoe in the absence of precipitation at valley sites, except with north or northwest air flow from the Great Lakes.

Lake-effect snowfall contributes a significant (25-30%) portion of the 450 cm annual snowfall in the high central Appalachians, approaching the 30% to 50% contribution within the snowbelts adjacent to the lakes (Changnon and Jones, 1972; Kelly, 1986). Based on these results, it is likely that lake-effect snowfall is important on all high land (>1000 m) in West Virginia, and the higher portions of Maryland and central Pennsylvania. Whether the lake-effect extends farther south to the 1700-2000 m peaks of

North Carolina, as suggested by Johnson (1987) remains to be seen.

These results have implications for paleoclimatic studies and for modeling future climate changes and their ecological impacts in the central Appalachians. Changes in winter circulation patterns over eastern North America, changes in Great Lakes ice cover, and changes in the stability of northwest air flows will all affect the frequency of lake-effect snow in the central Appalachians. Increases in lake-effect snowfall in the snowbelts were associated with colder winters in the 1960's and 1970's (Eichenlaub, 1970; Dungey and Braham, 1982). Climate changes on these scales or greater may be expected in coming decades. An understanding of the role that the Great Lakes and winter air circulation play in central Appalachian snowfall will assist in the interpretation of past environments and in preparing for future changes.

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