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Climate Change and Lake-Effect Snow

study conducted by

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Lake-effect snow is a common cold season phenomenon in the Great Lakes region, occurring most frequently in late autumn and early winter. This type of snow results from the rapid warming and moistening of Arctic air masses that pass over lakes that are still relatively warm. The Arctic air becomes unstable and the resulting convection forms clouds and precipitation. The precipitation falls over and downwind of the lakes. For very cold air masses, temperatures remain below freezing even after passage over the warmer lakes, causing the precipitation to fall as snow. Lake-effect snow causes considerable enhancement of snowfall in narrow snowbelts along the downwind lakeshores. For example, Detroit, Michigan, on the western (upwind) shore of Lake Erie receives an average of 42 in yr^{-1}, while Buffalo, New York, on the eastern (downwind) shore of Lake Erie, receives an average of 92 in yr^{-1}. Toronto, Ontario, on the northwestern (upwind) shore of Lake Ontario, receives about 54 in yr^{-1}, while Syracuse, New York, located to the southeast (downwind) shore of Lake Ontario, receives 109 in yr^{-1} and is the snowiest metropolitan area in the United States. The lake-effect snow season typically extends from November through February over all of the Great Lakes except for Lake Erie, which normally freezes over by the end of January, putting an abrupt end to the lake-effect snowfall in places like Erie, PA and Buffalo, NY for the remainder of the winter.

Lake-effect snow creates transportation problems and results in additional costs to keep roads clear. A major transportation artery, Interstate 90, passes along the southern shore of Lake Erie and is vulnerable to lake-effect snow storms. Increased property damage, injuries, and deaths due to accidents and exertion accompany such events. Major airports at Cleveland and Buffalo are also vulnerable to disruptions. The roofs of buildings in the snowbelts must be built to support heavier loads of snow than for locations away from the snowbelts [F3-1]. Retail sales may drop temporarily. A single severe lake-effect snowstorm near Cleveland, OH in November 1996 resulted in 8 deaths, hundreds of human injuries, widespread power outages, damage to numerous buildings, and over $30 million in economic losses ([F3-2]; S.A.Changnon, personal communication). On the positive side, there is a large private snow removal business sector that benefits from the snowfall. Sales of winter-related products may increase. Lake-effect snowfall also supports an important winter recreational industry in some parts of the Great Lakes. Although there is not a large downhill ski industry in the Lake Erie snowbelt, many of the Midwest's premier downhill ski resorts are located in the snowbelts of the other lakes in the region.

Abnormally light snowfall amounts during the winter season have also created significant negative impacts, particularly when snowfall deficiencies have been widespread and the associated losses have affected many locations throughout the Great Lakes region. Such was the case over most of the Great Lakes region during the 1997-1998 El Niño year. The widespread nature of this event resulted in impacts over a large area. For example, business at Midwestern ski resorts was down 50% and losses were estimated at $120 million (S.A.Changnon, personal communication).

Recent studies show that past changes in lake-effect snowfall on decadal time frames were related to climatic shifts. For example, lake-effect snowfall on the lee shore of Lake Michigan increased from the 1930s into the 1970s – coincident with a decrease in mean winter temperature [F3-3]. More recently, changes in heavy lake-effect snow events were evaluated as part of the current assessment for the Lake Erie snowbelt. Lighter events certainly occur more frequently and contribute significantly to the total annual snowfall totals, but Great Lakes residents have adapted to them so they are not nearly the societal concern that heavy events are. For the period 1950-1995, all occurrences of lake-effect snowfall in excess of 8 inches at Erie, PA and Westfield, NY were identified. Four surface conditions (air temperature, lake-air temperature difference, wind speed, wind direction) were found to be highly correlated with the occurrence of heavy lake-effect snow, when they occur within certain favorable ranges simultaneously. In the 1950-1995 observational data, favorable conditions occurred approximately 17 times per decade. In the HadCM2 simulation for the 1960-1989 period, favorable conditions occurred approximately 15 times per decade, very similar to the observational record.

The simultaneous occurrence of these favorable conditions decreases from 15 to 7 times per decade in the HadCM2 model between the 1960-1989 and 2070-2099 period. This decrease occurred – even though the lake-effect season was extended through the end of February to account for the fact that Lake Erie would no longer likely freeze over – almost entirely because of a drop in the number of days below freezing. When the simultaneous occurrence of the other favorable conditions was examined, there was very little difference between the 1960-1989 and the 2070-2099 periods. Even the frequency of occurrence of lake-air temperature differences did not change because the lake temperature increased about the same amount as the air temperature. This suggests that the decrease in heavy lake-effect snow may be accompanied by an increase in winter-time lake-effect rain events, which are now most frequent in the autumn [F3-4]. A similar analysis for the Lake Michigan and Lake Superior snowbelts indicates that the southern Lake Michigan snowbelt will experience a decrease in the number of below-freezing days in the late 21st Century similar to the Lake Erie snowbelt, but little change in the other variables. However, for the Lake Superior snowbelt, the mean winter temperature remains below 32°F and there is little change both in the number of below-freezing days and the frequency of favorable ranges of the other variables. Thus, there may be little change in the frequency of heavy lake-effect snow in the Lake Superior snowbelt and a substantial decrease in the southern Lake Michigan and Lake Erie snowbelts. The fact that air-temperature was found to be the primary determining factor in reducing the frequency of heavy lake-effect events in this study suggests that the frequency of light(er) events may be influenced in the same way. Figure F3.1 summarizes the anticipated regional impacts of climate change on lake-effect snow patterns – suggesting almost no change in the northernmost belts but approximately a 50% decrease in southernmost belts. The spatial variability demonstrates that the impacts of climate change as portrayed by the HadCM2 model can be greatly influenced by subtle regional differences. The overall warmer scenario portrayed by the CGCM1 model suggests an even greater reduction in lake-effect snow than was found here.

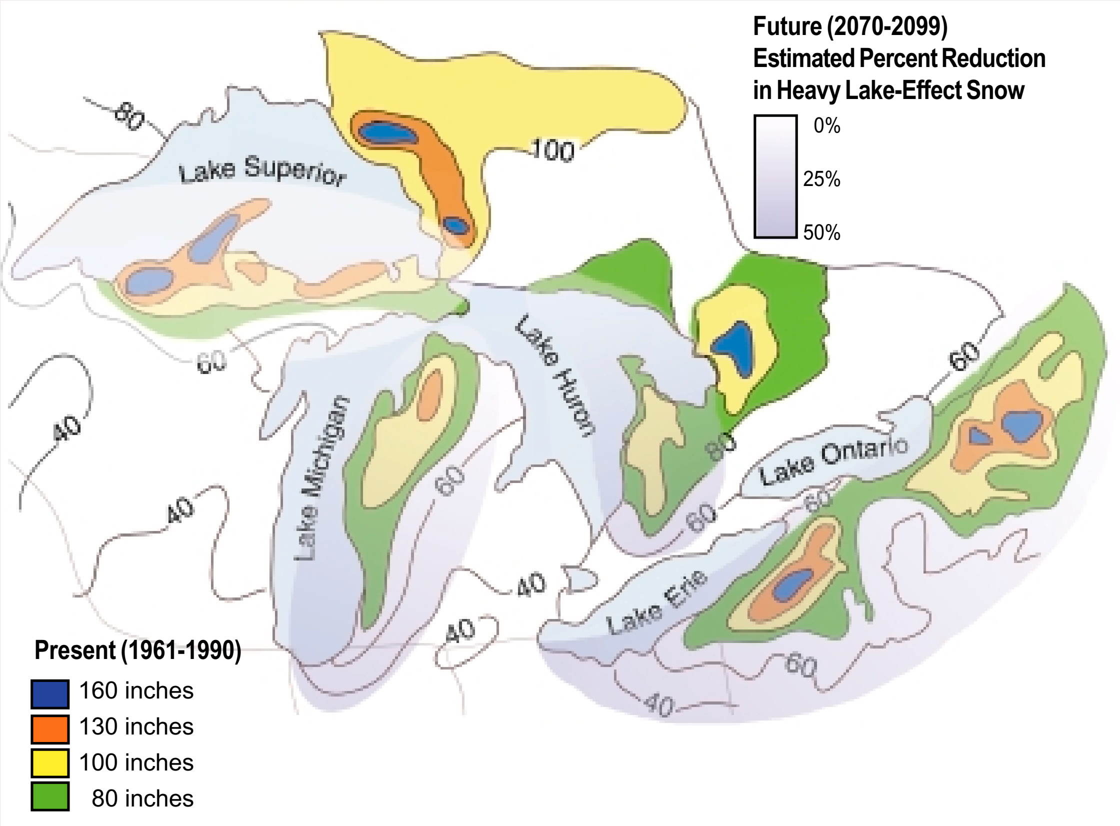

Figure F3.1: Annual snowfall totals, including both lake-effect and other types of snowstorms. Present amounts shown by contours (inches). Areas where the lake-effect causes a sizeable increase in snow amounts are highlighted in color. The impacts of climate change by 2070-2099 on heavy lake effect snow events, as estimated from HadCM2, is shown by the shading. Note that, although the shading covers the entire map, it strictly applies only to the lake-effect snow belts (colored regions) since this study did not look at all types of snow events.