SNOWFALL PROPERTIES OF LAKE ERIE AND ONTARIO STORMS

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1. Introduction

The Great Lakes snowstorm phenomenon represents one of the most pronounced examples of vigorous winter-time energy exchange to be found in the United States. These storms characteristically form as cold Arctic air passes over the relatively warm waters of the Great Lakes in late fall and early winter. The ensuing fluxes of heat, moisture, and momentum lead to intense horizontal and vertical gradients which, in turn, alter the horizontal winds, low-level convergence fields, and vertical motions. Sheridan (1941) and Wiggin (1950) pointed out the importance of large air-water temperature differences and long lake fetch in supporting such storms. When these mesoscale Lake effects couple with a synoptic scale trough, the most intense energy transfer and organization can take place (Paine and Jiusto, 1970).

As described by McVehil and Peace (1966), the snowbands seen forming south and east of Lakes Erie and Ontario are strongly related to the wind orientation. We characteristically observe the most intense snowfall with single large bands which form when the winds are from the southwest or west and consequently parallel to the lakes. Poorer organization (i.e., weaker multiple banded structure) is seen in northwesterly flow situations, thus mirroring the reduction in Lake fetch and intensity of airmass modification.

A climatological study was undertaken to better understand the snowfall patterns; namely, snowdepths and snow crystal types, and their dependence on wind direction, topography, inland distance, temperature, and time of year.

2. Statistical Analysis

A mesoscale station network to the lee of Lake Erie and Lake Ontario was devised utilizing class C, Cooperative Weather Bureau Stations. These stations generally report snowfall and meltwater equivalence values once a day, most typically at 0700E. Storm data were obtained from 75 stations in Ohio, Pennsylvania and New York. A total of 23 snowfall situations were studied which encompassed the period from November, 1966 to January 1969. Eleven of the more pronounced Lake storms were selected for extensive study in terms of the following 4 research objectives: a) plotting of areal snowfall and meltwater depths, b) calculation and plotting of snowfall-meltwater ratios and estimation of snow crystal type, c) determination of linear correlation coefficients to evaluate relationships between the snowfall depth and topography, inland distance, and snowfall-meltwater ratios, and d) integration of meltwater depths to determine total amount and areal coverage per storm.

For item c) above, the linear correlation coefficient r may be described by the following relationship:

$$r = \frac{N\Sigma xy - \Sigma x\Sigma y}{([N\Sigma x^2 - (\Sigma x)^2]\ [N\Sigma y^2 - (\Sigma y)^2])^{1/2}}$$

It was found convenient and meaningful to categorize these Great Lakes snowstorms in the following manner:

a. Intense Storms - SW to W air flow; heavy snow exceeding 20" in spots; concentrated snowfall.

b. Moderate Storms - SW to W winds; snow < 20 inches; distributed snowfall.

C. "Weak" Storms - NW winds; snow < 15 inches; distributed snowfall.

a. Snowfall Distributions

Of the eleven cases studied, three exhibited characteristics of the aforementioned intense storms. These were characterized by west to southwest winds at 5000 ft. One such case is noted in Figure 1 in which intense convergence may be evidenced from snowfall distributions oriented approximately parallel to both lakes with very heavy snowfall totals. Heaviest amounts to the lee of Lake Erie were characteristically found in the Sherman-Westfield-Erie area and to the lee of Lake Ontario in the Hooker 4-Highmarket-Boonville areas. It cannot be emphasized too strongly that these storms not only are the most intense but exhibit the best-organized mesoscale snowfall patterns.

In Figure 2, we see an example of the "weak" class of snowstorm. These storms are characterized by northwest to northerly air flow, becoming more frequent as the winter season progresses. There are at least three reasons for their relative weakness and diminished organization: 1) shorter air mass trajectory over the lakes, 2) often lower lake temperatures which reduces the flux of heat, moisture and momentum, and 3) weaker or nonexistent support from a synoptic scale trough and its pattern of positive vorticity advection. These northwesterly flow cases are typified by the more amorphous multiple snow bands lying nearly perpendicular to the long axis of both lakes with several snowfall maxima.

The remaining "moderate" storms exhibited characteristics of both "intense" and "weak" storms. While the total snowfall matched that of the intense storms, the area of snowfall was somewhat greater and more irregular.

b. Statistical Results

In Table 1 are shown the results of the computer program for determining the aforementioned correlation coefficients. From these results we may infer three rather significant tendencies in the data: 1) a negative correlation between snowfall and inland distance; 2) a positive correlation between snowfall-meltwater ratios and inland

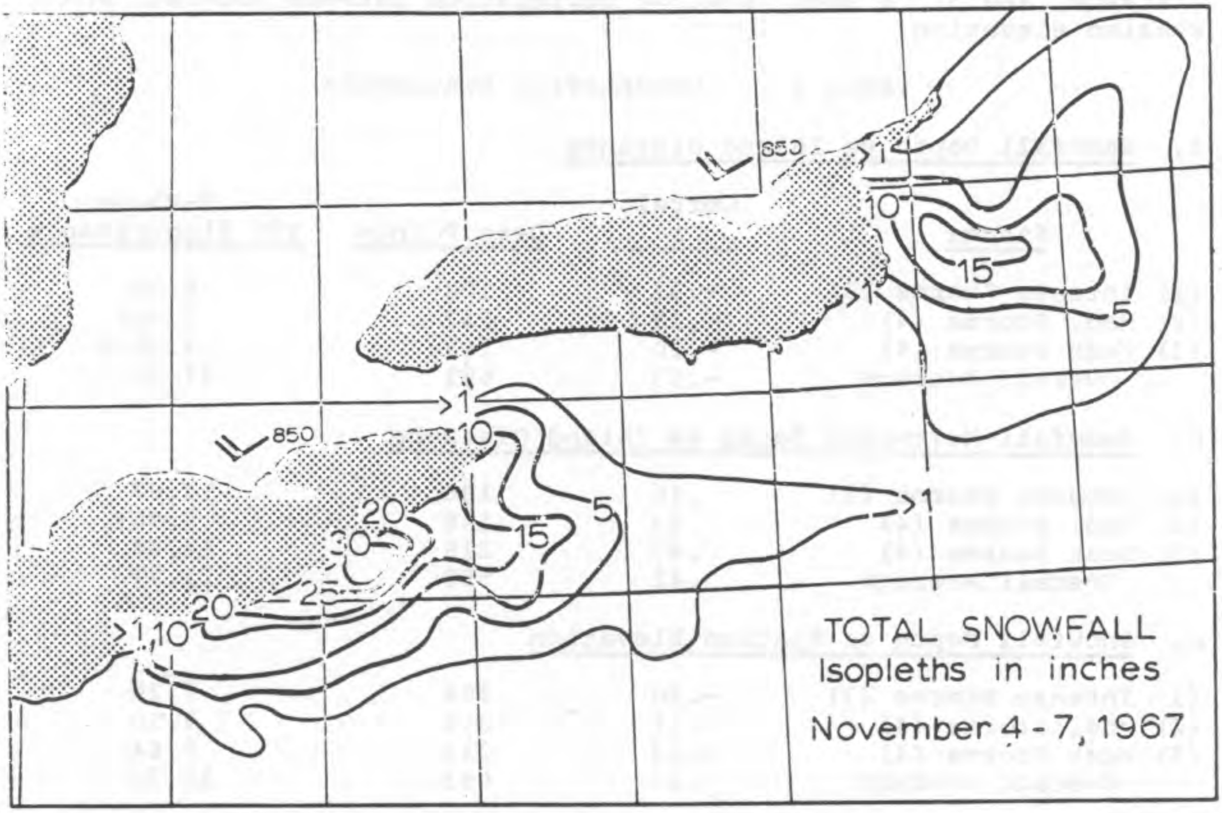

FIG. 1 INTENSE SNOWFALL PATTERN (SW FLOW)

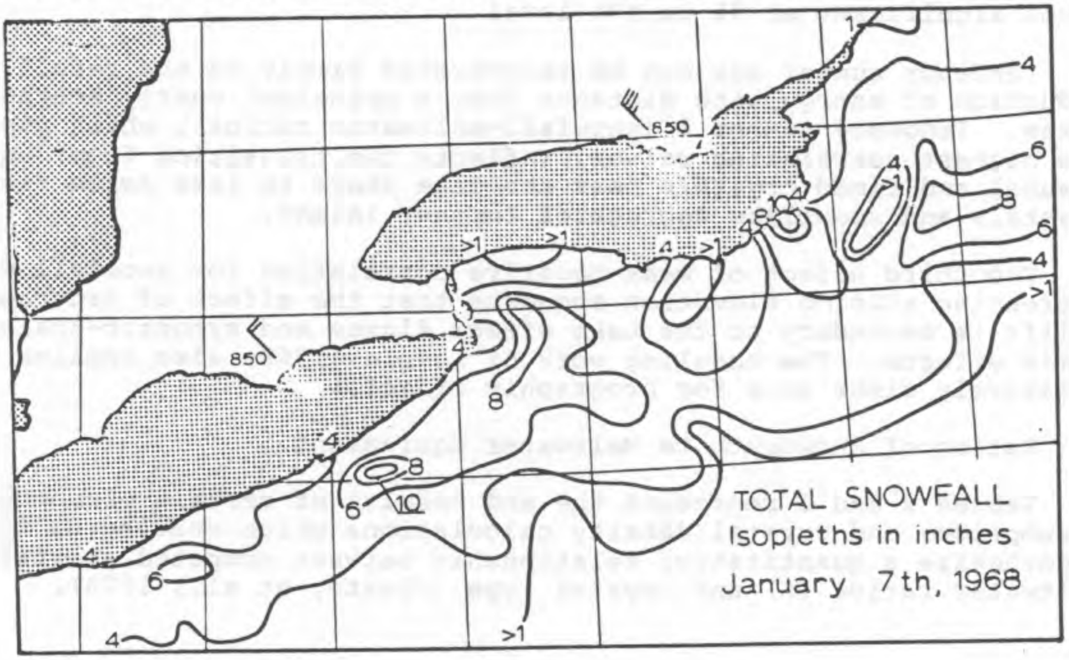

Fig. 2 "WEAK" SNOWSTORM (NW AIR FLOW)

distance, and 3) a weak negative correlation between snowfall and station elevation.

TABLE 1 CORRELATION STATISTICS

Storms	Correl. r	Data Points	F-Value 99% Significance
a. Snowfall Depth vs Inland Distance			
(1) Intense Storms (3)	-.33	182	8.02
(2) Mod. Storms (4)	-.25	247	5.52†
(3) Weak Storms (4)	-.10	262	3.15††
Overall Average	-.23	691	37.31
b. Snowfall-Meltwater Ratio vs Inland Distance			
(1) Intense Storms (3)	.46	136	14.67
(2) Mod. Storms (4)	.33	198	5.96†
(3) Weak Storms (4)	.47	216	14.84
Overall Average	.42	550	11.77
c. Snowfall Depth vs Station Elevation			
(1) Intense Storms (3)	-.20	206	7.26
(2) Mod. Storms (4)	-.11	274	7.60
(3) Weak Storms (4)	-.13	213	9.64
Overall Average	-.15	693	15.25

†95% level of significance
††Not significant at 95 or 99% level

Tendency number one can be interpreted simply as the result of the reduction of energy with distance from a principal energy source - the lakes. Tendency number 2 (snowfall-meltwater ratios), which yielded the highest correlation values, reflects the transition from dense graupel and rimed crystals near the lake shore to less dense dendritic crystals and snowflake aggregates further inland.

The third effect of weak negative correlation for snowfall versus increasing station elevation suggests that the effect of orographic uplift is secondary to the Lake effect fluxes and synoptic-scale dynamic effects. The modeling work of Lavoie (1968) also implies a relatively minor role for orographic effects.

3. Ratios of Snowdepth to Meltwater Equivalent

Tables 2 and 3 represent the end results of certain microphysical assumptions and crystal density calculations which enabled us to hypothesize a quantitative relationship between computed snowfall-meltwater ratios (R) and crystal type (Jiusto, et al., 1970).

TABLE 2 SNOW CRYSTAL DENSITIES

	ρ	$1/\rho$
Plane dendrites	0.484	2.1
Stellars-solid	(0.726)*	1.4
Hexagonal Plates	0.968	1.1
Columns	(0.90)*	1.1
Needles	0.230	4.3
Rimed Crystals	0.172	5.8
Graupel	0.125	8.0
Snowflakes (compact)	0.050	20
Snowflakes (dendritic)	0.010	100
Spatial dendrites	.00954-.00381	105-260

*( ) indicate interpolated values

TABLE 3 SNOW DEPTH TO MELT WATER RATIO
R vs CRYSTAL TYPE

Class	Crystal Type	R
I	Individual solid crystals	≤ 5
II	Rimed forms	6-15
III	Snowflakes	16-50+
IV	Spatial dendrites	> 50

Figure 3 provides one illustration of the results obtained in inferring snowfall crystal types from the R categories of Table 3. Most significant is the indication of graupel and denser rimed crystals to be prevalent near the shore of Lake Ontario with lighter snowflakes and dendritic crystals increasing inland. Such a trend is frequently observed in these Lake storms.

4. Total Precipitation Overland from Lake Storms

Areal charts of snowfall meltwater isopleths were integrated to determine the total amounts of water from these storms for both lakes. Table 4 presents the results from the 11 storm cases of most interest. It can be observed that the total mass of snowfall over land for both lakes combined averages approximately 2 to 3.5×10^{12} lbs. per storm type. Higher values were associated with storms possessing SW to W winds; i.e., long lake axis fetch, with 50% lower values associated with the weaker NW flow situations.

Probably more revealing in terms of the physics of these snowstorms are the following two results: 1) the snowstorms with greatest water mass were often the snowstorms with relatively small total areal coverage (e.g., the 4-7 November 1967 storm of Figure 1), thus implying the considerable mesoscale organization of W-SW band storms, and 2) when values of total water output were plotted for both lakes per storm as a function of time of year, November and early

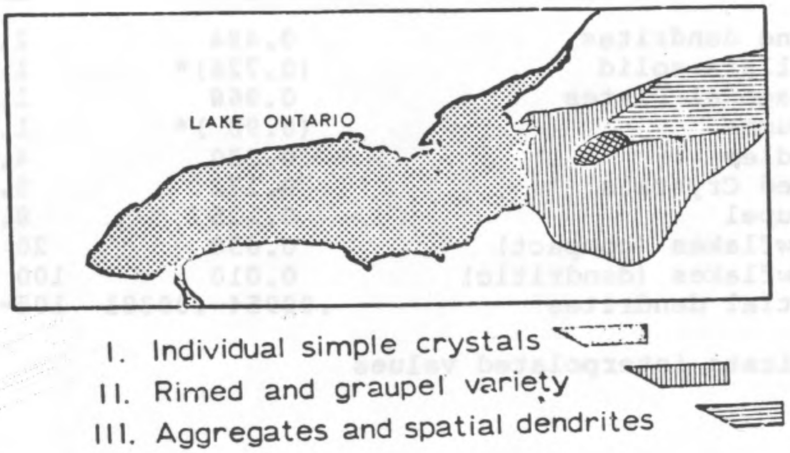

Fig. 3 SNOW CRYSTAL TYPE INFERRED FROM SNOW DEPTH - MELTWATER (R) DATA

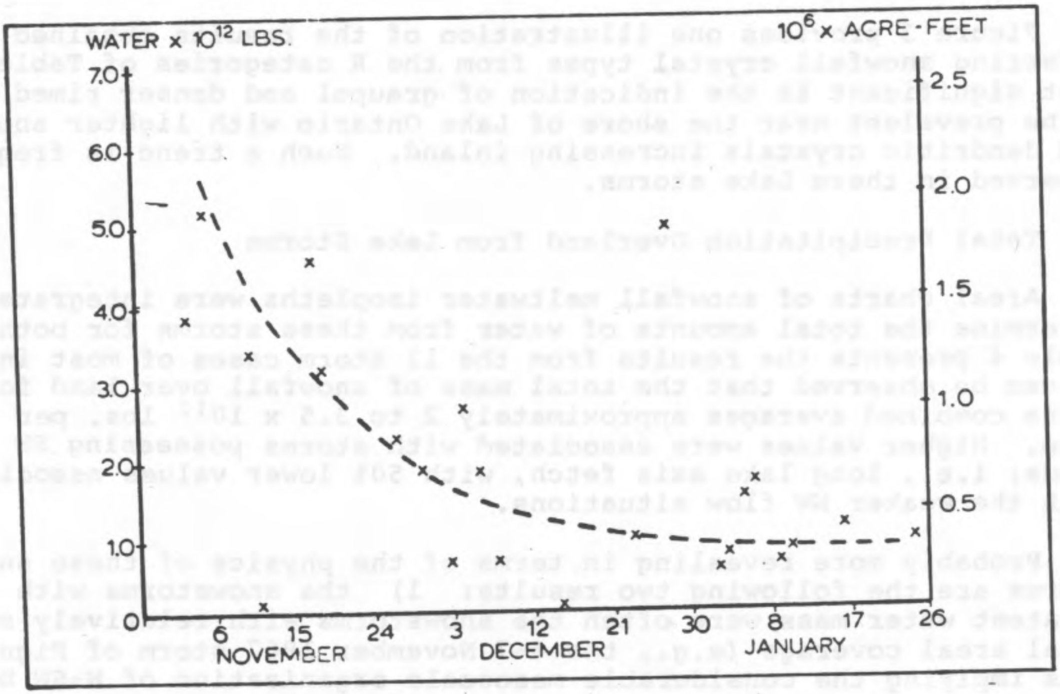

Fig. 4 TOTAL SNOWFALL (LAKES ERIE AND ONTARIO) PER SEASONAL STORM

TABLE 4 Total Mass and Area of Snowfall in Classic Lakestorms

	LAKE ERIE		LAKE ONTARIO		TOTAL - 2 LAKES	
	PRECIP. (lbs)	AREA (mi^2)*	PRECIP. (lbs)	AREA (mi^2)*	PRECIP. (lbs)	AREA (mi^2)*
I - 2 Dec 66	1.17×10^{12}	23,320	0.79×10^{12}	25,040	1.96×10^{12}	48,360
I - 4 Nov 67	2.73	17,360	2.36	16,050	5.09	33,410
I - 27 Nov 67	1.17	43,480	1.19	24,070	2.36	67,550
(Average)					(3.14)	(49,770)
M - 4 Nov 66	2.28	27,390	1.59	9,400	3.87	36,790
M - 29 Dec 66	1.59	29,920	3.14	29,290	4.73	59,210
M - 14 Nov 67	2.04	31,260	1.34	28,930	3.38	60,190
M - 4 Jan 68	0.38	23,840	1.21	25,970	1.59	49,810
(Average)					(3.39)	(51,500)
W - 10 Jan 67	0.35	27,530	0.53	26,350	0.88	53,980
W - 16 Jan 67	0.51	27,030	0.59	22,350	1.10	49,380
W - 18 Nov 67	3.55	31,010	1.04	27,620	4.59	58,630
W - 7 Jan 68	1.05	34,670	0.82	29,790	1.87	64,460
(Average)					(2.11)	(56,610)
OVERALL AVERAGES	1.53×10^{12}	28,800	1.33×10^{12}	24,000	2.86×10^{12}	52,800
STANDARD DEVIATIONS (σ)	0.98×10^{12}	6,400	0.75×10^{12}	6,200	1.4×10^{12}	10,700

* Nautical Miles

December storms were 2 to 5 times more productive than January storms as shown in Figure 4. Regarding item 2), the intensity of a storm, measured in terms of the total water output, is strongly dependent upon lake temperature and the resultant generation of moisture and thermal energy.

5. Summary

Three years of climatological data were employed to better describe and diagnose many of the physical characteristics of Lake-effect snowstorms. The study confirmed that snowfall was highly dependent on time of year and wind direction, late autumn occurrence and SW-W wind flows being associated with the most intense storms. A statistical analysis showed a tendency for snowfall depth to drop off rapidly with inland distance; for snowfall-meltwater ratios to be inversely related to inland distance; and for orographic effects to be less important than Lake effects in the total snowstorm phenomena.

The mapping of snowfall-meltwater ratios indicated a pattern of heavier crystal forms, i.e., rimed crystals and graupel to be concentrated near the coast and for lighter snowflakes to be most prevalent inland. Areal water distributions showed a strong tendency for intense snowfalls to be better organized and more compact with a strong dependence of total water on time of year (lake temperature).

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