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LAKE ONTARIO SNOWFALL OBSERVATIONAL NETWORK FOR CALIBRATING RADAR MEASUREMENTS

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ABSTRACT

A select network of weighing-recording precipitation gages was installed to provide improved measurements for evaluating the use of radar for measuring snowfall. The locations of the gages were chosen to provide a uniform distribution for one sector of the radar coverage. Each gage site was selected to provide the maximum amount of natural protection to minimize the adverse effects that wind movement has on gage measurement of snowfall. The importance of having reliable snowfall measurements for evaluating other measurement techniques is demonstrated by comparison of point and areal values among those from the special network, the radar estimates and regular climatic stations in the same area.

INTRODUCTION

Nearly all research, management, or operational activities in the field of snow and ice hydrology require for some reason or other an estimate of solid precipitation values. Unfortunately, it is generally agreed that most point estimates of solid precipitation based on precipitation gage readings are deficient due mainly to wind and its associated adverse effect on gage catch. The worth of areal precipitation estimates based on these point measurements is questionable. A possible technique for obtaining better areal estimates of solid precipitation is through the use of radar. The techniques and procedures which must be developed in order to utilize radar to measure snowfall have only recently begun to be investigated.

The National Weather Service (NWS), in cooperation with the International Field Year for the Great Lakes, has recently been involved with a program to obtain meteorological data by radar. A C-Band 5.3 cm MR-782 Weather Service Radar was installed south of Oswego, New York to make precipitation observations, especially solid precipitation observations in the high snow area just east of Lake Ontario. Storm precipitation values were determined from the radar observations and the appropriate Z-R relationships.

For comparison with the precipitation values determined from the radar equations, it was decided to install a special snow measuring network of 13 Universal weighing-recording precipitation gages. Each gage site in this network was carefully chosen to provide the maximum natural protection possible. The ultimate goal of the network was to provide the best possible input to the radar study.

The network was utilized to investigate the importance of gage location and the improvement in precipitation measurements which may be made by proper site selection and gage location. Point and areal comparisons were made between the special network, the radar estimates, and other stations in the area.

The University of New York at Oswego maintained and operated the network and radar. In addition, the University recruited special student volunteer observers who made snowfall observations during selected periods of time for comparison with the special network.

NETWORK DESCRIPTION

The snowfall observational network is located north of Syracuse, New York and east of Lake Ontario and covers an area of roughly 350 miles^2 (906 km^2) (Figure 1). The elevation generally increases from west to east and south to north across the network and varies from about 250 feet MSL (82 m) to 1300 feet MSL (427 m). The area is a combination of farmland and gently rolling woodlands.

An attempt was made to place all of the 13 network gages in what would be considered "well-protected" locations. In general, this would mean that each gage was sheltered in all directions by coniferous forest subtending angles of 30 - 45° from the gage orifice with the forest of sufficient depth to minimize eddy effects (Peck, 1972). However, since the gages were placed in natural openings, the exposure did vary somewhat from site to site.

OROGRAPHIC INFLUENCES

The seasonal precipitation during the period of observation ranged from near 14 inches (35.5 cm) over the western portion of the study area to near 22 inches (54.2 cm) on the east (Table 1). Most of the variation can be explained by elevation (Figure 2). An analysis of the individual departures from the elevation-precipitation line of Figure 2 indicated that there is a major influence due to the location of Lake Ontario. The maximum lake effect occurs slightly below the level of maximum elevation, but the lake and elevation effects are interdependent. This accounts to some extent for the high correlation (r = .93) for the best fit line in Figure 2. This dual effect may also be seen in the seasonal isohyet analysis shown in Figure 1.

TABLE 1
OSWEGO SNOW NETWORK
PRECIPITATION TOTALS
2 DECEMBER 1972 - 26 MARCH 1973

Gage Number	1	2	3	4	5	6	7	8	9
SUM (CM)	35.53	39.01	52.25	54.20	35.86	36.78	46.76	45.44	39.62
MEAN (CM)*	.37	.41	.55	.57	.38	.39	.49	.48	.42
STD. DEV.	.51	.54	.67	.68	.52	.54	.66	.64	.57

*N = 95

TABLE 1
(continued)

Gage Number	10	11	12	13	Camden	Mallory	Bennetts Bridge	Selkirk Shores
SUM (CM)	42.93	45.24	39.07	50.52	39.88	35.84	40.05	30.00**
MEAN (CM)	.45	.48	.41	.53	.42	.38	.42	.67
STD. DEV.	.59	.64	.54	.72	.67	.55	.58	.61

**N = 45 (Selkirk Shores only, total from 1 Dec.)

GAGE COMPARISONS

Of primary interest were comparisons between gages already located in the network area, mostly NWS climate gages, and the special network gages. The assumption was that most gage locations in the past were not primarily chosen to provide good gage exposure. Instead, the gages were generally placed at locations where people were willing to be volunteer observors. It was felt that gage sites which were specifically chosen for good exposure would probably provide a better estimate of point and areal precipitation for the radar study than would pre-existing gages from the same general area.

Table 2 tends to support the assumption that good exposure is essential for reliable snowfall measurements. Network gage #9 compared to the climate gage at Mallory for snow and mixed storms shows a monthly deficit for Mallory of -5 to -28% and a final four-month deficit of -14%. This is in spite of the fact that the observer at Mallory is extremely capable and conscientious. An inquiry as to this particular observer's observational techniques revealed that he goes to great lengths to provide the best solid precipitation data he possibly can. His system utilizes a standard eight-inch gage, two snowboards plus snowstakes. After each snowfall, a comparison is made between the gage reading and the snowboard readings with the most representative value being logged. The gage itself has little natural protection, one snowboard has natural protection from the east while the other snowboard has natural protection from the west. This particular example shows quite clearly that the most reliable observer will be deficient in his measurements of solid precipitation if the initial site selection was poor.

The comparison of catch at Bennetts Bridge with the average of gages #3, #4, and #7 showed a monthly deficit of -2 to -36% and a four-month deficit of -26%. The comparison of total catch at Selkirk Shores (a Lake Survey gage) with special network gage #1 showed a monthly deficit of -7 to -74% with a final deficit of -23%.

The climate gage at Camden when compared to network gage #12 showed no significant difference. This can perhaps be explained by several factors. First, the climate station at Camden is apparently fairly well protected being located in a barnyard with buildings on the north, south, and west. Second, network gage #12 site is the least protected location in the special network. Initial comments on this site prior to gathering any data was that protection to the east and south was marginal.

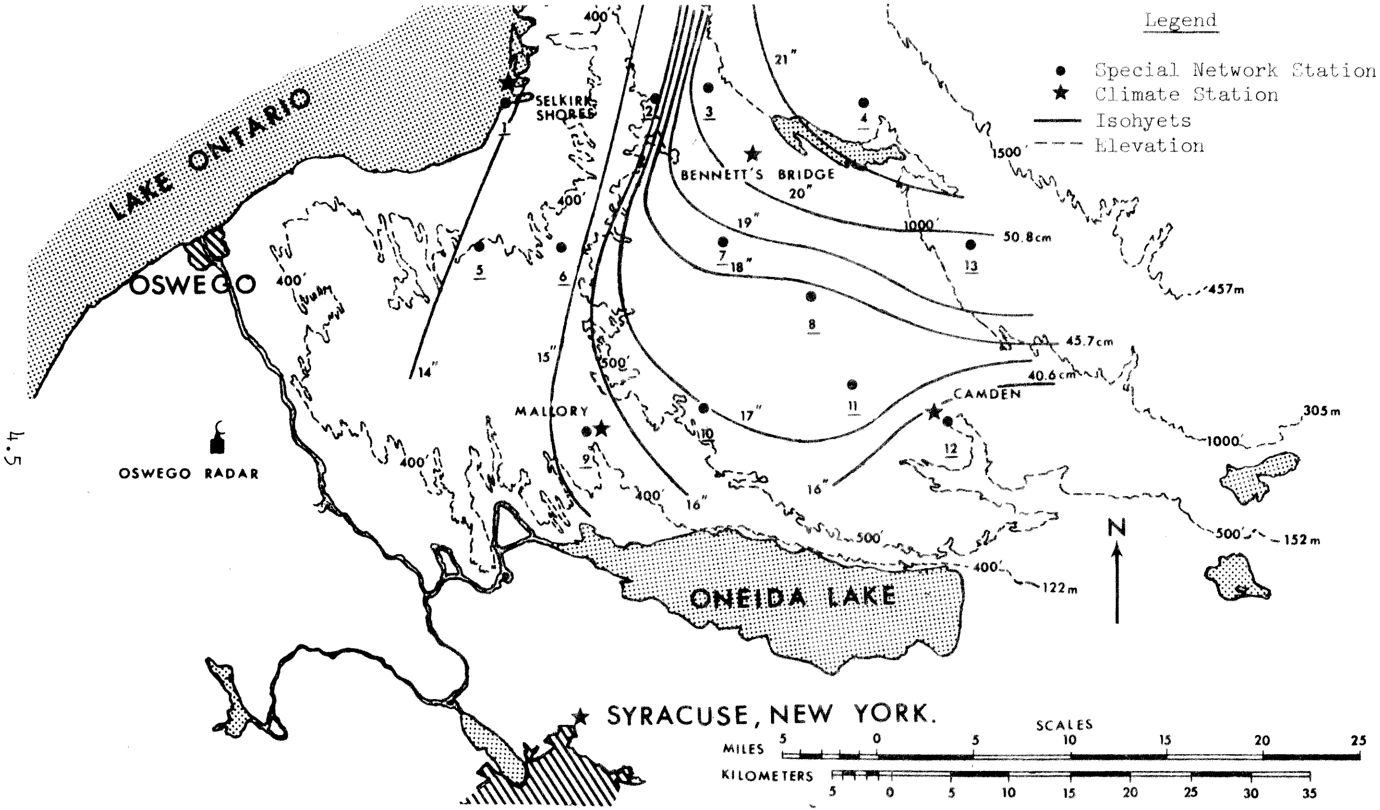

Figure 1. General location of Lake Ontario snowfall observation network.

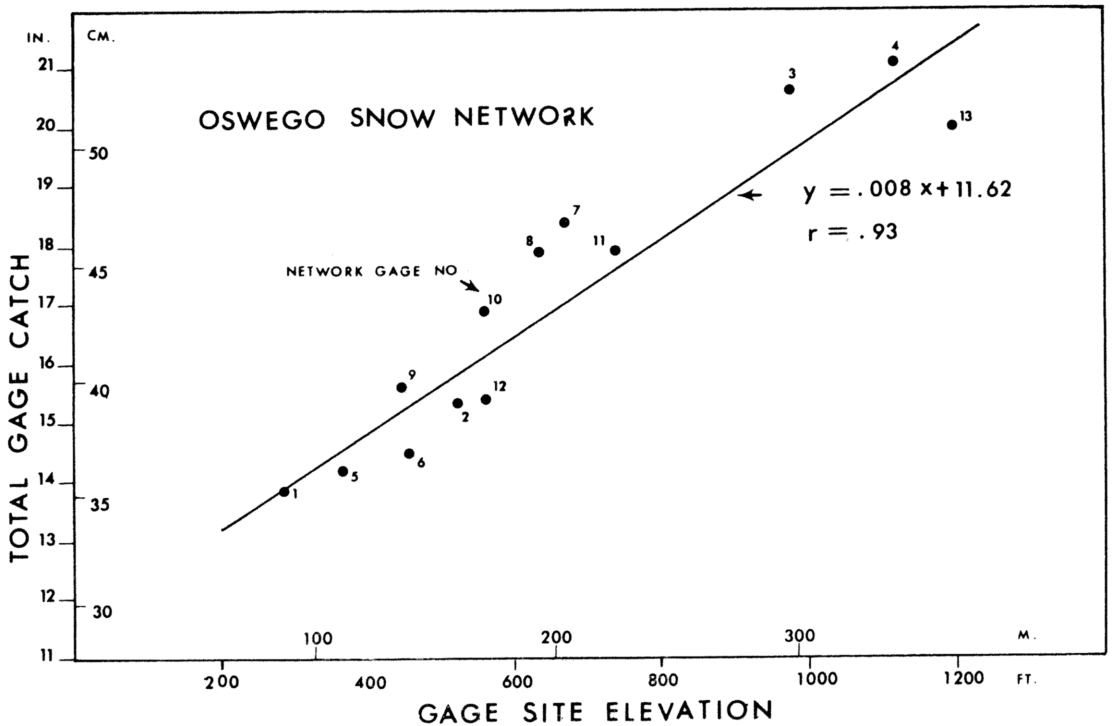

Figure 2. Gage catch versus gage site elevation.

TABLE 2
COMPARATIVE PRECIPITATION GAGE CATCHES
SNOW AND MIXED PRECIPITATION ONLY

Mallory Versus #9

Month	Nov.		Dec.		Jan.		Feb.		Mar.		Total	
Gage	9	M	9	M	9	M	9	M	9	M	9	M
Catch*	.81	.64	10.92	9.40	5.21	4.37	5.87	5.49	2.11	2.01	24.92	21.89
Diff.		-.17		-1.52		-.84		-.38		-.10		-3.03
% Diff.		-28		-16		-19		-7		-5		-14

Bennetts Bridge Versus Mean of (#3, #4, #7)

Month	Nov.		Dec.		Jan.		Feb.		Mar.		Total	
Gage	3,4,7	BB	3,4,7	BB	3,4,7	BB	3,4,7	BB	3,4,7	BB	3,4,7	BB
Catch*	4.34	3.28	16.48	12.12	7.98	6.63	8.38	6.68	4.70	4.62	41.88	33.32
Diff.		-1.06		-4.36		-1.35		-1.70		-.08		-8.56
% Diff.		-33		-36		-20		-25		-2		-26

Camden Versus #12

Month	Nov.		Dec.		Jan.		Feb.		Mar.		Total	
Gage	12	C	12	C	12	C	12	C	12	C	12	C
Catch*	2.67	2.69	11.76	12.17	5.11	4.93	6.63	7.04	2.18	2.29	28.35	29.11
Diff.		.02		.41		-.18		.41		.11		.76
% Diff.		1		3		-4		6		4		3

Selkirk Shores Versus #1

Month	Nov.		Dec.		Jan.		Feb.		Mar.		Total	
Gage			1	SS	1	SS	1	SS	1	SS	1	SS
Catch*			12.24	11.44	8.86	5.09	7.75	6.61	8.13	6.86	36.98	30.00
Diff.				-.80		-3.77		-1.14		-1.27		-6.98
% Diff.				-7		-74		-17		-18		-23

* (cm)

AREAL ESTIMATES OF PRECIPITATION

Areal estimates of storm and total precipitation values for the network were made using the Thiessen method. Comparisons were made between precipitation estimates based on the entire 13-gage special network, the four-gage climate network (i.e. Mallory, Camden, Bennetts Bridge, and Selkirk Shores), and the four-gage special network composed only of gages close to climate gages (i.e. #1, #9, #12, and average of #3, #4, #7). The total period (four months) areal precipitation values, based on the 13-gage special network was 17.5% greater than the result based on the climate gages. (If the analysis is based only on the four-gage special network, the result is that the special network produced an estimate of areal precipitation 16.2% greater than that based on the climate network.)

An estimate of sampling errors within the special network was made utilizing the assumption that the areal estimate based on all 13 network gages was correct. By reducing the number of gages in the special network and comparing the areal estimates with those from the 13-gage network for monthly data, the following results were obtained. For a network of eight to 10 gages and monthly precipitation of four to six inches, an error of 2% in an areal estimate of precipitation was obtained. The estimated sampling error for a five to seven gage network increased to 3% while the sampling error for a one to four gage network was about 8%. The relatively small increase in sampling error as the number of gages in the network was reduced can perhaps be explained by the fact that care was taken to insure that the remaining gages in each case were uniformly distributed throughout the network area and that each gage site in the network was carefully chosen to provide a uniform type of exposure from site to site.

EXPOSURE

Wind is the major cause of error in precipitation gage measurements. This error increases with wind speed and is larger for solid precipitation than for liquid precipitation (Kurtyka, 1953). A generally accepted theory is that, in addition to site turbulence, much of the total measurement error is a result of turbulence and increased wind speed in the vicinity of the gage orifice resulting from the obstacle of the gage itself to the windstream (Robinson and Rodda, 1969).

An analysis of gage catch deficiencies versus wind speed was performed for the climate sites. The gage catch deficiency was found by comparing the climate gage catch to the corresponding network gage catch. An example of the results from Bennetts Bridge are that at 10 mph (16.1 km/hr) the ratio of climate to network gage is .80 and at 20 mph (32.2 km/hr) the ratio is .65. This would indicate that wind has a greater adverse effect on the climate gage than on the network gage and therefore the climate gage exposure is probably inferior to that of the network gage.

It has been shown that an Alter shield will increase gage catch in windy situations (Warnick, 1956). Within reasonable limits, up to 25 mph (40.2 km/hr) (Weiss, 1961), the windier the gage site, the greater will be the difference in catch between a shielded and an unshielded gage. Conversely, if a gage site is well enough protected so as to eliminate or minimize horizontal wind speeds, then the Alter shield will make little difference in gage catch. In the 13-gage special network, five uniformly distributed gages (#1, #4, #7, #9, and #12) were installed with Alter shields. It is interesting to note that the average total catch for these five gages is 17.0 inches (43.1 cm) while the average total catch for the other eight unshielded gages is 17.1 inches (43.5 cm). This would indicate that within the network, gage sites are at least well enough protected so as to eliminate the beneficial effect of the Alter shield.

An excellent example of gage catch difference due to exposure is Selkirk Shores and gage #1. The Selkirk Shores gage is located very near the waters edge of Lake Ontario. Gage #1 is located nearby, but in a forest clearing. From December through March, gage #1 caught nearly 23% more precipitation due to better gage exposure.

The performance of each gage in the network as a function of wind direction was investigated. Unfortunately, sufficient snow data was not obtained to make definite conclusions as to the relationship between individual gage sites and wind direction. It did seem, however, that the sites which were initially evaluated as being weak in exposure in a given direction generally had lower relative catches from that direction.

ADDITIONAL OBSERVATIONS

Some 55 student observers were recruited throughout the network to provide additional input data to this study. One of their functions was to provide solid precipitation measurements through the use of snowboards. During the months of January and February (some 14 individual observation periods), the snowboard results were compared to the 13-gage network average and were found to be about 17% higher. The precipitation during these 14 observation periods represented about 70% of the total precipitation which fell during these two months.

Although snowboards are assumed to represent only new and actual snowfall, it should be recognized that the exposure of the snowboard site is critical. In some locations, blowing snow may add or detract from the snowfall measurement.

RADAR MEASUREMENTS

A thorough analysis of the radar results from this study are available in a companion paper by Wilson (Wilson, 1973). Some interesting results applicable to this paper are presented in Figure 3. In this figure, the ratios of total snowfall by gage catch and radar estimate are plotted against distance from the radar.

The lower line represents the best fit curve for the climate gages in the area while the upper line is the best fit curve for the 13-gage special network. It may be seen that the data for the special network results in a curve with a higher correlation coefficient (.90 to .64) and also with a smaller standard error (.10 to .28). The better fit of the data from the special network supports the contention that well-protected sites are essential for proper evaluation of radar measurements of snowfall.

CONCLUSIONS

The importance of gage exposure in the measurement of precipitation, expecially solid precipitation, cannot be overemphasized. In this particular study, properly exposed gages from the special snowfall measuring network averaged 16% greater catch than existing climate gages. Except for unusual situations, it is generally assumed that the larger the catch, the closer it represents the amount of precipitation which actually fell at the site (Brown and Peck, 1962). Wilson has shown that precipitation measurements from a properly protected gage provide a better index to areal precipitation than if the gage is poorly exposed (Wilson, 1954). It seems obvious therefore that both point and areal estimates of precipitation obtained from the special network in this study are more reliable and closer to "true" precipitation than similar data obtained from normal climate stations in the same area. It also seems obvious that the use of precipitation gages to calibrate or evaluate the effectiveness of radar in measuring precipitation (especially solid precipitation) must first be preceded by a careful analysis and evaluation of the gage exposure of existing gages and/or a careful site selection process for new gages.

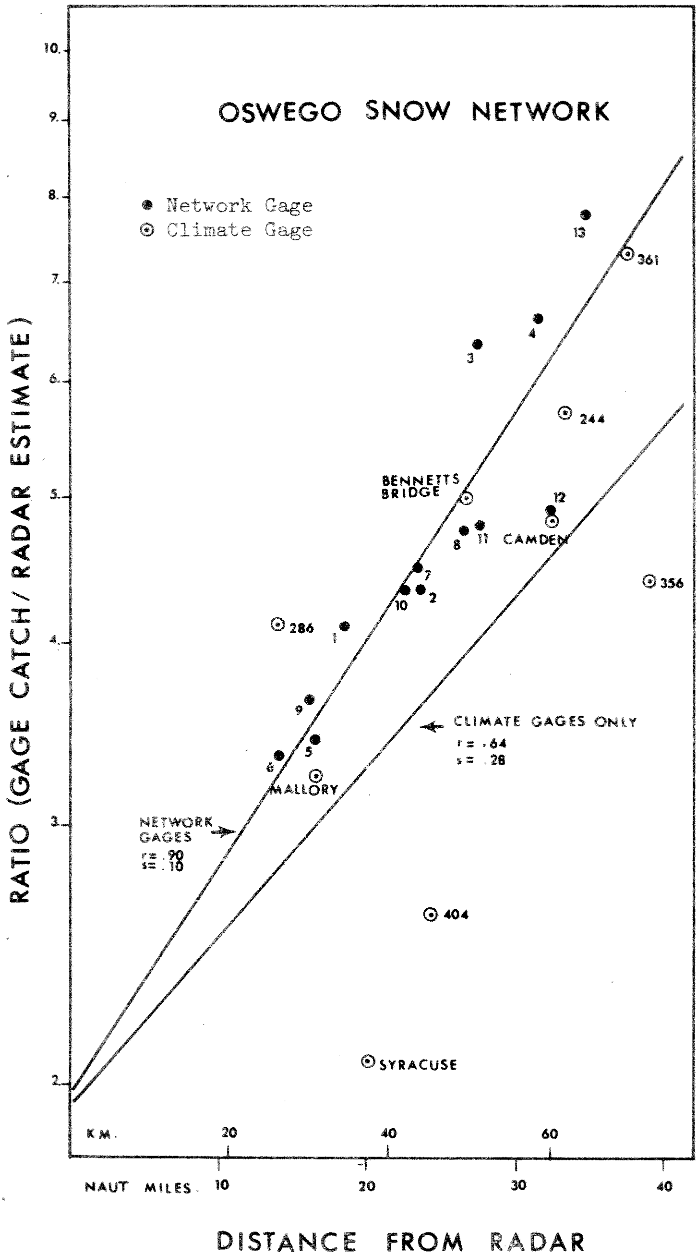

Figure 3. Gage catch/radar estimate versus distance from radar.

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