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A RELATIONSHIP BETWEEN SNOW ACCUMULATION AND SNOW INTENSITY AS DETERMINED FROM VISIBILITY

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Eastern Region

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UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATOMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE EASTERN REGION
Garden City, New York

NOAA TECHNICAL MEMORANDUM NWS ER-41

A RELATIONSHIP BETWEEN SNOW ACCUMULATION AND SNOW INTENSITY AS DETERMINED FROM VISIBILITY

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ABSTRACT

A procedure is presented for estimating hourly snow accumulation at LaGuardia Field, N. Y., from observations of snow intensity or visibility. A relationship between reported snow intensity and estimated snowfall is shown on independent data to be reliable. Results can be applied as an aid in forecasting additional snow accumulation and in estimating previous snowfall when this information is not available from direct measurements. This technique could be developed for any other location.

A RELATIONSHIP BETWEEN SNOW ACCUMULATION AND SNOW INTENSITY AS DETERMINED FROM VISIBILITY

INTRODUCTION

Reported snow intensity in a surface weather observation is determined from visibility observations rather than from any snow accumulation measurements. A poll* was conducted in which all 22 observers questioned stated that they determine snow intensity from visibility observations. Each of these 22 observers was located at a different city in the eastern United States. All 22 observers also stated that they do not know the current hourly rate that snow is falling or accumulation that is occurring at the time that they report snow intensity in a weather observation.

A need exists to assist forecasters and weather briefers by establishing a relationship between the current accumulation of snow, something that cannot be measured directly, and the reported snow intensity which, in turn, is estimated from an available visibility observation. If a relationship can be determined, then snow accumulation can be estimated for any period in which snow intensity is known or forecast. Snow accumulation is now known from measurements generally taken only once every six hours, except for very heavy snowfalls.

PROCEDURE

The development data used in this study consist of snow intensity reports and six-hourly snow depth measurements obtained during snowstorms at LaGuardia Field, N. Y. during the months of December through March for the 20-year period December 1949 through March 1969. Included in this study are only those storms in which a snow accumulation of at least 1/2 inch occurred. All such storms are included in their entirety with the exception of six-hourly portions of some storms in which precipitation other than snow occurred after snow was recorded. Also eliminated from consideration are storms in which precipitation types other than snow occurred together with snow. These restrictions represent an attempt to remove cases in which a six-hourly snow depth measurement does not represent the actual amount of snow that fell during the previous six hours. Obviously if rain follows snow, a considable amount of melting may have occurred before the six-hourly snow depth measurement was taken. It is recognized that in some

*Poll conducted February 24, 1971 at Surface Observations Seminar, National Weather Service, Eastern Region Headquarters

storms that ultimately produced at least 1/2 inch of snow, the first few hours of snow may have melted, resulting in no accumulation being recorded for that portion of the storm; nevertheless, this data is included in the study and may have an effect on the results. It is also recognized that any results based on measurements of snow depth contain some uncertainties due to the difficulty of obtaining a representative snow depth measurement.

For each accepted snowstorm or portions of a snowstorm, the snow accumulation was determined for six-hourly periods.Also determined for these six-hourly periods was the duration of each of three reported snow intensities, light snowfall (S-) moderate snowfall (S) and heavy snowfall (S+). Very light snowfall (S--) is ignored in this study since by definition S-- is snowfall that does not completely cover an exposed surface regardless of duration. It is assumed that periods of S-- contribute nothing to snow accumulation.

The definitions of intensity of precipitation have not changed since 1949. Table 1, on the following page, presents the definitions as they apply to snow. These definitions are taken from the Federal Meteorological Handbook No. 1, Surface Observations Change No. 1, (Tables A7-1 and A7-3) effective January 1, 1971. A definition is shown for intensity of precipitation on a rate-of-fall basis (liquid equivalent of precipitation); however it was previously shown that this definition is not applied by most, if not all, weather observers. The Handbook suggests the use of the visibility criteria except where obstructions to visibility other than snow exists. Then, the apparent rate-of-fall should be used to estimate the intensity of snow.

RESULTS

The hourly rate of accumulation of snow when S- is occurring was determined by examining those snowstorms in which the reported intensity was only S- throughout the history of the storm at LaGuardia Field. This occurred in a total of 49 different storms. For these 49 storms the total number of hours of reported S- was 452 and the total snow accumulation was 88 inches. The average hourly rate of accumulation of snow when S- is reported is thus determined to be 0.2 inches per hour.

There were 24 six-hourly snow depth measurements, occurring in 23 different storms , that pertained to periods in which only S and S- intensity occurred. (Every six-hourly snow depth measurement period studied had at least one hour of reported S-). After removing

	Intensity of Drizzle or Snow with Visibility as Criteria
Very light	Scattered flakes or droplets that do not completely cover or wet an exposed surface, regardless of duration.
Light	Visibility 5/8 statute mile or more.
Moderate	Visibility less than 5/8 statute mile but not less than 5/16 statute mile.
Heavy	Visibility less than 5/16 statute mile.
	Intensity of Precipitation (other than drizzle) on Rate-of-Fall Basis
Very light	Scattered drops or flakes that do not completely wet or cover an exposed surface, regardless of duration.
Light	Trace to 0.10 inch per hour; maximum 0.01 inch in 6 minutes.
Moderate	0.11 inch to 0.30 inch per hour; more than 0.01 inch to 0.03 inch in 6 minutes.
Heavy	More than 0.30 inch per hour; more than 0.03 inch in 6 minutes.

Table 1. Definitions of Intensity of precipitation applicable to snow, (from Tables A7-1 and A7-3, Federal Meteorological Handbook No. 1, Surface Observations, Change No. 1 effective January 1, 1971).

snow accumulation attributed to S- intensity, by using an hourly accumulation rate of 0.2 inches for S-, the remaining total snow accumulation attributed to S intensity in the 24 six-hourly periods examined was 29.7 inches, and the total number of hours of S intensity snow was 29.8. The average hourly rate that snow falls when S is reported is thus estimated to be 1.0 inches per hour.

For the 24 six-hourly periods in which only S and S- occurred, there were various ratios of hours of S to hours of S-. To minimize the effects of possible poor estimates of snow accumulation during hours of S-, the 10 six-hourly periods with the highest ratio of hours of S to hours of S- were examined to estimate the hourly accumulation for reported S intensity. The ratio of hours of S to hours of S- ranged from a minimum of one hour of S to 4.3 hours of S- to a maximum of four hours of S to two hours of S-. In the 10 six-hourly periods, there were a total of 19.2 hours of reported S with a total snow accumulation of 18.7 inches attributed to S after removing snow accumulation identified as S-. The average hourly rate that snow falls when S is reported is thus determined for these storm periods to be 1.0 inches per hour, identical to the average value when all 24 six-hourly periods were examined.

Having now determined that for reported intensity of S- an average of 0.2 inches of snow accumulated per hour, and for reported intensity of S, 1.0 inches of snow accumulated per hour, it is possible to determine the average hourly rate that snow falls when S+ is reported. There were only 17 six-hourly periods of snow depth measurements in which a report of S+ intensity occurred in the 20-year period studied. For these 17 periods, which occurred in 15 different storms, intensities of S and S- were also reported. After removing from snow depth measurements the snow accumulation estimated for hours of S and S-, there were a total of 19.3 hours of S+ intensity with a total estimated snow accumulation of 31.5 inches attributed to S+. The average hourly accumulation of snow when S+ is reported is thus determined to be 1.6 inches per hour. If we examine the 5 six-hourly periods that had the highest ratio of hours of S+, we find that for these periods the ratio of hours of S+ to combined hours of S and S- varies from a maximum of 4 to 1.5 to a minimum of 1.5 to 4. The average hourly rate that snow falls when S+ was reported during these 5 storm periods was 1.5 inches per hour, a figure quite close to the 1.6 inches per hour determined by examining all 17 storm periods. The 1.6 inches per hour figure is accepted here, but this may be refined when more data become available. A summary of these results is presented in Table 2.

Snow Intensity	Average Hourly Snowfall
Light (S-)	0.2 inches per hour
Moderate (S)	1.0 inches per hour
Heavy (S+)	1.6 inches per hour

Table 2. Average hourly snowfall versus snow intensity. Results are for LaGuardia, N.Y., December 1949 through March 1969.

It is of interest to compare the relationships in Table 2 to the rate-of-fall basis used to define precipitation intensity (lower half of Table 1). In making this comparison, one has to know the liquid equivalent of the snow. The average liquid equivalent for the snow measured in this study was that 9.3 inches of snow yields one inch of liquid precipitation, a ratio that is quite close to the commonly accepted 10 to 1 mean ratio.

Dr. Pack (1) found that for 12 winter seasons (1951-52) through 1962-63) at LaGuardia, N.Y., the mean ratio was 10.0 to 1. He also found that yearly means of this ratio varied from 6.6 to 1 in 1951-52 (wettest snow) to 11.3 to 1 in 1952-53 (driest snow) but 11 out of the 12 winters had a mean ratio greater than the 9.3 found here. Dr. Pack's study included other locations in New York State. He found that the ratio for LaGuardia was the lowest (wettest) and that the range varied to as high as a 20.2 to 1 yearly mean for Binghamton.

Using a 9.3 to 1 snow/water ratio and referring to the lower half of Table 1, we find that the intensity of snow would be defined as light when a trace to 0.9 inches of snow falls per hour, moderate when 1.0 to 2.8 inches fall per hour, and heavy when more than 2.8 inches fall per hour. These figures are not consistent with results presented in Table 2.

It appears that the rate-of-fall basis, if used to determine moderate and especially heavy snow intensity, would give results not consistent with the visibility criteria, assuming that the results presented in Table 2 are accepted. Reducing by 50% the rate-of-fall required in Table 1 for each precipitation intensity, when applied to liquid equivalent of snow, would be consistent with the results presented here.

TEST OF RESULTS

Two winters of independent data (December 1969-March 1970 and December 1970-February 1971) were used to test the results obtained. During these 2 years there were 12 storms that each yielded at least 1/2 inch of snow at La Guardia, N.Y. Snow accumulations during the test period were quite small with only one storm yielding more than four inches. Presented below (Table 3) for each of the 12 storms are the dates of the storms, the number of hours of snow, the estimated snow accumulation (based on reported snow intensity and relationships described in Table 2) and the measured snow accumulation.

Date of Storm	Duration of Snow (Hrs.- Min.)	Estimated Snow Accumulation	Measured Snow Accumulation	Estimation Error
12/25/69	6 - 15	1.3"	1.6"	-0.3"
12/27/69	8 - 25	1.7"	1.5"	+0.2"
1/6-7/70	11 - 28	2.3"	2.5"	-0.2"
1/12/70	10 - 04	2.0"	2.0"	0.0"
1/20-21/70	11 - 04	2.2"	2.5"	-0.3"
2/3-4/70	5 - 05	1.8"	1.7"	+0.1"
2/14-15/70	15 - 05	3.0"	2.5"	+0.5"
3/29/70	6 - 42	2.4"	3.0"	-0.6"
12/21-22/70	10 - 30	2.1"	1.0"	+1.1"
1/1/71	14 - 30	4.1"	5.7"	-1.6"
1/13-14/71	5 - 54	1.2"	1.7"	-0.5"
1/24-25/71	6 - 46	2.2"	2.4"	-0.2"
		Mean absolute error.....		0.47"
		Mean algebraic error.....		-0.15"

Table 3. Estimated versus measured snow accumulation at La Guardia, N.Y. for 12 independent test storms. The estimated snow accumulation is determined from reported snow intensity and the use of Table 2.

In addition to testing the results on independent data, a test was also performed on dependent data using storms that produced yearly extreme snow accumulation at La Guardia, N.Y. Table 4 presents for each of the 21 calendar years in the dependent data sample the measured snow amount for the storm that produced the greatest snow accumulation. Also presented is the estimated amount of snow accumulation determined from reported snow intensity and relationships in Table 2. Five of the 21 storms that appear in Table 4 (1950, 1951, 1953, 1954, 1958) are actually independent data. These 5 storms are included in this table even though the occurrence of light frozen precipitation other than snow excluded these cases from consideration in the development data. For these 5 cases, the periods of light frozen precipitation were treated as light snow in estimating accumulations.

Referring to Table 4, it is interesting to note that for the storm of February 3rd and 4th, 1961, for which a minus 10-inch estimation error occurred, there was a 10.5 hour period of time in which the snow intensity was reported as light, even though the visibility was below 5/8 of a mile during the entire time. The intensity of snow with visibility as a criterion is defined as moderate when the visibility is less than 5/8 statute miles but not less than 5/16 statute miles, and the intensity is defined as heavy when the visibility is less than 5/16 statute miles (Table 2 - upper half). In this case the observer chose to record an additional obstruction to vision, fog, as justification for not recording the snow intensity as moderate. Speculating for a moment, had the reduction of visibility to below 5/8 of a mile been caused by snow alone, the snow intensity would be recorded as moderate. This would have increased the estimated snow accumulation by 8 inches thus reducing the estimation error to only 2 inches. The case just discussed was the only one in 21 years in which the error of estimating snow accumulation exceeded 2 inches for the years most significant snow-storm.

Date of Storm	Hours of Snow	Estimated Snow Accumulation (Inches)	Measured Snow Accumulation (Inches)	Estimation Error (Inches)
2/28/49	17.5	10	10	0
2/13/50	25	5	4	+1
1/31/51	16	4	4	0
3/1/52	8	6	4	+2
1/8/53	12	3	2	+1
1/11/54	14	4	6	-2
2/2/55	16	4	4	0
3/8-19/56	27	9	10	-1
12/4/57	24.5	8	8	0
3/20-21/58	39	9	7	+2
3/12/59	15	5	6	-1
3/3-4/60	24.5	14	15	-1
2/3-4/61	26	9	19	-10*
2/9/62	8	2	3	-1
12/23-24/63	9	5	7	-2
1/12-13/64	30	8	10	-2
1/16/65	16	3	5	-2
1/29-30/66	16.5	6	6	0
3/21-22/67	19.5	7	8	-1
12/15/68	13	4	4	0
2/9-10/69	24	17	16	+1

*See text for explanation of this error.

Table 4. Estimated versus measured snow accumulation for yearly snowstorm with largest accumulation at LaGuardia, N.Y. 1949 to 1969. The estimated snow accumulation is determined from reported snow intensity and the use of Table 2.

APPLICATION OF RESULTS

The results presented here make it possible to estimate a past or current hourly rate that snow accumulates from a snow intensity observation, at least at La Guardia, N.Y. This information could aid considerably in the forecasting of additional snow accumulation or in the estimation of previous snow accumulation when information from direct measurement is not available. Since snow intensity observations are based mostly, or entirely on visibility measurements, (especially when snow is the only obstruction to vision), one can estimate the hourly snow accumulation directly from visibility observations. One would use the upper half of Table 1 to determine snow intensity and then use Table 2 to determine hourly snow accumulation.

An additional application by forecasters is the use of results presented here as a consistency check on forecasts. Aviation forecasters include estimates of the visibility and snow intensity in their aviation forecasts. Public weather forecasters include snow intensity and snow accumulation forecasts in their public releases. The results presented in Table 2 should be referred to, to avoid possible inconsistencies, such as aviation forecasts consisting of several hours of predicted moderate snow and low visibility while the public forecaster, predicting the same number of hours of moderate snow, is predicting an accumulation too low or too high to be consistent with results presented here. The aviation forecaster should be aware of the snow accumulations that he is implying, when he states in his forecasts an expected snow intensity and duration.

CONCLUSIONS

A technique has been presented for estimating hourly snow accumulation from reported snow intensity which in turn is based on visibility estimates. The technique works very well for LaGuardia, N.Y., the location for which relationships were specifically developed. It is not known how reliable this technique would be for other locations. However, relationships for other locations can and should be established following the procedure used here, and preferably using computers.

After additional data have been collected and anlyzed for LaGuardia, N.Y. as well as other locations, it may be possible to arrive at a

universal relationship between visibility, a regularly measured or estimated variable, and hourly accumulation of snow, a difficult variable to measure and currently not available.

Consideration should be given to making a statement in the Federal Meteorological Handbook No. 1, Surface Observations, that the definition of intensity of precipitation on rate-of-fall basis, as given in table A7-1 of that publication, is not applicable to liquid equivalent of snow. A revised table, applicable to snow, can be presented using results based on this or similar studies.

REFERENCE

(1) Pack, A.B.: "The Water Content of Snowstorms in New York State: Variations Among Different Physiographic Regions", Proceeding of the Twenty-Sixth Annual Eastern Snow Conference, February 6, 7, 1969.

List of Eastern Region Technical Memoranda
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NWS ER 40 Use of Detailed Radar Intensity Data in Mesoscale Surface Analysis. Robert E. Hamilton. March 1971(COM-71-00573)