# 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 from observations of snow intensity or visibility, with the procedure being tested for La Guardia Field, New York City. The relationship between reported snow intensity and estimated snowfall is shown on independent data to be reliable. Results should aid in forecasting additional snow accumulation and in estimating previous snowfall when this information is not available from direct measurements.

## 1. Introduction

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 of 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 at which snow is falling nor the accumulation 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 isn't measured directly every hour, 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 currently measured and reported only once every 6 hr, except for very heavy snowfalls.

## 2. Procedure

The dependent data used in this study consist of snow intensity reports and 6-hr snow depth measurements obtained during snowstorms at La Guardia Field, New York City 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 ½ inch occurred. All such storms are included in their entirety with the exception of 6-hr 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 remove cases in which a 6-hr snow depth measurement does not represent the actual amount of snow that fell during the previous 6-hr. Obviously, if rain follows snow, a considerable amount of melting may have occurred before the 6-hr snow depth measurement was taken. It is recognized that in some storms that ultimately produced at least ½ 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, these data are included in the study but they are not expected to have a significant 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 6-hr periods. Also determined for these same 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.

Table 1 presents the current definitions of precipitation applicable 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 1 January 1971. The definition of intensity of snow based on visibility has not changed since 1949. In 1951 the definition of intensity of rain on rate-of-fall basis was enlarged to include melted snow. No indication can be found that any investigation has been made to determine if the two definitions are consistent. Results presented here indicated that since 1951 a double standard may exist for determining snow intensity; however, it was previously shown that the definition based on rate-of-fall basis is probably not applied by weather observers.

TABLE 1. Definitions of intensity of precipitation applicable to snow.

| 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 $hr^{-1}$;maximum 0.01 inch in 6 min. |
| Moderate | 0.11-0.30 inch $hr^{-1}$; more than 0.01 inch to 0.03 inch in 6 min. |
| Heavy | More than 0.30 inch $hr^{-1}$; more than 0.03 inch in 6 min. |

## 3. 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 La Guardia 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 accumlation of snow when S- is reported is thus estimated to be 0.2 inch $hr^{-1}$

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 6-hr snow depth measurement period studied had at least one hour of reported S-.) Snow accumulation attributed to S- intensity was removed by using an hourly accumulation rate of 0.2 inch for S-. The remaining total snow accumulation 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 inch $hr^{-1}$.

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. The ratio of hours of S to hours of S- ranged from a minimum of 1.0 hr of S to 4.3 hr of S- to a maximum of 4.0 hr of S to 2.0 hr of S-. In the 10 six-hourly periods, there were a total of 19.2 hr 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 inch $hr^{-1}$, 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 inch of snow accumulated per hour, and for reported intensity of S an average of 1.0 inch 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 accumulations estimated for hours of S and S-, there were a total of 19.3 hr 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 estimated to be 1.6 inch $hr^{-1}$. 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 4.0-1.5 to a minimum of 1.5-4.0. The average hourly rate that snow falls when S+ was reported during these five storm periods was 1.5 inch $hr^{-1}$, a figure quite close to the 1.6 inch $hr^{-1}$ determined by examining all 17 storm periods. A summary of these results is presented in Table 2.

TABLE 2. Average hourly snowfall vs snow intensity (inches per hour). Results are for La Guardia Field, New York City, December 1949 through March 1969.

| Snow intensity | Average hourly snowfall |
|---|---|
| Light (S-) | 0.2 |
| Moderate (S) | 1.0 |
| Heavy (S+) | 1.6 |

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 9.3 inches of snow to 1 inch of liquid precipitation, a value that is quite close to the commonly accepted 10 to 1 mean ratio.

Pack (1969) found for 12 winter seasons (1951-52 through 1962-63) at La Guardia Field that 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.

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 inch of snow falls per hour, moderate when 1.0-2.8 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 inconsistent with the visibility criteria, at least for La Guardia Field. To be consistent with the results in Table 2, one would have to reduce by about 50% the rate-of-fall requirements in Table 1 for each precipitation intensity category.

4. Test of results

Two winters of independent data (December 1969-March 1970 and December 1970-February 1971) were used to test the results. During these two years there were 12 storms that yielded at least ½ inch of snow at La Guardia Field. Snow accumulations during the test period were small with only one storm yielding more than 4 inches. Table 3 presents the dates, the number of hours of snow, the estimated snow accumulation (based on reported snow intensity and relationship described in Table 2), and the measured snow accumulation for each of the 12 storms.

TABLE 3. Estimated vs measured snow accumulation for 12 independent test storms.

| Date of storm | Duration of snow (hours:minutes) | Estimated snow accumulation (inches) | Measured snow accumulation (inches) | Estimation error (inches) |
|---|---|---|---|---|
| 25 Dec. 1969 | 6:15 | 1.3 | 1.6 | -0.3 |
| 27 Dec. 1969 | 8:25 | 1.7 | 1.5 | +0.2 |
| 6-7 Jan. 1970 | 11:28 | 2.3 | 2.5 | -0.2 |
| 12 Jan. 1970 | 10:04 | 2.0 | 2.0 | 0.0 |
| 20-21 Jan. 1970 | 11:04 | 2.2 | 2.5 | -0.3 |
| 3-4 Feb. 1970 | 5:05 | 1.8 | 1.7 | +0.1 |
| 14-15 Feb. 1970 | 15:05 | 3.0 | 2.5 | +0.5 |
| 29 Mar. 1970 | 6:42 | 2.4 | 3.0 | -0.6 |
| 21-22 Dec. 1970 | 10:30 | 2.1 | 1.0 | +1.1 |
| 1 Jan. 1971 | 14:30 | 4.1 | 5.7 | -1.6 |
| 13-14 Jan 1971 | 5:54 | 1.2 | 1.7 | -0.5 |
| 24-25 Jan. 1971 | 6:46 | 2.2 | 2.4 | -0.2 |
| | | Mean absolute error | | 0.47 |
| | | Mean algebraic error | | -0.15 |

The data presented for independent snowstorms (Table 3) indicate that their was no significant bias in the procedure used to estimate snow accumulation and the mean absolute error of estimation, 0.47 inch, is 20% of the mean measured snow accumulation for a storm, 2.35 inches.

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 Field. 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. Six of the 21 storms that appear in Table 4 (1950, 1951, 1953, 1954, 1958, 1961) actually contain 6-hr periods of independent data. These six storms are included in this table even though the occurrence of light frozen precipitation other than snow excluded parts of these cases from consideration in the development data. For these six storms, the periods of light frozen precipitation were treated as light snow in estimating accumulations.

TABLE 4. Estimated vs measured snow accumulation for yearly snowstorm with largest accumulation at La Guardia Field, 1949-69. The estimated snow accumulation is determined from reported snow intensity and the use of Table 2.

| Date of storm | Hours of snow | Estimated snow accumulation (inches) | Measured snow accumulation (inches | Estimation error (inches) |
|---|---|---|---|---|
| 28 Feb. 1949 | 17.5 | 10 | 10 | 0 |
| 13 Feb. 1950 | 25 | 5 | 4 | +1 |
| 31 Jan. 1951 | 16 | 4 | 4 | 0 |
| 1 Mar. 1952 | 8 | 6 | 4 | +2 |
| 8 Jan. 1953 | 12 | 3 | 2 | +1 |
| 11 Jan. 1954 | 14 | 4 | 6 | -2 |
| 2 Feb. 1955 | 16 | 4 | 4 | 0 |
| 18-19 Mar. 1956 | 27 | 9 | 10 | -1 |
| 4 Dec. 1957 | 24.5 | 8 | 8 | 0 |
| 20-21 Mar. 1958 | 39 | 9 | 7 | +2 |
| 12 Mar. 1959 | 15 | 5 | 6 | -1 |
| 3-4 Mar. 1960 | 24.5 | 14 | 15 | -1 |
| 3-4 Feb. 1961 | 26 | 9 | 19 | -10 |
| 9 Feb. 1962 | 8 | 2 | 3 | -1 |
| 23-24 Dec. 1963 | 9 | 5 | 7 | -2 |
| 12-13 Jan. 1964 | 30 | 8 | 10 | -2 |
| 16 Jan. 1965 | 16 | 3 | 5 | -2 |
| 29-30 Jan. 1966 | 16.5 | 6 | 6 | 0 |
| 21-22 Mar. 1967 | 19.5 | 7 | 8 | -1 |
| 15 Dec. 1968 | 13 | 4 | 4 | 0 |
| 9-10 Feb. 1969 | 24 | 17 | 16 | +1 |
| | | Mean absolute error | | 1.41 |
| | | Mean algebraic error | | -0.81 |

The data presented for severe snowstorms (Table 4) indicate that there was a bias of underestimating snow accumulation by 10% of measured snow. The mean absolute error of estimation, 1.4 inch, is equal to 19% of the mean measured snow accumulation for a severe storm. It is interesting to note that for the storm of 3-4 February 1961, for which there was a 10-inch underestimate of the snow, there were 10.5 hr during which the snow intensity was reported as light, even though the visibility was below 5/8 of a statute mile during this entire time. The intensity of snow with visibility as a criterion is defined as moderate when the visibility is less than 5/8 mile but not less than 5/16 mile, and the intensity is defined as heavy when the visibility is less than 5/16 mile (Table 2-upper half). In this case the observer recorded additional obstructions to vision, light sleet, or blowing snow or fog as justification for not recording the snow intensity as moderate. 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 year's most significant snowstorm. If we exclude this storm from consideration, there was no significant bias in estimating snow accumulation for severe storms and the mean absolute error of estimation, 1.0 inch, is equal to 14% of the mean measured snow accumulation for the remaining 20 storms.

## 5. Application of results

The results make it possible to estimate a past or current hourly rate that snow accumulates from a snow intensity observation, at least at La Guardia Field. 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 avaiation forecasts. Public weather forecasters include snow intensity and snow accumulation forecasts in their public releases. The results presented in Table 2 could 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 forecast, based on the same number of forecast hours of moderate snow, includes an accumulation too low or too high to be consistent with results presented here. The aviation forecaster should be aware of the snow accumulation that he is implying, when he states an expected snow intensity and duration in his forecast.

## 6. Conclusions

A technique has been presented for estimating hourly snow accumulation from reported snow intensity which, in turn, is based on visibility estimates. The fact that the technique works well for La Guardia Field implies that the procedure may be of value when applied to other locations.

After additional data have been collected and analyzed for La Guardia Field, 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.

There is an apparent discrepancy between two methods of determining snow intensity as described in the *Federal Meteorological Handbook No. 1*. The rate-of-fall basis would have to be reduced by about 50% to be consistent with the visibility criteria.

## REFERENCES

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