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Snowfall Measurement in Respect to Current Weather Conditions

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ABSTRACT

Unless consideration is given to exposure, wind, drifting, snowflake and/or snow crystal features, compaction and evaporation, snowdepth measurements are often unrealistic. Particularly is this so if measurements are made at long intervals. However, an experimental procedure including consideration of average size of flakes, blowing snow, intensity of fall and visibility, yields promising estimations of accumulating snowfalls. Without sophisticated and costly devices, realistic snowfall amounts seem obtainable when nearly calm conditions prevail and when readings can be made at frequent intervals. An abvious present disadvantage is the need to watch weather events continuously since automatic recording of some of these particularly referenced variables seems not presently feasible.

OBJEC-TIVES

1. Terms of reference and objectives:

1.1 This paper does not represent finished research but rather is a progress report. It attempts to sharpen our views toward a very old problem: measuring snowfall. It is believed in these times of rapidly expanding modern technology that improved means could be available for obtaining sound information on the amount of falling snow. The nature and quantity of such snow result from physical processes in the atmosphere. All pose tough challenges for our understanding and forecasting. Requirements for snowfall information vary considerably depending upon needs and users. These can range from such extremes as avalanche forecasting to public highway maintenance. In contrast, snowcover information, in the senses of snowdepth and of snow water content, may be primary for many snow requirements. Important to this entire matter is clarification of what is implicit in the terms applying to different aspects about snow; e.g., snowfall, snowdepth, snowcover, etc. Finally, clearer understanding and standardization are needed about what, how, and when snow is measured.

Snow cover vs. snow-depth

Snowfall as new snow-depth

1.2 The main slant in this paper is directed at snowfall in the sense of a meteorological event. Concern is with the new snow. Therefore, snowdepth is herein used in the sense of depth of new falling snow, i.e., snowfall. It is assumed that snow as a precipitation form, is worth measuring as snowfall separately from its water equivalent or content. Certain questions naturally arise:

a) What is snowfall?

b) Is snowfall worth measuring?

c) What do we measure?

d) How do we measure?

e) What are the prospects?

Precipitation

2. First about the nature of snowfall. Consensus of several definitions identifies snowfall as precipitation. As a "fall of snow" concern is with the "amount of snow falling within a
(1) certain time and area --". "Fall" means "to drop from a higher to lower place or position--". In like fashion preci-
(2) pitation is the "depositing of moisture in the form of rain, hail, or snow --" or, from another source: "the deposition of moisture from the atmosphere upon the general surface of the earth." Summarizing, snowfall is considered as a form of
(1) precipitation. As such it falls to the earth. This precipitation form originates from water vapor and subsequently descends from clouds to the earth.

2.1 While some modification of the snow (crystals and/or flakes) may occur enroute to the earth, drastic changes in snow properties ensue subsequent to earth contact. These changes depend upon factors including wind, temperature, rapidity of snowfall, and the nature of the snow itself. In Oswego, New York, compaction of the snow and wind effects
(3) are commonplace. These drastically influence measurements of "new snow" as snowfall continues.

Snow as precipitation

2.2 Snow as precipitation results from sequences of physical processes. These transform the original water vapor into the varied forms common to our experience. Such precipitation by defination <u>would not include</u> these miscellaneous forms of snow which are subsequently transported over the surface after initial contacts and deposited in random fashion.

Snow cover vs. falling snow

2.3 Considering what may happen to the falling snow we should expect that the depth of newly fallen snow (snowfall) measured over a particular time interval and the ground depth of snow which has accumulated during the same period (snowcover - new) may have differing totals. Consider some of the rather common circumstances observable for 6-8 hours or so to the lee of Lake Ontario: heavy falling snow with visibility 200 yards or less, winds averaging 25-30 knots and temperatures ranging from 15-20° F. Under such circumstances we might expect one or more of the following to obtain:

Lake effects (4&5)

a) Variability in snowflake size with intervals when 3/4" to 1/2" may comprdse 50% or more of the falling snow. The instantaneous distribution of falling snow may be (snowfall intensity or density of snowfall) sufficient to reduce visibilities regularly to 50-100 yards or less due entirely to falling snow disregarding blowing snow or fog.

b) Variability in the looseness of flake structures and variability in cyrstal types and sizes.

c) "Stickiness" of the snow as shown by the ease of packing and the sense that the snow is "wet".

d) Revision of the snow surface (i.e., the surface snow) as wind effects reduce snow flakes into small fractions of the

Fracturing of snow (4) original sizes for flakes and/or crystals. This fracturing makes available many very small bits of ice, perhaps 1/50th to 1/100th or less the volume of the original flake (or crystal) sizes. This material is quite "dust-like" and may pass through

(4) the air occasionally in great quantities as "snow debris"

Snow water rations (4)

e) Extensive shifting over the surface leaving large areas so that large surface areas denude of significant new snow while extensive drifts, perhaps approaching snow-to-water ratios of 2.5 to 1 from original ratios of 25 or 30 to 1 in the falling snow, build up elsewhere. In such drifts snow-to-water ratios approaching 2.5 to 1 may develop from original 25 to 40 to 1 for the falling snow. Such changes may be expected even over areas close to the Lake Shores where snow amounts transportable from up-wind locations are naturally limited.

3. Consider the worth of measuring snowfall:

Snow mantle

Users

3.1 Who is interested and in what? These are questions of some concern to us. "Snow surveys" satisfy many aspects of the "need to know" for run-off, flooding, and similar needs. Water content of the snow mantle and subsequent additions, if of prime importance. Requirements of engineers, hydrologists and others may thus be quite well served through the results of these snow surveys and long established procedures including repeated depth and water content measurements in selected area within deciduous forest growths. Surely, climatologists and some meteorologists can find such water content information and changes throughout the mantle useful.

General public interest

Public problems

3.2 Concerning the general public, accumulation of snow as snowdepth information at a particular time fulfills many public needs. Snowdepth may be viewed then in terms of its nuisance or advantage aspects. The kind of falling snow, heavy and/or sticking, or, light and fluffy, may be of some concern. Of course, just the presence of any snow in the air and/or on the surface can be sources of public concern depending on time-of-day, transportation, activities, etc!

Side effects

3.3 Some difficulties arise in the public mind in respect to what may be reported through news media. News reports and their interpretations may vary according to individual personal experience. Snow information may be slanted or subject to certain "pressures". Perhaps a chamber of commerce would prefer snow information to be on the "low side. Figures more representative of actual fall of snow would in some areas be rather discouraging for business recruitments. Nevertheless, varying methods employed in measuring and reporting snowdepth and/or snowfall continually confuse the public. There remains, however, onepositive aspect; namely, snowfall is a good conversation item.

Practical applications

New snow vs. public activity

3.4 Certain business and service functions may be somewhat more concerned with actual depth of snow as it sccumulates; that is to say, in the operational sense. Thus plowing operations may be set to begin automatically when a depth reaches "so many inches". Sanding operations or similar precautions may be begun with lesser depths. Proceudres may vary depending upon - temperatures, surface conditions, wind, and other factors. Telephone and power companies have some special needs for snowfall information. A particular example is the "wet but clinging snow" which can hamper the safety of long lines. Different amounts of new snow may be of varying concern to public activity.

Meteorological needs (5)

3.5 Now what about a meteorological need for snow-fall information rather than just water content and/or periodic depth measurements? Snow can be considered as a product of different atmospheric processes. The crystals structure, size of flakes, rates of fall, and changes in these factors are indexes of physical activity at different levels and for different parts of the action. Vertical motions; moisture and electrical conditions; and, small particle distributions interplay to condition the snow that reaches the ground. Great variability in the so-called "lake effect snows" to the lee of lakes like Lake Ontario points to the complexity of such on-going processes. Environmental complications are added by the local geography and orography, stability, and the special but sometimes fickle tendency for confluence and convergence in air flows across the Lake. Such considerations cannot exclude the lake environment itself although these factors are beyond the scope of this paper.

Lake effect situations (5)

Snowfall vs. forecasting

3.6 Since a present requirement is to forecast wheather, there would seem to be a need to be concerned about true snowfall, as well as with crystals type and size, flakes, etc. Further, when considering weather modification possibilities there is even a further need to know what is really coming from the clouds as well as importance of environmental factors to changes in snowfall and snowcover. While such concern about snowfall may appear to be mostly related to research, ultimately the concern is a matter of public interest and purse.

What is measured

4. It is essential that we focus our attention on what we measure in snowfall.

Timing of measurements

Cooperatives

Factors causing changes

4.1 A little depends upon the mission of the measurer. First order weather stations are now required to measure snowdepth every six hours. If these has been some wind, what is measureable is precipitation-type snow, blown snow, or a combination of these. On the other hand, snowfall to the cooperative weather observer may be a "depth" measurement every 12 or 24 hours. During such intervals significant changes occur <u>throughout</u> the snow layer. Such causes are the well-known ones wrought by wind, temperature, sun, compaction, evaporation, sublimation to mention those of standard reference. Snowdepth measurements are further complicated by varying snow types falling on the surfaces where the measurements are made.

Airport facility

Snow to water ratios

4.2 Consider a typical airport weather station. Do we have a reasonable means to measure snowfall by taking 5-10 ruler depth measures? Will we get a better idea of snowfall by taking the melt water in a typical weighing precipitation recording gauge and then applying some factor of water equivalent to snow depth? Use of some such factor could be rather difficult when snow-to-water equivalents may vary during a season from perhaps 6-1 to 35-1 or higher. The ratios may even change significantly during an individual snow period with variations due to rapid changes from graupel (1/8" to 1/4" diameters) to very loose flakes (diameters ranging and varying from 1/4" to 3/4", less and greater). One can but wonder about snow measurements around the typical airport when open exposures conducive to high and gusty winds are so frequent. Open locations are dictated by factors other than weather.

Windiness

4.3 These are old problems. There seem to be some real doubts as to the meaning of resulting figures for snowdepth as a precipitation item as well as in many in instances even regarding the water content of the snow itself. It may be reasonable at times to conclude that "in bound" snow to the wind-blown area being measured equals "out bound" snow. However, one might well conclude from viewing reporting and recording stations that few of these areas fulfill even reasonable facsimiles of ideal areas for "precipitation exposures". In truth it appears that snow accumulations made up of residues from inputs, removals, compaction, evaporation, and other environmental effects, are really being measured rather than snowfall.

Water content

Representative areas

5. Several references have already been made to the methodology of measuring snowfall (snowdepth).

Common measuring method

5.1 The ruler is apparently the prime means of establishing depth. The choice of locations may be severly limited as at typical airport locations where operation buildings are frequently in pretty windy locations with local drifting common and with scant possibility for much uniformity of thickness in the layer of newly fallen snow.

5.2 In reference to the already cited weighing gauge we would emphasize its well known limitations when high winds exist. In the Oswego Area winds of 20 knots or greater with gusts can be expected upwards of about 75% of the time when we have snowfalls of 3-5 inches or more. Serious doubts must exist as to what goes into "catch cans" under such circumstances. What is said about the accepted rain gauge equipment is certainly even more true in regard to the "traditional snow board".

Weighing gauges

Wind effects (4)

5.3 Personal observations in the Oswego Area beginning in 1961, clearly identify wind as a major factor when considering local snow situations. Attempts to apply the accepted qualitative definitions of "light", "moderate", and "heavy" snow as visibility restrictions met with little success in trying to establish some relationship with what was falling. Resources for developing and applying optical and/or electronic devices for establishing snow accumulation in respect to some visibility criteria were unavailable for any local research. However, some experimental techniques were innovated by relating horizontal visibility, sizes of snowflakes and crystals, intensity of fall of flakes, to the depth of newly falling snow.

Snow boards

Common description

Visibility criteria

5.3.1 Recognizing the "uncertain ground" for such activities we nevertheless perservered to the extent of deriving a small experimental table which, slightly modified, is shown in Table 1. Considering the complexity of what happens to light transmission when small particles, pieces of ice crystals, and snow vary in the air while light intensities may also be varying due to cloud thicknesses, it is hardly surprising that one might be quite skeptical about the validity of the relationships

Complications

TABLE 1 Experimental chart

indicated in the table. However, it can be said that these suggestions were derived from extensive periods of continual snow watching, both day and night (when distant lights were used) over several years of time.

Need for theoretical consideration

5.3.2 Fog, blowing and drifting snow, and similar visibility deterents were excluded from consideration. The relationships have yet to be exposed to hard scrutiny in respect to theoretical considerations. The indicated relationships were obtained by observation.

TABLE 2 Synoptic snow intensity visibility chart

5.4 For a brief comparision the observational basis for relating visibility to snow intensity as used according to international criteria are shown in Table 2. Additionally, standard Weather Bureau observational provisions include descriptions of drifting snow, generally low (under 6 feet in depth) and generally high (over 6 feet in depth).

Drift

Testing difficulties

Low wind periods

5.5 Testing this estimation method has posed some problems since one would initially wish to consider snowfall under little or no wind condition. In the Oswego Area this is difficult since there are few snows of significant duration since there are few snows of significant duration without accompanying wind. During two recent periods there were light winds with no drifting evident so that visibilities during snowfalls <u>only</u> could be closely estimated, flake sizes could be estimated (using a strong light at night), snowfall intensity (relative amounts of snowflakes of different average sizes)could be estimated, and snow depths could be measured to a fixed under-surface with measurements at close intervals. Drifting and fog were not present.

Procedure

TABLE 3 Jan. 1969
TABLE 4 Dec. 1968

Future effort
Test intervals

5.5.1 The snowcover was removed after each of the short interval measurements. Simultaneously with these frequent snowfall measurements, the depths in "unremoved snow" were measured adjacently. Tables 3 and 4 show situations for January 2nd, 1969, and December 7th, 1968, respectively. Some comments on individual circumstances are included with each table. (An added approach of simultaneous measuring of the short interval snowfalls during repeated intervals for two or more different time periods has not yet been tried sufficiently to merit more than passing reference here. It is clear though that more than one observer is desirable if such close observations are to be made. So far 10, 15, 20, and 30 minute measurement intervals have been tried.)

Irregular snow surface

5.5.2 Commonly, six individual depths are made for both short interval measurements as well as total depth of the new snow measurements. More are made if individual measurements vary by $\pm$ 1/3 or more. It should be recognized that the upper surface of the snow can be exaggerated in terms of percentage of total depths during these short periods depending upon the sizes of the flakes and how they aggregate on the surface. Measurements are made into the shallow and deeper parts of the cover.

No graphical presentations at present

5.5.3 To date there has been no success in deriving useable graphical representations between visibility and time while considering <u>also</u> the other variables of snowflake sizes and wind.

Wind and horizontal visibility / *Wind and drift* / *Drift factors* / *Fracturing of flakes (4)* / *Telling snowfall from drift*

5.6 Of course when there is wind, horizontal visibility can become much influenced. Particularly this will be true if there is already a mantle of light, undrifted snow. After about three or four hours of wind action (say 20-25 knots for example), visibilities tend to improve over similar prevailing wind speeds. At present this is a qualitative statement without detailed supporting measurements. Temperatures, snow types, and wind speeds appear to be among those factors influencing drift characteristics within the prevailing environment. Of course the drift can become a visibility deterent. Original snowflakes averaging 1/2" to 3/4" in diameter may break down into small fragments through repeated fracturing. Indications as a result of some preliminary study under low magnifications, are that the fragments, or snow debris, can be flat slivers on the order of a 1/50th to 1/100ths or less of the original flake sizes. In strong light it is easy, however, to differentiate such bits from the flakes. The bits sparkle in the light reflected from a strong source quite differently than do the flakes.

Focus on new snowfall vs. snowdepth / *Tug Hill Pump Method*

6. It is believed worthwhile to focus some attention and hopefully some technical consideration, on the matter of snowfall versus snowdepth. While development of techniques and equipment for common application may be too expensive in terms of the public requirement, one can but wonder if continuance of existing methods and techniques is warranted either. The Tug Hill Pump Handle Method of snowdepth measurement a few years ago indicated some 400" of snow during a season. While this amount may or may not have been typical of"true" conditions, since conventional measurements were not made simultaneously, it is interesting to reflect on what the cook did at this particular camp. Several times a day when he went to pump water he cleaned the flat platform around the pump free of snow. Subsequently he measured the new accumulation and repeated the process but keeping a running tally. He ended up for the season with more than 400" of such increments for snowdepth.

Summary of experimental approach / *High winds indirect indications re: new snowfall* / *Drift transport*

6.1 Some experimental approaches have been used in the Oswego Area by relating visibility to certain aspects of snow. Interesting, if not encouraging, results developed during low wind periods. Satisfactory means for extending the estimation techniques and checking the results have not been developed for high wind situations. However, some indirect indications would seemto support a belief that at least a reasonable order of magnitude can be obtained in measuring snowfall byextending the low wind relationships at least into average wind conditions ranging 20-30 knots. The indirect supporting evidence shows in the magnitude of the drifts that result during such windy circumstances at locations where there can be little transport from up-wind. Yet, vast amounts of snow are represented in drifts as residues from deteriorated flakes.

Limitations in application

6.2 Several practical limitations are imposed by any method which requires continuous visual observations.

6.3 This paper has attempted to focus attention upon

Focus of paper and summary

snowdepth in the sense of accumulation of snow as it falls -- in other words, as a form of precipitation. Some empirical relations between visibility, snowflakes characteristics, intensity of fall, and depth of falling snow receive some attention. It is believed that uncertainties about snowfall, its meaning and measurement, call for study and clarification.

Postscript

6.4 Some remarks based upon discussion following presentation at Portland, Maine:

6.4.1 Mr. Oscar Tenenbaum, USWB at Newton, Mass. pointed out that Weather Bureau Airport stations are situated where they are due to needs other than weather.

6.4.2 Mr. Morlan W. Nelson, Boise, Idaho, indicated a need for the graphs relating the parameters to new snowfall accumulations and the water content in the new accumulating snow. He advised that such information would be useful to those concerned with avalanches. Some discussion on simultaneous weighing and depth measurements followed.

6.4.3 During the talk some personal experiences of 5 February 1969 of passing from North to South through an East/West snow band of some 20 miles width with light or no wind/snow visibilities of 40-100 feet were detailed. Some post-talk discussion related to these and similar "lee-of-the-Lake" conditions.

ACKNOWLEDGMENTS

U.S. Weather Bureau, Hancock Field, Syracuse, New York, for the contents of Table 2, snow intensity versus visibility.

Mr. L. Lansing, Boonville, New York, for his summarization of The "Tug Hill Pump Handle Method".

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TABLE 1

Experimental Current Snowfall - Visibility Accumulation Rate Chart

Average Horizontal Visibility	Average Flake Size	Reasonable Snow Accumulation
880 yards	1/8 inch	1/4 + inches/hours
880 yards(due to snow)	1/4 inch	1/2 to 3/4 inches/hours
440 yards	1/4 inch	1 inch/hour
220 yards	1/4 inch	1 & 3/4 inches/hour
150 yards	1/4 inch	2 inches/hour
75 yards	1/4 inch	nearly 3 inches/hours
10 yards	1/4 inch	nearly 4 inches/hour
20 yards	1/2 inch; about 50%	nearly 4 inches/ hour
20 feet	1/2 inch; about 50%	nearly 8-10 inches/hour

TABLE 2

Synoptic Snow Intensity - Visibility Chart

Intensity	Visibility	Description
Very light		Scattered flakes do not completely wet or cover an exposed surface regardless of duration
Light	≥5/8 mi.(1100 yards)	
Moderate	<5/8-5/16 mi.(550 yards)	
Heavy	<1/4mi.(440 yards)	

TABLE 3

Observations for January 2-3, 1969, at SW Oswego, N.Y.

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Time	Prevailing[1] visibility	Prevailing[2] Flake Size	Snowfall[3] Increments	Sun of[3] Increments	Total[3] Ground Cover (New Snow)
0730-2100	1/4-1/2	≥1/4 50	1 1/8*		
2100-2238	<1/4	≥1/4 75	0^4	1^5	
2238-2255	300	≥3/8 75	1^0	2^5	
Snow board down 2255					0 for Board
2310	200	≥1/2 60	0^6	3^3	6/8
2320	175	≥1/2 60	4	3^7	
2330	200	≥3/8 75	4	4^3	e 1^5
2340	175	≥3/8 75	5 ++	5	
2350	175	≥1/2 70	5 +	5^5	2^6
0000	200	≥1/2 50	4 ++	6^1	
0010	500	≥1/2 50	3	6^4	3^4
0020	≤1/4	≥1/2 50	3 +	6^7	3^6
0030	≤3/8	≥1/2 50	3 +	7^2	
0040	≤3/8	≥1/2 50	3	7^5	4^2
0050	<3/8	≥1/2 50	3	8^1	
0100	<3/8	≥1/2 50	3	8^3	4^5
0110	3/8	≥1/2 50	3	8^6	
0545	3/8	≥1/4 50	5^5	14^3	8^5
0600	3/8	≥1/4 50	2 +	14^5	
0620	5/8	≥1/6 65	3	15	
0630	e 5/8	≥1/8 65	3	15^3	
0645	3/4	≥1/8 65	3	15^6	
0645-1020			1^7	17^5	9^2
1020-1415			0^1	17^6	
1605	450	≥1/4 75	1^2	19^0	8^4
1615	425	≥1/4 75	0^5	19^5	
1630	500	≥1/4 75	0^6	20^3	
1645	500	≥1/4 75	0^5	21^0	
1700	3/8	≥1/4 70	0^4	21^4	
1800	≥1/2	≥1/8 50	0^3	21^7	
1845	2	1/16 60	0^2	22	10 + inches
2030			0^1 (_?)	22^2	

[1] miles/yards [2] inches diameter/percent; estimated [3] inches and eighths

+ = Conservative ++ = very conservative - = very close
Prevailing visibility, prevailing snowflake sizes and percentages are observational estimates. Snowfall data were ruler measurements except where estimated: "e"

See notes following Table 4 *Measure at end of time period indicated

TABLE4

Observations at SW Oswego, N.Y. for Dec. 7, 1968

Time	Prevailing[1] Visibility	Prevailing[2] Flake Size	Snowfall[3] Increments	Sum of [3] Increments	Total[3] Ground Cover (New Snow)
1120	300	≥1/8 90			1^0
1140	<250		0^5	1^5	1^4
1200	300	≥1/4 80	0^7	2^4	2^2
1210	75 ±	≥1/4 80	0^7	3^3	3^0
1220	175	+≥1/4 85	0^4	3^7	3^2
1230	<200	≥1/4 80	0^4	4^3	3^5
1240	175	+≥1/4 80	0^4	4^7	4^2
1250	300	≥1/4 80	0^4	5^3	4^5
1300	175	≥1/2 80	0^7	6^2	5^4
1310	150 +	≥1/2 80	0^6	7^0	6^2
1320	3/4 +	≥1/8 70	0^1	7^1	6^0
1330	5	+	+	7^1	5^7

[1] yards/miles [2] inches/percent; estimated [3] inches and eighths

Prevailing visibility, prevailing snowflake sizes and percentages are observational estimates. Snowfall data were ruler measurements.

NOTES ON TABLES 3 and 4:

1. During the time period covered by detailed new snowfall depth measurements (2255 2 January through 2030 3 January) some 62 observations were made. The reproduced information are partial extracts from the individual reports. Original reports were in much great detail on snowflake (and crystal) estimations and as well included sky, wind, temperatures, pressure, etc., entries as appropriate.

2. Similar commentary applies to Table 4. However, for the shorter period only about 32 observations were made.

3. Some interesting comparisons may be made between the Total Ground Cover and Sum of Increment columns in both tables. Note the slow cumulative build up of the ground snowcovers.

4, Application of the estimation criteria, allowing some tolerance for differing variables. contained in Table 1 would have in general "forecasted" somewhat less in new snowfall depths (from hour to hour) than the running totals of measured increments. Settling appears to have been about the same during both periods when the short interval measurements were made. During the January situation there were several periods for which measurements were made at the end of several hours new snow ground accumulation. Such measurements represent a "net"; no provision is made for settling which must have occurred. Drifting appeared not to be a factor in either instance. Surface and wind conditions were quite carefully noted throughout.