"True Snowfall"
An Evaluation of the Double Fence Intercomparison Reference Gauge

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ABSTRACT

Based on the analysis of WMO Intercomparison data from 1970 through 1990 at the Valdai Hydrological Research Station in Russia, this study found that blowing snow occurred during one-third of the snowfall events greater than 3.0mm. Wind direction during these events was primarily from the south where a small lake is located. After eliminating the snowfall events during which blowing snow occurred, there remains a systematic difference between the measurements of the bush gauge and the Double Fence Intercomparison Reference (DFIR) gauge, that is, the bush gauge catches more snow than the DFIR. Therefore the correction of the DFIR for wind induced loss is necessary in order to best represent true precipitation. Regression analysis indicates that the most important factor to the correction is mean wind speed during the storm. Correction equations for different types of precipitation have been developed. An example of the application of using the DFIR as a reference standard is demonstrated with two typical North American precipitation gauges.

INTRODUCTION

It is now widely recognized that, due to systematic errors (i.e. wind-induced, wetting loss and evaporation loss) in measurement by all types of precipitation gauges, the correction of precipitation measurements, especially snowfall measurements, is critically important for the study of the regional and global energy and water cycle and of climate variability and change. In an attempt to quantify these errors, the World Meteorological Organization's Commission on Instruments and Methods of Observation (WMO/CIMO) initiated the Solid Precipitation Measurement Intercomparison in 1985 and fifteen countries are participating in the experiment.

For the experiment to be successful, it was necessary to designate a reference standard for measuring snowfall precipitation against which all other measurements could be compared. After reviewing all possible practical methods of measuring "true" snowfall in a variety of climatic environments the organizing committee designated the octagonal vertical Double Fence (with Tretyakov gauge) as the Intercomparison Reference (DFIR) gauge (Goodison et al.,1988). Golubev (1986) stated that even the DFIR measurements, compared to the shielded Tretyakov gauge measurements in a sheltered bush site at the Valdai hydrological research station in Russia, are adversely affected by wind speed. He developed a correction equation for the DFIR measurement which uses wind speed, atmospheric pressure, mean air temperature and mean air humidity to correct the DFIR measurement to the sheltered bush site (Golubev, 1989). Subsequent analysis of the Golubev equation showed that for the same site, atmospheric pressure and humidity have little effect and the equation could be simplified to consideration of air temperature and wind speed only (Goodison and Metcalfe, 1992). To ensure the

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best possible results from the Intercomparison and to incorporate data recently collected at Valdai as part of the Intercomparison, it was deemed necessary to re-assess the DFIR correction procedure. Using the Valdai twice daily observations from 1970 through 1990, this study investigates the relationship between the DFIR and the shielded Tretyakov gauge in the sheltered bush site (bush gauge). The factors contributing to any significant difference between the two gauges are assessed to provide an evaluation of the accuracy of the DFIR measurements and to develop any necessary correction procedure for use by participants in the Intercomparison.

SITE AND INSTRUMENTATION

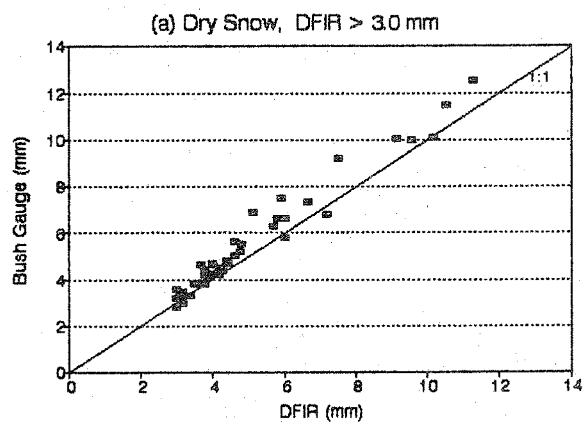
The Valdai hydrological research station is situated on the flat shore of Valdai lake. There are two DFIR's installed at the station in an open area of 200x200m with no significant obstructions nearby. Approximately 300m from the open site is the "bush gauge" (Tretyakov gauge with wind shield) placed in 2-4m high shrubs in a three hectare area. Within the 12m diameter working area of the gauge the shrubs are cut routinely to the gauge height of 2m. This gauge has been accepted as the working reference for winter precipitation measurement at Valdai station since 1970.

The bush gauge is considered as the most appropriate reference, i.e. "true" measurement for solid precipitation at this time and is comparable to the pit gauge for measuring rainfall (WMO, 1991). The gauges in both the open and bush sites at Valdai are measured twice daily at 0800 and 2000 (local time). The contents of the gauges were both weighed and measured volumetrically to determine precipitation amount and over a period of time an average wetting loss was determined. Since 1966, a correction for wetting loss of the Tretyakov gauge has been added to every volumetric precipitation measurement and therefore no additional correction for this systematic loss is required.

Wind speed and direction were measured at 2m height before September 1989 and a linear equation was used to estimate the wind speed at the DFIR height of 3m. Since then, wind speed at 3m has been measured directly. Atmospheric pressure, air temperature and humidity were also measured at the site.

DATA ANALYSIS

All of the Valdai precipitation data and auxiliary meteorological measurements measured from 1971 to 1978, and from 1988 to present have been submitted to the WMO Intercomparison international archive. The current analysis focused on the gauge catch ratio of the DFIR to the "bush gauge" as a function of wind speed at the height of the DFIR. In order to minimize the large variation in the ratio of bush gauge to DFIR that could occur when analyzing small absolute differences between gauges for small precipitation events, only amounts when the DFIR measurement was greater than 3.0mm were used in this analysis. For the period of October 1970 through April 1990, 368 twelve hour observations of precipitation greater than 3.0mm were recorded. The bush gauge measurements were found to be systematically higher than those of the DFIR for all types of precipitation. A strong linear relationship was found to exist between the two gauges except during blowing snow events (Fig. 1a, 1b). On average, the bush gauge caught 6.4, 8.5 and 10.8% more than the DFIR for rain, rain and snow mixed and snow, respectively (Table 1).



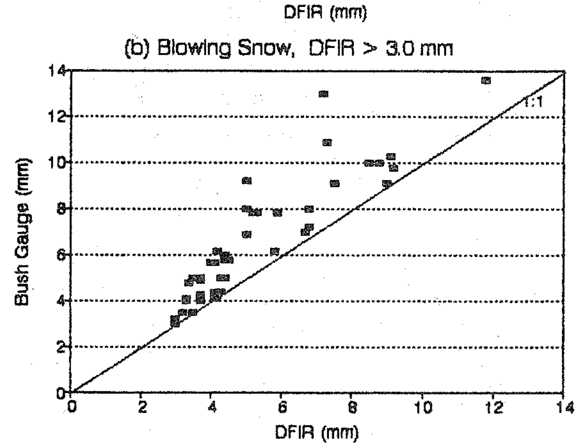


Figure 1. Bush gauge compared to DFIR at Valdai WMO Intercomparison site.

Table 1. Summary of all twice daily observations at Valdai WMO Intercomparison site.

Type of Precip.	*# Obs*	*Tx (°c)*	*Tn (°c)*	*Ws (m/s)*	*BUSH (mm)*	*DFIR (mm)*	*B/D (%)*
Rain	122	7.7	5.0	4.0	822.8	773.0	106.4
Mix.	88	2.0	-0.9	4.6	606.7	559.2	108.5
Snow	158	-1.7	-4.4	4.7	825.4	744.7	110.8

Notes: Tx = mean maximum air temperature;
Tn = mean minimum air temperature;
Ws = mean wind speed at 3 metres;
B/D = ratio of BUSH / DFIR.

Golubev (1992) analyzed winter precipitation totals for 35 months from November 1971 through December 1978, without consideration of blowing snow, and found that the DFIR at Valdai station gave 9% lower totals than the bush gauge. According to the report of WMO/CIMO (1985), types of snowfall occurrences should be described as light, moderate or heavy in intensity; wet snow, snow storm (shower), snow grains or pellets and every day with drifting or blowing snow were to be identified. Review of the original Valdai data observation sheets revealed that blowing snow was a serious problem at this site. There were 55 blowing snow cases identified in the total of 158 snow only events. Blowing snow generally takes place at wind speeds above 5m/s at this location. For the blowing snow cases (Table 2), the ratio of bush/DFIR is about 10% higher for winds blowing from the two southern quadrants, i.e. from the direction of the lake, than from the northern quadrants. During blowing snow events, the bush gauge at 2m caught, on average, 18% more snow than the DFIR at 3m height, for all wind directions. However, the average ratio of bush to DFIR, over all wind directions, is only 107-108% for both wet snow and dry snow conditions. In dry snow cases, the ratio does not change much with wind direction, except that the lowest ratio does occur with the lowest mean wind speed. The lowest wind speed is from the northwest quadrant which is the location of a forested area. For the wet snow events, the highest ratio is associated with southwest winds and the lowest with northwest winds. It is notable that the average highest winds, from the northeast, do not lead to a corresponding higher catch ratio or conversely a lower snowfall gauge catch, for any of the conditions, i.e. dry snow, wet snow or blowing snow. This fact strongly indicates the important influence of not only wind speed but wind direction to precipitation gauge catch at the Valdai site.

Table 2. Summary of snow only observations with DFIR > 3.0mm for three types of snow.

a) Dry Snow (Tmax < -2.0 °C)

WD (deg)	*# event*	*Tx (°c)*	*Tn (°c)*	*Ws (m/s)*	*BUSH (mm)*	*DFIR (mm)*	*B/D (%)*
1 - 90	12	-4.3	-6.7	4.3	65.5	61.1	107.2
91-180	12	-2.9	-6.0	4.0	65.1	59.5	109.4
181-270	16	-1.1	-3.2	4.0	80.4	72.9	110.3
271-360	14	-2.2	-4.3	3.3	68.5	65.7	104.3
All Dir	54	-2.5	-4.9	3.9	279.5	259.2	107.8

b) Wet Snow (-2.0 °C < Tmax < +2.0 °C)

WD (deg)	*# event*	*Tx (°c)*	*Tn (°c)*	*Ws (m/s)*	*BUSH (mm)*	*DFIR (mm)*	*B/D (%)*
1-90	3	0.8	-0.7	4.9	15.4	14.3	107.7
91-180	8	0.7	-0.5	4.2	37.2	32.8	113.4
181-270	21	0.6	-1.5	4.4	108.5	102.8	105.5
271-360	5	-0.3	-3.7	4.2	26.9	26.0	103.5
All Dir	37	0.5	-1.5	4.4	188.0	175.9	106.9

c) Blowing Snow

WD (deg)	*# event*	*Tx (°c)*	*Tn (°c)*	*Ws (m/s)*	*BUSH (mm)*	*DFIR (mm)*	*B/D (%)*
1- 90	4	-2.2	-6.0	6.4	19.7	17.6	111.9
91-180	13	-2.8	-5.0	5.7	85.5	71.4	119.8
181-270	25	-2.5	-6.0	5.9	142.9	118.6	120.5
271-360	13	-3.1	-7.7	5.2	78.0	68.8	113.4
All Dir	55	-2.7	-6.1	5.7	326.1	276.4	118.0

Notes: WD = wind direction; Tx, Tn, Ws and B/D are the same as those in table 1.

Regression analyses were conducted to assess the effect of wind speed, air temperature, relative humidity and atmospheric pressure as reported by Golubev (1989), after separating the data set into the three types given above and also into rain and snow mixed and rain only. For dry snow, wet snow and blowing snow events, the bush/DFIR ratio does not relate significantly to surface air temperature, humidity or atmospheric pressure and the only statistically significant factor is the mean wind speed (Ws) during the storm. Figures 2a to 2e show the best fit curves obtained by means of least squares estimation for the various types of precipitation. The equations for these are given below:

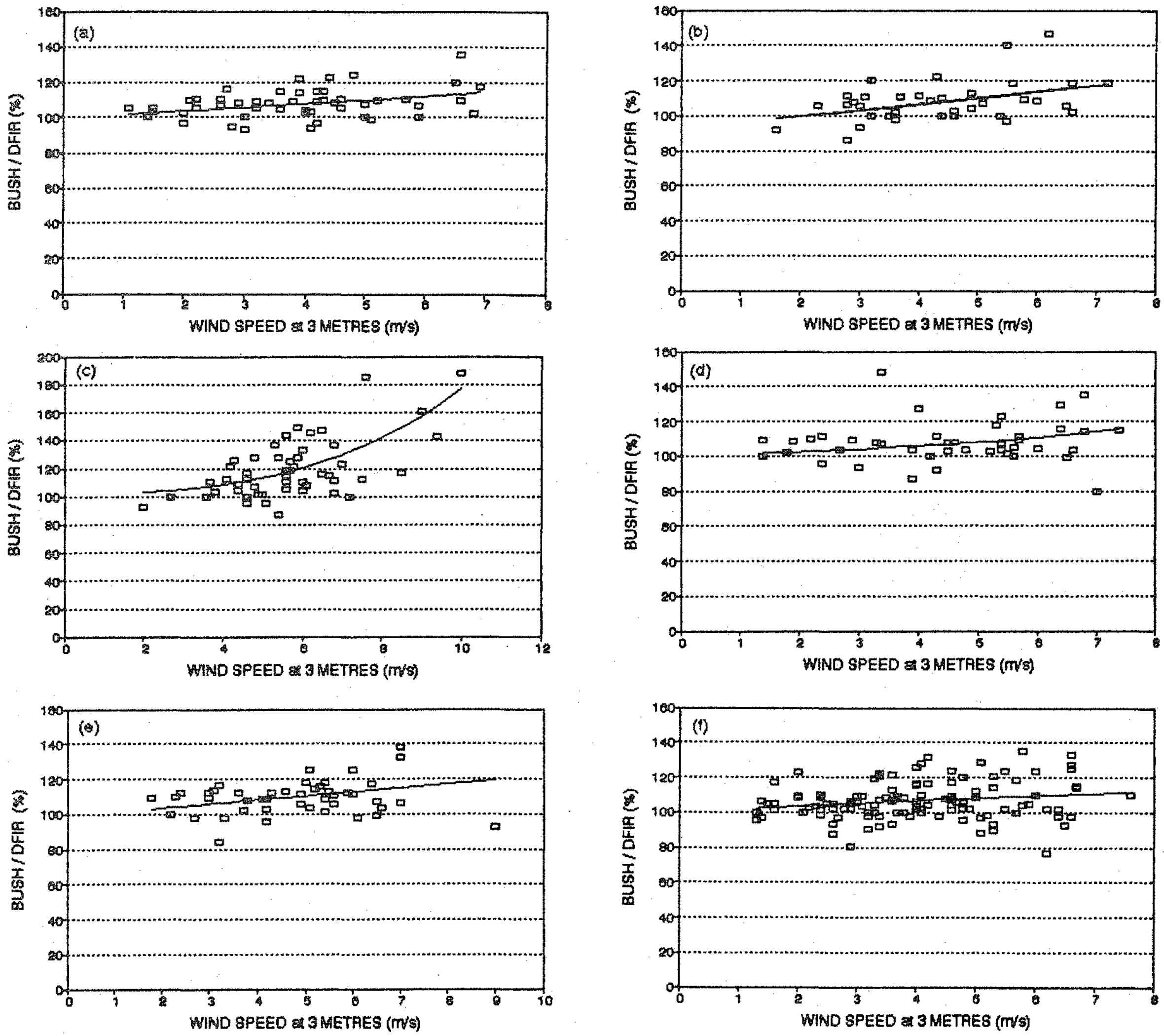


Figure 2. Ratio of bush gauge to the DFIR as a function of wind speed at the DFIR height of 3 metres, for dry snow (a), wet snow (b), blowing snow (c), rain with snow (d), snow with rain (e) and rain (f).

Dry Snow

$$BUSH\ /\ DFIR\ (\%) = 100 + 1.89\times Ws + 6.54E{-}4\times Ws^3 + 6.54E{-}5\times Ws^5, \quad (N{=}52,\ R^2{=}0.37) \qquad (1)$$

Wet Snow

$$BUSH\ /\ DFIR\ (\%) = Exp\ (4.54 + 0.032\times Ws), \quad (N{=}36,\ R^2{=}0.43) \qquad (2)$$

Blowing Snow

$$BUSH\ /\ DFIR\ (\%) = 100.62 + 0.897\times Ws + 0.067\times Ws^3, \quad (N{=}54,\ R^2{=}0.37) \qquad (3)$$

Rain with Snow

$$BUSH\ /\ DFIR\ (\%) = 101.67 + 0.254\times Ws^2, \quad (N{=}39,\ R^2{=}0.38) \qquad (4)$$

Snow with Rain

$$BUSH\ /\ DFIR\ (\%) = 98.97 + 2.30\times Ws, \quad (N{=}43,\ R^2{=}0.34) \qquad (5)$$

Rain

$$BUSH\ /\ DFIR\ (\%) = 100.3 + 1.67\times Ws - 2.40E{-}3\times Ws^3, \quad (N{=}120,\ R^2{=}0.22) \qquad (6)$$

RESULTS

Table 3 compares the catch efficiency of the DFIR to the bush gauge, i.e. "true" measurement at Valdai, as reported by Golubev (1986) and the recent analysis using the precipitation types defined at the beginning of the intercomparison (WMO, 1985). Wind speed during the storm period is the most statistically significant variable affecting catch. While the catch of the DFIR when there is no wind is very close to true, it measures on average about 90% of "true" for winds of 6 m/s. The difference in catch ratio as a function of precipitation type at the same wind speed is small, being about 2% between dry snow and rain. This is an important point because it supports the use of the DFIR as a reference - ideally the DFIR would measure the same as the bush gauge for all types of precipitation.

Table 3: Catch efficiency of the DFIR (%) for selected wind speeds based on Golubev (1986) and proposed equations

Wind Speed	*DFIR (Gol)*	*DFIR DS*	*DFIR WS*	*DFIR S/R*	*DFIR R/S*	*DFIR R*
1 m/s	100	98.1	103.3	98.8	98.1	98.0
2 m/s	100	96.4	100.0	96.6	97.4	96.6
4 m/s	95	92.8	93.9	92.4	94.6	93.6
6 m/s	87	89.3	88.0	88.7	90.3	91.0

Notes: DS = dry snow, WS = wet snow, R = rain,
S/R = snow and rain, R/S = rain and snow.

One could argue that use of different correction equations for different types of precipitation is not necessary, especially considering the inherent scatter in the measurements. Since the intercomparison depends on the DFIR as the reference for all other gauges, even small systematic differences have to be accounted for. We recommend separating the data and using the proposed equations. More importantly, a correction for undercatch of the DFIR for wind speed must be done - it is not a constant systematic loss at all wind speeds. The authors also suggest that a correction using only wind speed, if the data are segregated by precipitation type, is adequate and that correction for incorporating factors such as atmospheric pressure and humidity are not required.

Blowing snow conditions are a special case when correcting gauge data. Figure 2c shows that for all but four cases, the bush gauge caught the same or significantly more than the DFIR. It is the opinion of the authors that the bush gauge at Valdai overmeasure during these particular conditions. Therefore, correction of the DFIR when blowing snow is reported during the observation period (as opposed to after the cessation of snowfall) using a separate equation for blowing snow (i.e. equation 3) is not recommended. The measured DFIR can be corrected by using the dry snow equation.

The validity of correcting gauge data when blowing snow is reported during the snow event is also a question which users of precipitation data must decide. Certainly the flux of blowing snow is greater at 1.5 or 2 m than at the DFIR height of 3m, and it is possible that under certain conditions, any gauge can catch some blowing snow. Since wind speeds are generally greater during blowing snow events, a large correction "for undercatch" could be applied to a measured total already augmented by blowing snow. This problem would be most severe for gauges mounted close to the ground which are efficient in collecting snow passing over their orifice.

APPLICATION OF RESULTS

The effect of the correction on intercomparison event data is shown in Table 4. Equation 1 was applied to individual dry snow events > 3.0 mm for each Canadian Intercomparison site. The DFIR total is increased from 3% to 10%, depending on site exposure, regional climate and storm wind speed. It is not surprising to note that the largest correction corresponds to the station with the highest mean wind speed.

Table 4. Correction of dry snow measurement by the DFIR at six Canadian Intercomparison sites

Site	*# of Events*	*Mean Temp. (°c)*	*Mean Wind (m/s)*	*DFIR1 (mm)*	*DFIR2 (mm)*	*D2/D1 (%)*
Kortright	14	-5.5	2.7	148.4	156.9	105.7
Dease Lake	45	-11.0	1.7	380.7	393.2	103.3
Regina	21	-11.2	3.8	131.1	140.9	107.5
Trent	31	-8.2	2.2	208.1	216.8	104.2
Baie Comeau	48	-8.3	4.2	512.8	562.0	109.6
East Baltic	46	-6.8	4.6	638.4	699.3	109.5

Notes: DFIR1 = measured (including wetting loss),
DFIR2 = corrected for individual events,
D2/D1 = DFIR2 / DFIR1

The validity of using the DFIR as a reference for "true snowfall" was investigated by comparing correction curves developed in an earlier Canadian study (Goodison 1978) for two commonly used North American shielded precipitation gauges. Figure 3 shows the ratio of the Canadian Nipher Shielded Snow Gauge System and the Alter Shielded Universal (Belfort model 5915) gauge to corrected DFIR versus mean storm wind speed at gauge height. The data used are for events greater than 3.0 mm and were collected at both Canadian and United States Intercomparison stations. On the same graph the results obtained by Goodison (1978) for the ratio of the same two gauges to snowboard measurements at a single, sheltered site are also plotted for comparison.For wind speeds up to 2 m/s, the results are similar, although Goodison's Nipher curve indicates a slight over-measurement at this speed. At higher wind speeds, the current results indicate a catch ratio generally lower than that found in the earlier field study. Considering that two different methods of determining "true precipitation" were used and that the current Intercomparison involves sites in different climatic regions, the results from these two studies are quite compatible (Metcalfe and Goodison, 1993). Like the previous study, results from the Intercomparison indicate the Canadian Nipher Shielded gauge has a superior catch efficiency when compared to the Alter Shielded gauge.

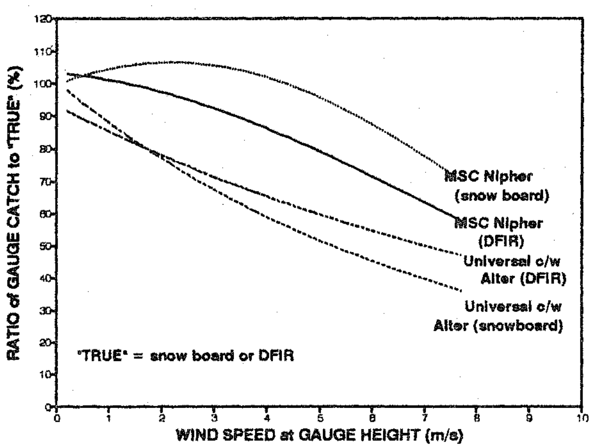


Figure 3. Comparison of catch ratios as a function of wind speed for Canadian Nipher shielded snow gauge and Alter shielded Universal gauge to "true precipitation". In one case "true" is the DFIR corrected for wind induced errors and in the other, snow boards in a sheltered location.

SUMMARY

In terms of measurement accuracy, the bush gauge is the only reference available to check the DFIR in the field. At Valdai, blowing snow, mainly from the lake in the south, occurred during one-third of the snow events greater than 3.0 mm. On the average, the bush gauge overmeasures snowfall by 10% during blowing snow conditions. Even after eliminating, as much as possible, the snowfall observations during which blowing snow occurred, there remains a systematic difference between the measurements of the two gauges, i.e., the bush gauge catches more snow than the DFIR. Therefore, the correction of the DFIR for wind-induced losses is necessary in order to best represent true precipitation. The most important factor for the correction is mean wind speed during the storm. Atmospheric pressure, air temperature and humidity have little or no influence. The correction equations for different types of precipitation, presented in this paper, have been recommended to correct DFIR measurements for wind-induced losses before comparative analysis with other gauge data (WMO/CIMO, 1993). Correction procedures like those demonstrated above will be developed for a large number of gauges, commonly used in many parts of the northern hemisphere, based on the DFIR as "true", to provide more accurate and representative spatial and temporal time series of solid precipitation measurements.

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