6.1 AN ASSESSMENT OF THE GEONOR T-200B INSIDE A LARGE OCTAGONAL DOUBLE FENCE WIND SHIELD AS AN AUTOMATED REFERENCE FOR THE GAUGE MEASUREMENT OF SOLID PRECIPITATION

Craig D. Smith*
Climate Research Division, Environment Canada, Saskatoon, SK, Canada

Daqing Yang
Water and Environmental Research Center, University of Alaska Fairbanks, Fairbanks AK, USA

1. Introduction

It is well recognized that the configuration of a precipitation gauge and wind shield (if used) have a significant impact on the extent of systematic bias in the observation of solid precipitation (see Weiss and Wilson, 1957 for a historical account). The presence of wind is the leading environmental factor causing systematic undercatch. Any precipitation gauge installed above the surface of the ground introduces a barrier to the flow of air around and over the gauge which in turn deflects hydrometeors from entering the orifice and being collected and measured in the bucket. The severity of this deflection is related to the profile of the gauge, the height of the gauge above the surface, the configuration and effectiveness of the wind shield (Sevruk et al, 1991), and the wind speed at gauge height. As a result, winter precipitation events in the cold region can be under-estimated by up to 100% (Goodison and Yang, 1995) and greatly impact data homogeneity over space and time.

Because all gauge configurations are influenced differently by wind, it is important that each configuration is compared to a known reference within a variety of climatic conditions. In 1985, the World Meteorological Organization (WMO) sanctioned a solid precipitation intercomparison with the following objectives: 1) determine errors related to wind in national methods of measuring solid precipitation, 2) derive standardized transfer functions for adjusting solid precipitation measurements, and 3) introduce a reference method for measuring solid precipitation to calibrate any type of precipitation gauge (Goodison et al, 1998). The reference gauge introduced was called the Double Fence Intercomparison Reference (DFIR) and consisted of a large octagonal double fence structure with an outer fence diameter of 12 m, an inner fence diameter of 4 m, and an approximate height of 3 m with a manually measured Tretyakov gauge in the centre (Figure 1). Since the focus of this WMO intercomparison was on manual precipitation gauges, the observation periods for the reference and the test gauges were identical and typically made once or twice daily. With the widespread use of automated (or recording) gauges, precipitation observations can be reported at much higher frequencies (i.e. hourly). This limits the utility of a manual reference for gauge intercomparison and the development of wind adjustment functions.

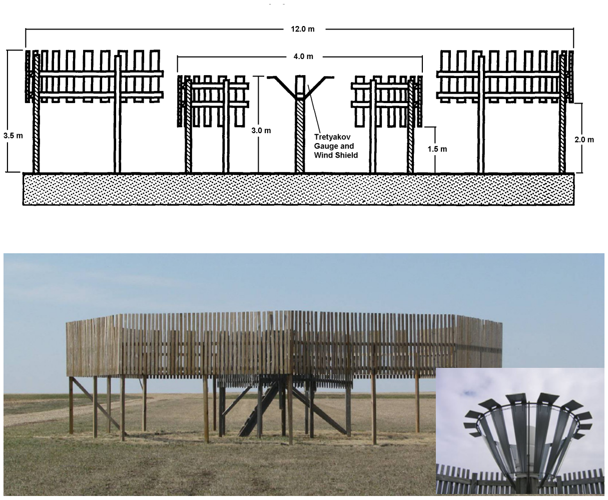

Figure 1: Schematic (top) and photo (bottom) of the Double Fence Intercomparison Reference or DFIR (Goodison et al 1998). A manually observed Tretyakov gauge (inset bottom right) is located in the centre of the fence structure.

**Corresponding author address:*
Craig D. Smith, Climate Research Division,
Environment Canada, 11 Innovation Blvd,
Saskatoon, Saskatchewan, Canada, S7N 3H5
e-mail: craig.smith@ec.gc.ca

For the purpose of comparing automated gauges, an automated reference is necessary. Consideration of the wind fence for the reference is more important than the choice of the gauge used inside. This study assesses the use of the Geonor T-200B (www.geonor.com) accumulating precipitation gauge inside a large octagonal double fence of the same specifications as the DFIR. The Geonor in the large double fence (Geonor-DF) is co-located with a DFIR at Bratt's Lake, Saskatchewan, Canada with supplementary data from Jokioinen, Finland.

2. Study Sites

The primary gauge intercomparison facility in this study is the Environment Canada research site located at Bratt's Lake, Saskatchewan, Canada (Figure 2). The site is centered in an agricultural area which exhibits very little topographical relief and only short vegetation cover. This long fetch and high exposure results in relatively high wind speeds at any time of the year. The average annual temperature and precipitation for this region is 2.8˚C and 388 mm, respectively. Snowfall > 0.2 cm comprises 22% of the annual precipitation and occurs an average of 57 days of the year. Measured 10 m above the surface, the daily average wind speed at the site is approximately 5 m/s.

Figure 2: Location of the Bratt's Lake intercomparison facility on the Canadian prairies.

Precipitation intercomparison data from Bratt's Lake is used to develop catch efficiency (CE) – wind speed relationship for the Geonor-DF that is then used to test wind bias adjustments at various temporal frequencies. Supplementary intercomparison data from Jokioinen Finland (60.8° N, 23.5° E) is used to support the relationships from Bratt's Lake and provide an independent test of the daily snowfall adjustment for wind. The data from Jokioinen was collected during the WMO Intercomparison (1988-1993) (Goodison et al, 1998).

3. Methodology

The data collection period for the Bratt's Lake intercomparison extended from December-2003 through March-2009. Only snowfall events greater than 1 mm (2 mm at Jokioinen) were used in this analysis to reduce the uncertainty in large variation of the CE ratio associated with small snowfall events. Although previous studies, including the WMO intercomparison, generally use a larger threshold of 3 mm (e.g. Yang et al, 1993; Yang et al, 2000), smaller thresholds are adequate if used with caution. The data were also filtered for temperature with events eliminated when the maximum temperature during the observation period exceeded -2° C. Warmer temperatures seemed to introduce spurious CE values which can be speculatively attributed to undocumented mixed precipitation, or wet snow sticking to the sides of the automated gauges. The temperature threshold of -2° C was experimentally determined for, and applied to, both the Bratt's Lake and Jokioinen data sets. The resulting data sets used in this study consisted of 43 intercomparable events at Bratt's Lake and 24 at Jokioinen.

DFIR observations at Bratt's Lake varied in length from 7 to 26 hours. The Geonor-DF bucket weights were recorded every 15 minutes and precipitation accumulated over the same period as the DFIR observation. Average wind speed at gauge height was also logged every 15 minutes and then averaged over the manual observation period. The DFIR observations were corrected for an experimentally determined wetting loss and adjusted for wind bias using the cold snow adjustment of Yang et al (1993). This adjustment is derived from the DFIR CE, as referenced to a bush gauge, and given by:

$$CE_{DFIR} = 100 / (100 + 1.89Ws + 6.54*10^{-4}Ws^{3} + 6.54*10^{-5}Ws^{5}) \qquad (1)$$

where Ws is the wind speed (m/s) measured at gauge height and averaged over the observation period. No corrections were made for evaporation.

4. Results and Discussion

4.1 *Geonor-DF CE vs. Wind Speed*

As with most precipitation gauges, the catch efficiency of the Geonor-DF, as referenced to the adjusted DFIR, decreases with increasing wind speed. This relationship, shown in Figure 3 (trend line in black), is defined as:

$$CE_{Geonor\text{-}DF} = -3.1*10^{-3}Ws^{2} – 3.4*10^{-3}Ws + 1 \qquad (2)$$

and has an r^2 0f 0.36 (n=43). Note that only the Bratt's Lake data (Figure 3, red circles) was used to develop this relationship.

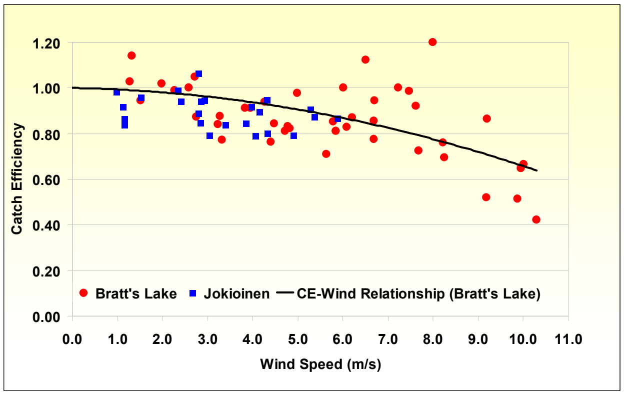

Figure 3: Relationship between catch efficiency (Geonor-DF /DFIR) and wind speed at gauge height at Bratt's Lake (red circles) and Jokioinen (blue squares).

The Bratt's Lake relationship shows that the CE of the Geonor-DF remains relatively high (> 90%) at wind speeds up to 5 m/s. In contrast, the single Alter shielded Geonor has a CE of approximately 40% at 5 m/s (Smith, 2007). This relationship is also very similar to the Yang et al (1993) curve (Equation 1) for wind speeds up to 6 m/s. At 6 m/s, the CE of the Geonor-DF decreases faster with increasing wind speed than does Equation 1.

The relatively low correlation coefficient (r^2) for Equation 2 of 0.36 is a result of the random noise present in the data and is similar to that shown by Yang et al (1993). It is possible that blowing snow is the cause of some of these errors although every attempt has been made to eliminate these events from the analysis. Other random errors could be caused by human error in the manual observation. If two data points, where CE is greater than 1 at wind speeds of 6.8 m/s and 8.0 m/s, are removed, the r^2 value jumps to 0.57 without changing the shape of the relationship.

Figure 3 also shows the CE data from Jokioinen (blue squares). These data suggest a similar relationship between CE and wind speed at the Finnish site, especially for winds below 6 m/s. However, wind speeds during precipitation events at Jokioinen are considerably less than at Bratt's Lake so the behavior of this relationship at higher wind speeds is unknown. Also, the climate at Jokioinen varies substantially from the climate at Bratt's Lake and temperatures during snowfall are considerably higher resulting in more wet snow at Jokioinen than at Bratt's Lake. Since the threshold for maximum temperature for this analysis was -2° C, only about 30% of the Jokioinen data (cold, dry snow) was included.

Because Equation 2 was developed using the complete Bratt's Lake data set, an independent test of the wind adjustment is not possible at this site. Therefore, the adjustment derived from Equation 2 was used with the Jokioinen Geonor-DF data. Figure 4 shows the adjusted (blue squares) and unadjusted (open squares) Geonor-DF as compared to the DFIR. Although the Geonor-DF CE was quite high prior to adjustment due to the lower wind speeds at this site, the adjustment does improve the data. Before adjustment, the total catch of the Geonor-DF at Jokioinen was 90% of the DFIR catch with an RMSE of 0.68 mm. After

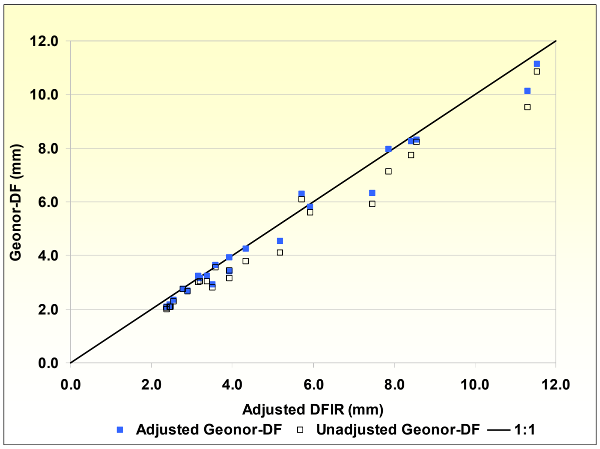

Figure 4: Adjusted (blue squares) and unadjusted (open squares) Geonor-DF snowfall measurements from Jokioinen, Finland collected during the WMO Intercomparison and adjusted using Equation 2.

adjustment, the Geonor-DF total catch increased to 95% while the RMSE decreased to 0.46 mm. Although not an independent test, the adjustment of the Bratt's Lake Geonor-DF increased the catch from 82% to 97% and decreased the RMSE from 1.1 mm to 0.61 mm.

4.2 *High Frequency Adjustments*

As with the above analysis, the high frequency (1-hour) adjustments are tested by referencing back to the precipitation event measured by the DFIR. Unfortunately, no high frequency data are available from Jokioinen so this test relies on the 43 Bratt's Lake observations. The 1-hour Geonor-DF precipitation measurements during each of the 43 observation periods were adjusted separately using Equation 2 and wind speed averaged over each 1-hour period. The 1-hour data was then accumulated over the manual observation period and referenced back to the DFIR. The 43 intercomparison points are shown in Figure 5 with the intercomparison statistics (including a 15-minute adjustment) shown in Table 1.

Adjustment Frequency	% of DFIR Total	RMSE (mm)
No adjustment	82%	1.07
Daily Adjustment	97%	0.61
Hourly Adjustment	102%	0.62
15-min Adjustment	102%	0.61

Table 1: Summary statistics for high and low frequency adjustments at Bratt's Lake.

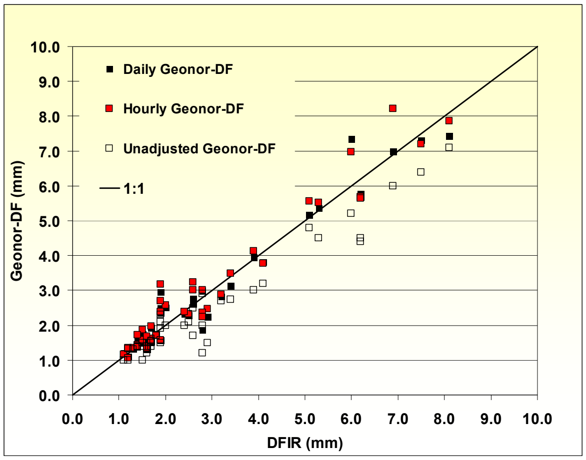

Figure 5: Daily adjusted (black squares), hourly adjusted (red squares), and unadjusted (open squares) Geonor-DF observations at Bratt's Lake as compared to the DFIR.

The adjustment of the high frequency data using Equation 2 resulted in a small over-adjustment (102% of the reference) as compared to a small under-adjustment of the daily data (97% of the reference). The RMSE values are nearly identical for each of the adjustments and each represent a marked improvement over the unadjusted data. Although this suggests the applicability of Equation 2 to high frequency data, there are two considerations: 1) this is not strictly an independent test since Equation 2 was developed with the same data set used in this analysis, and 2) because the high frequency data from Jokioinen is currently not available, it is unknown if Equation 2 will work as well at high frequencies at other sites in varying climatic conditions.

The reason for the small differences in the adjustment of daily and hourly precipitation at Bratt's Lake is the wind speed averages. The difference between the average wind speed over the manual observation period and the average hourly wind speed during precipitation > 0.1 mm is small. The comparison (Figure 6) shows the slope of the regression line being 1.07, with an r^2 of 0.86, indicating that the wind speeds averaged during precipitation events are only slightly higher than the wind speed averaged over the entire manual observation period. The mean difference in winds between the two methods is only 0.5 m/s. This may or may not be typical of wind speed characteristics at other sites and requires further investigation.

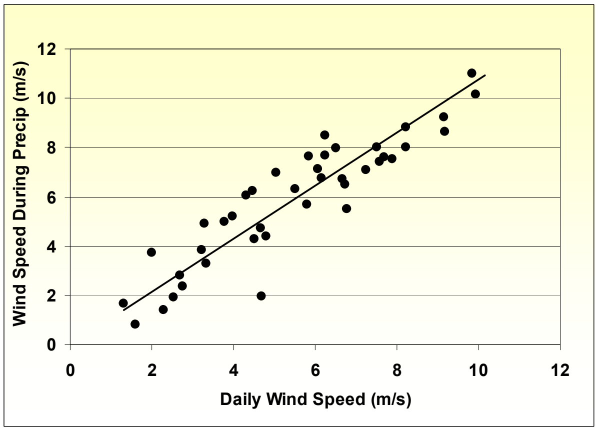

Figure 6: Comparison of Bratt's Lake wind speeds for 43 observation periods where wind speed is averaged two ways: 1) over the length of the manual observation period (daily), and 2) each hour with precipitation > 0.1 mm.

5. Summary and Conclusions

A snowfall catch efficiency – wind speed relationship was developed for the Geonor T200B precipitation gauge installed inside a large octagonal double fence wind shield (Geonor-DF) at Bratt's Lake, Canada by comparing its relative catch to the co-located WMO Double Fence Intercomparison Reference (DFIR). Results show a clear relationship between wind speed at gauge height and guage catch. Unlike other less adequately shielded gauges, the snowfall CE of the Geonor-DF remained relatively high (> 90%) at wind speeds up to 5 m/s. The adjustment has been tested on Geonor-DF snowfall observations made at Jokioinen Finland during the WMO Solid Precipitation Intercomparison study. Although the unadjusted catch of the Geonor-DF in Finland, as compared to the DFIR at the same site, was relatively high at 90% due to low wind speeds, the adjustment increased the total catch to 95% of the DFIR. Similarly, the adjustment reduces the RMSE from 0.68 to 0.46 mm.

The Bratt's Lake adjustment, developed from snowfall data with observation durations of 7 to 28 hours, was applied to the hourly Bratt's Lake Geonor-DF data. When the hourly adjusted data were accumulated for each of the 43 manually observed periods and compared to the DFIR, it was shown that the adjustment caused a small overestimation of precipitation (102% of the DFIR) but the RMSE was unchanged. This suggests that the Geonor-DF observations can be adjusted at much higher frequencies than the manual observation period without introducing further bias. However, caution is required since this is not truly an independent test of this adjustment method.

This study has shown that the snowfall catch efficiency of the Geonor-DF is comparable to the DFIR after adjustment of the Geonor-DF for the wind undercatch. The adjustment at Bratt's Lake can be applied at various time scales with only small deviations in performance. This makes the Geonor-DF a good candidate as an automated reference for the guage measurement of snowfall.

6. References

Goodison, B.E. and Daqing Yang, 1995: In-situ measurement of solid precipitation in high latitudes: The need for correction, *Proc. ACSYS Solid Precipitation Climatology Project Workshop*, Reston VA, WMO/TD-No. 739, 3-17.

Goodison B.E., P.Y.T. Louie, and D. Yang, 1998: WMO solid precipitation measurement intercomparison, *World Meteorological Organization, Instruments and Observing Methods*, Report No. 67, WMO/TD - No. 872, 88 pp.

Sevruk B., J.-A. Hertig and R. Spiess, 1991: The effect of precipitation gauge orfice rim on the wind field deformation as investigated in a wind tunnel, *Atmosp. Envir.,* **25A**, 1173-1179.

Smith, Craig D., 2007: Correcting the wind bias in snowfall measurements made with a Geonor T-200B precipitation gauge and Alter wind shield, *87th AMS Annual meeting/14th SMOI*, San Antonio, TX.

Weiss, L.L., and W.T. Wilson, 1957: Precipitation gage shields, *I.A.S.E. General Assembly of Toronto*, Pub. No. 43, IAHS, Gentbrugge, v. 1,462-484.

Yang, D., J.R. Metcalfe, B.E. Goodison, and E. Mekis, 1993: "True snowfall": An evaluation of the Double Fence Intercomparison Reference gauge, *proc. 50th Eastern Snow Conference/61st Western Snow Conference*, Quebec City, 105-111.

Yang, D., Douglas L. Kane, Larry D. Hinzman, Barry E. Goodison, John R. Metcalfe, Paul Y. T. Louie, George H. Leavesley, Douglas G. Emerson, and Clayton L. Hanson, 2000: An evaluation of the Wyoming gauge system for snowfall measurement, *Water Resources Research*, **36**, 2665-2677.