1.5 CORRECTING THE WIND BIAS IN SNOWFALL MEASUREMENTS MADE WITH A GEONOR T-200B PRECIPITATION GAUGE AND ALTER WIND SHIELD

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1. INTRODUCTION

The most significant systematic environmental error in the measurement of precipitation is due to wind. Any precipitation gauge installed above the surface of the ground introduces a barrier to the flow of air around (and over) the gauge. The severity of this deflection is related to the profile of the gauge, the height of the gauge above the surface and the wind speed at the height of the gauge (Sevruk et al, 1991). Turbulent air flowing over the gauge orifice deflects falling hydrometeors, preventing them from entering the collector and therefore creating an under-estimation of true precipitation. This under-estimation is exacerbated for solid precipitation (Goodison, 1978; Goodison et al, 1989) since frozen hydrometeors typically have slower fall speeds than liquid hydrometeors and are therefore affected more by wind turbulence around a precipitation gauge. As a result, winter precipitation events in cold regions can be under-estimated by up to 100% (Goodison and Yang, 1995).

Climate studies, hydrological modelling and water resource and weather forecasters require homogenous precipitation data. However, the homogenization of precipitation data is not trivial because the severity of the wind bias is dependent on other factors besides those that are environmental. Every gauge type and wind shield configuration will be affected differently by wind and therefore need to be examined. Several national agencies including those in Canada, the United States, and Europe have been using the Geonor T-200B accumulating precipitation gauge and Alter shield to measure winter precipitation for more than a decade in their national observation networks and research programs. The wide-spread use of this gauge in various climatic regimes necessitates continued development of bias adjustment and homogenization procedures for this instrument.

2. STUDY SITE AND INSTRUMENTATION

Environment Canada has several precipitation gauge intercomparison facilities in contrasting climate regimes across Canada. In 2003, the Bratt's Lake, Saskatchewan facility was upgraded to include Geonor precipitation gauges. The research facility is located approximately 20 km south of Regina, Saskatchewan, Canada (Figure 1), and 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, which makes this facility unique from the other Environment Canada intercomparison sites. The average annual temperature and precipitation for this region is 2.8˚C and 388 mm respectively with snowfall (> 0.2 cm) occurring an average of 57 days of the year (comprising 22% of the annual precipitation).

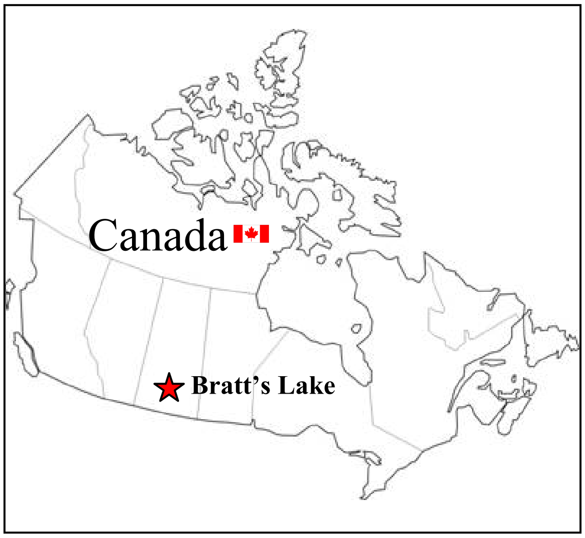

Figure 1: Location of the Bratt's Lake intercomparison facility on the Canadian prairies.

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The Bratt's Lake facility hosts a Double Fence Intercomparison Reference (DFIR) gauge which is the World Meteorological Organization (WMO) reference for the measurement of solid precipitation (see Goodison et al, 1998 for design specifications). Manual DFIR observations were made daily or twice daily. Geonor T-200B gauges were installed in two configurations: the single Alter (which is currently the standard configuration in the Canadian Reference Climate Station network) and the large double octagonal fence (with the same dimensions as the DFIR). These configurations are shown in Figure 2. Geonor bucket weights were obtained every 15 minutes with the differential bucket weights used to determine accumulated precipitation over the desired period. Wind speed was measured at 2 m (approximately gauge height) and temperature at 1 m. Both wind speed and temperature were observed one per minute and averaged over the desired period. Precipitation type was observed manually coinciding with the DFIR observation. A Doppler based Precipitation Occurrence Sensing System (POSS) was operational at the site since February 2005 and used occasionally to confirm precipitation type between manual observations. Several other types of precipitation instrumentation were operational at the site but not discussed here.

Figure 2: Alter-shielded Geonor T-200B (left) and a Geonor T-200B in a large octagonal double fence (right).

3. METHODOLOGY

During the 2003-2006 cold seasons, 21 observation periods with lengths between 8 and 26 hours experienced snowfall greater than 2 mm (snow water equivalent as measured by the DFIR). Measurements less than 2 mm were eliminated from the analysis to avoid high relative errors in the calculation of catch gauge catch efficiency (CE). The wetting loss error for the DFIR was determined experimentally from procedures outlined in Goodison et al (1998) to be 0.13±0.03 mm. Every DFIR measurement was corrected for wetting loss prior to being adjusted for wind under-estimation. The DFIR wind adjustment was based on the DFIR catch efficiency (CE) for dry snow as compared to a bush gauge (Yang et al, 1993). The CE (expressed as a percentage of "true" catch) for the DFIR is described as:

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

where Ws is the wind speed (m s^{-1}) measured at gauge height and averaged over the observation period. No corrections were made for evaporation.

For intercomparison with the DFIR, the 15-minute precipitation measurements made with the Geonor gauges were accumulated to the same period as the DFIR observations. Because the Geonor gauges are weighing gauges, no adjustments were necessary for wetting loss. Light weight motor oil was used to prevent evaporation and a 2:3 mixture of propylene glycol and methanol was used to melt collected snowfall. The CE was calculated for each observation as a ratio of the Geonor accumulated catch to the adjusted DFIR observation.

4. RESULTS

4.1 *Relative catch efficiency*

The relative catch efficiencies for snow and rain for the 2003-2006 periods are shown in Figure 3. During the 21 observation periods where precipitation was greater than 2 mm, a total of 122 mm was measured by the DFIR. The relative catch of the Geonor in the double fence (Geonor-DF) was 86% while the relative catch of the Alter-shielded Geonor (Geonor-Alt) was 36%. The average wind speed during these snowfall events was greater than 5 m s^{-1}.

These CE data showed that the catch for the Geonor-DF is relatively high but the Geonor-Alt catch is substantially lower. I believe that these CE values are typical for most precipitation measurements made throughout the Canadian prairies and arctic. Although a wind correction for the Geonor-DF is desirable, a correction for the Geonor-Alt is absolutely necessary.

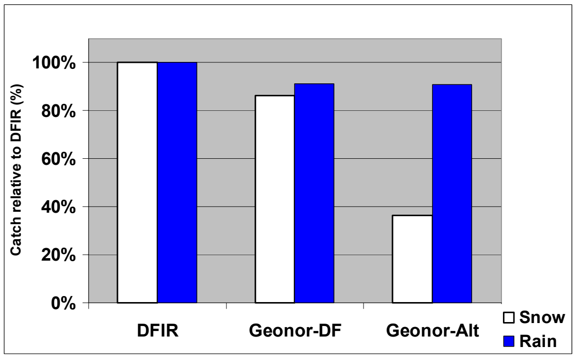

Figure 3: Relative catch of snow and rain (for observations > 2 mm) as compared to the DFIR for the 2003-2006 period at Bratt's Lake, SK.

4.2 *Catch efficiency – wind speed relationships*

Figure 4 shows the relationships between Geonor (-DF and -Alt) CE and wind speed at gauge height for the 21 snowfall events observed at Bratt's Lake. The best simple non-linear fit for the Geonor-DF was a 3rd order polynomial (Equation 2) exhibiting a correlation coefficient (r) of -0.40. The best fit for the Geonor-Alt was exponential (Equation 3) with a correlation of -0.60. Both curves had a forced intercept of 1.0 which followed the assumption that CE increases to 1 as wind speeds decrease to 0 m s^{-1}.

$$CE_{(Geonor\text{-}DF)} = 0.0004Ws^3 - 0.0077Ws^2 + 0.0118Ws + 1 \qquad (2)$$

$$CE_{(Geonor\text{-}Alt)} = \exp(-0.20Ws) \qquad (3)$$

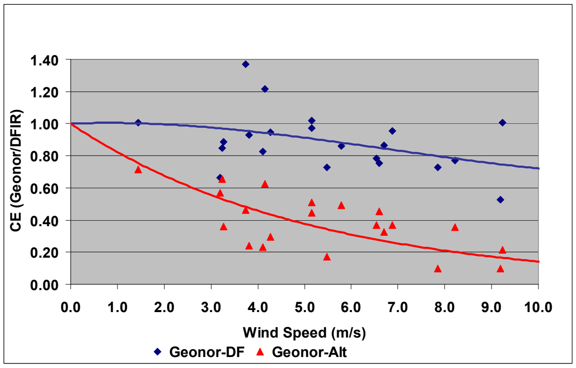

Figure 4: Relationships between catch efficiency for snow and wind speed at gauge height for the Geonor-DF (blue) and the Geonor-Alt (red).

4.3 *Adjusted precipitation*

An adjustment factor for the two gauge configurations can be calculated as 1/CE, where CE is determined using Equations 2 and 3 with the average wind speed during the observation. After applying the adjustment, the root mean square error for the Geonor-DF and Geonor-Alt were 1.3 and 2.6 mm respectively (as compared to 1.6 and 4.3 mm prior to adjustment). Adjusted and unadjusted precipitation accumulations for the 21 periods for each gauge configuration are shown in Figure 5.

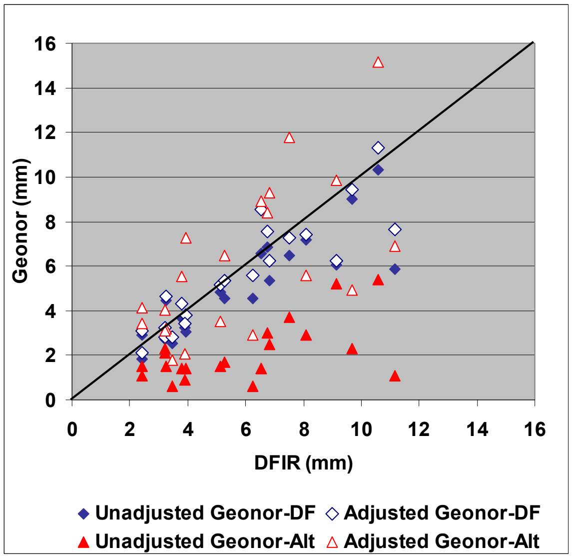

Figure 5: Adjusted and unadjusted accumulated precipitation for each of the 21 observation periods measured by the Geonor-DF (blue) and Geonor-Alt (red) as compared to the DFIR. 1:1 line is shown in black.

4.4 *Adjustments at various time scales*

Accurate snowfall observations are often required in near real-time. There are several issues that prevent real-time bias corrections in Canada. Firstly, most, if not all wind bias relationships have been developed for longer time periods (i.e. 12 to 24 hours). This is largely because of the limitations of manual observations (either precipitation or wind speed). With near continuous high-resolution measurements of precipitation and wind speed, this is no longer an issue. Secondly, there are usually limitations to continuous precipitation typing. Adjustment algorithms are dependent on precipitation type so this information is required for near-real time adjustments. Although beyond the scope of this paper, solutions are becoming available.

The adjustment curves for the Geonor-DF and Geonor-Alt (Equations 2 and 3; Figure 4) were applied directly to the 15-minute observations that comprise the 21 observations periods discussed above. The result was favourable for the Geonor-DF (bringing the adjusted accumulated total up to 99%) but produced an over-adjustment of approximately 16% for the Geonor-Alt. Equation 3 tends to over-adjust the Geonor-Alt at higher wind speeds, more so than Equation 2 with the Geonor-DF adjustments. This is exacerbated by the fact that wind speeds were typically higher when the average was confined to shorter intervals during precipitation (rather than averaging over the entire observation period). This suggests that a new relationship and adjustment protocols are required for the Geonor-Alt at shorter intervals.

Because the DFIR measurements are only made 1x or 2x daily, it cannot be used to calculate CE at shorter intervals. For this purpose, the Geonor-DF was adjusted for wind at 1-hour intervals using Equation 2 and used as the reference for calculating hourly CE for the Geonor-Alt. Observations less than 0.2 mm were eliminated to avoid large relative errors in the CE calculations. CE was then compared to the hourly averaged wind speeds resulting in an adjustment curve (Figure 6). As in Equation 3, the relationship is exponential with a correlation of -0.72 (Equation 4).

$$\mathrm{CE}_{(\mathrm{Geonor\text{-}Alt})} = 1.18*\exp(-0.18\mathrm{Ws}) \qquad (4)$$

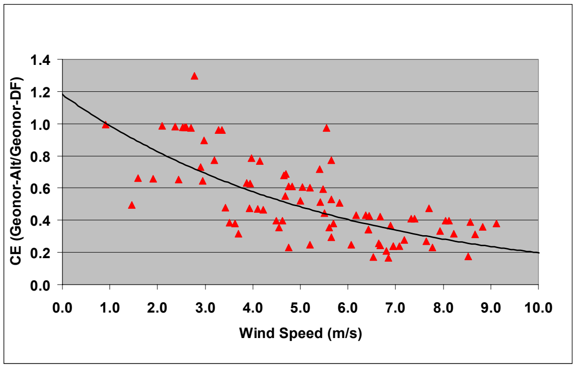

Figure 6: Relationship between catch efficiency of snow and wind speed for the Geonor-Alt where CE is determined using the adjusted Geonor-DF as the reference at intervals of 1-hour.

From Figure 6, the exponential decrease in CE of the Geonor-Alt with increasing wind is similar to that shown in Figure 4 (Equation 3). However, this relationship is not forced through an intercept of 1. Unlike Figure 4, the 1-hour data suggests that CE for the Geonor-Alt is 1 at wind speeds up to 1.2 m s^{-1}. After applying Equation 4 with 1-hour average wind speeds to adjust the 1-hour Geonor-Alt observations, the total accumulated catch for the 21 observation periods became 87% of the DFIR catch. The comparison for each of the 21 observations is shown in Figure 7. Equation 4 was also applied to the high resolution 15-minute precipitation observations using 15-minute wind speeds. The accumulated results were very similar to those shown in Figure 7.

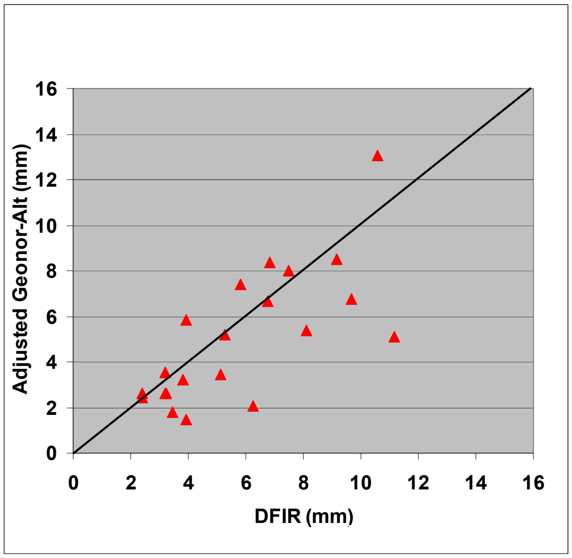

Figure 7: Adjusted (1-hour intervals) Geonor-Alt vs. the DFIR for each of the 21 observation periods (1:1 line shown in black).

5. DISCUSSION

The precipitation catch efficiency data shown above for the Geonor T-200B is typical for a relatively cold, dry, and windy environment such as the Canadian prairies and arctic. Gauge catch with an Alter shield configuration was shown to decrease exponentially with increasing wind speed. This result is consistent with other accumulating automatic gauges with similar profiles and Alter wind shields (for example, see Goodison, 1978 and Goodison et al, 1998). The lack of precipitation observations at lower wind speeds (< 3 m s^{-1}) at the Bratt's Lake facility (Figure 4) reduces the confidence in adjustments at lower wind speeds. However, intercomparison data collected as part of the WMO Solid Precipitation Measurement Intercomparison (Goodison et al, 1998) in Finland suggests a very similar curve for the Geonor T-200B at lower wind speeds (Yang, personal communication).

The application of the relationships seen in Figure 4 (Equations 2 and 3) at shorter time intervals adequately adjusted the Geonor-DF but resulted in an over adjustment of the Geonor-Alt and produced large errors in some individual observation periods. Equation 3 tended to over-adjust observations at higher wind speeds. Also, 1-hour wind speed averages confined to the occurrence of precipitation usually resulted in higher wind speed averages. By using the higher resolution observations of wind speed and adjusted Geonor-DF precipitation as the reference, a more robust relationship was developed so that precipitation could be adjusted at shorter intervals. Results showed that the CE calculated at shorter intervals also decreased exponentially with increasing wind speeds. However, it appeared that the CE for the Geonor-Alt remained 1 at wind speeds up to 1.2 m s^{-1}. This was not unexpected as the shield should nearly eliminate the turbulent effects of the wind on catch up to some wind speed threshold. The large double fence had the same effect up to a higher wind speed (4-5 m s^{-1}).

After adjusting the 1-hour Geonor-Alt measurements, the total precipitation accumulated over the 21 periods was 106 mm, or 87% of the DFIR total. Although significantly better than the original unadjusted total of 36%, the 1-hour adjustment still produced an under-estimate. The problem appears to be inherent in the 1-hour adjustment of the Geonor-DF using Equation 2, followed by the use of the adjusted Geonor-DF as the reference in the development of Equation 4. This, combined with random error, resulted in the under-adjustment of the accumulated 1-hour Geonor-Alt observations. More validation periods are required to assess this adjustment procedure.

Accurately measuring precipitation, especially snowfall, is still very difficult. Because of the large systematic errors involved in measuring snowfall, each precipitation gauge type and wind shield configuration needs to be closely compared to the WMO reference in order to develop adjustment curves for wind. In addition, snowfall measurements need to be compared to a reference at various time scales since the adjustment curve will change as the accumulation (and wind averaging) period becomes shorter. At observation periods less than 12 hours, the utility of the DFIR as the reference for snowfall becomes less. It is suggested that an automated reference be examined to replace the manual DFIR for future automated gauge intercomparisons.

6. REFERENCES

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