THE RELATIONSHIPS BETWEEN SNOWFALL CATCH EFFICIENCY AND WIND SPEED FOR THE GEONOR T-200B PRECIPITATION GAUGE UTILIZING VARIOUS WIND SHIELD CONFIGURATIONS

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ABSTRACT

It is well recognized that most precipitation gauges experience a significant systematic bias in the measurement of snowfall during windy conditions. This bias can be reduced by utilizing various wind shield configurations around the precipitation gauge, but the measurement error for snowfall during windy events often remains substantial and requires an adjustment. This holds true for the Geonor T-200B accumulating precipitation gauge which is employed by many national climate monitoring and research programs, including in Canada and in the United States, as the standard instrument for all-weather precipitation measurement. To adjust snowfall measurements made by the Geonor T-200B, the relationship between gauge (and wind shield) catch efficiency and wind speed at gauge height must be derived. The most accepted methodology is to compare the catch of the gauge to that of the World Meteorological Organization reference for solid precipitation, the Double Fence Intercomparison Reference (DFIR). Using the precipitation gauge intercomparison facility at Bratt's Lake SK, Catch Efficiency - Wind Speed relationships have been developed for the Geonor T-200B gauge utilizing single Alter, double Alter, and a large octagonal double fence (similar to the DFIR) wind shields. Intercomparisons show that the Geonor T-200B catch efficiency for snowfall typically drops off exponentially with increasing wind speed at gauge height. Of the shielded gauges that were compared to the DFIR, the single Alter exhibits the lowest catch efficiency followed by the double Alter. The large double fence exhibits the best catch efficiency but it too requires an adjustment at high wind speeds. (Keywords: snowfall measurement, precipitation gauge, wind shield)

INTRODUCTION

Wind causes the most significant systematic environmental error in the measurement of precipitation. This error is exacerbated for snowfall (Goodison, 1978; Goodison et al., 1998) as the slower falling hydrometeors are more prone to deflection by the air flowing 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 gauge height (Sevruk et al., 1991). As a result, winter precipitation events in cold regions under windy conditions can be under-estimated by up to 100% (Goodison and Yang, 1995).

Climate studies, hydrological modeling, and water resource and weather forecasting require homogenous precipitation data. Homogenization of precipitation data is not trivial because the severity of the wind bias varies substantially with the environment and the physical characteristics of the precipitation gauge and wind shield (if one is used). Since every gauge type and wind shield configuration is affected differently by wind, it needs to be compared to a known reference such as the World Meteorological Organization (WMO) Double Fence Intercomparison Reference (DFIR; Goodison et al., 1998) to assess this bias.

The Geonor T-200B is currently used by several national monitoring agencies including those in Canada, the United States, and Europe. Typically, the Geonor T-200B is installed with a single 1.2 m diameter Alter shield (Alter, 1937) but other shield configurations are used. These include the double Alter (which uses a second 2.4 m shield) and the large octagonal double fence (which has the same specifications as the WMO DFIR). The United States Climate Reference Network (USCRN) also employs a smaller double octagonal fence (which is 1/3 the scale of the DFIR) but this configuration is not examined here.

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STUDY SITE AND INSTRUMENTATION

Environment Canada currently operates several precipitation gauge intercomparison facilities in contrasting climate regimes across Canada. The Bratt's Lake facility is located approximately 20 km south of Regina, Saskatchewan (Figure 1), and is centered in an agricultural area that exhibits very little topographical relief and only short vegetation cover. The 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 with snowfall (> 0.2 cm in depth) occurring an average of 57 days of the year (comprising 22% of the annual precipitation).

Figure 1. Location of Environment Canada's precipitation gauge intercomparison facility at Bratt's Lake, Saskatchewan, Canada

At Bratt's Lake, manual DFIR observations of precipitation amount and type are made either daily or twice daily. Automated precipitation measurements are made every 15 minutes using Geonor T-200B gauges. The Geonor T-200B is an accumulating gauge with a 200 cm^2 orifice that measures the total weight of a collection bucket via a vibrating wire strain sensor (see www.geonor.com/precipitation_gauge.html for guage specifications). The T-200B gauges examined here are equipped with a single Alter (Geonor-SA; Figure 2a), a double Alter (Geonor-DA; Figure 2b) and a large octagonal double fence (Geonor-DF; Figure 2c) wind shield. Wind speed is measured at a height of 2 m (approximately gauge height) and temperature at 1.5 m. Both wind speed and temperature are recorded every minute and averaged over the desired period.

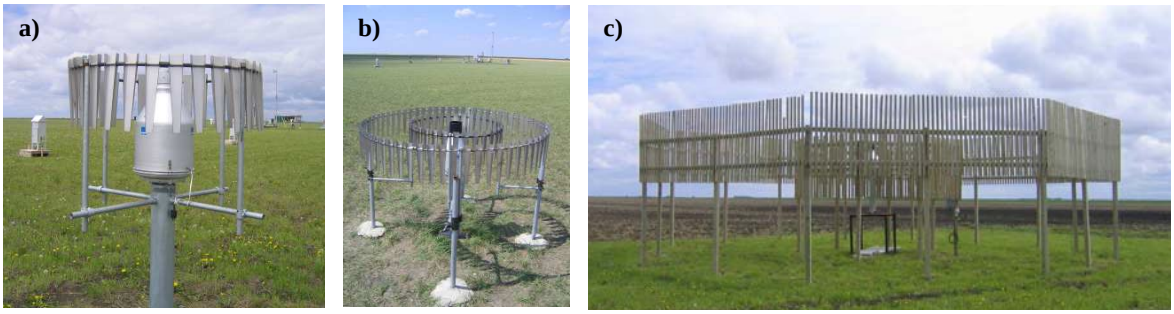

Figure 2. Geonor T-200B precipitation gauges installed in a) single Alter, b) double Alter, and c) large double fence configurations at Bratt's Lake.

METHODS

Three gauge/wind shield intercomprisons of the liquid equivelant of snowfall documented here are as follows: 1) Geonor-DF vs. DFIR, 2) Geonor-SA vs. DFIR, and 3) Geonor-DA vs. Geonor-DF. The Geonor-DF and the Geonor-SA are both referenced to the DFIR which is adjusted for an experimentally derived wetting loss (Campbell and Smith, 2005) and wind bias (Yang et al, 1993). The Geonor-DA is referenced to the adjusted Geonor-DF with a somewhat different methodology related to the study objectives outlined in Watson et al (2008).

To determine the relative snowfall catch of the Geonor-DF and the Geonor-SA, the 15-minute observations from the automated gauges are accumulated over the same period as the manual gauge observation. This period varies between 8 and 24 hours. The supporting meteorological data (temperature and wind speed) are averaged over this same period. Precipitation events not exceeding 2 mm were discarded from the analysis to avoid large relative errors in the calculation of snowfall catch efficiency (CE). Here, CE is defined as the snow water equivalent catch of the Geonor divided by the catch of the adjusted reference. Data collection occurred between December-2003 and March-2006.

The reference for the Geonor-DA intercomparison is the adjusted Geonor-DF rather than the DFIR. Data for this analysis were collected between November-2006 and March-2008. The intercomparison of two automated gauges has advantages in that the observation times are exactly the same. An exact 24 hour snowfall accumulation period is used and periods with less than 1 mm are eliminated from the analysis. Although the Geonor-DF requires no wetting loss adjustment, it does require a wind bias adjustment (as compared to the DFIR) when wind speeds exceed some threshold. Here, this wind threshold is set at 5 m/s which represents an 80% or greater CE for the Geonor-DF when compared to the DFIR. This adjustment is discussed further in subsequent sections. Using the adjusted Geonor-DF as a reference adds an additional level of uncertainty and makes it more difficult to directly compare wind speed adjustment curves for the different configurations. In the future, this analysis will be revised by comparing the Geonor-DA catch directly to the DFIR to make the intercomparisons consistent.

RESULTS

Geonor-SA and Geonor-DF vs. DFIR

From December-2003 through March-2006, 21 snowfall events greater than 2 mm were measured by the DFIR at Bratt's Lake. The average 2 m wind speed during these events is 5.2 m/s. Accumulating these events, the total precipitation observed by the adjusted DFIR, Geonor-DF, and Geonor-SA is 122 mm, 105 mm, and 44 mm respectively. This represents a CE of 86% for the Geonor-DF and 36% for the Geonor-SA (Figure 3). The bias of the Geonor-DF is high enough to require a wind adjustment, especially at higher wind speeds. A bias adjustment for the Geonor-SA is obviously necessary.

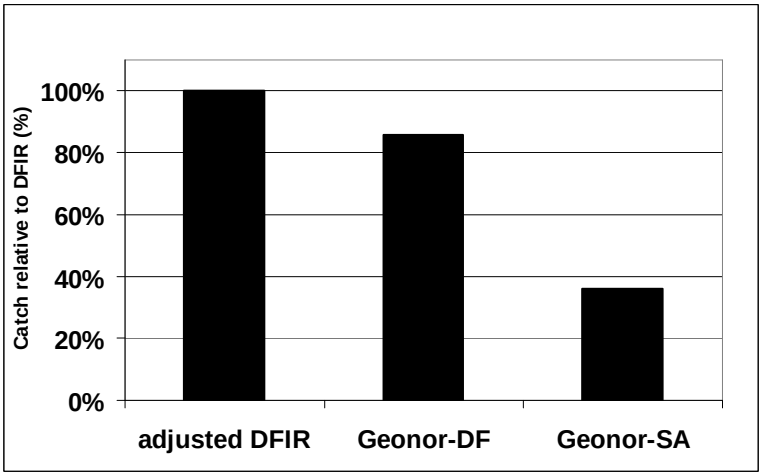

Figure 3. The relative snowfall catch of the Geonor-DF and Geonor-SA as compared to the adjusted DFIR at Bratt's Lake, SK.

Figure 4 illustrates how the relative catch of the Geonor-DF and Geonor-SA are affected by wind speed. The relationships are defined as:

$$CE_{Geonor\text{-}DF} = 1.06\ e^{-0.04Ws}\ ,\ r^2 = 0.36 \quad (1)$$

$$CE_{Geonor\text{-}SA} = e^{-0.20Ws}\ ,\ r^2 = 0.23 \quad (2)$$

where CE is the event based ratio of the Geonor catch to the adjusted DFIR catch, and Ws is the event average wind speed in m/s measured at 2 m. Equation 1 differs somewhat from that reported by Smith (2007) due to the removal of several data points during blowing snow events and the modification of the relationship from a more complex 3rd order polynomial to an exponential fit. The CE of the Geonor-SA is reduced much faster than for the Geonor-DF as wind speed increases. This is indicative of the higher effectiveness of the large double fence for increasing gauge catch.

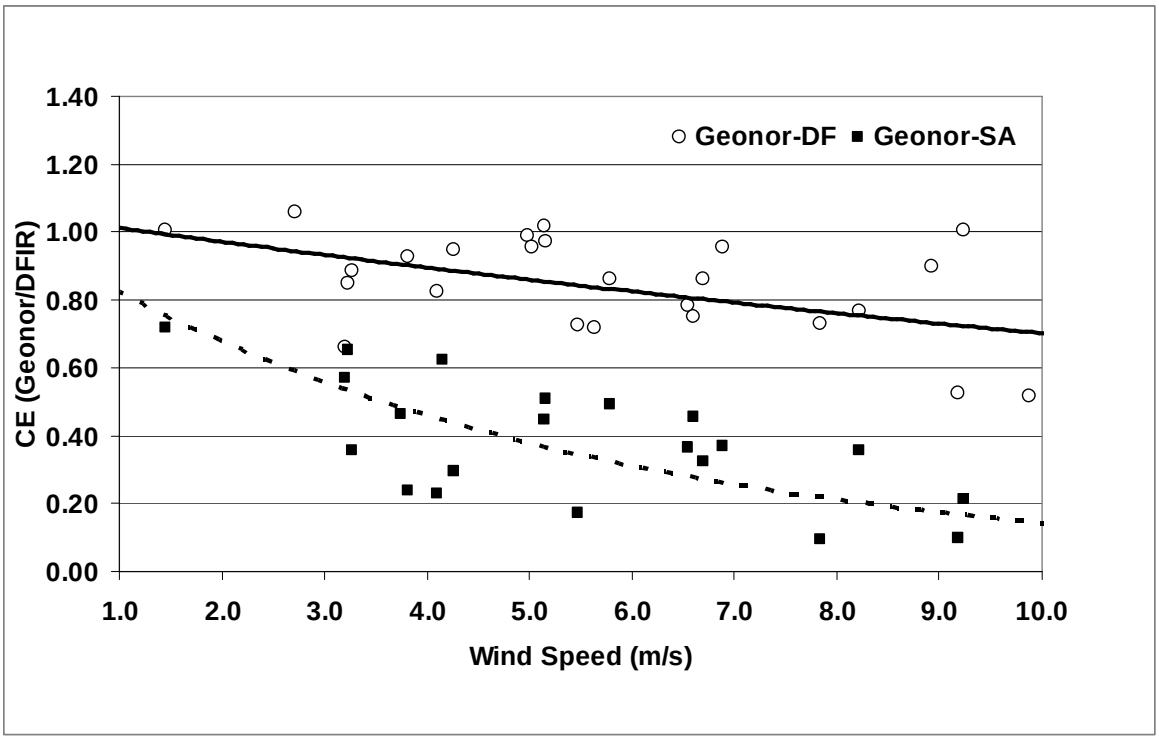

Figure 4. Relationship between the catch efficiencies of the Geonor-SA (black boxes with dashed line) and the Geonor-DF (open circles with solid line) and wind speed measured at gauge height.

Geonor-DA vs. Geonor-DF

The Geonor-DA and Geonor-DF intercomparison occurred between November-2006 and March-2008. Preliminary results are reported by Watson et al (2008). During the study period, the Geonor-DF measured 31 periods (of 24 hours each) with snowfall greater than 1 mm for a total of 121 mm (after adjustment for wind bias) of precipitation. The average wind speed at gauge height for these periods is 5.5 m/s. The Geonor-DA measured 80 mm (or 66% of the Geonor-DF). Similiarly, the Geonor-SA caught 52 mm (or 43% of the Geonor-DF). The relative catch is illustrated in Figure 5.

The catch of the Geonor-DA is also affected by wind. The relationship between the CE of the Geonor-DA and wind speed at gauge height is illustrated in Figure 6 and defined as:

$$CE_{Geonor\text{-}DA} = e^{-0.07Ws}\ ,\ r^2 = 0.35 \quad (3)$$

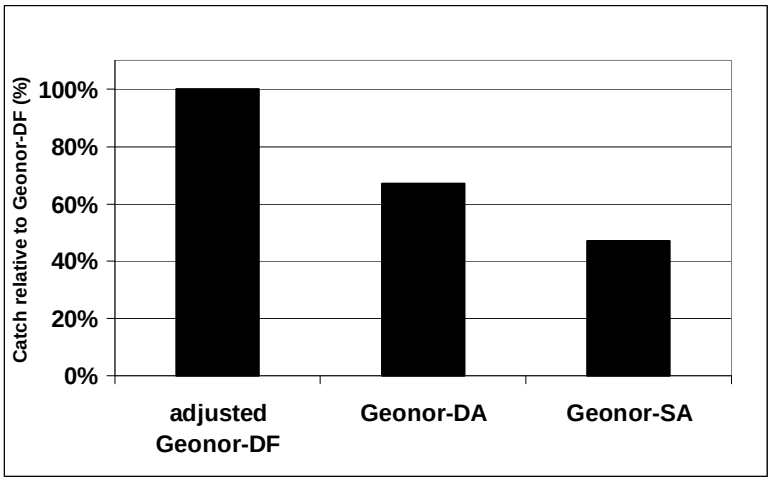

Figure 5. The relative snowfall catch of the Geonor-DA and Geonor-SA as compared to the adjusted Geonor-DF at Bratt's Lake, SK.

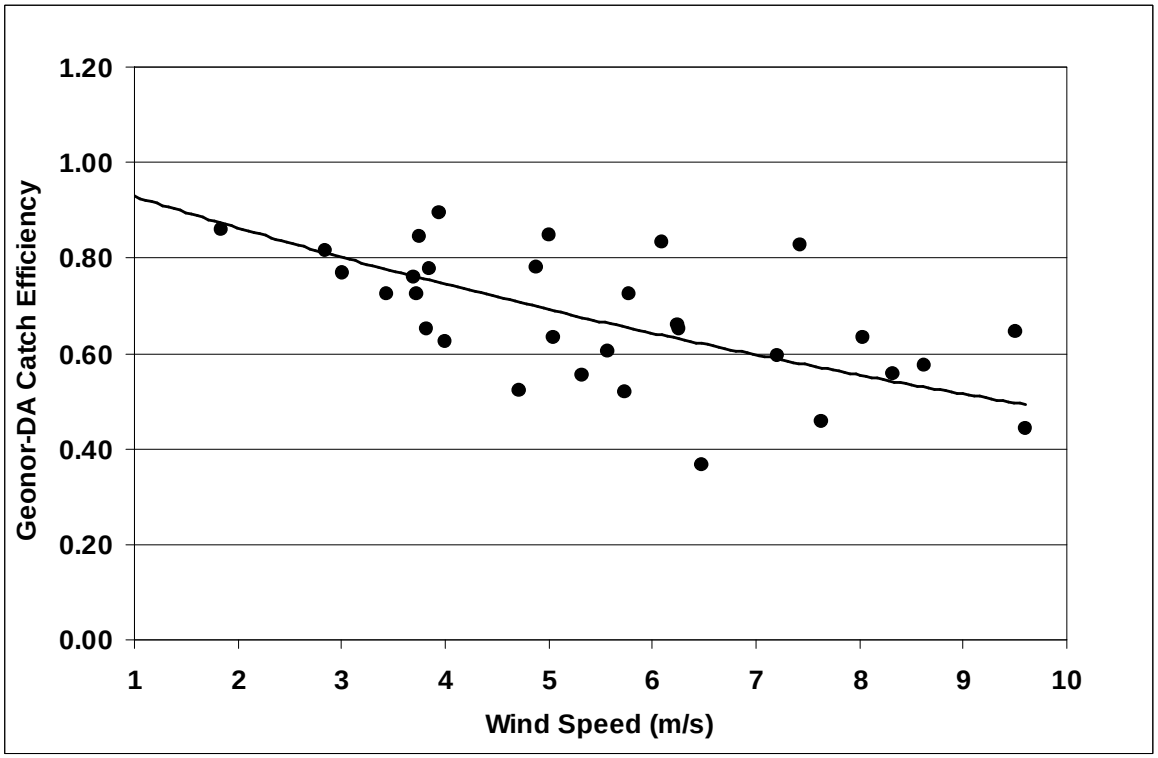

Figure 6. Relationship between the catch efficiency of the Geonor-DA (as compared to the adjusted Geonor-DF) and wind speed measured at gauge height.

DISCUSSION AND CONCLUSIONS

The negative bias in the Geonor T-200B observations of snowfall are very pronounced in windy environments. At Bratt's Lake, average wind speeds (at guage height) of 5 to 6 m/s during precipitation events results in an under-catch of snowfall that varies from 15% to nearly 70%, depending on the wind shield configuration (Figure 7). Catch efficiency is increased through more substantial shielding (e.g. the large double fence or the double Alter) but adjustments are still required for higher wind speeds.

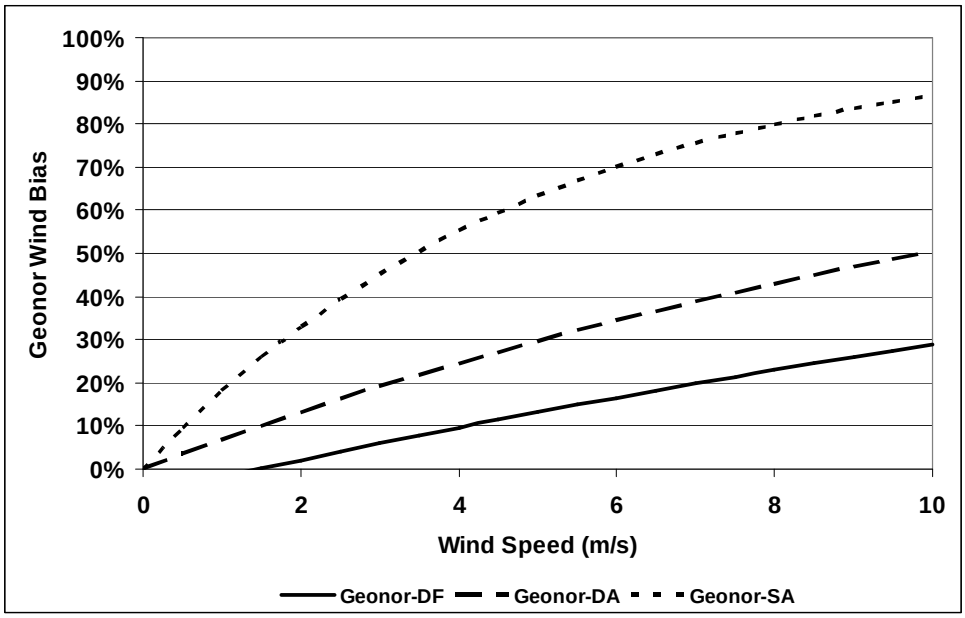

Figure 7. Relative wind bias of the three Geonor T-200B gauges with various wind shield configurations as tested at Bratt's Lake, SK. Note that the Geonor-DF and Geonor-SA are referenced to the adjusted DFIR while the Geonor-DA is referenced to the adjusted Geonor-DF.

Correlation coefficients for CE –Wind Speed relationships tend to be low with correlations (r^2) at Bratt's Lake ranging from 0.23 to 0.36. These are similar to those shown by Yang et al (1993) and summarized by Goodison et al (1998). In this study, these low correlations are likely due to random errors, blowing snow, lack of low wind speed precipitation events and a low number of samples. Random errors could include human error during the DFIR manual observation or from spatial variability in snowfall within the intercomparison facility. Although every attempt has been made to eliminate blowing snow events, the site is only manned during business hours so events can be missed. Blowing snow may unequally increase the snowfall catch of some of the gauges. Also, there is less confidence in the CE – Wind Speed relationships at lower wind speeds due to the lack of data observed at wind speeds less than 3 m/s at this site. This was partially resolved by combining intercomparison data from Finland collected during the WMO solid precipitation intercomparison (Goodison et al, 1998). When added to the Bratt's Lake data (not shown here), the data points generally fell along the curves shown in Figure 4 at wind speeds of 1 to 6 m/s, substantially increasing the strength of the CE – Wind Speed correlations.

As noted previously, it is difficult to directly compare the results of the double Alter analysis to those of the single Alter and large double fence since the reference gauge is different. This analysis will be revisited using the DFIR as the reference so that the relationships can be compared directly. Regardless of this, the Geonor-DA has a higher CE than the Geonor-SA, especially in windy environments. The Geonor-DA will not catch as much snowfall as a gauge inside a large octagonal double fence (such as the DFIR or the Geonor-DF) but constructing large double fences is not a practical solution to increasing gauge catch of snowfall due to their large footprint, high cost, and maintenance requirements. Using a double Alter is a potential compromise in windy environments provided that a suitable wind adjustment curve is available. Network managers and data users must also take into

consideration that the double Alter installation also incurs a significant cost and complicates network and data homogeneity when employed with other shield configurations.

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REFERENCES

Alter, Cecil J. 1937. Shielded Storage Precipitation Gages. Monthly Weather Review 65(7): 262-265.

Campbell, C. and C.D. Smith. 2005. The Bratt's Lake precipitation intercomparison project: estimating the systematic errors in measuring precipitation using the Geonor accumulating precipitation gauge. CMOS Bulletin SCMO 33: 47–51.

Goodison, B.E. 1978. Accuracy of Canadian snow gauge measurements. Journal of Applied Meteorology 17: 1542-1548.

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. WMO, no. 872, 212 p.

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. Atmosphere Environment 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, proc. 87th AMS Annual Meeting/14th SMOI, San Antonio, TX, http://ams.confex.com/ams/pdfpapers/118544.pdf.

Watson, Stephnie, Craig D. Smith, Marvin Lassi and Joe Misfeldt. 2008. An evaluation of the effectiveness of the double Alter wind shield for increasing the catch efficiency of the Geonor T-200B precipitation gauge. CMOS Bulletin SCMO 36: 168-175.

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.