Gauge Undercatch of Two Common Snowfall Gauges in a Prairie Environment

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ABSTRACT

Accurate measurement of snowfall is crucial to meteorology, climate and hydrology research. A comparison of two automated snowfall gauges and a manual gauge was conducted in the winter of 2005-2006 at St. Denis National Wildlife Area, south-central Saskatchewan. The automated gauges tested were the Geonor T-200B and Campbell Scientific Canada TE525 Tipping Bucket gauge with CS705 snow fall adaptor. Both gauges were equipped with Alter-shields and compared to a Nipher reference gauge to estimate gauge catch efficiency. The Nipher was calibrated to 'true' snowfall by WMO standard equations. During the snowfall periods a variety of storm sizes was observed, with all wind speeds less than 7 m s^{-1}. The results provided a mean calculated snowfall catch efficiency on an event basis (gauge to true) of 0.60 for the Geonor with Alter shield, and 0.40 for the Tipping Bucket with Alter-shield.. Cumulative seasonal efficiencies were higher, being 0.78 for the Geonor and 0.66 for the and the Tipping Bucket gauge. A relationship between catch efficiency and wind speed was developed for the Geonor.

Keywords: snowfall, corrected precipitation, true snowfall, snowfall gauges, wind undercatch, Alter-shield

INTRODUCTION

Accurate measurement of snowfall is crucial to meteorology, climate and hydrology research. The importance of correcting snowfall measurements based on gauge catch efficiencies has been identified in numerous field trials—the most notable being the 1985 Solid Precipitation Intercomparison of the Commission for Instruments and Methods of Observation (CIMO) of the World Meteorological Organization (WMO) (Goodison *et al.,* 1998). Gauge catch efficiency is the result of systematic gauge errors in design or from wind-induced bias in performance. Wind-induced bias is caused by a deformation of the wind field above the gauge orifice. This deformation causes a displacement and acceleration of snow particles which is turn results in an undercatch in recorded snowfall. Wind shields are designed to reduce wind bias by decelerating the wind above the gauge such that falling snow particles in strong winds fall into the gauge as if there were little wind. Two common wind shields are the Nipher, an inverted bell shaped shield used extensively in Canada until recently and the Alter, a series of vertical slats hung around the gauge and commonly used in many countries, including Canada in recent years. The effect that shielding has on the wind field above the gauge orifice was shown by Larson and Peck (1974). They found an improvement of 43% in gauge catch efficiency during strong winds with the installation of a wind shield (Figure 1) and so the use of a wind shield is very important for collecting reliable winter precipitation measurements.

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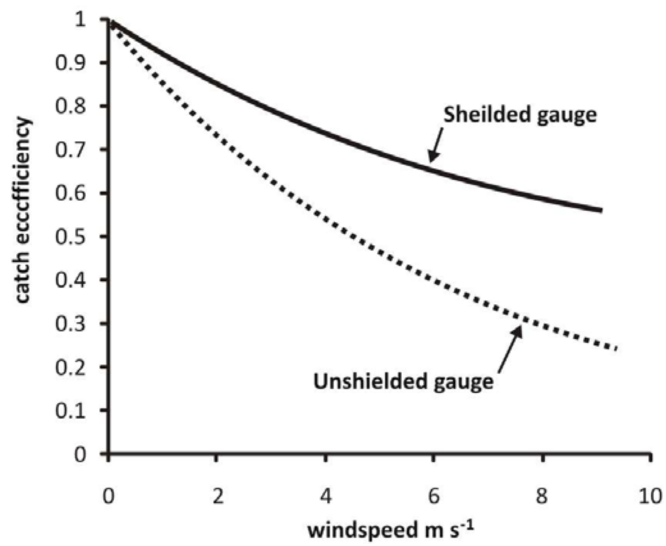

Figure 1. Catch efficiency comparison of shielded versus unshielded gauges. (adapted from Larson and Peck, 1974).

Gauge performance is normally described using catch efficiency (CE). Catch efficiency is defined as the ratio of measured snowfall in the gauge (observed snowfall) to true or reference snowfall (measured/true snowfall).

$$CE = \frac{P_m}{P_T} \qquad (1)$$

where CE is catch efficiency of the snowfall gauge, and P_m and P_T are measured and true snowfall respectively.

In some studies P_T is simply a reference snowfall from a known gauge and in others it is the 'true' snowfall determined from a gauge shielded by extensive shrubs or tall bushes or in a small wooded glade, sufficiently far away from the effect of trees, but sheltered from the wind.

The snowfall gauges evaluated in this study were chosen for their widespread use in snowfall measurement in Canadian hydrology studies For instance, many research basins from the Mackenzie GEWEX Study (MAGS) and earlier studies used a Nipher-shielded gauge that required manual emptying, but recent automation of Alter-shielded gauges by Geonor and Campbell Scientific Canada has led to the installation of Alter-shielded gauges in many research basins. The interest in such studies is normally in the winter cumulative snowfall as snowmelt provides much of the annual runoff in cold regions basins. However process studies of snow dynamics require accurate event based snowfall quantities. The Meteorological Service of Canada (MSC) has also changed its climate reference network precipitation gauge shields from the well known and understood Nipher, to the Alter-shielded Geonor. So there is also tremendous interest in the comparability of the Nipher to the Alter shield for climate and weather studies. For this experiment, the Alter-shielded Geonor T200-B automated gauge and Alter-shielded Campbell Scientific Canada TE525 tipping bucket gauge with CS705 snow adaptor (TBSG) were compared to a Environment Canada MSC (1990's standard) Nipher-shielded storage gauge.

The Nipher-shielded MSC gauge has been extensively tested for accuracy and found to be close to true snowfall in low wind speed conditions with a relatively small correction necessary at strong wind speeds (Goodison *et al*, 1998). The Nipher's performance is comparable to the Double Fence Intercomparison Reference (DFIR) gauge which is the normal reference measurement in international studies (Goodison *et al*, 1998). The reliability of the Nipher-shielded MSC, ease of installation and high CE were the basis for choosing it as the reference for this study. By combining equations that calculate catch efficiency for the Nipher snowfall to DFIR and the catch efficiency of the DFIR to true snowfall using equations published by (Goodison *et al, 1998)*, the following catch efficiency for the Nipher to 'true' snowfall can be found as a function of wind speed at gauge height (U) in m s^{-1}:

$$CE_{Nipher} = 1.00 + 0.004\ U^2 + 0.003\ U \quad (2)$$

This equation will be used to convert Nipher measurements to true snowfall for the purposes of this study.

The objective of this study is to gain a better understanding of the performance of two snowfall gauges that are becoming more frequently used in Canadian hydrology studies in respect to a well known gauge that is calibrated to true snowfall. This will be achieved by evaluating the seasonal performance of the three gauges in a Canadian prairie winter, examining gauge errors with regard to the design of the gauges and then quantifying gauge undercatch as a function of wind speed in order to devise a calibration curve for correcting snowfall observations in hydrology research basins.

EXPERIMENT

The experiment was conducted on the St. Denis National Wildlife Area approximately 45 km east of Saskatoon. The site has a typical climate of the northern Canadian Prairies, with winter snowfall of approximately 90 mm. Snowfall events in the year of study were characterized by 2-m height wind speeds < 6.0 m s^{-1} while the mean 2-m wind speed during snowfall events was 3.8 m s^{-1}. Maximum wind speeds can range as high as 20 m s^{-1} which causes wind redistribution of snow across the landscape (Fang and Pomeroy, 2007). The local terrain is knob-and-kettle or hummocky terrain with substantive hills and valleys. Vegetation zones reflect slope position with vegetation changing from native or cultivated grasses on upslope positions and shrubs/trees occupying the moist lowlands around ponds. Snow accumulation after wind redistribution may vary from 60 mm on knolls to 260 mm in mid-slope depressions and cannot be easily related to snowfall.

The gauge comparison relies on a reference observation for true snowfall. A Nipher-shielded MSC manual gauge was installed with the top of the shield at 2 m. Accumulated snow in the Nipher copper snow reservoir was collected on a weekly basis, or as snowfall events occurred (whichever was more frequent). Collection consisted of exchanging the reservoir for a dry reservoir, melting the accumulated snow and recording the fluid volume from its height in a graduated cylinder. A calibrated Weathertronics 3-cup anemometer with a reed switch closure and a stall speed of 0.544 m s^{-1} was installed at gauge height and controlled by a Campbell Scientific Canada CR10X datalogger, which took 15 minute interval wind speed measurements in m s^{-1}. Fetch at the site was unobstructed in the primary wind direction and gauges were installed at a locally level site with low vegetation. The observed snowfall in the Nipher was adjusted to true snowfall data using Equations 1 and 2.

The Geonor is an automated weighing storage gauge which continuously measures the weight of accumulated snowfall in a reservoir (bucket) containing an antifreeze solution which melts the snow to reduce the volume in the reservoir. The reservoir is suspended on a wire strain gauge which vibrates at a frequency proportional to the applied strain. The reservoir and strain gauge are in a protective housing which is surrounded by an Alter-shield. The gauge has a resolution of 0.10 mm SWE and an accuracy of 0.1 %.

The TBSG gauge uses a cylinder reservoir with an antifreeze solution which overflows into a tipping bucket when snow enters the reservoir. The reservoir is perched above a funnel above the tipping bucket and is Teflon treated to minimize any snow bridging effects that might block snow entry. As snowfall accumulates within the reservoir, the antifreeze solution is displaced into an overflow tube and forced through the tipping bucket which records the flow rate as it would for rainfall. The TBSG has 0.254 mm SWE resolution and accuracy of 1.0 %.

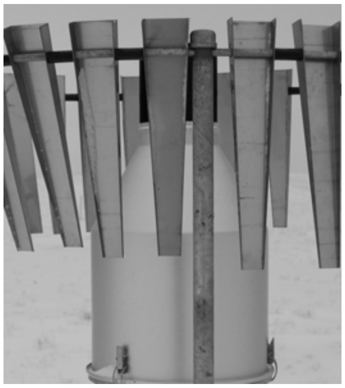  

Figure 1. Geonor T200-B with Alter-shield (left) Campbell Scientific with Alter-shield (centre), and Nipher-shielded MSC manual gauge (right).

The Geonor and TBSG both use an antifreeze solution consisting of propylene glycol and methanol for the reservoirs. The ratio was kept, as directed, at 1:1 for cold temperatures (< 20 ^{o}C) throughout the winter to maintain the ability to act as a solvent to the snow and keep the reservoir from freezing. The reservoirs were also capped with a light oil in order to prevent any evaporative losses. Regular site maintenance was performed to prevent frost accumulation, icing, and snow bridging or electronic problems. The most important role of site maintenance was to ensure that the gauge capacity was not exceeded – this entailed emptying the antifreeze solutions before the reservoirs overflowed.

RESULTS

The data collection period was over the winter season from October 2005 to April 2006. The reference Nipher-shielded MSCgauge recorded 91 mm SWE in 14 snowfall events over the season, with event-based correction for wind bias using Eq.s 1 and 2 this became 99 mm SWE. Wind speed peaked at gusts of 12.1 m s^{-1} while the mean 15 minute wind speed over the snow accumulation period was 3.5 m s^{-1}.

The Geonor recorded a total of 78 mm SWE, and the TBSG recorded a total of 66 mm SWE over the season (Fig. 2). These result in seasonal a CE of 0.79 and 0.67 for the Geonor and TBSG respectively, when compared to the Nipher seasonal total, corrected using Eq. 1 and 2. The seasonal CE can differ substantially from the event-based CE because of the effect of a few large snowfall events on the seasonal totals. For the Geonor, the mean CE for individual snowfall events was 0.60 with a range from 0.47 to 0.95. For those events where it was possible to calculate a CE for the TBSG the mean was 0.10 with a range from 0.30 to 0.50. The reasons it was often not possible to calculate event based CE for the TBSG are discussed below but arise from the mechanisms whereby the snow is dissolved into the reservoir and the antifreeze was displaced.

The effectiveness of the Geonor in recording the timing of the occurrence of snowfall was good due to its vibrating wire gauge which permitted rapid mass measurement. Snowfall occurrence was based on manual observations and collection of the snowfall in the Nipher-shielded MSC reservoir. Fig. 2 shows the timing of the snowfalls as defined by the manual collections as compared to that recorded in the automatic gauges. No bridging of snow in the gauge orifice was observed. The Geonor timing of snowfall aligned well with both the Nipher snowfall and with manual observations on site visits (Fig. 2). At windy sites, wind vibration or wind pumping can create noise in Geonor output data (Smith, 2006). Wind vibration noise can be effectively removed from the data set using “boxcar” algorithms which smooth the data and developed within EC (Lamb and Durocher, 2004). However in this study noise was minimal and unimportant to estimating event based snowfall.

The TBSG did not record the occurrence of snowfall as accurately as did the Geonor and missed or delayed the recording of some events as shown in Fig. 2. The TBSG missed five of the snowfall events completely (while timing was off by days in other cases) and so it was not possible to calculate an event-based CE for all snowfall events Prominent errors observed in the TBSG were due to snow bridging inside the collection reservoir and clogging of the overflow tube apparatus. For instance, it was observed that adhesion between the snowfall and collection vessel allowed for large snowfalls to cap over the antifreeze reservoir, which hindered the displacement of the solution into the tipping bucket mechanism. The fluid overflow mechanism design is such that displaced antifreeze solution must pass through the opening of the tubing and flow up and out of the reservoir. A two-fold problem was observed:

1) the slit in the top of the tube may become covered either clogging the tubing or creating a siphon;

2) a small portion of antifreeze solution may occupy the arched portion of the overflow tubing where small wrinkles in the tubing wall alter the flow from the reservoir causing clogging and bursts of flow (Fig. 3). Both effects cause delayed recording of precipitation events. The latter of these effects has been corrected in a study in North Dakota (Carcoana and Enz, 2000) by altering the construction of the overflow tubing and by integrating a commercial surfactant, SILWET L77 (a silicone based polyether) to the antifreeze solution.

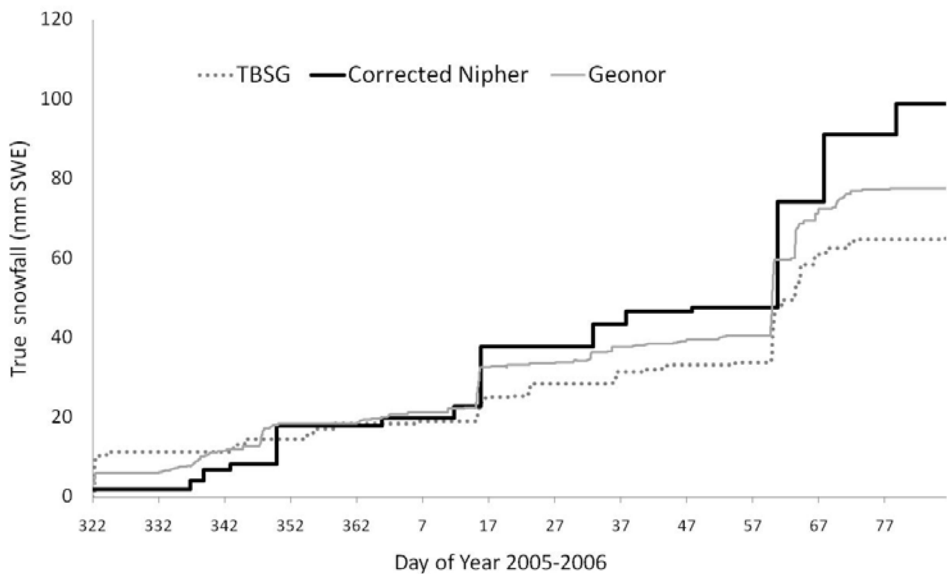

Figure 2. Uncorrected values of observed seasonal snowfall in mm SWE.

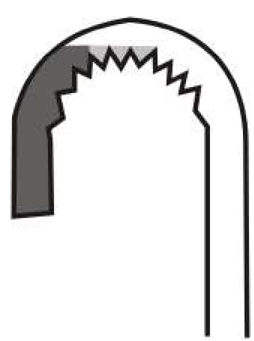

Figure3. Tipping Bucket Snow Gauge CS705 overflow tube design flaw.
Light grey indicates adhesion of antifreeze solution to tubing wrinkles
which creates a burst effect and delayed precipitation recording. (after Carcoana and Enz, 2000).

ANALYSIS

Event based CE were compared to wind speeds in order to determine a correction equation, similar to Eq. 2 for the Alter shielded gauges. Because the TBSG often did not record snowfall events at the time of their occurrence, this analysis was restricted to the Geonor. In calculating CE as a function of wind speed, appropriate time steps and input data for the study of interest must be used. Prairie wind speeds vary rapidly and differ between snowfall and non-snowfall periods; as such the use of daily or longer term mean wind speeds rather than snowfall event-based wind speeds can bias the calculation of CE from wind speed. Smith (2006) used daily mean wind speeds, an efficient method to correct large MSC databases, but a technique that will not compare well to event based snowfall corrections based on event based wind speeds that are needed for hydrology and snow process studies.

An exponential function of wind speed was chosen over a linear relationship as it provided for the best fit to the data ($r^2 = 0.75$, Standard Bias = 0.05) and provides for CE ranging between 0 and 1 (Fig. 4).

$$CE_{Geonor} = 1.010\ e^{-0.09\ U} \qquad (3)$$

where CE_{Geonor} is the event-based catch efficiency referenced to true snowfall, and U is the wind speed at gauge height measured in m s^{-1}.

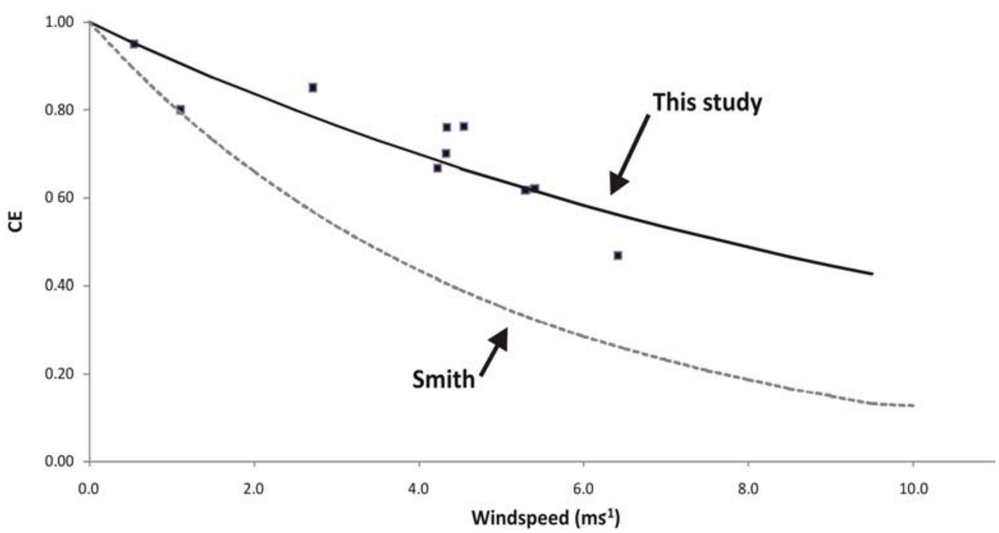

Figure 4. Catch efficiency (CE) in relation to true snowfall,
observed and modelled for the Alter-shielded Geonor.

The importance and difficulties of calculating corrected snowfall are illustrated in Fig. 5. Fig. 5 shows corrected (Eq. 3) and uncorrected Geonor results and true snowfall from the corrected Nipher. It can be seen that for high snowfall events there is slight over prediction of snowfall by the Geonor with the correction. This is a concern as the relationship in Eq. 3 is not weighted for magnitude of snowfall event but is simply a fit between CE and wind speed. As a few large snowfall events can have an inordinately important effect in governing seasonal snowfall, techniques that consider the magnitude of the event as well as the relationship between CE and wind speed might be more appropriate in creating gauge correction equations. Standard error in the Geonor was found to be 0.50 for the measured snowfall, and 0.05 once corrected. The Geonor corrections reduced the Root Mean Square Error (RMSE) from 7.7 mm SWE to 1.1 mm SWE once the calibration curve (Eq. 3) was employed.

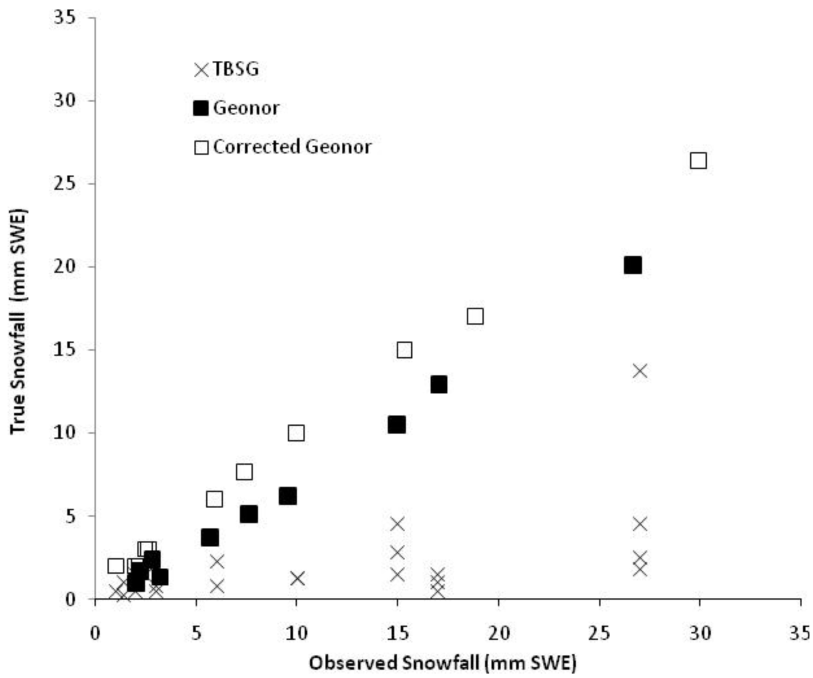

Figure 5. Geonor T-200B and Campbell Scientific 525 tipping bucket snow gauge catch efficiency.

DISCUSSION

Smith (2006) calculated catch efficiencies due to wind induced undercatch of the Geonor with Alter-shield from data collected in the Canadian Prairies. This expression was with reference to the DFIR reference snowfall gauge, but is here presented with reference to true snowfall by using the DFIR CE from Goodison *et al.* (1998).

$$CE_{smith} = a\ e^{-0.190\ U} \tag{4}$$

where: CE is catch efficiency referenced to true snowfall and the subscript smith refers to Smith's (2006) equation (Eq. 4), U is windspeed at gauge height measured in m s^{-1} and a is a calibration coefficient for adjusting DFIR to true snowfall values (Goodison *et al.*, 1998), where,

$$a = \left[1 + 1.89E-2 + 6.54E-6\ U^3 + 6.54E-7\ U^5\right]^{-1} \quad . \tag{5}$$

The difference in CE between Smith's results and those from this study is notable as shown in Figure 4. Smith (2006) applied daily mean wind speed values to calculate CE for a large number of snowfall events in southern Saskatchewan in order to create an easily repeatable method of calibrating gauges for the MSC network. A difference between Smith's equation (Eq. 4, 5) and Eq. 3 is that the original CE relationship by Smith only corrected the observed snowfall data to DFIR snowfall and the research here can only directly relate observed snowfall data to Nipher snowfall. Both equations depend on the WMO Solid Precipitation Intercomparison Study (Goodison et al., 1998) for relating Nipher to true snowfall and DFIR to true snowfall. While we have high confidence in the WMO results, any errors in these equations might compound the differences between Eq. 3 and Eq.s 4 and 5. For hydrological and snow process purposes the corrections need to be to true snowfall and so any errors in relating standard gauges such as the Nipher and DFIR to true snowfall need further investigation.

CONCLUSIONS

Evaluation of two Alter shielded snowfall gauges in relation to a Nipher shielded gauge, has shown that when the gauge is capable of measuring snowfall on a snowfall event basis then it can also be reliably corrected for wind induced undercatch. With suitable corrections for wind undercatch (RMSE = 1.1) the Geonor snowfall gauge with Alter shield was able to reasonably reproduce true snowfall as estimated by a Nipher storage gauge with WMO correction for wind-induced undercatch. However, for the Campbell Scientific Canada TBSG, internal errors resulting from snow bridging and fluid storage in the meant that no wind-induced undercatch calibration could be calculated. These problems are of primary concern in cold environments where light snowfalls are frequent. The internal errors in the TBSG were likely larger than errors due to wind induced undercatch in this study.

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