COMPARISON OF SNOWFALL BETWEEN A STANDARD PRECIPITATION GAUGE AND SNOW BOARD MEASUREMENTS

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ABSTRACT

The measurement of snowfall precipitation is important for ecosystem and watershed research, and avalanche forecasting. Obtaining accurate measurements of solid precipitation, or snow, remains challenging. Literature values suggest that measurement errors can range from 20% to 80% due to undercatch resulting from wind and other such variables. Some sources report overcatch. In 2007 a site was established by the Rocky Mountain Research Station on the Fraser Experimental Forest in the north central rocky mountain region of Colorado to compare snowfall between an unshielded standard Belfort Universal Gauge and snow board snow core measurements. The period of record for this study was within the winter months, defined by the accumulation of measurable snow typically between November and May, and including the water years of 2008 through 2012. Catch comparisons were made for 24 hour event periods. In addition, comparisons were made for annual accumulation of snow water equivalence between the gauge and the snow board. The null hypothesis was that catch deficiency in the unshielded Belfort Universal Gauge is statistically insignificant compared to snow board measurements for individual events, as well as the annual cumulative total for the winter months. The relationship between the event catch of the rain gauge and the snow board measurements was nearly one to one, and an R^2 close to 0.94. Seasonal differences of 4% on average were statistically significant with the rain gauge undermeasuring solid precipitation.
(KEYWORDS: Fraser Experimental Forest, rain gauge, snow board, solid precipitation, Colorado)

INTRODUCTION

The accurate measurement of snowfall is extremely important for ecosystem and watershed research, hydrologic modeling, and avalanche forecasting. These measurements are particularly important in areas that have snow melt dominated hydrologic regimes. Obtaining accurate measurements of solid precipitation, or snow, is challenging. Numerous studies have documented reduced gauge catch by as much as 20 - 80% for various types of gauges (Sugiura et al., 2006; Yang et al., 1998). Many studies have noted that wind-induced errors are the major cause of this undercatch (Fassnacht, 2004; Goodison, 1978; MacDonald et al., 2007; Sugiura et al., 2006; Yang et al., 1998). Gauge performance is described using catch efficiency (CE), defined as the ratio of measured snowfall collected in the rain gauge to "true" snowfall. True snowfall is determined from another rain gauge or by snow board measurements that are sheltered from the wind. Gauge catch efficiency is reduced, non-linearly, with increased wind speed.

The measurement of precipitation using various gauge types has been ongoing at many sites within the Fraser Experimental Forest (FEF) since the early 1940's. At the FEF headquarters meteorological site, both solid and wet precipitation is measured using an unshielded standard Belfort Universal gauge (hereafter rain gauge). The period of record for the collection of precipitation at this site extends from 1976 to the present. This data record is important to the Experimental Forest as this site is often used to characterize the long-term character of various meteorological parameters, including precipitation, for the entire experimental forest. In 2007, a snow board site was established at the headquarters site to measure daily snowfall. This addition provided us with the opportunity to compare snowfall between the unshielded rain gauge and daily snow board measurements. Here we evaluate the hypothesis that the unshielded rain gauge measures no difference in solid precipitation as compared to snow board measurements for individual events, as well as the annual cumulative total for the winter months.

STUDY SITE

The Fraser Experimental Forest is located 137 km west of Denver, CO, west of the Continental Divide. The study site is located within the cleared area surrounding the Experimental Forest headquarters meteorological

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station at an elevation of 2725 m a.s.l. The clearing is 30 m in diameter, and is surrounded by 12-20 m tall lodgepole pine trees. Approximately 90% of the surrounding trees are standing dead, as a result of the recent mountain pine beetle outbreak. Mean annual precipitation at this site is 584 mm (range 467-837 mm), nearly two-thirds of which falls as snow from October to May (Alexander et al., 1985). The study site receives a predominantly westerly wind, and during winter months for the period of this study the mean wind speed was 1.2 m s^{-1} and with a maximum recorded gust of 24 m s^{-1}.

METHODOLOGY

Snowfall Collection

The period of record for this study was the winter months, defined by the accumulation of measurable snow typically between November and May, and includes the water years of 2008 through 2012. Catch comparisons were made for daily (24 hour) event periods. For this analysis an event is equal to the 24 hour snowfall total as measured by automated collection in the rain gauge and by physical collection at the snow board.

Precipitation has been collected at the Experimental Forest headquarters main meteorological site continuously since 1976 using a standard 8" (20.3 cm) diameter recording rain gauge. The rain gauge has an orifice height of 2.5 m and is unshielded. The rain gauge records the weight of new precipitation every 30 seconds using a load cell. The weight is converted to depth in millimeters and is recorded as a 10 minute average. During post-processing the 10 minute data are rounded to the nearest millimeter to reduce temperature-induced noise. Snow board measurements are made every morning using a tube and scale that converts the weight of the sample directly to water equivalent in millimeters. The snow board has a base dimension of 0.41 m x 0.41 m (0.17 m^2 total area), and the sampling tube is 305 mm tall with an inside diameter of 57 mm. Water equivalence is recorded to the nearest 0.5 mm, but for the sake of comparability with the rain gauge, these data are also rounded to the nearest mm.

Wind Speed

Wind speed was measured (R.M. Young 05103 Wind Monitor) at the meteorological station located between the rain gauge and the snow board. The anemometer was positioned 2.5 m above the ground and wind speed is sampled every 10 seconds and recorded as a 10 minute average.

Statistical Analysis

For this analysis we used a mixed model, where EVENT DATE is the random effect, and collection method is fixed. This analysis is the same as a paired t-test, testing the null hypothesis of mean difference between methods of 0, or no difference. To examine the effect of wind speed, we added wind as another fixed effect and included the interaction between method and wind speed to determine whether wind speed had a differential effect on method.

RESULTS

Individual event measurements were compared between the rain gauge and the snow board to ascertain whether or not a strong correlation exists between the methods for each individual event. Regression analysis (Figure 1) showed the relationship between the collection methods to be significant ($p<0.0001$) at alpha = 0.05, with an $R^2 = 0.94$. It should be noted that the regression analysis does not take into account any difference between the measuring devices, but only measures the strength of the linear relationship between the two methods of collection. The liner relationship, represented in the figure as a solid line, is slightly shifted down as compared to the dashed one to one (1:1) line in the figure. This would suggest that the rain gauge collects less snowfall then the snow board.

A comparison of the annual winter precipitation totals from water years 2008 through 2012 shows that the total amount of water collected by the snow board was greater than that of the rain gauge (Table 1). On average the rain gauge annually collected approximately 4% less water than the snow board. Results from the mixed model statistical analysis supports this finding and show that the mean difference was significant ($p=0.004$) at the 0.05 significance level. Furthermore, the mean difference of the rain gauge minus snow board was -0.26 mm per event, with a confidence interval of -0.43 to -0.08mm. These analyses indicate that the rain gauge under measures snow compared to the snow board.

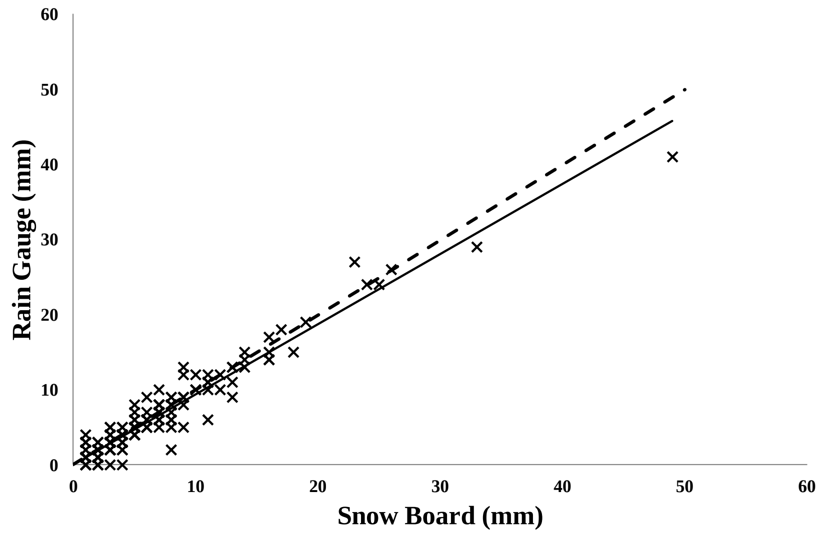

Figure 1. Event comparison between the rain gauge and snow board measurements for all events. The solid line is the linear relationship and the dashed line is the 1:1 line.

Table 1. Water year winter season total snowfall water equivalence for the rain gauge and snowboard (n = number of samples)

Water Year	n	Rain Gauge (mm)	Snow Board (mm)
2008	71	342	360
2009	59	337	355
2010	38	167	176
2011	43	284	297
2012	26	153	156

Wind can have a significant effect on precipitation collection in a rain gauge. To evaluate the impact wind speed has on the relationship between collection of snow on the snow board or in the rain gauge, wind speed was added to the statistical model noted above. Model results show that the effect of wind on measured precipitation appears to depend on both the speed and method (Table 2). The interaction p-value between method and wind speed was 0.067. At low wind speeds, the difference between methods is significant with the rain gauge measuring less than the snow board. At higher wind speeds, the difference is not significant.

Table 2. Mixed model results for catch differences with the addition of wind speed as a fixed effect

Wind Speed (m s^{-1})	Difference: Rain Gauge – Snow Board (mm)	Confidence Interval (mm)	P-Value
0	**-0.6**	**[-0.92, -0.19]**	**0.003**
1	**-0.3**	**[-0.47, -0.11]**	**0.002**
2	**0.0**	**[-0.33, 0.27]**	**0.859**
3	**0.2**	**[-0.32, 0.79]**	**0.404**
4	**0.5**	**[-0.33, 1.33]**	**0.236**

DISCUSSION

Many factors can influence the collection of snowfall in precipitation gauges or on snow boards. The results from this study indicate that for this site though the correlation between the two methods is strong (R^2 =

0.94), the statistical analysis suggests that the difference in collection between the methods is wind-speed dependent. There appears to be a distinct wind speed cutoff that may explain these findings.

At low wind speeds, less than 2 m s^{-1}, the rain gauge catch was less than the measured accumulation on the snow board. At these lower wind speeds the effect of scour on the snow surface is greatly reduced, therefore reducing impacts to accumulation on the snow board. At low wind speeds, falling snow can still be affected by gauge-induced wind vectors. These wind vectors, up-and-over, or out-and-away-from the orifice can lead to decreasing catch efficiency. Therefore, at low wind speeds the snow board more accurately collects the "true" amount of snowfall.

At higher wind speeds, greater than the 2 m s^{-1} cutoff, the effect of scour on the snow board surface may be equal to the amount of precipitation undercatch by the rain gauge. In this instance neither method accurately collects the "true" amount of snowfall.

CONCLUSION

Wind has an impact on the collection and measurement of snow fall at the Headquarters meteorological site at the Fraser Experimental Forest. Both high and low wind speeds can influence rain gauge catch efficiency. Low wind speeds appear to be less of an issue for the snow board; however, at higher wind speeds, scour may reduce deposition or remove accumulated snow before measurements are taken.

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