COMMUNICATIONS

Differences between Nipher and Alter Shielded Universal Belfort Precipitation Gages at Two Colorado Deposition Monitoring Sites

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Introduction

In the last decade the United States and Canada have made significant progress in establishing spatial and temporal estimates of atmospheric deposition throughout North America. Fundamental to the wet-deposition portion of these estimates is the accurate and precise measurement of precipitation amount.

Goodison and others (*1–3*) have reported on a new type of shielded snow gage known as the Canadian MSC Nipher shielded snow gage. Because this shielded snow gage has been shown to be superior to other precipitation gages for the estimation of snowfall amount, its design was adapted to the Universal Belfort precipitation gage (*4*), the dominant precipitation gage used at deposition monitoring sites in the United States. Favorable results taken from monitoring sites using this modified Nipher shielded snow gage (*3–6*) have prompted the U.S. Environmental Protection Agency and the Electric Power Research Institute to adopt the Nipher shielded Belfort gage as a standard piece of equipment in the Acid MODES and Operational Evaluation Network (OEN) monitoring programs and to propose that it be included as a standard snow gage in other North American deposition monitoring programs.

This communication details preliminary results from two of nine NADP/NTN deposition monitoring sites selected by the Environmental Protection Agency to compare Nipher shielded Belfort precipitation gage volumes to volumes obtained from the standard Belfort gage used in the NADP/NTN monitoring program.

Experimental Section

The two sites used in this preliminary analysis represent two types of topography and meteorology commonly found in the western United States. The Loch Vale site is located at an elevation of 3160 m within the Loch Vale Watershed of Rocky Mountain National Park in Larimer County, CO. The site is in complex, subalpine forest terrain and would be classified as "fairly well protected" according to the classification scheme of Brown and Peck (*7*). The instrumentation sits on the windward side of a narrow, 1.8-hectare bench, just below tree line at the head of a glacial valley and at the confluence of two steep glacial canyons. Walls of the canyons rise beyond 3650 m. Forest vegetation surrounding the instrumentation is spotty, allowing the wind to sometimes preferentially scour the snow from beneath the telemetry instrumentation.

The site receives approximately 80% of its precipitation in the form of snow and routinely records 2-min-average wind speeds in excess of 8 m/s. The median of the daily wind estimates for days with measurable snowfall ($n = 135$) during the study period was 5 m/s, but the estimates were highly variable. Total precipitation for the study period (rain and snow) was 103 cm (water equivalent), measured from the Alter shielded gage. Approximately 63% of the volume was in the form of snow.

The Pawnee site is located at the Central Plains Experimental Range (CPER) adjacent to the Pawnee National Grasslands in Weld County, CO. It is a flat, short-grass prairie site, located at an elevation of 1641 m. By the classification scheme of Brown and Peck (*7*), the site would be classified as "very windy". This site typically receives 40% of its precipitation in the form of snow and has average hourly wind speeds of 1–4 m/s. The median of the daily wind-speed estimates during periods of measurable snow at this site for the study period ($n = 38$) was 4 m/s. Snowfall amounts were 10 cm (water equivalent, measured from the Alter shielded gage), which represented 28% of the total volume for the study period.

Daily precipitation values from Nipher shielded and Alter shielded 5-780 series Belfort precipitation gages, collected between October 1987 and April 1989, were analyzed for significant volume differences by using both parametric and nonparametric tests (*8, 9*). These differences were plotted against concurrent wind-speed measurements in an effort to explain variability. Precipitation amount and type (snow, rain, unknown) information were derived from standard NADP/NTN data records (*10, 11*), while wind estimates were obtained by weight-averaging hourly summaries of telemetry information for those hours when precipitation occurred at each site. The weighting algorithm used was as follows:

$$\text{daily wind estimate} = \sum P_i(\bar{w}_i)/\sum P_i$$

where P_i is the total precipitation for the hour; $\bar{w}$ is the estimated hourly wind speed. At the Loch Vale site $\bar{w}$ is a 2-min average of speed taken on the hour. A the Pawnee site $\bar{w}$ is the hourly average of measurements taken each minute.

Wind instrumentation was located on a 7-m tower within 8 m of the precipitation gages at Loch Vale. This placed the instrumentation approximately 4 m above the precipitation gages and at the height of nearby trees. At the Pawnee site, wind instrumentation was located within 75 m of the precipitation gages and approximately 2 m above gage height.

Both precipitation gages at each site were charged with antifreeze during winter operation. Three of the gages used

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Table I. Results of Multiple Linear Regression Analyses[a]

site	β_0	β_1	β_2	β_3	β_4	β_5	N	r^2
Loch Vale	0.126	**	–0.014	**	**	**	131	0.05
Pawnee	0.163	–0.278	**	**	**	0.023	38	0.11
both sites	0.113	**	–0.011	**	**	**	169	0.03

[a] The model used was $\mathrm{DIFF} = \beta_0 + \beta_1 A + \beta_2 W + \beta_3 (W - \bar{W})^2 + \beta_4 (A - \bar{A})(W - \bar{W}) + \beta_5 (A - \bar{A})(W - \bar{W})^2$ where DIFF is the Nipher minus Alter precipitation (in cm), A is the precipitation amount (as measured in the Alter shielded gage) (in cm), and W is the precipitation-weighted wind speed (m/s). ** signifies a lack of significance for this model term.

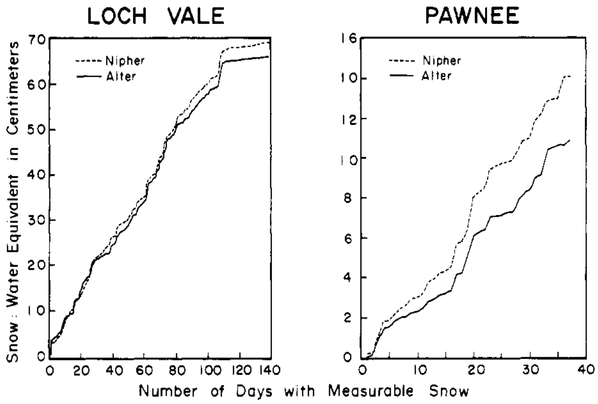

Figure 1. Cumulative sums (in cm) of water-equivalent snowfall amounts from Nipher and Alter shielded gages at two Colorado deposition monitoring sites.

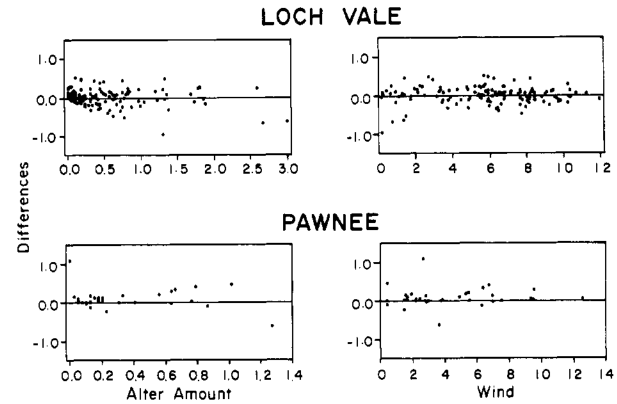

Figure 2. Gage differences (in cm) versus precipitation amount (in cm) and wind speed (in m/s) for snow days at two Colorado deposition monitoring sites.

English unit charts (inches) to record precipitation amounts. Snowfall amounts recorded by the Alter shielded gage at Loch Vale were transmitted on the hour by telemetry.

Results and Discussion

At Loch Vale, 135 days of paired snow measurements were available with complete meterological information. This represented 67% of the total number of snow days during the 18-month study. At Pawnee, 38 paired days were available, representing 78% of the snow days. Missing data represented 17% of the snow volume at Loch Vale and 5% of the volume at Pawnee.

Cumulative sum plots of the paired snow days at both sites (Figure 1) revealed a positive bias in Nipher-derived precipitation amounts. Wilcoxon signed rank tests of the paired data showed statistical significance of $P = 0.05$ at Loch Vale and $P < 0.01$ at Pawnee. Paired t tests showed significance ($P < 0.05$) only at the Pawnee site. Overall differences between the paired days were 3.8% (3.1 cm) at Loch Vale and 23% (3.5 cm) at Pawnee. On a weekly basis the snow differences averaged 0.05 cm at Loch Vale and 0.07 cm at Pawnee. Both averages were within the stated accuracy of the Belfort precipitation gage.

Plots of the gage differences versus wind speed at each site revealed distinct site differences (Figure 2). At Pawnee, gage differences were almost always positive, indicating that more snow was caught by the Nipher shielded gage than was caught by the Alter shielded Belfort gage. At Loch Vale, however, gage differences appeared to be equally positive and negative. Further, at Pawnee, Nipher catch appeared to improve only slightly with increased wind speed; while at Loch Vale, the improvement appeared conclusively only in the 2–3.5 m/s wind regimes. Beyond these speeds differences appeared to be random.

Four large negative differences that occurred at Loch Vale during low wind confused the interpretation of wind plots below 2 m/s. Field observations made during these 4 snow days suggested that the negative differences were the result of snow capping over the bell and orifice of the Nipher shield. With these days trimmed from the data set, the remaining data showed a significant improvement (paired t test, $P < 0.01$) of 10% in Nipher catch over that of the Alter shielded gage. For monitoring sites collecting precipitation amounts on a daily or weekly basis, this capping has serious implications. Since the four days trimmed from this data set accounted for 12% of the snowfall examined during the study, we are concerned about other similar circumstances that might produce a significant amount missing or inaccurate precipitation data.

That the difference at Loch Vale over two snow seasons is only 10% is surprising considering that Loch Vale has much more snow and wind than the Pawnee site. This lack of difference might be explained in part by the 8-m vertical and 4-m horizontal separation of the anemometer from the precipitation gages, or, by the "fairly well protected" Brown and Peck (*7*) rating given the Loch Vale site. The implication is that wind speeds measured were not representative of wind at the gages and differences were not to be expected at sheltered sites (*4*). However, because of the sparse and variable height of the timber surrounding the site, the regular occurrence of wind shake associated with the Nipher chart readings, and our observation of the wind's scouring effect on snow beneath both the gages and the anemometer tower, we conclude that the location of the gages is windy. Even if the wind speeds at the gages were lower than those at the anemometer location, the relationships reported by Goodison and others (*1–3*, *5*) suggest improvements in snow catch of at least 15% (*2*, *3*).

Multiple linear regression analyses (*12*) were performed on the snow data for each site, and for a combined (both sites) data set (Table I), in an attempt to explain the differences in gage catch in terms of wind speed, precipitation amount, and interactions between these predictors. The trimmed data set was used to represent Loch Vale data. A linear model was chosen because there was no reason to suspect that the predictors of the differences between the gages would contribute to the bias in anything but an additive manner and preliminary analyses of covariance had indicated significant interactions between the predictors. The squaring of the wind difference term was included in the model based upon the inverse-exponential wind relationship to gage catch reported by Goodison et al. (*5*), Larson and Peck (*13*), and Struzer (*14*).

When the model was optimized by backward elimination (*12*) of insignificant predictors ($P > 0.10$), only 5% of the variance in gage difference at Loch Vale and 11% at Pawnee could be explained. The correlation was even weaker for the combined data set, as is expected due to the inconsistent gage behavior between the sites. The lack of significance of the regression coefficients and the generally low r^2 could be due to the separation of the wind instrumentation from the gages or the weighted wind estimate used. It could also be due to the use of gage differences as the dependent variable as opposed to the percent of "true" snowfall amount. In spite of these differences in methodology from previous studies, we expected wind to be a better predictor of gage differences at both sites.

Conclusions

Our findings in general support those of Goodison (*5*) that Nipher shielded Universal Belfort precipitation gages yield higher snowfall measurements than their Alter shielded counterparts. However, capping problems in low wind, during heavy snowfall, and perhaps at sheltered sites may cause snowfall amounts to be underestimated. This problem can only be exacerbated by the common practice in deposition monitoring programs of collecting snowfall amount information on a nonevent basis (i.e., daily or weekly).

The smaller improvements in snow catch recorded in our study over previous studies lead us to believe that there are site-specific factors such as storm intensity or wind turbulence about a site that modify the Nipher's catch. In that these factors may be related to sheltering and are not yet well understood, we suggest the use of the Nipher be confined to open areas where sheltering does not interfere with the aerodynamic design of the shield. Deposition monitoring programs adopting the Nipher shielded Belfort gage may want to consider locating the gage in more open areas to take advantage of the Nipher design while minimizing the capping problem.

Finally our study suggests that sites needing only annual or seasonal precipitation values and that are susceptible to Nipher capping problems (low wind, heavy snows) should consider the use of an Alter shielded Belfort precipitation gage as an acceptable alternate to the Nipher shielded Belfort snow gage. The performance of the Nipher shielded Belfort appears to be dependent upon site-specific factors other than wind speed during precipitation and sample volume amount.

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