COMPARISON OF PRECIPITATION AS MEASURED IN GAGES PROTECTED BY A MODIFIED ALTER SHIELD, WYOMING SHIELD, AND STAND OF TREES

By
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INTRODUCTION

Undermeasurement of precipitation falling as snow is most severe in non-forest regions where gages are fully exposed to wind. The measurement error becomes more important as precipitation data are utilized in more sophisticated applications. The accuracy of hydrologic models for example, is limited by validity of precipitation input values. Winter precipitation values are also an essential parameter in design of snow fence systems to protect highways from drifting snow and for projects that capitalize on blowing snow as a water resource.

The shield developed by Alter (1937), and later modified by Warnick (1953), reduces the deleterious effects of wind on gage performance. However, gage catch still is deficient at higher windspeeds when Alter shields are used for gage protection (Larson and Peck 1974). A more elaborate shielding system to use in exposed locations was developed by the University of Wyoming (Rechard and Wei 1980). Its use has improved accuracy of winter precipitation measurements. Measured precipitation at Barrow, on Alaska's Arctic Slope tripled after gages were protected with the Wyoming shield (Benson 1982). Black (1954) earlier had noted that snow on the ground at Barrow contained two to four times more water than winter precipitation measured in standard gages operated by the U.S. Weather Bureau.

This study compared monthly precipitation recorded at gages protected by a Wyoming shield, and by a modified Alter shield, with precipitation measured in nearby forest stands which provided protection from wind. A relationship to predict undermeasurement of precipitation at the gage protected by the Wyoming shield in relation to windspeed also was developed.

STUDY SITES AND METHODS

Wyoming Shield

The Wyoming shield test site was in southcentral Wyoming, about 32 km west of Saratoga. The study site is on a gently sloping bench, just off the northern flank of the Sierra Madre mountain range. Average annual precipitation for the 8-year period, 1976-1983 was 55.4 cm, of which 75% was snow. Average annual temperature for the 3-year period, 1981-1983 was 1° C. Windspeeds are at a maximum in winter and average more than 5 m/s from November through April (Table 1). Prevailing wind direction is from the southwest.

The forest-protected gage was at an elevation of 2,465 m, in a 18-ha grove of lodgepole pine known locally as Twin Groves. Trees were 15 m tall, and the grove was surrounded by low-growing vegetation dominated by big sagebrush about 30 cm tall. A storage and a recording precipitation gage were placed in an opening 0.75 tree height in diameter (fig 1). Gages were equipped with modified Alter shields in November of 1982, and receivers were about 3 m above the ground. The distance from gages to the upwind tree margin was 360 m for southwesterly winds.

The gage protected by the Wyoming shield was placed on sagebrush rangeland 2,445 m in elevation. The Wyoming shield was 970 m upwind from the forest-protected gage and was constructed to specifications outlined by Rechard and Wei (1980) (fig. 1). Shielding was designed to transport drifting snow under the gage while stilling air at the gage opening (Rechard 1972). The precipitation gage was surrounded by two concentric rings of Canadian

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Table 1. Monthly climatic characteristics, and calculated precipitation, for sites where precipitation gages were protected by a Wyoming shield and a modified Alter shield.

Parameter	Years of record	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
						Wyoming Shield Gage Site							
Temp. (°C)	3	0.8	-5.6	-12.1	-7.2	-7.7	-4.5	1.1	3.0	9.2	13.6	14.6	8.8
Wind speed (m/s)	3	4.8	6.1	7.7	6.6	7.2	5.9	5.3	4.2	4.0	3.5	3.1	4.1
"True" precip. (cm)	8	5.6	4.8	4.9	5.4	3.9	6.0	5.1	7.4	2.0	3.7	3.4	3.4
Calculated precip. shielded gage (cm)[1]		4.4	2.4	1.8	3.1	1.6	3.1	3.3	5.4	1.9	3.7	3.1	3.0
						Modified Alter Shield Gage Site							
Temp. (°C)	14	2.8	-4.2	-8.3	-8.9	-6.8	-4.8	0.6	6.9	12.6	16.6	15.6	10.4
Wind speed (m/s)	10	4.6	5.8	7.6	8.3	6.9	6.4	5.0	4.1	3.9	3.4	3.5	3.9
"True" precip. (cm)	14	6.0	4.0	5.4	5.1	4.2	5.3	6.2	6.0	2.9	3.0	2.1	2.4
Calculated precip. shielded gage (cm)[1]		4.2	2.5	3.0	3.4	2.6	3.3	4.6	5.1	2.6	2.7	1.6	1.8

[1] "True" precipitation multiplied by monthly gage catch ratio

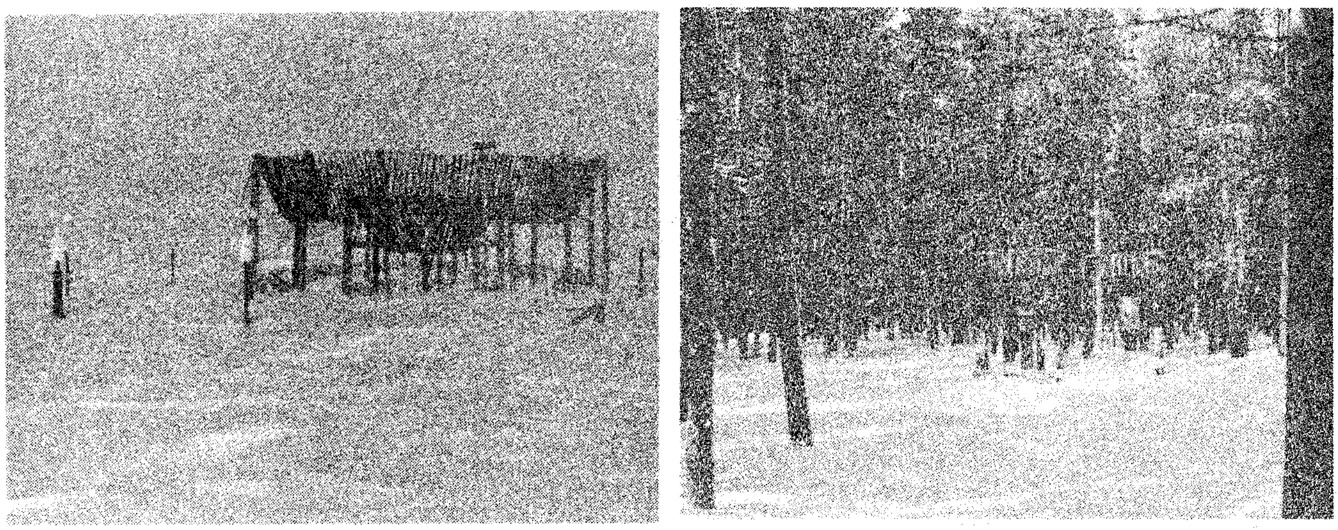

Figure 1. The recording precipitation gage protected by the Wyoming shield (left) was about 1 km from Twin Groves where the storage gage protected from wind by a stand of lodgepole pine was located (right).

snow fence 1.2 m in height which had a solid density of 40% to 50%. The outer ring was 6.1 m in diameter, and the top of the fence was 2.6 m above the ground surface. The top of the inner ring was 2.3 m above the ground, and was 3.05 m in diameter. The gage opening was the same height as the top of the inner ring of snow fence. The outer and inner rings of fencing were inclined downwards toward the precipitation gage at angles of 30° and 45° from vertical, respectively.

Comparisons of monthly precipitation were based on the period November 1976 to December 1983, with the exception of one summer when gages were not operated.

Alter Shield

The storage gage protected by the modified Alter shield was 5.2 km north of the Twin Groves test site, on sagebrush rangeland 2,330 m in elevation. The storage gage was placed at a homestead where Colorado blue spruce and aspen had been planted to shield ranch buildings from the wind (fig. 2). Trees were about 14 m tall, but were not dense

Figure 2. The storage gage protected by a modified Alter shield was located at a homestead where planted trees provided additional protection from wind (left). This gage was paired with a Pearson storage gage located in an aspen stand to provide protection from wind (right).

enough to still the wind; there was substantial snow drifting at the site. The opening of the gage was 5.1 m above the ground. Interval precipitation was determined from the rise of fluid in a storage reservoir as determined by reading a measuring tape embedded in the side of the gage. The tape was marked in increments of 1.3 mm. The reservoir had an area 2.25 times larger than the gage orifice; tape readings were multiplied by this correction factor to calculate interval precipitation.

Precipitation measured by the storage gage protected by the modified Alter shield was compared to that measured by a Pearson storage gage in an aspen grove 5 km north of the homestead (fig 2). Elevation at this gage site was 2,365 m. The aspen stand was 15.4 ha, and trees surrounding the opening averaged 17.5 m in height. The opening was about 1 tree height in diameter. A recording precipitation gage was operated in conjunction with the Pearson gage. Gages were equipped with modified Alter shields and were placed so that their openings were about 3 m high.

Monthly precipitation comparisons involving the Alter shield were based on the 11-year period from November 1972 to December 1983. Because of the 5-km distance between gages, the data reflect actual differences in precipitation, particularly in summer when rain often falls from localized convectional storms. However, the record period is sufficiently long to average short-term variations in local precipitation. Localized differences were less pronounced at other times of the year when the source of precipitation was usually cyclonic storms.

All precipitation gages utilized in this study had orifices 20.3 cm in diameter. Gages usually were serviced near the beginning of a month. "True" precipitation was accepted as that measured by the standard gage in the forest opening, which was determined from change in gage weight. The reservoir of recording gages was also weighed, which provided a check on precipitation indicated by the chart trace and a check on precipitation measured at the standard gage. Periods of questionable data validity were not used for analysis. Precipitation on the chart of the recording gage was corrected to the total measured by the standard gage. Data from the gage protected by the Wyoming shield were checked for internal consistency by comparing interval precipitation indicated by the chart trace with that indicated by the change in reservoir weight.

Windspeed and Deficiency in Gage Catch at the Wyoming Shield

Precipitation events at Twin Groves were analyzed to determine if a relationship existed between windspeed and precipitation measured by gages protected by the Wyoming shield and forest stand. Windspeed, wind direction, and air temperature, were recorded at a 2-m height by a mechanical weather station at the Wyoming-shielded gage.

A lack of time synchronization between recording meteorological and hydrological instruments was noted by scientists of the Agricultural Research Service as a major instrumentation problem (Johnson, Farrell, and Blaisdell 1982). Comparison of the precipitation measured by the Wyoming-shielded gage with that measured in the forest opening in relation to windspeed and air temperature required a high degree of time control between recording gages. A stepper motor was used to advance the chart drum of recording precipitation gages. Movement of the motor was controlled by a time keeping system using a quartz crystal. Time control on the chart providing wind and temperature information was provided by marks placed every 12 hours. The marking system was independent of the mechanical chart drive, and also used a quartz crystal for time measurement. This system, developed by the Rocky Mountain Forest and Range Experiment Station, was accurate to 2 minutes per month. Solar panels (Bird 1980) kept batteries supplying power to recording instruments fully charged at all times which further increased instrument reliability.

Data collected from 1981 to 1983 were used to relate windspeed to performance of the gage protected by the Wyoming shield. Entire storms or segments within a storm having readily identifiable patterns of precipitation were analyzed if accompanied by winds reasonably uniform in speed and direction. Those events with less than 3.8 mm precipitation, or that had winds with an azimuth between 60° and 135° were excluded from analysis; the Wyoming shield was downwind of the lodgepole pine stand for these wind directions. The terrain and vegetation surrounding the Wyoming shield was uniform for distances of 800 m to 1,600 m during storms that had an acceptable wind direction. The distance from the gage site in the trees to the tree margin varied from about 100 m to 450 m for storms with an acceptable wind direction.

DATA ANALYSIS

The evaluation of the performance of gages protected by the Wyoming and modified Alter shield was based on the ratio: monthly precipitation measured at the shielded gage to "true" monthly precipitation. Comparisons were restricted to months receiving at least 0.64 cm of precipitation and to months when no gross errors were present in data.

A gage catch ratio of 1.0 indicated that identical amounts of precipitation were measured by shielded and forested-protected gages. The standard error and the 95% confidence interval about mean monthly gage catch ratios were calculated for data sets involving the Wyoming shield and Alter shield. Differences in precipitation measured by the gage protected by the Wyoming shield and in the forest opening were identified as statistically significant when the confidence interval about a mean monthly gage catch ratio did not include 1.0.

Regression analysis was used to determine if a relationship existed between average storm windspeed and differences in precipitation measured by the gage protected by the Wyoming shield and "true" precipitation. Precipitation events were separated into three temperature strata for statistical analysis: (1) greater than 2° C when precipitation fell as rain or hail, (2) between ± 2° C when precipitation fell as wet snow, rain/snow, or rain, and (3) less than -2° C when precipitation fell as snow.

RESULTS

Wyoming Shield

There were between 5 and 8 years of data in different months that could be used to evaluate performance of the Wyoming shield (Table 2). Precipitation measured from September through May at the gage protected by the Wyoming shield was significantly lower than that measured at the forested gage site (fig. 3). Monthly gage catch ratios were 0.4

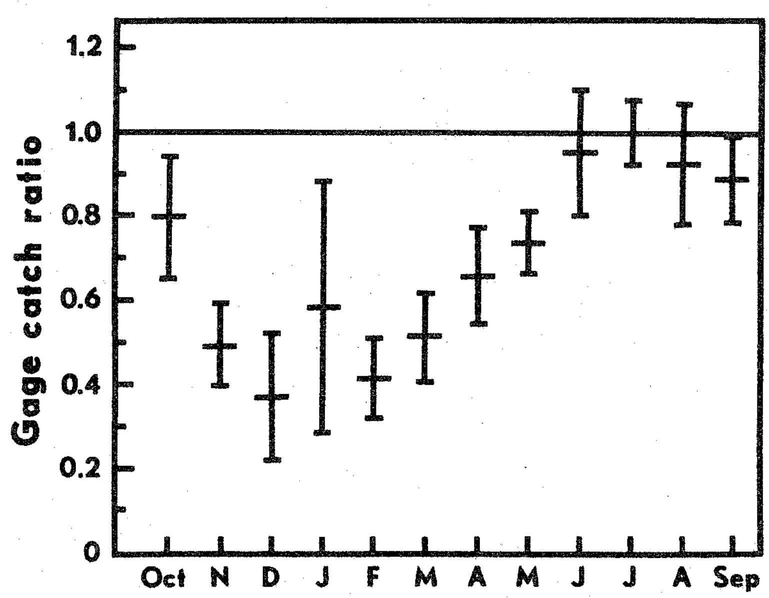

Figure 3. Average monthly gage catch ratio and associated 95% confidence interval for precipitation gage protected by a Wyoming shield.

to 0.6 from November through March, when precipitation fell as snow and air temperatures were well below freezing. July and August were the only months free of snow at the study site. Gage catch ratios in different years were both above and below 1.0 in July and August as well as in June and September. Most, or all of precipitation was rainfall in these months.

Table 2. Monthly precipitation measured by forest-protected gage, monthly gage catch ratio (Wyoming shield/"true" precipitation), and standard error of mean monthly gage catch ratio, for data involving the Wyoming shield.

Year	Oct.		Nov.		Dec.		Jan.		Feb.		Mar.		Apr.		May		Jun.		Jul.		Aug.		Sep.	
	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio	True Precip. cm	Ratio
1976			**	--	2.55	0.693																		
1977	3.40	0.799	4.80	0.630	4.25	.173	1.70	1.105	3.15	0.557	6.65	0.694	3.55	0.914	*	--	*	--	*	--	*	--	*	--
1978	1.50	1.067	4.80	.439	7.70	.409	*	--	5.60	.318	3.95	.449	5.20	.663	8.70	0.740	1.35	0.943	1.20	1.104	3.30	0.961	3.20	0.708
1979	7.95	.751	2.80	.409	1.45	.362	5.80	0.616	2.75	.509	7.10	.564	3.85	.589	5.05	.724	1.70	.791	1.20	1.000	4.60	.802	1.30	.788
1980	5.45	.688	1.95	.623	2.40	.558	9.95	.523	4.20	.449	6.10	.427	2.20	.581	9.10	.780	**	--	2.30	0.978	5.70	.947	3.65	.993
1981	13.85	.817	1.60	.548	7.55	.296	1.95	.338	2.70	.402	4.05	.557	3.95	.632	14.05	.814	1.95	.908	1.95	.882	1.15	1.087	1.05	1.000
1982	5.95	.557	7.00	.411	5.00	.209	4.85	.586	2.80	.373	6.15	.347	4.20	.533	5.10	.761	2.55	1.120	2.60	1.010	**	--	9.70	.856
1983	3.35	.863	13.30	.381	10.35	.253	2.90	.313	4.25	.270	7.90	.537	5.65	.676	10.50	.601	3.70	1.000	6.25	1.029	3.40	.821	6.30	.915
n (years)		7		7		8		6		7		7		7		6		5		6		5		6
Avg.	5.90	0.792	5.20	0.492	5.15	.369	4.55	0.580	3.65	0.411	6.00	0.511	4.10	0.656	8.76	0.736	2.25	0.952	2.60	1.000	3.65	0.924	4.20	0.887
St. error*10^2		5.95		4.30		6.34		11.67		3.86		7.67		4.69		3.01		5.41		2.96		5.19		4.07

* Data missing
** Less than 0.64 cm precipitation in service interval

Alter Shield

Evaluation of the performance of the gage equipped with a modified Alter shield and partially protected by trees was based on 9 to 11 years of record for different months (Table 3). Monthly precipitation measured by this gage also was significantly less than that measured by the forest-protected gage, except in June and July (fig. 4). Monthly

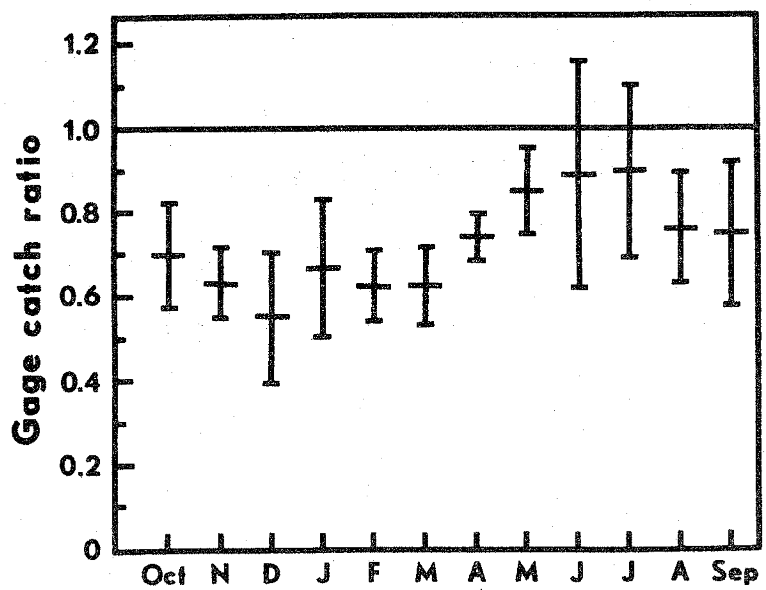

Figure 4. Average monthly gage catch ratio and associated 95% confidence interval for precipitation gage protected by a modified Alter shield.

gage catch ratios during winter were about 0.6 and were more consistent from month to month than ratios at the gage protected by the Wyoming shield. The 5-km distance between exposed and forested gage locations introduced additional variation into data collected from June to September, when precipitation fell primarily as rain. The standard error for these months was consistently greater than standard errors at Twin Groves, where exposed and forested gages were only about 1 km apart. The standard error in months when precipitation fell as snow was usually similar for data involving the Alter and Wyoming shields.

Windspeed and Deficiency in Gage Catch at the Wyoming Shield

The analysis of individual rainfall events indicated that wind had no effect on performance of the gage protected by the Wyoming shield (fig. 5). Precipitation measured by the shielded gage sometimes exceeded that measured by the forest gage and visa versa. Gages were about 1 km apart, and large deviations from a gage catch ratio of 1.0 were associated with real locational differences in rainfall. These differences averaged out over a longer time period, as monthly gage catch ratios were not significantly different in June, July, and August.

A strong correlation ($r = 0.86$) existed between windspeed and the deficit in precipitation at the gage protected by the Wyoming shield for events with air temperatures below -2° C (fig. 5). The data set included 48 snowfall events with windspeeds that ranged from 0.7 m/s to 11 m/s; storm temperatures were as low as -19° C. Undercatch was 90% of precipitation measured by the forest-protected gage at a windspeed of 10.2 m/s. The regression coefficient indicates that the deficit in measured precipitation increased 7.6% for each 1 m/s increase of windspeed.

A weak, but statistically significant relationship ($r = 0.49$), existed between windspeed and the precipitation deficit at the gage protected by the Wyoming shield when air temperatures were between ± 2° C (fig. 5). A total of 32 storms were available for analysis and individual events scattered widely about the mean regression line. The data set included both rain and snow events.

Table 3. Monthly precipitation measured by forest-protected gage, monthly gage catch ratio (modified Alter shield/"true" precipitation), and standard error of mean monthly gage catch ratio, for data involving the modified Alter shield.

Year	Oct. True Precip. cm	Oct. Ratio	Nov. True Precip. cm	Nov. Ratio	Dec. True Precip. cm	Dec. Ratio	Jan. True Precip. cm	Jan. Ratio	Feb. True Precip. cm	Feb. Ratio	Mar. True Precip. cm	Mar. Ratio
1972			4.15	0.616	3.55	0.807						
1973	0.85	0.647	*	--	7.60	.639	8.35	0.432	3.65	0.424	*	--
1974	4.15	.798	1.15	.756	4.25	.399	4.90	.819	3.85	.748	1.95	0.895
1975	5.65	.658	5.20	.824	7.05	.324	8.00	.587	3.70	.664	7.90	.470
1976	.80	.387	**	--	2.55	.630	2.20	.644	7.00	.491	4.70	.667
1977	3.15	.726	4.40	.678	3.80	.487	1.70	.672	2.60	.767	6.95	.597
1978	3.05	.517	4.60	.528	*	--	5.05	.652	4.50	.667	4.60	.624
1979	9.45	.633	5.65	.559	1.20	.128	*	--	2.75	.778	7.35	.644
1980	5.85	.613	2.10	.470	1.35	.962	11.05	.569	3.65	.549	*	--
1981	6.75	.974	5.15	.719	9.00	.446	1.70	.672	3.25	.535	3.55	.560
1982	5.25	.681	5.75	.643	2.45	.577	3.35	1.206	2.80	.505	5.65	.608
1983	2.35	1.032	12.05	.486	7.15	.641	1.85	.384	2.70	.682	7.10	.521
n (years)		11		10		11		10		11		9
Avg.	4.30	0.697	5.00	0.628	4.55	0.549	4.80	0.664	3.70	0.619	5.55	0.621
St. error *10^2		5.59		3.74		6.92		7.20		3.72		3.99

Year	Apr. True Precip. cm	Apr. Ratio	May True Precip. cm	May Ratio	Jun. True Precip. cm	Jun. Ratio	Jul. True Precip. cm	Jul. Ratio	Aug. True Precip. cm	Aug. Ratio	Sep. True Precip. cm	Sep. Ratio
1972												
1973	*	--	*	--	0.65	0.920	4.90	0.880	2.20	0.908	3.20	0.808
1974	9.85	0.724	1.30	0.865	7.10	.643	0.65	.885	0.65	.885	2.65	.648
1975	5.10	.672	10.55	.567	2.00	.570	2.85	1.000	.85	1.030	1.15	.511
1976	6.70	.856	2.60	.981	5.20	.878	2.55	1.010	.75	.793	**	--
1977	6.30	.613	5.55	1.005	*	--	5.50	1.166	2.85	.857	0.85	.824
1978	2.35	.731	8.80	.810	2.15	.941	1.30	.539	4.00	.354	3.50	.657
1979	3.95	.756	3.80	.940	2.30	.500	**	--	3.15	.452	0.95	1.184
1980	*	--	*	--	*	--	*	--	3.25	.717	2.25	1.124
1981	4.05	.811	11.70	.833	2.45	1.698	3.00	0.378	1.45	.790	2.45	.464
1982	4.40	.776	4.10	.839	1.40	.804	2.85	1.152	2.30	.802	9.15	.654
1983	6.95	.697	5.55	.772	3.95	1.013	3.80	1.053	4.15	.761	5.80	.590
n (years)		9		9		9		9		11		10
Avg.	5.50	0.737	6.00	0.846	3.00	0.885	3.05	0.896	2.35	0.759	3.20	0.746
St. error *10^2		2.44		4.37		11.75		9.00		5.92		7.67

* Data missing

**Less than 0.64 cm precipitation in service interval

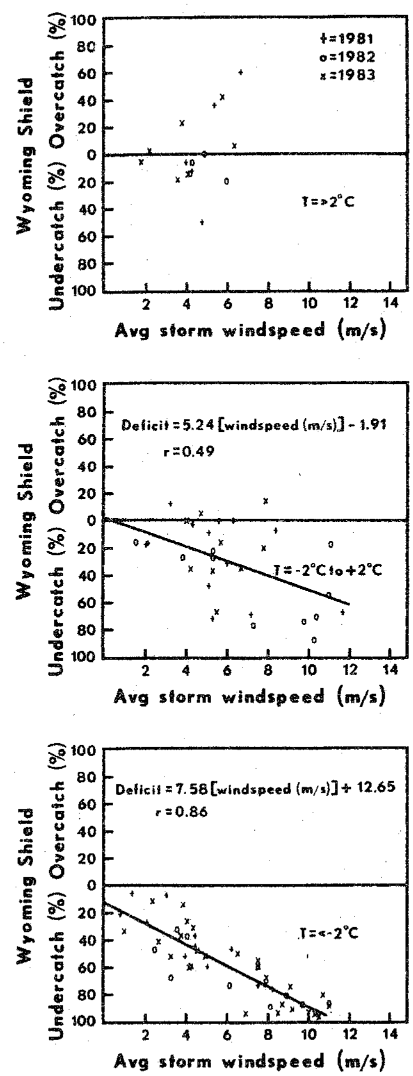

Figure 5. The relationship between windspeed and performance of the gage protected by the Wyoming shield. Precipitation events were stratified into three temperature regimes. Top--Temperatures greater than +2° C. Middle--Temperatures -2° C to +2° C. Bottom--Temperatures less than -2° C.

DISCUSSION

Monthly gage catch ratios for the Alter-shielded gage were higher than for the Wyoming-shielded gage throughout the winter. In addition to the Alter shield, trees at the homestead also provided protection from wind, while the Wyoming shield was fully exposed to ambient winds. These results indicate that additional protection to reduce windspeed will improve performance of precipitation gages in winter.

Protection provided by a Wyoming or modified Alter shield was not sufficient to permit "true" winter precipitation to be measured in exposed locations. Adequate protection was provided by the Wyoming shield when precipitation fell as rain, because confidence intervals about mean monthly gage catch ratios included a value of 1.0 in June, July, and August (fig. 3). The Atmospheric Environment Service of Canada evaluated various types of shields for measuring winter precipitation. Preliminary results suggested that the Wyoming shield was superior to both unshielded gages and gages equipped with an Alter shield (Goodison 1978). Wyoming-shielded gages, however, measured less precipitation than a standard Neipher snow gage. More recently, Goodison and Metcalfe (1982) concluded that gages protected with the Wyoming shield caught about 25% less precipitation than a standard Neipher snow gage, based on data collected from three widely scattered locations in Canada.

The current study was based on relative amounts of precipitation caught by gages in exposed and forest-protected locations. The representativeness of precipitation measured in forest openings to actual precipitation is unknown for this study, as it is for all studies utilizing this experimental approach. Recent studies of snow accumulation in relation to forest harvest practices indicate that more snow accumulates in small openings than under the forest canopy. Golding and Swanson (1978) found that water content of snow in openings 0.75 and 1.0 tree heights in width was 34% and 38% greater, respectively, than in the forest; only 14% of the increase could be attributed to a lack of tree interception. The remainder stemmed from changes in air flow across the forest canopy and to snow redistribution at the opening-tree margin. Similarly, Gary (1980) found that an opening one tree height in width contained 17% more water than the undisturbed forest. The increase was balanced by a snow deficit in the forest immediately downwind of the clearing. Whether the deficit developed during snowfall or from relocation of snow after precipitation was not determined. Thus, it appears that precipitation may be overmeasured in small forest openings; but the magnitude of the overmeasurement is unknown.

A linear relationship between windspeed and the deficit in precipitation at the Wyoming-shielded gage provided the best fit for study data. Theoretically, such relationships should be curvilinear as a precipitation deficit in the absence of wind is not expected, and at extremely high windspeeds, the deficit should approach 100% asymptotically. The derived relationship for storms with air temperatures less than -2° C unaccompanied by wind indicates a precipitation deficit of 12.65% $\pm$ 3.87% (95% confidence level) (fig. 5). The reason for such a large departure from zero is unknown; but one possible interpretation is that it represents the magnitude of precipitation overcatch in the forest opening. Overmeasurement would cause precipitation deficits calculated for gages exposed to the wind to be too large. For example, if the relationship for storms with an air temperature below -2° C was shifted upward to pass through the origin while retaining the same slope, the calculated deficit for a storm with an average windspeed of 10.2 m/s would decrease from 90% to 77.3%.

The study site was in a high snow transport area. A topographic snow trap at Twin Groves contained 495 m^3 of water per meter of distance transverse to the wind, and accumulation in a nearby trap was even larger (Tabler 1975). There was no evidence that the Wyoming shield intercepted sufficient drifting snow to cause an overmeasurement of precipitation. The gage is placed sufficiently high inside the Wyoming shield so as to be above the zone of greatest snow transport. Data on vertical distribution of blowing snow in Antarctica indicates transport is concentrated near the snow surface (Mellor 1965). Compared to the Arctic or Antarctic, bonds quickly form between surface snow particles at the study site because of warm air temperatures and a high radiant energy flux. Unless strong winds immediately follow a storm, shear forces exerted by the wind are usually sufficient to transport snow as creep or saltation.

Study results suggest that precipitation values obtained from gages equipped with a Wyoming shield should be regarded as conservative estimates of actual precipitation. Use of winter precipitation data obtained from exposed gages to design projects involving management of blowing snow would lead to serious errors. There was a 42% undercatch of precipitation between October and May by the Wyoming shield and a 32% undercatch by the modified Alter shield (Table 1). Data from the Wyoming shield would need to be inflated 72% to equal precipitation measured at the forested gage site in these months.

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