OVERCOLLECTION OF SOLID PRECIPITATION BY A STANDARD PRECIPITATION GAGE, NIWOT RIDGE, COLORADO

Tim Bardsley† and Mark W. Williams†‡

INTRODUCTION

Accurate measurements of the water content of snowfall are problematic. Numerous studies have shown that snowfall measurements by all types of ordinary snow gauges can underestimate actual snowfall by as much as 50-100% [e.g. Goodison, 1978; Woo et al., 1983; Sevruk, 1985; Goodison and Metcalfe, 1989]. Many investigators have shown that wind is the major cause of error in precipitation gauge measurements [Gray and Male, 1981]. In particular, Larson and Peck [1974] have shown that catch efficiency decreases non-linearly with increasing windspeed. Considerable attention has been given to the problem of representative catch efficiency in windy environments, including improving site location, shielding, and gauge design [Barry, 1992].

Blowing snow has potentially compromised precipitation measurements at the Niwot Ridge Saddle, located in an alpine tundra ecosystem at an elevation of 3515 m (Figure 1). Niwot Ridge is one of 18 Long-Term Ecological Sites (LTER) in the US, and the only alpine site. The location of the Niwot Ridge LTER research site on the Niwot Saddle has forced the location of the precipitation gauge in a windy site with no natural vegetation to act as a wind shield. Here we evaluate the hypothesis that blowing snow has resulted in the overcollection of snow by the precipitation gauge.

SITE DESCRIPTION

The site used for this experiment is located at the Saddle on Niwot Ridge in the Indian Peaks of the Colorado Front Range west of Boulder (Figure 1). Tree line in this alpine zone is about 3350 m. The Saddle, within the LTER site, is an alpine tundra ecosystem at an elevation of 3515 m, 6.5 km east of the Continental Divide (40°03' N, 105°35' W). Solid precipitation is collected by a standard rain gauge, a shielded Fergusson-type weighing rain gauge made by Belfort. Precipitation amount is measured continuously at the Saddle on Niwot Ridge and also at a companion site called D1 located two kilometers to the west of the Saddle at an elevation of 3749 meters (Figure 1). The Saddle is scoured by westerly winds, with mean wind speeds of 13 m s^{-1} during winter months and a maximum recorded gust of 69.5 m s^{-1} [Greenland, 1989]. The Saddle site has an uninterrupted fetch of about two kilometers and the D1 site is located

Presented at the Western Snow Conference, Banff, CANADA, 1997

†Institute of Arctic and Alpine Research and ‡Department of Geography, Campus Box 450, CU-Boulder, CO 80309

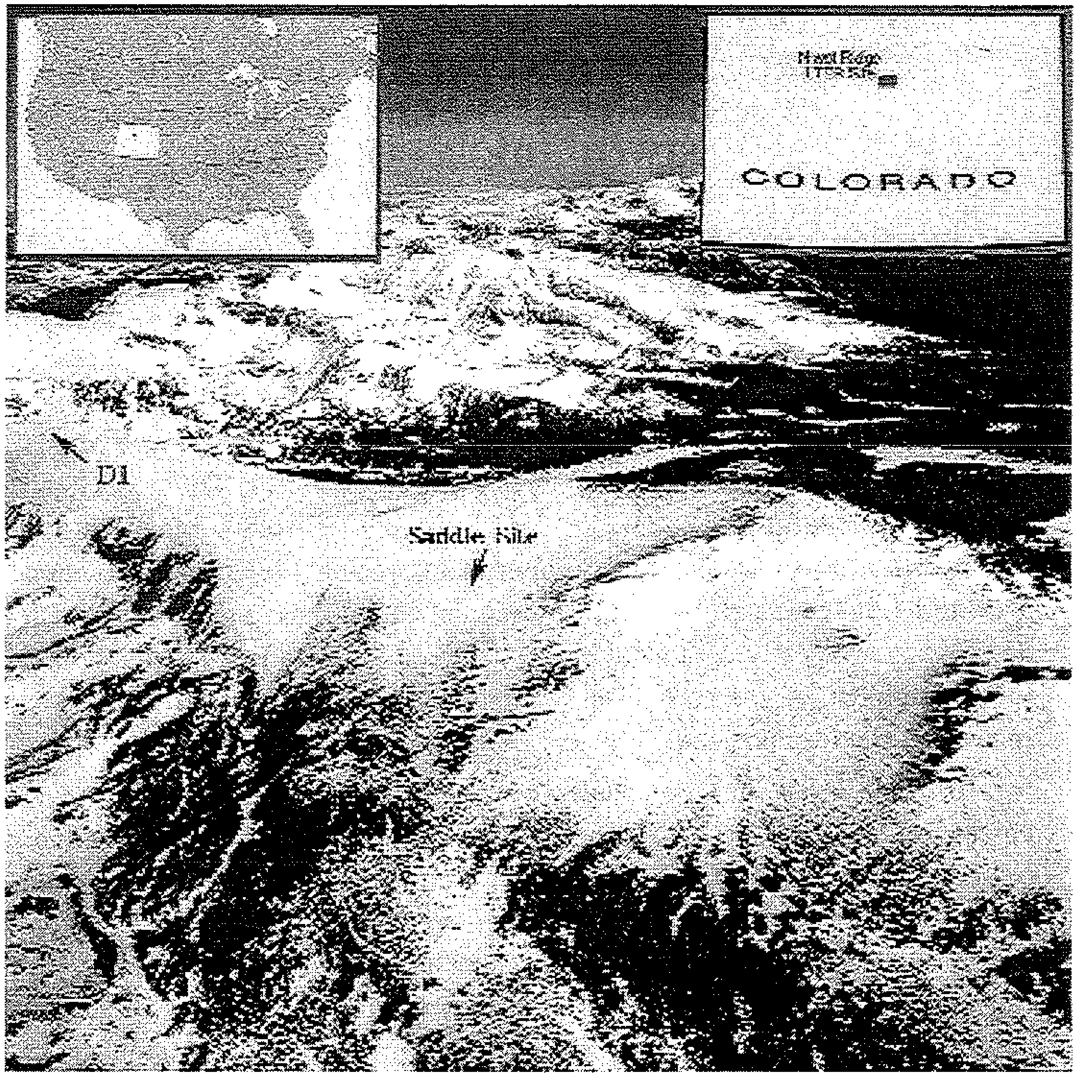

Figure 1. Location of study site and aerial view of Niwot Ridge during the snow-covered season. Precipitation recording gauges were located at D1 (3749m) and at the Saddle on Niwot Ridge (3515 m).

close to the continental divide with little fetch (Figure 1).

METHODS

Precipitation amount has been collected by the University of Colorado at Boulder continuously since 1951 at D1 and since 1981 at the Niwot Saddle with shielded Belfort recording gauges. Here we compare solid precipitation measurements at the Saddle site to the precipitation measurements at D1.

In a further effort to calibrate the Belfort measurements of solid precipitation amount at the Saddle, event measurements were made in 1997 using a 1000-cc density cutter and Acculab field scale (precision ± 1 gram). For each event, a snowpit was excavated down to the old snow surface or to the ground and density measurements were made in the wall of the snowpit continuously in 10-cm increments from the snow-atmosphere interface to the old snow surface (Figure 2).

Figure 2. Manual measurements of snowfall amount. The Belfort precipitation gauge at the Saddle site is in the background.

Wind speed was measured continuously at a height of 2 meter by a RM Young anemometer. Here we report average wind speed for the duration of the snow event. Access to the site involves a 2-hr ski which must be made at the correct time in order to make hand measurements of storm amounts before the onset of blowing snow.

Additionally, we used solar radiation, field observations, and a precipitation sensor to remove blowing snow events from the precipitation record. Solar radiation was measured with a LiCor LI-200. The precipitation sensor is part of a National Atmospheric Deposition Program (NADP) wet chemistry collector at the Saddle site. The sensor opens the wet chemistry bucket during precipitation events and closes the bucket in between events. Field observations have proven this sensor to work surprisingly well. For January and February, 1997, we investigated these blowing snow events by determining that blowing snow was occurring when there was no precipitation if two of these three criteria were meant:

[1] Solar radiation was greater than the five year monthly average

[2] The precipitation sensor on the NADP wet chemistry collector was closed.

[3] Personal observations.

RESULTS

A comparison of annual precipitation totals from 1987 through 1996 show that the average precipitation amount of 1854 mm measured at the Saddle site was 54% greater than the 1200 mm measured at D1 (Figure 3). A paired t-test shows that this difference was significant at the alpha = 0.05 level (p = 0.002, n = 10). Furthermore, the standard deviation of annual precipitation at the Saddle of 580 mm was about twice that of the 206 mm at D1. We hypothesize that the higher standard deviation at the Saddle site may be caused by blowing snow. Wind speed, available snow, and surface hardness are the three main variables controlling snow redistribution and are highly variable with time.

Annual rainfall amounts (June-September) over the ten years were similar at the two sites: A paired t-test shows no significant difference in rainfall amount between the two sites (p = 0.82,n = 9) (Figure 4). The oversampling of annual precipitation amount therefore appears to occur during the winter and not during the summer. However, annual solid precipitation (October-May) of 1514 mm measured at the Saddle was 61% more than the 938 mm measured at D1 and accounted for the difference in annual precipitation amount at the two sites (Figure 5). A paired t-test shows that precipitation amount at the Saddle was significantly greater than at D1 (p = 0.001, n = 9).

Event measurements (Figure 6) show that in general snowfall amount was undersampled at the Saddle site by the Belfort recording gauge. Consistent with many other studies, the Belfort gauge undersampled precipitation amount during storm events as a non-linear function of wind speed.

The overcollection of snow by the Belfort recording gauge appears to occur during blowing snow events when there is no precipitation. For January and February, 1997, we removed the blowing snow events from the precipitation record using solar radiation, field observations, and a precipitation sensor. The adjusted January and February data were similar to the 10-year average, with the recorded precipitation amount at the Saddle being 69% greater than the adjusted values for January and February, similar to the long-term overcatch at the Saddle of 61% (Figure 7). The slightly higher overcatch that we report for 1997 compared to the long-term average is most likely because January and February have higher winds and more snow available for transport than earlier or later in

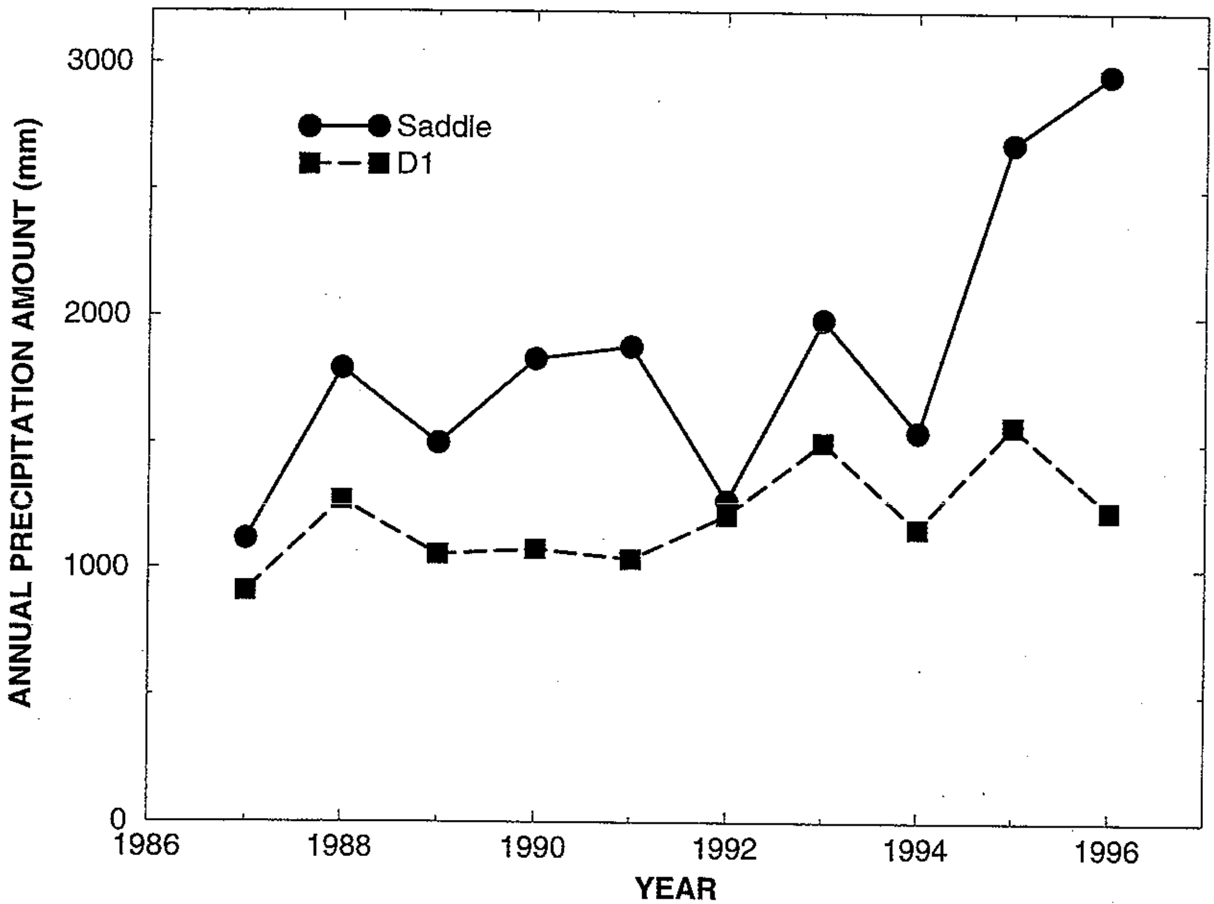

Figure 3.
A comparison of annual precipitation totals from 1987 through 1996 show that the average precipitation amount of 1854 mm measured at the Saddle site was 54% greater than the 1200 mm measured at D1.

the winter.

DISCUSSION

Measurement of true winter precipitation amount at the Saddle on Niwot Ridge is difficult because of its exposed position and logistical problems. Mean wind speed during the winter is 10-13 m/s. After precipitation events wind speeds are often greater than 20 m/s. These high wind speeds, combined with low surface snow hardness after storms, results in large amounts of blowing snow.

There appears to be three patterns of snow catch by the Belfort precipitation gauge at the Saddle on Niwot Ridge:

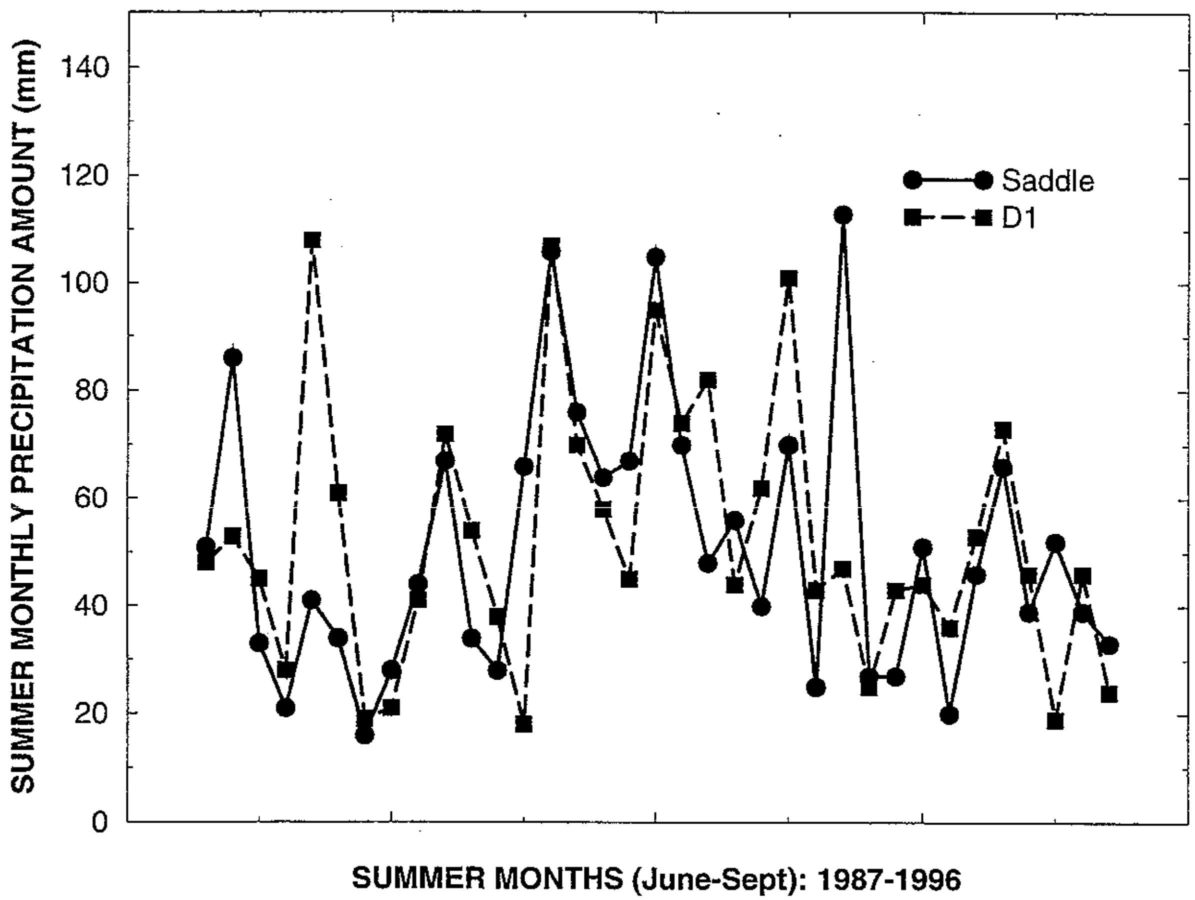

Figure 4. Annual rainfall amounts (June-September) over the ten years were similar at the two sites. Please note that the summer of 1995 was removed from this graph because of large snowfall events.

[1] Infrequent storms with low wind speeds and large amounts of precipitation. Some under-catch.

[2] Frequent storms with high wind speeds and light snowfall. Significant under-catch of falling snow is compensated for by collection of blowing snow. This blowing and snowing event requires further investigation to determine the extent of overcollection of snow.

[3] Blowing snow events. Occur primarily as storms clear, with no new precipitation.

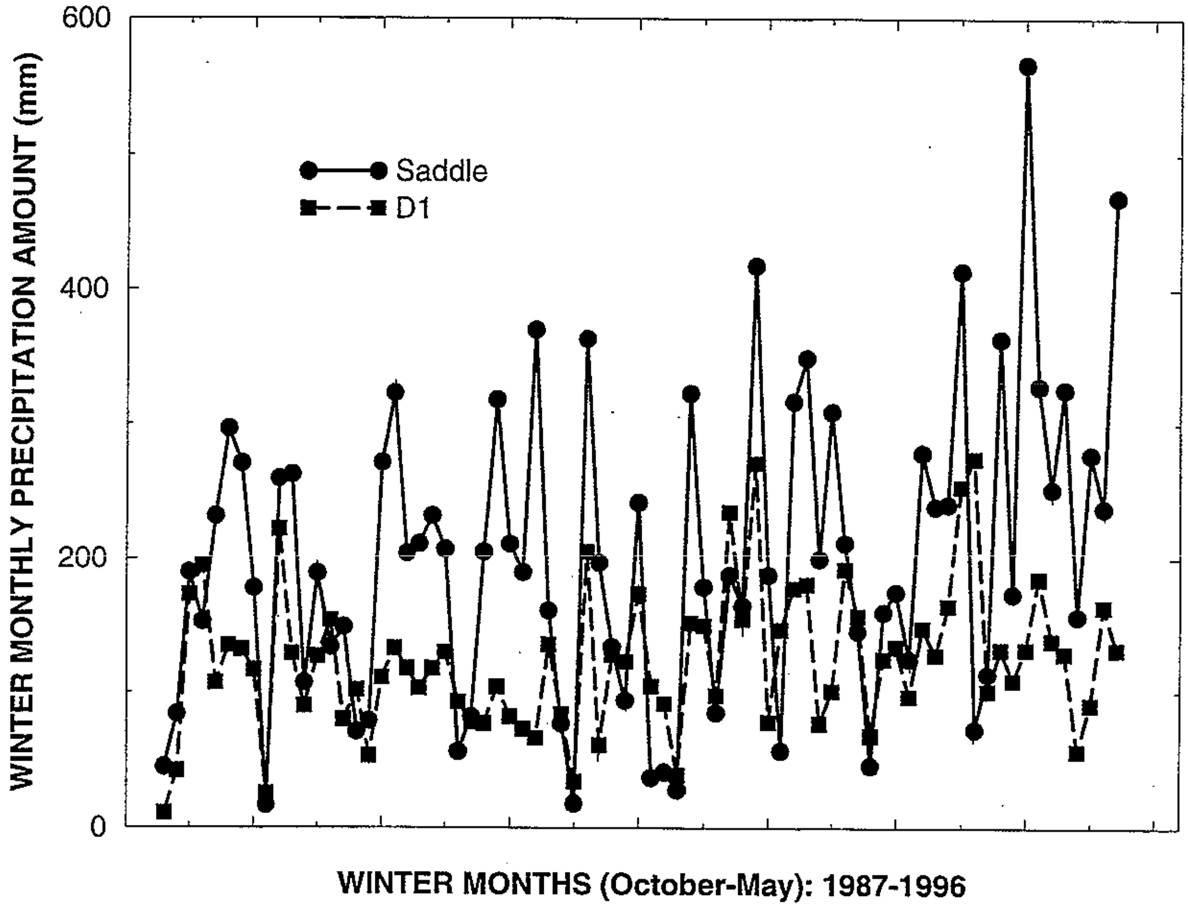

Figure 5. However, annual solid precipitation (October-May) of 1514 mm measured at the Saddle was 61% more than the 938 mm measured at D1 and accounted for the difference in annual precipitation amount at the two sites.

SUMMARY AND CONCLUSIONS

- Event measurements show that in general individual snow events were undersampled as a function of wind speed.
- Blowing snow events caused the Belfort gauge to oversample snow by about 50% over the course of a winter season.
- These blowing snow events generally occurred directly after storms.

ACKNOWLEDGEMENTS

Thanks to Mark Losleben for all the years he's put into maintaining such a great meteorological data set on Niwot Ridge. Thanks to Lee Turner and Tom Davinroy for help with graphics; Don Cline supplied figure 2. This research was funded by NSF grant DEB 92-11776 to the NWT LTER project, NSF EAR-9526875 (Hydrology), and Army

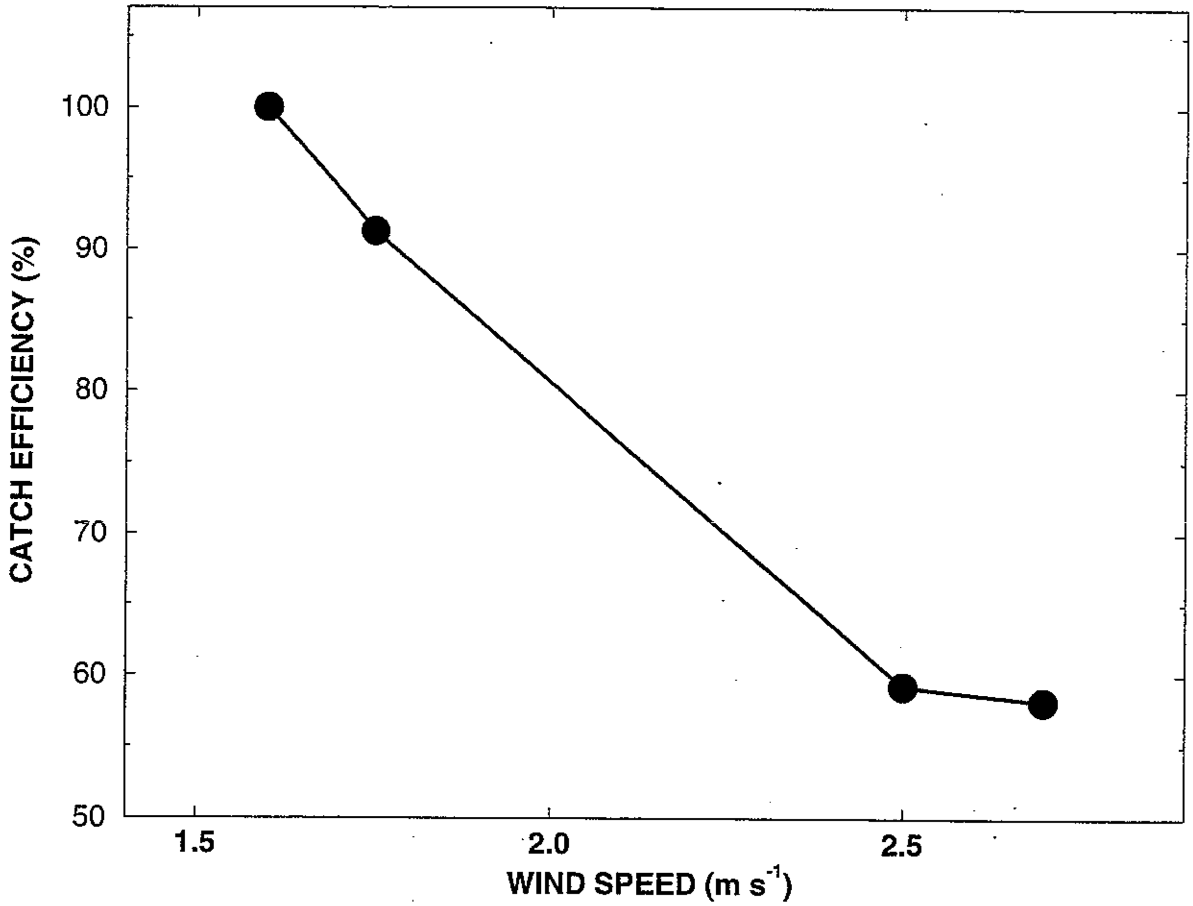

Figure 6. Consistent with many other studies, the Belfort gauge undersampled precipitation amount during storm events as a non-linear function of wind speed.

Research Office grant DAAH04-96-1-0033, and the Mountain Research Station of INSTAAR and CU-Boulder.

REFERENCES

Goodison, B. E., Accuracy of Canadian snow gauge measurements, *J. Appl. Meteorol.*, *17*, 1542-1548, 1978.

Goodison, B. E. and J. R. Metcalfe, Canadian participation in WMO Solid Precipitation Measurement Intercomparison: preliminary results, *Proceedings of the International Workshop on Precipiation Measurement*, 121-126, St. Moritz, Switzerland, 1989.

Gray, D. M. and D. H. Male, eds., *Handbook of Snow*, Pergamon Press, New York, 1981.

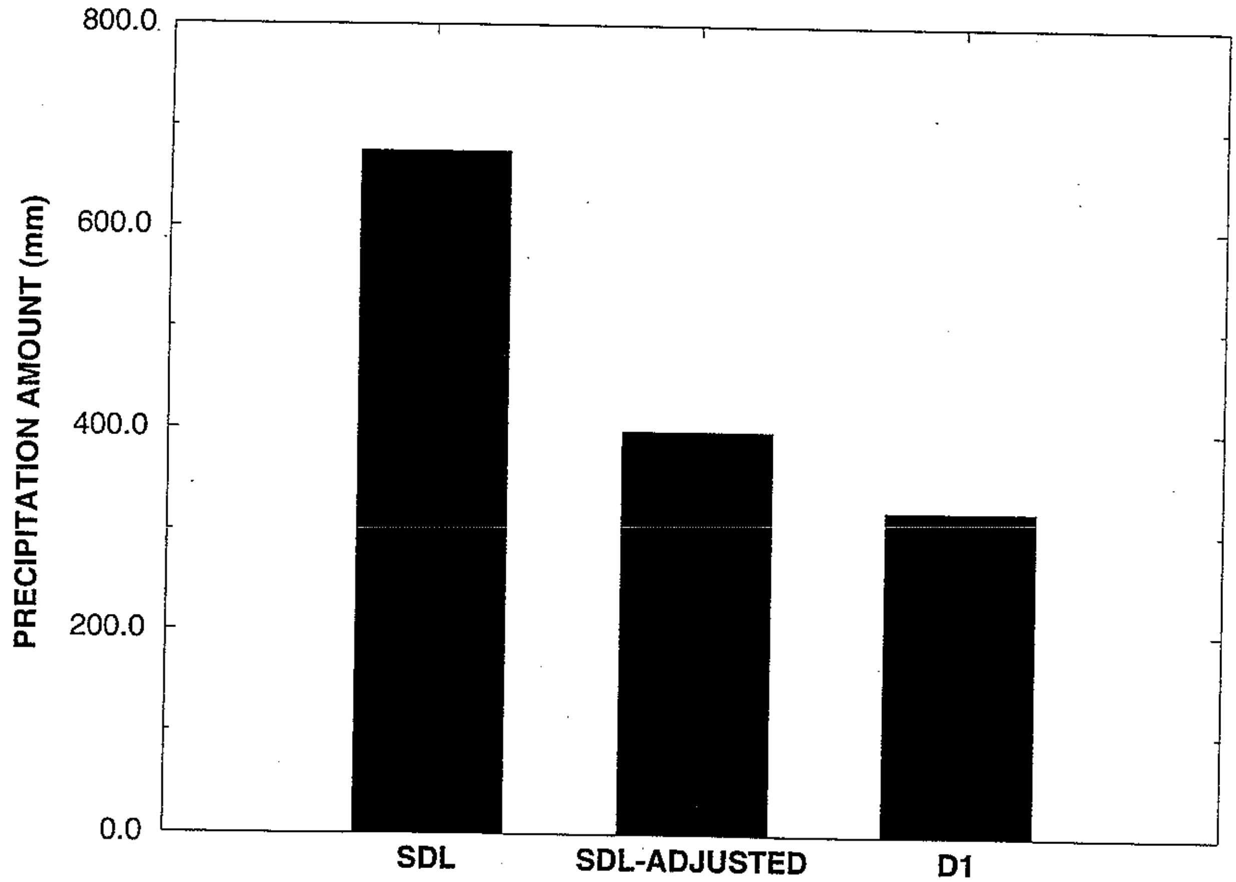

Figure 7. The adjusted January and February, 1997 precipitation amounts were similar to the 10-year average, with the recorded precipitation amount at the Saddle being 69% greater than the adjusted values for January and February, similar to the long-term overcatch at the Saddle of 61%.

Greenland, D., The climate of Niwot Ridge, Front Range, Colorado, U.S.A., *Arctic Alpine Res.*, *21*, 380-391, 1989.

Larson, L. W. and E. L. Peck, Accuracy of precipitation measurements for hydrologic modeling, *Water Resour. Res.*, *10*, 857-863, 1974.

Sevruk, B., Correction of precipitation measurements: summary report, *Proceedings of the International Workshop on Precipiation Measurement*, 13-26, St. Moritz, Switzerland, 1985.

Woo, Ming-ko, R. Heron, P. Marsh, and P. Steer, Comparison of weather station snowfall with winter snow accumulation in high Arctic basins, *Atmosphere-Ocean*, *21*, 312-325, 1983.