Peer-reviewed Techniques Article

Comparison of Field Techniques for Measuring Snow Density at a Point

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Introduction

Field measurements form the basis of snow data from western North America, where mountainous topography often makes acquiring remote data problematic. Field data are used to determine peak snow water equivalent, assess flood hazard level, predict water supply, and ground-truth remotely acquired values of snow depth, snow density, and snow water equivalent (SWE). Measuring and understanding snow processes require methods that are known to be accurate and reliable over a range of conditions. However, few studies have evaluated the accuracy and comparability of field-based snow-sampling methods (e.g., Goodison 1978; Woo 1997). While previous studies have focused mainly on long-term, unattended installations such as snow pillows or weighing lysimeters (e.g., Lundberg and Halldin 2001), this study focused on manual point measurements of snow density.

Point snow measurements are often collected using snow tubes (e.g., Federal, Adirondack, ESC) to obtain depth, bulk density, and SWE measurements. However, detailed snow profiles can also be sampled using a combination of handheld density cutters and visual analysis to provide high-resolution data of vertical variations in snow density, crystal structure, and SWE.

This pilot study assessed the accuracy of both handheld density cutters (Snowmetrics and SnowHydro) and snow tube (Federal) techniques by comparing each method to a control sample. Measurements from both an open and a sheltered subalpine stand were used to assess the suitability of each technique given known snowpack heterogeneity over small spatial scales (e.g., Sturm and Benson 2004). Based on these results, this article offers recommendations on the most appropriate field application of each measurement type.

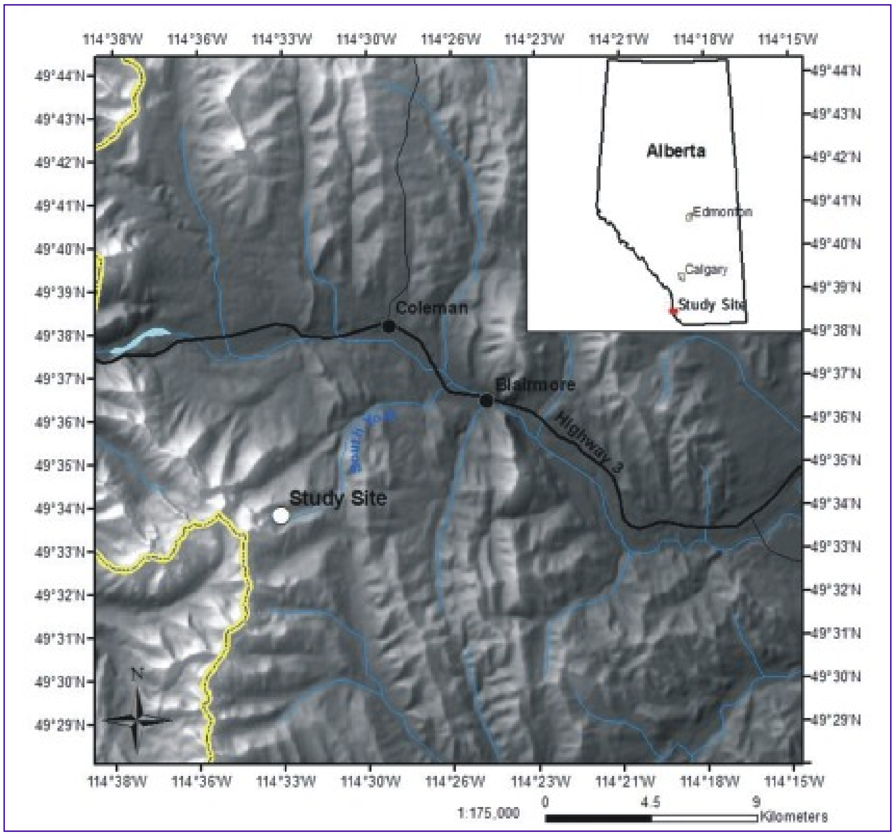

Figure 1. Study site location in the Crowsnest Pass, Alberta. The basin in which the sample sites are located is within 2 km of the British Columbia border and is delineated by the white line.

Study Area

This research is part of the Southern Rockies Watershed Project (SRWP; Silins and Wagner 2007). Field sampling was conducted on February 23, 2008 in the Crowsnest Pass, Alberta (49°33.8′ N, 114°33.1′ W; 1900 m above sea level; Figure 1), in a forested area dominated by subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*). Average annual snow water equivalent in these high-elevation headwater basins is approximately 400 mm. The region is typical of the Rocky Mountain alpine continental climate, with extreme temperatures and high precipitation variability due to dry/warm winter chinook winds (Barry and Chorley 1998). These winds result in freeze–thaw cycles that produce crusts, ice layers, and other crystalline changes within the snowpack (McKay and Gray 1981).

Methods

World Meteorological Organization (1994) standards were referenced when selecting sample sites, as they form the basis for international hydrometeorological data collection protocols. Snow measurements at open sites are to be collected in areas with good wind protection, and at forested sites in openings sufficiently large enough for snow to reach the ground without being affected by canopy interception. Based on these recommendations, samples were extracted from a snow pit in an open area with wind protection (Figure 2a; opening diameter > one tree height), and from a sheltered opening within the forest (Figure 2b; opening diameter < one tree height). These locations were selected to maximize forest cover differences and to reduce topographic variability by locating the sites within 50 m of one another at equivalent slope positions.

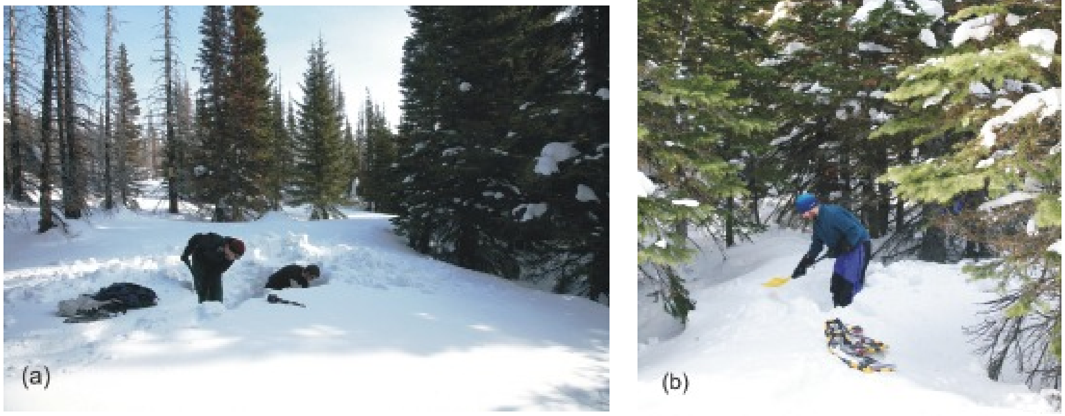

Figure 2. Open (a) and sheltered (b) pit locations.

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This study focused on snow density measurements which, when combined with snow depth, are used to calculate SWE. The following instruments were tested:

1. A 100-cm^3 density cutter manufactured from spot welded stainless steel by Snow-Hydro (Alaska)
2. A 250-cm^3 and a 1000-cm^3 (20 and 16 gauge, respectively) stainless steel density cutter with fully welded seams, manufactured by SnowMetrics (Colorado)
3. A standard Federal snow tube, manufactured by Carpenter Machine Works (Seattle) (Figure 3)

Weather conditions on the day of sample collection were sunny and clear, with air temperature approximately 5°C. Each pit took four field personnel an average of five hours to complete, including digging the pit, and collecting and weighing samples.

At each pit, a trench was dug from the snow surface to the ground, and a trowel was used to clean the south-facing pit face prior to sampling. This face was selected to provide maximum light to show layers and crystal structure. Flat tongue depressors served as markers between layer boundaries, providing an overall assessment of snowpack structure. A graduated 240-cm avalanche probe was placed against the snow pit face to measure layer thickness, with the zero marker at the snow-ground interface.

For the control measurement, a snow column of known volume (15 x 15 cm x snow depth cm) was collected in each pit using a rope saw (sheltered) or a knife (open). Each column was divided into smaller pieces and placed in numbered, sealed plastic bags for weighing. The accuracy of the control measurement was a function of the frequency with which the dimensions of the column top were measured. While it was difficult to maintain absolute column dimensions during cutting, which results in potentially over/underestimating density, the advantage of this method was that it incorporated all snow within a specific volume and was unaffected by edge effects or sampler size. However, given the time required and the volume of snow collected, this method is impractical in routine sampling. Comparison of sampler results with those from the control volume provided a relative measure of error.

Within each pit, snow samples were collected from the pit base to the snow surface using each density cutter, creating a vertical snow-density profile (Figure 4). The 100-cm^3 cutter was inserted with the cutting edge parallel to the snow layers. Once fully inserted, the instrument was moved gently from side to side to separate the snow sample from the snowpack. The cutter was then removed from the pack and a cutting square laid over it to extract exactly 100 cm^3 of snow. The 250- and 1000-cm^3 instruments were inserted into the pack with the cutting surface perpendicular to the snow layers. Once the cutter was fully inserted, a metal lid was inserted parallel to the top of the cutter, capturing the snow within the cutter. Each density sample was placed in a numbered, sealed bag for weighing.

Three snow cores were extracted approximately 30 cm behind each snow-pit face, using the standard Federal snow tube (BC Ministry of Environment 1981). Snow depth and height of the snow column in the tube were recorded. After removing the soil plug from the base of the core and recording its length, the sample snow core was placed into numbered, sealed plastic bags for weighing.

All samples were weighed in the field using calibrated digital scales (Ohaus 200 ± 0.1 g for density cutter samples, or 2000 ± 1 g for snow tube and control volume samples). Empty bags were weighed in the lab. The weight of each sample was calculated by subtracting the numbered bag weight from the weight of both the bag and sample. Density was calculated by dividing the sample weight by the sampler volume.

Results

The snowpack in the open pit was 205 cm deep and contained 15 layers. Ice layers were found at 10 and 40 cm above the ground surface (8 and 3 cm thick, respectively) and at the snow pit surface (1 cm thick). Depth hoar development was observed at the base of the snowpack, 5–10 cm above the

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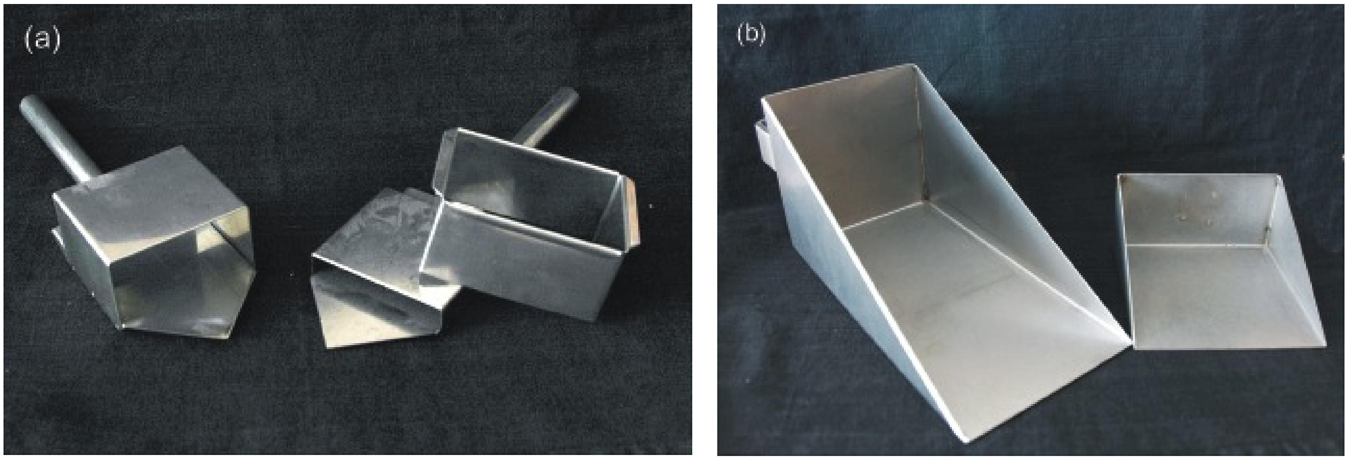

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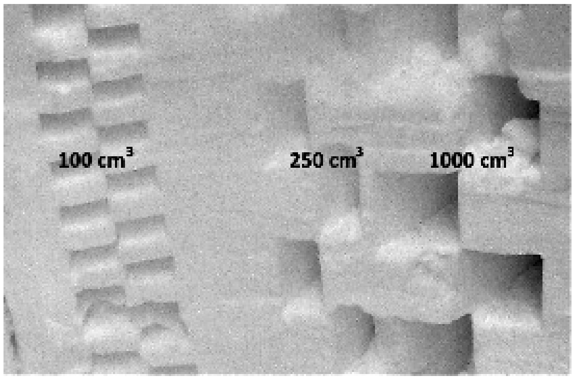
Figure 3. Photograph (a) shows 100- and 33-cm^3 (not used in this study) density cutters; photograph (b) shows 1000- and 250-cm^3 density cutters; and, photograph (c) a Federal snow tube.

ground surface. The snowpack in the sheltered pit was 180 cm deep and contained nine layers. Ice layers 5 cm thick were observed directly at the ground surface, at 75 cm above the ground, and at the snow surface. A 5 cm thick layer of depth hoar was observed directly above the basal ice layer.



Kevin Bladon

Figure 4. Sampling pattern for 100-, 250-, and 1000-cm^3 cutter density profiles (left to right).

Given the dimensions of each density cutter, a greater number of samples was collected with the 100-cm^3 cutter ($n = 60$ and 50 in the open and sheltered pits, respectively) than with the 250- and 1000-cm^3 cutters ($n = 20$ and 19, respectively, in both pits).

Error in the control column measurement is estimated as ± 6%, based on an average 3.8 cm^2 deviation in the surface area of the column with depth. Average density calculated from each vertical profile was greatest in the sheltered pit (Figure 5). All measurement techniques underestimated the average density of the control column in each pit. The average density of the 250-cm^3 profile was closest to that of the control column, and had the lowest relative percent error in both the open and sheltered pit (Table 1). The 100-cm^3 cutter had the greatest relative percent error in the sheltered pit, and the 1000-cm^3 cutter had the greatest relative percent error in the open pit.

Divergence between density profiles was observed between the 250-cm^3 cutter and the 100/1000-cm^3 cutters in both pits, particularly in the sheltered pit (Figure 6). In the open pit, vertical density profiles fell within a relatively narrow range, with only two samples from the 250-cm^3 cutter noticeably beyond that range. In the sheltered pit, however, variability between profiles was much more pronounced and the range of density values was much greater. At several levels within the snowpack, the range in density values measured by each cutter was greater than 200 kg/m^3.

Discussion

Density differences between the open and sheltered snowpack may have been driven by several factors. Canopy drip can form higher density ice layers within the snowpack, increasing snow density in sheltered locations (Kershaw 1991; Bründl et al. 1999). Snow-density variability in the sheltered pit may also have been a function of the proximity of the surrounding trees. Ice lenses sampled in one profile were not present in adjacent profiles depending on proximity to the tree crown edge; thus, the profile in which ice layers were not present had a lower average density. The resulting spatial heterogeneity in snowpack density meant that density

Table 1. Relative percent error in the density measurement of each snow sampler versus the control column

Instrument	Open (%)	Sheltered (%)
100 cm^3	–7.6	–17.2
250 cm^3	–4.3	–4.8
1000 cm^3	–9.9	–11.1
Snow tube	–5.9	–11.8

profiles sampled in each pit did not represent identical conditions. However, comparisons can be drawn between samplers at locations where similar crystal structure is observed between profiles. Field observations of sampler performance within each profile can also be used to determine the utility of each under varying pit conditions. Spatial snowpack heterogeneity, in combination with errors in control column collection, also increases the difficultly in assessing absolute differences in sampler accuracy. However, relative differences can be addressed.

The 100-cm^3 cutter had difficulty sampling ice layers given its small size and thin metal construction, thus underestimating snow density in the sheltered snowpack. The larger samplers, however, had no trouble sampling ice layers. In some cases, density samples contained air pockets where snow broke off during the extraction process—depth hoar in particular lacked cohesion to fill the cutters. Samples with air pockets were resampled immediately, as loss of snow from a sample would underestimate snowpack density.

The density cutters were difficult to manoeuvre at the base of the snow pit as the cutting edge caught either on the ground surface or on the basal ice layer. Snow also adhered to the cutters as a result of sunlight or warm hands, melting and refreezing to the steel and potentially decreasing density measurements. Additionally, the lid of the 250- and 1000-cm^3 cutters was in some cases difficult to insert flush with the cutter, thus samples may have contained more than the defined volume. Outliers in the open and sheltered density profiles (Figure 6) may therefore be the result of air pockets (density underestimated) or oversampling (density overestimated).

While some of these errors can be minimized by following careful field procedures, under- and over-sampling problems are more difficult to avoid. Additionally, if a less accurate density cutter is used (e.g., 1000 cm^3), a larger sample set must be collected to overcome the effect of measurement error (Winkler and Spittlehouse 1995), thereby increasing the sampling time required.

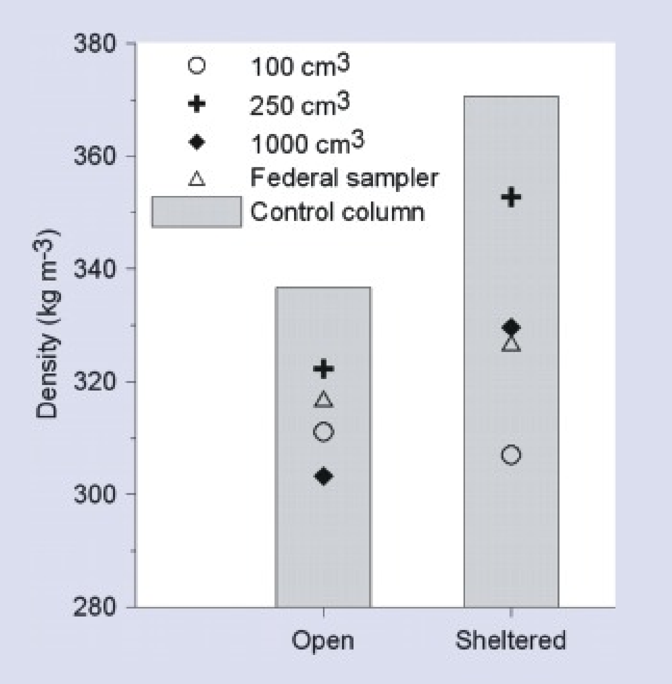


Figure 5. Average snow-pit density from each measurement technique.

Previous studies have found that the Federal snow tube has an approximate 10% error (Farnes et al. 1982). Comparison of the open and sheltered snow tube samples with the control columns gives 5.9% and 11.8% error, respectively. The open pit was thus within the previously reported error bounds, while the sheltered pit slightly exceeded it. While snow tubes often have greater percent error in shallow snow cover (Work et al. 1965), in deep snowpacks, such as those at the SRWP study site, the Federal snow tube continues to be an appropriate method for measuring snow density.

Conclusion

The 250-cm^3 cutter is best suited for measuring density profiles in deep snowpacks, as it captures some variation between snow layers while also maintaining the lowest relative percent error versus the control volume in both pits, and can also cut through ice layers. Unfortunately, the 100-cm^3 cutter cannot sample ice layers, and requires three times the number of samples when compared with the 250- or 1000-cm^3 cutters. This makes it more useful in shallow, ice-free snowpacks. The 1000-cm^3 cutter requires the greatest care to prevent oversampling, but could be most useful for incorporating high snowpack heterogeneity into a larger volume sample. Since the vertical dimensions of the 250- and 1000-cm^3 cutters are identical, the same time will be required to collect a complete sample set. Relative to the snow tube, cutters are smaller, lighter, and less cumbersome to transport, but require more time and energy to collect measurements and cannot efficiently collect spatially distributed samples. While increasing the number of snow-pit profiles examined with cutters would be expected to reduce the error, the time requirements for this type of sampling effort are most likely to be prohibitive. For a 2-m snowpack, a snow tube sample requires 2 to 5 minutes per sample site, while the density cutters require upwards of 45 minutes. The snow tube is the preferred method for extracting average density, or measuring spatial variability in SWE, as error in individual measurements can be averaged over a larger number of measurements. It is also most useful when a large number of samples are required (e.g., when estimating differences between stand types or treatments). In situations where a detailed density profile is desired, however, the density cutters are recommended.

It is important to note that the specific data requirements of each snow sampling study will determine which point snow measurement technique is selected. For spatially distributed estimates of maximum SWE required for flood forecasting or water availability, the snow tube is most appropriate given the speed and accuracy of sampling over large areas. For process-

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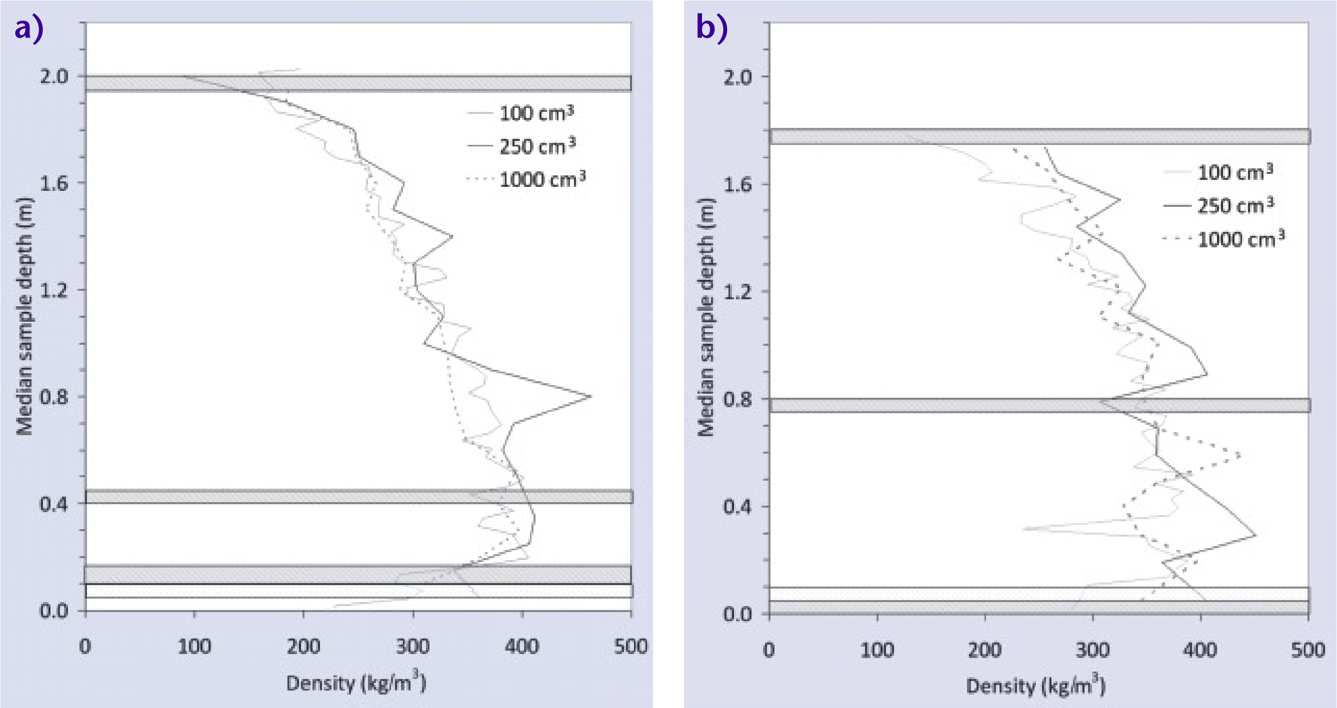

Figure 6. Vertical density profile in the open (a) and sheltered (b) snow pits. Zero cm is the snow-ground interface. The shaded bar indicates an ice layer and the white bar indicates depth hoar layer.

based studies, detailed information on density profiles is often desirable to assess snowpack processes and to validate output from remote sensing platforms that can be affected by internal snowpack stratigraphy. In these situations, the 250-cm^3 cutter is recommended due to its low relative error, and its ease of use in deep snowpacks with internal ice layers. The 100-cm^3 cutter has slightly lower relative error than the 250-cm^3, and can be effective in shallow snowpacks without ice layers, where the greater time investment for sample collection and the inability to sample ice layers are less of a problem. The 1000-cm^3 cutter is difficult to manoeuvre and most likely to oversample, but could be useful when sampling a deep, snowpack where larger sample volumes are required to overcome snowpack heterogeneity.

This research is being expanded to assess the utility of each measurement technique at different times of year and with varying elevation, aspect, and vegetation cover, and to assess the accuracy of various methods of control column sampling. This will help identify the optimal measurement technique to apply over a range of real-world conditions.

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References

Barry, R.G. and R.J. Chorley.1998. Atmosphere, weather and climate, Routledge. British Columbia Ministry of Environment. 1981. Snow survey sampling guide. Water Management Branch: Surface Water Section. Province of British Columbia.

Bründl M., M. Schneebeli, and H. Flühler. 1999. Routing of canopy drip in the snowpack below a spruce crown. Hydrological Processes 13:49–58.

Farnes, P.E., N.R. Peterson, B.E. Goodison, and R.P. Richards.1982. Metrication of manual snow sampling equipment by Western Snow Conference Metrication Committee.In Proceedings 39th Eastern Snow Conference. Reno, Nevada.

Goodison, B.E. 1978. Accuracy of Canadian snow gage measurements. Journal of Applied Meteorology 17: 1542–1548.

Kershaw, P.G. 1991. The influence of a simulated transport corridor on snowpack characteristics, Fort Norman, NWT, Canada. Arctic and Alpine Research 23:31–40.

Lundberg, A. and S. Halldin. 2001. Snow measurement techniques for land-surface-atmosphere exchange studies in boreal landscapes. Theoretical and Applied Climatology 70:215–230.

McKay, G.A. and D.M. Gray.1981. The distribution of snowcover. In Handbook of snow: Principles, processes, management & use. D.M. Gray and D.H. Male, (editors), Pergamon Press Canada Ltd.

Silins, U. and M. Wagner. 2007. Southern Rockies Watershed Project. 2nd Interim Report (2004–2006). 41p.

Sturm, M. and C. Benson. 2004. Scales of spatial heterogeneity for perennial and seasonal snow layers. Annals of Glaciology 38:253–260.

Winkler, R. and D.L. Spittlehouse.1995. The importance of sample size in forest/clearcut snow accumulation comparisons. In Proceedings of the Canadian Water Resources Association Symposium, Vancouver, BC. B.T. Guy and J. Barnard (editors), Cambridge: CWRA, p. 39–45.

Woo, M-K. 1997. A guide for ground based measurement of the Arctic snow cover. Geography Department, McMaster University.

World Meteorological Organization. 1994. Guide to hydrological practices, data acquisition and processing, analysis forecasting and other applications. WMO Report 168, WMO, Geneva.

Work, R.A., H.J.Stockwell, T.G.Freeman, and R.R. Beaumont. 1965. Accuracy of field snow surveys, western United States, including Alaska. Tech. Rep. 163, U.S. Army Cold Reg. Res. Eng. Lab., Hanover, N.H.