

ACCURACY OF SNOW SURVEY DATA AND  
ERRORS IN SNOW SAMPLER MEASUREMENTS

J. Turčan  
Institute of Hydrology and Hydraulics  
Slovak Academy of Sciences  
Bratislava, Czechoslovakia

and

H. S. Loijens  
Water Resources Branch  
Environment Canada  
Ottawa, Ontario, K1A 0E7

ABSTRACT

Measurements of snow water equivalent with a snow sampler are subject to instrument and measurement errors. The measurement error, resulting from snow compression in the sampler tube and blocking of the sampler opening, is mathematically expressed in terms of snow core length, depth of the snowpack and snow density. A simple correction procedure is derived and illustrated using data from selected snow surveys.

INTRODUCTION

A snow sampler is widely used to measure the water equivalent of the snowpack. Although many experiments have been carried out to determine the sampler's accuracy, [McKay and Blackwell, 1961; Work et. al., 1965; Freeman, 1965; Turčan and Kozlík, 1970] most studies were limited to instrument error.

The Federal (Mount Rose) sampler is extensively used in Canada and the U.S. because of convenience and portability. This sampler, however, generally overmeasures the water equivalent by about 10% [McKay and Blackwell, 1961; Work et. al., 1965]. The error is attributed to the shape and arrangement of the cutting teeth. This error may not be significant when using the data as indices, but when the measured values are used as a "standard" in a comparison with other measuring systems (e.g., snow pillows, radioactive isotope gauges, and airborne gamma-ray surveys) or for water balance calculations, the instrument errors may become significant.

This paper is concerned with errors resulting from blocking of the sampler opening and compression of snow in the sampler tube. Analysis of field data indicates that the water equivalent of the snowpack is likely underestimated.

MATHEMATICAL FORMULATION

The main source of systematic measurement of errors in snow samplers with small cross-sectional area is the shortening of the snow core with respect to the original depth of the snowpack. This may be caused by:

- a) blocking of the opening of the sampler by snow or ice layers when the sampler is being inserted into the snowpack;
- b) compression and the resulting increase in density of the snow in the sampler caused by friction between the snow and the walls of the sampler;
- c) a combination of (a) and (b) above.

An exclusive occurrence of either the first or the second cause for the decrease in snow core length,  $h'$  (Figure 1), is merely a theoretical possibility, which may be encountered only in exceptional circumstances. Therefore, we shall restrict our attention to case (c) which is most commonly encountered in practice.

The water equivalent of the snowpack at a given point can be expressed as the product of the depth of the snow cover,  $h$ , and its average density,  $\rho$ . Snow density will be used in the following analysis to compare measurements made under different snow conditions. It is also assumed that snow density is uniform over the sampling area as well as with snow depth, i.e., the snowpack is considered to be homogeneous.

In a typical situation, it may be assumed that the snow initially enters into the sampler without obstruction, but later its penetration rate will slow down due to friction as compared with the penetration rate of the sampler into the snowpack. Consequently, the density of the snow core will increase. The difference between snow core length,  $h'$ , and sampler depth is denoted by  $\Delta h_b$  (Figure 1). If the density of the snow core is much higher than that of the snowpack, the opening of the sampler will be blocked and the remaining snow in the profile will not enter or will be pushed sideways. The equivalent depth of snow which cannot enter the sampler is denoted by  $\Delta h_a$  (Figure 1).

The true snow density is:

$$\rho_s = \frac{G}{h f} \quad (1)$$

where  $G$  is the unknown weight (mass) of a sample,  $h$  is the total snow depth, and  $f$  is the cross-sectional area of the sampler (Figure 1).

The following variables are known as a result of a measurement: weight of the snow core,  $G_c$ ; the snowpack depth,  $h$ ; and the snow core length,  $h'$ . From these variables snow density can be calculated as:

$$\rho = \frac{G_c}{h f} \quad (2)$$

The weight of the snow core can also be expressed in terms of the true snow density:

$$G_c = \rho_s (h' + \Delta h_b) f = \rho_s (h - \Delta h_a) f \quad (3)$$

Substituting these expressions into equation (2) and using the notations

$$\Delta h = \Delta h_a + \Delta h_b, \quad \delta = \frac{\Delta h}{h}, \quad \delta_a = \frac{\Delta h_a}{h}, \quad \delta_b = \frac{\Delta h_b}{h}$$

we get after rearrangement:

$$\rho = \rho_s (1 - \delta_a) \quad (4)$$

$$\rho = \rho_s (1 - \delta + \delta_b) \quad (5)$$

Equations (4) and (5) are represented graphically by line 3 in Figure 2.

Equations (4) and (5) can also be written as:

$$\rho_s \delta_a = \rho_s - \rho \quad (6)$$

$$\rho_s \delta_b = \rho - \rho_s(1-\delta) \quad (7)$$

Equations (6) and (7) are illustrated in Figure 2. The limiting cases mentioned above in item (a) (blocking) and item (b) (compression) are represented respectively by line 1 and 2 in Figure 2. The actual value of snow density,  $\rho_s$ , is found at the intersection of line 3 with the axis of ordinates  $\rho$ .

Fig. 3 Experimental sampling procedure.

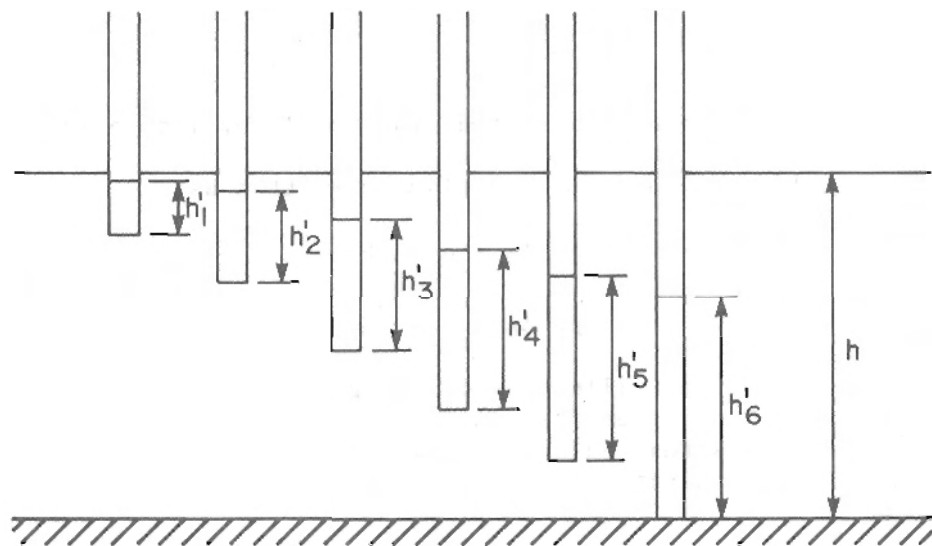


Fig. 2 Graphic illustration of blocking and compression (equations 4, 5, 6 and 7).

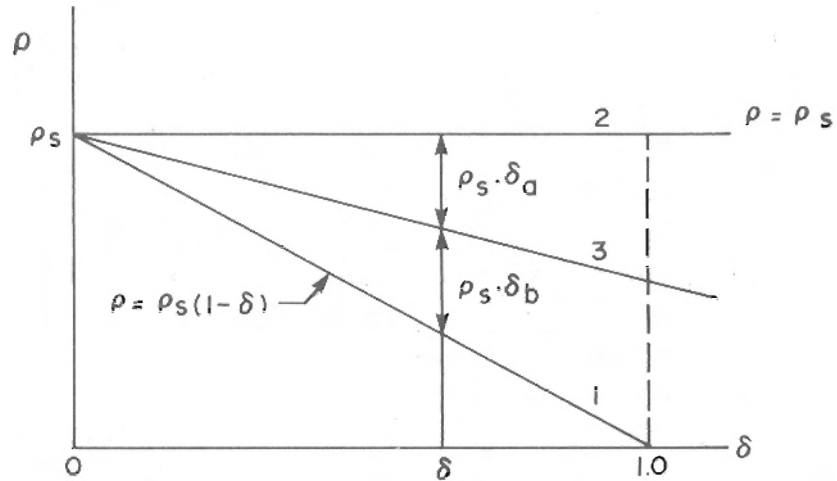
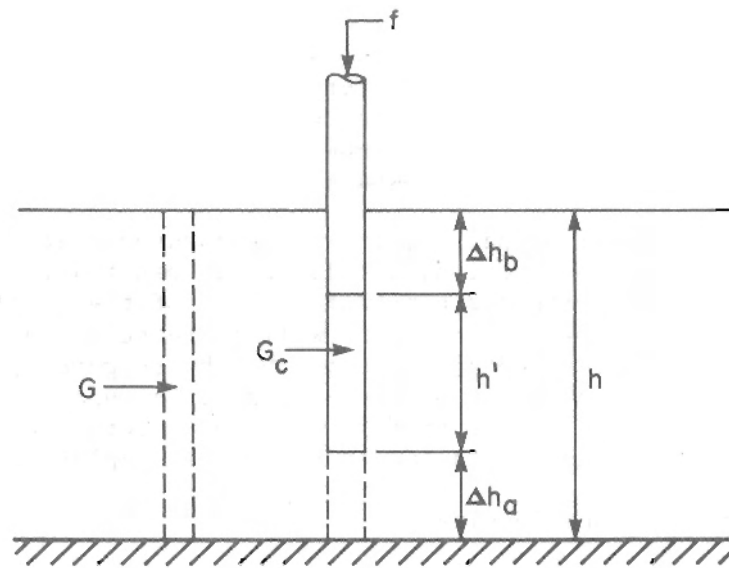


Fig. 1 Definition of symbols.



The assumption of homogeneity of the snowpack is not satisfied in reality. From the physical properties of snow it follows that snow with a lower density is more compressible; i.e., when a snow core is being taken, friction between the walls of the sampler and the snow will cause compression and thus increase the snow core density. Snow with higher density is less compressible, but it usually contains several ice layers, increasing the probability of the sampler becoming blocked. As a result, the ratio,  $\Delta h_a/\Delta h_b$  will vary with snow density.

Assuming that  $\rho_s \neq$  constant,  $\Delta h_a/\Delta h_b \neq$  constant and that both are random, the functional relationships given by equations (6) and (7) will become regression relations. The smaller the variability of snow density over the sampling area the better this relation will be. By the same token, if a number of measurements are made close to each other, one expects the regression relation to approach a clearly defined functional relationship. On the other hand, if measurements are made far apart and the variability of snow density is large, the regression relation will vanish. Another reason for the scatter of points is the variability of snow density within the snowpack. This variation, however, is neglected (averaged out) because the values of  $\rho$  are fitted by a linear equation.

### RESULTS OF MEASUREMENTS

To verify the linear regression relationship, two series of measurements were made in such a way that the sampler was entered into the snow to different depths (Figure 3); the different lengths of the snow core,  $h'$ , together with the total snow depth,  $h$ , were used for the computation of the  $\delta$  value. Snow density,  $\rho$ , was calculated using the total depth of the snow cover,  $h$ , for all measurements. The data are listed in Table 1 and the results are presented in Figure 4. The value of the correlation coefficient is - 0.993. This result seems to confirm the justifiability of using a straight line for the correction of field data when blocking of the sampler occurs.

TABLE 1 Two series of Snow Depth and Water Equivalent Measurements in Gatineau Park (Quebec) on 12 March 1974 Using a Federal Snow Sampler.

Series	Sample Depth (cm)	Snow Core Length $h'$ (cm)	Water Equivalent (cm)	Depth Correction $\delta$	Snow Density $\rho$
I	11	10	3	0.84	0.05
	24	22	9	0.64	0.15
	32	30	11	0.51	0.18
	45	32	13	0.48	0.21
	54	33	14	0.46	0.23
	61	36	16	0.41	0.26
II	13	9	3	0.83	0.06
	24	22	9	0.59	0.17
	32	27	11	0.50	0.20
	45	39	17	0.28	0.31
	54	52	21	0.04	0.39

To show the order of magnitude of the described correction, several examples taken from the Canadian snow course network are presented (Figure 5). The data are taken from unpublished reports by the collecting agencies. A summary of Canadian snow course data is published annually [Atmospheric Environment Service].

Figure 5 shows results from measurements at the snow course High Falls, Ontario (Ontario Hydro, Toronto) in January and February, 1973. The average measured snow density,  $\bar{\rho}$ , appears to be underestimated by 49% in January and 18% in February. Figure 5 also illustrates data from the snow course Ptarmigan Hut, Alberta (Water Survey of Canada, Calgary) on 30 April 1973. The measurement error is 11%.

GATINEAU PARK (QUEBEC)  
12 MARCH 1974

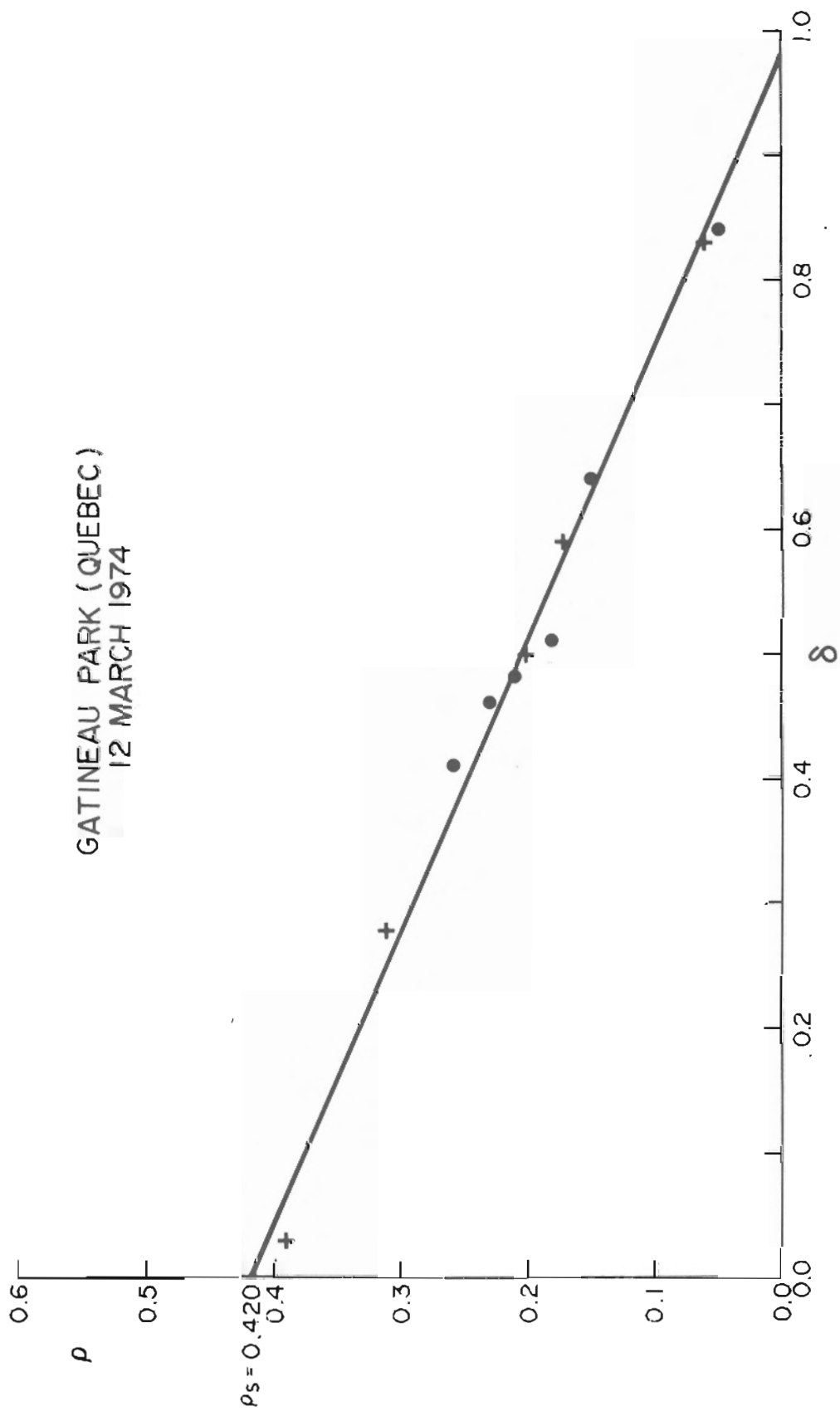


Fig. 4 Linear regression relationship shown by the results to two series of measurements to different depths in the snowpack using a Federal snow sampler.

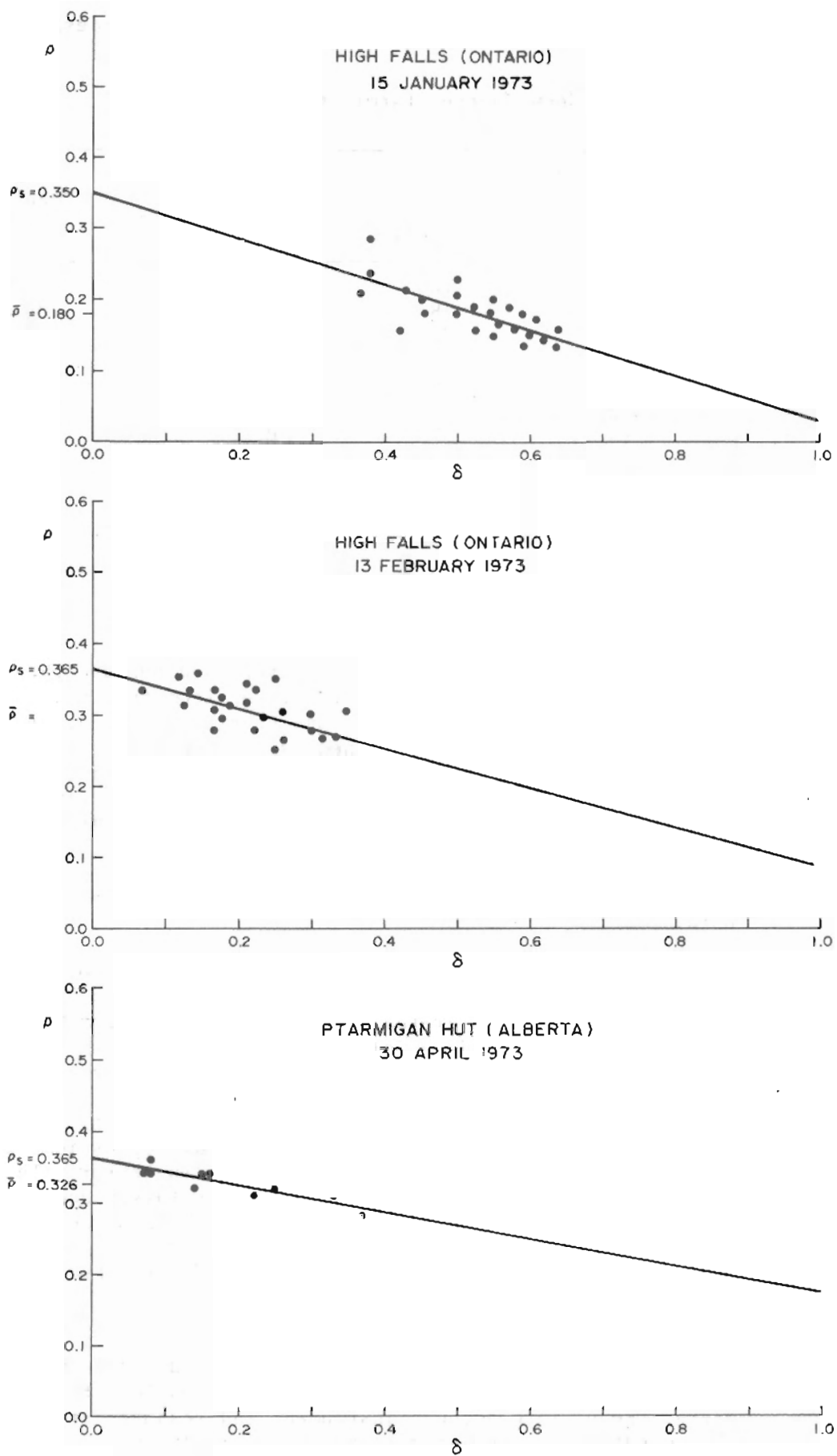


Fig. 5 Results for selected snow courses.

The measured data and the computational procedure for calculating the described correction is outlined in Table 2.

TABLE 2 Snow Survey Data from Snow Course Ptarmigan Hut (Alberta)  
30 April 1973

Sample No.	Snowpack Depth h (cm)	Snow Core Length h' (cm)	$\Delta h$ (h - h')	Depth Correction $\delta$	Snow Density $\rho$
1	123	113	10	0.08	0.36
2	119	111	8	0.07	0.34
3	114	105	9	0.08	0.34
4	111	83	28	0.25	0.32
5	97	81	16	0.16	0.34
6	117	79	38	0.33	0.31
7	81	64	17	0.22	0.31
8	97	61	36	0.37	0.28
9	117	99	18	0.15	0.34
10	112	95	17	0.15	0.32

$$\bar{\rho} = 0.326$$

In some cases, the correction cannot be determined because the values of  $\delta$  are not sufficiently scattered, as shown in an example taken from the snow course on Pink Mountain in British Columbia (B.C. Water Investigations Branch, Victoria) of March 1 1967 (Figure 6). The only factor which can be established is the uncertainty limit in the measurement. In this particular case, the uncertainty is given by an interval  $I = 0.126$  shown in Figure 6. The width of this interval is found by drawing two limiting lines through the center of mass of the point field. By doing this, we assume that only blocking of the sampler could have occurred when the measurements were taken (line 1); or that only compression of snow in the sampler occurred (line 2). The actual snow density will be between 0.184 and 0.310. To find its precise value a different method of measurement must be used.

On 12 March 1974, ten snow depth and water equivalent measurements were taken in the Gatineau Park near Ottawa, Ontario within an area of about 100 x 100 m in a random fashion using a Federal sampler (diameter 3.77 cm) and a Canadian MSC sampler (diameter 7.05 cm). The correction procedure followed the outline given in Table 2. Results are presented in Figure 7. The Federal sampler indicates a corrected mean snow density of 0.440 and a measurement error of 20%. The MSC sampler shows a lower density, 0.375, with an error of 14%. The results obtained with the Federal sampler of smaller diameter are 17% higher than the larger MSC sampler. The linear regression lines in Figure 7 show that for both samplers blocking is the main sampling error. The difference in snow density is caused by instrument error; however, the instrument accuracy of these different types of samplers is a problem on its own and should be analyzed separately because, as shown in Figure 7, the results from the MSC sampler are not free of measurement errors, although its  $\bar{\delta}$  is significantly lower than the  $\bar{\delta}$  for the Federal sampler.

## CONCLUSIONS

Measurement errors of snow density (water equivalent) due to snow compression and blocking of a snow sampler have been quantified. A re-evaluation of the measurement accuracy of snow samplers, taking into account instrument and measurement error, sampling technique and snowpack properties is suggested to establish guidelines for the correction of field data to obtain 'true' snow water storage. For shallow snowpacks, the larger diameter MSC sampler is preferable over the Federal sampler.

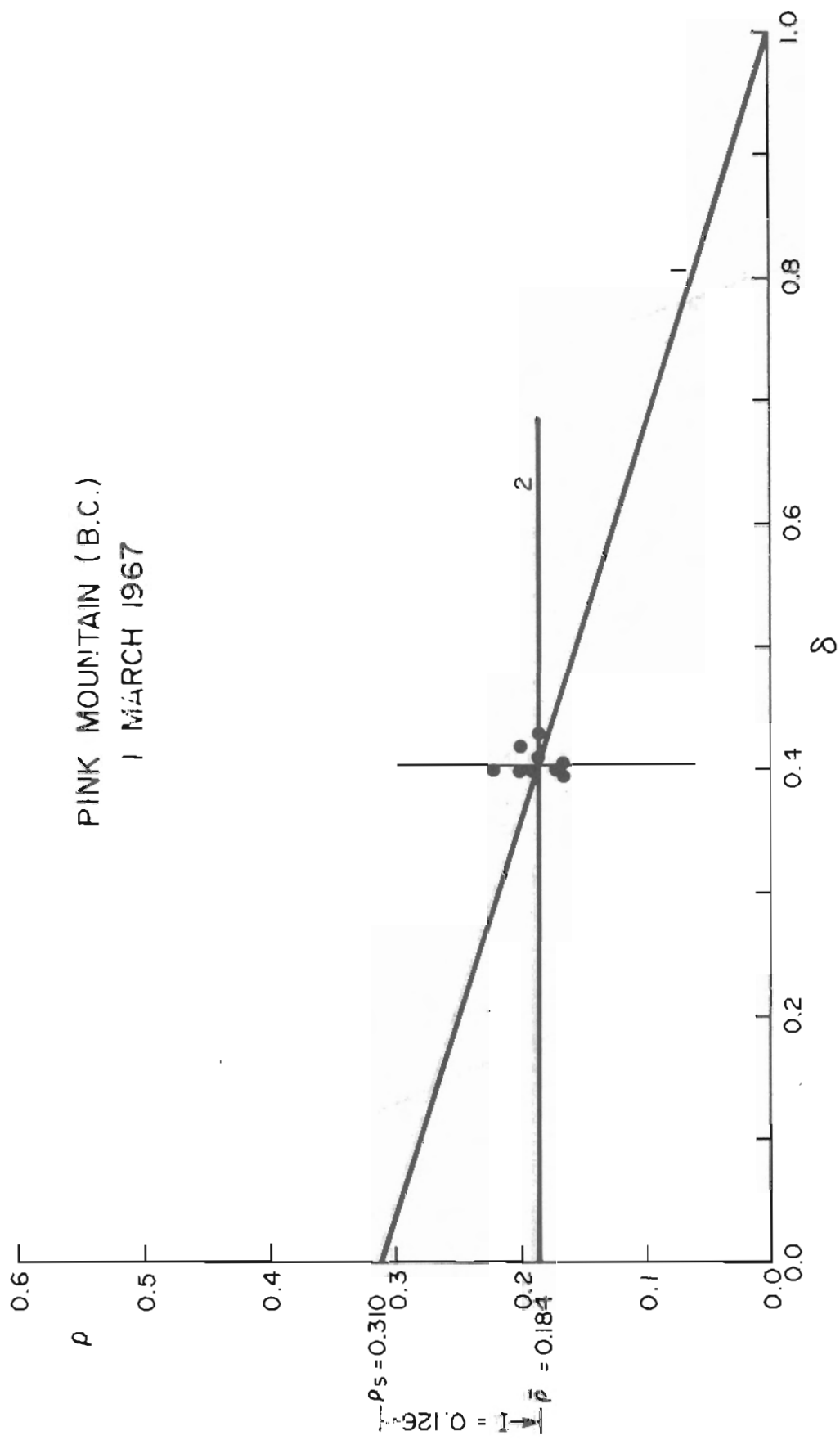


Fig. 6 An example showing errors limits in measurements of snow density.



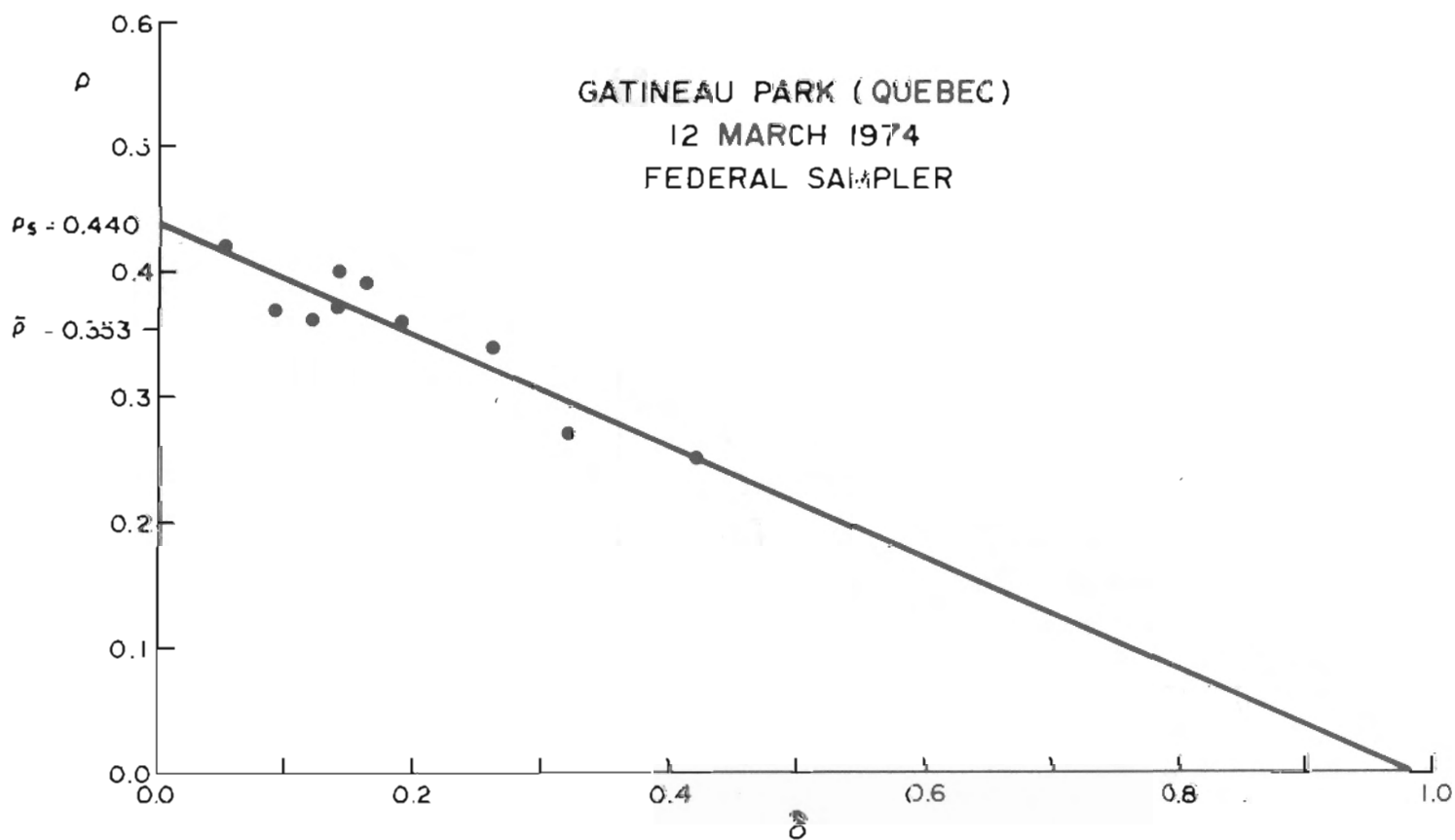
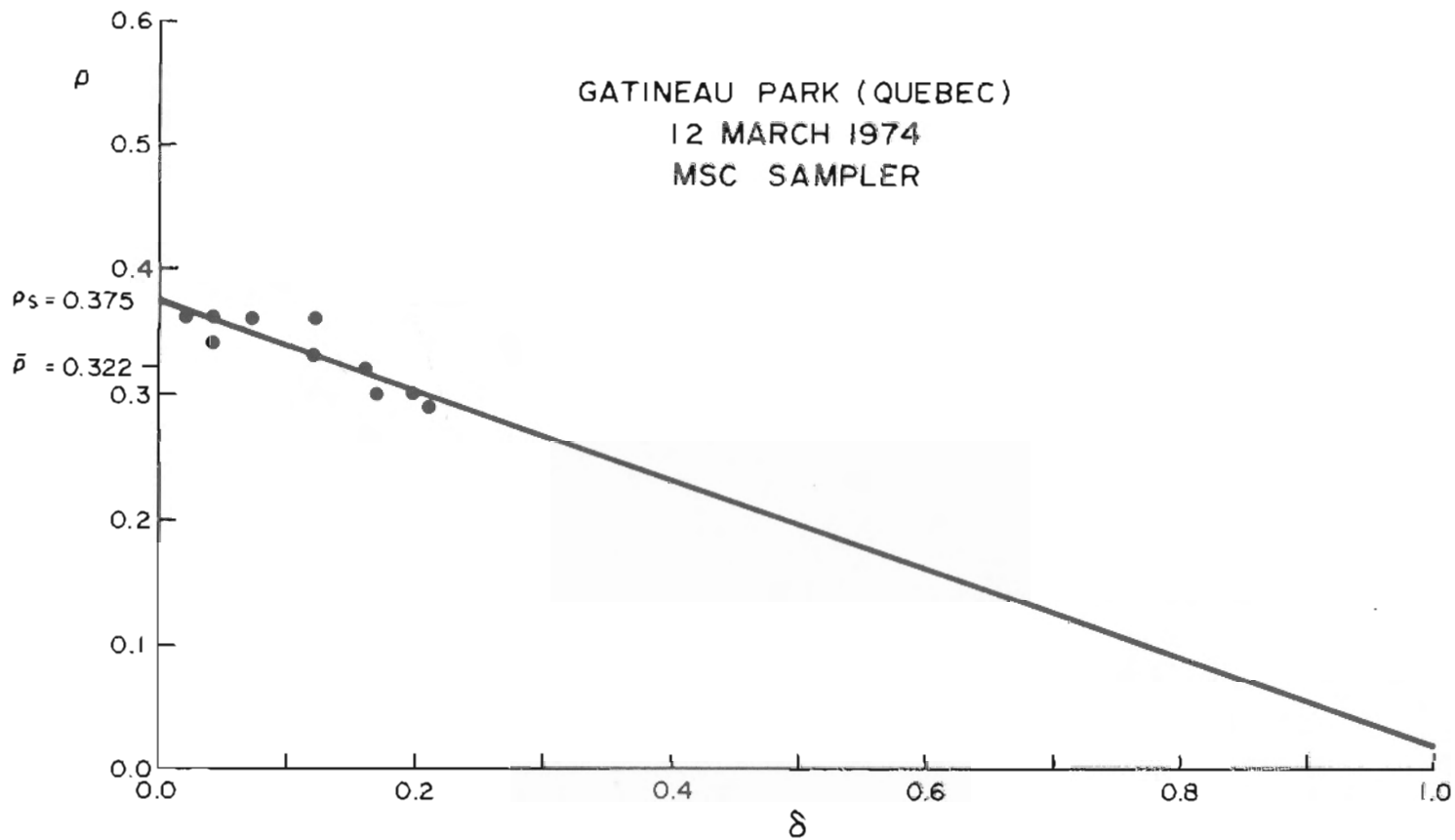


Fig. 7 Snow density measurements in the same area using two different types of samplers.

## Acknowledgements

We wish to thank provincial and federal agencies who made original snow records available. This report was conceived while the first author was visiting Canada on a scientific exchange program administered by the National Research Council of Canada and the Czechoslovak Academy of Sciences.

## REFERENCES

- Atmospheric Environment Service, Environment Canada, Downsview, Ontario.  
Snow cover data Canada. Annual series.
- Freeman, T.G., Snow survey samplers and their accuracy. Proc. 22nd meeting, Eastern Snow Conference, February 4-5, 1965, pp. 1-10.
- McKay, G.A., S.R. Blackwell, Plains snowpack water equivalent from climatological records. Proc. 29th meeting, Western Snow Conference, Spokane, Washington, April 11-13, 1961, pp. 27-42.
- Turčan, J., V. Kozlík, Method of Elimination of Errors from Snowpack Density Measurement. Proc. Vth Conference of the Danube Countries on Hydrological Forecasting, May 12-14, 1969, Yugoslav Committee for I.H.D., Belgrade, pp. 33-38, 1970.
- Work, R.A., H.J. Stockwell, T.G. Freeman, R.T. Beaumont, Accuracy of field snow surveys in Western United States, including Alaska. Technical Report 163, U.S. Army CRRELL, Hanover, N.H., 43 p., 1965.