A PORTABLE PROFILING SNOW GAUGE

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RESULTS OF FIELD TESTS ON GLACIERS 1/

By

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Introduction

The DIGIRAY PSG 1 portable profiling snow gauge was designed primarily to monitor the deep forest snowpacks of the Sierra Nevada. This paper describes tests of the instrument made in the rather different environment of the seasonal snowpacks on glaciers in British Columbia and Alberta.

Instrument description

A detailed description of the instrument has been given by Blincow and Dominey (1974); therefore only a brief description is given here. The Digiray is a single probe instrument designed to be used in conjunction with a standard Mt. Rose sampler. A core is removed from the snowpack and the empty Mt. Rose tube is replaced in the pack. The Digiray is then fixed to the top of the Mt. Rose tube and a density profile made. A probe containing both a Kr-85 gaseous source and a Geiger Müller tube are lowered at either 0.5 or 1.0 cm/sec into the pack. Backscatter counts, proportional to the snowpack density are accumulated over either a 3-second or a 6-second time interval. The change in density can be monitored visually on a dial or can be recorded on a strip-chart recorder. The total water content of the pack can be read from a total count accumulator. The probe can be halted at any point in its descent or ascent of the tube to gain a more precise reading for a particular layer - the total water indicator is not affected by such a halt. Density of a donut shaped volume some 5 cm thick and from just outside the Mt. Rose tube to a distance of some 30 cm from the tube is monitored at any given instant. This represents a volume of 10,000 to 15,000 cm^3. It is important that the snow in this volume is in situ and has not been affected by the sampling procedure.

Glacier snowpacks

The seasonal snowpacks on glaciers sampled in the course of testing the Digiray were varied in their characteristics. On the continental Peyto Glacier in Southern Alberta pack depth at the end of winter varied between 1.5 m and 4 m and temperatures within the pack ranged to as low as $-6.0^{\circ}C$; at the end of summer the packs were at most 2 m deep and were isothermal at $0^{\circ}C$. The maritime Sentinen Glacier, Coast Range, British Columbia had packs up to 8 m deep at the end of winter, up to 6 m deep at the end of summer. Mean pack density is usually between 0.3 and 0.6 g/cm^3 at all times. A characteristic of glacier packs, most especially before they become isothermal at $0^{\circ}C$ is that they are very compact due either to wind or to the refreezing of liquid water in the form of lenses or pipes. The standard method of measuring pack density adopted throughout the International Hydrological Decade on these glaciers was by digging a pit and taking cores from the pit walls. This procedure, described by Østrem and Stanley (1969), can be a very time-consuming operation. Indeed it is often such a slow process (a deep pit might take 10 man-days or more to excavate) that few pits are dug. Thus, not only is the sample of mean pack density measurements very small, but pits are often made on occasions several days apart which can lead to non-comparable results especially if any melting takes place between successive measurements in different pits. Schytt (1973) has documented the rapid changes in density which take place on Storglaciären, Sweden, and has pointed out the desirability of simultaneous sampling of the pack over the whole glacier surface either before melting has started or after the snowpack has ripened.

Instrument operation

Transportation: As the instrument is used on several glaciers, large distances apart, it has to be packaged in solid boxes for transportation. We have found it convenient

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to have two boxes which not only contain the Digiray components but also the Simpson X-Y recorder, the Mt. Rose sampling equipment, spare batteries, rolls of chart paper and repair tools. A critical factor determining the dimensions of the boxes is the capacity of the helicopter used to reach the glaciers. The instruments themselves stand up very well to much rough handling with the exception of the cable for lowering the probe which is liable to break if left taut during transport.

Once the glacier has been reached by helicopter it is found most convenient to carry the instruments in rucksacks to the sampling locations. Depending on the condition of the glacier, either two or three men are needed for this part of the operation.

Drilling the hole: In shallow packs, only 2-3 m deep, or in deeper packs which are isothermal at 0°C there are essentially no major problems in making a Mt. Rose bore hole. However, when the pack is cold, which is the usual case in spring surveys, and especially when it is deep there can be considerable difficulties in making the hole. The main reason for this is that when a partial core is removed from the pack small quantities of liquid melt water can form on both the inside and the outside of the tube. On re-entering the bore hole this water can refreeze thus either jamming the sampler in the hole or jamming the snow inside the tube thus halting progress. A common result is that too much turning force is exerted by the operator and a connecting collar may fail. Patience and perseverance are often required in large quantities.

A special problem encountered in the accumulation areas of maritime glaciers is that the transition between seasonal snow cover and underlying firn is often indistinct. Thus pack depth is difficult to determine by probing and often cannot be determined from a core. Experiments are underway to determine the feasibility of using chicken wire to mark the base of the seasonal pack. Once the position of the wire has been located by a metal detector the core can be taken down to that level.

Ease of instrument handling: Once the borehole has been made and the empty Mt. Rose sampler has been put back into the snowpack, with sealed end-tube replacing the cutter, the laborious work is at an end and measurements can be taken. The probe is lowered, if necessary, until it is at the level of the snow/air interface, the depth counter and total water index are set to zero, the X-Y recorder is set in motion and the probe is allowed to descend the tube. The probe itself or the electrical coil above it can snag on even very small irregularities within the tube such as roughness at tube joints or small pieces of ice frozen to the tube wall. The main danger is that the probe will suddenly free itself and drop, snapping the cable and plunging to the bottom of the hole.

Although the instrument specifications indicate that the probe will descent 10 m, it has been found that it will only descend to approximately 8 m; the electrical coil cable will not stretch further without a heavier probe.

Measurement accuracy

Total water equivalent: The accuracy of the total water equivalent (w.e.) index is high. Providing the instrument is properly calibrated, total w.e. of the pack measured in a pit core and by the Digiray usually agree within 2-5%. (This is excellent as there can be considerable horizontal variability within the pack itself.) Agreement is highest when packs are deepest. Furthermore the repeatability of measurements of total w.e. is high. If repeated measurements are made within the same hole, no matter which combination of travel speed and time constant is used successive measurements of total w.e. will be within about 5% of each other in a 1 m pack, and within 1-2% of each other in a 5 m pack. This is a very satisfactory result.

Profile of density with depth: While the results of total w.e. are very encouraging the profile results are not so encouraging. There are a number of reasons for this, some inherent in the nature of the pack being monitored and some due to instrument design. Illustration of these points is given in Figure 1, in which all the profiles were made at a travel speed of 1.0 cm/sec.

Figure 1 shows that, except in the top 20-30 cm of the pack, there is very little overall change in density with depth. The density in each successive meter of pack is fairly constant. This condition may well not prevail at all times of the year, especially when melt water, travelling down through the pack is temporarily ponded by ice layers. The Digiray will certainly be able to detect any gross density variations.

Figure 2 shows a detailed section through the top 150 cm of the pack, a profile typical of a maritime glacier pack in late summer. There are few really thick ice layers, but many thin, discontinuous lenses. Even the 5 cm thick layer at 80 cm depth is not horizontal. Thus any ice lens is likely to occupy only a small proportion of the volume being sampled at a particular instant. As the probe will be continuously moving while in the profiling mode density will be integrated over a larger volume. For these reasons even thick ice lenses may not show clearly on the density profile.

If the probe is held immobile at a particular depth in the snowpack the read-out of density will vary (greater variation will occur at higher densities; variation will decrease with a longer time constant). With a time constant of 3 seconds (T1) the standard deviation of the variation ranged from 0.005 g/cm^3 at a density of 0.03 g/cm^3 to 0.014 g/cm^3 at a density of 0.60 g/cm^3. With a time constant of 6 seconds (T2) the standard deviation of the variation ranged from 0.004 g/cm^3 at a density of 0.03 g/cm^3 to 0.010 g/cm^3 at a density of 0.60 g/cm^3. Error bands are plotted at 2 standard deviations from the central read-out line in Figure 1. It is evident in comparing the T1 and T2 outputs that the T2 error band is narrow but that the T2 graph is smoother, i.e. local irregularities due in part to the presence of ice lenses tend to be obliterated. Even on the T1 trace it is only possible to detect the presence of substantial ice layers.

It can also be seen that the graphs are shifted vertically compared to the true positions of ice lenses. Because of the time lag in the output the presence of a lens will not be registered until after the probe has passed it. The same phenomenon is seen as the probe travels from the air into the pack - it is not until the probe is about 20 cm into the pack that the true density is registered (there was no layer of less dense snow at the surface). This effect is clearly seen in Figure 1 when the downward and upward T1 traces are examined. The 5 cm ice layer at 80 cm depth is displaced downwards in the down trace and upwards in the up trace. A composite of a down and up trace must be made if the depth at which ice lenses occur is to be accurately plotted.

A minor source of error is that the collars joining sections of Mt. Rose tubing together register a small reading - thus the density at the level of a collar will be increased by 2-5%.

An irritant, although not necessarily a source of error, is that while the chart paper on the X-Y recorder moves at a constant speed, there is a difference in the upward and downward speeds at which the probe travels. Travelling with gravity on the downward profile, the probe moves about 10% faster than on the upward profile. The upward graphical trace is thus an elongated mirror image of the downward trace; this means that the traces cannot be overlaid to make comparisons. In Figure 1 such distortions have been eliminated.

Summary and recommendations

For the glacier snowpacks used in the tests described here it has been found that when the Digiray is used only to measure total w.e., it is highly satisfactory and is particularly useful in deep snowpacks where pit digging is so laborious. The instrument is not nearly as satisfactory as a profiling instrument; however, this is not so much a criticism of the instrument as an observation on the structure of a typical glacier snowpack. The instrument does have an important advantage in that it is sampling a large volume of undisturbed snow, which cannot be claimed for the Mt. Rose sampler in its conventional usage.

For glacier packs the instrument is best suited to depths of 3-6 m. Below this depth, pits are usually not hard to dig, while above this depth there are often difficulties in making a core with the Mt. Rose sampler. It is proposed to continue to dig at least one pit per glacier so that standard measurements can be compared to Digiray measurements. Unfortunately back-up equipment will have to be available for digging pits in case of an instrument malfunction.

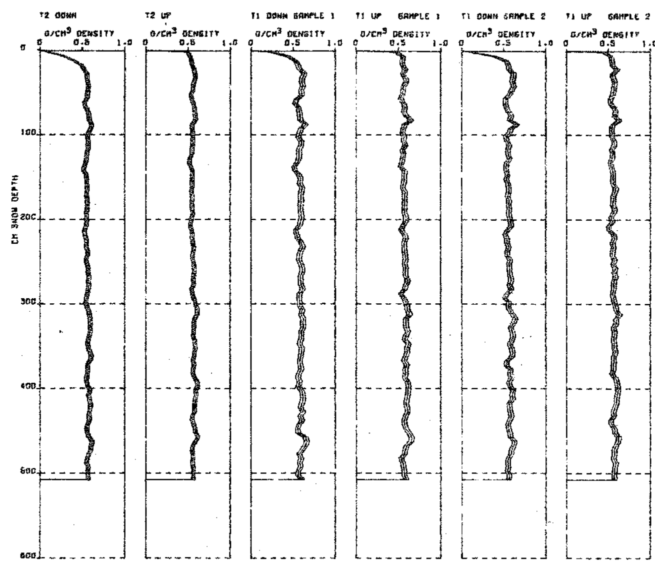

Figure 1. Digiray profiles, Sentinel Glacier 23 Sept. '74

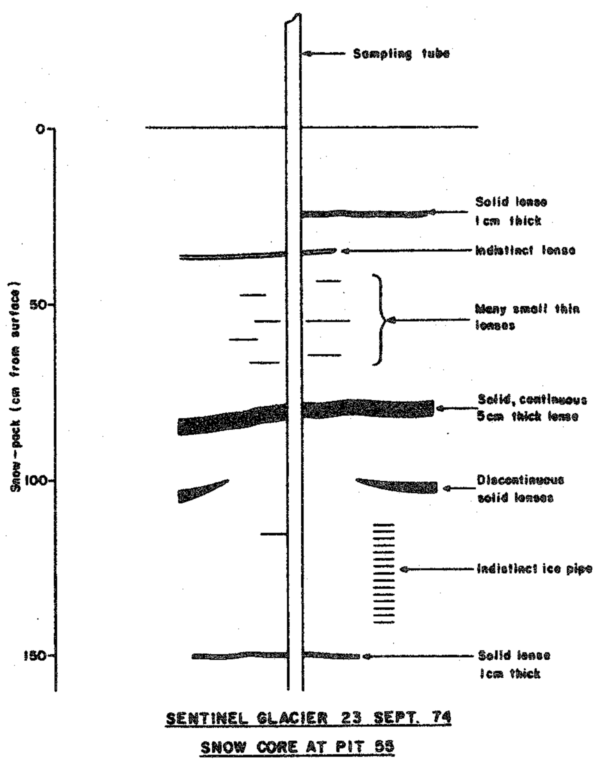

Figure 2.

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