NOTE ON THE FREE WATER CONTENT OF AUSTRALIAN SNOW

by

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1. INTRODUCTION.

An extensive snow cover isfound on the Australian Alps each year from May until October or November with isolated drifts persisting well into the summer. Information about this snow has been and is being collected by various water and power supply authorities but these observations appear to have been restricted so far to the extent and the thickness of the snow cover together with some estimates or measurementsof its liquid water equivalent. While this information permits a prediction of the total amount of water that will probably become available, it does not help towards assessing details of the melting process, such as e.g. the rate at which the snow will turn into water under different weather conditions, which can be of crucial importance from the operational point of view.

It might seem at first sight that a prediction of these details would require information regarding the temperature of the snow as function of location, depth, and time. However thermodynamic considerations taking account of the low thermal conductivity and specific heat of snow together with its large heat of fusion lead to the conclusion that the temperature of the snow must be 32°F throughout the cover before appreciable melting can take place (Wilson, 1941). Otherwise any water percolating downwards after melting has occurred at the snow surface will simply freeze again in the colder snow before reaching the ground. But while the uniform temperature of 32°F throughout the snow cover is a necessary condition for an appreciable release of melt water, it is not a sufficient one since snow can hold a good deal of liquid water in suspension against gravity by capillary forces. This incidentally implies that once the melting temperature has been established throughout the cover it will tend to persist even with considerably lower air temperatures. The latter will merely lead to the freezing of a thin top crust while lower layers do not cool to the completely frozen state.

To apply the foregoing to the Australian Alps we note that even at their highest points the air temperature rarely falls for more than 3 or 4 days below 32°F and can substantially exceed that value at any time during the winter. It follows then that the Australian snow cover, apart from a top crust a couple of inches thick, should throughout the year be at the temperature of 32°F and contain a proportion of unfrozen or "free" water. The release of this water requires no heat apart from the comparatively small amount needed to destroy or perhaps merely change in some way the surrounding ice matrix.

The free water content of snow has been intensively studied overseas in the higher latitudes and mountain regions of the northern hemisphere. There, however, it represents largely a spring feature and thus only one of many problems associated with snow, whereas its role under Australian conditions seems likely to be a central one. In view of this the free water content of Australian snow was made the subject of a research program at the Meteorology Department, University of Melbourne, with preliminary results and future aims outlined in the following.

2. PRELIMINARY METHODS AND RESULTS

The simplest method of determining the free water content of snow employs a hot water calorimeter (Bernard and Wilson, 1941). If S grams of snow, including F grams of free water, are injected into a calorimeter of water equivalent X containing W grams of water at the initial temperature t_0, the water temperature will eventually drop to the final steady value t_1. We have then the heat balance relation

$$(W + X)\, t_0 = (W + X + S)\, t_1 + 80\,(S - F) + H \quad . \quad . \quad (1)$$

where 80 cal/gr is the heat of fusion of ice and H represents a heat loss incurred during the insertion of the snow sample (the losses during the rest of the measurement can in general be disregarded). From Eq. (1) the free water content in percent is obtained as

$$f = 100\, F/S = 100 + 5(t_1 + H/S)/4 - 5(W+X)(t_0 - t_1)/4S \quad . \quad . \quad (2)$$

The water equivalent X is determined by inserting water of known temperature into the calorimeter instead of snow. The heat loss H is unknown and is generally neglected in computing f. However some of its characteristics can be determined from a series of free water content measurements using different quantities of the same snow. Thus if H were largely independent of the size of the snow sample, f should show an apparent increase with S. On the other hand if H would increase with the size of the snow sample (being e.g. directly related to the outflow from the calorimeter of the warm air replaced by the snow sample) f should no longer depend on S but might possibly show a spurious change with the initial amount of water W.

The foregoing can be illustrated by the results of preliminary free water content measurements made by the author at an altitude of approximately 5600 feet near Mt. Hotham in Victoria in September 1955. Without a sufficiently light and accurate balance the snow and water quantities were determined by volume rather than weight; tests showed this procedure to be accurate to the nearest gram or cc of water. The water equivalent of the quart-size thermos flask used as a calorimeter was found to be 13 grams. The snow was inserted into the calorimeter at first by means of a scoop; this was later replaced by a cylinder with a sliding lower panel which permitted the snow sample to be injected in one rapid movement.

Fig. 1 shows the results of all free water content measurements plotted against the weight of the snow, S. The observations with the two implements are indicated by different symbols. It appears from these that the heat loss for the first measurements (open circles) seems to have removed most of this effect. This is confirmed also by the consistency of a series of measurements of f which have been plotted against the time of day in Fig. 2. The first six values were obtained with snow from a few inches below the surface of a slope facing north, and in calm and sunny weather. The next measurement was made in the same way after sunset, while the remaining value represents the apparent free water content for snow from the frozen top crust. The negative water content derived in this case from equation (2) could be interpreted more realistically as arising from completely frozen snow at a temperature slightly below 0°C. Thus by putting $F = 0$ in Eq. (1) and adding a term $0.5\ t_1$ on the right, where t_1 is the temperature of the ice (of specific heat 0.5 cal/gr) we obtain a relation for t_1 which in this case gave the value of $-2.8^{\circ}C$ for the temperature of the dry ice crust immediately above the melting snow with 8 to 9% of free water.

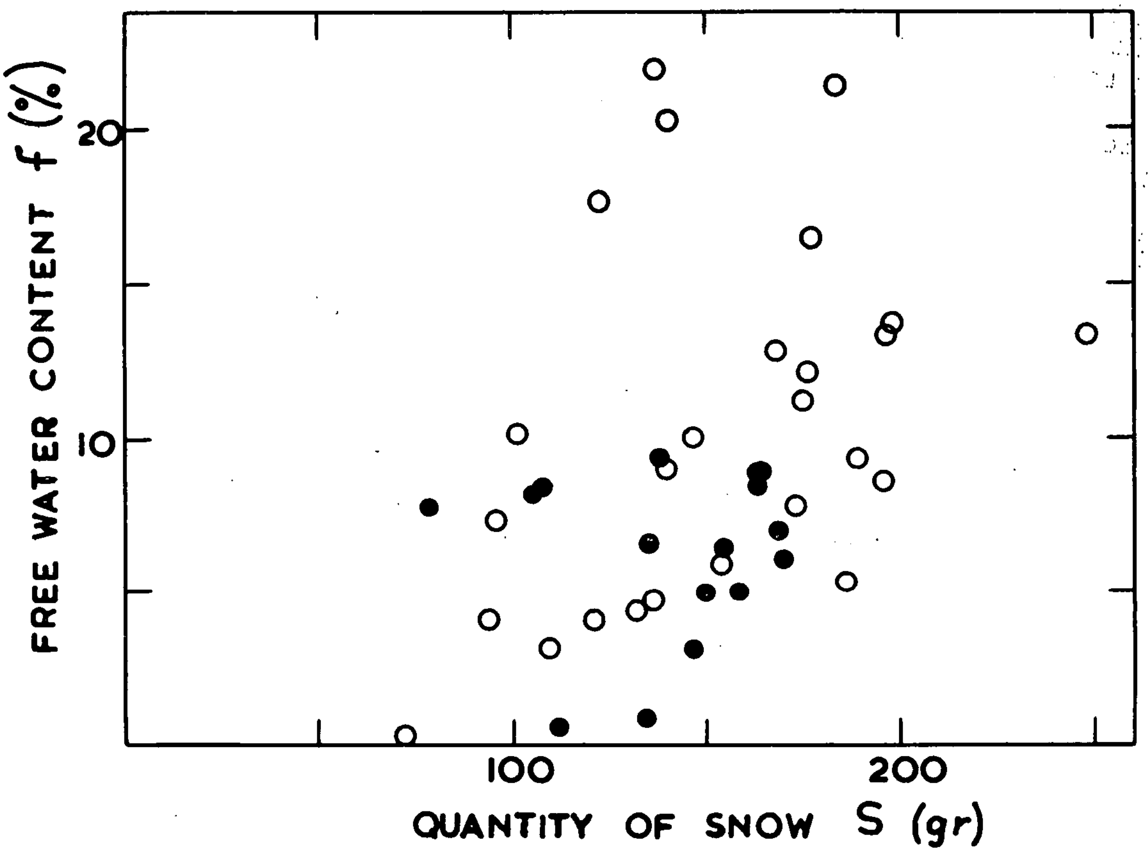
FREE WATER CONTENT f (%)
20
10
100
200
QUANTITY OF SNOW S (gr)

FIG. 1.

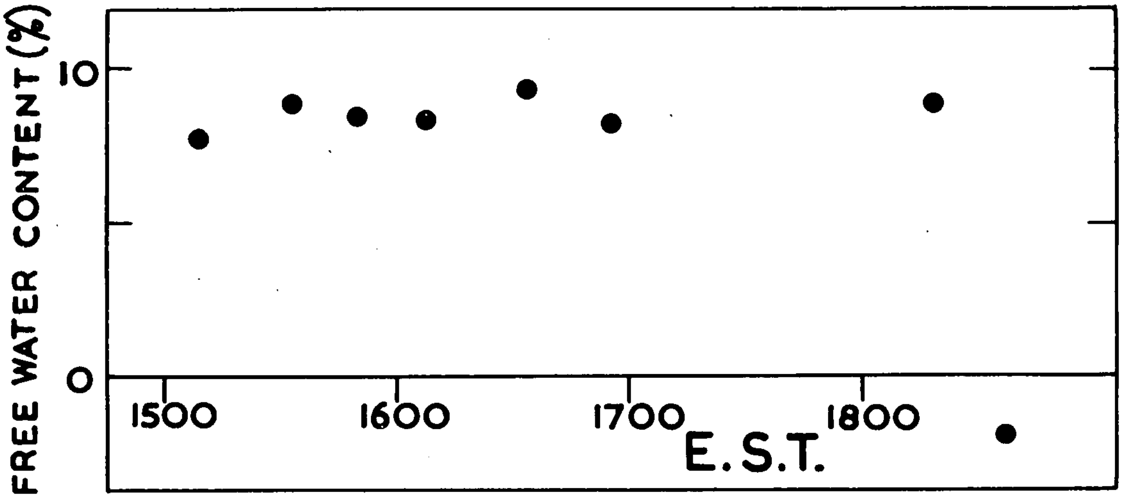
FREE WATER CONTENT (%)
10
0
1500
1600
1700
1800
E.S.T.

FIG. 2.

3. FUTURE PLANS

Further work will have to establish in the first place the variation of the free water content of the Australian snow with location and time of the year. This raises the problem of a simple technique since for the extensive field measurements required the hot water calorimeter is hardly suited. The same can be said of most other methods evolved so far which have been reviewed by Halliday (1950). For example there is an attractive method due to Croce which avoids the heat loss problem by leaving the calorimeter at 32°F while the snow is being melted by means of a measured electric current. The difficulty lies in the amount of current required. Assuming 100% efficiency and a 12 volt battery, 28 ampere seconds are needed to melt one gram of ice, or a current of 0.1 ampere for about 5 minutes. It is clear therefore that only a few small samples could be handled by this method in the field. Other published methods requiring accurate chemical analysis or centrifuge equipment would seem to involve corresponding difficulties for a large-scale field program.

A solution may however be provided by a very simple technique recently developed in Canada by Williams (personal communication from Mr. L.W. Gold), which utilizes the behaviour of the snow under compression. A very attractive feature of this approach is that it might lend itself to being incorporated in the procedure of establishing water equivalents developed by Church in the U.S.A. and used in Australia by the Snowy Mountains Hydroelectric Authority. In this procedure a snow core is obtained by forcing through the snow to the ground a long tube composed of 2'6" sections, each of which is subsequently weighed with the snow core inside it. It would probably not be difficult to apply a compressibility test to the same snow cores in order to determine the free water content of different layers. Experiments along these lines are planned for the coming winter.

In addition to the climatological problem of variation in the free water content with location and time, there is what might be termed the glaciological one of the differences in the structure of the supporting ice matrix which account for the changes in the free water content. This will probably require observations before and after periods of intense heating at the snow surface, viz. of strong warm and/or moist wind; Wilson (1941) has shown that other factors such as radiation or warm rain are much lessimportant. The free water content measurements in this case would be more in the nature of laboratory ones and might be made by means of an instrument developed by Gerdel (1954) which utilizes the different dielectric constants of ice and water. As this technique yields instantaneous and point valuesit could be used in conjunction with a microanalysis of the ice matrix.

Results of the work along these two main lines cannot be anticipated but there is justification for the hope that they will contribute to a better understanding of the hydrology of SE Australia.

4. ACKNOWLEDGEMENTS

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