DIURNAL FLUCTUATION OF FREE-WATER CONTENT AND DENSITY IN A MELTING SNOWPACK

By S. E. Rantz 1/

INTRODUCTION

This paper presents the results of a study made in 1948 as part of the research program of the Cooperative Snow Investigations of the Corps of Engineers, U. S. Army, and the U. S. Weather Bureau. The U. S. Geological Survey and other Federal agencies were minor participants in the program. The objective of this particular study was to determine whether there were measurable diurnal fluctuations in free-water content and density in a melting snowpack. Because the writer is not aware of any similar experiment performed in the last 14 years, it does not appear inappropriate to discuss the study at this late date.

DESCRIPTION OF EXPERIMENT

This study was made at the Central Sierra Snow Laboratory in California at an altitude of 6,900 feet. For sampling purposes, a pit was dug in the snow near the headquarters building in an area where the ground and snow surfaces were level. The cross section of the snowpack showed six principal snow layers separated by ice planes (old crusts); in the lower layers there were numerous minor ice planes that affected the homogeneity of those layers. Each of the six main snow layers was sampled at 4-hour intervals by removing a horizontal snow core from midway between the ice planes. These cores, which were 20 inches in length, were taken from the south face of the pit. The density of the cores was determined by weighing, and the free-water content was determined by calorimetric methods. At approximately the same time that horizontal samples were removed from the pit, two vertical snow cores were taken from the snowfield about 30 feet south of the experiment site, to determine the average density and water equivalent of the entire depth of the snowpack. This measured total water equivalent and average density agreed closely with composite values of density and water equivalent that were computed by weighing the mass of each horizontal sample in accordance with the depth of the snow layer from which it was extracted.

DISCUSSION OF RESULTS

Three days prior to the start of this experiment, there had been a snow storm that brought 19.1 inches of snow having a water equivalent of 1.99 inches. There was little thaw immediately after the storm because of the low temperatures that prevailed. Consequently, when the tests began at 11 a.m. on May 3, the snow in the top layer was comparatively fresh. The snowpack at that time was 65 inches deep and was isothermal throughout at 32°F. The top layer of snow had a density (specific gravity) of 22 percent; the density of all other layers was about 40 percent. By the evening of May 3, however, the density of the upper layer reached 38 percent and finally 40 percent, but it never quite equaled the higher density of the other layers, which also increased during the course of the experiment. The experiment was concluded at midnight on May 4, 37 hours after it had started. By this time the snowpack was 54 inches deep, having shrunk 11 inches. Most of the shrinkage was in the upper two layers.

The results of the experiment are presented graphically in Figure 1. Graph (a) at the top of the figure shows the air temperature observed about 5 feet above the snow surface at a site 50 feet from the sampling pit. The diurnal fluctuation associated with clear weather is apparent. Incident solar radiation, not shown on the graph, followed a similar diurnal pattern that was out of phase with air temperature only to the extent that the peak radiation occurred at noon, whereas the maximum air temperature occurred at about 2 p. m. Below the plot of air temperature are graphs (b), showing the free-water content in each of the six snow layers. In each of these graphs the horizontal sample is identified by its elevation above the ground at the start of the experiment. These elevations decreased with time as the snowpack shrank but the various layers, of course, retained their relative positions. The six curves were drawn to average the plotted points. The curves clearly show a diurnal trend that is closely related to the diurnal variation in air temperature and solar radiation, which indicates that the fluctuation in free-water content is in phase with the diurnal fluctuation of the snowmelt rate.

The scatter of the plotted points is attributed partly to observational error and partly to the heterogeneous composition of the snowpack. Anyone who has ever added fuchsine dye to the surface of a melting snowpack to trace the drainage path of melt water is immediately struck by the spotty character of the water-retaining and water-transmitting areas of the pack. Fuchsine dye applied to the surface of the snow in the immediate vicinity of the test area showed this snowpack, too, as having the commonly-observed characteristic of non-uniform distribution of melt-water drainage. The dashed lines connecting the peaks and troughs of the graphs indicate a lag of about 3 hours in the drainage of free water from the upper layers to the ground. It will be noted that the maximum percentage of free water in the upper layers exceeded the maximum percentage in the lower layers. This difference is explained by the facts that (1) the lower layers are not exposed

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either to solar radiation or to the warm air above the pack, and therefore experience no appreciable melting; and (2) in its transmission through the pack, some of the melt water is temporarily stored in the pack. The troughts of the graphs indicate that capillary water retained in the pack amounted to about 3 percent of the water equivalent of the snowpack. Free water in excess of 3 percent was gravitational water in transit through the pack. Graph (c) shows the diurnal variation in free-water content computed for the weighted average of the six samples.

The diurnal variation of average density in the snowpack is shown in graph (d). This curve, as would be expected, closely resembled the graph of average free-water content, because changes in density were due primarily to changing amounts of free water released by snowmelt. No curves are shown on Figure 1 for density variation in the individual snow layers, but density variations in these layers were quite similar to those for free-water content then in the individual layers. These density fluctuations were superimposed on a generally increasing trend in density.

Graph (e) presents the change in the depth of the snowpack as melting progressed. The flat portions of the curve represent conditions at night when the melting process ceased or was negligible. Graph (f), showing the variation in water equivalent of the snowpack, has a downward trend because of ablation of the pack, but in addition, there is a slight diurnal fluctuation that follo the variation in density. In places on the graph the pattern of fluctuation shows the water equivalent to have increased somewhat as melting progressed, which is an apparent contradiction of the law of conservation of mass. This anomaly may be due in part to sampling error, in part to observational error, and in part, possibly, to the fact that melt water originating elsewhere may have been in lateral transit through the test area. Normally much of the movement of free water in an old snowpack is lateral along horizontal ice planes until a permeable part of the ice plane is reached; at that time vertical drainage occurs.

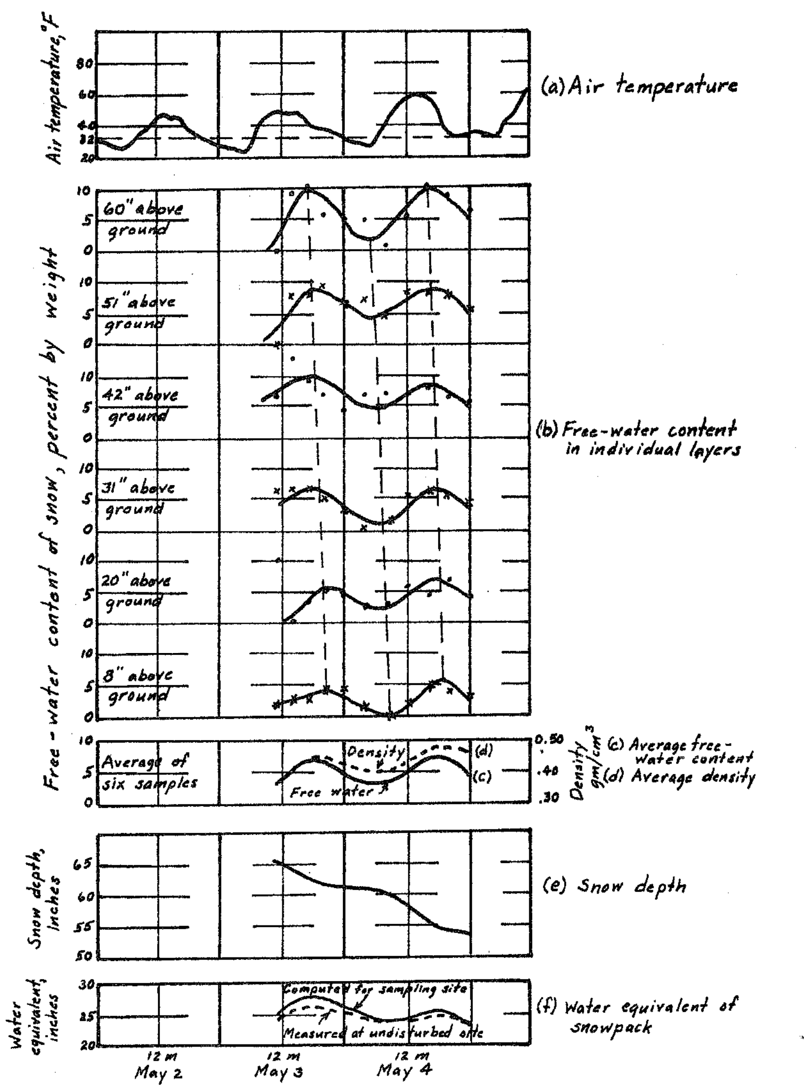

Figure 1.- Diurnal fluctuation of snowpack characteristics, Central Sierra Snow Laboratory, May 1948.