BRIDGER DATA SYSTEM MULTIPOINT SNOWPACK THERMOMETRY

By

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Introduction

In the spring of 1966, a program designed to study various aspects of the thermal regime of the seasonal mountain snowpack was initiated by Montana State University at its Bridger Hydrometeorological Research Area. One phase of this study has been an investigation of the stability and magnitude of the air-snow interface temperature gradient. The purpose of this study is to determine if the interface temperature gradient can be used as a reliable indicator of the snow surface.

Preliminary data indicated that the air-snow interface was commonly characterized by a sharp inflection in the temperature gradient existing across it. This suggested that such an inflected gradient, if it were found to be an essentially constant phenomenon, could be used to delineate the snow depth at points of interest where on-site visits were impractical. In the fall of 1966, an experiment designed specifically to investigate the constancy of this inflection under the variety of climatic variations which occur at the test site during an entire winter was undertaken. This paper presents a preliminary evaluation of the data obtained during the 1966-67 winter together with selected data from the tests in the spring of 1966. The data suggest that the measurement of the thermal regime across the air-snow interface on an essentially continuous basis may be a useful approach to the determination of snow depth and also short term accumulation rates.

Location

The Bridger Hydrometeorological Research Area is located 19 miles (30 km) north of Bozeman, Montana, on the east flank of the Bridger Range. The area includes several ski lifts, a variety of buildings, and an extensive data acquisition system. A complete description of the area has been made by R. Rickabaugh (1967). The environment is primarily subalpine with a yearly snowpack which ranges in depth from a maximum of 350 cm. to 150 cm.

The two research sites used for this experiment are located at an elevation of 7,200 ft. Both sites are in open glens with good wind protection afforded by surrounding stands of mountain fir and spruce. The area used in the spring of 1966 is identified by an area location number R-20. The area used for the winter of 1966-67 is identified as location V-23 (Rickabaugh, 1967). 2/

Equipment

This study was conducted using a 30 thermistor thermometer, (Figure 2), attached by cabling to the Bridger Area data acquisition system. The thermometry system consisted of 30 YSI thermistors with a 3000 ohm resistance at 25°C., spaced at 10 cm. intervals along a 3.5 m. plastic pipe from 10 cm. above the ground surface to a maximum height of 3.00 m. Each thermistor was protected by a 2.5 mm. length of nylon tubing to provide flexibility during periods of snow settlement and the entire assembly was painted a flat white to minimize radiational heating. This unit was then mounted to an "A" frame (Figure 1) located in a small clearing, attached to the data acquisition system and the entire unit, consisting of the thermistors, the thermistor bridge, cables and the analog to digital encoder, was calibrated using the data system and a precision decade resistor which demonstrated an accuracy of $\pm .2^{\circ}C$. During both test periods, the instrument and the "A" frame mount were installed prior to the first permanent snowfall of the season so as to disturb the natural stratigraphy of the snowpack as little as possible.

Normally, each of the thermistors was read by the data system on an hourly basis although during certain selected periods, this reading rate was increased to five minute intervals. Snow depth at the sensor was observed visually on a daily basis during the test period and is considered accurate to within $\pm$ 2 cm.

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Results -- Spring 1966

Operational Results.-- Operation during the spring of 1966 indicated normal operation of the equipment. The scanner and commutating networks were located at the site M-20.2/ This necessitated the use of storage batteries for operation of the equipment. During this period over 16,000 individual temperatures were taken and recorded. Settlement and melting of the spring snowpack caused bending of the individual thermometer elements and of the array support pipe. This was largely due to settlement and creep on the 23° slope. This change in thermometer position probably accounts for a 2-3 cm. uncertainty in the actual thermometer position. While settlement caused the thermometers to bend down, creep caused the thermometer column to kick out in a down slope direction. Due to this fortuitous compensation the net displacement was smaller than it would have been on a slope not subject to creep.

Rodents or porcupines apparently tried to eat some of the potting compounds which were used to support the thermistor beads. This resulted in the loss of the thermometers from 20 to 80 cm.

Experimental Results.-- Data taken during the six week period in the spring of 1966 was plotted by the computer in a series of temperature-versus-depth plots for each hour. A small section of this plot is shown in Figure 5 to illustrate the correlation between the measured snow depth and the point of inflection between the air temperature thermistors and the snow temperature thermistors. A scaler for estimating temperature has been provided in the lower left hand corner of Figure 5. The scale is 1°/C. per 1/10 inch of horizontal displacement.

Eleven thermistors were used to measure the air-snow temperatures. Thermistor locations are with reference to the ground as 0 cm. A spacing of 20 cm. was maintained between each thermistor in the snowpack and in the snow-air interface. The hourly plots start at 1800 on the 25th of April, 1966, and run to 2400 on the 26th of April, 1966. The measured snow depths at either end of the plot were obtained by linear interpolation from observed snow depths on adjacent days. This assumes a constant settlement rate.

Typical spring conditions of warm air and intense solar radiation prevailed prior to the period. The pack was isothermal up to 600 on the 26th of April at which point a cold front moved through the area dropping the air temperature to below freezing. A typical mid-winter dry snow followed with winds from 5-10 mph. Snowfall stopped at about 1500 on the 26th. This resulted in a total accumulation of 40 cm. to renew snowpack depth of 200 cm. at 2400. Air temperatures during this period of snowfall were below zero, with a low of -6° at 2400.

The effect of this cooling on the snowpack is shown by the strong positive surface gradient which developed during the last 12 hours. The snow surface can be easily estimated from the temperature data by noting the point of inflection in the temperature versus depth curve. This is very strongly evident in the 1200 to 2400 period on April 26. The error between the observed depth of 173 cm. at 1800 (4/25/66) and the estimated depth (dashed line) is largely due to the 20 cm. spacing used for the temperature measurements.

Results -- Winter 1966-67

Operational Results.-- The multipoint thermometer and its support structure were moved to a new site. This site had roughly the same exposure and elevation as the old site, with the exception that the slope angle was only about 5°. The thermometer was connected through the cabling system, to the scanner and digitizer in the Bridger Data Center. This eliminated the use of storage batteries at the site. Data collection began on the 12th of December, 1966. During this period of investigation, roughly 76,000 individual temperatures have been taken and recorded. Regular observations of snow depth and thermometer operation have also been made.

The principal problems which have been associated with the thermometer arrangement have been the development of wind holes around the thermometer column, the obstruction of settlement by the projecting thermometer tubes, and bending of the individual thermometer elements. Only one failure of the nylon thermometer tube has been observed. This occurred during the settlement of a very heavy sun crust which caused the nylon tube to be sheared from the main thermometer support column. Some creep of a very minor nature has been noted. This may become more of a problem during the warmer spring months.

Experimental Results.-- For the purposes of this paper several typical days have been selected and the temperature data examined. The ability to measure snow depth from gradient inflections depends upon essentially constant differences existing among the air, snow and interface gradients. Gradient 1 consists of that snow temperature gradient which exists immediately beneath the surface of the snowpack.

The second gradient results from the temperature drop across the snow-air interface. A third gradient consists of the zone between the first two pairs of thermometers above the surface. The position of these gradients is shown schematically in Figure 3.

An examination of the data from two days, January 9 and 9, will illustrate how the various gradients vary and relate. Snowfall during this period occurred in short showers of very low density dry snow. Air temperatures dropped to roughly -12^{o}C. at night and rose to a few degrees below zero during the day. The average temperature gradients during this two day period were as follows. Gradient 1, which is in the 10 cm. layer below the snow surface, was .08^{o}C./cm.; gradient 2, which was established across the snow-air interface was .08^{o}C./cm.; gradient 3, which was measured in the 10 cm. immediately above the snow-air interface was .04^{o}C./cm., or roughly half of the snow temperature gradients. The gradient 4, (See Figure 3), which was from 10 cm. above the snow-air interface to 1 meter above the surface averaged .001^{o}C./cm. From this data the surface gradient or inflection in the temperature curve is seen to be from twice to almost 100 times the upper air gradient.

If the temperature gradients are plotted against time for the two day periods examined, curves such as plotted in Figures 5 and 6 result. A visual examination of these curves indicates that only rarely do the air and surface gradients have the same magnitude. This is particularly true when inversions form such as at 1300 to 2400 on 10 February 1967. Significant differences are generally present in the early morning hours while at noon small gradients and gradient reversals appear to dominate. The period between 1500 on the 9th and 1200 on the 10th covers a period of snowfall during which the air temperature remained almost constantly at -5^{o}C. During this period snow and surface gradients were small and slightly negative. This would be expected under conditions of small radiant heat transfer and constant moderate air temperatures. Following the storm on the 10th strong back radiation from the snowpack evidently resulted in the development of the strong surface inversion which developed from around 1300 hrs. into the rest of the evening.

To determine the ability of an untrained observer to detect the snow-air interface by comparison of snow and air temperature gradients, the following test was set up.

The observer was given data from the Bridger data system. This consisted of serial numeric temperature readings typed in teletype format. The readings were ordered from the lowest thermistor, which in this case was located at 50 cm. from the ground surface to the highest thermistor located at 300 cm. from the ground. The observer knew that the thermistor at 300 cm. always gave the air temperature. With this information he was asked to locate the snow-air interface on the basis of the first significant temperature break. The results were plotted as estimated depth against actual depth and are shown as Figure 7. For convenience the 100% correlation line has been plotted through the data. With the exception of one point, 13 readings were within the instrument error of 10 cm. This uncertainty is mainly due to the spacing used in the construction of the probe.

Conclusions

1. The use of multipoint thermometry as a means of detecting the snow surface shows some promise. This method has potential use at remote locations where the amount of equipment and available power is limited.

2. The accuracy of the thermometry technique depends upon the spacing of the individual probe elements and upon the position of the maximum temperature gradient relative to the snow surface. From preliminary data the delineation of the snow surface appears to be best early in the morning and late in the day with the period around 1200 providing the poorest resolution.

3. Improvement of the instrument resolution can be achieved by reducing the probe spacing.

REFERENCES

2/ Rickabaugh, R. J., "Bridger Hydrometeorological Research Area and Facilities," Electronics Research Laboratory Interim Report, Montana State University, Bozeman, Montana, January 30, 1967.

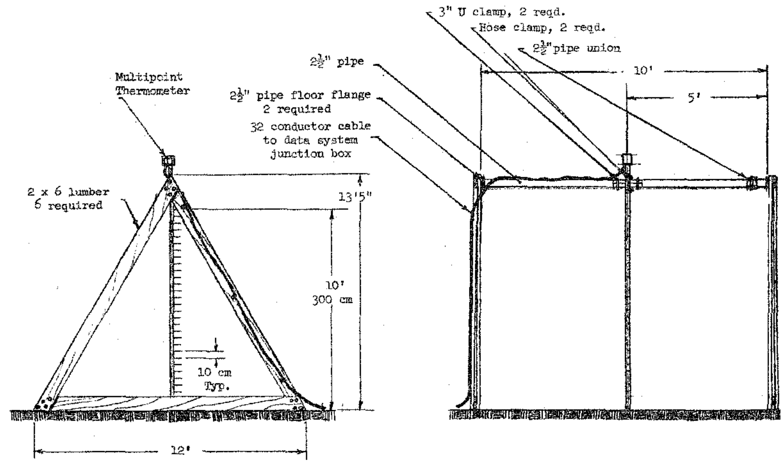

Figure 1. Multipoint Thermometer and Support Stand

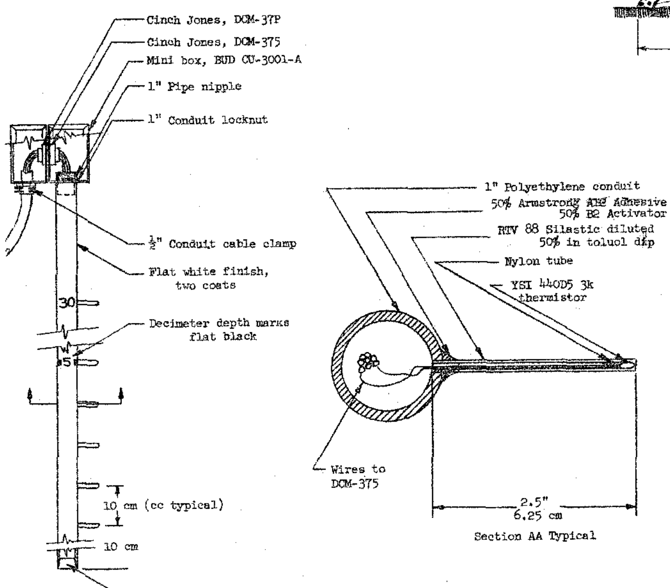

Figure 2. Multipoint Thermometer

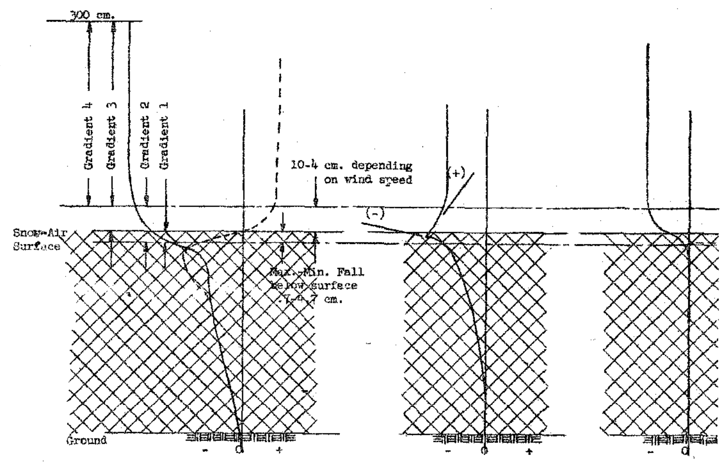

Figure 3a
Winter Pack

Figure 3b
Winter Night Inversion

Figure 3c
Isothermal Sp
Snow Pack

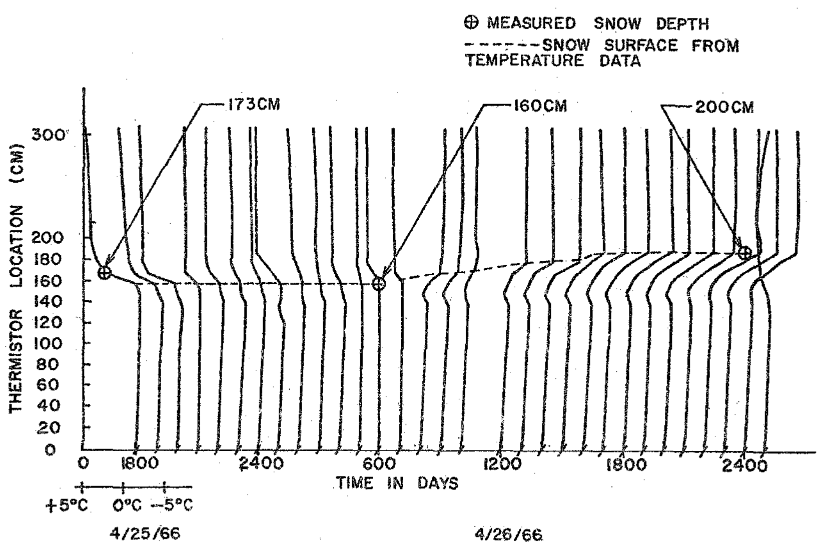

FIGURE 4 COMPUTER PLOT OF SNOW PACK
TEMPERATURE GRADIENTS SPRING 1966

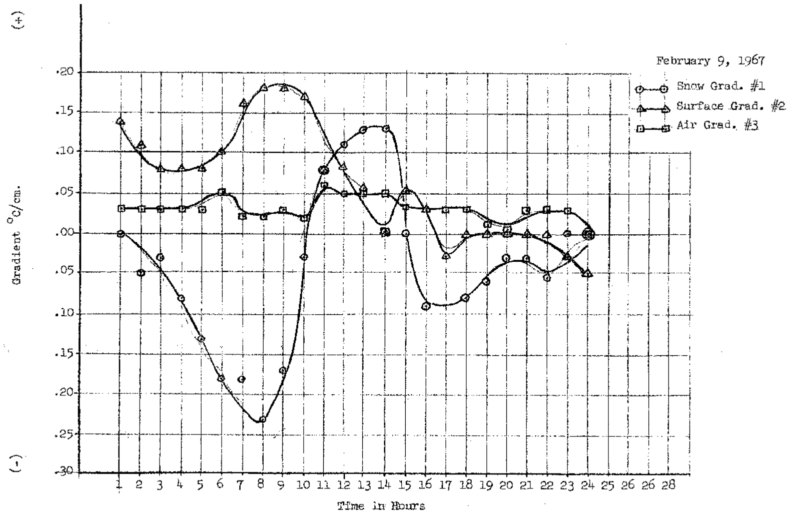

Figure 5. Snow-Air Temperature Gradient

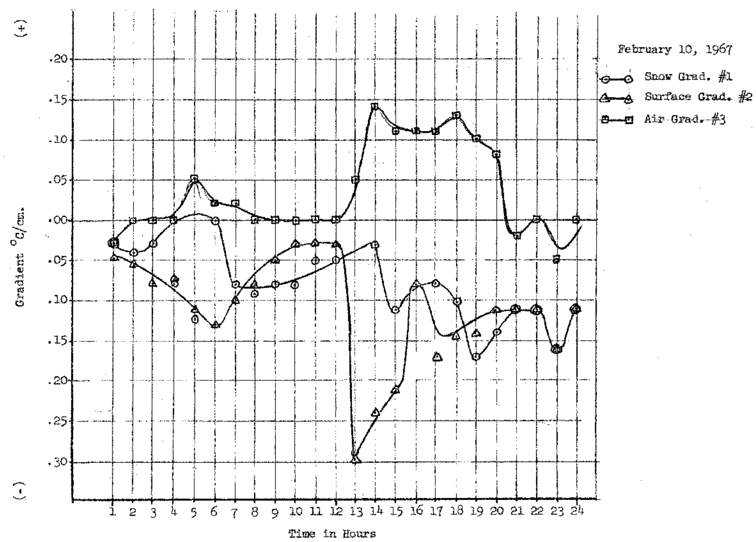

Figure 6. Snow Temperature Gradient

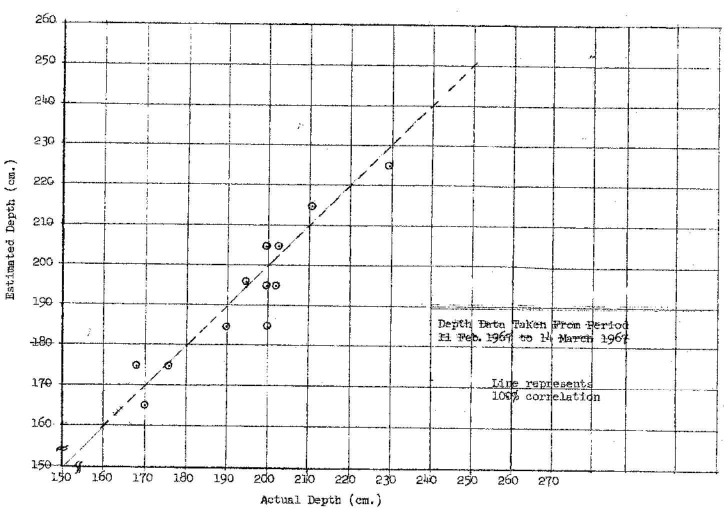

Figure 7. Estimated Depth Vs. Actual Depth