Minimizing Measurement Errors in Automated Snowpack Profile Temperature Measurements

by

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INTRODUCTION

Extensive snow research has been conducted over the years, but few techniques have been developed to accurately measure snowpack profile temperatures over a snow season. Accurate snowpack temperature measurement is critical for both avalanche and snowmelt-runoff forecasting. A continuous record of snowpack temperatures provides information on snow metamorphism, initiation of runoff, and snowpack depth over a season.

Several methods have been used to measure snowpack temperatures for example, snow thermometers, thermistors, and thermocouples. The most common method is to use snow thermometers in conjunction with an excavated snow pit. This method is impractical due to the labor required and destructive nature of excavating snow pits. Another method is to continually measure snowpack profile temperatures with thermistors. Thermistors are typically constructed from 24 gauge (0.51 mm diameter) or greater diameter copper wire. The high thermal conductivity of the copper wire in conjunction with the low conductivity and low heat capacity of the snowpack can cause large errors in temperature measurements. The errors are due to heat being conducted along the wires through the snowpack from the air above the snow surface. These errors can be greatly reduced by using small gauge thermocouple (TC) wire made of materials other than copper.

Two common types of thermocouples (TC) are copper-constantan (Type T) and chromel-constantan (Type E) TC wire. Common size wires are 24 gauge (0.51 mm) and 30 gauge (0.25 mm). Chromel-constantan thermocouple wire is preferable to copper-constantan. The thermal conductivity of both chromel and constantan is approximately 20 times lower than that of copper wire. For these reasons, we chose 30 gauge (0.25 mm diameter) Type E TC wire. The smaller diameter wire reduces the path for heat conduction by a factor of four over that provided by 24 gauge wire.

Tanner and Gaza [1990] recorded snowpack temperatures using a 17 junction TC string constructed from 30 gauge Type E TC wire. The TC string was constructed to minimize heat conduction from exposed TC wire by using a common constantan wire, minimizing the TC bundle to 18 wires. Nevertheless, heat conduction down the TC bundle resulted in recorded snow temperatures greater than 0^{o} C to depths of 400 mm below the snow surface in an isothermal snowpack. The purpose of this study was to develop a TC string which further minimized heat conduction and subsequent influence on snowpack temperature measurements.

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SITE DESCRIPTION AND METHODS

The study was conducted at Beaver Mountain ski resort (45°00'N, 111°30'W) located 32.9 km northeast of Logan, Utah. The study plot was constructed at 2600 m elevation on a 15° northeast aspect slope in a mixed deciduous and coniferous forest.

Thermocouple Ladder

In designing the supporting structure for the TC string, there were two primary objectives:

1. This objective was to horizontally separate the TC junction, at each measurement height, from the vertical bundle of wires comprising the TC string. This separation dampen the effects of heat conducted through the TC string.

2. The other objective was to minimize the destructive effects of the support structure, due to cavitation around support members, on the snowpack. The problem of cavitation plagues any in-situ snowpack profile measurement study.

The resulting design consisted of a ladder constructed from fine (11.3 kg test) mono-filament fishline (Figure 1). The ladder was suspended from an overhead supporting structure. The ladder structure supported 20 TCs from 100 to 2000 mm, at 100 mm spacing, in the snowpack. The TCs were routed from the ground surface, up the side of the ladder, and then, horizontally across for 300 mm on the mono-filament ladder rungs.

Instrumentation

TCs were connected to a 32 channel analog multiplexer (Campbell Scientific, Model AM416) and measured with a Campbell Scientific 21X Micrologger. Snowpack profile temperature measurements were taken every hour from February to complete snow ablation in early June. Each hour the datalogger rapidly measured each TC junction 10 times and recorded an average temperature for each TC junction. Data were collected automatically every 24 hours from Beaver Mountain to Logan, Utah over a radio telemetry link. The system was powered by a deep cycle marine battery continually trickle charged by a 10 watt solar panel.

Thermocouple Measurements

Thermocouples produce a signal proportional to the temperature difference between the measurement and reference junctions. In this case, the reference junctions were the analog multiplexer terminal wire connectors. Absolute temperature was determined by measuring the multiplexer connector temperatures with a thermistor taped to the multiplexer. Any temperature gradients existing between the thermistor location and the multiplexer connectors produce an error in the measurement of the TC junctions. To minimize temperature gradients, the multiplexer was housed in a picnic cooler buried in the snowpack.

The thermistor offset error (0.07° C) was determined with an ice bath calibration. The results presented in this paper have been corrected for this offset. The thermistor circuitry has a sensitivity of 377 *u*V at -10° C and 210 *u*V at 0° C, producing a resolution of 0.003° C and 0.005° C, respectively, when measured by the 21X Micrologger.

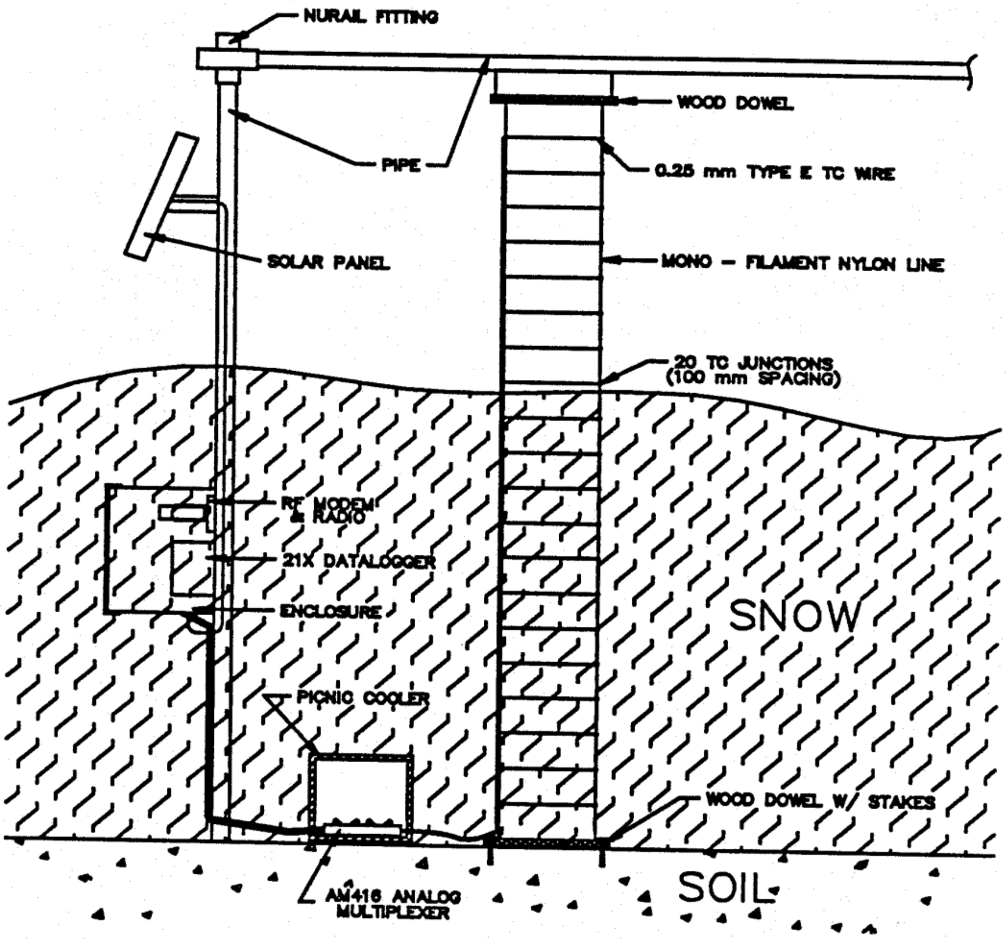

Figure 1. Graphical illustration of TC ladder construction and deployment at Beaver Mountain.

Type E TCs provide a 61 $uV^o C^{-1}$ signal and were measured with a resolution of $\pm 0.005^o$ C using the 5 mV measurement range with a 2.7 ms integration time on the datalogger. Considering the worst case scenario, overall measurement resolution is the sum of both the thermistor and TC resolution, or approximately 0.01^o C. To determine the extent of heat conduction errors in snowpack temperature measurements, we examined temperature data taken during wet, or isothermal conditions, where the entire snowpack was 0^o C.

RESULTS AND DISCUSSION

Snow depths reported in this paper were measured manually to provide exact information on the number of exposed TC junctions, number of buried TC junctions, and the depth of burial for the first TC junction under the snow surface. Average snowpack density was determined by snow tube measurements (Standard Federal Snow Sample Kit) and snow pit density measurements (Strong Stitch Density Scale) on the particular days examined in this paper.

Figure 2 is average hourly snowpack profile temperatures measured at 2400, 0400, 0800, 1200, 1600, and 2000 hours on May 5. On May 5, the snowpack was 1320 mm deep with an average density of 320 kgm^{-3}. Air temperature fluctuated from -6^o C to $+4^o$ C which resulted in the 1300 mm TC junction fluctuating from -1^o C to $+1^o$ C deviation from the actual temperature of 0^o C. This TC junction was 20 mm under the snow surface. This error must be due to the conduction of heat in and out of the TC string junctions to and from the warmer/colder air above the snowpack. Heat conduction errors are undetectable in Figure 2 for TC junctions buried by 100 mm or more of snow. In Figure 3, temperatures for TC junctions buried by more than 100 mm deep (1200 mm, 1100 mm, 1000 mm, and 900 mm) have been plotted for the 24-hour period on May 5.

In Figure 3, measured temperatures fluctuated from -0.15^o C to $+0.03^o$ C during the 24-hour period. This deviation from 0^o C is most likely due to heat conduction, as previously discussed, and radiant heating from incoming solar radiation penetrating the snowpack and subsequently heating of TC junctions immediately below the snow surface. For example, the 1200 mm TC junction closely follows the other TC junctions, but deviates from 1100 to 1600 hours which, is the period of maximum incoming solar radiation. After 1600 hours, the TC ladder is no longer exposed to direct solar radiation, and the 1200 mm temperature rapidly drops to closely track the other TC junctions.

On May 5, hourly average air temperatures recorded at 2400, 0400, and 0800 hours for the 1400 mm TC junction were colder than the temperature measured immediately above and below this level. The fact that the temperatures were warmer above and below eliminates conduction as a possible source of error because no colder source is available to conduct heat. The cooling must be the result of long-wave radiant cooling producing a thin layer of colder air above the snow surface. Likewise, the average hourly air temperature recorded at 1200 hours by the 1400 mm TC junction was warmer than the junctions immediately above and below. Unlike the previous example, this is most likely the result of incoming and reflected solar radiation heating the TC junction.

Average hourly snowpack profile temperatures are shown for May 8 in Figure 4. The snowpack depth was 1280 mm with an average density of 300 kgm^{-3}. The total average air temperature fluctuation was 12^o C resulting in a 2^o C temperature fluctuation at the 1200 mm TC junction. The 1300 mm TC junction shows the effects of radiant cooling at 0400 hours, similar to May 5. The influence of solar radiation on snowpack temperature measurement is evident in Figure 5.

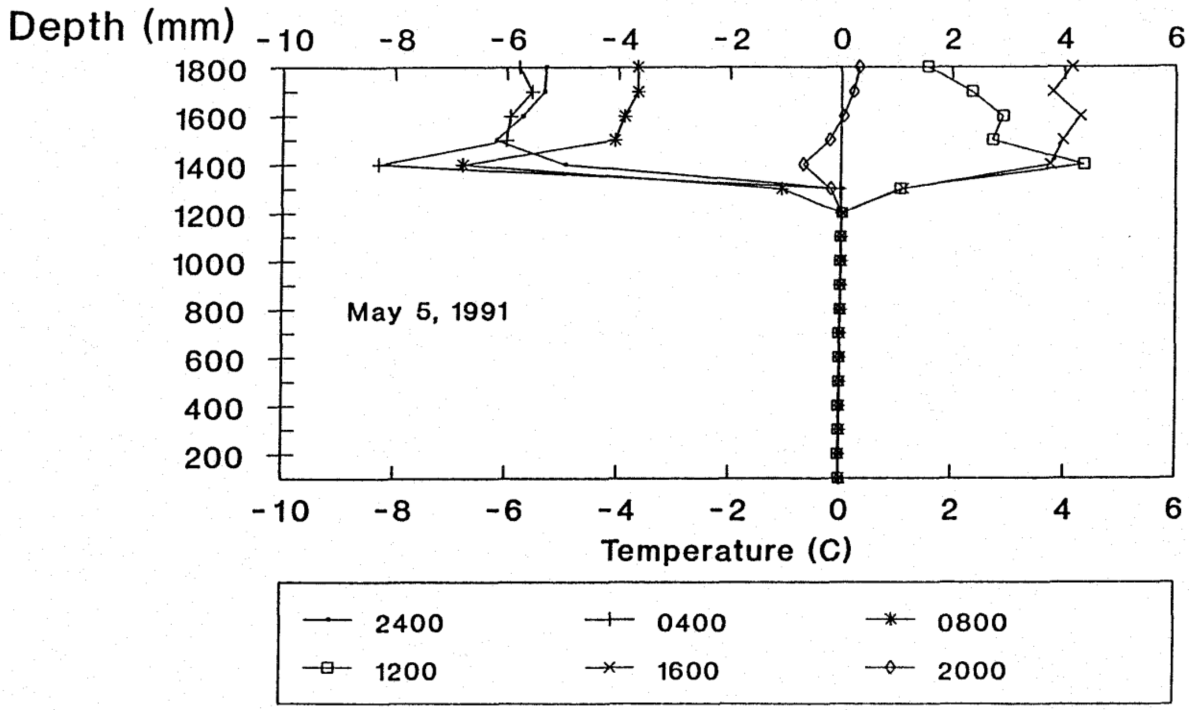

Figure 2. Hourly average temperature profile measurements in an isothermal snowpack on May 5, 1991. The snowpack was 1320 mm deep with an average density of 320 kgm^{-3}.

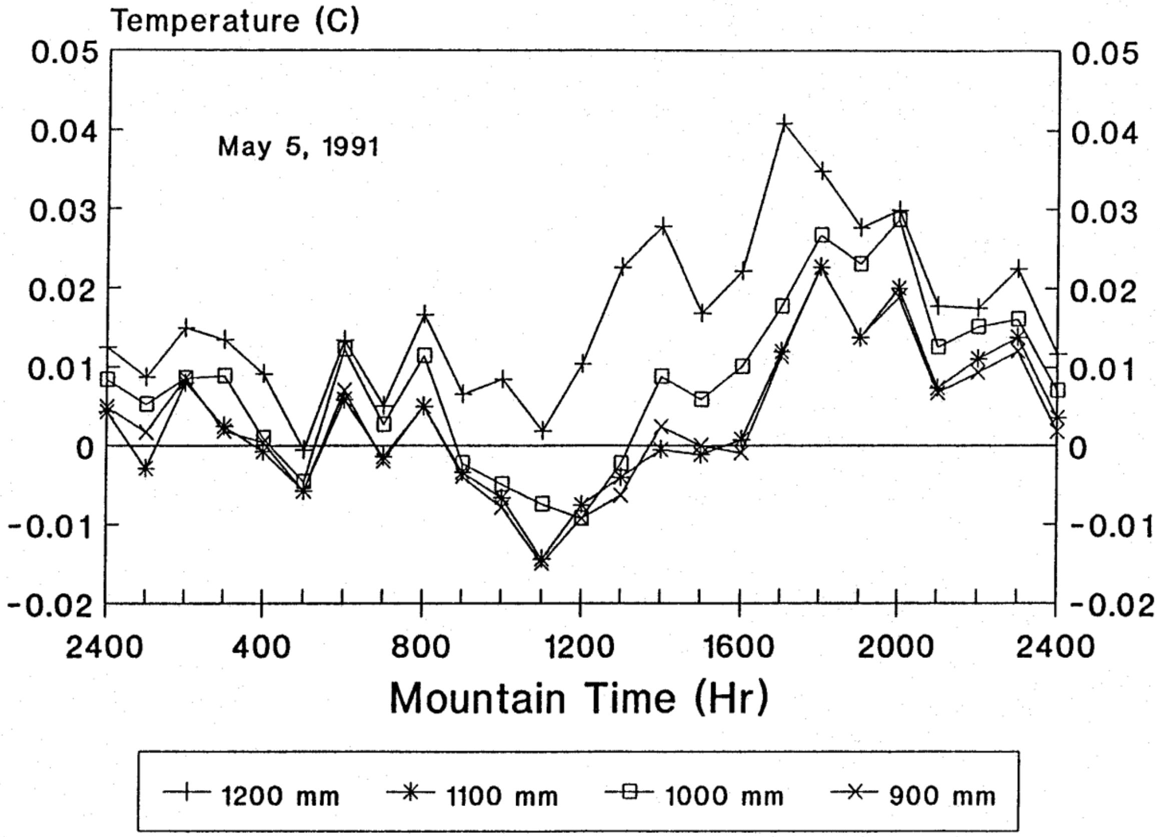

Figure 3. Average hourly snow temperatures for four TC junctions closest to the snow surface buried a minimum of 100 mm for a 24-hour period on May 5, 1991.

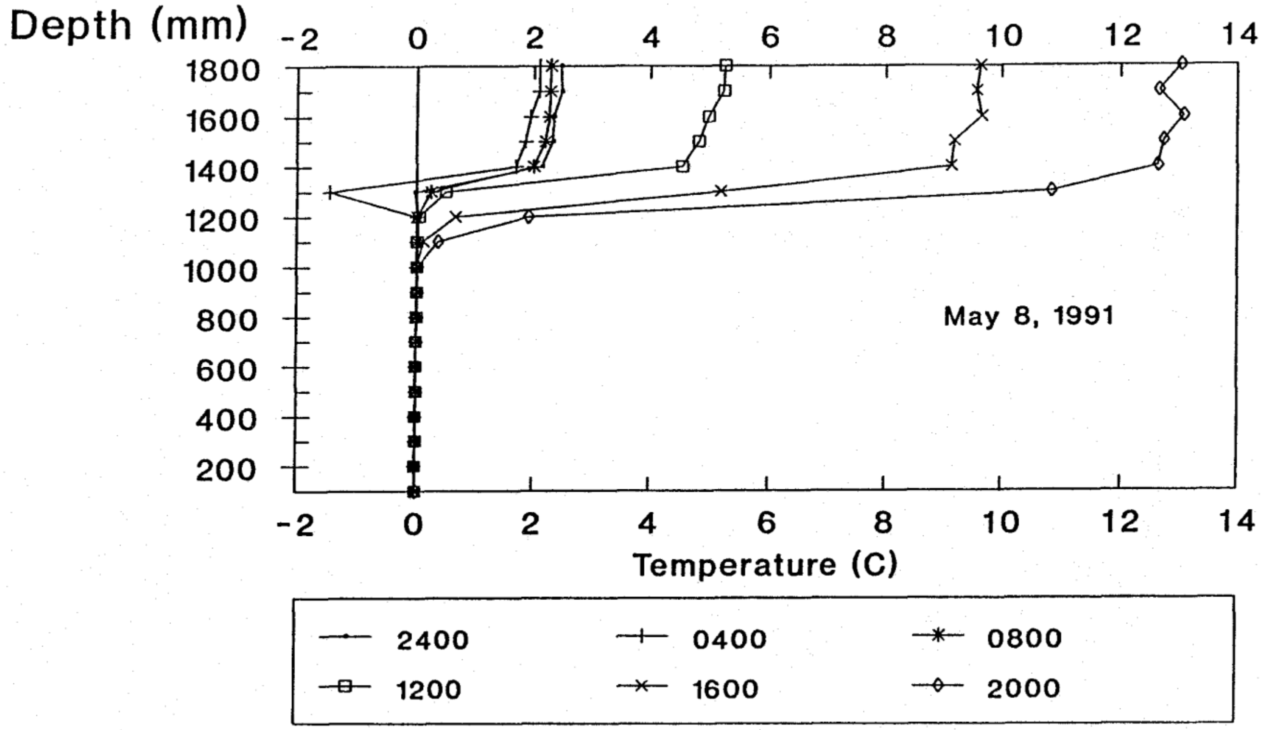

Figure 4. Hourly average temperature profile measurements in an isothermal snowpack on May 8, 1991. The snowpack was 1280 mm deep with an average density of 300 kgm^{-3}.

In Figure 5, the average hourly snowpack temperature recorded at 1100 mm fluctuated from 0° C to 0.4° C. The 1100 mm TC junction strongly reflects the influence of radiant heating from penetrating solar radiation. This junction closely follows the other TC junctions but deviates approximately 0.4° C between 0900 and 1600 hours, the hours of maximum incoming solar radiation. After 1600 hours, the TCs are no longer exposed to direct solar radiation, and the 1100 mm TC junction quickly drops back to track with the other TC junctions.

A winter (non-isothermal) snowpack is colder, drier, and less dense compared to a spring time isothermal snowpack. This results in the thermal conductivity being lower in a winter snowpack. The lower thermal conductivity reduces the snowpack's ability to transfer heat to or from the TC string, which increases the likelihood of the TC string being influenced by air temperature fluctuations. During winter conditions, it becomes difficult to differentiate conduction errors from actual fluctuations in snowpack temperatures. Heat conduction occurs from warm to cold environments. Under non-isothermal conditions, it is conceivable the TC string could cool, assuming the surrounding snowpack is incapable of supplying adequate heat to maintain the transfer of heat from the TC string to TC junctions exposed to the colder air. This cooling produces TC junction measurements less than the actual temperature of the surrounding snowpack.

Figure 6 (March 5) is an example of a non-isothermal snowpack. On March 5 the snowpack was 1350 mm deep with an average density of 290 kgm^{-3}. Average hourly air temperatures fluctuated from -14° C to 0° C and appears to influence the entire TC string. The largest fluctuation was -4° C to -2° C at the 1300 mm TC junction decreasing to negligible values at less than 400 mm.

CONCLUSION

This paper examines the effectiveness of automatically measuring snowpack profile temperatures with a specially constructed thermocouple ladder. Snowpack temperatures were analyzed during isothermal and non-isothermal conditions. During isothermal conditions, errors due to conduction were minimal, less than a few hundredths of a degree Celsius at depths of only 100 to 200 mm below the snow surface. During non-isothermal conditions, the entire TC string was possibly effected by conduction errors. Nevertheless, only the TC junctions buried 100 to 200 mm below the snow surface experienced significant fluctuations. Separation between conduction errors and actual temperature fluctuations is difficult in a non-isothermal snowpack.

This method appears to be a very promising technique for automated measurement of snowpack profile temperatures. Future studies need to incorporate snow temperature profile measurements to gain further knowledge on processes controlling snow metamorphism and snow ablation in and directly above the snowpack.

REFERENCES

Tanner, B.D. and B. Gaza (1990) Automated snow depth and snowpack temperature measurements. Proceedings, Western Snow Conference, Vol. 58, pp. 73-78.

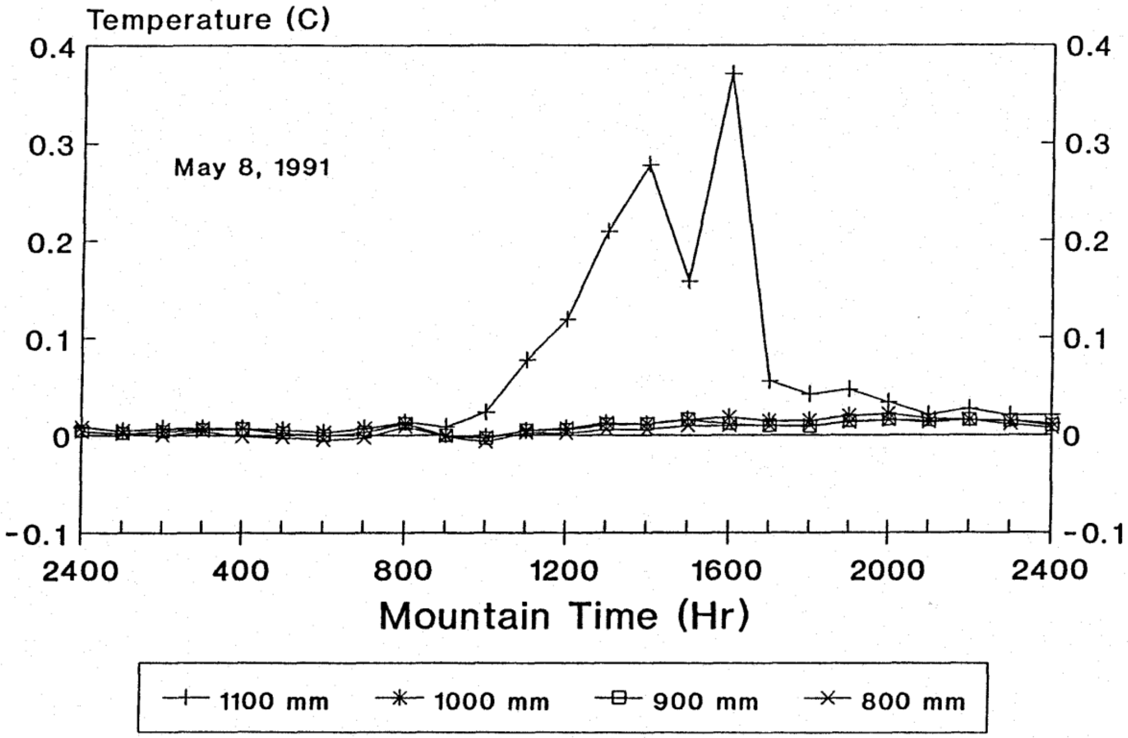

Figure 5. Average hourly snow temperatures for four TC junctions closest to the snow surface buried a minimum of 100 mm for a 24-hour period on May 8, 1991. The effects of solar radiation penetrating the snowpack is evident at the 1100 mm TC junction.

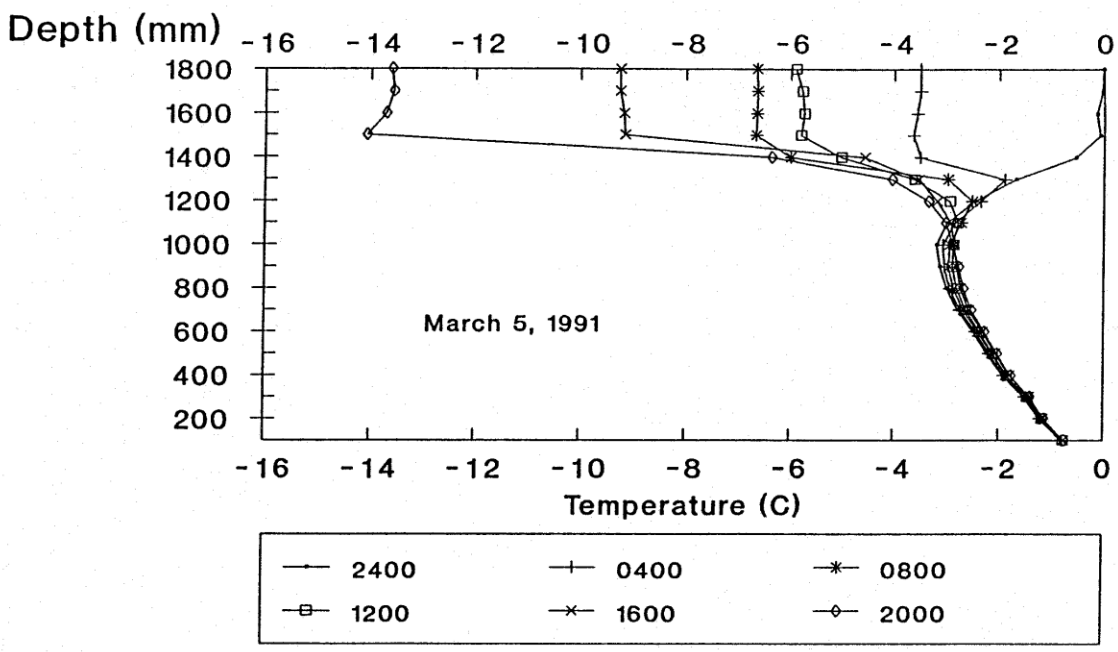

Figure 6. Hourly average temperature profile measurements in a non-isothermal snowpack on March 5, 1991. The snowpack was 1350 mm deep with an average density of 290 kgm^{-3}. Heat conduction down the thermocouple string is evident in measurements of the upper portion of the snowpack.