AUTOMATED SNOW DEPTH AND SNOWPACK TEMPERATURE MEASUREMENTS

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INTRODUCTION

Hourly snow depth and snowpack temperatures were measured in the Wasatch mountains of northern Utah during the winter of 1988-89. The record of snow depth was needed to support adjacent snow temperature measurements and provided a field test of a recently developed commercial acoustic ranging sensor. Basic specifications of the sensor and its current modifications are discussed, and field measurements are presented.

Accurate measurement of snowpack temperatures over the course of a winter is difficult due to thermal conduction of heat along the sensor wires. Additionally, the snow cavitates about any support stakes placed in the pack, thereby disturbing the environment. A thermocouple (TC) string designed to minimize these problems was used to measure profiles of snowpack temperature. The influence on the measurements of heat conduction along the sensor is evaluated and the use of the measurements in estimating pack height explored.

SITE DESCRIPTION

The measurement site is located 32.9 km northeast of Logan, Utah at an elevation of about 2700 m. The snow depth and temperature measurements were made in an area partially sheltered by conifers, 50 m down the lee side of an open ridge. The surface beneath the snow sensor was sloped at about 20°. Measurements were retrieved over a line-of-site radio frequency (RF) link using a repeater atop a mountain adjacent to Logan, Utah. Figure 1 diagrams the RF path and the path elevation projected onto the straight line distance between the base in Logan and the remote site.

INSTRUMENTATION DESCRIPTION

Two tripods made of galvanized pipe were used to support a cross-member for mounting the snow sensor approximately 1.8 m from each tripod. The sensor was 3.2 m above the ground. A staff ruler for obtaining manual readings of snow depth was secured to the cross-member within 1 m of the snow sensor. The enclosure housing the datalogger (Model CR10, Campbell Scientific, Inc., Logan, Utah) and a 5 W VHF radio (Model HT90, Motorola, Corp.) were mounted on one of the tripods along with the RF antenna. A specially constructed 17-junction thermocouple (TC) string was hung from the cross-member to measure temperatures at 10 cm intervals to a height of 160 cm. A third tripod was deployed on the open ridge 50 m from the snow sensor site for mounting the wind speed and direction sensors and a 10 W solar panel.

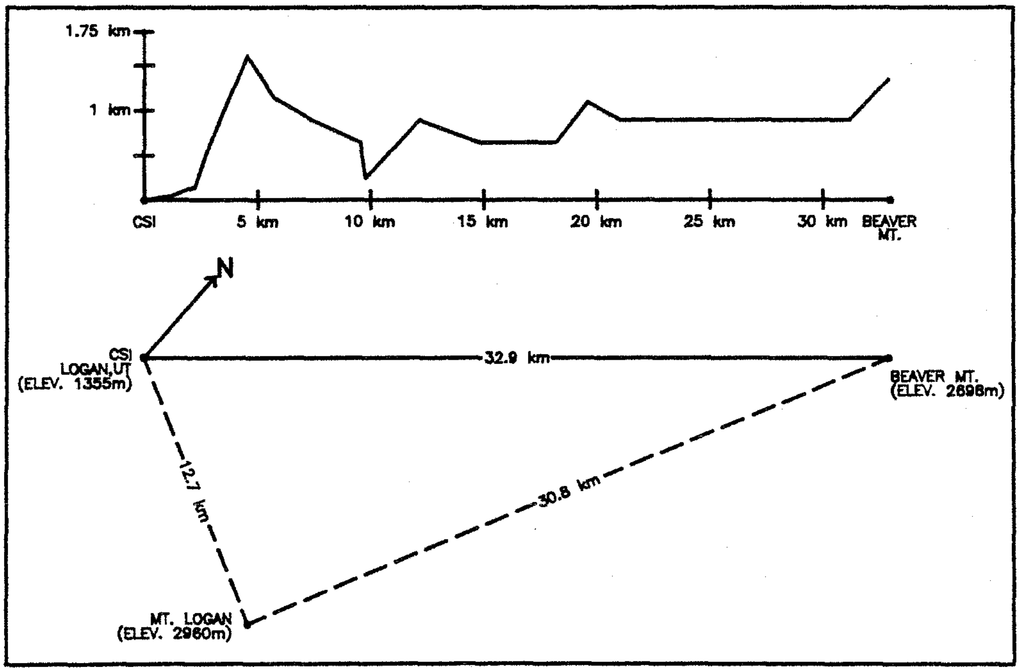

Fig. 1. Site location with respect to Logan, Utah and elevation profile of RF path projected on base line between the central and remote site.

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Thermocouple Measurements

The TCs were connected to an analog multiplexer (Model AM32, Campbell Scientific, Inc.) housed in a common picnic cooler buried in the snowpack. Using the multiplexer all TCs were read with a single input channel on the datalogger. The temperature of the TC reference junctions formed at the multiplexer input connections was measured with a thermistor. Measurement errors due to temperature gradients between the thermistor and the TC reference junctions were minimal in the isothermal environment of the buried cooler. The Model CR10 datalogger has a resolution of ±0.005°C for Type E TC signals (61 μV/°C), but during the course of the season, an input range having only ±0.05°C resolution was erroneously used.

Thermocouple String

The TC string was designed to minimize the effect of heat conduction along the wires. Chromel-constantan (Type E) TCs were used instead of the more common copper-constantan (Type T) because chromel has a thermal conductivity approximately 20 times lower than copper (constantan's conductivity is similar to chromel). Thirty gauge wire (0.25 mm diameter) was used to further minimize heat transfer. The string was constructed by soldering 17 individual chromel leads at 10 cm spacings to a single constantan wire. The number of wires entering the snowpack was thereby reduced by 16 as compared to conventional construction. The junctions were insulated with a silicon coating and covered with a short piece of white shrink tubing.

Snow Depth Sensor

The acoustic snow depth sensor (Model CSMAL01, Campbell Scientific Canada, Edmonton, AB) was the type developed by the Atmospheric Environment Service, Canada and described by Goodison et al. (1984, 1988a, 1988b). Distance to surface is obtained by measuring the travel time in air for a 49.4 kHz acoustic pulse to reach the surface and reflect back to the transducer. Air temperature measurements are required to correct for the dependency of the speed of sound on temperature. The Model CSMAL01 contains a processor chip and a solid state temperature sensor accurate to 1°C over a ±50°C range. Travel times from 16 pulses are averaged, corrected for temperature and the target distance reported via a 1.8 kHz output signal (0-5 V) having a resolution of 1 pulse/mm.

The Model CSMAL01's 200 mA current drain from 12 VDC is high for remote applications. An external relay controlled by the datalogger was used to switch power to the sensor prior to hourly measurements. A five minute warm-up period was required by the voltage regulator used in the temperature measurement.

Model UDG01 Snow Depth Sensor

Modifications to the Model CSMAL01 by the manufacturer in 1989 removed the processor, on-board temperature sensor and related circuitry. The Model UDG01 is simpler, lower cost and less power consumptive than the Model CSMAL01 but relies upon the data acquisition system to measure air temperature and perform processing and communication functions. The acoustic ranging functions performed by the Polaroid ultrasonic transducer and the TI Sonar Ranging Module are common to both models. An accuracy of ±1 cm or 0.4% of target distance is stated over a useable acoustic path of 0.6 m to 10 m.

The reduced current drain of the UDG01 is 20 μA's quiescent and 60 mA's for 0.2 s during measurement. The sensor powers up when address selected, eliminating the need for an external relay. Only a 10 ms delay is required before measurement. Multiple gauges may be controlled and read by a single datalogger; three programmable digital I/O ports (0-5 V) are needed to address the sensors and clock readings (counts) back to the datalogger. The Model UDG01 may be used with cable lengths of up to 300 m.

SNOW DEPTH SENSOR MEASUREMENTS

Factors affecting the quality of the snow depth measurements are discussed by Goodison et al. (1988a). The most serious are the loss of a reflected acoustic pulse during periods of heavy snowfall or blowing snow, and the inability to accurately distinguish the surface of new low density snow. The former problem results in a loss of measurement; the second in an underestimation of snow accumulation until the surface consolidates.

Hourly snow depth measurements were made over 159 days from Dec 19 through May 26. Of 3,816 possible readings, 730 were invalid due to the loss of an acoustic reflection. The longest period without a valid reading was 34 hours but generally valid readings were available within each 24 hour period.

Figure 2 shows midnight readings of snow depth over the measurement period. For 26 of the days shown, midnight readings do not exist and measurements typically within ±4 hours of midnight were used. In the latter part of the record, points shown for 6 days are at times more closely matching those of the manual readings. Matching the times of measurement when the pack was melting improved the comparison of sensor and manual readings but made little difference earlier in the season.

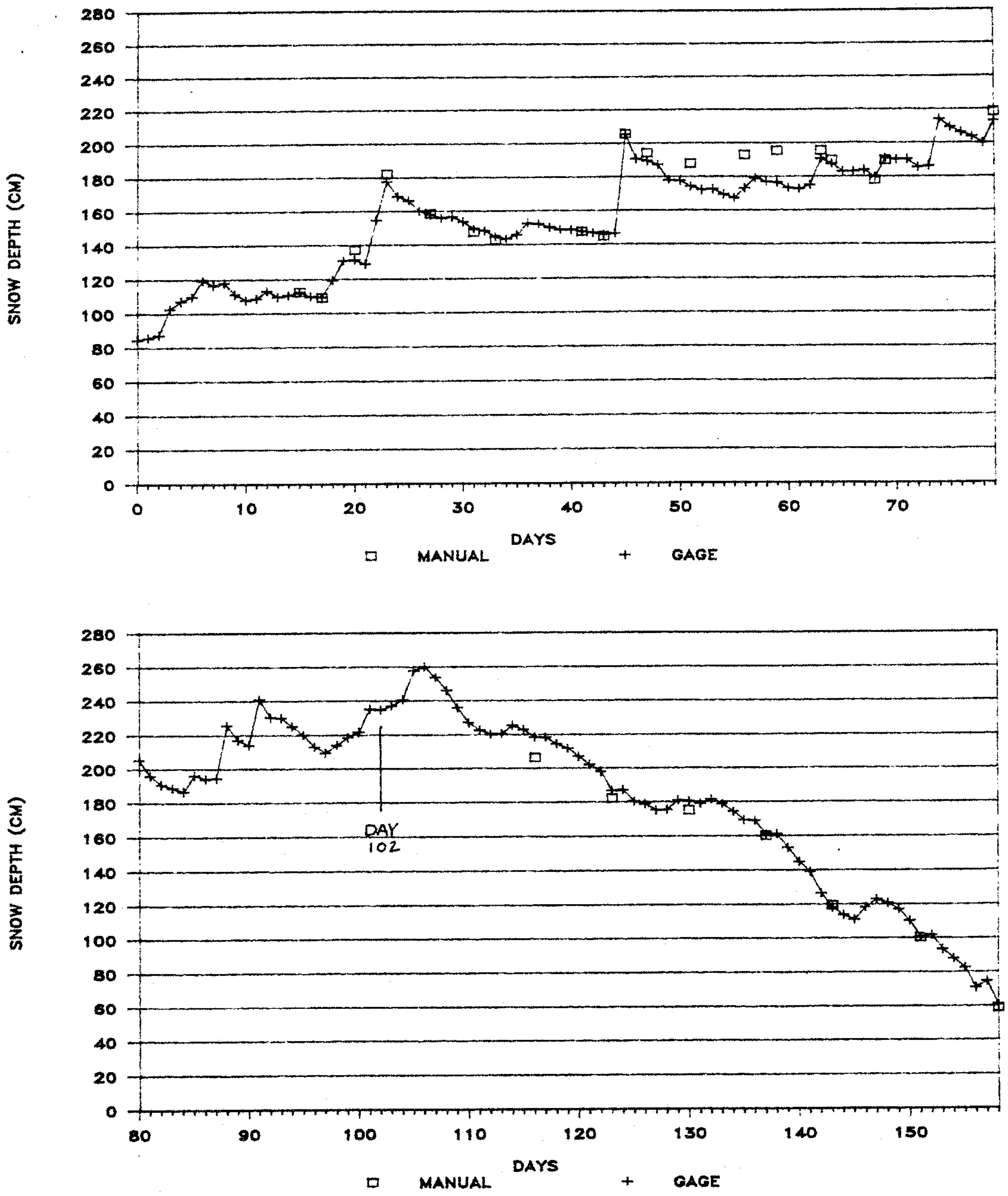

Fig. 2. Daily snow depth measurements from acoustic sensor (top) Dec. 19, 1988 - Mar. 20 (bottom) Mar. 21 - May 26, 1989. Manual readings indicated by + symbol. Day 102 that site disturbance was discovered is noted.

Manual readings of snow depth were obtained for only 24 days over the measurement period. During an extended period from day 79-116 no manual readings were made. On day 102, however, the snow surface beneath the gauge was found disturbed with a small man-made mound. The effect of this tampering on the relationship between the sensor and manual readings was never adequately quantified, in part because of the legitimate accumulation resulting from a storm two days earlier.

Comparisons of the automated and manual readings are characterized by three periods shown in Table 1. Reasonable agreement is found over the first period but the gauge readings are consistently lower than the manual readings during the second period. The difference in readings also has greater variability. The third period follows the surface disturbance and the sensor initially reports greater snow depths than the manual readings. The first manual reading (day 116 shown in Fig. 2) following the disturbance is not used in the comparisons of Table 1.

Table 1. Maximum, mean and standard deviations of difference (z′=manual-sensor) in snow depth obtained by manual readings and sensor. The number of comparisons for the period shown is n.

days	n	max. z′ (cm)	mean z′ (cm)	s.d. z′ (cm)
15-45	10	5.7	0.6	2.4
48-79	7	16.4	8.9	6.1
122-157	6	-5.3	-1.8	2.4
all days	23	----	2.5	5.8

Hourly measurements for three different periods are plotted in Figure 3. Loss of measurements due to stormy conditions is seen in the first two periods but the second trace shows excellent stability following an accumulation of 25 cm of new snow the previous day.

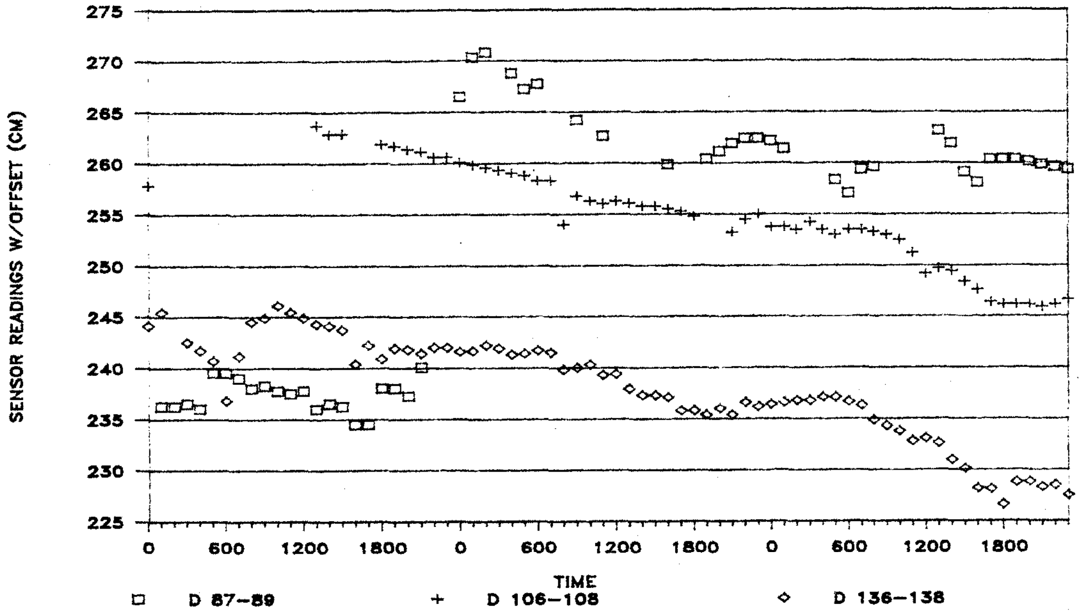

Fig. 3. Hourly snow depth sensor measurements for three different periods of record. Values shown for the first and third periods have offsets of 75 cm and 45 cm, respectively, added to the measured depth.

SNOWPACK TEMPERATURE MEASUREMENTS

Temperatures were measured on the hour at all 17 levels throughout the period of record. An example of profile measurements in a frozen snowpack is shown in Figure 4 for different times of January 31. Despite the design of the TC probe, the low heat capacity and thermal conductivity of the snow, and high conductivity of the TC bundle resulted in measurements being influenced by air temperature to depths of 35 cm (110 cm height) for this day. The 0000 and 0800 hour measurements show the layer at 15 cm beneath the surface (130 cm height) to be the coldest portion of the pack. The 1400 hour reading warms to -4.7°C because of heat conduction from the 4°C warmer air. Evidence that the temperature of the snow layer is actually much colder is seen in the 1900 hour reading where the junction maintains the 4°C gradient with the air but again cools below any other part of the profile. Assuming that the layer has changed little from the 0000 and 0800 temperatures, the 1400 hour measurement is in error by up to 4°C.

Hourly measurements for the same day are plotted in Figure 5 for four depths and air temperature. Air temperature effects on the measurements are minimal at the 45 cm depth. Measurements at the ground vary 0.06°C RMS about a mean temperature of -0.07°C. Whether or not this variation is related to thermal conduction along the wires is difficult to conclude because the variation is of the same magnitude as the measurement's digital resolution.

The damping of air temperature variations by the snowpack was investigated as a means of estimating snow depth. Figure 6 plots the difference between the maximum and minimum temperatures obtained over a day at each height. The steepness with which the air temperature variation is damped increases the size of the variation. The first TCs under the snow are circled for three of the days shown. Day 131 is an example of snow depth 20 cm above the highest junction. By day 150, some cavitation had developed around the TC string, reducing the effectiveness of the snow in damping the temperature variations.

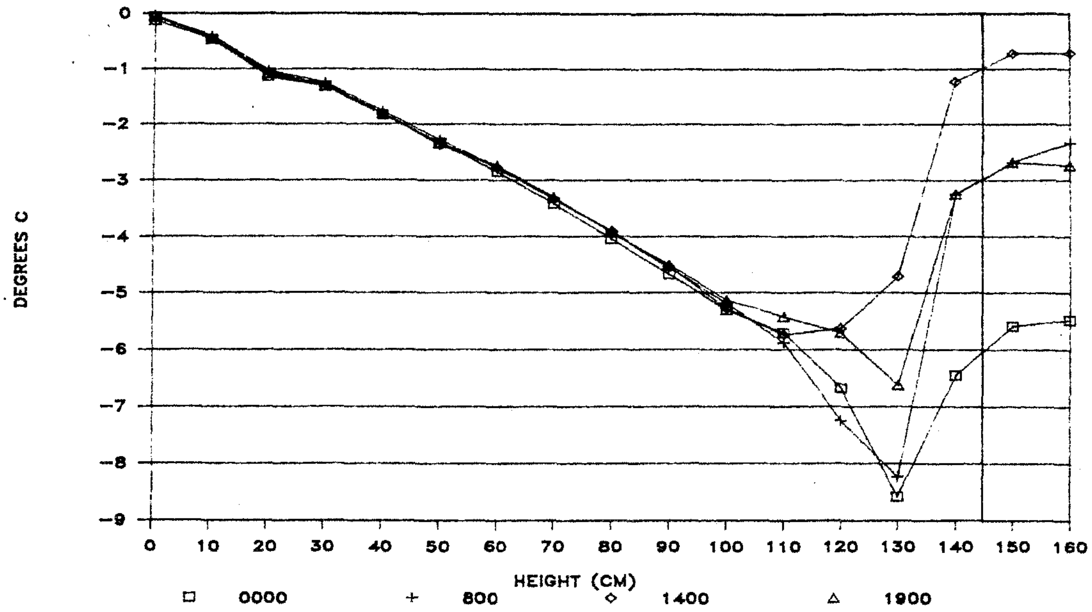

Fig. 4 Temperature measurements within a frozen snowpack during day 43. Heat conduction down the thermocouple wire is seen in the measurements of the upper portion of the pack. The snow surface is indicated by the vertical line.

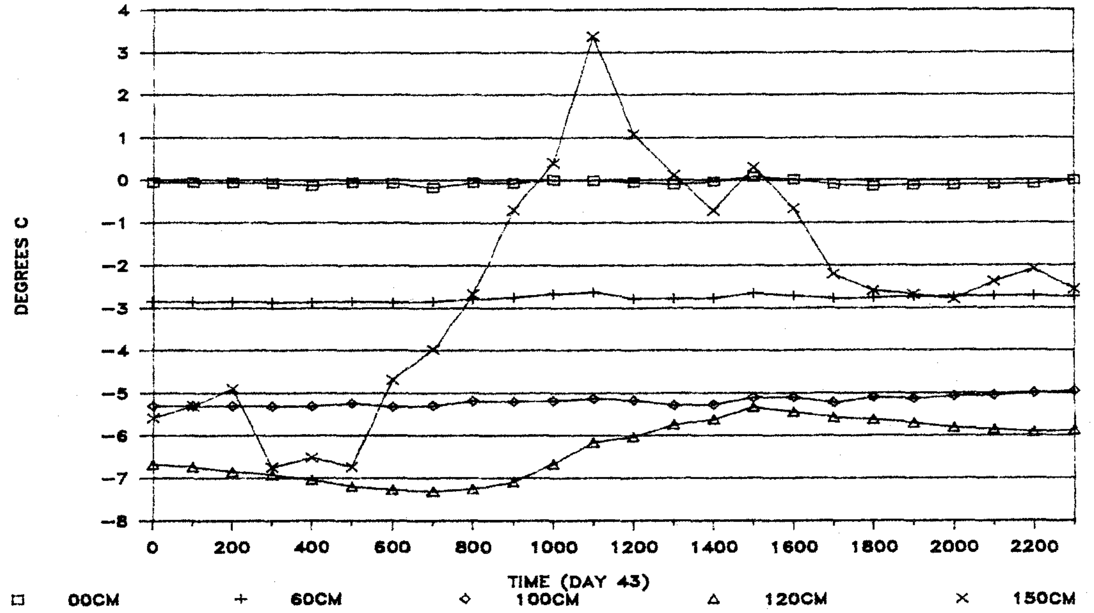

Fig. 5 Hourly measurements of temperature in the air and at four levels within the snowpack for day 43.

SUMMARY

Instrumentation deployed in a remote mountainous area for automated measurement of hourly snow depth and snow temperature profiles operated without failure over the course of a winter. The ability to retrieve measurements with RF communication provided real-time verification of system performance, greatly reducing the number of site visits otherwise required.

The acoustic snow depth sensor performed well but often failed to receive an acoustic reflection during periods of snowfall or wind blown snow. Accumulations of new low density snow tended to be underestimated for a few hours until the surface consolidated. With these exceptions, the sensor provides a useful means for obtaining remote snow depth measurements accurate to within ±2-3 cm.

Accurate measurement of snow temperature profiles is difficult because of thermal conduction along the sensor wires. The TC string used in this study was constructed to minimize conduction yet showed the influence of heating from the air in measurements of the upper pack. Running the TCs individually instead of combining the conductors into a single string would reduce the distance affected by thermal conduction but measurements at different levels would have horizontal offsets. The maximum daily temperature variations dampen sharply below the snow surface. A formal analysis is not presented but this inflection point is within 1-2 TC spacings of the actual depth for several comparisons.

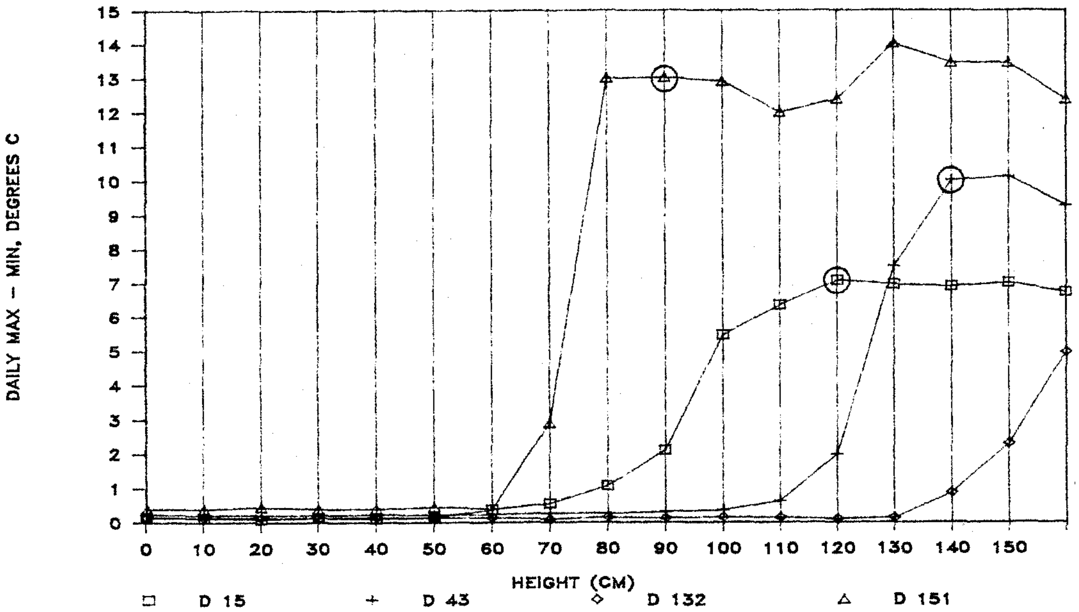

Fig. 6 Estimation of snowpack surface from maximum daily temperature differences measured at 10 cm heights. Circles indicate first thermocouple junction under the snow surface. Top junction (160 cm) under 20 cm of snow for day 151.

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