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REVIEW PAPER

Measurement of Temperature Gradient in Seasonal Snowpack using Improved Automated Temperature Profiler

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ABSTRACT

Snow temperature profile is an important input parameter for assessing the thermal state of snowpack. The individual layers of a snowpack can be weakened by various metamorphic processes occurring due to temperature gradient present within the snowpack and may result in avalanche hazard. The profile of snowpack temperatures also affects snowmelt runoff magnitude and timing, and hence, may cause wet avalanches. The design of an automated instrument for the measurement of snow temperature profiles in a snowpack is discussed. The instrument was designed to operate in stand-alone mode and is capable of measuring and logging data of twelve vertical temperature-sensing probes throughout the winter. It is suitable for measurement of snow temperature profiles in areas which are inaccessible to human during winters. The design considerations, field deployment, results, and future scope of work for the instrument is discussed in detail.

Keywords: Snowpack, stand-alone temperature profiler, thermistor, datalogging

1. INTRODUCTION

During snowfall, the snow crystals accumulate on the ground and gradually form a complex porous media composed of air, water vapour, ice, and sometimes liquid water. This ground-lying snow transforms with time, depending on the physical parameters of the environment[1]. Conduction of heat from the snow surface into the snowpack depends on the temperature profile within the snow that results from the history of previous energy exchanges and surface temperatures interacting with snowpack thermal properties[2]. Temperature gradient-driven metamorphic processes within a cold snowpack can stabilise or weaken individual layers, and hence, determine the likelihood of avalanche activity[1]. Therefore, accurate measurement of temperature profile within a seasonal snowpack is very important for the modelling of the metamorphic processes within the snowpack[3]. Hence, its study has major issues in avalanche forecasting and is an active research field in snow and ice community.

Snow temperatures vary over many scales of space and time, from within a single profile to an entire mountain range and from diurnal fluctuations to seasonal changes[4]. The temperature profile reveals much about both the current physical state of the snowpack and its likely future behaviour[5]. The profile of snowpack temperatures affects the ability of the snowpack to buffer extreme melt events. Also, the geography of snow temperatures influences snowmelt runoff magnitude and timing[6], and can present a significant full-depth, wet avalanche hazard[7].

The requirement for the measurement of vertical (temporal) snow temperature gradient can be classified into two distinct functional areas:

(i) Measurement of temperature profile within the snow in areas which are inaccessible to human beings during winter, and
(ii) Measurement of temperature profile during snow stratigraphy.

Measurement of snow temperature profiles is traditionally carried out by snow stratigraphy or by active microwave radar systems like FM-CW radar[8, 9]. While radar systems are costly, stratigraphy is cumbersome, error-prone, and requires human effort. Several penetrometer type instruments are also available for measurement of quantitative snow properties in snow covered areas[10]. Some of these instruments can measure hardness profiles[11] while others can measure both hardness as well as temperature profiles of the snowpack[12,13]. However, these penetrometers require human intervention to measure and record the snowpack profiles. To find a solution to this problem, a stand-alone type temperature profiler has been designed. The instrument has been designed to measure and record data of twelve temperature-sensing probes throughout the winter without any human intervention. The instrument was installed prior to winter at a location where snow temperature profile was desired. The instrument was tested in the field during winter of 2007 at Field Research Stations of Snow & Avalanche Study Establishment (SASE) at Manali and Dhundhi, India. The design and development, deployment, results and future scope of work for the instrument are discussed.

2. DESIGN AND DEVELOPMENT

2.1 Sensor

The idea was to develop a temperature profiler with the sensing elements placed vertically and spirally around a

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central column at equal distances. Model 107B temperature probe of Campbell Scientific inc., Canada was chosen as the temperature-sensing element. The reason behind selecting these temperature sensors is that these sensors are rugged and have found extensive use in measurement of water and soil temperature profiles. These temperature probes use thermistors to measure temperature and are capable of measuring temperatures in the range of –24 °C to +48 °C with an accuracy of ± 0.4 °C. These are designed to be buried in soil or snow up to 86 psi (60464 kg/m^2) (Instruction manual, Model 107 & 107B temperature probes, 2003).

2.2 Mounting Structure and Datalogging

Twelve temperature probes were fitted onto a MS central column of 4.5 inch diameter and 3 m (300 cm) height having 2-inch long hollow protrusions of 1.5 inch diameter at 45° angles which were spirally arranged around the central column. The probes were push fitted onto 12 screwable hollow Teflon pipes of 1.5 inch diameter and 2 inch length. The Teflon pipes were then screwed onto the hollow protrusions of the central column. The Teflon pipes were used for providing thermal insulation to the probes. Each of these Teflon pipes were separated by 25 cm and held one temperature probe each. The temperature probes were held hermetically to the Teflon pipe with airtight santoprene rubber washers. Santoprene rubber washer was chosen for its resistance to temperature extremes, moisture, and UV degradation. The base of the metallic central column was welded on to a 15 inch square base plate for fixing the temperature profiler on to the ground. The leads of each of the 12 temperature probes were brought out of the metallic pipe from near the bottom. A lid was put at the top of the central column to avoid ingress of snow and to facilitate maintenance. The diagrammatic description of the mounting structure of the temperature probes is shown in Fig. 1.

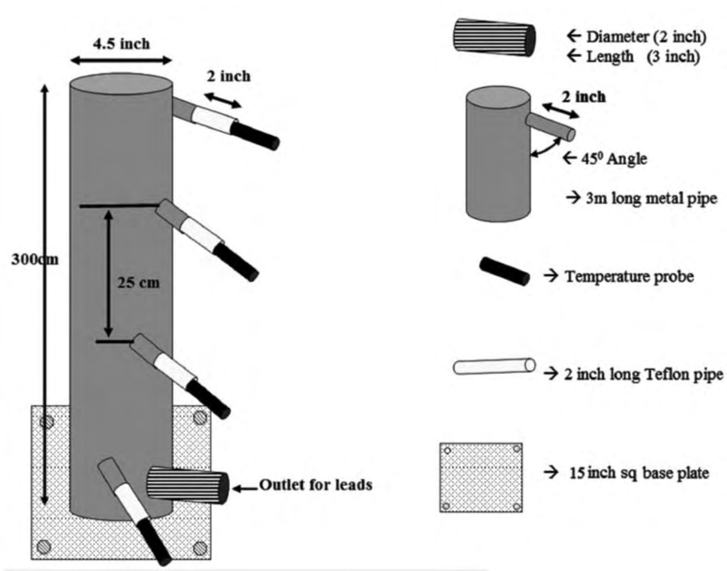

Figure 1. Mounting structure of temperature profiler.

The temperature probes were placed at 45 °C from the metallic central column so that snow would not accumulate on the probe and would not load it. The metal central column was powder coated so as to provide resistance to thermal conduction of solar heat to the snowpack. A Campbell Scientific Inc., Canada make datalogger, model CR23X, was programmed to make single-ended measurements from the temperature probes and log data on hourly schedule. The datalogger sampled each probe every five minutes and logged the average every hour. The data could be downloaded onto a memory storage module or onto a laptop via an interfacing unit. The datalogger is powered by a rechargeable 12V/65 Ah lead acid sealed maintenance free battery which in turn is charged by a 20W solar panel. The schematic diagram of the setup with data downloading option with a laptop is shown in Fig. 2. The sensors are shown marked as ST.

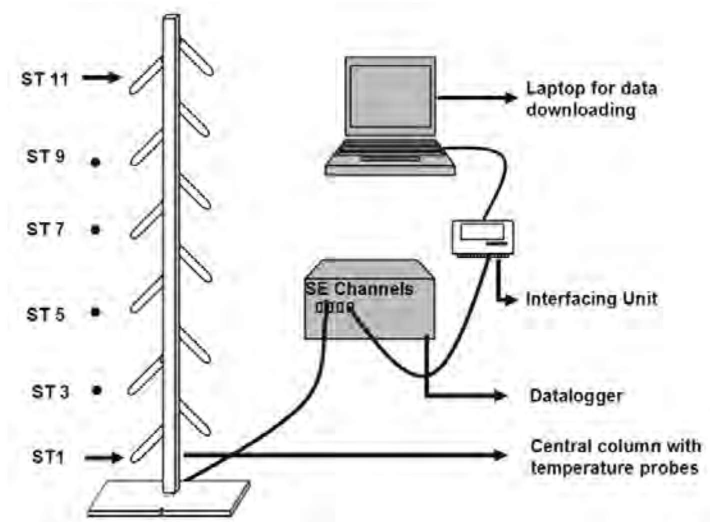

Figure 2. Schematic diagram of the sensor setup.

The metallic central column with all the temperature probes was installed near a triangular tower where the datalogger and the battery were placed inside an IP-66 NEMA-IV enclosure. It was attached to the triangular tower with a clamp to give it more strength to survive creep. The tower also held the solar panel for charging the battery. The wires of each temperature probe, coming out from the 3 m metallic pipe, were integrated to the single ended channels of the datalogger through an underground duct.

2.3 Field Deployment

The temperature profiler was installed at Dhundhi field research station of SASE which is located at an altitude of 3050 m above mean sea level in the Pirpanjal ranges and at a distance of 20 Km from Manali (H.P), India before the onset of winter of 2007. The datalogger, placed inside the NEMA IV enclosure that also housed the battery and the charging circuit, was installed on a triangular tower that was erected a few meters away from the temperature profiler. An ultrasonic snow depth measuring sensor was also installed on the triangular tower and integrated to the datalogger to keep record of standing snow depth. Twelve single ended channels of the datalogger were used for recording data from the temperature probes. The central column also had provision for tying up guy ropes for added strength to withstand snow creep and glide forces. The temperature profiler with the datalogger, battery, and solar panel in the field is shown in Fig. 3.

3. RESULTS

The temperature profiler was able to measure and log data throughout the winter. Data was retrieved on 14 February 2008 and 8 April 2008. There was no other instrument to compare the data of the temperature profiler. However, it can be observed that there was consistency in the data recorded by the profiler as no sensor showed any abrupt variation in the measured temperature values when compared to its nearest neighboring sensors. The snow depth sensor measured the maximum standing snow as 2.5 m on 18 January 2008, 7 February 2008, and 9 February 2008. This implied that the top two temperature probes were not buried in snow at all throughout the winter.

The graph showing the average temperature profiles and average snow depth acquired hourly for the period December 2007 to March 2008 is shown in Fig. 4. It can be observed that towards the end of March 2008 the snowpack had a height of approx 1 m and the snowpack had become isothermal, which agrees to previous years stratigraphy data. It was observed that the sensor nearest to the ground had average temperature above zero which also agrees to previous stratigraphy experimental data. For clarity of vision, data of all the sensors are not shown.

Figure 3. Photograph of the temperature profiler taken on 14 February 2008.

The hourly averages of snow temperature and snow depth were plotted for 9 February 2008 when the standing snow was observed to be maximum during the experimental period as shown in Fig. 5. For clarity of vision, data of all the sensors are not shown. It was observed that the lower most sensors, i.e., ST_1 to ST_3 measured temperatures that were near 0 °C. This is because the temperature at the snow-soil interface for unfrozen soil remains around 0 °C even in cold winter seasons if the amount of snow is enough to insulate the soil from the air temperature[14,15]. The middle sensors, i.e., ST_5 to ST_7 recorded little variation within the temperature range of –3 °C to –4 °C because beneath the snow, temperatures fluctuate more slowly and with a reduced amplitude[16]. The upper sensors, i.e., ST_9 and ST_10 though initially showed lesser variations in temperature but the variations increased as the snowcover started to settle, exposing the sensors to the temperature variations in the ambient environment. It was observed from the graph that the upper sensors showed rapid fall in temperatures as night fell. This behaviour of the sensors can be used to measure snow depth by identifying the thermistors buried inside snow based on the damping of temperature fluctuations that is caused by the snowpack compared with the temperature fluctuations in the air. It was also observed that the temporal variability of snow temperature decreased with depth in agreement with previous studies[17,18].

4. FUTURE WORK

In the month of April 2008, during second visit to the installation site of the temperature profiler, it was observed that a void had occurred in the snowpack surrounding the central metal column. It was deduced that due to the rise in temperature the column had conducted heat to the snowpack and as a result

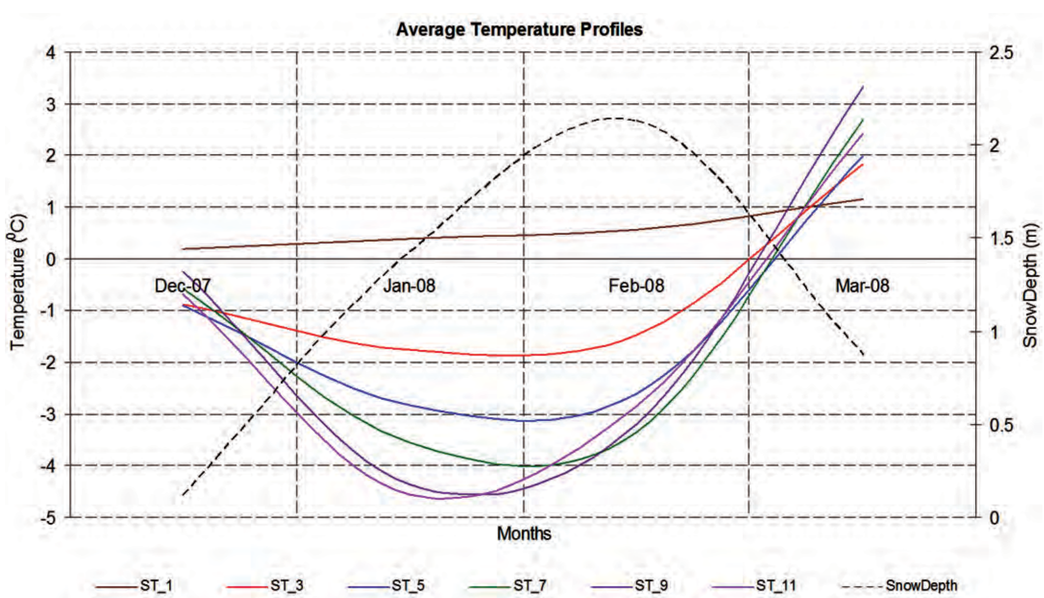

Figure 4. Average temperature profiles during December 2007-March 2008.

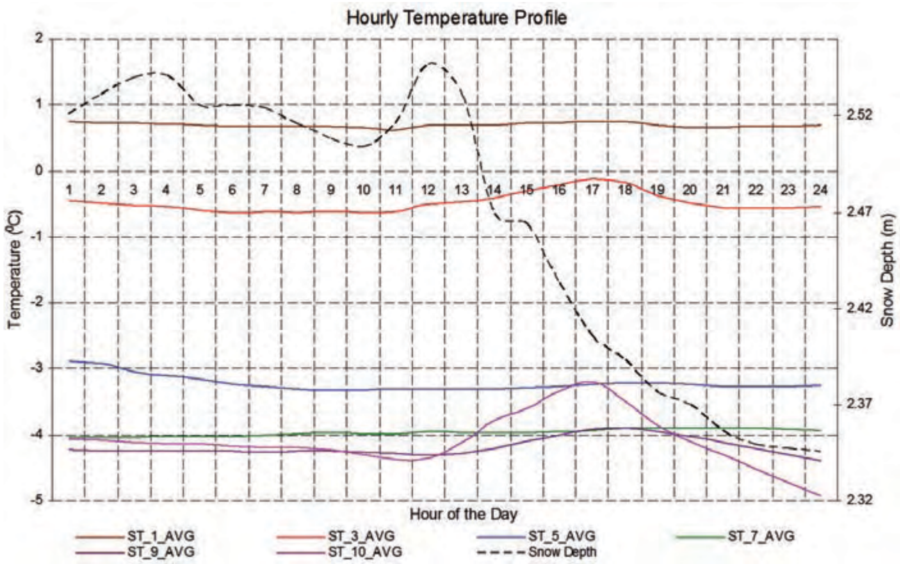

Figure 5. Temperature and snow depth variability on 9 February 2008.

the snowcover surrounding the pole had melted. This may lead to wrong measurement being made especially if a period of higher temperature occurs in between two successive snow falls. A picture of the void surrounding the central column is shown in Fig. 6.

Figure 6. Void that developed around the central column.

The future research in this area should intend to remove this discrepancy. The problem could be solved by considering three different solutions as enumerated below:

(a) Making the Teflon insulators longer so that the temperature probes could be placed further away from the metallic central column. This way the heat from the body of the column will not reach the temperature probes.
(b) Making the central column from non-metallic thermal insulators like fiber reinforced plastics or by painting the central metal column with thermally non-conductive paints.
(c) Reducing the surface area of the central column with improvised portable design where the profiler could be made from central columns of smaller diameter and smaller lengths which could be screwed to each other to obtain the desired length.

5. CONCLUSION

The temperature profiler was designed and developed for the stand-alone measurement of vertical snow temperature profiles in areas which are inaccessible to human beings during winter. This is the first time that an indigenously developed automated snow temperature profile measuring instrument has been successfully deployed in India. The temperature profiler has shown excellent data integrity due to its unique design and configuration. This instrument will definitely reduce the effort in measuring snow temperature profile required for assessing the thermal state of snowpack. As future work, minor modification in the design is recommended for better performance of the temperature profiler.

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