

A NEW APPROACH TO MEASURE SNOWPACK TEMPERATURE

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ABSTRACT: Snowpack temperature profiles are critical to calculate cold content needed to predict snowmelt timing and can be valuable to assess temperature gradients that can lead to the formation of weak layers and affect the stability of the snowpack. However, to date, there is no successful operational method to efficiently measure snowpack temperature profiles and a major gap in our ability to validate modeled snow temperature at a watershed scale exists. Leveraging the success of cooperative snow survey programs, this project will use a non-contact infrared Snow Temperature Profiler (STP) in conjunction with the cooperative snow surveys in the western United States. The STP is designed for use during manual snow surveys and is intended to be lowered into the hole left behind by federal snow samplers. This measurement alone will provide the snowpack temperature profile. When combined with snow water equivalent and snow depth data collected from the federal sampler, it allows the calculation of cold content, which is a necessary parameter to calculate snow melt rates, timing, and volume. This poster will describe the STP and method to obtain observations, provide an overview of the three-year project to implement the STP, and summarize initial year-1 testing of the STP in various snow climates.

Keywords: snow temperature, snowmelt, infrared temperature.

1. INTRODUCTION

Key components to understand snowpack stability, thermodynamic state, and melt potential are vertical profiles of snow temperature and cold content. Estimates of these variables are needed to run operational snowmelt and water supply models around the globe. There are currently no successful operational methods to observe snow temperature profiles and this presents a major gap in our ability to validate modeled snow temperature and cold content at watershed scales. We are currently unable to improve simulated snow temperatures let alone incorporate observations directly into operational snowmelt models. Here, we present a new method to measure snowpack temperature profiles and estimate cold content using a non-contact infrared Snow Temperature Profiler (STP) to be deployed with manual snow surveys. The STP is designed for use during manual snow surveys and is intended to be lowered directly in the borehole left behind by federal snow samplers and incrementally measure snowpack temperatures throughout the entire profile without digging a snowpit. When combined with the snow water equivalent (SWE) and snow depth data collected from the federal sampler, it allows the calculation of bulk cold content. Bulk cold content is a necessary parameter to calculate snowmelt rates, timing, and volume. Implementation of the Cooperative Snow Temperature Survey

will span three years. This paper highlights the results from ongoing field testing conducted during the 2023-2024 winter in diverse snow climates in three Western United States locations: California, Colorado, and Montana.

During winters 2024-2025 and 2025-2026 the STP will be tested by operational snow surveyors in California, Nevada, Colorado, and Montana at a total of 53 sampling points. The data collected by our snow survey partners will be assessed in collaboration with the California-Nevada River Forecast Center (CNRFC), Colorado Basin River Forecast Center (CBRFC), M3Works (modeling group for Airborne Snow Observatories, Inc.), and US Army Corps of Engineers (USACE) to compare the snow temperature observations to model outputs (e.g., SNOW-17, iSnobal, HEC-HMS) and examine the feasibility of operational integration. The long-term overarching goal of the project is to make STP measurements a regular part of operational snow surveys throughout all of the Western United States (over 1,100 sites), with the potential to expand to global applications.

2. DATA AND METHODS

The STP uses an infrared temperature sensor specifically designed to measure profiles of temperature throughout the snowpack. The STP is cabled and data is transmitted via wireless Bluetooth adapter to a cell phone application where the real-time changes can be monitored (Figure 1). Two STPs were provided to each field crew in the Sierra Nevada (CA and NV), Upper Gunnison (CO), and the intermountain west in Montana (MT) in an

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attempt to capture the diverse snow climates of the western U.S. Each set of observations consisted of a temperature profile from a snow pit using a Taylor model 9878E digital thermometer with a stated accuracy of ± 0.05 °C and a STP measurement down and back up the snow tube hole just behind the snow pit wall. Data were collected at 10 cm increments from the snow surface. The STP and the temperature probe were lowered simultaneously to each 10 cm increment. However, in Colorado the observation was not possible as a team, so the temperature of the snow pit was measured and then the STP was lowered and raised and then the snow pit temperature was measured again. Data was written in a field notebook and then transcribed to a spreadsheet for analysis upon returning to the office.

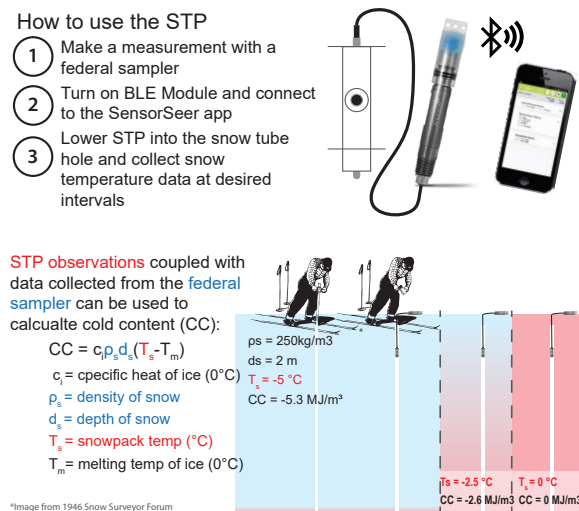


Figure 1: Overview of the intended use for the STP with a diagram of the STP assembly, cold content calculation, and schematic of the process to make the observation in the field.

The sensor makes four temperature measurements: (1) the IR window, (2) the die cast, (3) sensor housing, and (4) air temperature. Observations from the IR window are compared against snow pit temperature probe observations. A snow pit is dug at each location and a federal sampler is used to collect SWE, depth, and density and leaves behind a hole to lower the STP, which is compared to standard snowpack temperature profile from the snow pit. Photos shown in Figure 2 outline the year 1 measurement process. Methods varied at each location with two sensors tested in California, one lowered and raised with snow pit profiles made before and after and testing of cooling the sensor before lowering into the snow pit hole in Montana.

3. RESULTS

Comparisons between STP and probe temperature profiles are shown in Figure 3 for a total of 12

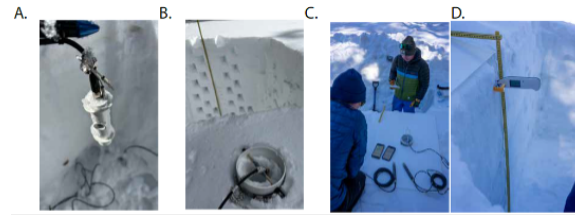


Figure 2: STP measurement process. Check the STP window is clear from snow (A), lower the STP into the snow tube hole (B), collect the data from the SensorSeer app (C), lower the temperature probes with the STP to validate the observation (D).

pairs of observations that were made during the 2023-2024 winter. Eight observations were made at the University of California Berkeley Central Sierra Snow Laboratory in Soda Springs, CA, four observations in Crested Butte, CO, and a single observation at the Summit Ranch SNOTEL in Colorado and Lolo Pass SNOTEL in Montana. Snow temperature at the base of the snowpack was assumed to be 0 °C and the temperature data were interpolated linearly from the last observation. While it is generally safe to assume the snow soil interface is 0 °C in the Sierra Nevada, we acknowledge that this is not generally true in other regions and verifying the temperature of snow soil interface would improve the interpolation. However, the snow soil interface was 0 °C in all observations except the January snow pit in Colorado.

Below the top 50 cm the sensor reads within 0.1 °C on average compared to the probe with a minimum and maximum difference of -0.9 °C and 2.2 °C, respectively. After calculating the average snowpack temperature, the difference between the STP and the probe was -0.5 to 1.3 °C with a R^2 of 0.74. The majority, 11 out of 12, observations were within ± 0.5 °C. When calculated to cold content the STP was within 0.1 MJ/m² of the snow pit with a minimum and maximum difference of -0.57 MJ/m² and 0.75 MJ/m² (Figure 4.B), respectively. The average snowpack temperature observations at the CSSL were compared to iSnobal and SNOW-17 modeled snowpack temperature (Figure 4.C).

4. DISCUSSION

Data shown in Figure 3 supports the hypothesis that if a 0 °C layer is encountered below the first 50 cm, it is reasonable to assume that the remainder of the snowpack is also 0 °C. The largest variation between the STP and the Taylor probe was in the top 50 cm and solar heating can cause 0 °C reading on and near the snow surface. More observations are needed to identify the cause for the variation near the surface.

Our first year of testing with the STP revealed several limitations. First, depth hoar at the bottom of the snowpack can impede observations as it did in Colorado. The snow tube hole collapsed and the sensor could not be lowered to the bottom of the snowpack. Second, the sensor cannot reach the lowest layer of the snowpack and measure the snow-soil interface. In future versions of the sensor, it will be important to have the sensor window be located on the bottom most portion to measure as close to the snow-soil interface as possible. Third, the STP cannot measure snow surface temperature and this measurement, if needed, should be made with a shaded temperature probe in line with standard snow pit procedures.

Finally, some refining of our methods will likely improve data quality. Preliminary tests were done with cooling the sensor in snow before the observations or placing a white board to provide shading in a sunny location. The teams concluded that it is best to make the federal sampler observations immediately before the STP observations with cold tubes that will not heat or melt the snow surface. The sensor should also be lowered into the snowpack from the snow surface and not lowered and then raised up. As more observations are made over the next two years the methods will be documented and refined to ensure a repeatable measurement by all snow surveyors.

Future research will include the development of a STP Version 3 that will not have the air temperature sensor and allow the IR sensor to read closer to the base of the snowpack and will have a direct readout display that will not require Bluetooth or a cell phone application. Over the next two years (WY 2025 and 2026) we will continue snow pit measurements in collaboration with a team of snow surveyors at a total of 53 locations. In an effort to improve simulated snow temperature we will work with our collaborating agencies that run operational snow models to incorporate STP measurements into their workflow and, if possible, develop bias-correction or calibration techniques.

5. SUMMARY

Snow temperature is a critical variable for understanding snowpack stability and snowmelt generation processes yet little work has been done to validate and improve modeled snow temperature at large spatial scales. This project aims to work towards addressing this gap and we introduces a novel non-contact infrared Snow Temperature Profiler (STP) developed to be used during manual snow surveys, a technique that has been around for over 100 years. We provide promising results from our first year of testing in California, Nevada,

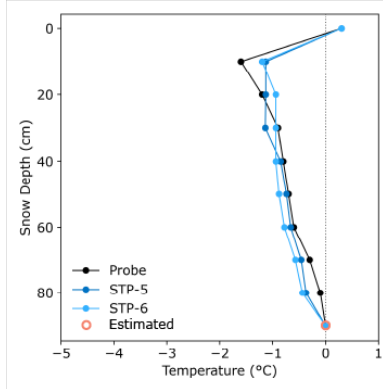
Colorado, and Montana. The STP, when combined with other snow data, calculates bulk cold content, essential for determining snowmelt rates, timing, and volume. Initial field tests in various snow climates have shown good results when comparing STP measurements to snow pit observations, highlighting the potential for operational integration and future improvements in snow temperature measurement methods.

ACKNOWLEDGEMENT

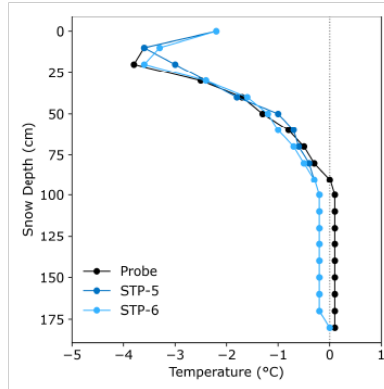
This work was funded by US Department of the Interior Snow Water Supply Forecasting (SWSF) Grant No, R24AC00024-00

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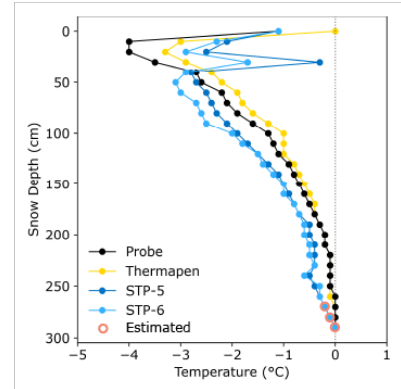
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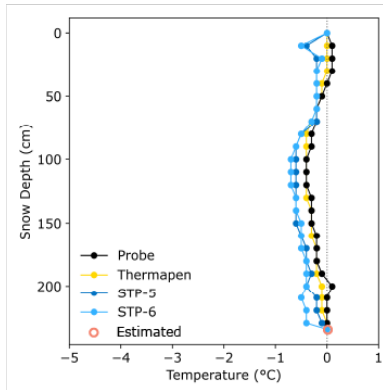
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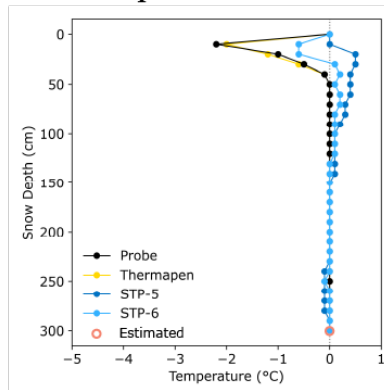
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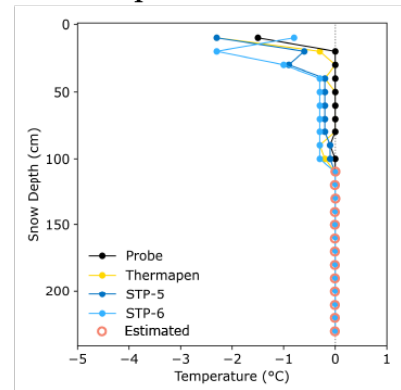
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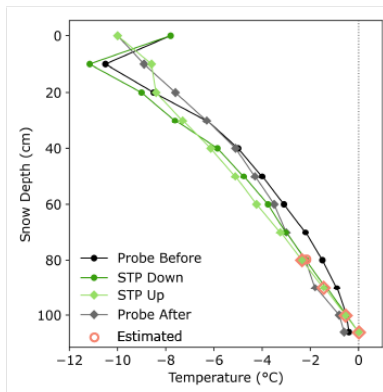
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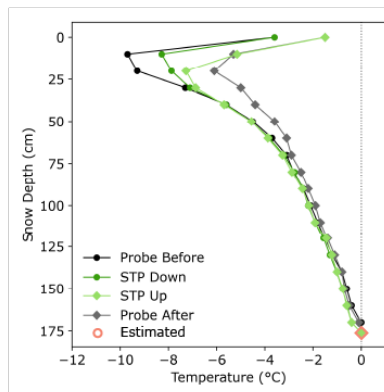
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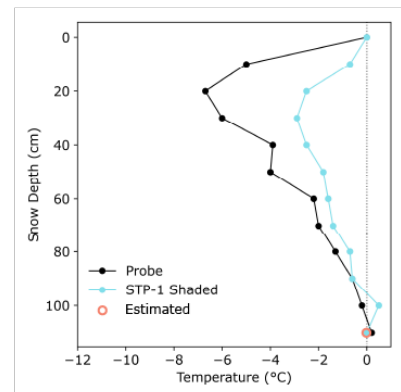
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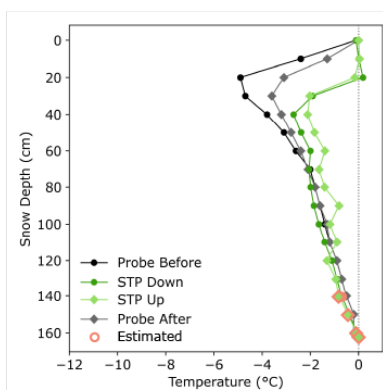
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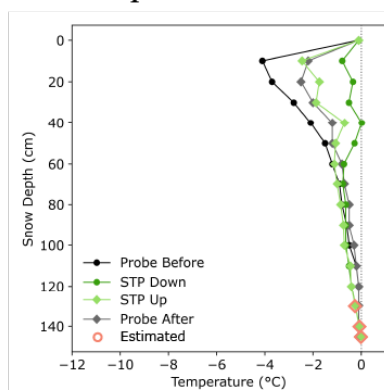
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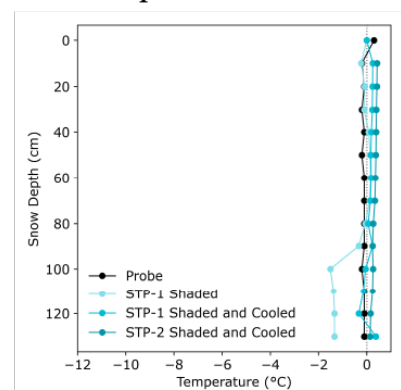


Figure 3: Snow temperature profile comparison for the 12 observation pairs in California, Colorado, and Montana.

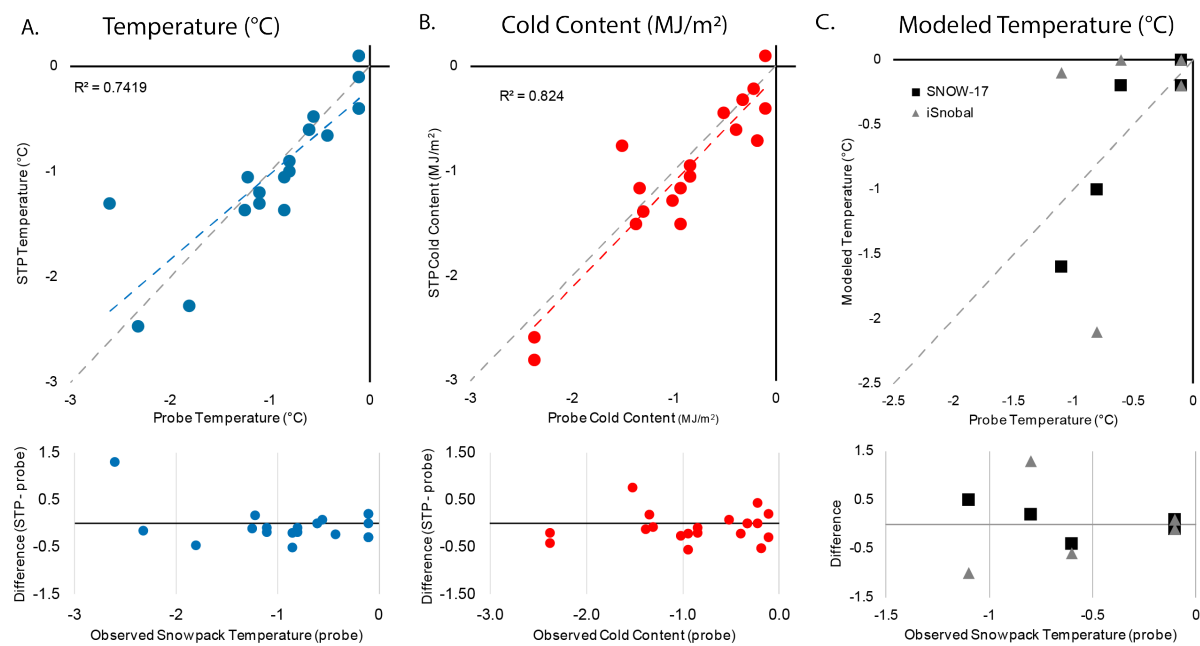


Figure 4: The upper panels show the comparison of STP snowpack temperature (A), STP calculated cold content (B), and model temperature with observations from the temperature probe from the snow pit. The lower panel shows the difference between the probe and the STP (A and B) and modeled temperature (C).