iBUTTON THERMOCHRONS – AN AFFORDABLE AND EFFECTIVE TECHNIQUE FOR MEASURING TEMPERATURE GRADIENTS

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ABSTRACT: iButton thermochrons are small, affordable, easily deployed devices that measure and log temperatures within a seasonal snowpack. These devices record temperatures at a specified interval and are accurate to within 0.5°C. Forecasters at the Utah Avalanche Center (UAC) have deployed iButtons in a variety of field settings for the past nine seasons, finding them especially useful for measuring temperature gradients near the snow surface corresponding to diurnal near-surface faceting events. We have identified steep gradients (in excess of 150°C/m) in the top 1-3 cms of the snow surface during periods of cold, clear weather, conditions that lead to the rapid development of near-surface facets. Graphical plots of measurements have identified steep temperature gradients as well as diurnal temperature fluctuations. Our analysis have helped us better communicate the faceting process to the users of our daily UAC avalanche forecasts as well as part of our educational toolset. Formal avalanche education programs may also find iButton thermochrons useful for instructional purposes.

Keywords: metamorphism, temperature gradient, near-surface facets, ibutton

1. INTRODUCTION

An **iButton thermochron** is a temperature sensor and data logger that records temperature measurements from -30°C to 85°C, and is accurate to within 0.5°C. iButton thermochrons are small – measuring 17 mm x 6 mm – and encased in water-resistant stainless steel where the equilibrated temperature of the container is recorded (Figure 1). iButtons can be easily configured and deployed, and recordings of temperature measurements can be later retrieved and analyzed.

Figure 1: iButton thermochron.

Forecasters at the UAC have deployed iButton thermochrons in various field settings to record temperatures throughout the snowpack, and have found them to be especially useful for temperature measurements in the top 1-3 cms of the snow surface during periods of high pressure when steep temperature gradients and diurnal temperature fluctuations provide ideal conditions for the growth of near-surface faceted crystals.

We have found Maxim's iButton DS 1922L (shown in Figure 1) to be the most cost-effective thermochron that operates within the minimum requirements for accurately recording snowpack temperatures. It costs approximately $65 USD. The hardware required for configuration and data access to a standard PC or laptop (DS 1402D iButton receptor and DS 9490R USB port adapter) costs approximately $70 USD. Although battery life is dependent upon many conditions such as operating environment and frequency of data gathering, the expected battery life of an iButton exceeds five years.

2. RELEVANCE AND PRIOR WORK

The mountains of Utah (USA) are primarily an *intermountain* snow climate at mid-latitudes with abundant seasonal snowfall where some stations exceed 1200 cms annually. A typical weather pattern of the region is alternating periods of cold storms with low-density snowfall followed by high pressure systems, a scenario that often leads to the development of weak, faceted snow at the surface. 47% of avalanche fatalities in Utah from 1940-2018

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involved persistent slabs and 22% deep slabs. More recently, of the 21 avalanche fatalities in Utah since the beginning of the 2009/10 season, 11 have involved buried faceted snow as the weak layer.

The role of vapor pressure gradients – a direct result of temperature gradients – is covered in Armstrong (1985) which describes how a vapor transfer between snow grains creates faceted crystals. Much of the early work monitoring near-surface facets (i.e. Birkland et. al., (1998)) involved deploying thermocouples to monitor and record temperatures. The primary disadvantages of thermocouples are cost and difficulty in deployment. In 2009, (Kobernik and Wagner (2010)) began investigating diurnal near-surface faceting events using iButton thermochrons, and their initial work demonstrated the promise of these small devices to accurately capture and log snowpack temperatures. Since that time, UAC staff have deployed iButton thermochrons in a variety of field settings, and have found them to be a practical and cost-effective tool for recording near-surface faceting events due to diurnal recrystallization. Additional experiments are planned for 2018/19.

3. METHODOLOGY

A pair of iButton thermochrons is an effective setup for recording temperatures near the surface of the snowpack. The devices are positioned 2 cms apart and wrapped in reflective tape to reduce the effects of solar absorption. Once configured, the pair is inserted orthogonally into the snow, 1 cm and 3 cms below the surface (Figure 2).

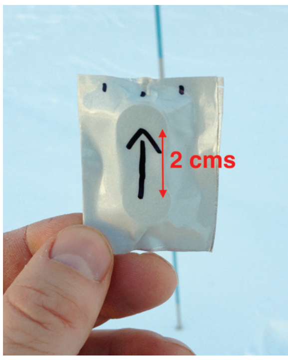

Figure 2: Two iButton thermochrons positioned 2 cms apart and wrapped in reflective tape.

3.1. Configuration

Prior to deployment, the iButtons are connected to a PC (either macOS or Windows) via a USB connection, and configured to record temperatures at a specific interval, typically every 15 minutes. They are then deployed in the field, recording and logging temperatures 1 cm and 3 cms below the surface of the snowpack. The deployment period is typically from one to five days. Upon retrieval, the temperature logs are extracted and analyzed using standard spreadsheet software.

3.2. Deployment Challenges

We have found (1) settlement, (2) creep, and (3) solar absorption the primary challenges of accurately recording empirical field data in a dynamic winter environment using iButtons. Settlement can be addressed by manually re-positioning the iButtons every few days if necessary. Snow creep can be minimized by placing the iButtons on a relatively flat surface, less than 5°in steepness. Lastly, reflective tape mitigates the effects of solar absorption. Most persistent slab avalanches in Utah occur on slopes facing northwest through east, so the ideal deployment is on low-angled, wind-sheltered northerly aspects. It is crucial to deploy iButtons so they are not easily visible to other winter travelers. To prevent losing the iButtons during a wind or snow event, a line of thin filament is attached to the taped pair of iButtons and connected to an adjacent probe (Figure 3).

Figure 3: Field deployment of iButtons.

4. RESULTS

For the past eight years, we have deployed iButton thermochrons at the onset of high pressure periods, ideally after fresh snowfall of low-density stellar crystals. Several datasets were gathered prior to an active period of natural and human-triggered avalanches after the persistent weak layer was buried by fresh snow. Temperature logs show very steep temperature gradients in the top 3 cms of the snow surface and diurnal fluctuation at the snow surface. One particularly interesting data set was gathered 1-6 December 2015 on a northeast aspect at 3000 meters with a 70 cm snowpack. Figure 4 illustrates the temperature measurements in the top 3 cms of the snow surface during this period. It highlights diurnal temperature swings where the 1 cm of snow at the surface surface (green line) is warmer than 3 cms below (purple line) during daylight hours, and colder during the nighttime.

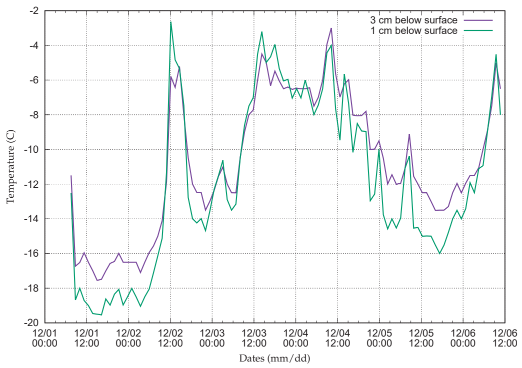

Figure 4: Temperature measurements 1 cm and 3 cms below the snow surface.

Figure 5 graphs the temperature gradient between 1 cm and 3 cms below the snow surface. This graph is normalized to C/m by multiplying the temperature difference between the two devices by 50. This graph highlights the steep gradients, in excess of 150°C/m in some instances.

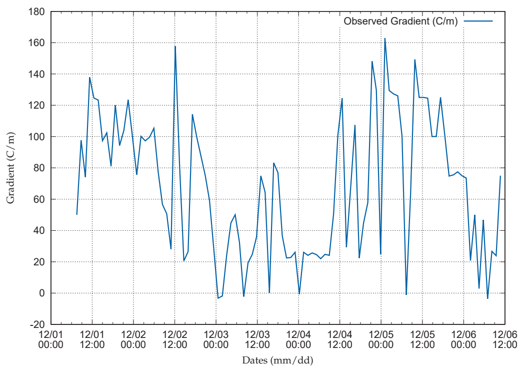

Figure 5: Temperature gradient (C/m) at 1 cm and 3 cms below the snow surface..

4.1. Crystal Metamorphism

It is especially effective during data recording to also observe metamorphism of the snow crystals at the surface of the snowpack, thereby aligning periods of steep temperature gradients with the development of small-grained near-surface faceted crystals. Figure 6 illustrates the metamorphism of snow crystals at the surface from (a) stellars to (b) fine-grained near-surface facets over a period of five days.

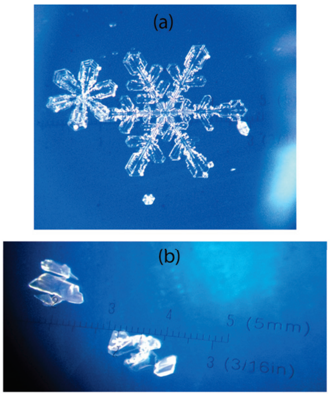

Figure 6: Metamorphism of snow crystals at the surface over a period of five days.

5. FUTURE WORK

Additional experiments using iButton thermochrons are planned by UAC forecasters for the 2018/19 winter season. We hope to better understand the effects of aspect, elevation, and snowpack depth on the growth of near-surface faceted crystals. Additionally, although the ratio of 1°C/10 cm is well understood as the minimum threshold gradient for facet development, steeper gradients are required when lower mean snow temperatures are present. We are hoping to refine a model we have developed (but not covered in this presentation) that determines the required minimum gradient based upon mean snow temperature.

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