The Affect of Snow Density On The Temperature Gradient

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Abstract: Temperature data loggers were positioned on three marked layers during the early season in the Collins Snow Study Plot, Alta, Utah. A series of pits were dug every two or three days over the next two months adjacent to the data loggers. The depths of the layers of interest along with the snow densities between the layers were recorded. Over 6000 temperature measurements and over 1000 density measurements were taken in 23 snow pits from Feb. 14, 2000 through April 12, 2000. After recovering the data loggers and analyzing the results, a graph of temperature gradient vs. snow density was created. The graph shows a trend of lower gradients for low-density snow, high gradients for medium densities (150 Kg/m3 to 240 Kg/m3), and lowest gradients for high-density snow. A theory to explain this relationship is presented. The application of this theory is then applied to help understand the accelerated growth of weak faceted crystals in the upper part of the snowpack under certain conditions and in the lower part of the snowpack on skier compacted slopes.

Keywords: snow compaction, snow density, snow settlement, snow temperature

Introduction

In several steeper snowfields within the Alta Ski Area the snowpack on skier compacted slopes often develops a different degree of faceted crystals than the snowpack on immediately adjacent slopes that are not skier compacted. This occurs even though the aspect, elevation and the slope at both locations are identical. The only difference seems to be skier compaction. Each of these locations includes a popular ski run that is adjacent to a less popular run with the same snow and terrain conditions. These adjacent slopes often produce different results on avalanche control mornings.

Because the main difference in these locations, besides faceted crystal development, is the skier compaction resulting in much different snow densities in the snow slab, several questions came to mind. How are the thermal insulating properties of the snowpack affected by the snow density? How does this change the transfer of heat and cold through the snowpack? Does this affect the temperature gradient and process of metamorphism? An experiment was designed and conducted to help answer these questions.

Experimental Procedures

Early in the 1999 – 2000 ski season a protected area adjacent to the Collins Snow Study Plot was roped off. The snowpack was allowed to develop until it was 1 or 2 meters deep. Then on February 9, 2000 a temperature data logger was placed on the snow surface in the study site. A collection of sawdust and pine needles was sprinkled on the rest of the snow surface within the site, staying about 2 meters away from the temperature logger. The sawdust and needles would allow us to find this layer as the snow pack developed.

On February 16, 2000, after the first logger was buried under a meter or more of snow, a second temperature logger was placed over the first one and more needles and saw dust were sprinkled on the snow surface. Then on February 28, 2000, after more snow, a third logger was positioned and more sawdust and needles were sprinkled over the snow surface. There were now three loggers measuring and recording snow temperatures every hour at three different layers in the snowpack.

The first snow pit was dug February 14, 2000. Each pit was dug deep enough to find the lowest sawdust and needle marked layer. Snow density was measured and recorded every 10 cm. from the surface down to the last marked layer. The air temperature and the snow surface temperature were also recorded. From February 14 through April 12, 2000, 23 snow pits were dug in the study site.

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On April 12, 2000, the three temperature loggers were recovered. Their actual depths in the snowpack were recorded and the data was down loaded to the computer. The approximately 2 month test produced over 6000 temperature measurements and over 1000 density measurements.

Results

There were several interesting results from these data. First, a plot of the snowpack temperatures, air temperatures and snow depth vs. time for the period right after burial was made (Figure 1). This showed the snowpack temperature affected by daily air temperature cycles until the logger was buried under new snow about 40 cm. deep.

The average snow density was calculated for each portion of the snow pack between temperature loggers. The temperature gradient was also calculated for these same times and snow layers.

This large data set included relatively thin surface layers (less than 10 cm) of new snow with densities that ranged from 17.5 kg/m^3 to 200 kg/m^3. The gradients calculated for these layers ranged from less than 1 °C/m to almost 50 °C/m. The current and recently past weather conditions seemed to play an important role in the temperature gradient for these surface layers. These data were not included in the study.

The data also included layers that had a range of densities greater than 50% of the average density. These layers were further divided into sub-layers that had a narrower range of densities. A temperature gradient was then calculated for each sub-layer based on gradients of other layers with similar densities and the total gradient measured for the combined layer.

After this data reduction the meaningful data were plotted on a graph of temperature gradient vs. snow density (Figure 2). This plot shows lower gradients for snow densities below about 150 kg/m^3. The highest gradients were for snow densities from about 150 kg/m^3 to 250 kg/m^3. The lowest gradients occurred over portions of the snowpack where the densities were greater than 250 kg/m^3.

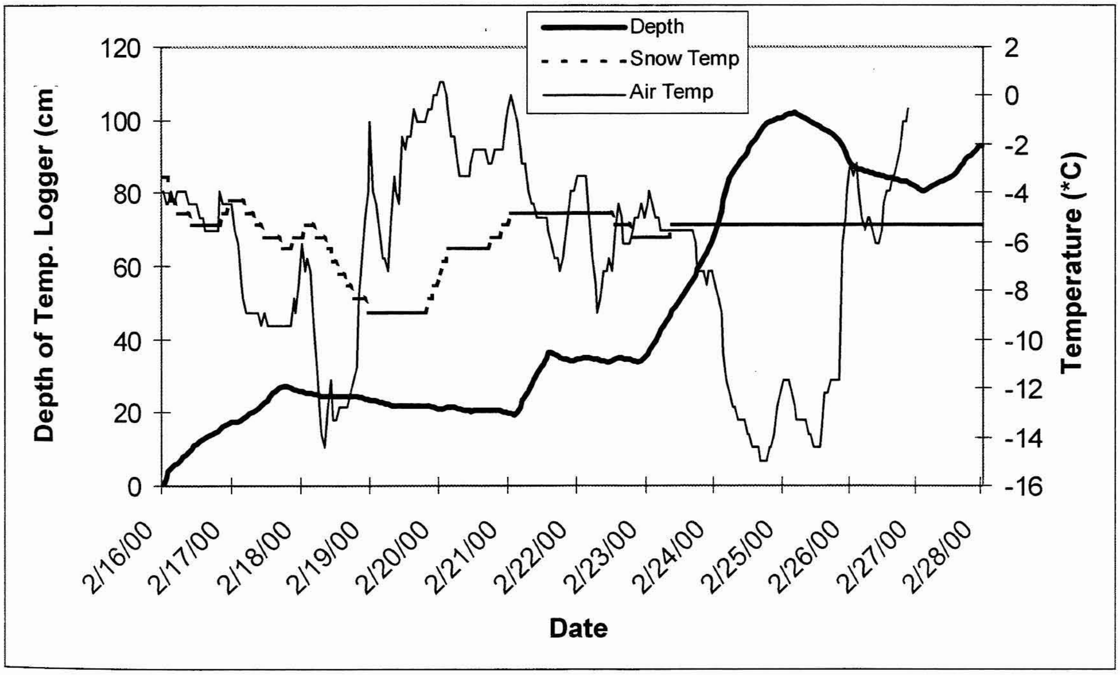

Figure 1: The snow layer temperature showed a short term response to changes in air temperature until it was buried by new snow about 40 cm deep.

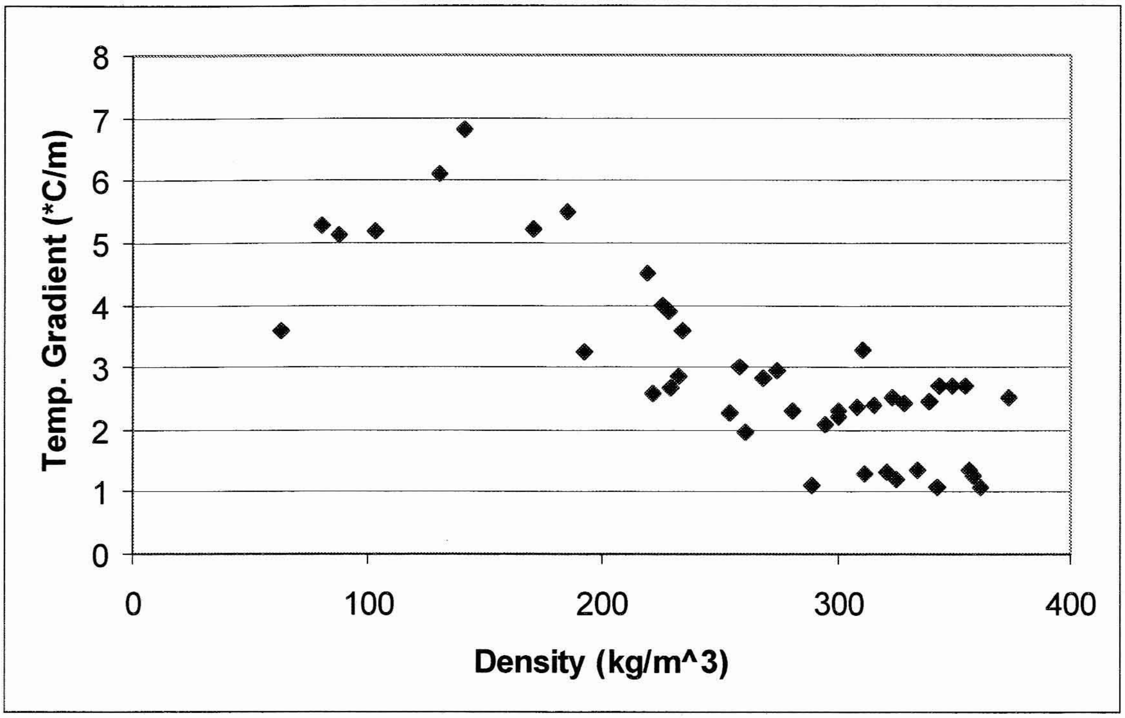

Figure 2: The temperature gradient between layers vs. the average snow density for those layers.

Near the end of the experiment period the upper part of the snowpack changed to more melt-freeze grain types. Also during this period the air temperatures were typically warmer when the pits were dug and densities measured. This was also the period when most of the settlement had occurred and the largest densities were measured. The results were examined to determine if this could have influenced the results for the higher density snow layers. Even at the end of the experiment the snowpack throughout the layers of interest was made up of fine grained round snow crystals. Temperatures at the layers of interest remained below 0° C during the entire test period. The average air temperature when pits were dug was -3.9° C for February, 0° C for March, and 4.5° C for April. However, on February 14, 2000, when the first pit was dug, the air temperature was a warm –0.5° C and on April 3, 2000, it was –3.3° C. Additionally, even though warmer daytime temperatures were recorded when pits were dug in April the snowpack remained cold. The author believes this had a minor influence on the temperature gradients measured for high density snow.

Conclusions

High temperature gradients result from well-insulated, thin partitions. A well-insulated layer provides poor heat transfer. This causes a large difference in temperature to develop across the layer. If the layer is also relatively thin the temperature gradient can be quite large.

The results of this experiment suggest the following theories. First, low-density snow, below 150 kg/m^3, where we measured lower gradients, must not insulate very well. The high porosity of the low-density new snow probably allows the air to move easily transferring heat across these layers. Second, the high-density snow, above 250 kg/m^3, also must insulate poorly. The large bond areas and high percentage of solid ice probably conducts heat very easily making it difficult to develop much of a temperature gradient across these layers. Finally, the medium density snow, from 150 kg/m^3 to 250 kg/m^3, developed the largest temperature gradients and must insulate the best. In these layers some settlement has occurred. Broken new snow crystals have filled in many of the air spaces preventing efficient air movement. However, the strong large bonds between snow grains have not developed yet so the ice matrix has not yet become a good conductor.

These theories suggest several possible snow pack conditions. A snowpack with a uniform density would have a uniform constant temperature gradient. Medium densities at the top of the snowpack can create ideal conditions for large temperature gradients and result in upper level facet growth. On a popular slope, skier activity can quickly compact the upper snowpack to a medium density while the adjacent slopes remain at low densities. During the period immediately following a storm when the nights are often clear and cold, faceted crystals may develop on the skier compacted slope and not on the adjacent slope. As the skier compacted slab continues to increase in density, it will likely reach higher densities than the adjacent slopes. This higher density slab can conduct the cold deeper into the snowpack creating larger temperature gradients at the bottom for more rapid depth hoar growth. If the low gradients that are typical with densities above 250 kg/m^3 are the result of well-developed bonds this may also be indicative of strong stiff slab formation.

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