A New Thermal View

Cora Shea and Bruce Jamieson
ASARC - Applied Snow and Avalanche Research, University of Calgary

"*What do you think will happen?*" In 2006, Dave Gauthier wrote those words in this journal. At the time, ASARC was developing and testing the Propagation Saw Test, and he was at the forefront. With these words, he captured the essence of research: If you don't know what will happen, but you really *want* to know, you might actually be on to something.

On the surface, it might seem like times have changed. The number of snowpack tests currently in development by ASARC is zero. To some of us in ASARC, that is unsettling. But maybe, just maybe, the next way to figure out what the snowpack is doing involves thinking outside the box.

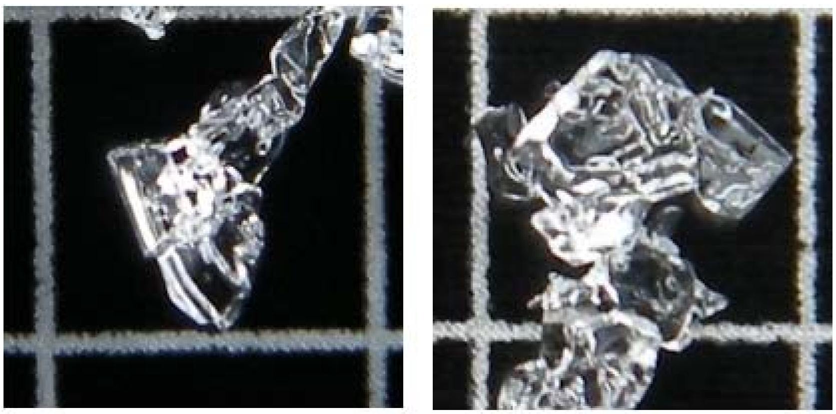


Figure 1: Typical facet growth above the buried crust between February 20 and 22.

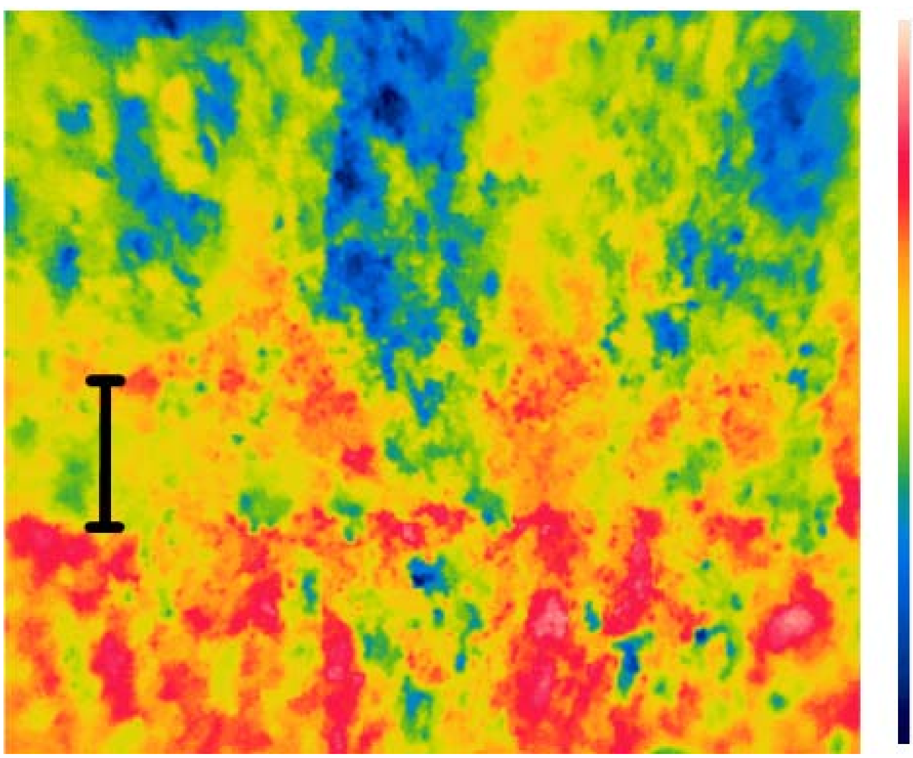


Figure 2: Saying the crust is relatively warmer or cooler than the surrounding snow doesn't capture half the complexity. The 1.5 cm thick crust can be seen on the pit wall in this thermal image, and it is marked by a black line. On average, the crust is warmer than the snow immediately above and below, but this is certainly not obvious, and the complex structure of the temperature gradients might play a larger role than just relative warmth or coldness.

I'm sure most of you have heard of ASARC using a thermal camera in the field. Now, I'm not saying the thermal camera is necessarily the next new thing. But I am saying first, it is outside the box, and second, it gives us interesting results we've never had before and don't yet know what to do with.

This past 2010-11 winter, Bruce and I used a thermal camera to closely follow temperature gradients around a crust in the Rocky Mountains. We measured some very, very interesting temperature gradients, both in structure and duration, which have not been observed before.

In January, on the first day the crust was buried, the crust edges had temperature gradients of more than one degree C across less than two millimetres of distance. Something interesting was going to happen, we knew. But we thought — incorrectly — that we had a handle on things.

On that day in January, the crust appeared to be warmer than the snow above and below. Based on a theory by Richard Armstrong for buried wet layers, as the heat in the crust leaked out into the snow around it, it would bring water vapour along for the ride and facets would grow at the crust boundaries.

So we expected to see the crust gradually cool over time and facets grow above and below. Sure enough, two days later the crust was cooler than the snow above and below, and stayed cooler three days after that. We figured: that's it, the heat is gone, and the crust is done growing facets.

But three days later, the crust was relatively warm again. Three days after that, it was cool. Then warm. Then still warm. Then cool.

"*What temperature do you think the crust will be today?*" A simple question with no obvious answer.

Our bafflement turned into a bet of coffee each day. Bruce would guess the relative crust temperature -- warmer or cooler -- and if he was right, I bought him coffee. If he was wrong, the coffee was on him. We really wanted to know: does a relatively warm crust mean future facet growth above and below? Does a relatively cold crust mean that the crust is itself faceting out? But though we gave scientific reasons for our guesses, I think we were both just blindly guessing and drinking a lot of coffee.

For a time, we thought it might be the camera showing us large gradients that did not really exist. So we spent a lot of effort correcting the thermal images for various types of error, and we also did a lot of thinking, and worrying, and pencil chewing. At that point, Karl Birkeland joined in and gave the two of us some much-needed perspective, direction, and support.

And in the end, when we compared the big gradients we were seeing using the thermal camera to macro photographs of the actual crystals, the crystals were certainly changing. So, *something* was going on.

Figure 1 shows, as an example, the crystals above the crust on February 20 and 22, almost a month after burial. The average temperature gradient, measured by the thermal camera, at the top crust edge on February 20 was 0.4 °C across the pixels above and below. Those pixels spanned a distance of 0.75 mm. Scaling up, this works out to about 50 °C per ten centimetres. But, pushing one's thermometers in above and below the crust on February 20 would not have shown this gradient...as the snow temperature above and below the crust were, on average, about the same.

So these temperature gradients we saw with the thermal camera, hidden between typical thermometer spacing, were big. And often, big facets followed. We took this to mean we were measuring something interesting, even if we couldn't intuitively guess what we would see before actually pointing the thermal camera at the snow.

In March, Karl suggested that the three of us try a different tack. Since we were not getting answers by waiting a day or so between visits, we should try measuring these temperature gradients as often as possible.

So, I performed the perfect graduate student job — staying overnight and digging a lot of snow. Twenty-five fresh pit walls dug over twenty-one hours later, we still had no firm answers. During a period of sky clearing and cooling in the morning, not only did strong temperature gradients appear around the crust, but they reversed and then disappeared in a matter of hours.

Temperature gradients of the magnitude seen in these daily and hourly visits can strongly affect the structure of the snow crystals. Some of the large gradients we observed have the ability to move a quarter of the ice they cross in two to three days. Which, by Figure 1, is certainly realistic.

Not only did facets form, but the crust overall entirely rebuilt itself. It formed crystals that were no longer small and randomly oriented by melt, and were instead large and long and aligned vertically with the heat flow (Figure 3). Like a parking garage.

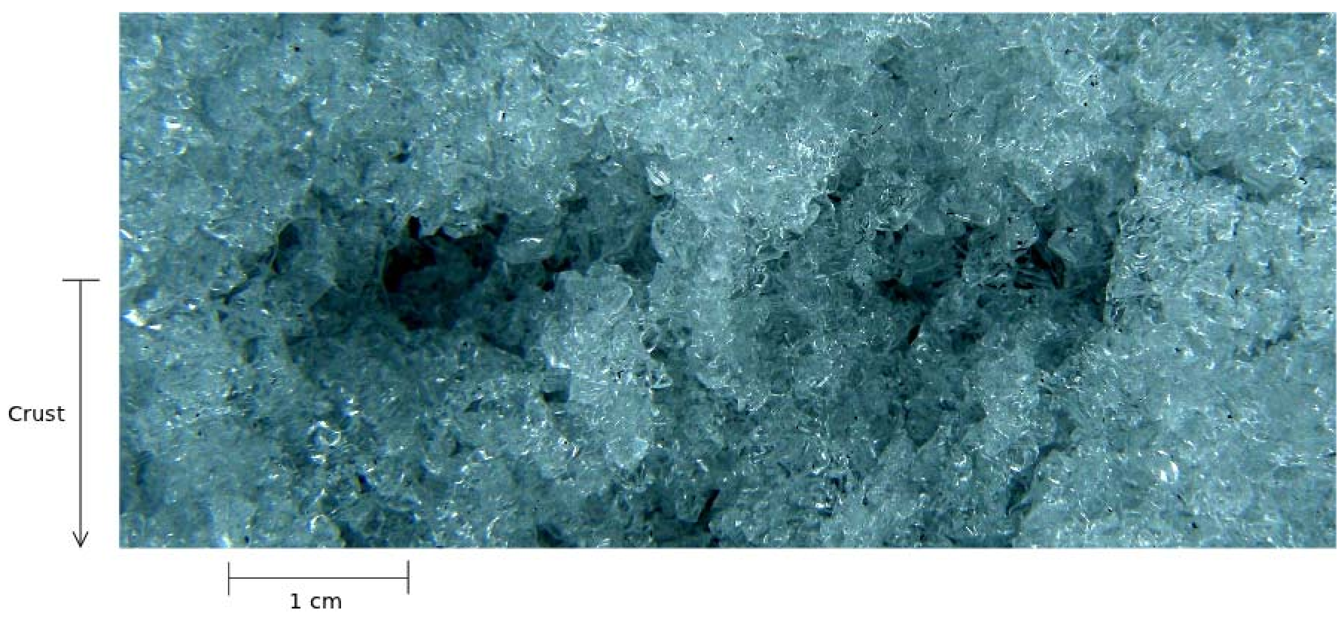
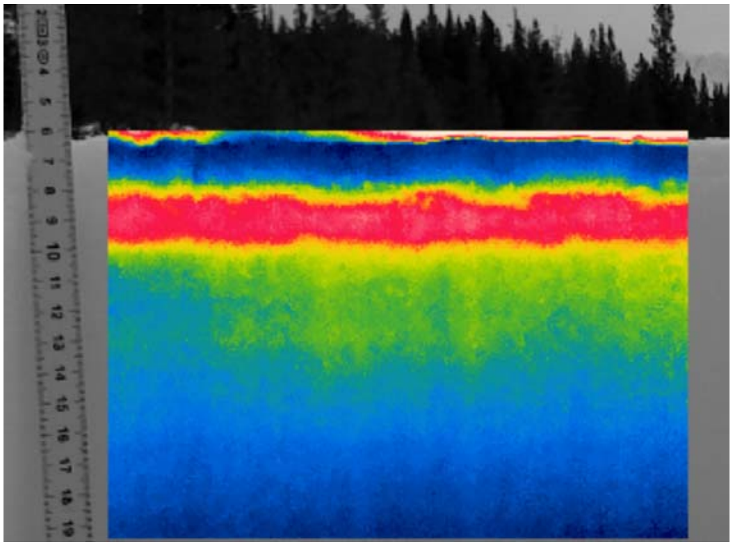


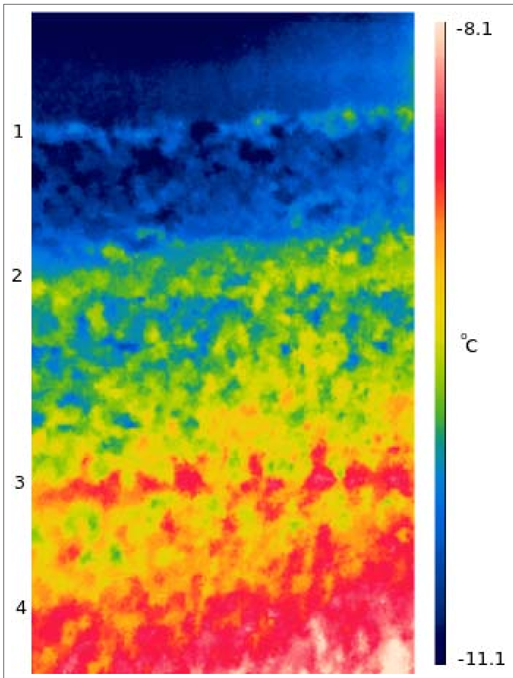
Figure 3: The top boundary of the crust on March 16. The crust is displaying what we call pinning and gapping, which refers to the vertical connections to the crust at the photo's centre and sides, and the gaps between them. The pins are actually polycrystals, oriented vertically. This type of lateral variation could affect how likely the facets are to initiate and/or propagate cracks.

To quote Dave Gauthier again, "I know what I *think* this means." I also know what we all *hope* it means: that we can start doing things like really predicting when facets will grow around thin layers, what crusts will do after burial, and how weak layers will become laterally supported (or not) over time. Will the thermal camera actually give us those abilities in the future? I really don't know. But there are more winters — and coffee — in the future for us to find out.

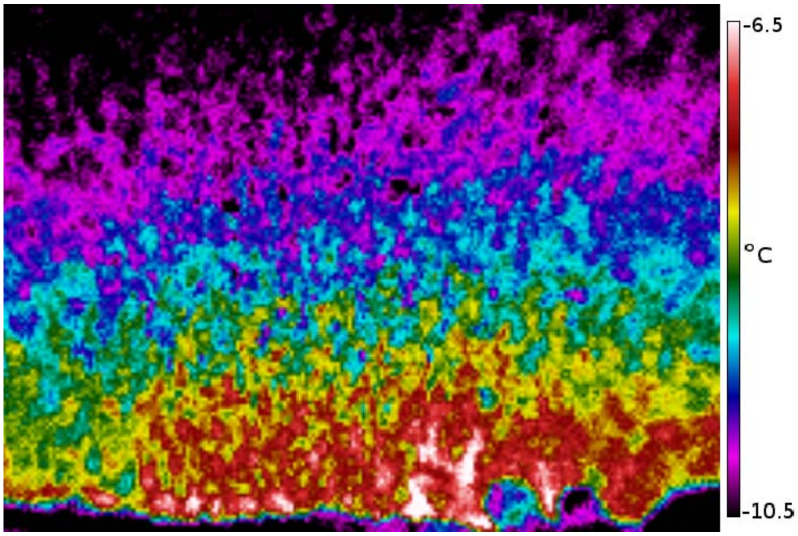
Examples of Thermal Images



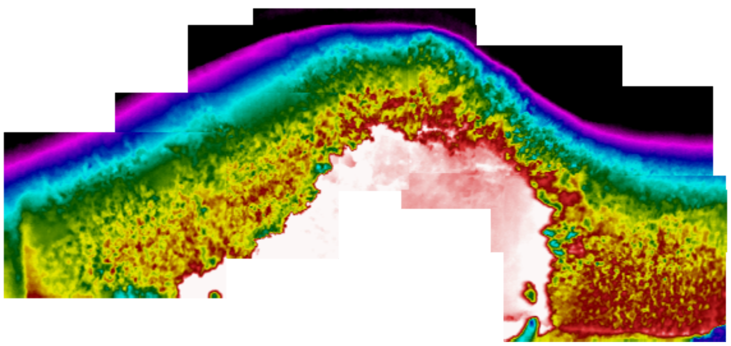
This thermal image (embedded in a visual image) captured heating of the snow below but not at the surface. This sub-surface heating grew near-surface facets via radiation recrystallization. The ruler provides centimetres for scale. The red snow layer is at 0.0 °C. The temperature of the dark blue snow above and below is -2.0 °C.



This thermal image captured temperature gradients appearing on the pit wall during the clearing of the sky in the morning. The relatively warmer layers 1 and 2 are facets, 3 is a crust, and the yellow-red transition at 4 is the edge of the depth hoar. These temperature differences only appeared for a few hours, until the sky clouded over again, and then they almost entirely disappeared.



This thermal image captures isothermal "chains" in buried facets. These chains are fingers of the same temperature reaching up and down vertically. These structures of temperature grow because they decrease the steepness of the temperature gradient from ground to sky. These thermal facet chains can be found even before striations are present on the snow crystals.



This composite of multiple thermal images shows the complex temperatures in a thin snowcover over a rock. The rock and snow surface was exposed by digging away the snow to a flat observation wall that ran over the top of the rock. The rock is the white area at the centre bottom, and all other colours (purple, blue, yellow, red) show the thermal structure of the overlying snow. The temperature scale ranges from -10 °C (white) to -25 °C (purple).