LEAVE YOUR THERMOMETER AT HOME... BUT DON'T FORGET YOUR LOUPE!

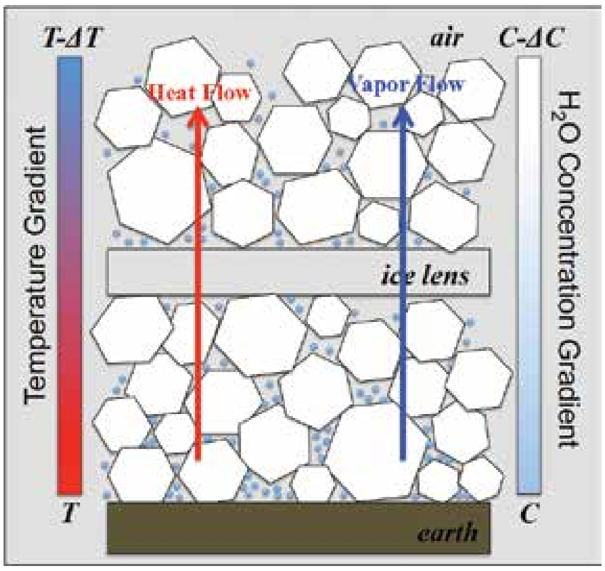
Editor's Note: *We first printed Kevin and Ethan's article in the April TAR, but inadvertently omitted some important graphics. Please enjoy it in its entirety.*

Recent AAA funded research shows that rather than capturing coarse resolution temperature profiles in your midwinter snowpit, your time may be better spent analyzing the snowpack stratigraphy and characterizing snow grain types found near suspected weak layers.

BY KEVIN HAMMONDS & ETHAN GREENE

As it turns out, spending many an extra cold and blustery minute trying to get those last few temperature readings from your snowpit wall for a textbook perfect "every-ten-centimeter" temperature profile may not be all that helpful, and if anything can even be misleading. Based on recent laboratory research conducted at the Dartmouth Ice Research Laboratory (see Hammonds et al. 2015) and succeeding other earlier but similar work (see Greene 2007), it would appear that perhaps the most critical of temperature gradients are those that cannot be directly measured…at least not with your standard field-based instrumentation.

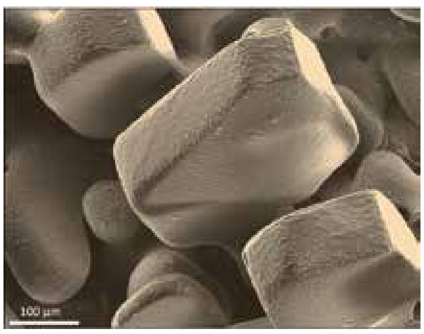
In Hammonds et al. (2015), a study funded by the AAA, the authors created an artificial snowpack consisting of an ice lens sandwiched between two layers of old natural snow grains. They placed the sample under a controlled temperature gradient for 48-hours and observed the microstructural evolution of the ice-snow interface via micro-CT imaging while recording the temperature gradients within the sample with a custom built micro-thermocouple array. From the micro-CT imaging, new ice crystal growth occurred from the bottom surface of the ice lens while the top remained smooth. This observation was in line with the previous work of Greene (2007). In addition to Greene (2007), however, were the temperature gradients that were recorded near the ice-snow interface on a sub-millimeter scale. At these small scales, local temperature gradients were observed to be as much as 40 times that of the bulk temperature gradient that had been imposed over the sample. These results are thought to be of significance to avalanche forecasters for two primary reasons:



FUNDAMENTALS OF THE ICE/SNOW INTERFACE: Phenomenological representation of how an ice lens may affect the thermophysical properties of an ice-snow interface. Developing a better understanding of what happens to the heat and vapor flux at the ice-snow interface was the motivation behind Hammonds et al. 2015.

1. Slab avalanche activity has long been observed to occur near icy layers or crust/facet combinations in a region of the snowpack that did not necessarily have a measurable temperature gradient indicative of kinetic snow metamorphism. (Jamieson et al. 2001, Greene & Johnson 2002, and others)
2. Hammonds et al. (2015) showed that very large increases in the temperature gradient occur at very small scales in the snowpack around ice crusts. Such localized jumps in the temperature gradient on a sub-millimeter scale are not currently measurable with standard field instrumentation. Most temperature probes are themselves two millimeters in diameter and the typical resolution of a good dial-stem thermometer is +/- 0.5 °C.

"What causes the jumps in the local temperature gradient near the ice-snow interface?" This occurs because such icy layers can act as thermal discontinuities to an otherwise thermodynamically homogeneous snowpack. Such results are not exactly intuitive…"isn't snow just made of ice?" The answer is "yes", but due to the crystalline structure and long range atomic order of solid ice versus the more disordered and loosely packed icy version of what we know as snow, thermal conductivities of ice compared to snow can differ by as much as a full order of magnitude (Petrenko & Whitworth 1999, Riche & Schneebeli 2013). This causes problems when individual snow grains come into contact with solid ice, as the pathway for conduction through the snow/ice matrix is compromised by the finite number of contact points that actually exist between the two, termed the thermal contact resistance. A function of the connectivity between the ice lens and the adjacent snow layers, the thermal contact resistance has been shown in a secondary study (Hammonds & Baker 2016) to be ultimately what is responsible for the marked increases in the sub-millimeter scale temperature gradients observed near the ice-snow interface. Although never before directly measured, many have suggested in the past (Colbeck 1991, Colbeck & Jamieson 2001, Greene 2007, and others) that such super-temperature gradients were likely to exist near an ice-snow interface and that enhancements in kinetic snow metamorphism could result. As a pertinent and memorable example of this scenario, large and widespread avalanche cycles associated with the Martin Luther King (MLK) rain crust in 2011 *(see TAR Vol. 30 No. 3)* were more than likely the result of such enhancements in kinetic snow metamorphism occurring near the ice-snow interface. This MLK crust was observed to be a repeat offender as it would avalanche and then reload with a new snow slab. This is thought to have occurred because once formed, such ice lenses can only degenerate by the natural mechanisms of sublimation (slowest), destruction by an avalanche (fastest), or by becoming so significantly buried that compressional forces of the overlying snow slab aid in the bonding of the adjacent snow layers to the icy layer itself, thus limiting the effects of thermal contact resistance (most unsure and unsettling scenario).



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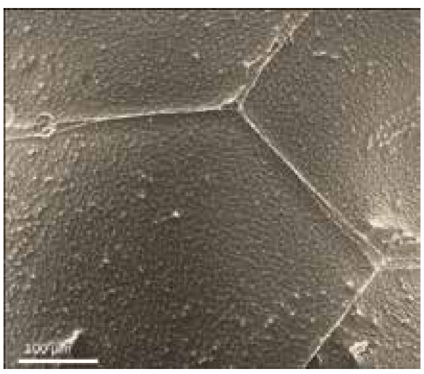

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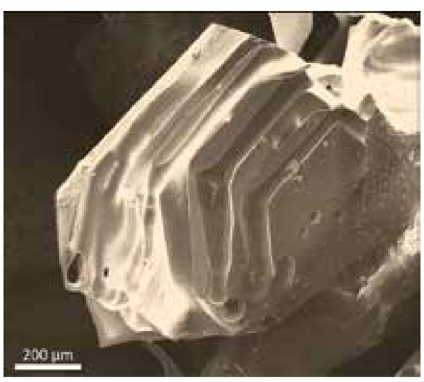

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Scanning electron microscope images show (a) ice crystal growth on the bottom surface of the ice lens, (b) smoothness of the top surface of the ice lens, and (c) kinetic snow metamorphism of an adjacent snow grain above the ice lens after 48 hours under a -100 °C/m temperature gradient. Figure adapted from Hammonds et al. 2015.

So, to answer the question "Is it always worth getting a perfect every-ten-centimeter temperature profile in your snowpit?" The answer is quite simply "No." In fact, focusing too much on such large-scale temperature gradients can even be misleading as it may add bias to your opinion of what your observations of grain type actually mean. For instance, if you measure a bulk temperature gradient less than -10°C/m and identify a faceted crystal structure, it becomes very easy to assume the regime of "facets-going-to-rounds", when it may actually be the opposite that is occurring. Thus, based on physical evidence from recent laboratory testing (Hammonds et al 2015) that is in direct support of long-standing avalanche theory (Colbeck 1991, Colbeck & Jamieson 2001), it would seem most advantageous for us all to begin spending less time looking at our temperature plots and perhaps more time looking through the lenses of our loupe. ▲

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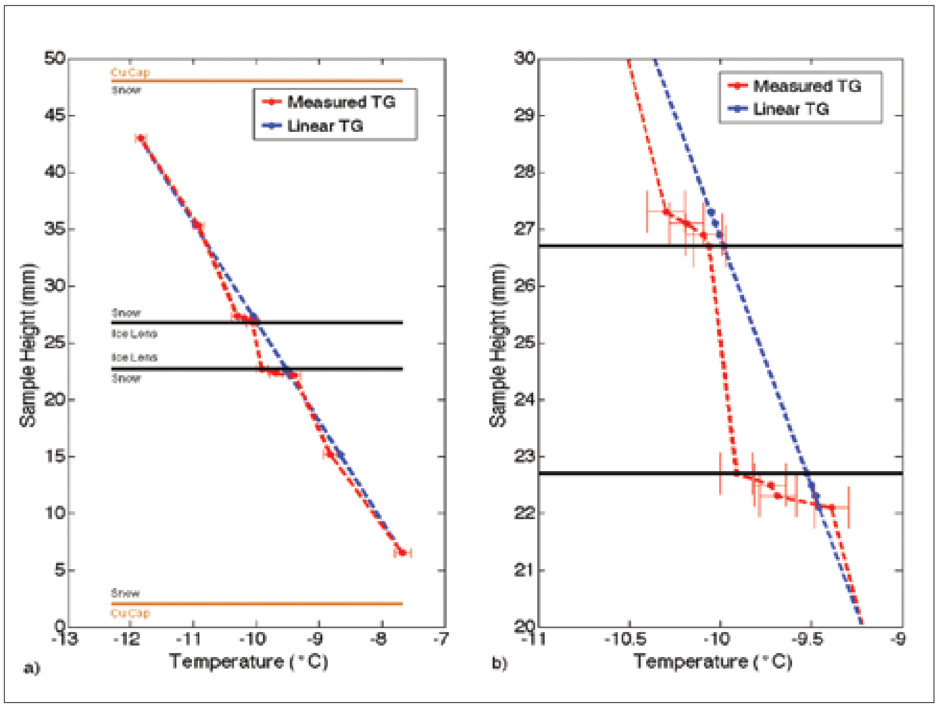

Temperature gradient measurements taken with a micro-thermocouple array near a 4 mm ice lens over (a) the entire height of the sample, and (b) within one millimeter of the top and bottom surface of the ice lens. Figure adapted from Hammonds et al. 2015.

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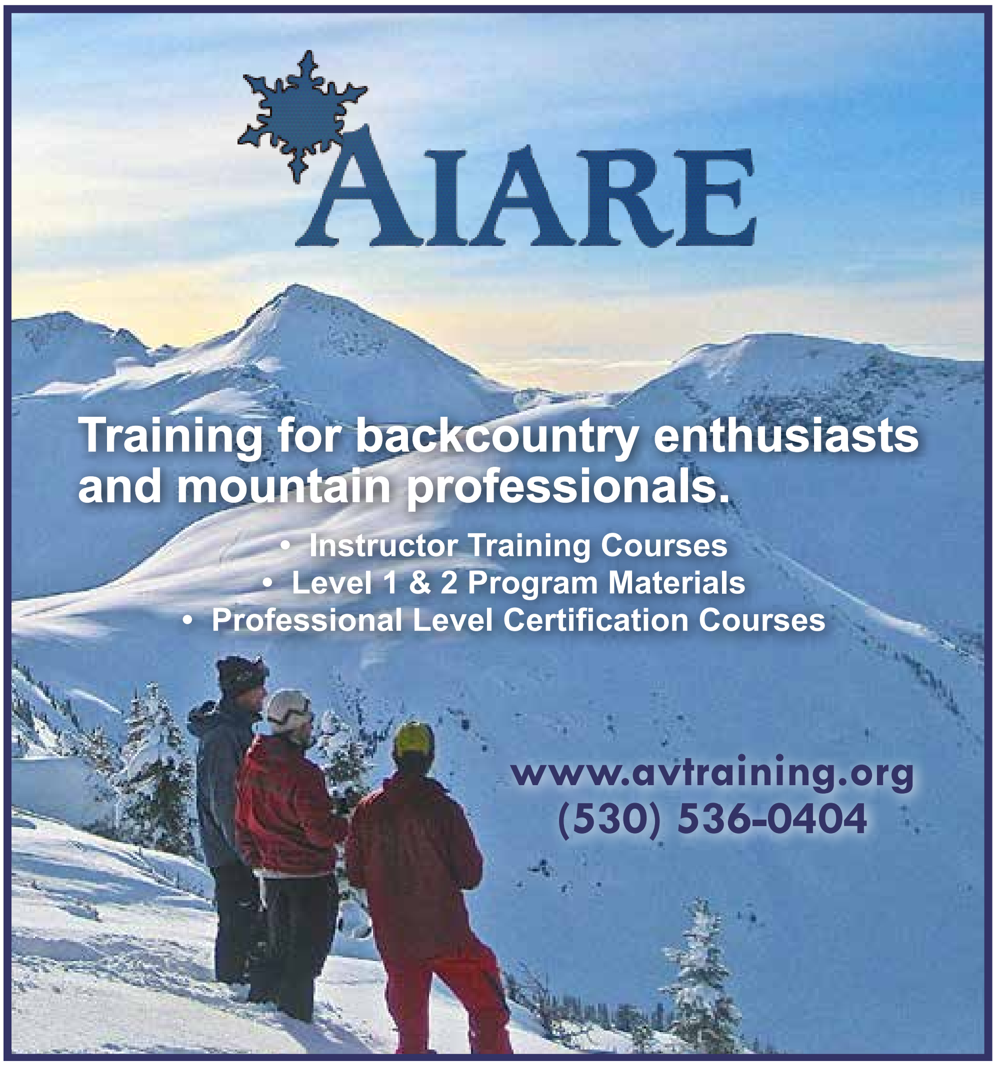

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