Review of *Seasonal evolution of the effective thermal conductivity of the snow and the soil in high Arctic herb tundra at Bylot Island, Canada*

Journal: The Cryosphere (TC) Title: Seasonal evolution of the effective thermal conductivity of the snow and the soil in high Arctic herb tundra at Bylot Island, Canada Author(s): F. Domine, M. Barrere, and D. Sarrazin MS No.: tc-2016-107 MS Type: Research article

In this paper the authors report on the evolution of the thermal conductivity (k_{eff}) of the tundra snow cover of Bylot Island. It is an interesting paper, with a key finding being that the contrast in k_{eff} between depth hoar and wind slab is on the order of 1:10. While this finding is not new, it is a useful piece of information that is neither widely appreciated nor captured by snow models (as the authors show). Overall, I recommend the paper be published….but not until it has been shortened considerably. The number of readers who will want to wade through all the detail currently in the paper in order to glean the main points is limited, and as consequence, the impact of the paper will be reduced

One other key point: if the 1:10 contrast in k_{eff} is the big take-away message of the paper, then the authors have missed an opportunity to discuss a key aspect of how tundra snow functions, in a way that is convolved with this 1:10 contrast. As seen in the authors' Figures 2 and 7, the relative percentage of depth hoar vs. wind slab controls the bulk thermal conductivity of tundra snow covers to a large extent. The number of windstorms, the relief of the underlying tundra tussocks (inter-tussock depth hoar), and the sequence of snowfall events all combine to determine what these percentages will be, hence how conductive the snow cover will be. This is a sensitive balance, one that could easily change if the climate, wind regimes, and snow-up dates, change. Discussing this would be valuable and for those readers that this paper aims at possible new information.

Other specific comments follow:

1. The authors have a tendency to cite new rather than seminal work, and philosophically, I find this distressing. It leads to the field "forgetting" facts and findings, then these have to be rediscovered. For example, that there are large amounts of organic matter in the permafrost was well known and reported on in the 1960s and 1970s: see Lachenbruch and Ferrians among other authors. A similar comment on references in the snow literature.
2. Line 117: Convection in snow. This was a lot of attention paid this topic in the 1980s and 1990s. The authors should see and cite:
    - Powers D, O'Neill K, Colbeck SC (1985) Theory of natural convection in snow. Journal of Geophysical Research 90:10641-10649.
    - Sturm M, Johnson JB (1991) Natural convection in the subarctic snow cover. Journal of Geophysical Research 96 (B7):11657-11671.
    - Sturm M (1991) The Role of Thermal Convection in Heat and Mass Transport in the Subarctic Snow Cover. USA-CRREL Report 91-19.
3. Line 151: Alternate methods of measuring thermal conductivity: It is not clear that guarded hotplate methods would produce more accurate or appropriate values $k_{eff.}$ ---just different. While the dynamic method of the needle probe has some problems (pointed out by the authors) so too do steady-state methods. For example, real snow covers rarely, if ever, develop a steady-state non-varying temperature gradient. Also, when snow is subjected to uni-directional gradients, the thermal conductivity evolves through

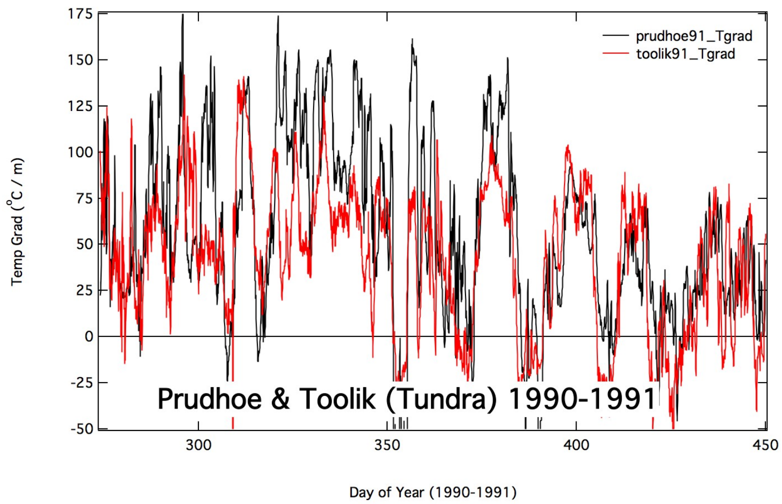
metamorphism, leading to a varying value of k_{eff} (or alternately, such mild gradients have to be imposed that the resultant tests are equivocal). I suggest altering the statement to indicate that the alternate methods are impractical, and *may not even be more accurate*.

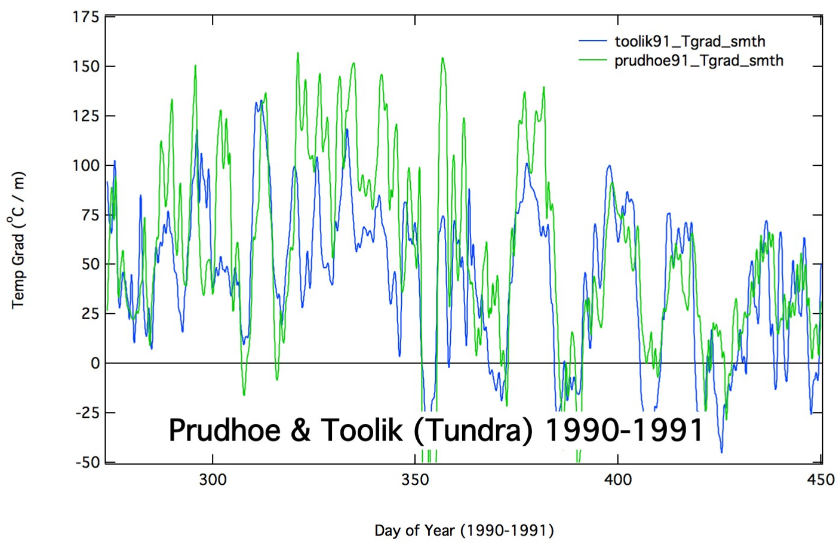
4. Line 156: Do you have to worry about pore water migration in measuring thermal conductivity of the soil using a needle probe?
5. Lines 185 and 265-270: ***Indurated depth hoar***. I would like to see a more comprehensive discussion of this snow texture. I believe the lead author and I discussed this snow texture when working jointly on snowpits in Alaska about a decade ago. He is correct that no formal symbol for the material exists in the International Classification, but that arises in part from the fact that I don't think the committee charged with revising the classification believed such a material existed. The symbol I have been using for almost 20 years for this type of snow is a combined symbol of wind slab (black circle with a slash) and depth hoar (chains of grains or just cups). This is not that different than the one introduced in the paper, and it would be good to mention both as many of my students continue to use our older symbol. In addition, Carl Benson and I described this texture in our 1993 paper the phenomenon, though it was a few years later I introduced the term "indurated":

   > *Elsewhere wind slabs are adjacent, one on top of the other. As the winter progresses even dense wind slabs can begin to metamorphose into depth hoar. We have observed wind slabs as dense as 0.35 g cm metamorphose into depth hoar by the end of the season.*

   Before introducing that term I corresponded with Dr. Akitaya (arguably at the time *the* expert on depth hoar) regarding it. He had never seen this texture in Japan because the temperature gradients are too low to produce it.

6. **Temperature Gradients**: (Lines 313-317) In order to turn wind slabs into indurated depth hoar, strong gradients are needed (see authors Figure 11). While the gradients a Bylot Island are super-critical (> 25°C/m) for much of the winter, they are less strong than I would have expected. I attach comparable data from Alaska's North Slope. Not only are the gradients stronger than those in the paper, but they start earlier in the winter. In a second graph, I have smoothed the data (48 hour running average), as the authors have done. The result is noticeably milder. I suggest the following changes/additions: a) don't smooth the gradients. In 48 hours a lot of metamorphism can take place. Smoothing makes the graph cleaner but less "physical" as far as metamorphism is concerned, b) show the critical gradient….whether that of Marbouty or Colbeck or Armstrong. It gives readers an appreciation of what drives the changes, c) consider computing something like an integrated metric called "time under a strong gradient" or the like. Right now the paper mainly focuses on the agreement between the thermistor and NP values, but that misses the BIG point of what is actually driving the physics. And while Lines 325-330 provide the vapor gradient (and state that it can grow depth hoar), the values are really meaningless unless they are translated into something like a growth rate. Consider as an example computing how fast these vapor gradients could grow a thin sheet of ice…like the skirt on depth hoar cup. That would make the values mean something.





8. **Soil to Snow Fluxes**: These have been measured during depth hoar metamorphism. See:
   - Trabant D, Benson CS (1972) Field experiments on the development of depth hoar. *Geological Society of America Memoir 135:*:309-322.
   - Santeford HS Snow Soil Interactions in Interior Alaska. in Modeling of Snow Cover Runoff, USACRREL, Hanover, NH, pp. 311-318.
   - Sturm M, Benson CS (1997) Vapor transport, grain growth and depth hoar development in the subarctic snow. Journal of Glaciology 43:42-59.

9. Line 341: There is a large literature on depth hoar and subnivean animals. Possibly the best starting point is W. O. Pruitt's 1957 paper:
   - Pruitt Jr, W. O. (1957). Observations on the bioclimate of some taiga mammals. *Arctic*, *10*(3), 130-138.