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Discussions

Interactive comment on “Use of a thermal imager for snow pit temperatures” *by* C. Shea et al.

C. Shea et al.

cashea@ucalgary.ca

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Previous comments are *in italics*, responses are in normal text.

See the attached PDF for a version including an equation.

I like the paper. The study of snow would benefit greatly from a mechanism to rapidly measure temperature profiles at very fine depth resolution. The paper makes the case for this need. The interpretation of the results (Section 8) is particularly pertinent.

Thank you, in particular for your theoretical perspective below. We appreciate the time you took to examine our methods.

WEAKNESS

The problematic feature of the paper is the misinterpretation of the relationship between temperature and flux emitted from the surface in the wavelengths the camera senses.

In Section 7.1, the discussion following equation (2) asserts, “To obtain temperature from watts, one uses the Stefan-Boltzmann law.” However, the FLIR B300 measures infrared radiation from 7.5 to 13 mu-m. The Stefan-Boltzmann equation is the integral of the Planck equation over wavelengths 0 to infinity. At temperatures from -30 to 0C (243-273K), blackbody emitted radiation from 7.5-13 mu-m is 26.7%-31.9% of the Stefan-Boltzmann emission. Moreover, the relationship in this temperature and wavelength range is proportional to $T5.5$ *instead of* $T4$.

Agreed. This was a misleading attempt to provide a physical basis for what is ultimately an empirical relation developed at the factory between the microbolometer sensor and known temperature flat fields. The discussion of the Stefan Boltzmann law and corrections on wattages has been removed. However, as old Equation 3 (new Equation 2) is how the voltages are changed to adapt to atmospheric conditions, it has been retained. The paragraphs in question are now located at new section 7.1, starting at new line 227.

Probably, these errors do not affect the interpretation of temperature gradients, but it would be a shame for The Cryosphere to propagate the misunderstanding. The question is, how best to translate the output from the camera to actual absolute temperatures? The website of the FLIR B300 says the “Measurement mode” is “Delta T.” The paper would benefit from a more precise description of what the camera says it measures, and how we convert those data into temperature.

FLIR’s use of the term "Measurement Mode" is simply a way to describe the marketing-type features available on the camera. The "Delta T" feature in measurement mode is the ability for the user to select two different points on the screen and obtain a temperature difference between the points from the camera’s software.

The question of how to convert voltages into absolute temperature is a very difficult engineering question, and that is why one of our concluding statements (in both versions, now new lines 568-569) is that future work would be needed to assess the use of absolute temperatures obtained from a thermal imager for use independently of gradients in snow studies. We have also added this statement to the abstract, new lines 15-16. As the main value of interest is the thermal gradients – between-pixel values – and these are subject to microbolometer noise (0.05 C) rather than absolute temperature accuracy (2%), the thermal imager is still very useful despite the engineering difficulties behind obtaining absolute temperatures.

The engineering difficulty is knowing what temperature the microbolometer is at, so one may know the resistance and heat absorption of the connections used to measure the change in resistance of the pixel. And of course, if one tries to measure the temperature of the microbolometer, one runs into a sort of chicken and egg problem where then you need additional connections to measure the microbolometer temperature, which themselves have changing resistance over temperature, and so on. A more complete description of these engineering distinctions have been added to the paper in new section 7.1, starting at new line 227.

However, this type of resistance fluctuation can be somewhat minimized by allowing the microbolometer (i.e. the imager as a whole) to equalize slowly and completely with the ambient atmosphere before using it. We had this as part of our field routine from the beginning, primarily from fear of equipment condensation. This may be the reason why combining images – as discussed in the response to reviewer P. Lahtinen – was so straightfoward within our data: as long as the microbolometer is at a stable temperature, the resulting absolute temperatures may be a bit off (to a maximum of 2%), but they are the same amount off for each image taken with an equalized microbolometer. This is how, for example, the temperature variation from the left side of Figure 6 was obtained, and even then the focus of the interpretation is less that the absolute temperature changes, and more that parts of the images warm up and create stronger gradients. However, as the concluding statement about absolute temperatures implies, the effect of this equipment equalization (and other methods of reducing variation in absolute temperature measurements) needs a bit more formal study before using ab-

solute temperatures as numeric rather than relative, and as the only data source rather than in conjunction with gradients.

OTHER COMMENTS

Section 3.1 Line 15. This definition of a temperature gradient is inconsistent with the paragraph above, with general usage, and with usage throughout the paper. I think you mean "the difference in temperature between two points, divided by the distance between them, as an absolute value."

Agreed. This and the following sentence have been fixed and clarified, new lines 110-112.

Sections 4, 6, 6.1. The emphasis to work quickly is entirely correct. The thermal IR emissions from the surface come from 1-2 mm from the surface, and the surface can rapidly equilibrate with the energy from the surroundings (air, body of the worker, etc). In this case, especially for deep pits, perhaps we should photograph as we excavate, whereas our usual practice with dial stem thermometers is to dig the pit, then measure temperature and density profiles.

Stem thermometers measure a short distance into the snowpack (12-18 cm) and so have a insulating buffer of snow between them and the surface. We do outline a method for iteratively uncovering the pit wall, located at new lines 197-203.

Section 6, point 2. Theoretically, why is it important to have a smooth pit wall? Near nadir, emissivity is not very sensitive to view angle (Dozier and Warren, 1982). Similarly, do you need to have the camera pointed nearly orthogonally to the surface?

We did discuss our theories behind why snow and its complexity is somewhat more subject to non-nadir angles than a flat field, now located on new lines 293-305. But, the real reason is that the differences in temperature we are interested in are very small, so non-nadir effects needed to be examined. Correcting gouges from the shovel, for example, involves needing to amplify snow data only slightly more distinct than the gouge data. Their presence is certainly not totally disastrous, but since they are so easy to avoid with practice and finicky to correct for later, we chose to propose using as flat a wall as possible.

Section 8.1.3. Equation (5) appears to be the saturation vapor pressure over water, not ice. Bohren Albrecht (1998) use a slightly more complicated form. See the attached PDF for those equations.

Yes. We initially chose water vapour pressure to describe pore space air-only transfer. But we agree with your suggestion, especially with such a gross estimation, that it is easier to simply go from ice to ice. This has been changed, new lines 435-436, and 444-449.

This is a good reference, thank you, and also thank you for the two equations in the supplement. We also considered using the expansion from Kaempfer and Plapp (Phys Rev, 2009). However, as reviewer Z. Courville points out, the estimation is gross at best. The most inaccurate assumption is probably the attachment rate as it is currently an unknown, followed closely by the 1:50 shape assumption. The more complex pressure estimation equations, though certainly helpful if we were actually modelling, would be enhancing the more precise portion of a rather scrubby estimation. As our focus is on field and engineering-based techniques, we intentionally retain the most simplified version.

REFERENCES Bohren, C. F., and Albrecht, B. A.: Atmospheric Thermodynamics, Oxford University Press, 402 pp., 1998. Dozier, J., and Warren, S. G.: Effect of viewing angle on the infrared brightness temperature of snow, Water Resour. Res., 18, 1424-1434, 10.1029/WR018i005p01424, 1982.

Interactive comment on The Cryosphere Discuss., 5, 2523, 2011.