

The Cryosphere Discuss., referee comment RC1
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Comment on tc-2021-247

Ryan Webb (Referee)

Referee comment on "Mapping liquid water content in snow at the millimeter scale: an intercomparison of mixed-phase optical property models using hyperspectral imaging and in situ measurements" by Christopher Donahue et al., The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-247-RC1>, 2021

This study uses NIR spectral reflectance measurements to estimate the LWC of snow, and compare those estimates to an independent dielectric measurement. This investigation conducts laboratory scale tests to determine which reflectance model is most appropriate. This model is then applied in the field to a single snow pit face to demonstrate the field applicability. This study was able to show a final uncertainty of $\sim 1\%$ for larger grain sizes as methods were not very promising for small grain sizes (not surprising, but excellent effort that was worth a shot).

Overall, I really liked reading this paper. It is well written and easy to follow. These methods will advance capabilities in observing LWC in the snow, a long-standing challenge in the field. With that being said, there are a few improvements that I think could really help expand the impact of the final paper. Most of these are relatively minor (at least I think so) and should not be too difficult to address. I put the comments in order of appearance in the paper, generally listed by line number. One general comment is that there are a number of recent studies investigating water flow through snow that could/should be cited (some are listed in the comments below).

Title: given the recent advances in mapping liquid water content at various scales (from pore scale to hillslope and watershed scales), I think specifying what scale this paper addresses in the title is justified.

L 23: "unprecedented detail" may be a bit of an overstatement. I think the method has the potential to do so in the future, but not in the current study. The previous paper that comes to mind is Williams et al. (2010) who were able to provide a 3-D model of a 1 m x 1 m cube of snow at 1 cm³ resolution showing the meltwater flow patterns throughout. While the current study has higher resolution, it is limited to a single pit face. However, the Williams study should be referenced and potentially added as a comparison in the discussion.

Williams, M.W., Erickson, T.A. and Petzelka, J.L. (2010), Visualizing meltwater flow through snow at the centimetre-to-metre scale using a snow guillotine. *Hydrol. Process.*, 24: 2098-2110. <https://doi.org/10.1002/hyp.7630>

L66-70: Please clarify a little more as these processes often happen at the same time in a natural snowpack. Especially early in the melt season (Hirashima et al., 2019; Eiriksson et al., 2013). These studies could also improve the discussion as to potential future applications of the presented methods.

Hirashima, H., Avanzi, F., & Wever, N. (2019). Wet-snow metamorphism drives the transition from preferential to matrix flow in snow. *Geophysical Research Letters*, 46, 14548– 14557. <https://doi.org/10.1029/2019GL084152>

Eiriksson, D., Whitson, M., Luce, C.H., Marshall, H.P., Bradford, J., Benner, S.G., Black, T., Hetrick, H. and McNamara, J.P. (2013), An evaluation of the hydrologic relevance of lateral flow in snow at hillslope and catchment scales. *Hydrol. Process.*, 27: 640-654. <https://doi.org/10.1002/hyp.9666>

L80: The Williams et al. (2010) study quantified spatial distribution using dye tracers.

L207-209: So an entire snowpit profile was taken prior to imaging. What effect do you think this had on the liquid water content of the pit face. For example, Shea et al. (2012) found that 90% of temperatures changed in a statistically significant manner in the first 90 seconds of exposure to the air and continued to change over time. I think you still demonstrate the applicability of this method in the field, but this should be a consideration for future studies that focus on the field applications.

Shea, C., Jamieson, B., and Birkeland, K. W.: Use of a thermal imager for snow pit temperatures, *The Cryosphere*, 6, 287–299, <https://doi.org/10.5194/tc-6-287-2012>, 2012.

L225-226: Maybe an iterative approach could overcome this? Essentially, the sum of LWC mass and dry density should equal the density cutter bulk density. For example, if the SLF sensor gives you 6% LWC, that is 60 g of water for a 1 L density cutter, and if the dry density estimate for that is 350 kg/m³, then you can compare 410 g (350 + 60) to the actual bulk measurement from the cutter and adjust accordingly. The SLF sensor records and logs the measured permittivity with the calculated LWC so this should be relatively straight forward using the equations in the manual. Feel free to reach out if this does not make sense.

L242: I do not recall if you specify that you are referring to volumetric LWC. Please double-check that this is done somewhere.

Figure 7: This is a really cool figure. It did take me a minute, though, to get used to blue being dry and yellow being wet. Please consider inverting the color scheme. Also, a scale bar and dashed lines for the SLF sensor footprint could be quite helpful to see how much variability occurs in the footprint of the instrument. Possibly even histograms of just the SLF sensor footprint, if they differ from the whole ROI.

L338: did you take grain size measurements at the end of the experiments also to look at grain growth? This might also have an impact (as you mention in the discussion).

L3339: "this data" please correct to "these data"

L345: the 2% RMSE is also the stated accuracy for the SLF sensor I think (maybe worth mentioning), so these are great results!

L474: Please see previous comment for iterative approach.

L511: I was really hoping for a lot more discussion towards this in the 'discussion' section. Questions kept popping up like: why is this useful? How might this method be helpful in the field for future studies? What improvements can you suggest to reduce the impact of the rapid changes after exposing the face (as previously mentioned) and to capture the entire pit face down to the ground? etc. A paragraph or two to this affect could really help the impact of the paper.

L515-523: This final paragraph reads much more like discussion than conclusions, in my opinion. I recommend moving to the discussion section.

I would like to re-iterate how much I like this paper and my comments are meant to be constructive. Please feel free to reach out by email or in the interactive discussion if something that I wrote is unclear or you wish to discuss further.

-Ryan Webb