Review of:
In situ measurements of meltwater flow through snow and firn in the accumulation zone of the SW Greenland Ice Sheet
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Summary:
This paper presents in situ measurements of water flow through firn in Southwest Greenland. The authors leveraged two methods. The first used a portable lysimeter, which measured vertical percolation of water sprayed by a sprinkler through blocks of firn that had been excavated from a pit. The second method used salt dilution and dye tracing experiments to investigate lateral meltwater flow velocities.

This work is an important contribution to the glaciological community: the fate of surface meltwater on the ice sheets is not well constrained, but it is becoming increasingly important to understand surface meltwater processes as an increasing area of Greenland is subject to melt. The research presented by the authors is novel and an important step in filling that gap in our knowledge; in situ measurements of any firn/meltwater processes are exceedingly rare.

This paper will be a good contribution to *The Cryosphere* after several issues, which I outline below, are addressed.

General comments:
1. My general feeling about this paper is that I was very excited about the science that was done, but the paper did not provide adequate discussion (1) about why the results were what they were; (2) about the broader implications of the research; and (3) about assumptions and uncertainties.

An example is that the theoretical, modeled lateral flow rates were 3 orders of magnitude less than the observed lateral flow rates. This is a very large discrepancy, but the discussion section does not include discussion of why this large discrepancy might exist. I encourage the authors to work on the discussion section to add more discussion of how their results corroborate or challenge our current understanding of firn meltwater hydrology. It might be useful to provide a simple, qualitative description of how these flow processes operate on different spatial scales based on the results. To add to the implications, can your results add any perspective to our understanding of the fate of firn meltwater; e.g. on longer time scales, what percent of meltwater is running off? Can your results be extrapolated to non-ice slab regions, or are they spatially limited?

The paper does not include uncertainty or error analysis, which I would like to see in a field study like this. I realize it can be difficult to quantify uncertainty in work like this, but even a short section qualitatively describing the uncertainties would improve the paper. For example, does permeability change during percolation with ROSA? How will that affect your quantitative results?

2. A central assumption around your analyses is that the flow is Darcian. It may be the case that this is a valid assumption, but I think it would be appropriate to include justification. Is preferential flow in fingers/pipes Darcian? Would you calculate a different hydraulic conductivity if you conder Richard's Equation vs. Darcy's law? Is there a point at which you expect your Darcian assumption to break down? Your abstract says that for the ROSA experiments, "flow predominantly occurring through preferential flow fingers". Is there a difference in the conductivity between the preferential flow fingers and the matrix-flow instances? Do your calculated hydraulic conductivities (Equation 7 and line 198) represent a 'bulk' conductivity (that might represent conductivity for matrix flow) or the conductivity in the preferential flow pipes?

I think that it would also be appropriate for the introduction to more information on the current state of the science of matrix and preferential flow in firn(matrix flow is not mentioned until section 6), and subsequent sections could include more detail on how your experiments/results fall into these regimes. For example, in the ROSA experiments you observed preferential flow. Was it preferential flow from the start of the experiments, or was it initially matrix flow that evolved to preferential flow? If so, is there a timescale or threshold of when it transitioned? Is all flow in the lateral experiment assumed to be matrix flow?

2. For the ROSA experiments, water was introduced via a sprayer. This sounds to me like it is more simulating a rain on snow event than surface meltwater production due to a surface energy budget excess. I think it would be useful to discuss any differences you might expect in your results if it was surface meltwater production, which I would expect would be more uniform across the surface. Are the rates of water you are spraying comparable to the rate of meltwater production on a warm sunny day in SW Greenland? On line 231 you state that peak water flow caused a fast, large temperature increase, which made me wonder: was the sprayed water at 0C? It is probably worth specifying that in you methods.

3. A structural comment: Consider adding a bit of text at the end of the intro describing the structure of the paper, i.e. outlining, to clarify that there are two distinct but related experiments. You mentioned in the introduction that there were two field seasons/two experiments, but as I read section 4 I kept wondering about the other experiment.

4. The slush vs runoff limit finding is mentioned in the abstract, which indicates that it is an important result/outcome of the work. However, the discussion of this is only briefly mentioned at the end seems disparate from the results. I think it would be useful to add a bit more about how this 4 km is calculated and more discussion about the implications, including what additional "essential data" are required.

Specific comments:
Line 89: It may be worth specifying what a 'ripe' snowpack is for TC readers not familiar with snow hydrology.

136: “systematic measurements of parameters which are required to determine the hydraulic conductivity and water retention capacity of icy firn”: this is very vague. Can you specify how they are systematic, and what the parameters are?

165ish: I would like a bit more detail about the samples here. What are the dimensions of one sample? Are the firn samples taken from different depths in the pit, or side-by-side extractions, (which would allow you to understand spatial variability, perhaps)? Table 1 could include a column that states the depth interval that the firn came from in the pit.

170: Can you be more specific about what is on this checklist?

201: Is the densification just due to adding mass to the sample, or is there compaction (volume change) too? Also, what is the ‘apparent rate of densification’? Is that different than the actual rate?

203-205: I found the description of steps here a bit hard to follow. I suggest putting the description into past tense and write as a narrative; e.g. the water flow started, went this long, we observed X, then this happened, etc.

220: Is there a difference between piping and preferential flow? If not just say preferential flow was visible. Also, this is the only instance in the paper in which you use ‘piping’; otherwise you use ‘fingers’, which I think is an interchangeable term. I suggest sticking with a single term.

Figure 5 – I suggest coloring the hydraulic conductivity axis (ticks and label) to be blue (same as the dot color) to be consistent with “density” and “added mass” axes. For clarity, I would remove the date_time portion of the subfigure titles, which will make the figure titles consistent with the naming in Table 1 and 2.

242: What parameters? I think you say in the next paragraph, but as a reader my initial reaction is that this is vague. I suggest reworking the text a bit to avoid this.

244: This is vague: what is ‘shallow’? How deep were the snow pits?

246-249: The method here is vague – can you briefly explain the steel-tape method? Are you implying that you remove snow from the hole after drilling the borehole? Doesn’t drilling a borehole inherently remove snow?

275: I think it would help clarify the text if your methods above use the same language of ‘slush matrix properties’ – it took me a moment to realize that your ‘slush matrix properties’ described in 5.2.1 were just the properties you were describing in 2nd and 3rd paragraphs of section 5.1. Also – it might be useful for you to include a more formal definition of what you mean by slush matrix.

Figure 10: It would be useful to add a bit more description to the caption, describing what it is that the reader should take away from the figure. Admittedly, I am not sure what I should take from the figure – simply that these are uncorrelated? I am not sure this figure is actually needed in that case; I think it suffices to state in the text that you did not find correlation.

Section 5.2.2/6.1.2: The discussion of the large variation (a factor of 10) in observed flow velocities is not adequately discussed. Why is there this large variation? Is it just local storage? Snow pack properties?

313: Consider adding language like “modeled flow velocities” throughout the text to clearly differentiate between when you are calculating theoretical velocities from an equation and your measurements.

Figure 12: I am not sure that this figure is needed, or if you want to include it consider adding a meltwater flux calculation from a surface energy balance model.

335: Can you be a bit more specific about which measurements are comparable? I.e., are the previous measurements that your data agree with capturing the same process?

340: typo, unsaturated

372: vague sentence – what is relatively large? What is ‘more generically’?

387: “laterally meltwater flowing” – do you mean laterally flowing meltwater?

395: this seems to be a restatement of earlier, but still no why
447: rewrite sentence – incomplete at this point.