

Interactive comment on “Hourly surface meltwater routing for a Greenlandic supraglacial catchment across hillslopes and through a dense topological channel network” by Colin J. Gleason et al.

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This is a novel piece of research addressing an important area of glaciology. It uses a well-established ‘off the shelf’ hillslope-channel hydrological model used previously in terrestrial settings, to route meltwater across a supraglacial catchment on the Greenland Ice Sheet. It provides a useful steppingstone, therefore, to one day developing fully coupled surface mass balance – surface water routing – subglacial water routing – glacier dynamics models. The paper adds to valuable previous work produced by this group. A series of experiments are created using four different runoff series from widely cited surface mass balance models (HIRHAM5, MAR3.6, RACMO2.3, and MERRA-2)

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and for routing model sets ups that consider a coarse and a fine density channel network, and which either consider or do not consider hillslope routing processes. So 16 separate experiments are performed in total. Model parameters are calibrated by comparing outputs with measured discharges in a surface stream at the catchment outlet over a few days in July, which have been published elsewhere. Parameter space is explored, and the patterns of parameter values are used to infer the importance of catchment processes, for example the role of hillslope friction, which is high compared to terrestrial settings and which, it is argued, may represent shallow subsurface routing through a weathering crust.

The paper is nicely structured and generally well written, and the Figures and Tables are clear and useful. The work is thorough, generally acknowledges previous work (with a few exceptions that could be added at the authors’ discretion – see below) and provides a valuable contribution to the literature.

There are five places where I think things need to be explained in more detail or where the results could be discussed further. These are:

1. On line 210/11 you tell us the channel widths that are produced for the fine network. But how are channel widths determined? Was this explained? I’d assumed they’d be dictated by the DEM grid size? Why don’t you also tell us the widths of the channels produced for the coarse network here?
2. On line 222. You say “and lakes are represented by wide, shallow ‘throughflow’ river segments. . .” Is this a major limitation of this work? How do lakes fill and drain? Surely, the filling and draining of lakes will have a major impact on the relation between distributed runoff and the hydrographs at the catchment outflow and yet this important process is not incorporated. I’d like to see more discussion of this. How many sinks are there in the catchment that need to be filled? Where are they? What are their volumes? What are the implications for water routing?
3. On line 397 you show that after calibration, hillslope friction values were on occasion

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very high – up to the max. threshold allowed of 25. These do seem very high. To what extent are these high because you didn't allow channel frictions to rise very high (Table 2)? Could you explain a bit more about the range of parameter values considered in Table 2 and the implications of this?

4. Related to point 2 above. On lines 398-405, you find very slow water transport rates on hillslopes here and suggest this may be due to slow transport through an ice crust. But what role does ignoring travel through lakes as they fill up and overtop their outlet channels play on your results?

5. You need to introduce a runoff correction coefficient (Rcoef) to match modelled with measured hydrographs and this turns out in the calibration to always be less than one which means runoff from all the SMB models is over predicted or measured discharge at the catchment outlet is under predicted. This is discussed to some extent in the Discussion but I think more thought could be given to this. You suggest water may be stored (and possibly freeze) in a weathering crust but is this feasible? What volumes are we talking about and could storage in a weathering crust really explain it? Related to above, is it possible lakes may be filling over this period which would explain the discrepancy. Could it also be due to leakage into the ice sheet via crevasses?

Other than these five points, I have just a series of questions / suggestions regarding improving clarity as follows.

L27. 'routed to match measured flows' could be deleted as it's repetition.

L29/30. '...explicitly including hillslope flow and routing runoff through a realistically fine channel network...' It's difficult to fully understand this without reading the rest of the paper. Could you somehow add "as opposed to not including hillslope processes" and "as opposed to a coarse channel network"?

L38. 'with unique and complex hydrologic process distinct from terrestrial hydrology' This is rather convoluted. Could it just be changed to 'which is distinct from those in

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terrestrial settings'?

L48. Should 'ice' be changed to "glacier" or "ice sheet" or "snow, firn and ice"?

L54. After 'lake impoundment' you could consider referring to: Arnold, N.S., Banwell, A.F. and Willis, I.C., 2014. High-resolution modelling of the seasonal evolution of surface water storage on the Greenland Ice Sheet. *The Cryosphere*.

L63/4. As well as Banwell et al 2013, could also refer here to Banwell, A., Hewitt, I., Willis, I. and Arnold, N., 2016. Moulin density controls drainage development beneath the Greenland ice sheet. *Journal of Geophysical Research Earth Surface*, v. 121, p.2248-2269.

L64. Immediately before the sentence beginning 'Liston and Mernild (2012)' you could add another sentence summarising and referring to the work of Leeson et al 2012: Leeson, AA, Shepherd, A, Palmer, S, Sundal, A & Fettweis, X 2012, 'Simulating the growth of supraglacial lakes at the western margin of the Greenland ice sheet', *Cryosphere*, vol. 6, no. 5, pp. 1077-1086.

L75-77. Would it be better to say: "These previous efforts successfully modelled melt-water transport on the GrIS ablation zone, but their relative simplicity allows space for more sophisticated routing models from terrestrial hydrology to be applied to ice sheet surfaces"? Or something like this.

L80. '...at the global...'

L81. Is 'paradigm' a little grand? Would "approach" be better instead?

L85. What is meant by "explicit routing"? As opposed to implicit routing? What about saying "...accurately routing water at the catchment scale across the GrIS"?

L86. What is meant by "explicit" here?

L87/88. "...but to our knowledge no automated, large scale network extraction and topological connection work exists for the GrIS". Do you mean for the whole of the GrIS

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- here ? There are examples of this at smaller scale surely.
- L89. “these issues” What issues? You’ve not explicitly referred to ‘issues’ above.
- L90. “. . . a model such as . . .”
- L90 change “science” to “understanding” ?
- L92. What are “network scales”? You’ve referred to catchments and (I think) the entire ice sheet previously which I understand but what are these?
- L93. Delete the word “these” as you’ve not referred to processes previously.
- L93. Suggest change ‘are interacting’ to “interact”.
- L96. What is meant by “spatially explicit”?
- L97/8. I think the semicolons would be better as periods.
- L104. Would it be clearer to say “. . . test how the representation of hillslope processes and network density (as derived by our automated network generation process). . .” or something like that?
- L115. Delete “(Section 2.2) as you’re referring to Smith et al 2017 here.
- L116-119. Would it be clearer to say: “Previous work in the basin includes: i) a comparison of SMB runoff and field measured discharge using a simple routing method (Smith et al., 2017); ii) a study of subsurface water storage in bare-ice weathering crust (Cooper et al., 2018); iii) albedo mapping (Ryan et al., 2017); and iv) mapping the catchment’s supraglacial channel network via satellite and un-crewed aerial vehicle (UAV) remote sensing (Ryan et al., 2017; Yang et al., 2018)”?
- L120. Suggest change “. . .basin: we here. . .” to “. . .basin. Here we. . .”
- L122. ‘of a summer”
- L122. Delete “as”

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- L124. Consider changing “. . .catchment. However. . .” to “. . .catchment, but the. . .”
- L128/9. Perhaps add Banwell et al 2016 to this list?
- L134. Would “. . .2 m resolution portion of the ArcticDEM was obtained. . .” sound better than “. . .2 m resolution ArcticDEM DEM was obtained . . .”?
- L134 “The ArcticDEM has been. . .”
- L135. Could reference Pope et al, and Moussavi et al somewhere here as they use the ArcticDEM in the context of representing GrIS surface lake bathymetries
- Pope, A., Scambos, T. A., Moussavi, M., Tedesco, M., Willis, M., Shean, D., and Grigsby, S.: Estimating supraglacial lake depth in West Greenland using Landsat 8 and comparison with other multispectral methods, *The Cryosphere*, 10, 15–27, <https://doi.org/10.5194/tc-10-15-2016>, 2016.
- Moussavi, M. S., Abdalati, W., Pope, A., Scambos, T., Tedesco, M., MacFerrin, M., and Grigsby, S.: Derivation and validation of supraglacial lake volumes on the Greenland Ice Sheet from high-resolution satellite imagery, *Remote Sens. Environ.*, 183, 294–303, <https://doi.org/10.1016/j.rse.2016.05.024>, 2016.
- L138-143. Can you better explain here how you deal with the very different grid sizes between the 2m DEM and the various (I assume) grid sizes of the 4 models? How do you interpolate across the finer scale grid? Is the Rio Behar catchment entirely within a SMB model grid?
- L154. Suggest “. . .hydrology and its discharge values are frequently. . .”
- L154. Suggest “. . .(Gleason and Durand, 2020). Further reading. . .”
- L157. Suggest changing “and ending” to “to”.
- L161-2. “allowing us to calibrate the free parameters of the routing model (Section 3.2) and to adjust water excess of the SMB models to best match these observations.” Suggest delete this as this was explained earlier.

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L174/5. I don't quite follow this sentence. Do you mean "Our overall goal for this study is to improve current understanding of supraglacial hydrological transport processes through application of a hydrological model, which includes classical hillslope and channel routing processes, to a catchment on the GrIS" ?

L192. "framework to guide"

L193. " Figure 1 shows an overall schematic of our approach." This sentence comes too late as Fig 1 has already been referred to. Could just delete or move to after first sentence of this section on line 175.

L195/6 "we are interested in generalizing the process of water routing from satellite image collection to water routing" doesn't make sense to me.

L199-203. I don't quite follow these two sentences. Could they say "Having done this, conventional network generation was confounded due to two large topographic depressions, one located in the upper part of the catchment and one located near the catchment outlet. Standard DEM preparation for hydrological analysis (in which the upstream depression was filled while the outlet depression was preserved) generated unrealistic parallel drainage channels upstream and no channels in the outlet depression of the catchment" ?

L204 delete "Rio Behar"

L25 "ultimately"

L210/11 Why don't you also tell us the widths of the channels produced for the course network here? This would be useful. How are channel widths determined? I assumed they'd be dictated by the DEM grid size.

L212-214. Would it be better to say: "It would be possible to derive expected rates of incision (and additional meltwater supply) due to frictional heating of the channels, but without including a radiation budget and ice property data we could not model how..."

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L215/16. I don't follow this sentence. Should this say "...we model the networks as static snapshots within HRR, which is..." ? I assume networks should be plural as there is the coarse one and the fine one. Need to explain what you mean by "loosely coupled to SMB runoff" or delete this.

L217. Could delete "ultimately"

L219. Suggest "...higher order) and the fine network had seven..."

L222. You say "and lakes are represented by wide, shallow 'throughflow' river segments..." But where are these in Fig 2? Is this a major limitation of this work? How do lakes fill and drain? See also my main point 2.

L229/30. Unless I missed it, Section 2.1 does not describe how channel widths were derived. It refers to Section 3.2 but that doesn't describe it either. How are channel widths derived?

L232. "...Section 3.2 is required..."

L233-5. Sentence here seems misplaced. Better to justify using HRR earlier, when you first introduce it - i.e. Section 1.

L278-80. This sentence doesn't quite makes sense. Suggest rewrite to clarify.

L282. What is a "population member"? This is not explained.

L282/3. On L175 you refer to "two experimental settings (inclusion/exclusion of hillslope flow, coarse/fine channel network densities)". See also nomenclature used in Fig 1 e.g. "hillslope coarse" or "non hillslope fine". Can you use consistent terminology so it's clear that you're running tests that both include and exclude hillslope processes and also that the 'coarse' and 'fine' refer to the network density? The terms you use here "non-hillslope tests", "coarse hillslope test" and "fine hillslope test" are a bit sloppy and rather confusing and don't match earlier. See also legend in Fig 3.

L315-18. Confusion over whether you're defining routing delay to be generic or specifi-

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cally in terms of comparison of peaks. Would it be better to say something like: "Finally, we calculate routing delays for each of our 16 calibrated routing models. Routing delay will be a function of both time of day and discharge but here we calculate routing delay as the difference in ADCP peak and the unrouted SMB runoff peak. This delay is the shortest for MERRA2 (1-3 hours) and longest for MAR and RACMO2 (5-6 hours). These values provide an estimate for daily peak flow delay between runoff forcing and the calibrated HRR model."

L349. "...large data sets..."

L350. "Figure 5"

L366/7. You say "across inclusion/exclusion of hillslope process and across coarse/fine networks". So this nomenclature matches initial terminology (line 175) but not that used in other places – see comment re L282/3

Fig 7 Heading. You say "Mean" but these are box whisker plots so explain what all features represent. What are the dots?

In the body of the paper, can you explain the reason for the very anomalous results for bin 3.16 km and 10 km where Manning's n is very high?

L382. Should 'and/or' just be 'and'? The runs that included hillslope processes and had a fine channel network were best right?

L387. In addition to ref. Karlstrom and Yang, 2016 you could also include:

Koziol, C., Arnold, N., Pope, A. and Colgan, W., 2017. Quantifying supraglacial meltwater pathways in the Paakitsoq region, West Greenland. *Journal of Glaciology*, as they too model channel incision.

In addition to Yang et al, 2020 you could also refer to:

Banwell, A., Hewitt, I., Willis, I. and Arnold, N., 2016. Moulin density controls drainage

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development beneath the Greenland ice sheet. *Journal of Geophysical Research Earth Surface*, v. 121, p.2248-2269.

and

Koziol, C.P. and Arnold, N., 2018. Modelling seasonal meltwater forcing of the velocity of land-terminating margins of the Greenland Ice Sheet. *The Cryosphere*, v. 12, p.971-991

as they too couple SMB models to surface and subglacial routing models to examine basal water pressures.

L398-405. You find very slow water transport rates on hillslopes here and suggest this may be due to slow transport through an ice crust. But what role does ignoring travel through lakes esp. while lakes may be filling play on your results?

L427. You say "...parameters should be able to accurately applicable to flow route watering in..." This is not grammatically correct. Also, what is 'watering'? I'm not sure this statement is correct is it? Don't you imagine there is a huge evolution on some of these parameter values over the summer?

L434-5. Regarding this sentence, lakes may be filling over this period which would explain the discrepancy. Could it also be due to leakage into the ice sheet via crevasses?

Interactive comment on *The Cryosphere Discuss.*, <https://doi.org/10.5194/tc-2020-273>, 2020.

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