Review of “GlaDS-2: modeling subglacial drainage including ice uplift and free-surface flow in two dimensions”
By Wells et al.
Submitted to *The Cryosphere*

<u>Overview</u>

This manuscript presents an expanded version of the Glacier Drainage System (GlaDS) model that includes the relevant physics for open-surface flow and glacier uplift in addition to the pressure-driven flow of the earlier formulation. Overall, it is great to see this work incorporating these end-member flow regimes in a physics-based subglacial hydrology model, as this has long been an outstanding thing to improve upon. A nice set of example simulations demonstrates the new capabilities.

The paper is well written and I enjoyed reading it. I have some minor questions and suggestions as described below in the general and specific comments. With a bit of further thought and polishing, this will make a nice contribution to the literature.

<u>General comments</u>

1. Including the transition to open-surface flow in the proglacial environment is a great development for smoothly integrating subglacial hydrology with downstream hydrology. I also like how it seems to solve a lot of the boundary condition difficulties. Well done getting this set up.
2. While the end-member flow transitions are great advances, the model retains many of the limitations of the original GlaDS model. In the move toward a more “unified” model, why did you choose to retain the separation between sheet and channel components? And the new model still uses the same set of parameters, many of which are unconstrained and influential on results, and must be chosen by the modeler (such as sheet and channel conductivities, bed bump height and spacing, sheet width contributing to channels, channel spacing, and englacial void ratio). I think it would be helpful to test and comment on at least the following aspects and how they influence results of the new extensions. Many readers will be interested to know the impact of unconstrained parameter values on the blister results and both new flow regimes in general.
    a. What are the implications of assuming turbulent flow everywhere in the distributed sheet component of the model and how the end-member flow regimes respond? I was slightly surprised to see this carried over in the new version of GlaDS, considering other work that has studied the importance of incorporating transitional flow or laminar flow (e.g. Hill et al., 2024; Jenson et al., 2026; Sommers et al., 2018)

        Hill, T., Flowers, G. E., Hoffman, M. J., Bingham, D., & Werder, M. A. (2024). Improved representation of laminar and turbulent sheet flow in subglacial drainage models. *Journal of Glaciology*, *70*, e24.

Jenson, A., Amundson, J. M., Truffer, M., Pohle, A., & Ultee, L. (2026). Capturing runoff-driven seasonal velocity variations of fast-flowing outlet glaciers in coupled ice-hydrology simulations. *Geophysical Research Letters*, *53*(14), e2026GL124023.

Sommers, A., Rajaram, H., & Morlighem, M. (2018). SHAKTI: subglacial hydrology and kinetic, transient interactions v1. 0. *Geoscientific Model Development*, *11*(7), 2955-2974.

   b. With the sheet opening by sliding and channels opening by melt, how does the parameter value for sheet width contribute to the channel impact results (in particular the blister experiments)? Similarly, how much does the channel spacing parameter impact the blister experiment? It is shown that the short duration of the lake drainage event is not sufficient to form a fully channelized network in this case, but does yield high rates of dissipation melt which seems like it could possibly lead to different results with different choices for these parameters.
   c. GlaDS-2 requires prescribing uniform and constant values for sheet and channel “conductivity”. How much does the value of each of these impact the behavior of uplift and transition to open-surface flow in your experiments? Conductivity in reality would vary in both space and time, and this seems especially pertinent when transitioning to the end-member flow regimes.
3. I have some questions related to time stepping. The typical time step size that comes out of the calculation in Section 2.5 is mentioned in the limitations section as being on the order of tenths of a second to tens of seconds. This is extremely small compared to typical glacier or ice sheet model time steps of days to years, and also quite a bit smaller compared to typical subglacial hydrology model time steps of hours to days.
   a. Can you say anything about the challenges that this time-step discrepancy poses to running large-scale/long-term fully coupled ice sheet or glacier simulations? A brief mention is made about ambitions to port a future version to solve on GPUs to make it more computationally tractable, without any details about what would be required or other limitations that might arise.
   b. It would be good to comment more on the implications of the time step dependence on the englacial void ratio e_v term, beyond just the influence on run time. The comparison in Section 4.1.1 using different e_v values demonstrates pretty different behavior for high storage capacity compared to low storage capacity. Acknowledging that the englacial void ratio is generally not known and varies in both space and time, what recommendations can you give for how to improve knowledge of this parameter (i.e. what field measurements would help?) or how best to use it?
4. The use of superscripts in figure labels is in contrast to the use of subscripts in captions and text. These variable names should be consistent in their notation to avoid confusion.
5. How does GlaDS-2 compare in computational efficiency to the original GlaDS? Based on the typical time step size, it is likely much more expensive, but it would be good to include some comments about this.

6. In the limitations section, good discussion of challenges of validation and new opportunities to potentially validate using downstream discharge. Perhaps this will inspire some future research to help!
7. I appreciate the examples showing the importance of the subglacial state before big drainage events.
8. The Zenodo repository has restricted access, so I was not able to see the archived code associated with this paper.

Please see also the specific comments below.

<u>Specific comments</u>

Line 131 (Eq. 6): “conductivity” does not have units of typical hydraulic conductivity (also in table). I realize this carries over from GlaDS, but could be described for clarity about what exactly this represents and how it differs from conventional hydraulic conductivity (which has units of m/s).

Line 153: Are there portions of the sheet that do not contribute to channel melt? How is the melt produced within those areas accounted for in mass and energy conservation?

Line 173: The assumption that water volume in channels is negligible needs more attention or justification. If average sheet thickness is likely on the order of mm or cm, while channels can be on the order of m, the volume of water present in channels at any given moment in time could be large.

Lines 221-222: What is a typical time step size for these values of e_v? Maybe this is described later in the examples, but would be useful to mention order of magnitude here for comparison.

Figure 3 and elsewhere: The legend uses superscripts for the different potentials plotted in (a), while the caption and text use subscripts. These should be made consistent (also mentioned in general comment 4 above).

Section 3: What is the imposed boundary condition at the terminus in the synthetic stepped glacier 1D comparison simulations? How long were these simulations to achieve steady state? What range of time step sizes was required?

Line 277 and elsewhere: I wonder if it might be more clear to distinguish water inputs to the bed as something other than “melt input”. This terminology could lead to confusion with basal melt rate. Moreover, water reaching the bed could come from liquid precipitation that drains directly and is not strictly melt. You might consider “liquid water input” or something similar.

Lines 306-308: Neat to see a residual channelized structure produced and remain open at the terminus after the flood cessation!

Lines 348-349: In the blister simulations with channelization, how do the results change with 1) different grid spacing of where channels can form, and 2) different values of l_c? It would be good to test these and present results – whether they are influential or not on the blister behavior after some time. (See general comment 2).

Line 360: Did you consider applying some kind of free-flowing boundary condition at the left edge of the domain off ice? Why not apply a constant sheet thickness boundary condition in the proglacial region? Like you say, this boundary is probably far enough from the ice-covered area of interest to have too much effect from the no-flow condition, but it seems like the water sheet thickness could pile up significantly over some time at the edge of the domain.

Fig. 8a: It would be great to also include some zoomed-in spatial plots showing the area surrounding the lake and blister more clearly.

Fig. 8 caption has a typo (c is listed twice, but should reference d for channel cross-sectional area).

Fig. 8d: I assume the y-axis is limited to focus on the channel evolution near the lake drainage. How high does the channel cross-sectional area actually extend in the places where it is cut off?

Line 397: Why not prescribe the more site-appropriate constant h b.c. for the proglacial region?

Line 507: What would it take to shift the current formulation to be solvable on GPUs?

Line 550: I did not see a sensitivity of parameters such as conductivity and bed bump height and spacing that would also presumably influence the behavior described here (see general comment 2).