Review of “A fast and unified subglacial hydrological model applied to Thwaites Glacier, Antarctica”

By Kazmierczak et al.

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In this paper, the authors present a novel subglacial hydrology model that includes efficient and inefficient drainage systems on bed rheologies that range continuously from soft to hard. The model can be run on the same spatial scales as ice flow, which makes the model computationally efficient. The model is applied to Thwaites Glacier in Antarctica and the response to present day climate forcings is analyzed for hard, soft, and mixed beds for efficient and inefficient drainage systems.

I think the development of a model with these capabilities is an exciting and important step in modeling coupled ice flow and subglacial hydrology on the ice sheet scale. There are a few things that I believe should be clarified and adapted in the writing before publication.

General comments:

Although assuming hydrologic equilibrium are most likely appropriate for Antarctica, it should be made clear that this model would not be appropriate for modeling places with more highly variable water fluxes such as mountain glaciers or the Greenland ice sheet (or atleast the margins) where the subglacial hydrological system is often not in equilibrium due to external meltwater input which varies on much shorter timescales than changes in ice geometry. There could be an argument that this model could be applied to the Greenland Ice Sheet on long timescales (that neglect short term changes resulting from subglacial hydrology), but this would need to be thoroughly addressed and justified. Add to the abstract and conclusion that this model is appropriate for modeling subglacial hydrology where changes in water flux are on the same timescales as changes in ice geometry.

Does the thermomechanical ice flow model determine where there is basal melting? If so, does this evolve in time? How is water routed through areas with a frozen bed? Is there refreezing? Elaborate more on this, perhaps in section 2.1.

There are a few places in the manuscript where references are made to literature with different timescales and rates of change being discussed than in this paper. In this model, the assumptions around hydrologic equilibrium (melting balances closure in Eq. 5b) imply that the changes in time in the subglacial hydrologic system are small enough to neglect ($dS/dt = 0$). However, the manuscript contains references to Schoof (2010) and Iken (1981) which are specifically referring to when dS/dt is not zero. In line 267, there is a reference to Schoof (2010) and the importance of the meltwater variability rather than meltwater input, but these processes are time-dependent changes that occur on timescales of hours to days, at most months. From

Schoof (2010), “Further acceleration must then be driven instead by **short-term temporal variability** in water supply.” In this model, it is assumed to be in steady state which means that these short term increases in water pressure due to varying water flux on short timescales that result in conduit growth are inherently neglected. The same is true for the reference in line 292 in the manuscript, which I believe is referring to the following statement in Iken (1981). “It has been seen that the effect of a water pressure pw on the sliding velocity is largest at the instant of separation and then gradually decreases **until steady cavities have formed**.” This is again talking about when the system is not in steady state, unlike the model presented here. To be clear, I think the assumption of steady-state is reasonable given the context of Antarctica, where changes in water flux occur on long-timescales, but these references and associated statements (specifically noted in the line-by-line comments) are not applicable in this context.

Line-by-line comments:

Line 5: This is worded strangely. Perhaps, “We find that accounting for subglacial hydrology in the sliding law accelerates the grounding line retreat of Thwaites Glacier under present-day climatic conditions.” or something similar .

Line 13: ‘behavior’ since using American spelling elsewhere.

Fig 1. Figure could be made part of Fig. 9 or moved to before Fig. 9, but I don't feel strongly about this.

Line 71: introduce variable before introducing product of variables “... N is the effective pressure, C is a friction coefficient limiting the shear stress to a maximum plastic value CN, ..”

Line 90: Replace “that is much smaller than the global one” with “ that is on the order of meters” or what the scale actually is.

Line 93: The term 'conduit' may be confusing, as it is often synonymous with channels and efficient drainage in the subglacial hydrology literature. Although, I don’t have a better suggestion…

Lines 105 - 106: Bueler and van Pelt (2015) ran the model efficiently on the Greenland ice sheet, but these statements are generally true.

Line 111: Elaborate on what these conditions are. “This domain evolves over time according to internal and external conditions.”

Eq 3: Lw is confusing with L being the length of conduit. Use cursive L or something else to denote latent heat.

Line 120-123: This assumption is only reasonable in Antarctica and locations where changes in water flux are only through changes in ice geometry which happen on long time scales. Make this more clear in the text.

Line 128: Delete “anticipating what follows”.

Fig 4: This is how the channel might look in theory. In the caption of Fig 4, it should also be stated that this is what you are trying to capture and not the actual geometry you have described in your model (which is square channel?).

Line 220-224: Elaborate on how this relates to theory and observations. Are your model results what we expect for these cases?

Fig 5:

Wouldn’t we expect much higher effective pressures for that high of water flux in an efficient system? Or is this because it is the average of effective pressure over a larger scale than the channel? This could be made more clear either in the text or in the figure caption. On first glance at the figure, I find this result surprising.

On a related note, do you ever observe this high of water fluxes in channels far from the grounding line in the model? How exactly is the water fluxes on the local scale in the efficient system related to the effective pressure which is an average over a larger area presumably?

On what scale are these calculated?

Line 226-229: You mean efficient/inefficient, not effective/ineffective. The system still transports water, so it isn’t ineffective. It just doesn’t transport it efficiently.

A discussion about how effective pressure behavior differs near the grounding line and far from the grounding line would be helpful.

Line 236: Does this mean the whole bed is temperate in this experiment since melting is uniform?

Fig 6b. Why does the effective pressure go down by 2 MPa in both the soft and hard bed cases at x=0?

Fig 7: Are the light pink and red areas in (a)-(c) related to the colors in (d)? If so, it is not clear how. Add something to the caption about this (or remove from the background?).

Fig. 9a: It would be helpful to have a sense of scale in the 2D either by adding a scale bar or axis.

Line 267: This does not apply on the timescales you are analyzing. The theory from Schoof (2010) on meltwater variability is referring to time-dependent changes that occur on timescales of hours to days, at most months. In this model, it is assumed to be in steady state which means that these short term increases in water pressure due to varying water flux are inherently neglected.

Line 282: What do you mean by “the latter”. If referring to a smaller ice sheet results in grounding line retreat, replace “the latter” with “consequently” or similar. Both slower velocities and a smaller ice sheet can result in grounding line retreat.

Line 318: This is not a unit of mass, but a unit of length. Rephrase to say something like, "Note that the mass loss for the NON experiment results in sea level rise on the order of 10 mm by 2100…”

Line 341: All of the models result in the collapse of Thwaites within how many years?

Line 392: As mentioned before, I have questions about how the assumption of steady state allows you to relate to the time variability of other work such as in the comment that follows. “This observation aligns with the work of Iken (1981), specifying that the highest velocities is not observed where effective pressures is lowest, but rather when cavities enlarge due to an increase in subglacial water pressure.” I think this statement should be removed.

Line 396: How does a lower effective pressure in the soft bed system slow down grounding line retreat? Maybe I am missing something.

Line 434: add “(retrograde)”.

Line 440: “(prograde)”

Line 465: add ‘considering’ or ‘modeling’ so that it reads “considering subglacial hydrology enhances the ice-sheet response to sliding”.

Line 467: This reference to Schoof (2010) is appropriate.

Line 470: Making the connection to changes when the system is explicitly not in steady state (“when basal cavities are growing”) does not make sense here since you assume steady state and therefore neglect time-dependent changes in cavity growth.