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Discussions

Interactive comment on "The past, present, and future viscous heat dissipation available for Greenland subglacial conduit formation" *by* K. D. Mankoff and S. M. Tulaczyk

Anonymous Referee #1

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This paper calculates the energy content of supraglacial runoff from the Greenland ice sheet that is available for melting of subglacial conduits on its path to the ice margin. The paper discusses the energetics of water flow englacially and subglacially, and uses historical and future (model) estimates of runoff from the ice-sheet surface to estimate the consequent amount of viscous heat dissipation at the bed.

I am hesitant to recommend publication for two reasons. Firstly, I find the calculations rather simplistic, and am not sure there is anything new in it that is not already well understood. Secondly, I think there are some issues with the methodology, or at the least with its unnecessarily convoluted explanation in the manuscript. I address these in turn.

It is a central part of the established theory of subglacial conduits, due to Rothlisberger and Nye among others, that conduits enlarge through the transfer of gravitational potential energy, via viscous dissipation, to latent heat for melting the conduit walls. The rate at which this energy transfer occurs is proportional to the volume flow rate of water and the rate of change of hydraulic potential with distance, with corrections for the advection of heat required to keep the water at the pressure melting point. Changes in kinetic energy are relatively small compared to these other terms, and most estimates except in volcanic environments suggest that the excess heat in the water above the pressure melting point is also negligible. These facts are included in most models of subglacial hydrology, and lead to the often quoted result that a larger volume flux of water causes increased melting of the conduit walls and can therefore be driven out from under the glacier by a smaller potential gradient, despite the larger flux. The fact that increased runoff is therefore expected to lead to larger conduits is quite well established, and the fact that this is due to increased viscous heat dissipation goes without saying. It seems to me that the results of this study essentially re-express the modelled increase in surface runoff (from other studies) in terms of gravitational potential energy. There is a modification for the pressure melting effect, but this is nonetheless the essence of what is done. Perhaps some readers may find it helpful to have the runoff increase re-expressed in this way, but I did not find it particularly illuminating.

Secondly, I found some aspects of the presentation confusing. It was not totally clear what calculation was actually performed to produce the final numbers. As far as I can work out, the energy available for viscous heat dissipation at the bed is the change in gravitational potential at the basal elevation from where the runoff reaches the bed to where it leaves, plus 90% of the gravitational potential energy due to the ice thickness where the runoff reaches the bed (the first 10% being assumed lost to the atmosphere), minus the fraction C_T*rho*c_p (∼0.3) of this potential due to ice thickness (which is required to keep the water at the melting point). Couldn't it be explained in a paragraph or with one explicit equation?

The part of this that I am most uncertain about is the gravitational potential taken at the outflow - in section 3.6 it suggests that this is taken to be sea level, which seems quite a simplification. If this is what is done, what was the point of the hydraulic potential routing? I would have thought that such routing tells you what elevation the water leaves the ice, and that making an ad-hoc assumption about what elevation it leaves at is therefore unnecessary (though using sea-level is correct for any outflow below sea-level, where the hydrostatic 'pressure energy; cancels the negative gravitational potential energy).

There seemed to be a lot of repetition in the methods description, particularly about the pressure melting point. The comment in section 3.2 that the influence of the pressure melting effect is not 'zero sum' may be true if one is concerned with the energy balance only at the bed, but it must be zero sum when considering the energy balance over the whole path of the water from ice surface to margin, which is what seems to be under consideration in other parts of the manuscript (eg figure 1). If the water descending through the moulin has cooled and lost sensible heat, that heat must have gone somewhere (presumably into melting the surrounding ice, as in the subglacial conduits).

Figure 1 is rather confusing. What is meant by 'amount of energy' as shown in the bars? Is this the energy of a fixed mass of water, and if so how do you account for the energy used to increase the mass of water (from melting the conduit walls)? I could not understand the meaning of the phase transition temperature in this diagram - how is this expressed as an energy (yellow hash)? It seems to increase from the top to the bottom of the moulin (during pressurisation) and then to increase again on the passage to the margin (during depressurisation). This cannot be right as the change is in the opposite sense (the temperature decreases during pressurisation, and increases during depressurisation). Similarly, there is some confusion about gravitational potential energy, which should continue to decrease (becoming negative) in the moulin as the water goes below sea level, exactly cancelling out the 'overpressure'.

Specific comments

Equation (1). Why use gamma here, and rho elsewhere, and in some places m. Couldn't the notation be made more consistent?

Equation (3). What is z_o taken as here? Potential energy always needs to have a reference point, but it does not make sense to have a different reference point for different parcels of water (as seems to be the case here, since elevation at the terminus would vary) - comparison of potential energies is then meaningless.

Equation (6). Delta phi here is a change in potential, but when plotted in the figures it seems to be a gradient (with units Pa/m). Which is it?

Figure 6. Why are there gaps in the data in panel c? There are also clear issues here with taking a numerical gradient of the discrete data, and some form of smoothing to calculate the gradient might yield cleaner results.

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