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Interactive comment on "Incorporating modelled subglacial hydrology into inversions for basal drag" *by* Conrad P. Koziol and Neil Arnold

Anonymous Referee #1

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This manuscript describes how to incorporate the effective pressure computed by a subglacial hydrology model into a basal drag inversion. Three different sliding laws are used: (1) a linear sliding law that does not depend on the effective pressure, (2) a "Budd"-type sliding law and a (3) a Schoof sliding law that both depend on the effective pressure. The authors propose here to do an inversion based on the first sliding law (1), to get a good initial guess of basal sliding, then run a subglacial hydrology model for the winter season, which computes the basal melt rate and basal water pressure that is then used to invert for the basal friction parameters used by the two other laws (2) and (3). They find that the basal drag and sliding ratio (ratio between the surface and basal velocities) of the linear and Budd sliding laws are in good agreement, but that their results using the Schoof sliding law show higher spatial variability.

Overall, this manuscript is easy to read and the methods are explained in detail, so that this manuscript is accessible to readers that are not necessarily familiar with model inversions. While I enjoyed reading it, I would have liked to see more discussion on their results instead of focusing mainly on the technical aspect. In its current state, the manuscript is limited to the introduction of a new model and a new approach, which would be more suitable to GMD for example. I do think that there is potential here for more scientific discussion. I am also a bit puzzled by their results with the third sliding law (see below), and why the slip ratios are so different. Since the same viscosity parameters are used for all three models, if the basal velocities are the same, the surface velocities should also be the same. Since we are trying here to reduce the misfit between InSAR velocities and modeled surface velocities, I would expect to see the same basal sliding velocities in all three cases, and this is not what is found here.

1 Major comments

I have one main concern, I don't understand the results of the Schoof sliding law. I read several times the explanations (page 22), but I still don't understand why the results are so different.

First, and maybe I am wrong, I don't think we need to do a second inversion once we have a good estimate of basal drag (τ_b) and basal velocities (u_b) because there are always ways to change the friction parameters of different sliding laws to end up with the same basal velocities. If this is achieved, then the surface velocities are the same since the internal deformation is the same irrespective of the sliding law. In other words, one can invert for basal friction using a linear sliding law, and then use the results of a subglacial hydrology model to constrain the parameters of a different law using the results of the first inversion without performing another inversion.

For example, here, the three sliding laws are:

$$\tau_b = -\beta^2 u_b \tag{1}$$

$$\tau_b = -\mu_a N_+^p {U_b}^q \frac{u_b}{U_b} \tag{2}$$

$$\tau_b = -\mu_b N_+ \left(\frac{U_b}{U_b + \lambda_b A_b N_+^n} \right)^{1/n} \frac{u_b}{U_b} \tag{3}$$

and the authors invert for β in (1), μ_a in (2) and μ_b in (3). If we invert for β and compute U_b and N_+, one can determine μ_a and μ_b by simply doing:

$$\mu_a = \frac{\beta^2 U_b}{N_+^p {U_b}^q} \tag{4}$$

and

$$\mu_b = \frac{\beta^2 U_b}{N_+ \left(\frac{U_b}{U_b + \lambda_b A_b N_+^n} \right)^{1/n}} \tag{5}$$

Using these values for μ_a and μ_b, the forward model should produce the same surface velocities and therefore the same misfit to observations. The only problem might be the smoothness of these fields. So, I guess I have 2 questions:

- Why do we need such a complicated procedure, when a simple single inversion would potentially enough?
- Why are the results of the Schoof sliding law so different? Is it because the inversion converged in a local minimum?

It would be nice to try and start with the μ_a and μ_b from equations 4 and 5 and see if you indeed get the same sliding ratio for all 3 sliding laws.

2 Specific comments

- p3 equations 3, 4 and 5: I think you are missing a minus sign for all these equations (basal drag opposes motion)
- p3 eq 5: use `\left(` `\right)` rather than simple parentheses.
- p3 l20: I would rather call this equation a Budd sliding law since he is the one who introduced effective pressure in basal stress.
- p3 l24: you should take the norm of τ_b here (not the vector) since you are comparing to a scalar
- p4 eq 6: minus sign missing here two?
- p4 l8: maybe mention “outward pointing”
- p6 l27: “is the control parameter.” (period missing)
- p7 l11: $\exp\left(\zeta\left(x,y\right)\right)$. (parenthesis missing)
- p8 l4: with respect to the initial input
- p8 eq 26 and 27: I think you should use capital B_i at the numerator since your are deriving the function, not its output. Equation 26 should therefore be

$$\delta J = \left(\prod_{i=N}^{1} \frac{\partial B_i}{\partial b_{i-1}} \right) \frac{\partial B_0}{\partial \phi_i} \delta\phi_i \tag{6}$$

- p8 l27: to generate a *derivative*?
- p8 l29: derivative?

- p9 l2: gradient of *a* function
- p9 l6: forward accumulation AD tool: I think this method is generally referred to as “Object Overloading”
- p12 l9: 500 m (space missing)
- p13 l2: An L-curve analysis
- p15 figure 14: I think what matters is not so much that the sliding laws 2 and 3 are non linear, what is important here is that they depend on the effective pressure, so I would replace the third box to “Inversion: effective pressure-dependent sliding Law”.
- p16 l2: 500 m (space missing)
- p17 l1: the the
- pp17 l15: maybe mention water sheet thickness?
- p17 l17: is it really mPa or MPa?
- p18 l10: Figure 14 and 17 (no parentheses needed)
- p22 l2: will account for some of the effects, which would (comma missing)
- p23 l1: hydrology runs are reflective
- p28 l6: we would like to thank M. ...

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