Application of a regularised Coulomb sliding law to Jakobshavn Isbræ, West Greenland

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Response to Referee Comment #1 (https://doi.org/10.5194/egusphere-2024-1040-RC1)

Referee comments are in black, author responses are in blue, *suggested changes are in italic blue*.

Trevers et al. test several glacier sliding laws to see how well they reproduce the flow dynamics of Jakobshaven Isbrae gathered from 2009 to 2018. Specifically, they compare the more widely used Weertman and linear sliding laws to a regularized Coulomb sliding law. Theory suggests that the regularized Coulomb sliding law can account for basal cavitation and heterogeneous bed materials important for controlling glacier slip whereas the former two sliding laws cannot. Both the Weertman and linear sliding laws produce very poor model results. To improve model performance, Trevers implements an active reparameterization scheme that allows the model to update its parameters with changes in the glacier's velocity field. While this reparameterization scheme improves model performance, its reliance on the velocity data prevent its use for any ice flow projections. In contrast, the regularized Coulomb sliding law can generally reproduce the variable sliding velocities at Jakobshaben Isbrae without reparameterization. The manuscript's subject matter is of general interest to the earth science community as improving the sliding law parameterization is pivotal for accurately forecasting future sea-level rise. I found the manuscript to be well written and their conclusions to be well supported by their results. I had a few suggestions that I think would clarify some points, all of which are relatively minor. However, I am enthusiastic about this manuscript being published and think it is a significant contribution to the field.

We would like to thank the reviewer for taking the time to read and review our manuscript, and for their insightful, constructive and encouraging remarks.

General comments:

I think some clarification is needed for understanding what experiments you carried out and why. For instance, the suffix 'TRANS' was confusing for the model experiments that did not vary the C and phi parameters. I would emphasize why you are allowing the LV model to vary these parameters. My understanding is that it is to show that the RC model can produce essentially the same model fit without having to use detailed velocity data. This allows the RC model to be used more effectively for projections. I think this point is really important, but it wasn't obvious during my first reading. I would suggest setting up the problem a bit better in the introduction and throughout the manuscript so that this impressive result isn't saved until the discussion.

Thank you for spotting this mistake. 'STAT' and 'TRANS' are intended to refer to non-evolving and evolving C/phi parameters respectively. This crept in as a typo when we changed the experiment naming convention, and is certainly confusing for the reader.

We will correct 'WE_TRANS' and 'RC_500_TRANS' to 'WE_STAT' and 'RC_500_STAT' wherever they occurred throughout the document.

It is unclear to me how you are defining the 'grounding zone'. More of the glacier is grounded beyond the box. I think my confusion here can be resolved with a change in word choice of grounding zone or clarification on what you mean by grounding zone. It follows that I was unsure how you determined the grounded area. Please elaborate on this in the text.

The Grounding Zone (GZ) is a box that we have drawn around site M0 encompassing several square km. It is convenient for analysis since the grounding line retreats and advances across it during hindcast simulations. The Grounded Area is then simply calculated from the number of cells inside the GZ with grounded ice.

We will keep the name 'Grounding Zone' but we have added some additional text to the paragraph where it is first mentioned in Section 4.1 to more clearly define it. We will also add a label to Figure 1b, and reference Section 4.1 in the Figure 1 caption.

Specific comments:

Abstract – It is unclear from the abstract if you assimilate velocity data with the other sliding laws. I also think you can better setup the problem that you are trying to solve with these experiments to really drive home the importance of the work you've done here.

We agree that the abstract did not do a good job of priming the reader for the aims and message of the study.

We will add text to the abstract to explicitly link the regular assimilation (time-series inverse model) with the linear viscous sliding law, and an additional sentence to highlight that this is a limitation which the regularised law is able to overcome.

Section 1 - I think it's worth pointing out here that the form of the hard bedded and soft bedded slip laws is similar. Otherwise, I don't think your point about a universal slip law makes sense.

We agree that the equivalence of the hard and soft bedded laws is important to highlight.

We will split up the final sentence of paragraph 2 of Section 1, and add a clause to the beginning of the sentence to highlight the equivalence.

Section1 – continued - I think here is where you should also setup the problem and talk the reader through your hypothesis and how you are setting about to prove it. That is, lay the foundation for the importance of the experiments you are going to run in the paper.

We agree that we could do more to set up the problem addressed by the study.

Along with the aforementioned changes to the abstract, we will add a paragraph to the end of Section 1.1 to outline the problem, the limitation in the linear viscous law and how we show the improvement with the regularised law.

Line 52 – Maybe too detailed, but I was interested in if we know why change in water circulation happened.

There are complicated oceanographic drivers of this. It's beyond the scope of this study to explain them, but Khazendar et al. (2019) contains much more detail.

We will briefly mentioned that these are linked to cooling of the North Atlantic sub-polar gyre.

Line 127 – Why?

The inverse method is effectively optimising the basal stress so it should be insensitive to the sliding law used. It is therefore easier to just perform it once for a single sliding law rather than having to rescale α_C in Equation 11 to achieve the same thing.

We will extend the final sentence of this paragraph to include this reasoning.

Line 142 – What is the resolution of BedMachine?

150 m resolution. We will include this detail.

Line 143 – Please define GIMP.

Greenland Ice Mapping Project. This detail will be included

Line 158 – How did you make the different datasets compatible spatially? Did you do any resampling?

Yes, all datasets were resampled onto the 150 m BedMachine grid. This will be mentioned at the end of this paragraph

Line 166 – I would suggest moving this to the beginning of the next paragraph.

We will move this sentence to the beginning of the first paragraph of Section 2.2.1, where we feel it is most appropriate.

Line 192 – What is the temporal and spatial resolution of RACMO?

The data were provided at annual temporal resolution and 1 km spatial resolution, resampled on the BedMachine grid. We will include this detail.

Line 210 – I found the name scheme here a bit confusing. I thought the 'STAT' or 'TRANS' part of the names related to static to transient evolutions of C and phi. Is that incorrect? Also, I would put the name of the Weertman model here since you did it for all the others.

As mentioned above, the use of 'TRANS' instead of 'STAT' here was in error, and this will be corrected everywhere in the manuscript. We will also clarify the sliding law names in Table 1, and the experiment name for the Weertman law will be mentioned in line 208.

Line 210 – Why didn't you use a transient C and phi with the Weertman and RC models? Again, I think this goes to better setup the problem you're trying to solve.

The point was to demonstrate that the linear viscous model required the transient inputs in order to accurately reproduce the observed velocities, but that this is a problematic modelling strategy. The RC model was able to overcome these limitations without requiring transient inputs. We hope that the changes already mentioned above will address this question and prep the reader better on the motivation for this study.

Line 226 – Please explain somewhere why you didn't establish an initial state with the different flow laws.

Upon evaluation, we realised that the explanation we had provided for the poor performance of RC_500_STAT early in the experiment was not satisfactory. *We will remove this explanation*. We aren't able to provide an alternative satisfactory explanation, although we note that RC_500_STAT only performs really badly in 2009, after which it reproduces the annual range

quite well during 2010 and 2011, while still overestimating the after flow speeds. *We will highlight this.*

We are content that it is legitimate to use the same relaxed state for all experiments, since the initial velocities are equal in all experiments, and differences in the flux divergence between simulations early on are small relative to the magnitude of the flux divergence (see Supplementary Figure S7). *We will add a sentence to justify this to the end of Section 2.2.2.*

Line 229 – Please elaborate on this last point. At first, I didn't quite follow why the inverse model would allow the LV_TRANS model to perform better after 2016.

This point wasn't phrased very clearly. LV_TRANS isn't capturing any physics that the other models aren't, simply it's assimilating the slower velocities and then reproducing them.

We will change the text of this sentence to clarify this point.

259-267 – This is well explained here but I felt like the impact of this statement could have been setup better in the introduction and results. It took me reading it a few times to realize why the RC model was so much better even though it doesn't look much different from the LV_TRANS model results.

We hope that the aforementioned changes to the abstract and introduction will help to prep the reader better on the significance of this explanation.

274 – I'm having a difficult time understand how you calculated the grounded area. Are you somehow accounting for cavities or is it just the percent of the glacier that is not floating above the "grounding zone".

The grounded area is simply calculated from the number of cells within the GZ that contain grounded ice. However, this sentence omitted the detail that grounded area is calculated within the GZ.

We will include this detail here. We will also update the Figure 7 caption accordingly

305 –Somewhere in this section I would suggest explaining why it is better to be able to vary u_o over *m*.

In practice there may be little difference, but we suggest that a spatially varying u_0 may be a more natural way to model this because u_0 governs the transition between regimes.

We will add a sentence to the end of this paragraph to make this argument.

310 – Fast-sliding speed is u_o correct? Please just use the symbol once you define it earlier on. You can define it again in the section heading or early in this section. I was a bit confused at first because you first introduce u_o with a lot of other variables and I quickly forgot the meaning of this specific one. I think putting parenthesis or commas around the symbols would also help the readers follow the definitions of these variables.

We agree that this is confusing for the reader. *We will use u_0 instead throughout this paragraph.*

314 – Woodard et al., 2023 also talks about this.

Woodard JB, Zoet LK, Iverson NR, Helanow C. Inferring forms of glacier slip laws from estimates of ice-bed separation during glacier slip. *Journal of Glaciology*. 2023;69(274):324-332. doi:10.1017/jog.2022.63

This will be included as a reference.

Section 5 – I found this whole paragraph to be difficult to follow. Please consider rewriting. I'll put a few specific issues I had below.

324 – LV can but it needs to be re-parameterized with velocity data. Maybe merge the first and second sentences to avoid confusion.

We won't merge the sentences but we will include a qualifier to say that this is for non-evolving inputs.

331 – Unclear to me what you mean by transition speed here. Is this u_o?

Yes. We will change this.

Figure 5 – I had a hard time seeing the colors in the legend. Consider making the points larger.

We will increase the point size, and the colour scheme will also be changed.

Figure 7 – I had a hard time seeing the yellow in these plots. Especially the axis text. Please consider changing the color.

We will change the colour scheme for this figure, along with Figures 4 to 8 and S8 to S10 to keep them in line with the same colour scheme. This colour scheme should be clearer and still be colour-blindness friendly.

Figure S1 – I could not tell from this where the tongue was. Consider outlining the tongue to help orient the readers. A north arrow I think would also help here.

We agree that it's not easy to tell where the glacier is grounded or afloat.

We will change the images in this figure so that they're closer to a year of separation. We will also outline the glacier terminus for both years, add a North arrow, and change the figure caption as well.