Response to reviewers

Reviewer comments in black - *Answers in blue italic*

Reviewer 2 (Manuela Köpfli):

Summary

The manuscript titled “Creep enhancement and sliding in a temperate, hard-bedded alpine glacier” by Roldán-Blasco et al. examines the basal sliding and internal ice deformation of an alpine glacier. The authors observe an increasing creep factor with depth, which they attribute primarily to changes in water content. However, they suggest that seasonal changes are more likely due to variations in stress distribution within the glacier, as neither the increase in water content nor the stress change alone fully accounts for their observations.

The study is based on approximately 20 tiltmeter measurements along a borehole over an 8-month period. These data are complemented by glacier flow velocity measurements from the glacier surface and bed. Additionally, the authors employ a modeling approach to better understand stress distribution within the glacier. By connecting the modeling output with the tilt and discharge measurements, they quantify the Glen’s flow law creep factor, investigate the water content within the ice relative to depth, and analyze stress distribution within the glacier.

Finally, they link their findings to the state and evolution of the subglacial water system. Overall, this manuscript presents significant observations regarding Glen’s flow law creep factor and the seasonal evolution of the subglacial water system. Minor comments for improvement focus mainly on enhancing readability.

Manuela Köpfli

We thank the reviewer for her careful reading and correction, which improved the quality of the manuscript.

General questions

- Would you assume to see similar inclinometer measurements for all boreholes, if they would have worked properly and the installation/drilling would have been perfect?

The purpose of drilling several boreholes was to have a more robust interpretation if the same behaviour was observed in all of them. Given their similar position on the centreline, we would expect similar behaviour, but it is hard to know as the measurements are difficult to interpret. However, as shown in Figure 2 of the manuscript, the average behaviour appears to be similar.

- I understand that you mainly focus on the tilt measurements. If possible, I would appreciate seeing a figure of the initial and final borehole shape as Figure 1.b but also showing the final borehole shape.

We have now added the final shape of the BH2 borehole to Figure 1b.

- In Figure 2, BH3 shows this larger value at depth around -160m. Do you think this is real? If so, do you have any explanation for that since your boreholes BH2 and BH3 are very close?

This large value is clearly a measurement artifact due to a poorly stabilized tilt measurement. This can be seen in the raw data in Fig. S2 (BH3#6), where a sudden increase in tilt occurred in August 2020, affecting the calculated mean value of du/dz. We now mention this in the revised manuscript (lines 218-219).

- In Figure 5 you show your data with a daily resolution. Would it be possible to to "zoom in" to the first half of May and have a higher time resolution for velocities and discharge. It would be very interesting to see, if you see a delay between glacier speed up and discharge.

The speed up events and their relation to discharge have been closely investigated in a recent paper from our group :

Togaibekov, A., Gimbert, F., Gilbert, A., and Walpersdorf, A.: Observing and Modeling Short-Term Changes in Basal Friction During Rain-Induced Speed-Ups on an Alpine Glacier, Geophysical Research Letters, 51, e2023GL107999, https://doi.org/10.1029/2023GL107999, 2024.

We now refer to this paper in the revised manuscript for more details on the speed up events.

Comments Text

Note: I recognized that you used different ways to write a date: 15th of February, 15th February, 15th February. Maybe you choose one format and keep it through the whole manuscript. I just wrote “date” and the corresponding line.

Title: I would use “bedded” instead of “beded”

Done.

L.32-35: I would break the sentence into two sentences.

Done. This sentence has also been changed following the comments of reviewer 1.

L.94: date

Done.

L.139: date

Done.

L.201: To me, the 2020 is a bit misleading. I would exchange it with something like “over one year (2020)” or “over eight months (2020)” or even remove the 2020 completely.

Done.

L.205: To me, there are no residuals of the reconstructed velocities. As I understand, the residuals are more between the reconstructed and observed velocities

Ok, we clarified the sentence in the revised manuscript.

L.214: I don't really understand the word “threshold” in this context.

Yes, the sentence was unclear and has been removed as not relevant here.

L.214-215: unit goes over the line and exponent is not really an exponent (for both units: m a-1 and m3 s-1)

This sentence has been removed.

L.223-237: I’m a bit confused by n and m. If they are not the same, could you add a sentence and describe the difference?

Ok, we added a sentence in the revised manuscript.

L.228: I would write m italic that it is immediately clear that you are not talking about meters (like L. 235)

Done.

L.236: Normally you used Eq. instead of Eqn.

This has been corrected.

L.242: I prefer the italic writing of parameters: A(z)

This has been modified.

L.246: Maybe change this sentence to: “Averaged deformation rate profiles, computed from tilt measurements (see methods in Section 3.1) at BH2, BH3, and BH4 between February 15 and October 15, 2020, are shown in Figure 2.”

Done.

L.247: date

Done.

L.275: October 1st to 31st (second superscript is missing), date

Done.

L.298: Normally, you wrote section starting with a capital letter

Done.

L.307: date

Done.

L.313: Normally, you wrote section starting with a capital letter and italic du/dz

Done.

L.314: Italic du/dz

Done.

L.345: For these reasons we do not include Lliboutry and Duval (1985) is not included in Table 2…

This has been corrected in the revised manuscript.

L.364: … either a stress … OR a change…

This has been corrected in the revised manuscript.

L.397: use % instead of writing percent

Done.

Comments Figures

Figure 1: Make sure that all blue dots are visible (especially BH1). Maybe use a different color for the label of the GPS station “ARG1” so that it is immediately clear that this is something different and there is no blue dot behind the green dot. Add to the last sentence in the figure caption, why you start your analysis on 15th of February. date (in the figure caption)

The figure 1 has been modified accordingly and the legend completed.

Figure 2: Start figure caption with a capital letter. I would rewrite the figure caption as “Average measured deformation rate profiles with monthly minima and maxima at BH2, BH3 and BH4 including the monthly minima and maxima for BH2. The continuous lines show the average measured deformation rate profile at each borehole for the period between the 15th February and the 15th October 2020, and the shadowed region the range between monthly averaged minima and maxima deformation rate values (shown only for BH2). Every symbol represents a tiltmeter.” date (in the figure caption)

The caption has been corrected.

Figure 4: Labels a), b), c) are missing in the figure. Is in subplot c) W only inferred for the orange markers? Is the assumption for the blue line, C & P (2010), that W is constant. If so, I would change the label of the orange line/markers also to A(z) and only mention the water content W in the figure caption (as you do).

Ok, the figure 4 has been modified accordingly.

Figure 5: I would use a different color for the discharge vs basal velocity, just for clarity. Maybe you want to mention again, that you convolved/averaged your data on a daily basis and you did the same for the discharge? Because, I would assume some daily variation in the discharge over the melting season.

The color of basal velocity has been changed and the fact the data are at daily time scale is mentioned in the caption.

Figure 6: date (in the figure caption)

Done.

Figure 7: It is correct what you are saying in your figure caption but when I first read that, I did not believe that you wanted to say that the friction increases during melting.

To avoid that, I would add that this is due to “efficient drainage” or an “evolved drainage system”.

Ok, we clarified the caption.

Comments Supplement

Figure S9: I would use Δt instead of “Delatat” and du/dz instead of dud and decide if Error should have a capital letter or not (title vs. color bar label)

The figure has been modified accordingly.

Figure S10: Again, i would prefer Δt instead of “Delatat” and ud instead of “du”

The figure has been modified accordingly.

Figure S11: I’m not sure if you need that many positions after decimal point for the std.

True, we kept one decimal only.

Figure S16: The orange line is hard to see. Also the label for (a) is missing. I would suggest making two figures out of the one figure, just take your figure S16a as one figure and add S16b as S17. This allows you to make S16a bigger and easier to understand. Please check the linewidth of the orange line or change the order you are plotting the lines so that blue and orange are in the front.

Ok, the figures have been modified accordingly.