Response to Reviewer1:
Weak relationship between remotely detected crevasses and inferred ice rheological parameters on Antarctic ice shelves; C., Gerli, S., Rosier, H., Gudmundsson, S., Sun

Anonymous Referee #1, 31st Dec 2023

Improve the image quality and readability of some figures.

- Figures 1 and S2 can be difficult to read and would benefit from higher resolution.

Response: The figures in the Word document are at lower resolutions but a higher resolution vector format PDF version will be produced for each figure and will be submitted with the resubmitted article.

- Figures 1 and S2 have difficult to read legends partially due to resolution and partially due to the low contrast between text color and background color.

Response: Legend text will be made bigger and easier to read

- Figure S1: I recommend changing the top left box in each matrix to a lighter background color with better contrast. It can be difficult to read the numbers on a printed copy.

Response: Light blue color for top left box of matrix will be applied

Include some additional technical details to better understand the study's methods.

- Line 160: you interpolate the field "A" onto the regular crevasse mask coordinates. Could you briefly name or explain the interpolation method?

Response: The interpolation method was performed using a linear interpolation which is appropriate for the linear elements used in the model.

- Are results robust to changes in the other regularization parameter? The paper focused on sensitivity in one parameter, but not the other.

Response: We will perform a second set of simulations for a $\gamma_a = 0$ instead of $\gamma_a = 1$, which allows A to change in terms of its magnitude, fitting the velocities of 2019. We will add an additional figure in the Supplementary material displaying the sensitivity analysis to γ_a.

- Is there a numerical threshold or method for determining the "consistent agreement" mentioned at the end of the Figure 4 caption?

Response: We will change "consistent agreement" in the caption and clarify with further text.

In Figure S3(b) for the highly damaged case, the ROC curves become close to random classifiers at high values of the regularization parameter. However, the opposite is true for the "all crevasse" case in Figure S3(a). What is the reason for that behavior?

Response: By adopting larger γ_s values in the inversion problem, the solution of A becomes more and more uniform throughout the domain (we will add a figure in the Supplement Material regarding this). For the cases of total uniformity, until the A threshold is not surpassed, all crevasses remain undetected. Once the threshold is surpassed, the model accurately identifies all crevasses, but at the cost of misclassifying all the noncrevassed areas as crevassed. This, therefore, provides a ROC curve that is a straight diagonal line from the bottom-left (0-0) to the top-right (1-1), indicating that the model's performance is as good as random, and providing a 100% TPR and 100% FPR. For the cases in the ROC analysis where we see an S-shaped curve, i.e., $\gamma_s = 10^7$ or $5*10^8$ (We will add a figure in the Supplement), the solution of A has not yet reached a total uniformity changing just slightly throughout the domain. Whenever performing the ROC analysis, the predictions and the misses are not 100% but are still split, thus the estimated curve takes the form of an s-shaped one. An s-shaped ROC curve represents a biphasic behaviour, reflecting different levels of classification at different thresholds, which does not necessarily mean a better classifier, but rather a two-phase discriminative ability as a function of the threshold. However, as uniformity becomes more pronounced (and A becomes spatially uniform), the ROC curve transitions towards resembling that of a diagonal line, characteristic of a random classifier. This transition underscores the diminishing ability of the classifier as it struggles to differentiate between classes effectively (crevasse and no-crevasse). We will make sure this is clear in the Supplementary.

Provide some additional context/clarity for some background information and conclusions.

- Lines 35-38: Can you provide citations for the impact of surface crevasses in different situations?

Response: We will provide some citations.

- I was confused by the "(see details below)" note in line 48 and the "(described further below)" in line 56. Can specific sections or subsections be referenced to make that information more clear?

Response: We will add it in the text.

- I find it interesting that for the analysis on Pine Island Ice Shelf including only heavily damaged crevasses (Figure 3b), the relationship no longer behaves like a random classifier. I would be interested to know what attributes "heavily damaged crevasses" have that other crevasses lack in the input data. I think that some brief discussion of the input data's classification method could provide valuable context to the "heavily damaged" result.

Response: For the heavily damage crevasses map, we adopt the methodology of Izeboud et al., 2023, which classifies areas of surface structural damage on ice shelves using multi-source satellite imagery through a feature contrast approach. This methodology provides a continuous damage map (D), which has values ranging from 0 for intact ice, to 0.5 for fully damaged ice, with heavily damaged regions defined as areas with values greater than 0.1. We will add it to the text in the manuscript.

Is there a different well-motivated choice in sliding law or sliding law exponent (e.g. regularized Coulomb friction) that would affect the results of this study? How dependent is the spatial variation of "A" dependent on the sliding law for this study?

Response: The inversions were performed adopting a Weertman sliding law for the grounded ice as our model domain extends beyond the floating shelf. We will not test the application of other sliding laws since the aim was to perform inversions to find the solution of A on the floating ice, which relies on the strain rates and velocity. There is therefore no necessity to evaluate the impact of sliding laws for this analysis.

- Lines 365-366: You state "We find that for any threshold value, the performance of this predictor is like that of a random classifier". That seems inconsistent with the "high damage" study in the manuscript. I don't think that the "high damage" study weakens the paper's overall conclusions, but is an interesting result that perhaps merits some additional discussion.

Response: Indeed, these results show that surface features identified as heavily damaged crevasses are correlated to a greater degree with the ice rate factor obtained through inversion methods. However, the AUC values are still not satisfactory enough to be considered significant since, in classification analysis, any AUC value between 0.7 and 0.8 is generally interpreted as poor (Metz et al., 1978). If we still were to assume this was satisfactory, and we adopted the A-threshold given by the ROC curve for this case, the classifier accurately identifies 50 % of the crevasses but also incorrectly flags almost 20 % of no-crevasse regions as crevasses (Fig. 5). The probability of a match between inverted and remotely-detected damage remains limited even in this setting, so we believe that these results do not show any clear or robust relationship between damage inferred by an ice sheet model and damage identified via remote sensing. We will make it clear in the text.

Lines 382-384: you mention the possibility of surface crevasses penetrating to the water line. Can you give additional context to the correlation between surface crevasses reaching the water line and inferred variation in ice rheology?

Response: The theoretical findings by Lai et al. in 2020 highlighted the possibility of surface crevasses extending down to the water line. Here, we have not and will not investigate this; further information regarding the crevasses reaching the water line can be found at Lai et al., 2020. The inverted ice rate factor A obtained in our work by fitting observed velocities is a depth-integrated solution. Our results show ice weakening along the ice shelf margins, specifically of Pine Island Ice Shelf, where crevasses and damaged ice are present and expected.

- I quite like Figure S6 as a visualization for the classification. Can a similar figure for the Filchner-Ronne Ice Shelf be included as well?

Response: We will add an additional figure for the Filchner Ronne Ice Shelf in the supplementary as requested.

Technical Corrections:

- The acronym OPTtimal operating PoinT (OPTPT) defined in the text (lines 184 and 197) differs from the acronym used in Figures 2 and 3 (OPT-PNT), assuming the two have the same meaning like I believe they do. We will correct it.
- Table T2: Column 2, Row 3 has an extra "tab" space that should be deleted. We will correct it.
- Notation for the equation in section 1.3 of the supplementary information should be made consistent. Most of the terms use forward slashes but "Cost(P|N)" uses a vertical bar in the text. We will correct it.