

The Foundations of the Patagonian Icefields



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Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality

24th Aug 23

Dear Dr Fürst,

Please allow me to apologise for the delay in sending a decision on your manuscript titled "The Foundations of the Patagonian Icefields". It has now been seen by 3 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file. Please note that one of our requirements for publication is that data be made publicly available in an online repository.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:

[Link redacted]

** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Joe Aslin

Senior Editor,
Communications Earth & Environment
<https://www.nature.com/commsenv/>
Twitter: @CommsEarth

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

I'm convinced of the scientific aspects described in the manuscript and their contribution to progress in your research discipline.

Introduction

The main question was addressed by the research in the introduction. The introduction provides sufficient background and includes relevant references.

Materials and Methods

The methods were sufficiently documented to allow replication studies. The statistical methods are valid and correctly applied.

Results and discussion

The glaciers ice volume, areal retreat rates, mass loss and frontal ablation information were estimated using conventional approach. The results of the manuscript contribute to precise glacier monitoring and the findings of this study could be applied to future research to verify the trends of the Patagonian Icefield glaciers and assess the factors contributing to these changes.

-The quality of the figures is satisfactory, except the Figure 1. Please, add the coordinating system information in figure 1.

-Please, summarize the implications of the findings of this study in Patagonian Icefield glaciers to water resources, communities and ecosystems.

-The complete database products could have been made available to the scientific community in an online repository.

Conclusions

The conclusions are supported by the results.

Reviewer #2 (Remarks to the Author):

This paper represents a first attempt to model the ice volumes of the Patagonian icefields by making use of a wealth of direct thickness data and past glacier outlines to map the basal topography. This represents a very important contribution. The new dataset is used to make some extremely interesting observations regarding the relative importance of frontal dynamics versus surface mass balance in accounting for mass loss. A commentary on the potential future stability of various individual outlet glaciers based on their upglacier topography is provided. The new 2D thickness maps are systematically compared to previous studies, with discrepancies accounted for in the discussion. I find the authors have taken a very realistic approach to their data and its uncertainties. The approaches taken to build the basal topography map are explained well and can be clearly followed, particularly for someone like myself who could not claim to be an expert in these techniques.

One area where the authors should perhaps consider adding some additional context relates to the observations of upglacier basal topography for the San Quintin, Upsala, Grosse, Exploradores, Nef and Upsala glaciers. The authors suggest significant overdeepenings extend upglacier for all of these but the Upsala, where they identify a prograding bed. The interpretation is that the former glaciers may experience more unstable retreat in the future, whereas the latter may be more stable. Given most of these glaciers have experienced recession in recent decades, do the data on recent frontal change show any additional support for these inferences? For example, is the frontal recession of Upsala at a lower rate than the other mentioned? I should think a quick assessment of this based on a study such as Davies and Glasser (2012: <https://doi.org/10.3189/2012JoG12J026>) or similar might help provide some extra weight to these suggestions and ground the future scenarios in the context of recent change.

Overall, I think this is a sound study with impactful conclusions (and no doubt a really useful data resource for future studies) that is worthy of publication. However, I do think that the clarity of the message would benefit from being improved in a number of places, and have made several suggestions to this end on the annotated pdf "4050_0_art_file_79169_rx7sr7_convrt_HL". I would recommend that the authors consider these suggestions.

Harold Lovell
University of Portsmouth
10th August 2023

Reviewer #3 (Remarks to the Author):

This is an interesting paper which advances the knowledge of the Patagonia Ice fields. Perhaps the most useful output is an improved 'bed topography' dataset which could be of interest for further studies looking at future lake formations.

Clarity needs to be added when discussing which year specific results refer to. For example, the headline volume figure stated in the abstract appears to relate to the year 2000, some 23 years ago. Whilst I understand why the SRTM DEM was used a reference, I think this needs further explanation.

The manuscript could also be improved by discussing the implications of the results and reinforcing the importance of these glaciers beyond their potential for sea level rise.

I think it would be useful to include a figure detailing the location of the direct thickness measurements used in the main manuscript, especially as this is stated as an important part of the study. This could possibly replace the current Fig 2, which isn't critical to the manuscript (although it is a nice photo!).

Specific comments

Line 40: Perhaps add that it is also the distribution of the ice which is relatively poorly studied and of interest to this study.

Line 50: This total value corresponds to the year 2000 (23 years ago). I think this needs to be clear here.

Line 56 (and introduction in general): Whilst the sea level rise potential is correct, it is worth

mentioning the importance of these glaciers for local water supply (hydropower, irrigation, potable water etc)

Line 66: a similar situation occurs in the New Zealand Southern Alps – maybe some interesting comparisons to be drawn here?

Line 74: Are you able to reference/quantify the amount of thinning which has been taking place at all?

Line 87: This seems to contradict line 40 in the abstract – perhaps one/both of these needs re-wording

Line 95: it is also worth mentioning that methods based on a 'perfect plasticity' assumption do not perform well for lake/marine terminating glaciers

Line 123: The ice thickness is based on the SRTM elevation model which is now 23 years old (as stated). Would it be possible to generate an estimate for a more recent time period?

Line 130: Here you state the SPI volume as 4227 km³ whilst in table 1 it is 4228 (possibly a rounding error?)

Discussion/Conclusion: what are the implications of your results? Are you able to say anything about potential future changes? What does it mean for water supply etc

Line 291: You state that: "the new basal topography represents an important quality increase" – one of the major uses of such datasets is for assessing the likelihood of lake formation – I think this should be mentioned here as a key piece of research impact.

Point-by-Point Reply to Reviewer Reports on the manuscript entitled
The Foundations of the Patagonian Icefields
by J.J. Fürst et al.

First of all, we want to thank all reviewers for the critical and useful comments on the manuscript. It was with great pleasure that we read their general appreciation of our work and the unanimous recommendation for publication. In the following, all review comments are repeated and were addressed. Our responses are indented. Answers are given in blue and actions in orange. *Italic font* is used for citing newly added or existing text passages in the manuscript.

First, we want to inform the editor and the reviewers about the fact that, during the revision, we noted that we overlooked data of extensive GPR measurements on Soler Glacier in the central parts of the Northern Patagonian Icefield. These measurements were now included. In addition, a code error was noted in the averaging procedure necessary for an intrinsic flux correction. The averaging was corrected. The entire reconstruction was thus repeated and all results are affected. Difference remain, however, moderate.

REFeree #1

I'm convinced of the scientific aspects described in the manuscript and their contribution to progress in your research discipline.

INTRODUCTION

The main question was addressed by the research in the introduction. The introduction provides sufficient background and includes relevant references.

Thank you for your appreciation of the introduction.

ACTION: No actions required.

MATERIALS AND METHODS

The methods were sufficiently documented to allow replication studies. The statistical methods are valid and correctly applied.

Thank you for this positive assessment.

ACTION: No actions required.

RESULTS AND DISCUSSION

The glaciers ice volume, areal retreat rates, mass loss and frontal ablation information were estimated using conventional approach. The results of the manuscript contribute to precise glacier monitoring and the findings of this study could be applied to future research to verify the trends of the Patagonian Icefield glaciers and assess the factors contributing to these changes.

- The quality of the figures is satisfactory, except the Figure 1. Please, add the coordinating system information in figure 1.
- Please, summarize the implications of the findings of this study in Patagonian Icefield glaciers to water resources, communities and ecosystems.
- The complete database products could have been made available to the scientific community in an online repository.

Thank you for this comment, it is an excellent remark. We added a section on the socio-economic and ecological implications to the introduction and conclusion. Concerning the coordinate system of Fig. 1, we used UTM 18S. Finally, we anticipate to publish the dataset alongside the article publication at <http://qfuego-patagonia.org/>. This repository is pertinent for this region and comprises inter-disciplinary data on the Fuego-Patagonia region.

ACTIONS:

- The coordinate system has been added to Figure 1.
- Relevant datasets will be published at <http://qfuego-patagonia.org/>.

- A text passage on the socio-economic and the ecological importance was added to the introduction and the conclusion. See details in answers to main comments of referee #3.

CONCLUSIONS

The conclusions are supported by the results.

ACTION: No actions required.

REFeree #2

This paper represents a first attempt to model the ice volumes of the Patagonian ice-fields by making use of a wealth of direct thickness data and past glacier outlines to map the basal topography. This represents a very important contribution. The new dataset is used to make some extremely interesting observations regarding the relative importance of frontal dynamics versus surface mass balance in accounting for mass loss. A commentary on the potential future stability of various individual outlet glaciers based on their upglacier topography is provided. The new 2D thickness maps are systematically compared to previous studies, with discrepancies accounted for in the discussion. I find the authors have taken a very realistic approach to their data and its uncertainties. The approaches taken to build the basal topography map are explained well and can be clearly followed, particularly for someone like myself who could not claim to be an expert in these techniques.

Thank you for your extremely positive evaluation with regard to the importance of our contribution. It is true that we report on some striking differences in estimates of frontal ablation, here relying on a vast amount of previously ignored thickness data. Furthermore we are glad that the description of our approach is comprehensible even beyond the community of designated experts in these techniques.

ACTION: No actions required.

One area where the authors should perhaps consider adding some additional context relates to the observations of upglacier basal topography for the San Quintin, Upsala, Grosse, Exploradores, Nef and Upsala glaciers. The authors suggest significant overdeepenings extend upglacier for all of these but the Upsala, where they identify a prograding bed. The interpretation is that the former glaciers may experience more unstable retreat in the future, whereas the latter may be more stable. Given most of these glaciers have experienced recession in recent decades, do the data on recent frontal change show any additional support for these inferences? For example, is the frontal recession of Upsala at a lower rate than the other mentioned? I should think a quick assessment of this based on a study such as Davies and Glasser (2012: <https://doi.org/10.3189/2012JoG12J026>) or similar might help provide some extra weight to these suggestions and ground the future scenarios in the context of recent change.

It is indeed true that we did not much cover the relation of basal characteristics to recent glacier evolution. This is partially explained by the journal format. In the appendix to this rebuttal, we took the chance to shed some light on the recent and the centennial evolution of the MALT glaciers, that we highlight in the article. The highlighted glaciers are however not the best examples to link evolution and basal topography because some might not yet have shown any

sign of accelerated retreat. For others, we have no information on pro-glacial lake depths. We therefore decided to refer to other glacier examples, for which we have evidence that fast retreat occurred along over-deepened bathymetry. Our selections prioritises glacier examples in Patagonia and Tierra del Fuego.

ACTION: A brief discussion was added to the results and discussion section at the relevant passage where glacier over-deepenings are presented. We introduced the following sentences:

‘This susceptibility assessment is based on paleo-evidence from an Arctic outlet glacier (Briner et al., 2009) as well as centennial glacier retreat in Patagonia and Tierra del Fuego (Rivera et al., 2012; Bown et al., 2019; Koppes et al., 2009; Davies and Glasser, 2012; Meier et al., 2018). Episodes of fast retreat of MALT glaciers preferentially occurred along over-deepened bed sections.’

Another challenge is to estimate the conditions and the timing of the onset of such fast retreats in the past and the future. It is certainly a very interesting question the reviewer raises here but we fear that a conclusive answer will require a regional model application that comprises an appropriate description of frontal ablation (Zekollari and Huybrechts, 2015). Down to the present day, we are not aware of such a study for the past nor the future in Patagonia with centennial scope. A first attempt has however been made to include the calving (frontal ablation) process in the last de-glaciation history of the Northern part of the Patagonian Ice Sheet (Cuzzone et al., 2023). Yet, even this modelling study admits that the timing of glacier retreat in the Lake District remains challenging. Therefore, we refrain from speculating about future evolution of the specific MALT glaciers that show expressed overdeepenings. We rather state the general challenges associated with forecasting glacier demise, and especially phases of fast retreat, and refer the interested reader to relevant literature.

ACTION: A short outlook and discussion was added with regard to glacier demise and fast retreat. The following text was added:

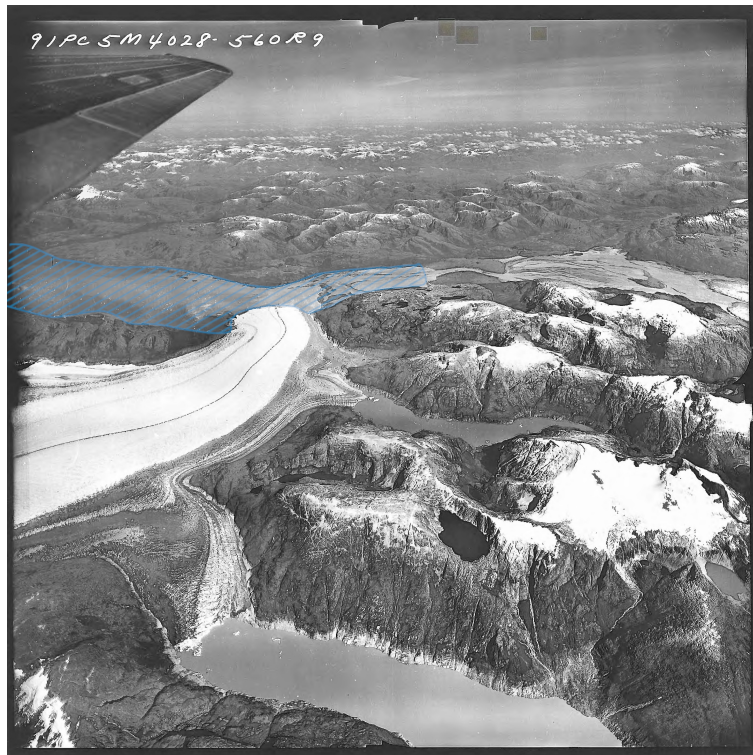
‘The identification of over-deepened bed sections can only be the first step to point out susceptible glacier setups. Yet, the pre-conditioning, the onset and the duration of phases of fast retreat is complicated as they not only depend on the exact bedrock details. These phases are additionally controlled by the general ice-flow regime (Zekollari et al., 2022), the thermal and circulation conditions in the pro-glacial water bodies (Sugiyama et al., 2016; Minowa et al., 2021; Sugiyama et al., 2021; Minowa et al., 2023), the climatic or SMB history (Weidemann et al., 2018; Temme et al., 2023) as well as glacier response times (Zekollari and Huybrechts, 2015).’

Overall, I think this is a sound study with impactful conclusions (and no doubt a really useful data resource for future studies) that is worthy of publication. How-

ever, I do think that the clarity of the message would benefit from being improved in a number of places, and have made several suggestions to this end on the annotated pdf “4050_0_art_file_79169_rx7sr7_convrt_HL”. I would recommend that the authors consider these suggestions.

We want to truly thank the reviewer for providing this annotated PDF. All copy-edits are highly appreciated and do surely improve the clarity of the manuscript.

ACTION: Most of the copy-edits have been directly implemented. A hatching was added to Fig. 2 to indicate the glacier advance of Pio XI Glacier since 1945 (see figure below).



Harold Lovell
University of Portsmouth
10th August 2023

REFeree #3

This is an interesting paper which advances the knowledge of the Patagonia Ice fields. Perhaps the most useful output is an improved 'bed topography' dataset which could be of interest for further studies looking at future lake formations.

We are very glad about the reviewer's positive assessment of utility of the presented bedrock map with regard to future lake formation/expansion.

ACTION: No action required.

Clarity needs to be added when discussing which year specific results refer to. For example, the headline volume figure stated in the abstract appears to relate to the year 2000, some 23 years ago. Whilst I understand why the SRTM DEM was used as a reference, I think this needs further explanation.

Concerning the time stamp of specific results, we have scrutinised the entire manuscript and added this information where missing. Thank you for pointing this out. The reviewer is right that our headline volume refers back to the year 2000 — quite some time ago. There is obviously the Copernicus DEM 2011-2015 and the Chilean glacier inventory from 2014. Yet the prominent Argentinian glaciers are not covered. In absence of complete and contemporaneous information on glacier outlines and elevation, it is not evident to present another consistent geometric state in terms of a more recent thickness map. Apart from that, we already reference the most prominent and recent literature on volume changes of the PIs (Braun et al., 2019; Dussaillant et al., 2019; Hugonnet et al., 2021). All these studies are based on SRTM as reference DEM and thus also refer to the year 2000. In summary, we are convinced that the 2000 baseline is an appropriate compromise for presenting a self-consistent map of the PI glacier geometries.

ACTION: Where required, time referencing has been added. We added additional justification for the baseline year 2000 as follows:

'Unfortunately, we cannot provide a second thickness map for a more recent period. An option would be the 2011-2015 Copernicus DEM (EU & ESA, 2019). However, the somewhat contemporaneous national glacier inventories of Argentina (IANIGLA & CONICET, 2018) and Chile (DGA, 2014) show no complete coverage.'

The manuscript could also be improved by discussing the implications of the results and reinforcing the importance of these glaciers beyond their potential for sea level rise.

We are caught red-handed here and we must admit that our manuscript is indeed

biased towards sea-level relevance. This comment is well justified and calls for a remedy. The way that results are currently presented, it is however difficult to discuss socio-economic and ecological importance of glaciers without oversimplifying the regional picture or plunging into very specific catchments. Both options seem not satisfactory. We therefore decided to invoke the general importance of glaciers in the introduction and the conclusion apart from global sea-level rise.

ACTION: Added general text passage on glacier importance to introduction:

‘Apart from the mere interest in the ice volume or its spatial distribution, glaciers are key elements with socio-economic and ecological importance (Gruber and Haerberli, 2007; Huss and Hock, 2018; Cauvy-Fraunié and Dangles, 2019; Farinotti et al., 2019; Immerzeel et al., 2020). In terms of natural resource, they act as natural water reservoirs. In this role, questions arise such as when peak water is reached under future warming and to what extent glaciers continue to buffer fresh-water shortage during dry seasons. Such questions rely on future glacier projections. Their reliability is ultimately tied to the knowledge of present-day ice thickness (Zekollari et al., 2022; Rounce et al., 2023). As glaciers retreated in recent decades, new pro-glacial lakes formed while others expanded (Shugar et al., 2020). Although such lakes are potential sites for future hydro-power generation (Farinotti et al., 2019), they also pose a threat to downstream communities, if dams break. In a review of glacier related hazards for Chile and Argentina (Iribarren Anaconda et al., 2014), the authors appeal for a research intensification in mountainous regions on the influence of cryospheric changes on slope failures and on outburst floods. The basis for such research is solid knowledge on the basal topography beneath the ice cover. Finally and on global scales, there is evidence that glacier retreat impacts positively on biodiversity Cauvy-Fraunié and Dangles (2019). This idealistic picture is moderated by the fact that specialist species, adapted to glacial conditions, are often losers under these changes. In Chile, it has further been shown that fjord systems in Tierra del Fuego show phytoplankton biomass reduction as glacier retreated with negative consequences for predator species Giesecke et al. (2019). In summary, glacier thickness mapping is relevant far beyond the mere interest in sea-level relevant melt volume.’

ACTION: Added text passage to the conclusion:

‘In summary, our basal topography map is key to reliably project future changes of the mountain cryosphere in Patagonia (Zekollari et al., 2022). Such projections will present a solid basis to assess changes in regional fresh-water availability (Huss and Hock, 2018), hydrological turnover, biodiversity (Cauvy-Fraunié and Dangles, 2019) and natural hazards (Iribarren Anaconda et al., 2014). Apart from the timing of future glacier retreat, the high quality of this map allows an improved identification of future lake formation - i.e., potential

sites for hydro-power production (Farinotti et al., 2019)'.

I think it would be useful to include a figure detailing the location of the direct thickness measurements used in the main manuscript, especially as this is stated as an important part of the study. This could possibly replace the current Fig 2, which isn't critical to the manuscript (although it is a nice photo!).

The reviewer raises a fair point here. During manuscript preparation, there was a figure showing thickness observations. It was removed last minute. We have now added it again as Supplementary Figure S5. It shows all used observations as well as only GPR, seismic and borehole measurements for both icefields. We refrain from removing the current Figure 2. We consider it important as it substantiates the model capabilities in regions without direct thickness measurements.

ACTION: Supplementary Figure S5 was added and shows locations of thickness measurements.

SPECIFIC COMMENTS

Line 40: Perhaps add that it is also the distribution of the ice which is relatively poorly studied and of interest to this study.

ACTION: Corrected as suggested:

'However, not much is known about the total ice volume they store - let alone its spatial distribution.'

Line 50: This total value corresponds to the year 2000 (23 years ago). I think this needs to be clear here.

ACTION: Corrected as suggested:

'We redact a total volume for both icefields in 2000 of 5 351km³.'

Line 56 (and introduction in general): Whilst the sea level rise potential is correct, it is worth mentioning the importance of these glaciers for local water supply (hydropower, irrigation, potable water etc)

ACTION: Added new text passage on socio-economical and ecological relevance to the introduction. See above.

Line 66: a similar situation occurs in the New Zealand Southern Alps – maybe some interesting comparisons to be drawn here?

We admit that this analogy is indeed interesting. Yet this study does not claim to have a deliberate atmospheric focus. In our view, such a comparison would

rather distract readers from the central research questions and the regional focus. We therefore refrain from adding a comparison to atmospheric conditions over the New Zealand Southern Alps.

ACTION: No action undertaken.

Line 74: Are you able to reference/quantify the amount of thinning which has been taking place at all?

Obviously thinning rates have been accurately quantified by the referenced studies. We did not mention specific mass loss rates in this section because we wanted to keep this passage rather a qualitative description. The main message is that the PI area stands out globally with high values in terms of glacier mass loss rates. Interested readers can certainly refer to specific values given in the referred literature.

ACTION: No action undertaken.

Line 87: This seems to contradict line 40 in the abstract – perhaps one/both of these needs re-wording

On first view, this passage could be perceived a contradiction. Several attempts have been made to estimate the ice volume of the PIs. Yet none of them has systematically incorporated the wealth of available thickness surveys. So in general, none of them is well-constrained. We therefore stand by our assessment of the abstract that ‘[...] not much is known about the total ice volume they store [...]’, despite the past reconstruction attempts.

ACTION: No action undertaken.

Line 95: it is also worth mentioning that methods based on a ‘perfect plasticity’ assumption do not perform well for lake/marine terminating glaciers

The notion that perfect plasticity approaches do not perform well over the flat sections of MALT glacier tongues is already invoked later in Lines 101-102 (now Lines 106-107). The same is actually true for approaches that use the shallow-ice approximation. As our approach relies on mass-conservation along these fast flowing parts (2nd step), this problem is moderated.

ACTION: No action necessary.

Line 123: The ice thickness is based on the SRTM elevation model which is now 23 years old (as stated). Would it be possible to generate an estimate for a more recent time period?

As explained above, we could unfortunately not identify contemporaneous in-

formation on glacier extent and elevation, which could serve this purpose. The creation of a multi-temporal product would therefore exceed the scope of this study. A little relief is that the 2000 baseline offers a perfect link to available mass changes studies (Braun et al., 2019; Dussaillant et al., 2019; Hugonnet et al., 2021), which also rely on the SRTM reference.

ACTION: No action undertaken.

Line 130: Here you state the SPI volume as 4227 km³ whilst in table 1 it is 4228 (possibly a rounding error?)

Thank you for pointing out this rounding error. As all volume estimates have been updated this slip has been corrected.

ACTION: Corrected.

Discussion/Conclusion: what are the implications of your results? Are you able to say anything about potential future changes? What does it mean for water supply etc

We feel very much attracted by the reviewer's enthusiasm in the implications of our findings with regard to future glacier evolution and water supply. This is certainly one of our next research goals. Yet reliable projections involve a fully fledged framework for glacier system modelling. This comprises selection of suitable climate models on global and regional level, as well as projections of changes in surface mass balance over the coming decades and centuries. In Patagonia, a major challenge will be frontal ablation for assessing future phases of fast retreat over over-deepened bathymetry. From this little research outline, we are sure that it becomes evident that reliable assessments will require another independent and dedicated modelling study. Here, we deliberately limit ourselves to assessing first & tentative implications of the lower values that we find for ice discharge as well as of glacier settings with over-deepened beds. With regard to the next comment, we extended our assessment to future lake formation.

ACTION: We extended the discussion to lake formation. See next answer.

Line 291: You state that: "the new basal topography represents an important quality increase" – one of the major uses of such datasets is for assessing the likelihood of lake formation – I think this should be mentioned here as a key piece of research impact.

ACTION: We added the following text passage on the research impact to the conclusion:

'In summary, our basal topography map is key to reliably project future changes

of the mountain cryosphere in Patagonia (Zekollari et al., 2022). Such projections will present a solid basis to assess changes in regional fresh-water availability (Huss and Hock, 2018), hydrological turnover, biodiversity (Cauvy-Fraunié and Dangles, 2019) and natural hazards (Iribarren Anaconda et al., 2014). Apart from the timing of future glacier retreat, the high quality of this map will allow an improved identification of future lake formation - i.e., potential sites for hydro-power production (Farinotti et al., 2019)'.

APPENDIX

Past glacier evolution of selected glaciers

We present additional details on the past evolution of selected glaciers of the PIs. These details were collected during the revision but would exceed the above rebuttal. The focus is on the evolution between the Little Ice Age (LIA) and present day as well as on the recent decade, both w.r.t. over-deepenings in the basal topography. Consider this section supplementary.

San Quintin: *As the glacier retreated, it freed a large lagoon since the (LIA). The retreat was almost radial. It is difficult to quantify in terms of a distance but fell between 2-5km until 2000 and was at most ~2 km afterwards (until 2016). Current frontal lowering is moderate and values do not exceed 5m/yr neither in 2000-2012 nor in 2012-2016 (Abdel Jaber et al., 2019). Velocity changes are very heterogeneous and might show a small increase (Mouginot and Rignot, 2015). From our bedrock map, which is constrained by measurements near the front, the glacier retreat now leads into an overdeepening. At this moment, we cannot confirm that this retrograde bed did already trigger a self-sustained acceleration/retreat.*

Upsala: *Since the LIA, the glacier retreated by more than 10 km. Between 2000 and 2014, the glacier showed a 3-4 km retreat, which occurred contemporaneous to a gradual velocity increase near the front (Mouginot and Rignot, 2015). Frontal lowering showed extreme values of 10 m/yr near the tongue (2000-2012) but did recently abate (Abdel Jaber et al., 2019). Reasons for the fast retreat in the past and in recent years is the very deep marine bed trough - known from near-front bathymetric measurements (Sugiyama et al., 2016). The recent ice front resides already in a shallower bathymetry - suggesting a prograde setup. For Upsala, we therefore find evidence that the basal topography did exert control on the past retreat evolution.*

Goose: *For Goose Glacier in the north of NPI, the retreat amounts to 2.5 km between the LIA and 2000 with an additional ~ 700 m since. Elevation changes are small and steady from 2000-2016 (Abdel Jaber et al., 2019). Typical values are -2 m/yr on its tongue. The LIA retreat with 2.5 km stands somewhat out w.r.t. to nearby glaciers. An explanation could be that the glacier freed a large pro-glacial lake during this retreat (unknown depth). More recently, there is no sign of a self-accelerating retreat despite the over-deepening that we infer upglacier.*

Exploradores: *Also in the north of NPI and next to Goose, Exploradores showed a smaller retreat bot since the LIA and from 2000 to 2016 (~ 300 m). Frontal surface lowering is smaller than for Goose (Abdel Jaber et al., 2019) but intensified somewhat between 2000-2012 and 2012-2016. Also this glacier shows an extensive bed over-deepening at lower elevation. Yet, there is no sign of self-acceleration.*

***Nef:** In the eastern part of NPI, Nef Glacier showed an expressed 5-km retreat until 2000, followed by at most 300 m since. Frontal elevation changes are again moderate but remain above -5m/yr (Abdel Jaber et al., 2019). Some acceleration of the surface lowering might be perceptible in 2012-2016. Furthermore, we have high confidence in the basal topography there, which is constrained by a dense GPR survey. There remains a bed over-deepening further upglacier but the glacier currently ends on a 'basal sill'. The topography that became ice-free until 2000 is covered by a pro-glacial lake - we have no information on lake depths. There might certainly have been some control of the basal topography on the past retreat. In recent years, the stabilisation is also explainable.*

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12th Oct 23

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Reviewer #2 (Remarks to the Author):

The authors have done a comprehensive job of addressing the three sets of reviewer comments. I have no further suggestions and recommend acceptance.

Reviewer #3 (Remarks to the Author):

I would like to thanks the authors for clearly addressing all points raised during the initial review.

I feel all my concerns have been suitably resolved. In the few instances where changes were not actioned, I feel the rebuttal statements provide good evidence for this.

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