

Dear authors,

Thanks for addressing all the referees' comments, questions and suggestions. Your manuscript really has been revised significantly. I also think that it has improved.

I have read through the revised manuscript in detail and there is still quite a lot of editing to be done. Please see my comments and suggestions below. Besides these I encourage you to carefully read through the manuscript again for additional inconsistencies - I know that many of these are probably due to the amount of editing you have done based on the reviews.

Best,  
Louise Sandberg Sørensen

Dear Luise Sandberg Sørensen,  
Thank you so much for your comments and suggestions. We went through the manuscript and corrected as suggested.  
We hope that we captured all the typos now, we also found some typos in Figures and missing citations/references. The search for additional typos was carried out in the changes accepted version, as I experienced that some of the typos are visible in the change track version.  
Kind regards, Andrea Fischer

-----  
The abstract is written in a passive voice which makes it difficult as a reader so understand what has been done by you and what has been done previously by others. I would suggest that you revise the abstract to be in an active voice.

We rewrote the abstract accordingly.

L 18-19: - 0.6 -> -0.6  
changed

L 21: -0.8 m  $\pm$ 0.1 w.e./year -> -0.8  $\pm$ 0.1 m w.e./year  
changed

L 30: I don't think that mapping glaciers is necessary to *tackle* climate change. Maybe *assessing* is a better word?  
Yes indeed, changed.

L 39: for example debris-covered -> for example mapping of debris-covered  
changed

L 43: enhanced -> improved  
changed

L 48: I don't think that you have defined DEM at this point. Also, which of the DEMs you mentioned here is the one outlined with the black line in figure 1? This is not clear to me. Maybe add that information in the figure caption.

DEM explained, sentence rephrased to:

Now a repeat federal LiDAR DEM is available for several regions in Austria, as the Silvretta range where the DEM Vorarlberg dates from 2017 and the DEM of the Tyrolean Silvretta from 2018 (black polygon in Figure 1).

Information to caption added: The DEM of the Tyrolean part dates from 2018 (black outline), of Vorarlberg from 2017.

L 58: Repeat LiDAR -> repeated LiDAR measurements.  
tackle -> map

changed

L 59: .. since then. Since when? 2003?

Yes, changed to: since 2003

L 61-62: I did not understand this sentence. Would the suggested change make sense?:

The evolution of the other glaciers in the region is similar, so that it was necessary to include the interpretation of volume changes to delineate the debris-covered glacier margins. -> The evolution of the other glaciers in the region is similar, making it useful include the derived volume changes in the analysis to delineate the debris-covered glacier margins.

Yes, this is exactly what we mean -> changed.

L 65: Heavy -> Large

changed

Is topology the right term here? I would use the term topography.

What we refer to is the disintegration of larger glaciers into smaller ones, in terms of polygon outlines a change in topology. As these is mixing up real world and GIS, we follow your suggestion and stay in real world -> using 'topography'.

L 69: lager -> larger

changed

Figure 2: What do the red arrows on the figure indicate?

Exposed ice in the close ups-> caption changed.

Figure 4 caption: Bare ice exposed at Schnapfenkuchl glacier V in the orthophoto of 2015 (red arrows), with stratigraphic layers (yellow arrows) indicating sedimentary ice or firn. ->

Bare ice exposed (red arrows) at Schnapfenkuchl glacier V in an orthophoto from 2015 (red arrows), with stratigraphic layers (yellow arrows) indicating sedimentary ice or firn.

L 86: Is it *classical* or *classic* glacier? And could you briefly define what a classic(al?) glacier is?

Also, in the following sections you use simply 'glacier'. Should this also be classic glacier?

It seems to be the clearest and most appropriate phrasing to just use the term 'glacier' instead of 'classic' or 'classical glacier'. Changed.

L 87: If I understand correctly, I would suggest the following edit:

Schnapfenkuchl H glacier can be clearly identified as glaciers, while in 2009, 2015 and 2020 we would hardly map Schnapfenkuchl V and H as glaciers compiling the first glacier inventory of the region -> the Schnapfenkuchl H glacier can be clearly identified as a glacier, while in 2009, 2015 and 2020 we would hardly map Schnapfenkuchl V and H as glaciers compiling the first glacier inventory of the region, due to the debris cover.

changed

L 94: What does *this process* refer to?

Rephrased so that it should be clearer that we discuss the evolution of the debris cover.

L 96: what do you mean by *former* firn area?

Where prior to 2003 the firn cover was located. We skipped that part of the sentence, as there is no need to discuss which parts of the glacier are NOT covered by debris here.

L 97: w.e. per year?

Yes, changed.

L 96-99: This whole section is unclear to me. How exactly are the small glaciers in previous inventories affected by the high melt rates? Please rephrase and clarify, as this seems to be an important point.

The section is rephrased to: The small glaciers which remained fairly unchanged in the last inventories (Abermann et al., 2009) were affected in a way which is relevant for compiling glacier inventories: the formerly

ice covered and now exposed steep rock faces release rock and debris onto the glacier surface. Melt rates of more than 1 m w.e. per year recorded at the Jamtalferner even in elevations above 3000 m (Fischer et al., 2016c) were recorded after 2003, removing the firn layers and decrease albedo. The ice thickness in higher elevations is often smaller than at the glacier tongue, that an annual melt rate of 1 m could correspond to 5% of the total thickness (e.g. Fischer and Kuhn, 2013), exposing rock outcrops of a rough bed topography..

L 106-107: This is important on a local and global level, as even small glaciers contribute to sea level rise (Bahr and Radic, 2012) and can be significant for local hydrological and hazard management. -> This is important on a local and global level, as small glaciers not only contribute to sea level rise (Bahr and Radic, 2012) but can also be important for local hydrological and hazard management.  
changed

L 110: are a perfect test site for analysing -> are perfect for testing and analysing  
changed

L 113: aims at tackling -> can be used to estimate  
changed

L114: This raises the research questions which of the potentially transient cryogenic structures (e.g. Figure 5, year 2020) should remain part of a glacier inventory, and what the effect of neglecting ice remnants on inventory data would be. ->  
This raises the following research questions: Which of the potentially transient cryogenic structures (e.g. Figure 5, year 2020) should remain part of a glacier inventory, and what is the possible effect of neglecting ice remnants in the inventory.  
changed

L 118: presents -> presents:  
changed

Figure 5 caption: again, is it *classical* glacier?  
Changed to 'glacier'

L 136: Spatial -> The Spatial  
changed

L 137: You should define DEM when you use it first – not here.  
Changed, skipped here.

L 141: What do you want to say bt by stating that coregistration is not considered state of the art? If it is not, why do you do it (if you did – which is not clear)?  
The sentence says that the coregistration of the full waveform DEM is not state of the art, as point clouds and algorithms referring not the all points in the same way are used. The sentence is rephrased.

L 143: what is a pass area?  
Changed to control area: flat areas with the exact elevation known from DGPS surveys.

L 150: changes to the LIA -> changes relative to the LIA  
Did you define LIA?  
Changed & defined

L 156-157: Is this the same information as you provide in lines 146-147? If so, delete this text but move the reference to the right place  
No, here the accuracy of previous DEMs is described, above the uncertainty of 2017/18 DEMs is given.

L 163: What is meant by *intended* point densities?  
We skip the 'intended' here, as it is obvious that the point density also depends on surface topography, and so the effective point density on a rough surface can differ from the one measured at a flat ground.



L 228: uncertainty in area -> uncertainty in the glaciated area?

Changed to glacier covered area

L 230: did you define  $\Delta A$ ?

done

L 234: from volume -> from the volume

Changed

L 241: When you write that the firn layer has melted do you mean that it has completely disappeared or that it has decreased in thickness/extent?

Rephrased to 'melted completely'.

L 242-244: It is not clear to me why a slower ice velocity leads to more cavities. Is this due to more stable hydrological channels in the ice?

Yes.

Equations: please go through the manuscript carefully to ensure that you have the same formatting of variables in the text as they have in the equations. These are inconsistent in several places.

Done

L 261-262: Please specify the periods that you refer to here as yyyy-yyyy.

Changed

area 0.303 -> area of 0.303

changed

L 263: visible, mean -> visible, and mean

changed

L 265: What does it mean that the *ice merely melted*?

Correct, ice does melt or not, we skipped 'merely'.

L 277: Here you use the term specific direct mass balance. How does this differ from the specific mass balance used previously?

It is the specific mass balance, we skipped the emphasis that this is a directly measured in situ balance.

Table 4: Would it be a good idea to briefly explain in the main text the difference between the different mass balances (*geodetic, specific geodetic, annual specific geodetic*) and why it's interesting to show all results?

Also, please go through the manuscript and ensure that you use a consistent terminology wrt mass balances.

You use many different terms – and I am not sure if some of them are actually the same or not; besides those just mentioned you also use *specific mass balance* and *specific direct mass balance*.

*As there are so many papers on comparing direct and geodetic mass balances, we actually do not want to open this floor, as this is an extra topic. To explain what actually lead to the difficulties in mapping glacier, we consider it helpful to briefly mention the directly measured mass loss. The geodetic mass balances are defined in section 3.3.*

L 292: delete *extremely*

done

L 293: how can a stable location be due to loss of ice? Do you mean disappearance of ice / retreat of ice cover?

Rephrased to 'total loss of ablation area'.

L 296: significant is a word with statistical meaning. Unless you have actually checked this, I suggest you change it to *high*

*We skipped 'significant', as we quantify the impact later on.*

L 298: what balance do you refer to here?

We added 'geodetic'.

L 300: mass balance -> mass balance estimates

changed

L 299: maybe it's due to my limited knowledge on permafrost, but why would you consider to include this in a glacier inventory?

I suppose this refers to L 309; We could want to include all the ice remnants of a glacier in an inventory, to avoid very complicated definitions what to include and what to exclude.

Figure 9 caption: volume change -> elevation change

done

2006-2018 -> 2006-2018

done

L 346: Please provide references for those inventories you mention here

(Paul et al., 2020) added

L 354: The purpose of the sentence "This the area affected by volume change can be constrained" is unclear. What do you want to say here?

We skipped the sentence, it is clear from the Figure that we can delineate the area where ice was located at the beginning of the period.

Actual presence -> actual current presence

changed

L 368: provide units on the 0.098

km<sup>2</sup> added

Page 21: I would suggest to move these citations to the supplementary material. It takes up a lot of space in the manuscript, and doesn't seem very important. Is the main point that the definitions have changes – but maybe not so much exactly how?

Done

L 405: Cogley et al. (2011) does not appear in the reference list. Please check that all references are there.

Done

L 411: please define with years the period you mention

Done

L 433: I would suggest to delete 'real world'

Done

L 450: but but -> but

changed

L 460: based <1m -> based on <1m

changed

Figure 12: I do not think that this figure is in the right place. It belongs in the methods section as it was also pointed out by one of the referees.

changed