Response to Reviewer 1

The study of Ramzan and Ghuffar presents a set of geodetic mass balance estimates for glaciers in a sub-region of the Hindu-Kush in High Mountain Asia, over the period 1979-2002. They use declassified American spy satellite imagery (acquired by the Hexagon KH-9 panoramic camera) and more contemporary SPOT-5 images to generate a pair of DEMs, from which they derive surface elevation change estimates and subsequent mass balance data. The methods they have followed to undertake these analyses are robust and follow best practice established by previous studies. Consequently, I trust that their results are robust and have captured the mass change rate of the studied glaciers accurately. Their findings are highly relevant to the journal and the field and extend our view of the multi-decadal evolution of glacier mass balance in a part of High Mountain Asia where data coverage is currently sparse.

We thank the reviewer for the thorough and thoughtful review. We appreciate the positive assessment of the methodological robustness and the relevance of the study for understanding glacier change in a data-sparse region of High Mountain Asia. We have carefully considered all comments and have clarified several aspects of the manuscript, particularly regarding the glacier sample used for the mass balance analysis.

I believe the analyses and presentation of the results could be improved. At the moment, the paper presents mass balance estimates for a subset of the local glacier population, which is considerably larger than indicated by the figures in the paper. The paper doesn't describe how or why the subset was chosen or what portion of the local glacier population it represents. The size of individual glaciers covered by the sample of mass balance data is only briefly mentioned at the end of the discussion (2-89 km2). The characteristics of the glacier sample are important because the reader needs to know whether they can make a fair comparison between the results of this study and other studies which likely have generated results for glaciers of a diverse size. I would therefore encourage the authors to update their manuscript to include this information, along with a justification of why they have selected the glaciers they present results for.

We thank the reviewer for highlighting this important point. We agree that the criteria used to select glaciers for the analysis were not sufficiently described in the original manuscript. We will improve it in the revised manuscript.

In the study, the main criteria for exclusion was the minimum glacier area i.e. a threshold of 2 km^2 was applied to RGI because the smaller glaciers have a higher uncertainty in their estimated mass balance. Additionally, glaciers outside the spatial overlap of the KH-9 panoramic imagery and SPOT-5 stereo imagery were excluded because elevation change could not be calculated reliably and glaciers with less than 25 % valid elevation-change pixels after filtering were excluded to avoid unreliable mass balance estimates.

The glaciers included in the analysis therefore range in size from approximately 2 km² to 90 km². If no glacier is excluded then the total glacier area is around 1200 km².

Following the reviewer's suggestion, we will provide additional information describing the glacier sample, including: the number of glaciers analyzed, the total glacierized area represented, and the range and distribution of glacier sizes.

We will also include a figure illustrating the glacier area distribution to allow readers to assess how representative the analyzed sample is relative to the regional glacier population.

Aside from this main point, there are several other areas of the manuscript where I think more clarity is needed. These are mainly related to the more concise description of the results, and I have made some suggestions about how this could be achieved below.

Below are our detailed responses to each comment, with corresponding manuscript modifications indicated.

Abstract: I'm missing a clear statement within the abstract which describes how these findings advance our knowledge of glacier behaviour in the region. If these are the first observations prior to the more contemporary period, I think it's worth stating so.

We agree with the reviewer that the novelty of the study should be emphasized more clearly. To the best of our knowledge, no geodetic mass balance estimates exist for these glaciers prior to 2000. The study therefore extends the observational record of glacier change in the Hindu Kush by roughly two decades.

We will add the following lines: "These observations represent the first geodetic mass balance estimates for the Eastern Hindu Kush prior to 2000, extending the temporal record of glacier change by two decades and revealing that moderate mass loss (-0.13 ± 0.12 m w.e. a^{-1}) has been sustained since the late 1970s, consistent with post-2000 observations."

Introduction:

L13: I'd suggest adding a brief description of where these studies based on historical images apply to. The previous sentence cites global studies, but I believe those cited on L13 apply to HMA.

This will be updated as suggested. The studies of Bhattacharya et al., 2021 and Zhao et al. (2020) were focused on areas within the High Mountain Asia.

L16: Again, if this discussion is focussed on HMA, this should be emphasised.

Changed the line so it starts with : However in the High Mountain Asia

L25: Would suggest rewording 'the melting period' to 'ablation primarily occurs'.

We will change this as suggested

L26: (Scher et al., 2021) in brackets.

We will correct this.

L33: I think ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) needs defining on first use. Same for Digital Elevation Model (DEM).

We will correct this.

Fig. 1: I think all RGI7 outlines should be shown on this Figure. I think I would probably also suggest the use of true colour optical imagery as the background for the figure, which would provide more information about the different glacier types present in the study region.

We will revise the figure according to these suggestions. We will include all the RGI7 outlines in this area.

L36: I think it would be useful to state the ranges of elevation change values Wang et al. (2017) measured if they are markedly more variable over shorter timeframes than the other studies cited in this section.

The text will be revised to include the reported mean elevation change trend of −0.48 m a^{-1} for Hindu Kush glaciers derived from ICESat observations during 2003–2008 in Qiang Wang et al. (2017). This value will be added to provide quantitative context for the magnitude of glacier thickness change during this period. For a more detailed discussion of the interannual variability reported in that study, the reader is referred to the original publication.

Data and methods:

L50: Suggest stating clearly at the beginning of this section that the KH-9 panoramic camera imagery is of significantly higher resolution than either the alternative declassified images (KH9 mapping camera) used in previous studies mentioned above – this is an improvement on previous work. The post-processing approach applied to the derived elevation change data is consistent with previous studies and applies robust techniques to remove potential biases and anomalies stemming from area of lower image quality.

Thank you for these comments. We will update the text to incorporate these suggestions.

L50: A clear omission from this method section is information about the subset of glaciers that the elevation change data (and therefore mass balance) covers following post-processing. RGI7 contains many more glaciers over the study region than the authors present mass balance data for (~1500 in RGI7 over the extent of Fig.2? see below) so I feel the authors should present information on the portion and number of the local glacier population their data covers. It would also be useful for the authors to provide information and/or an illustration of the range of glacier areas that their mass balance estimates cover. If the sample of mass balance data is biased towards larger/smaller glaciers, the calculated regional mass balance signal may not reflect the mass loss rate of all glaciers. This should be made clear to the reader.

Here, the exclusion of glaciers in the region is based on three criteria: 1) We first applied a threshold of minimum glacier area of 2 km^2 to avoid large uncertainties 2) The glaciers which were not covered within the footprints of SPOT-5 and KH-9 images were also not included. 3) We also removed the glaciers which had data less than 25 % of the glacier area after the filtering process. The current glacier sample range from 2 km^2 to 90 km^2.

I'd also suggest showing the full coverage of RGI7 on Figures 1 and 2, which currently suggest that glacier over in the region is fairly sparse compared to my Fig.1 above. The RGI7 outlines could be shown as thinner outlines and the glaciers for which the authors have mb data could have thicker outlines?

We will change this

Fig.2: I'd really like to see elevation change data over the full extent of the figure, rather than over glacier surfaces from which the authors have derived mass balance estimates. The absence of elevation change data over stable areas (off-glacier) would illustrate the success of the methods applied, which is common practice in most geodetic studies. This is shown in the supplement (over a very large range of values) but would be useful here.

We will add zoomed areas of elevation change over stable surface along with the full extent in the supplement. We will also publish the complete elevation change dataset.

I'd also suggest tweaking the colour ramp slightly to have a broader range of values illustrating no/little change as white (+/- 0.5 m/yr perhaps?). This would help separate and illustrate the opposing signals of thinning/thickening associated with surging slightly better.

We will apply this

In the 4x4 grid at the bottom (b and c), I think panels III and IV could be combined to show the outlines from different time periods over the dHdT data. The two IV panels should use the same colour bar and range of values as the main panel A in my opinion, also showing off-glacier data.

We will change this.

Results:

L97: Would suggest just shortening this first sentence to 'During the period 1979-2002, the mean mass balance of glaciers we studied was -0.13….'

We will apply this change

L99: More detail required here. Which post-2000 dataset did the authors use and what was the mean mass balance (with uncertainty)?

We computed mass balance using the elevation change datasets of Brun et al. (2018), Shean et al. (2020) and Huggonet et al. (2021) for comparison with post-2000 results. Here, we will also refer to Figure S4, so the reader has more clarity.

L101: Are the highest thinning and retreat rates associated with surging glaciers? If so, I'd signpost this at the start of this paragraph to clarify the point and then present your observations.

We do not intend to imply here that high melting at the terminus of glaciers in the study area is related to surging glaciers. In this paragraph, we highlight that Noroghikun is a surging glacier (a possible surging glacier according to Guo et al., 2023), as it is an important characteristic of the glacier. We observed high retreat and thinning on both surging and non-surging glaciers, which we attribute to the debris-free ice.

L111: I'd suggest removing this last sentence citing Sarikaya et al. (2012), I'm not sure it adds a great deal.

We will remove this

L112: Do they really influence the mean mass balance significantly as it is only two out of the full glacier sample (the total size of which remains unknown without discussion in the methods section). I can see how their mass balance would influence the total mass loss budget, but would only impact the mean mass balance if the sample size was very small.

We will change this statement and make changes relevant to this in the revised manuscript. The two glaciers have a comparatively larger size compared to the sample, with respective sizes of 82 km² and 90 km² which occupy around 19 % the total glacier area in the study region.

L111: The paragraph from L111-L127 contains a lot of information but it's hard to place these in the context of the wider. The paragraph begins by mentioning two of the larger glaciers in the sample – are the rest of the glaciers in this paragraph also of a larger size? A sentence signposting the characteristics of the glaciers discussed in this paragraph in particular would help better understand these results (as the next paragraph does about surging glaciers).

The paragraph generally explains the behavior of glaciers in the study area. The two glaciers mentioned at the start have relatively larger sizes than the rest, but this is not an indication that the mass balance results are presented here with reference to the glacier area. We will add here an additional line at the start and will arrange the first 3 lines of this paragraph as follows:

"The individual glaciers of the Hindu Kush region show a variable and complex melting pattern. Atrak and Tirich (also known as Upper Tirich glacier), which have the largest size in the study area, are losing mass at -0.21±0.22 m w.e a^{-1} and -0.21±0.05 m w.e a^{-1} during the study period, respectively."

L144: I think it's unlikely that the lower parts of Noroghikun Glacier would experience heightened ice loss in response to surge activity, when ice mass gain normally occurs over the lower parts of the glacier. I'd agree that the glacier would experience higher ice losses at low elevation after a surge, simply due to a large volume of ice sitting in higher temperatures

We understand that surge activity initially reveals thickening, which is eventually followed by thinning at the glacier terminus. Here, we expect this because we generally observe that retreat has occurred below the elevation of 3900 m in the study area.

L149: I think this sentence needs some clarification. I don't really follow 'Most of the retreating glaciers in the region are debris-free and range from slight to above 1 km2 of the retreated area.'.

Here, we highlight that the retreating debris-free glaciers are higher in number compared to retreating debris-covered glaciers. We further explain that the retreated area of each debris-free glacier ranges from slight to above 1 km². We will also update the revised manuscript with more clarity

Fig. 3: This is a nice figure. I think it could be presented as one row with three sub-panels. This would suite the journal format better and avoid so much white space. Alternatively, you could add a fourth panel showing the mass balance contrast between debris covered and debris-free glaciers?

As per your suggestion, we will include here a fourth panel so that the x-axis of panels a and b remains aligned.

Discussion

L165-169: I think this paragraph could be reworded to state the overarching results with more clarity. As I see it, the main points are that the results capture glacier mass loss rates over a period where observations are scarce. The results suggest that glacier mass loss rates have remained steady over at least the last 50 years in this part of the Hindu Kush, with this studies results being very similar to those of the Brun/Shean/Hugonnet studies.

We will modify lines165-169 to as follows:
In this study, we present our results on mass balance for the glaciers of Hindu Kush which contribute to extending the existing knowledge regarding the state of these glaciers to nearly two decades in the pre-2000 period. We employ state of the art sensors available during the study period and report the mass balance of glaciers which, to our knowledge, has not been documented before. Our estimated mass loss is slightly negative which is in agreement with Brun et al. (2017), Shean et al. (2020), and Huggonet et al. (2021) within their respective uncertainties. Our results combined with literature, suggest that glaciers in Hindu Kush have maintained a nearly stable rate of mass loss for at least four decades which is in contrast with the accelerated mass loss generally observed in parts of High Mountain Asia such as the Nyainqentanglha and the Tien Shan (Bhattacharya et al., 2019). We further re-assessed the retreating glaciers in the region and estimate a higher retreat compared to previously documented (Sarikaya et al., 2012).

As the discussion is currently rather short, the authors could tie these main points to supporting information that might show a record of climatic variability over a similar period, which could indicate why mass balance has remained relatively stable?

We agree that providing additional climatic context would strengthen the discussion and help interpret the glacier mass balance observed during the study period. In the revised manuscript, we will include a short discussion of regional climate variability using meteorological observations from a nearby weather station and historical climate datasets like ERA-5. An analysis of the weather station data indicates a warming trend of approximately 0.33 °C per decade, while precipitation shows substantial interannual variability but no significant long-term trend. Despite the observed temperature increase, glaciers in the region exhibit only moderate mass loss.

We will also discuss possible mechanisms that may moderate glacier mass loss, including the influence of winter precipitation associated with westerly disturbances, which provides the main source of accumulation in the Hindu Kush, as well as the presence of debris cover on many glaciers, which can reduce melt rates at lower elevations.

L171: It's not clear what 'overall moderate conditions' are to me.

We will rephrase to this: 'overall moderate mass balance conditions'

L171: This is the only information I can see on the size of glaciers examined in the study. Was 2 km2 a minimum area threshold set at the beginning of the work or is it an arbitrary number which happens to be the size of the smallest glacier with suitable data coverage?

We applied a threshold of minimum glacier size of 2 km² to avoid uncertainties due to the pixel size. We will mention this in the Data and Methods section. The smallest glacier in the Eastern Hindu Kush has an area of 0.02 km²

L177: Discrepancies in glacier outlines from different sources were mentioned at the beginning of the discussion and they are again highlighted here, but I don't think I've seen a clear comparison between area change rates calculated as part of this study against those from the literature. I think the paper could be strengthened by calculating area changes rates for this earlier study period and comparing them specifically against any more contemporary results that area available. This would support the statements that are made about improving the record of glacier area change here which are currently not substantiated.

We agree that a quantitative comparison of glacier area change rates would strengthen the discussion and help place our results in the context of previous studies and we will incorporate it in the revised manuscript. As noted in the manuscript, the glacier outlines in our study were adjusted to account for glacier retreat between the two observation periods. The resulting outlines are broadly consistent with those used by Sarikaya et al. (2012), although preliminary inspection suggests that the retreat rates derived in our study may be somewhat higher. One possible reason for this difference is the methodological approach: Sarikaya et al. (2012) primarily identified glacier terminus positions using Landsat and ASTER optical imagery, whereas the present study additionally uses elevation change information and high resolution orthorectified imagery derived from KH-9 and SPOT-5 stereo data, which may allow glacier margins to be delineated more consistently in debris-covered or shadowed areas. Including this area change estimates will allow us to more directly compare our results with previous studies and better substantiate the statement that this work improves the observational record of glacier change in the Eastern Hindu Kush.