Earth Syst. Sci. Data Discuss., author comment AC4
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Reply on CC2

Shakil Ahmad Romshoo et al.

Author comment on "Evaluation of the global and regional glacier inventories and assessment of glacier elevation changes over the north-western Himalaya" by Shakil Ahmad Romshoo et al., Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2021-28-AC4, 2021

CC#2

General Comment: The authors derive a new glacier inventory for selected Himalayan river basins using manual delineation and various data sources. The authors also highlight the strength of their inventory through the field data. The derived inventory is compared with RGI, ICIMOD, and GAMDAM inventories and highlighted the limitations in the mentioned inventories. In addition to the comparison of inventories, the authors estimated the surface elevation changes of glaciers in the basin between 2000 and 2012. It is important and interesting to see the comparison of various inventories (e.g., Muhammad et al., 2019a) to support the glaciological community to use the most appropriate inventory for their research. I only review part of the manuscript and suggest few comments to incorporate in the revision to strengthen their manuscript.

Response: We express our gratitude to the reviewer for suggestions and comments on the manuscript. The comparison of the present study with Muhammad et al., (2019) has been incorporated in the revised manuscript. However, the point by point response to the detailed comments and suggestions raised by the reviewer are provided as follows:

Comment#1: Interesting to see that ICIMOD inventory is not only underestimating (as in the Karakoram (Muhammad et al., 2019a) but also overestimating. The main reason for underestimation in the Karakoram by ICIMOD inventory is the slope criteria. Most of the glaciers are avalanche-fed in the Karakoram and the accumulation falls on the steep slopes which is mostly not considered. However, I found that the inventory here shows that there is overestimation as well in the ICIMOD inventory. The authors are suggested to discuss the overestimation in ICIMOD inventory and its potential reasons and also discuss the results in comparison with Muhammad et al., 2019a.

Response: The overestimation observed in case of the ICIMOD inventory is largely attributed to the misinterpretation of snowpacks as glaciers as demonstrated in the Fig. 5. Furthermore, the description of the results with respect to Muhammad et al. (2019) is provided in the revised manuscript. Both these points have been discussed in details in the revised manuscript.

Comment#2: The authors manually digitize the glaciers which is extremely inconvenient in the presence of state of the art automatic techniques considering the >2000 glaciers.

Mapping only a single (medium to large) glacier with manual digitization takes several hours. Usually, automatically derived extents are improved using manual digitization but the approach is different here. The authors may explain why they selected manual digitization.

Response: Agreed that the automatic glacier boundary delineation followed by manual correction is one of the preferred approach for glacier mapping from satellite images especially over large regions because of the less time required when compared to the manual digitization techniques. However, automatic glacier delineation technique poses a significant challenge for mapping debris covered glaciers particularly the glacier terminus in the Himalaya. In fact, the reflectance of the supra-glacial debris cover is similar to the surroundings which results in the exclusion of such areas from the glacier extents. Furthermore, seasonal snow, cloud cover and shadow also pose a significant challenge in mapping Himalayan glaciers using automatic image delineation techniques. Therefore, to overcome these challenges in mapping glaciers in the Himalaya, we used multiple data sets including thermal data, high resolution imagery, time series of satellite data etc. which is not possible to use in the automatic approach. Furthermore, the local knowledge/field experience of an analyst also proves very useful in precise glacier delineation which is again not possible in the automatic approach. Since a considerable number of glaciers in the present study have debris-covered termini and we found it appropriate and necessary to map the glaciers manually to minimize the errors and uncertainties in the glacier inventory. Furthermore, advantage of the manual approach over the automatic approach for mapping glaciers when debris covered, shadowed and seasonal snow-covered area has been previously demonstrated by Paul et al. (2013); Nuimura et al. (2015).

KUGI improved the mis-mapped glacier outlines/boundaries from the automatic approach and any mismatches of the glacier geometry due to the seasonal/temporal snow cover and shadows were manually corrected using additional Landsat images and Google earth images. Further the mapped glaciers with better geo-referencing were overlaid with high resolution images in Google Earth environment for validation wherever available. Though, the mis-mapped/mis-located outlines, observed on the global/regional inventories, may have only limited effect on measurements of glacier area, but can introduce serious errors into applications that rely on absolute positioning (e.g. co-registration to other datasets such as DEMs). The only realistic way to correct them is to provide more accurate outlines using manual approach as was done in the KUGI which would serve as source of improved outlines for the scientific community interested in conducting various application studies using the glacier outlines.

Comment#3: Also, it is unclear why the authors use topographic parameters if they use manual digitization? These parameters are useful when the glaciers are automatically mapped.

Response: As specified in the methodology section (section 4.1), under the surface conditions on headwalls with slopes (topographic parameter) exceeding 40°, we specifically verified such glaciers from the Google Earth image for accurate delineation of glacier extents. Further, the satellite images draped on DEM (hillshade) was found useful in demarcating glacier outlines when the ridges particularly in the accumulation zone were covered with seasonal snow (Paul et al. 2004; Paul et al. 2009). The overall visualization of a glacier in 3D helped in the precise mapping of glacier outlines in KUGI.

Comment#4: The authors indicate field surveys data for glacier inventory validation but did not show the results of the survey anywhere (in any figure or text). The authors are suggested to add detailed information of the field survey including 1) the number of glaciers surveyed in the field, 2) what kind of information/data collected in the field, 3) how the survey information/data improved/validated the remote sensing results?

Response: In the present study, we have done field surveys on 20 glaciers located across the study area, which we visit almost annually for other glaciological studies. The locations and the field photographs of these glaciers has been provided as Supplementary figure in the revised manuscript. We have collected the snout positional data of the debris-covered tongues of these glaciers to validate the glacier delineation. The field measurements of these glaciers acted as an interpretation tool for delineation of the debris-covered glaciers in the study area. The terminus of the heavily debris covered glaciers like the Hoksar glacier in Jhelum basin was not easily mappable even using the thermal and google earth imagery. We therefore, mapped the glacier terminus in the field and further observed that the debris on the glacier is relatively smooth and aligned in the direction of glacier flow when compared to the debris-cover in the surroundings which was found a useful field-based information for mapping debris-covered termini of other glaciers when viewed on Google earth images. Further, eight of these twenty glaciers have been designated as benchmark glaciers and are continuously studied for mass balance, GPR, debris thickness, Surface mapping temperature profiling and other glaciological studies since the last 5-8 years. In addition, the glacier outlines of several other glaciers in the vicinity of these 8 glaciers in the three basins have been verified during annual glacier field expeditions during the last 5-8 years.

Additionally, all the heavily debris covered glaciers and a majority of the clean glaciers, numbering more than 850, were qualitatively verified on the Google Earth image for the rectification of any delineation error. A similar approach of quality check using Google Earth has been previously adopted by Nagai et al. (2016) and several others and is an accepted method for validation of such a large number of glaciers located in inaccessible complex terrain.

Field photographs of the about 20 selected glaciers in the three basins, which have been visited over the last few years for field measurements/validation along with their GLIMS ID are presented in the revised manuscript (The field photographs of some of these glaciers are provided below). A locational map of these glaciers in the form of a KML file would be provided as a supplemental material in the revised manuscript ((The field photographs have also been attached as a supplement file in pdf format)).

Comment#5: References

Farhan, SB, Zhang, Y, Ma, Y, Guo, Y and Ma, N (2015) Hydrological regimes under the conjunction of westerly and monsoon climates: a case investigation in the Astore Basin, Northwestern Himalaya. Clim. Dynam., 44(11–12), 3015–3032

Muhammad, Sher, Lide Tian, and Asif Khan. "Early twenty-first century glacier mass losses in the Indus Basin constrained by density assumptions." Journal of Hydrology 574 (2019a): 467-475.

Muhammad, S., Tian, L., & Nüsser, M. (2019b). No significant mass loss in the glaciers of Astore Basin (North-Western Himalaya), between 1999 and 2016. Journal of Glaciology, 65(250), 270-278. doi:10.1017/jog.2019.5

Response: The suggested literatures references have been incorporated in the revised manuscript.

Please also note the supplement to this comment:
https://essd.copernicus.org/preprints/essd-2021-28/essd-2021-28-AC4-supplement.pdf