

Review for “Halving of Swiss glacier volume since 1931 observed from terrestrial image photogrammetry”

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General Comments:

Study uses tens of thousands of terrestrial photographs collected from ~85% of the glaciers located in Switzerland to generate historical surface elevations and determine ~85-year mass balance change. The amount of work performed in this study is extraordinary and the results are very exciting. The methodology used by the authors for elevation derivation, calculating mass balance, and estimating error is sound. The majority of my comments in the manuscript are to do with seeking a bit more clarification in the text.

“Historical” and “Historic” are used throughout. “Historic” is subjective on the authors’ part, so the more appropriate adjective is “historical”.

The word “taken” in referring to image acquisition is colloquial. It is better to use “acquire” or “collect” instead.

In Section 2.3, because glacier outlines are being derived from historical topographic maps and datums/ellipsoids evolved constantly throughout the timeline of this study, it is necessary to mention whether digitized versions of the Siegfried maps and the LK50 maps are currently available in their original horizontal projections, or if transformations were performed so they align with the more current datasets like the swissALTI3D DEM. Admittedly, I am not that familiar with the historical Swiss topographic series, but I am assuming that a different datum was used in its assembly than what is in practice today. This is certainly the case with the American 7.5 minute series topo maps, where XYZ values derived using NAVD29 have a horizontal shift of ~400-500 m for regions of greater topographic terrain variability. For the sake of transparency of potential error sources, it is necessary to at least mention whether all datasets were transformed to the same map projection.

With several recent studies using datasets comprised of multi-temporal acquisitions (Rignot et. al., (2021); Haubner et. al., 2018; De Rydt et. al., 2021; etc.) as discrete timestamps, I very much appreciate the authors’ efforts to standardize the historical elevations’ timeline. I wish more studies were as arduous and feel this paper is an example of “best practices” that I hope future multi-temporal glaciological research would benefit by following. The one addition that I request be included with the temporal error assessment is to show the absolute differences with a sample of dh results from specific timestamps to the standardized timeline.

The state of the manuscript is that of a methodology paper. If that is the intent of the authors, then ignore this next part. However, the impact of this paper could be significantly improved if in the discussion section you were to include the broader impacts of your mass balance results with topics like future predictions of Swiss glacier volumes, future melt-water flux to stream discharge rates, anthropomorphic impacts from 1916-2016, etc. You’ve achieved an amazing

temporal scale for mass balance changes over such a large spatial extent that it would be beneficial to the glaciological community if you could include its relevance in a broader scope.

Specific Line Comments:

Line 8: I think you mean “conducive” rather than “conductive”

Line 20: “understand” is odd in this context. “resolve” would be a more appropriate word.

Line 33: Does Switzerland refer to the country or its glaciers?

Line 40: does “photographed position” refer to the camera’s position or the image’s full extent?

Line 44: using the term “re-process” is confusing. I am assuming that you are referring to the processing that was done with these images to generate the original topo maps in which case it would be better to say “digitally process” instead of “re-process”.

Line 53: Replace “houses” with “contains”

Line 56: Delete “of”

Line 69: Replace “will be” with “is”

Line 76: Replace “5” with “five” for continuity

Line 77: It is unclear exactly what “frame appearances” means. Maybe “frame geometry” would be better?

Line 126: Can you go into more details about the similarity transformation and how it is performed?

Line 129: Is “marks” referring to fiducial marks?

Line 132: “Manual data” is awkward; is the model that is being referenced the same as the previous sentence?

Line 137: “manually mark” is unclear. Do you mean “identify”?

Line 144: Is the metadata digital or analog? Where do the image positions come from?

Line 150-151: Verb tense is in the past. Also, the difference value being reported, is that a vertical difference? Can you also provide the horizontal difference?

Line 152: Did you perform the map digitization? If not, then the heading should reflect generating glacier outlines instead.

Lines 153-163: Please include somewhere in this section what the average glacier area is to provide scaled-context for researchers primarily doing work in Greenland and Antarctica.

Line 153: “digitizing the scanned and georeferenced LK50 map series.” It is unclear here whether the maps are being digitized or the glacier outlines.

Lines 154-155: The verbs in this sentence are written in the past tense. Also, use “sporadic” or “inconsistent” rather than “spotty”

Lines 161-161: The verb in this sentence are written in the past tense.

Lines 165-166: Suggested rewrite for “version 1.6.5 by dividing the images in subsets, and processing each subset individually (Table 1).” with “version 1.6.5 in separate subsets (Table 1).”

Line 166: Replace “one” with “each”, “taken” with “acquired”, “certain” with “specific”, and “at a certain” with “over a single”.

Line 167: Should “groups” be “subsets”? If not, then you need to define what a “group” is.

Lines 167-168: Replace “subset, as the used cameras might vary in their distortions parameters, depending on their construction and in which year they were used;” with “subset because of varying distortion parameters for each camera;”

169-170: Do you have evidence to support this statement? It really should have a citation or maybe documentation from historical metadata.

Line 171: Are stereo-panoramas one per subset? Are these the camera models generated in the previous paragraph? If so, then say something like “the computed camera-models” so there is no question that potentially new camera-models have been introduced.

Line 172: It is unclear what “others” is specifically referring to. Is it other “panoramas” and/or is it other image subsets? This also applies to “them” on Line 174.

Line 177: In referring to the co-registration, you need to define what is being co-registered in regards to stable terrain or over entire generated data coverage.

Lines 180-187: In determining the conversion of DEM grids from 3D point clouds, how did you decide on the cell size? What did you determine for a cell size? Was the entirety of each point cloud utilized in DEM conversion? Studies using oblique aerial imagery have found that there is a distance from point of image acquisition that the generated elevations are no longer reliable (Girod et. al., 2018); was this phenomenon a factor with the terrestrial imagery? If so, was this consistent across all historical acquisitions?

Line 180: Is the stereo-panorama alignment being applied to all panoramas generated from the ~21,000 images or to just panoramas from a single subset?

Lines 182-183: It is untrue that details for the confidence parameters are not available. White papers written by Agisoft Metashape are readily available online that describe how the confidence parameter is determined based on the contributing depth maps. Simply reporting a value of “2” without any supporting evidence to validate its use systematically appropriate is imprecise—please amend this.

Lines 183-184: It is unclear what relevance draping the orthoimages over the DEMs has for the processing and I recommend deleting “and after orthoimages are draped on the DEMs,” from the sentence.

Line 186: Alter “position and rotation” with “positional and rotational errors”

Line 187: Include “historical” before “DEMs”.

Line 189: I suggest calling the “correction” an “adjustment” or “standardizing” because time itself is not in error.

Lines 190-192: The parameters described in the first two sentences have already been explained previously in the manuscript. You are not technically correcting the temporal scale, but instead standardizing it to specific years. It would be better in this paragraph to explain why the temporal scale requires standardizing, the specific timeline of standardization for each dataset, and the potential errors that may arise when rates are not based on the absolute temporal scale.

Line 193: Alter “correct” with “adjust”

Line 195: Delete “anomalies in” because you are using the full extent of mass balance calculations and not just anomalies.

Line 198: It is unclear if “respective region” refers to each of the four glaciers separately or all of them lumped together.

Line 199: It is unclear with the “factor” is.

Line 200: Alter “corrected” with “standardized”

Line 205: Alter “corrected” with “standardized”

Line 207: State whether the percentage of missing data is the result of image coverage extent or processing, or both.

Line 208: Delete “the whole”

Line 209: Can you quantify “significant trend”? What is the trend in reference to? Verb use is in past tense.

Line 212: Referencing “xdem” needs a citation or a reference that it is a python module.

Line 214: What is the “threshold” in reference to? This needs more details and if the threshold is based on other research, a citation as well.

Line 215: Delete “the”

Line 216: Are full data gaps replaced with the single value or is there a maximum distance where new values are not assigned when using this interpolation technique? Please include either scenario in the text.

Line 218: Recommend altering “each entry of the SGI2016 individually.” with “each SGI2016 outline.”

Line 221: Alter “historic” with “historical”

Line 236: What are the “elevation measurements”? Are these the generated historical elevations? If so, then say “stochastic processed elevation errors” instead because “elevation measurements” sounds like altitudes collected *in situ*. Otherwise, state where these measurement come from.

Line 237: Alter “corrected” with “standardized”

Line 239: Alter “presented through” with “within”

Line 240: Suggested rewrite of “from the scale of pixels to that of glacier, and that of glaciers to regional scales,” with, “from scales of pixel to glacier and glacier to region,”

Line 250: For the stable terrain, do you include all surface slopes as well?

Lines 257 and 258: Phrases “might be affected” and “might cancel out” are too uncertain and do not support your argument. Either provide a reference to past research who has identified similar results, or a statistical assessment to be able to assert that the quantity of DEMs in this study is indeed the reason DEM differencing is unaffected by terrain parameters like slope. Also, “these” on Line 258 referring to the attribute-dependent errors?

Lines 270-272: What about the maps’ error? There absolutely was error in the *in situ* triangulation estimates and original photogrammetric work—are there no estimates of the actual maps’ accuracy?

Line 272: Are there no references as to the years of data collection by map? Do the maps not contain this information? Were any reports written with the topo maps? US and UK topo maps contain temporal information and often had supplemental reports written to validate methods used when compiling the maps.

Line 273: It is unclear what “degree” is specifically referring to.

298: “Polluted” is an odd word choice. I recommend using something like “biased” instead.

Line 301: It’s annoyingly pedantic, but “small scale” is actually referencing a very large extent. For continuity with the rest of the text, it would be better to reference either “pixel-scale” or “glacier-scale”.

Lines 302-303: “largely independent among glaciers of a given region.” Does this mean the errors are independent by glacier, or by region?

Line 305: Recommend altering “correction” to either “adjustment” or “standardized”

Line 307: Is this uncertainty based on mass balance derived from remote sensing methods? If so, that should be stated.

Line 321: The minus symbol is unnecessary because you say there is a “loss”.

Line 323: For continuity in the text, please also provide the 1931 glacier volume.

Line 341: Are these “glaciers” also Swiss? Please provide a regional reference to the glaciers.

Line 351-353: This sentence is difficult to understand, particularly the portion on Line 353.

Line 354: What specifically are the “components” referring to?

Line 356: Suggest altering “when considering the entire period of interest.” with “for the study’s timeline.”

Line 356: Suggest altering “The comparison to results of the present study” with “Comparing those results to this study’s”.

Line 358: Replace “smaller” and “study” with “less” and “estimates” respectively.

Line 359: What year is the map data from? Is it the same as the imagery? Was the map data and the derived historical DEM data referenced in the same vertical datum? If they weren’t, then what transformation was used with the map data?

Line 405: Alter “improving” to “improve”; is “description” the word you meant here? If so, it is unclear what you are specifically referring to.

Line 432: Include commas after “approach” and “ago”; verb tense in this sentence is past.

Line 446: “high potential” is awkward.

References:

De Rydt, Jan, Ronja Reese, Fernando S. Paolo, and G. Hilmar Gudmundsson. "Drivers of Pine Island Glacier speed-up between 1996 and 2016." *The Cryosphere* 15, no. 1 (2021): 113-132.

Girod, Luc, Niels Ivar Nielsen, Frédérique Couderette, Christopher Nuth, and Andreas Kääh. "Precise DEM extraction from Svalbard using 1936 high oblique imagery." *Geoscientific Instrumentation, Methods and Data Systems* 7, no. 4 (2018): 277-288.

Haubner, Konstanze, Jason Box, Nicole Schlegel, Eric Y. Larour, Mathieu Morlighem, Anne Solgaard, Kristian K. Kjeldsen et al. "Simulating ice thickness and velocity evolution of Upernavik Isstrøm 1849-2017 with ISSM." In *AGU Fall Meeting Abstracts*, vol. 2017, pp. C11B-0911. 2017.

Rignot, Eric, Lu An, Nolwenn Chauche, Mathieu Morlighem, Seongsu Jeong, Michael Wood, Jeremie Mouginot et al. "Retreat of Humboldt Gletscher, north Greenland, driven by undercutting from a warmer ocean." *Geophysical research letters* 48, no. 6 (2021): e2020GL091342.