Dear Dr Reinhard Drews

Please find below our answers to the reviewers comments, which summarizes the mpovements made to our manuscript.

Kind regards,

Justyna Dudek

Answers to the first review:

R: Dudek & Petlicki digitize and co-register a set of six topographic map sheets from the Institute of Geophysics of the Polish Academy of Sciences (IGF PAN) covering Sørkapp Land (the southern tip of Svalbard) from 1961. Dudek & Petlicki then compare the digitized 1961 elevation data to DEMs created by the Norwegian Polar Institute for 1990 and 2010. They conclude with some observations and hypotheses for what factors drove the observed changes in glacier thickness and extent between 1961 and 2010. Overall, I think this manuscript is much improved from the original submission. The text is easy to understand, and the figures are illustrative and well-done. I hope that my general, specific, and technical comments below will help the authors improve the manuscript.

A: We appreciate your valuable feedback and we corrected our manuscript (the text and figures) according to these suggestions. We believe that they helped substantially to improve the quality of our work. Below we included our answers. Referee text (R) and author responses (A) are indicated.

General comments

R: Figure 1 (illustrating the coverage of photogrammetric campaigns from the Norwegian Polar Institute) indicates that there is 100% complete coverage of Sørkapp Land from air-photos in 1960 and 1961. Given the availability of this imagery and the fact that there are now tools (e.g., Agisoft, MicMac) to make structure-from-motion photogrammetry a relatively fast and effective strategy for 3D reconstructions of Svalbard glaciers (Mertes et al., 2017; Midgley and Tonkin, 2017; Girod et al., 2018; Holmlund, 2021; Geyman et al., 2022), are you able to justify why digitizing contour lines from maps (constructed from more qualitative photogrammetric approaches) is the approach you take, rather than making the 3D model directly from the 1961 imagery?

A: We ran some trials on the images we possess (using Agisoft software), unfortunately without satisfying outcomes, due to the low-quality version of our photos. Delivery of a high-quality output dataset requires a high-quality input dataset, which we do not have access to.

R: Based on the description in section 4.2, it sounds like you made a DEM from the digitized 1961 contour lines (TIN interpolation of the vector contours), and then differenced that DEM to the modern (2010) NPI DEM. It would be much better to instead difference the 1961 contour lines to the 2010 DEM, and then interpolate these lines of 1961-2010 *difference* values. Finally, you would add this interpolated difference map back to the 2010 DEM in order to recover the 1961 DEM. The reason for doing the DEM difference this way is that ice

elevation changes are much smoother in space than topography is. For example, if the ice melted -50 meters during the period of interest in one place and -60 meters at a nearby location, it is likely that the ice elevation change halfway between is about -55 meters. In contrast, if the elevation at one point is 600 meters, and the elevation at a nearby point is 700 meters, it is far less likely that your guess of 650 meters for a point halfway in between is accurate.

A: Thank you for this advice. In our revised version of the manuscript we differentiated 2010 DEM directly from contour lines (converted to points with 5 m spacing along the lines), and we obtained our 1961 DEM by subtracting difference values from 2010.

Specific comments

R: Lines 16-17: You may want to add a reference after this sentence. Nordli et al. (2014) or Nordli et al. (2020) would work well.

A: We decided to add Nordli et al. (2020) to the lines 17-18, and Nordli et al. (2014) was already cited in that paragraph.

R: Lines 63-66: You might consider citing Geyman et al. (2022) here, since they provide 3D photogrammetric reconstructions of all the glaciers in the area from the Norwegian's 1936 air photo archive.

A: Added

R: Lines 70-71: "No other set of data of the same spatial extent was created until the year 2010 (Fig. 1)." -> See above comment—this isn't true, as there are published 1936 reconstructions of glacier extents and volumes.

A: Although the data for 1936 is very important for reconstructions of glacier extents after the end of LIA it consists of oblique images that have some limitations (i.e. in presenting parts of the glaciers hidden behind the high peaks). In this sentence, we rather meant that after 1961 we had to wait almost half of the century for another data set that would be comparable in coverage and uniformity to the data from 60. (namely vertical images covering uniformly all glaciers in Sørkapp Land).

R: Table 1: Note that Geyman et al. (2022) covers the entire peninsula in 1936.

A: Added

R: Figure 16: Since the colorbar on the image spans such a large range (-100 to +100 m), it would help the reader if you point to the broad area of light pink in Breinesflya and wrote what the average delta z is for that region. Is it -5 m, -25 m, etc.?

A: We changed the range of the colorbar on the images for areas used to validate DEM to (-50 to +50 m). For glaciers we kept a range (-100 to +100 m). For Breinesflya average delta z does not exceeds -5 m.

R: Lines 301-302: “may result from processes going on in the natural environment, e.g. melting of dead ice in marginal zones of glaciers…” You might want to rephrase this sentence, because the melting of dead ice on the marginal zones of glaciers is still of interest to all of the scientists interested in quantifying the ice loss and contribution to sea level rise from Svalbard.

A: Yes, you are right, these zones are very dynamic and this is the reason why they shouldn’t be considered as ‘stable areas’ suitable as a reference surface for DEM validation. Our final version of DEM can be used for quantifying the melting of dead ice.

R: Lines 313-314: “The mean elevation difference (the bias) between the compared models was 2.28 m, with a standard deviation of 3.18 m, indicating that the 1961 model is higher.” Another important statistic for you to report is the mean absolute error – take the absolute value of the delta z map, and then compute the mean. This gives the reader a good sense of the spread of the data.

A: In our revised manuscript we performed corrections for each sheet separately, and we obtained different results.

R: Figure 20: Something that makes me nervous about this delta z map is that there seems to be a systematic trend with elevation: the low elevation regions tend to have negative delta z, and the high elevation regions tend to have positive delta z. I recommend adding a figure to show this pattern. Do you have ideas for why it appears, or ways to fix it?

A: These differences does not exceed 5 m (a values falls in the accuracy defined for the reference dataset for 2010). In the revised version of the manuscript we decided to show differences in unglaciated area between the years 1990 and 2010, both extracted by NPI directly from aerial photographs and we observed that each dataset we used in manuscript have regions of positive or negative delta z, regardless of methods used for data production.

Line 319: “The measure for examining the extent and pattern of glacier retreat in the years 1961–1990–2010 was changes in their surface area, the rate of frontal recession and – where data allowed (i.e. for land-based glaciers) – changes in thickness.” What do you mean by “land-based glaciers”? All glaciers on Svalbard are land-based. The ice also is all grounded. Additionally, there are bathymetry compilations of Svalbard’s fjords, so you should be able to compute glacier mass loss for all glaciers in your region, regardless of whether they terminate on land or in the ocean. Since you address this question partially in lines 456-460, you might consider moving that paragraph here (e.g., line 319).

A: In this context by the “land-based” glaciers, we meant the glaciers terminating on land and for better understanding, we changed that term to “land-terminating” in the entire manuscript. For marine terminating glaciers (referred to as “tidewater” glaciers in our text) we are lacking some data that has been removed from the IGF PAS maps - namely the thickness of glacier fronts. In the newest version of our manuscript we added Table 5 with information about thickness change for each glacier and for the whole glaciated area.

R: Lines 329-337: I think this paragraph would be well supported by a figure that plots 1961-2010 elevation change (delta z) on the y-axis vs. altitude on the x-axis (you could use either the 1961 or the 2010 elevation to define this axis, just specify). That way, readers can see

how elevation (and therefore, through the adiabatic lapse rate, temperature) affects mass balance.
A: This is very good suggestion, but for final version we decided to reduce the number of figures and table to improve readability of the manuscript.

R: Figure 21: the blue (positive delta z) area in the upper reaches of Mendeleevbreen looks suspicious to me. Have you done any tests to make sure that there isn't a mistake with the georeferencing or warping there?

A: Mendeleevreen it is a surging glacier. In the period of 1961-1990 it was in a quiescent phase, with building up of accumulation zone. Glacier surged in 2004, and if we compare the elevation dataset from the year 2004 (for example ASTER DEM) with the data for 2010 we can clearly see that a "build up" was at the front of the glacier, which indicated surging phase. Moreover NPI dataset for 1961 which also covers that glacier, shows similar patern.

Lines 461-463: are you able to report what the average dh/dt was during 1961-1990 for all of the valid glacier area in your region? That is a number that would interest many glaciologists.

A: We now included this information for the period 1961-2010 together with dh for each glacier in the table 5.

Line edits (typos and technical corrections)

Line 2: "their geometry" -> "glacier mass, extent, and geometry"

A: Corrected

Line 2: "them" -> "archival maps"

A: Corrected

Line 5: "The research objective" -> "the objective of this research"

A: Corrected

Line 7: "in in" -> "in"

A: Corrected

Line 96: add parentheses to the Isaksen et al. (2016) reference.

A: Corrected

Line 115: "To the east, it…" -> "To the east, Samarinbreen…"

A: Corrected

Lines 139-140: "consisted primarily of data presenting topographic surface (topographic maps and DEMs), supplemented with imagery (aerial photos and satellite images)" ->

“consisted primarily of topographic maps and DEMs, supplemented with aerial photos and satellite images”

A: Corrected

Line 156: Delete “to elaborate results (especially on changes in glacier thickness)”

A: Corrected

Line 157: Do you mean “level of accuracy” rather than “specificity”?

A: We rather meant “specifity”, but it does relate to the level of accuracy as well.

Line 160: Delete “prepared”

A: Corrected

Line 164: Use a consistent dash width between 1961-1990-2010.

A: Corrected

Lines 189-190: Delete “Their specification is provided below (Fig. 5)” and put the “(Fig. 5)” reference at the end of the previous sentence.

A: Corrected

Line 428: Delete “in places”

A: Corrected

Line 454: Use a consistent dash width between 1961-1990-2010.

A: Corrected

References

Geyman, E.C., JJ van Pelt, W., Maloof, A.C., Aas, H.F. and Kohler, J., 2022. Historical glacier change on Svalbard predicts doubling of mass loss by 2100. Nature, 601(7893), pp.374-379.

Girod, L., Nielsen, N. I., Couderette, F., Nuth, C., and Kääb, A.: Precise DEM extraction from Svalbard using 1936 high oblique imagery, Geosci. Instrum. Method. Data Syst., 7, 277–288, https://doi.org/10.5194/gi-7-277-2018, 2018.

Holmlund, E. (2021). Aldegondabreen glacier change since 1910 from structure-from-motion photogrammetry of archived terrestrial and aerial photographs: Utility of a historic archive to obtain century-scale Svalbard glacier mass losses. Journal of Glaciology, 67(261), 107-116.

Mertes, J. R., Gulley, J. D., Benn, D. I., Thompson, S. S., Nicholson, L. I.: Using structure-from-motion to create glacier DEMs and orthoimagery from historical terrestrial and oblique

aerial imagery, Earth Surface Processes and Landforms, 42(14), 2350-2364, 2017.

Midgley, N. G., Tonkin, T. N.: Reconstruction of former glacier surface topography from archive oblique aerial images, Geomorphology, 282, 18-26, 2017.

Nordli, Ø., Przybylak, R., Ogilvie, A., Isaksen, K.: Long-term temperature trends and variability on Spitsbergen: The extended Svalbard Airport temperature series, 1898–2012, Pol. Res., 33, 21349 (2014).

Nordli, Ø. et al. Revisiting the extended Svalbard Airport monthly temperature series, and the compiled corresponding daily series 1898–2018. Polar Res. (2020).

A: We added all suggested references to our corrected manuscript

Answers to the second review:

This is my first review of this study by Dudek and Petlicki. I carefully reviewed the revised manuscript as well as the previous reviews and replies by the authors. I unfortunately could not find a way to access the original manuscript to assess the progress since the review. Overall, this study is relatively well written, the methods are sound and the results seem satisfactory. The study is interesting as most studies working with archival topographic maps, that I am aware of, usually address the issues related to this data in a very synthetic way (e.g. Ye et al., 2015; Nuimura et al., 2012). However, I share the impression of the previous reviewers that the method is not extremely novel (see main comment below).

A: We appreciate your valuable feedback and we corrected our manuscript (the text and figures) according to these suggestions. We believe that they helped substantially to improve the quality of our work. Below we included our answers. Referee text (R) and author responses (A) are indicated.

General comments:
- Methods and methods description:

R: I stand with R1 and R2 who highlight that the methods need to be clearly presented and novel enough for this study to be a benchmark for other studies analyzing topographic maps. I also do not find the methods extremely novel, but the results seem satisfactory anyway. There are two ways of improvements though, that have already been brought up by the previous reviewers that could be considered:
Interpolate the elevation difference map (DoD) rather than interpolate the contour lines with TIN. This was brought up by R1 and considered to be addressed by the authors, but I noticed that the latter method is still used in this version. I quickly checked the data available on the Zenodo repository, and the slope derived from the provided 1961 DEM shows interpolation artifacts. This could probably be improved with R1's suggestion.

A: Thank you for this suggestion. In order to minimize the impact of DEM artifacts in our latest revised version we used contour lines only (converted to points with spacing 5 m) and we interpolated the elevation difference data (DoD) instead of contour lines with TIN/ grid. We obtained much better results, nevertheless it has to be noted that new method is much more time consuming and requires more memory and disk space for data processing.

R: There are still relatively large and systematic elevation differences in stable terrain (e.g., in the west of the study area on Figure 20). It looks like the elevation difference shows a step-like pattern at the junction of two sheets. I see at lines 313-314 that you correct for a mean bias, but if I understand correctly, you calculate a single bias for the DEM mosaic of all sheets at once? If so, I would recommend estimating this bias for each sheet individually. If this does not work, I would encourage you to follow the suggestion of R2 to apply a blockwise coregistration. I understand your preference to use the topographic point for the horizontal alignment, but you could still apply this method to correct for a smooth vertical offset.

A: In the first version of our manuscript we calculated bias for a mosaic of all sheet at once. In revised version we performed correction for each map sheet separately. As a first step we calculated mean shift for each map using algorithm developed by Nuth and Kääb in 2011. Second step consisted of feature adjustment (for each sheet separately), correction for Z and then merging all the data. Between two map sheets 8 and 10 there was some small step at the junction and we diminished this error, although it is still visible. Since elevation bias for Breinesflya at the map sheet 10 does not exceeds ~ 5 m we decided to accept that. We also observed some small steps when comparing the data from NPI for 1990 and 2010 which we use as a reference dataset and we believe that currently the elevation data for Sorkapp Land that would not contain some small errors does not exist.

R: I would also include in the text some parts of your replies to the reviewers, especially concerning 1) your unsuccessful attempt to process low quality scans of the images unsuccessfully 2) your attempt of applying the Nuth & Kaab (2010) method to all stable terrain and the issue of non-rigid transformation (i.e., a shift alone is not enough).

A: In revised version of our manuscript we now mentioned Nuth & Kaab (2011). We processed each map using this method, and we estimated differences between the data from 1990 and 2010 published by NPI.

R: Finally, I believe that the methods would need to be more detailed to make this work fully reproducible.
Figure 7 provides a nice list of the different steps and commands used in ArcGIS. I have never worked with ArcGIS, however, I assume that there are several tools e.g., in the "ARC SCAN/VECTORISATION" box and several options for each tools. It would be extremely useful to provide the exact tools and options that were used (e.g., in a supplementary table if this takes too much space) and whenever possible, provide a clear description of the algorithms, so that this could be reproduced with open-source alternatives. For example, what are the steps in the "RASTER CLEANUP" or "FEATURE CLEANUP"?

A: In the first version of our manuscript we added more detailed description of tools we used for data processing and we removed them as per suggestion of the reviewers. For the second revision we added more information to the figure listing processing steps, but it is still slightly less than in the preprint.

- Results

R: It is a shame that the authors spend so much effort in generating a DEM from the archival map, but the only results that are presented are only vague numbers of maximum thinning

and a map. I don't think it would be much more effort to calculate an actual glacier-wide mass balance or at least a mean elevation change for each glacier and for each period. This could then be compared to existing estimates in the literature for this area of the whole of Svalbard and make this study more valuable.

A: Good suggestion. In the revised version of our manuscript we added information about mean elevation difference for glaciers.

R: I also wondered why you did not use the information on the 1984 map to generate glacier contours for 1984. You said that the elevation contour lines were not updated, but the color were changed to reflect glacier area changes. With this information, you could include a fourth period in your tables.

A: We decided to focus our research on the years for which we have both: information about area and elevation of glaciers.

- Overall structure
R: Although the manuscript reads relatively well, there are still some parts that could be better structured to be more easily followed, or some sections that are not completely appropriate.
The introduction lacks acknowledgment of recent studies using archival terrestrial and aerial images: Girod et al. (2018), Holmlund et al (2021), Geyman et al. (2022). The first two are briefly mentioned in the discussions, but definitely belongs to the introduction as they are part of the state-of-the-art. The last one is very recent and not yet referenced but would deserve to be acknowledged as well.

A: In revised version we added all three suggested references

R: The Results and Discussion sections are not so well structured. The use of subsections could help guiding the reader. There sometimes seem to be repetitions. Some of it stems from the fact that you first describe land-terminating glaciers then marine terminating glaciers, but this is not always very clear.

A: Thank you for this suggestion.

R: The conclusions should summarize the main findings and methods. Instead, the current conclusions enter too quickly in very specific details of the study, such as the map date. It also does not summarize the findings on area changes. Hence, I suggest rewriting the conclusions.

A: Our main aim was the description of data derived from old maps, therefore we focused on data processing, quality, and its applicability in polar research. We aimed to reflect that goal also in our conclusions.

Specific comments:

R: l 30: you could add references to the studies by Girod et al. (2018) or Geyman et al. (2022).

A: Added

R: L 52-54: Mannerfelt et al. (2022), already referenced elsewhere, is another good example of use of historical terrestrial images in Svalbard.

A: We added this reference in line 34 of the manuscript, where is more relevant.

R: L 85: Maybe the currents that you discuss could be represented on Figure 2?

A: After trying to fit them on the figure we decided to leave it as it is.

R: Table 1, line 1936. You could include the references to Girod et al. (2018) and Geyman et al. (2022) in the list of references.

A: We added Geyman et al. (2022) and the work of Girod et al. (2018) was omitted in the table since it did not concern the peninsula itself (nevertheless we cited it elsewhere in the manuscript).

R: L 96: the reference does not have the right format

A: Corrected

R: Figure 2: This figure should probably appear first and be referenced at the first mention of the Sorkapp Land peninsula. Could you please indicate the source of the background map?

A: Corrected

R: L 139: “analyzes”, do you mean “analysis”?

A: Yes, corrected.

R: L 183: remove “therefore” as it is redundant with “since”.

A: Corrected

R: Figure 7: The figure could be improved to include the inputs and outputs. Also see my comment on detailing the individual steps a bit more.

A: We developed the figure by adding several steps.

R: L 239 “The six maps shared 189 points representing the same places” I understand from this sentence that the different sheets have some overlap. What is the size of this overlap (in map units)? Could this not be used to first align the sheets relatively to each other? This would be particularly useful for sheets with little topographic points or stable terrain.

A: The map sheets from IGF PAS representing the year 1961 do not overlap. In this sentence, we meant that we found the same points in the datasets from 1990/2010, and based on these points we performed co-registration of the data from 1961.

R: - L 286: “The vector data thus processed was then used to generate a DEM” You may want to briefly re-state how you derive the DEM, or refer to the appropriate subsection. It took me some time to realize it was explained further up.

A: We rephrased this sentence.

R: - Figure 16 and 20: I would adapt the color scale for these figures to better show the residuals. A min/max value of about -50/50 or less would probably be more appropriate.

A: Corrected

R: L 313-314: “The mean elevation difference (the bias) between the compared models was 2.28 m, with a standard deviation of 3.18 m, indicating that the 1961 model is higher.”. Could this bias correction be done individually for each sheet? Also it is recommended to use the median rather than mean, because it is less sensitive to outliers (Höhle & Höhle, 2009). The 3.18 m standard deviation seem surprisingly low when looking at figure 20. Maybe the change of colour scale would show it is not. Or maybe it would be useful to display the areas masked?

A: For the final version of the manuscript we added absolute error a suggested by the second Referee

R: Figure 21: The legends are too small to be read.

A: Corrected

R: Table 3: Brackets are lacking in the table (for percentage).

A: Corrected

R: L 381 “insolation thickness” -> “insolation, thickness”

A: Corrected

R: L 389-395: this whole paragraph simply repeats what is in the introduction. This should all be moved to the introduction (as the references).
A: We moved this chapter to the Introduction section

R: L 393: There are a lot more recent and appropriate references for the declassified spy satellite studies, such as Maurer et al. (2015); Maurer et al. (2019); Dehecq et al. (2021), Bhattacharya et al. (2021). You do not need to cite them all of course.

A: Added

R: L 395: you could reference Geyman et al. (2022) here.

A: Added

R: L 400: I believe the reference to Zekollari et al. (2020) would be more appropriate here.

A: Corrected

R: Supplementary: In the supplementary table, you should describe the table content (it should be understandable without searching in the main text) and the meaning of each column, as it is not very clear.

A: Corrected

References:

Bhattacharya, A., Bolch, T., Mukherjee, K., King, O., Menounos, B., Kapitsa, V., Neckel, N., Yang, W., Yao, T., 2021. High Mountain Asian glacier response to climate revealed by multi-temporal satellite observations since the 1960s. Nat Commun 12, 4133. https://doi.org/10.1038/s41467-021-24180-y

Dehecq, A., Gardner, A.S., Alexandrov, O., McMichael, S., Hugonnet, R., Shean, D., Marty, M., 2020. Automated Processing of Declassified KH-9 Hexagon Satellite Images for Global Elevation Change Analysis Since the 1970s. Front. Earth Sci. 8. https://doi.org/10.3389/feart.2020.566802

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Nuimura, T., Fujita, K., Yamaguchi, S., Sharma, R.R., 2012. Elevation changes of glaciers revealed by multitemporal digital elevation models calibrated by GPS survey in the Khumbu region, Nepal Himalaya, 1992-2008. Journal of Glaciology 58, 648–656. https://doi.org/10.3189/2012JoG11J061

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Zekollari, H., Huss, M., Farinotti, D., 2020. On the Imbalance and Response Time of Glaciers in the European Alps. Geophysical Research Letters 47, e2019GL085578. https://doi.org/10.1029/2019GL085578

A: Thank you for these suggestions, we cited some of the proposed positions where appropriate.