

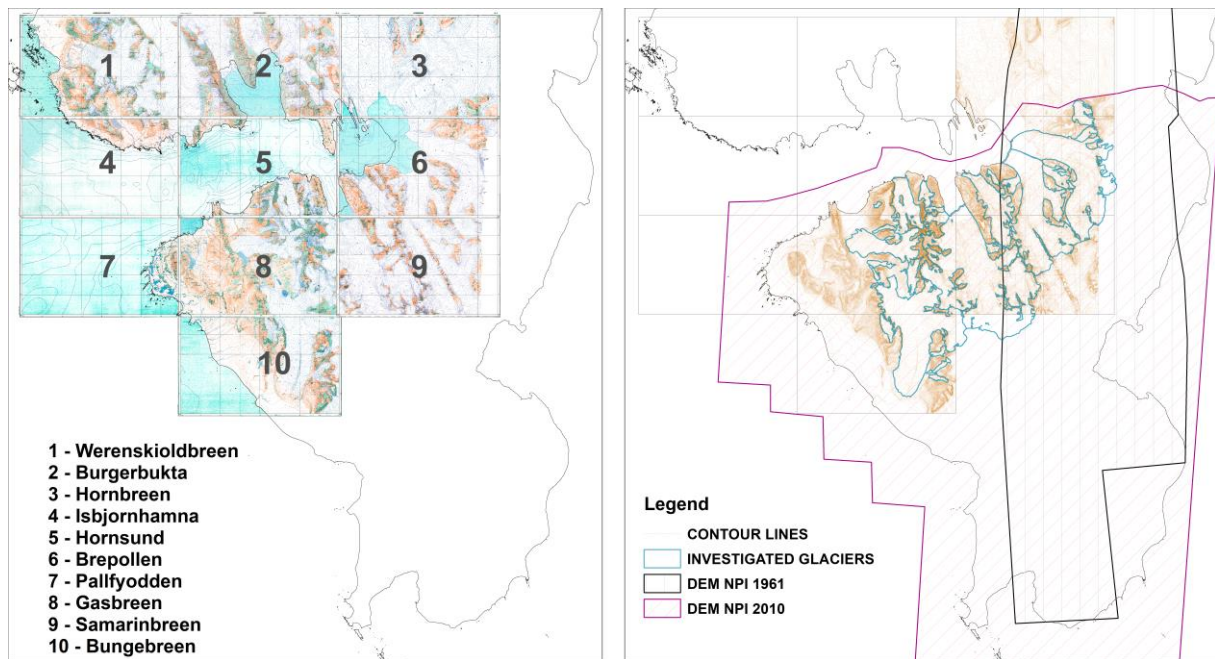
## General comments:

R: Dudek & Pełlicki digitize and georeference three topographic map sheets covering the western portion of Sørkapp Land, Svalbard. They clearly outline the steps they took to digitize the contour lines, generate a raster digital elevation model (DEM), use triangulation points to co-register the historical map to a more modern (1990) DEM of the area, and assess the uncertainty in the final historical DEM using elevation differences to the reference DEM over non-glaciated terrain. A notable contribution of this paper is that it establishes that the contour lines in the IGF PAN map sheets represent the 1961 glacier elevations, rather than the elevations from the 1980s, which is when the maps were updated and published.

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.

R: In my view, there are two categories of shortcomings in this work. The first pertains to the question of whether this paper presents a substantial new dataset to the community—a question that the Topic Editor raised some skepticism about. In lines 97-100, the authors explain that they digitized three of the ten sheets in the IGF PAN topographic map. But they don't provide an explanation for why they didn't digitize the other seven. Since Dudek & Pełlicki reconstruct the historical (1961) geometry of just a handful of the ~1,600 glaciers in Svalbard (König et al., 2014), this manuscript reads more like a nice recipe for digitizing historical topographic maps for analysis of geodetic glacier change, rather than presenting a large new dataset.

A: In our manuscript, we focused on the map sheets of the PAS series that in our opinion presented the highest value for glaciological research. The three sheets we initially have chosen for processing (5, 8, 10) cover the peninsula further inland and present the complete surface of 14 land-based glaciers. We agree that this is only a small sample of glaciers of Svalbard, nonetheless a very important one. The remaining map sheets were already partly covered by the DEM published by NPI (based on original aerial photographs from 1961), or presented only frontal parts of the tidewater glacier (updated to the period of 1982-1984, when PAS field measurements took place), or did not cover the glaciers. We still believe that our initial choice was valid, nonetheless, we also agree that it would be better to show larger spatial coverage. For the revised version of our manuscript, we decided to significantly enlarge our study both spatially and temporally by adding the 2010 data and additional 4 map sheets (as shown in the attached figure). This way we will use all 7 maps produced for Sørkapp Land and overlapping with the data from the latest flight campaign.



R: If this paper is going to be a template to help others digitize and georeference historical topographic maps, it becomes especially important that the methodology in the paper is careful and robust. That brings me to the second potential shortcoming of this work. In my view, there are three ways that the others could generate improved 1961 elevation reconstructions from the data already available to them. First, the authors use a TIN interpolation of the contour lines to create a DEM directly from the contour map. They could get more accurate glacier change observations by differencing just the contour lines to the reference DEM, and then interpolating the difference map. The reason is that glacier elevation change between two time points ( $\Delta h$ ) varies in space more smoothly than the topography at any one time point. This kind of problem is discussed tangentially in McNabb et al. (2019).

A: We agree that the applied method of georeferencing must be improved in order to reassure that the results are robust and reproducible. We did our best to add new processing steps, suggested by the reviewer, that allow data processing less dependent on the operator. Yes, we see that the glacier elevation change can be better quantified with the use of contour lines only and it will help to minimise the impact of DEM artifacts on ice elevation change estimates. We will address this in more detail and add relevant references, including Rolstad and others (2009).

R: Second, the final co-registered map (Fig. 14) still has large regions of positive  $\Delta z$  and large regions of negative  $\Delta z$  over ice-free land areas. Figure 14 suggests that the authors could still improve the georeferencing of the map by correcting for regional warping (see comment #3 below for some ideas how to do this).

A: Agree. We have improved our georeferencing following your suggestions, please see further responses for more details.

R: In summary, although I think that the digitization of historical datasets is an important and worthwhile task, the small coverage of the digitized maps presented here, and the fact that the digitization could be done in better ways given the methods already described in published literature, makes me question whether the manuscript warrants publication in ESSD. However, I think that digitizing more of the map sheets, and following some or all of the 3 suggestions mentioned in the paragraph above, would substantially improve this contribution.

A: We fully agree with this comment and we made our best effort to expand our study by digitizing 4 more maps and improving methods of dem processing. In the revised version we included all maps covering Sørkapp Land and overlapping with dataset from 2010.

### Specific comments:

R: 1. If I recall correctly, the 1990 NP DEM for Sørkapp Land has a spatial resolution of 20 m. That relatively low resolution means that the DEM elevation at the pixel location of mountain peaks will consistently underestimate the peak elevation. How do your georeferencing results compare when you only georeference to steep mountain peaks vs. only georeference to flatter terrain?

Also, now that Norsk Polarinstitutt (NP) has released a 5 m regional DEM (2010) for Sørkapp Land (geodata.npolar.no), you might want to experiment with the georeferencing results when you use the 5 m reference. Finally, for your discussion, you might consider evaluating the two time periods (1961-1990 vs. 1990-2010). Were thinning rates and retreat rates similar over those two periods? Have they increased/decreased?

A: Good suggestion. Now we use as a reference the 2010 NPI DEM that has a higher resolution of 5 m. We have expanded the discussion with evaluation of the ice elevation change over this two epochs. Answering the question shortly: the thinning/ thickening rate of investigated glaciers changed in the period of 1990-2010. Most of the glaciers retreated faster in the second period, however for 2 glaciers (Bungebreen, Mendeleevbreen) we observed thickening in the ablation zone and thinning in their accumulation zone – which is indicative of surging process. We also observed thickening of small glaciers lying in the highest mountain massifs. In our revised manuscript we discuss that in more detail.

R: 2. You say in lines 135-139 that you analyze the original 1961 aerial photographs from the Norwegian Polar Institute. Can you use structure-from-motion to make a 3D model from those images? This has been done successfully for Svalbard glaciers numerous times. See, for example, Mertes et al. (2017), Midgley & Tonkin (2017), Girod et al. (2018), Kavan (2020), Holmlund (2021).

A: Unfortunately, we do not have access to high quality scans of aerial imagery from 1961 that could be used to generate new DEMs using stereophotogrammetry or structure-from-motion methods. We tried to process low quality scans that we possess with Agisoft Photoscan, however the results were not satisfactory. The main focus of the study was a use and recovery of historical maps and not to generate completely new dataset from the source data, to which we do not have access.

R: 3. You do the co-registration based on the few dozen “triangulation points” listed in Tables 2-4. How would the co-registration differ if you instead applied the Nuth & Kaab (2011) procedure using all DEM pixels in stable ice-free areas? The reason I ask is that, in Figure 14, there remains a considerable amount of spatial structure in the dz map over land areas (i.e., large regions that are consistently blue, transitioning to large regions that are consistently red). That suggests that you might want to change the way you do the co-registration. For example, you could compute the dx, dy, dz offsets using the Nuth & Kaab (2011) method for individual patches of ~2 km x ~2 km (and you should explore the sensitivity to that window size), then unwarp the map using the vector field you generate, where the “vector field” is the <dx, dy, dz> vectors at the grid of locations where you extracted co-registration chips).

A: We applied original Nuth & Kaab (2011) method of DEM co-registering but it did not help much as still the models exhibited some warping. Following this comment of the reviewer we

applied the co-registration method in a moving window and it indeed improved the results. The window size has to be much larger though (approx. 5x5km) because the eastern Sørkapp Land is highly glaciated and there are very little rock outcrops that can be used as a reference for co-registration. The drawback of this method is that it does not make use of available point features from the map such as mountain top positions and therefore we are inclined to use it as a second step of data processing, after the rubber-band correction of the isolines.

**Line comments:**

R: Line 2: you might consider changing “reliable comparative” to “quantitative”

A: corrected

R: Line 9: change “from” to “on”

A: corrected

R: Lines 13-15: this first sentence needs a citation. Also, the word “dynamic” connotes ice dynamics (e.g., the flow of ice, surge behavior, etc.). But it seems like you are trying to say that melting is happening more rapidly in Svalbard than other places in the world. Perhaps you could start by saying that Svalbard is warming more rapidly than elsewhere (Nordli 2020), and then relate that warming trend to negative mass balance (e.g., Nuth et al., 2010; Morris et al., 2020). Or, you could skip straight to the negative mass balance.

A: By ‘more dynamic’ we mean that changes in Spitsbergen (such as progressive disappearance of ice) are occurring faster than in other parts of the European Arctic (and the world). We will rephrase this sentence and add suggested references.

R: Line 26: What is “this scientific field” referring to? Glaciology or remote sensing?

A: Glaciology. In the revised manuscript we rephrased this sentence to make it clear.

R: Lines 54-55: Clarify what you mean about aerial images being “more competitive” than terrestrial photographs, and why.

A: We will rephrase this sentence. By ‘more competitive’ we meant more useful for the research covering larger area.

R: Table 1: Should you clarify in the caption that these mapping campaigns were done by the Norwegian Polar Institute, since, in the main text, you just discussed the Polish mapping efforts?

A: Corrected. We added: “Norwegian Polar Institute photogrammetric campaigns carried out over the Sørkapp Land peninsula.”

R: Table 1 (a more general comment): I wonder if the information in this table would be conveyed more effectively by having a series of 8 simple line maps of Sørkapp Land, lined up side by side and colored to show the regions covered by each photogrammetric mapping campaign?

A: We would like to keep the table (with added column with references as suggested in the second review) but we also prepared and added the figure with all photogrammetric campaigns.

R: Line 60: replace “first decade of the 21st century” with “2000s”

A: Corrected.

R: Lines 65-74: These two paragraphs would benefit from a little more clarity. Is the IGF PAN topographic map for Sørkapp Land the result of analyzing the Norwegian 1960/1961 photos in a stereoplanograph?

A: IGF PAN did not provide such detailed information on the maps.

R: Line 76: Missing a space at the end of the sentence.

A: Corrected.

R: Lines 76-77: Perhaps you should cite Ziaja & Ostafin (2015) here? Is it correct to call Sørkapp Land an island if it is still connected to Spitsbergen via the isthmus?

A: In this context by the Island we mean Spitsbergen (which is the biggest Island of Svalbard archipelago). The Sørkapp Land is its southern peninsula. We rephrased that section: “Sørkapp Land is the southern peninsula of Spitsbergen, the largest island of the Svalbard archipelago. It is separated from the rest of Spitsbergen by a narrow glaciated isthmus of Hornbreen-Hambergbreen (Ziaja and Ostafin, 2015) and there is an ongoing speculation whether it will form a separate island when the ice is gone (Pälli et al., 2003; Grabiec et al, 2017)”

R: Line 79: why do you say “as many as 14 land-terminating glaciers,” rather than simply “14 land-terminating glaciers”?

A: Corrected.

R: Line 97: clarify which topographic map.

A: Corrected.

R: Lines 97-100: where are the other 7 sheets? Is there a reason you chose not to digitize those ones?

A: For the revised version of this article we added another 4 sheets covering Sorkapp Land. Sheet no 7 (which does not cover any glaciers), and sheets no 3, 6, 9, covering parts of the glaciers ending in the Hornsund fjord. The fronts of tidewater glaciers (within the extents 61-84) were removed from these sheets, and this limits their suitability for glaciological research. This was the reason why primarily we focused our research on the areas with the elevation dataset covering entire glacier surfaces.

R: Line 103: cite Fig. 2 again at the end of this sentence for clarity.

A: corrected

R: Line 112: what does “made in desk research” mean?

A: The term “desk research” used in our manuscript was directly cited from the map description meaning compilation, analysis, and processing of data and information from existing sources (in this case aerial photographs). We might rephrase this sentence in the revised manuscript.

R: Line 121-122: tell the reader here what the answer is, rather than saying “the question was answered.” Do the contour lines represent the glacier elevations in 1960s or the 1980s? You get to that in lines 131-134, but you might improve clarity by telling the reader up front that the glacier contour lines represent the 1961 surface, and then go into the paragraph of how you determined that (lines 123-130).

A: We will rephrase this sentence.

R: Lines 141-144: I suppose you began this research before NPI had released the 2010 DEM for Sørkapp Land. Would that be a better reference dataset, since it is 5 m resolution rather than 20 m resolution?

A: Yes, we began our work before this recent data release. In our revised manuscript we included 2010 DEM as a reference dataset and compared it to both DEMs: from 1961 and 1990.

R: Figure 4: Readers will see that this dz map resembles a hillshade map, due to delta-x and delta-y offsets between the two DEM datasets (i.e., poor co-registration--Nuth & Kaab, 2011). You should explain that in the caption. You already explain it nicely in the main text (lines 174-176), so just add a brief explanation in the caption, too.

A: Corrected.

R: Lines 172-173: You don't need to say how you subtracted one raster layer from another (i.e., which GIS module you used).

A: Corrected.

R: Figure 5: Reference Figure 2 so people know where sheet 8 comes from. Also, in Figure 2, you might consider adding (a), (b), and (c) and clearly labeling which sheet is which.

A: Corrected.

R: Lines 177-179: You don't need to tell the reader which of the 3 sheets you worked on first.

A: Corrected.

R: Lines 180: Add "elevation points" after "195"

A: Corrected.

R: In Figures 5, 6, and 8 (the maps showing triangulation points for the 3 sheets), it would be helpful if you plotted vector arrows pointing in the direction of the dx, dy offset to the NPI reference map. That would let readers see if there are consistent patterns of warping across the map sheets.

A: Good suggestion, we will add vector arrows to all figures showing triangulation points.

R: Lines 214-216: Rather than referring to "visual assessment" of the model accuracy, can you give a quantitative metric of the elevation accuracy. For example, the root mean square error (RMSE) between the 2 DEMs on ice-free land?

A: This information will be provided for all 7 map sheets in the revised manuscript, along with a global value and a related histogram.

R: Lines 224-226: This sentence will be more compelling if you provide some stats. For example, use the NPI DEM to say XX% of the glaciated area in Sørkapp Land has slopes < 20 degrees."

A: This information will be provided for all 7 map sheets in the revised manuscript

R: Line 230: remove "for obvious reasons"

A: Corrected

R: Line 242: to improve clarity, you could say "The mean elevation difference (the bias) between..."

A: Corrected

R: Line 291: Missing space after “zone”

A: Corrected

Line 308: You might want to cite Nuth et al. (2013) here, since it investigates similar datasets across Svalbard.

A: Corrected.

Line 313: Be specific: say “structure-from-motion (SfM) photogrammetry” or structure-from-motion (SfM)-multi-view stereo (MVS)” rather than “modern methods”

A: Corrected.

R: Line 341: remove “very”

A: Corrected.

R: Line 343: what does it mean for an air mass “to be in effect”?

A: This was indeed poorly translated. Here we mean that the climate of Southern Spitsbergen, controlled by the latitude, is modified by a significant thermal difference between sea masses. Warmer Atlantic water (West Spitsbergen Current, the last branch of the Gulf Stream) that reach Sørkapp Land flowing along its western coast, affects local climate conditions. This produces relatively little glaciation and more intense ablation of the small, westward, low-lying valley glaciers.

R: Lines 367-369: Rephrase this sentence for clarity and remove the word “ignorance.” Make it clear that you are saying that, even though the map sheet is labeled as 1984, the glacier contour lines reflect the 1961 elevations.

A: We rephrased that sentence according to the suggestion from the second review: “Although the IGF PAN field campaign was conducted in the early 1980s, the maps published after the expedition were based on elevation data taken from aerial photos from 1961, upon which only glacier extents were updated (with a change in colour of contours). Crucially, contour lines were not updated in this 1984 edition, and continued to represent the elevations of 1961.”

R: Lines 384-386: You could remove this final sentence of the manuscript.

A: Corrected.