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Dear Editor,

Please find enclosed a revised version of our manuscript (MS) entitled, “The Pléiades Glacier Observatory: high resolution digital elevation models and ortho-imagery to monitor glacier change”. To facilitate your assessment, we uploaded a clean and track-change version of the revised MS.

We thank David Shean for its further technical comments on our manuscript. Below, you will find a copy of all comments and, in blue, a point-by-point response to them. When relevant, the revised text is provided in italics.

We hope that these corrections/clarifications make our paper suitable for publication in *The Cryosphere*.

Yours sincerely,

Etienne Berthier on behalf of the co-authors

Reply to David Shean

Many thanks to the authors for considering all of my detailed comments, and providing a thorough response document. I know how much time is involved to do this. The revised manuscript reads well, and I believe is ready for publication.

There are a few items below which I encourage the authors to consider in their final revision/proofs, as well as ongoing product distribution, and future efforts to update PGO products and use for analysis. I am recommending acceptance, and I don't require a detailed response to this second round of comments, but I know the PGO team will understand these points, and I am happy to follow up on any of this, provide further explanation, and discuss corrections outside of the review process. Hoping we can get these things right, to establish best practices and deliver the best possible products for the community.

We thank Dr. Shean for his continued help to improve our paper. Despite his statement that "I don't require a detailed response" **we, nevertheless, think a response is still useful for the editor (and later all readers), in particular to discuss why we did not incorporate some suggestions provided by Dr. Shean in the current paper (these suggestions will be included in future releases of the PGO).**

Product availability

I was able to log in and download sample products! I noted that transfer rates to Seattle, WA were ~300-500 KB/s. The file I chose was 2023-11-11_0503585_Mera_ASE.tgz is 579 MB, so this required 15-30 minutes to transfer - not ideal, but fine.

After decompressing the archive, I noticed that the tif files were not tiled or compressed. I ran my gdal_compress.sh utility (https://github.com/dshean/gdal_tools/blob/master/gdal_compress.sh) using lossless LZW compression for the 4 tif files, which significantly reduced file size:

- 2023-11-11_0503585_Mera_ASE_1B_DEM_BM_2m.tif from 673M to 203M
- 2023-11-11_0503585_Mera_ASE_1B_DEM_BM_20m.tif from 6.7M to 3.0M

I created a new tar.gz archive with these files, the total archive size was reduced from 579 MB to 387 MB. I recommend that the PGO team runs similar gdal_translate commands to tile and compress the tif files, creates new archives, and replaces the existing archives on the distribution site before official release. This will reduce archive storage and file transfer times for the community.

We are relieved to read that the reviewer could access the data and we have informed the team managing the distribution platform (A2S) about the transfer rate. They answered that the server itself has a much higher transfer rate than indicated by D. Shean and they suggested that the slow rates of transfer could rather come from the end user. We downloaded the same file as D. Shean (2023-11-11_0503585_Mera_ASE.tgz) from home in 15 seconds.

Regarding file compression. We made the same test as the reviewer on a PGO DEM and ended with contrasted results:

- **uncompressed tif 562 MB,**
- **compressed using D. Shean suggestions (gdal_translate -co COMPRESS=LZW) = 342MB**
- **compressed as done in the PGO (tar -czvf) = 317 MB**

Still it seems wise to compress the tif files as suggested by the reviewer and this is something we will implement for forthcoming products.

Bias correction using ICESat-2 data : “The author’s response is likely incorrect. While I don’t think integrating altimetry is necessary for this paper, I encourage the authors to explore the available coverage from the 5+ year ICESat-2 archive. At lower latitudes, systematic ICESat-2 off-pointing fills gaps between reference ground tracks, and even with missing data due to clouds, there should be sufficient coverage (1000s of ATL06 points) for a typical PGO DEM footprint. Try running SlideRule ATL06-SR query for one of your low-latitude footprints.

The use of ICESat-2 data will require some further analysis. We would like to point out that for some of the PGO sites (for example San Quintin Glacier or Grey Glacier in Patagonia), the fraction of OFF glacier terrain in some of the Pléiades data is low. Hence, the number of actual laser footprint is extremely low. The coregistration could be tested ON glaciers using near-contemporaneous ICESat-2 data (to increase the number of ICESat footprints), but this will be appropriate if the time difference between Pléiades and ICESat-2 is only a few days; otherwise the signal of elevation changes will be too strong.

56 - Minor point - these are not "raw," they are Level-1B or “Primary” products, with many corrections by Airbus before delivery

We concur. “raw” was incorrect and we deleted the term as the level of production “primary” is already mentioned L148.

70 - suggest "stereo images can be acquired in an along-track pair". **Changed as suggested.**

226 - delete "the demcoreg package, as described above". **Deleted.**

228-230 and responses doc, regarding the 5th order polynomial fit to cross-track residuals.

The reviewer raise many good points here

We checked the Gardelle et al., 2013 IDL scripts and can confirm that they followed the same order as us, first the cross track correction and then the along-track one. Unfortunately, the order is not properly reflected in their description in the article.

We followed the same order (now clarified in the revised article) but did not perform any analysis to further justify the order. This analysis is clearly something to explore in the future. The Makalu example proposed by D. Shean would be a good case study to start with. We anticipate only a minor influence overall.

We added (L222ff) “*We note that the order of these corrections (first across-track then along-track) were taken from Gardelle et al. (2013) but were not studied further and could be the topic of future analysis.*”

For the Gulkana case study, we note that a linear correction would have been relevant but the 5th order correction did not introduce any unexpected bias.

However, we agree with the reviewer (and observe) that in some cases (mostly when stable terrain is rare or badly distributed), this high order fits do not work well. Hence we included a note on that in the revised text (L224ff): “*We also emphasise that the quality of these bias corrections depends on the availability of sufficient and well-distributed stable terrain. We therefore strongly encourage users to check the relevance of these automatic corrections using the plots associated with each elevation difference map and, if necessary, generate themselves the elevation change map using the PGO DEMs.*”

264-267 - I appreciate the tests with different reference DEMs. Just to confirm, this was all done by first transforming the reference DEM to match the local UTM zone of the PGO DEM?

Yes, the reference DEM is reprojected using gdal_warp to match the projection (same UTM zone) and extent of the PGO DEM.

While it shouldn't be an issue within a UTM zone, I'm still wondering about projection distortion issue with latitude. Distance, direction, and pixel area are all important properties for Nuth and Kaab, and these will be distorted by different amounts depending on projection choice and latitude. One way to test this is to repeat the co-registration using a local planar projection (like orthographic, or stereographic with clat,clon defined by center of DEM).

We tested the potential impact of such a latitudinal distortion in Iceland (>60°N). We co-registered nine Pléiades DEMs generated in the local projection system (ISN93, EPSG:3057) to a lidar DEM, and next tested re-projecting the same DEMs to UTM (UTM27N) and then perform the coregistration to the lidar. The difference of the shift vectors is at most less than 1 m (max 0.7 m in easting, 0.9 m in northing, 0.3 m in Z). The average difference is close to 0 (0.2 m in easting, 0.2 m in northing, 0.0 m in Z). This is an order of magnitude smaller than the latitude shifts discussed in our previous response letter so this appears not to be the cause of the northward shift at high latitudes.

267-272 and responses doc, regarding the 2.4 m vertical bias and refraction/aberration correction

We thank D. Shean for digging so deeply in the release of ASP. We plan to test the CSM linescan model implementation for Pleiades in the future. In our present work, however, we decided not to implement this test because, thanks to the systematic coregistration to Cop30, the PGO products are not affected by the bias.

319: lidar data source. Thanks for including Pelto reference for the BC lidar surveys. It is disappointing to see that no corresponding information was included about the Norway lidar collections in the text or the responses. According to the author contributions section, presumably co-authors JMCB and LMA provided the airborne lidar data for Norway and can track this down? Hopefully someone can include citations or some text with information about those surveys, even if the lidar data are not publicly available. As a community, we need to be more careful assuming "lidar is truth" and "all airborne lidar data have the same accuracy."

Good suggestions. The lidar surveys were made by TerraTec AS (2018, 2019a, 2019b). We have now added references to these reports. Unfortunately, they are only in Norwegian. NVE retrieves the data in UTM projections in the local zone (32 or 34 N).

324-327 - regarding lidar data preparation and vegetation masking.

I think the authors missed my point about the vegetation. The lidar point clouds should be filtered to preserve first returns to produce a DSM, or vegetation should be masked before co-registration.

I agree that showing and analyzing offsets over vegetation is valuable, but the current approach will potentially lead to incorrect co-registration and bias output DEMs.

When creating a DEM using ASP's point DEM, you are using points from all lidar returns (top of canopy, canopy, understory, ground). This will lead to systematic bias in the gridded values over vegetated areas - the final point2dem weighted average elevation for the output grid cell is not the top of canopy and not the ground, but somewhere in between (excatly where depends on point density).

The example in Figure 7 A/B shows vegetation bias in blue with relatively small areal coverage (maybe 5%), so it shouldn't impact the robust co-registration approaches used (automatically eliminate outliers). But using the same strategy will have a much bigger impact for other sites with greater vegetation cover (>20-30%).

I'm not suggesting reprocessing everything, but please be careful of this in the future - either isolate first returns from the lidar point cloud to create a DSM, or mask vegetation during co-registration. You can then perform the same analysis using the unmasked products, which will show the important dh difference over vegetation. Hopefully that makes sense.

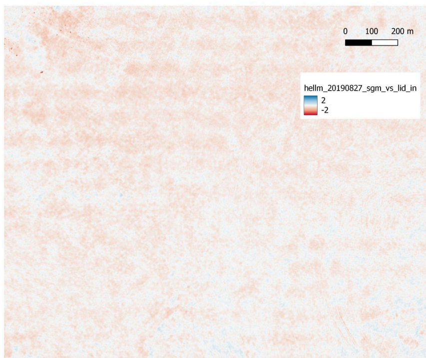
We take good note to be careful about this aspect in the future. The Canadian team (from ACO) usually generates the DEMs only from the ground returns. Because Pléiades DEMs typically map the summit of the canopy (or an horizon between the canopy and the ground), we processed the lidar pointcloud differently here. Figure 7 shows that Lidar and submeter stereo "see" the vegetated terrain very differently (we note that these differences will vary between seasons). We agree that a global vegetation mask could be systematically (and relatively easily) added to the coregistration. Added to the PGO improvement list.

Fig 7 - NMAD for BM and SGM compared to lidar for Hellstugubreen

I think the authors misunderstood my earlier comment. It appears that there is larger residual horizontal geolocation error in the BM product compared to the SGM product, likely introduced during the independent co-registration process for each. Please check the translation vectors for the dh maps used to produce 7c and 7d - I can't do this because the products involving lidar data are not available (which is fine, but limits reproducibility).

I'm having a hard time understanding how the on-glacier NMAD values in Table 3 for the Hellstugubreen BM DEM (0.12 m, Fig 7c) is lower than the on-glacier NMAD for theHellstugubreen SGM DEM (0.15 m, Fig 7d). Just looking at these difference maps (with identical color ramp), there appears to be more spread in the BM dh product than the SGM dh product (reproduced above for clarity). I'm wondering if there was potentially a mistake in the analysis/plotting code or labeling in the figure? Maybe double-check, and if necessary, modify the statement on linked 364-366:

We checked the NMADs (because we were also surprised by this result) and can confirm our numbers. This is the illustration that a color scale/representation can be misleading or, rather, not reflect the statistics. Below we zoom in on a very smooth area of Hellstugubreen, away from any crevasse field. These subsets illustrate very similar noise levels in the two correlation algorithms. As these smooth areas occupy most of the glacier, this likely explains why the NMAD are similar.

	
Zoom on the block matching (BM) elevation change map for Hellstugubreen	**Zoom on the semi-global matching (SGM) elevation change map for Hellstugubreen**

492 (Fig 10 caption) - "mass balance estimates" instead of "mass balances"

469 - same

Corrected twice.

New References

Terratec AS: Rapport for luftbåren laserskanning. Langfjordjøkelen 2018, 14 pp, 2018.
Terratec AS: Rapport for luftbåren laserskanning. Gråsubreen 2019, 14 pp, 2019a
Terratec AS: Rapport for luftbåren laserskanning. Hellstugubreen-Memurubreen 2019, 14 pp, 2019b.