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Interactive comment on "Glacier topography and elevation changes from Pléiades very high resolution stereo images" *by* E. Berthier et al.

Anonymous Referee #2

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The manuscript "Glacier topography and elevation changes from Pléiades very high resolution stereo images" of Etienne Berthier and others provides detailed technological and methodological information for glacier thickness change determination from data of the very new Pléiades satellite. This concerns in particular DEM extraction and data post-processing from these very high resolution stereo images. It is of high interest for glaciological related work with this very new available data and underlines the high potentials of this sensor for coming research activities. Overall, this study provides results that are of high interest for people that are dealing with Pléiades DEM extraction and their post-processing as well as for coming glaciological research activities. It emphasizes the suitability of Pléiades for geodetic mass balance estimates from optical stereo data in very different topographies.

This is clearly a competent and amazing study, and I would recommend this manuscript for publication after revision process. Please consider in this regard my general and specific comments:

GENERAL COMMENTS

- For me it is not 100% clear what the stated objective of this manuscript exactly is. It is great in regard of Pléiades data processing and comparison for the determination of glacier elevation changes, but it is submitted to a journal that is more interested in glaciological findings. Apart from the high quality of methodological and technological description, what are the core glaciological findings and conclusions that result from your work? What could moreover be of particular interest in regard of the scope of this journal?

- The introduction focuses on geodetic mass balances from various remote sensing data, so I would expect the same for this paper with Pléiades as the core result. Why was the study not conducted to an end for more glaciers in the difference image of Pléiades to SPOT-5? Two mass balances were calculated, but there are more glaciers in this region. The section of geodetic mass balance determination is in general pretty short. You have great data and results, so readers would be surely interested in further glaciological results.

- Please overwork the structure of this manuscript. Make it more clearly by re-arranging and shortening sections chapters. Cross-references to subsequent text passages make it hard to read. Sentences particularly at the beginning are often long and phrasing in such cases is complicated. There are often long and multiple parentheses even in one single sentence. Please try to avoid too many parentheses in the text if possible. I would prefer shorter and more precise sentences to easier extract your information (e.g. P4852, L15-22).

- Several parts of this study are extensively described (e.g. about the NMAD and the settings of PCI), but other important parts are in my opinion too short. This concerns

for example DEM post-processing with quality assessment and outlier detection to the final mass balance.

- You did not fill DEM voids, but there was no statistical evaluation of extracted terrain values conducted in order to exclude DEM pixels of poor quality. How was outlier detection employed? This is surely an issue in glacier accumulation zones were terrain extraction might be hampered due to low contrast. I would still expect areas of poor elevation estimates in snow covered glacier areas despite the sensors high radiometric resolution (12-bit). The study sites "Tungnafellsjökull" and "Astrolabe" show in Figure 2 low contrast alterations. A hillshade of your extracted DEMs in general, but particularly at these areas would be interesting to see. Low contrast alterations might be also an issue in the DEM of SPOT-5 that you used for differencing. You can generate an additional score channel image when extracting a DEM with PCI which provides information of the correlation coefficient for each extracted DEM pixel. Wouldn't it be advisable to use a correlation threshold for the exclusion of poor quality terrain? I wonder how good this correlation coefficient would be in snow covered areas of Antarctica.

- In comparison with Pléiades, you used a lot of different data at very different study site. Once with LIDAR, once with SPOT-5, sometimes with and sometimes without GCPs... This can be confusing for the reader and it is not always easy to correctly relate the data and sites to each other. So you should try to make these things a little more clear in your text what is probably not easy.

- Horizontal co-registration: Why did you not follow horizontal co-registration according to Nuth and Kääb (2011)?

- Vertical co-registration: Figure 3 indicates that your Pléiades DEM is sort of tilted related to your reference surface. Same is in my opinion still visible in Figure 6. In this regard you mention spatially-varying elevation changes that are however low (P4859). Instead of reducing the mean offset of elevation difference, why did you not calculate a linear trend surfaces to evaluate and remove your tilt as probable result of satellite

attitude parameters? I am not sure, but maybe a polynomial trend surface of second order might be also suitable to correct for eventual further systematic influences that caused these offsets.

- The chapter of "Pléiades stereo images (2.2)" is very informative, but quite long, can you shorten it and make it more precise? It is quite technical for the scope of the journal, but surely of interest for glaciologist that intend to work with this data. I also ask myself if part of this information should not be better discussed in chapter 5, "Discussion and conclusion", which is by the way relatively short compared to the other chapters. Particularly your text from Line 21(P4858) to Line 8 (P4855) has not much to do with Pléiades imagery itself, but with the specific data which was used in this study and which is well explained in Table 1. Maybe make a new section for it. Line 9 to Line 19 on this page (P4855) is about uncertainty estimation and should be placed elsewhere.

- Captions of tables and figures are generally too detailed, please provide such information somehow in your manuscript text in order to make the captions more short and precise

- In regard of your GCPs, how was their distribution in the scene? Isn't this an important influence factor how equally well distributed these GCPs are in your DEM? Where all of them clearly visible in the data?

SPECIFIC COMMENTS

P4851: L7: What kind of validation was employed? Rather study sites? L10-11: For what study sites you used GCPs? L13-14: What do you mean with "around these biases"? L23-24: Why welcome? I don't think this the words "tools" and "welcome" fit to the context

P4852 L5-9: Sentence too long and therefore complicated L15-22: Sentence way too long and also too complicated also because of parentheses. There are five paren-

theses in one sentence which is hard to read. L22-24: What gap do you mean since Pléiades DEMs can be extracted at high resolution?

P4853 L1-4: Pléiades-data by ISIS of CNES was available after the launch and not immediately for all European researchers (particularly those that are not affiliated to ORFEO member states) L19: "... launched on..." L20-23: Again, too many parentheses with long text make this sentence hard to read. Try to avoid such parentheses and include their information as part of the sentence

P4854 L25 (P4853)- L4: Too long parentheses, hard to read. Form new sentences... I think 12 bits should be clear and must not be explained in particular L6-9: You are quite sure about this statement, based on the higher radiometric quality of Pléiades. But still, can you state it in this way? L10-11: Don't use the expression "thanks to". Include "along-track" and "pitch" as part of the text if possible... just in general, I am not against parentheses, but there are just a lot of them your manuscript. L11-12: Please make it more clearly since you probably only mean the data of your study. Since Pléiades triplet-stereo images are also available for other parts of the world... L12-16: Again the parentheses issue... and I would not provide such a long URL at this place due to readability. Maybe it would be of interest as additional information somewhere else? L16-L20: Particularly for the second sentence, can you provide a reference for this? L21-L8(P4855): Much information is here provided about Table 1, and in the caption of table 1 there is also much information given . Try to fuse both information and make it more precise. Remove or omit unnecessary information that is not essential and that can be easily extracted out from the Table. Moreover, some of this information might be maybe better placed elsewhere in your manuscript. L22-25: Try to include the parenthesis as part of the sentence

P4855 L9-10: I have problems to correctly understand this sentence. I understand that all elevation differences are errors in the Pléiades DEM. This would mean that there should be no elevation differences at all, what is right on stable terrain, but not on glacierized areas. L8-19: This section concerns DEM uncertainty estimation and

should be placed in a separate chapter, maybe elsewhere. L10-14: Make multiple sentences out of this single and complicated sentence. L14: I do not clearly understand what upper bound does mean

P4856 L1: To what extent was the result not improved? The DEM should be as double as fine as with 4m I think... L6: Cross-reference to subsequent text makes it hard to read. Is it possible to re-arrange your chapters to make reading more fluent? L11: PCI can generate an additional score channel image when extracting a DEM to assess the correlation coefficient for each extracted DEM pixel. This can be another metric to describe the DEM quality. Why have you not considered this option? L22: "Statistics after horizontal co-registration... ". Why did you not employ both horizontal and vertical co-registration to calculate the statistics afterwards? L23: Why did you not used the methodology of Nuth and Kääb (2011) for horizontal co-registration? L28-L2 (P4857): What does detectable horizontal shift mean? How have you conducted this verification? Visually? Of what magnitude were these shifts, particularly when you mention "small shift" on L2?

P4858 L5: "...prominent features such as large boulders..."? L21: "The last column of this table...". Make it a little more clearer that this and the previous text is still referring to Table 3 L11-L24: Your approach with tiles is good, but why did you not calculate trend surfaces to evaluate the spatial pattern of these varying errors? It would be interesting of what polynomial degree this trend surface is, should be linear in case of satellite attitude recordings, isn't it? This section is quite detailed and long, and again explained in the caption of Figure 3, you should shorten it I think.

P4860 L3-8: Try to reduce these three parenthesis L16-21: Precision of Pléiades DEMs: In your study you have a very good reference surface and the resolution of your DEM is probably well adapted to the resolution of this DEM reference. So I would not expect considerable curvature effects and dispersion as result of different DEM resolutions in your study which is well proved by your low NMAD. You argue that precision is more influenced by the landscape than by the DEM processing what is surely right.

I might be wrong, but what about the precision in regard of my statements for the other studies that you mention?

P4861 L5-25: Maybe I misunderstood, but you generally have employed correction of spatially-varying elevation errors to correct for mean vertical biases? Make this maybe more clear L26: Write out the abbreviation for TP or explain

P4862 L6-11: Why has a nadir/back-pair stronger distortions? I would expect this for backward/forward views, probably you meant these views, since in L11 you again mention nadir/back. L11-15: The way you combined both DEMs is good. But why did you not use the DEM pixel that obtained the higher score? You can use such a setting in PCI (Score channel). Then you would not use the mean elevation, but the elevation value with the higher quality. L21-L23: What do you mean with homogenous? Did you observed that vertical biases showed less "noise" in regard of their spatial distribution, or was it less systematically and trend-like?

P4863: L12-16: How good is the agreement? Try to include the parenthesis in your sentence

P4864 L9-14: You observed thickening in the accumulation zones. I would expect that there are DEM elevations in such snow covered areas which are of poor quality because of high saturation, despite the high radiometric resolution of Pléiades imagery. Terrain extraction might be hampered in such areas and when regarding your difference image in Figure 5 I wonder if obviously high noise of difference elevation values in these accumulation zones are not an indicator of such worse DEM pixels.

P4865 For geodetic glacier mass balance determination, have you conducted some statistical analysis to exclude outliers of elevation differences within your glaciated areas? In Figure 6 I remark some noisy areas of elevation differences within your glacier accumulation areas. Also, have you filled gaps within glacier areas particularly in the accumulation zone? To my understanding I would first try to eliminate described outliers and then fill remaining gaps of elevation differences for each glacier. Then I would

calculate the mass balance from the gap-filled and cleaned difference image for each glacier. What do you think? You difference a SPOT-5 DEM for your Pléiades DEM. Due to the worse radiometric resolution of SPOT-5, I particularly wonder how good its quality is particularly in such snow covered glacier accumulation zones.

P4866 L2: His name is Kropacek (I omitted the accents here)

Table 1: You mention for the format of the datum is DDMMYYYY, but in the table column "Pléiades date" is written DD Month (not as number) YYYY. There are too many parenthesis in the caption text. You explain B/H-Factor very well, but better do this in the manuscript text. On the other hand, I would be interested what "Stop and Go" GNSS exactly is.

Table 2: Parameter settings are particularly the case for PCI software, no other software. You tested various settings, but in regard of terrain type and DEM detail you only tested the most extreme settings which are not the default settings (for terrain type). What about the other terrain types (e.g. hilly) and DEM detail settings (e.g. extra high)? Also this caption text is quite long, explain some details maybe in the manuscript text.

Table 3: Which settings were finally used?

Table 4: This is obviously the most important table, but I have problems in completely understanding it. You mention that the front/back views were often not applicable, so maybe it is not necessary to mention it here. This table mentions the accuracy / precision measures of your DEMs. Which are the final and valid uncertainty estimates of your work? You provide here different values depending on the number of GCPs and your image combination. What was finally used or can be seen as valid? Why do you provide these values on-glacier and not strictly off-glacier? For some study sites you provide both, but for some sites only for on-glacier surfaces. I would not expect accuracy estimates from on-glacier surfaces... or I do get something here completely wrong...

Figure 2: Your ortho-images are pretty small and do not show much information to my opinion. In some of them it is hard for me to get an idea of the terrain and the environment. You should not use a similar color for your scale bar and for the limits of the Lidar DEM.

Figure 3: Nice looking map! I wonder for the most south-eastern tile, this is covered by almost no values of your difference image. From a statistically point of view, how can you be sure that 0.10 is representative for the median when there are only very few values?

Figure 4: The scatter plot is comparably small compared to your difference image, particularly in regard of the pretty thick scale bar. You should adapt the colors that you attached to your elevation changes. I think it is not a good idea to use two different colors (red and blue) for only negative values. Blue communicates ice mass gain, what is not the case here. Better use only the red color. Why is the highest loss a much larger class (-7 to -4.5m)? Better mention more as -4.5m loss.

Figure 5: It is generally good, as you also did in your other figures, to provide the entire difference image and not to cut the glaciers. How confident / trustable are the difference values particularly in the glacier accumulation zones? What about outliers in regard of the noise of elevation differences in this region? Please have in this regard a look to my comments that I made for P4864 and P4865. The triangle signatures in this figure are hard to see. I think a hillshade in the background (here instead of SPOT-5) in combination with your difference image at a certain transparency would improve its quality. I remark gaps in this difference image, where are they coming from? Is it because you did not employ void filling during DEM extraction? Have you filled these voids by some way in glacier areas for mass balance calculation? From a cartographic point of view, it is not good to use more as about seven to ten different classes, because it is then hard to correlate the colors from your scale bar to the map. Or use a continuous color scale bar instead when having many classes. Use <-7 and >+7 instead of the maximum value of +-22.

Figure 6: Please consider similar remarks as for Figure 5 in regard to the scale bar and in regard to outlier detection of poor quality difference values. This is particularly in regard to differencing from a SPOT-5 DEM at worse radiometric quality. Why have you not used a background image at all (I would prefer a hillshade)? The inset figure is too small, the text and numbers in this inset figures are almost not readable. Same for the text boxes in the main figure, they are too small (or the figure is simply not large enough here). I also wonder in regard of the stable (non-glacier) terrain, some of it is quite blueish (too high), particularly to the north and south, and to the east it seems that stable terrain is quite redish (too low). When regarding your color scale bar, I would expect this at a magnitude of about +-10m. Is there still some spatially dependent offset existing, maybe a tilt? What could be the reason of it?

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