Answers to "Letter to authors"

Thank you for the review and summary of the referees reports. We also want to thank referee#3 for reviewing our manuscript and his comments. Below please find our responses to your suggestions. The revised manuscript is attached below wherein all changes we made are marked.

Suggestions:

1. Increased conciseness in places and providing insightful, quantitative comparisons with other published work would substantially strengthen the paper and increase its impact. As a suggestion, that I also share, referee #3 proposes: "the introduction provides a number of other scenarios where time-lapse photography has been used, but this is done in a somewhat descriptive list-like manner (paragraph 3, Page 2). A more critical analysis of these preceding works (and this maybe only really needs to be of the glaciological ones) would help put the authors' contributions in better context. For example, the basic details of the papers could be collated in a table - e.g. to list process being monitored, stereo/mono, image interval/duration, feature or area matching and algorithm, approximate accuracies achieved etc., - then the key advantages/limitations of these works discussed in a way that highlights how the authors' advances addresses particular limitations. Image registration/camera stability is an obvious area in which previous authors have done work; a clear recognition of this would enable the quality/flexibility of the approaches covered in the review to be discussed/compared rather than just described.

   We fully agree with referee #3 that a review paper on the subject has not yet been written and that it would be of high interest for scientists in this field. We ourselves would highly appreciate such a paper. But the paper we submitted was not primarily meant to be a review paper, it was rather written as a methodical paper introducing our approach of terrestrial time-lapse measurement. The manuscript has undergone an intensive review already and the first two referees now agreed to it.

   At this stage, we do not want to completely change the focus of our paper by turning it into a method review. We understand that the proposed table would be a compromise to somehow refer to referee#3's main comment.
   But each measurement application is very different: There are reasons to use high resolution or low resolution cameras, wide angle lenses or narrow angle lenses, camera housing with optical glass, simple window glass,... Beside these technical specifications of the measurement setup, the measurement results are influenced by the objects size and velocity, the terrain and the weather conditions of the measurement set. The scientific question defines the recording time interval, the absolute time of observation and the accuracy requirements. It seems impossible to condense all this into a table, and as a consequence such a table would also earn criticism. Therefore we would prefer to leave it with the "descriptive list-like manner", in order to give the reader an overview who else has been working on the subject, but without claiming completeness.

   How much better are the authors' camera registrations than those achieved by others?

   We stated that if we calculate the DEM and the camera orientation together in one adjustment, this will result in better accuracies for the scaled trajectories than for the registration of an image sequence to an external DEM (usually done via spatial resection on the basis of corresponding points, that need to be defined in the image and on the DEM). This is a qualitative assessment that can be made by considering the fact that in the case of a bundle adjustment that integrates the time-lapse camera each object point of the DEM contributes to the image registration whereas in the case of the external DEM only the

measured corresponding points will do so. Furthermore, the errors of an external DEM will have an influence on the image registration and thus propagate into the measured trajectories. A quantitative comparison depends very much on the actual application and can only be made if the different methods are applied to one and the same measurement object.

What do we need to do to improve things?"

More research of course … ;-)
This is a question, which also can hardly be answered in general because it depends on the individual conditions of a specific measurement task as described above. Reliable energy-saving high-resolution camera sets would help a lot in many applications – but this is not primarily a scientific problem. On the algorithmic side, future research might for instance look deeper into feature-based image matching techniques.

2. Referee #3 suggests renaming the discussion to case studies. I'm aware the authors already changed the name of this section to discussion following a suggestion of one of the referees in the first review of the manuscript. Additionally, in page 25, first paragraph, it's already stated 'The discussion is based on the results of previous case studies on determining glacier motion data with the method presented here'. Therefore, in my opinion, I do not thing renaming the section is an essential change. Having said that, one suggestion I do thing would improve the manuscript is trying to be more critical in the conclusions, as pointed out by the referee, highlighting the advantages or advances of the authors' specific approach in comparison with similar work (as the referee commented, "Can the authors pick out the key contributions from their work (e.g. dealing with shadows) and focus on these to give a more concise and inspiring summary of their advances?").

   We shortened the conclusion and rephrased parts to highlight our key contributions. (pp. 27-28)

3. Finally, the referee also suggests if the software (stated in page 28, acknowledgments) is already available and if there is any possibility to be linked directly in this manuscript. As the referee indicated, "this would be an excellent way of providing something substantially new within the work; I encourage the authors to try and do this".

   We fully agree. The requested link is now provided in the paper on page 28. The software will presumably be available on the linked webpage by the end of this year.

<u>Minor queries/suggestions:</u>

4. P2; paragraph 3: volcanological applications could also be relevant, e.g. .papers by Walter's group on domes: 10.1111/j.1365-246X.2011.05051.x; 10.1002/2016JB013045; 10.1002/jgrb.50066; or USGS: doi.org/10.1016/j.epsl.2009.06.034; or other on lavas: 10.1007/s00445-011-0513-9; 10.1016/j.isprsjprs.2014.08.011

   Thank you! We added the aspect of volcanological applications and two of the proposed references (p.2, l.17).

5. P2; Line 32: Should this be James et al (2016)? This work dealt with very difficult imagery, for which fully automated tracking was not possible – an interesting comparison for discussion elsewhere in the paper?

   This was a mistake; we changed the year to 2016

6. P5; L5: Ensure that photogrammetry terminology is either avoided or explained carefully at first use. Here, maybe rephrase/explain ‘inner accuracy’?

   We removed 'inner' on page 5 because the term' inner accuracy' is explained on page 17, where it occurs for the first time now.

7. P6; L11: Replace ‘avoid’ with ‘reduce’.

   We changed this

8. P8; L9: The phrasing could indicate that the algorithms cited are specifically for glacier point tracking, whereas the references are for general image registration. Rephrasing would clarify, e.g. ‘A wide range of algorithms are available for point tracking in image sequences (e.g.…’
   That’s true, we changed this

9. P10; L5/19: ‘imported’ → ‘important’

   We changed this.

10. P18; L14: So which variants from P 7 can be employed with PhotoScan?

    We added the accordant information.

11. P18; L19: ‘to warrant up-to-dateness’ → ‘To ensure continued validity’?

    We changed this.