Dear Editor,

We carefully analyzed the Reviewers' comments. The manuscript entitled "Analysis of glacial and periglacial processes using structure from motion" has been revised accordingly with the comments and suggestions received by the Reviewers. In particular, we revised the manuscript focusing on the main objective that is the application of the SfM-MVS method for monitoring glacial and periglacial processes. We attach below a complete list of the comments made by the Referees and the specific reply given by the authors.

Kind regards,

Livia Piermattei

REVIEWER 1 – C504

General Comments:

NOTES	CORRECTIONS
This paper presents an application of the automatic photogrammetry technique known as Structure-from-Motion to investigate glacial and periglacial processes in the Italian Alps. Authors assess the accuracy of datasets acquired during field surveys using ALS datasets as benchmark. These techniques are of growing interest for Geoscientists and, in my opinion, the paper deserves for the definitive publication in Earth Surface Dynamics. The structure is correct, the methods are properly executed and described and results are, in my opinion, interesting for the scientific community. I include below some minor suggestions or comments that could be of interest for the authors to be incorporated in the final version of the manuscript.	The manuscript has been edited following the reviewer's comments and suggestions.

Specific Comments:

NOTES	CORRECTIONS
1) THE TITLE: In my opinion, the title does not describe exactly the content of the paper because currently the title "Analysis of glacial and periglacial processes using SfM" focus on the processes. The processes are addressed in the paper, but the focus is set on the factors influencing the accuracy of the SfM models. The time devoted to understand the global and spatial distribution of the accuracies is longer than the time used to explain the glacial and	We agree with the reviewer on the relative importance of the contributions. According to the suggestion, we changed the title in: "Suitability of ground-based SfM-MVS for monitoring glacial and periglacial processes"

periglacial processes. I suggest that this aspect should be included in a new title for the paper. Something like "Analyzing the suitability-accuracy of SfM to monitor glacial and periglacial processes…" would be more adequate in my opinion.	
2) REAL LEVEL OF GEOMORPHIC CHANGE AND LEGEND INTERVALS: In some figures (for example figure 6 or 19) present a different number of decimal places in the legend, I recommend you to be consistent and the use of the same number of decimal places for the intervals. On the other hand, the use of intervals or classes smaller than 1 m in the legend, in my opinion, is not supported by your results. I mean, if you are getting accuracies of around 1 m, using intervals from -0.05 to 0.05 (i.e. 10 cm) is below your real level of detection. I recommend fitting the legend of these figures to the real accuracy of you datasets.	We made the figures and legends uniform using two decimal places, as suggested. Regarding the choice of the interval of the elevation differences between the SfM-MVS DEMs and the ALS DEM, we tried to find a good compromise between the obtained accuracy and the need for an efficient visualization of the analyzed glacial and periglacial processes. Therefore, we decided to distinguish the positive and negative values using intervals lower than 1 m for both case studies. Different intervals for the two surveyed areas were chosen according to the different resolution and accuracy of the SfM-MVS DEMs. For the glacier we extended the interval around zero to +/- 0.25 m; for the rock glacier we changed the interval to +/- 0.10 m. While the overall accuracy is limited, as correctly noted, rather in the meter (or a bit better) domain, there are still large areas, where conditions are better, and the accuracy is higher. Thus, also large areas with differences below +/- 10cm are given. With the legend we do not want to claim, that we can detect 10cm differences everywhere.
3) 3D SURFACE CHANGES: The estimated changes among the different DTMs are assumed to happen in a predominant way in the vertical direction, i.e. the vector of change is normal to the horizontal plane, which is not very often the case in mountainous and glacier landscapes. It is well known that DTMs are not real 3D records of the landscape. In my opinion, the use of an analysis based on 2.5D datasets (DTMs) instead of 3D actual approaches should be justified and discussed on the manuscript. In your case it is quite a simple issue because the most interesting area for you is the glacier that presents low slopes and changes tend to happened in the vertical direction (which is the one that you assume when you use a DoD approach).	In this paper we analyzed i) elevation changes and ii) surface displacement rates. The first is computed along the vertical direction, by definition. The second is calculated in the horizontal plane, and are not the result of DoD. 3D displacements in rock glaciers are the result of vertical and horizontal components, but in our case only horizontal components were of interest. Sentence and reference added in Section 3.3.
4) LINE OF SIGHT ANALYSIS: The analysis of the relationship between the line of sight and	As suggested, we calculated the mean of the incidence angle considering 5 representative

the elevation difference is limited to the line of sight for a specific camera (five camera locations); however, I guess that from a methodological viewpoint it would be logical to investigate the average incidence angle for a cell (estimating the average angle using every camera) and the Z difference. Additionally, the number of times every pixel is visible from a camera can explain a part of the variance in Z differences. This analysis would be interesting, otherwise you could justify that the selected camera is representative of a number of camera poses.	camera positions. We analyzed the relationship between the viewshed analysis and the elevation accuracy considering all camera positions.
5) DTM, DEM and DSM: Along the paper, the DTM term is used to describe the gridded model resulting from the processing of the point clouds. The term DTM is widely used to describe models representing different topographic attributes (i.e. elevation, slope gradient, curvature, etc.). In this line, the term DEM is specifically used to describe the DTM that represents the altitude and the term DSM is specifically used to describe the Digital Surface Model. I recommend to use the specific acronyms in the text to avoid misunderstandings.	We used the suggested terminology changing the acronyms from DTM to DEM.

Technical corrections:

NOTES	CORRECTIONS
L5-P4, L10-P4, I suggest the use of uppercases for "lidar", please extend this to rest of the manuscript.	Ok, modified accordingly with LiDAR
L9-P4, I suggest the use of consumer-grade or conventional instead "common".	Ok, edited.
L22-L26-P4, In general and along the manuscript, I suggest the use of the passive voice instead of the first person style. For example, L6-P13 (1357) "the accuracy of the photogrammetric reconstruction for the different substrata was investigated" instead of "WE : : :".	Ok, modified accordingly.
L23- P5, I suggest the use of "repeated" instead of "repeat"	Ok, edited.
L17-P7, You refer to Figure 4, however, in the list of figures, this figure presents the workflow instead the location of the camera, and I guess	Ok, modified accordingly.

you refer to figure 5, please check.	
L29- P11, I suggest leaving out the last sentence about the unfavorable line of sight because later, you will state that there is not significant relationship between the incidence angle (line of sight to normal vector) and Z differences.	Actually we found a significant correlation between the mean of the incidence angles and the elevation differences, so we kept this sentence.
L29- P11, I suggest trying to explain this 0.41 m mean value for 0-10 degrees of slope areas using the visual and physical properties of the materials. Probably differences in texture or any other aspect are causing this value to be higher than expected.	The role of the surface texture and unfavorable line of sight is already mentioned in the text. We edited the text to improve clarity.
L15- P17, longer than what? I suggest the use of "long".	Ok, edited accordingly.
TABLE 5: please check caption: ": : : stable are off: : :" .	Ok, fixed.
FIGURE 1: I recommend a thicker line to delineate the glaciers.	In our opinion the line is thick enough, but we will consider thickening it when we have the final layout of the figure.
FIGURE 5: I understand that you are using the same north arrow and scale bar for the a) and b) maps and I recommend you to include these between the two maps and not inside b).	Ok, modified accordingly.
FIGURE 6: please use the same number of significant decimal places in the legend. On the other hand, and according to your methods. I think is not justified the use of intervals in the legend smaller than 1 m, you are using a DTM of 1 m pixel size and your estimations of the vertical accuracy of the SFM-DTMs clearly point out to a level of detection of geomorphic change > 1 m.	Ok, we changed the decimal using two decimal places. Regarding the choice of intervals, please see the comments above in "Specific comments (2)".
FIGURE 7: For me it is very difficult to understand figure 7 in its present form. The lines of the profile are superimposed and even in the zoom window, it is difficult. I do not understand how you include camera locations in a 2 dimensional plot.	We fully agree that the lines of the profiles are superimposed, because there is no exaggeration of the elevation values but we maintained the same scale for both axis. However, the plot on the bottom show the differences between the elevation profiles with large scale (+-3m). Both profiles and the camera positions were projected onto the xz-plan. We removed the inset and we added an explanation in the figure caption.
FIGURE 8: the legend of figure 8b could be located on the bottom-right part of the graph for a better visibility of the columns. The mean and the standard deviation are good parameters but I miss in your manuscript the use	As suggested we included in the plot the mean of the absolute values of the Z differences. We improved the location of the legends in the figure. Errors for high-slope areas in bare ground are likely due to residual inaccuracies deriving

of an absolute value of the differences that probably would correlate with slope. The mean value is not very rich unless you have systematics errors in your data. This is the case of high slopes in bare ground, any explanation?	from the use of natural features as GCPs. Sentence added in the text.
FIGURE 9: an interesting approach here would be the analysis of the relationship between the number of times an object is visible from a different camera and the Z differences.	We changed the figure according to the suggested analyses. The results were added in the text (Section 4.1)
FIGURE 19: please use the same number of significant decimal places in the legend. On the other hand, and according to your methods I think is not justified the use of intervals in the legend smaller than 1 m, you are using a DTM of 1 m pixel size and your estimations of the vertical accuracy of the SFM-DTMs clearly point out to a level of detection of geomorphic change > 1 m.	Ok, we changed the decimal using two decimal places for each interval. See the reply to the Specific Comment (2) for the choice of intervals.

REVIEWER 2 – C508

General Comments:

NOTES	CORRECTIONS
The manuscript by Piermattei et al. compares the outcome the use of terrestrial photogrammetry using normal digital images and subsequent Structure from motion (SfM) analysis with laser scans as a benchmark. For geomorphologists working with surface changes and movements SfM combined with careful measurements of GCPs is a highly valuable tool to address surface dynamics easily and with a high accuracy. The manuscript does not give scientifically completely new information or techniques, but reproduces findings by other colleagues, and comes up with useful recommendations. These are certainly helpful for other colleagues, especially when working in high-alpine or arctic environments. Within this respect the manuscript is a valuable contribution for the geomorph community and deserved attention. The manuscript has some issues which should be addressed before publications. I here only focus on general issues, smaller details are already addressed by the other	The manuscript has been edited following the reviewer's comments and suggestions.

reviewer and needs not to be duplicated.	

Specific Comments:

NOTES	CORRECTIONS
1. Title: As review 1, change the title, I strongly support this	The title was change in: "Suitability of ground-based SfM-MVS for monitoring glacial and periglacial processes"
2. Abstract: The abstract is lengthy and very general, you should give some major results and key numbers there (e.g. some obtained accuracies and major finding etc).	We modified the abstract accordingly, providing quantitative information about the obtained results for both case studies.
3. Focus: The focus is on the techniques, not necessarily on the interpretation of glacial/periglacial processes. It is enough to write that the measured changes are in line with field-based mass balance measurements, or the velocities obtained on the rock glacier seems ok. P. 1359, the whole paragraph is a method, and should be moved there, but I would simply suggest strongly reducing this part (along with changing the title). If you want to keep it as is, you should also really discuss the geomorphology/glaciology, but this would change focus of the paper.	According to the suggestion of the Reviewer we moved this paragraph in section 3.3 and significantly reduced it
4. Introduction: Lengthy, lots of citations, and is almost a small review. Maybe there should be a review about SfM applications and limitations in geomorphology, but this is not the focus of your paper. So I would reduce the intro, and really focus on what you want to tell the reader. Your main message is that SfM is "easy" and especially "cost-effective" monitoring for many researchers, even in difficult places. I agree, so emphasize on that, and emphasize to come up with clear recommendations, other colleagues can find useful.	We reduced the introduction as suggested, focusing on the SfM technique and emphasizing the advantages of this survey technique.
5. Case study: p. 1349, maybe "Setting" is better as heading	We modified the heading as follows: "Geographical setting and case studies"
6. Method: p 1350, l 5: This introduction is not necessary, takes only space.	Ok, we removed this paragraph.
7. Results: There are several places, you introduce new methods in the result chapter, and this is a bit confusing, like on p. 1356 and 1359. Consider to revise.	We moved the methodological parts in Section 3.3, as suggested.

For the maps of elevations changes, also consider to enlarge a bit the areas without significant changes, or give a reason of choice or the classification in the figure (Fig. 6 etc). As you of course are aware of, considering general error propagation laws, the mean error adds up, and this gives large relative errors when subtract things. Like Fig. 14, the colorless class is +- 5 cm, is this justified or should then class be bigger?	We slightly modified the figures, increasing the interval in grey color, i.e. with no significant changes. Please, see the reply to the Specific Comment (2) by Reviewer 1.
And: Be careful with the term "geodetic mass balance" for a one year period, as ice fluxes and varying snow density or re-freezing of melt water is not taken into account. The latter is certainly important on small glaciers in a permafrost environments, however, small glaciers have normally little ice fluxes, probably compensating other factors.	In the paper we estimated the geodetic mass balance from surface elevation changes, without considering other processes. In our opinion, given the specific case study, this is a reasonable simplification. Clarified in the text (Section 3.3).
8. Discussion: Could be structured with two headings: Maybe: "Data processing and assessment" and "Recommendations" or so.	We divided the Discussion according to the suggestion of the Reviewer.
9. Figures: These are certainly nice, but unfortunately totally unreadable because of small size. I had to use the original pdf and zoom 589% to read the smallest numbers :-) The only figure which is readable is Fig. 14. Therefore it is also the only on I have commented above. Only printing this is totally useless.	We agree some figure are small, in particular the legend. However, we will check appropriate figure sizes when we have the layout.
Maybe the numbers of Figures (#20!) is a bit too much, so check if some of the figures you want to give can be coupled somehow, or if all are really necessary.	We preferred to keep all figures because we consider them important for a better understanding of the results.