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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Combination of UAV and terrestrial photogrammetry to assess rapid glacier evolution and conditions of glacier hazards" *by* Davide Fugazza et al.

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Summary:

In this manuscript, the authors describe and analyse geomorphological features on the tongue of a hazard-prone glacier in the Italian alps with the help of different (close-range) remote sensing methods. They found that the merging of point clouds generated from two methods (UAV- and terrestrial photogrammetry) present the best product in order to map glacier hazards. The idea for this "data fusion" is new and potentially interesting, however it is not sufficiently described. The manuscript has nice Figures, well-displayed tables and is written in an easy-to-follow language style, that I appreci-

ated to read. However, sections are missing and there is a need for a re-shuffling work (i.e. put the information in the right sections). The authors also invested a lot of effort in the text by inserting a great deal of information but the manuscript is overall too long and needs shortening. This work on analysing glacier hazards for the population is surely valid but a stronger emphasis on its scientific relevance is needed. Due to these issues, I think this manuscript needs major revision.

General comments:

The next paragraphs of this review contain the general issues in each manuscript sections.

Introduction (Sec. 1):

- Better define the aim and workflow of your work:

The introduction section is constituted of three parts that are not well linked together. One of the main issue is that there is no clear "story" . I understand what the authors did in term of analysis but how they linked their results to the "evolution and conditions of glacier hazard" question mentioned in the title) was unclear to me. In order to better understand how the authors plan to use the remote sensing products in order to map (or analyse? This is also not clear) the different glacier hazards, including a dedicated method section would be very valuable.

- Link the paragraphs to prepare the reader and move information to other sections:

o In the first part, the two first paragraphs (Lines 27 to 63) explains changes of glacier and permafrost environment to climate change and gives examples of changes and hazards. The GLOFs are also mentioned and not mentioned again until the conclusion, which is unsettling for the reader. Maybe listing the glacier natural hazards that will be analysed in this study would be useful for the reader.

o In the section 1.1, the first paragraph (Lines 65 to 85) is on remote sensing and natural hazards monitoring (what the title promises), while the second (Lines 86 to

113) is on the general use of UAV on glaciers. These two subjects do not link together and the reader is not prepared to read the second paragraph. Maybe it would be good to include it in a new method section? This depends on the “story” you want to tell.

o The third paragraph of subsection 1.1 (Lines 114 to 126) does not include what the title suggests. Instead of a detailed text about remote sensing and glacier hazards, it identifies the research gap and the aim of the study. I suggest to merge everything (all introduction subsections) in one longer introduction and write a text that prepares the reader for the coming section (e.g. data,results,. . .), as well as states a clear research question and description of the methods used to answer it.

o In my opinion, reading about the study area (Subsection 1.2; Lines 127 to 155), in the introduction is very uncommon. I would merge it in another section (e.g. in the data section or in the new? Method section). This section however is too long and it should be shortened, containing only the information the reader needs to understand your work.

Data Sources: acquisition and processing (Sec. 2):

- Shorten the whole section:

A lot of information in this section is not crucial for the reader that gets lost. I suggest rewriting it in a more succinct way and remove text. See more details in the short comments.

- Re-order the subsections:

It is hard to follow this Sec. 2 because, the reader is starting to read a section about a new UAV survey, then terrestrial survey, TLS, control points (that belong to UAV and TLS), and finally a UAV survey again. I suggest that the different subsections should be divided per surveying method rather than the different datasets. For instance:

———————————————

2.1 UAV photogrammetry

2.1.1 Dataset 2014

Content example: Type of UAV, flights, GCP network, software to generate products (and eventually workflow), resolution of end product.

2.1.2 Dataset 2016

2.2 Terrestrial photogrammetry

2.3 TLS

2.4 Aerial photogrammetric survey

———————————————

Results (Sec. 3):

- Shorten and merge sections:

o The first part of the result section (subsection 3.1 and 3.11) is about statistics describing the point clouds, and is too long. The subsections could be merged and shortened, the number of tables and figures reduced. A large part of the text in these two sections also belong to the discussion section (see short comments).

o Some methodological description seems to be “hidden” in the result section. I suggest that the text is re-shuffled and shortened. More details can be found in the short comments.

o Part of the text in subsubsection 3.1.2 (Lines 517 to 570) belongs to the discussion section (see short comments for more details).

- Clarify “accuracy” and “comparison”:

Subsubsection 3.1.2 (Lines 517 to 570), concerns the assessment of the point clouds’ accuracy. In principle, the absolute accuracy of such point clouds can only be as-

sessed with perfect validation data (e.g. long-term precise GPS data). Each method has its advantages and drawback and thus, generates products with different kind of errors (i.e. they are all differently imperfect/inexact). Therefore, the accuracy of a point cloud cannot be calculated using a point cloud generated from another method; but a comparison can be made. The analysis performed with the help of cloud compare, looks at the differences between the 3D geometry of point cloud pairs only. I would make a clear distinction and use of these terms in the text.

- Add information:

o It is not clear how the glacier thickness information (Section 3.2 and in general) is used in the assessment of glacier hazards. Could you please provide more information in the text?

o Subsection 3.3 (Lines 571 to 602) also requires more information on how this dataset merging has been made. A method section would be useful, especially when you cite this merging be the best product to monitor glacier hazards in the conclusion. This could be a very interesting point! And maybe the main novelty of this study and should better be highlighted.

o Subsection 3.3 (Lines 571 to 602) present the fusion of two point cloud datasets. It is very confusing for the reader to switch between point cloud (Section 3.1 and 3.3) and DEM sections (Section 3.2). Can you maybe change the section's order?

o It was very unclear to me after reading the results section, why the authors performed all these different analyses (i.e point cloud statistical analysis, point cloud accuracy, point cloud fusion and glacier thickness change), when at the end (Discussion section) you present a map of the glacier hazards (location of collapse, Fig.15) generated with the help of UAV orthophotos?. Could you please better explain their link in the introduction and method section?

Discussion (Sec. 4):

- Link the discussion to the result section:

The discussion section (Lines 611 to 687) is divided into two parts: One on the geomorphological evolution of the glacier tongue and the second about glacier-related hazards and how to risk is reduced through hazard mapping. Although the information is interesting, almost none of the discussion is based on the result section, and this is what the reader expects. Can you please change the text accordingly?

- Discuss your results by comparing them to results of other studies:

Comparing the different point clouds with a) statistical numbers, b) point density and c) completeness, and judging the best mapping method based on them, follow a correct method workflow and give good results but the later are not new. There are many papers that state the drawbacks of the surveying methods in a mountain terrain e.g. that the TLS data have a lot of "holes" and that the UAV data do not represent the vertical geometry well. I would consider making reference to them and compare your results.

Conclusion (Sec. 5):

- Shorten and clarify the main message:

The conclusion (Lines 688 to 730) are a mix of different sections, that are, presently, not well linked together. In particular, a clear conclusive message is missing. My advice would be to revise this part and to include, amongst other, a short summary for how and why this study has been done, which would help to present a better " overall story".

Short comments:

The short comments are listed in a supplement .pdf file.

Comments on Figures and Tables:

I generally enjoyed looking at the figures and tables. The colors, the size and the contast of the Figures are well chosen and their appearance encouraged me to read

the text. Hereafter are a few suggestions of changes.

Figure 1: I suggest to reduce the area of figure 1a and to merge it with Figure 1b (Only one figure for the glacier's location). Can you please specify what are the black outlines and from which year? The location of the TLS standpoint would also be valuable.

Figure 2: It would be helpful to see where these pictures are located on the glacier. Maybe enlarge the glacier on Figure 1 and set the letters (a-e) at the correct location? Or make a new overview map similar to Figure 7.

Figure 3: b) A more exhaustive caption (with UAV name) and presentation of the other objects would be useful. Other that, Figure 3 does not seems to add much information. Consider merging it with Table 1.

Figure 4: Many other figures in the manuscript display the glacier tongue. Would it be possible to put the GCP location on one of them instead of creating a new image just for this? Caption: Add UAV in the caption, such as: "of the 2016 UAV survey".

Figure 5: Please increase the resolution of the image so that the GCP numbers are readable. Consider specifying the year of this survey (2016). Moreover, it would be nice to twist the images so that they have the same view angle (e.g. that on both images the GCP12 is front and GCP10 right).

Figure 6: This is a nice but large image that does not give much information. If you want to show the GCP or measuring device, part of the image can be cropped and merged in Figure 3 or another one.

Figure 7: Please start numbering with 1 on the upper left corner. The background image could be brighter. Caption: Please elaborate (e.g. Location of different glacier features or hazard-prone areas on the tongue of Forni glacier were the point cloud comparison has been performed. The background image is the dense point cloud generated from the 2014 UAV survey).

Figure 8: Figure 8 display part of the information of Table 5. As it does not show new

information, consider removing it.

Figure 9 & 10: I think both images show the same information, so maybe remove one of them? Please enlarge the numbers on the scale bars.

Figure 12: This is the same image than the background image of Figure 7 right? Either remove it and refer the reader to Figure 7 instead of 12, or show an image where the reader can see the difference between the 2014, the 2016 and the merged point cloud.

Figure 15: Please explain the differences between the red and the blue lines on the glacier. Rewrite the caption so that not only a year is given. A "N" close to the arrow would give a meaning to the arrow itself! The year of the glacier outline should be mentioned.

Table 1: This is a nice summary table but most of the useful information are already in the text. The added value to the paper is minor. Consider removing this table or merge it with Figure 3.

Table 2: The # symbols should be removed or indicate that it means "numbers".

Table 3: The last column should display the elevation differences "with" co-registration right?. How do you explain that the standard deviation values are still of several meters? This should be discussed in the discussion section.

Table 4: For the #, same comment as for Table 2. The i, ii, iii are not necessary here, or define them. Giving a volume as size is very uncommon and I suggest using area (m2). Consider merging this table with Table 5.

Table 5: Please specify that the mean and standard deviation is calculated with a function computing local point density. Same note for i, ii and iii as above. Merge with Table 4.

Table 6: Caption: As it is, the reader does not understand what the M3C2 is. Please define so that every image can be understood as stand-alone.

Table 7: The information of Table 8 is more useful in the sense that we can compare the the mean thickness change etc. over the same area of interest (of 0.32 km2). I would not include Table 7 in the manuscript.

Table 8: Remove the last sentence. The reader will usually read the text if he/she wants more information ;-)

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-198/nhess-2017-198-RC2-supplement.pdf

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