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The Cryosphere Discussions

Interactive comment on "Where are the avalanches? Rapid mapping of a large snow avalanche period with optical satellites" *by* Yves Bühler et al.

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Mapping nearly 19000 avalanches in about 600 hours is quite a feat. As somebody that has mapped many thousands of avalanches myself (although in radar images) I am very impressed by the amount of work that went into creating this unique dataset. It should be also stated that nobody has every assigned this amount of avalanche activity to a single extreme event. We often state that avalanches are rare natural phenomena, however, I wonder if this statement holds true when applying new technology to an old and seemingly trivial problem: counting how many avalanches when and where release in a given area. The field of avalanche activity monitoring using satellite data is

young and exciting and this paper is a great contribution. I am kindly asking to consider the issues that I am raising and the questions that I have in the following:

Short summary of major issues and questions: 1. Reporting of period I: There are two sections with a table and a figure introducing a lot of different data that are not used in the study. I got very curious about a comparison of avalanche detection in these different data, however, this is not done. I think the authors could consider shortening this section substantially, or even deleting it. 2. Mapping methodology: I very much believe in visual interpretation of satellite images as a sound scientific method. However, not everyone does. It would be great if you could give much more detail on how the mapping was done. I have raised a couple of questions further below that deal with uncertainties in digitizing the outlines and assigning avalanche attributes to the detected features. 3. Validation approaches: Validating satellite image interpretations is very difficult, however, highly critical if we want to install more trust in our methods from other scientific communities. The accuracy of the mapped outlines is one thing, a simple error of omission study (are the mapped features really avalanches and what are you missing?) is another possibility that I would like you to consider including. 4. In your aim of this paper you are stating that a nearly complete database of avalanche activity could be used to validate the avalanche bulletin. This is, however, missing, and could easily be added in the discussion. 5. This is a case study from Switzerland. Since satellites cover pretty much all snow-covered mountain areas worldwide, it would be interesting to read a short discussion on the potential of doing this anywhere else. Here data availability, revisit time, max spatial coverage, cloud cover and shadow problematic and also acquisition costs could be discussed.

Here are my detailed comments:

Title: I believe that the title does not entirely represent the work that you have done. Data acquisition was rapid; however, mapping took 600 hours. Is 'large' the correct term when talking about a period of time? And in the end, you are only using Spot6/7 data, so maybe you could simply say so. Maybe the title could be something like: 'Map-

ping of an extreme avalanche cycle in the Swiss Alps using Spot6/7 optical images'.

1 Introduction You are introducing the concept of AAI in the introduction. Is that of interest here to the reader? If yes, could you calculate the AAI for period II and show it in results? Thereby you could compare period II to other extreme events (1999 winter for example) and arrive at a quantitative assessment of period IIs magnitude.

2 Avalanche periods and data acquisition 2.1 Avalanche periods 2018 There are a lot of Swiss place names in this section. I – and probably the majority of readers – are not familiar with where all those places are. You could either provide a map, or leave this place names out.

2.2 Rapid satellite data acquisition period I (8-10 January 2018) As mentioned above, I am a little bit unsure if all the detailed information you are providing here is necessary to get the full story of your paper. You are introducing a lot of data in a table and a figure, however, only a very tiny fraction of it is actually used for age-tracking of detected avalanches. At the same time, this section and also 2.3 read like discussion with some valuable information about which datasets to use for mapping purposes. So I am wondering if 2.2 and 2.3 could be deleted and some of the information could go into the discussion instead?

2.4 Rapid satellite data acquisition period II (21 – 23 January 2018) Figure 2 caption Study area in the caption, however research area in the legend. Also, maybe write 'danger level 5'.

You are writing that 30 cm of snow and strong winds made avalanche detection more difficult. This is a statement that kind of contradicts the tone of the rest of the paper, stating that you have great success in mapping avalanches in optical imagery and your dataset is reliable.

3 Mapping methodology You used additional information for the mapping. How were these data layers used? Did you mask out areas that were not considered avalanche

terrain or did you blend these layers in and out?

The flow direction check, was that done also by visual interpretation or with a GIS tool?

The rechecking of accuracy of outlines and completeness. Could you give more details here as to what is meant by accuracy and what completeness means?

Could you explain in some sentences if one or more experts visually interpreted the images? If the rechecking was done by the same person as the mapping? I think this is operational implications as to whether the person mapping was an expert in remote sensing image interpretation or if this is a task that a less experienced person with avalanche background could also do?

What is meant by feasible attributes that were described and which image examples were added when appropriate? These statements are not entirely clear to me.

Figure 2: I wonder if you could delete this figure since you are showing the extent of forecasting area and study area in Figure 4.

Table 2: Description of avalanche attributes This is a great list of attributes that is of critical importance when mapping avalanche activity. I wonder when in the process this list was established. Before all the digitizing took place or after? I am missing a differentiation between dry and wet snow avalanches. Since you state correctly that wet snow avalanches are easier to detect in radar images, I wonder if the same holds true for optical images? How did you attribute avalanche trigger and fracture type to the detections?

4 Results and discussion 7.5 % of the total investigation area (you have called it also research area and study area) were covered by avalanches. It might be probably more interesting how much of avalanche terrain was covered?

Figure 3: I am very interested in which attributes were assigned to these avalanches according to Table 2. What is the quality outline of these avalanches and could you maybe indicate by different line coloring where it is exact, estimated and created? I

am in particular also interested in where the start and deposit zone altitude are and the fracture width. In example 2), the digitized avalanches show only parts of the slide path and the depositional area. Why are you not showing the start zone? How sure are you of the interpretation of the two avalanches in the shadow and is there maybe a third avalanche in the path to the left? Can you explain a little bit more in detail how the flow direction interpretation works when dealing with overlapping avalanches and indicate it in the figure?

Figure 4 and related text: I am curious about in which regions high avalanche activity was suspected. You are also talking about the effects of a high snowline in two valleys; however, I don't know where these valleys exactly are. Could you provide more topographic information in Figure 4 for all non-Swiss readers? I wonder if a shaded relief as background would improve this figure too. Finally, the examples of avalanche density per km2 appear to be transparent. These small squares are very hard to see. Could you please improve the image quality or make these squares a little bit larger? In these examples you are going from 5 to 75 % coverage in 10 % steps. I wonder if you could do the same in the map. You would end up with fewer classes which would maybe increase the contrast between classes. Or how about using the AAI from Schweizer 2003 to represent avalanche activity?

You state that the avalanches with exact outline tended to be smaller than the others. Do you have any idea why that is?

The largest portion of avalanches falls under the estimated category. Is it possible for you to quantify how much of the outline had to be estimated and what the most common problems were that led to the estimation of the outline? I am also interested which parts of the avalanche had to be most often estimated and which avalanche type?

Figures 5 and 6: This is just a minor issue; however, these two figures could be visually slightly more pleasing. Related to Figure 6, I would find it very interesting to see

examples of the different avalanche types and avalanche sizes. If it is too much for this article, maybe in an appendix figure.

4.1 Age of the mapped avalanches Where are the Mattertal and Lower Engadine valley?

Can you estimate or even quantify how many avalanches were not visible anymore after the 6 or 8 January because wind or snowmelt removed them?

Figure 7: The largest of the blue outlines seems to go uphill (from the left upper corner towards the middle of the image) and then downhill again. Could you indicate flow directions maybe? These images are very hard to interpret as it is not really possible to understand where up and down is. Maybe contours or other topographical information would help here. Are these the smoothed lines or the raw digitized ones?

4.2 Validation approaches This is a good effort to validate your visual interpretations even though the test dataset is very small. Furthermore, I think that the results from Table 4 and Figure 8 are very good and quite satisfying. However, I am wondering why you are not using the dataset of field observed avalanches in the Davos area to at least analyze how many of these avalanches you were able to digitize? Digitizing the outline correctly is one problem, however, as you state in your list of important problems and uncertainties, there are possibilities that you miss avalanches entirely or that you interpret high surface roughness wrong. As somebody with little experience at interpreting optical images I am not fully convinced that I would have found the avalanches presented in Figures 3 and 7. I would like to suggest therefore to consider doing a two-part validation: Number one showing the reader that you are capable of detecting avalanches by comparing to a field observed dataset of avalanche activity and number two the validation you did so nicely already.

Figure 8: I would be interested in seeing a comparison for the starting zone as well since you are only showing the depositional parts. Furthermore, the two Spot 6 images as background appear to have different resolution, with the left one having a lower one.

In your list of problems and uncertainties you state that some old and new avalanches were mapped as single avalanches. Do you think these avalanches were given attribute 'Yes' or 'Partly' according to Table 3?

4.3 Potential improvements and follow up analysis You are talking about using machine learning for automatic analysis. Could you expend on these thoughts a little bit more and explain how such a workflow might look like and which kind of algorithms would be suitable here. You mention that a lot of background knowledge and map interpretation skills are involved in mapping. Is there a way that machine learning could incorporate these skills too? And how confident are you that a ML algorithm could classify avalanche types?

You state that you have a detailed avalanche terrain map for Switzerland. Wouldn't it be great for this study to run this map over all your detections and see if any of the avalanche outlines are outside the avalanche terrain and thus rather unlikely to be real avalanches (given they are not very large avalanches). One could at least report on how many features where outside and maybe even visually recheck if these features were avalanches. This would be another great validation tool!

Was danger level 5 confirmed by your analysis?

What do you think about the up and coming swarm satellites and their potential for rapid mapping?

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