The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2019-119-AC1, 2019
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The Cryosphere Discussions
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Interactive comment on "Where are the avalanches? Rapid mapping of a large snow avalanche period with optical satellites" *by* Yves Bühler et al.

Yves Bühler et al.

buehler@slf.ch

Received and published: 2 August 2019

Dear Markus

Thank you very much for your constructive and careful review of our paper. Please find in the following our answers to the issues and questions you raised:

1. Reporting period:

It is true that we only use SPOT6/7 optical satellite data for the mapping of the second avalanche period. However, it was extremely important to go through the process of tasking and interpreting the other satellite datasets. Only by comparing and interpreting

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all other sensors we could come to the decision to further apply SPOT6/7. Therefore we see the chapters 2.1, 2.2 and 2.3 as essential parts for understanding the big picture. In particular in chapter 2.3 we name a lot of our findings that led to the decision to further use SPOT6/7 and that are of great interest for potential future applications. We believe this part is very interesting for the readers and we want to keep it to help them understand the scope of these investigations for our mapping. We did not further expand this part on our findings as it would be in our opinion too much detail for this paper.

2. Mapping methodology:

Thank you very much for the helpful comments you raised. We will carefully go through all the points and expand the information wherever possible in the revised manuscript to make the methodology even more clear.

3. Validation approach:

You are very right in stating that a validation of the number of missed and the number of falsely identified avalanches would be very meaningful information. We tried hard to set up a validation like this. Unfortunately, it is not possible. The reason is the quality of the manual mapped avalanche dataset of Davos for the time period needed. In the paper we already state that “For validation we were confronted with the difficulty of finding a meaningful dataset for such an extensive mapping campaign. At the SLF, avalanches in the region of Davos are mapped systematically over the whole winter from photographs taken in the field. Unfortunately, the quality of outlines generated with this technique only allows for a comparison of methods and not for a real validation. A comparison using very well visible avalanches from SPOT 6 imagery, showed that the satellite-based mapping is clearly more accurate than the manual mapping from ground-based photographs”. In some cases it is not even clear, which of the avalanches clearly visible in the SPOT6 data corresponds the one mapped in the region by hand. In ongoing studies, focusing on the mapping from 2019 where we were able to collect

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more supplementary data, we will further investigate different mapping methods and will present strengths, weaknesses and capabilities.

4. Validation of the avalanche bulletin:

In the meantime, we performed different validation approaches for the bulletin. We will add a paragraph with some examples to the revised manuscript.

5. Application in other regions:

We will add a section in the discussion to debate the potential of the presented methodology for other alpine regions.

Title:

You are right with your remark on the title. We will change it to "Where are the avalanches? Rapid SPOT6/7 data acquisition to map an extreme avalanche period in Switzerland" based on your suggestion.

AAI concept:

The AAI is mentioned because we are trying to list other methods used to capture avalanche activity. We could calculate the AAI for the time period where we expect most avalanche releases happened. Then we could compare the "normal" AAI added up for several days with our results We have tried that and as mentioned in the introduction, it shows that only a fraction of avalanches that are released are normally reported.

Local names:

We will drop the local names in the manuscript and replace them with globally understandable terms, e.g. southwestern valley etc. to make it better understandable for non-Swiss readers. If local names are used, we will depict them in a map or figure.

Figure 2:

We would like to keep this figure as it gives the readers a better resolved overview on

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the entire research area.

Table 2, avalanche attributes:

The example key/ the attributes were defined before the mapping was conducted. The attributes heavily rely on the ones used in Protools (https://www.slf.ch/en/services-and-products/protools.html) as we wanted to ensure compatibility. Wet and dry snow avalanches may not be distinguished in the mapping. Per definition the classification wet or dry avalanche refers to snow temperature in the release area of the specific avalanche. If a dry avalanche entrains wet snow in the avalanche track it still remains a dry avalanche. To distinguish these fine differences is not possible in our experience. Additionally, rain after the avalanche release will increase contrast (and the snowfall line was at times very high in our case). For those reasons the humidity of the avalanches remains unknown for the whole dataset. But we have benefited from the better contrast of wet snow for identifying avalanches just like for the radar images you mentioned.

The attribute fracture type is taken from the images. As noted in Table 2, this is only possible for old snow fractures close to the ground (as the ground will then be shining through red in the near infrared band). All other fractures are unknown as they may not be differentiated in the imagery.

As also described in Table 2, the trigger type is partly taken from the images and partly from additional information. All glide snow avalanches are natural releases as they can't be artificially triggered. Avalanches where the points of explosion are visible have been artificially released. Additional information (i.e. Protools) is used to classify remaining artificially released avalanches and natural ones especially in ski areas. The remaining avalanches are classified as natural except they are inside a ski area then they will be classified as unknown. This procedure was designed especially for mapping in exceptional avalanche situations and may have to be adapted should triggering by skiers also be an option.

Avalanche terrain:

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We are not yet there that we calculated all avalanche terrain for Switzerland. We are now calculating different regions in Switzerland, Italy and further abroad after the method of Bühler et al. 2018. So we cannot give this number now.

Figure 3:

We are showing only part of the outlines on purpose because the focus of the example to the right was to show the differences between illuminated and shaded areas. The outlines of the two avalanches in shade are estimated- the deposit and parts of the track can be identified well. Overlapping avalanche outlines occur when crowns of slabs are visible or the contrast between tracks/ deposits suggests two separate avalanches. Flow direction plays a minor role in that process. We will perform some test to find a way to display even more information without overloading the figure.

Figure 4 and related text:

High avalanche activity was suspected where very high avalanche danger (danger level 5) was forecasted. We already have tried a shaded relief as background and it did in our opinion not improve the map. So we will again try to add more topographic information without overloading the figure. As for the classes- a reduction of classes would not happen if the steps from the examples were used since the maximum value is 88%. But we could use steps of 15% to reduce classes if that is wanted, but in our opinion the 10% steps are the best option. AAI is already dealt with when mentioned the first time in this answer.

Avalanche outlines:

For smaller avalanches the probability that parts of the outline are in the shade or not so well visible is simply smaller than for the ones with longer outlines. We have no record about what part of the outline had to be estimated. But per definition estimated means that a couple of meters in-between can't be identified. This implies that part of deposition, track and release area are identifiable in an exact manner. The estimation

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of an outline might be caused by wind blurring part of the “avalanche border”, by part of the outline not being illuminated or passing under trees. The share of the different avalanche types for the quality of outline estimated is 85% for slab avalanches, 9% for unknown type, 4% for glide snow avalanches and the remaining 2% for loose snow avalanches. Concerning created avalanches, for 85% the deposit could be identified but the release area had to be created.

Figures 5 & 6:

Providing more examples would go beyond this papers scope but they are several additional examples provided within the example key that is delivered with the dataset that is available on request on Envidat (Hafner and Bühler 2019).

Age of the mapped avalanches:

The outlines shown in Figure 7 are the final and therefor smoothed outlines. We will try to improve figure 7 with additional topographic information (contour lines).

Figure 8:

The two SPOT examples have the same resolution but are shown at a different zoom level. The old and new avalanches being mapped as one avalanche laying inside the “age testing area” were certainly given the attribute partly at some point if on an image before the 24th of January the avalanche was partly already there. But as mentioned in the definition “partly” is equally applicable for avalanches in the same avalanche track with a decisively different deposit pattern.

Potential improvements and follow up analysis:

We will extend this section based on your suggestions. However We will not be able to give a detailed outline for machine learning strategies as we just started to research into this direction. We already state in the paper “We did not yet start to follow this track but we estimate a big potential for successfully detecting the 6’117 avalanches mapped with exact boundaries (33 %). For the remaining 12’620 avalanches (67 %),

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however, we estimate a low success rate as it requires a lot of background knowledge and interpretation to map those avalanches as a whole outline (see section 3)" The point on the avalanche terrain map is already answered above.

In the revised version of the paper we will carefully consider all further points you raised and try to incorporate them into the document.

References:

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