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Interactive comment on "Mapping avalanches with satellites – evaluation of performance and completeness" *by* Elisabeth D. et al.

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Dear reviewer #1,

thank you very much for your comments and suggestions for our paper. Below we provide specific answers to the processing and analysis of Sentinel-1 data. However, we like to emphasize that the paper's objective is the comparison of different sensors rather than an in-depth comparison of different radar-specific methods. For this reason, and because the paper has already a considerable length, we consider several aspects (and questions) to be beyond the scope of this paper. For a more detailed description of SAR data processing we refer to Leinss et al. (2020).

RC: Adding a processing scheme of the SAR data processing from Ground Range

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Discussion paper

Detected High Resolution (GRDH) images to local resolution weighting images would be very useful.

- Thank you for this valuable point. As input we used SLC not GRDH images. We will add this information to Table 2: Mode = (IW, SLC). Please find at the end of this comment the complete processing flow chart for processing of the radar images. We will add this flow chart to the appendix of the final paper. See also https://forum.step.esa.int/t/sar-simulation-terrain-correction-no-output-of-simulated-intensity/23513/12.

RC: It is a very good option to use radiometrically flattened and terrain-geocoded SAR observations according to the methodology proposed by Small (2011). How the difference in observation time between the pixels of the ascending and descending image is handled?

- We use terrain flattening according to Small (2011) and used the simulated SAR image as a weight for LRW according to Small (2012) as described in the paper. The difference between ascending and descending image is 1.5 days. Because the main avalanche activity (with level 4 and 5, see Fig. 2) happened not within these 1.5 days, it is unlikely that avalanches have occurred within these 1.5 days. Instead, most of the detected avalanches must have occurred between the pre- and post-acquisitions. Furthermore, as the weight used for LRW is linear to the illuminated area (which is proportional to the (linear) backscatter intensity) the image composition follows rather an almost binary weighting (especially for non-horizontal terrain) than an equally weighted average (which is only used for nearly horizontal terrain). This makes LRW a good method for image composition and the chance to miss avalanches by averaging is very low. We will add these points to the discussion of our paper.

RC: ...and what about the differences in observation angle?

- In Leinss et al. (2020) we list reasons why the relative brightness of avalanches is stronger for slopes facing away from the radar. As these slopes are weighted stronger by LRW, LRW enhances the visibility of avalanches. We will add this information to line 25, page 7.

RC: Would it be better to merge images in this [LRW] way or to keep the ascending and descending or-bits separated (but still corrected for the radiometric effects of topography)? And then merge the binary detected avalanche debris pixels?

- It depends on the application: In our case, LRW can reduce radar speckle and can therefore enhance the apparent spatial resolution which makes detection of smaller avalanches possible, when acquisitions are selected for a specific event. For an operational application, where acquisitions are not selected for a specific avalanche event, keeping ascending and descending separate allows for a slightly better temporal resolution in the detection. By merging the binary maps, the temporal resolution is lost again, therefore, if ascending and descending is merged anyway, we consider LRW as the optimal solution. We will add this information to the discussion.

RC: For avalanche detection, areas that show an increase in the radar backscatter signal in the difference of the LRW-image before and after the avalanche event are targeted. So what is the threshold you used? Did you looked at the signal variation in an observed avalanche corridor to validate the choice of threshold?

- As shown in the attached processing-graph, avalanches were manually detected based on the apparent visual brightness and the shape and size of bright pixels. No pre-defined threshold was used as the mapping was manually done. We will clarify this in line 10, page 13.

RC: Once the pixel detection is done, I do not really understand how you go from the detected pixel to a detected event? This is an important step because it is more relevant in my opinion to look at detections in terms of events rather than pixels.

- As we are interested in a size-resolved comparison, avalanches with S1 were mapped as avalanche polygons based on the visible area of bright pixels. In some cases, polygons in the same avalanche corridor were joined to one event. See line 25-30, page 12 for more information.

RC: The month of January 2018 was exceptional in terms of avalanche activity and avalanches that were recorded on January 24 (In SPOT) may in fact have occurred earlier in the month. How can this effect be taken into account? Have you filtered the events to retain only the most recent ones?

- We agree that differing release and acquisition dates pose a challenge for an investigation as ours. In order to take these effects into account we rely on ground truth from different days in January (Figure 2). Through that we filtered the events for the desired validation period by excluding 48 confirmed avalanches from analysis as described in 3.4. Hence this effect of older avalanches distorting the results could be eliminated for 2018 (and 2019).

RC: Given the test area, some other SAR images would be suitable from different ascending/descending orbits (A117, D129) in addition to [the used orbits] A15 and D168.

- We chose the orbits A15 and D168 (IW3) because they were acquired in far-range (larger incidence angle, compared to A117 and D129: IW1). This minimizes layover and should make avalanches better visible (see Leinss et al., 2020). Note: In a paper - to be submitted soon - we have quantified and confirmed the incidence-angle dependent avalanche brightness.

RC: As you mentioned in the paper, there are areas that are less well observed using SAR measurements. And this could induce bias in the detection of debris depending on the orientation of the slope. Have you looked at the results of detections by main orientation?

- Such an analysis would be beyond the scope of this paper which focuses on the comparison of different sensors rather than a specific SAR analysis. But we propose that the avalanche polygons published by Bühler et al., 2019 could provide a good basis for such an analysis.

RC: Similarly, given the difference in observation time between ascending and descending orbits, one would also expect a noticeable difference in detection results between the two orbits, which also argues in favor of separating the morning and evening orbits.

- As argued above, LRW selects the best visible slope from each orbit. This way, the areas visible from either ascending or descending orbits are analyzed in one go. Also, as argued above, we focused our analysis on one event, not on specific morning or evening events.

RC: Regarding contingency tables, while the notion of true positive is simple to elaborate, the notion of false negative is more questionable. Because outside the ground truth, it is difficult to say if a satellite detection is "false" (difference in observation time, rain/snowfall after event, . . .).

- We have excluded all mapped avalanches located outside our ground truth from the analysis as mentioned in section 3.4. As soon as ground truth is available, the determination of true positives, false positives and false negatives does not pose a problem.

RC: Is it possible to explain the detection difficulties with Sentinel-2? Is it a matter of information content or pre-processing or band selection?

- For Sentinel-2 we believe the detection difficulties are caused mainly by the spatial resolution. The pre-processing and band selection are similar to SPOT which has shown to give good results.

RC: Regarding SAR weaknesses, I think that more effort should be put on methodologies to better isolate avalanche debris signals in images (adaptive thresholding depending on the type of surface, or efficient image analysis methods to detect signal change). These data are rich in information but unfortunately complex to use in the absence of an open and ready-to-use database of pre-processed Sentinel-1 measurements for scientists.

- There is significant effort put into processing methods of Sentinel-1 imagery for Avalanche detection at various research institutions in France, Norway, Switzerland. A detailed analysis of LRW for preprocessing including a database of radar-detected avalanches is planned, but is beyond the scope of this paper. In our opinion the apparent absence of ready-to-use pre-processed Sentinel-1 is of advantage because it provides the space for avalanche-specific pre-processing of SAR data, starting from GRDH or SLC data. "Analysis-Ready-Data" from Sentinel-1 for Switzerland might be available soon on https://www.swissdatacube.org/index.php/2018/12/05/first-sentinel-1-analysis-ready-data-ingested/.

Bühler, Y., Hafner, E. D., Zweifel, B., Zesiger, M., and Heisig, H.: Where are the avalanches?: Rapid SPOT6 satellite data 25acquisition to map an extreme avalanche period over the Swiss Alps, The Cryosphere, 13, 3225–3238, doi:10.5194/tc-13-3225-2019, 2019. Leinss, S., Wicki, R., Holenstein, S., Baffelli, S., and Bühler, Y.: Snow Avalanche Detection and Mapping in single, multitemporal, and multiorbital Radar Images from TerraSAR-X and Sentinel-1, doi:10.5194/nhess-2019-373, 2020.

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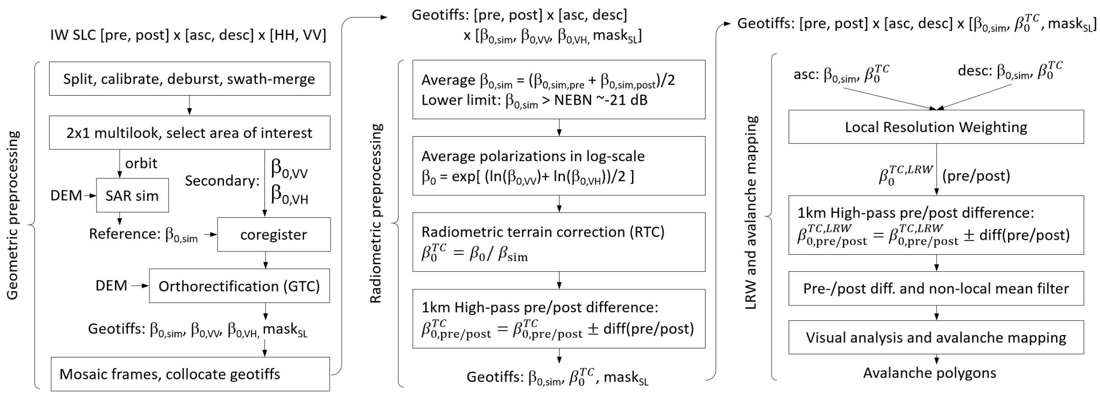

Fig. 1. Processing Workflow for the SAR imagery.