MONITORING AVALANCHE DEBRIS IN THE FRENCH MOUNTAINS USING SAR OBSERVATIONS FROM SENTINEL-1 SATELLITES

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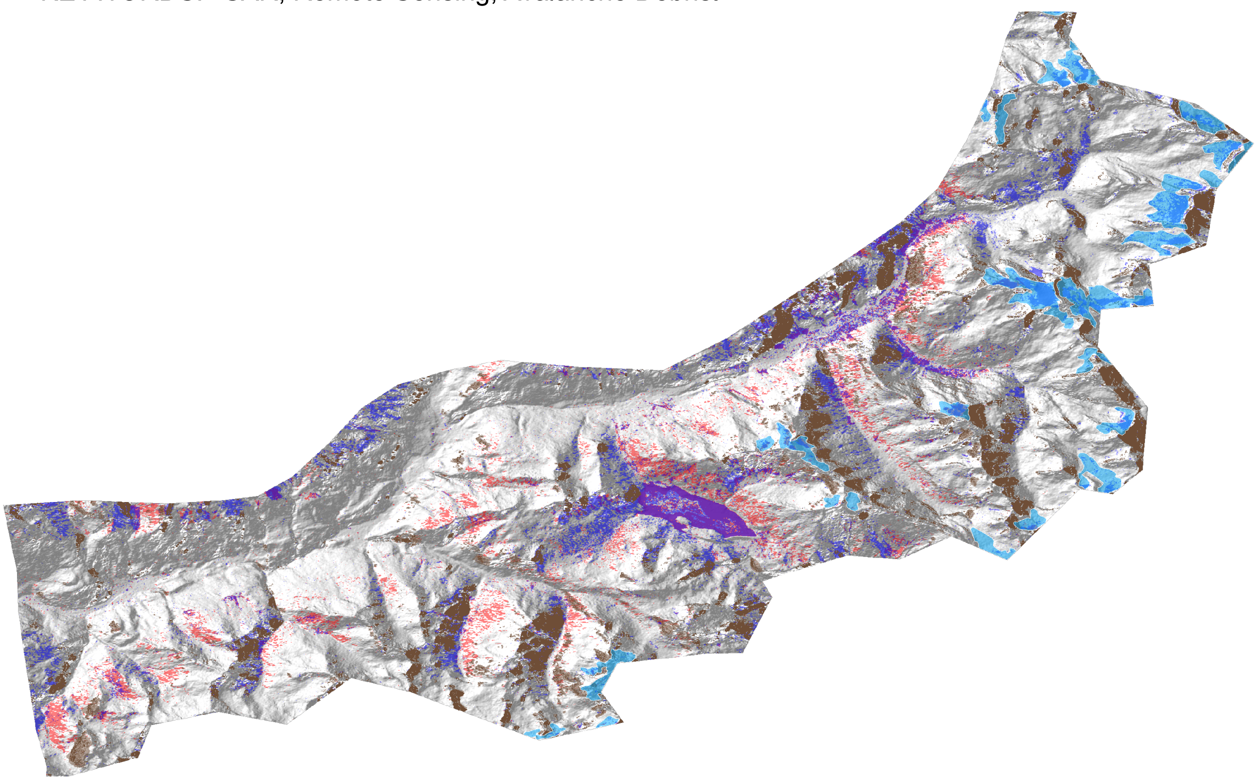
ABSTRACT: Remote sensing of avalanche debris in mountain areas offers new opportunities to improve our understanding of avalanche activity and to evaluate the physical models of avalanche hazard forecasts. The location of avalanche debris and the estimation of their sizes are of great interest for studies dealing with the stability of the snowpack and also for studying the variability of natural avalanche activity, which could be related to climate change. In addition, time series of avalanche events, with relevant time and space resolutions, would be highly relevant to better identify avalanche risk zones and periods. Such time series would complement some other existing database mostly based on visual observations (for instance Enquête Permanente sur les Avalanches (EPA) database, Sensitive Avalanche Paths (SSA), and the CLPA database (Localization Map of Avalanche Phenomena)). Sentinel-1 satellites offer a unique tool to monitor some properties of the snowpack using a C-band Synthetic Aperture Radar (SAR) with a high spatial resolution (20m) and with a revisit frequency of 6 days over the French mountain massifs. We use a change detection algorithm to isolate avalanche debris-like features based on the backscatter contrast between avalanche debris and the surrounding undisturbed snowpack. The debris detection is based on major changes in the backscatter coefficients due to changes in snow properties following the avalanche event (height, density, roughness, ...), with the medium around the avalanche remaining almost unchanged. Our algorithm has been successfully tested in the French Alps and Pyrenees. Multi-temporal evaluations between Sentinel-1 avalanche masks and available in-situ data (EPA) have been performed. An overview of the method will be given as well as avalanche detection results during the 2017/2018 season. Some statistics about the method performances will also be presented.

KEYWORDS: SAR, Remote Sensing, Avalanche Debris.



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1. INTRODUCTION

The main objective of this study is to use Sentinel-1 observations to map snow avalanche debris over the French mountains and to infer from these new products useful information about avalanche activity in mountains. Under the assumption that avalanche debris, due to increasing roughness, are associated with rather higher backscatters, Sentinel images can be used to detect avalanche features as tongue-shaped, elongated and downslope-stretching. Only few trials with Sentinel-1 data have been performed (see for instance Eckerstorfer & Malnes (2015), Dieuwertje et al. 2017).

For avalanche debris monitoring, we rely on backscatter coefficients observed using Sentinel-1 Synthetic Aperture Radar (SAR) operating at C band. It is a constellation of two satellites developed and operated by the European Space Agency (ESA) within the Copernicus Programme. In this study we used the Interferometric Wide Swath (IW) acquisition mode which is the main acquisition mode over land. We used Level-1 Groud Range Detected (GRD) products available from ESA web site (https://scihub.copernicus.eu/dhus/) with a spatial resolution of 20 m in VV and VH polarizations.

2. DATA AND METHOD

We used 4 Sentinel-1 tracks (with 2 ascending and 2 descending modes) to cover the entire French alpine region. Figure 1 shows the four Sentinel-1 Tracks used in this study.

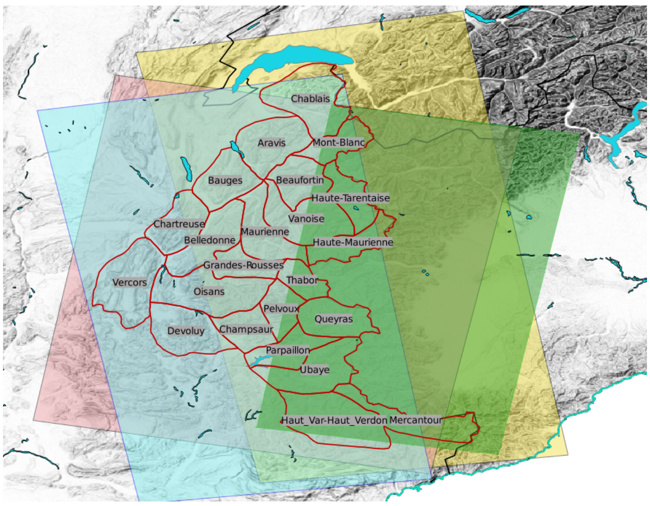


Figure 1: The most suitable Sentinel-1 Tracks over the French Alpine region: ascending modes with Track 88 (in yellow) and Track 161 (in blue) and descending modes with Track 139 (in red) and Track 66 (in green). Two Sentinel-1 slices have been assembled for each track. Red curves represent French massifs.

The French alps are commonly represented by massifs which are assumed to be homogenous (23 massifs in the Alps displayed in Figure 1). The combined use of ascending and descending orbits is essential in mountains because according to the direction of the orbit Sentinel-1 observes only some mountain slopes (west slopes for ascending orbits and East oriented slopes for descending orbits).

Dates						
	Satellite1	*Mode*	*Time UTC*	Satellite2	*Mode*	*Time UTC*
2017-12-22	S1A	Descending	05h44			
2017-12-23	S1A	Ascending	17h30	S1B	Descending	05h34
2017-12-24				S1B	Ascending	17h23
2017-12-28				S1B	Descending	05h44
2017-12-29	S1A	Descending	05h34	S1B	Ascending	17h30
2017-12-30	S1A	Ascending	17h23			
2018-01-03	S1A	Descending	05h44			
2018-01-04	S1A	Ascending	17h30	S1B	Descending	05h34
2018-01-05				S1B	Ascending	17h23
2018-01-09				S1B	Descending	05h44
2018-01-10	S1A	Descending	05h34	S1B	Ascending	17h30
2018-01-11	S1A	Ascending	17h23			
2018-01-15	S1A	Descending	05h44			
2018-01-16	S1A	Ascending	17h30	S1B	Descending	05h34
2018-01-17				S1B	Ascending	17h23
2018-01-21				S1B	Descending	05h44
2018-01-22	S1A	Descending	05h34	S1B	Ascending	17h30
2018-01-23	S1A	Ascending	17h23			
2018-01-27	S1A	Descending	05h44			
2018-01-28	S1A	Ascending	17h30	S1B	Descending	05h34
2018-01-29				S1B	Ascending	17h23
2018-02-02				S1B	Descending	05h44
2018-02-03	S1A	Descending	05h34	S1B	Ascending	17h30
2018-02-04	S1A	Ascending	17h23			
2018-02-08	S1A	Descending	05h44			
2018-02-09	S1A	Ascending	17h30	S1B	Descending	05h34
2018-02-10				S1B	Ascending	17h23
2018-02-14				S1B	Descending	05h44
2018-02-15	S1A	Descending	05h34	S1B	Ascending	17h30
2018-02-16	S1A	Ascending	17h23			
2018-02-20	S1A	Descending	05h44			
2018-02-21	S1A	Ascending	17h30	S1B	Descending	05h34
2018-02-22				S1B	Ascending	17h23
2018-02-26				S1B	Descending	05h44
2018-02-27	S1A	Descending	05h34	S1B	Ascending	17h30
2018-02-28	S1A	Ascending	17h23			
2018-03-04	S1A	Descending	05h44			
2018-03-05	S1A	Ascending 6	17h30	S1B	Descending	05h34
2018-03-06				S1B	Ascending	17h23
2018-03-10				S1B	Descending	05h44
2018-03-11	S1A	Descending	05h34	S1B	Ascending	17h30

*Figure 2: Sentinel-1 images over the French alps used in this study. * are missing data*

The study period covers the winter of 2017-2018, which was marked by a particularly high avalanche activity records. Figure 2 shows table with some Sentinel-1 SAR images used in this study. The period of study ranges from December 16th 2017 to April 29th 2018. All these relevant orbits have been pre-processed using the ESA Sentinel-1 Toolbox. The pre-processing includes assembling slices, thermal noise removal, speckle filtering, radiometric calibration and terrain correction.

3. AVALANCHE DEBRIS FROM SAR: SOME FIRST RESULTS

Figure 3 shows scatterplots of backscatter coefficients at VV polarisation extracted where an avalanche event which occurred the 9th of January 2018 near «Les Houches » around 8am. Data are extracted and compared for dates well before et juste after the avalanche event (15th of January, 21th of January) as function of summer conditions (August 25th 2017). One should notice that backscatter coefficients vary in time but the magnitude of the backscatter change is quite large when it comes to the date juste after the avalanche event (represented in red). This means that summer observations can be used as proxy to isolate situations which are likely associated with avalanche debris signature (increase in the backscatter of at least 4 dB).

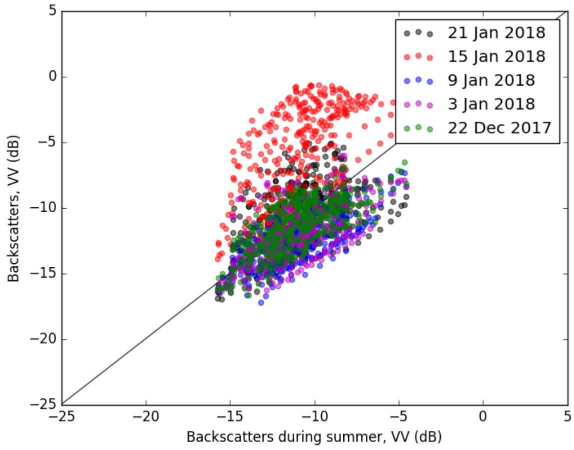


Figure 3: Scatterplots of backscatter coefficients in the location of an avalanche event for different winter dates as function of a summer observation (near Les Houches: the avalanche occurred between observations of 09/01/2018 and 15/01/2018)

To process SAR data towards avalanche debris mapping, two mains steps are needed: (1) computation of backscatter ratio between the SAR image and a summer reference (for each track) and then apply a threshold of 4 dB to select pixels likely associated with an avalanche debris event (called indicator1 hereafter). (2) Since SAR images from the same track are available every 6 days, we compute an indicator2 which select pixels likely associated with an avalanche event by comparing indicator1 computed at two successive dates: only new detections are kept in indicator2.

Figure 4: Map of Indicator1 over the Haute Maurienne massif using data from 18/03/2018 (D66 Track, descending, in blue) and data from 18/03/2018 (A161 track, ascending, in red). The gray background of the map represents relief hillshade. Glaciers areas have been screened in light blue (using Corine Land Cover product). Zones with geometric distorsion are screened in chocolate color.

Figure 4 show an example of indicator1 over Haute Maurienne massif in Savoie. Results are displayed for track D66 and A161 observed 18/08/2018 (in the morning for D66 and afternoon for A161). Maps from ascending and descending orbits show the necessary complementarity between the orbit modes (displayed in blue for D66 and in red for A161). Glaciers are screened (in light blue) as well as radar geometric distortion areas (in chocolate color). Figure 5 complement Figure 4 by zooming in the area highlighted by a red circle.

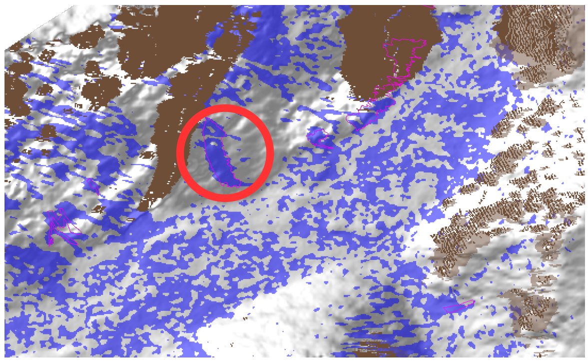
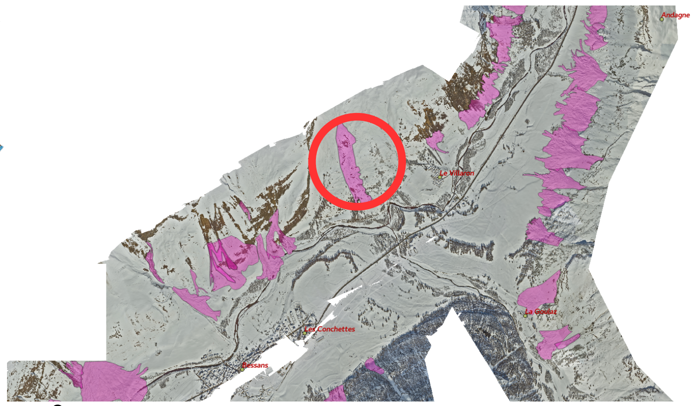


Figure 5: Same as Figure 4 but with a zoom on the red circle area.

In Figure 5 only results from Sentinel-1 D66 are displayed in blue and one could notice a rather huge avalanche debris detected. This debris has also been identified over a series of ortho-images performed by Irstea and displayed in Figure



6.

Figure 6: Series of ortho images observed near Bessans between January 2018 and March 2018. Avalanche debris have been expertise and highlighted in pink. The avalanche debris located in the circle occurs in March 2018.

4. CONCLUSIONS

An automatic avalanche debris detection algorithm is developed and is under evaluation over a wide area in the French Alps. The method combines ascending and descending orbites from Sentinel-1 satellites. First results show that the algorithm is quite relevant to isolate pixels (20m of resolution) likely associated with avalanche debris. On going studies deal with a more in depth evaluation of satellite products by comparison with other databases such as Enquête Permanente sur les Avalanches (EPA) database, Sensitive Avalanche Paths (SSA), and the CLPA database (Localization Map of Avalanche Phenomena)). The use of webcam images is also investigated. An effort is made to assess the quality of our products and to extract useful information about avalanche activity from satellite products to infer some new indicators at massif scales or higher scales. Such indicators could be of great interest to evaluate models at different scales.

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