THE USE OF SAR SATELLITE OBSERVATIONS TO EVALUATE AVALANCHE ACTIVITIES IN THE FRENCH ALPS DURING REMARKABLE EPISODES OF THE 2017-2018 SEASON.
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ABSTRACT: A good knowledge of the avalanche activity over wide mountain areas is a perquisite for accurate avalanche forecasts. This requirement is rather difficult to satisfy since target episodes are usually associated with severe weather conditions during which in-situ observations are very difficult to make. In this work, we use avalanche debris maps for the entire French Alps derived form C band SAR observations of Sentinel-1 satellites (Karbou et al. 2018) as a tool to infer the alpine avalanche activity every 6 days. We focus on the period ranging from December 20th 2017 to April 22th 2018 during which several avalanche cycles caused by strong storms occurred in winter and unusual wet snow avalanche activity occurred in spring. A cross evaluation of the satellite products against well documented avalanches events (from in-situ observations) has been performed. The meteorological conditions given by meteorological forecasts from Numerical Weather Prediction models as well as snowpack analysis/forecasts from the Crocus model have also been considered. The use of all available data and models allows relevant feedback on avalanche forecasts and also some guidance to the limits of the current version of the avalanche debris SAR product as well as potential improvements of forecast methods/models. In particular, a focus is made on elaborating strategies to better identify avalanche risk zones and periods to complement other existing database mostly based on visual observations.

KEYWORDS: Avalanche observation, .

1. INTRODUCTION

Throughout the winter season, Météo-France issue regional avalanche forecasts at a massif scale. The bulletins provide information (snow conditions, weather forecast and detail avalanche) summarized by a danger level, using the five-level European Avalanche Danger Scale. For the most critical situations, the forecasters lack information to qualify the magnitude of the avalanche activity. Remote sensing of avalanche debris could offer opportunities to improve our understanding of the spatial distribution of the avalanche events in mountain areas. In addition it could well complement existing databases mostly based on human observation with a limited representativeness.

In this paper, we use results from Sentinel-1 images provided by the European Space Agency (ESA) within the Copernicus Program. The image processing method is described by Karbou et al. (2018). The output from the algorithm called Indicator2 was evaluated over the alpine massifs and compared to a daily index of observed avalanches.

2. DATA SETS, STUDY PERIOD AND AVALANCHE CONTEXT

In this section data sets of avalanche observations from different sources and avalanche debris maps derived form C band SAR observations of Sentinel-1 satellites are introduced. We focus on some massifs located in the Northern part of French Alps during the winter season 2017-2018, from mid-December to the end of April.

2.1 Avalanche data

The avalanche data set come from the human observation network of Météo-France, mainly ski patrollers. They report twice a day information on the avalanche activity as well as on the weather and snow surface conditions. Avalanche observations are provided through an international code that depicts the number, type, altitude and aspect of the release areas, according to the type of release (natural or accidental). In this study we mainly used a daily index, based on the number of avalanches and the type of release, which cumulates events reported by all the sites located in a given massif.

Another interesting source of avalanche data is the EPA database (*Enquête Permanente sur les*

Avalanches). Field observations on more than 2000 paths are collected by forest rangers and stored by Irstea research institute. Avalanche occurrences are recorded, along with quantitative and qualitative data (runout altitudes, release cause, damages, etc.). The control of the data of the winter season 2017-2018 was not complete, so we only used it as additional information during this study.

Both avalanche databases suffer from uncertainty, error sources and other limitations due to visual field observation. Nevertheless they are complementary and they can give relatively accurate view of the spatio-temporal variations of the avalanche activity all over the season.

2.2 SAR data

It is important to mention that both descending and ascending Sentinel-1 tracks are necessary to cover mountains areas, as illustrated on figure1 by the distinct detected areas mapped in green (D) and red (A). It is worth noting that the delay between two complementary tracks is about 1 day and that coupled tracks are available every 6 days. From computed data, Indicator1 and Indicator2, we derived at massif scales the percentage of pixels of the coupled tracks as a synthetic index. In this study, we used 4 SAR tracks (2 ascending, 2 descending). A more detailed description of the data and method is available in Karbou et al. (2018).

2.3 Snow avalanche and meteorological context

The main feature of the winter season 2017-2018 in the Northern Alps was the remarkable amount of precipitation. From December to March, the average excess of precipitation reached 30% to 100% and locally more. The average winter temperature was lightly cold except a warm January. Numerous heavy snow falls occurred in mountains, often with strong to stormily wind. This winter was also characterized by several warm and rainy spells in the heart of winter, rising up to unusually high altitudes (up to 2000-2400 m depending of massifs). Snowpack was thus very different with altitude : usual below 1100m high, deep from 1100 to 1300 m, very deep from 1400 m and exceptional above 1800 m, but very irregular because of strong winds and with several rain crusts below 2400 m. Such snow and weather conditions led to numerous natural avalanches (the highest number of avalanches reported in EPA) and several peaks of avalanche activity (December 9-11 and 29-30, January 3-4, 7-9 and 20-22) during the first part of the winter. Snow melt period sped up at the beginning of April and some very large avalanches were reported.

3. PRELIMINARY RESULTS

The evaluation of avalanche debris detection algorithms usually focused on the ability to detect local events. First results at this local scale have found the algorithm developed at the CEN research institute to be consistent. Several detected shapes fit very well photos of large avalanche deposits. Thus, the goal here is to evaluate the ability of detecting a signal of the avalanche activity at the massif scale or larger scales.

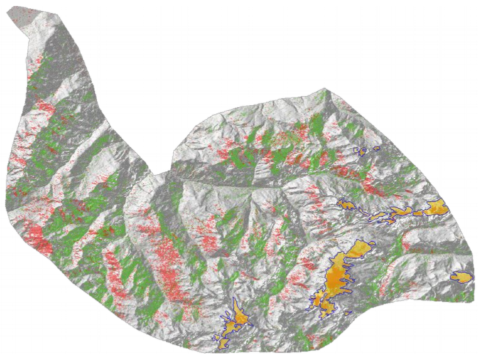

Figure 1: Map of Indicator1 over the Vanoise massif using data from 16/01/2018 (A161 track, ascending, in red) and data from 15/01/2018 (D139 track, descending, in green). Background with relief hillshade, in grey. Glaciers areas (Corine Land Cover), in yellow.

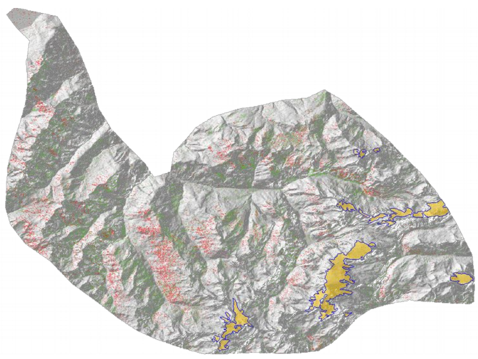

Fig 2: Map of Indicator2 over the Vanoise massif. Legend color is the same as figure 1.

In figure 2, the spatial distribution of the detected pixels seems to be different within the massif of Vanoise (more pixels detected in the West and North part). Such representation could be useful to highlight the heterogeneity within the massif in some situations. However, in that case (15-16/01/218), the diagnostic of detection seems overestimated.

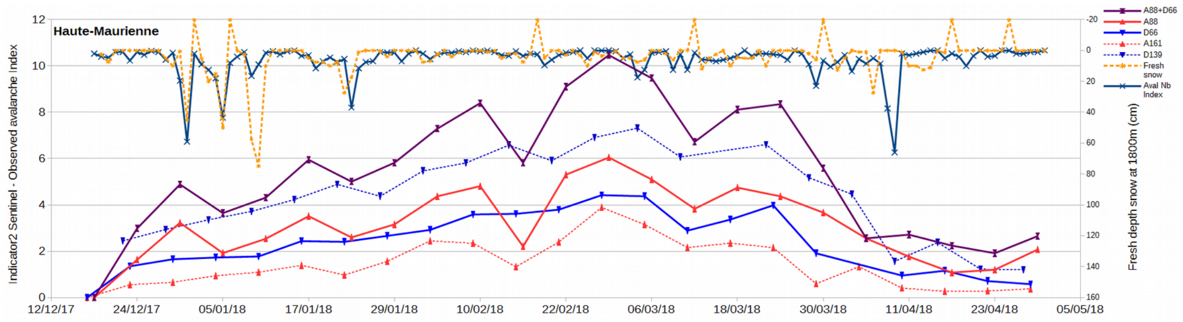

Figure 3: Time-series of Indicator2 over the Haute-Maurienne massif. Ascending tracks A88 is colored in red, descending track D66 in blue, their sum in purple. A161 and D139 are plotted in dashed line. At the top of the graph, the observed avalanche index is plotted in blue and the depth of fresh snow at 1800m in orange (negative values indicates rain fall at this elevation).

In figure 3, the purple curve, sum of blue D66 and red A88 curves, represents the evolution of the avalanche Indicator2 over the Haute-Maurienne massif for the winter season 2017-2018. For this massif, the two other images available are plotted in dashed line. The lower values on the red line (A161 track) is easily explained by an incomplete view of the massif with this track. On the opposite the persistence of a higher number of pixels detected throughout the winter with the D139 track (in blue) is more questionable.

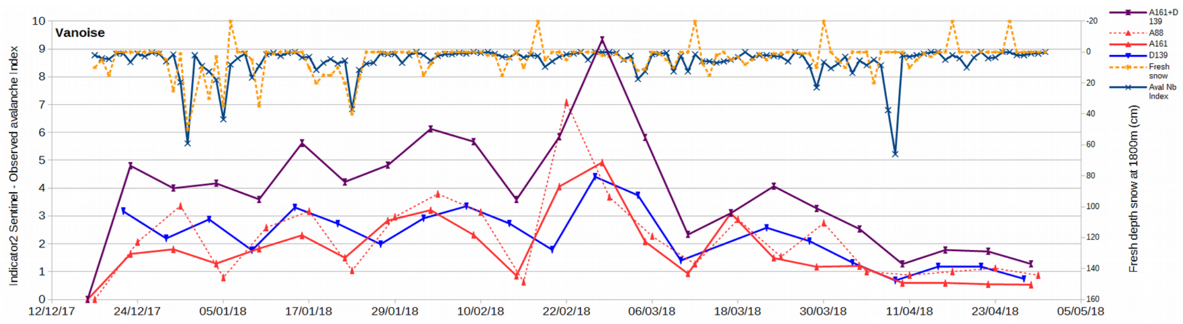

Figure 4 Time-series of Indicator2 over the Vanoise massif.

On the top of the graph in figure 3 and figure 4, time series of a daily index of observed avalanches is plotted. For the both massifs of Vanoise and Haute-Maurienne, the Indicator2 does not fit to explain the chronology of avalanche events. During the first part of the season, in December and January, the rapid succession of heavy snow falls with changing rain-snow limits have led to important changes of the snow packs. That can explain the difficulty of detection based on the comparison between 2 views spaced from 6 days. The high values that mostly remained in February and the low signal during the melting period in April show a clearer overestimation.

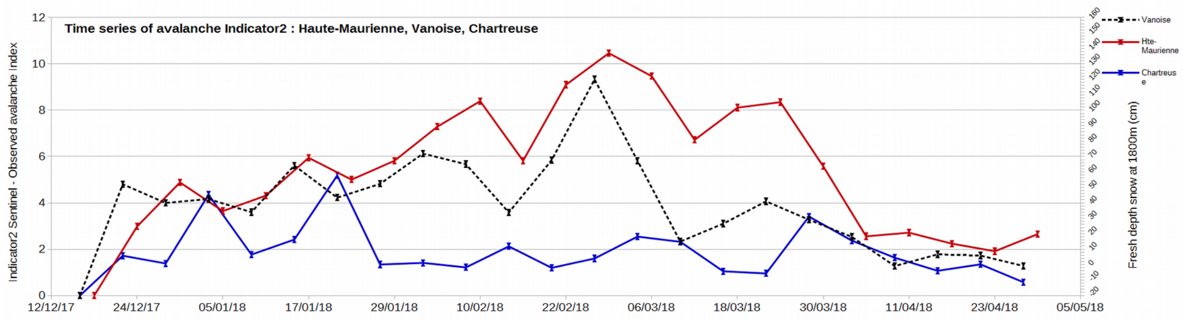

Figure 5 : Time series of Indicator2 over the Haute-Maurienne massif in red (data from D66/A88 tracks), Vanoise massif in dashed black and Chartreuse massif in blue (data from A161/D139 tracks).

In figure 5, we plotted Indicator2 over the Chartreuse massif (in blue), massif with lower elevations. It shows a lower signal and seems more relevant to detect the main period of avalanche activity.

4. CONCLUSIONS

An automatic avalanche debris detection algorithm using Sentinel-1 satellites images is under evaluation. First results show that the algorithm is quite relevant to isolate pixels likely associated with avalanche debris. However, the preliminary results of the evaluation over wide areas need more in depth studies. The main problem is probably a large overestimation of the detected pixels. Further improvements of the preprocessing are needed along with more investigations. It is necessary to have a better understanding of what could be observed, which type and size of avalanche deposit, how a new snow fall or a rain event impact the signal, etc. More in depth evaluation could be conducted at a lower spatial scale, for instance by focusing on the located path of the EPA then compared to the observed avalanches. Finally, a more accurate diagnosis could be performed while modifying the indicator, coupling it with an indicator of wet snow or adding auxiliary information to improve the quality of the detection.

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