The Seismic Detection of Avalanches: an information tool for the avalanche forecaster

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ABSTRACT: The estimation of natural avalanche activity is currently based on visual observations. However, these observations are imprecise and impossible by night, or when the weather is cloudy; consequently, the avalanche activity is often not well known. For several years, studies have been developed at the Centre d'Etudes de la Neige (CEN – Snow Research Centre), a laboratory of Meteo-France, to solve this problem and to help the avalanche forecaster, in using the possibility of Seismic Detection of Avalanches (SDA). Three stations of SDA have been operational for several winters in mountainous massifs of the French Alps, near Grenoble.

The signals recorded by SDA are analysed and identified by the software SARA (developed by the CEN) which is implemented in each SDA and the results are transmitted by satellite every hour.
In 2008, new developments have been made for the SDA system, involving notably a WIFI-ADSL transmission for the Ornon station and the implementation in SARA of new analyses to better identify the signals. The new analyses are based on the automatic recognition of narrow energy bands in the Time-Frequency-Representation, that are characteristic of some non-avalanche signals, generated for example by helicopters. The installations, the operational running of SDA and different results obtained during the last year are presented

KEYWORDS: avalanche activity, seismic detection of avalanches.

1 INTRODUCTION

During the winter, Météo France is responsible to forecast the evolution of snow-pack and give information on the avalanche hazard for the mountains of the French Alps, French Pyrenees and Corsica. To analyse the situation, the avalanche forecasters of Meteo-France have different information from models, and bi-daily observations.

The assessment of avalanche activity is provided by the observers of the snow-weather network and is currently based on human visual observations. But these observations are dependent on human presence and good visual conditions. So, they are sometimes fragmentary, imprecise, and practically impossible at night or when the weather is bad (snow, cloud, etc...). Nevertheless, reliable and rapid information on the avalanche activity is necessary and useful. The knowledge of avalanche activity is primarily useful for the forecaster to follow in real-time the avalanche activity, especially during sensitive periods or a crisis but also for having an objective feedback with regards to forecasting.

To solve this problem and to help the avalanche forecaster, the CEN (Snow Research Centre, a laboratory of Météo-France) has investigated for several years, the possibility of detecting avalanches by using the seismic method. So, a system of Seismic Detection of Avalanches (SDA), then a small experimental network of SDA are been developed by the CEN. The aim of this SDA network is to provide, regardless of weather conditions, an objective and rapid information (close to real-time) on the natural avalanche activity in some mountainous massifs of the French Alps, near Grenoble (Isère department).

2 SEISMIC DETECTION OF AVALANCHES & PREVIOUS STUDIES

Several studies have been conducted on the seismic waves generated by avalanches and on their applications in order to detect and/or to characterize avalanches, for example by the avalanche team of the University of Barcelona (Surinach, 2001; Vilajosana, 2007). A system for automatic seismic detection of avalanches, rock falls and debris flows on the road has also been developed in Iceland (Bessason, 2007).

The SDA is based on the fact that avalanches in motion, can generate seismic waves more or less strong according to the dynamics of flow, the mass of transported materials and the topography of the avalanche

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paths. But avalanches are not the only phenomenon that produces seismic signals in mountainous areas in winter and many other seismic signals can be generated by episodic events such as earthquakes, helicopters , blasts, rock falls, thunder, animals, etc,. So, avalanches represent a small portion of seismic signals recorded by the SDA during winter (on average, less than 10% on our sites).

This is a problem and it is therefore important that the SDA system should automatically recognize the avalanche signals from the other signals; hence the development of the SARA software by the CEN (SARA stands for Systéme d'Analyse pour la Reconnaissance des Avalanches or Analysis System for Avalanche Recognition).

3 THE SARA SOFTWARE FOR RECOGNITION OF AVALANCHE SIGNALS

This software was originally developed in the CEN by B. Leprettre in the years 1995 - 1998. It has undergone subsequently two phases of significant changes. In the first stage (2001-2004), the expert rules associated with fuzzy- logic, used for diagnoses in the original version, have replaced with conditional rules defined for parameters which are specific to each type of event. In 2008, a new analysis module was added to classify the signals from their Time-Frequency Representation (TFR).

For each signal, the analyses are performed in the time domain, in the frequency domain, in the polarization domain and in the time-frequency domain:

In the frequency domain, two types of analyses are used. The large-band analysis - or DSP (power spectral density) gives the percentage of signal energy on eight over-lapping bands of frequencies. The AR-CAP analysis (Leprettre, Jan. 1998) is used to calculate the dominant frequencies of the signal and their evolution over time.

The TFR analysis module was developed by E. Bourova; it is based on the recognition of shapes in the TFR of the signal and the image of Chanfrein-distances (Figures 1 and 2). This module aims to correctly identify the time-frequency representations which present narrow bands of energy and are characteristic of certain types of signals (from helicopters, works, rock falls, etc ...).

In the SARA software, the recognition of the signals is currently based on a process of a progressive elimination that first tries to see if the signal is from a non-avalanche event, according to conditional rules defined with parameters specific to each type of events. The different types of events cannot be identified by the same groups of parameters; this explains why we have not developed a process based on a unique single "nearest neighbour" type of formula.

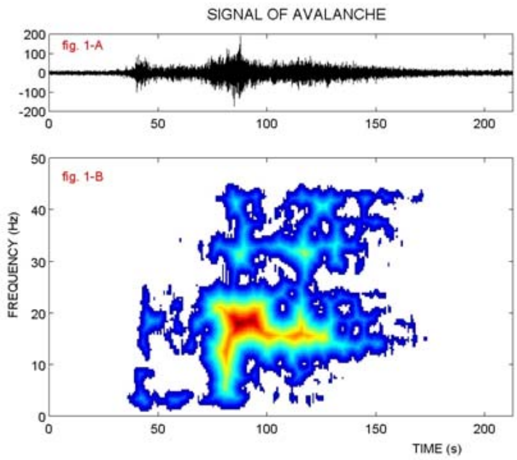

Figure 1: Signal and image of Chanfrein-distances for an avalanche

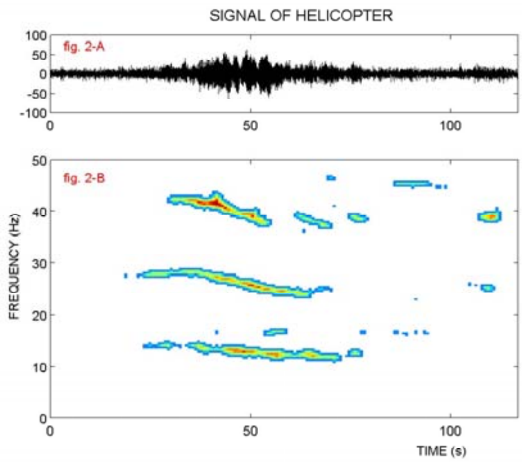

Figure 2: Signal and image of Chanfrein-distances for a helicopter.

4 INSTALLATIONS AND TECHNICAL FEATURES

Since the winter of 2006-07, we have been using an experimental network of three SDA stations, located respectively in 3 massifs of the Isere department: Belledonne, Oisans and Taillefer (figure 3). These stations are separated by several tens kilometres: about 40 kms between St Christophe and Gleyzin, and about 20 kms for the nearest. Given the local geography of these sites, the avalanche paths in Ornon and Gleyzin are concentrated on the same slopes as the stations, on both sides of the stations. On the other hand, the station in St Christophe has the ability to detect avalanches from different sides.

Figure 3. Location of the 3 SDA stations near Grenoble: Gleyzin at the top, Ornon (bottom, left) and St Christophe (bottom, right).

Each of the three SDA stations is composed of the same basic equipments (figure 4):
- A three-component seismic sensor (Mark Product geophone L 22D - 2Hz);
- A seismic data logger (Osiris – AGECODAGIS, 3 channels, with the optional WIFI);
- An electronic module, or MPS module (for Management and Processing of recorded Signals) developed by the CEN; this module is based on a BASIC Stamp microcontroller, compact-flash cards and a PC-104 card on which the SARA software is running;
- A MeteoSat emitter (ELTA Society), for the transmission of result messages by satellite;
- The power set is supplied with three batteries recharged by two or three solar cells (according to the sites).

Figure 4: The SDA Ornon station in the Taillefer massif, at an altitude of 1450 m.

We added a transmission-line WIFI-ADSL to the Ornon Station in 2008. The WIFI transmission is a link between the isolated SDA station and one point of the ADSL network in the valley (distant of about 1 km). This mode of transmission, which allows repatriating all the signals for analysis, was tested and used throughout the winter of 2008-09.

The detection of seismic signals is performed on a threshold trigger (ratio STA/LTA). The values of STA and LTA are respectively calculated on 2 and 40 s. and the sampling frequency is 100 Hz. Each signal is recorded with a given pre-event of 40 s. The recording time of signals is variable and based on a double criteria of ending.

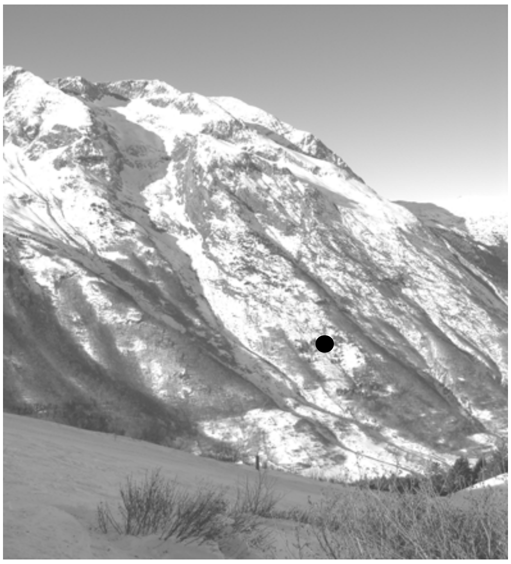

Figure 5: Location of the Ornon SDA in Taillefer massif and view of detected avalanche paths (east side).

5 OPERATIONAL RUNNING

The signals recorded by each SDA station are regularly analysed on site according to an hourly cycle and the results of the diagnoses are transmitted to the CEN. Thus, once an hour, all the signal detected during the previous hour are analysed by the SARA software.

The results (i.e. the time of the signal, its principal characteristics and the diagnosis made by SARA) are encoded as a “result line” and stored in a result file. Once all the signals are analysed a 646 byte file is written, including a header and the last ten result-lines, then loaded into the MeteoSat emitter for transmission to the CEN. The header contains some parameters on the station (voltage, etc) and on the weather (temperature).

Dernières avalanches détectées Sites provisoires – Données expérimentales		
ORNON	**SAINT-CHRISTOPHE**	**GLEYZIN**
Aujourd'hui : néant	Aujourd'hui : néant	Aujourd'hui : néant
06.04 : Néant 05.04 : Néant 04.04 : Néant 03.04 : Néant	06.04 : Néant 05.04 : 12h17 Durée 90s Conf. 4/5 04.04 : Néant 03.04 : 20h58 Durée 57s Conf .2/5 20h53 Durée 45s Conf .2/5	06.04 : 16h11 Durée 42s Conf .2/5 05.04 : Néant 04.04 : Néant 03.04 : 18h47 Durée 155s Conf. 5/5
Dernière détection le 07 à 06h25 *Dernière mise à jour le 7 à 08h49*	*Dernière détection le 07 à 06h25* *Dernière mise à jour le 7 à 08h30*	*Dernière détection le 07 à 07h47* *Dernière mise à jour le 7 à 08h30*

Figure 6: Example of information given on a web page; results displayed for the 07 April 09 at about 9h UTC. “Durée” is the useful duration of the seismic signal that may be longer than the avalanche.

Every hour, the messages from the three SDA stations are processed automatically to the CEN by an application, before being made available to the avalanche hazard forecasters of the Isère department. In this application, the results of the three stations are first compared and cross-checked in order to minimize any false alarms. This comparison is based on the fact that signals detected at the same time (with an interval of a few seconds) on 2 or 3 sites distant of several kilometres, are very likely to correspond to an earthquake (or to a strong blast in a quarry), but not to an avalanche. For this comparison, the application also takes into account the detections recorded on 3 stations of the Sismalp seismic network (including 2 stations located in Isère). Currently, the results are made available to avalanche forecasters as a summary form on a web page (figure 6). This example of web page corresponds to a period of small avalanche activity, with few avalanche diagnosed signals; the SDA of St Christophe and Gleyzin are more favourable to detect spring avalanches.

For each detected avalanche signal, information is given on the exact date, the useful duration and a parameter that indicates the reliability of the diagnosis (mainly based on the useful duration of the signal). This configuration allows the avalanche forecaster to know the exact time when avalanches occurred with a delay not exceeding about 1 h 30’. Thanks to the useful duration and some characteristics of signal (average amplitude…), the avalanche forecaster can also have initial information on the size of the avalanche.

5 QUALITY OF THE DETECTION PROCESS

It is difficult in our case to evaluate the exhaustive quality of the detections and the diagnoses (avalanche or non-avalanche), because we obviously cannot have accurate information (human observations) on all avalanches around the different SDA sites. Nevertheless, we have a lot of deferred information that allows us to cross-check the credibility of the various diagnoses; for example, data on seismic activity, data quantifying the avalanche activity (snow-weather network), information on local events (or some avalanches) by residents, staff of the equipment (or Office of Forests), etc... This information allows us several types of deferred comparisons regarding the quality of our diagnoses:

- Quality of diagnoses for identified signals (earthquakes, works, avalanches …),
- Concordance between the diagnosed avalanche signals and strongly avalanching periods
- Analysis of false alarms (i.e. signals mistakenly classified as avalanches) for periods where avalanches are impossible.

A study of 2003, using data from the Saint Christophe DSA, showed that about 30% of diagnosed avalanches were false alarms, at that time. We applied the new version of SARA (with the TFR analysis module) on signals that were originally diagnosed avalanche by SARA during the winter 06-07 at Ornon. The results showed that this latest version is very effective for a better diagnostic of certain signals (from helicopters, works…) and thus to reduce the false alarms.

6 RESULTS OBTAINED AT ORNON DURING THE WINTER OF 2008-09

This winter has not been a source of many natural avalanches in the Isère department. Between the 15 December and the 30 April, we have only two days where the forecast degree of natural avalanche hazard is 4 (according to the European avalanche hazard scale) for the Taillefer or Oisans massif: the 23 and 24 January.

At Ornon, between the first January and the 30 April, we recorded 940 signals, of which only

30 were diagnosed as avalanche. Half of these signals relate to the 20-25 January period (figure 7), and especially on 23 January, where we recorded signals of avalanches with durations significant. The other signals diagnosed as avalanche are spread over February-April (with never more than one avalanche per day).

For this period of 20-25 January, the SDA of Saint Christophe gave similar results, namely: 2 avalanches on the 20 January, 8 the 23, 1 the 24 and 4 the 25.

The figure 8 shows the signal of 23 January to 13:40 UTC, recorded at Ornon and that was diagnosed as avalanche: avalanche identified, corresponding to the avalanche path "*La Planchette*", near the SDA station (located on the right of the station on the view of Figure 5).

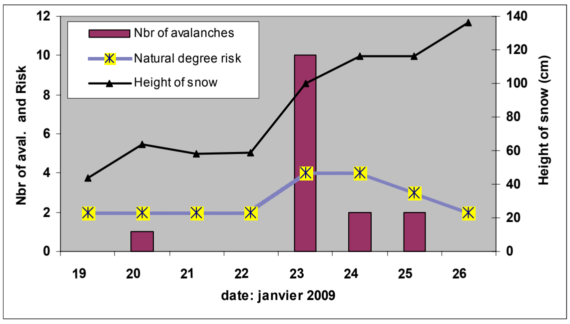

Figure 7: Number of daily detected avalanches by the Ornon station between 19 and 26 january 2009 compared with other data: Forecast degree of natural avalanche hazard for the Taillefer massif and total height of snow at the *Les Ecrins* Nivose (Oisans massif, 2978 m).

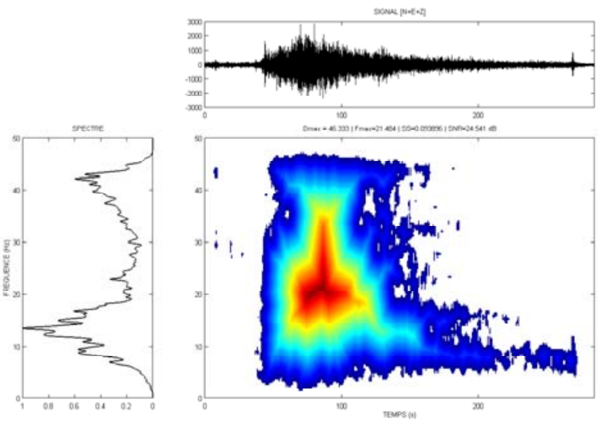

Figure 8: Signal, spectrum and image of Chanfrein distances of the avalanche detected at Ornon the 23 January to 13:40 UTC.

7 CONCLUSION

The latest developments (TFR analysis) of the SARA software have made significant improvements; and thus, this mini-network of SDA can provide useful information to avalanche forecasters of the Isère department. The running of several SDA allows to crosscheck the results and thus to give information more reliable. The tests conducted on the WIFI-ADSL transmission of the signals throughout the winter of 2008-09 were positive. This mode of transmission (when it will possible), will enable to simplify the equipments on site and provide the forecasters with a more ergonomic presentation of results.

Some difficulties remain, however, for the discrimination of small avalanches or for some atypical signals. The localization of avalanches is still a topical question. The results of analyses based on the polarization of signals avalanches are not very reliable, given the strong heterogeneity of the ground in the mountains. A study with the LGIT-OSUG (CNRS-UJF, Grenoble) is currently underway on this subject.

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