Evaluation of an avalanche triggered by a local earthquake at the Vallée de la Sionne (Switzerland) experimental site

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ABSTRACT: The snow avalanche group of the University of Barcelona in a collaboration with the SLF (Institute for Snow and Avalanche Research, Davos (Suiza)) monitors snow avalanches using infrasonic and seismic measurements at the experimental site of Vallée de la Sionne (VDLS). Snow avalanches are infrasonic and seismic sources in movement. The friction between the lower parts of the avalanche and the snow cover is the main source of the seismic signals. However, the interaction between the external parts of the avalanche (saltation and powder parts) with the air produces the main source of the infrasonic signal. Our installation allows us to record not only snow avalanches but also earthquakes, explosions and other seismic and infrasonic sources.
On 6 December 2010, the snow avalanche alarm system of VDLS was triggered by a local earthquake 43 km from VDLS (ML 3.1; 6:41:24 UTC) with the hypocenter in France (46.05 N; 6.94 E; 3 km). At first, this alert was not considered as an avalanche because no data were recorded by the routine monitoring instruments. A subsequent analysis of the infrasonic and seismic data showed that seconds after the arrival of the earthquake a signal generated by an avalanche appeared. This avalanche did not descend along the main channel but along the secondary one.
The analysis of the data of this avalanche probably triggered by the earthquake is presented. The study of the characteristics of the infrasound data allows us to delimit the interval time of the release of the avalanche. Subsequently, values of the ground vibration (PGA, I_a, T_d) produced by this earthquake are compared with those of other earthquakes that did not trigger an avalanche. Finally, the weather and snow conditions of the days on which these events occurred are compared and evaluated according to the quantification of stability conditions. It may be concluded that the snowpack conditions are a determining factor in avalanche formation.

Key words: Avalanche, earthquake, seismic data, infrasound, snow stability factor

1 INTRODUCTION

Snow avalanches triggered by natural seismicity are an important collateral hazard associated with earthquakes. This phenomenon is common in natural environments with high seismicity and snow covered mountain areas with steep terrains (Podoloskiy et al., 2010a). However, few historical cases of earthquake-induced snow avalanches have been documented (Podoloskiy et al., 2010 a). The exact mechanism by which seismic loading can release avalanches is not well understood because of the lack of measurements (Podoloskiy et al., 2010b). Laboratory experiments carried out with fresh snow over a shaking table (Chernouss et al., 2006; Podoloskiy et al, 2008; Podoloskiy et al., 2010b) have revealed that the snow shear strength decreases owing to vibration. Different experiments have been carried out in the Khibiniy Mountains, in Russia, to study snow avalanches released by the seismic loading caused by open pit and underground mine explosions (Mokrov et al., 2000; Chernouss et al., 2006 a, b). The relationship between an avalanche release and the seismic effect is related to the distance from the source, the local conditions (geology, topography, snowpack stability, etc.) and to the characteristics of the source: amplitude, frequency and duration of the vibrations acting on the slope (Suriñach et al., 2011). In addition, some works (i.e. Geli et al., 1988; Pedersen et al., 1994) have shown a large amplification of seismic waves on mountain tops, where an avalanche can be released. Thus, the oscillations generated by an earthquake can account for a fracture in a weak layer and hence in avalanche formation.

We present the study of the seismic and infrasound signals generated by an avalanche and the local earthquake that probably triggered the avalanche. The earthquake (ML 3.1; 6:41:24 UTC) with the hypocenter in France (46.05 N; 6.94 E; 3 km) occurred approx. 43 km from the

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Vallée de la Sionne (VDLS, Switzerland) dynamic test site (SLF). The seismic hazard in VDLS (situated in Valais, southeast of the Alps), is higher than in the rest of Switzerland, where the seismic hazard is moderate (Swiss Seismological Survey, 2004). One historical example of an avalanche induced by an earthquake in the surroundings of VDLS site is that produced by the second M 6 earthquake of the 1946 earthquake sequence (Moore et al., 2012) that triggered a rock avalanche in Valais.

2 EXPERIMENTAL SITE AND DATA

The experimental site of Vallée de la Sionne (Figure 1) was built in 1998 by the Swiss Federal Institute for Snow an Avalanche Research (SLF) to study the dynamics of snow avalanches (Amman, 1999; Issler, 1998). Snow avalanches of different types and sizes are released, naturally or artificially, at the site. Most of the snow avalanches are released from two main starting zones: Crêta Besse 1 (CR1), oriented in a East/south-east direction, with slope angles between 35º-40º and heights of 2300-2500 m a.s.l. and Crêta Besse 2 (CR2), oriented in a South-east direction, with slope angles between 30º-35º and heights of 2500-2700 m a.s.l. (Figure 1). The starting zones become channelled between 2050 - 1800 m a.s.l. in two different channels: the main channel, known as channel 1 and a secondary one, known as channel 2 (Figure 1). The runout zone is common for the two channels with slope angles between 5º-20º from 1800 to 1450 m a.s.l.

The University of Barcelona (UB) deployed in the area seismic and infrasound stations. The seismic stations currently consist of a three-component seismometer Mark L4-3D and a data acquisition system REFTEK DAS-130-01. All the measurements are recorded at a sampling rate of 100 sps in two streams, continuous and trigger.

One of the UB seismic stations is installed at cavern B (1900 m a.s.l.) next to a Syscom seismic system of SLF, the same Syscom system that is at cavern A (2300 m a.s.l.). A second seismic station is located at cavern C, close to an instrumented pylon at 1650 m a.s.l., at the start of the runout zone (Sovilla et al., 2008; Sovilla et al., 2010). The third seismic station is situated at cavern D, in the opposite slope of the avalanche track, at few meters from a shelter that operates as an instrumented control centre. In addition to the seismic stations, one infrasound sensor has been installed since the 2008 winter season (Kogelnig et al., 2011) near cavern D. The infrasound sensor is a Chaparral, Model 24. This sensor is connected to the same data acquisition system of the seismic station of cavern D with a common base of time. Furthermore, in the shelter a GEODAR radar (Frequency Modulated Continuous Wave Phased Array radar) measures the position and front velocity data of the avalanches along the main path (Vriend et al., 2013).

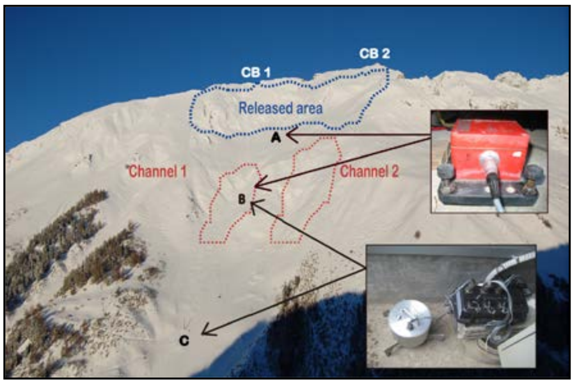

Figure 1. Experimental site of Vallée de la Sionne (VDLS). CB1, CB2: avalanche release areas. A, B and C instrumented caverns. Channel 1 and 2: main and secondary channels, respectively.

The amplitudes of the seismic and infrasound data were processed and converted to physical parameters (ground velocity, m/s and air pressure, Pa) using the corresponding transfer functions. All the signals were filtered (1Hz to 45Hz) with a 4th order Butterworth band pass filter to homogenize the data. This frequency range is sufficient for the study of the phenomenon (Biescas, 2003: Vilajosana, 2008; Kogelnig, 2012). Data were analyzed in the time and frequency domains. The running spectra that show the evolution in time of the frequency content of the signals was calculated using the Short Time Fourier Transformation with a Hanning Window (length 1.28 s) and a overlap of 50% (0.64 s).

3 THE EVENT OF 6 DECEMBER 2010

On 6 December 2010, the snow avalanche alarm system of VDLS was triggered by a local earthquake (ML 3.1; 6:41:24 UTC) with the hypocentre in France (46.05 N; 6.94 E; 3 km) approx. 43 km from VDLS. The trigger in the avalanche warning system caused by the earthquake was initially discarded because of the identification of the earthquake. No images were available because of the bad weather. However, a subsequent analysis of the infrasonic and seismic data showed that a signal generated by an avalanche appeared seconds after the arrival of the earthquake. Apart from these data, the only available data for this avalanche were acquired with the GEODAR radar. This avalanche did not descend along the main channel (1) but along channel 2 (field observation). As a result, no data were recorded by the other monitoring instruments situated in the main avalanche channel. After the storm temporally cleared, a small deposit of this avalanche was visible in channel 2 (Figure 2)

Figure 2. Photographs before and after the 6 Dec. 2010 earthquake where the avalanche imprint is observed in the secondary channel (right). (Photo courtesy of SLF).

The earthquake and the snow avalanche were recorded at all the seismic stations (A-D caverns). Figure 3 shows the time series and the spectrograms of the seismic (E-W component) and infrasound signals of the whole event. Figure 3 displays two differentiated packets of energy in the seismic time series, corresponding to the earthquake and subsequent avalanche. The spectrograms of Figure 3 show that the signals overlap. The energy corresponding to the coda of the earthquake overlaps the beginning of the seismic signal of the snow avalanche (approx. 50 s).

The arrival of the earthquake is observed at all the stations at approximate 16 s (the origin of time is arbitrary). Note the clear and sudden appearance of the energy at all frequencies in the seismic spectrograms (Figure 3). This is a characteristic of the earthquakes. The maximum amplitudes in the earthquake time series were recorded at 23 s, approximately. After the coda of the earthquake (approx at 50s) the increase in amplitude of the seismic signals produced by the snow avalanche is observed at different times in the different seismic records. This is a consequence of the relative position of the avalanche and the sensors. The gradual appearance of the energy at the different frequencies in the seismic spectrograms is a characteristic of mass movements (Suriñach et al., 2005). The evolution of the frequency content allows us to estimate the different relative position of the snow avalanche with respect to the seismic stations. This observation is consistent with the fact that the avalanche did not flow over cavern B located in channel 1 because it descended along channel 2 (field observation). The infrasound time series presents a spindle shape with a maximum value of 1.4 Pa in the [70-100 s] interval (Figure 3) that also corresponds to the maximum in the spectrograms. The infrasound energy interval coincides with that of the seismic signals although the frequency content is lower, up to 20 Hz (Figure 3). However, the infrasound energy distribution is different. Very low amplitudes are observed in the earthquake interval (up to 50 s), whereas higher amplitudes are present in the snow avalanche interval. The maximum amplitudes of the infrasound signal were recorded in the time interval [70-110] s when the avalanche was moving along channel 2**.** Although the data provide important information on the earthquake and avalanche, the overlap of the signals of these two sources makes it difficult to establish the exact instant of the start of the snow avalanche. The comparison of seismic and infrasound data allows us to determine the time interval in which the avalanche was released. This is important to ascertain whether the avalanche could be triggered or not by the earthquake.

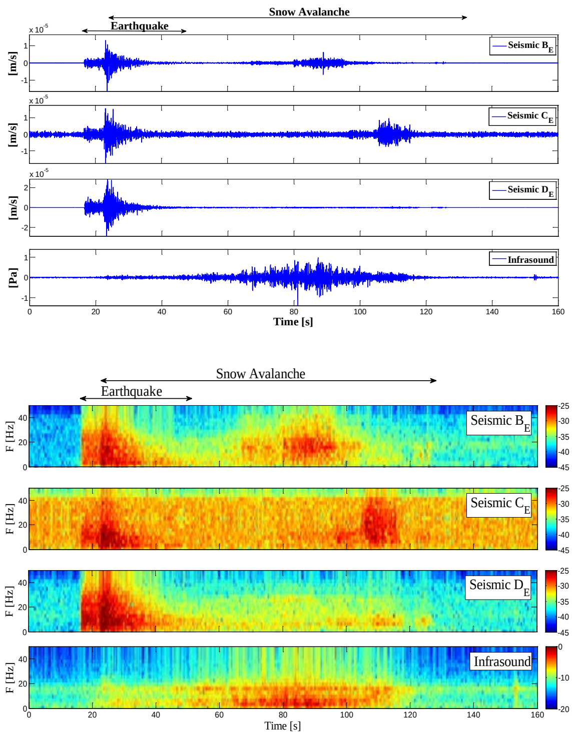

Figure 3. Top: Seismic (E-W component) and infrasonic time series at the different sites in VDLS of the event on 6 Dec. 2010 (earthquake and snow avalanche). Bottom: Respective seismic and infrasonic spectrograms.

4 DETERMINATION OF THE STARTING TIME OF THE SNOW AVALANCHE

Snow avalanches are extended moving sources of seismic and infrasound waves. Recent studies have shown (Kogelnig et al., 2011) that the suspended powder cloud and the dilute layer are the main sources of infrasound, whereas the interaction between the dense core of an avalanche and the basal friction is the main source of the seismic signal. Earthquakes also generate infrasound waves by different mechanisms (Ichihara et al., 2012). In this study, the different types of infrasound and seismic waves generated by an earthquake and by a snow avalanche are analysed.

To determine the time interval in which the avalanche was released we compared the seismic and infrasound signals of the 6 December 2010 event, the subject of our paper, with those from two regional earthquakes recorded at the experimental site that did not trigger a snow avalanche. These earthquakes are the one on 11 February 2012 which occurred 132 km from VDLS (ML 4.2; 22:45:26 UTC) with the hypocenter in Switzerland (47.15 N; 8.55 E; 32 km) and the one which occurred on 21 March 2012, 4 km from VDLS (ML 2.1; 11:01:57 UTC) with the hypocentre in Switzerland (46.32 N; 7.34 E; 0.1 km). For the sake of brevity, only the study of the 11 February 2012 earthquake is presented.

The comparison of the different shapes of the seismic and infrasound signals was carried out with the envelopes of the seismic and infrasound signals recorded at cavern D. The envelopes of the seismic signals were calculated using the norm of the three seismic components smoothed each 50 points (0.5 s).

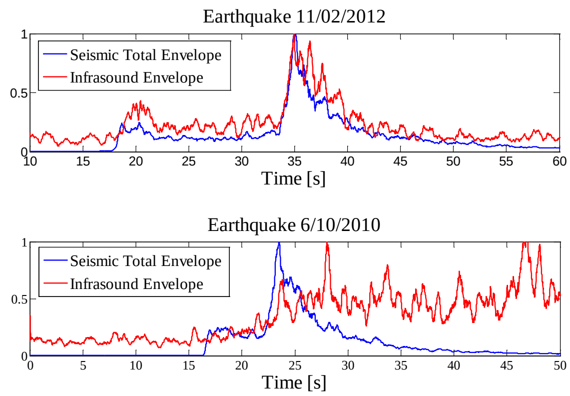

Figure 4. Normalized envelopes of the seismic (m/s) and infrasound (Pa) time series of the earthquakes on 11 Feb. 2012 (top) and 6 Dec. 2010 (bottom), which was followed by an avalanche, obtained at cavern D.

Figure 4 shows the corresponding envelopes of the whole seismic signals and that of the infrasound signals for the 11 Feb. 2012 earthquake and the 6 Dec. 2010 earthquake. The 11 Feb. 2012 earthquake shows a high similarity between seismic and infrasound envelopes (top, Figure 4). However, for the 6 December 2010 event (earthquake and avalanche) (bottom Figure 4) a different behaviour between the seismic envelope and the infrasound envelope is observed. The common decrease in amplitudes of the coda section observed in the infrasound and seismic envelopes of the earthquake (top Figure 4), is not visible in the case where earthquake and avalanche are present. The decrease in the seismic envelope amplitude does not match a decrease in the infrasound envelope amplitudes. By contrast, the infrasound envelope amplitude increases and at 28.01s reaches a maximum that exceeds the envelope amplitudes of the earthquake (bottom Figure 4). Measurements of the GEODAR radar confirm the movement of an avalanche in the interval [29-30] s. (J. N. McElwaine, personal communication). In this time interval the returned radar signal indicates the start of an avalanche at the approximate height of the cavern A. However, owing to the fact that the alarm system of the VDLS was triggered by the arrival of the maximum amplitudes of the earthquake (≈ 25 s) and the GEODAR needs several seconds to record the first data no information of the starting time of the avalanche was obtained in the GEODAR.

These acquired data indicate that the avalanche was probably released after the arrival of the earthquake. Whether the avalanche was triggered by the shaking caused by the earthquake or whether it was a coincidence is an open question. A quantification of the ground motion generated by the earthquakes could provide us with more information.

5 EARTHQUAKE GROUND MOTION QUANTIFICATION

The probability of an avalanche to be induced by a seismic source is related to the characteristics of the source and to its effects produced at a specific site. A slab avalanche can be released by the accelerated loading due to an earthquake. This loading produces an amplification of the stress that can cause a fracture between the snow layers (Higashiura et al., 1979). The shear stress amplification is greater at higher accelerations which depend on the earthquake magnitude, the epicentral distance and local conditions (site effect). Earthquakes with longer duration of shaking are more prone to cause a failure in the slab (Podolosky et al., 2010 a).

To study the possibility that the ground motion of the 6 December 2010 earthquake could trigger the subsequent avalanche we considered the snow slab to be released as a structure.

In order to quantify shaking, three indices that are commonly used in earthquake engineering to measure the effect of the ground motion or shaking produced by an earthquake in a structure at a specific site are used. These indices take into account the amplitude and duration of the ground acceleration time signal and give us a measure of the potential of a certain ground movement to induce an avalanche. The indices used are: the PGA (peak ground acceleration), the Arias Intensity, I_a, (Arias, 1970), and the Trifunac duration, T_d, (Trifunac and Brady, 1975).

To determine whether the 6 December 2010 earthquake was able to trigger the avalanche the PGA, I_a and T_d parameters of this event were computed and compared with those of the earthquake on 11 February 2012 with no avalanche release.

The selected parameters were computed using the seismic records of cavern A on the assumption that the earthquake shaking in the release area was the same as the motion recorded at cavern A, the nearest station.

Taking into account that the shaking is a 3D phenomenon, the parameters were calculated for the three seismic components of motion in space. These components, normally N-S, E-W and Z, were rotated in order to match the slopes of the avalanche channel for a more realistic evaluation. The new components are:

- Coord. Z: Component normal to the inclined plane (40 º) of the slope at cavern A.
- Coord. X: Component along the slope downwards at cavern A.
- Coord. Y: Component perpendicular to X direction and parallel to the slope plane.

The recorded seismic signals were converted into acceleration to calculate PGA.

The calculated values of PGA, I_a and T_d are lower for the 6 December 2010 event than for the 11 Feb 2012 event (Table 1) which is consistent with the respective earthquake characteristics: the former is closer to the area but of a smaller magnitude. The PGA values are of the same order but smaller for the 6 Dec. 2010 earthquake than for the 11 Feb. 2012 earthquake. In the case of Arias intensity, I_a, the values for the 6 Dec. 2010 earthquake are one order of magnitude smaller than for the 11 Feb. 2012 earthquake. We highlight the value of this parameter for the component along the channel, component X, which is greater than the other components and may indicate some favourable seismic directivity on the 6 December 2010 earthquake. Finally, the Trifunac duration shows longer time records for the 11 Feb. 2012 earthquake than for that on 6 Dec. 2010, which is normal because this earthquake is of a lower magnitude and is closer to VDLS than the 11 Feb. 2012 earthquake.

Event	**PGA [m/s^2]**
6/12/2010	$(2.5\cdot10^{-3}, 3.4\cdot10^{-3}, 2.7\cdot10^{-3})$
11/02/2012	$(4.9\cdot10^{-3}, 5.3\cdot10^{-3}, 6.4\cdot10^{-3})$

Event	**I_a [m/s]**
6/12/2010	$(6.2\cdot10^{-7}, 9.8\cdot10^{-7}, 7.5\cdot10^{-7})$
11/02/2012	$(2.6\cdot10^{-6}, 3.5\cdot10^{-6}, 4.5\cdot10^{-6})$

Event	**T_d [s]**
6/12/2010	$(16.4, 15.9\ ,\ 16.7)$
11/02/2012	$(30.3, 29.9\ ,\ 26.7)$

Table 1. PGA, I_a and T_d values for the X, Y an Z components of the earthquakes studied recorded at cavern A.

The parameters obtained show that the 11 Feb. 2012 earthquake is more powerful than the 6 Dec. 2010 earthquake although no avalanche was released at cavern A.

Given that the values obtained do not yield any specific characteristic of the 6 Dec. 2010 earthquake to trigger an avalanche, it is necessary to consider other factors that may play a role in the triggering in combination with the ground shaking.

6 METEOROLOGICAL, SNOWPACK CONDITIONS AND ANALYSIS OF BLOCK STABILITY

The meteorological and snow cover conditions of the two days considered were different. The avalanche on 6 Dec. 2010 was released after a snow precipitation of 25 cm in the preceding 24h on a snow cover of 80 cm (meteorological station of Donin Du Jour, 2390 m a.s.l.). The air temperature in the release zone was −4 °C (VDLS station, 2696 m a.s.l.) at 8:00 am (local time). The National avalanche bulletin no. 28 for Monday, 6 December 2010 (issue date 5.12.2010, 18:30 hours) forecasted the possibility of dry avalanches on steep slopes in all exposures above approximately 1800 m a.s.l.. An increase in air temperatures expressed as an “ascending snowfall level, therefore naturally triggered moist and wet avalanches are expected about 2400 m a.s.l. of the early morning hours” was also forecasted. One of the triggering causes of large avalanches is the rapid heating of cold, non cohesive, layers (Föhn, 1992).

These meteorological conditions favour snow instability below and above the freezing level. SLF profiles of these days indicated the existence of a weak, poorly cohesive layer (faceted crystals) over a hard crust due to refreezing which was formed on 12 November (personal communication SLF). According to the aforementioned bulletin, “The avalanches can break through down to the old snow”, thus affecting the new fallen snow layer until possibly reaching the weak, faceted crystals layer. Moreover, the bulletin also indicated that “the south-westerly wind will be strong in this area, transporting fallen fresh snow and old snow”. The danger level was 4 (on a scale of 5 degrees) and 11 avalanches (wet and dry snow avalanches) occurred around the VDLS test site on the day, confirming the forecast.

By contrast, on 11 February 2012 the temperature of the air was -17 ºC and there was no precipitation on the previous days. The weekly report of the SLF indicated a danger level 2 at Valais because the wind from the northeast was low in this part of the Alps. According to SLF data, there were no natural snow avalanches on the day before and after the earthquake with the result that the snowpack was fairly stable.

Comparing the meteorological and snow cover information of both days we can conclude that the conditions were more favourable for an avalanche release on 6 December 2010 than on 11 February 2012.

The existence of weak, non cohesive, layers on the snowpack on 6 December 2010, together with the rapid loading produced by the shaking of the earthquake, the loading produced by the snow precipitation during the previous hours and the rapid increase in the air temperature were the factors that contributed to the avalanche release.

Below a quantification of the stability factor is obtained to evaluate whether the accelerations generated by the earthquake are enough to trigger an avalanche or not. Following Chernouss et al., (2002) and Chernouss et al., (2006) the dynamic conditions for the block stability (the sliding mass is assumed to be a rigid block) in the presence of a ground vibration can be expressed through a relationship between the shearing forces and the retaining forces as:

$$\rho h(g sin\alpha + a_x) < c + f\rho h(g cos\alpha - a_z) \quad (1)$$

where g is gravity acceleration; ρ snow density; c snow cohesion; f friction coefficient between the snow element and the underlying surface; h slab depth; α slope inclination; a_x and a_z tangential and normal acceleration of the ground due to seismic waves. According to this equation, the ground acceleration due to any seismogenic source can cause an increment of the down slope pointing shearing forces and release an avalanche. The relationship between the retaining forces and the shearing forces, according to the Mohr- Coulumb failure criterion, gives the stability factor of the slope F (Chernouss et al., 2002):

$$F = \frac{c + f\rho h(g cos\alpha - a_z)}{\rho h(g sin\alpha + a_x)} \quad (2)$$

When factor F > 1 the snow slab is stable and if F ≤ 1 it is unstable. However, field observations show that this condition is necessary but not sufficient for an avalanche to occur.

For the quantification of the stability factor the snowpack conditions were assumed according to the information supplied by the SLF (public and personal communication): profiles, bulletin and new snow depth map. Despite being aware that the values considered are just approximations, we believe that they are good enough for a preliminary evaluation.

According to the snowpack information, we consider two possibilities to calculate the stability factor:

1. The avalanche broke through upwards the old snow. In this case Eq (2) is valid and we considered the snow slab of 300 kg/m^3 (Sergent,1993) with a thickness of 0.25 m approx.

2. The avalanche broke through downwards the old snow In this case Eq. (2) is converted in:

$$F = \frac{c + f(\rho_s h_s + \rho_f h_f) \cdot (g cos\alpha - a_z)}{(\rho_s h_s + \rho_f h_f) \cdot (g sin\alpha + a_x)} \quad (3)$$

where the new variables are: h_f the snow faceted layer depth and ρ_f the density of the faceted snow. We considered the snow slab as in the previous case and the faceted layer of 0.6 m thick and a mean density of 200 kg/m^3 (Sergent, 1993).

Typical ranges of the parameters presented in Table 2 (Mellor, 1975; McClung, 1987; Sweicher, 1999; Van Herwijnen and Heierli, 2009) were used to evaluate the stability factors. In addition, the PGA values of the acceleration (a_x, a_z) produced by the earthquake on 6 December 2010 in the release area were used for the evaluation. This is one special case where real data are considered.

The stability factor in the case of possibility 1 as a function of the friction parameter (Eq.2) for different values of cohesion, snow density and the acceleration data of the earthquake is presented in Figure 5. In this case, the unstable region (F<1) (in red) corresponds only to values of f< 0.31 and c= 300 Pa.

Figure 6 corresponds to possibility 2 (Eq.3). In this case the unstable region has increased (the area below F =1 in red) and the upper boundaries of the parameters of friction are f = 0.6 for c= 300 Pa and f= 0.43 for c= 600 Pa.

Parameter	Range
Cohesion c [Pa]	300- 2000
Friction μ	0.3- 0.8

Table 2. Typical values of cohesion and friction parameters for slab and weak layers.

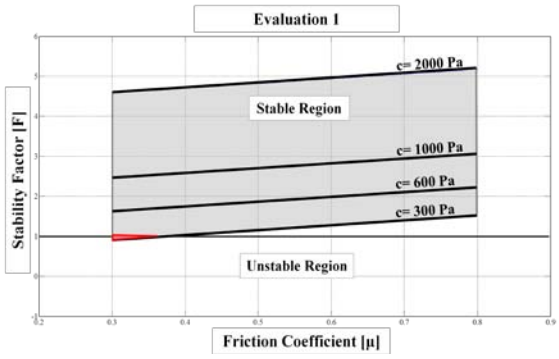

Figure 5. Stability factor as a function of the friction coefficient (μ) and the cohesion (c) coefficients for possibility 1 (Eq. 2). The stable region satisfies F> 1 and the unstable region (red) F< 1.

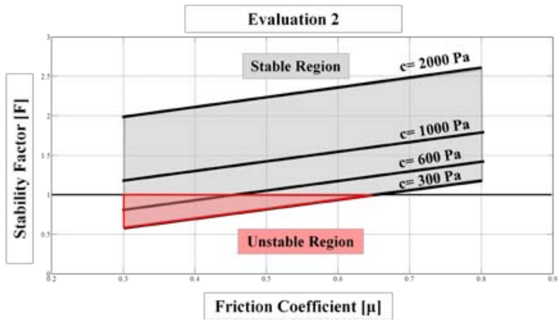

Figure 6. Stability factor as a function of the friction coefficient (μ) and the cohesion (c) coefficients for possibility 2 (Eq. 3). The stable region satisfies F> 1 and the unstable region (red) F< 1.

This result indicates that if we consider the weight of the old layer of snow to the equation of the stability factor, the unstable region increases and includes a wider range of cohesion and friction values (Figure 6).

7 CONCLUSIONS

We analyzed a minor magnitude earthquake on 6 December 2010 at 43 km from the VDLS test site that could trigger an avalanche at the site.

The study was carried out using the seismic and infrasound data generated by the earthquake and avalanche obtained at different locations along the VDSL test site and those of another earthquake which did not trigger an avalanche. The joint analysis of the two types of data (seismic and infrasound) allowed us to estimate a time interval in which the avalanche occurred. This time is compatible with the arrival of seismic waves from the earthquake. The possibility that the earthquake triggered the avalanche cannot be excluded at present.

The quantification of the earthquake ground motion shows that the PGA, I_a, T_d values of the 6 December 2010 earthquake are not particularly high or do not show determining features that allow us to affirm that it triggered the avalanche.

In consequence, the nivo-meteorological conditions involved in those days must be considered. The nivo-meteorological conditions of the December 6, 2010 event were prone to the natural avalanche release, with the result that the earthquake shaking could trigger the avalanche despite being a moderate motion.

Moreover, the snowpack conditions and the stability analysis presented above demonstrate that the possibility of the avalanche being triggered by the earthquake is very plausible.

The methodology presented is a powerful tool to recognize and quantify avalanches and other mass movements induced seismically in the proximity of the monitoring stations.

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