Detecting snow avalanches with seismic stations in North-east Italy: first results of dataset analysis

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ABSTRACT

The Regional Agency for the Environmental Prevention and Protection of Veneto (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto, ARPAV) was established in October 2007 to monitor and prevent environmental risks in the Veneto region, in North-eastern Italy. The Italian National Institute for Oceanography and Experimental Geophysics (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, OGS), after the strong earthquake (magnitude M=6.4) occurred in 1976 in the Friuli-Venezia Giulia region, started to operate the North-east Italy (NI) seismic network: it currently consist of 11 very sensitive broad band and 21 more simple short period seismic stations, all telemetered to and acquired in real time in the Seismological Research Center (Centro di Ricerche Sismologiche, CRS) of the OGS in Udine. In June 2007 OGS installed in cooperation with the Italian National Institute for Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia, INGV) a broad band seismic station in Agordo, a site located in the Dolomites mountains in the Veneto region. During the last 2008/09 winter season, in the whole Dolomites, above the altitude of 1,200m, between 250 and 350 cm of fresh snow have fallen: similar snowfall events occurred in the last 80 years only in 1951, 1959, 1960 and 1979. The large amount of snow fell failed to consolidate and in the Dolomites, the study area of this work, the spontaneous avalanche phenomena was very intense, with several large avalanches reaching the bottoms of the valleys, and that were also detected by the OGS seismic network: avalanches of such characteristics were not observed since February 1977 and January 1987. In this work we correlate seismic parameters (such recording length) with physical characteristics of the avalanches triggering them (such run-out).

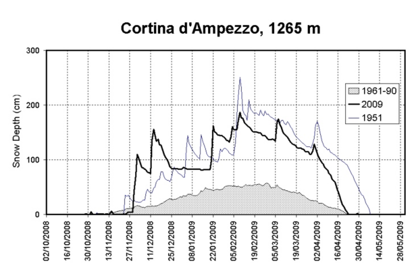

Figure 1. Snow depth at the Cortina d'Ampezzo weather station.

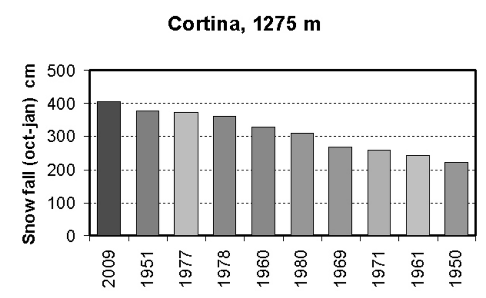

Figure 2. Total snowfall from October to January at the Cortina d'Ampezzo weather station. The figure shows the snowiest winters between 1930 and 2009.

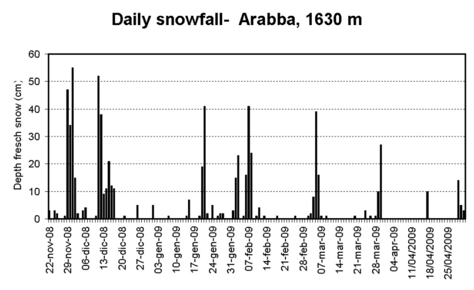

Figure 3. Daily snowfall at Arabba.

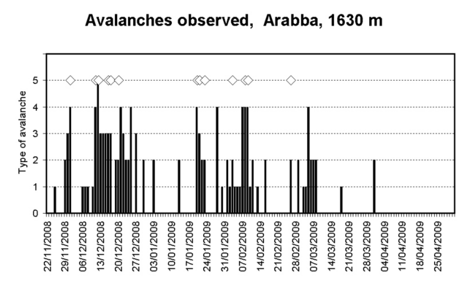

Figure 4. Types of avalanches recorded at Arabba and days with major avalanches recorded in the Dolomites

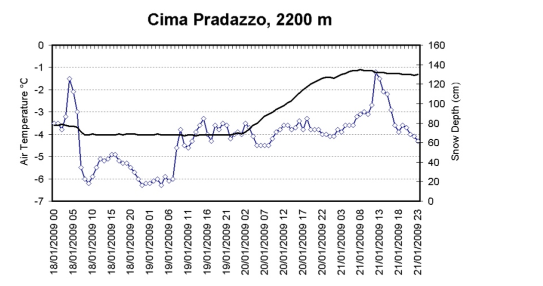

Figure 5. Winter air temperature and snow depth at Cima Pradazzo. The start of avalanche activity coincides with peak air temperature on January 21.

1.THE 2008- 2009 WINTER SEASON

1.1.General trends

The winter season was characterized by abundant precipitation throughout the Alpine chain, with a deep snow cover as early as December (Fig 1). Almost everywhere, snow depth was above-average (1961 - 1990) and in many cases it reached or surpassed the values recorded in winter 1950-1951, the snowiest winter since 1930.

Seasonal cumulative values for fresh snow (snowfall over the previous 24 hours) were quite significant and second only to those of the above-mentioned winter of 1951, at both low and high elevations.

In particular, at the end of January, total snowfall was already above 350 cm in many areas of the Dolomites and Alps (Fig. 2).

At the Arabba station, located in the middle of the Dolomites at an elevation of 1600 meters, and which is representative of the Dolomites as a whole, there were as many as 41 days with snowfall (Fig. 3), including 8 days with snowfall over 30 cm, and 3 days with snowfall over 45 cm, in the period between November 29 and March 8 (100 days).

1.2.General avalanche activity

The winter was characterized by intense natural avalanche activity. Given the long periods of bad weather and the great quantity of avalanches, careful recording of each single event proved difficult.

Observations of natural avalanches made at the Arabba station, in accordance with AINEVA directives (Cagnati, 2003), are reported in Fig. 4.

In particular, the heavy snowfall between November 28 and December 3 already led to the first major avalanches of the season, some of which reached the valley bottom. The snowfall of December 9-16 led to even more frequent and large avalanches. Almost all of the 50-to-100 year avalanches fell in the southern Dolomites.

With the return of fine weather between December 17 and 19, a series of avalanche prevention activities - artificially triggered avalanches - were undertaken in ski resorts and along the main communication routes.

The snowfall of January 19-22 led to another period of intense avalanche activity, with numerous large avalanches reaching the valley bottoms, all more easily because their paths were already covered with snow.

In this period, the snow pack was made up of thick intermediate and surface layers of angular crystals, as a consequence of the cold weather in the first decade of January 2009 (it should be kept in mind that the Venice Lagoon froze on January 5), and a superficial layer of frost along most steep slopes, regardless of exposure.

The first avalanches began to fall in the late afternoon of Monday, January 20, along the steepest slopes, leading to the closure of mountain passes in the Dolomites. The highest number of avalanches fell in the early afternoon of Tuesday, January 21, 2009: from 12:30 on, medium-sized avalanches began to fall from slopes at all exposures. It is worth noting that avalanches began once air temperature started to drop after having increased in the morning (Fig. 5)

Between the end of January and the beginning of February, a new period of unsettled weather added another 30 to 50 cm of snow at high elevations, causing numerous surface avalanches and slabs of ice to fall, in part due to the strong winds that followed the snowfall. Once the weather had improved on Friday February 3, more artificial avalanches were triggered, especially in the Arabba ski resorts.

After this period of intense avalanche activity, the winter season featured yet another period with major avalanches on February 7-8, after additional snowfall, and again during the first decade of March. Other periods of frequent avalanche activity came with rising temperatures in spring, and with late-spring precipitation in April (16-17, 27-29).

1.3.Artificial triggering of avalanches

In order to reduce the danger from avalanches to roads, towns, and ski resorts, numerous avalanches were artificially triggered over the course of the winter, thanks to explosive charges dropped from helicopters, and through the Daesy Bell system.

Figure 6. OGS seismic network

Figure 7. Agordo seismic station

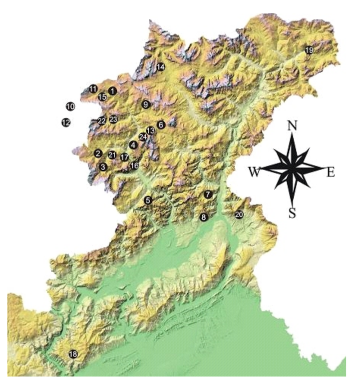

Figure 8. Map of natural avalanches

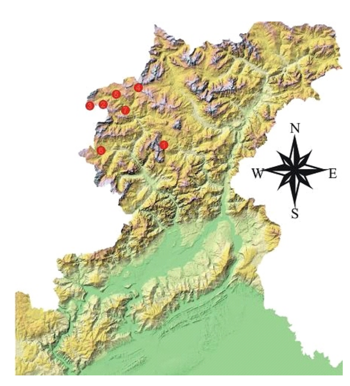

Figure 9. Map of controlled explosions

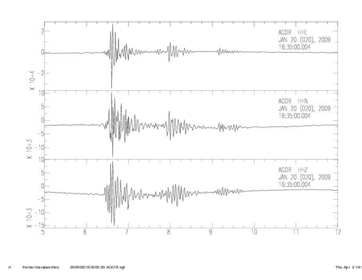

Figure 10. Natural avalanche seismograph

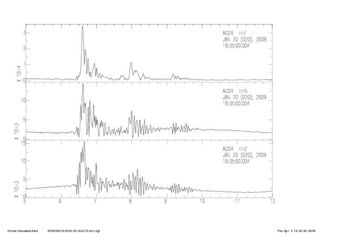

Figure 11. Natural avalanche envelope

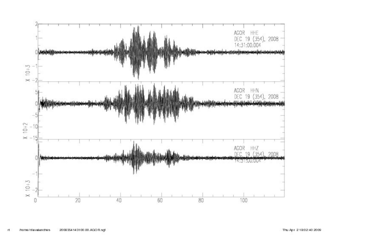

Figure 12. Explosion seismograph

1.USE OF SEISMIC STATIONS FOR AVALANCHE MONITORING

The use of seismometers was tested at sites where the speed of avalanches was experimentally measured, such as Boì Taull an Nuria in the Catalonian Pyrenees, the Sion Valley in Switzerland, and Ryggfonn in Norway. Lennartz 0.2 Hz/5 second Le-3D seismometers, installed either within or immediately adjacent to avalanche tracks, were used for this type of research (Vilajonana et alii, 2004). In these sites, it was possible to measure the speed of avalanches and design filters for distinguishing between the various types of avalanches, as well as distinguishing avalanches from other seismic waves (Biescas et alii, 2003, Vilajonana et alii, 2007).

The signal produced by a small, local seismic event, of intensity comparable to that produced by a snow avalanche, is different in terms of spectral composition from the signal produced by an avalanche. Any seismic event features an initial arrival of P-waves, and a subsequent, stronger arrival of S-waves: in both cases, the dominant signal has a frequency of a few Hz. On the other hand, snow avalanches show an initial signal peak at the beginning of the phenomenon, when the avalanche detaches itself from the snow pack, followed by a large-amplitude signal due to the friction caused by snow sliding over snow (Biescas et alii, 2003).

2.THE Agordo SEISMIC STATION

The Agordo seismic station is part of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) network in North-eastern Italy (Fig. 6), whose data is transmitted in real time to the Centro di Ricerche Sismologiche (CRS) in Udine.

The seismic network comprises both short-period and high dynamics broad-band stations. The Agordo broad-band seismic station, which became operational in June 2007, is located in the artificial gallery that was built over several years by the students of the "U. Follador" Mining Institute underneath the slopes of Mount Framont (Fig. 7).

The station comprises a Quanterra Q680 24-bit data logger, and a tri-axial, broad-band Streckeisen STS-2 seismometer with flat frequency response from 50 Hz to 120 seconds. The instruments are the same as those used by the GSN global seismic network for recording seismic activity at the global level; nevertheless, the high dynamic and sensitivity of the instruments allow them to also record weak local events.

Other seismic stations located near Agordo of the OGS network are: Forcella Aurine (FAU), Alpe Faloria (AFL), Casso (CSO), and Cimolais (CIMO).

3.RESULTS

We analyzed seismic signals from 27 natural avalanches (Fig. 8) and 12 artificial avalanches (Fig. 9) triggered by controlled explosions recorded by 5 OGS seismic stations in northern Veneto region: AFL (Alpe Faloria), AGOR (Agordo), CIMO (Cimolais, Friuli), CSO (Casso), FAU (Forcella Aurine).

The short-period seismic stations (AFL, CSO and FAU) did not record any avalanches, due to distance and low sensitivity. The high-dynamic, broad-band Cimolais (CIMO) station did not record the avalanches sufficiently well, probably due to distance. It is worth mentioning here that the natural snow attenuation factor is a major obstacle to the recording of avalanches with seismic stations.

The use of a single seismic station made it impossible to adopt the usual seismic detection techniques (triangulation, etc.). Furthermore, the low signal-to-noise ratio prevented the use of wave polarization directional techniques for detecting events from a single seismic station.

Nevertheless, it was possible to determine the duration of 21 natural avalanches, through high-pass filtering at 1 Hz and envelope calculation, thus managing to correlate the duration of two avalanches with their run-out distances, as was done by Biescas et alii [2003]. The low statistics is mostly due to the unavailability of complete physical avalanche parameters, such as duration and run-out distance.

An example of a seismograph generated by a natural avalanche is illustrated in Fig. 10. It shows the seismograph generated by the avalanche recorded on January 20, 2009 at 17:30 along regional road n. 638 (Passo Giau), which, among other things, ran over a van full of tourists from the Czech Republic, fortunately without harm. The site of the avalanche was located at a distance of 23 Km in direction 4°N, with an easterly exposure.

For this natural avalanche, we calculated the envelope after high-pass filtering at 1 Hz: the result is illustrated in Fig.11. The duration of this episode was 3.3 seconds.

Regarding artificially triggered avalanches, on the late afternoon of December 19, 2008, the Daesy Bell aerial system was used at Falcade, at a distance of 16.8 km in direction 300°N, without triggering any avalanches, and therefore the signal illustrated in Fig. 12 was produced by the aerial explosions on the snow pack and, through the latter, on the ground beneath.

The analysis of the envelope of the seismic signals generated by 21 natural snow avalanches reveals durations between a minimum of 9.3 seconds to a maximum of 23.9 seconds. The duration of these signals is correlated with the vertical displacement of the avalanches themselves: comparing the time necessary for a falling body to complete its fall given the vertical distance covered, we obtain the following values for the two episodes: 17.5s (observed) and 10s (calculated), 9.3 (observed) and 3.3 (calculated). There is thus an agreement, albeit limited due to the low statistics, while differences between the observed and calculated periods are due to the approximations in the physical model used, particularly the fact that snow-snow attrition - an important factor - was not taken into account.

4.CONCLUSIONS

In this paper, we illustrate the trends of the 2008-2009 winter season and show the usefulness of using the traditional seismic network for recording avalanche activities during particularly intense snowfalls. With regards to the seismological aspects of our study, we reached our minimum objective of correlating the physical parameters of avalanches with the characteristics of seismic station signals, albeit with an insufficient number of cases. The seismic signals recorded by the Agordo station, with the typical characteristics of avalanche movements, make it possible to reconstruct periods of avalanche activity, providing useful support for the verification of the avalanche risk bulletins issued in nearby areas. Our research suggests that it would be useful to install a denser seismic network dedicated to recording avalanches. Such a dedicated seismic network would be eventually calibrated using artificially triggered avalanches.

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Ackowledgements

We would particularly like to thank all of the Arabba Avalanche Centre (ARPAV Centro Valanghe di Arabba) observers; Renato Zasso, Alvise Tomaselli and Anselmo Cagnati of the Unità Operativa Neve e Valanghe and Dr. Antonio Rovelli of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome for his advice and help with data analysis.