INFRASONIC MONITORING OF SNOW AVALANCHES IN THE ALPS

Ulivieri G.[1*,4], E. Marchetti[1,4], M. Ripepe[1], I. Chiambretti[2], V. Segor[3]

[1] *Dipartimento di Scienze della Terra, Università di Firenze, Via la Pira 4 50121 Firenze, Italy*
[2] *AINEVA, Trento, Italy*
[3] *Regione Autonoma Valle d'Aosta, Italy*
[4] *Item srl, Italy (www.item-geophysics.it)*

ABSTRACT: Validation of risk assessment of snow avalanches requires to identify the occurrence of avalanches. For this purpose, after a pilot experiment in Gressonay during the 2009-2010, in December 2010 we installed a permanent 4-elements, 140 m aperture, infrasound array in the Ayas Valley (Italian Alps) where natural avalanches are expected and controlled events are performed. The array consists in high sensitivity (10^{-3} Pa, 0.5-50 Hz) infrasonic sensors and a 4 channels, 24bits, A/D converter sampling at 100 Hz. Timing is achieved with a GPS receiver. Data are transmitted to the Department of Earth Sciences of the University of Firenze, where are recorded and processed in real-time. A multi-channel semblance analysis is carried out on the real-time infrasonic data set as a function of slowness, back-azimuth and frequency content in order to detect all the possible signals. The results gained during 3-years-long test indicate that small-to-medium size powder avalanches can be detected in the short-to-medium range (<5 km). Despite array analysis allows to discards many natural (microbarom, earthquakes) and artificial (airplane, explosions) sources of infrasound, a network of 3 arrays will be deployed on Summer 2012 for a precise and automatic source location, which should allows a better discrimination between "noisy" and avalanches sources of infrasound. Precise location together with real-time monitoring automatically will provide information on potential sectors where avalanches might have occurred during the last 24h, thus providing crucial and reliable information for improving risk assessments.

KEYWORDS: infrasound array network, snow avalanche monitoring, risk assessment

1 INTRODUCTION

Snow avalanches generate infrasonic (~ 20 Hz) acoustic waves propagating through the atmosphere at the speed of sound. Infrasound generated by avalanches is well documented (e.g. Bedard, 1994; Chritin et al., 1996; Naugolnykh and Bedard, 2002; Comey and Mendenhall, 2004; Scott et al., 2007; Yount et al., 2008; Mayer and Lussi 2010; Ulivieri et al., 2011). Two main problems affect the infrasound measurement, i) the infrasonic noise, which can strongly reduce the signal identification, and ii) the existence of many sources of infrasound produced both by natural (e.g. mountain wave, microseism, earthquakes) and human (e.g. industrial activity, traffic) processes. Wind is the most source of infrasonic noise, which applies all the more to weak signal produced by avalanches. Recently, the use of infrasound arrays (different infrasonic sensors deployed in a regular geometry to be used as an antenna) rather than single sensors has increased the signal-to-noise ratio improving the identification of signals (Adam et al., 1998; Comey and Mendenhall, 2004; Scott et al., 2004; Scott et al., 2006; Scott et al., 2007; Mayer and Lussi, 2010; Ulivieri et al., 2011). In the last two decades moreover, infrasound technology has been improving greatly, in terms of sensor design, noise reduction systems and processing procedures. For infrasound monitoring of avalanches a proper instrument design and array installation as well as an adequate treatment of environmental noise and a careful data processing are critical to ensure good array sensitivity (Ulivieri et al., 2011).

* Ulivieri G., Dipartimento di Scienze della Terra, Università di Firenze, via G. La Pira 4, 50121 Firenze, Italy; tel: +39 0552757574; fax: +39 055218628; email: gulivieri@unifi.it

Avalanche infrasound monitoring is commonly limited to relatively small areas (few km^2) around the deployment in practical highway and recreational area settings (Scott et al., 2007; Yount et al., 2008; Mayer and Lussi, 2010). This is mostly related to the great amount of infrasound signals detected by an array, as a result of the small attenuation of infrasonic wave in the atmosphere.

Recently, efficiency of infrasound to monitor natural avalanches has been tested in Italy (Ulivieri et al., 2011) over wide areas around the array with the aim of validating avalanche observations and thus improving danger assessments.

Here we describe the results of 3-years-long (2009-2012) of infrasound monitoring of snow avalanches in North-western Italian Alps (Valle d'Aosta). Besides the promising result, the many (thousand) infrasound events automatically detected by one array and compatible with the signal produced by an avalanche, cannot uniquely referred to real avalanche. For these reason, a network of 3 infrasonic arrays has been designed in order to improve source location and thus the avalanches identification capability.

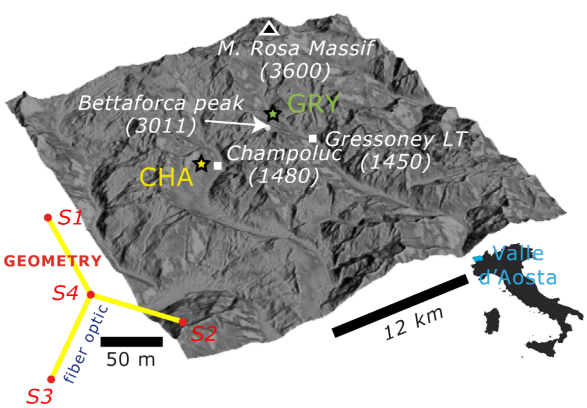

Figura 1. DTM of the eastern Valle d'Aosta region with the position of the two (CHA and GRY) small-aperture, star geometry (yellow lines with red dots), infrasonic arrays.

2 INFRASOUND MONITORING OF SNOW AVALNCHE IN ITALY: RESULTS

Infrasound monitoring of snow avalanches in Italy started on the 2009-2010 with an experiment in the Lys valley immediately south of Monte Rosa at ~ 2000 m of elevation (GRY in Figure 1). Since Dec. 2010, a permanent infrasonic array with real-time data transmission was installed in the adjacent Ayas valley (CHA in Figure 1). Instrument design, array installation solutions as well as reduction of environmental noise, and suitable automatic data processing procedure were the main target tested during this phase (Ulivieri et al., 2011).

The system consists of 4-elements infrasonic array with a triangular geometry and ~140 m of aperture (Figure 1), equipped with OptimicTM 2180 infrasonic microphone with high sensitivity (109 mV/Pa) in the 0.5–20,000 Hz frequency band. All the array elements are connected to the central station by using fiber optic cables to reduce drastically the damage from lighting. Data are digitized using a 24 bit Guralp CMG-DM24 at the sampling rate of 100 Hz, recorded on a local hard disk and transmitted in real time with UMTS protocol. Time synchronization was achieved with a GPS receiver. The low power requirement of the entire system (~2.5 W) allowed continuous operation of the infrasound array during the winter season with two solar panels (Figure 2c) of 85W each and 6 gel-cell batteries.

We deployed the array in a forest (Figure 2a) and the infrasonic sensors are installed inside boxes completely covered by snow (Figure 2b) to reduce the effect of wind on the sensor (Adam et al., 1998).

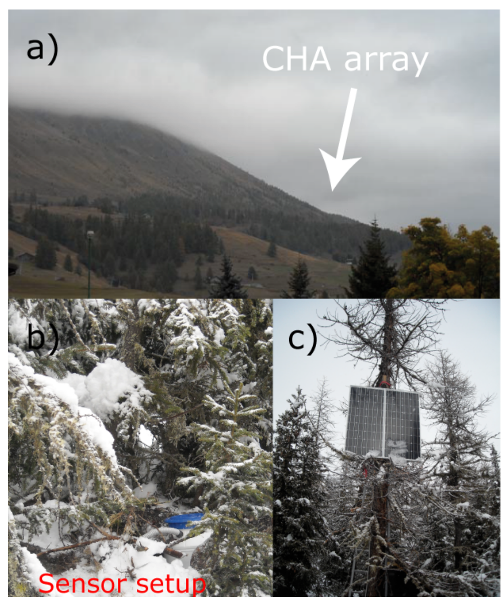

Figura 2. The permanent CHA array was deployed in a forest (a) and the sensors were installed inside boxes completely covered by snow and vegetation (b). 85W solar panels (c) guarantee the complete autonomy of the monitoring system.

Low noise level consistent with the low wind median curve (Figure 3, red dotted line) from globally distributed arrays (Bowman et al., 2005) was achieved in this alpine valleys (Figure 1 and Figure 3).

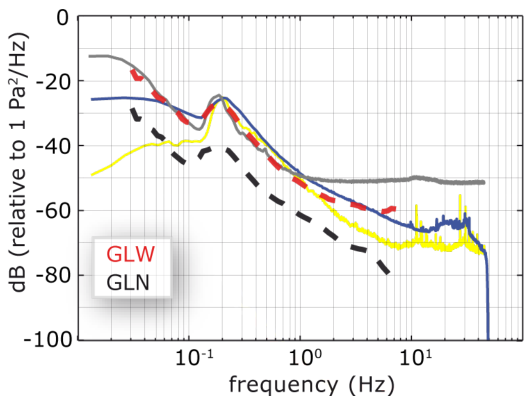

Figura 3. Average infrasonic noise levels at the CHA (blue line) and GRY (grey and yellow lines) sites, using two different sensors: differential pressure transducers (grey line, Marchetti et al., 2009) and high sensitive optical microphones (blue and yellow lines). The dashed lines indicate the global low wind (GLW) and global low noise (GLN) median curves (Bowman et al., 2005).

A multi-channel correlation analysis (MCCA, Ulivieri et al., 2011) is applied to infrasonic data in order to identify signals from noise in terms of wave propagation *back-azimuth* (the direction from where the signal is coming from) and *apparent velocity* (the velocity, m/s, the wave would travel if it would propagate in the same plane as defined by the array geometry and it is related to the incident angle and thus to the altitude of the source).
MCCA allowed to perfectly detect a powder avalanche at a distance of 2 kilometres (Figure 4a) with an accuracy of 1° in the back-azimuth and a decreasing incident angle compatible with an average front velocity of 25 m/s, coherent with this type of avalanche and with the average velocity obtained from video-recordings. Based on wave-field parameters, the array analysis give helps to automatically discard high altitude infrasound sources not compatible with an avalanche, such as airplane (Figure 4d-f), ocean and/or mountain waves.

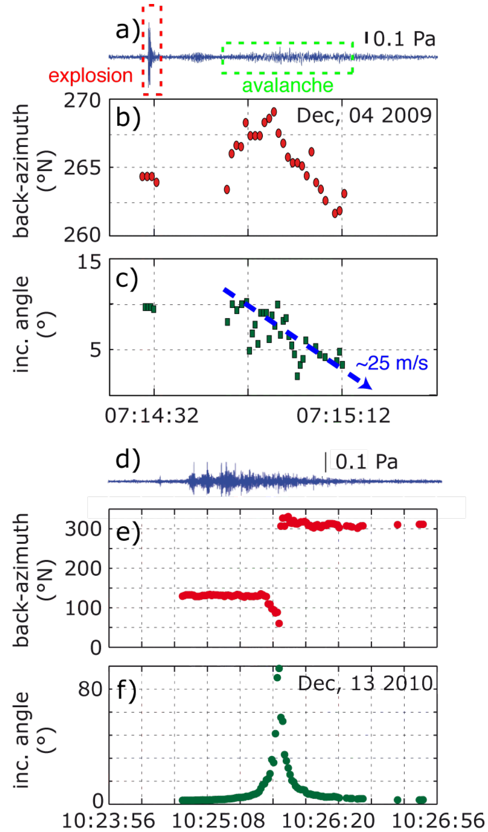

Figura 4. Infrasonic records (a and d), back-azimuth (b and e) and incident angle (c and f) of a man-made powder snow avalanche (a-c) 2 km far from the array and an airplane (d-f), as the results of automatic multi-channel correlation analysis (MCCA).

Even if a single array provides a precise description of the infrasound wave-field and the automatic discrimination of some sources not compatible with an avalanche (Figure 4), the amount of event identified during three winter seasons of continuous monitoring (Figure 5) cannot be explained only in terms of natural avalanche activity. Hundreds of events were identified during the first experiment in 2009-2010 with low sensitive differential pressure sensors (GRY array in Figure 1, Figure 5a), which became thousands with higher sensitive optical microphone (CHA array in Figure 1, Figure 5b and 5c), but only a portion of them (~30%, Figure 5c) can be automatically identify as no-avalanche signals using a single array.

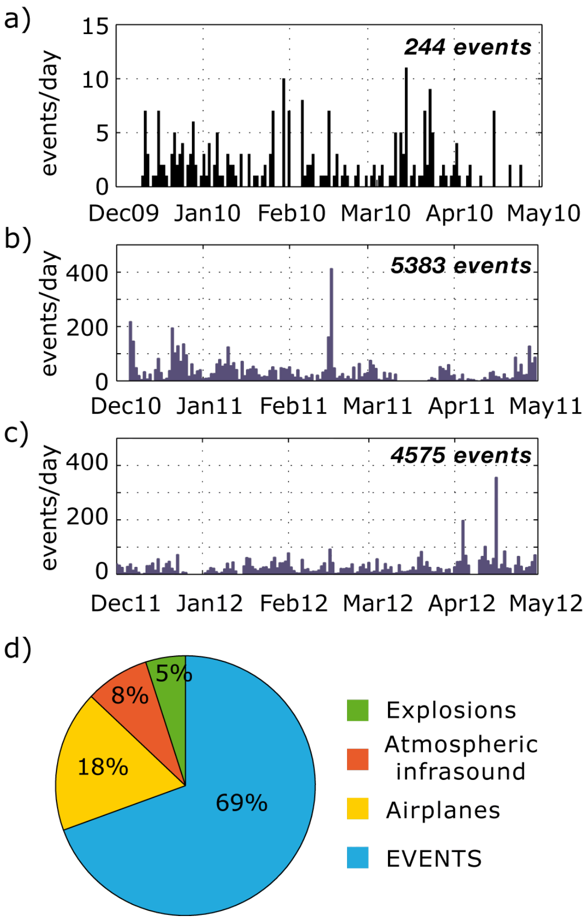

Figura 5. a-c) Trends of the daily infrasonic events detected by GRY (a) and CHA (b and c) arrays. (c) Pie graph of the automatically identify infrasound events. The class EVENTS represents the sources compatible with avalanches.

Most of these infrasonic detections (EVENTS in Figure 5) are probably produced by the human activity. The coincidence between the azimuthal distribution of acoustic energy and the major axis of the valley where the array is located is a clear evidence of this hypothesis.

3 NETWORK OF ARRAYS DESIGN PROJECT

A single array does not provide a precise source location but simply the propagation direction. Precise locations can be obtained only by using two or more arrays at once. The intersection of two or more propagation directions in fact, provides precise geographical location (Figure 6, green dot as an example), which can be used to better identify possible avalanche sources.

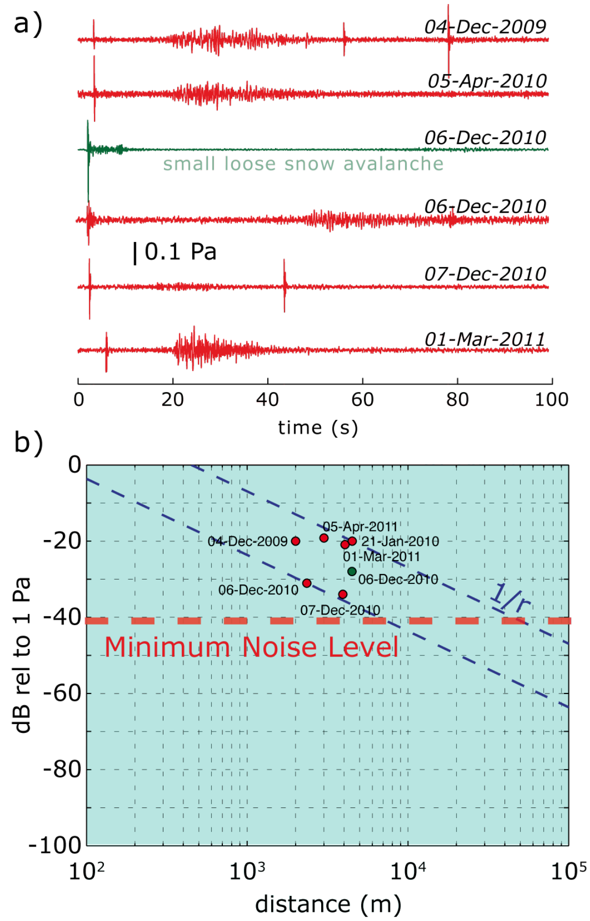

Figura 6. a) Some examples of man-made, powder (red) and loose snow (green), avalanches record. b) Amplitude versus distance from the array of the signals in a. The blue dashed lines indicates the infrasound attenuation from simple geometrical spreading. Red dashed line indicates the minimum infrasonic noise level of the CHA site (see Figure 3).

In order to improve the infrasonic monitoring system in the western Alps, the geometry of the network has been re-designed by estimating the theoretical array maximum detection distance. For this purpose we used ground-truth small-to-medium size man-made avalanches (Figure 6a), with well-known distance from the array, and assuming only attenuation by geometrical spreading (Figure 6b, blue dashed lines), we propagate the amplitudes from the source at a given distance. Then, considering the smallest recorded avalanche (Dec 6, 2010) and an average noise level of -40 dB relative to 1 Pa (Figure 6b, red dashed line), compatible with the computed noise level in the 1-10 Hz frequency band (Figure 3), a maximum threshold of

detectability of ~10 km has been estimated for the smallest detectable snow-powder avalanche.
By adding two arrays eastward and westward from the existing CHA array at a distance of ~ 10 km, we are confident to be able to detect infrasonic events in an area of about 250 km^2 within of M. Rosa Sky Resort (Figure 7, coloured areas).
The infrasonic array network has already been planned and the installation activity started in July 2012.

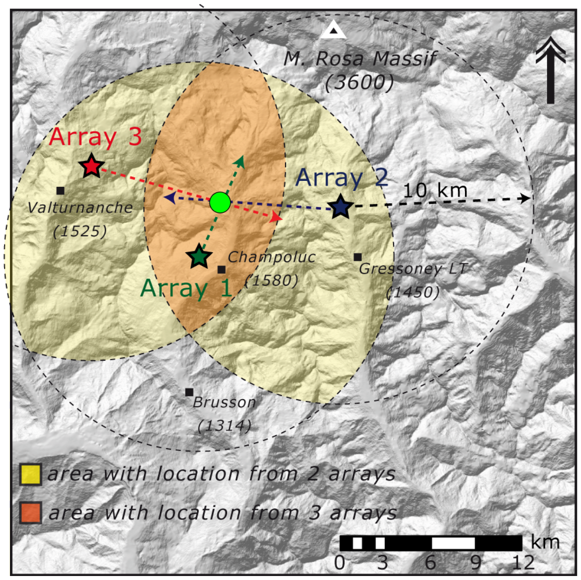

Figura 7. Theoretical location of one avalanche using a network of 3 (Array 1-3) infrasonic arrays.

4 CONCLUSION

Infrasonic array monitoring offers a unique opportunity to extract real-time information (location and precise time of occurrence) of natural snow avalanches activity: these information are crucial for improving avalanches risk assessment in the Alpine areas.
Results of 3-years-long of infrasonic array monitoring of snow avalanches in the Alpine area (Italy) confirm the efficiency of infrasonic monitoring also for small to medium-sized (~500 m^3) avalanches up to distances of ~5 kilometres from the deployment.
A robust validation based on the comparison of infrasonic detections and well-documented avalanches is still needed, as most of the events detected by the array were not observed. However, for small to medium-sized avalanches, observation and their timing is difficult and quite incomplete.
We show how a network of 3 arrays will provide a more precise (geographical) source location, which will allow us to improve the efficiency of the avalanche infrasonic monitoring system.

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References

Adam, V., Chritin, V., Rossi, M., Van Lancker, E., 1998. Infrasonic monitoring of snow-avalanche activity: what do we know and where do we go from here? Annals of Glaciology, 26, 324–328.

Bedard, A., 1994. An evaluation of atmospheric infrasound for monitoring avalanches. Proceedings, 7th International Symposium on Acoustic Remote Sensing and Associated Techniques of the Atmosphere and Oceans, 3–5 October 1994, Boulder, CO.

Bowman, J.R., Baker, G.E., Bahavar, M., 2005. Ambient infrasound noise. Geophysical Research Letters 32, L09803. doi: 10.1029/2005GL022486.

Chritin, V., Rossi, M., Bolognesi, R., 1996. Acoustic detection system for operational avalanche forecasting. Proceeding of International Snow Science Workshop, Banff, Alberta, 6–11 October 1996, pp. 129–133.

Comey, R.H., Mendenhall, T., 2004. Recent studies using infrasound sensors to remotely monitor avalanche activity. Proceeding of International Snow Science Workshop, Jackson, WY, 19–24 September 2004, pp. 640–646.

Marchetti, E., Ripepe, M., Poggi, P., 2009. Low Cost Differential Pressure Transducers Used to Investigate Low Frequency Volcano Infrasound. Infrasound Technology Workshop 2009, Brasilia.

Mayer L. and D. Lussi, 2010. Remote detection of snow avalanches in Switzerland using infrasound, Doppler radars and geophones. Proceeding of International Snow Science Workshop, Squaw Valley, CA, 17–22 October 2010, pp. 7–12.

Naugolnykh, K., Bedard, A., 2002. A model of the avalanche infrasound radiation. Proceedings of the 24th Canadian Symp. Rem. Sens, pp. 871–872.

Scott, E.D., Hayward, C.T., Kubichek, R.F., Hamann, J.C., Pierre, J.W., Corney, B., Mendenhall, T., 2007. Single and multiple sensor identification of avalanche-generated infrasound. Cold Regions Science and Technology 47, 159–170.

Scott, E. D., Hayward, C.T., Kubichek, R.F., Hammon, J.C., and Pierre, J.W., 2004. Results of recent infrasound avalanche monitoring studies. Proceedings of International Snow Science Workshop, Jackson, WY, 19–24 September 2004, pp. 696–704.

Scott, E. D., Hayward, C.T., Colgan T.J., Hamann J.C., Kubichek R.F., Pierre J.W., Yount J., 2006. Practical implementation of avalanche infrasound monitoring technology for operational utilization near Tecton Pass Wyoming. Proceedings of International Snow Science Workshop, Telluride, CO, 1–6 October 2006, pp. 714–723.

Ulivieri G., M. Marchetti, M. Ripepe, I. Chiambretti, G. Derosa and V. Segor (2011). Monitoring snow avalanches in Northwestern Italian Alps using an infrasound array. Cold Regions Science and Technology 69, 177–183.

Yunt J., Naisbitt A., Scott E.D., 2008. Operational highway avalanche forecasting using infrasonic avalanche detection system. Proceeding of International Snow Science Workshop, Whistler, BC, 21–27 September 2008, pp. 268–276.