AVALANCHE DETECTION THROUGH SEISMIC TECHNIQUE [1]

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Abstract. A two years experiment was conducted in La Plagne (Savoie) in order to check the reliability of avalanche release recording through seismic technique . Dayly numbers of signals collected are in good agreement with direct observation . Moreover signal analysis might yield a valuable information about avalanche characterization .

INTRODUCTION

Avalanche runouts monitoring gives to every forecaster a precious feedback information to actualize his dayly prediction, and enables a statistical approach or a control of prediction methods. Direct observation is not available in remote areas and may be impossible in severe weather, due to poor visibility and dangerous access.Seismic detection could be a way of monitoring avalanche runouts in such cases. Previous experiments were reported namely by StLawrence and Williams (1976) and Harrisson (1976) and gave evidence of seismic signals generated by avalanches. Bonnet (1980) recorded numerous avalanche signals in Bonneval-sur-Arc for several winters, and pointed out a few characteristic patterns. Following his work, we conducted for two seasons a seismic detection experiment in La Plagne, a ski area of Savoie in the french Alps. This was done in relation with the ski patrols who carry out an extensive avalanche control and a dayly observation of all the avalanches in and around the ski area, thus allowing a comparison between seismic recordings and direct observation.

This paper describes our experiment and the first results obtained in estimating "avalanche activity" from seismic data.

EXPERIMENTAL DEVICE

We used a seismic data collecting device developped by Laboratoire de Géophysique (CEA/LDG) for his operational detection network. A short period vertical seismometer was located in the upper part of the ski area, around 2500 meter a.s.l., in an assumed undisturbed place. The amplified analogic signal was sampled 50 times per second, digitalized on twelve bits, and recorded in Pulse Coded Modulation on a magnetic tape each time the signal to noise ratio reached a given threshold of 9 dB. The tapes had to be replaced every two or three weeks, depending on the number of events detected. To allow a better accessibility even in severe weather conditions the recording device was located about 1.5 kilometer away from the seismometer, on top of Roche de Mio (2700 meter a.s.l.), a permanent radio transmission being used between recording and measuring site. The records were later played back and analysed through graphical outputs at various speeds (1 to 5 mm/s). Additional low-pass and high-pass filters were used, so that the final amplification rate was $0.25\ 10^6$ at 1 Hz for regular outputs, with the response curve shown in figure 1 .

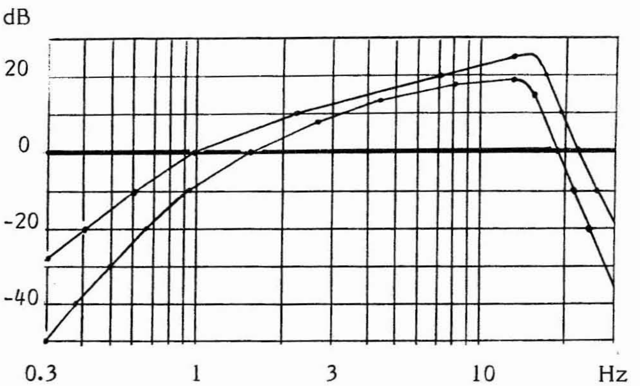

Figure 1. Response curves of the measuring device without (top line) and with (bottom line) output filters. The useful frequency range lies between 2 Hz and 10 Hz . Low frequencies are mainly concerned by far earthquakes and swell-generated natural noise . Frequencies over 10 Hz are disturbed by industrial noise of skilifts and cable-car motors .

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SURVEY PROCEDURE

The first purpose of this study was a global approach of runouts frequency estimation through seismic detection. Three kinds of information were available: locally recorded events, earthquakes reported and direct observation. During the whole winter 82-83, these data were compared in order to determine which events were due to avalanche runouts and to derive patterns of avalanche seismic signals. During the next winter (83-84) seismic records were analysed without any reference to direct observation, as mentionned in figure 2. Seismic data and observed avalanche occurency were then compared to each other as two really independent information sources.

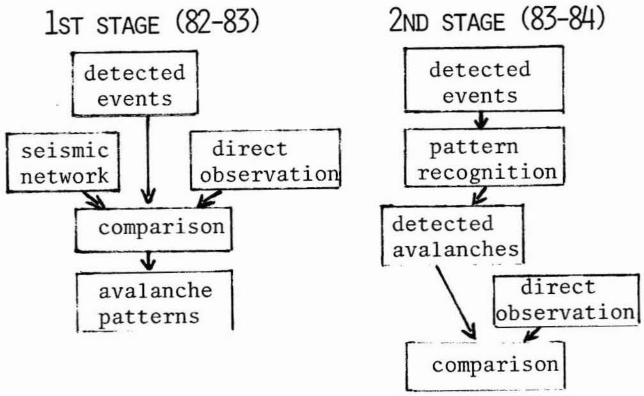


Figure 2. Scheme of survey procedure .

The second purpose was to try a characterization of signal shape or frequency in relation to site, snow-type or flow-type. This implied an additional direct observation of various particular cases.

AVALANCHE RECOGNITION

As signal frequency is known to be regularly decreasing with increasing distance from the event source, local events should not be confused with distant earthquakes : beyond 1000 km frequency is mainly under 2 Hz, avalanche signals appear to be within 2 to 9 Hz. The main problem is to discriminate avalanches from other local events such as local earthquakes (within 1000 km) , mine shots, wind effects or local noises . This can be achieved by considering signal shape . Comparing avalanches to other events, we notice that they show a gradual increase in amplitude corresponding to the acceleration stage of the snow runout, while earthquakes or mine shots usually present a sharp start. Wind signals offer an unachieved shape and typically appear in a repetitive way during several hours. Industrial noise has a fixed frequency and may be bound to working hours . Other very local noises caused by humans or animals are typically shorter than avalanches and should be unfrequent in a good measuring site.

A typical feature of seismic signals is that they are made up of several phases , starting with direct Pg and Sg waves and -beyond 200km- refracted Pn and Sn waves , the time elapsed between their arrivals being a function of the distance from the event origin . For mine shots as for local earthquakes, Pg and Sg waves are spaced of about one second for every 8 kilometers and well recognizable : S wave is higher in amplitude than P wave , but with a slightly lower frequency . If several phases may be distinguished in an avalanche signal , as in figure 3-5 , 3-6 , and 3-7 , it is a result of time evolution of the avalanche itself , but , according to the short distance from the source , it cannot be an effect of wave spacing through ground propagation .

Moreover , for a local earthquake , signal frequency is decreasing with time , which is not the case for an avalanche . Eventually , avalanche signals may get various forms , as shown in figure 3 , but we find out that most of them are not compatible with seismic patterns , so that a careful analysis taking into account frequency , shape , and time spacing of the distinct phases enables a real discrimination between avalanches and extraneous events .

It may be helpful to get additional data from a seismic network , or at least from a second seismometer . If the distance between the two seismometers is greater than twice the range of avalanche detection (for instance : 2 x 10 miles) , every doubtful event recorded by both sensors could not be due to an avalanche and could be obviously eliminated .

COMPARISON OF DETECTED AND LOCALLY OBSERVED EVENTS

Data recorded in La Plagne from december 83 to may 1984 were classified as shown in table 1 .

Table 1. Numbers of events of each kind detected in La Plagne. Left column is a percentage and right column is a dayly mean value

EVENT	%	DAYLY NUMBER
Distant earthquake	32	3,2
Local earthquake	14	1,4
Mine shot	24	2,4
Avalanche (certain)	8	0,7
Avalanche (likely)	2	0,2
Wind effect	5	0,5
Ambient noise	6	0,6
Unknown origin	10	1

Taking into account only the days when both seismic data and observed data were available , we looked for a relation between them . As the release time of the avalanche is not reported with a sufficient accuracy by the ski patrols , we could seldom doubtless associate a detected signal to a defined observed avalanche . Noting that direct observation is performed on a dayly basis, while seismic control is continuous , we compared dayly

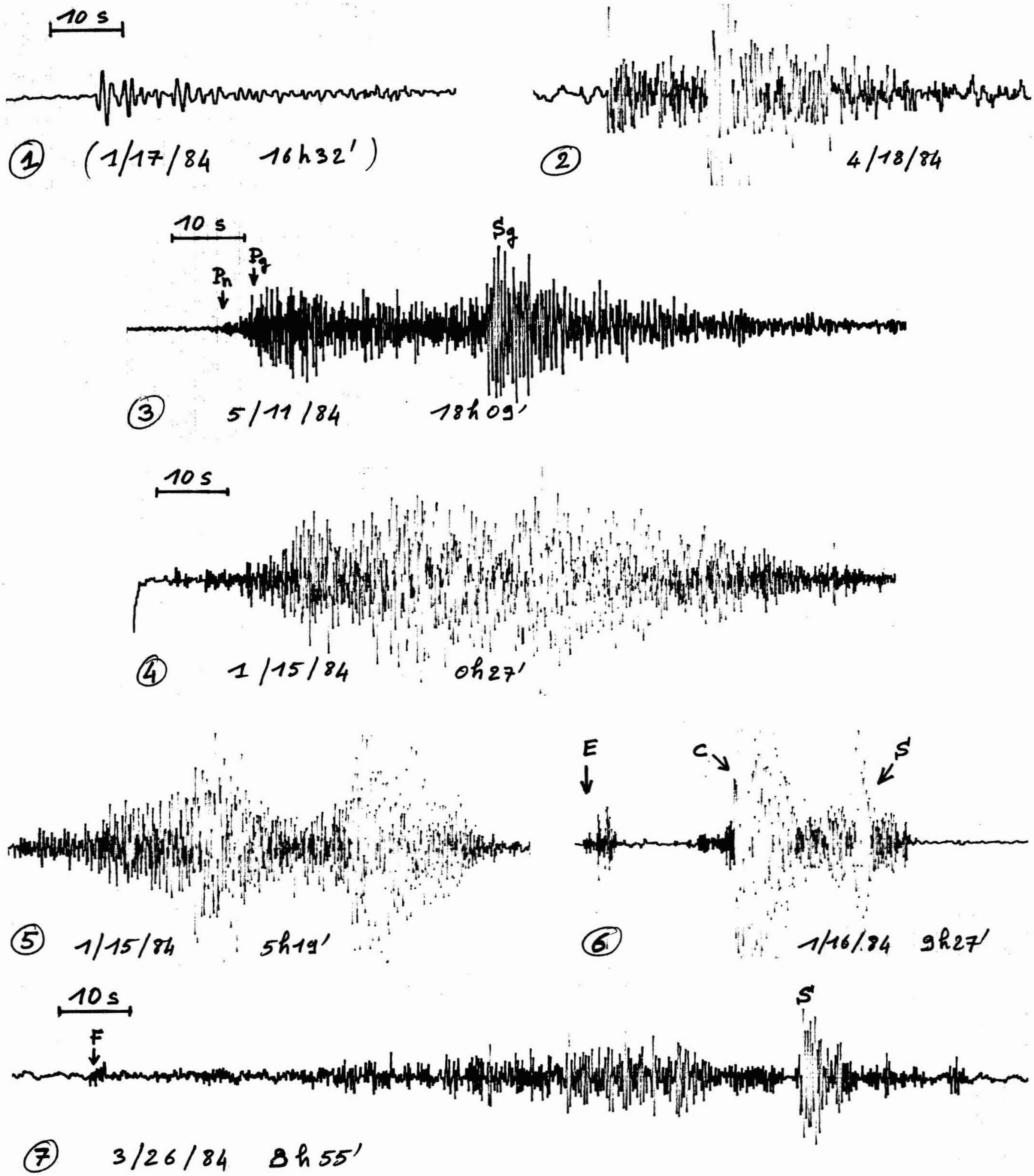


Figure 3. Various kinds of seismic and avalanche signals . 1=distant earthquake ; 2=Mine shot (110 Km) ; 3= local earthquake (270 km) ; 4 and 5= powder snow avalanches ; 6= artificial released avalanche (1km) , E=explosion, C=jump over a small cliff, S=stop ; 7= slab avalanche released with ski, F=fracture, S=stop .(distance:0.7 km) .

numbers of avalanches from both sources of information but the correlation obtained was weak , around 0.5.

It appears that 65 % of the observed avalanches are small size artificial releases which are little significant , few of them are detected by the seismometer. On the other hand, 75 % of the detected avalanches are known to be naturally released , occuring at night , or during snowstorm when no avalanche control could be done . In any case , little or no information is available from direct observation about them .

Moreover, as the seismometer is located in a remote place in the upper part of the ski area, many of the detected avalanches are probably naturally released outside the controlled area and thus cannot be observed .

GLOBAL RELEASE FREQUENCY [3]

It thus appears that seismic detection could not be exactly fitted to direct observation from the controlled area, being not related to the same individual events . At a wider scale , however, they may be yet compared as two indexes of snow instability and release frequency, resulting fromthe same weather effects . Classifying the whole season into days-with avalanche and days-without-any-avalanche according to the seismometer or according to observation, we obtained a rate of simultaneous occurence of 75 %, as shown in table 2 .

Table 2.

DAYS	with observed avalanche	without observed avalanche
with detected av.	18	11
without detected avalanche	12	56

A morecomprehensive result is given by figure 4 which shows the evolution of the dayly numbers of detected and observed avalanches . These numbers are plotted from december to april, except from 2/17/84 to 3/26/84 , due to a recorder failure . Detected events are in good agreement with observed ones . Most events are found to belong to one of four instable sequences which are associated to known weather condition, and concerned various types of snow .

First sequence: The first avalanche sequence (12/17/83 to 12/24/83) began with a cold snowfall, was early detected but remained underestimated until it turned to mild weather and moist snow runouts. All three other sequences were well detected .

Second sequence: From 1/14/84 to 2/1/84 several heavy snowfalls generated numerous fresh snow and powder snow avalanches, and up to 17 releases were detected on the same day .

Third sequence: Considerable snowfall occurred, followed by stormy wind, from 2/7/84 to 2/13/84, causing a high snow instability . Many fresh snow and slab avalanches were detected, while only a few could be observed by the ski patrols, due to severe weather conditions .

Fourth sequence: From 4/19/84 to 4/23/84 a warm sequence generated many wetsnow runouts. A gradual increase in avalanche activity is well shown by seismic data, but underestimated by observation, for it is mainly occuring in the late afternoon while the ski patrols are no longer in the area .

Out of these four instable sequences, a few events were either observed or detected, but do not seem to be related to a significant avalanche activity .

A global avalanche release frequency index is being used by Centre d'Etudes de la Neige in prediction control, which takes into account the number of spontaneous releases dayly observed by several skis areas of the same district . In spite of its wide spatial scale (order of magnitude:1000km^2) the agreement is slightly better with seismic data, for this index is more representative of natural instability than a single observation station .

SIGNAL CHARACTERISTICS

In order to relate signal characteristics to snow or path parameters we compared to one another the signals which could be associated to known observed avalanches . Although few direct measurements were available , several governing factors could yet be pointed out .

distance : Ground propagation of a seismic signal induces an attenuation in amplitude, a frequency decrease and an overall smoothening . Comparing avalanche signals received from close and distant sections of the experiment area during various snow conditions it appears that this change is quite significant, frequency becoming roughly twice lower when the distance between avalanche and seismometer increases from 1 to 7 kilometers (fig.5).

sliding surface : Depth and type of snow under the sliding surface have to be taken into account, for this bottom layer may be acting as a filter . For a given distance, the highest frequencies are obtained for full-depth avalanches . A strong signal with a high frequency of 9 Hz was also given out by a hard slab sliding on a layer of old refrozen depth-hoar (fig.3-7). Inversely , at a similar distance and on the same day, slabs sliding on thick snow layers in frequently controlled slopes could not be detected .

slope profile : Signals of close origin may present quick jumps in amplitude which are obviously an effect of path discontinuities such as cliffs or sharp bends. In such cases, every avalanche released in the same path will generate the same characteristic features. Some avalanche paths thus can be recognized through their signal pattern (fig.3-6).

3 . in this paragraph we did not take into account the artificially released avalanches reported to be "small" .

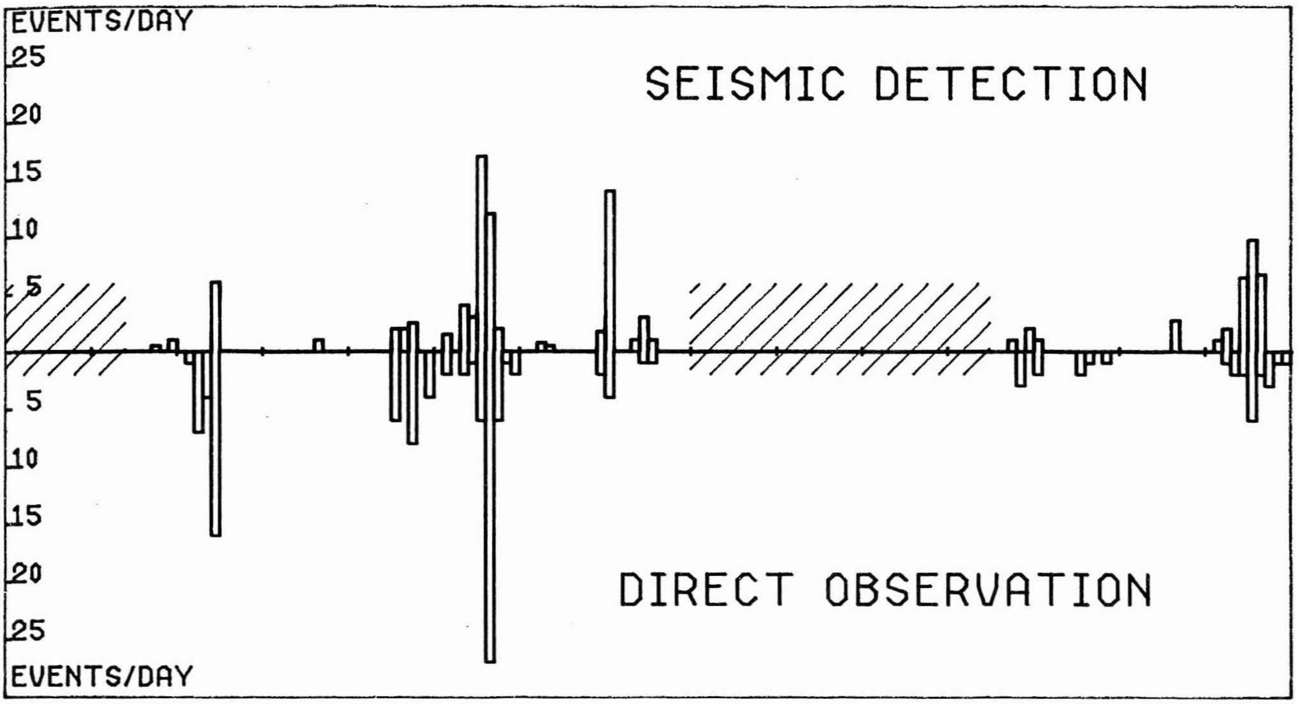


Figure 4 . Dayly numbers of detected (upwards) and observed (downwards) avalanches . The artificially released reported to be "small" avalanches were not taken into account . Hatchings were drawn when no data were available because of a lack of observation in early december and recorder failure in march .

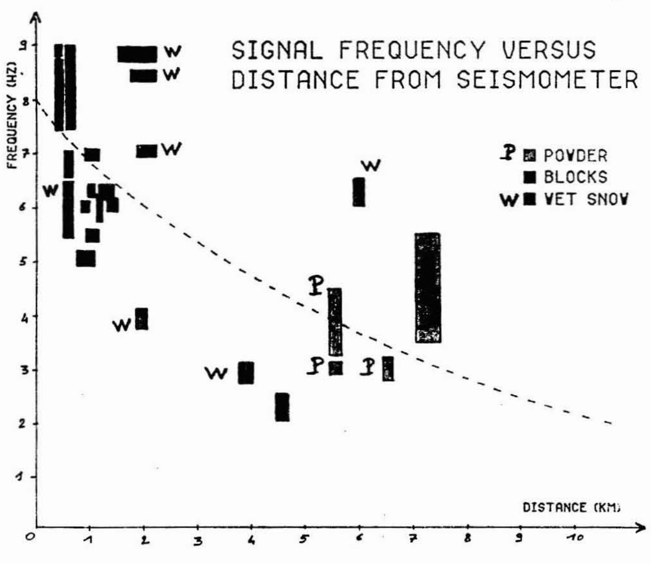


Figure 5. A rectangle was plotted for every avalanche whose distance and frequency were known. Rectangle size describes frequency range and distance range between top and bottom of avalanche path. The dashed line is an exponential decrease shown as a comparison: $f = f_0 \exp(-k\,d)$ with $f_0 = 8$Hz $k=0.13\,(\mathrm{km})^{-1}$
The wide range of frequency obtained for a given distance is a result of various conditions regarding snow-type, slope, and position of sliding surface .

<u>avalanche dynamics</u> : Signal shape often brings an additional information about avalanche dynamics . The initial crack of a slab release is sometimes clearly detected. When no slope discontinuity is present, we get a gradual increasing then decreasing amplitude, which yields the time length of acceleration and deceleration stages .

A typical feature of dense flow avalanches is the sharp rise in amplitude observed after the deceleration stage, as moving snow eventually stops , coming back to a static equilibrium . This final phase does not appear in signals generated by powder snow avalanches whose amplitude may have a quick rise when the snow-dust cloud starts, but which decreases in a gradual way as it vanishes in its final stage .

At this step of the experiment it was not possible to perform a systematical spectral analysis of the data collected, but a significant evolution of frequency with time is to be seen, which could be related to speed fluctuations and density variations during avalanche.

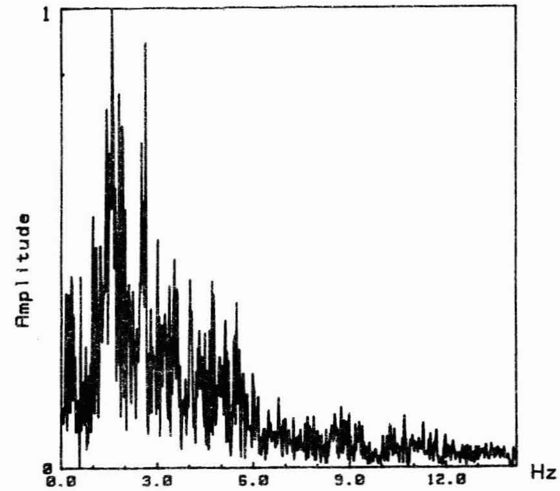
Maximum frequency is often reached in the final phase if it is present , but several brief high frequency sections may also appear during the main signal phase . In this latter case, it could be due to changes in sliding surface along the path .

An attempt was made to get an evidence of these effects by filming artificially released avalanche, but it was not successful due to poor visibility .

CONCLUSION

These first results already show the reliability of seismic detection to monitor avalanche activity . In severe weather conditions a seismometer will still give out a valuable information although direct observation would not be possible . Seismic detection is especially convenient for remote areas because of poor accessibility and low ambient noise level. The range of detection is depending on device sensibility and ambient noise. Some big avalanches may not be detected, but it must be pointed out that several strong signals were obtained from avalanches released doubtless up to 7 km from the detection place, and associated to various snow conditions .

The next step of this experiment will be to check automatical recognition criterion based on time-evolution of computer spectral analysis . We also aim to collect additional field data regarding dynamics of detected avalanches in order to precise the relation between signal shape and avalanche characterization . (fig.6)



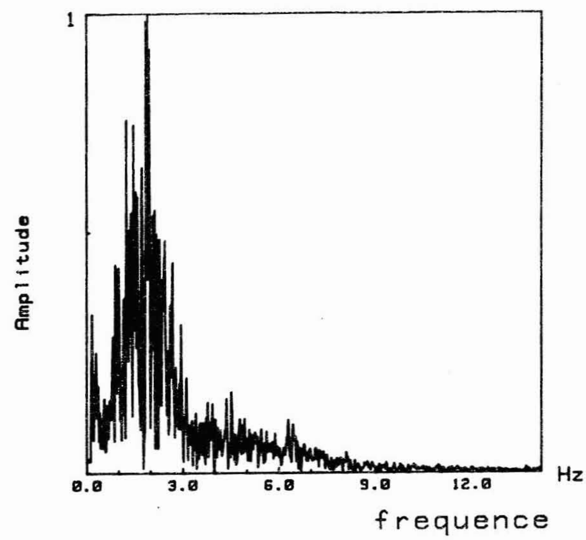


Figure 6. Spectral analysis of two typical signals : Above,powder-snow avalanche of 1/23/84 21h55'. Below, local earthquake of 1/30/84 20h08' .

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REFERENCES

StLawrence,Williams, and T.R.Williams.1976. Seismic signals associated with avalanches.J.of glaciol. vol 17,N°77.

Harrison,J.C.1976.Seismic signals from avalanches. In Armstrong and Ives. Avalanche release and snow characteristics. San Juan mountains,Colorado INSTAAR occas.paper N°19,pp145-150.

Bonnet,G.1980. Detection d'avalanches par méthode sismique. Neige et avalanches, Revue de l'ANENA. N°24,pp30-41,november 1980.