DETECTION OF AVALANCHES USING ATMOSPHERIC INFRASOUND

by

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ABSTRACT

Long-range detection of avalanches may be feasible by analyzing low-frequency acoustic waves generated by avalanche processes. A review of recent measurements of long-range atmospheric infrasound associated with avalanche activity indicates that unique acoustic signatures are launched by avalanches, perhaps providing a means of characterizing avalanche details at distances of hundreds of kilometers. This paper reviews progress to date and indicates the form that an infrasonic avalanche detection system could take. A key conclusion is that the small explosives and equipment used for avalanche control measures could not have caused recorded infrasonic signals related to avalanche occurrences. The potential uses of a reliable detection system include avalanche forecast verification, comparisons with prediction models, and better definition of regional avalanche statistics.

INTRODUCTION

Bedard et al. (1989) reviewed evidence indicating that avalanches radiate low-frequency sound waves detectable at distances of hundreds of kilometers. Monitoring such "avalanche sound" has potential, practical value in terms of responding to needs for improved avalanche prediction and warning summarized in Fig. 1. Acoustic techniques could possibly be used to characterize avalanche details such as snow depth and avalanche path length (Bedard et al. 1989). However, Bedard et al. (1989) also indicated the following needs: to measure acoustic energy near controlled avalanches, to understand the mechanisms that radiate sound waves, to measure the acoustic signature near the source (eliminating propagation effects), and to document the acoustic signatures of avalanche control devices. The last need that is addressed here. The measurement of the sounds produced by avalanches requires insurance that the control devices do not produce the acoustic energy. Following sections provide an example of the power spectra of signals associated with distant avalanches, describe the instrumentation assembled to perform source-region measurements, and describe measurements of sounds produced by two avalanche control procedures. Neither of the control methods or devices monitored could account for atmospheric infrasound measurements associated with avalanches.

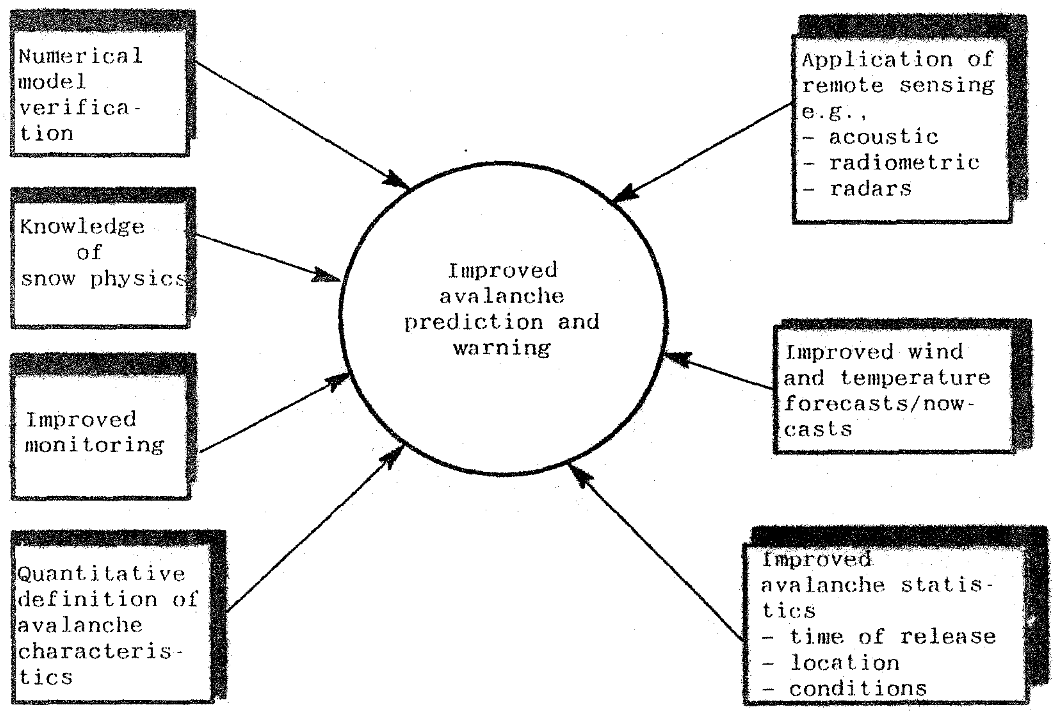

Figure 1. Elements contributing to improved avalanche prediction and warning.

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INFRASOUND ASSOCIATED WITH A DISTANT AVALANCHE

The power spectral plot shown in Fig. 2a (top) together with pressure time series plots for two microphone channels (Fig. 2. bottom) are for data recorded on 11 February 1988 from an azimuth from the direction of Loveland Pass, Colorado (Bedard et al. 1989). The power spectrum derived from the combination of four microphone channels time shifted for best correlation shows that two quite similar signals occurred. The power spectra data shown in Fig. 2 (top) are weighted by multiplying by the cube of the correlation coefficient r, thus emphasizing the spectral content of regions showing high correlation coefficient. For this case as well as other cases observed the speed of propagation across the array was the local acoustic trace speed. On this date eleven avalanches were reported for Loveland Pass (east and west sides of the Eisenhower tunnel), Vail and Berthoud. The frequency (about 0.5 Hz) was lower and the amplitude (about 2 μbar) higher than can be expected from guns or explosives used for avalanche control. Bedard et al. (1989) present five examples of signals recorded during times of avalanche activity. One of these corresponded in azimiuth and time to an avalanche released by small explosives. Additional measurements have encouraged us to continue these investigations, which have involved estimated acoustic propagation paths of typically 100 km.

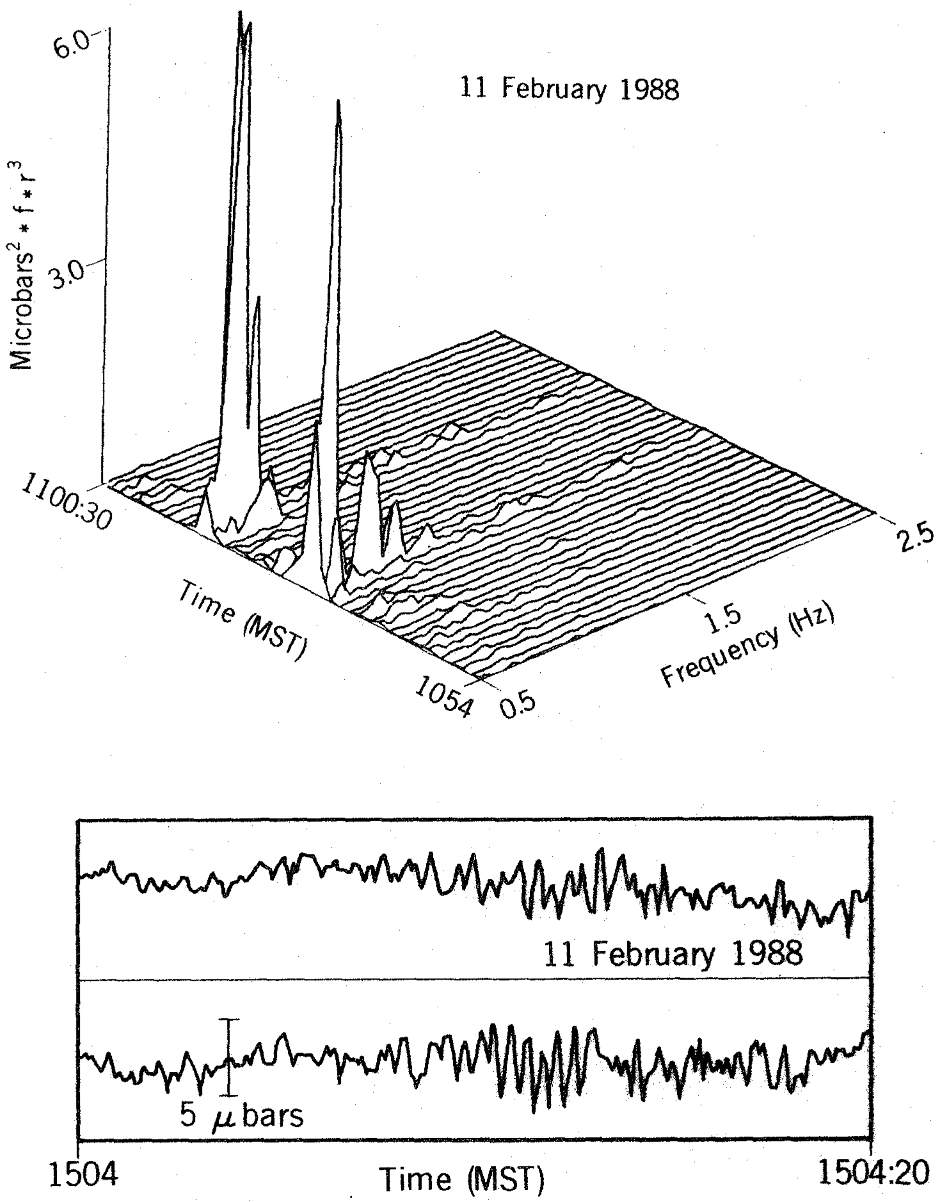

Figure 2. Acoustic power spectrum (top) and a pressure time series for two microphone channels (bottom) for the acoustic signal on 11 February 1988.

CHARACTERISTIC FREQUENCY OF EXPLOSIVE SOURCES

The dominant frequency as a function of energy release from explosive sources has been measured by a number of investigators. Past measurements of long-distance propagation from explosive sources provide a reference point for estimating the frequency containing the most energy (e.g., Ericsson, 1962).

The frequency may be estimated from the empirical relation

$$f = \frac{1}{2.8W^{1/3}} ,$$

where f is the dominant frequency and W is the power of the explosion expressed in terms of the explosive weight in kilotons. According to Fig. 3, explosions of less than 100 lb produce dominant acoustic energy at frequencies >10 Hz; for explosions of almost 1 kt, the dominant acoustic energy is at a frequency of about 0.5 Hz. Avalanche-related sounds apparently concentrate acoustic energy into sharp spectral peaks, and there is a need to understand this process. However, the sources used to trigger controlled avalanches are far less energetic, and the acoustic frequencies generated from control mechanisms are consequently higher.

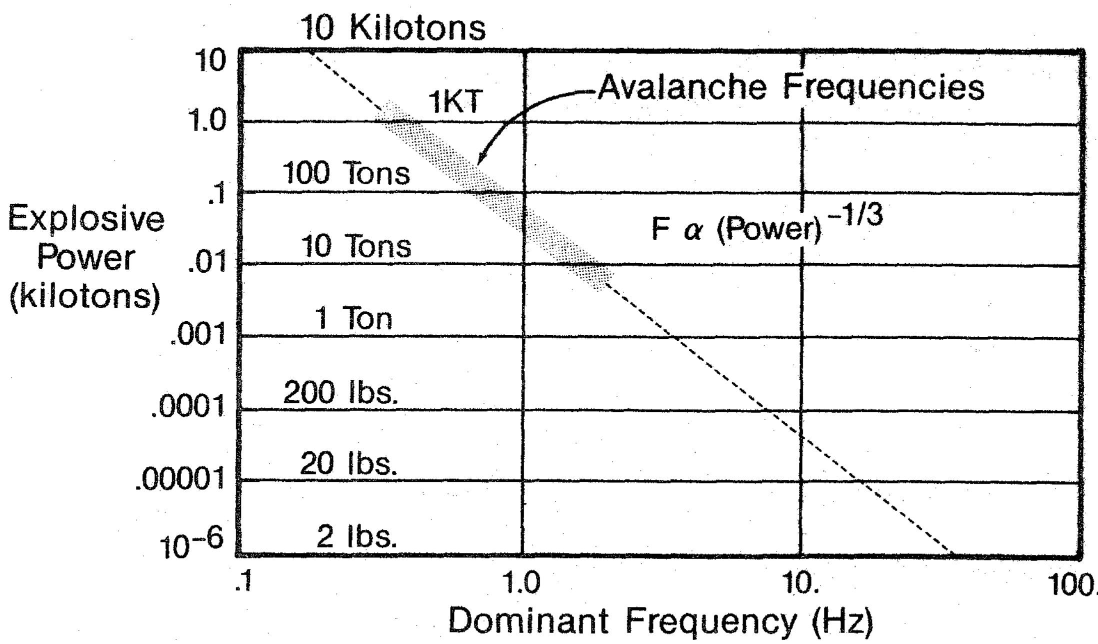

Figure 3. Prediction of dominant acoustic frequency as a function of equivalent explosive power in kilotons, based upon analytical reasoning and empirical results.

PORTABLE INSTRUMENTS FOR AVALANCHE SOURCE REGION MONITORING

To make source-region measurements we assembled a set of instrumentation as summarized in Fig. 4. The LF microphone has 3 dB points at about 0.13 and 10 Hz; during one experiment the sensor had a length of porous tubing attached to reduce wind noise (Bedard, 1977). An inverter with battery backup was used to provide a mobile power source.

Data recording was performed in two ways: a dual-channel chart recorder was operated to monitor the pressure sensor outputs, and a Rockland 4840A FFT analyzer, which could store six data sets in a variety of formats for inspection and subsequent analysis was operated. An audio level meter was also part of the equipment data set, but data were not recorded at these higher frequencies during the first two experiments performed.

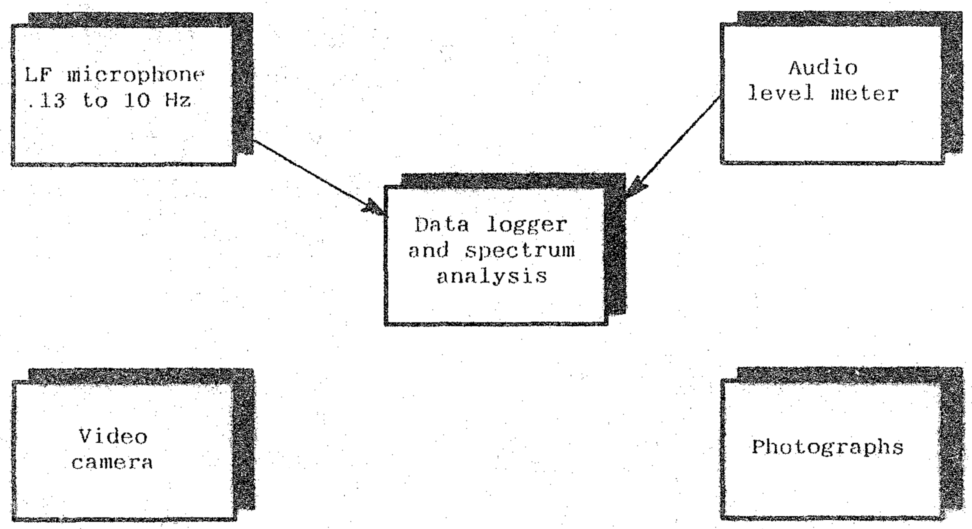

Figure 4. Source-region portable measurement system.

EXPERIMENTAL RESULTS

The portable instruments were operated at locations to the east of Berthoud Pass on 2 days (5 and 6 April 1989). The first tests were in the vicinity (within about 100 m) of a 105 mm recoilless rifle (Fig. 5a) on 5 April 1989 at a frequent-avalanche location called Stanley. Several shots were fired and recorded but no avalanche was released. The second tests were recorded about 50 m from an "avalauncher" on 6 April 1989. This device uses the release of gas from a cylinder of compressed nitrogen to propel a shell to potential avalanche region targets (Fig. 5b). Avalanches were not released at either of two sites (Disney, Aspen).

Figure 5a. A 105 mm recoilless rifle mounted in a vehicle for avalanche control work.

Figure 5b. An avalauncher mounted in position for avalanche control.

The avalauncher produced no significant energy in the passband below 10 Hz. In fact, no evidence of the gas release sounds were detected. The subsequent shell detonation (2.2 lb of explosive) produced acoustic energy for a short duration at higher frequencies, and much lower amplitudes than required to explain our distant measurements of infrasound.

The 105 mm recoilless rifle produced energy detected in the 0.13 to 10 Hz passband, and the energy from the shell containing 4 to 5 lb of explosive was also detected. A time series showed a sharp initial positive pressure shock followed by some lower frequencies (~3 Hz). For both the recoilless sound and the shell impact, the frequency content is too high and the sound level too low to explain our distant observations. A third method used to release avalanches is to drop charges (4 to 6 lb of explosives) from a helicopter. The conclusion from our measurements, analysis, a consideration of propagation effects, and past experimental results by other investigators on explosives is that none of these control techniques can account for the distant sounds observed.

CONCLUDING REMARKS

In the past seismic data have been related to avalanches. The seismic signals recorded by LaFeville and Danielou (1985) usually showed power at frequencies between 2 and 9 Hz. They used the envelope of recorded signals as a method of discriminating between avalanche, seismic signals, and other sources. They provided examples of signals associated with different types of avalanches and documented the statistics for various signal source types. These investigators concluded that it would be possible to detect avalanches automatically in real time. The data they presented were for avalanches within 8 km of the seismometer, indicating that seismometers should be located near the avalanche zone for effective discrimination, which was made more difficult by propagation effects. In the future it will be valuable to make measurements near avalanches using both seismometers and infrasonic microphones to determine the mechanisms causing both signals. It is possible that combined use may provide additional information for characterization.

Figure 6 indicates the location of infrasonic observing locations well-suited for triangulating on avalanche areas in the Colorado mountains. Thus far we have had only bearing information from a single array of microphones and this combination of recording sites would permit us to locate source origins (for key segments of the region to within about 1 km). Data could be sent at intervals to a central location, and the source positions and times could be identified on a regional map. Because of the unique signature of atmospheric acoustic signals related to avalanches (a sharp spectral peak), the use of an algorithm for effective automatic identification is promising.

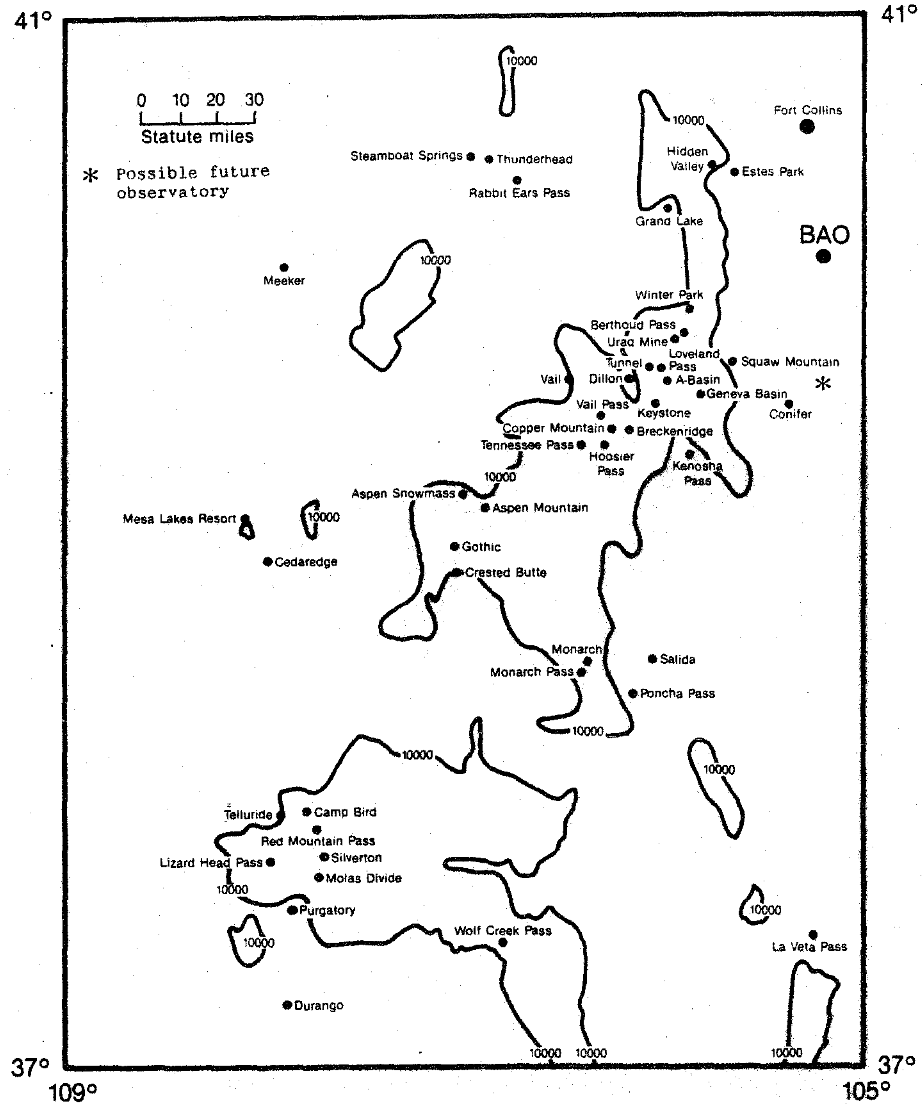

Figure 6. Possible baselines for acoustic triangulation. The existing observatory at the Boulder Atmospheric Observatory (BAO) could be used either with a site near Fort Collins (for the northern mountains) or with a site near Colorado Springs (for the central and southern mountains).

In the process of making preliminary acoustic measurements near avalanche control procedures, it became clear that practical difficulties are posed by the increasing use of mountain regions for hiking and cross country skiing. There is a need to insure that people are not near avalanche-prone areas targeted for explosives (a difficult task). Figure 7 indicates several concerns and possible solutions. It is hoped that future research will provide improved technologies to help those performing these needed control services.

One final cautionary remark is to reiterate the need to obtain multi-station acoustic detections so that the source region is unambigously defined. Our hope is to simplify both our processing and instrumentation, making two-station measurements with automatic displays of source positions on a routine basis.

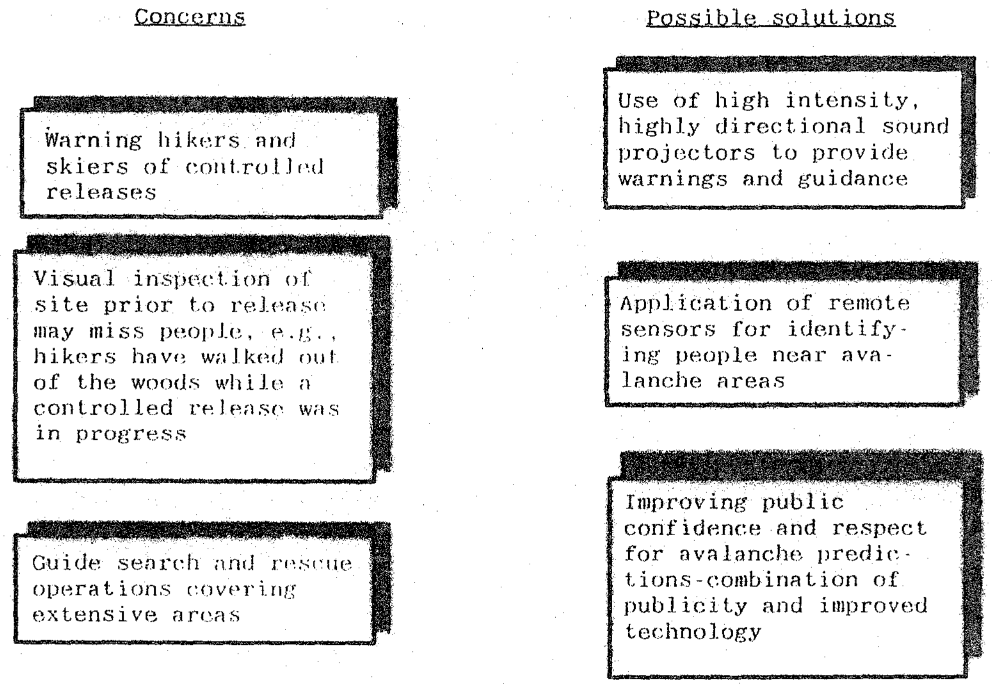

Figure 7. Future avalanche control considerations.

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