THE BOLIVIAN ALTIPLANO INFRASOUND ARRAY IS08

Estela Minaya, Guido Avila, Cristina Condori, Alejandro Córdova, and Francisco Vega

Observatorio San Calixto

Sponsored by Defense Threat Reduction Agency

Grant No: F49620-97-1-0214

ABSTRACT

The main purpose of an infrasound station is to detect acoustic waves generated and transmitted in the atmosphere that are associated with nuclear explosions, volcanic eruptions, meteorological processes, and some large earthquakes such as the one that occurred on the Peruvian coast on June 23 of 2001 with magnitude Mw 8.4. That earthquake was recorded in the IS08 (International Monitoring System [IMS] designation) infrasound array located in the Bolivian Altiplano, 63 km from La Paz City, Bolivia. That array includes four microbarographs – three located at the vertices of a 1-km equilateral triangle and the fourth at the middle of the triangle. Transmission is via satellite communication to Departament Analyse Surveillance Environnement, France (DASE) and from there to the International Data Centre (IDC) in Vienna. Communication to the National Data Center (NDC) at the Bolivian Observatorio San Calixto is by a telemetric system with three relays.

Monitoring started in November 2001 and the first observations indicated some apparent anomalies. We compared to the infrasound data reported in the bulletin of CEA (Commissariat a l'Energie Atomique, France), and we found that 57 signals recorded by the array were not reported in that bulletin. To understand the discrepancy, we have analysed the monthly statistical data obtained by our transmission and the data received at CEA to see if the signal loss could be due to transmission gaps. The time at which the data losses occurred does not coincide with those recorded at the CEA, so we are trying to see what could be the cause of that difference. Our monitoring shows a signal that coincides with a small earthquake (magnitude 3) that occurred on March 23, 2002, and was located 84 km away from the array. This signal was recorded by only three elements of the array. We are still working to find the cause. We are applying software to determine the frequencies of that signal and other parameters that allow us to find some associations with any known source that generates acoustic infrasound waves.

OBJECTIVE

The objective of this research is to study all aspects related to the acoustic waves generated in the atmosphere and recorded by the infrasound array IS08 and to determine waveform, origin or cause of generation.

RESEARCH ACCOMPLISHED

Introduction

The installation of the infrasound array in the town of Peñas in the Bolivian Altiplano, approximately 63 km to the northwest of La Paz City, was completed in December 1999 and complements the other South America stations that form part of the International Monitoring System (IMS) of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Station IS08 began infrasound monitoring and transmitting data in December 2001. The monitoring consists of the routine analysis of the microbarographs, obtained by the four elements that comprise the infrasound array IS08. The monitoring allows us to determine any type of physical interruption to the equipment and the quality of transmissions to data analysis centres. This routine analysis has allowed us to do

1. statistical analysis of the telemetric transmission of the signals;
2. comparison of the telemetric transmission (to OSC - CND, La Paz - Bolivia) and VSAT (to DASE); and
3. signal discrimination that corresponds to an acoustic source or other types that are not yet defined.

The previous experience that we have consist of investigations with data recorded by an infrasound acoustic array installed in 1966 as an asymmetric array with seven microbarographs, with more than 2 km of separation between the elements (Table 1).

The major part of this previous analysis covers nuclear explosions, large earthquakes, volcanic eruptions and some signals generated on the surface area of the south Pacific (Fernández, 1969) that the infrasound array in the Bolivian Altiplano registered effectively, especially for waves from large distances. Escobar (1971) indicated that this effect was caused by a small attenuation factor due to large wavelength. These results are influenced by several factors that exist in the area, i.e., the altitude, 4000 m.a.s.l. and low air density, aspects that have a beneficial effect on the signal/noise ratio. Because of the meteorological conditions in the Bolivian Altiplano, the infrasound noise at night is 20 times lower than the noise during the day. The asymmetric distribution of the first array was a factor in the study of events with long periods and large distances between the focus of the events and the locations in the array.

Those studies did not consider local events because at short they distances do not generate long-period waves. But it is very important to know about the process of generation of that kind of infrasound wave. For example La Paz City, on February 19, 2002, suffered a sudden and very severe storm that lasted for 45 minutes (about 70 people dead and great structural damage). The distance from the city to the array is 63 km, but this natural phenomenon (severe storm) apparently was not recorded by the infrasound array IS08. On the other hand, a large earthquake that occurred in Peru on June 23 of 2002 was recorded very clearly due to the generation of long-period waves as shown by Le Pichon (2002).

Table 1. Former infrasound array located in Peñas

CODE	DATE	LATITUDE	LONGITUDE	ALTITUDE (mt)
A	1966-1975	16.2135°	68.4397°	4120
B	1966-1975	16.2885º	68.4186º	4005
C	1966-1975	16.2659º	68.4717º	3960
D	1966-1975	16.2397°	68.4735°	3970
E	1970-1975	16.1996°	68.3268°	4660
F	1970-1975	16.2944°	68.2585°	4680
G	1970-1975	16.3922°	68.3074°	4300
LP1B	1999-	16.2173º	68.4442º	4071
LP2B	1999-	16.2022º	68.4559º	4032
LP3B	1999-	16.2150º	68.4552º	4042
LP4B	1999-	16.2215º	68.4636º	4017
Relay				
Patamanta		-16.3182º	-68.2962º	4480
Cruce Chacaltaya		-16.3833º	-68.1666º	4628
El Alto		-16.4814º	-68.1677º	4020
OSC (Reception)		-16.4905º	-68.1325º	3658

IS08 infrasound array

The infrasound station IS08 is located in the Peñas region, specifically in the area of Isquillani and Tuquia, Department of La Paz, at about 63 km La Paz City. It was installed at the end of 1999. The array has a symmetric distribution. It is composed of four sensors (Figure 1) and has three at the vertices of an equilateral triangle and one at the center with a separation between them of 1 km. There are two modes of data transmission, one through telemetry to the Observatorio San Calixto, La Paz Bolivia, and the other by VSAT (Figure 2) to Champagne (east of Paris) then to DASE and finally to the International Data Centre in Vienna, Austria. The telemetry transmission is performed by relay (Figure 2).

Each station has a sensor and an acquisition system and transmission unit, with a 12-V power supply and the transmission antenna. The sensor, model MB2000, was built by DASE. The sensor measures small variations of atmospheric pressure and also those generated at large distances. The sensitivity of the output is 1 MV/Pa, the frequency response is 0.001 to 40 Hz, and, for filtered output, 100 s to 27 Hz, electronic noise is less than 2 mPa rms (0.02~4 Hz).

The weather sensor is located next to LPN1 (Figure 1). The wind direction, speed, air humidity and temperature are recorded by telemetry in the Bolivian NDC, Observatorio San Calixto.

The data are transmitted from the central station LPN4 (Figure 1) to OSC to check and to validate the digital signals. Remote monitoring is performed by CRISTAL software at DASE and OSC.

Array environment

It is necessary to have a clear picture of the topography in the array environment; i.e., the region of the array and the relays. We need to know if the variation in topography can be the cause of generated infrasound waves, and how much the infrasound variations can be attributed to small changes in temperature near the array.

Local Geology

Geomorphologically, the station array is located on glacial lacustrine to fluvio lacustrine deposits, constituted of blocks of sand, slime and clay. Microthermal ground covered with moss and straw can be found on these sediments that form the Altiplano. There are small mountainous areas with some rivers in different directions.

Topography and average altitude

The topography of the area of the stations is quite moderate and almost flat with an average elevation of 4000 m.a.s.l. The infrasound stations are surrounded by a series of peaks; to the North is the hill Huari Umaña with a height of 4484 m.a.s.l., to the Southwest the hill Allkamarini and the hill Pucuni Arc with an elevation of 4156 m.a.s.l., and to the South the hill Peñas consists of a pair of peaks, Chucecani and Peñas with a height of 4333 m.a.s.l.

To the east of the station is a plain with elevations that rise as we approach the mountain Huayna Potosí and the relay station Patamanta (Figure 3), which is located on the hill Cotan Kkollu with an altitude of 4400 m.a.s.l., and finally the relay station Cruce Chacaltaya that is located at an altitude of 4500 m.a.s.l.

Analysis of signals

The parameters observed on the microbarograms do not show great regularity in periodicity or amplitude, they appear as isolated events with a specific arrival time and direction. This was confirmed by routine analysis that detected 57 signals from December 2001 to February 2002. The signals acquired by the array were not reported by the Infrasound Bulletin of IS08 published by CEA. Two signals are shown in Figure 4.1 and 4.2 and Table 2. The first signal is impulsive; has SE direction and 6.8 second duration, but an amplitude of only a few Pa. The second signal has SW direction, four second duration and is less clear than the first, especially on the LP4B sensor.

Table 2. Signal recorded by infrasound array IS08

Date	**Origin Time**	**Duration (s)**	**Azimuth**	**Speed**	**Filter (Hz)**
10/02/2002	09:24:43	6,38	NO CEA		0,1-9
11/02/2002	20:26:10	4	NO CEA		0,1-9
23/03/2002	21:11:00	4	NO CEA		0,3-3,5
12/04/2002	09:54:40	1.31	118,8	0,639	0,1-9
14/04/2002	18:59:20	4.7	74,9	0,383	0,1-9

NO CEA: Signals not reported by CEA Bulletin.

The main cause of those differences between the local analysis and the CEA bulletin was attribued to data transmission. To confirm this situation and to determine its cause, we compared the transmission of the data sent through telemetry and the data sent through satellite communication for each element of IS08 array (Figure 2) Statistical analysis was conducted of data losses during transmission reported each month. Figure 5 shows the analysis for February and no correlations were found between the comparative statistical analyses. We can say that the signals discussed above are very small and probably are local.

In this analysis the topography was considered as a probable generator of infrasound waves at short distances. The topography near to the array is almost flat, but the surrounding area has elevation differences due to the presence of the Cordillera Oriental. More work is needed to verify this hypothesis .

The third signal in Table 2 corresponds to a local earthquake with magnitude Ml 3, and 84 km distance from the source to the array. A filter of 0.8 to 3.5 Hz was applied. Figure 6 shows the seismic and infrasound waves recorded by three barographs. On LP1B, the signal is unclear, the arrival is emergent, and the spectrum shows a frequency of 2 Hz, which confirms the presence of a long-period wave.

Two signals are shown in Figures 7 and 8 that could be generated by local effects. Both records are local and the arrival waves are impulsive; the difference between them is the duration. The spectrum does not show considerable variation between frequencies, and there is background noise.

CONCLUSIONS AND RECOMMENDATIONS

Many of the signals recorded up to now should be considered a consequence of small vibrations with displacements or very small variations of temperature and pressure in the atmosphere that usually accompany infrasound waves.

The analysis shows that signals could give enough information to conduct more precise research. It will be necessary as a second step of this research to use software such as the Progressive Multi-Channel Correlation (PMCC, Cansi, 1995) to determine parameters such as velocity, phase, and azimuth and provide a classification of infrasound waves (Bass, 2001).

REFERENCES

Bass, H.E., K. Gilbert, M. Garces, M. Hedlin, J. Berger, J.V. Olson, C.W. Wilson and D. Osborne. (2001), Studies of microbaroms using multiple infrasound arrays, 23rd Seismic Research Review: Worldwide Monitoring of Nuclear Explosions, Jackson Hole, Wyoming, p. 73-104.

Brown, D.J., C.N. Katz, R. LeBras, J. Wang and A. Gault. (1998), Infrasonic processing at the Prototype International Data Center. In Proceedings of 20th Annual Seismic Research Symposium On Monitoring A Comprehensive Test Ban Treaty (CTBT), Santa Fe, New Mexico, pp. 555-562.

Brown, D.J., C.N. Katz, R. LeBras, J. Wang and A. Gault. (1999), Infrasonic processing at the Prototype International Data Center. In Proceedings of 21st Annual Seismic Research Symposium On Monitoring A Comprehensive Test Ban Treaty (CTBT), Las Vegas, Nevada, II pp.86-95.

Brown, D.J., C.N. Katz, J. Wang and R.W. Whitaker. (2000), Tuning of automatic signal detection algorithms for IMS style infrasound arrays. In 'Proceedings of the 22nd Seismic Research Symposium: Planning for Verification of and Compliance with the Comprehensive Nuclear-Test-Ban Treaty', 12-15 September, New Orleans, Louisiana.

Cansi, Y.(1995), An automatic seismic event processing for detection and location: the P.M.C.C. method. *Geophys. Res. Lett*., **22**, 1021-1024.

Escobar, G. (1971), *Ondas Infrasónicas: Ruido y Señales Observadas en la Estación Geofísica de Peñas*. Thesis, Universidad Mayor de San Andrés, La Paz, Bolivia.

Fernández, L.M. (1968), Infrasonic Research – Peñas Acoustic Array. Final Report, Grant No. AFOSR-67-1177C, Observatorio San Calixto, La Paz, Bolivia.

Fernández, L.M. (1969). Spectral Characteristics of Infrasonic Acoustic Waves and Related Seismic Research. Interim Scientific Report, Publication, Observatorio San Calixto, La Paz, Bolivia.

LePichon, A., Y. Cansi and B. Alcoverro. (1999). International Monitoring System. Infrasound Technical Training Program. CEA – Bruyères-le-Châtel – Département Analyse Surveillance Environnement DASE/LDG – France.

LePichon, A., J. Guilbert and M. Van de Walle. (2002), Ground – Coupled air wave and diffracted Infrasound from the Arequipa, earthquake by June 23, 2001, CEA, Lavoratoire de Détection et de Géophisyque, France. Poster

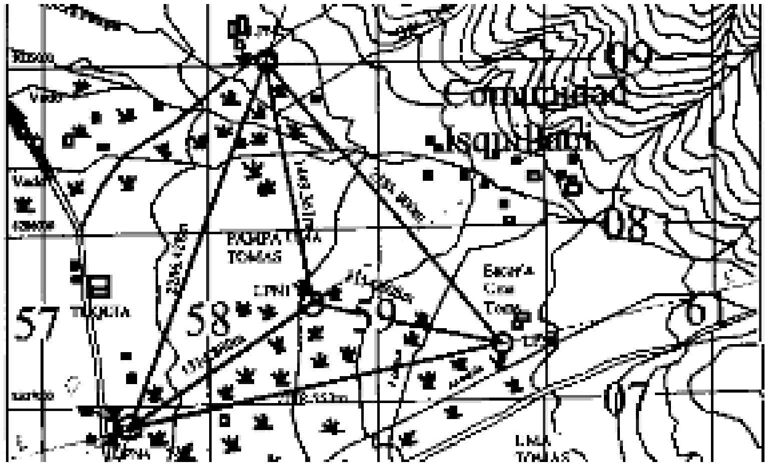

Figure 1: Map that shows the location of the infrasound array

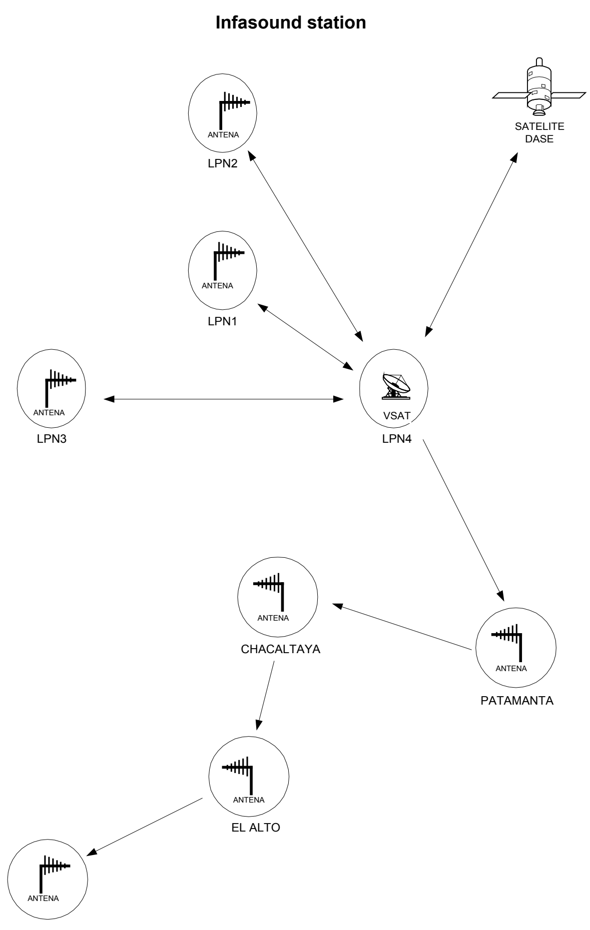

Figure 2: Diagram of the communication network.

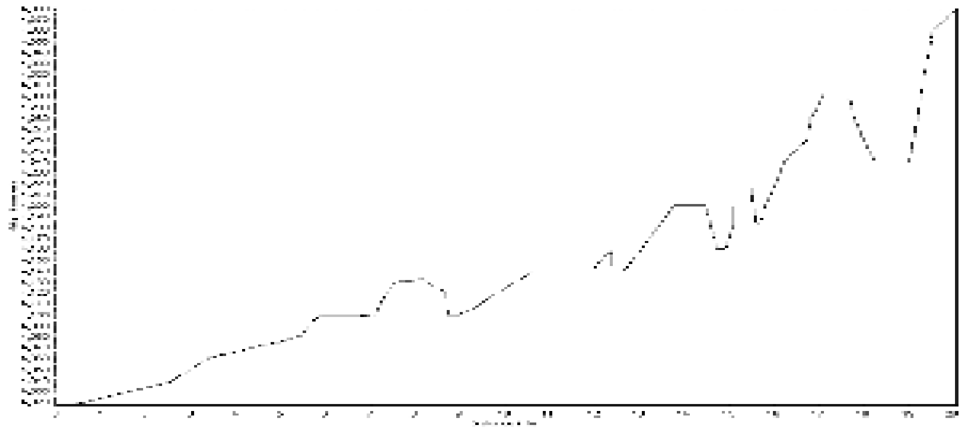

Figure 3: Topographical profile of the infrasound transmission from Peñas to Patamanta relay.

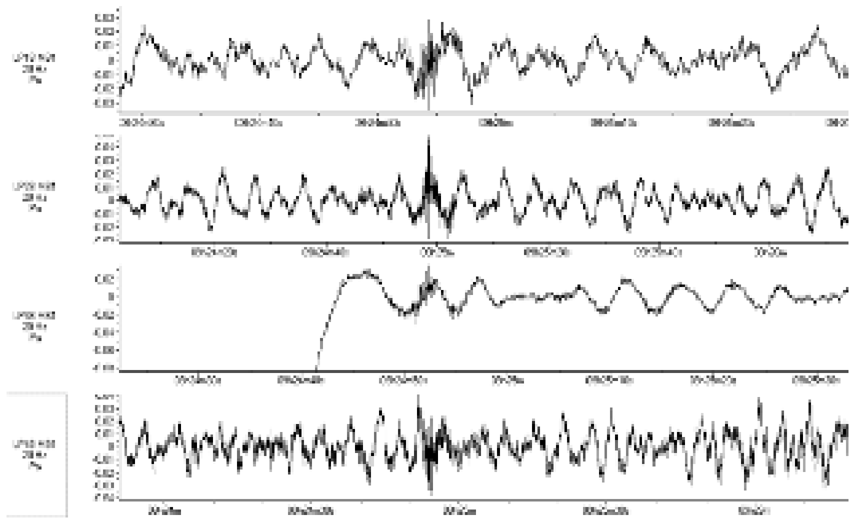

Figure 4.1: Signal of the 10/02/2002, 9:14 am, event, not reported by the CEA bulletin, with filter 0.1 to 9 Hz

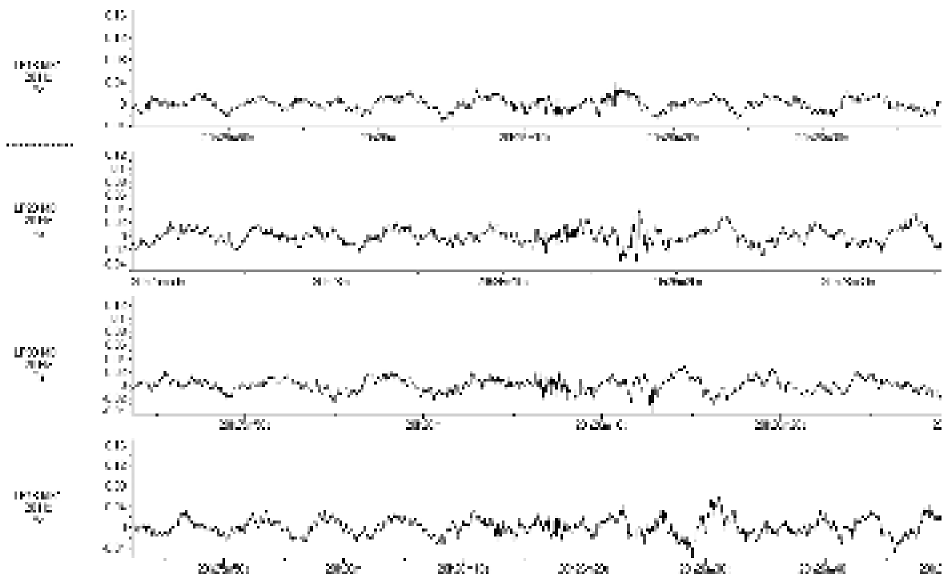

Figure 4.2: Signal of the 10/02/2002, 20:25 am event, not reported by the CEA bulletin, with filter 0.1 to 9 Hz

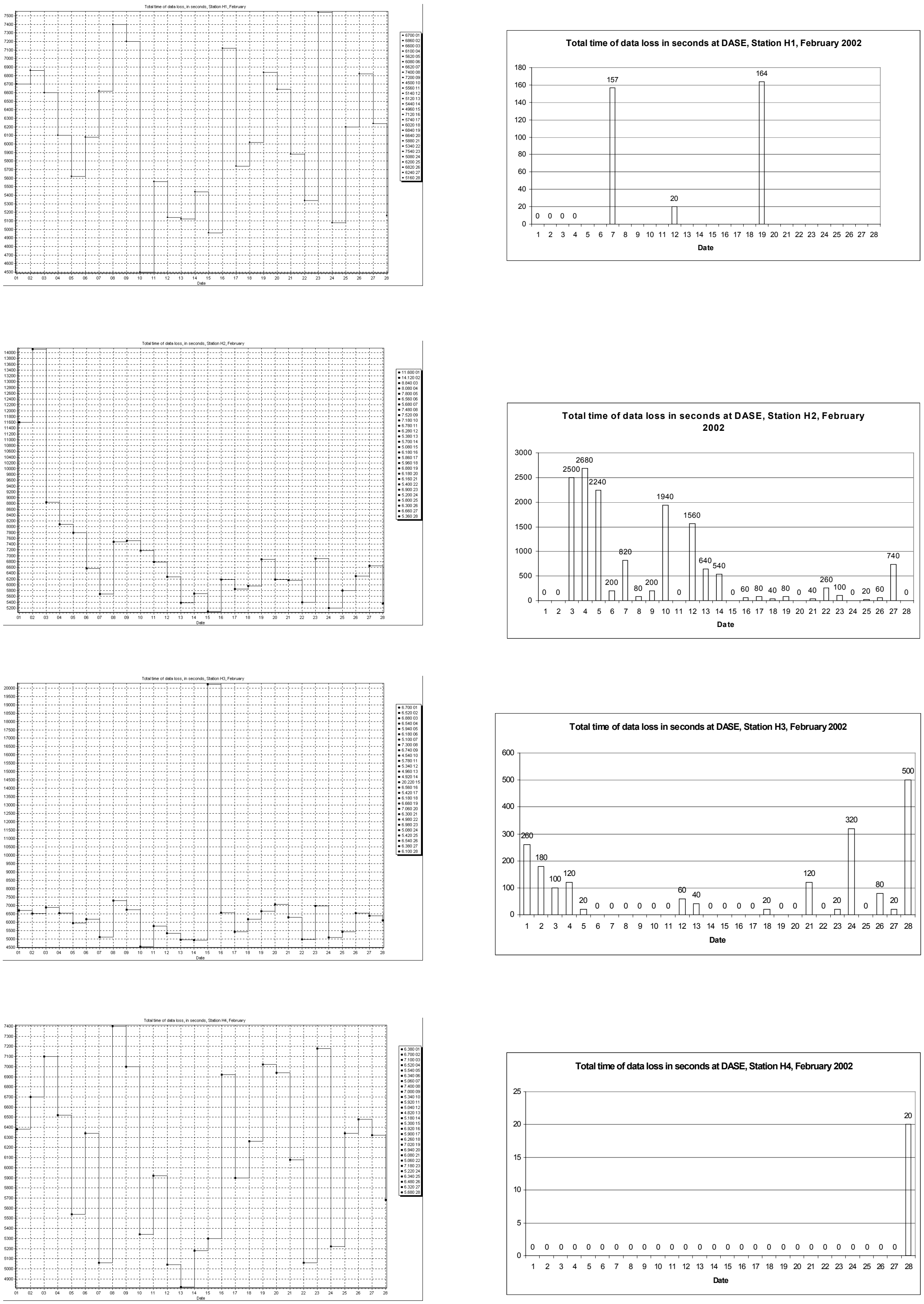

Figure 5: Comparative statistical analysis of data loss at the OSC and at DASE

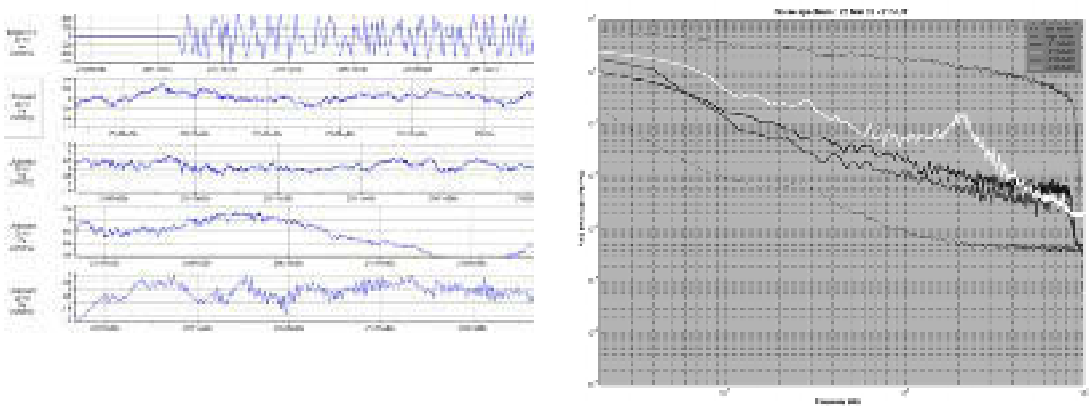

Figure 6: Local earthquake of 23/03/02, detected by the infrasound array, and its corresponding spectrum.

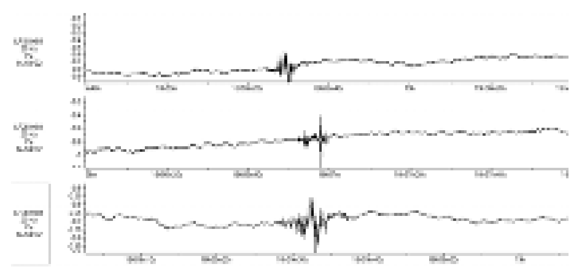

Figure 7: Signal recorded 14/04/02, 18:59

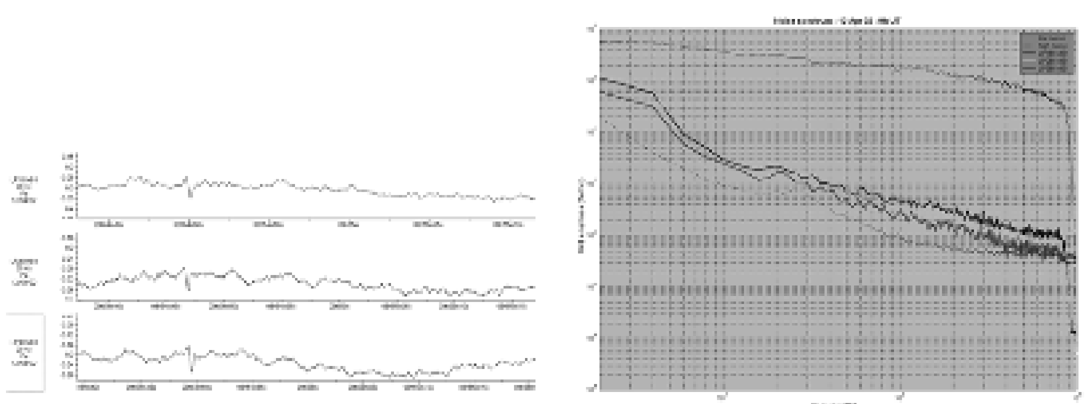

Figure 8: Signal recorded 12/04/02, 9:54 am, direction SE, speed 0.639 m/sec