OPTIMIZING THE PROGRESSIVE MULTI-CHANNEL CORRELATION DETECTOR FOR THE DISCRIMINATION OF INFRASONIC SOURCES

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ABSTRACT

We use the Progressive Multi-Channel Correlation (PMCC) detector to define the temporal and spectral characteristics of various infrasonic sources observed by diverse infrasonic array configurations. Previous work demonstrated the PMCC was not as vulnerable to aliasing as frequency-domain detectors, and it allowed recognition of coherent signals with signal to noise levels close to unity. PMCC is presently used to produce automatic bulletins of signals detected by the International Monitoring System (IMS) station I59US in Hawaii. We show the detection parameters and features for storm systems, volcanic eruptions, meteors, aircraft, and the Columbia STS-107 reentry as observed by various array geometries and locations, and describe how these detection features can be used for event discrimination. Future work will concentrate on the development of an automatic, intelligent event identification algorithm that can screen the large amount of events picked by automatic detectors.

OBJECTIVE

The aim of this paper is to illustrate the performance of the PMCC feature extraction algorithm (Cansi, 1995; Cansi and Klinger, 1997) when applied to different signals and array configurations.

RESEARCH ACCOMPLISHED

Introduction

The ambient infrasound field for frequencies above 0.1 Hz has been well characterized at I59US, Hawaii, by analyzing PMCC detections with fixed trigger setting for over a year. The PMCC algorithm and the automatic detection setting used at I59US are described in Garcés and Hetzer (2002). This paper consists largely of figures giving examples of the kind of signal features that can be extracted with PMCC for different kinds of infrasonic sources. The fist part of the paper discusses various signals observed in Hawaii and introduced in Garcés and Hetzer (2002). The second part of the paper discusses the forensic acoustic analysis of the tragic Columbia space shuttle reentry of February 1, 2003.

Microbarom Arrivals

Microbarom signals are believed to be generated by ocean swells, and source mechanisms are discussed in Garcés et al. (this issue, 2002). The upper panel of Figure 1 shows all the automatic microbarom detections at I59US for year 2002. The large mountains adjacent to the array appear to cause acoustic shadow zones for energy arriving close to the horizontal. The variation in azimuth shows the seasonal trends for storm systems in the Pacific, with N and NW swells dominating in winter and trade (E) and south swells predominant in summer. There was no obvious seasonal trend in the amplitude of the signal. The lower panel of Figure 1 shows the character of microbarom detections at I59US. Although the microbarom oscillations are continuous, most of the time they are uncorrelated across the array. This may be due to the relatively large aperture and low number of elements (4) at I59US. However, distinct microbarom bursts produce detection triggers on the order of hundreds per day, with a detection azimuth that is highly variable. Under some circumstances it may be desirable to preserve the coherence of the microbaroms, as it may then be easier to remove this contribution from a signal of interest.

Surf Arrivals

Some of the surf arrivals at I59US are believed to be produced by ocean waves trapped within specific bays along the coast of the Big Island. However, during periods of high surf, the western coast of the island is acoustically illuminated. A four-element portable array with an aperture of ~100m was deployed between the coastline and the airport in January-February 2002, concurrent with an epic episode of high swell. Figure 2 shows the detection azimuths and pressure amplitudes observed by the array as a swell started arriving on the coast. The swell height correlates directly with the acoustic pressure, opening possibilities for infrasonic surf monitoring. Gaps in the detections corresponded to periods of high wind. The PMCC detection parameters were similar to those used for automatic high frequency detections at I59US, as described in Garcés and Hetzer (2002).

Volcanic Arrivals

Although some tentative correlations have been found between infrasonic events at I59US and peaks of thermal activity in the Pu'u 'O'o crater, no unambiguous detections have been made. To assess the character of the infrasonic signals that could be expected from Kilauea volcano, we performed temporary array deployments ~2 km and ~13 km from the active vent. These deployments revealed a continuous vibration of the atmosphere, known as tremor, that may correspond to the resonance of the lave tube system that carries lava from the vent to the ocean (Figure 3). At a range of 13 km the signal was significantly reduced, thereby explaining why we do not observe infrasound from Kilauea at I59US, which is at a range of ~90km and blocked by Mauna Loa. Except for extension of the frequency band to 20 Hz, the PMCC detection parameters were as in the previous section.

Signals from above

Bolides, aircraft, and spacecraft may generate infrasound during flight. Two possible bolide signals are shown in Figure 4. The June 23, 2003 bolide was observed visually and by satellites, but the June 30 signal remains unconfirmed. The upper panel of Figure 5 shows the infrasonic signal for an aircraft takeoff observed by a temporary array deployed within 2 km of Keahole International Airport in Kona. This type of signal is periodically observed by I59US at a range of ~20 km. The lower panel of Figure 5 shows the takeoff pattern to the NW of the array as a function of time and apparent speed. Although these sources are above the array, the arrival angles appear close to the horizontal. The PMCC detection parameters were similar to those used for automatic high frequency detections at I59US.

Columbia reentry of February 1, 2003

The tragic reentry of Shuttle flight STS-107 was recorded by most of the stations in the North American infrasound network except for Hawaii and Alaska. Data was analyzed from the International Monitoring System (IMS) arrays located in Pinon Flat, CA, Fairbanks, AK, Kona, HI, Newport, WA, and Lac du Bonnet, Manitoba, from experimental infrasonic arrays operated by Los Alamos National Laboratory (Department of Energy) at St George (UT), Los Alamos (NM) and Pinedale (WY), from arrays operated by Southern Methodist University at Mina, NV and Lajitas, TX, a NOAA array located near Boulder, Colorado, and a temporary array at White Sands Missile Range operated by the Army Research Laboratory (Bass, 2003). ISLA personnel used PMCC to analyze all available data to look for anomalous signals during the reentry. We experimented with various PMCC settings, starting varying from 30s to ~5s windows. The latter settings enhanced the detection of short duration bursts. We also had the hope of finding a signal feature set that could trigger a detection at the Hawaii and Alaska stations. Despite multiple reanalyses, these two stations did not yield any signals associated with the reentry.

Figure 6 shows the Columbia detections at TXIAR , Texas, the station closest to the final moments of the Shuttle. Note that the pattern of the azimuth plots in Figure 5 and Figure 6 look similar, although the plane is moving west to east while the Columbia was moving east to west. Since supersonic objects move faster than the acoustic propagation speed, the temporal order of the signal arrivals is reversed with respect to a subsonic source. The infrasonic signal at TXIAR consisted of a series of high-amplitude pulses followed by signals that corresponded to the approach trajectory. Although there is a substantial scatter in the azimuth plot of Figure 6, we can look at short windows around the peak pulses to extract their main features. Table 1 provides the onset time, azimuth of the main arrival and the group, peak pressure of the dominant pulse, and peak period of the dominant pulse. Table 2 provides the detection parameters used for this analysis. Thus it appears that the main pulses appear to originate from a similar region, a remarkable observation for a source that is moving at Mach 19. Herrin (personal communication, June 2003) hypothesized that a tire might have exploded at that stage of the trajectory. For an unloaded inflation pressure at STP of 2.2 MPa, the equivalent explosive yield of a tire burst may range from a few pounds to tens of pounds of TNT, depending on the temperature of the gas in the tire and the external pressure inside the wing.

Figure 7 shows the PMCC detections at SGAR, Utah, for STS-107 and STS-78, both with orbital inclination angles of 39 degrees. Many of the features appear similar, except that for STS-107 the late arrivals come in from the west whereas for STS-78 most of the late energy arrives from the east, illustrating the effects of the predominant winds in winter (STS-107, February 1) and summer (STS-78, July 7). The coda of the STS-107 signal lasts almost an hour and deflects well south of the expected trajectory, suggesting contamination from the ambient infrasonic clutter. Analysis of all the available infrasound data did not yield any obvious signs of distress except during its final moments and helped eliminate hypotheses that bolides or lightning might have damaged the shuttle.

Table 1. Time, azimuth, pressure, and period for the main pulses observed at TXIAR

Pulse Onset Time (GMT)	Azimuth, Deg (Group)	Peak Pressure, Pa (- /+)	PP Pressure, Pa	Peak Period (s)
14:29:30	14.5 (16.4)	-0.1622, 0.1315	0.2937	5
14:29:50	17.4 (19.0)	-0.4032, 0.4595	0.8627	3
14:30:30	18.0	-0.1980, 0.2784	0.4764	1
14:31:13	18.6 (19.4)	-0.7146, 0.5537	1.2683	3.5-5
14:31:54	17.0 (17.7)	-0.4209, 0.6799	1.1008	4.5
14:33:32	17.0 (16.3)	-0.2903, 0.5683	0.8585	6

Table 2. PMCC detection parameters and array apertures for the analyses at TXIAR and SGAR shown in Figures 6 and 7

Station (Event)	Frequency Band (Hz)	Window Length (sec)	Window Overlap (sec)	Max Consistency (sec)	Trace Velocity Limits (km/s)	Maximum Aperture (km)
TXIAR (STS-107)	1-5	10	8	1	0.2-0.7	1.6
SGAR (STS-107)	1-4	5	4	1	0.2-2	0.2
SGAR (STS-78)	1-4	5	4	1	0.2-1	0.2

CONCLUSIONS AND RECOMMENDATIONS

The PMCC feature extraction algorithm is used automatically at I59US to produce updated bulletins every four hours. With thousands of automatic detections per month at I59US, it is necessary to develop intelligent event classification algorithms. PMCC also performed well when exposed to different signals and array configurations, demonstrating that this algorithm is robust, flexible, and well suited for infrasonic applications.

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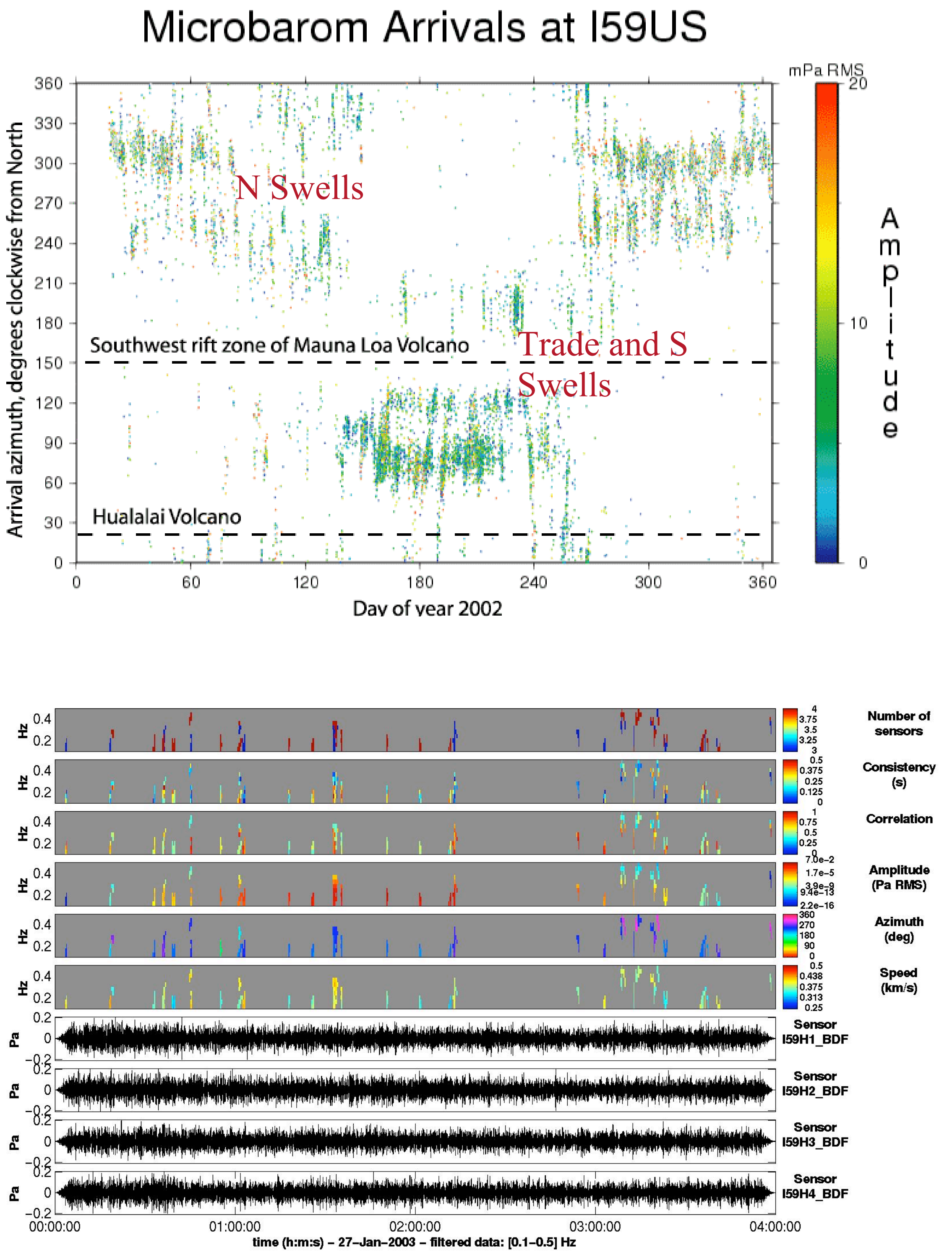

Figure 1. Microbarom detections for 2002, showing blocking by mountains and seasonal pattern. The lower panel shows typical microbarom bursts observed at I59US.

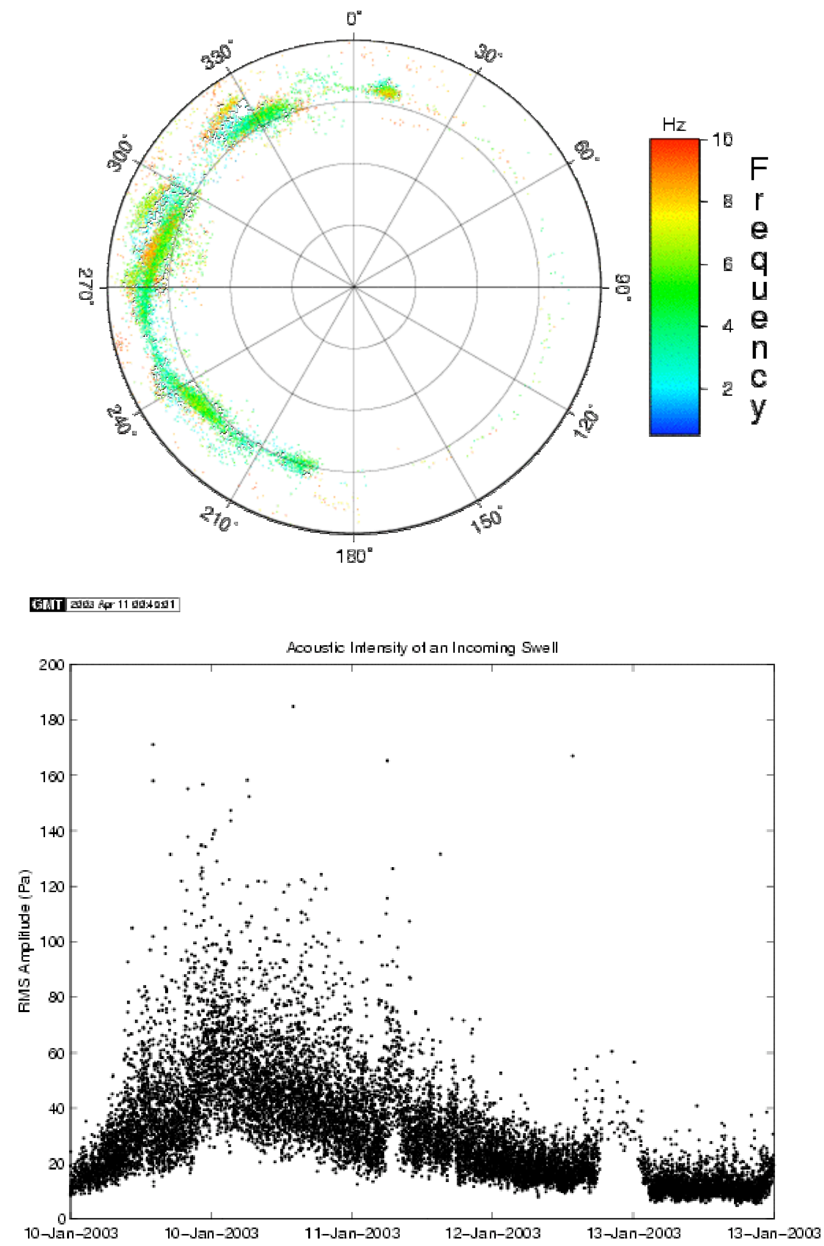

Figure 2. Surf detections and pressure amplitude (mPa) captured by a portable array near the coastline, January 10-13 2003.

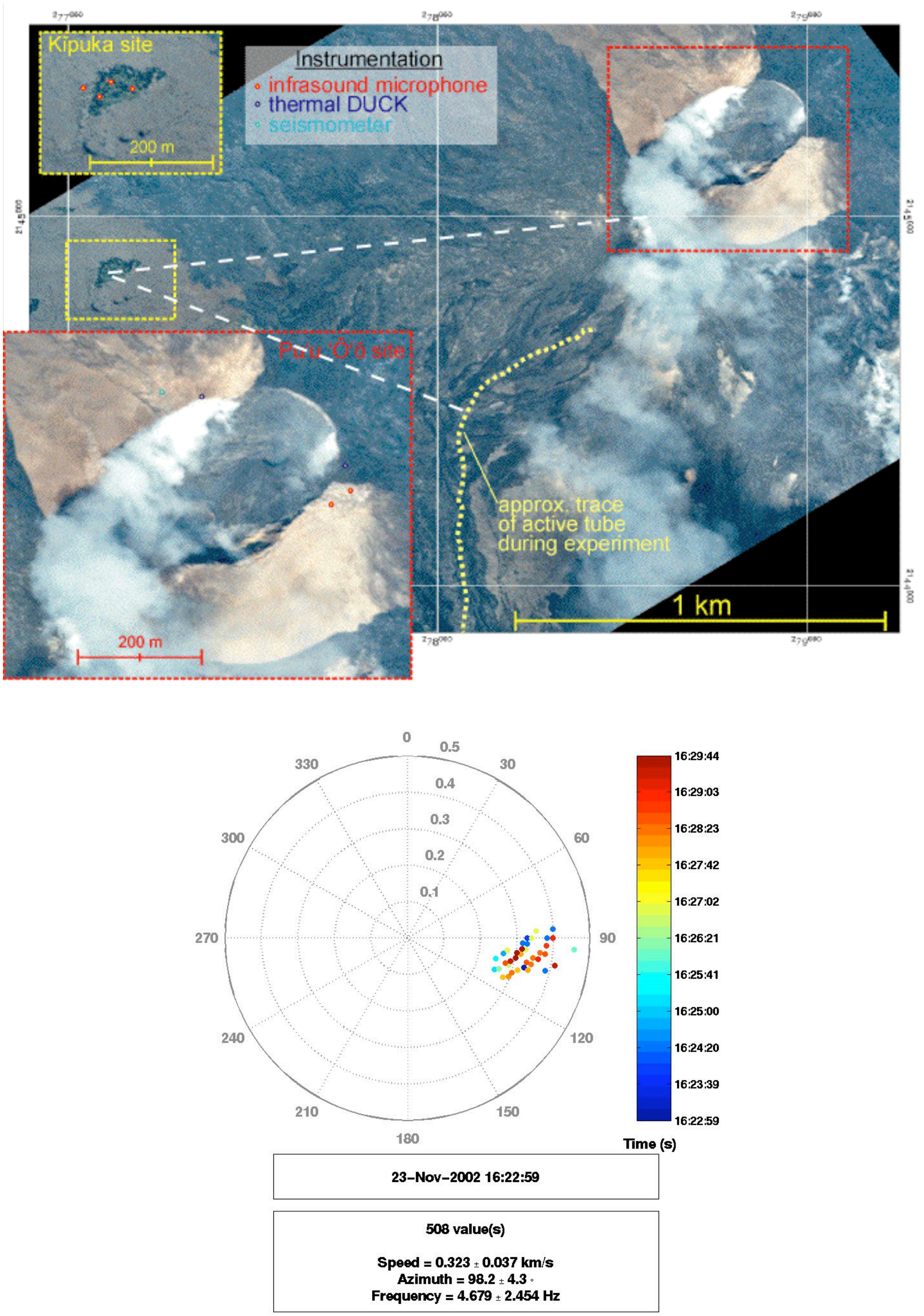

Figure 3. Volcanic tremor at Kilauea volcano, Hawaii, observed by a small-aperture array approximately 2 km from the active vent of Pu'u O'o.

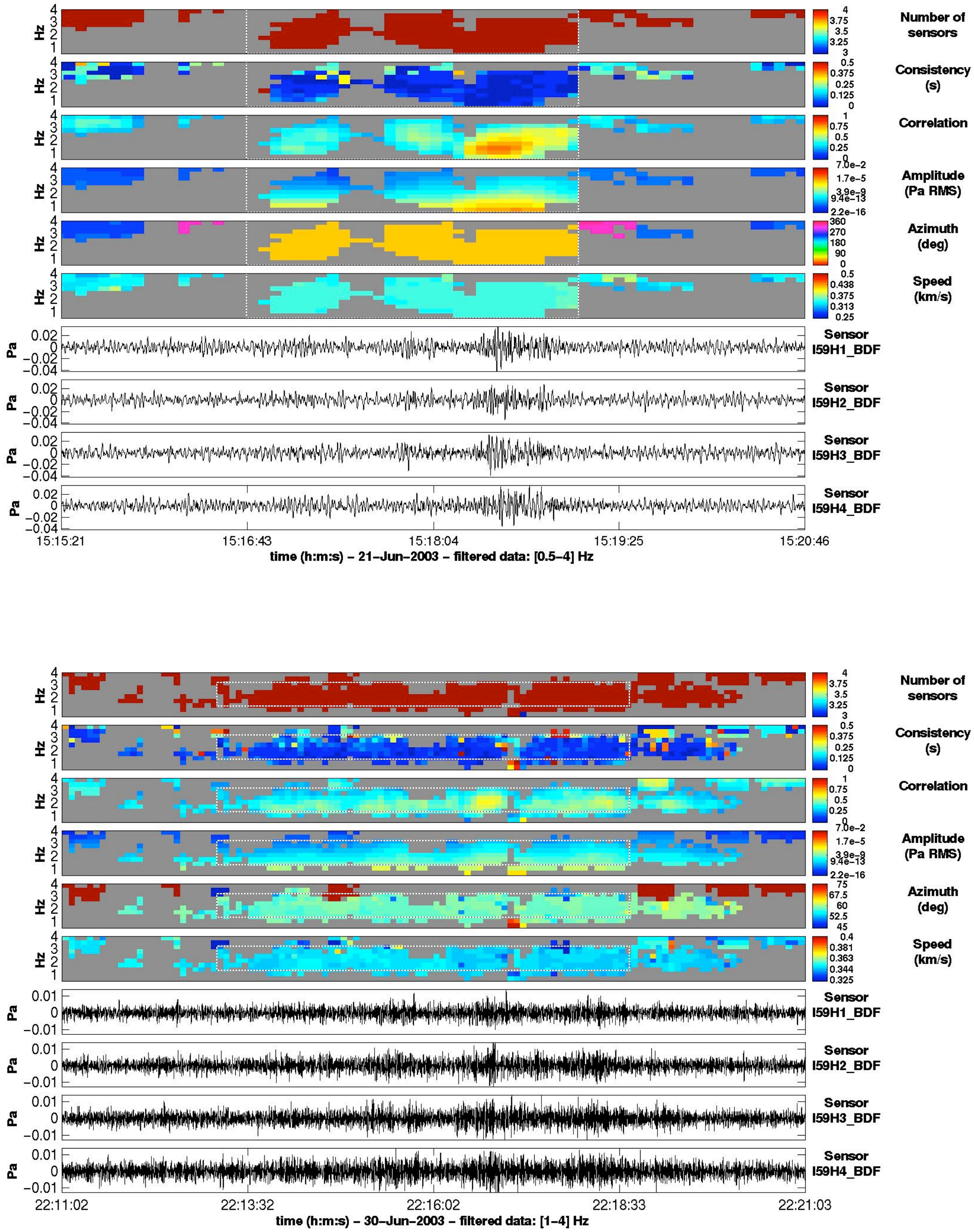

Figure 4. Possible bolides observed at I59US but outside the detection range of other IMS stations. The June 21 bolide was observed visually and by the DOD/DOE satellite monitoring system.

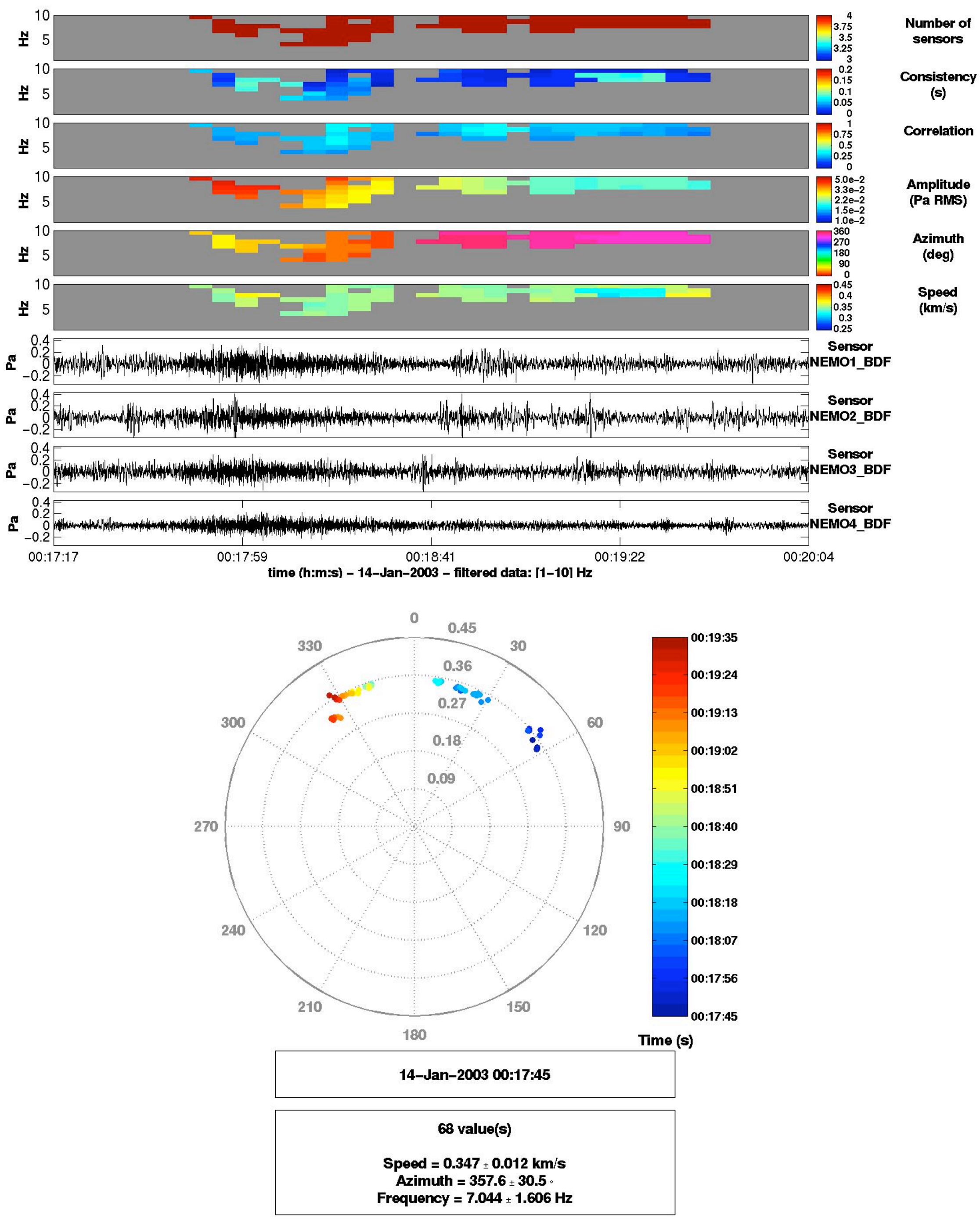

Figure 5. Aircraft takeoff observed by a portable array near Keahole International Airport.

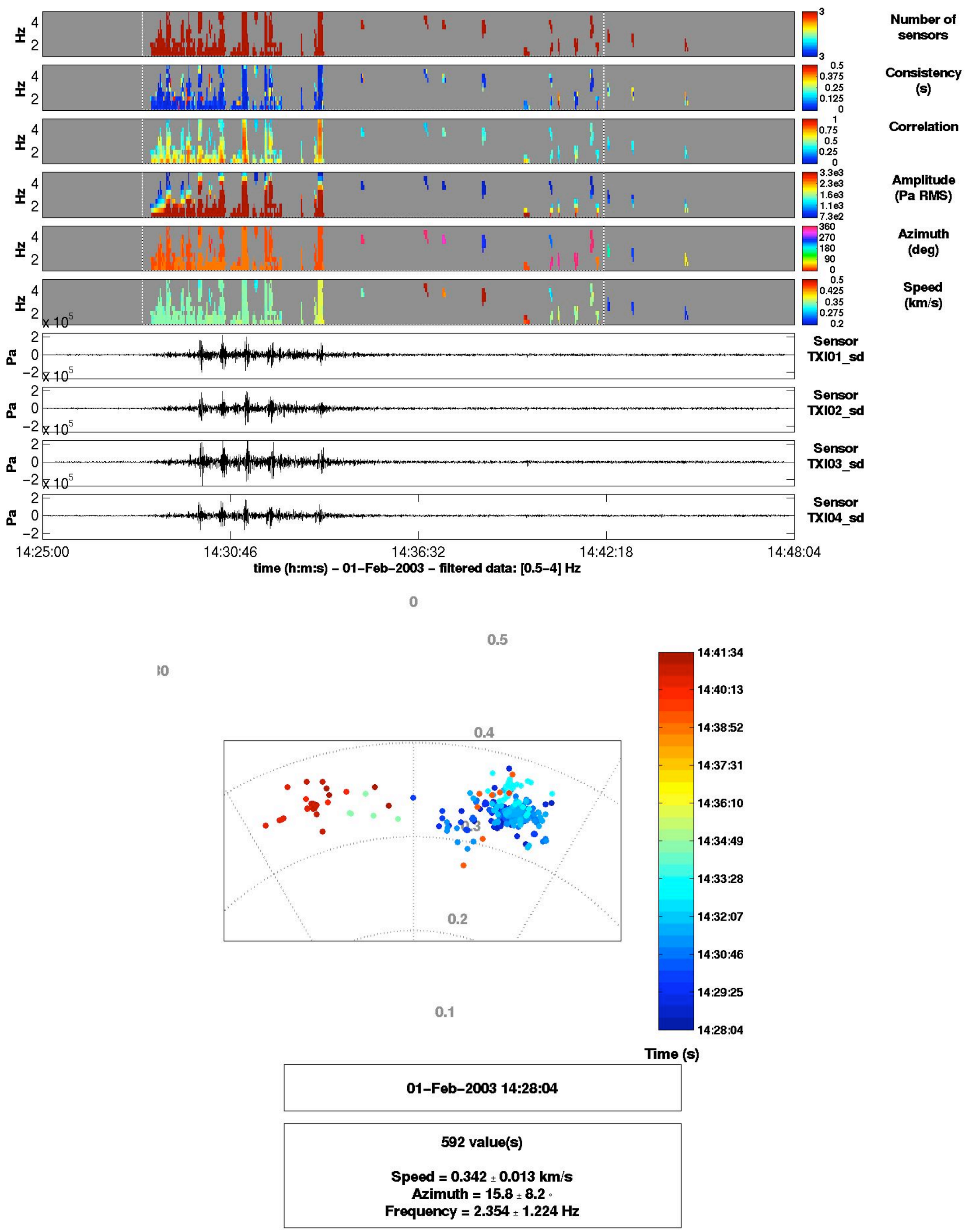

Figure 6. Columbia reentry observed at TXIAR, Lajitas, Texas.

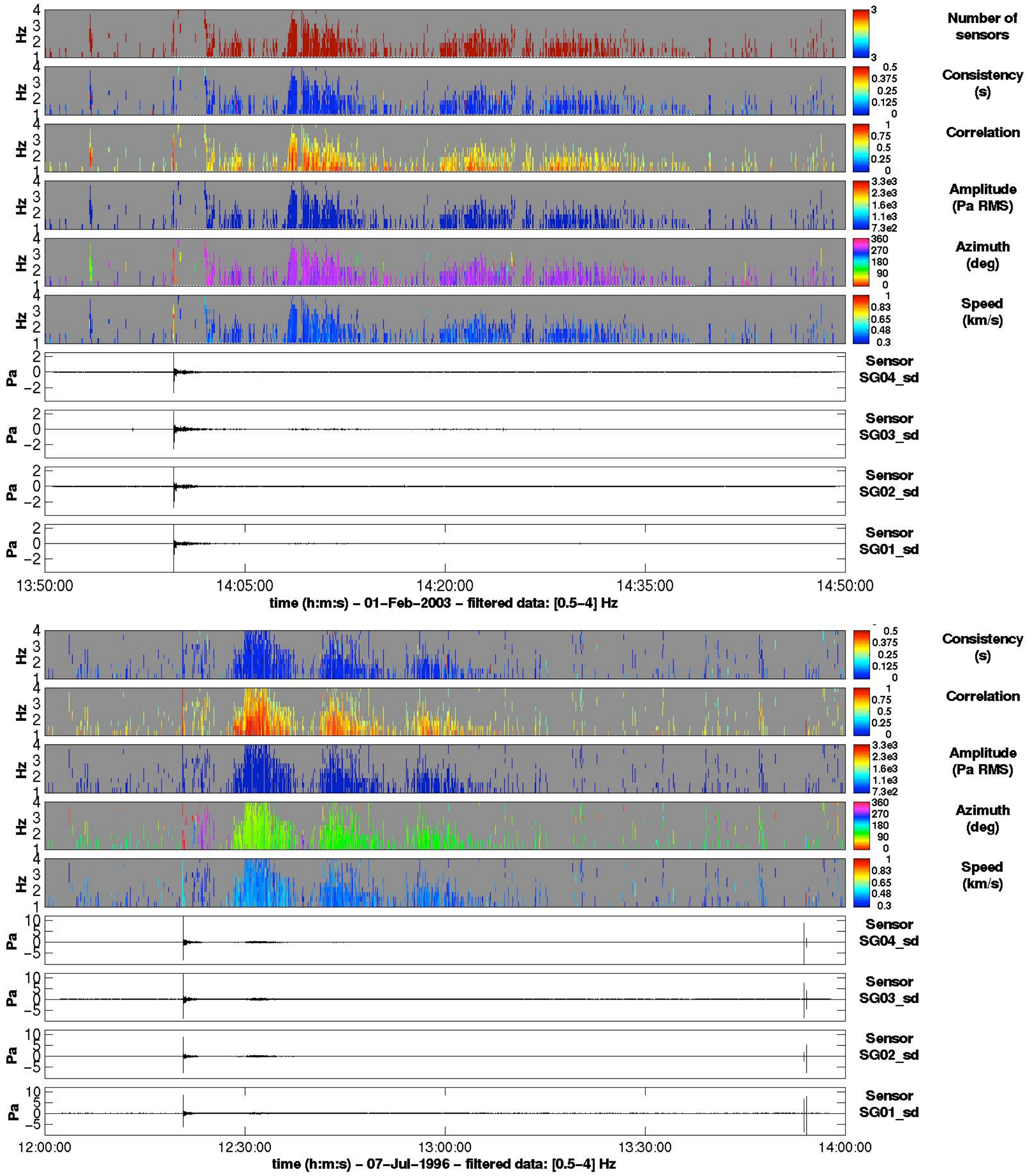

Figure 7. Reentries for shuttlesSTS-107 (upper panel) and STS-78 (lower panel) recorded at SGAR, Utah.