INFRASONIC SIGNALS DETECTED BY THE KONA ARRAY, HAWAII

Milton A. Garcés and Claus H. Hetzer

University of Hawaii, Manoa

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ABSTRACT

International Monitoring System (IMS) infrasound array IS59, also known as the KONA array, has been operating since May 25, 2000, and is scheduled for certification into the IMS in September of 2001. A catalog of observed infrasound signals is routinely produced for IS59 and includes Phase, Date and Time UT, Azimuth, Slowness, and Remark fields, as well as Amplitude in millipascals after February 20, 2001. Selected events have been characterized and tentative source identifications made through a combination of field inspections, collaborations with government personnel or agents, and improvements in data analysis. Most of the events have been observed only at KONA, but some have been recorded by two or more arrays.

Sources for infrasonic events recorded at KONA include aircraft noise from nearby Keahole International Airport, surf impact, earthquakes, offshore activities, severe weather, and meteors. Other unidentified local signals are also catalogued. Phase names based on source identification have been devised to aid in classification. From June 19, 2000, to July 2, 2001, 1280 events were recorded, of which 0.31% were confirmed to be telesonic. Approximately 31% were surf-related, 19% associated with weather, and 16% associated with aircraft. More than 59% of recorded events were identified as local.

Various useful analysis tools and techniques have been acquired or developed by Infrasound Laboratory (ISLA) personnel include modified versions of Sandia National Laboratories' MatSeis and Los Alamos National Laboratory's InfraTool, which determines instantaneous azimuth, trace velocity and correlation, as well as a simple STA/LTA-based automatic detector and the Tau-P software of Garcés et al. (1998). Currently the STA/LTA detector is used to detect more impulsive events and InfraTool to detect longer-duration arrivals, and traditional FK analysis as implemented within MatSeis is used to determine back azimuth and trace slowness.

KEY WORDS: infrasound, IS59, KONA

OBJECTIVE

The primary objective of assembling the KONA events catalog is to identify trends in the background infrasonic field in Hawaii. Knowledge and recognition of recurrent events allows the analyst to efficiently screen incoming data and discriminate trivial events from high-priority detections. The establishment of a library of identified arrivals is the first step toward automated identification of suspect events. The catalog also allows events to be selected for research on sound propagation and source identification. Over 1200 events have been recorded and assigned phase names based on tentative source identification.

RESEARCH ACCOMPLISHED

Analysis Techniques

Most of the tools currently in use work with the Sandia National Laboratories' (SNL's) MatSeis software platform. ISLA personnel have modified and customized some of the functions of MatSeis in order to optimize its use for infrasonic analysis, and renamed the result MatSound. MatSound is currently the main analysis tool used at ISLA, as it offers a graphical user interface (GUI) to many powerful functions and is easily extendable to new tools.

For local signal detection, a waveform record is passed through a Butterworth zero-phase 2nd order high-pass filter above 1 Hz to remove microbarom contamination, and the resulting traces are examined for arrivals. Any arrivals seen by the analyst are subjected to FK analysis to determine arrival azimuth, which is used in conjunction with waveform characteristics such as onset quality, duration, and amplitude to identify local phase. A simple STA/LTA-based detector has been developed to automatically identify local arrivals. The detector first computes a 3-second/27-second STA/LTA value for a 4-hour CSS database record, then scans through the result using a 20-second window with 75% overlap. If an STA/LTA value greater than a preset threshold value, currently 1.8, is detected in that window on at least three of the four channels, the average normalized cross-correlation coefficient of the channels is calculated. If the average coefficient is greater than another preset threshold (currently 0.4), the window is marked as an arrival and flagged for analyst attention. FK analysis is performed on the marked window, and the event is automatically assigned a preliminary azimuth and slowness. The detector takes approximately 8-20 minutes (depending on CPU load) to analyze a 4-hour data segment. The false alarm rate of the detector is very low due to the coherence requirements, but the detector is less sensitive to long emergent arrivals, probably because STA/LTA values for emergent events tend to be lower than those of short-duration events with impulsive onsets.

Long-duration, emergent arrivals are identified using the Los Alamos National Laboratory's (LANL) InfraTool program (Figure 1), which has been integrated into the MatSound toolbox. InfraTool steps through array data using a window of adjustable length and overlap and computes an instantaneous azimuth, trace velocity and correlation coefficient for each segment. ISLA personnel have modified the original InfraTool so that slowness is displayed instead of velocity, and an additional display window has been added for the F-statistic. The InfraTool controls have been moved to a separate panel (Figure 2) to facilitate addition of buttons and controls for new tools as they are developed. The original InfraTool allowed a time-window to be selected within the azimuth axes and a mean value computed; functionality has been added to place similar windows in the slowness and F-statistic axes as well, and the windows can be moved simultaneously. The InfraTool control panel can be used to zoom the main MatSound display to the selected time-window, to initiate an FK analysis, and to mark an arrival. Long-duration arrivals such as ITS (see below) are indicated by periods of constant azimuth and slowness along with increased correlation and F-statistic. The InfraTool detector has performed well even in cases where the signal-to-noise ratio is close to unity.

Once an arrival has been identified and cataloged, the Tau-P software of Garcés et al. (1998) can be used to begin epicentral location. The Tau-P code calculates range, travel-time, and several other travel-path parameters for the first infrasonic skip based on meteorological data (for example Figure 3). The original code has been modified to not only compute parameters for the entire slowness plane but to separate out arrival areas within the slowness plane that correspond to different turning heights and therefore to different infrasonic phases. The code can then be used to help calculate origin times for arrivals detected on various arrays, thus allowing an over-all origin time to be estimated by minimizing time residuals (Garcés et al., this Proceedings).

Over the time period from June 19, 2000, to July 2, 2001, over one thousand infrasonic events have been identified at KONA. Each arrival is recorded as an entry in a CSS .arrival database. Sources have been identified through a combination of field inspection, cooperation with government sources, and improvements in data analysis. At present the main sources of these events are severe weather, surf, and unidentified offshore activities. A more detailed discussion of each phase follows.

Aircraft Signals: "IA"

Aircraft signals are generally extended, emergent events with signal-to-noise ratio (SNR) of ~2-4 and durations between 30 and 120 seconds. They are identified based on these waveform characteristics and a back azimuth corresponding to Keahole International Airport. Back azimuth is variable due to different take-off and landing approach paths, but averages to 316.49°. These signals can be confused with certain IN events (see below), which are often detected at similar azimuths. Generally IA events can be recognized by a smoother amplitude taper (Figure 4). During the time period under consideration, 204 signals were identified as IA.

Surf Signals: "IK" and "IWS"

Surf signals are generally sets of impulsive events with variable SNR and single-cycle duration (Figure 5). The frequency content of these signals is between 2 and 5 Hz. They tend to be present in groups of pulses and can occur for hours at a time. Early IK detections were recorded at the analyst's discretion; currently surf signals are recorded only if marked by the STA/LTA detector, and only the first such signal from each azimuth is actually recorded. The number of signals marked by the detector is indicated in the comment field of the CSS database. Two phases are currently used for identification of surf signals, and the distinction is based on back azimuth. The most consistent surf signal comes from Kualanui and is characterized by a back azimuth of about 232.7°. Over the course of the analysis 263 IK signals have been identified.

The IWS phase (also previously called INW) is used to indicate apparent surf noise from any other direction, but is seen most often from a back azimuth of about 320 and may be produced by surf in Makako Bay. At present 139 IWS signals have been identified.

Weather Signals: "IM"

IM signals are generally found within the microbarom passband of 0.1-0.4 Hz. Comparison of recorded back azimuths with regional wave-height diagrams generated by the U.S. Navy's Fleet Numerical Meteorological and Oceanography Center suggests that the signals are generated by strong weather patterns that can be several thousand kilometers away. Occasional inability to correlate strong weather with IM signals suggests that local weather conditions can overwhelm distant signals. FK analysis of these events has been used to track nearby tropical storms. Because the signals are generated by regional weather patterns, there is no typical back azimuth. Over the course of the analysis 242 IM signals have been identified.

Earthquake Signals: "IEP"

Although KONA is an infrasound (not a seismic) array, several local earthquakes have been recorded by the instrument. IEP signals are characterized by very low slowness and the presence of two distinct impulsive arrivals (Figure 6). Although several researchers (e.g. Young & Greene, 1982; Cook, 1971) have shown that surface waves can be coupled into the atmosphere, the arrival time and recognition of both P-wave and S-wave arrivals suggests that in these cases the microphone is sensing ground vibration from the incident seismic body waves. Deep (>20-30 km) earthquakes appear to be preferentially recorded, probably because P-waves from these earthquakes tend to displace the sensor vertically. The array has detected 14 local earthquakes, with a magnitude detection threshold of $M_D = 2.7$.

Waveform appearance in Figure 6 varies significantly across the array due to differences in wind-noise-reducing filter configuration. When this earthquake occurred, sites H1 and H3 were equipped with PVC wind-noise-reducing filters, while H2 and H4 were equipped with porous-hose wind-noise-reducing filters. The extra mass of the PVC filters in contact with the ground improves body wave coupling into the instrument and tends to increase signal-to-noise for the earthquakes on H1 and H3. Also, coupling at H3 is more efficient than at H1 because the filter assembly at H3 is more firmly attached to the ground. The diameter of the H1 filter system is 18m, whereas the diameter of the H3 system is 12 m.

Offshore Signals: "IN"

These signals are normally characterized by slightly lower slowness and a dispersed appearance, and can range in appearance between sharp, impulsive arrivals and long emergent arrivals (Figure 7). The impulsive IN events can be mistaken for surf but are generally higher amplitude and more irregular. Emergent IN events can resemble airplane signatures but tend to arrive from azimuths not associated with local airports and are less smooth; some resemble a series of pulses that have been broadened by propagation. The frequency band is variable, and may extend from 0.5 Hz to 6 Hz. Although 177 IN events have been marked, specific activities that produce these signals remain unidentified.

Pohakuloa Training Area Signals: "IP"

IP signals generally arrive from a back azimuth between 30° and 90°, encompassing an area occupied by the Pohakuloa Training Area. Typical IP events feature a series of sharp, impulsive arrivals at irregular intervals, but some bear a resemblance to IA signals. ISLA has identified 138 signals as IP.

Telesonic Signals: "ITS"

Telesonic signal identifications are based on long durations (generally >2 minutes), generally low SNR (< 3), possible dispersion, and confirmation from other stations. Because of these characteristics, they do not lend themselves to time-domain detection and can be difficult to detect by simple visual examination. A modified version of LANL's InfraTool has proven efficient for detecting these signals, even in cases of SNR close to unity. Four ITS events have been selected. At least two ITS events have been identified as bolides (Figure 9); sources of the other events remain unconfirmed but it seems most likely that they too are related to bolide events.

Unidentified Local Signals: "IW"

This category is a general term for local events that cannot be easily associated with any of the above sources. Often IW events resemble IA signals but arrive from azimuths not associated with an airport, or resemble isolated surf events from azimuths along which the nearest coastline is 50 or more kilometers away and therefore an unlikely source. As analysis techniques improve, designation of signals as IW has become less frequent, but is still necessary. Thus far, 99 events have been designated IW.

CONCLUSIONS AND RECOMMENDATIONS

The KONA Event Catalog is the result of extensive work and has prompted the development of several useful software tools. Analysis techniques at ISLA have evolved and improved over time. A basic understanding of the background infrasonic field of the central Pacific Ocean and the Kona area has been accomplished and the characteristics of many common signals have been determined. This information is essential for the development of automatic, real-time event detection and identification algorithms.

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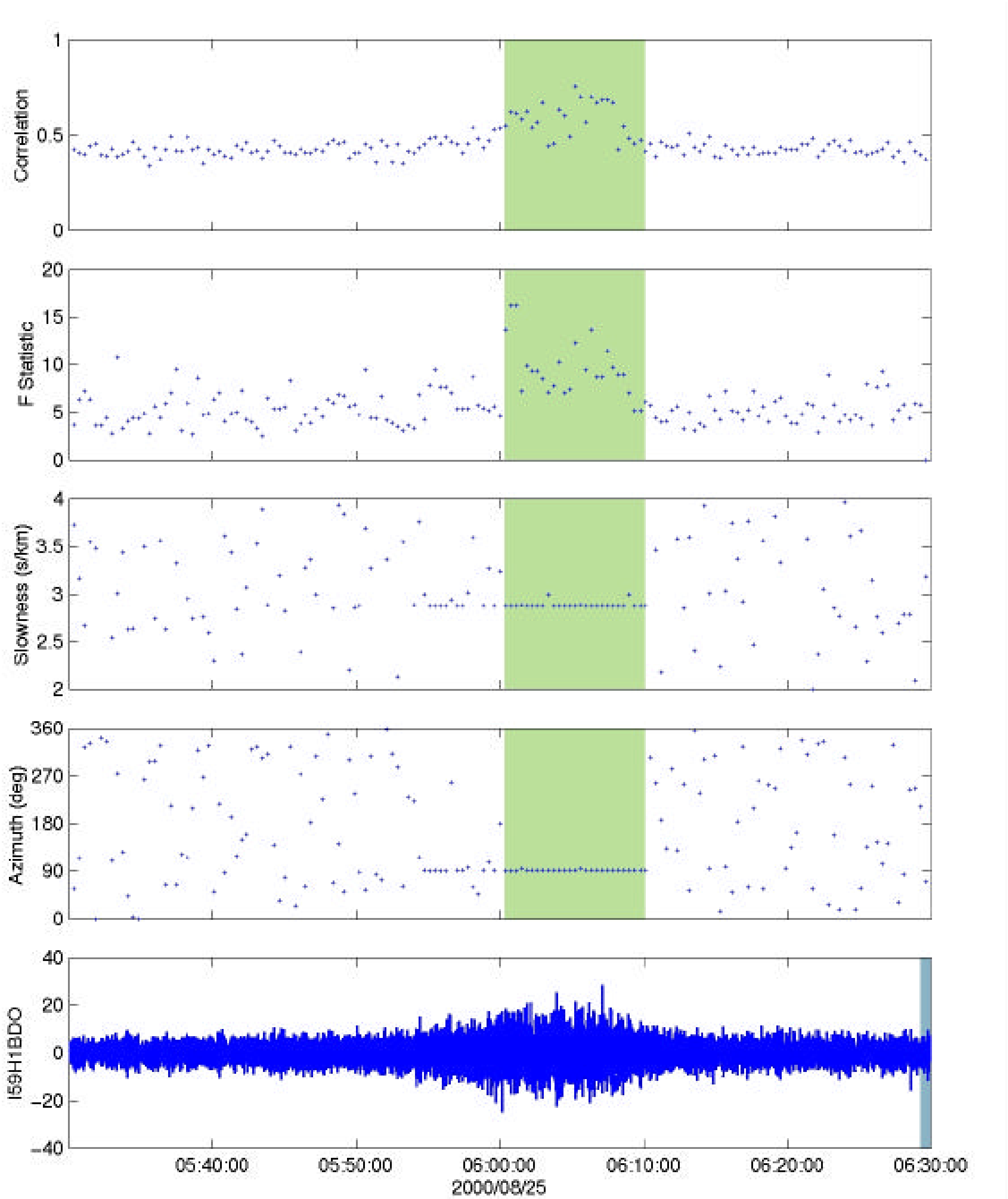

Figure 1. Main InfraTool window showing analysis of an ITS bolide arrival on 8/25/00. Boxes in Azimuth, Slowness, Correlation, and F-Statistic windows correspond to time segments over which mean azimuth and slowness were calculated (Figure 2).

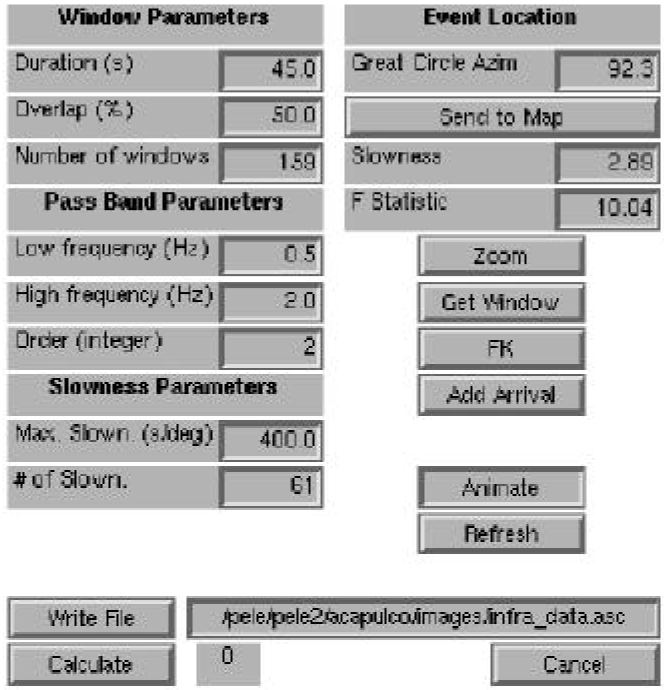

Figure 2. InfraTool control panel showing typical ISLA analysis parameters, mean azimuth and slowness, and available tools.

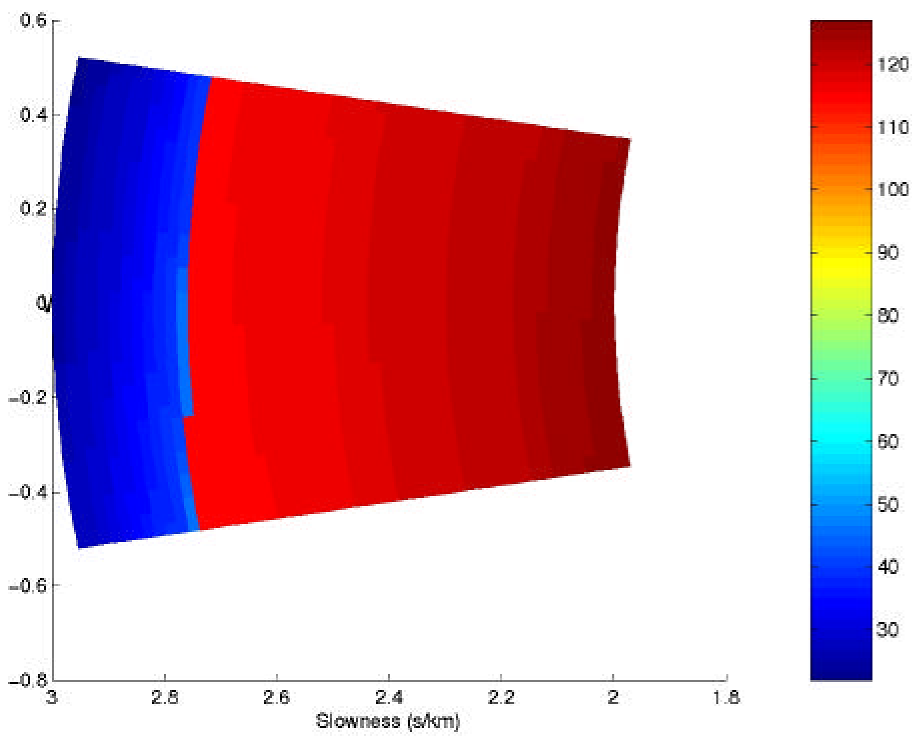

Figure 3. Plot showing turning height for first-skip infrasonic waves for a segment of the slowness plane as calculated by the Tau-P software of Garcés et al. (1998). The outer portion corresponds to a stratospheric phase, the inner to a thermospheric phase.

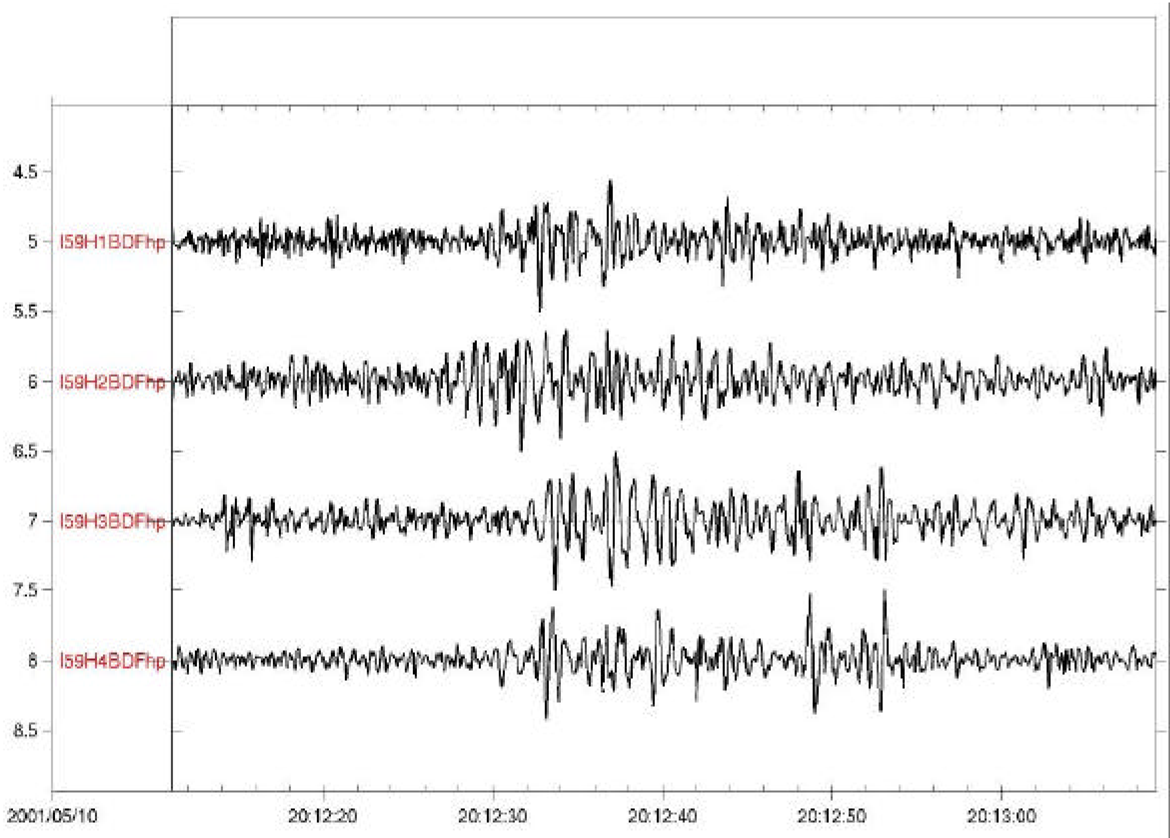

Figure 4. High-pass-filtered waveform showing typical IA arrival.

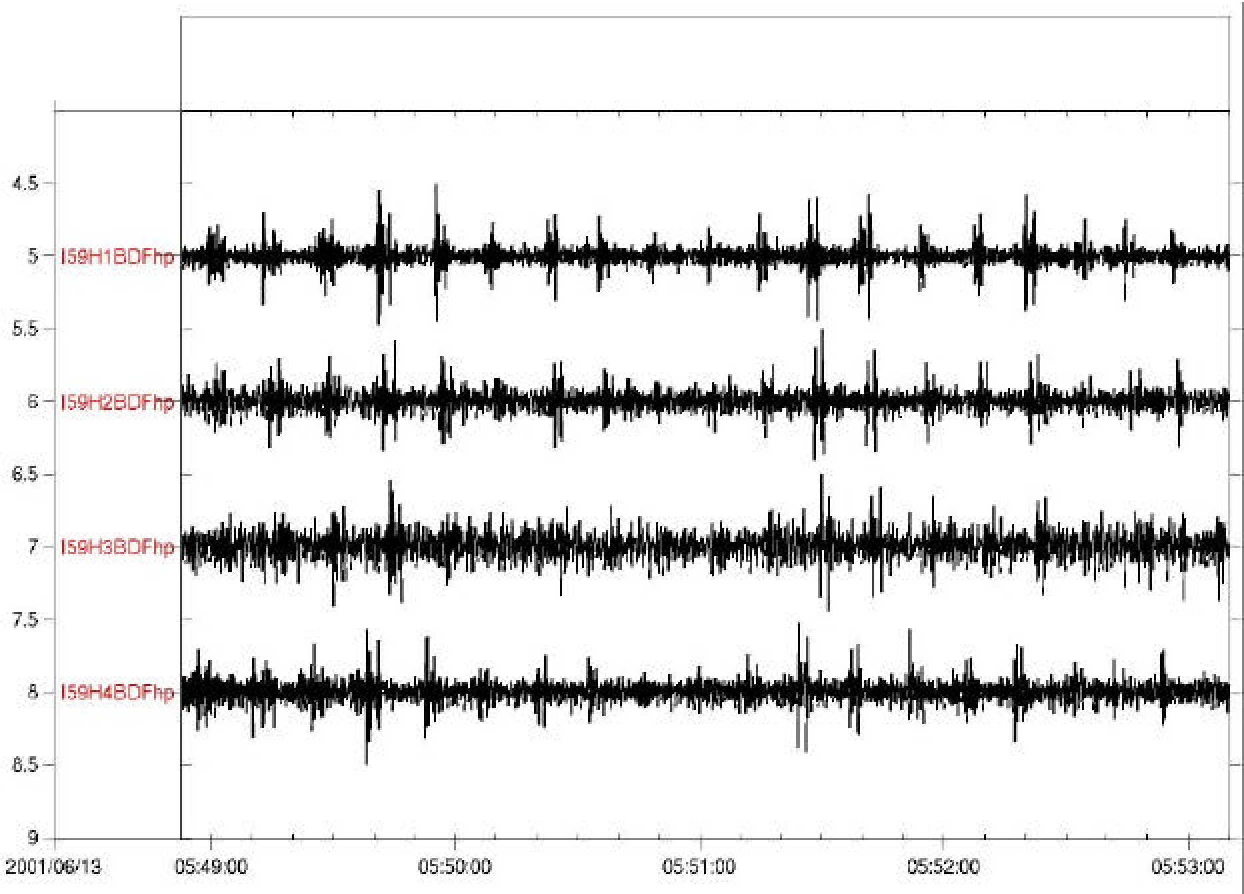

Figure 5. High-pass-filtered waveform showing typical IK arrivals.

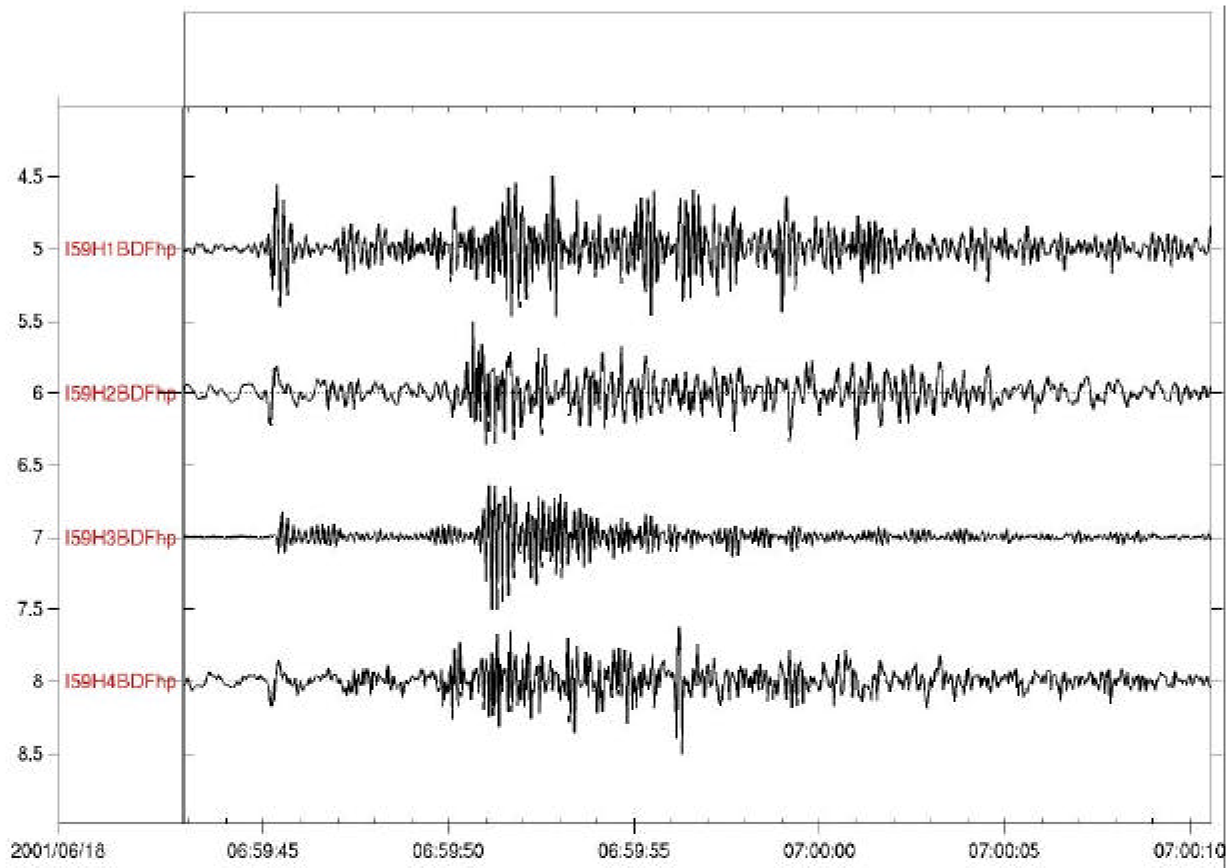

Figure 6. High-pass-filtered waveform showing typical IEP arrivals. Note severely increased signal-to-noise ratio on channel I59H3BDF due to presence of PVC wind-noise-reducing filter in contact with the ground.

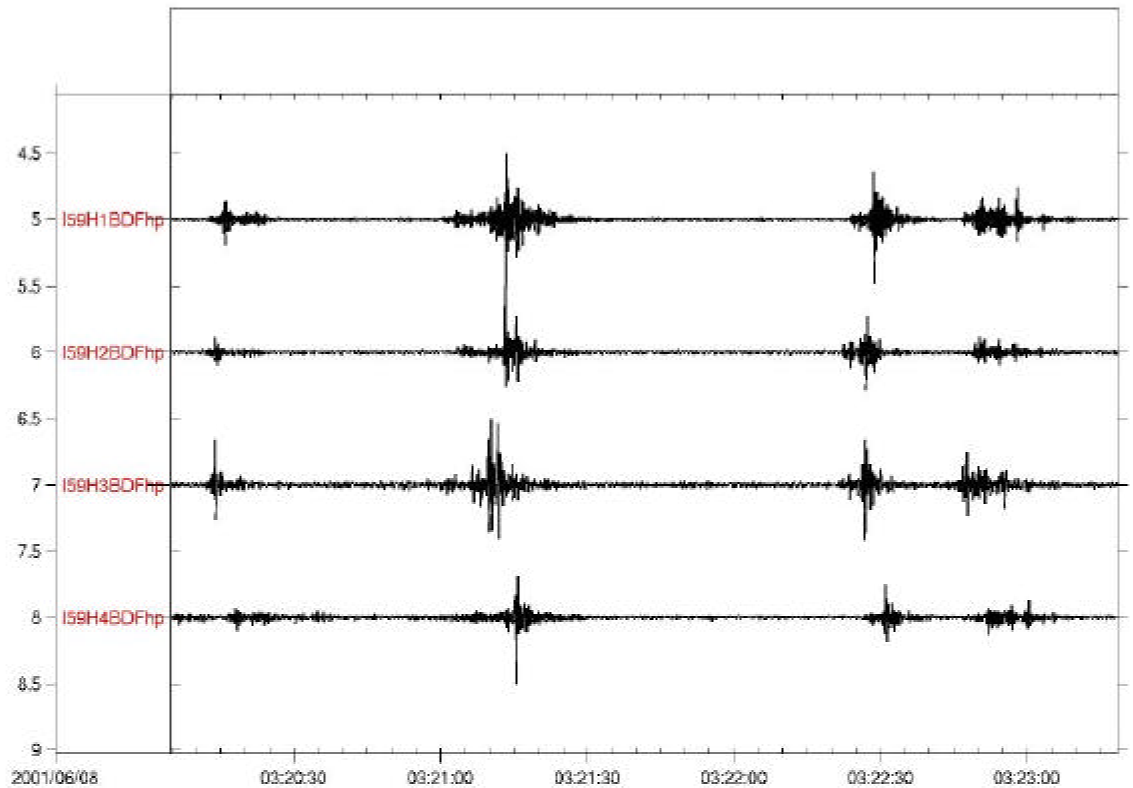

Figure 7. High-pass-filtered waveform data showing typical IN arrivals.