ENHANCEMENTS TO THE CTBTO OPERATIONAL AUTOMATIC INFRASOUND PROCESSING SYSTEM

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Comprehensive Nuclear-Test-Ban Treaty Organization

ABSTRACT

The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is exploring methods to enhance the current operational infrasound processing system at the International Data Centre (IDC) for infrasound data recorded by the International Monitoring System (IMS). Several enhancements are under development and are currently being tested.

The first enhancement is the incorporation of methods for determining signal amplitude. The following signal amplitudes are being determined for each infrasound detection: peak-to-peak amplitude, root mean squared (RMS) amplitude, and instantaneous amplitude as revealed by the analytic trace via the Hilbert Transform. Initial efforts consider a variety of frequency bands, with the utility in network processing being of primary importance.

A second enhancement is the incorporation of station noise characterization in terms of the power spectral density (PSD). This determines the noise field at each station for various times of day and as a function of season. This information is useful in determining network detection capability.

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OBJECTIVES

The objective of this work is to provide both CTBTO and external users of IDC data products with the ability to determine more accurate measures of IMS infrasound network capability.

This goal will be achieved through enhancements to the current automatic infrasound processing system that will

i. provide infrasound signal amplitudes, and

ii. provide a notion of the background noise characteristics at each station.

RESEARCH ACCOMPLISHED

Amplitude Determination

Signal amplitudes are being determined for each automatic infrasound detection using three different methods.

The peak-to-peak amplitude, RMS amplitude, and instantaneous amplitude as revealed by the analytic trace via the Hilbert Transform are being calculated for each arrival ID (**arid).**

The peak-to-peak amplitude is used typically in empirical infrasound amplitude attenuation laws (Whitaker, 1995; Blanc et al., 1997) and so provides a useful addition to the IDC Bulletin. The RMS amplitude, however, is a running average taken over a user-specifiable time interval and is more representative of the average signal strength than the peak signal strength, as revealed by the peak-to-peak amplitude. The RMS amplitude will, for example, assign small-to-modest amplitudes to short-duration spurious signals that consist of a single cycle or oscillation, since the neighboring uncorrelated data points will likely figure in the calculation and reduce the measure of the amplitude accordingly. The analytic trace amplitude is the formal definition of instantaneous wave amplitude, and its features may be useful. Assume $\mathbf{x}(t)$ is an infrasonic waveform and $\mathbf{H}(t)$ its Hilbert Transform (e.g., Bracewell, 1986). The analytic trace $\mathbf{A}(t)$ is written simply as the complex time-series $\mathbf{A}(t) = \mathbf{x}(t) + i\mathbf{H}(t)$, where i is the unit complex number. The following identifications are then made:

a) instantaneous amplitude: $A(t) = \sqrt{\mathbf{x}^2(t) + \mathbf{H}^2(t)}$ (1)

b) instantaneous phase: $\theta(t) = \arctan\left(\frac{\mathbf{H}(t)}{\mathbf{x}(t)}\right)$ (2)

c) instantaneous frequency: $f(t) = \partial\theta(t) / \partial t$ (3)

Although the peak-to-peak amplitude is the preferred amplitude measure that is recorded in the amplitude table and thus will appear in the Bulletin, the two alternative amplitude measures are recorded for internal IDC use. The analytic trace amplitude, for example, may find application in a future microbarom classifier following Olson's microbarom analysis (Olson et al., 2000), whereas the RMS amplitude may find application in an infrasound detection 'measure-of-significance' value.

In a practical scheme, a band-pass filtered beam aligned with slowness appropriate for a given **arid** is formed, and each amplitude type determined. Two band-pass filters are typically used, viz: a Finite Impulse Response (FIR) filter, where the high- and low-corner frequencies are determined by the signal content as revealed by the pmcc detection algorithm; and a FIR filter in which the high and low corner frequencies are user specifiable.

As an example, amplitudes have been determined for an acoustic signal recorded at station IS26, located in Germany, from the Buncefield Oil Depot explosion in Hertfordshire, UK, in December 2005. The band-pass filtered data are shown in Figure 1.

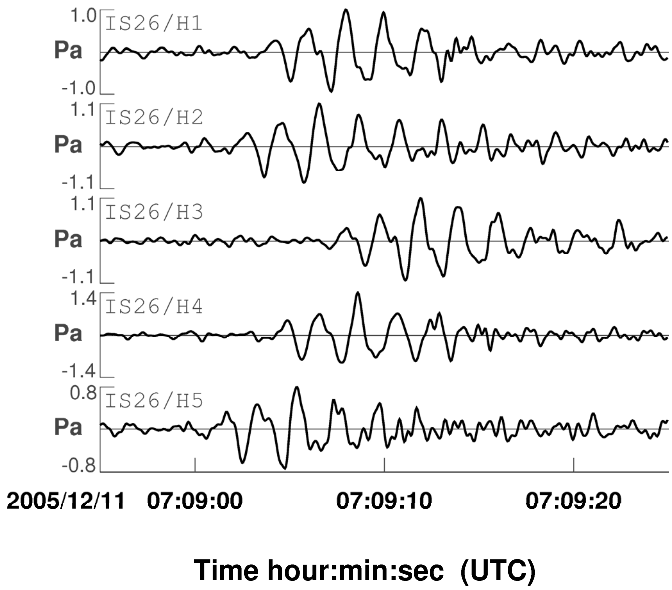

Figure 1: Acoustic waveform recorded at station IS26, Germany from the December 2005 Buncefield oil depot explosion in Hertfordshire UK. Data have been band-pass filtered from 0.5 to 2.0 Hz.

Figure 2 shows the time-aligned beam channel with the analytic trace (red) and a trace derived from the RMS amplitude channel (blue), assuming a 2 second sliding window, superimposed over the beam channel data.

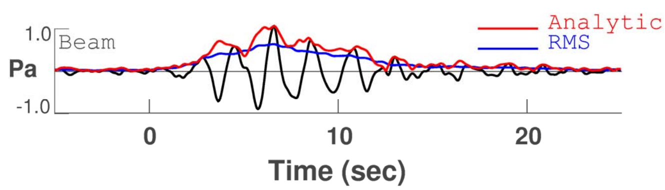

Figure 2: **Time aligned beam with analytic trace (red) and RMS Trace (blue) superimposed. The RMS amplitude trace was determined with a 2-second sliding window.**

For this signal, the peak-to-peak amplitude was found to be 1.90 Pa, analytic trace amplitude 1.04 Pa, and RMS amplitude 0.62 Pa. As one would expect, the analytic trace amplitude agrees exactly with the zero-to-peak amplitude at the maximum point of the signal. As can be seen from the figure, the averaging nature of the RMS amplitude may be useful in discarding less significant signals.

Station Noise Characterization

Station ambient noise conditions are being represented by the PSD, which provides a measure of the differential power contained in the signal at each frequency. Implicit in the use of the PSD is that both the mean and autocorrelation of the sampled waveform are time independent, which is assumed to hold approximately true in general as the propagating acoustic signals are considered to be short-lived transitory phenomenon and will thus provide an only minor impact on the statistics.

PSDs are being determined for each station four times per day at hours 03:30, 09:30, 15:30, and 21:30 local station time. A one hour data interval is used in each case and, except for minor departures, the PSDs are being determined using the processing schema outlined in Bowman et al. (2005). In this scheme, the one-hour data interval is divided into 21 three-minute intervals, each slightly overlapping the adjacent windows, and an average PSD determined. A Hanning-type window function is applied to each 3-minute interval to dampen spectral leakage and improve amplitude resolution.

Spectral information is recorded in a binary data file in two forms:

a. The base 10 logarithm of the power spectral data for each sensor for each station determined for each frequency picket in the sequence $\left\{\frac{n}{N}\Delta\right\}; \text{ for } n = 0,\cdots,N/2$ where N is the total number of sample points and Δ the sample rate. The sample rate is typically 20 samples-per-second, so with the 3,600 data samples in a 3-minute window, a PSD using 1800 frequency pickets is typically computed. As an example, the raw data for day 2007183 hour 21:30 on station IS22 (Port Laguerre, New Caledonia) is shown in Figure 3.

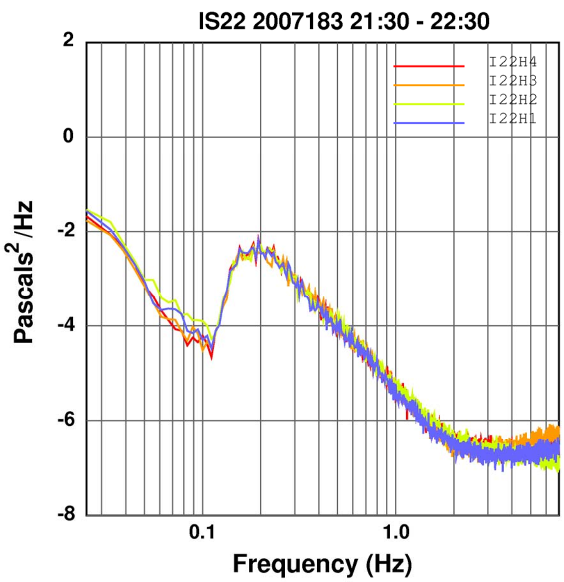

Figure 3: **Raw PSD data for station IS22 from 21:30 to 22:30 local time on day 2007183**

b. Monthly-averaged and smoothed logarithmic data for each station recorded at the frequency pickets $f_j = \log_{10}(\frac{\Delta}{N}) + \frac{1}{M}(\log_{10}(\frac{\Delta}{2}) - \log_{10}(\frac{\Delta}{N}))\left(j - \frac{1}{2}\right)$ for j = 1,…,M where M is typically 100. This choice of frequency picket facilitates linear abscissa on a log-log plot. The data are also smoothed with a 6th order 11-point Savitzky-Golay filter. Also recorded is the standard deviation for each data set. The mean and standard deviation data are updated each time new data become available. The monthly data for stations IS07 (Warramunga, Australia) and IS22 (Port Laguerre, New Caledonia) for July 2007 are shown in Figures 4 and 5, respectively.

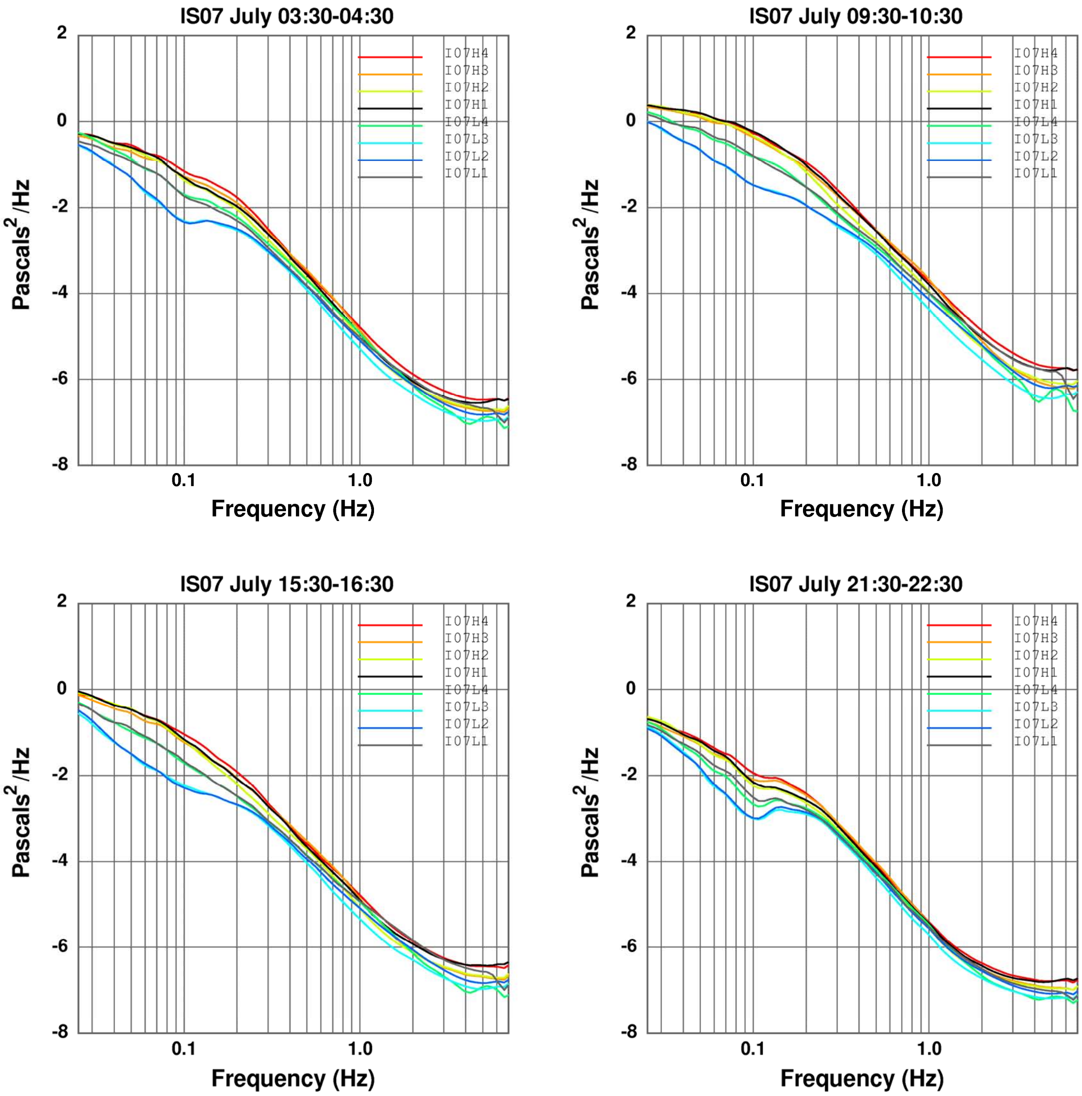

Figure 4: The mean PSD data for station IS07 for the month of July 2007 taken at the four times: 03:30-04:30, 09:3-10:30, 15:30-16:30, and 21:30-22:30 local time. A 6th-order, 11-point Savitzky-Golay filter has been used to smooth the data.

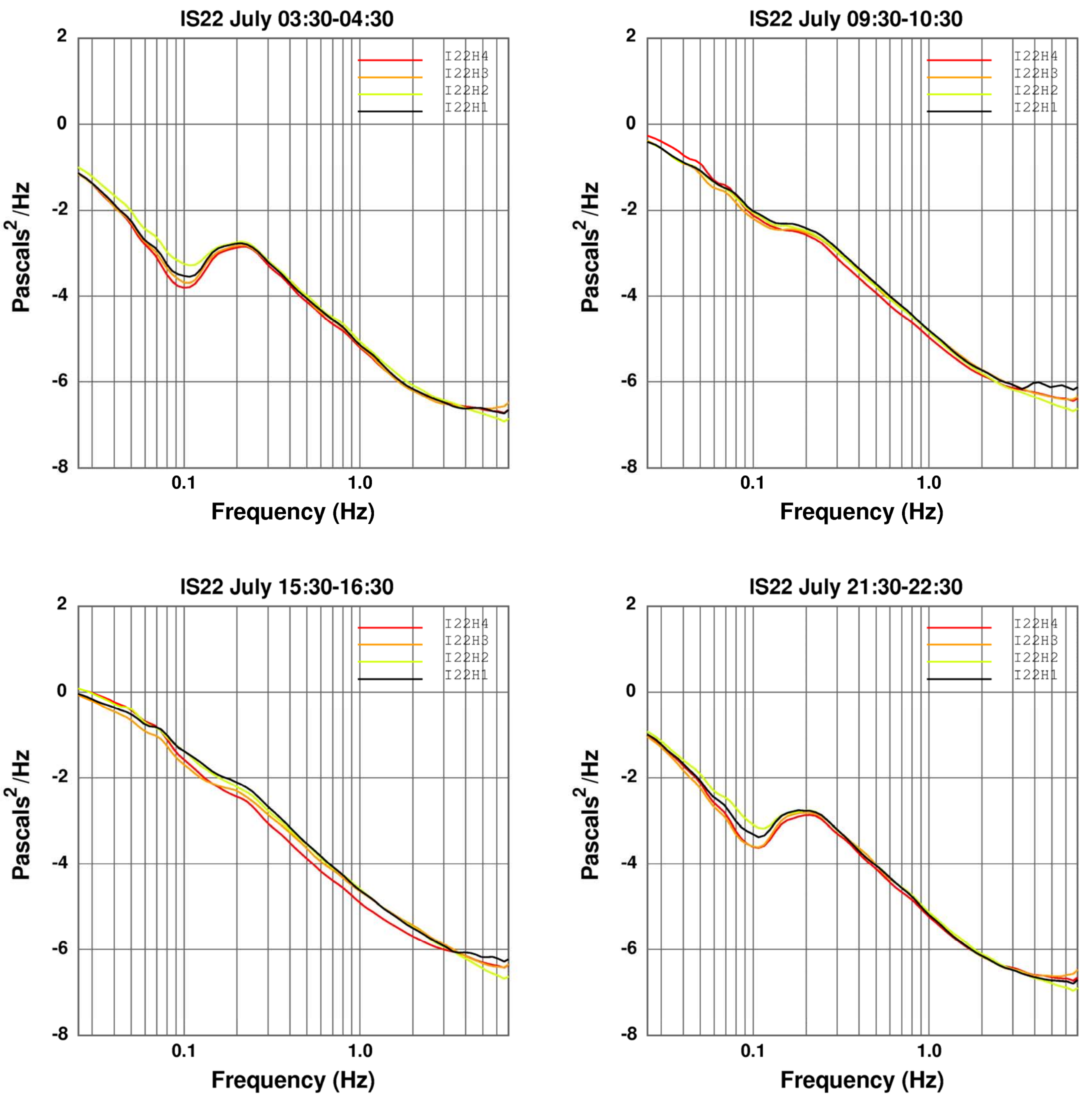

Figure 5: The mean PSD data for station IS22 for the month of July 2007 taken at the four times: 03:30-04:30, 09:3-10:30, 15:30-16:30, and 21:30-22:30 local time. A 6^th-order, 11-point Savitzky-Golay filter has been used to smooth the data.

To provide an indication of the daily variation, spectral data for a single sensor, together with the mean μ and standard deviation, are presented for station IS07 and IS22 for the month of July 2007 in Figures 6 and 7, respectively.

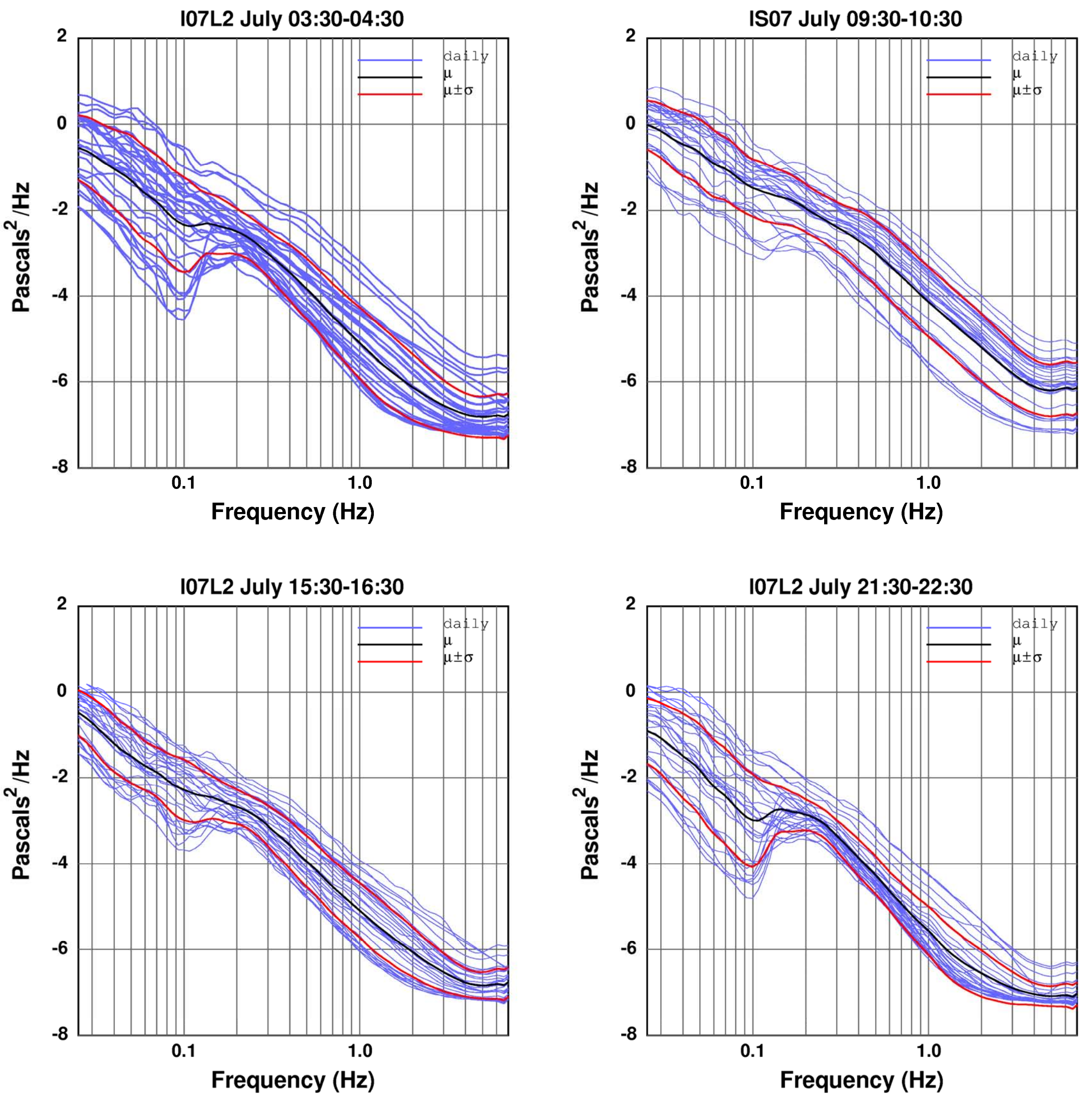

Figure 6: **Daily spectral data , the mean μ , and mean ± one-standard deviation σ for sensor I07L2 for all days in July 2007 for the hours 03:30-04:30, 09:30-10:30, 15:30-16:30, and 21:30-22:30 local time.**

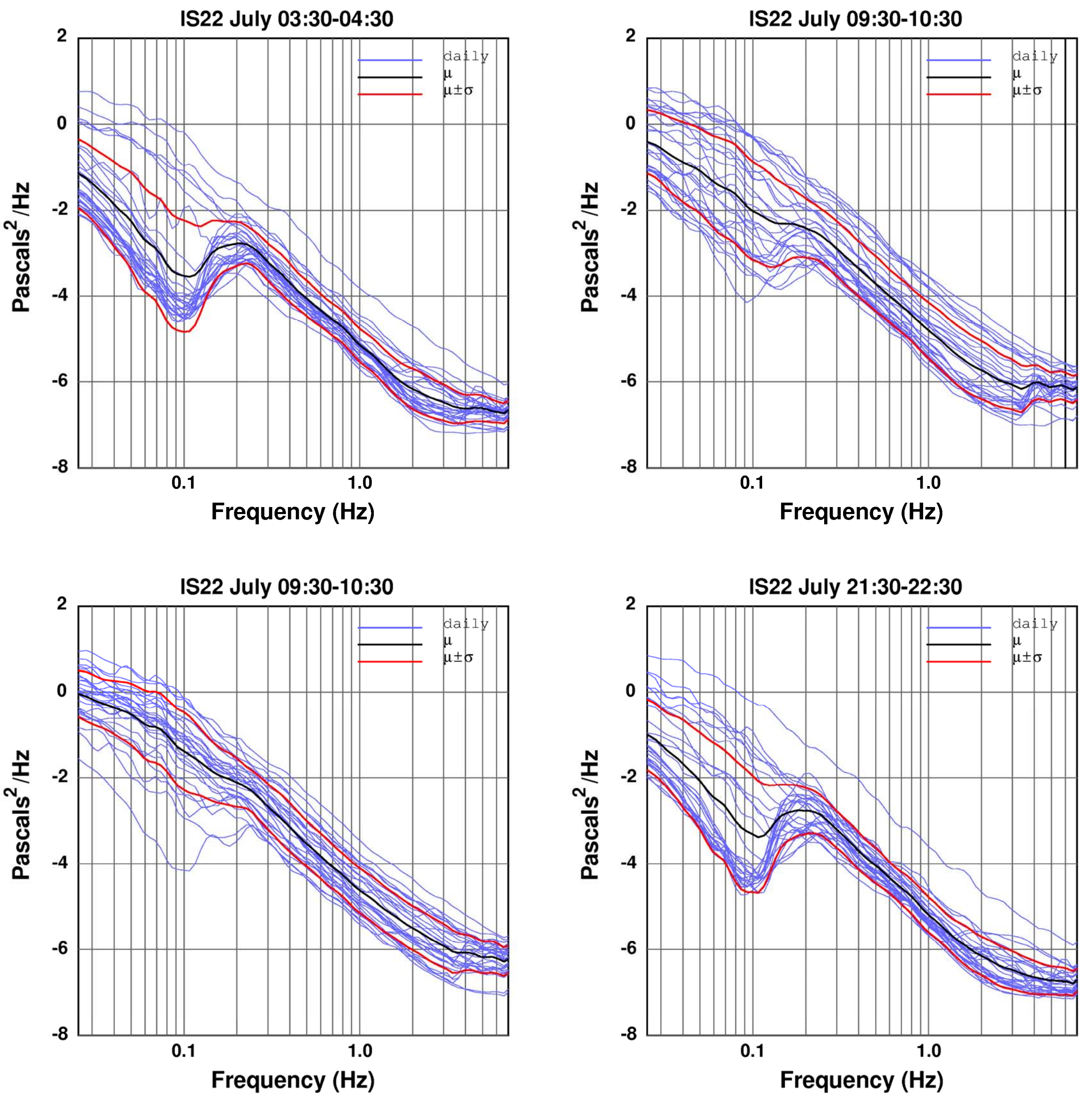

Figure 7: **Daily spectral data, the mean μ, and mean ± one-standard deviation σ for sensor I22H1 for all days in July 2007 for the hours 03:30-04:30, 09:30-10:30, 15:30-16:30, and 21:30-22:30 local time.**

The diurnal differences are quite obvious from these figures. Day-time convection has increased wind-noise to such a level that the microbarom peak is generally not visible during the day. Interestingly, the night-time hours seem to exhibit most variation, but neither station exhibits a situation in which no microbaroms are present, even if it is being masked by noise due to turbulence.

Spectral data are being written to binary files with the intention that users with access to IDC external data products be able to access them using conventional methods.

CONCLUSIONS AND RECOMMENDATIONS

Amplitude and spectral information of the sort considered here provides a welcome addition to the IDC Bulletin, additionally providing external users of IDC data products vital knowledge concerning network performance.

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