



# Analysis of Infrasound Sources Detected by the I57US array

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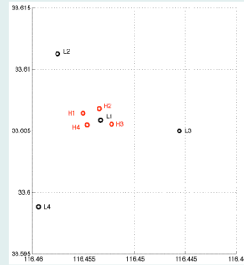
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## Abstract

We have written a code based on the PMCC method initially developed by Cansi for the detection of seismic phases, that allows for analysis of very short data segments. This code has been applied to several sources detected at the I57US array, including rocket launches from Vandenberg airforce base, the space shuttle Columbia, and a source with acoustic velocities and back azimuths consistent with an aircraft.

## I. Array configuration and source locations

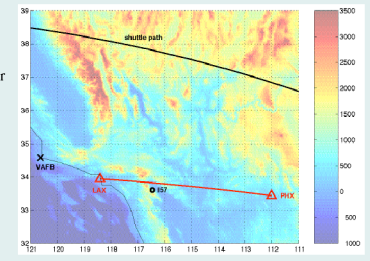


### I57US Array configuration

The I57US array configuration, shown at left, consists of a total of 8 sensors. Four sensors (H1 through H4) are attached to 18-meter, high-frequency, rosette filters. Sensors L1 through L4 use 70-meter long-period filters.

The location of the I57US array with respect to sources that generated signals analyzed in this poster is shown to the right. Sources analyzed in section III are tentatively identified as flights from Los Angeles to Phoenix; the geodesic path from LAX to PHX is marked in red. Signals from the space shuttle Columbia - path marked in black - are analyzed in section IV. Signals from a Delta II rocket, launched from Vandenberg airforce base (VAFB), are analyzed in section V.

### Location of sources with respect to I57US



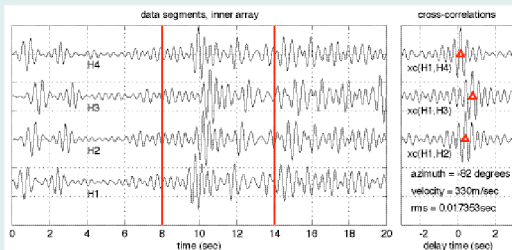
## II. New version of PMCC (progressive multi-channel correlation)

Our version of the PMCC code is similar to that of Cansi (1995) with the main difference being that our code allows for the analysis of shorter time windows. This allows for a more detailed analysis of variations in acoustic group velocity and source azimuth as a function of time. We briefly describe the code here, using as an example a short segment of data from January 4, 2003 which is described in greater detail in section III.

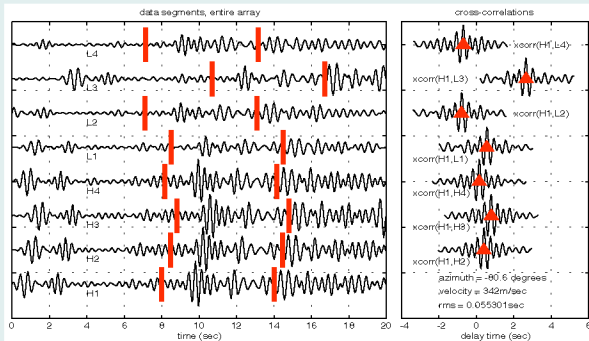
The data are analyzed over a series of bandwidths. For each bandwidth, we divide the data into a series of time windows. Each window must be long enough so that, for the innermost part of the array, there is sufficient overlap between corresponding signals that results of cross-correlations are meaningful. In general, the overlap between waveforms should be at least half the window length. For the I57US array, the H1-H4 sensors form the innermost part of the array (see Figure 1). As in the Cansi method we first determine whether delay times, computed from cross-correlations between signals, are consistent with a detection. That is, if

$$\Delta t = t_2 - t_1 - \frac{r_2 - r_1}{v} \quad (1)$$

is sufficiently close to zero, a detection is registered. If equation (1) is satisfied for the innermost sensors, we make an initial estimate of the source azimuth and phase velocity using relative delay times between sensors.

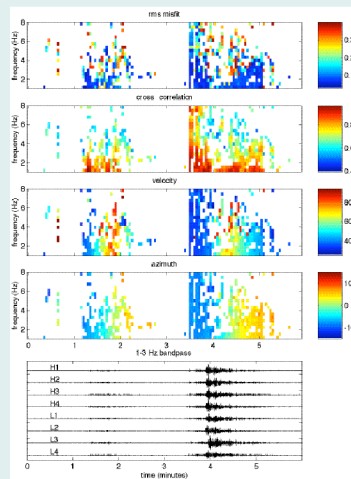


An example is given for a 6 second time window shown by the red lines in the left panel above. The data have been bandpassed from 2-3 Hz. Delay times are computed using cross-correlations between the first (reference) sensor and each other sensor. Cross-correlation functions are shown in the right panel below; the maxima of these functions yield the delay times, which are then used to compute an approximate azimuth and horizontal group velocity across the array. For this segment of data, the delay times are consistent with an acoustic plane wave with a velocity of 330m/sec arriving at a back azimuth of -82 degrees. This yields an rms misfit of 0.017 seconds, less than the sample rate. Because of the small size of the inner array, arrivals are highly correlated. This allows for good initial estimates of the source azimuth. However, accurate estimates of the azimuth and velocity require an array with a larger aperture. Therefore, we use the entire array to compute more accurate estimates.



The initial plane wave velocity and azimuth estimates are used to select staggered windows for cross-correlations across the entire array. For the initial source estimates determined above, the staggered windows in the left panel below should show corresponding arrivals. Cross-correlations are computed again to refine the delay times relative to the reference station, as shown in the right panel below. These delay times are used to refine the source azimuth and velocity. In this case, the best-fitting plane wave has a back azimuth and velocity of -80.6 degrees and 342m/sec, with an rms misfit of 0.055sec, slightly greater than the sample rate.

## III. Sources with rapidly-varying back azimuth



An example of the analysis is shown to the left for a pair of arrivals within a 6 minute time span (0023.0029) on Jan 4, 2003. For each bandwidth and window segment, an azimuth and group velocity are derived for the best-fit plane wave. The rms misfits to the plane waves are shown in the top panel, the average cross-correlation values between the reference sensor and each other sensor are shown in the next panel, then group velocities and back azimuths for each window are shown in the panel above the filtered data segment. A detailed analysis of an arrival at about 3.5 minutes was shown in section II.

A large number of sources of the type shown in the panels to the left are observed in low noise conditions. PMCC analysis shows that both the acoustic group velocity and azimuth change rapidly over the 1-2 minutes that they are observed. Given these characteristics, and the sources' estimated velocities (see below) we tentatively identify these as signals from aircraft.

If we assume that the aircraft travels at a constant height, as well as constant speed and heading, we can use our results to derive the plane's approximate path. The azimuth changes most rapidly with time at the plane's closest approach to the array, which appears to be almost directly to the North. So the plane appears to have been headed from west to east at some distance to the north of the array. For a constant ground speed, we can deduce from geometrical considerations that the plane was travelling at a speed of approximately 600 km/hour at a minimum distance of about 3 km N of the array. To put these aircraft tracking abilities in perspective, an observer could get a better fix on the plane's location just by looking up at the sky.

Given these parameters, we estimate that any plane within about 15 km of the array could be detected. Given the proximity of the array to the great circle path - the presumed flight path - between Los Angeles and Phoenix and that there are many flights between these cities every day (at least 15/day on southwest airlines alone), this could yield a lot of detections each day.

## IV. Columbia space shuttle

The space shuttle Columbia broke up on Feb 1, 2003 on its final landing approach. Acoustic signals from the shuttle's approach were recorded at I57US, as shown here. Back azimuths derived for the first arrival on the plots to the right indicate that this phase is not associated with the shuttle's approach. Two distinct arrivals at about 1424 and 1425.6 are associated with the shuttle's approach. The latter of these two may have arrived from as much as 10 degrees further to the east, however, the precise azimuths can't be determined because of scatter in the derived back azimuths.

