RECENT INFRASOUND ANALYSIS

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ABSTRACT

We will discuss analysis of several fairly recent events using the Matseis package, Infra_Tool. The events include a recent explosive test, Watusi at the Nevada Test Site (NTS), recent earthquakes, a recent bolide, and the tragic return of the shuttle Columbia. Watusi, with a charge weight of 19 tons, was recorded at four Los Alamos National Laboratory/Department of Energy (LANL/DOE) infrasound arrays. Summary results will be presented and followed by a comparison to other HE (high explosive) data recorded by LANL arrays. Analysis of moderate earthquakes (m_b < 5.0) has continued and results are beginning to suggest that larger (km) sized arrays do not see these events as well as smaller (100 m) arrays, which is good for monitoring applications. For Columbia, the LANL arrays were close to the flight path and recorded N wave records, which will be presented. We will illustrate the new location software in Matseis, which utilizes simple travel time curves for three infrasound phases. This new software performs the same type of location as LocSat but can be run separately from the LibLoc library.

OBJECTIVE

We will discuss the analysis of infrasound data from several recent events. We used Infra_Tool to perform the primary analysis; this tool is part of the Sandia National Laboratory (SNL) analysis software, Matseis.

RESEARCH ACCOMPLISHED

Watusi was a high-explosive (HE) test executed at the Nevada Test Site (NTS) on 9/28/02 at 2:25 pm PDT (21:25 UTC) with an explosive force of 38,000 lbs of TNT equivalent yield. The configuration was a cylindrical container, which was partially above ground level. Group EES-8 (now EES-2) made infrasonic measurements at four arrays: NTS; St. George, UT, (SGAR); and two arrays in Los Alamos, LSAR and DLIAR. The coordinates of the arrays are listed in Table 1. Data were collected at all four arrays. The geographical coordinates of the test were: 37˚.099 N and 116˚.092 W in Area 4 of the NTS. The Los Alamos National Laboratory (LANL) Dynamic Experimentation Division (DX) planned and executed the test.

Table 1. Coordinates of the Watusi test.

Array Name	Latitude (degrees)	Longitude (degrees)
NTS	36.7056	-115.9631
SGAR	37.0153	-113.6153
LSAR	35.867	-106.334
DLIAR	35.867	-106.334

Each of the arrays has four microphones in rectangular or triangular configurations. The first three arrays have sensors spaced approximately 100 m apart, while the last array, DLIAR, is a larger array with 1.2 km baseline. LSAR sits inside the area of the DLIAR array, and for purposes here, has essentially the same location. Sampling rates were 20 samples per second (sps) for the first three and 10 sps for DLIAR. Sensors in the first three arrays are Chaparral Physics Model 2 microphones with a nominal frequency range of 0.1–100 Hz; however, only data below 10 Hz are used for the current sample rate. DLIAR uses the Chaparral Physics model 5 microphone with a frequency range of 0.02–100 Hz, but only data below 4 Hz are used with its current sample rate. Distances of the arrays from the event were: NTS, at 45 km; SGAR, at 219 km; and LSAR and DLIAR, at 883 km.

Data processing was performed with the SNL analysis package Matseis; a general package for waveform analysis built around MATLAB. Matseis allows easy processing of array data for correlation analysis, spectrograms, power spectral density (PSD), waveform display, and amplitude measurements.

For amplitude data, we took the peak-to-peak values of the largest single-cycle feature in the region of peak correlation. This measure of amplitude follows our practice for other tests we have measured since the early 1980s. For each array, the average of the four channels was found and converted to microbars. The results are given below in Table 2:

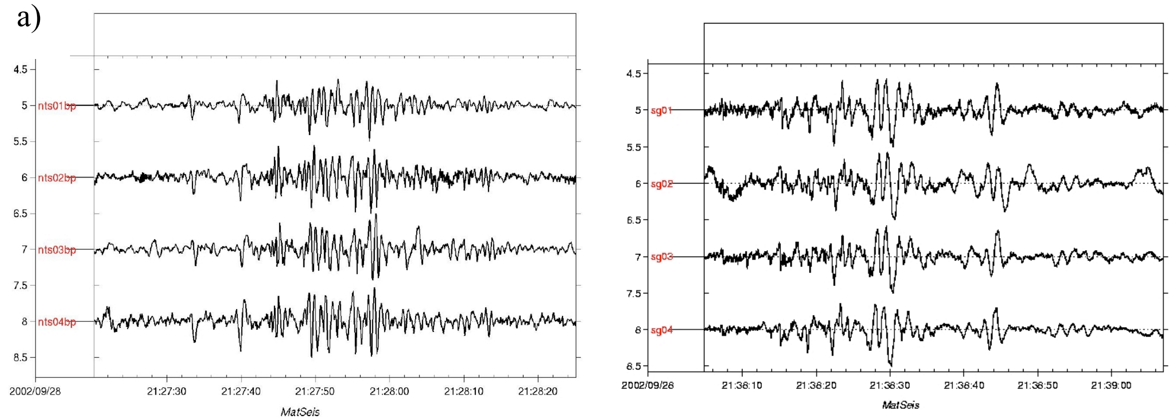
Table 2. Conversion of each array into microbars.

Array	Amplitude (microbars)
NTS	3.2
SGAR	4.07
LSAR	0.58
DLIAR	0.53

As used in airblast measurements, scaled ranges are used to make amplitude comparisons for events of different yields. For the HE data, we use the charge weight in kilotons, including a factor of two for being on the surface, raised to the 0.5 power. This formulation follows from traditional scaling relations where equal pressures are found at scaled ranges. The use of 0.5, rather than the near-field value of 1/3, is to account for the long range of our measurements.

The waveform data are presented in Figure 1 for all four arrays.

a)



b)

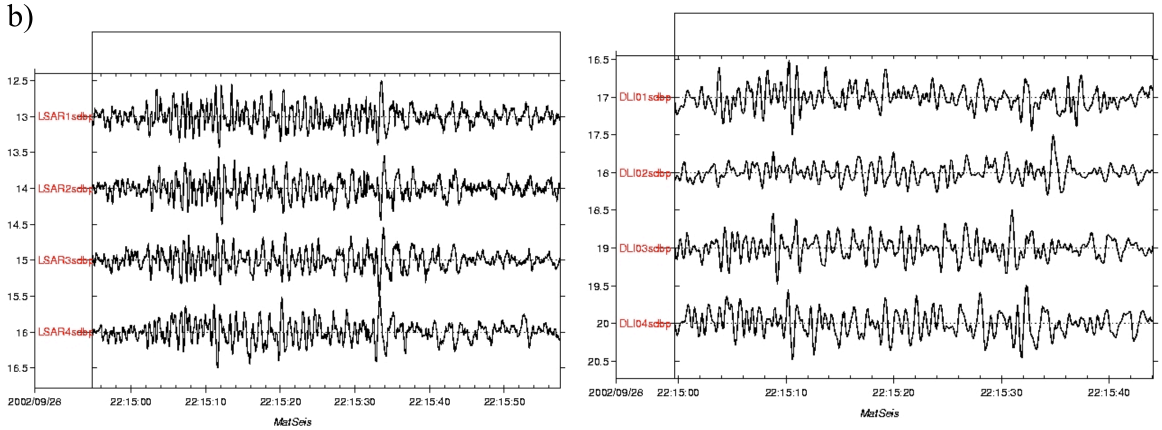


Figure 1. Waveforms (normalized amplitude versus time) are shown in a) above from the NTS array, left, and St George array, right. In b) we show waveforms for LSAR, left, and DLIAR, right. All plots are around the time of peak correlation.

Figure 2 shows the Watusi data for St. George and Los Alamos (squares) on the plot for the eight Defense Nuclear Agency (DNA) events. Here we plot the wind corrected amplitudes as a function of scaled range. The wind correction (or normalization) adjusts for the effects of atmospheric winds at 50 km (Mutschlecner et al. (1999)). Dr. Douglas Drob, Navel Research Laboratory (NRL), provided the wind profiles for the time of the event (Drob, 2003), and through the combination of observations and models gives a value of 12 m/s for the zonal wind at 50 km. This value gives normalized amplitudes at St. George and Los Alamos of 2.48 and 0.353 microbars. For scaled ranges we used two times the charge weight in kilotons raised to the 0.5 power.

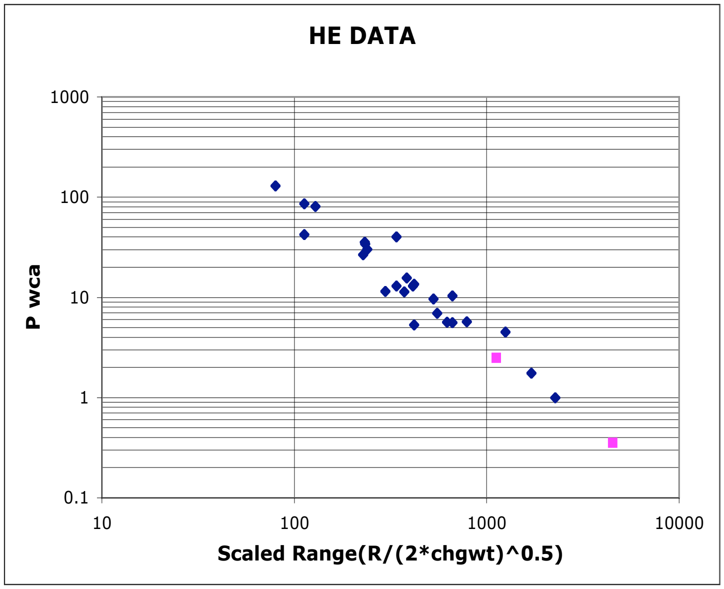


Figure 2. Wind corrected amplitude vs scaled range for USMR 9 (diamonds) and Watusi (squares) data.

The other events in Figure 2 (diamonds) are from a series of, then DNA, large-scale explosive tests at White Sands Missile Range (WSMR). There were eight tests from 1981 to 1993 ranging from 24–4,880 tons of ammonium nitrate and fuel oil (ANFO). The ranges of infrasonic measurements were from 250–5,300 km. The Watusi data are in good agreement with the Watusi data. We did not include NTS, as this station was close enough to the event to see different propagation paths. LSAR and DLIAR are collocated but LSAR uses a sampling rate of 20 sps, whereas DLIAR uses 10 sps. The LSAR sensors are the same type used in the earlier measurements, so we used the LSAR data in Figure 2. With the addition of the Watusi data, our relation now spans almost two orders of magnitude in scaled range. The least squares regression of the data yields:

$$P = 59457*(SR)^{-1.4072} \text{ with an } R^2 \text{ of } 0.93$$

In this relation, P is wind corrected amplitude and SR is scaled range.

Next we show results for some recent earthquake infrasound signals, which will also illustrate some of the newer features of the Matseis Infra_Tool (Figure 3). First is an earthquake from 10/16/1999, at 9:46:44 UT, with a magnitude of 7.0 located at 33.6˚ N and 116.27˚ W. The Infra_Tool plot given below shows correlation, trace velocity (km/s), azimuth (degrees), and a channel of raw or bandpassed data. In the current Infra_Tool, one can cycle through all the channels selected in the Matseis data window, switch between correlation and Fstat, change parameters of processing and do a quick update in Infra_Tool, and get standard deviations for the three plotted variables that fall within the vertical green averaging window. Features from earlier versions remain in the newest version.

This event shows a strong seismic surface-wave arrival, about 09:50 UT, before the main acoustic arrival, just after 10:30 UT. The surface wave amplitude is larger than the acoustic arrival amplitude, which is not always the case for infrasound data. Also we should note that the back azimuths from the acoustic signals for earthquakes might not always be on the epicenter as that may not be the region of greatest ground motion.

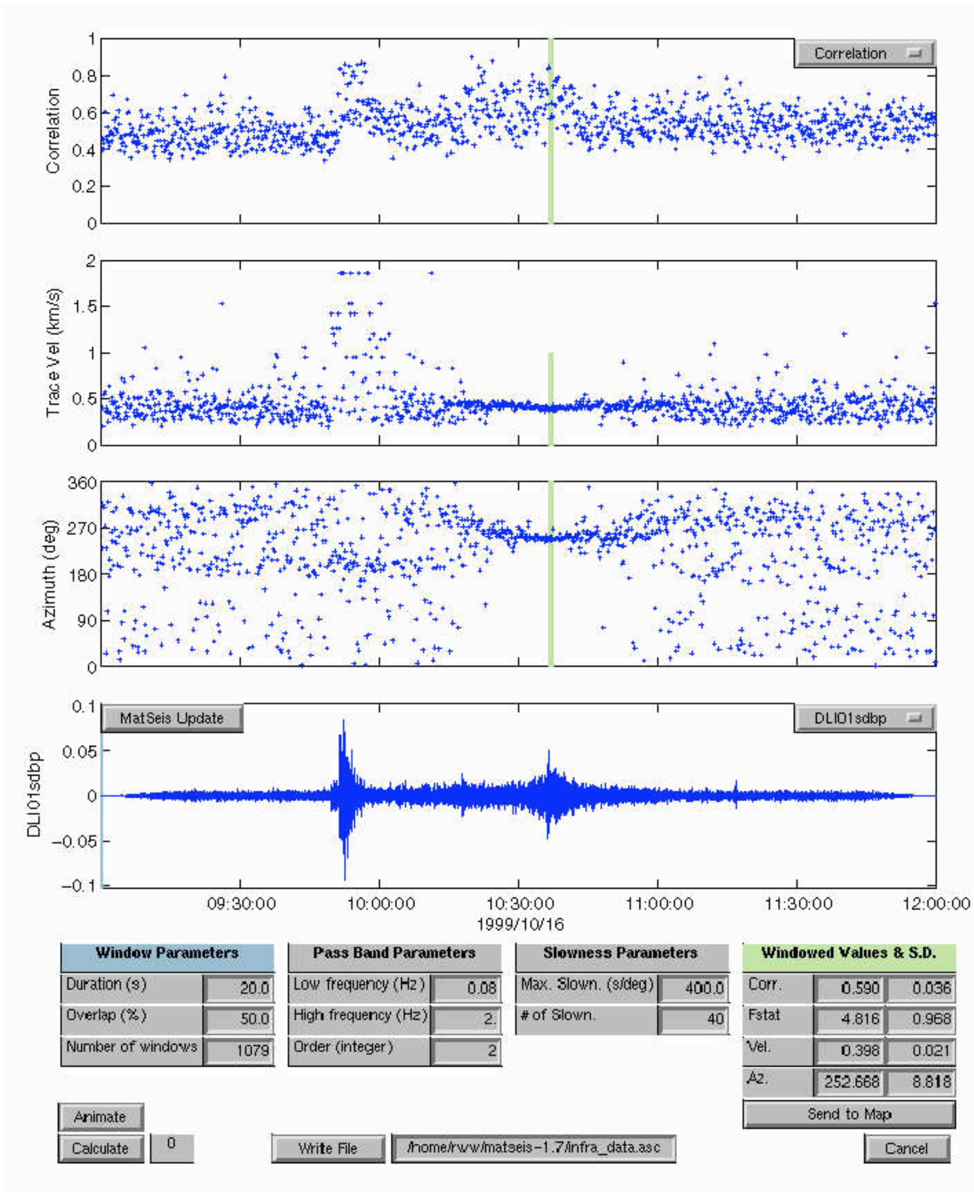


Figure 3. Infra_Tool analysis for the 10/16/1999 earthquake.

In Figure 4 we show selected results for the 11/03/2002 Alaska earthquake, which was a magnitude 8.5 event with epicenter of 63.52˚ N and 147.44˚ W at 22:12:41 UT. An impressive surface wave arrives at DLIAR (4,133 km distance) at 22:32 UT and lasts for over four minutes. The main acoustic arrival follows at 01:50 on 11/04. Figure 4 shows the raw channel data for the surface wave as recorded on DLIAR. The larger amplitude part of this signal has a peak Fstat over 2,500, in a band of 0.02—2.0 Hz.

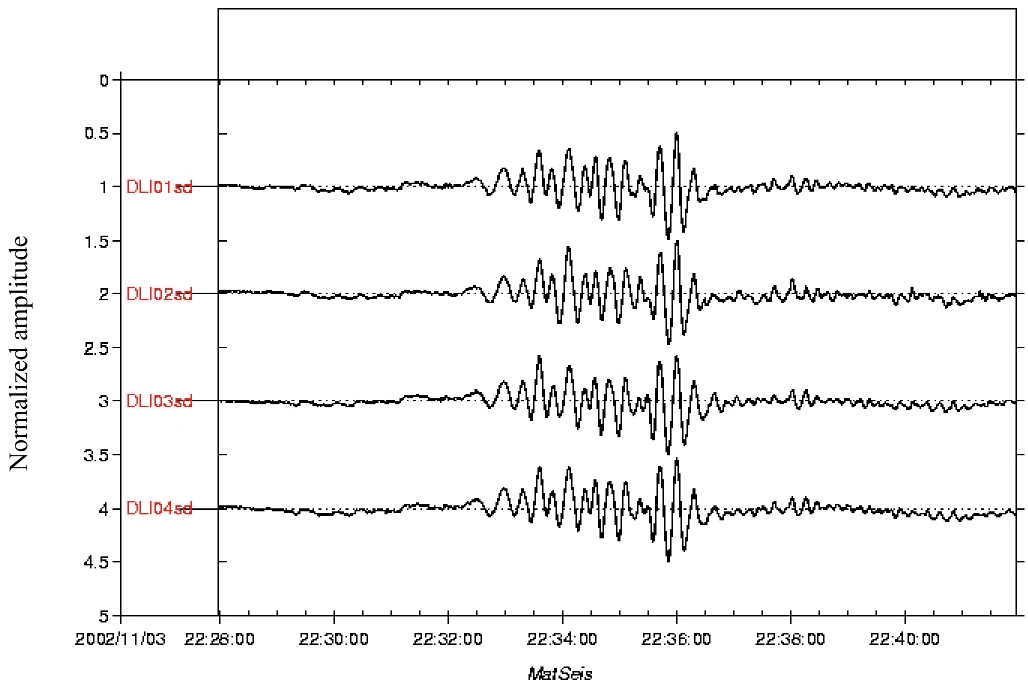
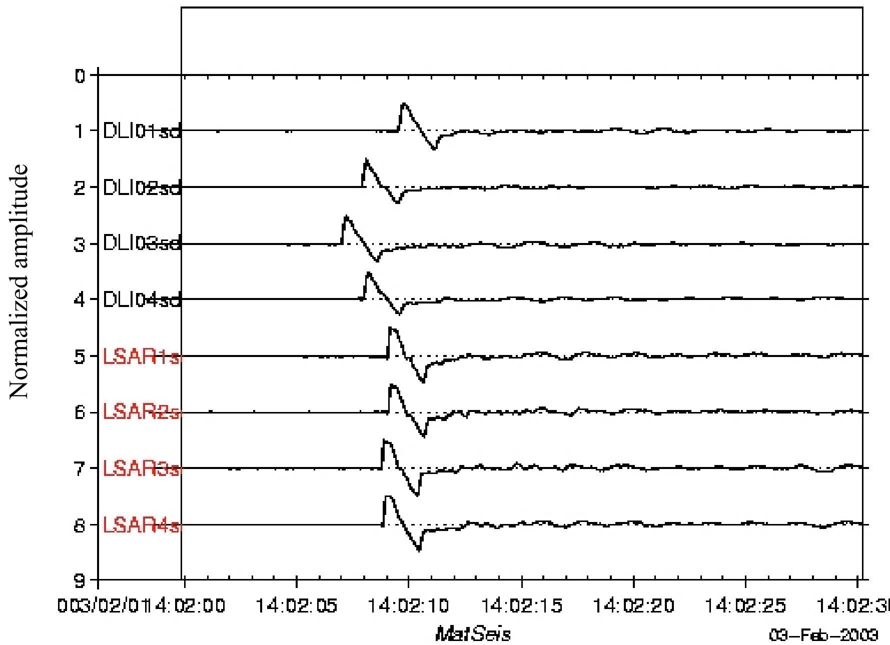


Figure 4. The seismic surface wave recorded at DLIAR for the 11/03/2002 earthquake.

Other recent efforts on earthquake analysis have concentrated on searching for signals from smaller regional events that might be detected by our arrays in the Southwest United States. In earlier Seismic Research Review (SRR) meetings, we have shown data from our earthquake detections, generally from events above magnitude 5.0. Now we are concentrating on events below 5.0. Our work is just beginning and we are not seeing as many of the lower magnitude events as we might have expected. Vertical ground motion is necessary to generate the infrasound signal, and smaller magnitude events may not have significant vertical motion. As we continue our analysis, we can begin to look at which events have some good ground motion data that may shed light on the source issues. In addition we can also approach this issue from a modeling perspective using a code that calculates the near-field acoustic signal from a source of ground motion by doing a numerical integration of the Rayleigh integral over the ground motion area. This approach could help bound expected near-field signal levels for different ground motion models. The modeling coupled with the observations should bring a better understanding of the infrasonic earthquake signal generation.

Several infrasound stations observed the tragic re-entry of space shuttle Columbia, STS 107, on 2/1/2003. LANL arrays were close to the ground track and obtained excellent data from the hypersonic shock wave and data from other parts of the trajectory. Such data illustrate the wide variety of man-made and geophysical signals that can be recorded by infrasound arrays. In Figure 5 (below) we show the raw channel plots of the N wave signals from the re-entry of the space shuttle, Columbia recorded on four LANL arrays: NTS, SGAR, DLIAR and LSAR.

a.



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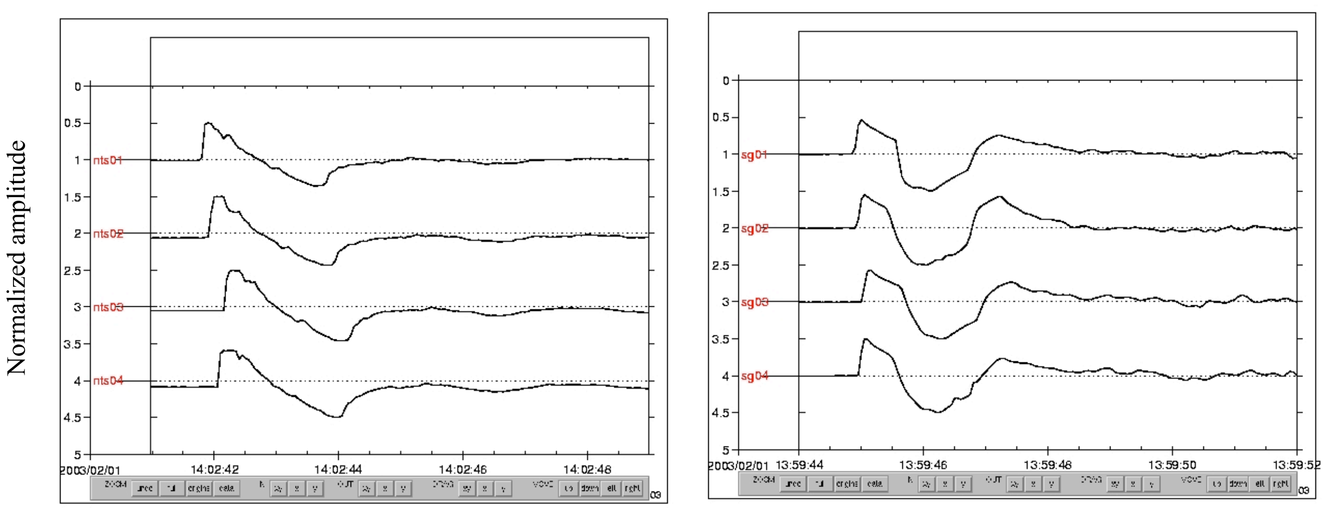

Figure 5. (a) N waves recorded by DLIAR and LSAR, (b) for NTS on the left and SG on the right.

The peak-to-peak amplitudes were: NTS 37.6, SG 36.9, DLIAR 94.4, and LSAR 93.3, all in microbars. While there is some structure in the post-peak N wave data, the cause of that structure probably is related to propagation effects.

Another event was the March 9, 2002, Pacific bolide recorded by several infrasound stations (Figure 6). There was an official announced position, 6.9 N and 147.3 W, with an energy estimate of about 1.1 kt. Figure 6 also shows results of analysis with Matseis for the International Monitoring Systems (IMS) stations I10CA, I57US, I59US, and the LANL array at St. George, UT. The plot gives the back azimuths from the Infra_Tool processing for each station and the announced rough location shown as the circle. No propagation corrections have been applied to the bearings.

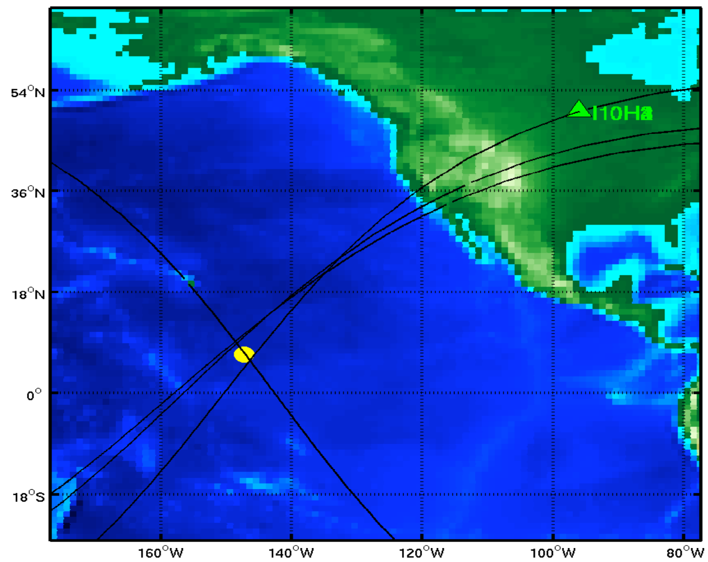

Figure 6. March 9, 2002, Pacific bolide recorded by several infrasound stations.

Figure 7 shows the results of a simple application of the new Matsies MS Locator Tool using just the I59US station and the NTS array. Normal Infra_Tool processing is done for each station getting back azimuths of 143.46 for I59US and 231.9 for NTS. We input average travel-time curves for stratospheric paths (constant velocity) and pick arrivals where the travel-time curves cross the waveforms. We defined time and azimuth location with sigmas of 30s in time and three degrees in azimuth (nominal rough values). The locator tool achieved a solution in four iterations. The four-pointed star is the announced position, and the circle is the iterated location. The back azimuths are the white lines, and the error ellipse is shown as well. This error ellipse is based on nominal estimates for the uncertainty in time and azimuth. The MS Locator Tool uses the same algorithm as used in LocSat but is a stand alone dot M file, avoiding platform dependent LibLoc problems.

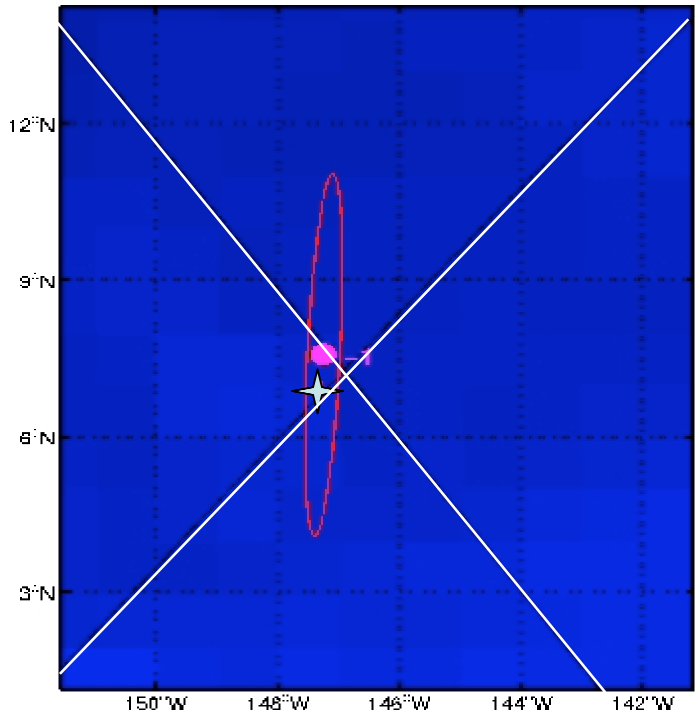

Figure 7. MS Locator Tool results for the 3/9/02 Pacific bolide.

CONCLUSIONS AND RECOMMENDATIONS

We have shown interesting results for recent events. The overall agreement of the Watusi measurements with the earlier tests at WSMR is quite impressive and pleasing. New features have been added to Infra_Tool enhancing its functionality. The new location software in Matseis was exercised using travel times and azimuths for two stations; however, more could be added. The main point is that this is all working well.

ACKNOWLEDGEMENTS

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REFERENCES

Drob, Douglas (2003), personal communication.

Mutschlecner, J.P., R.W. Whitaker and L.H. Auer, (1999), An Empirical Study of Infrasonic Propagation, LA-13620-MS, Los Alamos National Laboratory.