Nevada Bureau of Mines and Geology Special Publication 36

# Infrasonic Observations from the February 21, 2008 Wells Earthquake

*by*

Relu Burlacu[1], Stephen Arrowsmith[2], Chris Hayward[3],Brian Stump[3],
[1] University of Utah Seismograph Stations, [2] Las Alamos National Laboratory
[3] Department of Geological Sciences, Southern Methodist University

2011

## ABSTRACT

Infrasonic signals from the February 21, 2008 Wells earthquake were observed at five infrasonic arrays in Nevada, Utah and Wyoming. The records include acoustic signals generated in the epicentral area that propagated through the atmosphere to the arrays and signals generated by ground motion at the infrasonic array (local infrasound) that coupled into atmosphere close to the array (before reaching the arrays these waves propagated as seismic waves). There are also observations that we associate with infrasonic signals generated by secondary sources—regions that can be remote from the epicenter.

## INTRODUCTION

Infrasonic signals, that correspond to acoustic energy at frequencies below the audibility range of the human ear (about 20 Hz), can be generated by avalanches, meteors, ocean waves, weather systems, volcanoes, explosions, earthquakes, and communication between animals (Bedard and Georges, 2000). Low frequency infrasound (<5Hz) propagates efficiently and can be detected at large distances (>300 km). Sound velocity, a function of altitude dependent temperature and wind distribution, controls where the upward radiated acoustic energy turns downward in the atmosphere and reaches the stations on the ground. Measuring infrasound using arrays of sensors allows for the estimation of phase velocity and the direction (backazimuth) of the signal wavefront and separation of signals from local noise source. Infrasound is one of the technologies used to monitor nuclear explosions, especially those in the atmosphere, using infrasonic arrays installed as part of the International Monitoring System (http://ctbto.org).

Several studies document infrasound generated by medium to large earthquakes (Cook, 1971; Kim and others, 2004; Mutschlecner and Whitaker, 2005; Le Pichon and others, 2006) and describe three possible mechanisms to explain this process: (1) conversion of surface ground motions to sound pressure in the epicentral area and propagation through atmosphere to the infrasound recording stations (also known as epicentral infrasound); (2) induced pressure changes due to vertical ground displacement of the seismic waves that travelled from the epicentral area and coupled acoustically near the infrasound recording station (local infrasound); (3) radiated pressure waves as a result of the interaction of seismic surface waves with mountain ranges (diffracted infrasound). For some infrasound sensors, the local infrasound can be in part contaminated by the response of the microbarometer (sensor) to ground motion (Alcoverro and others 2005; Le Pichon and others, 2006). The sensors used in this study are relatively insensitive to ground motion and thus minimize this problem.

Understanding how earthquakes generate infrasound—including the effects of magnitude, depth, source mechanism—is an active area of research. Most studies documenting earthquake generated infrasound are based on the analysis of very large earthquakes (Le Pichon and others, 2002, Kim and others, 2004, Le Pichon and others, 2006). The Wells earthquake is an interesting case because it is a moderate to strong earthquake that was recorded regionally by multiple arrays, providing a good opportunity to advance our understanding of the mechanism by which earthquakes generate infrasound. The recordings of the Wells earthquake at five infrasonic arrays in Nevada, Utah and Wyoming allow us to estimate phase velocity and back-azimuth values using array processing techniques and to use this information in a location exercise based on infrasound data only.

On February 21, 2008 at 14:16:02 UTC an earthquake of magnitude $M_W$ 6.0, epicentral coordinates 41.153°N, 114.867°W, depth 6.7 km [University of Nevada, Reno (UNR) solution on the U.S. Geological Survey website, http://earthquake.usgs.gov/ eqcenter/eqinthenews/2008/us2008nsa9/], with a focal mechanism indicating normal faulting, occurred in the proximity of Wells, Nevada. The earthquake was felt in Nevada, Utah, California, Idaho, Montana, Wyoming, Arizona, Oregon, and Washington. More than 3100 entries in more than 300 ZIP areas were reported on the "Did You Feel It" website (http://pasadena.wr.usgs.gov/shake/STORE/X2008nsa9/ciim_display.html).

This event was very well recorded by many seismic stations, including the EarthScope TA stations, and was also recorded by three infrasonic arrays in Utah (BGU, EPU, NOQ), one in Nevada (NVIAR), and one in Wyoming (PDIAR). Figure 1 shows the map with the UNR location of the Wells event (red star) and the five infrasonic arrays. Also shown is the infrasound location polygon (red lines) resulting from the application of a grid-search location scheme implemented in the InfraMonitor software package (Arrowsmith and others, 2008).

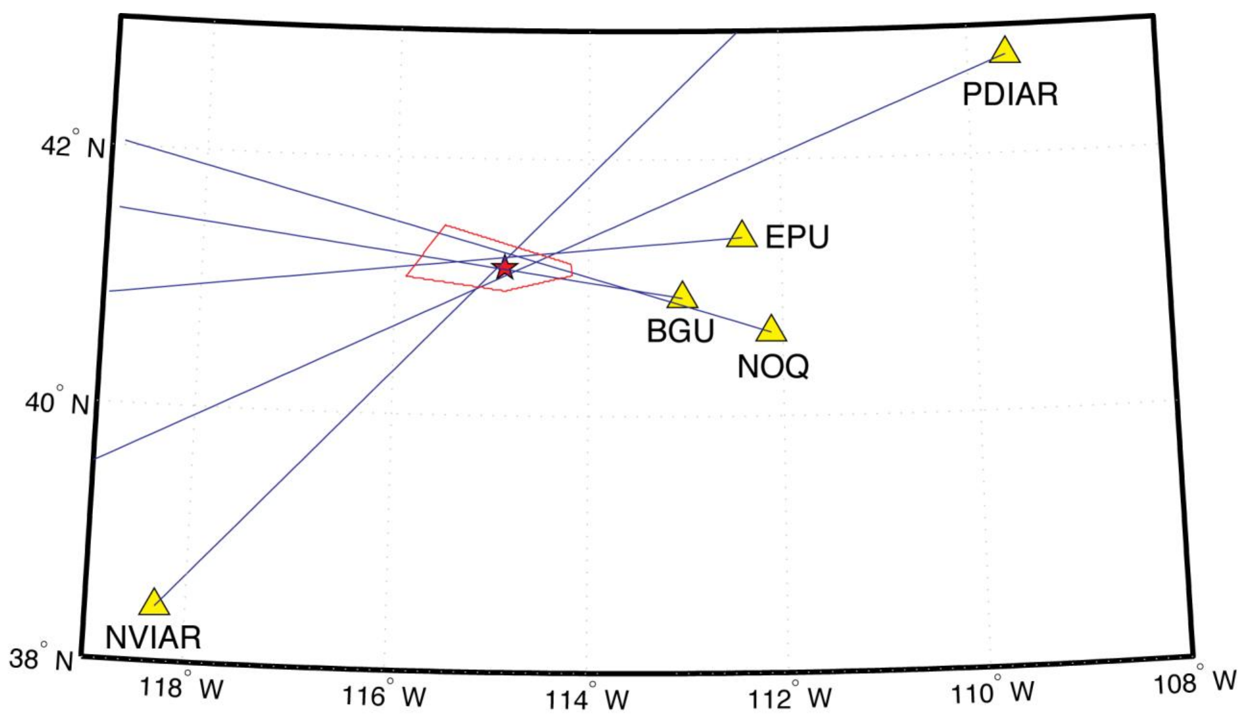


**Figure 1.** Location map of the Wells epicenter (red star) and the five infrasonic arrays (yellow triangles) in Nevada (NVIAR), Utah (BGU, EPU, NOQ) and Wyoming (PDIAR). Also shown is the location polygon (red line) resulting from the grid-search location scheme implemented in InfraMonitor.

## THE UTAH INFRASONIC ARRAYS

The University of Utah Seismograph Station (UUSS) has integrated three infrasonic arrays into its regional seismic network. The infrasound integration was related to an experiment conducted during the summer of 2007 in order to measure seismo-acoustic signals associated with the rocket motor detonations in northern Utah (Stump and others, 2007). The infrasonic arrays, co-located with UUSS-operated seismic stations BGU, EPU, and NOQ, record continuous data. Each array consists of four infrasound gauges with 3 gauges on a triangle about 100 m on a side plus one in the center of the triangle. To reduce wind noise, the infrasound sensors are attached to a set of porous hoses.

The array design (geometry of the sensor distribution, distance between sensors) allows for signal enhancement through beam-forming of the coherent signals from individual sensors. Array processing techniques take advantage of the coherent signals to estimate phase velocity and back-azimuth values for the signals of interest. An important source of inherent noise for the infrasound sensors is wind and this noise increases with wind velocity (Stump and others, 2004).

Data from all three arrays are telemetered in real-time to UUSS, at the University of Utah, in Salt Lake City. Table 1 presents the characteristics of the Utah infrasonic arrays.

**Table 1.** Characteristics of the infrasonic arrays installed in Utah

| Characteristics | NOQ array | BGU array | EPU array |
|---|---|---|---|
| **Number of elements** | 4 | 4 | 4 |
| **Sensor type** | Chaparral 2 | Chaparral 2 | Chaparral 2.5 |
| **Digitizer** | REF TEK 130 | REF TEK 130 | REF TEK 130 |
| **Real-time telemetry** | Yes | Yes | Yes |
| **Average distance between sensors (m)** | 118 | 115 | 119 |
| **Installation date** | May 4, 2006 | April 17, 2007 | July 13, 2007 |
| **Co-located seismic station type** | Broadband (BB) | Broadband (BB) | Short Period (SP) |
| **Start date of the archived data** | May 4, 2006<br>IRIS DMC | April 17, 2007<br>UUSS | July 13, 2007<br>UUSS |

## INFRASONIC OBSERVATIONS

Using the UNR location for the Wells main event, the great circle distance between the epicenter and the four arrays is estimated between about 160 km and about 470 km, with azimuths between about 65° and about 100°. Table 2 displays the information related to distance, azimuth, and back-azimuth values from the earthquake to the five infrasonic arrays. The waveforms recorded at the four infrasonic arrays (band-pass filtered between 1 and 5 Hz), shown in figure 2, have durations from 15-18 min for BGU, EPU, and NOQ to about 30 min for NVIAR and PDIAR. The main characteristics of the waveforms from the five arrays are: (1) the presence of signals corresponding to P and S arrivals—they are the result of the coupling-to-air of the seismic waves that traveled to the vicinity of the infrasonic stations (local infrasound); (2) the presence of signals corresponding to a secondary source of infrasound between the source and receiver; and (3) the epicentral infrasound (acoustic energy that was generated by the ground motion at the epicenter and traveled through the atmosphere to the arrays at air sound speed). Due to large differences between seismic and air sound speed, the epicentral infrasound arrives at the stations well after the local infrasound. Table 3 presents the amplitude measurements (in Pa) for the three Utah arrays (waveforms filtered between 1 and 5 Hz) for local infrasound from both P and S waves and epicentral infrasound.

**Table 2.** Distance, azimuth, and backazimuth values from the earthquake to one element of the infrasonic arrays.

| Array | Dist (km) | Az (deg) | Baz (deg) |
|---|---|---|---|
| BGU | 157 | 99 | 280 |
| EPU | 208 | 82 | 264 |
| NOQ | 238 | 103 | 284 |
| NVIAR | 422 | 225 | 43 |
| PDIAR | 472 | 66 | 250 |

Figure 3 compares the acoustic signal recorded at one of the sensors of the arrays BGU, EPU, and NOQ (blue traces) with the seismic signal recorded on the vertical component of a co-located seismic station (red traces). BGU and NOQ are equipped with broadband instruments, while EPU is a short-period seismic station. Waveforms from seismic and infrasound sensors were band-pass filtered between 1 and 5 Hz. P and S waveforms for the main event and the aftershock that occurred at 14:21 (M 4.7) are evident on the seismic records at BGU, EPU, and NOQ. The waveforms recorded at the infrasonic arrays exhibit more complex features (local and epicentral infrasounds from the main event are observed on all the arrays).

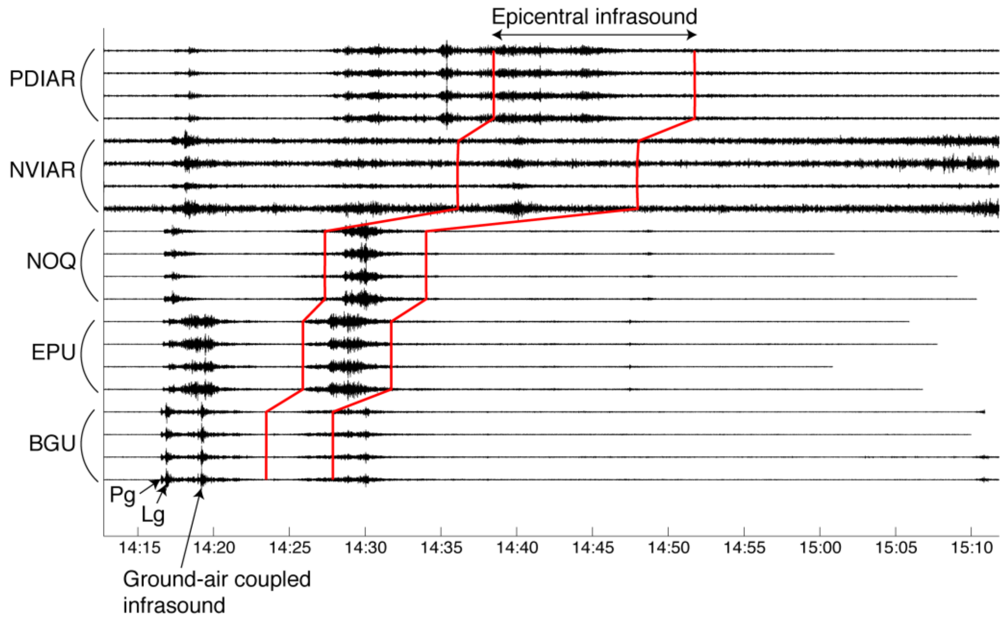


**Figure 2.** Waveforms recorded at the five infrasonic arrays. Data were filtered between 1 and 5 Hz. Note the presence of the P and S groups (local infrasound), ground-air coupled infrasound between the source and receiver, and the epicentral infrasound time windows defined by red vertical lines.

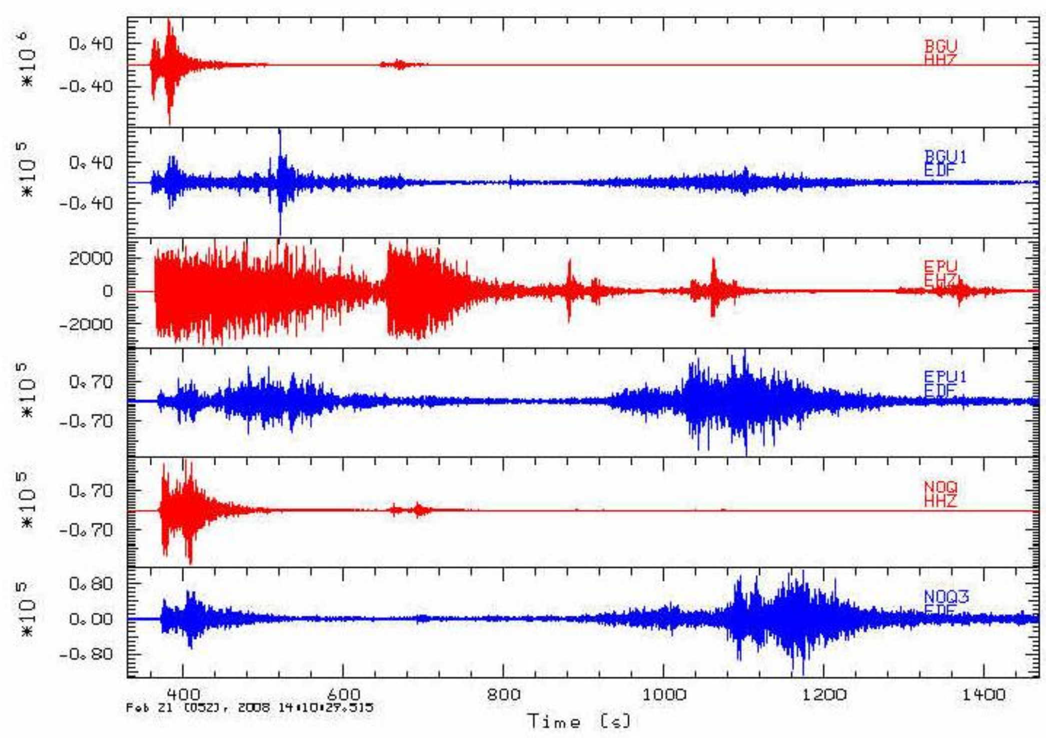


**Figure 3.** Comparison between the infrasound (blue) and seismic (red) waveforms recorded at BGU, EPU, and NOQ. The seismic stations BGU and NOQ have broadband instruments, and EPU is a short-period seismic station. The amplitude scales are different and the seismic signal at EPU is clipped. Seismic and infrasound data were band-pass filtered between 1 and 5 Hz. P and S waveforms for the main event and the aftershock that occurred at 14:21 are evident on the seismic records at BGU, NOQ, and EPU. The infrasound waveforms recorded at the infrasonic arrays exhibit more complex features (local and epicentral infrasound from the main event are observed for all the arrays). This figure was generated using GSAC, part of the Computer Programs in Seismology by R. B. Herrmann (http://www.eas.slu.edu/People/RBHerrmann/CPC330.html).

To understand the infrasound signal character, we used the software programs PMCC (Cansi, 1995), InfraTool (MatSeis, Hart and Young, 2005), and InfraMonitor (Arrowsmith and others, 2008). These software programs use array processing techniques to estimate the phase velocity and the back azimuth of coherent signals. InfraMonitor uses a coherent detector with an adaptive noise hypothesis to account for variations in ambient noise (Arrowsmith and others, 2009). Using the bulletin data generated by the coherent detector, the InfraMonitor software package searches a geographic region (using a grid-search algorithm) to locate the source based on estimated back azimuths and inter-array delay times. The location of the Wells event using epicentral arrivals only (with corresponding uncertainties) is represented in figure 1 by the outlined area in red.

Results from the preliminary analysis of the waveforms recorded at the BGU infrasonic array, using InfraTool (Hart and Young, 2005) are shown in figure 4. The panels in figure 4 present, from top to bottom, results of correlation, trace velocity, azimuth, and the waveforms of one of the BGU sensors. The phase velocity and azimuth estimates for the epicentral infrasound (well correlated waveforms from14:25 to 14:30) are 370 m/s and 281°, respectively. The azimuth value is in good agreement with the great circle back azimuth of 280° (table 2). This agreement suggests that the observed signal originated in the epicentral area (conversion from seismic waves to sound pressure) and traveled through the atmosphere to BGU, following a path along the great circle between the epicenter and the recording station. The long duration of the epicentral infrasound can be attributed to the complexity of the propagation paths, including possible refractions at different atmospheric heights and multiple bounces of the acoustic energy on the ground surface.

Two interesting signals identified on the records at BGU occur at approximately 14:19 and 14:24 and are presented in figure 5. This figure shows the results of beamforming using the PMCC software (Cansi, 1995) for the signals at approximately 14:19 (top) and 14:24 (bottom). They have similar waveform characteristics, a phase velocity of approximately 350 m/s, an azimuth of approximately 265°, and dominant frequency of 3 Hz. The good correlation of the two signals (the delays that resulted from the beamforming process are very similar) and the fact that the maximum amplitude for the first signal (approximately 14:19) has a corresponding travel time (with respect to the $M_W$ 6.0 event) equal to the one of the maximum amplitude of the second signal (approximately 14:24) relative to the origin time of the aftershock at approximately 14:21, suggest that: (1) the two signals are related to two different events (mainshock and aftershock), and (2) they seem to share a similar mechanism. For each event, the group velocities associated with the arrivals at approximately 14:19 and 14:24 are too slow to be pure-seismic and too fast to be pure-acoustic signals. A possible interpretation of this mechanism is that the seismic surface waves from the mainshock (or the aftershock) traveled from the epicenter to an area where they coupled to the atmosphere and generated pressure waves that arrived at the station traveling through the atmosphere along an azimuth (265°) different from the station-event azimuth (280°). Based on the arrival azimuths (and the associated uncertainties) and the travel times, this coupling location may correspond to the Floating Island, an isolated mountain, northeast of the area of Bonneville Salt Flats State Park, in the western Great Salt Lake Desert, Utah. If this model is correct, the area where the coupling occurred acts as a secondary source (the approximate location of the Floating Island is 40.915° N, 113.638° W). A detailed analysis of these signals will be presented in a forthcoming paper. The interaction of the seismic surface waves from earthquakes with topographic features, acting as secondary sources of acoustic energy, is often described as a diffraction process (Le Pichon and others, 2002; Mutschlecner and Whitaker, 2005).

## CONCLUSIONS

Infrasonic observations from the Wells earthquake were recorded at five infrasonic arrays in Nevada, Utah and Wyoming. A preliminary analysis of the waveforms recorded at the infrasonic array BGU indicates the presence of local and epicentral infrasound, as well as infrasound generated by a secondary source. The Wells earthquake presents an interesting case study that can improve our understanding of how earthquakes generate infrasound. To make this improvement, detailed studies that relate the seismic wave field to infrasound are needed. Also, modeling studies are necessary to better identify the source of different infrasonic signals recorded by the five arrays.

## ACKNOWLEDGMENTS

We thank Kris Pankow and Jim Pechmann for insightful discussions. Contract FA8718-05-C-0020, Air Force Research Laboratory, has supported the array deployments at BGU, EPU, and NOQ.

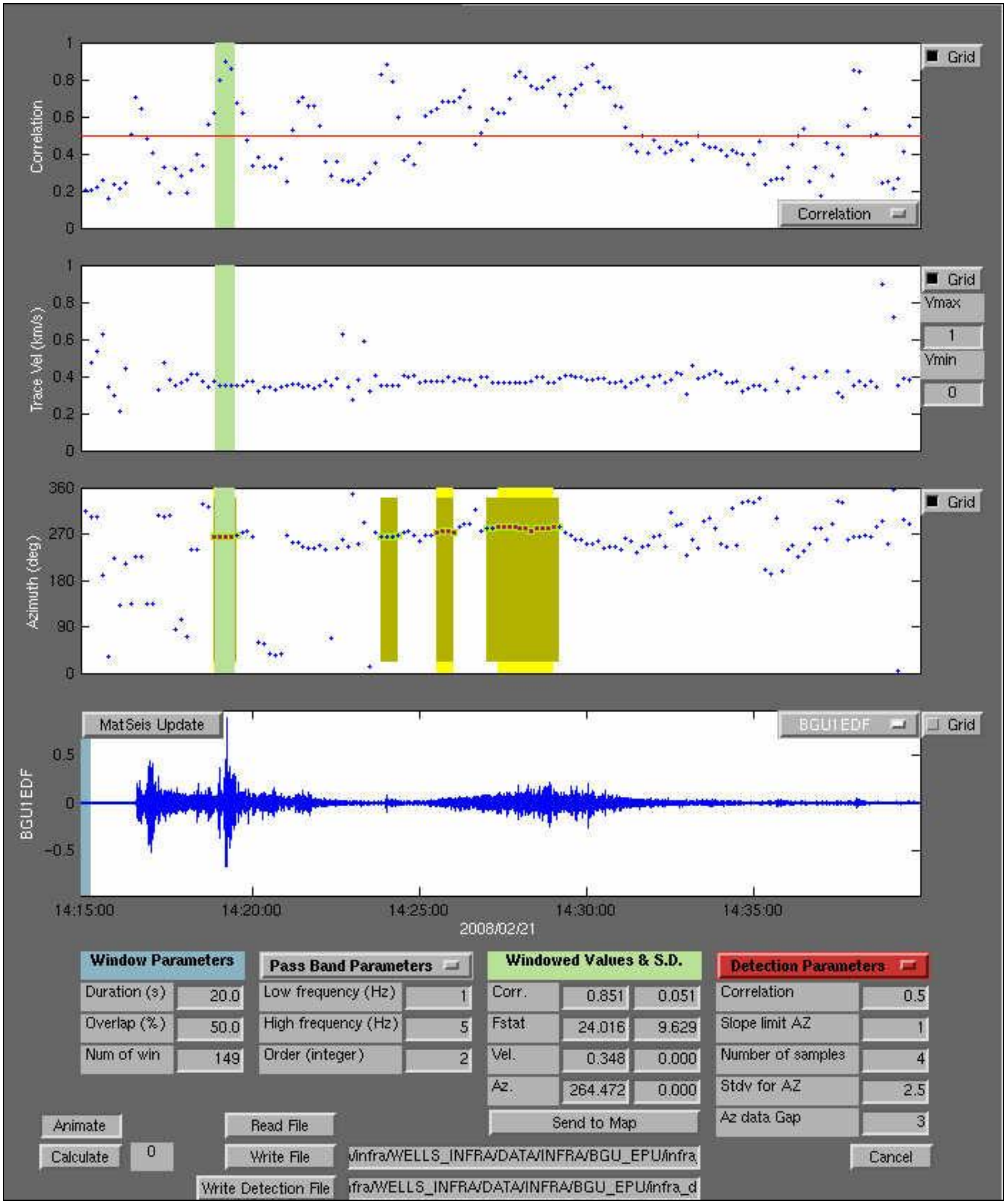


**Figure 4.** Analysis of the infrasonic signals recorded at BGU array using Infra Tool. From top to bottom, the panels represent the correlation, the phase velocity, the azimuth, and the waveforms at one of the array elements. The vertical lines indicate detections of correlated waveforms**.**

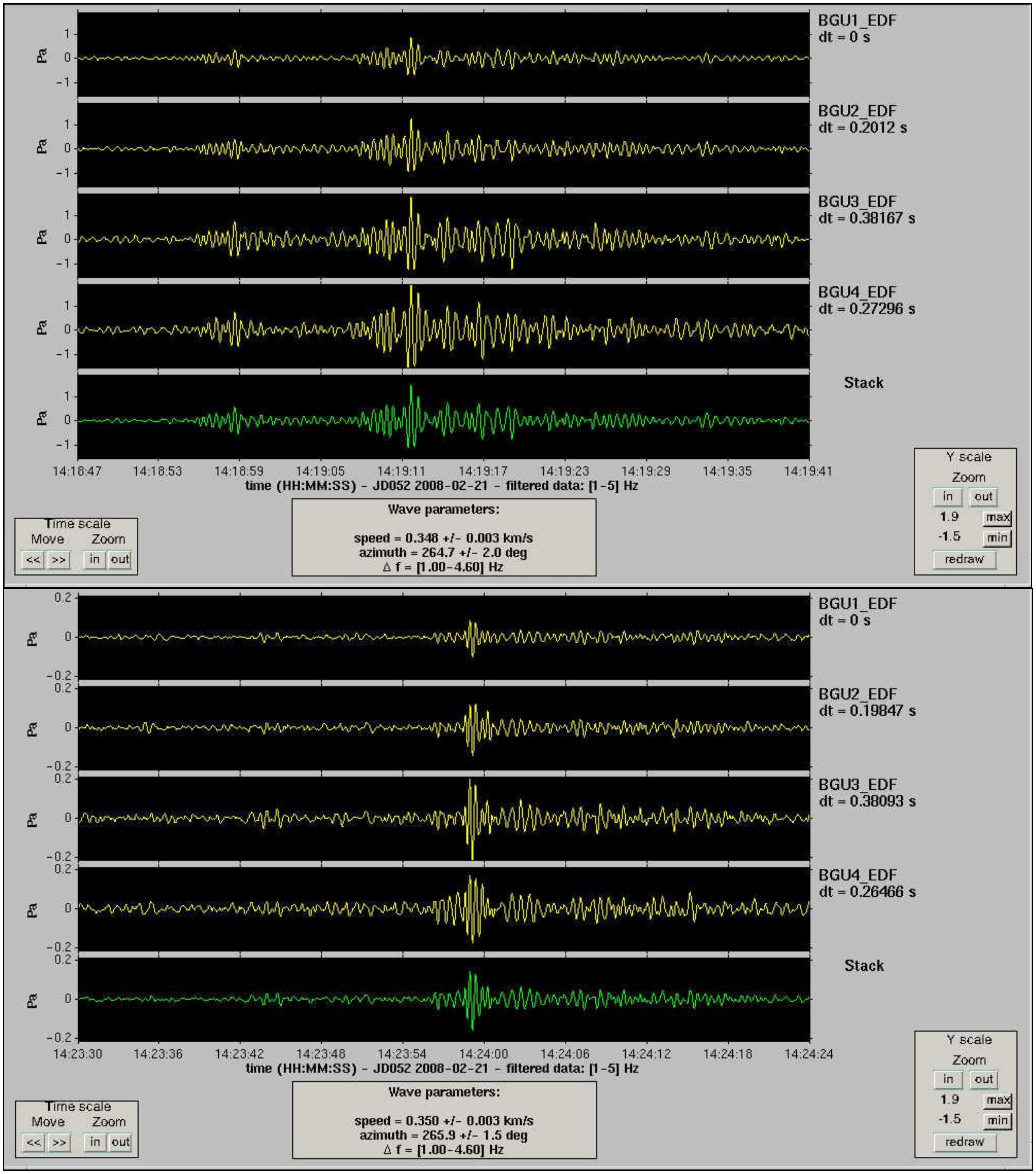


**Figure 5.** Beamforming results from PMCC for the signals at approximately 14:19 (top) and approximately 14:24 (bottom) recorded at the BGU array. The two signals are very similar and may represent acoustic energy from the mainshock and the 14:21 aftershock that resulted from coupling of the ground motion into the air in an area between the epicenter and the array.

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