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INSTALLATION OF THE FT. HANCOCK, TX Seismo-Acoustic Array

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Western US Experiment
Installation Note

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Introduction

As part of the DTRA funded contract no. DSWA01-98-C-0176, the Department of Geological Sciences at Southern Methodist University is conducting local and regional seismic and acoustic experiments in the Western United States. Sources for the seismic and acoustic energy will be rock fragmentation explosions at the copper mines in eastern Arizona and western New Mexico.

Acoustic and seismic energy from explosions in eastern Arizona and western New Mexico copper mines are routinely detected at the seismic and acoustic array, TXAR, in West Texas (Figure 1) (Sorrels *et al.*, 1997) which is 600 to 700 km from the mines. These explosions provide an opportunity to study long distance seismic and acoustic propagation in the western US, to study the relationship between industrial mining practices and the characteristics of these waves, and to study the relation of near-source seismic energy to the design of the industrial blasts. Near-source instrumentation within the mine provides the opportunity for collaborative studies with mine engineers to study the relationship between near-source seismic signatures, fragmentation efficiency, and explosive charge. The design and installation of the near-source instrumentation has been described elsewhere (Hayward *et al.*, 2000; Thomason, 1999; Stump and Hayward, 2000) and is deployed at Morenci, AZ and Tyrone, NM as illustrated in Figure 1 (yellow stars).

This document describes the installation, characteristics and preliminary data associated with one of the small aperture seismo-acoustic stations deployed at regional distances from the copper mines. The station, Ft. Hancock, is 200 - 300 km from the mines in Southwest Texas (Figure 1). This location provides an opportunity to document the development of both the seismic and acoustic signals as they propagate towards TXAR.

The installation trip occurred on 14-17 August 2000. During the trip, the following tasks were completed;

- 11 August
    - Shipped equipment from Dallas.
- 14 August
    - Traveled Dallas to El Paso.
    - Picked up shipped station equipment.
    - Unpacked equipment in Ft. Hancock, TX.
    - Purchased materials for seismic vault installation.
- 15 August
    - Met with Paul Loeffler, Regional Manager/range Specialist Asset Inspections, Texas General Land Office. Described the array and the geographical needs.
    - Picked the final site for the installation.
    - Began the installation of one seismometer and three infrasound sensors along with the data acquisition system.

- Designed barb wire fence enclosures to protect instruments.
- Buried all cables.

- 16 August

  - Completed the fences around the data acquisition system and seismometer and three acoustic installations.
  - Began data acquisition.

- 17 August

  - Checked array operation.
  - Returned to Dallas.

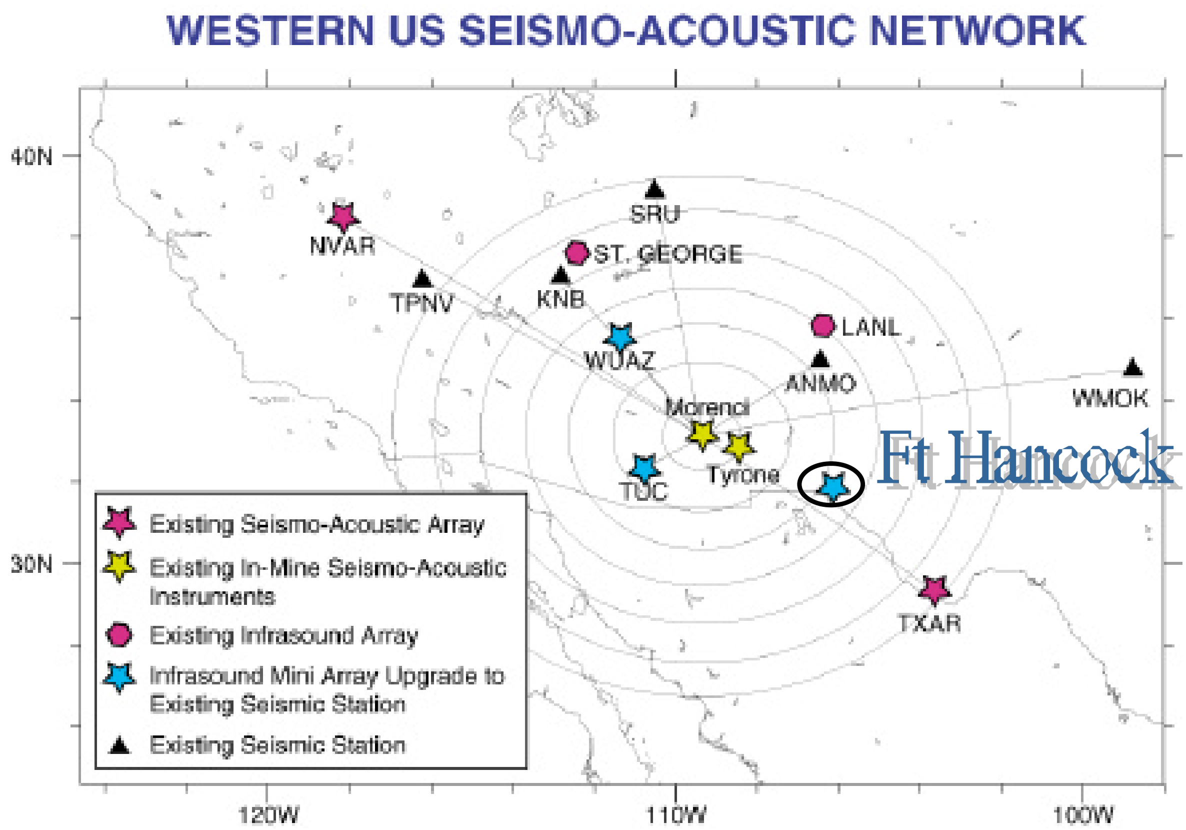

Figure 1. Map illustrating the existing and proposed stations that will make up the Western US seismo-acoustic network. The station installation described in this document is called Ft. Hancock and highlighted with a circle in the accompanying figure .

The array was designed to be compact and easily shipped. The complete set of equipment was air freighted from Dallas to El Paso where it was loaded into a single, light duty pick up for transportation to the site. Figure 2 illustrates the complete array as it was initially packed in the truck prior to deployment.

The array consists of three infrasound elements in a triangular pattern. A vertical seismometer is deployed at the center of the triangle along with the data acquisition system. Power is supplied by batteries that are charged by a solar panel providing autonomous operation.

Figure 2: Complete set of equipment necessary for installing the seismo-acoustic array at Ft. Hancock, Texas.

Site Location and Characteristics

The Ft. Hancock seismo-acoustic installation can be reached by traveling along Interstate 10, 55 miles to the southeast of El Paso, Texas to the town of Ft. Hancock, Texas (Figure 3a). From Ft. Hancock, one has to travel an additional 15 km to the northeast to the array (Figure 3b).

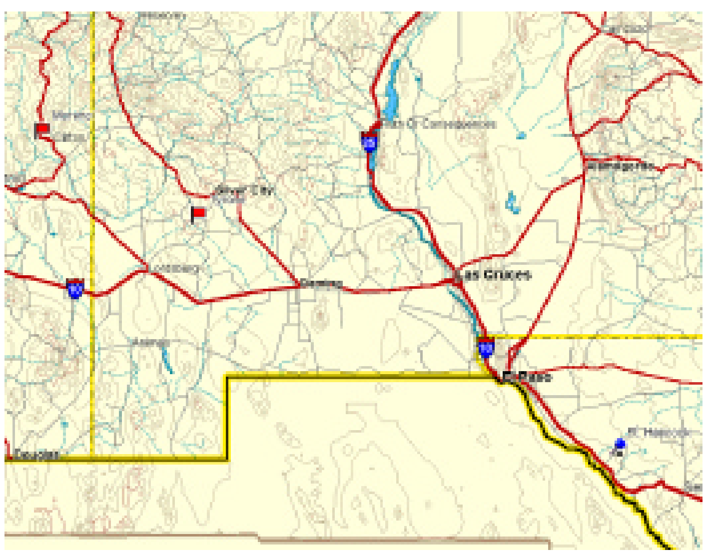

Figure 3a: Map illustrating the location of the Ft. Hancock array(blue push pin) relative to the cities of El Paso and Ft. Hancock. The mines at Morenci and Tyrone where ground truth information is obtained are also pictured (red flags).

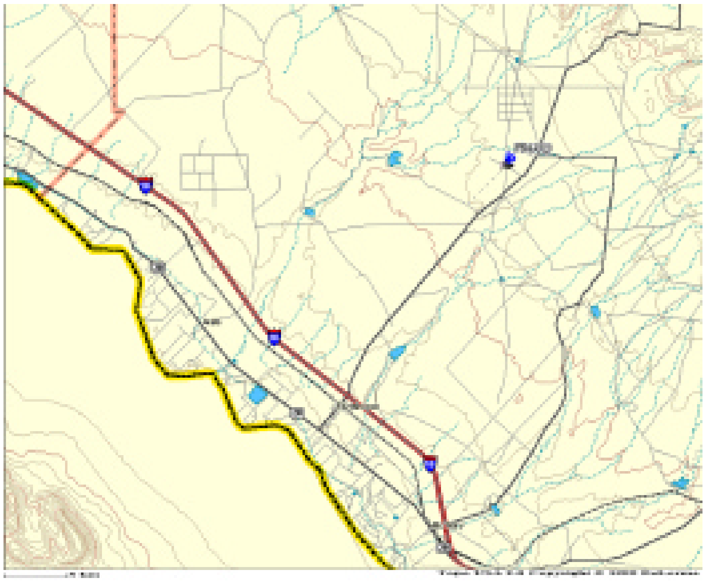

Figure 3b: The (blue push pin) is located 15 km northeast of the city of Ft. Hancock.

The site is northeast of Interstate 10 on the Campo Grande Ranch which is managed by the Texas General Land Office. The roads are all dirt and vehicular traffic in the area is limited. The area is used for grazing of cattle.

The seismo-acoustic array consists of three, outlying acoustic array elements in a triangular pattern with the center of the triangle occupied by the seismic vault and data acquisition system. The array element locations are listed in Table 1 with FTHAN0 being the location of the seismometer. The detailed map of the station locations is given in Figure 4.

Station Name	Latitude (N)	Longitude (W)
FTHAN0	31.40289°	105. 75791°
FTHAN1	31.40271°	105.75688°
FTHAN2	31.40211°	105.75842°
FTHAN3	31.40211°	105.75842°

Table 1. Latitude and Longitude of the stations in the seismo-acoustic array at Ft. Hancock. FTHAN0 is a seismometer while all other sites are acoustic gages.

The separation of the outside elements of the array where the acoustic gages are located ranges from 150 to 170 m as illustrated in Figure 4. The site was chosen to provide some distance from the road while maintaining accessibility. The final location was chosen to avoid possible run off during rare rain events in the area. There is a meteorological site that is used occasionally by the University of Texas, El Paso at the point where the road in Figure 4 makes its closest approach to array element FTHAN2. Despite the close proximity to the road, it is difficult to spot the array elements without walking into the desert area.

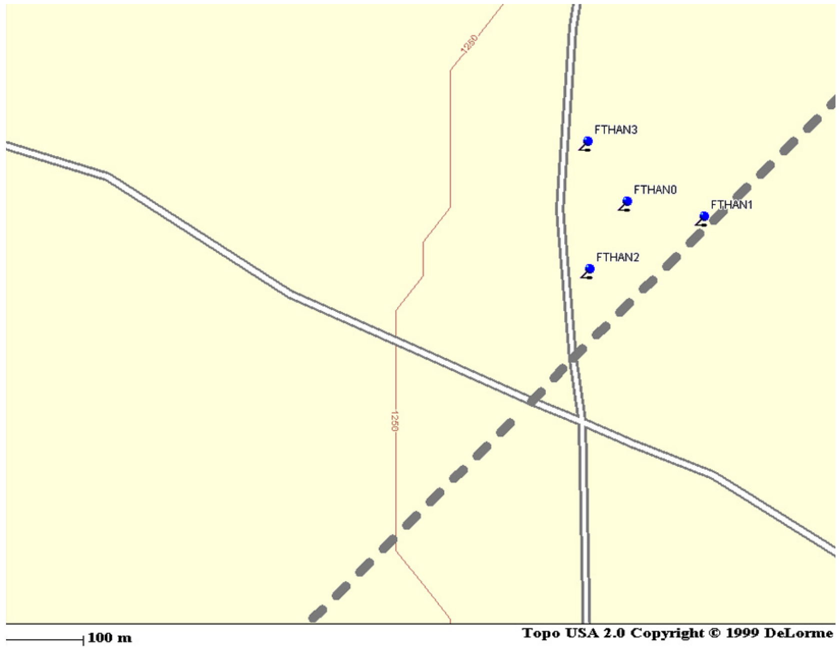

Figure 4:Detailed map illustrating the location of the array elements.

There is little topography at the site as illustrated in the panoramic view from the center of the array (Figure 5). The shallow sub-surface material is a sandy soil. The area has numerous mesquite bushes with spatial separations of 1-3 m and heights of 1 m or above.

Figure 5: Panorama of the Ft. Hancock seismo-acoustic site. The relative flat topographic, sandy soil and modest vegetation is illustrated.

Instrumentation

The central element of the array consists of the instrument enclosure that includes the digitizer, disk and battery. A solar panel is mounted on the instrument enclosure and maintains the battery. A seismic vault which houses a single, vertical GS-13 is placed approximately 2 m from the equipment enclosure (Figure 6).

A Refraction Technology 72A-06 digitizer was deployed with a 4 Gbyte disk for data archival. The data is continuously sampled at 40 samples per second for the three infrasound channels as well as the seismic channel. Preamp gains were set at 1 for the infrasound channels and 32 for the seismic channel based upon background noise levels observed at the site. The installation is intended to be operated unattended with an exchange of disks on a 6 week to 2-month time schedule. There is no modem access to the data logger.

Figure 6: The equipment enclosure that houses the digitizer (Ref-Tek 72A-06), disk and battery is shown to the left. The solar panel is mounted on the opposite side of the enclosure and the seismic vault (blue) is located about 2 m from the enclosure (right)

As illustrated in Figure 6, the equipment is designed to be easily installed with a minimum of environmental impact. Cinder blocks are used to anchor the enclosures to the ground and protect the system from winds. Installation of the seismic vault is documented in Figure 7. A 1m hole was dug with a cement pad placed at the bottom of the hole for the GS-13. An enclosure was then placed over the seismometer to isolate it from the weather and disturbance from animals.

Figure 7: Installation of the vertical, GS-13 seismometer at the central array element, FTHAN0. The seismometer is being leveled on a cement slab at the bottom of the hole prior to installation of the blue protective cap.

Each element of the tripartite infrasound array consists of a surface array of ten, 25 foot porous hoses that connect through a manifold to a Chaparral Model 2 microphone modified for 12 volt operation (Hayward, 2000). The surface array of porous hoses and the summing manifold are pictured in Figure 8. The Chaparral Model 2 microphone was placed subsurface and covered with a concrete plate for temperature stabilization. The 12-volt power for the microphones was supplied from the central hub along cables that were trenched into the ground to avoid animal disturbance. Intermediate size vegetation (~ 1 m height) at the site in the form of mesquite bushes provided some wind protection for the hose array.

Concern over disturbance of the hub and infrasound array elements by animals moving across the range land motivated the construction of barbed wire fences around the central hub and each of the infrasound sites. Figure 9 illustrates the installation of one of these fences. The barbed wire fence could be used to support small wind fences around each infrasound site for little additional cost. Such an installation will depend upon the analysis of the wind noise data from the site.


Figure 8: The infrasound gage is connected to ten, 25-foot porous hoses for purposes of wind noise reduction. The radial distribution of the hoses at one of the array sites is pictured to the left. The manifold, which connects the hoses to the acoustic gage (buried and covered by a concrete plate), is shown to the right.

Figure 9: Barbed wire fences were erected around each of the hose arrays and the central site in order to protect the instruments from intrusion.

No wind speed or direction information is currently being acquired at the site. The recording system has two additional data acquisition channels that could be employed for this purpose. An additional fourth acoustic site could also be added at the hub if necessary.

Preliminary Data

Data from the initial 8-week time period (Julian Day 229-285) was recovered for purposes of assessing the array installation. As noted earlier, the array is operated in an unattended mode with data recorded to disk. These disks are routinely recovered and the data analyzed. Data recovery during this initial time period was nearly 100 percent. Some examples of data are included in this report to illustrate the range of signals that are being captured by the array.

Example of noise segments from acoustic and seismic channels.

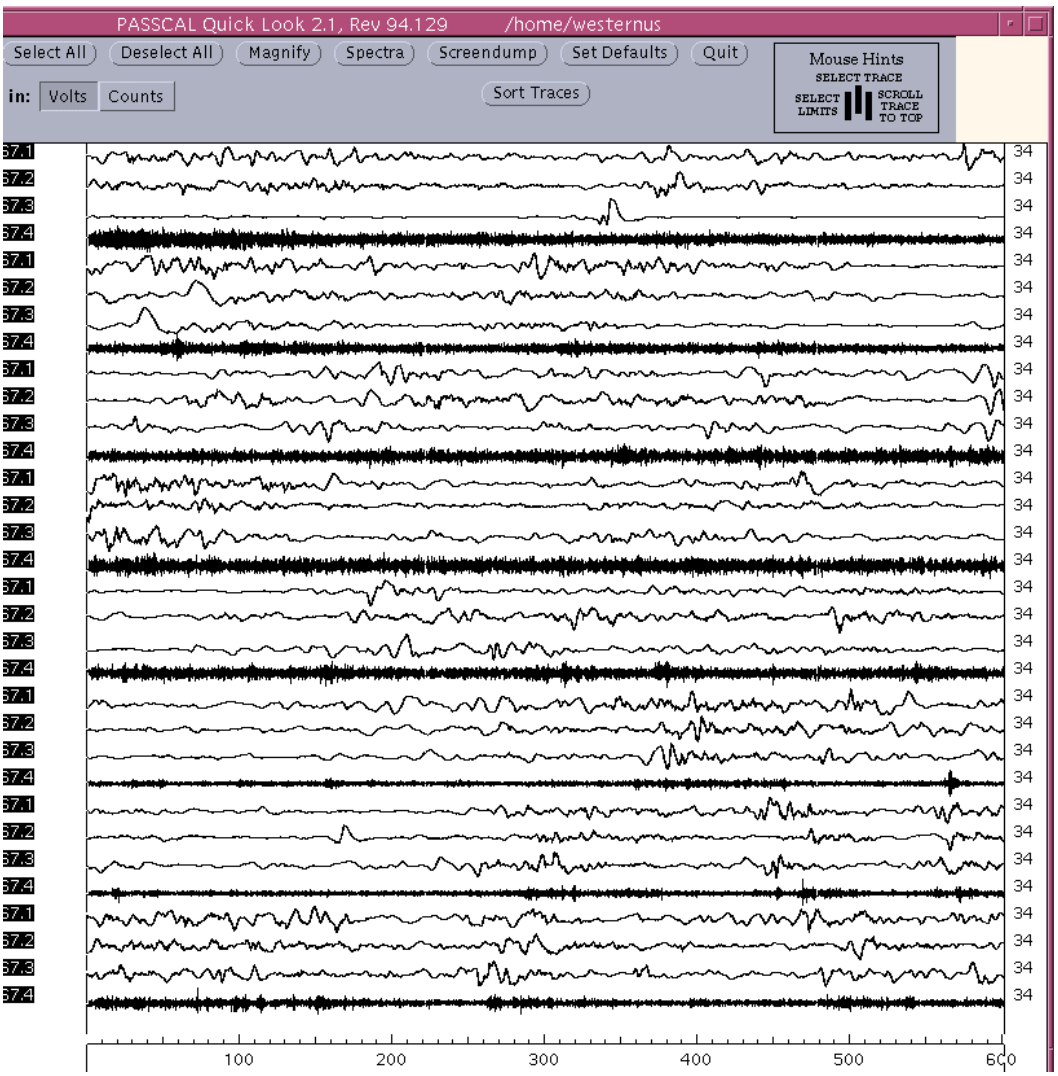

Figure 10: Eighty minutes of data from Julian Day 229 recorded at Ft. Hancock. Seven continuous, 600 sec, data segments are plotted. The seismic channel for each 600 sec sequence follows the three acoustic channels.

An eighty minute data sample from the acoustic and seismic sensors is reproduced in Figure 10. The lower frequency content of the acoustic channels compared to the seismic is illustrated. During this time period, the seismic noise is relatively constant with slight decreasing noise levels towards the end of time period. There is more variability of acoustic noise during this same time period. It is easy to identify relatively long period, ~10 sec, noise signals moving across the acoustic array. The velocities of these long period noise sources are on the order of a few m/sec. It is hypothesized that these long period noise bursts are a result of wind eddies moving across the array.

Example of acoustic signal.

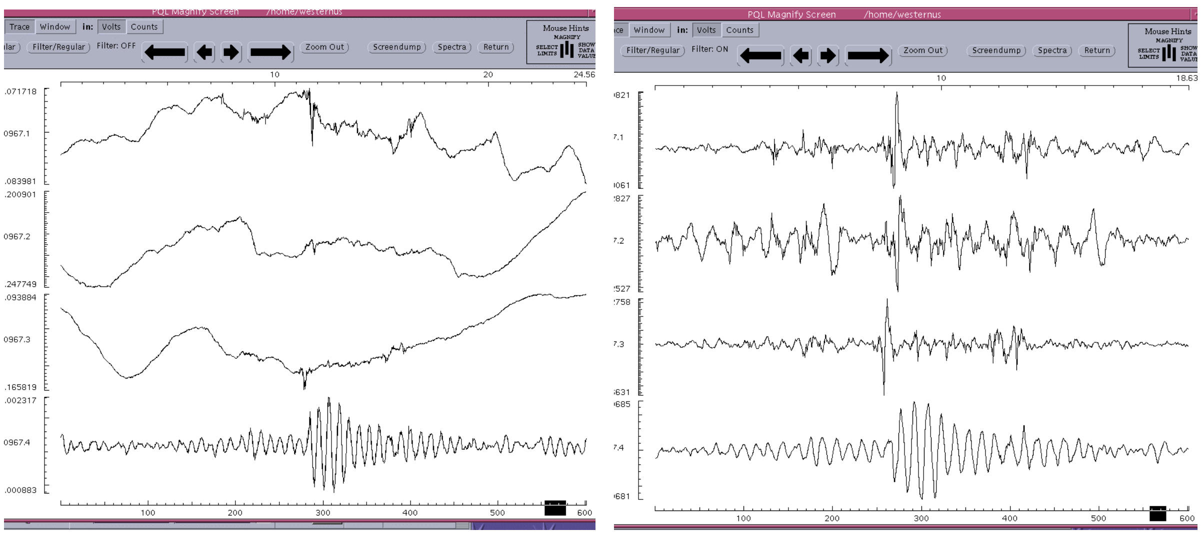

Figure 11: Example of an acoustic signal (Julian Day 229) across the array. In each of the above figures the top three records are acoustic signals and the bottom record is the seismogram. The signal on the left is broadband and the signal on the right is bandpass filtered between 1 and 5 Hz.

A preliminary review of the data indicates that there are numerous acoustic signals, particularly in the 1-5 Hz band. It is this band which has proven useful in the identification of infrasound signals from mining explosions (Sorrells *et al.,* 1997; Stump and Hayward, 2000). One of these signals is reproduced in Figure 11. The left panel of the figure illustrates the high frequency nature of the acoustic signals relative to the long period background noise. Strong cross coupling of the acoustic signal to the seismic channel is also apparent. In this case, the seismometer is emplaced at only 1 m depth in a sandy soil with very slow seismic velocities. Seismic velocities in weakly consolidated sands can be comparable to the acoustic velocity in air. It is easier to identify the arrival of the acoustic signal on the seismic channel prior to filtering.

After filtering (1-5 Hz), it is much easier to identify the acoustic signal. The relative high coherence in the acoustic signal in the 1-5 Hz can be observed in the figure. No attempt has been made at making back azimuth or phase velocity estimates with this initial data although the figure illustrates that this will be possible. If the transfer function between the seismic and acoustic channel can be determined, then the seismic channel might also be used in back azimuth and phase velocity estimation. The frequency content on the acoustic coupled seismic signal appears to be much narrower band than the acoustic signal. The seismic response from the acoustic signal is extended in time indicative of trapped, near-surface seismic waves. These seismic signals extend to over 10 sec.

Numerous signals such as those identified in Figure 11 were observed each day. The association of these signals with sources such as mining explosions will be investigated using this data as well as the data from the other seismo-acoustic installations in the western US (Figure 1).

Example seismic signal..

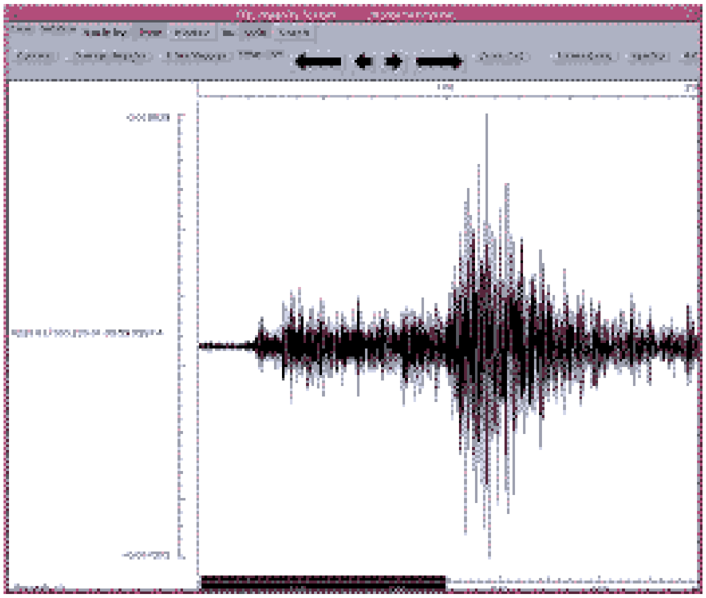

Figure 12: Regional signal from day 230 recorded at Ft. Hancock.

There are far fewer seismic signals than acoustic signals in the initial data base recovered from Ft. Hancock. This observation reflects a combination of the modest seismicity in the region as well as the surface vault installation for the seismometer and thus higher noise levels. An example of one of the regional seismogram recorded at Ft. Hancock is replicated in Figure 12. One can identify the P_n, P_g and L_g phases in this seismogram.

Lightning strikes.

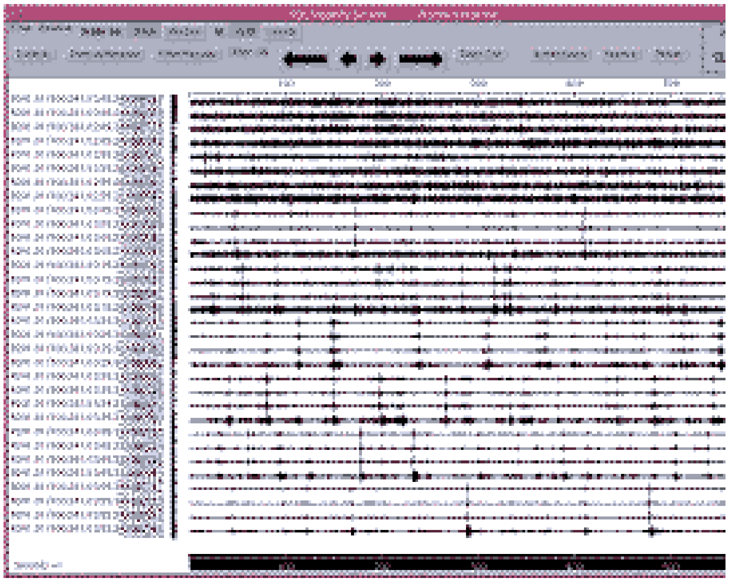

Figure 13: Eighty minutes of data from Julian Day 241 recorded at Ft. Hancock. Eight continuous, 600 sec, data segments are plotted. The seismic channel for each 600 sec sequence follows the three acoustic channels. Data was filtered from 1 to 5 Hz in order to illustrate the numerous seismo-acoustic signals that may be associated with a thunderstorm.

A high-density of acoustic signals were observed during several time periods ranging from one to several hours. The acoustic signals as illustrated in Figure 13 are impulse with time separations between events as close as 1 minute. Careful examination of the events illustrates that events close in time are coming from similar locations but over the duration of the signals the locations of the sources will migrate. These observations suggest that the source for these events are related to thunderstorms.

Southern New Mexico Gas Explosion.

During the initial period of the deployment there was the accidental rupture and detonation of a large underground gas pipeline in Southern New Mexico. A number of people were killed by this accident. This event occurred on August 19 (Julian Day 232) sometime between 11:25 to 11:35 GMT The resulting shallow explosion generated strong infrasound signals that were observed at Ft. Hancock with no accompanying seismic signals. The infrasound signals from this explosion are reproduced in Figure 14.

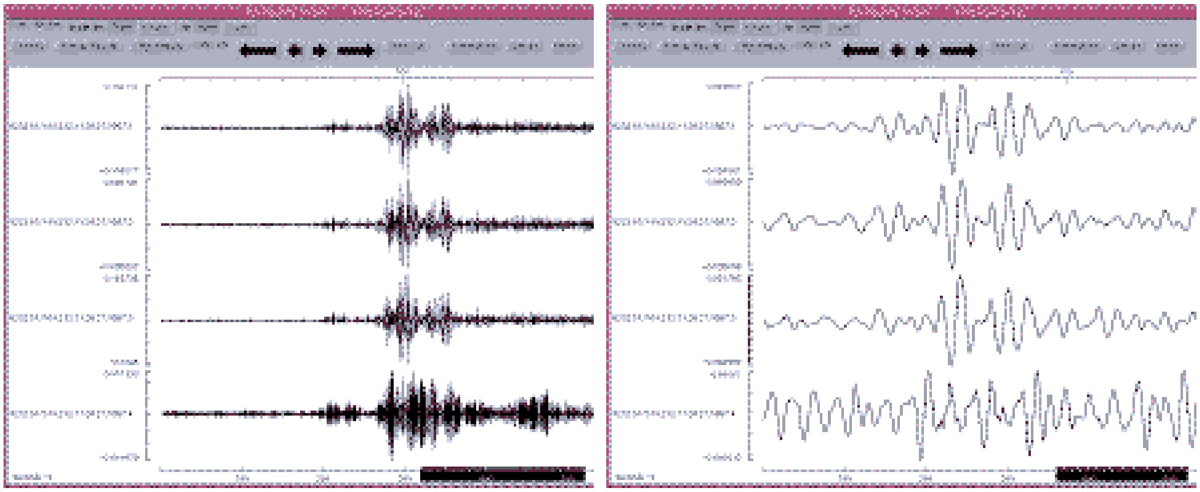

Figure 14: Infrasound signals from the 19 August 2000 Southern New Mexico gas line explosion as recorded at Ft. Hancock. The record to the left has been filtered in the 1 to 5 Hz band while the record to the right has been filtered from 5 to 10 sec.

The signal from the near-surface explosion is broadband extending from 10 sec to nearly 10 Hz. This frequency content is quite different compared to signals such as those in Figure 11 from possible mining explosions and those in Figure 13 from thunder storms. A search of the seismic data, indicated no signal above background despite the relatively close location of the explosion in Southern New Mexico (Figure 3). Data from the IMS array, TXAR, produced no associated seismic signal as well. The acoustic signal reproduced in Figure 14 is one of the largest for the time period of recording. These observations illustrate the utility of infrasound monitoring for characterizing explosions detonated near the earth's surface.

Both the high frequency and long period signals from the explosion indicated a good deal of complexity. In the case of the high frequency waveforms, there is an initial, small amplitude signal followed by a second large amplitude arrival approximately 20 sec latter. A third arrival follows by an additional 20 sec. These same arrivals can be identified in the long period portion of the signal, although the cross-coupling to the seismic is not as apparent. It is difficult to assess these signals as being a result of source or propagation path effects without some modeling and comparison with eye witness observations of the explosion.

Press reports from the explosion indicate that following the explosion that the gas from the pipeline burned for quite some time. Figure 15 illustrates eighty minutes of data starting with the initial signal at about 400 s. Coherent signals can be observed by eye for at least one hour following the initial explosion. In this case, the signal duration cannot be explained by a propagation path effect and must be attributed to the source. Based upon the eyewitness observations, the duration of the acoustic signal recorded at Ft. Hancock must reflect the burning of the gas from the pipeline that followed the explosion.

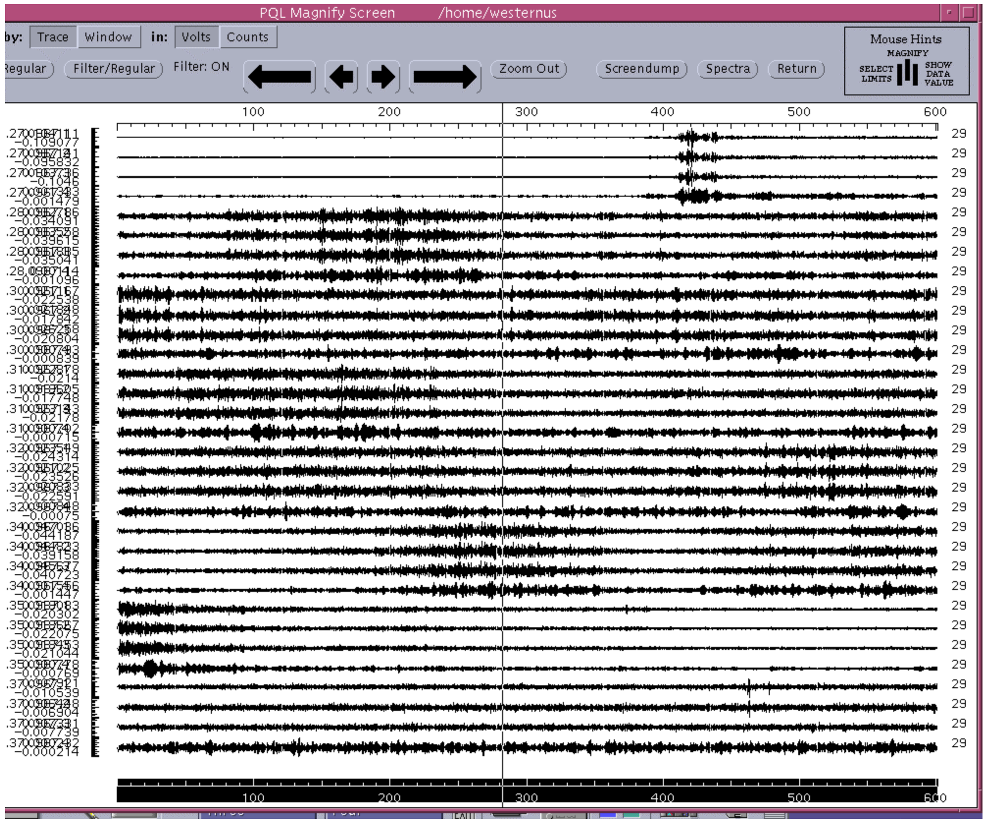

Figure 15: Infrasound signals from the 19 August 2000 (Julian Day 232) Southern New Mexico gas line explosion as recorded at Ft. Hancock. Eighty minutes of data are displayed with the initial explosion signal observed just before 400 sec.

High and low frequency infrasound signals.

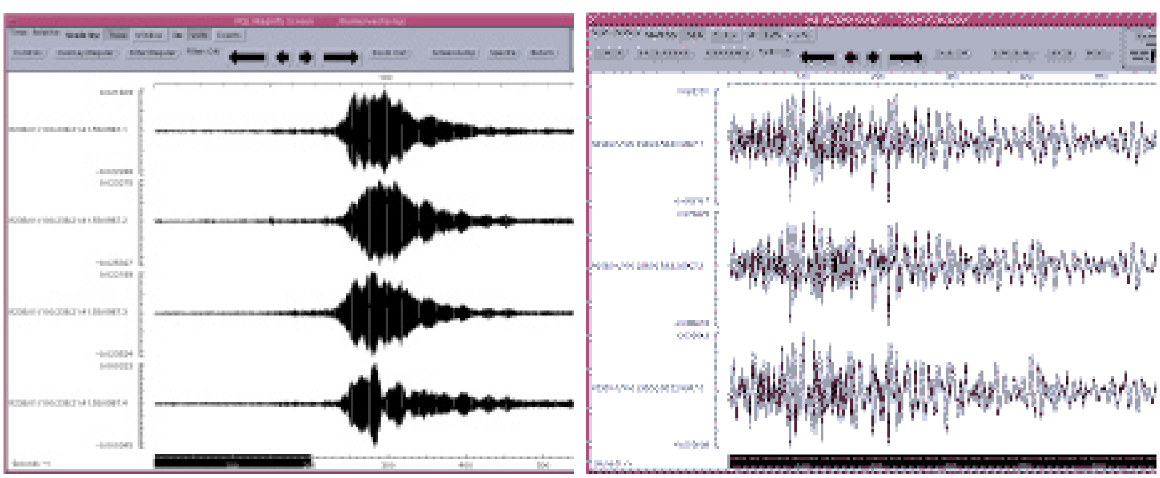

Figure 16: High frequency (8-16 Hz) signal (left, Julian Day 238) and low frequency (1-20 sec) signal (right, Julian Day 238) .

Finally, a high frequency (8-16 Hz) and a low frequency (1-20 s) signal are displayed in Figure 16. This data illustrates that there is a very broad frequency range of signals that will have to be studied and interpreted as more data is recovered from Ft. Hancock and the other elements of the Western US network (Figure 1). Combining the seismic and acoustic signals from the various elements of the array in conjunction with the in-mine ground truth will provide the mechanism for the interpretation of these signals.

Conclusions

A three-element infrasound array and single vertical channel seismic instrument were installed at Ft. Hancock, Texas in August over a three day period. The stand alone installation is designed to operate unattended for relatively long time periods providing seismo-acoustic data for purposes of quantifying source and propagation effects for both atmospheric and solid earth waves. The installation will complement the other elements of the Western US Seismo-Acoustic Network including the ground truth installations at Morenci and Tyrone (Figure 1).

The initial installation of the array was relatively simple. It was found necessary to fence each of the four elements of the array and trench all cabling in order to avoid disturbance by animals. The approximate100m separation between array elements requires substantial land area. Cooperation with the State of Texas provided the necessary land in this case.

It appears that the decision to simply record data to disk and then physically recover data on approximately two month time series was appropriate. The initial 8 week time period provided a complete data set. This data recovery is in stark contrast to data recovery from in-mine stations, which utilize a RefTek 114 computer and a dial-in/out capability. Several system failures with this latter configuration have been observed reducing the useable data set to small time periods. It is recommended that the RefTek 114 computers and telephone modems be removed from these other installations.

A wide range of signals were observed in the initial data acquisition period for Ft. Hancock. These signals range from signals similar to those observed from mining explosions at other locations to both high frequency and long period signals. Strong cross-coupling of the acoustic signals to the shallow buried seismometer has been observed. The cross-coupled seismic signal appears to be narrower band than the acoustic signals. It remains to be explored whether the seismic signal can be combined with the acoustic in array processing. It is of interest to note that previous studies of cross-coupling have focused on data from more deeply buried seismometers. In this case, the seismometer at its approximately 1 m depth is located in a weakly cemented soil with seismic velocities that are probably close to acoustic velocities in the atmosphere.

Infrasound signals from the surface explosion of a natural gas line in Southern New Mexico extended in frequency from 10 sec to 10 Hz. There is no accompanying seismic signal observed at Ft. Hancock or TXAR. The large amplitude acoustic signals (largest during observing period) illustrate the utility of a combined seismic and infrasound monitoring system to effectively detect and hopefully identify shallow buried or near-surface explosions. The long duration of coherent acoustic signals (in excess of 60 minutes) suggests a source with extended duration. Observations at the site of the explosion confirmed that the natural gas burned for some time following the explosion. The infrasound signals and their relations to the source will be further explored.

Acknowledgements

Special thanks to Paul Loeffler, Regional Manager and Range Specialist, Texas General Land Office for his help in identifying the site and in the installation. Diane Dozer at UT El Paso suggested the site. Mihan House, Chris Hayward and Brian Stump participated in the installation. Chris Hayward and Rhong-Mao Zhou helped with data retrieval. Carl Thomason designed and built the array.

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