THE NEVADA SEISMIC ARRAY (NVAR)
REGIONAL SEISMO-ACOUSTIC STUDIES

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Sponsored by Defense Threat Reduction Agency
Contract No. DSW-AOI-97-I-0024

ABSTRACT

Studies are underway at the Southern Methodist University Geophysics Laboratory to identify seismo-acoustic sources located at regional distances from the Nevada Seismic Array (NVAR). The objective of this project is to evaluate the seismo-acoustic method for the identification of mine blasts as well as other type of vented explosions. The studies involve the processing and analysis of regional seismic and seismo-acoustic data acquired at NVAR during selected daily intervals for a period of one year. Our assessment of the initial results of the studies show that NVAR is surrounded by regional seismo-acoustic sources The most active seismo-acoustic source is found near Hawthorne, NV where sequences of signals are generated several times aweek. In addition, multiple seismo-acoustic sources are located within the Carlin/Battle Mountains gold mining district in northcentral NV. Occasional seismo-acoustic signal generated by sources in western Utah and northwestern Arizona were also observed. Additional studies are underway to calibrate NVAR to locate events on the Nevada Test Site.

Key Words; Seismo-acoustic, array, regional monitoring, infrasound

OBJECTIVES

The objectives of the research projects whose initial results are summarized below are to:

- evaluate the seismo-acoustic method for the identification of mine blasts as well as other type of vented explosions.
- calibrate NVAR to locate events on the Nevada Test Site

RESEARCH ACCOMPLISHMENTS

Seismo-Acoustic Studies NVAR is well suited to be the focus for studies of seismo-acoustic phenomena. It is virtually surrounded, at regional distances by more than 60 active major mines. In addition, a US Navy ordnance disposal depot is located 30-40 km southwest of the array and there are multiple possible seismo-acoustic sources on the Nellis AFB Bombing and Gunnery Range, approximately 150-200 km southeast of the array. Thus, the first task of the NVAR seismo- acoustic study is simply to identify and select a subset of these sites for future detailed surveillance. The following procedures were implemented to carry out this task.

The NVAR seismic array data are continuously reviewed to identify and select regional events with "good" signal to noise ratios (SNRs) for inclusion in an experimental data set. The review is constrained to data recorded on normal workdays between the hours of 12:00 PM and 6:00 PM local time. The anticipated effect of this constraint is to maximize the percentage of commercially generated seismo-acoustic events in the data set. Approximate epicenters and origin times are calculated for each selected event using array back azimuth and S-P range estimates. A 0.25-0.34 km/s group velocity window is also calculated for each event. The NVAR infrasound and seismic data are then searched within the group velocity windows to identify possible associated infrasound signals. An association is declared if an infrasound signal is detected within the group velocity window and its back azimuth is within 15° of back azimuth of the prior seismic event. Potential seismo-acoustic sources are then identified by evidence of correlated temporal and spatial clustering, as well as by the occurrence of one or more seismic events with an associated infrasound signal within the apparent time-space cluster. The results of the application of these methods to data acquired at NVAR from 1April99 to 30June99 are summarized in the following paragraphs.

Over 500 of the regional seismic events detected at NVAR during the 91 day period beginning 1April99 were found to satisfy the SNR and occurrence time constraints described in the previous paragraphs. Figure 1 is a histogram illustrating the distribution of the occurrence times of these events, referenced to the local time base. Notice that the distribution is distinctly bimodal with significant clusters occurring in the 12-1 PM and the 3-4 PM time periods. Miners typically blast at or near the end of work shifts. The shifts usually end at noon or at the end of the normal workday. We believe that this practice accounts for the bimodal structure of the histogram seen in Figure 1. If this is the correct interpretation it then follows that that the regional seismic activity seen at NVAR on a typical workday afternoon is largely the result of mine blasts.

The spatial distribution of the regional seismic events in the experimental data set is illustrated in Figure 2. . The red dots seen on this map locate the event epicenters. The yellow triangle identifies the location of the center element of NVAR. The Polygon located southeast of the array outlines the boundaries of the Nevada Test Site (NTS). The dense cluster of epicenters enclosed by the ellipse centered a few hundred kilometers north-northeast of the array merits some further comment. The area enclosed by the ellipse roughly coincides with the Carlin /Battle Mountain Gold Mining Complex. There are at least seven major mines currently active within this Complex. The seismic activity generated by blasting at one of these mines (the Carlin East Open Pit) has been studied by Jarpe et al (1996). Their data shows that blasting activity at this site generates seismic events with magnitudes $m_b > 1$ at a rate of the order of a few per week. If the blasting activity at other major mines in the Complex is comparable to that found at the Carlin East Open Pit, then it is reasonable to assume that the majority of the events whose epicenters are enclosed by the ellipse are the result of mine blasts.

The epicenters seen in Figure 2 are color coded according to their daily occurrence time in Figure 3. The epicenters of the events that occurred during the two peak daily activity periods (see Figure 1) are shown in red. The epicenters that occurred at other times during the workday afternoon are shown in green. It is seen from Figure 3 that the majority of the events that locate within the Carlin /Battle Mountain Complex occur during the peak daily activity periods. This result lends additional support to the assumption that the majority of the seismic activity within the Complex is generated by mine blasts. It is also worth noting that the dimensions of the peak daily activity clusters that occur in the Complex substantially exceed any uncertainties in the individual epicenter estimates. Consequently, the dense concentration of epicenters in this region is believed to be the result of blasting activity at multiple mine sites.

Twenty-eight seismic events in the experimental data set were found to have associated infrasound signals. The distribution of their occurrence time coded epicenters is shown separately in Figure 4. While the population of regional seismo-acoustic events in the experimental data set is currently too sparse to provide any conclusive evidence of significant temporal or spatial clustering, there are some interesting properties that deserve further comment. First, note that the seismo-acoustic locations are well distributed in azimuth about NVAR and a few detections have been made at ranges greater than 500 kilometers. This result encourages us to believe that continued sampling using the procedures outlined above will yield a population of events that can be used to comprehensively evaluate the seismo-acoustic method of blast identification. Secondly, it is worth noting that the occurrence times of the seismo-acoustic events are approximately equally divided between the peak daily activity periods and off-peak time periods. This result suggests that vented explosive processes other than routine mine blasting may play a significant role in generating the regional seismic signals seen on workday afternoons at NVAR. Finally, the occurrence of seven of the events in the Carlin /Battle Mountain Complex confirm that at least some of the events in this region are indeed the result of mine blasts. It should also be noted that incipient seismo-acoustic clusters appear to be emerging at a site about 150 kilometers east of NVAR and at one near Mammoth Lake CA about 100 km south of the array. A quick inspection of Figure 2 shows that tight seismic epicenter clusters characterize both sites. These areas will be given further attention during the future expansion of the experimental data set.

A swarm of locally generated seismo-acoustic signals are recorded several times a week at NVAR. The swarms invariably originate at a point some 50-60 km southwest of the array and their duration is usually 3-5 minutes. An example of the records of a typical swarm is shown in Figure 5. In this figure, the code, sz, identifies the record from an element of the NVAR seismic array. The code, sd, identifies the record from an element of the infrasound array. Notice that while the seismic signals overlap, forming a complex wave train, it is clear from the infrasound records that the swarm in this particular case, consists of nine discrete events. We believe that swarms of this type are generated by the disposal of obsolescent ammunition at a site associated with routine operations at the Hawthorne Naval Ordnance Depot. The occurrence of strong "air-coupled" waves following the seismic signals should also be noted. These observations illustrate that that "air-coupled" wave data can be used in the absence of available infrasound observations to aid in the identification of local or regional seismo-acoustic sources.

Infrasound signals that cannot be associated with a seismic source are practically a daily occurrence at NVAR. Since a study of their properties is outside the scope of the current investigation, their occurrences are not normally logged into the experimental data set. Nevertheless, one type of unassociated infrasound signal has attracted our attention. It appears in a swarm-like pattern containing 10-12 discrete signals. The swarm may last for 10-15 minutes and the source is invariably located southeast of the array. An example of some of the signals in one of the detected infrasound swarms is illustrated in Figure 6. The absence of a corresponding seismic swarm suggests that the signals are the result of air blasts or possibly poorly coupled surface blasts. The fact that the Nellis AFB Bombing and Gunnery Range is also found south east of NVAR suggests that they may be a by-product of military training exercises that routinely take place on the Range.

Calibration Studies at NVAR The NVAR (Mina, Nevada) seismic array was calibrated for regional and teleseismic events. Back azimuth and phase velocity estimates were calculated using the crosscorrelation method. The database included 553 events, well located by NEIC, between March and December 1999 with $6.6 > m_b > 2.7$ and epicentral distance between 110 and 11225 *km*.
Elevation differences of up to 0.4 *km* and complicated geology made static corrections for each array element necessary. We used 57 core phases (*PKP, PKKP, PcP*) to determine static time corrections.
No pattern was observed in the back azimuth and phase velocity residuals as a function of azimuth at NVAR.
Detection capability and location accuracy at NVAR (Mina, Nevada array) was assessed using a sequence of 553 earthquakes ($M_L < 4.4$) that occurred from 07/31/1999 to 09/26/1999 near Scotty's Junction, about 60 km west of the Nevada Test Site. Based on the analysis of these data the 90% detection level for *Pg* was found to be 1.4 *nm* for a normal noise environment. 16 events ($M_L > 3.2$) in the sequence were identified as having similar location and source mechanism by crosscorrelation of their waveforms with a large, well located event. Backazimuth was calculated for each of these events using a crosscorrelation method (Tibuleac and Herrin, 1997). Epicentral distance was estimated using *Lg* - *Pg* arrival time differences. Arrival times for the *Pg* and *Lg* phases were determined using wavelet decomposition methods (Tibuleac and Herrin, 1999). The standard deviation for calculated epicentral distance was 2.8 *km*. The standard deviation for calculated backazimuth was 0.94 *deg*rees. This translates to a standard deviation of 2.6 *km* at a distance of 157 *km* (the distance from NVAR to Scotty's Junction).
Extrapolation of these results implies the 90% detection threshold at NVAR for events on NTS is less than 2.0 local magnitude units as determined by the University of Nevada at Reno. Using only the NVAR array for epicentral location we obtained an extrapolated 90% coverage area of less than 180 km^2 for events at NTS.

<u>REFERENCES</u>

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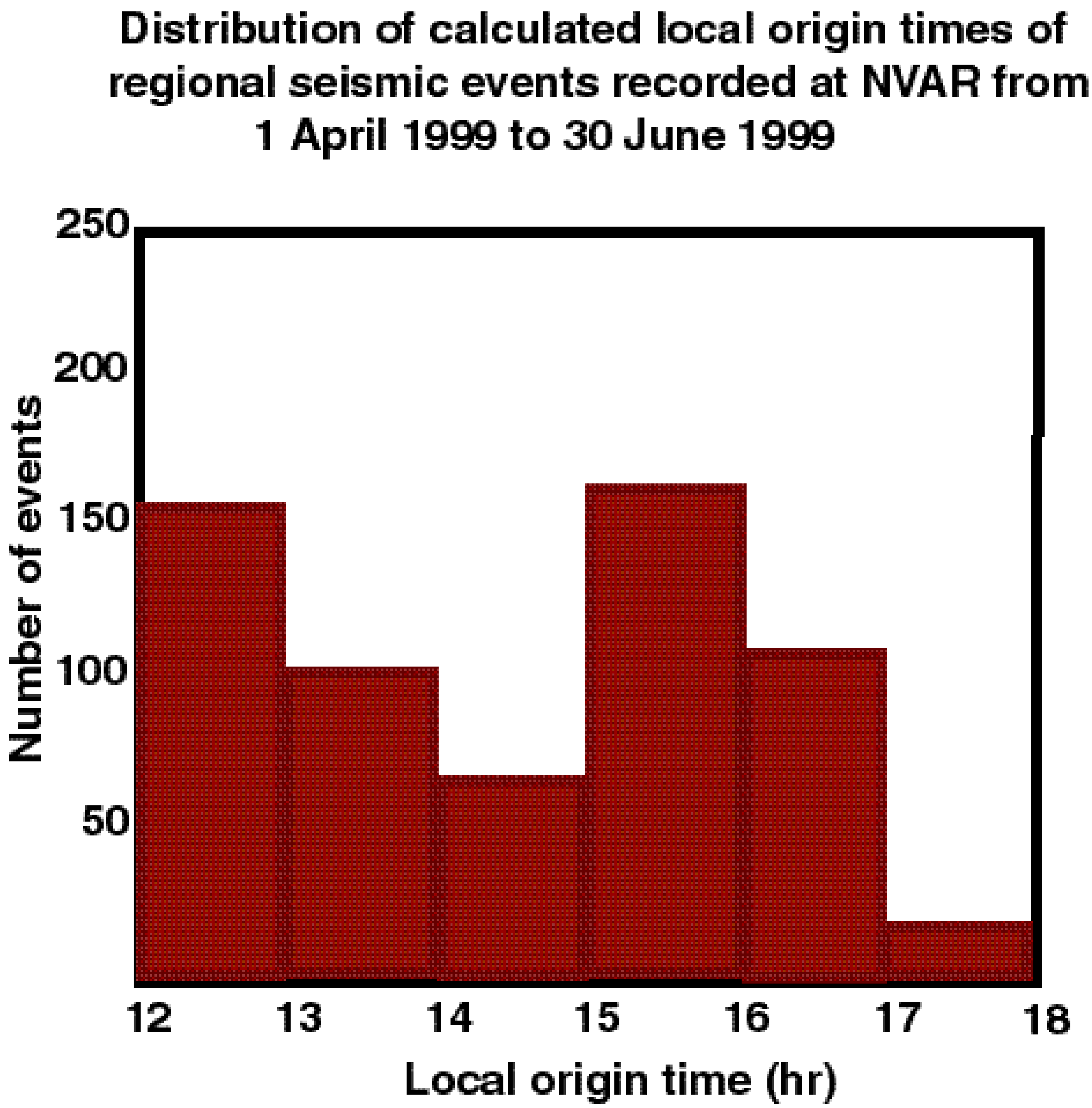


Figure 1. A histogram illustrating the distribution of daily occurrence times of regional seismic events detected on workday afternoons at NVAR from 1 April 1999 to 30 June 1999.

Epicenters of regional seismic events detected at NVAR between 1 April 1999 - 30 June 1999 with local origin time between 12.00 and 18.00.

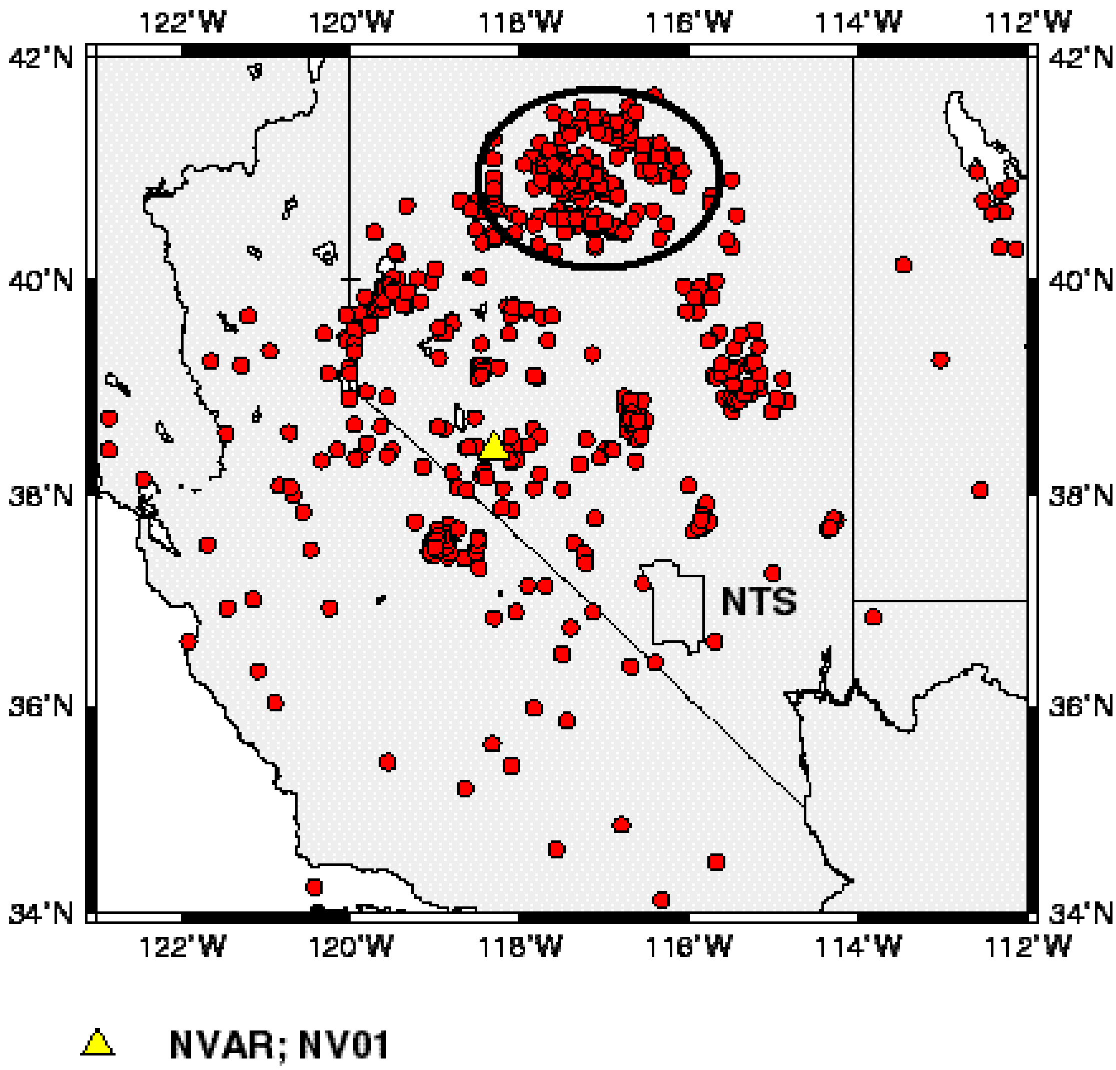
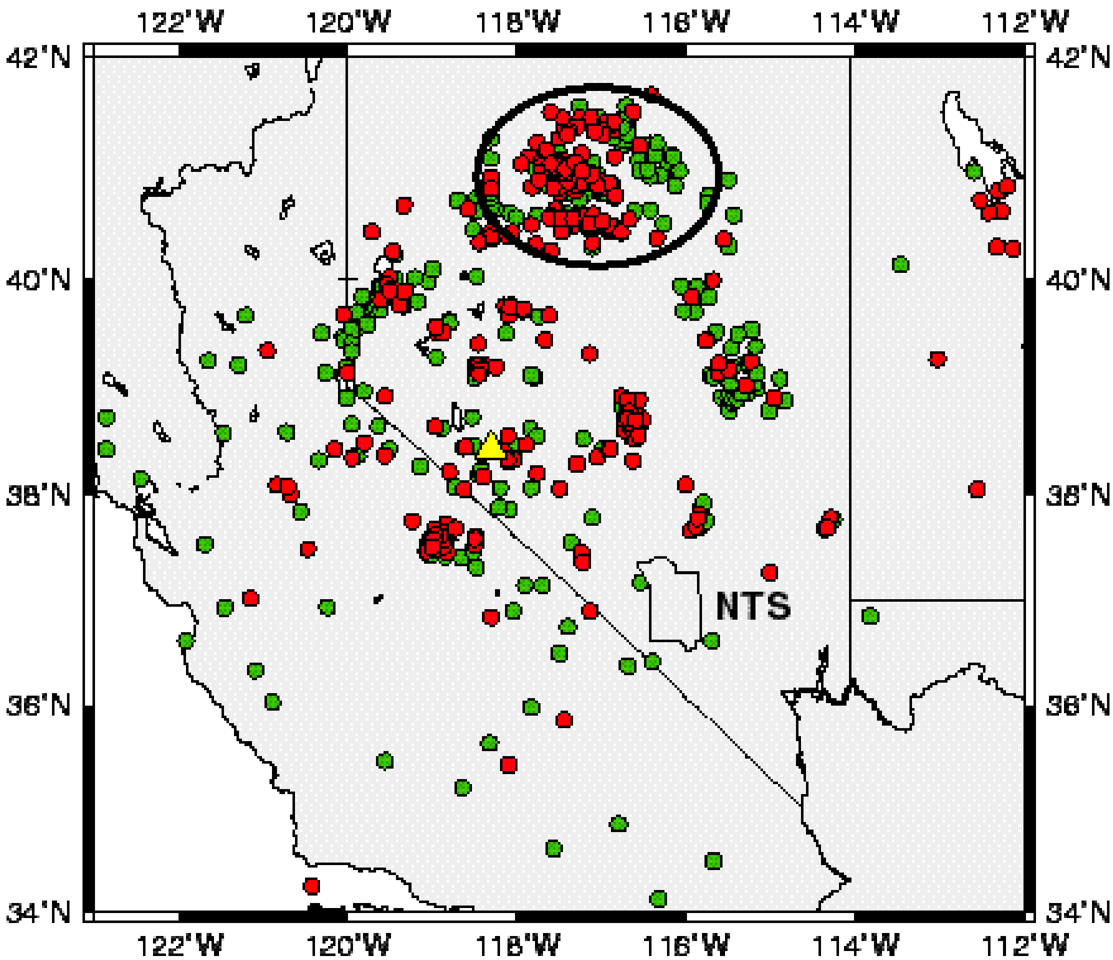


Figure 2. A map illustrating the spatial distribution of the epicenters of regional seismic events detected on workday afternoons at NVAR from 1 April 1999 to 30 June 1999.

Epicenters of regional seismic events detected at NVAR between 1 April 1999 - 30 June 1999 with local origin time between 12.00 and 18.00.



△ NVAR; NV01

● occurrence time during peak daily activity periods

● occurrence time during other periods

Figure 3. A map illustrating the spatial distribution of the occurrence time coded epicenters of regional seismic events detected on workday afternoons at NVAR from 1 April 1999 to 30 June 1999.

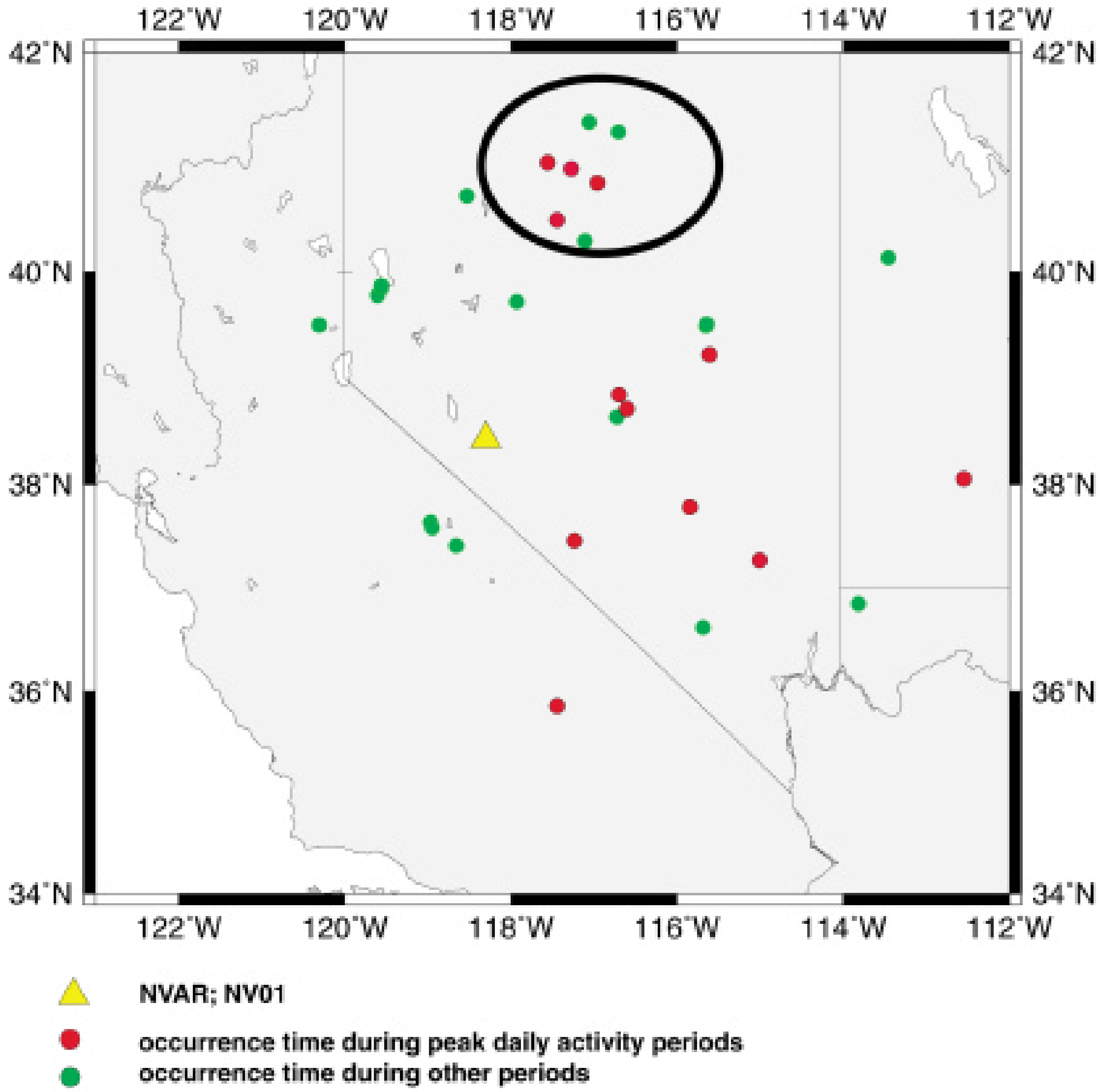


Figure 4. Spatial distribution of the occurrence time coded epicenters of regional seismo-acoustic events detected on workday afternoons at NVAR between 1 April 1999 - 30 June 1999

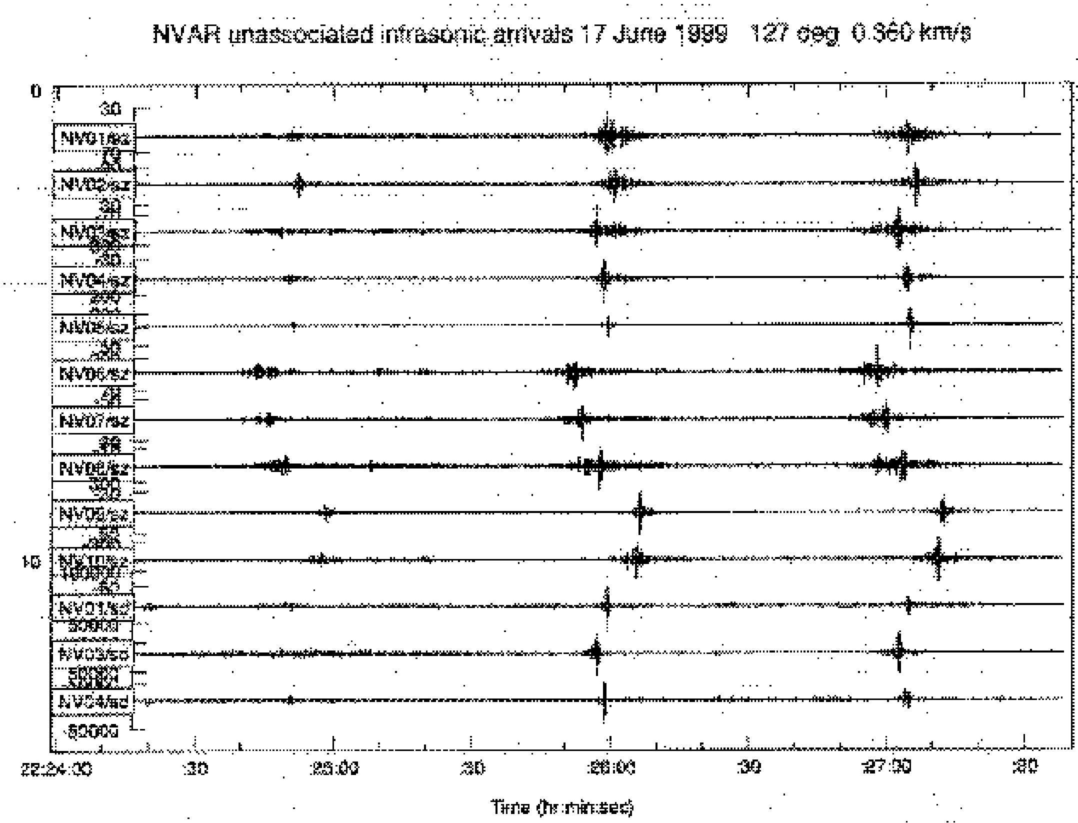


Figure 5. An example seismogram of a locally generated seismo-acoustic swarm detected at NVAR.

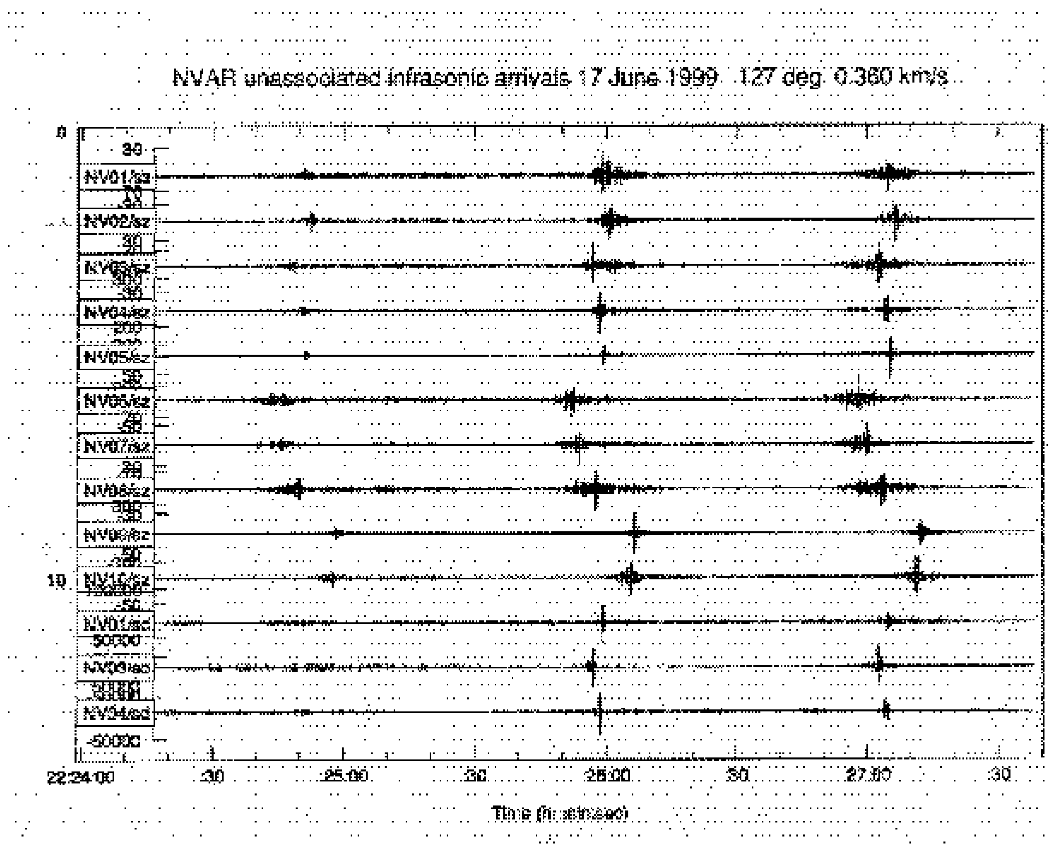


Figure 6. An example seimogram of an infrasonic swarm detected at NVAR.