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Installation of the Wupatki, AZ Acoustic Array

May 3, 2001

Western US Experiment
Installation Note

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Introduction

The Department of Geological Sciences at Southern Methodist University (SMU) is conducting local and regional seismic and acoustic detection experiments in the western United States, using the routine rock fragmentation explosions at the copper mines in eastern Arizona and western New Mexico. The project is funded by the Defense Threat Reduction Agency (DTRA) contract no. DSWA01-98-C-0176.

Acoustic and seismic energy from explosions in these Arizona copper mines is routinely detected 600-700 km away in West Texas at the TXAR seismic and acoustic array (Figure 1) (Sorrels *et al.,* 1999). The data collected during this experiment is used to study long distance seismic and acoustic propagation in the western US and to study the relationship between industrial mining practices and explosion signal characteristics. Near-source instrumentation within the mine collects data used in collaborative studies with mine engineers on 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 acoustic arrays deployed at regional distances from the copper mines. The station, Wupatki (designated WUAZ), is 150 - 200 km from the mines (Figure 1). This location provides an opportunity to document the development of both seismic and acoustic signals as they propagate from the mines. The infrasound WUAZ site in Wupatki, Arizona is nearly collocated with the existing WUAZ National Seismic Network (NSN) system.

The installation trip occurred on 30 April- 3 May 2001. During the trip, the following tasks were completed:

27 April

- Shipped 500 pounds of equipment from Dallas to Albuquerque by Southwest Airline Freight.

28 April

- Shipped remaining electronics, tools, and test equipment from Dallas to Albuquerque by Southwest Airline Freight.

30 April

- Chris Hayward and Rongmao Zhou traveled on Southwest from Dallas to Albuquerque.
- Picked up shipped station equipment at freight terminal. Shipment completely filled an F150 pickup.

- Purchased materials for installation (concrete blocks, butane, battery, small hardware).
- Traveled Albuquerque to Flagstaff.
- Dropped in to park headquarters at Flagstaff to meet Paul Whitefield.

1 May

- Hayward and Zhou met Paul Whitefield (FLAG_Natural_Resources@nps.gov), Dedri ????, and Nicole Tancreto (Nicole_Tancreto@nps.gov) to begin installation.

  Paul Whitefield
  National Park Service
  Flagstaff Area National Monuments
  6400 North Highway 89
  Flagstaff, Arizona 86004
  520-526-1157 x235
- Picked the final site for the installation.
- Completed the installation of four infrasound sensors and wind velocity along with the data acquisition system.
- Began normal data acquisition plus a test stream at 250 SPS on the central acoustic channel.

2 May

- Completed final installation and clean up.
- Gathered example data set.
- Documented the installation.
- Disposed of packing materials and repacked for return trip.

3 May

- Returned to Albuquerque and then to Dallas.

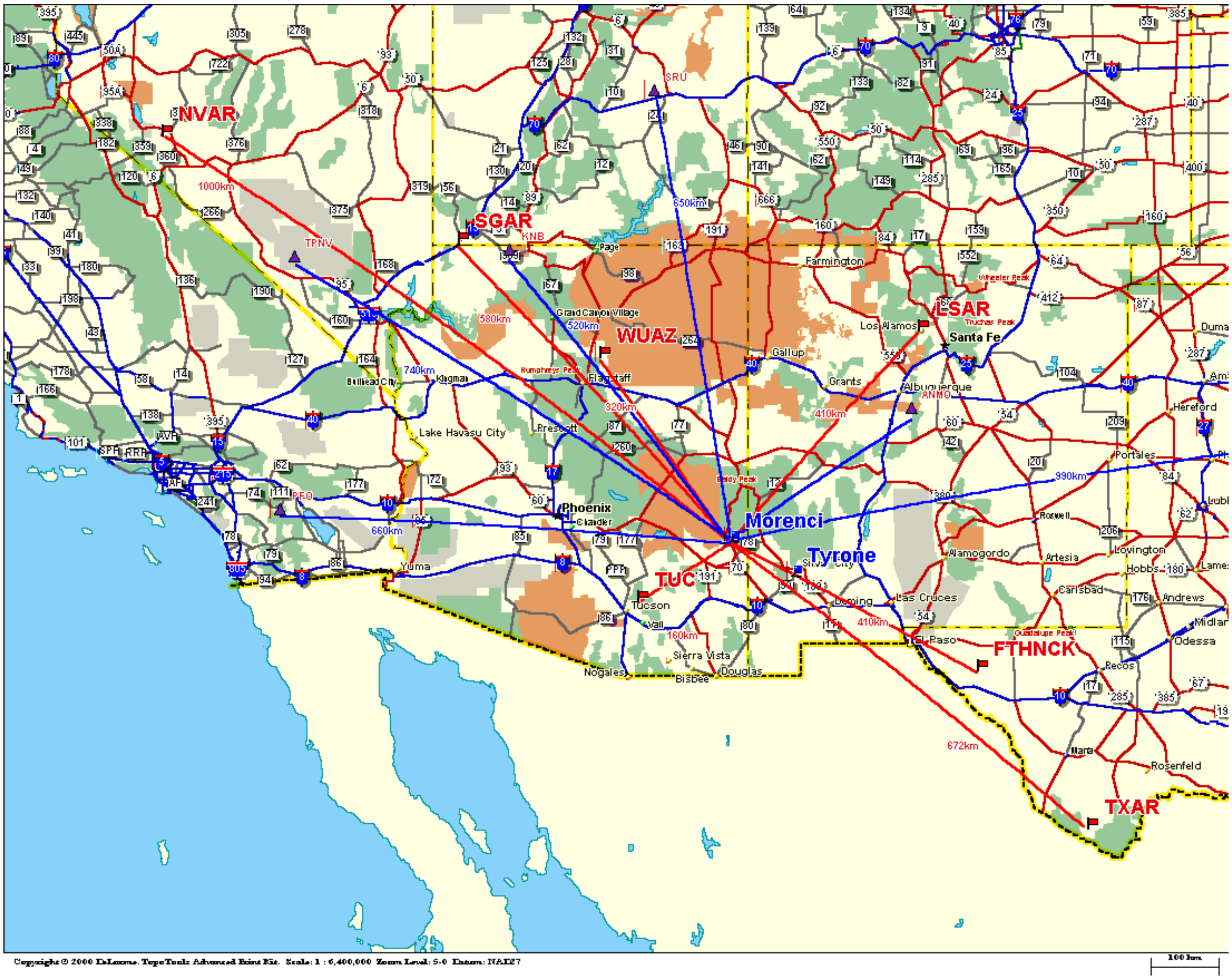

Figure 1. Map illustrating the existing and proposed stations that will make up the Western US seismo-acoustic network. Seismo-acoustic stations are shown as red flags, seismic only as purple triangles, and sources as blue pins.

This installation includes four acoustic gages, an anemometer, a digitizer, and disk and omits the seismometer used at other sites, since WUAZ is co-located with an existing seismic station. The central site (WUAZ0) equipment was placed 100 m from the existing WUAZ seismic vault. The infrasound equipment is solar powered and shares no resources (power or space) with the USGS equipment. A panoramic photograph of the site overlooking Wupatki is given in Figure 2. The infrasound elements are arranged in a triangular pattern with the fourth element at the center of the triangle.

Figure 2. Panoramic view looking north from the WUAZ seismic site.

Site Location and Characteristics

The Wupatki acoustic installation is 27 miles NNE of Flagstaff on Woodhouse Mesa just above the Wupatki National Monument Visitor Center (Figure 3 and 4). The detailed geometry of the acoustic array relative to the NSN station TUC, is given in Figure 5 (TUC0-TUC3 represent the four elements of the array). The latitude and longitude for each of four-infrasound sites and TUC are reproduced in Table 1.

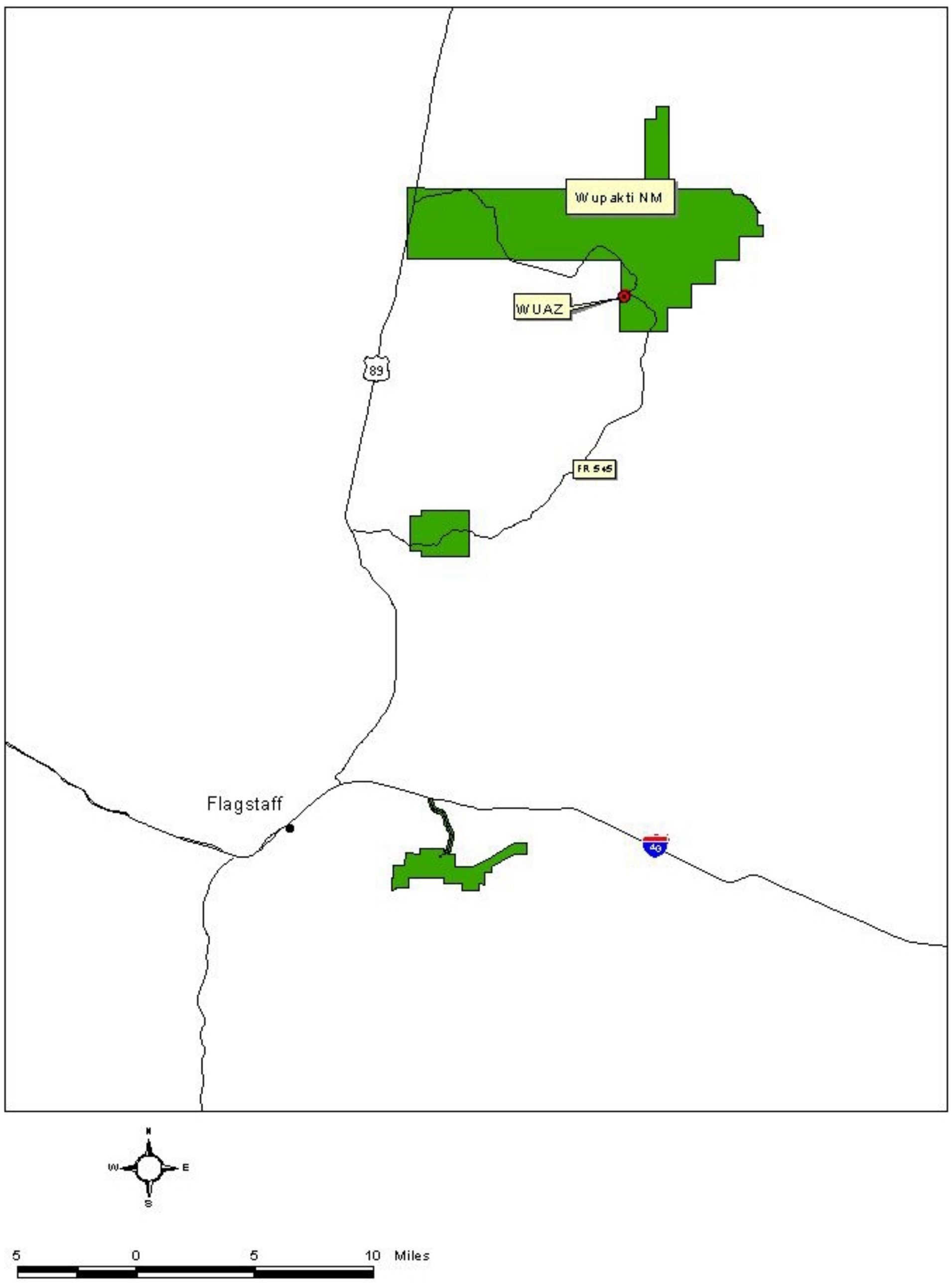

Figure 3. Map showing the location of the Wupatki infrasound array relative to Flagstaff.

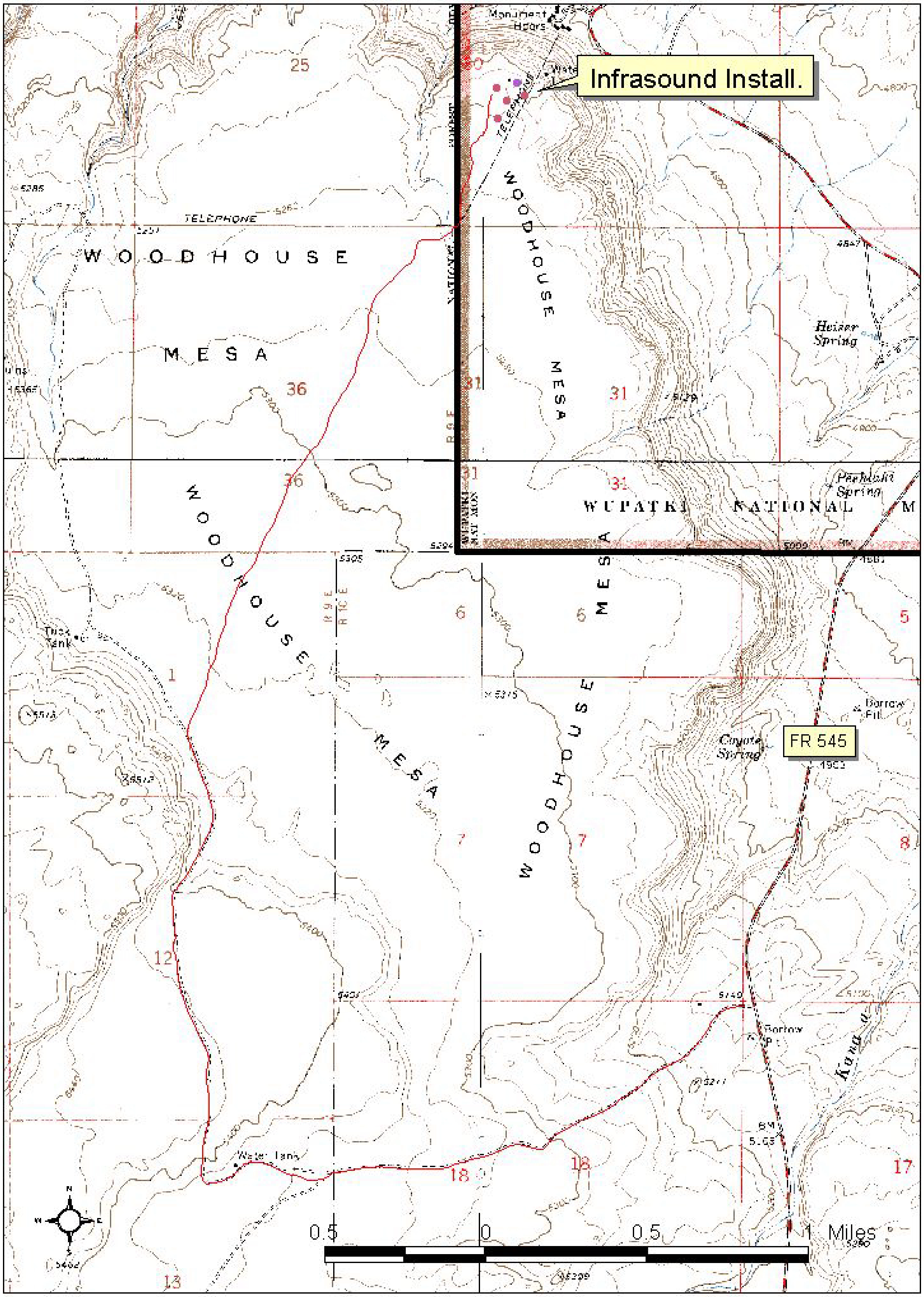

Figure 4. Route to WUAZ.

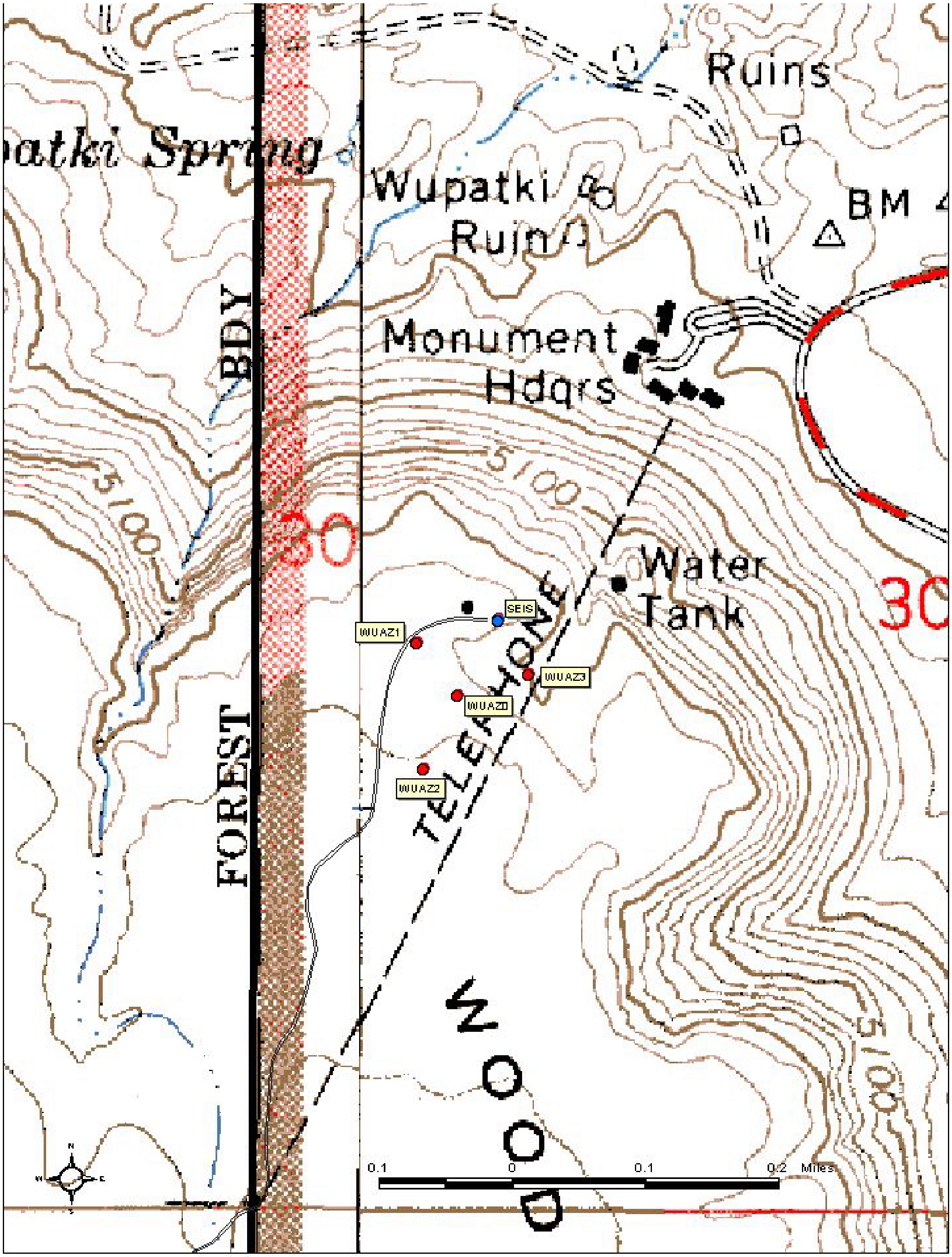

Figure 5. The location of the NSN station WUAZ and the four elements of the infrasound array (WUAZ0-WUAZ3). The gate across the Monument boundary is marked at the bottom of the map. The trail forks at the gate. The western-most trail leads directly to the WUAZ seismic site.

Table 1. Latitude and longitude of the acoustic instruments (WUAZ0-WUAZ3) and the seismometer (WUAZ) at Wupatki. Locations are referenced to NAD27-Central.

Station Name	Latitude (N)	Longitude (W)	Ref Tek Channel	Serial Number
WUAZ0	35.51622°	111.37390°	4	1312
WUAZ1	35.51677°	111.37447°	1	1315
WUAZ2	35.51539°	111.37437°	2	1299
WUAZ3	35.51638°	111.37300°	3	1296
WUAZ	35.51695°	111.37337°		

The sites are all located in on Woodhouse Mesa, a mesa supported by a lava flow cap. Soils are developed in porous cinder materials. Grass cover is sparse (high desert conditions) with most vegetation less than 50 cm high. Although junipers are present on the mesa, the area chosen for the infrasound sensors is devoid of all wind break or cover other than low grasses.

The WUAZ CMG-3 seismic sensor is in a sandbagged surface vault about 5m from a small building previously used as a radio repeater and now as an equipment enclosure for the USGS satellite equipment. Besides the standard USGS digital satellite telemetry (continuous recording), the data is also directly sent by analog RF through a repeater to the Sunset Crater Visitor Center where it is displayed on a helicorder. WUAZ seismic data is available through the USGS using autoDRM protocols.

The separation of the outside elements of the acoustic array ranges from 140 to 180 m (Figure 5). Distances from WUAZ0, the central element, and the three outlyers range from 80 to 100 m. The existing WUAZ seismometer is 100 m from central acoustic site (Figure 5). Although the array is on the Woodhouse mesa, the individual sites are at slightly different elevations. Sites WUAZ0 and WUAZ1 area nearly level. Site WUAZ2 is the highest and WUAZ3 the lowest. The elevation difference between WUAZ2 and WUAZ3 is estimated to be less than 20 meters.

The site is about 700m inside the Wupatki National Monument Boundary and is on a restricted access service road. Travel time from Flagstaff is about 1 hour. The site itself is not visible from outside the park fence. From the access road, the site is visible, but blends in well with the surrounding vegetation. Reflections off the cup anemometer or solar panel at particular sun angles are the most visible features. Road and visitor traffic is expected to be minimal.

Because the area is a sensitive area, the installation was done with minimal ground disturbance (no structures penetrating the ground surface). All cables were laid on the surface using 6-pair armored telephone cable. The enclosure was placed on a skid weighted with cinder blocks.

The site is in the path of area helicopter and aircraft tours and some low speed over flights may be expected. During the first day of installation several planes and one helicopter were observed. This is not expected to be a problem for the infrasound experiment, but may be useful if the equipment is also to be used for long term acoustic monitoring.

The remote location, collocation with station WUAZ, provides an infrastructure, a catalog of accessible high quality seismic signals, site access, and security. Paul Whitefield, Nicole Tancreto, and Jeri DeYoung, National Park Service, were invaluable with their cooperation, suggestions and assistance.

Figure 6. Area around one of the hoses at site WUAZ0. The Woodhouse Mesa area is densely covered with cultural sites. Shards of pottery, such as that circled above, drift down hill from sites. To avoid disturbing possible sites, the installation area was reviewed and sensitive areas flagged off by a cultural specialist prior to the installation.

Instrumentation

A Refraction Technology 72A-06 6-channel 24-bit digitizer was installed with a 4 Gbyte disk for data archival (Figure 4). All four infrasound channels are continuously sampled at 40 samples per second. Preamp gains were set at 1 to match the response of the Chaparral microphones. A Texas Electronic anemometer (1 volt/1000 RPM) is connected to channel 5 and sampled at 1 sample per second. Channel 6 is unconnected and reserved for other experiments. The data logger and power supply are housed in a standalone solar powered enclosure (Figure 7 and 8). Solar power is controlled with a small solar panel regulator to maintain the 12-volt battery. In the event battery power falls below 11.4 volts, the regulator will remove power to all equipment. Although this will protect the disk and RefTek 72A-06 from damage due to low power, the equipment will have to be reloaded with operating parameters once power is restored.

A short length of soft cable to the enclosure connects the central element of the infrasound array, WUAZ0. Six pair 24-gauge rodent proof (steel armored) telephone cable connect each infrasound sensor to the digitizer. These cables provide power to the active acoustic gauges and return the analog signals to the digitizer. In this installation, the ground (aluminum shield) was left unconnected. This type of cable also provides the opportunity to install the infrasound array without disturbing the soils in environmentally sensitive sites. The cable was purchased from ANIXTER and is identified as 0006PR/24 GR PE-89 TYPE (REA) FOAM SKIN/FILLED CORE/CACSP.

Each element of the tripartite infrasound array consists of a surface array of ten, 25-foot porous hoses that connect through a manifold (Figure 8) to a Chaparral Model 2 microphone modified for 12-volt operation (Hayward, 2000).

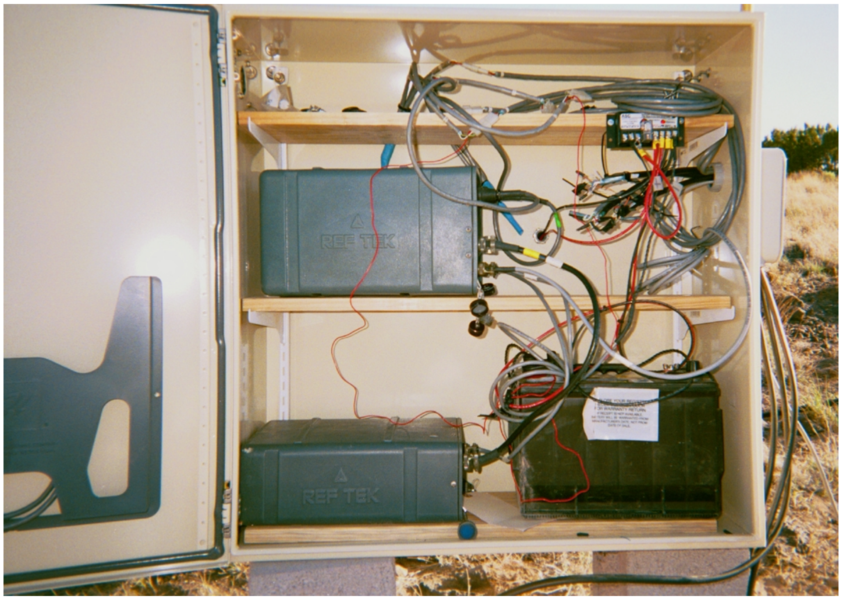

Figure 7. Installation of the RefTek 72A-06 digitizer, disk, and battery charger in the solar powered enclosure at Wupatki.

The test data was recorded with the following setup:

State of Health
01:028:08:43:26:488 ST: 1102
028:08:43:26 GPS: POSITION: N35:30:58.80 W111:22:27.87 +01551M
121:23:37:10 DSP CLOCK SET: OLD=01:028:08:43:28.007, NEW=01:121:23:37:10.007
121:23:37:10 DSP CLOCK DIFFERENCE: 8088822 SECS AND 0 MSECS
121:23:37:10 DSP CLOCK HAS CHANGED 4 TIMES
121:23:37:12 INTERNAL CLOCK TIME JERK # 1 OCCURRED AT 23:37:12.036
121:23:37:12 INTERNAL CLOCK RF DELAY IS 0 MSECS
121:23:37:12 INTERNAL CLOCK PHASE ERROR OF 0 USECONDS
121:23:37:13 DSP CLOCK SET: OLD=01:121:23:37:13.039, NEW=01:121:23:37:13.007
121:23:37:13 DSP CLOCK DIFFERENCE: 0 SECS AND -32 MSECS

121:23:37:13 DSP CLOCK HAS CHANGED 5 TIMES
121:23:54:06 GPS: POWER IS TURNED OFF

121:23:54:06 EXTERNAL CLOCK IS UNLOCKED
122:00:17:52 ACQUISITION STOP REQUESTED
122:00:17:53 PARAMETERS ERASED
122:00:17:53 WS
122:00:17:53 OM
122:00:17:56 NU
122:00:17:59 NC1
122:00:18:02 NC2
122:00:18:05 NC3
122:00:18:08 NC4
122:00:18:11 NC5
122:00:18:16 DD1
122:00:18:21 DD2
122:00:18:25 DD3
122:00:18:28 SC
122:00:18:29 XC

State of Health
01:122:00:18:30:571 ST: 1102
122:00:18:30 INTERNAL CLOCK PLL SET TO HARD 1HZ

122:00:18:30 DSP REPORTS 2 24-BIT A/D BOARDS
122:00:18:32 PARAMETERS IMPLEMENTED
122:00:18:32 DSP CLOCK SET: OLD=00:000:00:00:00.245, NEW=01:122:00:18:32.007
122:00:18:32 DSP CLOCK DIFFERENCE: 10455511 SECS AND 762 MSECS

122:00:18:32 DSP CLOCK HAS CHANGED 6 TIMES
122:00:19:02 SCSI COMMAND COMPLETE
122:00:19:52 CPU SOFTWARE V03.10A
122:00:19:52 ACQUISITION ENABLED WITH DELAY OF 00:00
122:00:19:52 LINK PARAMETER PACKETS

Station Channel Definition
01:122:00:18:31:647 ST: 1102
Experiment Number = 2
Experiment Name = westernUS
Comments - Continuous recording infrasound
Station Number = 4
Station Name = WUAZ
Station Comments - colocated 100m from seismic
DAS Model Number =
DAS Serial Number =
Experiment Start Time =
Time Clock Type = OTHR
Clock Serial Number = NONE

Channel Number = 1
Name - WUAZ1
Azimuth -
Inclination -
Location
X - Y - Z -
XY Units - Z Units -
Preamplifier Gain = 1
Sensor Model - Chapparal M2
Sensor Serial Number - 1315
Volts per Bit = 125.0 mV
Comments - modifeid for 12 V 40mV/ubar

Channel Number = 2
Name - WUAZ2
Azimuth -
Inclination -
Location
X - Y - Z -
XY Units - Z Units -
Preamplifier Gain = 1
Sensor Model - Chaparral M2
Sensor Serial Number - 1299
Volts per Bit = 125.0 mV
Comments - 40 mV/ubar

Channel Number = 3
Name - WUAZ3
Azimuth -
Inclination -
Location
X - Y - Z -
XY Units - Z Units -
Preamplifier Gain = 1
Sensor Model - Chaparral M2
Sensor Serial Number - 1296
Volts per Bit = 125.0 mV
Comments - 40 mV/ubar

Channel Number = 4
Name - WUAZ0
Azimuth -
Inclination -
Location
X - Y - Z -
XY Units - Z Units -
Preamplifier Gain = 1
Sensor Model - Chaparral M2
Sensor Serial Number - 1312
Volts per Bit = 125.0 mV
Comments - 40 mV/ubar

Channel Number = 5
Name - WUAZws
Azimuth -
Inclination -
Location
X - Y - Z -
XY Units - Z Units -
Preamplifier Gain = 1
Sensor Model - TV101
Sensor Serial Number - TV586973
Volts per Bit = 125.0 mV
Comments -

Wake-up Sequence Definition
01:122:00:18:31:647 ST: 1102

Power State : CP
Recording Mode : SC

Data Stream Definition
01:122:00:18:31:647 ST: 1102

Data Stream 1 Infrasound
Channels 1234
Sample rate 40 samples per second
Data Format CO
Filters
Trigger Type CON
Record Length (seconds) 600

Data Stream 2 Wind
Channels 5
Sample rate 1 samples per second
Data Format 32
Filters
Trigger Type CON
Record Length (seconds) 3600

Data Stream 3 acoustic
Channels 4
Sample rate 250 samples per second
Data Format 32
Filters
Trigger Type CON
Record Length (seconds) 60

Calibration Definition
01:122:00:18:31:647 ST: 1102
Start time : Year Day : :
Repeat Interval Days : :
Number of Repeats
Length of CAL (seconds)
Step OFF
Freq OFF
Noise OFF

State of Health
01:122:00:19:52:697 ST: 1102
122:00:19:52 ACQUISITION STARTED
122:00:19:52 STANDARD FORMAT EXTERNAL CLOCK
122:00:19:52 EXTERNAL CLOCK IS UNLOCKED
122:00:19:52 INTERNAL CLOCK RF DELAY IS 0 MSECS
122:00:19:54 SCSI COMMAND COMPLETE
122:00:22:42 AUTO DUMP CALLED
DAS: 1102 EV: 0003 DS: 3
FST = 2001:122:00:19:52:488
TT = 2001:122:00:19:52:488
NS: 15000 SPS: 250 ETO: 0
DAS: 1102 EV: 0004 DS: 3
FST = 2001:122:00:20:52:488
TT = 2001:122:00:20:52:488
NS: 15000 SPS: 250 ETO: 0
DAS: 1102 EV: 0005 DS: 3
FST = 2001:122:00:21:52:488
TT = 2001:122:00:21:52:488
NS: 15000 SPS: 250 ETO: 0

The individual infrasound sites, WUAZ1-WUAZ3, are pictured in Figures 9-13. The rocky soil with minimal vegetation is illustrated. Microphones have little protection from the winds in an area where winds can be substantial. These photographs also show the topography of the array and the mountain that rises above the array.

Figure 8. The solar powered enclosure for Wupatki where the digitizer (RefTek 72A-06), disk and battery are located. The solar panel is rated at 12 volts/ 64 watts and faces approximately south. The acoustic sensor and manifold are shown in the foreground.

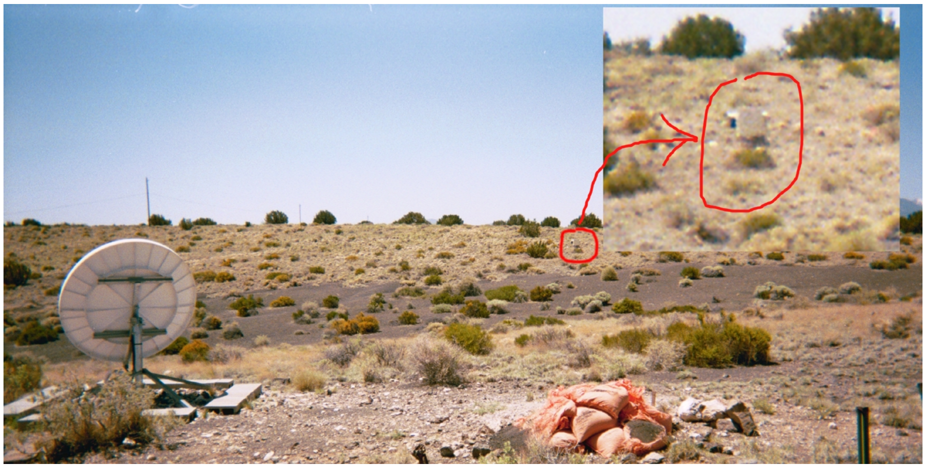

Figure 9. View from the WUAZ seismometer vault (orange bags) south towards the WUAZ0 central site of the array. The enclosure is barely visible from the WUAZ site (circled area and inset). Individual microphones are not visible from the central site.

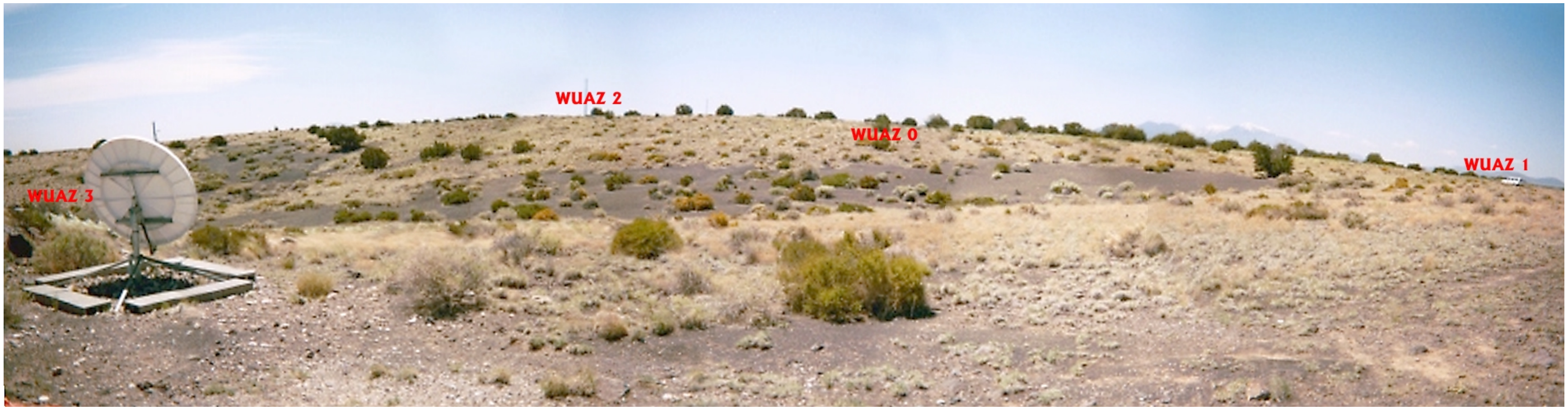

Figure 10. Panorama from WUAZ of the acoustic array. Field-of-view is about 220 degrees. Site locations are approximate.

Figure 11. Site WUAZ2 220 degree panorama. Site WUAZ1 is in the right 1/3 of the frame.

Figure 12. Site WUAZ1 is about 10 m from the service road.

Figure 13. Site WUAZ3 looking northwest towards WUAZ. The stiff connection cable has not yet relaxed enough to lie flat upon the ground. Even in the air, it is unlikely to result in significant additional wind noise.

All acoustic instruments have a sensitivity of 40 mV/μbar (400 mV/Pa).

Wind speed is recorded on channel 1 with a sensitivity of 1 Volt/1000 RPM. The specific calibration for the anemometer has not yet been determined. The recording system has one additional data acquisition channels that could be employed for sampling acoustic noise, other environmental information, or vertical ground motion.

Preliminary Data

Data from a 15-hour time period (Julian Day 122 of 2001) was recovered for purposes to assess the array installation. This initial data set spanned the time frame from Wednesday evening until late Thursday morning, a period starting with low wind conditions and ending during high winds.

The purpose of this analysis of a small amount of data is to demonstrate the operation of the sensors. A few possible problems were identified that need further investigation one the first data recovery is made.

Example of noise segments from acoustic channels.

Eighty minutes of noise data from the infrasound array are reproduced in Figure 14. One can identify the effects of the variable wind conditions. Relatively long-period signals of approximately 10 s move across the array at speeds of a few m/s. This effect was also observed in the preliminary analysis of the data from the Ft. Hancock array. The bottom four traces show a small signal about 240 seconds from the start of the trace.

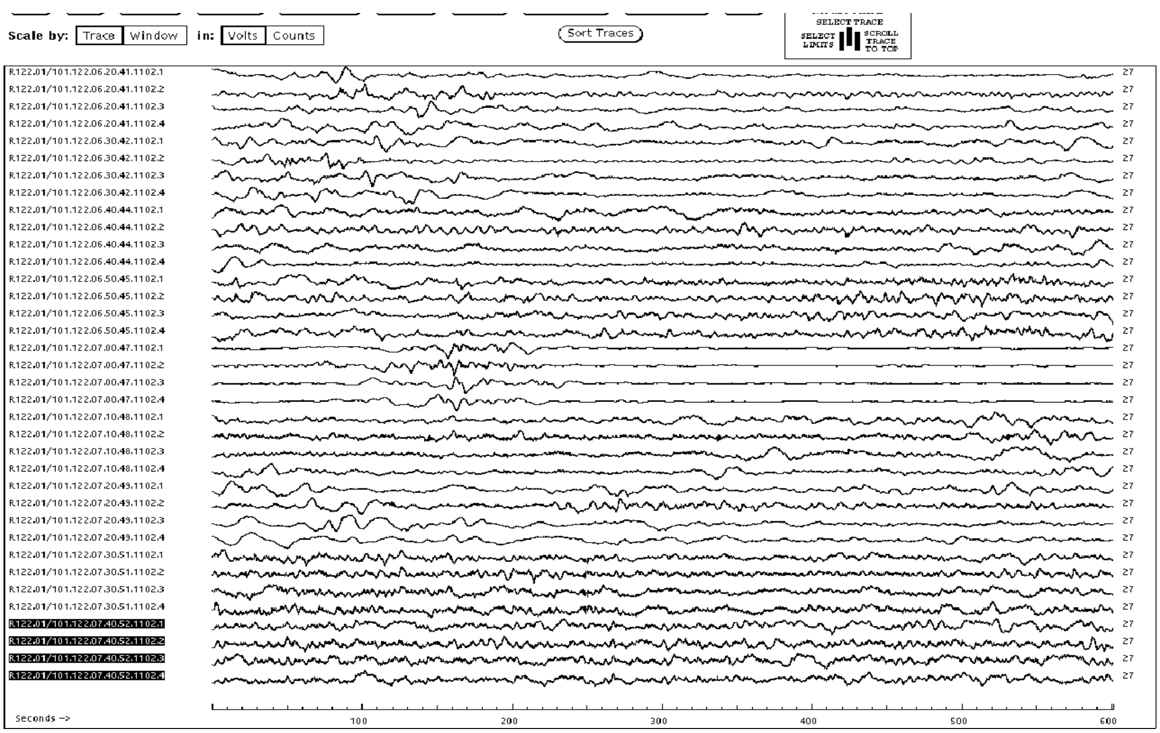

Figure 14. Ninety minutes of data from Julian Day 122 recorded at Wupatki. Nine continuous, 600-second data segments are plotted. Each set of four traces represents the data from the four acoustic sensors WUAZ1, WUAZ2, WUAZ3, WUAZ0. In this display the traces are trace independently scaled. Actual data traces for channels 3 (WUAZ3) and 4 (WUAZ0) are about ¼ that of the other two channels.

The channels are reasonably coherent during this relatively low wind condition. When all traces are scaled with a window constant scalar (Figure 15), it is obvious that the lower two are operating at a reduced gain. These two sensors, serial numbers 1296 and 1312 were in stalled in the field directly upon their repair at Chaparral. Either the gain switch is in the wrong position (low instead of high) or the sensor gain has been incorrectly adjusted.

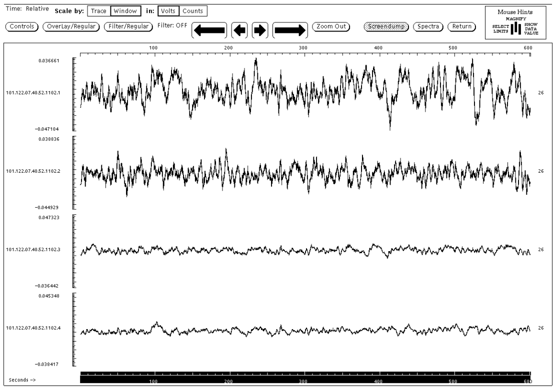

Figure 15. Ten minutes of data from infrasound sensors WUAZ1, WUAZ2, WUAZ3, and WUAZ0. The last two sensors have about ¼ the gain of the first two.

Example of acoustic signal.

An example of a small signal with coherence across the array is visible in the lower four traces of Figure 14. These signals are enlarged in Figure 16.

There are signals from four sensors displayed. The blue, red, green, black waveforms are from WUAZ1, WUAZ2, WUAZ3 and WUAZ0 sensors respectively. The data in Figure 8 has been filtered from 0.25 to 5 Hz in order to eliminate the long-period wind noise.

The signal is easily identified and coherent at all sites. It is lower frequency than those typically seen at other sites such as Tucson. On a single sensor it would be difficult to detect. One would expect that during high wind conditions, such signals will be impossible to recognize.

No other coherent signals traveling at acoustic velocities across the array were identified during this initial data sample. This observation is not surprising since most data was taken at night when manmade sources such as mining explosions typically do not occur. That data taken during the late morning is noisy due to the high winds.

Wind Speed Examples.

The output of the anemometer is minus 1 volt/1000 RPM of the cups. Nominal or actual calibrations of this anemometer head have not yet been made, but the system is believed to be reasonably linear at velocities above 2 mi/hr. Increasing wind speed results in a negative output voltage. Calm conditions result in nearly zero output.

Although the current system provides only relative wind conditions, it could be easily calibrated by referencing it to one of the two calibrated sensors we have available. This should be done for all systems prior to deinstallation.

Acoustic Data Samples.

During the installation test, channel WUAZ0, the central channel, was acquired at 250 SPS in order to test the system as a means of monitoring ambient noise. An overview of the acoustic channel is shown in Figure 18. The acoustic data stream was recorded in continuous 60-second records during the test period. It was then turned off for the normal operation. In the detailed Figure 19, five nonconsecutive 60-second records have been enlarged.

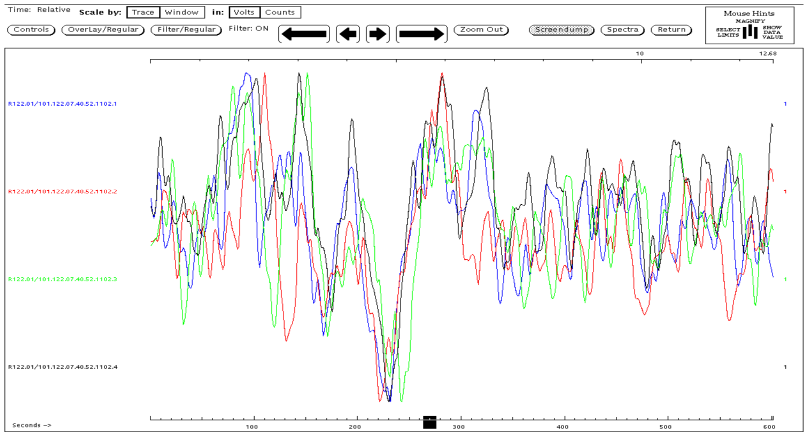

Figure 16. Overlay plot of the small signal in the lower four traces of Figure 14. The enlarged portion shown is 12.6 seconds long (top x scale) cut from the portion shown on the bottom scale. The black box indicates the 12.6 second window selected from the total 600 seconds of Figure 14.

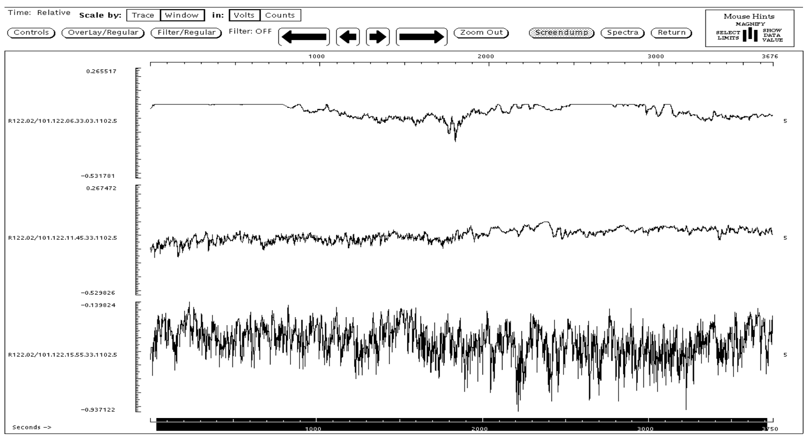

Figure 17. Wind speed recordings for three different hours. Anemometer output is sampled once per second. The top trace includes several minutes of dead calm. The bottom trace was recorded during high winds. Increasing wind velocity results in a negative (downward) deflection of the trace.

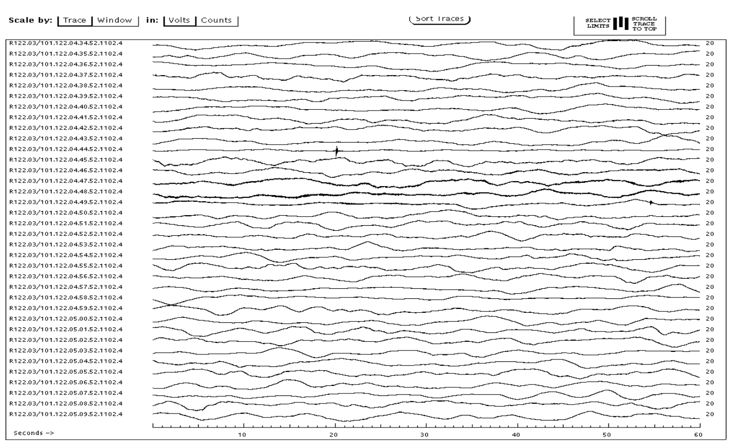

Figure 18. Overview of the channel recorded for ambient background monitoring. Each trace is only 60 second long and was recorded at 250 samples/second. The small signal on the 11th trace is probably a result of a footstep near the

acoustic sensor. The noise 14th and 15th traces, appearing as a heavier black line, is most likely to be either vehicle or aircraft noise.

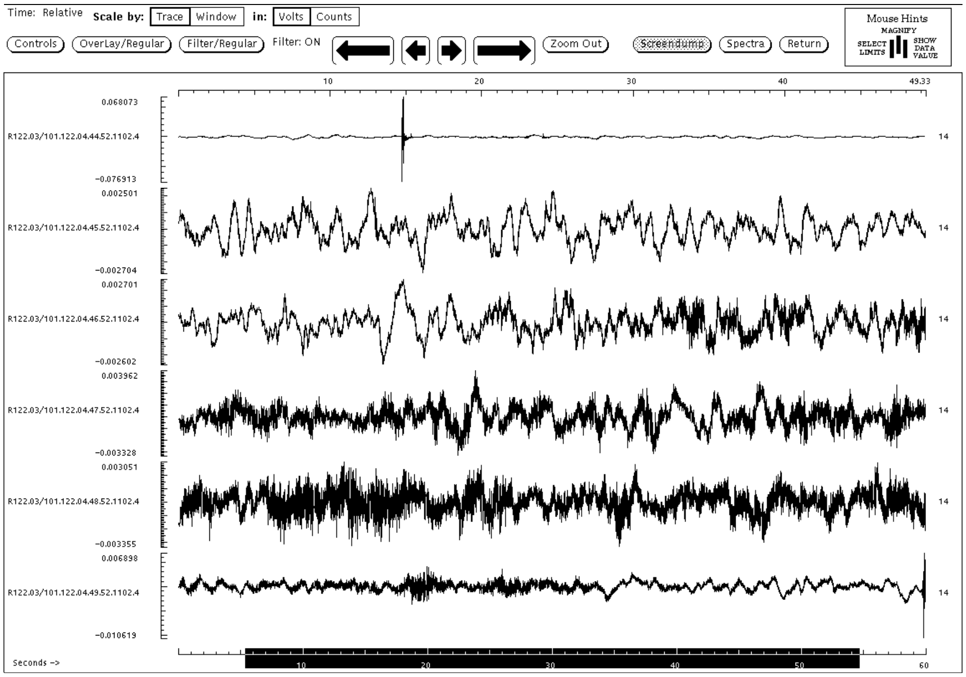

Figure 19. Site WUAZ0 recorded at 250 samples/second during 6 one-minute sampling periods. The high frequency noise on traces 4 and 5 is probably aircraft or vehicle noise. The spike on trace 1 is probably the result of a footstep or a vehicle door slam.

The enlarged traces indicate that although the sensor response begins to fall off at frequencies above 20 Hz due to the pipe array, there is still sufficient sensitivity to record some level of distant ambient noise. If this technique is to be used with the existing sensors, the complete instrument response including the pipe array will have to be determined for frequencies above 20 Hz. The alternative is to either use a sensor without the pipe array attached or to use a different sensor entirely.

Conclusions

A four-element infrasound array was installed at the site of the USNSN seismic station WUAZ on Woodhouse Mesa overlooking the Wupatki National Monument Visitor Center. As currently configured the stand-alone installation can operate unattended for up to three months providing 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, infrasound array at TXAR and Tucson and a seismo-acoustic station at Ft. Hancock, Texas (Figure 1).

The initial installation of the array was relatively simple. Co-location with WUAZ provides a database and access to seismic data. The enclosure and surface installation allowed a relatively unobtrusive installation with a minimum ground disturbance. The system is completely independent of the existing USNSN WUAZ station. Paul Whitefield, Nicole Tancreto, and Jeri DeYoung, National Park Service, were invaluable with their cooperation, suggestions and assistance during the installation.

Similar to the installation at Ft. Hancock, Texas, data from the array are recorded to disk that must be periodically exchanged. No provision was made for remote access to the data. Fourteen hours of nighttime data were acquired during the installation to assure that the sensors and data acquisition system was acquiring data. Since this data segment was at night, few events were identified. Long period noise, possibly associated with local winds, was identified and is consistent with local effects observed at other sites.

One problem was identified after study of the data. Two of the sensors appear to be switched to low gain. This could be a problem only for high frequency low-level signals taken during calm conditions. The months of May and June are typically windy. The problem will be addressed at the next site visit.

The current acquisition configuration is setup to record for as much as three months prior to requiring a site visit to change the disk. We anticipate changing disks more frequently during the summer until we have confidence in the installation.

Acknowledgements

Special thanks to Paul Whitefield, Nicole Tancreto, and Jeri DeYoung, National Park Service. Chris Hayward and Rongmao Zhou participated in the installation. Carl Thomason designed the array.

References

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