DATA REPORT

FOR

THE 1991 PIÑON FLAT BROADBAND ARRAY EXPERIMENT

***** PASSCAL Data Report 92-003 *****

Submitted by

H. Al-Shukri, T. Owens, G. Pavlis, S. Roecker, F. Vernon, and G. Wagner

May 1992

1. INTRODUCTION

During the winter and spring of 1991 the Kirghizia Seismic Array Committee (KSAC) of IRIS's Joint Seismic Program conducted a small aperture broadband array experiment in the vicinity of the Piñon Flat Observatory (PFO) in Southern California (Figure 1). This report is intended primarily to document the technical details of these data, their organization on data tapes that are the companion to this report, and any problems that are known to exist with these data. Piñon Flat was chosen as the site for this experiment because it is conveniently located near IGPP, UCSD, were key personnel in the experiment lived; because of the long history of this site as a geophysical observatory; and because existing seismic stations of the Anza and Southern California networks could provide related observational data. The PFO was also the site of the high frequency array experiment conducted by the same group during the Winter and Spring of 1990 (see PASSCAL Data Report #91-002), which provided additional constraints on the site condition, expected source characteristics, and wavefield properties at higher frequencies and wavenumbers than were possible with this experiment.

2. PROJECT SCIENCE TEAM

The Science Team for this experiment consisted of the following individuals.

Name	Institution
Haydar Alshukri	Indiana University
Tom Owens	University of South Carolina
Gary Pavlis	Indiana University
Steve Roecker	Rensselaer Polytecknic Institute
Frank Vernon	University of California, San Diego
Gregory Wagner	University of South Carolina

In addition, significant technical and software assistance was provided by the staff of the Institute of Geophysics and Planetary Physics at UCSD. The experiment would not have been as successful as it was without the effort and assistance offered by the following technical staff from IGPP: Glen Offield, James Batti, Phil Porter, and Adam Edelman. In addition, several people served as field personnel for periods ranging from 4 months to 1 week. These were, in order of length of service: Dan McNamara (University of South Carolina), Bing Jun Zheng (Indiana University), Paul Anderson (Indiana University), Chung Horn Lin (Rensselaer Polytechnic Institute), Rob Mellors (Indiana University), and Michael Hamburger (Indiana University). This project was also a joint effort with scientists from the USSR Academy of Sciences. The following Soviet scientists were involved in the execution of this experiment: Shumkar Bek, Vitali Bragen, Sergei Daragon, Peter Kasik, Ivan Kitov, Genedei Kolhelhev, Misha Krakov, Oleg Kuznetzov, Muktar Sartbaev, and Vasili Velikov.

3. ARRAY CONFIGURATION and INSTRUMENTATION

The Piñon Flat broadband array experiment was deployed with 28 sensors arranged in 5 concentric rings. The array configuration is similar to that of the NORESS array, but has an additional three-sensor ring with a diameter of 6 km (Figure 1). Stations are spaced at equi-angular increments around each ring. Figure 2 shows ring radii and sensor distribution.

The sensors used for this experiment were Streckeisen STS-2's and Guralp CMG-3ESP's. These are both broadband, 3-component sensors. The Streckeisen STS-2 has a velocity response that is flat from 0.00833 Hz (120s period) to 50 Hz. From 1-6 Guralp CMG-3ESP's were used when there were insufficient STS-2's to occupy all 28 sites. Guralp CMG-3ESP's have a velocity response that is flat from 0.033 Hz (30s period) to 30 Hz. The record of which station had what sensor is documented in calendar format at the end of this report.

Sensors were housed in mini-vaults designed and made at IGPP-SIO. These vaults consisted of a PVC tube with O-ring sealed, aluminum tops and bottoms, and an aluminum leveling plate (Figure 3). The purpose of these min-vaults was to provide a second level of defense against water for the STS-2, which was originally designed for installation in a conventional vault.

The experiment used Refraction Technology [Reftek] digitizers. The array was designed to have the A, B and C rings (16 sites) linked to the central recording site via wire lines, and the D and E rings (12 sites) linked via radio telemetry. Delays in radio deliveries resulted in the outer rings being operated as stand-alone PASSCAL stations for several weeks. Because of this mix of recording/communication methods, three different Reftek Data Acquisition Systems [DAS] configurations were used during the experiment:

- *Radio telemetry sites* - This experiment tested a new application of the Reftek digitizers. Standard PASSCAL recorders were converted to telemetry instruments by swapping the EPROMs in the 72A-02 Digital Acquisition System (DAS). In this mode the DAS digitizes the data locally and transmits data to the central receiving site (see below) by digital telemetry. A repeater located at site D1 was used to relay station D2's data to the central recording site. Figure 3 shows a schematic configuration of the radio telemetry site. All D and E ring sites, except D3 and E1 were run as radio telemetry sites after mid-March.

- *Wire line telemetry sites* - All A, B, and C ring sites were operated in telemetry mode for the duration of the experiment. At these sites, wires replaced the radio links used in the outer rings stations. From an end users perspective the most important difference with these sites is that a wire provides a more stable transmission media and hence these stations were subject to fewer telemetry dro-pouts than the radio stations. Figure 4 shows a schematic configuration of the wire line telemetry site.

- *Stand-alone PASSCAL sites* - Each stand-alone site was equipped with a standard PASSCAL DAS with a 320 Mbyte disk and an OMEGA clock. These sites recorded both 100 sample/sec triggered and 20 sample/sec continuous data. A LTA/STA algorithm was used for triggering decisions. Triggered data was recorded for a preset window length of 90 secs. Because of poor radio communications, stations D3 and E1 remained in stand-alone PASSCAL mode for the duration of the experiment. All D and E ring sites were operated in stand-alone PASSCAL mode from February 18 (day 049) to March 2 (day 061). Figure 5 shows a schematic configuration of the stand-alone site.

Data received at the central site were processed by a recording system developed at IGPP that was founded on principles developed by Reftek in the RT-44 telemetry system used by the ANZA network. The recording system consists of three functional units. An RT-44 receives inbound packets from all stations, time aligns all data, multiplexes the digital data, and transmits these data by a serial link to a second RT-44, which is in turn connected to a micro-VAX computer. The second RT-44 handles communications in both directions, but also records a 20 sps continuous data stream on a DAT drive. The micro-VAX makes trigger decisions using a standard STA/LTA algorithm along with a voting scheme. When a trigger is declared, the micro-VAX dumped data at 100 sps to a DAT tape. Figure 6 shows a schematic diagram of the central recording site.

All telemetry stations could be monitored from the central recording site. Mass recentering and calibration could also be performed from the central site. Both commands could be applied to individual stations or every station in the array. Some sensors required frequent recentering, but we were unable to reconstruct the complete recenter history of each station. In all cases stations requiring frequent recenters could be traced to one of two problems: (1) instability of the foundation of the mini-vault, or (2) ground loop problems at stations C2 and C3 (see below). Stations having instability problems can be identified from the history calendar for each station as those that had to be "reburied".

4. FIELD PROCEDURE and INSTALLATION

Sites were located using Global Positioning System [GPS] equipment borrowed from the GPS group at IGPP-SIO. The GPS equipment consisted of two Eagle, PC-based GPS receives and one Trimble hand held receiver. One of the PC-based receivers remained at the center site (A0) for the duration of the site location survey. The hand held GPS receiver was used to get a rough site location, and the second PC-based GPS receiver used to refine the location. When the desired site location was found, the remote and central PC-based receivers recorded location data simultaneously, using the same satellites, for 15-20 minutes logging a fix every 10 seconds.

Most measurements were made with 3 visible satellites, which does not allow elevation determination. Occasionally, more than 3 satellites were in the sky, but elevation from these locations were ignored. Instead, all station elevations were determined by plotting the GPS location on a photographically enlarged topographic map.

We used two GPS receivers in this mode to try to use relative GPS surveying. This is important since an absolute GPS fix is subject to a serious errors due to fluctuations in the apparent path length through the atmosphere. For this reason a fix from a single GPS receiver is generally quoted to be no better than ± 10m. Reduction of the GPS data collected at the beginning of the experiment indicate that the locations errors in these data are at best about ± 2.00 meters in both the N-S and E-W directions. This measure of error is based on scatter of individual fixes at an individual site. (See the file "GPS.report" in the auxiliary tape distributed with this report for details on how these data were reduced and how this error estimate was determined.) However, the results of plotting the determined points on a map indicates this may be overly optimistic. Locations that fall near clear landmarks (e.g roads or houses) suggest the typical accuracy of the estimates locations is about ± 10m. However, it is not clear to us that the topographic maps are accurate to this scale. Therefore, we suspect the ± 2 m error estimates are reasonable, but if you wish to be conservative ± 10 m is a reasonable upper bound on the station location errors.

The near surface geology at this site is very uniform. Every station except E2 lies on the granodiorite of the Piñon batholith. The top 1 m of ground is totally decomposed granodiorite. This grades into grus, then corestone, and becomes jointed granodiorite at a depth of 25 m or less [Wyatt, 1982] A hole was dug at each site to permit us, as best as possible, to situate the sensors on rock. Where possible holes were dug with a backhoe. These were: (1) all A and B ring sites; (2) C1 and C7; and (3) D9. Backhoed holes were dug as deeply as possible with the equipment. Where the backhoe could not be used, holes were dug by hand with pick and shovels as deeply as possible with these hand tools. Holes were from 0.5 to 2 meters deep. In all cases, the material at the bottom of the hole was weathered granodiorite that provided a solid base.

Mini-vaults were anchored to the bedrock using plaster. The mini-vaults were aligned to true north (note: D2 was accidentally aligned to magnetic north) and leveled during plastering. Sensors were installed as they arrived and had passed testing and field preparation at IGPP-SIO. After a sensor was installed, leveled, allowed to settle for several days, and releveled if necessary, the mini-vault was covered with a plastic garbage can and buried. In this process, we were careful to isolate the can from the mini-vault and its base to reduce the effect of settling of the soil around the can. Burying the sensors this way insulated them from the wind and from temperature variations. Nearly all sites were covered to the normal ground level. The only visible evidence of the presence of the sensor was a cable coming from the ground. The only exception was station D2 which was located on the side of a rock wall. This station had rock at the surface. To provide insulation, we covered the garbage can with rocks and soil scraped from the surrounding area. Several vaults were periodically unearthed to swap sensors, or to allow for sensor servicing or releveling (see auxiliary files for site history log).

The inner, wire line sites were the first to be occupied and record data. The A, B and C-rings began recording data on February 9, 1991 (Julian day 040). After the inner rings were operational assembly of the antenna and solar panel masts for the radio telemetry sites began (D and E-rings). When it became clear that radios would not be delivered until much later than expected, D and E-ring DAS's were collected from the field and reprogrammed to work in stand-alone PASSCAL mode. These DAS's were redeployed starting on February 18, 1991 (Julian day 049). Data was retrived from the stand-alone sites every other day. The 100 sps data collected this way was merged with the networked A, B and C-ring data. The merging of the 20 sps data was delayed until later.

Radio telemetry sites became operational over a two week period starting March 2, 1991 (Julian day 061). Radios required testing and adjustment before these functioned reliably.

Three additional stand-alone sites were deployed at the beginning of April to record a Nevada Test Site shot (event ID 91094190046). These three F-ring stations are shown on Figure 1. Because the exact date of the shot was not announced, several days of data prior the shot were also recorded. Each of these sites was equipped as a stand-alone station with battery power. These sites recorded only high and low gain 100sps triggered stream. The sensors were situated on rock outcrops, insulated with foam, covered with a plastic garbage can and camouflaged. These sites collected data for approximately three days.

On April 9 (Julian day 099), 12 sensors were removed from the array and shipped to the PASSCAL instrument center for distribution to other experiments. The remaining sensors were distributed to the D and E-rings to facilitate further testing of the radio telemetry hardware to be deployed in Kirghizia, USSR later in the year. Only four sensors remained in the inner rings (A0, C3, C5, C7). The last day of data collection was April 22, 1991 (Julian day 112), and the last event in this data set is the April 22, 1991, Costa Rican earthquake. Users should note that data from day 99 through day 112 should be viewed cautiously as the testing that was going on at the time was not fully documented. Consequently, these data may contain major deficiencies and should be treated skeptically.

5. DATA REDUCTION

The 100 sps field data was transferred to IGPP for preliminary processing and format conversion. As we mentioned earlier the field data was collected in two format. Data from the central recording site (VAX - RT-44 system) was recorded on DAT tapes in a modified ANZA network format. The second data format, which was collected from the stand alone stations, was recorded on EXABYTE tapes in Reftek field format. Both sets of media contained data from two different streams: the 100 sps triggered data stream and the 20 sps continuous data stream. This report relates to only the 100 sps triggered data stream.

The data was processed to its final form using the following procedure:

(1) Demultiplexing of network tapes. In this step we used a demultiplexing program called "rnt". This program took the input DAT tape written by the microVAX, demultiplexed the data, and wrote the output traces in CSS format.

(2) Trace editing. The objective here was to screen the data to remove false triggers. For the network data this was found to be dominated by false triggers caused by sudden increases in the level of microseism noise. For this step we used the "pql" (PASSCAL Quick Look) program which was modified by Gary Pavlis to read data files in CSS format. By the end of this step all trigger events were identified and tabulated as local, regional, teleseism, NTS shot, or noise.

(3) The edited triggered data files were archived on DAT tapes using the "ant" program. The original field tapes and the archived tapes are all at IGPP. Step 1 through 3 were continued to the end of the experiment and repeated for all tapes. The final archive tapes were then read to disk for the next processing step.

(4) Merge data. This step required a few preparatory operations for event identification and format compatibility. First, the field EXABYTE tapes from the stand-alone stations were read with the ref2segy program. This program produces single trace files in the PASSCAL SEGY format. Second, the array trigger times were identified using the network data files as reference. Finally, the network data and the sliced stand alone stations data was time aligned, merged, and all written out to disk in CSS format.

(5) Conversion of CSS format data to Standard Earthquake Exchange Data (SEED) format is accomplished by using the following programs:

1- mkseedhdr: Takes array station parameter database files and generates SEED blocketts.

2- css2seed: Generates SEED data records.

3- output: Merges SEED blocketts with SEED data records and writes logical SEED volume.

6. DATA DESCRIPTION

The trace data is written on 1 tape in SEED format. The SEED waveform data is written in original, unmodified digitizer counts. The SEED tape will contain SEED blocketts which describe sensor orientation and the complete response parameters for every channel. Using this information the true ground motion can be reconstructed within the errors of calibration. The user must be aware that they must not blindly assume a fixed orientation for a given channel on all stations due to alignment variations (see below). You should also be reminded that this experiment used a mix of Guralp and Streckeisen seismometers, and the SEED tape documents the response of each of these sensors.

In addition to the data tape we also supply a tape of auxiliary information containing a set of ascii files any user will find necessary. This tape was produced on a SUN4 computer running SunOS 4.1.1 in tar format. It contains the following ASCII files: ‘

(1) report.ms and report.ps: This Data Report in troff (ms macro package) and postscript format respectively.

(2) GPS.report and GPS.report.ps: A GPS data reduction report written by Tom Owens immediately after he reduced the GPS site location data. These two files

are in troff (ms macro package) and in postscript format respectively.

(3) event.log: Information about the events recorded by the array. This list was compiled from the Anza and Caltech catalogs.

(4) fig1.ps, fig2.ps, fig3.ps, etc.: Figures related to this report in postscript format.

(5) a0.ps, a1.ps, ..etc: Site log files in postscript format. These files provide a graphic description of the history of each station in a calendar format.

(6) station.xyz: Station location information. This file is a table containing station location information in two formats. First, station locations are listed in decimal degrees of latitude and longitude along with their elevation in meters. In addition, however, this table lists the location of each station in meters relative to station A0. In this coordinate system +x is East and +y is North. We include both location parameters for the convenience of the user as some software packages work better with relative coordinates while others need absolute coordinates. In particular, the user is warned that conversion of these data to formats that use a 32 bit IEEE floating point number to store the latitude and longitude of a station (e.g. SAC) can lead to insufficient accuracy of the relative location of that station (about ± 100 m in the E-W direction). This problem is one of the major reasons we have included this file rather than depend upon the values stored in the SEED headers.

The user should note that the number of samples per trace is highly variable from event to event. This is in contrast to event triggered data from instruments running in conventional stand-alone, trigger mode where the record length is constant for all stations. Furthermore, the user should also recognize that all traces for a given event have the same length. They also all start and end at the same time. The telemetry system produces traces this way automatically. Note, however, that we forced the same format for merging these different data sets. That is, stand-alone stations traces were truncated to start and end at the same times as the telemetry station traces. Time sections not overlapping with telemetry traces were set to positive full scale (16 bit word full scale is +32767) values to distinguished them from telemetry dropouts which are set to negative full scale.

The final processing and analysis of the triggered 100 sps data showed that from February 8 to April 20 1991 we recorded 270 distinct events. Of these, we were able to identify 130 as earthquakes located within 450 km of the array (see event.log file). In addition, we recorded three nuclear explosion from the Nevada Test Site. The triggers times for these three explosions are as follows:

Month	Day	Hour	Minute	Second
March	8	21	2	44.88
April	4	19	0	0.58
April	16	15	29	59.23

Figure (7) shows examples of a local event, regional event, a teleseismic event and one of the NTS shots.

As expected in most new experiments, there were a few problems that we feel are important enough to alert the future users of this data about. These problems include:

- Telemetry dropouts: These are easily identified as a negative full scale gliche with a duration of one second that occurs simultaneously on all 6 channels. Multiple dropouts lead to gliches spanning a multiple of 1 second.

- Merge artifacts: As described above we processed these data to merge data from stand-alone and telemetry stations. Because the stand-alone stations trigger at independent times, and for fixed intervals some times intervals may not have data from these stations. To clarify this, the software we used to merge the data set samples at these times to positive full scale to distinguish them from telemetry dropouts.

- Station operation interruption: Not all stations were operational at all times, especially at the beginning and end of the experiment. In most cases the dead channels were removed form the data set, but some dead traces are still present in this data release.

- Move-out time: During the period of initial radio installation, which was during the period between March 4 and March 9, we noticed that a few station have clear timing errors. This was caused by the fact that for the first several days of radio operation some stations had a reception problem on the command uplink. With this telemetry system time is transmitted periodically from the central site. Because the uplink radio was not receiving properly, this caused the time tags on data packets transmitted from each station to be wrong, and hence the RT-44 misaligned the data.

- We noticed that one event (trigger time: 91-104-08:42:33) that has zero move-out across the array. We believe this was caused by a transmission error between the RT-44 and the microVAX which led to dropping a 0.5 second buffer right at the time of the first arrival at the array. This is error occurred during the late stage when extensive testing was going on on the equipment, so this is a type example of a caveat on data from the closeout phase of the array (see above).

- Station alignment: The orientation of seismic channels recorded on the SEED tape is not consistent between different stations, but the proper orientation information is recorded on the tape and should be examined carefully to avoid errors. The actual pattern is simple, but must be recognized. For all Guralp sensors, channels 1 and 4 are vertical components with positive up; channels 2 and 5 are north-south horizontals with north positive; and channels 3 and 6 are east-west horizontals with east positive. This is a standard orientation convention. However, for all STS-2 sensors, with the exception of D2 (see below), channels 1 and

4 are vertical with up positive; channels 2 and 5 are east-west horizontal components with west positive; and channels 3 and 6 are north-south horizontal components with north positive. i.e. all STS-2 horizontal components are rotated counterclockwise by 90^o from the more standard orientation defined by the Guralps. This was caused by an orientation error when the sensors were installed which we chose to never correct as it would have required us to dig up most of the sensors in the array. Station D2 is an exception because it was mistakenly aligned to magnetic north instead of geographic north. At Piñon Flat the magnetic declination is 14^o East

- Array shut down: Due to heavy rains and subsequent flooding, the array was shut down during the period between February 28 and March 5.

- Sensors were not buried for several weeks at the beginning of experiment. Because of this some of the records may contain significant amounts of noise. Data may contain both long and short period noise which can be attributed to sources that include long and short period temperature variations, and wind vibrations. In addition, the STS-2's have a temperature stability problem. When the sensor undergoes a rapid change in temperature, the sensor can go into a long period oscillation that can last for many minutes. This problem occurred frequently during this earlier period to sensors at mid morning and in the late afternoon. (The site log files list the dates that sensors were buried.)

- Stations C2 and C3 experienced a peculiar ground loop problem that was not solved until March 21 (day 080). We discovered at that time that the wire lines used to supply power and return telemetry acted as 60 Hz ground paths for electric power in the area. This caused these stations to occasionally fail. Signals from these stations during these periods are easily identified as garbage, but the user needs to be aware of the problem and look at data from these two stations with caution. The problem was eventually solved by electrically isolating the sensors from the ground to prevent stray currents from flowing through signal ground wires.

7. ACKNOWLEDGEMENTS

A large number of people helped make this experiment a success. In addition to those noted above, we wish to acknowledge Marina Glushko for programming support for production of the final released data. We also thank Nadia Sena for handling logistical support for the large group of Soviet collaborators, and for Kate Harps and Kitty Hakk for administrative support. We are grateful to the PASSCAL instrument center staff at Lamont-Doherty for working with us in the loan of broadband sensors. Finally, we thank the U.S. Geological Survey for providing support for the visiting Soviet scientists who worked on this project.

References

Wyatt, F., Displacements of surface monuments, horizontal movements, *J. Geophys. Res.*, *87*, 979-989, 1982.

Figure Captions

Figure 1. 1991 Piñon Flat Broadband Array. Main map shows the location of Piñon Flat in southern California. The lower inset shows the geometry of this array. The upper onset shows an expanded view of the array relative to major faults in the region (dashed lines), the Anza Gap (shaded region, and local earthquakes recorded by the array (stars). It also shows the location of three temporary stations deployed to record NTS shot on April 4, 1991.

Figure 2. Station configuration of the 1991 Piñon Flat Broadband Array. The radius lengths of each ring are listed in the lower right corner.

Figure 3. Schematic configuration of the sensor's mini-vault and the ratio telemetry site.

Figure 4. Schematic configuration of the wire line telemetry site.

Figure 5. Schematic configuration of the stand-alone PASSCAL site.

Figure 6. Schematic diagram of the central recording site.

Figure 7. Typical events recoded at 100 sps by the 1991 Piñon Flat Broadband Array. Only the vertical components of local (Figure 6a), regional (Figure 6b), teleseism (Figure 6c), the April 4, 1991 NTS shot (Figure 6d) are shown.