

USArray Design Workshop

San Diego, CA

May 3-4, 2001

Introduction

The USArray Design Workshop was held in San Diego May 3-4, 2001 to discuss array design issues for USArray. The purpose of this focused workshop was to look at the array geometry and how it will affect the imaging science that will come out of the program.

The "Bigfoot" component of USArray will consist of 400 broadband stations on a 70 km grid. These stations will occupy a given site on the ground for approximately 18 months and then move to another location. To date two possible orientations have been looked at. One is to have the array configured as a square array 1400 km on a side. The second is to have the array configured as a more linear array in a North/South orientation across the US. The question addressed by the workshop was: Do either of these (or some other potential orientation) offer significant advantages for lithospheric and deep Earth studies, including tomography and other types of imaging?

The participants discussed a broad range of issues related to the types of scientific investigations that would be conducted with the data from the USArray. A summary of these issues and their impact on USArray operations is given in the following sections.

Tomography

For upper mantle body wave or surface wave tomography, a 70 km station spacing is sufficient. Denser deployments will not bring much improvement in the resolution. For resolution of crustal structure, however, deployments of the flexible array will be needed, in which 1 Hz instruments will be almost as useful as broadband sensors.

An array width of at least 1000 km is optimal. The 100 station permanent array is needed to tie results from different deployments together.

The usefulness of the ultra-high frequency instruments (4.5 Hz) would be improved if the sensors are also sensitive to teleseismic P waves (1 Hz) so that they could be deployed in short, local imaging experiments using passive sources.

The OBS deployment should be included as an integral part of the USArray effort. The OBS deployment should extend far enough offshore to record body wave rays that cross the subcontinental upper mantle at depth. While the complex upper mantle structure in the transition from the oceans to the continent could possibly be resolved in a deployment of a year's length, body wave tomography, in the higher noise ocean environment, will benefit from a deployment extending to two years.

Shear Wave Splitting and Receiver Functions

The array geometry will not have a significant effect on shear-wave splitting analyses since these have generally been done one station at a time. To understand rapid changes in polarization that are often seen, it will be important to maintain the planned station spacing of 70 km or less. Once the overall shear-wave splitting pattern is established with Bigfoot, the flexible array can be used to explore regions of rapid shear-wave splitting changes in greater detail.

In more advanced studies, migration of receiver functions uses processing methods that require multiple recordings of the same event. In this case, the geometry of the Bigfoot array will make a difference. However, as long as the minimum array dimension is at least 1000 km, there should be no problem in fully exploiting the data. For a 400 element transportable array at a 70-km instrument spacing, this restricts the aspect ratio of a rectangular array to be no greater than 2 to 1.

Data from the New England region will be most useful if data are collected from southernmost Canada at the same time in order to make the array wider and less pointed toward Maine, we recommend starting discussions with Canada to deploy USArray in southern Ontario and Quebec.

The Bigfoot array as designed can provide detailed images of the uppermost mantle from about 200km depth to the base of the transition zone using receiver function migration and direct wavefield imaging techniques. Shallower structures can be illuminated by stacked receiver function images that have low lateral resolution, but shallower structures cannot be generally illuminated with migrations of data from a 70km grid, given the expected frequency content of teleseismic signals. The only possibility to provide high lateral resolution of the crust and lithospheric/tectospheric mantle beneath USArray using receiver function migration imaging is to augment Bigfoot with the broadband and 1Hz flexible array to increase the station density. Some of the flexible array deployments should be designed to enhance the imaging capabilities of USArray as a whole, targeting the upper mantle, the lithosphere and tectosphere mantle, and the crust.

Numerical wave propagation theory suggests that instruments on a rectangular grid are optimally placed for event azimuths at 45 degrees to the array rows and columns. This will naturally occur for the main event back-azimuths from the northwest and southeast in the western US if the Bigfoot target grid is NS/EW in orientation. As USArray moves east the event azimuths will shift and there is no predominant event azimuth.

Deep Mantle and Core Investigations

Wavefield sampling for deep Earth applications typically involves 10°-15° distance ranges. This is the characteristic profile length for the study of expected waveform variations from deep triplications, scattering, interactions with deep slabs, core mantle boundary structure, and core phases.

Exciting target structures for discovery/analysis in the lower mantle are three-dimensional; therefore, two-dimensional station sampling is essential. A minimum array

dimension of 1000 km is well motivated by patterns of observed lateral variation in traveltime, amplitude and waveform anomalies. Most existing data involve less lateral sampling and often fail to uniquely resolve overall structures. There will be major advances in characterization of the structure with more extensive, uniform wavefield sampling. Variation in range is essential for reference phase identification and behavior, but comparable azimuthal coverage is equally important. Narrow linear configurations are to be avoided, but some asymmetry such as 2:1 ratio is not a problem so long as the minimum dimension is at least 1000 km.

A station spacing of 70 km on two-dimensional grids is valuable and necessary for resolving rapid gradients in structure. Spatial resolution of deep structure can be attained using suites of sources, enhancing wavefield sampling to necessary levels. Several examples of small-scale structures of great interest have been extracted from portable and fixed station deployments with 50-100 km spacing (e.g., Terrascope/BDSN, German National Array, S. Africa, Tanzania, Iceland). Migration of multi-event array recordings may be used to resolve sub-fresnel zone deep structure, but requires ~70-km, high station number sampling.

Deployment should be not less than 2 years at each site to accumulate data from sufficient and diverse sets of earthquakes. Also, good site quality as well as accurate horizontal component orientation is essential for broadband body wave data for the deep Earth applications listed above.

Logistics and operations

A North/South oriented array that runs from the Canadian border to the Mexican border is preferable from a logistics point of view. This orientation provides more flexibility in being able to work in the field all year. It also has the minimum driving distance for moving stations.

We are especially concerned about station calibration. The current level of errors in the orientation of the USNSN array, and also some GSN stations (up to 30° from N) is not acceptable. An error of 1° in orientation from N, or from vertical introduces an error of 40 dB in crosstalk signal (compared to the 140 dB cross talk of the data logger). We advocate a study to establish the correct test to administer after station installation, in contrast to the current calibration tests in the PASSCAL instruments. This test should also include some simple outside source (e.g. a ball of fixed weight dropped from a fixed height at fixed distances from E, W, N, S), and time stamps must be quality controlled (easy to do with telemetry in which the signal is received a fraction of a second after it is recorded).

Summary Recommendations and Suggestions

- A rectangular array spanning the US in a North/South orientation will be satisfactory as long as the minimum dimension is on the order of 1000 km.

- In order to provide more data from “permanent” stations it would be desirable to acquire the regional broadband data for the entire time the array is deployed in the US.
- As much as possible, the flexible array deployments should be designed to enhance the imaging capabilities of the entire array for crust-upper mantle studies using receiver function imaging. Many possibilities arise for image enhancement deployments.
- Calibrations and orientation are critical elements for post processing.
- Individual stations should be recorded for as much of the nominal 24-month deployment time as possible.
- The first few stations should be co-located with regional network sites to provide ground truth and system calibration.
- OBS deployments should be included as an integral part of the USArray effort.
- Need display software to easily view events recorded across the array
- Need data quality assessment software running in real-time.
- Need better ways to display state-of-health information and waveforms from 400 station arrays.
- The DCC must provide immediate feedback to field teams for data verification and problem identification.

Workshop Participants

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