3.1.8. IS-COORDINATED ACTIVITIES

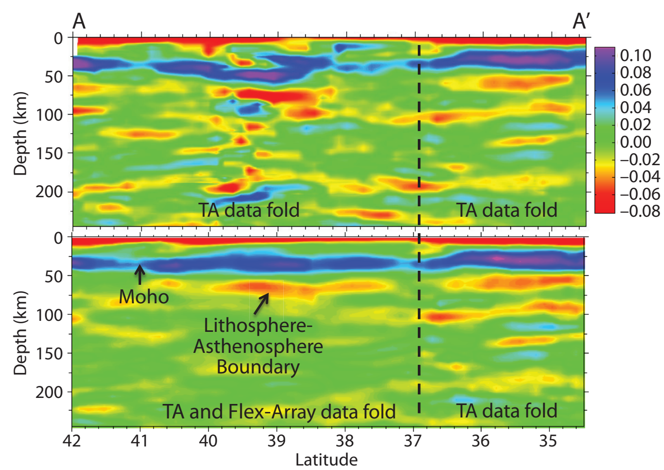
The forefront of seismological research is constantly evolving. New scientific questions drive new algorithms and techniques, which in turn stimulate the need for new observatory and equipment capabilities. The resultant new data sets lead to even newer techniques that better exploit the data and can lead to new geological hypotheses. This feedback loop has been present since the inception of IRIS as a community facility to implement and operate the seismological infrastructure that supports the ever-changing science requirements of the community. The revolution in instrumentation and data standards that emerged in the 1980s was championed and adopted in the early years of IRIS—24-bit data loggers, broadband feedback seismometers, real-time telemetry and advanced data management systems—and have served to put the US academic community at the forefront of global seismological research. While there has continued to be evolution in IRIS utilization of these technologies over the past 20 years, revolutionary technologies that are now available or on the close horizon offer the opportunity to stimulate another significant advance in seismological research. To this end, IRIS IS will undertake and coordinate four key instrumentation activities described below that will address the communities' future instrumentation needs; build the foundations of future observatories; and promulgate knowledge and best practices to enhance data quality, availability, and impact.

- Leverage new technological opportunities to define and demonstrate a forward-looking New Technology (NT) portable instrument pool to address the community's needs for infrastructure that supports the needs of the evolving science.
- Seed the exploration of a Global Array of Broadband Arrays (GABBA)—a worldwide distribution of arrays—for addressing a number of key science objectives, primarily in deep Earth structure and source dynamics of large earthquakes.
- Lay the groundwork for a possible Subduction Zone Observatory (SZO) spanning the margin of the eastern Pacific Ocean, over 18,000 km from the Aleutians to the tip of Tierra del Fuego.
- Share IRIS' instrumentation experience to improve international seismological networks for the benefit of both research and hazard applications.

3.1.8.1. PAN-IRIS NEW TECHNOLOGY

Instrumentation Services will implement leading-edge technology to support PIs whose science objectives exceed the capabilities of today's equipment. Virtually every field experiment, regardless of scale, seeks to use more sensors to improve resolution so as to avoid spatial aliasing, edge effects, and other characteristics of undersampling (Figure COORD-1). However, existing systems do not scale well to very large numbers of sensors. The logistics introduced by the size, weight, and power consumption of current systems limits the size of experiments, and the cost and complexity of the instruments have further limited the number of units that can be acquired and maintained.

The NT effort will create a prototype system to address the community's expressed desire for portable seismic sensing systems that can support large numbers of sensors ("large N") that can be deployed easily and quickly. Such systems open the door for PIs to realistically consider designing experiments requiring potentially hundreds to thousands of sensors in a single experiment (Figure COORD-2). A wide range of existing deployments are already hitting the limits of the current instrument pool, including traditional PASSCAL and Flexible Array experiments, polar deployments, and aftershock studies. Other experiments, such as passive-source high-resolution arrays, cannot even be implemented without a dramatic increase in the number of sensors and an equally significant decrease in the deployment-related field logistics. This need is particularly acute for relatively unstudied but operationally challenging environments such as volcanoes and glaciers, where the availability of large N systems has the potential to yield transformative scientific results.



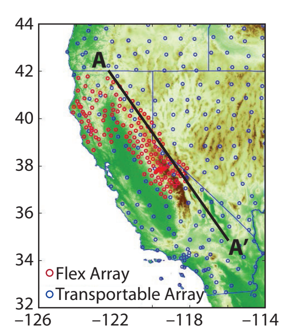


Figure COORD-1. (above) Receiver function image along the Sierra Nevada range. (top) Transportable Array (TA) data-only image. (bottom) TA data augmented with Flexible Array (FA) data. The TA-only image contains significant imaging artifacts and is unreliable. Yet, the combined TA and FA image is much higher quality, illuminating the negative velocity gradient associated with the lithosphere-asthenosphere boundary. The combined data image fold is enhanced five times. The filter band is 30–2 s and the image bin size is 100 km. (left) Topography, cross section, and station locations. The circles show the FA stations (red) and the TA stations (blue). *(Figure courtesy of Ken Dueker and Katie Foster)*

The key technical issues for creating next-generation portable systems are common across multiple IRIS programs. Thus, the NT effort will lead to increased observing capabilities and operational efficiency across IRIS. A side benefit of an equipment pool that contains a much larger numbers of sensors is increased instrument availability for small experiments, which may alleviate some pressure on the traditional broadband pool. Finally, the new technology effort will directly inform, if not directly address, other portable sensor pool recapitalization plans (e.g., the single-channel Texans or three-channel broadband instruments) by providing comprehensive user-needs analysis and validated technical performance characteristics. IRIS has been deferring its investments in refreshing the portable instrument pool while awaiting the maturation of developing new technologies that are now available and this project will guide these investments going forward.

While the technology applicable to seismic instrumentation is changing rapidly, there are no silver bullets as the fundamental laws of physics still apply (i.e., the physics dictates certain relations between weight, power, bandwidth, and telemetry). System configuration and performance tradeoffs must be made. To this end, user needs must be defined, system specifications and requirements set, and performance and interoperability validated. This systematic approach is key to realizing this first demonstration of a system that can be scaled to very large numbers of highly-portable sensors and relies on historical experience with current instrumentation. This IS-coordinated activity will define both the portable instrument pool of the future and will substantially expand the scientific opportunities for the design and implementation of all kinds of seismic experiments. There will also be an impact far beyond IRIS, as groups around the world follow IRIS' lead in technology selection, implementation, and operational practice—resulting in a multiplier effect for the scientific community based on IRIS' instrumentation investments.

Scientific Justification. A wide range of science objectives require deploying sensors in large numbers, whether in tight spatial arrays or distributed over larger areas. In May 2012, 27 researchers and instrumentalists representing a wide spectrum of seismology interests came together in Seattle for a full-day meeting to explore the science needs and goals for large N experiments. More recently, at the IRIS Workshop in June 2012, over 100 people participated in a standing-room-only special interest group discussion on "Next-Generation Instrumentation for Portable Seismology." Table COORD-1 is based on the discussions at these meetings and captures the key science objectives enabled by large N sensor systems.

Proposed Activities. This effort will use well-defined systems engineering processes to specify, acquire, integrate and deploy a sensor system based primarily on existing and emerging technologies (commercial off the shelf [COTS] or COTS-ready technology). The project will not, to any significant degree, be engaged in component design and development. The first year of the multiyear process will focus on conducting community-driven assessments designed to further identify user needs and match them to system performance specifications (e.g., bandwidth, dynamic range) and operational characteristics (e.g., size, weight, power). In subsequent years, the resultant system specifications will drive validation testing of the underlying technology, followed by acquisition, system integration, and testing culminating in the deployment of a demonstration system. The system will be designed to address the community identified engineering, logistical, and environmental challenges, and provide a means to develop and test practical field operations and instrument management protocols as well as evaluate data quality.

The number of sensors in the demonstration system will depend on the final cost per unit with the goal to create a system consisting of at least several hundred sensors in order to achieve the necessary scale for meaningful evaluation. In the fourth and fifth years of the award, the system will be tested in PI-led field experiments. Thus, even this demonstration system will enable new science. Critical lessons learned from the prototype

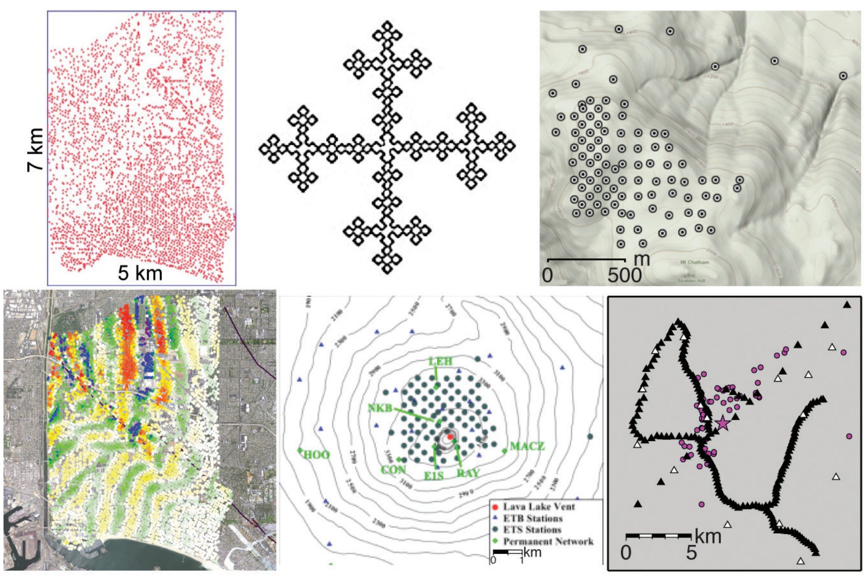


Figure COORD-2. Examples of large N instrument deployments and applications, assembled from the large N workshop, Seattle, WA, 5/24/2012. Top row, left to right: NodalSeismic Inc.'s deployment of 5,000 sensors across 35 km^2 in Long Beach, CA; fractal array (antenna) design concept (courtesy of Jesse Lawrence); array deployment to study episodic tremor and slip (courtesy of Ken Creager). Bottom row, left to right: Wavefield propagation imaged by the NodalSeismic Inc. deployment; a sample volcano array study on Mt. Erebus; traditional (white stations) and densified (black stations) rapid array deployments following the 2011 Virginia earthquake and its aftershocks (magenta symbols).

Table COORD-1. Summary of science targets and goals and associated sensor deployment strategies enabled by large N systems. These themes emerged over the course of the numerous presentations and extensive discussion at the Seattle and IRIS workshop meetings.

Target Subject	Science Goals	Required Sensor Deployments
Earthquake physics	• Distribution and timing of seismicity clusters • Deep fault structure • Evolution of faults with time • Interconnections of slip, tremor and earthquakes	• Proximal recordings over large regions of aftershocks • Long-term networks to capture fault rupture for significant earthquakes • Low noise, dense networks for small amplitude tremor signals
Structure/ imaging	• Earth structure without spatial aliasing and spurious imaging artifacts • Crustal structure and properties, such as anisotropy • Lithosphere structure and lithosphere-asthenosphere transition • Mantle and core structure - bridging gap between imaging scatterers and full volumetric heterogeneity • Determine empirical structure through slowness, amplitude and spatial evolution of wavefield	• Dense deployments across key crustal targets • High resolution 2D regional scale deployments • Array deployments optimized for continental and global scale observations • Array deployments optimized for continuum seismic recording and wavefield gradiometry
Volcanoes	• Temporal changes in magmatic systems • Seismic interferometry of highly scattering volcanic systems	• Deployments in harsh, remote volcanic environments
Energy and the environment	• Improved facies characterization • Imaging geology beneath high-velocity surface layers • Porosity / permeability estimates • Mapping thin layers with P and S attributes	• Deployments with extreme sensor densities normally only available via cabled systems • Operations in urban and rural settings
Polar, fluvial and cryosphere	• Sub-ice sheet Earth structure • Climate change • Sub-glacial waterflow and erosion • Ice thickness • Impact of sea level rise on calving glacier systems • Coupling of rivers and the solid earth	• Rapid deployment of instruments in environments with high field operations costs • Deployment on and around glaciers • Low impact deployments in sensitive environments • Extremely dense networks to capture scattered wavefield
Hazards	• Operational aftershock forecasting • 4D mapping of post-earthquake stress and strain fields • Detection, mapping, forecasting of eruptive activity • Pre-, during-, and post-earthquake analysis of the behavior of the built environment	• Rapid deployment of dense sensor arrays over aftershock zone - to enable use of exploration industry imaging techniques • Deployment around volcanoes showing pre-eruptive activity • Deployments in or near structures

array will be applied in future years to creating a sustainable portable large N system that supports PIs in acquiring unique and novel seismic data. The net result will be an enhanced capability to operate and maintain the portable instrument facility going forward in a cost-effective manner.

3.1.8.2. GLOBAL ARRAY OF BROADBAND ARRAYS

The proposed Global Array of Broadband Arrays will provide a detailed view into Earth via a global distribution of wide-aperture broadband arrays (Figure COORD-3). Clearly, the development of such a facility is a long-term international effort, but momentum for building such a facility is increasing. There were well-attended special interest group discussions on the topic at the fall 2011 meeting of the American Geophysical Union, followed by a subsequent community-driven meeting at the 2012 IRIS Workshop. A workshop on the same topic is planned for early 2013 and already a number of key international participants have indicated their interest in attending. The foundation of this ambitious effort will be a prototype GABBA array site within the conterminous United States, which can be created through the careful leveraging of NSF's investment in TA stations. This first of (hopefully) many GABBA sites will demonstrate the GABBA concept and provide a testbed for array capability and operational models. Locating the array in the eastern United States will provide scientific synergies with GeoPRISMS' Eastern North America primary site. The international community will be engaged to encourage follow-on GABBA arrays.

Scientific Justification. *The Seismological Grand Challenges* report (Lay, 2009) recognizes that seismic arrays offer great potential for resolving important questions regarding such

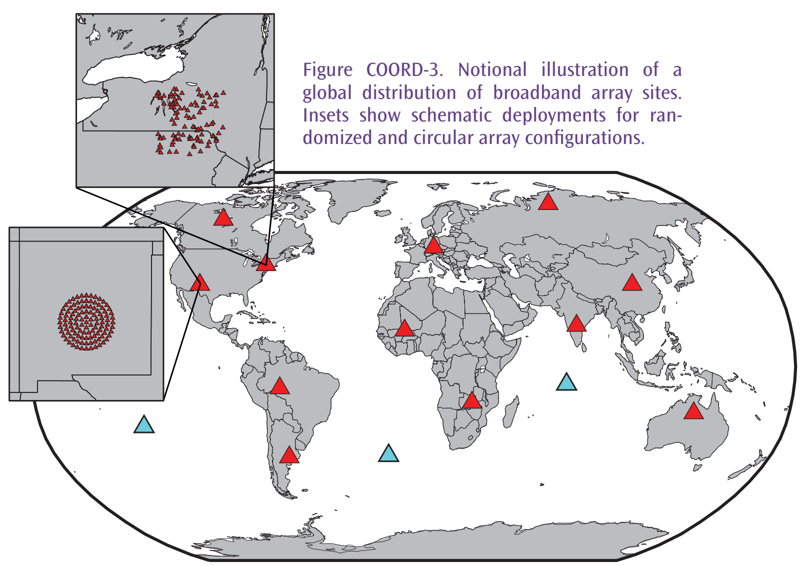


Figure COORD-3. Notional illustration of a global distribution of broadband array sites. Insets show schematic deployments for randomized and circular array configurations.