IRIS Observational Seismology - Looking Back and Looking Ahead

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Abstract

Over the past third of a century the Incorporated Research Institutions for Seismology (IRIS) has facilitated observational seismology in many ways. At the beginning of IRIS in 1984, and with the support of the National Science Foundation and in partnership with the US Geological Survey, IRIS embarked on deploying the Global Seismographic Network (GSN). Key characteristics of the GSN are its use of high-performance digitizers, very broad band seismometers, strong motion accelerometers, and high frequency sensors to provide multi-decadal observations across a wide frequency band and dynamic range. The IRIS Portable Array Seismic Studies of the Continental Lithosphere (PASSCAL) program has also operated since 1984. PASSCAL's extensive inventory of seismic equipment has been used by scientists to make observations on every part of the globe. The number and breadth of observations made with this equipment has fueled thousands of research papers and contributed to the education of hundreds, if not thousands, of students. More recently, the IRIS-operated EarthScope Transportable Array (TA) provided a breakthrough in the systematic collection of data using an array of unprecedented size. The success of the TA has ushered in a new era of "Large N" seismology, focused on dense spatial coverage of sensors to reduce aliasing and provide more complete recording of the full wavefield. The TA highlighted the power of survey mode data collection, where systematic, spatially-dense, and high-quality data fuel data-driven discovery, as opposed to deployments made to test a specific hypothesis. Key future directions in observational seismology include an increasing emphasis on wavefield measurements. Deploying instruments in large numbers requires reductions in the size, weight, and power of units, as well as a focus on dirt-to-desktop data management strategies that merge data and metadata while minimizing human intervention with the data flow from the sensor in the dirt to the scientist's desktop. Other critical frontiers include pervasive seafloor observations to enable studies of key structures like subduction zones, more accessible satellite telemetry to enable ubiquitous sensing of the environment, and new sensing technologies such as MEMS and Distributed Acoustic Sensing.

NSF
SAGE Seismological Facility for the Advancement of Geoscience

IRIS Observational Seismology - Looking Back and Looking Ahead

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Incorporated Research Institutions for Seismology (IRIS)

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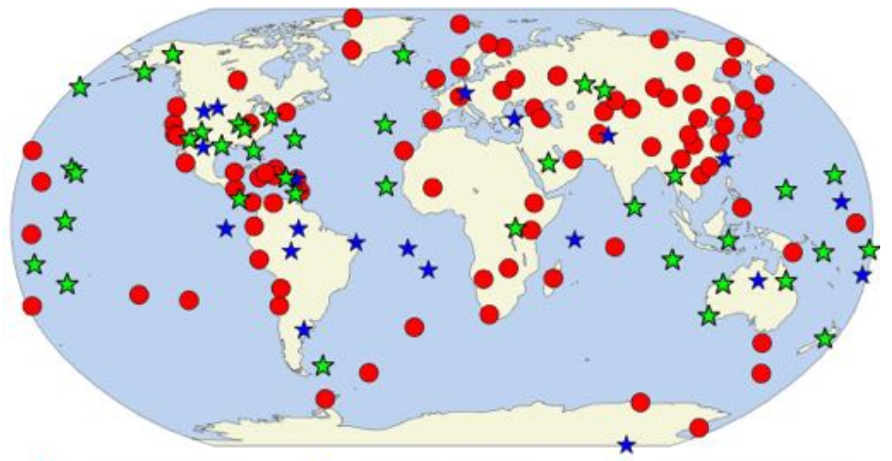
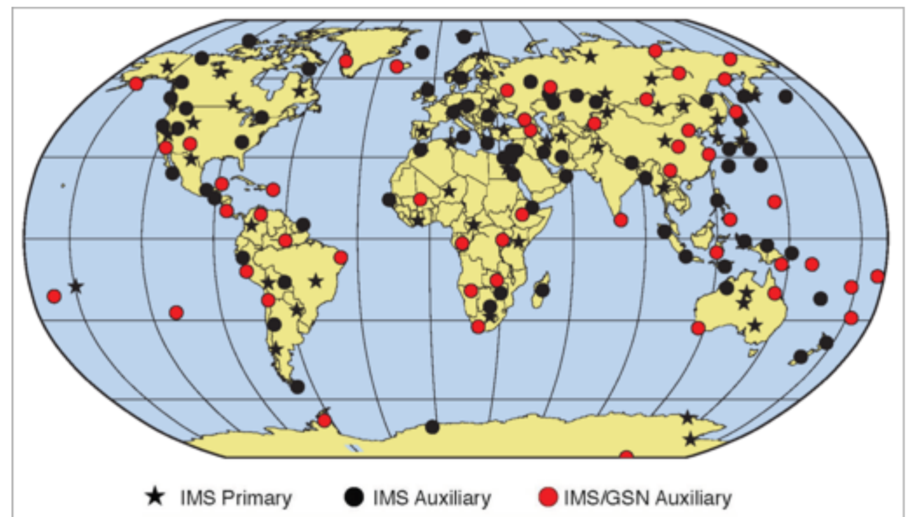
Operated by IRIS

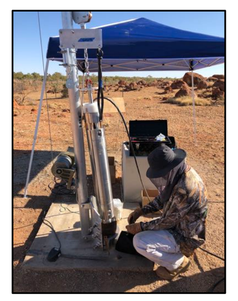


Current status of the GSN deployment, highlighting stations with recently upgraded VBB borehole seismometers



GSN stations are a critical component of worldwide seismic and nuclear monitoring networks, e.g., the International Monitoring System (IMS).

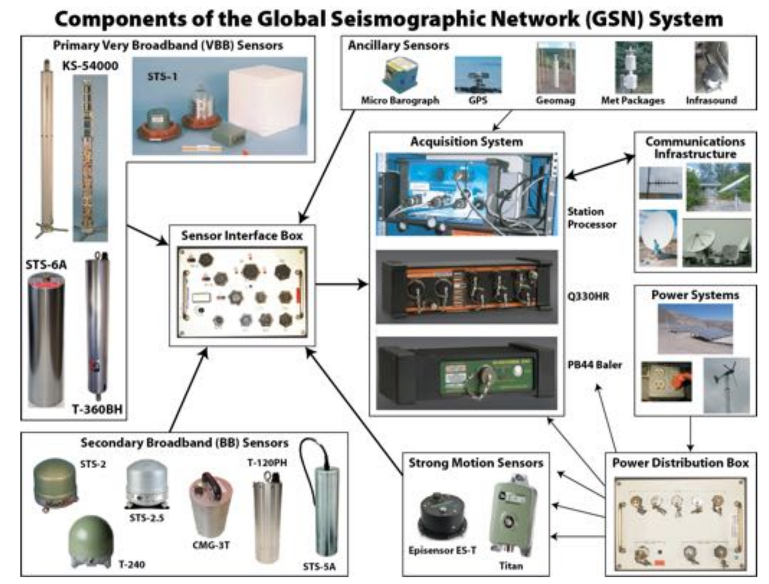


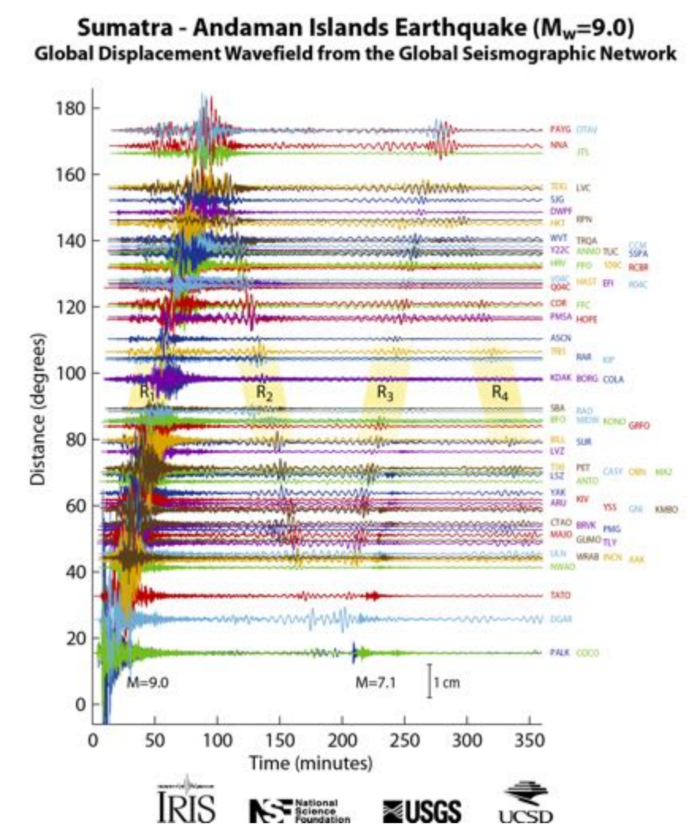


Borehole sensors at IDA network (II) stations KURK (Kazakhstan), MBAR (Uganda), and WRAB (Australia) were upgraded in 2019.

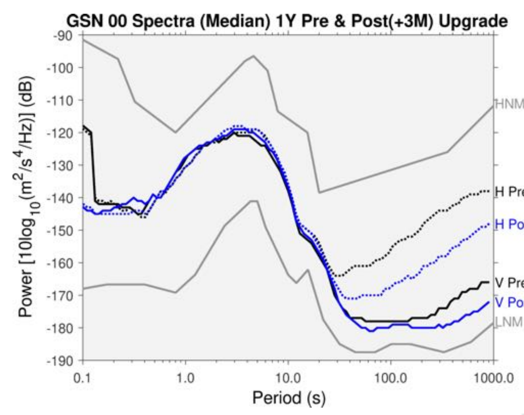
Global Seismographic Network

- Consistent, high-quality decadal-scale global observations
- Uniform, high-dynamic range observations combining very broadband and strong motion sensing at each site
- Full real-time telemetry, having evolved from (at the time) revolutionary international direct-dial access
- Strategies to minimize noise, including use of boreholes and tunnels
- Leveraged predecessor networks including WWSSN, DWWSSN, HGLP, SRO, ASRO, and GDSN
- Consistent efforts to maintain state-of-the-art instrumentation, communication and power technologies



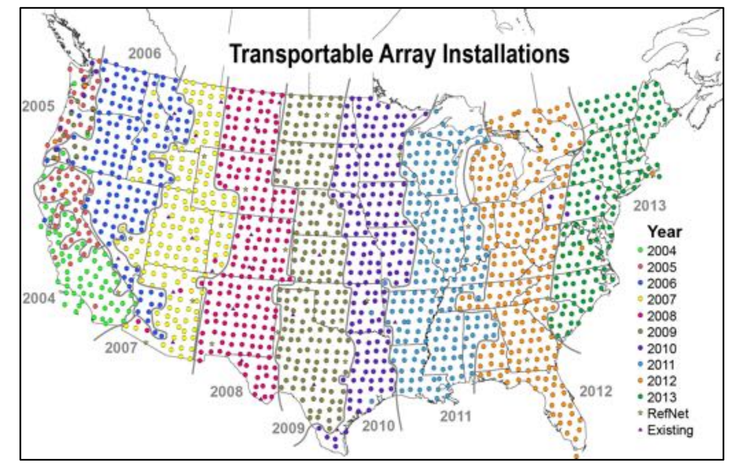


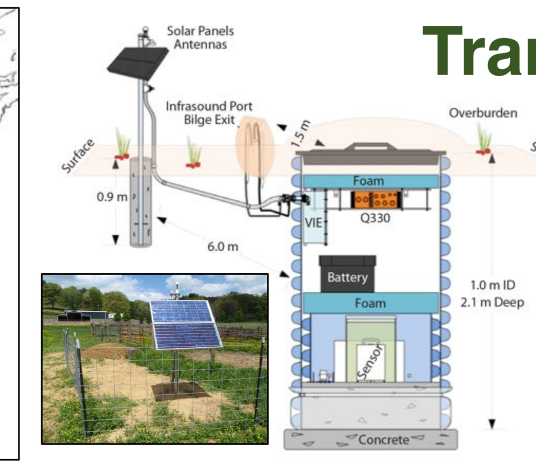
The GSN has recorded in extreme fidelity the very long-period signals generated by the 2004 Sumatra and other great earthquakes.

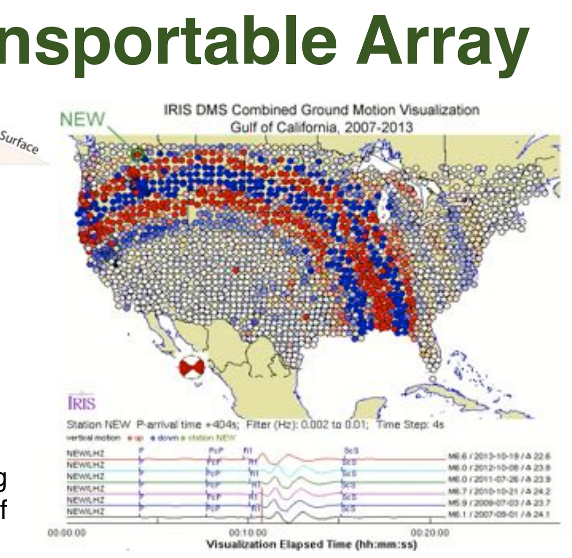


Left: As seen from the median ambient seismic spectra observed at upgraded GSN stations, the replacement of aging VBB primary seismometers has resulted in marked improvement in the performance of these stations at periods >30 seconds.

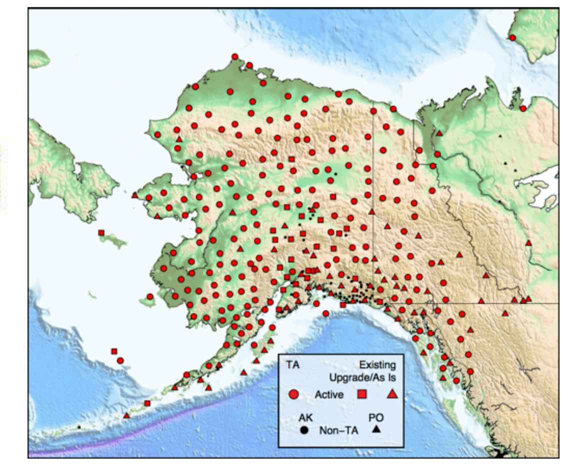
Transportable Array

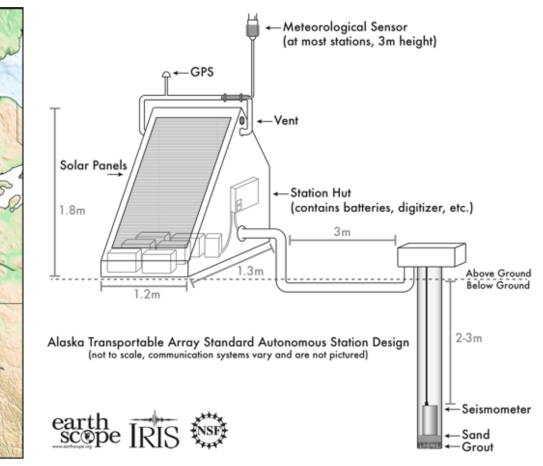






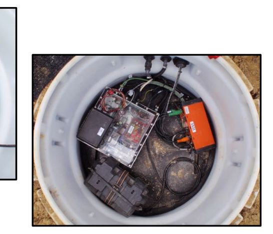
The Lower-48 TA (2004-2015) was migrated across the country from west to east, deploying seismometers in uniformly designed vaults with real-time dataflow and quality monitoring. This style of deployment and operation was unprecedented in its scale.

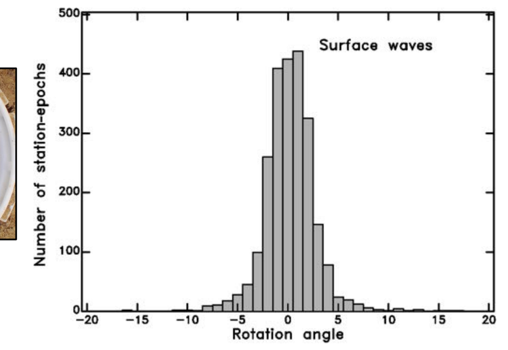


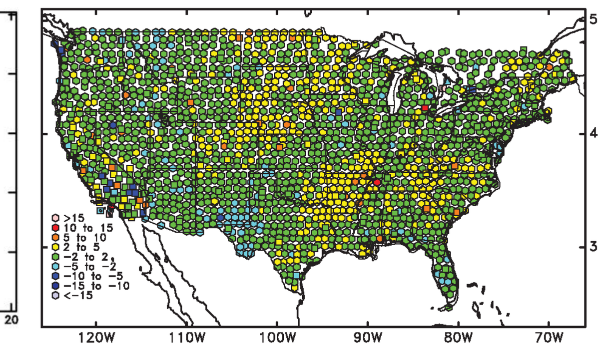


The Alaska TA (2015-2020) deployed a fixed array of posthole seismometers in remote locations using a portable drilling rig. Stations leveraged new power and communication technology to operate autonomously in harsh environments.



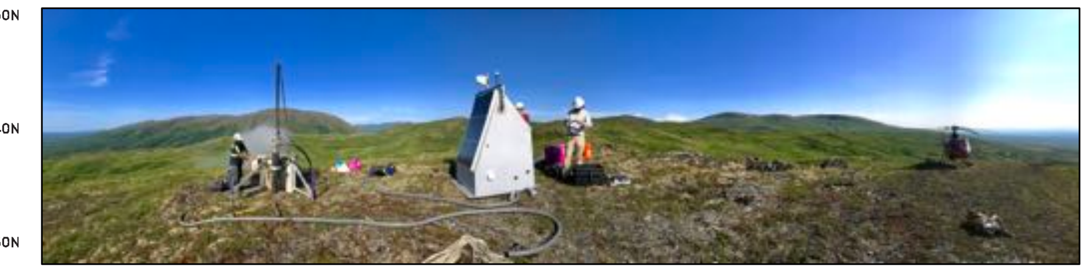


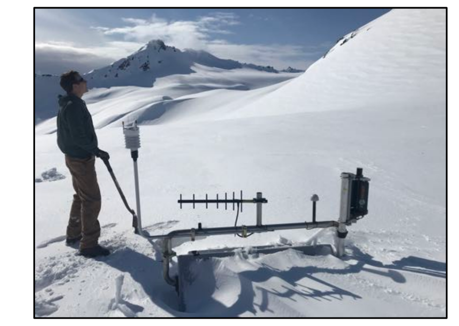




After initially using compasses for orientation, the TA switched to using the Octans fiber optic gyroscope and a differential GPS-based azimuthal pointing system to orient seismometers. Surface wave polarizations show that this yielded very accurate orientations (Ekström and Nettles, 2018).

Right: The Octans provided a reliable and efficient method of orienting seismometers emplaced in 3 m deep postholes.






- A manufacturing approach – high quality stations replicated thousands of times
- Consistency of design, operation, and quality control enabled unprecedented network performance
- Applied a survey driven, rather than hypothesis driven, approach to the data collection effort
- Collected uniform, high quality data, agnostic to underlying structure or hypotheses
- Created a legacy of stations that continue under auspices of other organizations (well over 250)
- Systematic collection of adjunct data – high precision infrasound, barometric, and meteorological data
- Wavefield observations across the lower 48 states and Alaska

Shared Principles Across Programs

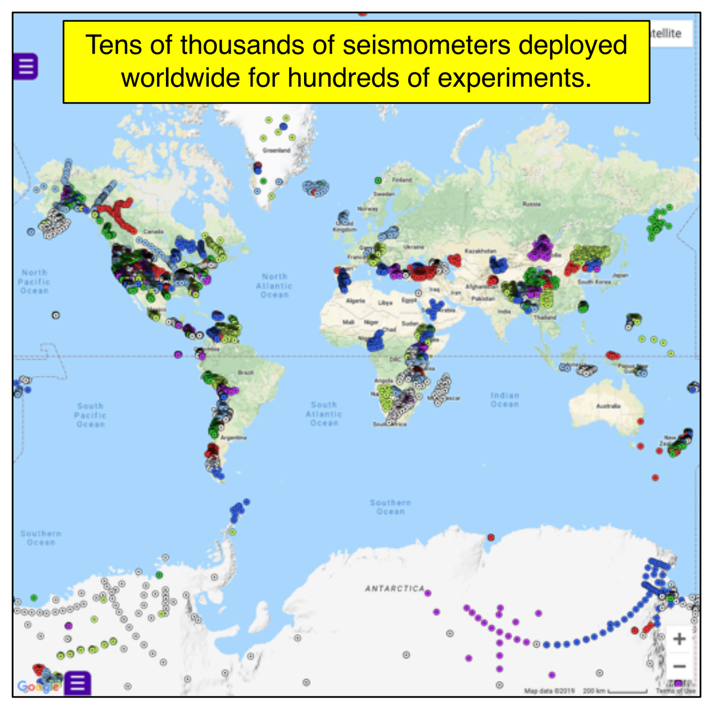
- Open access data
- A commitment to high quality data and metadata
- Design goals, capabilities, standards and formats are developed in close coordination with the seismological research community
- Field operations linked to network operations linked to data management
- Attention to optimal sensor emplacement
- Robust network command, control, and data collection procedures
- Calibration of sensors
- Test and evaluation of new technologies

IRIS Quality Principles

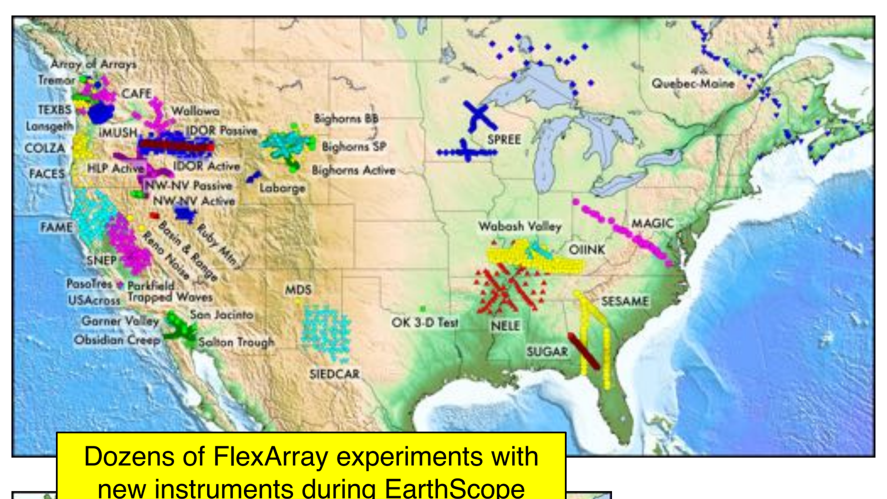
1. All users shall have information available to them that identifies the processes and methods by which the data were collected.
2. All users shall have information available to them that identifies the data quality assurance process utilized by the facility.
3. There shall be mechanisms for operators to pass through to data users key information obtained as part of their data collection and quality assessment processes, including information that quantifies the integrity and state of the data time series and the validity and goodness of metadata and data time series.
4. All users of data shall have metrics describing data quality available to them, in a manner that allows use either directly by humans (e.g., web browser) or through computer interfaces (e.g., web services) where metrics can be directly included in workflows.
5. The facility shall always strive to provide the most accurate metadata possible, and will update metadata when new information becomes available.
6. There shall be a mechanism for data users who register to report data quality information into the system.
7. There shall be a mechanism for data users to obtain updates regarding data or metadata changes.
8. IRIS-sponsored network / station operators shall have a quality plan, and implement quality processes that adhere to the larger facility-wide plan.

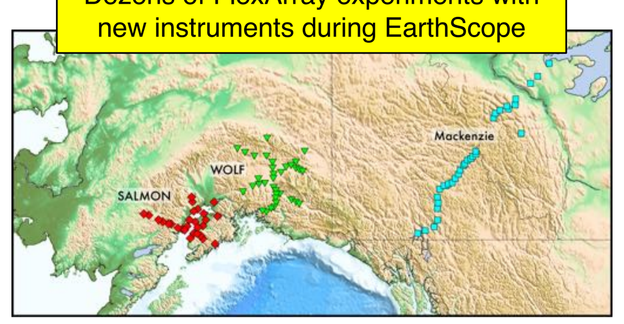
This material is based upon work supported by SAGE, which is a major facility operated by IRIS and funded by the National Science Foundation under award EAR-1851048.

PASSCAL



- Democratized access to state-of-the-art seismic instruments
- Supports PI led experiments with a common instrument pool
- Enables new scales of experiments – beyond what one person can own
- Encourages wide-spread seismic exploration of the planet
- Supports experiments ranging from broadbands sensing of the deep Earth to high frequency active source experiments targeting crustal structure
- Wide use of 1st gen nodes (Texans); now being replaced with 2nd gen nodes



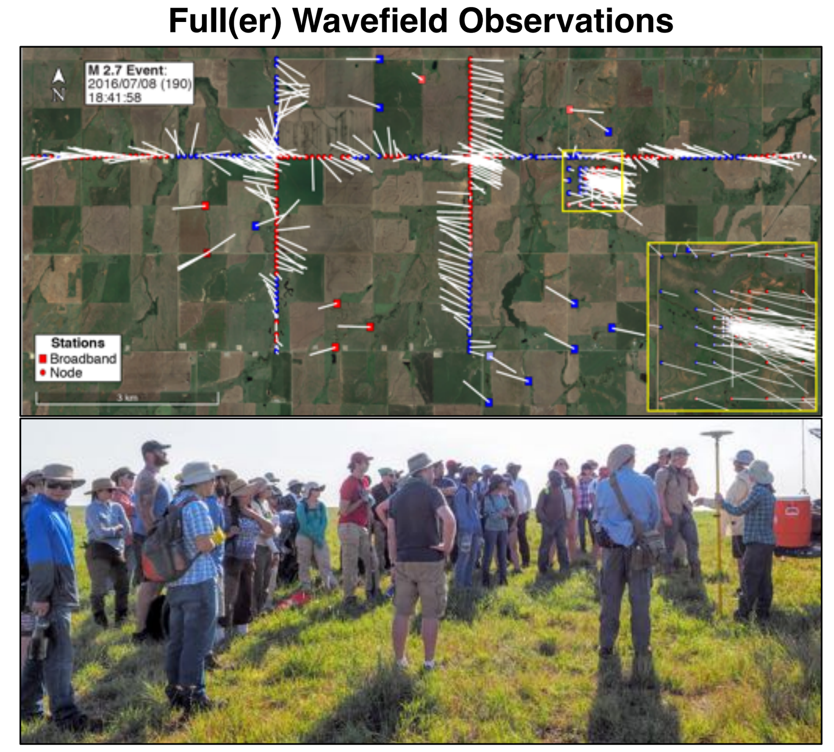








Full(er) Wavefield Observations



Left: The dense deployment of Nodal instruments (top) during the Oklahoma wavefields experiment shows a richly sampled wavefield of a local earthquake. Community participation and training for a range of interested groups during this experiment (bottom) was vital to its success and has helped establish a strong user base for this new technology.

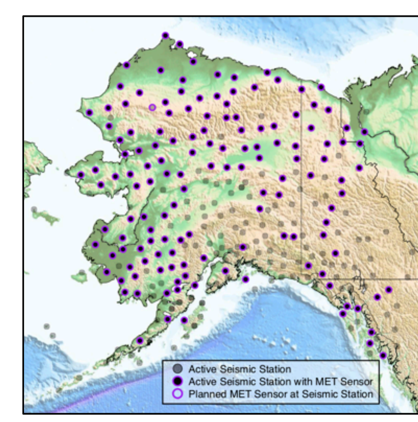
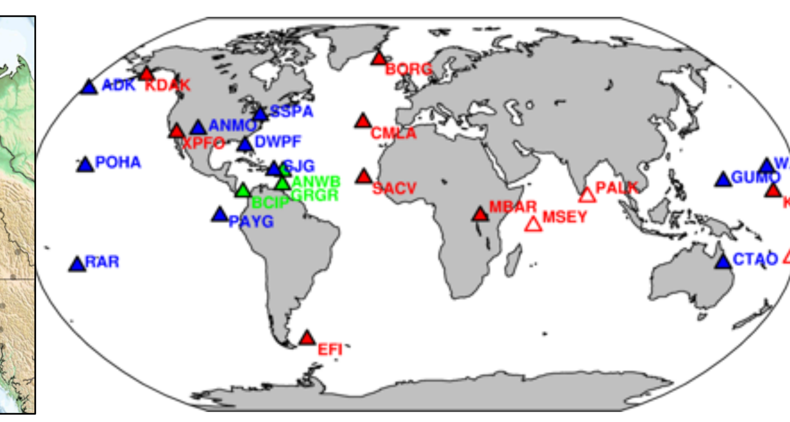
Facility Initiatives and Interests

- Improving wavefield observing capability using combined broadband, intermediate period and nodal sensors
- Creating a dedicated instrument pool for rapid response observations
- Improving access to explosive source technology
- Refining sensor emplacement techniques – with capacity building to widen usage
- Reducing the size, weight, and power of instruments for improved logistics
- Improving sensors/packaging for operating in extreme environments
- Expanding the SAGE facility model to other domains – e.g., magnetotellurics
- Supporting near-surface exploration with portable sources, GPR, and nodes
- Reviewing GSN design goals in light of newly available analysis techniques, new geophysical discoveries, and recent 21st century technology advances
- Expanding access to the facility through training and outreach to new users
- Enabling ubiquitous telemetry – even for very temporary experiments
- Exploring new sensing technologies – such as Distributed Acoustic Sensing
- Encouraging a Dirt-to-Desktop data and metadata management approach
- Instrumenting the seafloor: More coverage; longer term; key targets



Above: Operating a MT station near the PIC to characterize site conditions in preparation for future field testing of MT instruments.

Below: Operating adjunct sensors (e.g. infrasound, meteorological) in the TA and GSN provides complementary observations that broaden their scientific and monitoring utility.

Below: Global coverage of permanent, open broadband stations. Many regions still lack sufficient observations. We will continue to work towards capacity building and data sharing.