What is USArray?

...and IRIS for that matter...

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USArray Data Processing and Analysis Short Course

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Northwestern University
Evanston, IL
Founded in 1984, IRIS is…

**a CONSORTIUM** of 123 institutions (plus affiliates) focusing on academic research seismology, democratizing scientific progress.

**a FACILITY** that operates and manages seismological observatories, instrument depots, and data centers.
GROWING beyond its “core” programs by managing new facilities, e.g. USArray, Ocean Bottom Seismographic Instrument Pool, Greenland Ice Sheet Monitoring Network.

GOVERNED closely by the community it serves.
Study the three dimensional structure and evolution of the North American Continent

- 3.2 km borehole into San Andreas Fault
- 1100 permanent GPS stations
- 74 borehole strainmeters
- 6 laser strainmeters
- 78 borehole seismometers
- 100 Permanent seismic stations

- 400 transportable seismic stations occupying 2000 sites
- 20 magnetotelluric campaign systems
- 7 magnetotelluric backbone stations
- 100 campaign GPS stations
- 2146 campaign seismic stations
Popular Science Ranks EarthScope as the #1 Most Epic Science Project

#1 EarthScope

- 2 – Large Hadron Collider
- 3 – Spallation Neutron Source
- 4 – International Space Station
- 5 – Advanced Light Source
- 6 – Juno (Jupiter Orbiter)
- 7 – National Ignition Facility
- 8 – The Very Large Array
- 9 – Neptune Undersea Obs.
- 10 – Heavy Ion Collider

Some of the “metrics” used:
- Scientific utility
- What’s in it for you
- Wow factor
Pre-USArray

- Pre-EarthScope (late 2003), sparse or non-uniform station coverage
USArray through 2014

- Seismic, magnetotelluric, atmospheric
- Facility installed and operated components
- PI installed and operated components
A Ten Year Plan

Transportable Array Installation Plan

Year
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013

Station removal follows in 24 months.
Resolution After Shen and Ritzwoller, CU-Boulder, 2013 AGU Fall Meeting
Science Highlights

Crustal thickness measurements, Buehler and Shearer

Tip of the iceberg… at least 293 peer-reviewed USArray papers just during 2009-2013
Many of the major discoveries associated with USArray data were unanticipated when EarthScope was proposed.

Tip of the iceberg... at least 293 peer-reviewed USArray papers just during 2009-2013
A large percentage of events only reported by ANF with TA data
Astiz et al., *SRL*, 2014

Looking eastward, the Array Network Facility made a high percentage of unique event detections.
Characterizing Seismicity

Remote earthquake triggering at injection sites
Van der Elst et al., *Science*, 2013

Injection triggered earthquakes, Barnett Shale
Frolich, *PNAS*, 2012

TA deployment provided the opportunity to study uptick in seismicity in central and eastern U.S.
February 27, 2010, NEAR COAST OF CENTRAL CHILE, M=8.8

2010/02/27 06:39:39 UTC (328 s)  Distance 79.0°/8784 km  Azimuth 336.4°  Reference R27A

Time Since Earthquake (hh:mm:ss)
Automated IRIS back projection provides a reference

Backprojection analysis of Maule Kiser and Ishii, *GRL*, 2011
Imaging Melts and Fluids

Geoelectric images of the crust and mantle along Snake River Plain and Yellowstone

Kelbert et al., *Geology*, 2012

MT can identify melts and resolve ambiguities in seismic results, such as temperature vs. composition.

Mantle MT 3D model compared to seismic tomography for Yellowstone

Zhdanov et al., *GRL*, 2011
Exploiting acoustic to seismic signals, with distance and azimuth coverage, to illuminate traveltime branches
Hedlin et al., JGR, 2010

Gravity waves propagating across the TA
de Groot-Hedlin et al., EPSL, 2013
Mineral earthquake energy used to discern ancient hotspot track in Central U.S.
Chu et al., *Nature Geoscience*, 2013
An Imaging Revolution

Mantle discontinuity depth beneath the Western U.S.
Schmandt et al., *EPSL*, 2012

P-wave tomography model
Burdick et al., *SRL*, 2013

Many new models of North American crust and upper mantle structure from tomography and receiver functions

Ambient noise tomography discerns crustal deformation fabric
Moschetti et al., *Nature*, 2010
Impacts on Seismology

Pioneering new methodologies

Teleseismic backprojections

Backprojection of Tohoku-Oki earthquake
Kiser and Ishii, GRL, 2012

Ambient noise tomographic imaging
Ritzwoller et al., CR, 2011

Ambient noise tomography
Continent Scale Seismology: Reference Network & Transportable Array
Transportable Array

- 70 km spacing
- 200 stations / year removed and redeployed
- Year-round operations

- ~1,700 stations in 9 years
- All sites with real-time telemetry
- All data open & unrestricted
Traditional TA Station

A high precision manufacturing operation!
Traditional TA Station
Private landowners hosted most stations.

“Everyone we have dealt with at EarthScope has been extremely nice. It's been a pleasure to be a part of your operation. Thank you.”
In Their Words

“Great Job! You have very professional employees. Everyone we dealt with was outstanding! You are welcome on my land anytime!”

“My granddaughter took picture when it was installed. She made a presentation to class, teachers wanted to see it, too.”

“Happy with the project, very impressed with how nice everyone has been.”

“Thanks for letting us host the earth monitoring station. We enjoy the OnSite newsletter.”

“Everyone we have dealt with at EarthScope has been extremely nice. It’s been a pleasure to be a part of your operation. Thank you.”

“Thanks for letting us host the earth monitoring station. We enjoy the OnSite newsletter.”

“We hope the station provided helpful information to you and your fascinating project. We were pleased to have been a small part of it.”

“Thanks. I had a 4th grade tour of the site last summer; they liked it.”

“It’s been a good experience with EarthScope.”

“We appreciated having the earthquake station on our property. It did generate a lot of interest among the neighbors. If this is ever needed again, you are welcome back.”

“Glad to be a part of the project. I hope the data collected will benefit us in the future.”

So far, 468 vaults left at landowners’ behest!
Performance & Quality

Station noise highly uniform and quite low for temporary installations

TA data availability averaged >98%

For the first 958 completed stations: The median contiguous time series is 11.7 months long!

The quality and consistency of the data have been key to the science!
Impacts on Seismology

Value of standardized network operations

- Monitoring system renders data into actionable format
- Information feeds weekly management prioritization for all service activities

http://anf.ucsd.edu/tools/webdlmon
Value of automated quality control

- Automated process for command, capture, and analysis of calibration signals
- Real-time noise analysis identifies station performance issues
Improved sensor orientation practices

- Direct measurement of orientation of all stations on install/removal
  - Uses fiber-optic gyroscope
  - Measures orientation to < 0.2°
  - Validates empirical estimates
- As of 2011, 95.6% of the TA stations have polarization anomalies within ±3°.
- In 2008, this number was 79.9%.

TA station orientation, relative to north, from empirical analysis
Ekström and Busby, SRL, 2008
Flexible Array
Flexible Array

FA experiments have leveraged the TA and explored specific targets.

- 326 broadband, 120 short period, 1700 Texan (active source) systems
- 21 passive and 3 active source experiments supported during award period
Flexible Array
Standard Station Equipment

- Sensor vault systems
- Charge and power control systems
- Equipment enclosures

~410 stations worth of standardized equipment available
• FA broadbands in Chile

50 BHZ records of M6 aftershock on 4/2/10
Magnetotellurics

Mantle resistivity beneath the Pacific Northwest
Bedrosian and Feucht
Magnetotelluric Stations

- 572 temporary sites; 7 backbone sites
- Unprecedented coverage
- Move from profiles to 3D
- Uniform, open community data sets
Magnetotelluric Stations

- MT-TA station in 2-3 weeks per site
- Program collecting a first of-its-kind dataset, a powerful new complementary observation
EarthScope/GeoPRISMS iMUSH

Purpose: Image Magma Under St. Helens

EarthScope MOCHA

"Magnetotelluric Observations of Cascadia using a Huge Array" onshore-offshore MT project

Purpose: Characterize role of fluids in Episodic Tremor and Slip/Margin Segmentation/Megathrust Earthquakes

• EarthScope MT PI support didn’t exist in 2009!
• Now a significant activity
Data Archived During USArray O&M Award

Data Archived (Terabytes)

- _US-TA
- _US-MT
- _US-FA
- _US-REF

44.1 Tb archived

Oct-08  |  Jan-09  |  Apr-09  |  Jul-09  |  Oct-09  |  Jan-10  |  Apr-10  |  Jul-10  |  Oct-10  |  Jan-11  |  Apr-11  |  Jul-11  |  Oct-11  |  Jan-12  |  Apr-12  |  Jul-12  |  Oct-12  |  Jan-13  |  Apr-13  |  Jul-13
Data Shipped

Data Shipped During USArray O&M Award

- **211.36 Tb shipped**
- **Up to 12,438 unique users**
Open Data

iPad app that retrieves real time seismic data via webservices

EpiCentral+ App created by Chuck Ammon, Penn State
Data Products

Level 0-1
Time series data

Level 2-3 Products

- gmv
- emc
- event plots
- event bulletins
- Western US Ambient Noise X-Correlation
- backprojections
- ears

Most of these products did not exist in 2009
EARS

EARS Best Estimate of Thickness (2015/08/03 04:03:02 UTC)
EARS

- EARS transitioned to DMC and in routine operation

EARS Best Estimate of Vp/Vs (2015/08/03 04:03:02 UTC)

http://ears.iris.washington.edu/
Earth Model Collaboration

- User contributed models
- Reference datasets
- Web interface and model export

The ability to compare models was identified as critical cyberinfrastructure.
At least 12 new models available in Earth Model Collaboration have been generated with USArray data.
Outreach

“X-RAY EARTH”, aired May 15, 2011
Science Impact

Prominently featured in major scientific news publications

US seismic array eyes its final frontier

Moveable sensor grid will begin monitoring Alaska's next summer.

New Scientist

What is down there?

Earth's deep secrets revealed at last

nature

Scoping out unseen forces shaping North America

As it moves across America, the USArray network of seismometers is revealing an impressive but often hidden subsurface map of faults, dips, and plate movements beneath the nation.
Major publicity during award period!
International Coverage

Gruppe5 Film – Cologne, Germany
L49A near Milan, Michigan

• This coverage finds us.
• Often better coverage than in US
Research Webinars

- Routinely >100 attend live, hundreds of subsequent views
- 13 webinars directly linked to USArray data

- Research seminars broadcast live and archived for future viewing
- Broadly subscribed by national and international earth science communities
USArray Goes Viral

- For Virginia earthquake and other major events, IRIS content prominently used in blogs/social media
Marston Welcome Center

- IRIS developed content for EarthScope-themed exhibit
- Active Earth Display connected to the internet with associated signage
- Located near New Madrid, MO Southbound I-55, mile 42.4

More at: http://www.dnr.mo.gov/geology/geosrv/marstonwelcomecenter.htm
Short Courses

- **New scope**: Award supported 2010-2014 courses, IRIS brings expertise and organizing capacity
- 2009-2011, 2013-2014, 121 students in 6 courses
Impacts on Seismology

Jump starting professional partnerships and research foundations

2014 USArray Data Processing Short Course
USArray’s Legacy and Looking Ahead
TA in Alaska

Depth:
- Blue: 0-30 km
- Green: 30-100 km
- Orange: 100-150 km
- Red: >100 km

Size:
- M=3.0-3.9
- M=4.0-4.9
- M=5.0-5.9
- M=6.0-6.9
- M=7.0-7.9
- M>=8.0
Before USArray

- Limited station coverage, and some seismically active areas sparsely instrumented
TA in Alaska – So Far

- 2014: 9 new TA, 11 AK upgraded, 26 total
- 2015: 36 new TA, 47 integrations/upgrades
- 2016: 70 new TA

[Map of Alaska with markers indicating TA locations and upgrade status]

www.usarray.org/alaska
TA in Alaska / Yukon

Motivation: High quality data; all equipment designed for transport in fixed wing aircraft or helicopter.

- ~261 new & upgraded sites by 2017, spaced 85 km
- Broadband seismometers w/atmospheric sensors
- New/advanced power and communications
- Complex logistics
New styles of seismometer emplacement

Impacts on Seismology

Before: shallow tank

After: 5M posthole

40 dB noise reduction
USArray’s Enhanced Scope and Legacy

Atmospheric Gravity Waves on the TA
Catherine deGroot-Hedlin et al.
Atmospheric Acoustic Transportable Array

755 TA stations with high-resolution barometer and infrasound instruments
Infrasound detection of the Chelyabinsk Meteor on the TA

Google: IRIS infrasound
For events and detections

de Groot-Hedlin & Hedlin, EPSL, 2014
• Barometric pressure and infrasound at every TA station

• Multiple applications
  • Noise induced on vertical and horizontal seismic channels
  • Meso-scale atmosphere variation
  • Acoustic energy propagating in the atmosphere
  • Acoustic – seismic coupling
TA Cascadia

• 27 TA stations (w/atmospheric sensors and strong motion instruments) reinstalled in 2009-2010 to anchor the Cascadia Initiative offshore experiment

• 15 Oregon stations to be adopted by the state
Central and Eastern US Network

- Five year plan to operate 159 (37 reinstalled) TA stations for:
  - Research
  - Hazards assessment
  - Critical facilities

- Multi-agency collaboration
  - NSF, USGS
  - NRC, DOE

- “Good government”
  - Uniquely addressing multiple missions / needs

- Enhanced instrumentation/data
  - 100 s.p.s. broadband
  - 34 new strong motion instruments

More at: www.usarray.org/ceusn
Between TA and Cascadia-TA adoptions and CEUSN, potentially 235 new “permanent” stations in N.A. since 2008
USArray’s Unique Aspects

- **Bold** approach to seismology research facilities (size, scope, quality)

- **Diverse** offerings (telemetry, auxiliary instruments, etc.)

- **Biggest** open dataset for seismology…ever

- **Substantial community input** into evolution of the facility

- **Coordinated** and **collaborative** with other EarthScope programs
People Make it Happen

USAArray Transportable Array Team Photo on Completion of the TA in the Lower-48 States October 1, 2013
EarthScope is funded by the National Science Foundation.

EarthScope is being constructed, operated, and maintained as a collaborative effort with UNAVCO, and IRIS, with contributions from the US Geological Survey, NASA and several other national and international organizations.

On the Web

- EarthScope
  www.earthscope.org
- USArray
  www.usarray.org
- National Science Foundation
  www.nsf.gov

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