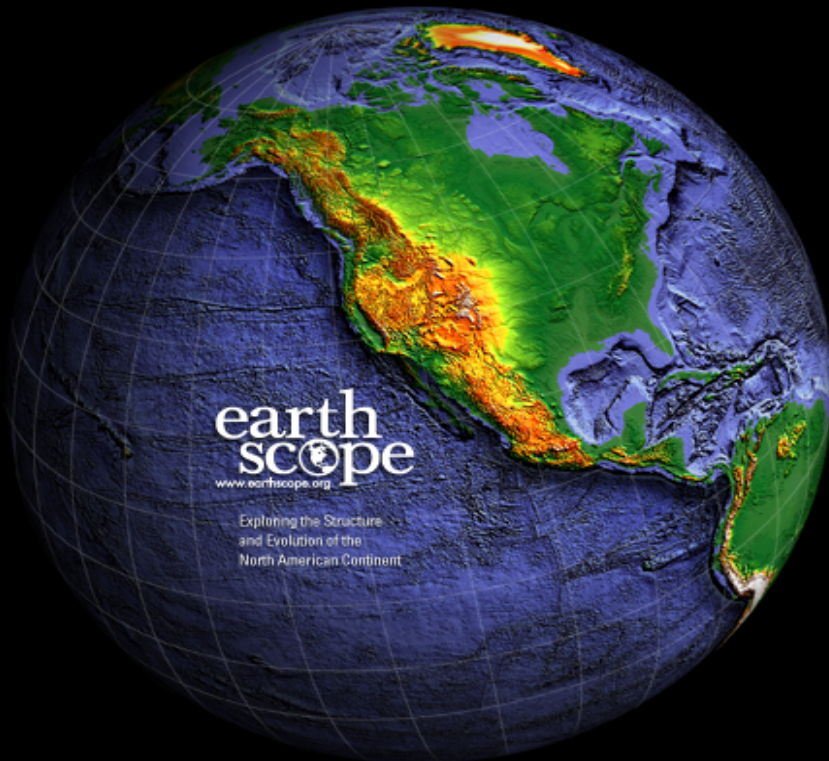


What is USArray? ...and IRIS for that matter...



Andy Frassetto
Senior Project Associate, IRIS
Given by: Justin Sweet

*USArray Data Processing
and Analysis Short Course*

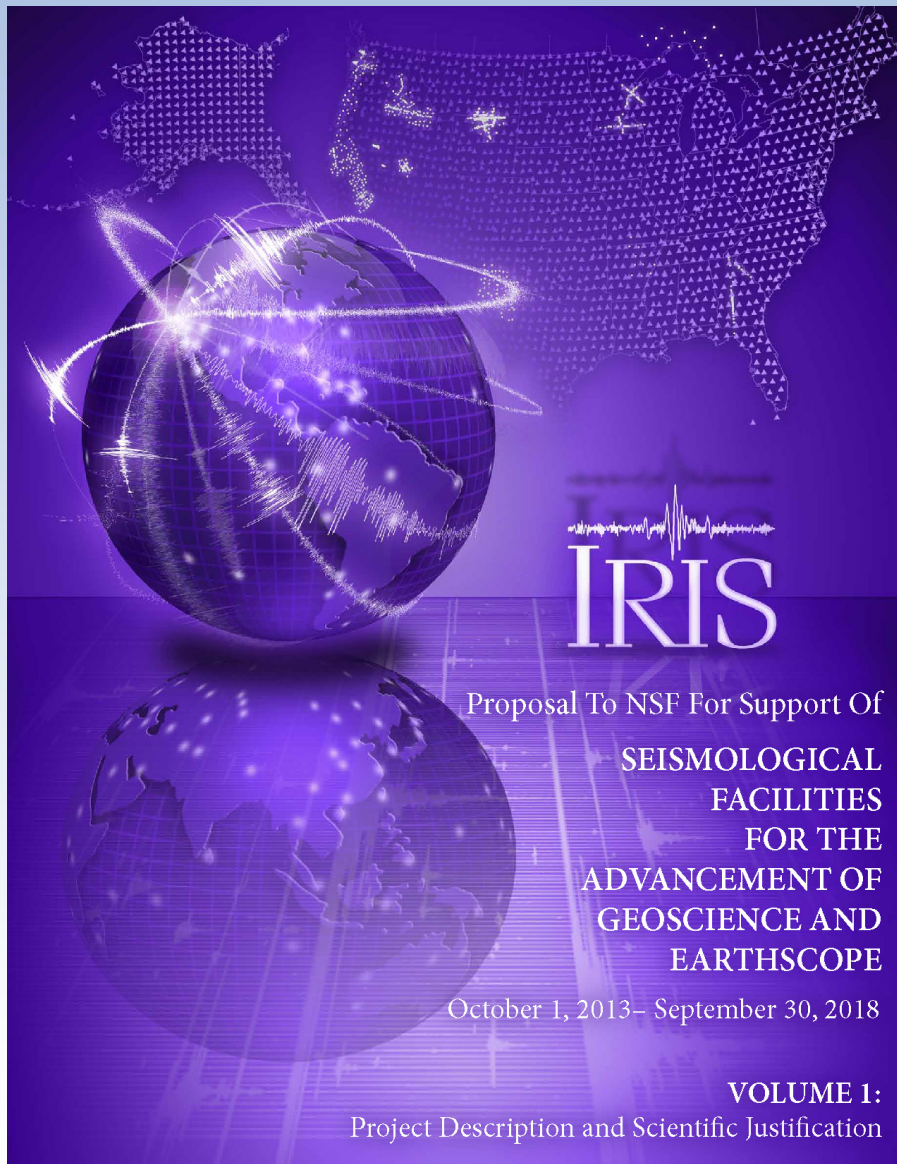
*August 1-5, 2016
Northwestern University
Evanston, IL*

Incorporated Research Institutions for Seismology

Founded in 1984, IRIS is...

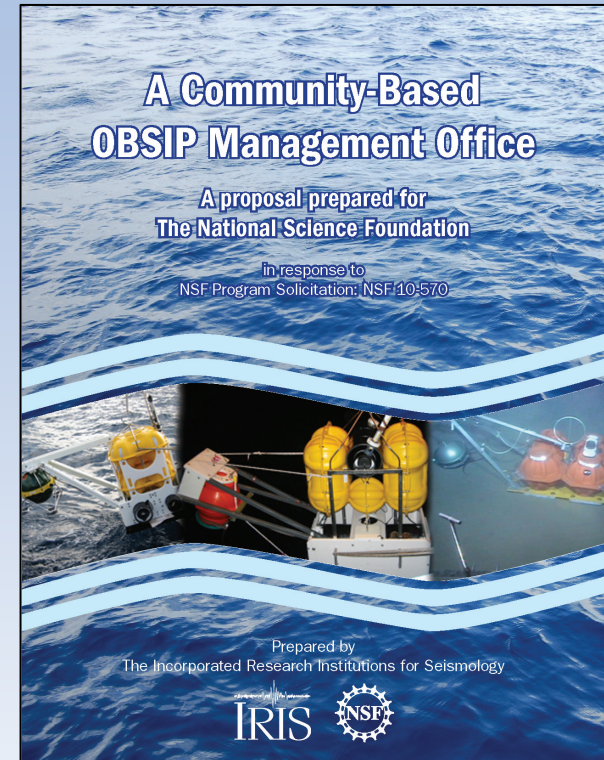
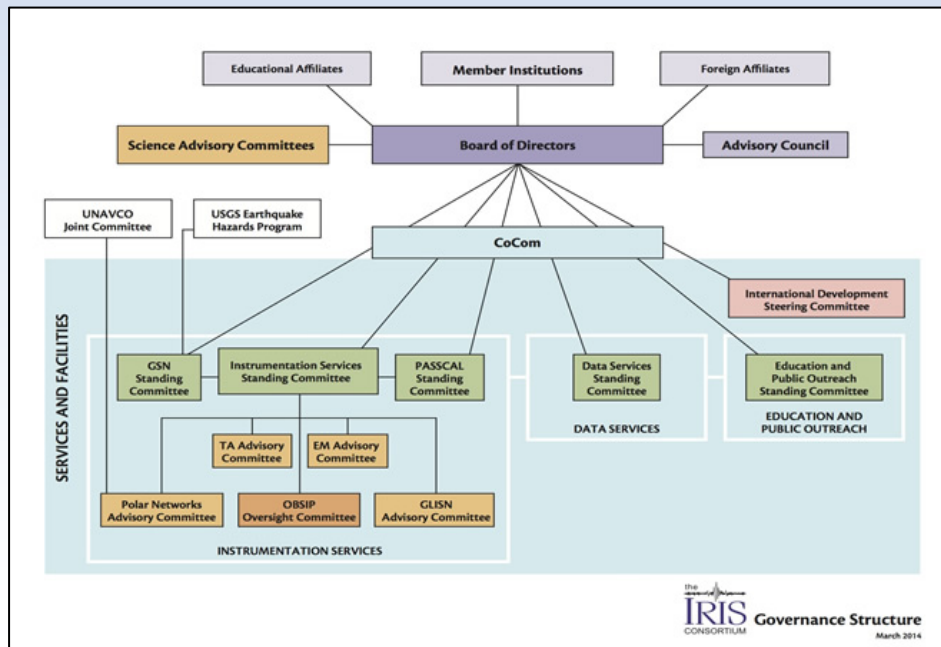
a **CONSORTIUM** of 123
institutions (plus affiliates)
focusing on academic
research seismology,
democratizing scientific
progress.

a **FACILITY** that operates and
manages seismological
observatories, instrument
depots, and data centers.



Incorporated Research Institutions for Seismology

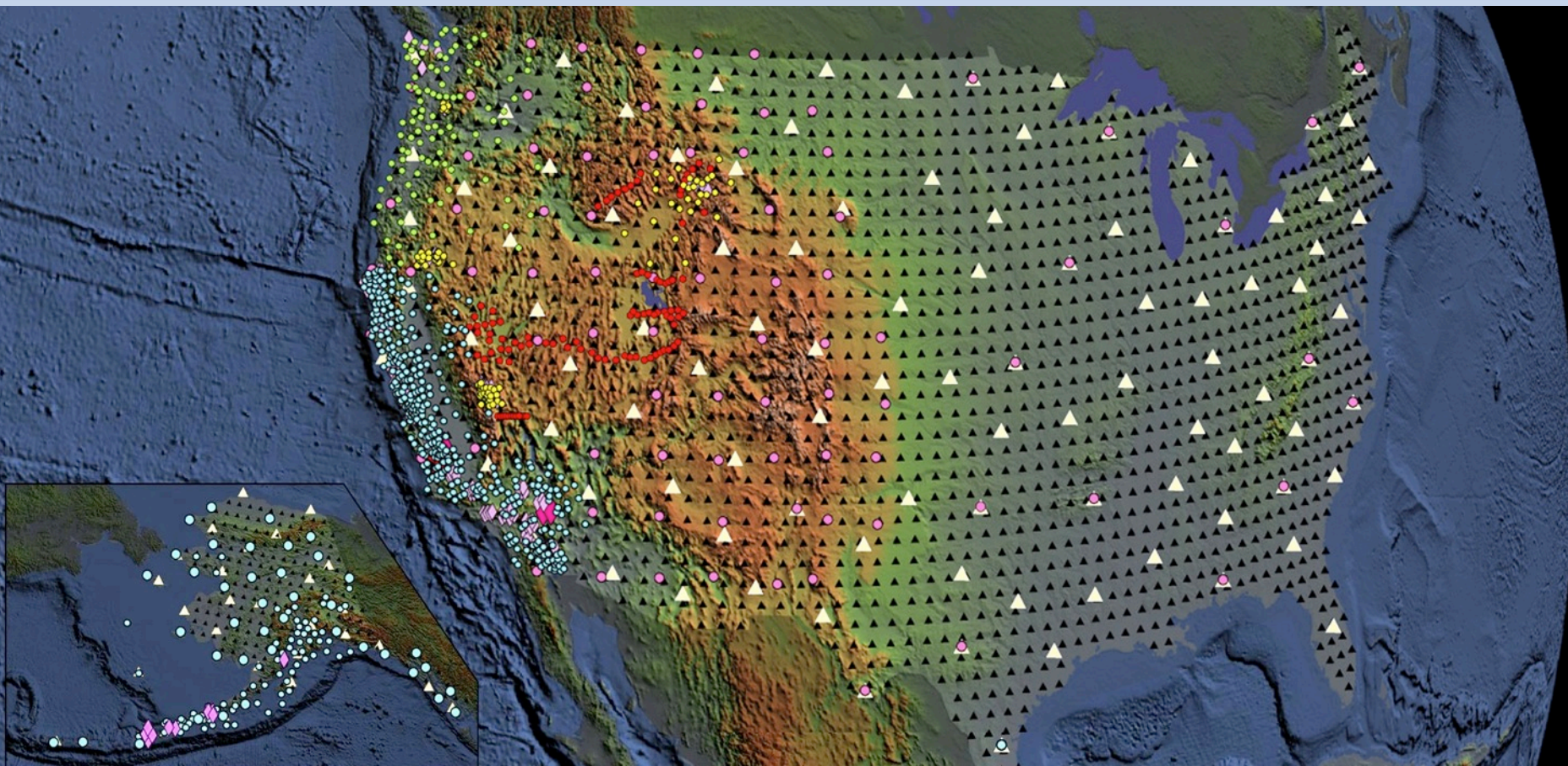
GROWING beyond its “core” programs by managing new facilities, e.g. USArray, Ocean Bottom Seismographic Instrument Pool, Greenland Ice Sheet Monitoring Network.



GOVERNED closely by the community it serves.

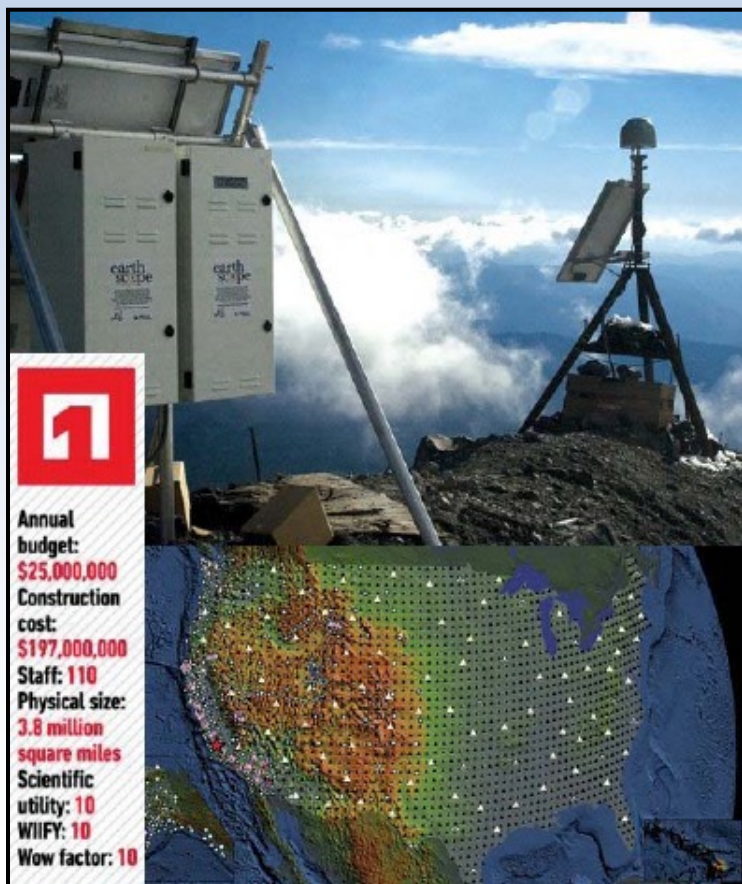
Study the three dimensional structure and evolution of the North American Continent

- 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



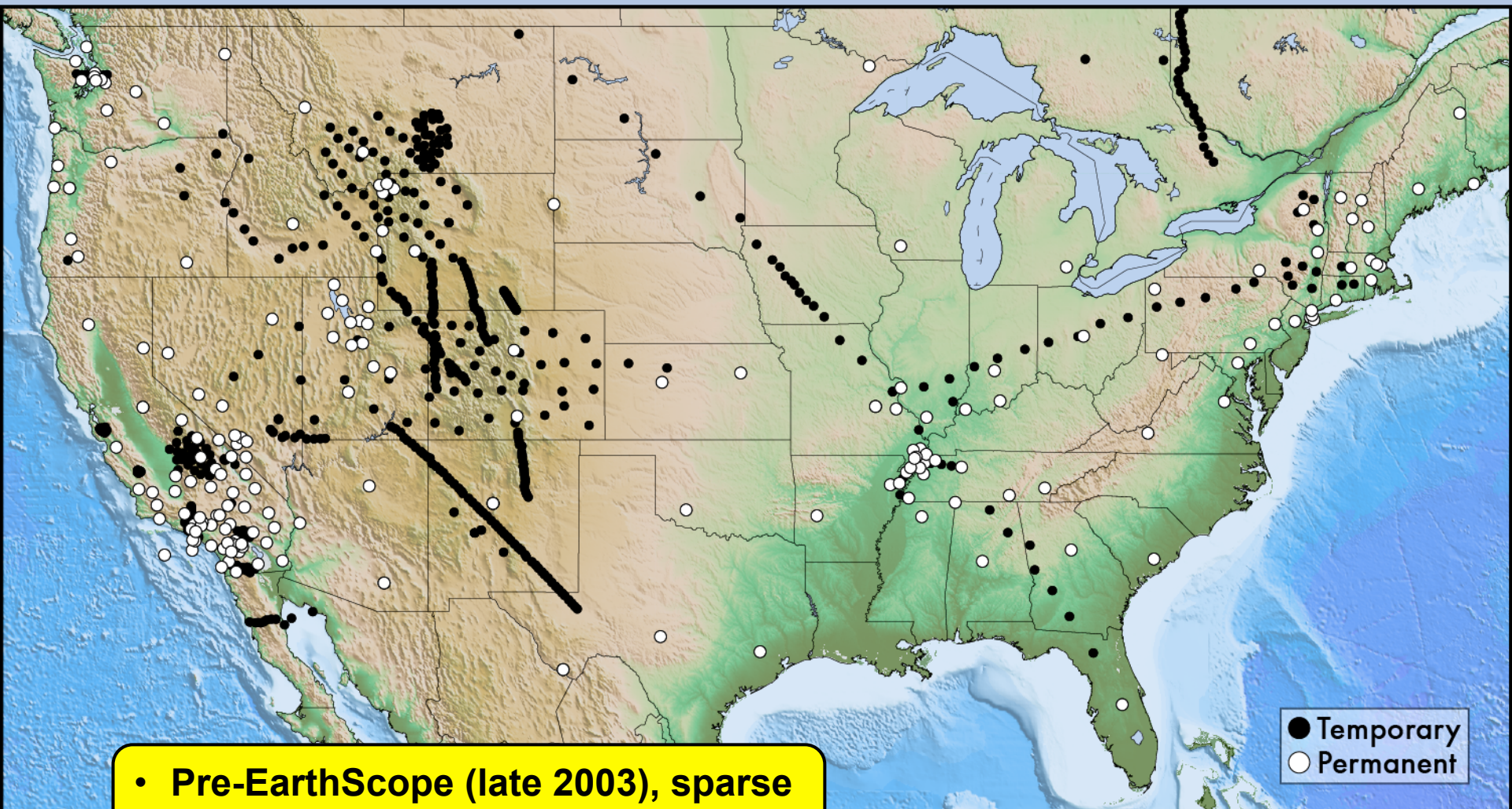
- 2 – Large Hadron Collider
- 3 – Spallation Neutron Source
- 4 – International Space Station
- 5 – Advanced Light Source
- 6 – Juno (Jupiter Orbiter)
- 7 – National Ignition Facility
- 8 – The Very Large Array
- 9 – Neptune Undersea Obs.
- 10 – Heavy Ion Collider

Some of the “metrics” used:

- Scientific utility
- What’s in it for you
- Wow factor

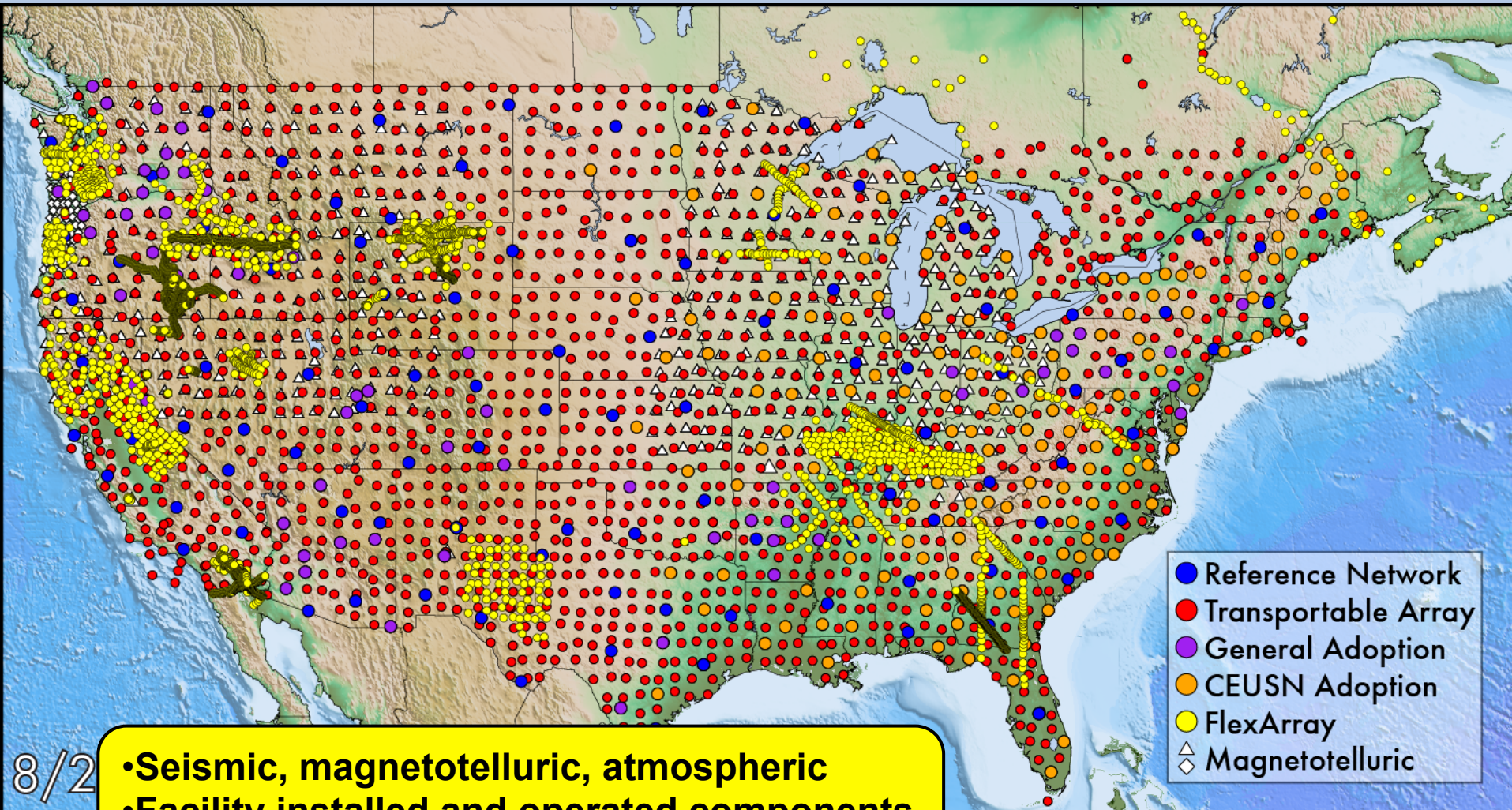
Annual budget: \$25,000,000
Construction cost: \$197,000,000
Staff: 110
Physical size: 3.8 million square miles
Scientific utility: 10
WIIFY: 10
Wow factor: 10

Pre-USArray



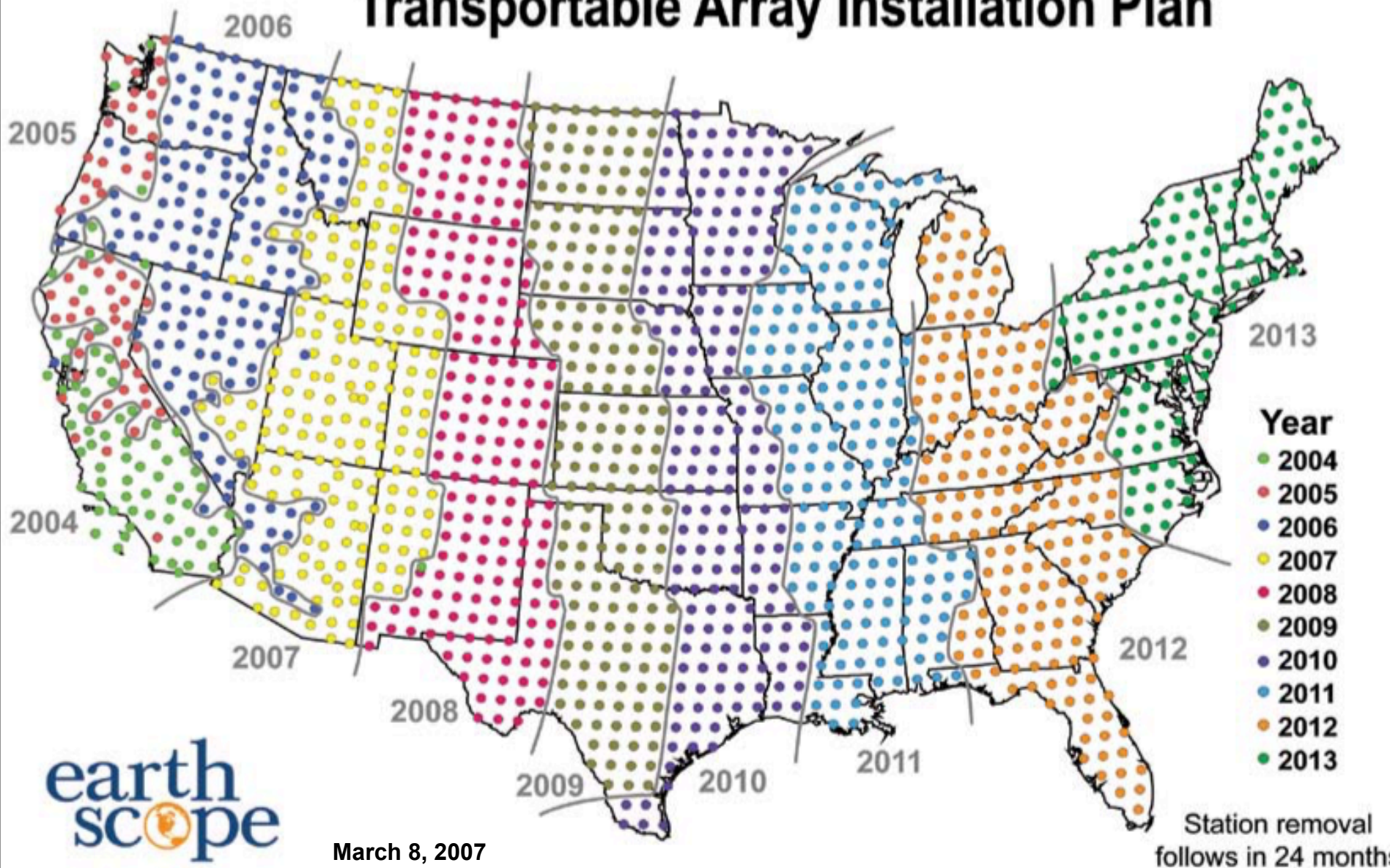
- Pre-EarthScope (late 2003), sparse or non-uniform station coverage

USArray through 2014

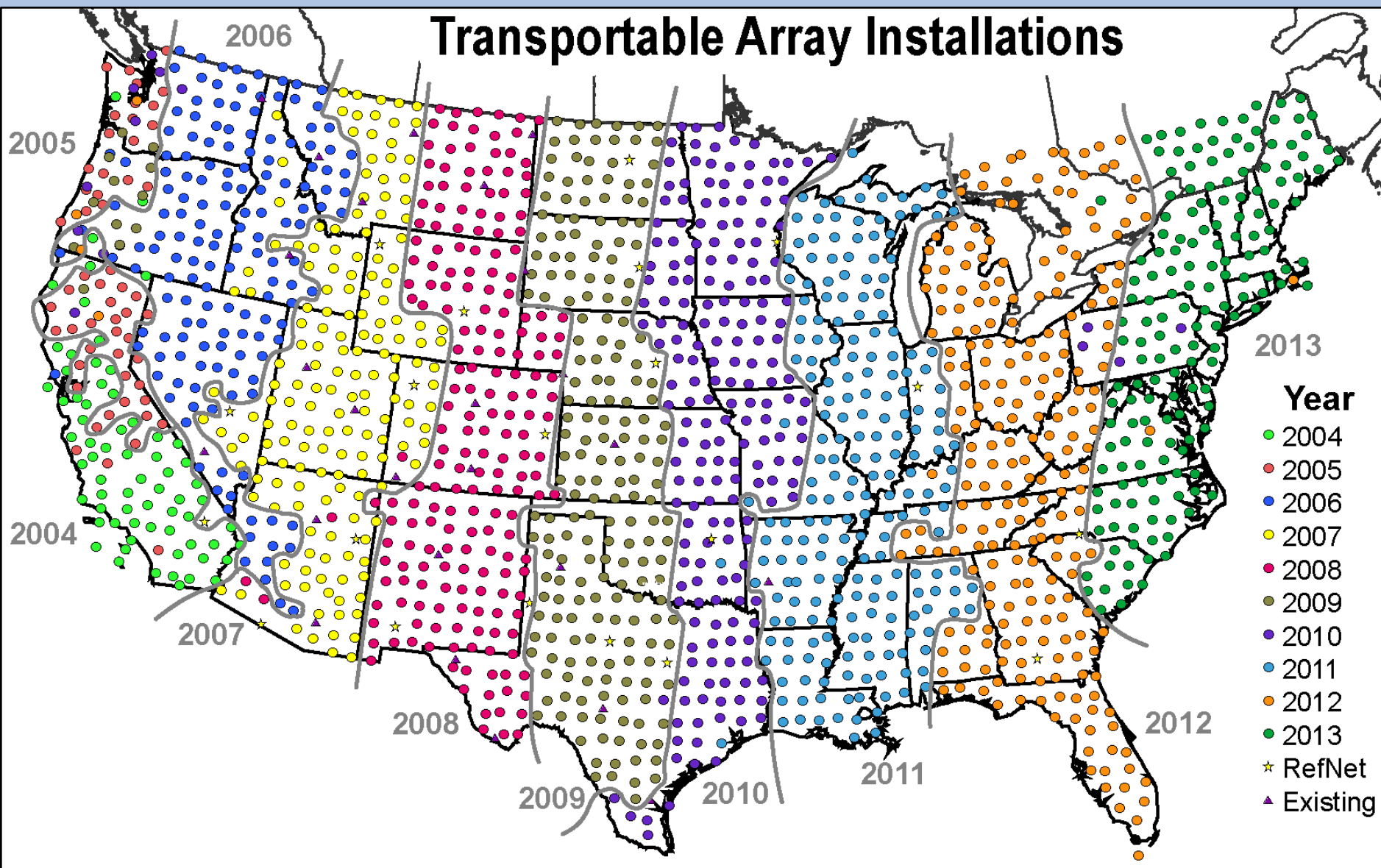


A Ten Year Plan

Transportable Array Installation Plan

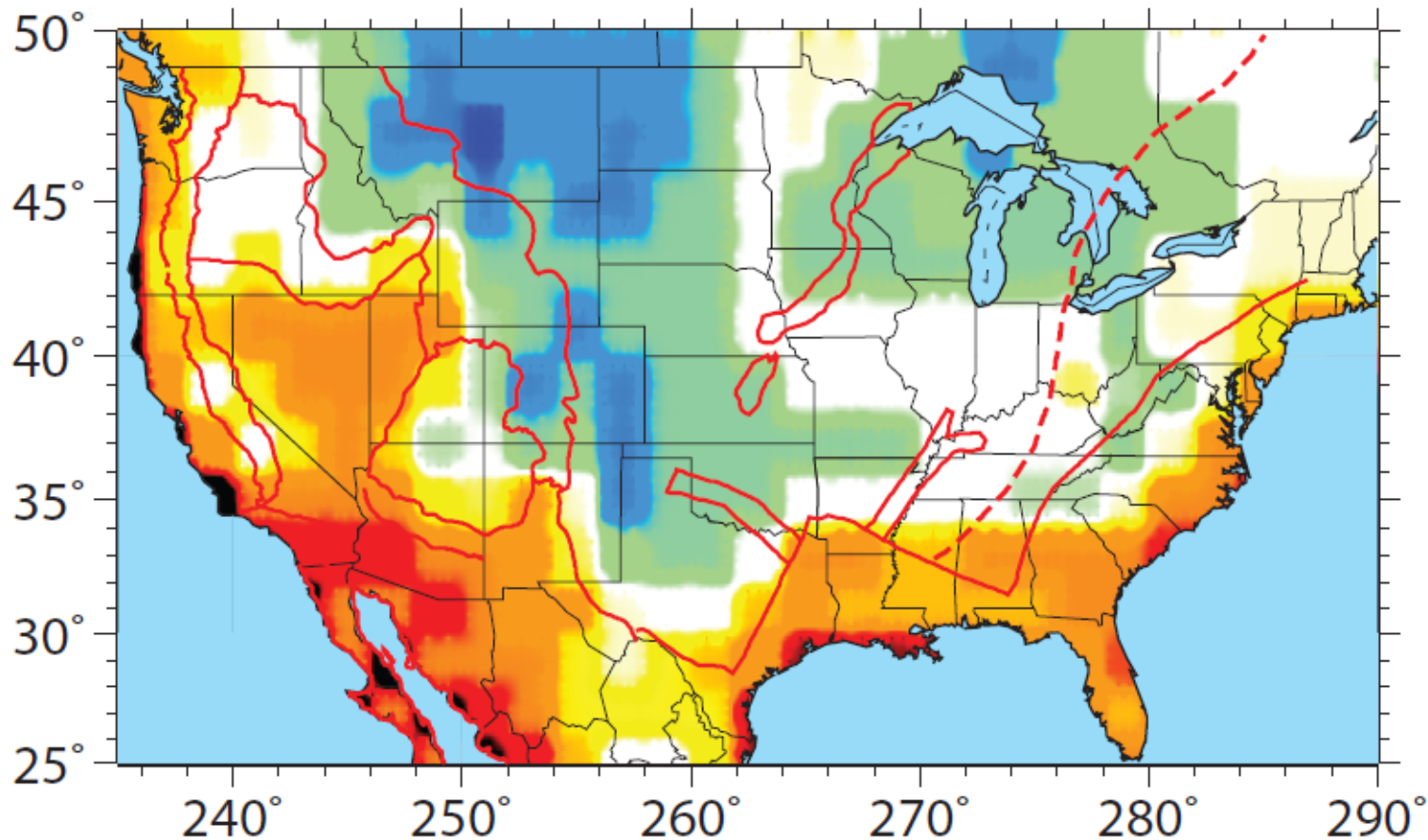


Ten Year "As Built"



Resolution Before

CRUST 2.0, 2000

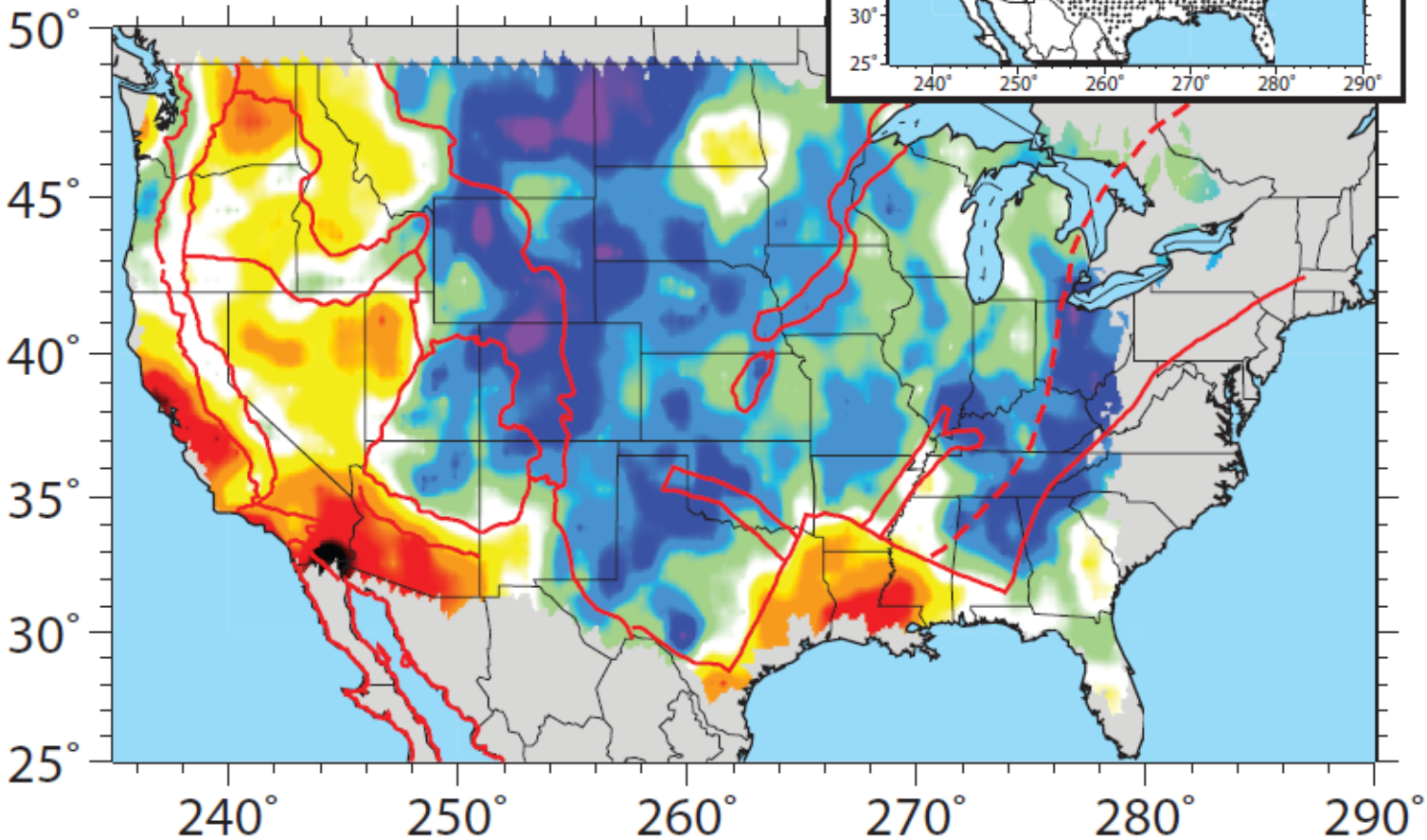
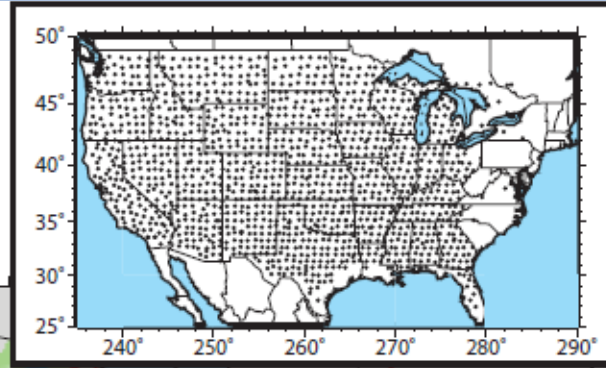
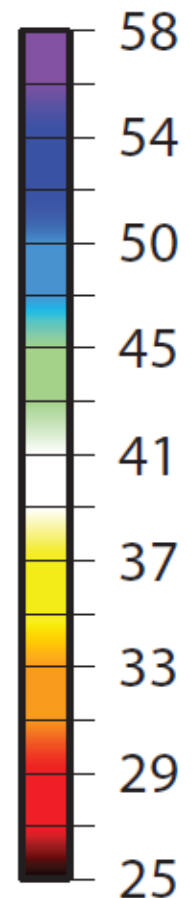


Bassin et al., 2000 AGU Fall Meeting

Resolution After

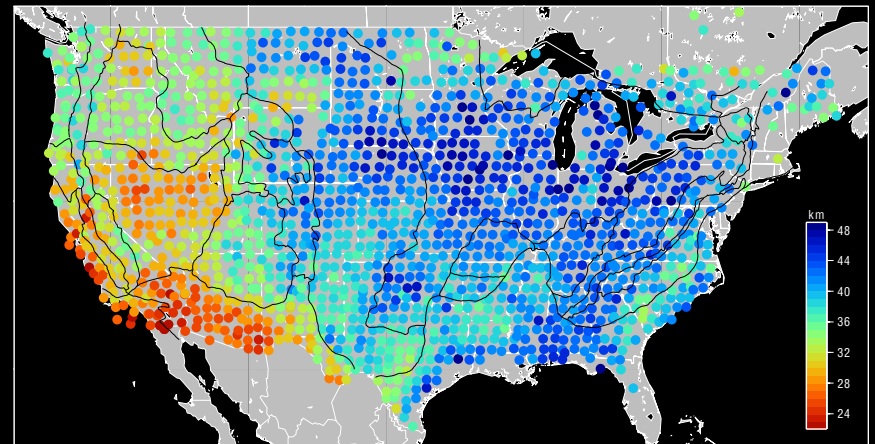
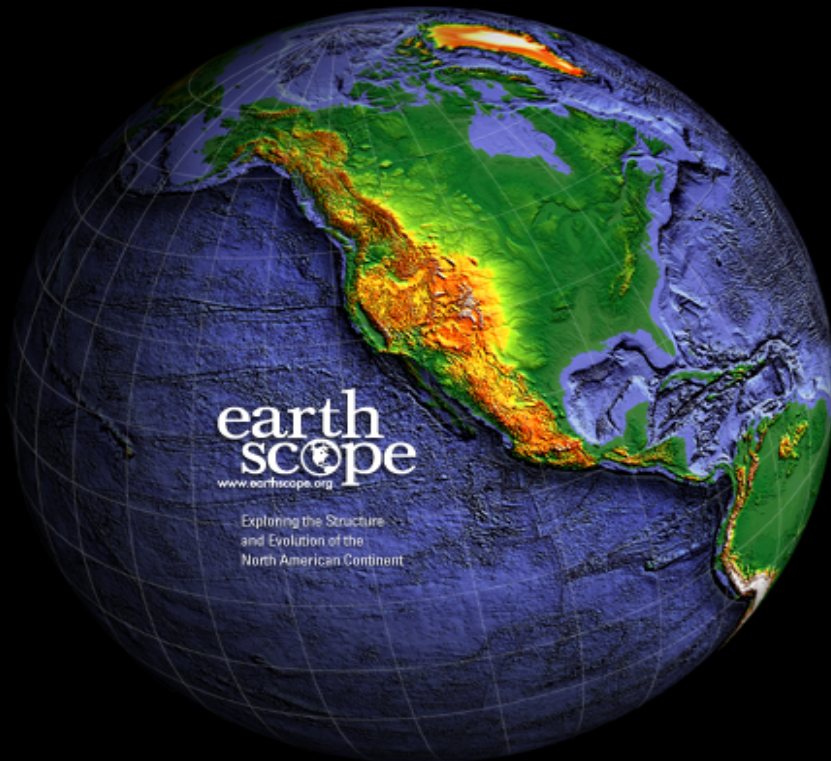
UCB Model, 2013
Resolution ~ 70 km

Depth of Moho
(km)



Science Highlights

Crustal thickness measurements, Buehler and Shearer



*Tip of the iceberg...
at least 293 peer-reviewed
USArray papers just
during 2009-2013*

Science Highlights

Crustal thickness measurements, Buehler and Shearer



Many of the major discoveries associated with USArray data were unanticipated when EarthScope was proposed.

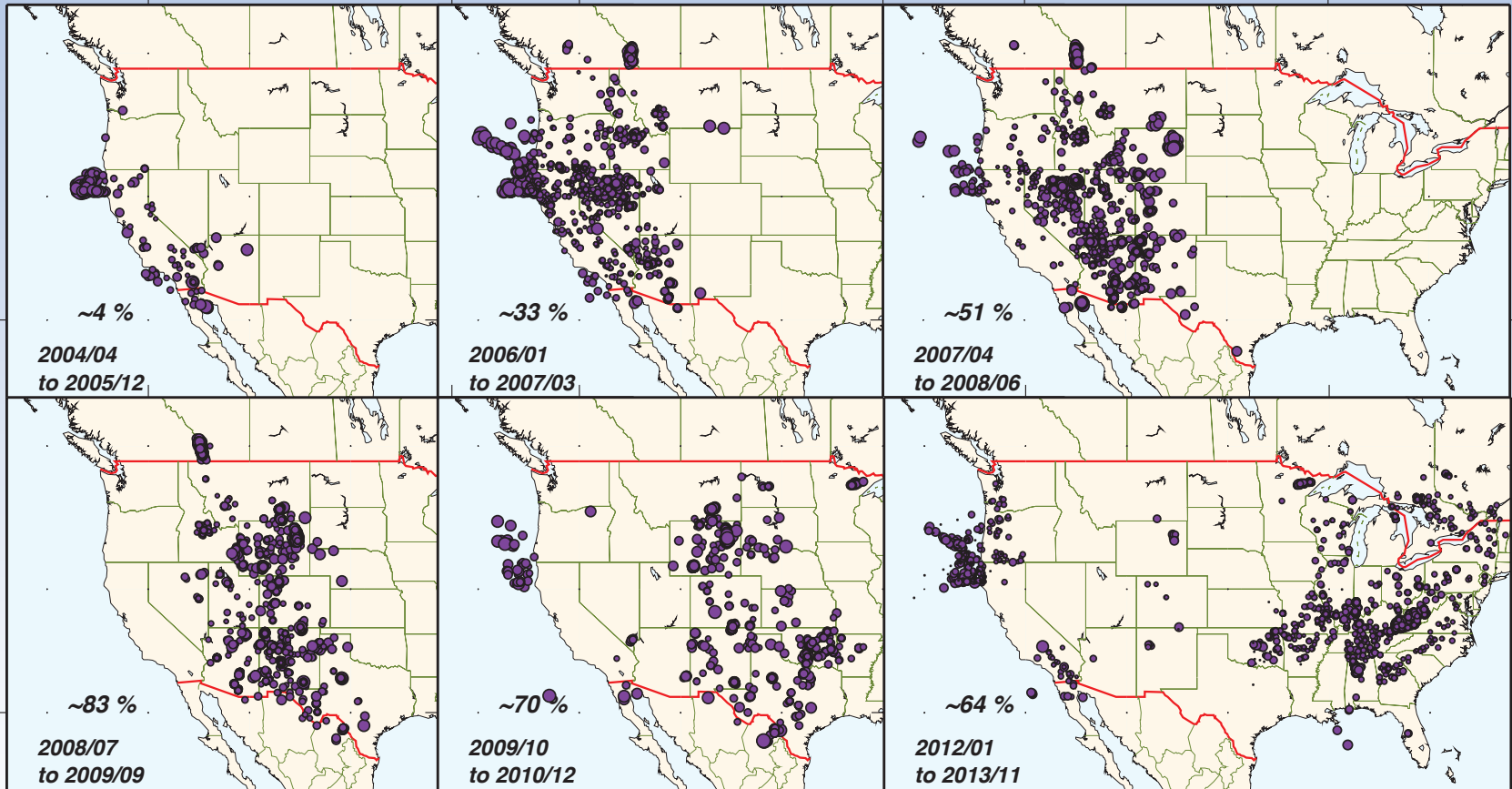
earth
scope
www.earthscope.org

Exploring the Structure
and Evolution of the
North American Continent

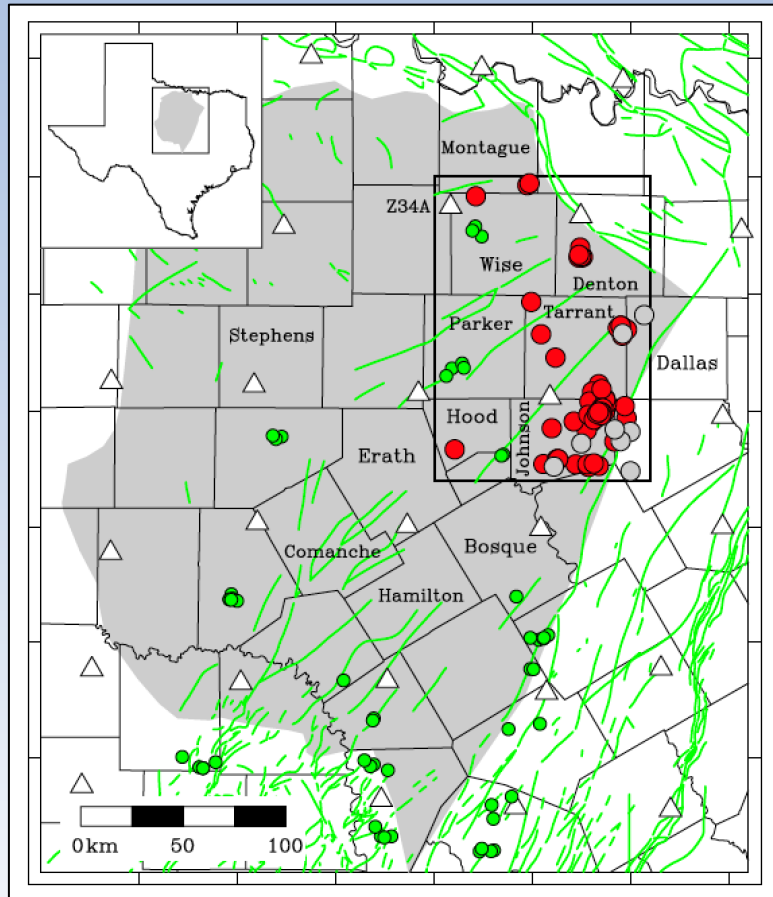
*Tip of the iceberg...
at least 293 peer-reviewed
USArray papers just
during 2009-2013*

Improved Event Detection

A large percentage of events only reported by ANF with TA data
Astiz et al., *SRL*, 2014

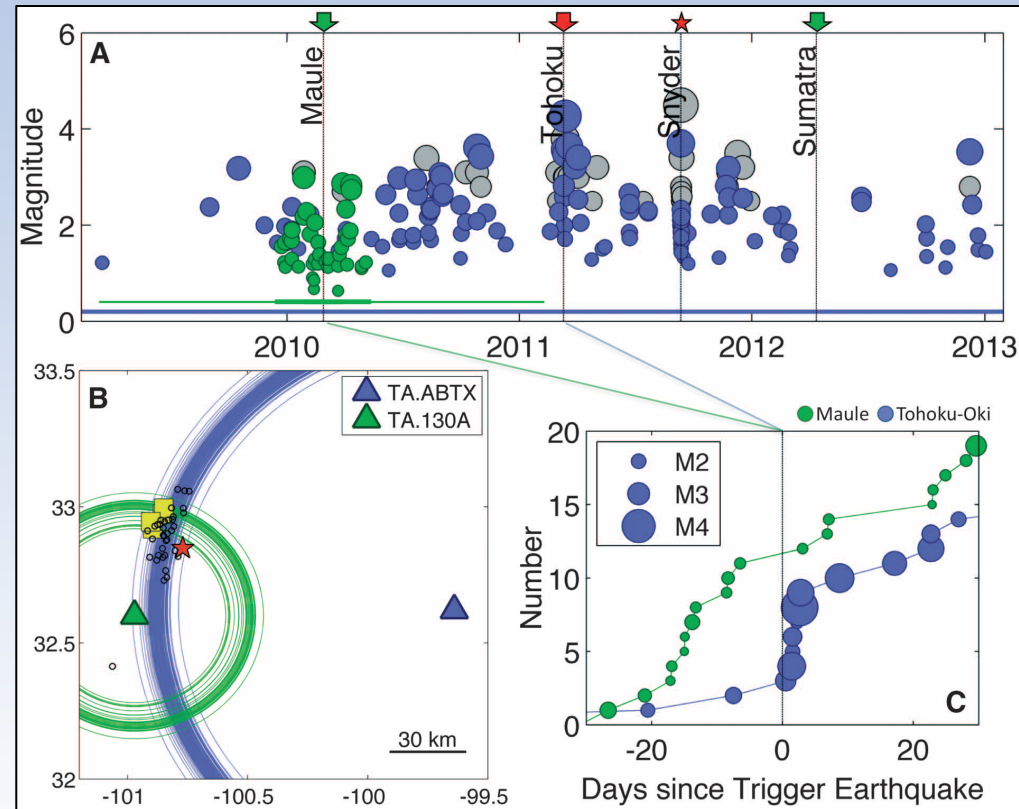


Looking eastward, the Array Network Facility made a high percentage of unique event detections.



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

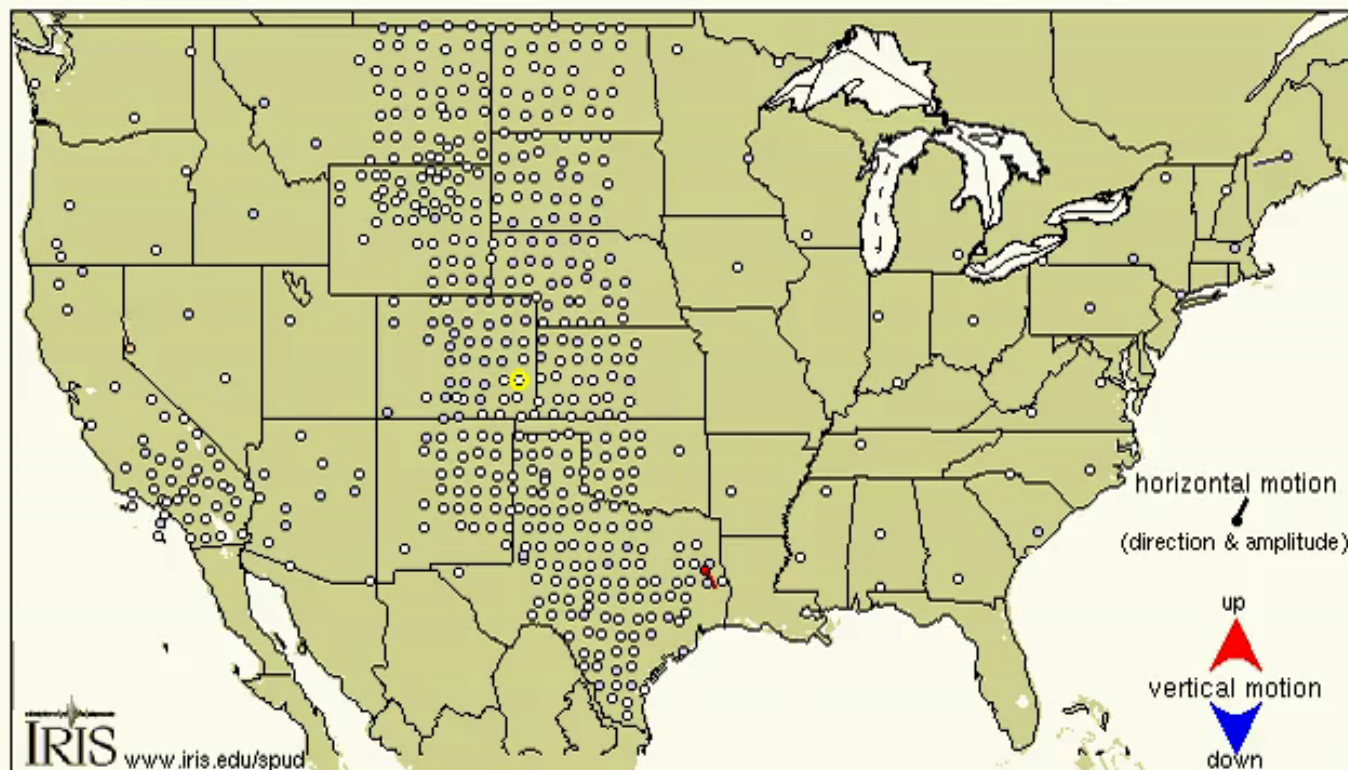
Remote earthquake triggering at injection sites Van der Elst et al., *Science*, 2013



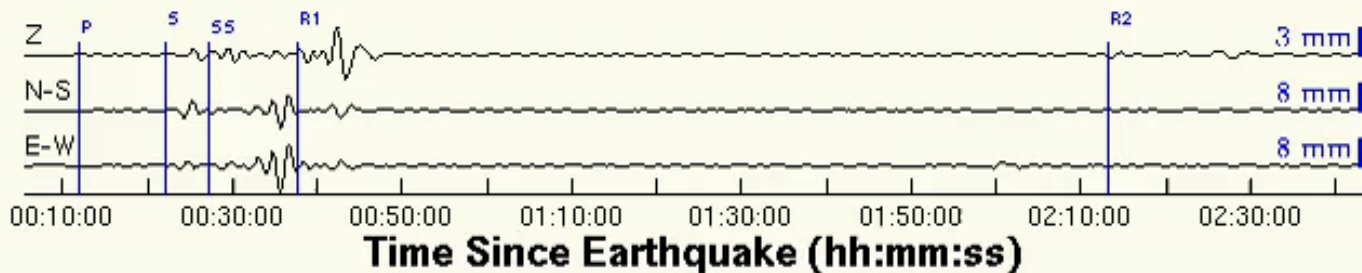
TA deployment provided the opportunity to study
uptick in seismicity in central and eastern U.S.

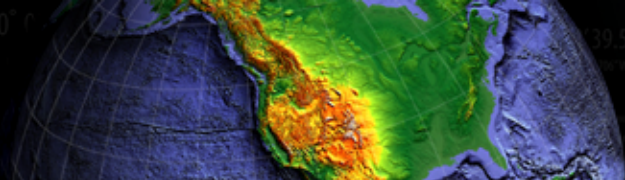
Understanding Great Earthquakes

February 27, 2010, NEAR COAST OF CENTRAL CHILE, M=8.8

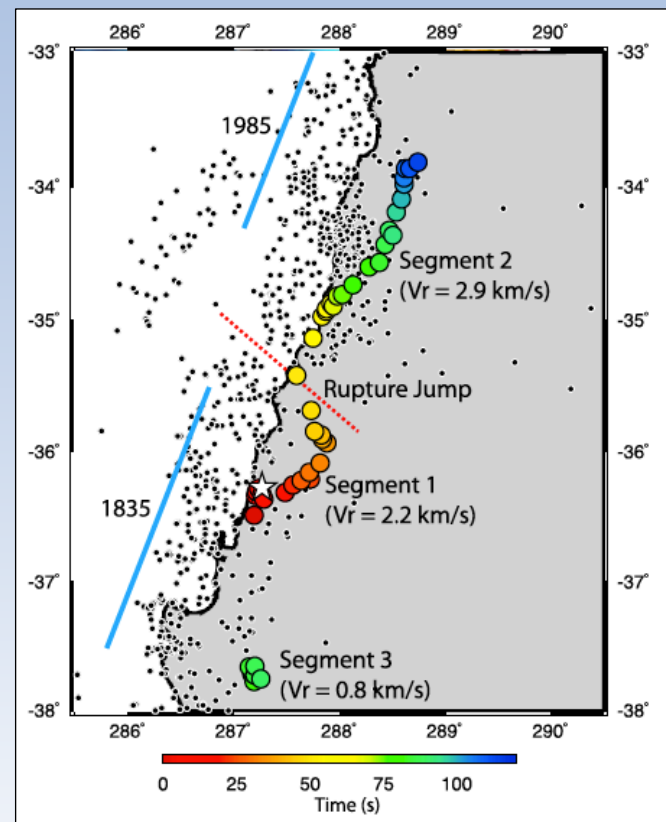
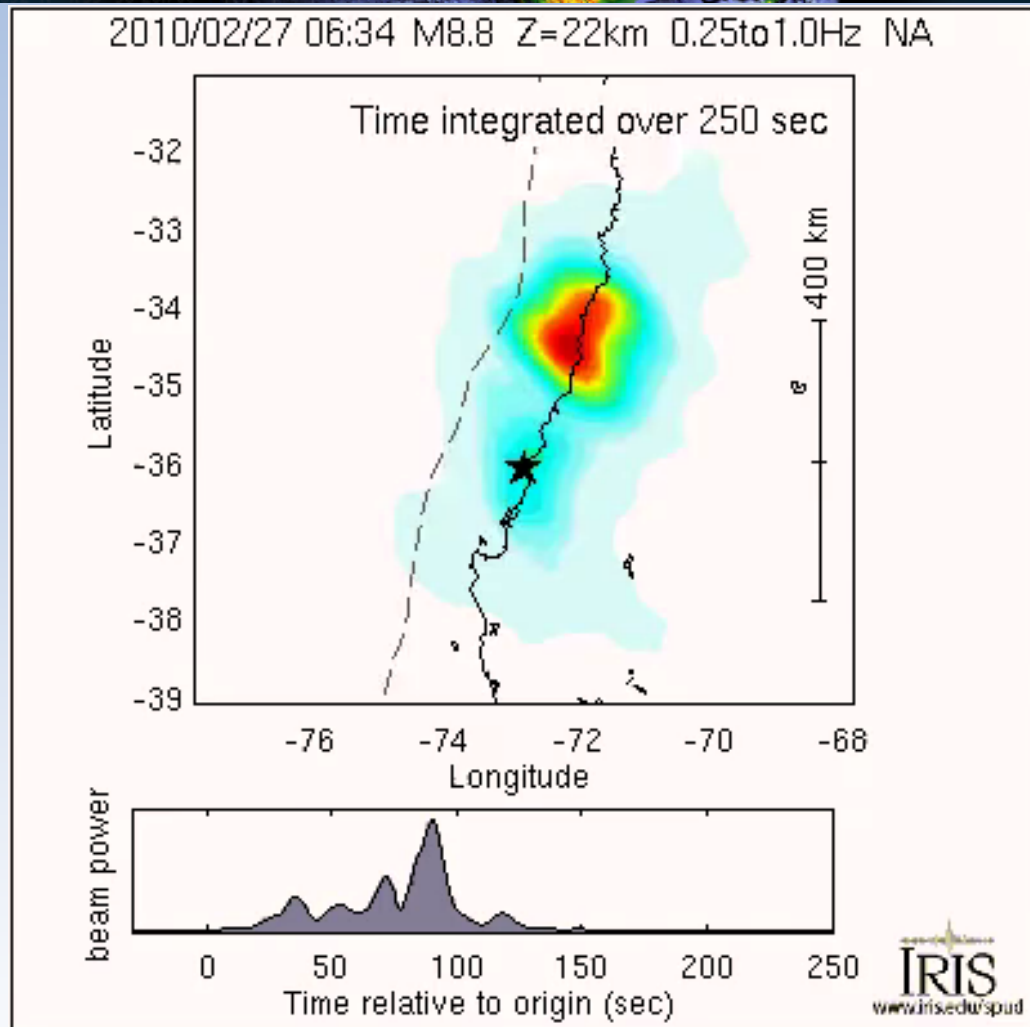


2010/02/27 06:39:39 UTC (328 s) Distance 79.0°/8784 km Azimuth 336.4° Reference R27A





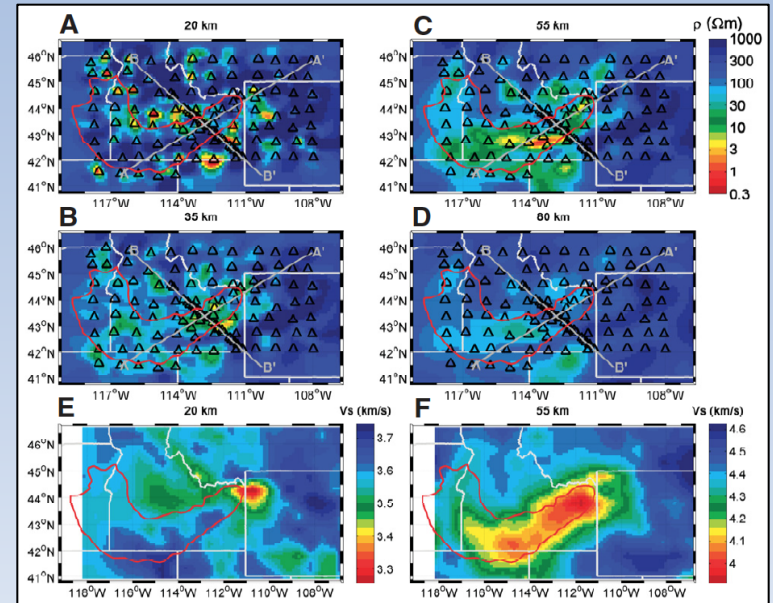
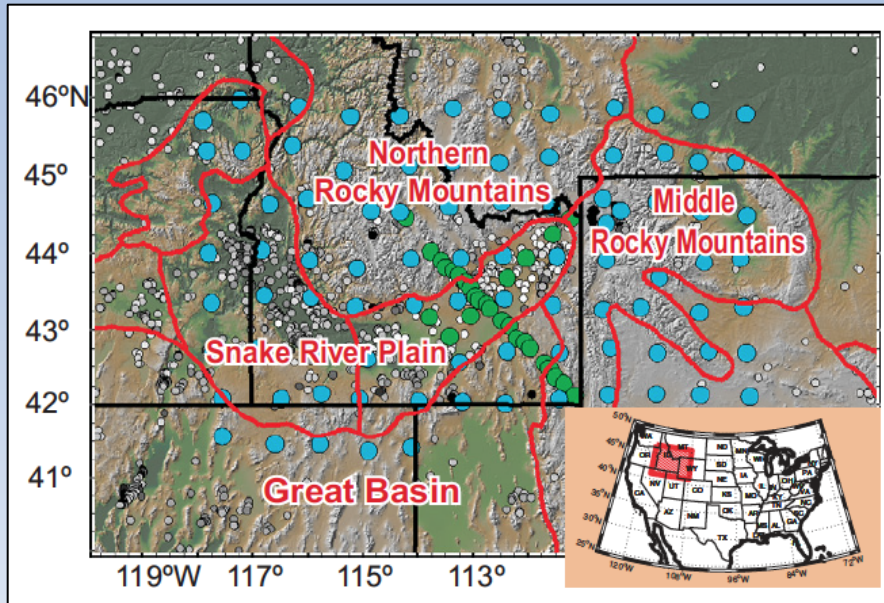
Understanding Great Earthquakes



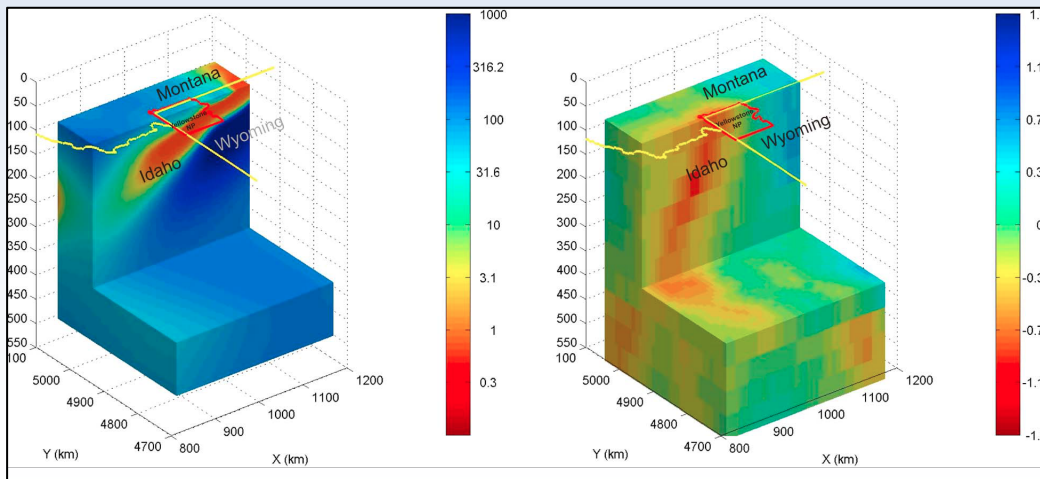
Backprojection analysis of Maule
Kiser and Ishii, *GRL*, 2011

Automated IRIS back projection provides a reference

Imaging Melts and Fluids

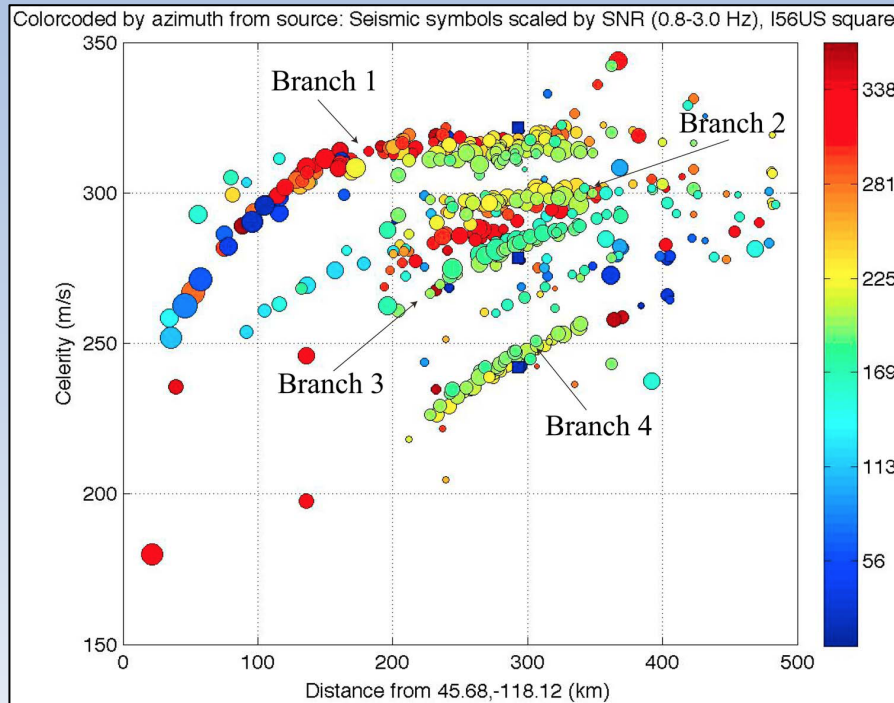


Geoelectric images of the crust and mantle along Snake River Plain and Yellowstone
Kelbert et al., *Geology*, 2012

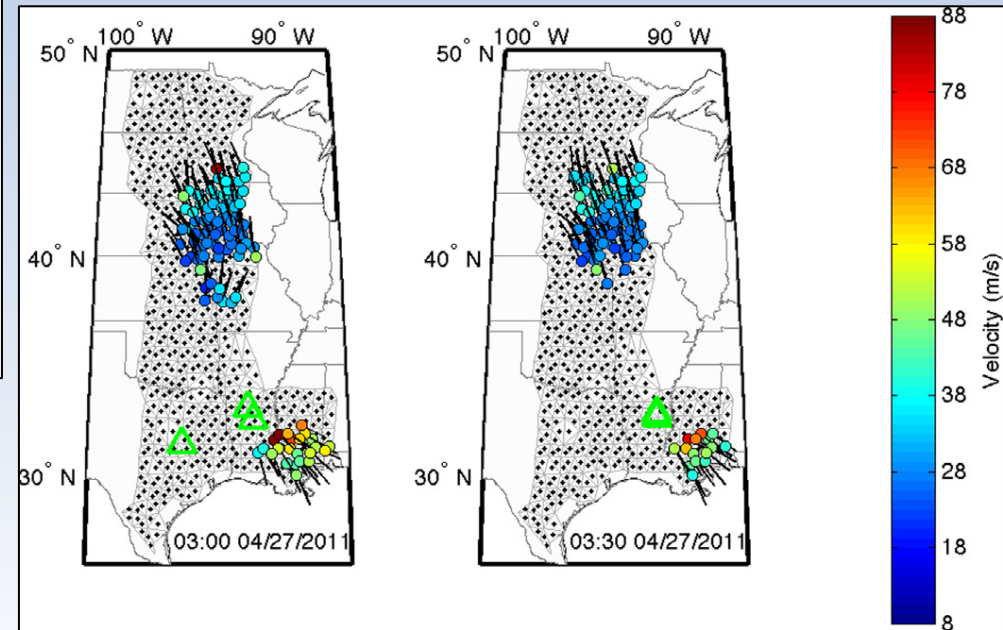


MT can identify melts and resolve ambiguities in seismic results, such as temperature vs. composition.

Mantle MT 3D model compared to seismic tomography for Yellowstone
Zhdanov et al., *GRL*, 2011

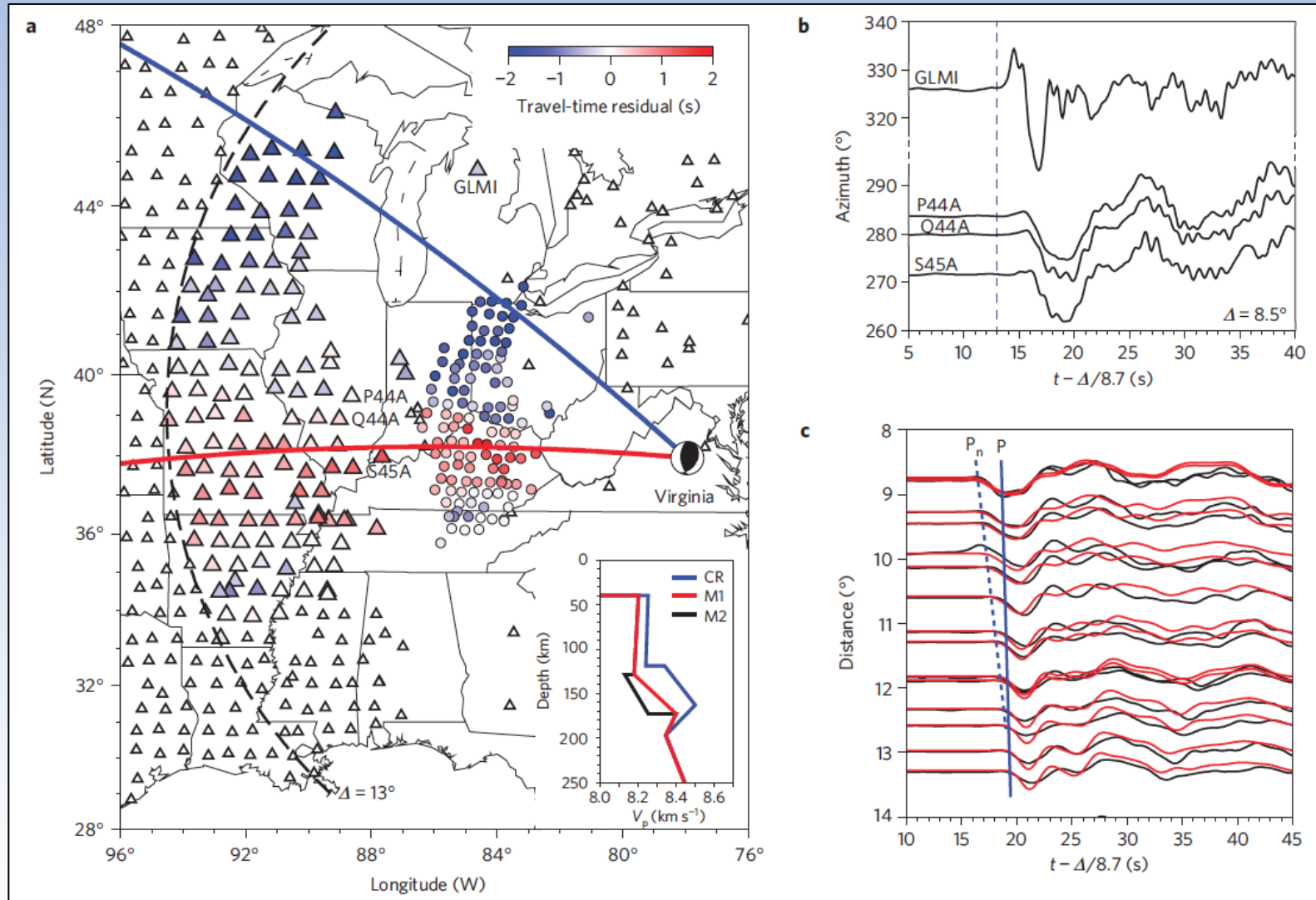


Exploiting acoustic to seismic signals, with distance and azimuth coverage, to illuminate traveltime branches
Hedlin et al., *JGR*, 2010



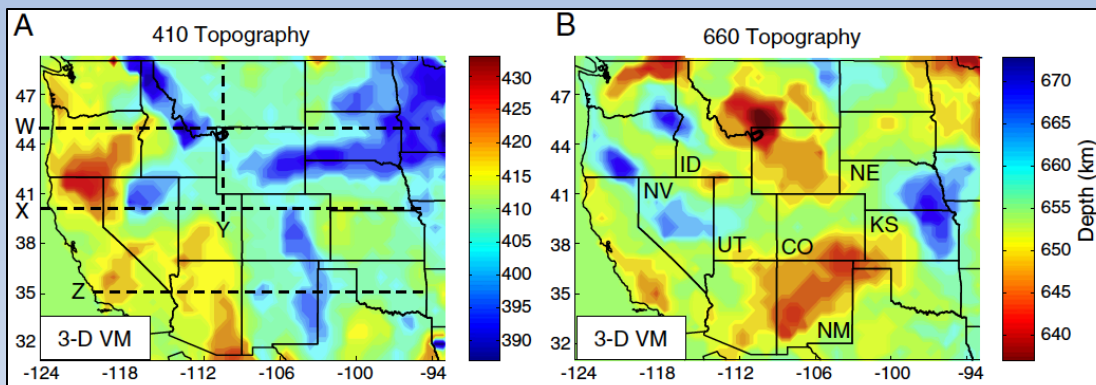
Gravity waves propagating across the TA
de Groot-Hedlin et al., *EPSL*, 2013

Using Regional Events

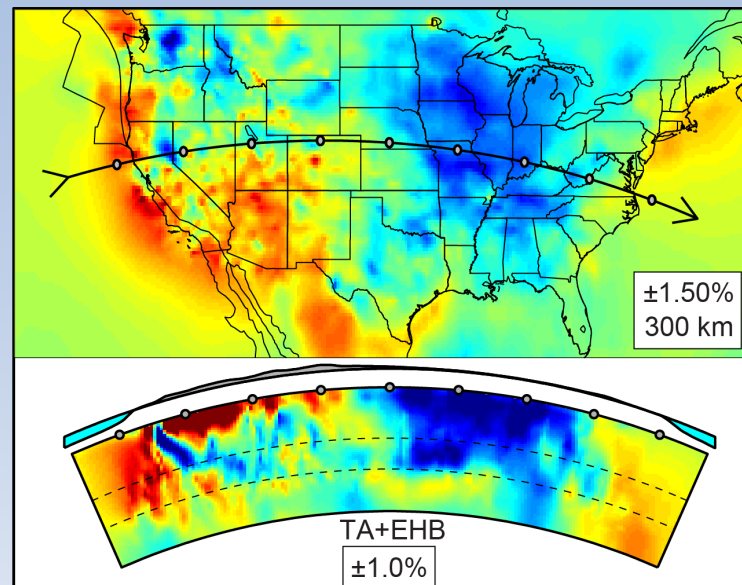
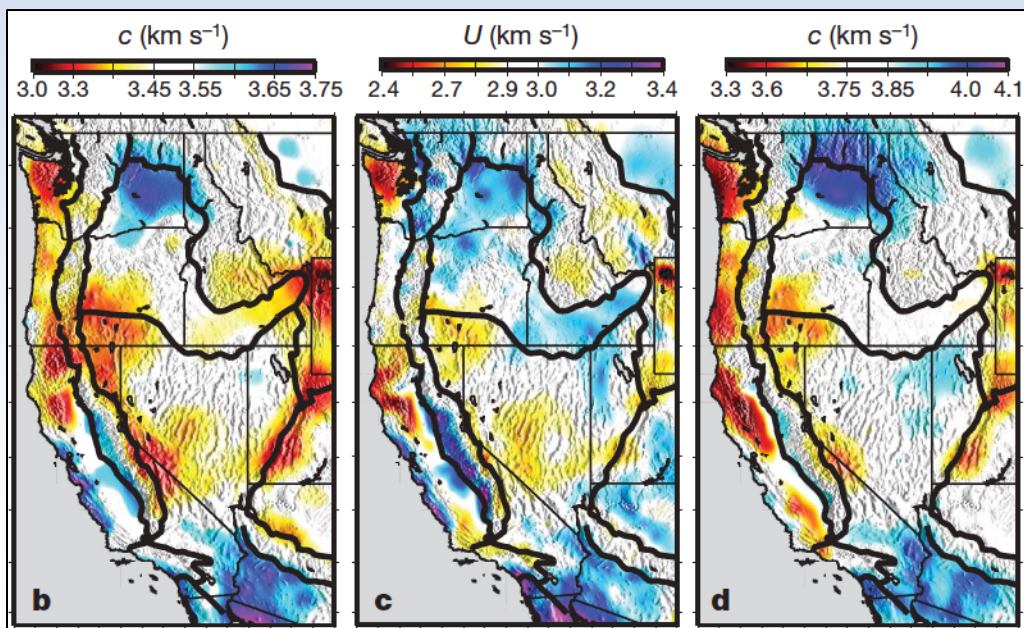


Mineral earthquake energy used to discern ancient hotspot track in Central U.S.
 Chu et al., *Nature Geoscience*, 2013

An Imaging Revolution



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



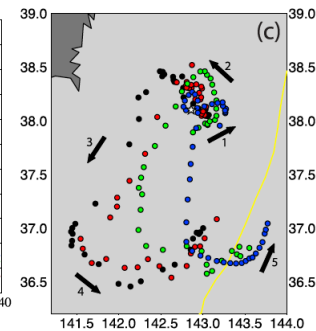
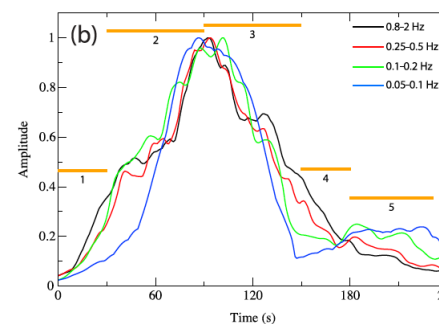
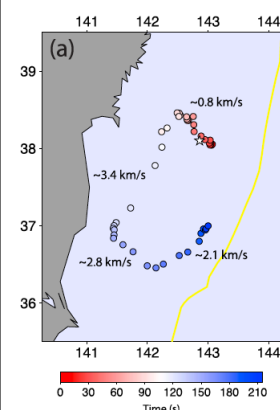
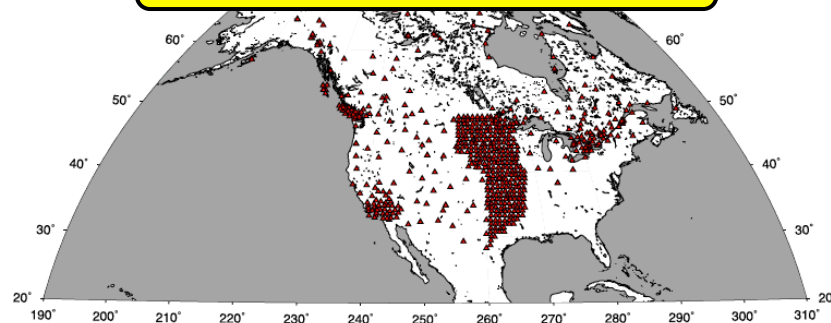
P-wave tomography model
Burdick et al., *SRL*, 2013

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

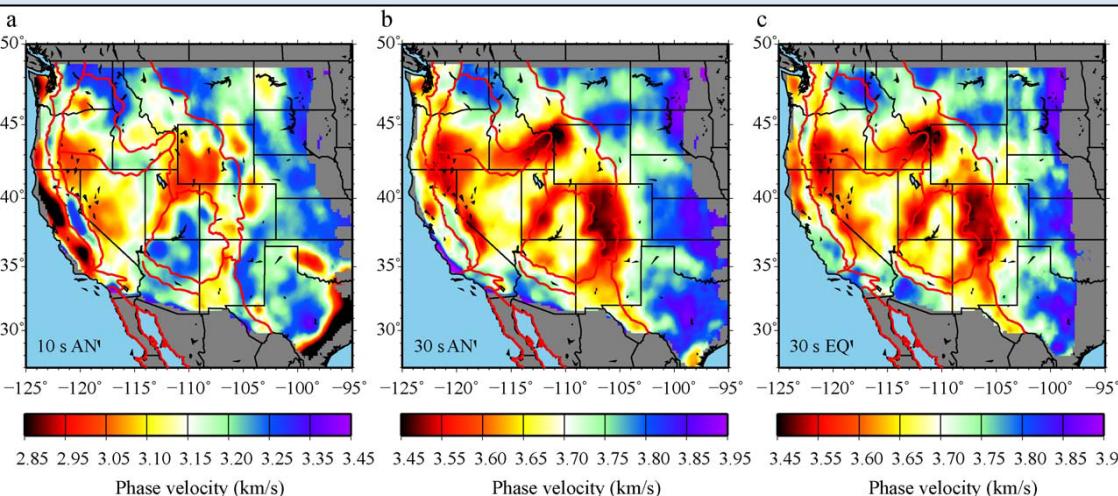
Ambient noise tomography discerns
crustal deformation fabric
Moschetti et al., *Nature*, 2010

Pioneering new methodologies

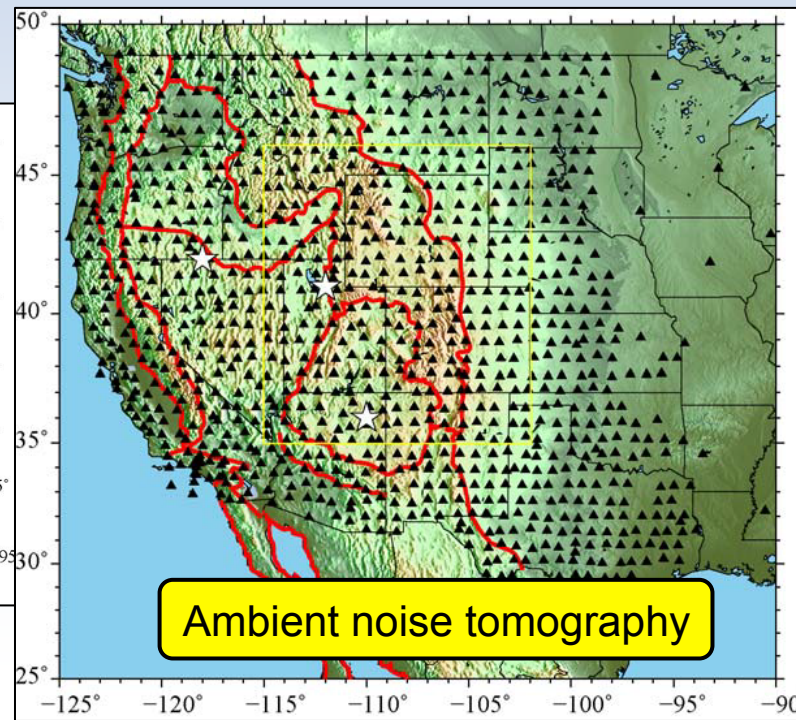
Teleseismic backprojections



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

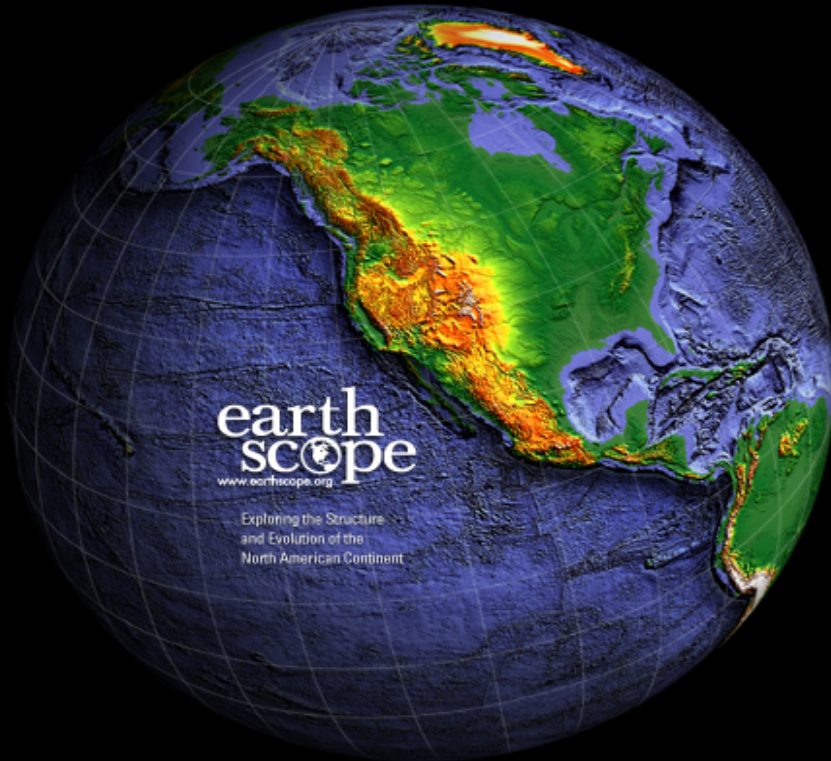


Ambient noise tomographic imaging Ritzwoller et al., *CR*, 2011

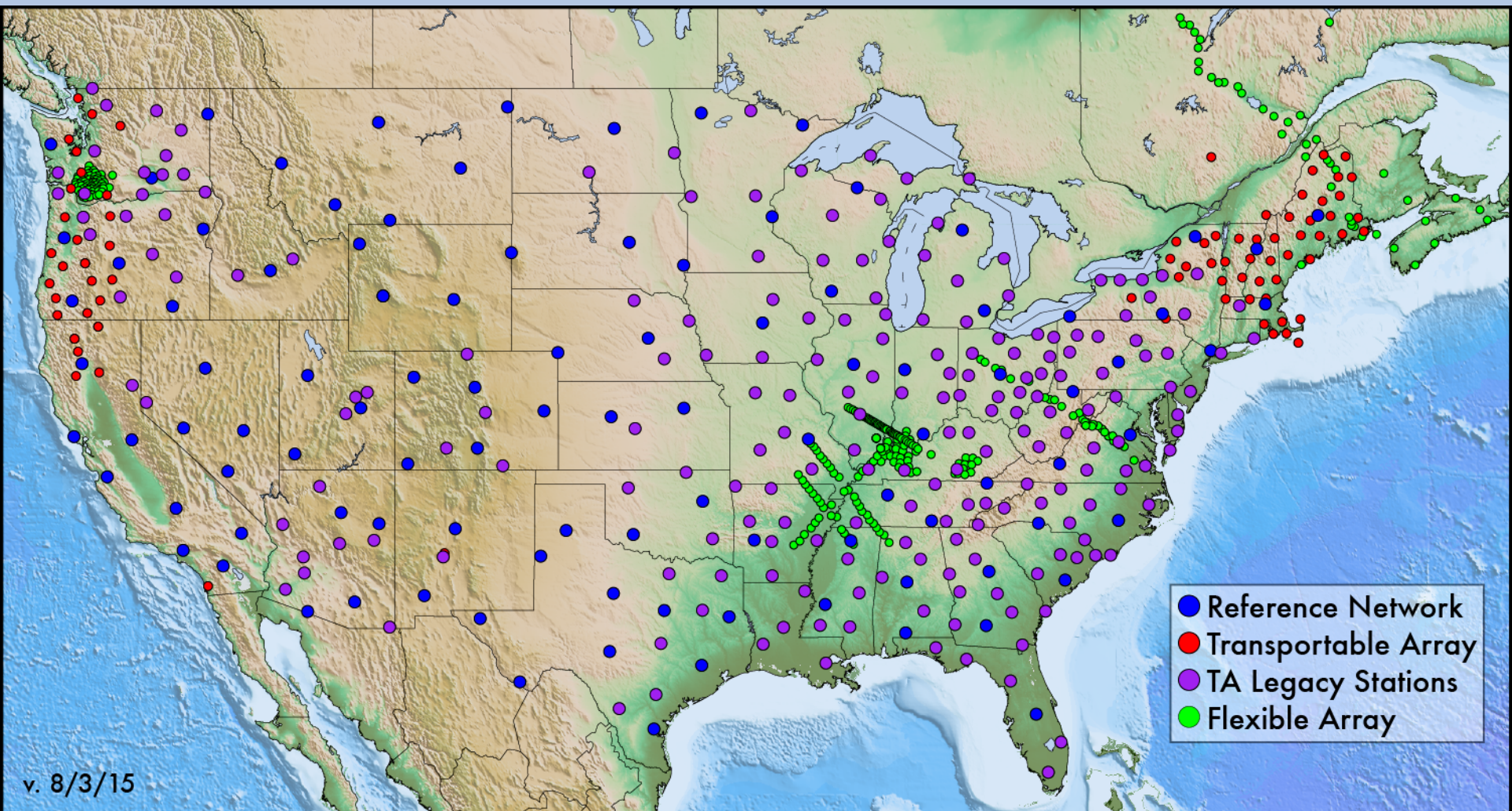


Ambient noise tomography

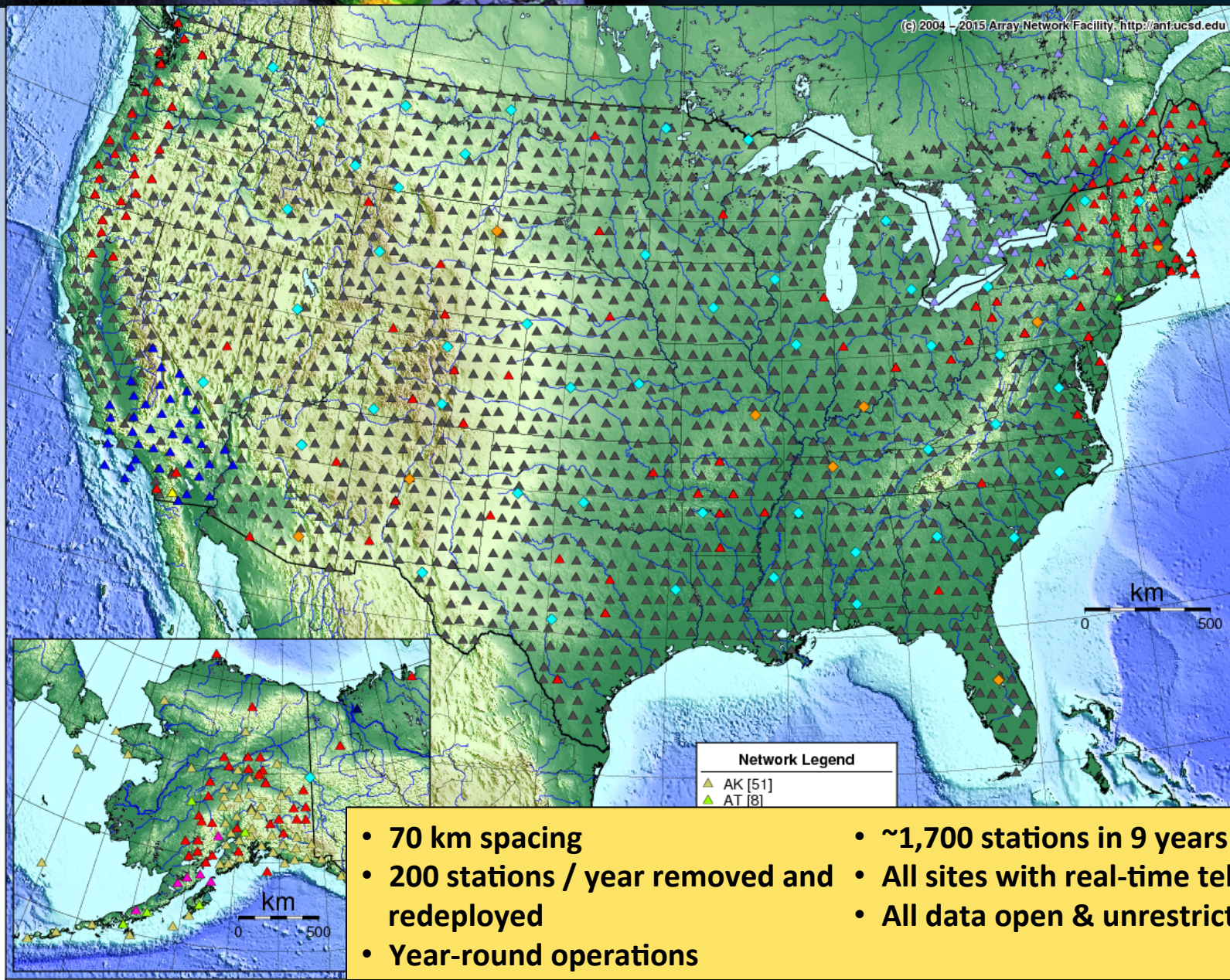
Continent Scale Seismology: Reference Network & Transportable Array



TA and RefNet

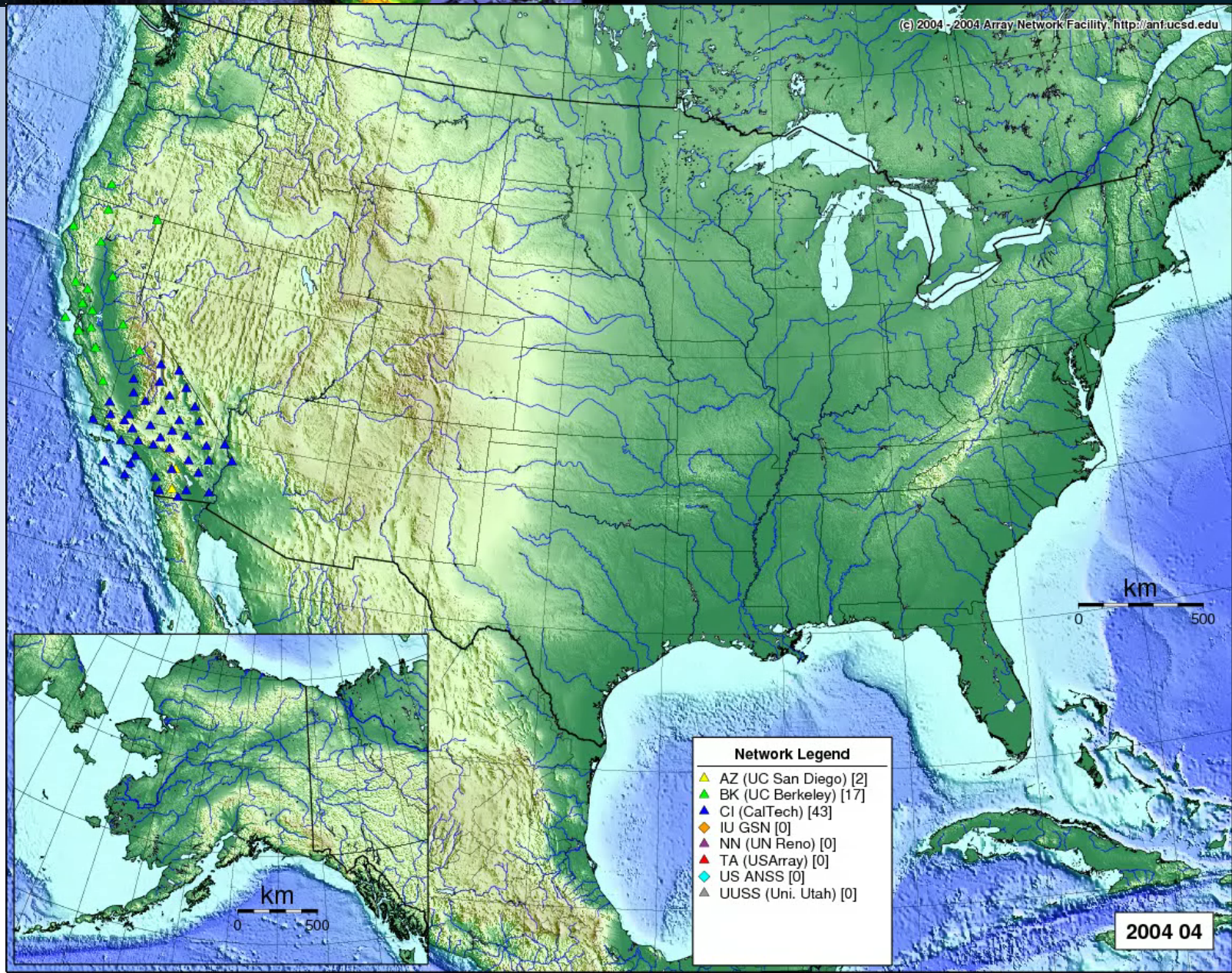


Transportable Array

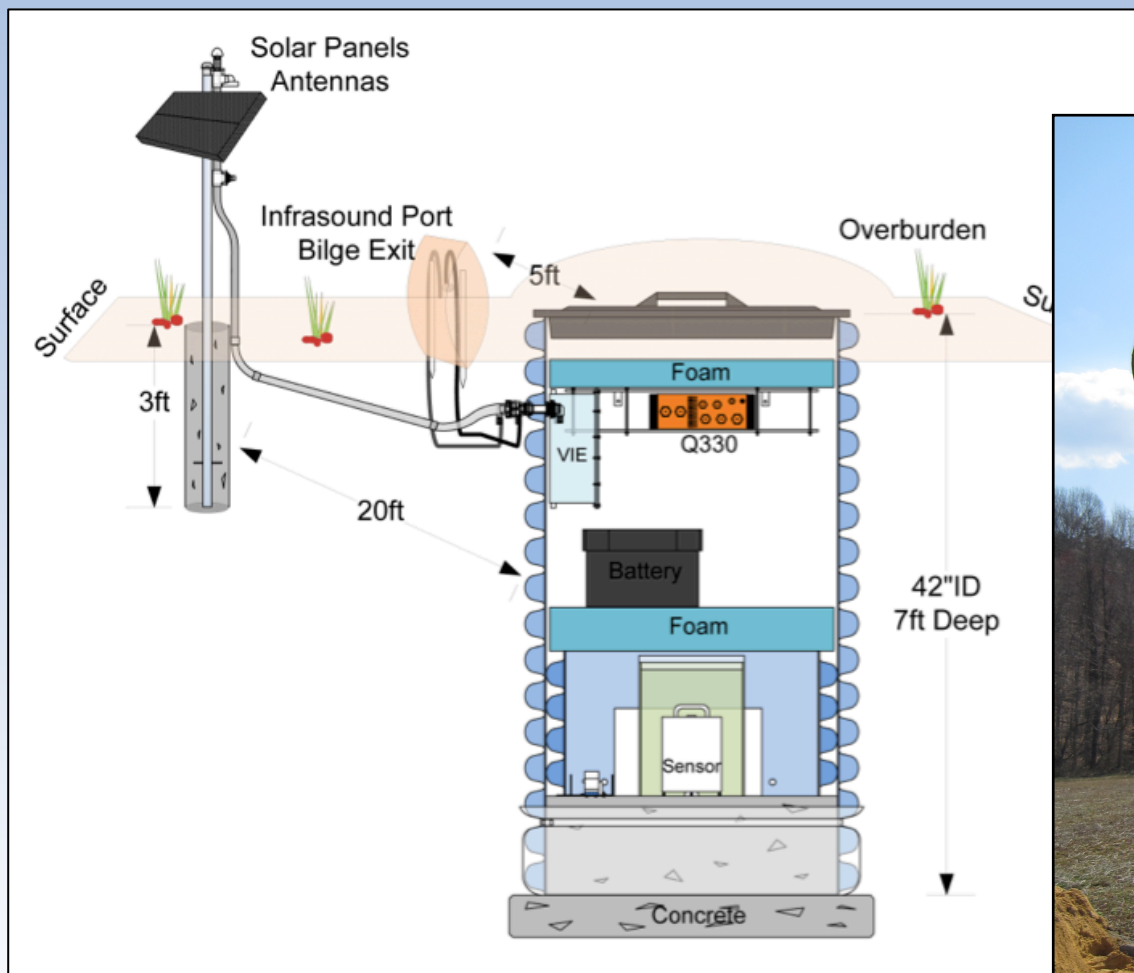


- 70 km spacing
- 200 stations / year removed and redeployed
- Year-round operations
- ~1,700 stations in 9 years
- All sites with real-time telemetry
- All data open & unrestricted

TA Rolling Deployment

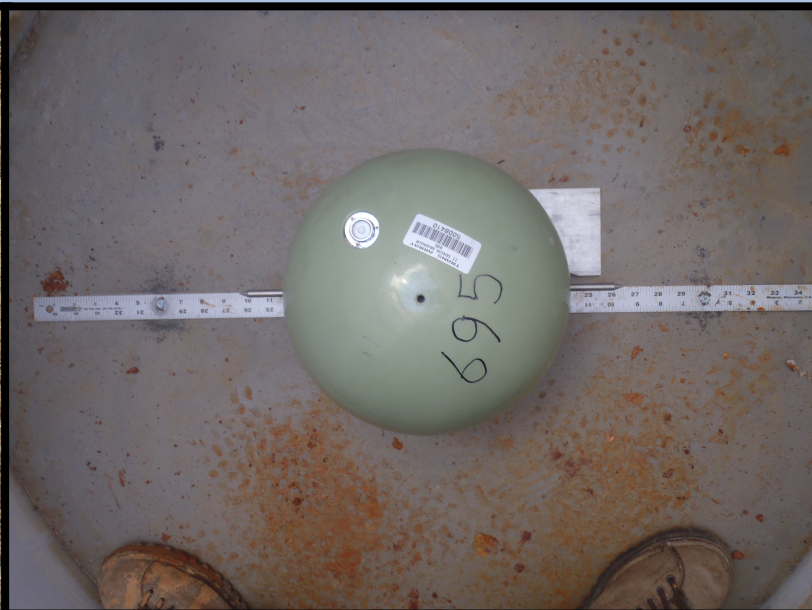


Traditional TA Station



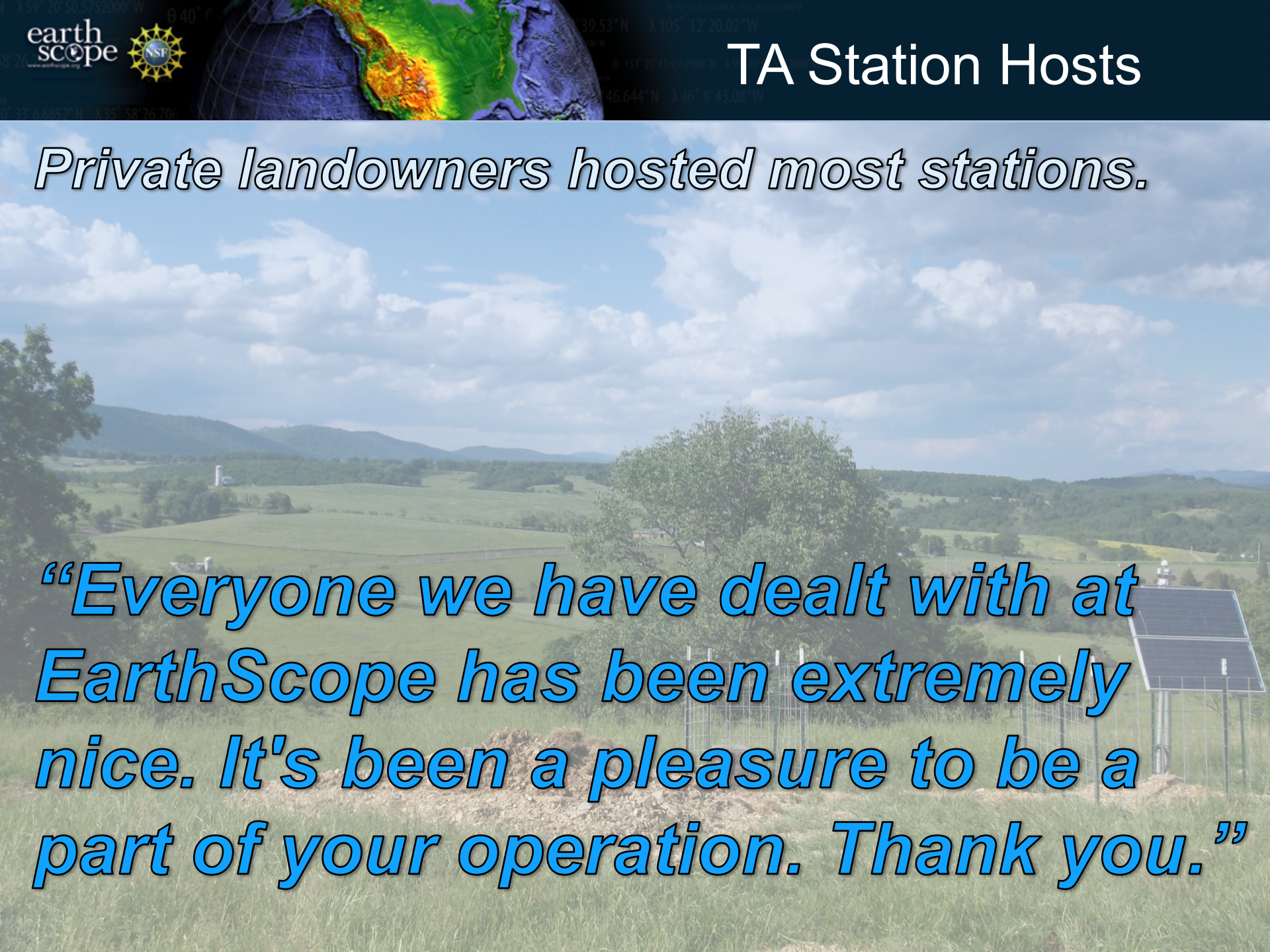
A high precision manufacturing operation!

Traditional TA Station





Private landowners hosted most stations.

A background image of a rural landscape with rolling green hills, a blue sky with white clouds, and a solar panel array in the foreground on the right.

“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.”

"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."

Science Impacts with Regular People

"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."

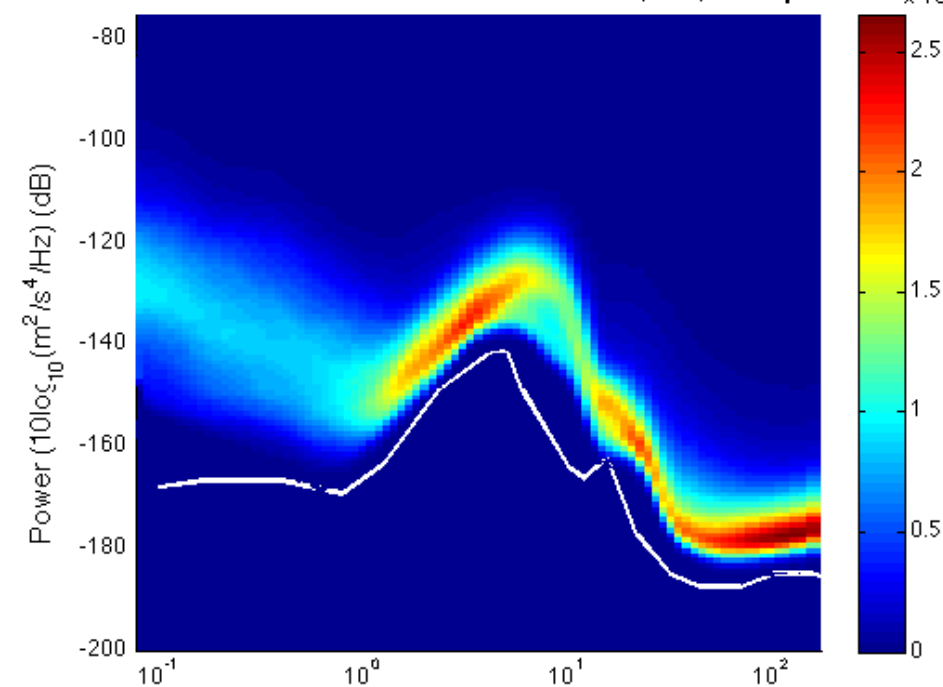
"Glad to be a part of the project. I hope the data collected will benefit us in the future."

"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."

So far, 468 vaults left at landowners' behest!

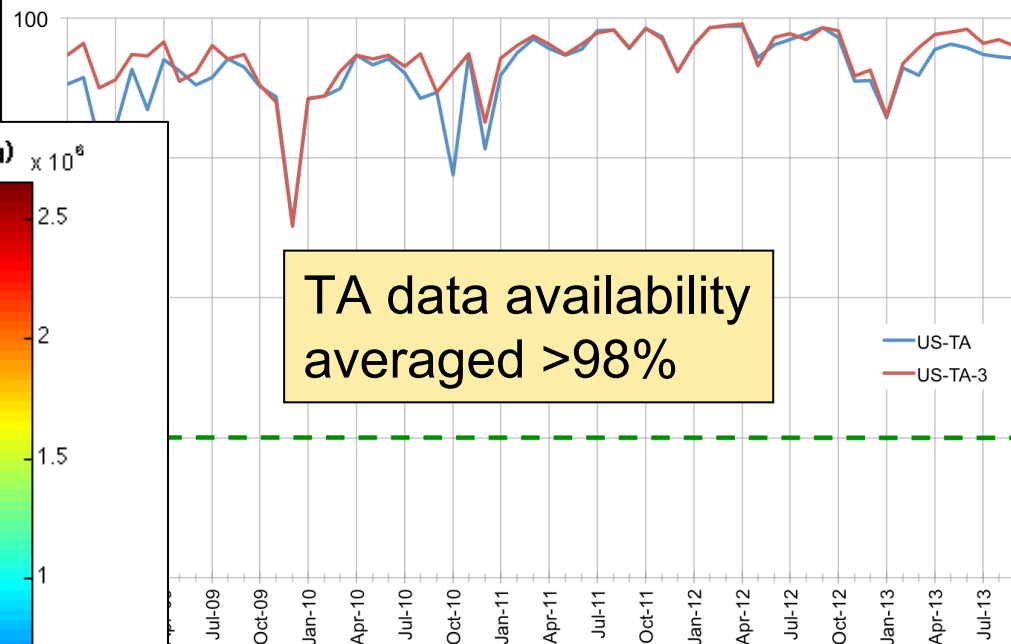
Performance & Quality

Cumulative PSD TA 2004-2010 BHZ (26,915,558 spectra) $\times 10^6$



Station noise highly uniform and quite low for temporary installations

Transportable Array Uptime %



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!

Value of standardized network operations

ANF Array Network Facility

Home Stations Tools Earthquakes Projects About

Home » Online Tools » Real-Time USArray Web-Based Data Logger Monitor V.2.0

Data in this table is 212 seconds old | [Customize the table fields for this browser](#) | [View the legend for the table](#) | [Show information about this page](#) | [Problems with this table](#)

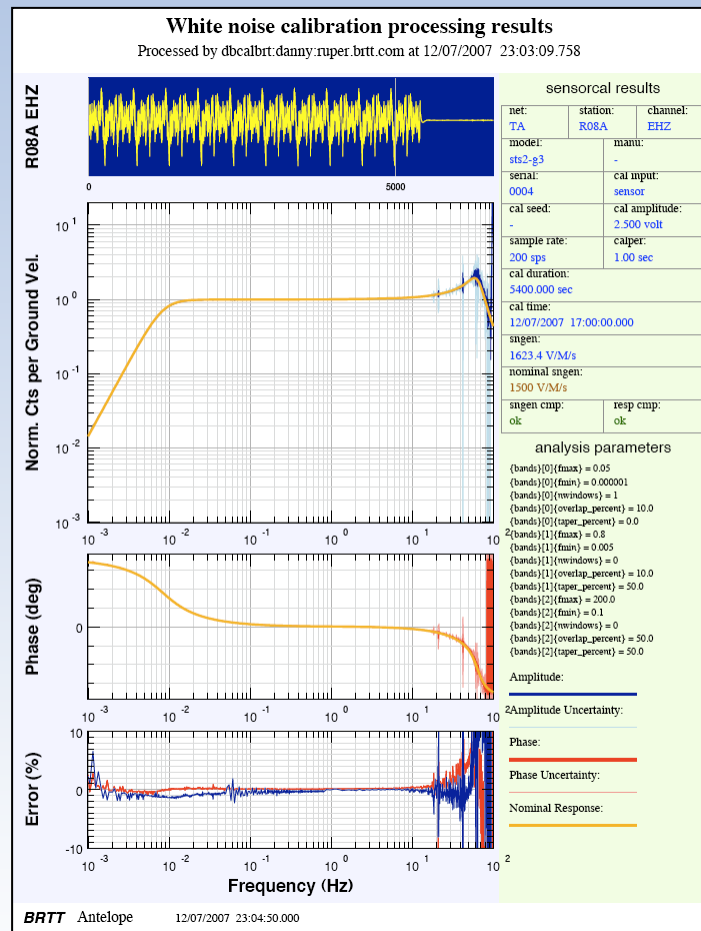
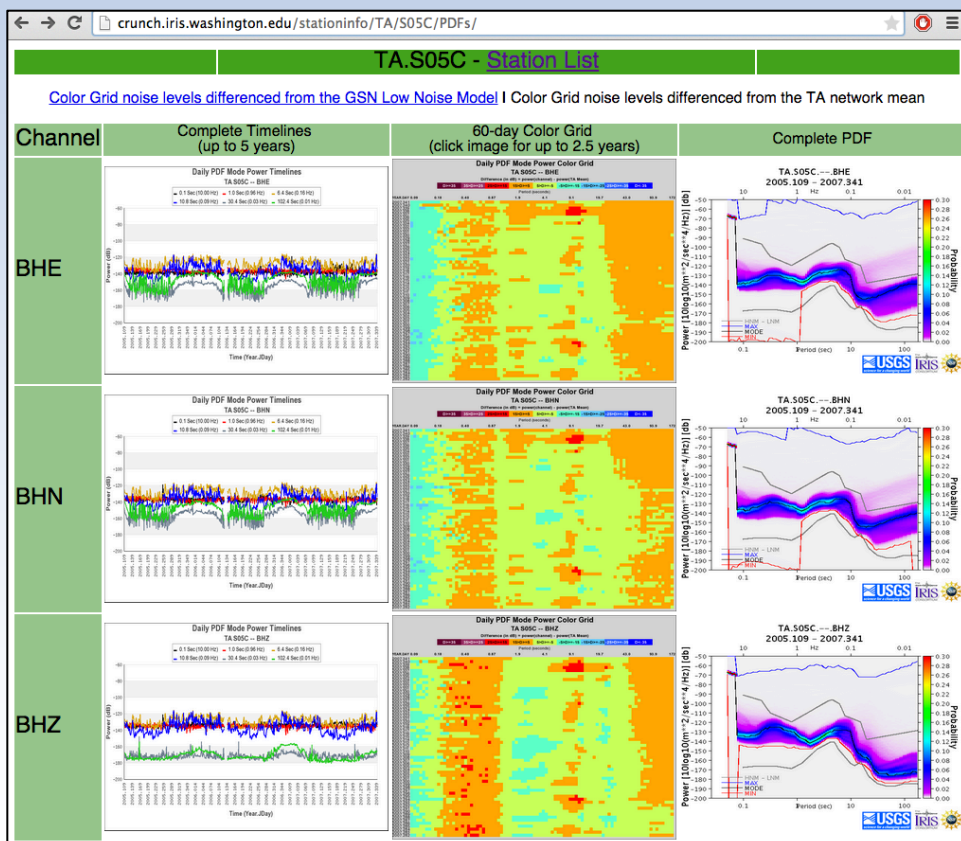
dlname	comp	gp24	nr24	pmp	dltnoy	runtm	tp	cme	bufr	nl24	np24	nr24	dr	br24	bw24	lcq	m0	m1	m2	temp	volt	amp	acok
TA_446A	Att	0s	0			8d16d2m34s	0			0	0	0	0	0k	0k								-
TA_A27A	WB	0s	0		32m44s	31m33s	0			8	7	0	0	24m	658k	100%	-29	-20	39	5C	13.5V	58mA	1
TA_X04D	VZ	0s	0		8d11d29m53s	8d11d28m41s	0			0	0	0	0	0k	0k								-
TA_002D	WB	0s	0		2m27s	1m13s	0.01			4	3	0	33	48m	591k	100%	1	-19	-2	11C	13.4V	74mA	1
TA_P23A	VZ	0s	0		1d4b12m24s	1d4b11m0s	0			0	0	0	0	0k	0k								-
TA_P29A	VZ	0s	0		3h5m13s	3h7m4s	0			2	1	0	0	26m	792k	60%	20	20	20	14C	16.1V	44mA	0
TA_P30A	VZ	0s	0		8d51m9s	8d50m5s	0			2	1	0	0	19m	660k	100%	23	12	21	15C	15.6V	64mA	0
TA_Q15A	Att	0s	0		2m7s	5s	0.06	100%		19	75	0	33	31m	703k	100%	-2	9	1	12C	12.9V	58mA	1
TA_T32A	WB	0s	0		2h3m8s	1h16m12s	0			25	39	0	0	30m	836k	100%	-1	-2	0	14C	12.9V	58mA	1
TA_WHTX	Att	0s	0		10m35s	8m11s	0			161	33	0	24	23m	729k	100%	7	-10	-6	26C	12.8V	82mA	1
TA_014A	Att	0s	0		3s	14b2m44s	1	100%	0%	2	1	0	2.4k	26m	901k	100%	9	4	-8	30C	12.5V	61mA	1
TA_015A	VZ	0s	0		3s	3h40m33s	1	100%	0%	26	359	0	2.7k	29m	822k	100%	20	7	1	32C	12.5V	60mA	1
TA_026T	VZ	0s	0		3s	17h48m27s	1	100%	0%	2	1	0	2.8k	30m	904k	100%	10	-4	-8	28C	13.4V	56mA	1
TA_109C	I	0s	0		2s	17h47m58s	1	95%	0%	1	1	0	2.8k	30m	911k	100%	-6	-14	0	24C	13.2V	67mA	1
TA_121A	VZ	0s	0		9s	17h48m35s	1	100%	0%	1	1	0	2.4k	22m	839k	100%	26	-41	14	22C	13.2V	72mA	0
TA_123A	VZ	0s	0		3s	10h51m58s	1	99%	0%	3	2	1	2.9k	30m	912k	100%	10	14	10	25C	12.9V	60mA	1
TA_134A	VZ	0s	0		3s	17h48m37s	1	100%	0%	2	1	0	2.9k	30m	904k	100%	34	-3	-28	24C	12.6V	61mA	1
TA_135A	Att	0s	0		3s	8h59m28s	1	100%	0%	2	1	0	2.9k	30m	900k	100%	-34	-8	8	22C	12.9V	59mA	1
TA_136A	Att	0s	0																				1
TA_137A	VZ	0s	0																				1
TA_138A	VZ	0s	0																				1
TA_139A	Att	0s	0		3s	3h1m44s	0.99	97%	0%	41	17	0	3.2k	27m	996k	100%	11	-13	-7	25C	12.3V	58mA	1
TA_140A	VZ	0s	0		3s	4h54m5s	1	99%	0%	3	2	0	3.6k	39m	868k	100%	15	21	-8	21C	12.6V	61mA	1
TA_141A	VZ	42m	1		3s	17h48m7s	1	99%	0%	2	2	0	4.3k	44m	882k	100%	9	13	28	21C	12.9V	58mA	1

<http://anf.ucsd.edu/tools/webdlmon>

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

Value of automated quality control

- Automated process for command, capture, and analysis of calibration signals

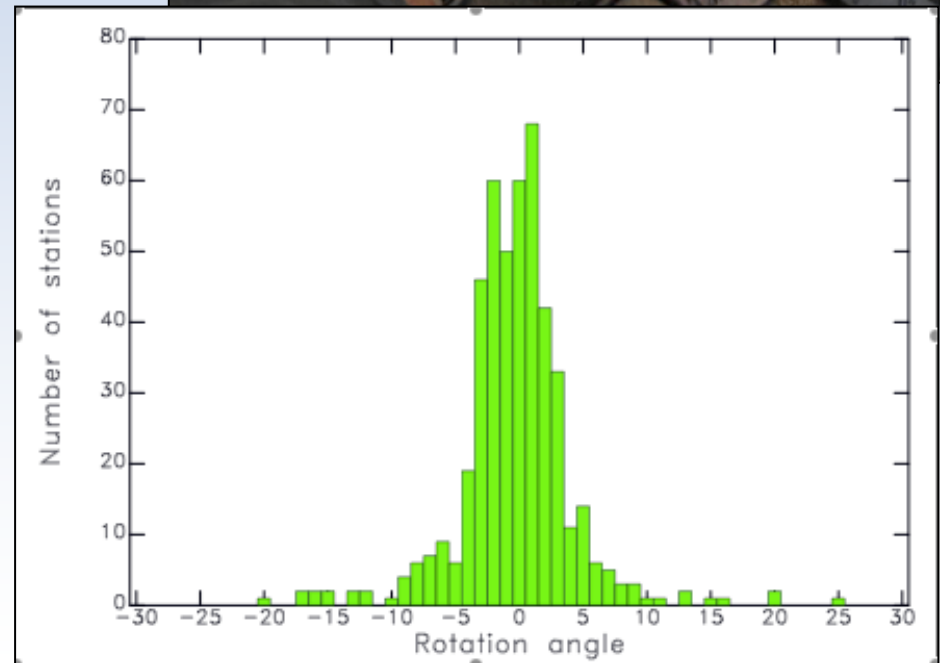
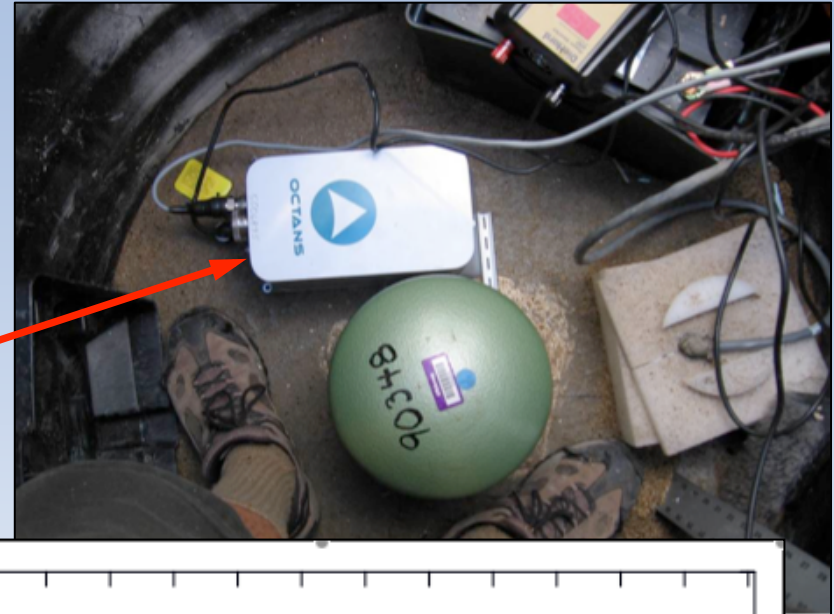


- Real-time noise analysis identifies station performance issues

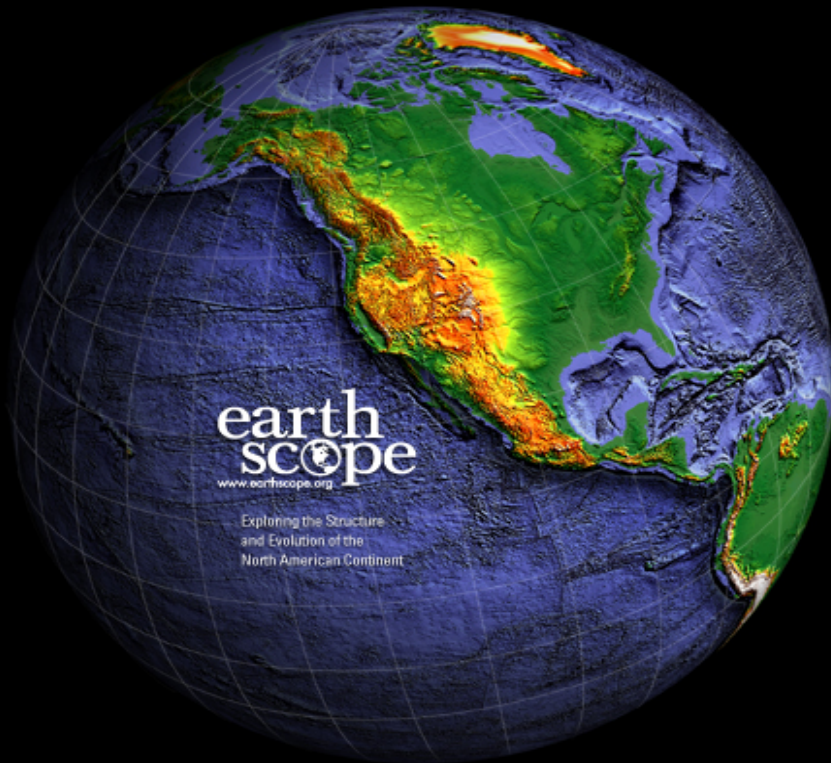
Improved sensor orientation practices

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

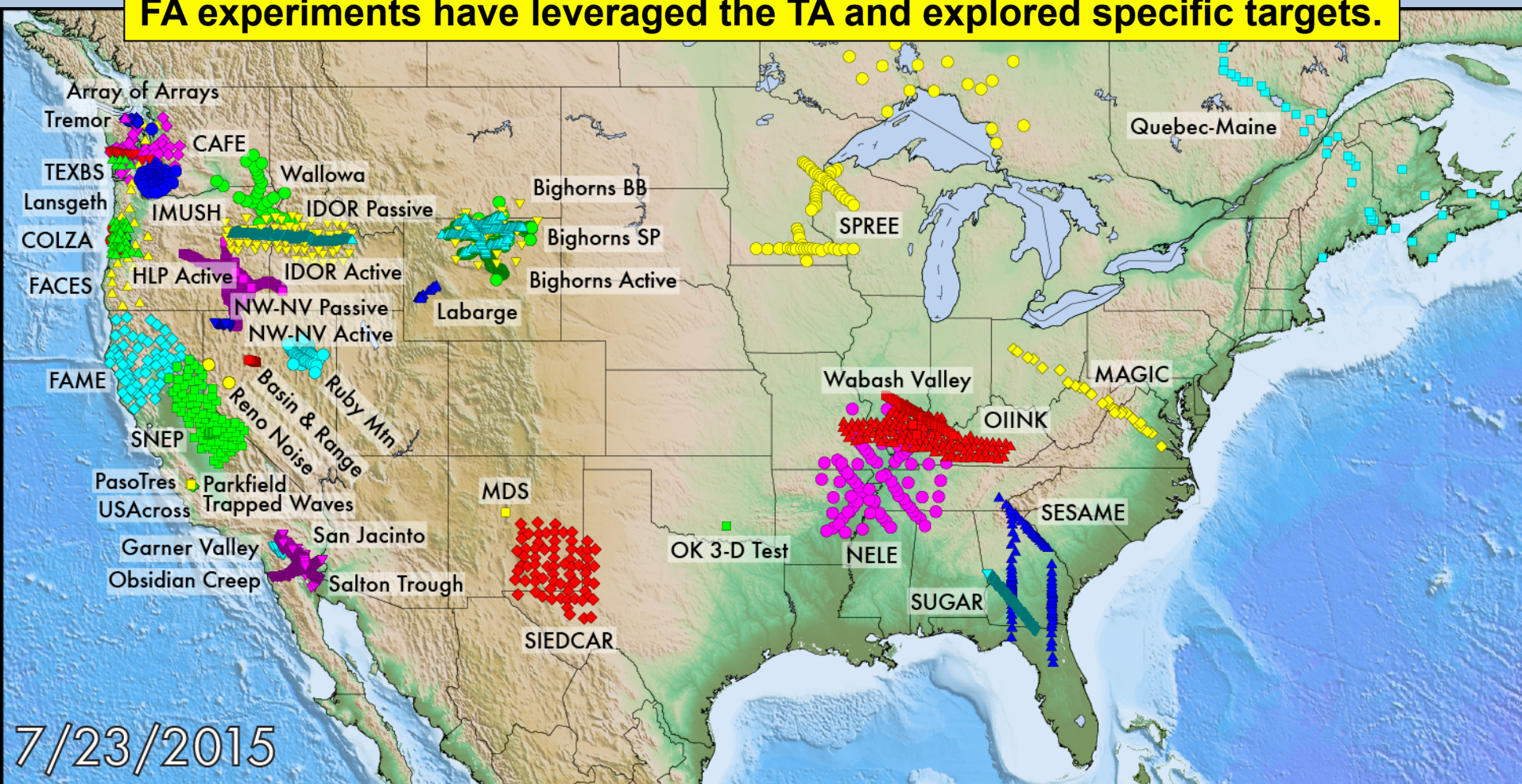
TA station orientation, relative to north, from empirical analysis
Ekström and Busby, SRL, 2008



Flexible Array

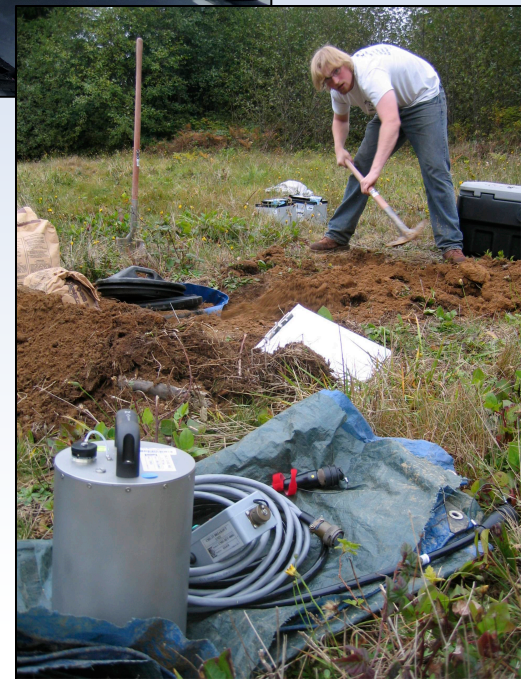
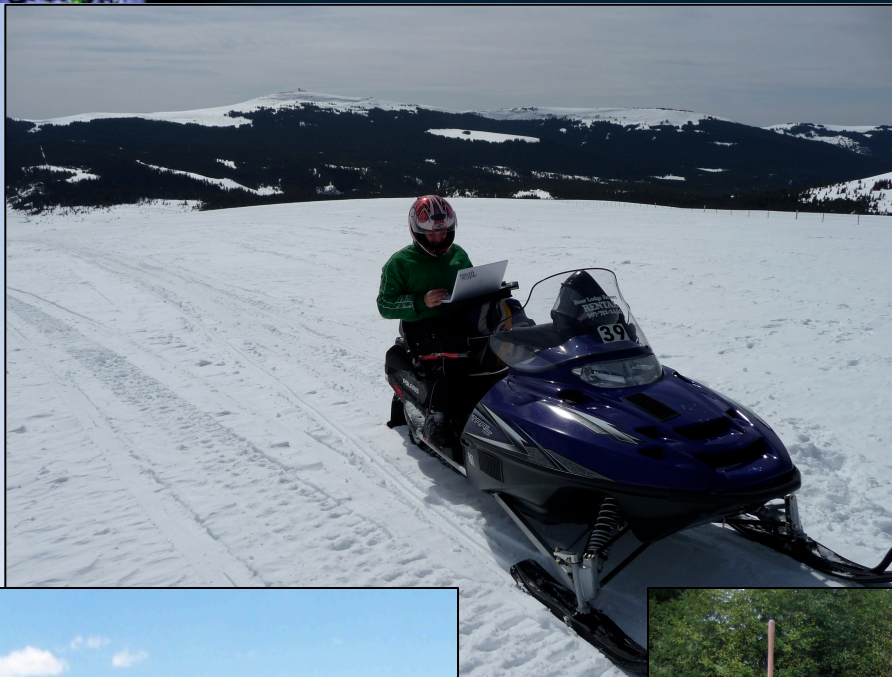


FA experiments have leveraged the TA and explored specific targets.



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

Flexible Array



Data Acquisition Systems

Reftek R125 "Texan"



Reftek R130



Station with radio communications
solar power system



Sensors

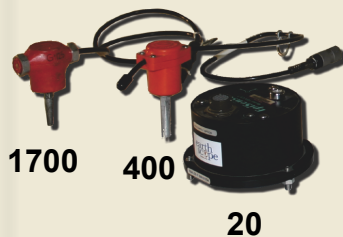
GS11
Hi F

L-40
Hi F

Episensor
Short-period

CMG- 40T-1HZ
Short-period

CMG- 3T- Broadband



20



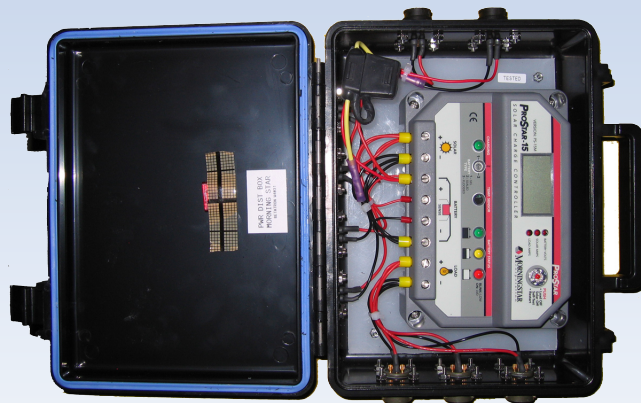
Field testing of broadband systems



Sensor vault systems



Charge and power
control systems

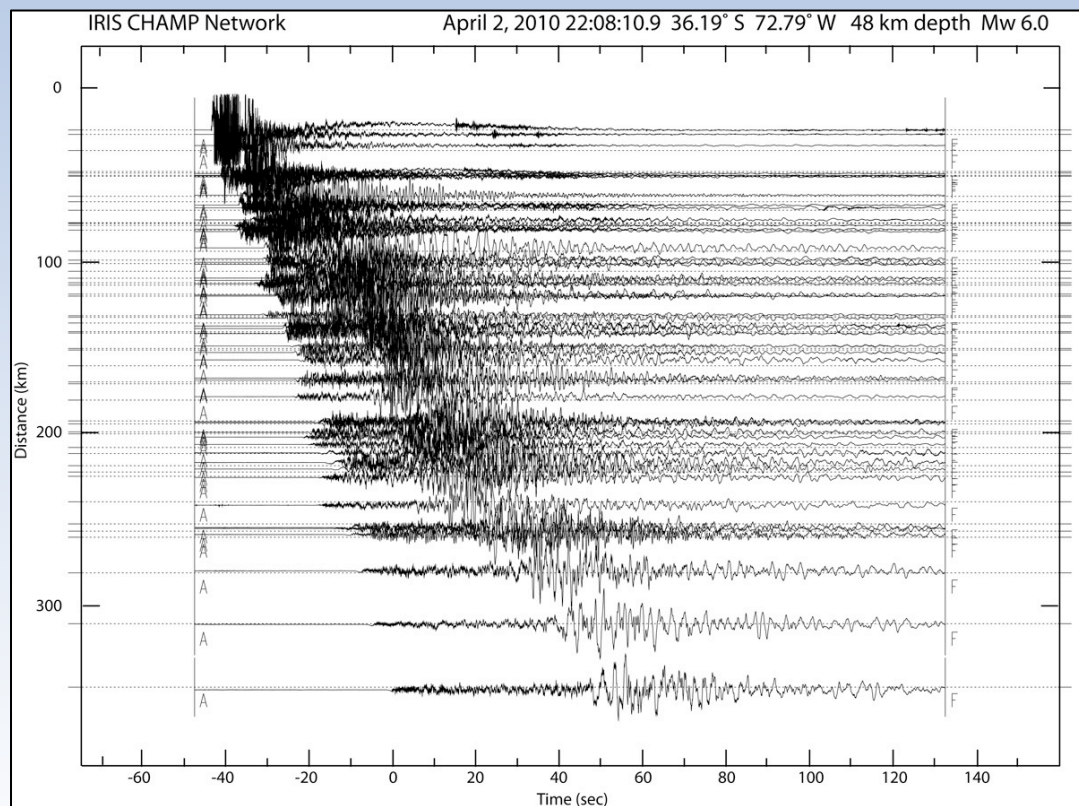


Equipment enclosures

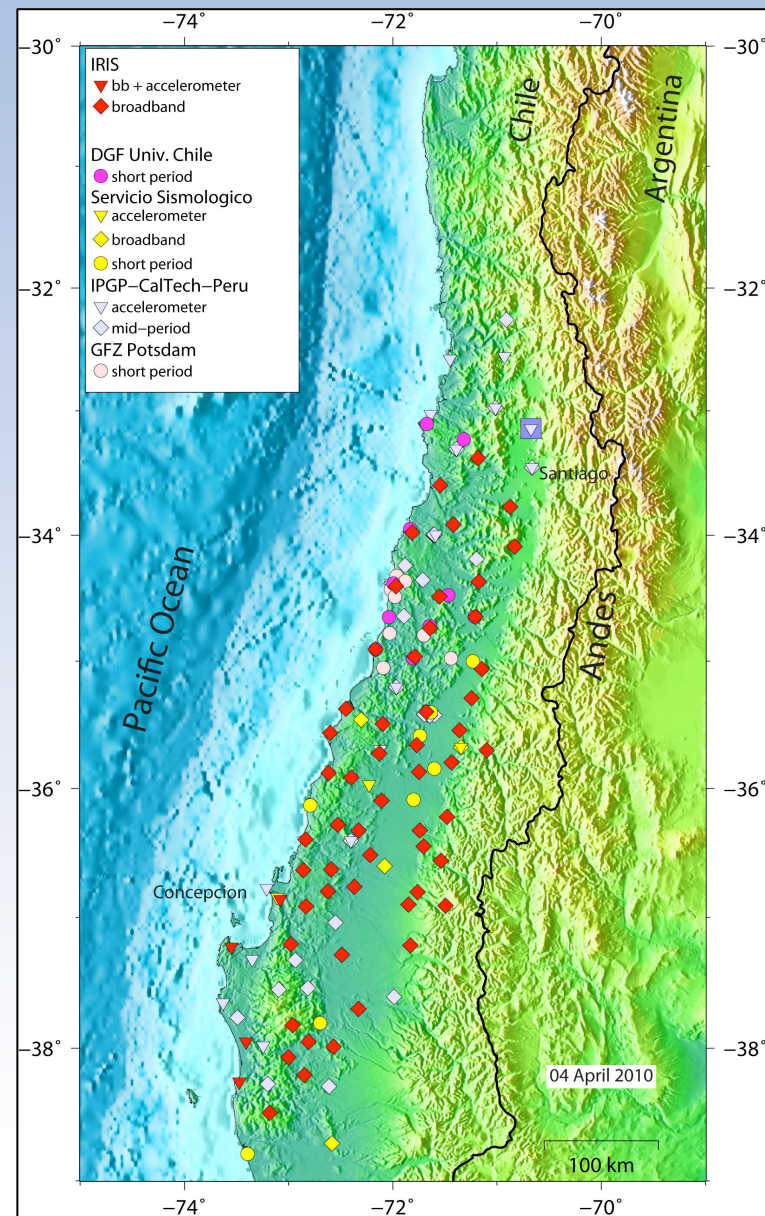


~410 stations worth of standardized equipment available

- FA broadband in Chile

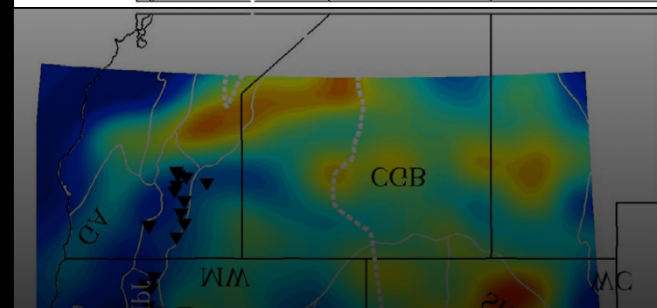
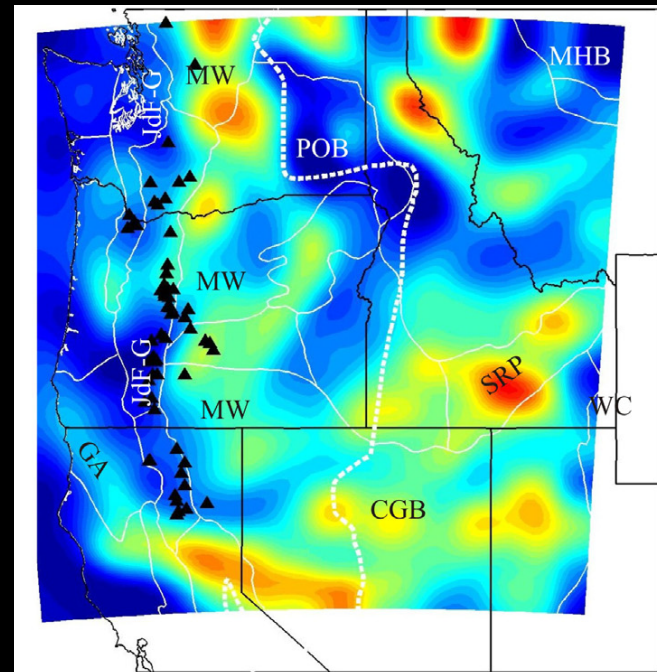
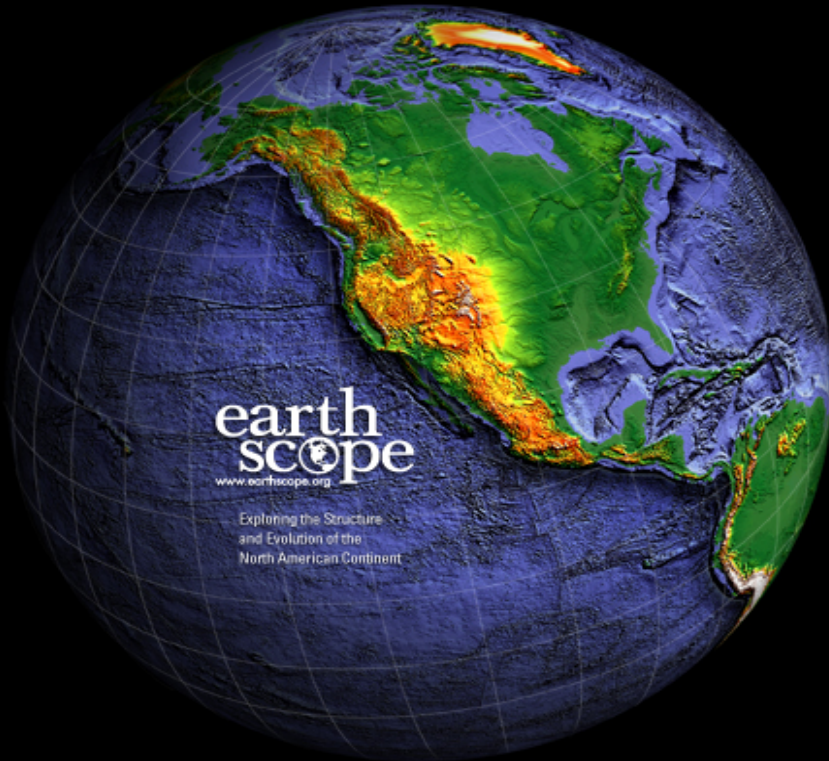


**50 BHZ records of M6
aftershock on 4/2/10**

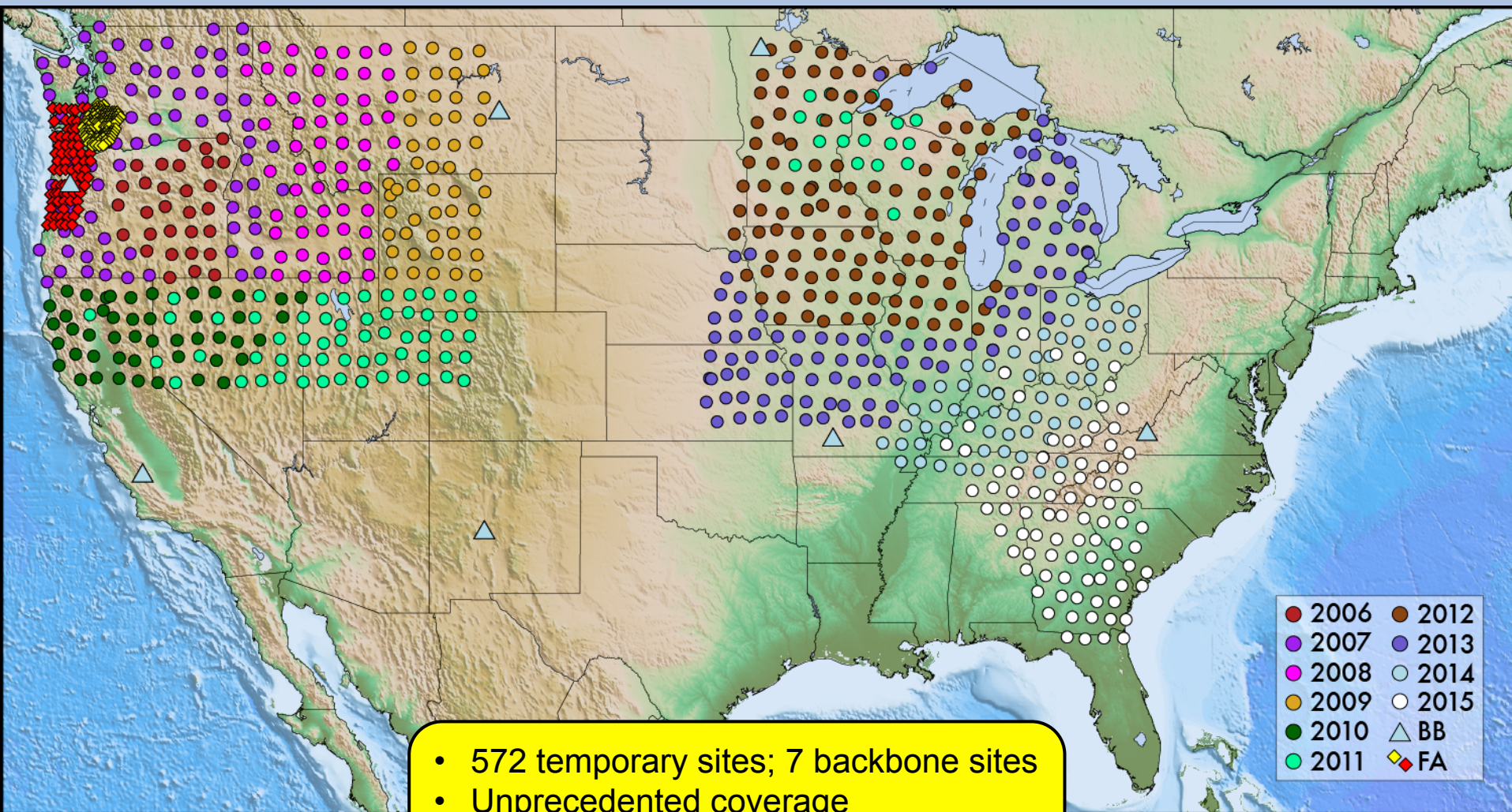


Magnetotellurics

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



MT – Flexible Arrays

EarthScope/GeoPRISMS iMUSH

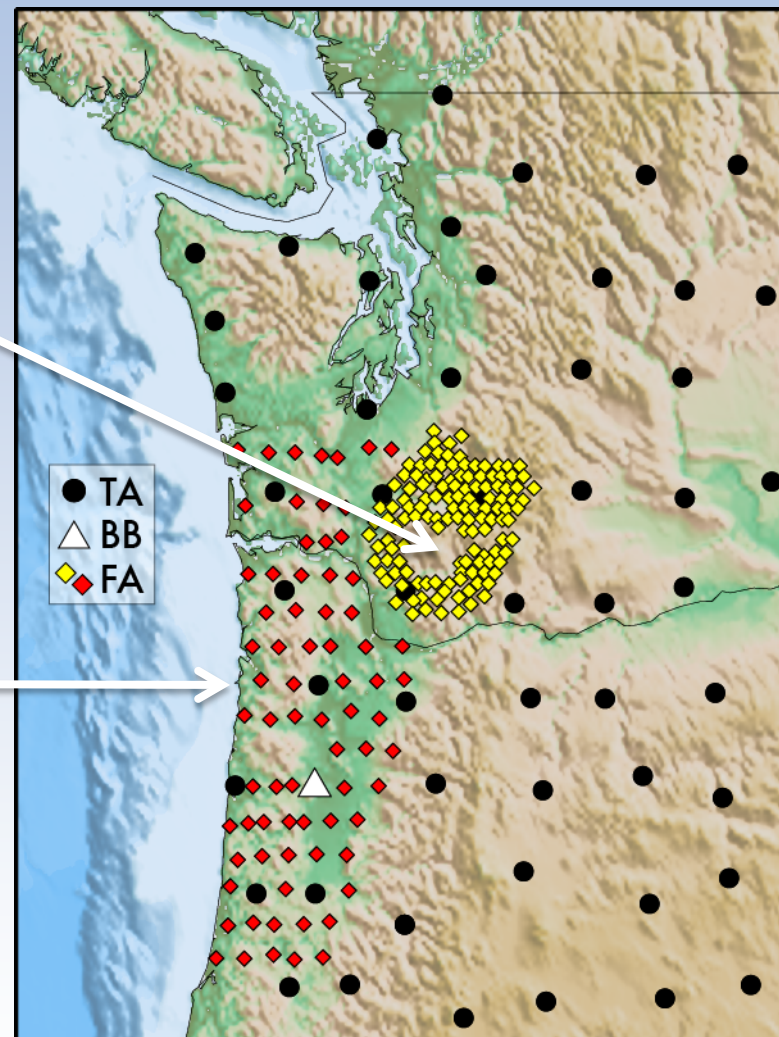
Purpose: Image Magma Under St. Helens

EarthScope *MOCHA*

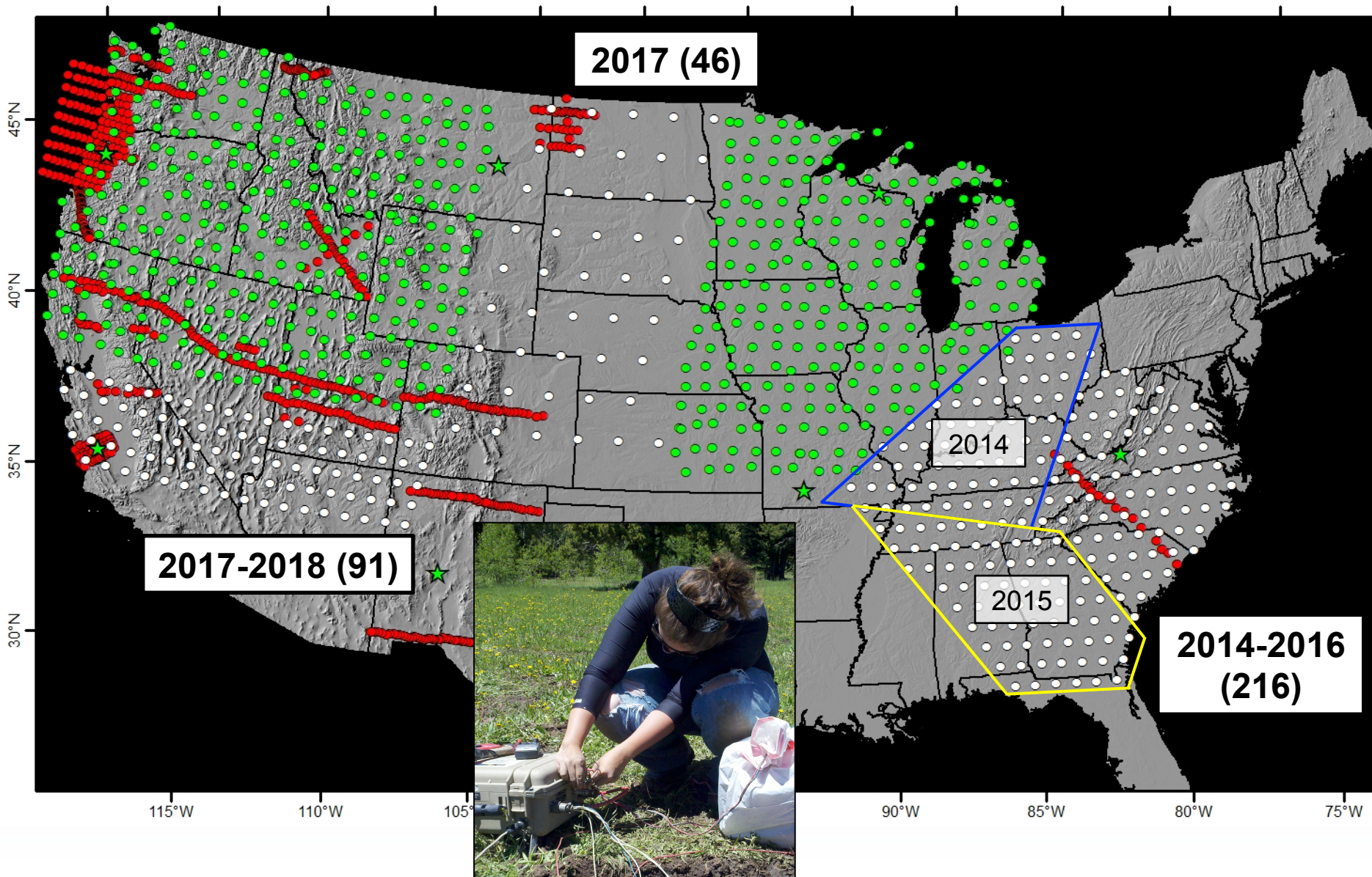
“Magnetotelluric Observations of Cascadia using a Huge Array”
onshore-offshore MT project

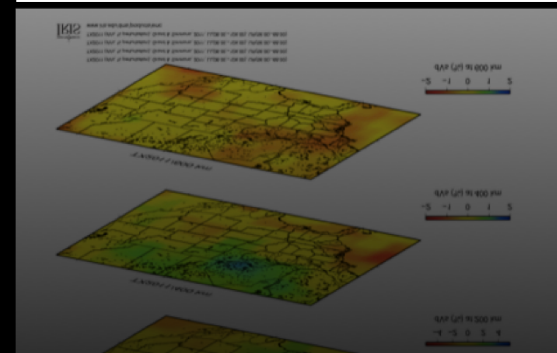
Purpose: Characterize role of fluids in
Episodic Tremor and Slip/Margin
Segmentation/Megathrust
Earthquakes

- EarthScope MT PI support didn't exist in 2009!
- Now a significant activity

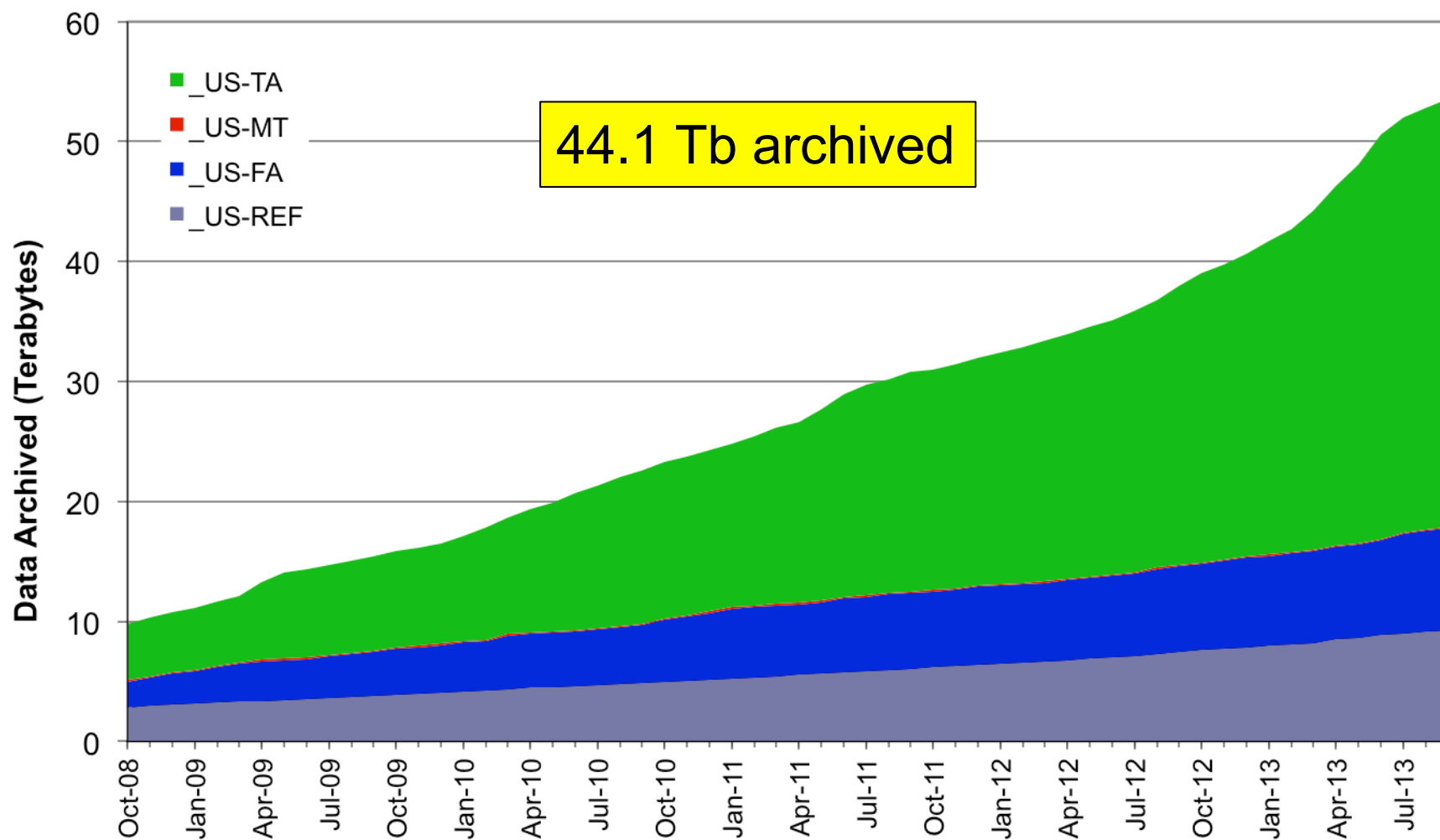


Looking Ahead

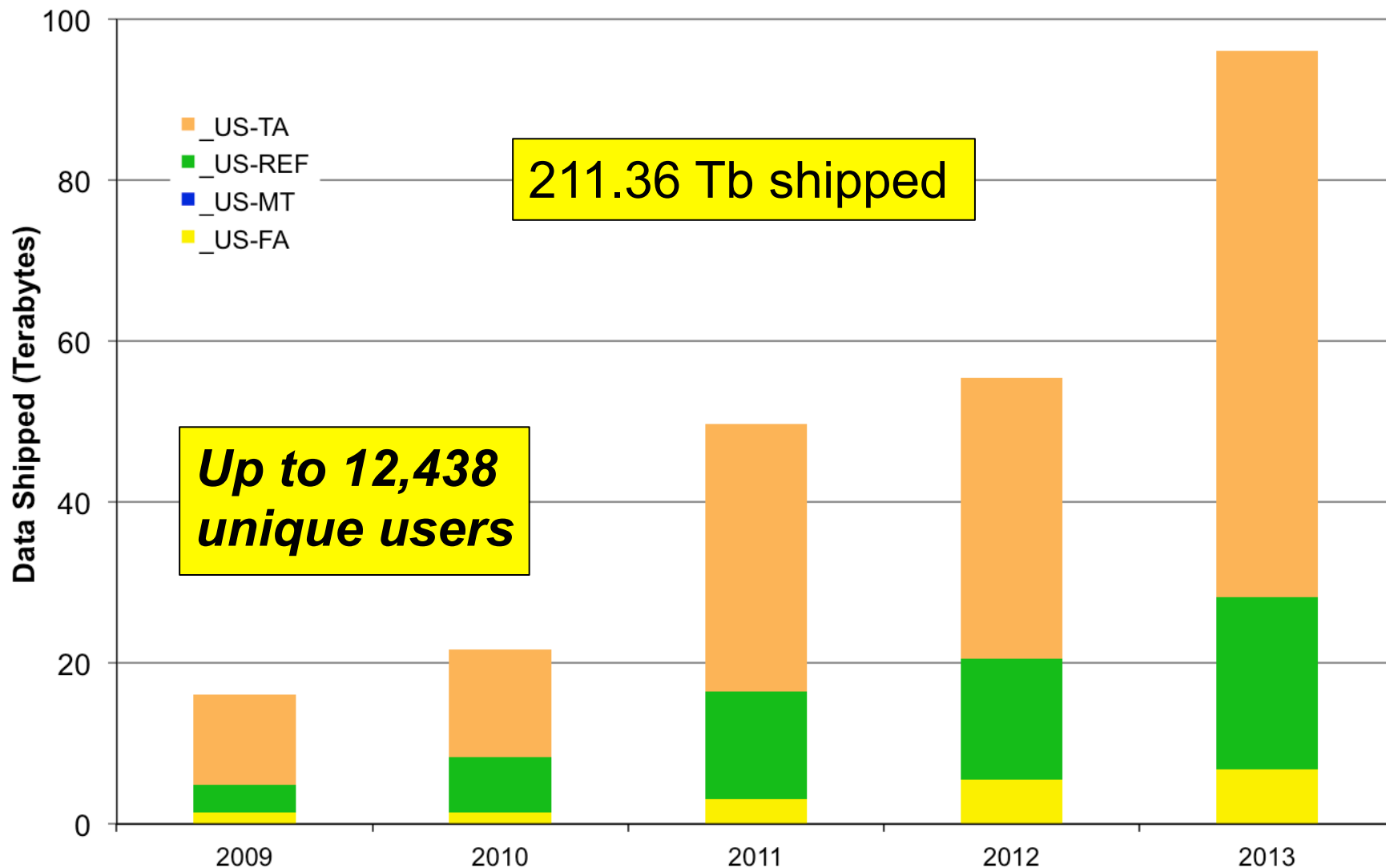




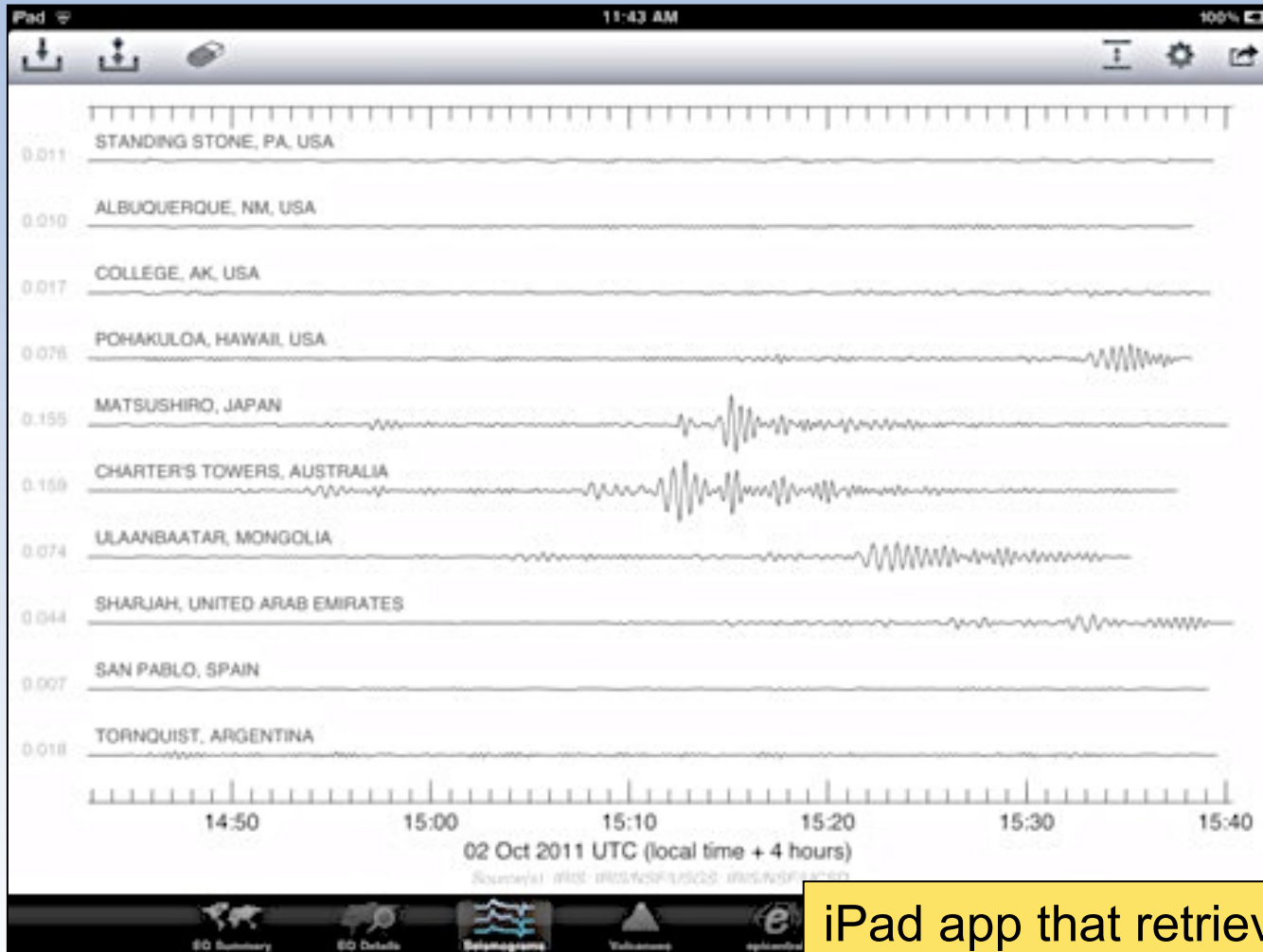
Data Archived During USArray O&M Award



Data Shipped During USArray O&M Award



Open Data



iPad app that retrieves real time seismic data via webservices

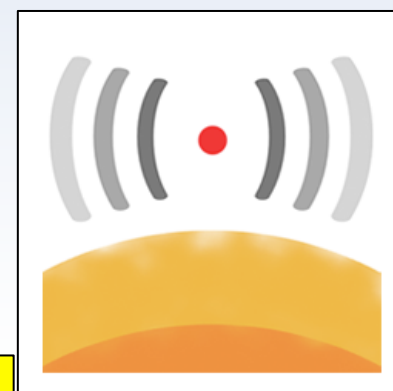
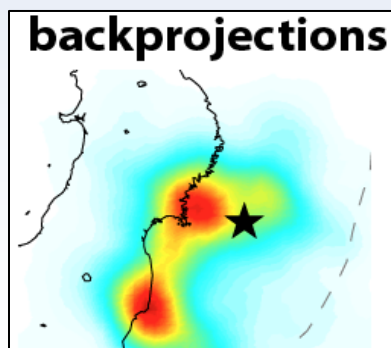
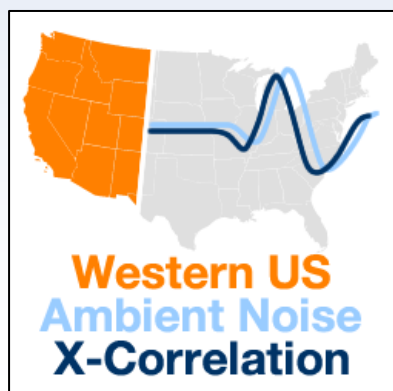
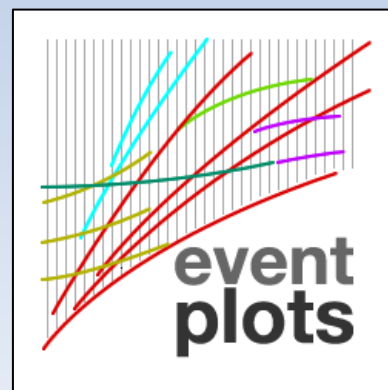
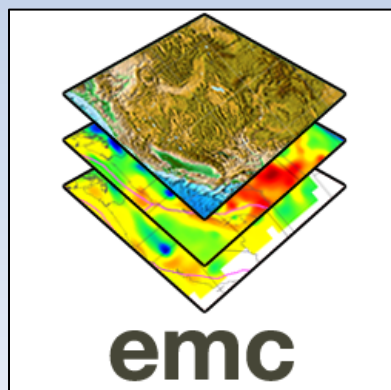
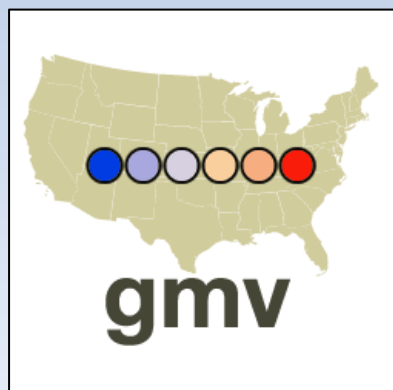
EpiCentral+ App created by Chuck Ammon, Penn State

Data Products

Level 0-1

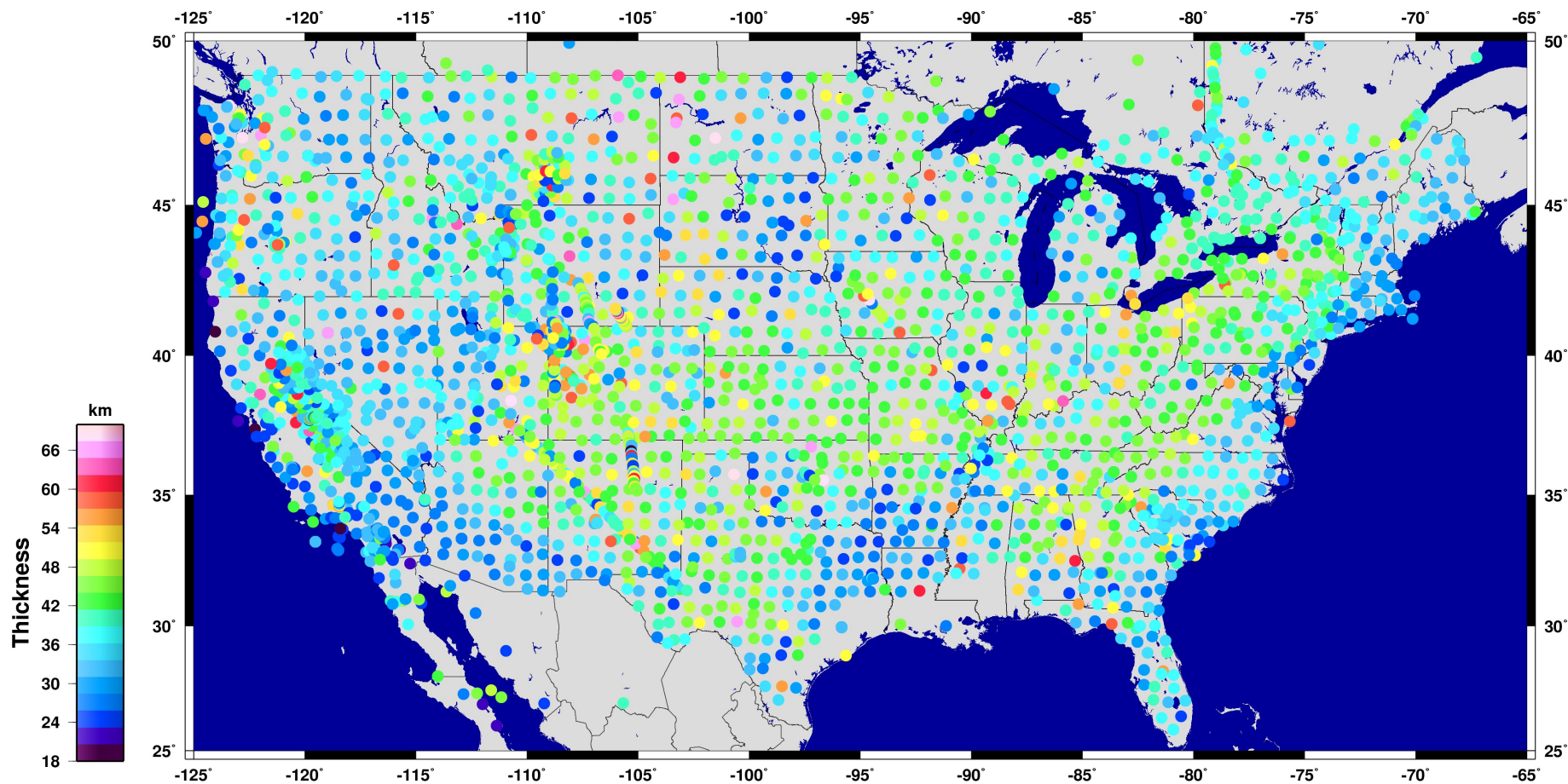
Time series data

Level 2-3 Products



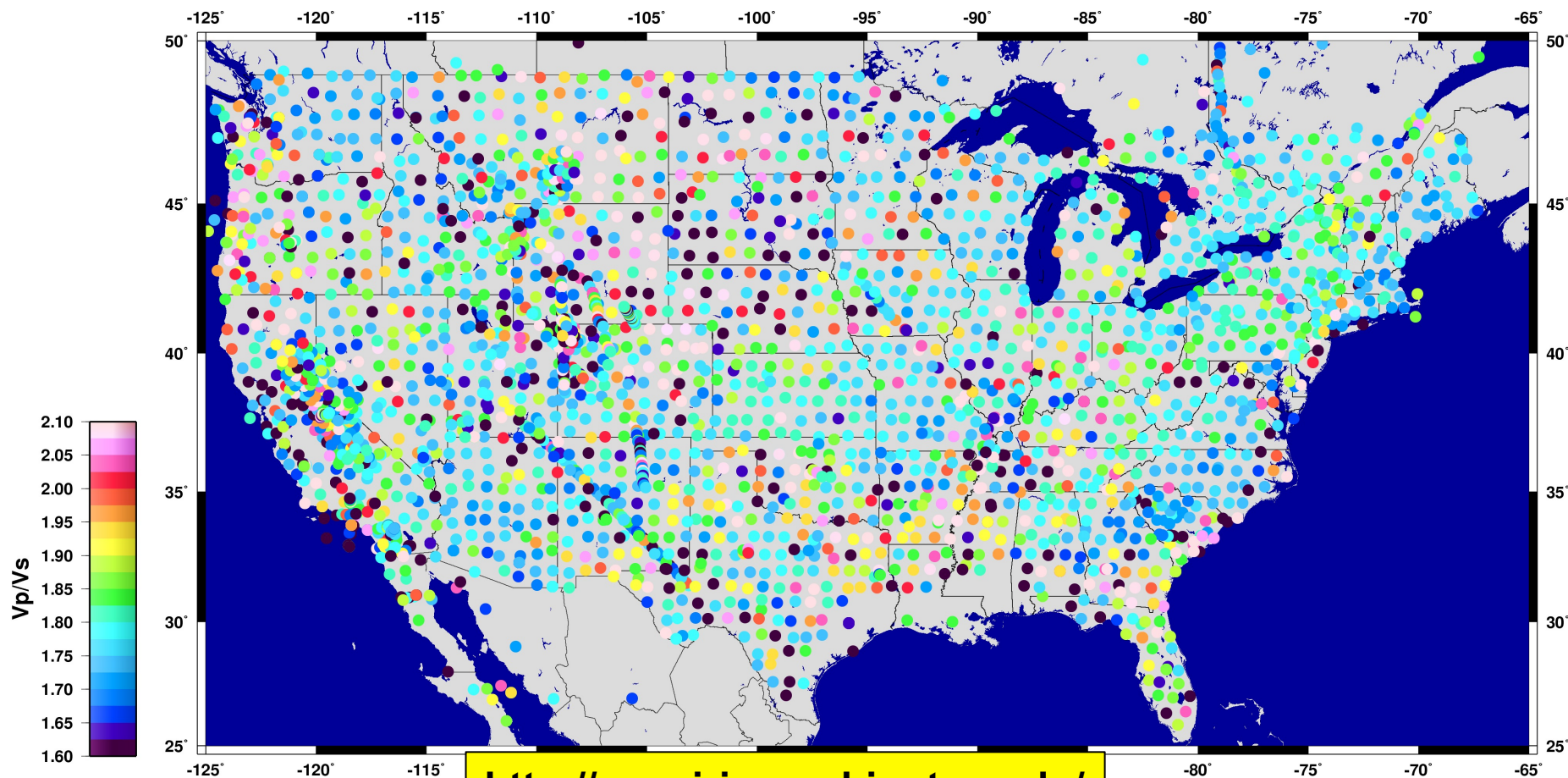
Most of these products did not exist in 2009

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



- EARS transitioned to DMC and in routine operation

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



<http://ears.iris.washington.edu/>

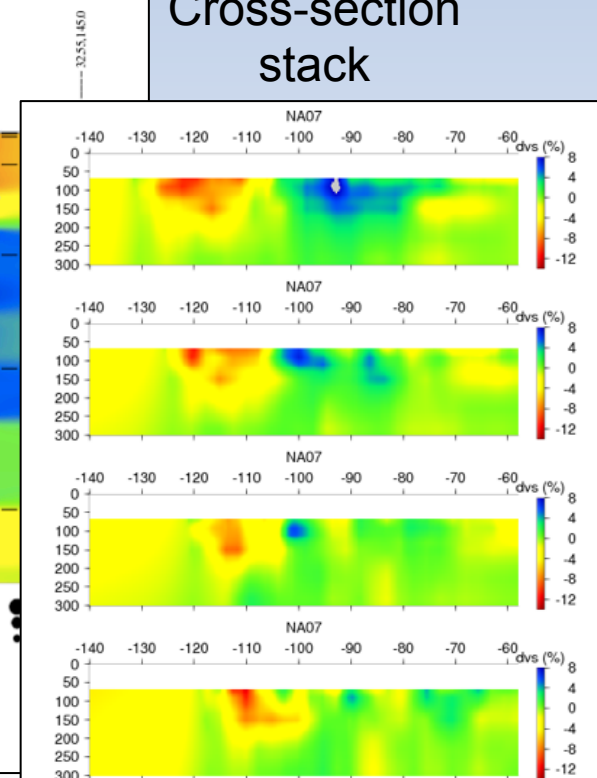
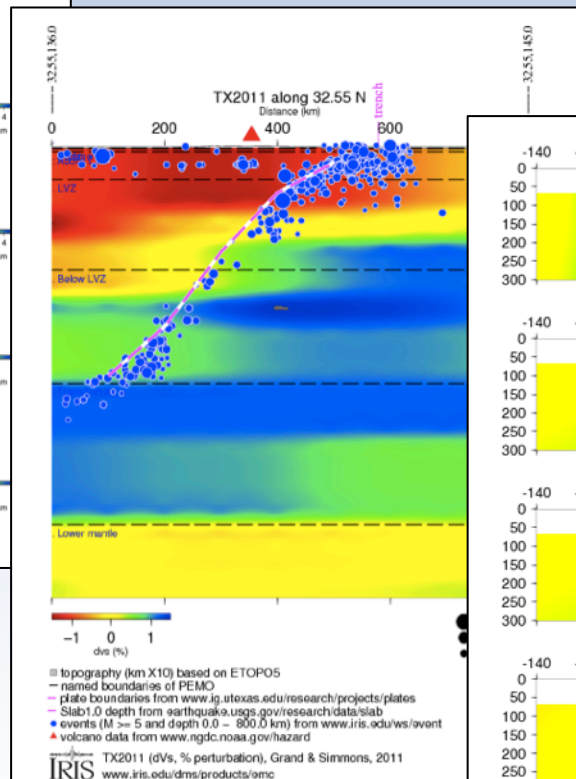
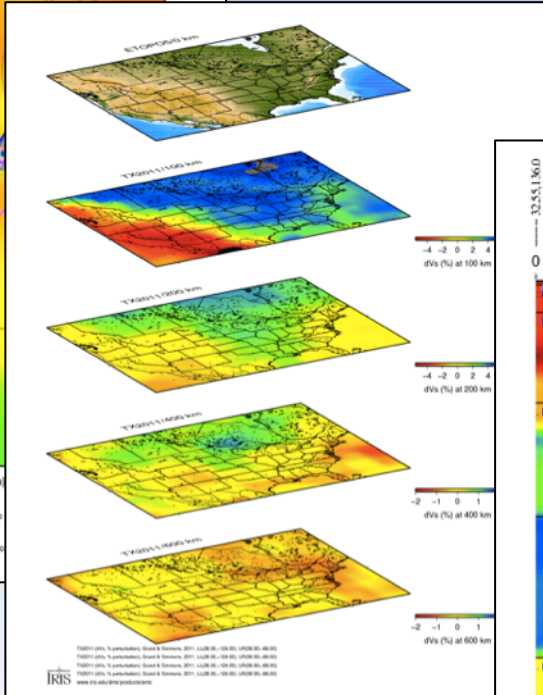
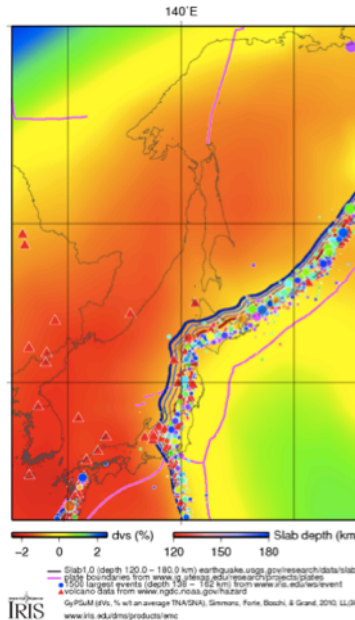
Slice

Slice - stack

Cross-section

Cross-section stack

Kamchatka/Kurils/Japan, GyPSuM dvS, Depth 150 km



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

The ability to compare models was identified as critical cyberinfrastructure

Community Models

Query Results: 37 items found

Type	Model Name	
1D Reference	AK135-F	ak135-F spherical average model
3D Tomography	GyPSuM	A global 3-D model of mantle shear wave (S) and compressional (P) speed
3D Tomography Earth Model	S362ANI+M	This model is an update to S362ANI and S362WMANI representing an a
3D Tomography Earth Model	US-SL-2014	P and S teleseismic body-wave tomography of the mantle beneath the U
1D Reference	STW105	A 1D Reference Earth Model
1D Reference	TNA/SNA	Average of the TNA and SNA models
1D Reference	PREM500	Modified PREM (Preliminary Reference Earth Model)
1D Reference	PREM	Preliminary Reference Earth Model (PREM)
1D Reference	PEM	Parametric Earth Models (PEM)
1D Reference	MC35	A 1D modified PEM-C S velocity model
1D Reference	IASP91	iasp91 velocity model
3D Tomography	LLNL-G3Dv3	A global P wave tomography model based on regional and teleseismic t
3D Q Model	QRLW8	A global upper mantle shear attenuation model
3D Tomography Earth Model	Taiwan.TTT.KWS.2012	3D P-wave velocity model of Taiwan from travel-time tomography
3D Tomography Earth Model	CASCADE.ANT.GAO-SHEN.2014	3D shear-wave velocity model of the Cascades from full-wave ambient r
3D full-waveform Earth Model	SEMum	A high-resolution global shear velocity model of upper mantle
3D Tomography	wUS-SH-2010	P and S teleseismic body-wave tomography of the western United State
3D Tomography	S2.9EA	A global model with higher resolution in the upper mantle beneath Eur
3D Tomography	S362WMANI	A global model of shear-wave velocities
3D Tomography	S362ANI	A global model of shear-wave velocities
3-D Regional Electrical Conductivity Model	SRPY-MT	Regional 3-D electrical conductivity model of Snake River Plain / Yellow
3D Tomography	TX2011	A global mantle shear-wave tomography model
3D Tomography	TX2000	A global mantle shear-wave tomography
3D Tomography	SAW642AN	Global radially anisotropic mantle S velocity
3D Tomography	SAW642ANb	Global radially anisotropic mantle S velocity
3D Tomography	SAW24B16	A global shear velocity structure of the mantle
3D Tomography	PNW10-S	3D S-wave tomography Earth model for the Cascadia Subduction Zone
3D Tomography	NWUS11-S	3D S-wave tomography model for NW United States
3D Tomography	NWUS11-P	3D P-wave tomography model for NW United States
3D Tomography	NA07	N. American upper mantle surface wave tomography
3D Tomography	NA04	N. American upper mantle surface wave tomography
3D Tomography	HMSL-S06	A global shear velocity model of the mantle
3D Tomography	HMSL-P06	A global compressional velocity model of the mantle
3D Tomography	DNA13	P- and S-velocity models for the western US integrating body- and surf
3D Tomography	DNA10-S	3D S-wave tomography Earth model
3D Tomography	DNA09	3D P- & S-velocity tomography Earth model
3D full-waveform Earth Model	SAWum-NA2	A high-resolution North American shear velocity model of upper mantle

ds.iris.edu/spud/earthmodel/9785430

Products - Help - **DNA10-S - 3D S-wave tomography**

Model Summary

Name: DNA10-S
Title: 3D S-wave tomography Earth model
Type: 3D Tomography
Sub Type: S velocity perturbation (%)
Year: 2010
Author(s):
Mathias Obrebski
Department of Earth and Planetary Science
University of California, Berkeley
California, USA
Richard M. Allen
Department of Earth and Planetary Science
University of California, Berkeley
California, USA
Fred Pollitz
US Geological Survey
Reston, VA USA
Shui-Huei Hung
Department of Geosciences
National Taiwan University
Taipei, Taiwan

Reference(s):
Obrebski, M., R.M. Allen, F. Pollitz, and S.-H. Hung. 2011. "Lithosphere-aesthenosphere interaction beneath the western United States from the joint inversion of body-wave traveltimes and surface-wave phase velocities." *Geophys. J. Int.* 185:1003-1021.

Depth Coverage:
0.0 - 1000.0 km

Areal Coverage:
Latitude: 30.0 to 50.0 Longitude: -126.0 to -98.0

Model Description:
The DNA10-S model integrates teleseismic body-wave traveltime and surface-wave phase velocity measurements into a single inversion to constrain the S-wave velocity structure beneath the western US (from the Pacific coast to ~100 deg W, from Mexico to Canada).
[Obrebski et al. (2011)] The station distribution that used in this study covers all the major magmato-tectonic features of the active western United States plus the westernmost part of the stable cratonic United States. This includes more than 1200 stations from the USArray transportable array, regional seismic networks, and temporary seismic deployments. Data were recorded from 2006 January to 2010 January. Relative traveltimes of teleseismic body waves (S and SKS) obtained from about 162 earthquakes, and surface wave phase velocity measurements from 167 earthquakes were used to constrain the model.

Data Set Description:
seismo.berkeley.edu/~rallel/research/dna/dna10
ds.iris.edu/se/products/emc-dna10-s

Web Page
EMC Page

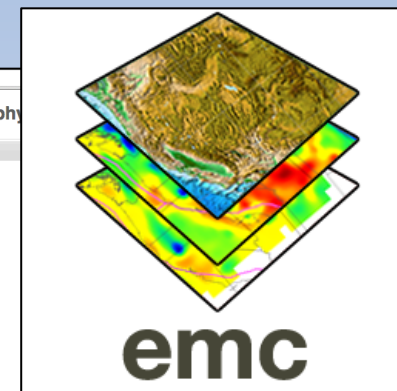
Model Data

Description	Size	Model
The netCDF binary for the above model.	2.2 MB	Download

Model URLs

URL	Description
http://seismo.berkeley.edu/~rallel/research/dna/dna10/download/DNA10.tar.gz	original model files from the model download page

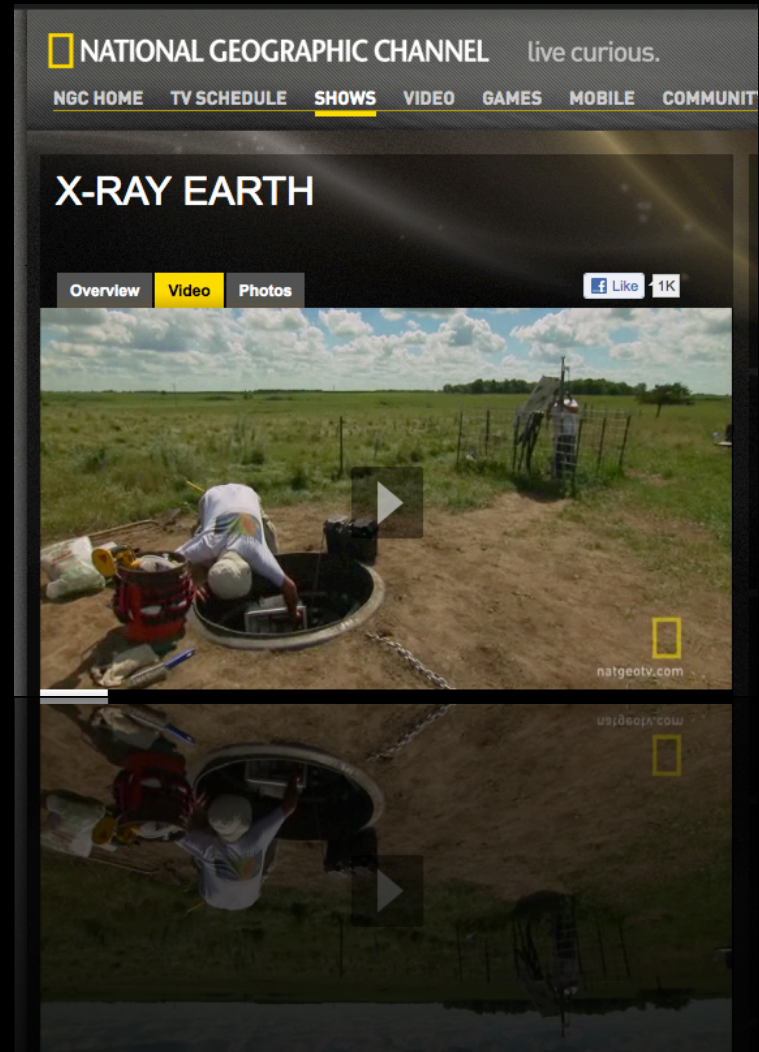
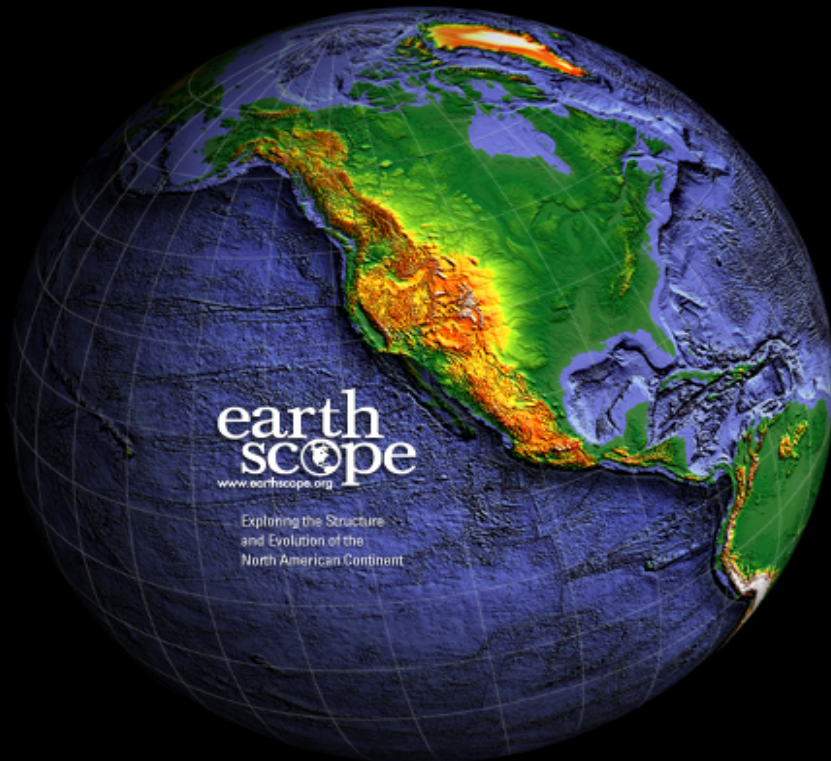
Figure below, Obrebski et al. (2011) , shows model DNA10-S S velocity perturbation at 8 depths.



At least 12 new models available in Earth Model
Collaboration have been generated with USArray data.

Outreach

“X-RAY EARTH”, aired May 15, 2011



NEWS IN FOCUS



Scientists tested rugged new equipment for the Transportable Array near Toolik Lake, Alaska, in 2011.

RESEARCH

US seismic array eyes its final frontier

Moveable sensor grid will begin monitoring Alaska next summer.

BY ALEXANDRA WITTE

On Maine's rugged coast, just north of the tourist town of Boothbay, an underground seismometer is listening for earthquakes. Engineers activated it on 26 September, completing the US\$90-million Transportable Array. Since 2005, the contiguous grid of sensors has been loaded on trucks and moved across the coast across Great Plains each spot, 14 instruments. The process is reaching its surface. The motion east of the Pacific rises in the hot spot deep beneath Yellowstone National Park in Wyoming.

"As the array has moved, the whole picture of what's under North America has gotten much sharper," says Andy Frassetto, a seismologist at the Incorporated Research Institutions for Seismology (IRIS) in Washington DC, which operates the stations. Now, the Transportable Array's operators are looking to the far north, in what may be its toughest challenge yet. Having almost finished the job in the lower 48 states, the seismometers will start to be relocated next spring to Alaska.

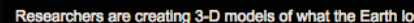
3.2-kilometre-deep hole drilled into California's San Andreas fault, although the effort was marred when instruments lowered down the hole stopped working after just days (see *Nature* 459, 20–21; 2009). But the first two parts of EarthScope are yielding plenty of insights. "We've learned a lot," says University of California, Berkeley, geophysicist Susan Hough. "We've learned a lot about the Earth's interior, and we've learned a lot about the Earth's surface."

14 | NATURE | VOL 503 | 7 NOVEMBER 2013
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Prominently featured in major scientific news publications





A mobile seismic observatory, rolling out slowly across the continent, is piecing together a startling picture of what lies beneath.

Their laughter fills the air of a small, oval office and just installed in-ear monitors. The equipment he has just installed is located at the bottom of the disc hole in a seismic source that sends vibrations from around the world to a network of sensors that are listening for the vibrations. The vibrations are the result of the source being fired, and the distance of the waves moving off. As the activity fades, the source will be left to stand on the shore of the ocean, waves the result of heavy stones, and the crash of the quiver of the water.

The seismograph is one of some 400 that make up the "Therapeutic Array," a network of sensors that has been working its way across the country since 2004. From its initial installation along the West Coast, the network has expanded to include a number of sites in the Midwest, and now 400 sites are planned from Minnesota to Florida. Each seismic source vibrates at its port to two points, playing data to a computing facility at the University of California, San Diego, until a recording of the seismic activity is sent to the east. When the array reaches the Atlantic seaboard next year, it will begin collecting the first batch of data needed to complete the first major mission, 3-D mapping of the mid-Atlantic North American continent. Initial results are already being used by scientists to study the processes that have shaped the continent, and the way the sea floor has been shaped by the ocean floor and the sea floor.

A Hubble Telescope Pointed Downward

The epic Telescopic Array survey is a work of the Incorporated Foundation for Science, and, as a collection of more than 100 volunteers, it is the largest citizen-science project first conceived of the year in 1998. "The Hubble telescope had just gotten going," Simpson says, "and everyone was talking about what the next big project should be." Scientist David Nolt suggested a giant, inward-looking telescope to survey our own world, and the idea took off. In 1999 the National Science Foundation agreed to provide \$10 million in funding. Starting in California, where the project could take advantage of existing science stations, students at state-affiliated universities were asked to get permission from their parents to travel overseas to set their pointers. The explosion of satellite communications in the early 2000s then eased a logistical hurdle by supplying a nationwide network that could transmit our survey data in real time.

Although the Transportable Army does not create pictures in the conventional sense, it is providing amazing vistas of the Earth's interior all the same. Matt Fouch, a geophysicist at the Carnegie Institution for Science in Washington, D.C., says that for decades scientists have struggled to make sense of the jumbled geology of the Pacific Northwest, the land of the soaring Cascade range and the explosive Mount Saint Helens. But without being able to peek at a big picture that *puts everything in context*, "you can't know how the parts fit together," he says.

One puzzle in the Northwest is the Yellowstone hot spot, a 300-mile-wide region dotted

With thousands of twisting geyser vents. Since the 1970s, prevailing opinion has held that Yellowstone's activity is driven by a giant plume of hot material rising up from the mantle, the third layer of the earth's interior. But new images from the Transposable Array are telling that idea into question.

Where researchers expected to find a huge mantle plume, the map of the geologic structure beneath Yellowstone instead seems to show a ghostly fragment of an old tectonic plate—a former chunk of Earth's rocky shell—lodged under the western United States. Right near the Yellowstone hot spot. The fragment is one of many that probably broke off from an ancient section of crust called the Pacific plate, which began forming 50 years ago under North America, moving from west to east some 200 miles per year.

Now, says a team of researchers from the University of Utah, "The Pacific plate's earliest activity is driven not by a giant mantle plume but rather by mantle material being pushed around the edge of the stranded Pacific Plate. Hot oil of the oil

Yellowstone's hottest area, Norris Geyser Basin, may be driven by a geologic smashup hundreds of miles below.

leagues agree, but "we finally have the whole picture," he says, "so we can agree meaningfully about what it means."

Is the East Coast Headed for a Crack-Up?

Engineers continuously displace Transportable Army stations, long-dragging sensors from the army's trailing waters edge ahead to the station. And line. As the project marches to the coast over the next months, it may shed light on another long-standing mystery. Beneath the eastern United States, scientists have observed an area where seismic waves travel more slowly than expected. Some say de Looz, a geophysicist at Northwestern University, thinks the slowdown might be due to water released by another fragment of the Pangea plate. Or, he suspects that the liquid could eventually weaken the crust beneath the Atlantic Coast and risk the continent's edge, causing it to break off from North America and sink back into the mantle. With-

few tens of millions of years, that process could make the East Coast as geologically active as the West Coast is today.

Van der Lee will have to wait for the Thermoplastic Army survey to be complete—which should happen around 2015—to put her theory to the test. But after a long wait, the answers could be hard to find. “All the hypotheses proposed over the last two decades,” Bouchays says, “I’m finally able to start figuring out which were right and which were wrong.”

On the plaza floor, Lashway—who works for Honeywell, the company contracted to install and maintain the army’s sensors—is doing his bit to make that happen. “Take your last look!” he yells as he prepares to bury the station in sand. “It won’t see the light of day for two years!” In the meantime, though, it’ll be in touch. 

Emily Clark is a freelance journalist and a coauthor of *Global Warming*, a book from the *Scientific American* Climate Catalog, published in July.

Jeff Martin, USA TODAY

It comes to studying earthquakes, Penn State University geology professor Billie Allread has a simple theory: The more that you know, the better people can prepare and protect themselves.

knowledge about faults in certain parts of the nation could lead to stricter building codes in those places so structures are less likely to topple, he says.

know about the hazards, then we can
ourselves at less risk," Lillie says.

part of a group of scientists involved in
ay, a nationwide research project that
scientists to study earthquakes in
cedented ways.

Emily Elert is a freelance journalist and a coauthor of *Global Weirdness*, a book from the foundation Climate Central, published in July.

Gruppe5 Film – Cologne, Germany L49A near Milan, Michigan



- This coverage finds us.
- Often better coverage than in US

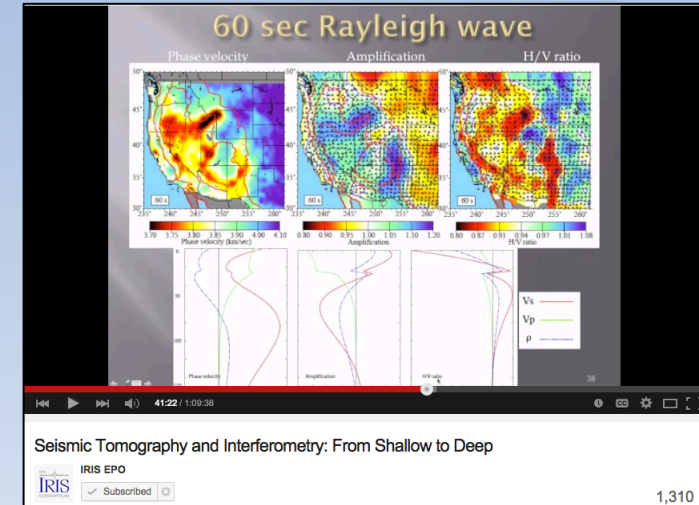
Three-dimensional Inversion of EarthScope Magnetotelluric Data: crustal and mantle conductivity beneath the NW USA

Gary D. Egbert, Oregon State University

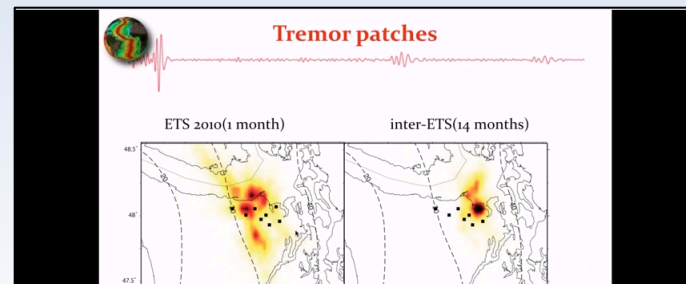
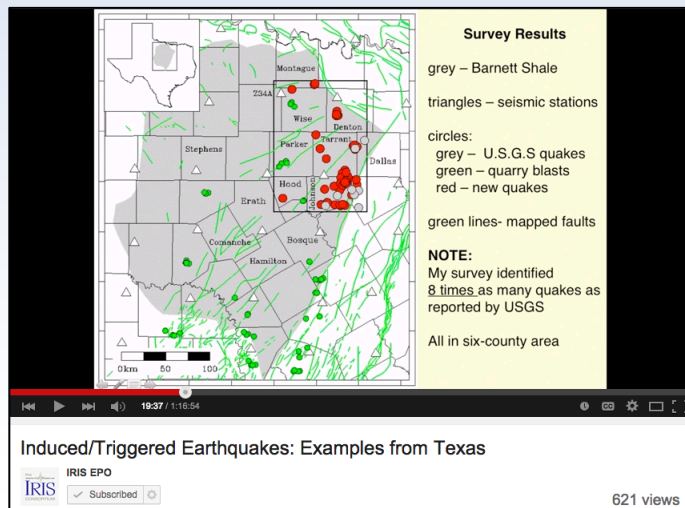
3D Inversion of EarthScope MT Data

IRIS EPO
✓ Subscribed

972 views



- 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

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BLOGS

D-brief | The Crux | Body Horrors | But Not Simpler | Citizen Science
Out There | Science Sushi | Seriously, Science? | Field Notes



Bad Astronomy

« Another jaw-dropping time lapse video: Tempest WISE finds coolest brown dwarfs ever seen! »

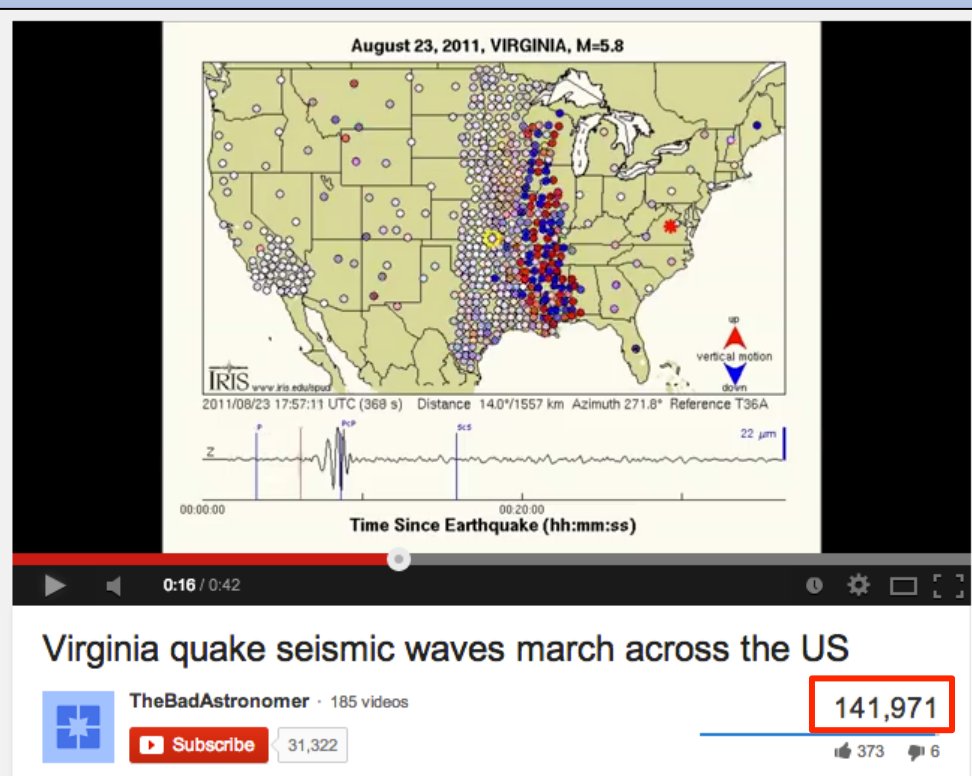
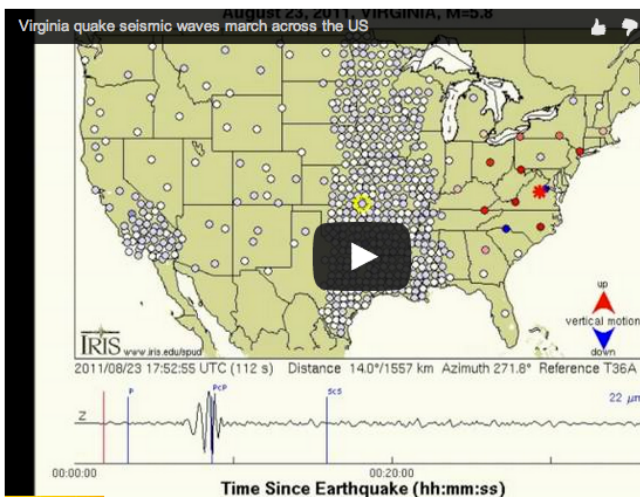
Virginia earthquake waves ripple across the US!

By Phil Plait | August 23, 2011 5:10 pm

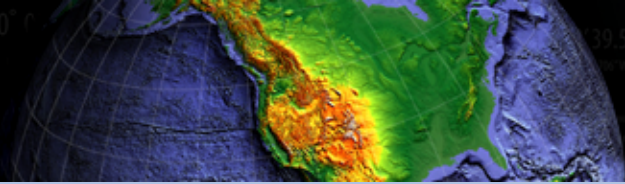


19

This is very cool: seismometers deployed across the United States detected the seismic waves from the magnitude 5.9 earthquake that hit Virginia on August 23, 2011. **In this animation showing the data** you can actually see the wave rippling across the country!



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



Displays for the Public

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>

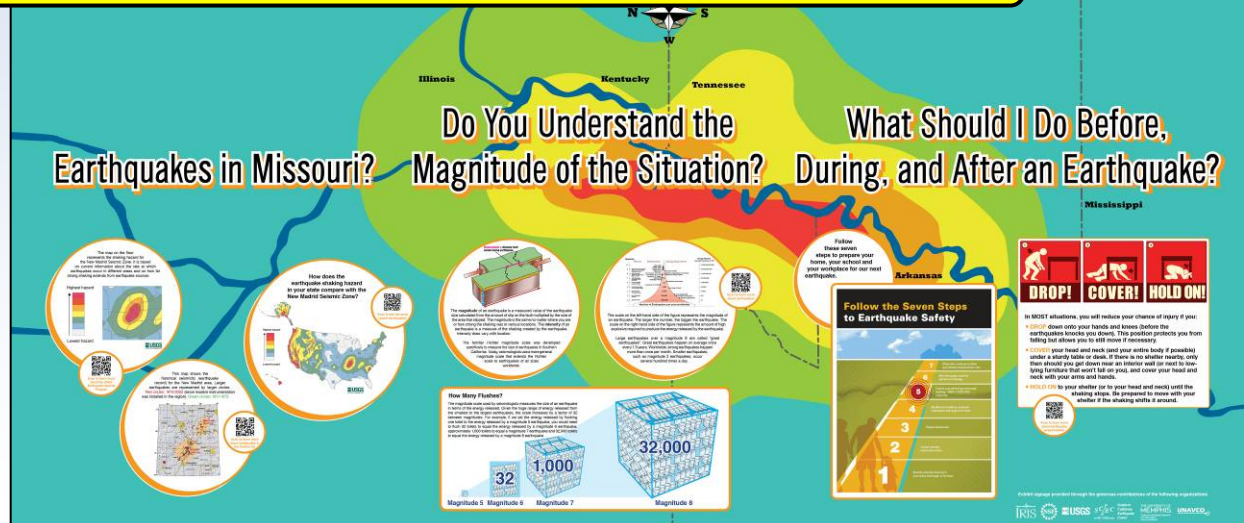
EarthScope Brings Seismometers to Missouri



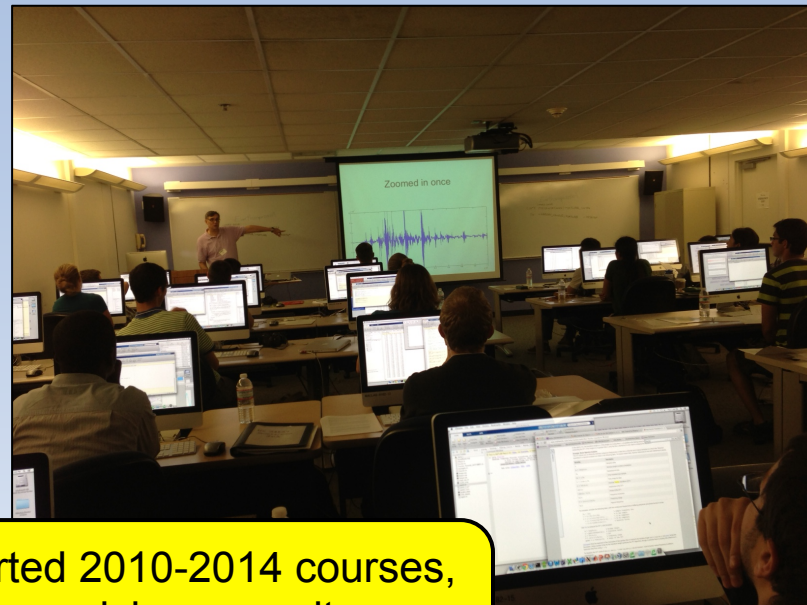
Do You Understand the Earthquakes in Missouri?

Magnitude of the Situation?

What Should I Do Before, During, and After an Earthquake?

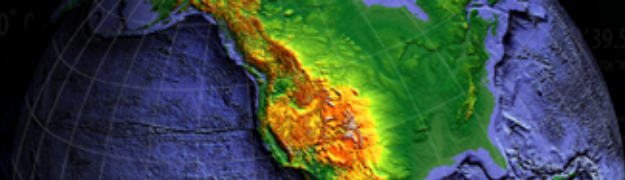


Short Courses



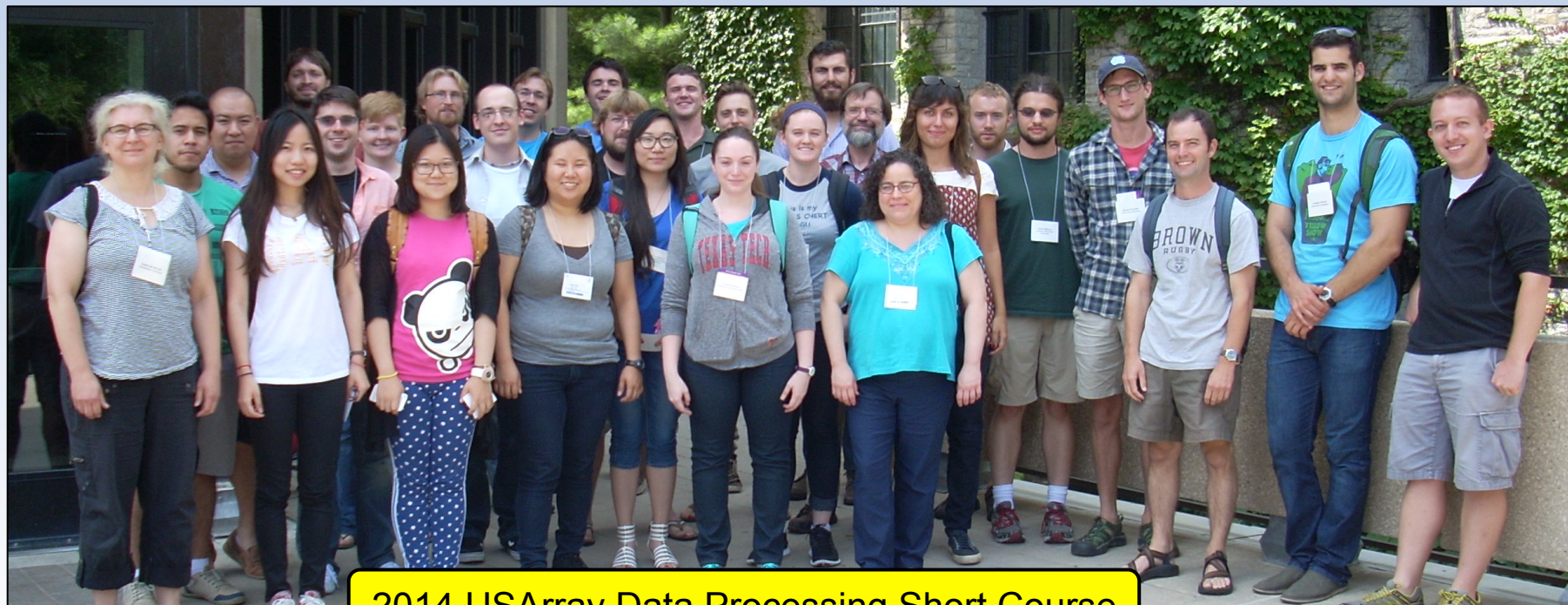
- **New scope:** Award supported 2010-2014 courses, IRIS brings expertise and organizing capacity
- 2009-2011, 2013-2014, 121 students in 6 courses





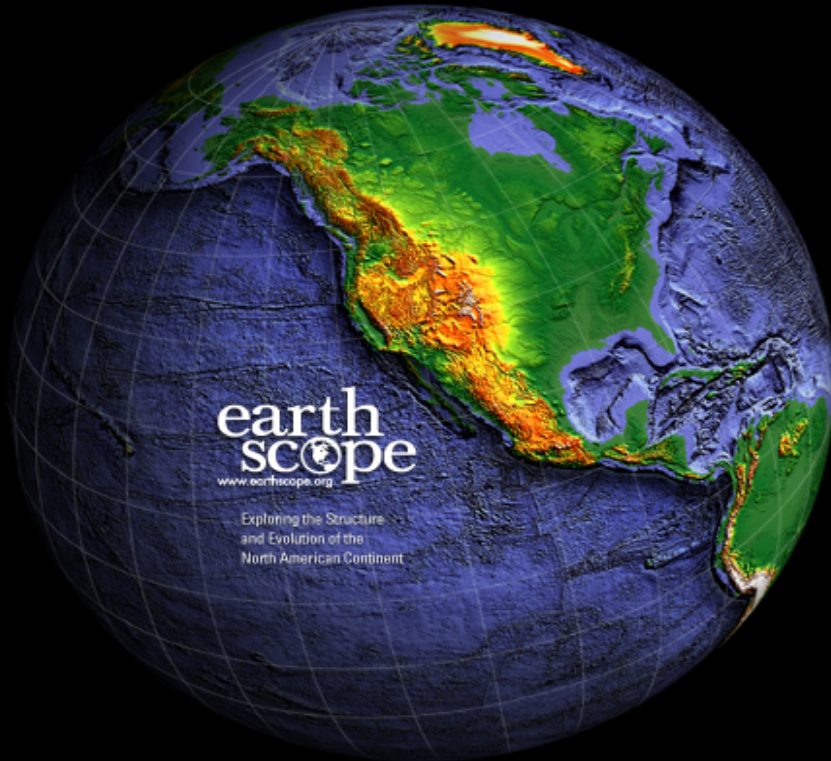
Impacts on Seismology

Jump starting professional partnerships and research foundations

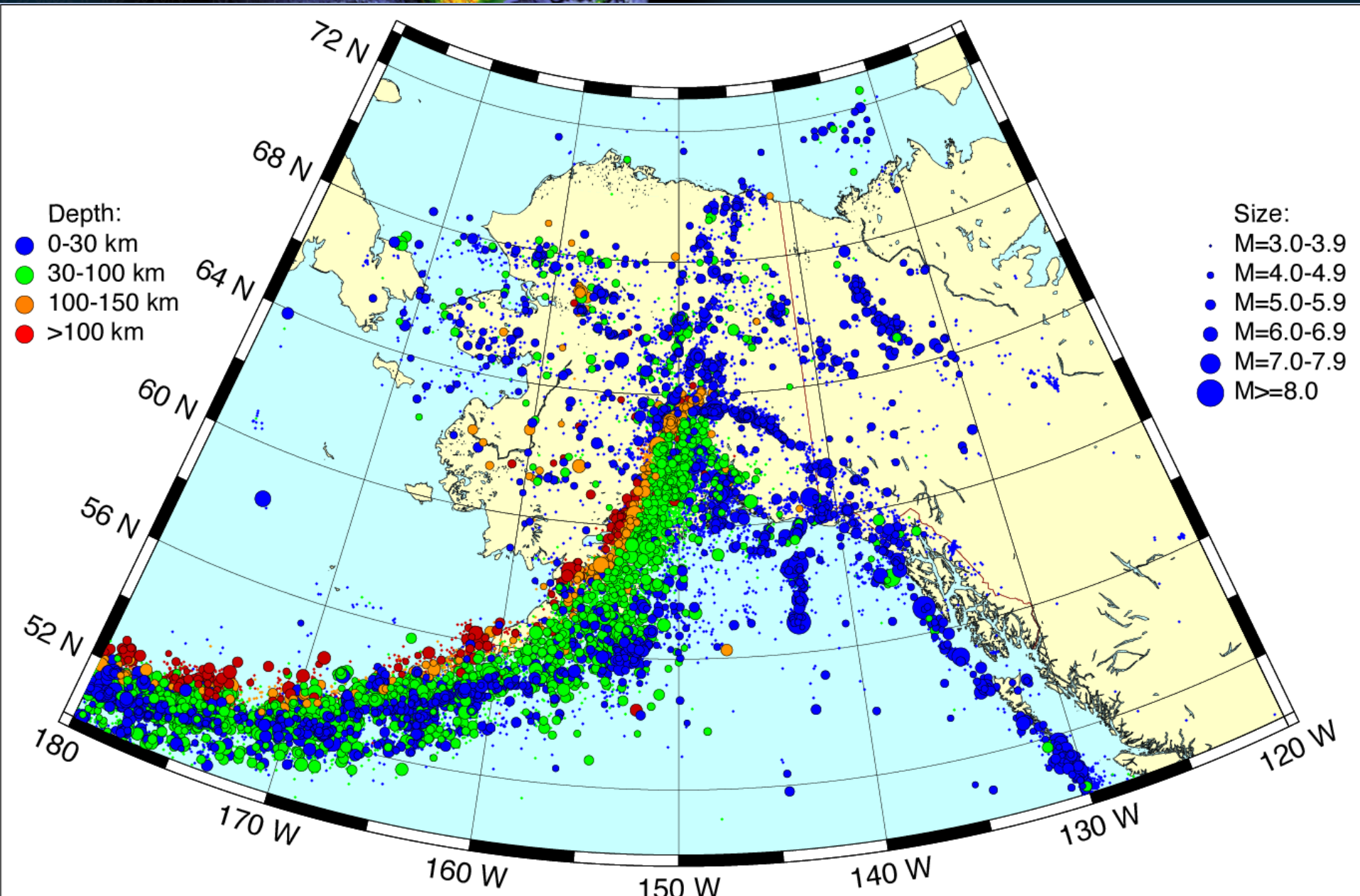


2014 USArray Data Processing Short Course

USArray's Legacy and Looking Ahead



TA in Alaska



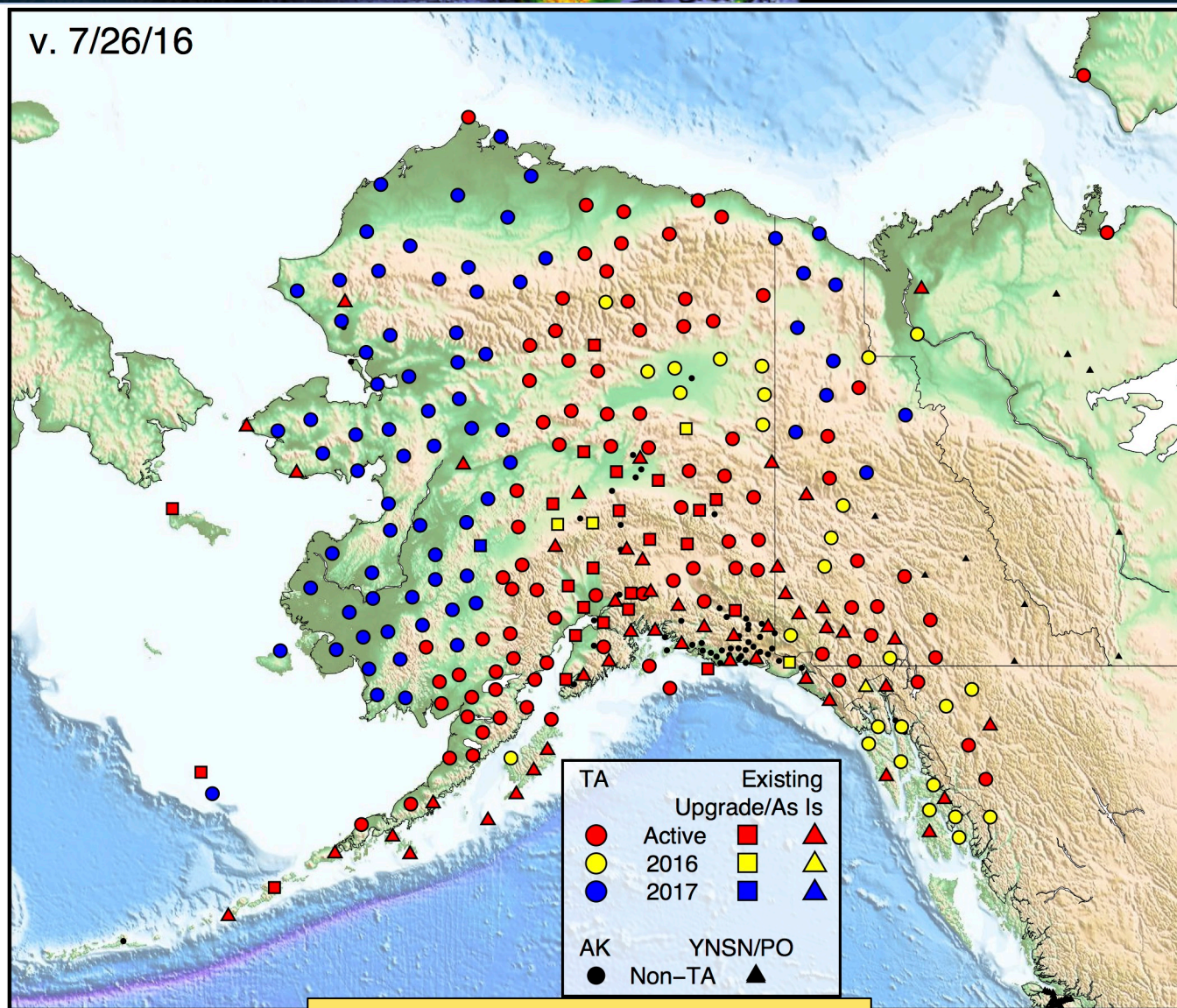
Before USArray



- Limited station coverage, and some seismically active areas sparsely instrumented

TA in Alaska – So Far

v. 7/26/16

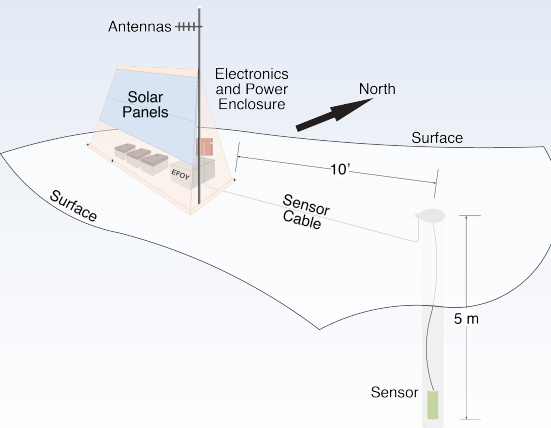


- 2014: 9 new TA, 11 AK upgraded, 26 total
- 2015: 36 new TA, 47 integrations/upgrades
- 2016: 70 new TA

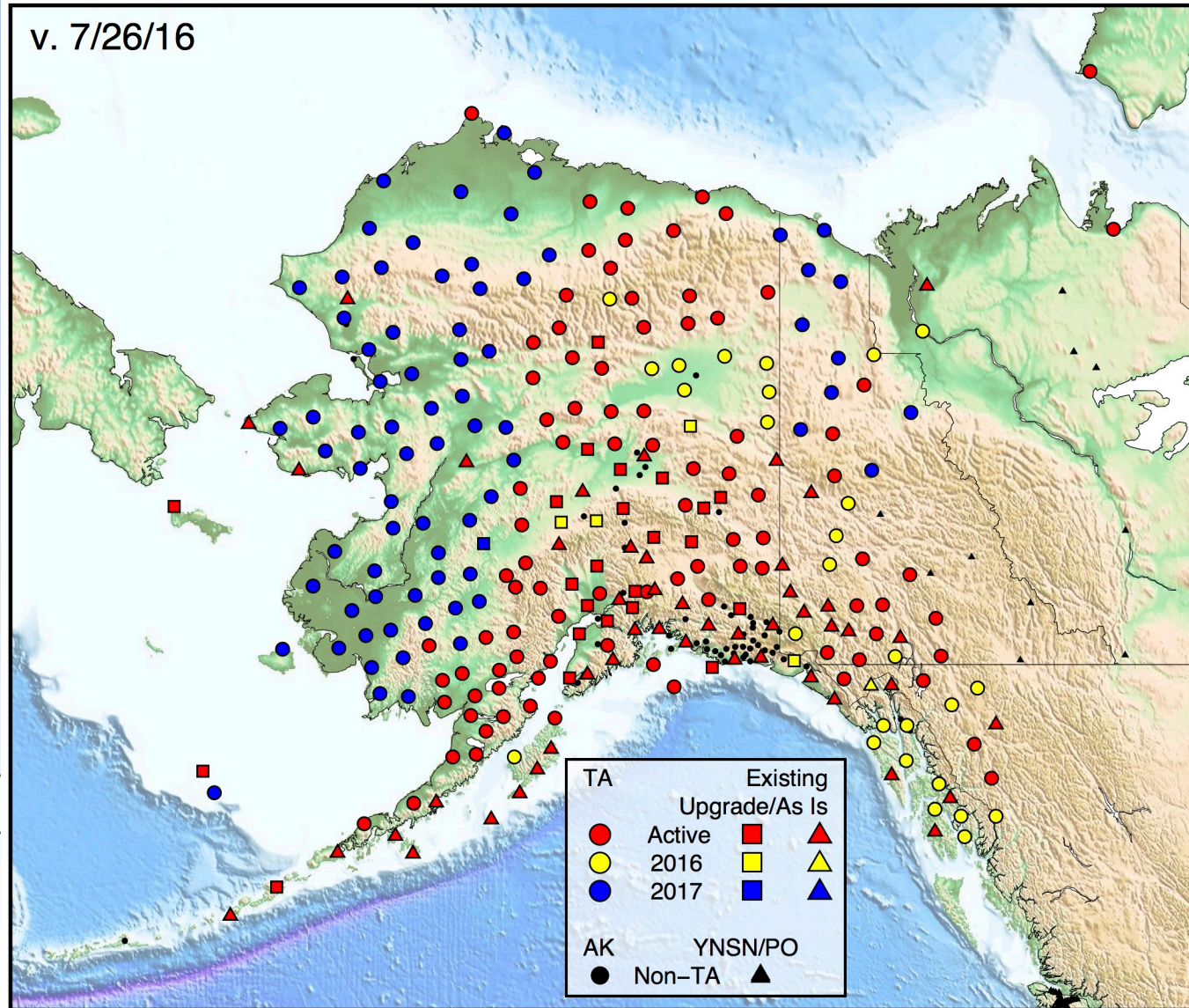


www.usarray.org/alaska

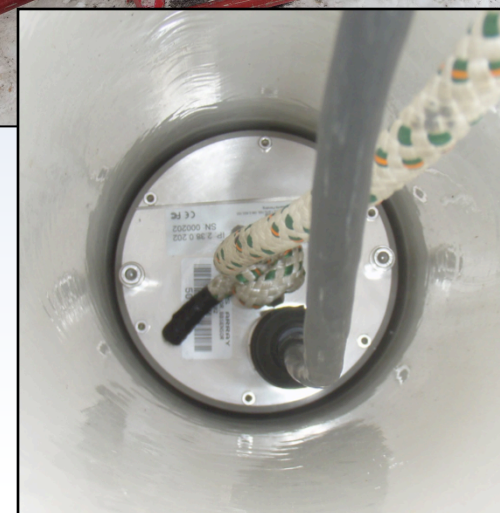
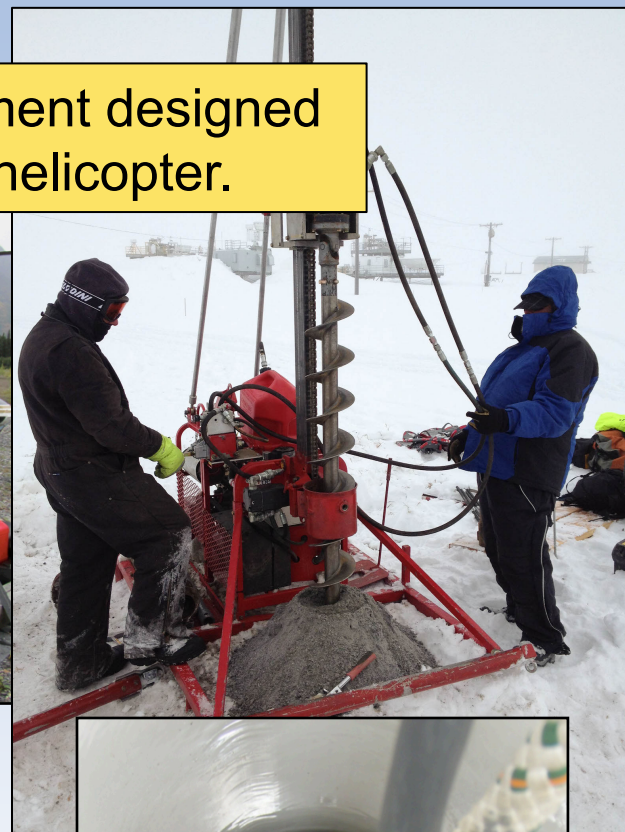
TA in Alaska - Plans



v. 7/26/16

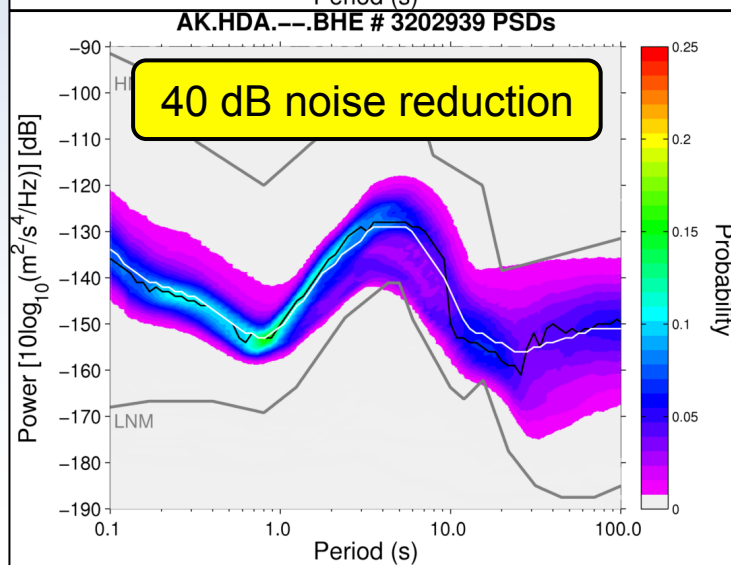
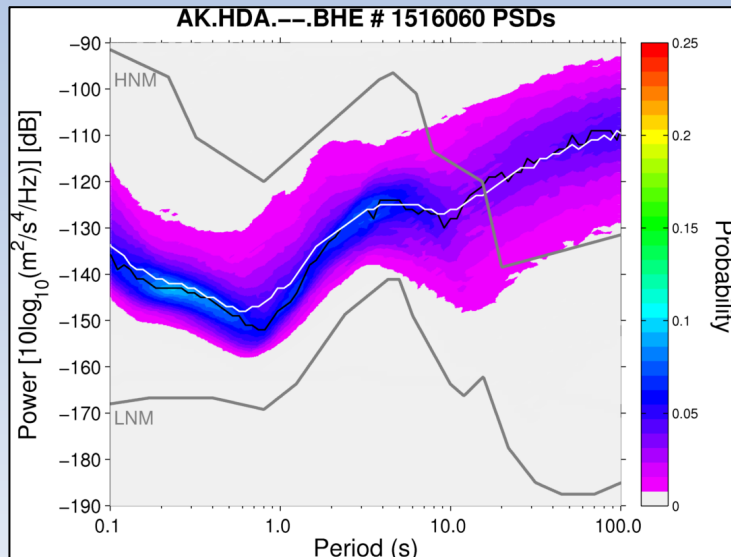


Motivation: High quality data; all equipment designed for transport in fixed wing aircraft or helicopter.



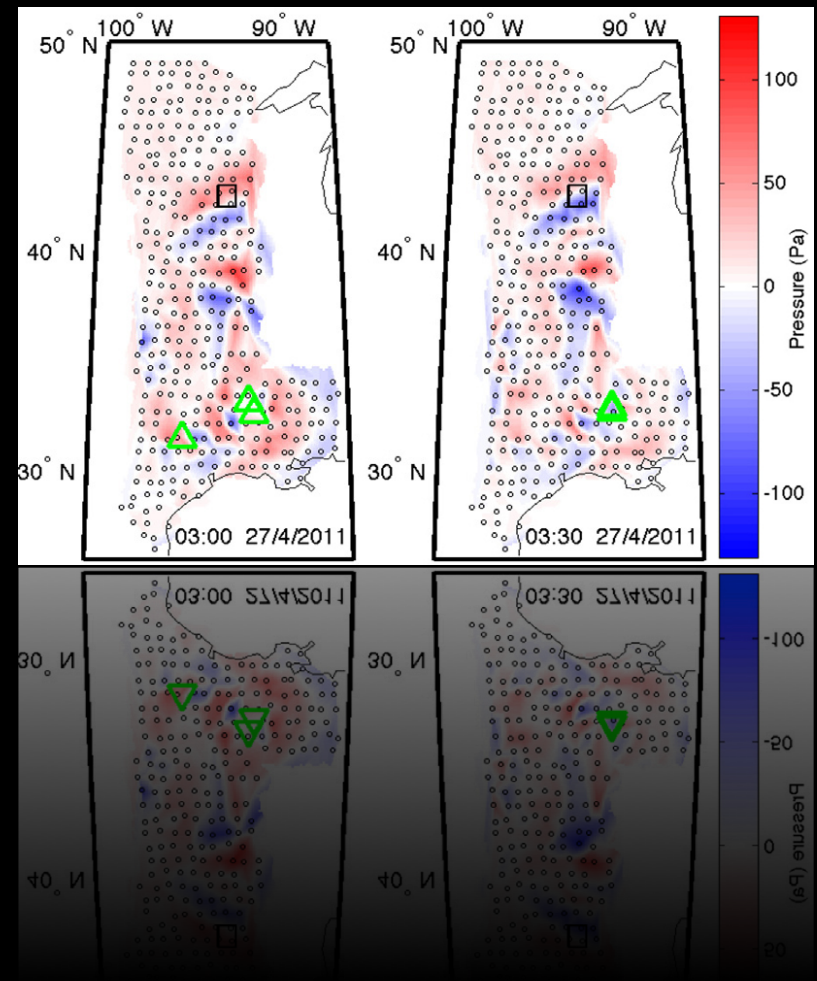
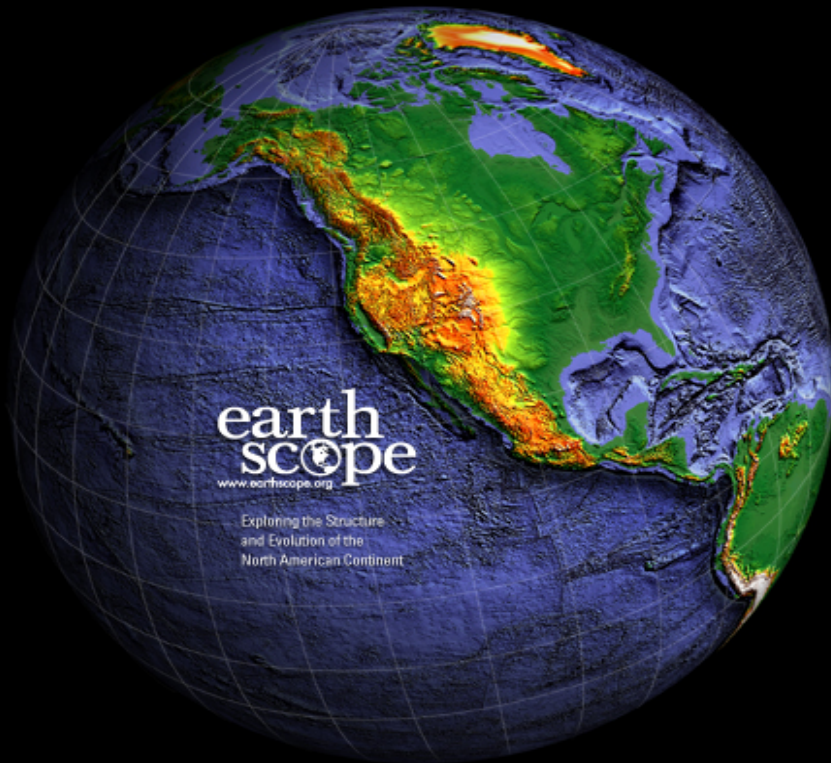
- ~261 new & upgraded sites by 2017, spaced 85 km
- Broadband seismometers w/atmospheric sensors
- New/advanced power and communications
- Complex logistics

New styles of seismometer emplacement

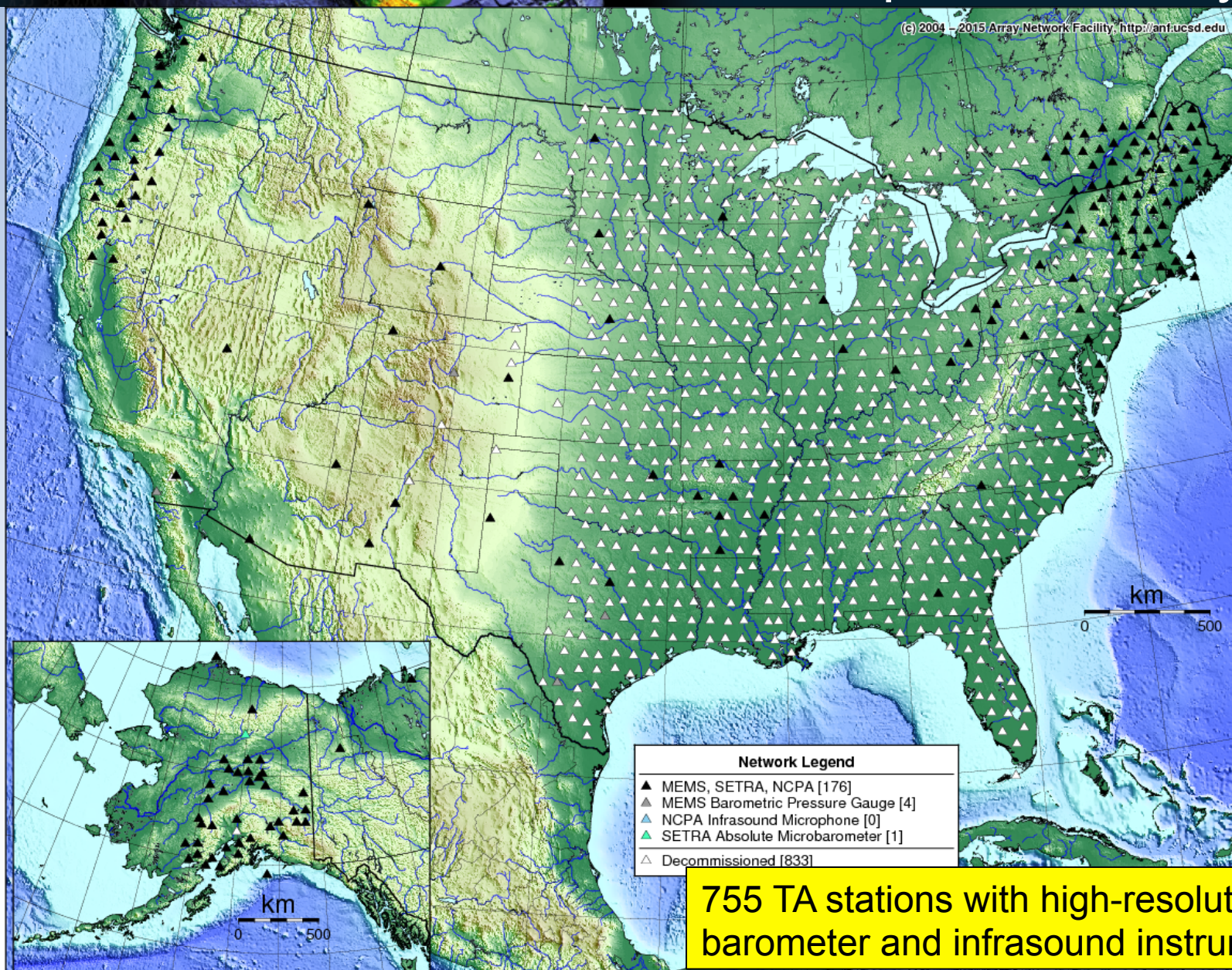


USArray's Enhanced Scope and Legacy

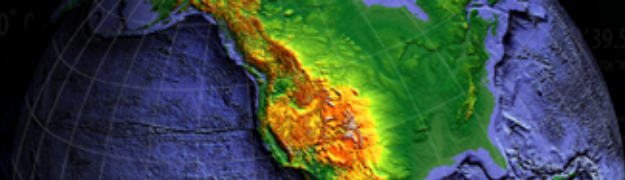
Atmospheric Gravity Waves on the TA
Catherine deGroot-Hedlin et al.



Atmospheric Acoustic Transportable Array

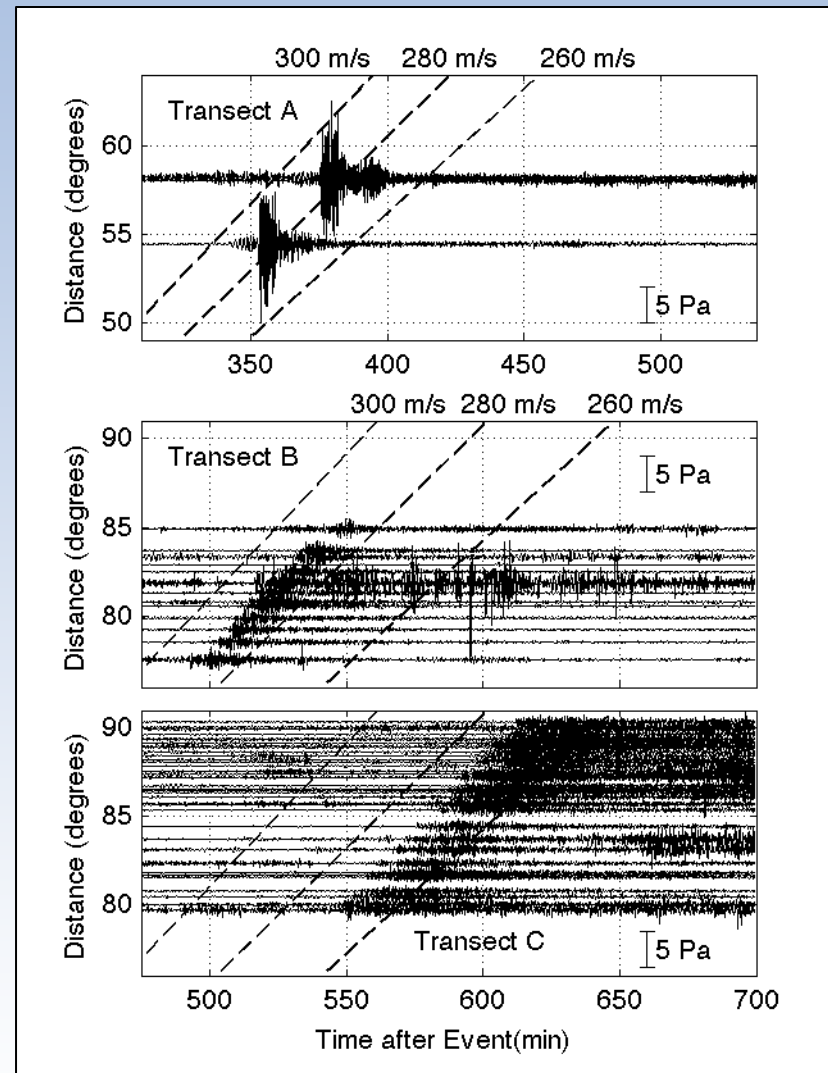
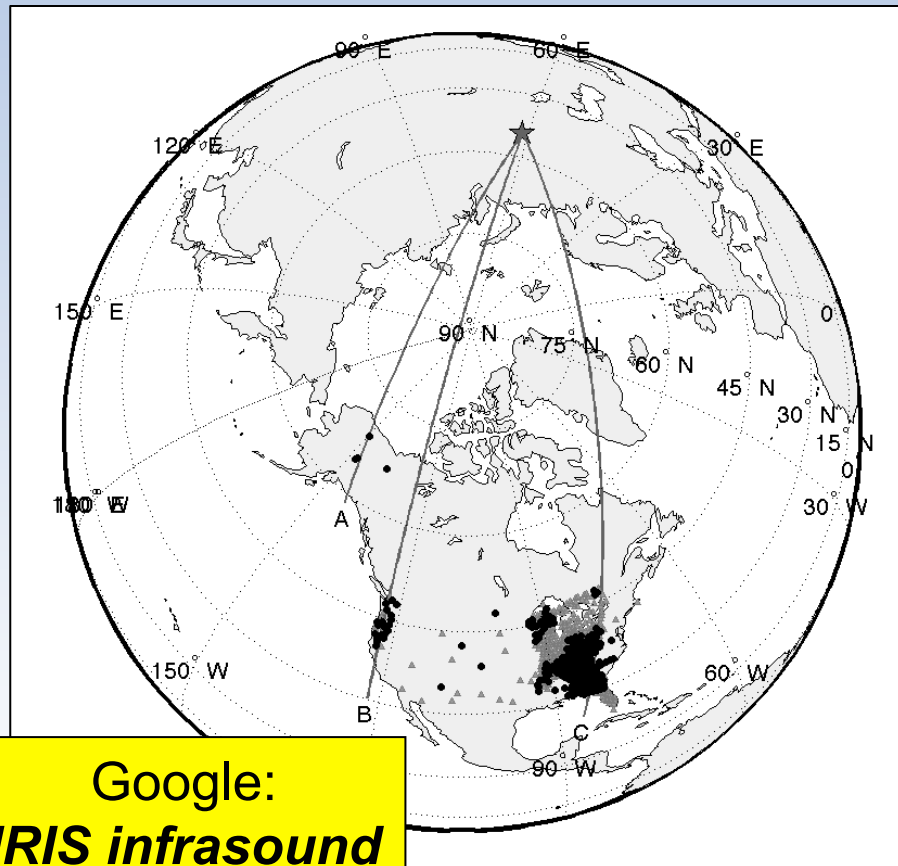


755 TA stations with high-resolution
barometer and infrasound instruments



Acoustic Transportable Array

Infrasound detection of the Chelyabinsk Meteor on the TA

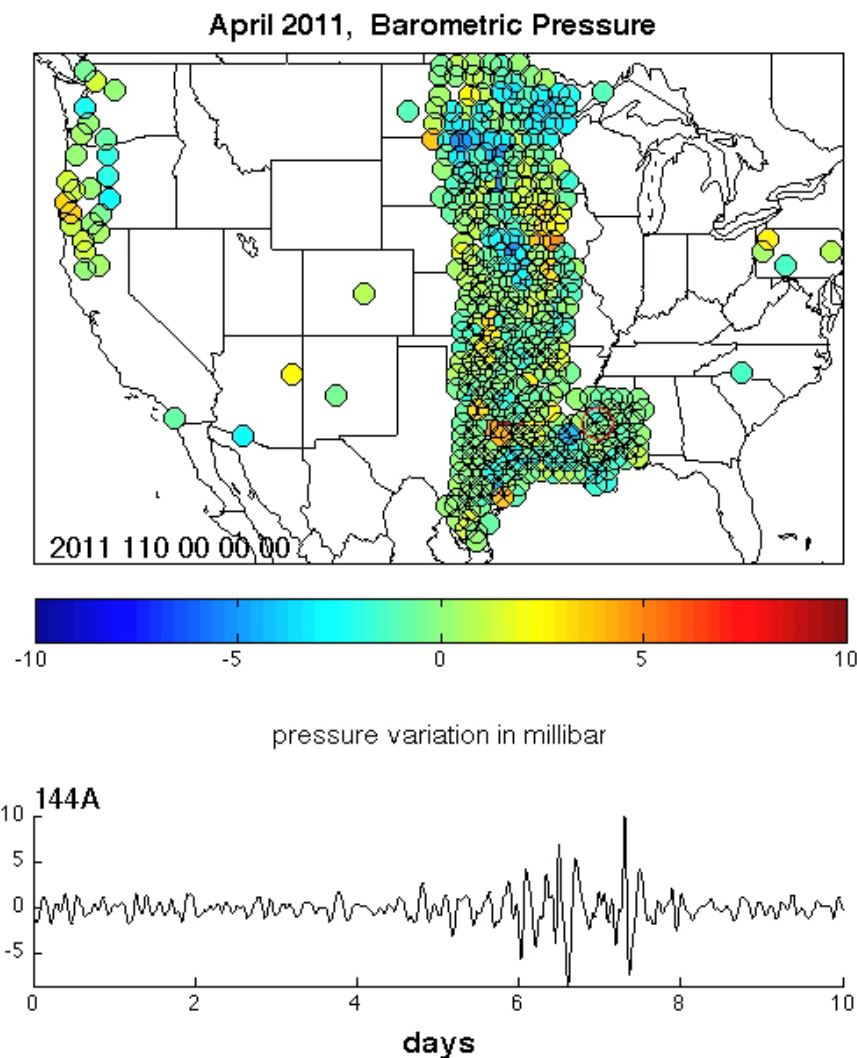
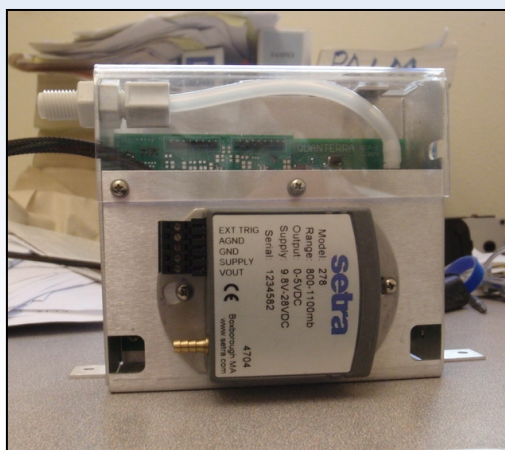


de Groot-Hedlin & Hedlin, EPSL, 2014

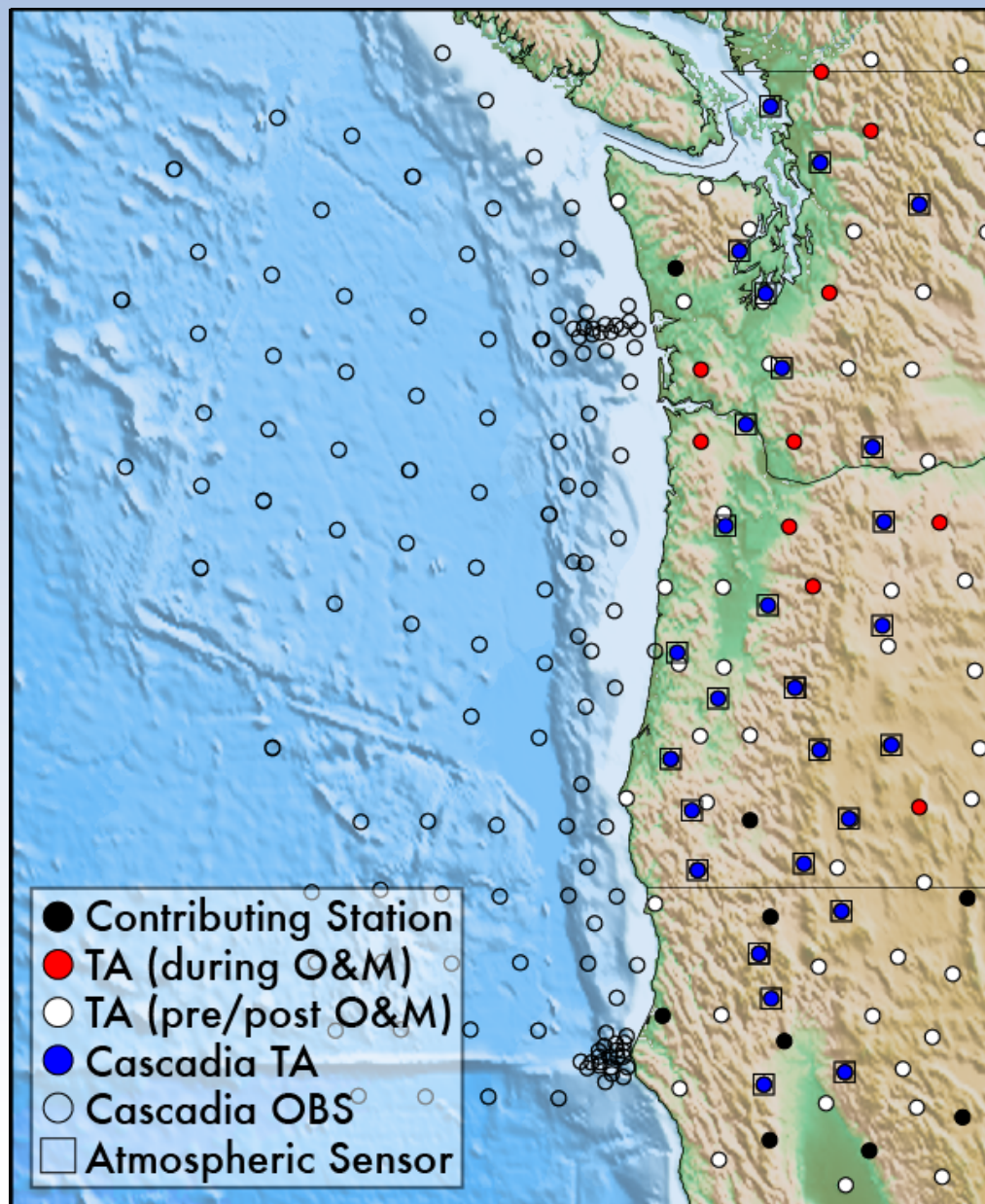
Google:
IRIS infrasound
For events and
detections

Acoustic Transportable Array

- 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

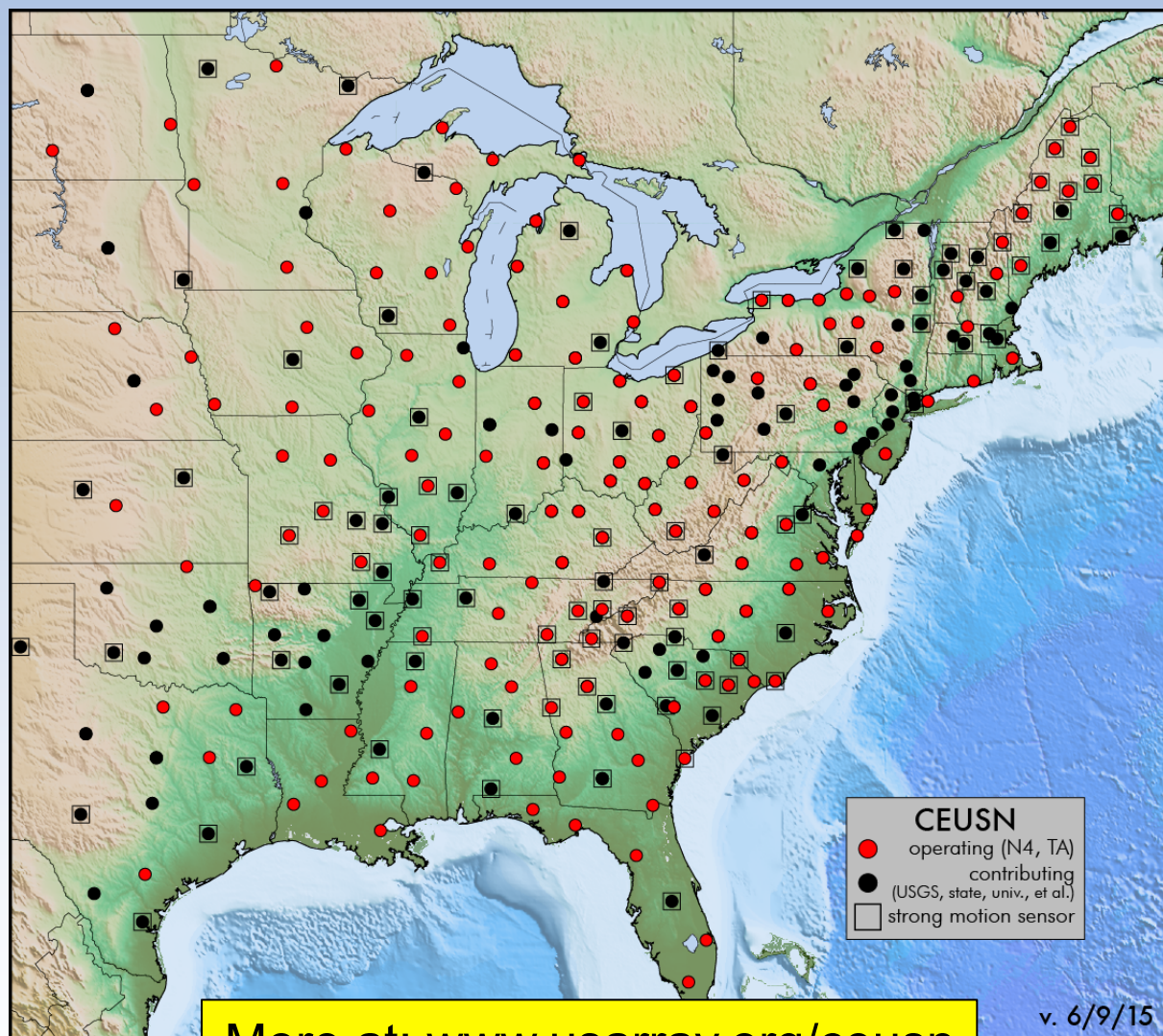


- 27 TA stations (w/atmospheric sensors and strong motion instruments) reinstalled in 2009-2010 to anchor the Cascadia Initiative offshore experiment
- 15 Oregon stations to be adopted by the state



Central and Eastern US Network

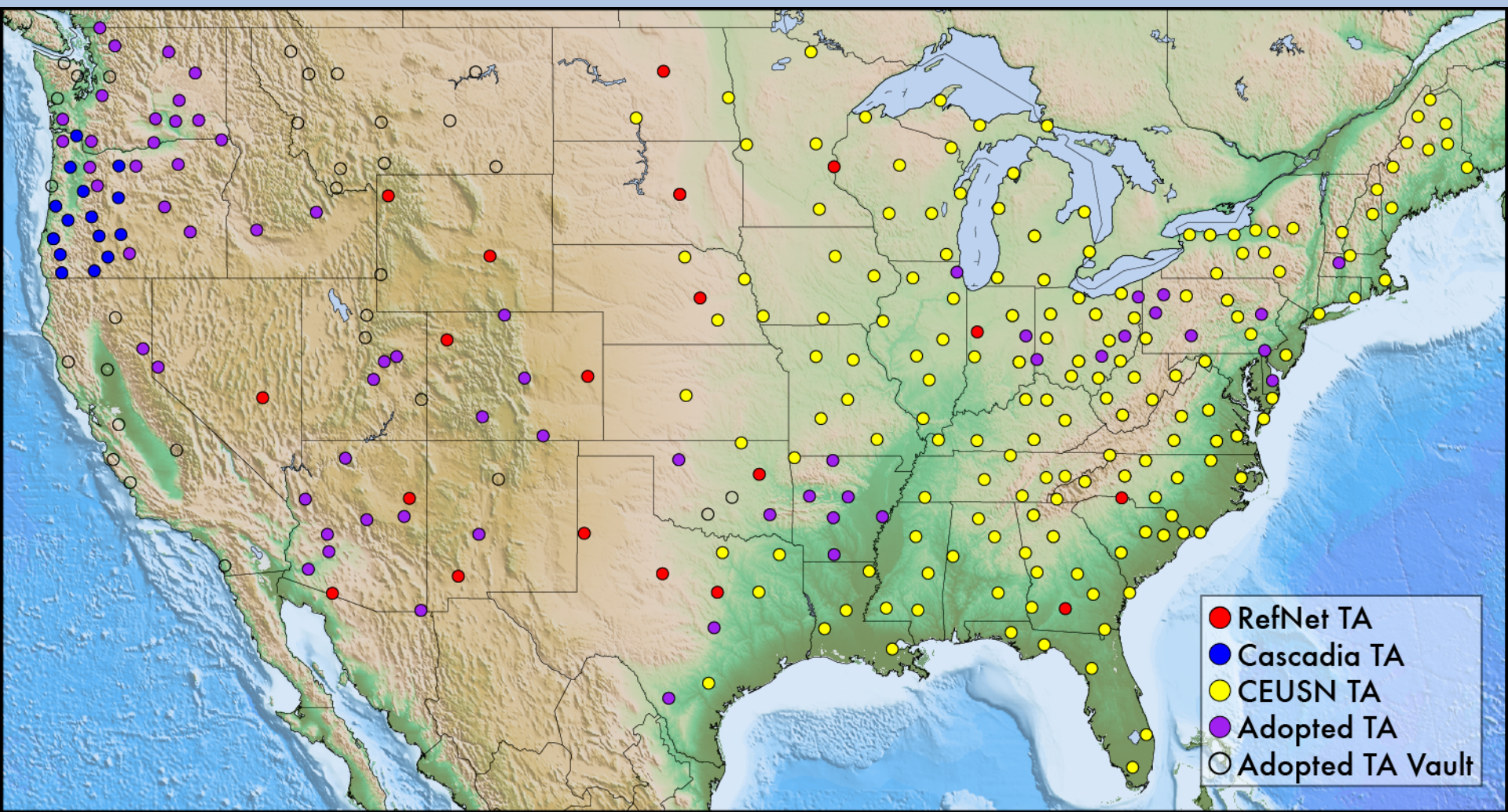
- Five year plan to operate 159 (**37 reinstalled**) TA stations for:
 - Research
 - Hazards assessment
 - Critical facilities
- Multi-agency collaboration
 - NSF, USGS
 - NRC, DOE
- “Good government”
 - Uniquely addressing multiple missions / needs
- Enhanced instrumentation/data
 - 100 s.p.s. broadband
 - 34 new strong motion instruments



More at: www.usarray.org/ceusn

v. 6/9/15

USArray Legacy Stations



Between TA and Cascadia-TA adoptions and CEUSN, potentially 235 new “permanent” stations in N.A. since 2008

- **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



**USArray Transportable Array Team Photo on
Completion of the TA in the Lower-48 States
October 1, 2013**

On the Web

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

woodward@iris.edu

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.