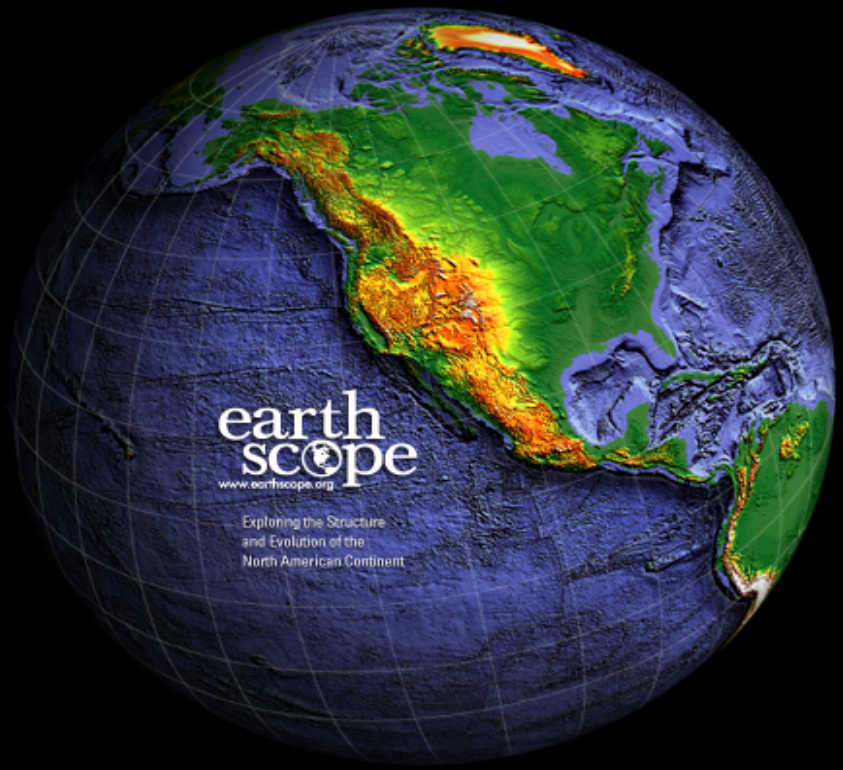
Lessons Learned from a Decade of Operating the USArray Transportable Array



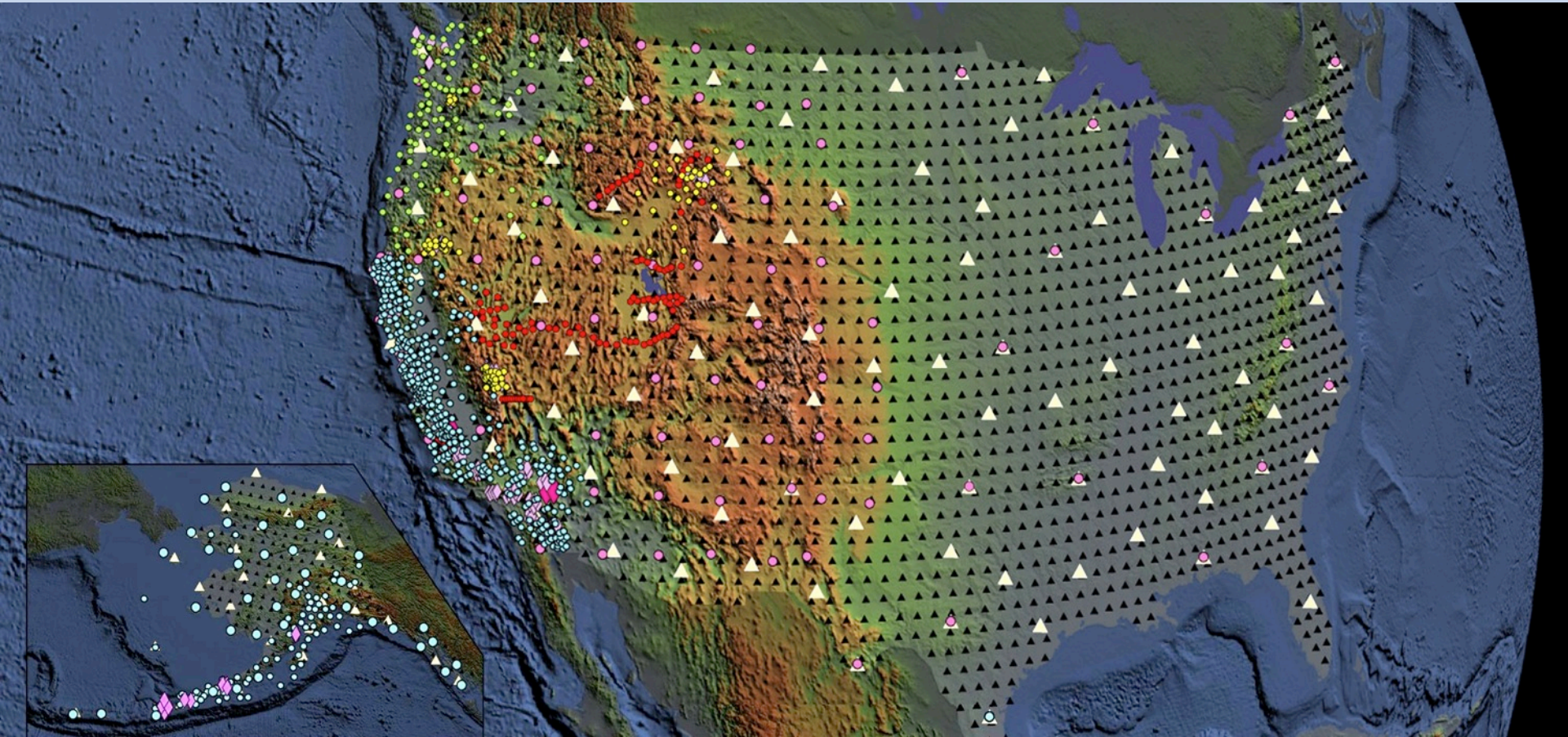
Andy Frassetto
Bob Busby – TA Manager
Katrin Hafner
Bob Woodward
Frank Vernon
Bob Detrick
David Simpson

Sustainable Networks Workshop
Universidad de Chile
May 25, 2015

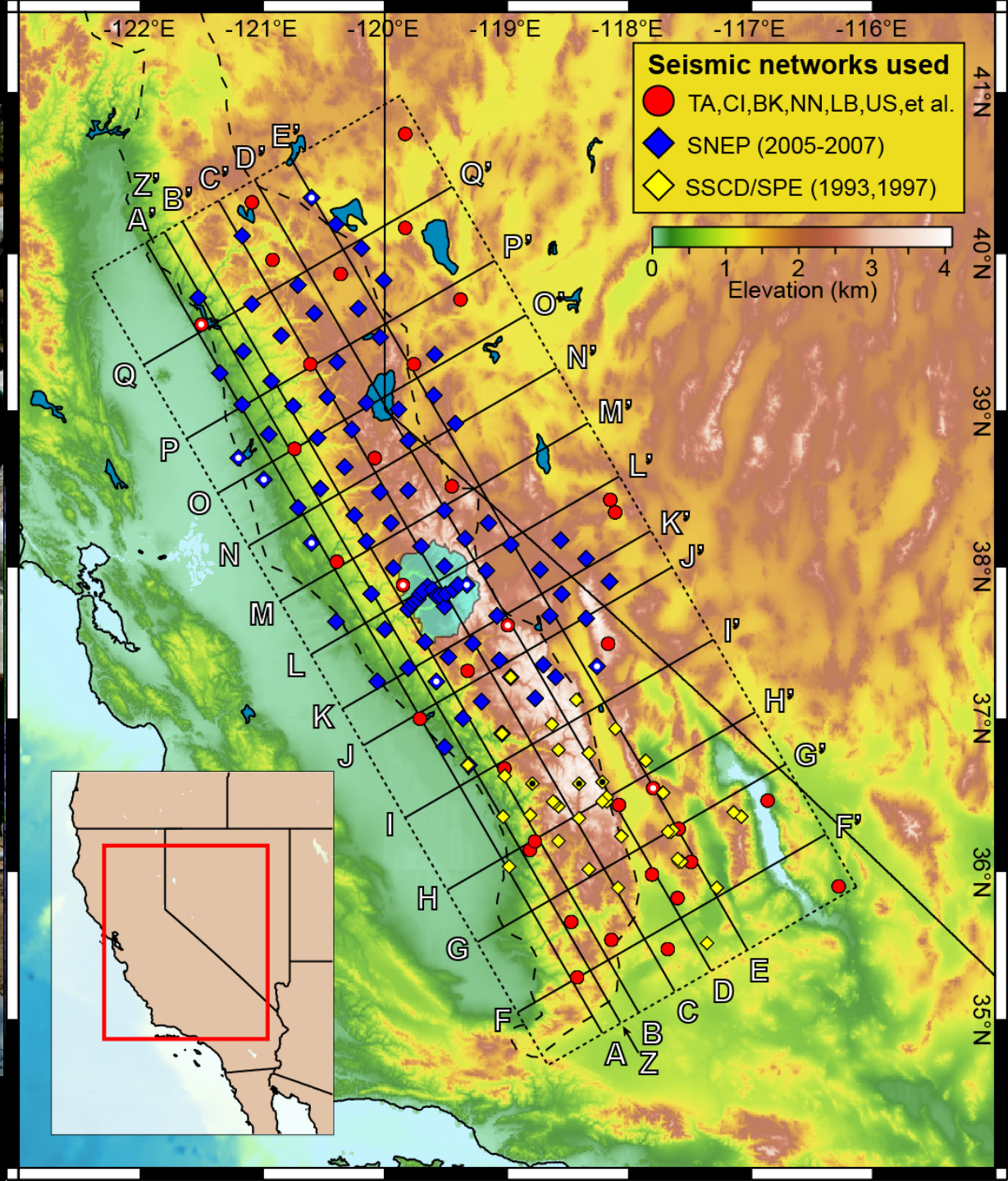
EarthScope (2003-2018)

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

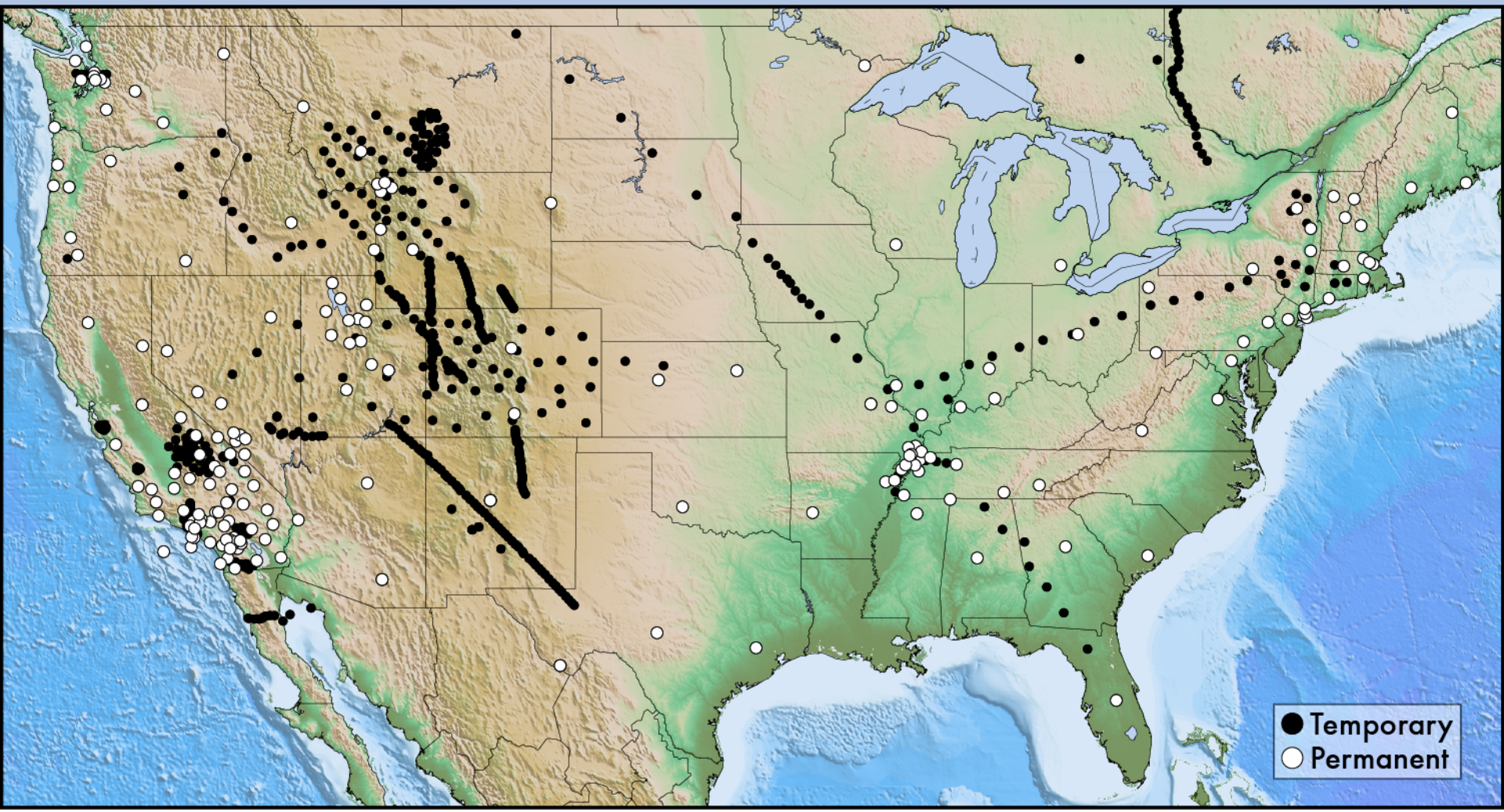
- 3.2 km borehole into San Andreas Fault
- 1100 permanent GPS stations
- 74 borehole strainmeters
- 6 laser strainmeters
- 78 borehole seismometers
- 100 Permanent seismic stations
- 400 transportable seismic stations occupying 2000 sites
- 20 magnetotelluric campaign systems
- 7 magnetotelluric backbone stations
- 100 campaign GPS stations
- 2146 campaign seismic stations



Me (2007)

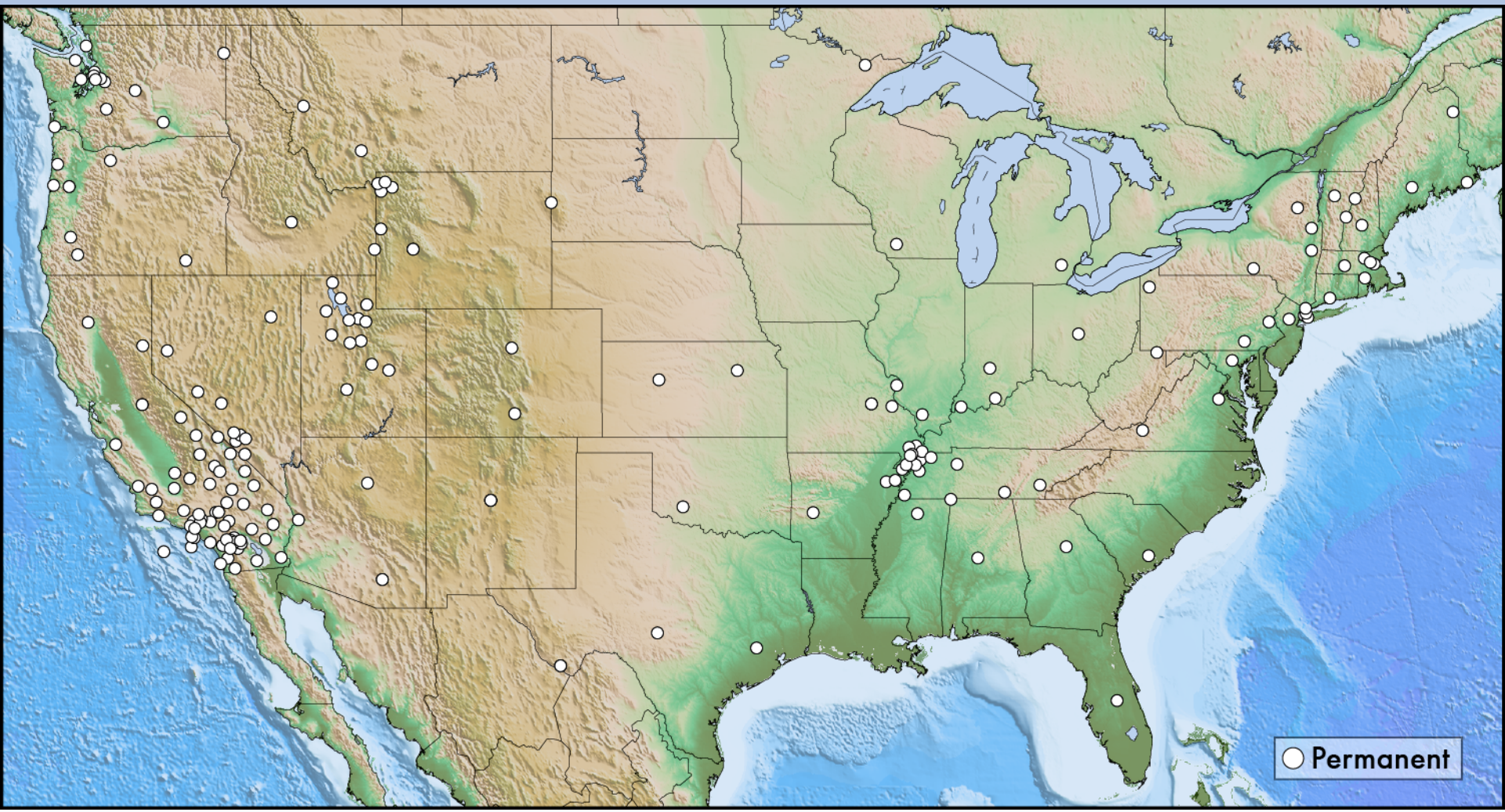

-122°E
-121°E
-120°E
-119°E
-118°E
-117°E
-116°E
41°N
40°N
39°N
38°N
37°N
36°N
35°N
Seismic networks used
TA,CI,BK,NN,LB,US,et al.
SNEP (2005-2007)
SSCD/SPE (1993,1997)
0
1
2
3
4
Elevation (km)
A'
B'
C'
D'
E'
Z'
F'
G'
H'
I'
J'
K'
L'
M'
N'
O'
P'
Q'
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
Z

Pre-USArray (2003)



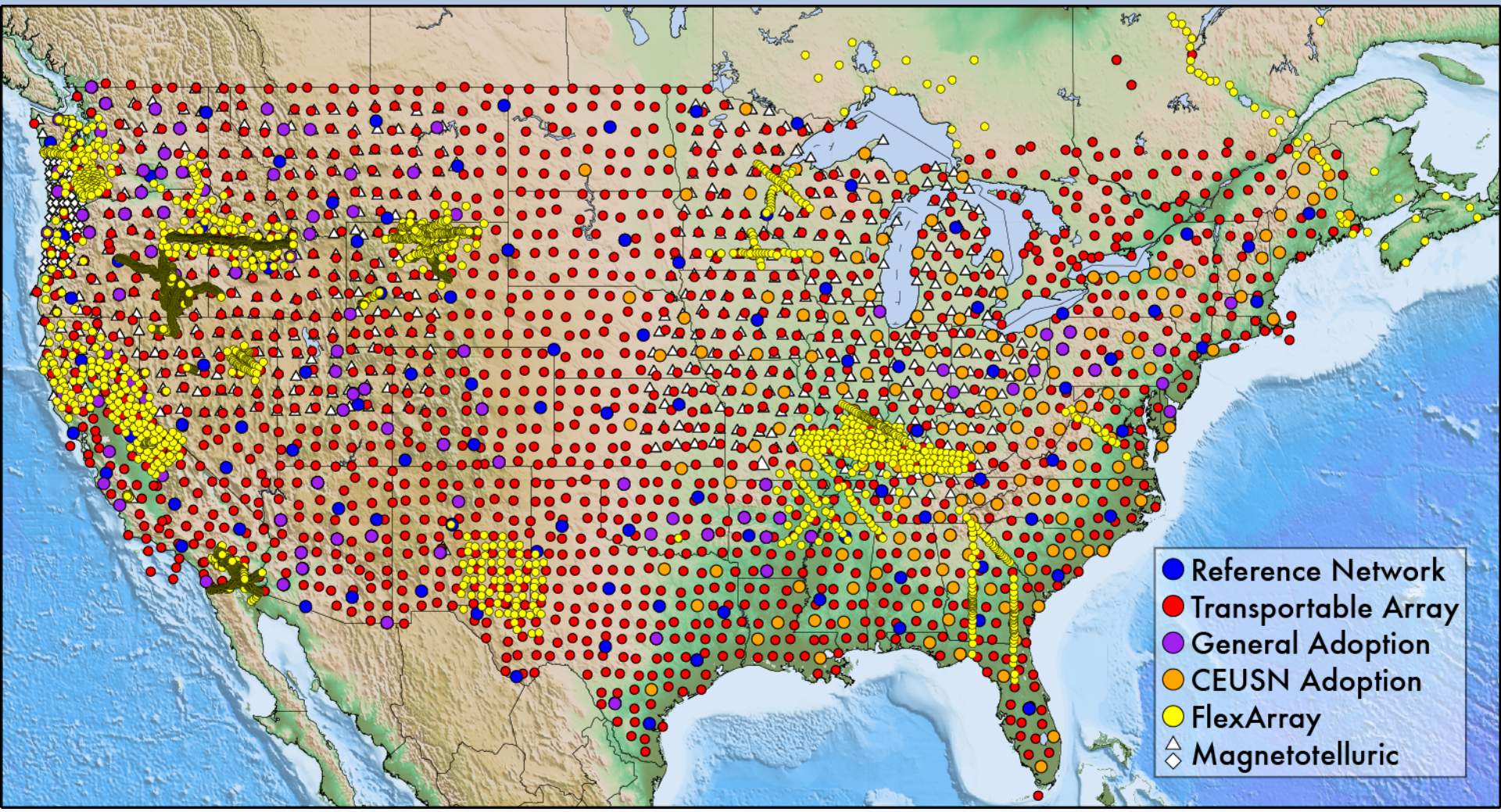
>700 temporary stations, typically deployed for a few months up to a year

Pre-USArray (2003)



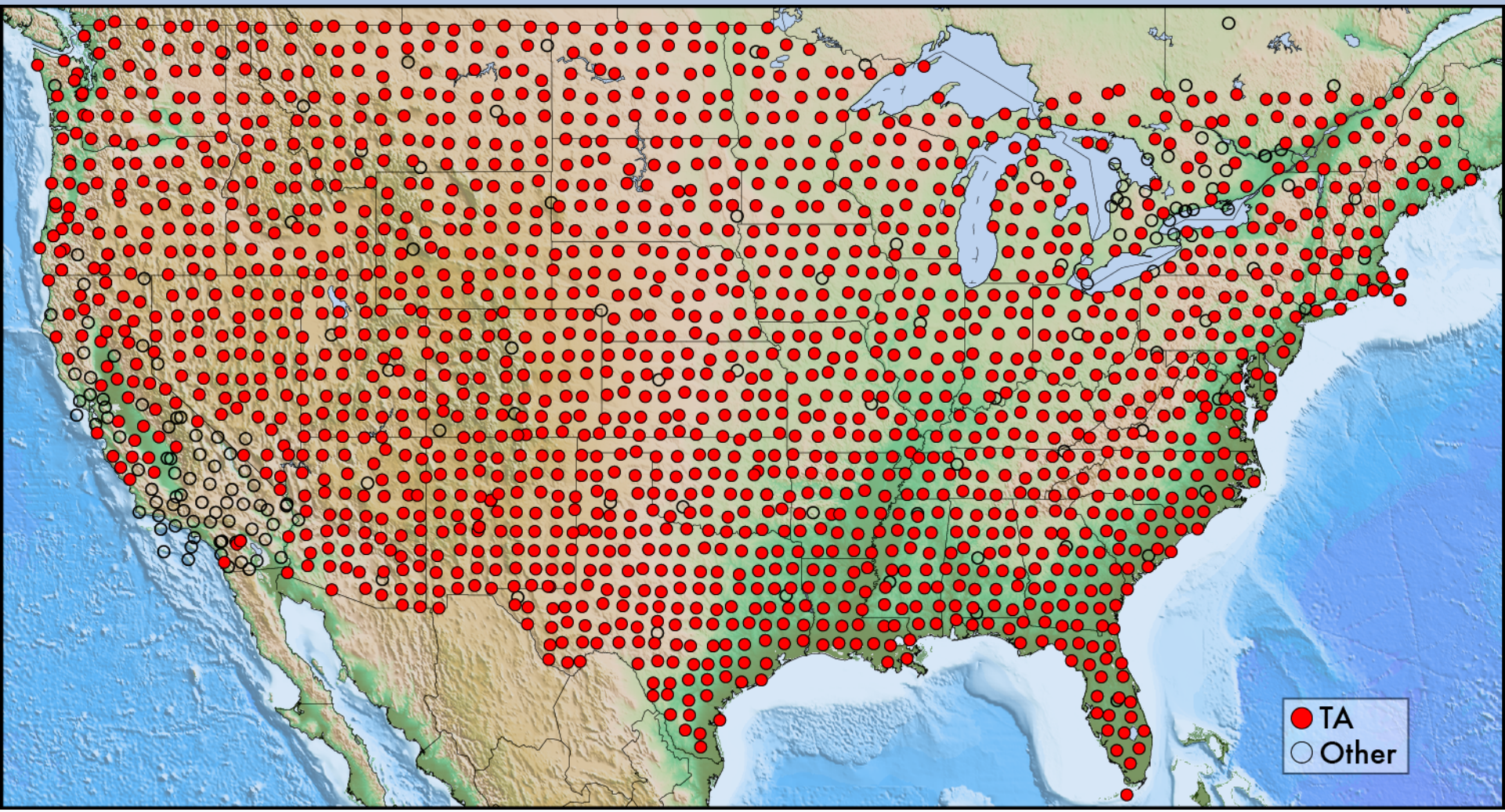
196 “permanent” broadband stations

USArray through 2014



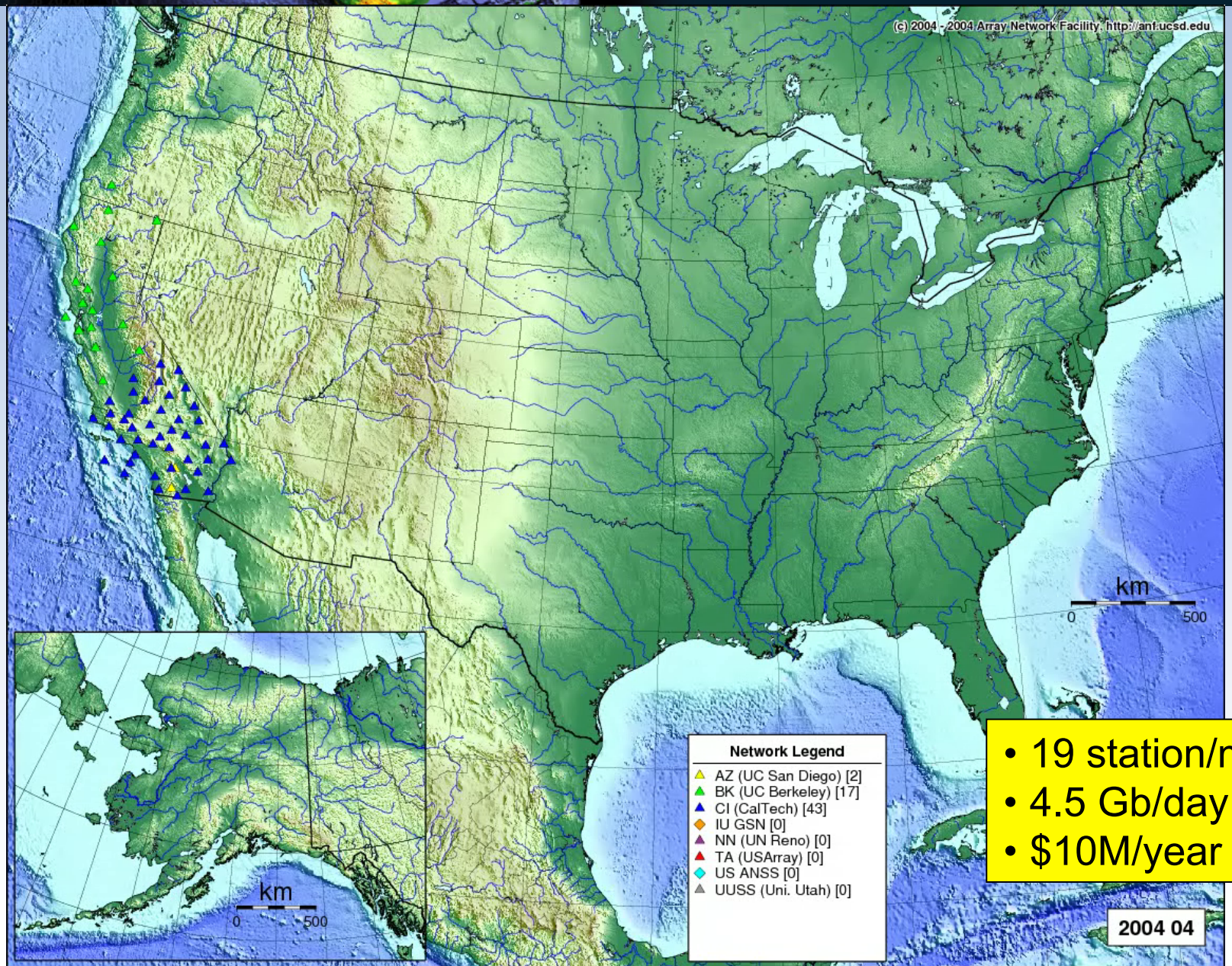
- Major seismometer deployment in support of EarthScope
- IRIS operates and collects TA data directly, all data are immediately open

Transportable Array



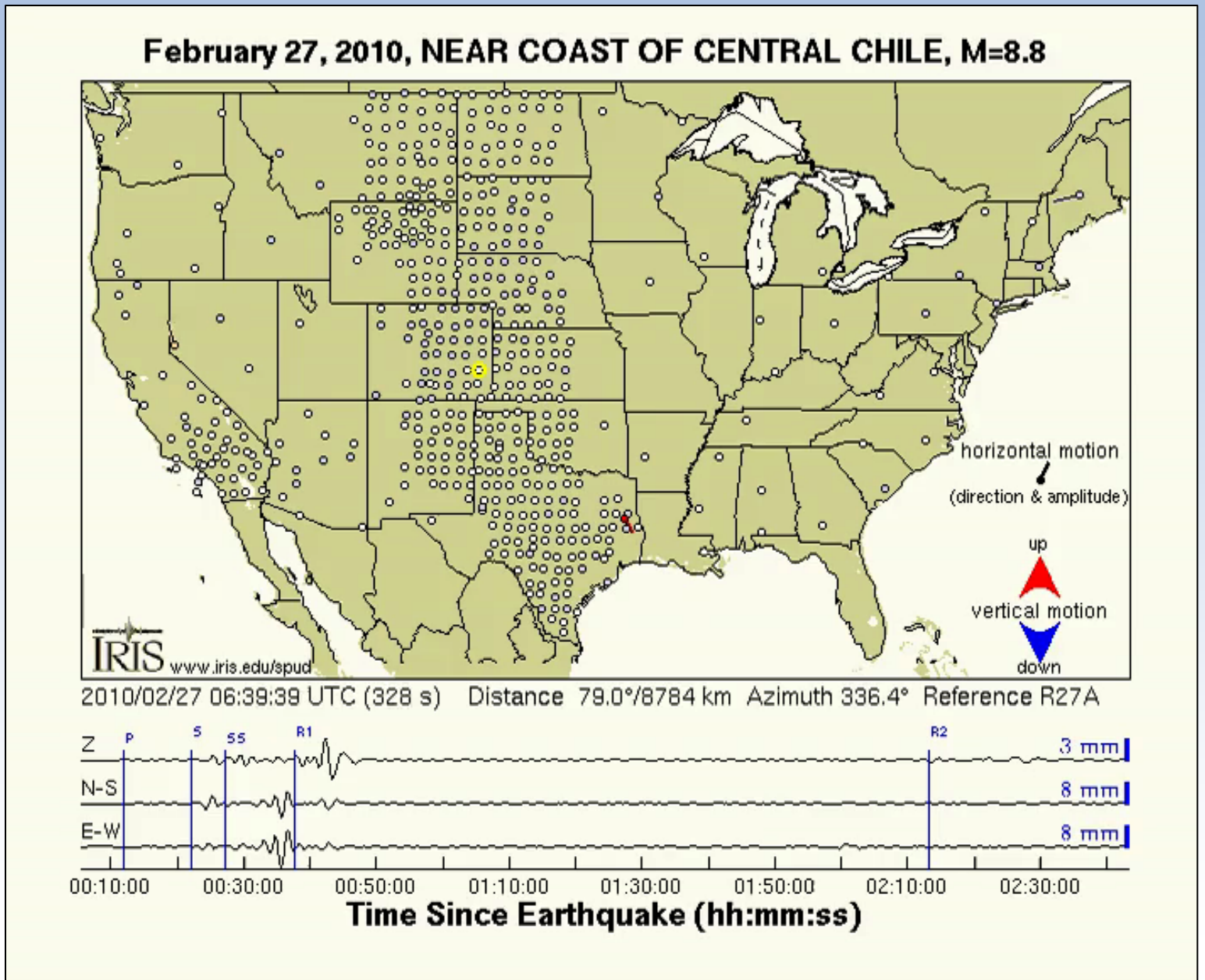
- 400 stations, 70 km spacing, 2 years/station deployed, +1,700 stations total
- Deployment completed on schedule and under budget

11 Years of TA Stations

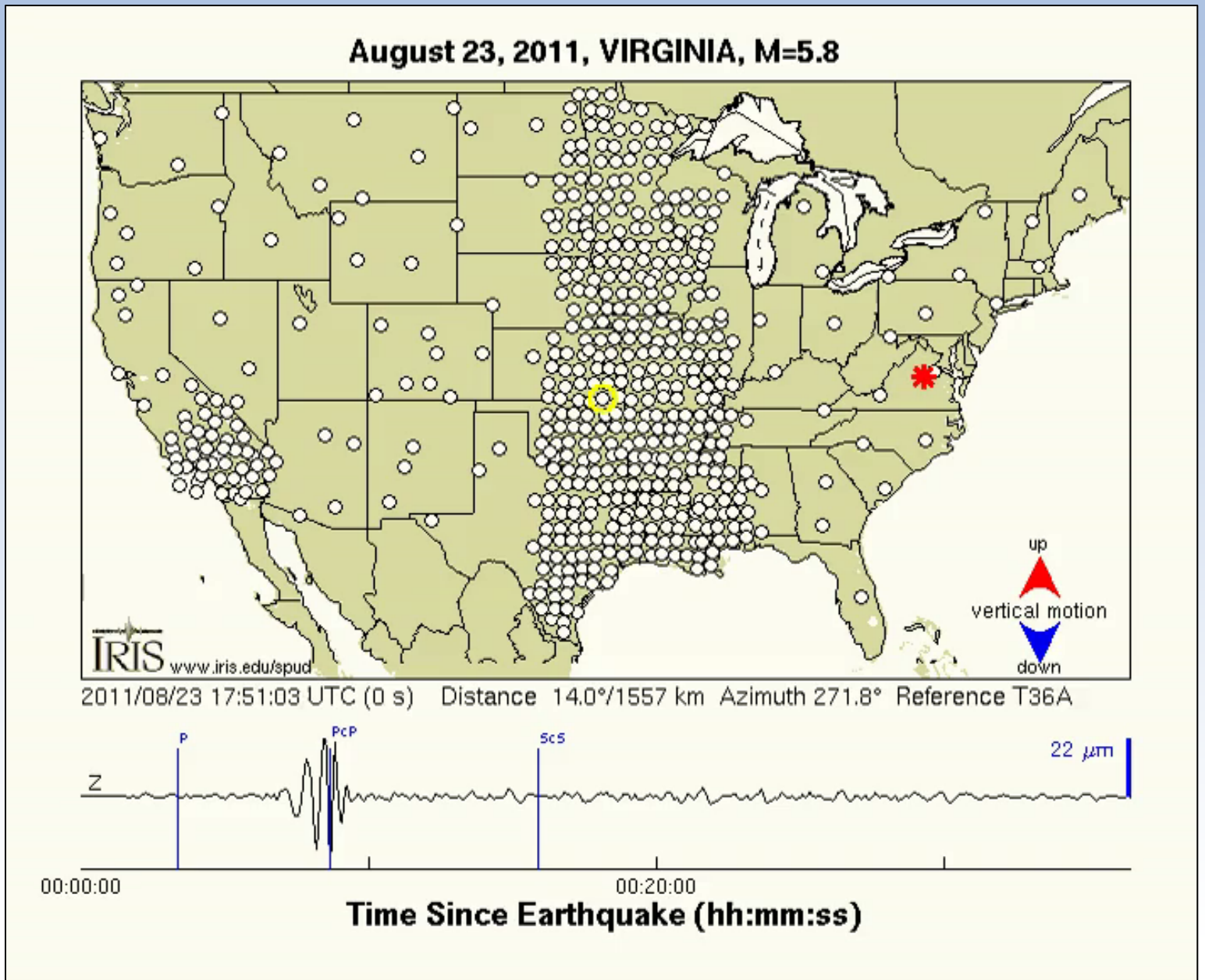


- 19 station/month
- 4.5 Gb/day
- $10M/year

2010 Maule Example



2011 Virginia Example



Lessons Learned

What “best practices” made the TA successful?

Have a clearly defined organization (different tasks – different people):

- Permitting (STUDENTS found most sites, private landowners)
- Construction/Removal Teams (Honeywell Contractors)
- Installation Team (Honeywell Contractors)

- **Array Operations Center** (PASSCAL Instrument Center) – Coordinates permitting, crew schedules, procurements, equipment inventory and testing, etc.

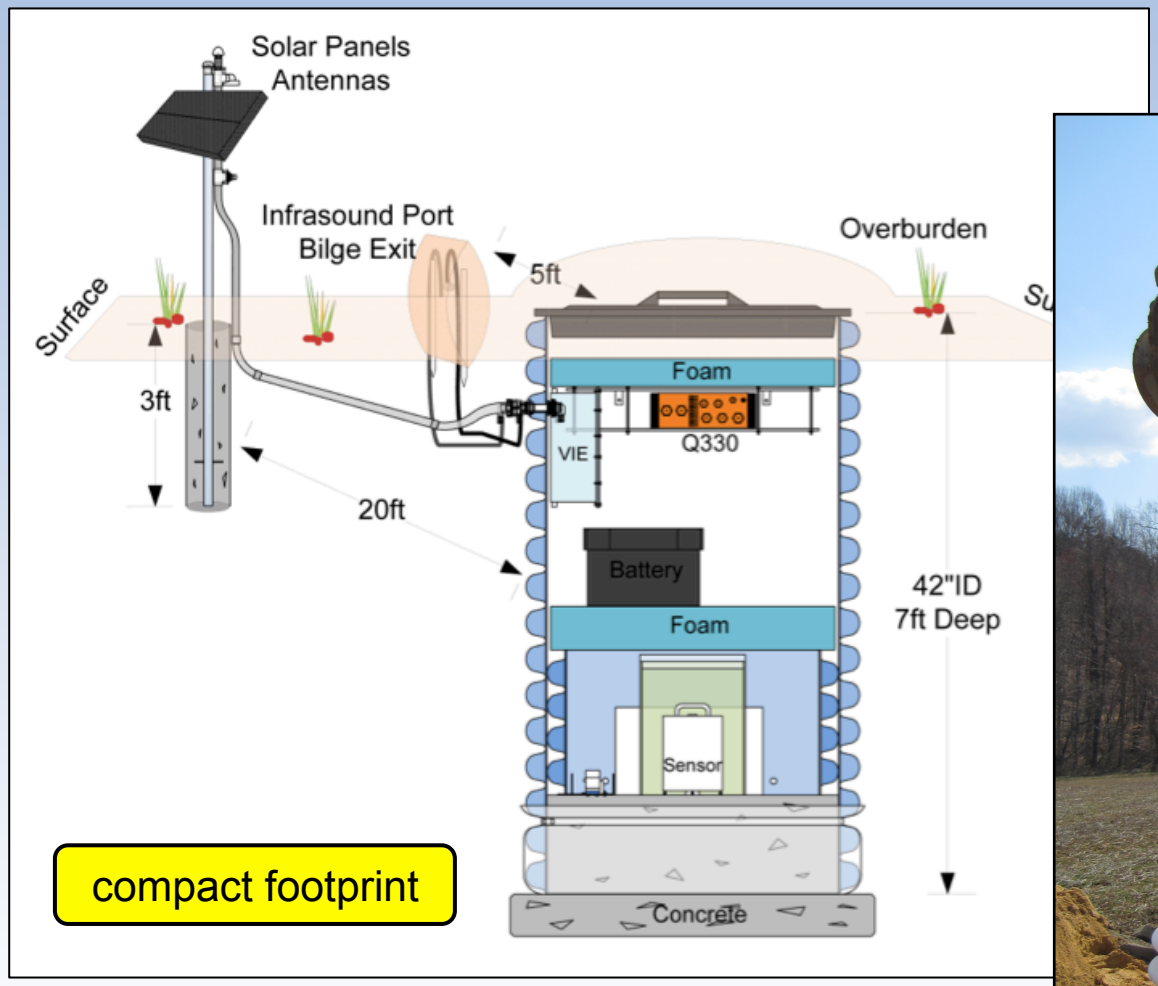
- **Array Network Facility** (Univ. California-San Diego) – Monitors metadata, data flow, overall network performance, state of health, creates event catalogs (Jennifer Eakins & Juan Reyes)

- **IRIS Data Management Center** – Handles waveform quality assessment (Mary Templeton)

Standardized, autonomous design optimizes activities

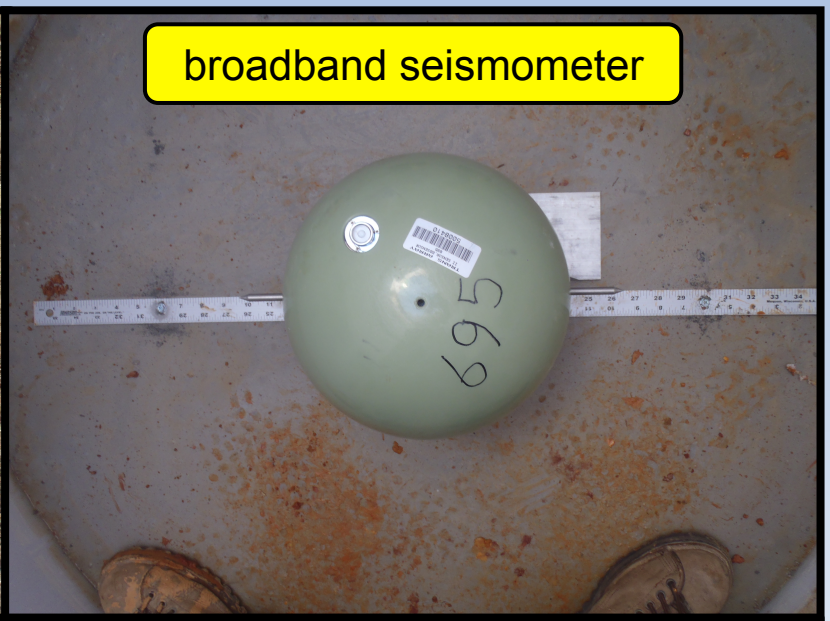
Same design, construction materials, and hardware. Sites were selected for uniform installation and to operate undisturbed for at least 2 years.

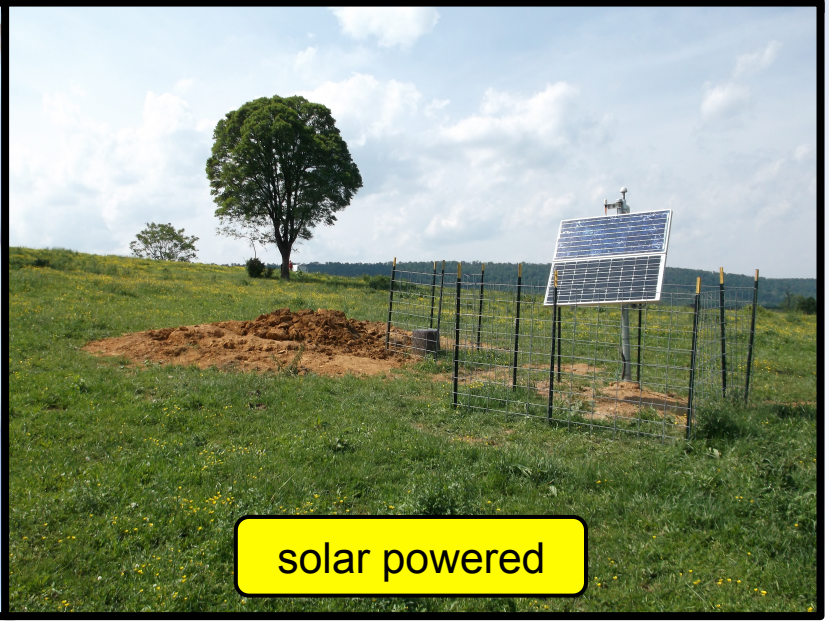
Typical TA Station



TA station design evolved (cautiously), but was always standardized.

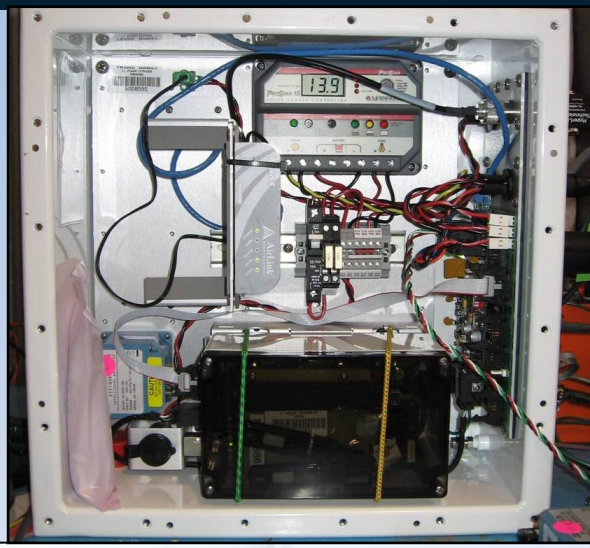
Typical TA Station





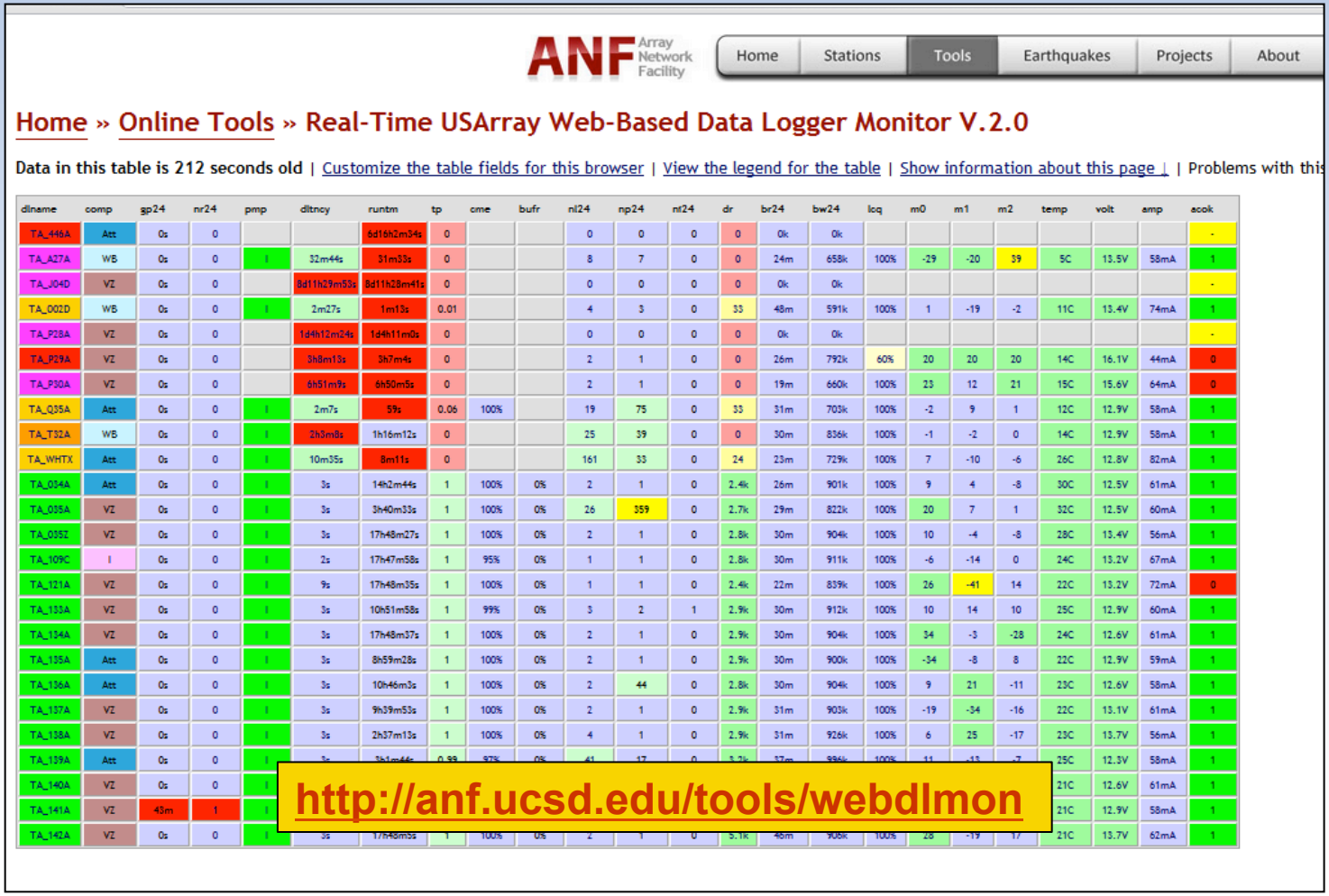
Uniform Design

- Plastic molded vault design
- Modular communications (90% cell modems, 10% VSAT)
- Vault interface enclosure
  - Encloses everything but the DAS and seismometer
- Low-power autonomous operation (batteries charged off 1 or more panels)



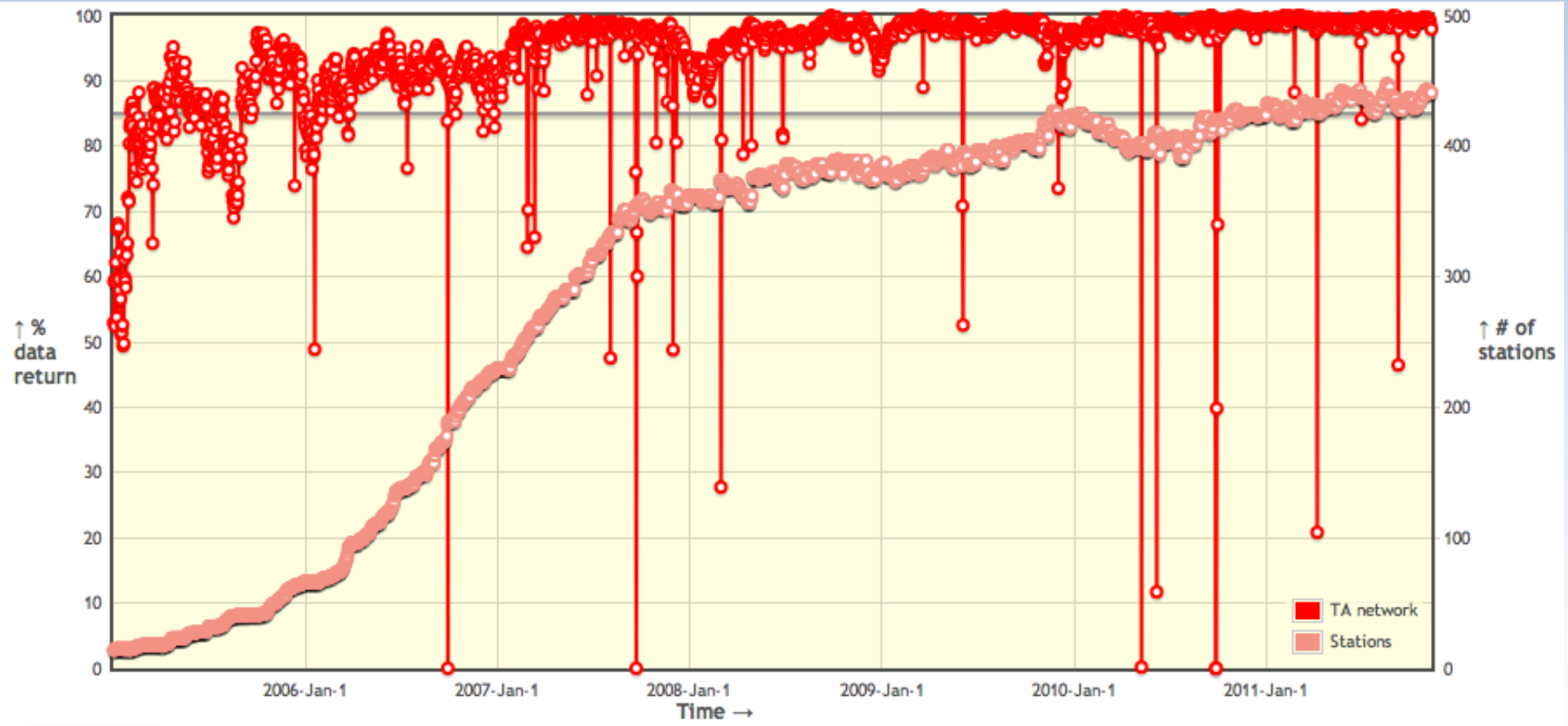
Station deployment treated as a high-precision manufacturing operation

Data Monitoring and Quality Control: Completeness + integrity, signal quality



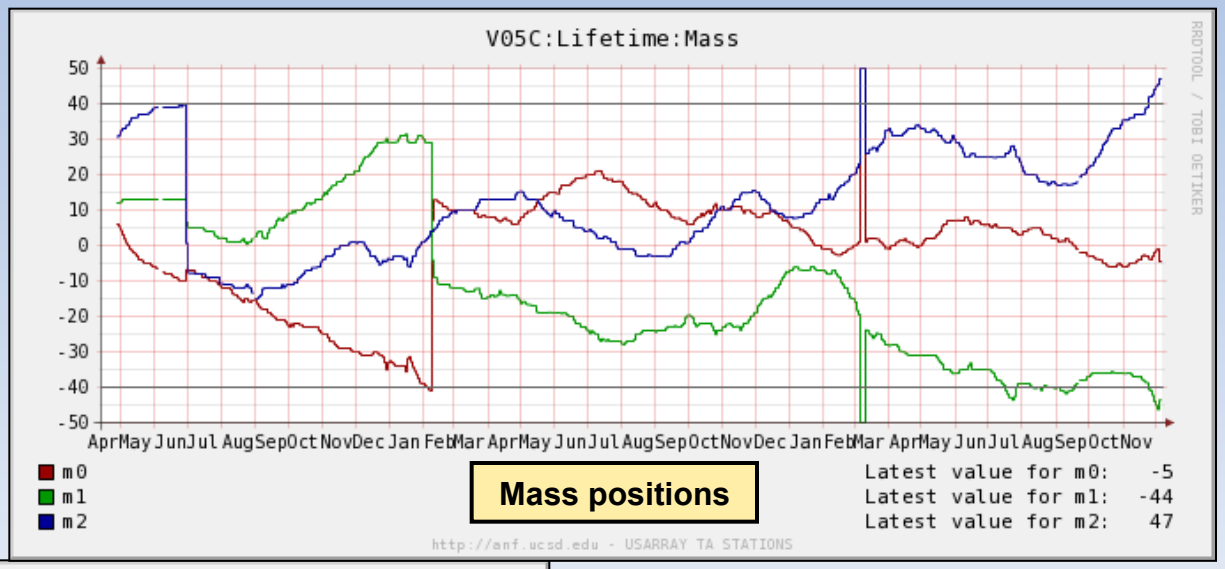
TA Real-time Data Return

2505 days of data
6 days with 100% data return
97.78% Median daily data return

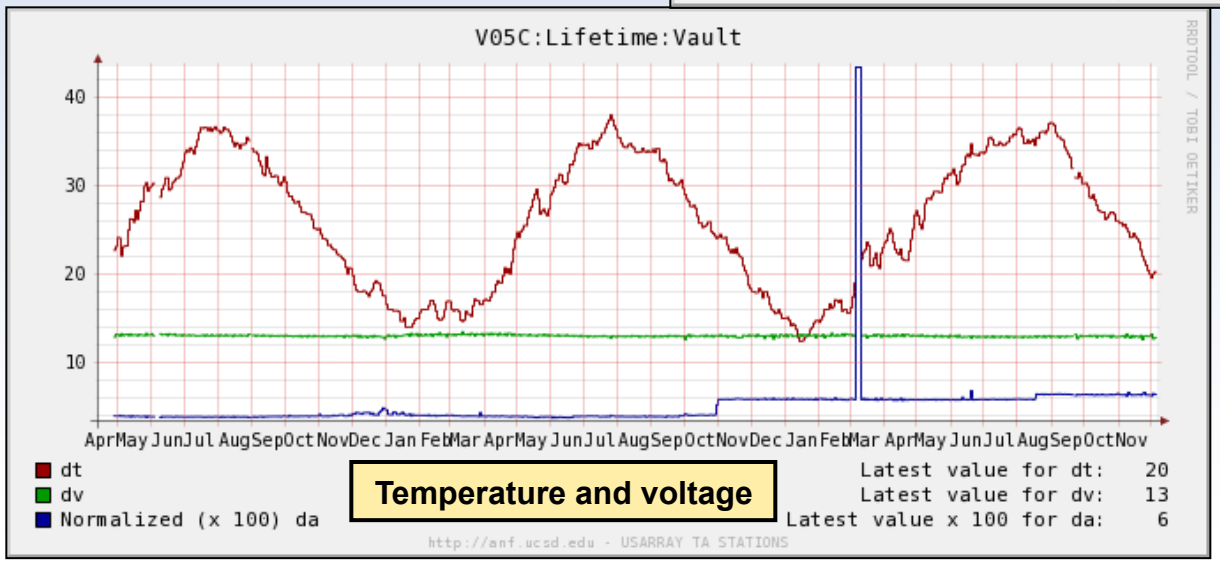


State-of-Health Review

- Real-time monitoring
  - Detect problems
  - Initiate corrective actions
- Station QC & SoH on the web



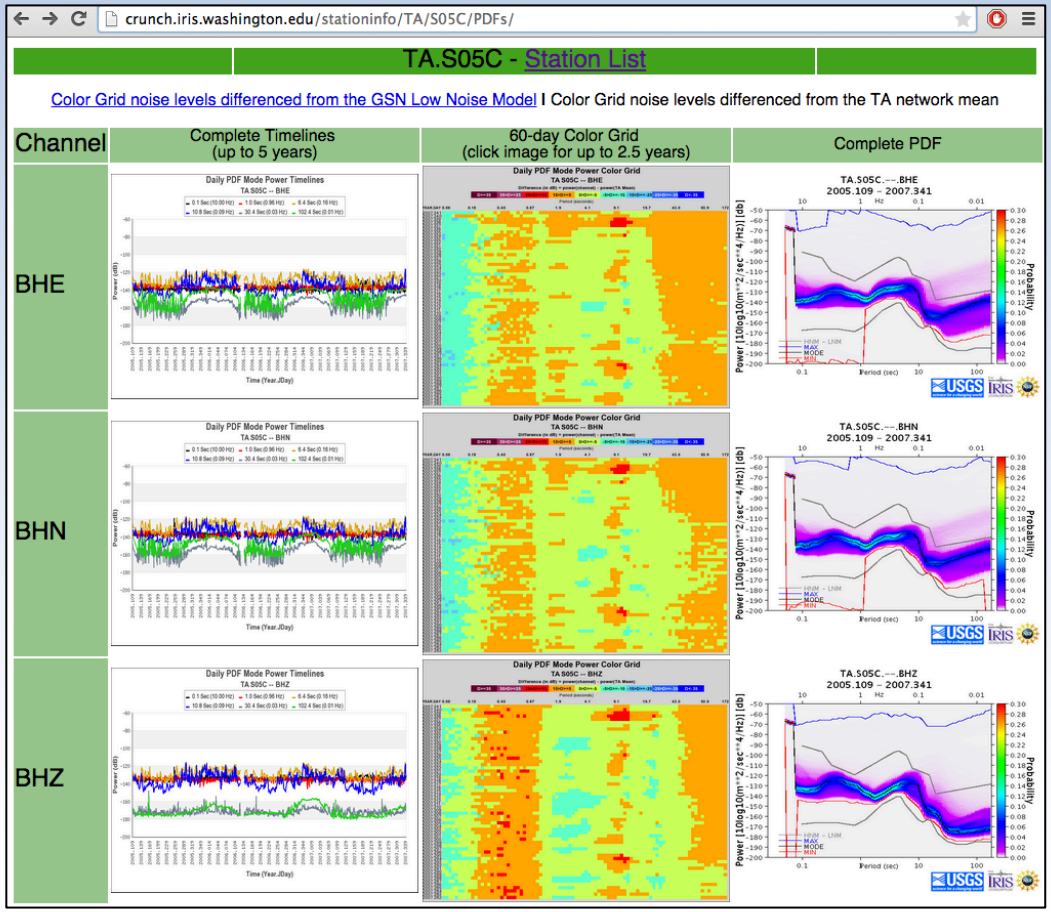
Mass positions

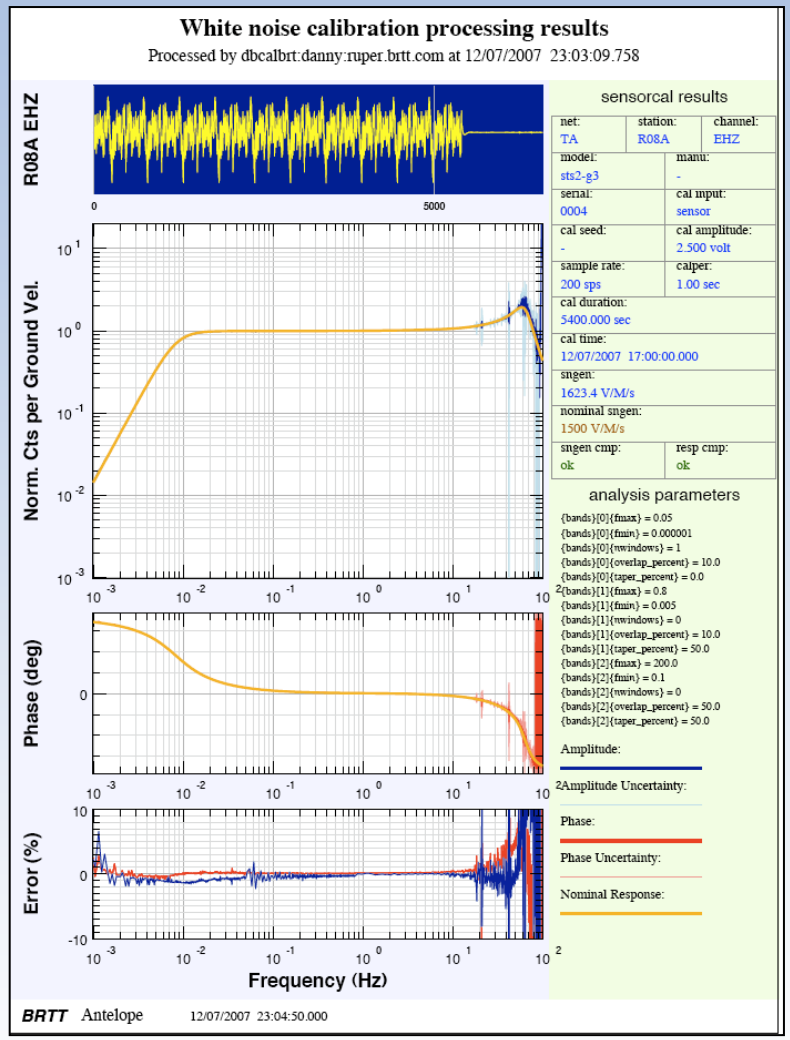


Temperature and voltage

Automated Procedures

Automated process for command, capture, analysis of calibration signals





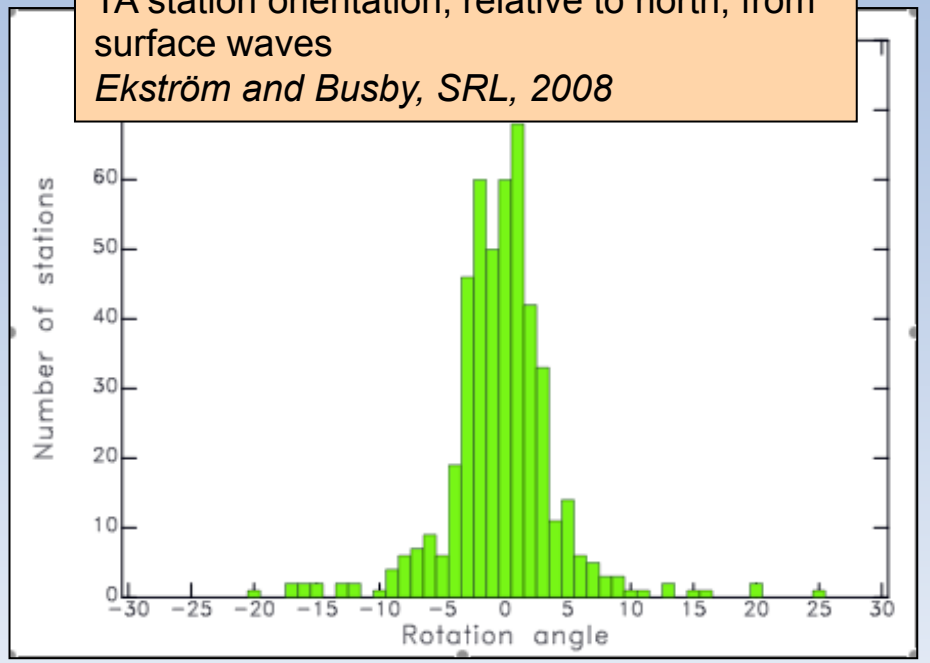
Real-time noise analysis identifies performance issues

Lesson 4

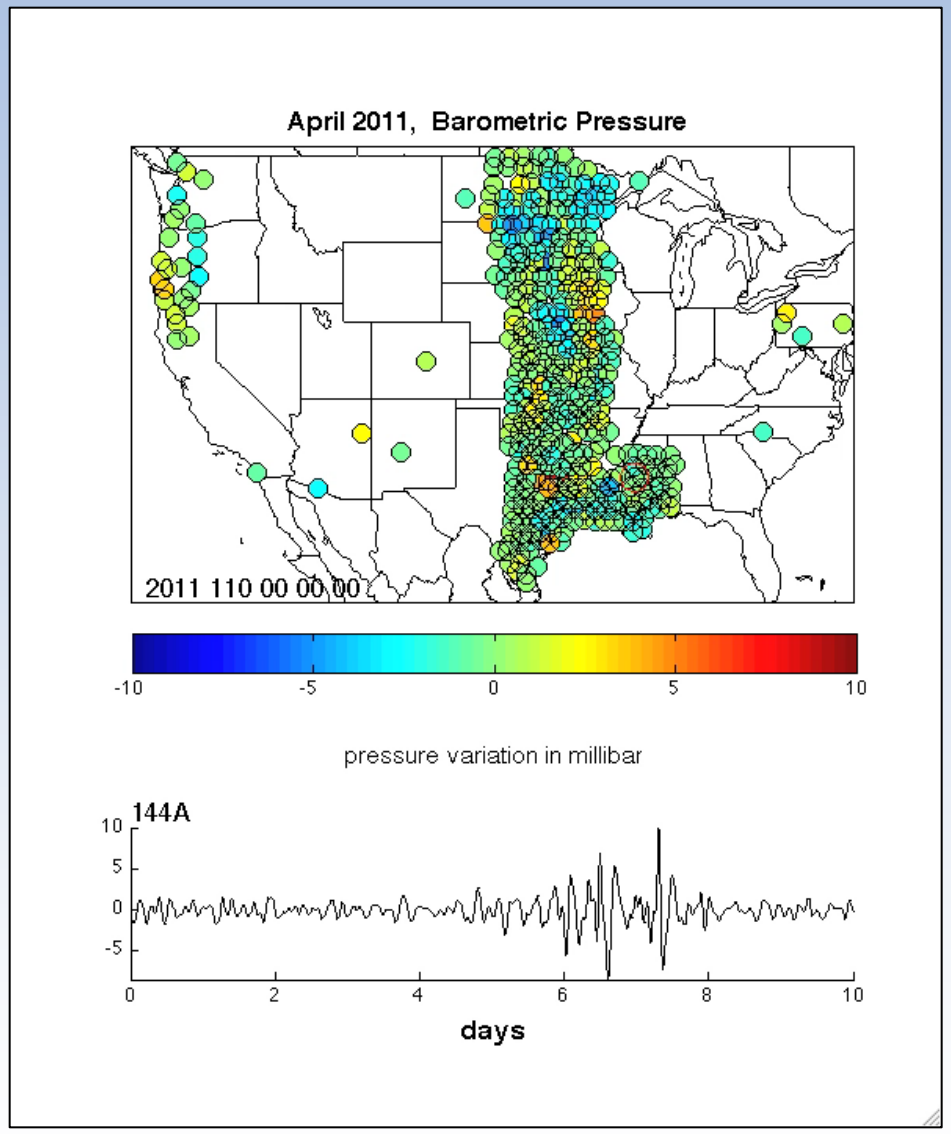
Be open to improvement and growth…

- 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 surface waves
Ekström and Busby, SRL, 2008

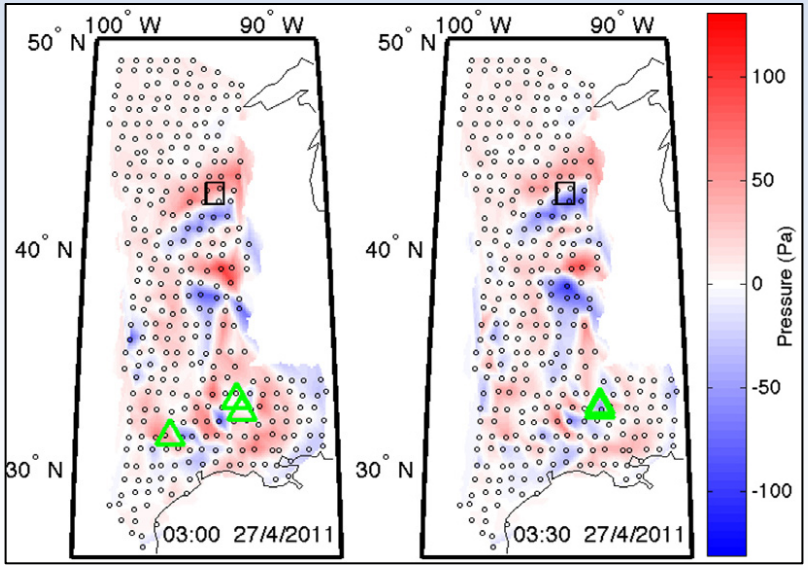


Atmospheric Acoustic Transportable Array

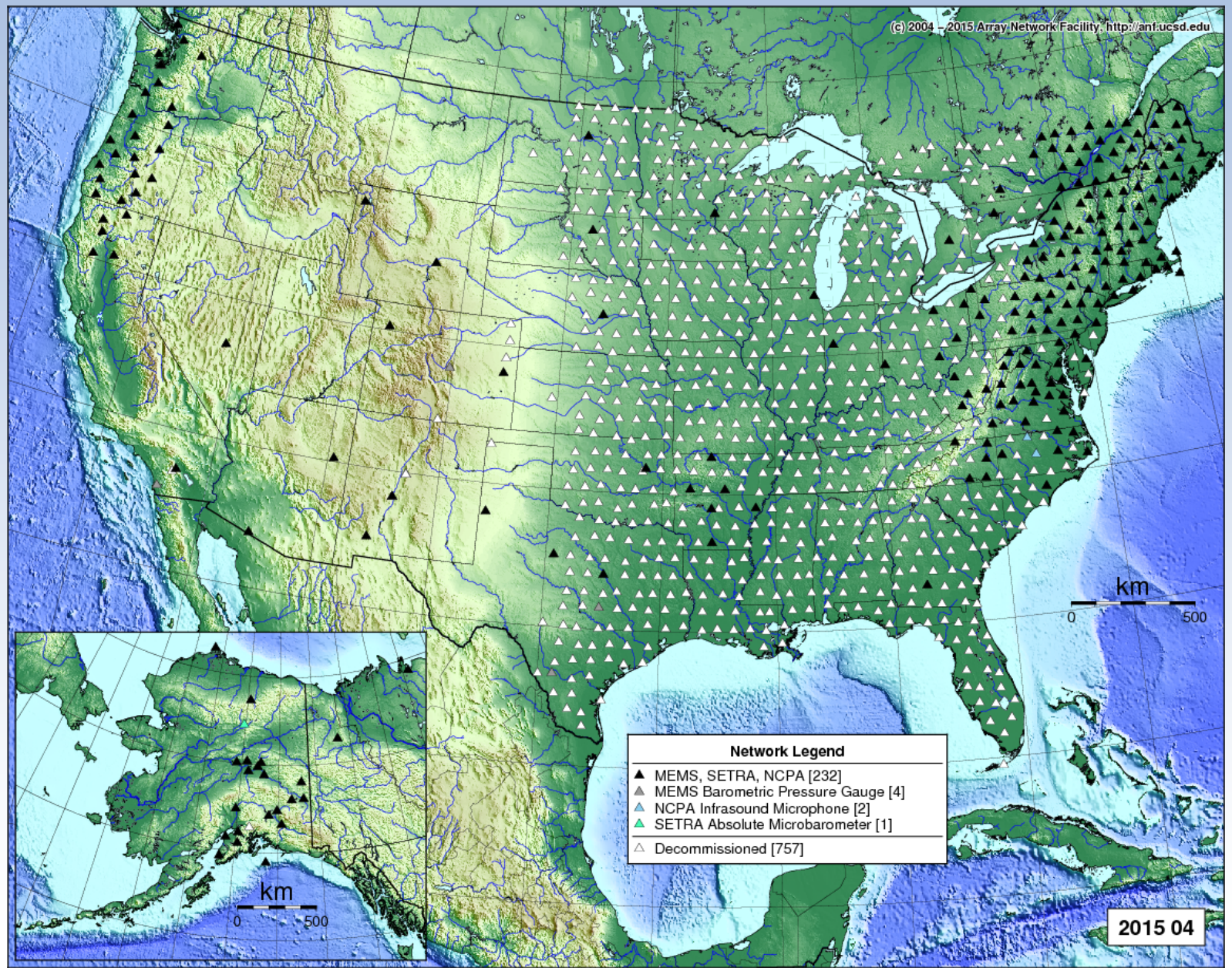


- Addition of barometers and infrasound to TA (NSF-MRI award to UCSD) in 2010
- TA became platform to better understand major atmospheric/ weather signals.

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

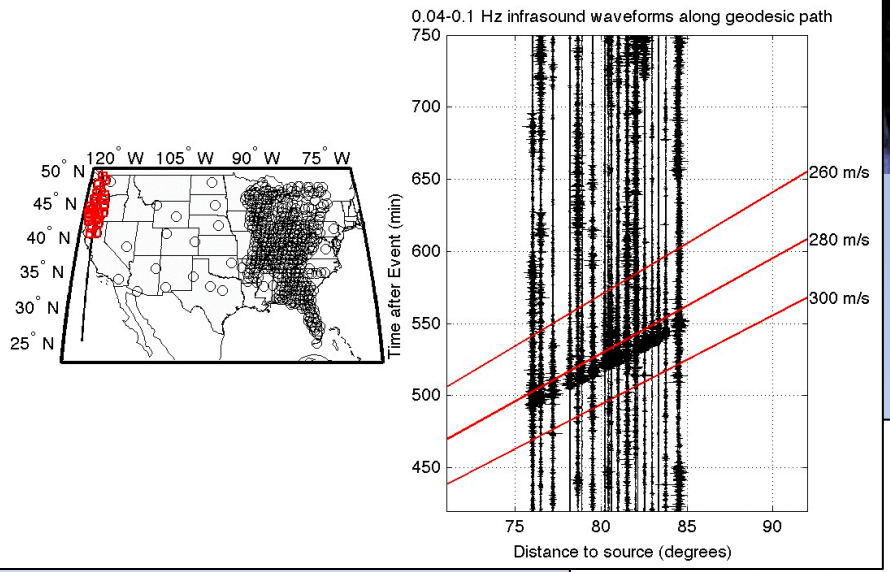


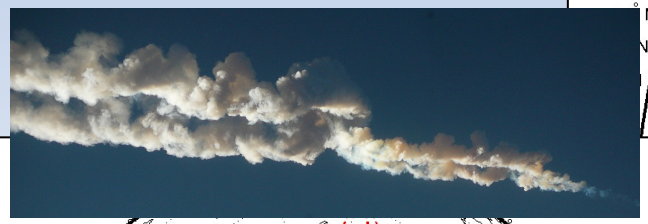
Atmospheric Acoustic Transportable Array

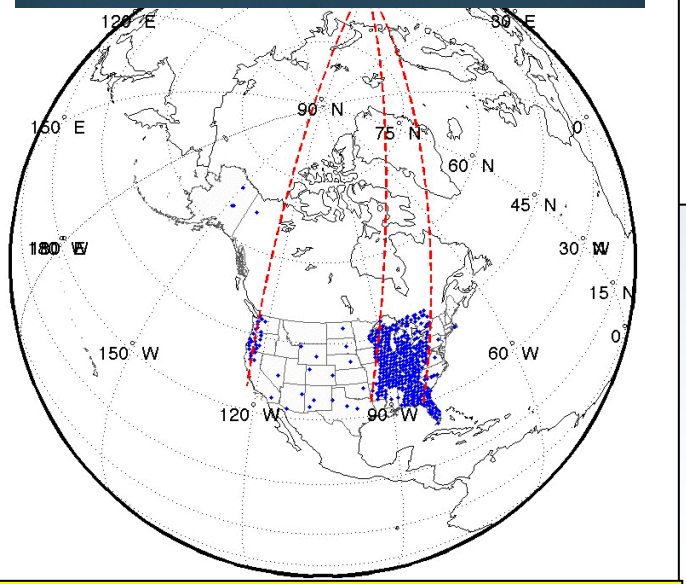


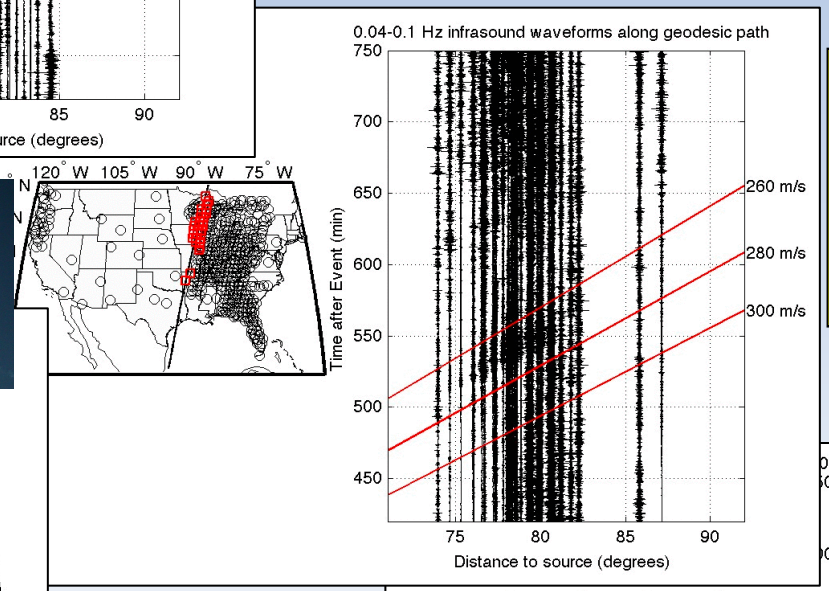
Atmospheric Acoustic Transportable Array

Infrasound data provides unprecedented profiles for azimuth and distance

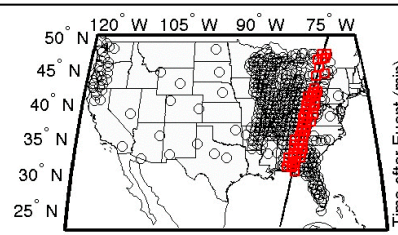


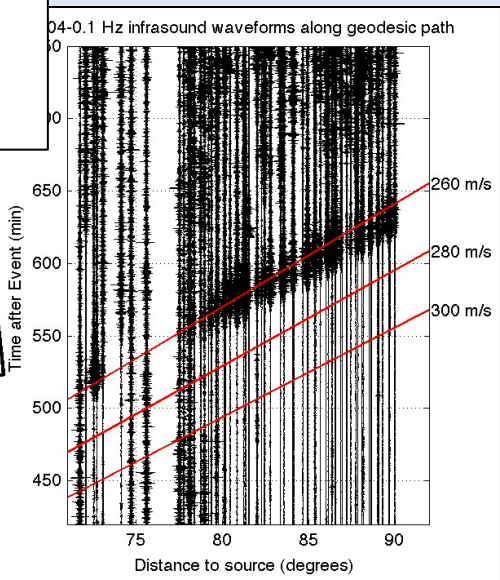






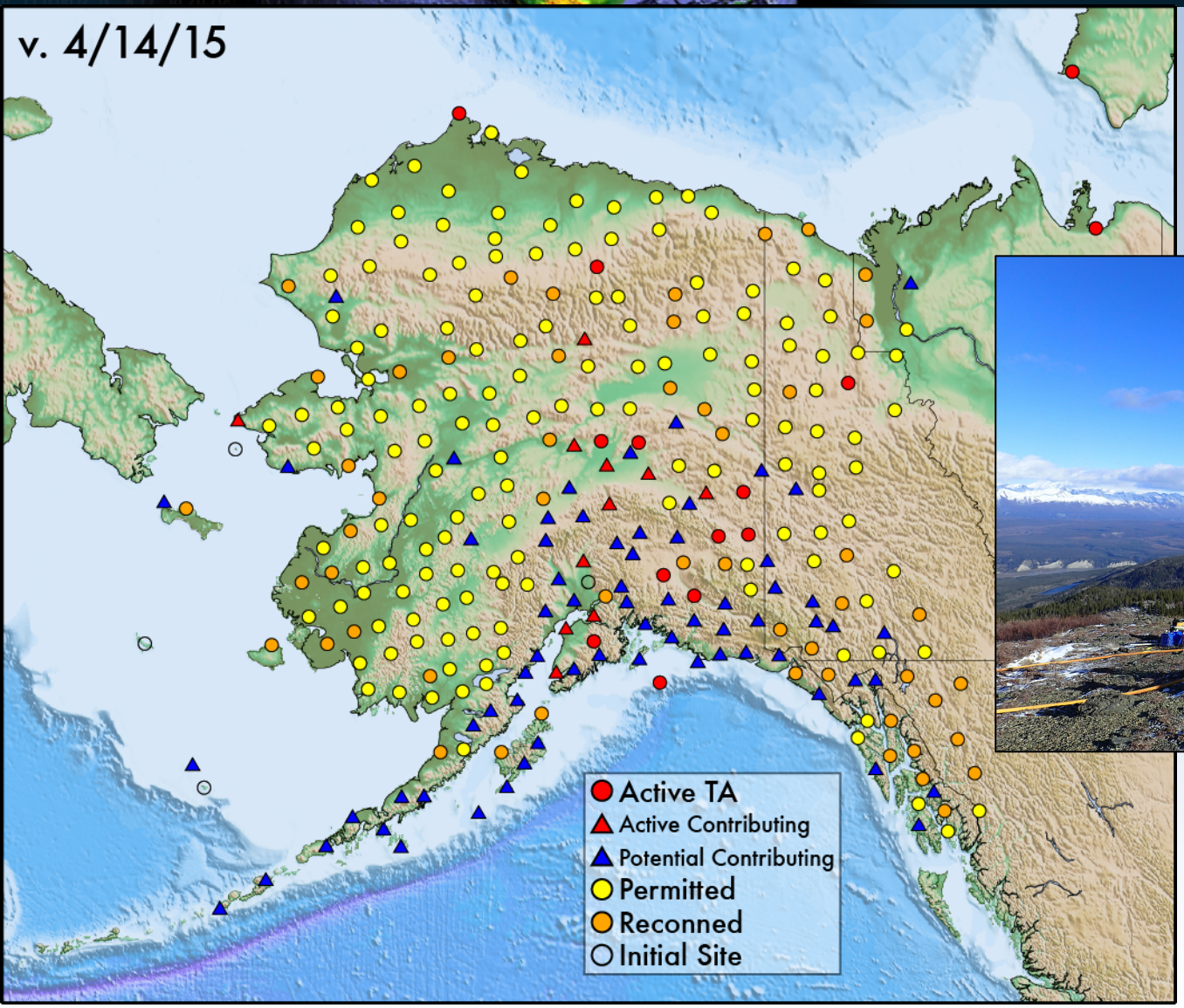
Google:
IRIS infrasound
For events and detections

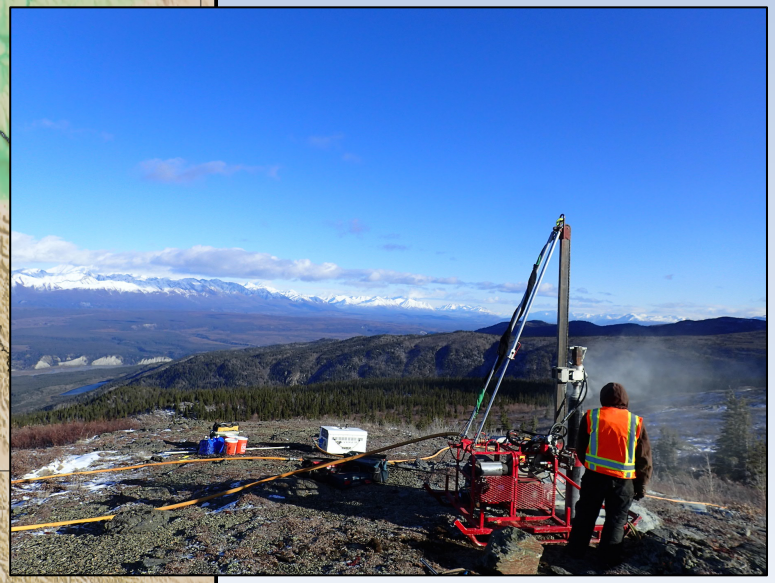




Figures from Catherine deGroot-Hedlin, UCSD

Moving to Alaska



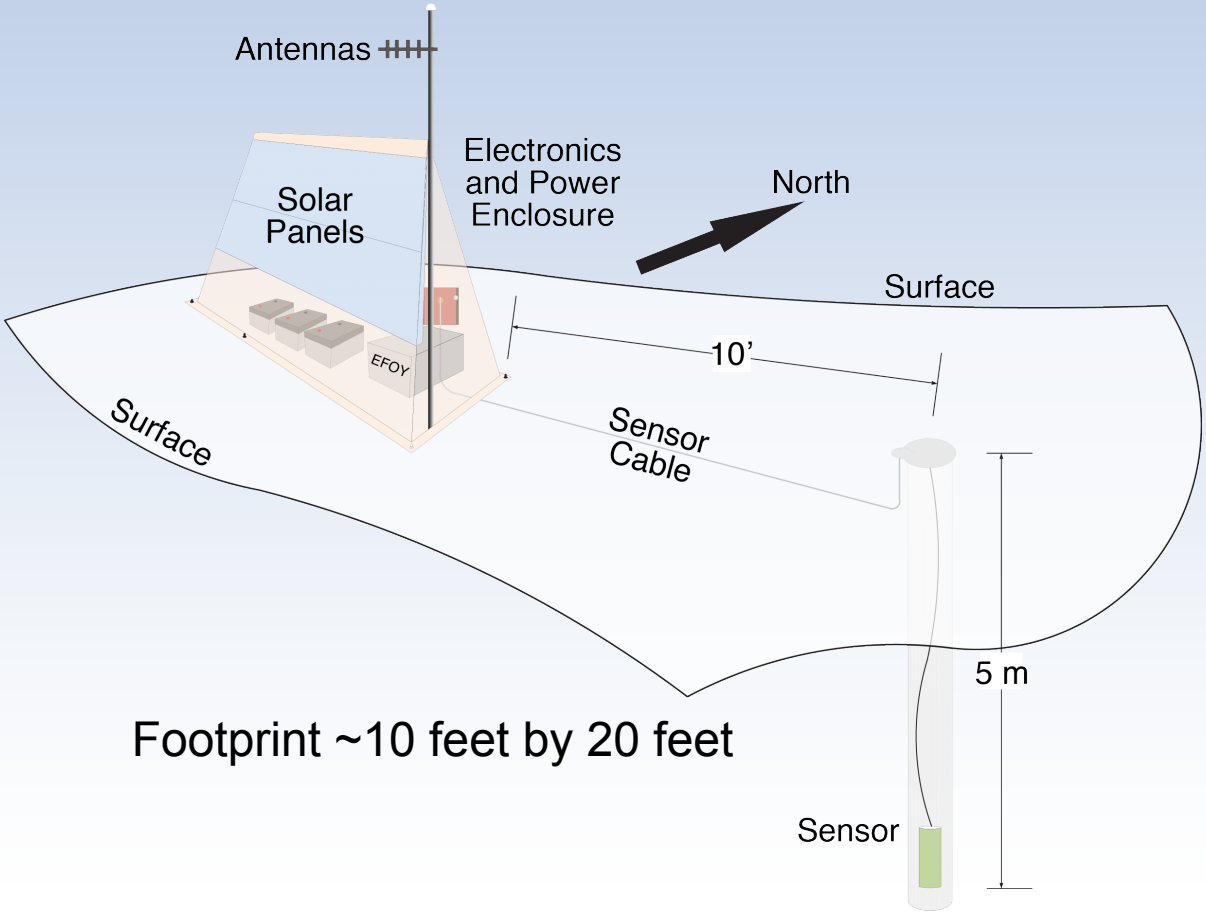


Alaska: ~80 stations planned for 2015, 188 in 2016/2017

www.usarray.org/alaska

Test Stations (2011-2013)

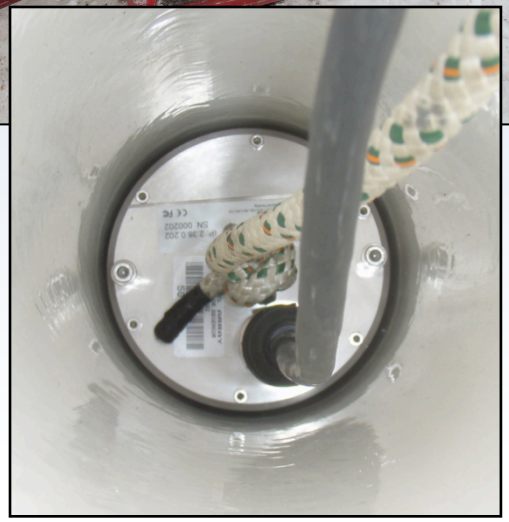
- Sensor: 3-component “post-hole” broadband seismometer
- Datalogger & local data storage
- Flexible power & telemetry



Footprint ~10 feet by 20 feet

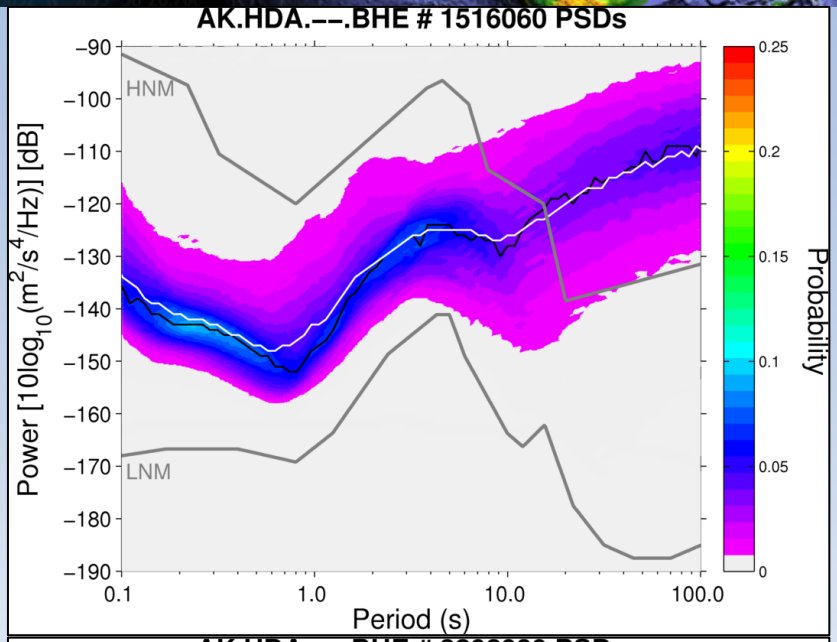
- Toolik Lake test station installed August 2011
- 6 others in 2012 & 2013

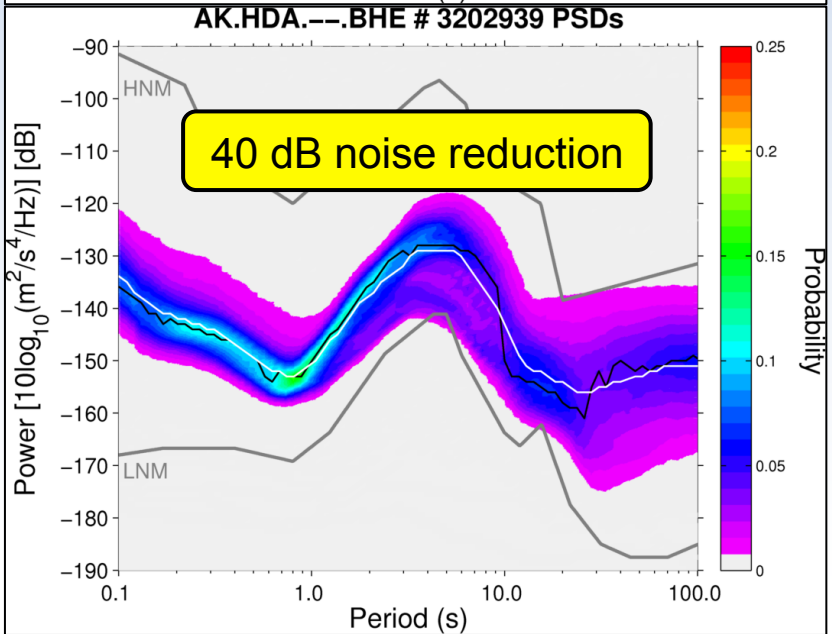
Main Deployment (2014-2017)



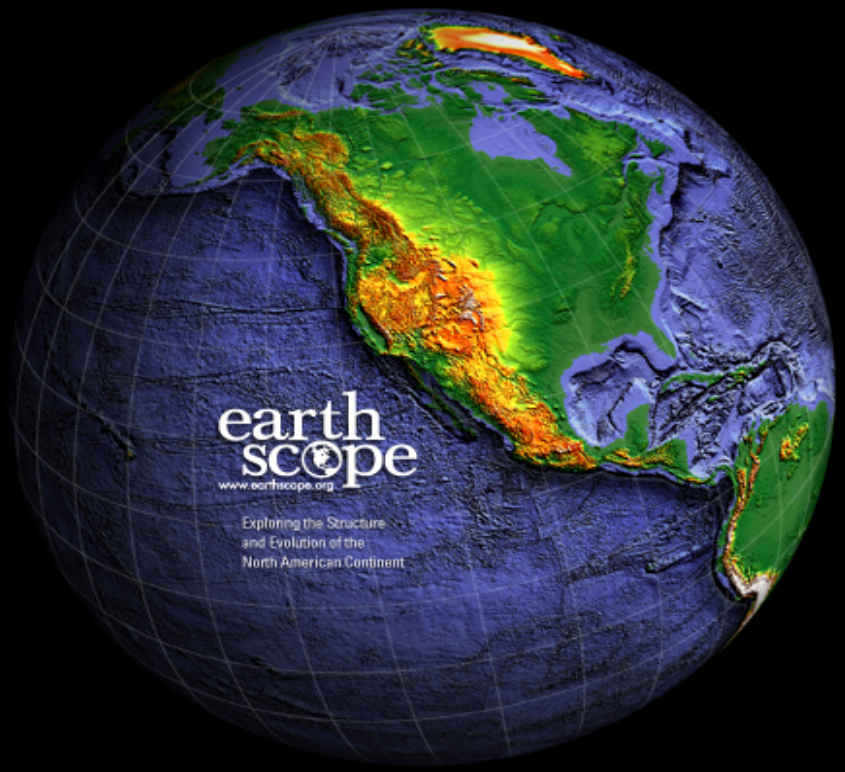
- ~280 new & upgraded sites by 2018, spaced 85 km
- Mostly down-hole hammer or augured holes
- Complex logistics

New Practices… Even Better Data

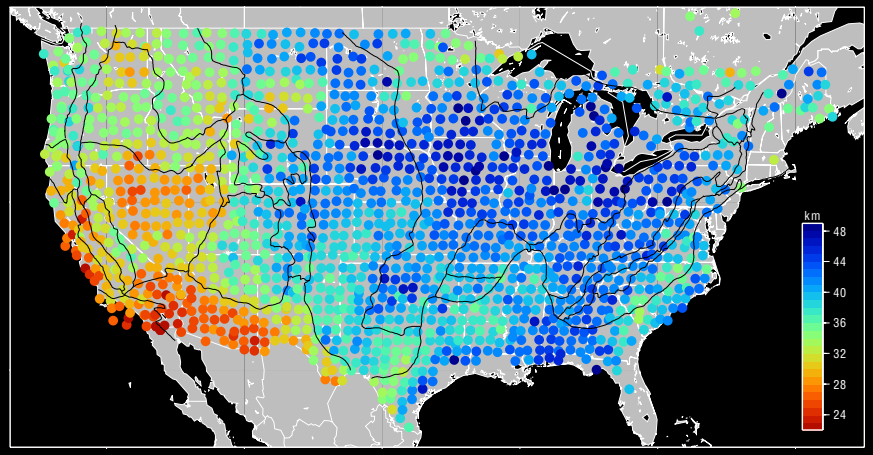




TA Science Highlights

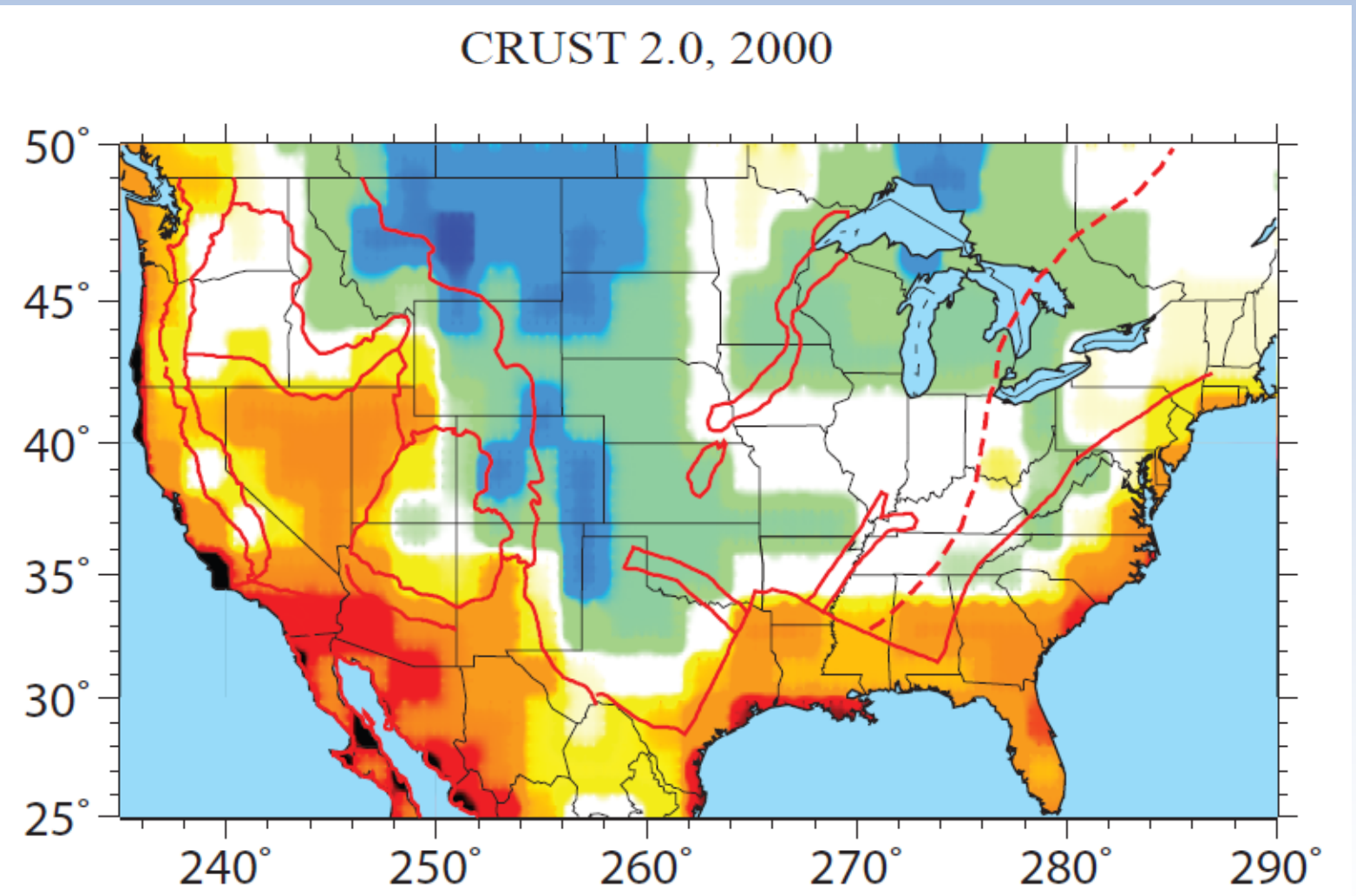


Crustal thickness measurements, Buehler and Shearer



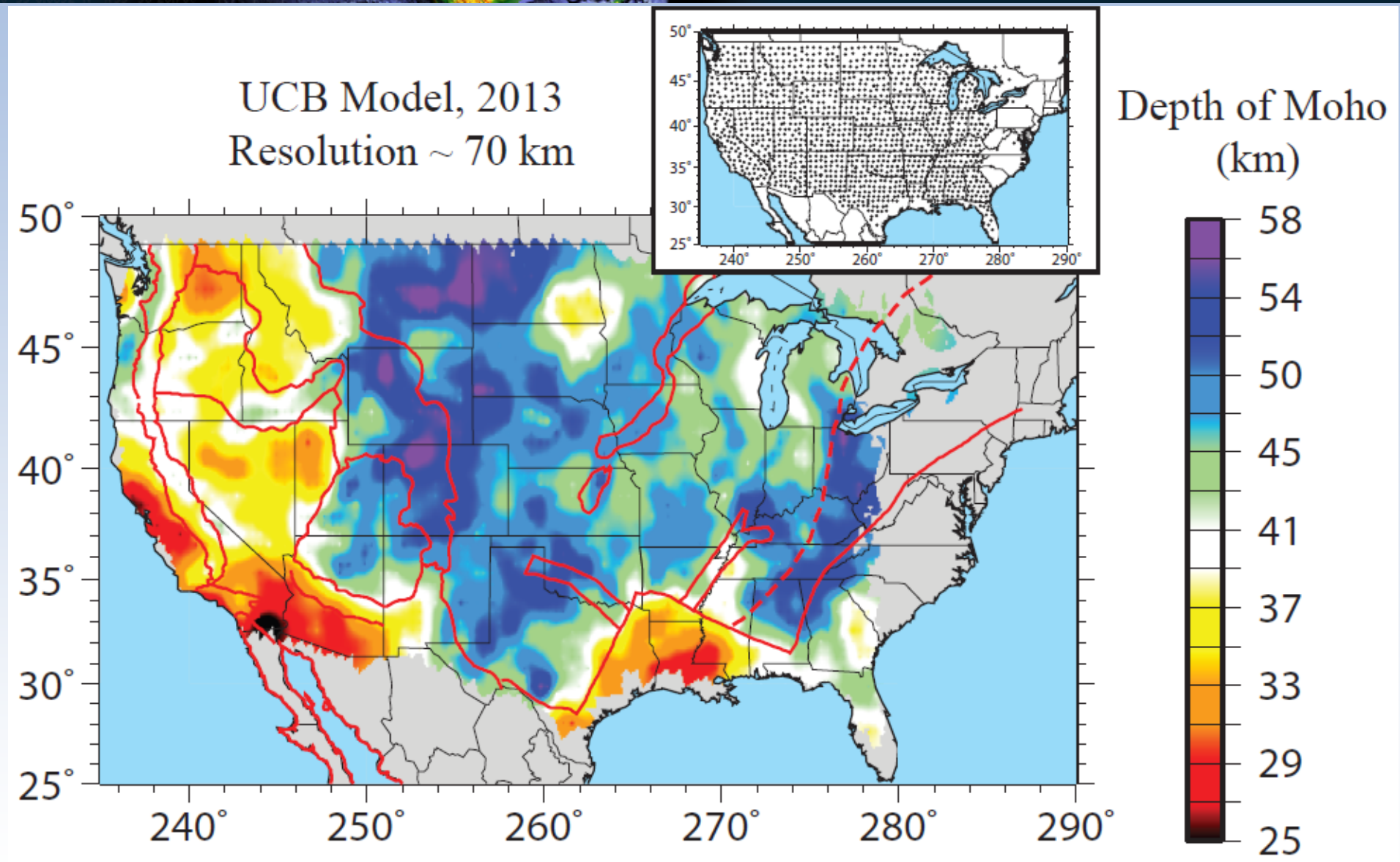
Tip of the iceberg…
at least 293 peer-reviewed USArray papers just during 2009-2013

Resolution Before



Bassin et al., 2000 AGU Fall Meeting

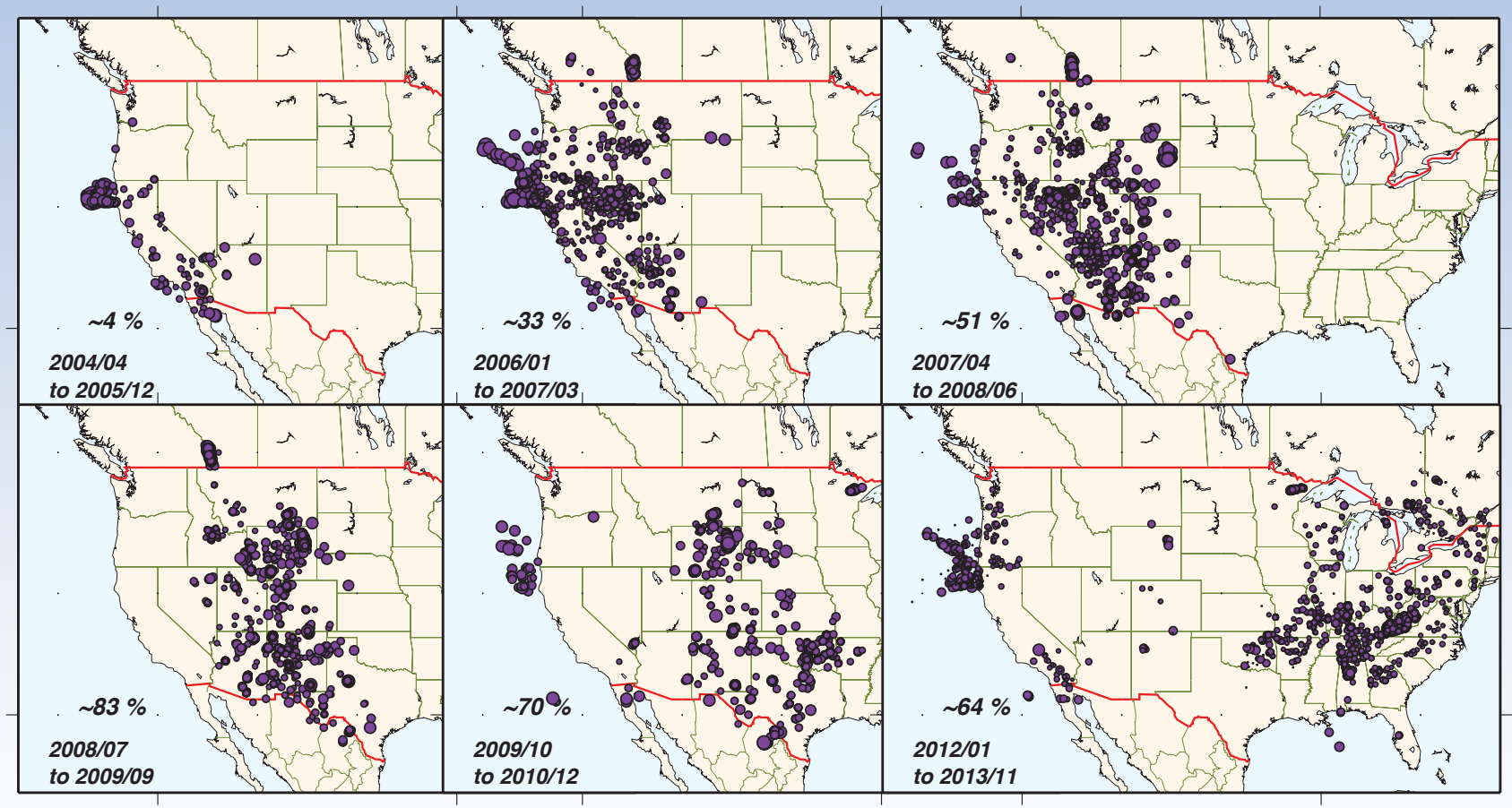
Resolution After



Shen and Ritzwoller, CU-Boulder, 2013 AGU Fall Meeting

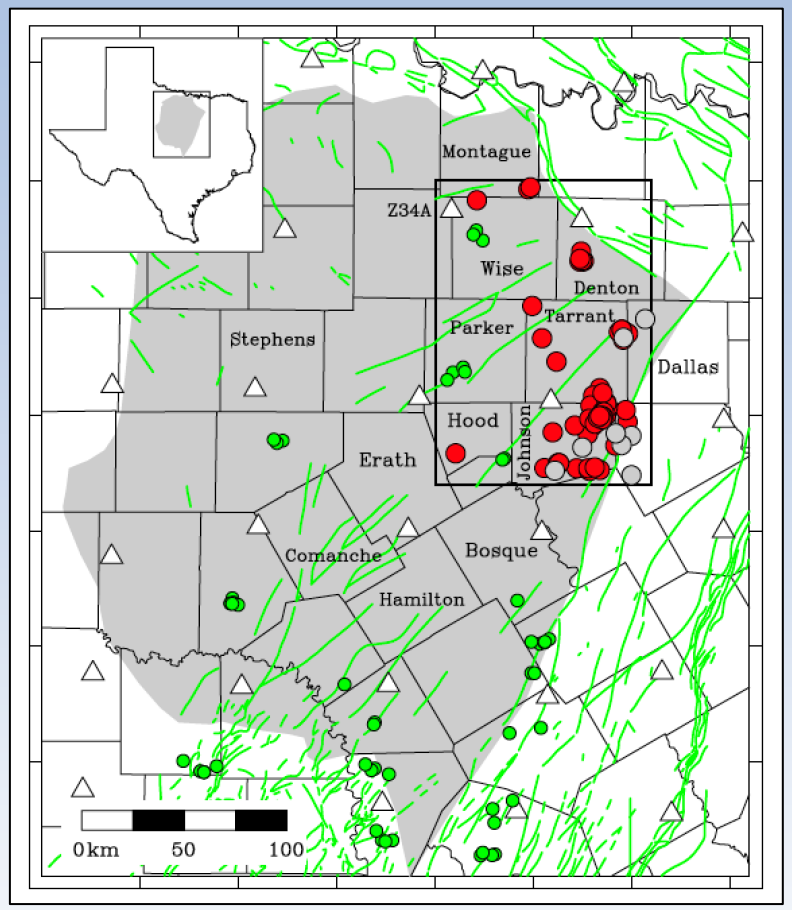
Improved Event Detection

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



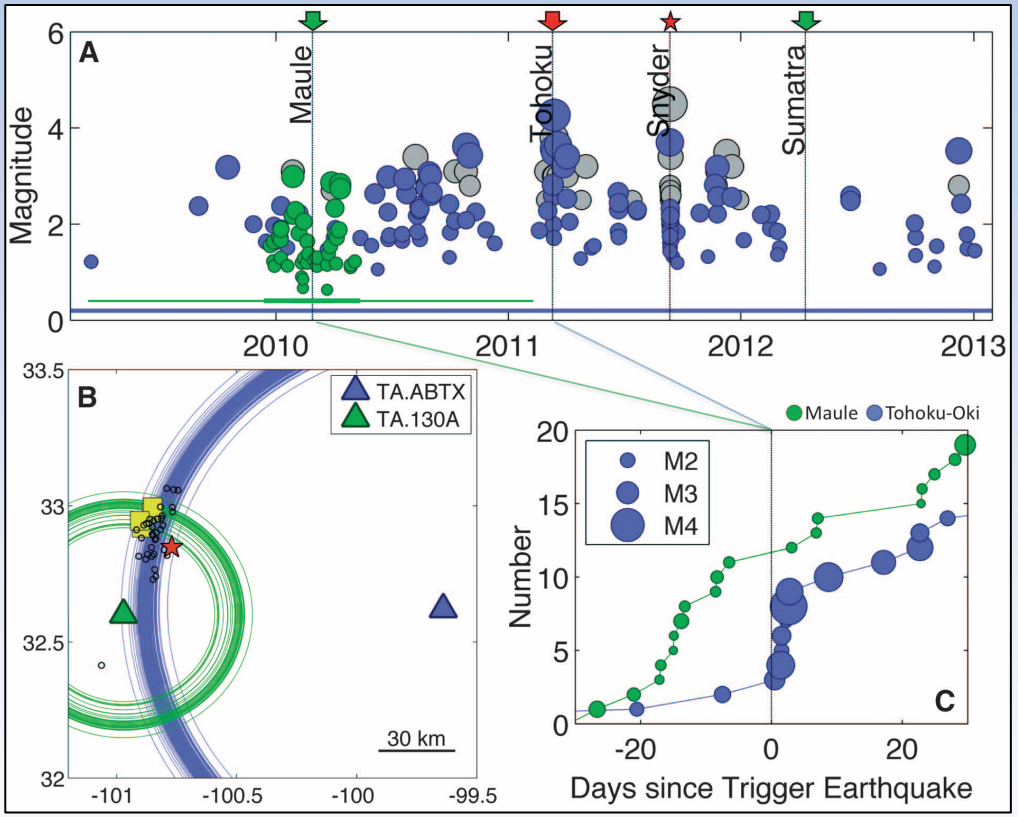
Looking eastward, the Array Network Facility made a high percentage of unique event detections.

Characterizing Small Earthquakes



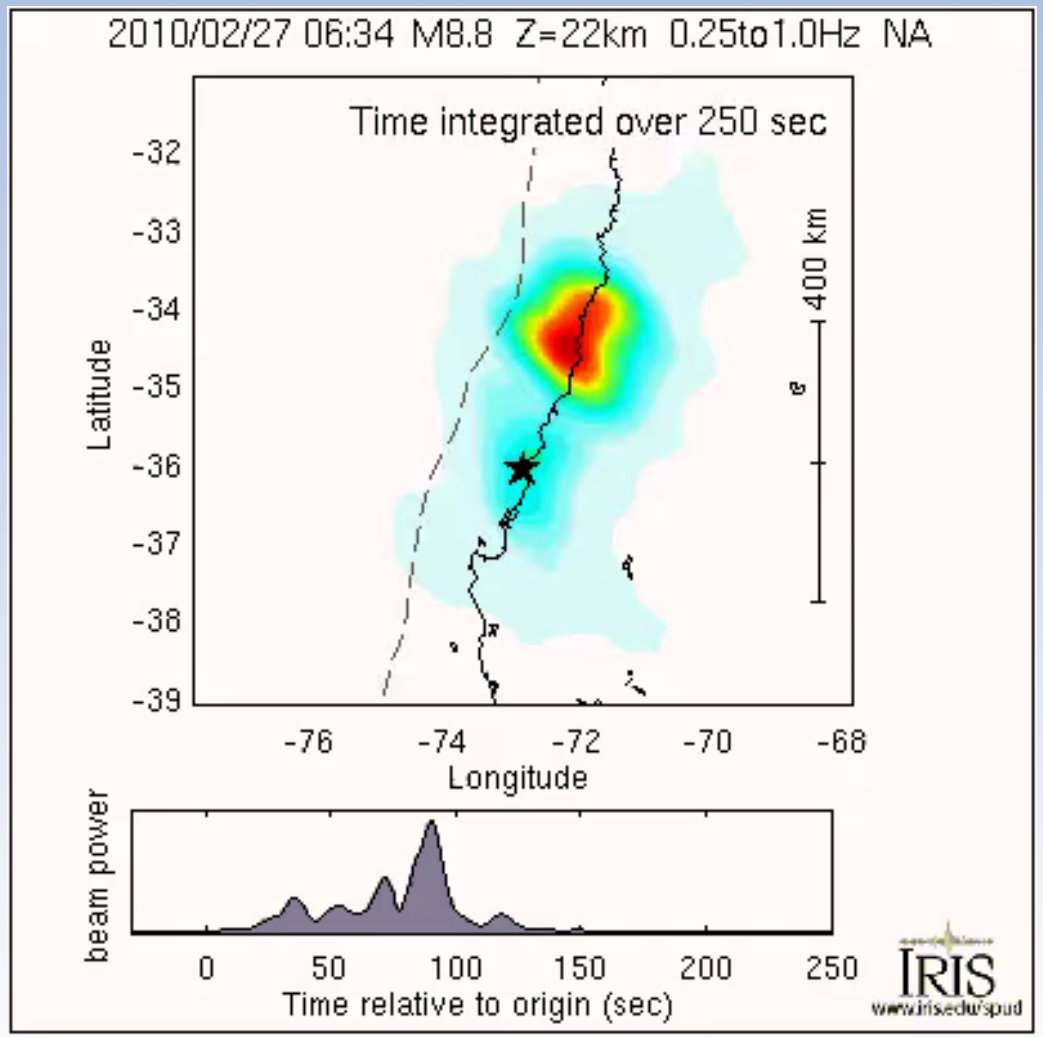
Injection triggered earthquakes, Barnett Shale
Frolich, *PNAS,* 2012

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

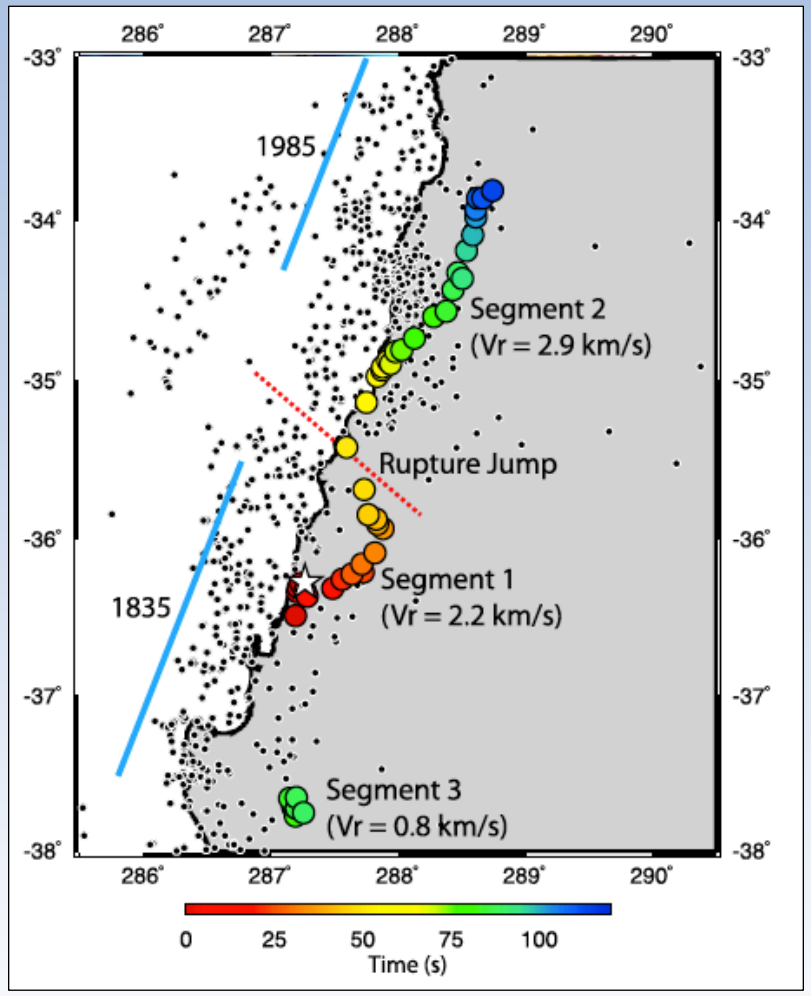


TA deployment provided the opportunity to study uptick in seismicity in central and eastern U.S.

Better Understanding Great Earthquakes

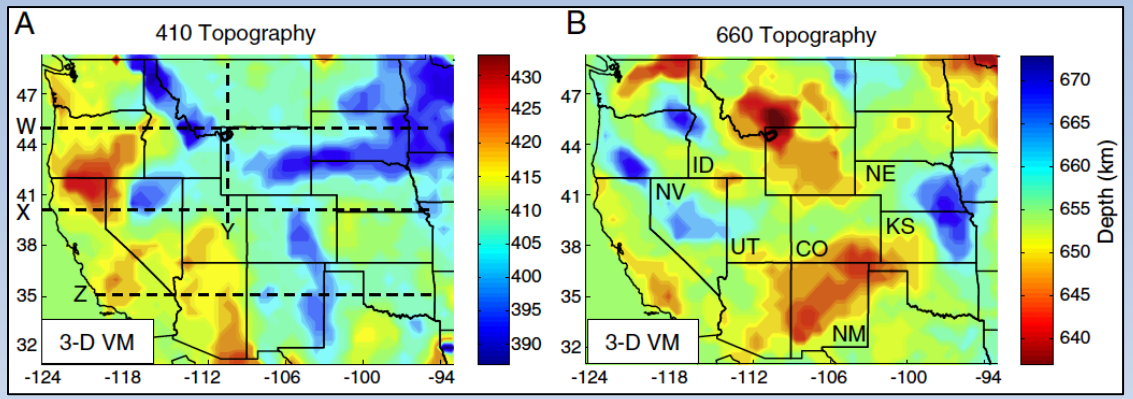


Automated IRIS back projection provides a reference

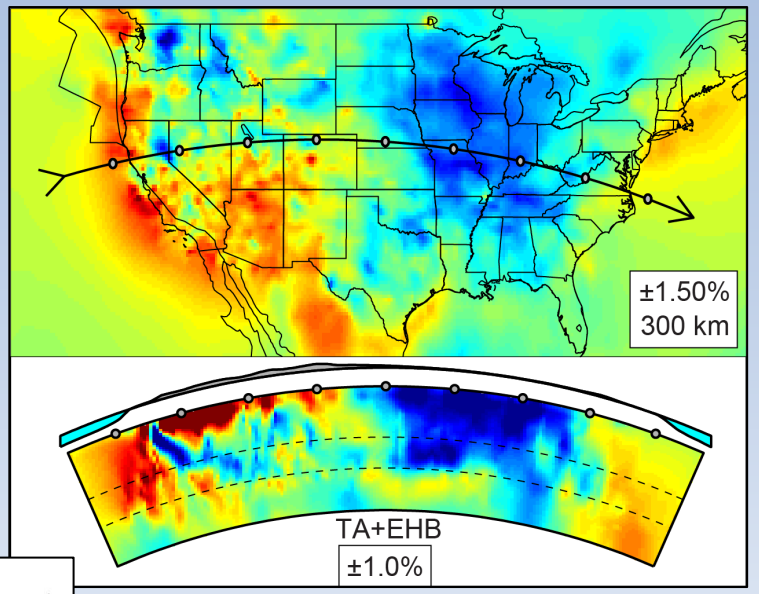


Backprojection analysis of Maule
Kiser and Ishii, *GRL*, 2011

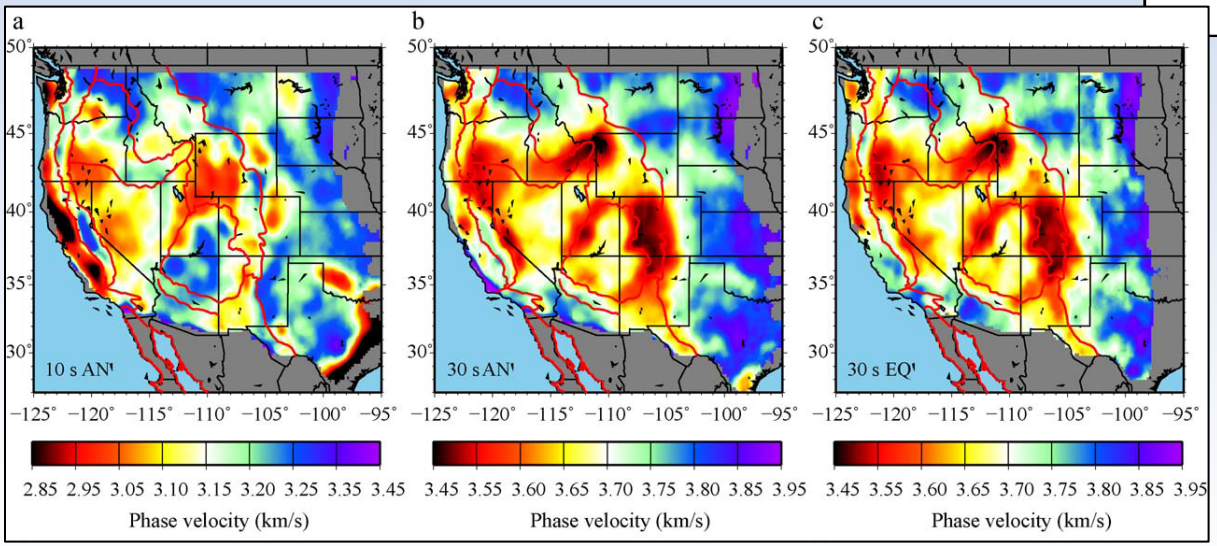
New Seismic Images



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



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



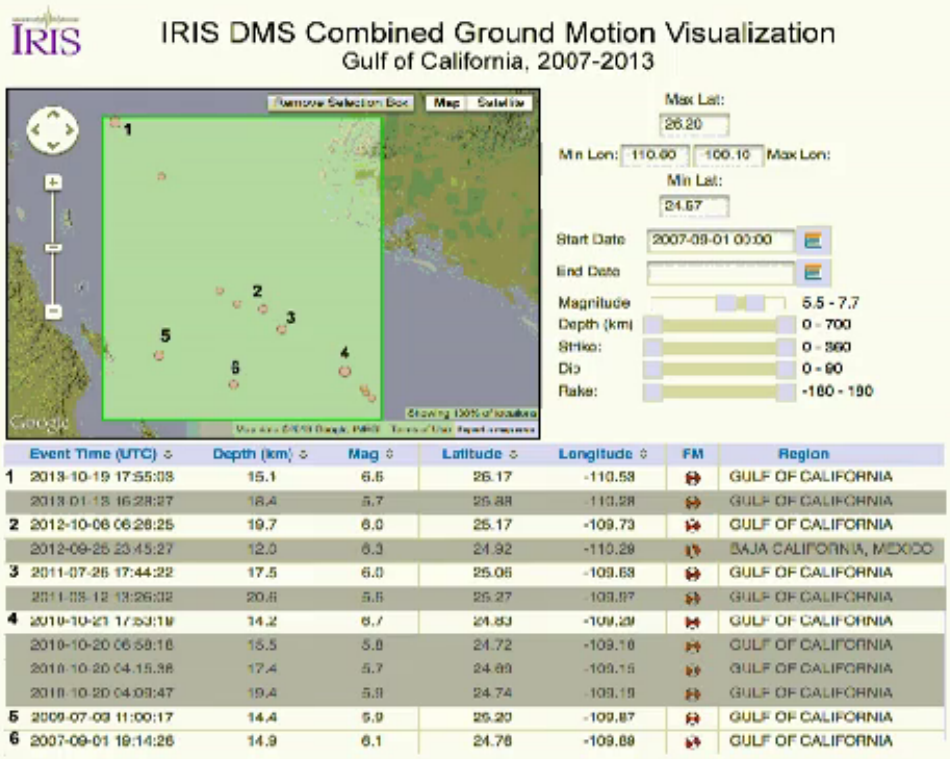
Ambient noise tomographic imaging
Ritzwoller et al., *CR*, 2011

New models of North America from tomography and receiver functions

TA “Super” GMV

IRIS DMS Combined Ground Motion Visualization

GULF OF CALIFORNIA 2007 - 2013



	Event Time (UTC)	Depth (km)	Mag	Latitude	Longitude	FM	Region
1	2013-10-19 17:55:03	15.1	6.6	26.17	-110.53		GULF OF CALIFORNIA
	2013-01-13 16:28:27	18.4	5.7	25.88	-110.28		GULF OF CALIFORNIA
2	2012-10-06 06:28:25	19.7	6.0	25.17	-109.73		GULF OF CALIFORNIA
	2012-09-25 23:45:27	12.0	6.3	24.92	-110.29		BAJA CALIFORNIA, MEXICO
3	2011-07-26 17:44:22	17.5	6.0	25.06	-109.63		GULF OF CALIFORNIA
	2011-03-12 13:26:02	20.6	5.6	25.27	-109.87		GULF OF CALIFORNIA
4	2010-10-23 17:53:19	14.2	6.7	24.83	-109.29		GULF OF CALIFORNIA
	2010-10-20 06:58:16	15.5	5.8	24.72	-109.16		GULF OF CALIFORNIA
	2010-10-20 04:15:38	17.4	5.7	24.69	-109.15		GULF OF CALIFORNIA
	2010-10-20 04:03:47	19.4	5.8	24.74	-109.19		GULF OF CALIFORNIA
5	2009-07-09 11:00:17	14.4	5.9	25.20	-109.87		GULF OF CALIFORNIA
6	2007-09-01 19:14:26	14.9	6.1	24.76	-109.89		GULF OF CALIFORNIA

People Make it Happen

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

Want More Info?

On the Web

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

andyf@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.