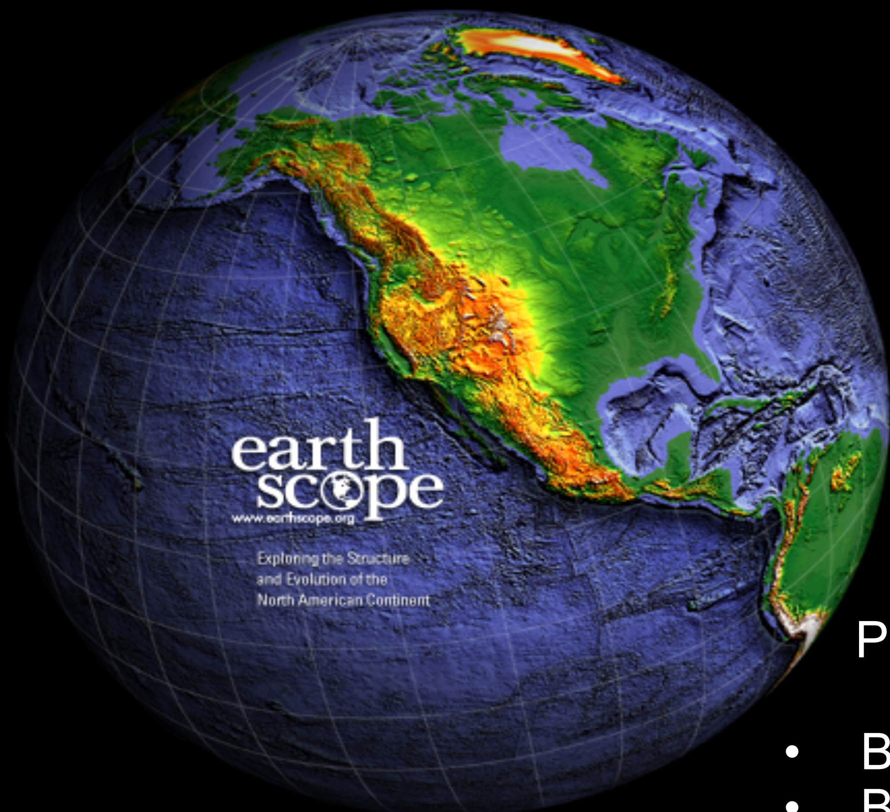
EarthScope's Transportable Array -an overview



Project Team

- Bob Busby, TA Manager
- Bob Woodward, Director IRIS Instrumentation
- Kasey Aderhold, Project Associate

Overview

- Review the Transportable Array observational approach
- Give some examples of what this approach has yielded scientifically.
- Current status and implementation plan in Alaska
- Preview some diverse observations Kasey Aderhold will present later.

Background

- The Transportable Array is one component of the NSF-funded EarthScope project - see EarthScope.org

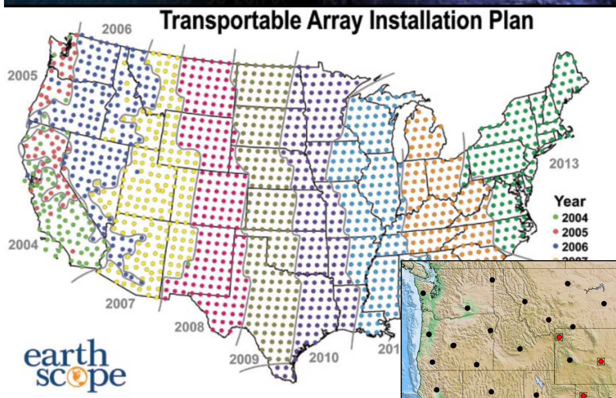
- EarthScope is in the 13th year of a 15 year effort to study the structure and evolution of the North American continent

- During the first 10 years, the Transportable Array was focused on the lower 48

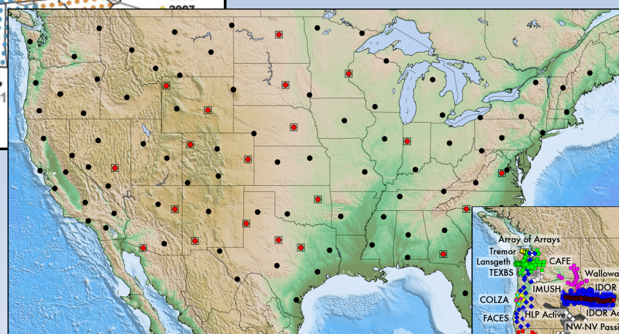
- During the 5 years FY14-FY18 the Transportable Array is focused on Alaska and NW Canada
  - Utilizes >$12M in instrumentation, 60% newly replenished specifically for AK.
  - Funding of ~$40M over five years from NSF EAR Division
  - In summer, the operational burn rate is $40 K/day, comparable to UNOLS vessels

- The Transportable Array is deployed and operated by the Incorporated Research Institutions for Seismology (IRIS) – a non-profit consortium of ~120 US universities, located across the street in AAAS building.

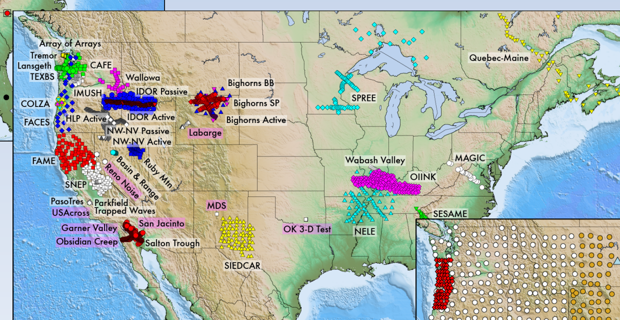
USArray: An Integrated Approach



Transportable Array
Systematic survey

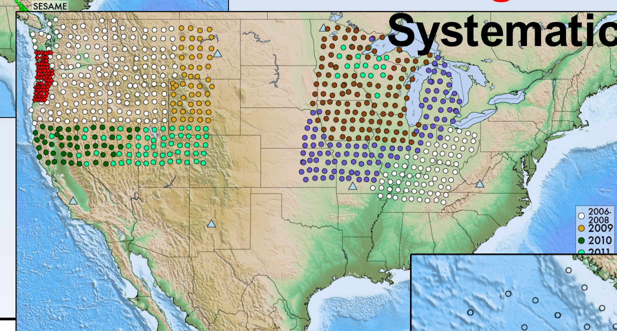


RefNet
Fiducial network

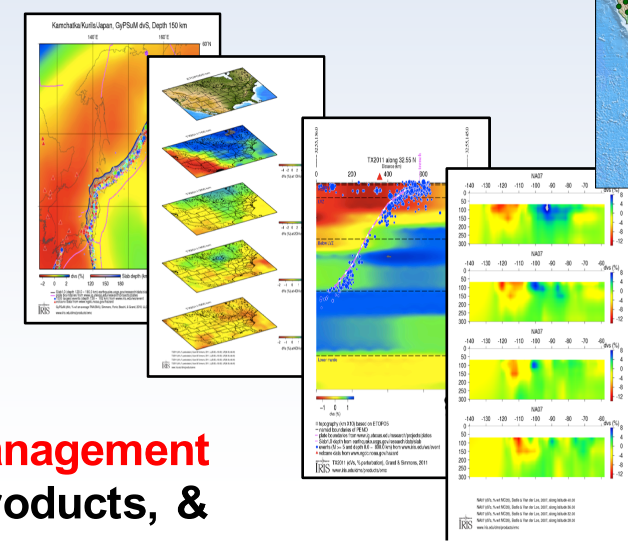


Flexible Array
Focused targets

Magnetotellurics
Systematic survey

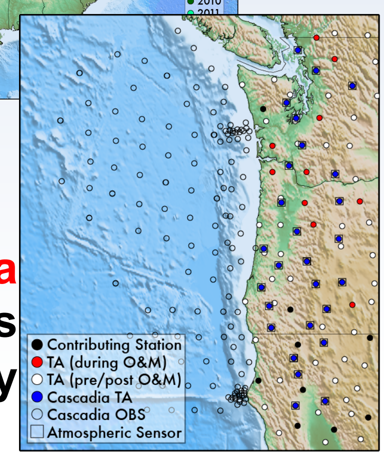


Siting Outreach
Siting, education, outreach,

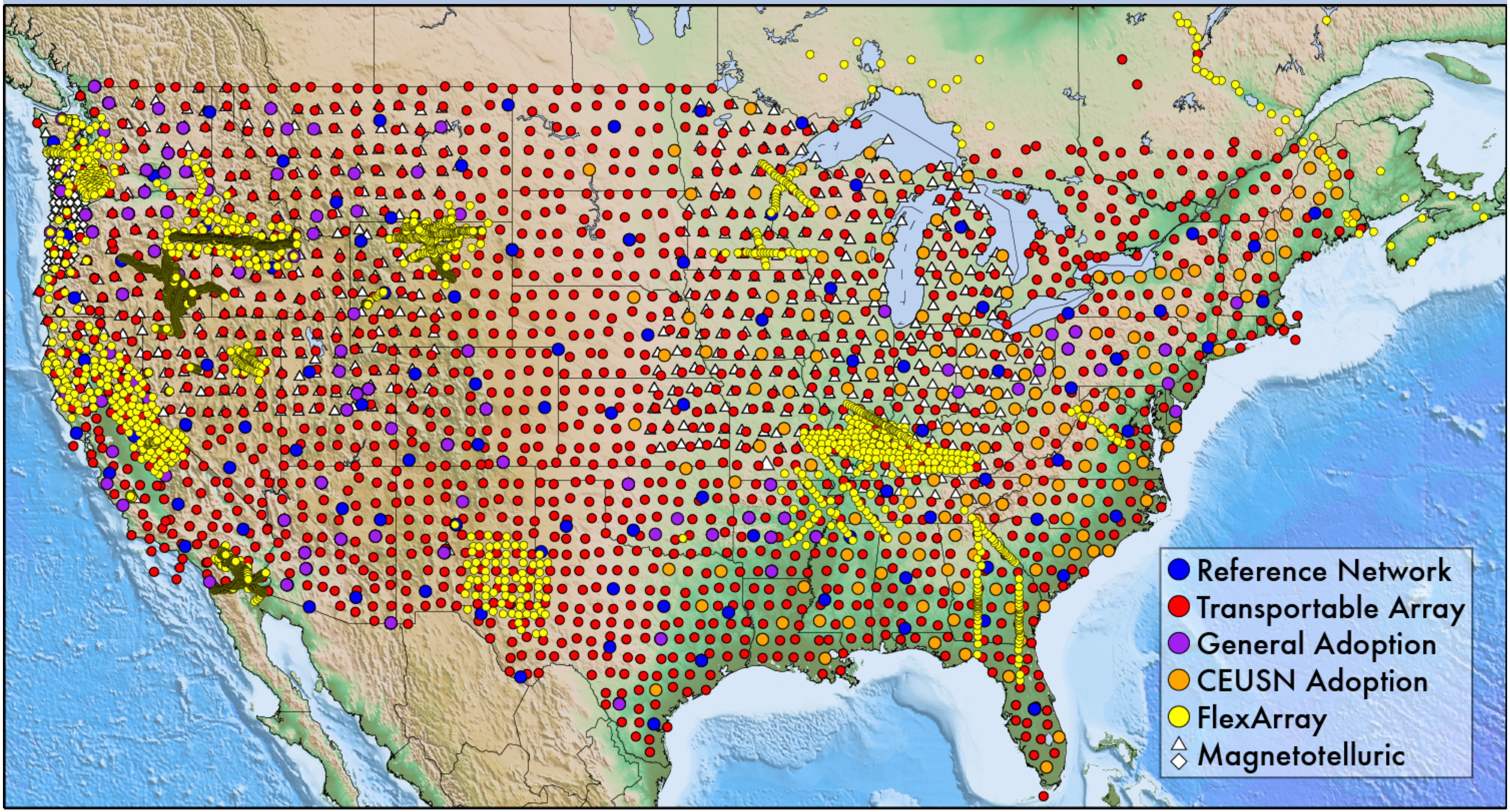


Data Management
Data, products, &

Cascadia
Amphibious
Array



USArray through 2014



Studies of Earthquakes

EarthScope's Transportable Array (TA)

Observes earthquakes that are used several ways:

Seismicity patterns: Map out the **size and location of earthquakes** uniformly-even when you don't think there are any. Identifies active faults or activites that create earthquakes.

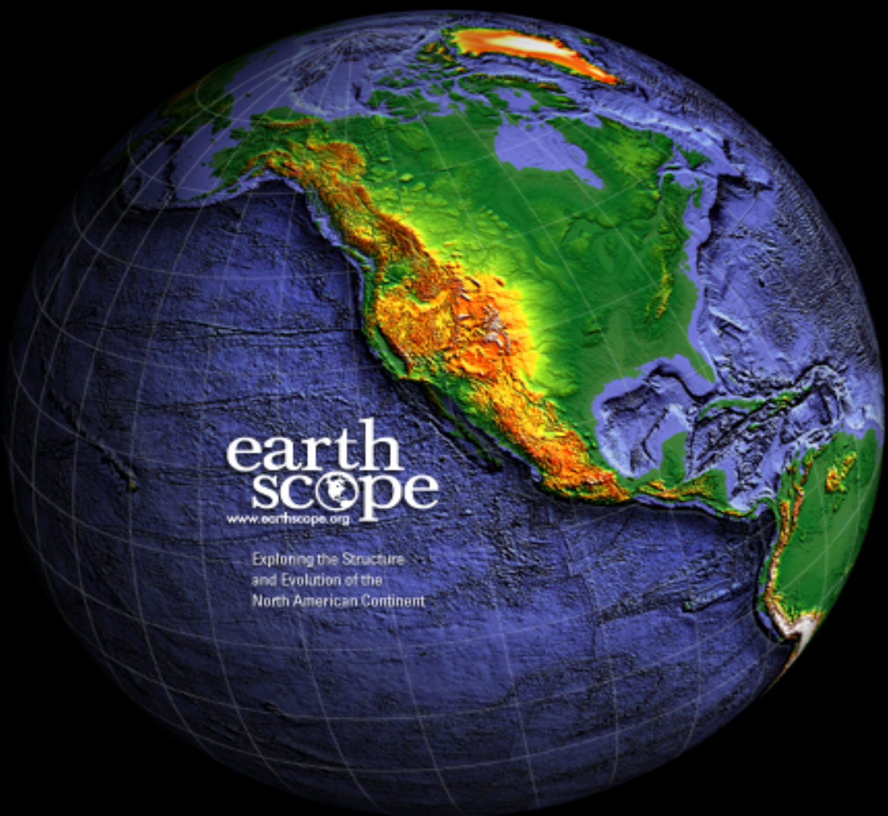
Observe earthquakes with many stations to study **the type of fault and details of rupture, stress drop and state of stress**.

Use the signals from many earthquakes and many stations **to image and create models of earth structure**-what causes tectonic plates to move and produce earthquakes.

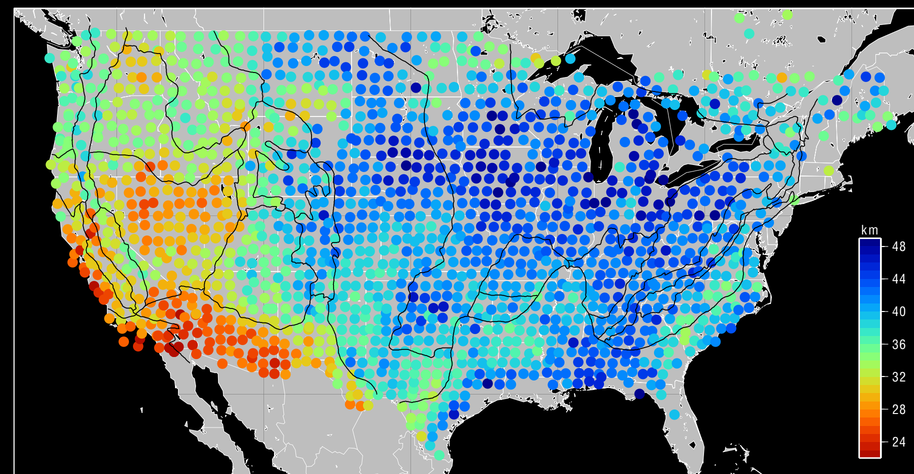
Use projections to study the **characterize very large earthquakes** that produce tsunamis, infer from worldwide events how the alaska/cascadia subduction zone works.

We've made some videos that illustrate the actual data and its use.

Science Highlights



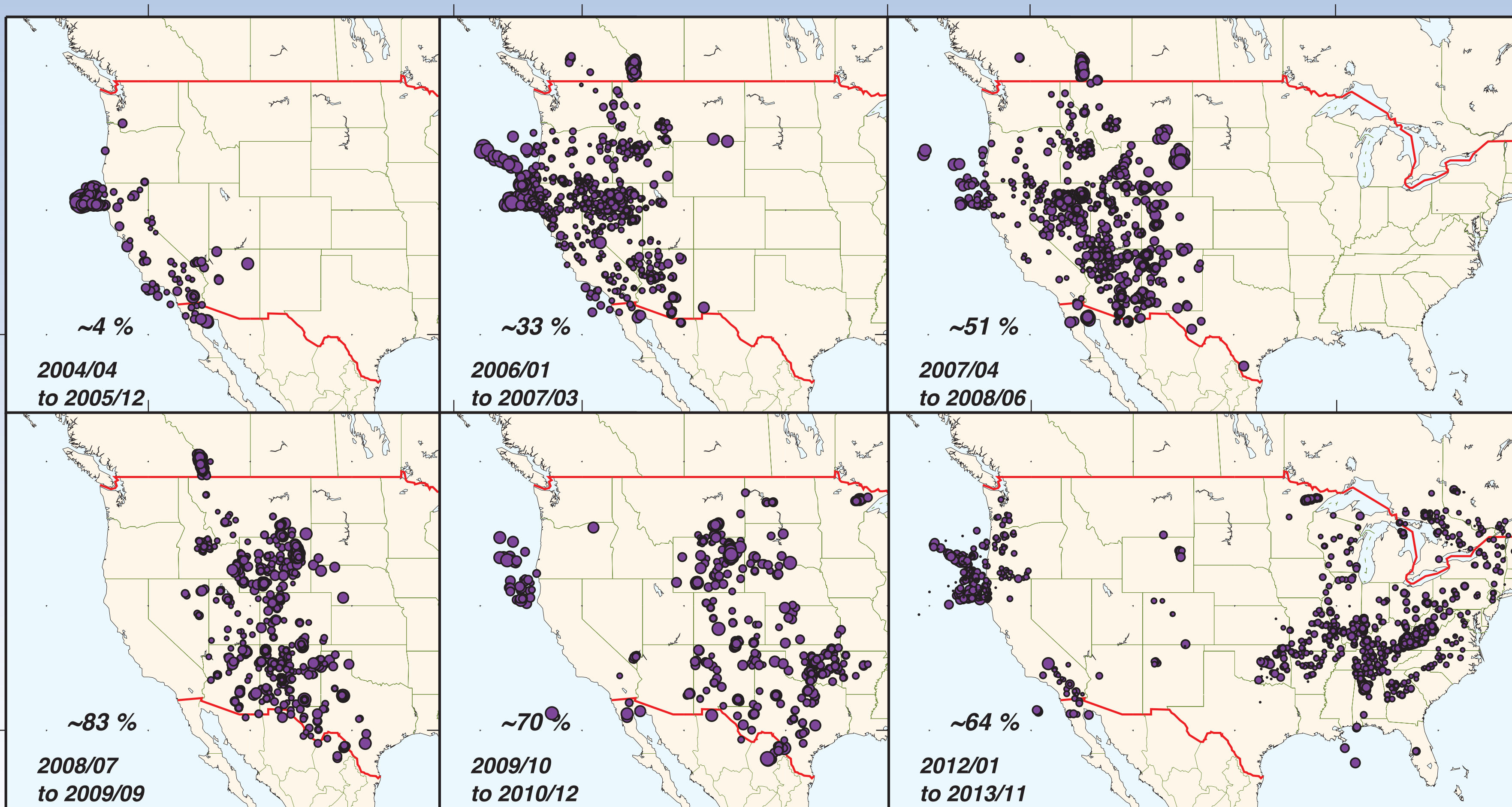
Crustal thickness measurements, Buehler and Shearer



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

Improved Event Detection

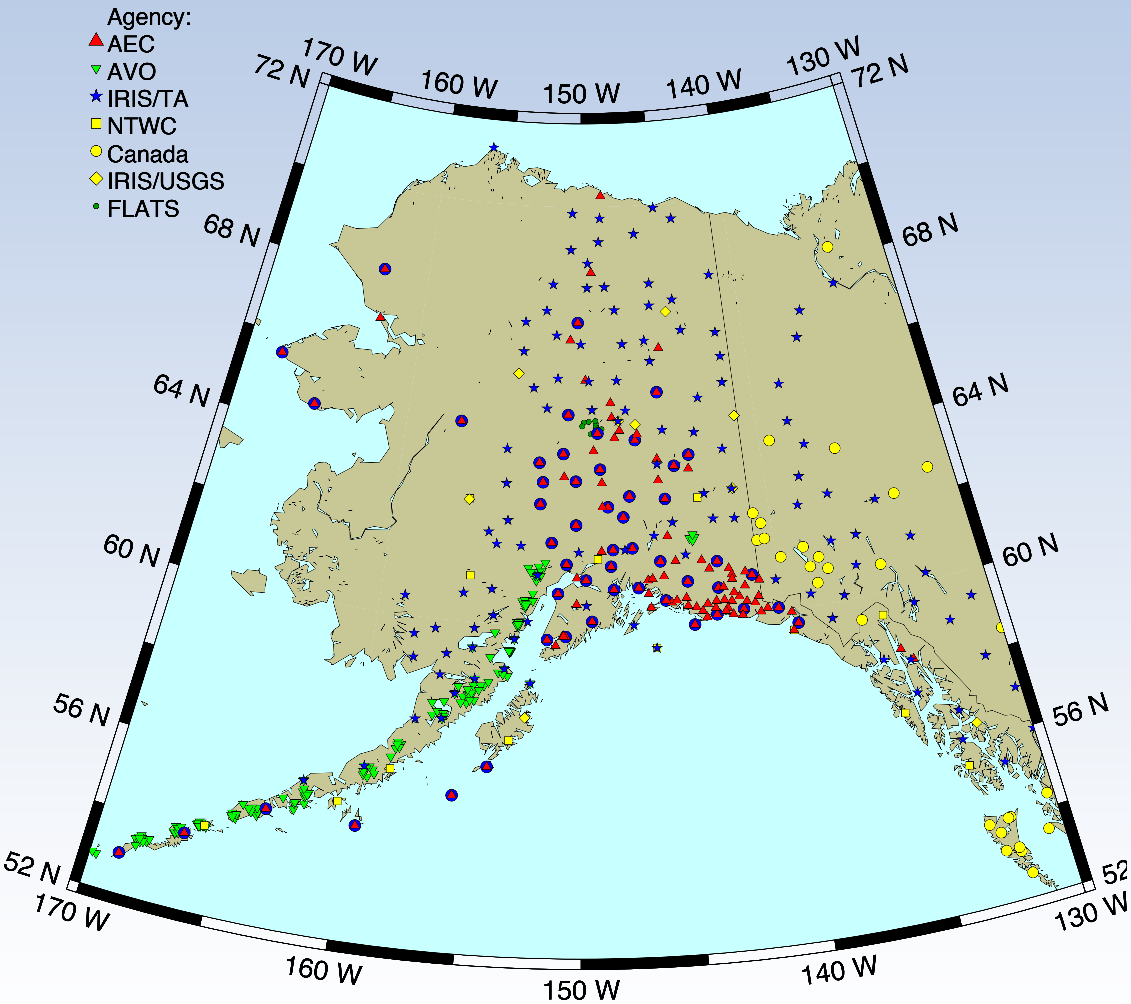
A large percentage of events only reported by ANF with TA data
Astiz et al., *SRL*, 2014



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

Increases in Observations

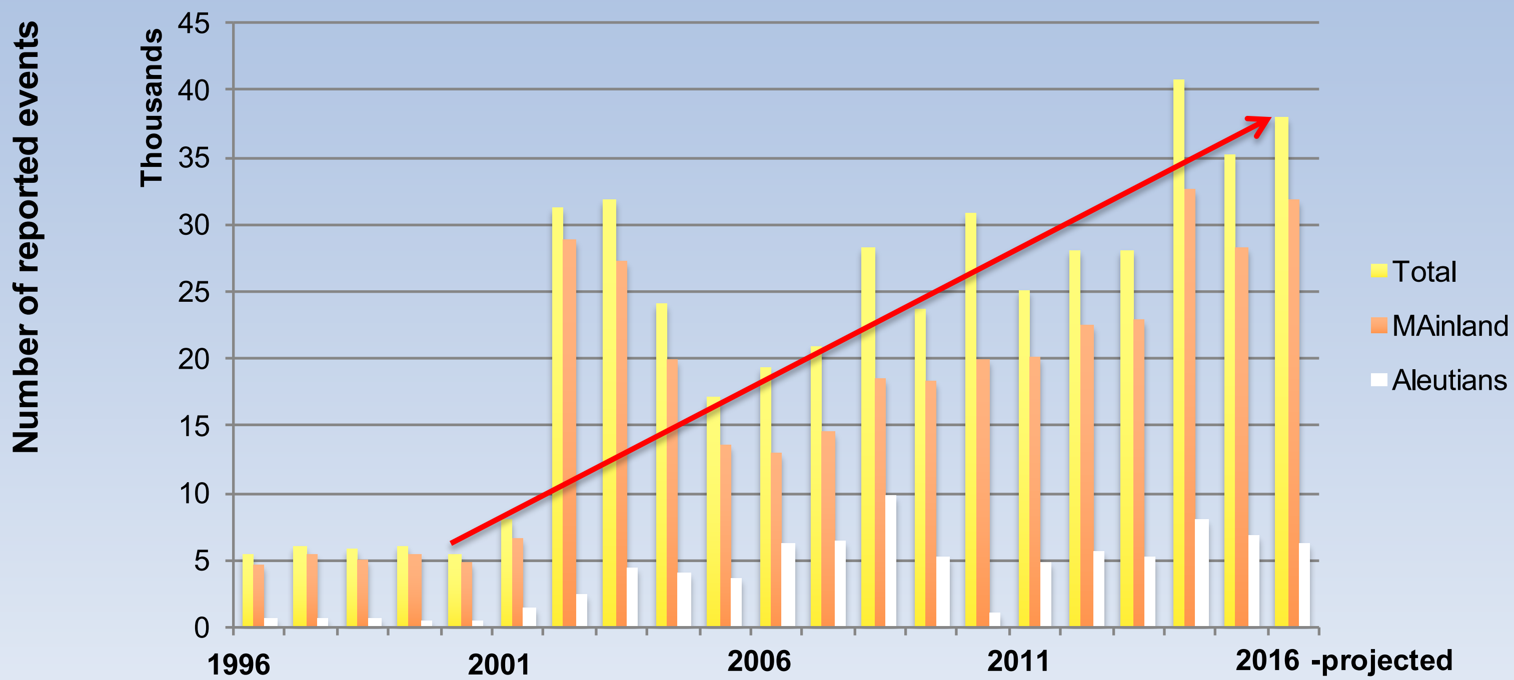
Seismic Network



About 500 sites total in Alaska and western Canada (not including urban strong motion networks)

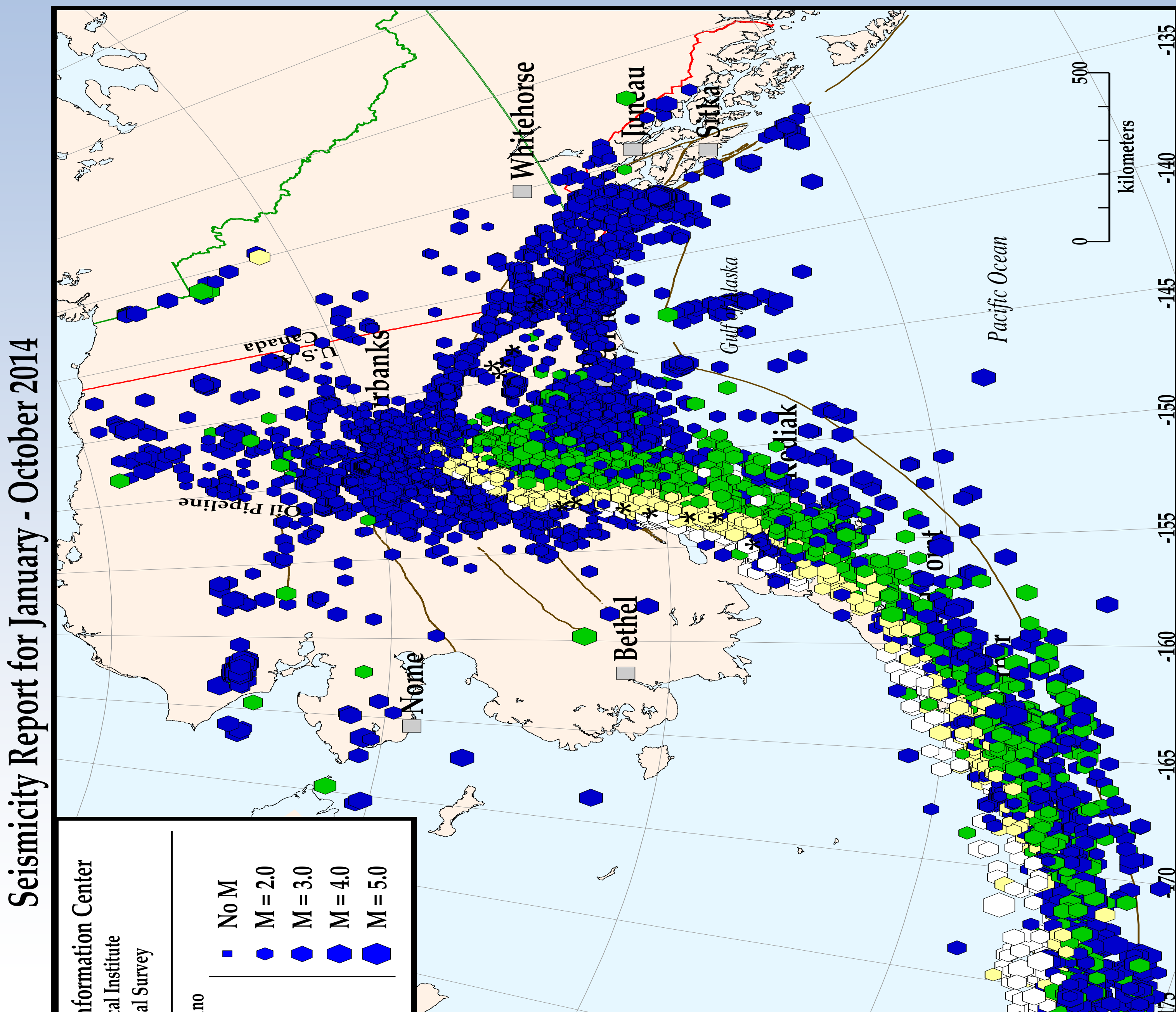
- **AV – 42%,**
- **AK – 25%,**
- **TA – 23%,**
- **Remaining – 10%**

Reported seismicity in Alaska



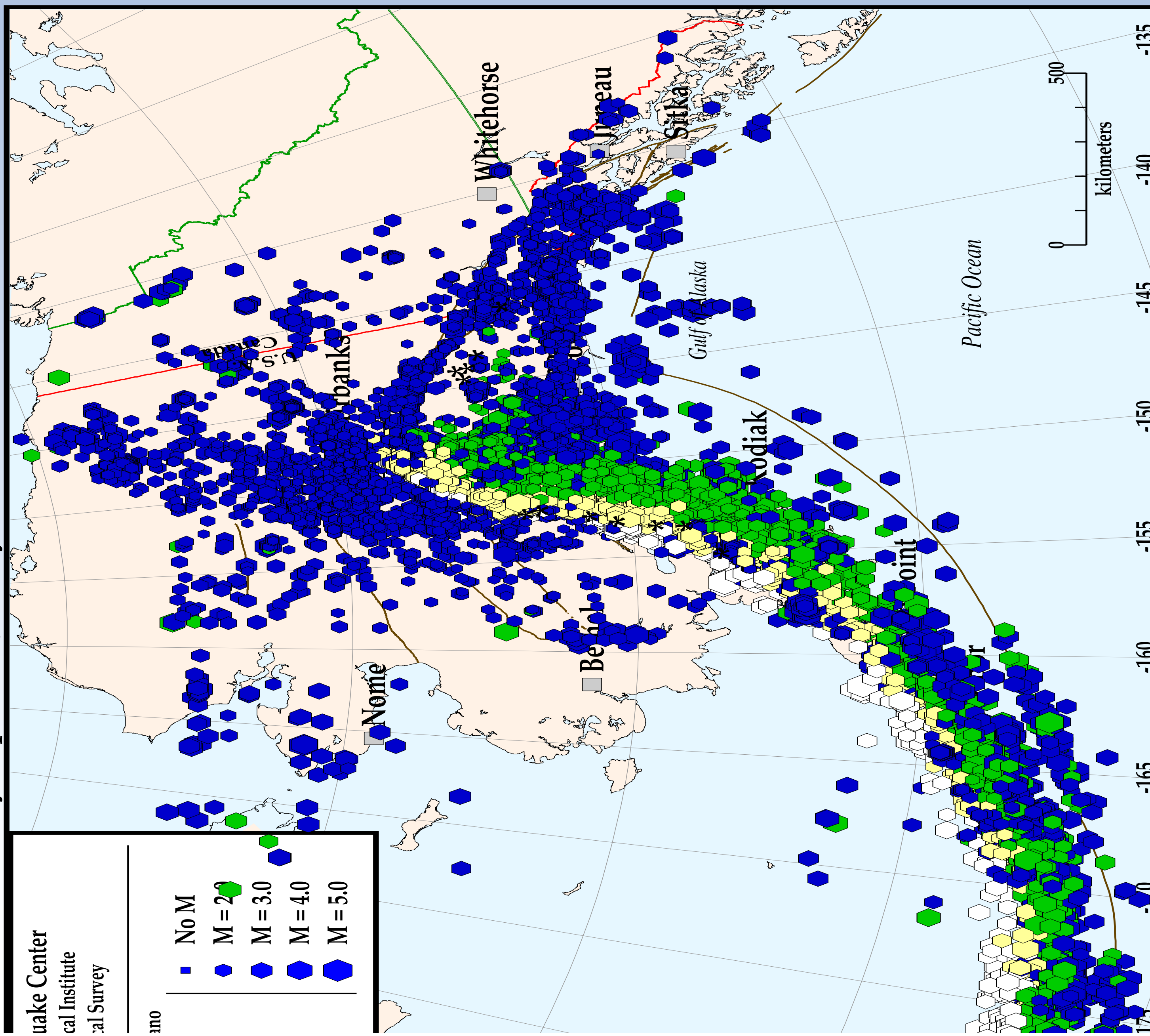
- End 1990s – early 2000s:
  - Alaska Earthquake Center started conversion into broadband instrumentation;
  - Alaska Volcano Observatory started expansion into the Aleutians.
- 2002 M7.9 Denali fault earthquake produced about 55K aftershocks in 5 years.
- Number of reported events has been steadily increasing with each year due to improvements in instrumentation and detection.
- Current rate of reporting is on average 100 events/day or 1 event every 15 minutes.
- 2016 increase is associated with additional TA stations.

AK Seismicity 2014

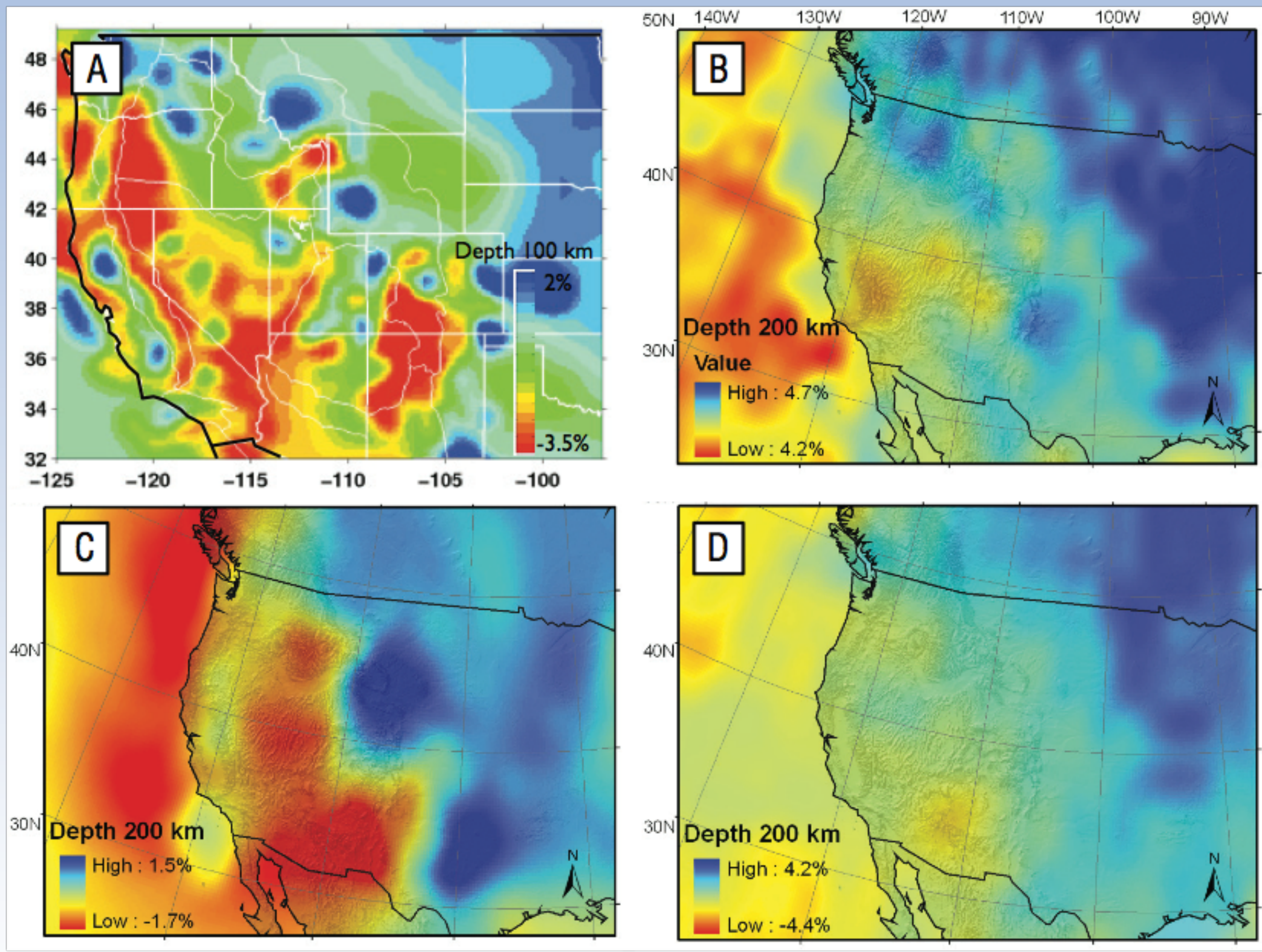


AK Seismicity 2016

Seismicity Report for January - October 2016

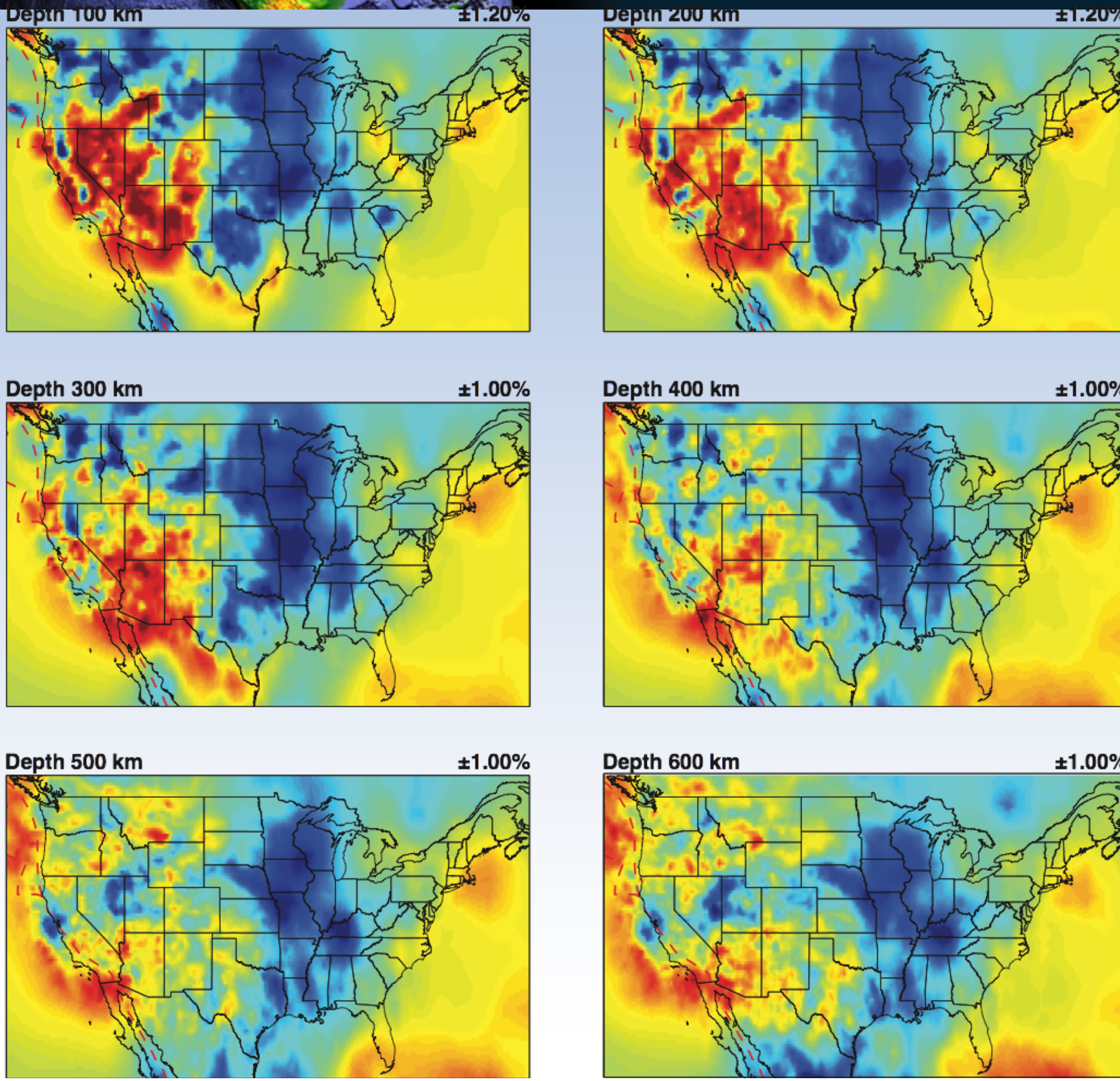


Tomography Before TA



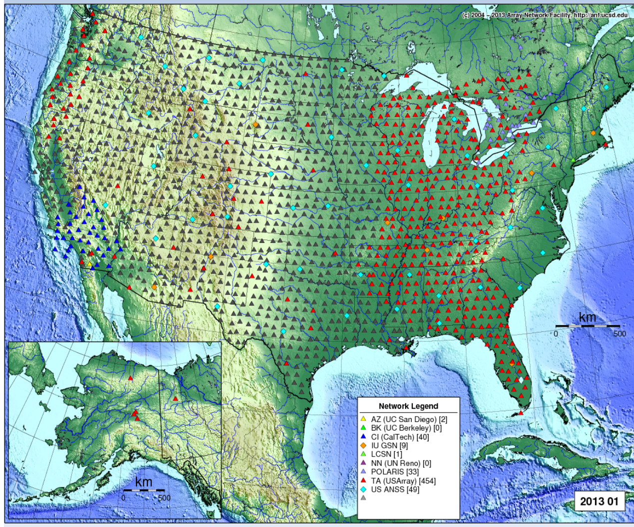
▲ **Figure 1.** (A) Model made by piecing together local tomography studies from Humphreys and Dueker (1994) and inverting with global data set (after Dueker *et al.* 2001). (B) Global *S*-wave model from surface wave diffraction (Ritzwoller *et al.* 2002). (C) Global *P*-wave model using finite frequency kernels (Montelli *et al.* 2004). (D) Global *S*-wave travel-time model (Grand 2002).

Tomography
Burdick et al. 2012

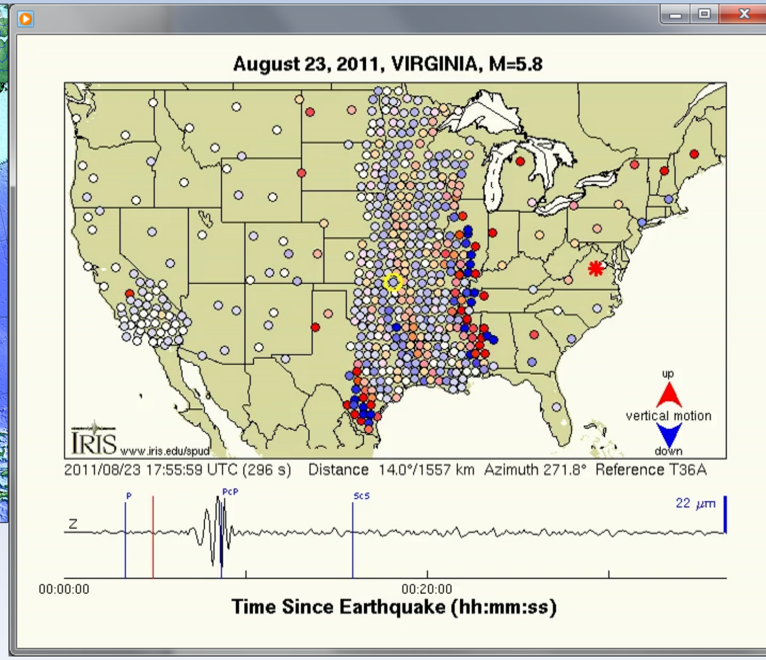


Videos

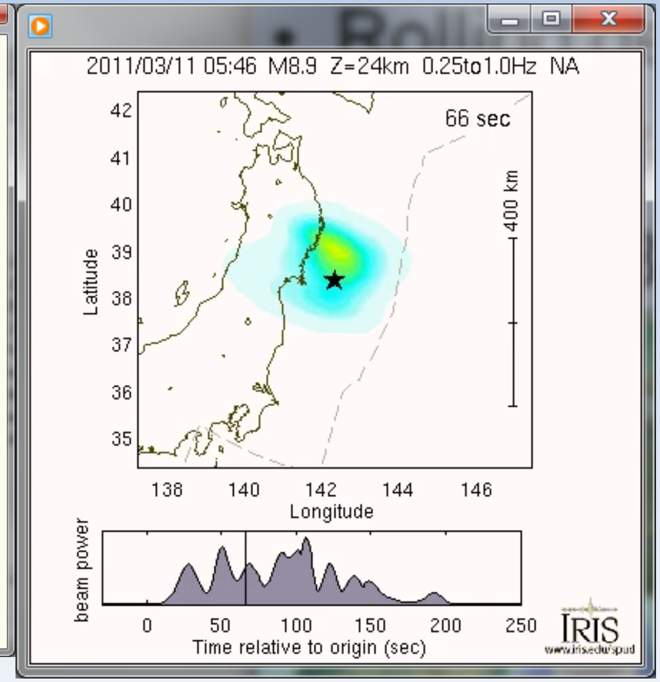
Rolling Deployment --- 3D Ground Motion --- Back Projections



Dots appear in a time sequence of how the stations were installed, and removed. The box, lower right, identifies the month shown.



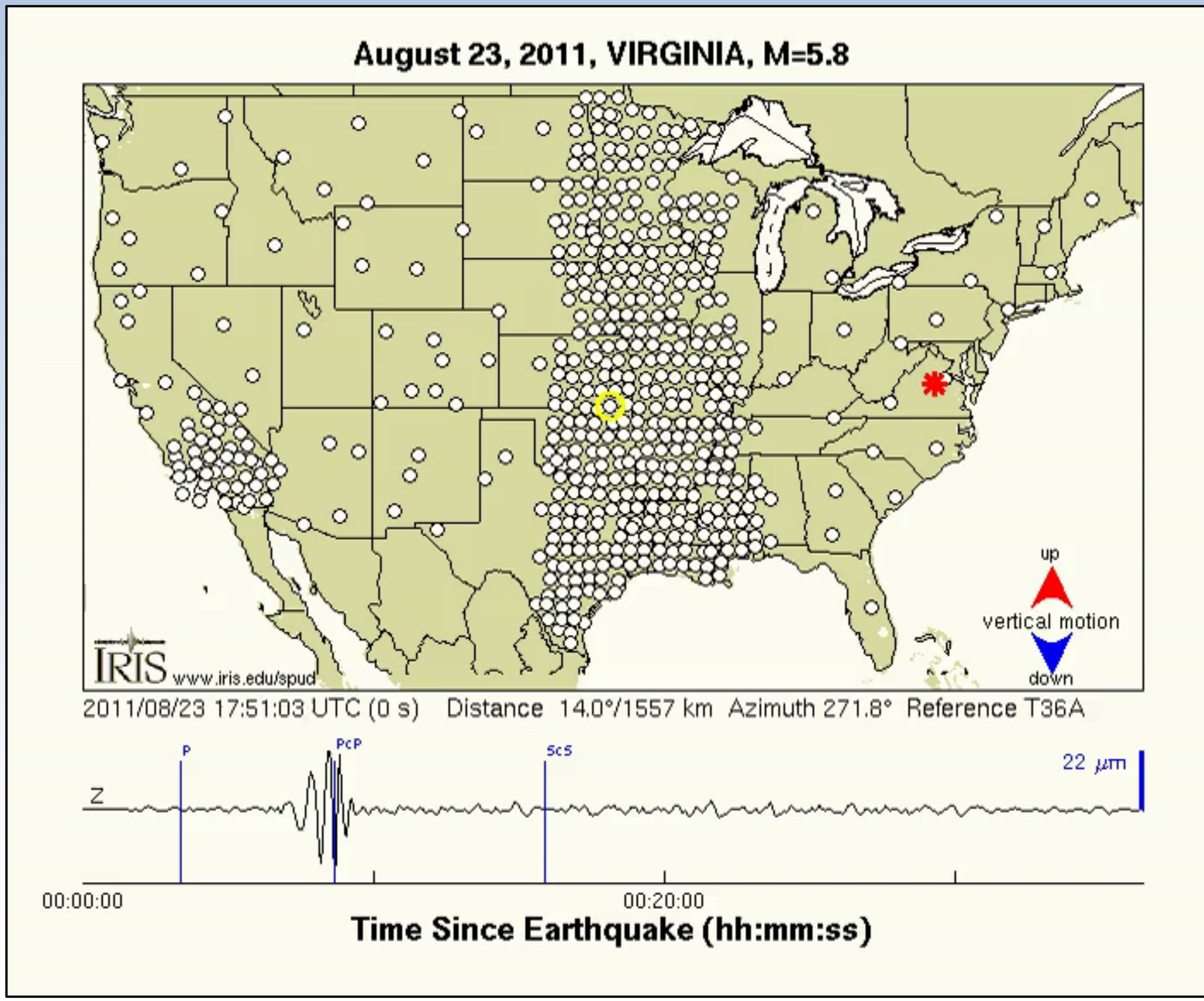
Dots show the up/down motion of the ground surface from distant earthquakes. Red goes up, blue goes down. 3D versions add the tilting of the surface, represented by a waving golf pin flag. Distinct kinds of waves are apparent, as well as the complexity of motion as later waves mix with reflections. The distortion of the wave front, gives a measure of structure beneath. The typical seismogram is displayed along bottom from one station-circled in yellow.



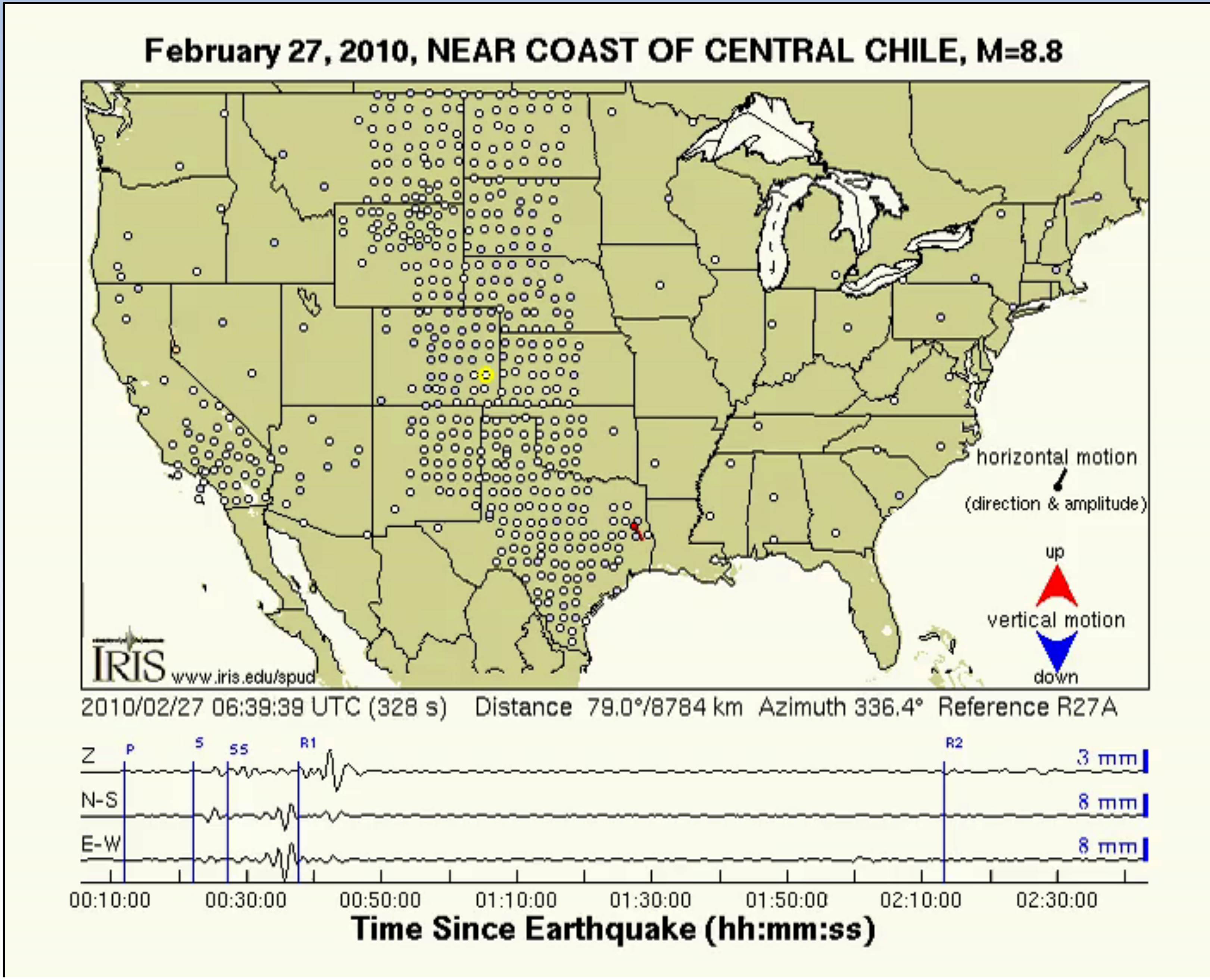
These Back Projection movies show a view of the earthquake source-mapping where the rupture is occurring over a period of time.

Typical Earthquake

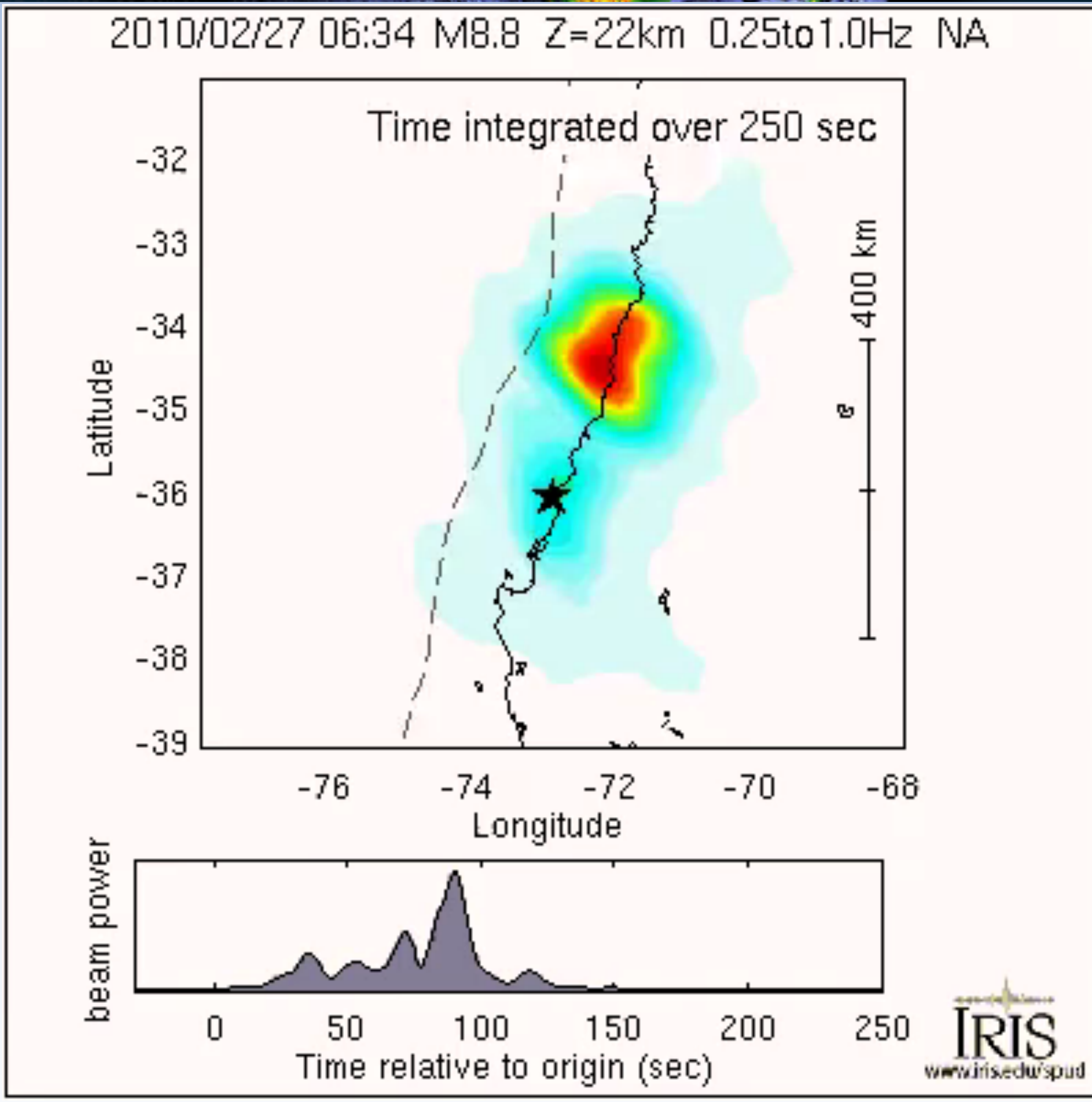
Like ripples on a pond…

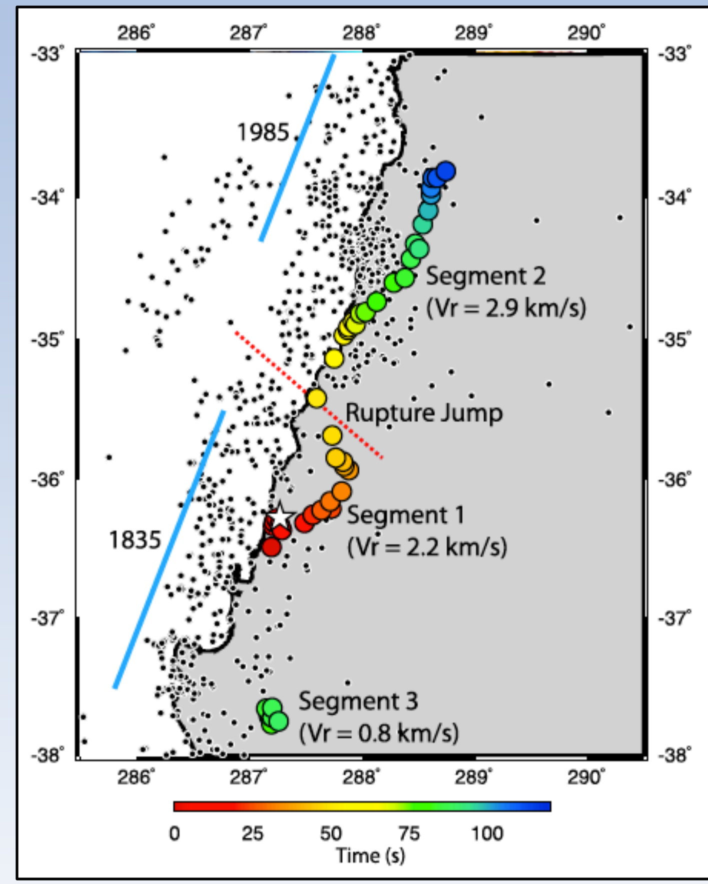


Understanding Great Earthquakes



Understanding Great Earthquakes

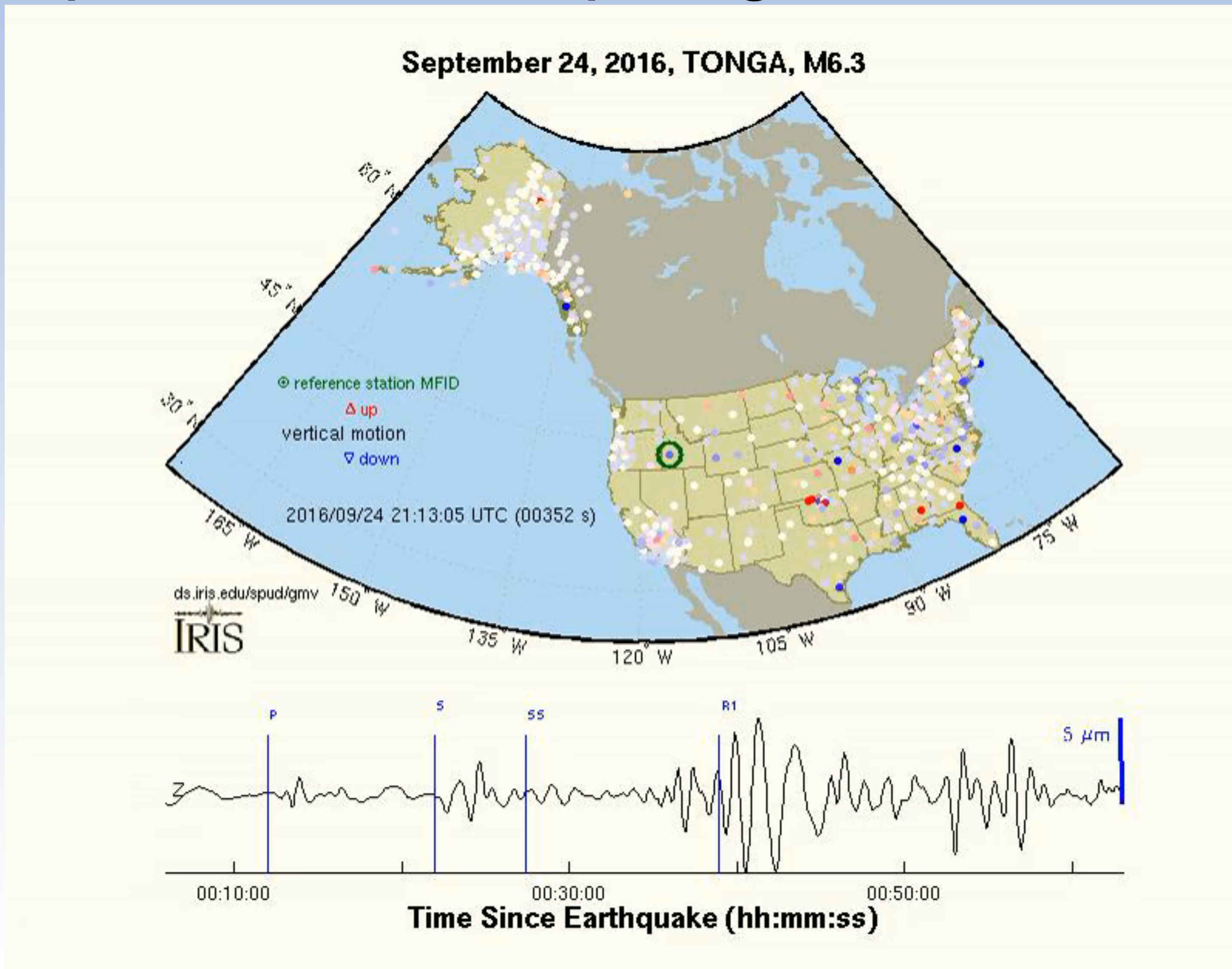




Backprojection analysis of Maule
Kiser and Ishii, *GRL*, 2011

Binocular View

- http://ds.iris.edu/spud/gmv



Public Impact

Major publicity during award period!

NATIONAL GEOGRAPHIC — Inspiring people to care about the planet since 1888

NATIONAL GEOGRAPHIC CHANNEL — live curious.

X-RAY EARTH

Researchers are creating 3-D models of what the

USA TODAY

Technology » Science & Space

An EarthScope field engineer piles dirt on the sealed vault for Transportable Array station I28A near Midland, S.D. The station is powered by solar energy and continuously transmits its data via cellphone.

Incorporated Research Institutions for Seismology

Nationwide project lends new details on earthquakes

Updated 6/17/2010 11:31 AM

By Incorporated Research Institutions for Seismology

A seismometer is installed on a cement floor in the EarthScope Transportable Array station H28A lower compartment. A lid is placed on the vault before it is sealed and covered with dirt to insulate it from large temperature fluctuations.

By Jeff Martin, USA TODAY

When it comes to studying earthquakes, Oregon State University geology professor Bob Lillie has a simple theory: The more that is known, the better people can prepare and protect themselves.

More 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.

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

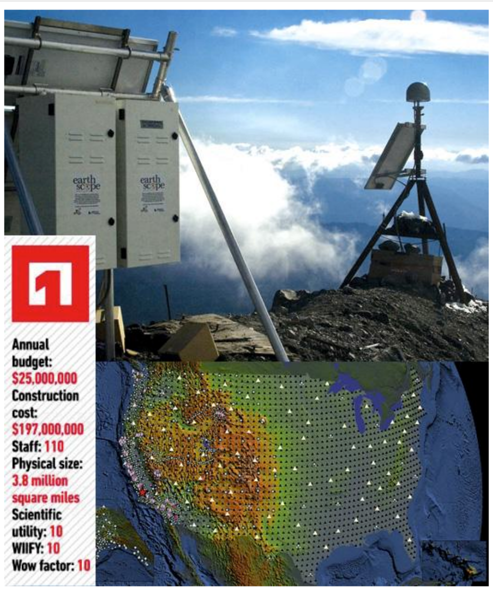
Lillie is part of a group of scientists involved in USArray, a nationwide research project that allows scientists to study earthquakes in unprecedented ways.

POPULAR SCIENCE

SCIENCE

Big Science: The Universe's Ten Most Epic Projects

By Gregory Mone, Brooke Borel, Katherine Bagley and Jennifer Abbasi Posted 07.16.2011 at 8:06 pm



10 OF 10

1: The Earthscope

EarthScope

A telescope to peer deep into the h… track North America's geological evo… science project on the planet. This e… records data over 3.8 million square… 4,000 instruments have amassed 67… equivalent to more than a quarter of… Congress and add another terabyte… Scientific Utility Researchers are usi… of many kinds of experiments, to exa… America's geological composition. A… Puerto Rico, 1,100 permanent GPS u… land's surface caused by tectonic shi… to the active San Andreas Fault in Ca… while rock samples pulled from a dri… the fault reveal the grinding and stra… the two sides of the fault slide past each other during an earthquake. And over the course of 10 years, small crews have hauled a moveable array of 400 seismographs across the country using backhoes and sweat. By the time the stations reach the East Coast next year, they will have collected data from almost 2,000 locations. What's In It For You Collectively, EarthScope's measurements could help explain the forces behind geological events such as earthquakes and volcanic eruptions, leading to better detection. So far, data from the project has shown that rocks in the San Andreas Fault are weaker than those outside it and that the plume of magma under Yellowstone's supervolcano is even bigger than previously suspected.

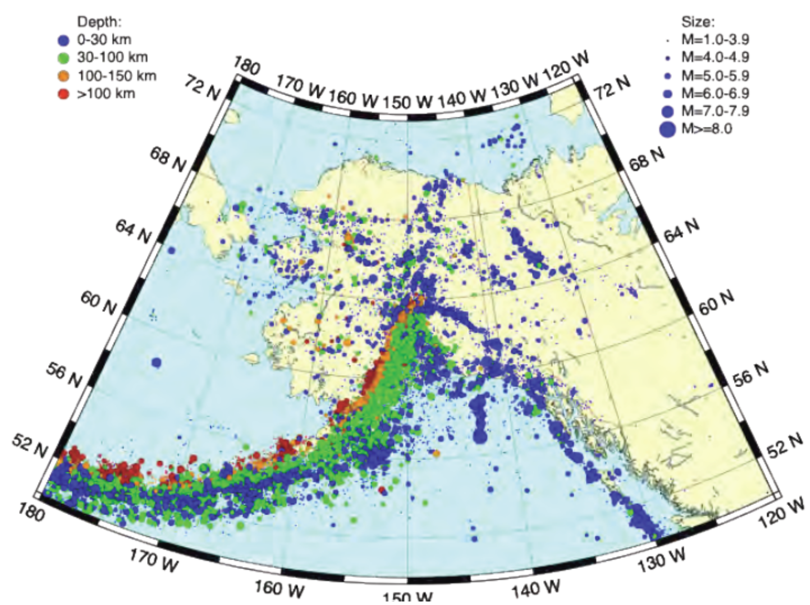
Read the article: Big Science: The 10 Most Ambitious Experiments in the Universe Today

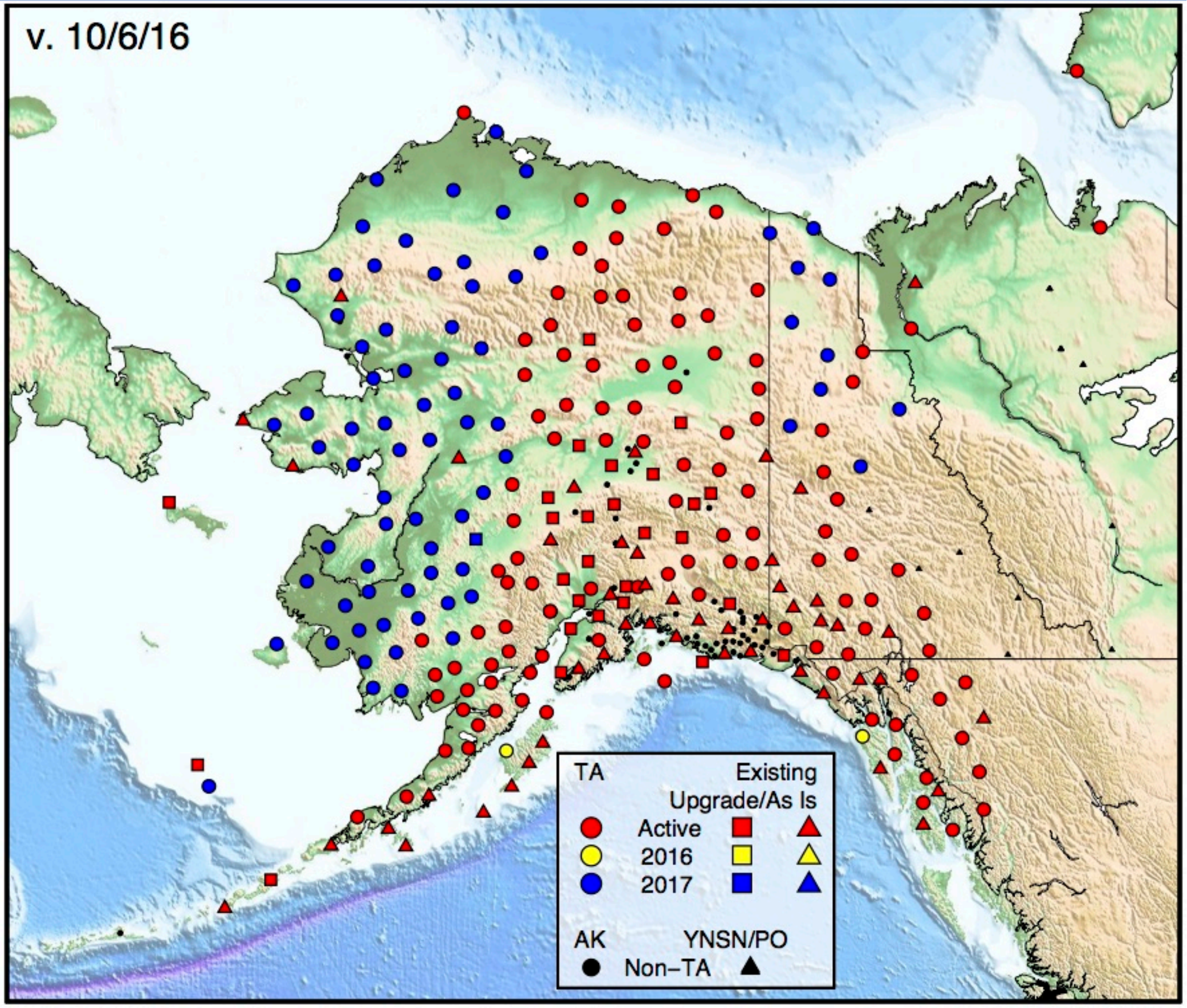
TA in Alaska / Yukon

- ~268 sites
- 85 km spacing
- Broadband Seismometers

  Infrasound, pressure
  - Some met packages
- <4hr Communications
- Fully deployed 2017

Seismicity in Alaska & Yukon

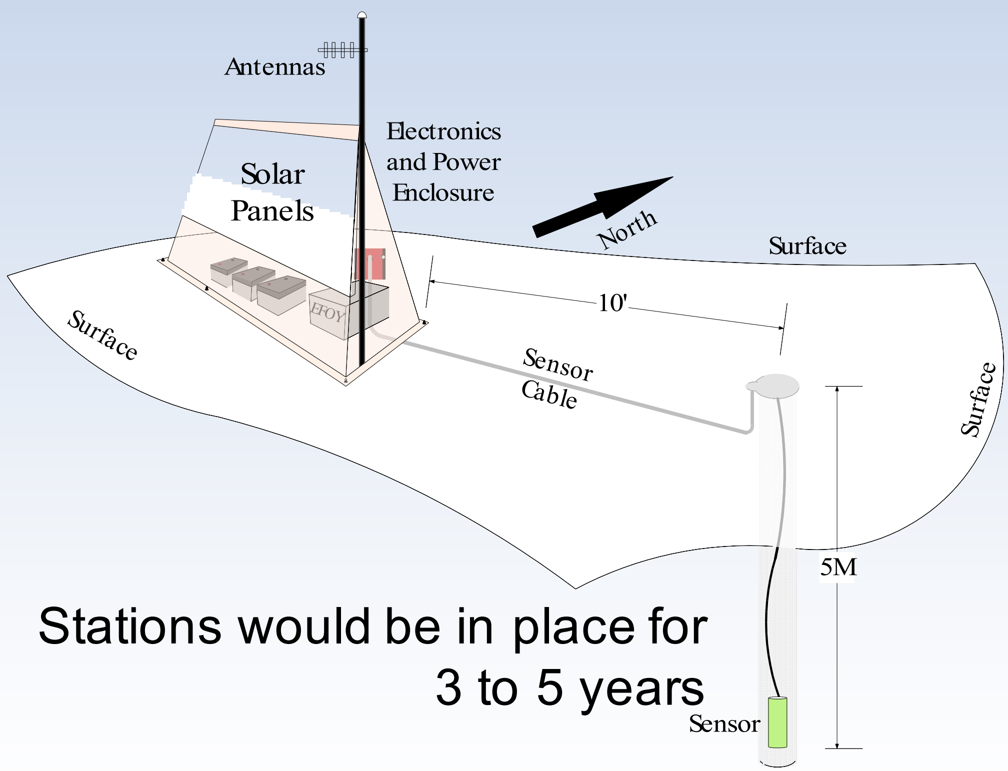




www.usarray.org/alaska

Basic Description of Buried Sensor Design for AK

- Sensor: 3 component Broadband seismometer & auxiliary sensors
- Datalogger & local data storage
- Power & data telemetry

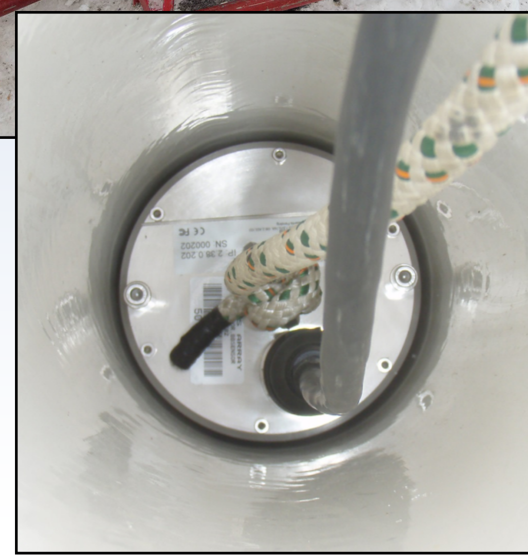


Stations would be in place for 3 to 5 years

Footprint ~10 feet X 20 feet

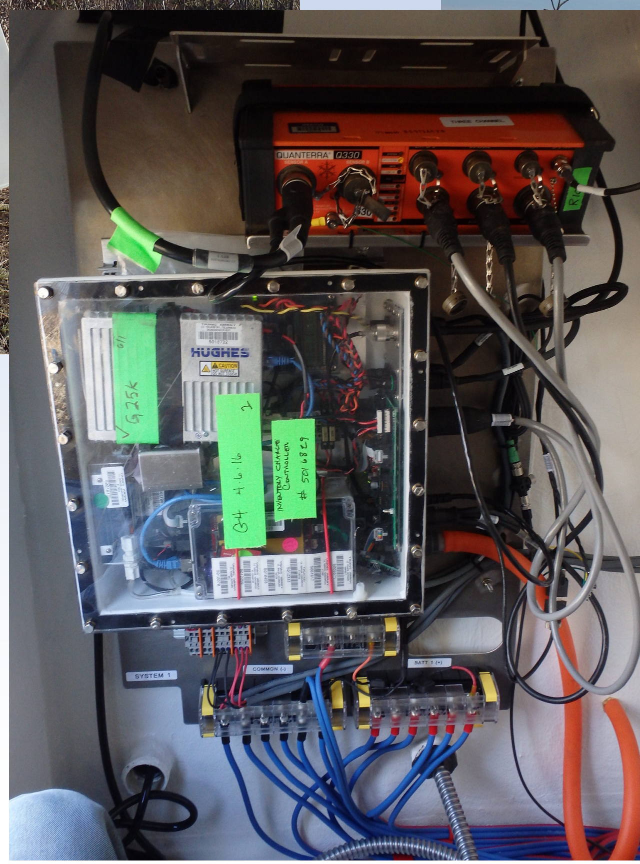
N25K Seismic Station

TA in Alaska / Yukon



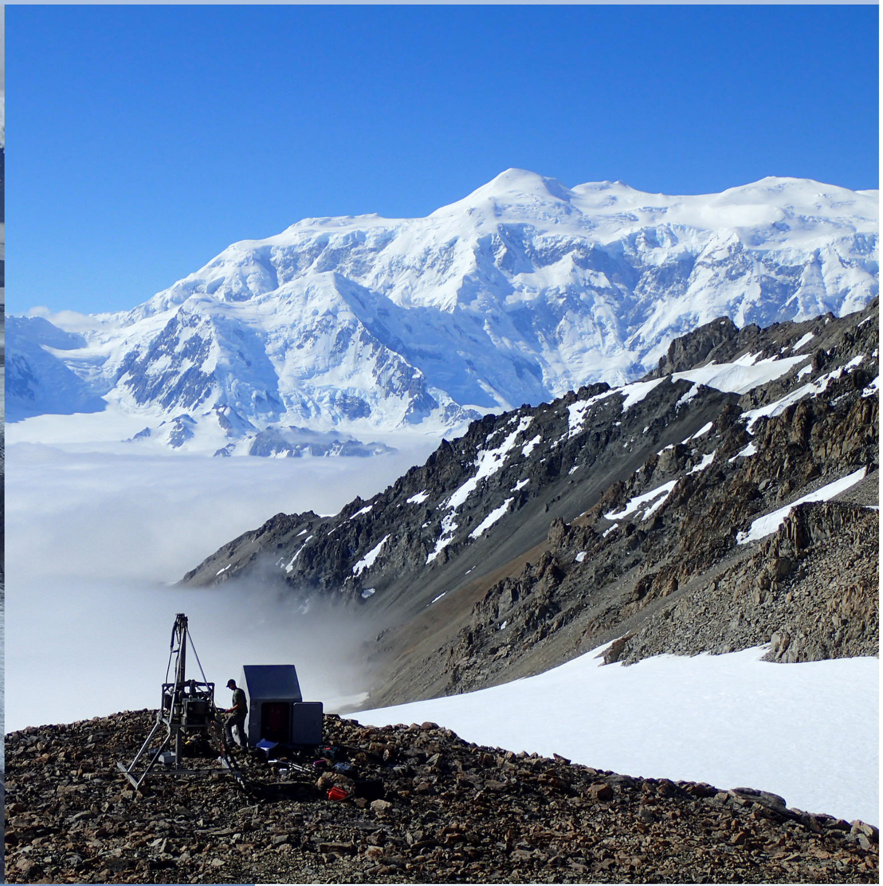
- ~266 new & upgraded sites by 2017, spaced 85 km
- Broadband seismometers w/atmospheric sensors
- New/complicated power and communications options
- Complex logistics

FY16 Operations



G25K: Hut Exterior view showing Hut antenna Mount and interior view of electronics panel and Battery bag. $64k in equip.

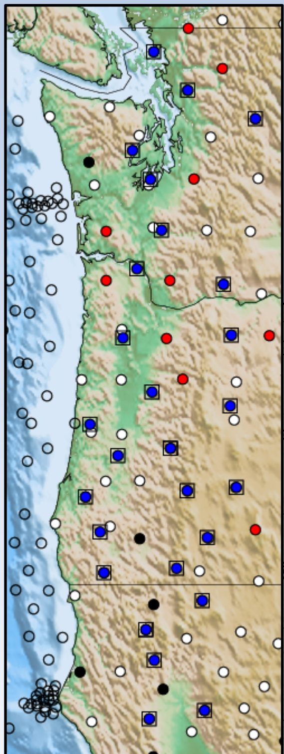
FY16 Operations

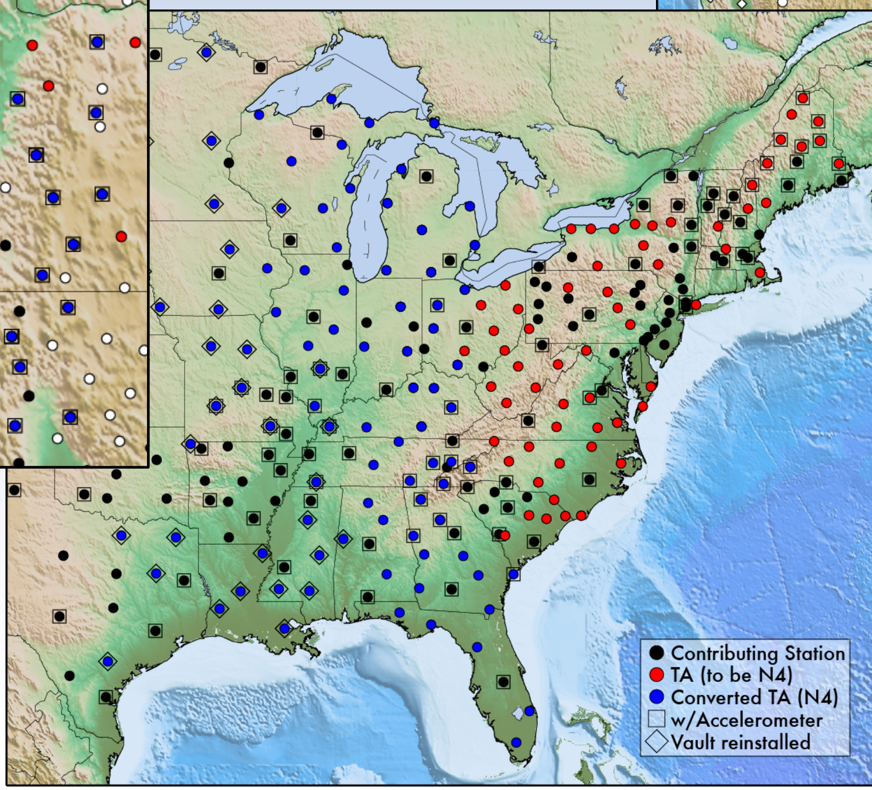


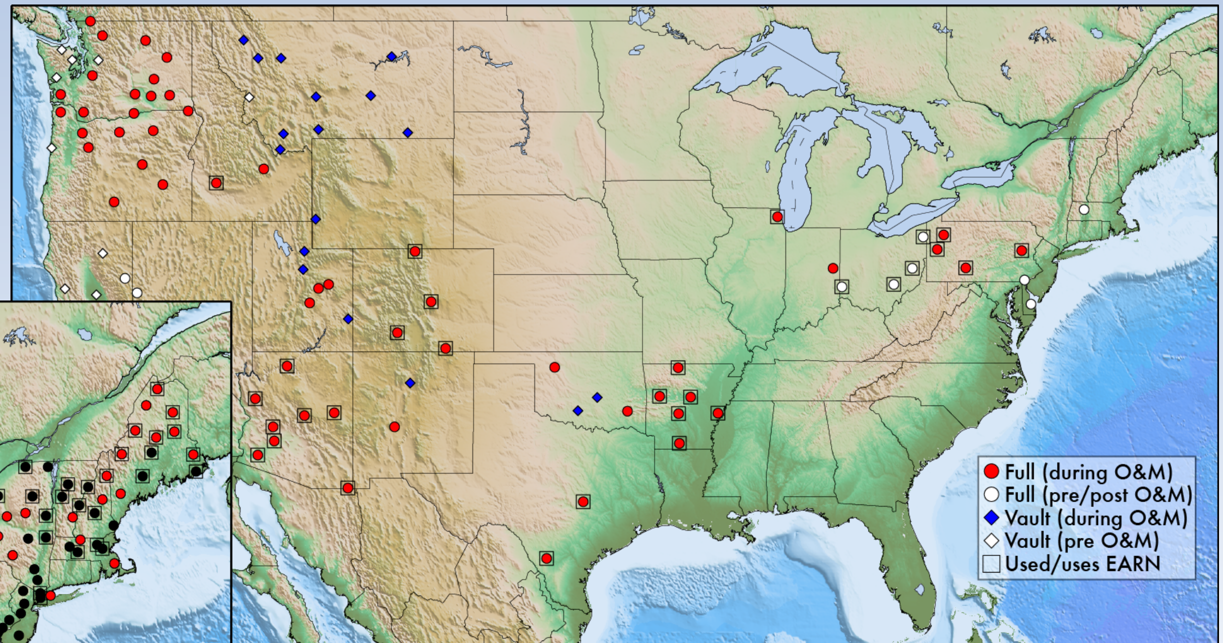
O28M: Mt Upton, Kluane Nat. Park-Kluane First Nations

Impacts on Society

Fundamental improvement in long-term science and monitoring capacity

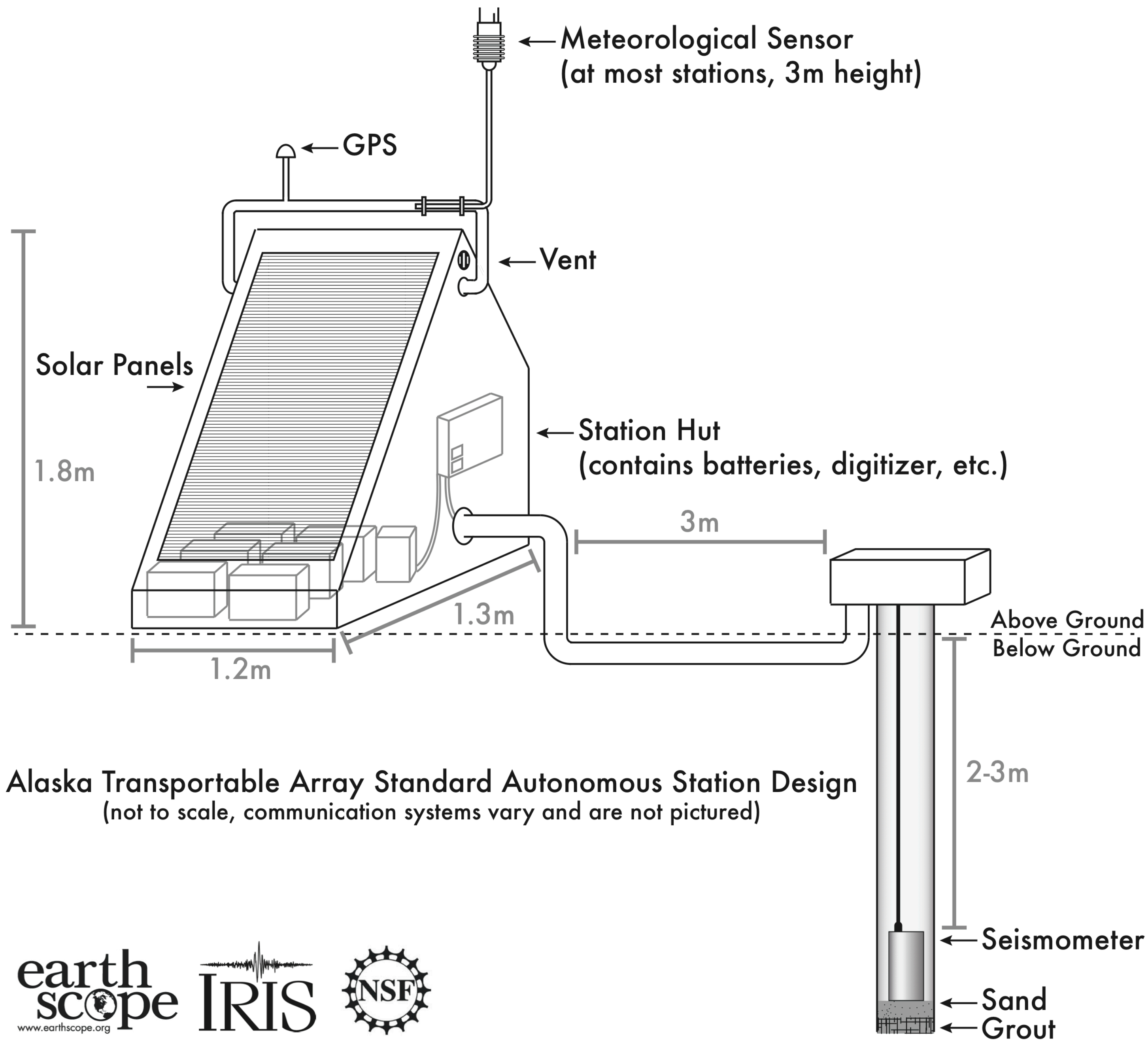






- Among TA, Cascadia adoptions and CEUSN, potentially 235 new "permanent" stations in N.A. since 2008

The Swiss Army knife …



Equipment & Instruments

Basics:
Power, shelter and data comms

Added:
Barometric Pressure
Infrasound

In Alaska:
Strong Motion Instruments

Meteorlogical Packages

Soil Temperature profilers

And applied the observational technique in other fields;

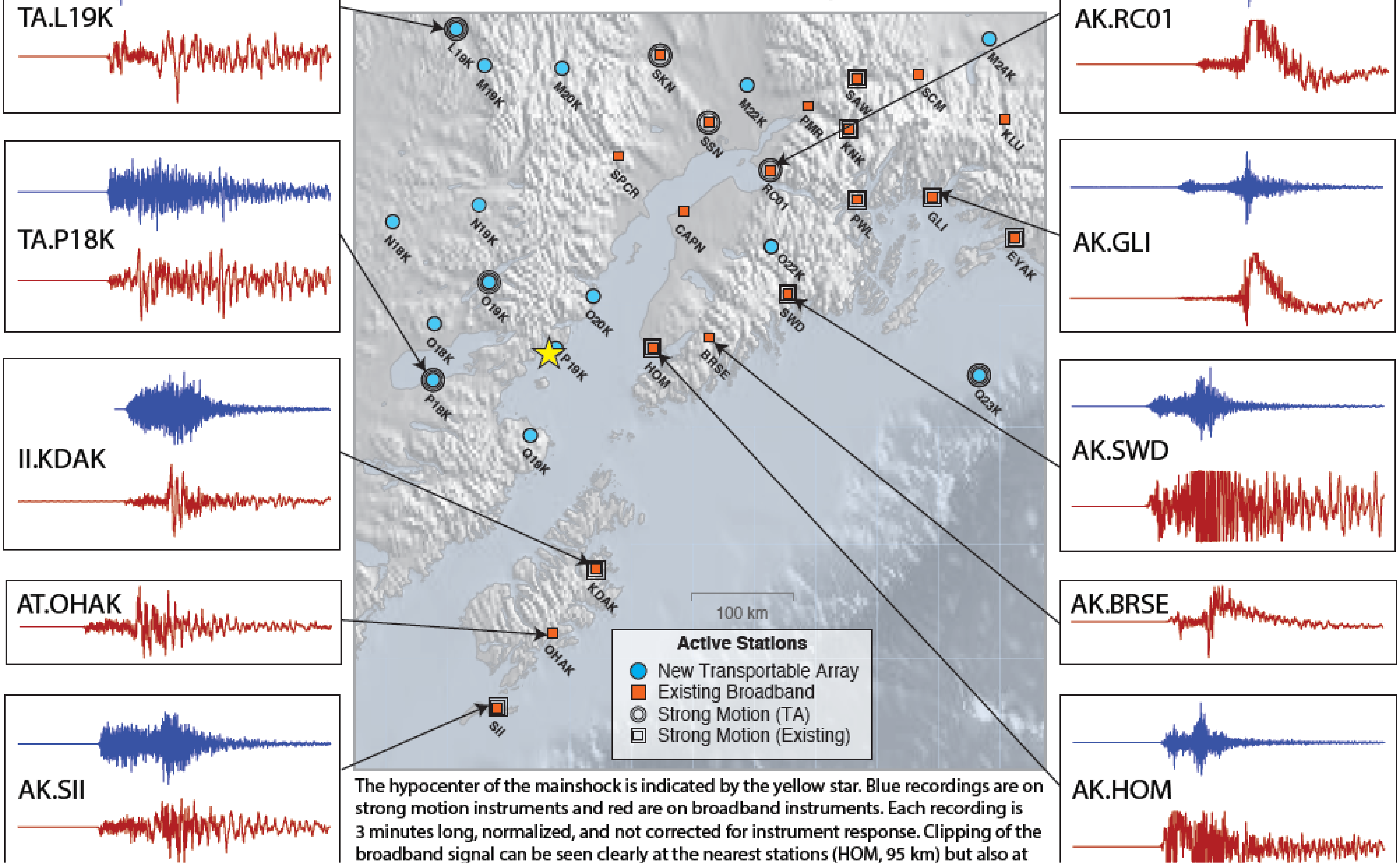
Landslide detection

Sea Ice thickness monitoring

Distributed barometric pressure

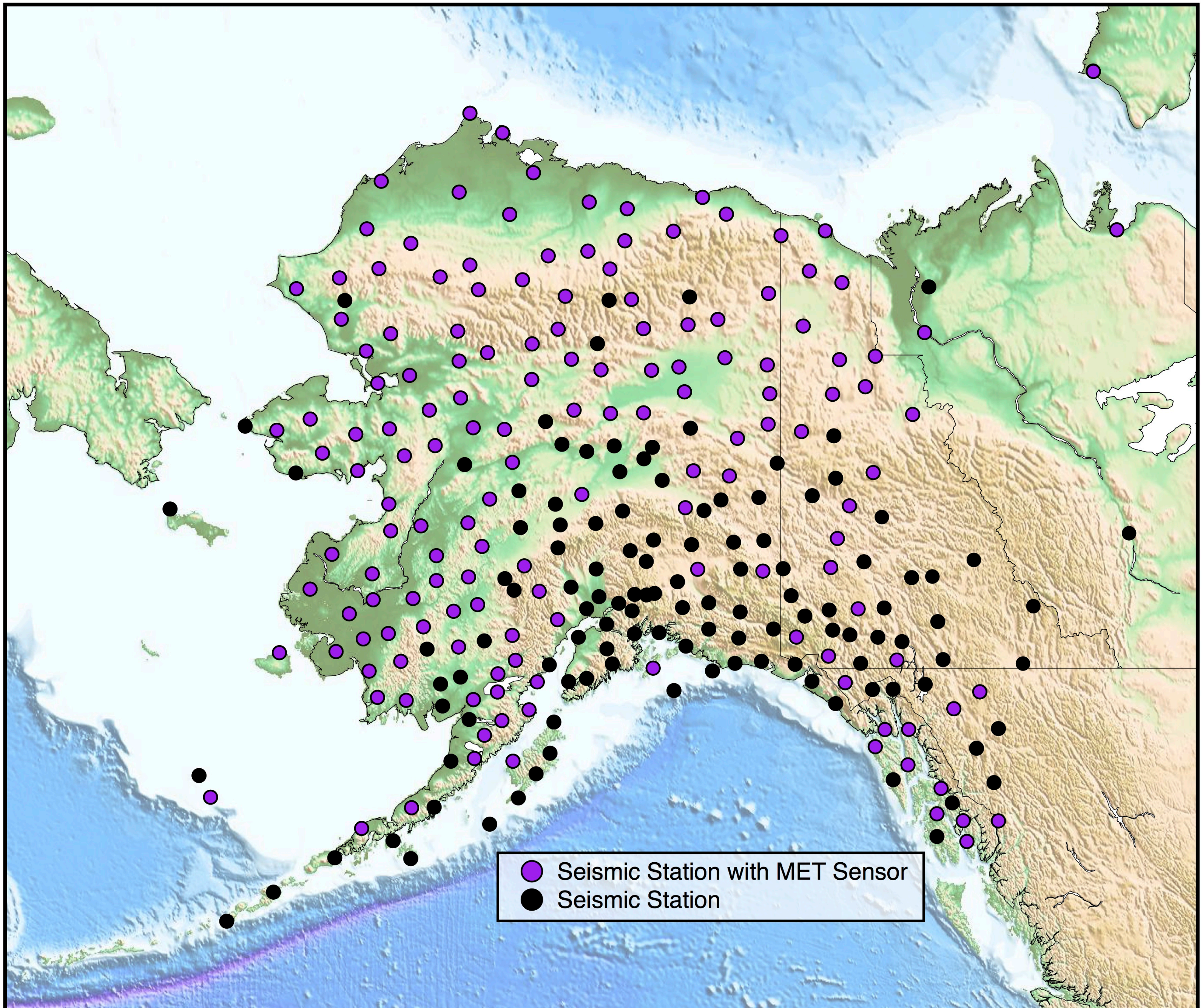
Iniskin, Cook Inlet

Broadband and Strong Motion Recordings of the 2016 M7.1 Iniskin Earthquake



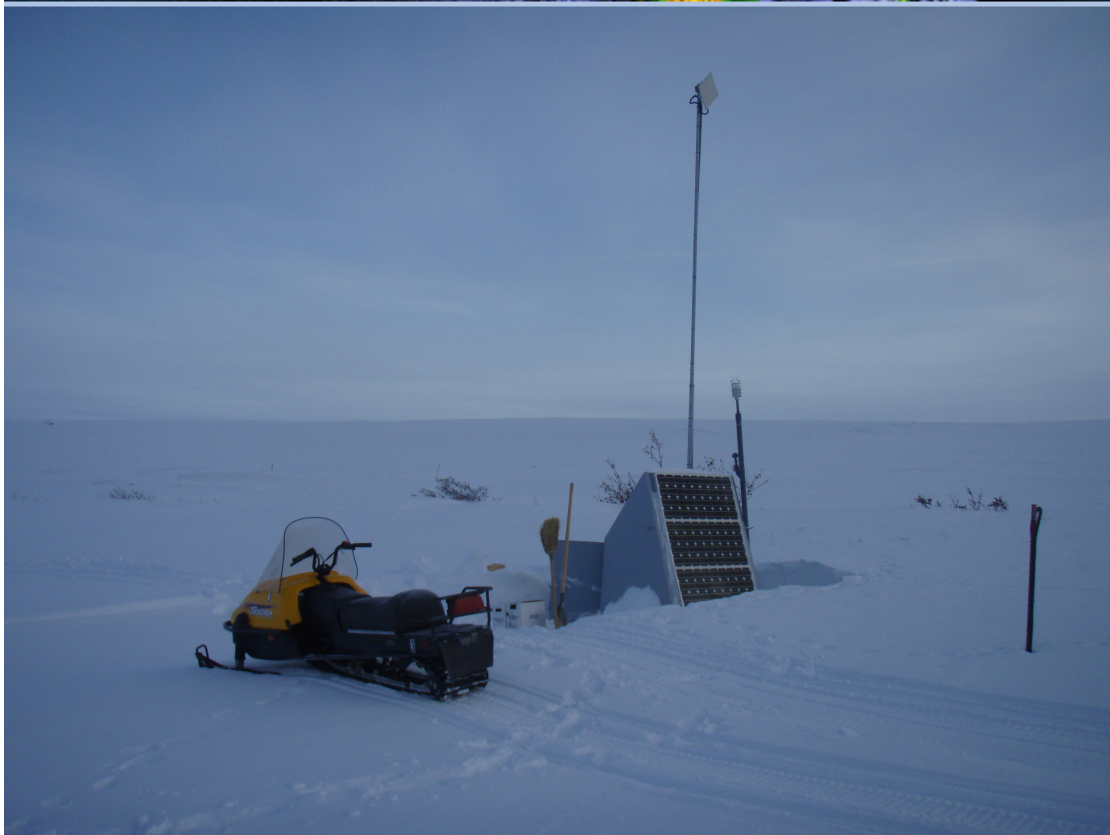
The hypocenter of the mainshock is indicated by the yellow star. Blue recordings are on strong motion instruments and red are on broadband instruments. Each recording is 3 minutes long, normalized, and not corrected for instrument response. Clipping of the broadband signal can be seen clearly at the nearest stations (HOM, 95 km) but also at

Met sensors in AK



30 TA supplied
35 UCSD
52 NOAA NWS
40 NASA ABoVE
2 Yukon

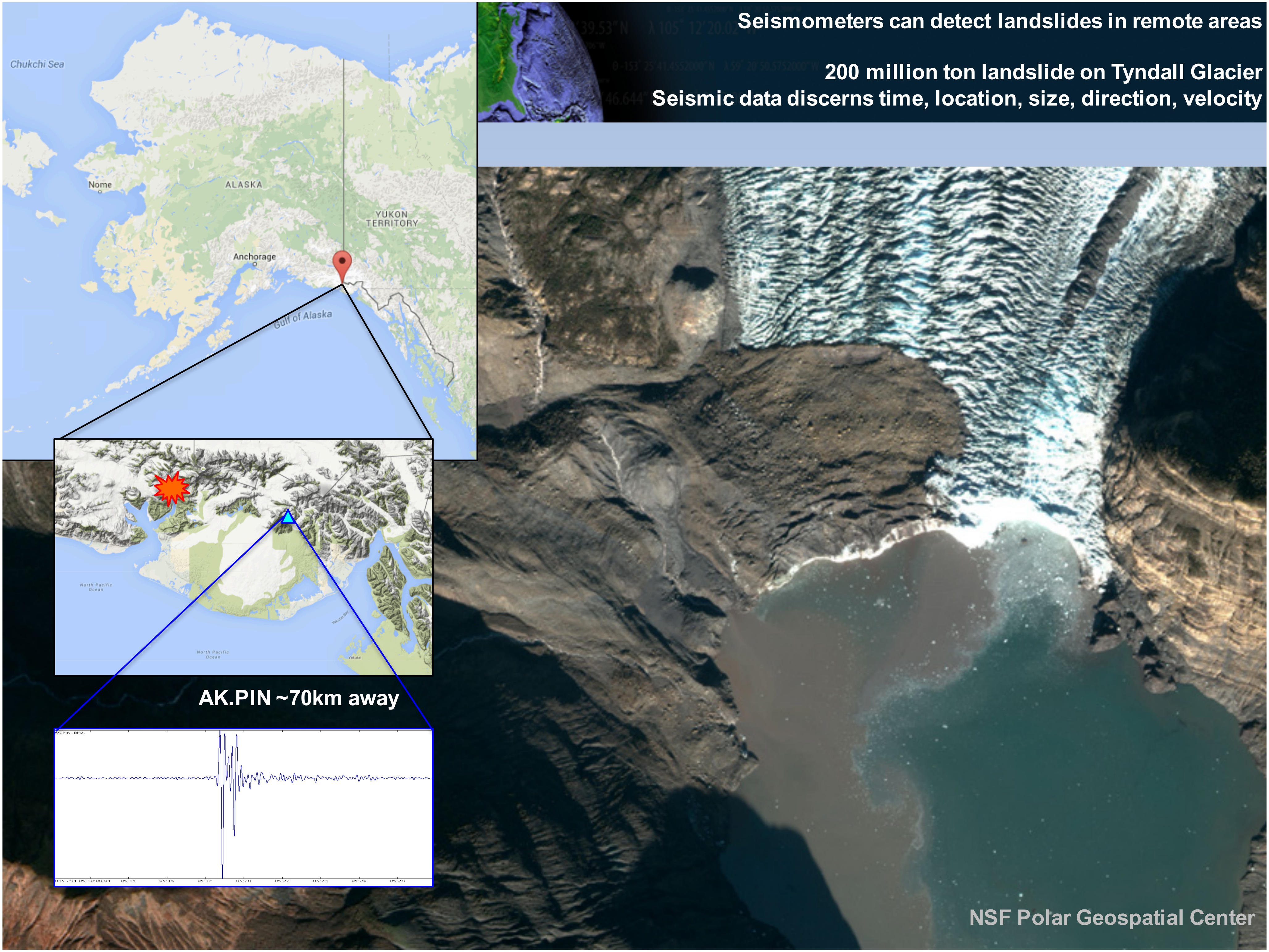
Met sensors in AK



Feb 2013, Toolik Lake, North Slope Alaska

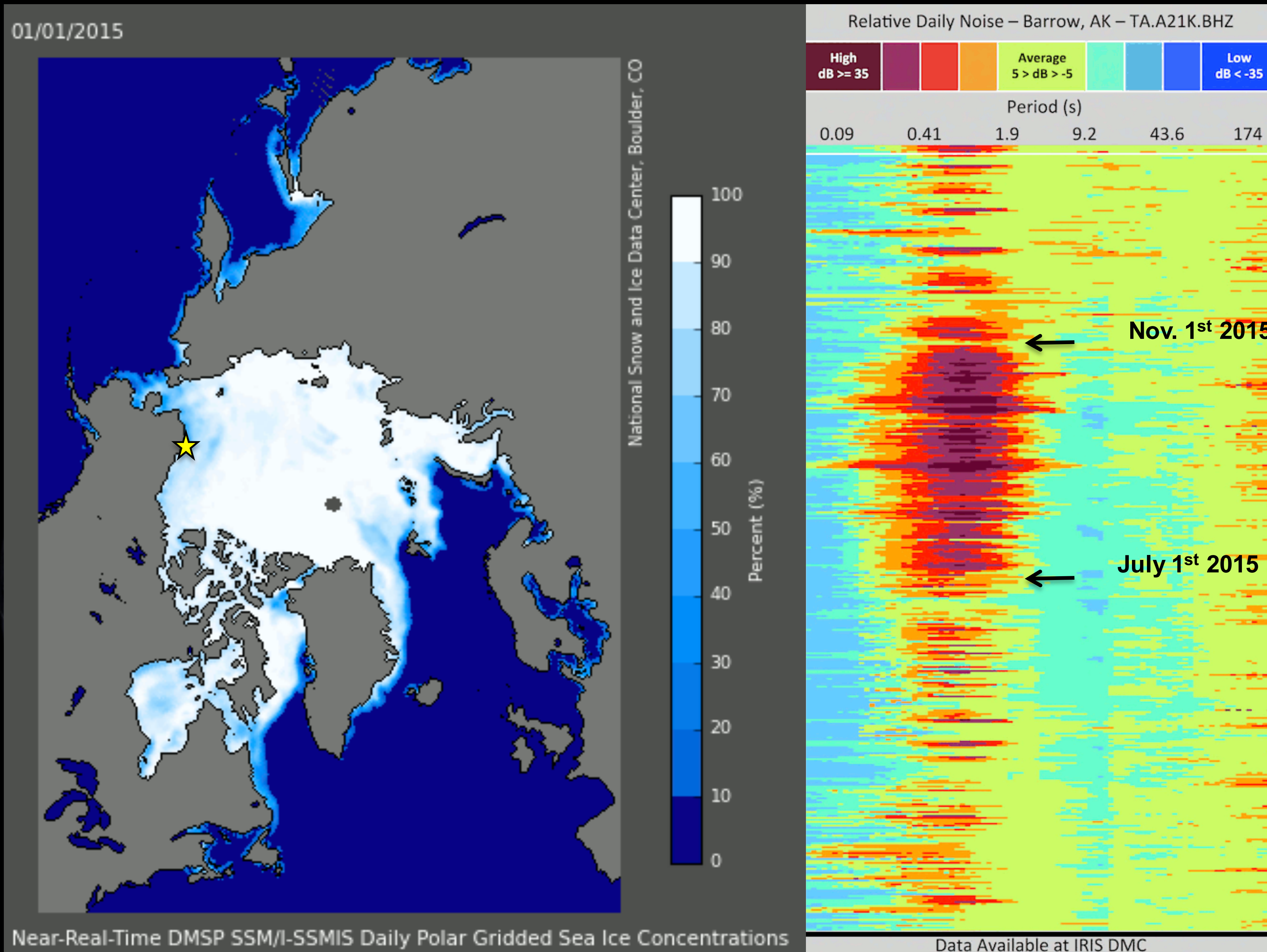
Hut mount, in consultation with NOAA NWS Alaska Region

Feb 2016, Yukon Crossing, Dalton Highway Alaska



Seismometers can detect landslides in remote areas
200 million ton landslide on Tyndall Glacier
Seismic data discerns time, location, size, direction, velocity
Chukchi Sea
Nome
ALASKA
YUKON TERRITORY
Anchorage
Gulf of Alaska
North Pacific Ocean
North Pacific Ocean
AK.PIN ~70km away
NSF Polar Geospatial Center

Seismometers can track the status of sea ice extent in northern Alaska
High noise (red) corresponds to open water after the peak of summer

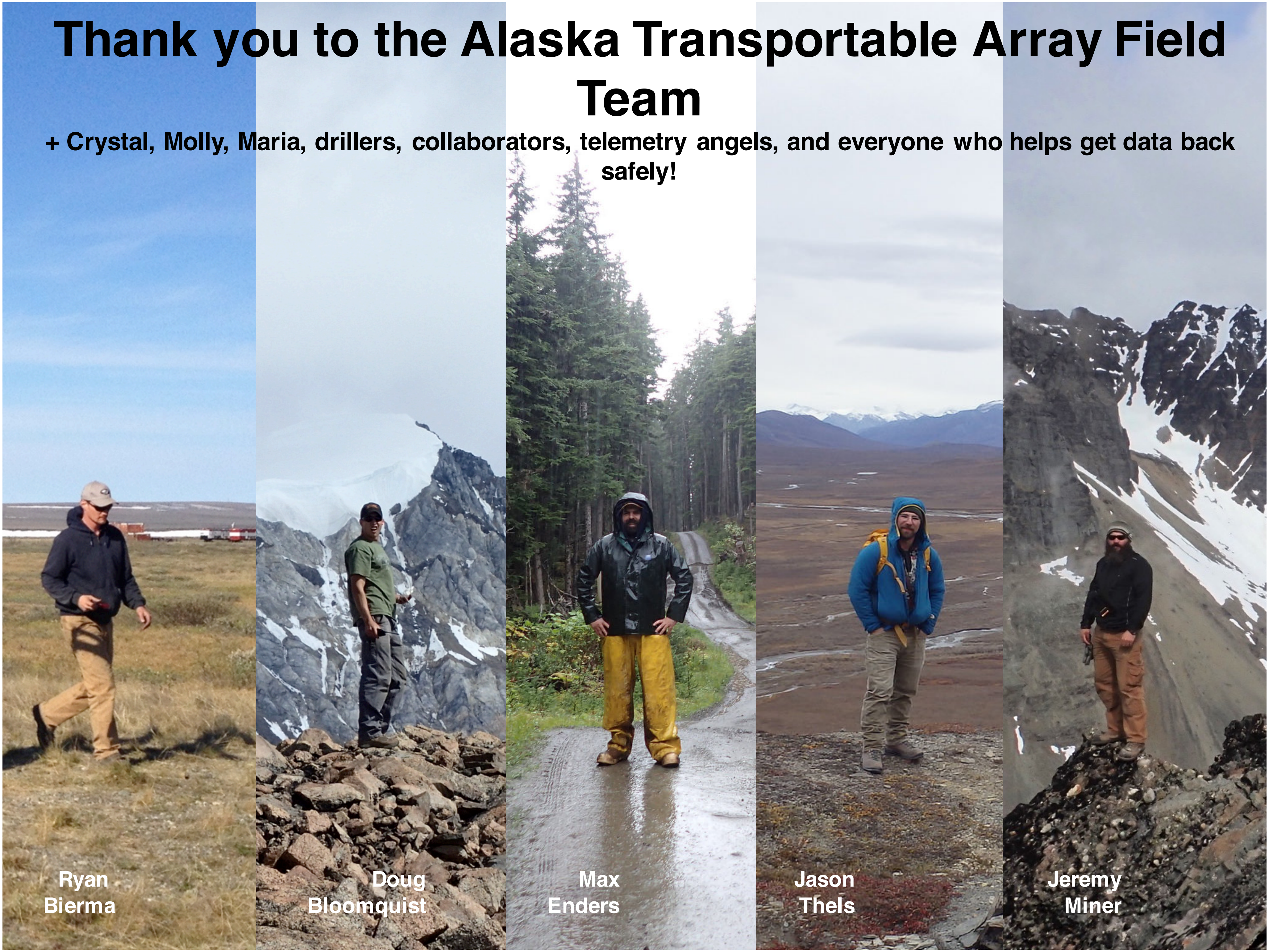


People Make it Happen

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

Thank you to the Alaska Transportable Array Field Team

+ Crystal, Molly, Maria, drillers, collaborators, telemetry angels, and everyone who helps get data back safely!



Want More Info?

On the Web

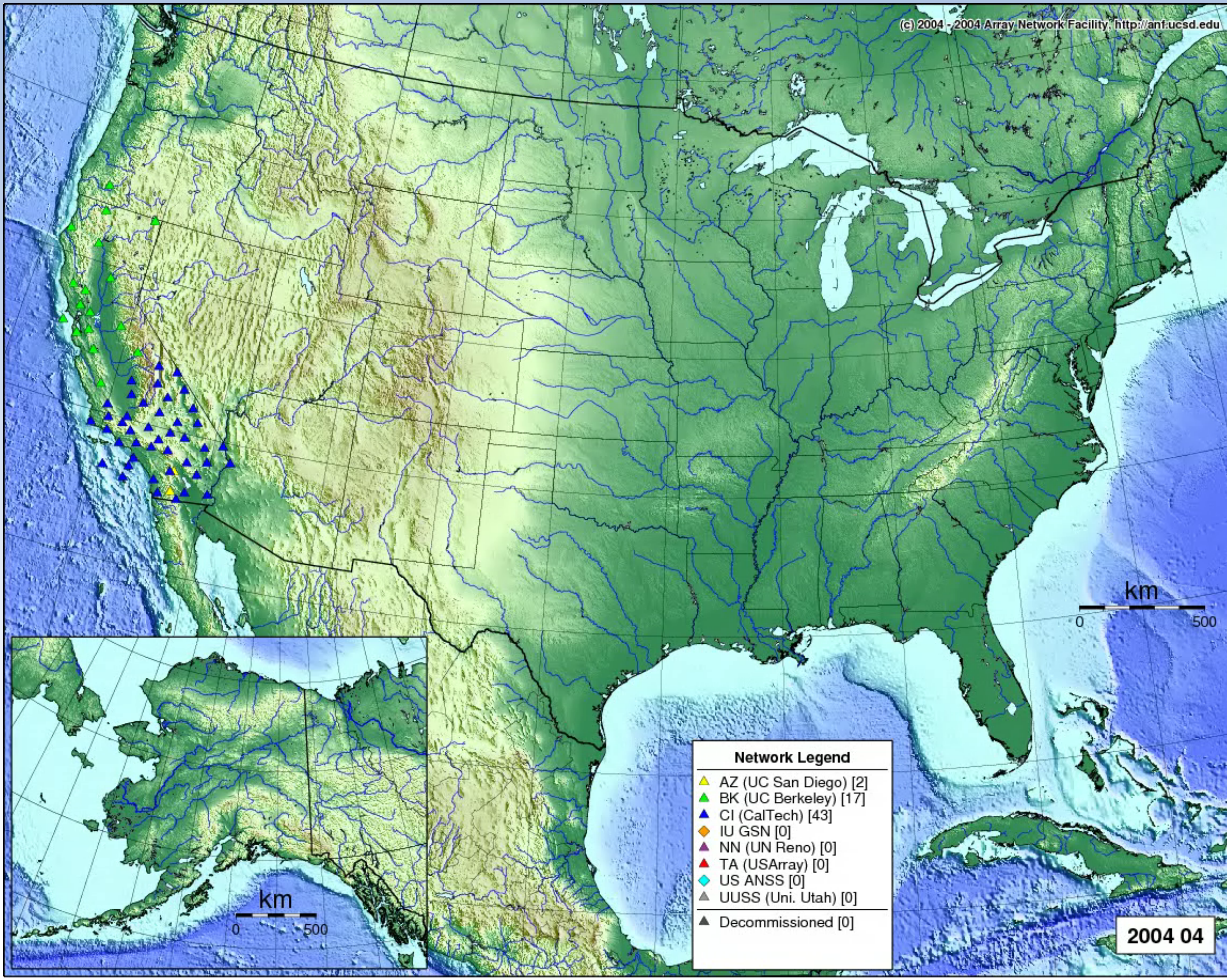
- EarthScope
  www.earthscope.org
- USArray
  www.usarray.org
- National Science Foundation
  www.nsf.gov

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.

TA Animation



“Fracking”

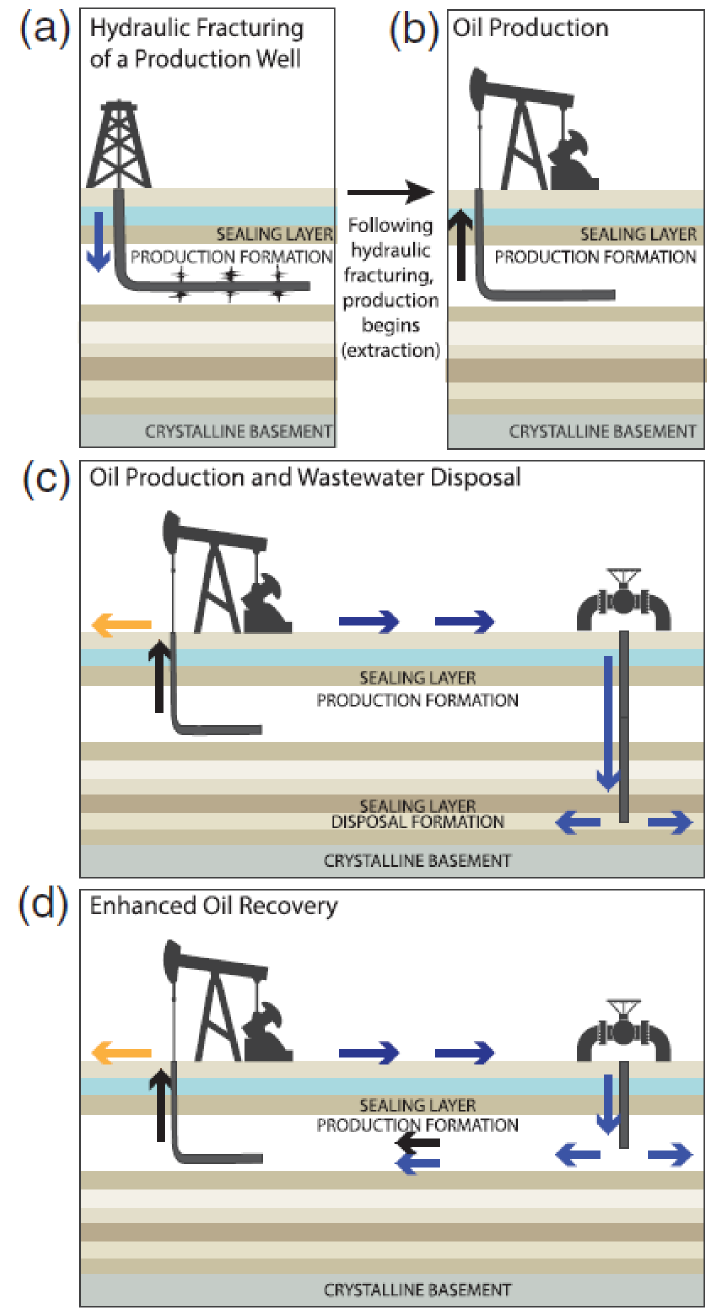
Certain oil and gas recovery methods have produced earthquakes. Both the fracking process and more commonly, the wastewater injection related to disposal of production water, have induced earthquake activity. These earthquakes are small to moderate sized and only in exceptionally rare cases (Tulsa and Youngstown OH) have created a hazard due to shaking.

Understanding the geologic conditions of the capped layer and the underlying basement as well as the hydrologic conditions and fault history can help constrain the levels at which injection might operate without inducing earthquakes. Monitoring for small events is an objective method to assess this hazard.

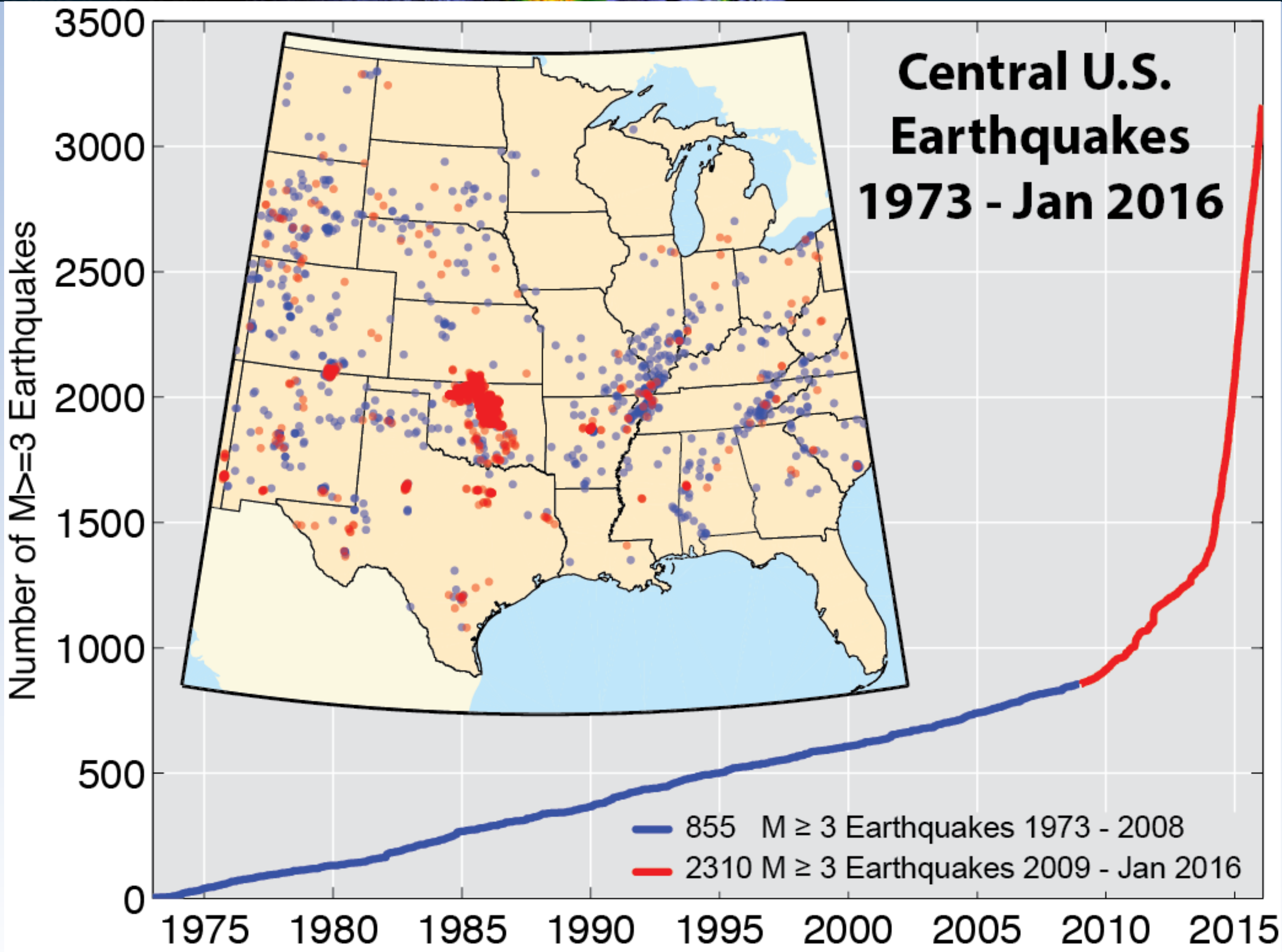
For the public, the hazard due to ground shaking from induced earthquakes is small. However, that the earthquakes occur is sending a message that the concept of a cap layer separating the disposal fluids from layers above it, including surface or aquifer contamination, may no longer be valid. When earthquakes occur, the conditions of disposal are far more complex-and are changing in time, than perhaps proposed. If disposal of fluids, whether the small amount used in fracking, or the large amount in wastewater injection, is regulated and such regulation can include the introduction of tracers that uniquely identify the injection source, then the prospect of legal liability should such contamination be found would balance the risk of development.

The earthquakes are just telling you the situation is complex, but they are not really the hazard.

Rubinstein & Mahani, Seismological Research Letters, July/August 2015



Induced Earthquakes



Updated from Rubinstein & Mahani, Seismological Research Letters, July/August 2015

TA “Super” GMV

IRIS DMS Combined Ground Motion Visualization

GULF OF CALIFORNIA 2007 - 2013

IRIS

IRIS DMS Combined Ground Motion Visualization
Gulf of California, 2007-2013

Max Lat: 26.20

Min Lon: 110.60 | 100.10 Max Lon:

Min Lat: 24.67

Start Date 2007-09-01 00:00

End Date

Magnitude 5.5 - 7.7

Depth (km) 0 - 700

Strike: 0 - 360

Dip 0 - 90

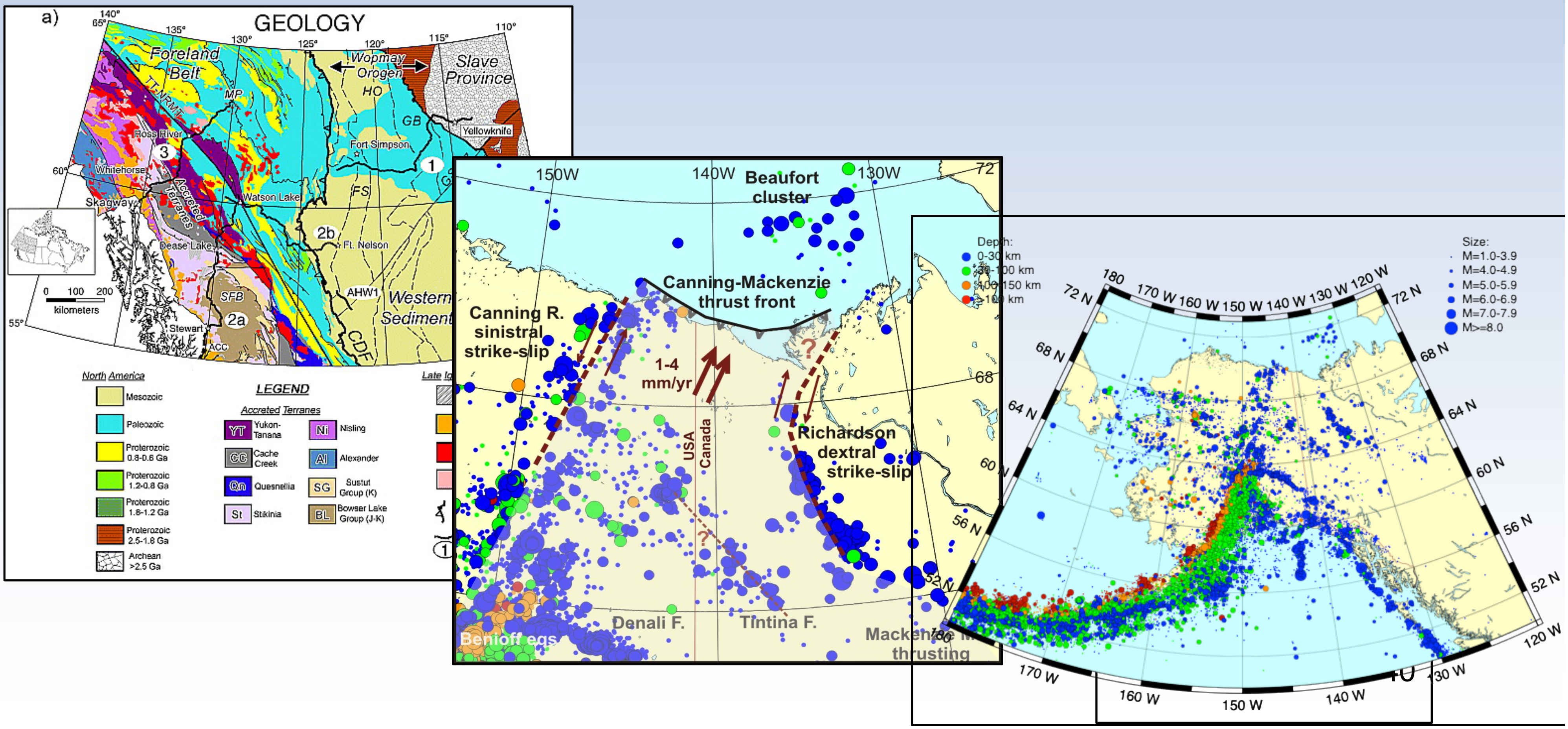
Rake: -180 - 180

	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	2012-10-08 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	2010-10-21 17:53:18	14.2	6.7	24.83	-109.20		GULF OF CALIFORNIA
	2010-10-20 06:58:16	15.5	5.8	24.72	-109.10		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	-109.15		GULF OF CALIFORNIA
5	2009-07-03 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	-109.69		GULF OF CALIFORNIA

Science Outlook for AK

Alaska deployment will produce transformative results

- First order geophysical targets
- Extensive seismicity
- “Uncharted” terrain



Sensor Emplacement

All proposed sites visited for permit app

Most sites are installed via helicopter

Drill a 6 inch diameter hole 3-5 m into soil or rock

Multi-person team constructs site and installs equipment

Operations based out of Anchorage


Drill in Skyvan, bound for Middleton Island


Hammer Drilling, AK.SCRK


Hammer drill, N25K


Mike Lundgren auger in Palmer AK