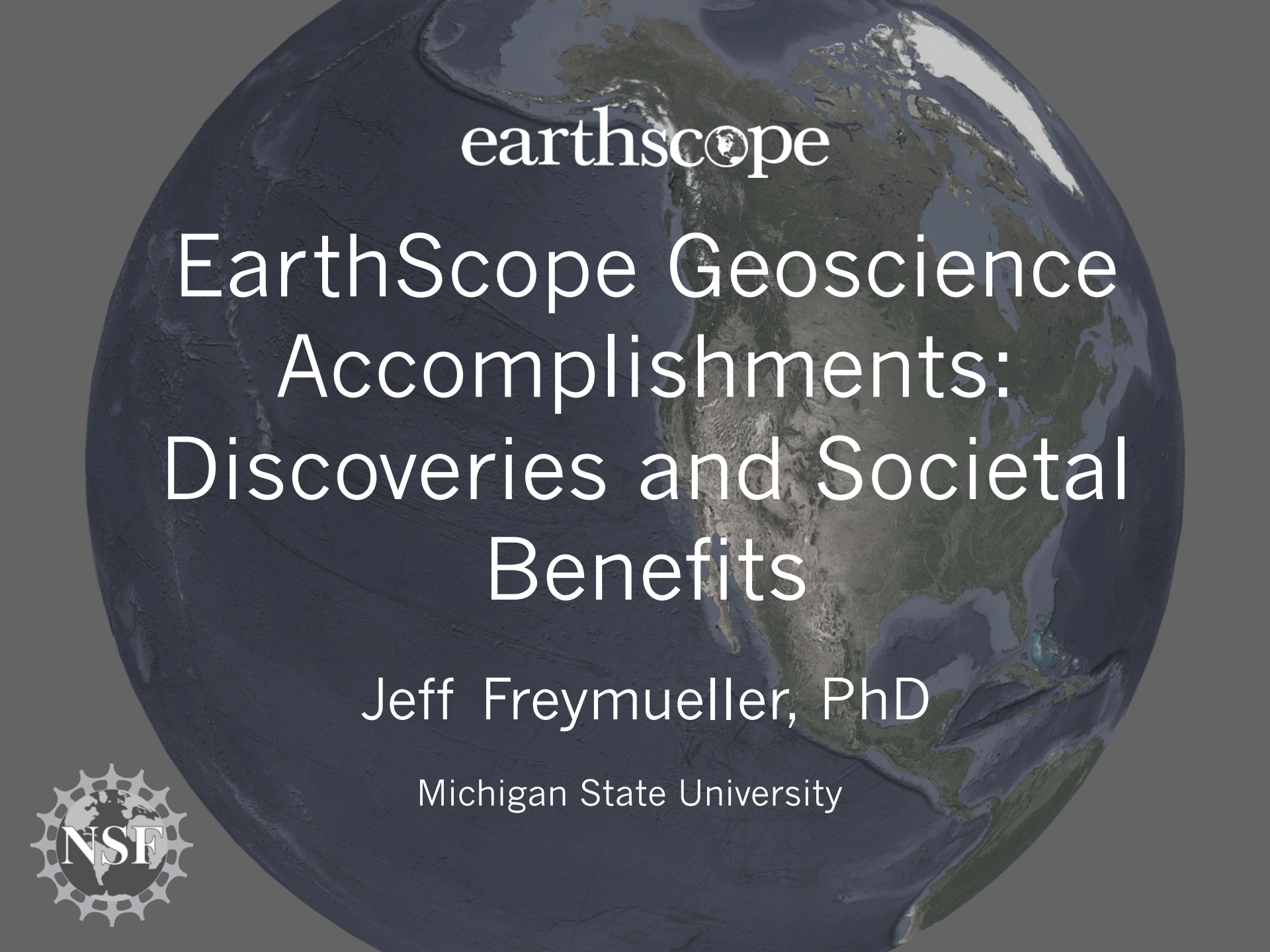


earthscope

# EarthScope Geoscience Accomplishments: Discoveries and Societal Benefits

Jeff Freymueller, PhD

Michigan State University

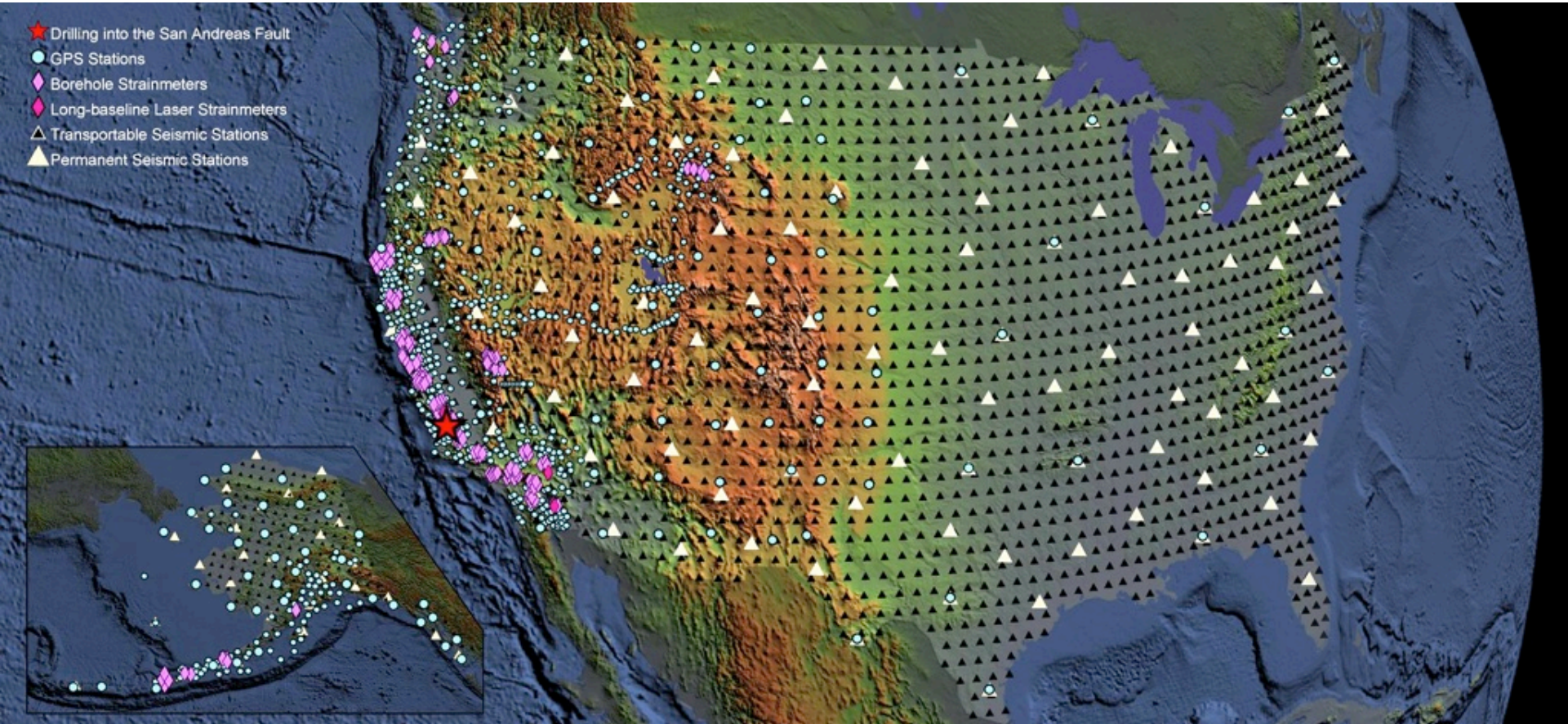
NSF

# What is EarthScope?

**A distributed observatory in 3 components across North America**

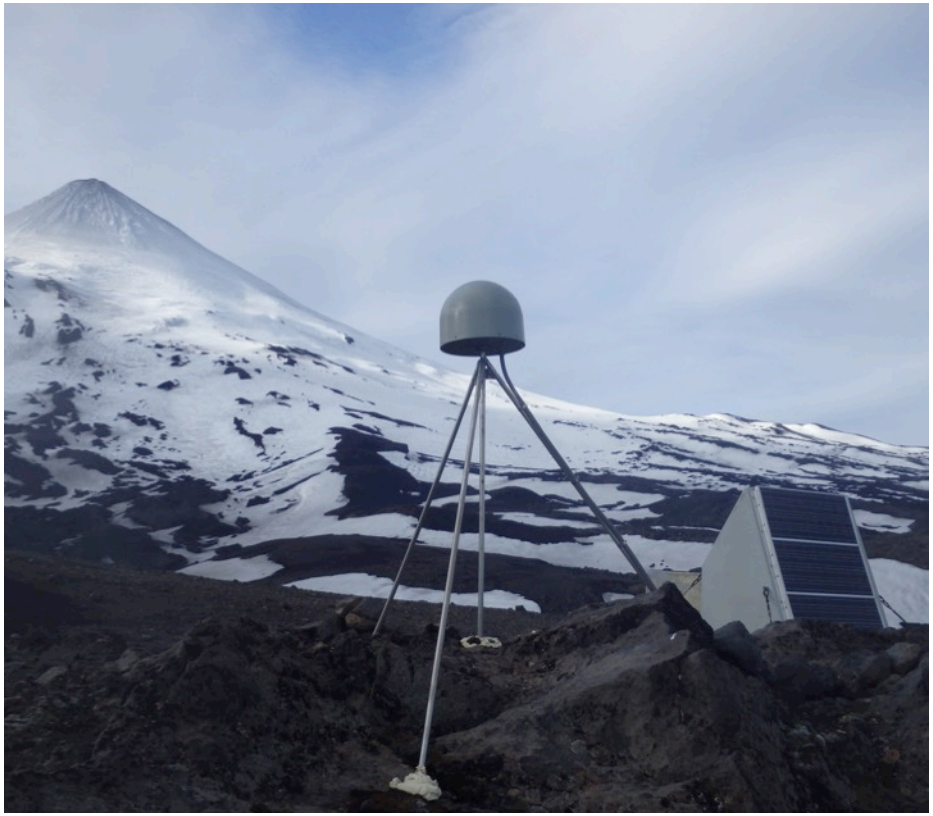
USArray (seismic network)
Plate Boundary Observatory (GPS network)
San Andreas Fault Observatory at Depth

**Like the Hubble Space Telescope, pointed down to look inside the Earth**



# Instrumentation

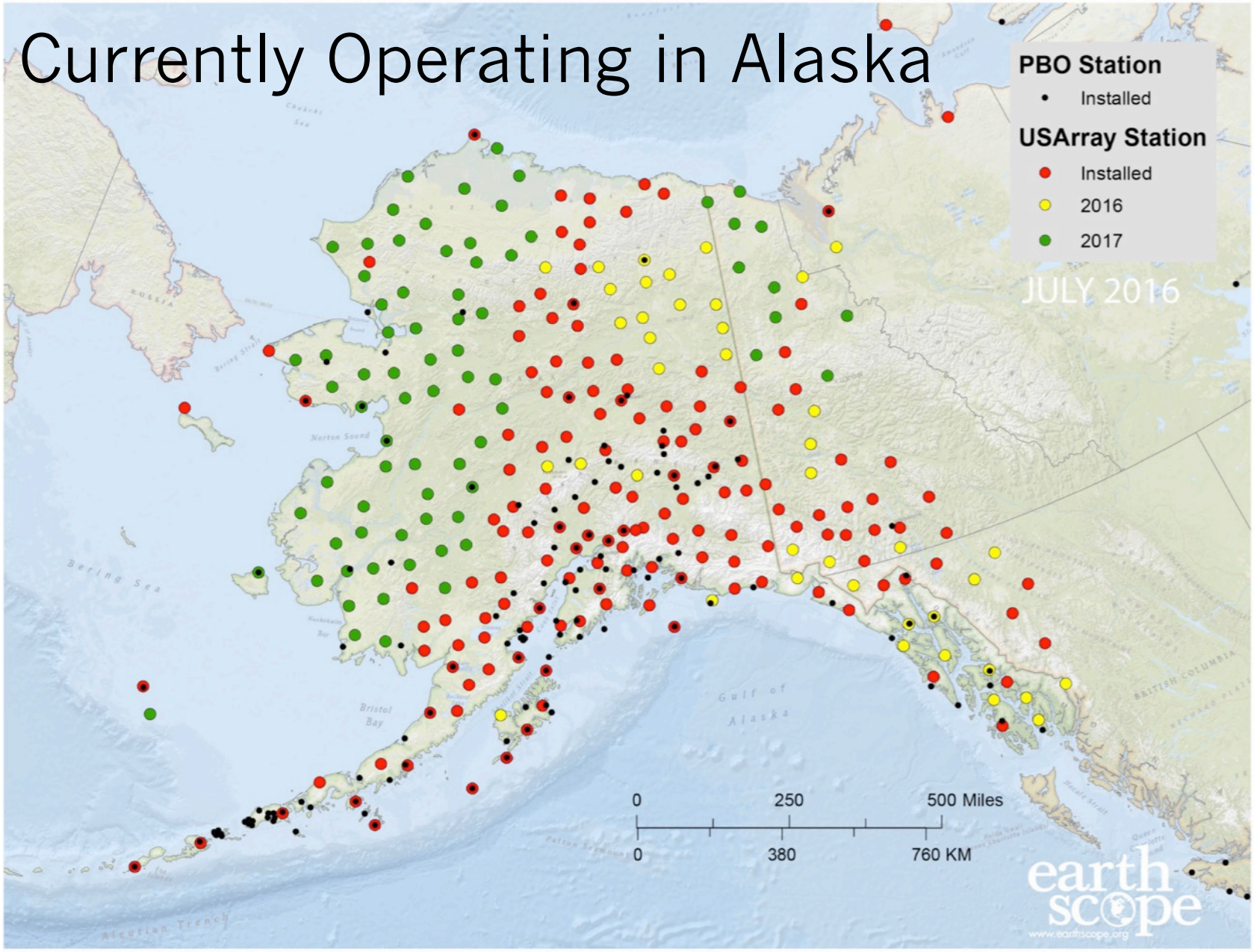
Seismometer



High precision GPS

earthscope

# Currently Operating in Alaska




NSF earthscope

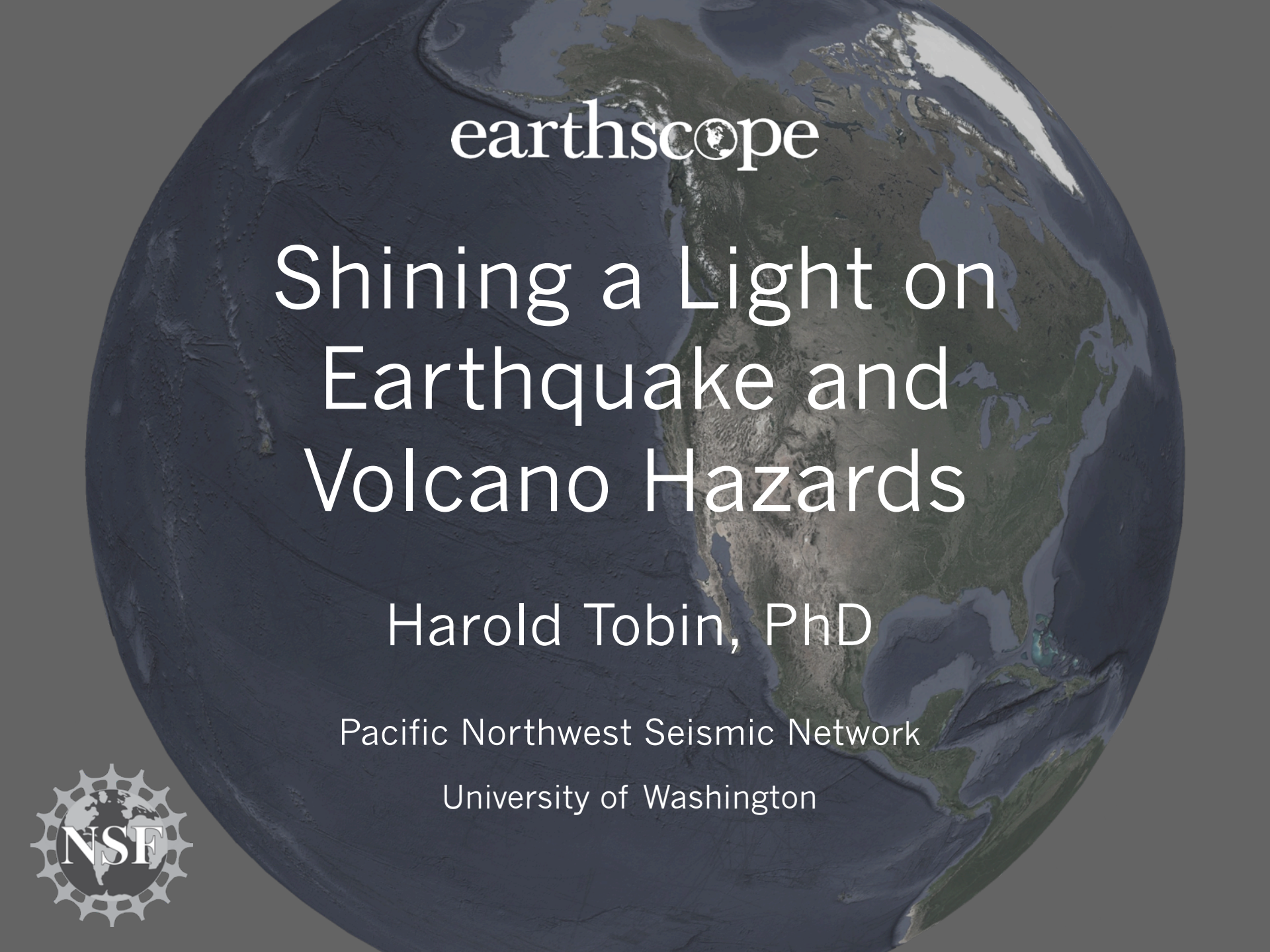
# Our Speakers

**Dr. Harold Tobin**
*University of Washington*
*Hazards*

**Dr. Beth Pratt-Sitaula**
*Central Washington University*
*And UNAVCO*
*Workforce*

**Dr. Michael Brudzinski**
*Miami University (Ohio)*
*Discoveries*

NSF earthscope



earthscope

# Shining a Light on Earthquake and Volcano Hazards


Harold Tobin, PhD

Pacific Northwest Seismic Network

University of Washington

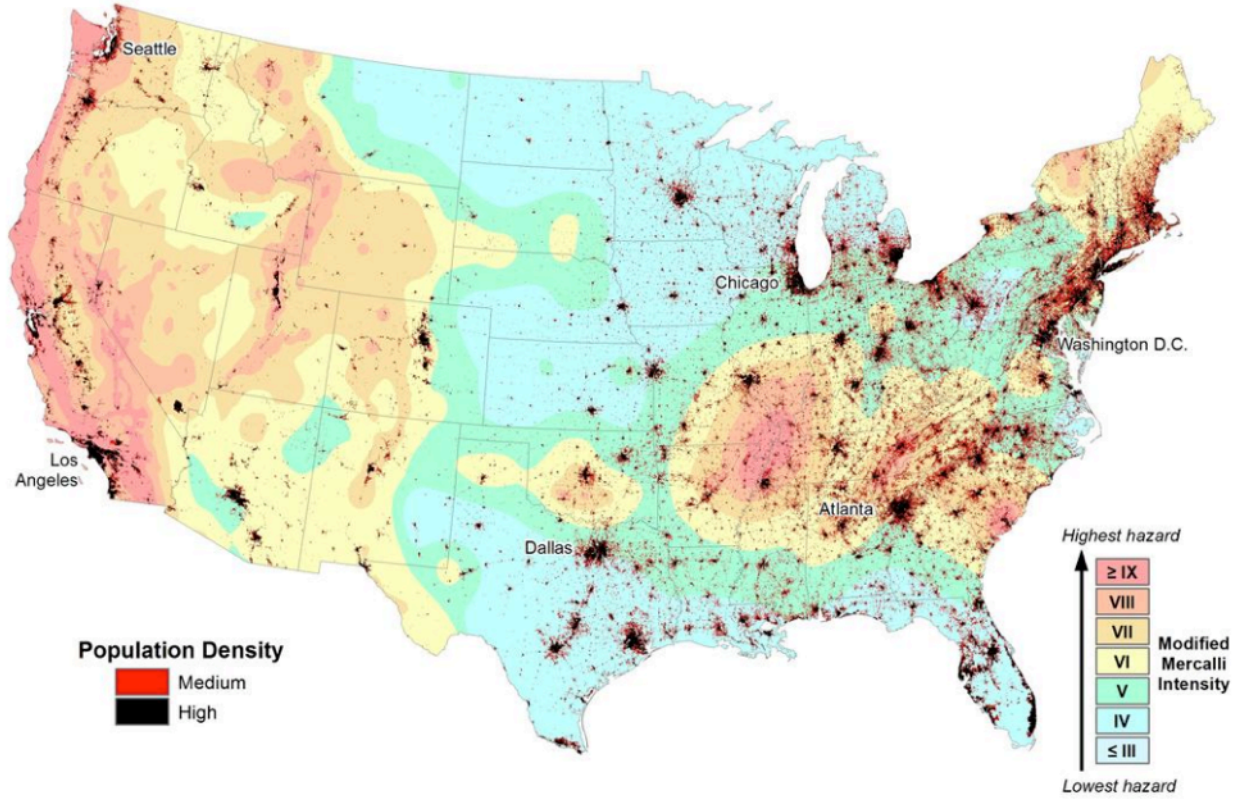

NSF

Japan earthquake & tsunami – March 11, 2011

**“Civilizations exist by geological consent, subject to change without notice.” - Will Durant,** *historian*

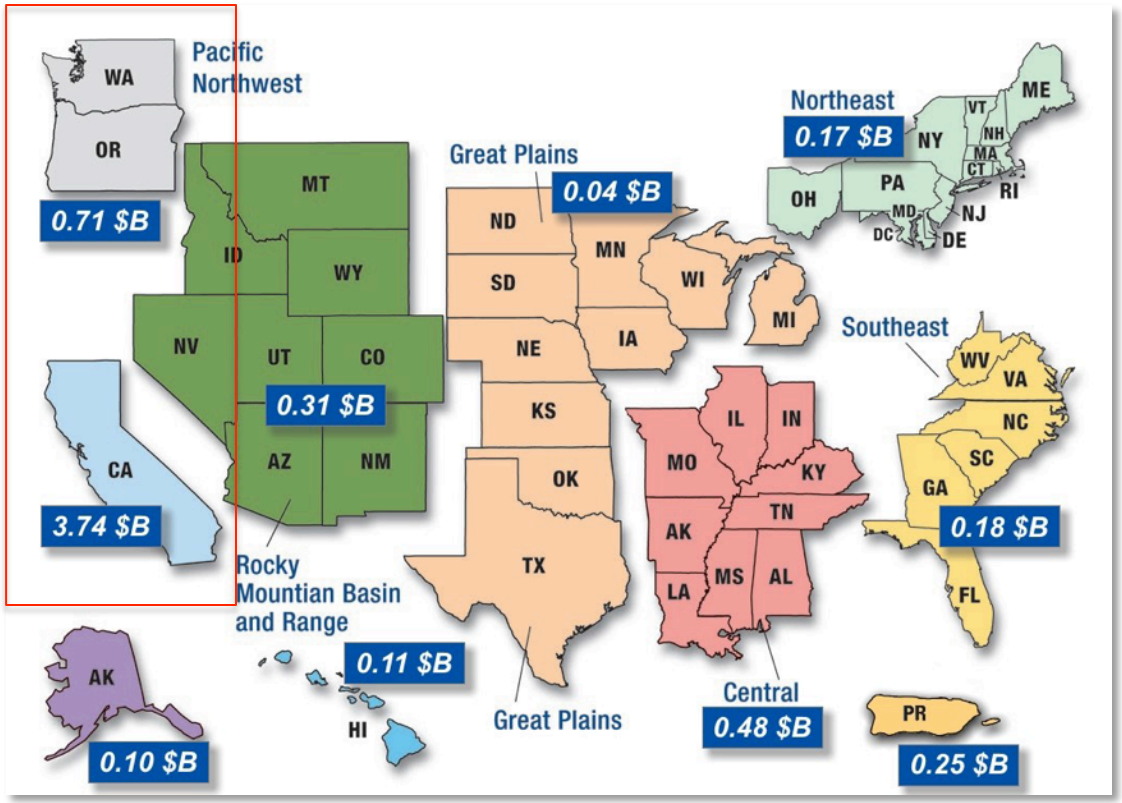
# Nearly half of all Americans are exposed to potentially hazardous earthquakes (as well as tsunamis and volcanoes)

USGS
science for a changing world



# *Annualized* **Earthquake Losses, $6.1B**

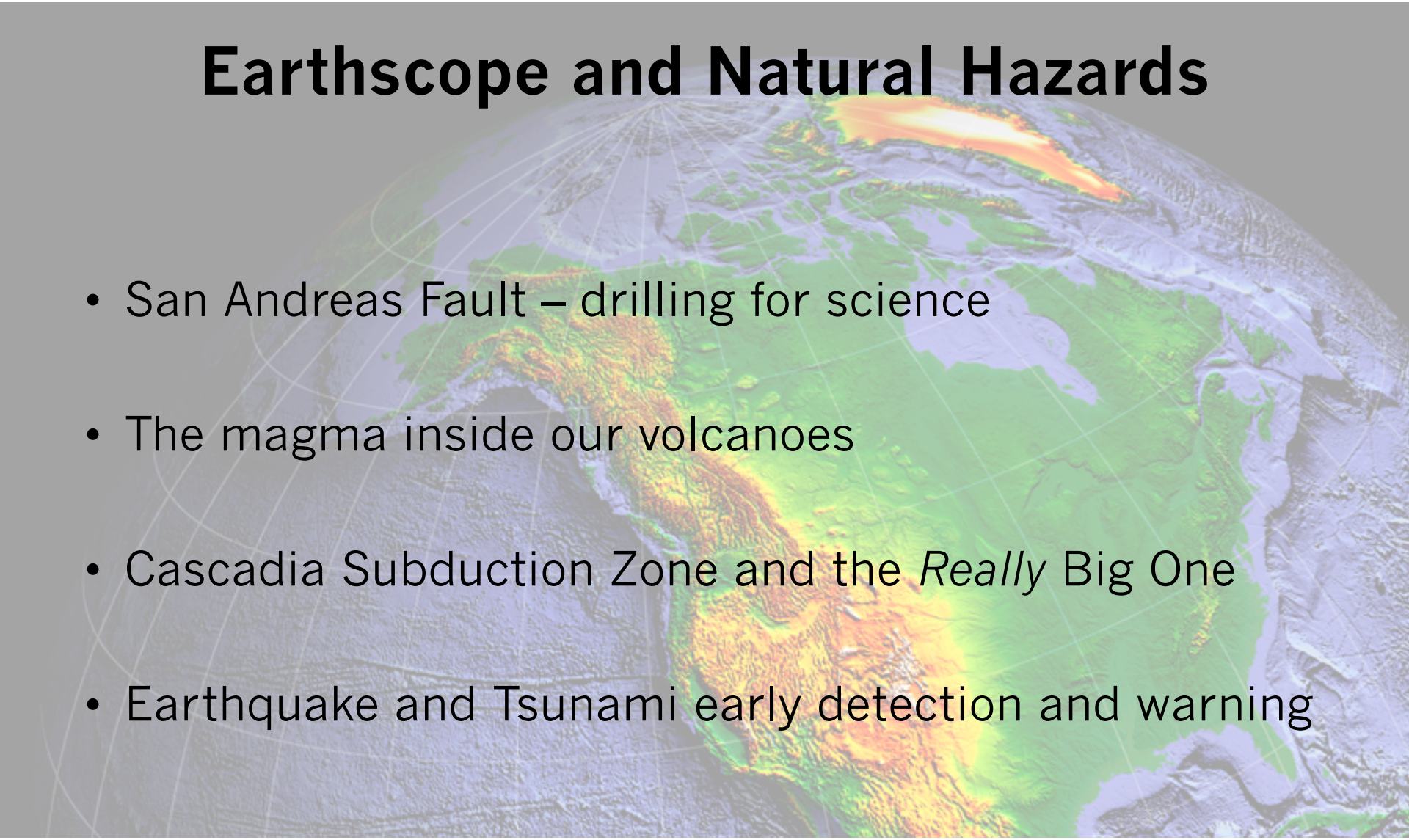
**61% in California, 73% on West Coast ($4.5B)**




*FEMA, P-366, 2017*

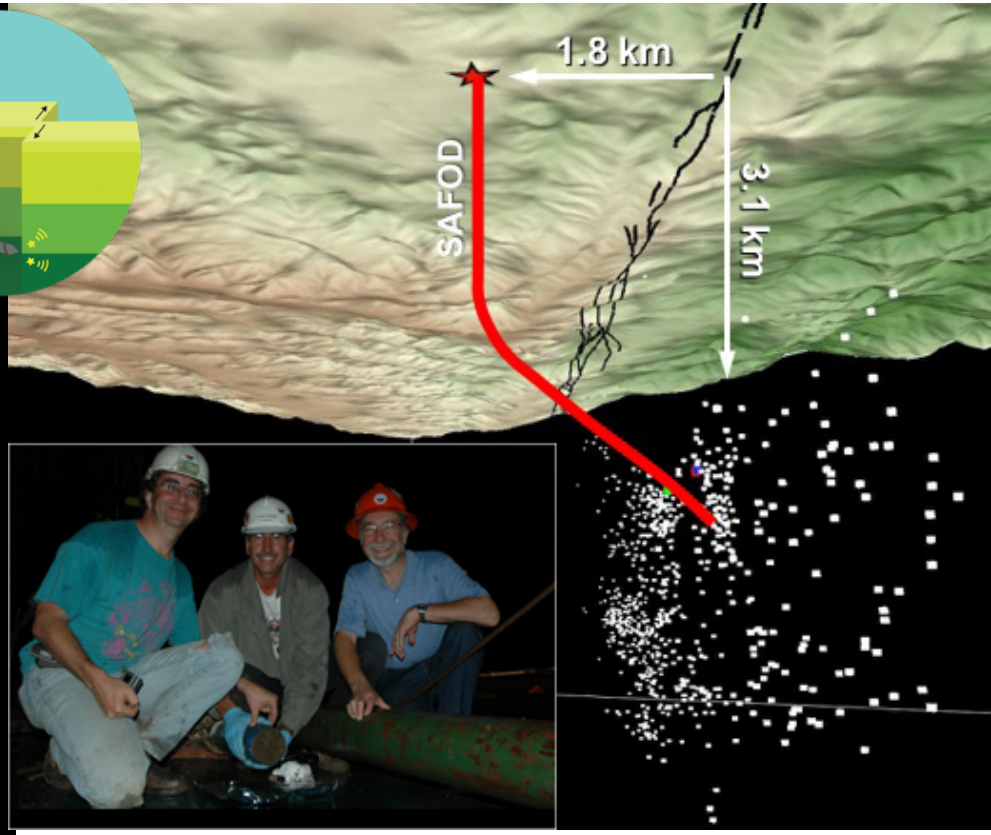
NSF earthscope

# Earthscope and Natural Hazards



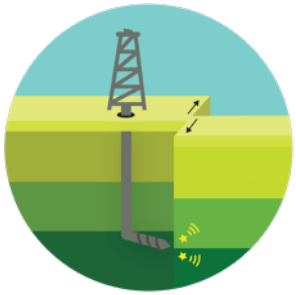
- San Andreas Fault – drilling for science
- The magma inside our volcanoes
- Cascadia Subduction Zone and the *Really* Big One
- Earthquake and Tsunami early detection and warning

NSF earthscope


# SAFOD:
# The San Andreas Fault Observatory at Depth

NSF earthscope



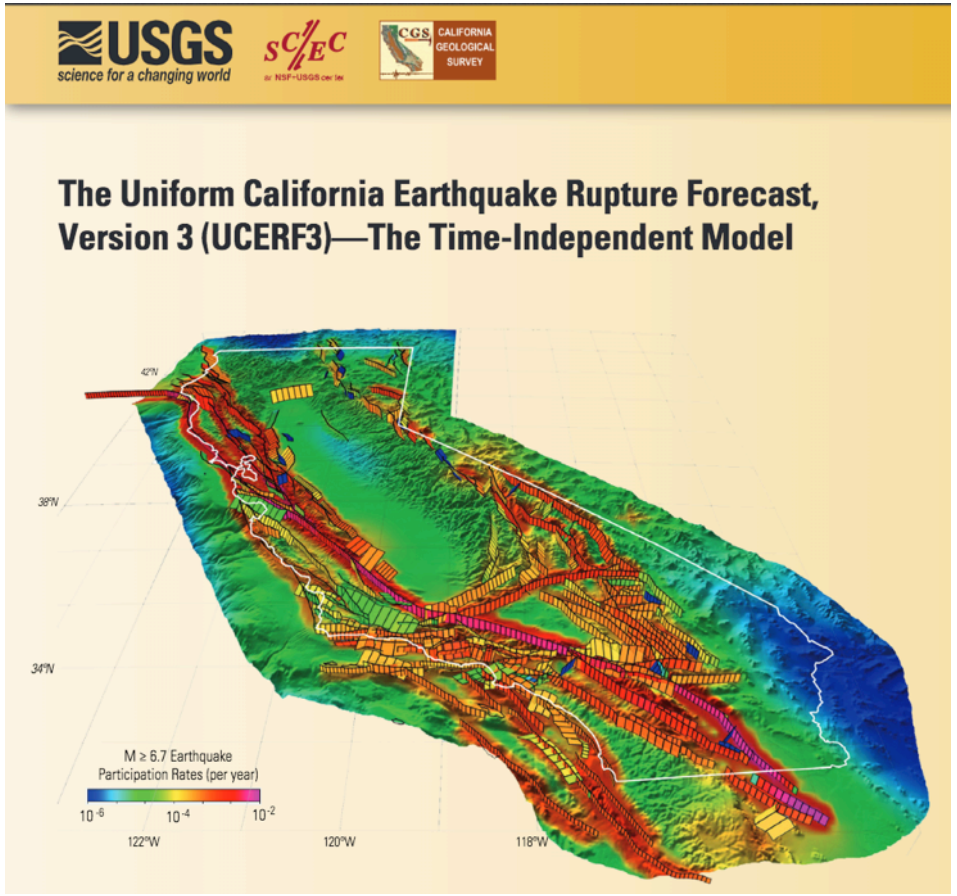
*Core samples from the actual San Andreas Fault at earthquake depths*

Showed us how the specific minerals and makeup of the fault zone control its seismic properties

NSF earthscope

# The California Hazard Model (UCERF3)

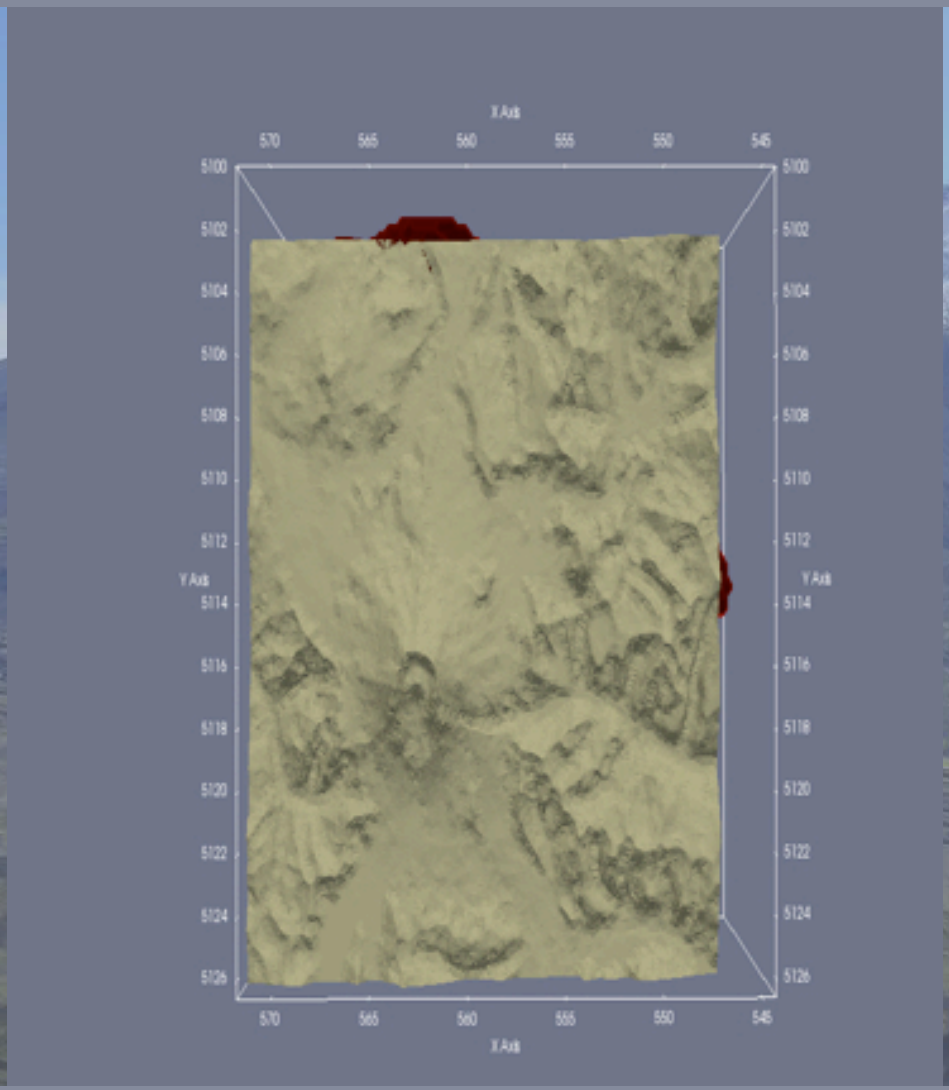
- A comprehensive earthquake hazard model
- Combines seismology, geodesy, and geology in a unified framework

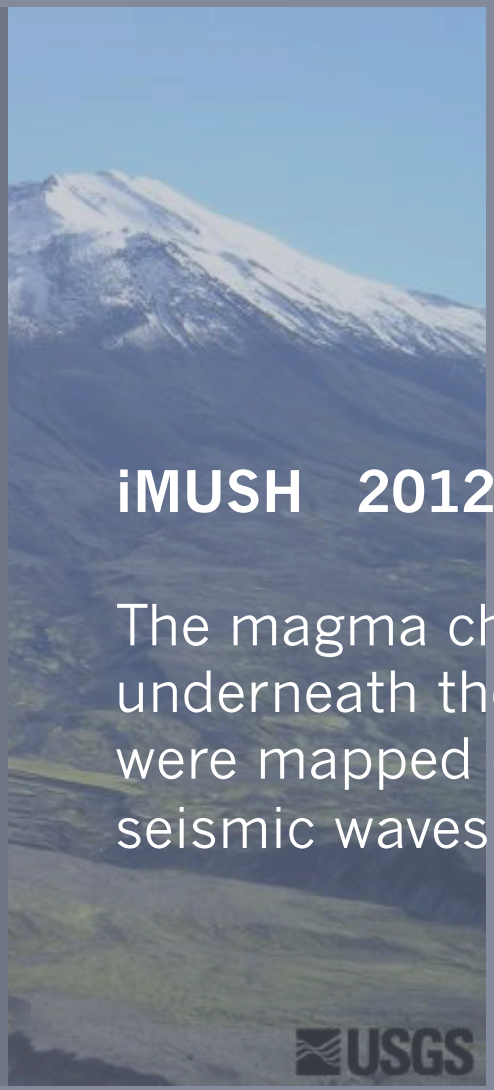



NSF earthscope

# *iMUSH:* Imaging Magma Under St. Helens

Thousands of seismometers were deployed all over Mt. St. Helens to "see" the underlying plumbing





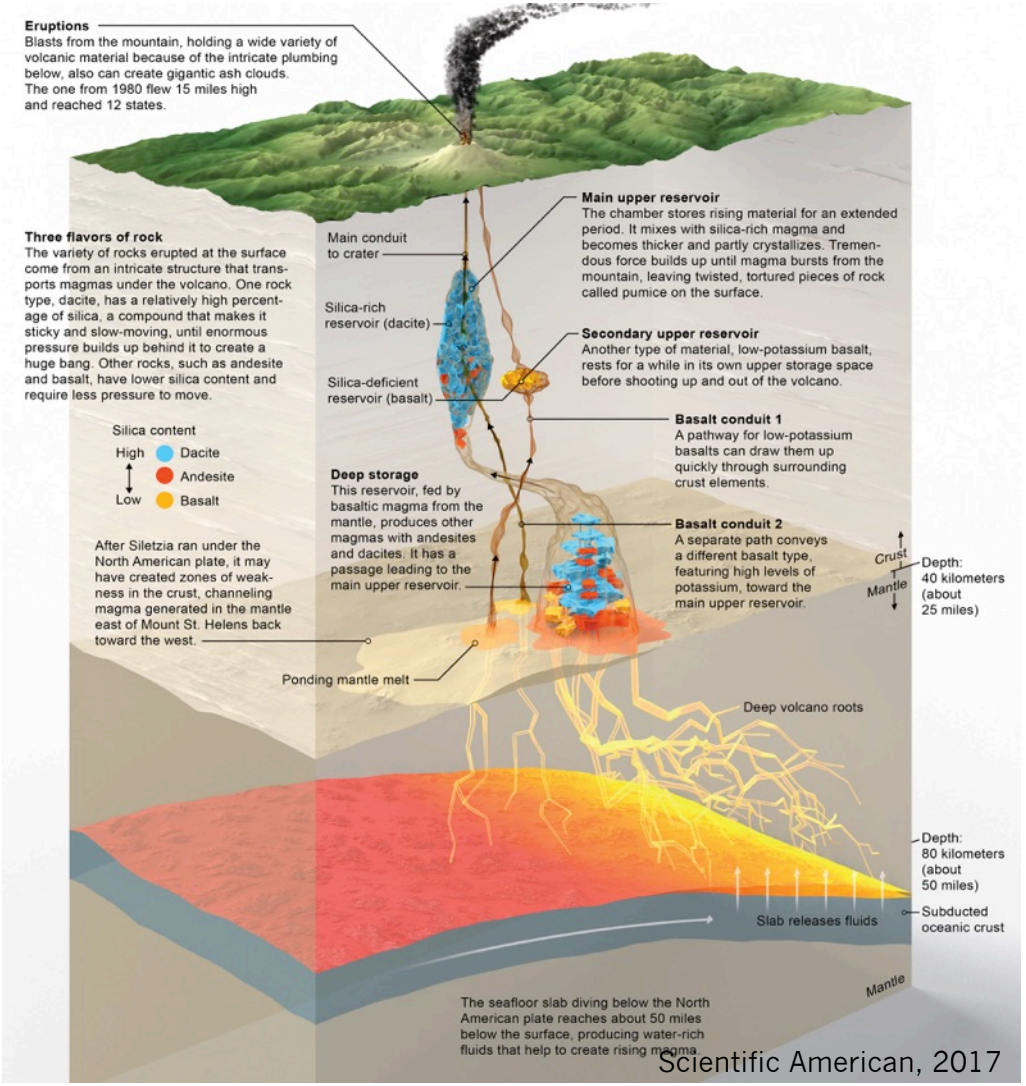
## iMUSH 2012 – 2016

The magma chambers underneath the volcano were mapped out in 3D by seismic waves

NSF earthscope

# iMUSH view of the guts of Mt. St. Helens

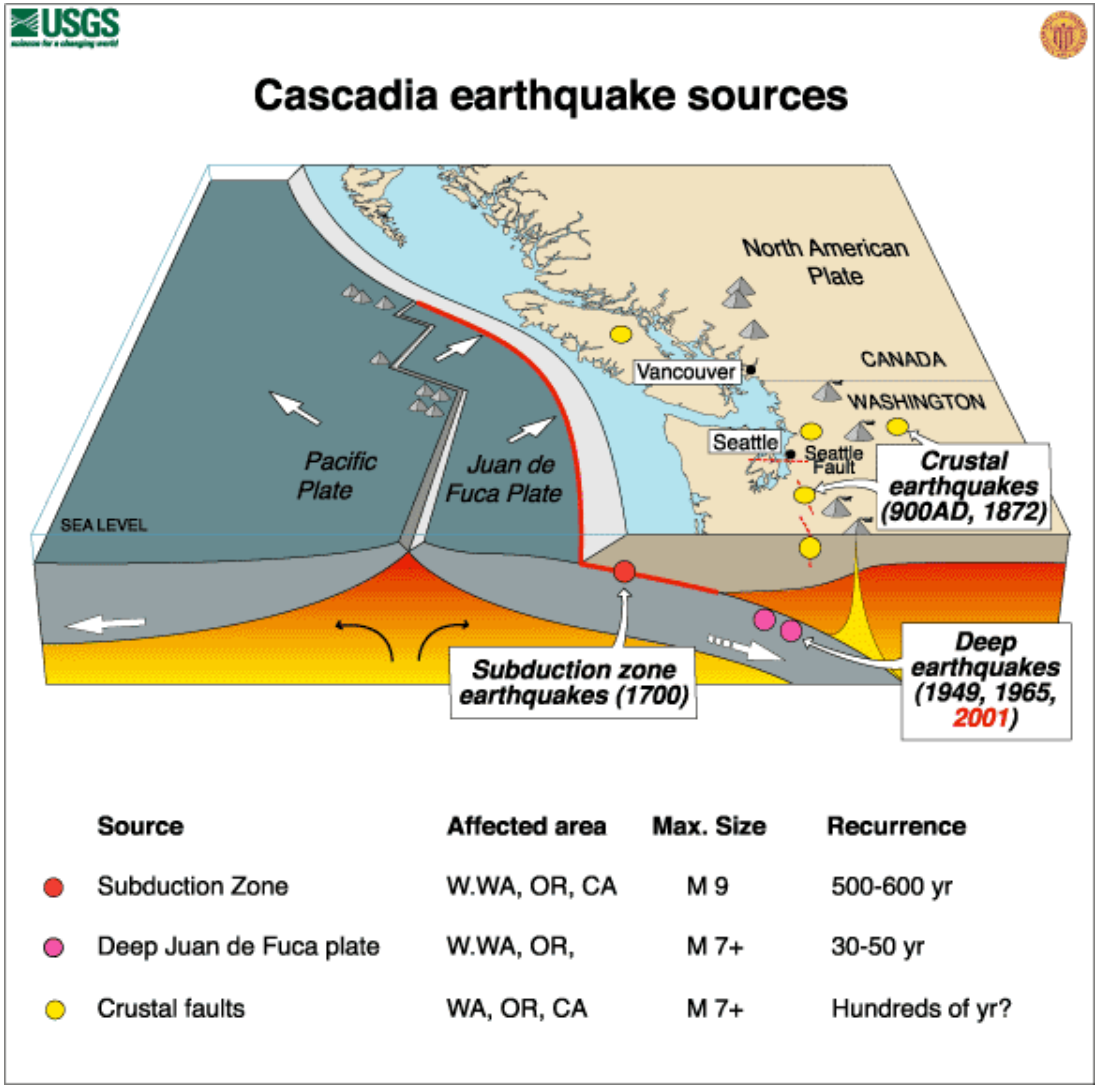
- Magma exists in multiple pools at different depths
- Insight into what swarms of earthquakes mean and when they suggest impending eruptions (and when they don't)



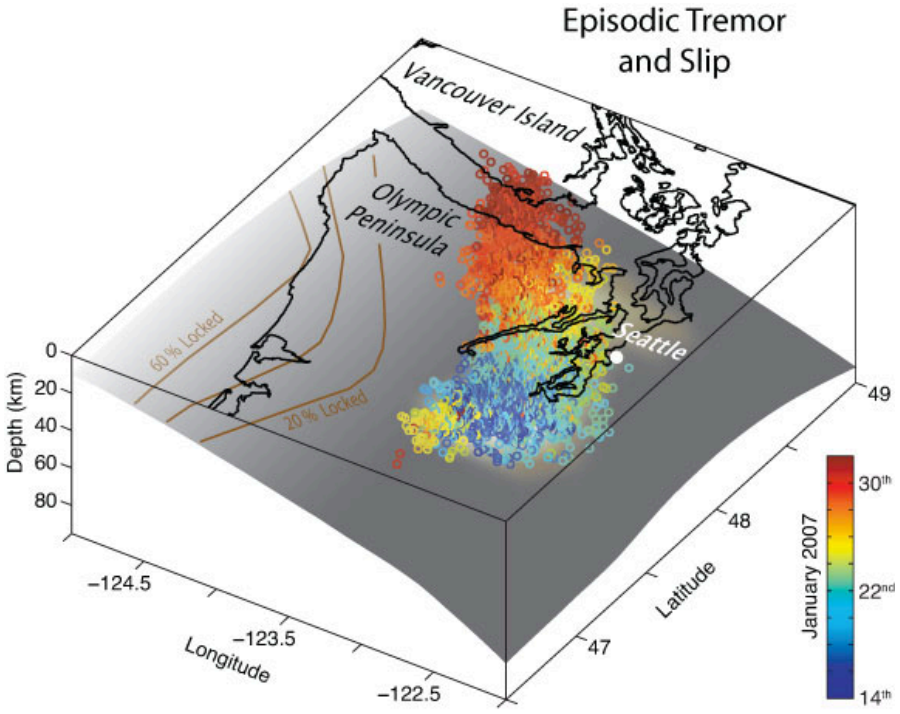

Scientific American, 2017

NSF earthscope

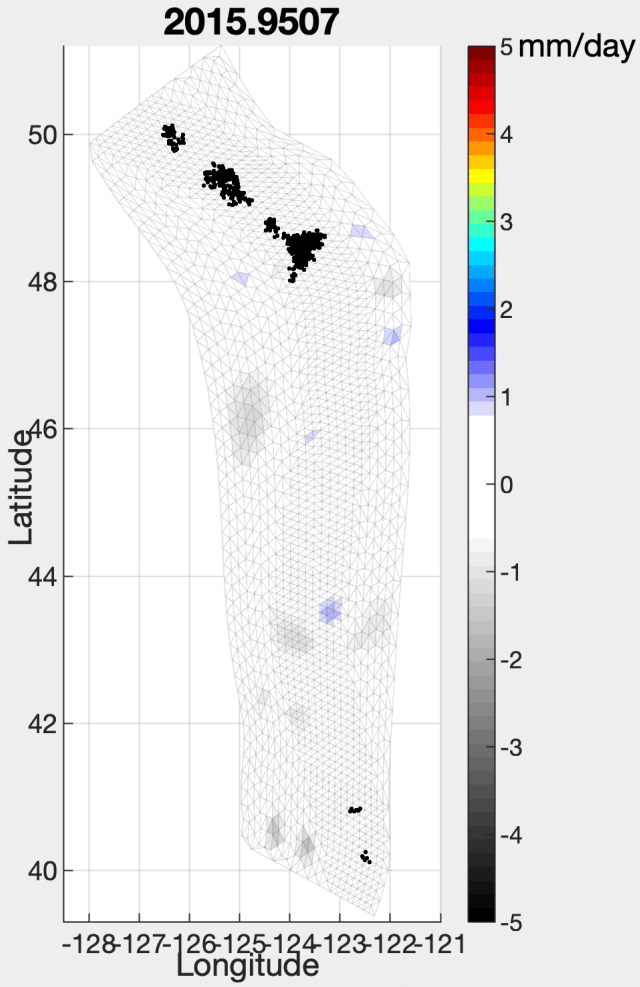

British Columbia
Explorer Ridge
Explorer Plate
Sovanco fracture zone
Nootka fracture zone
Vancouver Island
Vancouver
Seattle
1.5 in/yr
Juan de Fuca Ridge
Juan de Fuca Plate
Washington
Portland
Pacific Ocean
Newport
Blanco fracture zone
Oregon
Gorda Ridge
Gorda Plate
California
0
100
200
Miles
Mendicino fracture zone


USGS
Cascadia earthquake sources
North American Plate
CANADA
Vancouver
WASHINGTON
Seattle
Seattle Fault
Crustal earthquakes (900AD, 1872)
Pacific Plate
Juan de Fuca Plate
SEA LEVEL
Subduction zone earthquakes (1700)
Deep earthquakes (1949, 1965, 2001)
Source
Affected area
Max. Size
Recurrence
Subduction Zone
W.WA, OR, CA
M 9
500-600 yr
Deep Juan de Fuca plate
W.WA, OR,
M 7+
30-50 yr
Crustal faults
WA, OR, CA
M 7+
Hundreds of yr?

# The plate edges are alive in ways we didn't know before




Creager et al., 2008




Animation by Noel Bartlow

NSF earthscope

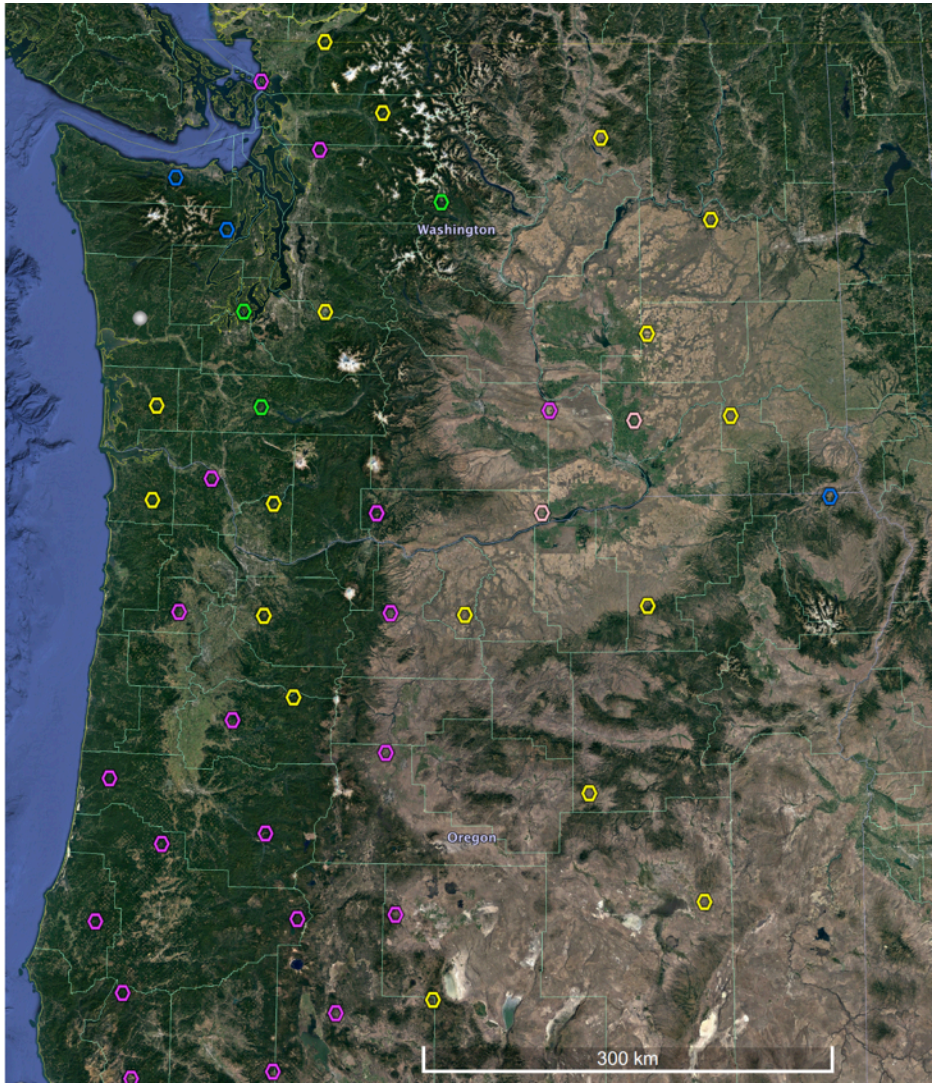
**EARTHSCOPE seismic monitoring stations that were permanently "adopted" by the Pacific Northwest Seismic Network**

- contribute directly to the new earthquake early warning system called *ShakeAlert*

- Improved our ability to detect earthquakes & determine their magnitude *in real time*

ShakeAlert

PNSN
Pacific Northwest Seismic Network

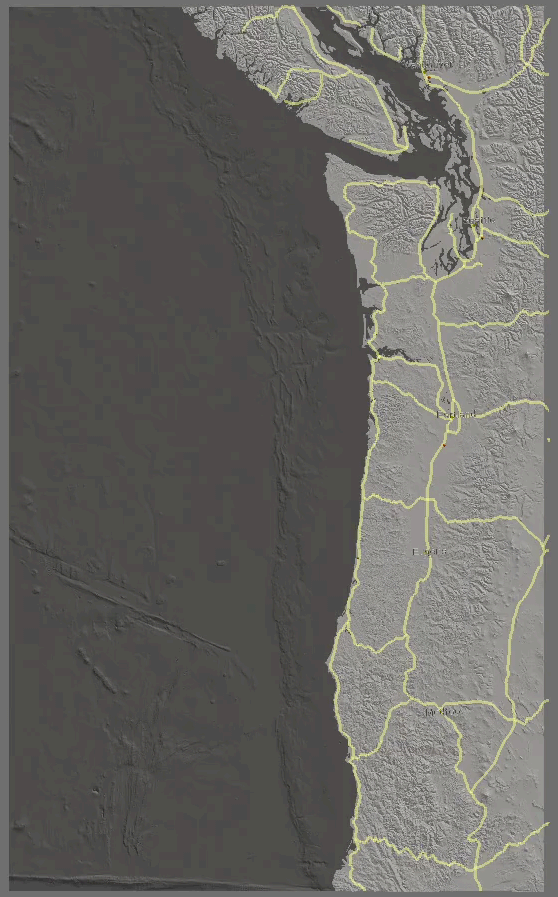


SDSU

Daniel Roten · San Diego State

# The *Really* Big One:

# Understanding the hazard from the Cascadia Subduction Fault



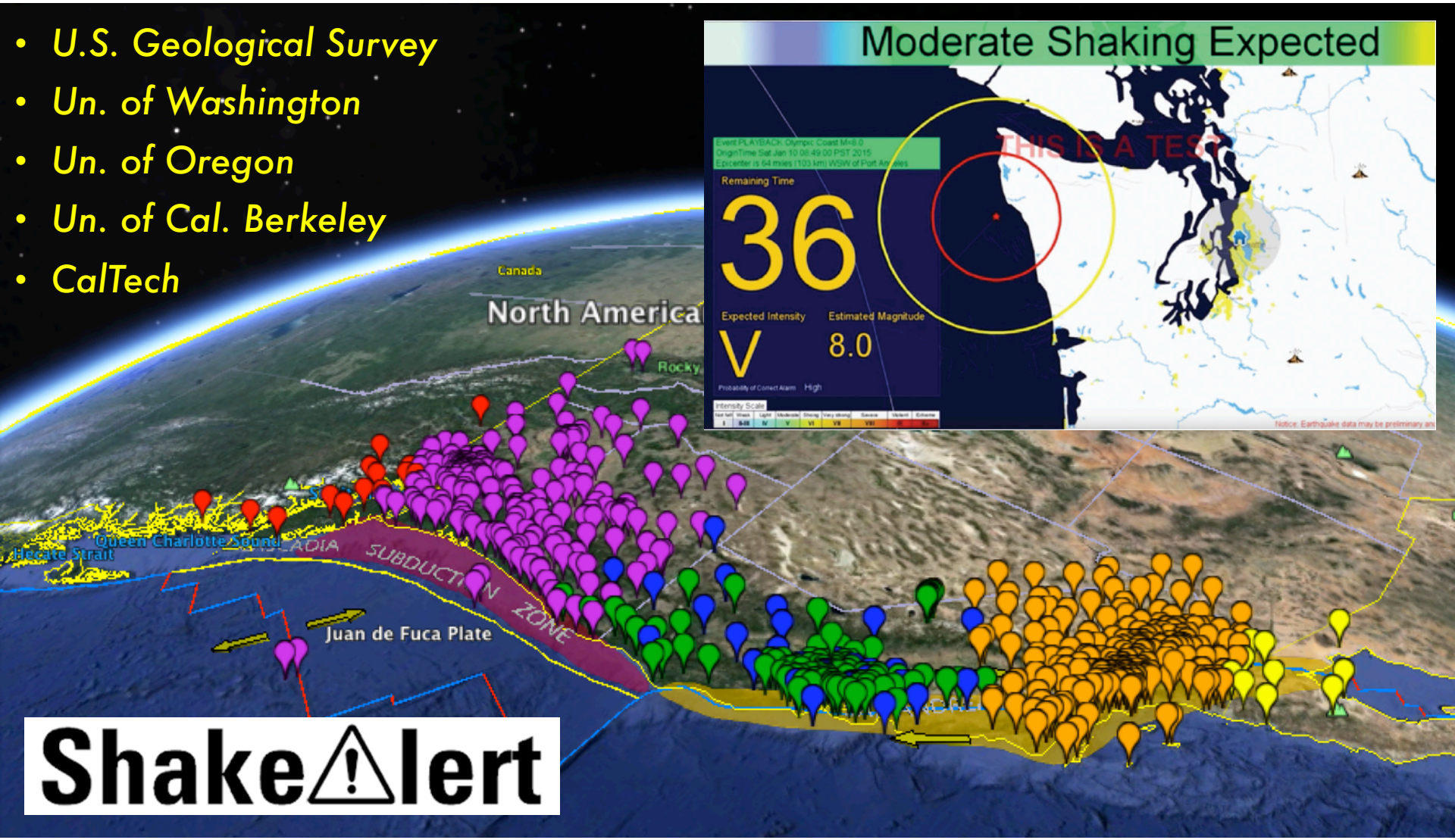
Plastic Strain (log10)
-4 -3 -2 -1

EW-Velocity (m/s)
-0.6 -0.3 0.0 0.3 0.6

0.3 s

NSF earthscope

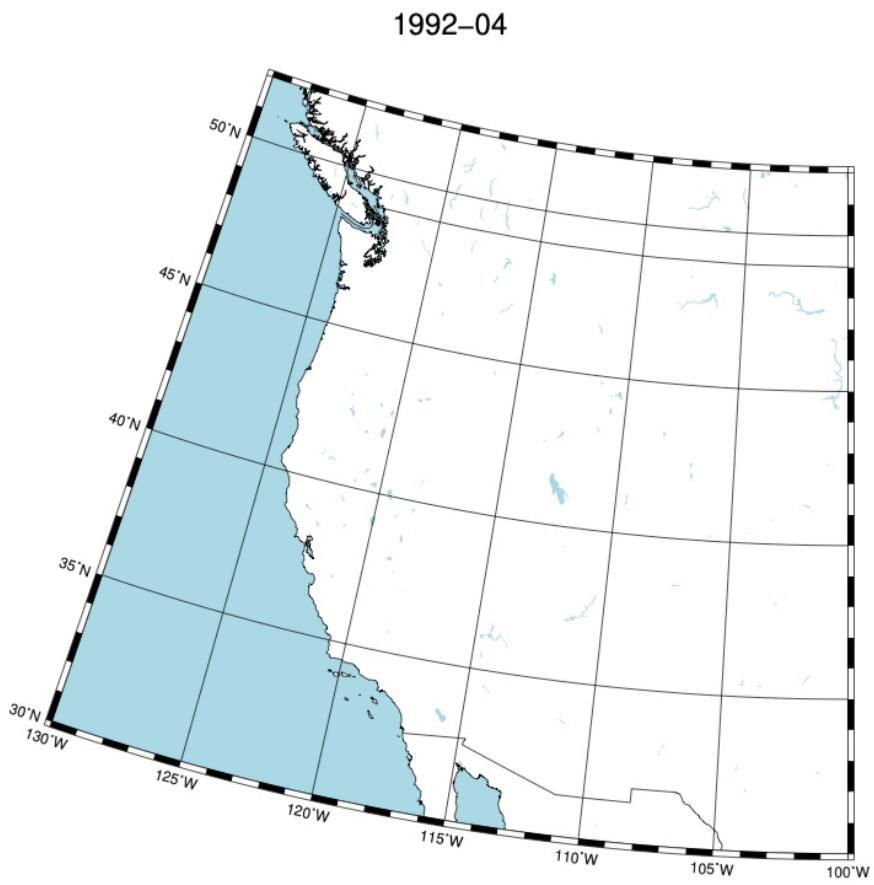
- *U.S. Geological Survey*
- *Un. of Washington*
- *Un. of Oregon*
- *Un. of Cal. Berkeley*
- *CalTech*



# Plate Boundary Observatory (PBO) GPS fixed stations

- 1278 PBO stations were installed to measure the motion of the tectonic plates
- Direct answers: where are the faults and are they "stuck" leading to major earthquakes?

PBO GPS station buildout

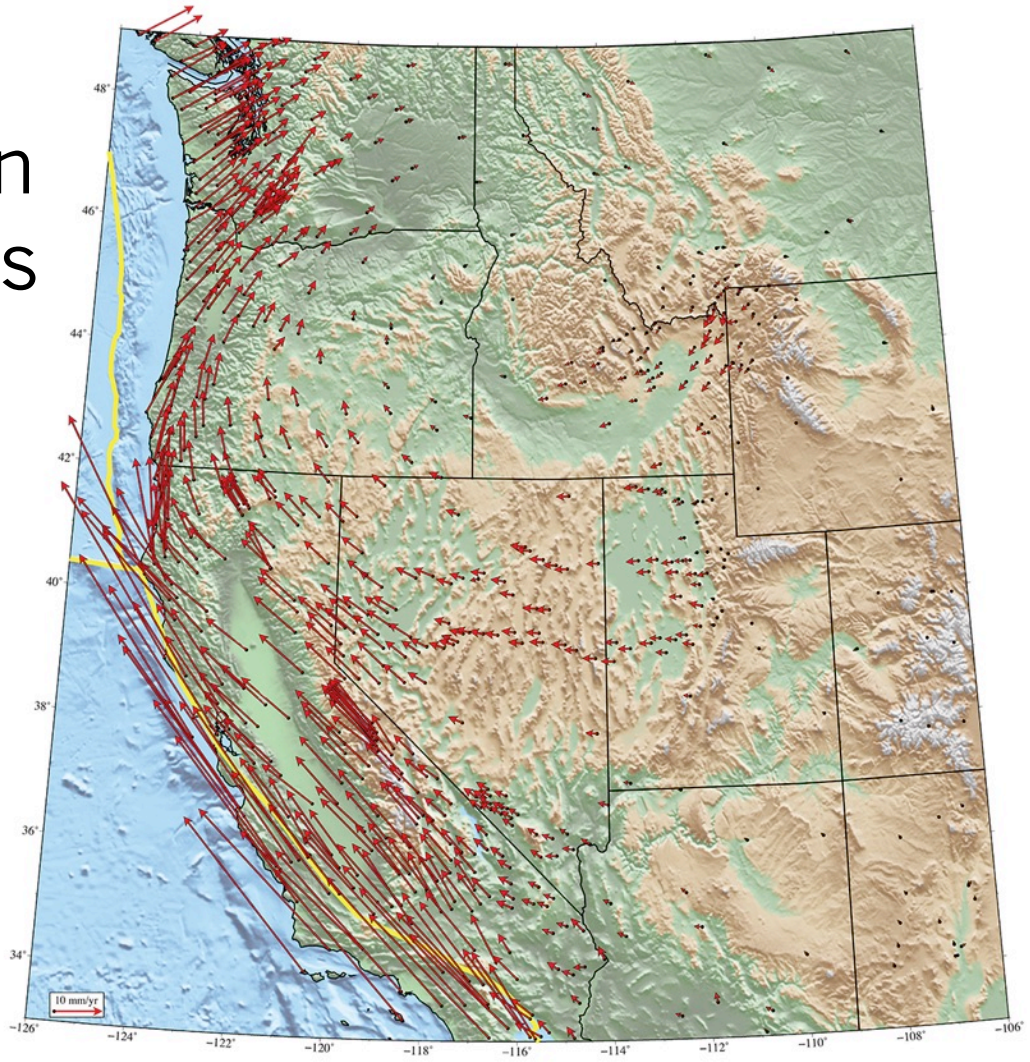



Courtesy of Dave Mencin

NSF earthscope

# Earthscope PBO measures the motion of the tectonic plates

- The arrows show the inches of motion per year
- The plates are stuck at their edges
  - San Andreas
  - Cascadia
  - numerous other faults

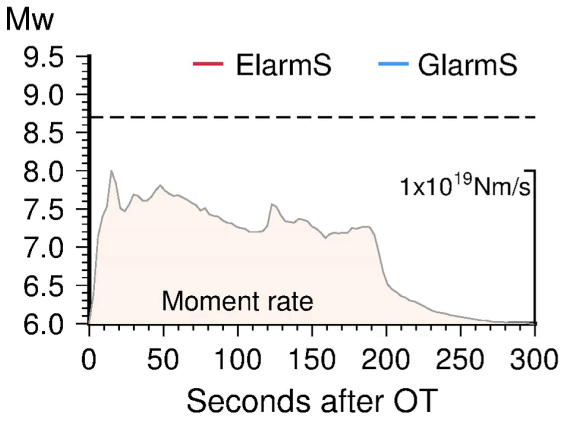


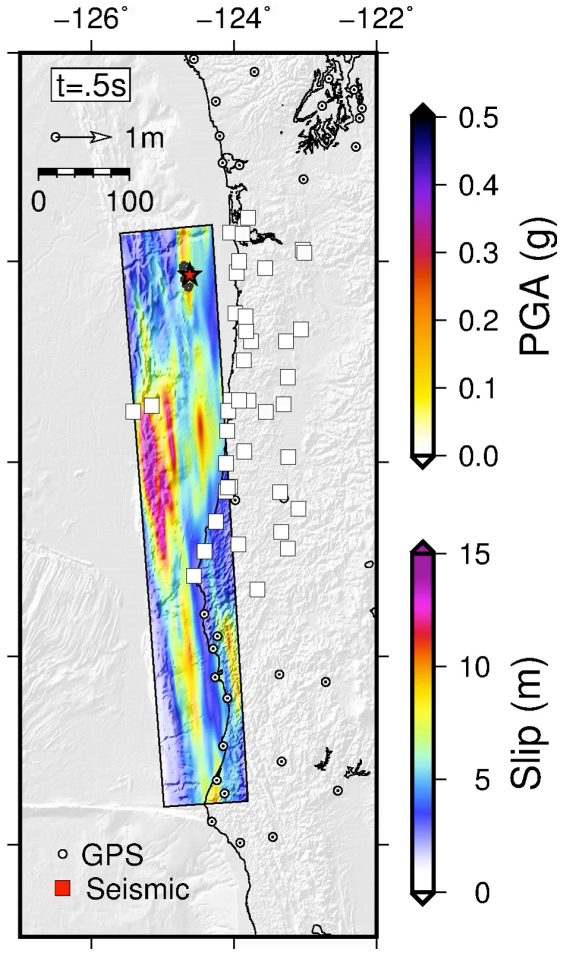

NSF earthscope

# *Pilot New Application:*

Using GPS to measure the movements of the Earth's crust *during* the earthquake itself *in real time*

Rapidly determine earthquake magnitude and tsunami potential!



# Earthscope has contributed so much to understanding of these and other hazards

- Earthquakes, what leads up to them, detection and early warning
- Volcanic activity and precursors of eruptions
- Tsunami forecasting in real time
- Earthquakes in new areas (Oklahoma, eastern seaboard)
- Drought
- Electromagnetic storms


earthscope


Questions?


# Science as a Springboard for Resilience

Beth Pratt-Sitaula, PhD

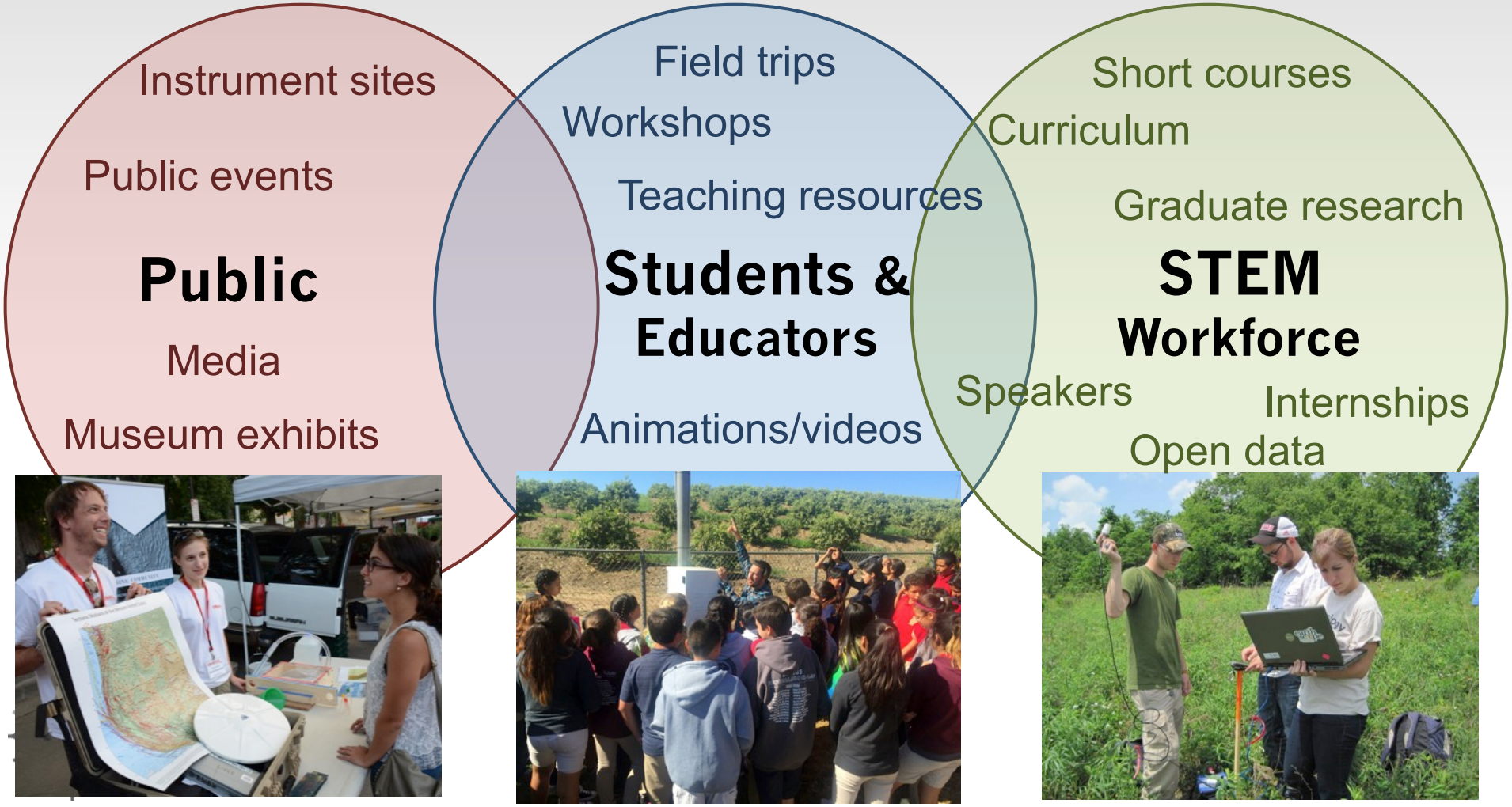
UNAVCO

Central Washington University

NSF

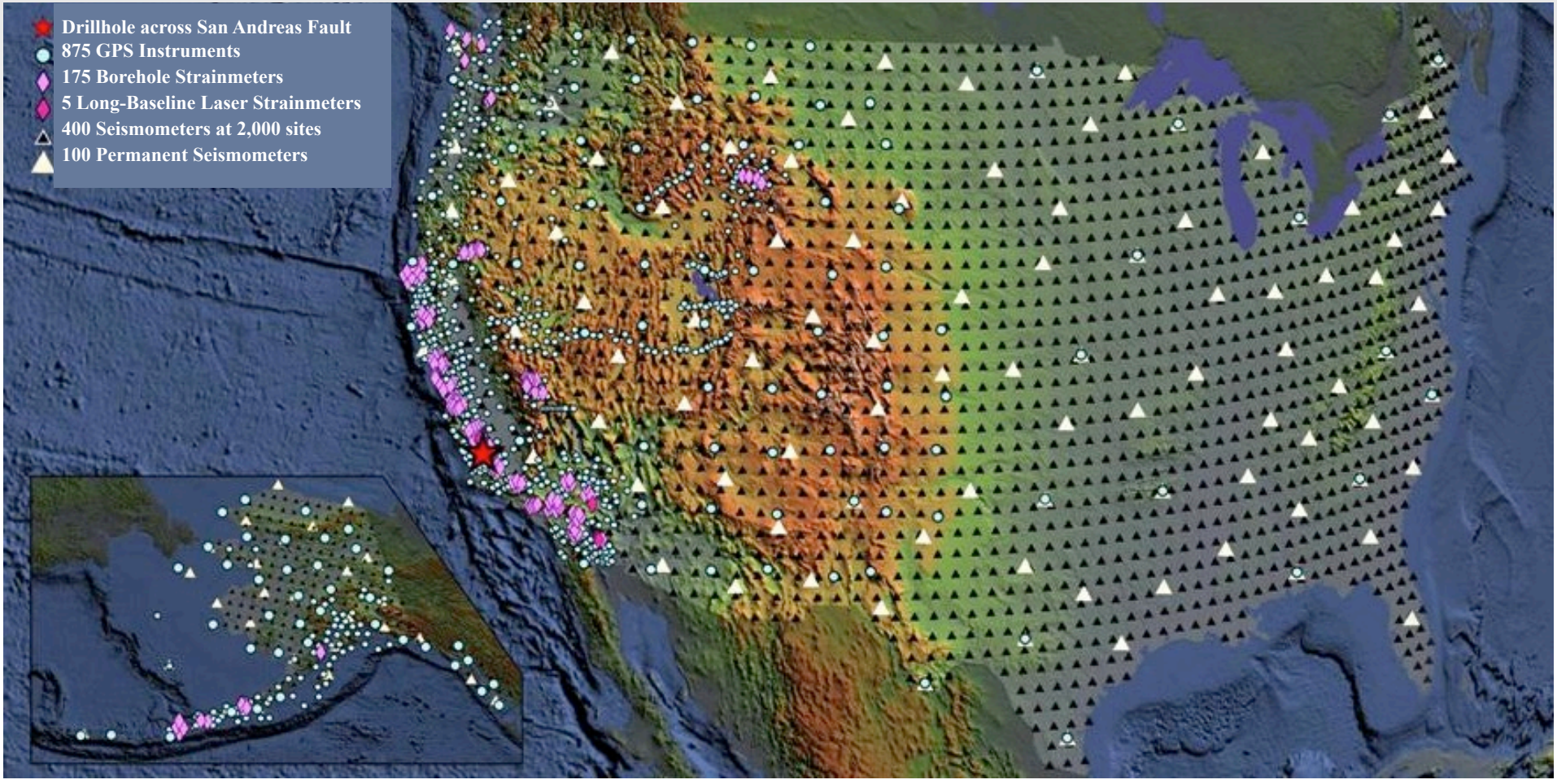
# National Opportunity

- Outreach-Education-Workforce Training
- Increase resilience to natural hazards



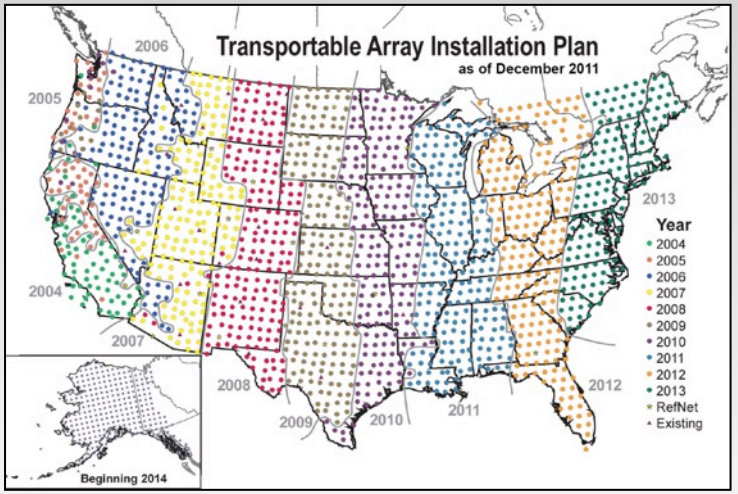
# Instrument Siting

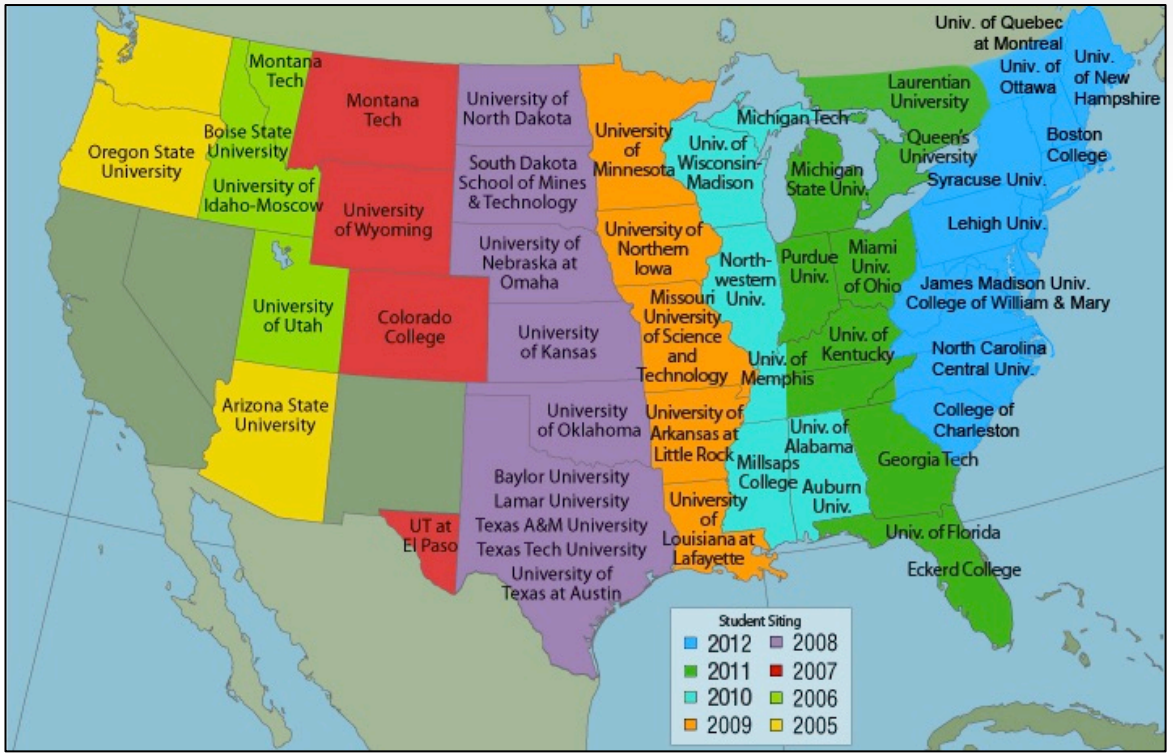
- Outreach/public education & workforce training
- >7000 instrument sites



# Students help instrument siting

- 9 workshops
- 135 students
- 51 institutions
- ~1375 sites identified
- Learn science communication
- Learn siting considerations
- Participate in major research effort




NSF earthscope

# Land Owners Learn EarthScope Science

- >7000 instrument sites
- Many thousands residents reached
- Science follow up with some (schools, parks, critical sites)


PBO SiteLog

An Update on the EarthScope Plate Boundary Observatory

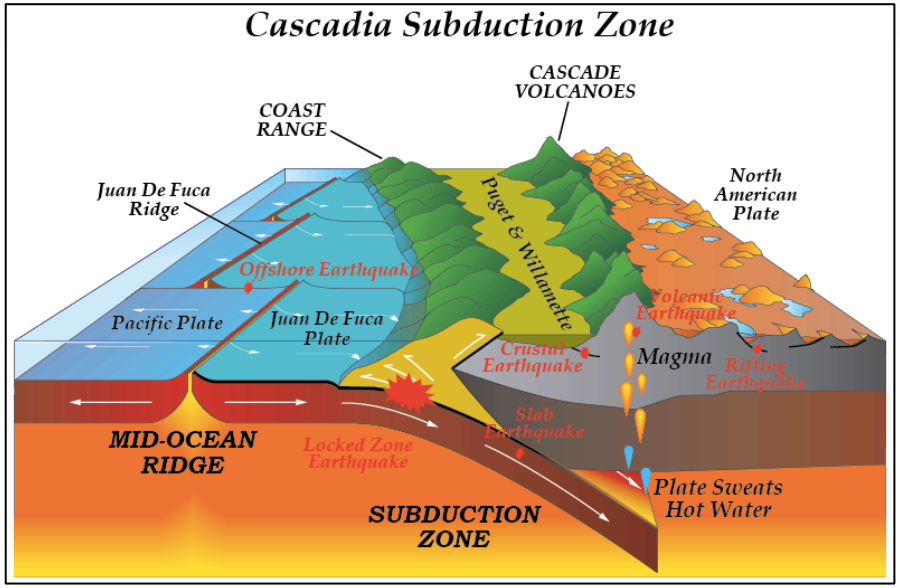

earthscope

# Geoscience Education Workshops

- Working with educators to spread the impact of science learning & preparedness
- >40 workshops
- >1300 educators directly reached (teachers, park/ museum interpreters, emergency/safety educators)
- >600,000 learners & other educators impacted

# Cascadia EarthScope Earthquake & Tsunami Education Program

- Challenges
  - Mag 9 earthquakes (last one was Jan 26, 1700)
  - Massive locally generated tsunami wave set
  - Coastal educators do not have knowledge to teach the science
  - Preparedness not well integrated to science and safety
  - Educators often isolated

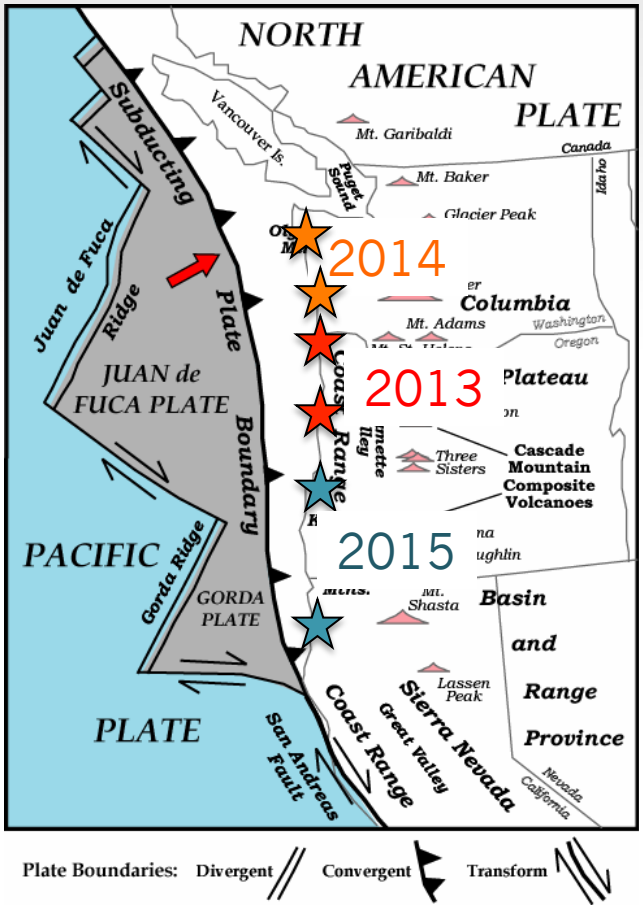



NSF earthscope

# Goals & Scope

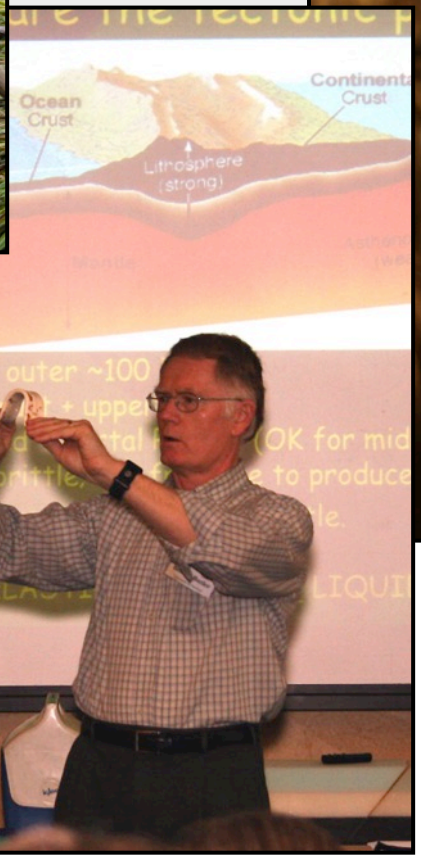
- Primary Aim: Improve disaster resilience through educator professional development
- Goals – Participants:
  - Learn Geoscience
  - Understand Risk
  - Take Action
  - Collaborate

- 2 workshops/yr
- ~25 participants
- 4 days
- 1 Share-a-thon/yr

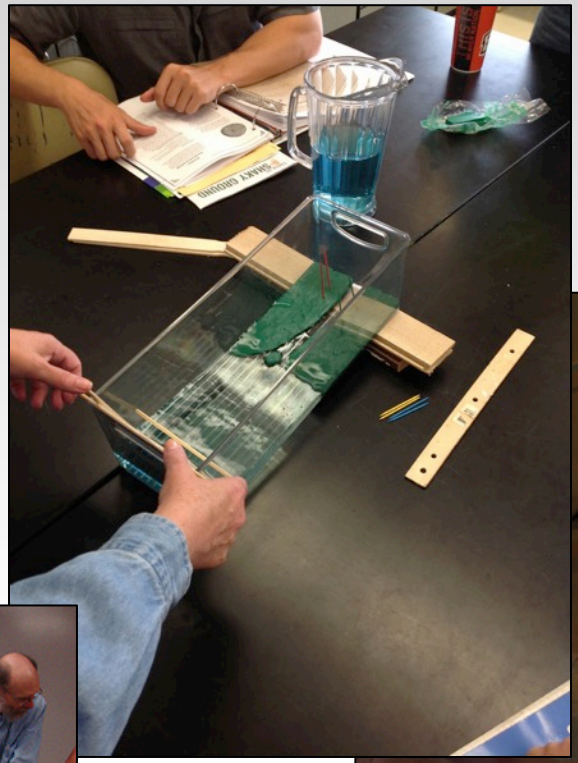



NSF earthscope

# Earth Science Content


# Best Practice Teaching Methods




# Extension Examples

- Museum tsunami community day

- Student-led preparedness assemblies


- 6th grade tsunami research & preparedness plan

NSF earthscope

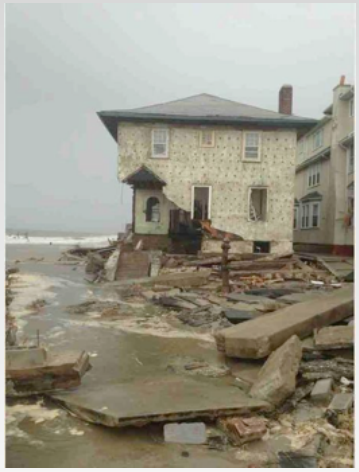
# Undergraduate Education

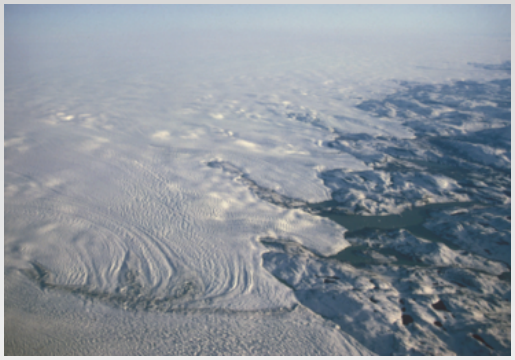
- Workforce training – better teaching resources and professional development for instructors


  - EarthScope funds helped to initiate
  - Online teaching modules
  - Workshops for instructors

NSF earthscope

## Solving societal challenges





## Increasing student STEM engagement

**Complementary paths to improvement**

NSF earthscope

# Measuring Water Resources with GPS, Gravity, and Traditional Methods

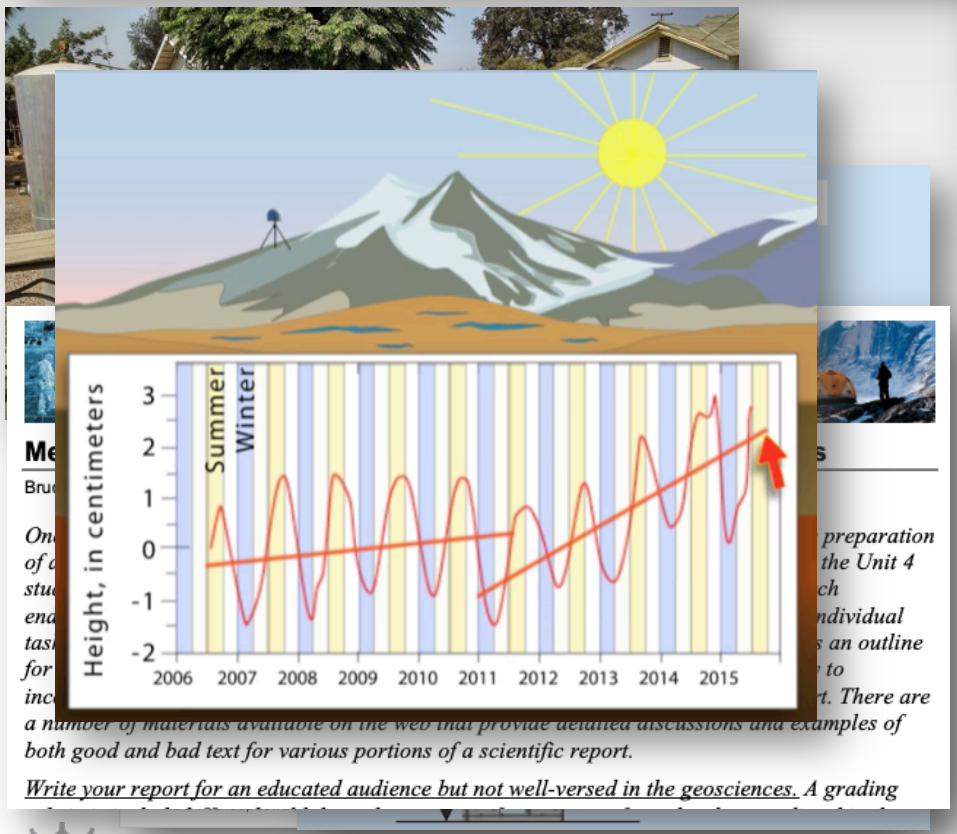
100 200 300 400

Intermediate-Advanced

2-3 Weeks

4 Units

Bruce Douglas (Indiana University-Bloomington)
Eric Small (University of Colorado at Boulder)
Editor: Beth Pratt-Sitaula (UNAVCO)



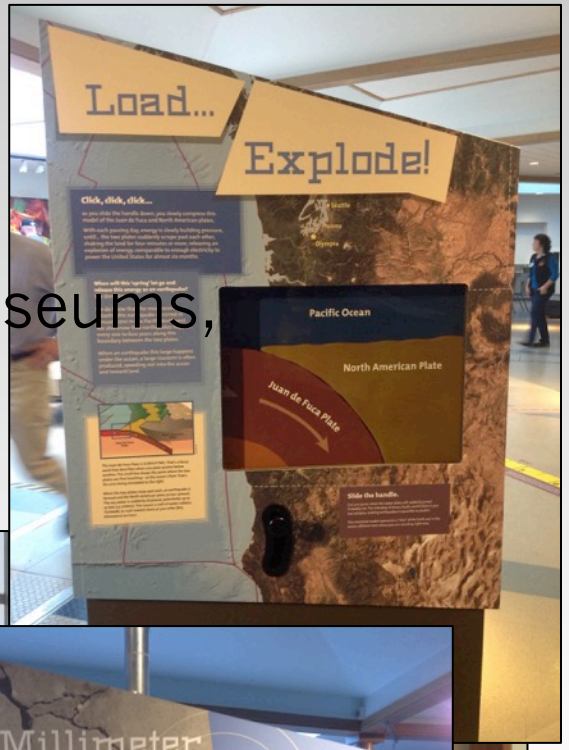

## Table of Contents



NSF earthscope

# Museum Displays

- Focus on hazards and seismology
- 100 "Active Earth" kiosk displays at museums, universities, and visitor centers

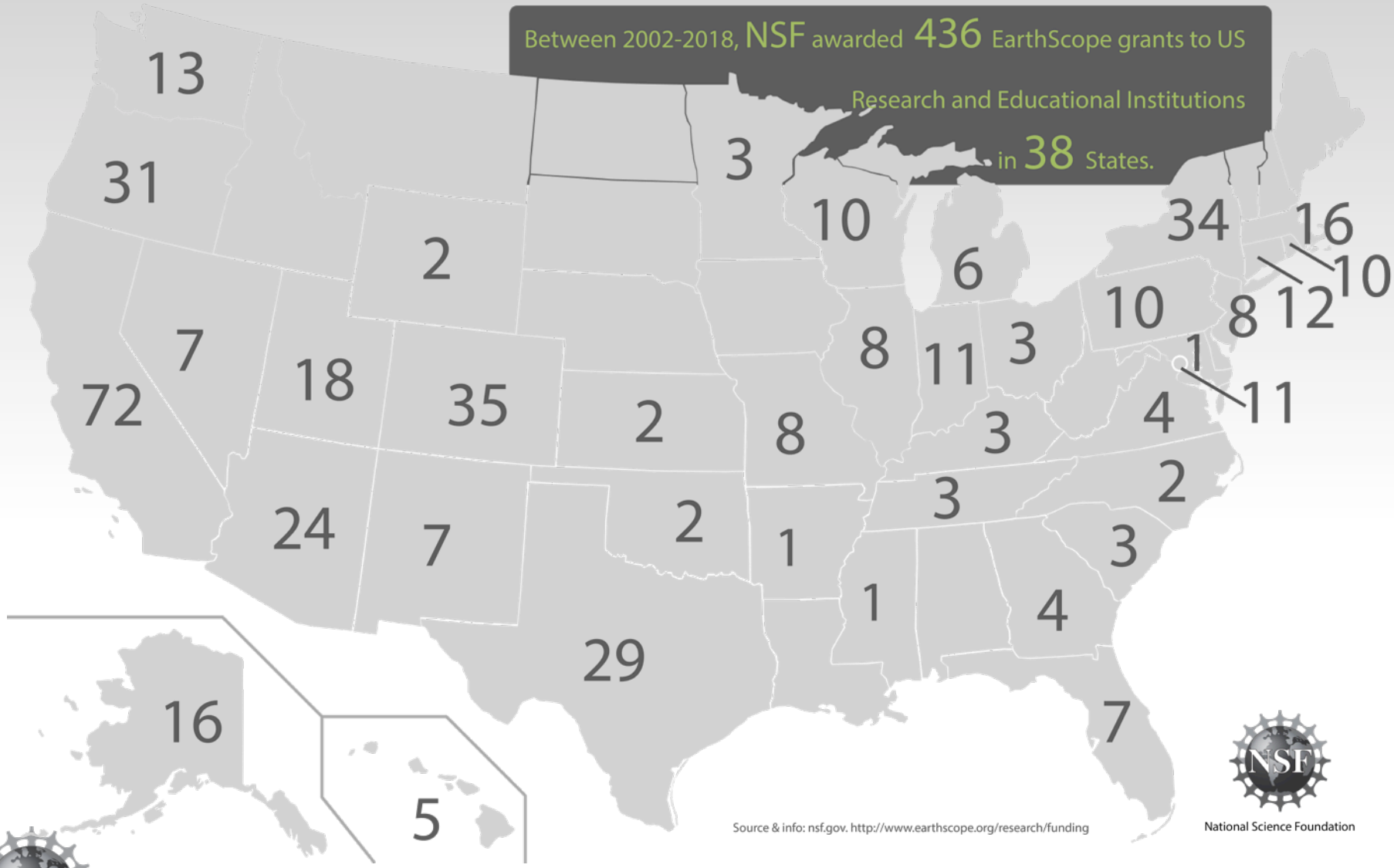






- Focus on measuring plate motion, earthquakes & preparedness
- 730,000 visitors so far…
- 2 museums (Oregon & Washington)

NSF earthscope

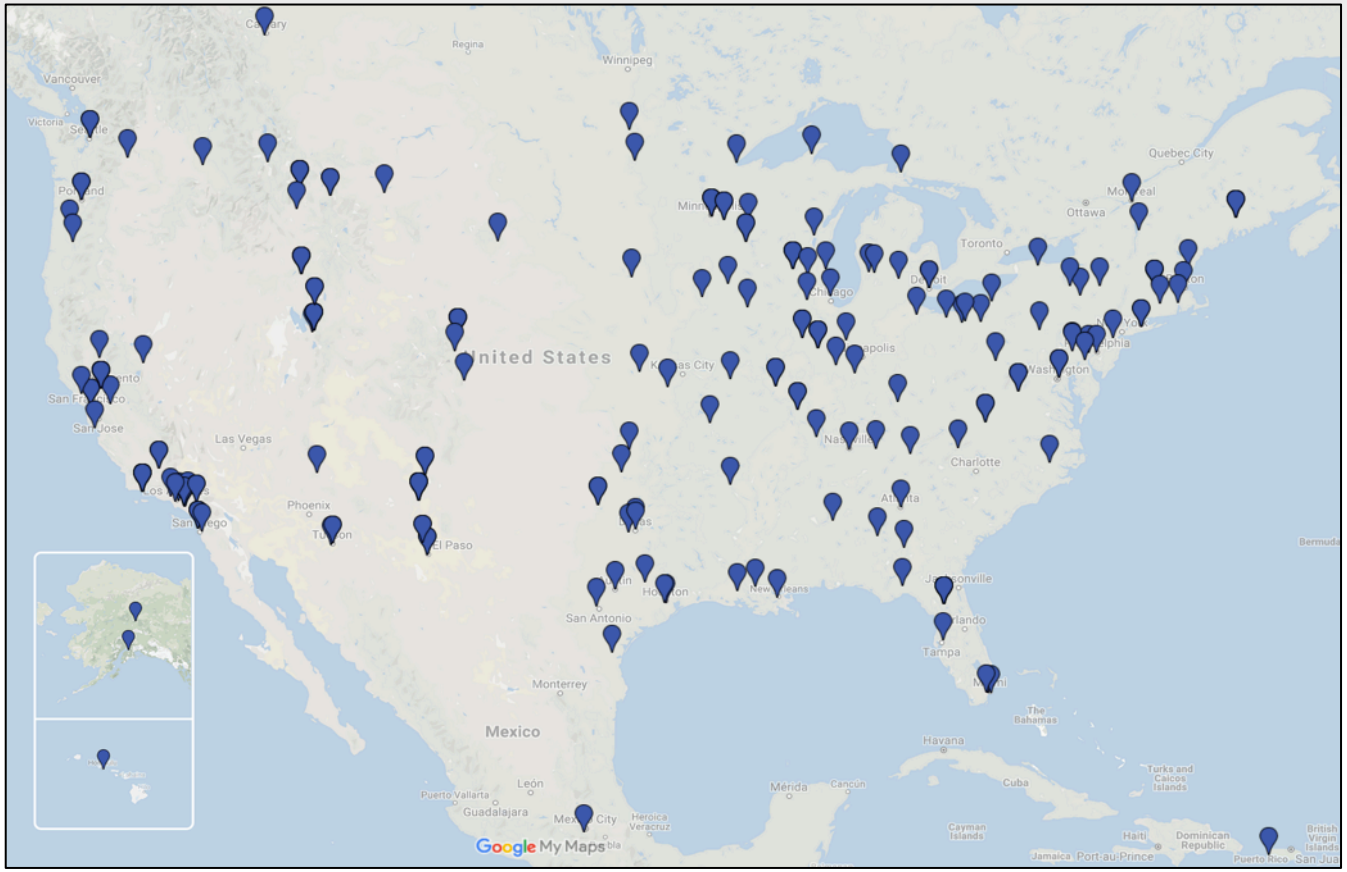
# National Reach




earthscope

# EarthScope Speaker Series

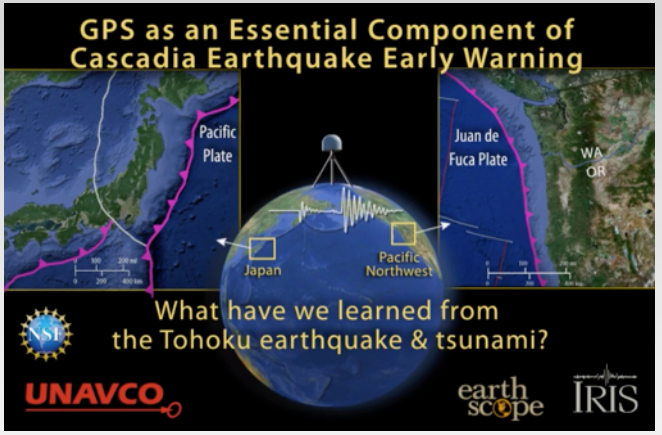
- 55 speakers over 11 years
- 210 colleges/universities
- >15,000 people reached




NSF earthscope

# Other Education Activities

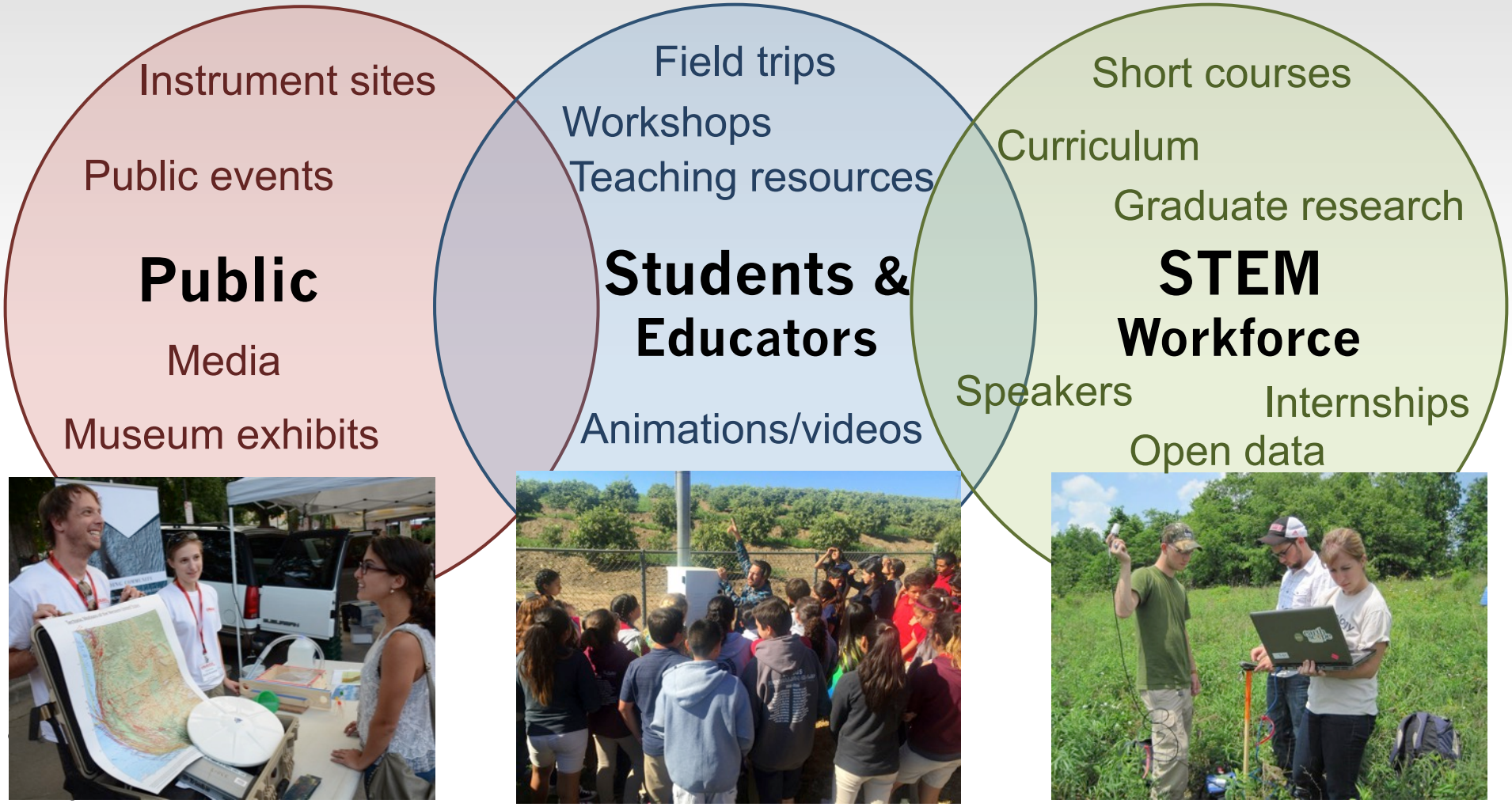
- Videos/animations: >6 million views of resources
- 100,000s media/public events
- ~200,000 undergrads used text book with EarthScope data
- >1000 students on travel grants, short courses, other internships
- Also many thousands of calendars, maps, posters, etc.



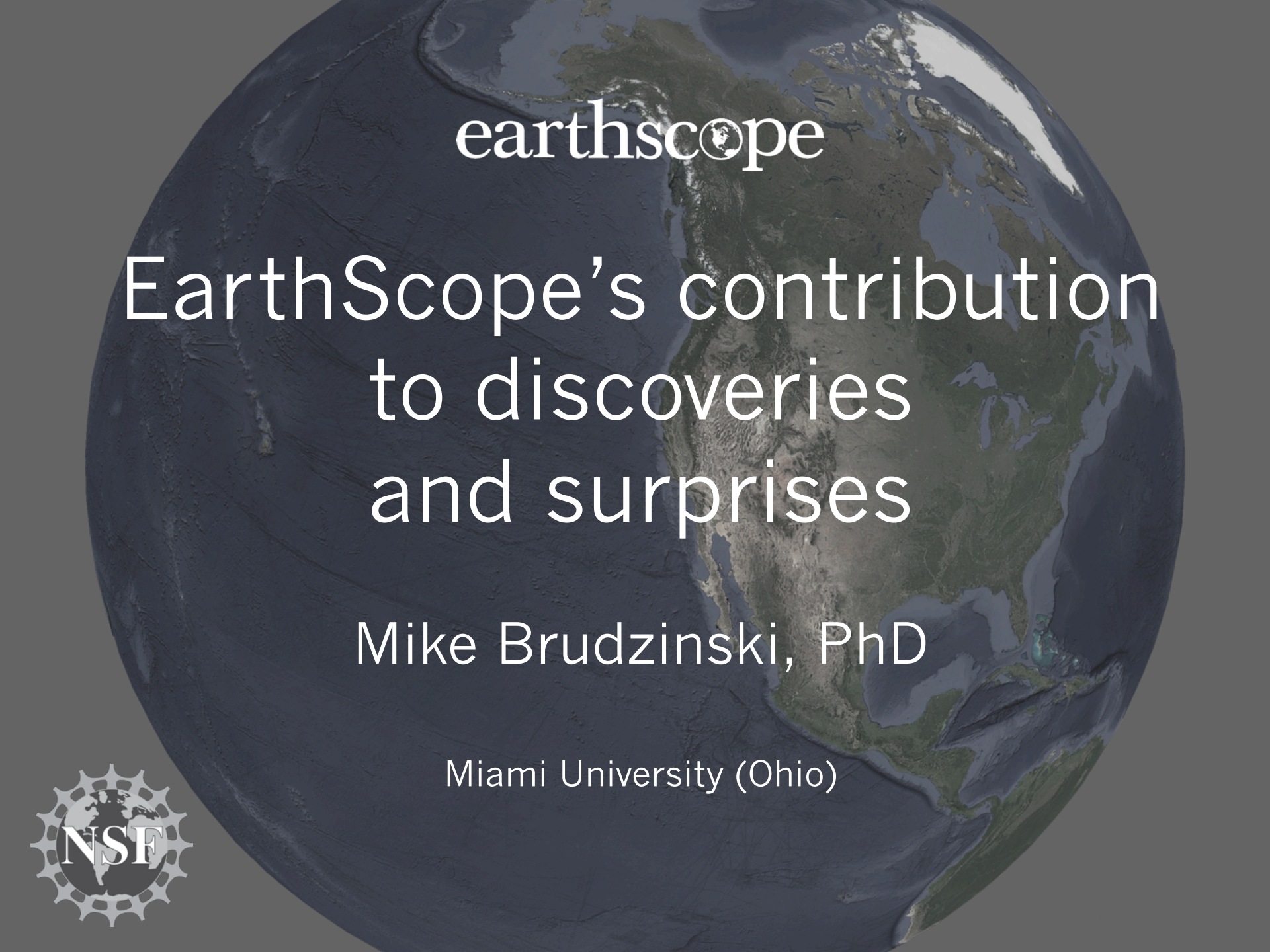



# National Opportunity

- Outreach-Education-Workforce Training
- Increase resilience to natural hazards




Questions?



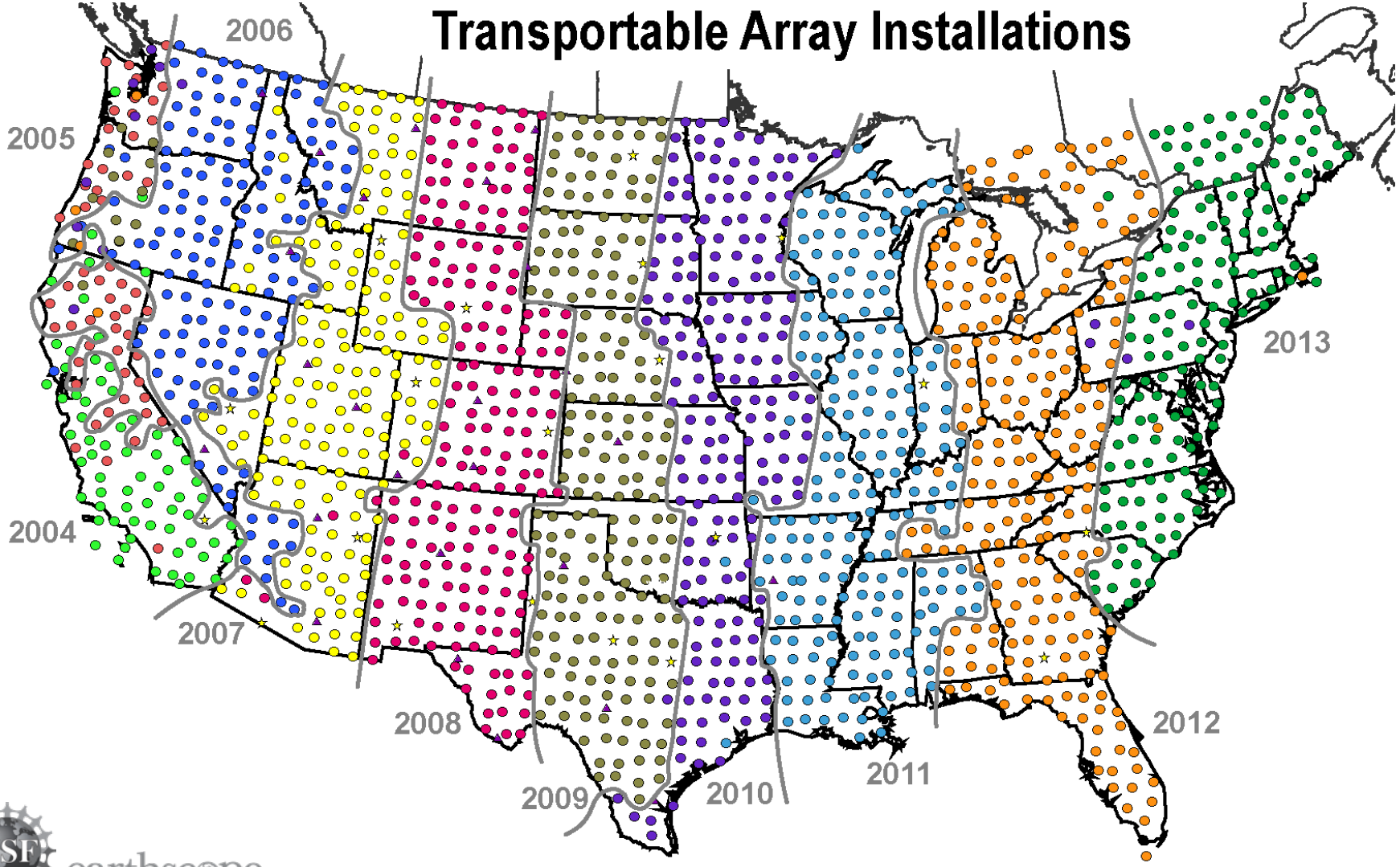
earthscope

# EarthScope's contribution to discoveries and surprises

Mike Brudzinski, PhD

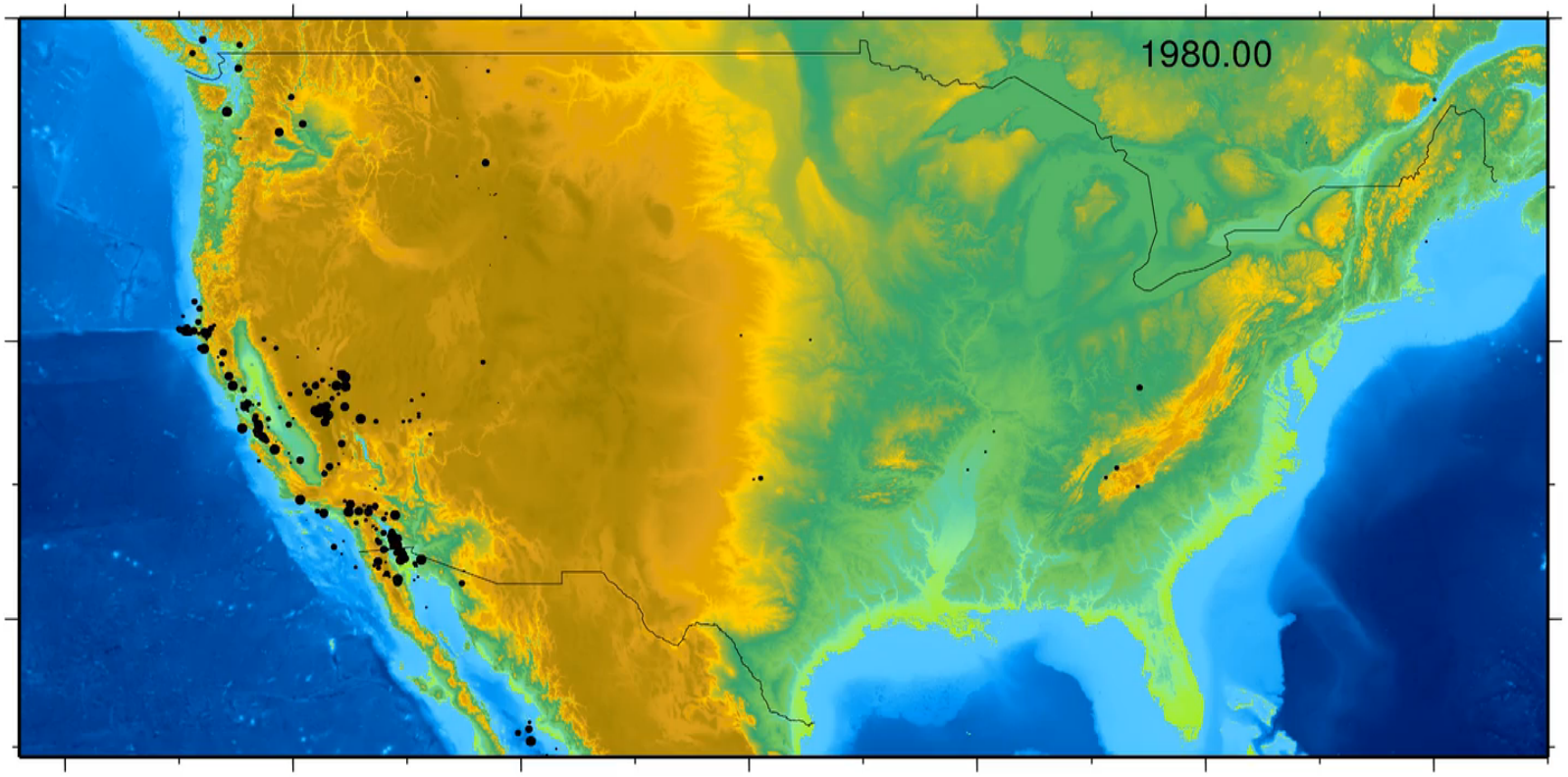
Miami University (Ohio)

NSF

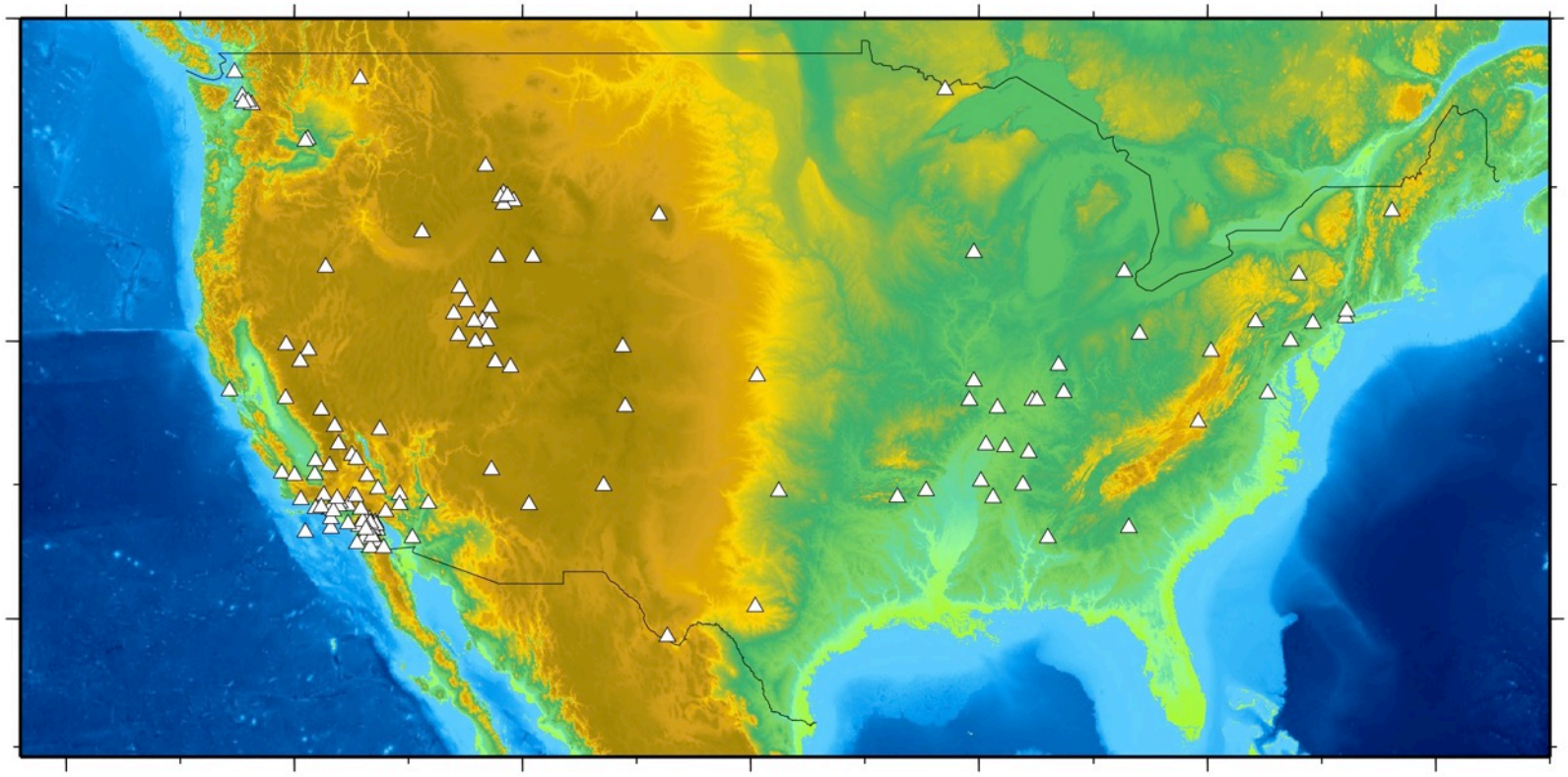

Transportable Array Installations
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

earthscope

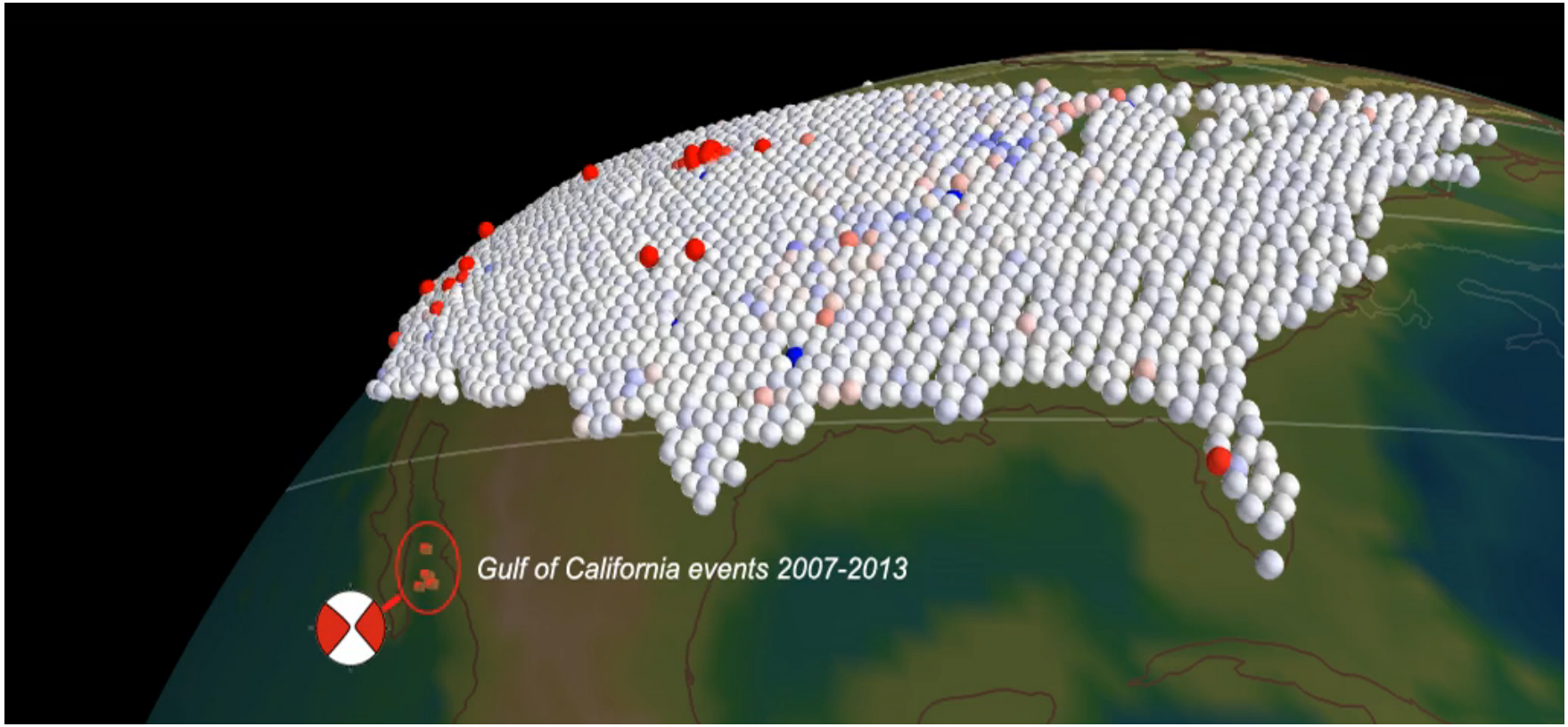
# Distribution of Earthquakes Were Not Uniform



# Broadband Seismic Stations Before EarthScope

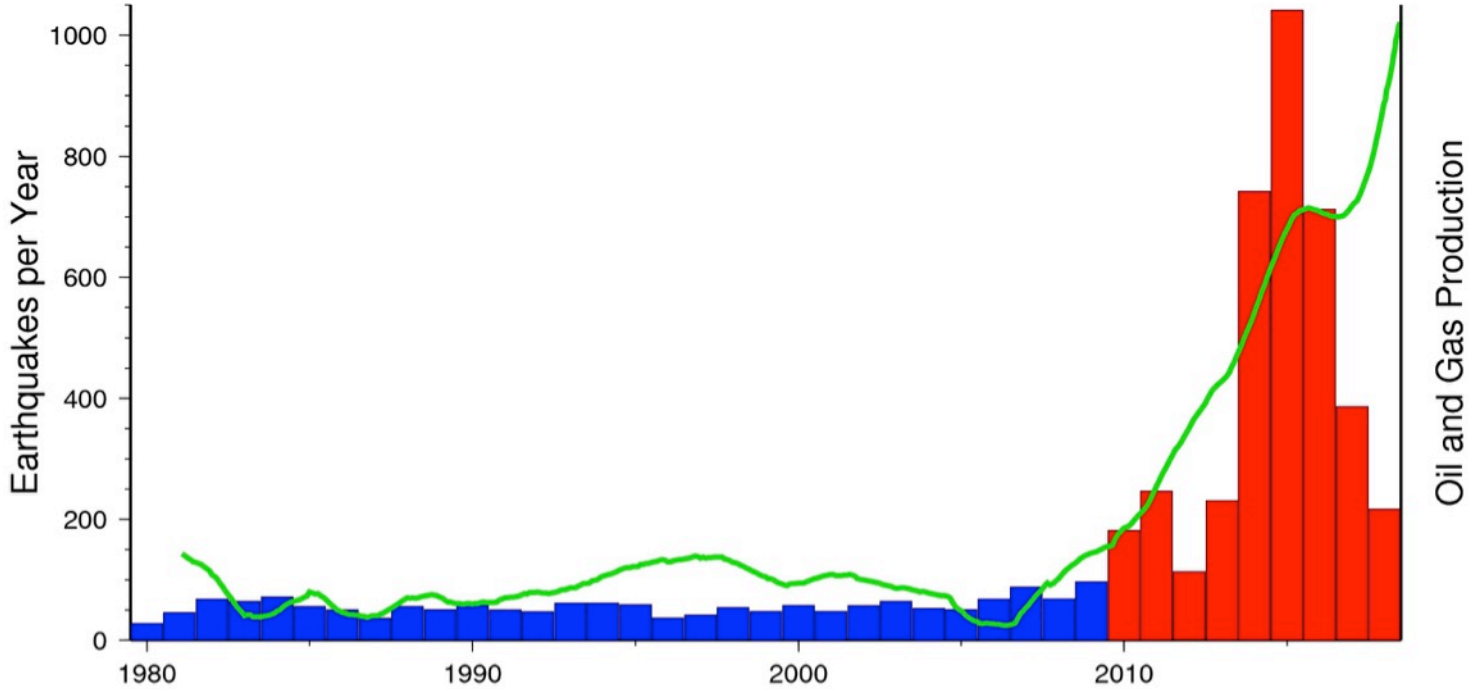


# Use Seismic Waves from Distant Large Earthquakes

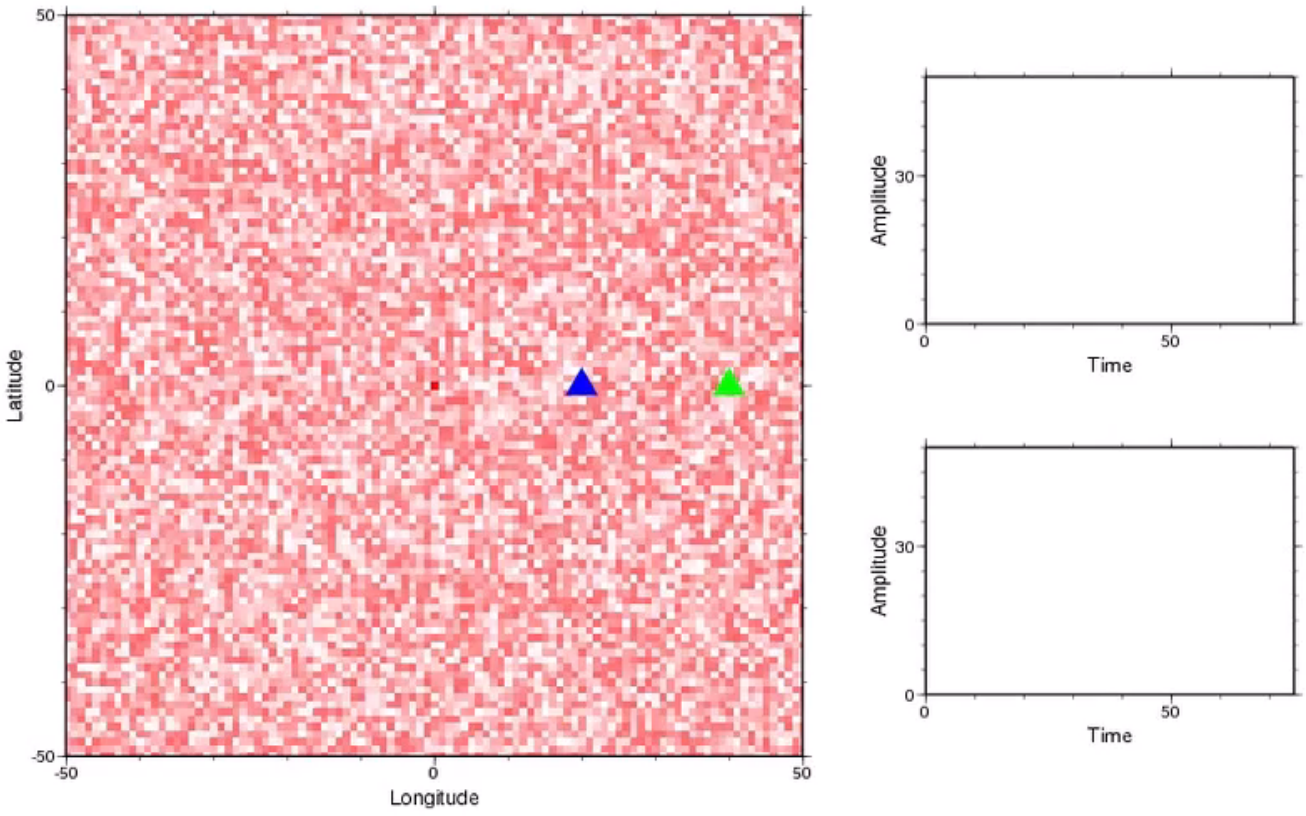


# Surprise 1: More Earthquake Than Expected

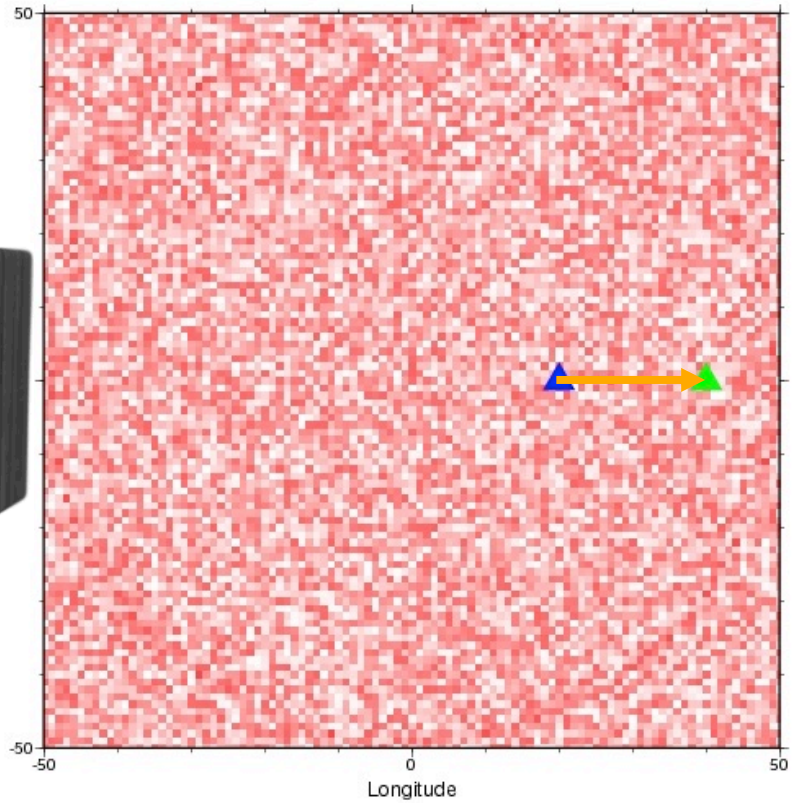
- Human-induced earthquakes in the Central and Eastern US

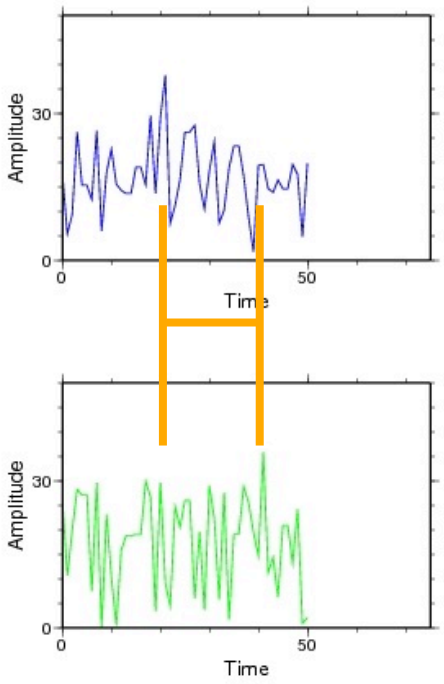



# Surprise 2: New Technique to Scan with Noise

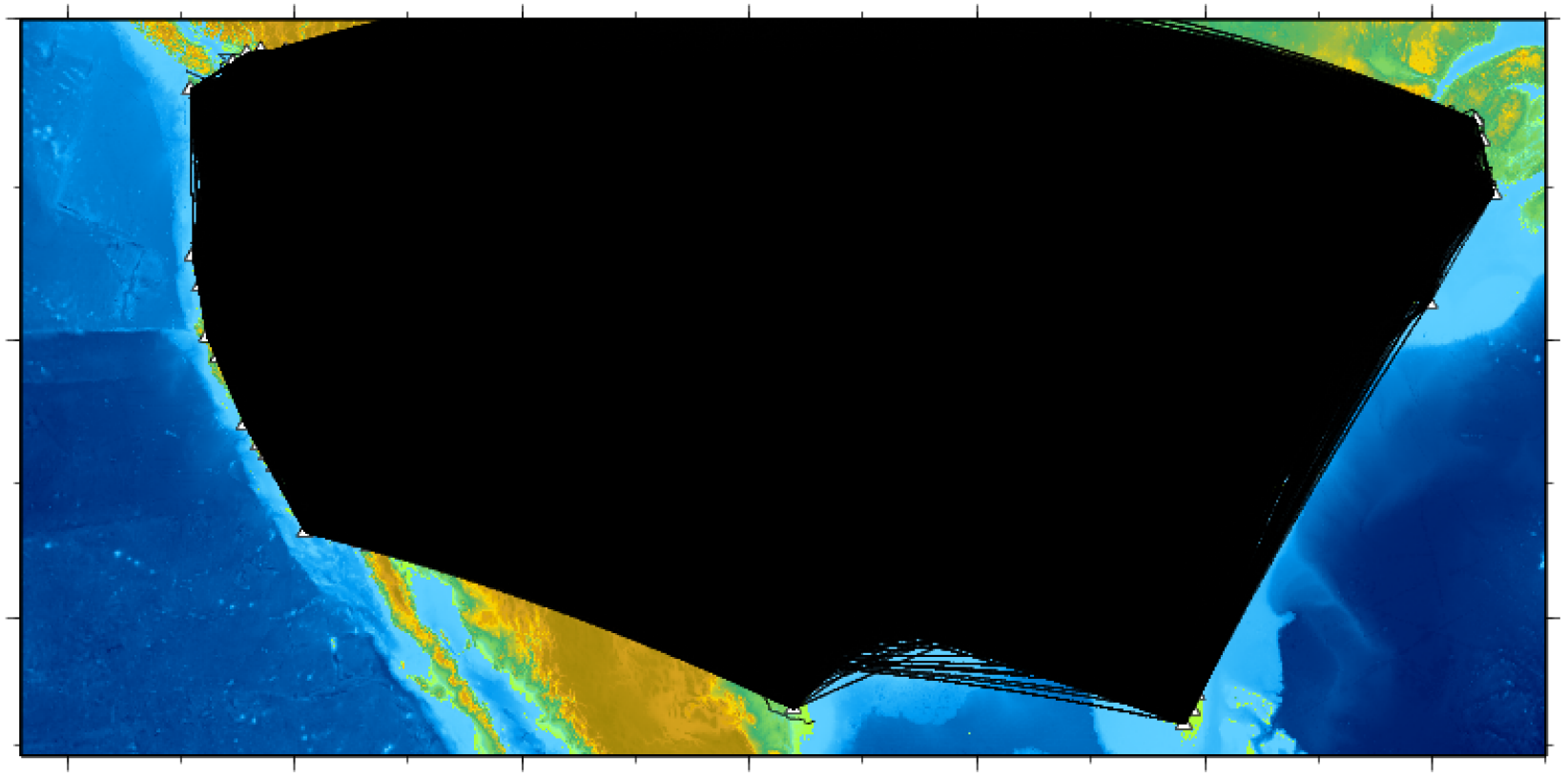


# Surprise 2: New Technique to Scan with Noise

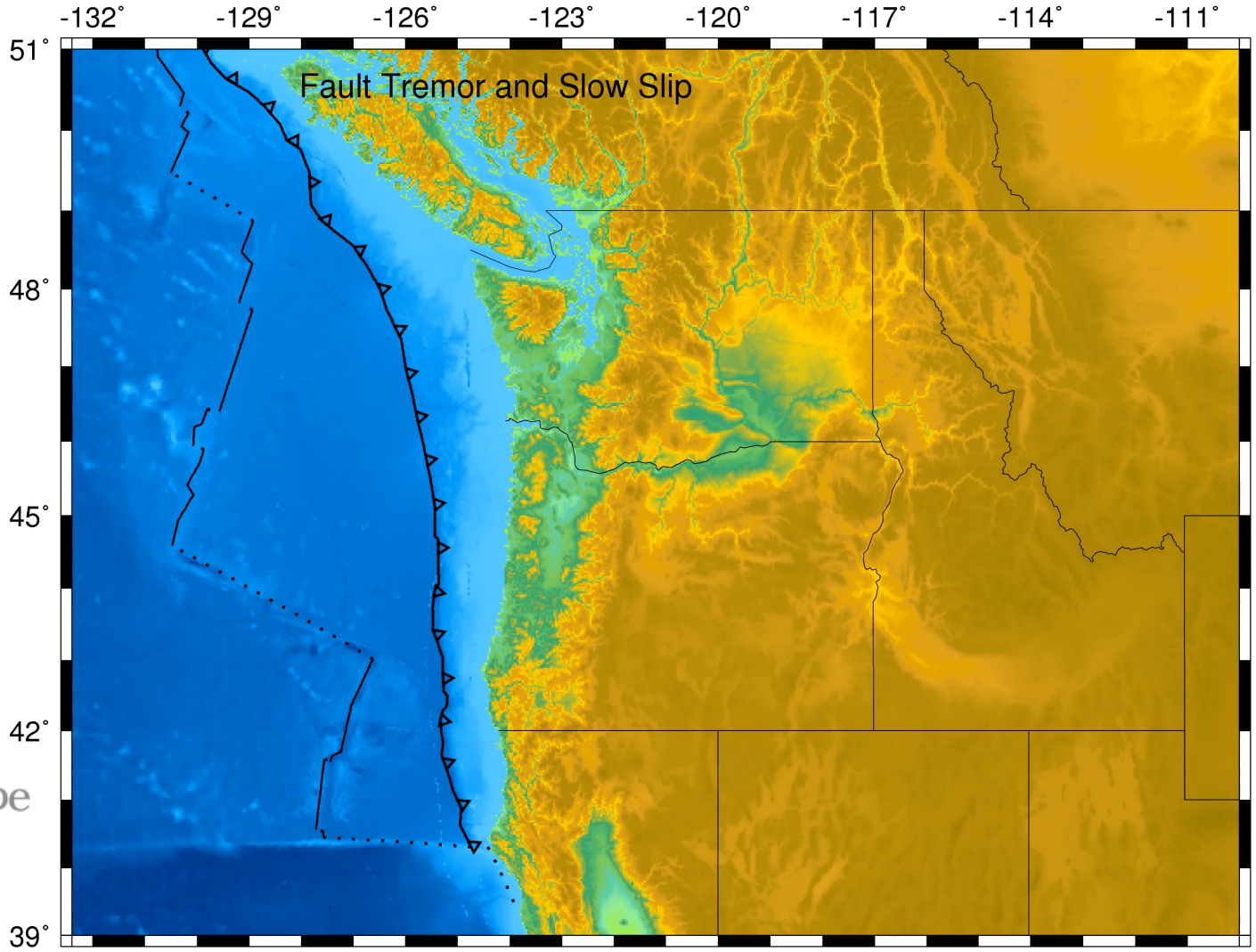


# Truly Enabled an EarthScope CAT Scan



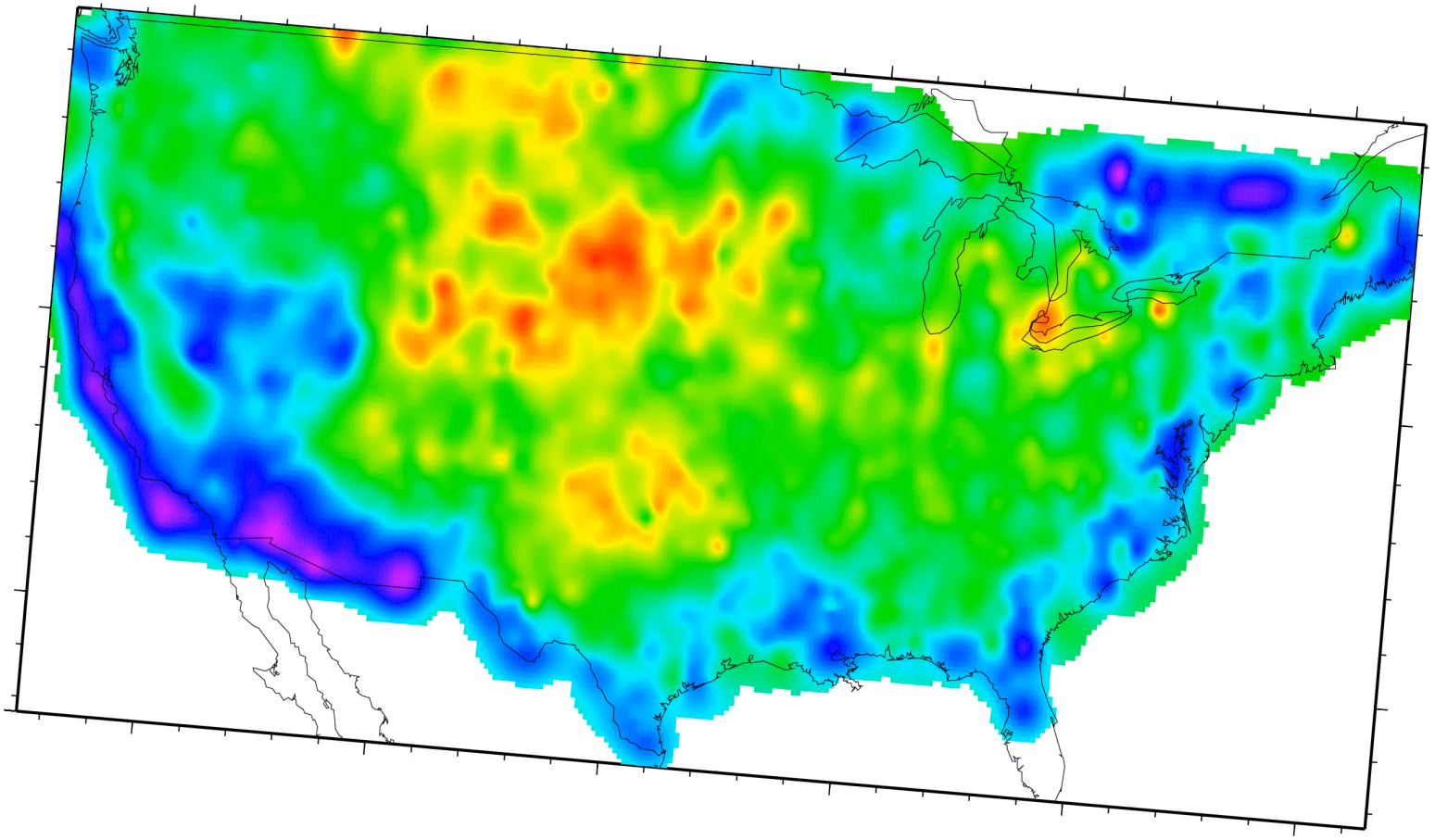
# Surprise 3: Fault Tremor




earthscope

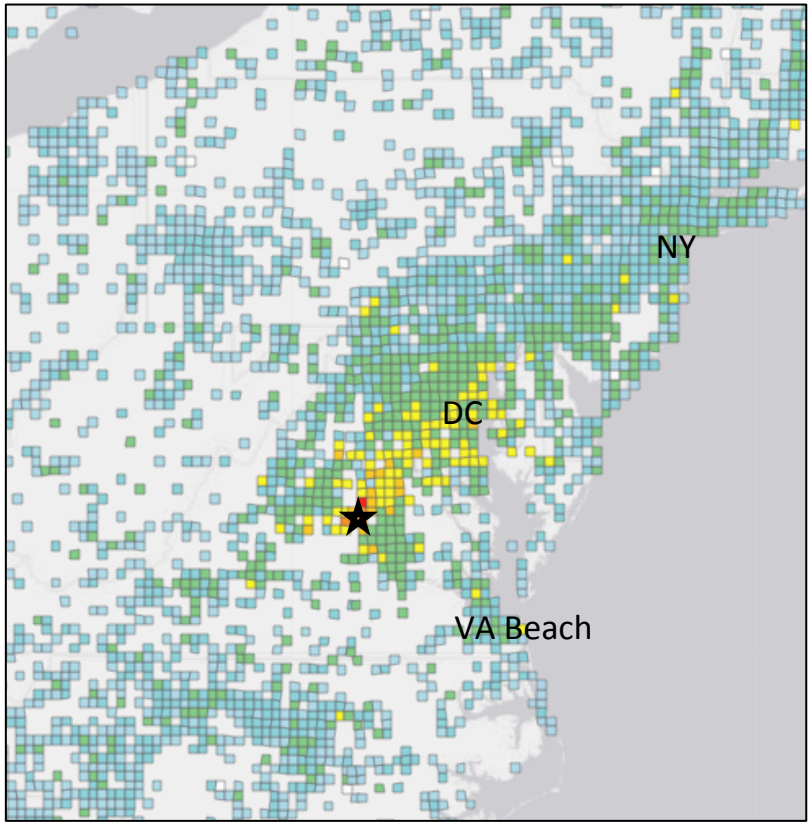
# Flex Array

# Complexity of the Continental Crust



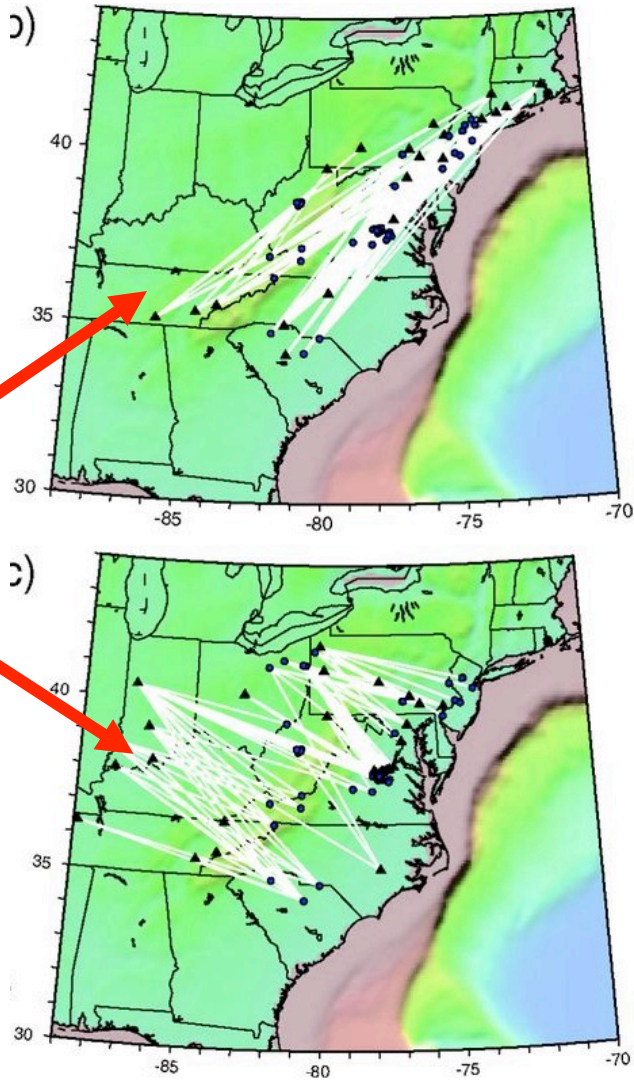
earthscope

# Crust Structure Explains Shaking from the 2011 Virginia Earthquake

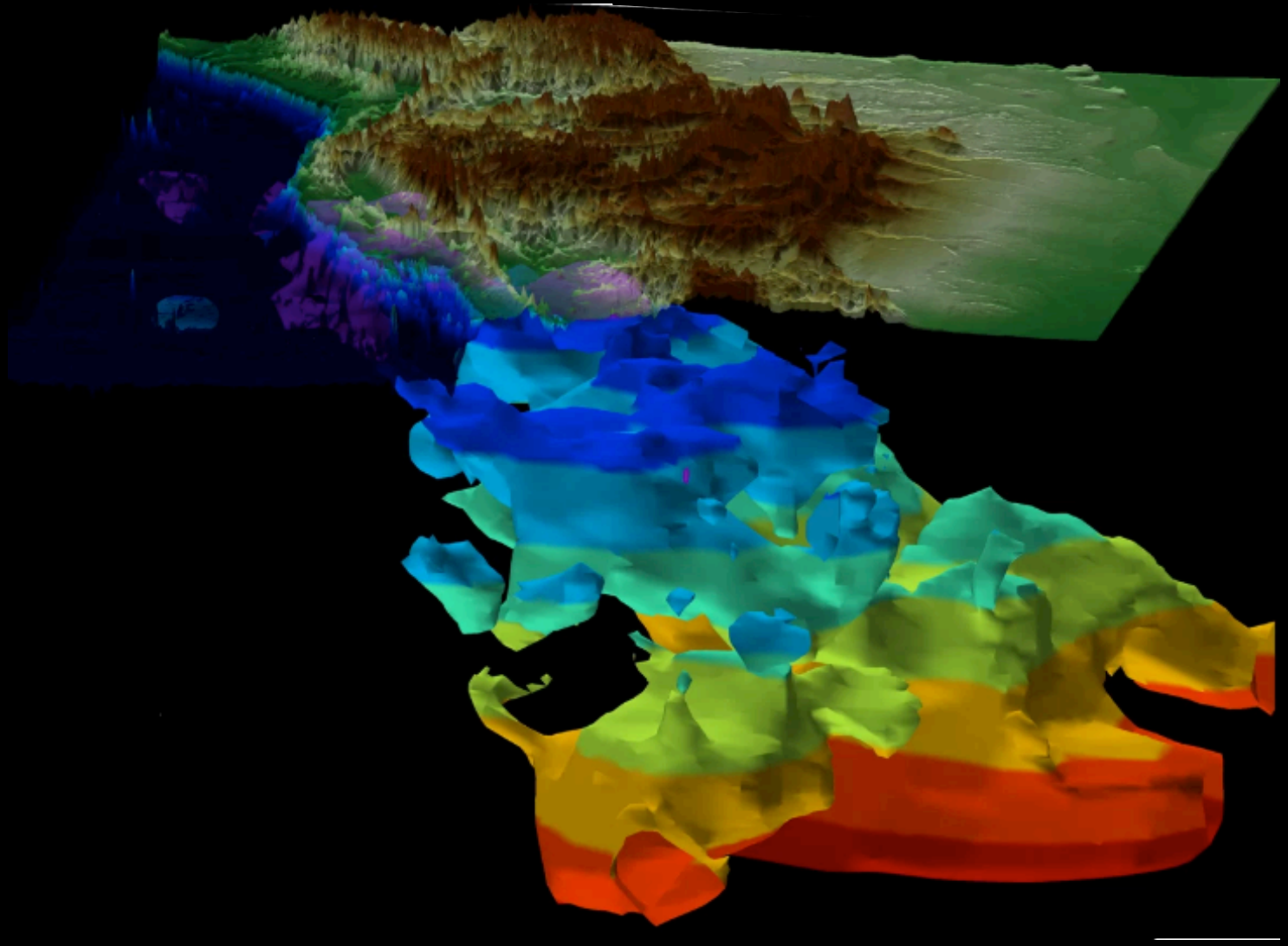



Strong Shaking

Weak Shaking

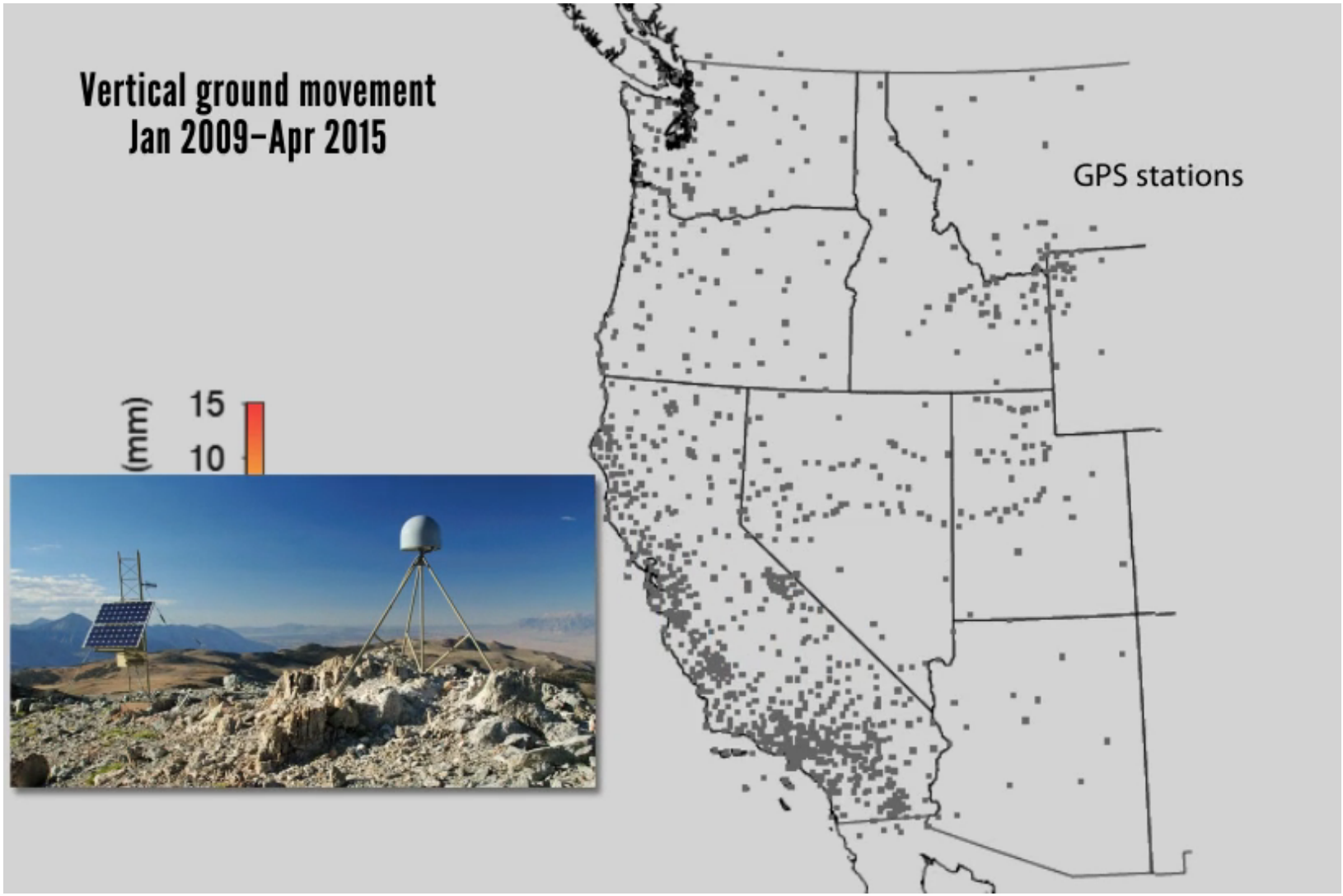


# A Buried Tectonic Plate



From 145 million years ago

to 65 million years ago


Vertical ground movement
Jan 2009–Apr 2015
GPS stations
(mm)
15
10

# So, So Grateful for EarthScope

- A Complete Game-Changer
  - How we assess and prepare for hazards
  - How we train and educate
  - How we understand the Earth


Thank you
Questions?