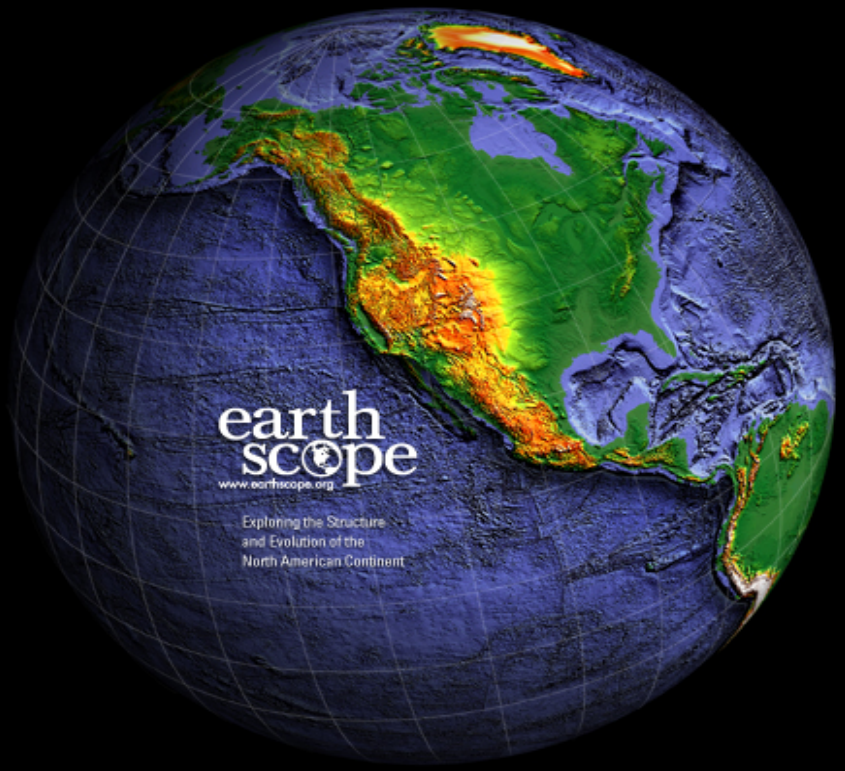
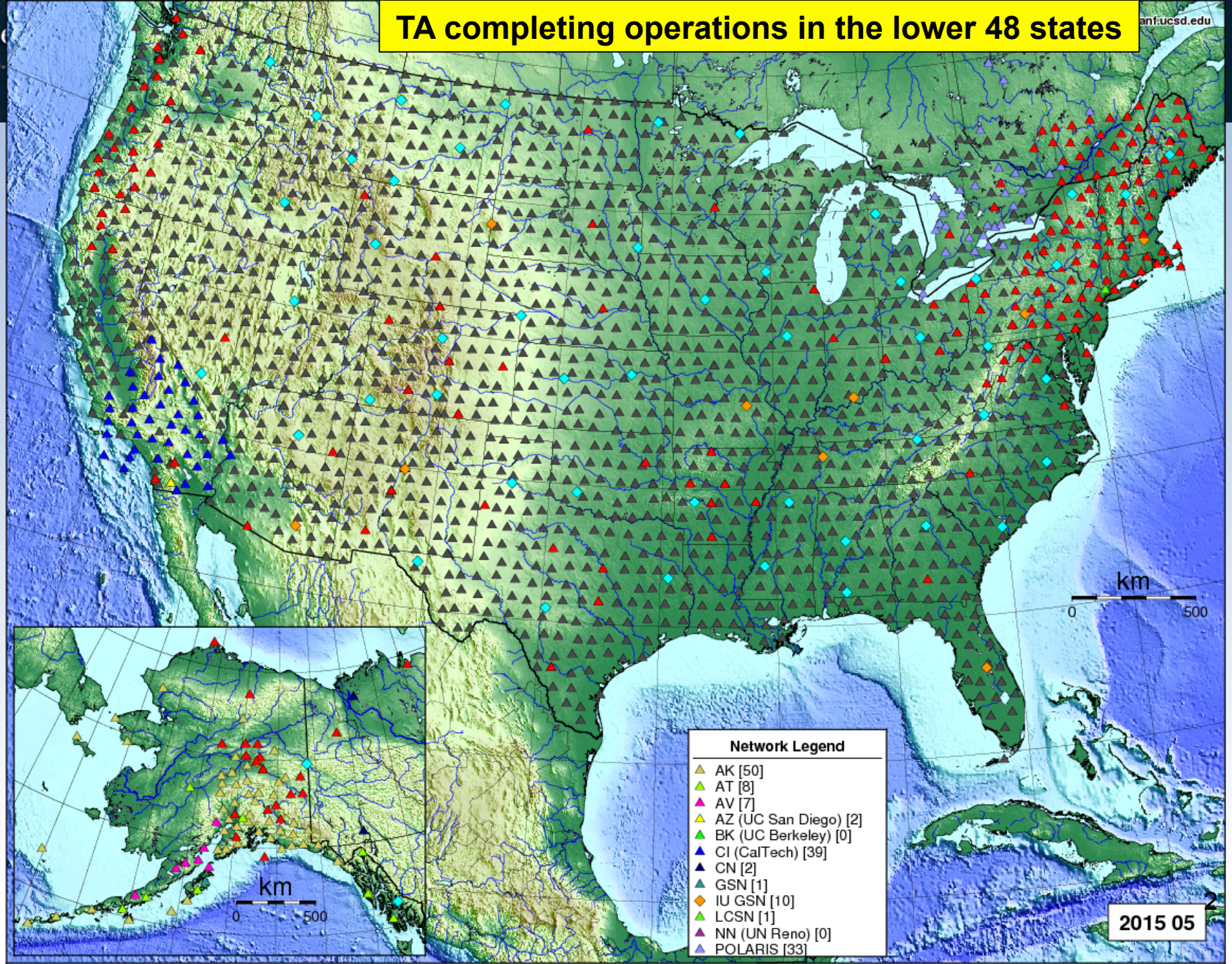
Central and Eastern US Network: A Status Update



Bob Woodward
IRIS
Director of Instrumentation Services

CEUSN Meeting
IRIS HQ
Washington, DC
June 11, 2015

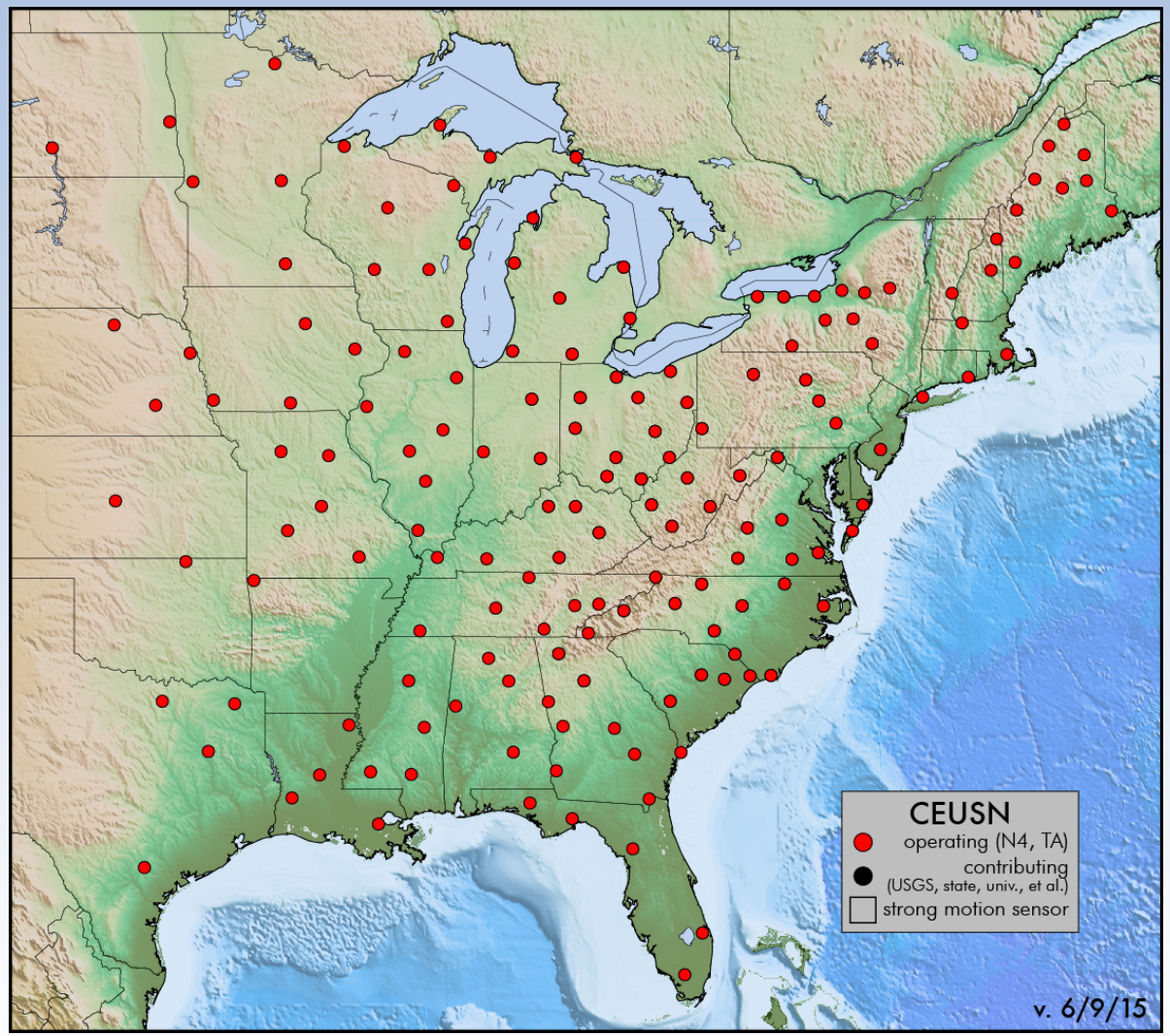

TA completing operations in the lower 48 states
anf.ucsd.edu
km
0
500
km
0
500
Network Legend
AK [50]
AT [8]
AV [7]
AZ (UC San Diego) [2]
BK (UC Berkeley) [0]
CI (CalTech) [39]
CN [2]
GSN [1]
IU GSN [10]
LCSN [1]
NN (UN Reno) [0]
POLARIS [33]
2015 05

CEUSN: A Brief History

- Concept emerged in ~2008
  - Leave behind one out of every four TA stations in the central and eastern US
- Implementation started in 2013
  - Multiagency collaboration
  - Example of good government- Recognition of a unique opportunity to address multiple missions / needs
  - Benefits to NSF, USGS, US NRC, and DOE
- TA Site Selection Working Group
  - Charged by NSF and USGS
  - Selected and prioritized potential sites: hazard, critical infrastructure, coverage
- TA-to-CEUSN station conversions started in 2013

Central and Eastern United States Network

- Operate 159 TA seismic stations through 2017
- Multi-agency collaboration
  - NSF
  - USGS
  - US NRC
  - DOE
- Enhanced instrumentation/data
  - Higher sample rates (100 s.p.s.)
  - 34 new strong motion instruments



www.usarray.org/ceusn

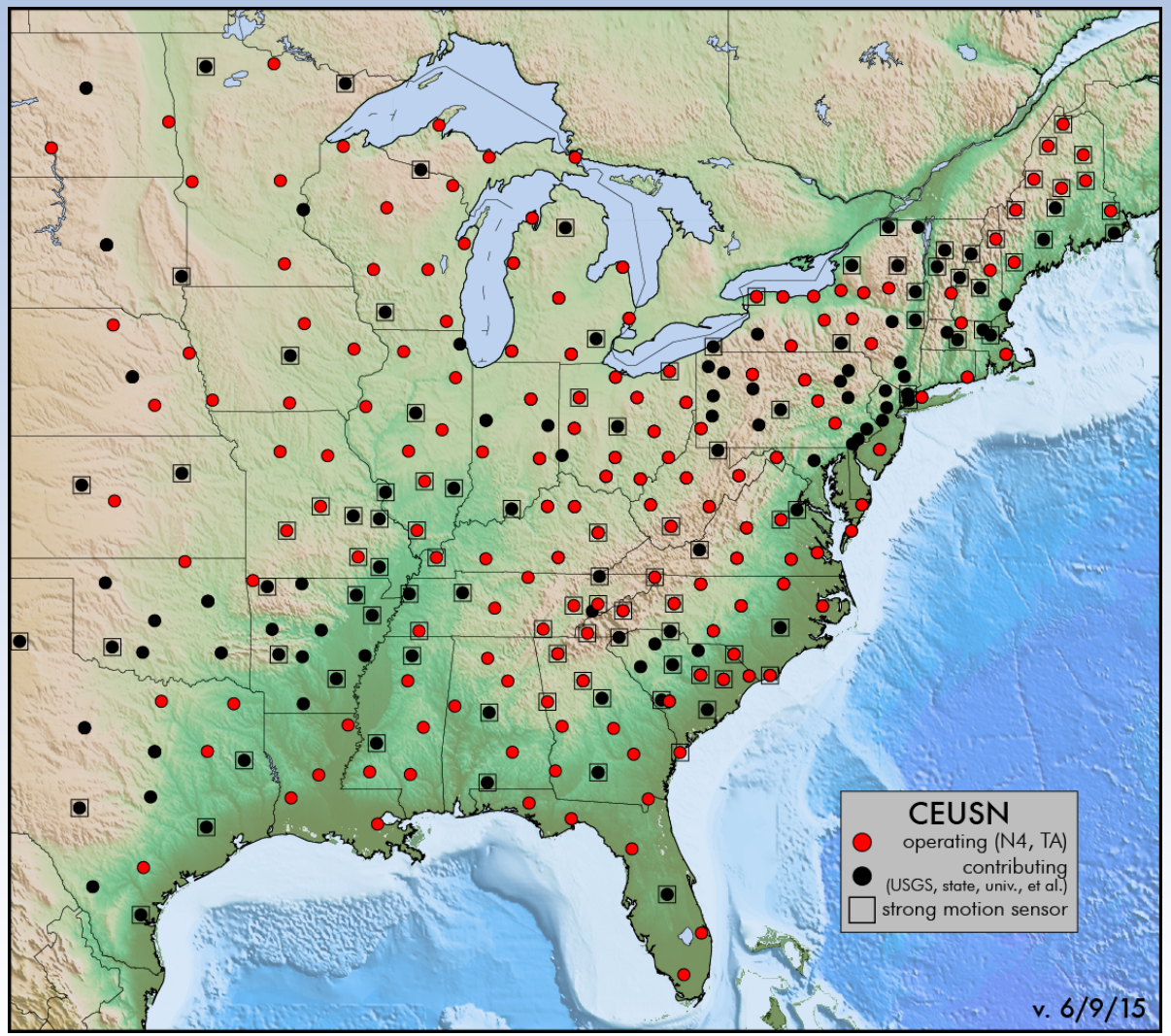
CEUSN: A Broader Capability

- The broader CEUSN capability is more than N4

- Over 300 broadband stations in the CEUS
  - N4 stations
  - Pre-existing regional network and other stations

Important capabilities

- Station proximity to high hazard areas
- Proximity to critical facilities
- Areal coverage



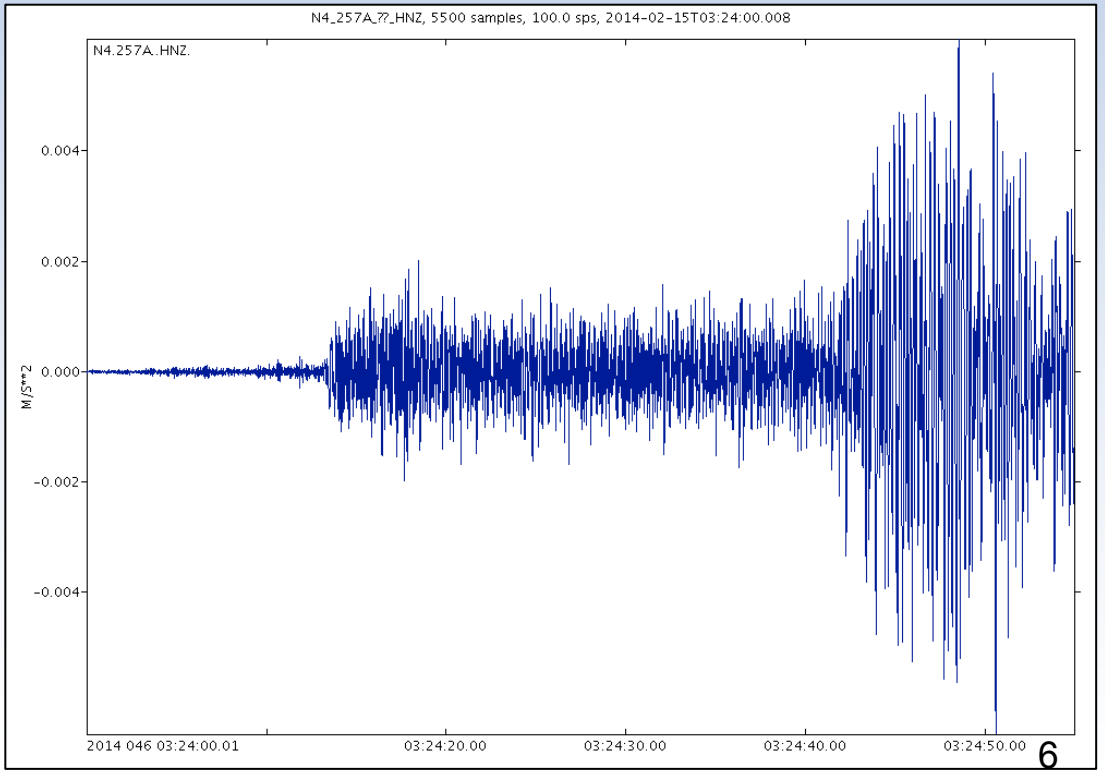
www.usarray.org/ceusn

Current Status

- 137 stations have been converted from TA to CEUSN (network code **N4**)
- Remaining conversions will be complete in fall 2015

Example from Edgefield, SC earthquake

- Savannah River Site and Vogtle Power plant site ~80 km from the earthquake
- Strong motion record from CEUSN site 257A, at ~225 km from the earthquake

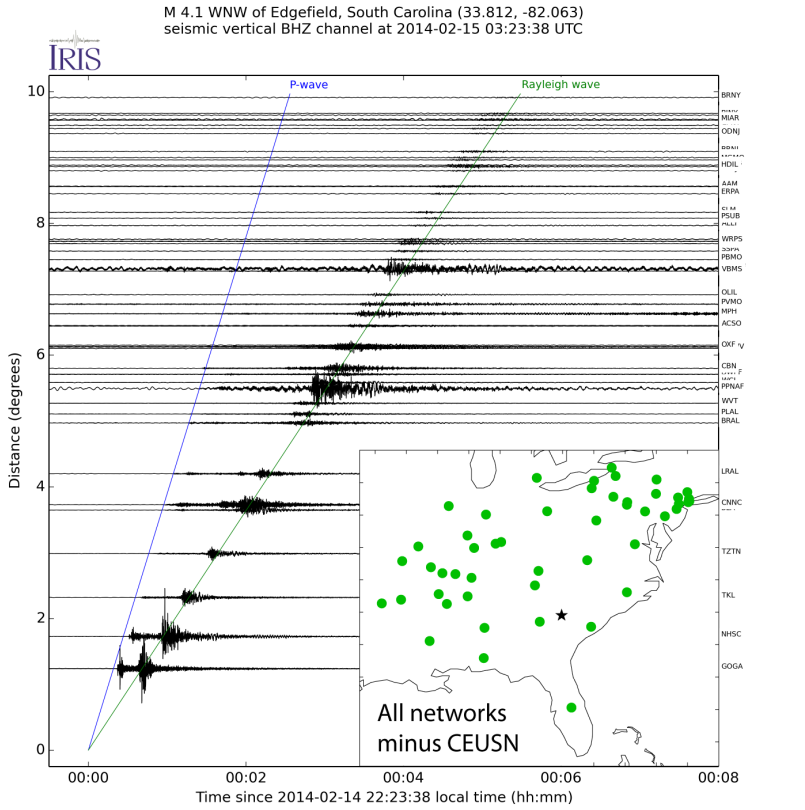


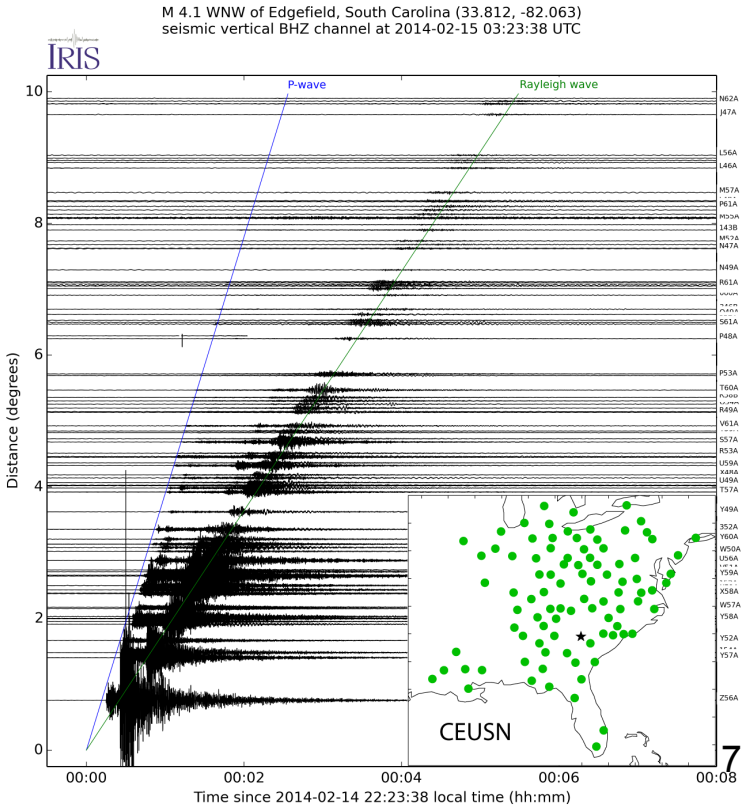
This URL will extract these data and make the plot, using IRIS DMC web services:

http://service.iris.edu/irisws/timeseries/1/query?net=N4&sta=257A&cha=HNZ&start=2014-02-15T03:24:00&end=2014-02-15T03:24:55&output=plot&loc=++&scale=AUTO&demean=true

Example: Impact of CEUSN on Coverage

- CEUSN stations provide enhanced coverage for small events and events near critical facilities
- Left figure shows broadband station coverage without CEUSN
- Right figure shows just N4 stations





Funding

- NSF has committed to build and operate the CEUSN through 2017
  - $9.5 M to-date, includes some USGS contribution

- Funding history / plan
  - 2013 - $2.4 M
  - 2014 - $4.0 M
  - 2015 - $3.1 M
  - 2016 - $1.3 M (planned)
  - 2017 - $1.3 M (planned)

- NSF (with some USGS contribution) funding acquisition and operations through 2017; USGS intends to fund operations after that time

- USGS working towards obtaining budget increase necessary to operate and maintain the CEUSN

Looking Ahead

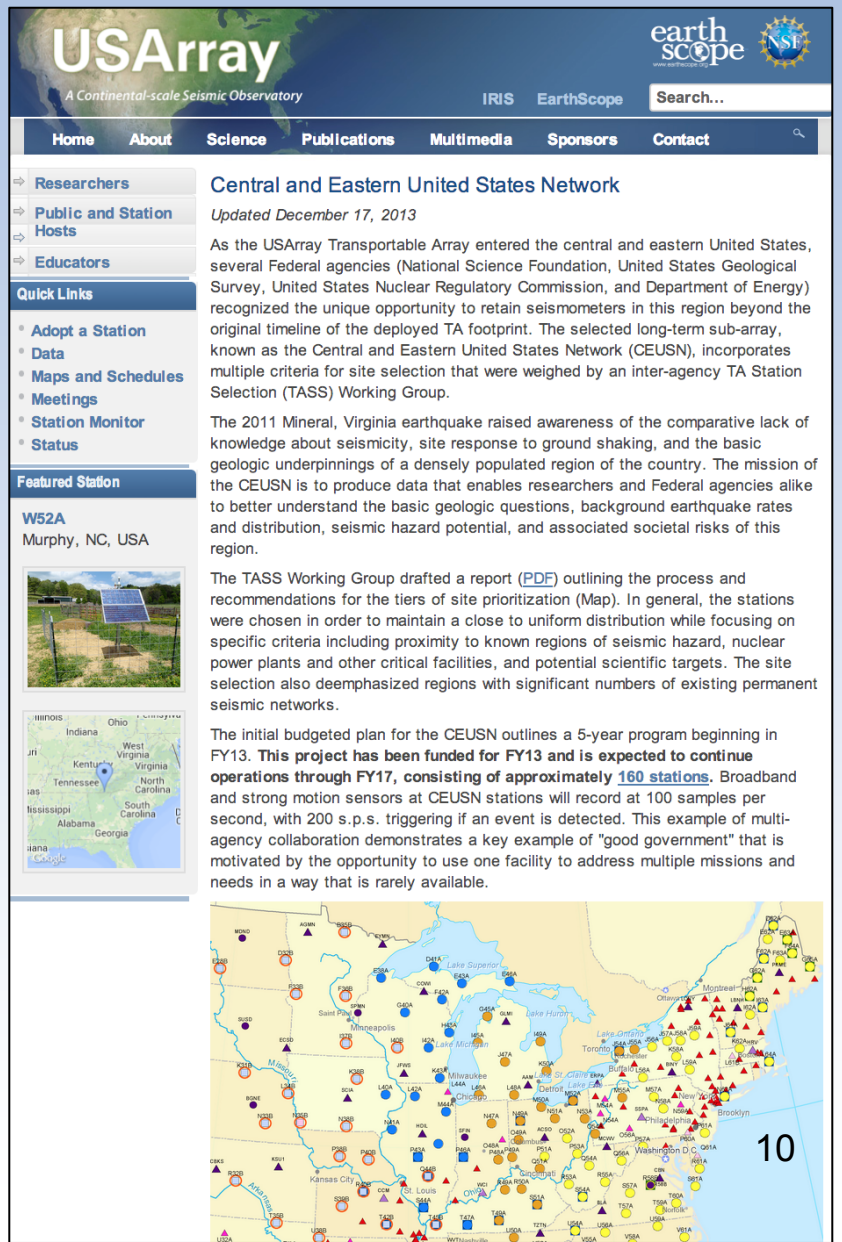
- The broad CEUS capability that now exists (over 300 broadbands alone) provides a foundation capability for addressing CEUSN observing challenges

- Opportunity to leverage this capability for multiple purposes
  - Improve completeness thresholds to lower magnitudes
  - Address site response and attenuation at critical facilities
  - Establish background seismicity before injection of waste water and enhanced geothermal or oil/gas recovery
  - More accurate depth, stress drop, other source parameters for induced events

- Visibility and sustainment of the CEUSN is important
  - Various entities have funded station transitions, but support for ongoing O&M seems unlikely
  - State government support, e.g., analogy to adoption in PA and other states?
  - DOD support - develop processing for arrays in support of nuclear monitoring?
  - DOE Office of Science support - relevance to new energy extraction technologies?

Info on the Web

- General information
  - www.usarray.org/ceusn
  - Status map
  - Google Earth KMZs
- Detailed operational information
  - ceusn.ucsd.edu
- Data
  - www.iris.edu/data



For More Information

On the Web

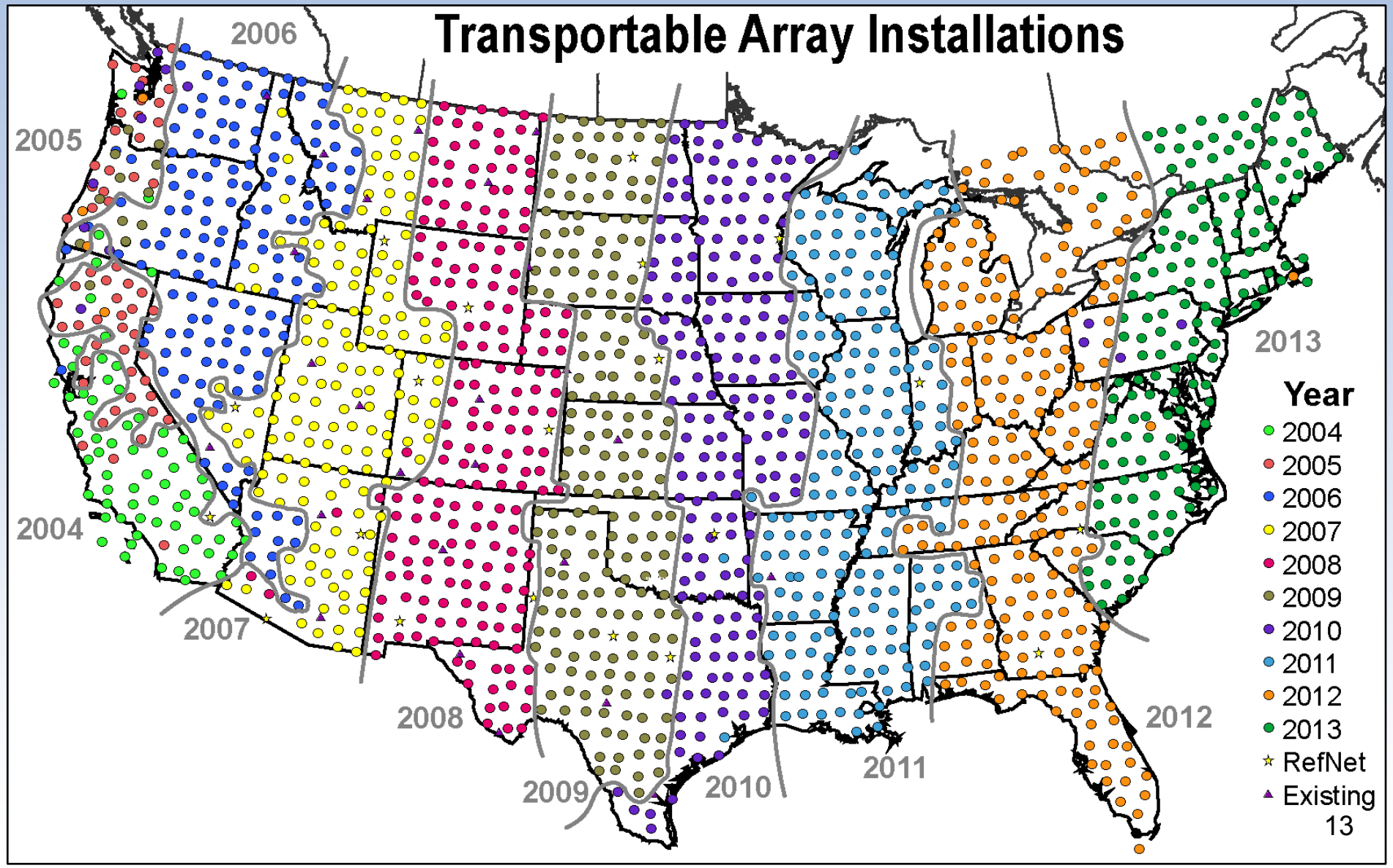
- IRIS
  www.iris.edu
- USArray
  www.usarray.org
- National Science Foundation
  www.nsf.gov

EarthScope is funded by the National Science Foundation.

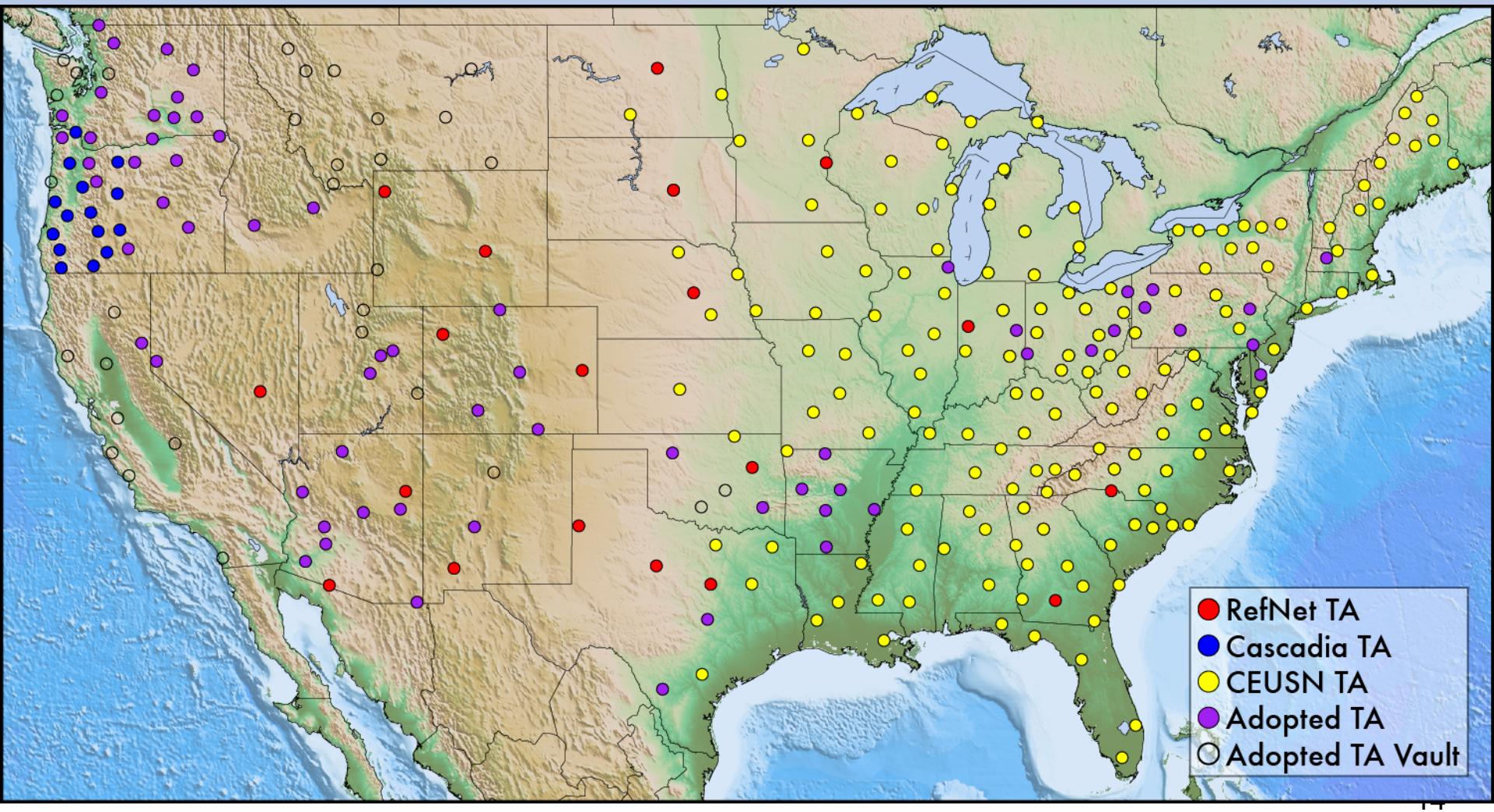
EarthScope is being constructed, operated, and maintained as a collaborative effort with UNAVCO, IRIS, and Stanford University, with contributions from the US Geological Survey, NASA and several other national and international organizations.

BACKUP SLIDES

The TA: Ten Year "As Built"



TA Legacy

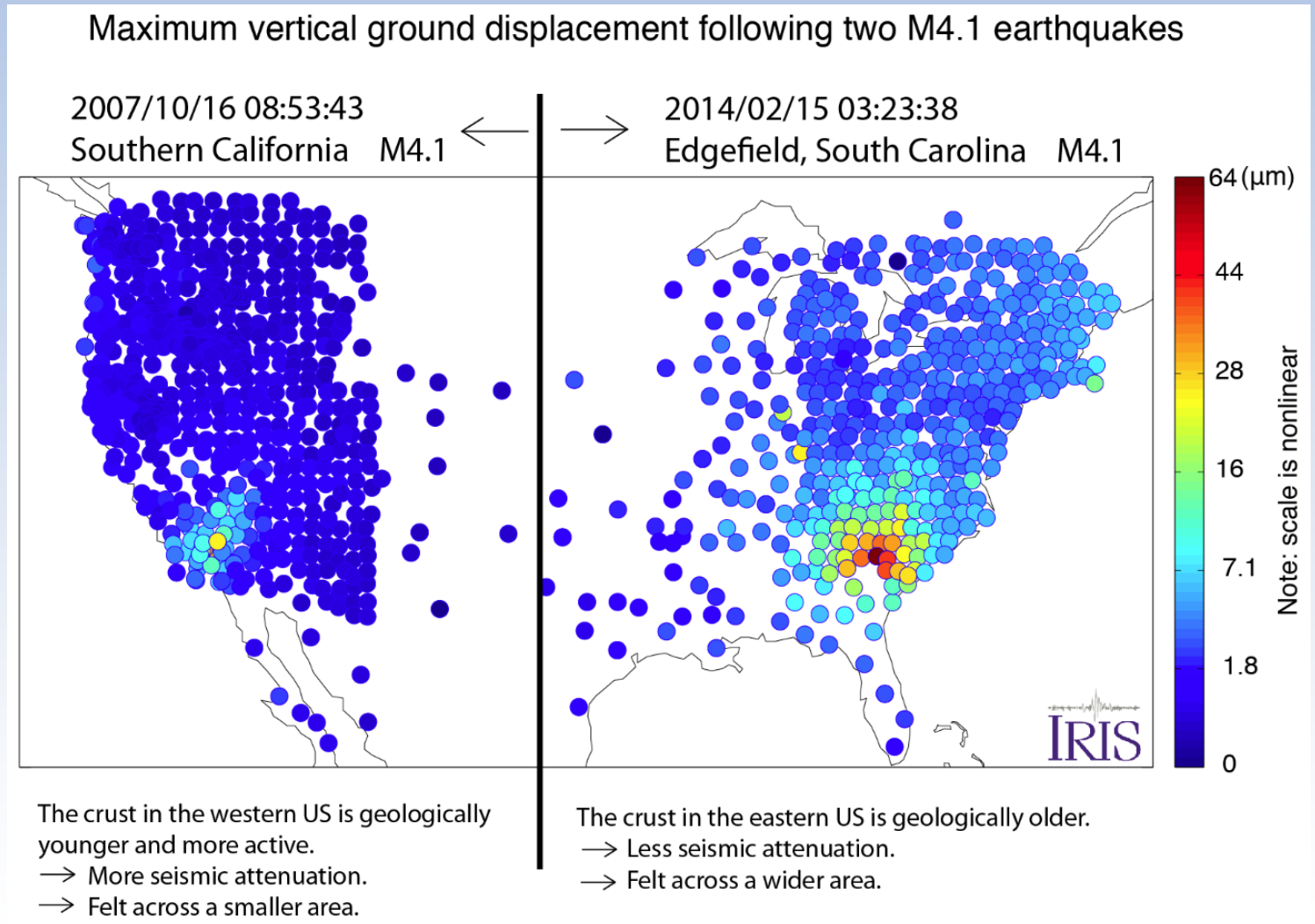


Legacy of Permanent Stations

Auguest 23, 2013

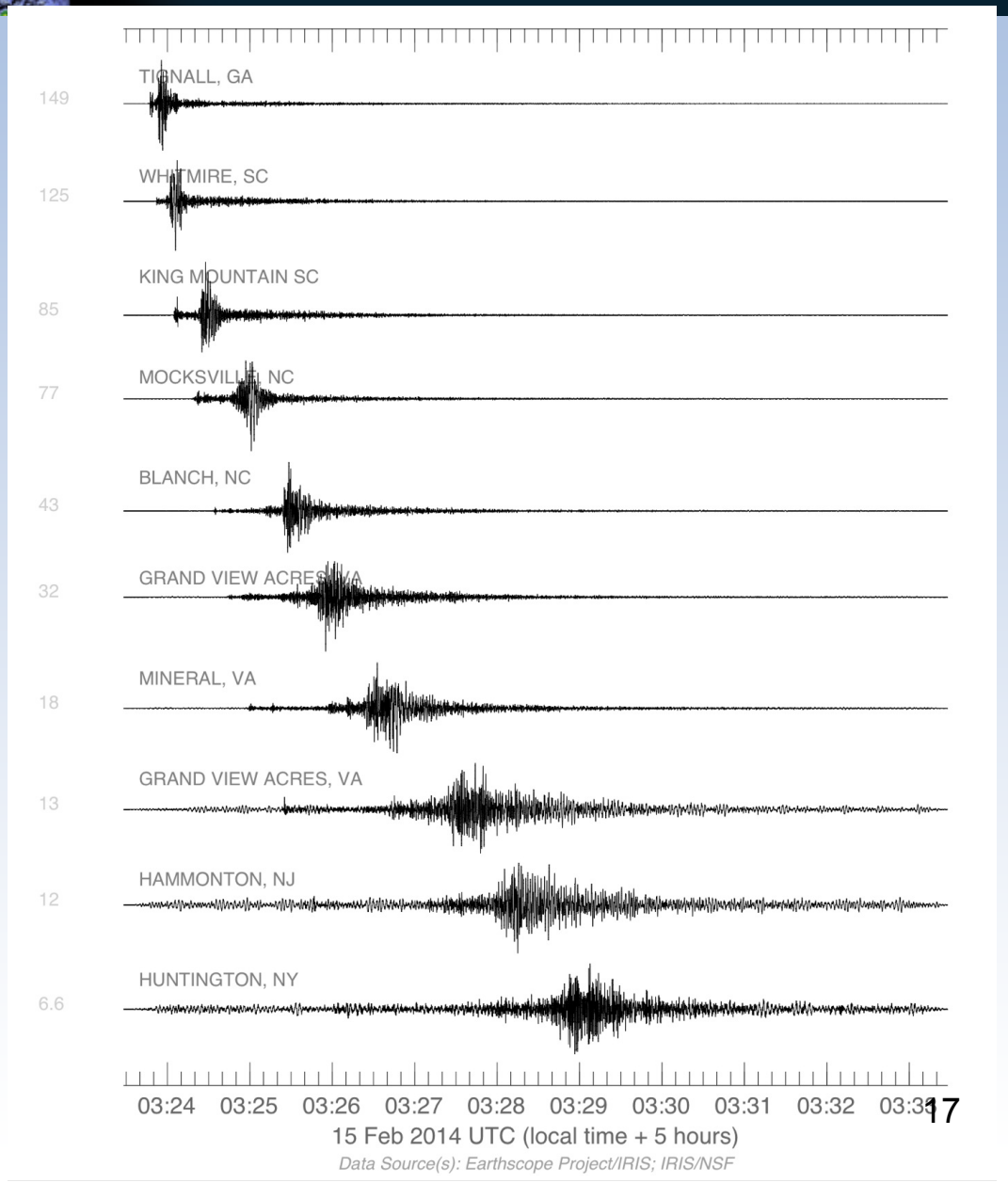
Comparison of Earthquakes in West and East

- A nice illustration of low attenuation in eastern US



Citizen Seismology

- A beautiful north-south station profile made using a $1.99 iPad app, which downloads real-time data from NSF-sponsored data archive



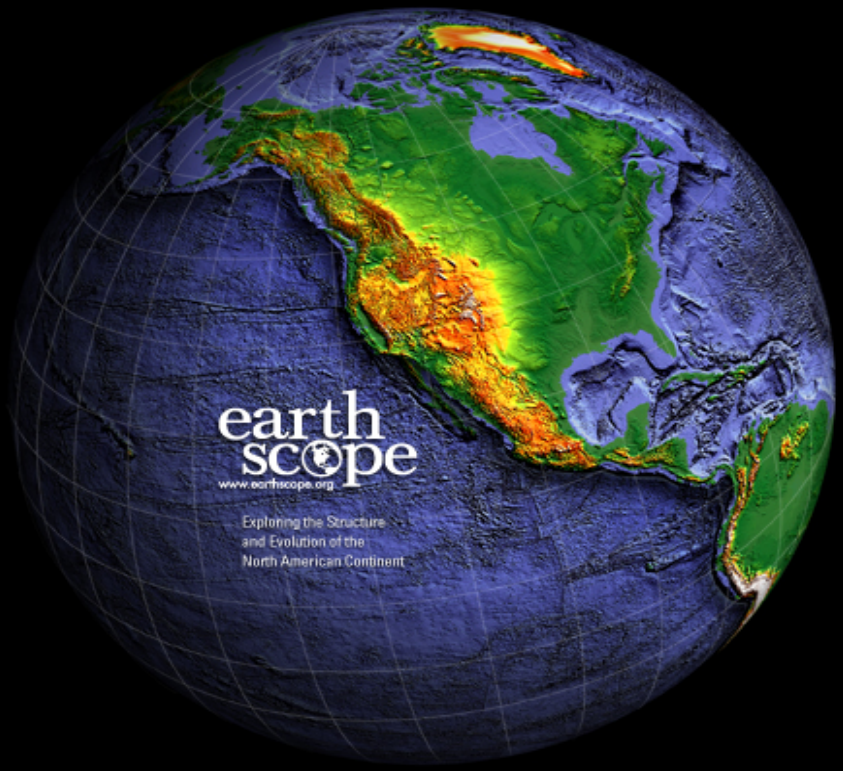
Brief History

- TA Site Selection Working Group set about selecting and prioritizing target stations
  - Chaired by Harley Benz, USGS
  - Included representation of USGS, US NRC, DOE, regional network operators, state geologists, academic seismologists
- TASSWG report prioritized 200 stations
  - Proximity to seismic hazard (and where additional coverage was required)
  - Proximity to critical infrastructure (e.g., nuclear power plants)
  - General areal coverage
- Target station configuration
  - Broadband continuous telemetry at 100 sps
  - Triggered recording at 200 sps
  - Some sites with 3 comp strong motion
  - Sites retain atmospheric sensors

Current Status

- All CEUSN stations will be in the ground by February 2014
  - Some in CEUSN configuration; Network code N4
  - Some still as part of TA
- Westernmost stations that had been removed are being re-constructed and re-installed
- Stations west of footprint that were not removed are being reconfigured
- All other CEUSN stations operating as part of active TA footprint. These will be reconfigured at the point they would otherwise be removed
- USGS intent to work towards obtaining budget increase necessary to operate and maintain the CEUSN
- Advocacy for the CEUSN is important
  - Important to highlight the value of these stations to support the ongoing funding

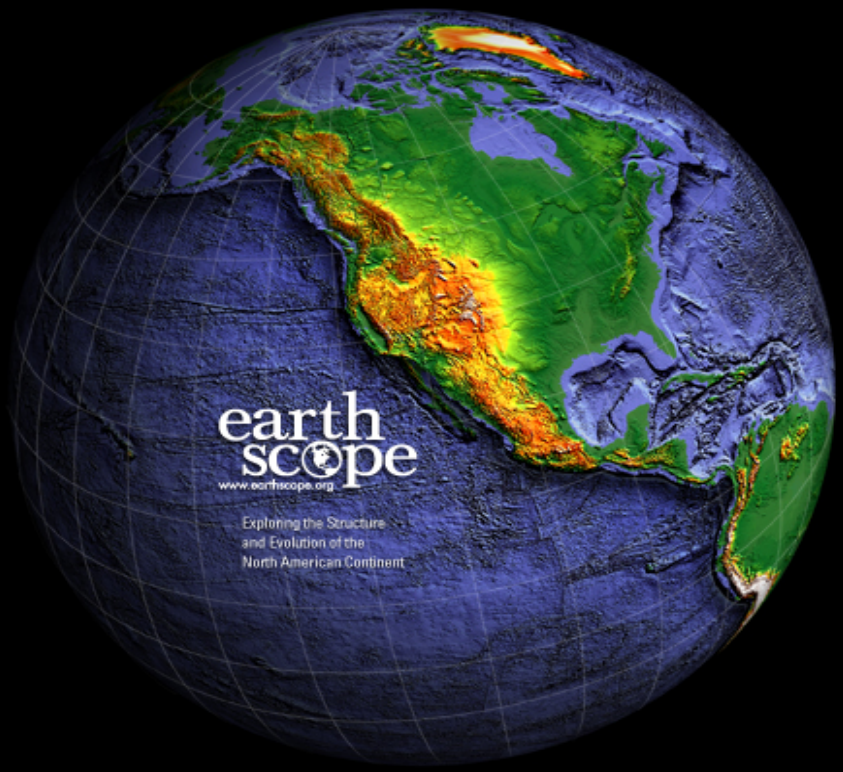
Central and Eastern US Network



Greg Anderson
NSF

CEUSN Meeting
IRIS HQ
Washington, DC
June 11, 2015

Central and Eastern US Network

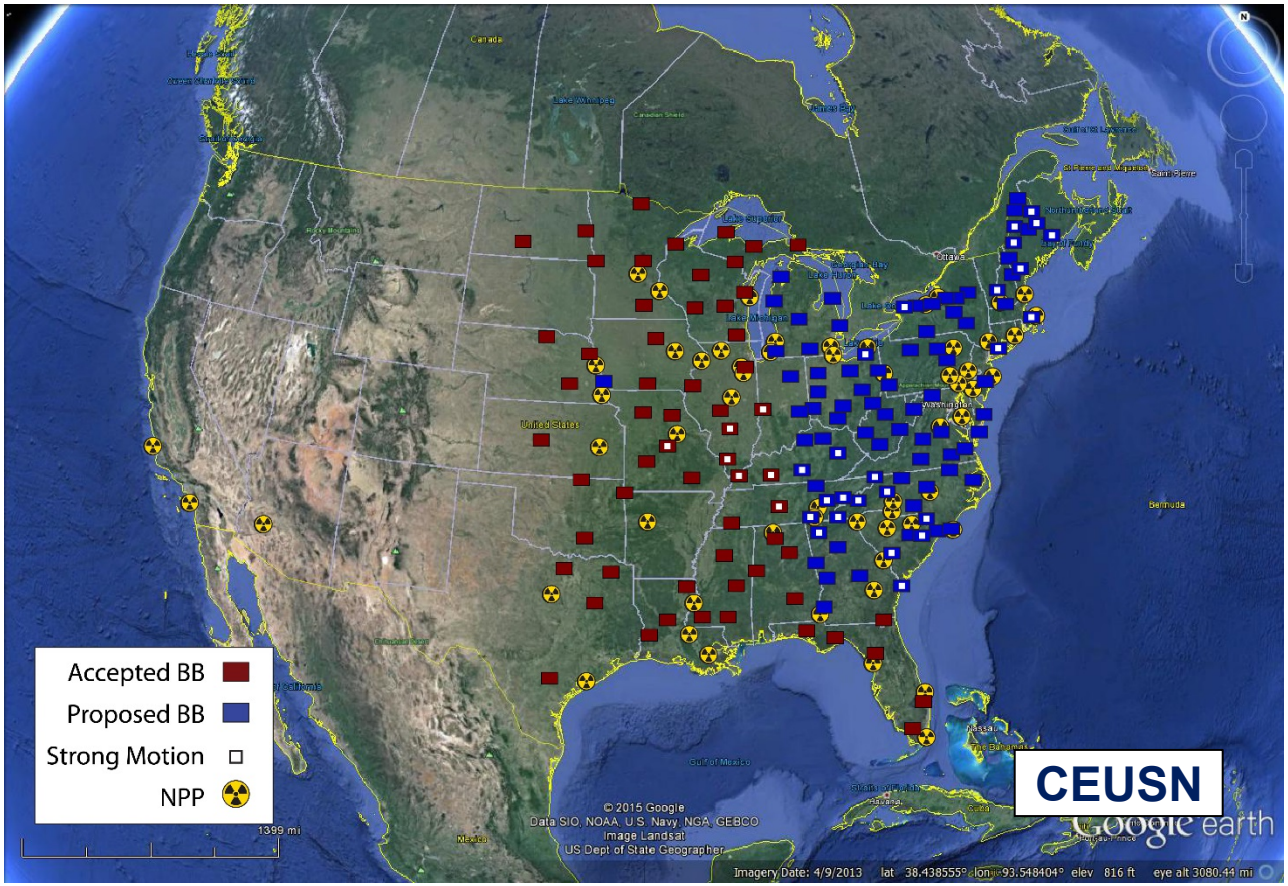


Bill Leith
USGS

CEUSN Meeting
IRIS HQ
Washington, DC
June 11, 2015

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

CEUSN Meeting, June 11, 2015



Rasool Anooshehpoor
Office of Nuclear Regulatory Research
NRC

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

NRC Perspective:

Long-term:

Improved seismic monitoring in the CEUS will enhance NRC's understanding of the seismic hazard of this region and will also inform NRC's regulatory rulemaking.

Short-term:

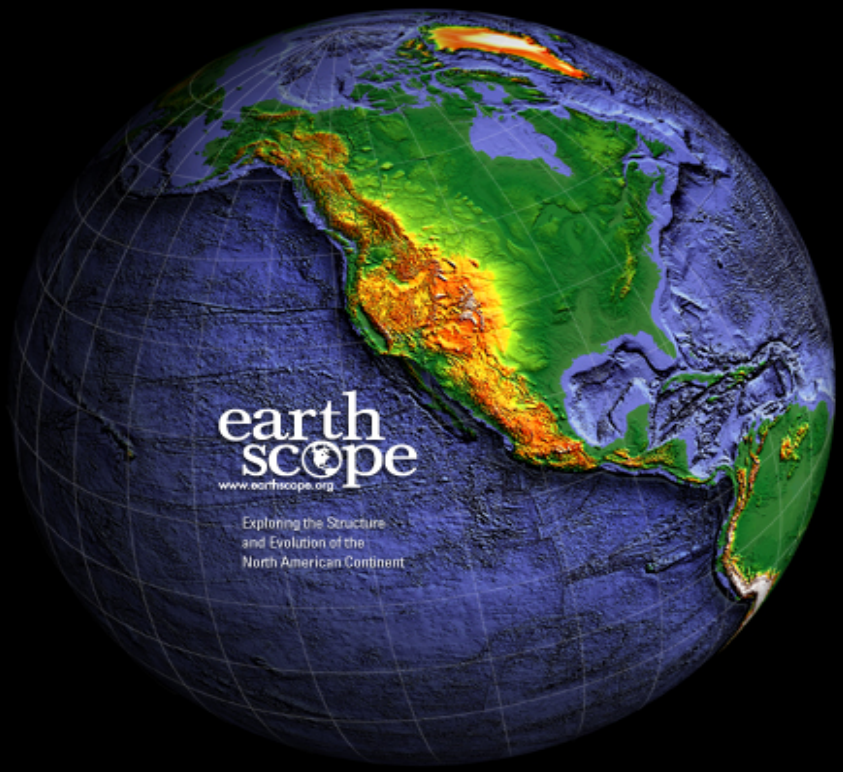
Recording strong-motion data near NPP sites to support NRC ShakeCast, and provide data for better evaluation of the OBE exceedance and site-specific response

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Current Issues with Seismic Stations at NPPs:

- The best place to put seismic stations would be in free field at the NPP sites. However, the industry has been reluctant to comply, primarily because the licensees do not want to share real-time data with the USGS.
- The NRC has been unable to justify requiring the industry to upgrade/install seismic instruments from the cost-benefit point of view because it does not prevent any safety related incident during large earthquakes.

Central and Eastern US Network

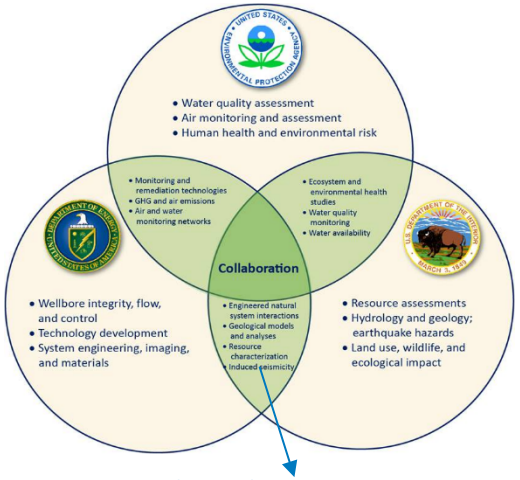


Grant Bromhal and Dustin Crandall
DOE

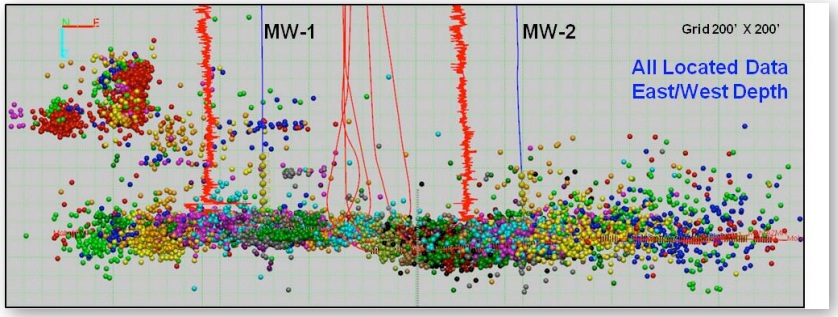
CEUSN Meeting
IRIS HQ
Washington, DC
June 11, 2015

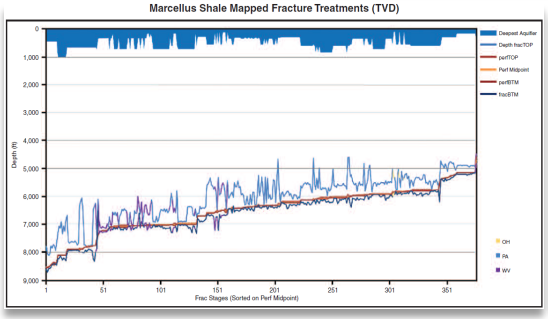
CEUSN Webinar - DOE

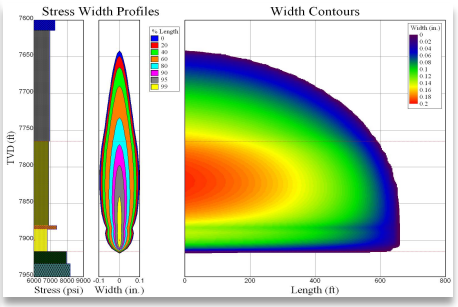
- Very interested in induced seismicity, in particular
  - Oil and gas operations (multiagency collaboration)
  - Carbon storage
  - Geothermal
  - Other energy-related injection/production
- National Risk Assessment Partnership
  - Probabilistic Hazard/Risk Analysis
  - Forecasting models
  - Seismicity-induced leakage
- DOE Fossil Energy is investing in several new field studies
  - Large scale carbon storage studies and RCSPs
  - Shale gas field laboratories
  - Frontier Observatory for Research in Geothermal Energy (FORGE)
- DOE Subsurface Crosscut
  - New initiative
  - Crosses several program offices
    - FE, EERE, NE, EM,…
  - http://www.energy.gov/subsurface-tech-team



Induced seismicity







Induced Seismicity R&D

With high volumes of "used" frack water needing disposal, induced seismic events are rising significantly

Background

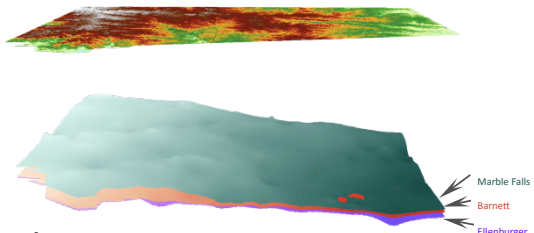
- Increasing seismic activity appears to be linked to increased waste water injection and gas well stimulation in certain regions

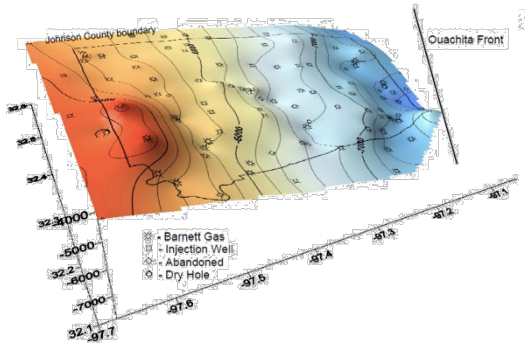
Objectives

- Compile geologic and injection information to populate geomechanical + flow models
- Perform simulations to evaluate changes in stress conditions that could lead to fault movement
- Add'l project focused on big data + probabilistic analyses to predict induced seismicity risks

Findings to Date

- Linkages between wastewater injection and induced seismicity based on observations and modeling

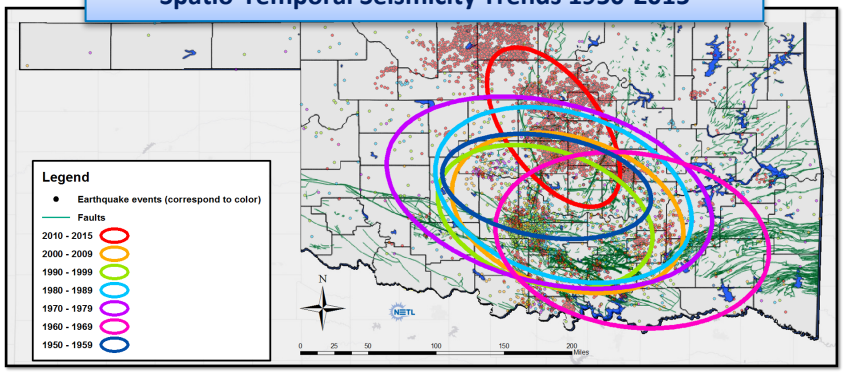




hadoop

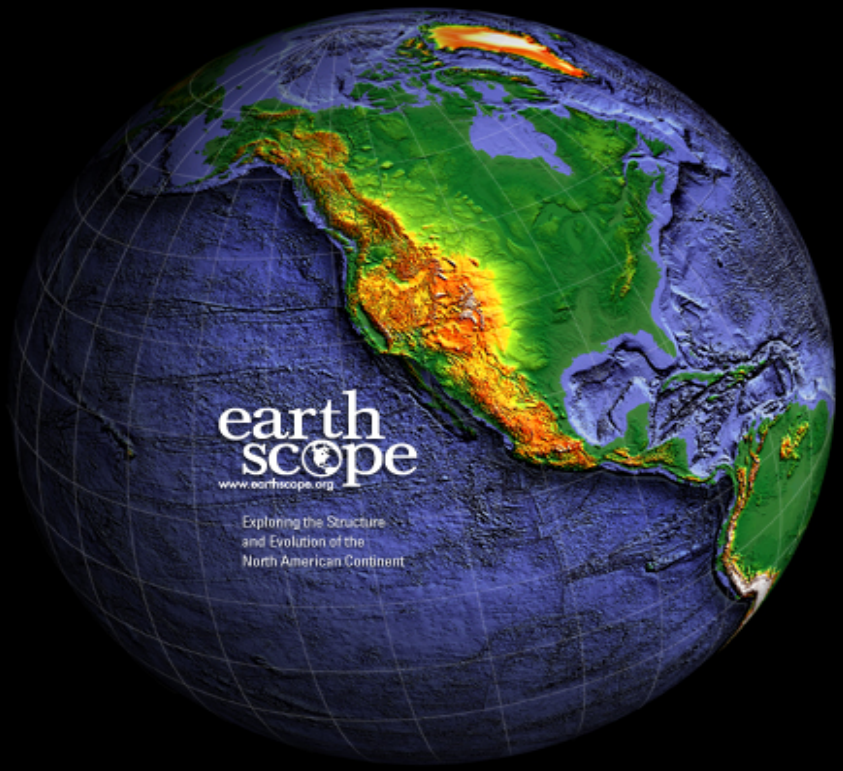
EDX
A Product of NETL

Spatio-Temporal Seismicity Trends 1950-2015



Implications for understanding system behavior, improving efficiency, reducing risk & uncertainty, & environmental sustainability

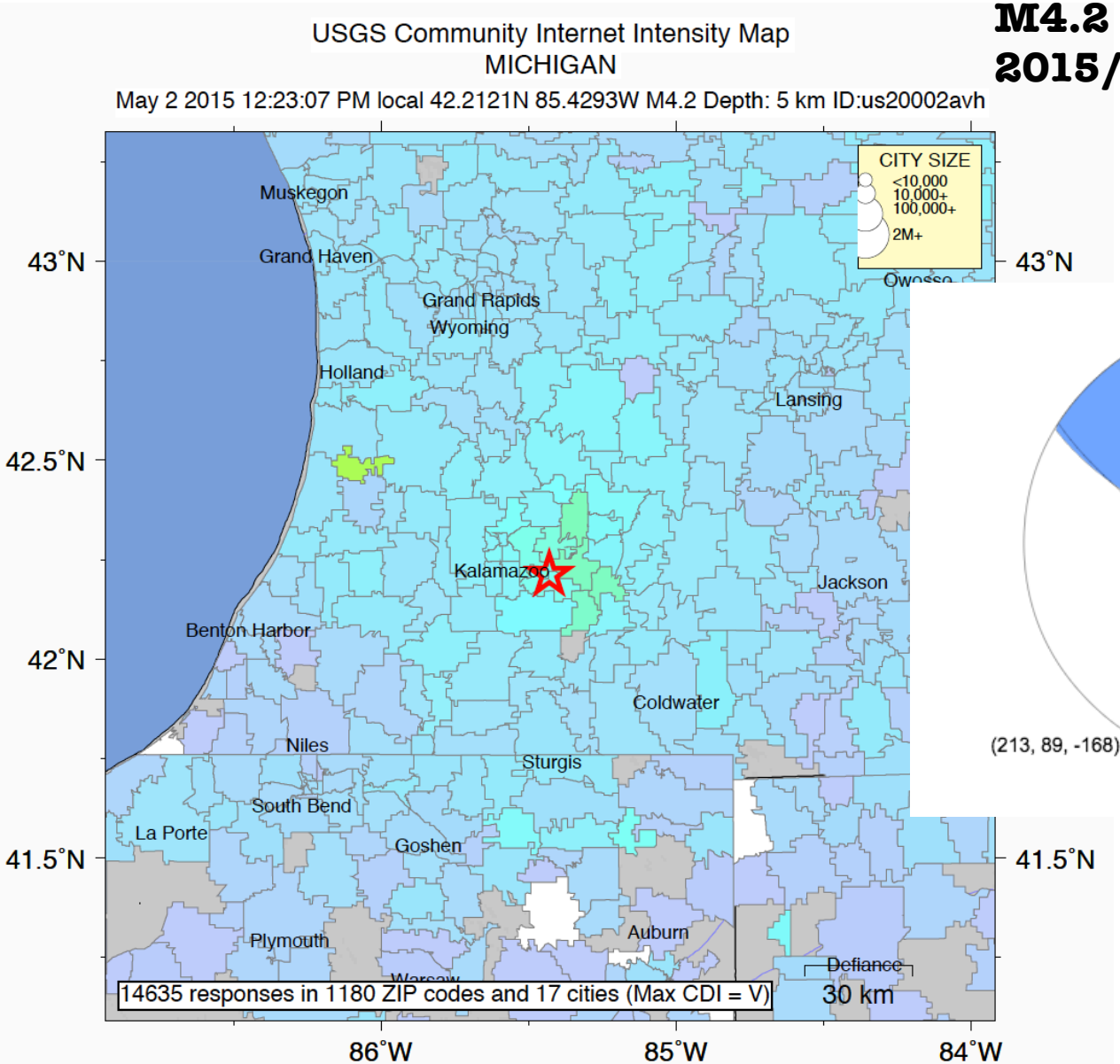
Central and Eastern US Network

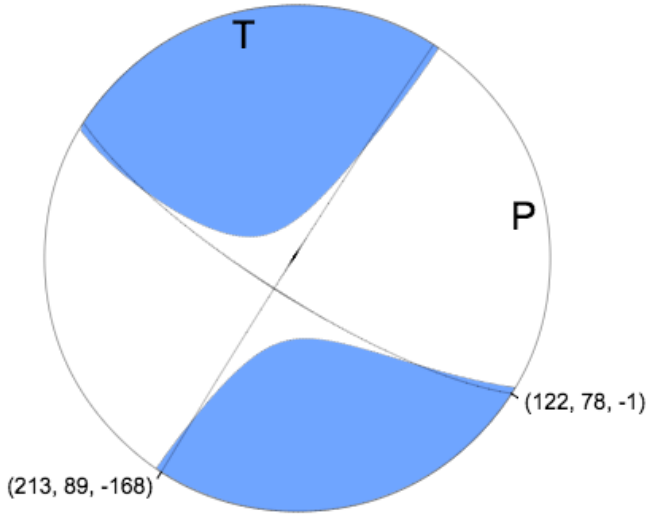


Harley Benz
USGS

CEUSN Meeting
IRIS HQ
Washington, DC
June 11, 2015

M4.2 Michigan Earthquake 2015/05/02 16:23





INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

Processed: Wed May 13 01:12:23 2015

20002AVH - Magnitudes - Hydra v2.5.2 - M 4.2 - MICHIGAN

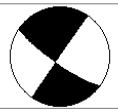
OT: 16:23:07 2015/05/02 Lat: 42.212° Lon: -85.430° Depth: 5.4 km Mag: 4.2 Region: MICHIGAN

Options

Preferred: 4.2 Mwr | -.- Mwc | -.- Mwb | 4.2 Mwr | -.- km Mwd | 4.2 Mwp | 4.2 mb | -.- mB_BB | 3.3 Ms_VX | 3.5 Ms_20 | -.- Ms_BB | 4.9 ML | 4.6 mb_Lg | 5.1 Md | -.- Mww | Composite

Summary | Solution Plot | Mw Details | Passport

Moment Summary

Parameter	Value	Uncertainty
Pref. Magnitude	4.2 Mwr - NEIC	+/- 0.0
Region	MICHIGAN	
Time	16:23:07.98 2015/05/02	
Location	42.212°, -85.430°	+/- 2.40 km, +/- 1.00 km
Depth	5.4 km	+/- 5.50 km
Time Since	010 Day(s) 23:59:43	
Magnitude	4.2 Mwr	+/- 0.0
Observations	109(109)	
Mw'	4.2	+/- 0.3
Source	NEIC - rmt_module	
Associated By	NEIC - rmt_module	
Moment	2.150 E 22 (dyne-cm)	
Solution Depth	8.00 km	
Fit	0.74	
Var. Red.	0.00	
Percent DC	79.12%	
Focal Mech.		
Nodal Plane 1	Strike: 124.65 Dip: 79.57 Rake: -0.79	
Nodal Plane 2	Strike: 214.79 Dip: 89.22 Rake: -169.57	
Input Source	Undefined ()	
Source Time Function		
Solution Method		
Solution Location		
Solution Time		

Options | Save | Edit Comment

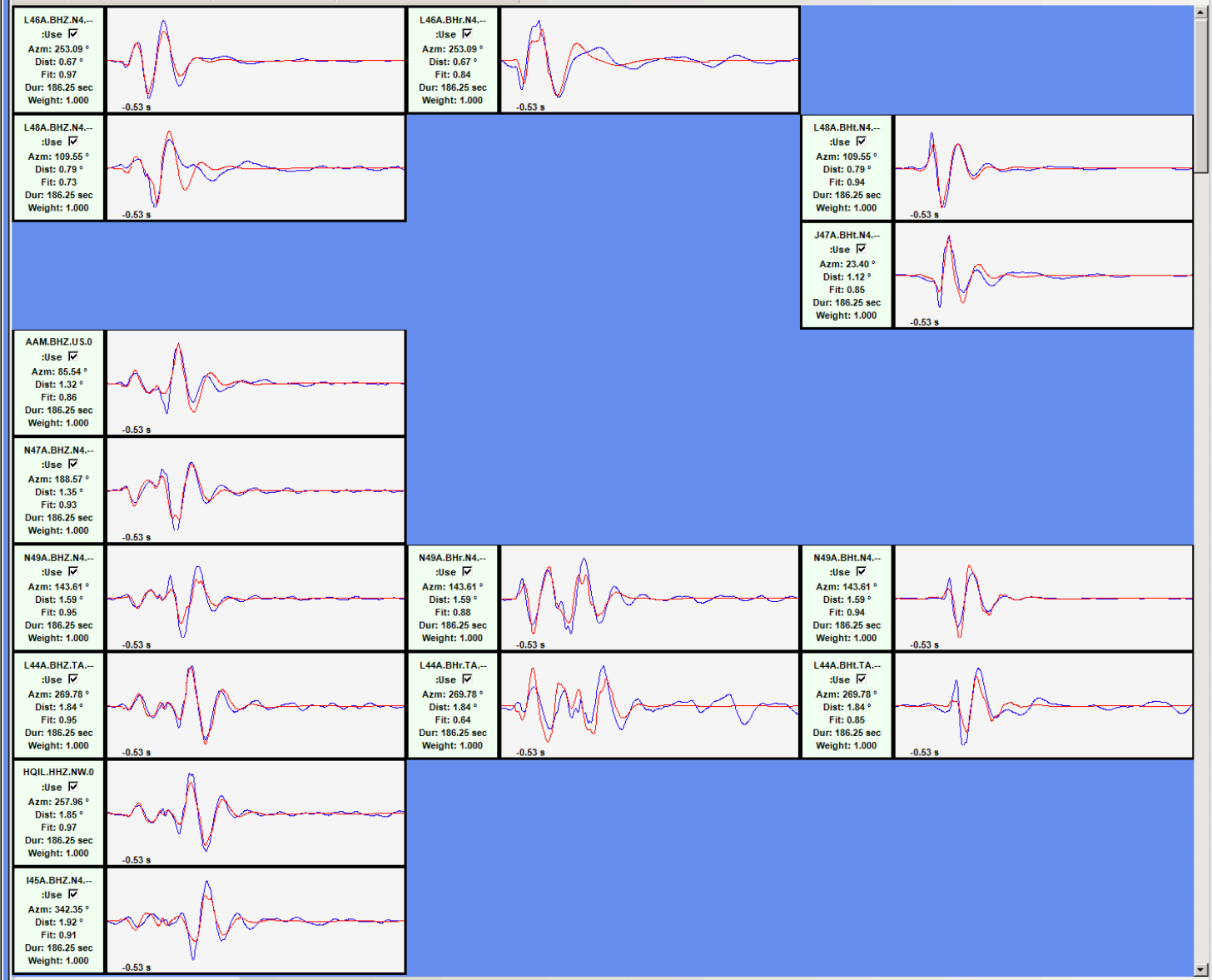
Contributed Magnitudes:

Pub.	Pref	Pref. For Type	Focal Mech.	Author	Value
☑				rmt_module	4.2
☑		☑		John Bellini	4.2

Magnitudes: 2 shown Options

Waveform Fits:

Sorting: | Station | Network | Location | Distance Asc | Azimuth | Vertical Fit | Radial Fit | Tangential Fit

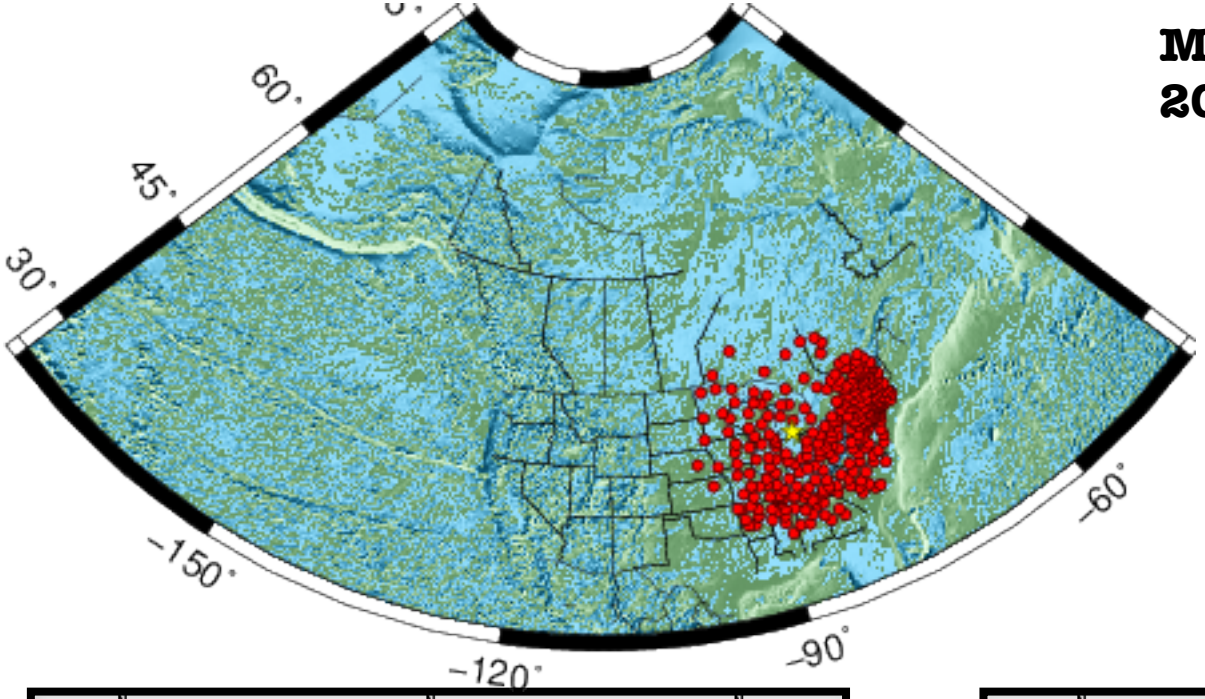


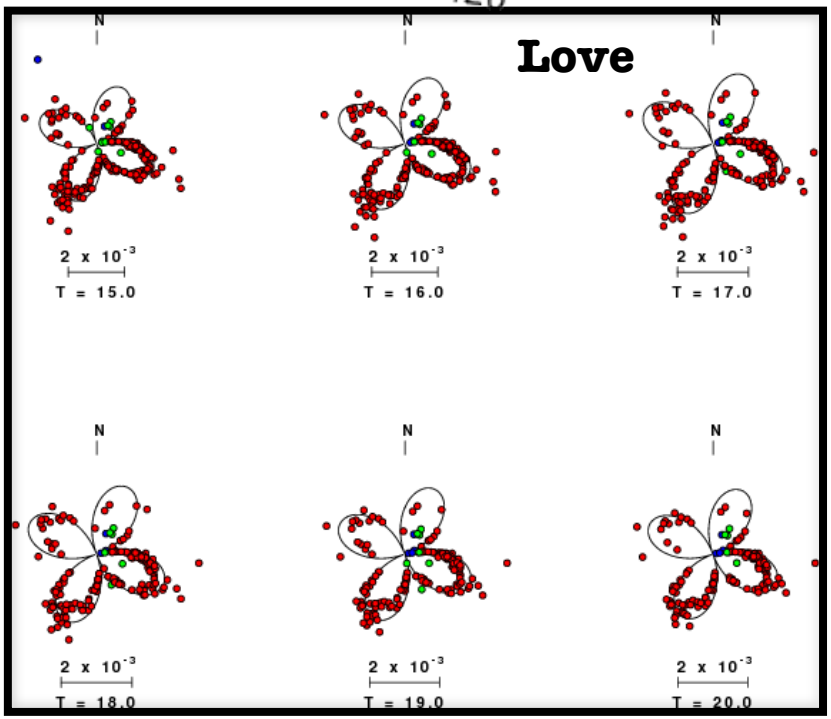
Show: 9 Waveforms (53 Total Stations)

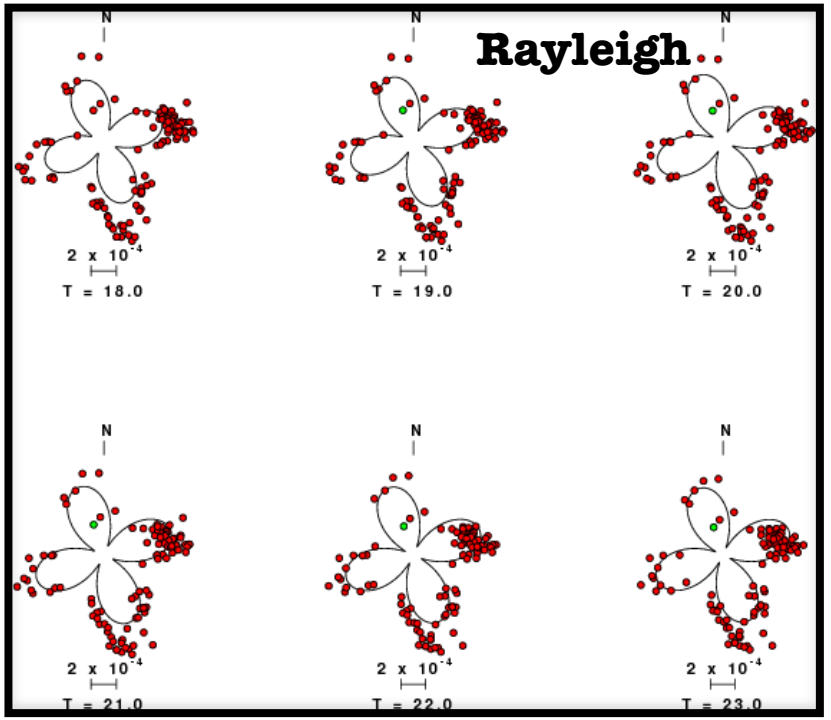
Create | Summary | Location | Traveltimes | Merge | Waveforms | Publication | History | Delete | Snapshot | Reject | Close Event | Review By ID | Help | Rework | Refresh | Close

Loading Progress: | Event Status: Fully Processed | System Status: Active

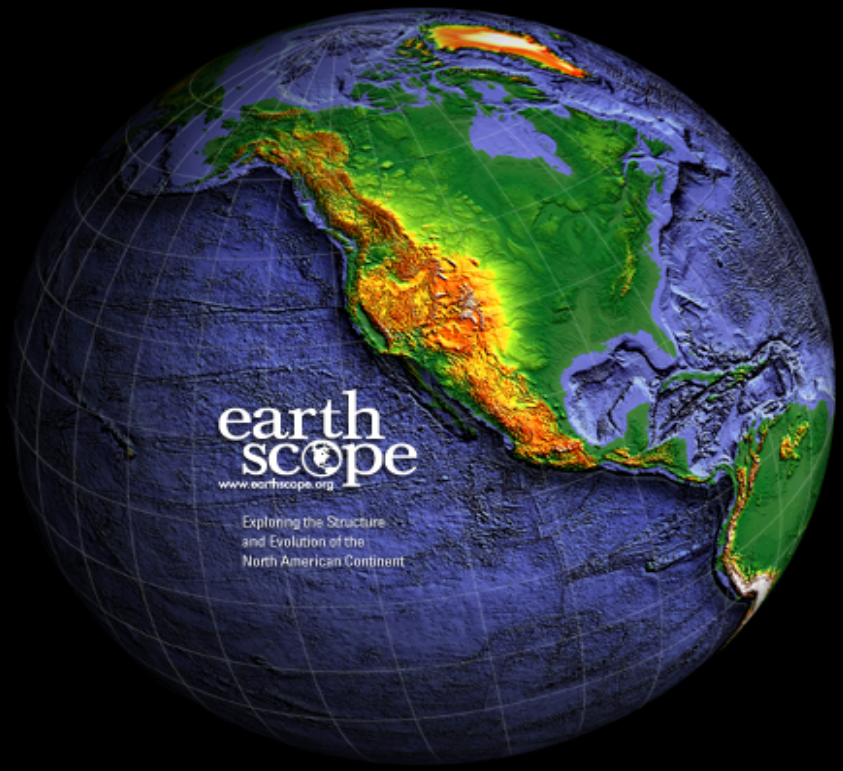
M4.2 Michigan Earthquake
2015/05/02 16:23







Central and Eastern US Network

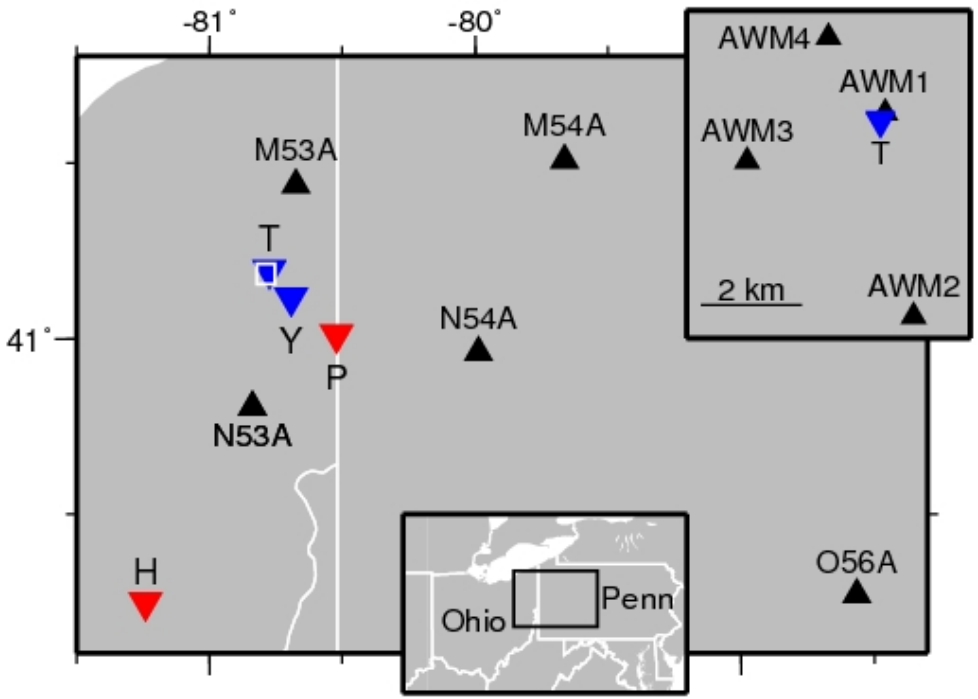


Mike Brudzinski
Miami Univ. of Ohio

CEUSN Meeting
IRIS HQ
Washington, DC
June 11, 2015

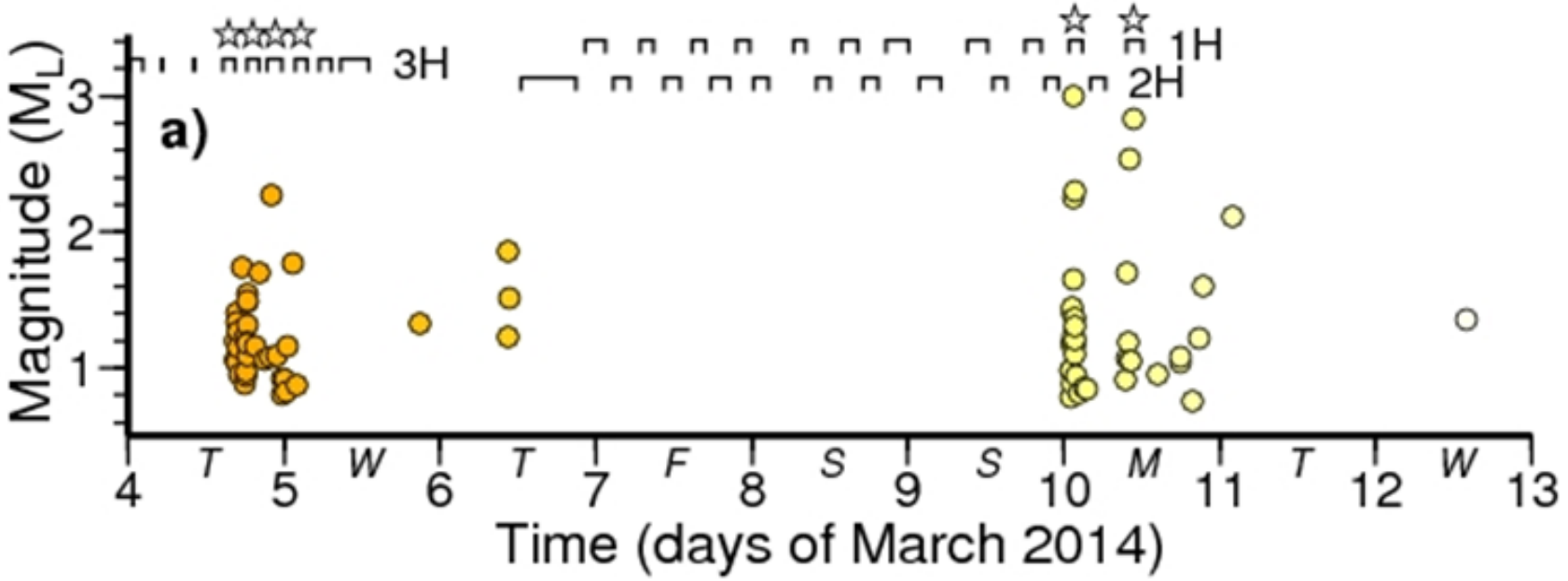
Seismic Networks used for Ohio Induced Seismicity

- Youngstown: M54A, N54A, O56A
- Poland: N53A, M53A, N54A
- Trumbull: AWM1, AWM2, AWM3, AWM4



Detection with 3 Station Template Matching

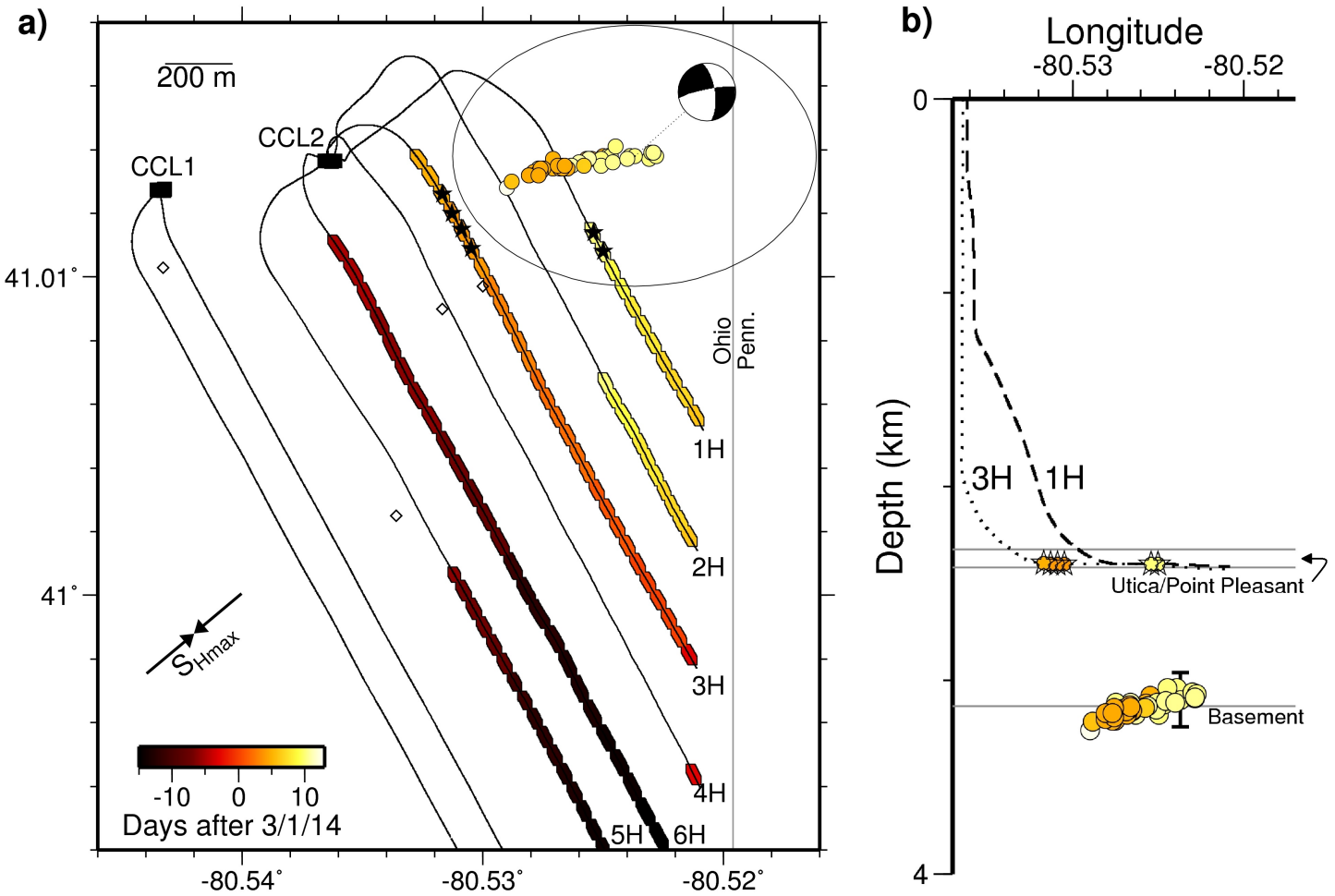
- A felt earthquake used as a template
- 77 events detected within an hour of notification
- Nearly all earthquakes during 6 hydrofrac stages
- Operations halted in <24 hours



Skoumal et al., BSSA, 2015

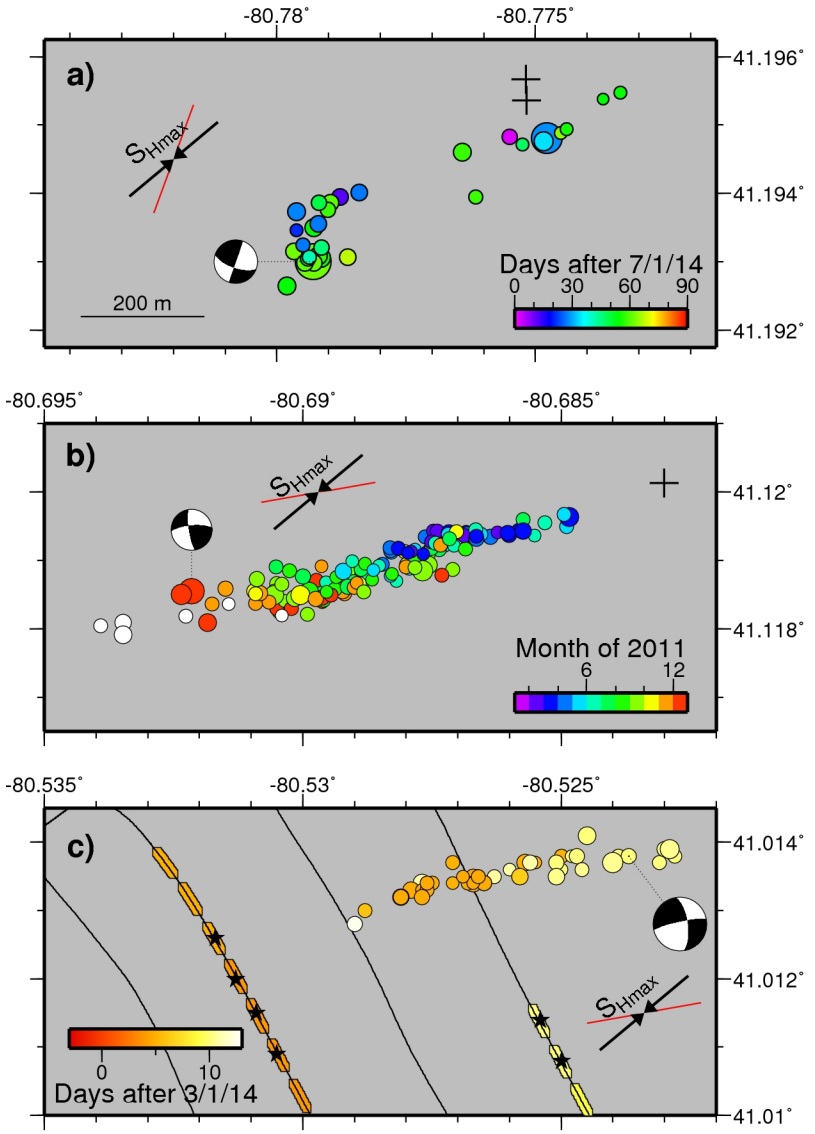
Poland Township

- Earthquakes occurred during closest stages

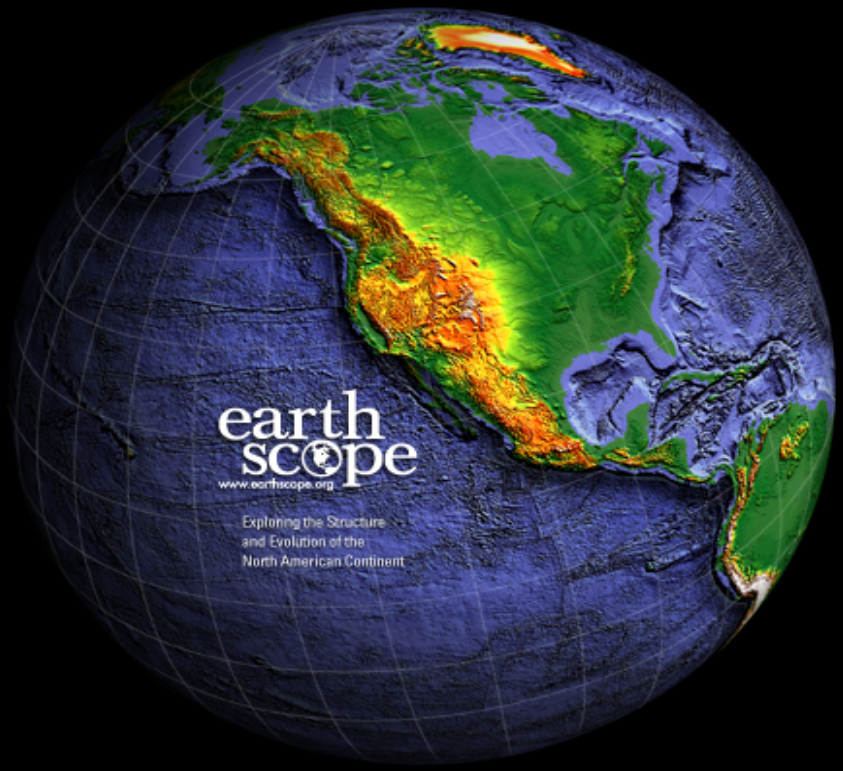


Relative Locations and Focal Mechanisms

- Regional networks can produce double difference relative locations and focal mechanisms to characterize faults
- Hypocentral distribution and focal mechanisms outline strike-slip faults oriented 30° from the regional maximum horizontal stress (S_{Hmax})



Central and Eastern US Network



Gail Atkinson
Western University

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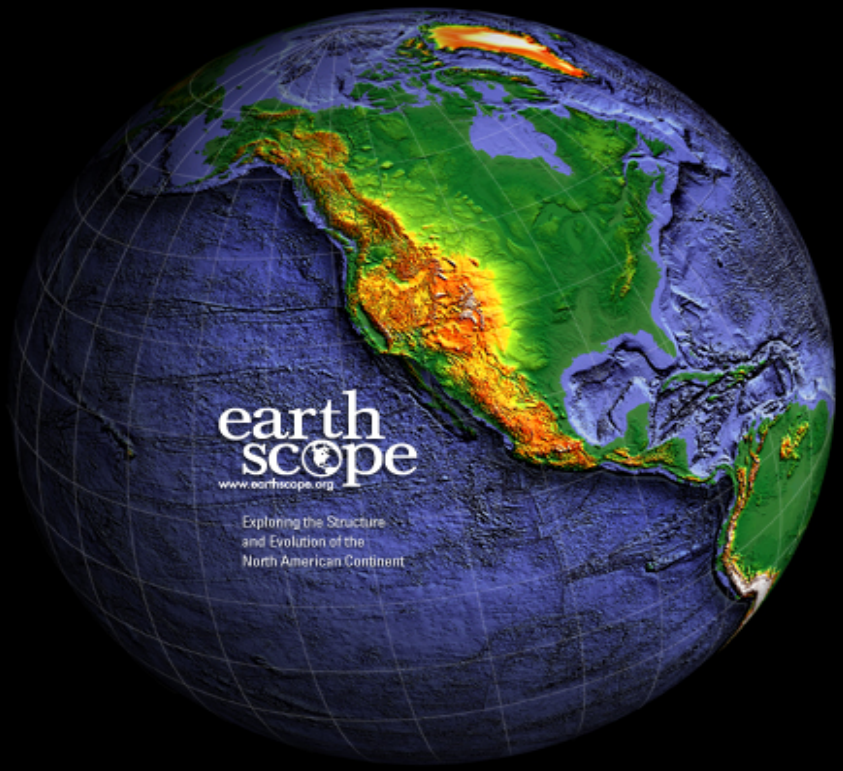
Central and Eastern US Network



Andy Nyblade
Penn State University

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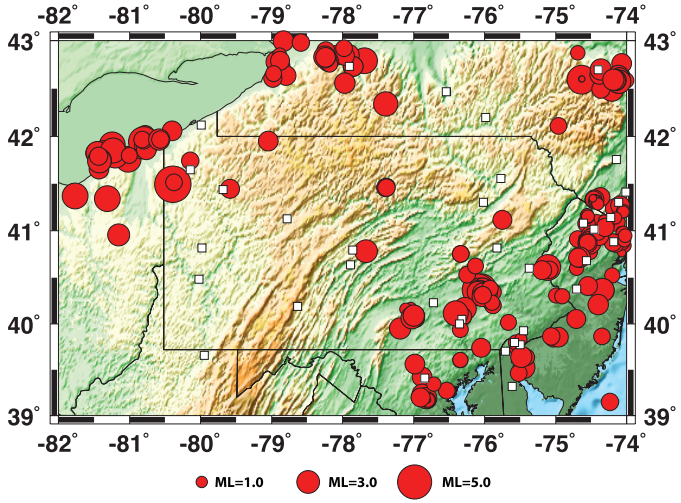


Figure 1: Earthquake locations from the LCSN/USGS catalog from 1990-2010

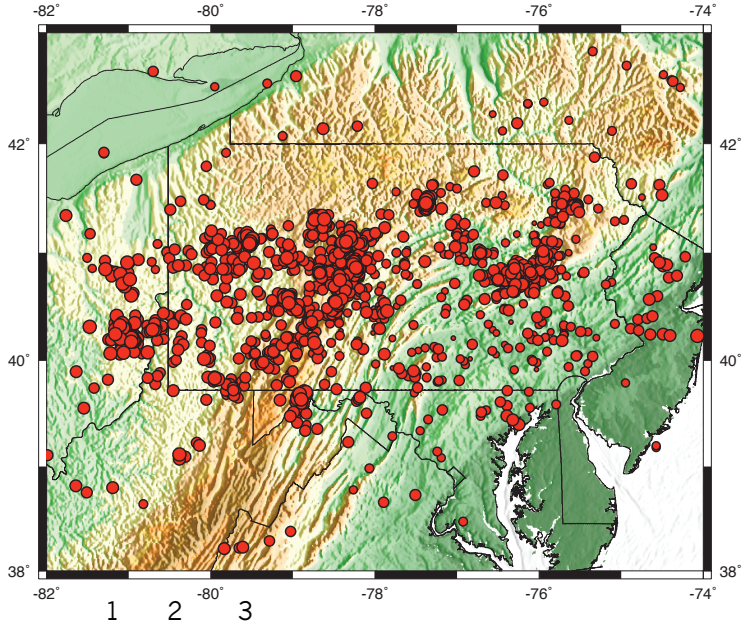
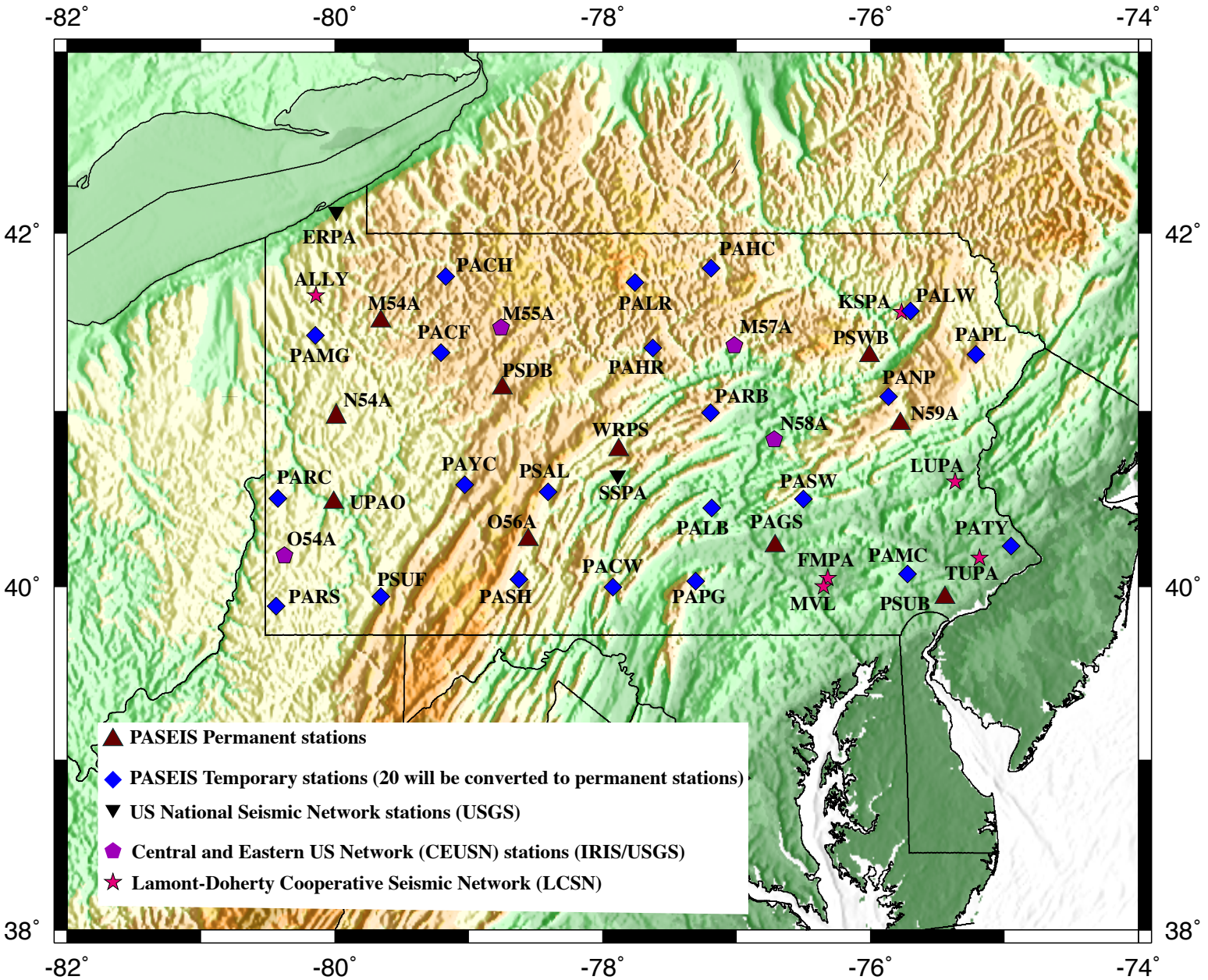
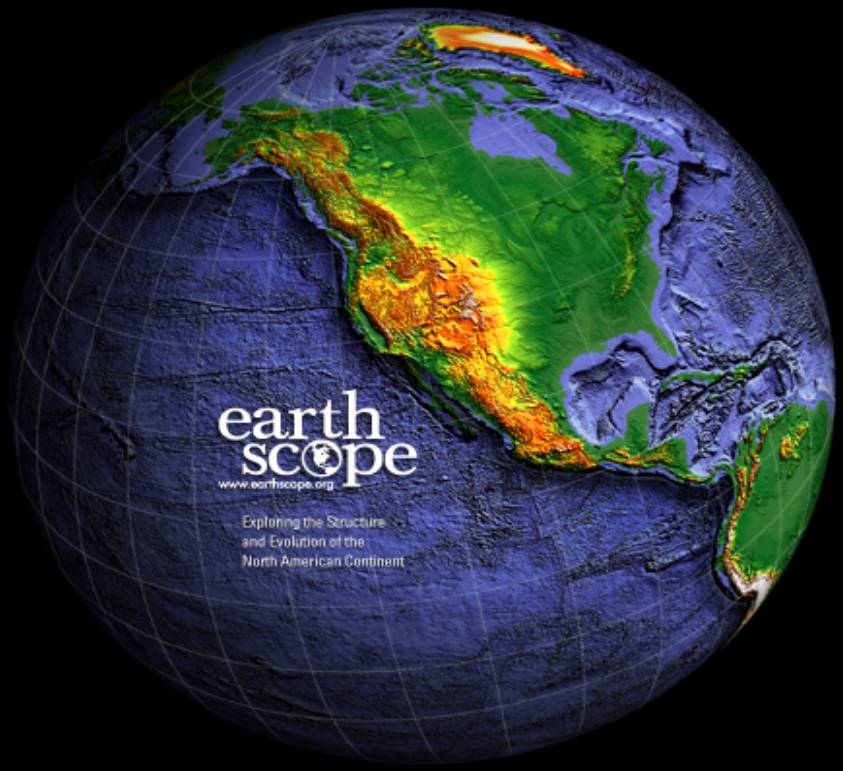


Figure 3: Event epicenters scaled by magnitude (Ml)


-82˚
-80˚
-78˚
-76˚
-74˚
42˚
40˚
38˚
ERPA
ALLY
PACH
M54A
M55A
PACF
PAMG
PSDB
N54A
PALR
PAHC
M57A
PAHR
KSPA
PALW
PSWB
PAPL
PANP
PARB
N58A
N59A
WRPS
SSPA
PAYC
PSAL
PARC
UPAO
O56A
O54A
PACW
PALB
PAGS
PASW
LUPA
PATY
FMPA
PAMC
TUPA
MVL
PSUB
PSUF
PARS
PASH
PAPG
PASEIS Permanent stations
PASEIS Temporary stations (20 will be converted to permanent stations)
US National Seismic Network stations (USGS)
Central and Eastern US Network (CEUSN) stations (IRIS/USGS)
Lamont-Doherty Cooperative Seismic Network (LCSN)

Central and Eastern US Network



Won-Young Kim
Lamont-Doherty Earth Observatory

CEUSN Meeting
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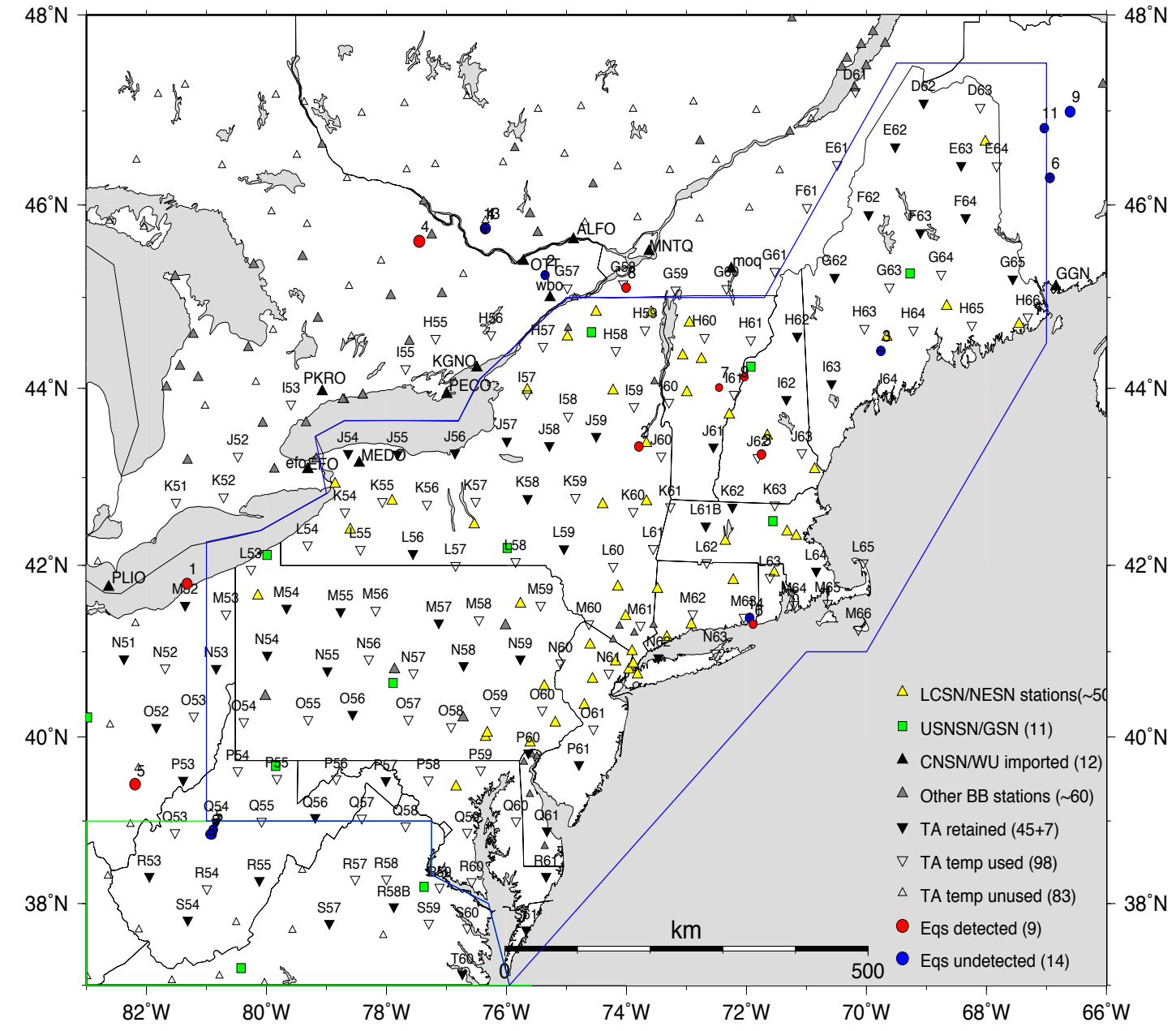
June 11, 2015

Contribution of TA stations on Earthquake Monitoring & Research: *12 January 2015 Moosup, CT Earthquakes*

Won-Young Kim
Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, USA

- Full Deployment of TA stations in the NEUS at the end of Oct. 2013.
  - TA Data are Integrated into Permanent Stations of RSN/ANSS in Real Time
  - Automatic Earthquake Detection, Location and Information Dissemination in Real Time became Reality in the Northeastern US due to TA station deployment,
  - ShakeMaps & Focal Mechanism from Regional Waveform Modeling are routine for events with Mw > 3.5,
  - Integrated CEUSN allow Detailed Tomographic Studies of Crust & Uppermost Mantle Velocity Structure in the Region
  - Reliable Characterization of Earthquakes with uniform Detection Threshold
- An earthquake sequence that began on Jan. 12, 2015 at eastern Connecticut provided an example of how TA station data contributed on our earthquake monitoring, and to studies of those small earthquakes.
- We observed infrasound/sound waves from the Mw 3.2 earthquake in Moosup, CT which were recorded by infrasound sensor at TA stations.

TA and Regional Network Stations in the NEUS



TA stations are fully deployed in the Northeastern US by late October 2013,

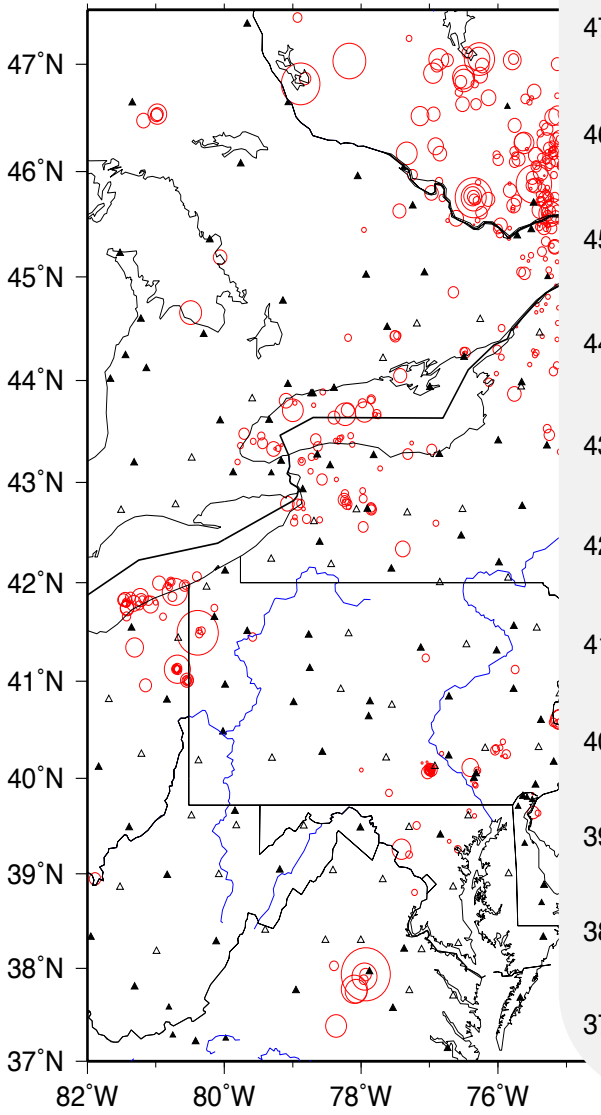
150 TA station data are integrated into LCSN real time earthquake monitoring system

Following the 2009 ARRA upgrade of RSN stations in the region (~50), and GSN/CNSN/USNSN (23), PE(5)

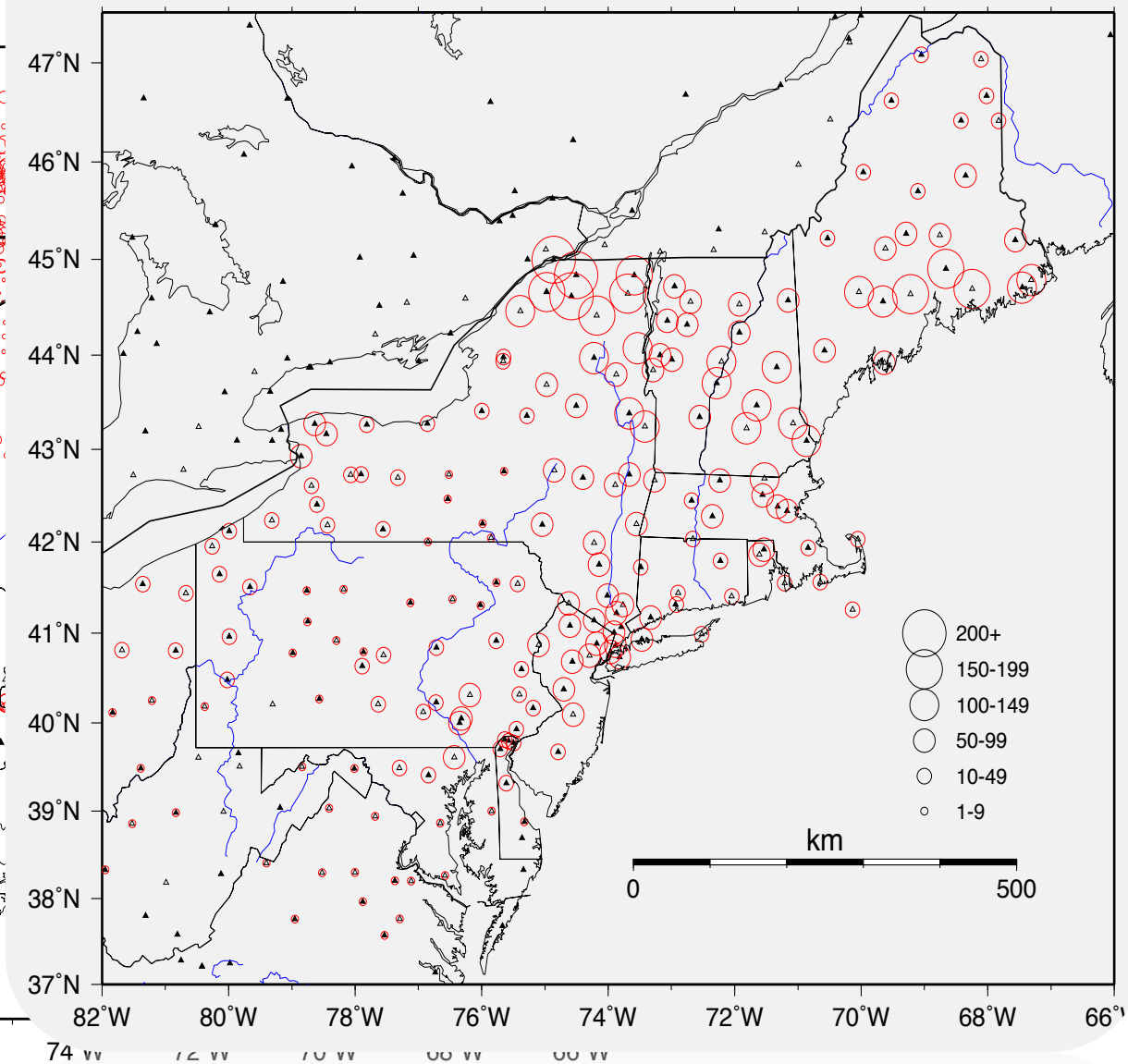
230 stations are available since the late 2013. Automatic Earthquake Location works in real time.

Earthquakes in the NEUS 1998-2014 and Station Hit Map

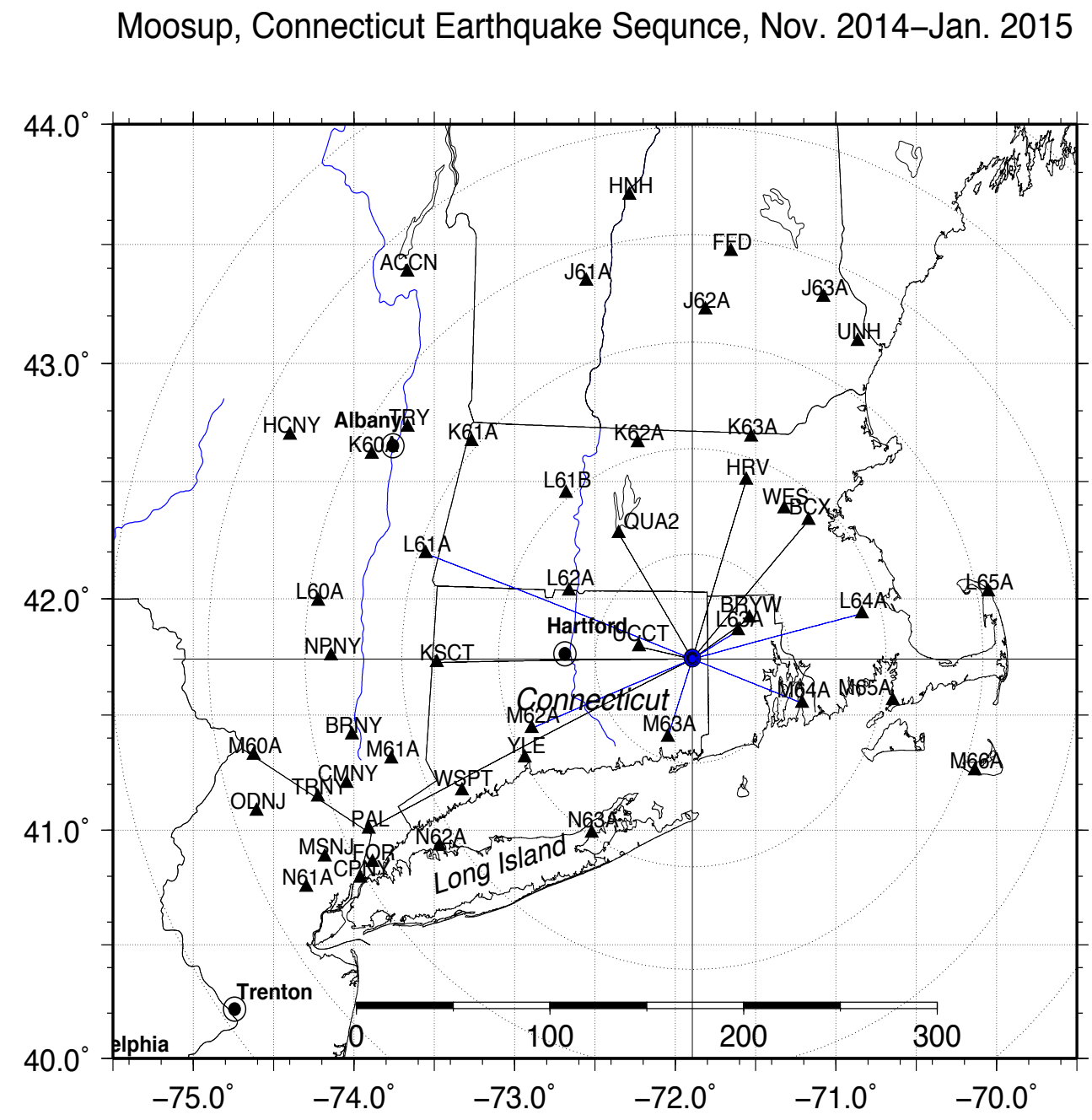
Earthquakes in northeastern U



Number of event hit counts of stations for earthquakes in 1998-2014

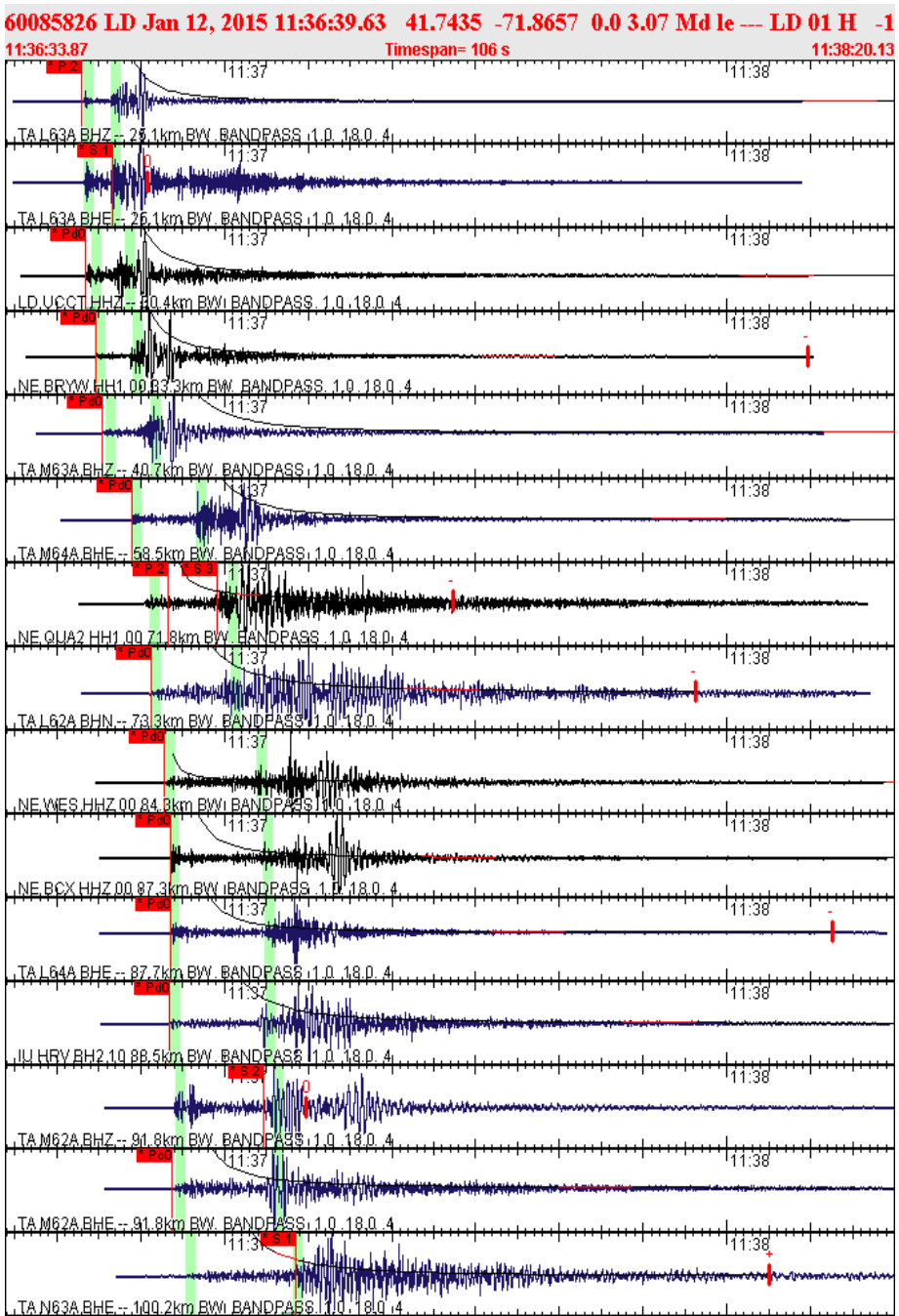


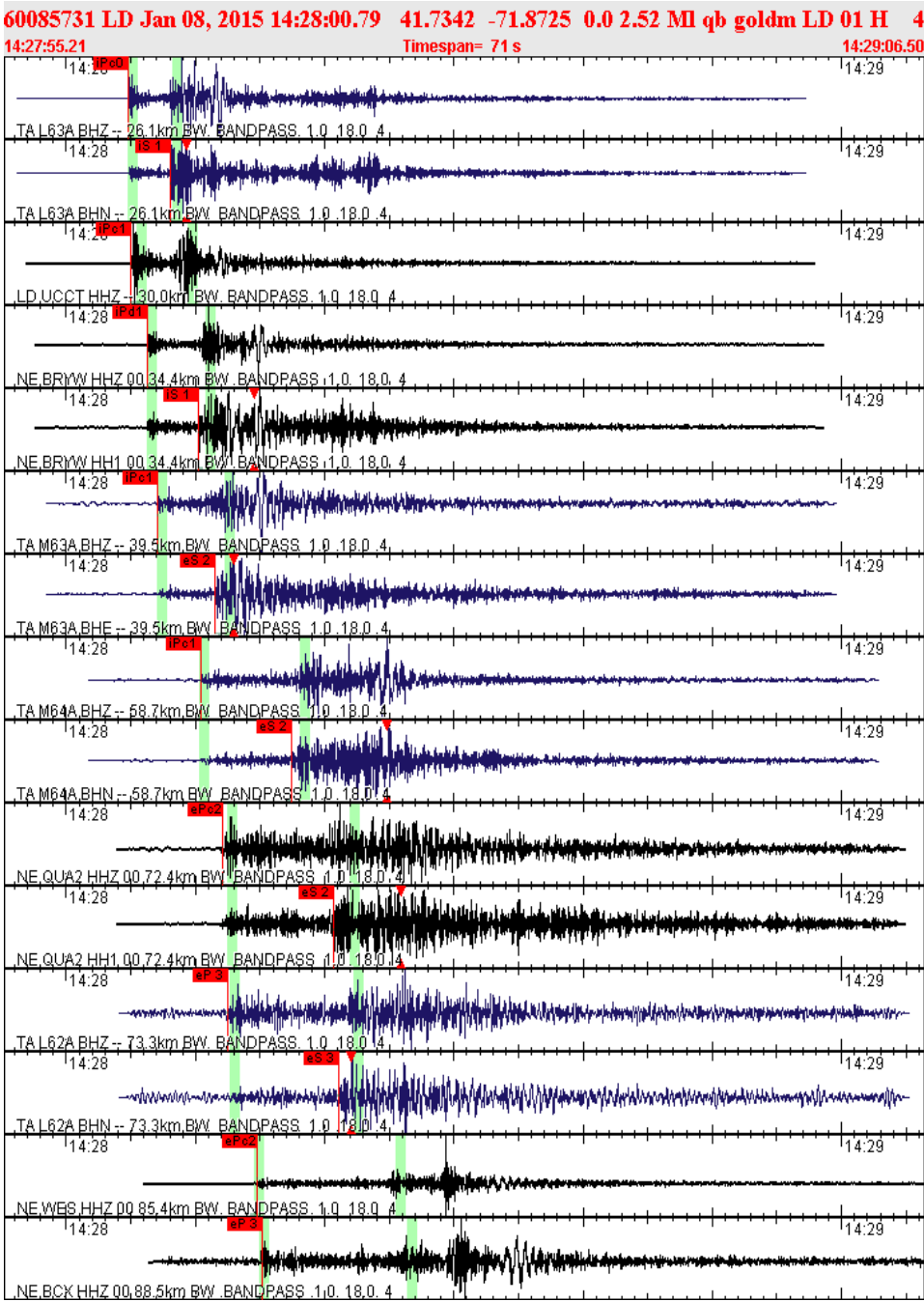
Case Study: Mw 3.2 Moosup, CT Earthquake on 12 Jan. 2015



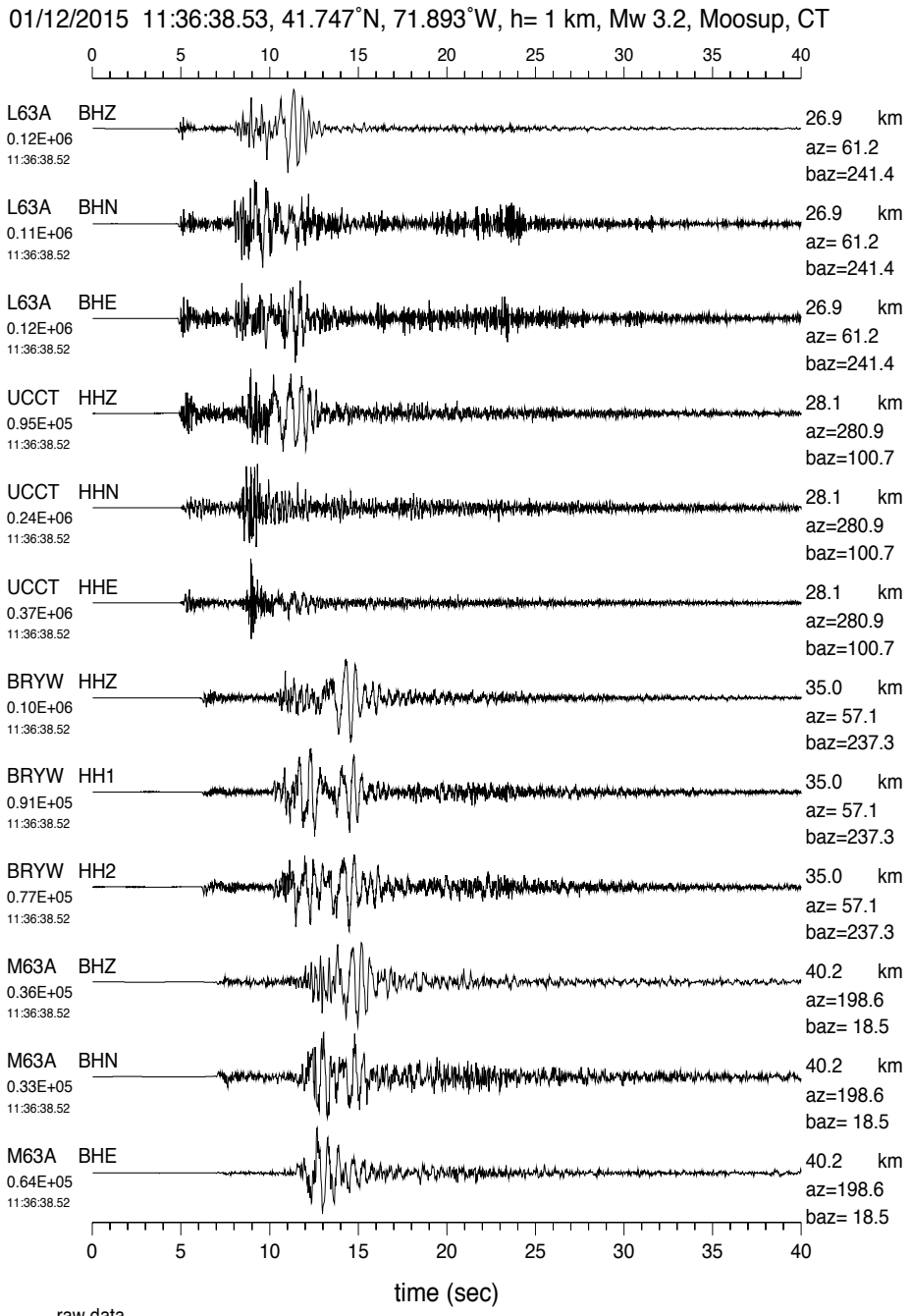
- Mw 3.2 mainshock occurred in eastern Connecticut near Moosup-Danielson area on 12 Jan. 2015.
- Shock is detected and located by AQMS and are reported within 5 minutes since well covered by TA and other permanent stations in the region.
- ShakeMap is generated,
- Focal mechanism is determined,

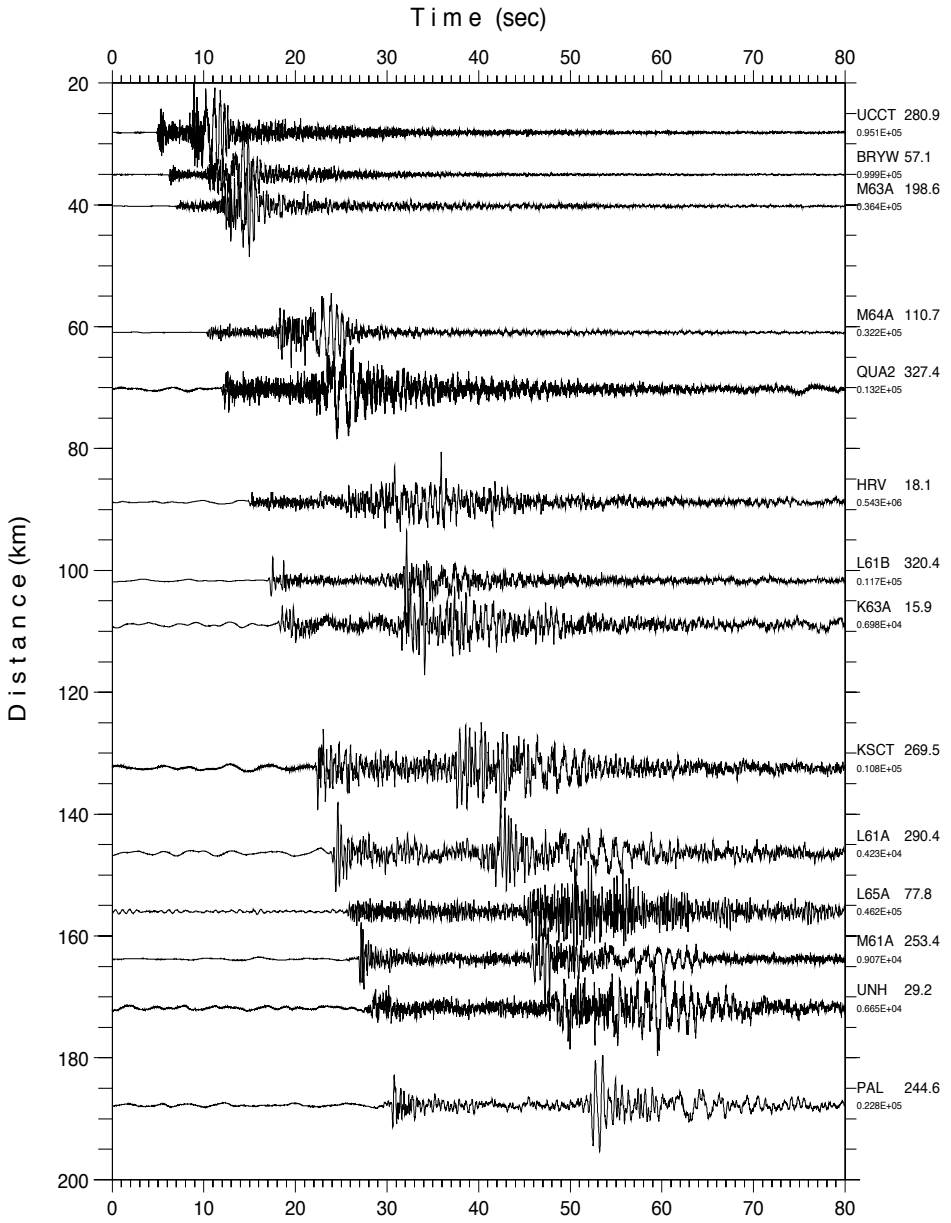
Automatic Processing using ANSS Quake Management System (AQMS) – DutyReview





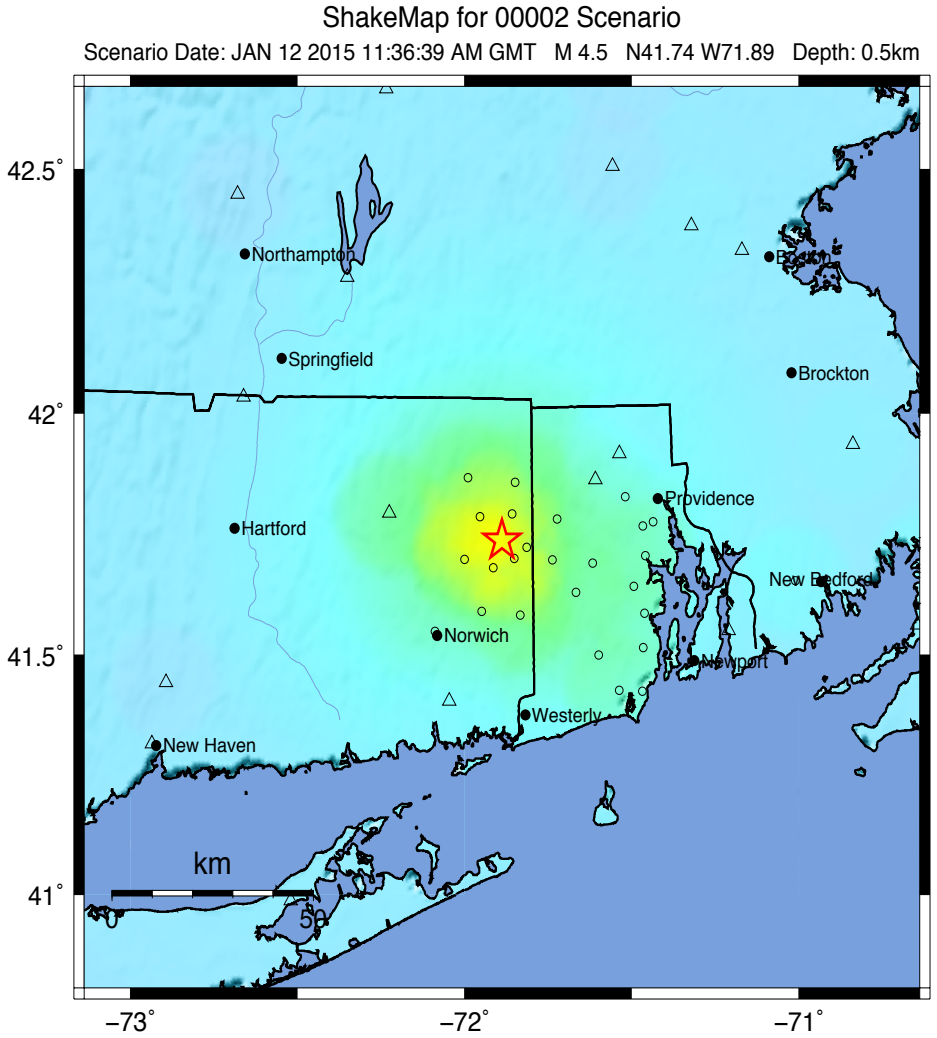
Strong Short-period Rayleigh Waves Indicate Typical Shallow Event





raw data

ShakeMap with peak ground acceleration can be generated from seismic data



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2011)

It is observed that within 50 km from the epicenter, peak ground acceleration is at around 20-30 Hz in the region, hence TA station data with 40 sample/sec underestimated the ground motion. Because useful data were limited to 16 Hz.

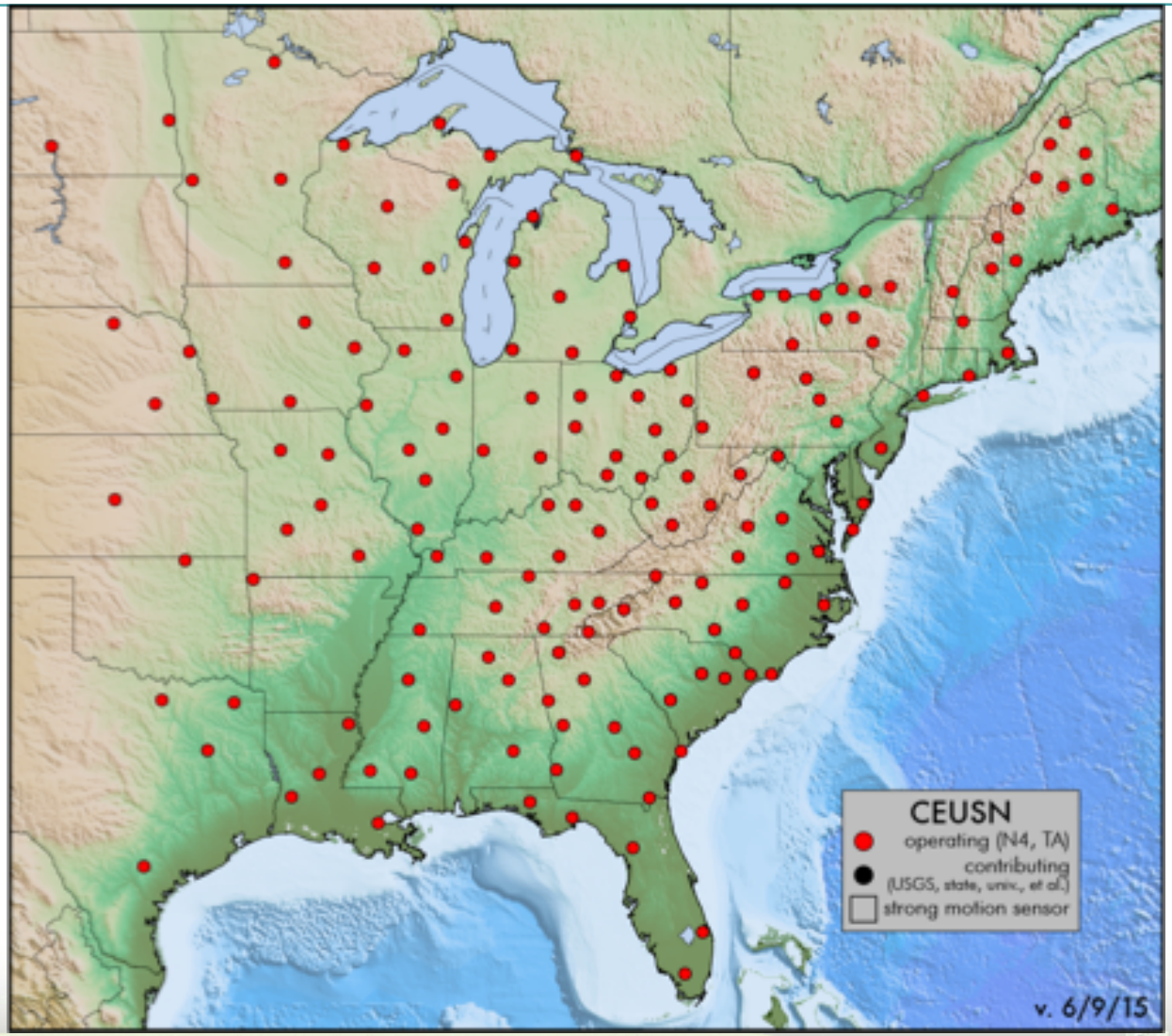
However, these TAs and N4 stations in the region had been upgraded to 100 samples/sec at the end of Jan. 2015.

Atmospheric pressure and Infrasound Monitoring

From the Mississippi River to the Atlantic Ocean

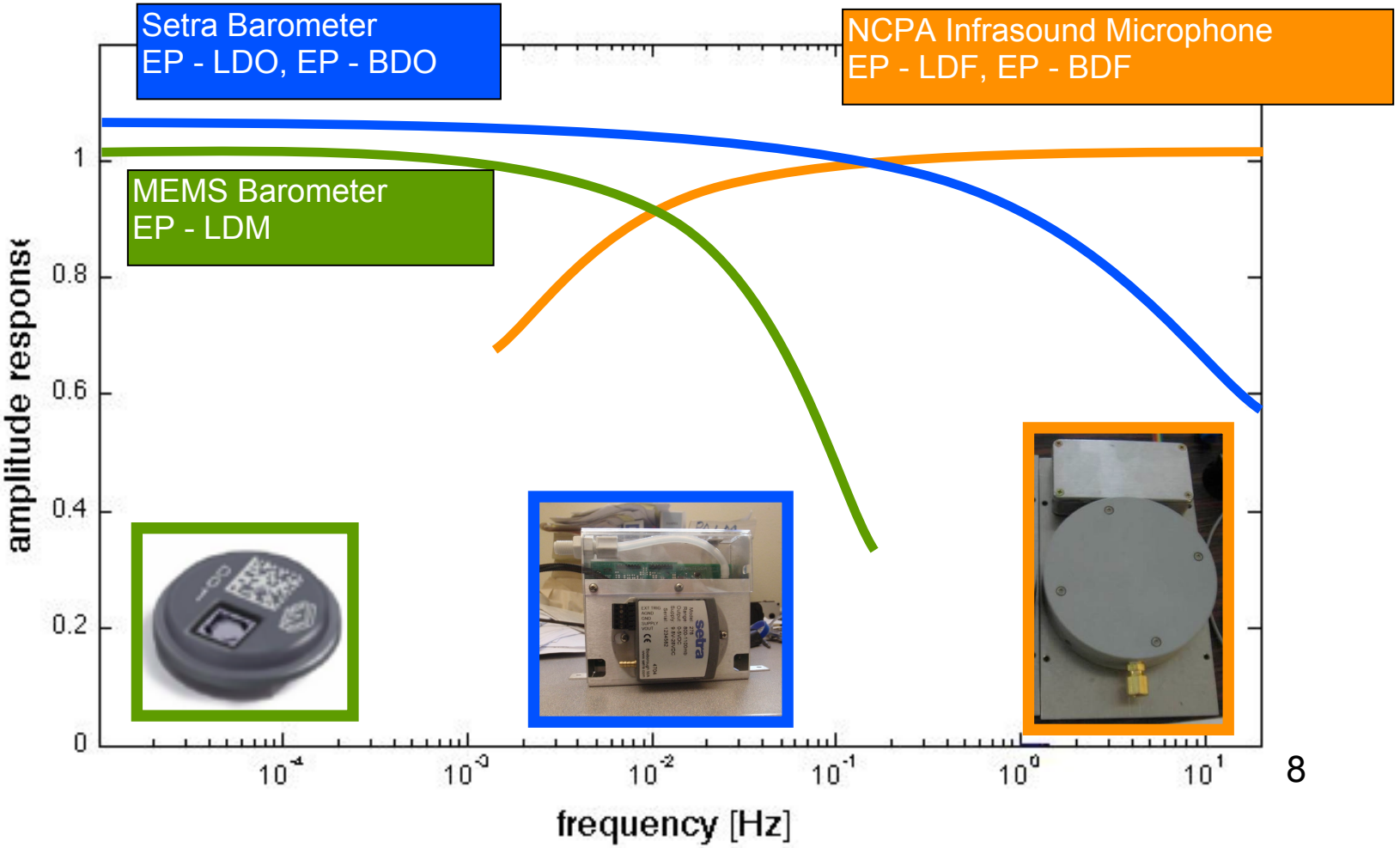
Frank Vernon, SIO, UCSD

CENTRAL & EASTERN U.S. NETWORK

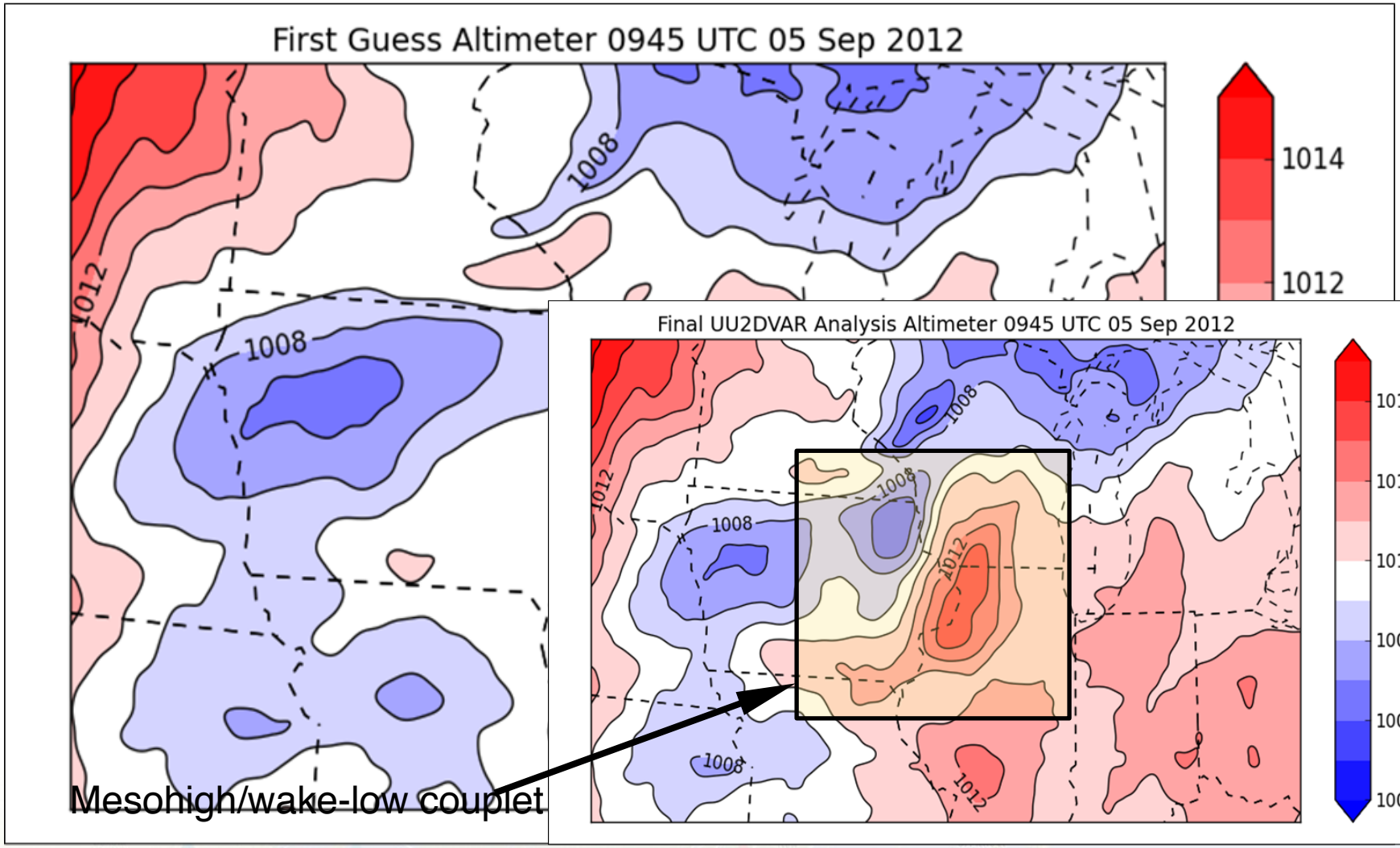


NSF
the IRIS CONSORTIUM
earthscope
UNITED STATES NUCLEAR REGULATORY COMMISSION
USGS
science for a changing world

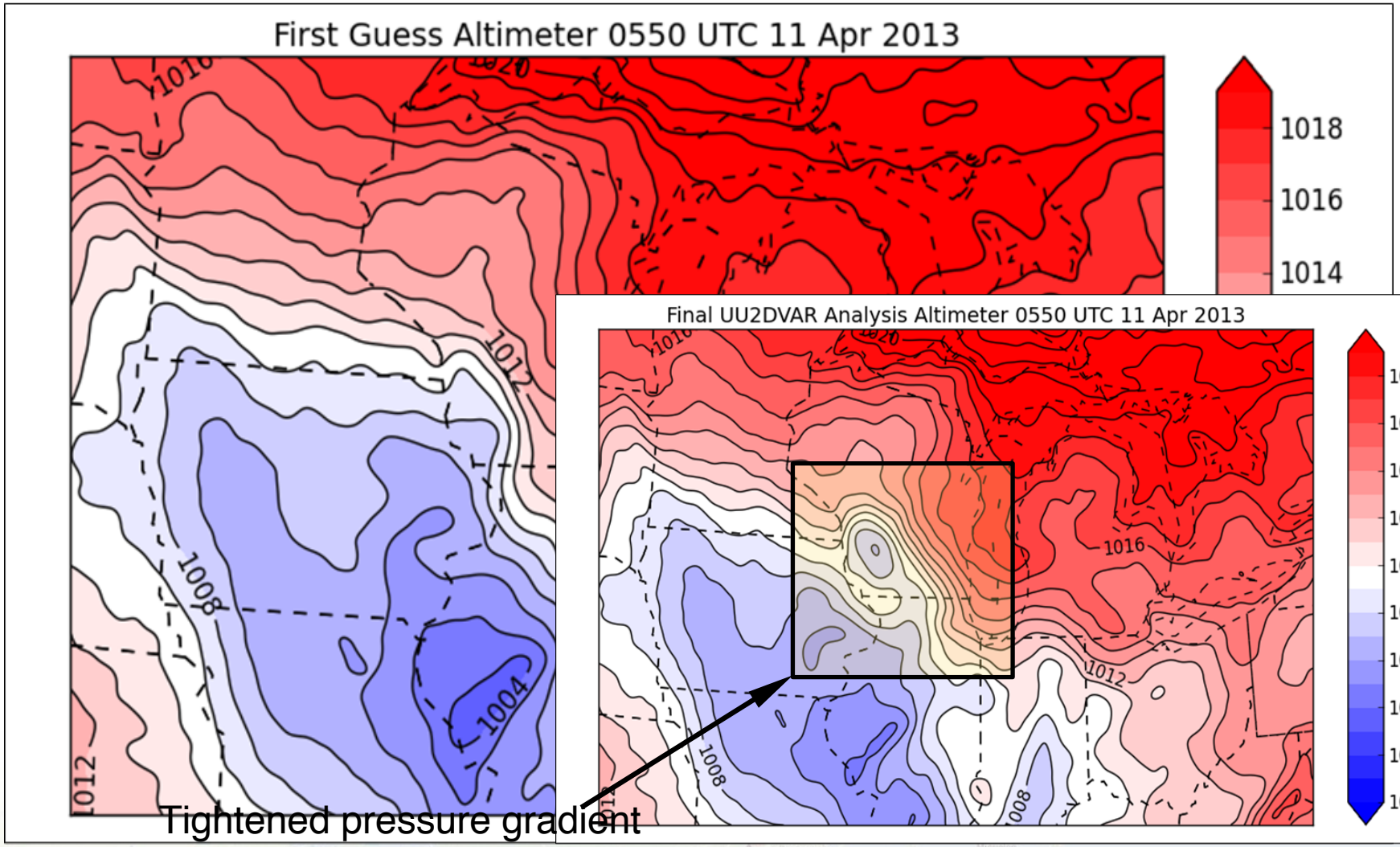
- Overlapping pass-bands provides continuous coverage from DC to 20 Hz



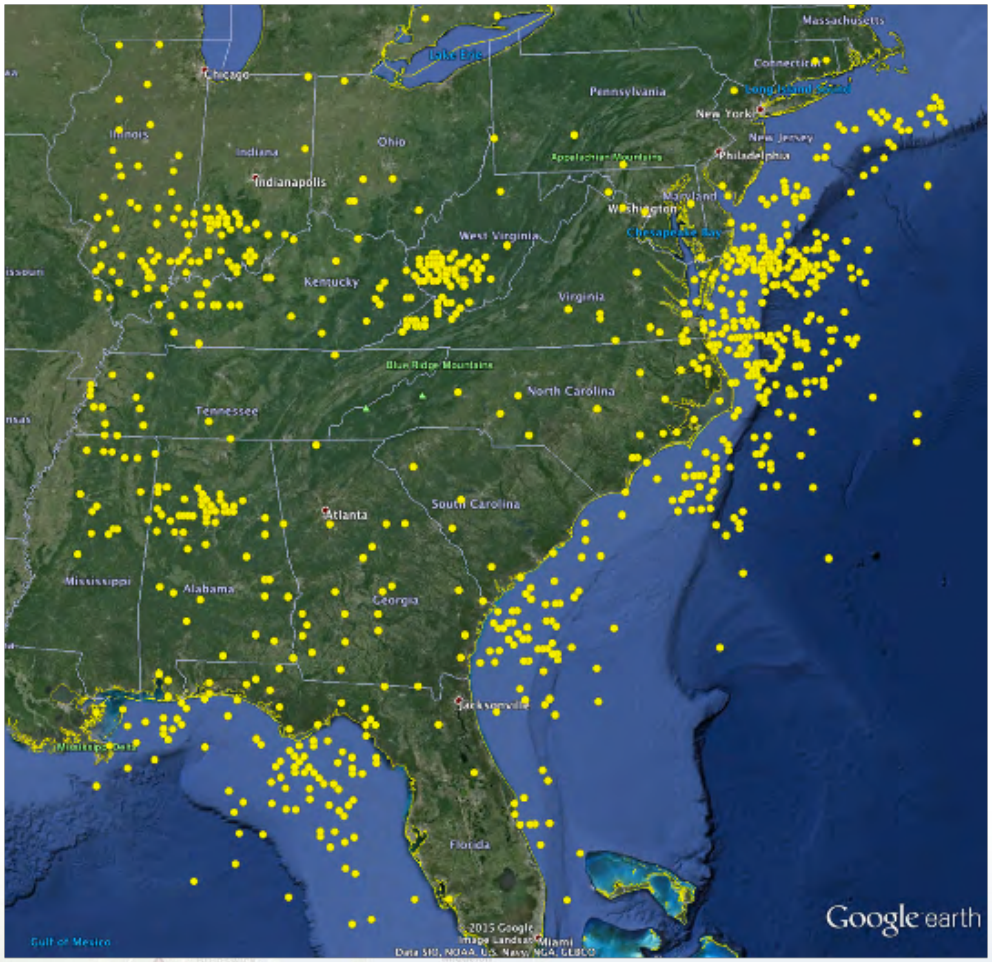
Propagating Mesoscale Convective System



Mesoscale Gravity Wave Event



Infrasonic Sources



- 0.5 to 2 Hz frequency band
- correlates with coal mines in West Virginia, Kentucky, Illinois, Indiana
- Offshore probably related to aircraft

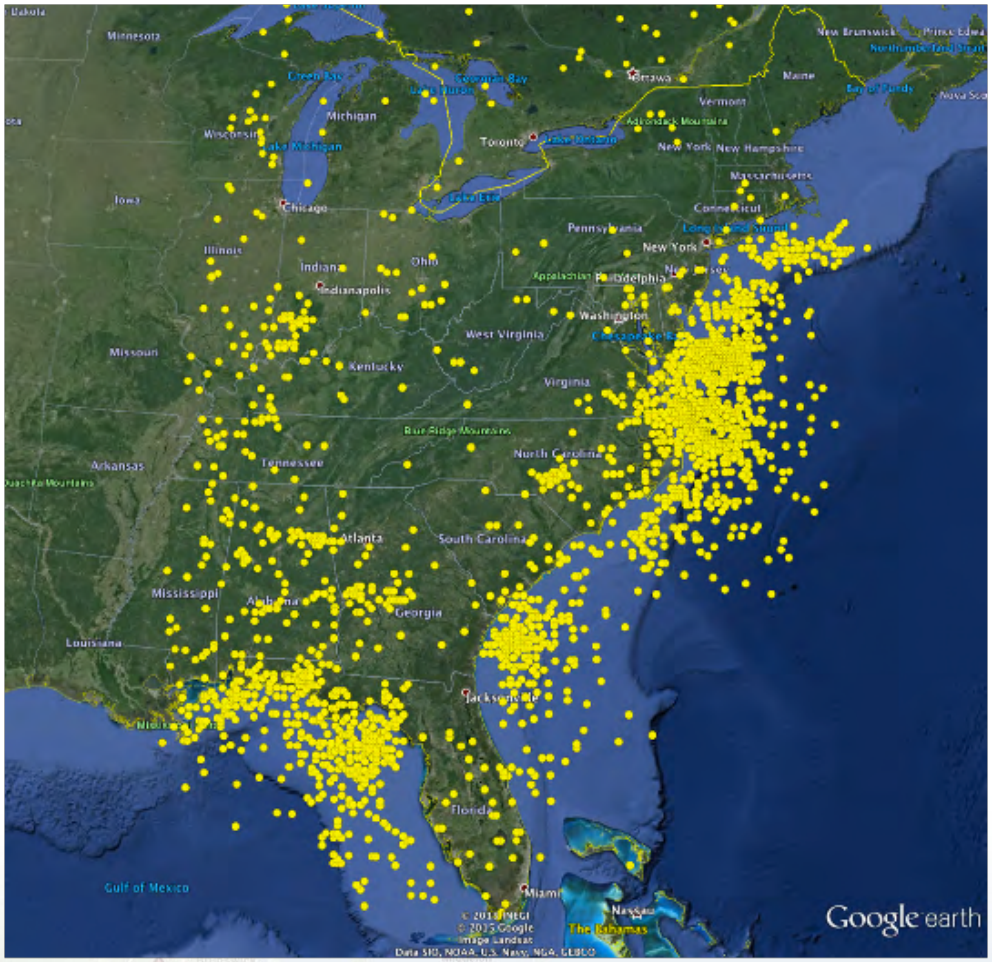
Google earth

miles 600
km 1000

IRIS CONSORTIUM earthscope USGS science for a changing world NSF

Infrasonic Sources

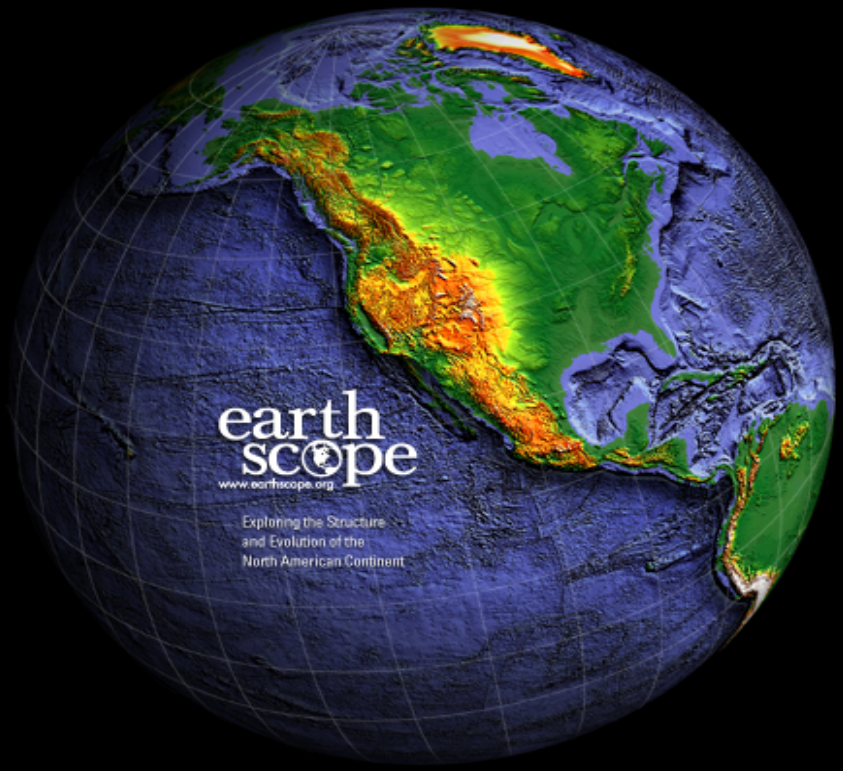
- 2 to 8 Hz frequency band
- Dominantly in offshore regions
- Offshore probably related to aircraft



Conclusions

- Meteorological sensors can enhance understanding of seismic data
- Seismic networks provide sites, permitting, real time telemetry
- Meteorological sensors can create opportunities for collaboration between different scientific communities
  - real time monitoring
  - hazards
  - civil defense
- MesoWest at University of Utah
  - Accessing data through web services
  - Downsamples data
  - Provides to NOAA Meteorological Assimilation Data Ingest System

Central and Eastern US Network



Alex Hutko
IRIS Data Services

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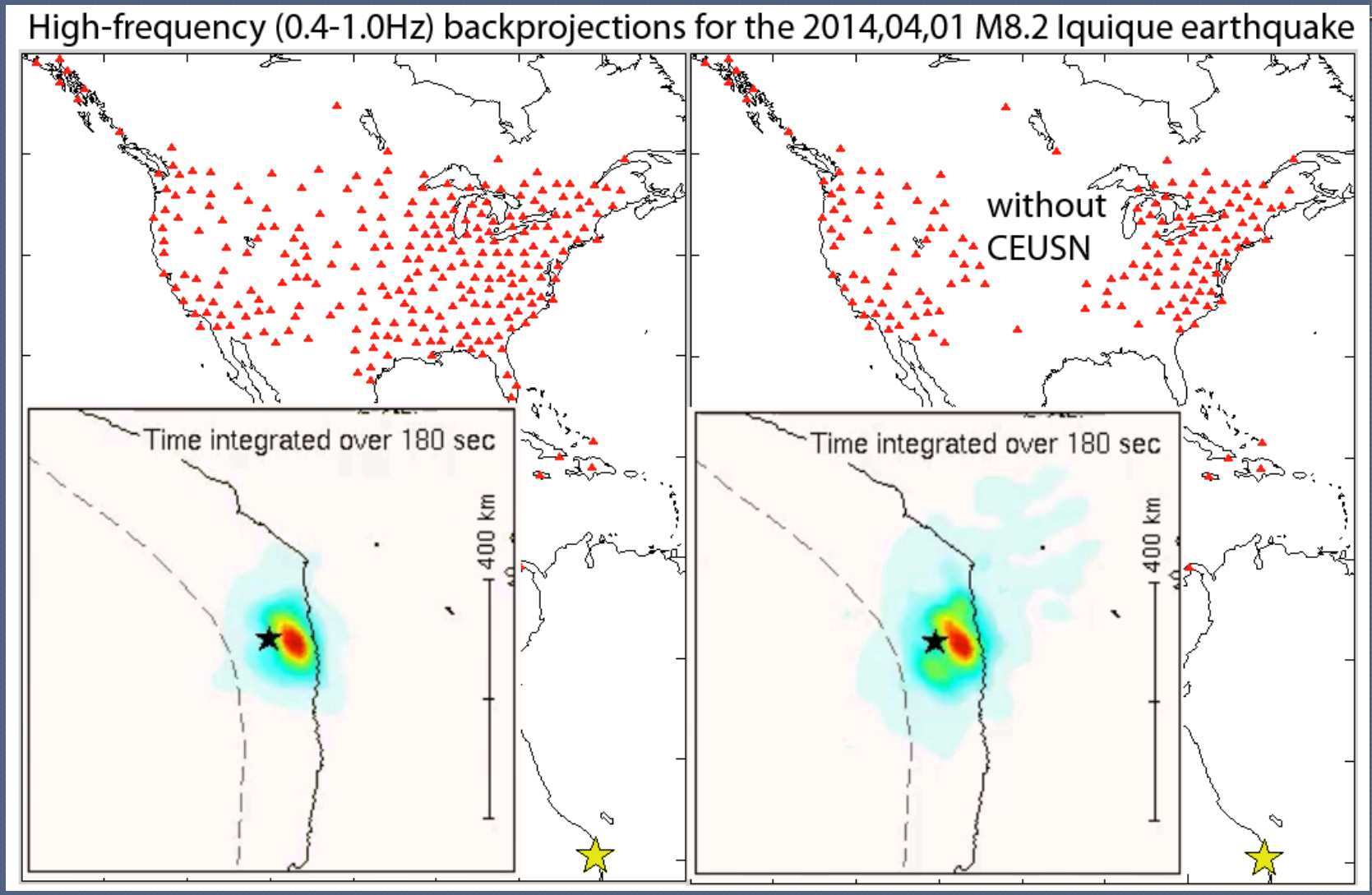
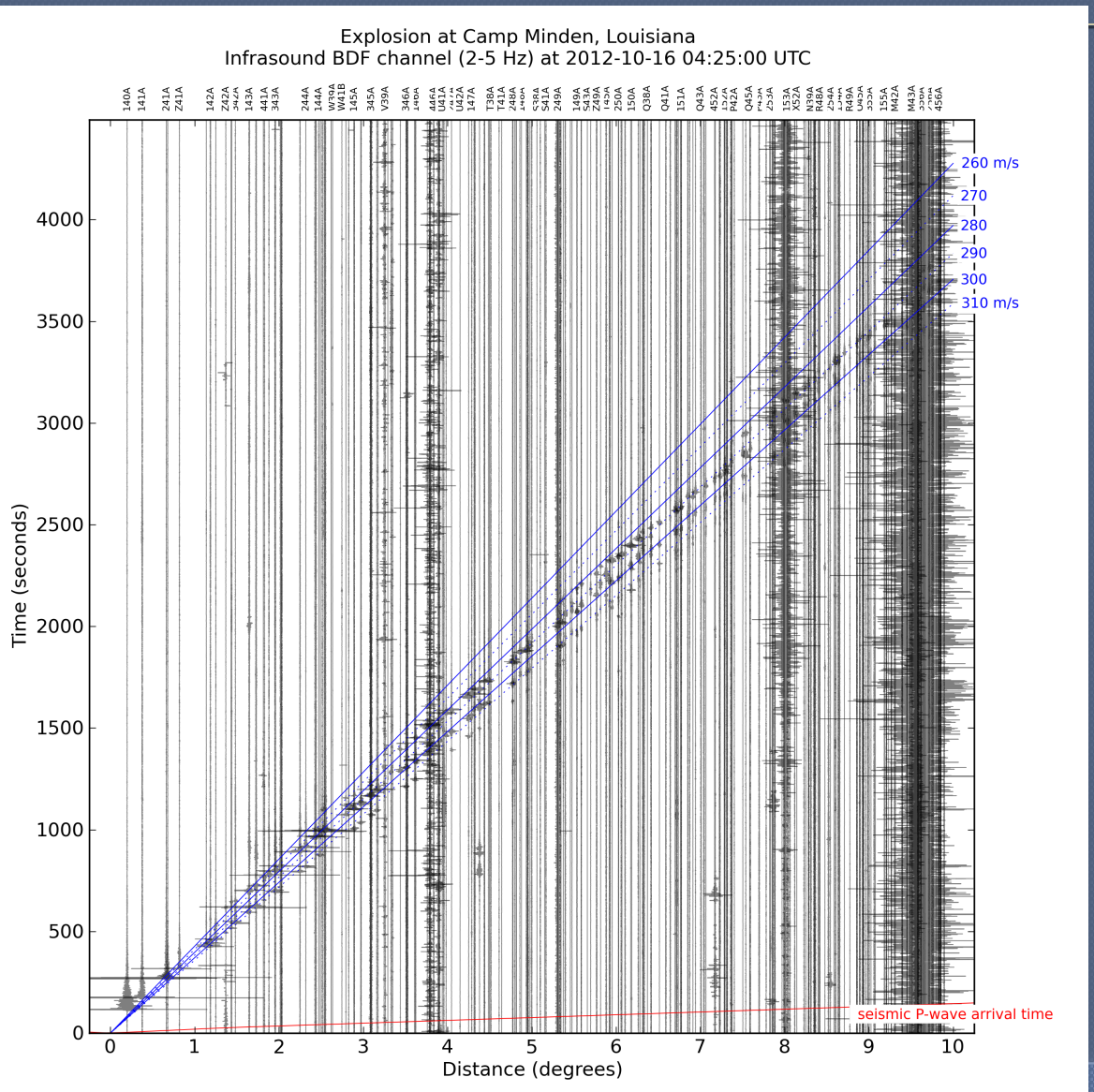
Effect of CEUSN on backprojection rupture imaging:
-none in spatial resolution (array aperture same)
-greater suppression of artifacts



TAID (TA Infrasound Detections) detects explosion at Camp Minden, Louisiana



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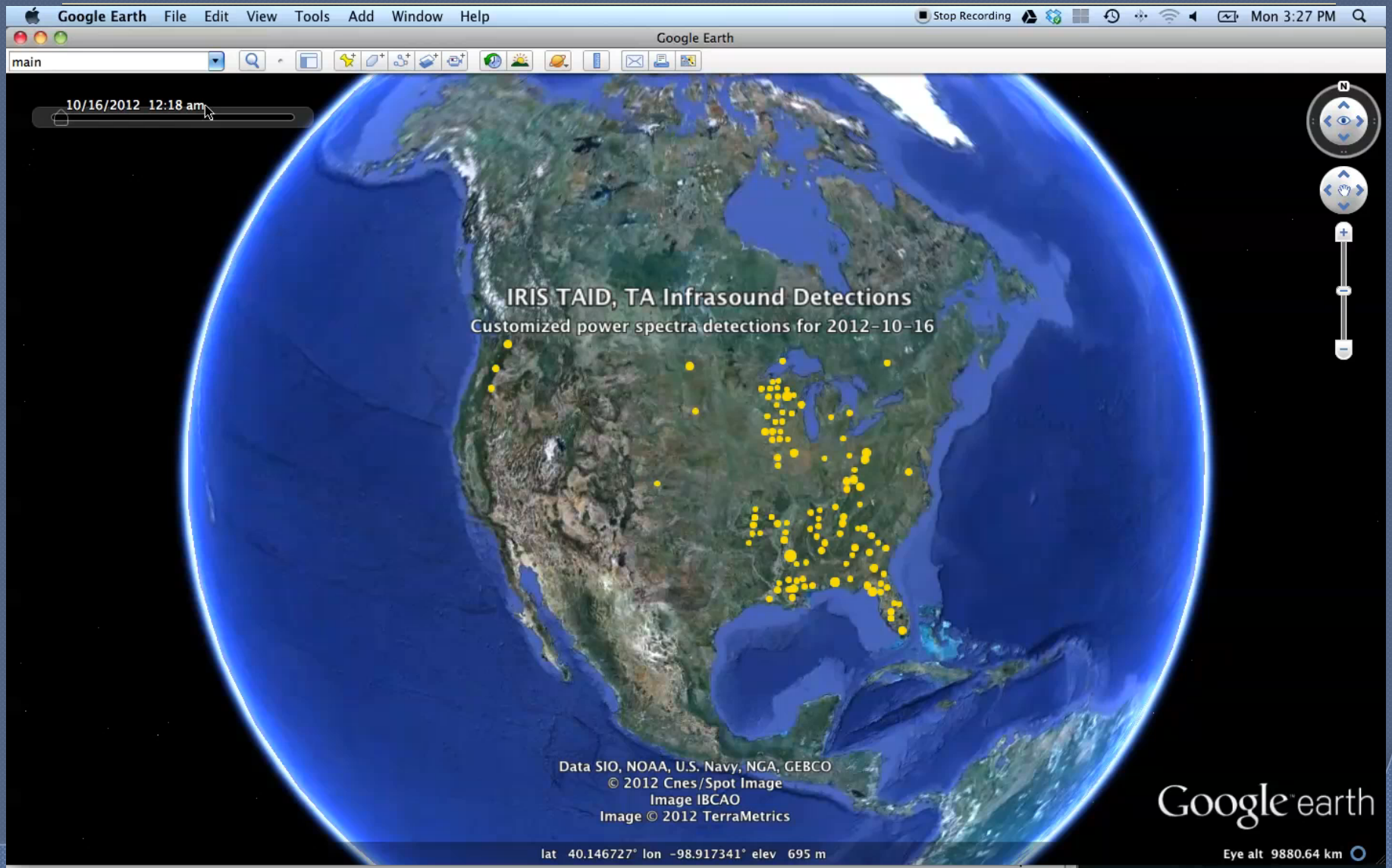

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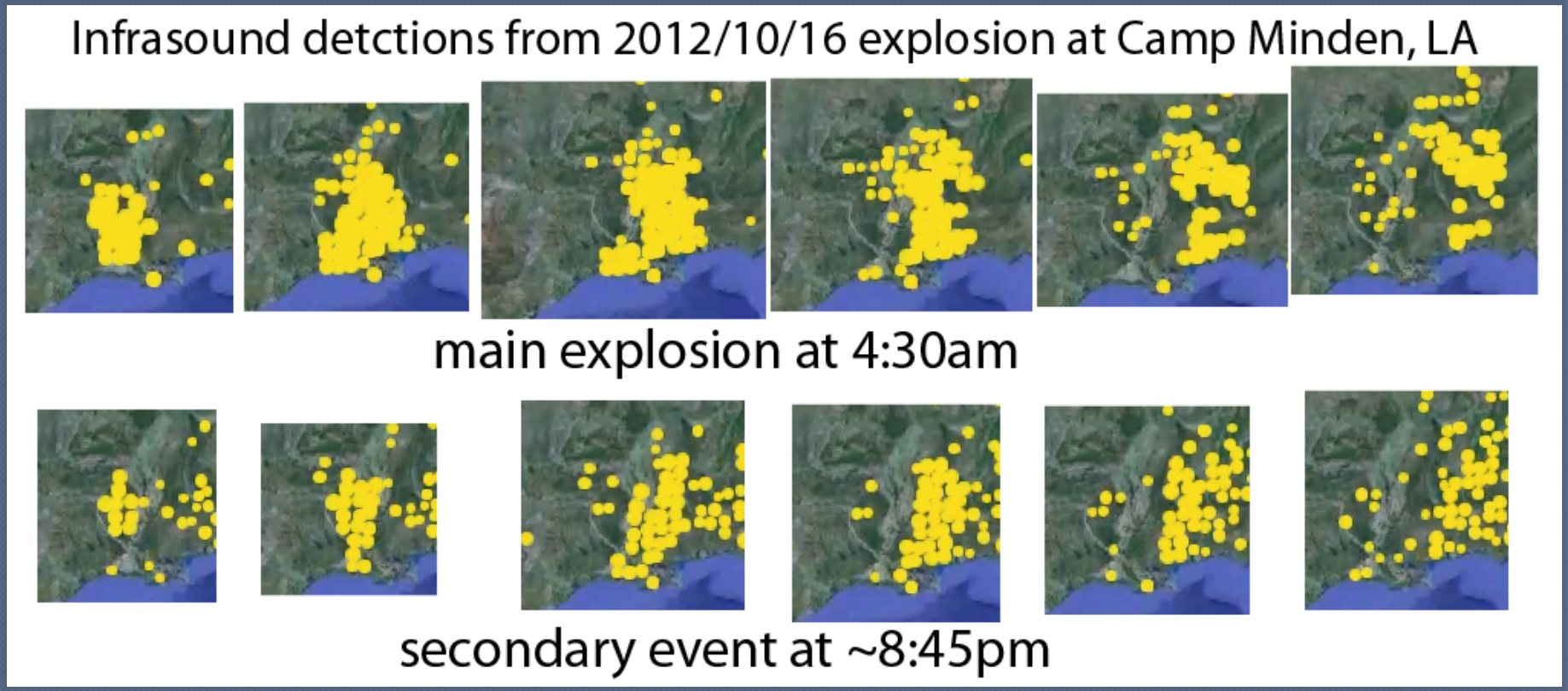
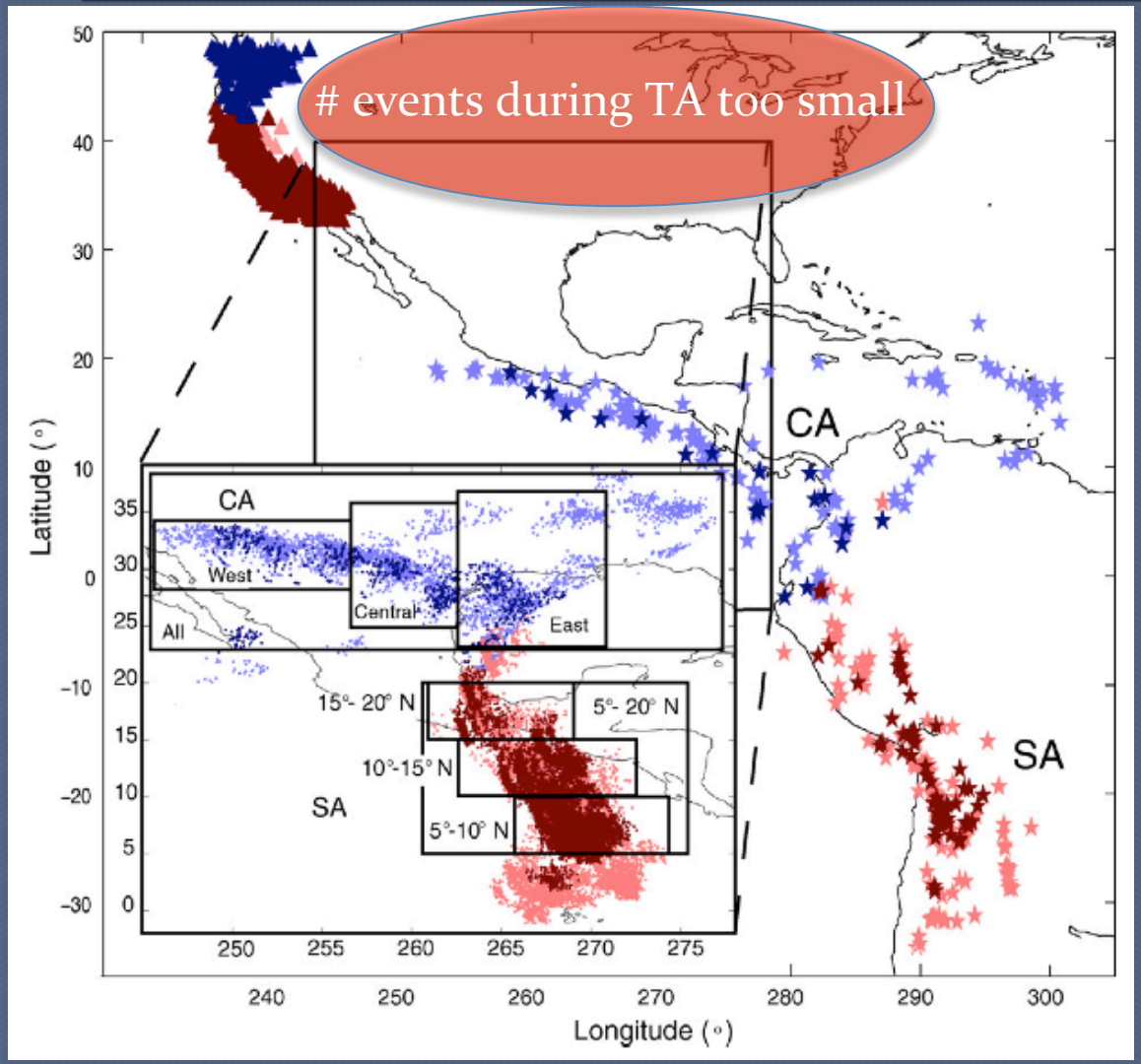


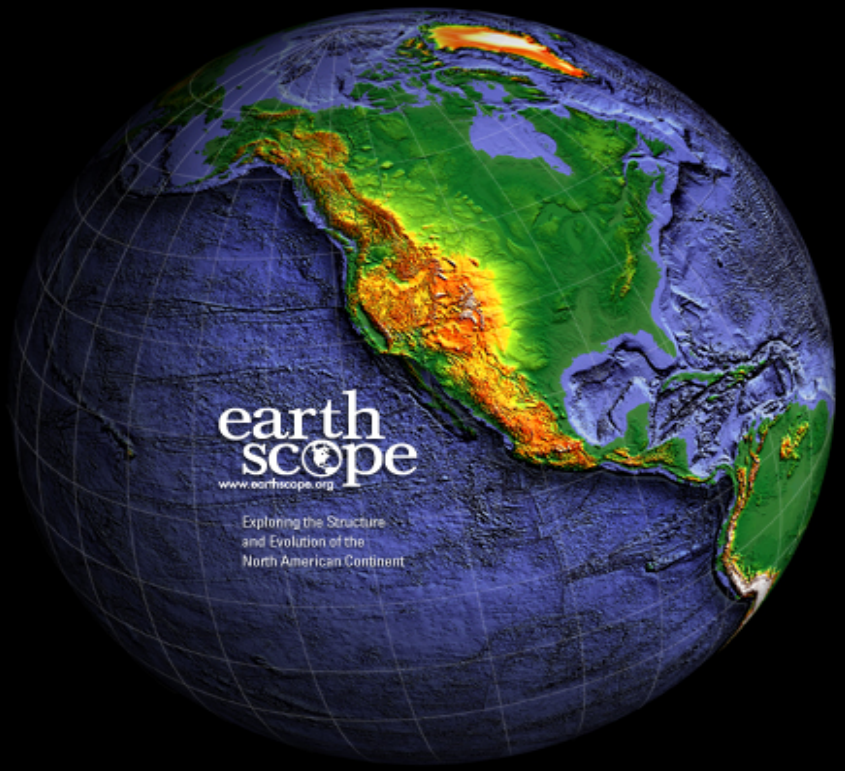
Sometimes 2 years of data aren't enough…



Large PcP based CMB study used 12,000 traces from 80 intermediate/deep events spanning 2 decades.

Hutko et al (2009, PEPI)

Central and Eastern US Network: Closing Remarks and Open Discussion



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IRIS
Director of Instrumentation Services

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