Observations of Atmospheric Phenomena from USArray and ANZA Observing Systems

Frank Vernon

Antelope User Group Meeting
Muscat, Oman

2-4 March 2013

Array Network Facility

The Array Network Facility (ANF) at UC San Diego

- **Specializes in real-time data acquisition, quality control, dissemination of seismic and met data**

Two main projects:

- **USArray Transportable Array Network (anf.ucsd.edu)**
- **Anza Network – UCSD operated seismic network in SoCal**

Collaboration with the High Performance Wireless Research and Education Network (HPWREN)

- **Research**
- **Education**
- **Public Safety**
- **Weather data (real time)**
- **Cameras!**

Acknowledgements

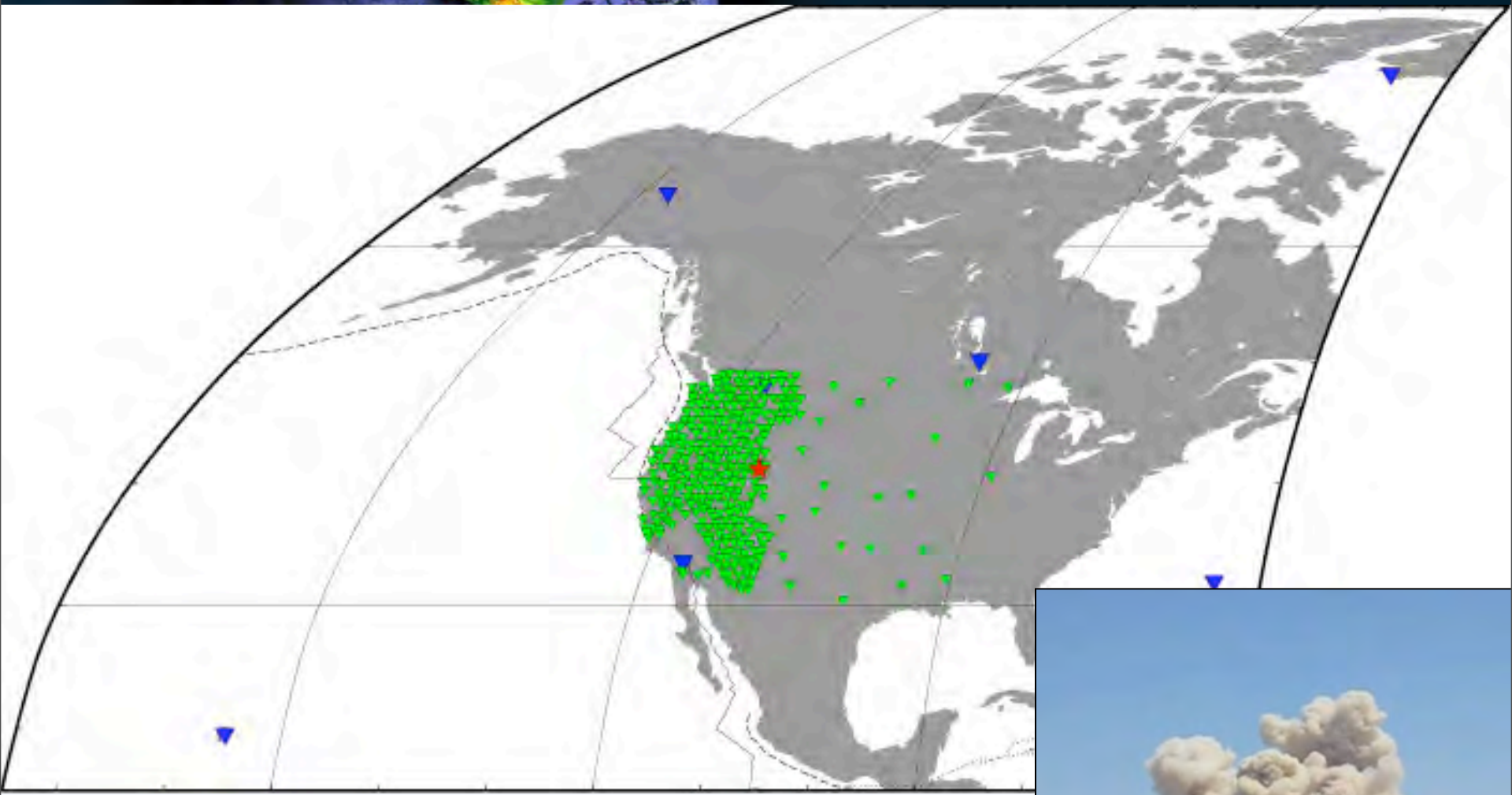
EarthScope is funded by the National Science Foundation.

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.

Seismic Noise

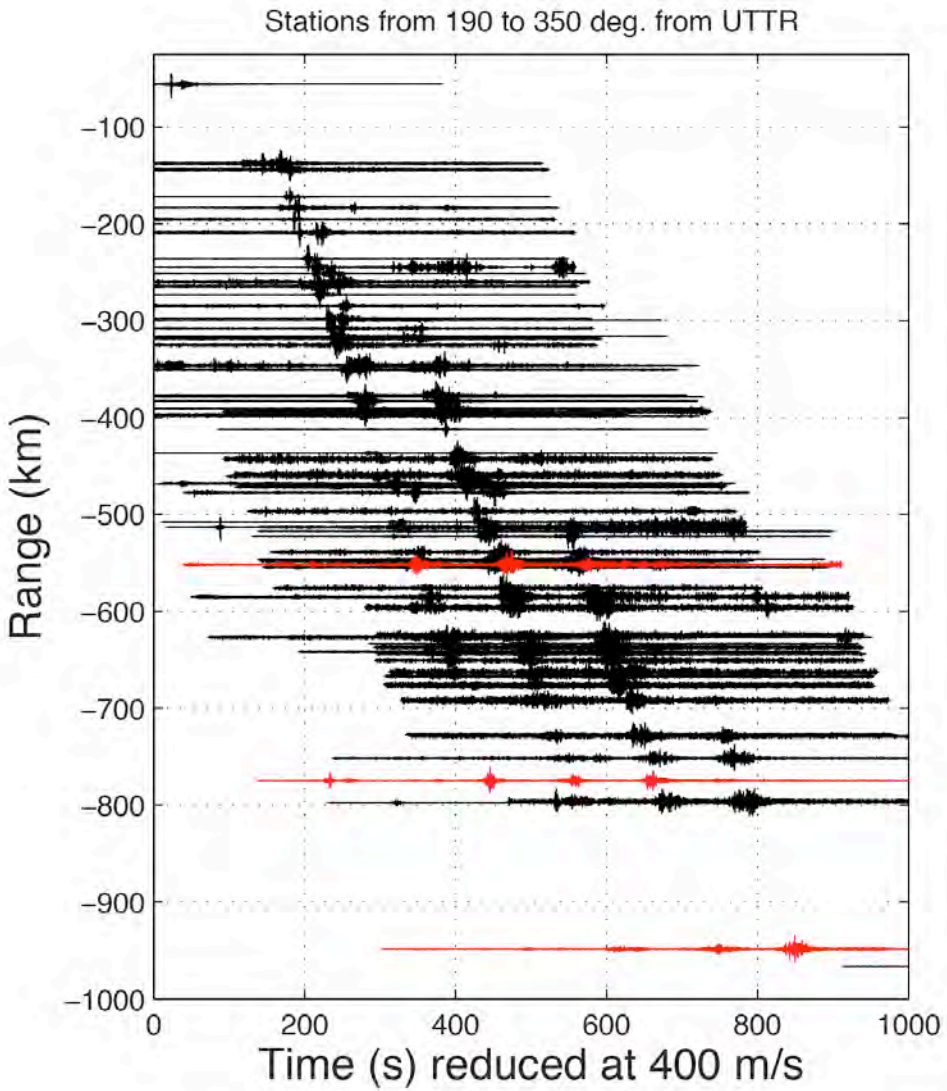
- **Multiple sources of seismic noise:**
  - **Anthropogenic**
    - **Planes**
    - **Trains**
    - **Automobiles**
  - **Natural**
    - **Wildlife**
    - **Rainfall**
    - **Hail**
    - **Wind**
    - **Thunder**
    - **Storms**
    - **Bolides (meteorites)**

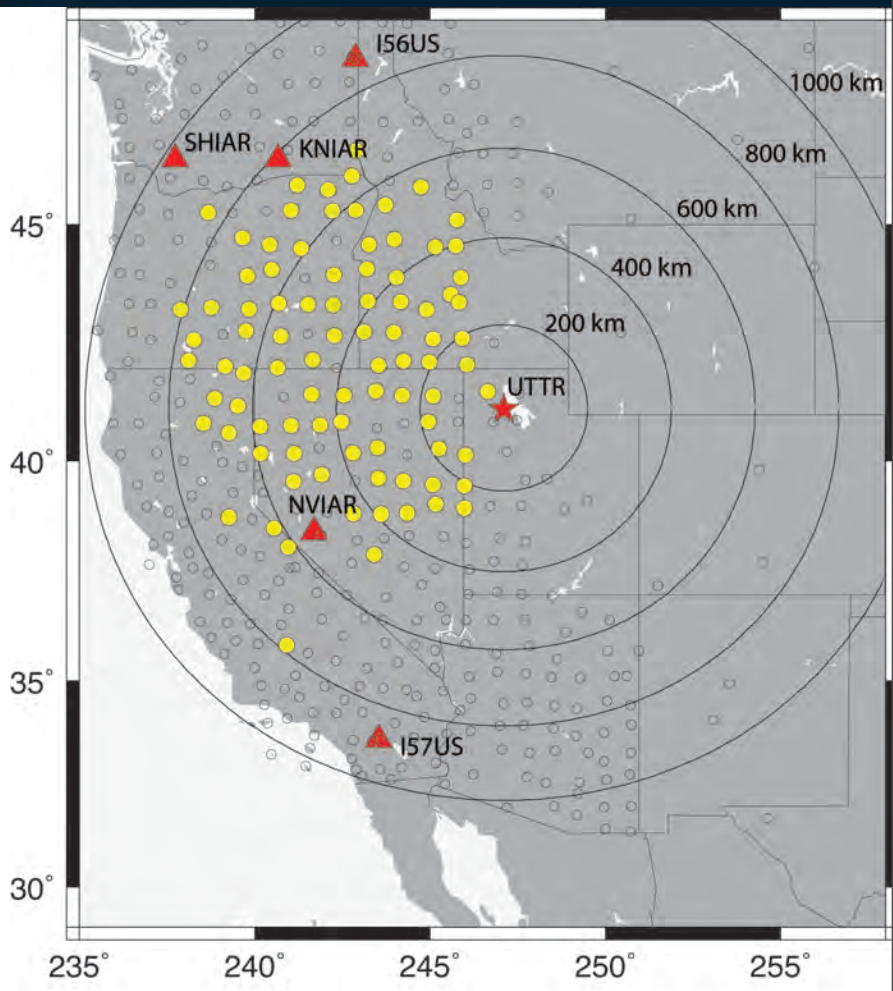
IMS Infrasound arrays and USArray TA in June, 2007



11 rocket motor detonations from May to September

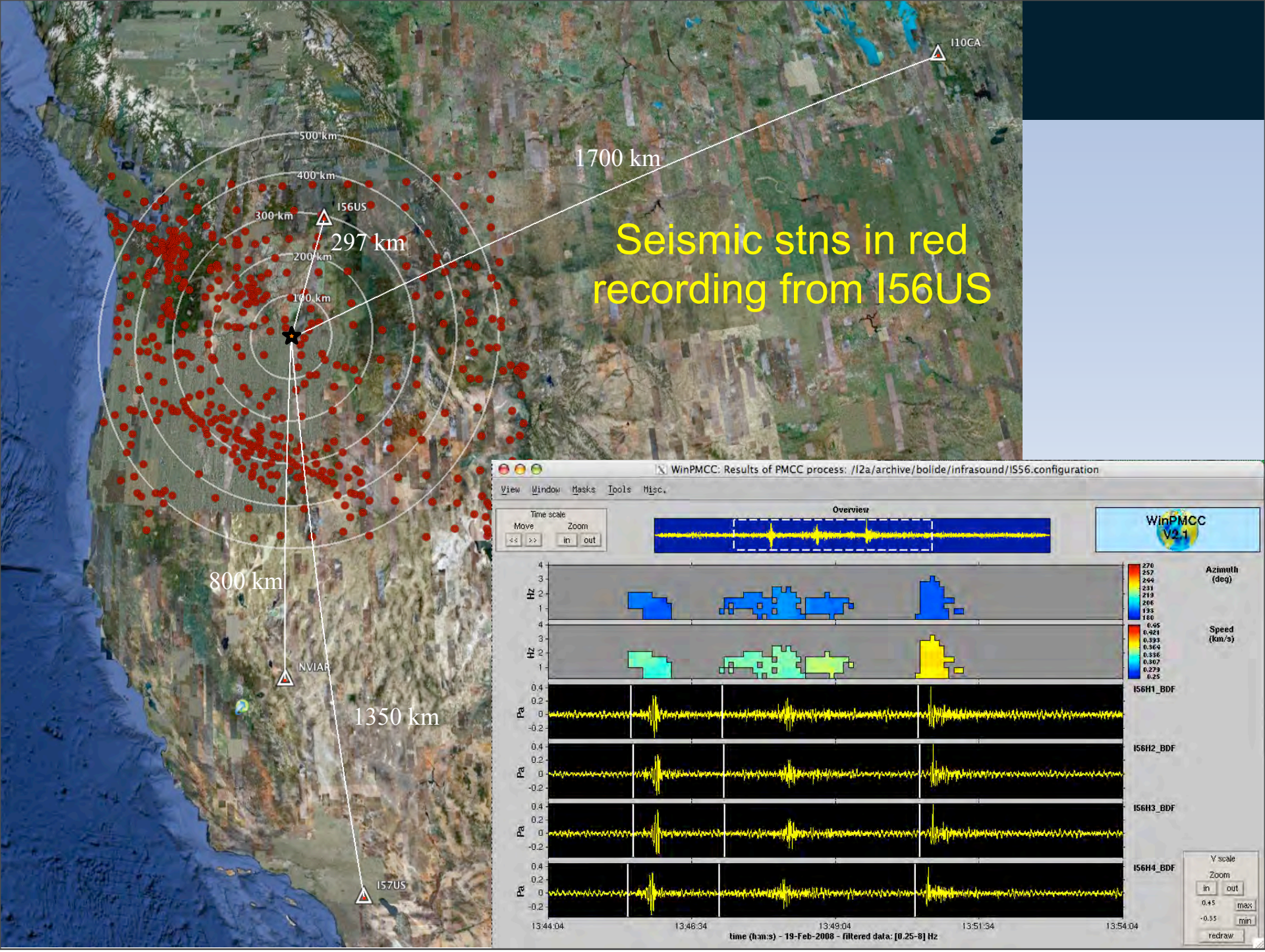
IMS Infrasound arrays and USArray TA in June, 2007





Oregon Bolide 2008-02-19

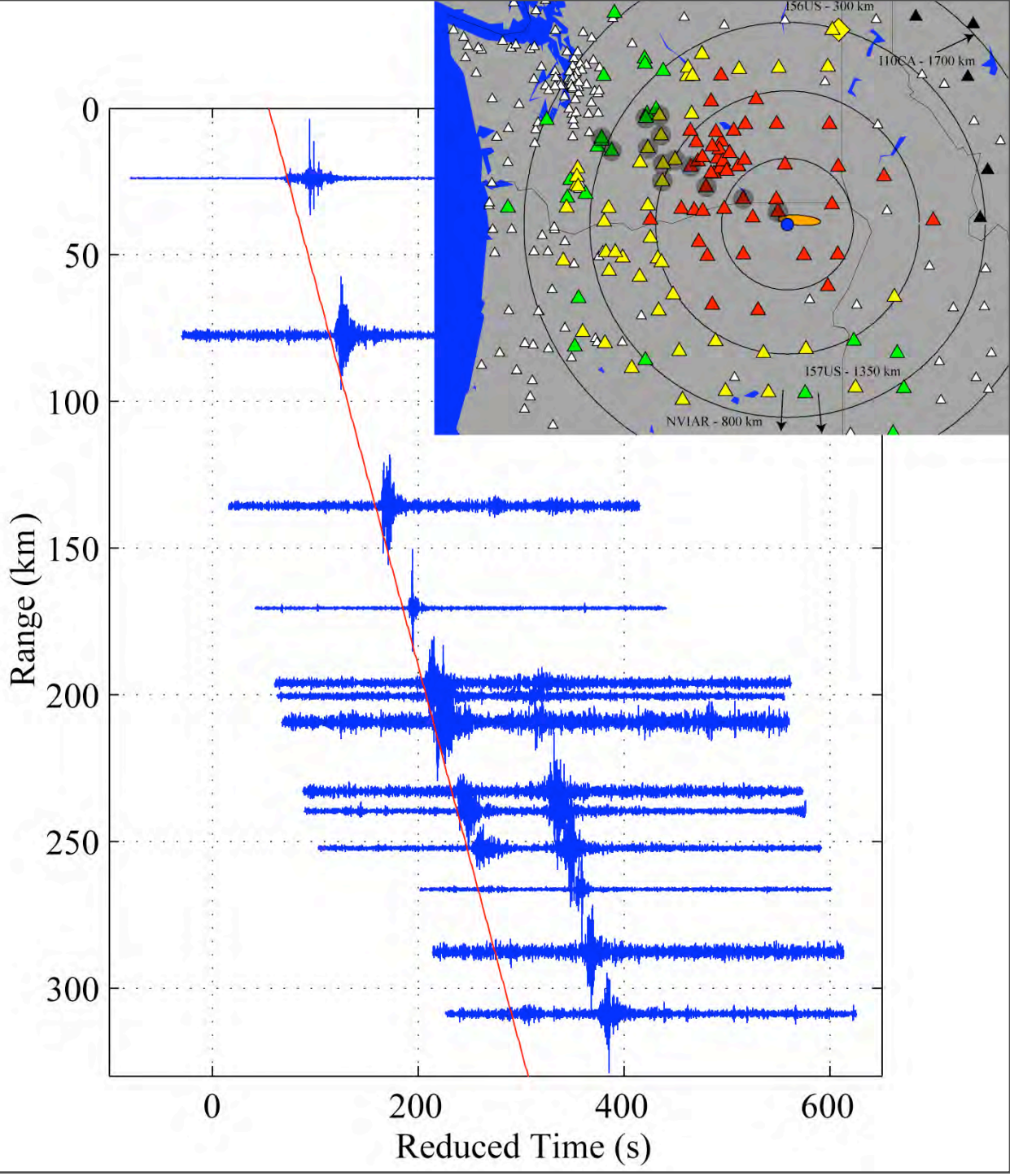
- A bolide burst above NE Oregon at 05:30 AM local time on Feb 19, 2008
- The event was recorded by 4 infrasound arrays and several hundred seismic stations in the USArray and regional networks
- The seismic stations reveal how infrasound signals vary with range and azimuth
- Celerity (horizontal distance traveled/travel time) vs range plots may shed light on propagation paths and provide useful information about atmospheric structure


I10CA
1700 km
500 km
400 km
300 km
I56US
297 km
200 km
100 km
Seismic stns in red
recording from I56US
800 km
NVIAR
1350 km
I57US
WinPMCC: Results of PMCC process: /I2a/archive/bolide/infrasound/IS56.configuration
View
Window
Masks
Tools
Misc.
Time scale
Move
Zoom
Overview
WinPMCC
V2.1
Azimuth
(deg)
Speed
(km/s)
I56H1_BDF
I56H2_BDF
I56H3_BDF
I56H4_BDF
Hz
Pa
Y scale
Zoom
max
min
redraw
13:44:04
13:46:34
13:49:04
13:51:34
13:54:04
time (h:m:s) - 19-Feb-2008 - filtered data: [0.25-8] Hz

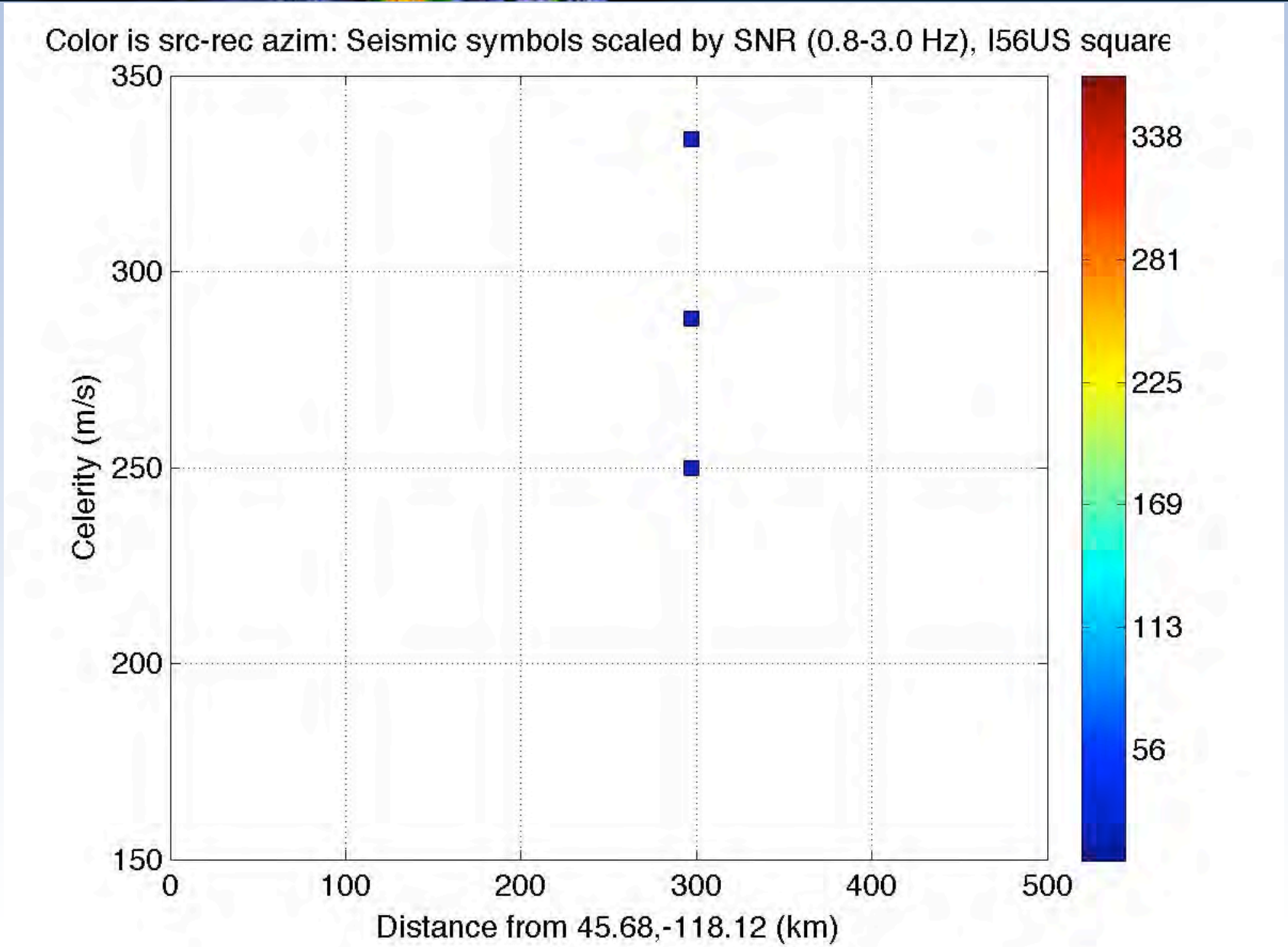
Sample record section to west of event

Z components

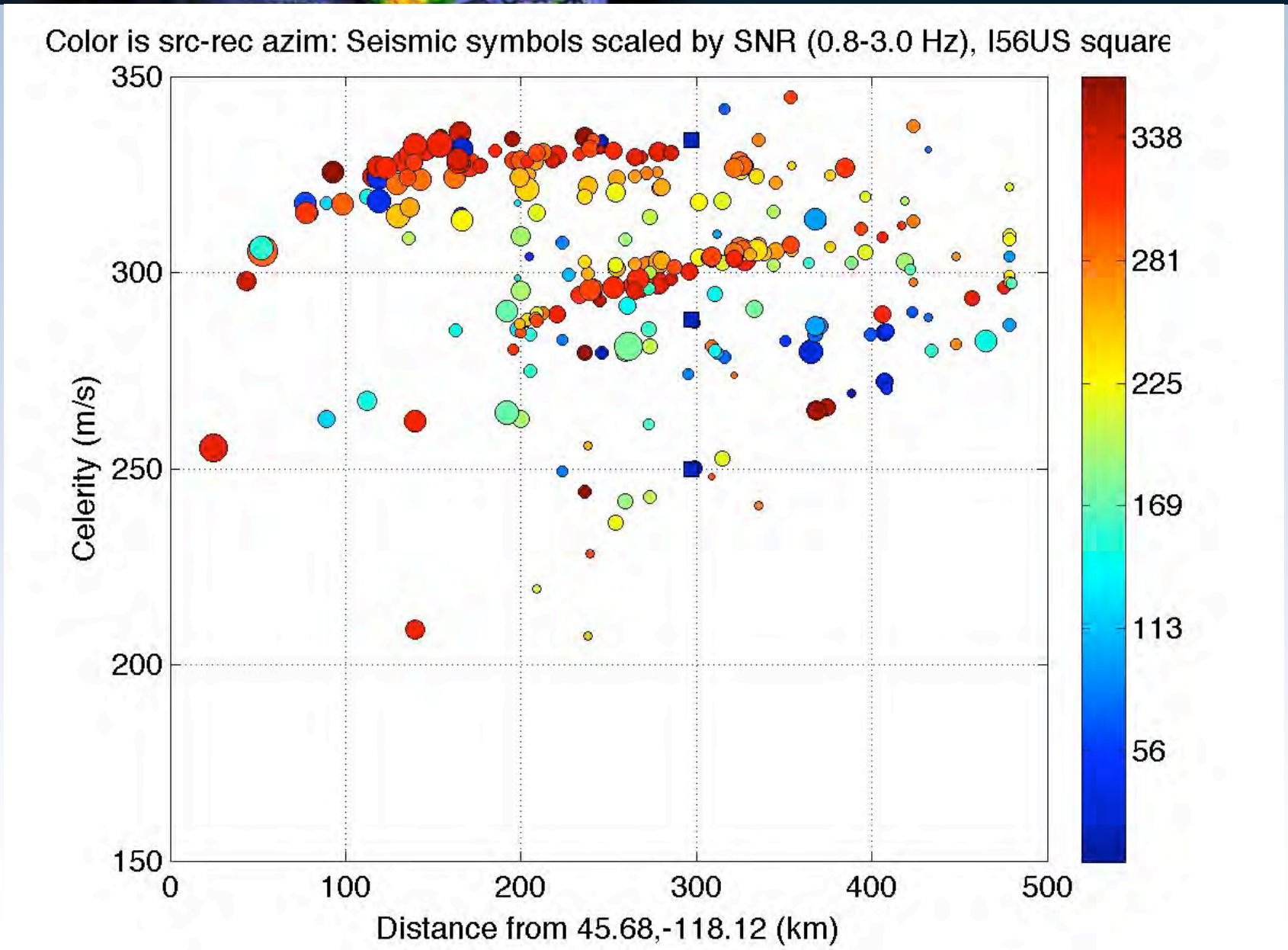
Bp 0.8-3.0 Hz



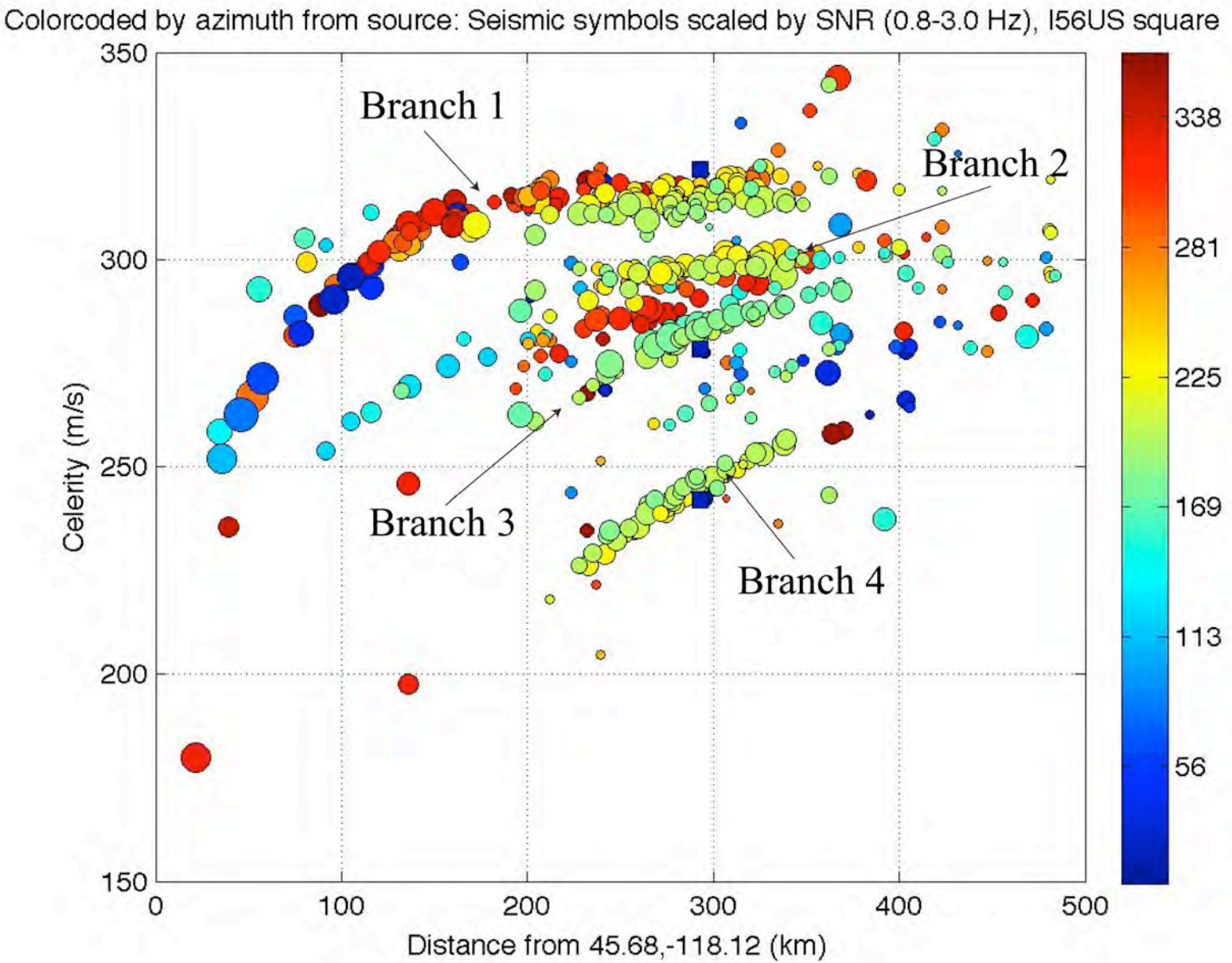
Array Celerity



TA + Array Celerity

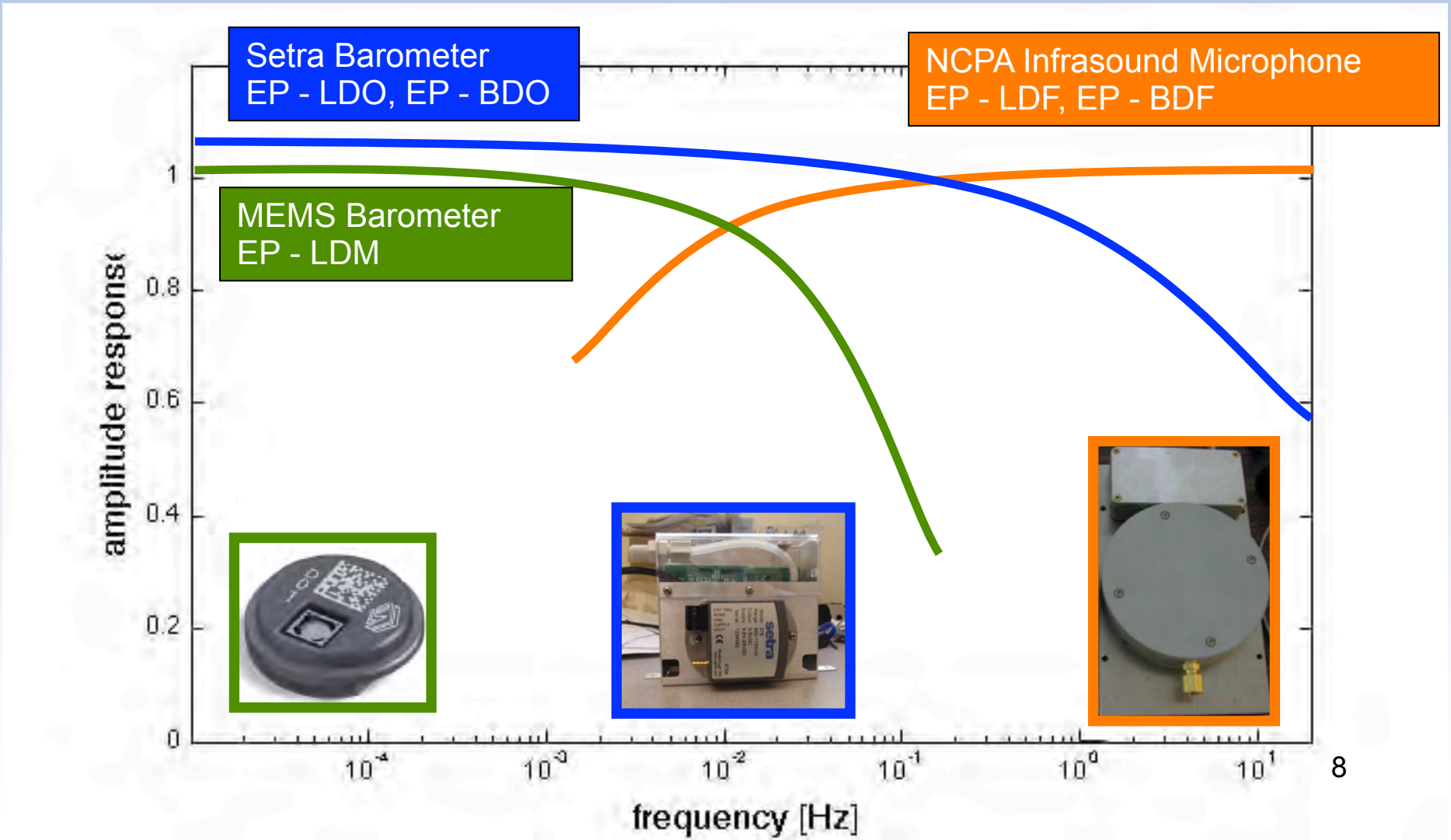


Acoustic branches Hedlin et al 2010



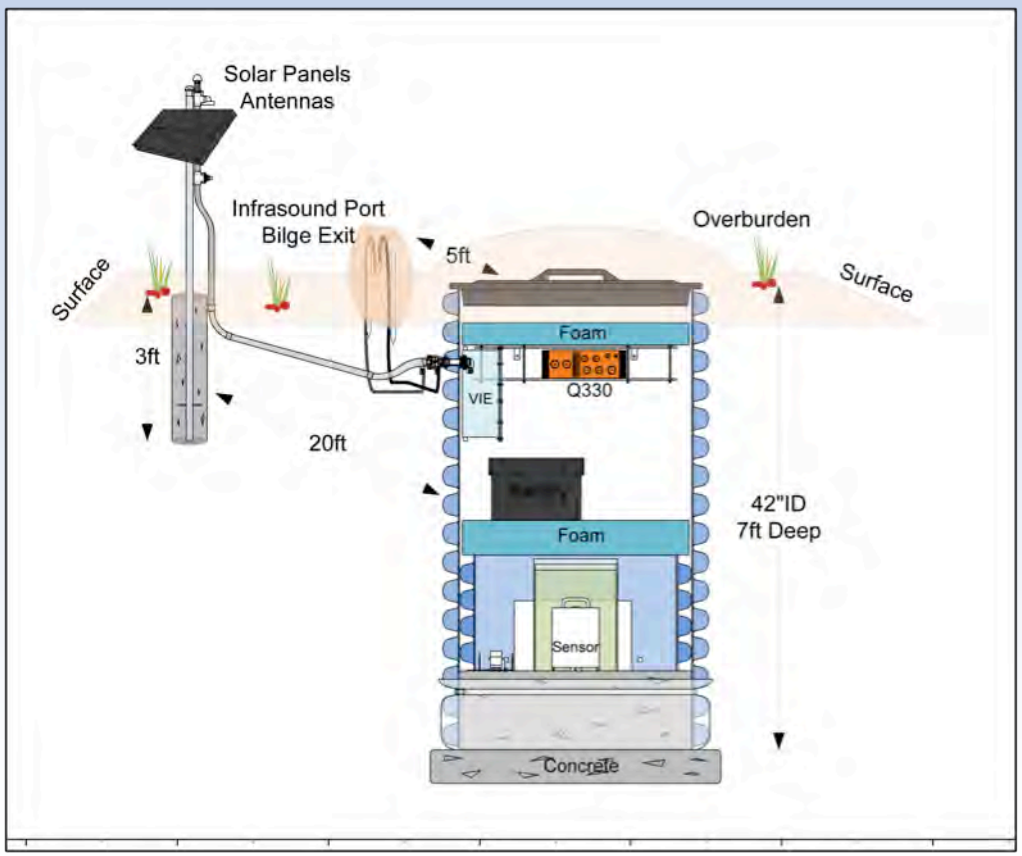
Pressure Sensor Response

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



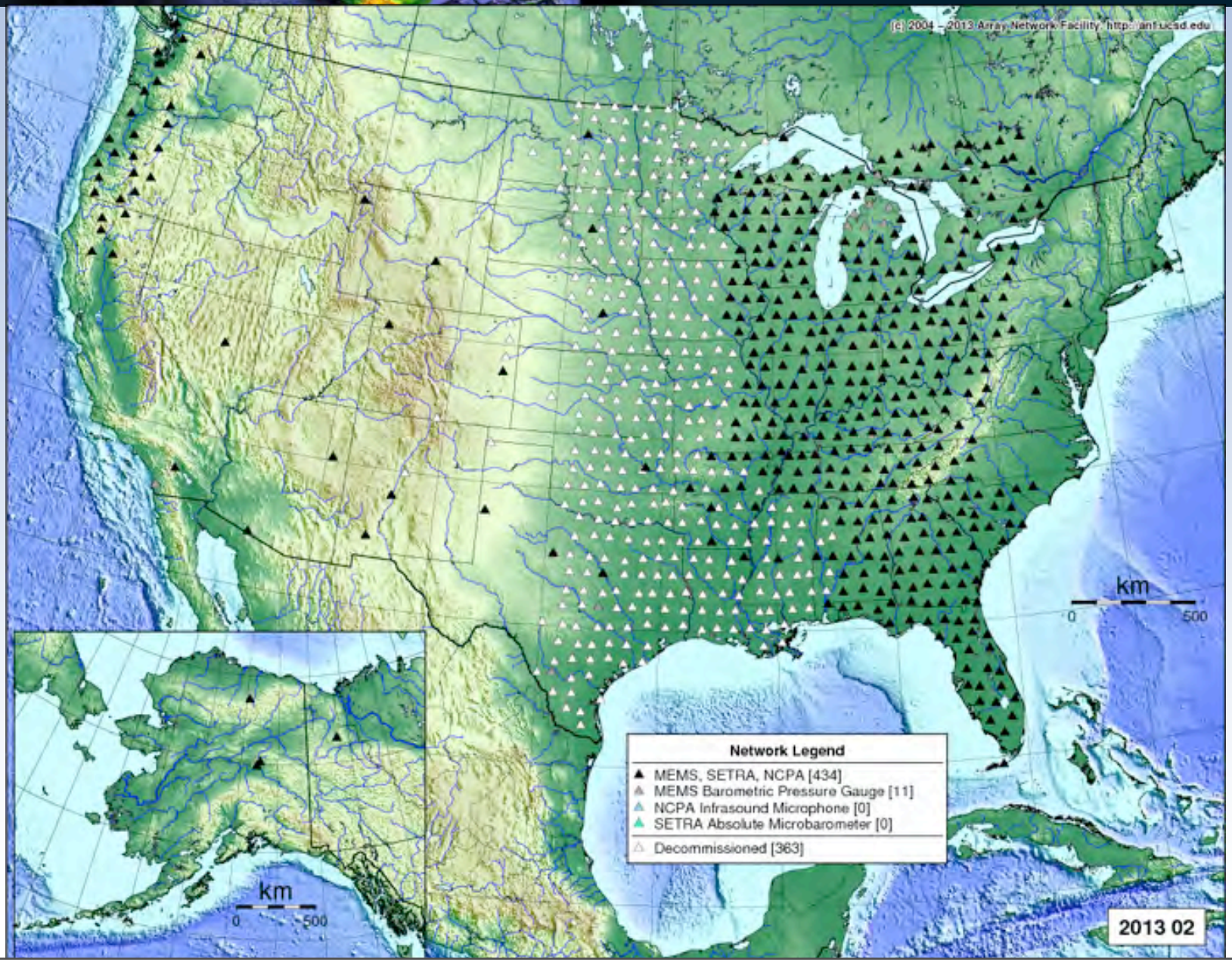
Basic Description

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



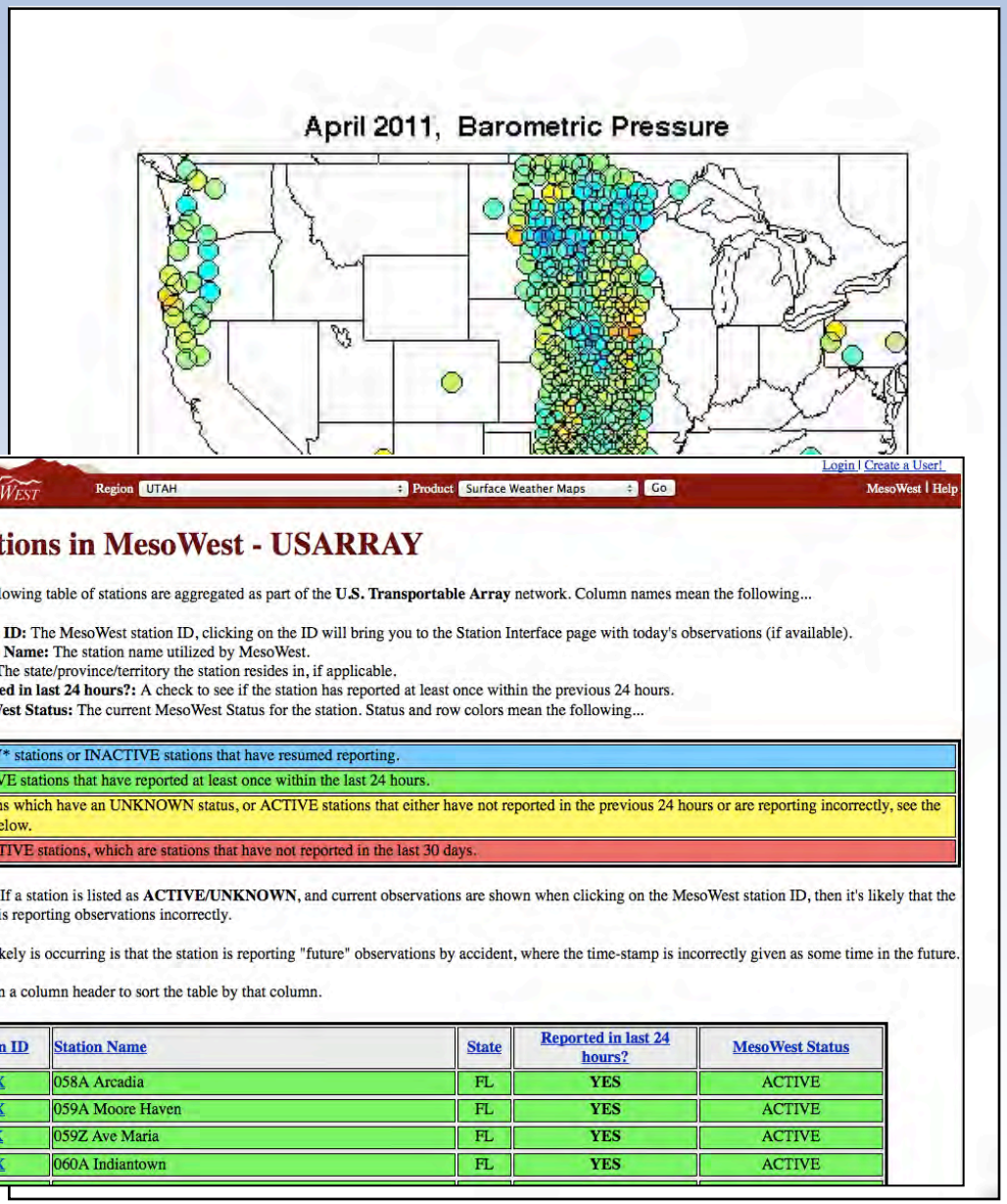
TA Station 345A, MS

Implementation of Atmospheric Pressure Sensors



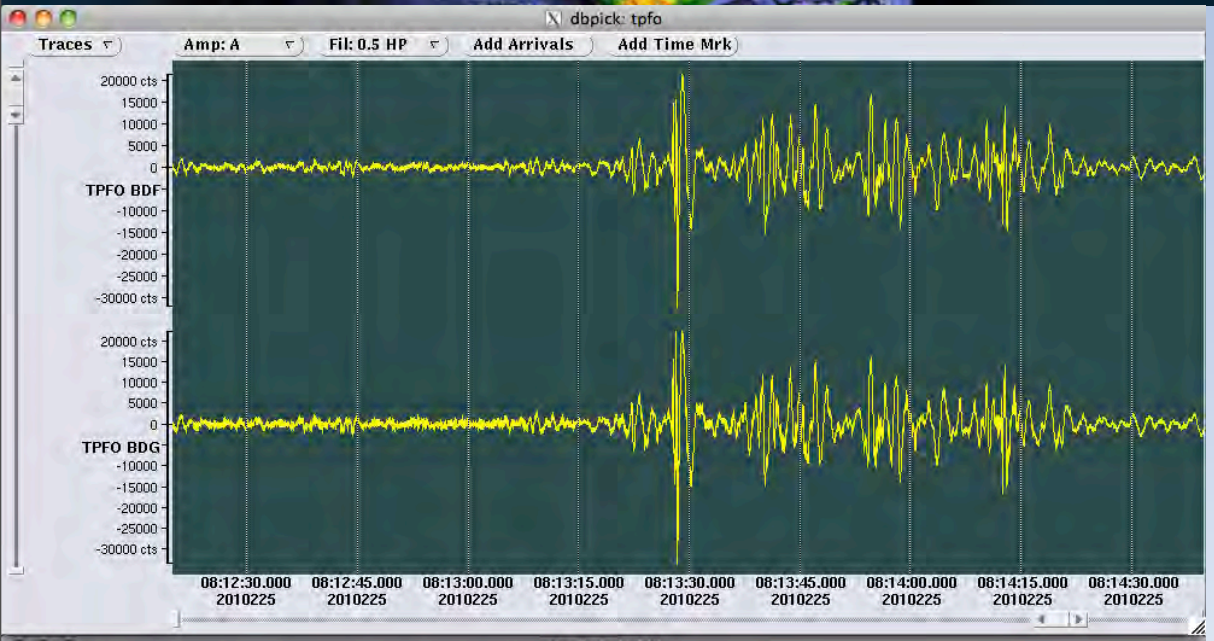
Pressure Observations

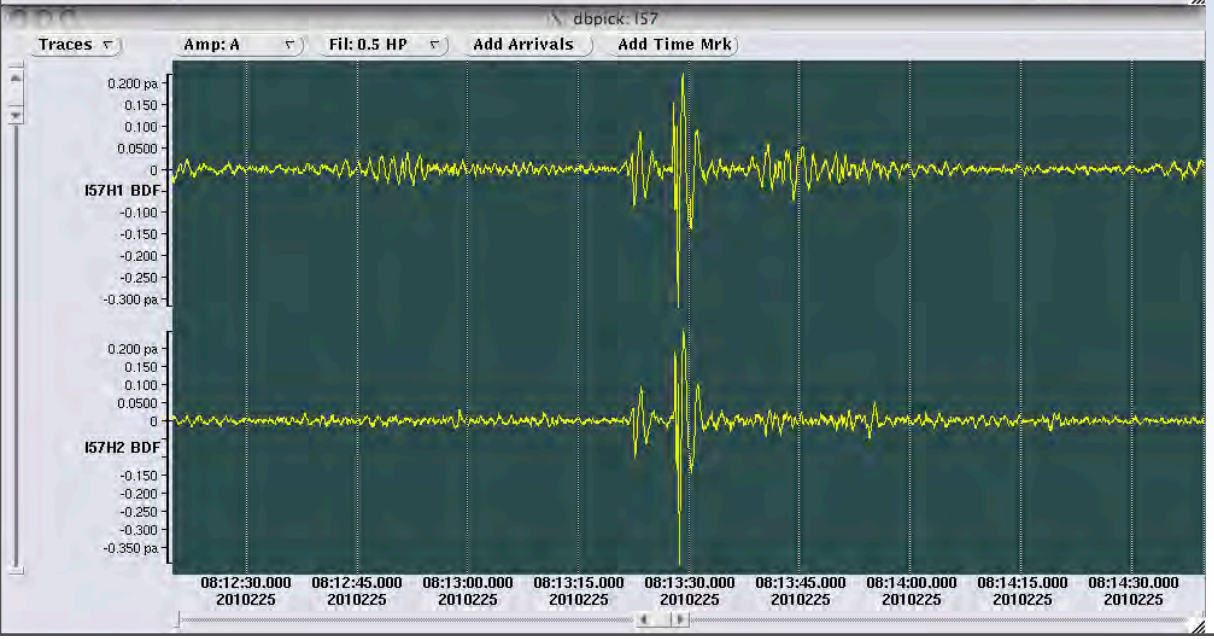
- Pressure and infrasound at every TA station
- Sampled at 40 samples per second
- Pressure fluctuations from DC to 20 Hz
- Multiple applications
  - Noise induced on vertical and horizontal seismic channels
  - Meso-scale atmosphere variation
  - Acoustic energy propagating in the atmosphere
  - Acoustic – seismic coupling



MesoWest is accessing data via web services

Atmospheric Acoustic Transportable Array





TA-TPFO
One port
Bag of gravel
Both tubes inside gravel

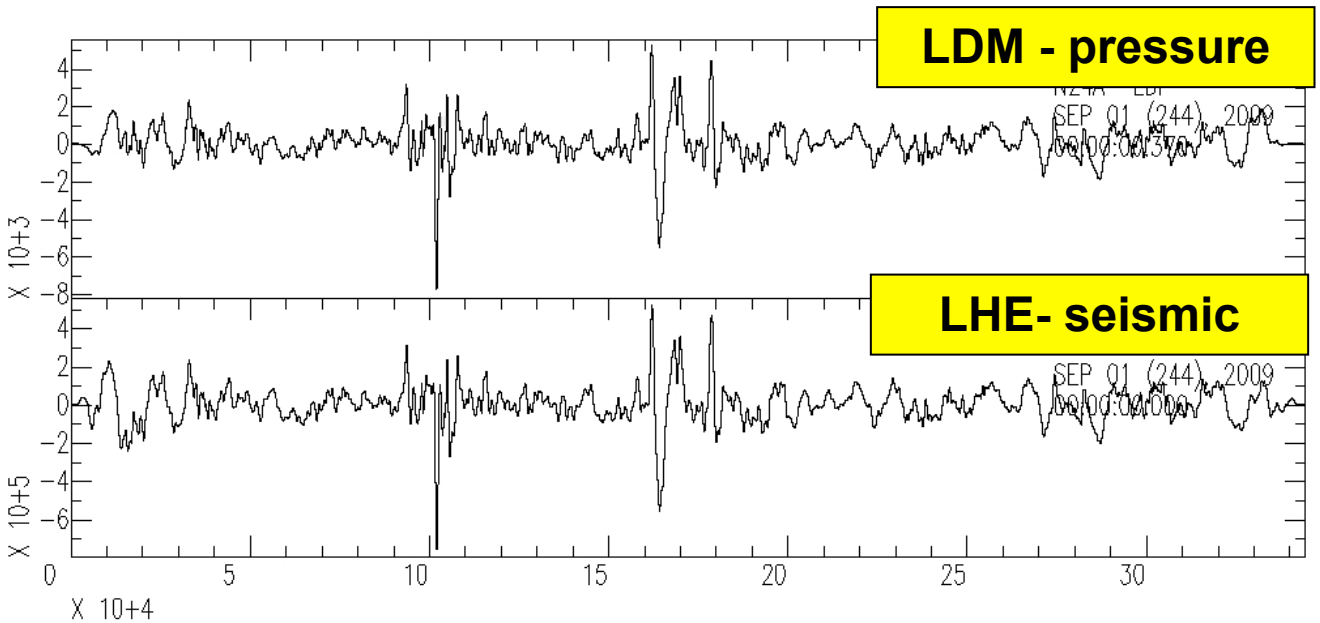
IMS57
70M aperture
25 element array

Adjacent arrays near TPFO

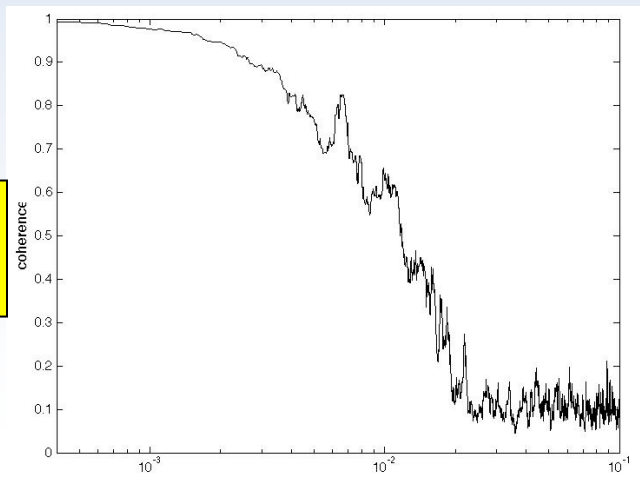
2 minute trace length

Basic Observation

- Pressure observations show strong correlation to seismic data



Pressure – Seismic Coherence

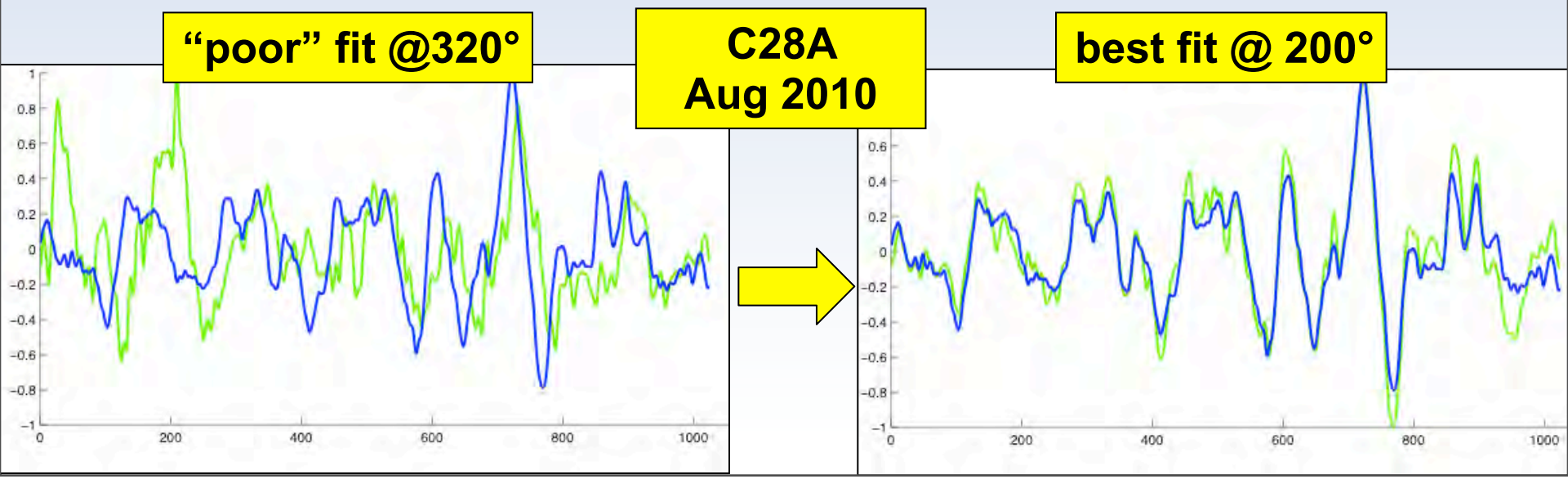


Pressure-Ground motion

- Pressure-seismic coherence is well observed for both vertical and horizontal components
  - Multiple studies have used the pressure signal as a means of de-noising the seismic data
- Vertical component
  - At long periods (e.g., 2-4 mHz) verticals have a gravity contribution from the mass of air and deformation effect (Zürn & Widmer, 1995)
- Horizontal components
  - Pressure fluctuations introduce multiple tilt effects (Sorrells, 1971)
  - Traveling Wave Model
    - Depends on pressure variation in time and space
  - Local Deformation Model
    - Depends on time variation of pressure, not spatial variation
    - Assumed to be specific to local site - collective response of sensor, vault, local site conditions , . . .
    - Like pushing on a three-legged stool with one weak leg – the result of pressure fluctuations from above will produce tilt in the same direction

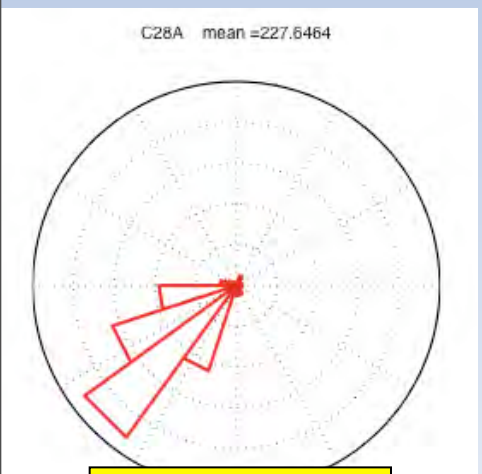
Method

- Use 30 day time series, bandpass filtered 2,000 s – 100 s
- Sliding ~3 hour window, 50% overlap
- Compute coherence in band around 1,000 s
  - Rotate horizontals to maximize coherence
- Process several months of data
  - ~450 coherence estimates per station per month
  - Plow through noise, earthquakes, etc.
- Focus on spatial characteristics of pressure-seismic coherence, not amplitude relationship (e.g., admittance)

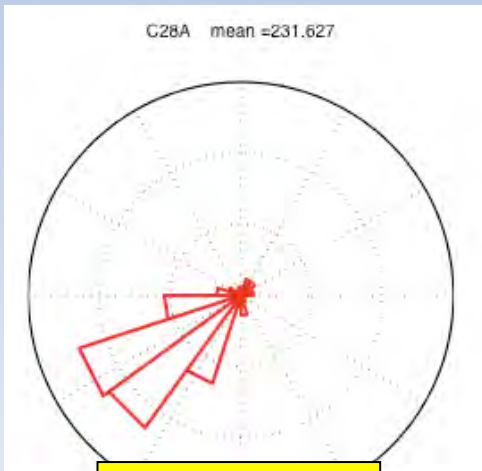


Coherent Behavior at Neighboring Stations

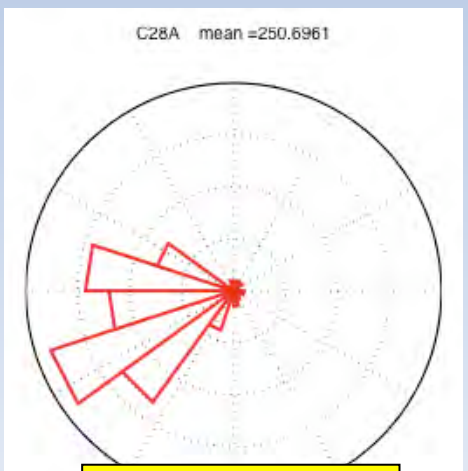
- Preferred orientation stable, but changes with time
- Neighboring stations C28A-D28A (70 km) behave similarly



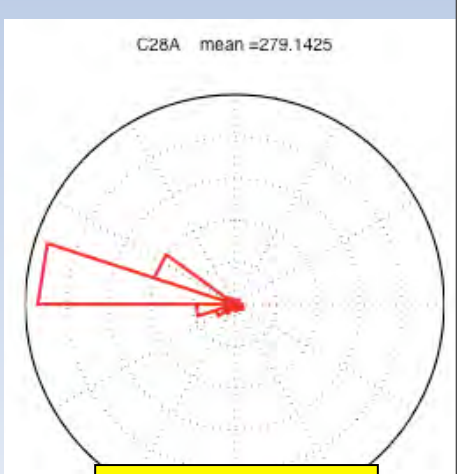
Aug 2010



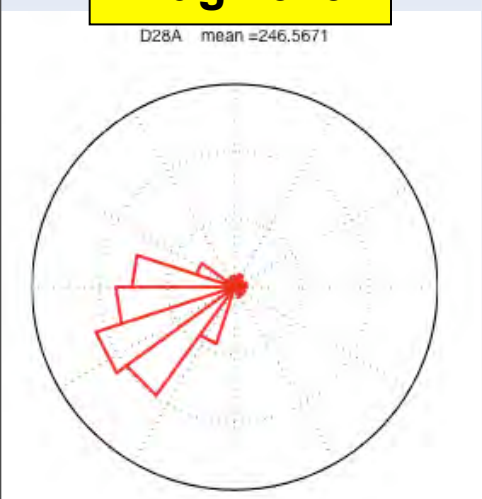
Sept 2010

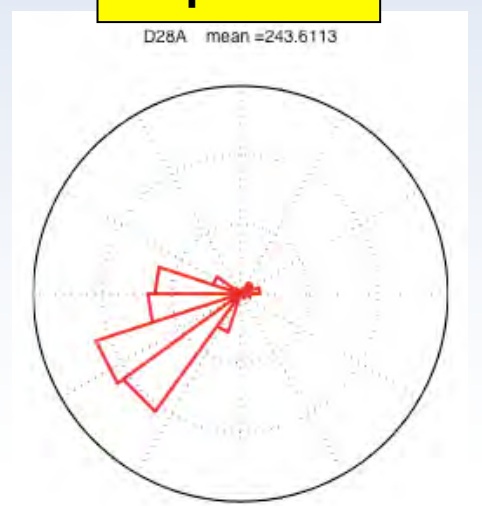


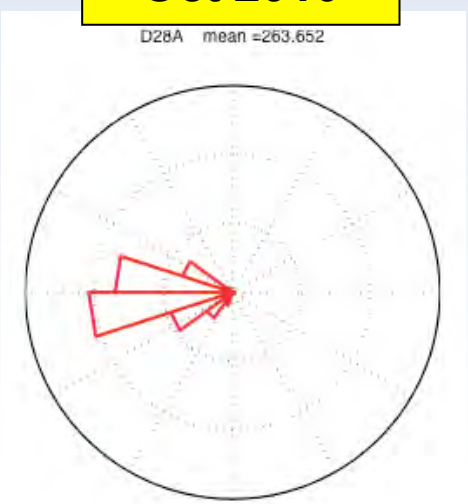
Oct 2010

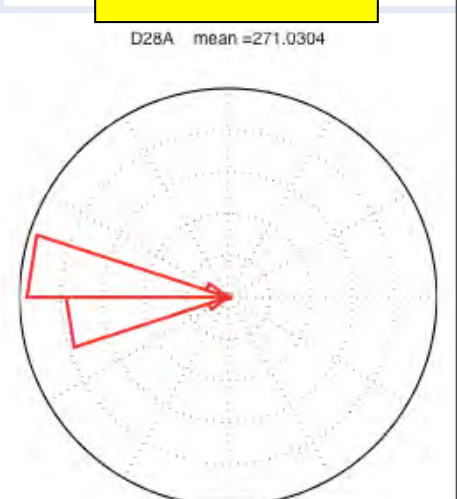


Nov 2010

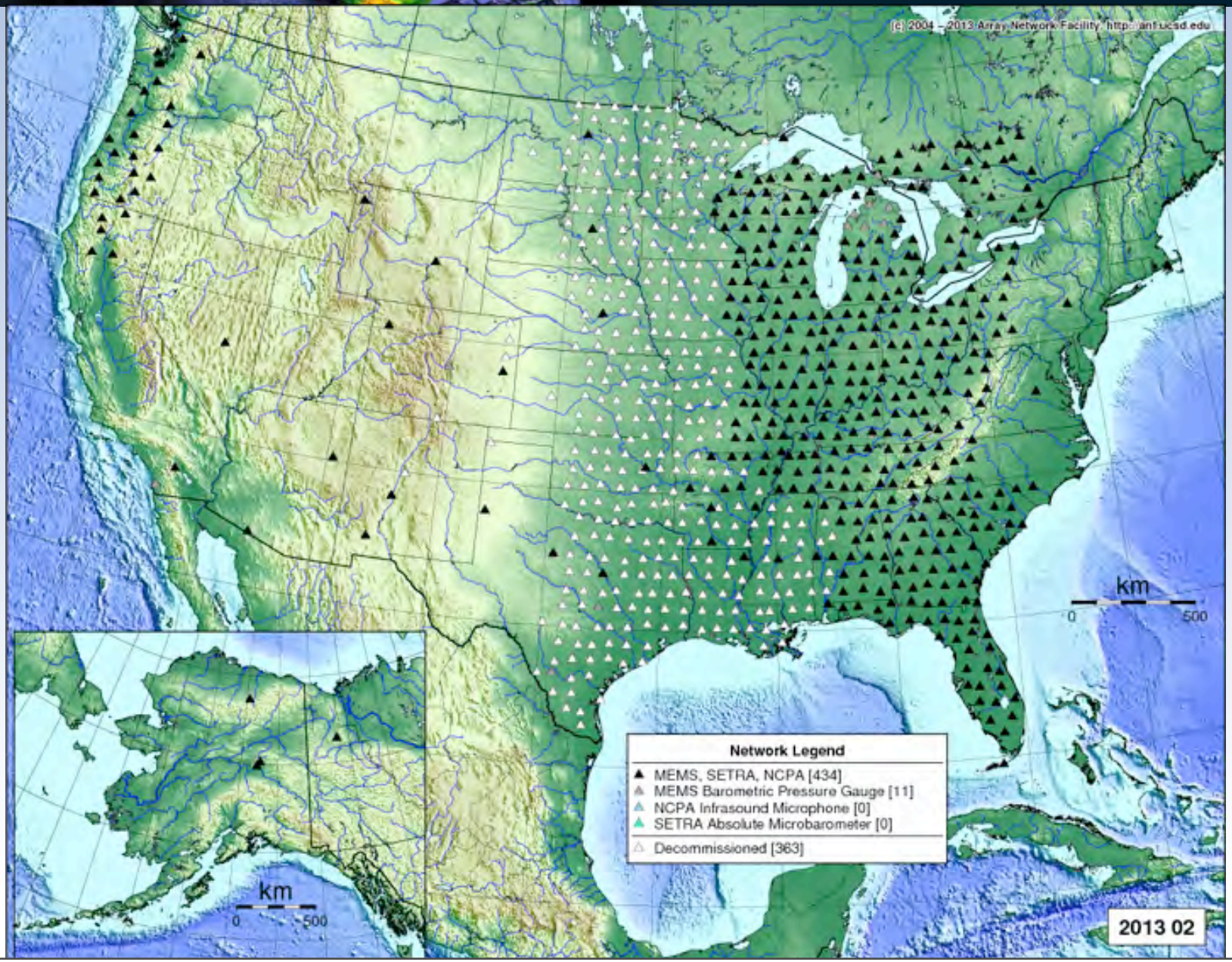


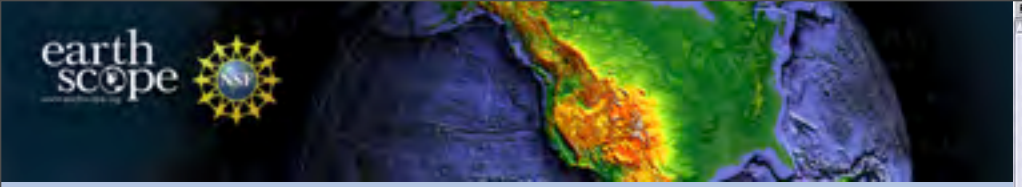




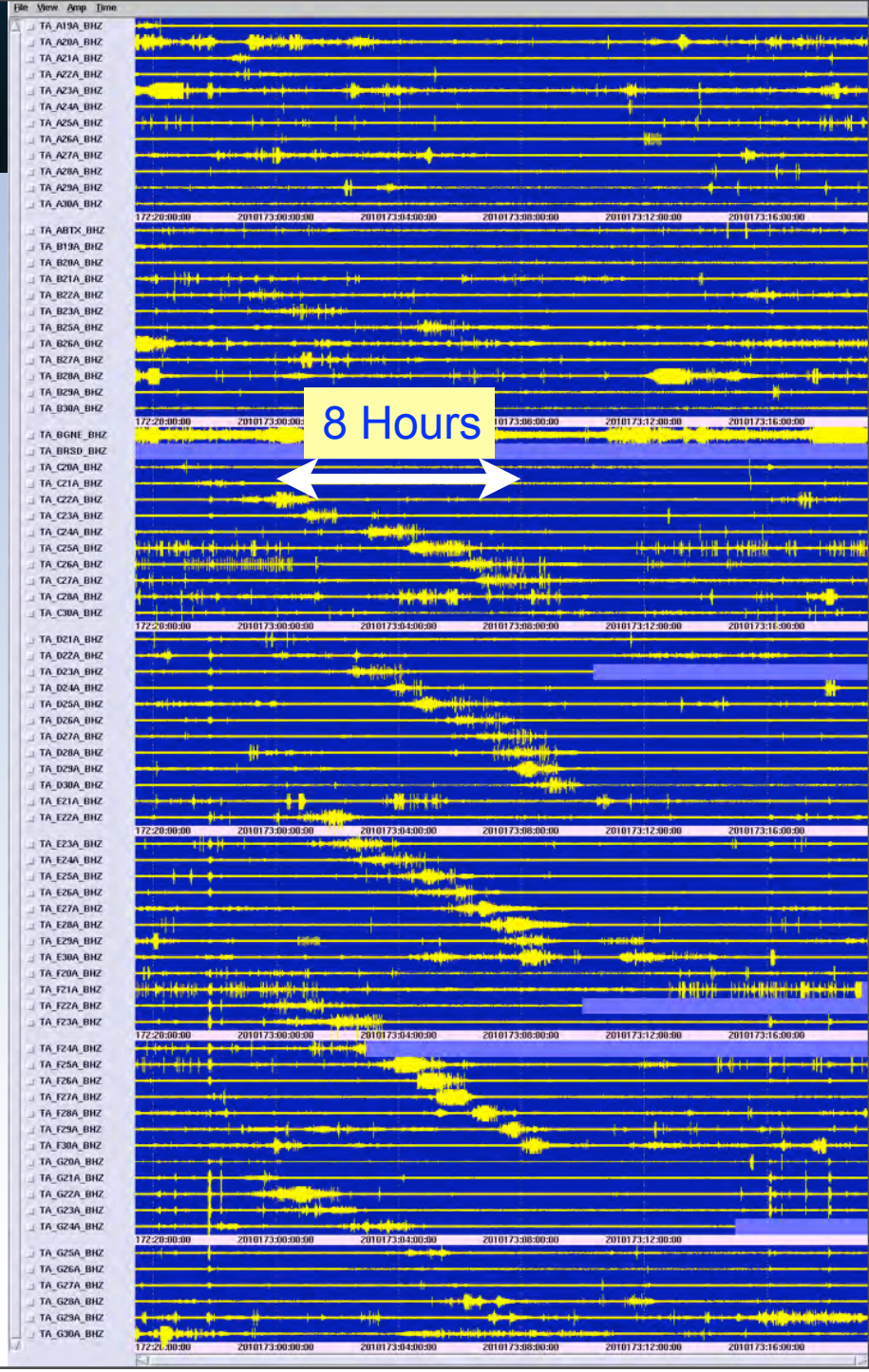


Implementation of Atmospheric Pressure Sensors

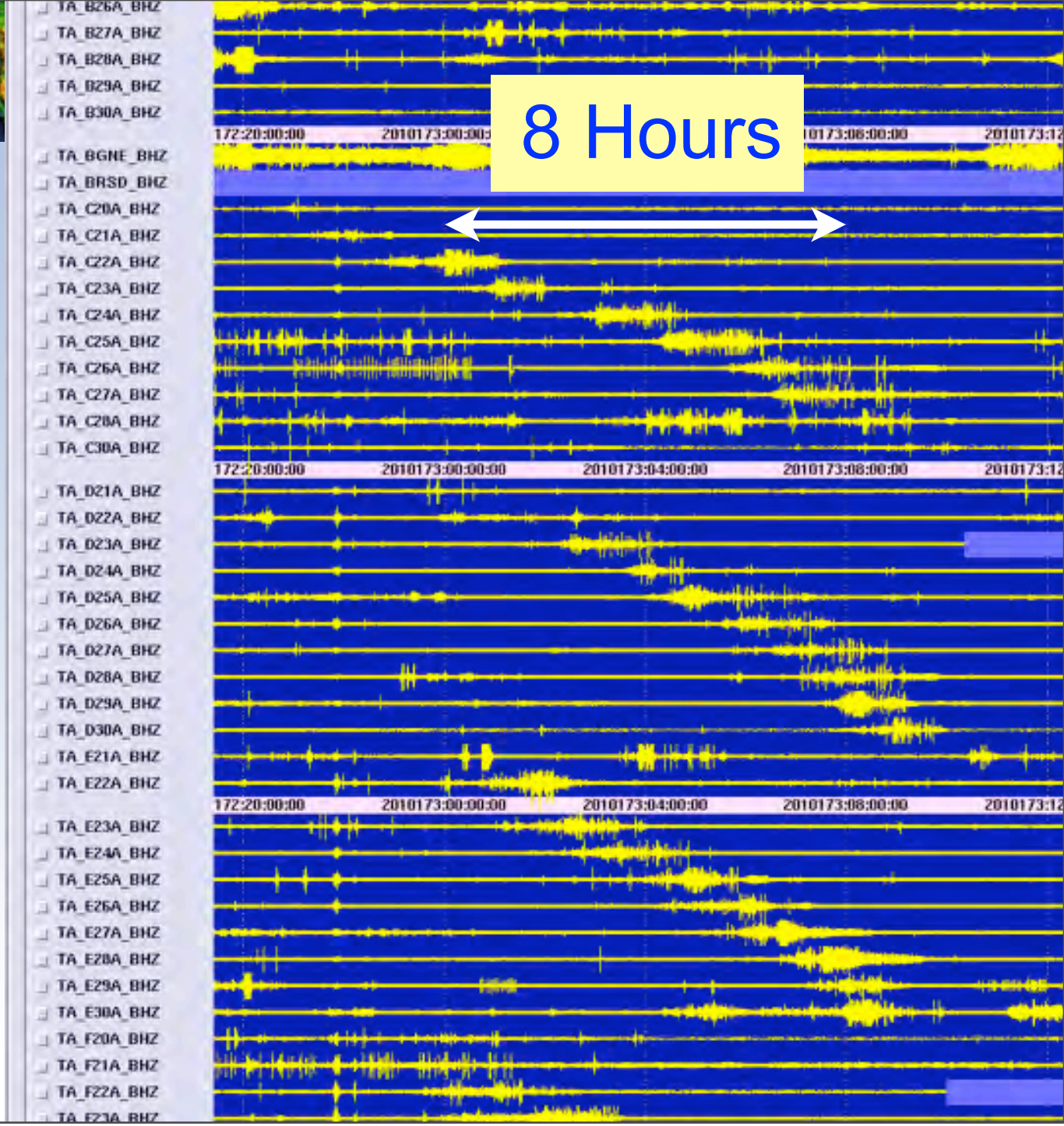


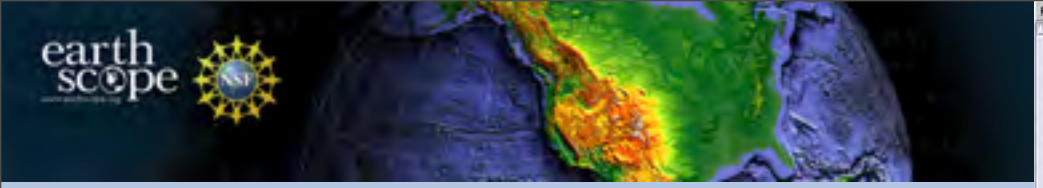


- **Strange signals**
- **Correlated across stations**
- **Slow move out**
- **Too slow for seismic**
- **Too slow for infrasound**

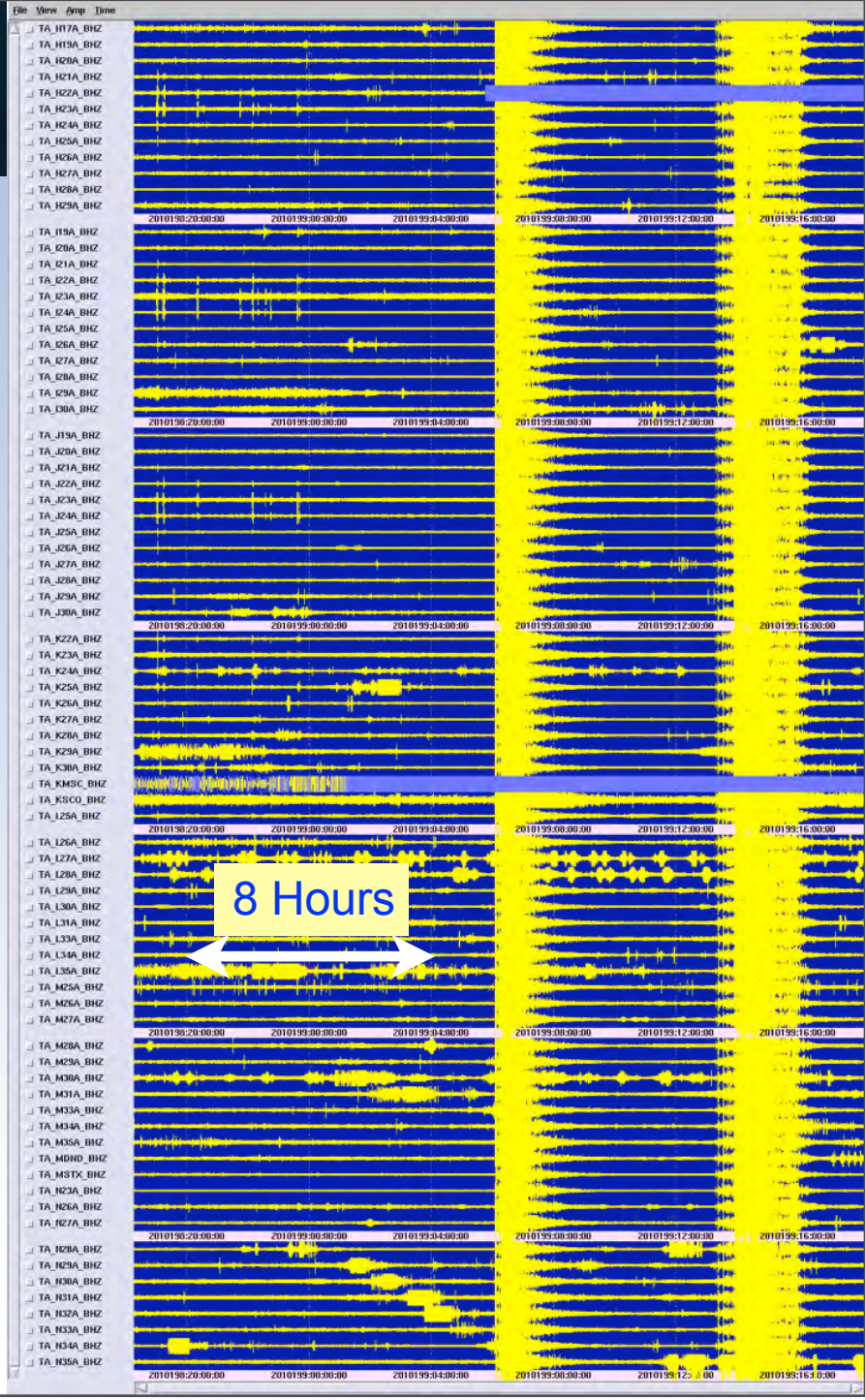


- Strange signals
- Correlated across stations
- Slow move out
- Too slow for seismic
- Too slow for infrasound

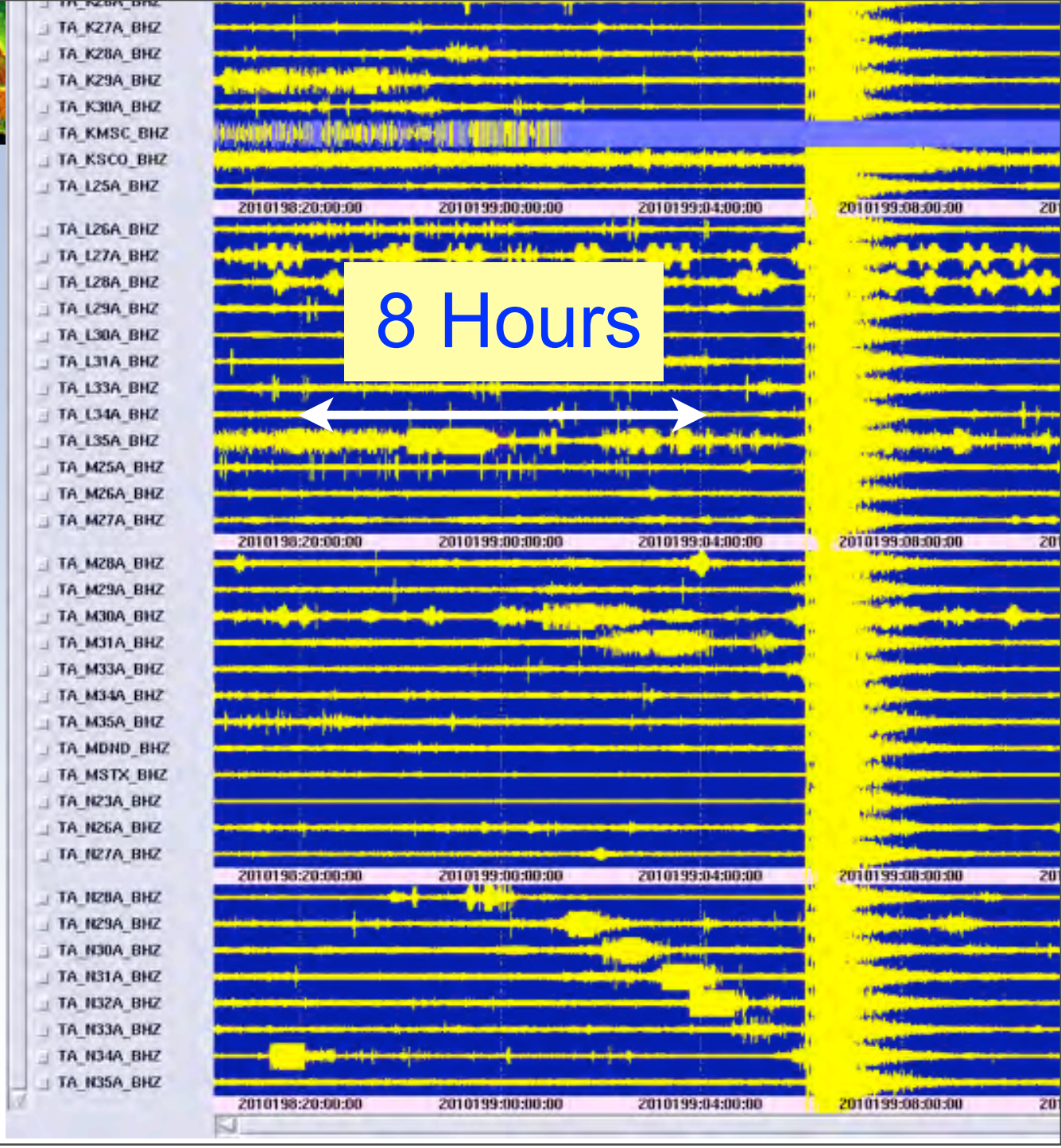




- 6.7 Aleutian Islands
- 6.9 New Britain
- 7.3 New Britain
- Slow move out
  - Too slow for seismic
  - Too slow for infrasound



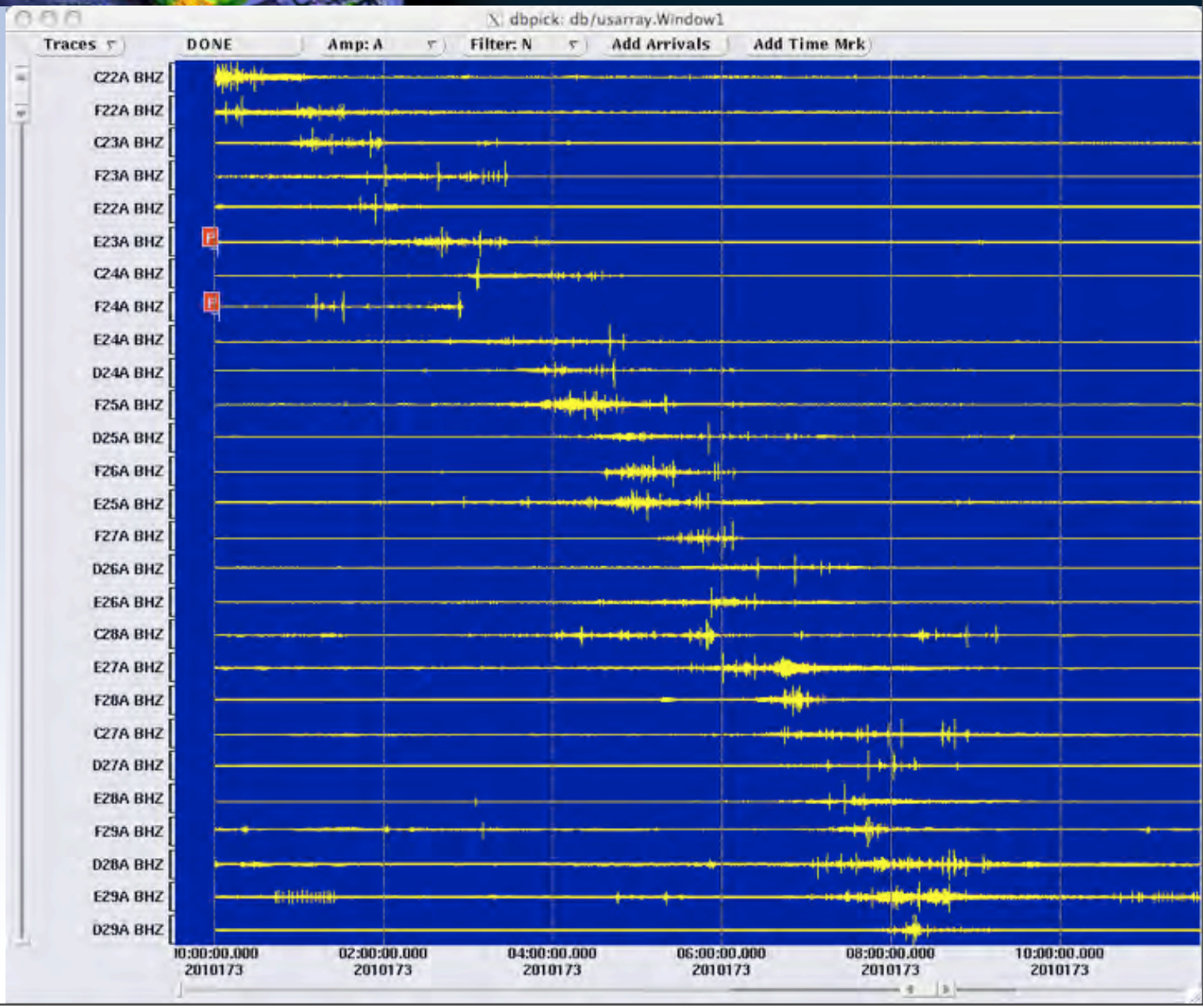
- 6.7 Aleutian Islands
- 6.9 New Britain
- 7.3 New Britain
- Slow move out
  - Too slow for seismic
  - Too slow for infrasound



Interesting Signals

40 sps

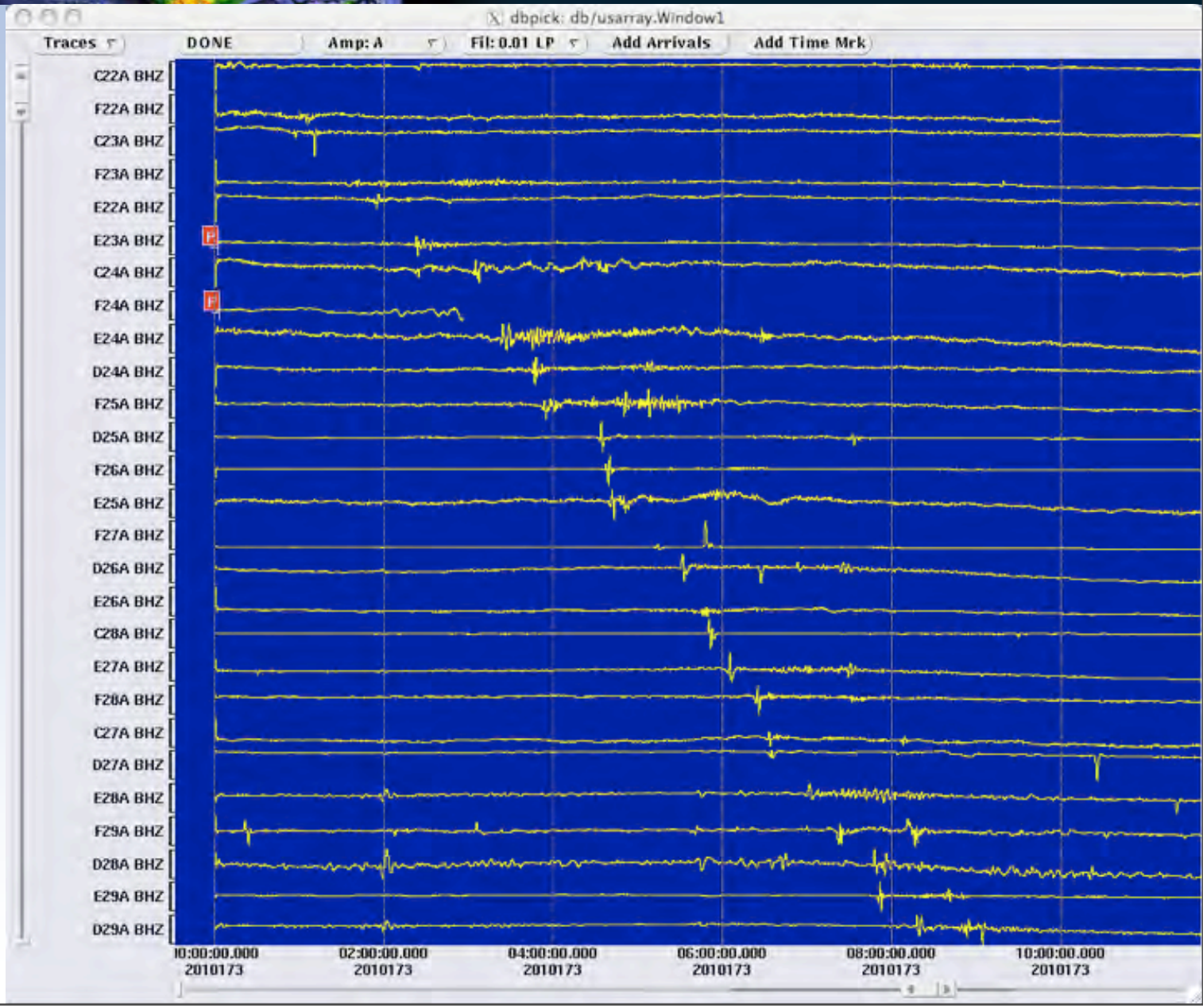
Unfiltered



Interesting Signals

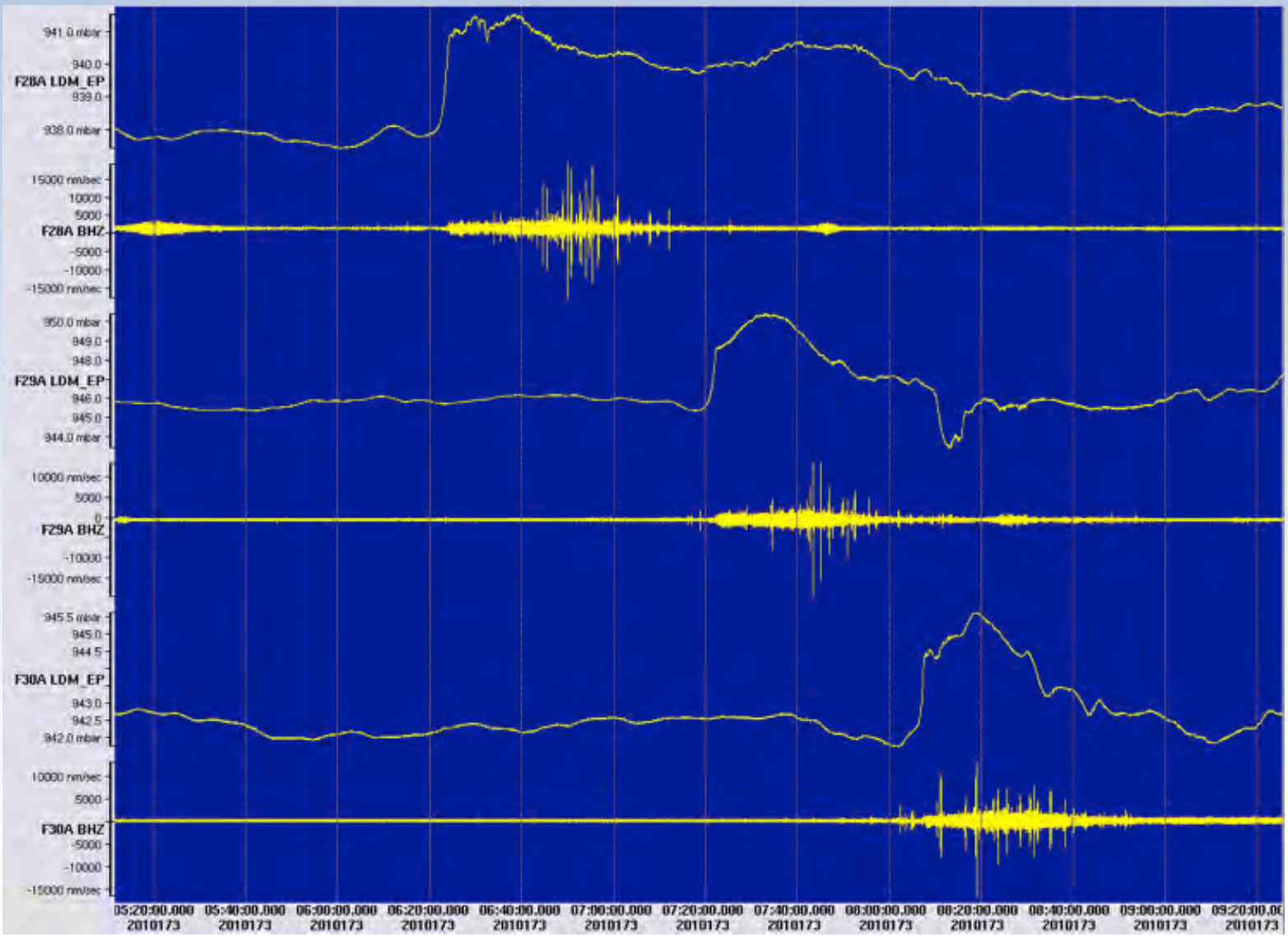
40 sps

DC - 0.01 Lowpass Filter



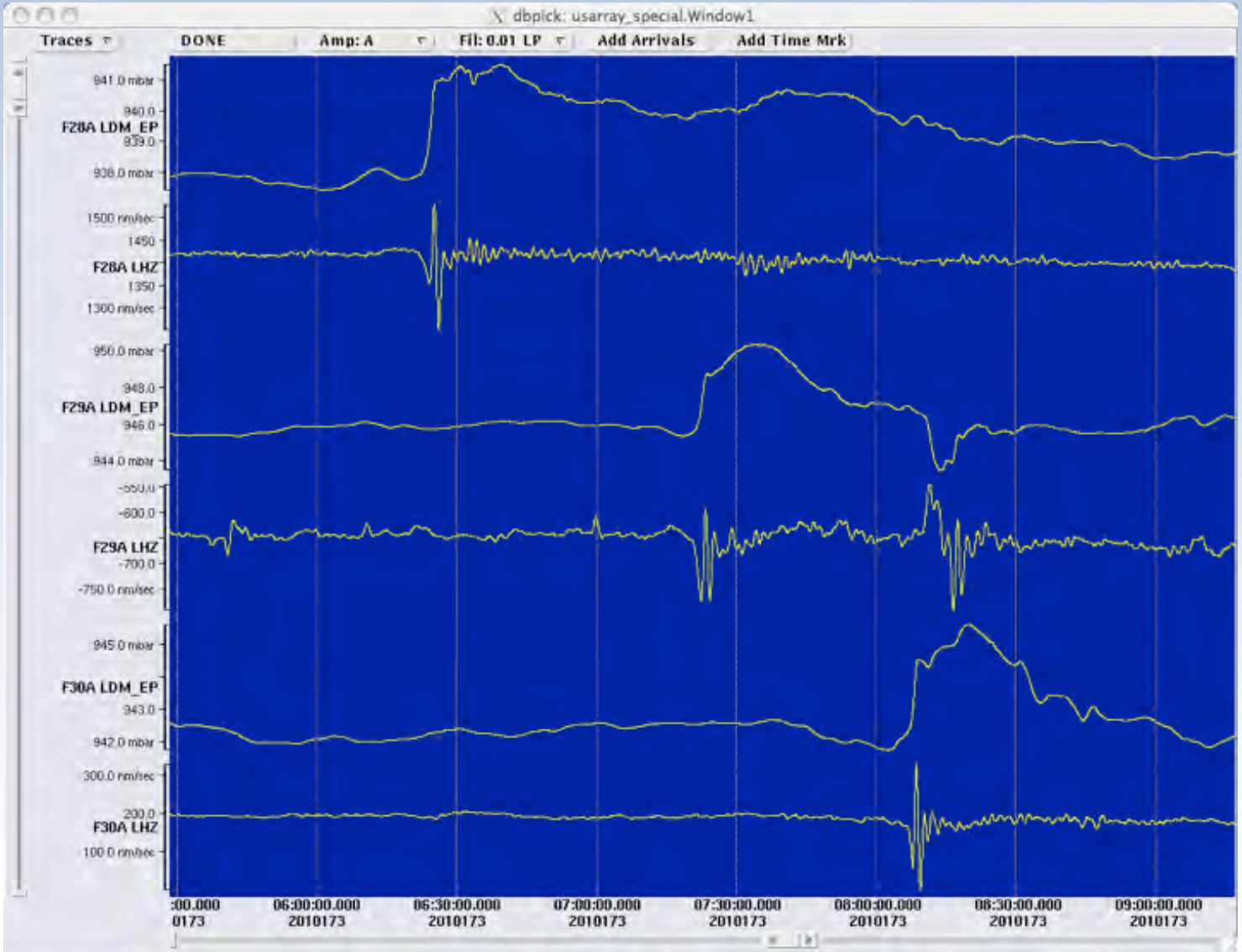
Interesting Signals

Broadband Seismic (40 sps) compared to Atmospheric Pressure (1 sps)

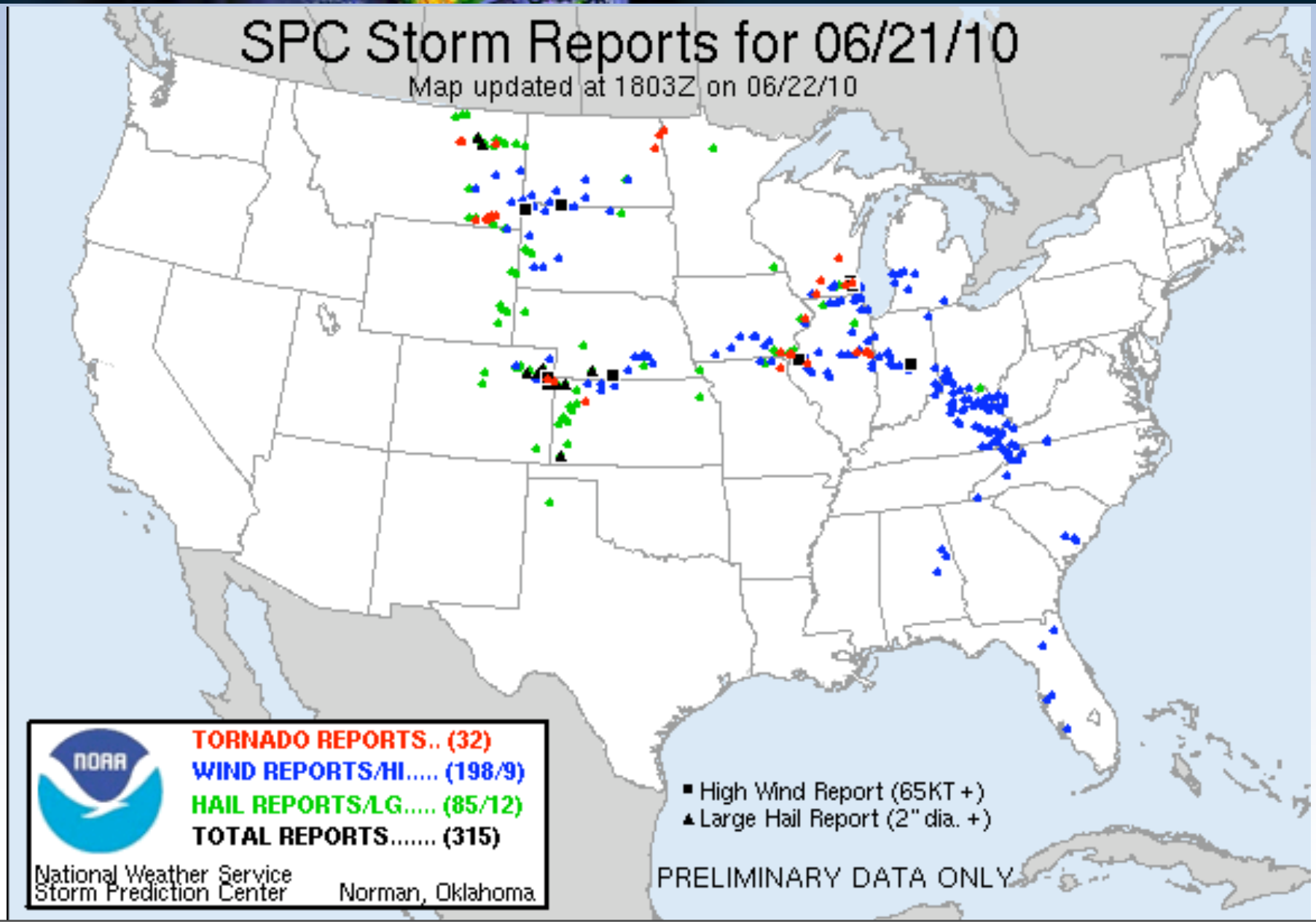


Interesting Signals

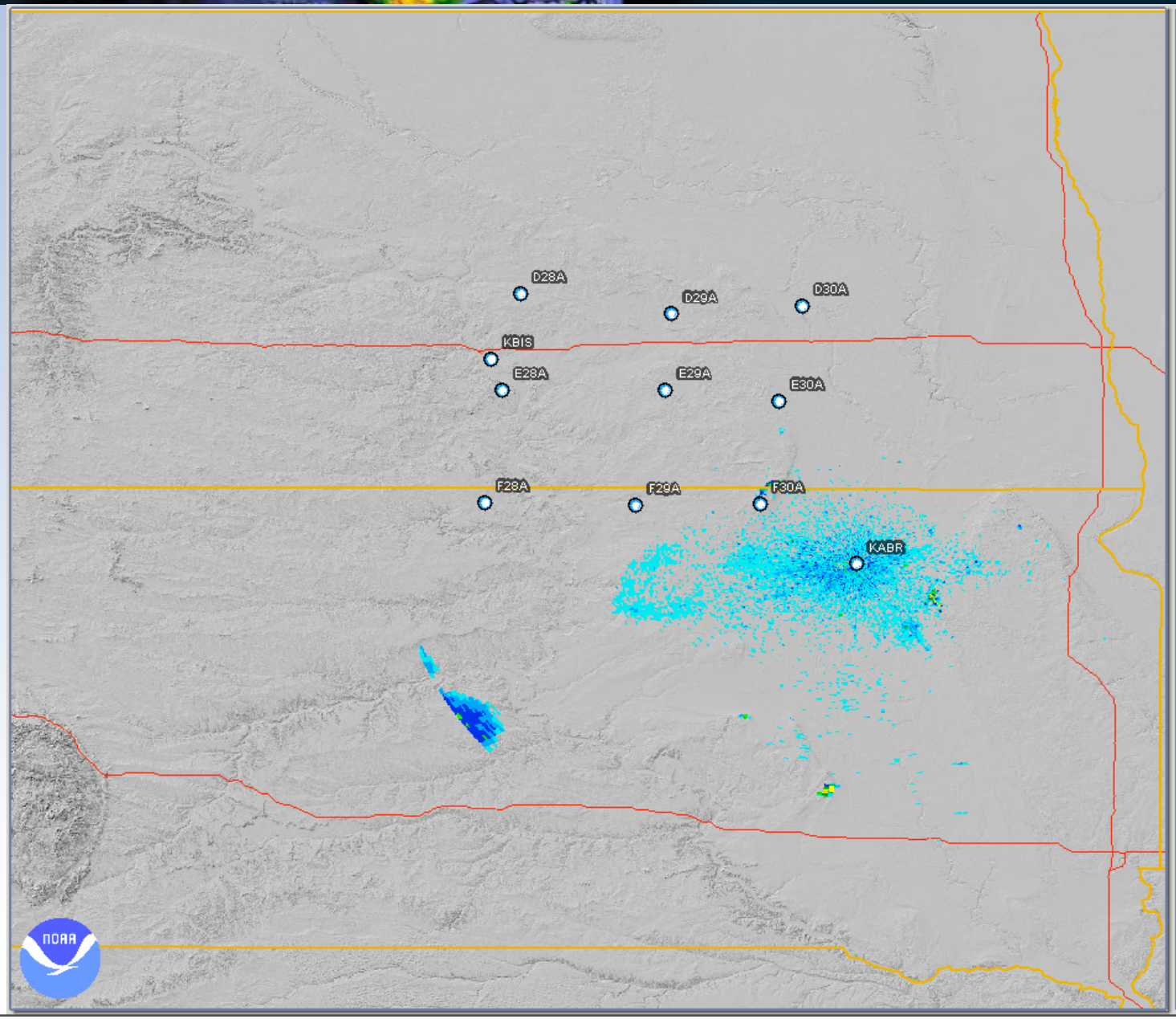
Low Frequency Seismic (< 0.01 Hz) compared to Atmospheric Pressure (1 sps)
Ground deforming to pressure increase



Storm Reports



Interesting Signals



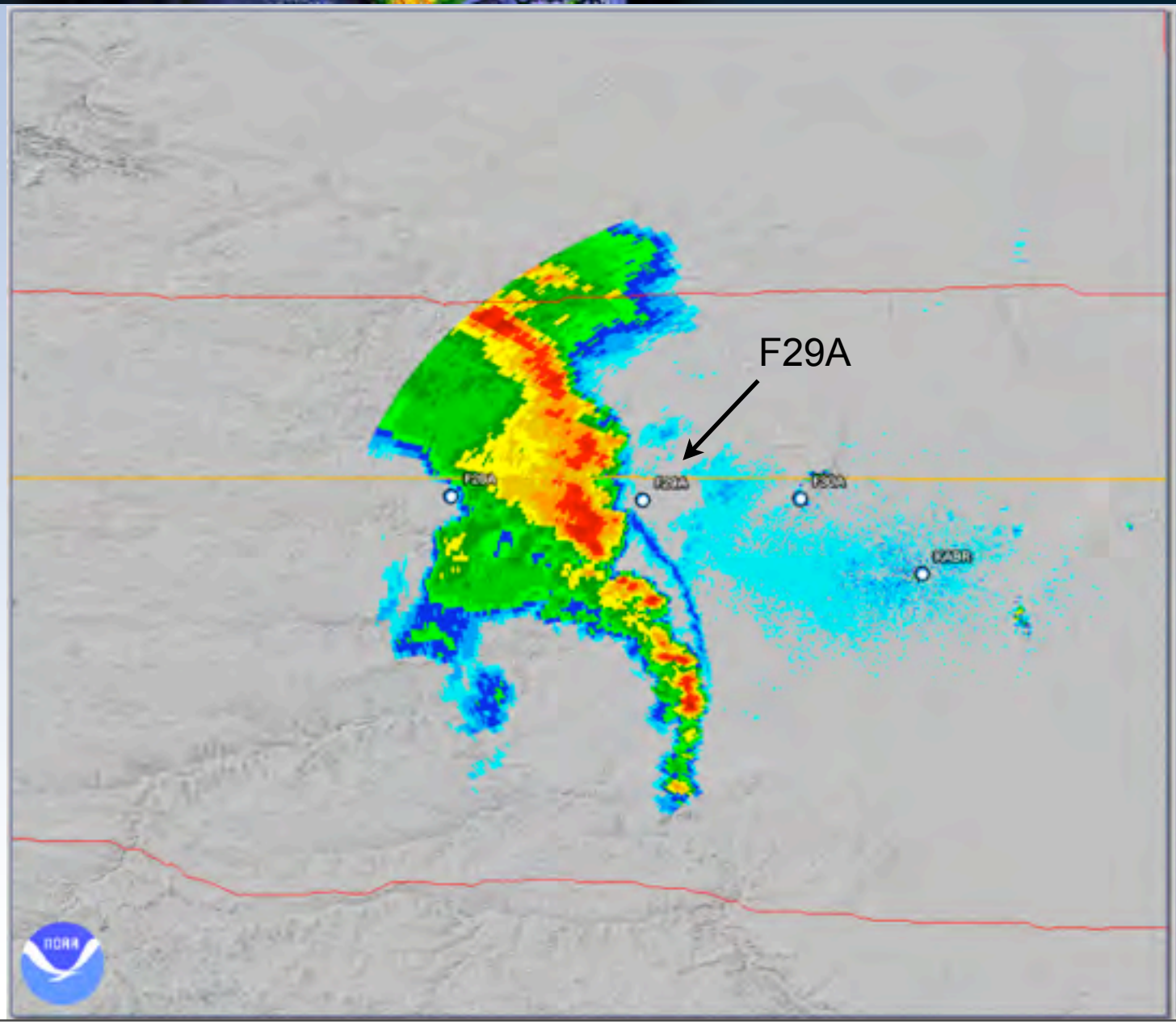
NEXRAD LEVEL-III
BASE REFLECTIVITY
KABR - ABERDEEN, SD
06/22/2010 04:58:35 GMT
LAT: 45/27/21 N
LON: 98/24/46 W
ELEV: 1383 FT
MODE/VCP: A / 212

ELEV ANGLE: 0.50 °
MAX: 46 dBZ

Legend: dBZ (Category)

	75 (15)
	70 (14)
	65 (13)
	60 (12)
	55 (11)
	50 (10)
	45 (9)
	40 (8)
	35 (7)
	30 (6)
	25 (5)
	20 (4)
	15 (3)
	10 (2)
	5 (1)

Radar Image 1 - F29A



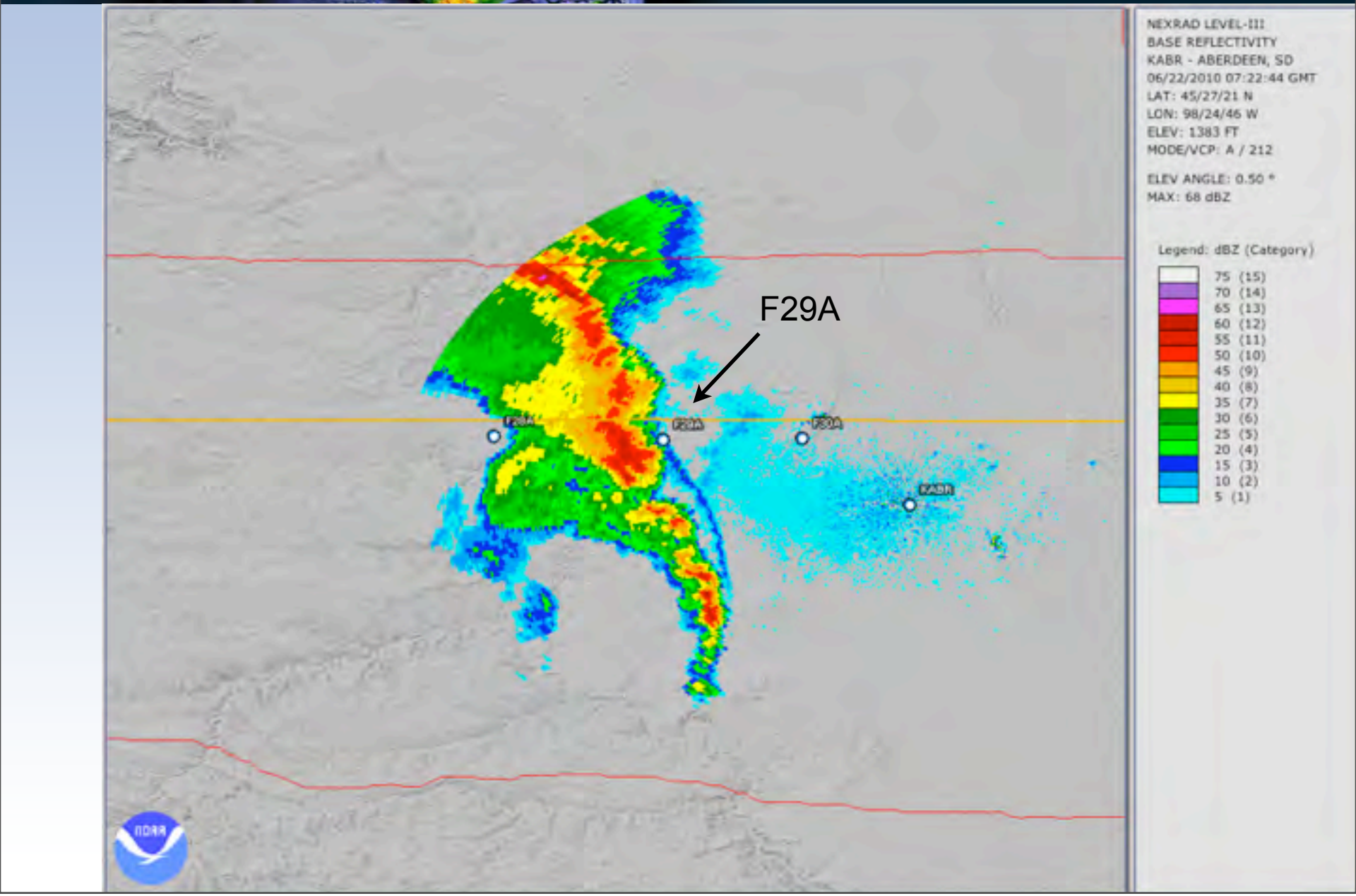
NEXRAD LEVEL-III
BASE REFLECTIVITY
KABR - ABERDEEN, SD
06/22/2010 07:18:15 GMT
LAT: 45/27/21 N
LON: 98/24/46 W
ELEV: 1383 FT
MODE/VCP: A / 212

ELEV ANGLE: 0.50 °
MAX: 63 dBZ

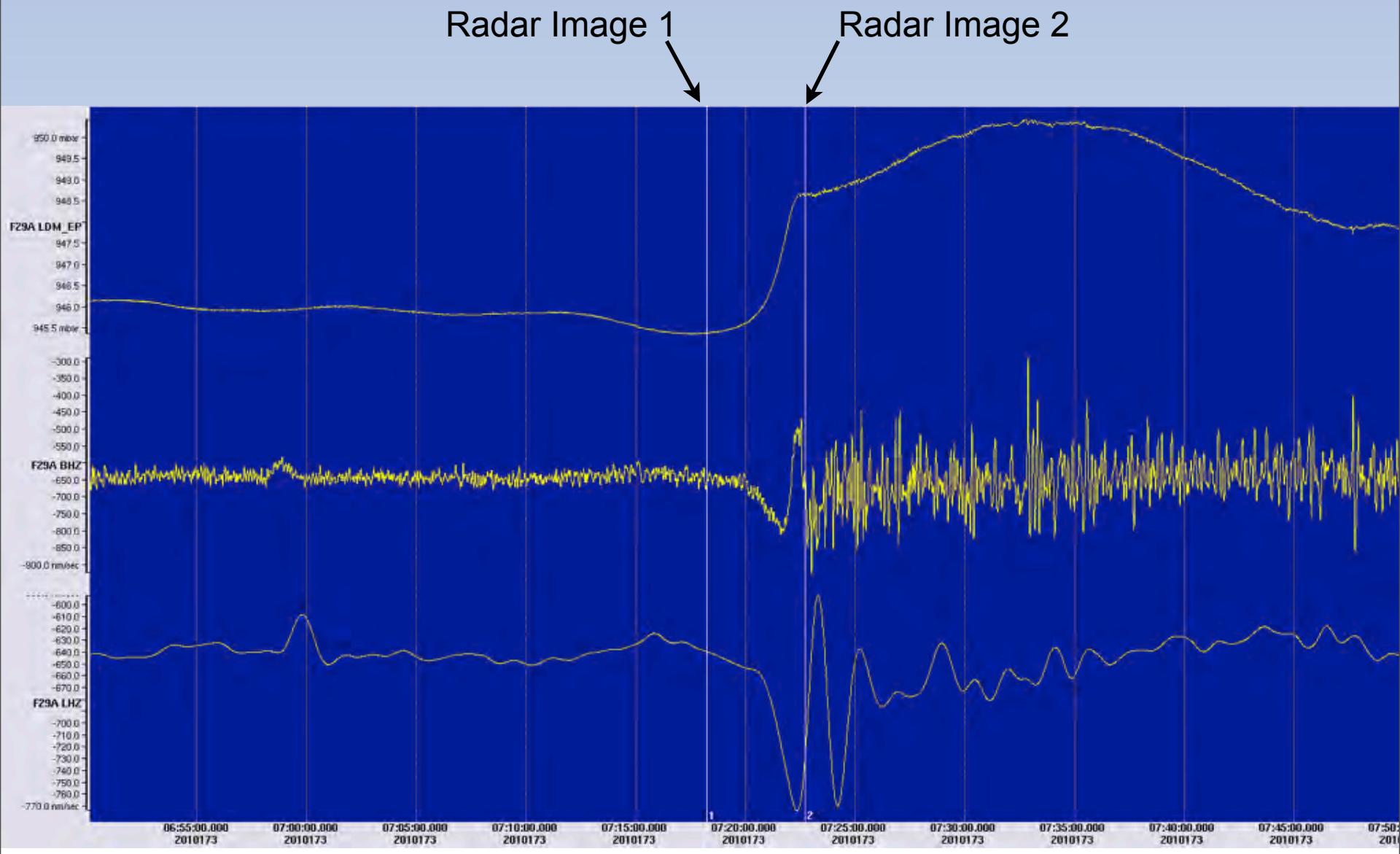
Legend: dBZ (Category)

75	(15)
70	(14)
65	(13)
60	(12)
55	(11)
50	(10)
45	(9)
40	(8)
35	(7)
30	(6)
25	(5)
20	(4)
15	(3)
10	(2)
5	(1)

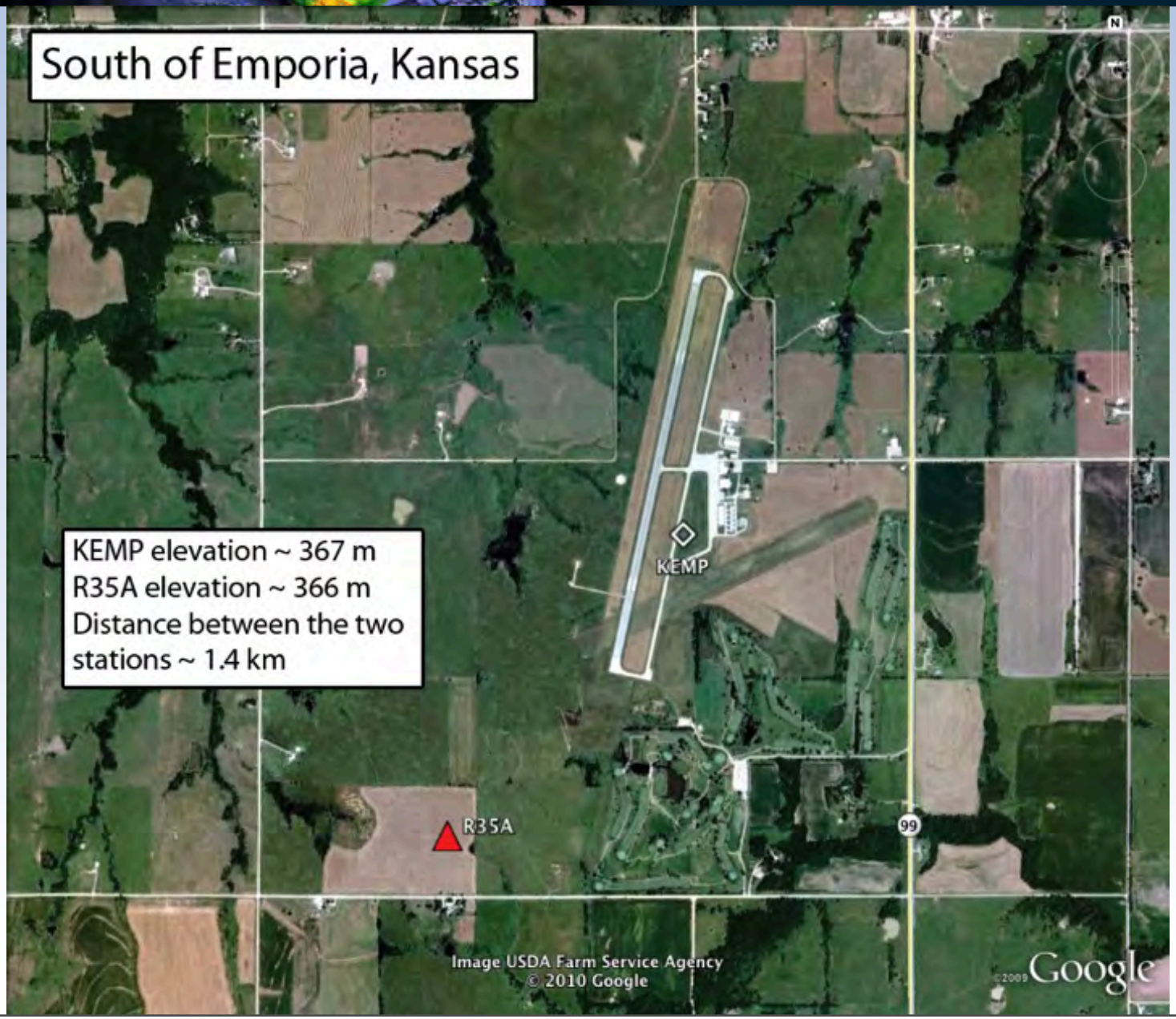
Radar Image 2 - F29A



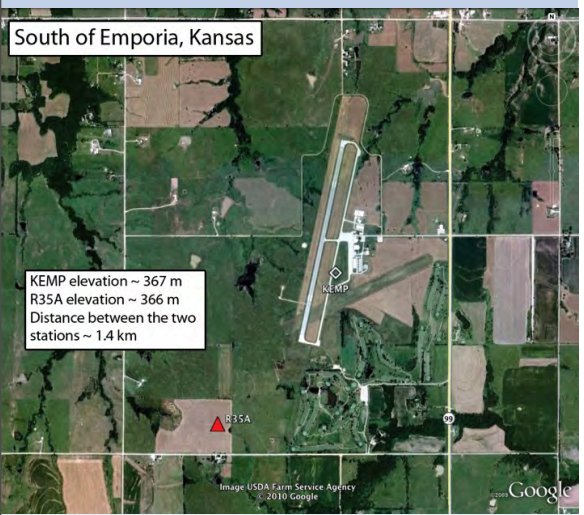
F29A Pressure and Seismic

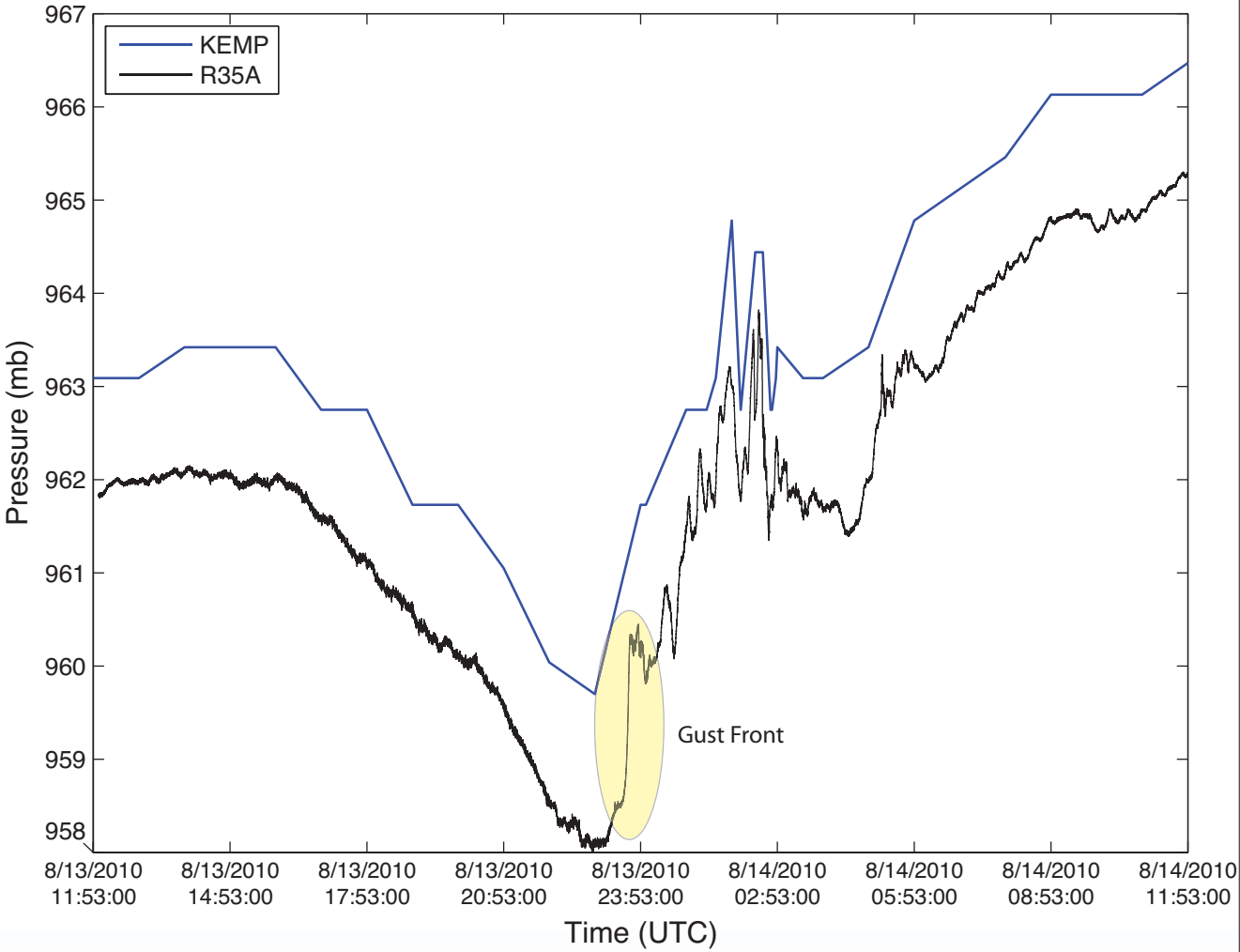


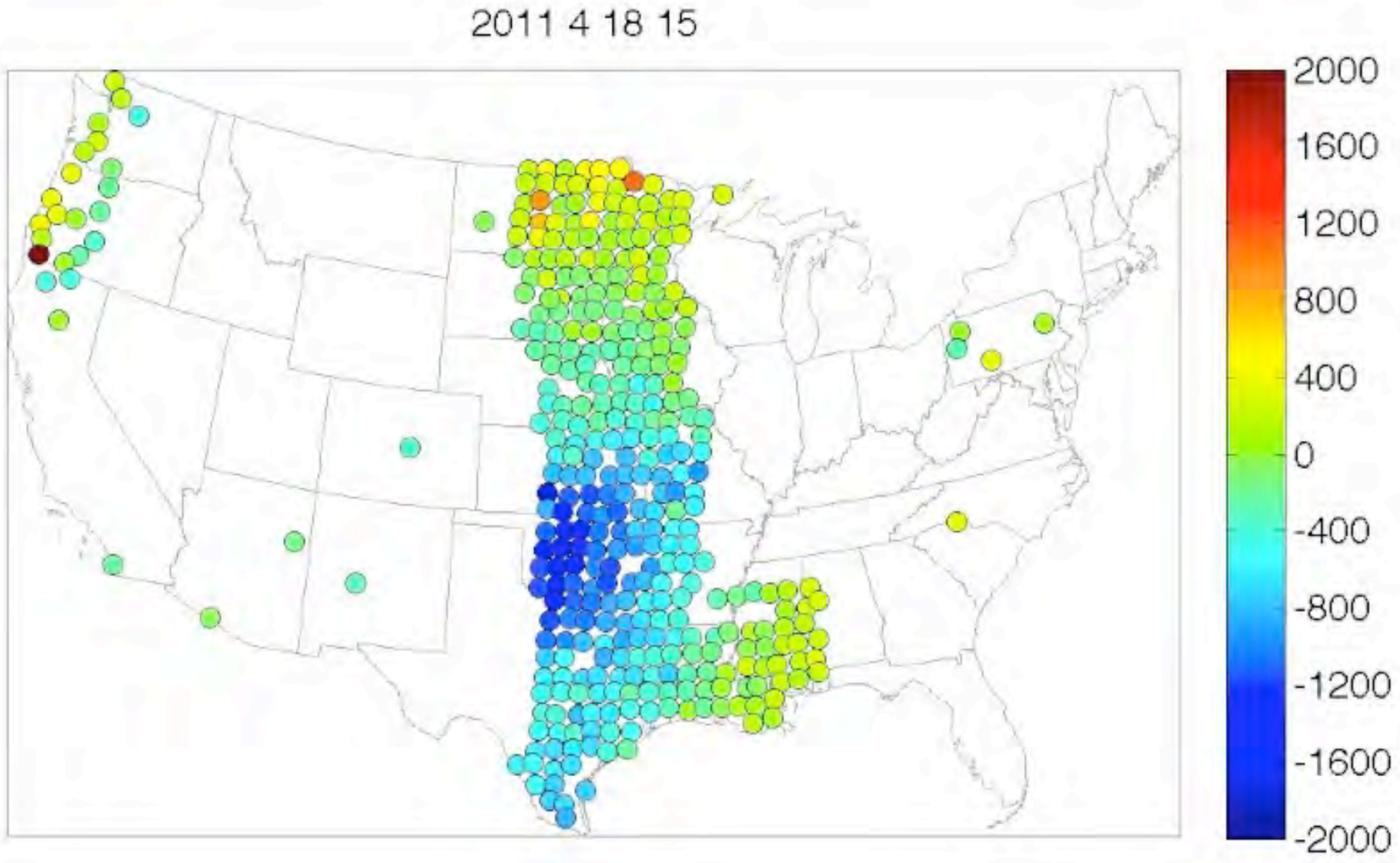
NWS Comparason



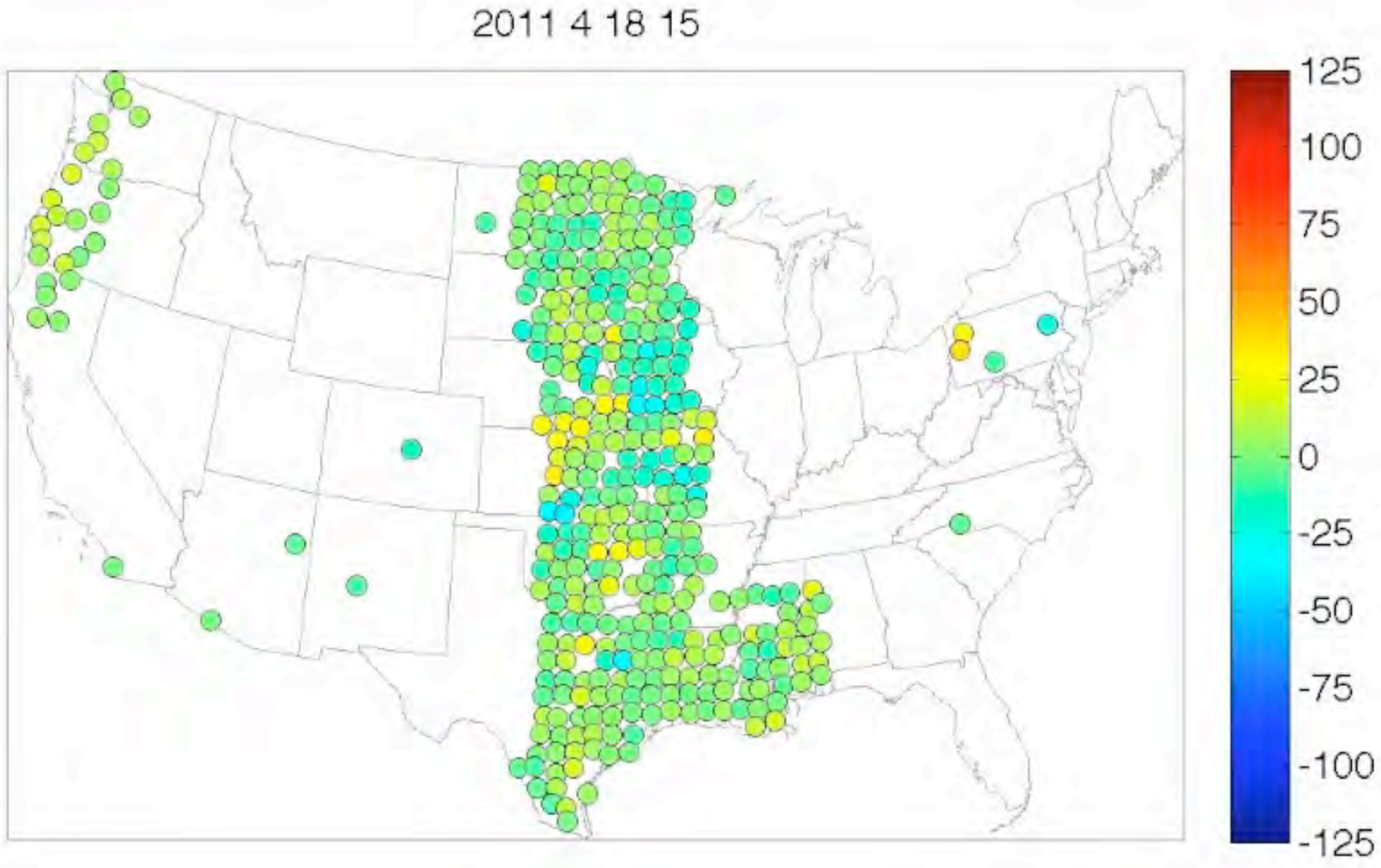
NWS Comparason





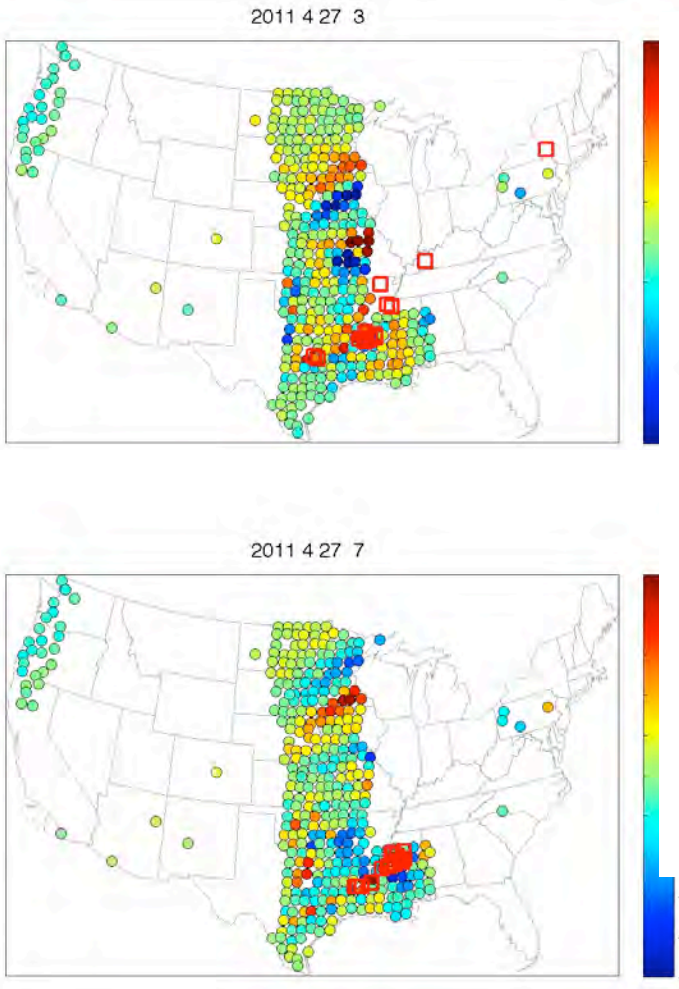


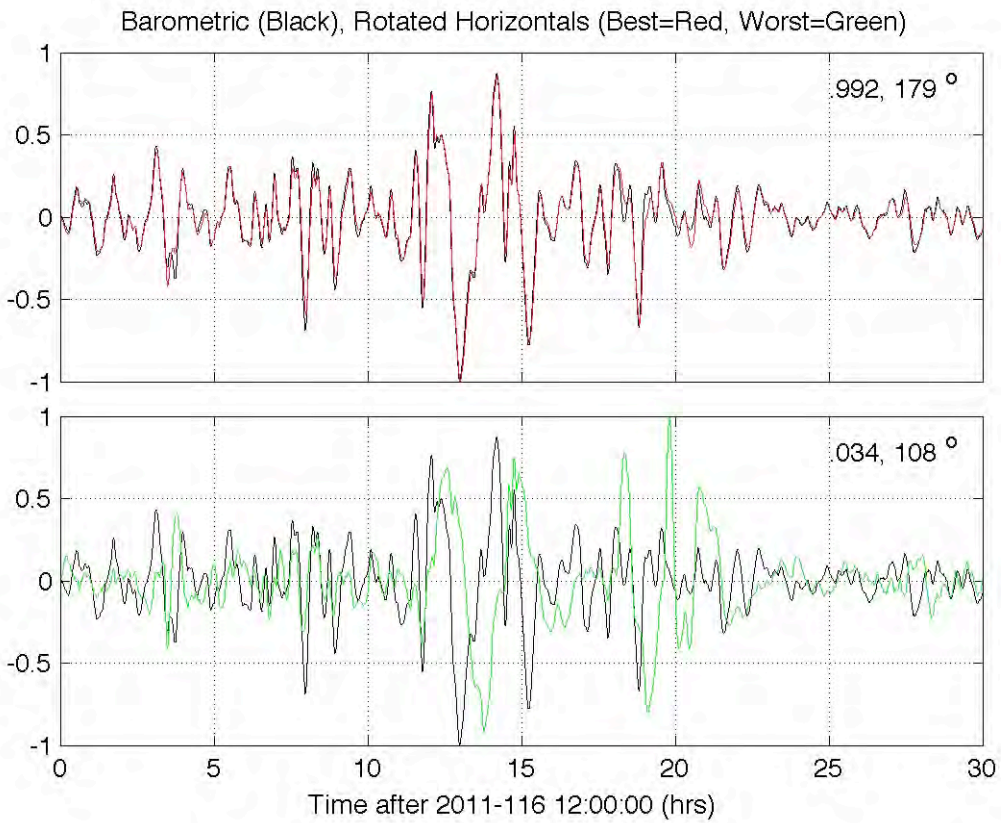
Barometric Pressure Variations
Unfiltered Data



Atmospheric Gravity Wave Band
Periods - 2 to 6 Hours

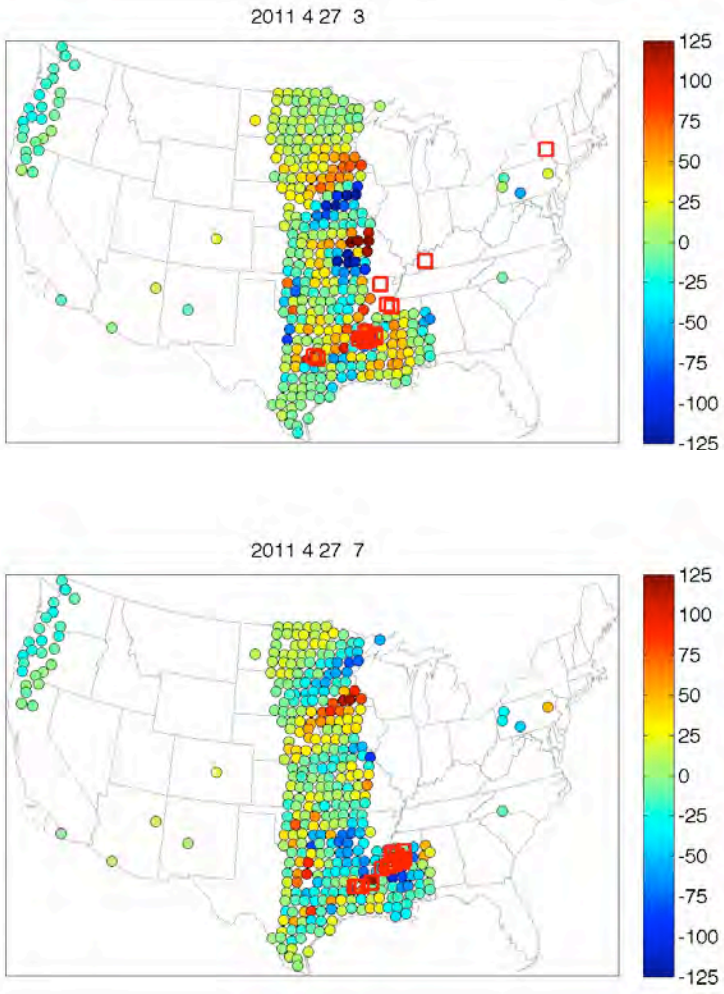
North propagating 2-6 hr GW

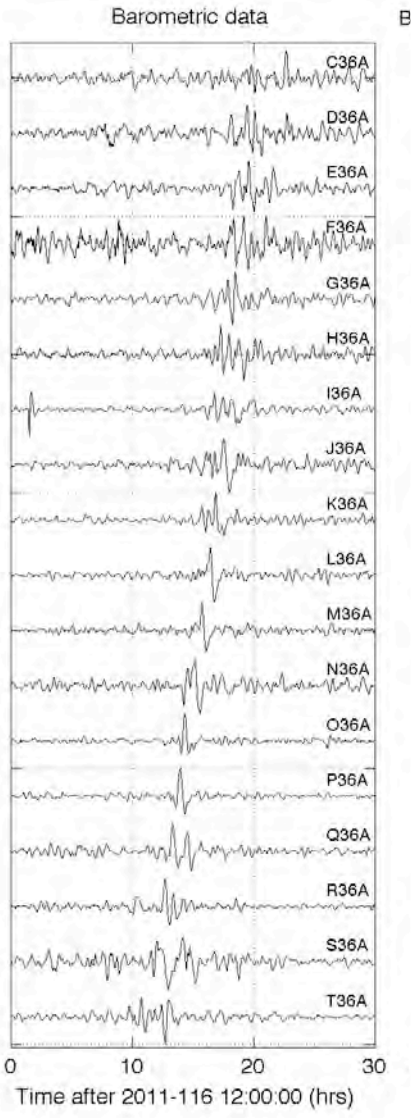




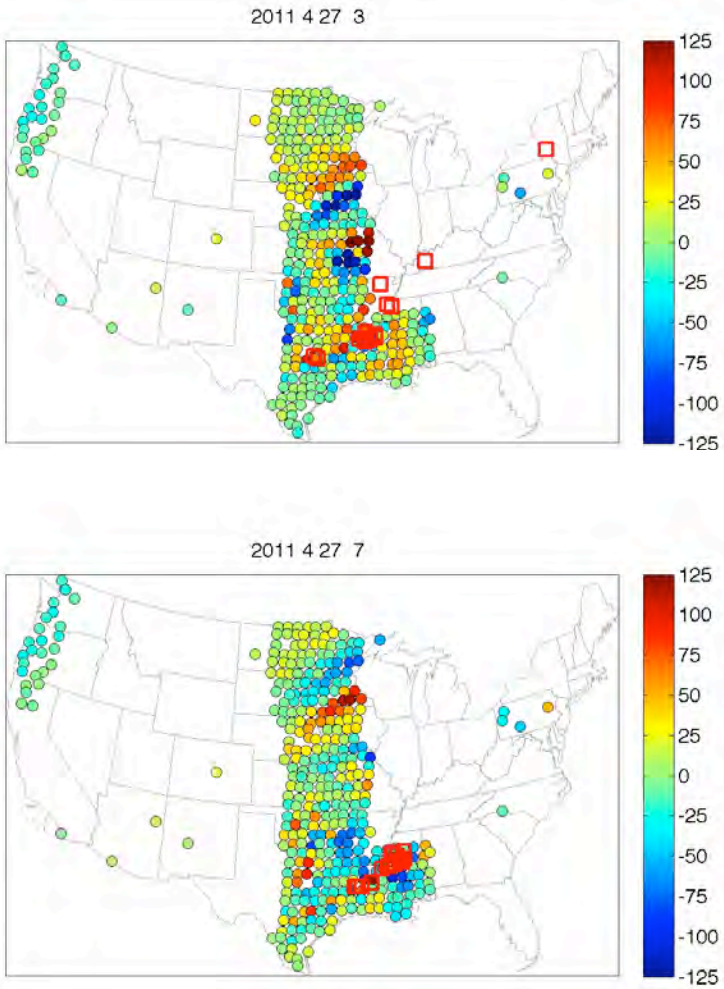
S36A: 1,800 to 8,000 s

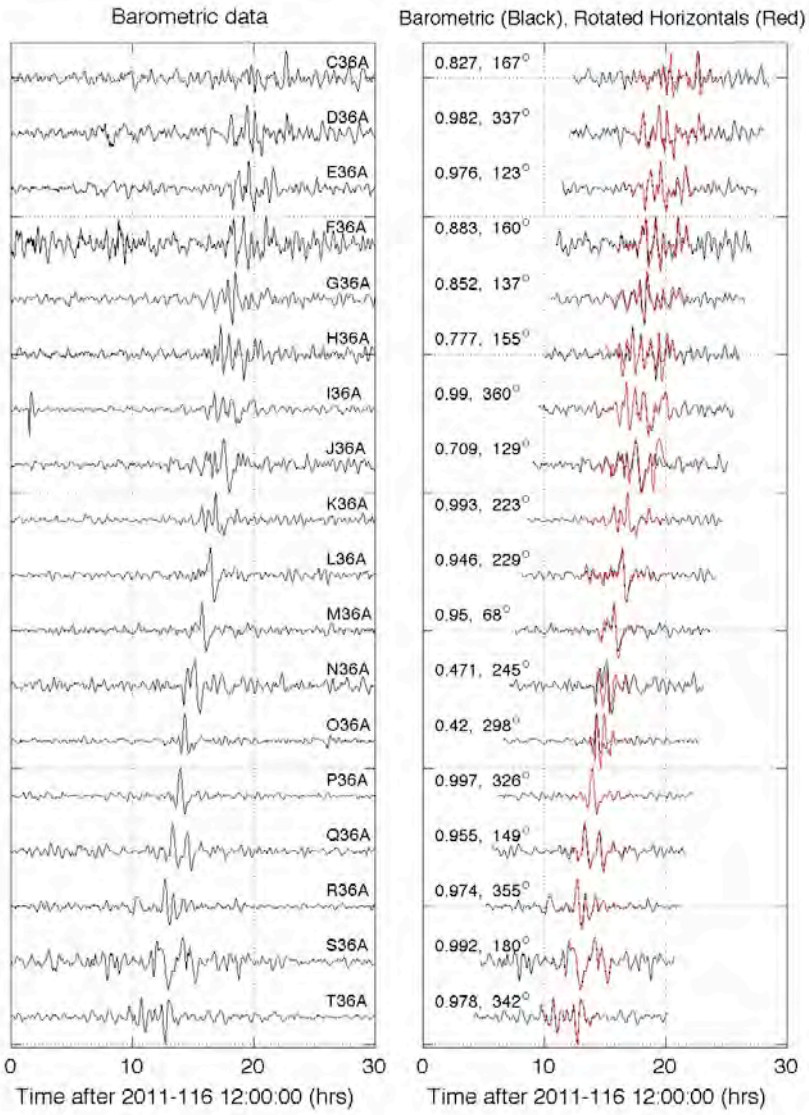
North propagating 2-6 hr GW



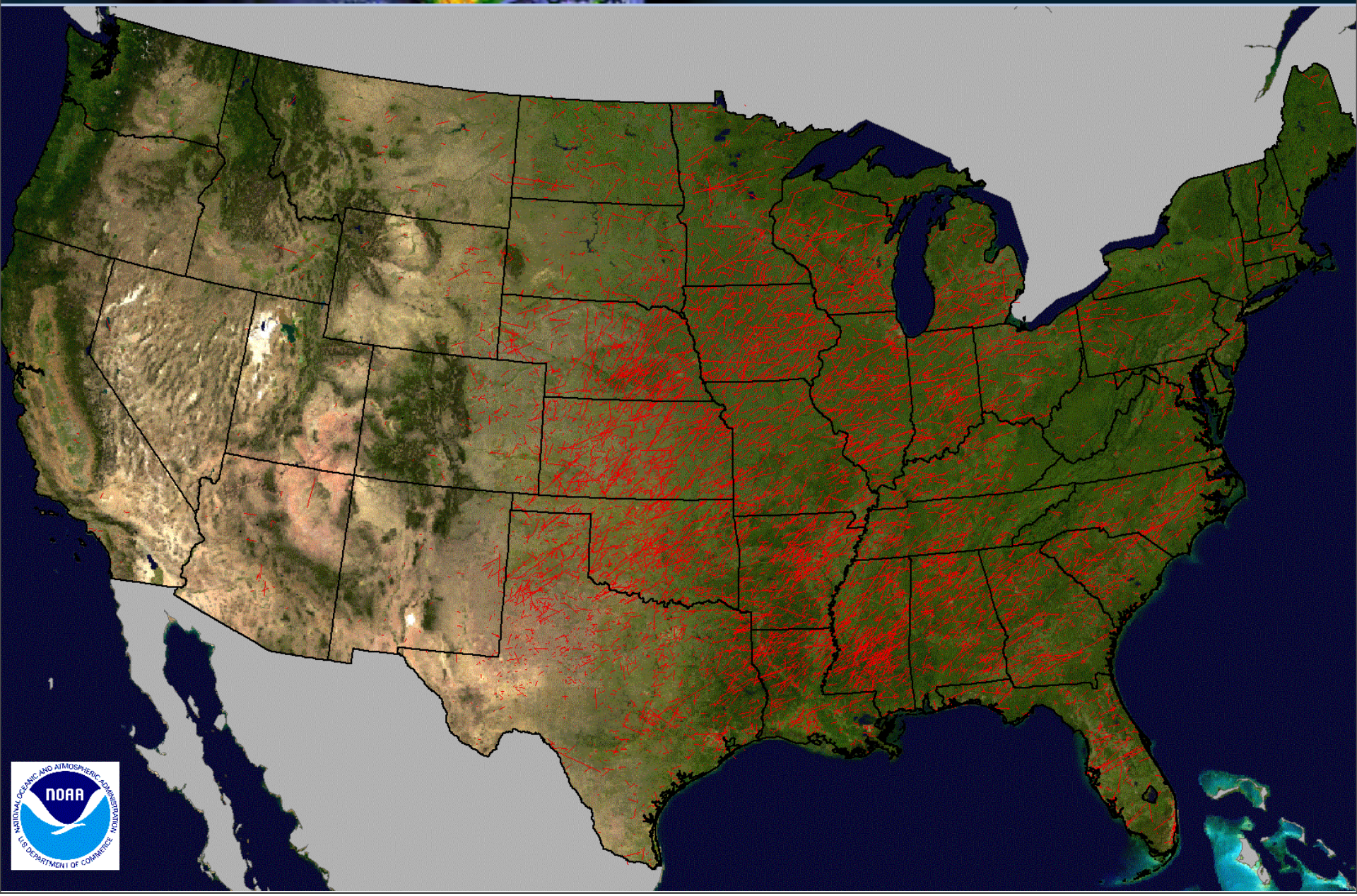


North propagating 2-6 hr GW





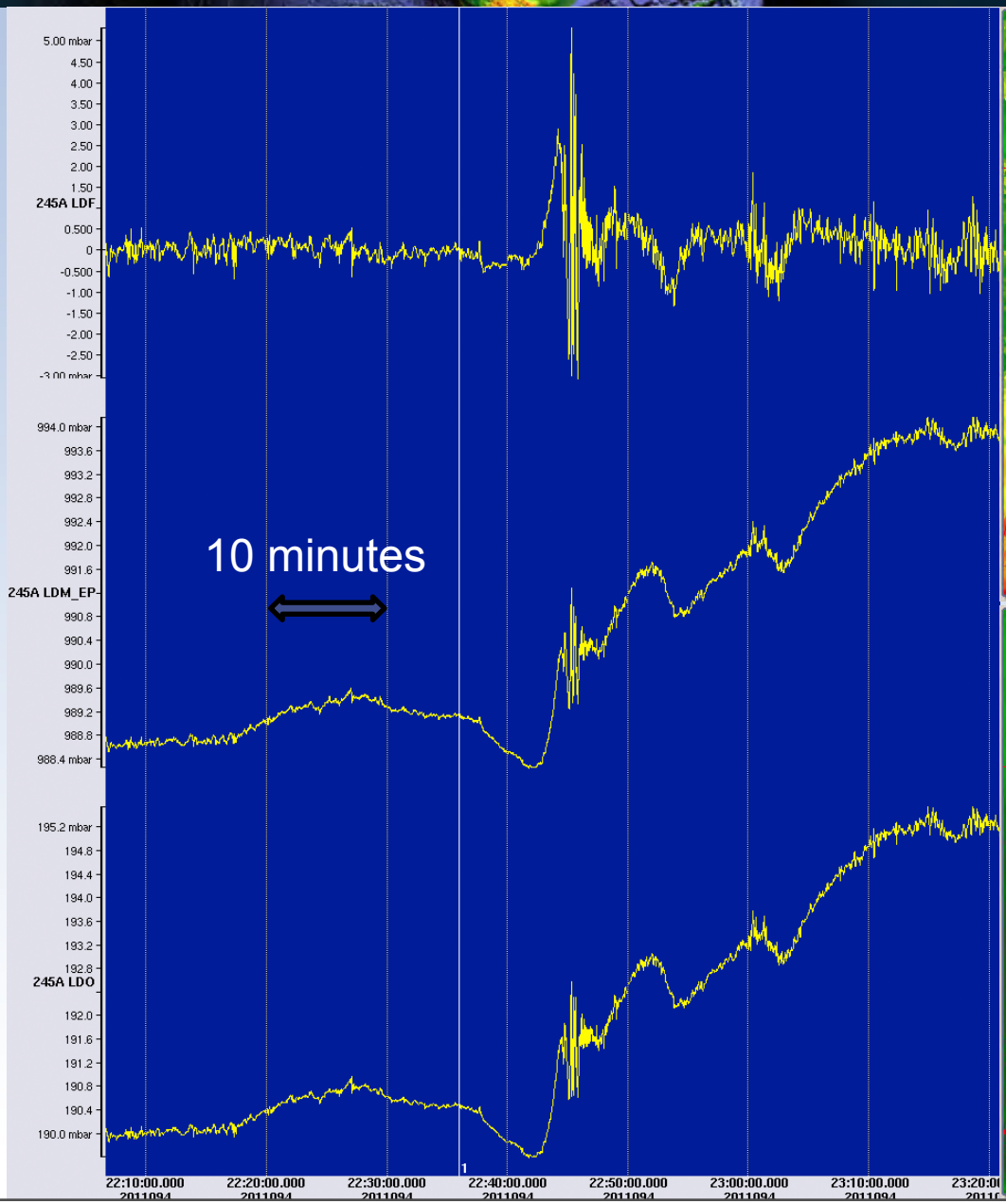
Tornado Prevalence

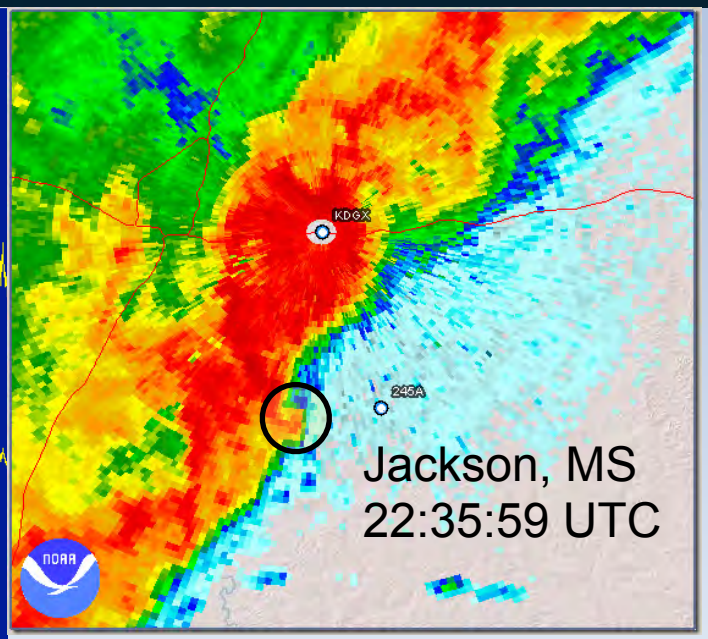


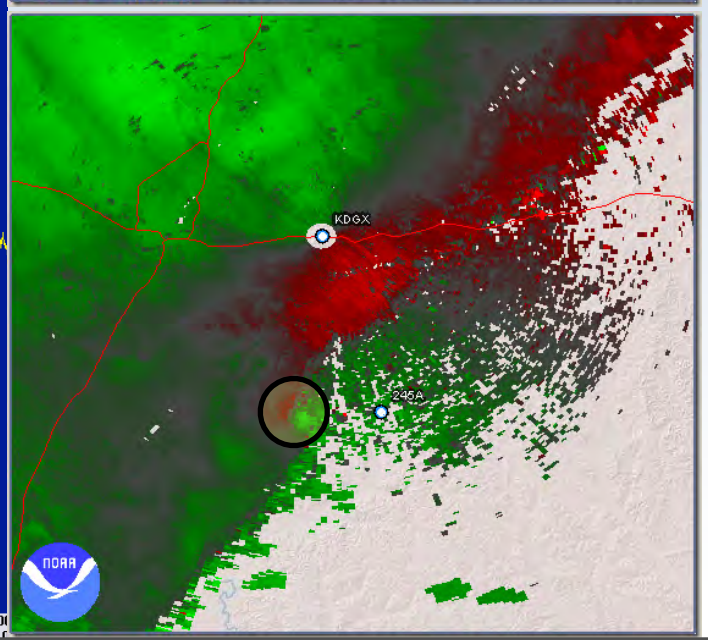
Wednesday, May 29, 13

Jackson Tornado on 4/15/2011 – 245A

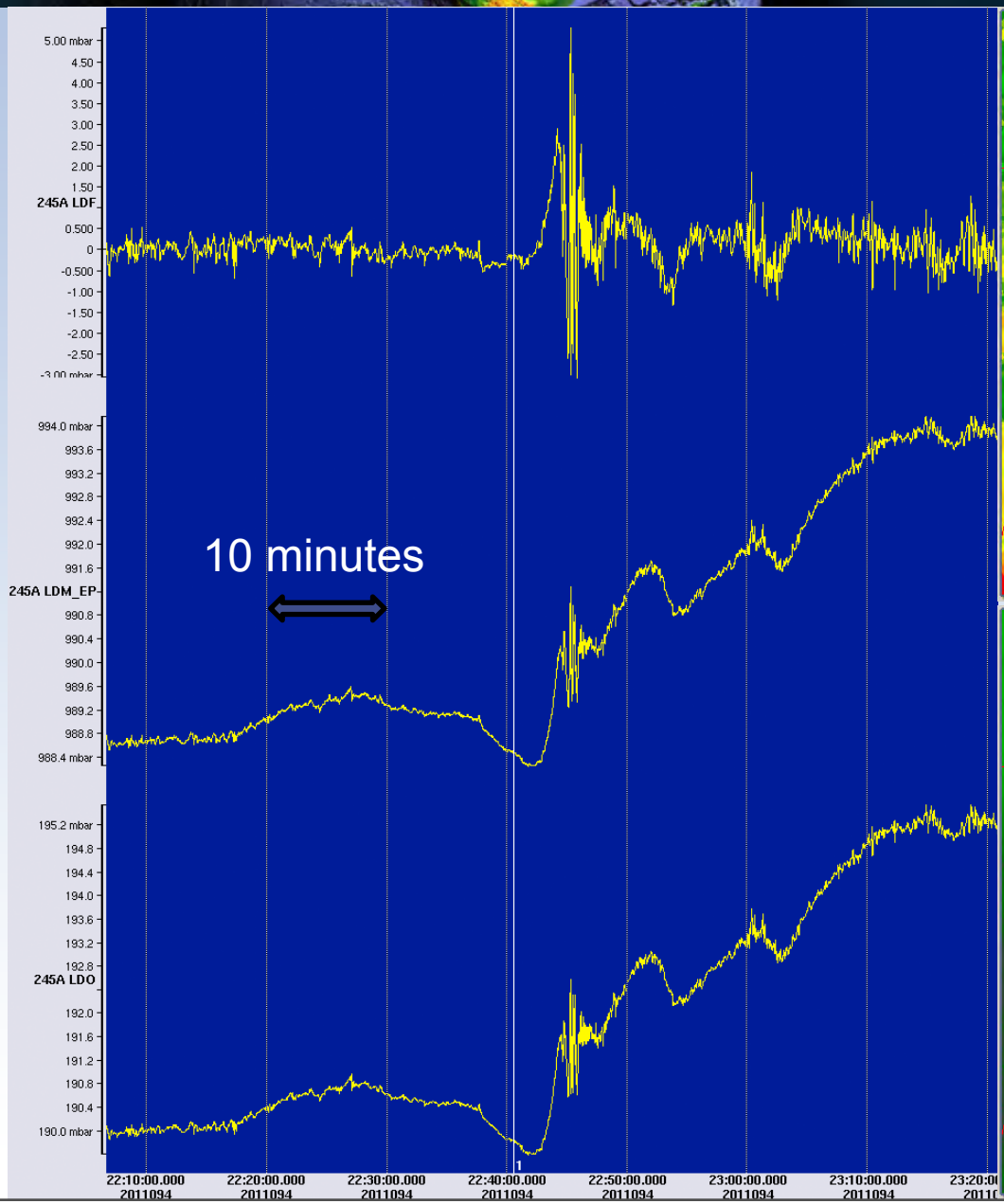
Jackson Tornado on 4/15/2011 – 245A

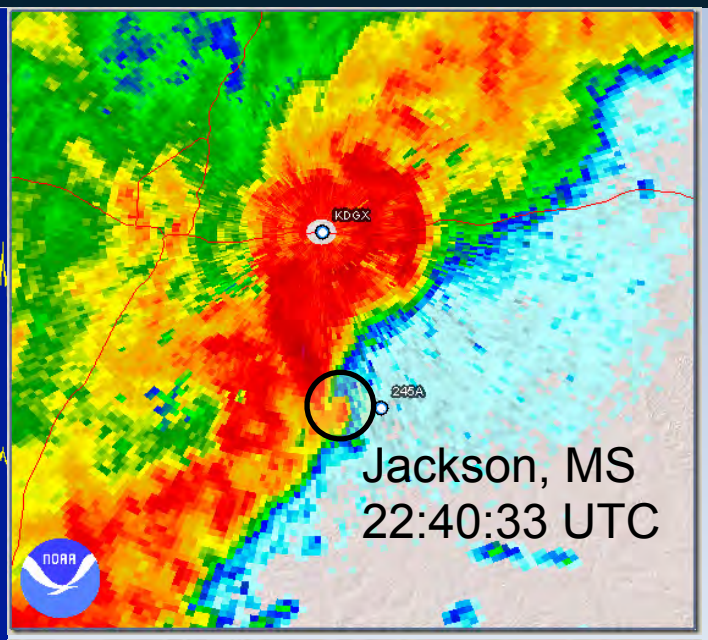


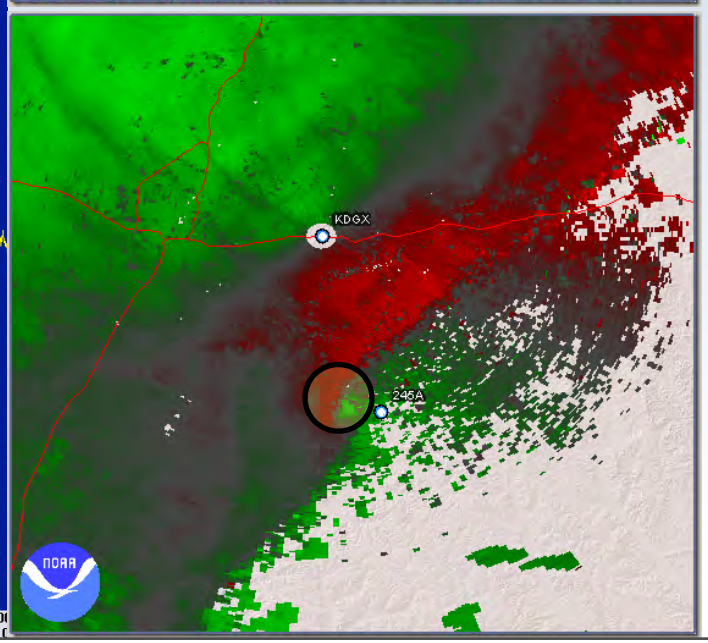




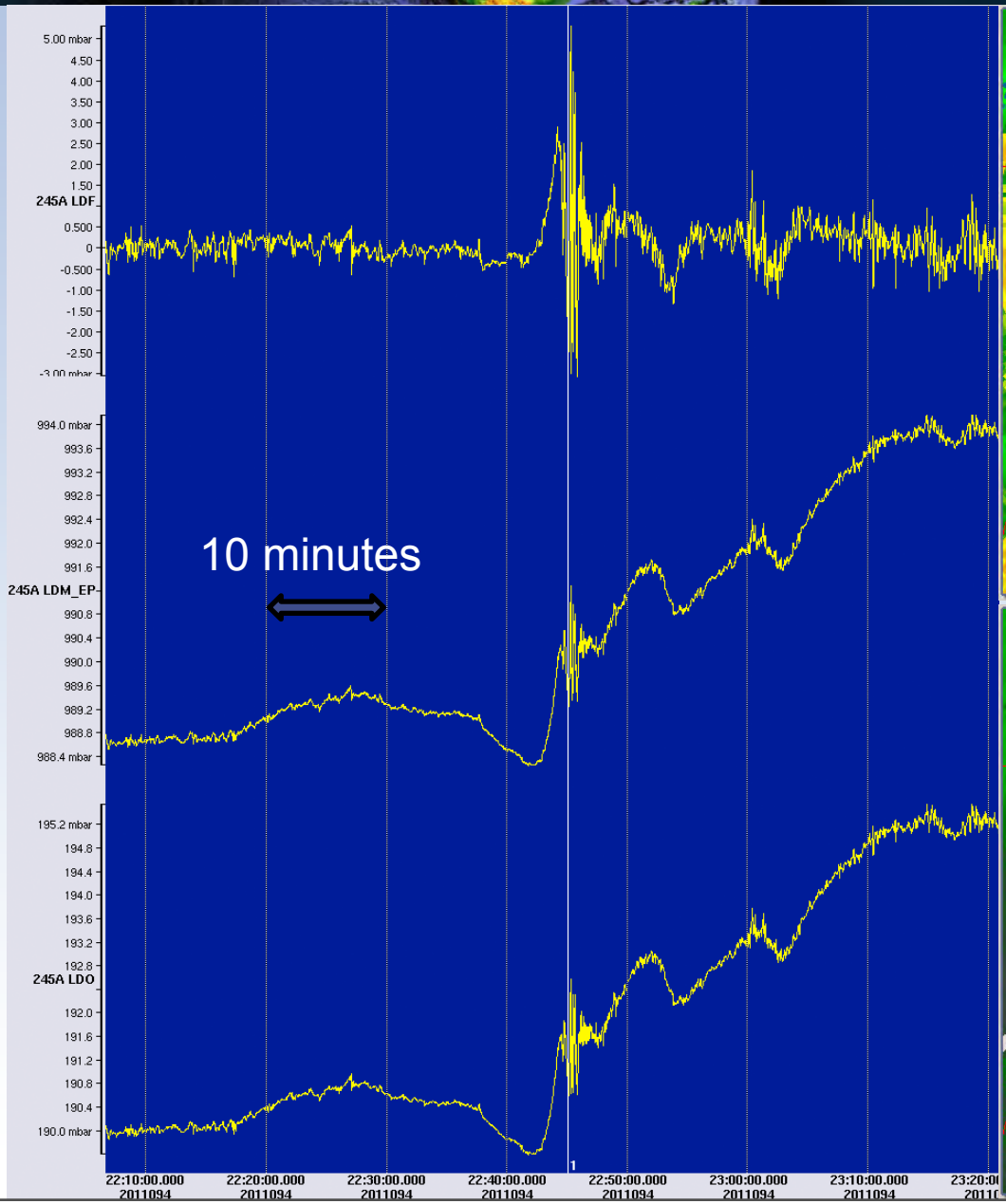
Jackson Tornado on 4/15/2011 – 245A

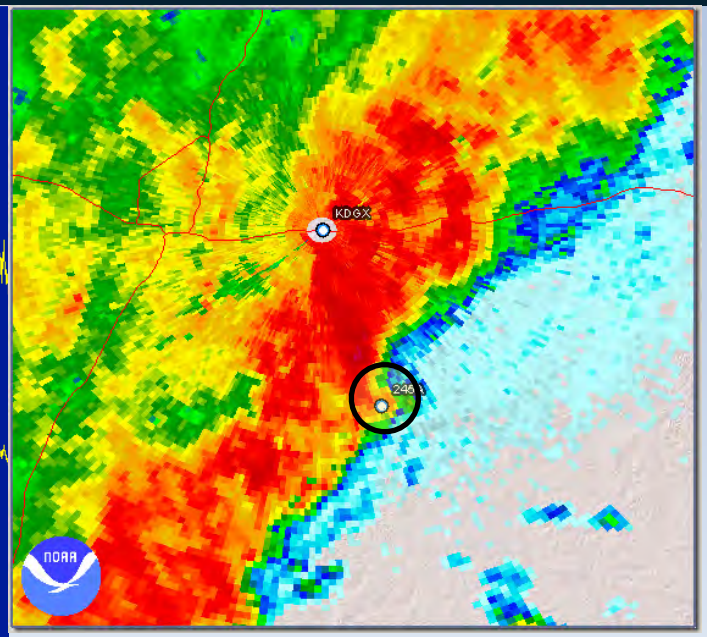


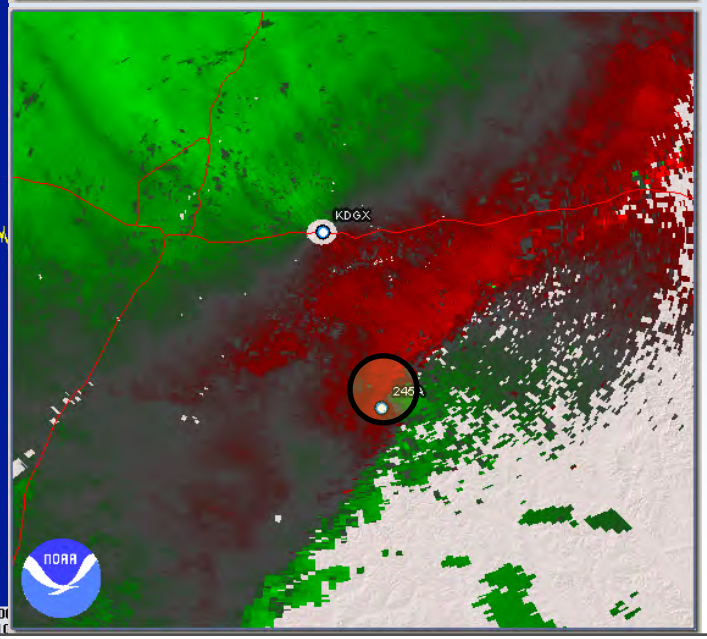




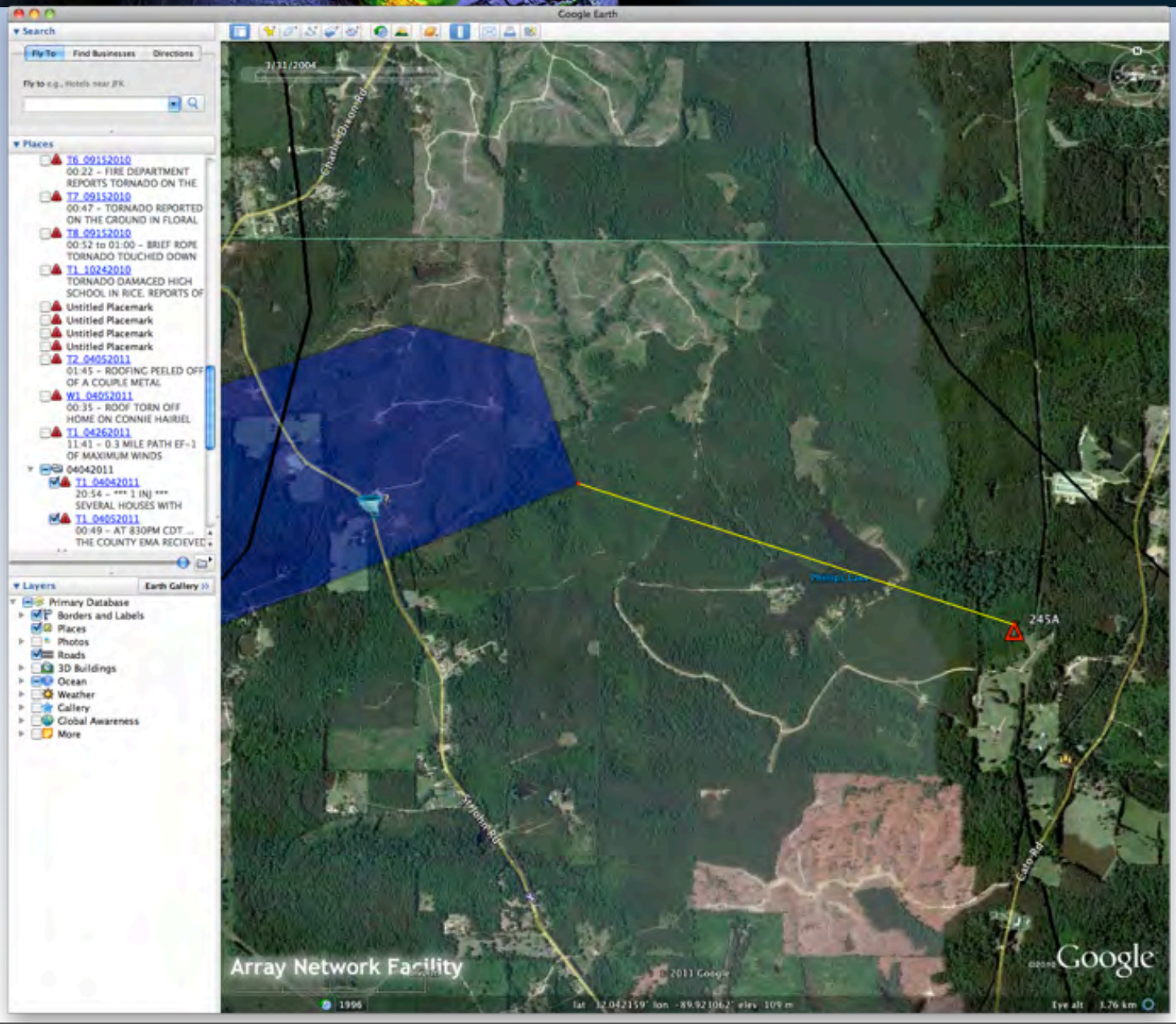
Jackson Tornado on 4/15/2011 – 245A



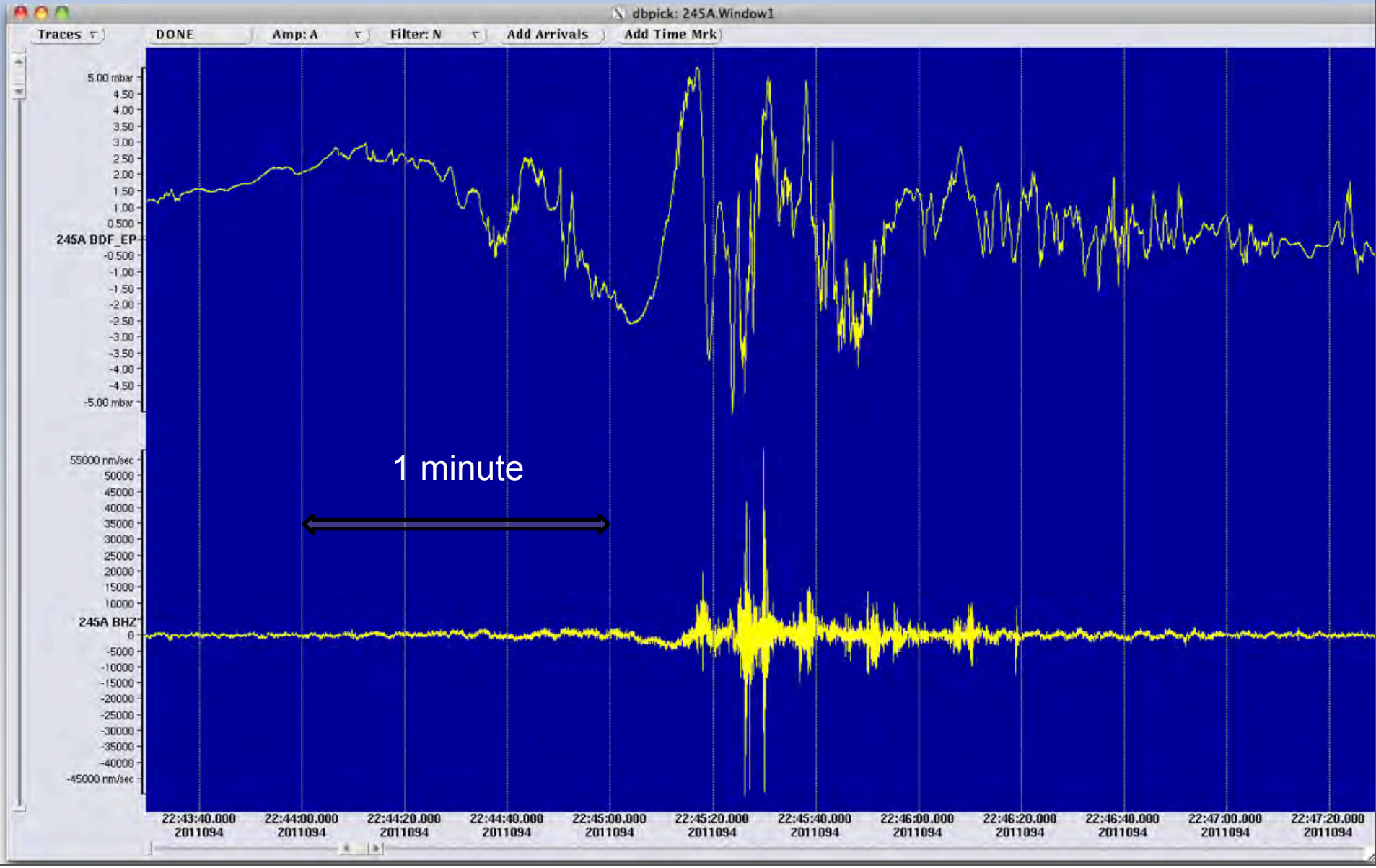




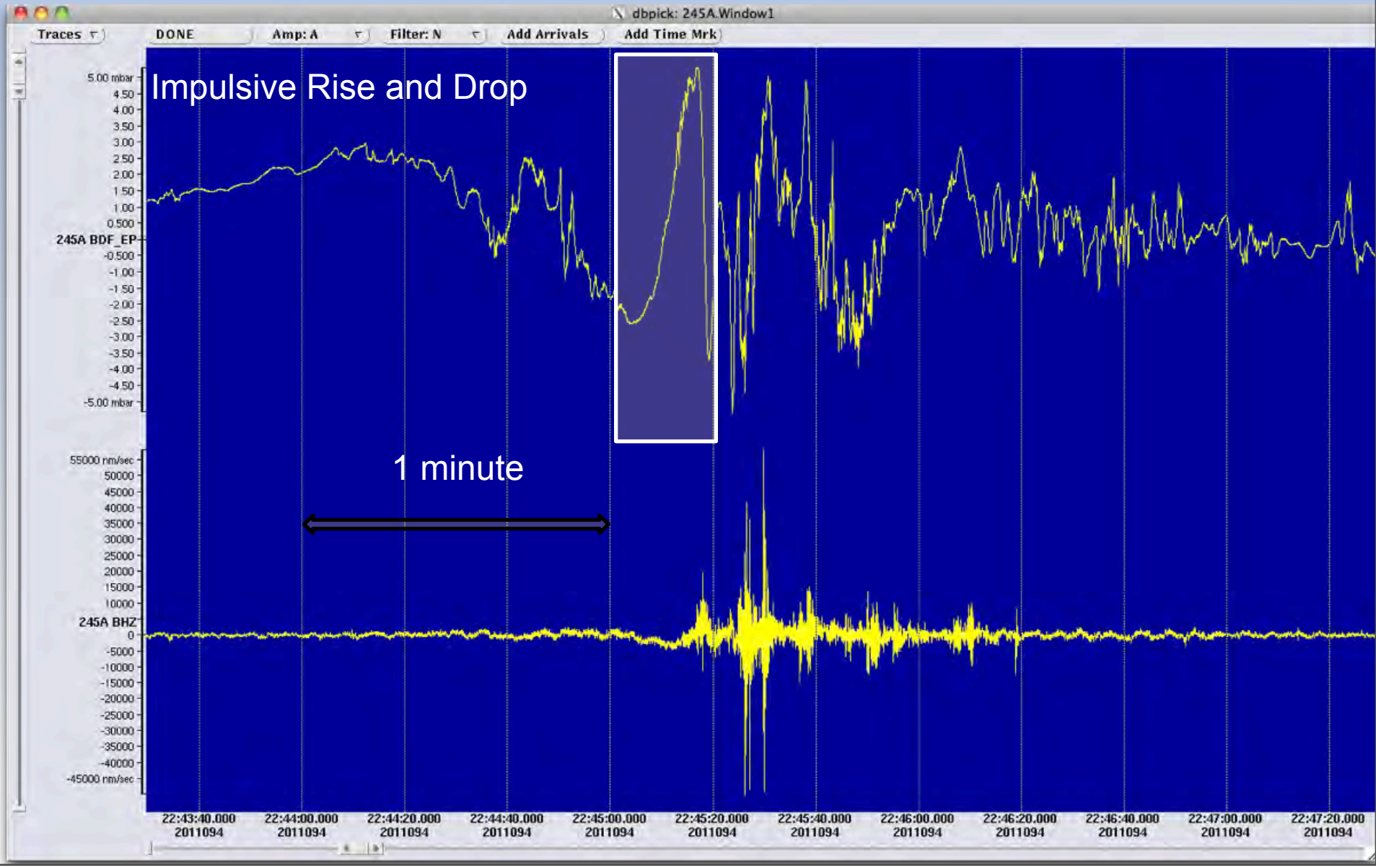
Jackson Tornado on 4/15/2011 – 245A



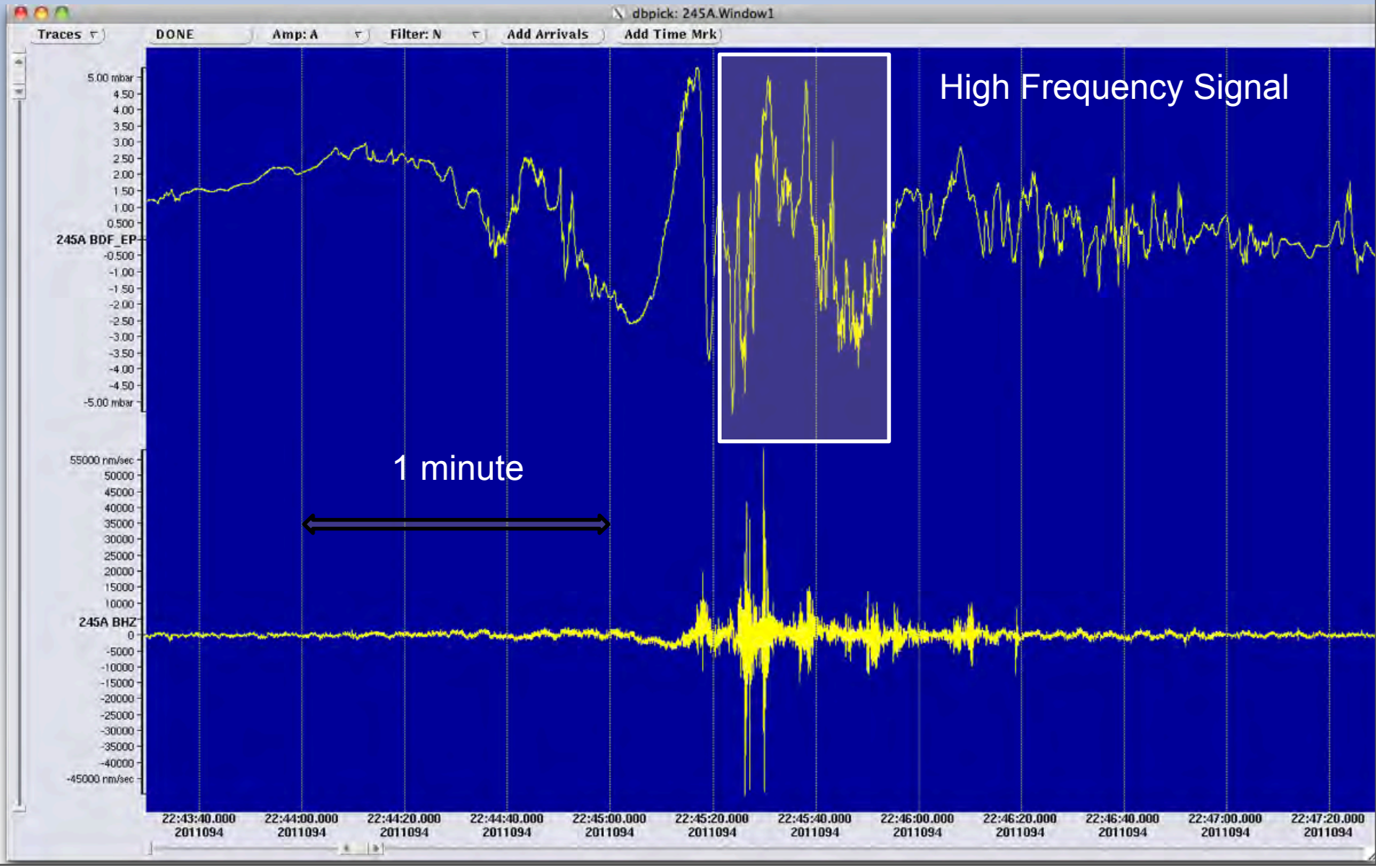
Jackson Tornado on 4/15/2011 – 245A



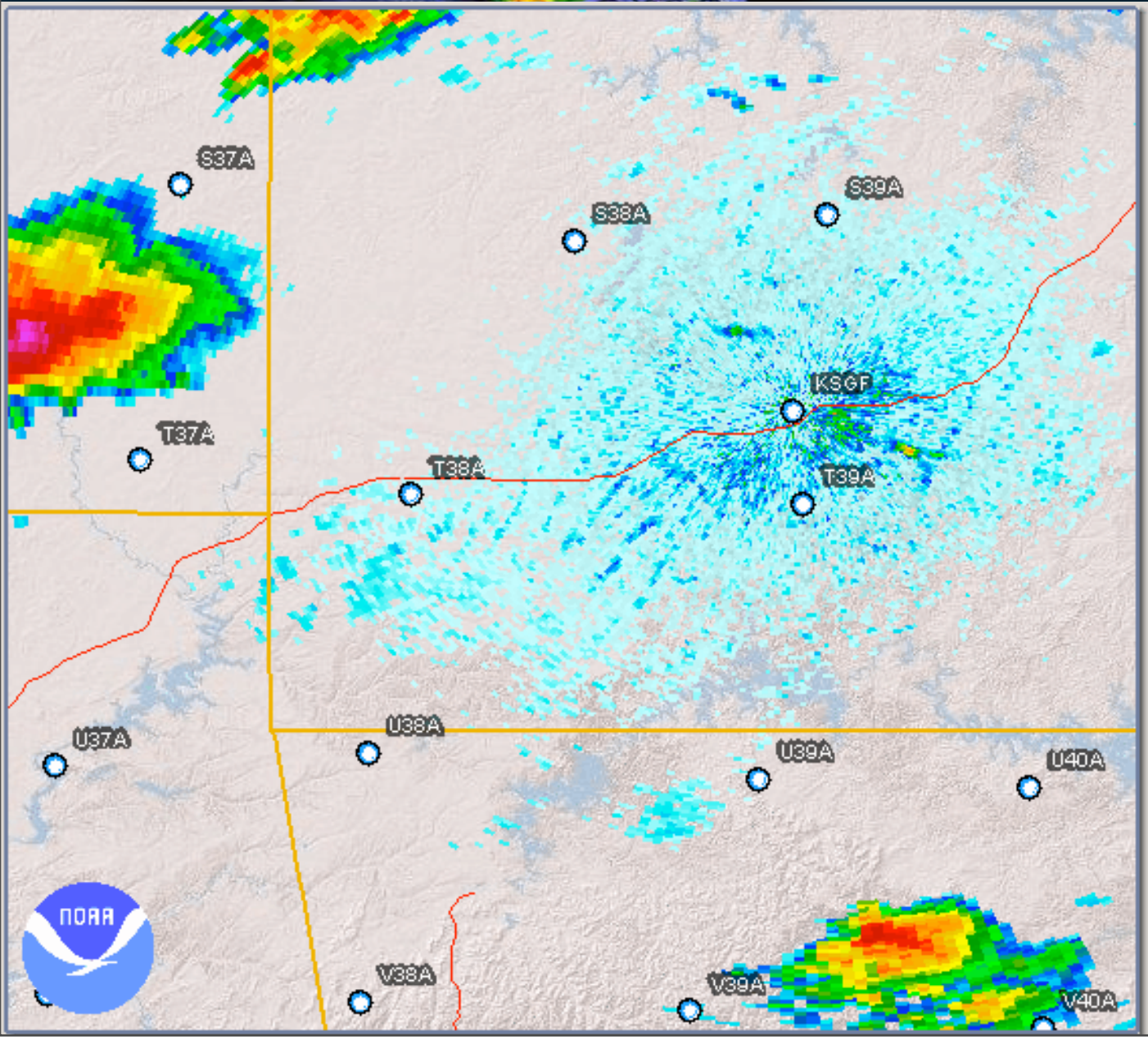
Jackson Tornado on 4/15/2011 – 245A



Jackson Tornado on 4/15/2011 – 245A



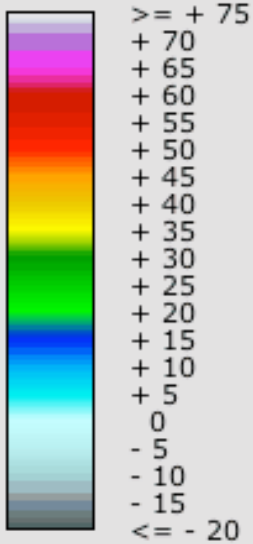
Joplin Tornado 5/22/2011 – T38A



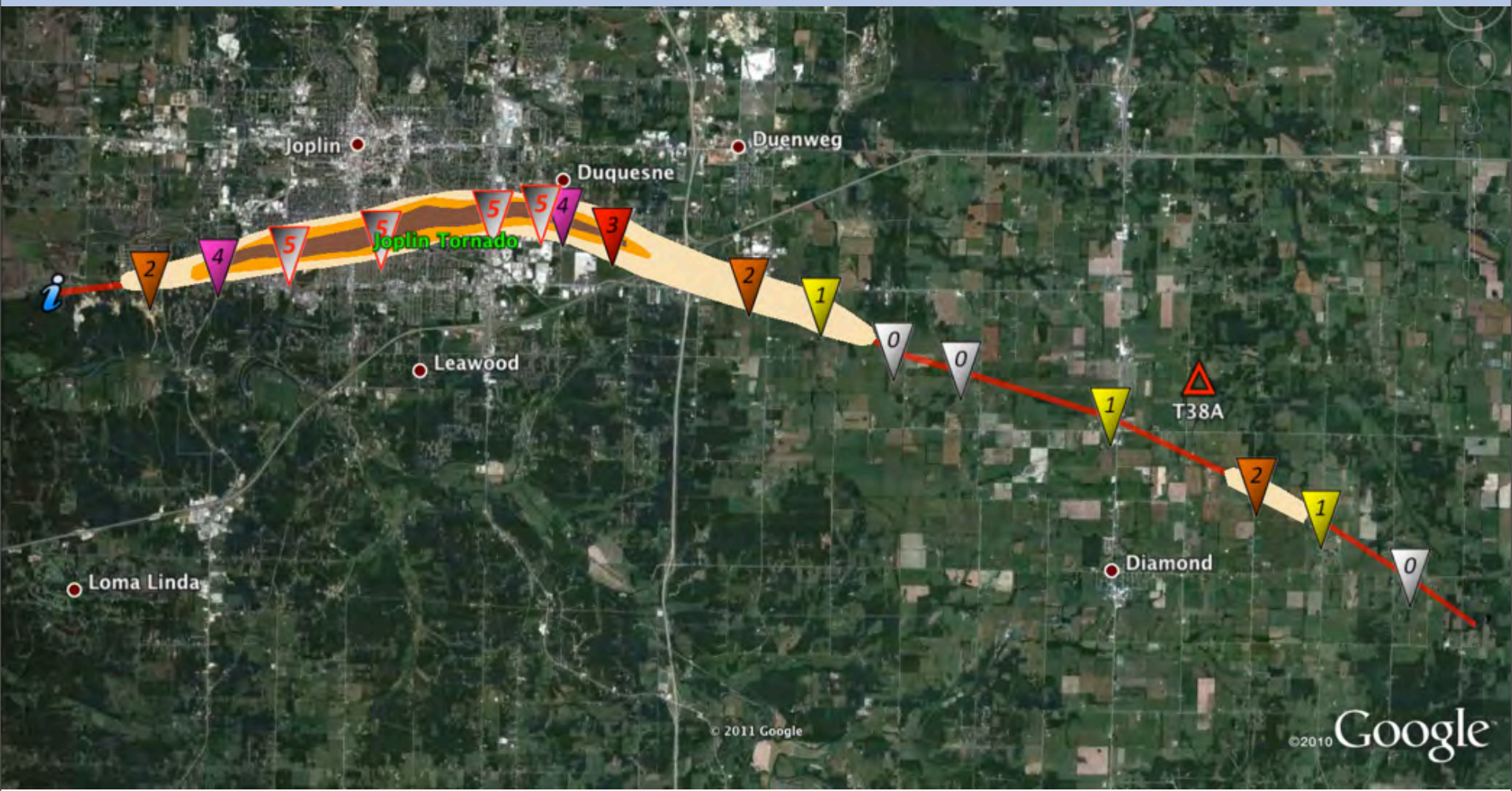
NEXRAD LEVEL-III
BASE REFLECTIVITY
KSGF - SPRINGFIELD, MO
05/22/2011 21:02:17 GMT
LAT: 37/14/05 N
LON: 93/24/00 W
ELEV: 1375 FT
MODE/VCP: A / 211

ELEV ANGLE: 0.50 °
MAX: 66 DBZ
RANGE: 248 NM

Legend: dBZ

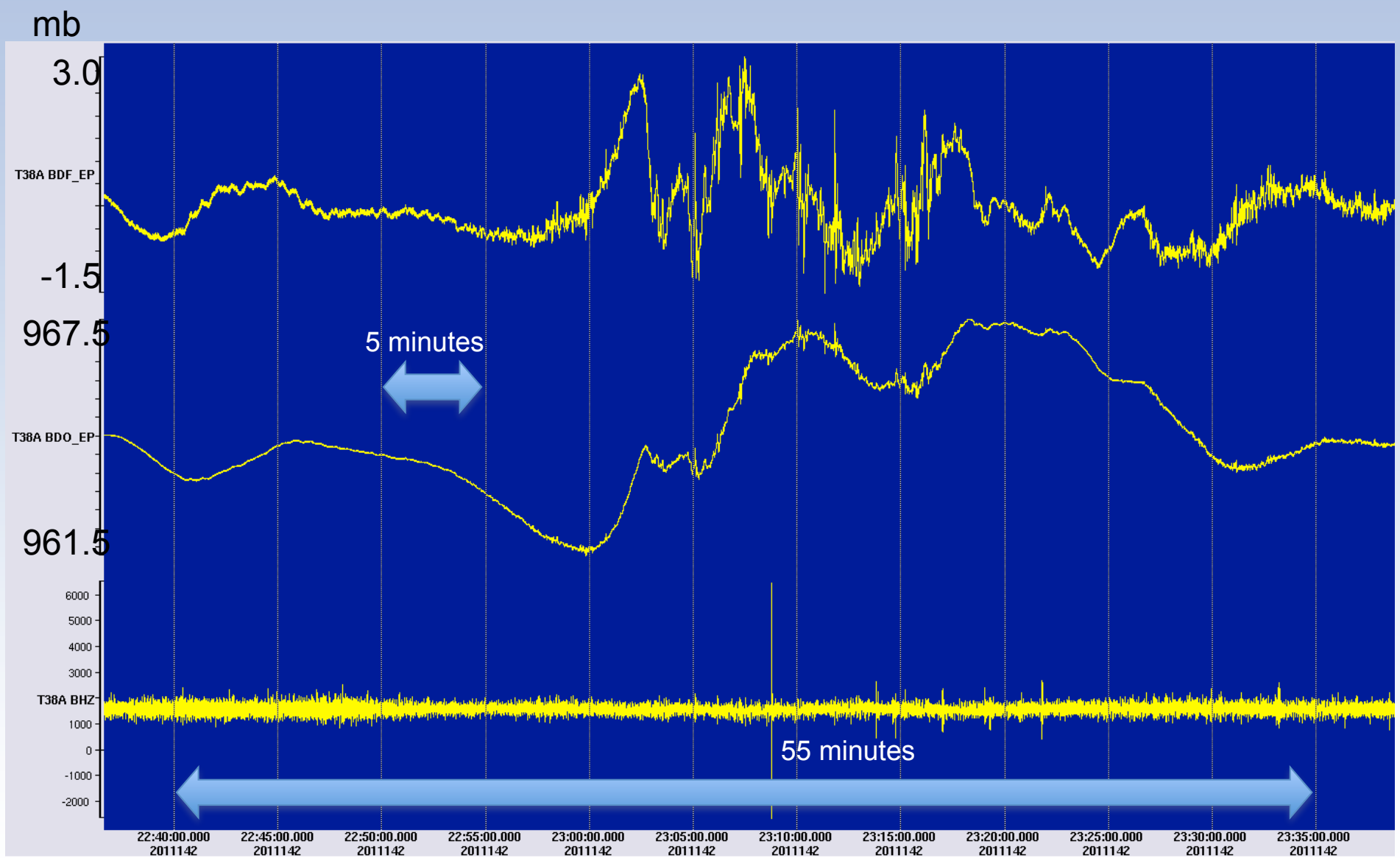


Joplin Tornado 5/22/2011 – T38A

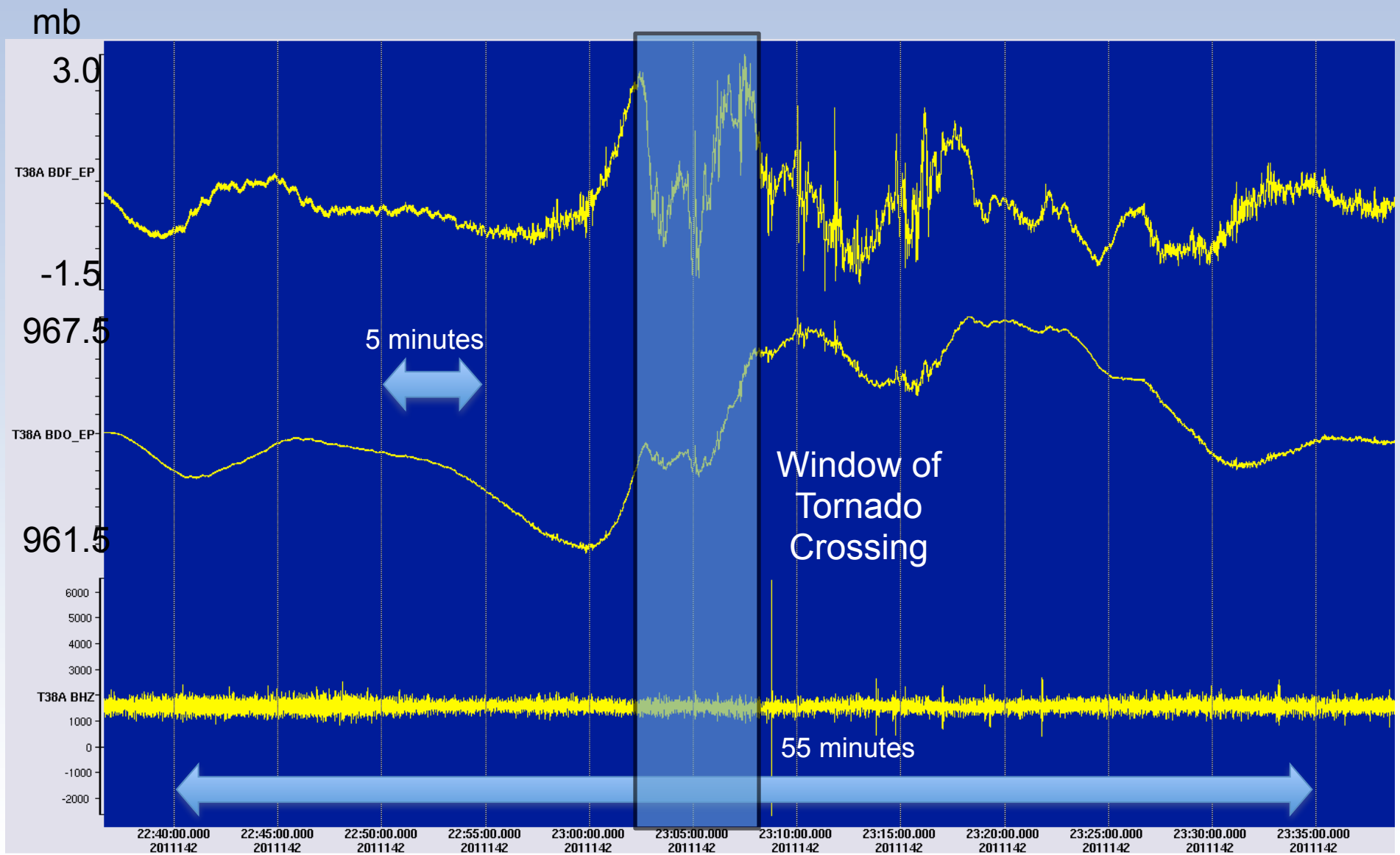


Joplin Tornado 5/22/2011 – T38A

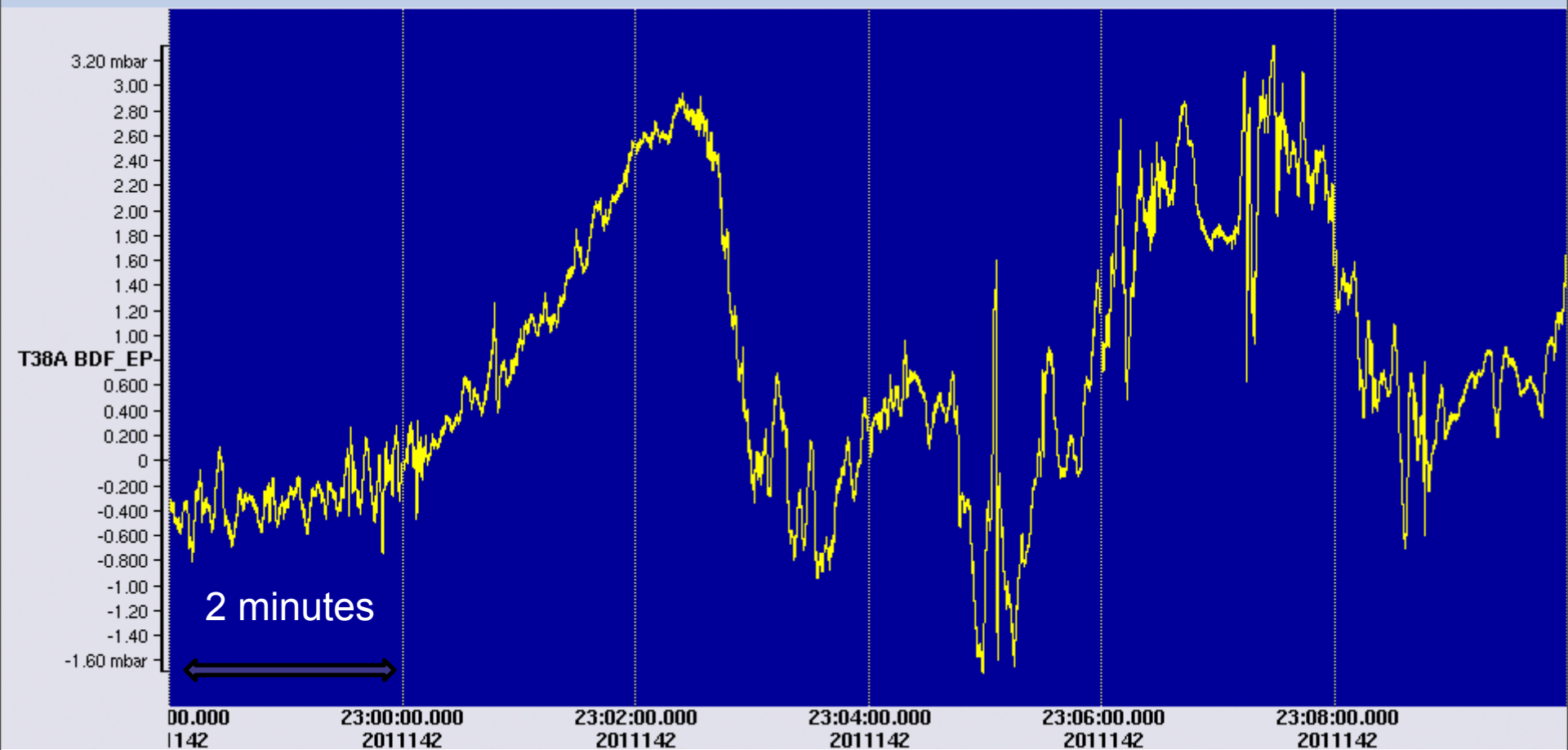
Joplin Tornado 5/22/2011 – T38A



Joplin Tornado 5/22/2011 – T38A

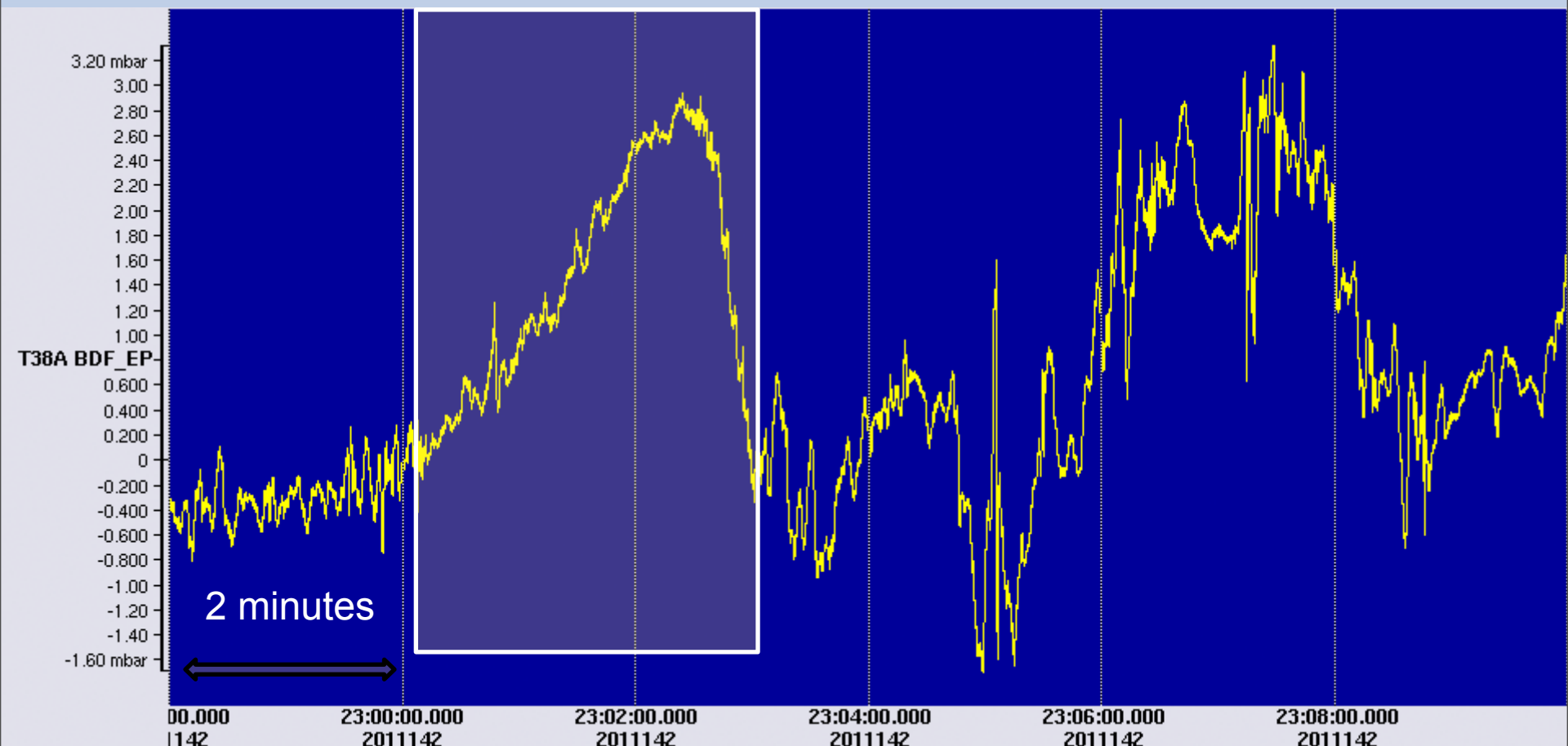


Joplin Tornado 5/22/2011 – T38A



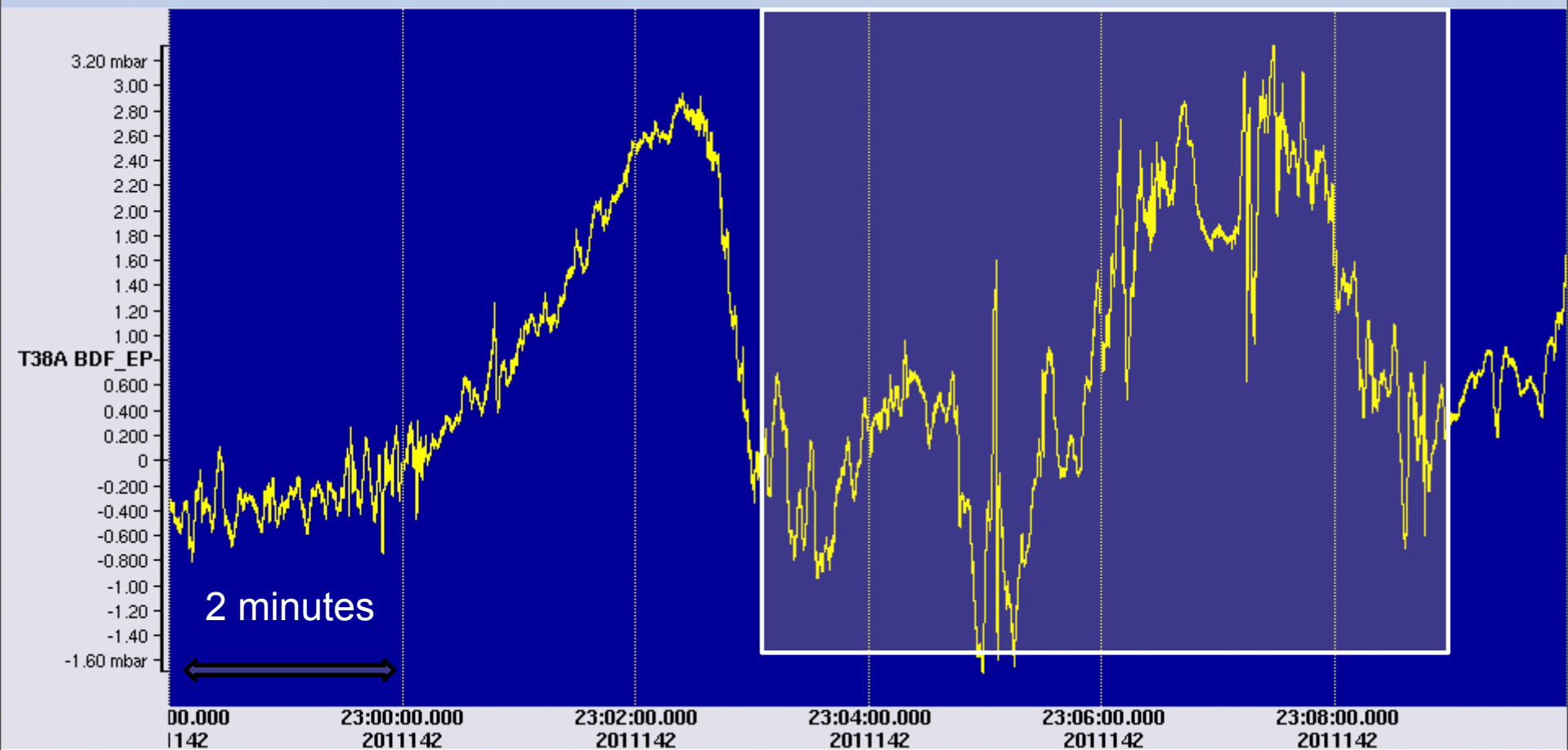
Joplin Tornado 5/22/2011 – T38A

Impulsive Rise and Drop

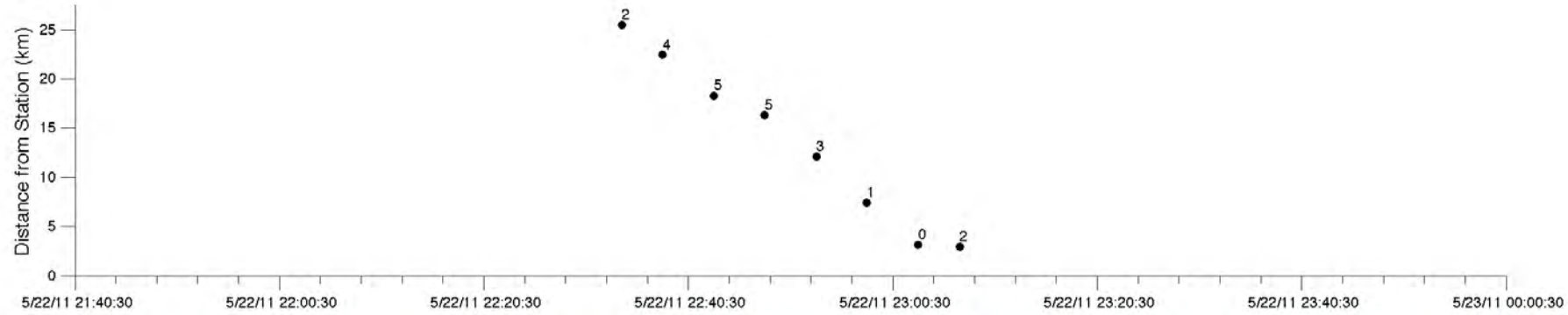


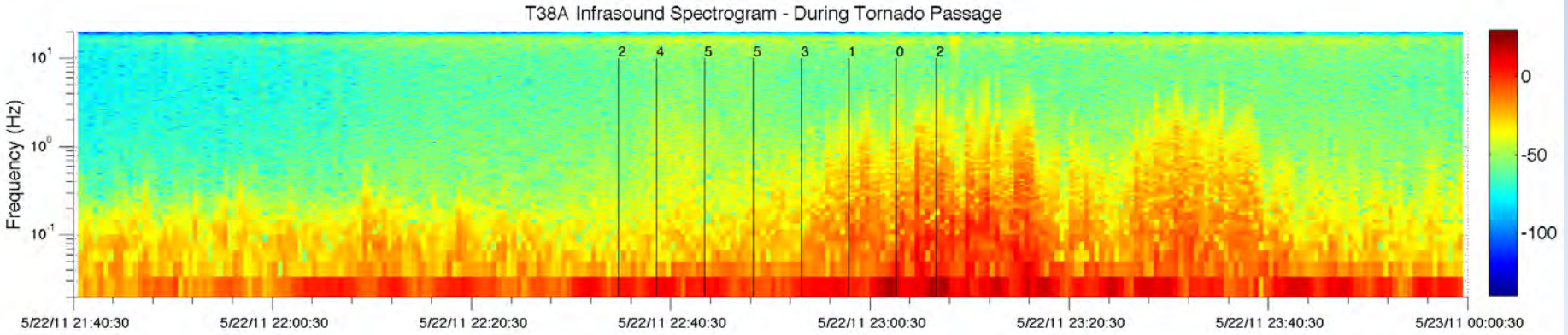
Joplin Tornado 5/22/2011 – T38A

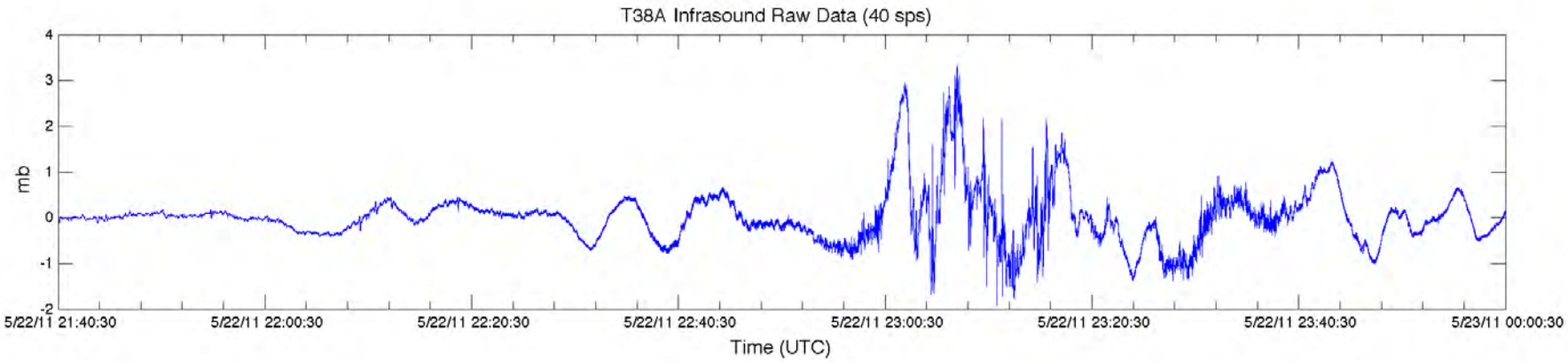
High Frequency Signal



Joplin Tornado 5/22/2011 – T38A

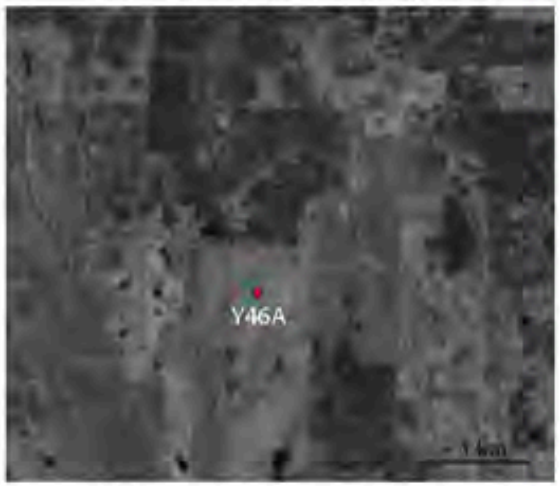




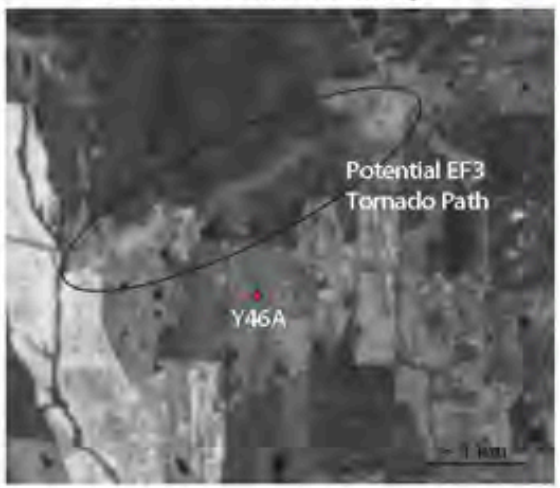


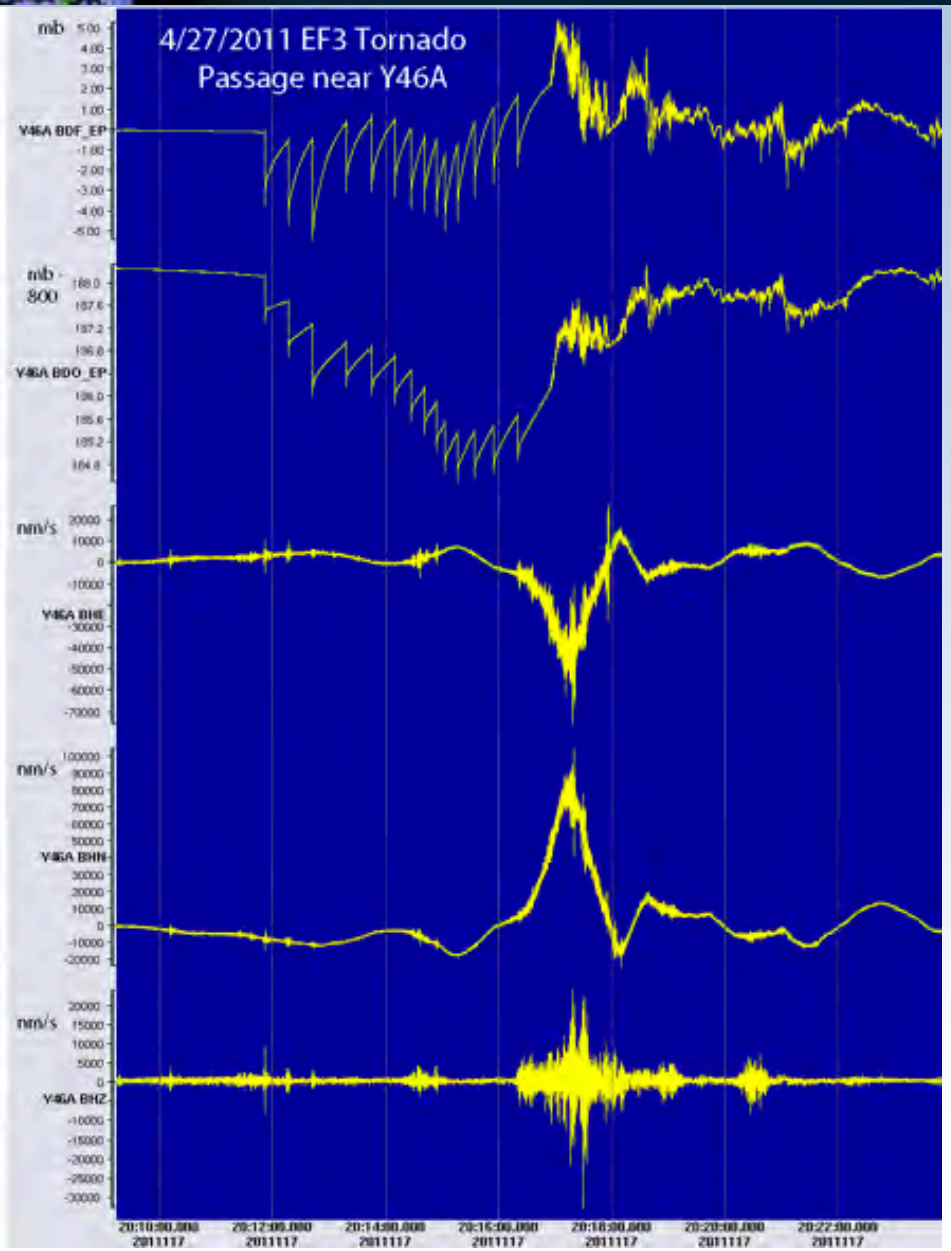
Oklahoma Tornado on 4/27/2011 – Y46A

3/16/2011 LandSat Image

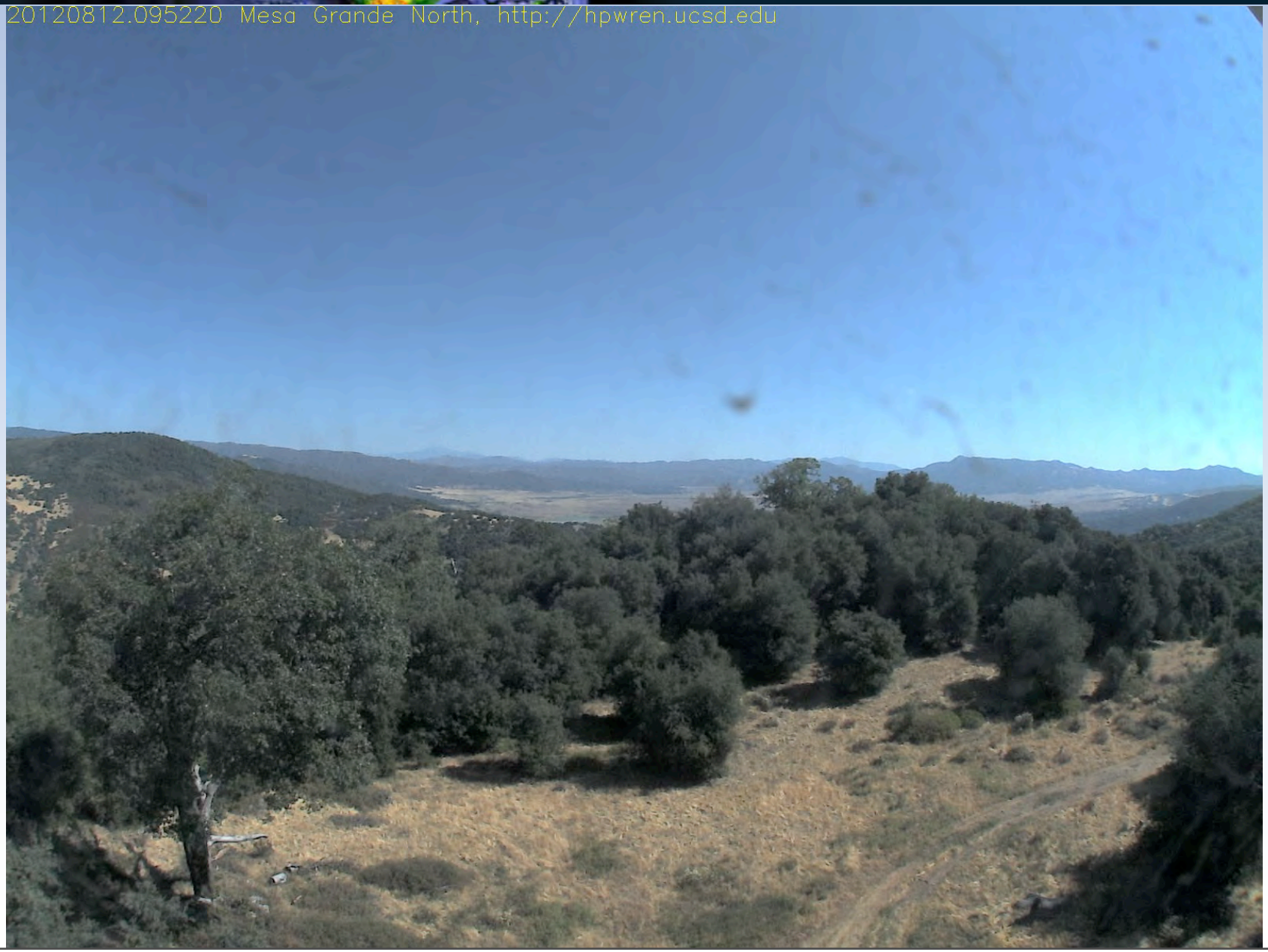


5/19/2011 LandSat Image



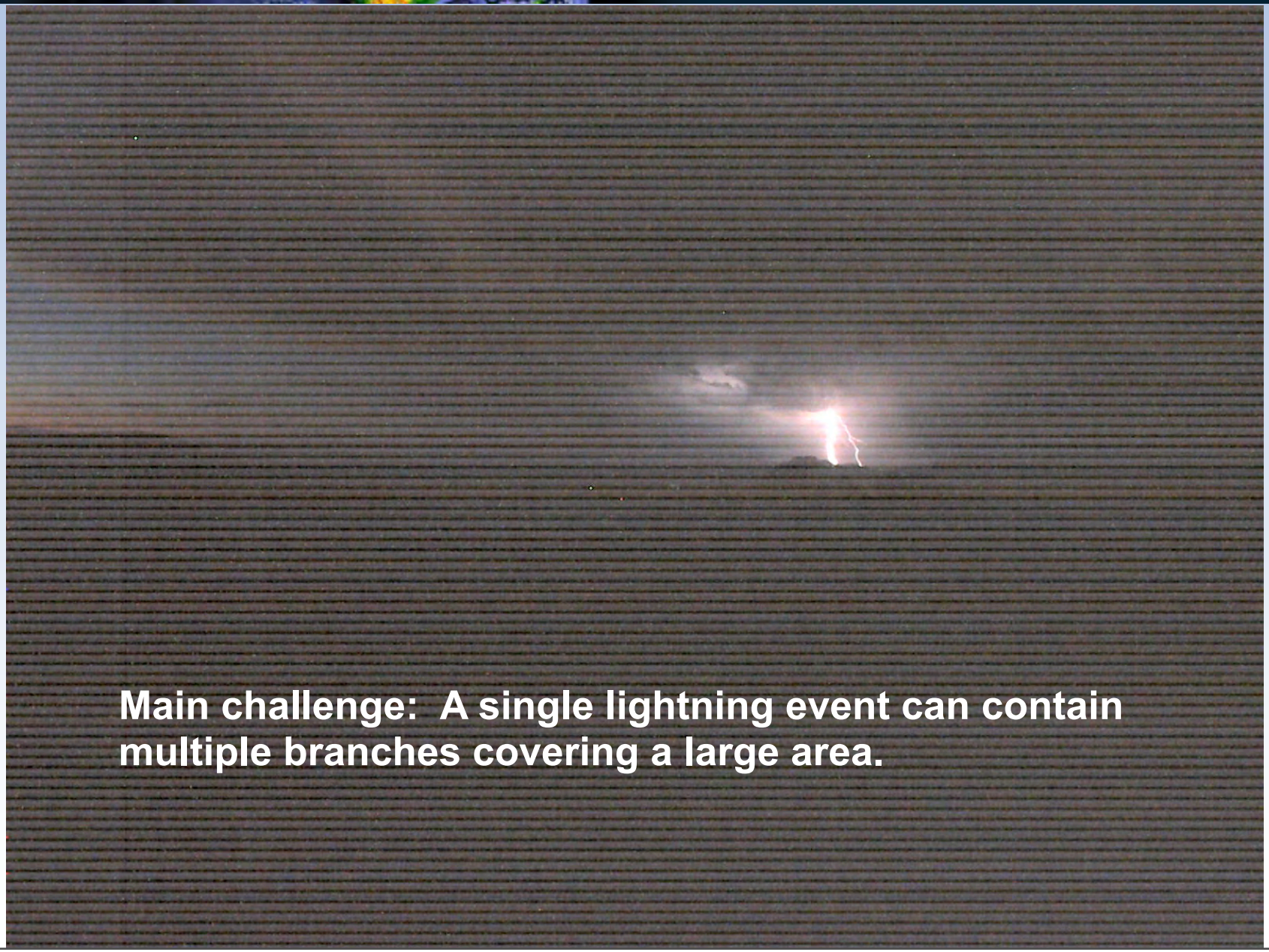


Mesa Grande View



Mesa Grande View

HPWREN Photo

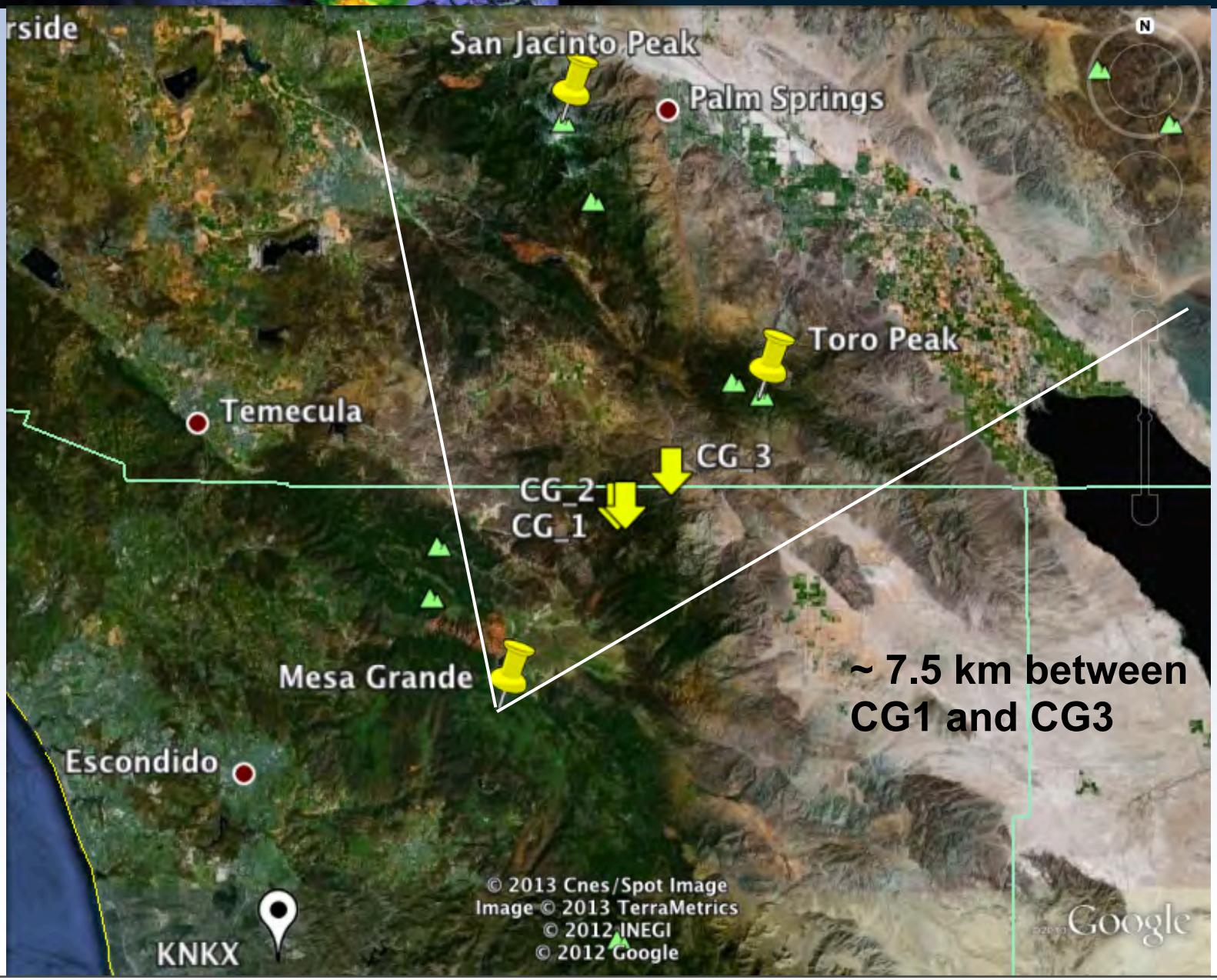


Data Integration

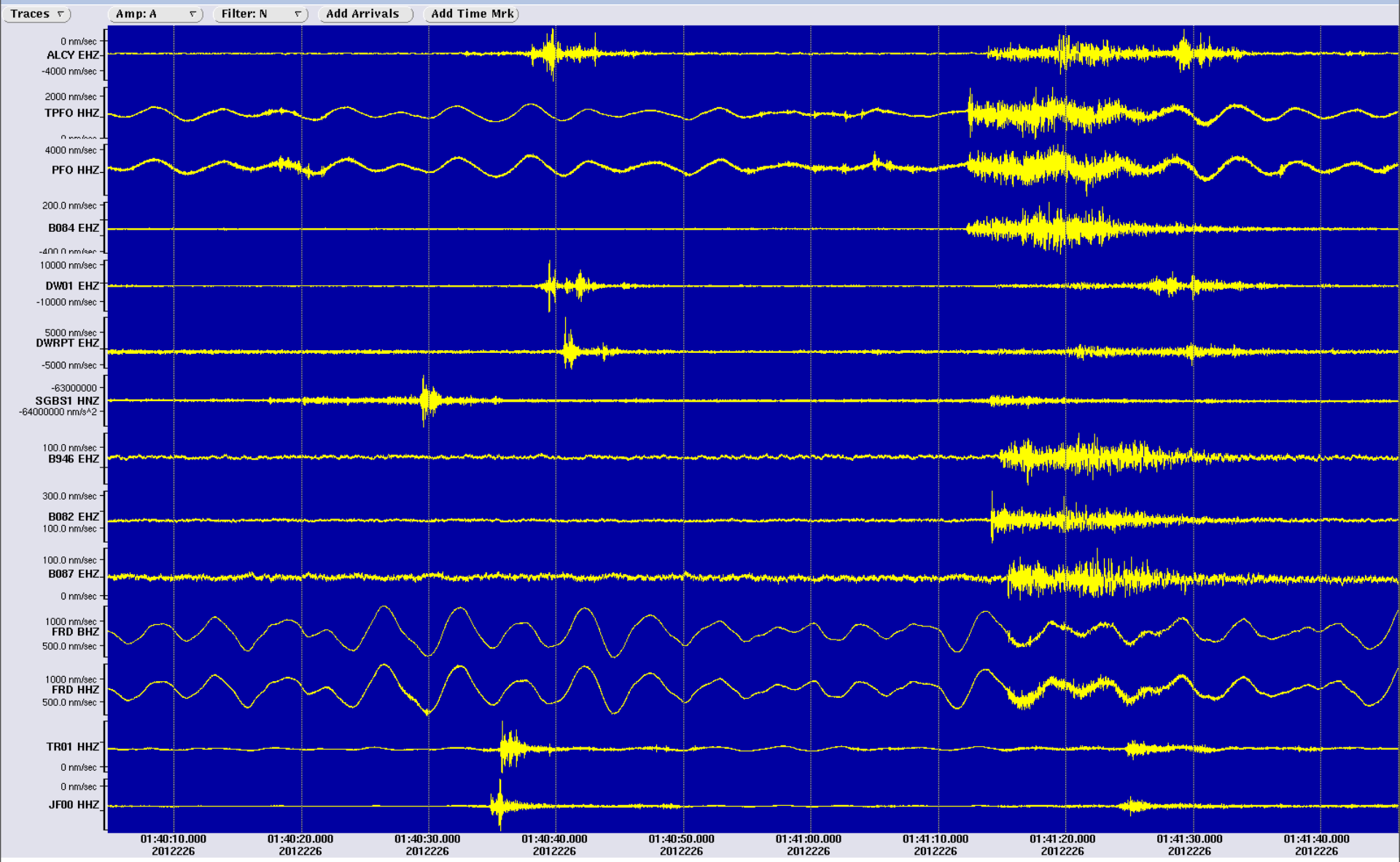
- **The ANF is collaborating with Earth Networks and their Total Lightning Network (ENTLN) in order to identify thunder noise in our seismic data.**

  All lightning locations shown are from the ENTLN

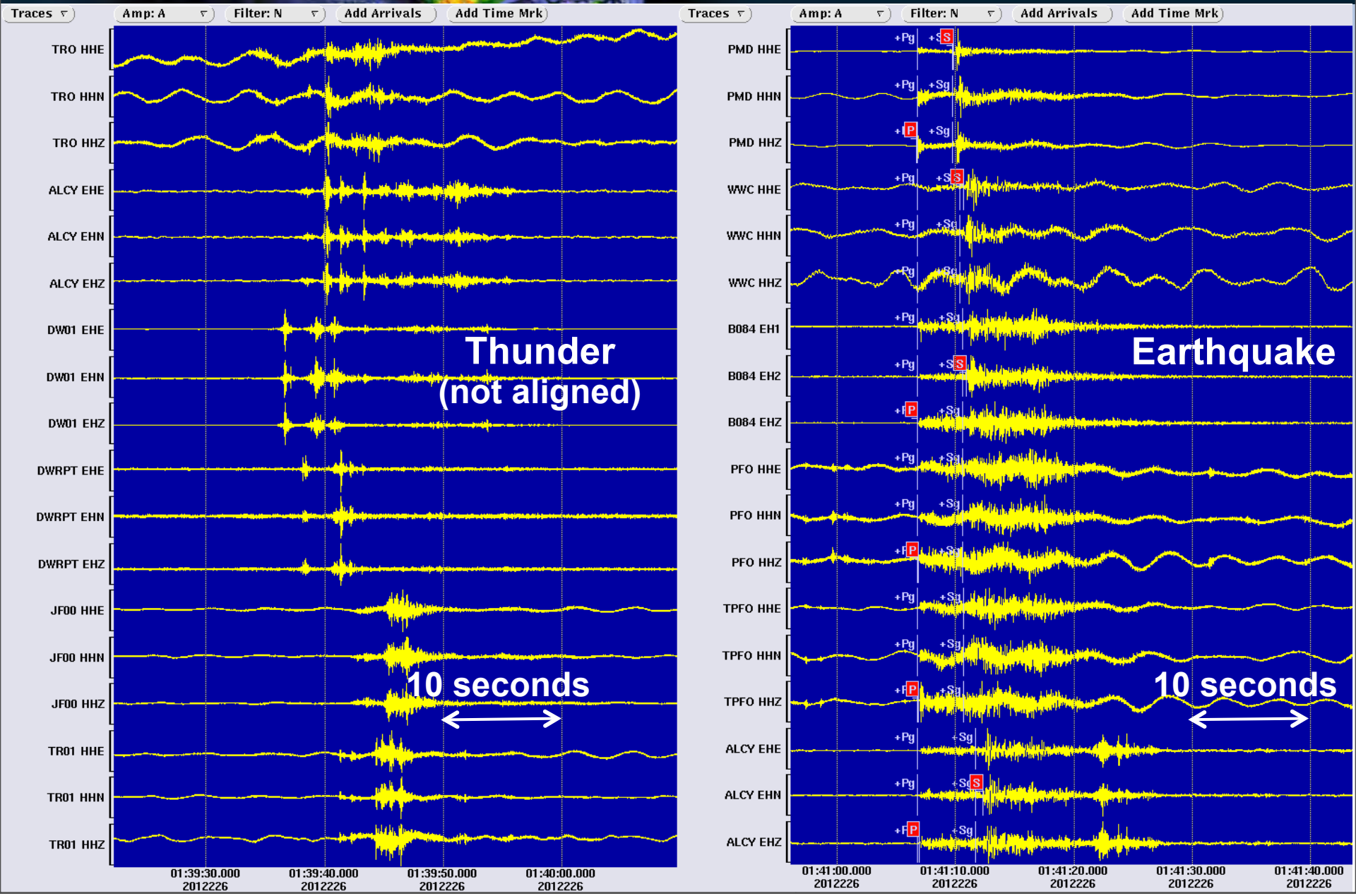
Mesa Grande Lightning



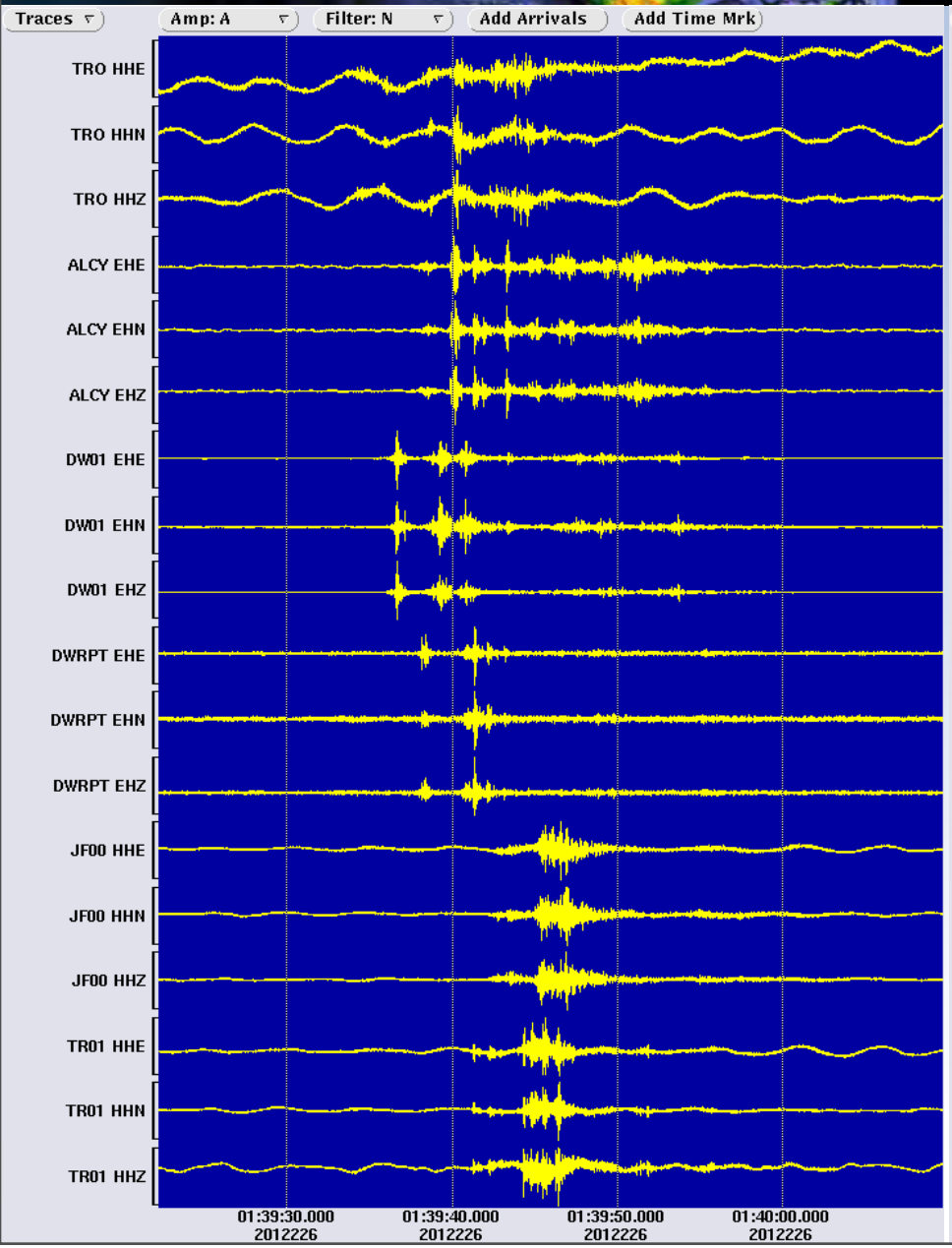
Seismic Data

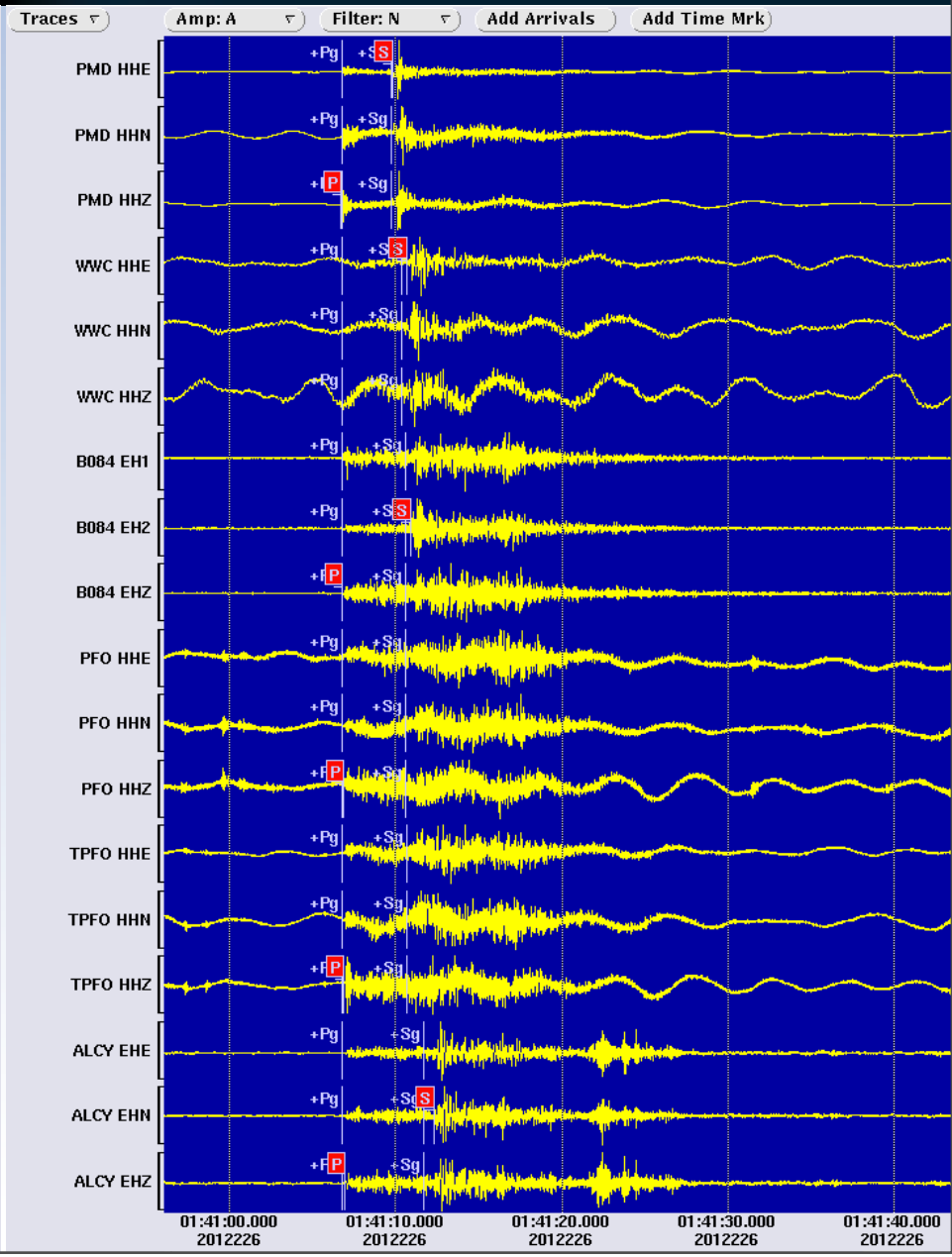


Earthquake & Thunder

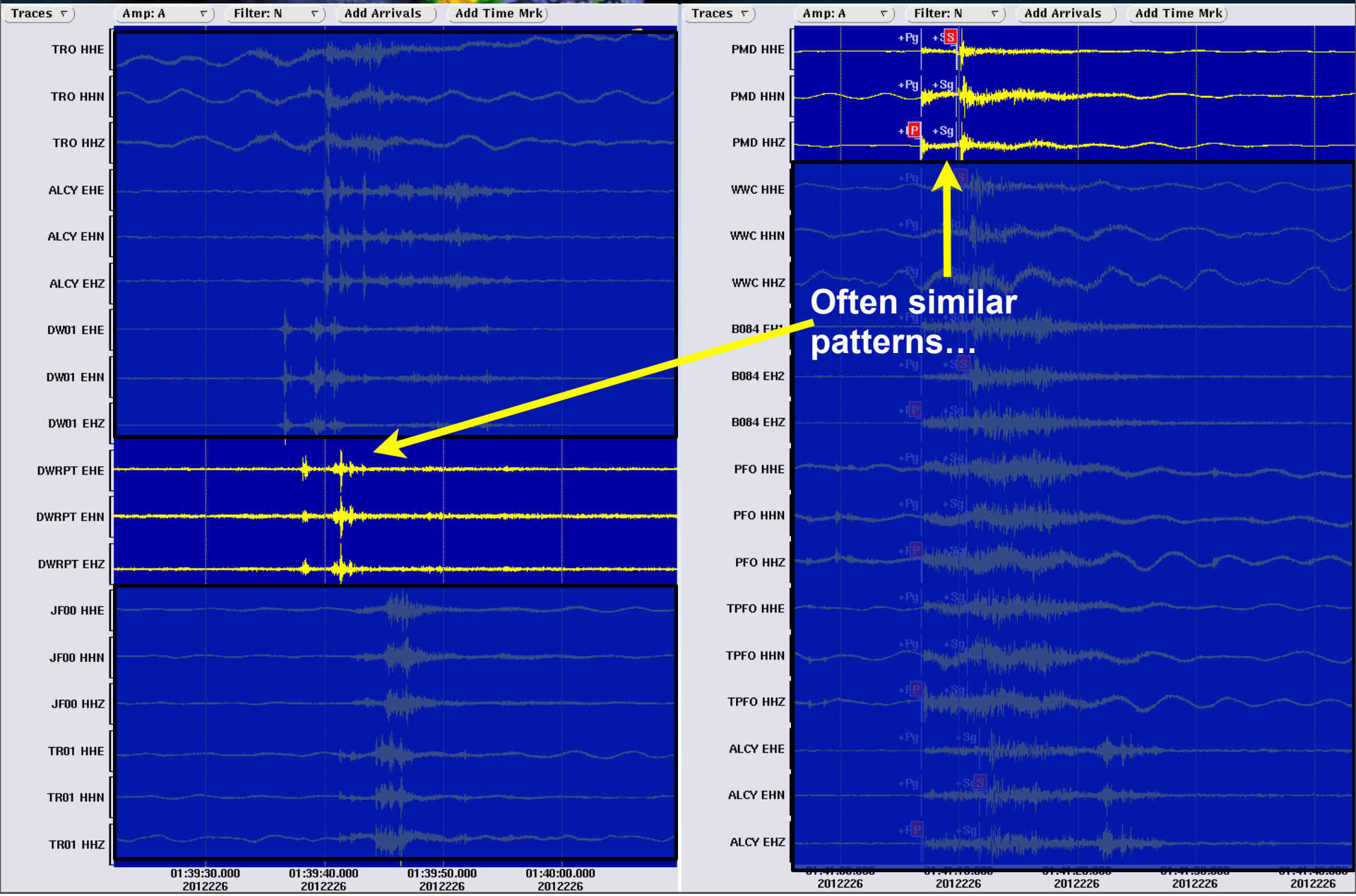


Earthquake & Thunder

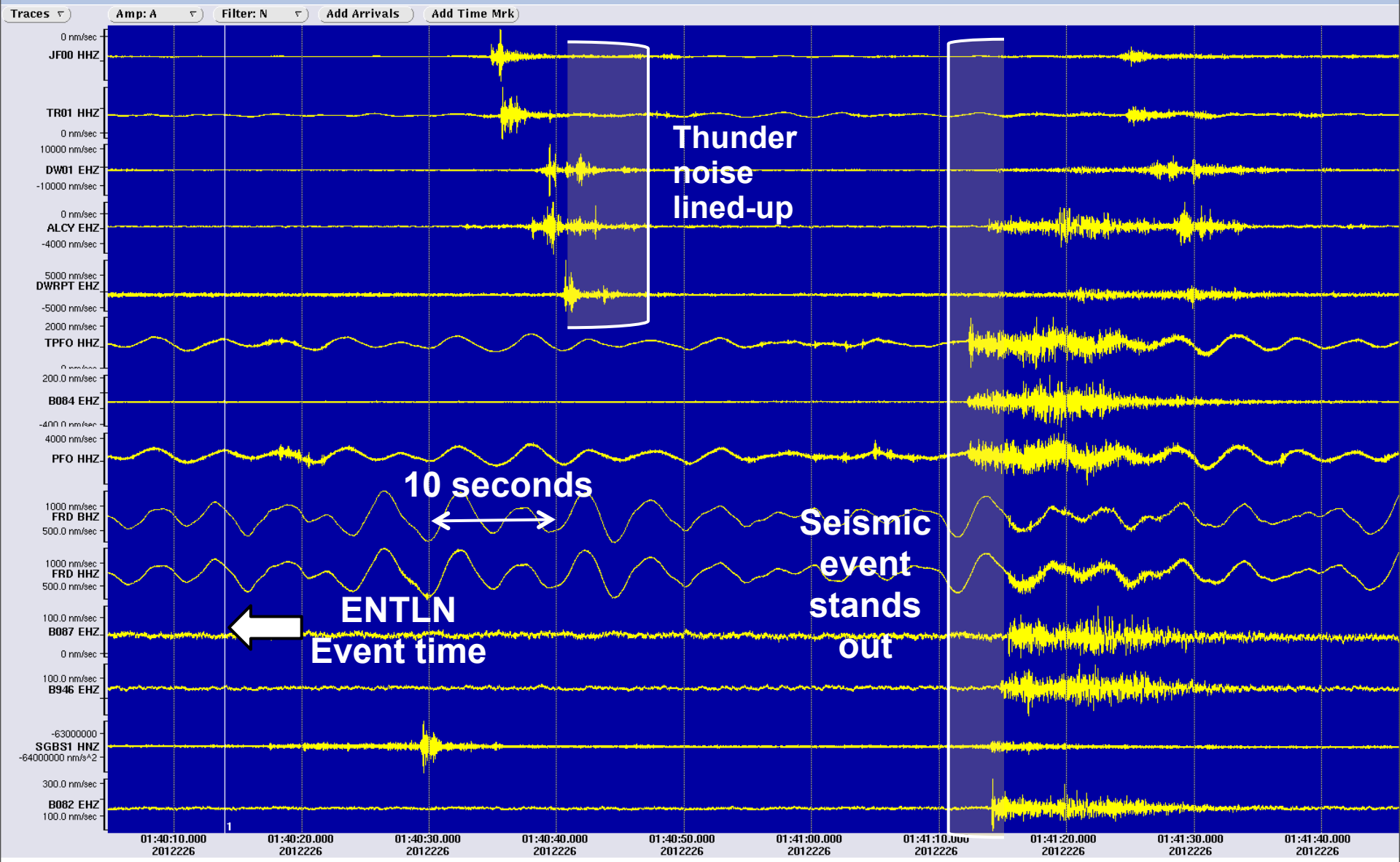




Earthquake & Thunder



Earthquake & Thunder



Ground Truth Example

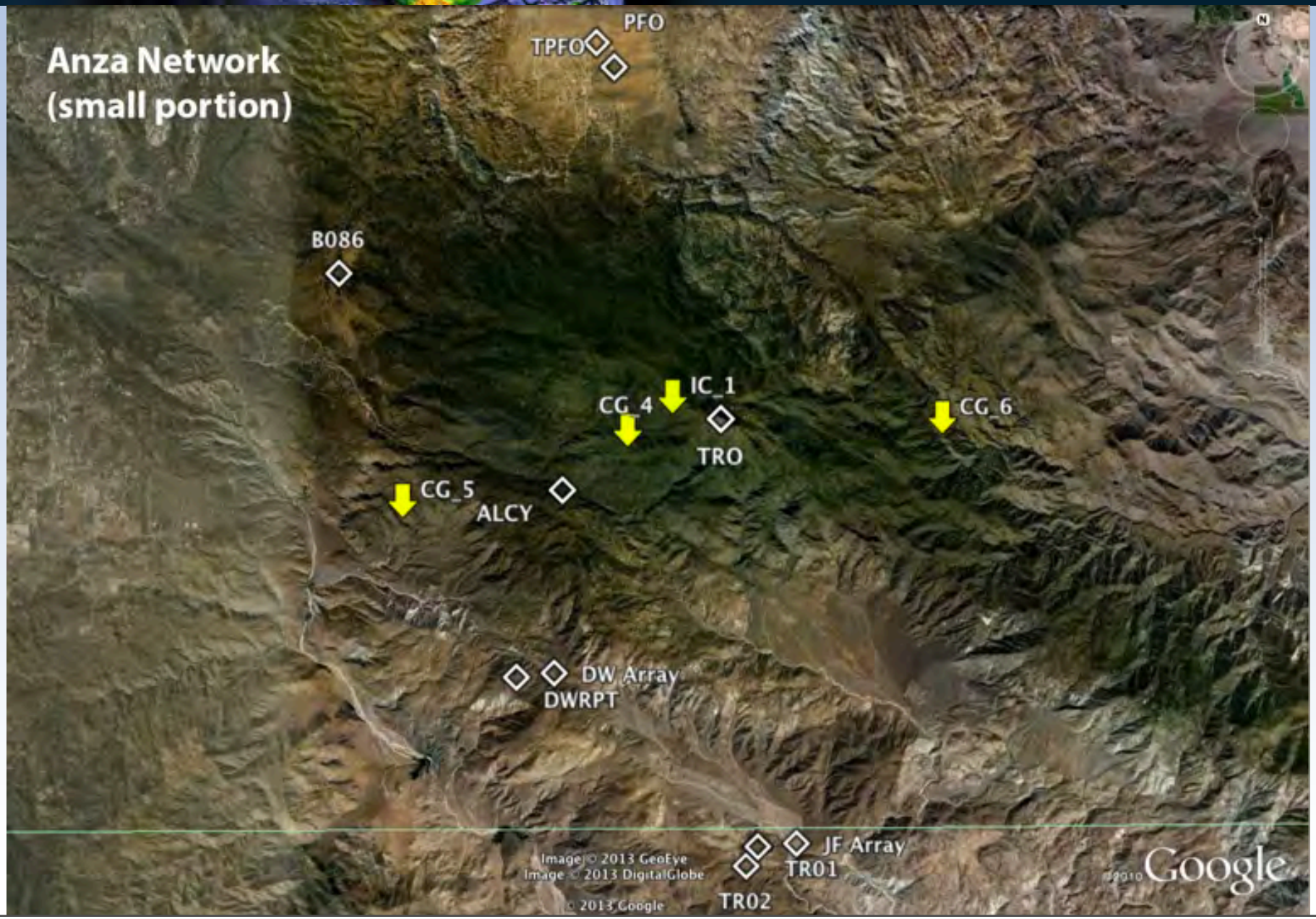
Starting from a single event group from the ENTLN, identify thunder noise in seismic:

lat	lon	altitude (km)	time	label
33.5243	-116.4387	14.4427	8/13/2012 (226) 2:34:15.32626	IC_1
33.5169	-116.4508	0	8/13/2012 (226) 2:34:15.37642	CG_4
33.5008	-116.5121	0	8/13/2012 (226) 2:34:15.46867	CG_5
33.5201	-116.3625	0	8/13/2012 (226) 2:34:15.52661	CG_6

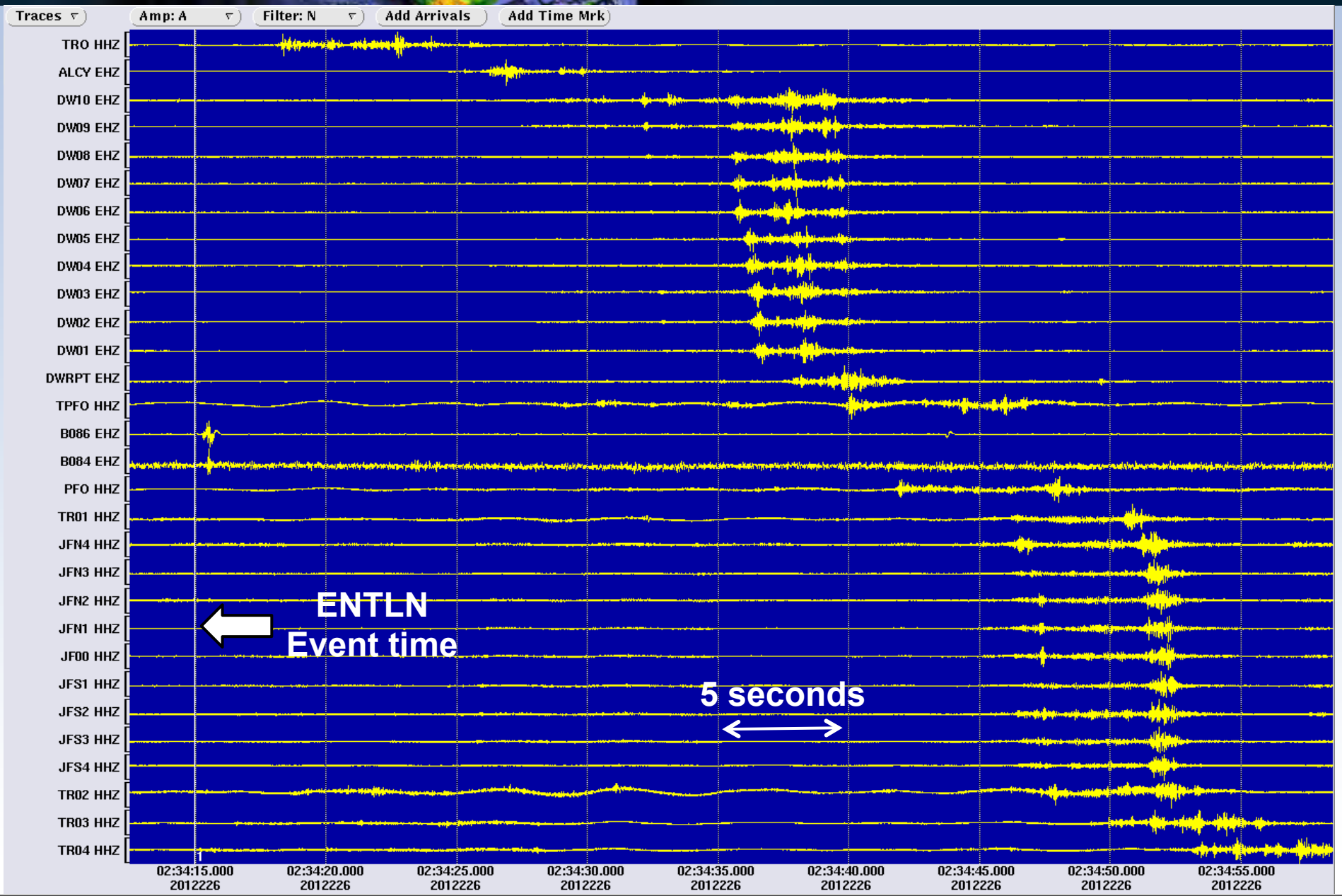
One “event” with four separate “origins”

IC - Cloud to Cloud
CG - Cloud to Ground

Ground Truth Example



Ground Truth Example



Thunder review

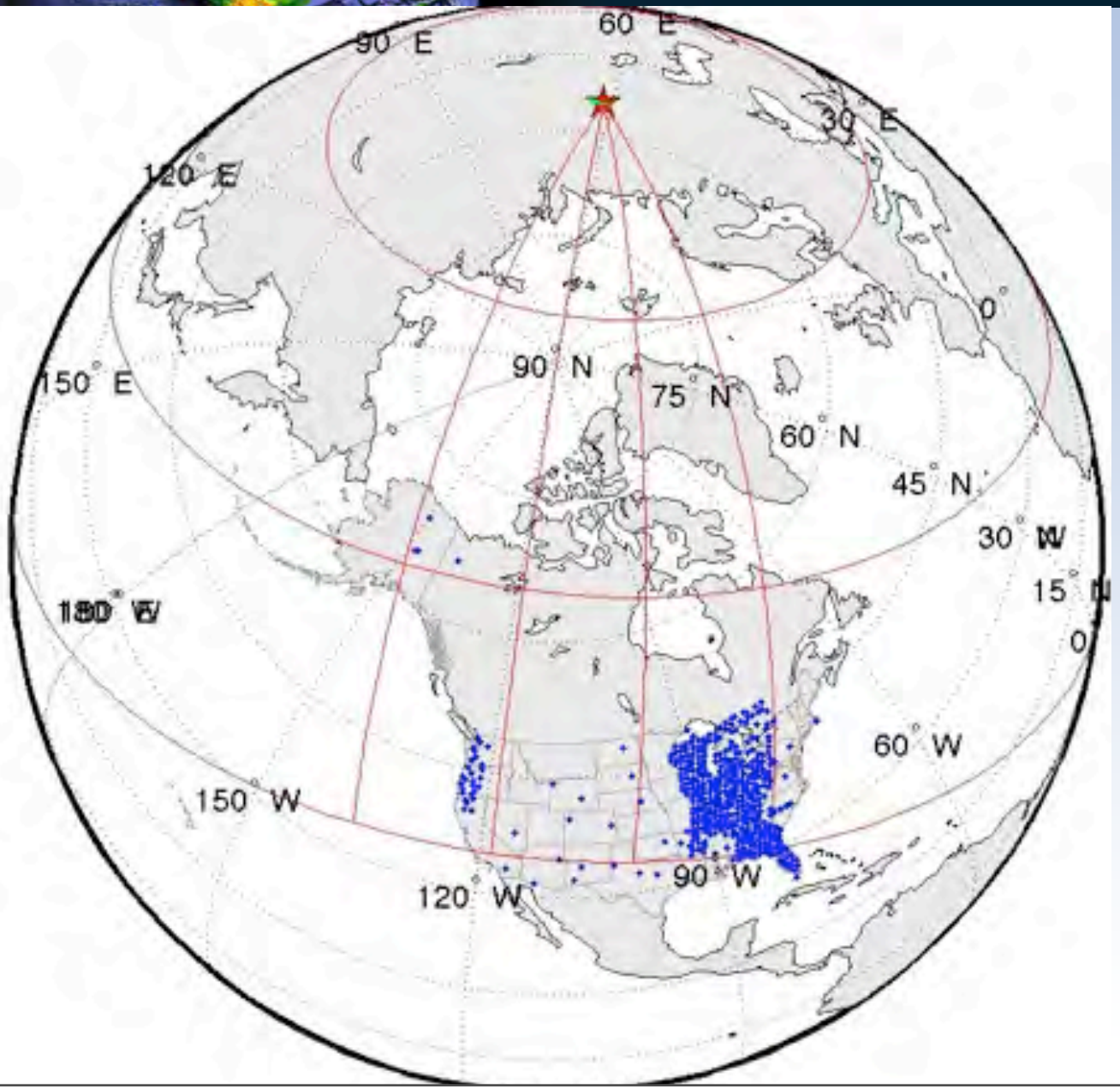
- Thunder noise from lightning events readily poses challenges for seismic analysts
- Lightning can cover large areas vs. isolated seismic sources
- Large area acoustic signatures difficult to determine arrival times in data (though "ballpark" estimates possible)
- Signals from thunder can overlap, cross-over, and distort seismic waveforms

Data Fusion

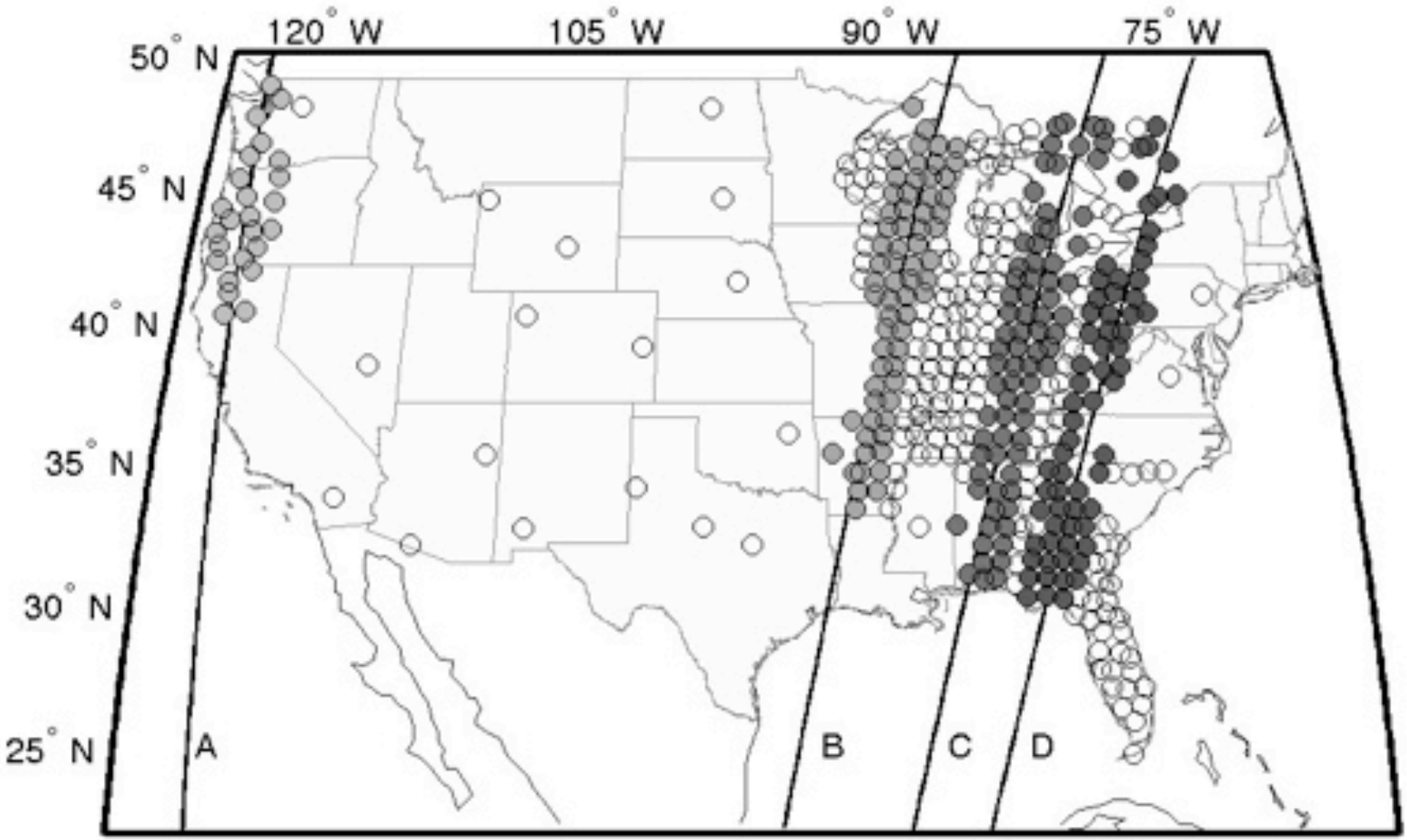
- **Earth Networks' comprehensive Total Lightning Network (ENTLN) helps isolate specific thunder obs.**
- **Seismic analysts can regroup waveforms using lightning events as point source "regions" – this helps isolate earthquake signatures**
- **Possibility of developing a real-time detector, though this would be difficult without supplemental data such as ENTLN**

Russian meteor 2013-02-15

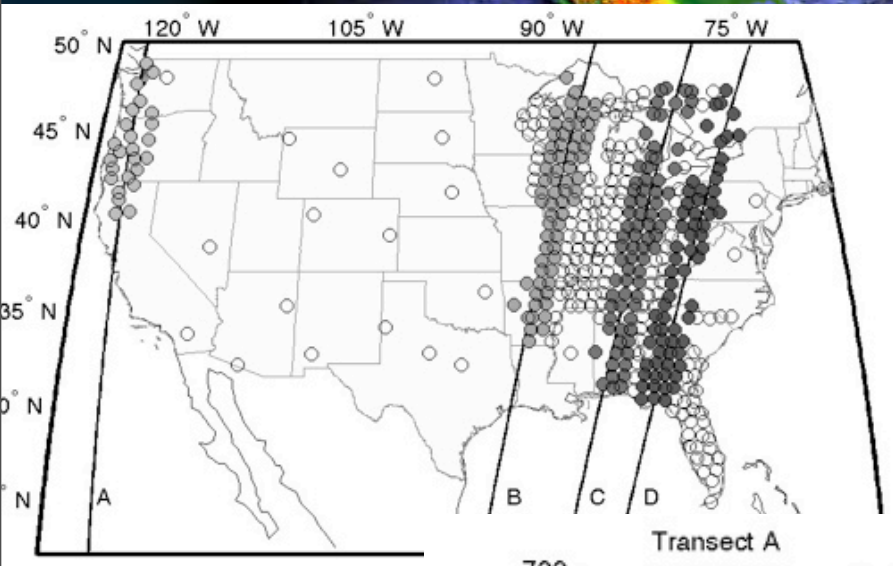
Russian meteor 2013-02-15

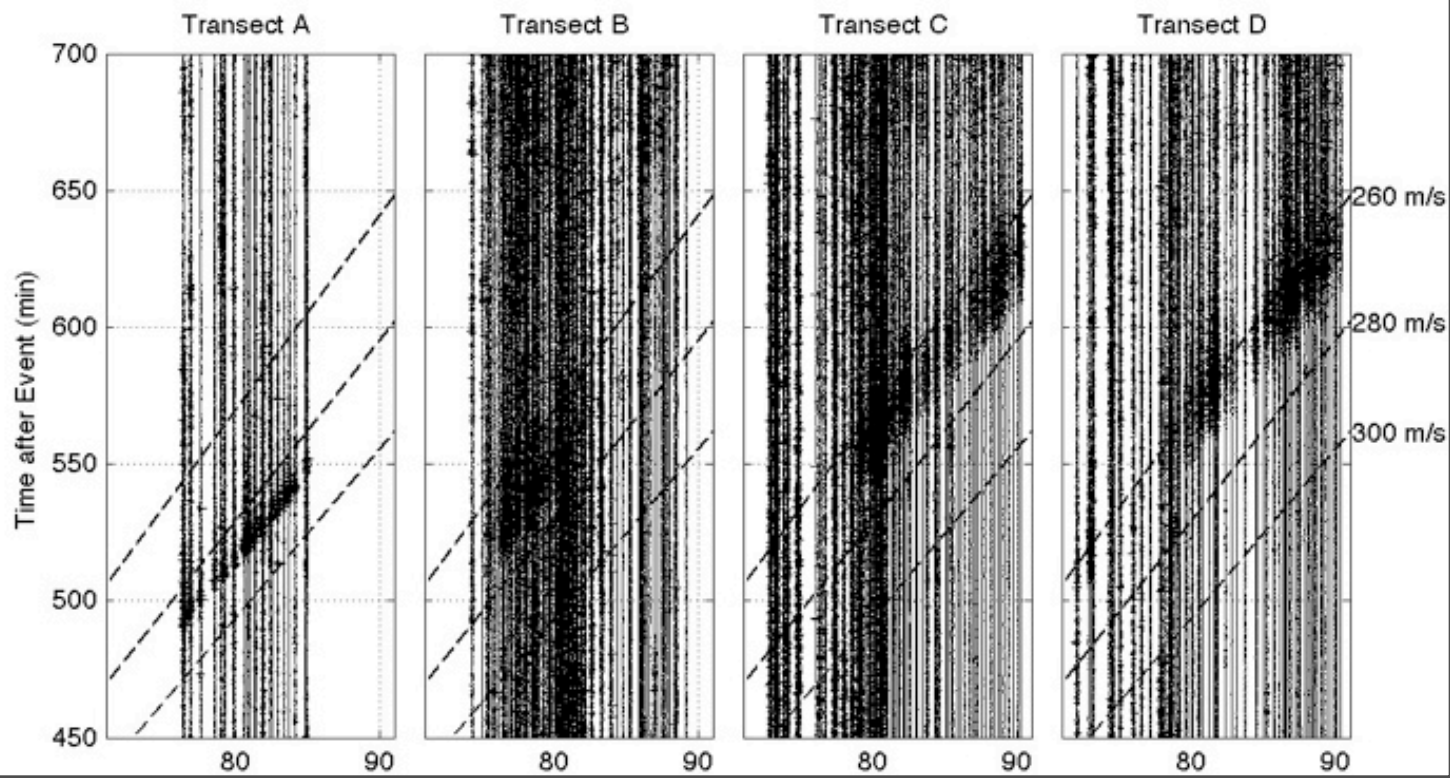


Russian meteor 2013-02-15

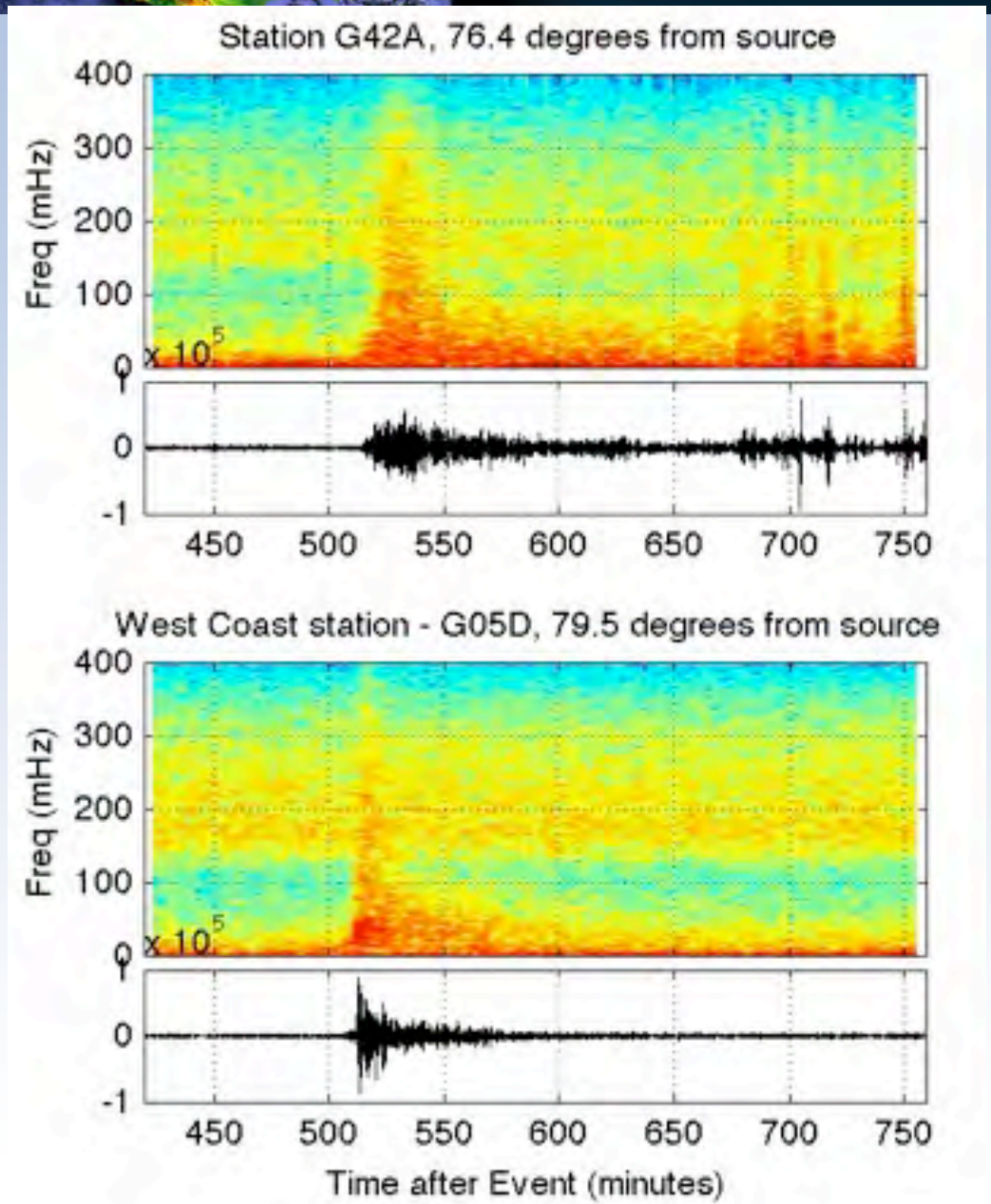


Russian meteor 2013-02-15

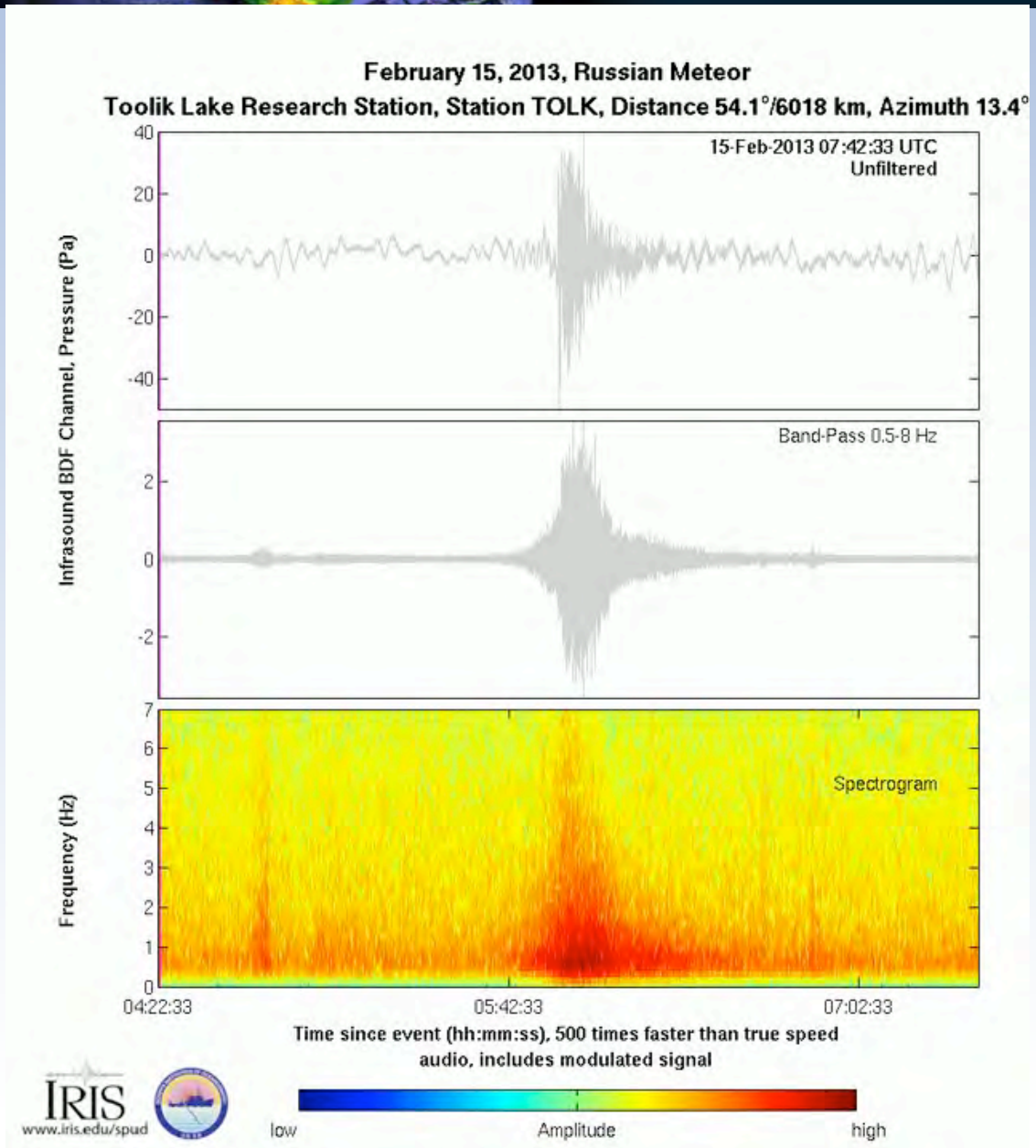




Russian meteor 2013-02-15



Russian meteor 2013-02-15



Russian meteor 2013-02-15

Conclusions

- Meteorological sensors can enhance understanding of seismic data
- Meteorological sensors can create opportunities for collaboration between different scientific communities
  - real time monitoring
  - hazards
  - civil defense
- Seismic networks provide sites, permitting, real time telemetry
- Networks in Middle East using USArray technology are easily adaptable to extended environmental monitoring capabilities