

# Observations of Atmospheric Phenomena from USArray and ANZA Observing Systems



Frank Vernon

**Antelope User Group Meeting  
Muscat, Oman**

2-4 March 2013

## **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**

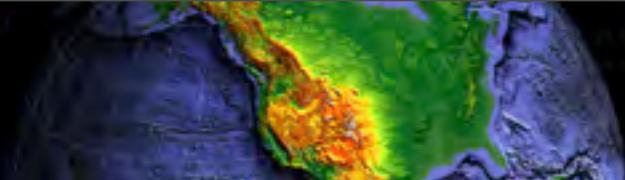
## **Collaboration with the High Performance Wireless Research and Education Network (HPWREN)**

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

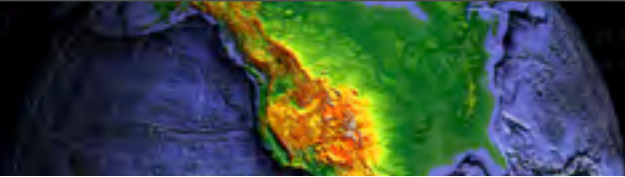
**EarthScope** is funded by the National Science Foundation.

**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.

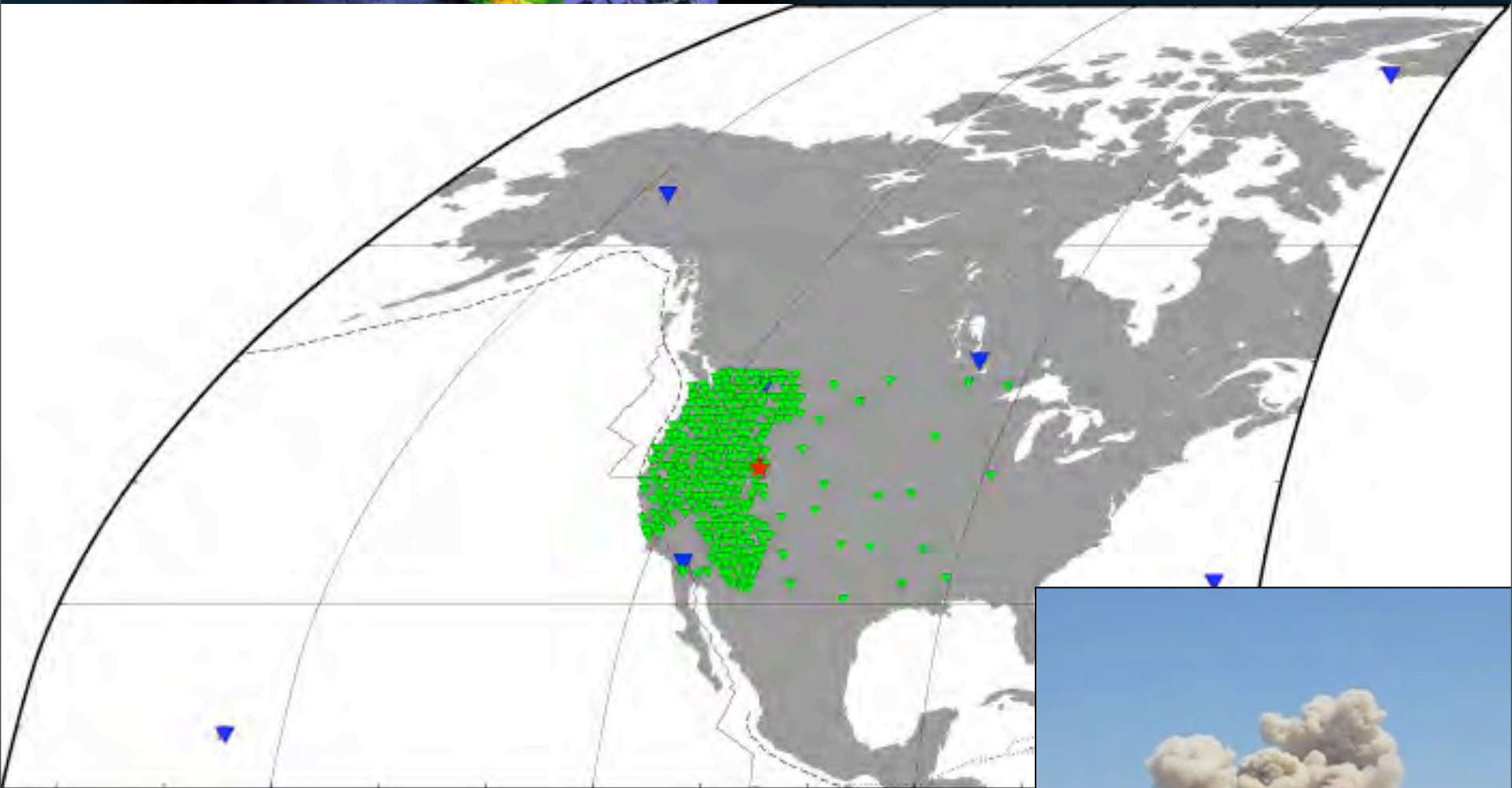




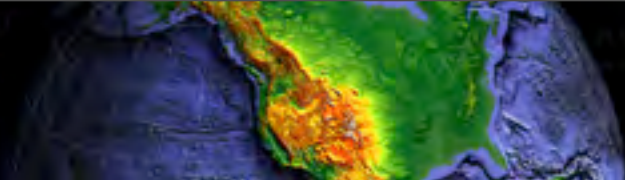
- **Multiple sources of seismic noise:**
  - **Anthropogenic**
    - Planes
    - Trains
    - Automobiles
  - **Natural**
    - Wildlife
    - Rainfall
    - Hail
    - Wind
    - Thunder
    - Storms
    - **Bolides (meteorites)**



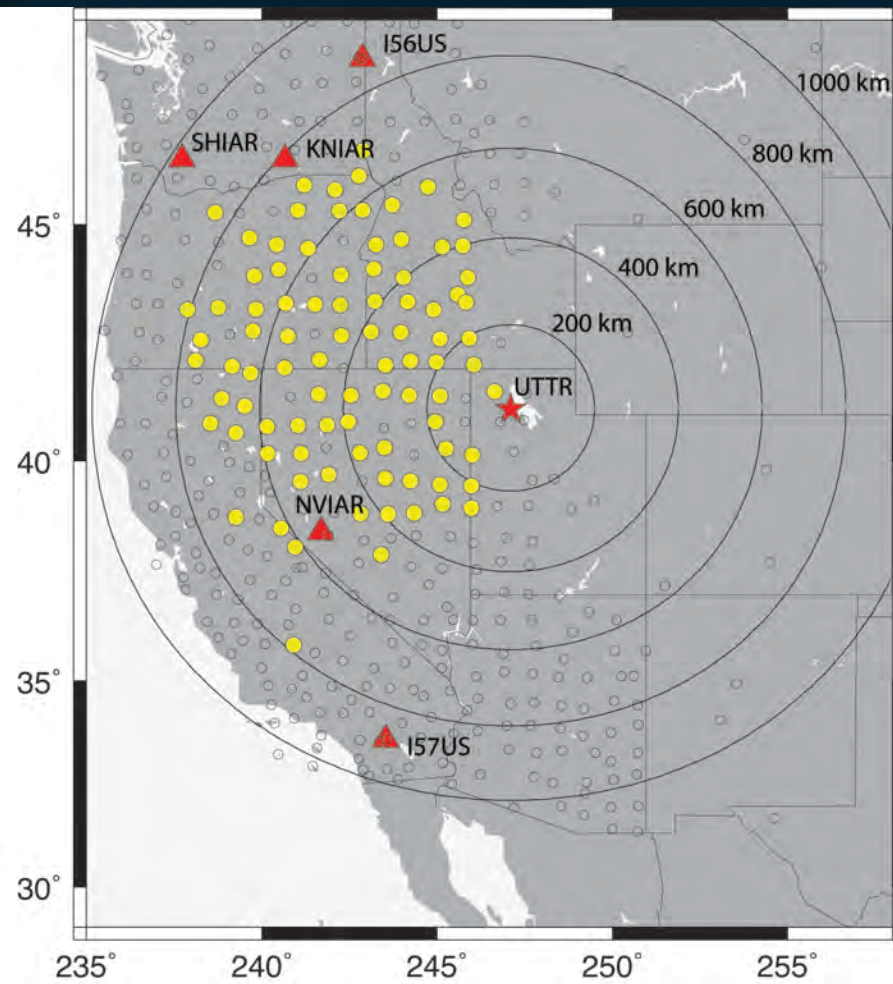
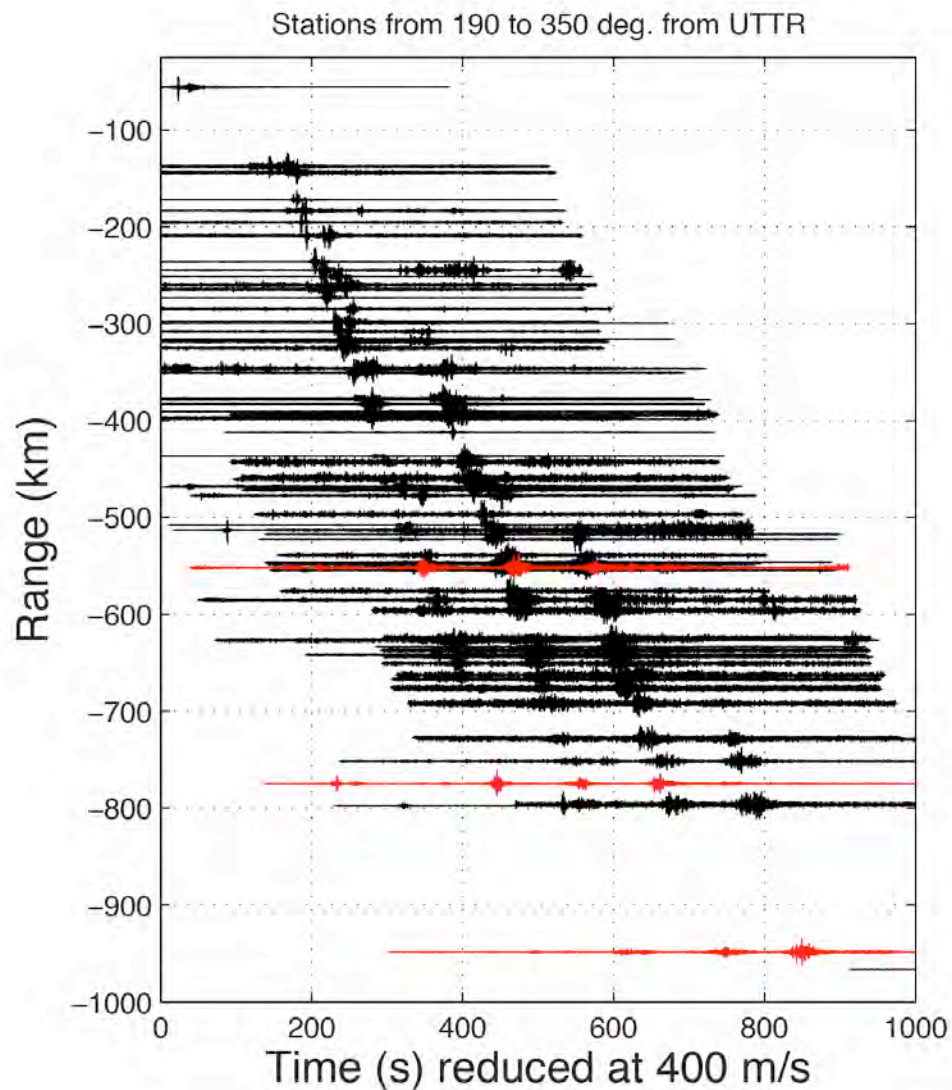
# IMS Infrasound arrays and USArray TA in June, 2007



11 rocket motor detonations from May to September

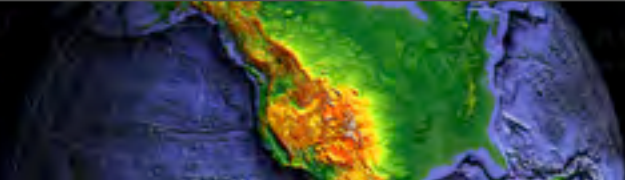


# IMS Infrasound arrays and USArray TA in June, 2007



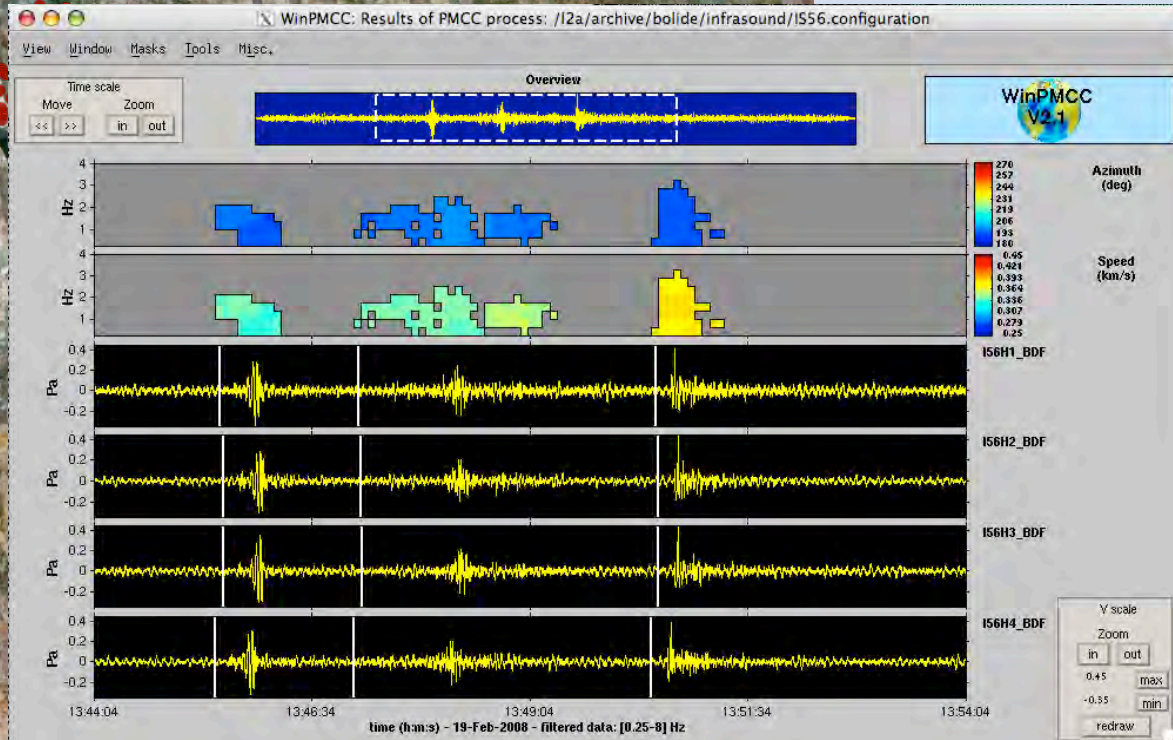
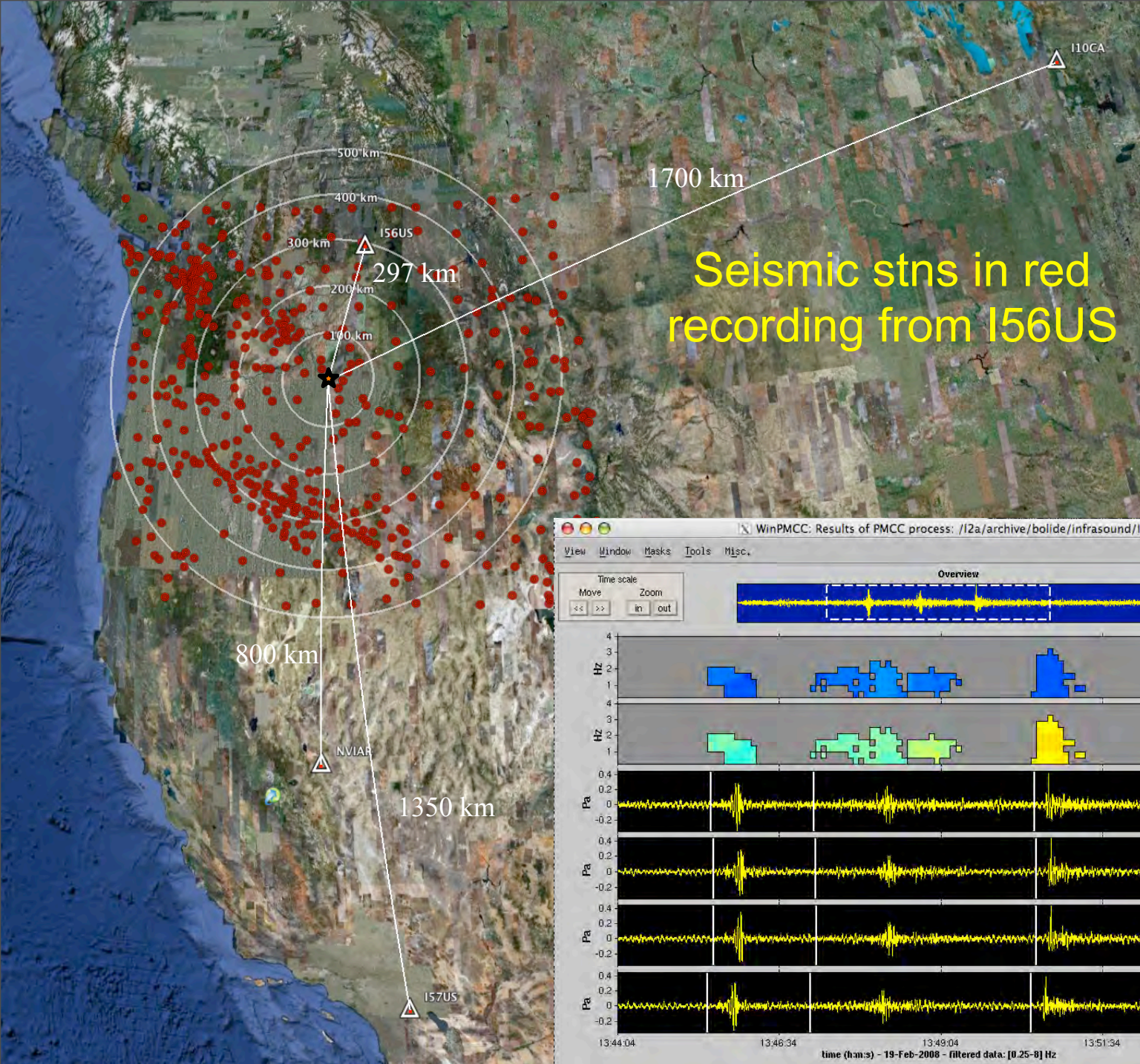


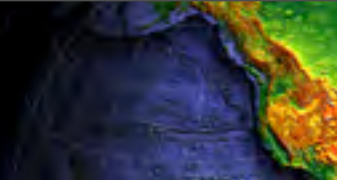
Wednesday, May 29, 13



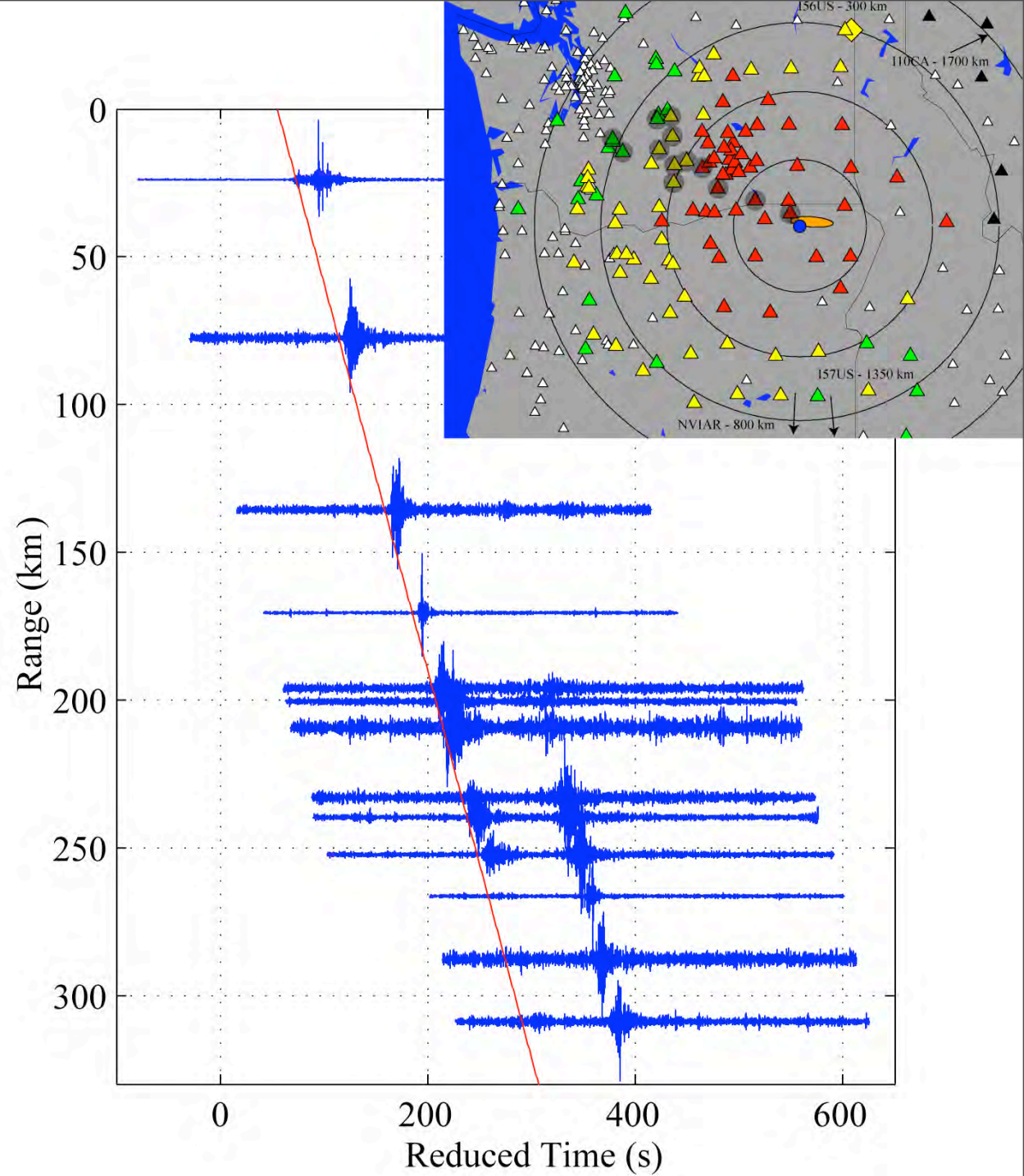
- A bolide burst above NE Oregon at 05:30 AM local time on Feb 19, 2008
- The event was recorded by 4 infrasound arrays and several hundred seismic stations in the USArray and regional networks
- The seismic stations reveal how infrasound signals vary with range and azimuth
- Celerity (horizontal distance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

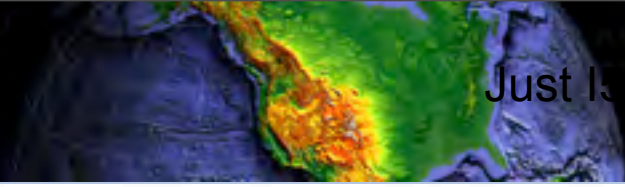






Sample record section to west of event  
Z components  
Bp 0.8-3.0 Hz

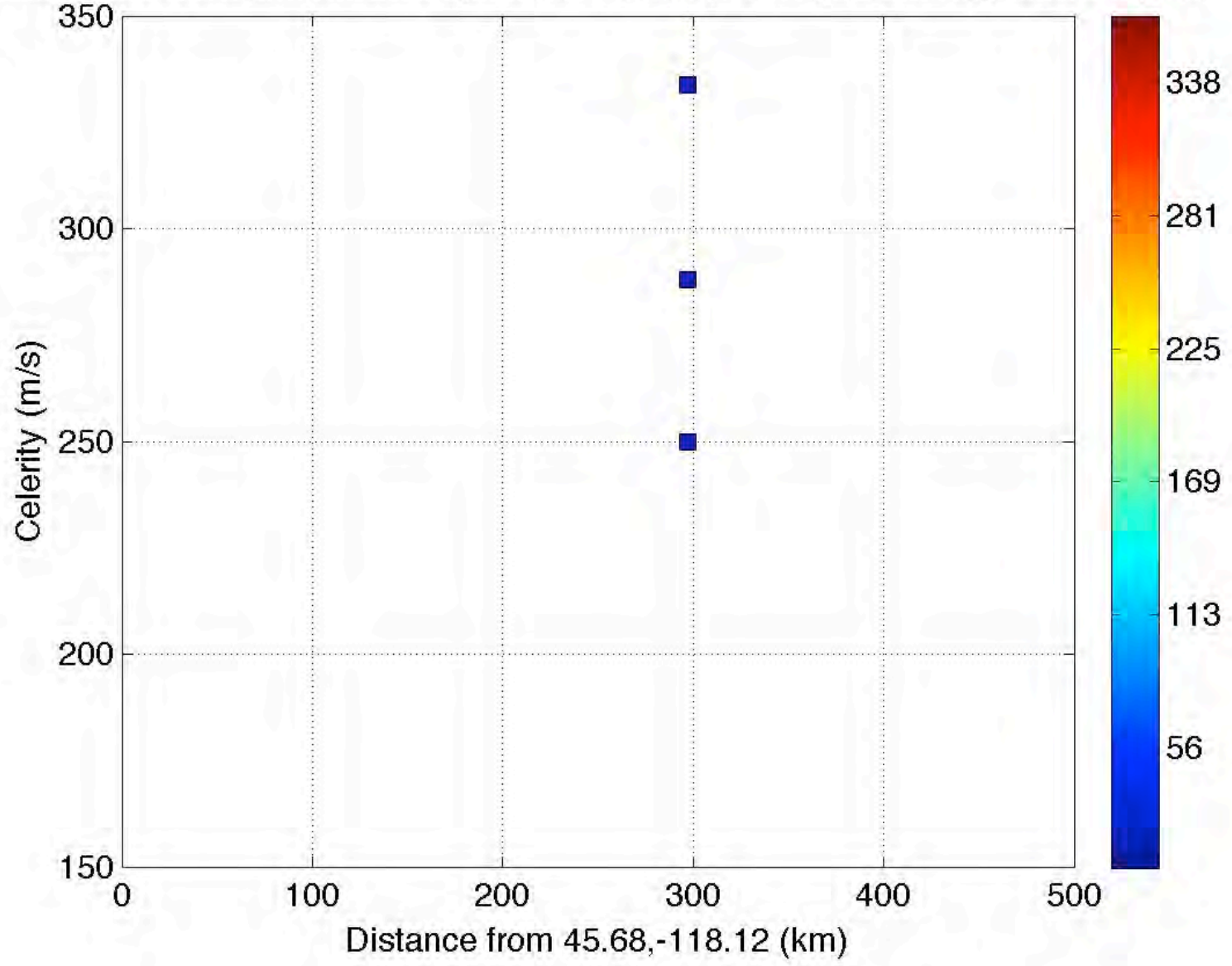


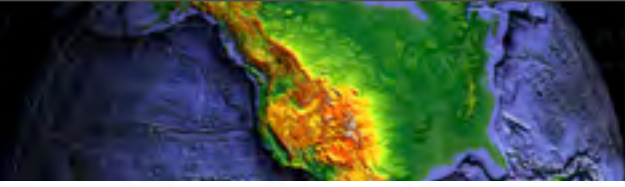


Just 156US

# Array Celerity

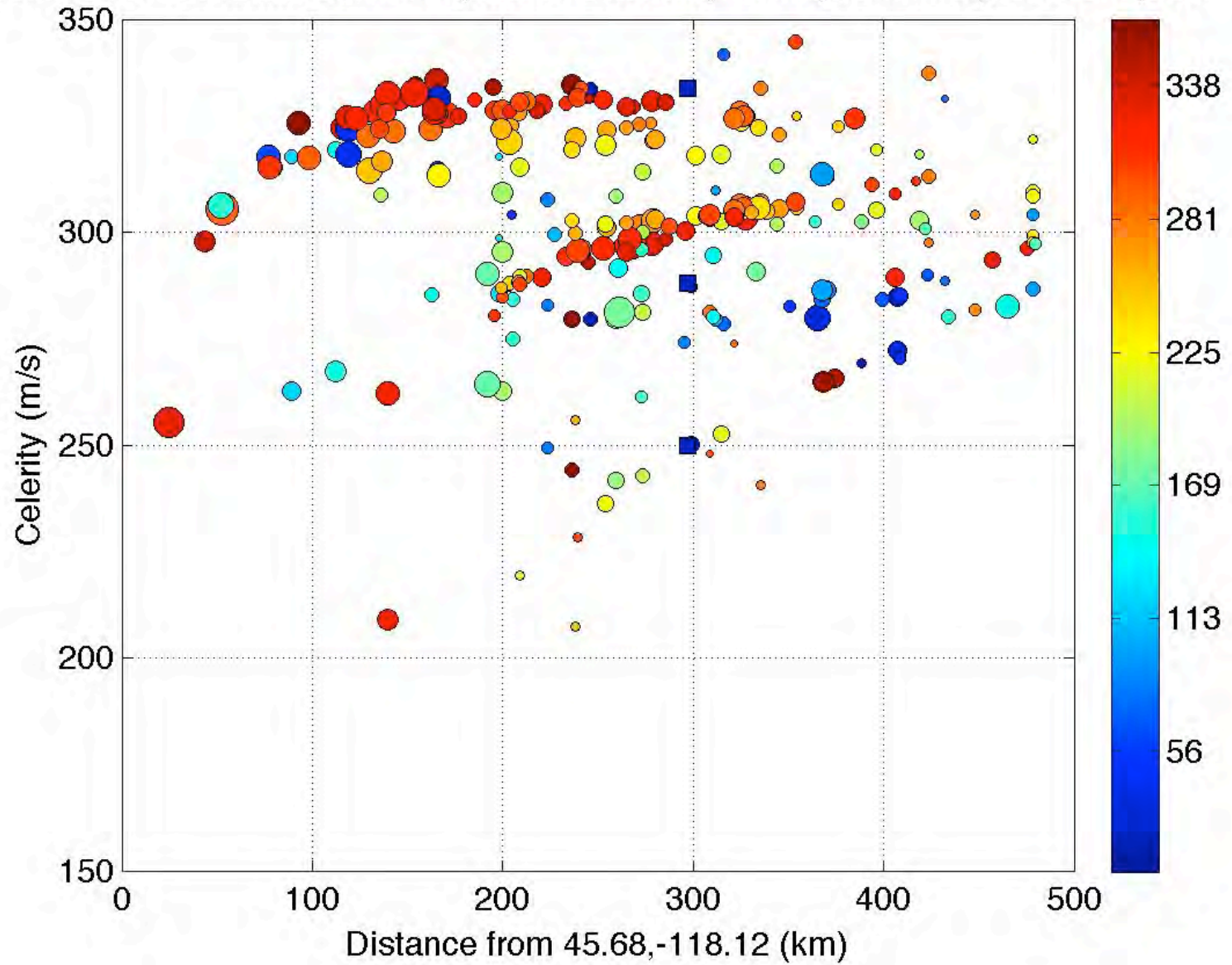
Color is src-rec azimuth: Seismic symbols scaled by SNR (0.8-3.0 Hz), I56US square



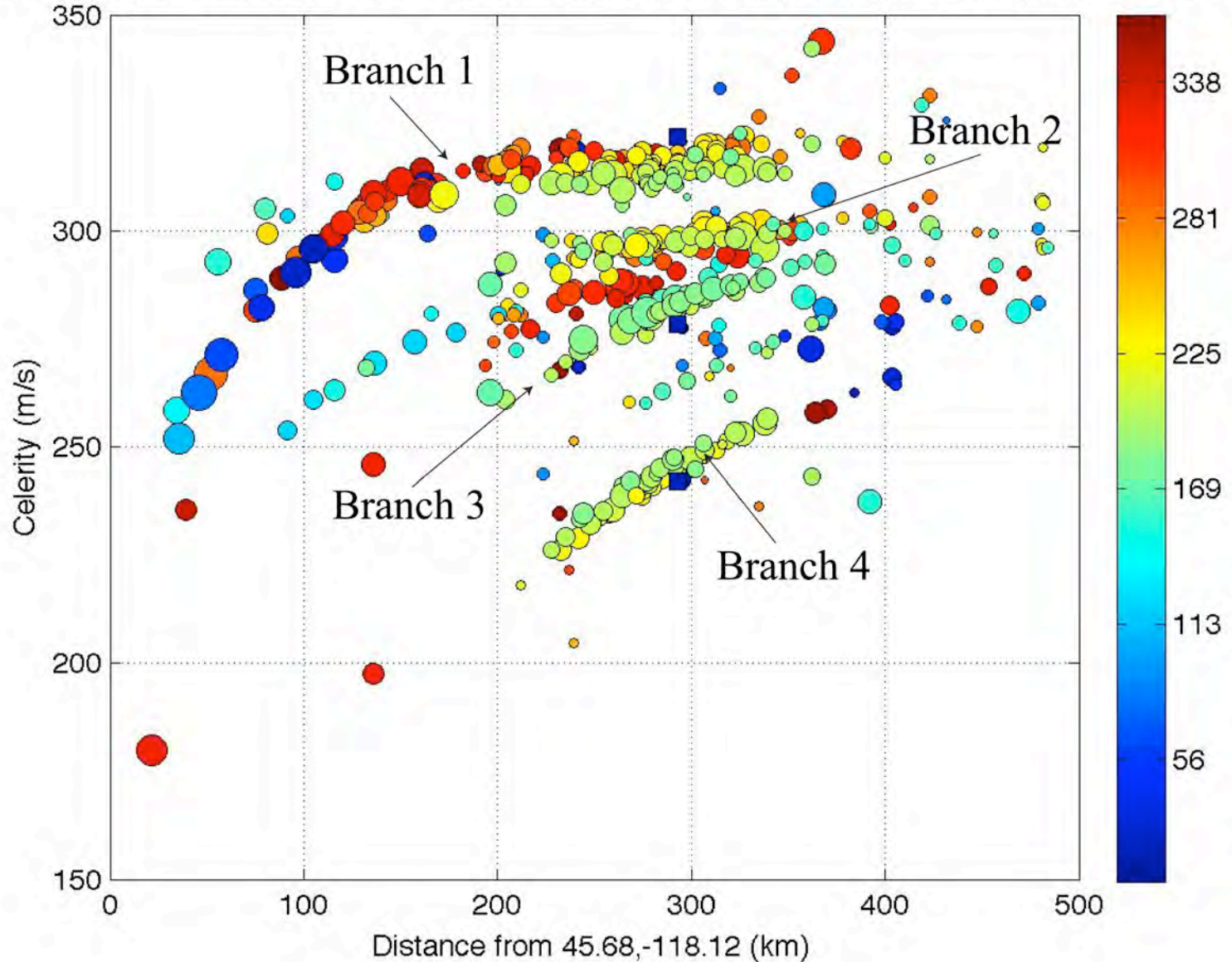


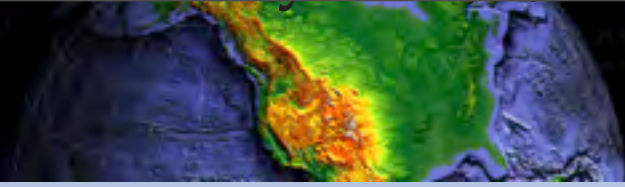
# TA + Array Celerity

Color is src-rec azim: Seismic symbols scaled by SNR (0.8-3.0 Hz), I56US square



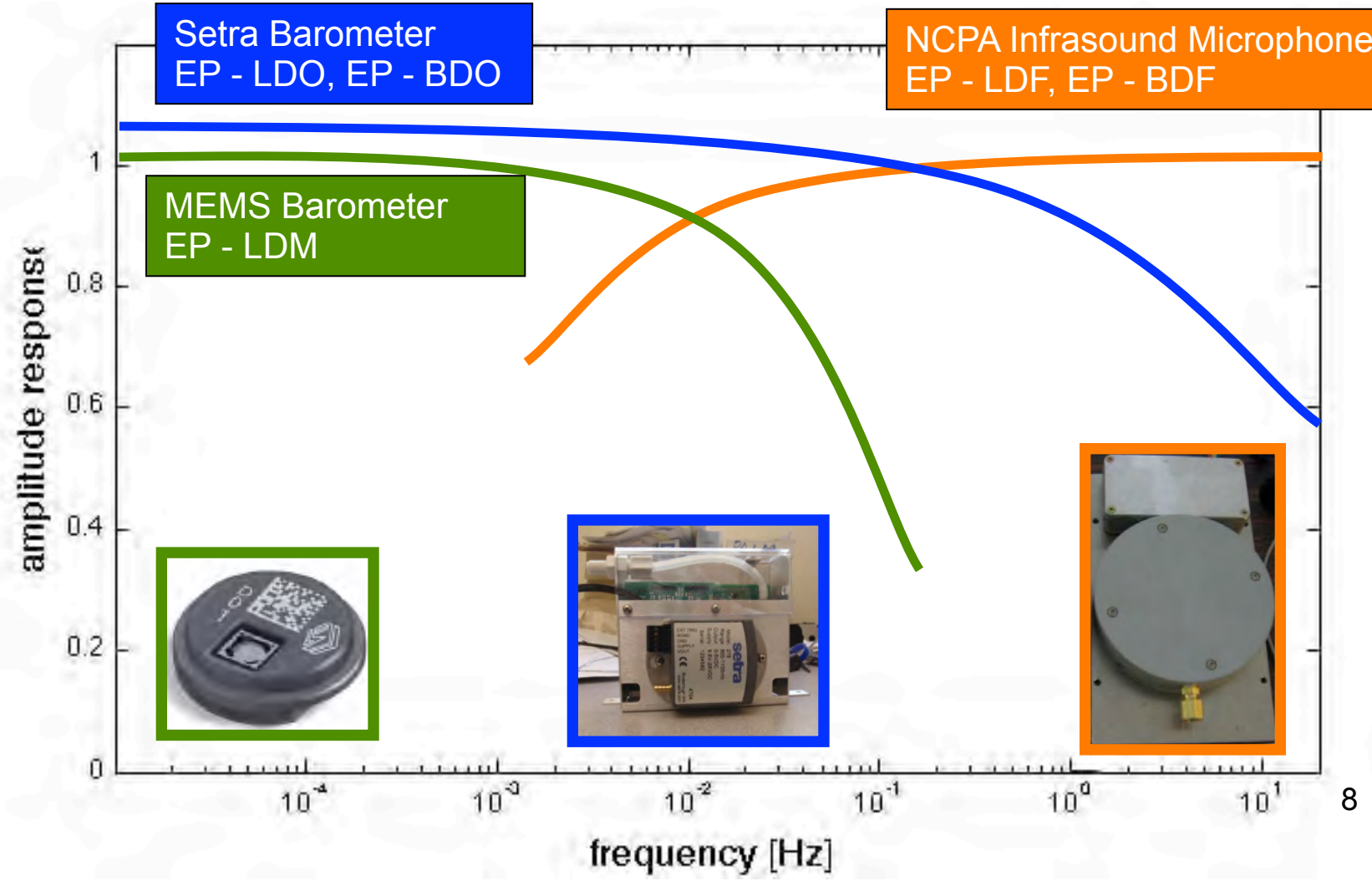
Colorcoded by azimuth from source: Seismic symbols scaled by SNR (0.8-3.0 Hz), I56US square

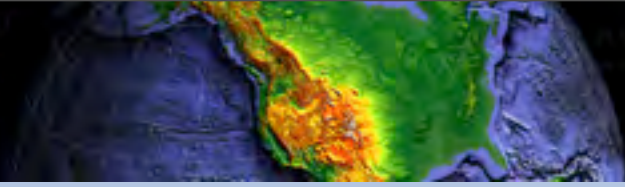




# Pressure Sensor Response

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

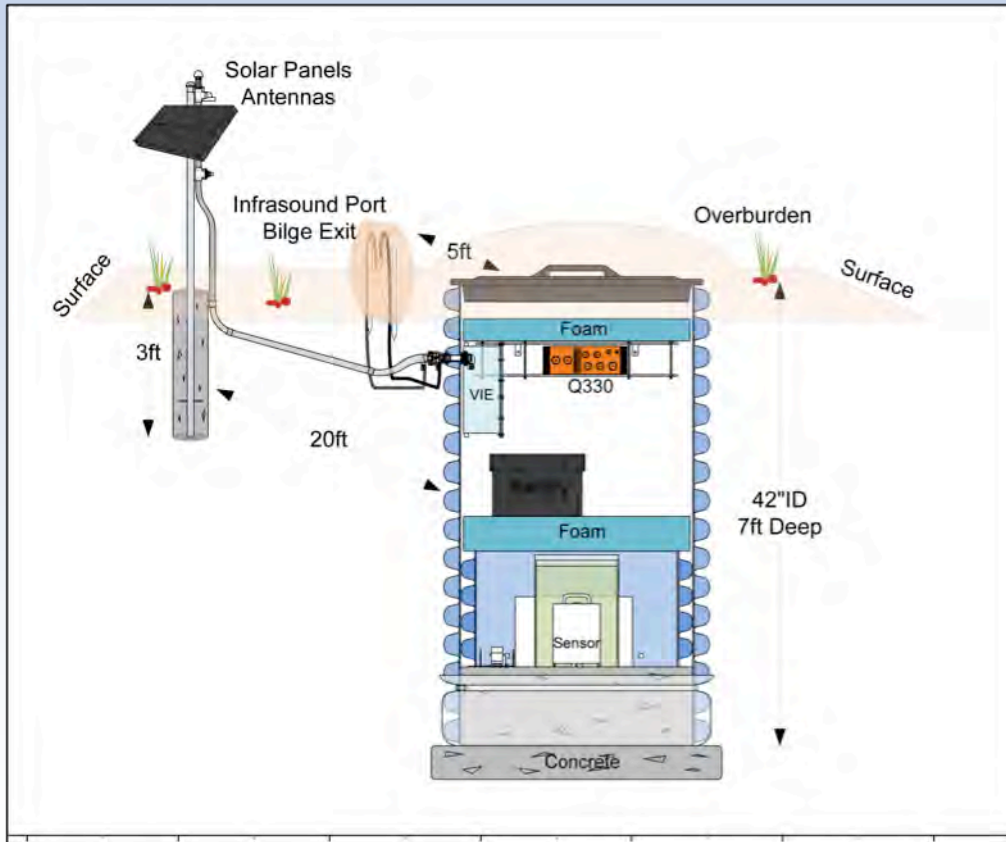




# Basic Description

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

TA Station 345A, MS

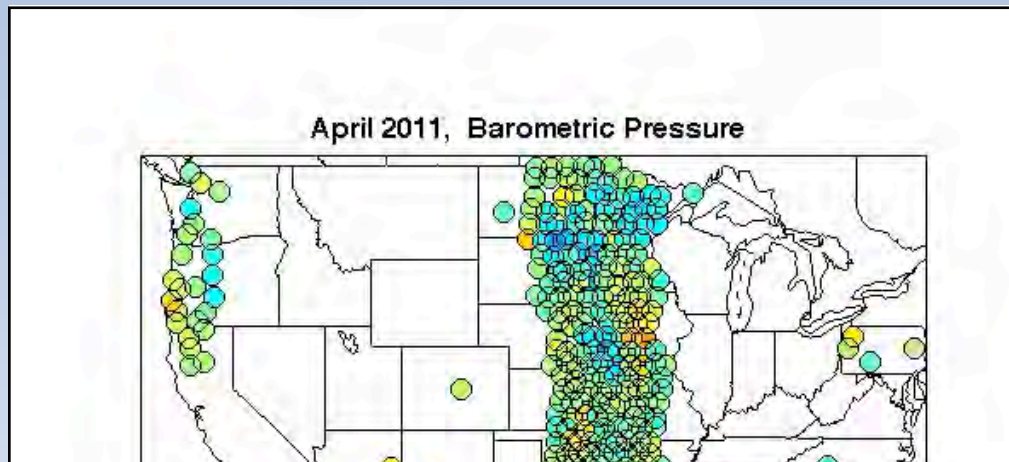


# Implementation of Atmospheric Pressure Sensors





- Pressure 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 Region: UTAH Product: Surface Weather Maps Go

### Stations in MesoWest - USARRAY

The following table of stations are aggregated as part of the U.S. Transportable Array network. Column names mean the following...

**Station ID:** The MesoWest station ID, clicking on the ID will bring you to the Station Interface page with today's observations (if available).  
**Station Name:** The station name utilized by MesoWest.  
**State:** The state/province/territory the station resides in, if applicable.  
**Reported in last 24 hours?:** A check to see if the station has reported at least once within the previous 24 hours.  
**MesoWest Status:** The current MesoWest Status for the station. Status and row colors mean the following...

*NEW* stations or INACTIVE stations that have resumed reporting.
ACTIVE stations that have reported at least once within the last 24 hours.
Stations which have an UNKNOWN status, or ACTIVE stations that either have not reported in the previous 24 hours or are reporting incorrectly, see the note below.
INACTIVE stations, which are stations that have not reported in the last 30 days.

**\*Note:** If a station is listed as ACTIVE/UNKNOWN, and current observations are shown when clicking on the MesoWest station ID, then it's likely that the station is reporting observations incorrectly.

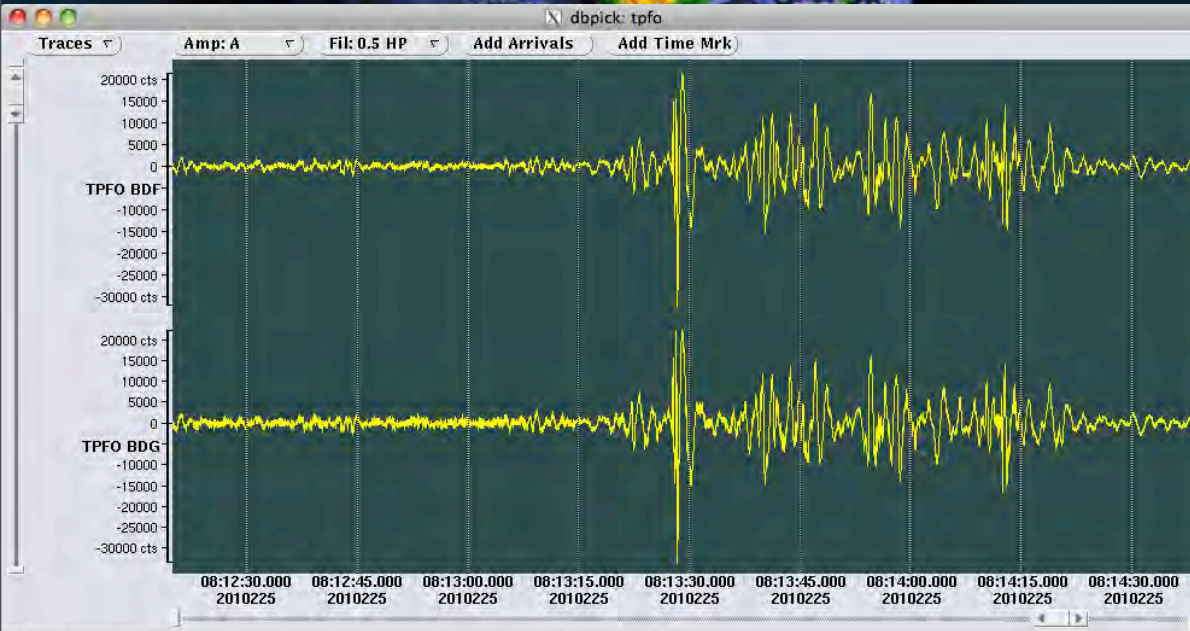
What likely is occurring is that the station is reporting "future" observations by accident, where the time-stamp is incorrectly given as some time in the future.

Click on a column header to sort the table by that column.

Station ID	Station Name	State	Reported in last 24 hours?	MesoWest Status
058AX	058A Arcadia	FL	YES	ACTIVE
059AX	059A Moore Haven	FL	YES	ACTIVE
059ZX	059Z Ave Maria	FL	YES	ACTIVE
060AX	060A Indiantown	FL	YES	ACTIVE

MesoWest is accessing data via web services

# Atmospheric Acoustic Transportable Array

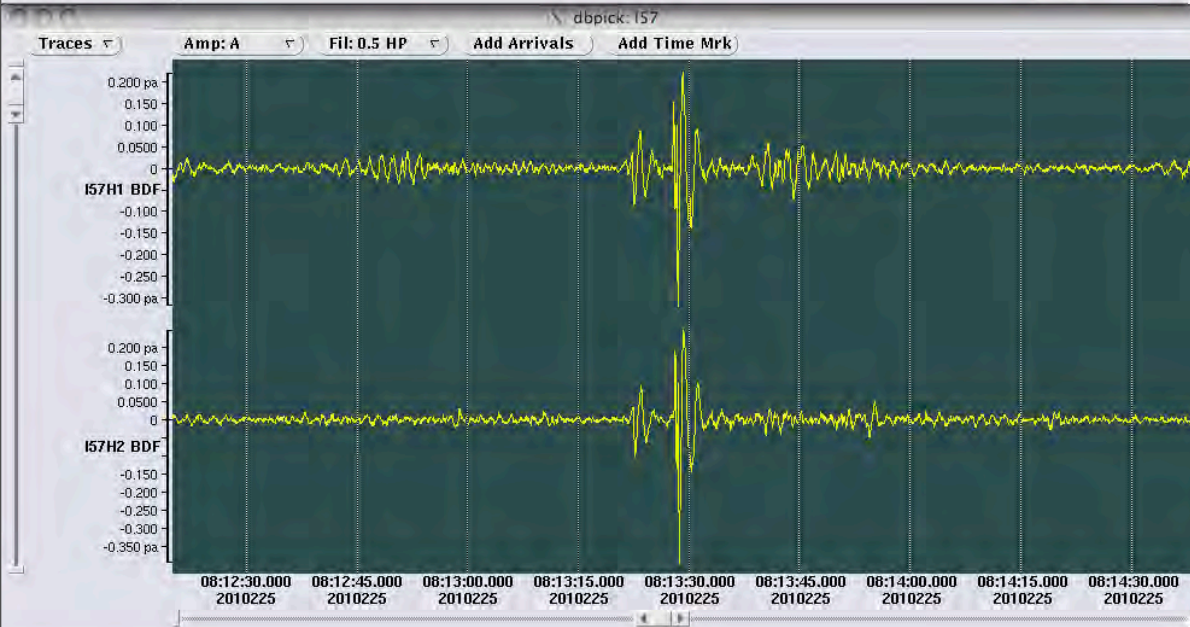


**TA-TPFO**

**One port**

**Bag of gravel**

**Both tubes inside gravel**



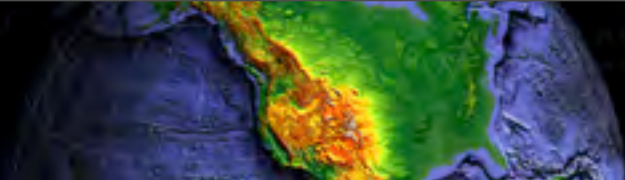
**IMS57**

**70M aperture**

**25 element array**

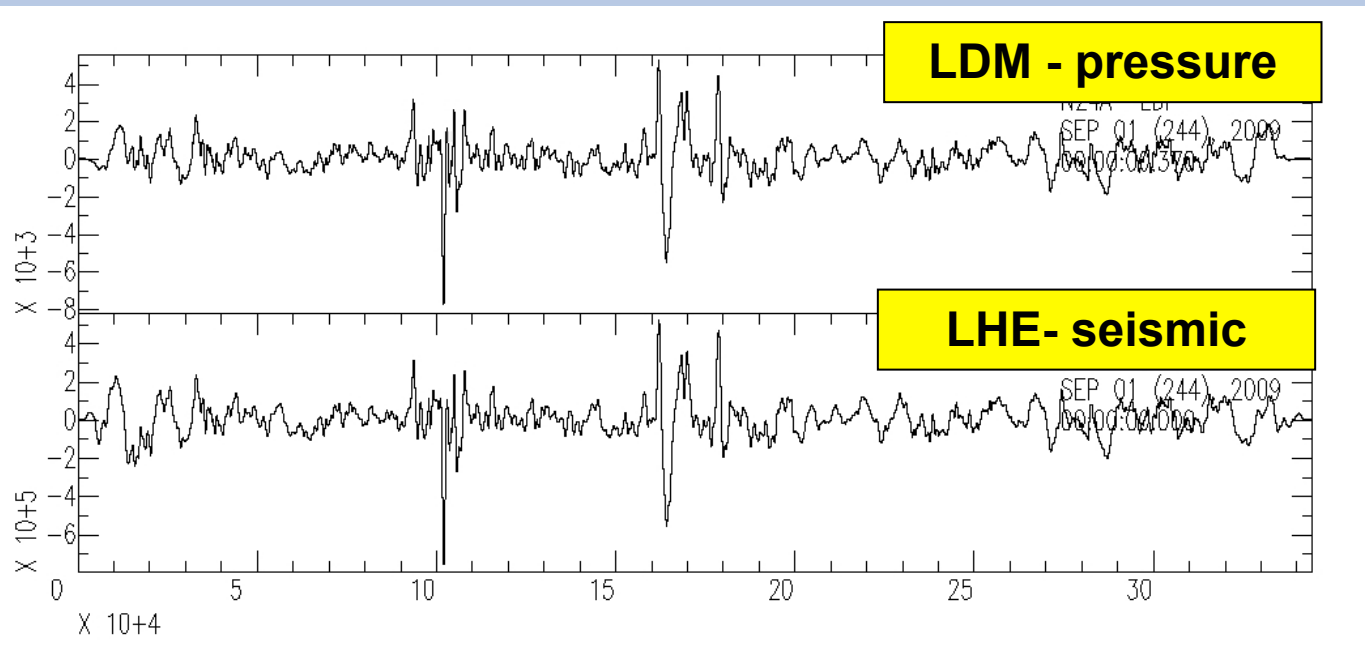
**Adjacent arrays near TPFO**

**2 minute trace length**

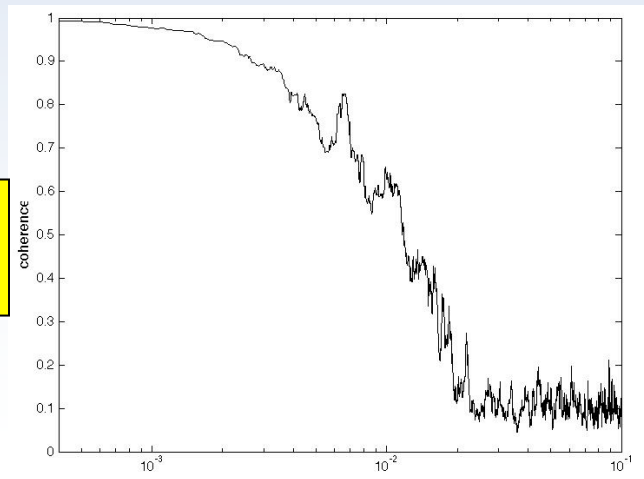


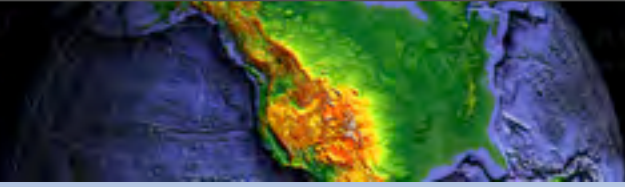
# Basic Observation

- Pressure observations show strong correlation to seismic data



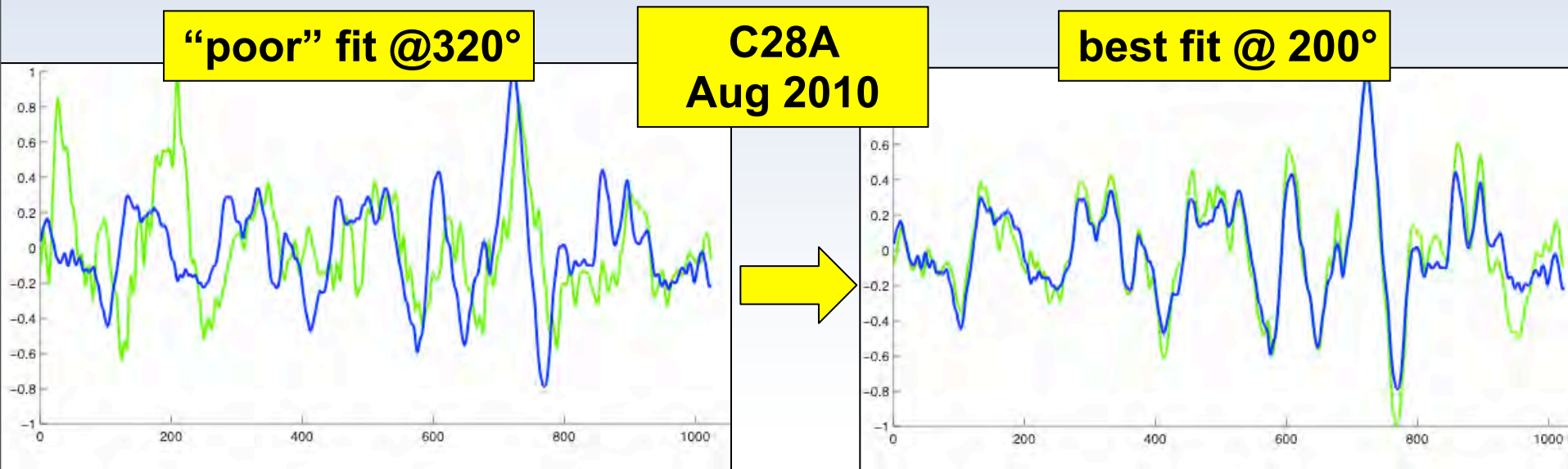
**Pressure – Seismic Coherence**





- Pressure-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

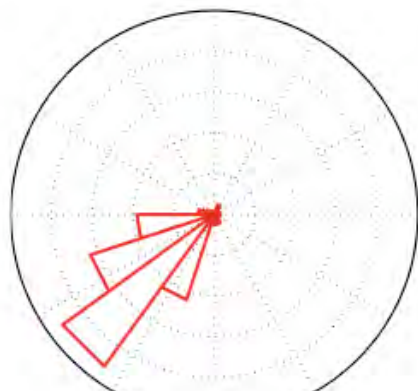
- Use 30 day time series, bandpass filtered 2,000 s – 100 s
- Sliding ~3 hour window, 50% overlap
- Compute coherence in band around 1,000 s
  - Rotate horizontals to maximize coherence
- Process several months of data
  - ~450 coherence estimates per station per month
  - Plow through noise, earthquakes,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



# Coherent Behavior at Neighboring Stations

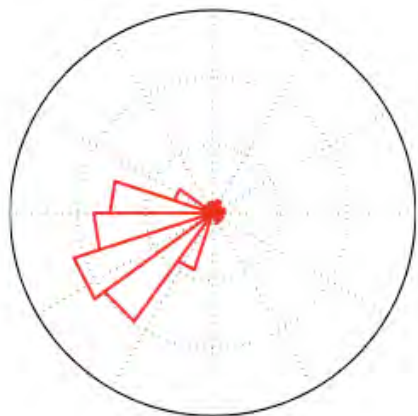
- Preferred orientation stable, but changes with time
- Neighboring stations C28A-D28A (70 km) behave similarly

C28A mean =227.6464

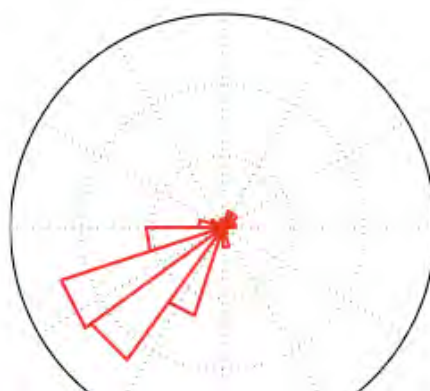


**Aug 2010**

D28A mean =246.5671

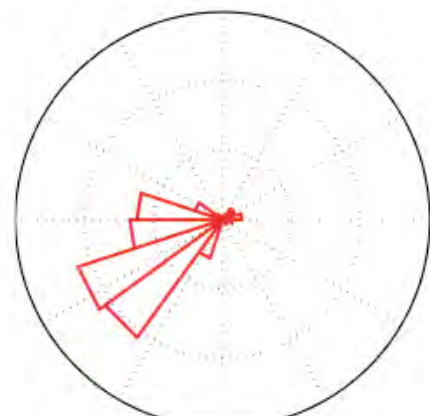


C28A mean =231.627

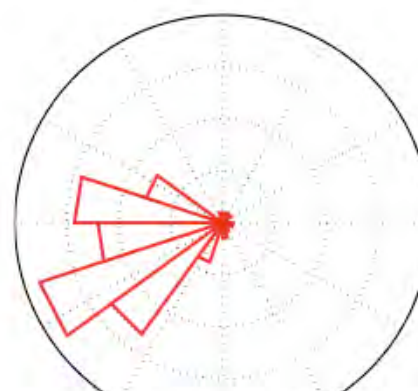


**Sept 2010**

D28A mean =243.6113

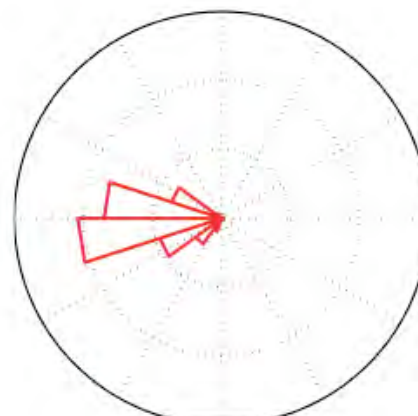


C28A mean =250.6961

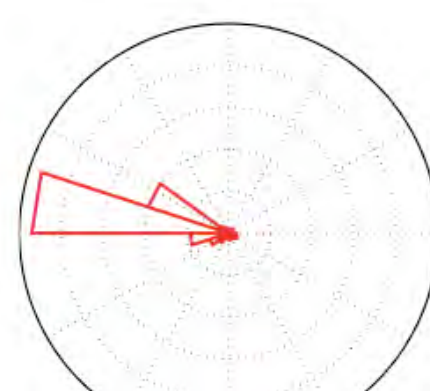


**Oct 2010**

D28A mean =263.652

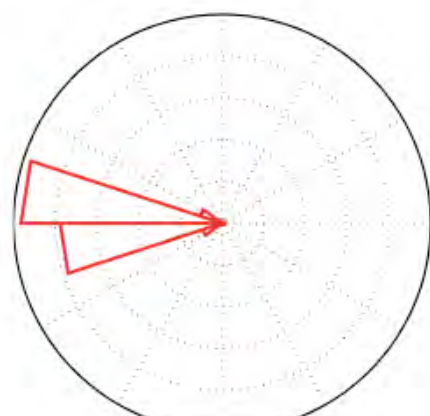


C28A mean =279.1425

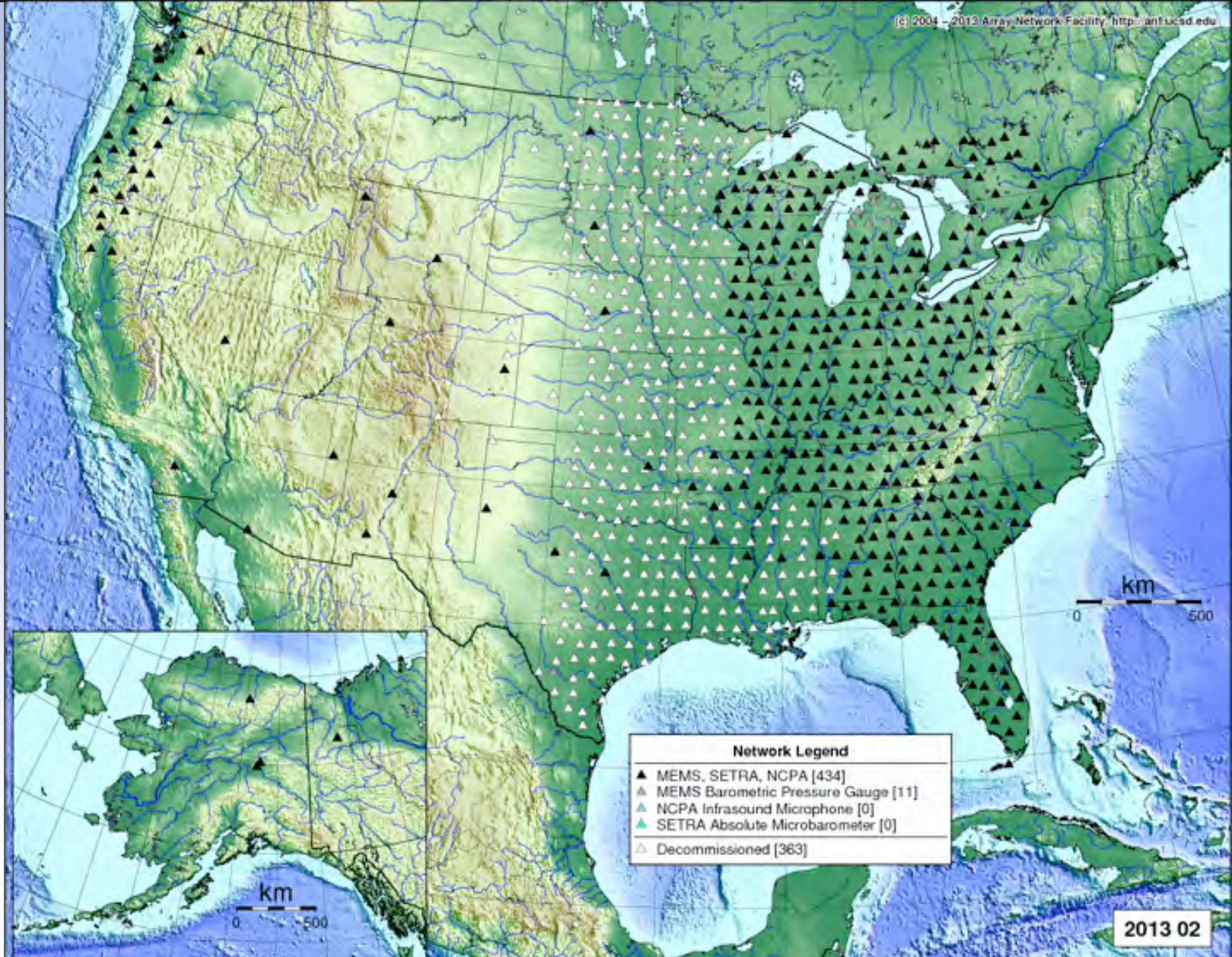


**Nov 2010**

D28A mean =271.0304

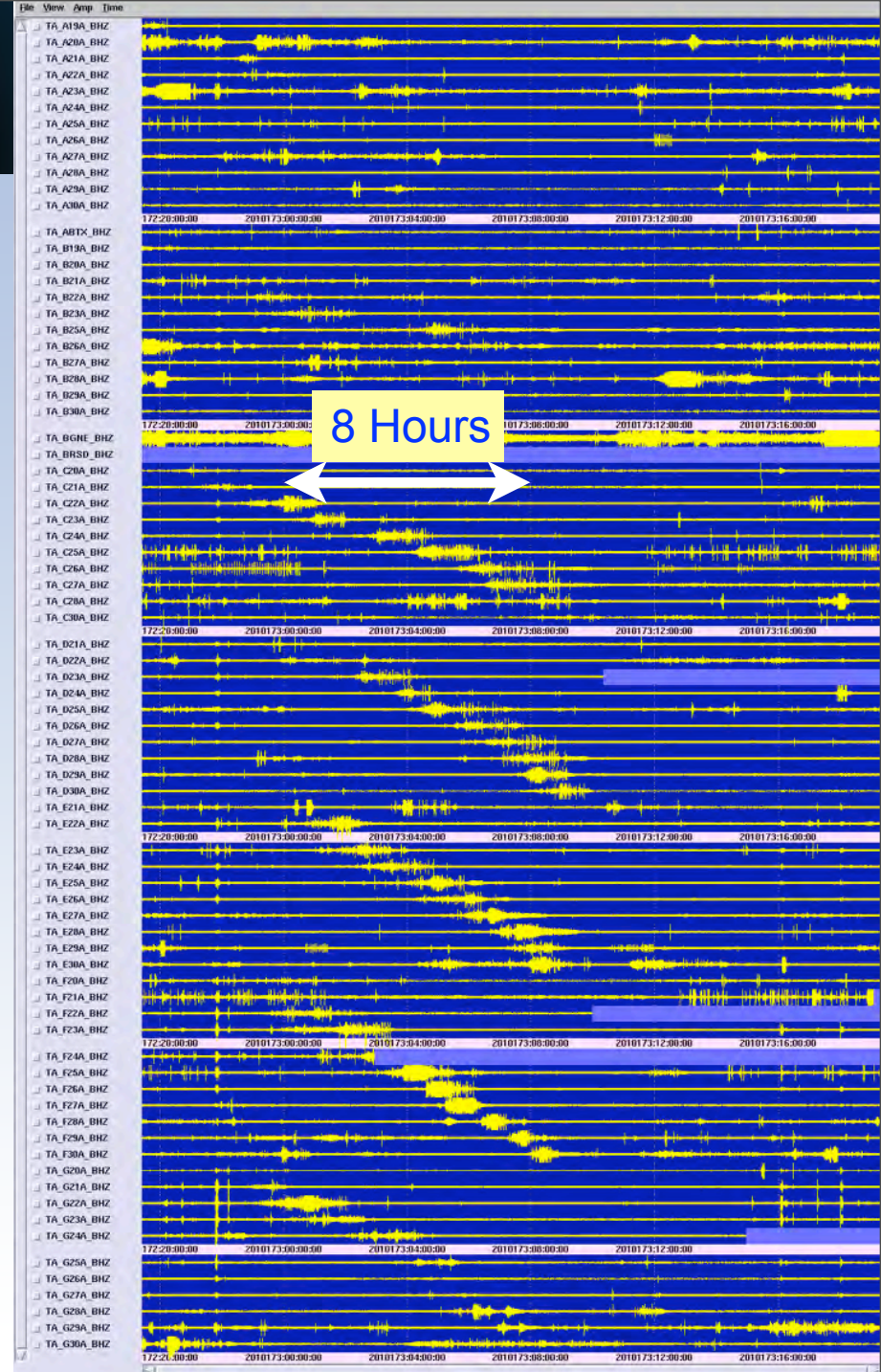


# Implementation of Atmospheric Pressure Sensors



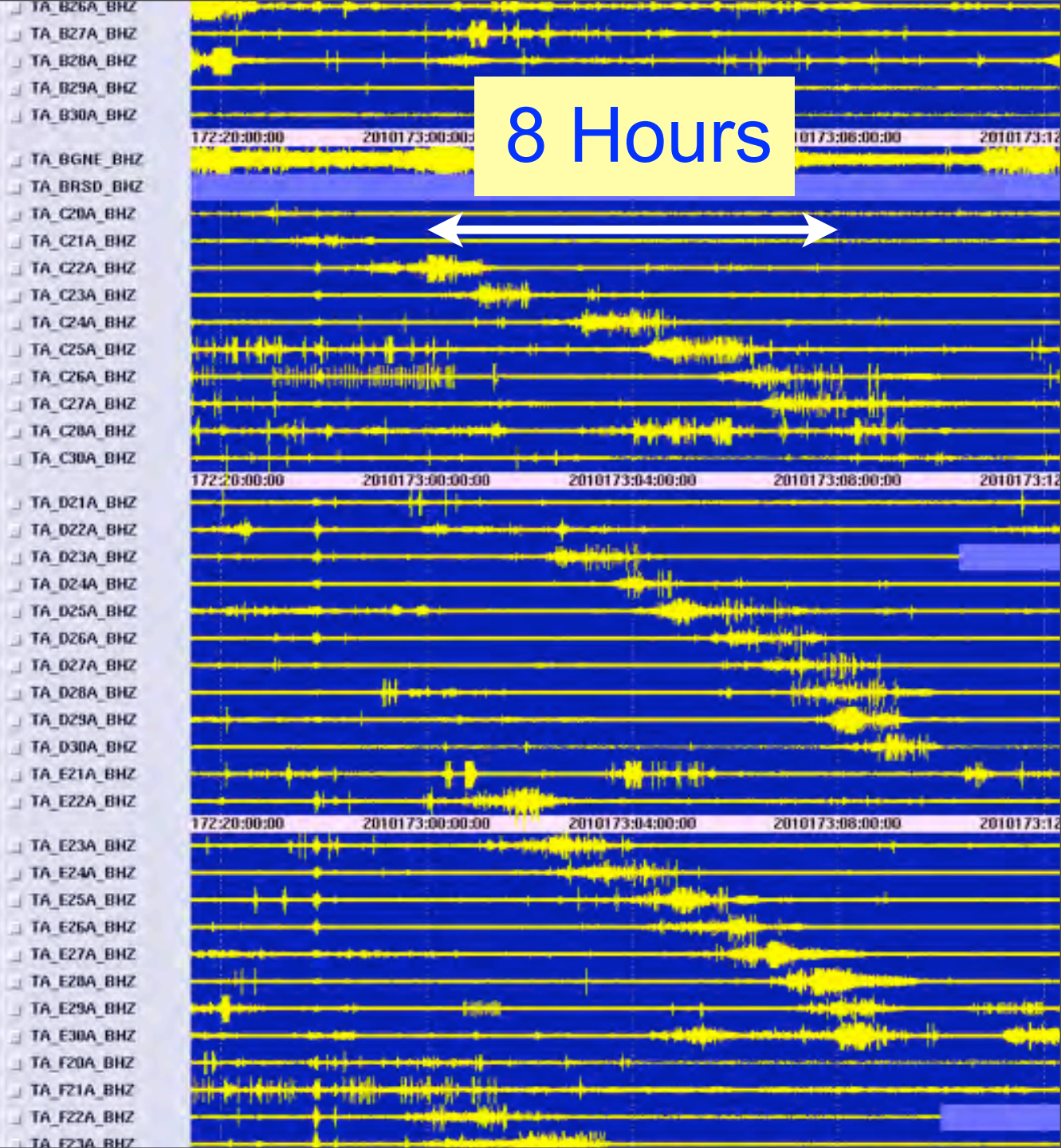


- **Strange signals**
- **Correlated across stations**
- **Slow move out**
- **Too slow for seismic**
- **Too slow for infrasound**

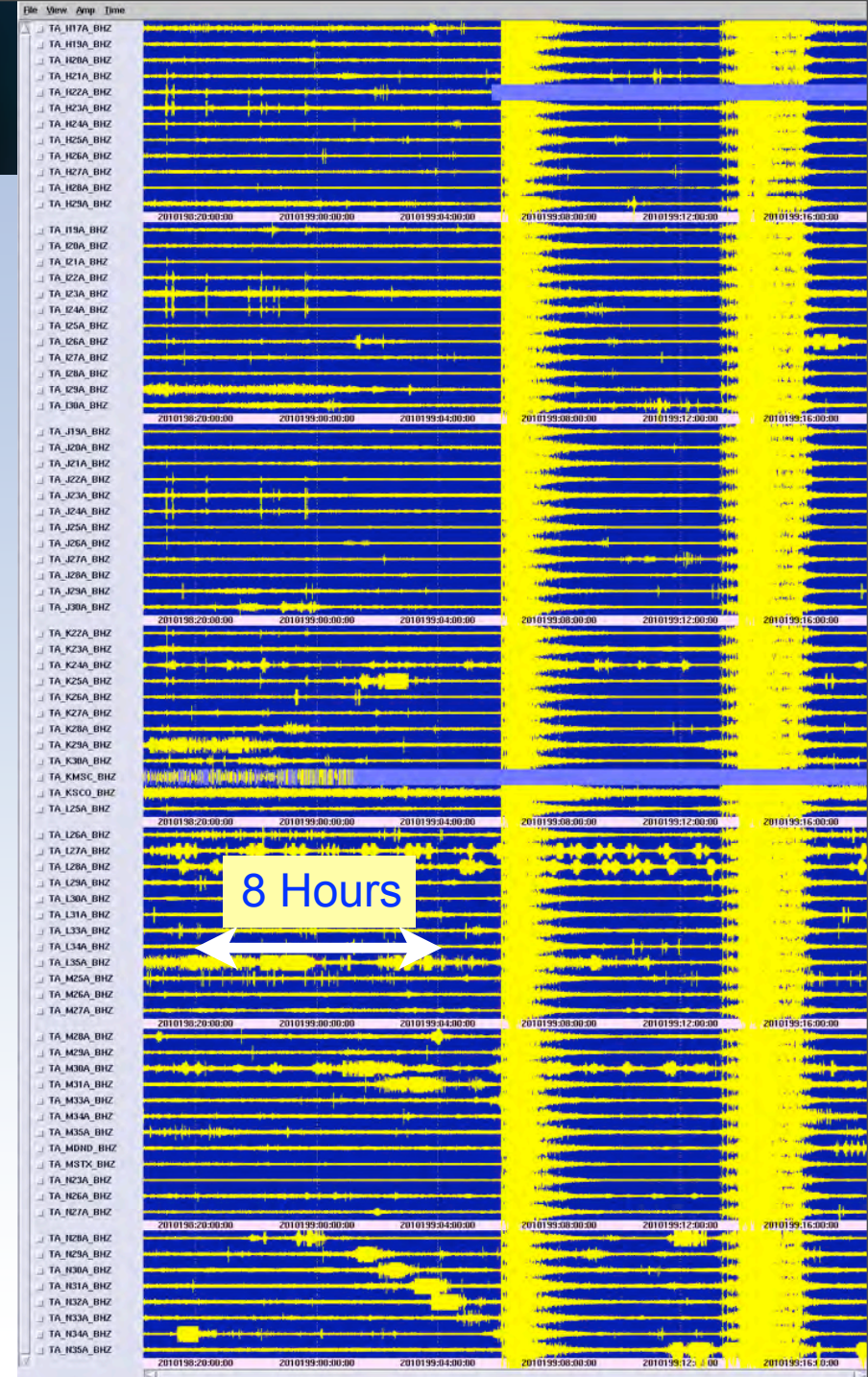




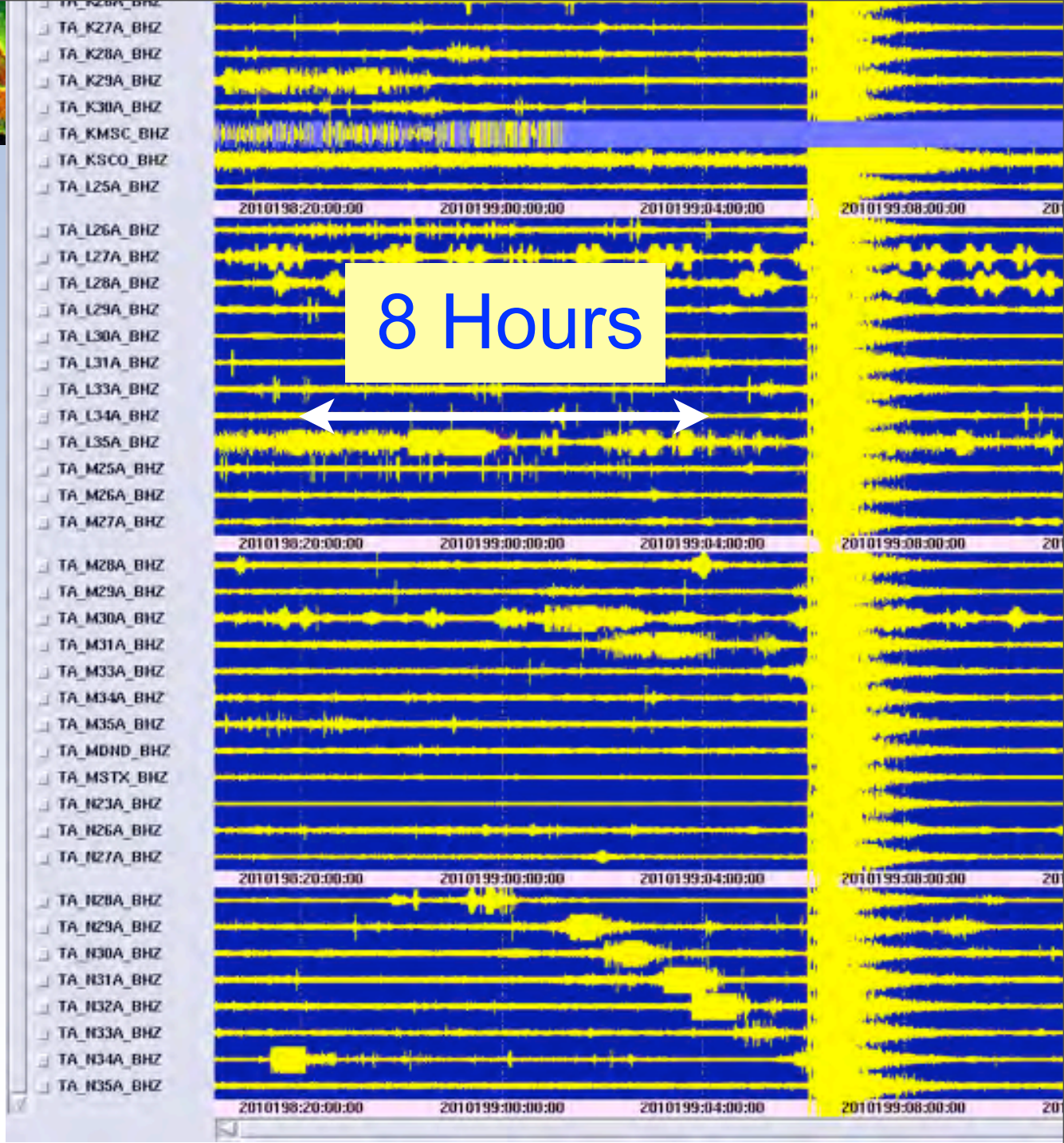
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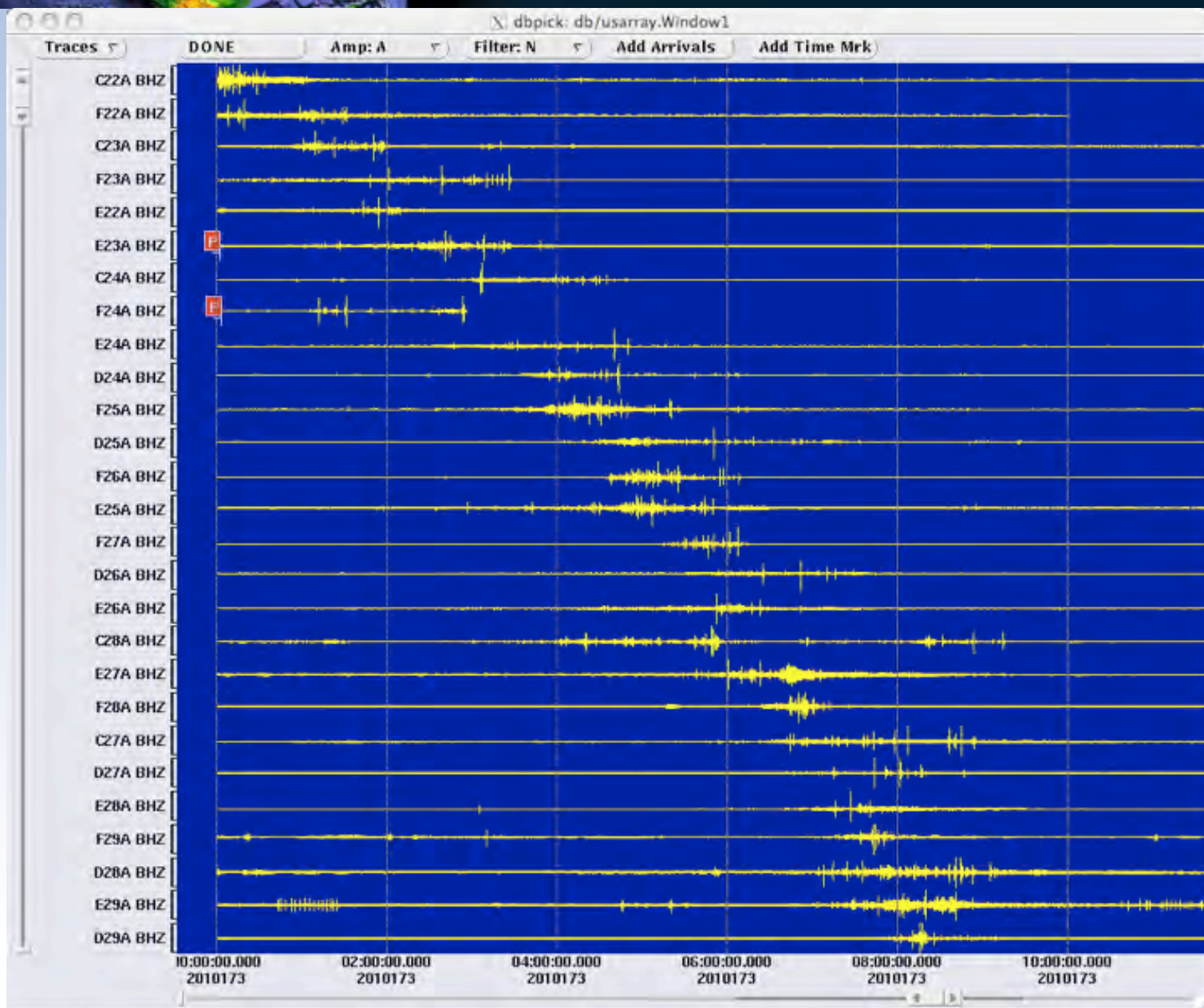
- 6.7 Aleutian Islands
- 6.9 New Britain
- 7.3 New Britain
- Slow move out
  - Too slow for seismic
  - Too slow for infrasound



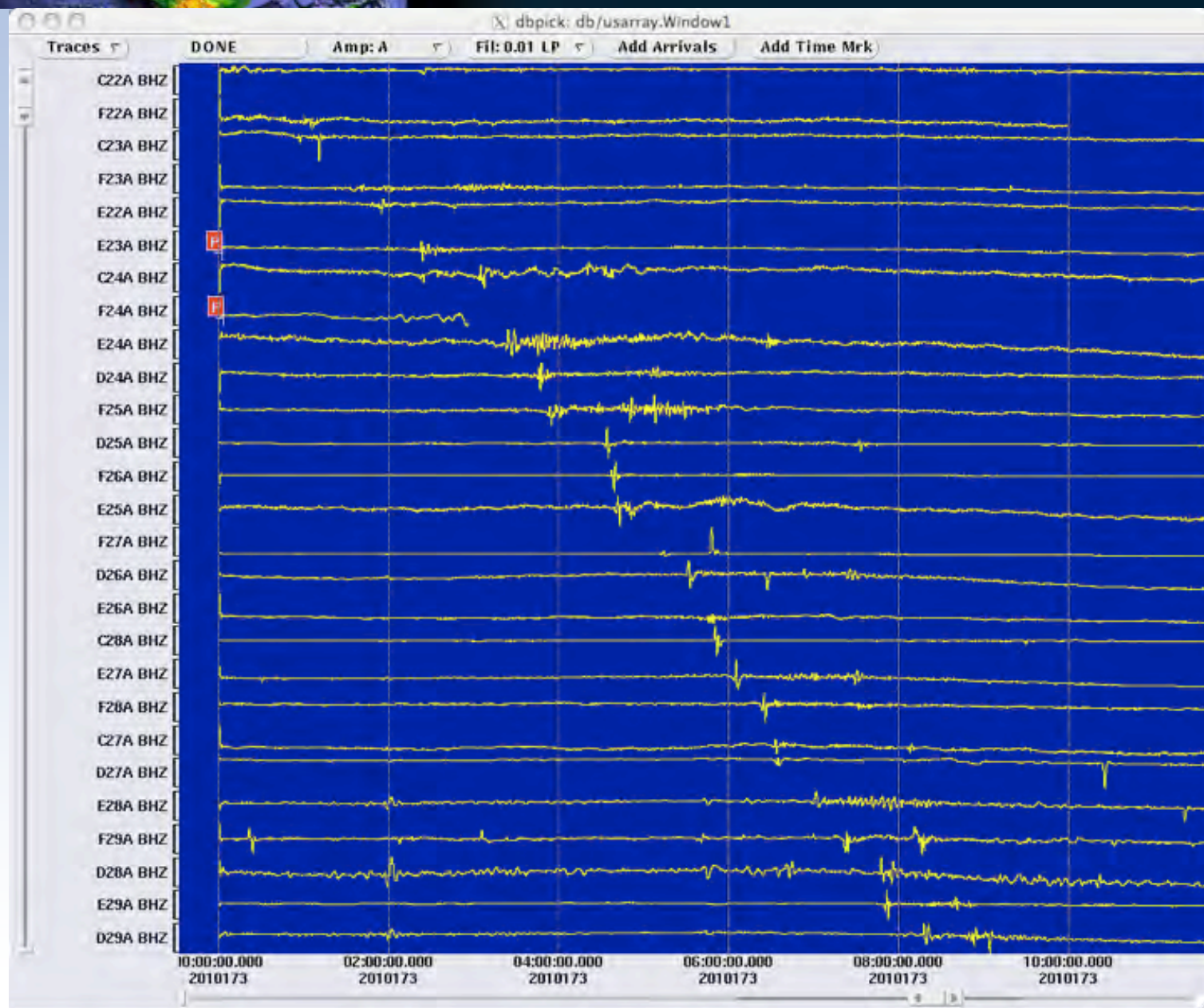
- 6.7 Aleutian Islands
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- 7.3 New Britain
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40 sps  
Unfiltered

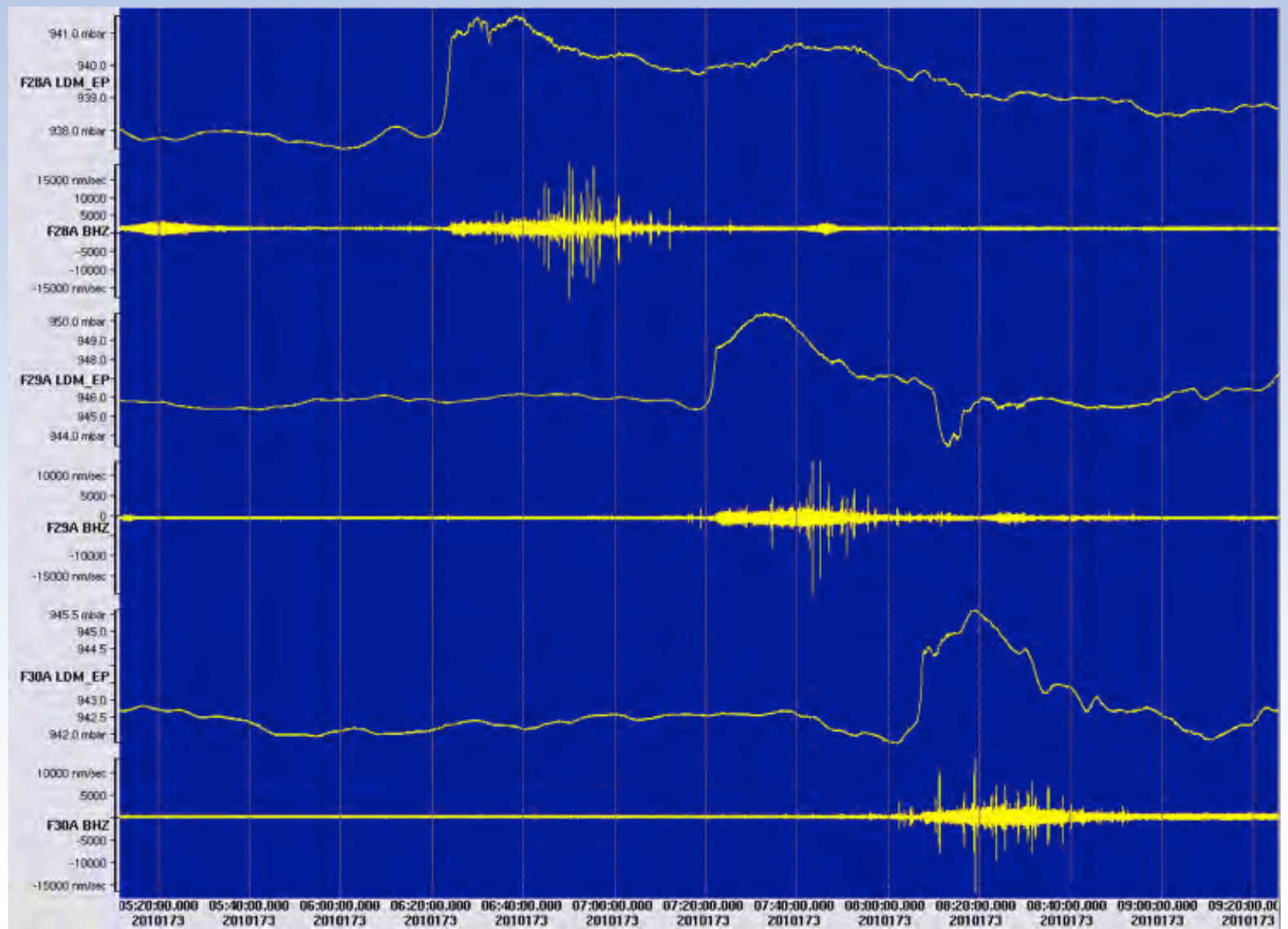


40 sps  
DC - 0.01  
Lowpass  
Filter



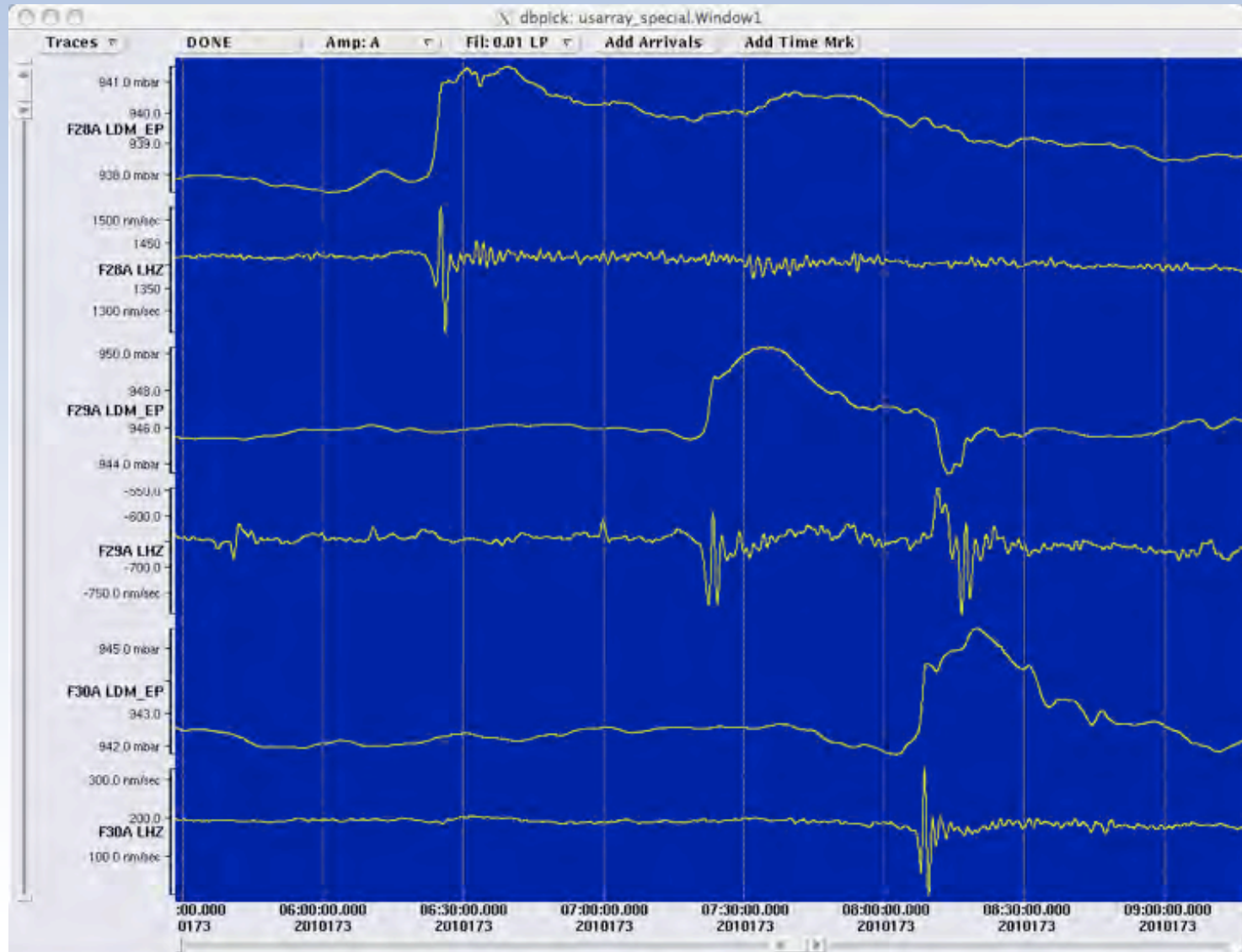
# Interesting Signals

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



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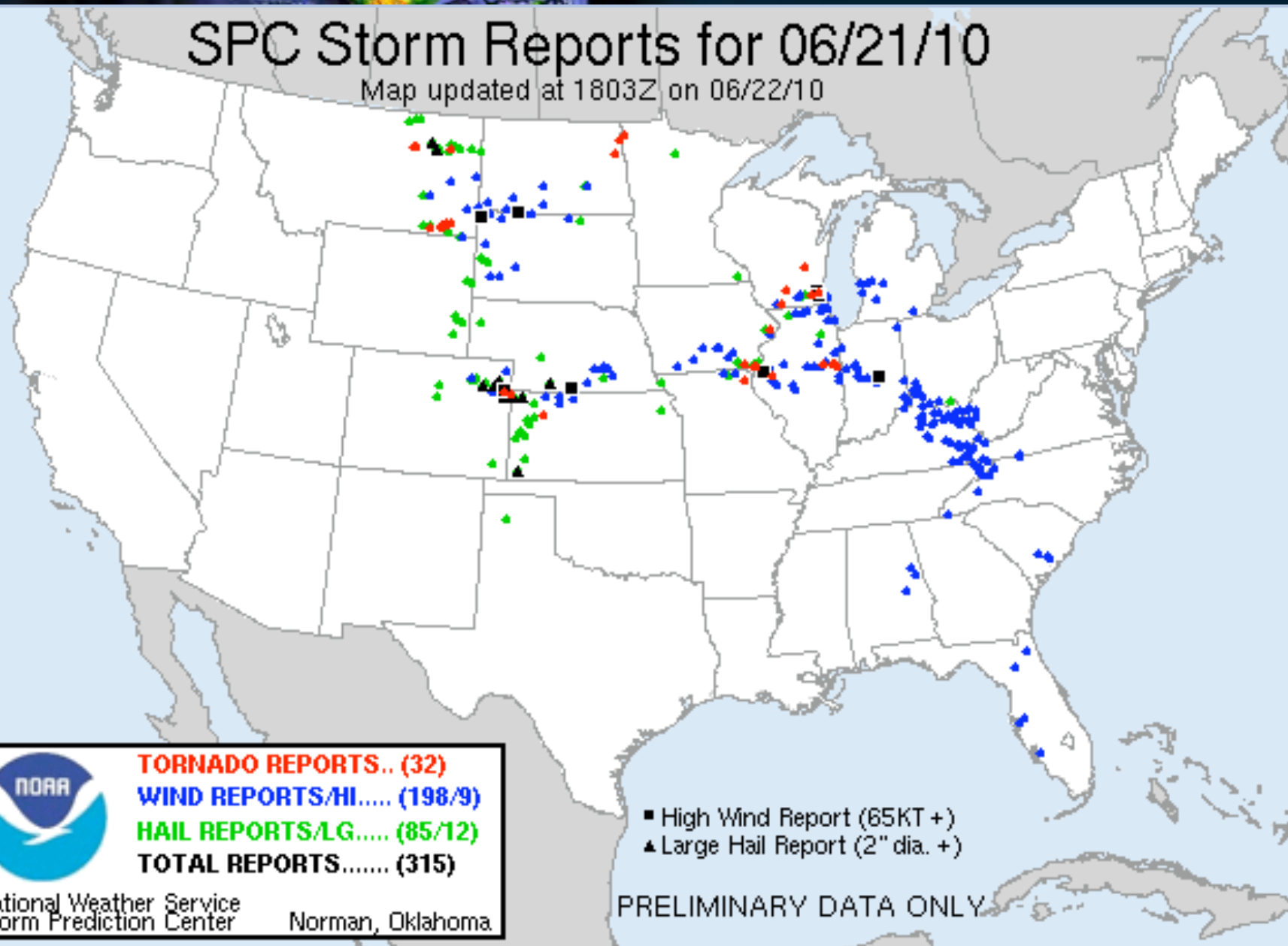
Low Frequency Seismic (< 0.01 Hz) compared to Atmospheric Pressure (1 sps)  
Ground deforming to pressure increase



# Storm Reports

## SPC Storm Reports for 06/21/10

Map updated at 1803Z on 06/22/10



**TORNADO REPORTS.. (32)**  
**WIND REPORTS/HI..... (198/9)**  
**HAIL REPORTS/LG..... (85/12)**  
**TOTAL REPORTS..... (315)**

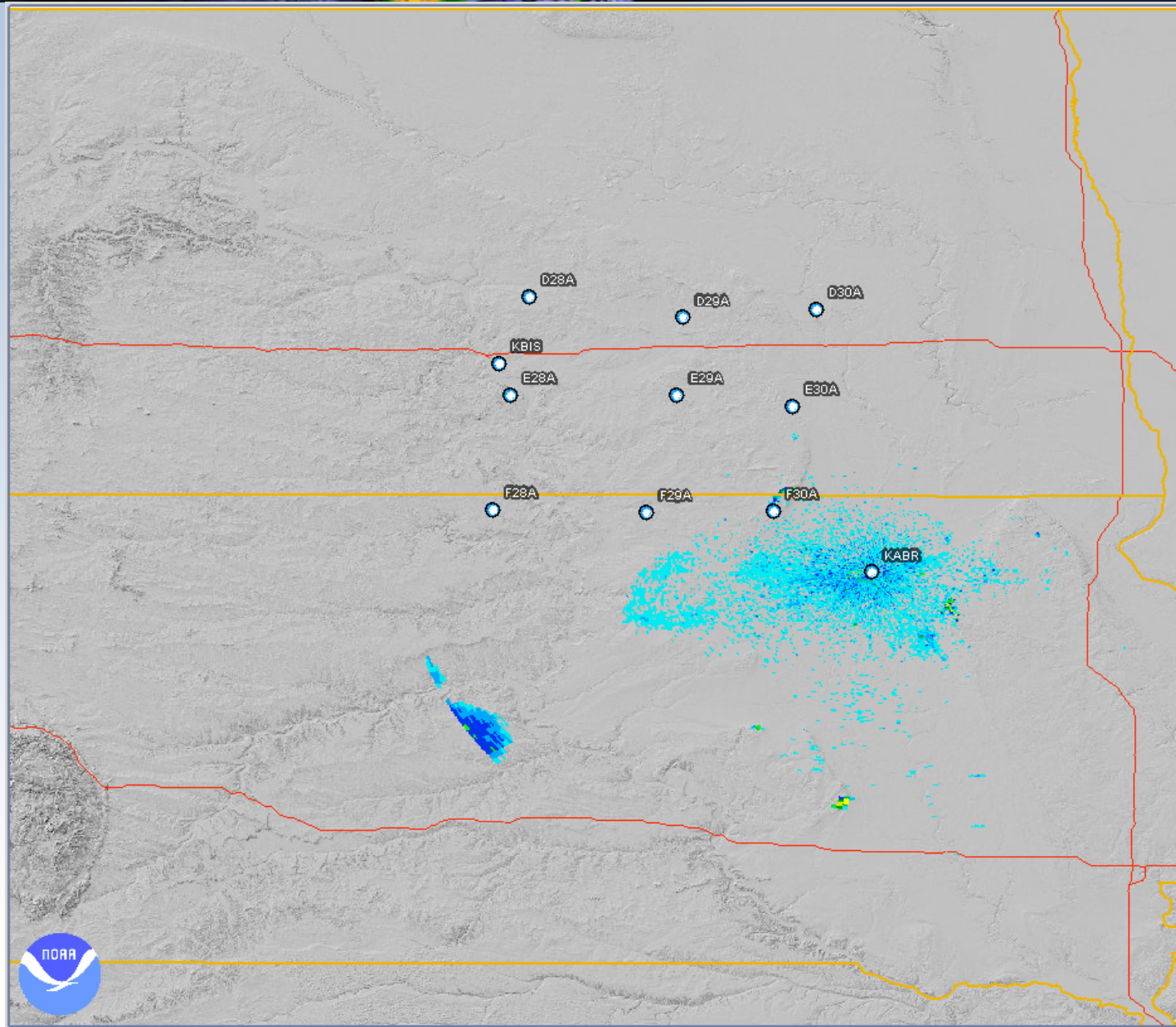
National Weather Service  
Storm Prediction Center      Norman, Oklahoma

- High Wind Report (65KT +)
- ▲ Large Hail Report (2" dia. +)

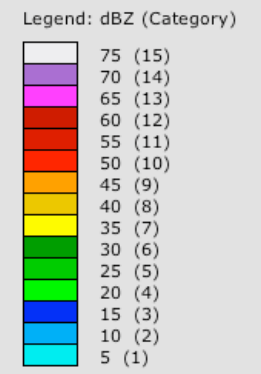
PRELIMINARY DATA ONLY



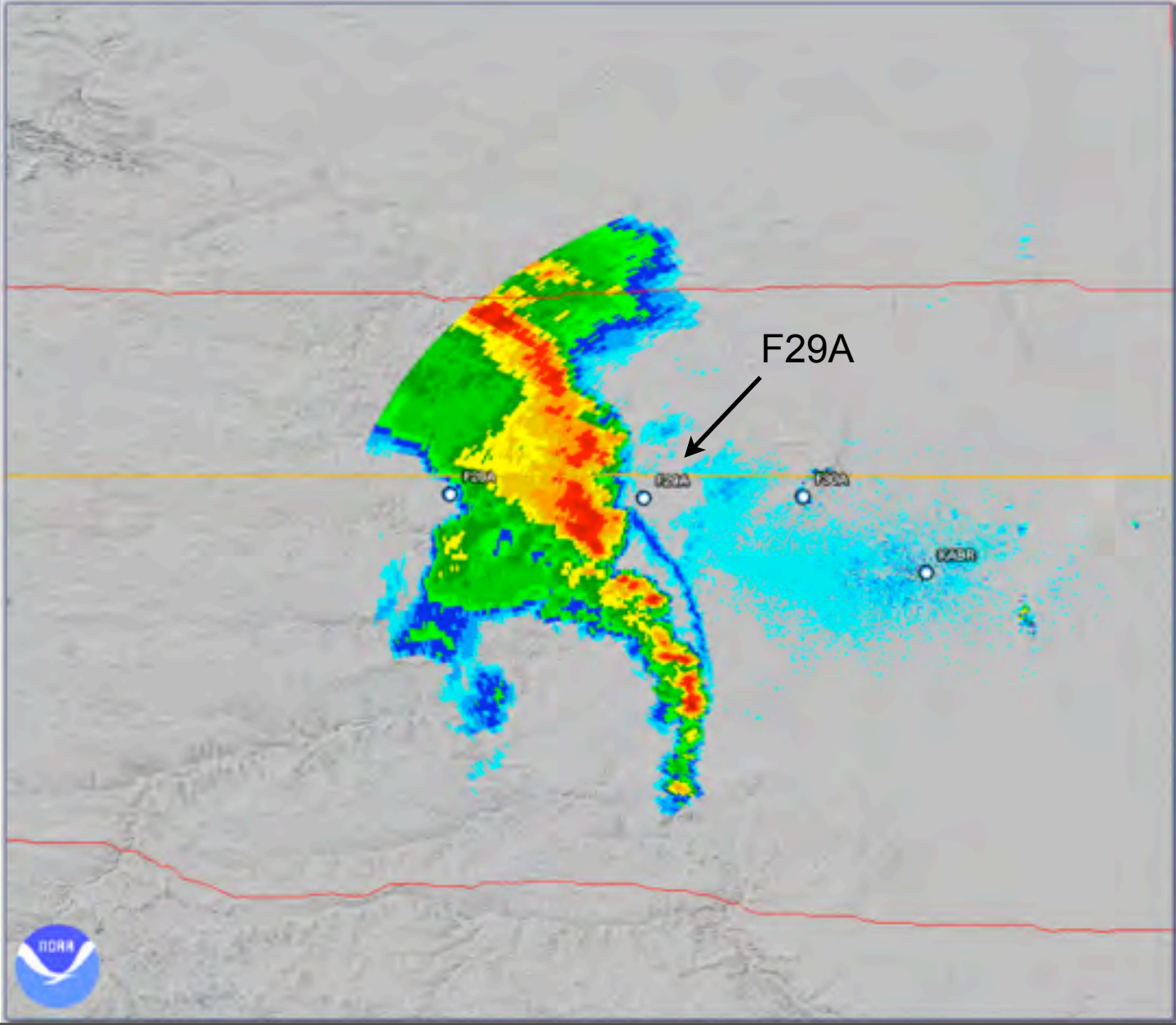
# Interesting Signals



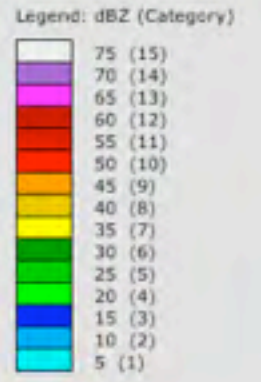
NEXRAD LEVEL-III  
BASE REFLECTIVITY  
KABR - ABERDEEN, SD  
06/22/2010 04:58:35 GMT  
LAT: 45/27/21 N  
LON: 98/24/46 W  
ELEV: 1383 FT  
MODE/VCP: A / 212  
  
ELEV ANGLE: 0.50 °  
MAX: 46 dBZ

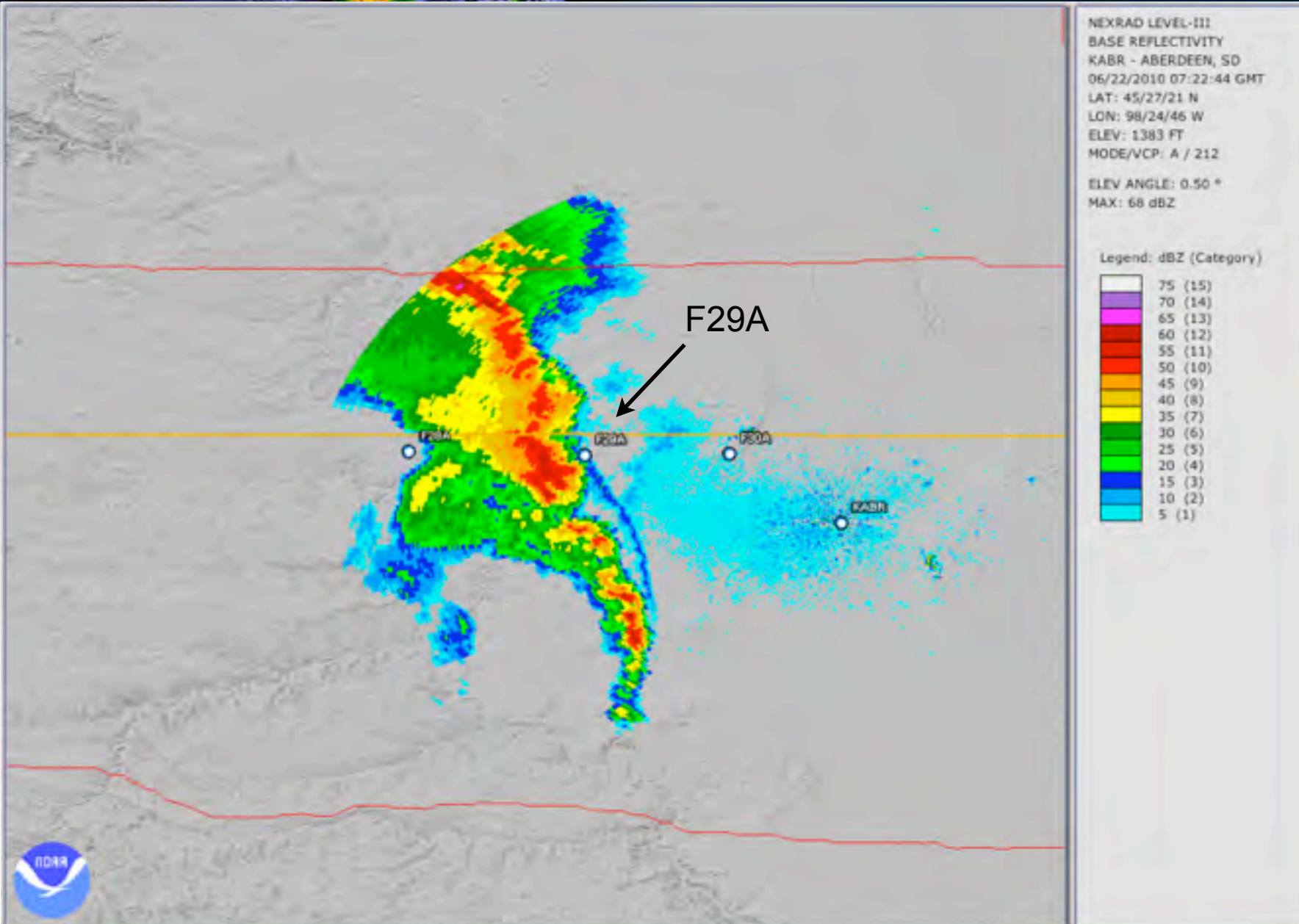


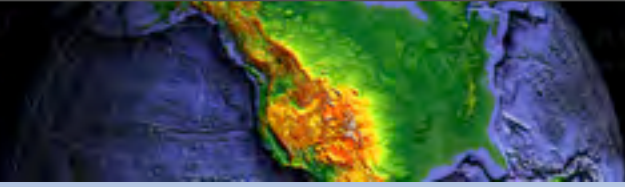
# Radar Image 1 - F29A



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



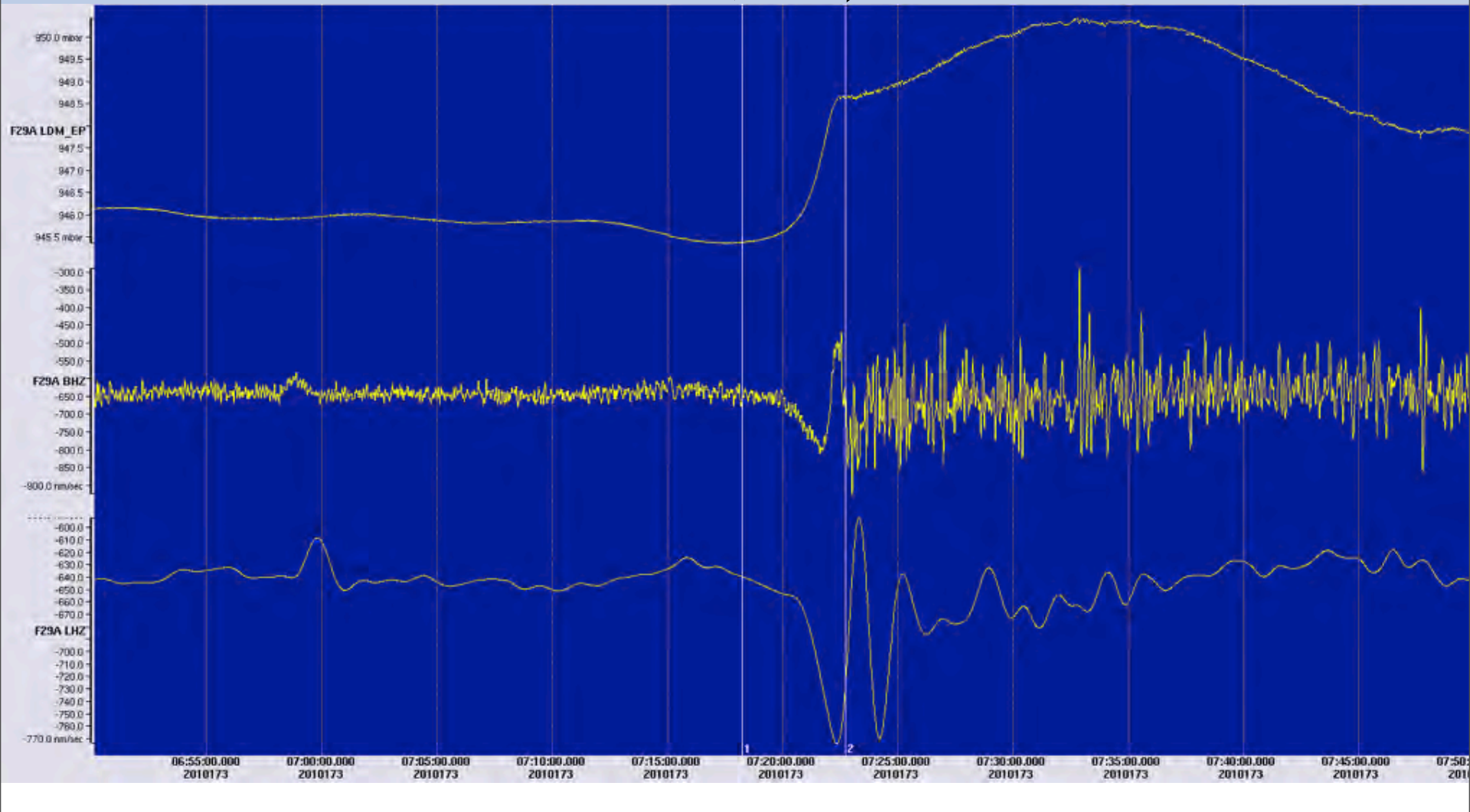


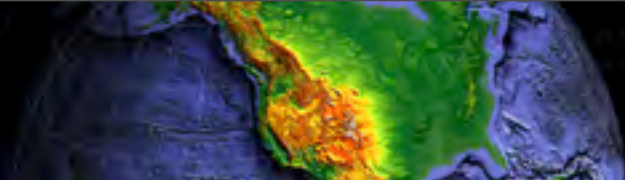


# F29A Pressure and Seismic

Radar Image 1

Radar Image 2

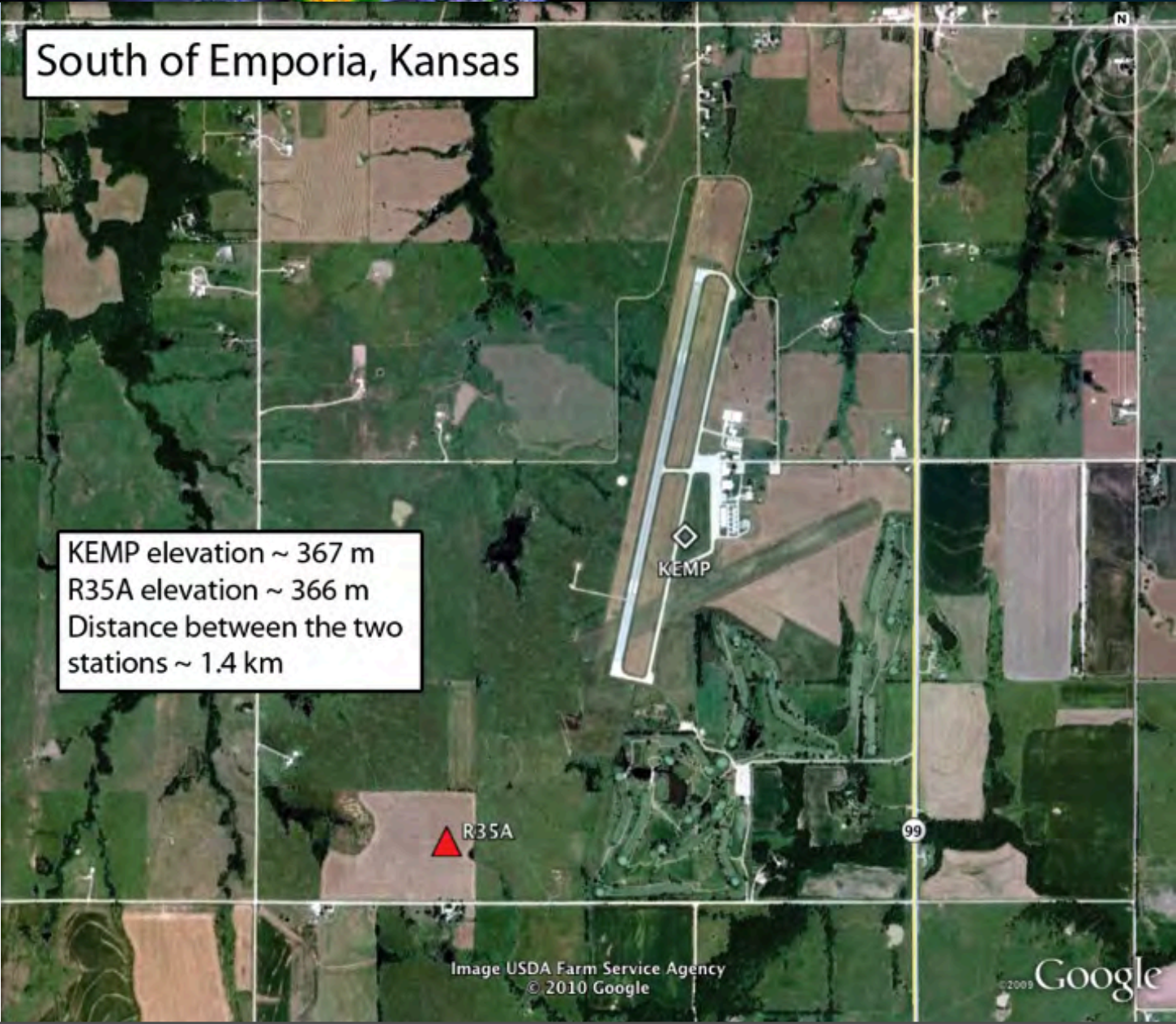


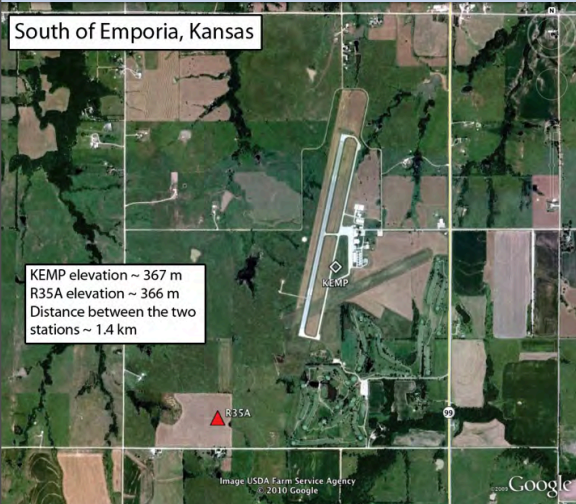


# NWS Comparason

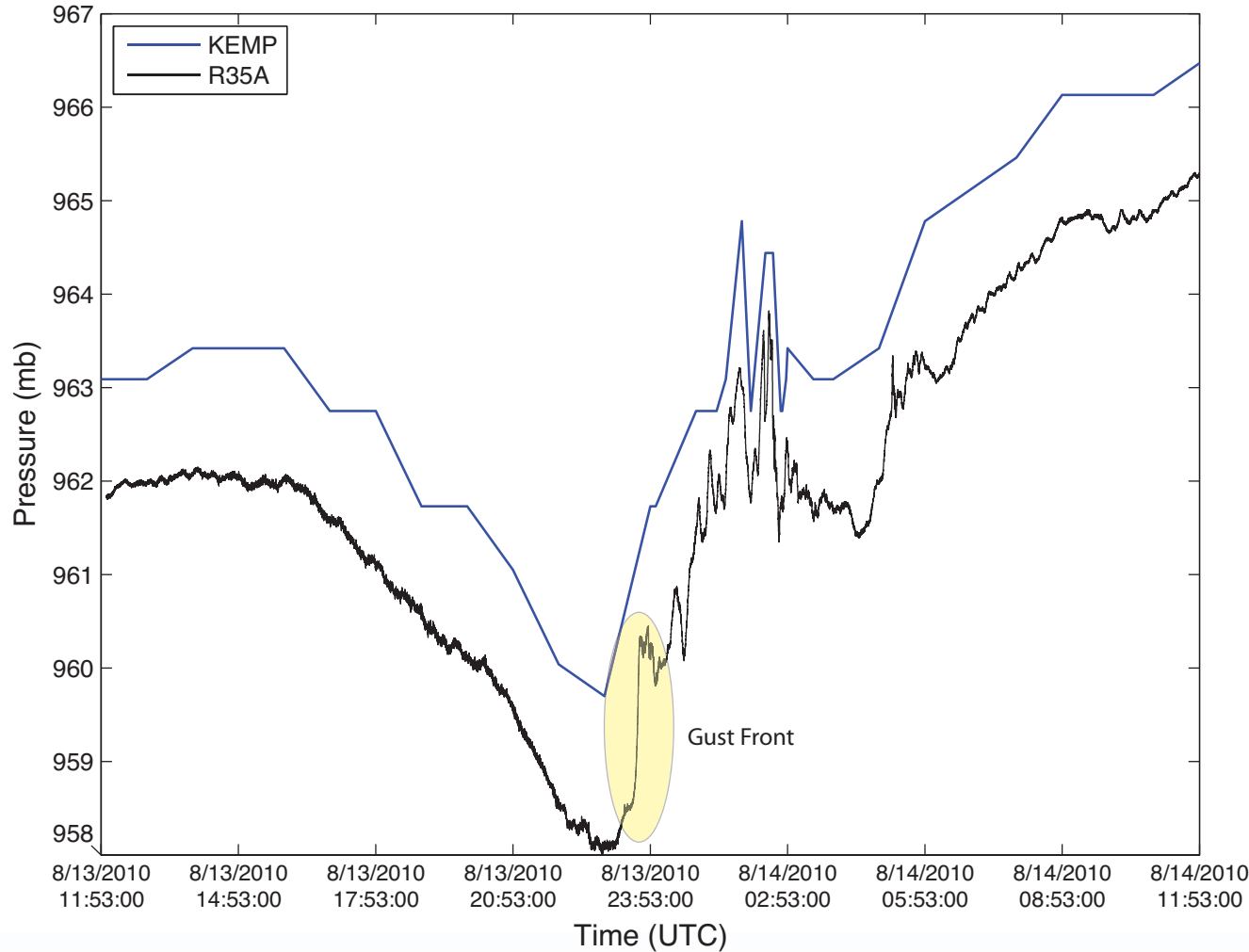
South of Emporia, Kansas

KEMP elevation ~ 367 m  
R35A elevation ~ 366 m  
Distance between the two  
stations ~ 1.4 km

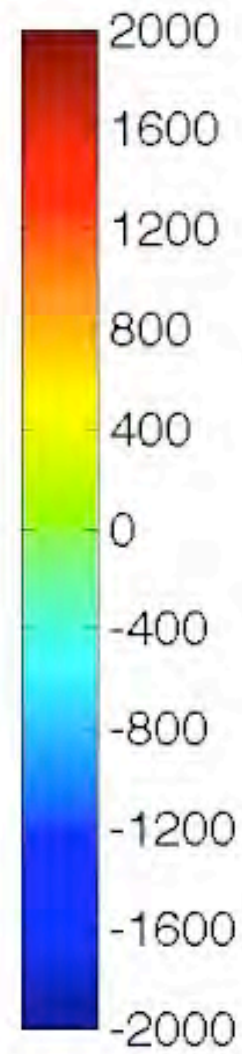




Data Sampling Comparason  
 ASOS Station KEMP vs. TA Station R35A



2011 4 18 15



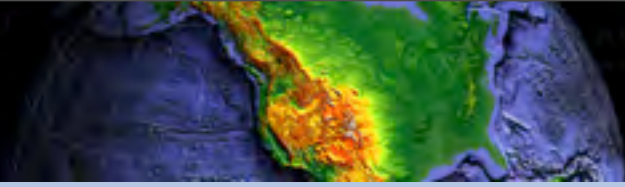
# Barometric Pressure Variations Unfiltered Data

2011 4 18 15



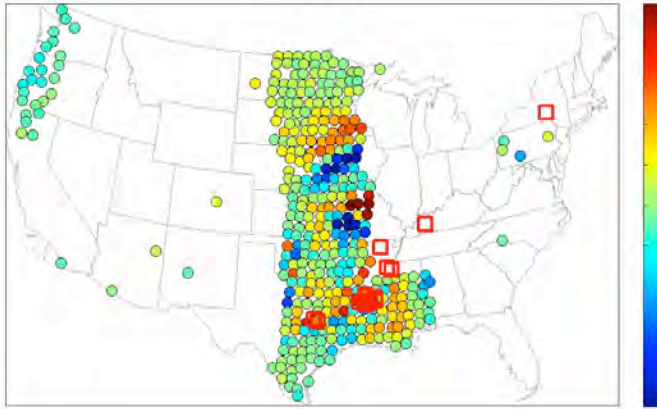
## Atmospheric Gravity Wave Band Periods - 2 to 6 Hours



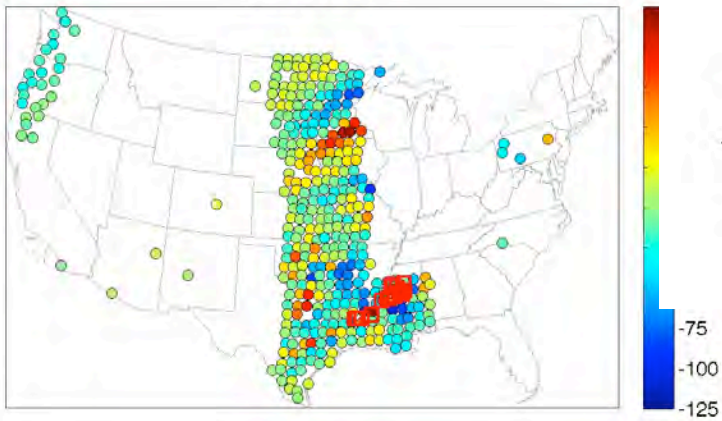


# North propagating 2-6 hr GW

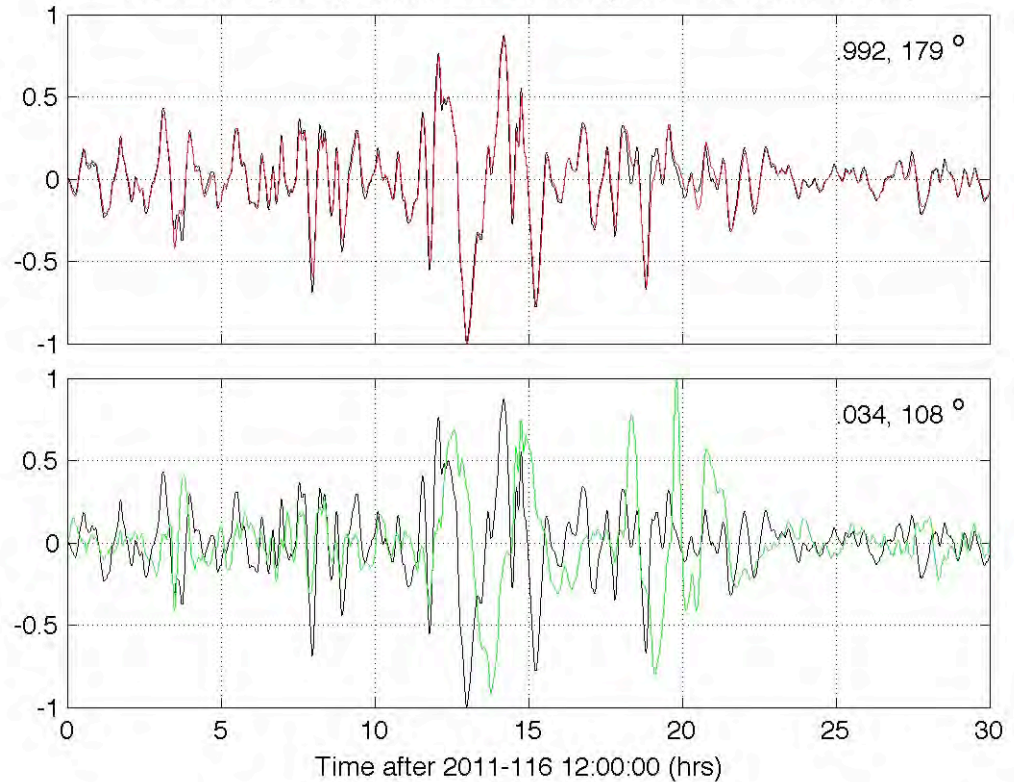
2011 4 27 3



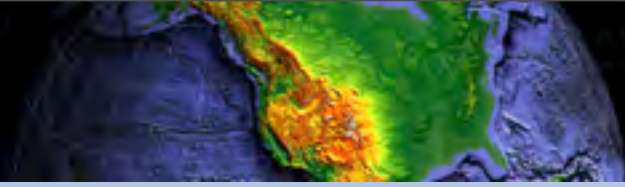
2011 4 27 7



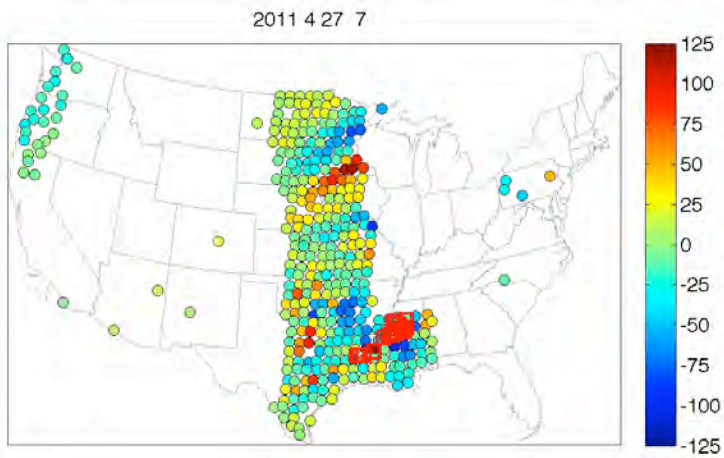
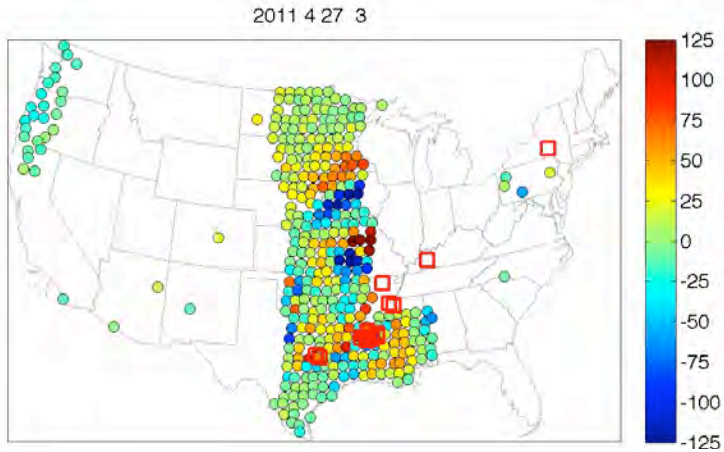
Barometric (Black), Rotated Horizontals (Best=Red, Worst=Green)



S36A: 1,800 to 8,000 s

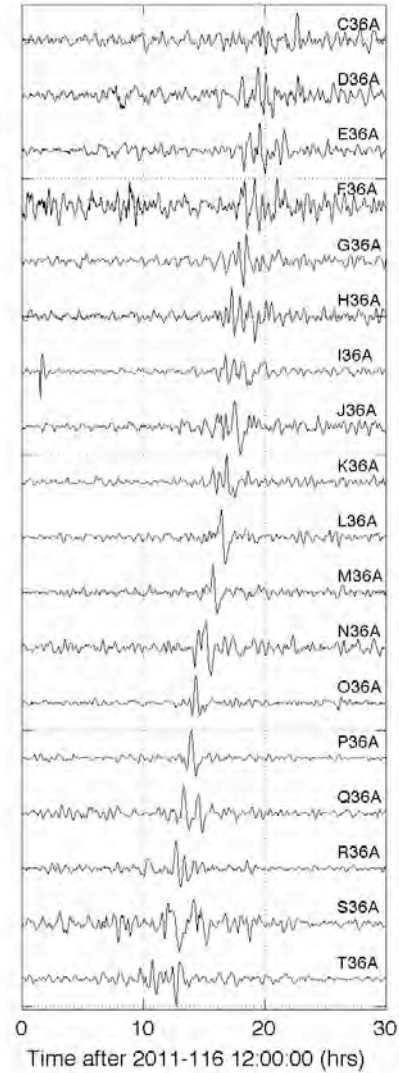


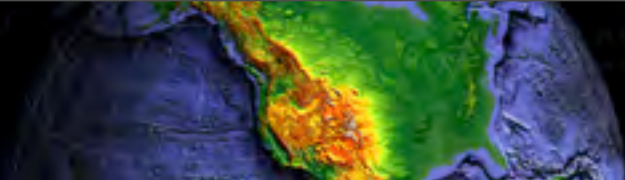
# North propagating 2-6 hr GW



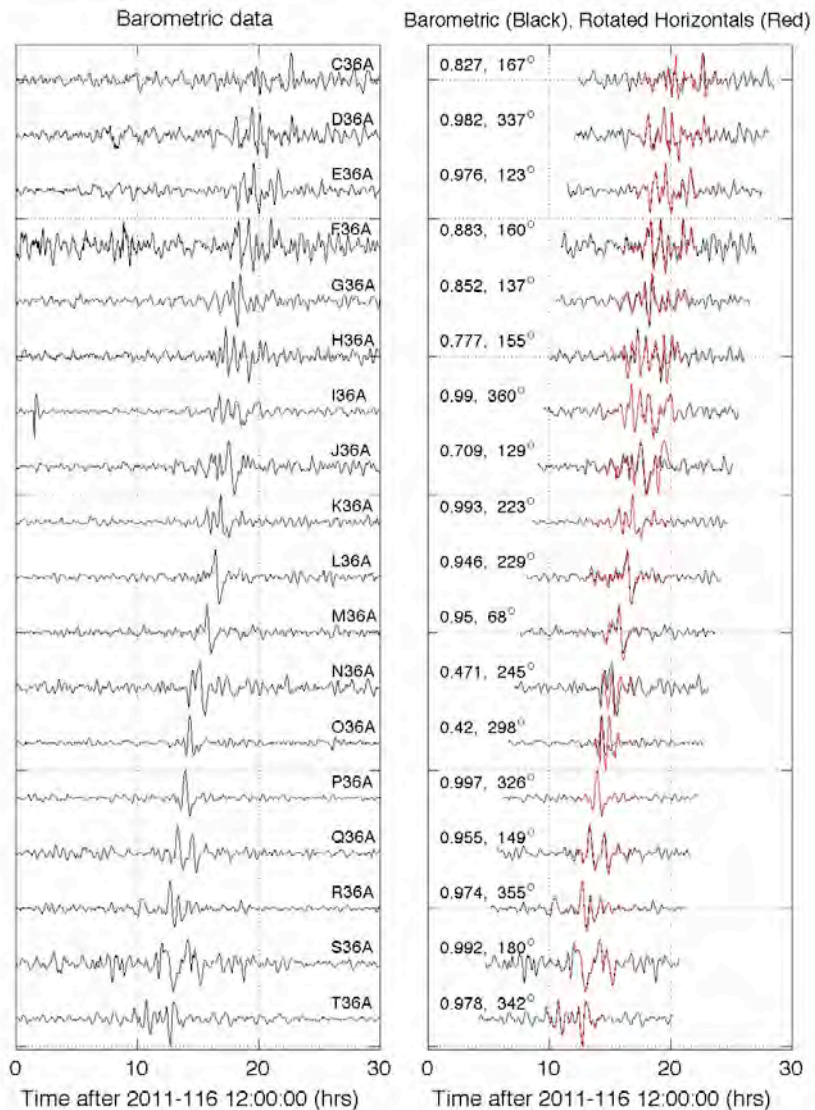
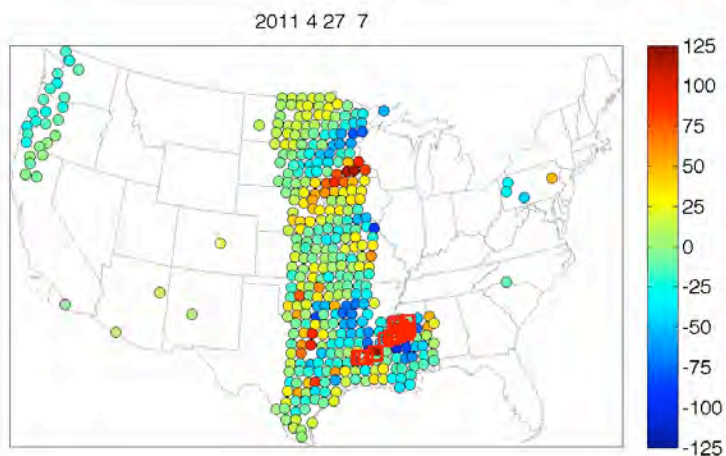
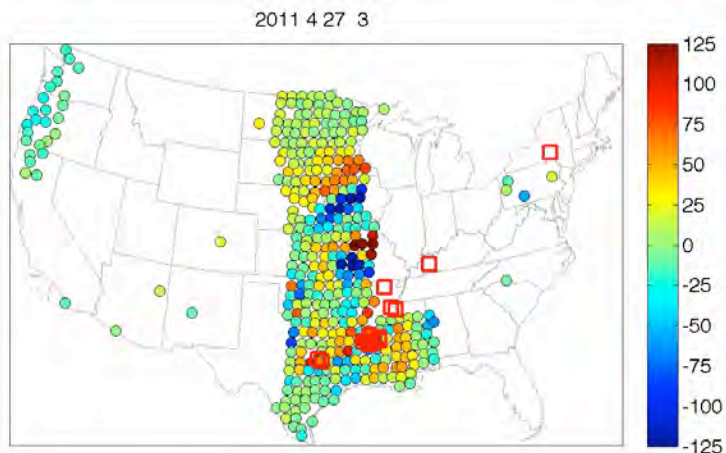
Barometric data

B



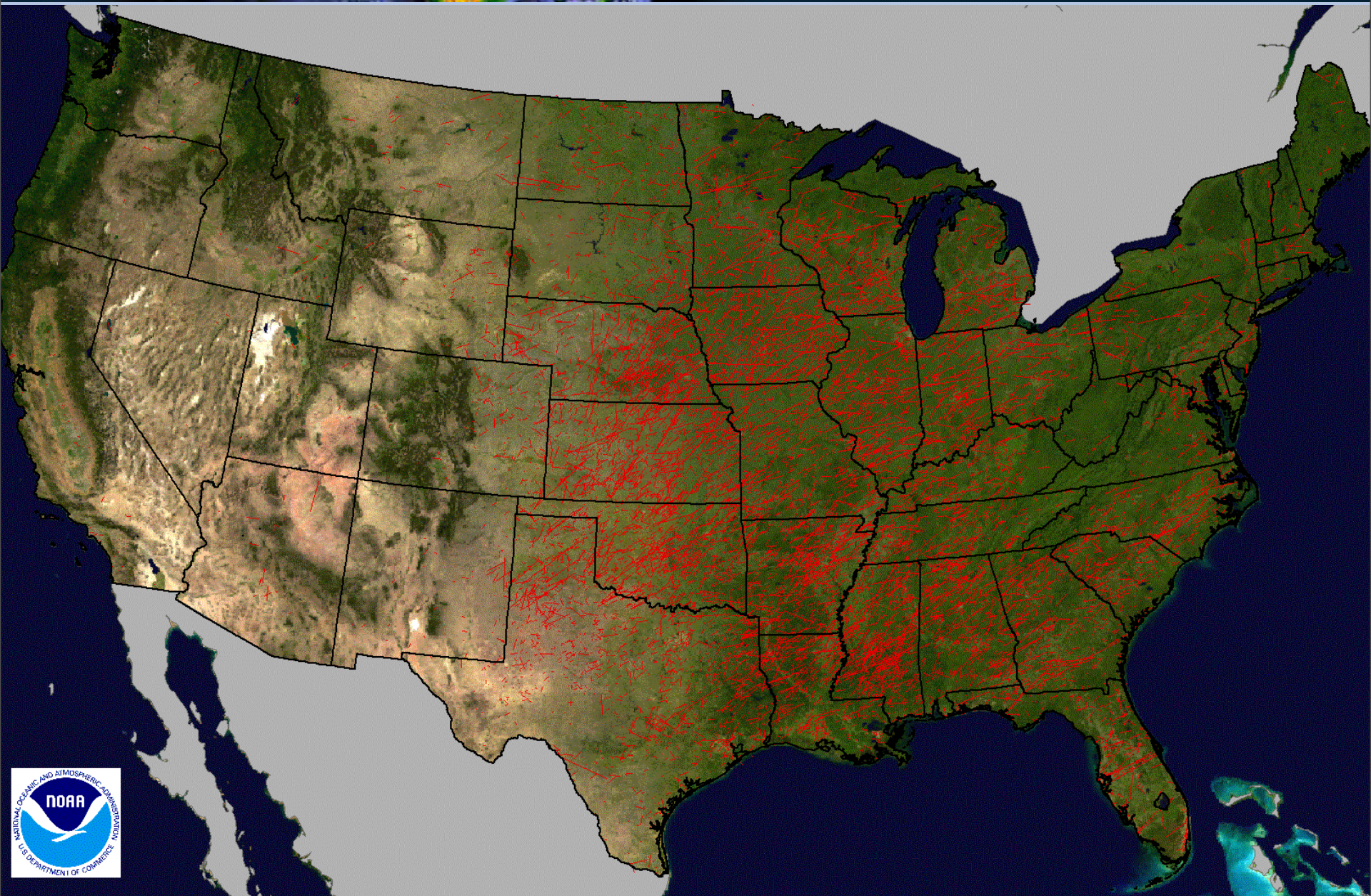


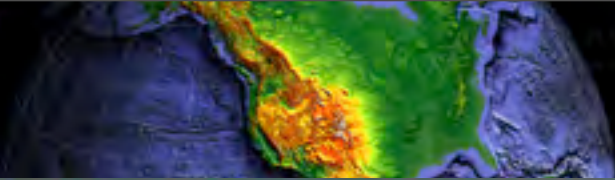
# North propagating 2-6 hr GW





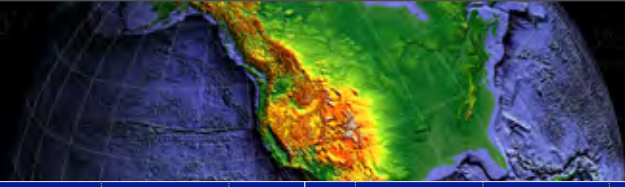
# Tornado Prevalence



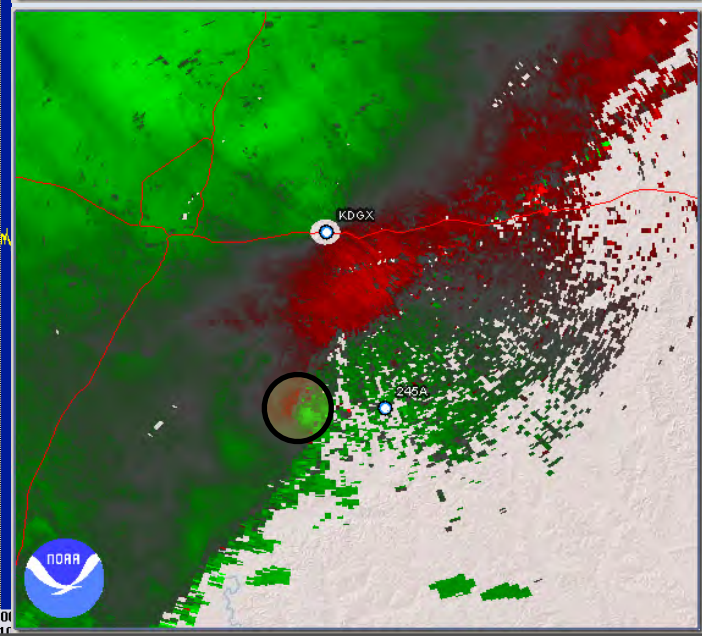
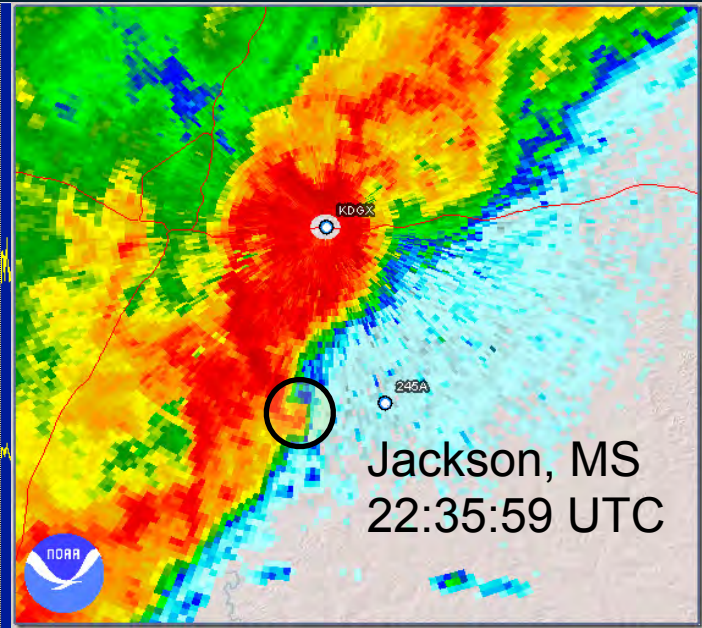
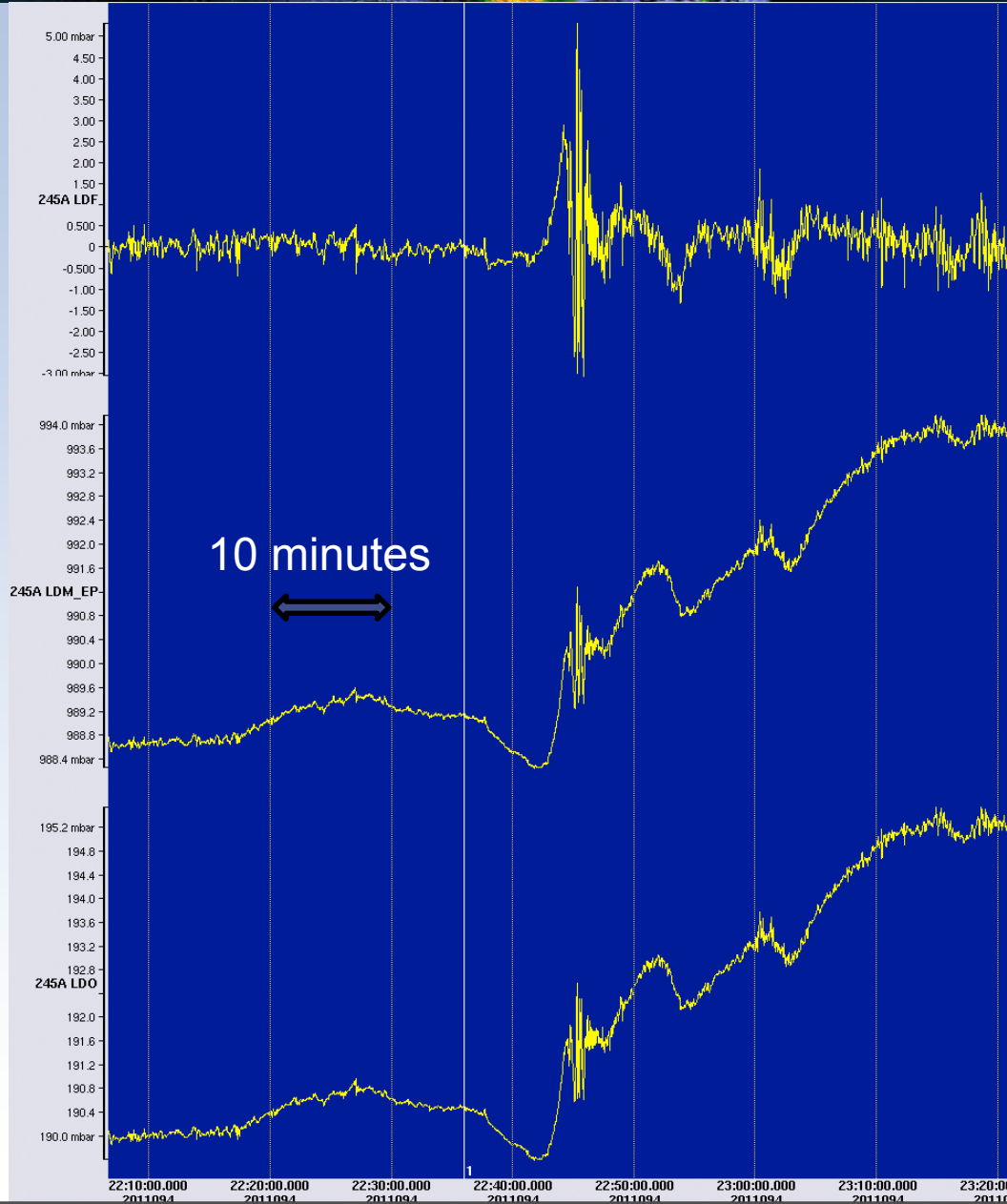


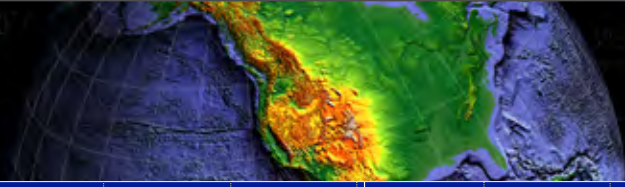
# Jackson Tornado on 4/15/2011 – 245A



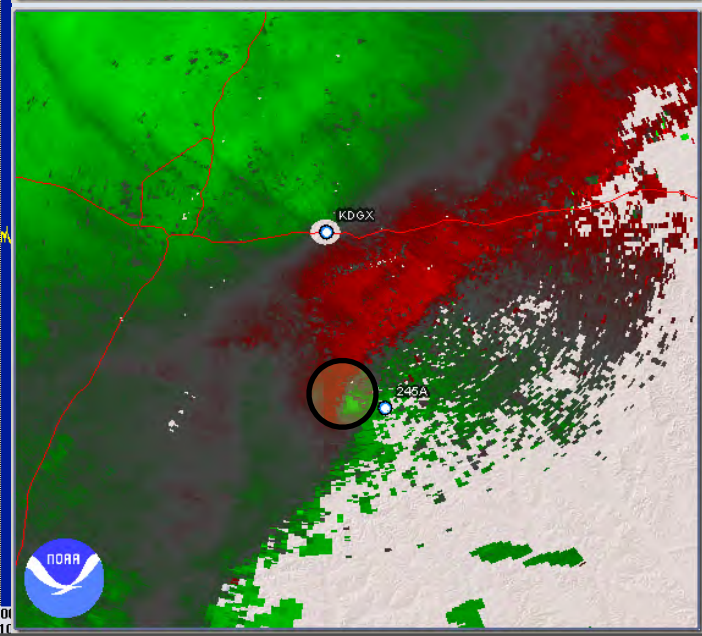
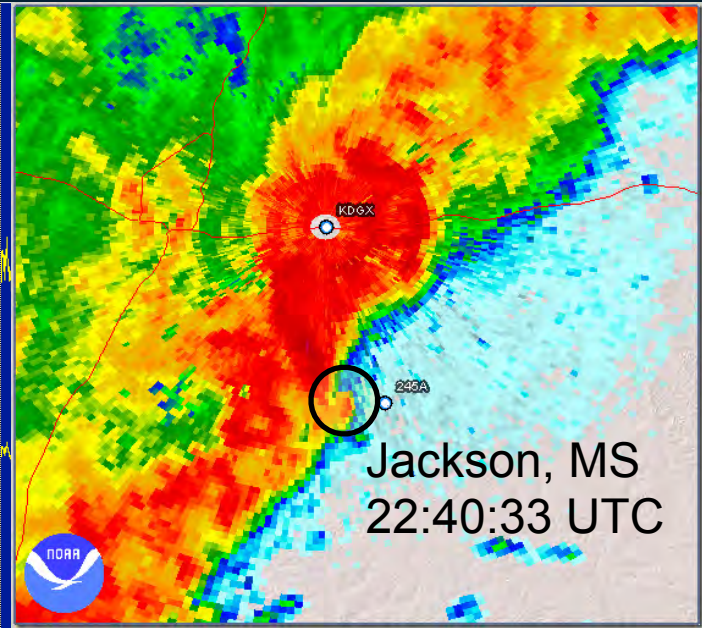
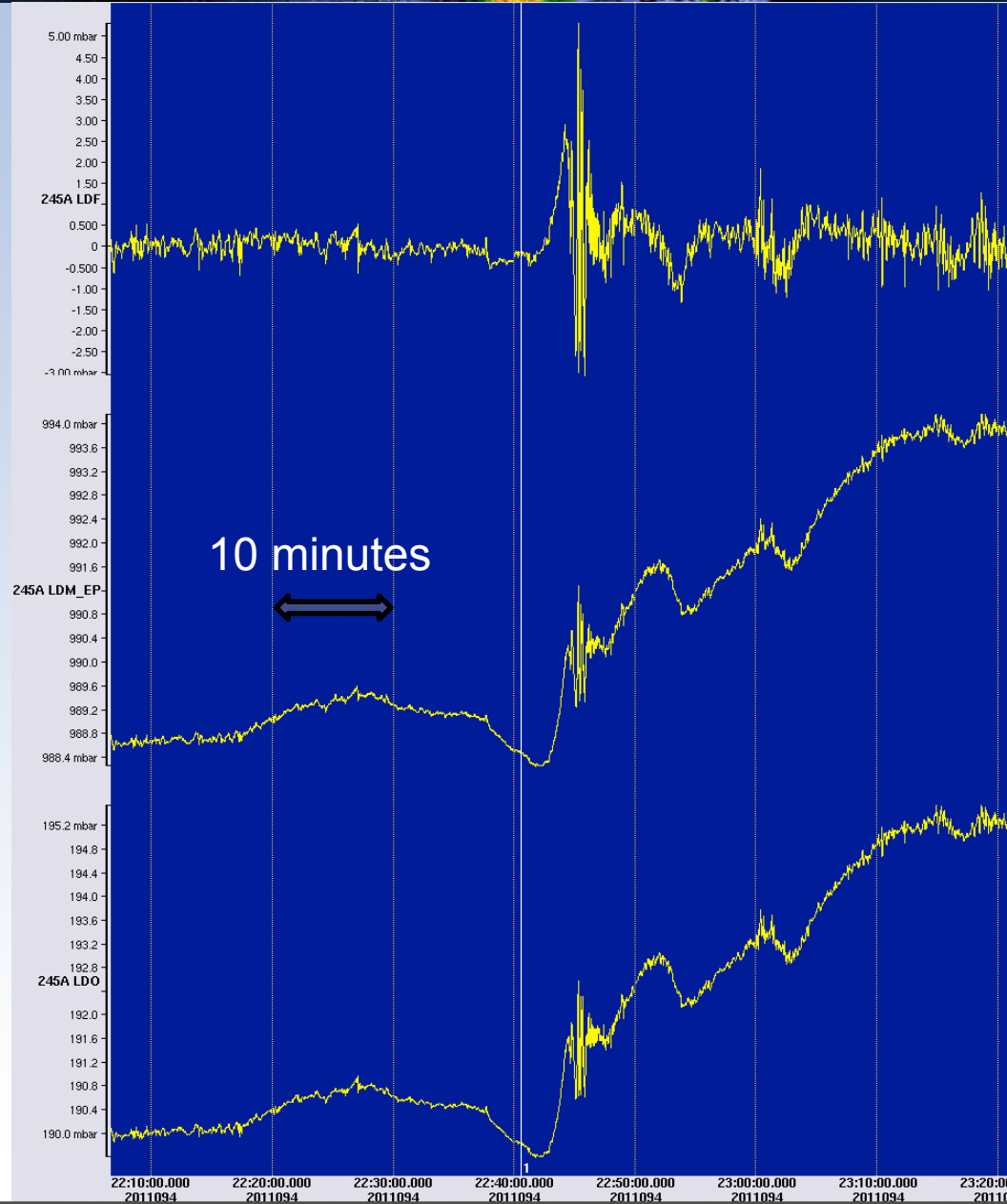


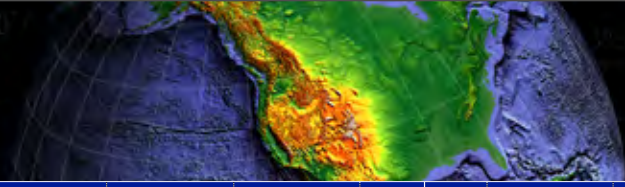
# Jackson Tornado on 4/15/2011 – 245A



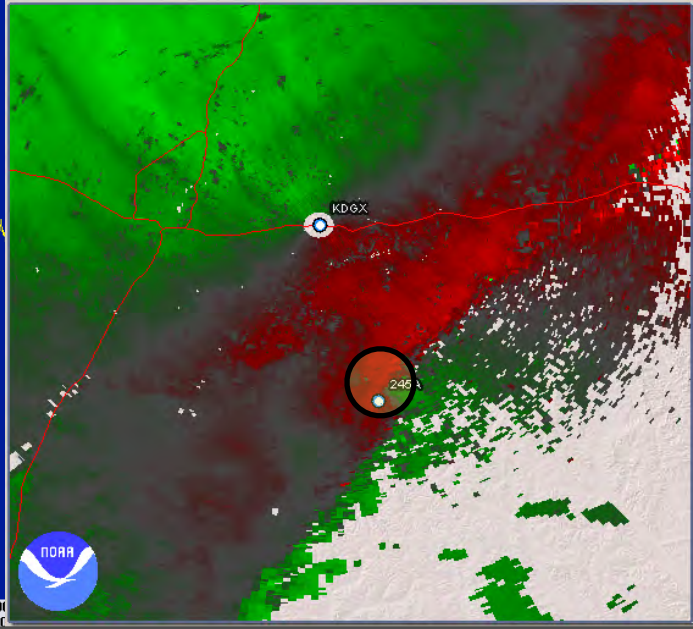
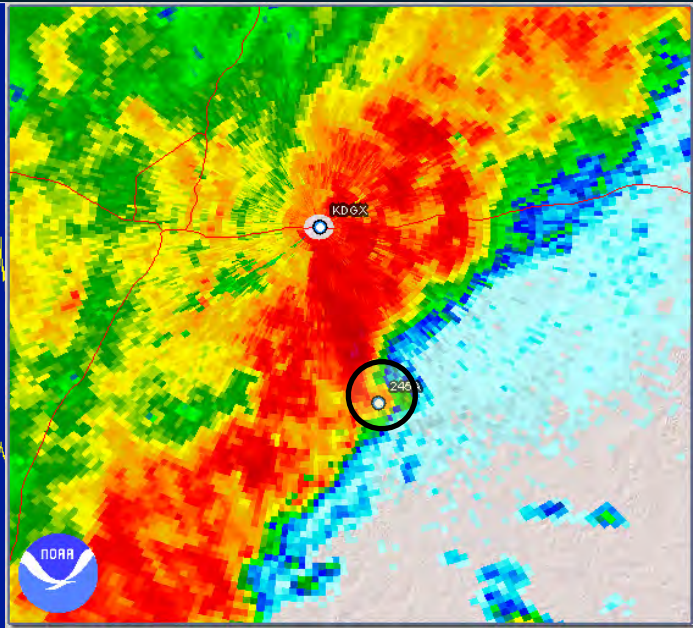
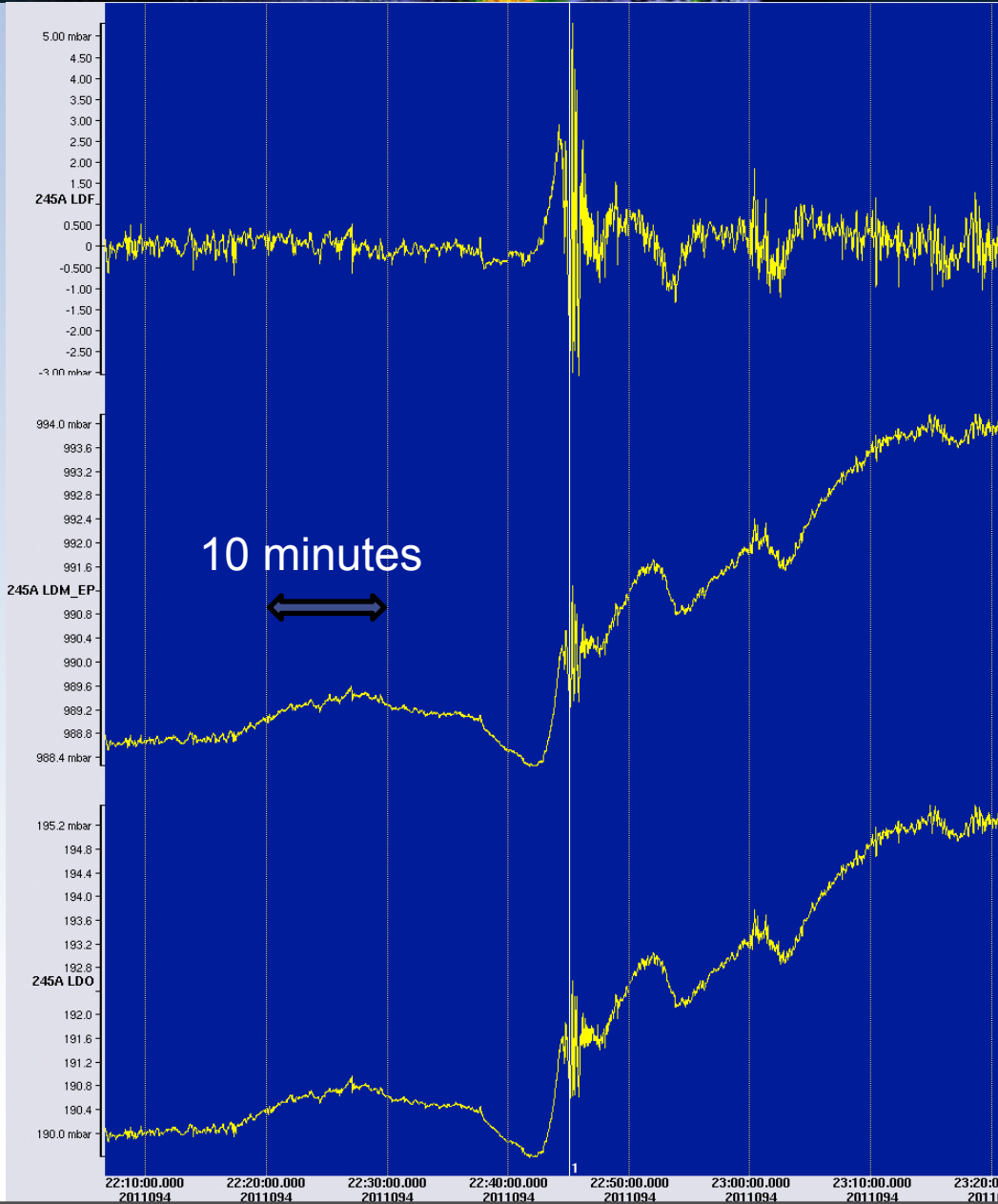


# Jackson Tornado on 4/15/2011 – 245A

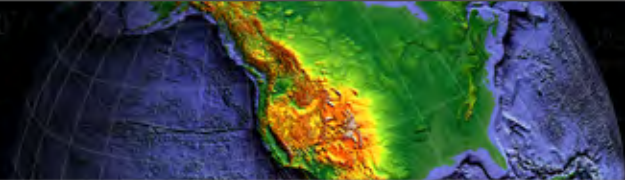




# Jackson Tornado on 4/15/2011 – 245A

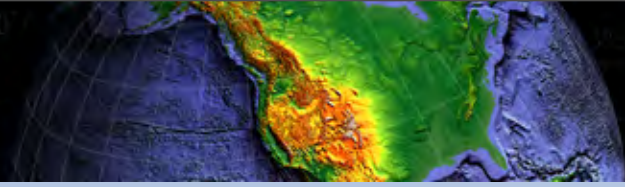




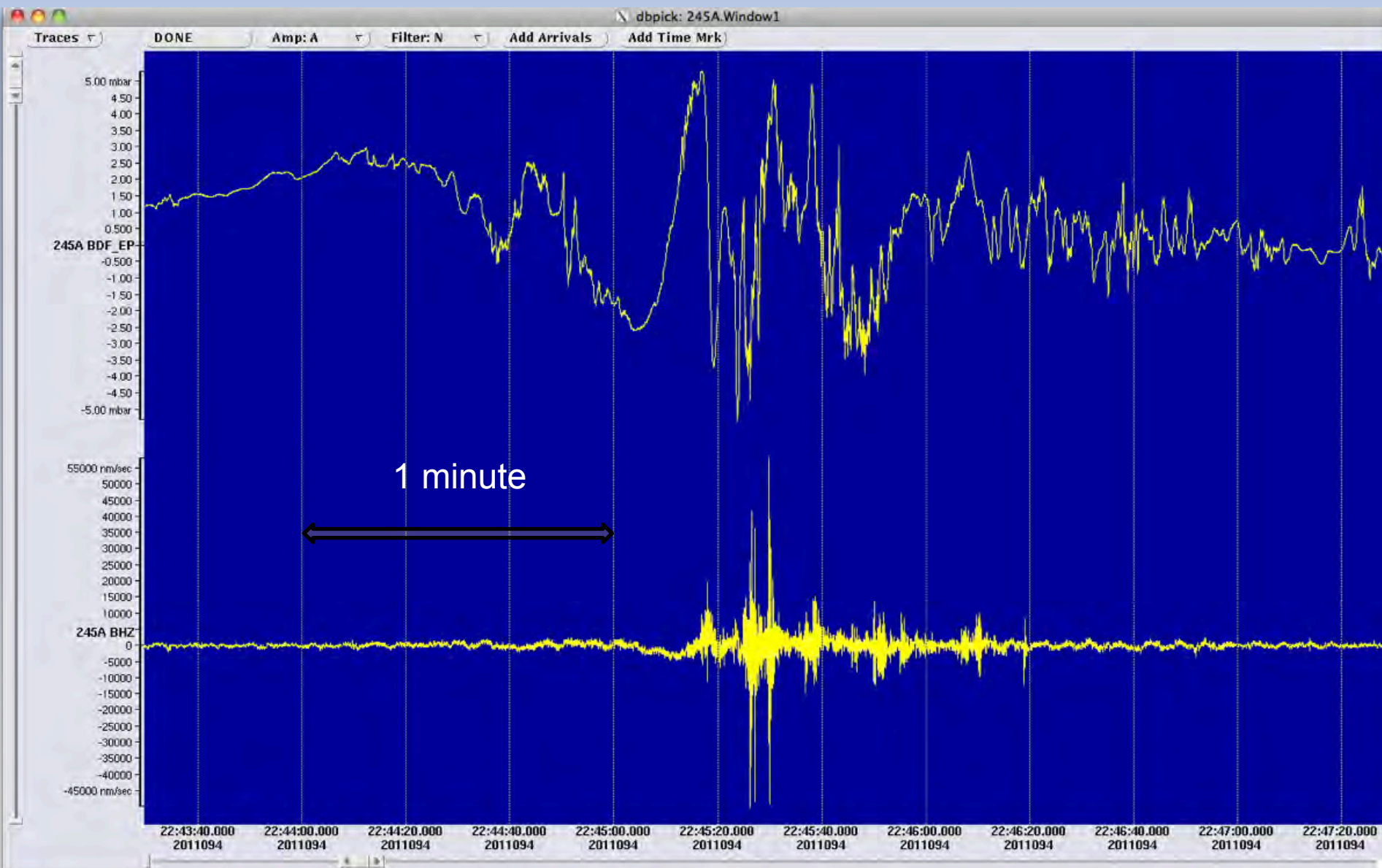


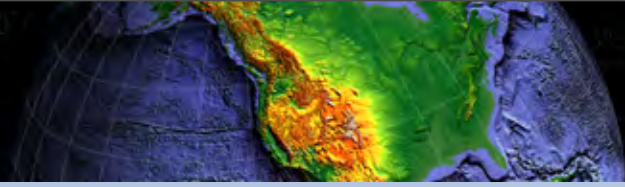
# Jackson Tornado on 4/15/2011 – 245A

Google Earth interface showing a satellite view of a rural area. A blue shaded region is visible on the left side of the map. A red triangle marker labeled '245A' is located on the right side of the map. The interface includes a search bar, a 'Places' list, and a 'Layers' panel. The 'Places' list contains several entries related to tornado damage reports, including 'T6\_09152010', 'T7\_09152010', 'T8\_09152010', 'T1\_10242010', 'T2\_04052011', 'W1\_04052011', 'T1\_04262011', and 'T1\_04052011'. The 'Layers' panel shows various map layers such as 'Primary Database', 'Borders and Labels', 'Places', 'Photos', 'Roads', '3D Buildings', 'Ocean', 'Weather', 'Gallery', and 'Global Awareness'. The map shows a road labeled 'Phillips Lane' and a red triangle marker labeled '245A'. The 'Array Network Facility' is labeled at the bottom left of the map. The Google logo is visible at the bottom right of the map. The status bar at the bottom shows the year '1996', coordinates 'lat 32.042159° lon -89.921062° elev 109 m', and 'Eye alt 1.76 km'.

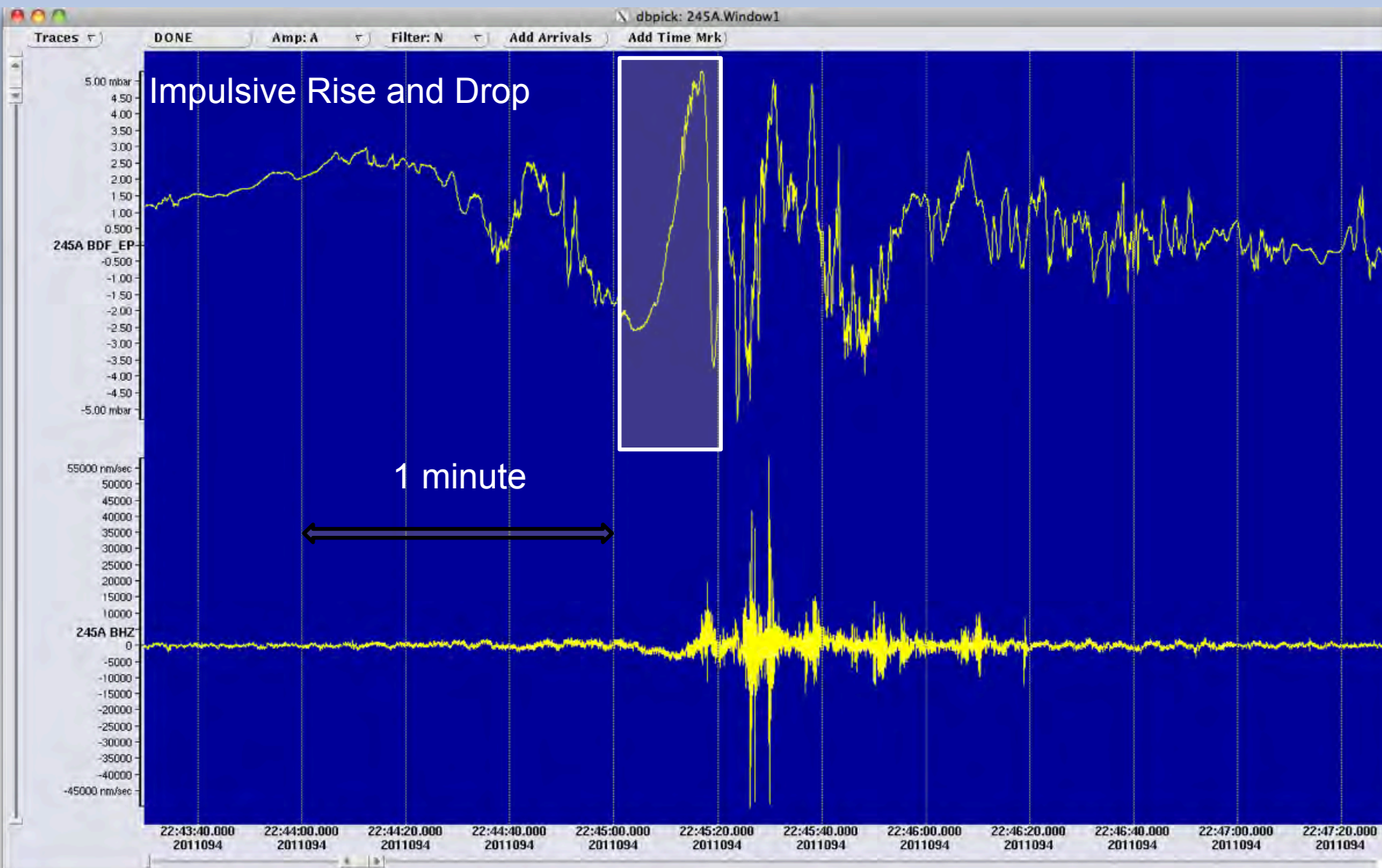


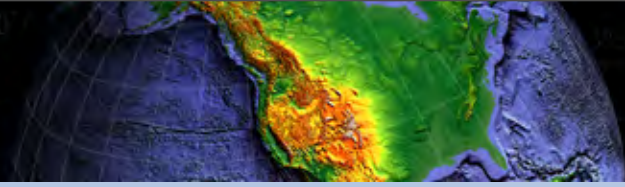
# Jackson Tornado on 4/15/2011 – 245A



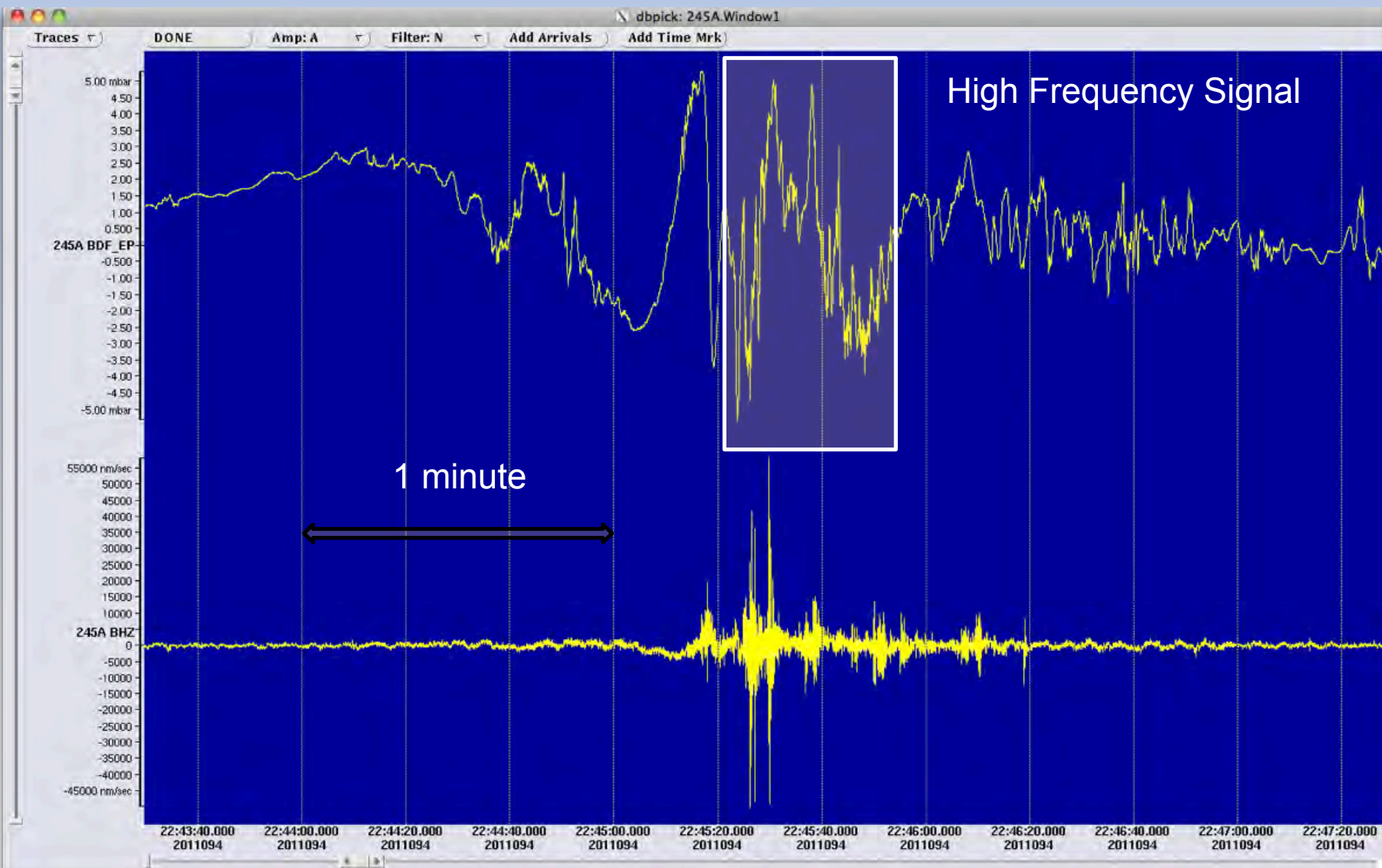


# Jackson Tornado on 4/15/2011 – 245A

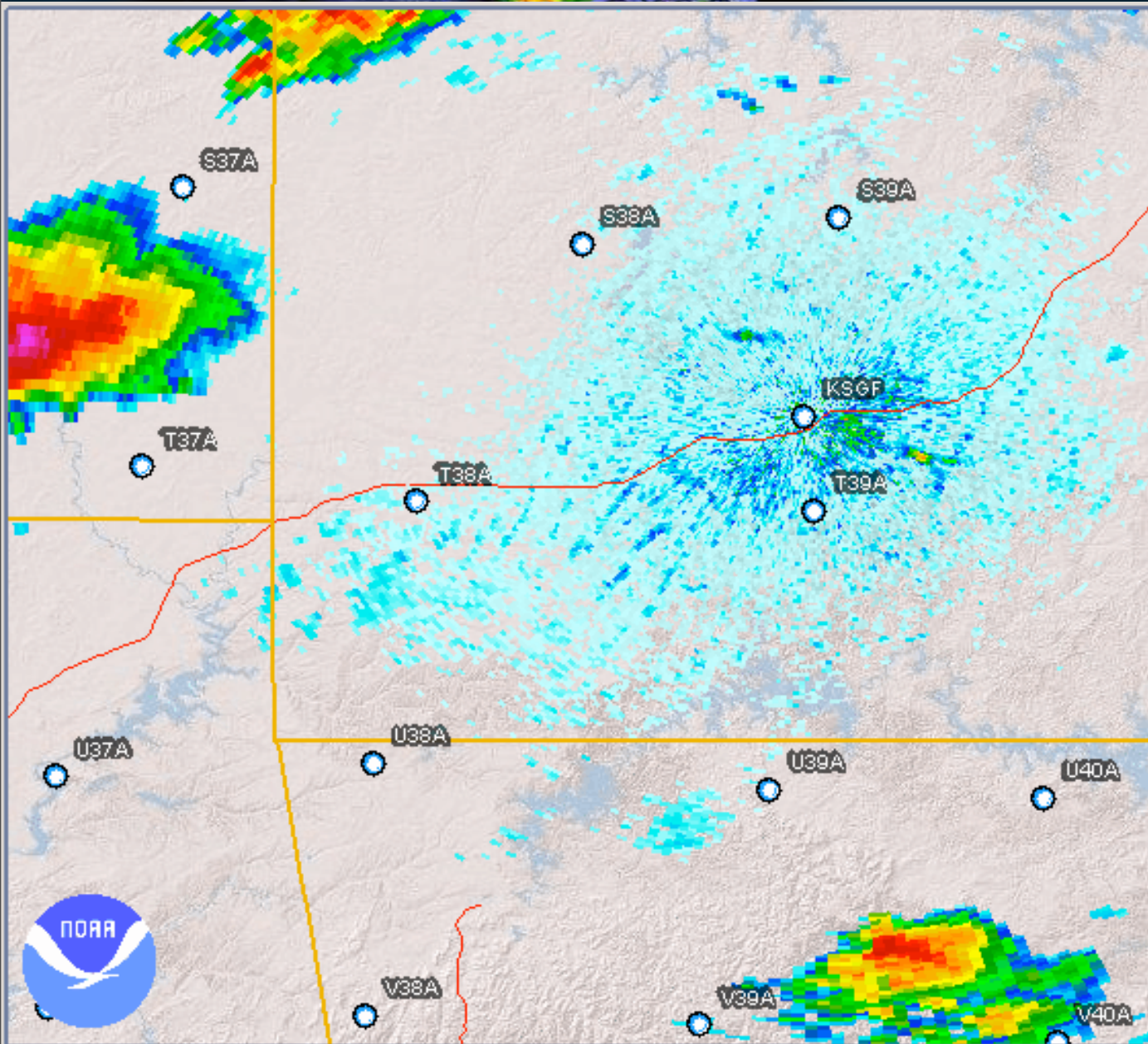




# Jackson Tornado on 4/15/2011 – 245A

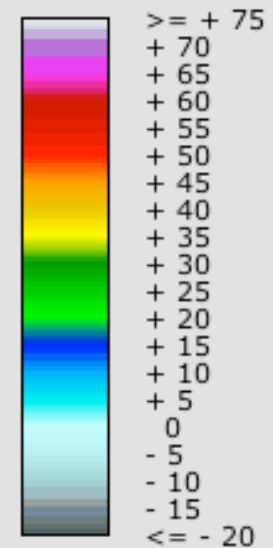


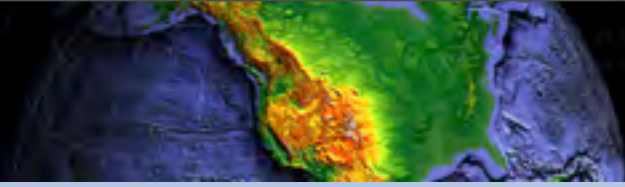
# Joplin Tornado 5/22/2011 – T38A



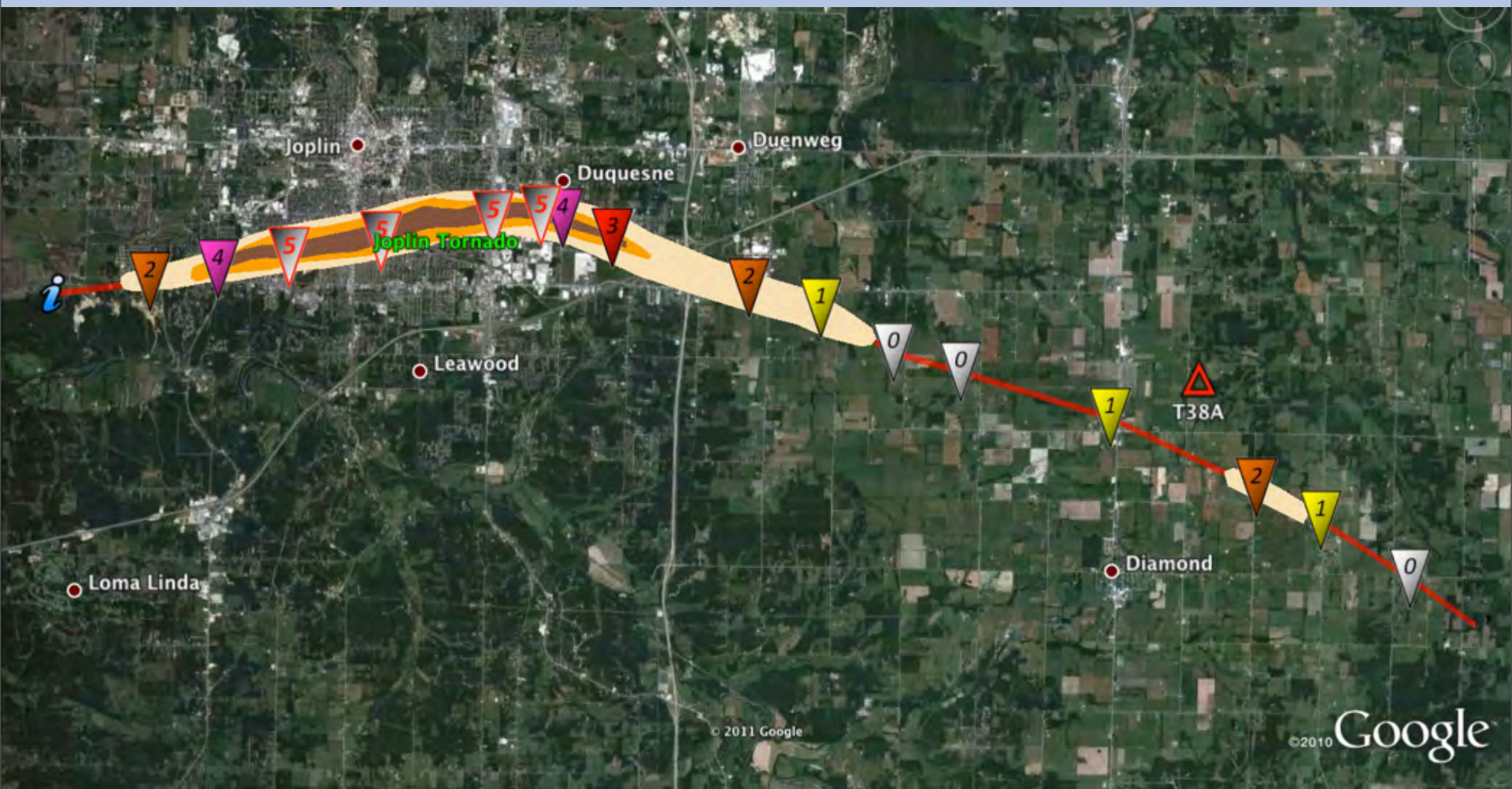
NEXRAD LEVEL-III  
BASE REFLECTIVITY  
KSGF - SPRINGFIELD, MO  
05/22/2011 21:02:17 GMT  
LAT: 37/14/05 N  
LON: 93/24/00 W  
ELEV: 1375 FT  
MODE/VCP: A / 211  
  
ELEV ANGLE: 0.50 °  
MAX: 66 DBZ  
RANGE: 248 NM

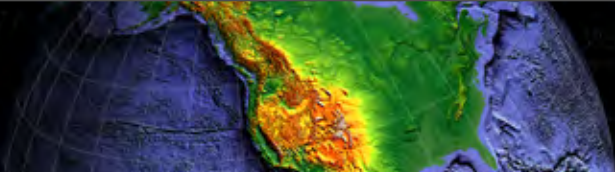
Legend: dBZ





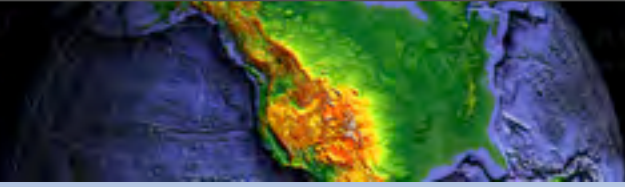
# Joplin Tornado 5/22/2011 – T38A



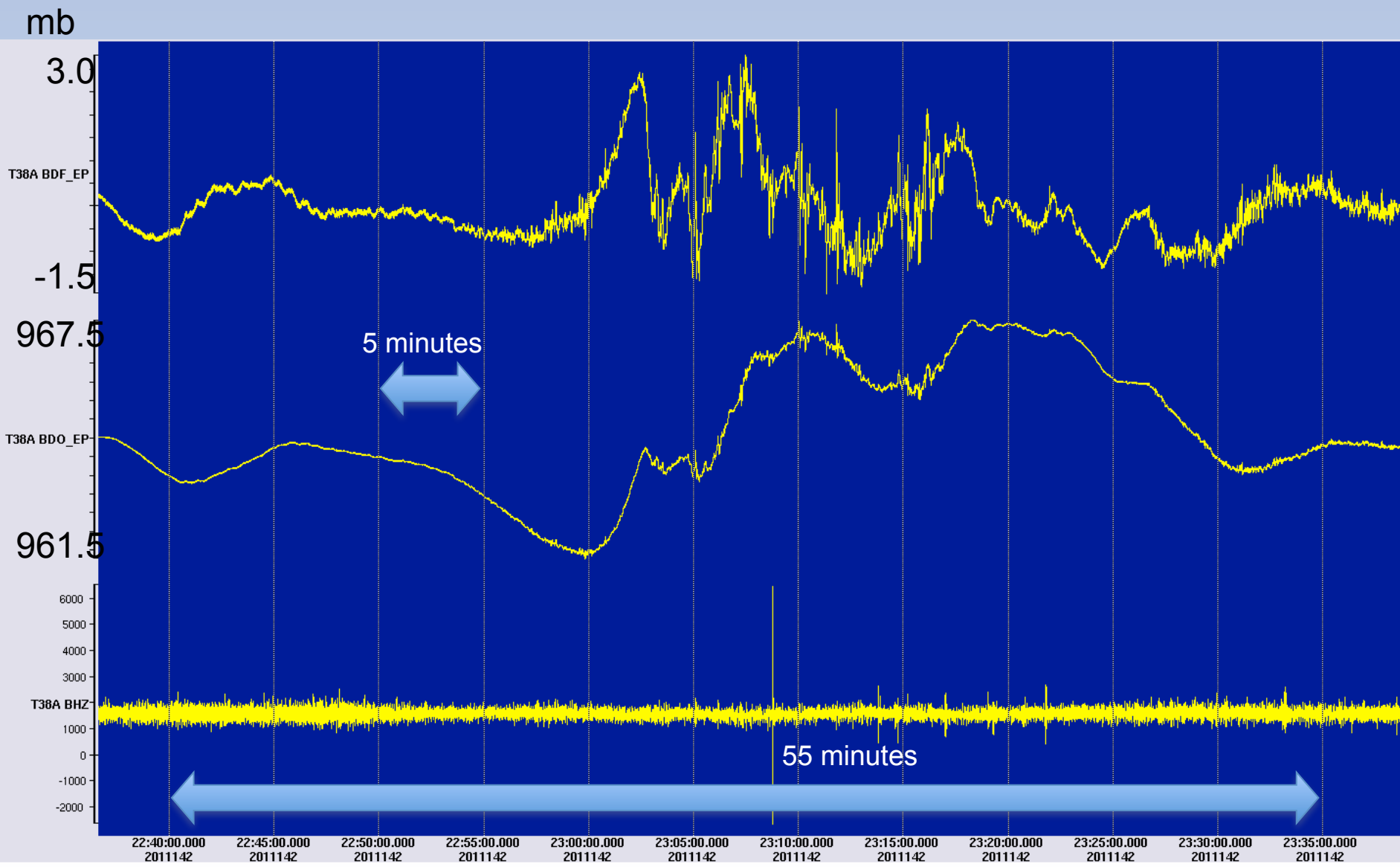


# Joplin Tornado 5/22/2011 – T38A

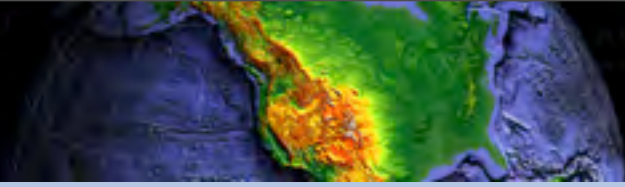




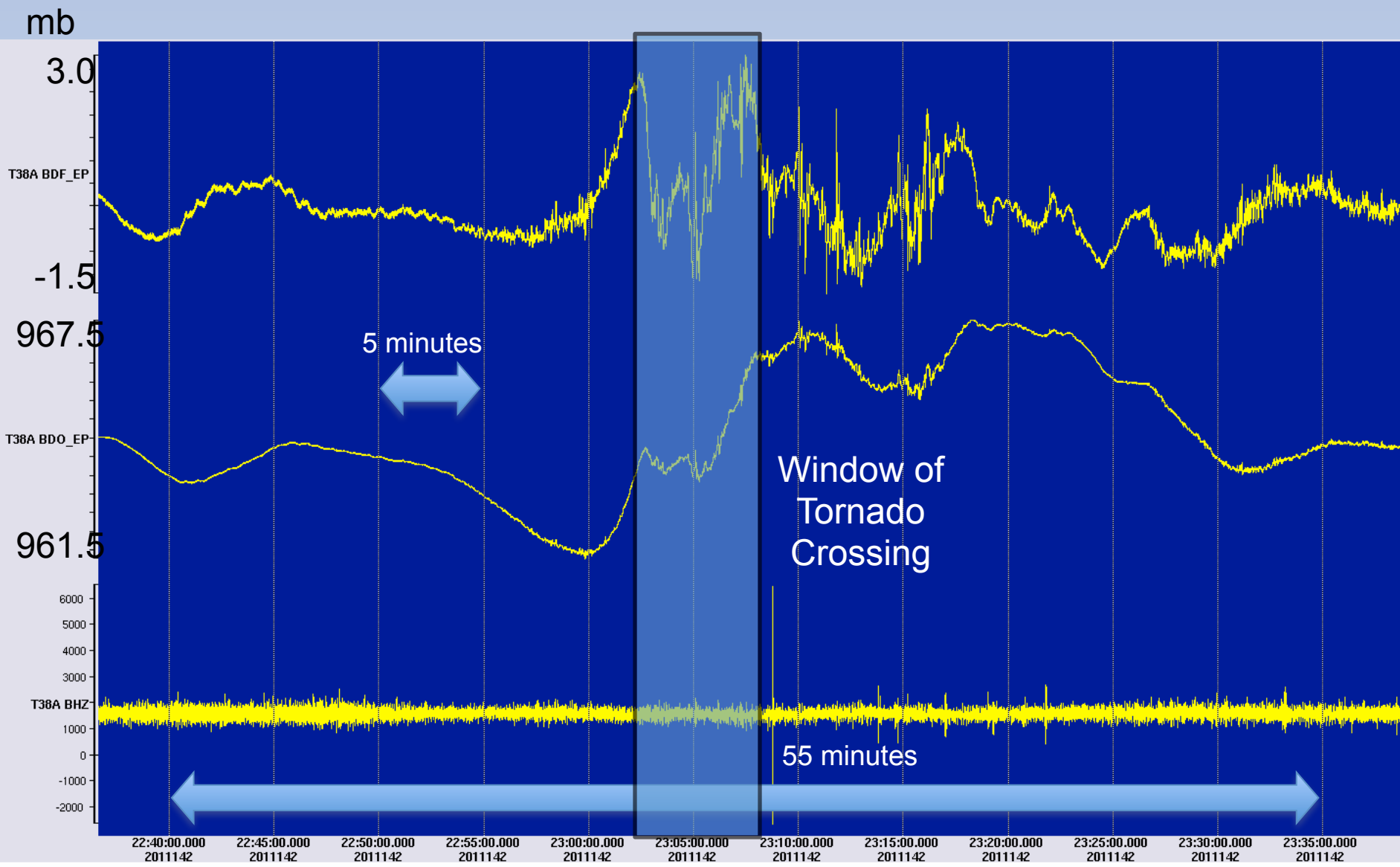
# Joplin Tornado 5/22/2011 – T38A

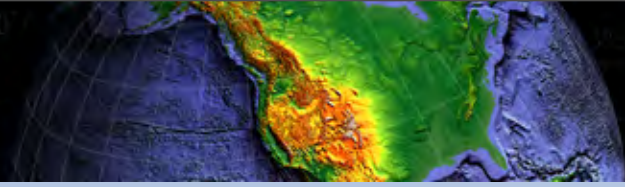




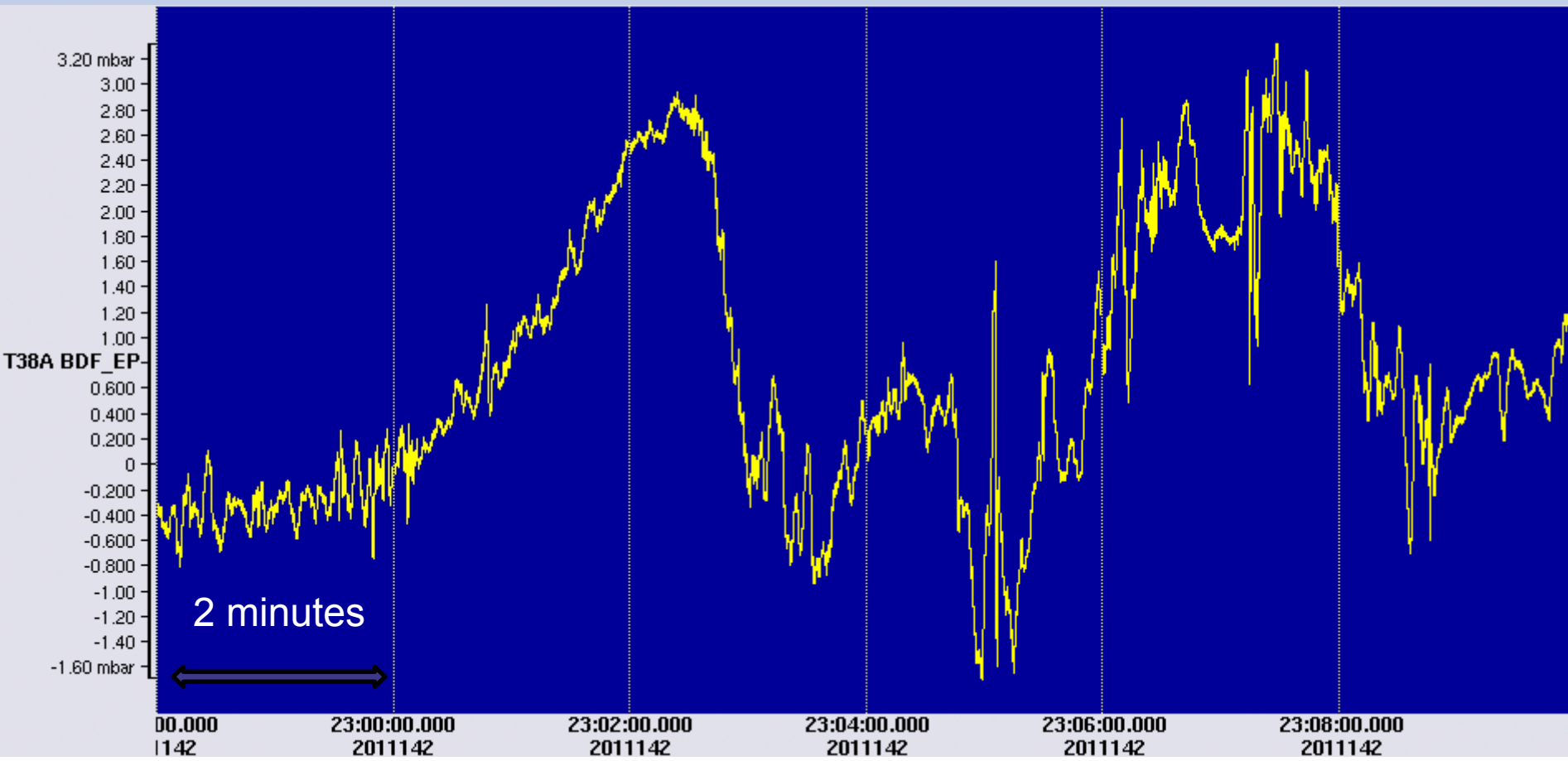


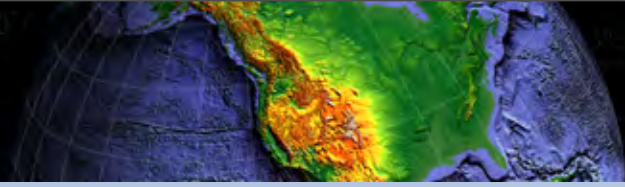
# Joplin Tornado 5/22/2011 – T38A





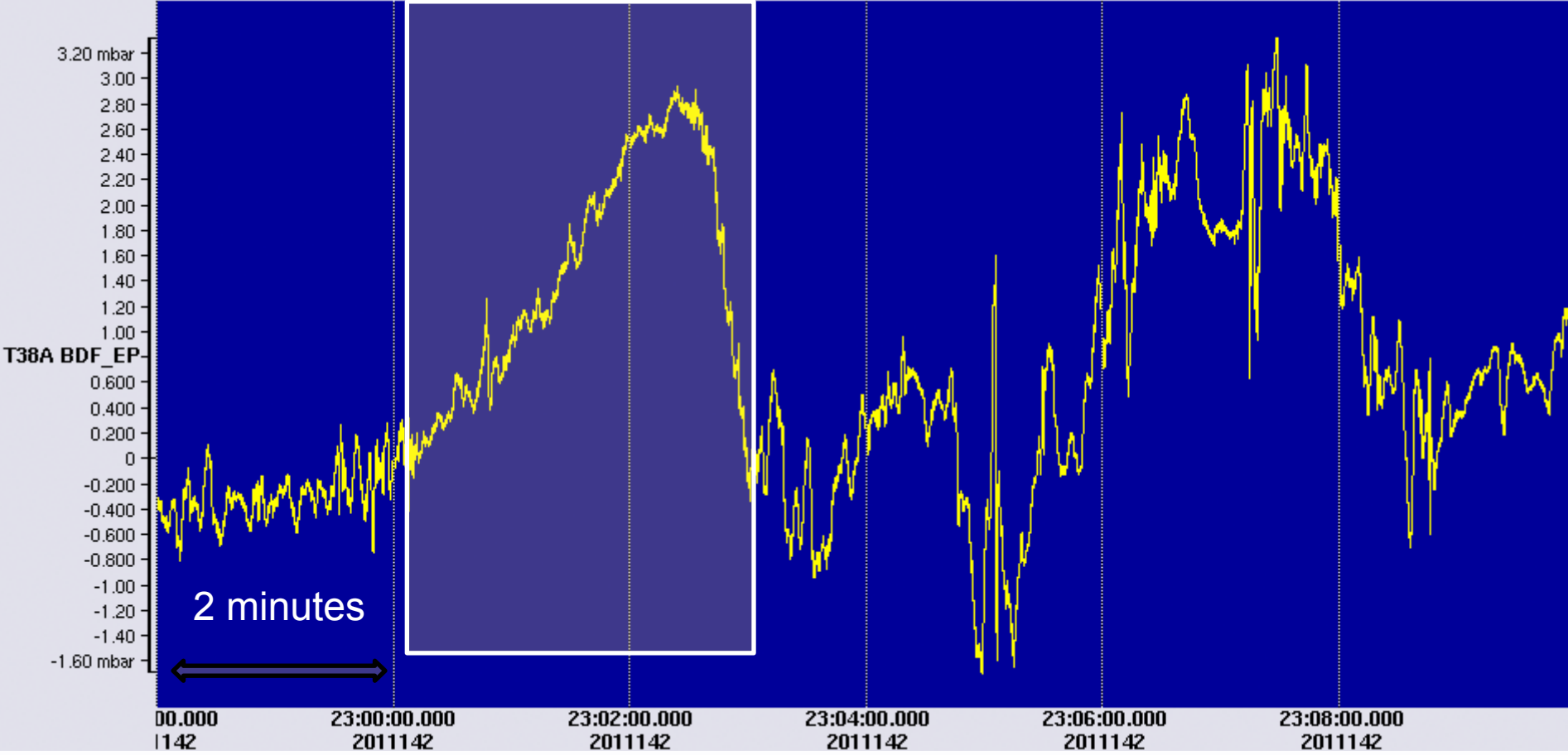
# Joplin Tornado 5/22/2011 – T38A

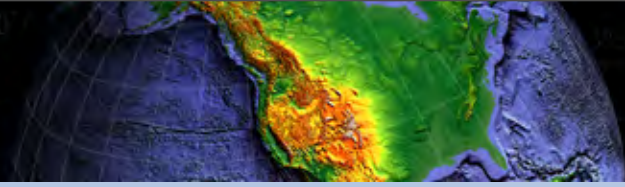




# Joplin Tornado 5/22/2011 – T38A

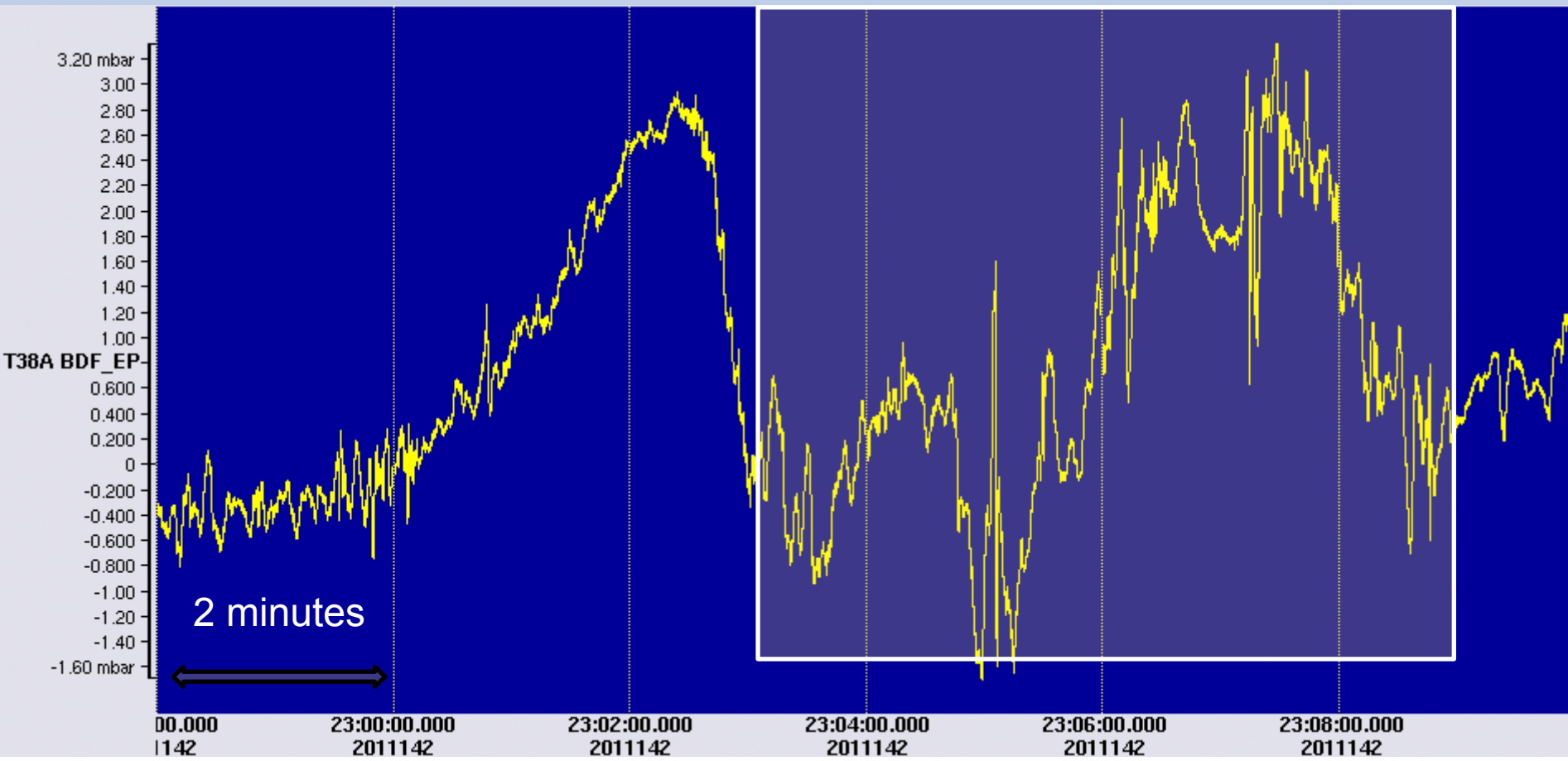
## Impulsive Rise and Drop

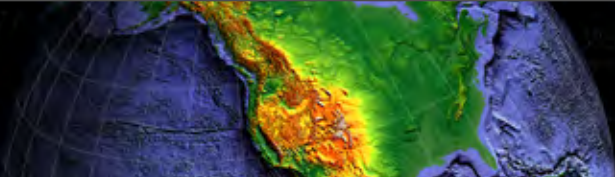




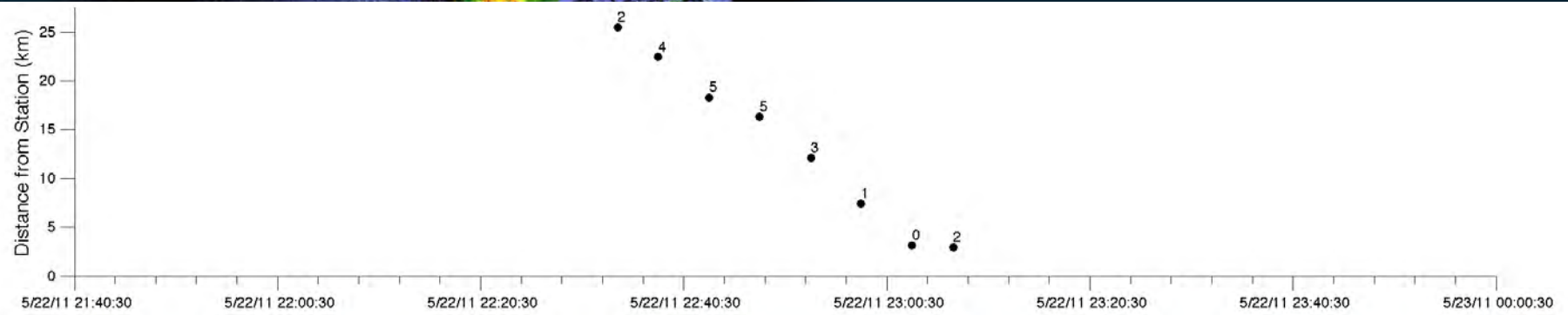
# Joplin Tornado 5/22/2011 – T38A

## High Frequency Signal

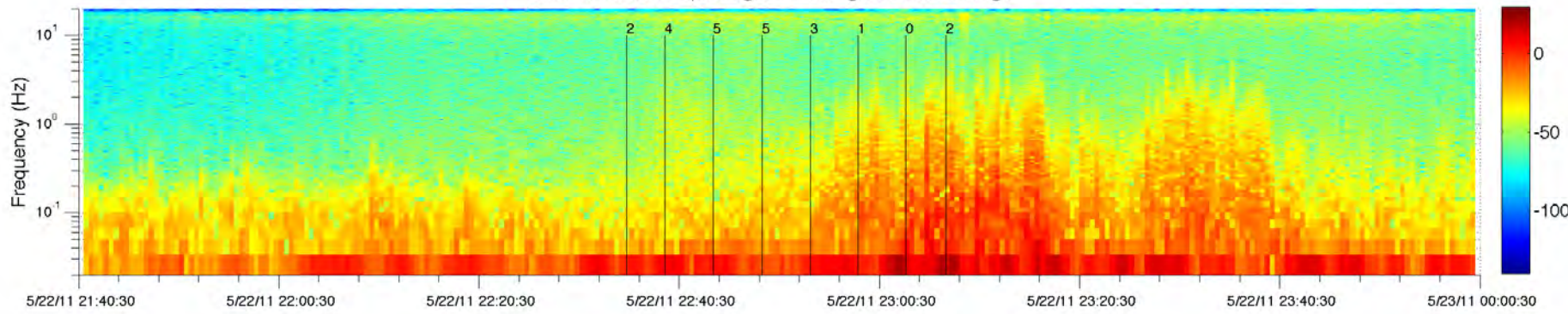




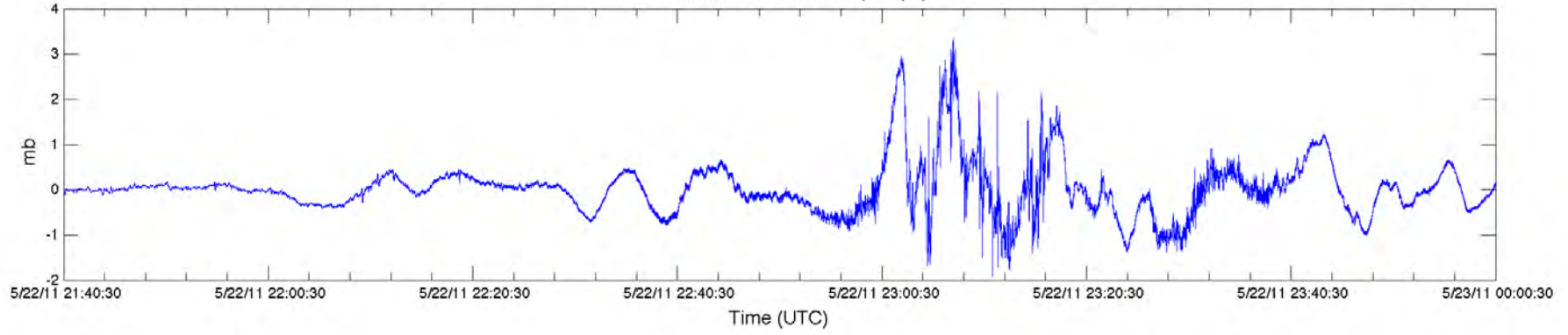
# Joplin Tornado 5/22/2011 – T38A

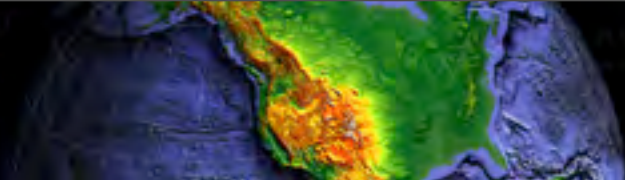


T38A Infrasound Spectrogram - During Tornado Passage



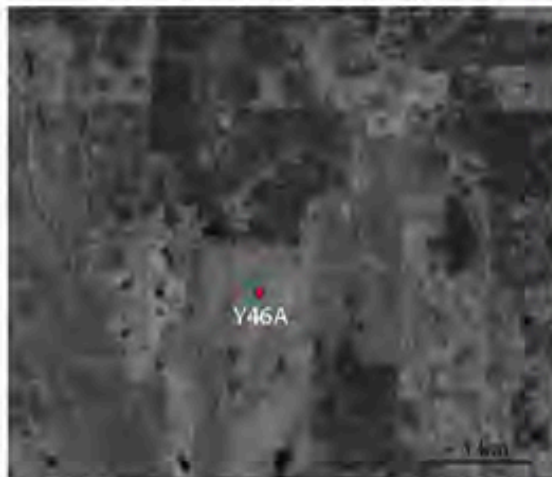
T38A Infrasound Raw Data (40 sps)



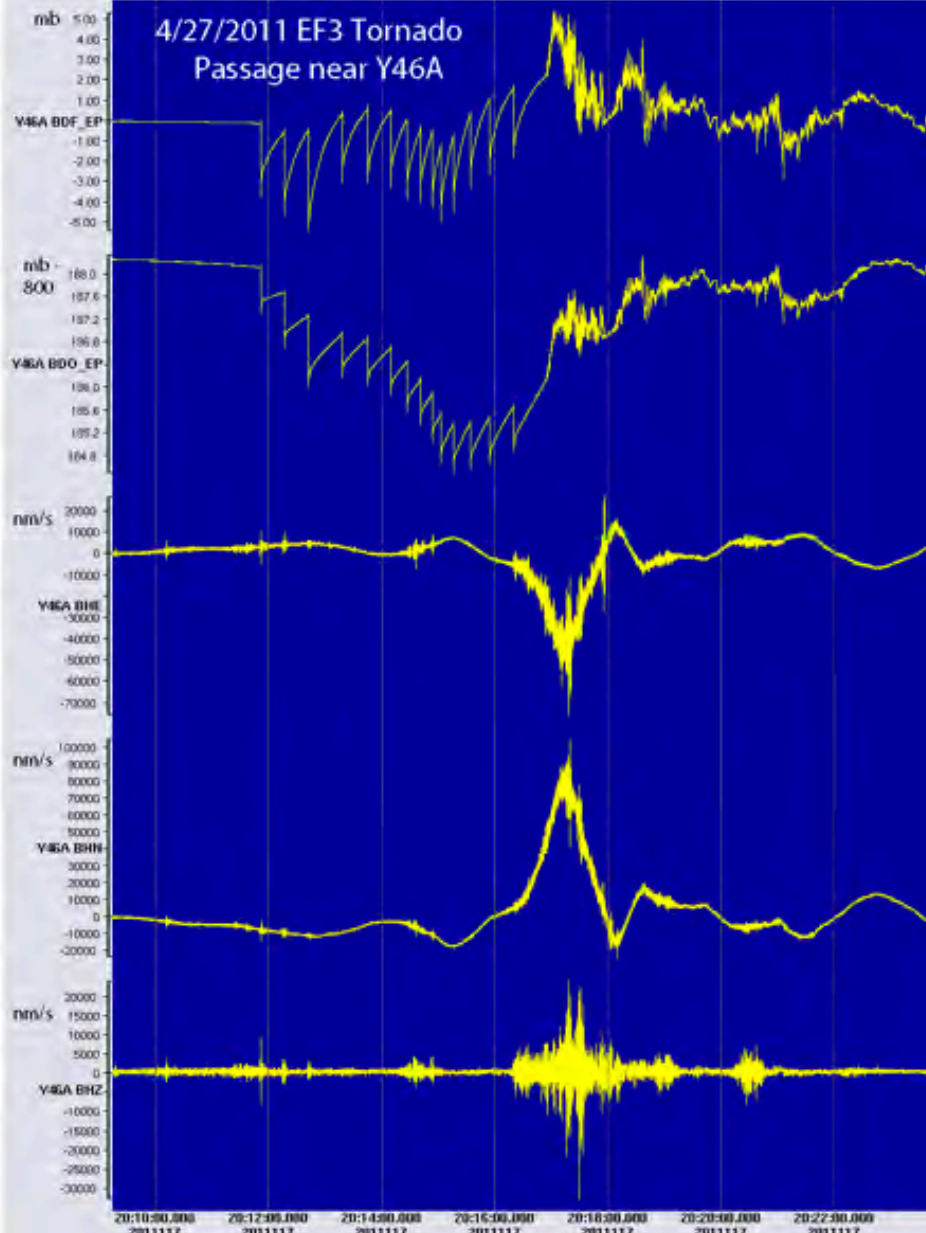


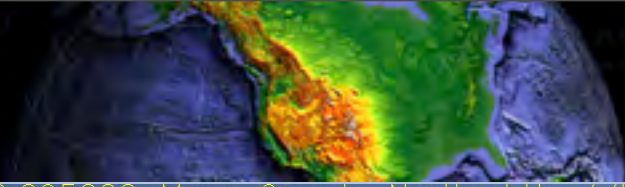
# Oklahoma Tornado on 4/27/2011 – Y46A

3/16/2011 LandSat Image



5/19/2011 LandSat Image

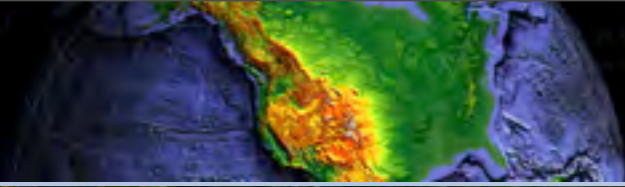




# Mesa Grande View

20120812.095220 Mesa Grande North, <http://hpwren.ucsd.edu>

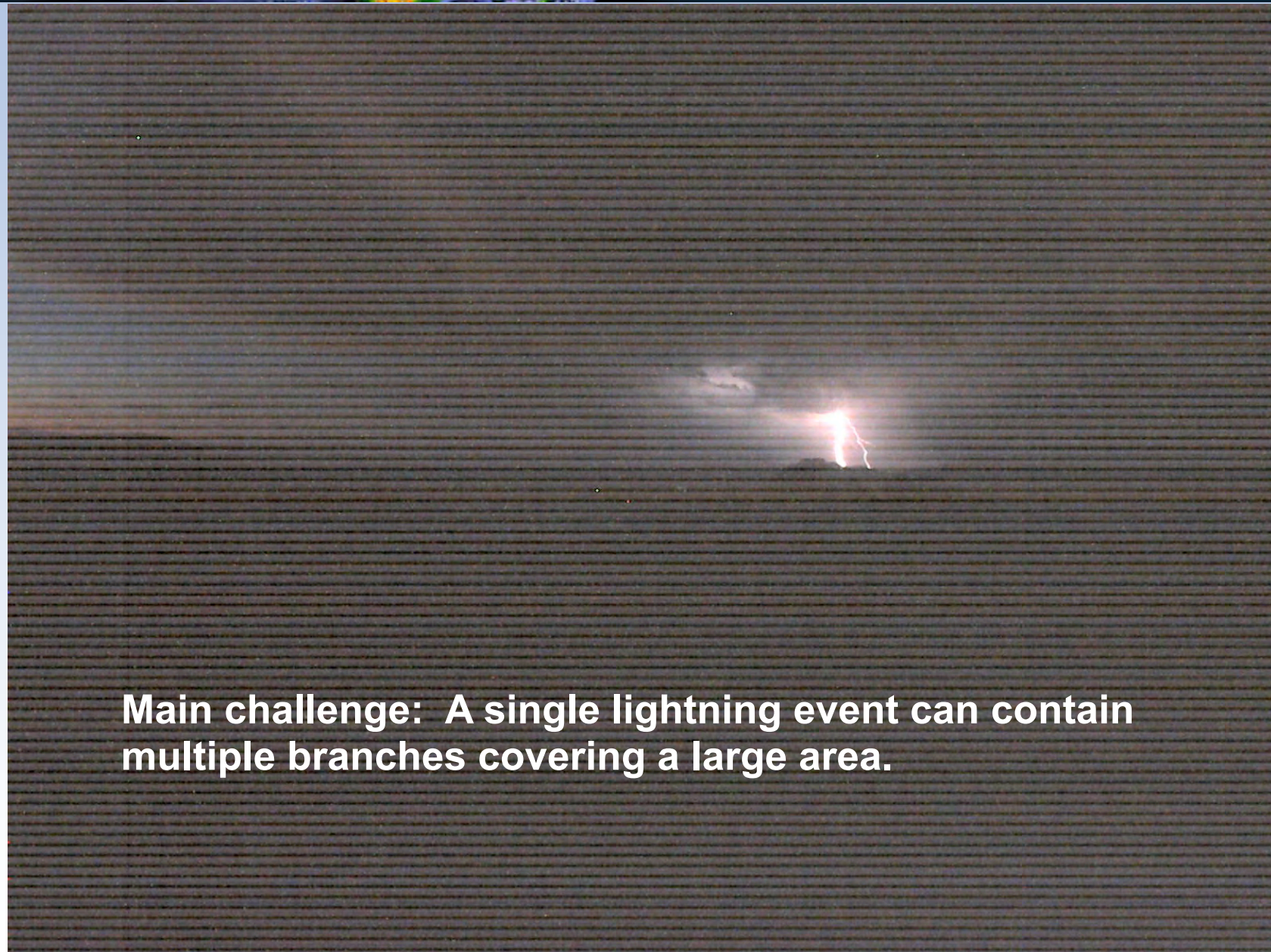
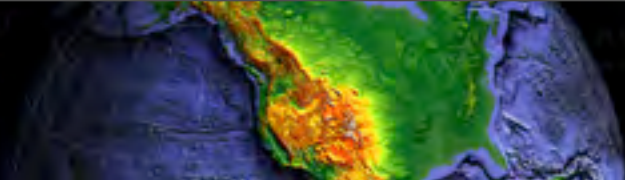




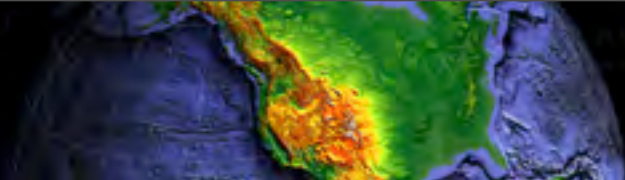
# Mesa Grande View







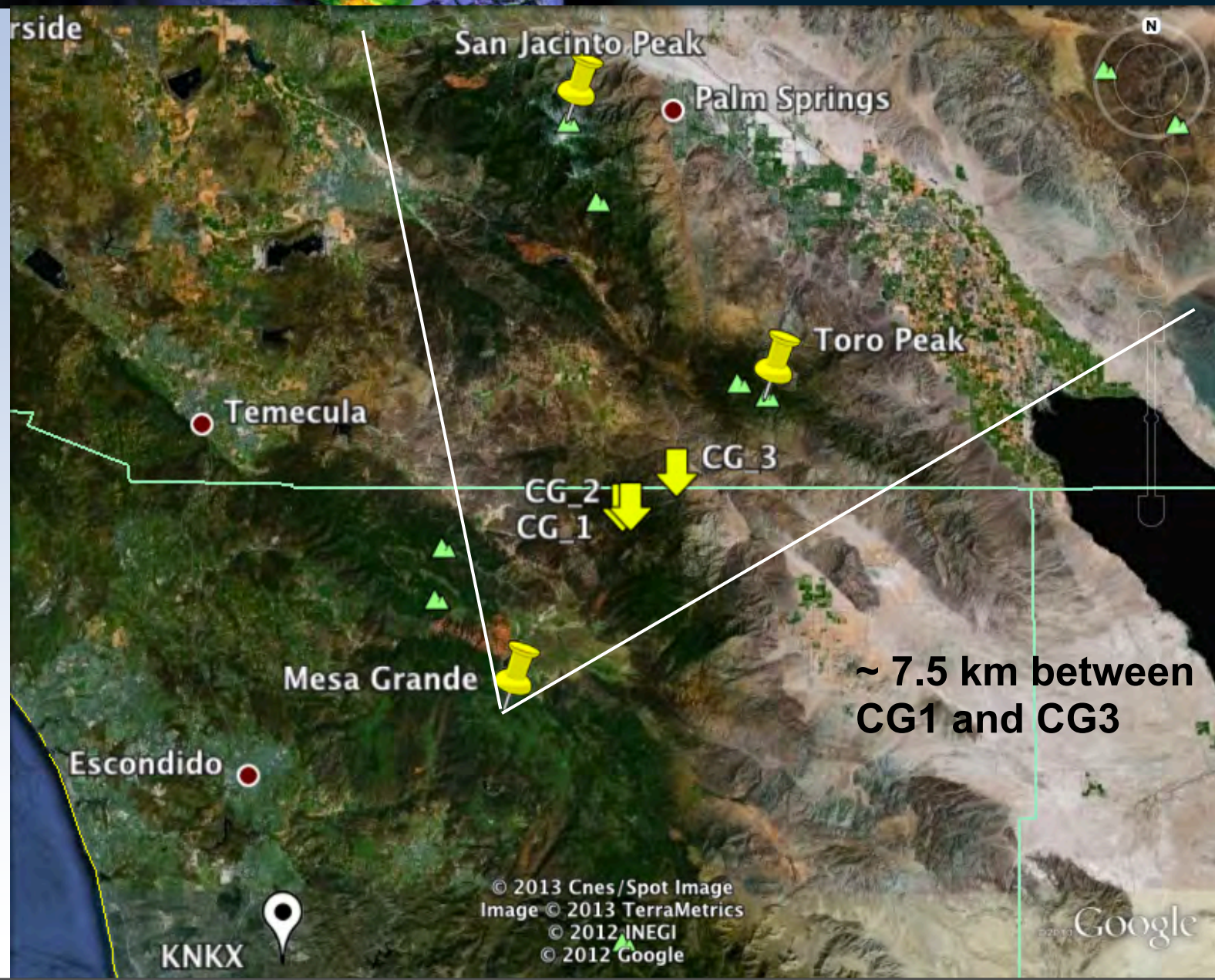
**Main challenge: A single lightning event can contain multiple branches covering a large area.**

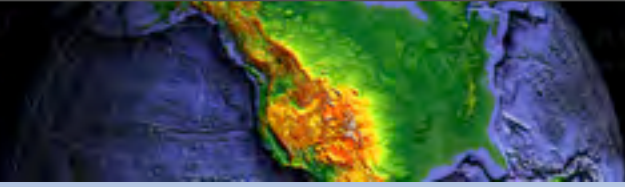


# Data Integration

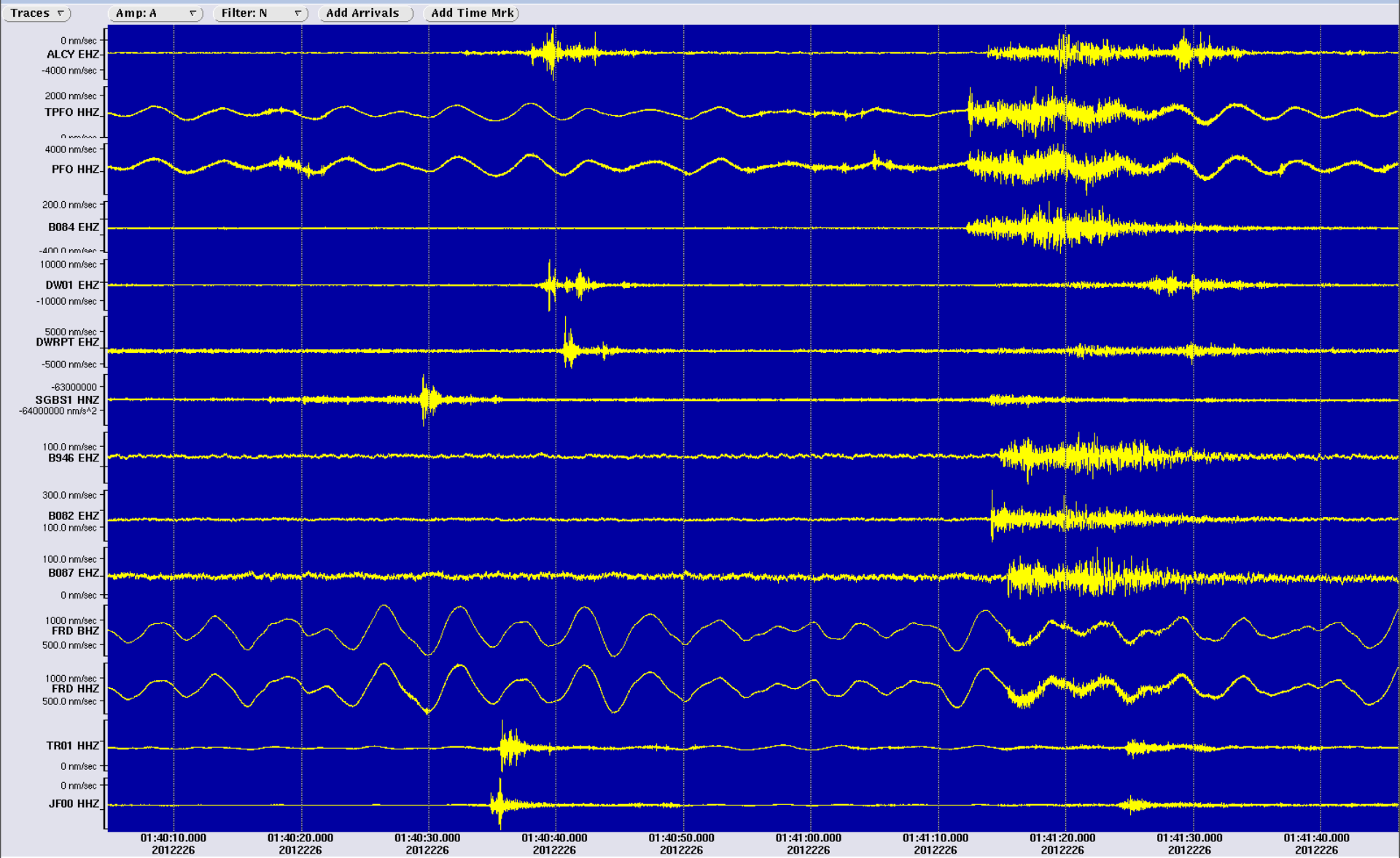
- **The ANF is collaborating with Earth Networks and their Total Lightning Network (ENTLN) in order to identify thunder noise in our seismic data.**

**All lightning locations shown are from the ENTLN**

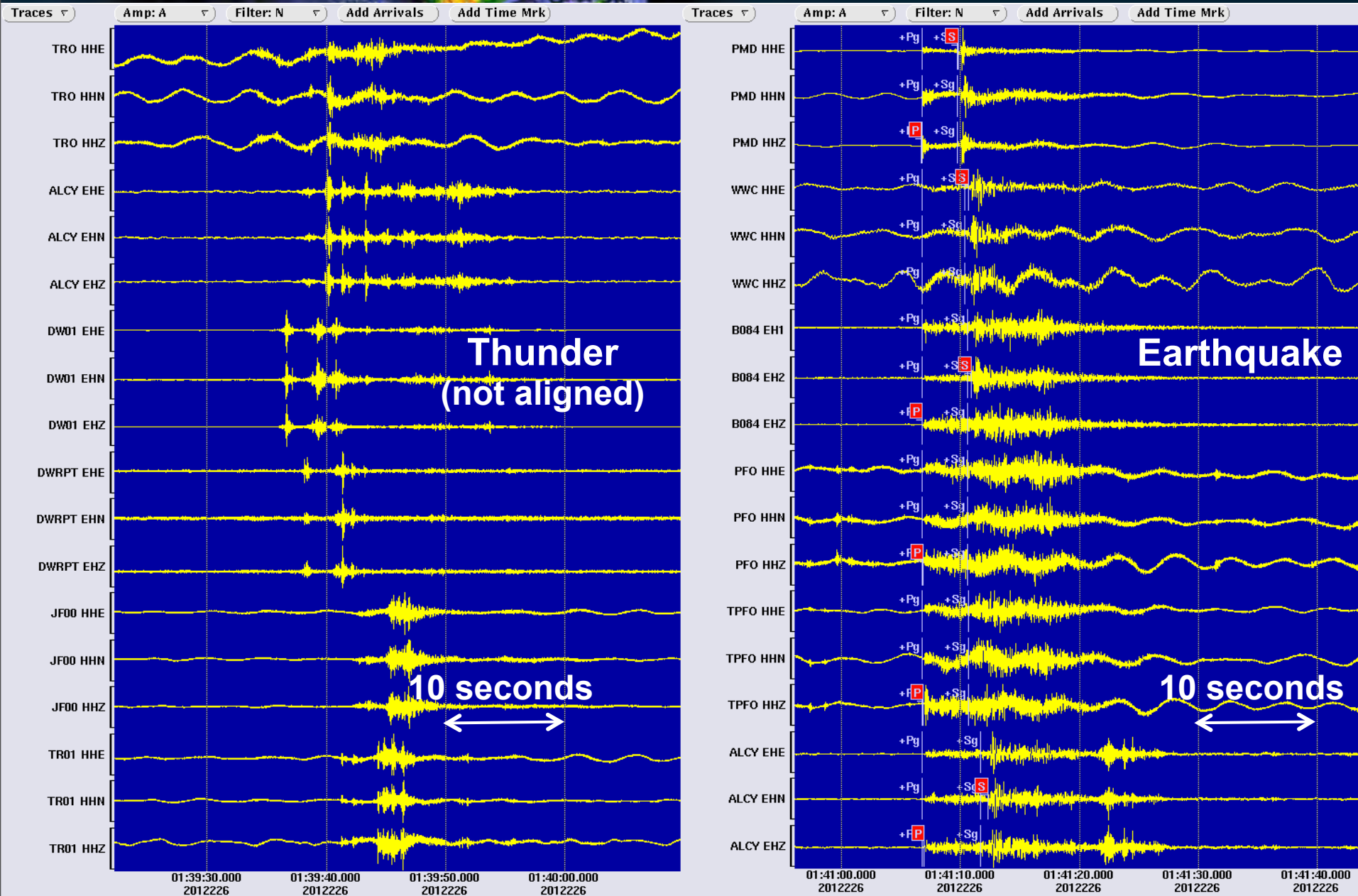




# Seismic Data

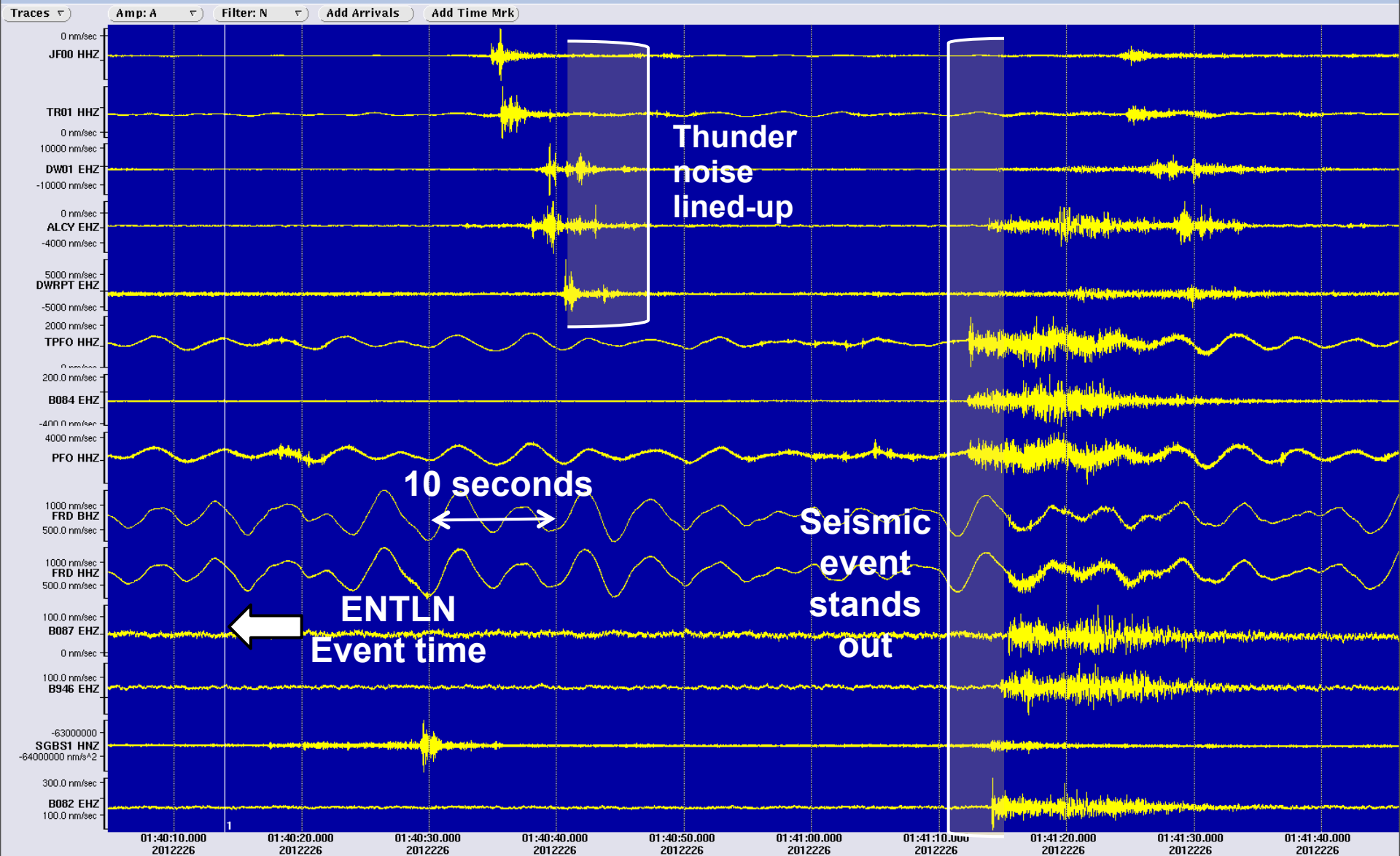


# Earthquake & Thunder











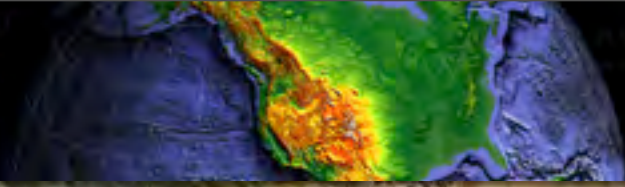
Starting from a single event group from the ENTLN, identify thunder noise in seismic:

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



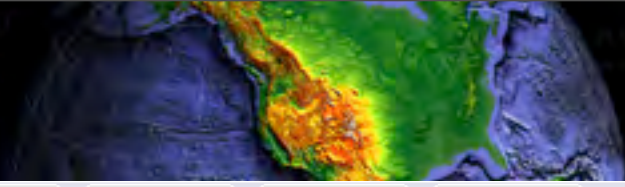
# Ground Truth Example

Anza Network  
(small portion)

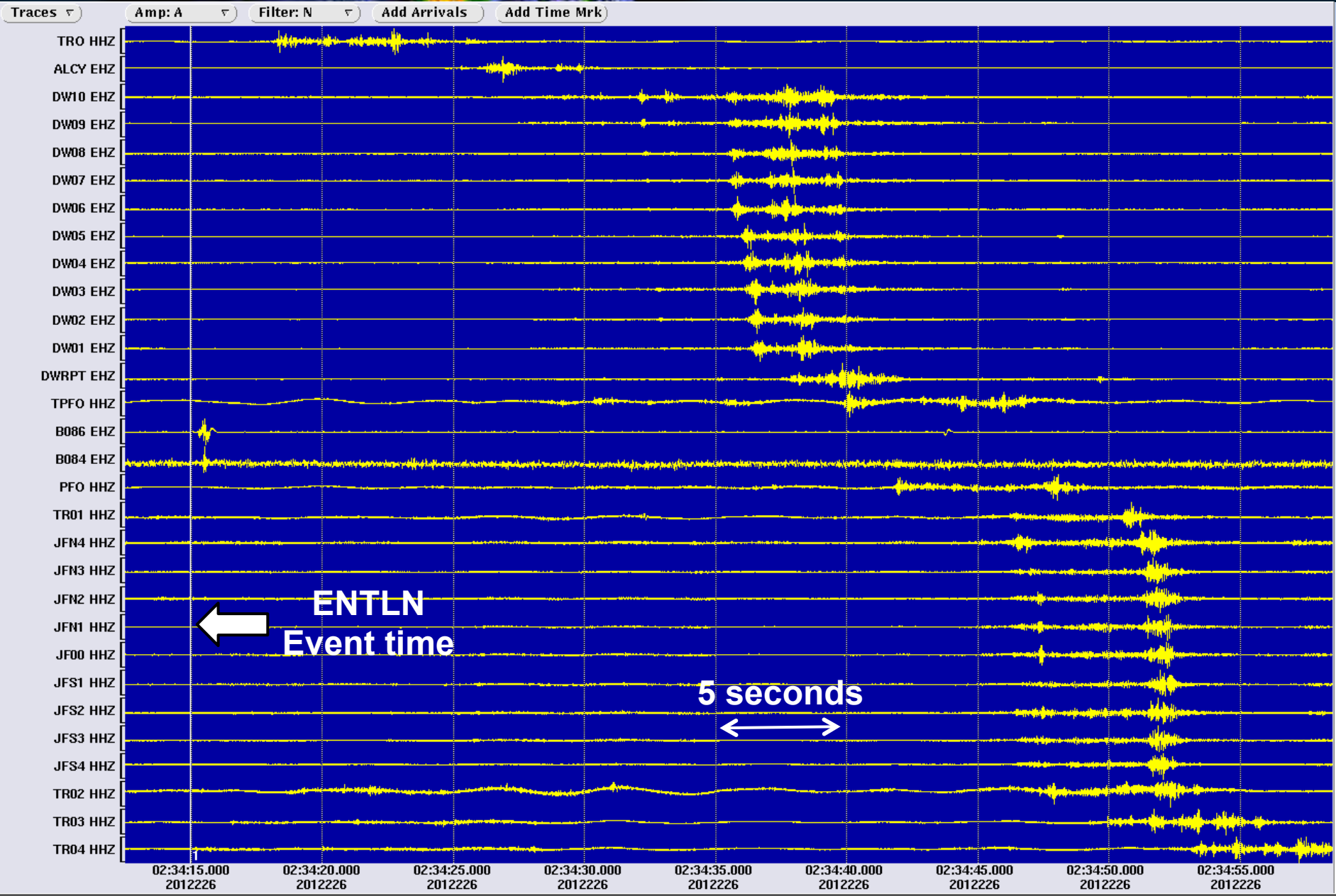


Image © 2013 GeoEye  
Image © 2013 DigitalGlobe  
© 2013 Google

Google

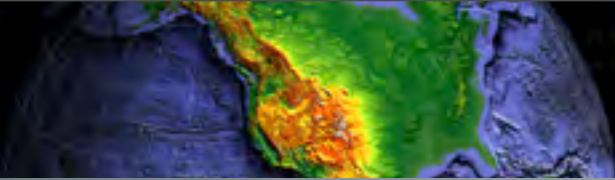


# Ground Truth Example



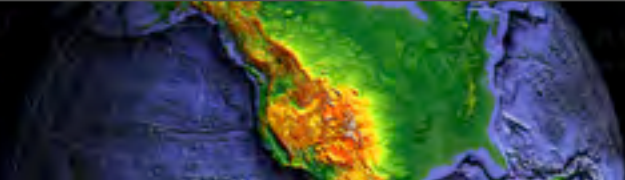
- **Thunder noise from lightning events readily poses challenges for seismic analysts**
- **Lightning can cover large areas vs. isolated seismic sources**
- **Large area acoustic signatures difficult to determine arrival times in data (though “ballpark” estimates possible)**
- **Signals from thunder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

- **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**

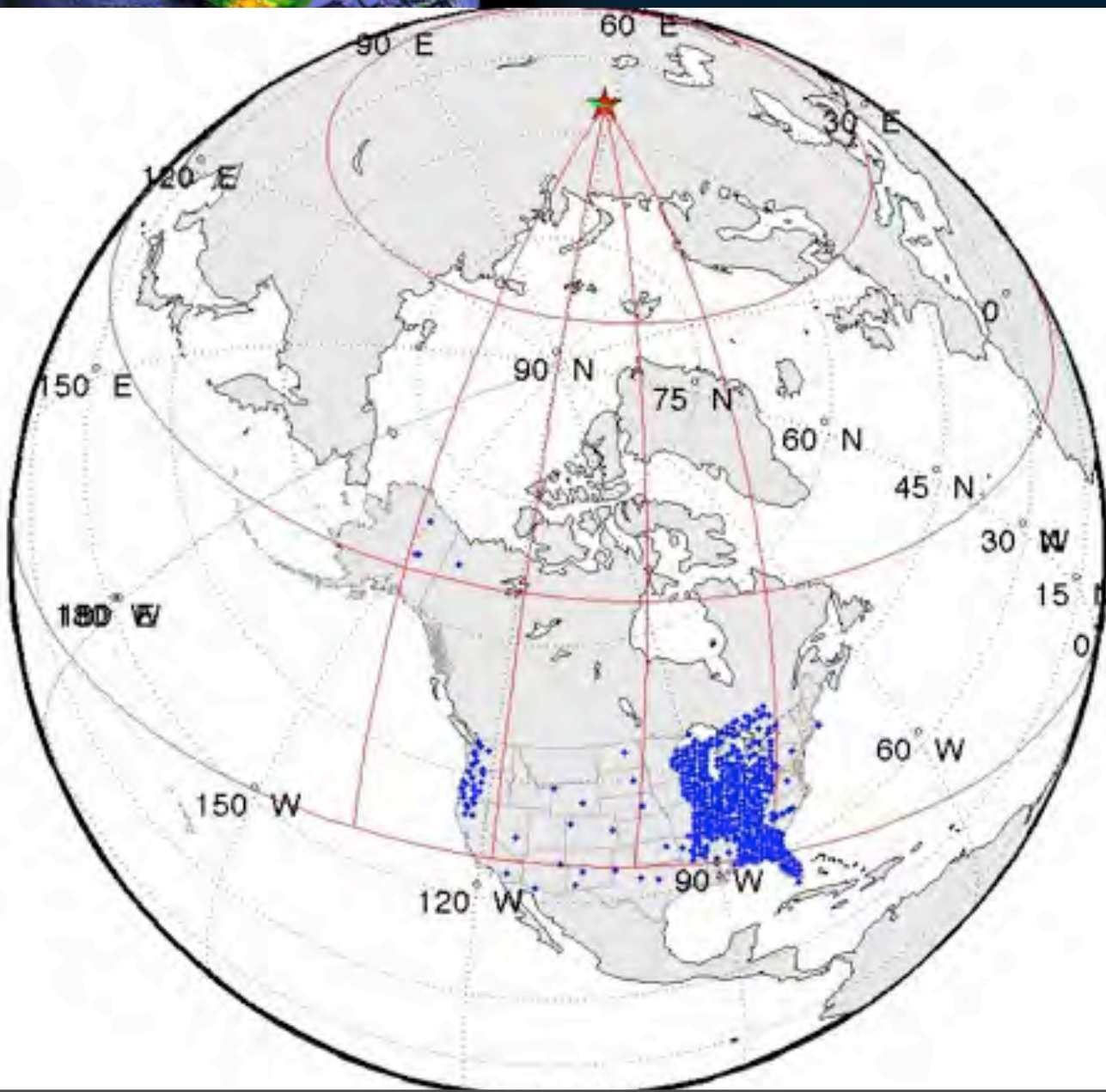


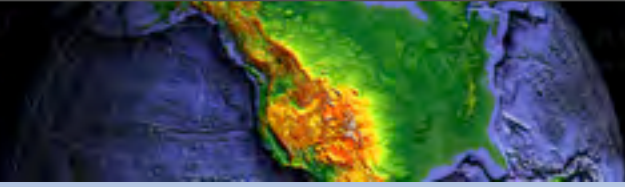
2013/02/15 09:26:15



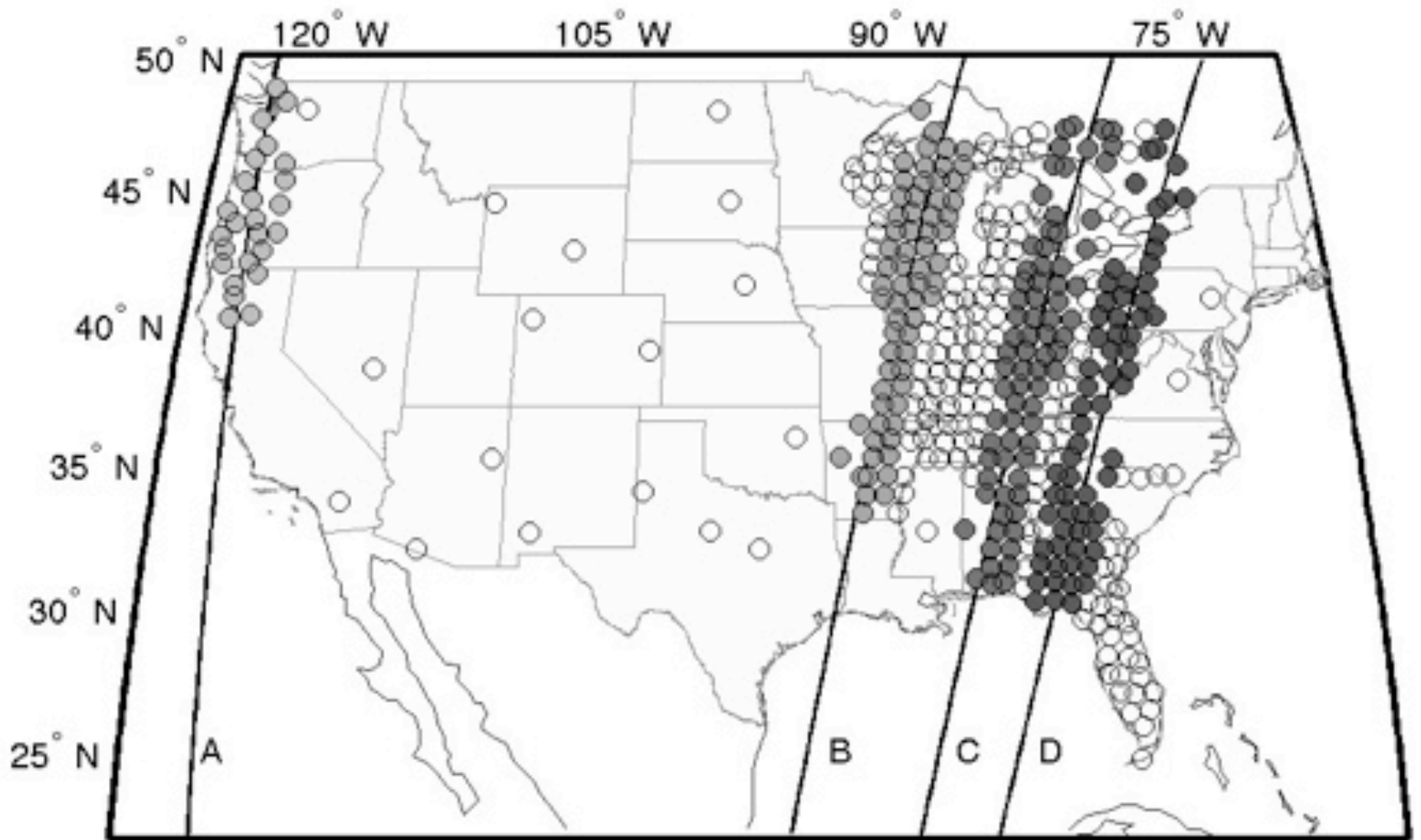


# Russian meteor 2013-02-15

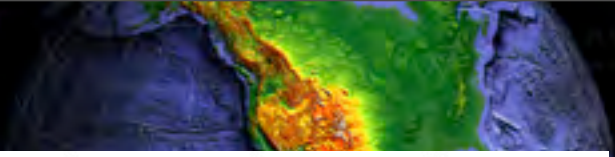




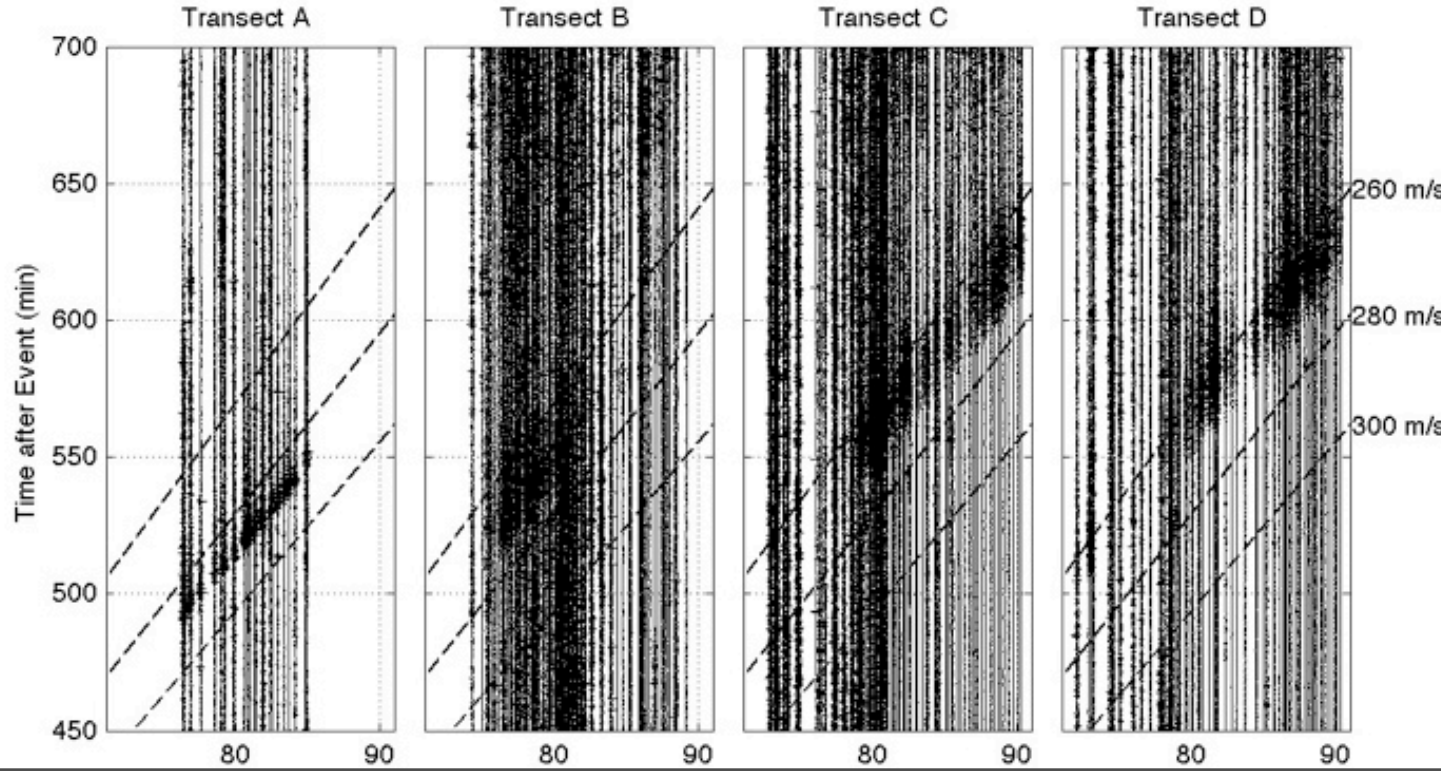
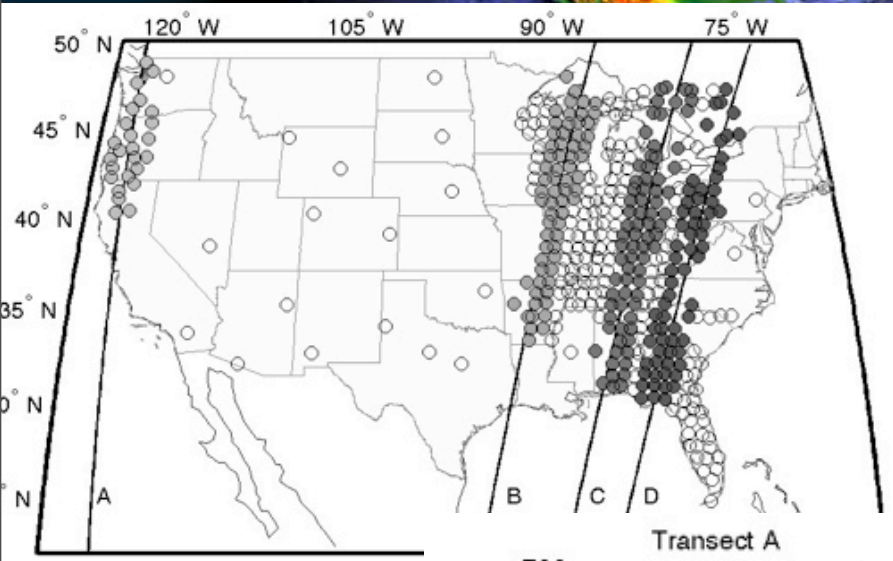
# Russian meteor 2013-02-15

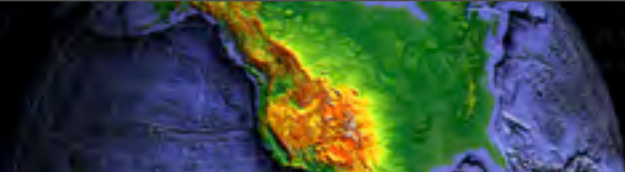




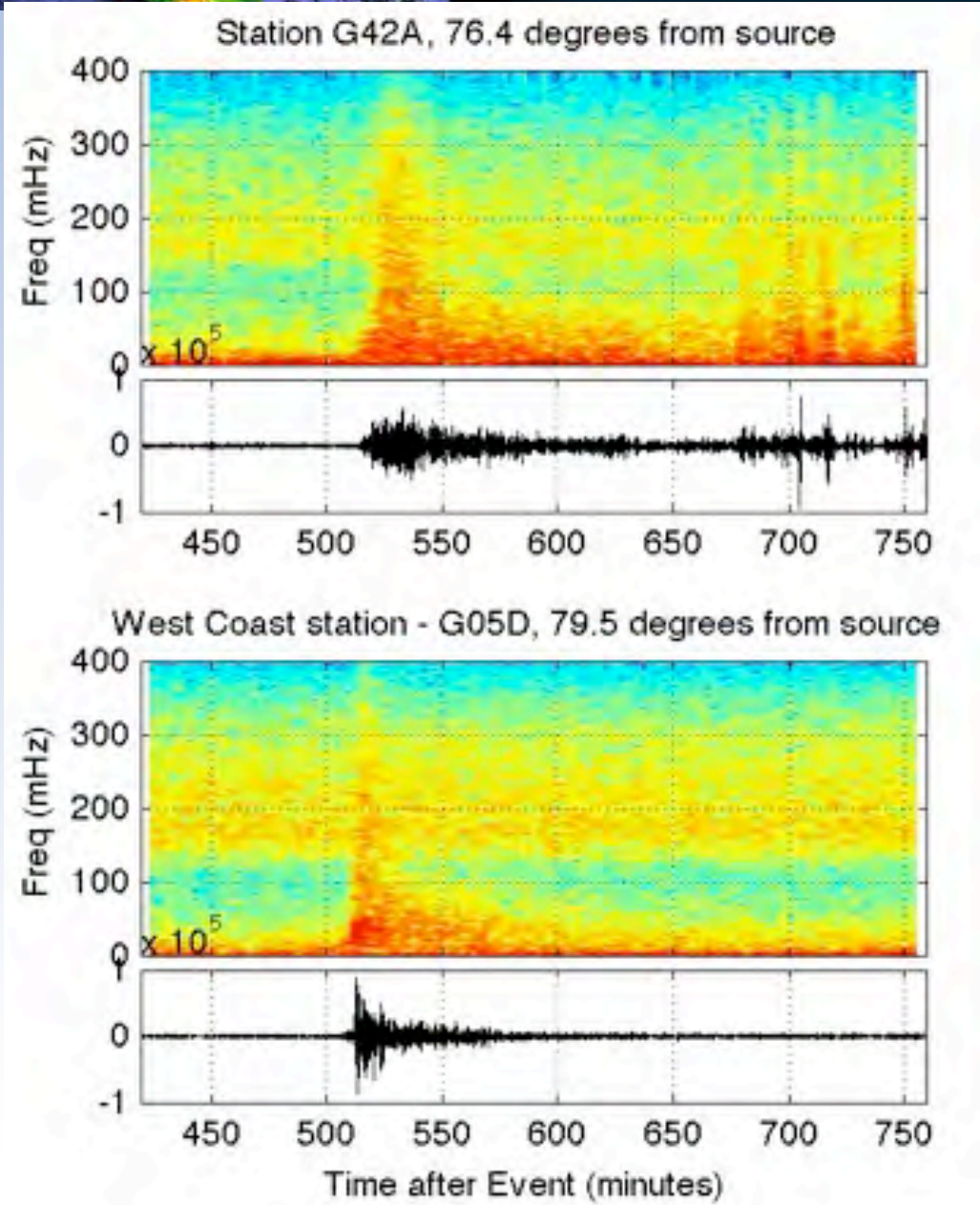


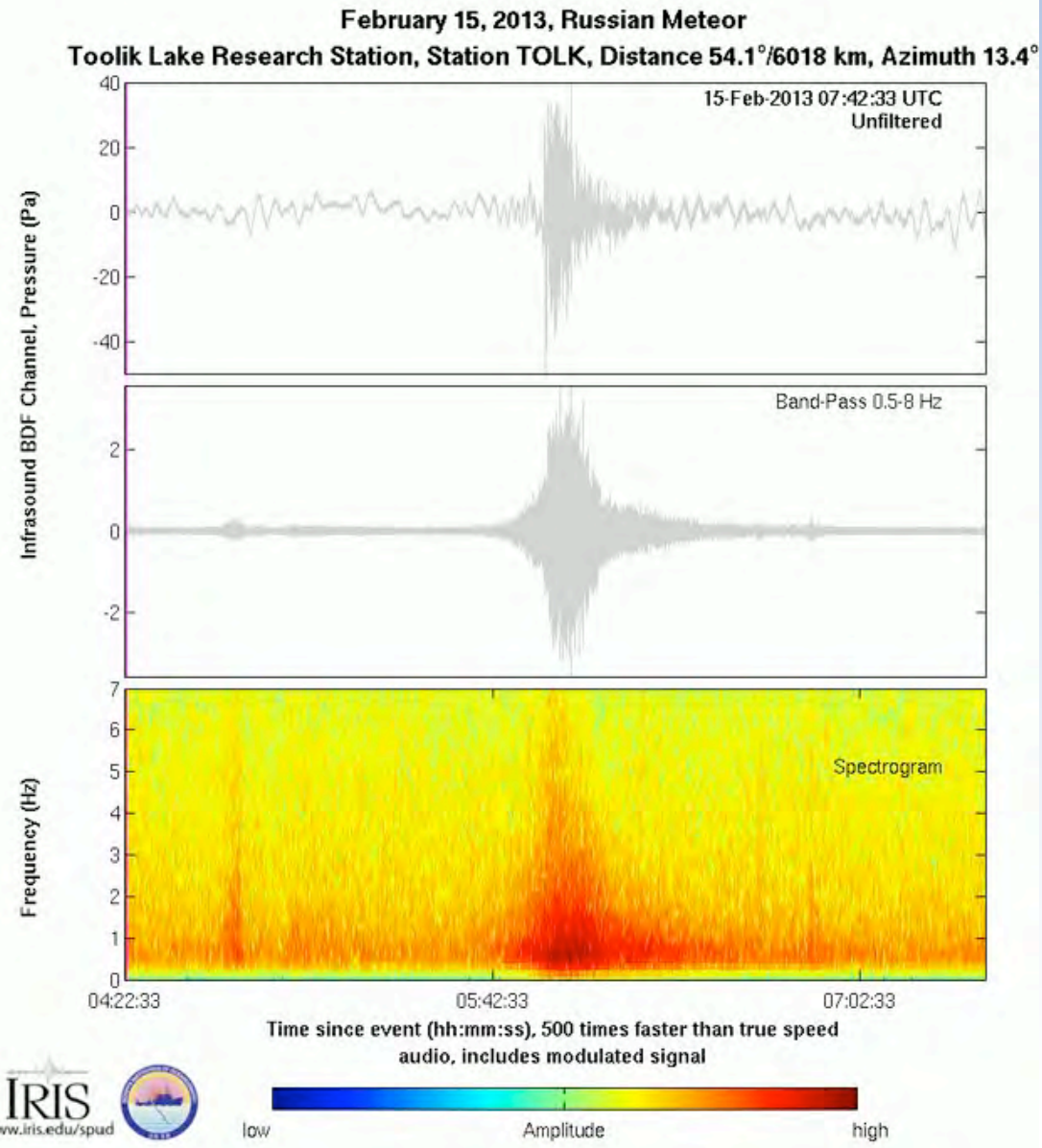
# Russian meteor 2013-02-15

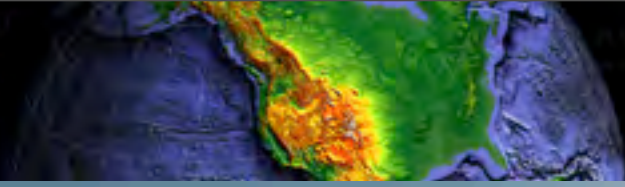




# Russian meteor 2013-02-15

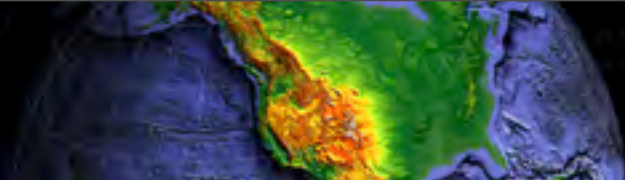






# Russian meteor 2013-02-15





# 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