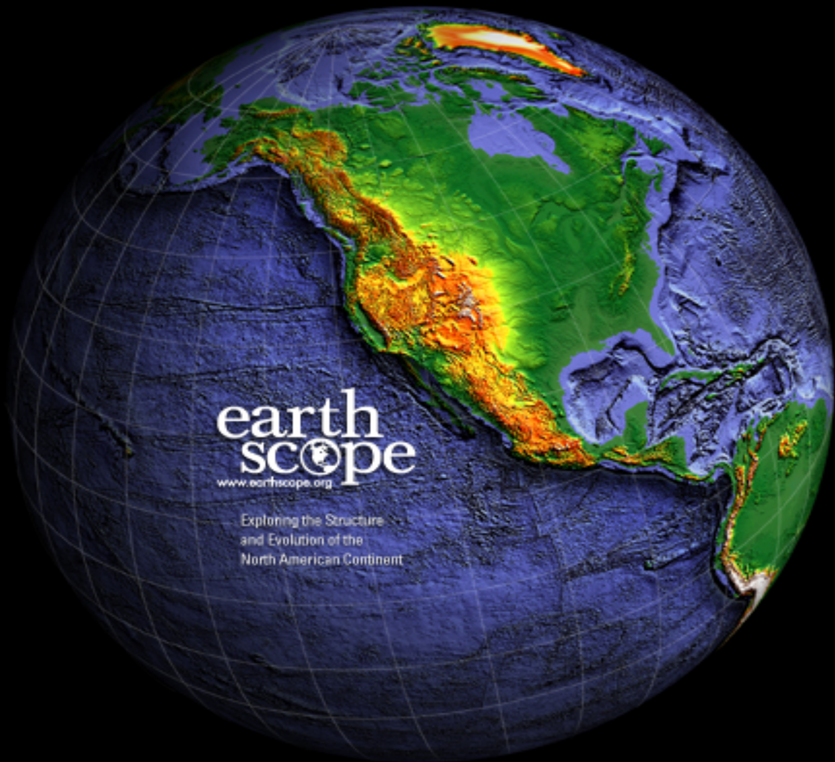
USArray: Evolution of Operations and Recent Science Results



Frank Vernon representing the ANF

Scripps Institution of Oceanography
University of California, San Diego

Antelope User Group
Trieste, Italy
22 February 2012

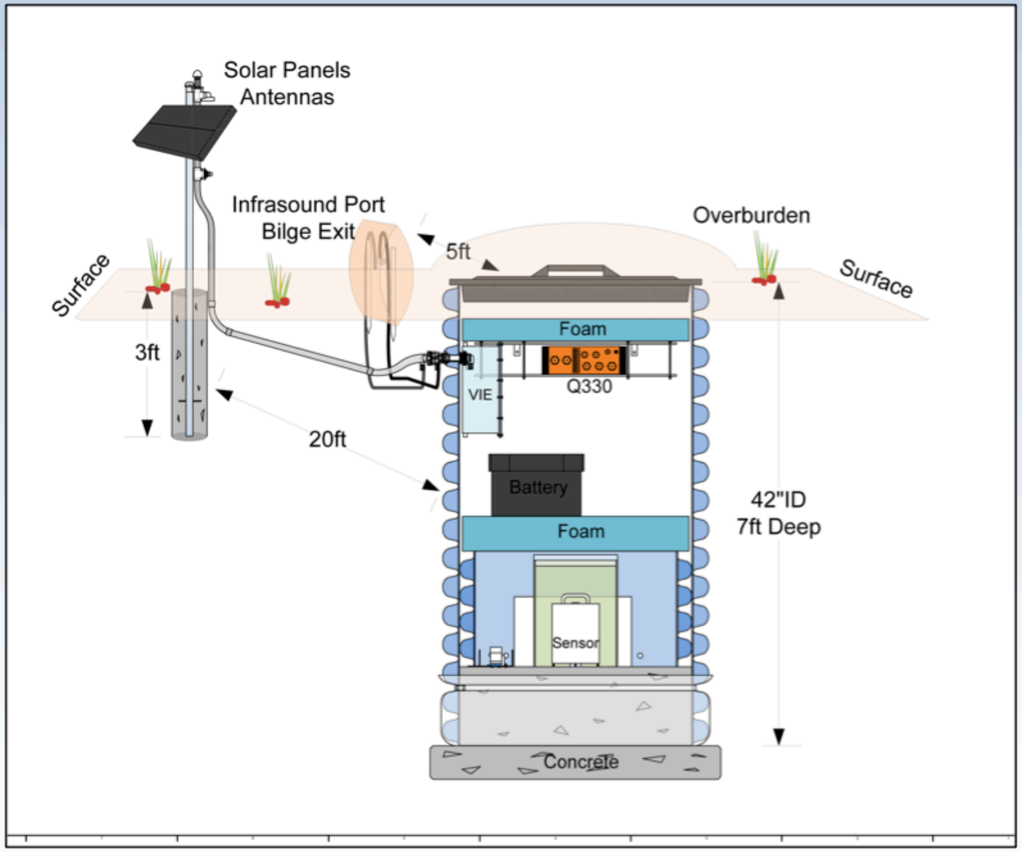
USArray Facilities

Observatory components of USArray

- •Reference Network
  - ~100 permanent seismic stations
  - A “fixed” fudicial network
- •Transportable Array
  - 400 seismic stations, 70km grid
  - Rolling across the country, west to east
- •Flexible Array
  - 2146 portable seismic instruments
  - Used by individual experiment teams
- •Magnetotelluric
  - 7 backbone stations providing a fixed background network
  - 20 portable instruments deployed each summer

Basic Description

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



TA Station 345A, MS

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Data Center Requirements

- Dynamic Metadata
  - On average install and remove one station for every work day
- High Data Quality
  - Accurate timing (~1μSec)
  - Calibrations
  - Orientation
  - Data completeness
- Minimize data latency
- Automatic event processing
  - Detectors
  - Associators
  - Magnitude Calculators
- Automatic event association to external catalogs
- Analyst review
- Data Archive

Data Center Requirements

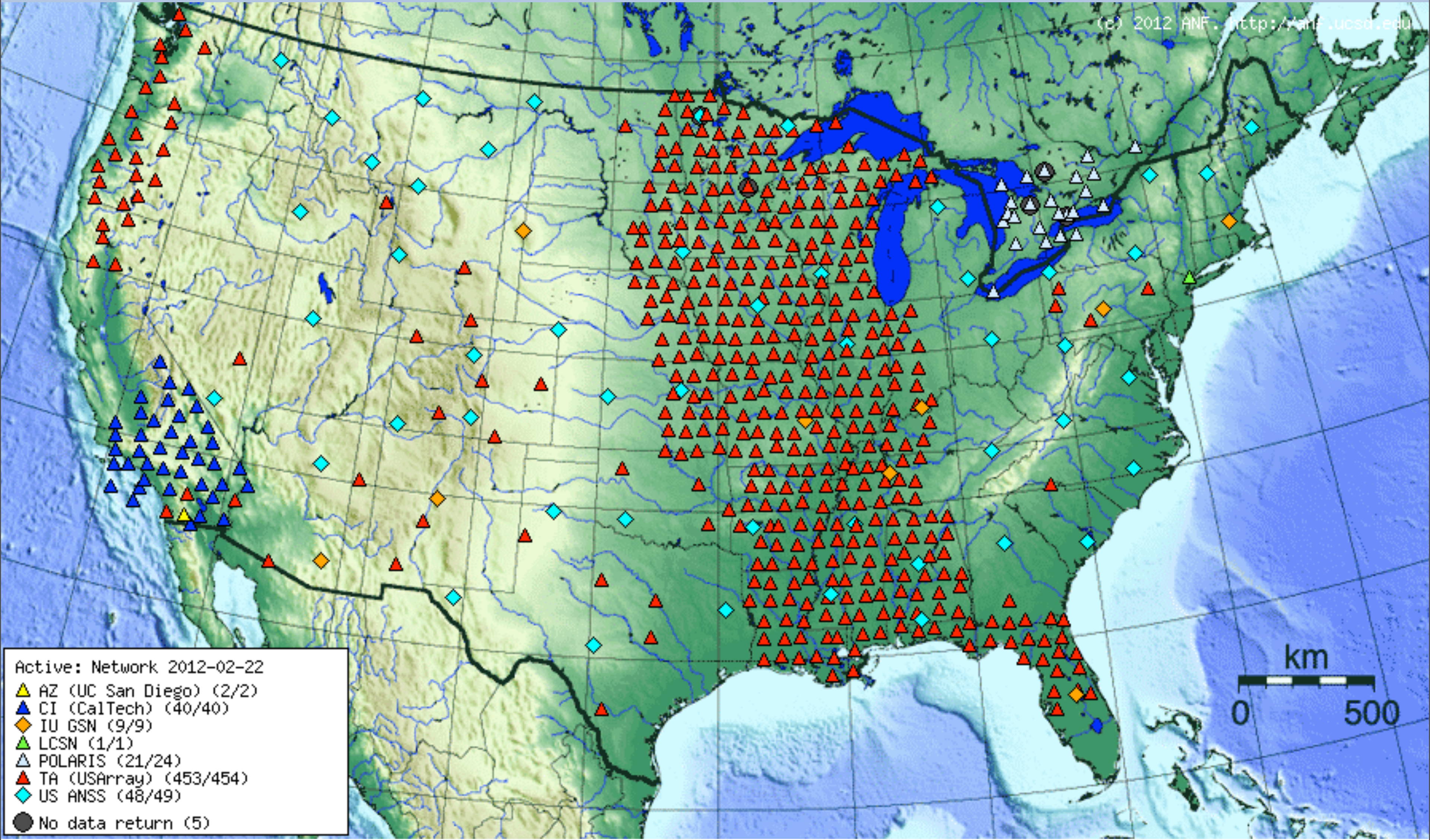
- Operational 24-7-365
  - Redundant power supplies
  - Redundant network interfaces
  - Virtualized computing and storage
  - Moved to new collocation facility at San Diego Supercomputer Center
- Staffing
  - Normal work hours (Monday-Friday - 8 am to 5 pm)
  - Key personnel on-call
    - Earthquake response
    - Systems Failure
- State of Health Monitoring (Web Accessible)
  - Sensor
  - Datalogger
  - Time Quality
  - Baler
  - Power supply
  - Telemetry
  - Networking

USArray Data Flow

- 10.2 Tbytes of compressed data April 2004 - November 2011
- As of November 2011
  - 11 Gbytes/day compressed data
  - 2.4 Mbit/sec data export
  - 441 seismic stations
  - 5319 seismic channels
  - 1519 barometer and infrasound channels
  - 10326 soh channels

(c) 2004 - 2004 Array Network Facility, http://anf.ucsd.edu
km
0
500
Network Legend
AZ (UC San Diego) [2]
BK (UC Berkeley) [17]
CI (CalTech) [43]
IU GSN [0]
NN (UN Reno) [0]
TA (USArray) [0]
US ANSS [0]
UUSS (Uni. Utah) [0]
km
0
500
2004 04

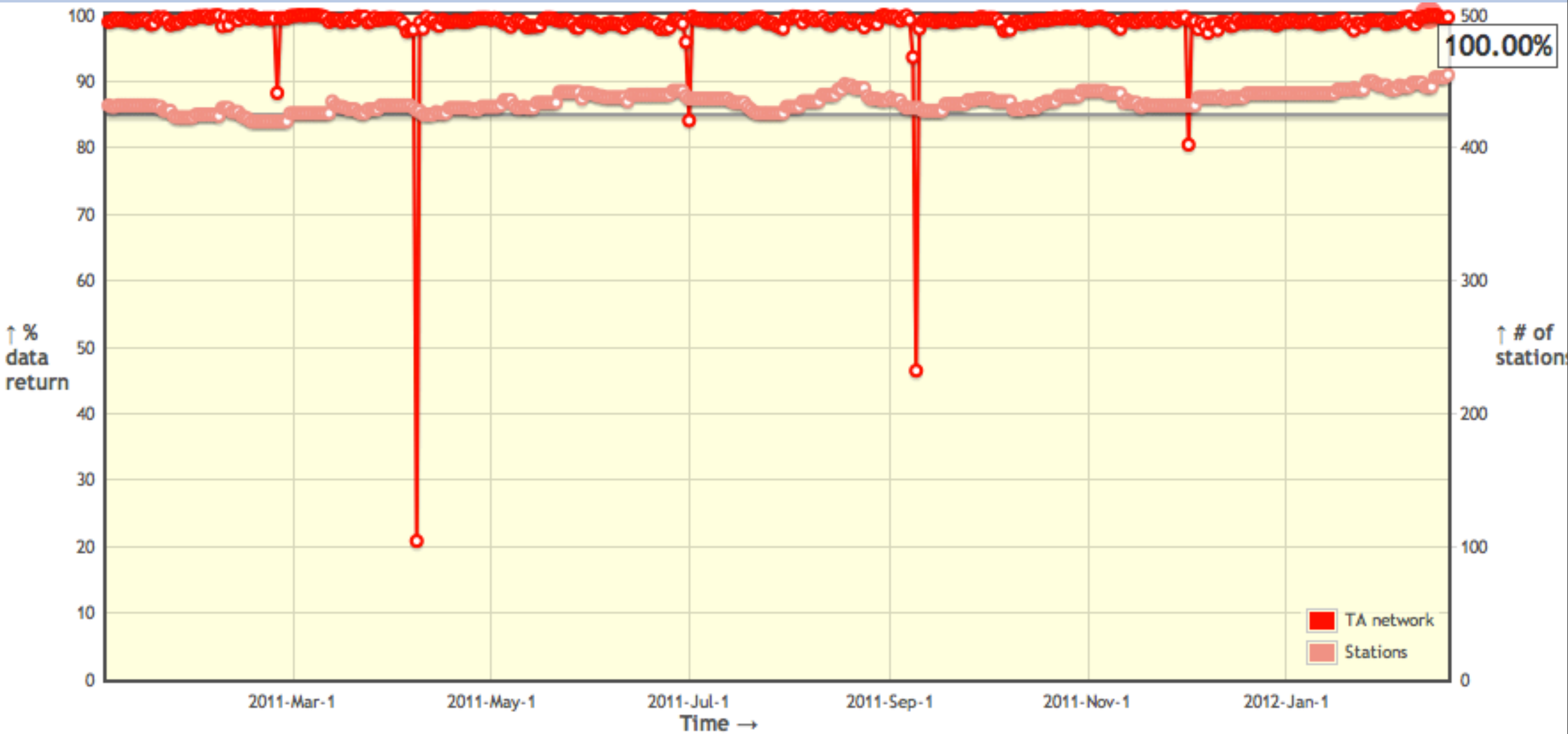
USArray 22 Feb 2012



TA 2011-12 RT Data Return

4 days 100.00% Data Return

Mean Data Return - 98.67%
Median Data Return - 99.15%



ANF Operations Year 1 - 2004

- TA Field
  - 13 TA Stations
  - 66 Contributed stations (CI, BK, AZ)

- Server Hardware
  - Sun Blade 1000

- Software
  - Nagios - system monitoring

ANF Operations Year 5 - 2008

- TA Field
  - 442 TA Stations
  - 57 Contributed stations (CI, AZ, NN, US)
- Server Hardware
  - Sun Cluster - 3 V240s and 3 T2000
  - Installed 3 Sun T5220 for web support
  - SRB Brick
  - iSCSI Storage Area Network 15 TBytes
  - Decommissioned Sun Cluster File System
    - PxFS replaced with QFS
    - Discovered Sun Cluster does not support iSCSI
    - Kept zone functionality
- Software
  - intermapper - system monitoring installed
  - cfengine - system configuration
  - Confluence installed for ANF Wiki

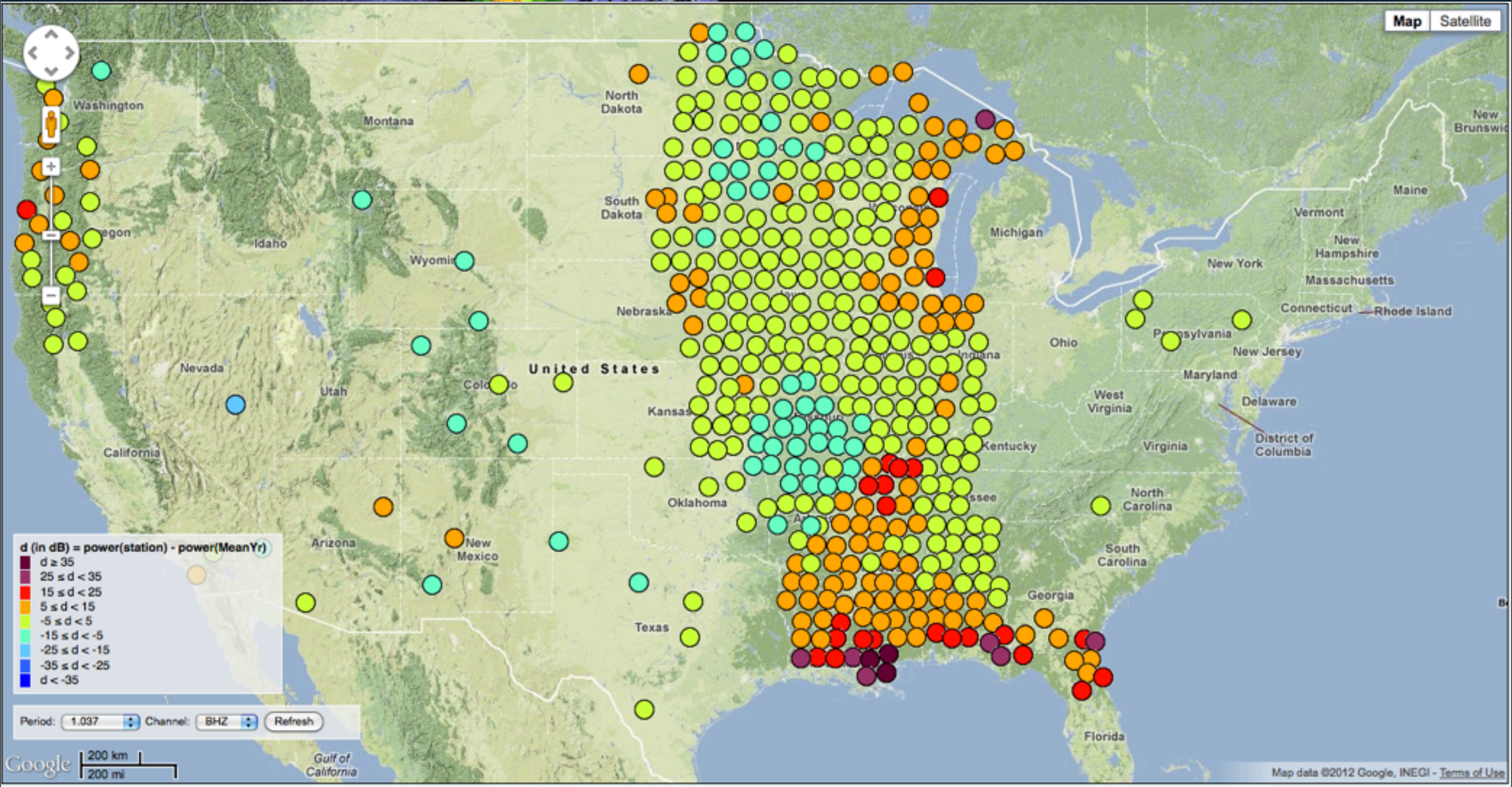
ANF Operations Year 7 - 2010

- TA Field
  - 442 TA Stations
  - 57 Contributed stations (CI, AZ, NN, US)
- Server Hardware
  - Sun Cluster - 3 V240s and 3 T2000
  - 3 Sun T5220 for web support
  - Mac XServe
  - JetStore
  - iSCSI Storage Area Network 15 TBytes
- Software
  - intermapper - system monitoring installed
  - cfengine - system configuration
  - Confluence installed for ANF Wiki

ANF Operations Year 9 - 2012

- TA Field
  - 454 TA Stations
  - 121 Contributed stations (CI, AZ, IU, LD, US, PO)
- Server Hardware (Production)
  - Sun Cluster - 3 V240s and 3 T2000
  - 3 T5220 for web support
  - Mac XServe
  - Compellant ~ 100 TBytes of storage
- Server Hardware (Testing)
  - 3 Dell PowerEdge R710
- Software
  - intermapper - system monitoring installed
  - cfengine - system configuration
  - Confluence installed for ANF Wiki
  - JIRA - Ticketing system

Station Noise Ranking

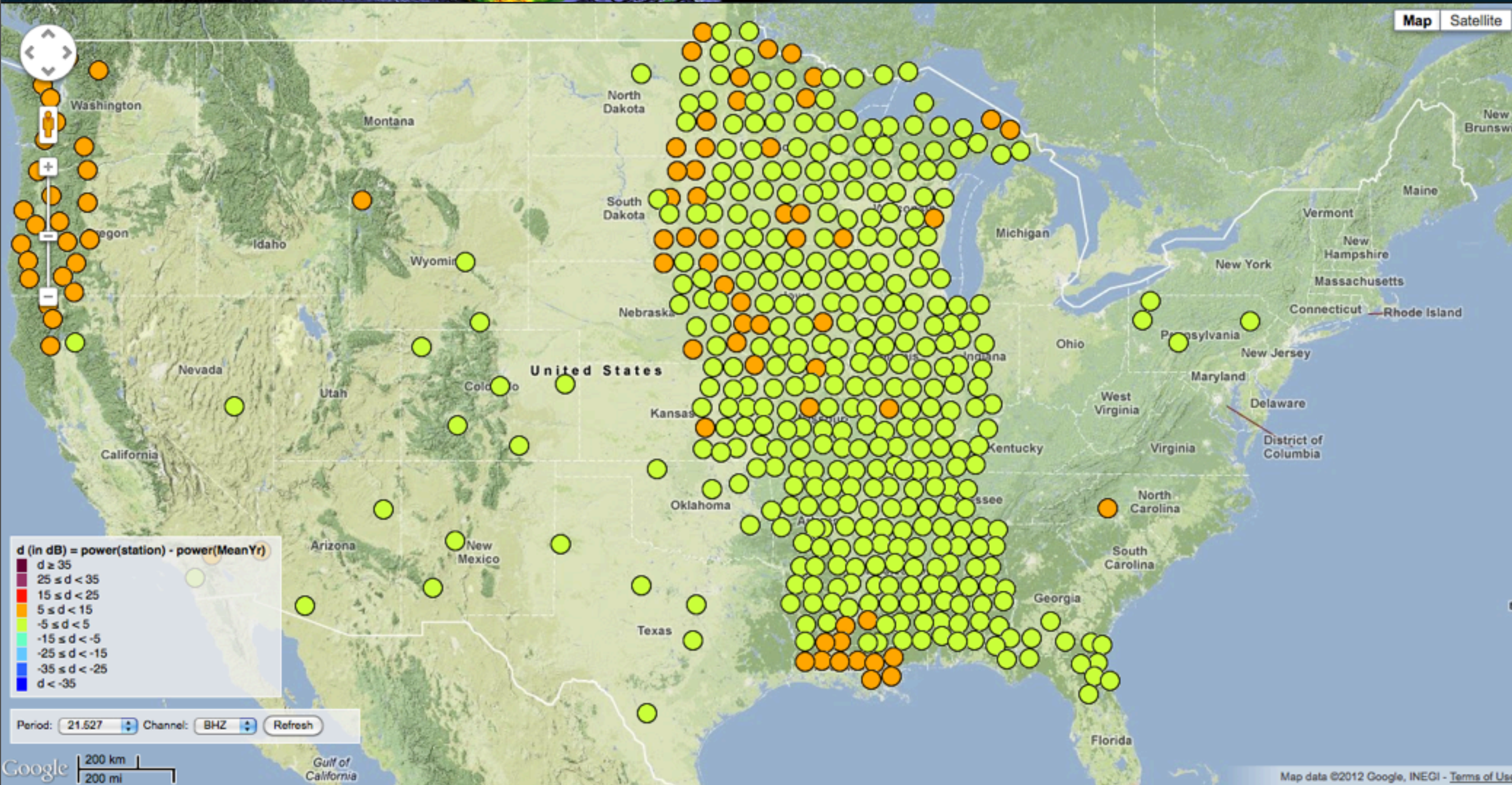


1 Second Period Band

Station Noise Ranking

7 Second Period Band

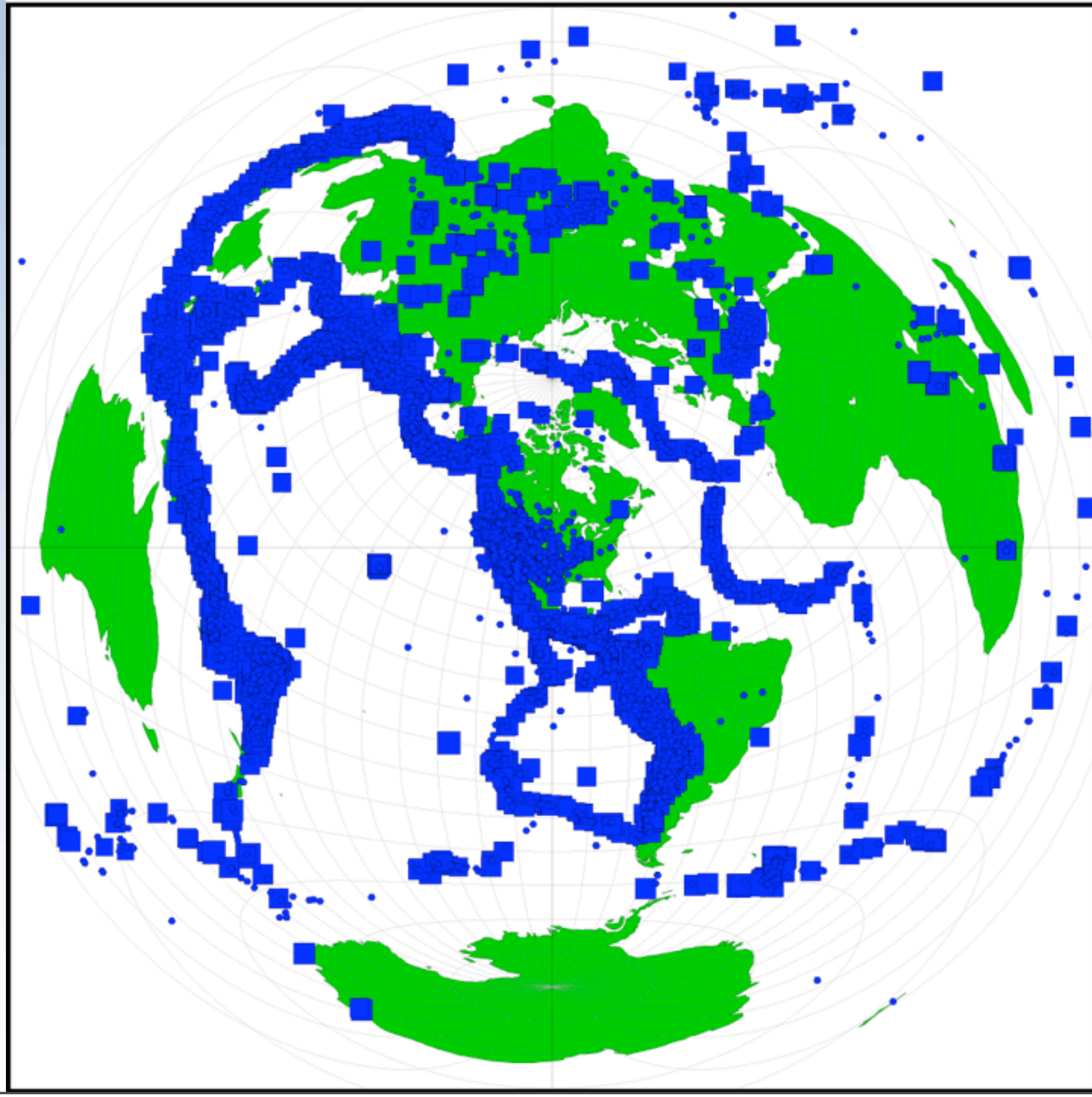
Station Noise Ranking



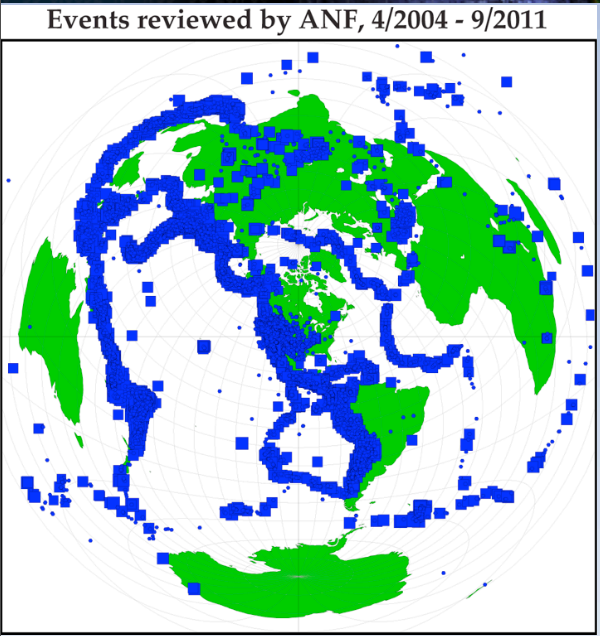
20 Second Period Band

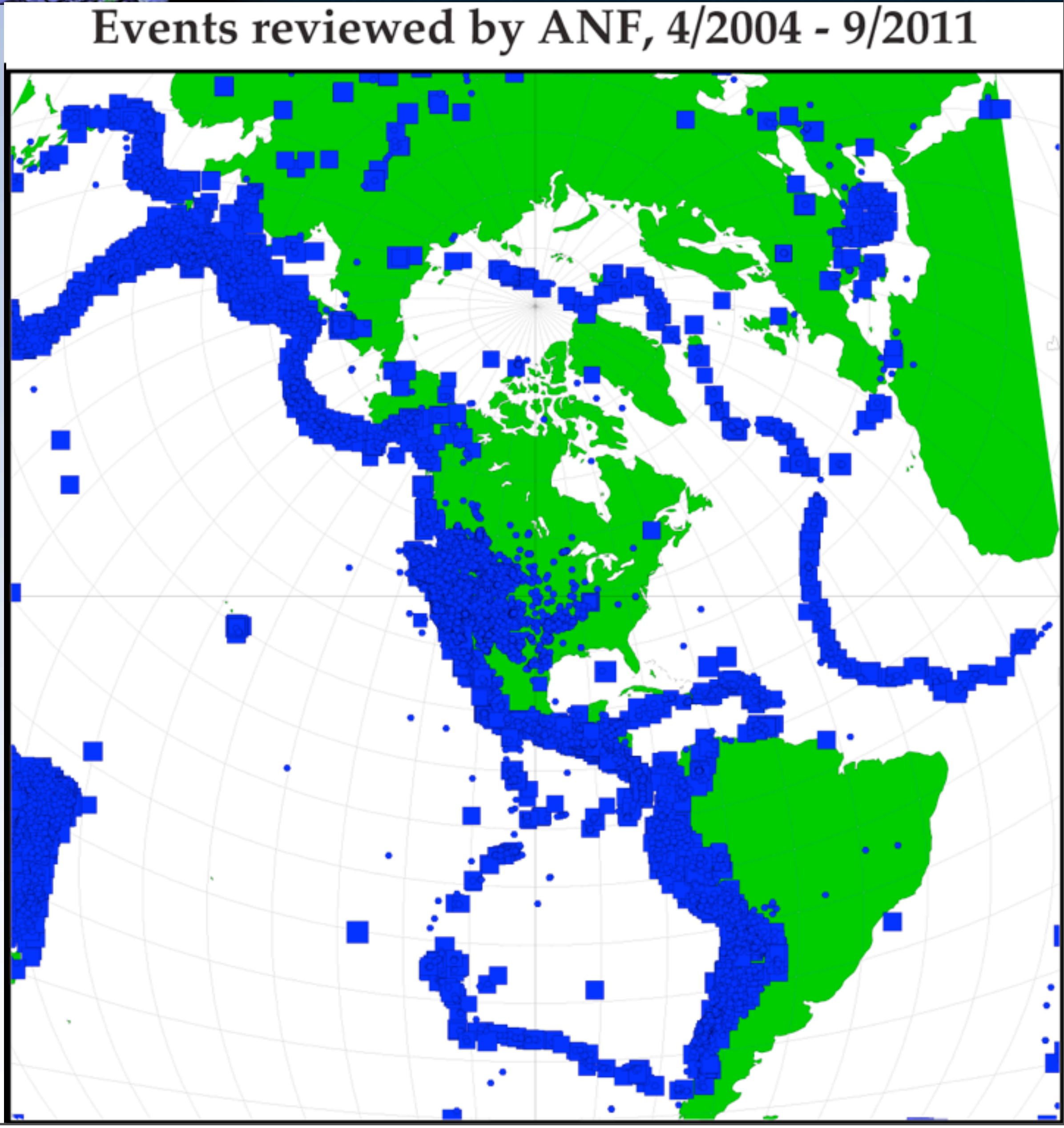
TA Seismicity

Events reviewed by ANF, 4/2004 - 9/2011



TA Seismicity





TA Seismicity

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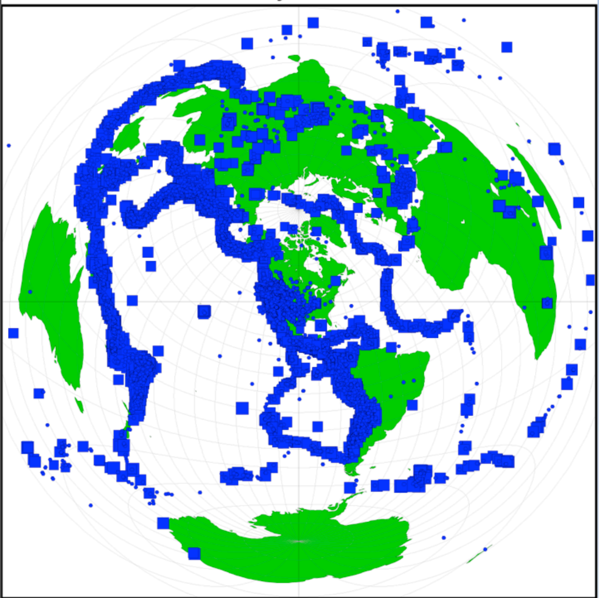
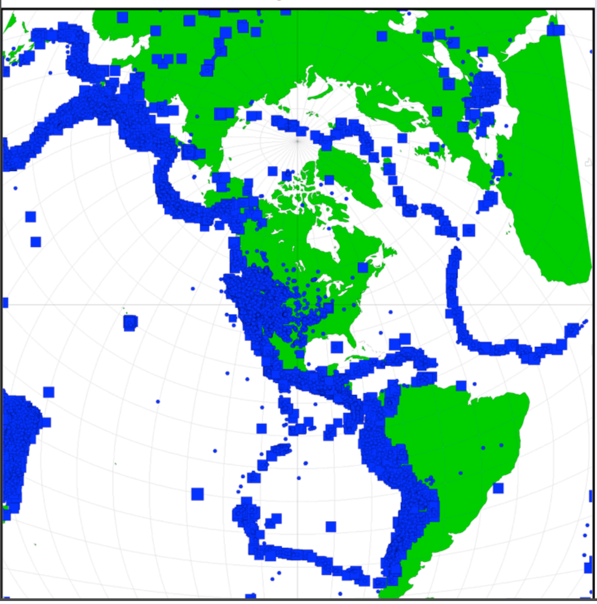
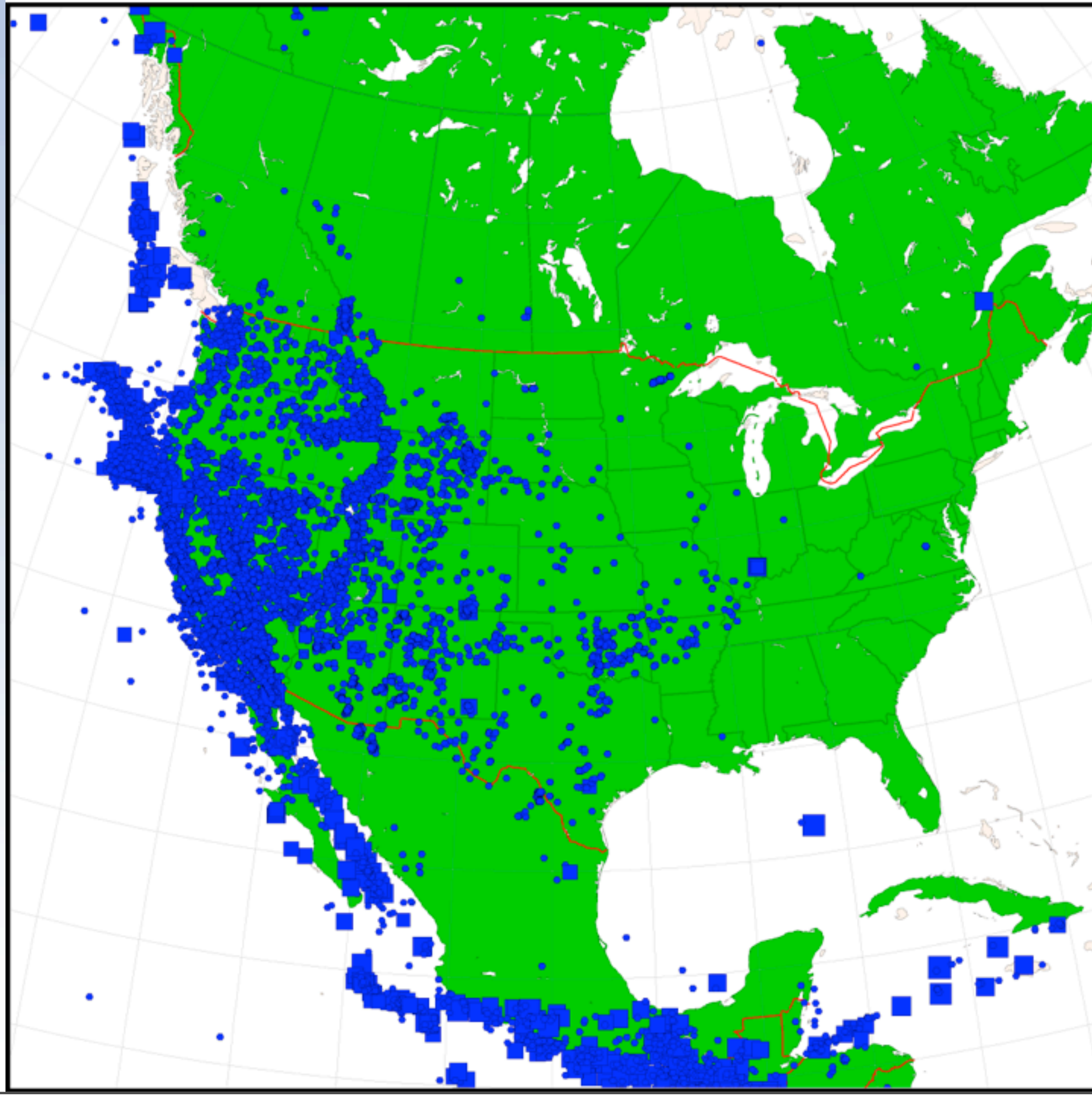


Events reviewed by ANF, 4/2004 - 9/2011



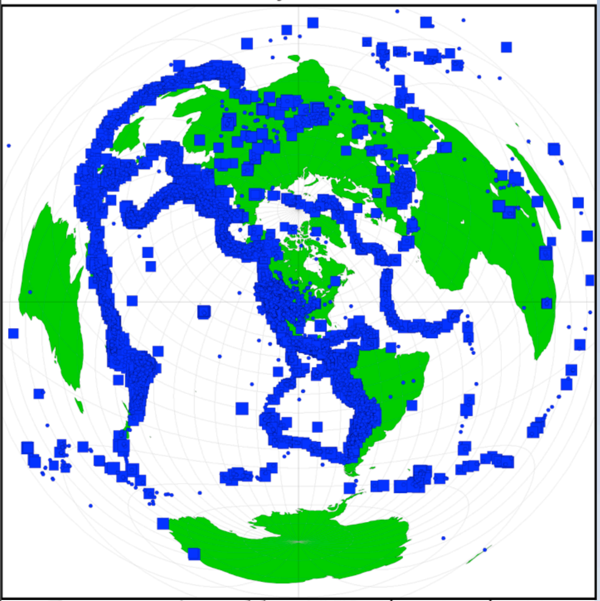
Events reviewed by ANF, 4/2004 - 9/2011



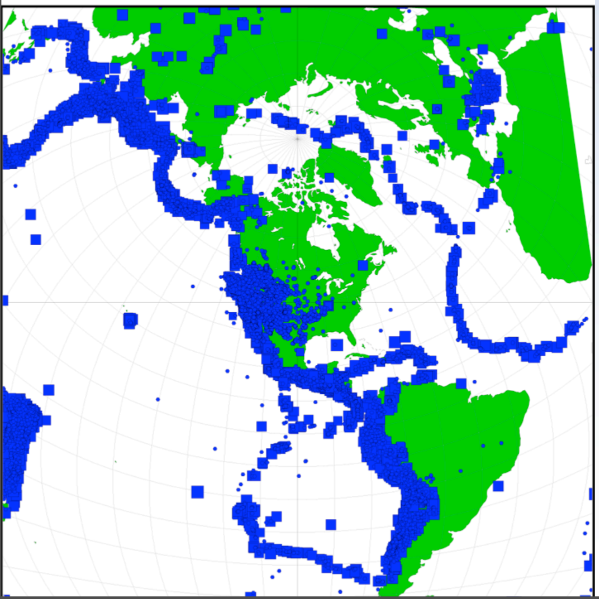
TA Seismicity

- 4.7M reviewed arrivals
- 61,000+ reviewed events

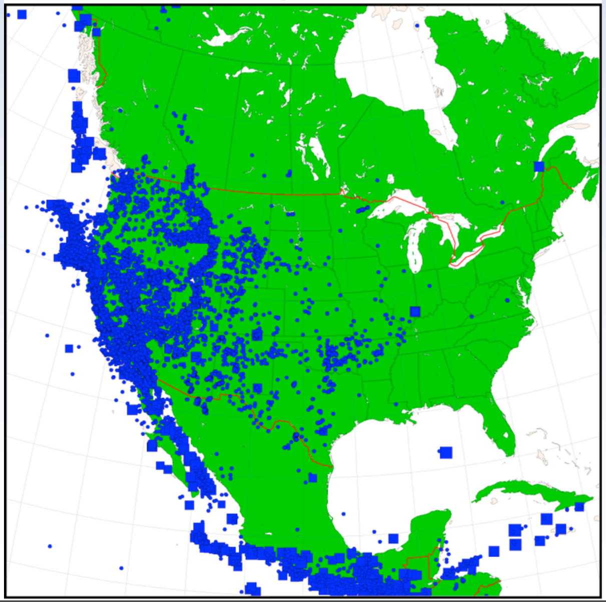
Events reviewed by ANF, 4/2004 - 9/2011



Events reviewed by ANF, 4/2004 - 9/2011

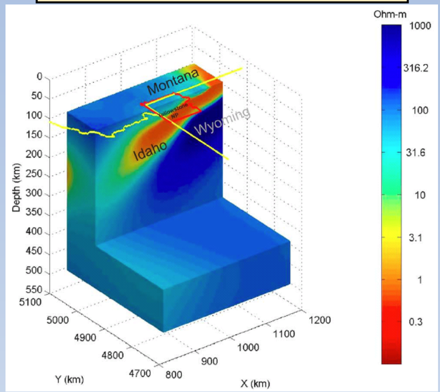


Events reviewed by ANF, 4/2004 - 9/2011



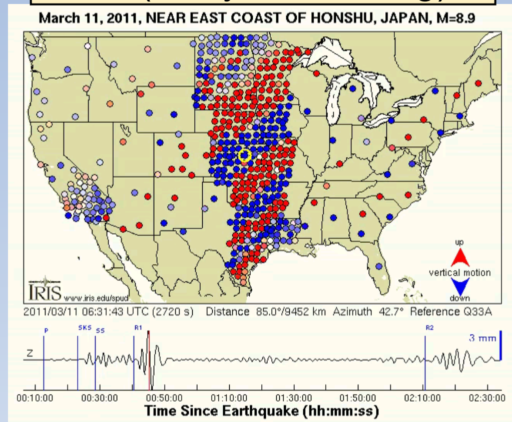
Science Impact

TA (Magnetotellurics)



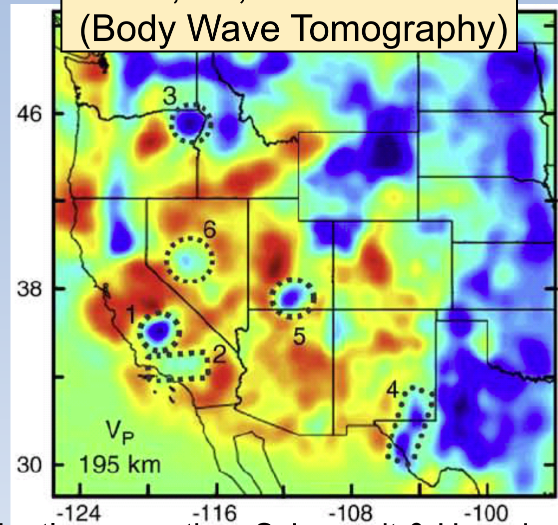
Plumes : Zhdanov et al.

TA (Array Processing)



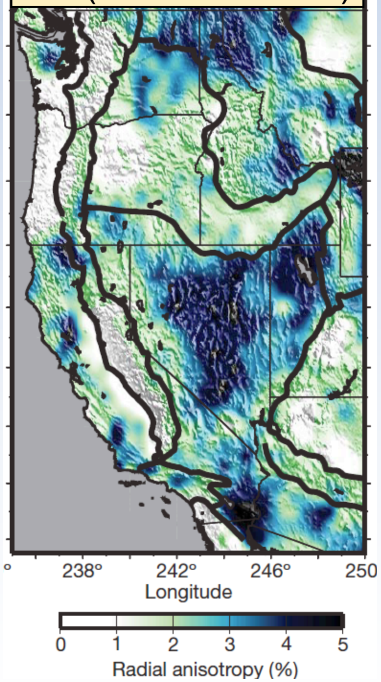
Visualizing great earthquakes: IRIS DMC

TA, FA, & PASSCAL (Body Wave Tomography)



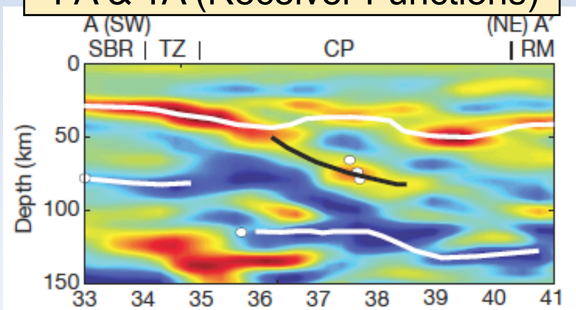
Mantle convection: Schmandt & Humphreys

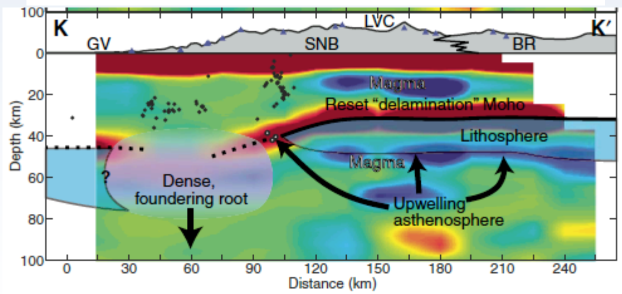
TA (Ambient Noise)



Crustal anisotropy: Moschetti et al.

FA & TA (Receiver Functions)

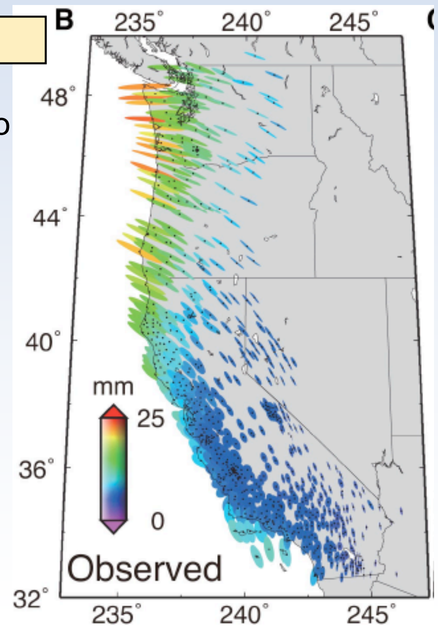




Lithospheric foundering: Levander et al., Frassetto et al.

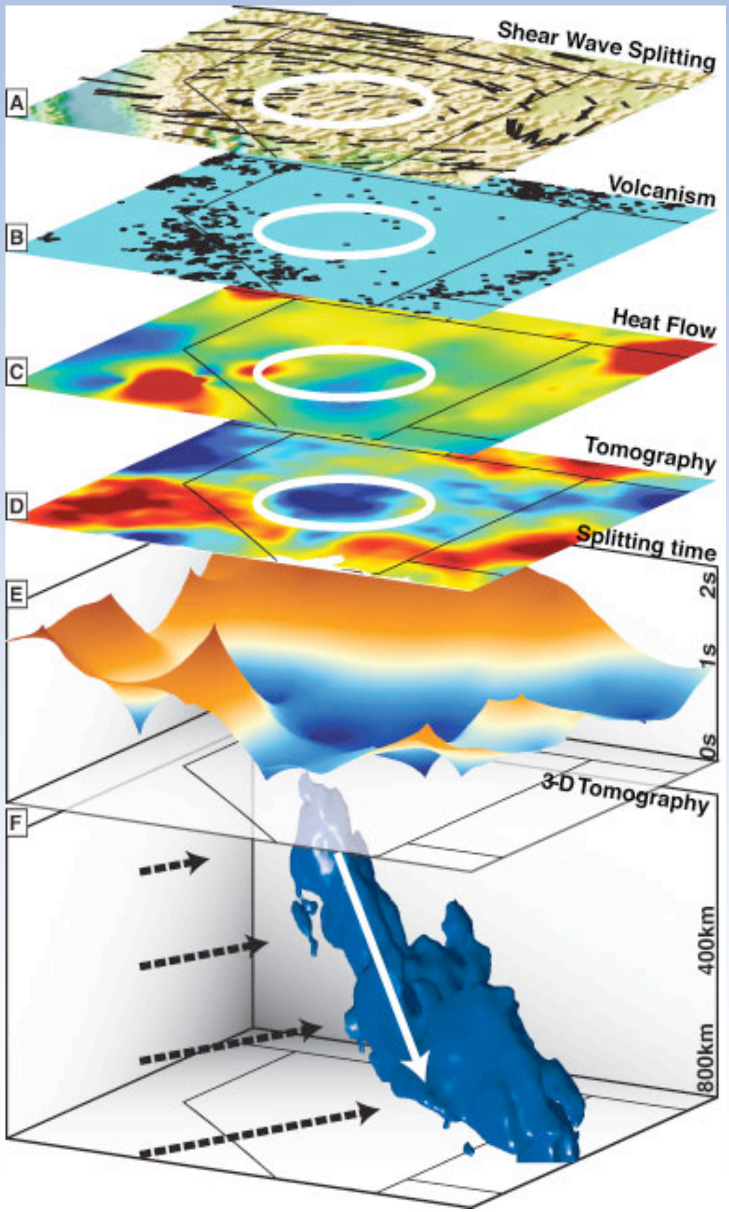
PBO (GPS)

Modeling mantle rheology: Ito & Simo



150+ papers in 2010-2011

Lithospheric Drips



Regional mantle downwelling, Great Basin, Western US

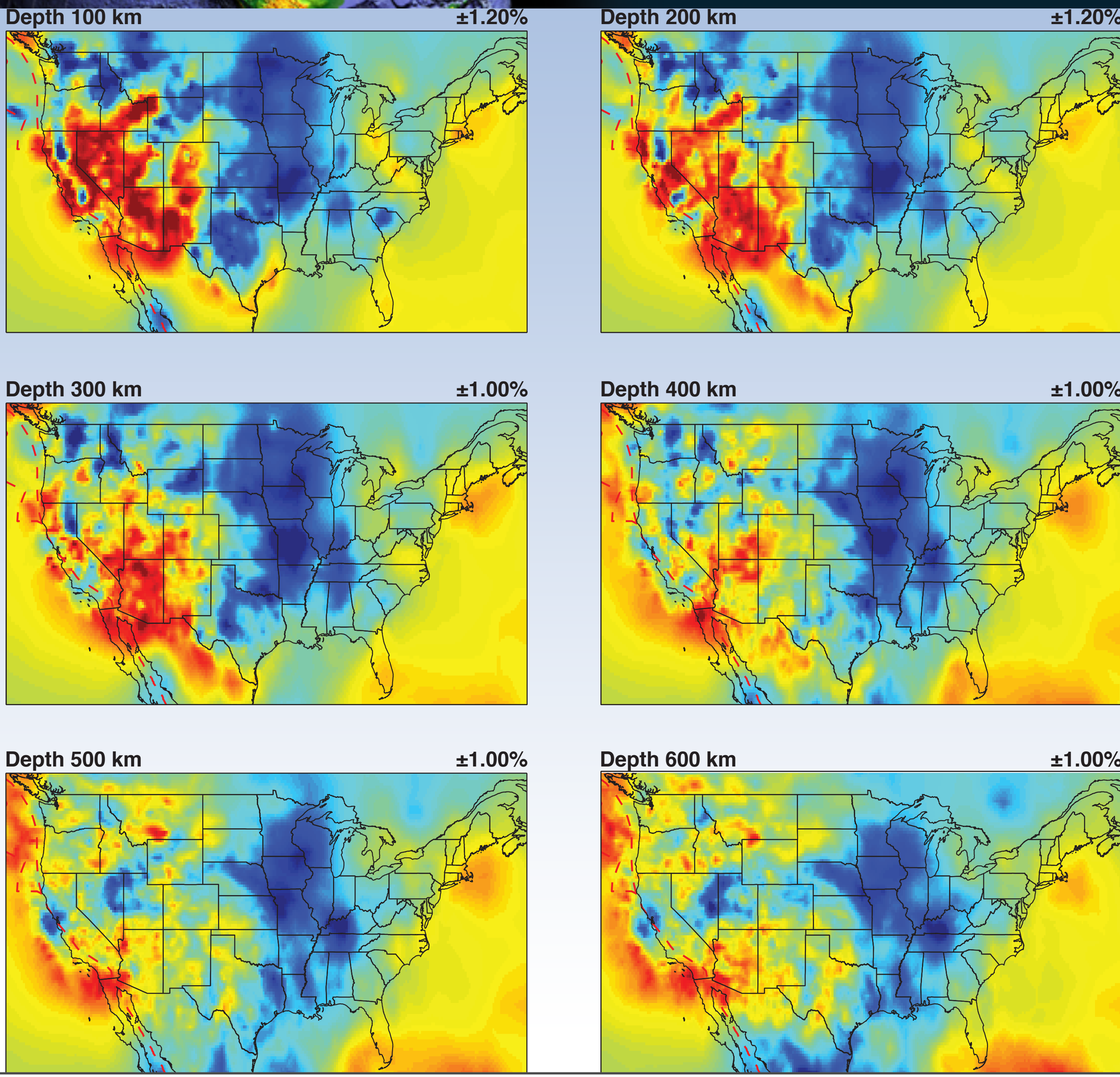
USArray TA and regional broadband data.

Shear wave splitting, 3-D tomography, heat flow, petrology.

Cylindrical core of fast seismic velocities; mantle flow shifts rapidly from horizontal to vertical.

West et al. 2009, *Nature Geoscience*

Tomography
Burdick et al. 2012



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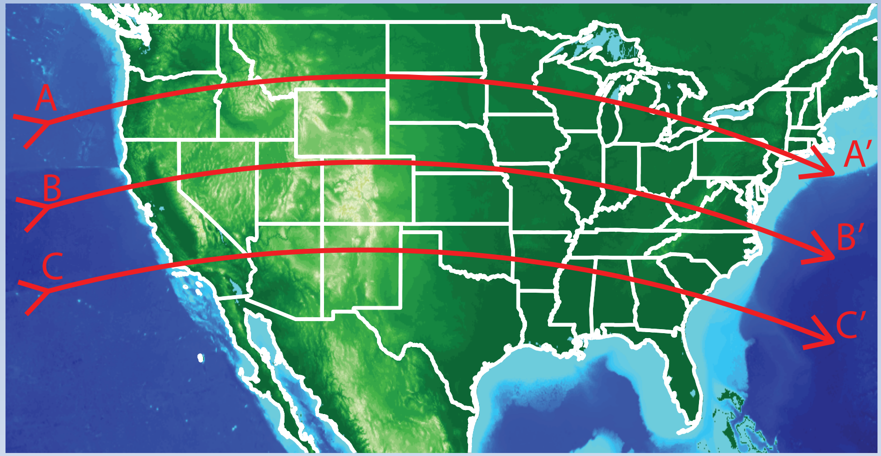
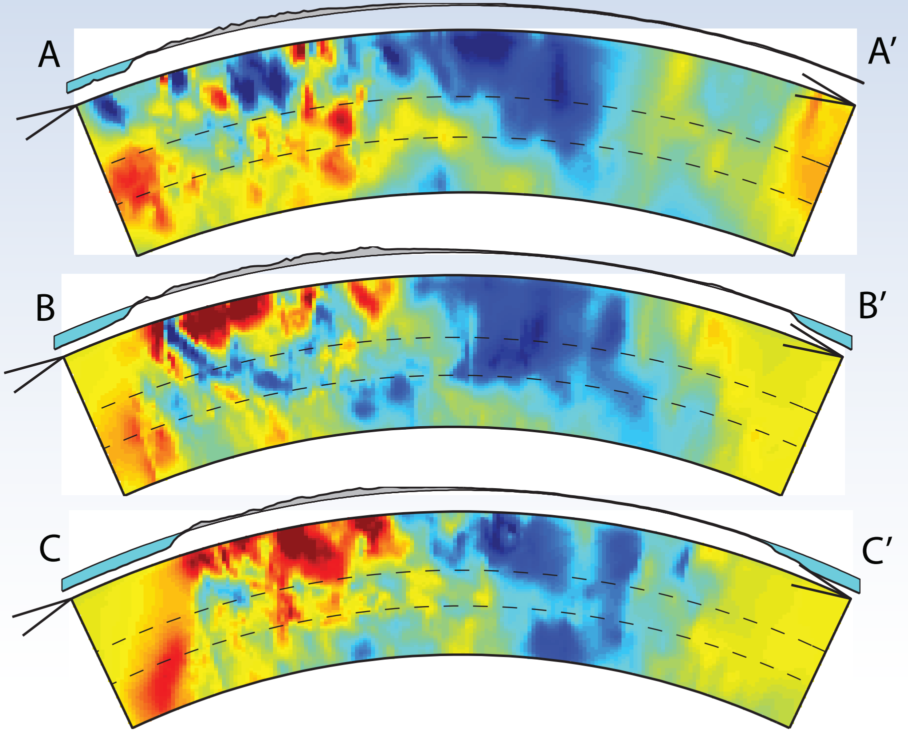
Tomography
Burdick et al. 2012





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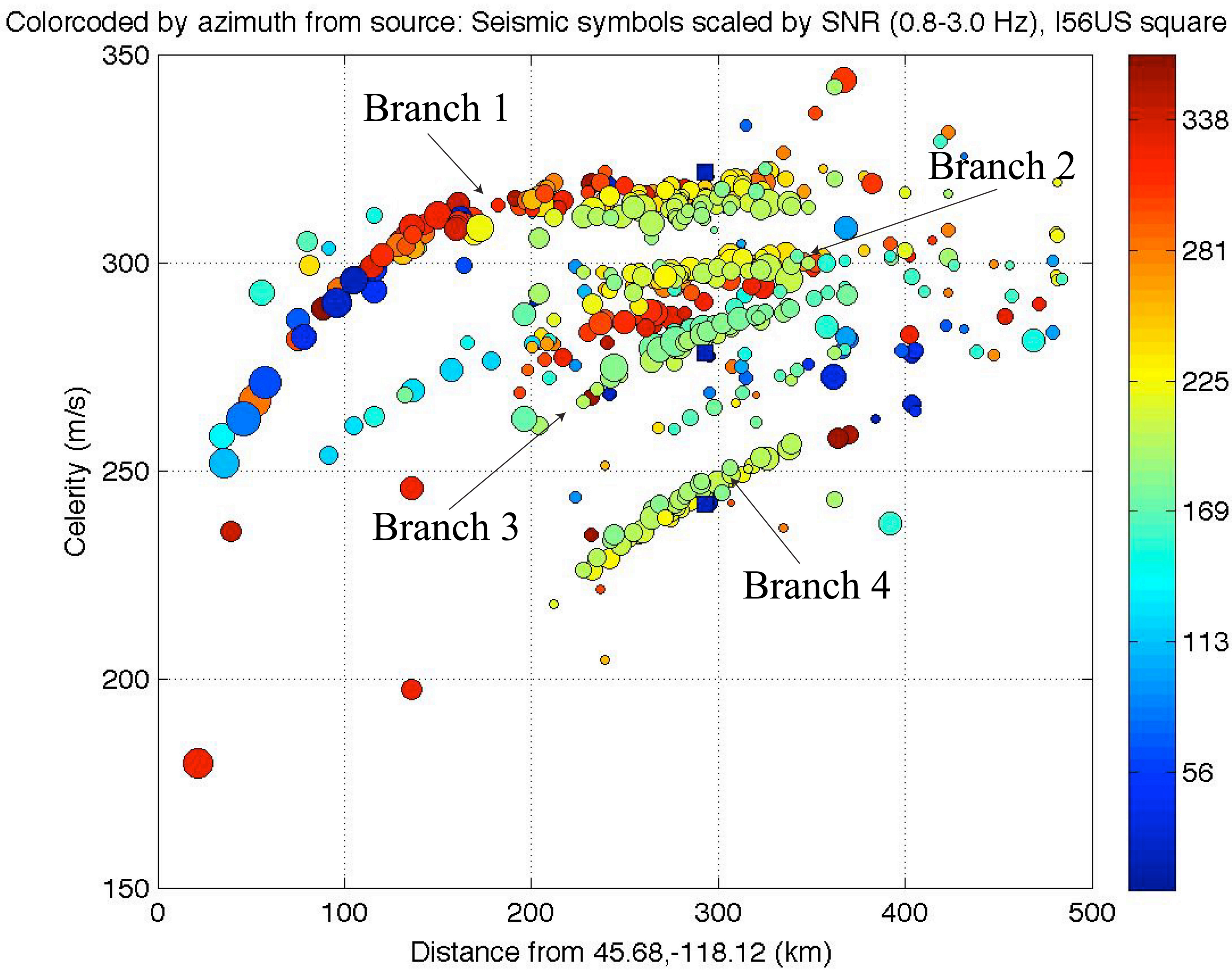
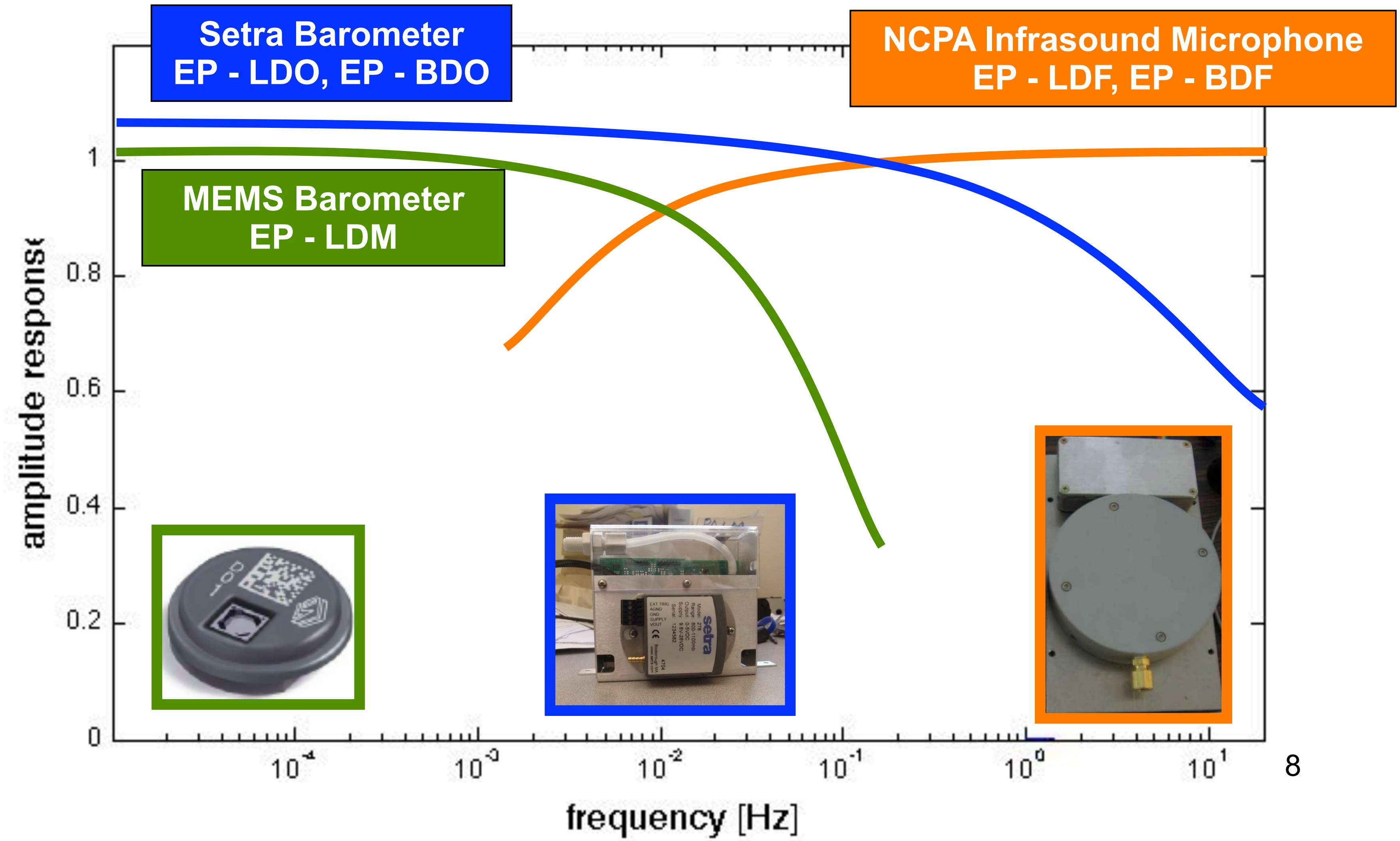
Case study – a bolide Hedlin et al 2010

Acoustic branches Hedlin et al 2010

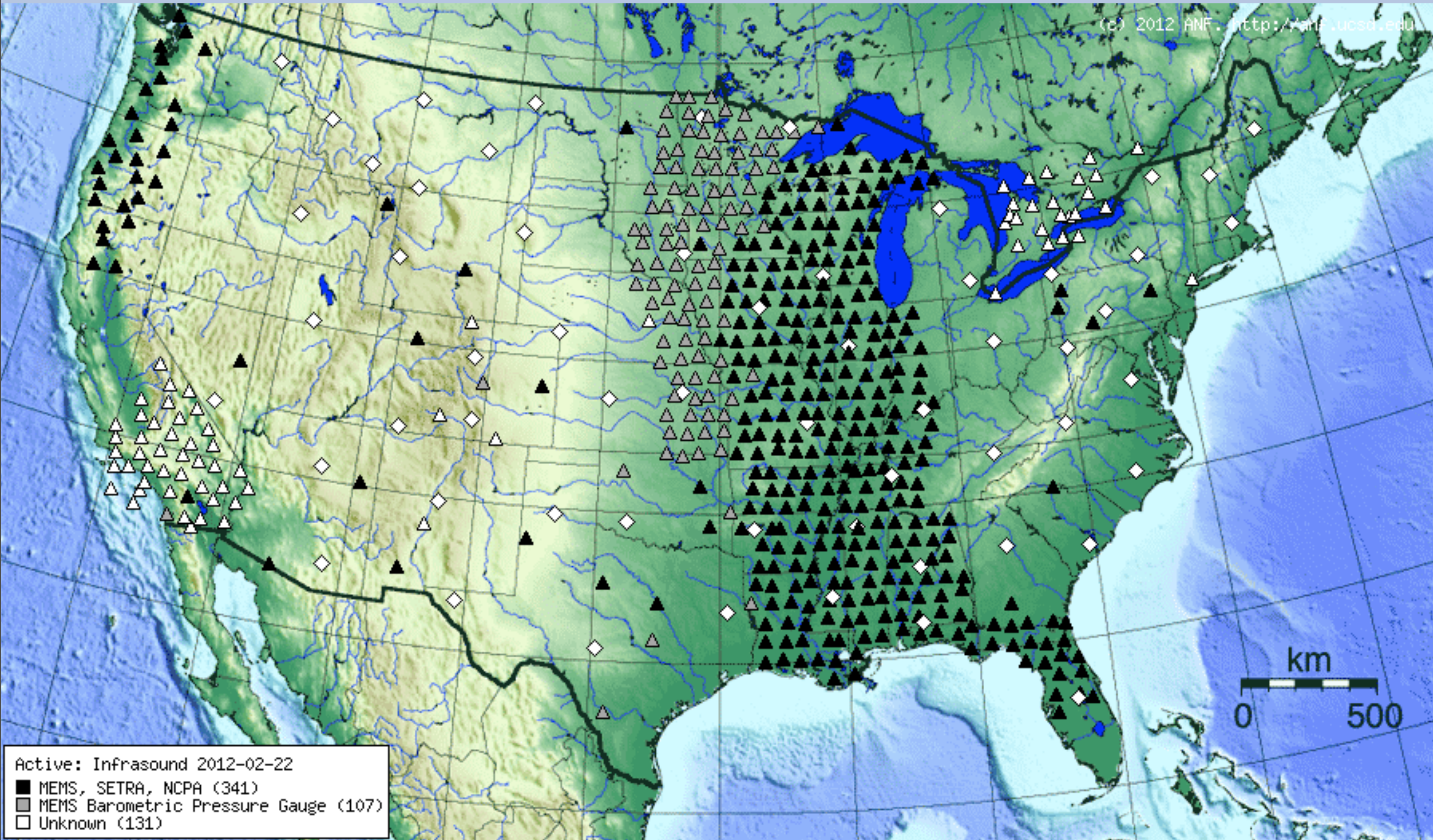


Pressure Sensor Response

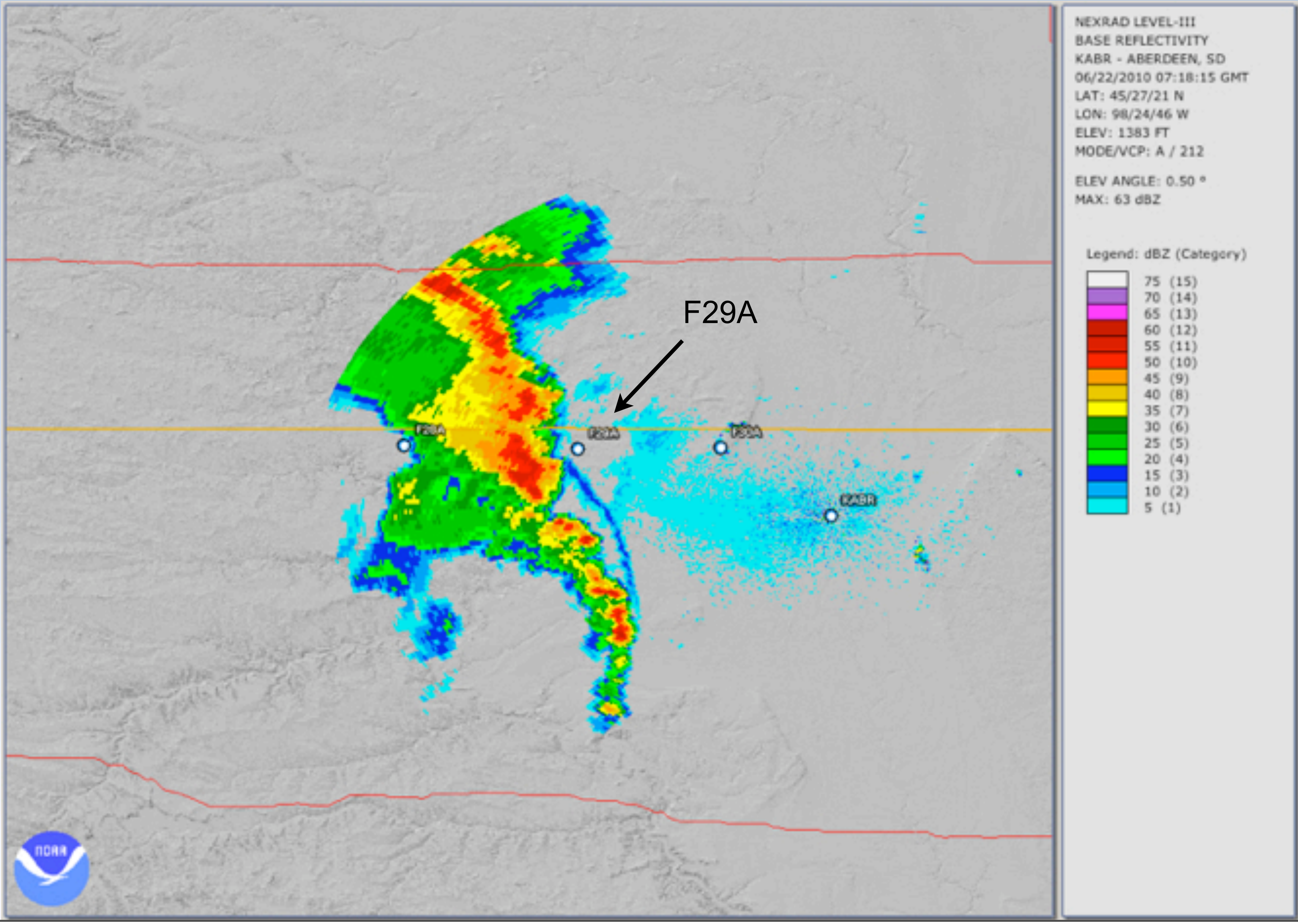
- **Overlapping pass-bands provides continuous coverage from DC to 20 Hz**



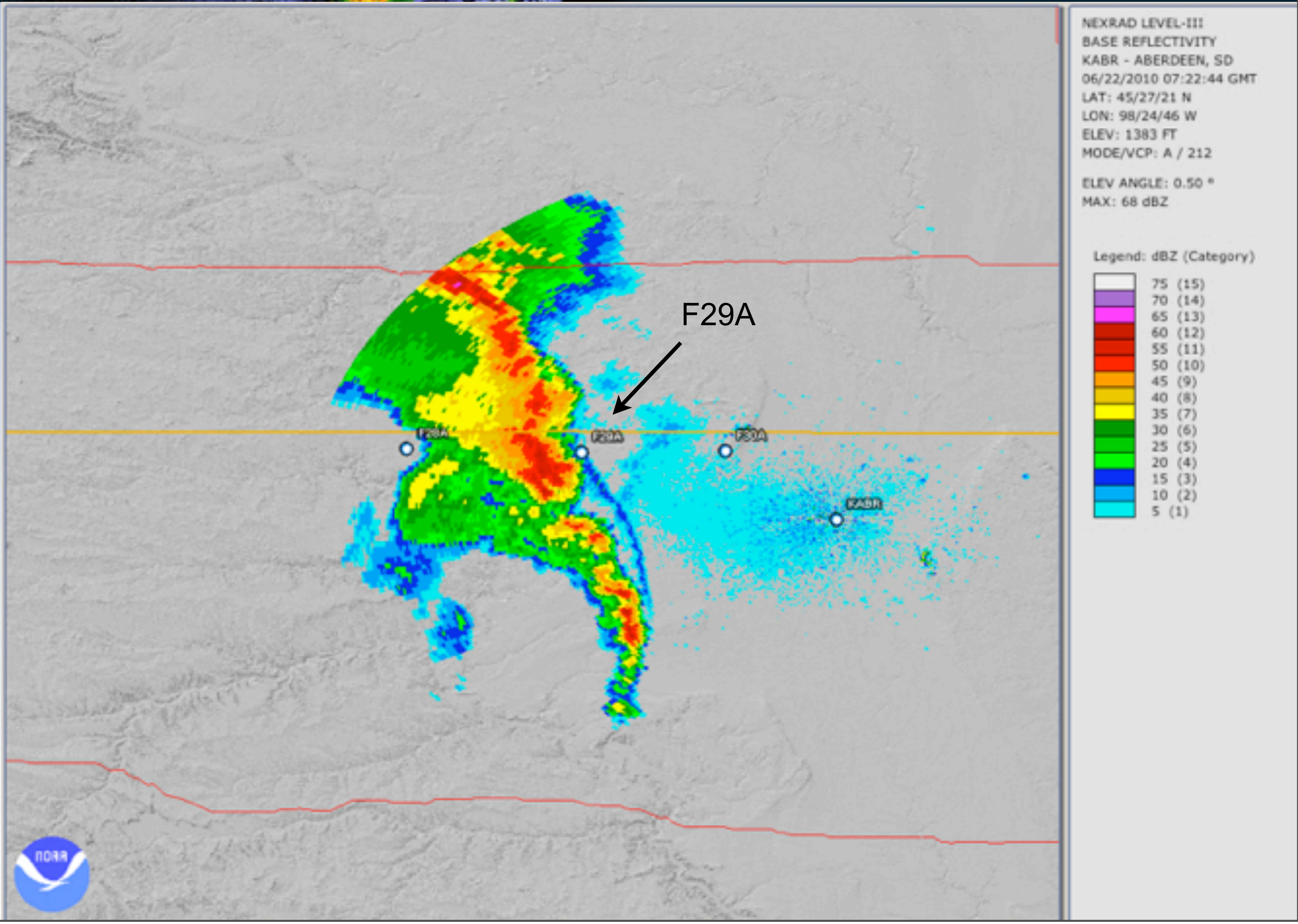
Current MEMS Barometer Deployment



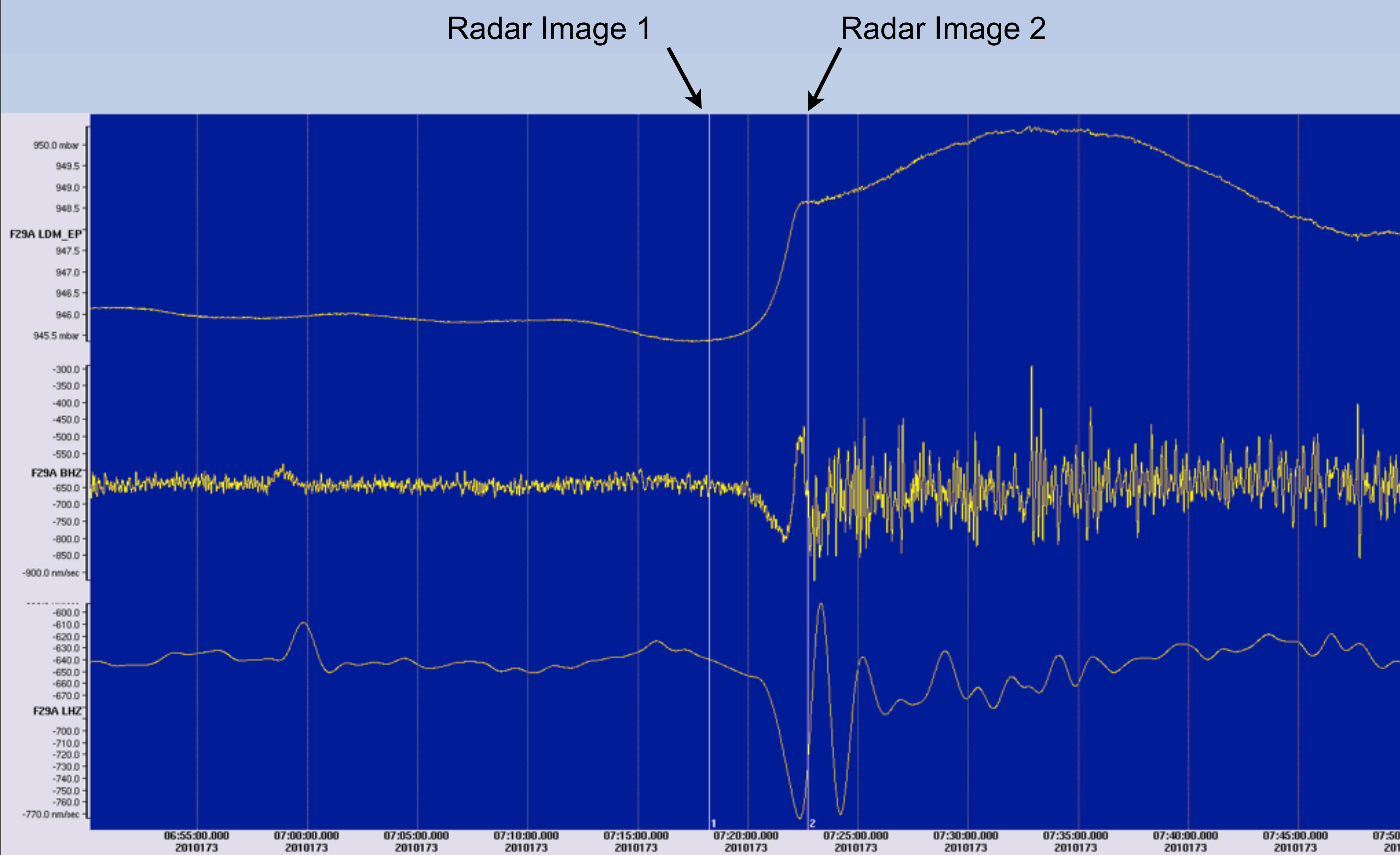
Radar Image 1 - F29A

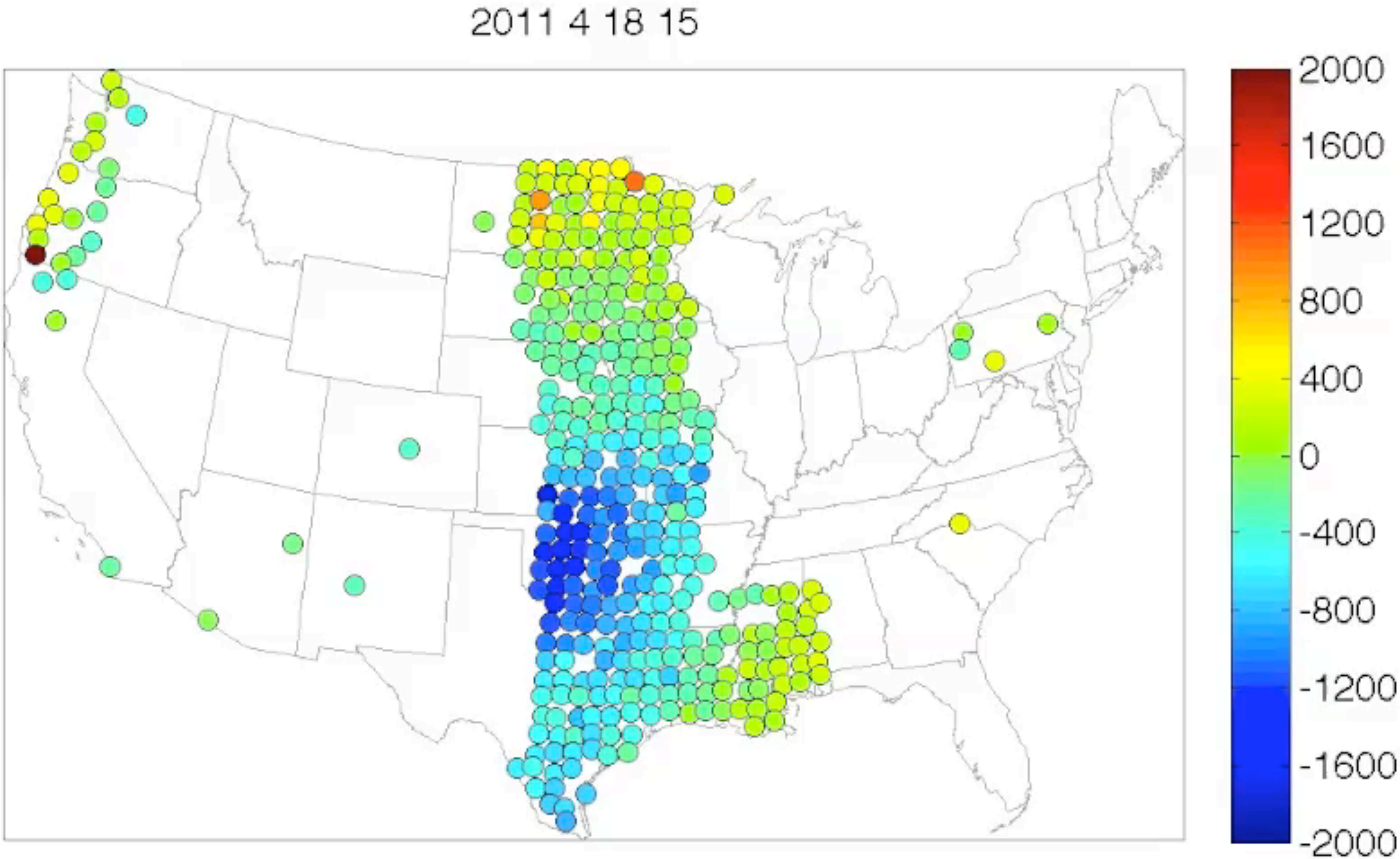


Radar Image 2 - F29A

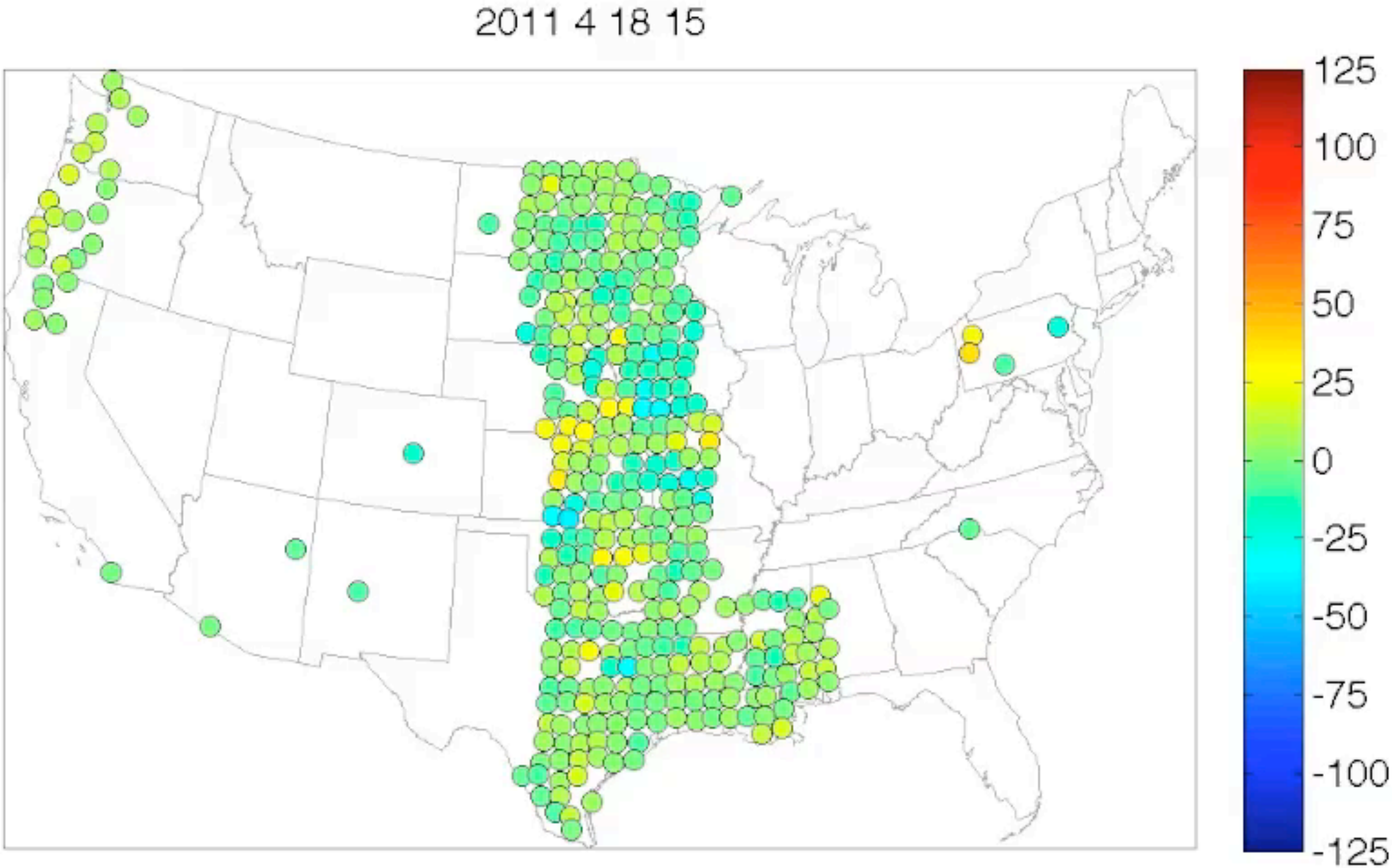


F29A Pressure and Seismic



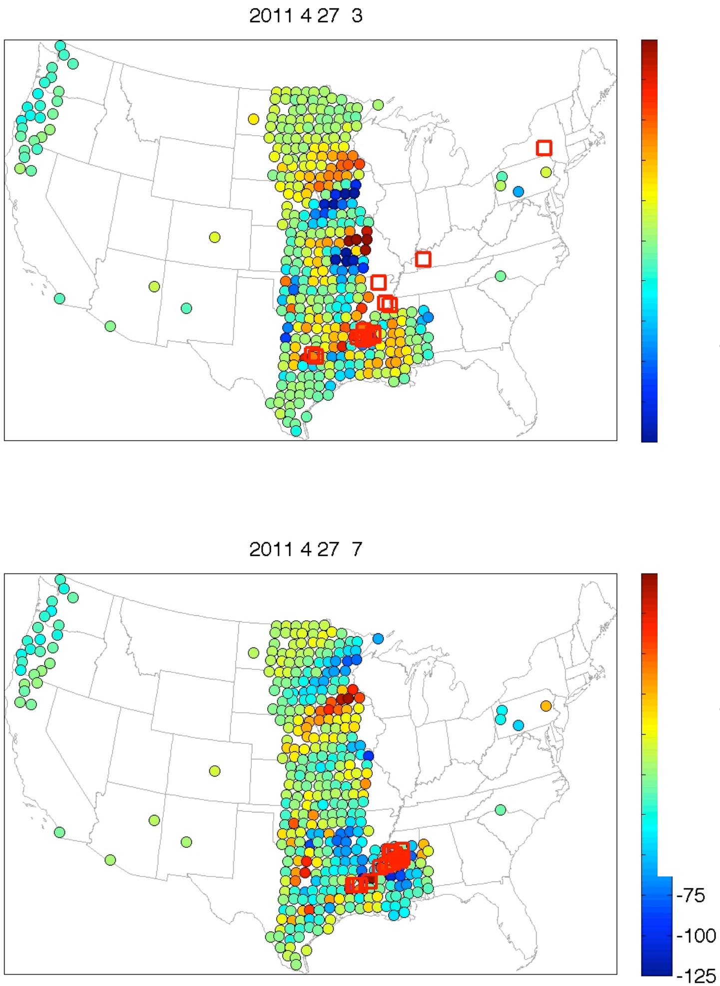


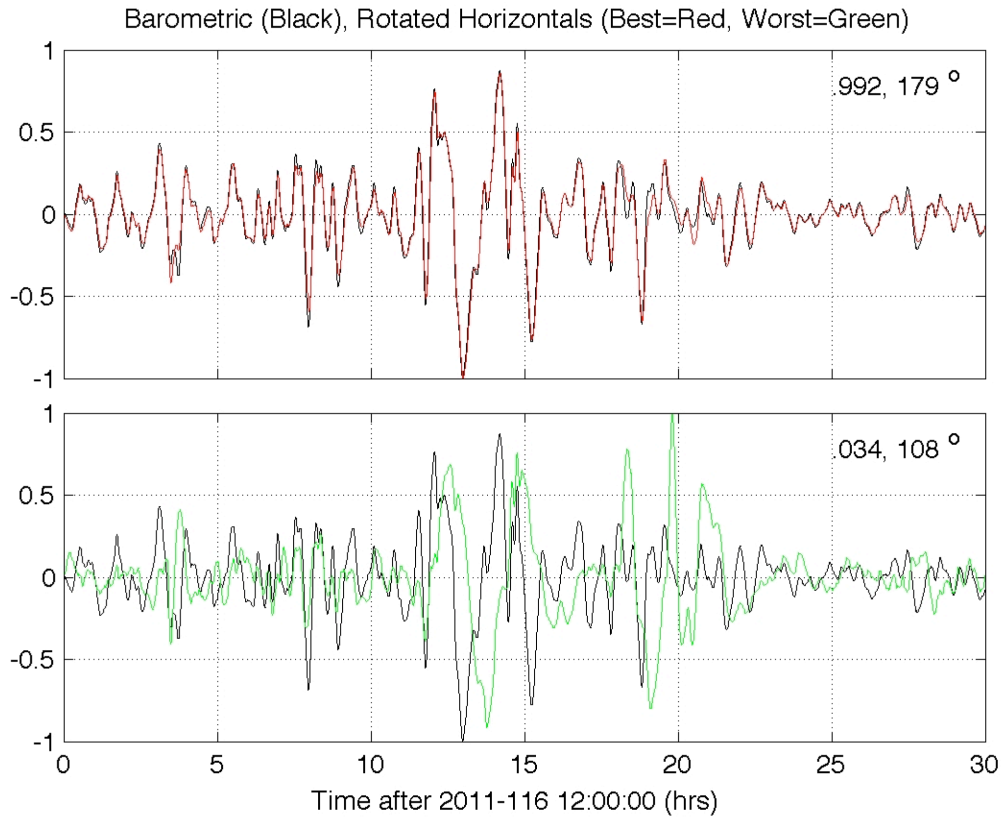
Barometric Pressure Variations
Unfiltered Data



Atmospheric Gravity Wave Band
Periods - 2 to 6 Hours

North propagating 2-6 hr GW

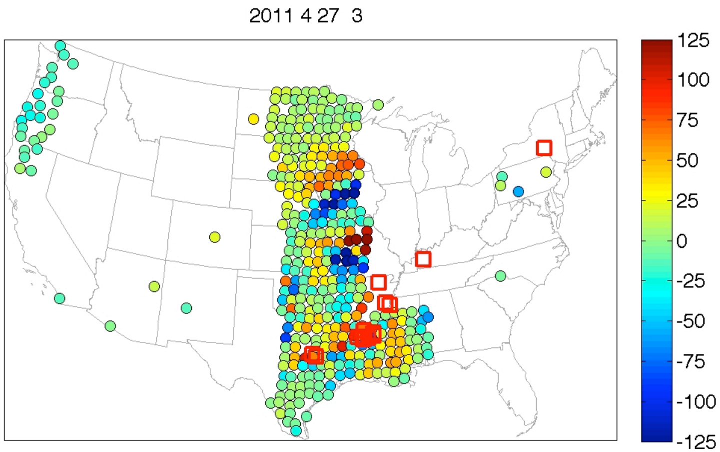


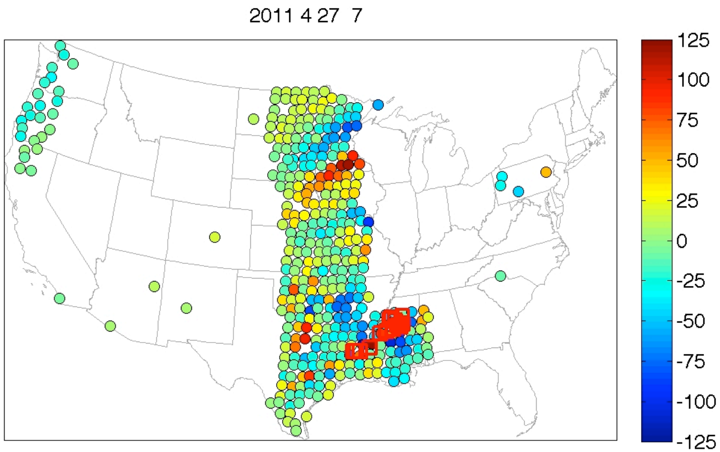


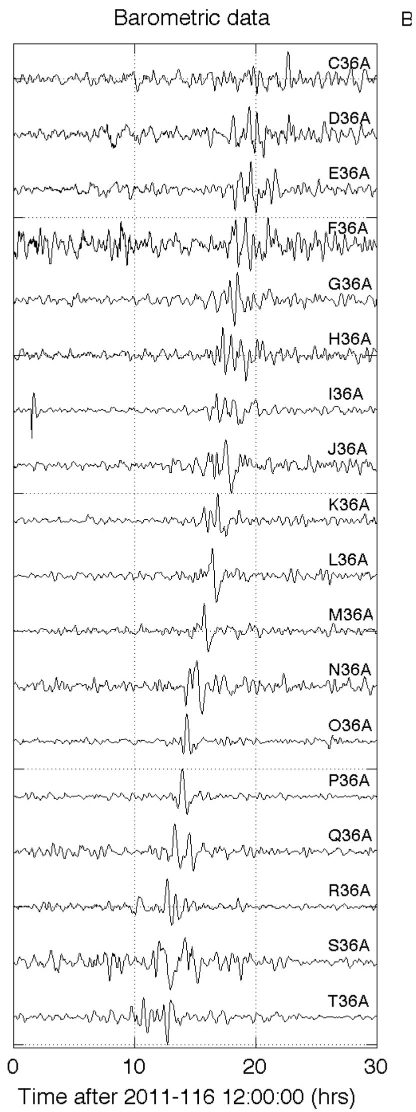
S36A: 1,800 to 8,000 s

12

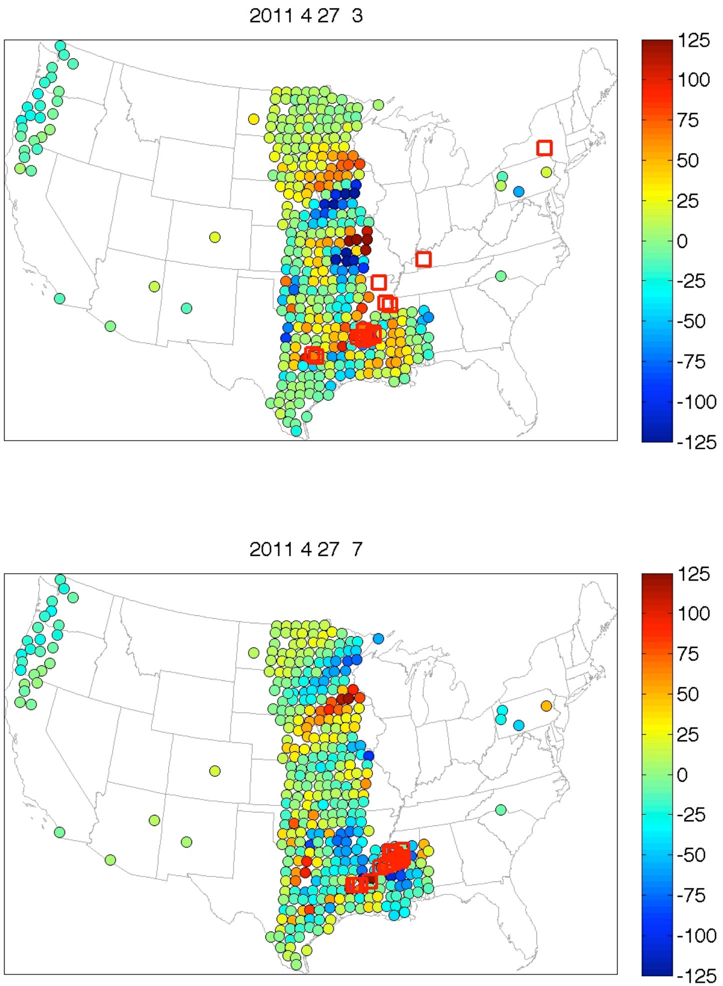
North propagating 2-6 hr GW

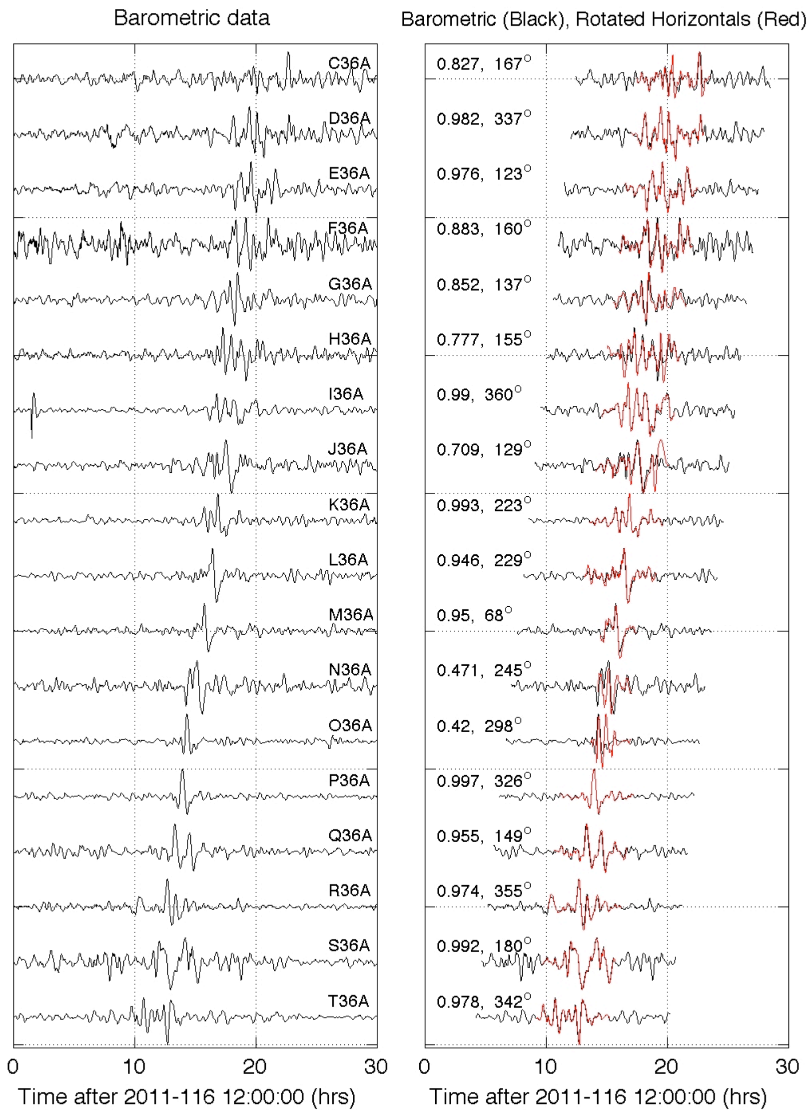






North propagating 2-6 hr GW





Jackson Tornado on 4/15/2011 – 245A

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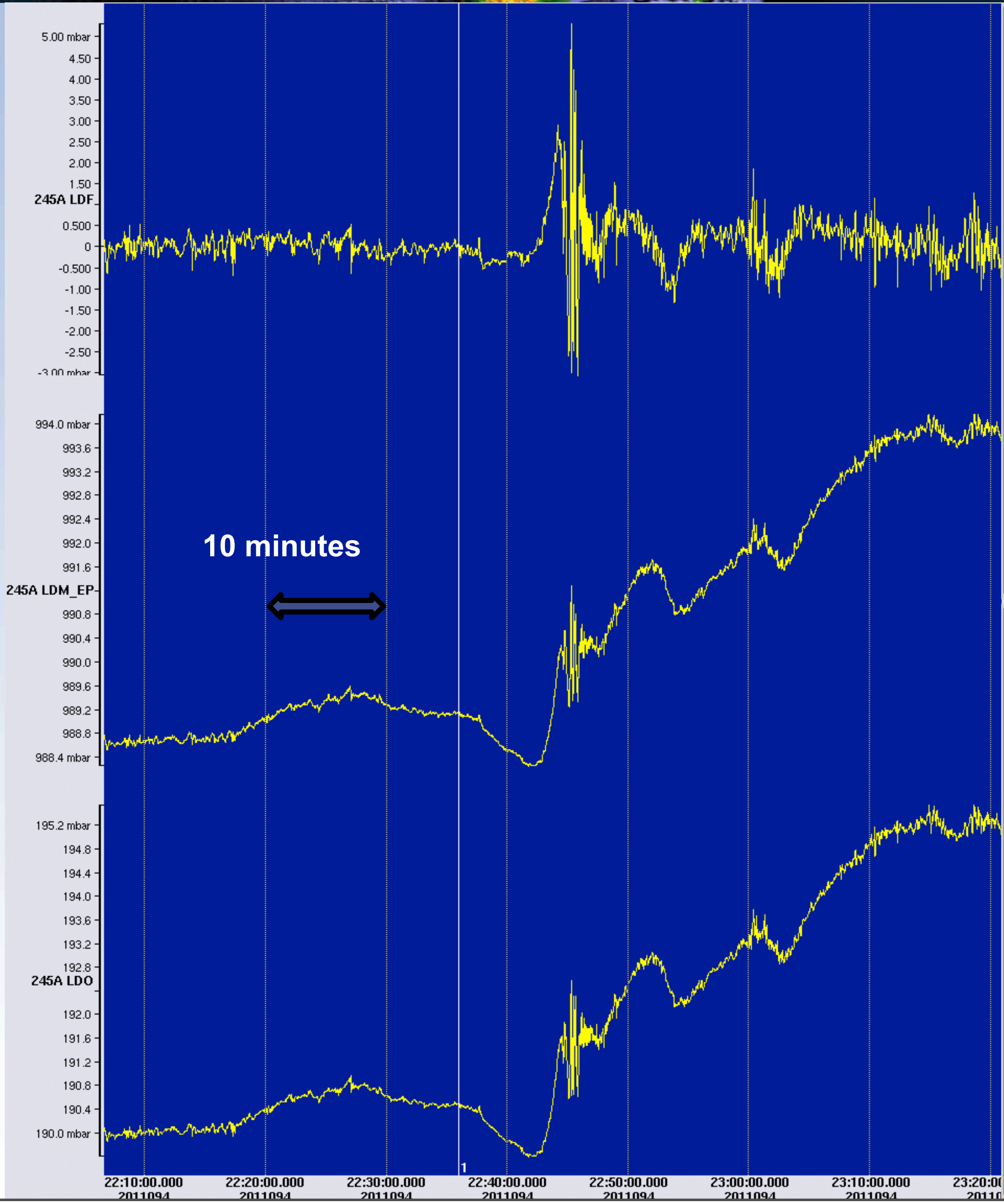
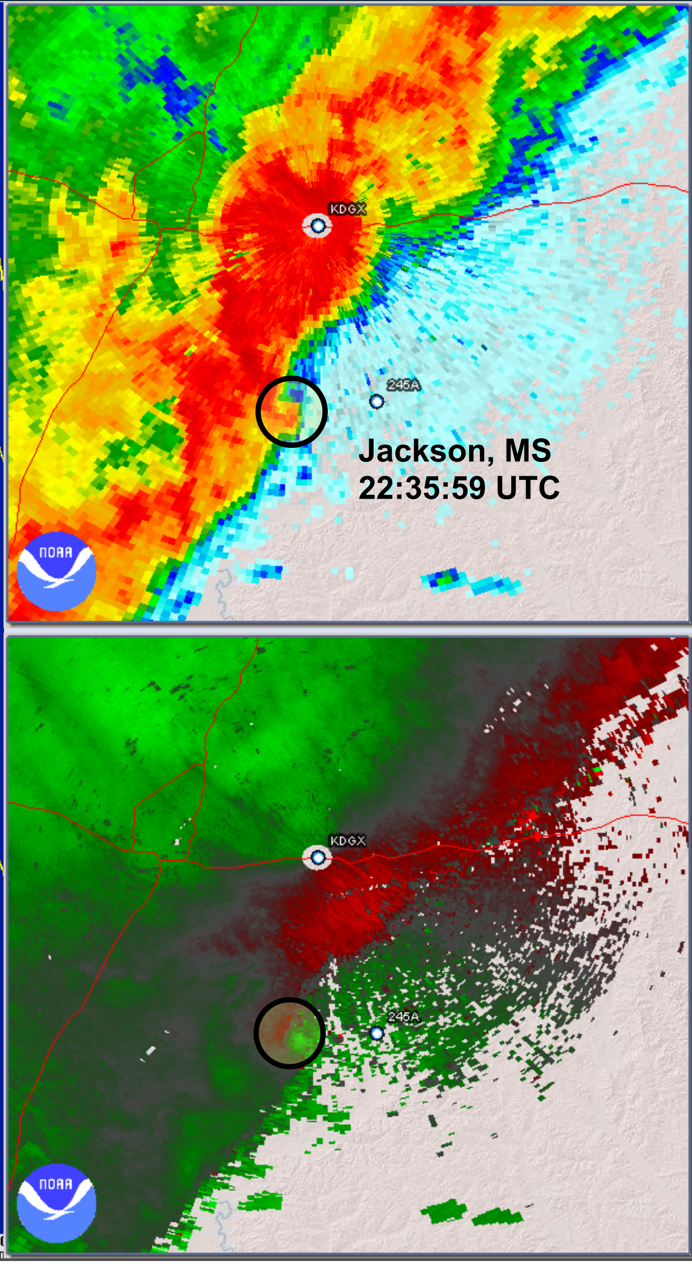
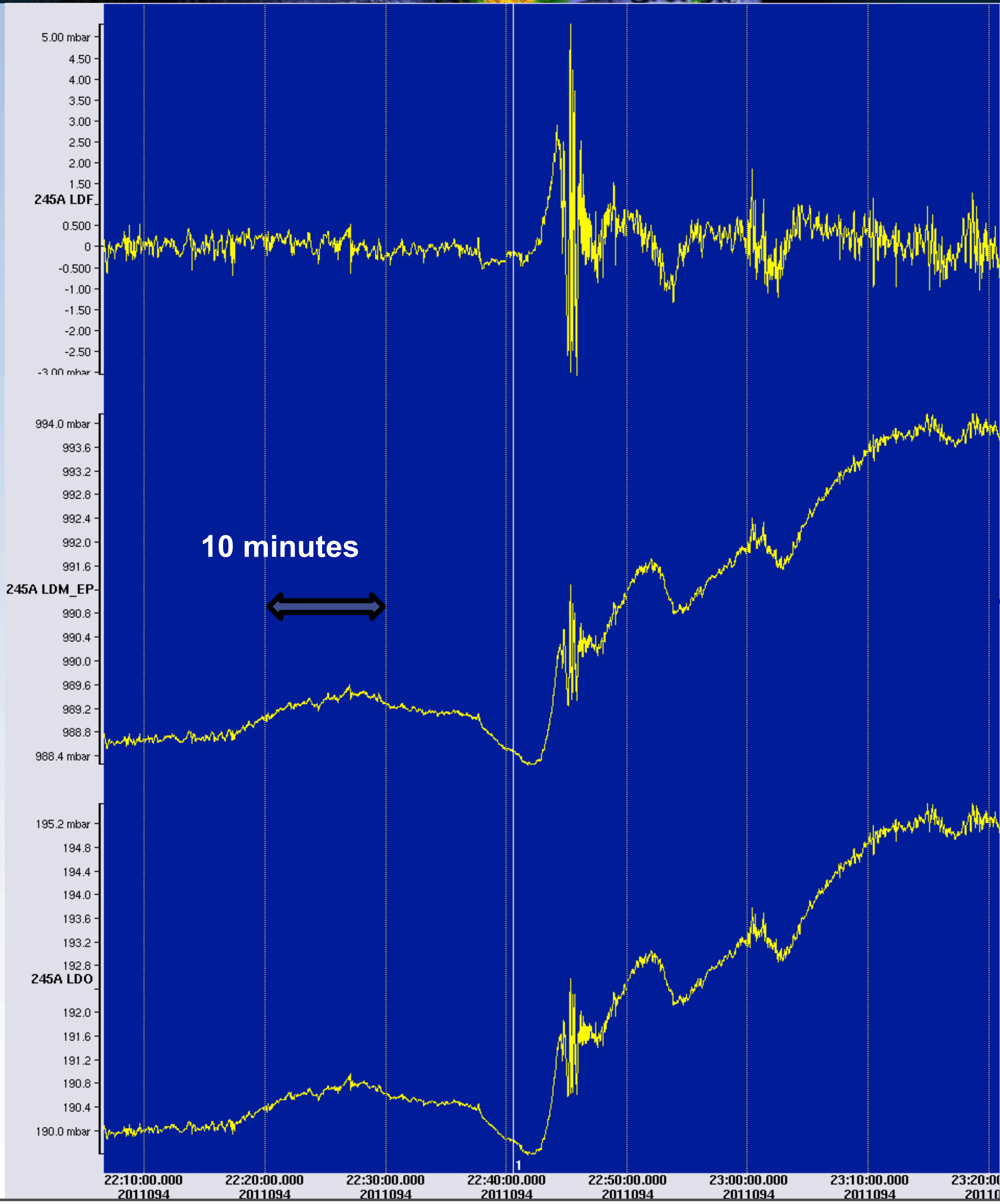
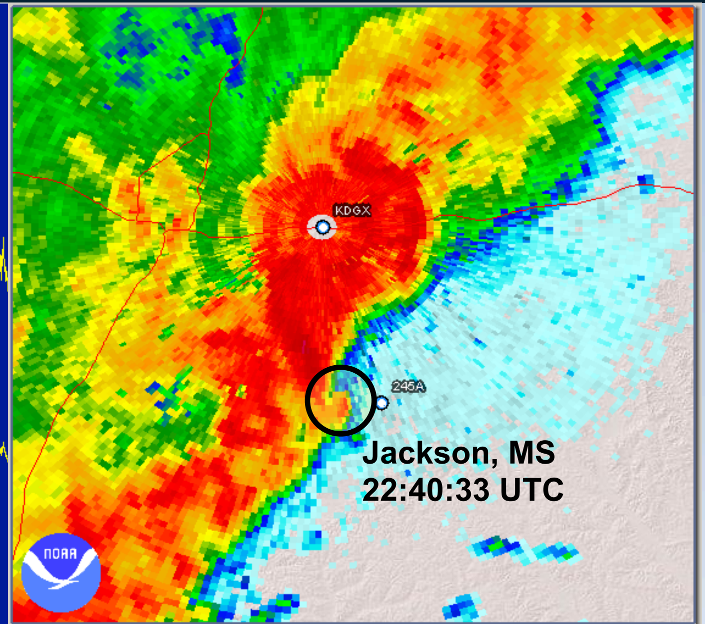
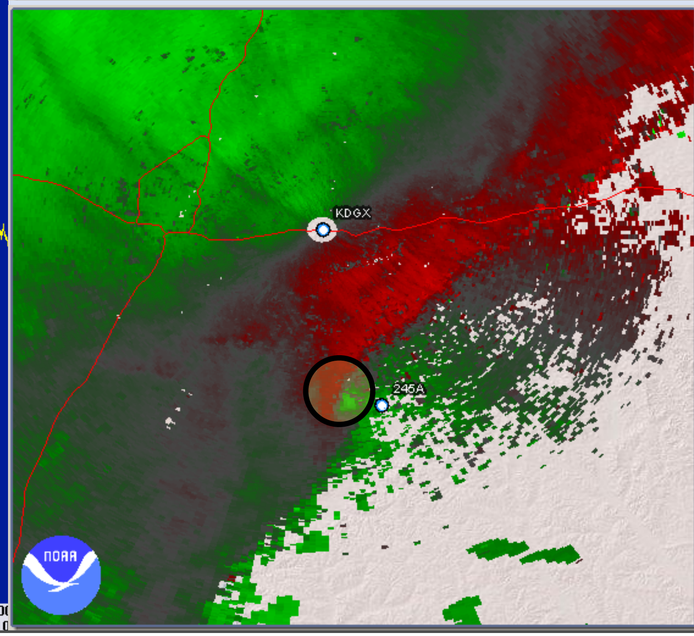




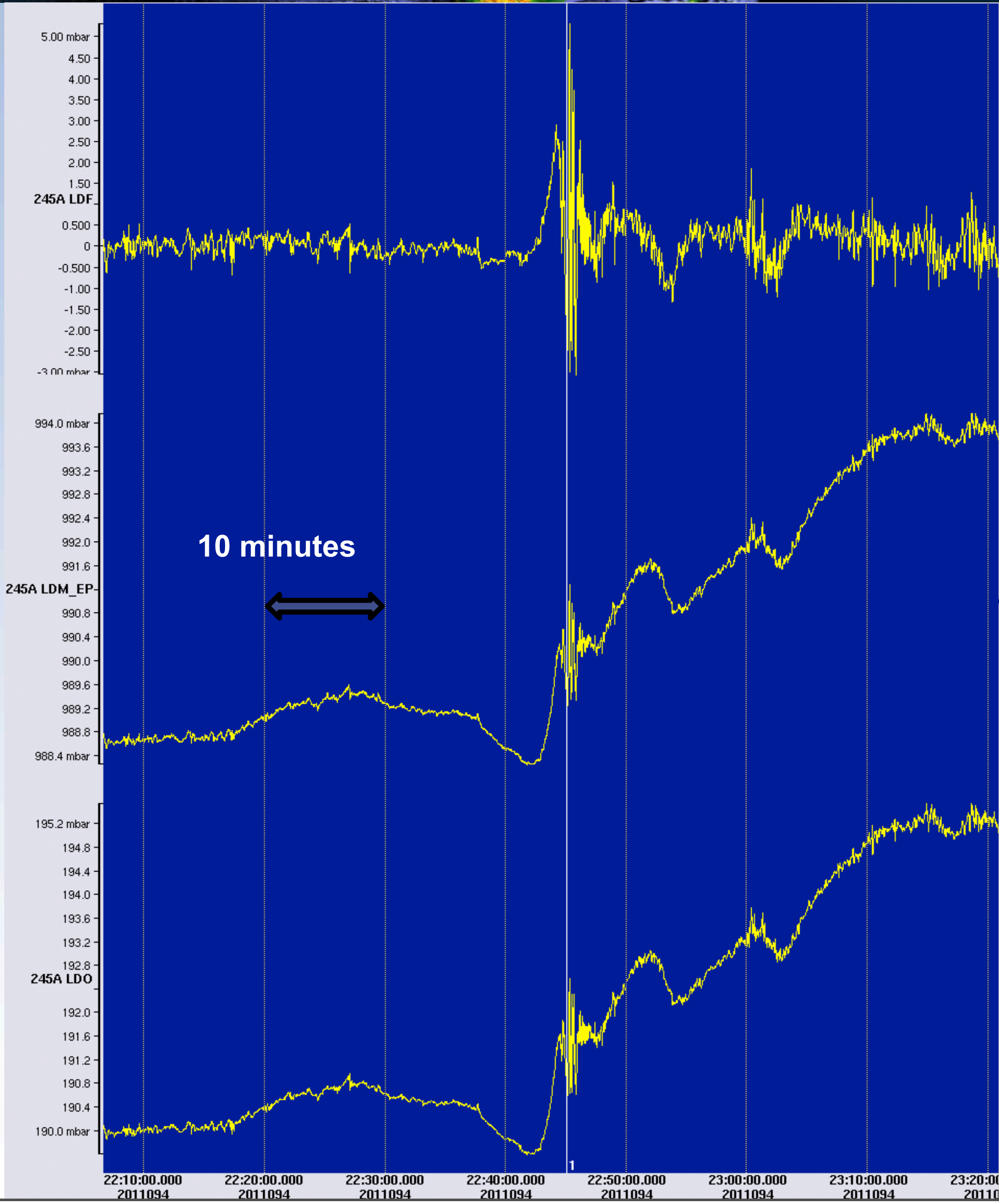
Jackson Tornado on 4/15/2011 – 245A

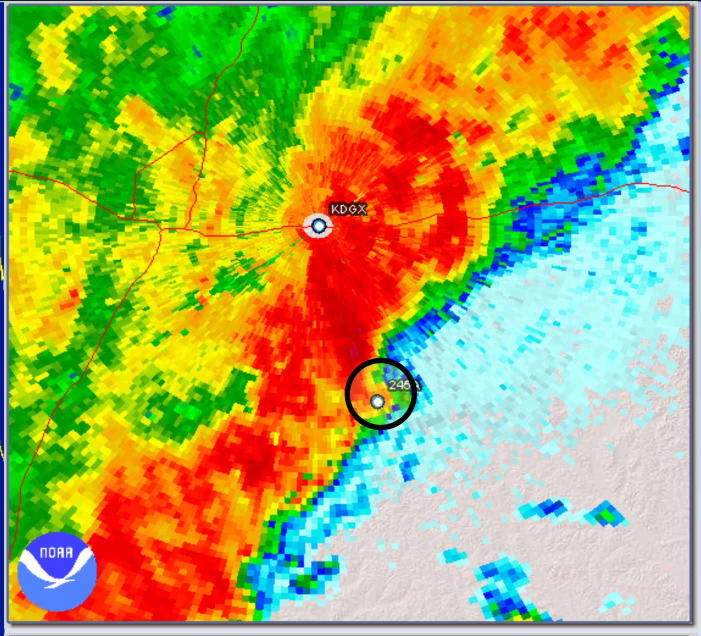


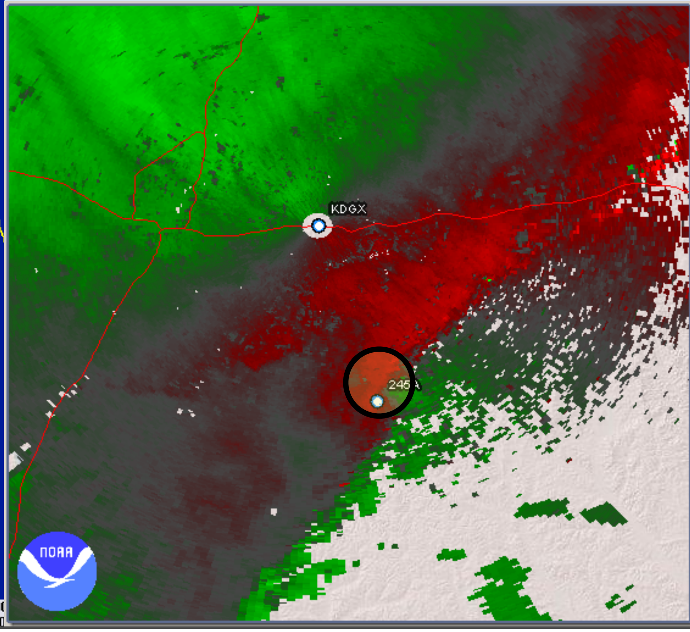




Jackson Tornado on 4/15/2011 – 245A







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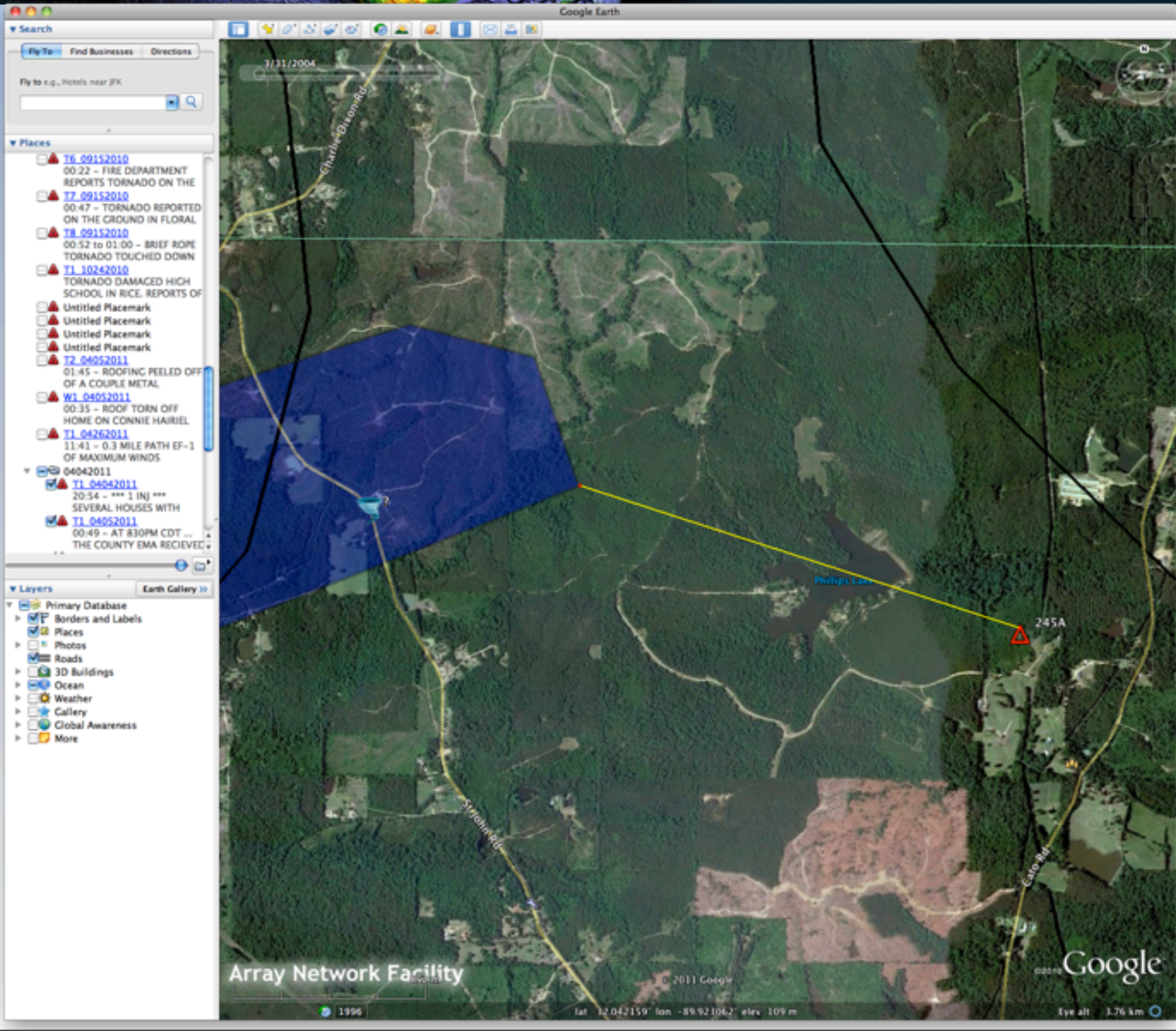

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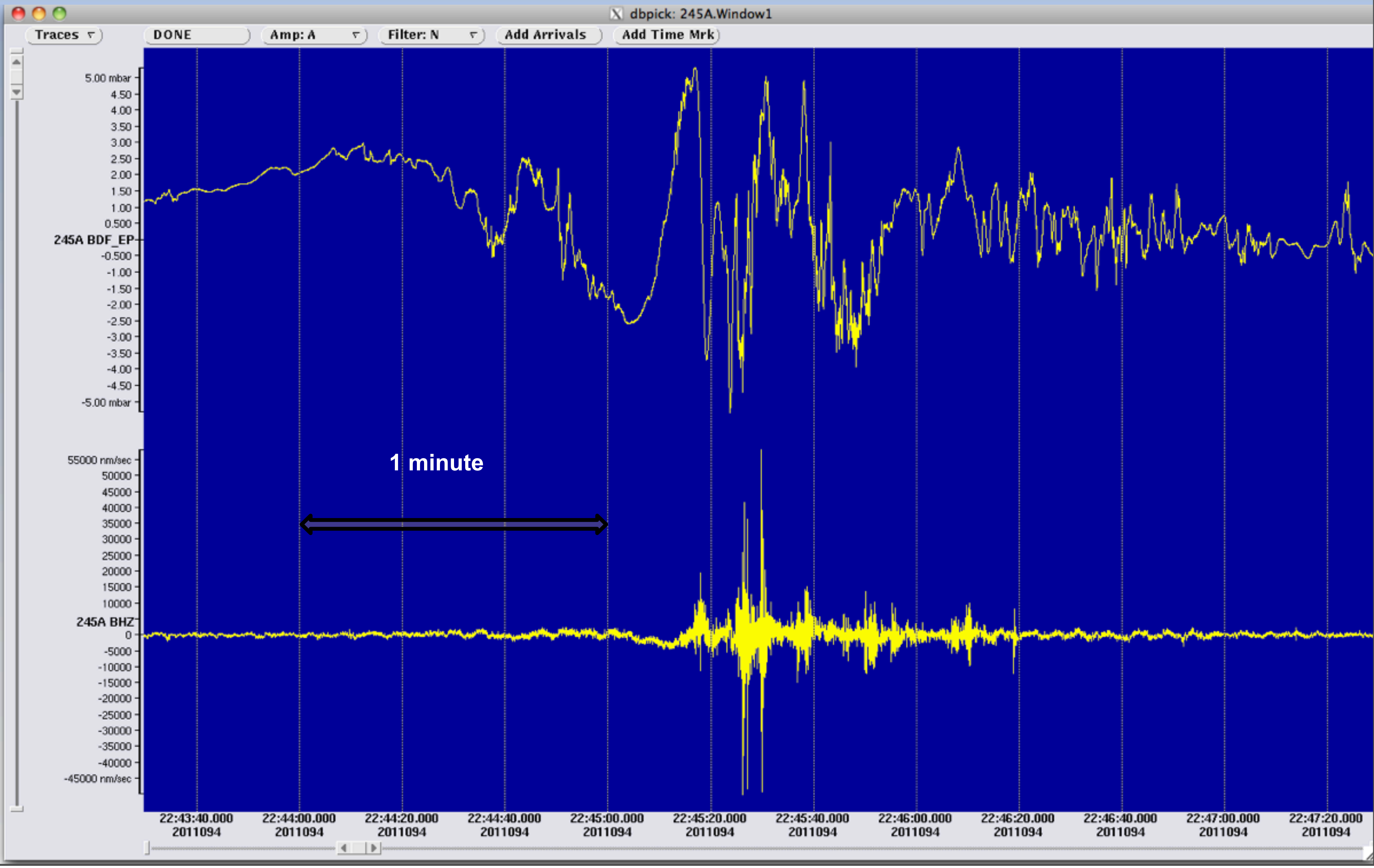

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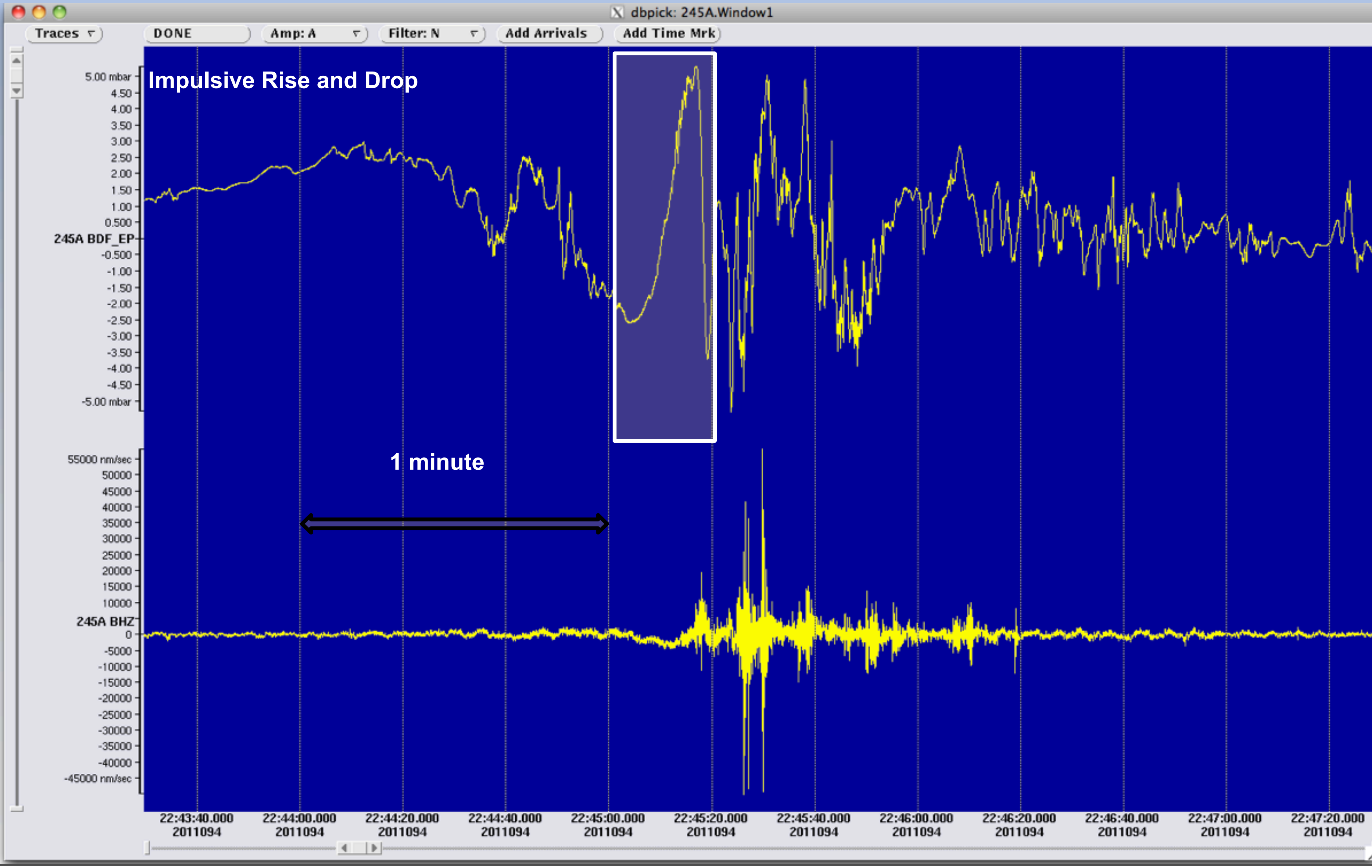
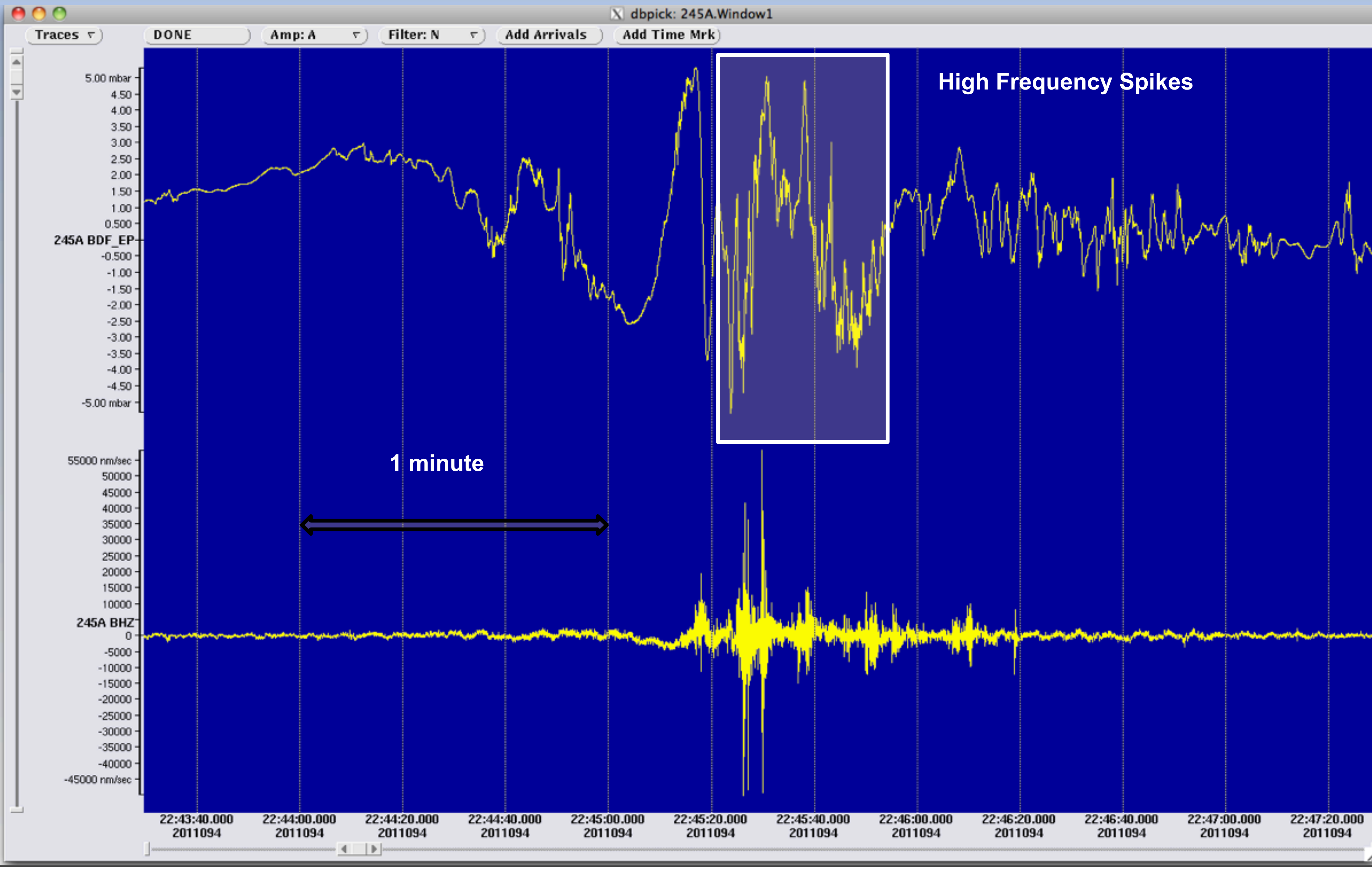
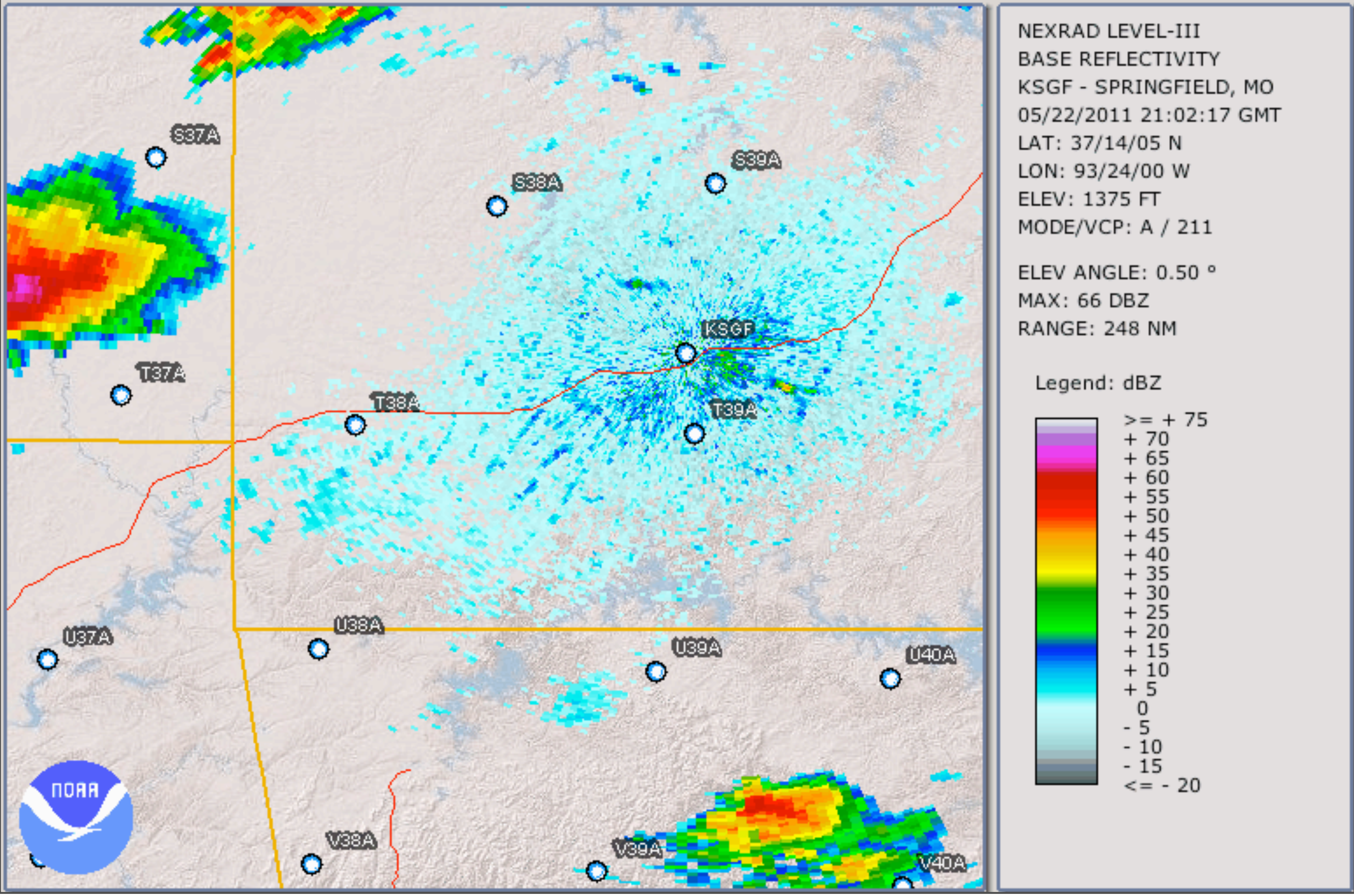


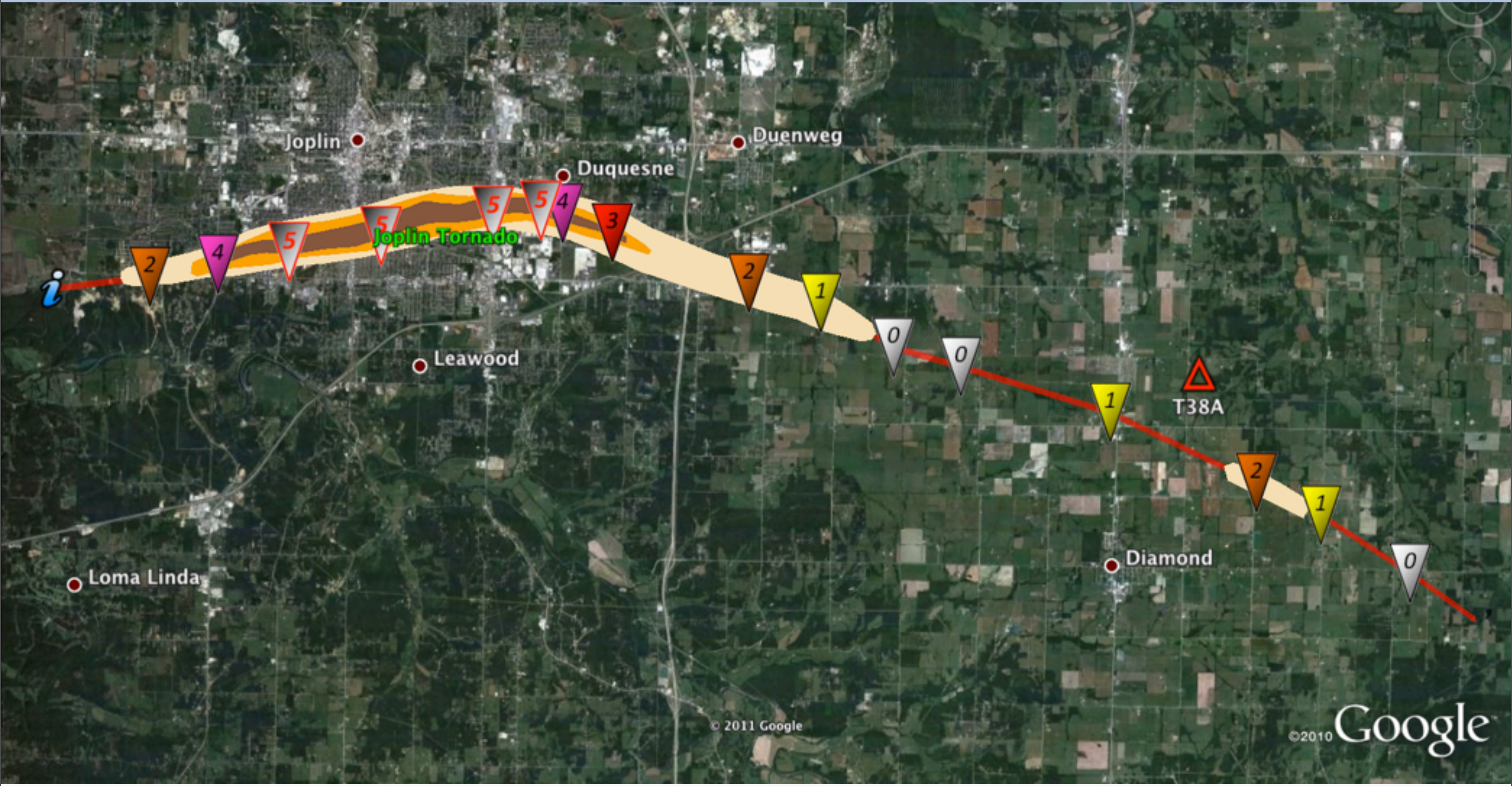
Jackson Tornado on 4/15/2011 – 245A



Joplin Tornado
5/22/2011 – T38A

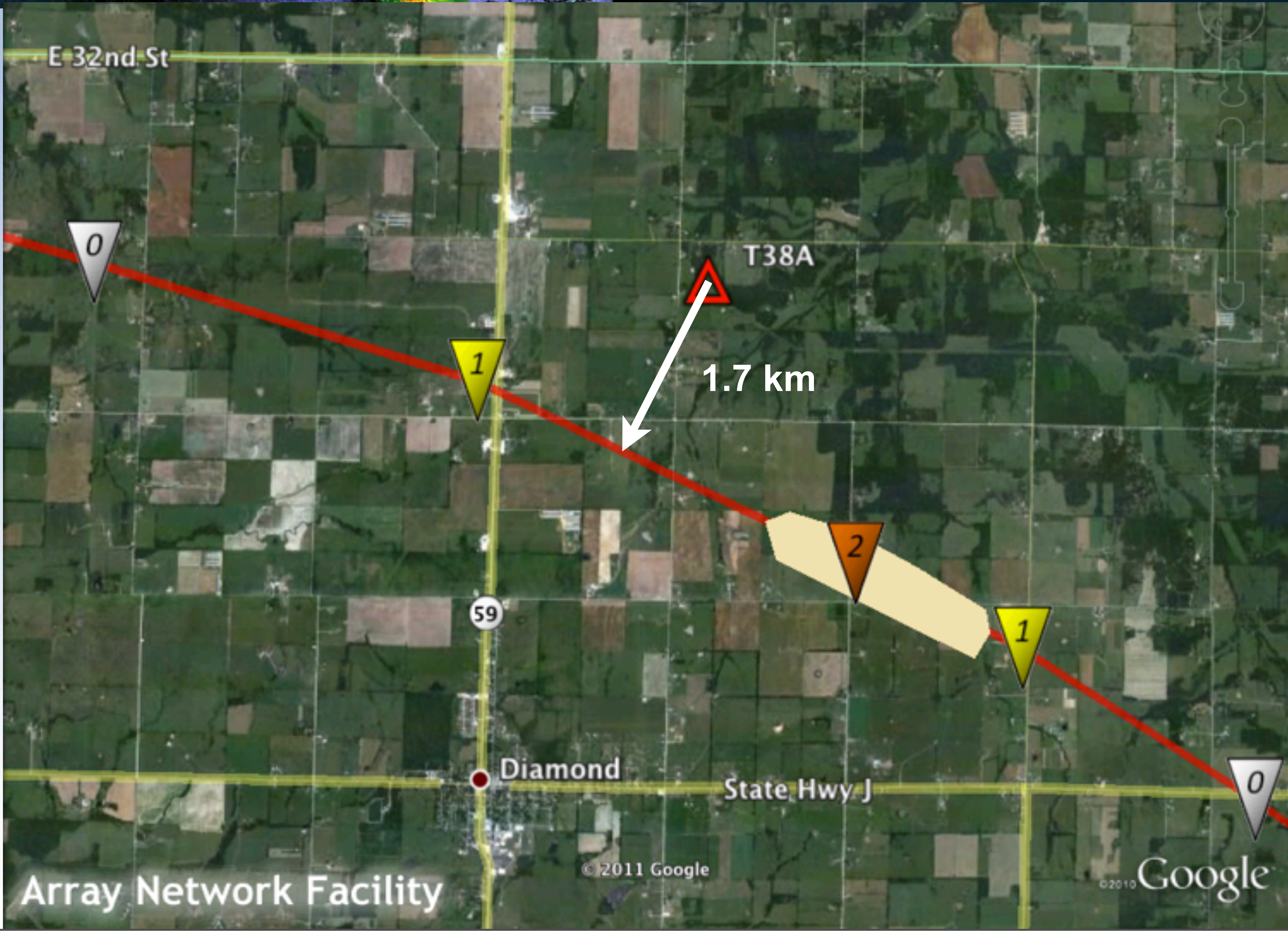


Joplin Tornado
5/22/2011 – T38A

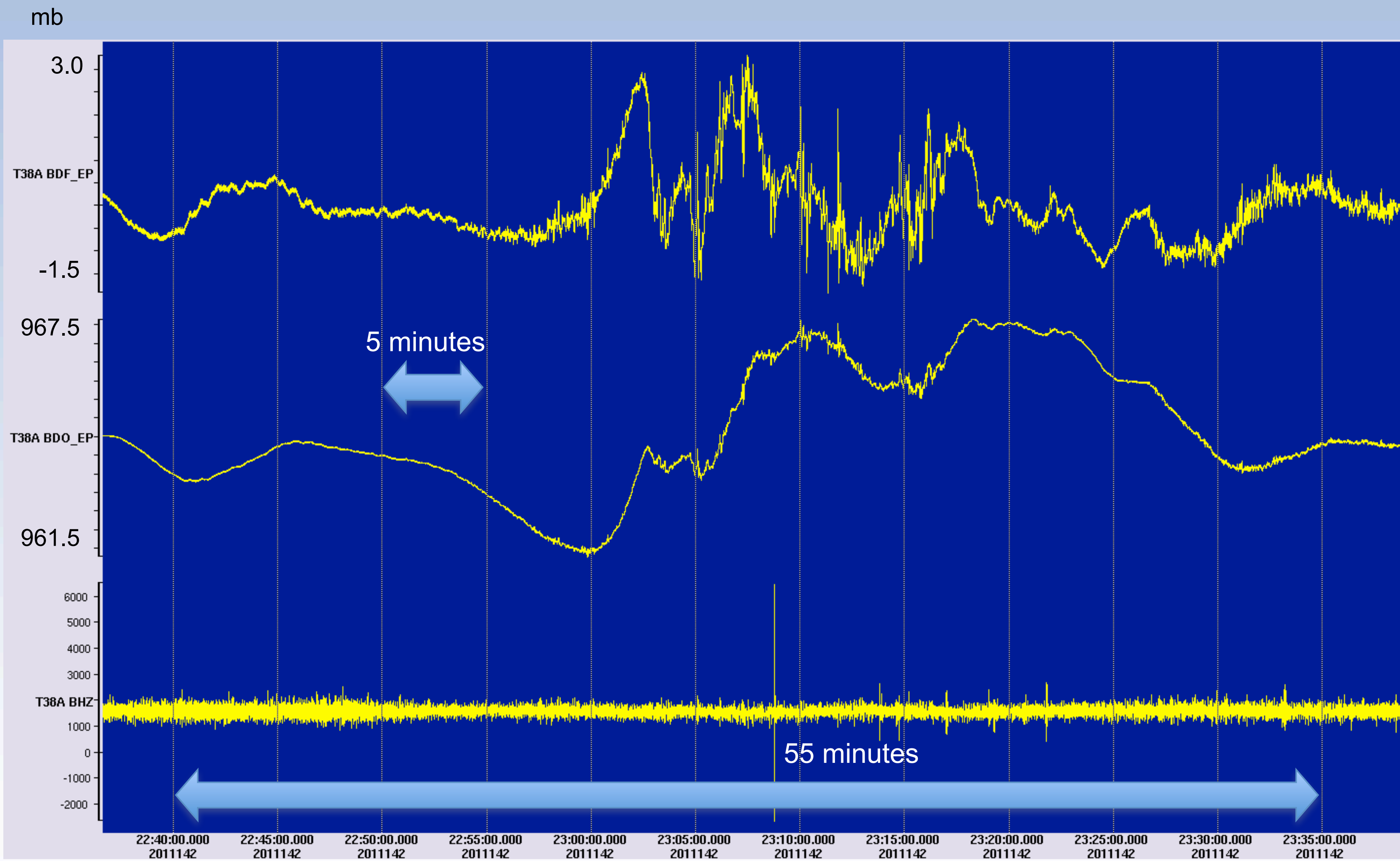


Joplin Tornado 5/22/2011 – T38A

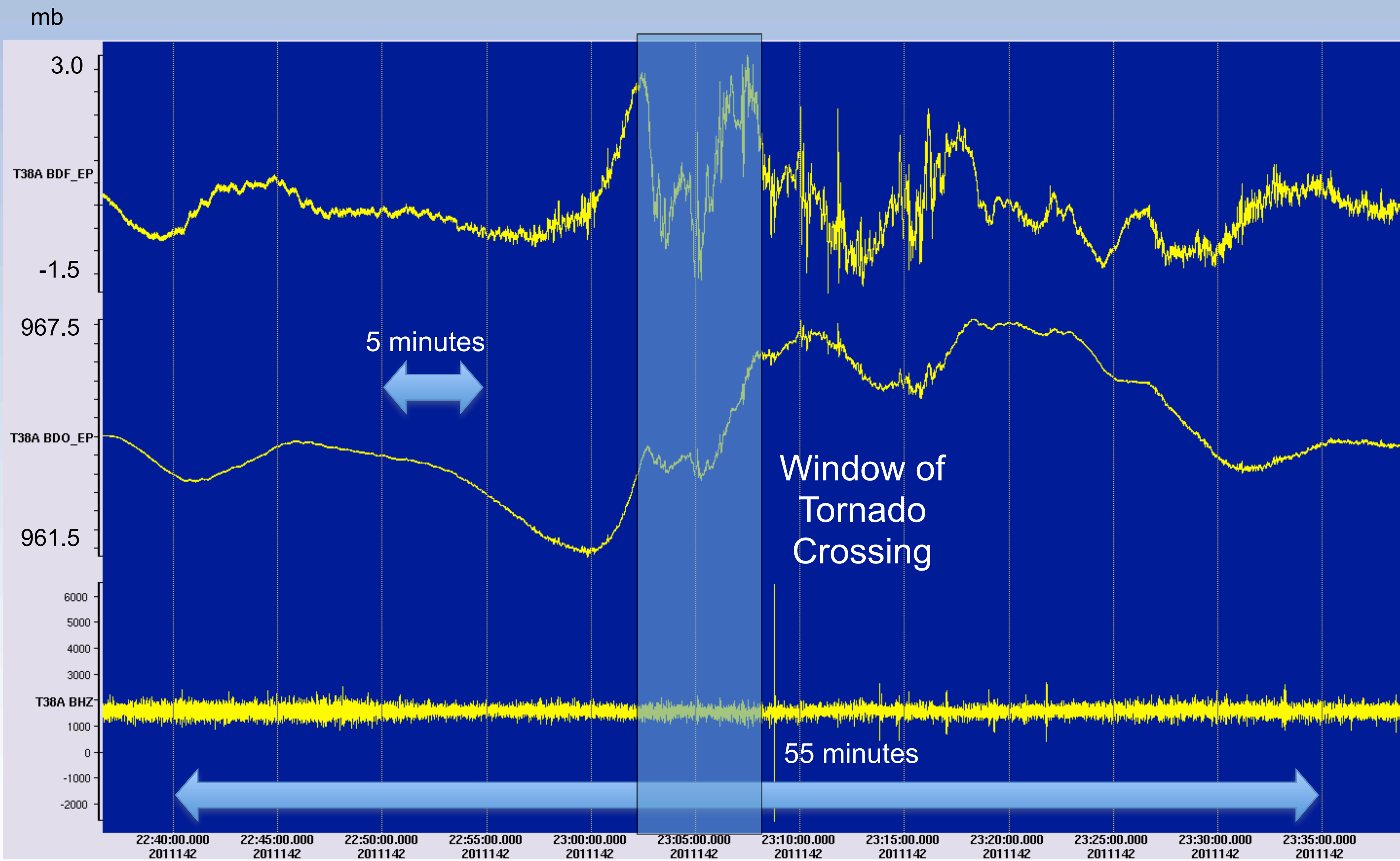
Joplin Tornado
5/22/2011 – T38A



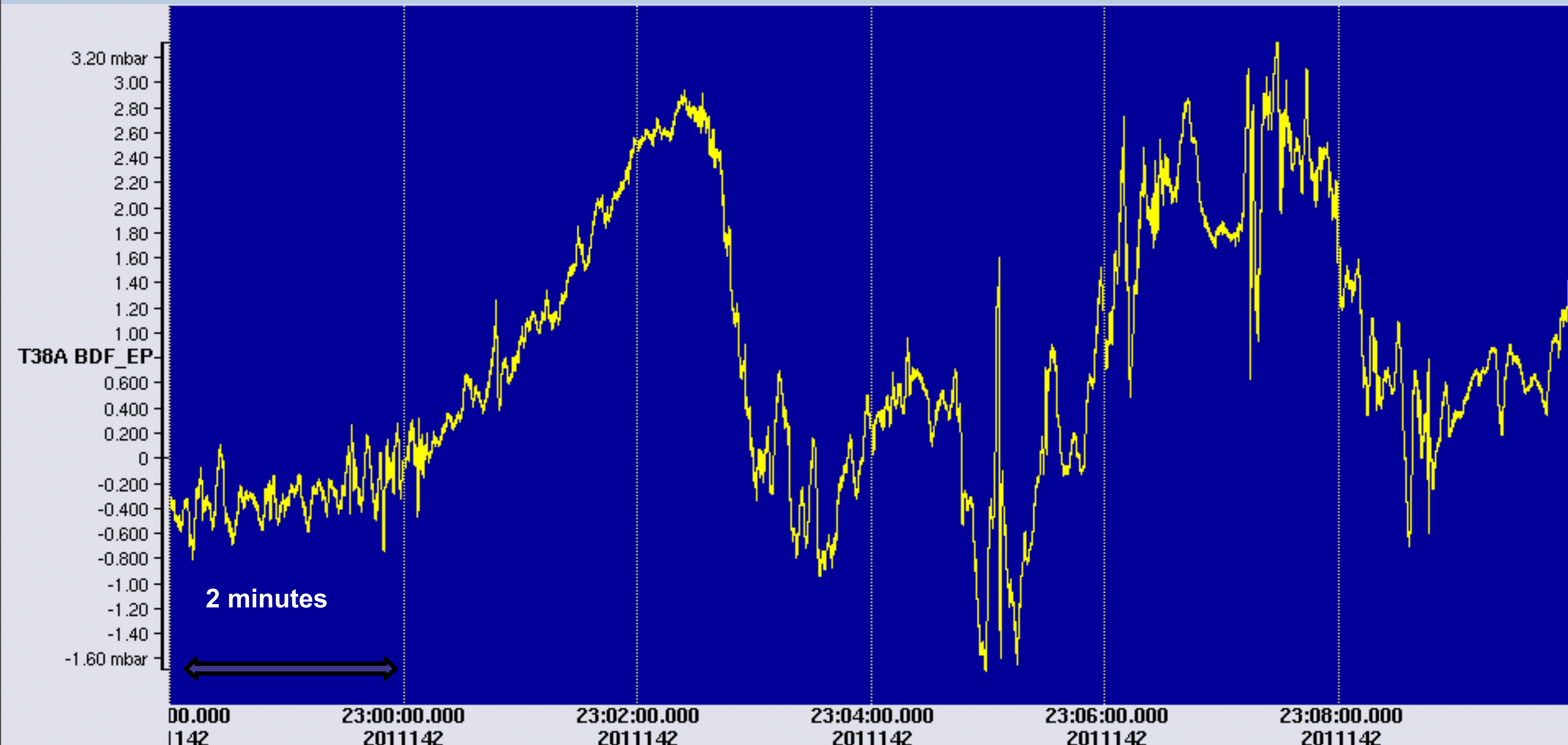
Joplin Tornado
5/22/2011 – T38A



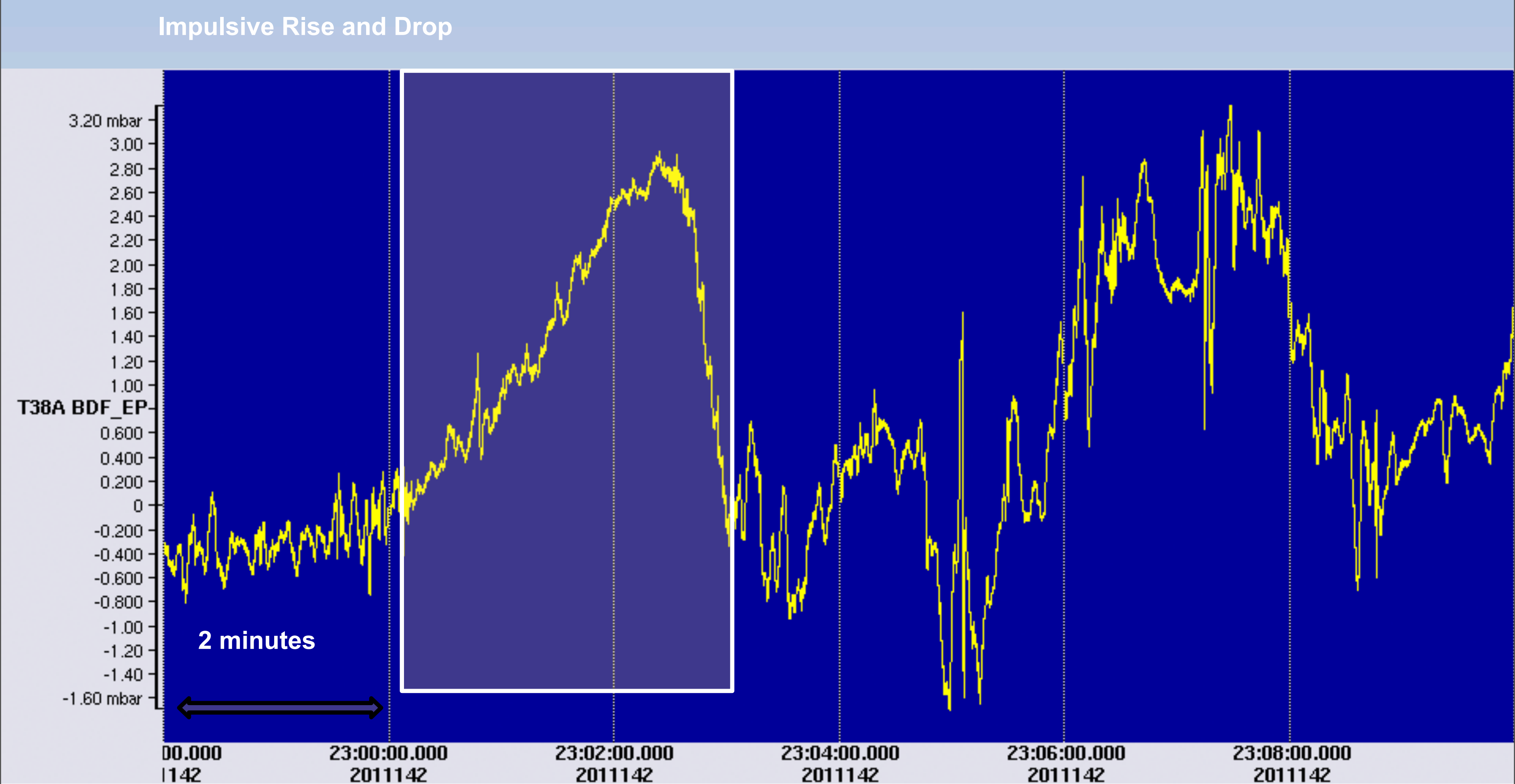
Joplin Tornado 5/22/2011 – T38A



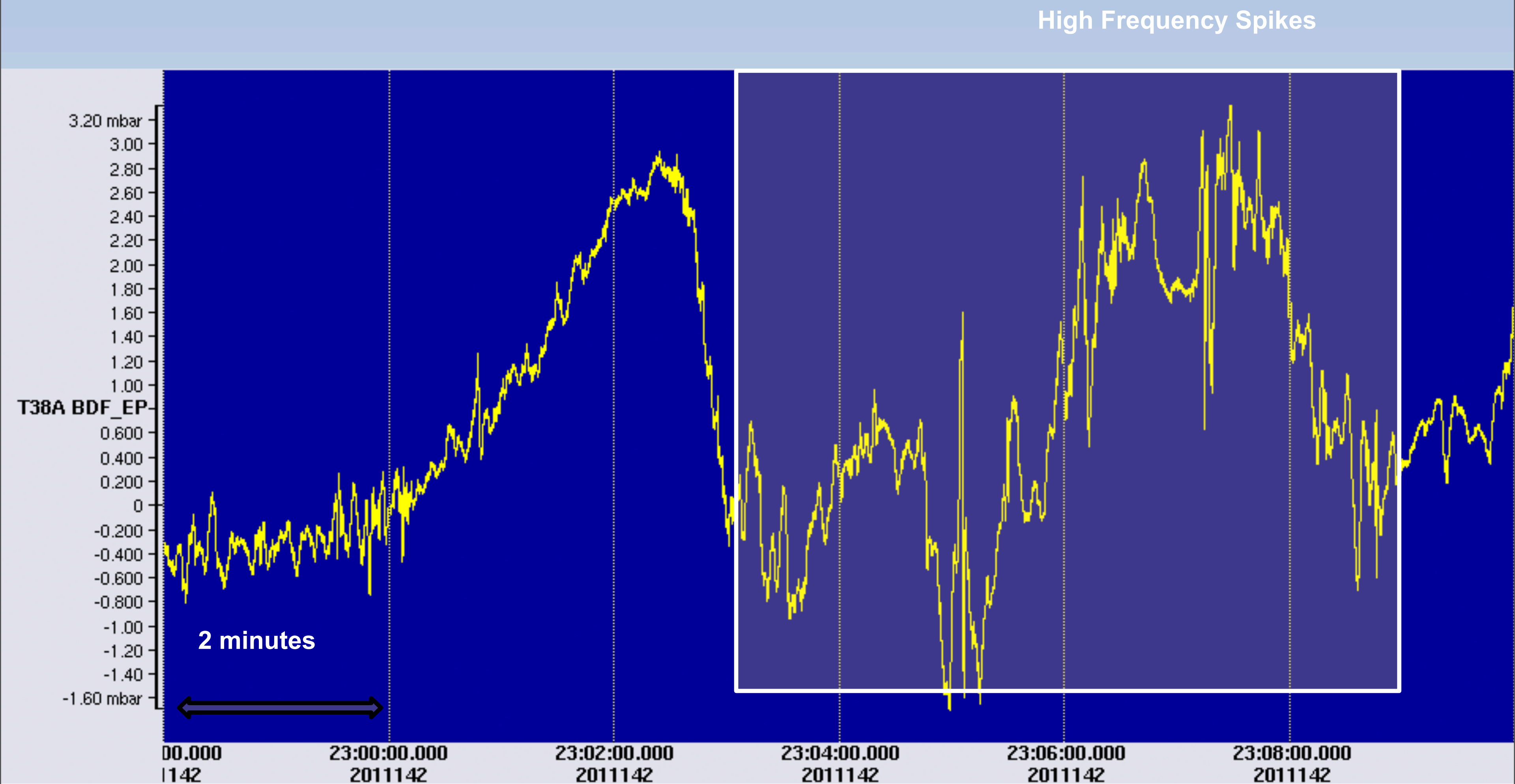
Joplin Tornado
5/22/2011 – T38A



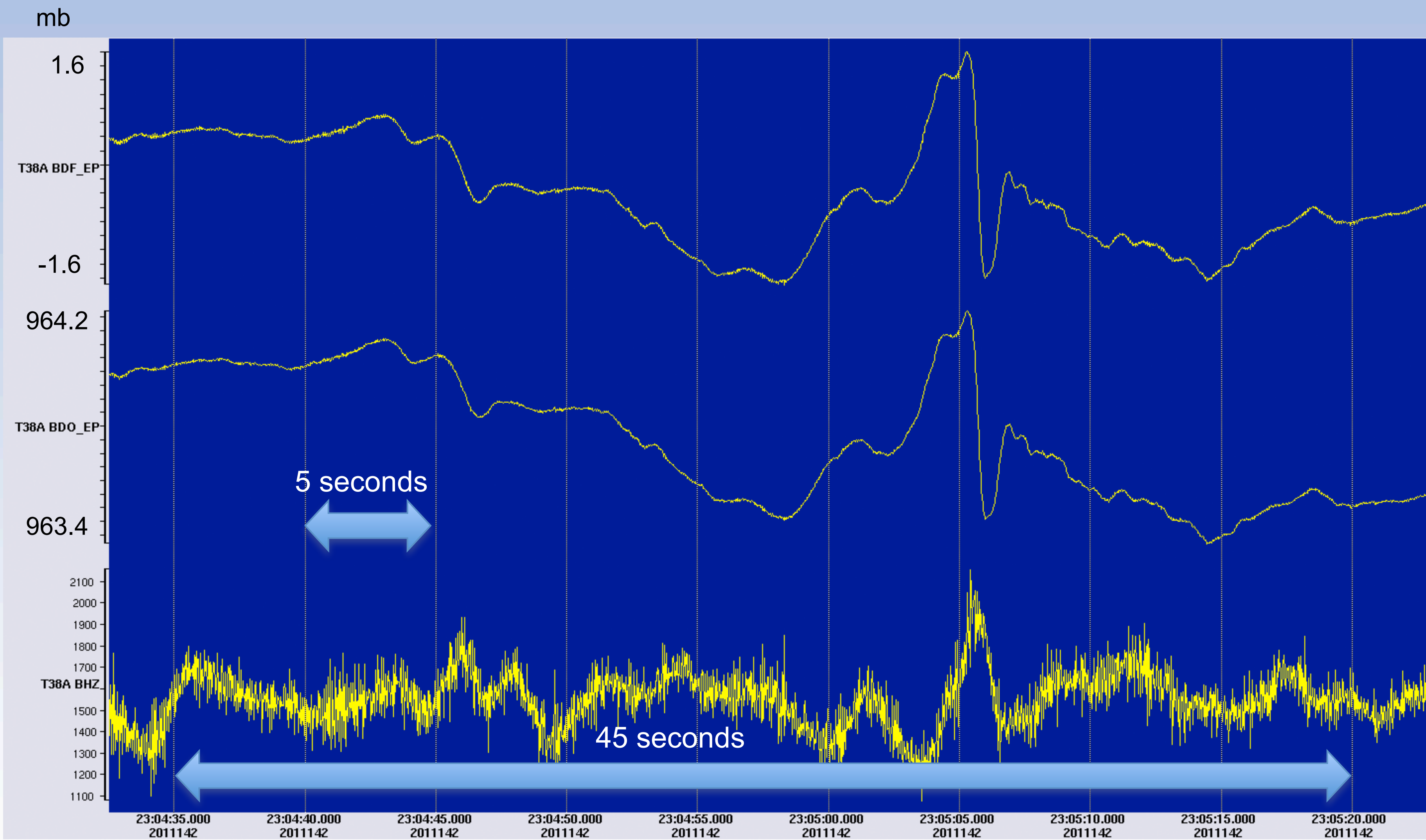
Joplin Tornado 5/22/2011 – T38A



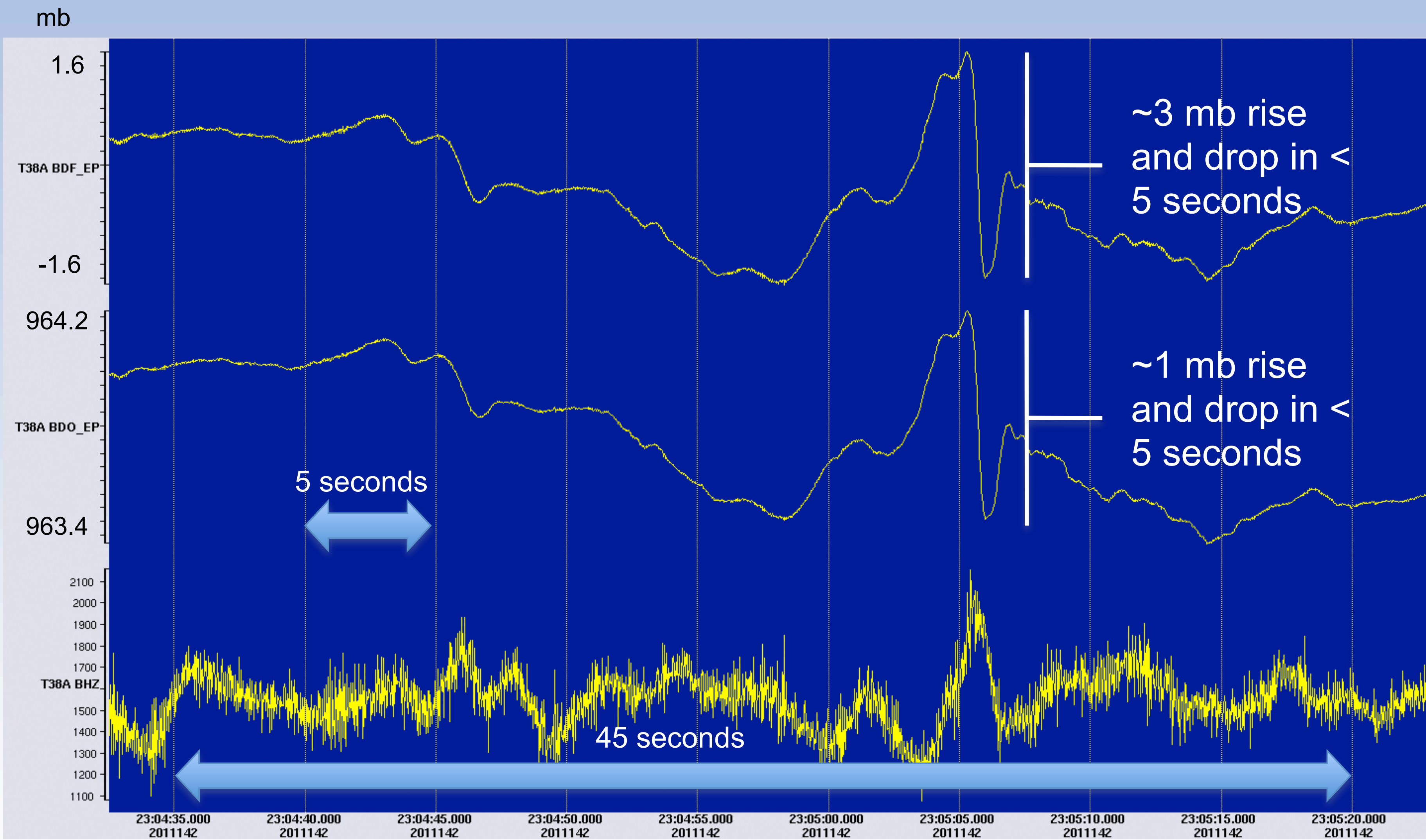
Joplin Tornado
5/22/2011 – T38A



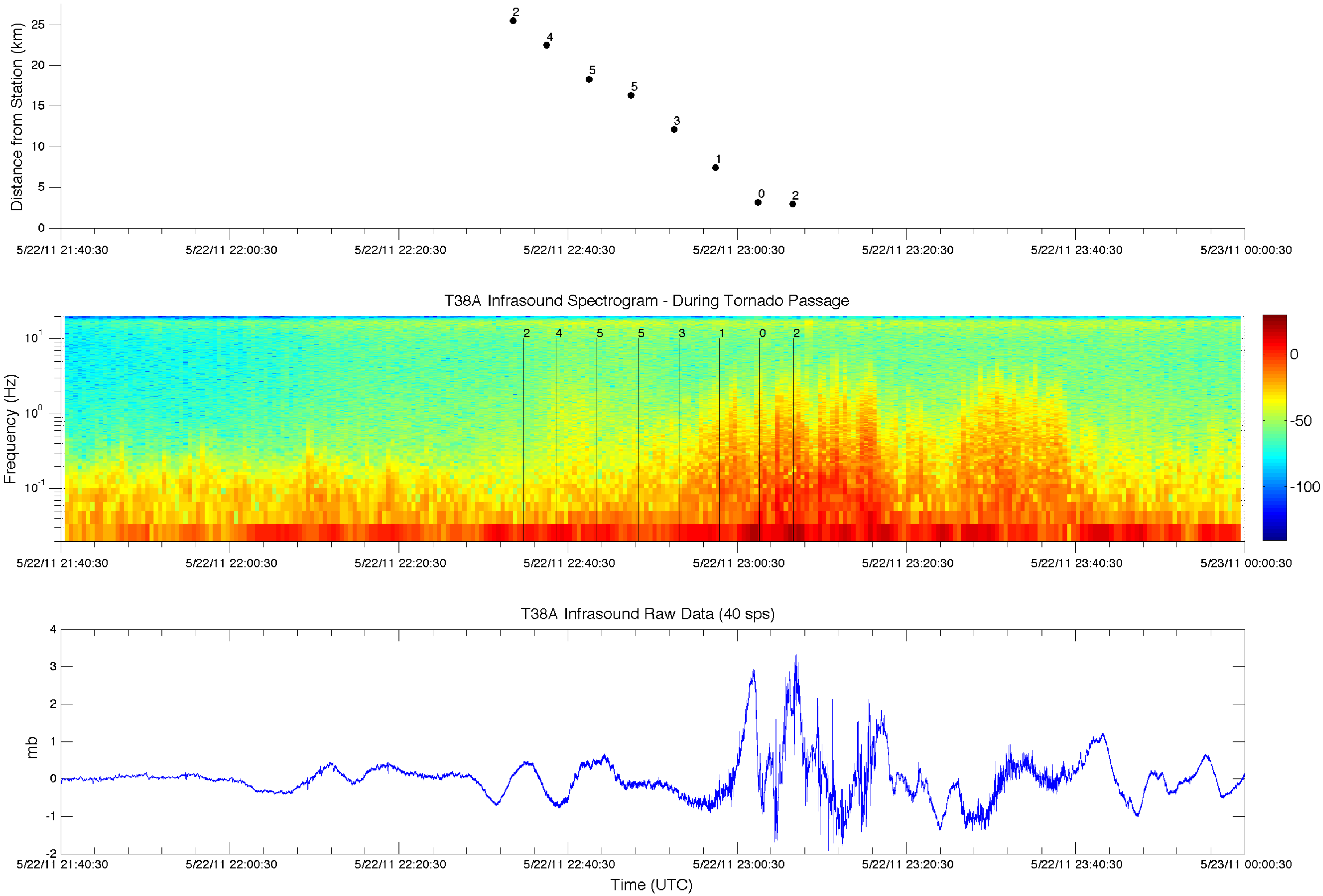
Joplin Tornado
5/22/2011 – T38A



Joplin Tornado
5/22/2011 – T38A



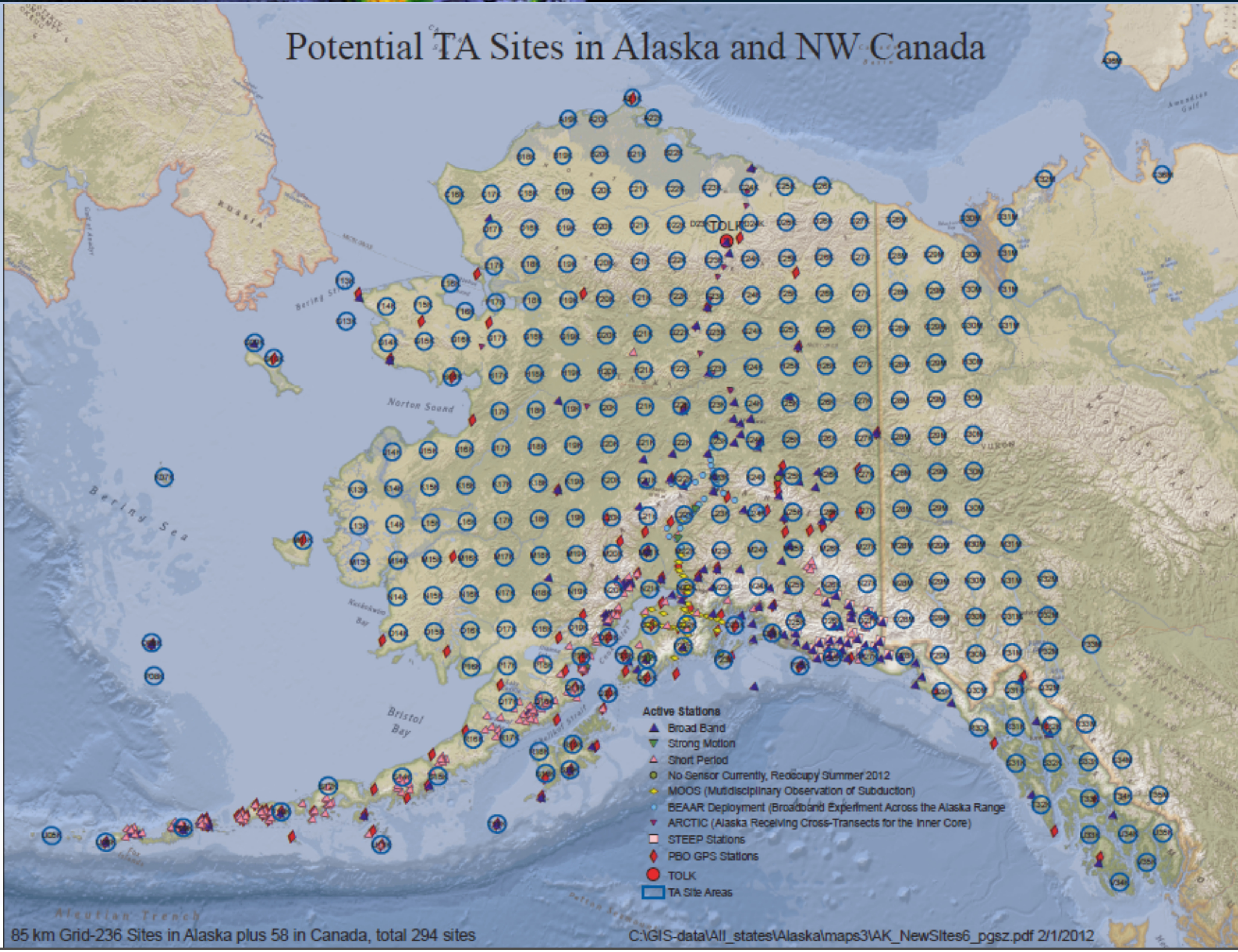
Joplin Tornado 5/22/2011 – T38A



Status and Questions

- USArray TA completing rollout of infrasound and pressure sensors
- ~36 stations to be outfitted with full met packages
- Near field signals associated with tornadoes
  - Large amplitude high frequency pressure signals
- Looking forward to full array data in 2012
- Pressure data collected across 2,000,000 km2 illuminating meteorological phenomena, traveling waves
- 2014 TA rolls off east coast and on to Alaska
  - Should be fertile ground for seminal research

Alaska 2013-2018



Keys to Success

- Near real time data
  - Reliable communications
  - Quality control
  - Immediate scientific results
- Centralized data management
- Meticulous metadata management
- Extensive state-of-health
- Integrated system design
  - Hardware
  - Software
  - Extensible platform
- Open data
- Engagement of Science Community

Thanks!

Preliminary Results of the Moment Tensor Code in Antelope

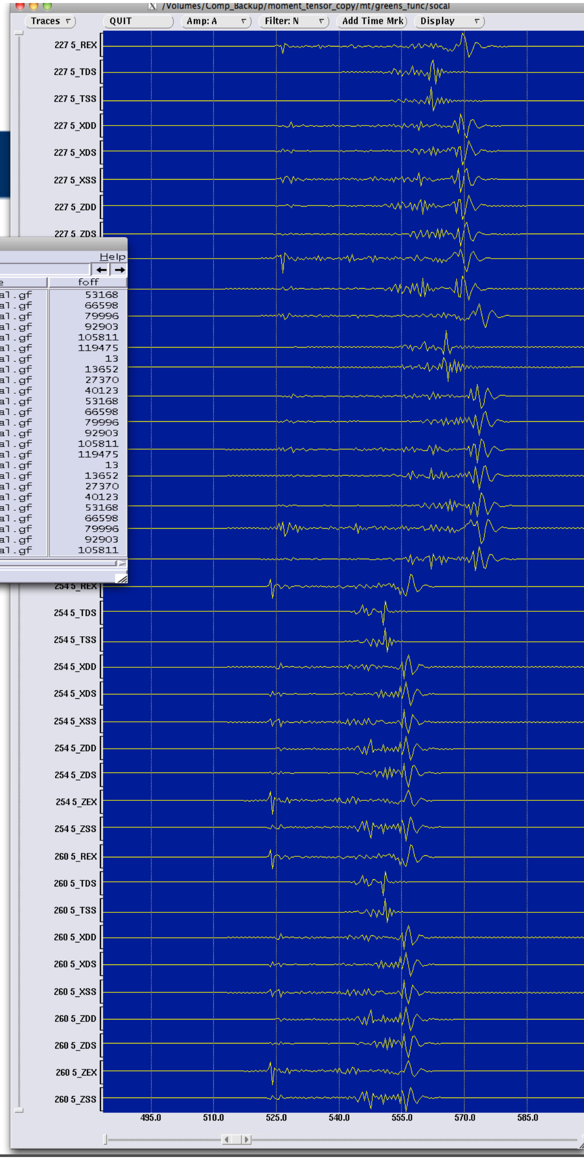
Frank L. Vernon
Juan C. Reyes
Robert L. Newman

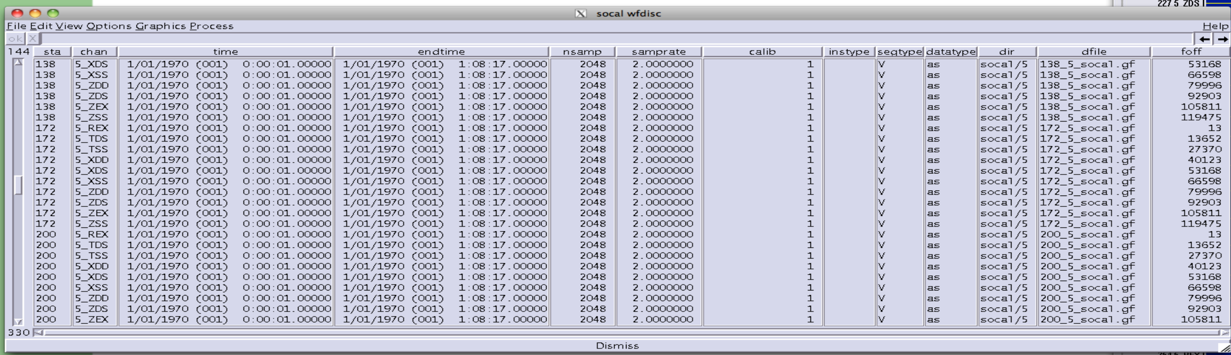
Moment Tensor and Focal Mechanism Code

So far...

- Get origins from Datascope tables.
- Subset stations in quadrants.
- Get Green's Functions from Datascope based on distance and depth of event.
- Extract, rotate and filter data from stations.
- Reject stations with bad cross-correlation.
- Invert the MT and extract the eigen values/vectors.
- Update Datascope with results.

Green's Functions Archive





socal wfdisc

File Edit View Options Graphics Process Help

sta	chan	time	endtime	nsamp	samprate	calib	instype	segtype	datatype	dir	dfile	foff
138	5_XDS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	138_5_socal.gf	53168
138	5_XSS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	138_5_socal.gf	66598
138	5_ZDD	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	138_5_socal.gf	79996
138	5_ZDS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	138_5_socal.gf	92903
138	5_ZEX	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	138_5_socal.gf	105811
138	5_ZSS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	138_5_socal.gf	119475
172	5_REX	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	13
172	5_TDS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	13652
172	5_TSS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	27370
172	5_XDD	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	40123
172	5_XDS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	53168
172	5_XSS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	66598
172	5_ZDD	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	79996
172	5_ZDS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	92903
172	5_ZEX	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	105811
172	5_ZSS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	172_5_socal.gf	119475
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200	5_TDS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	200_5_socal.gf	13652
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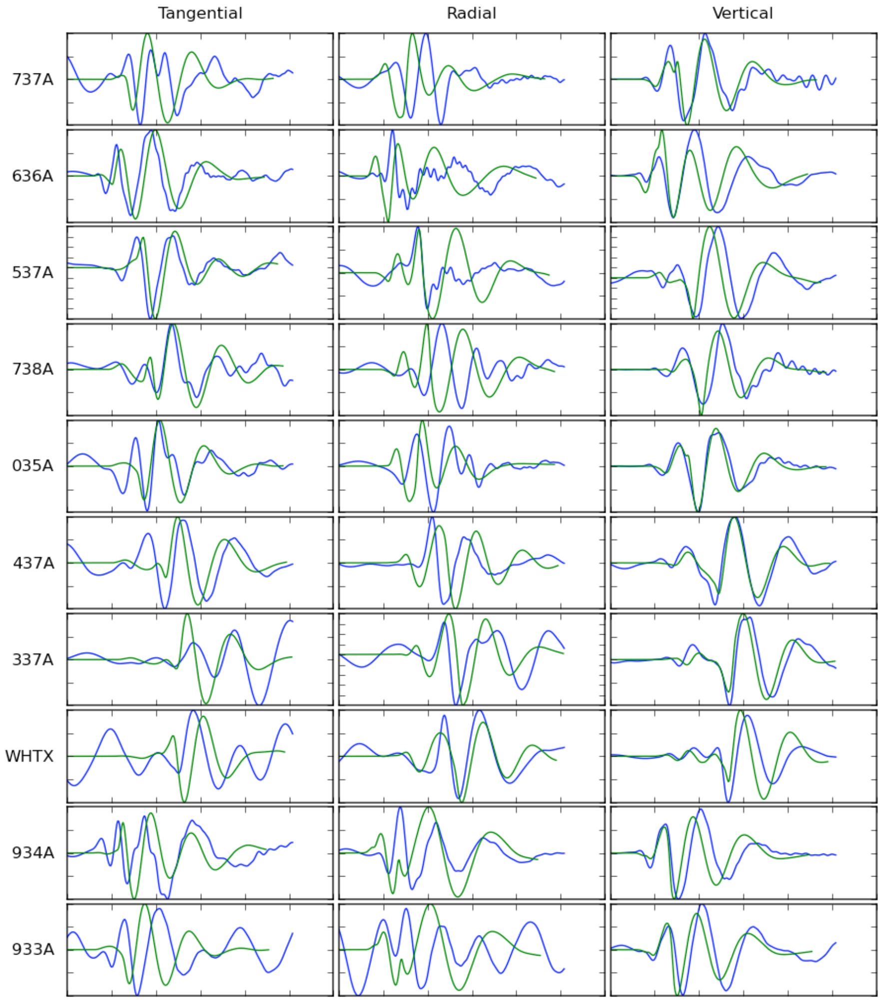
200	5_XDS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	200_5_socal.gf	53168
200	5_XSS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	200_5_socal.gf	66598
200	5_ZDD	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	200_5_socal.gf	79996
200	5_ZDS	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	200_5_socal.gf	92903
200	5_ZEX	1/01/1970 (001) 0:00:01.00000	1/01/1970 (001) 1:08:17.00000	2048	2.0000000	1		V	as	socal/5	200_5_socal.gf	105811

144 330

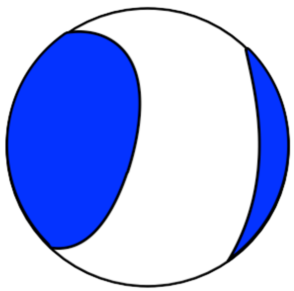
Dismiss

Green's Functions are build dynamically upon request if not already present in archive. Newly constructed functions are stored on a database referenced by a wfdisc table.

Texas 2011/10/20 4.8Mw



orid = 3830971
time = 10/20/2011 12:24:40
Strike 1 = 78
Rake 1 = -72
Dip 1 = 72
Strike 2 = 211
Rake 2 = -137
Dip 2 = 24
Mo = 1.340E+23
Mw = 4.718
% DC = 28.644
% CLVD = 71.356
% ISO = 0.000
VR = 3.624E-09
VAR = 3.624E-09



Texas 2011/10/20 4.8Mw

USGS/SLU Regional Moment Solution

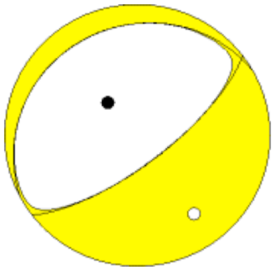
SOUTHERN TEXAS

```
11/10/20 12:24:40.58

Epicenter:  28.803  -98.154
MW 4.8

USGS/SLU REGIONAL MOMENT TENSOR
Depth   5          No. of sta: 22
Moment Tensor;    Scale 10**16 Nm
  Mrr=-1.05        Mtt= 0.73
  Mpp= 0.32        Mrt=-1.14
  Mrp=-0.91        Mtp= 0.46
 Principal axes:
  T  Val=  1.78  Plg=27  Azm=145
  N        0.03      3       53
  P       -1.80     63      318

Best Double Couple:Mo=1.8*10**16
 NP1:Strike= 53 Dip=72 Slip= -93
 NP2:       241     18       -82
```



Antelope Regional Moment Solution

orid = 3830971
time = 10/20/2011 12:24:40
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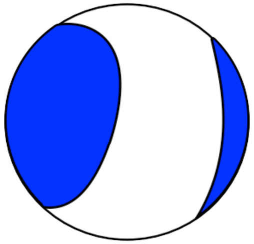

dbmoment execution time

vista{reyes}% time dbmoment -v -r '637A|833A|936A|435A|436A|435B|035Z' 3830971

real 0m7.819s
user 0m5.673s
sys 0m1.610s

*** with green's functions in database ***

Modular build (use your code)

dbmoment.pf

```
# parameter file for dbmoment

# Name of the library to use
# for Green'sFunction class
gf_lib fkrprog

# Name of the library to use
# for Inversion class
inv_lib inversion

# Name of the library to use
# for Event class
data_lib get_data

# channel to use in MT-inversion,
default is LH.
chan_to_use LH.*

# Name of the model parameter file
model_name SOCAL_MODEL
# Use displacement (d) or velocity (v)
model_type v

...
```

inversion.py

```
from __main__ import *      # Get all the libraries from parent

class MomentTensor():
    """
    Class for building moment tensors and doing the inversion

    """
    def __init__(self, distance_weighting, isoflag, trim_value, verbose=False, debug=False):
+---  8 lines: ----------------------------------------------------------------------------------------------------

    def _log(self,message):
+---  7 lines: ----------------------------------------------------------------------------------------------------

    def construct_data_matrix(self, stachan_traces):
+--- 37 lines: ----------------------------------------------------------------------------------------------------

    def plot_cross_cor(self, a, b, shift, maxval,xcor=None,a_name='',b_name=''):
+--- 51 lines: ----------------------------------------------------------------------------------------------------

    def _cross_cor(self, a, b):
+--- 22 lines: ----------------------------------------------------------------------------------------------------

    def get_time_shift(self, data, greens ,delta = False):
+--- 64 lines: ----------------------------------------------------------------------------------------------------

    ...

    def determine_solution_vector(self, dict_AIV, dict_B):
+--- 71 lines: ----------------------------------------------------------------------------------------------------

    def decompose_moment_tensor(self, matrix_M):
+---166 lines: ----------------------------------------------------------------------------------------------------

    def fitcheck(self, dict_g, dict_s, matrix_M, m0, ev2sta, size):
+--- 74 lines: ----------------------------------------------------------------------------------------------------

    def quality_check(self, vr):
+--- 22 lines: ----------------------------------------------------------------------------------------------------
```

EGU 2012

Moment Tensor code for the Antelope Environmental Monitoring System

Poster Session

Development Repo

Github:
https://github.com/jreyes1108/antelope_contrib/tree/moment_tensor