Timing Issues in Observing Systems

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Premise 1

Many autonomous sensor deployments have traditionally utilized local (apparent) time in autonomous instruments

The limitations of this approach become apparent when measurements utilizing different notions of local time are compared

Premise 2

The single parameter that makes a set of instruments into an observatory is a standard (synoptic) notion of time throughout the network and through the life cycle of the observatory

It is a key responsibility of observing systems to provide accurate, synoptic time throughout the network, and associate time with every measurement

Premise 3

Correction of data for time errors by end users in an observatory environment should never be required

Premise 4

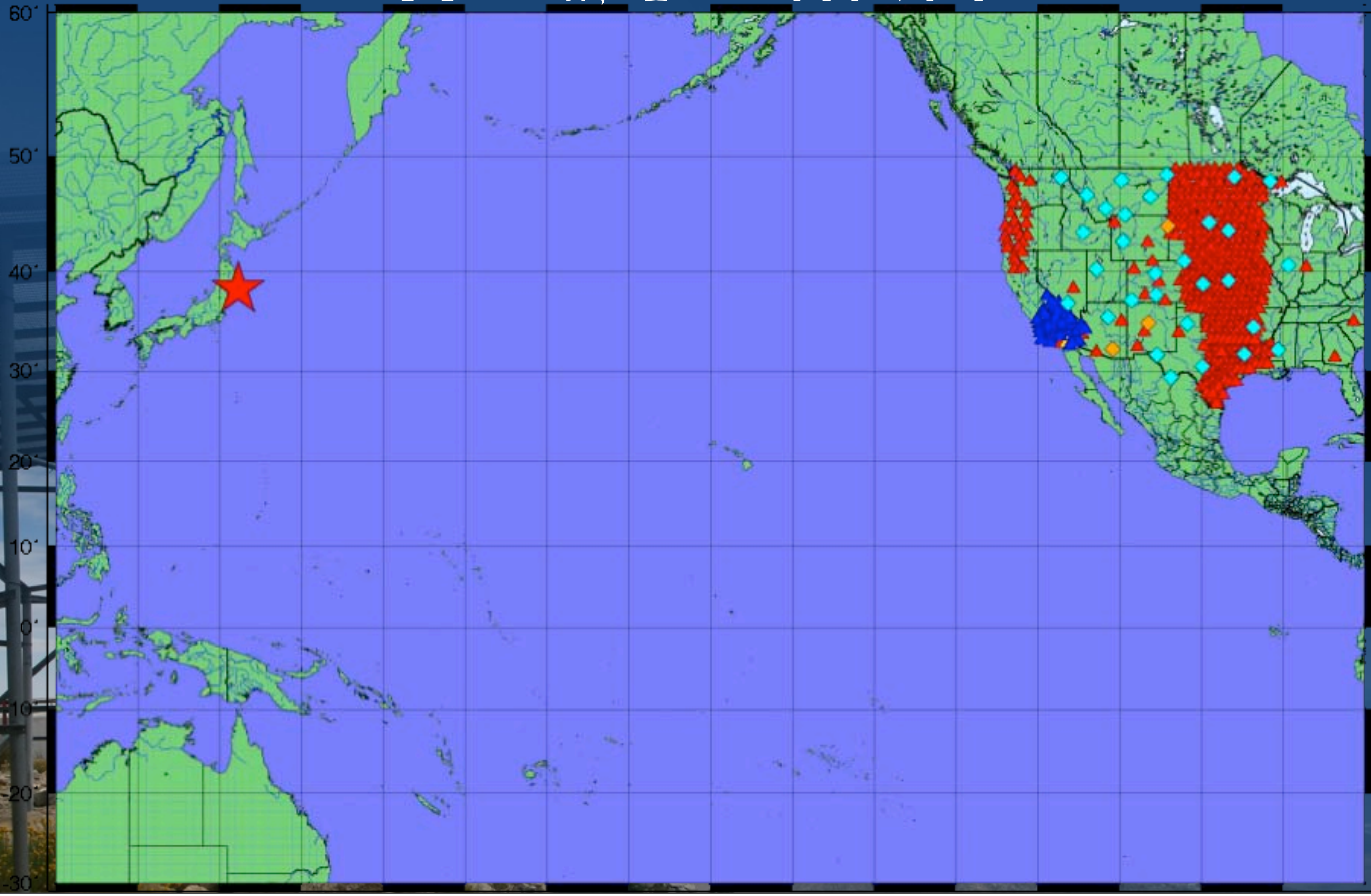
There is a 50+ year experience base in constructing and running terrestrial observatories, primarily for seismology and astronomy, now for geodesy

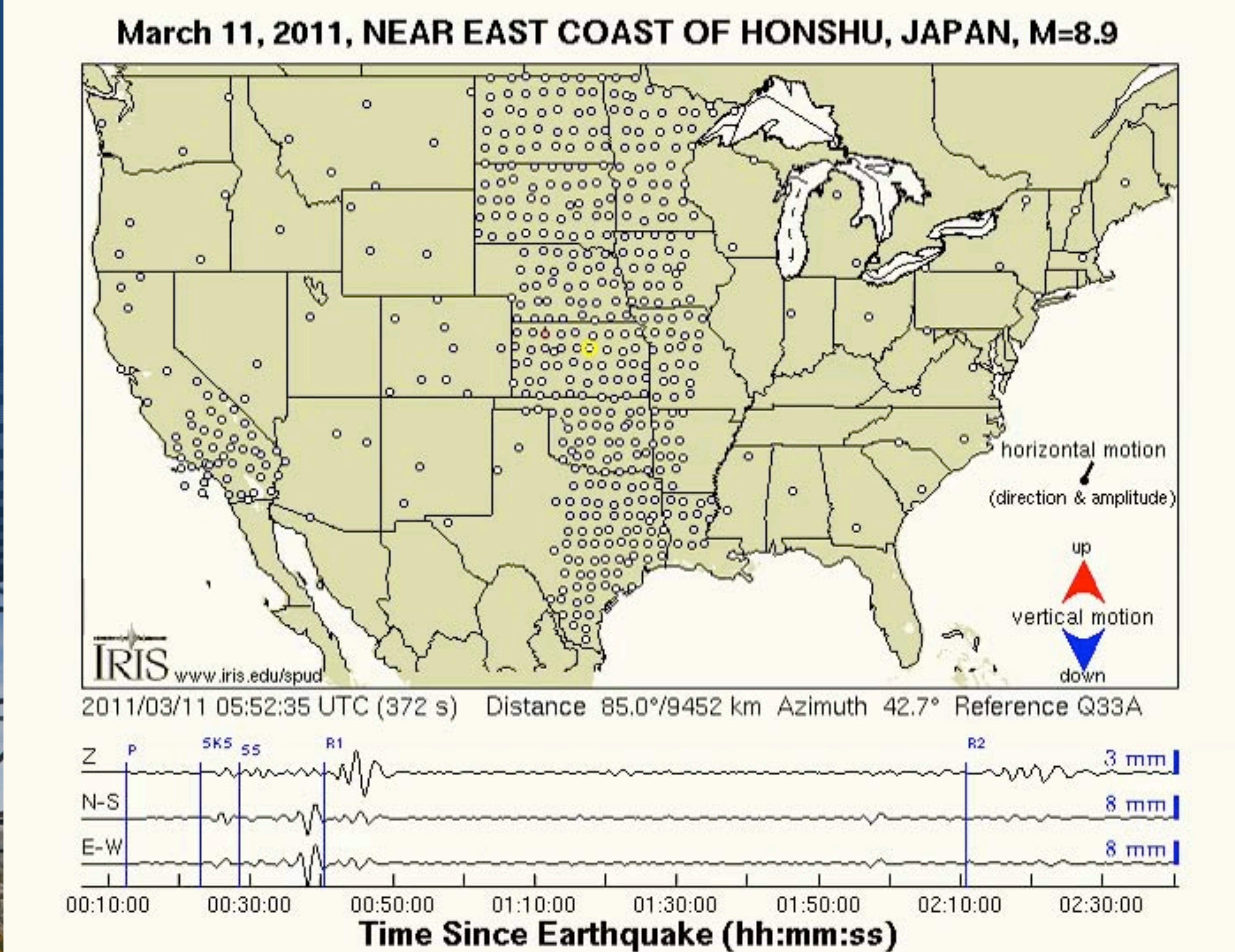
One of the key lessons learned is that failure to provide accurate, synoptic time stamps leads to data problems and considerable labor expenditure for their correction

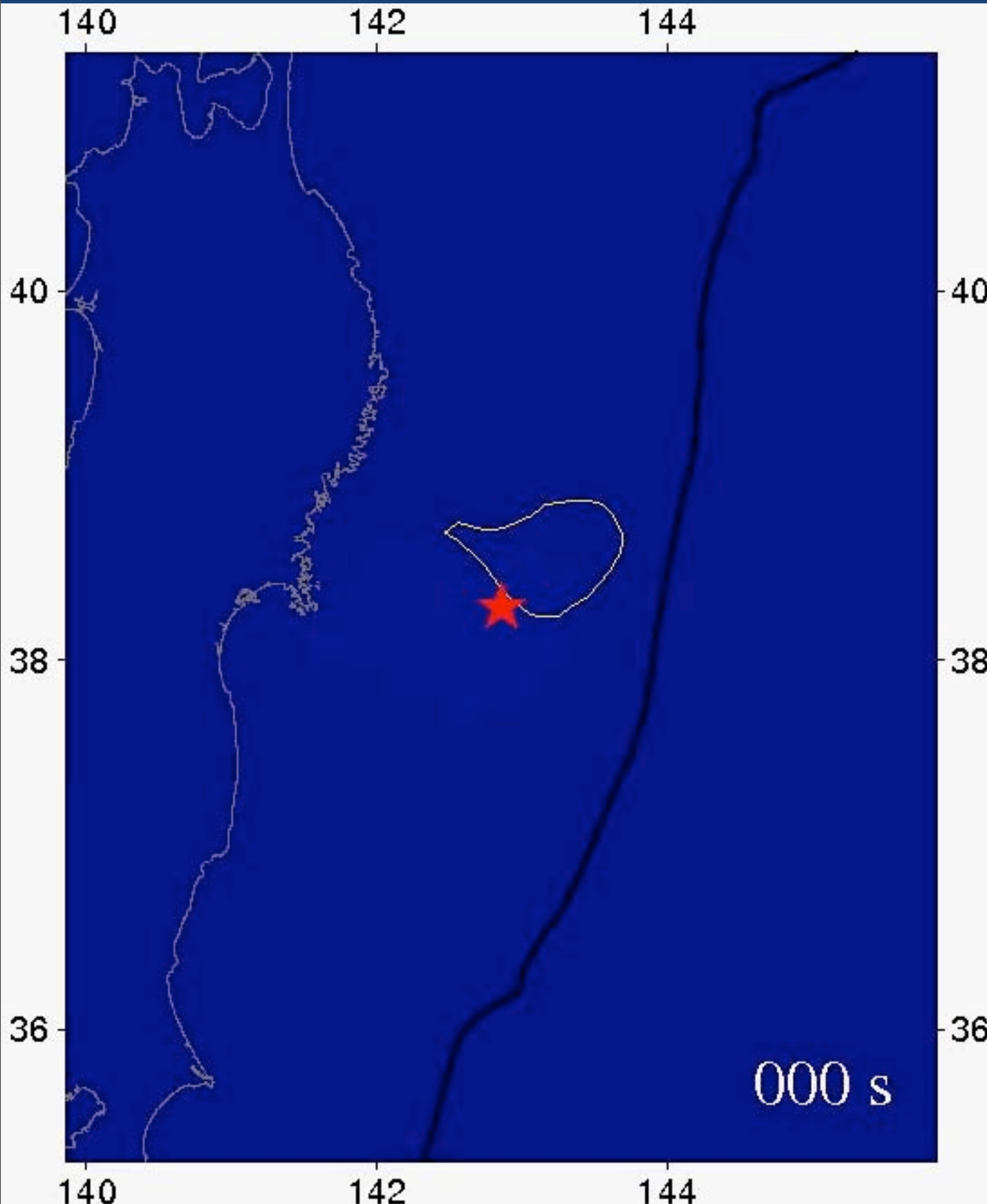
Premise 5

Future observing systems should take a long term (25 y or more) perspective on time rather than making short term decisions that may preclude important science a decade from now

11 March 2011 Mw 9.0 Source and USArray TA Receivers




March 11, 2011, NEAR EAST COAST OF HONSHU, JAPAN, M=8.9
horizontal motion
(direction & amplitude)
up
vertical motion
down
IRIS www.iris.edu/spud
2011/03/11 05:52:35 UTC (372 s) Distance 85.0°/9452 km Azimuth 42.7° Reference Q33A
Z
N-S
E-W
P
SKS
SS
R1
R2
3 mm
8 mm
8 mm
00:10:00
00:30:00
00:50:00
01:10:00
01:30:00
01:50:00
02:10:00
02:30:00
Time Since Earthquake (hh:mm:ss)



Back projection rupture image of the 11 March 2011 Mw 9.0 Tohoku-Chiho Taiheiyo-Oki Earthquake

Kiser and Ishii, 2011
http://www.seismology.harvard.edu/research_japan.html

Time Problems We Have Seen

Sample on demand (triggered) system

- Non-real time systems (e.g., Linux) request data which introduces sample jitter that is load dependent
- Unknown time offset between sample and time stamp
- Not correctable

Time Problems We Have Seen

Instrument notion of time is independent of observatory notion of time

- Free running clock on sensor
- Time stamp applied by recording computer
- Non-real time systems (e.g., Linux) introduce sample jitter that is load dependent
- Unknown time offset between sample and time stamp
- Not correctable

Time Problems We Have Seen

Free-running clock with intermittent phase lock to standard time

- Unknown time offset between sample and real time before resetting clock
- Not correctable

Time Problems We Have Seen

1 pps signal with associated time string

- Loss of phase lock that is not logged
- Incorrect decoding/association of time string
- Creates gaps or overlaps in data
- Difficult to correct

Time Problems We Have Seen

Multiple notions of time within a single measurement system

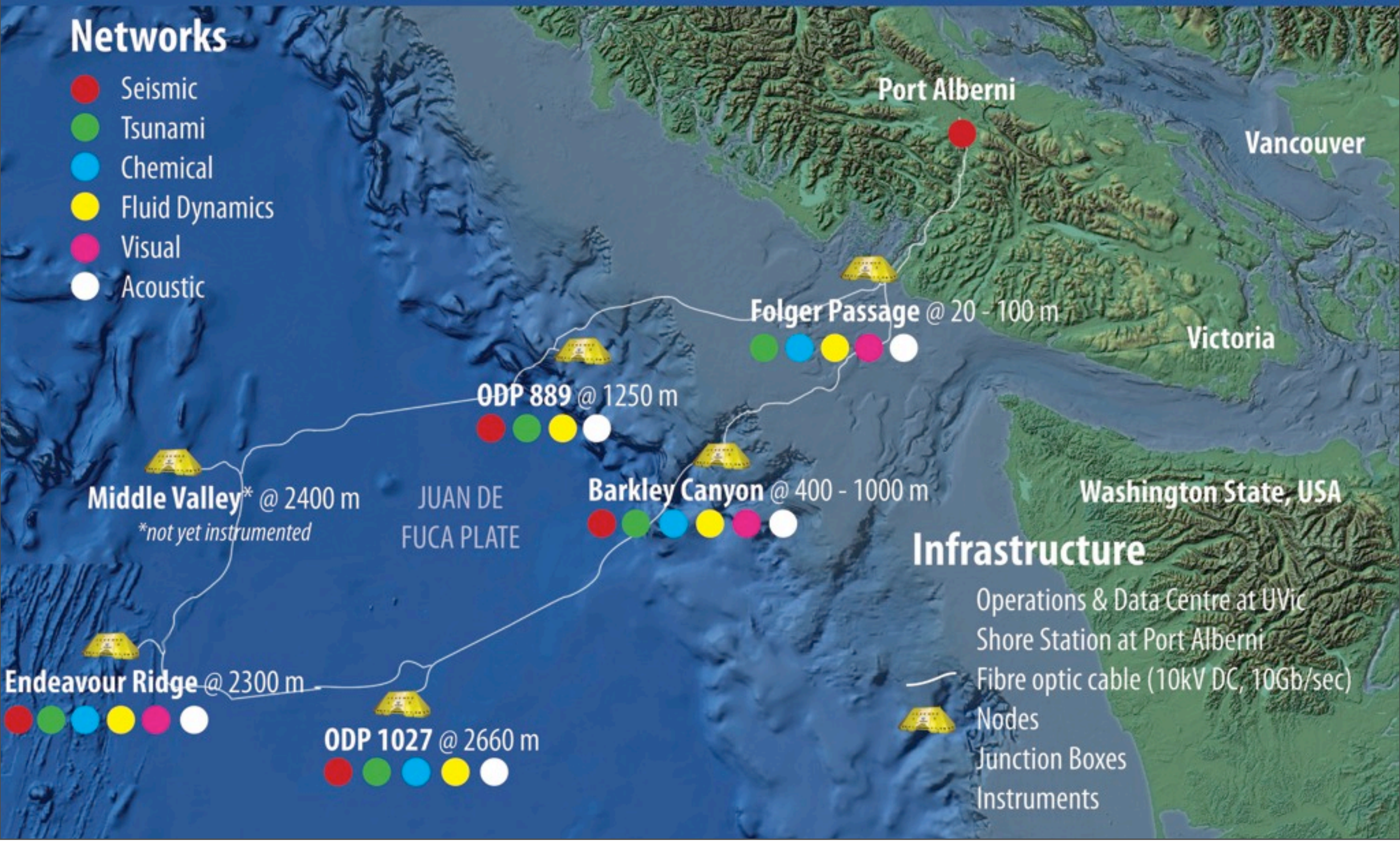
- Free-running oscillators on different data loggers phase locked intermittently to standard time
- Time-varying offsets between measurement groups
- Interference between oscillators
- Correctable with difficulty (maybe)

Time Problems We Have Seen

Out of phase sampling

- One A/D used to sample multiple channels
- Correctable with proper documentation

IP Sensor Networks - Neptune Canada



Time Problems We Are Starting to See

- There is variable latency and jitter depending on path and load on the IP network

- Apparent time becomes

$$\Delta'_j = \Delta + \alpha_j \delta \qquad j = 1,....,N$$

- Assume $\delta < \Delta$ and model $\alpha_j \sim U(-1,1)$

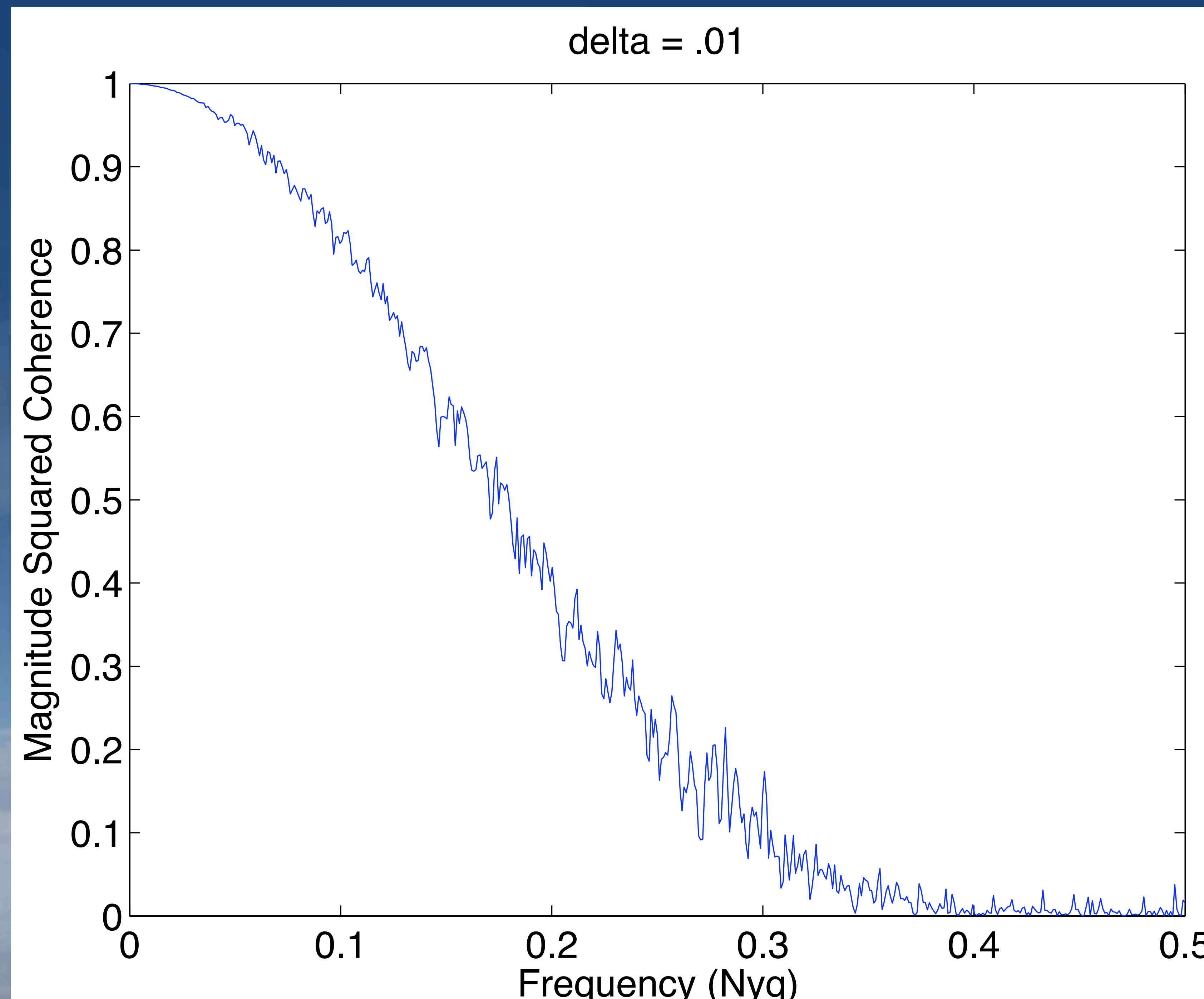
- Optimistic model since IP jitter is long-tailed and model precludes time stamping such that data are out of order

Time Problems We Are Starting to See

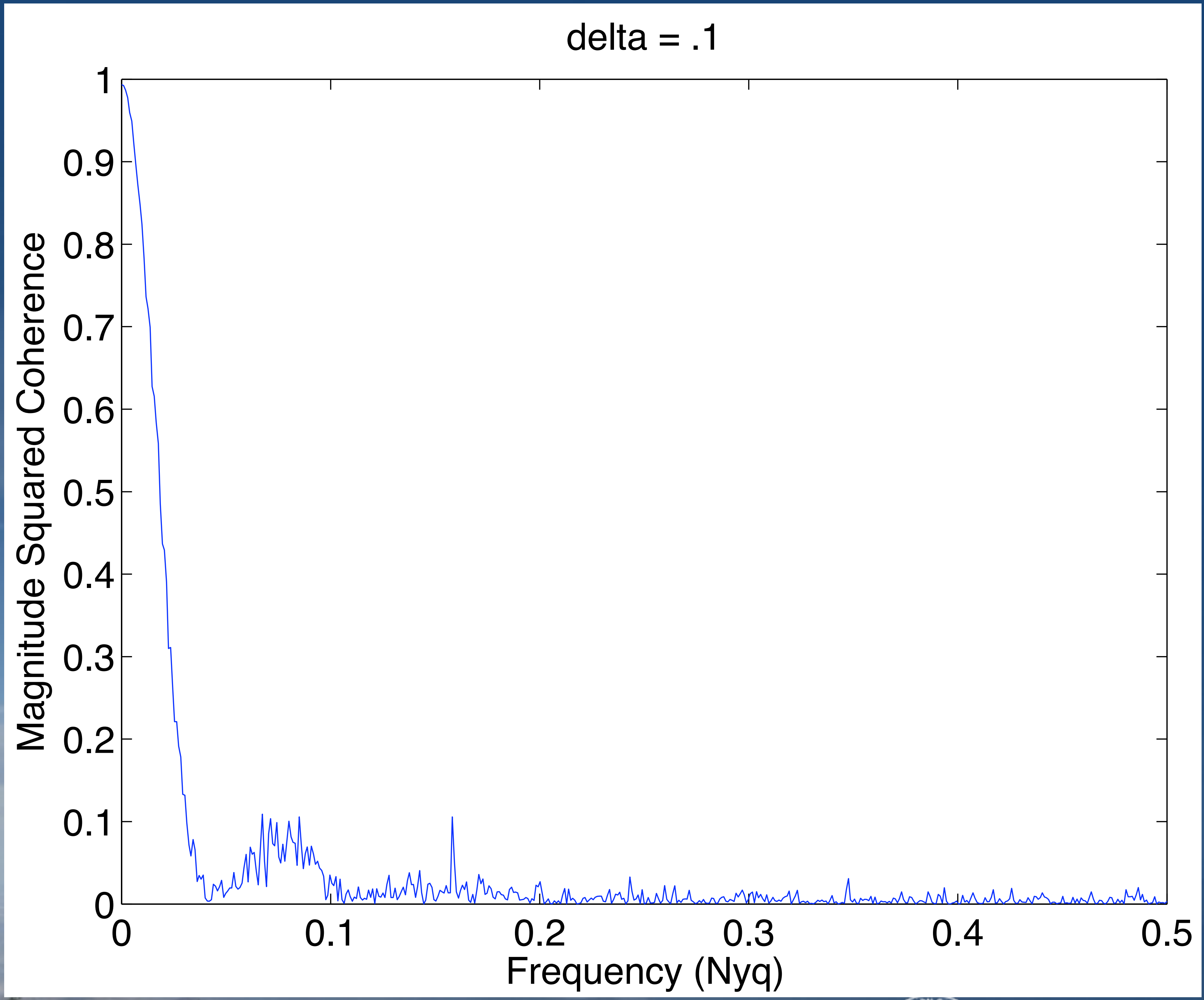
- Assume $\Delta = 1$ so that Nyquist frequency is 0.5
- The magnitude squared coherence (MSC) of the two data series is unity at all frequencies in the absence of time errors
- If $\delta = 0.001\Delta$

  the MSC ranges from 1 to 0.985 as frequency goes from 0 to the Nyquist

Time Problems We Are Starting to See



Time Problems We Are Starting to See



Time Problems We Are Starting to See

If time stamping at the shore station to 1 s accuracy is sufficient

- From the model, data with a sample interval of 10 s are useless
- From the model, data with a sample interval of 100 s lose 3/4 of their scientific utility
- From the model, data with a sample interval of 1000 s are relatively unaffected

Message: time stamps must be applied as close to data acquisition as possible with the highest possible accuracy

Original OOI RSN Time System

- Standard time is applied at the shore station
- Primary infrastructure supplier provides a proprietary 1 pps system phase locked to GPS
- 1 pps system has a time string embedded
- 1 pps system operates on a shared out-of-band system
- Loopback at installation will allow one-time correction for latency to asserted 1 microsecond accuracy
- Delivers 1 pps signal to science ports

Standards Based Network Time

Network Time Protocol (NTP)

- WAN technology to synchronize clocks with 10-100 millisecond accuracy
- Capable of 1 millisecond on LAN with NTP-aware switches
- Sync time of minutes to hours
- Moderate network/CPU load
- Traceable to USNO standard

Standards Based Network Time

Precision Time Protocol (PTP) aka IEEE 1588

- LAN technology to synchronize clocks with sub-microsecond accuracy
- Sync time of seconds to minutes
- Mature technology with rev 2 standardized in 2008
- Increasing use in industrial and wireless Ethernet applications
- Self organizing master-slave operation
- Low network/CPU load

IEEE 1588

Highest accuracy requires

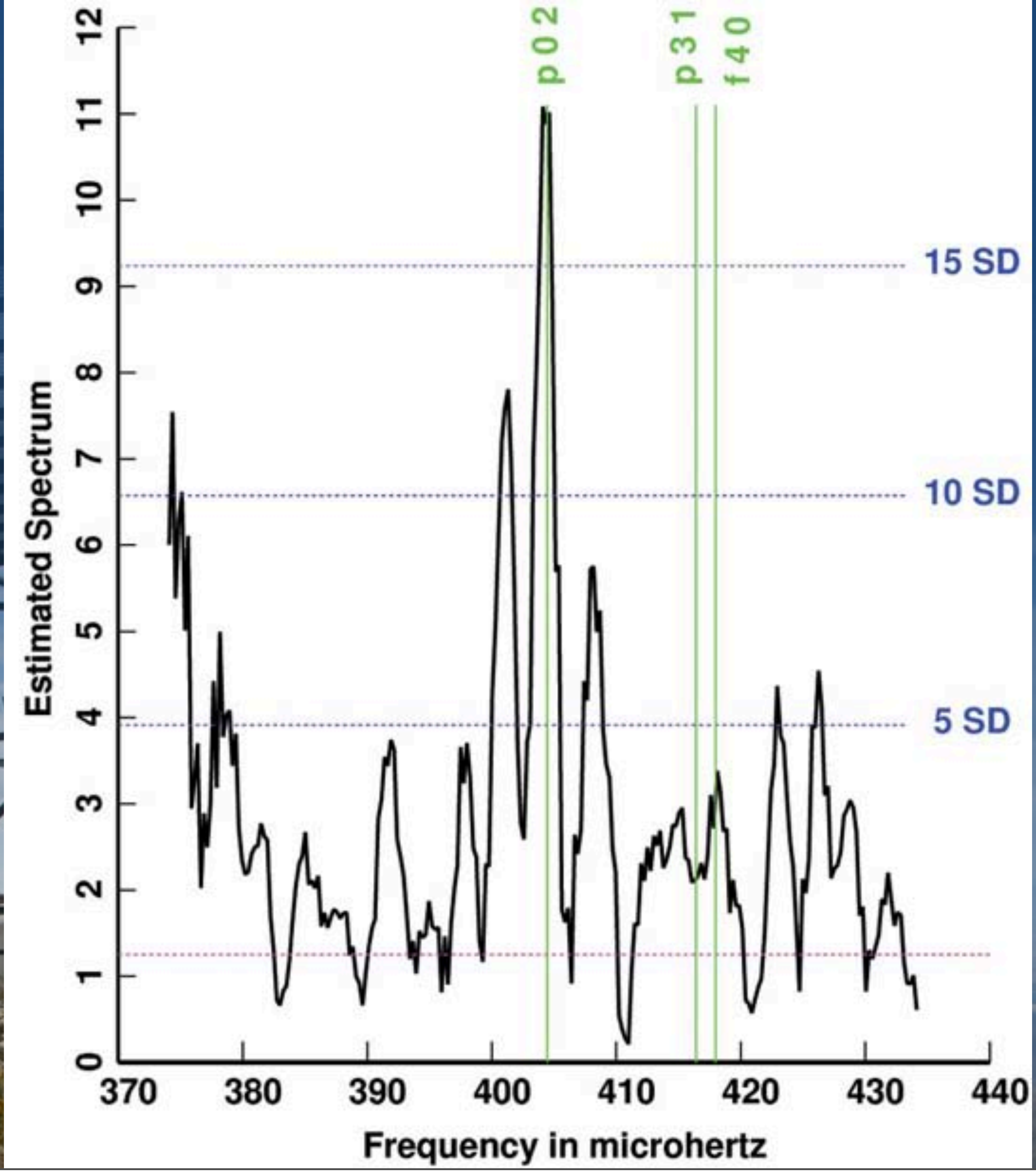
- Hardware time stamping to remove latency/jitter in protocol stack
- PTP-aware switches using boundary or transparent clocks to remove queuing latency/jitter

Best master clock algorithm ensures that failed master will be replaced quickly

Open source PTP daemons available for Unix and Windows

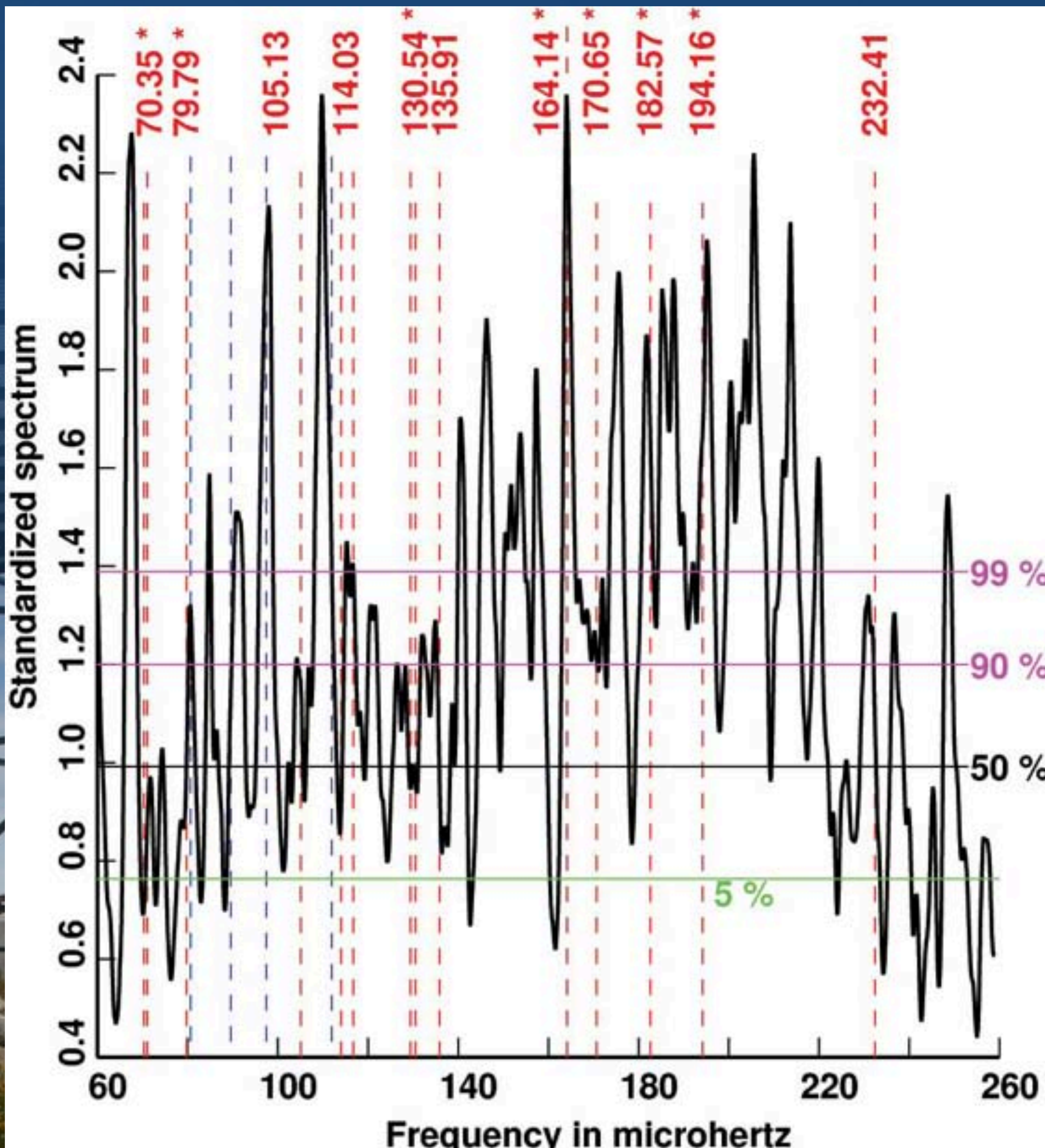
Clock sync occurs 1-100 times/second

Long Continuous Time Series



BFO barometer data from March 3 to August 24, 2000.
The central peak at 404.1 μHz is approximately 22σ above background with an estimated Q 1600.
The frequency corresponds closely to that predicted for the solar $p_{0,2}$ mode.

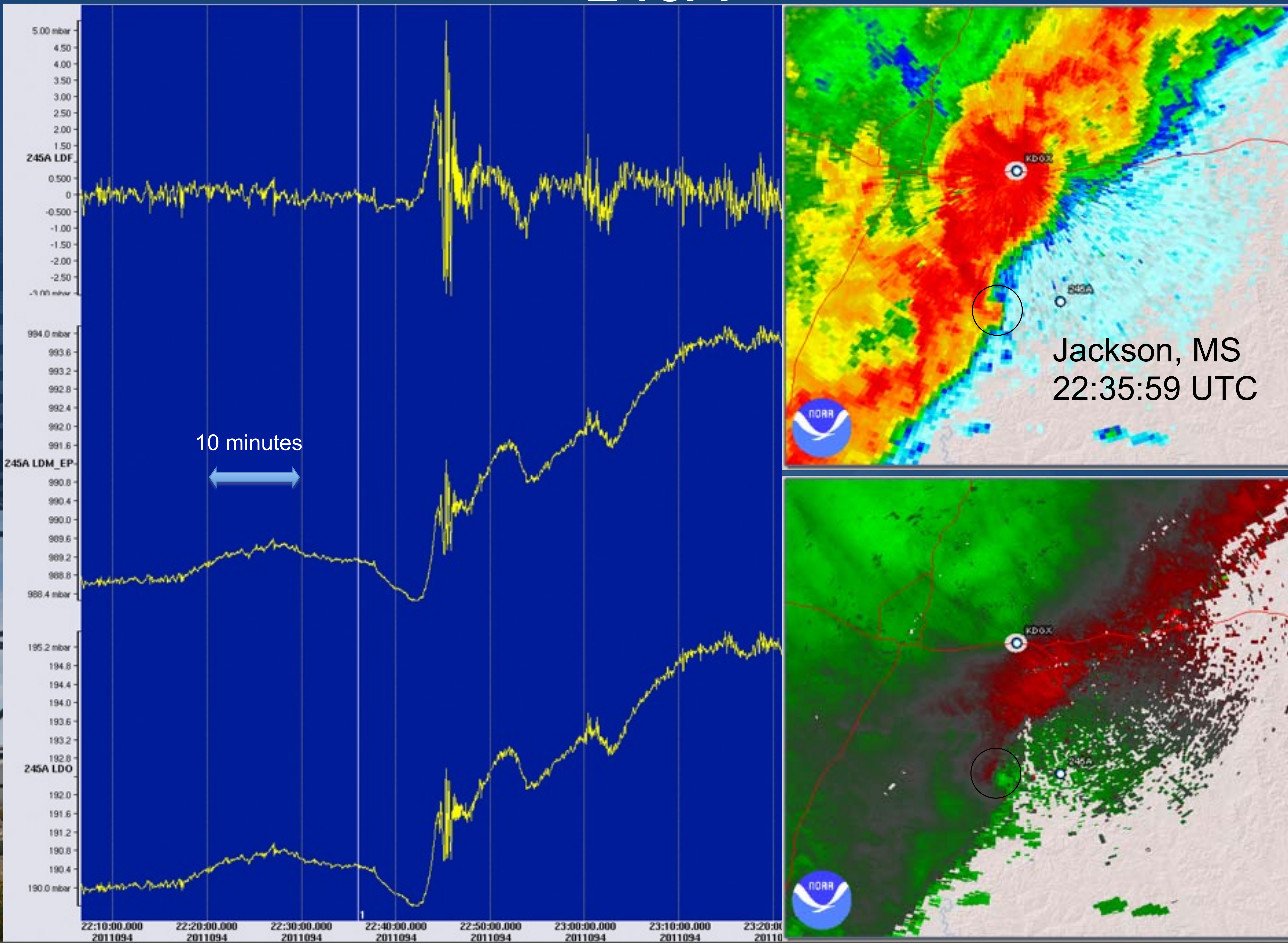
Long Continuous Time Series



Part of the median low-frequency spectrum from PFO vertical seismic data between January 15 and August 14, 2004.

Seven 45-day sections offset 50% were used with 8 windows per section and an effective bandwidth of 1.2 μHz.

Possible Tornado Signature on 4/04/2011 – 245A



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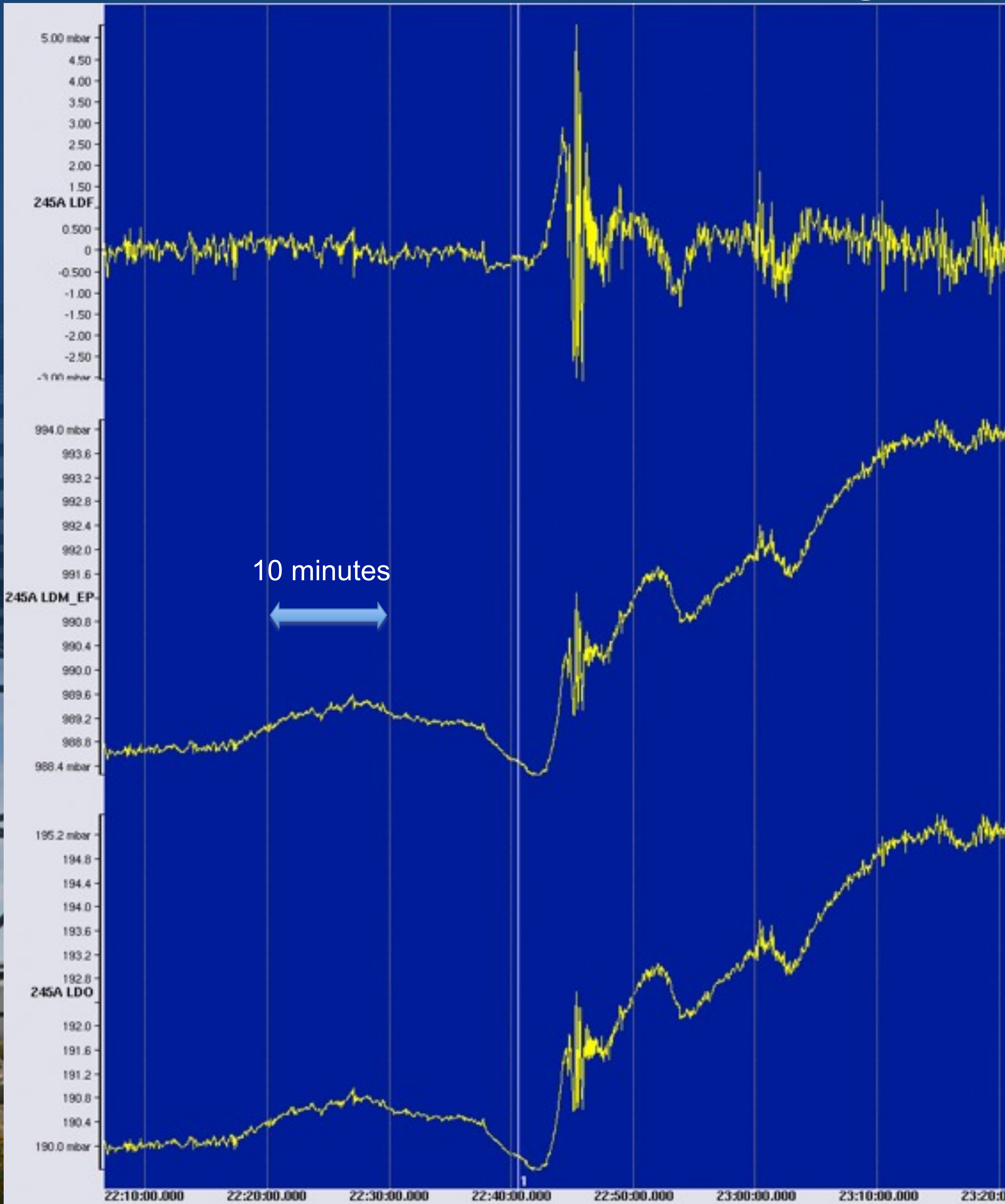

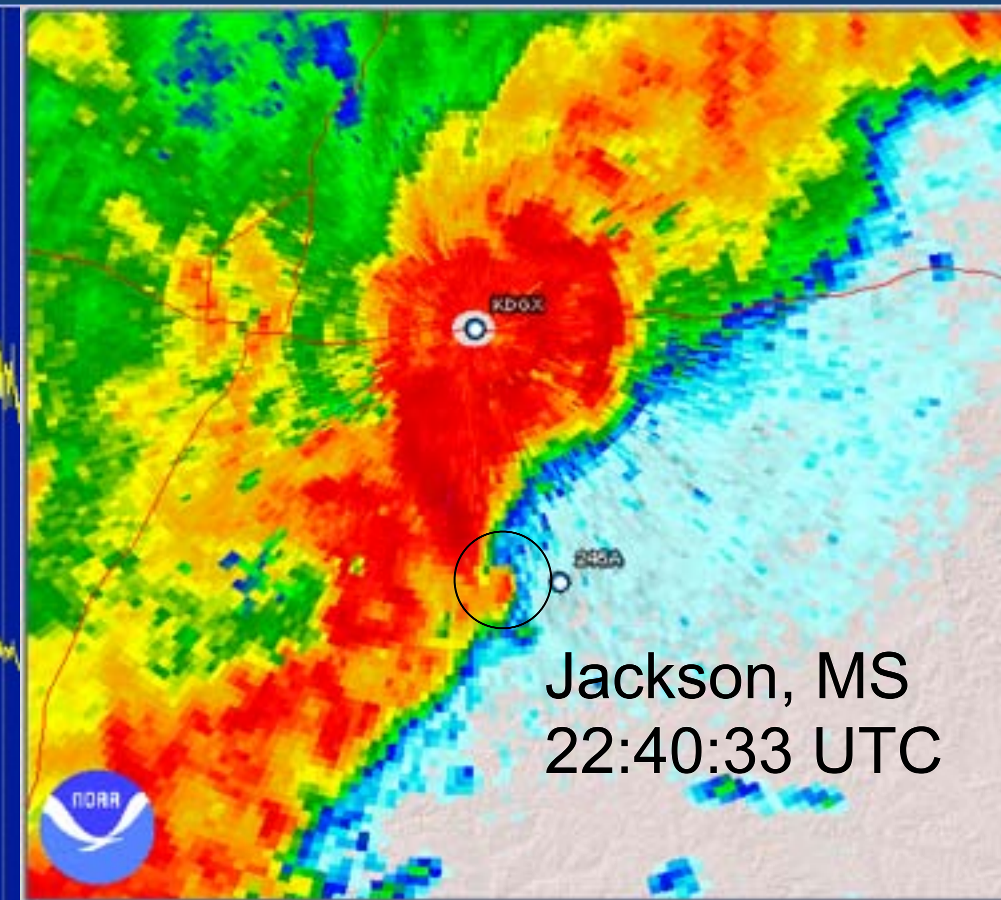

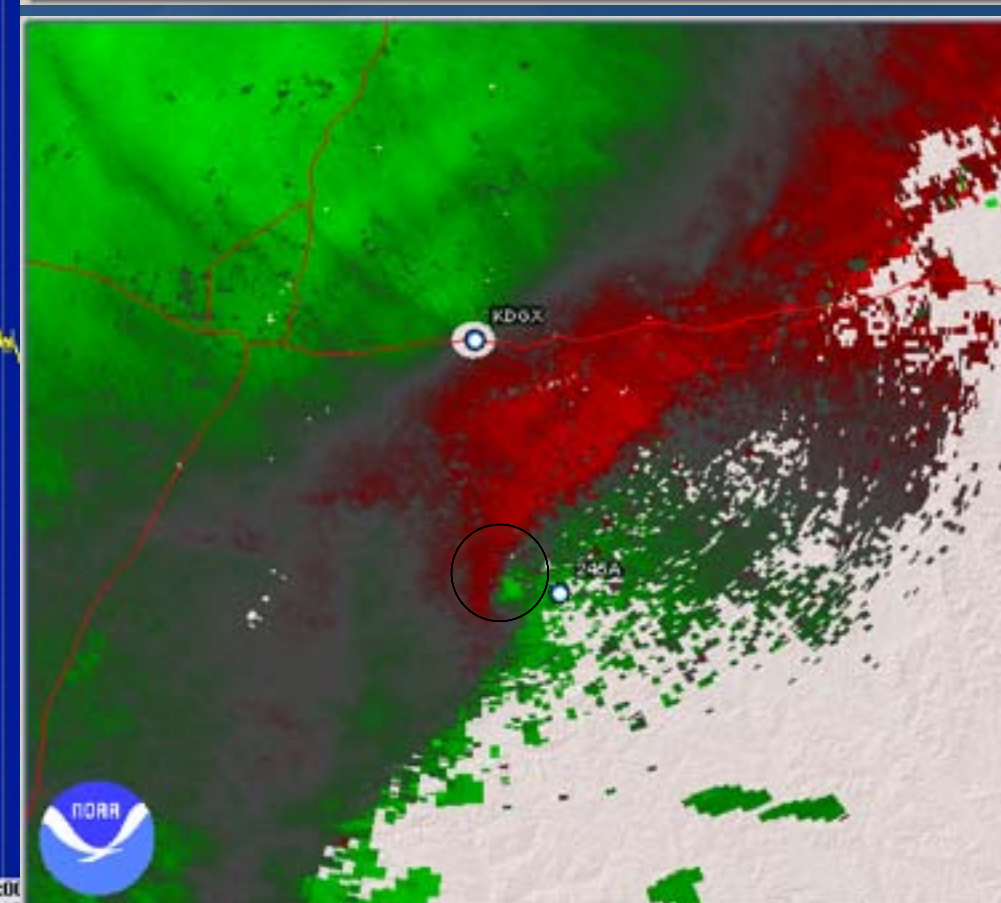

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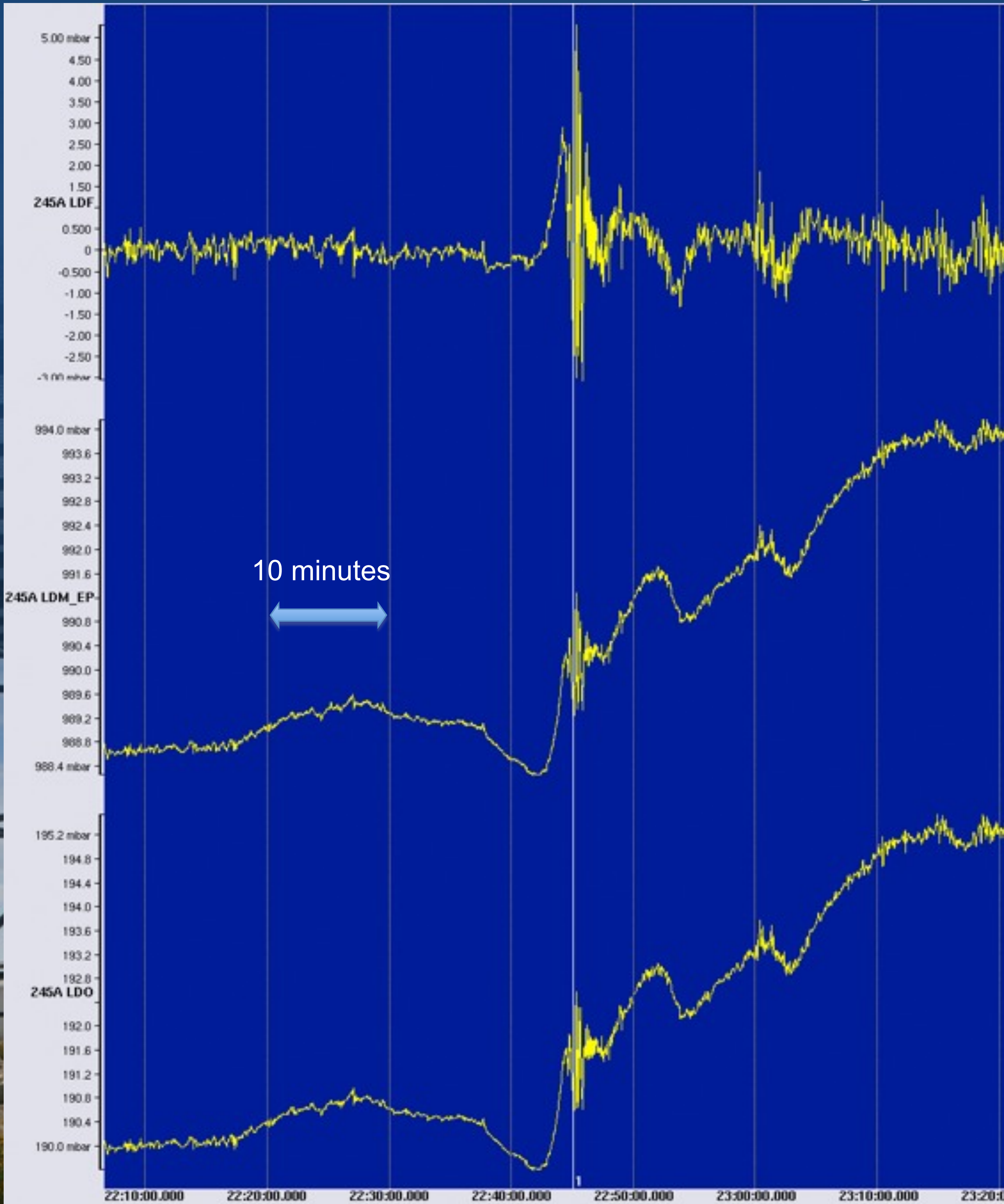

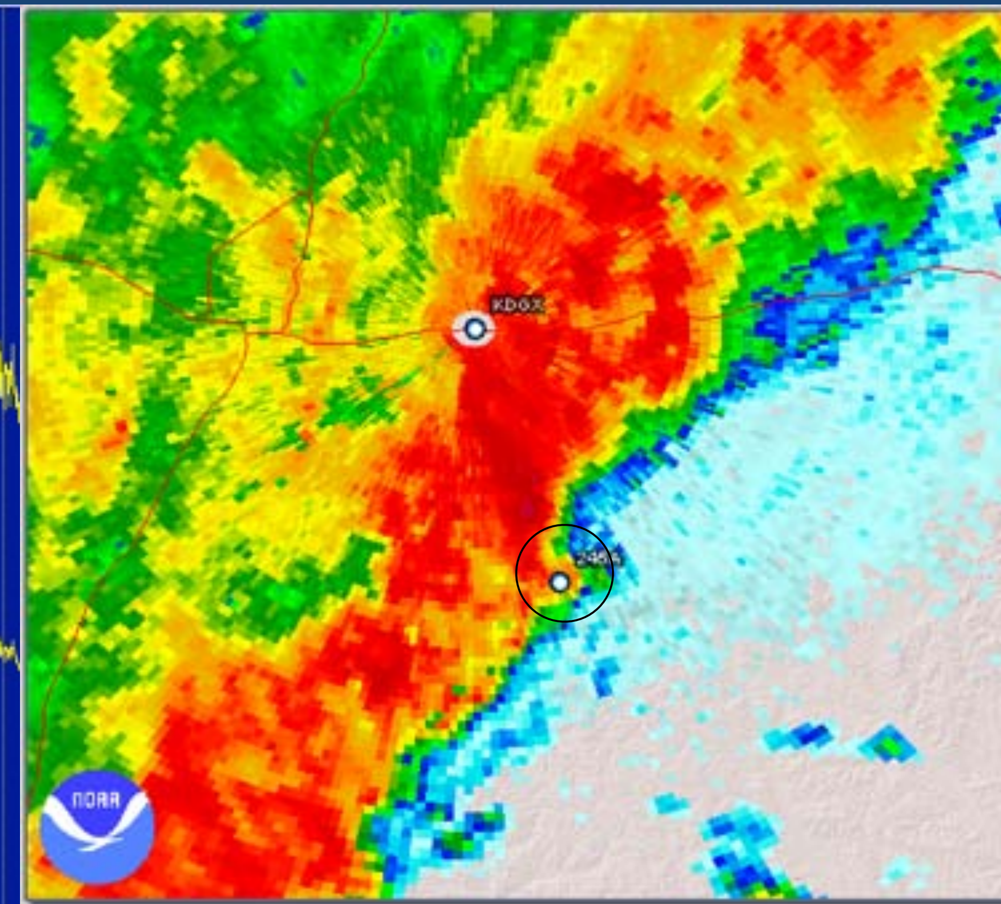

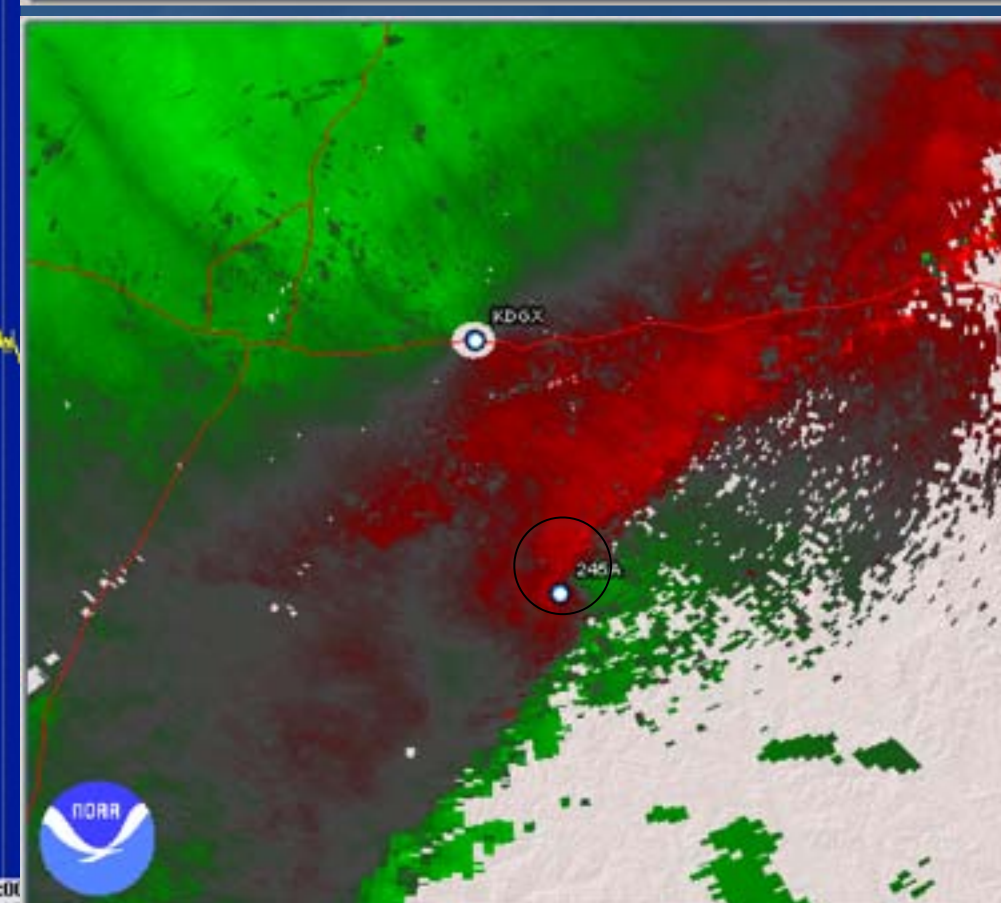

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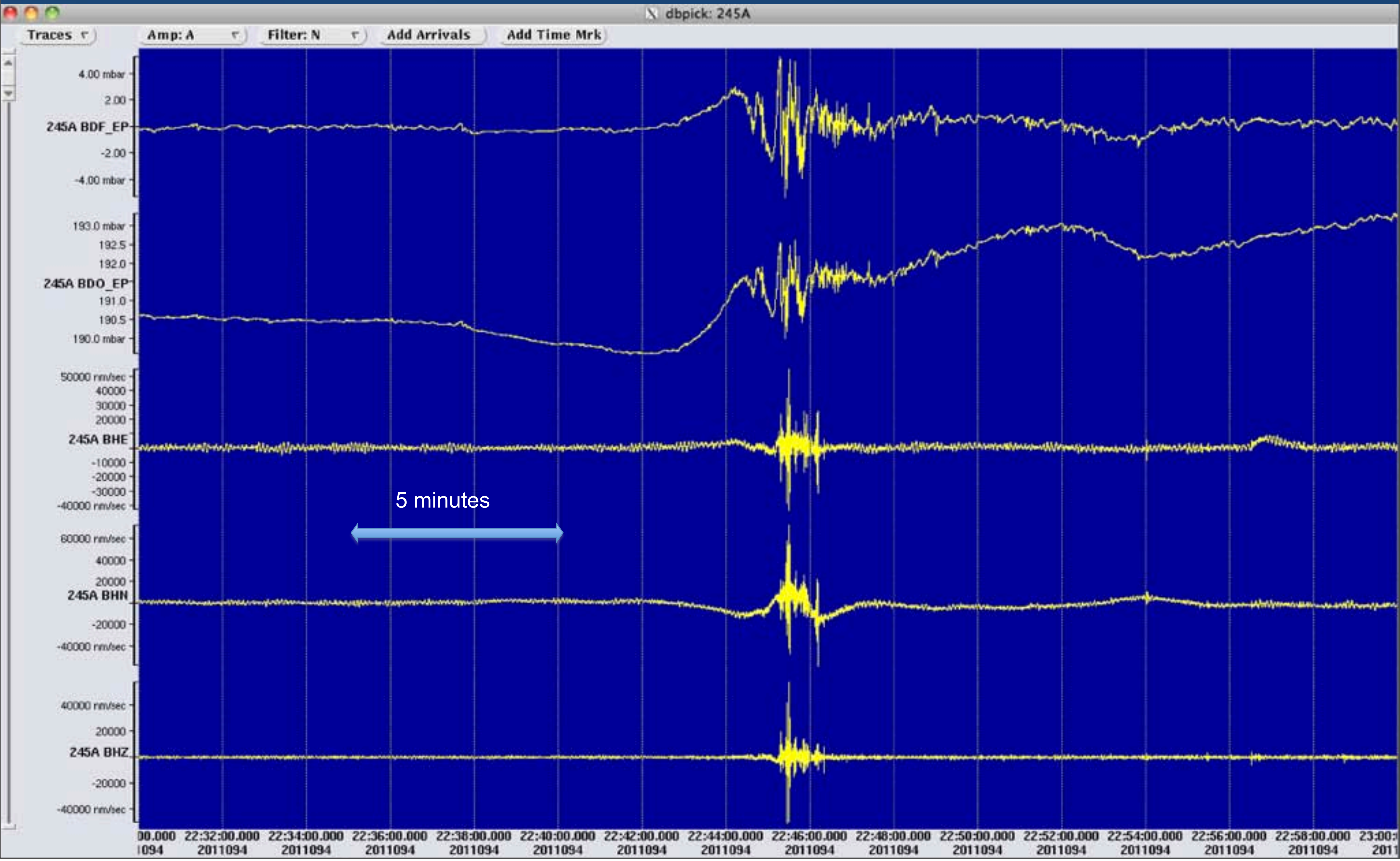

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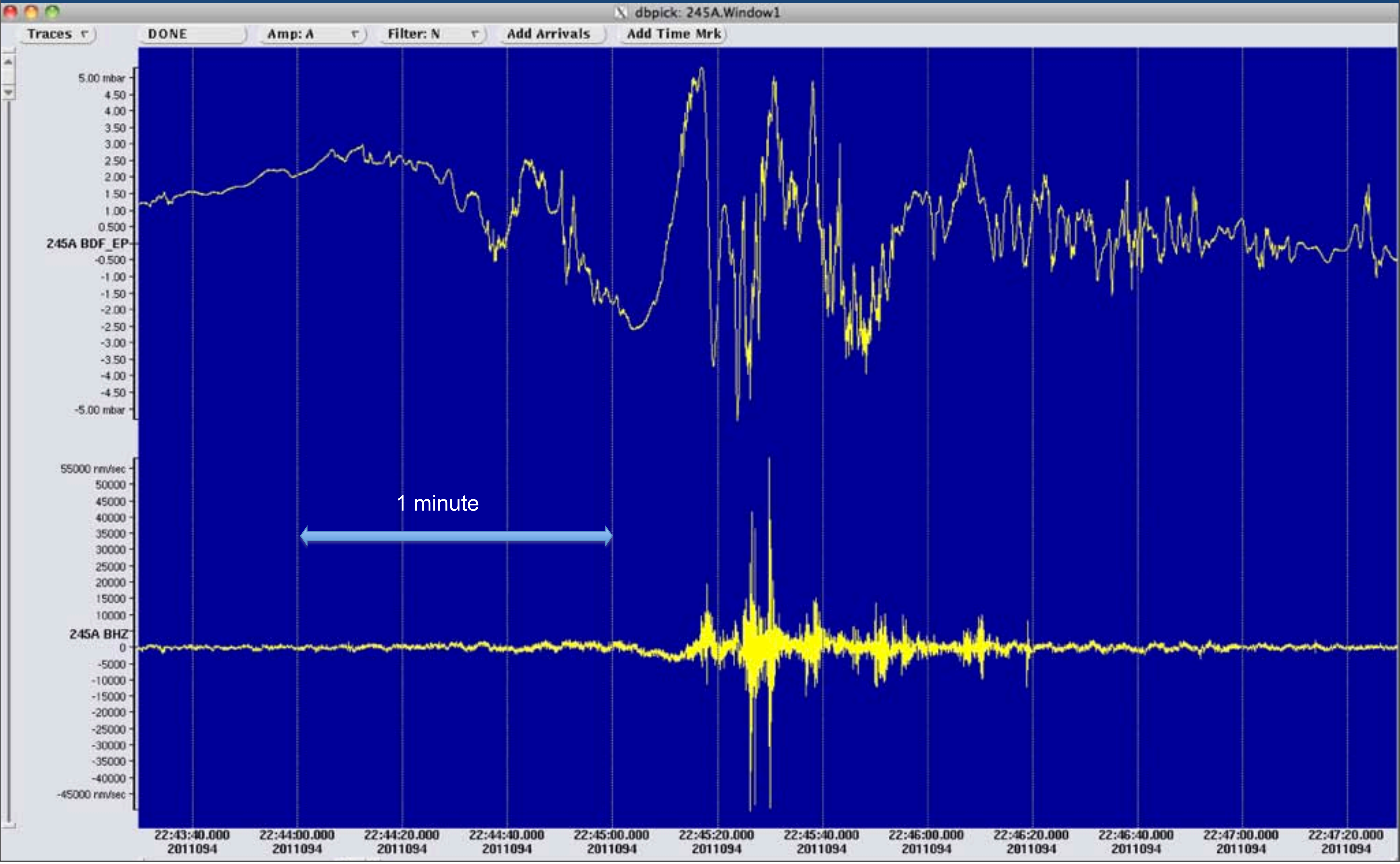

Future Directions

Remote environment

- Extended use of phase locked sampling to GPS time

Networked environment

- Generalized adoption of PTP (IEEE 1588)
- Transition to near real time

Disconnected environment

- Atomic clocks on chips
  - Symetricom
  - drift rates $\sim 10^{-10}$ (< 0.01 sec/year)
  - ~ 110 mWatt