Moment Tensor Inversion

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Course

You will be provided with a complete functioning system that will permit you to perform regional and teleseismic moment tensor inversion.

You will use data from data archives, apply quality control and basic seismology to define the moment tensor

Moment Tensor

This is a mathematic description of the seismic source. Using these parameters with an Earth model and wave propagation code, synthetic seismograms are made that fit the observations.

For some models of the source, the moment tensor can define the possible fault planes from earthquake data.

The numerical value of the moment tensor defines the size of the earthquake

Why do we determine moment tensors?

- Define the source in terms of depth, size and type of faulting
- Do this for many earthquakes to define the regional tectonic stress field
- Test the locations of earthquakes
- Calibrate local magnitude scales
- Test the calibration data of seismic stations and the operation of instruments

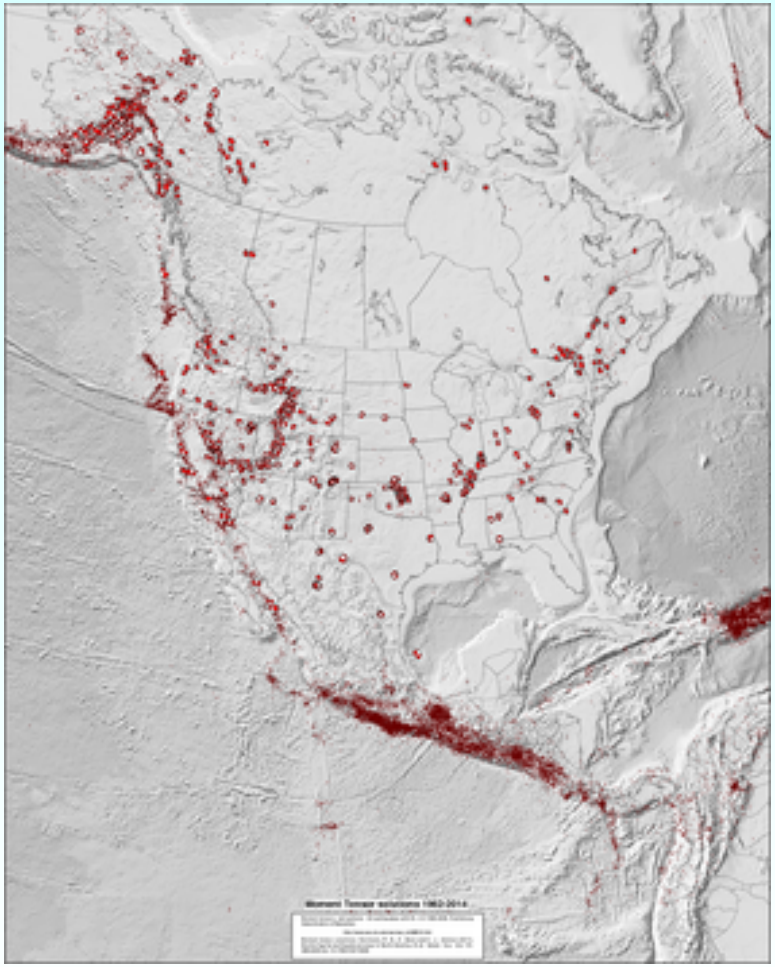
My web page

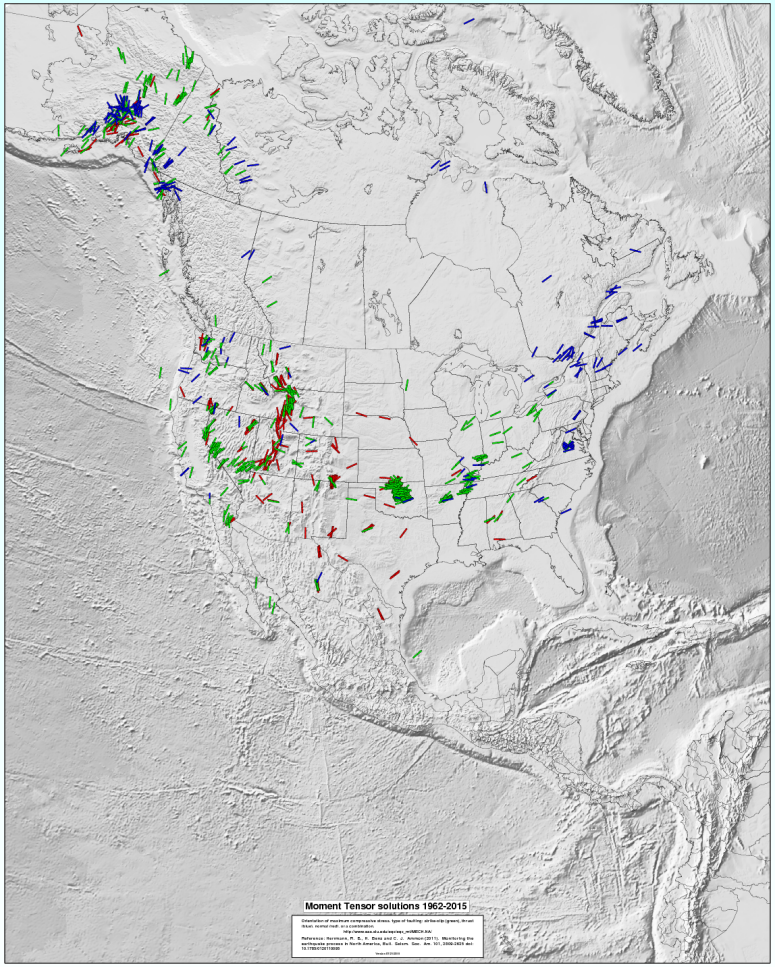
www.eas.slu.edu/eqc/eqc_mt/

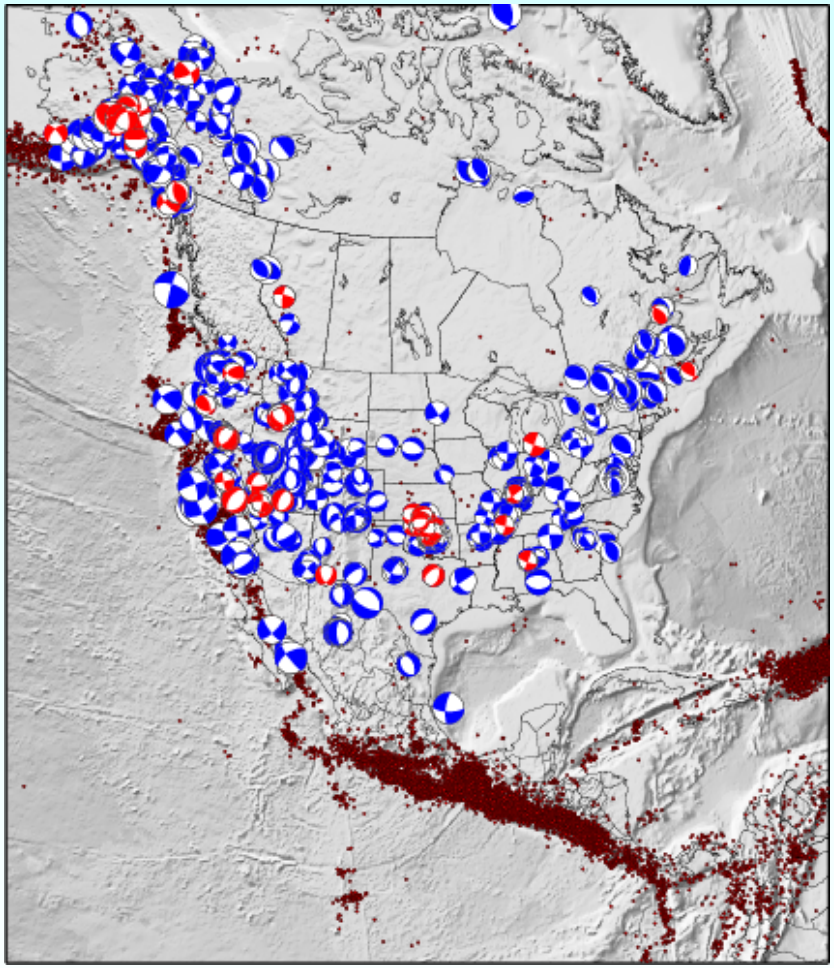
North America, Italy, Europe, Korea, Teleseism

Primary emphasis on North America and Italy

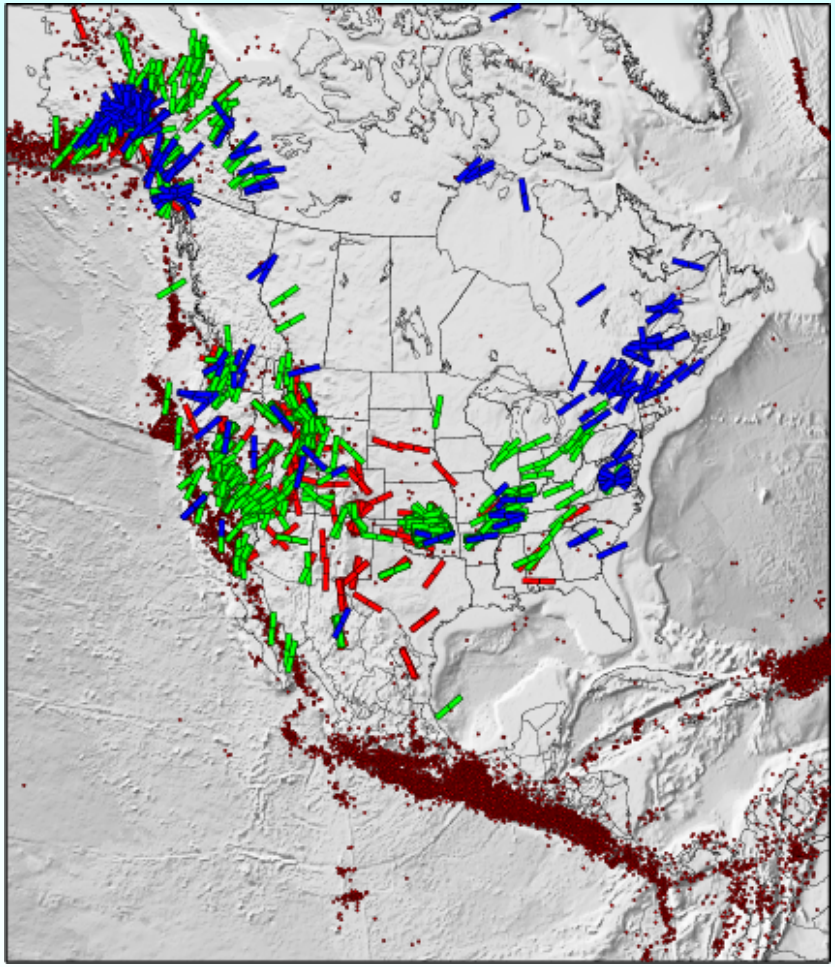
North American Moment Tensor







- Focal mechanism plots
- Shaded quadrant represents compression
- Red color indicates those determined in 2015



Type of faulting and direction of maximum compressive stress

Green – strike-slip

Blue – thrust faulting

Red – normal faulting

Look at spatial patterns

Look at regional with no earthquakes

What is done?

- Get earthquake location
- Get waveforms and calibration information from a data center
- Remove the instrument response to give ground velocity in m/s
- Rotate recordings to vertical, radial and transverse
- Review waveform quality using knowledge of instrumentation and seismology

- **Select appropriate velocity model**
- **Compute or use pre-computed Green's functions for different epicentral distances and source depths**
- **Perform the inversion. *In this course we will use a grid search over all possible shear-dislocations (focal mechanisms)***
- **Review quality of solution and remove bad waveforms and change the frequency band**

This procedure is implemented to be easy to use, but note that this is the result of many years of effort that involved knowledge of

- **Computer programming**
- **Computer graphics**
- **Elastic wave theory**
- **Seismic instrumentation**
- **Signal processing and spectral analysis**
- **Mathematics**
- **etc**

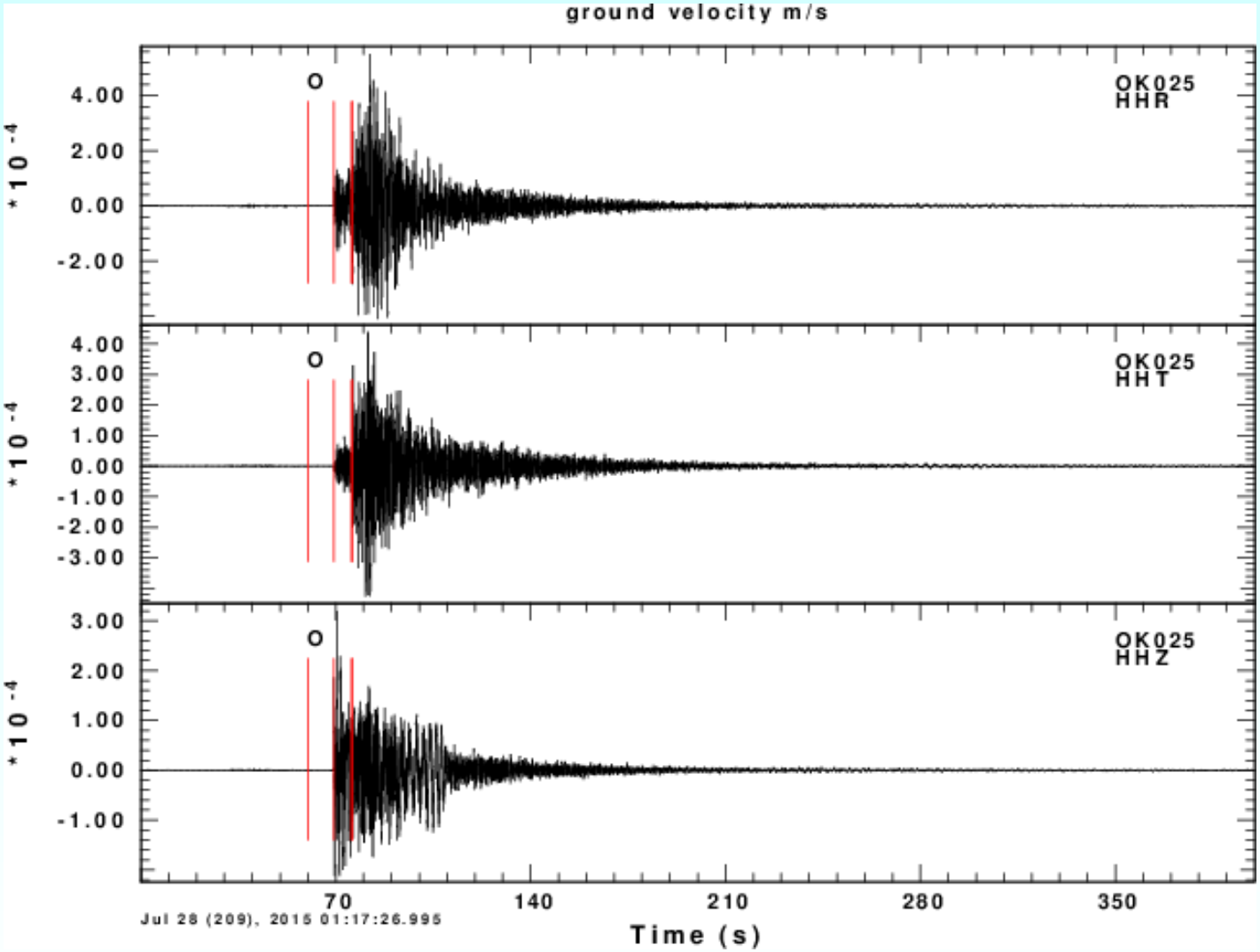
Limitations

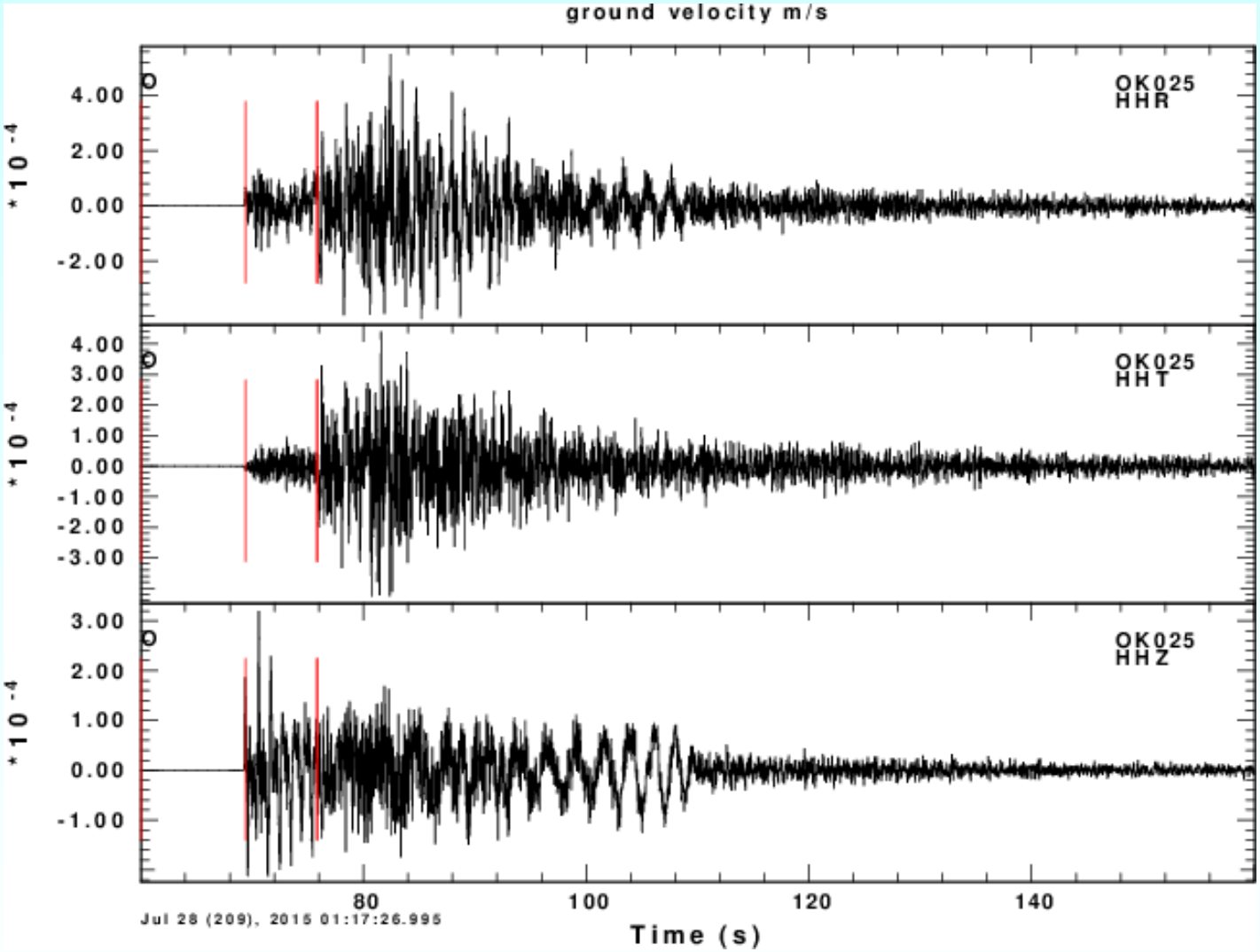
To perform a moment tensor inversion, you need high quality, calibrated, on-scale waveforms with

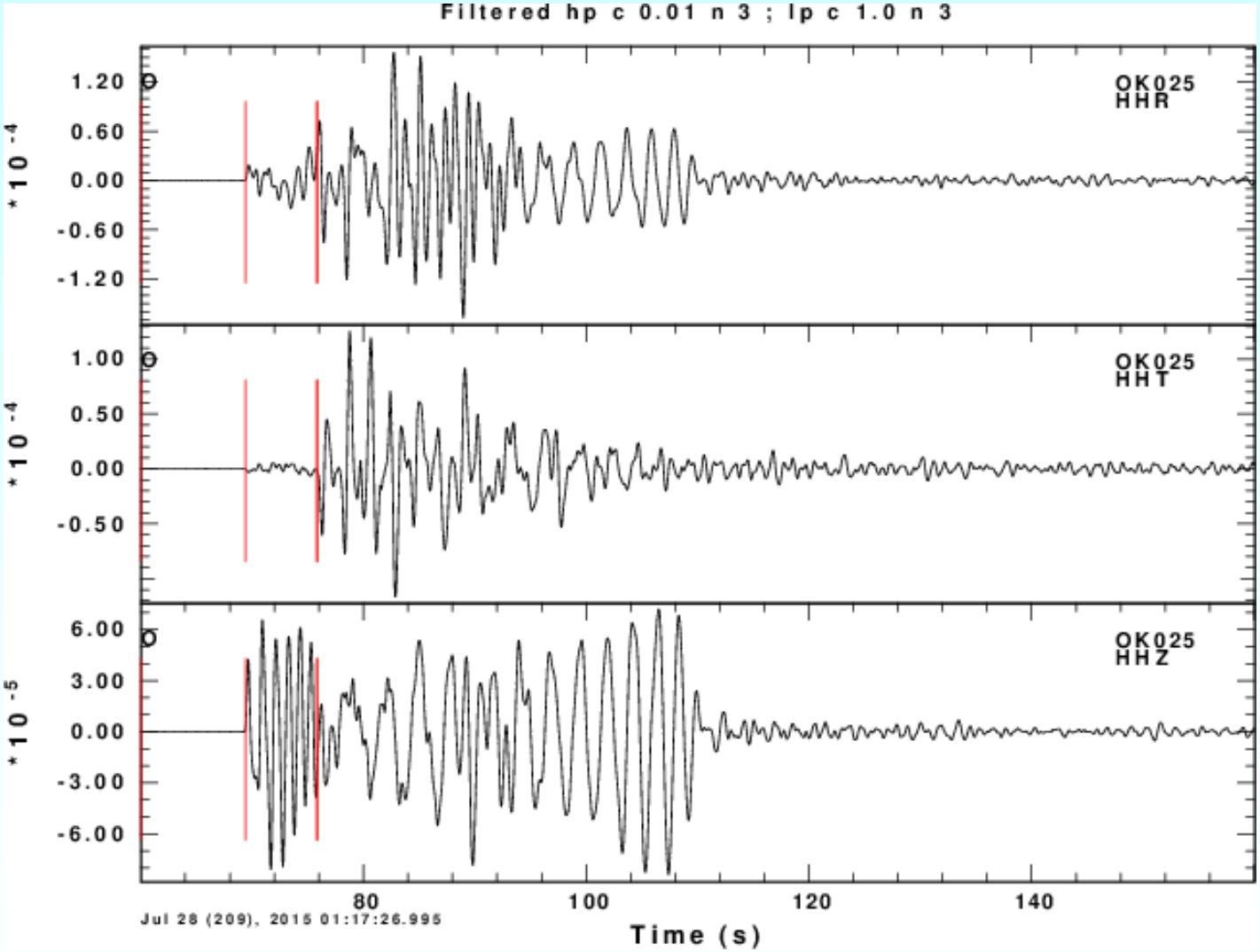
Good signal-to-noise in a frequency band.

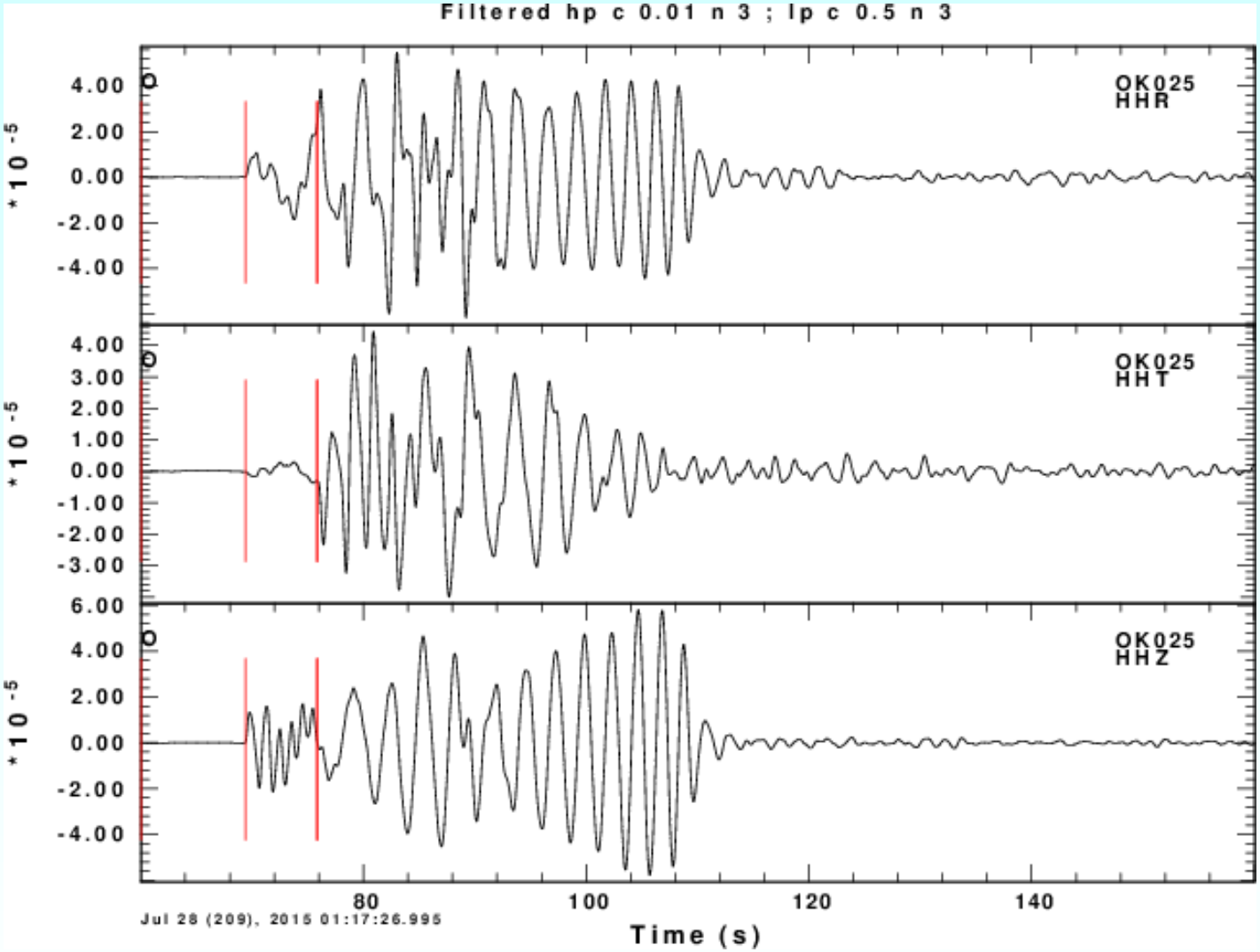
You can look at very small earthquakes if you are a short number of wavelengths away.

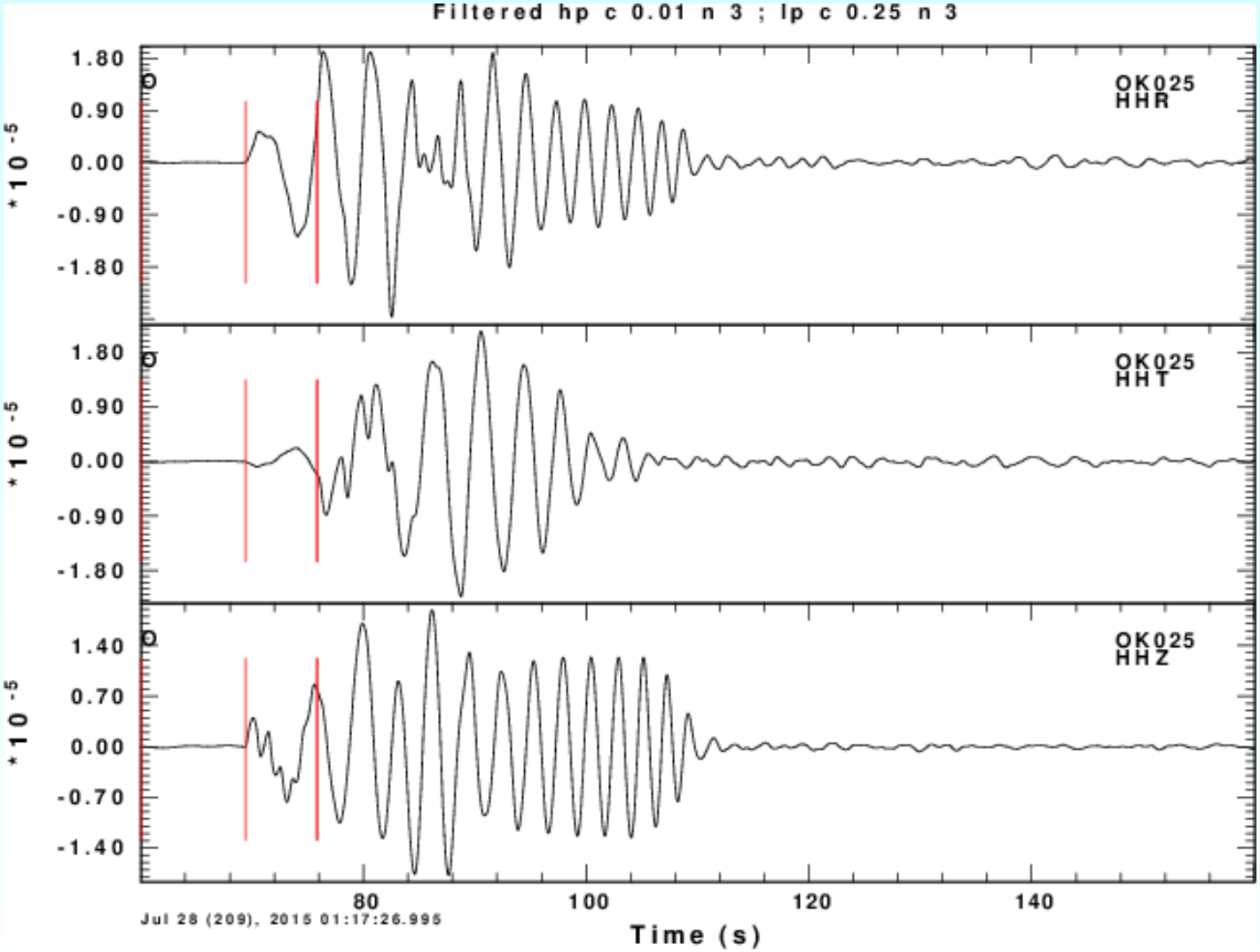
Frequency band

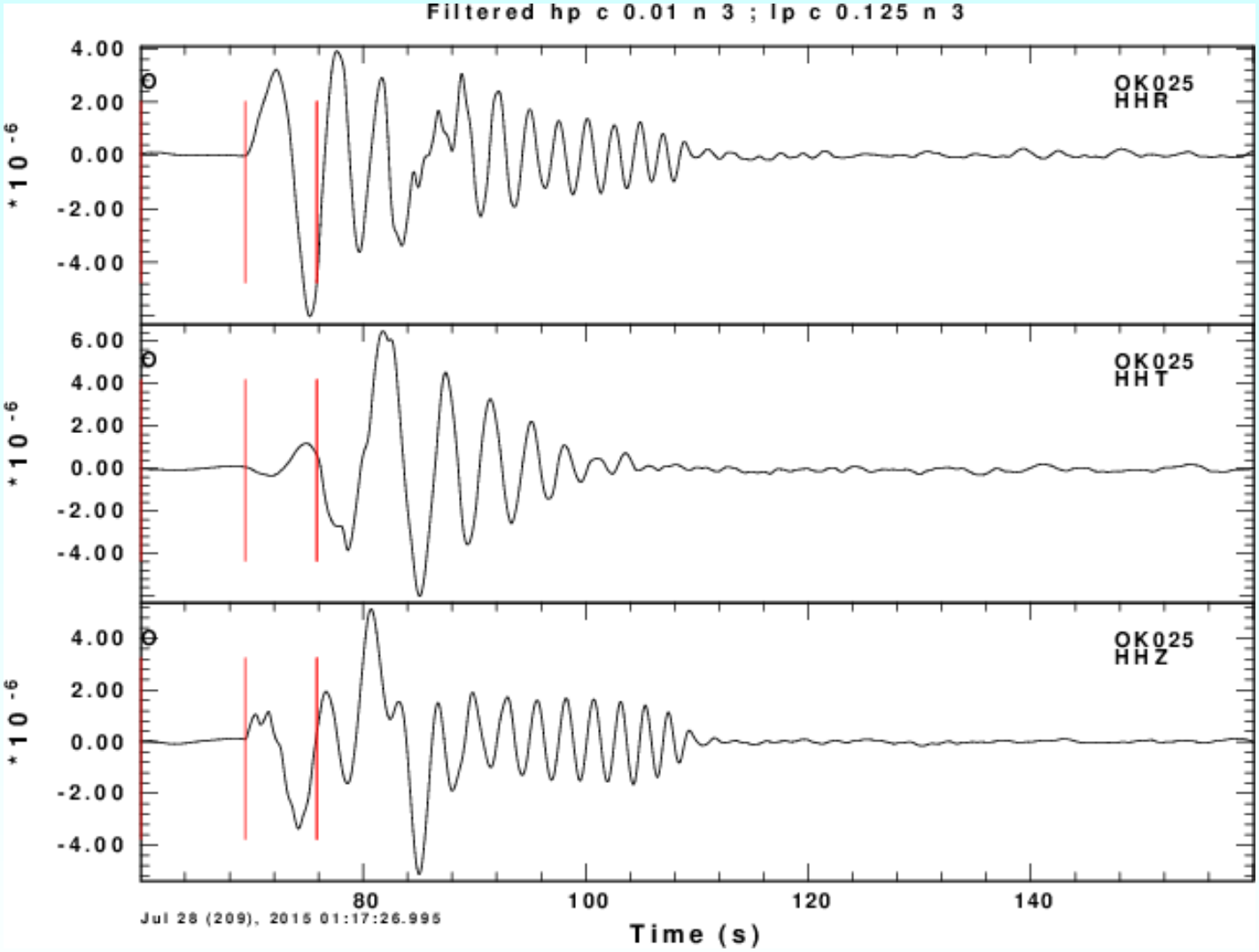


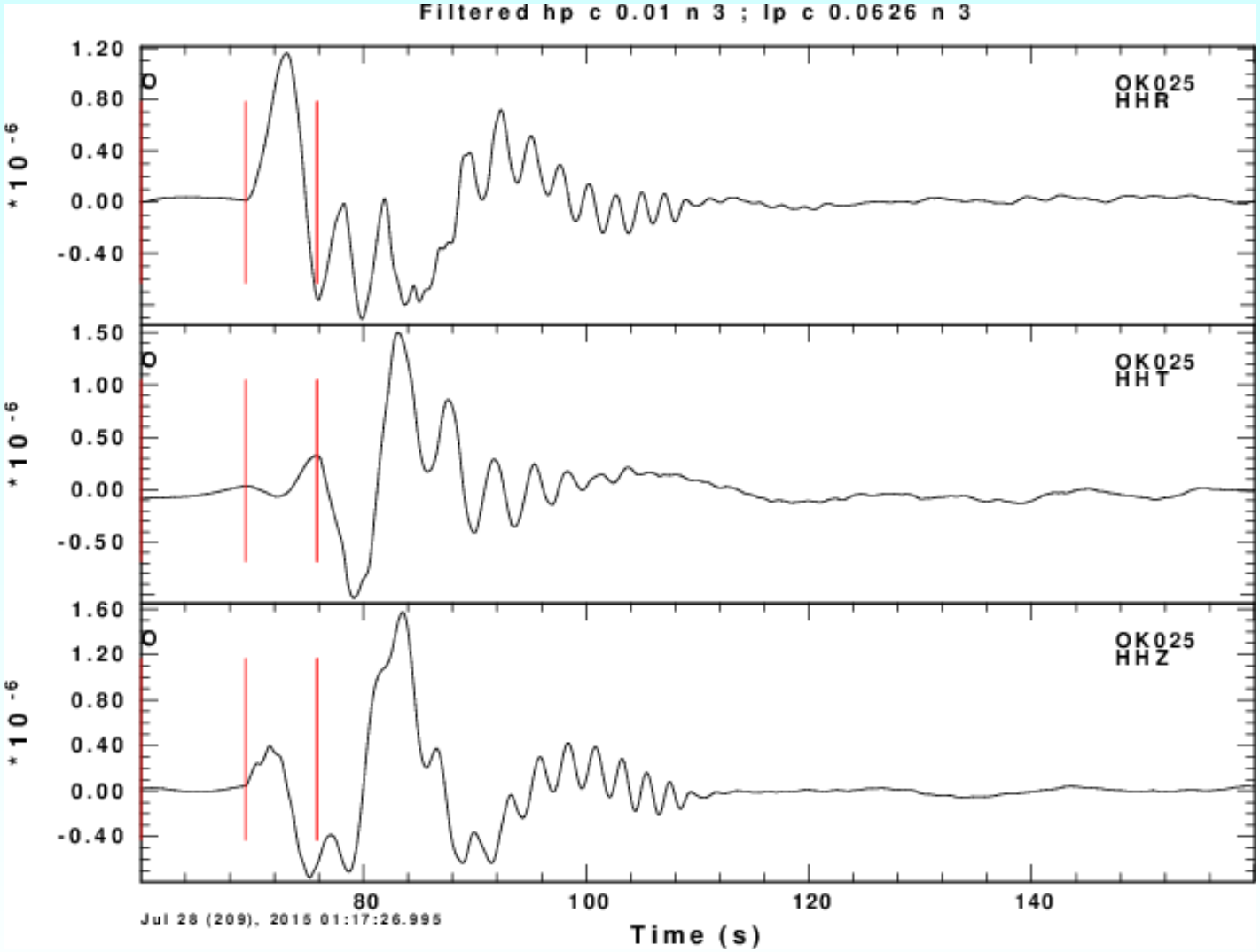

ground velocity m/s
OK025
HHR
OK025
HHT
OK025
HHZ
*10 -4
4.00
2.00
0.00
-2.00
3.00
1.00
-1.00
-3.00
80
100
120
140
Jul 28 (209), 2015 01:17:26.995
Time (s)


Filtered hp c 0.01 n 3 ; lp c 1.0 n 3
OK025
HHR
OK025
HHT
OK025
HHZ
1.20
0.60
0.00
-0.60
-1.20
*10 -4
1.00
0.50
0.00
-0.50
*10 -4
6.00
3.00
0.00
-3.00
-6.00
*10 -5
80
100
120
140
Time (s)
Jul 28 (209), 2015 01:17:26.995


Filtered hp c 0.01 n 3 ; lp c 0.5 n 3
OK025
HHR
OK025
HHT
OK025
HHZ
*10 -5
4.00
2.00
0.00
-2.00
-4.00
3.00
1.00
-1.00
-3.00
6.00
80
100
120
140
Jul 28 (209), 2015 01:17:26.995
Time (s)


Filtered hp c 0.01 n 3 ; lp c 0.25 n 3
OK025
HHR
OK025
HHT
OK025
HHZ
1.80
0.90
0.00
-0.90
-1.80
1.40
0.70
-0.70
-1.40
*10 -5
80
100
120
140
Time (s)
Jul 28 (209), 2015 01:17:26.995

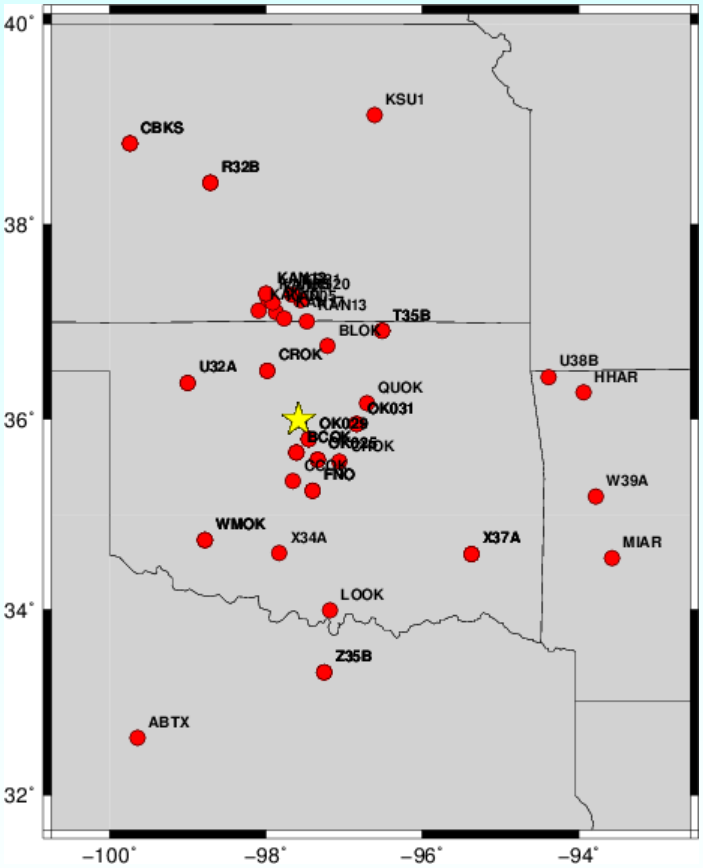

Filtered hp c 0.01 n 3 ; lp c 0.125 n 3
OK025
HHR
OK025
HHT
OK025
HHZ
*10 -6
4.00
2.00
0.00
-2.00
-4.00
6.00
80
100
120
140
Jul 28 (209), 2015 01:17:26.995
Time (s)


Filtered hp c 0.01 n 3 ; lp c 0.0626 n 3
OK025
HHR
OK025
HHT
OK025
HHZ
*10 -6
1.20
0.80
0.40
0.00
-0.40
1.50
1.00
0.50
0.00
-0.50
1.60
1.20
0.80
0.40
0.00
-0.40
80
100
120
140
Jul 28 (209), 2015 01:17:26.995
Time (s)

These slides showed the effect of difference frequency bands. Since we normally use a simple 1-D velocity model, we cannot model the high frequency squiggles.

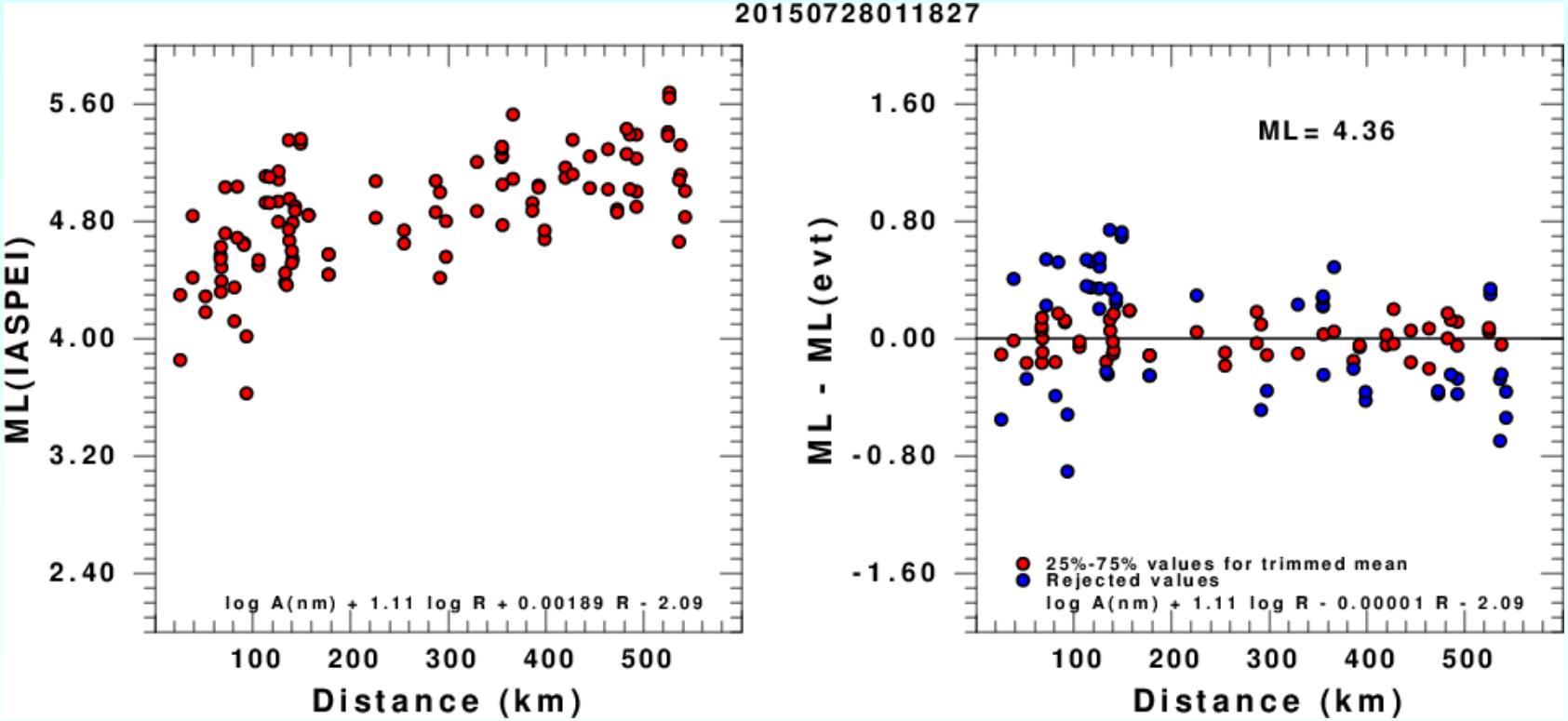
This set of seismograms shows the effect of shallow sedimentary structure. Thus these recordings have information on the structure.

2015/07/28 01:18 Oklahoma



- Most active region in NA for 2014-2015.
- May be related to disposal of waste water from oil/gas production
- Note the number of broadband instruments

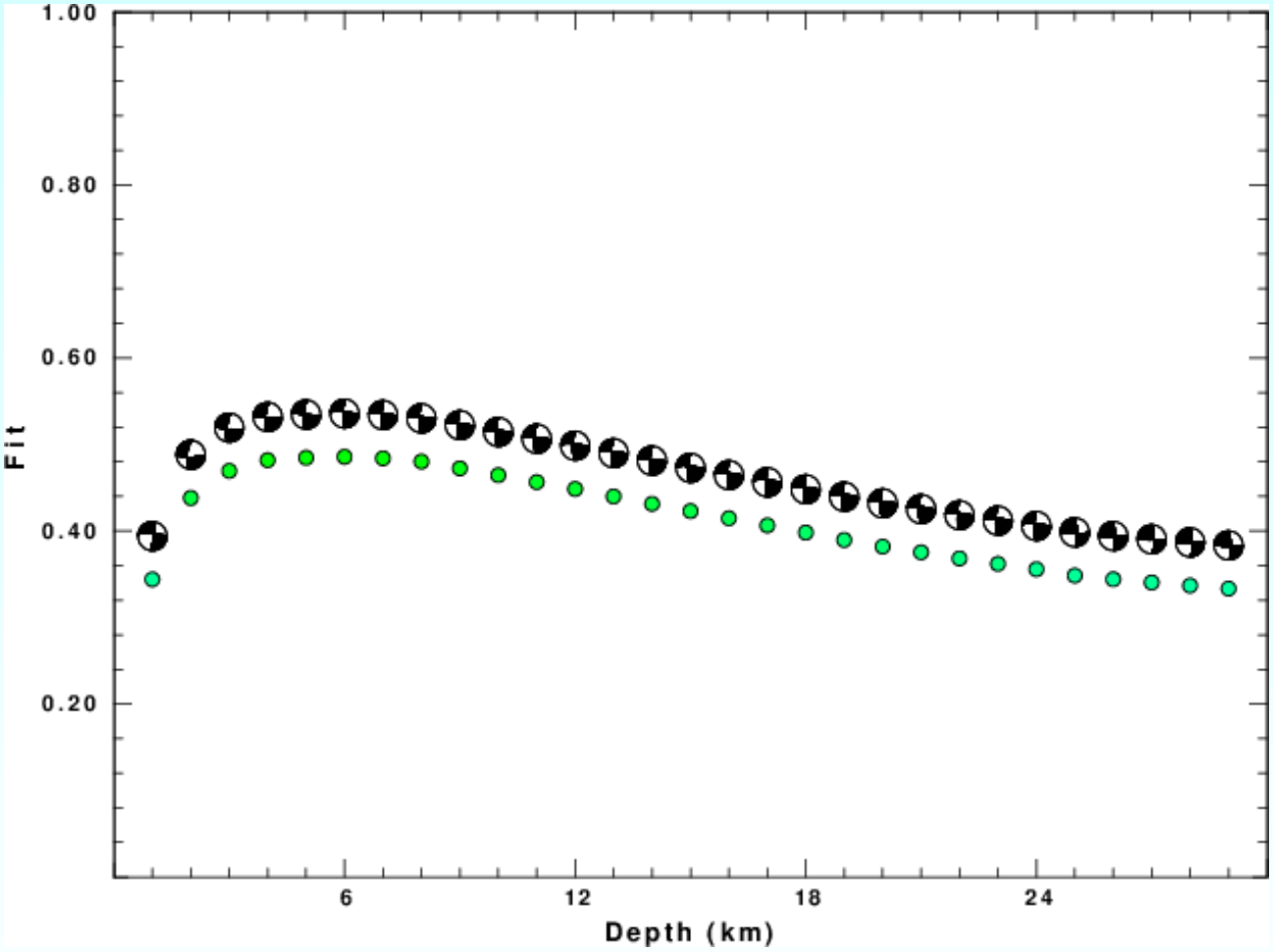
ML


20150728011827
ML(IASPEI)
5.60
4.80
4.00
3.20
2.40
log A(nm) + 1.11 log R + 0.00189 R - 2.09
100
200
300
400
500
Distance (km)
ML - ML(evt)
1.60
0.80
0.00
-0.80
-1.60
ML = 4.36
25%-75% values for trimmed mean
Rejected values
log A(nm) + 1.11 log R - 0.00001 R - 2.09
100
200
300
400
500
Distance (km)

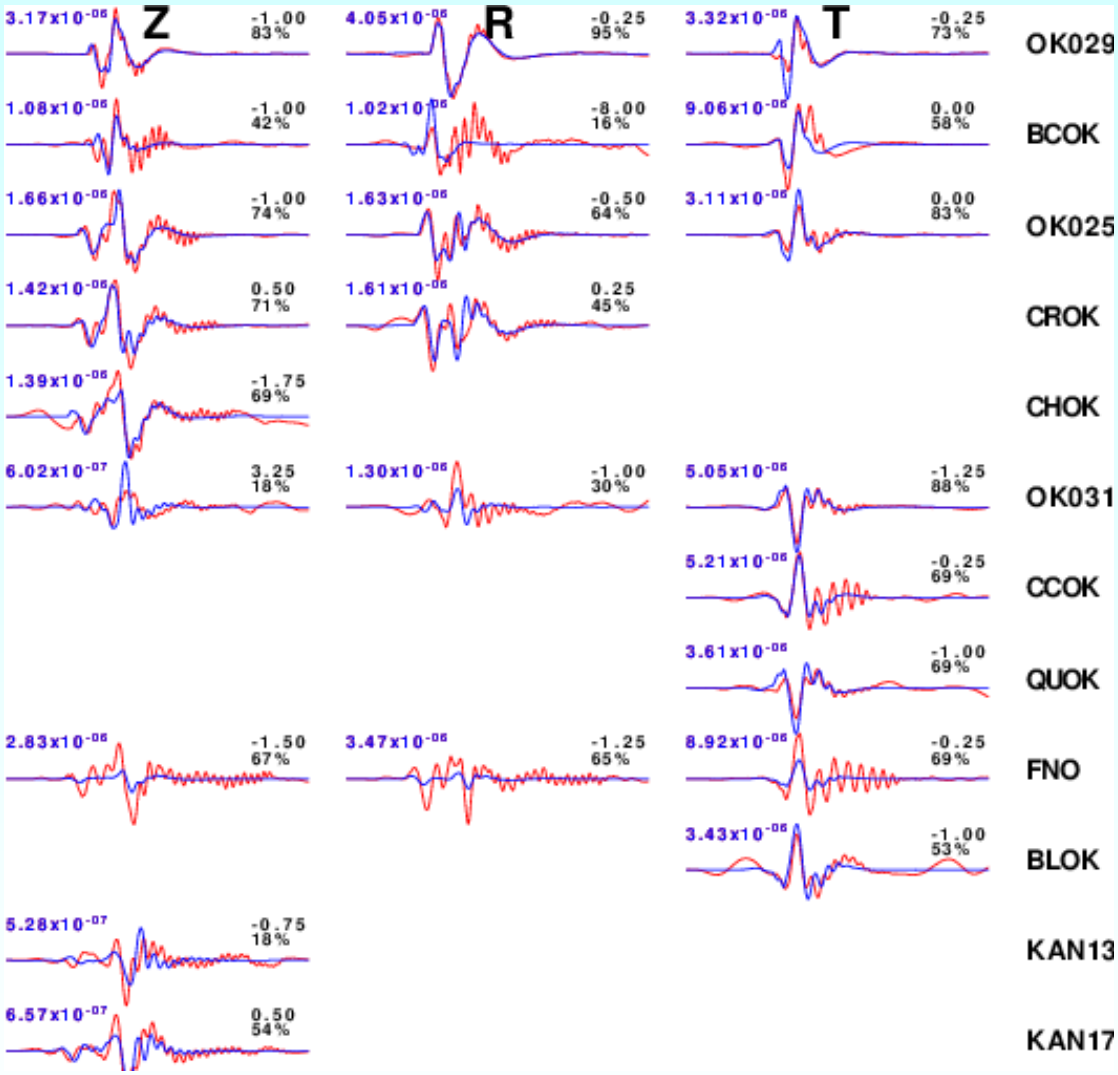
Processing

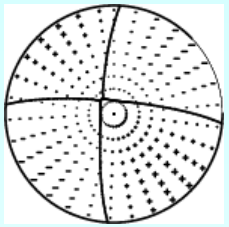
```
cut o DIST/3.3 -30 o DIST/3.3 +70
rtr
taper w 0.1
hp c 0.03 n 3
lp c 0.07 n 3
```

Grid search



Waveform fit



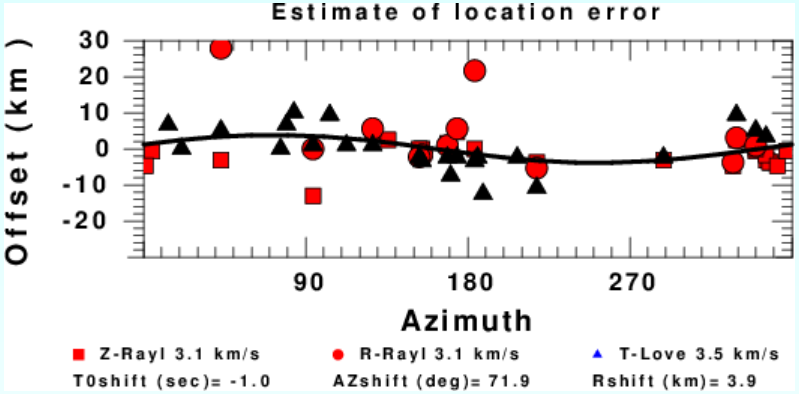


Is the location good?

The waveform search permits a time shift between the observed and predicted waveforms because

- **The Green's functions are not computed at the exact distance,**
- **The velocity model used for Green's functions is not perfect,**
- **The initial location is not perfect**

So use the time shift as a function of azimuth to check on the initial location. If the fit is bad, relocate the earthquake

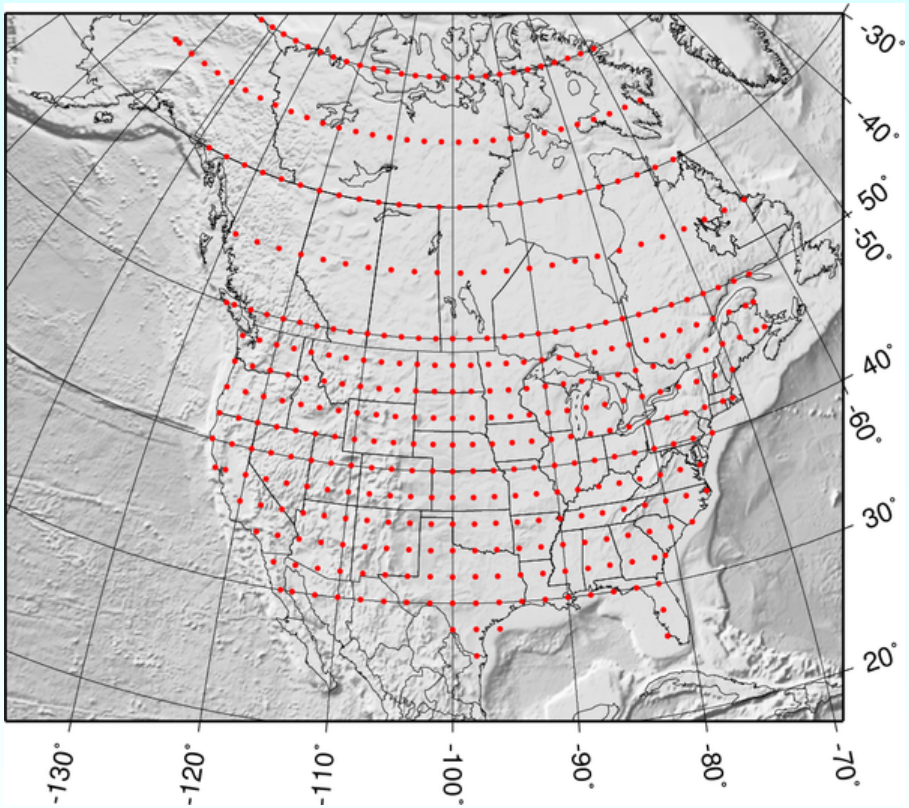

Estimate of location error
Offset (km)
30
20
10
0
-10
-20
90
180
270
Azimuth
Z-Rayl 3.1 km/s
R-Rayl 3.1 km/s
T-Love 3.5 km/s
T0shift (sec)= -1.0
AZshift (deg)= 71.9
Rshift (km)= 3.9

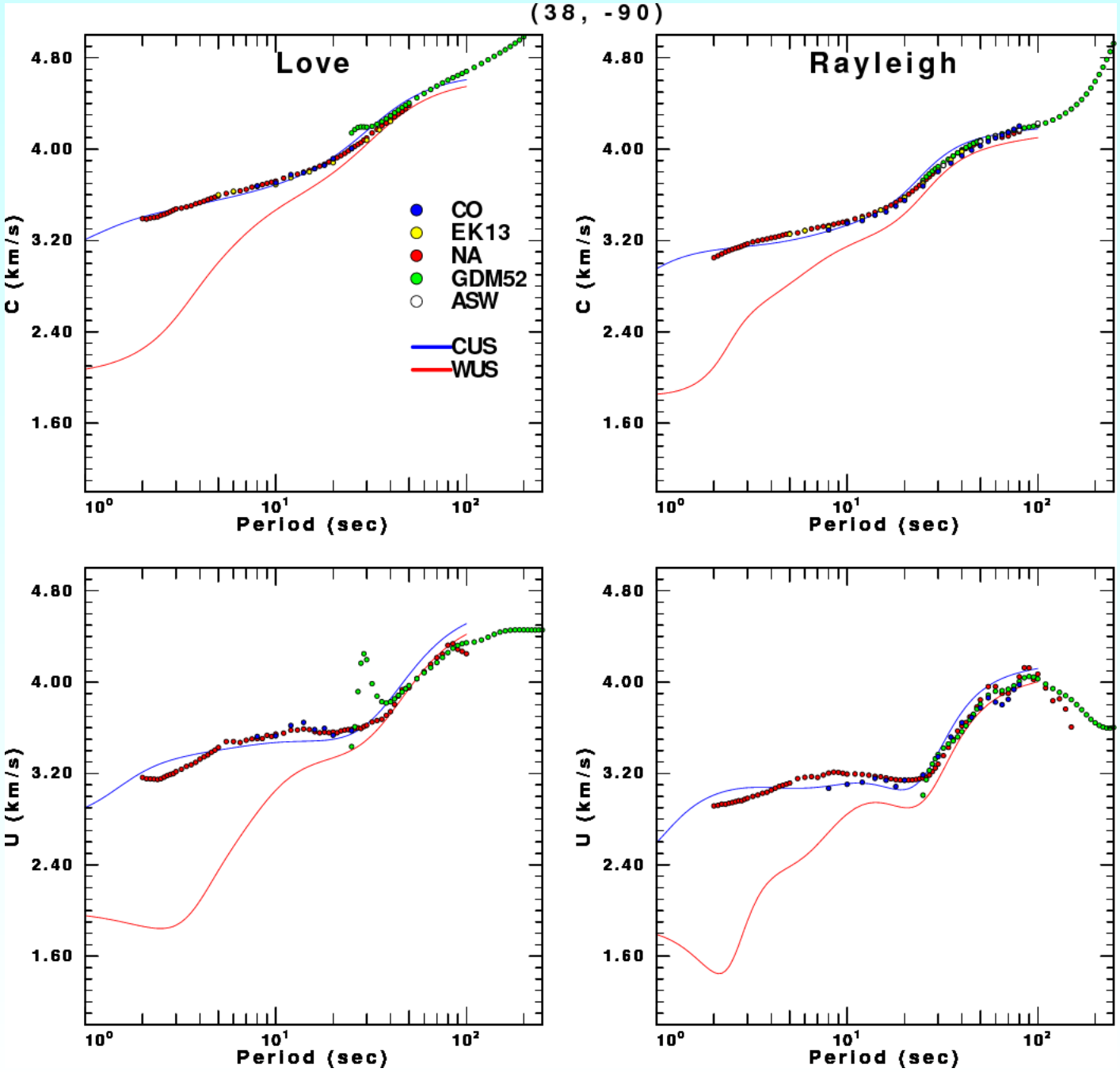
Velocity Models

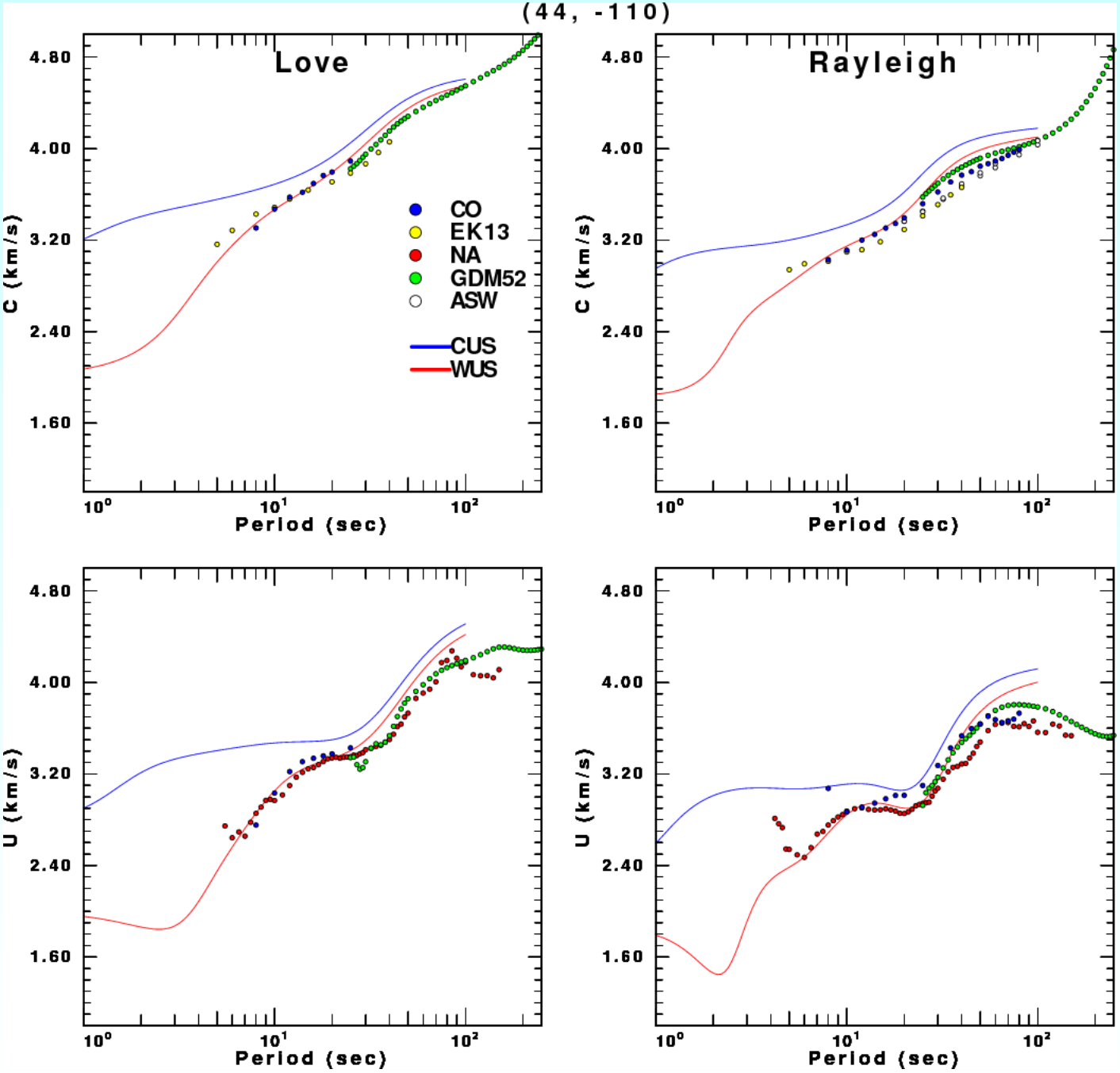
- What is required of the velocity model?
  - The model must be able to predict the waveform shape in the frequency band used
  - Since waveforms are simpler at lower frequencies, a simpler model can be used

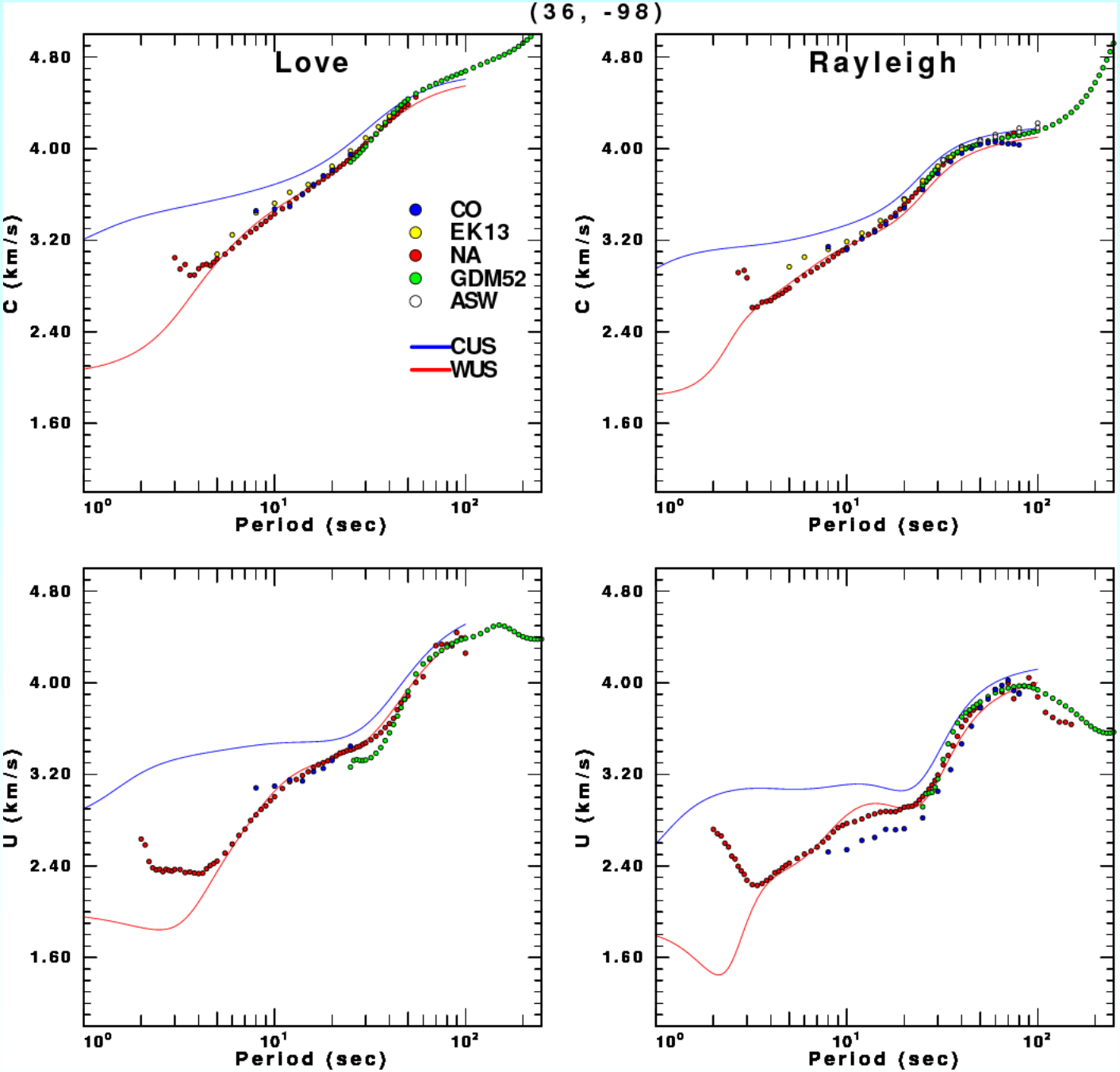
Model Selection

- For North America I have Green's functions computed for two velocity models
  - CUS – for the continental craton
  - WUS – for areas with a thick sedimentary rock section
- For North America I have group and phase velocity tomography results from
  - Earthquake
  - Ambient noise data sets


-30°
-40°
-50°
-60°
20°
30°
40°
50°
-70°
-80°
-90°
-100°
-110°
-120°
-130°


(38, -90)
Love
Rayleigh
C (km/s)
U (km/s)
4.80
4.00
3.20
2.40
1.60
10^0
10^1
10^2
Period (sec)
CO
EK13
NA
GDM52
ASW
CUS
WUS


(44, -110)
Love
Rayleigh
C (km/s)
U (km/s)
Period (sec)
4.80
4.00
3.20
2.40
1.60
10^0
10^1
10^2
CO
EK13
NA
GDM52
ASW
CUS
WUS


(36, -98)
Love
Rayleigh
C (km/s)
U (km/s)
Period (sec)
4.80
4.00
3.20
2.40
1.60
10^0
10^1
10^2
CO
EK13
NA
GDM52
ASW
CUS
WUS

Earthquake data can be use to obtain the group velocity between the source and the station.

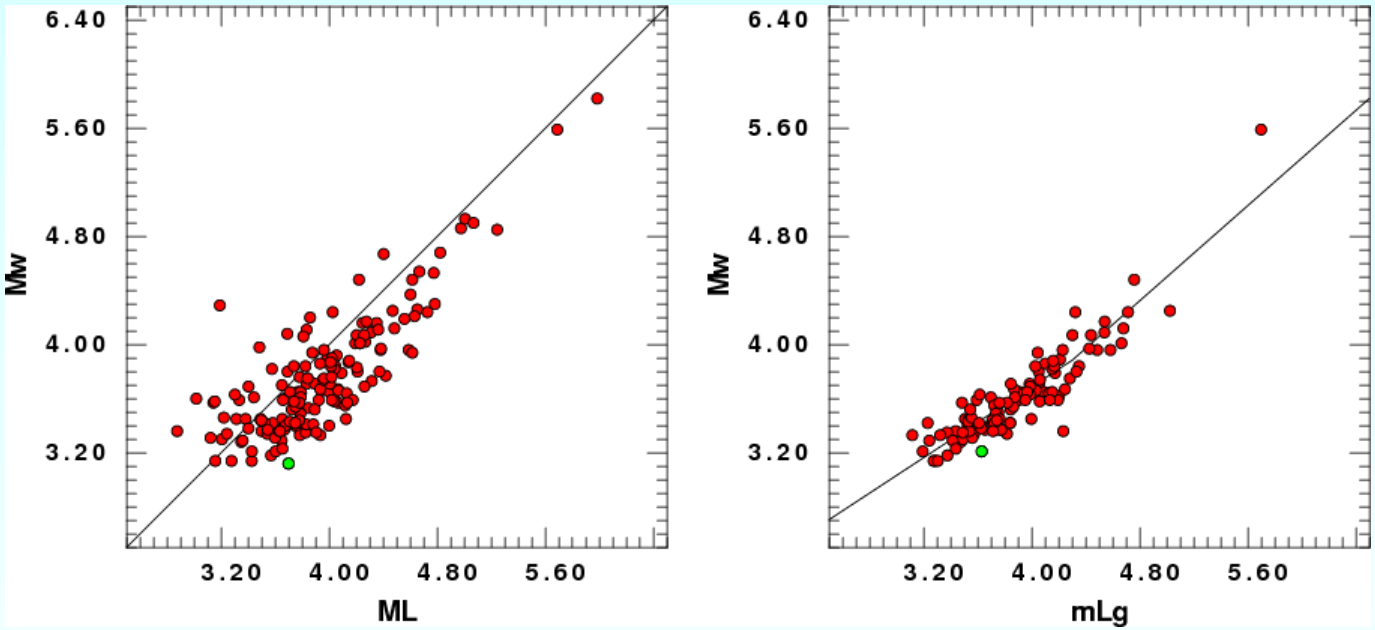
Calibrated continuous archived data can be used to use ambient noise techniques to obtain phave and group velocity between station pairs.

Both of these require CALIBRATED, HIGH QUALITY data from data centers.

Final Thoughts

Using waveform amplitudes required well calibrated, functioning instruments. This is more difficult that locating earthquakes using arrival time measurements.

Be patient, it can be done.


6.40
5.60
4.80
4.00
3.20
Mw
3.20
4.00
4.80
5.60
ML
6.40
5.60
4.80
4.00
3.20
Mw
3.20
4.00
4.80
5.60
mLg