# The Earthquake Process in Oklahoma*

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## Abstract

The use of modern broadband moment tensor inversion has led to a catalog of over 180 earthquakes, with moment magnitudes > 3.0, of which 140 have been determined since the beginning of 2014. With the exception of a few normal faulting events near Kansas, the vast majority involve strike-slip faulting with compressive stress axes oriented NE-SW to E-W. The alignment of one of the nodal planes with the linear patterns of epicenters determined using multiple event relocations (McNamara et al., 2015) permits the specification of the fault plane for many areas. The other significant feature is that the majority of events are shallow as evidenced by the moment tensor depths and the excitation of short period fundamental mode surface waves. Since the depths depend on the local velocity model used, a region specific crustal model was developed that accounts for surface-wave Love/Rayleigh phase/group velocity dispersion in the 2–100 period range, teleseismic P-wave receiver functions and short-period transverse component recordings at distance to 50 km. Finally the high frequency recordings from about 1000 components and 1400 earthquakes are examined to constrain ground motion prediction models in the 0.25 – 20 Hz band used in seismic hazard analysis.

## Reference Cited

McNamara, D.E., J.L. Rubenstein, E. Myers, G. Smoczyk, H.M. Benz, R.A. Williams, G. Hayes, D. Wilson, R. Herrmann, N.D. McMahon, R.C. Aster, E. Bergman, A. Holland, and P. Earle, 2015, Efforts to Monitor and Characterize the Recent Increasing Seismicity in Central Oklahoma: The Leading Edge, v. 34/6, p. 628-639. doi: 10.1190/tle34060628.1

# The Earthquake Process in Oklahoma

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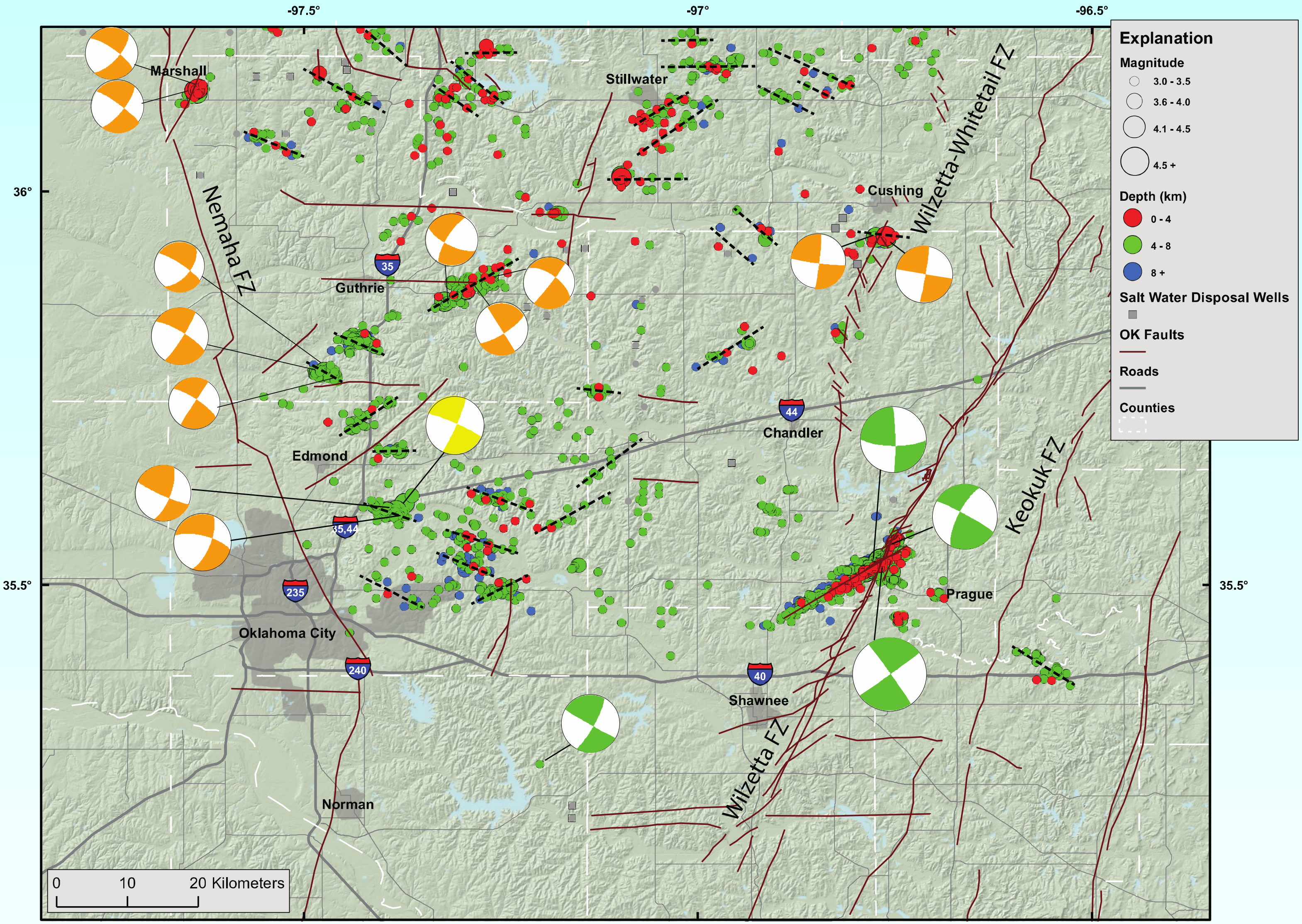
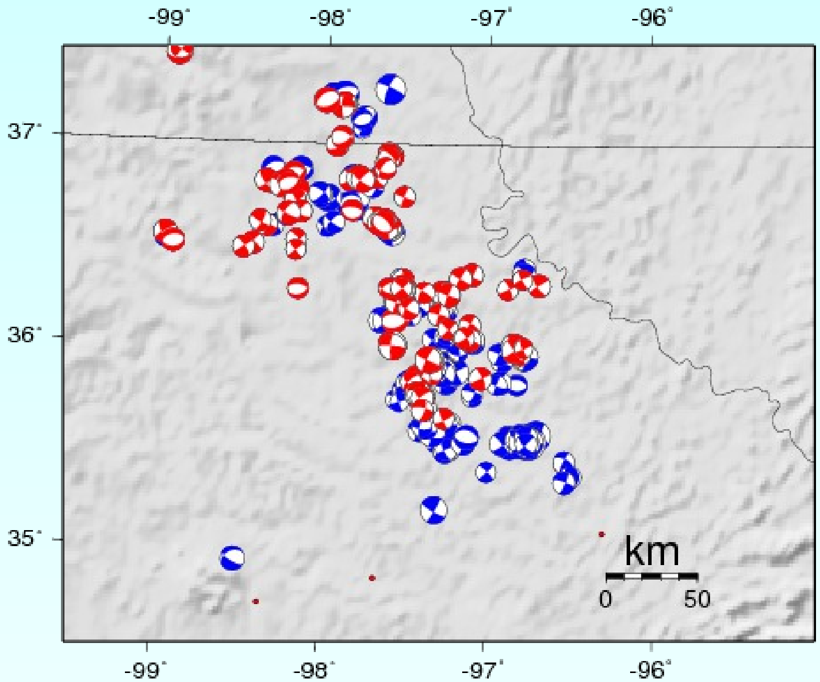
# SLU Contribution

- **Determine Regional Moment Tensors (RMT's) for M > 3 earthquake, using**
  - **Broadband (0.03 – 0.10 Hz ) ground velocity to estimate**
    - **Strike, dip and rake of nodal planes**
    - **Source depth**
    - **Moment magnitude**

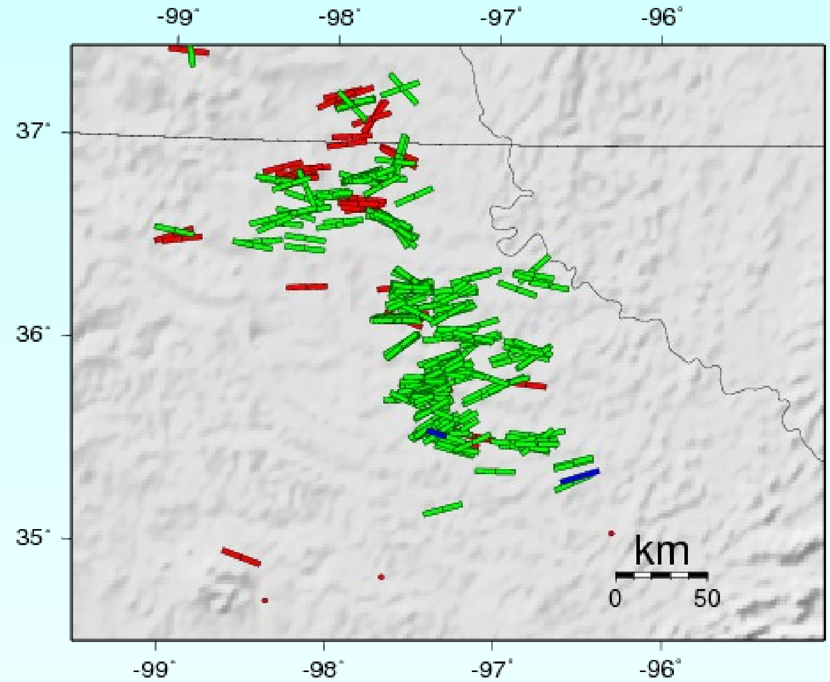



McNamara, D. E.., J. L. Rubenstein, E. Myers, G. Smoczyk, H. M. Benz, R. A. Williams. G. Hayes. D. Wilson, R. Herrmann, N. D. McMahon, R. C. Aster, E. Bergman, A. Holland and P. Earle (2015). Efforts to monitor and characterize the recent increasing seismicity in central Oklahoma, the Leading Edge 34, 6, 628-639. doi: 10.1190/tle34060628.1

# Regional Moment Tensors




Focal mechanisms
2010-2015 Mw > 3
(red 2015)

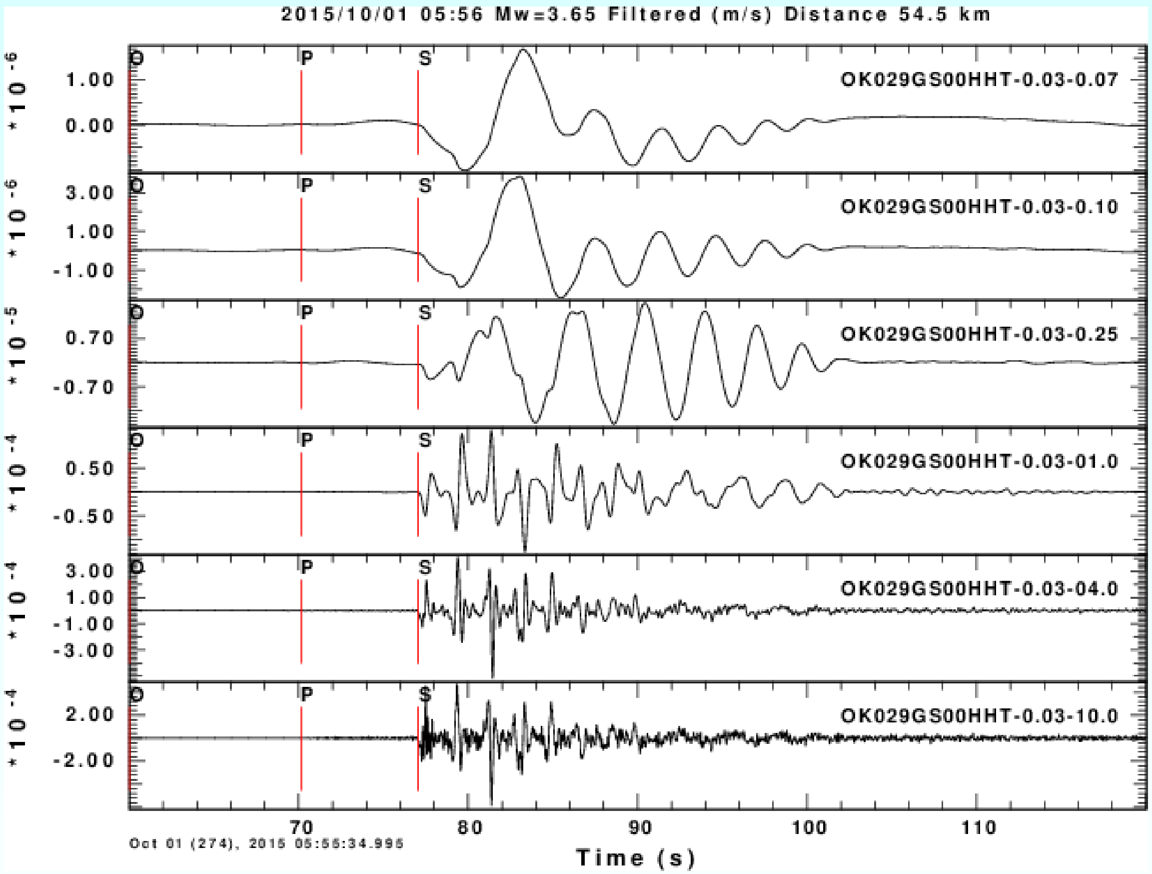



Direction of maximum compressive stress
Red: normal faulting
Green: strike-slip

# Earthquake 2015/10/01 05:56

- Collect Data
- Select frequency band (0.03 – 0.07 Hz)
  - Avoid short period surface waves
  - Avoid long period noise
- QC seismograms
- Select velocity model for Green functions
- Grid search over strike, dip, rake and depth
- Mw=3.65, mLg=3.88, ML=4.10

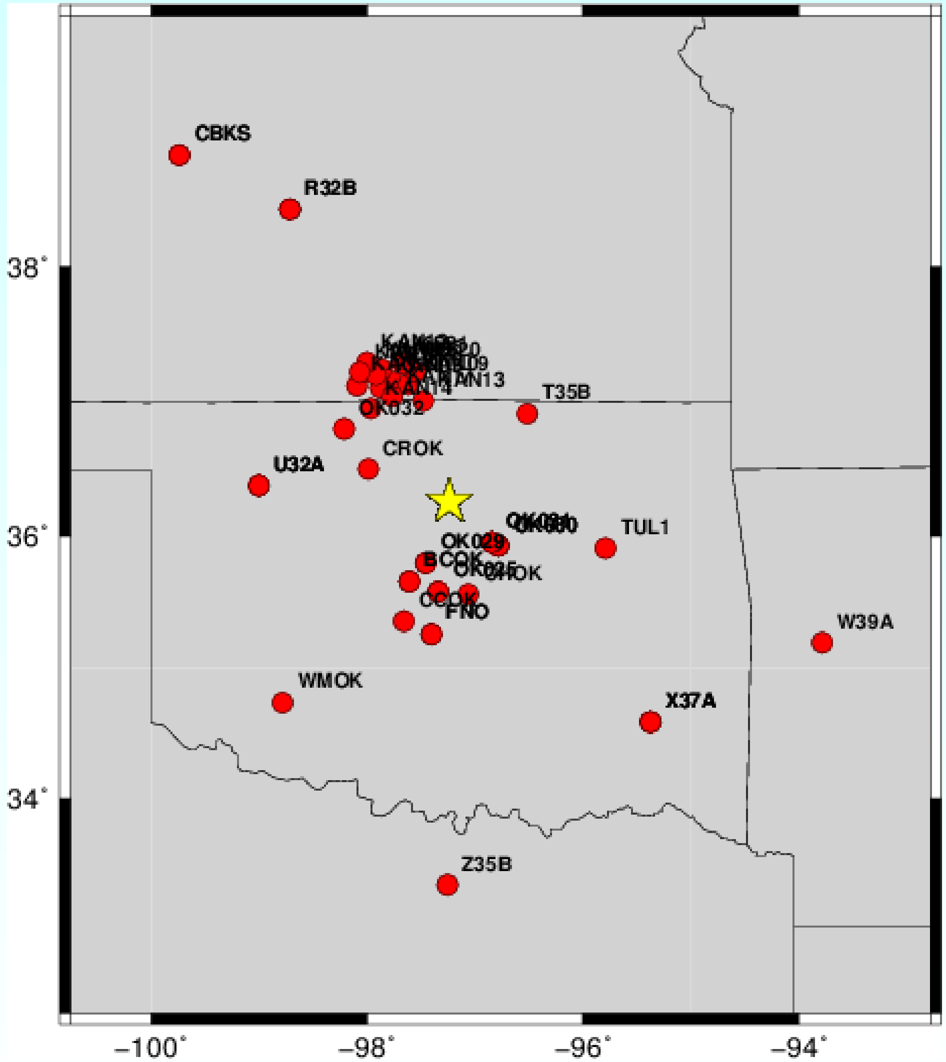
# Select frequency band for which record is "simple"



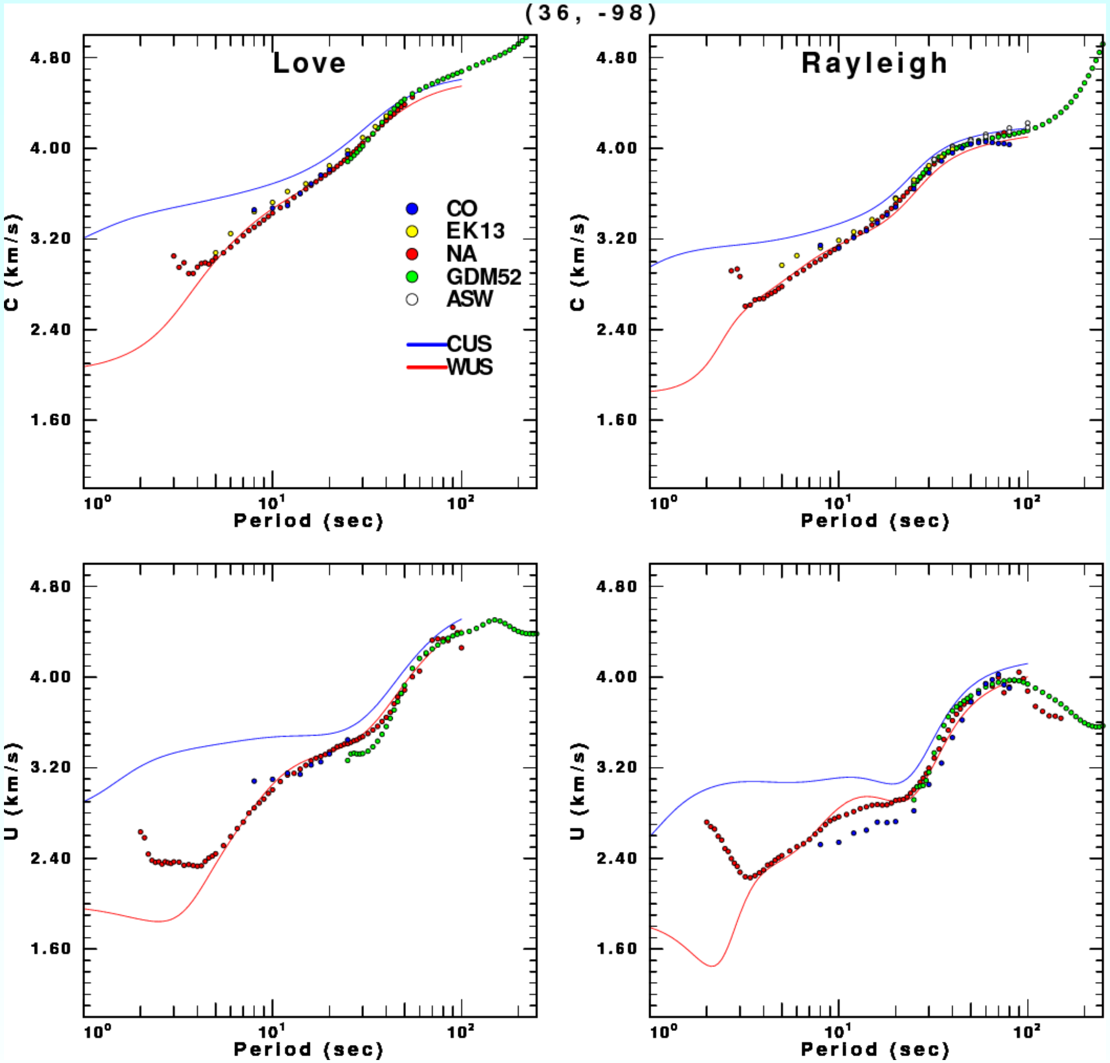

Higher frequencies require more detailed structure, even 3-D

Note spikey record at higher frequencies

# Broadband stations used for RMT



# Select velocity model

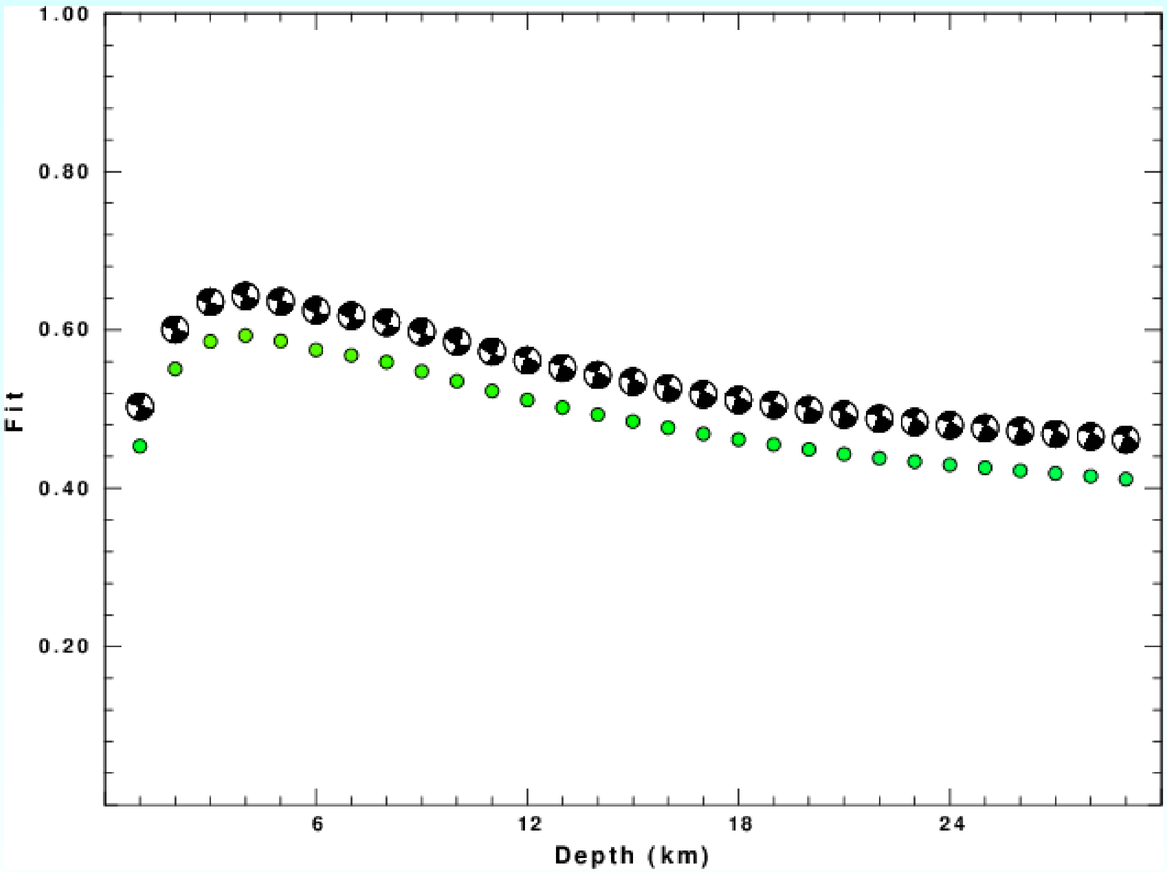



Waveform in 0.03 – 0.07 Hz band is fundamental mode surface wave

Use tomography results for source area to select model

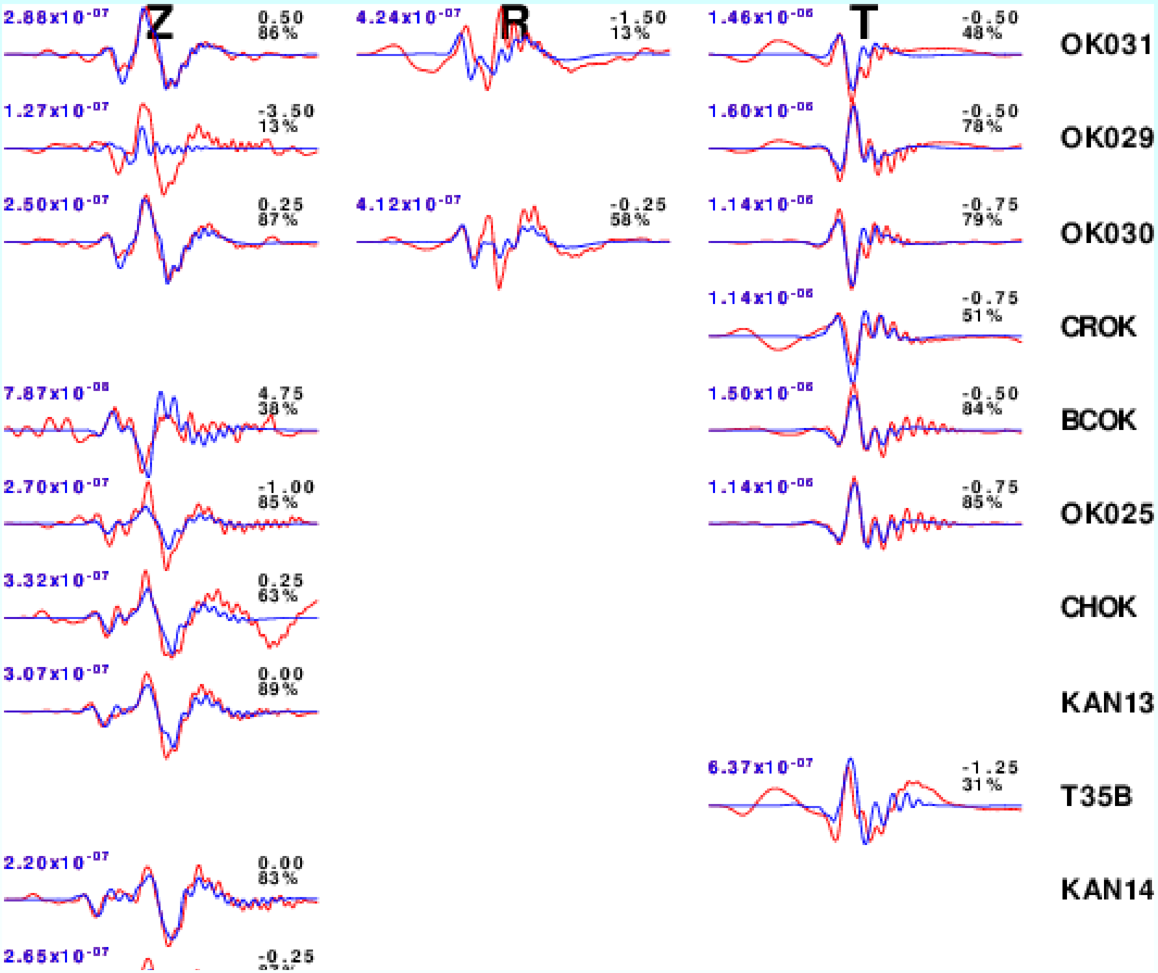
Blue: CUS
Red : WUS

# Grid search results for best solution as a function of depth




Solution is strike-slip at depth of 4 km

# Waveform fit for best solution




Filtered ground velocity (m/s)

# Questions

Validity of the generic model used for source inversion

Validity of source parameters, especially moment magnitude and source depth, based on that model

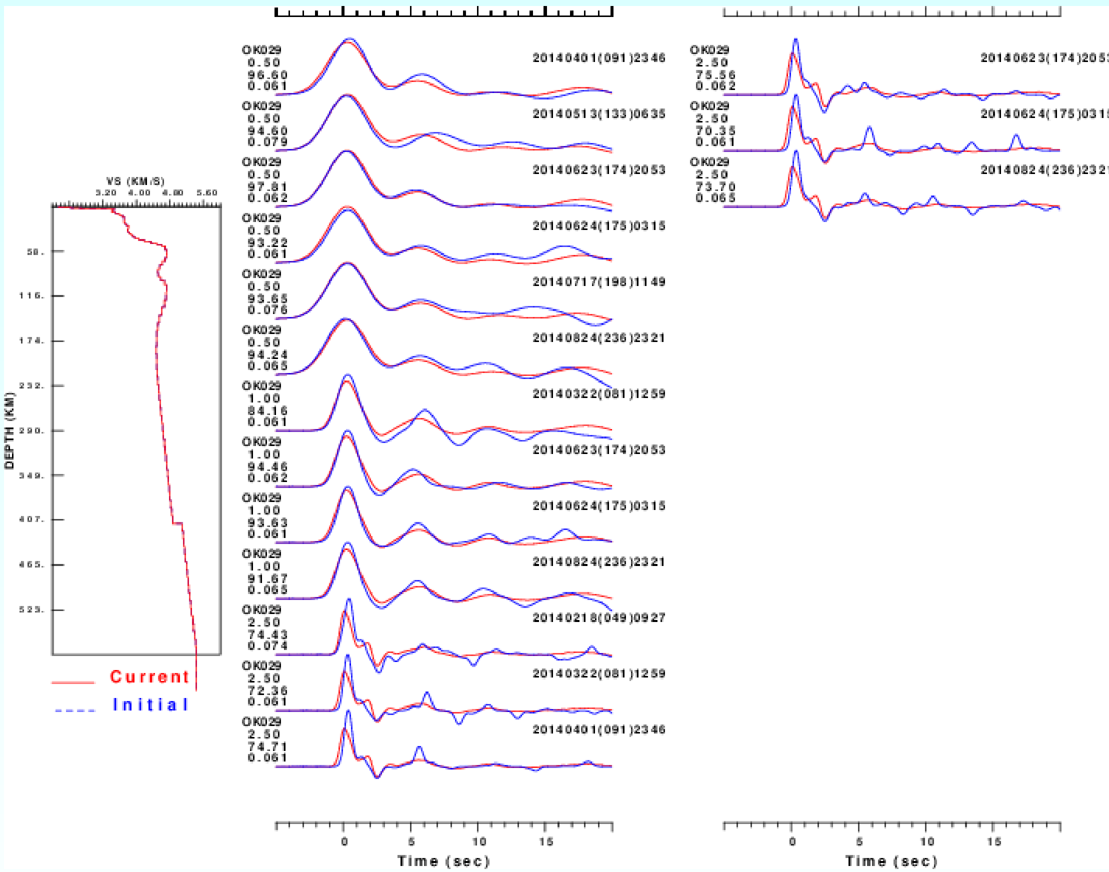
# Approach

- Develop a local velocity model based surface wave dispersion and teleseismic P-wave receiver functions
  - For dispersion analyze ambient noise to get dispersion in 2 – 50 second period range
  - Perform regional surface Love/Rayleigh phase/group velocity tomography
- Test with independent data set

# Joint Inversion

- Iterative linearized least squares inversion of dispersion and receiver functions
  - Weight phase velocities 2X
  - Use GSOK029 (35.79N 97.45W)
  - Force a discontinuity at 3 km (depth to basement)
  - Start with modified Global AK135 to ensure deeper structure agrees with global seismology (no assumptions about crust)

# Receiver function fit




P-wave receiver function is a filter that converts vertical trace to radial. It is affected by the structure beneath the seismograph and not by the source



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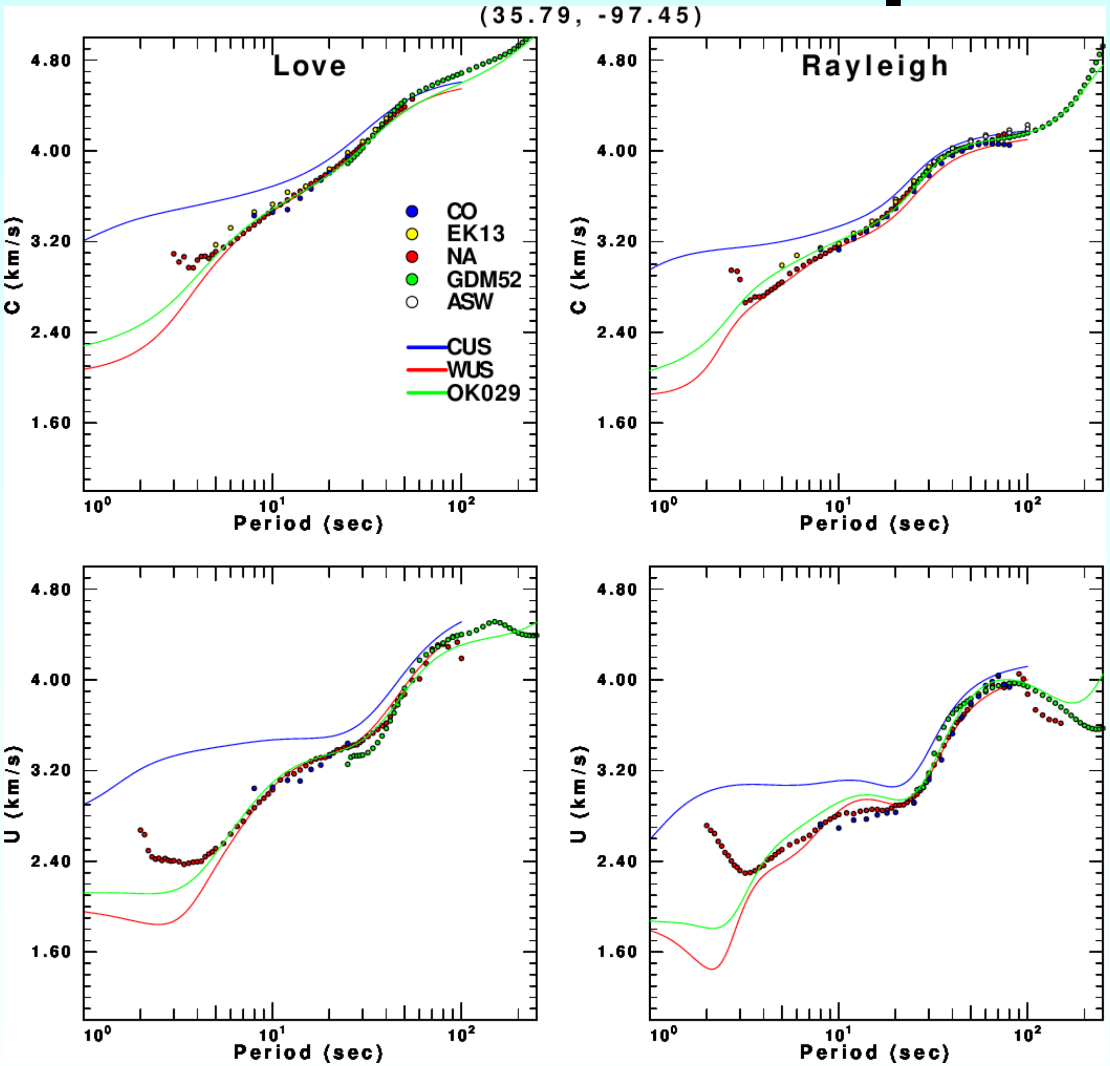
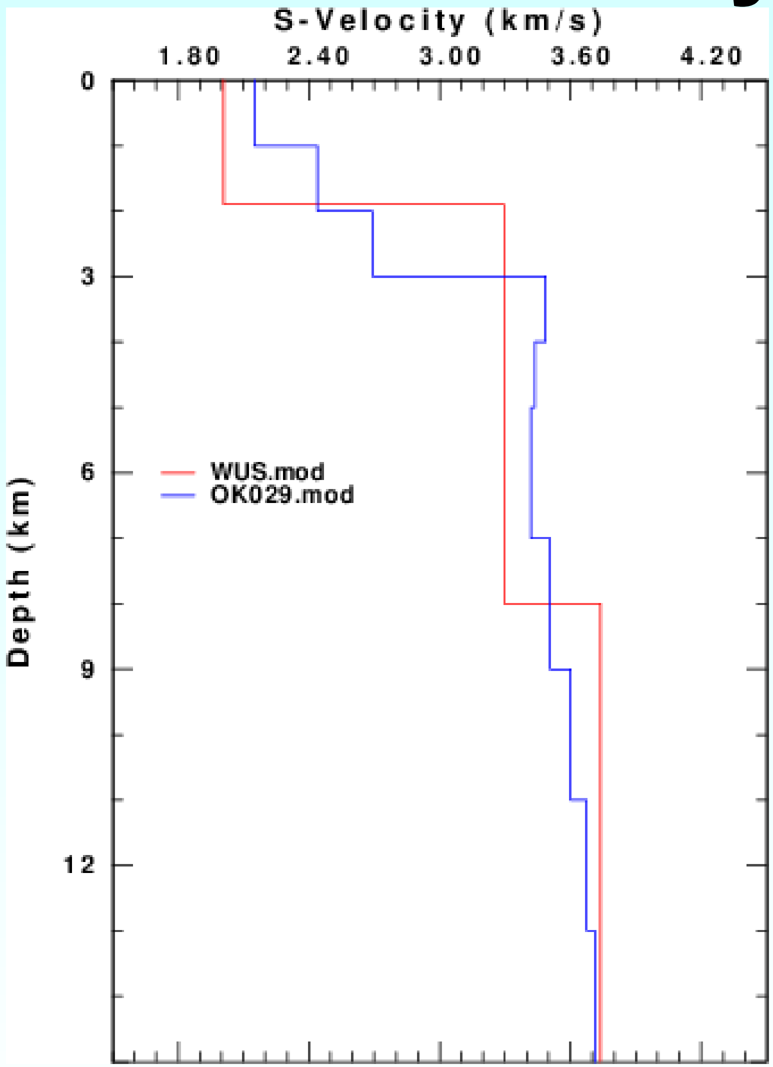
# Fit to dispersion



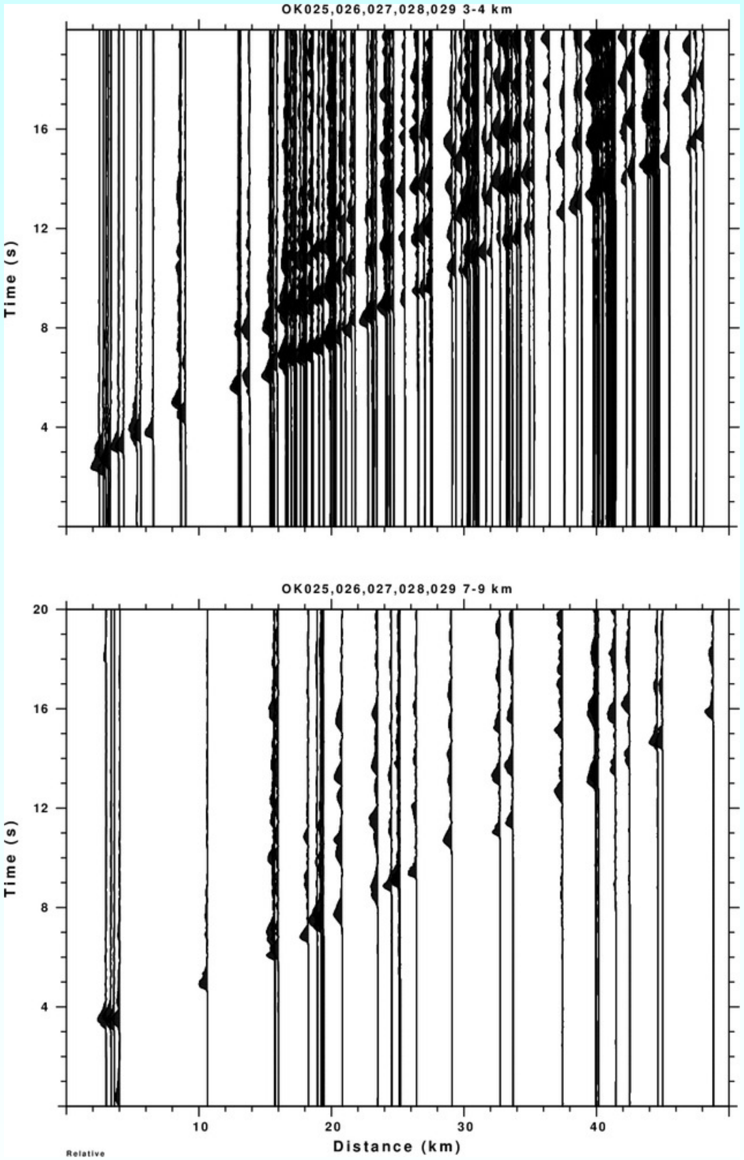

OK029 model fits dispersion as well as WUS model for periods > 3 sec

# Comparison of velocity models



# TEST – model spikes on OK02? stations

- Use McNamara et al relocations to set origin time
- Group by RMT depths (3-4 km) and (7-9 km)
- Filter 0.5 – 2.0 Hz
- Plot envelope to focus on times and not effects of radiation pattern




Record section for GSOK02? Stations

Filtered 0.5 – 2 Hz

Envelopes

Most RMT depths are 3-4 km deep, some are 7-9 km

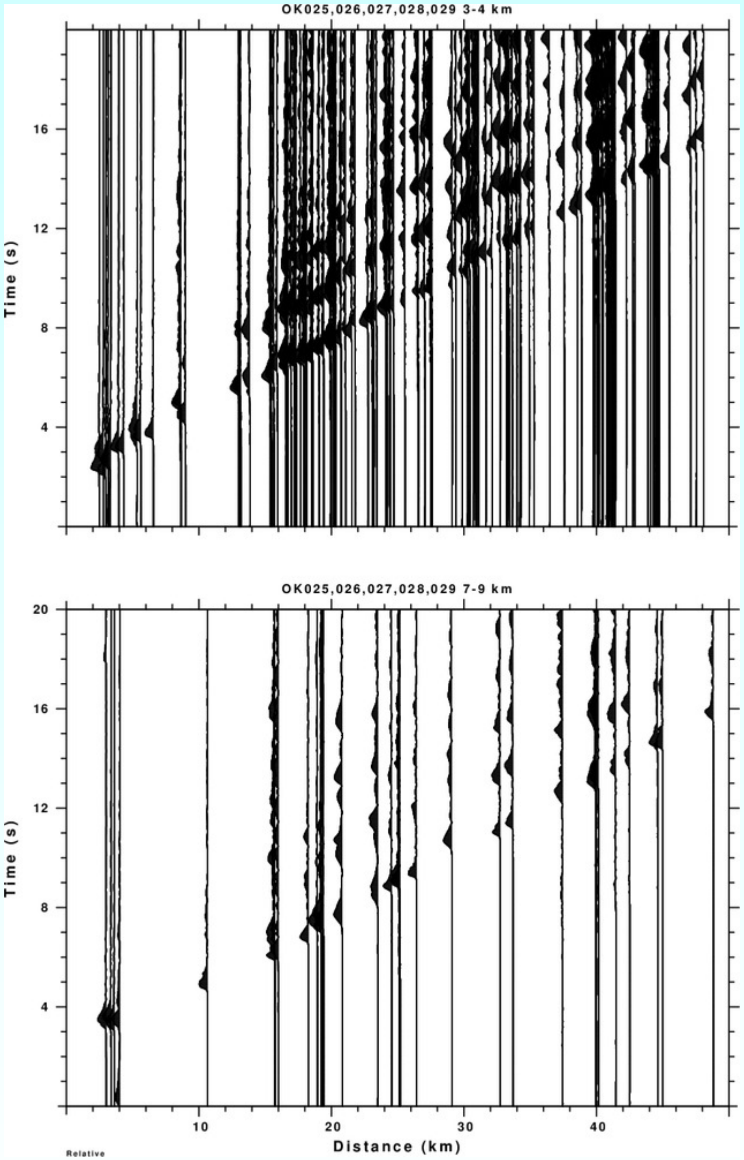
Note that pattern for deeper depths does not build up as rapidly

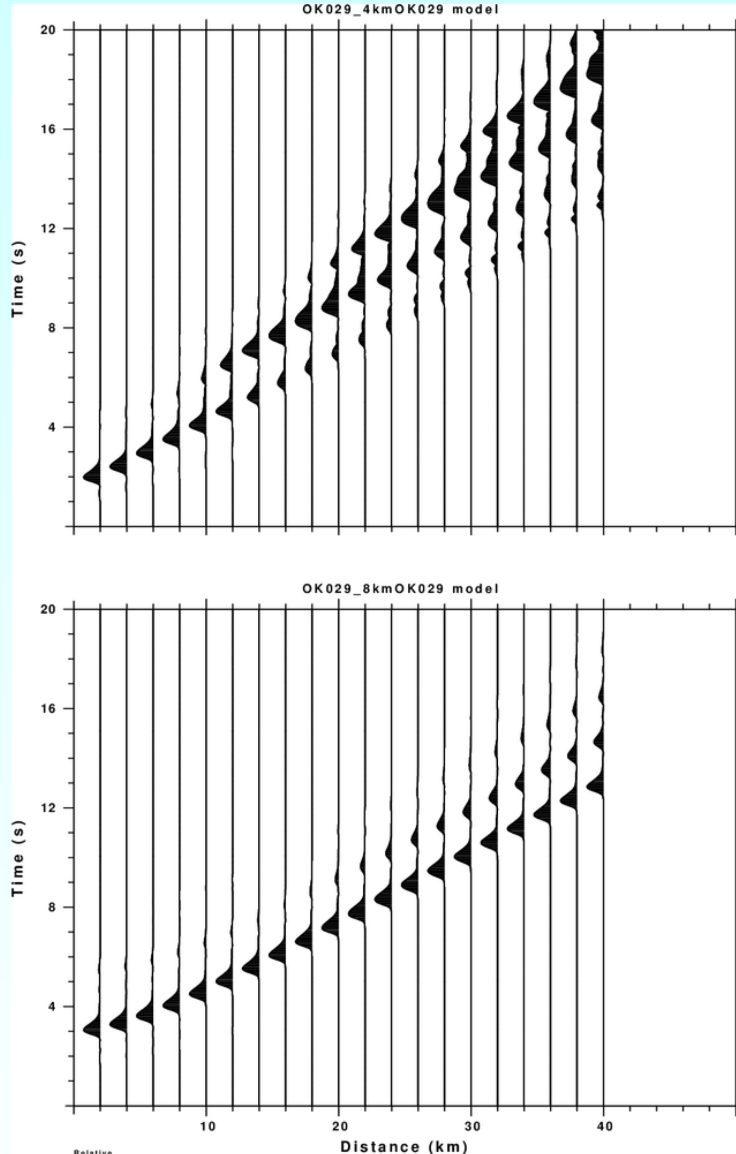
# Rays

Grazing rays are almost super-critical in the layer and thus have large amplitude.

The pattern expands with distance.

- **Model using OK029 model to make transverse component for strike-slip source**
- **Filter and present synthetics in the same way**


OK025,026,027,028,029 3-4 km
OK025,026,027,028,029 7-9 km
Time (s)
Distance (km)
Relative

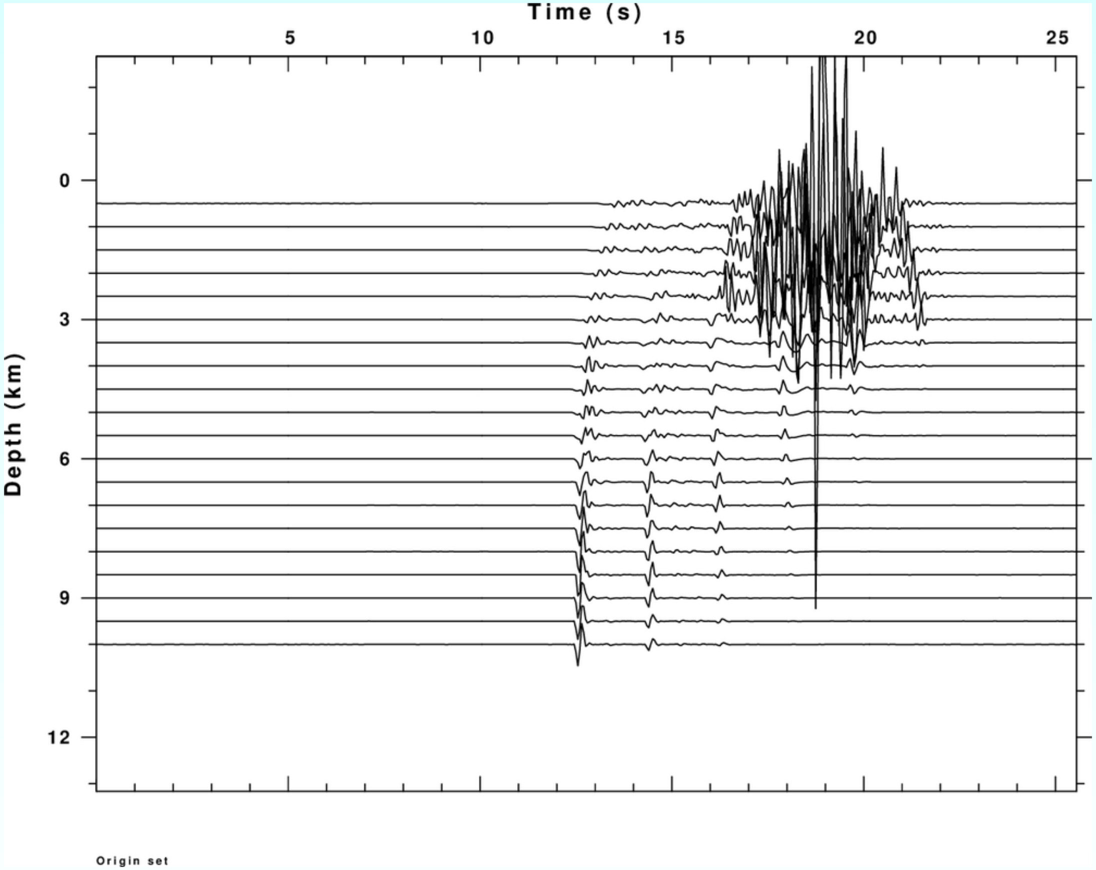

OK029_4kmOK029 model
OK029_8kmOK029 model
Time (s)
Distance (km)
Relative

Fits are good with respect to timing

Pattern shows depth sensitivity to pattern

Can the earthquakes be shallower?

- Make a depth profile for epicentral distance of 40 km




True amplitude section at 40 km epicentral distance shows that surface wave dominates for shallow depths

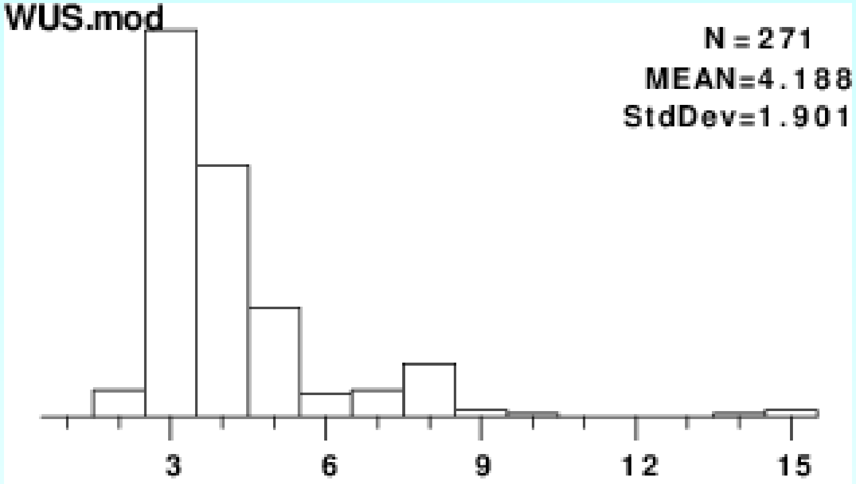
Not observed

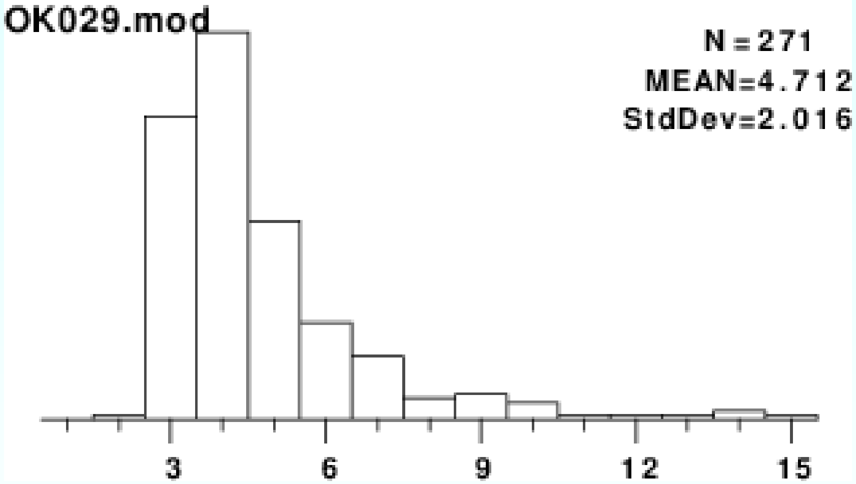
Thus depths are in basement



# Comparison of Source Parameters of WUS and OK029 models

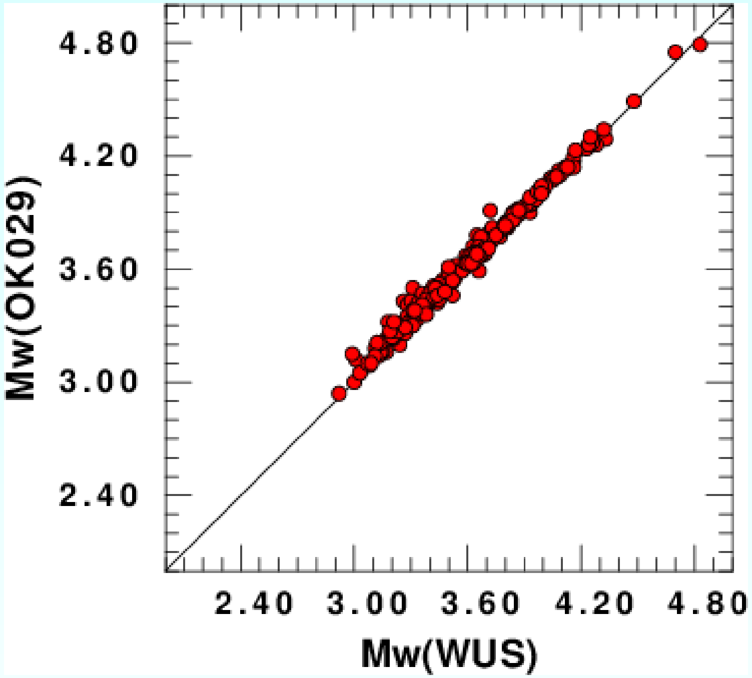
- Does the new locally based crustal model give different depths, Mw's or fits?
- For OK029 model, compute Green's functions (12 hours)
- Reprocess 271 RMT's from 2010 – 2015 ( 8 hours)

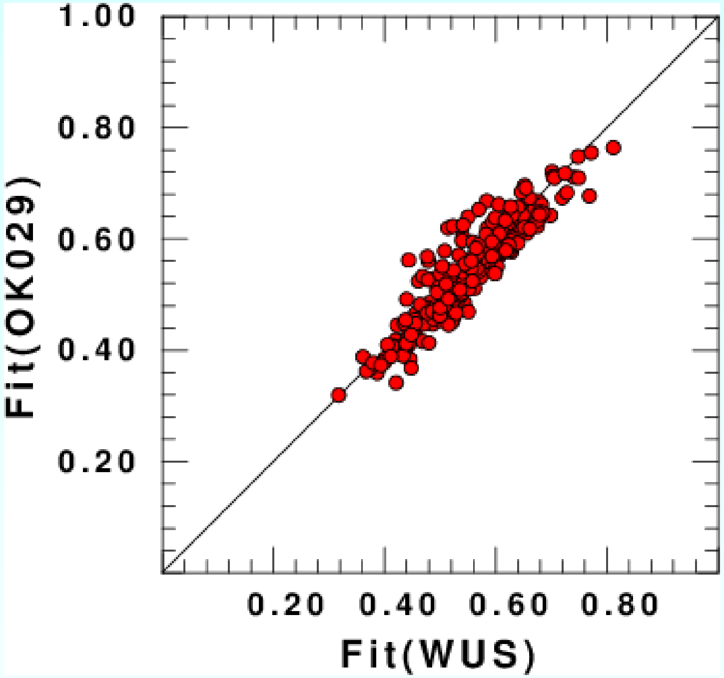



Regional model gives depths in basement

# Comparison of Mw and Fits for the two models

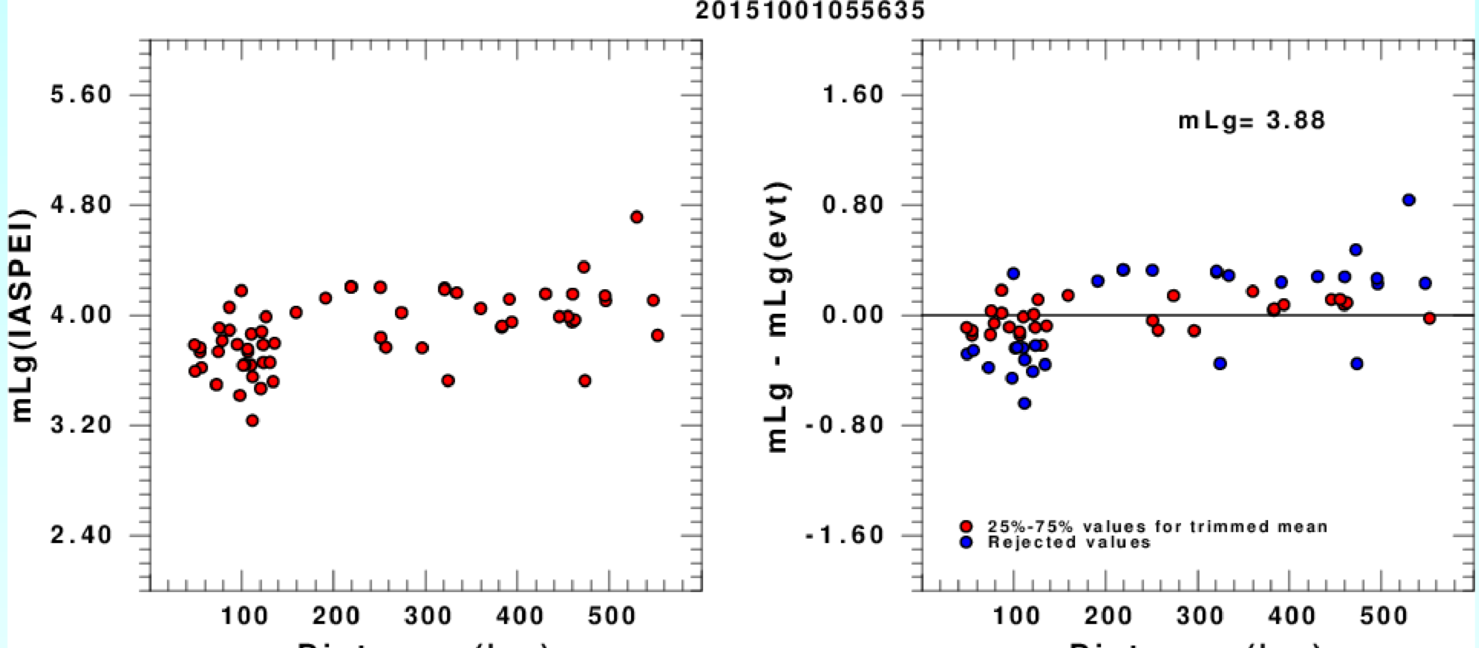


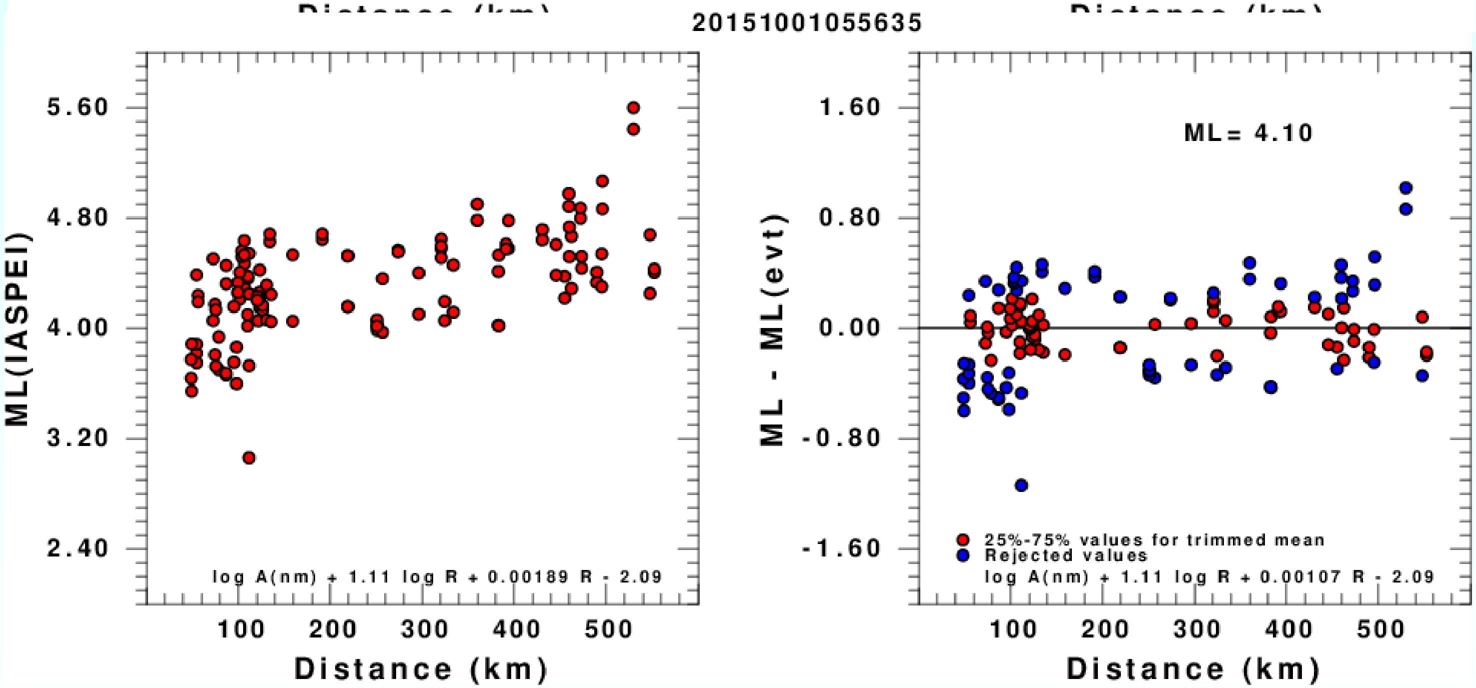




WUS model results are acceptable

# High frequency ground motions

- Requires QC of instrument responses
- Preliminary study of regional mLg and ML magnitudes indicates that ground motion is similar to other locations in Central and Eastern US


20151001055635
mLg(IASPEI)
5.60
4.80
4.00
3.20
2.40
100
200
300
400
500
mLg - mLg(evt)
mLg= 3.88
1.60
0.80
0.00
-0.80
-1.60
25%-75% values for trimmed mean
Rejected values


20151001055635
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)
ML= 4.10
1.60
0.80
0.00
-0.80
-1.60
25%-75% values for trimmed mean
Rejected values
log A(nm) + 1.11 log R + 0.00107 R - 2.09
Distance (km)

# Summary

- The development and application of an Oklahoma specific crustal model gives confidence to previous regional moment tensor inversion results
  - The depths, moment magnitudes and mechanisms are valid
- The new velocity model should be used for detailed relocations of earthquakes

# Thanks

**This documentation of the earthquakes is only possible because of the quality data provided by various broadband seismic networks operated by OGS, IRIS, USGS (Menlo Park), USGS (ASL)**

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