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

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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
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.
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
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
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
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)