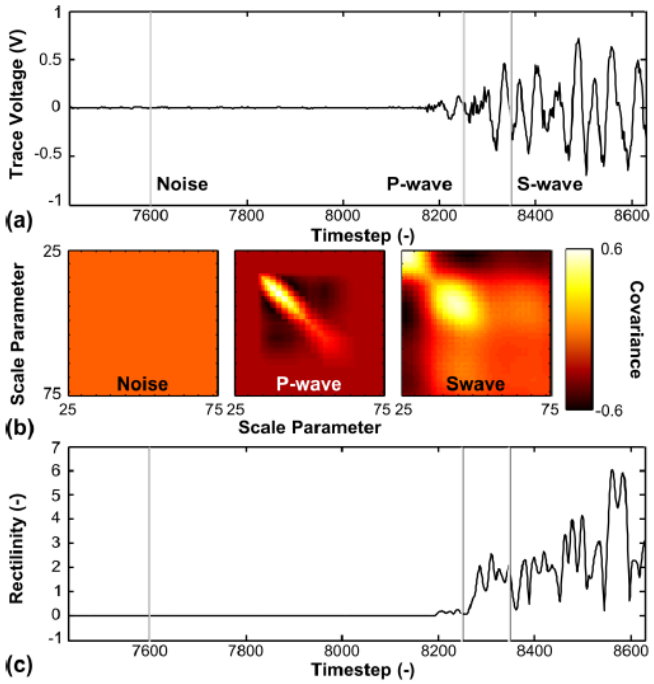
Using wavelet covariance models for simultaneous picking of overlapping P- and S-wave arrival times in noisy single-component seismic data

Theme 1. Fluid-Driven Geomechanics
Challenge 3. Controlling Emergence



Acoustic event from laboratory fracture test with (a) detected signal; (b) covariance matrices in noise interval, P-wave coda and S-wave coda; and de-noised rectilinity values

Scientific Achievement

Developed robust and efficient method for determining arrival times of overlapping P- and S- wave arrivals in noisy seismic signals

Significance and Impact

By automating arrival picking, method can be used for machine learning for discerning CO2 plume tomography and possibly fracture propagation during subsurface injection

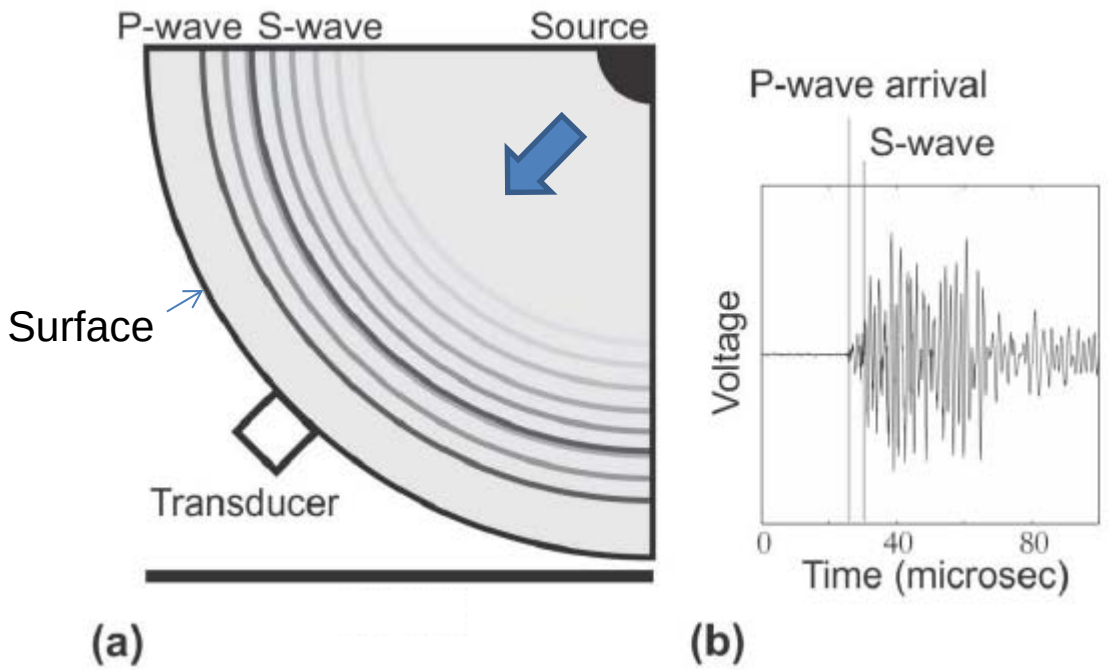
Research Details

- **Use statistics of temporal covariance to discern arrivals in low signal-to-noise waves as are common in near-source micro- and pico-seismicity monitoring, e.g. injection sites**
- **Acoustic emissions during lab fracture test (worst case) used to develop and demonstrate proof-of-concept**

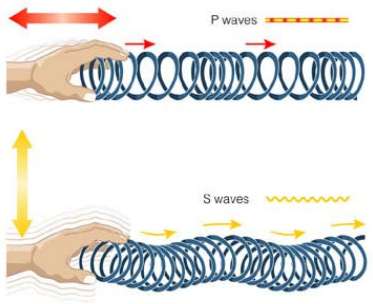
Alex J. Rinehart, Sean A. McKenna, and Thomas A. Dewers, 2016, Using wavelet covariance models for simultaneous picking of overlapping P- and S-wave arrival times in noisy single component data, Seismological Research Letters, v. 87, no. 4, p. 1-9, doi: 10.1785/0220150130

Work was performed at Sandia National Laboratories with help from UT

Common Problems in Seismic Wave Detection and Analysis



(a) a schematic of the elastic waves propagating from source to transducer in an elastic medium; and (b) raw trace (in volts) with P-wave and S-wave arrivals indicated



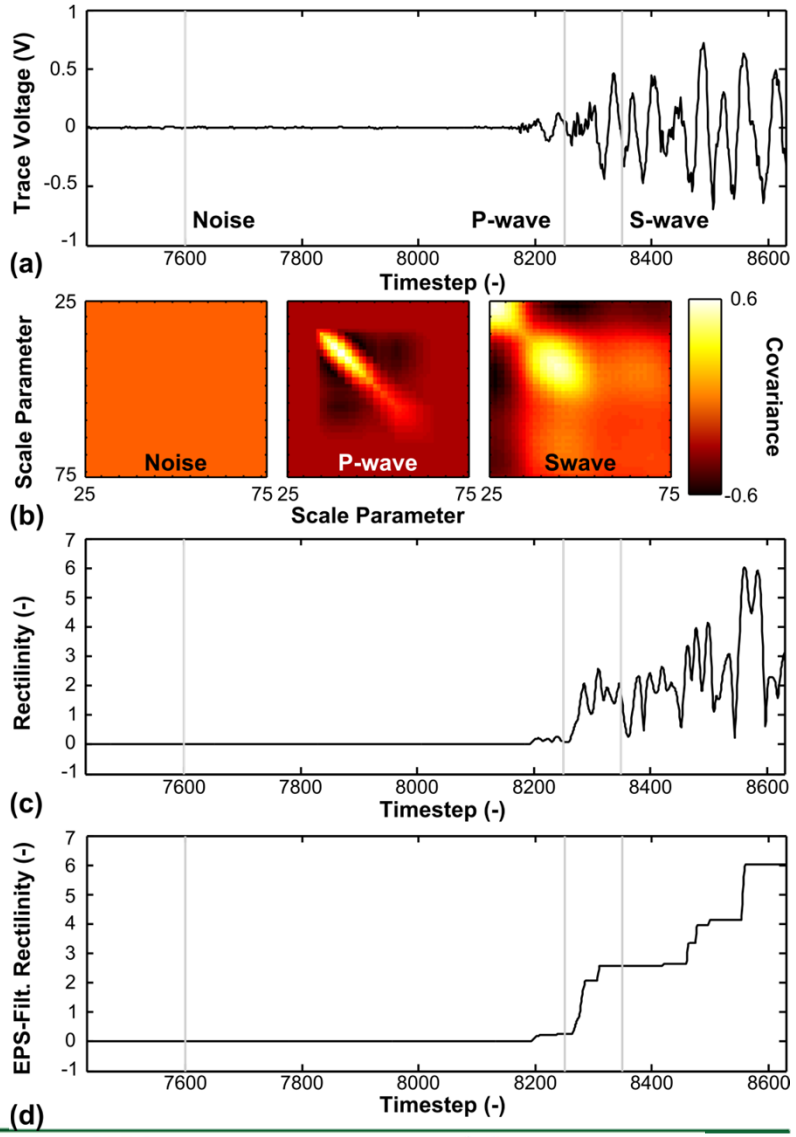
Challenges associated with estimating both P-wave and S-wave arrival times in near-source acoustic signals:

- S-waves (shear) travel more slowly than P-waves (compressional)
- Over large distances there is a clear separation, e.g. for earthquake seismology
- Near source, S-wave signatures are lost in the p-wave “coda” & noise
- Huge amounts of data typical

New Methodology

Upon analysis of multiple continuous wavelet transforms of acoustic events in benchtop testing, it was discovered that the ***wavelet scale covariance*** showed consistent changes at the arrival of P- and S- waves. This suggested the following methodology:

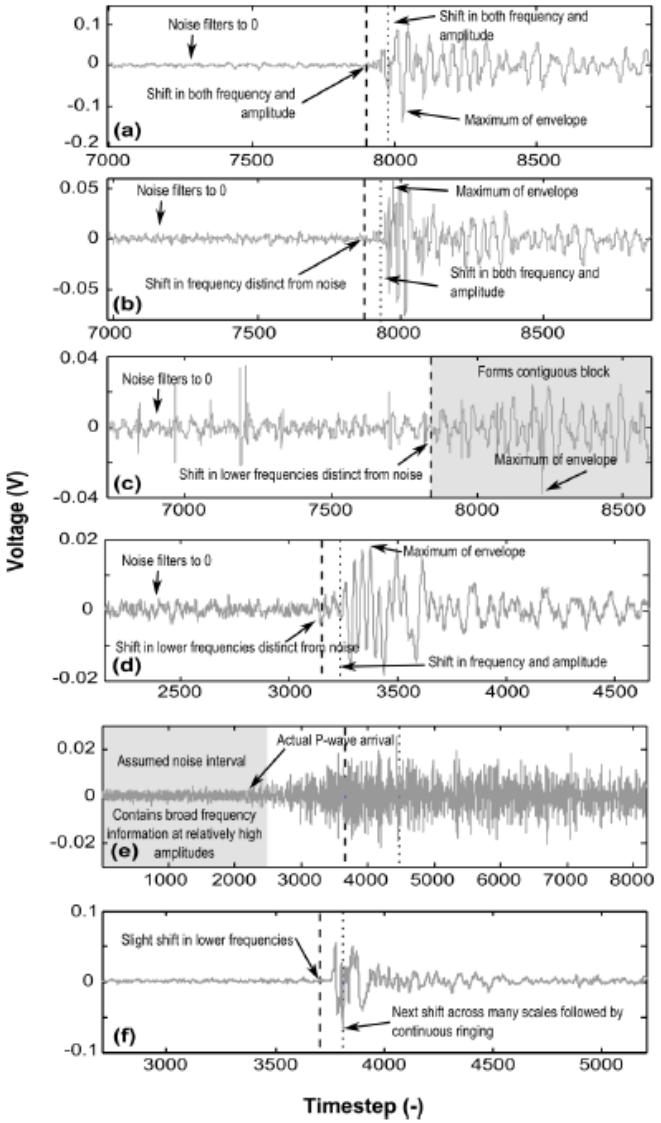
- Combine wavelet-based de-noising with filtered metrics based on the covariance of the continuous wavelet transform (b) of the signal (a)
- An edge-preserving rectilinity function captures the variance and rate of decay of eigenvalues of the covariance matrices (c).
- P- and S-wave arrivals are found sequentially by thresholding (d)



Robustness of the Method: Benchtop Proof of Concept

- High success rate in automated picking for P- and S-waves
- Not so good for low-magnitude “rumbling events” and with high electrical noise
- Low amplitude long term events could be discerned by further thresholding in amplitude

Examples of different event traces with P-wave arrival time (dashed) and S-wave arrival times from fracture toughness tests in aluminum (a-c) and more complicated events from Cranfield caprock failure tests (d-f).



Conclusions and On-Going Work

- The novel parts of our approach are quantifying the covariance of scales of a continuous wavelet transform, then using a filtered non-normalized rectilinity function to have a usable quantification of these changes
- By using the *covariance* rather than the *correlation*, we capture both magnitude and correlation information
- Method is being adapted to near-real time imaging and velocity tomographic reconstructions of localized shear failure and fracture in lab tests
- Method is being applied to cross-borehole tomographic reconstruction of induced fracturing at field site in Socorro, NM (part of a DOE-SubTER “seedling” project)
- With modification, method could be tuned to detect P-to-S conversions at propagating fracture fronts (e.g. associated with injection stimulation or hydrofracturing), long wavelength low-magnitude “tremors” associated with fluid movement in fracture planes, and in near-real-time recognition of precursors to injection-induced seismic events

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