Modeling surface deformation in the New Madrid seismic zone

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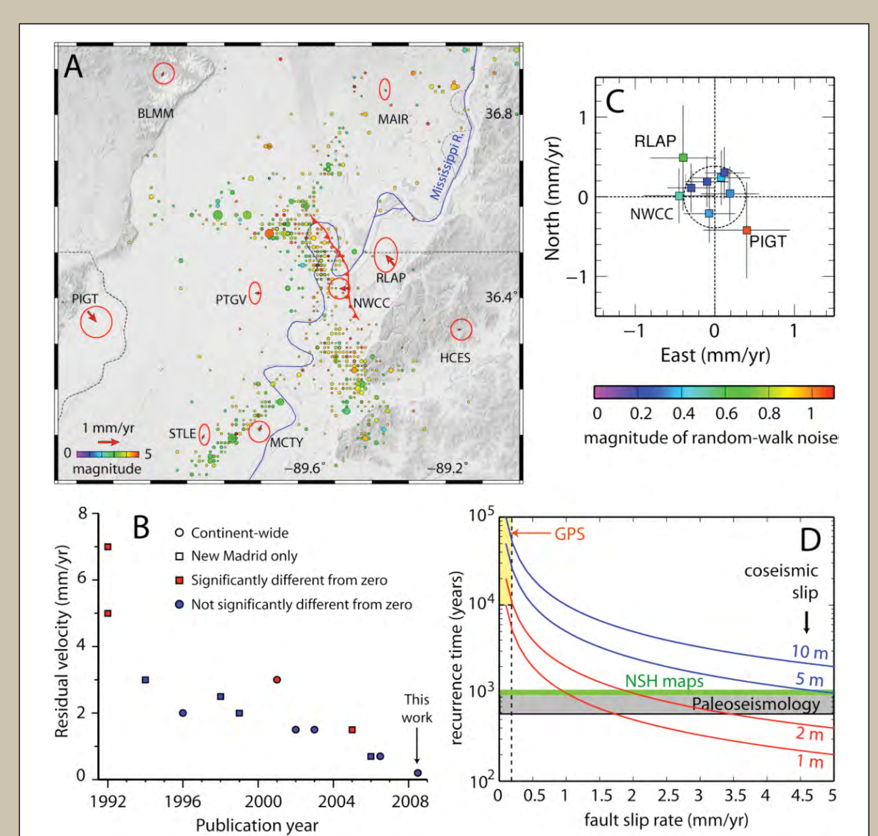
Abstract

We model the surface deformation and strain rate signal associated with steady-state creep on deeply buried faults beneath the Mississippi embayment and post-earthquake viscoelastic relaxation from the 1811-1812 New Madrid earthquakes and compare these results with geodetic observations. This comparison has not previously been done primarily because of expectations of low signal-to-noise ratio for the geodetic data in this stable intraplate region of the North American plate. Improvements in the precision of geodetic measurements indicate very low rates of surface deformation, on the order of 10^{-9} strain/yr, which appear to be inconsistent with the ~500 year return periods of large earthquakes in the New Madrid seismic zone. We build upon previous studies and seek to answer the following questions: How much signal is in our data and what variance reduction can we expect to achieve? How do viscoelastic relaxation and steady-state creep, if present, translate into surface deformation? What are the far- and near-field drivers of stress, and how do they affect surface deformation? The answers to these questions will help us to constrain and address questions significant for earthquake hazard assessments.

Conundrum

Geodesy

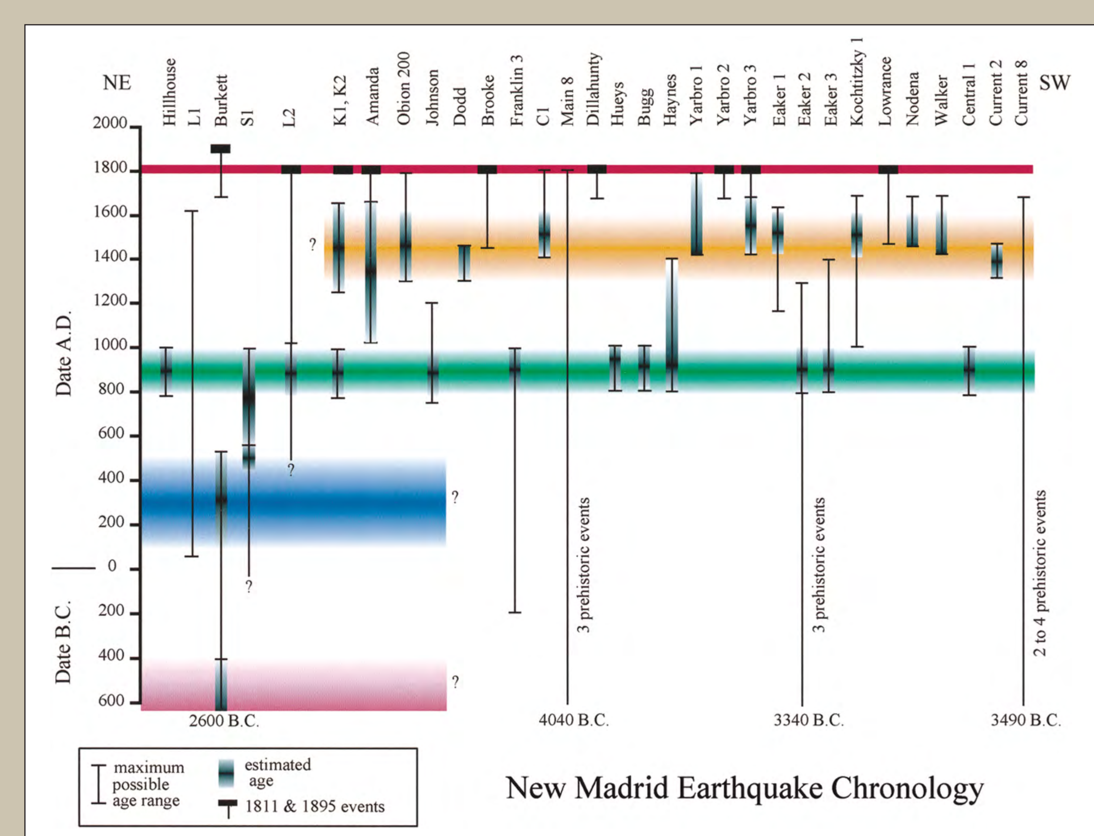
Researchers using GPS data collected over the last decade suggest that very little deformation is currently being accommodated across the New Madrid seismic zone.



From Calais and Stein, 2009

Paleoseismology

Dating of paleoliquefaction features in the New Madrid seismic zone indicates clusters of very large earthquakes of M7–8 occurring, on average, every 500 years.



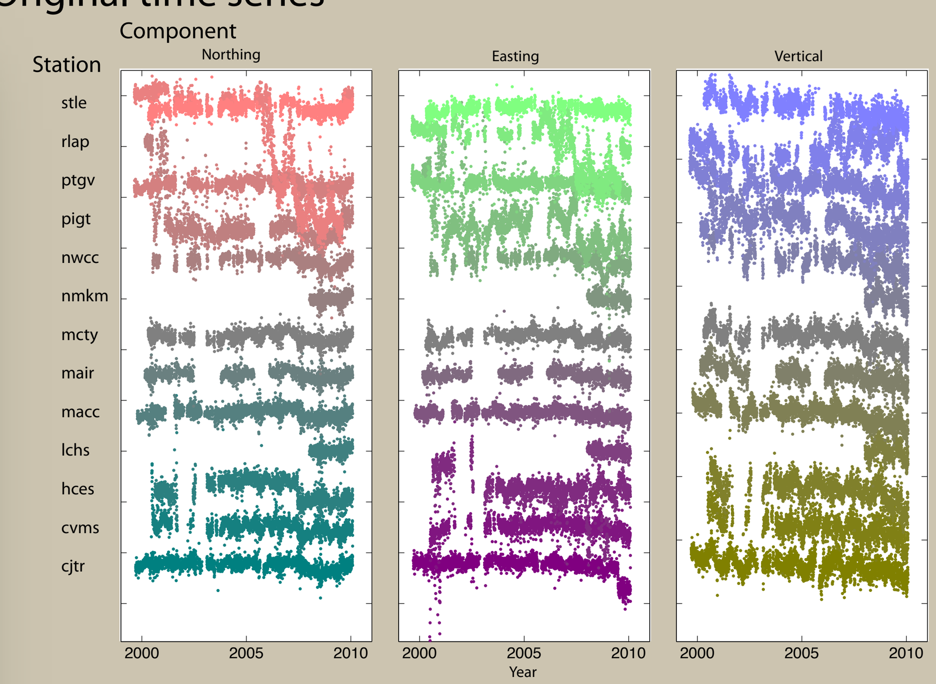
From Tuttle and others, 2002

Observations

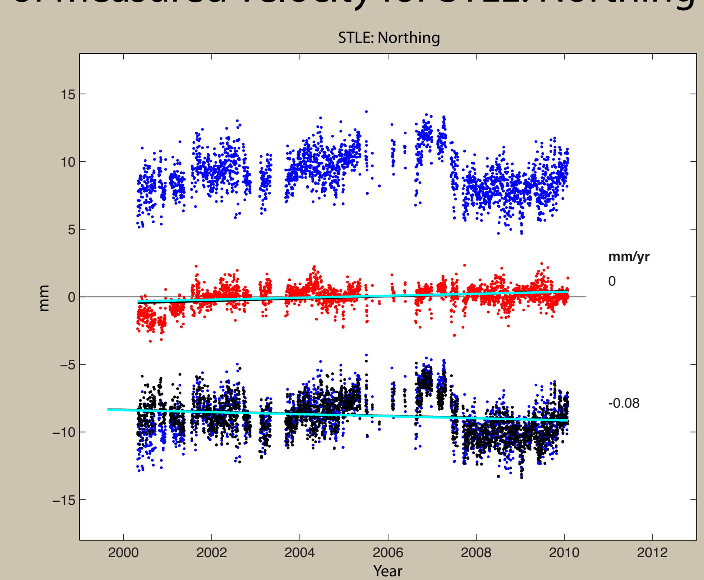
Re-evaluation of the geodetic data

We look more closely at the GPS time series, removing bad secions of data, offsets and annual and semi-annual signals. We then determined site velocities by measuring the slopes of time series relative to a stacked, reference time series (black series in figures to the right).

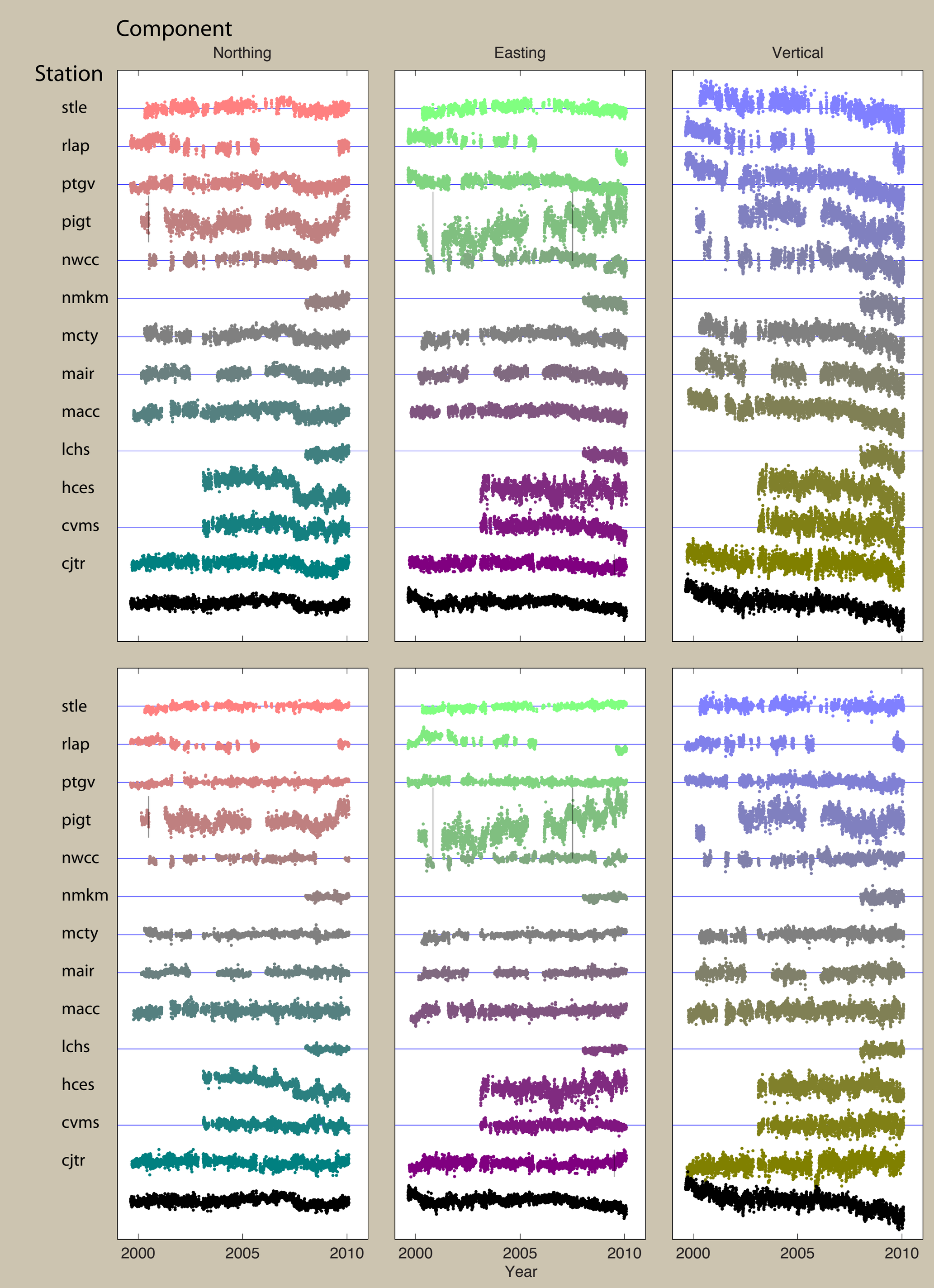
Original time series



Example of measured velocity for STLE: Northing



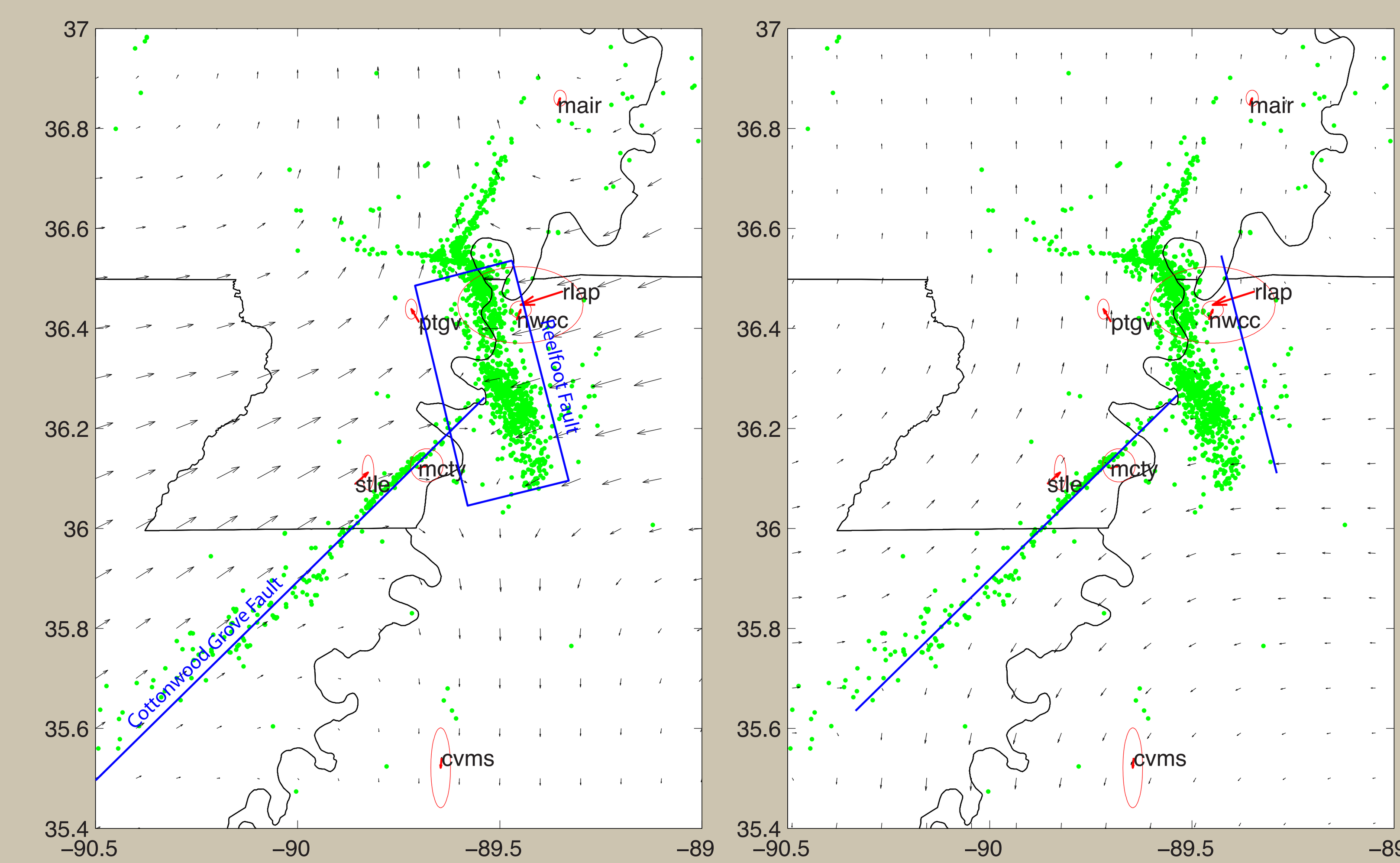
Cleaned (top set) and differential (bottom set) time series



Modeling

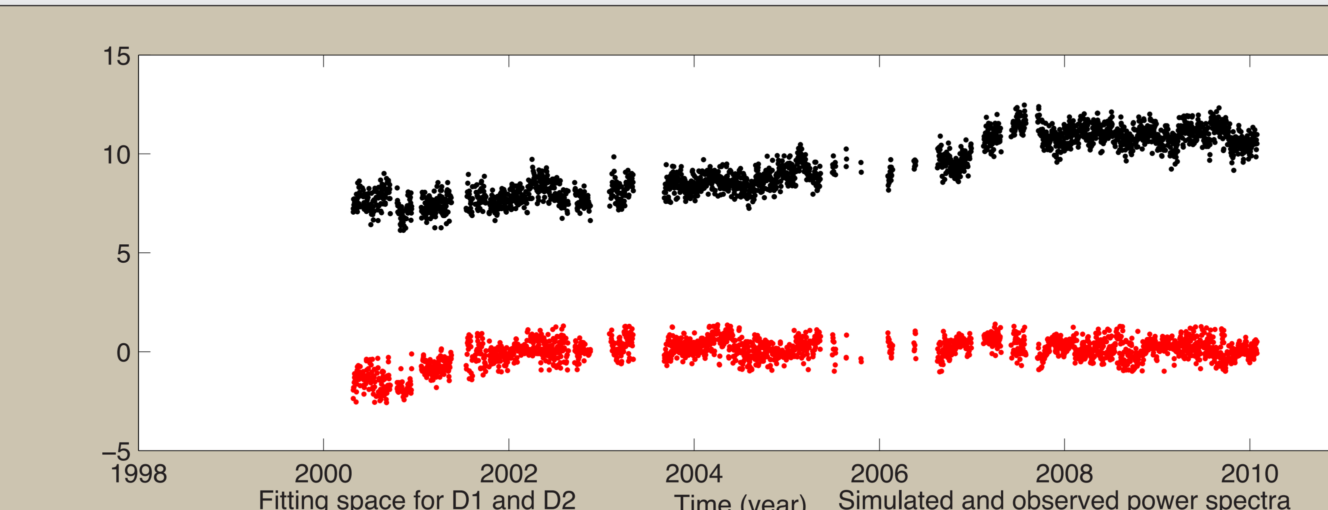
Analytic modeling

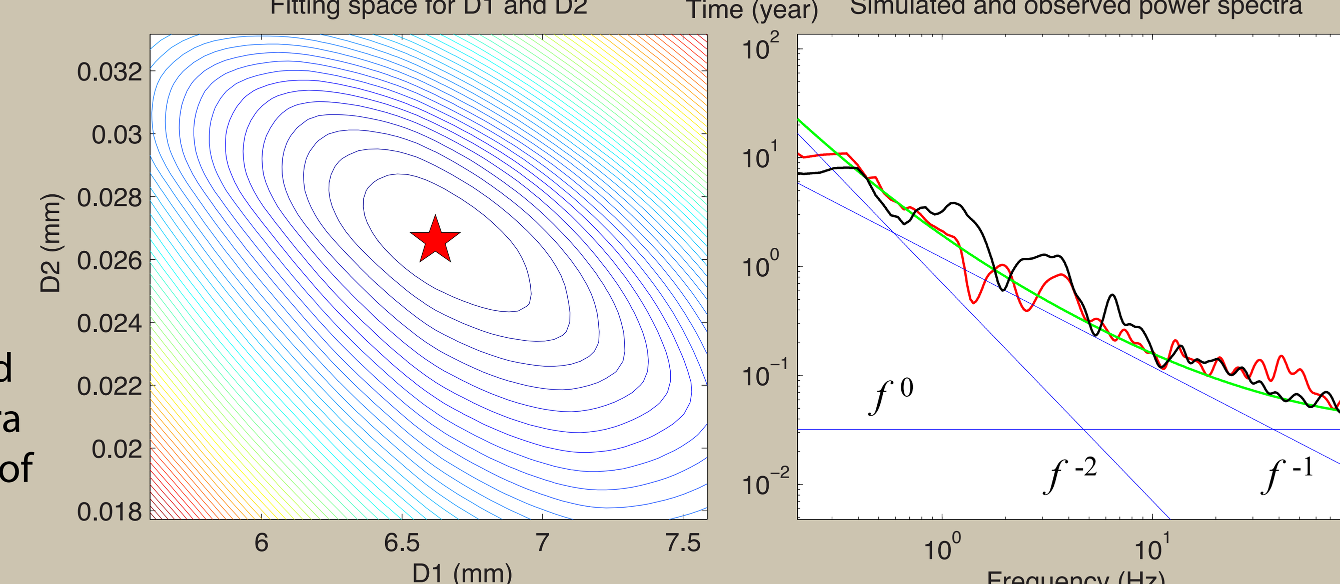
We model the relative site velocities by either viscoelastic response to two of the 1811-1812 earthquakes (left) or as steady creep on buried dislocations beneath present trends in seismicity (right). For a viscosity of 10^{21} PaS beneath 20 km depth, we are able to achieve 50% variance reduction with an average displacement of a little over 1 m on both the Cottonwood Grove and Reelfoot faults, which corresponds to M7 earthquakes. The same variance reduction can be achieved for larger displacements, i.e. larger magnitude earthquakes, by increasing the viscosity. Hence it may be possible to constrain the magnitude of the New Madrid earthquakes by knowing the subsurface rheology. If we assume creep on down-dip extensions of the faults, we are able to achieve 25% variance reduction with 2–3 mm/yr of right-lateral creep on the Cottonwood Grove fault. Appreciable creep on the Reelfoot fault degrades the fit.



Uncertainty

Uncertainties are found by matching observed and simulated power spectral densities assuming that sources of uncertainty are random walk ($P \propto F^{-2}$), flicker ($P \propto F^{-1}$), and white noise ($P \propto F^{0}$). Once a match is found, time series are simulated 1000 times to estimate uncertainty in the velocity vector. Most of the uncertainty in the velocity vectors arises from random walk and may be about 1 mm/yr$^{1/2}$ in the northing and easting and 3–4 mm/yr$^{1/2}$ in the vertical. The random walk component of uncertainty is very difficult to estimate with the limited data that is available.





Observed (red) and simulated (black) time series and spectra for the northing component of station STLE