NON-DOUBLE-COUPLE EARTHQUAKES: NET FORCES AND UNCERTAINTIES

G.R. Foulger, B.R. Julian

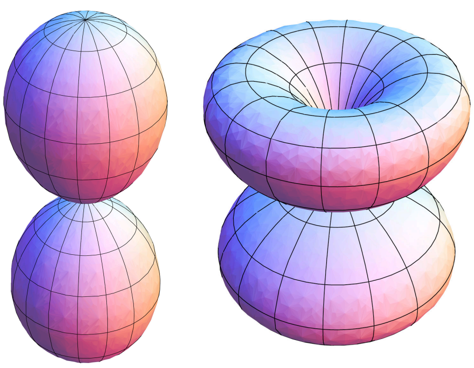
University of Durham, Dept. Earth Sciences, Durham, U.K

g.r.foulger@durham.ac.uk

Accurate and theoretically complete earthquake source mechanisms are increasingly needed in many fields, and recently have even appeared as evidence in a court case involving a fatal mining disaster. A particularly rapidly growing application is to hydraulic fracturing in geothermal and gas-shale reservoirs. The source mechanisms of microearthquakes induced by such operations provide key information regarding the mode of failure and the permeability of created fractures. Consequently, a great deal of work is currently being done to refine the theory and practice of source-mechanism determination, and most importantly, to estimate observational uncertainties.

We recently extended the amplitude-ratio method of Julian and Foulger (1996) (Earthquake mechanisms from linear-programming inversion of seismic-wave amplitude ratios, *Bull. seismol. Soc. Am.*, **86**, 972-980) to include net forces in the mechanisms. Net forces are theoretically required to describe earthquakes involving fluid motion, such as hydraulic fractures. Even with perfectly accurate data, there are situations where the source mechanism cannot be determined uniquely. For example, horizontally polarized shear (SH) waves cannot resolve sources such as vertical dipoles. When source mechanisms include net forces, even more ambiguities arise. For these reasons, determining net forces using real data is challenging.

We have therefore developed methods to compute confidence regions for source mechanisms. We determine the minimum value of an objective function that measures the misfit between observed and computed polarities and amplitude ratios, and then constrain the objective function to lie below a somewhat larger value chosen on the basis of *a priori* estimates of measurement errors and Earth-model uncertainty. The solution is then moved in six-dimensional moment-tensor space (or nine-dimensional moment-tensor + net force space) in various directions to obtain a suite of solutions that fit the data adequately. We will illustrate the application of our software to data from a recent hydrofracturing experiment in the Desert Peak, Nevada, geothermal area.



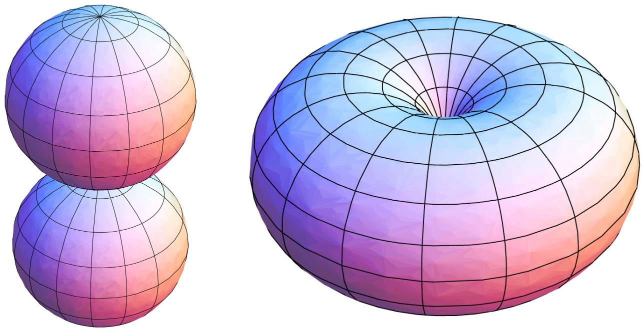


Figure: Left pair: Radiation patterns of elastic compressional waves (left) and shear waves (right) from a vertical force dipole. The upper and lower lobes for compressional waves have the same polarity, while those for shear waves have opposite polarities. Right pair: Radiation patterns like those shown in left pair, but for a vertical force, a mechanism that is not representable by a seismic moment tensor. For compressional waves (left), the upper and lower lobes have the same polarity.