

TOMO4D: Temporal Changes in Reservoir Structure at Geothermal Areas

Bruce Julian, Gillian Foulger, Andrew Sabin, Najwa Mhana

Temporal changes in seismic wave speeds in the Earth's crust have been observed at The Geysers and the Coso geothermal areas, California, using three-dimensional local-earthquake tomography repeated on a year-to-year basis. These results are based on comparing models derived by inverting data for different epochs independently, and assuming that any differences found represent true temporal variations in structure. Such an assumption can be unsafe, however, because variations in the seismic ray distribution from experiment to experiment could cause tomographic models to vary even in the absence of structural changes. This problem can be particularly serious where changes in the distribution of earthquakes are systematic, *e.g.*, if earthquake locations are radically different from one epoch to another.

The strong, persistent, and systematic changes in structure derived for the geothermal reservoir at The Geysers using conventional repeat tomography are probably real (Gunasekera, R. C., Foulger, G. R. and Julian, B. R., Four dimensional tomography shows progressive pore-fluid depletion at The Geysers geothermal area, California. *J. Geophys. Res.* **108**, 2003). In contrast, changes at the Coso geothermal area are subtle, and require confirmation. To that end, we developed a new tomography program, **tomo4d**, that inverts multiple data sets simultaneously (Julian, B. R. and Foulger, G. R. Time-dependent tomography. *Geophys. J. Int.* **182**, 1327–1338, 2010), imposing constraints to minimize the structural differences calculated for different epochs. This approach is similar to that of seeking models similar to some *a priori* initial assumption, and it can be solved using a method similar to damped least squares.

In the first applications of this method to real data, we applied **tomo4d** to data from Long Valley caldera and the Coso geothermal area, both in California. Long Valley caldera has a recent history of volcanic and seismic unrest, and independent tomographic inversions for 1997 and 2009/10 show considerable differences, especially in V_p/V_s . For the Coso geothermal area, independent inversions are now available for most years from 1996 to 2012. These inversions show more subtle changes from year to year. We will present the results from **tomo4d**, compare them with those from the conventional tomography, and interpret the structural changes in terms of evolving reservoir properties.