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An objective mechanical modelling approach for estimating the distribution of fault creep and locking from geodetic data

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Knowledge of the extents of locked areas on faults is a critical input to seismic hazard assessments, defining possible asperities for future earthquakes. On partially creeping faults, such as those found in California, Turkey and in several major subduction zones, these locked zones can be identified by studying the distribution and extent of creep on those faults. Such creep produces surface deformation that can be measured geodetically (e.g. by InSAR and GPS), and used as a constraint on geophysical models.

We present a Markov Chain Monte Carlo method, based on mechanical boundary element modelling of geodetic data, for finding the extents of creeping fault areas. In our scheme, the surface of a partially-creeping fault is represented as a mesh of triangular elements, each of which is modelled as either locked or creeping (freely-slipping) using the boundary element code poly3d. Slip on the creeping elements of our fault mesh, and therefore elastic deformation of the surface, is driven by stresses imparted by semi-infinite faults beneath the base of the mesh (and any other faults in the region of interest) that slip at their geodetic interseismic slip rates. Starting from a random distribution of locked and unlocked patches, a modified Metropolis algorithm is used to propose changes to the locking state (i.e. from locked to creeping, or vice-versa) of randomly selected elements, retaining or discarding these based on a geodetic data misfit criterion; the succession of accepted models forms a Markov chain of model states. After a 'burn-in' period of a few hundred samples, these Markov chains sample a region of parameter space close to the minimum misfit configuration. By computing Markov chains of a million samples, we can realise multiple such well-fitting models, and look for robustly resolved features (i.e. features common to a majority of the models, and/or present in the mean of those models).

We apply this method to a combination of persistent scatterer InSAR and GPS data covering the Hayward fault in northern California. Preliminary results show strong agreement between all models on the occurrence of creep across the full down-dip extent of the fault at its southeast end, and to a depth of 10 km at its northwest end. On the other hand, most elements in the central portion of the fault at depths of 4–12 km, thought to be the source region of the M$\sim$7 1868 Hayward earthquake, are locked in around half of the models, indicating that the fault is likely partially locked here, and that multiple possible configurations of locked and creeping elements can fit the data approximately equally well. Applying prior knowledge of specific elements that are creeping, from observations of characteristic repeating earthquake sequences or surface creep observations, reduces some of this ambiguity, increasing the proportion of models showing locking in this portion of the fault to between 60 and 80 percent.