Creep and locking on the Hayward fault estimated from geodetic data using an objective mechanical modelling approach

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We present a Markov Chain Monte Carlo method that can be used to find the extents of creeping fault areas, an important input to seismic hazard models, from mechanical boundary element modelling of geodetic data. 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 surface faults) that slip at the geodetic slip rate of the faults. 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 running multiple Markov chains, 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. SAR data were obtained through the WInSAR and GeoEarthScope archives; GPS data are taken from the BAVU compilation of continuous and campaign data. Without using any additional constraints other than the data, we find strong agreement between all models on the presence of regions of creep across the full down-dip extent of the fault at its northwest and southeast ends, in contrast with the central portion of the fault, where around half of the patches are locked in any given model, consistent with partial locking, and implying that multiple possible configurations of locked and creeping elements can fit the data approximately equally well. By applying additional observational constraints, e.g. by enforcing creep in areas where it is measured at the surface, and in the locations of characteristic repeating earthquake sequences, this ambiguity is significantly reduced.

This constrained model identifies a zone that is consistently locked in ~90% of models, at depths of 4-12 km between Oakland and Union City, consistent with kinematic inversions for fault creep and the inferred source region of the M~7 1868 Hayward earthquake. We believe this method could also be applied to other structures undergoing partial creep, such as subduction zones, or used to solve for variable locking depths in models of interseismic strain accumulation.

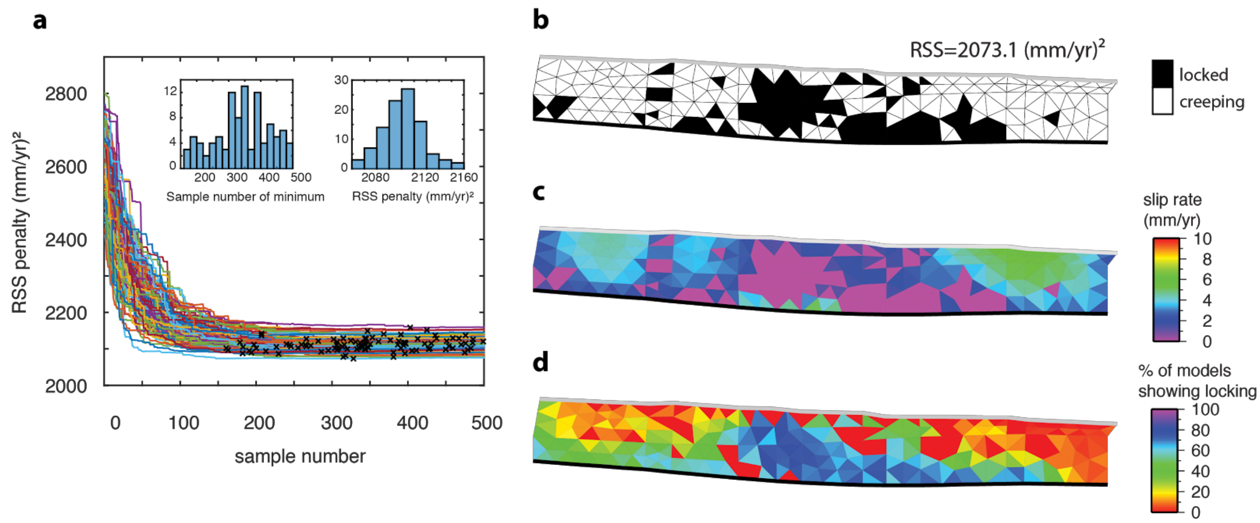

Figure: (a) Example of convergence of the Markov Chain Monte Carlo process. Crosses mark the minima of each chain. (b) Our best-fitting locking model. (c) Creep rate distribution implied by our best-fitting model, assuming a loading rate of 10 mm/yr from below. (d) Aggregate results from 100 Markov chains. Locking is consistently resolved in the central portion of the fault, and creep is consistently resolved at the fault ends, particularly at shallow depths.