From mega-thrusts to plate reorganizations: Bridging scales from local to global in forward and adjoint models

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Global plate motions are primarily driven by the negative buoyancy within subducted slabs, but there is little consensus on the strength and nature of resisting forces. Failure to reach consensus on the force balance of plate tectonics and mantle flow leaves fundamental questions unanswered and is partly related to the application of under-resolved forward models with simplified flow laws at large scales. We describe and apply a robust finite-element method that allows global models that span the entire depth of the mantle resolved at 100s of meters, where needed. We have addressed the recovery of non-linear rheological properties and the causes of the major change in Pacific Plate Motion at 50 Ma in forward and inverse models.

We solve these problems with *Rhea2* that allows scalability to extreme scales of 10^6 processor cores. The discretization is carried out by finite elements on adaptively refined hexahedral meshes. The problems are run on distributed–memory parallel computing clusters with parallel forest-of-octrees algorithms used for efficient, scalable mesh refinement/coarsening, mesh balancing and repartitioning. A hybrid spectral–geometric–algebraic multigrid (HMG) method is used for preconditioning and is robust in the presence of the highly heterogeneous viscosities. A nonlinear preconditioner is used to avoid poor convergence associated with highly nonlinear physics at plate fault zones.

We use plate motion data to better constrain uncertain mantle parameters by means of formulating an optimization problem. Within the optimization, we derive gradients using adjoints and we approximate the posterior distributions for stresses within plate boundaries. We apply these methods to the Pacific (Figure 1), with temperature distributions and fault zone geometries developed primarily from seismic and plate motion data. We find the best-fitting stress exponent, *n*, and the yield stress, and the normal and shear stresses on inter-plate fault zones.

Global plate circuits show the Pacific Plate abruptly changed motion from north to west-north-west at around 50 Ma -- the largest known plate reorganization since the Mesozoic. Several possibilities for explaining the change in Pacific Plate motion have emerged, including initiation of Izu-Bonin-Mariana (IBM) and Tonga-Kermadec subduction. We find traditional reconstructions incapable of pulling Pacific Plate northward before 50 Ma or causing any sudden change. We demonstrate how slab pull from intra-oceanic subduction drives the Pacific plate to the north while its Eocene demise leads to a sudden change in plate motion.

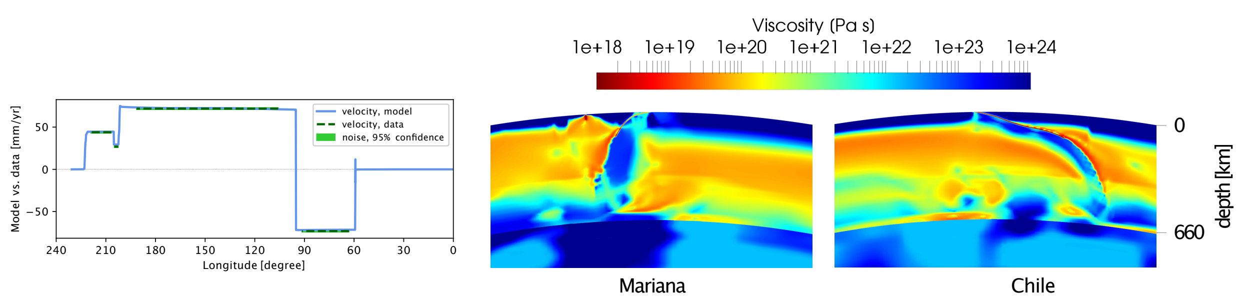

Figure 1. Adjoint-based inference that recovers non-linear rheological parameters and mega thrust strengths. Left, plate motion data (green) versus model (blue) and effective viscosity across two subduction zones.