Interpreting interseismic observations with elastic block models

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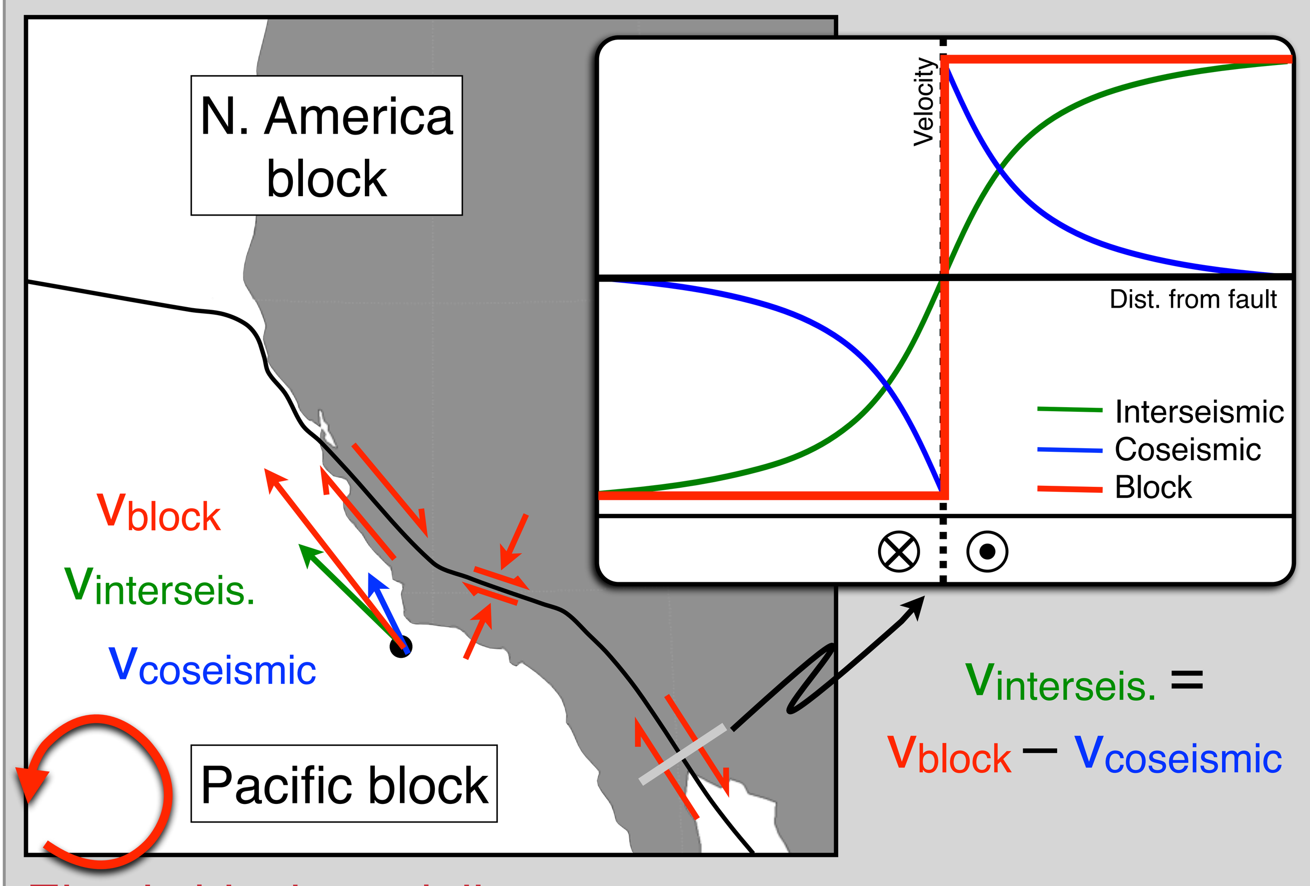
Introduction

Background

- Elastic block models consider nominally interseismic, steady-state GPS velocities to arise from a combination of:
  1. Rotation of microplates (blocks) about Euler poles;
  2. Elastic strain accumulation due to interseismically locked faults that define block boundaries; and
  3. Deformation within blocks due to processes not formally parametrized in the model
     - ➡ No *a priori* assumptions about relative contributions of these factors
- Block geometry defined as interconnected fault network, informed by maps of active fault systems



Elastic block modeling

- Block motion described as rotation about Euler poles
- Relative block motions projected onto 3D fault geometry to give kinematically consistent fault slip rates that inherently satisfy far-field plate motion constraints

Recent applications

Interseismic stress accumulation rates on the San Andreas fault

- Stress accumulation rates are linearly proportional to slip rates
- Total stress rate on the San Andreas fault is due to San Andreas slip ("self stress") plus contributions from neighboring faults
- Total stress exceeds 130% of self stress rate on Big Bend segments

Partitioning of on-fault vs. intrablock deformation in Tibet:

- Joint inversion of GPS velocity field and Holocene–Late Quaternary fault slip rates suggest that 89% of geodetically observed deformation is accommodated by slip on major faults
- The remaining 11% reflects deformation distributed within the blocks distinguishable from observational noise

Combined subduction zone and crustal deformation in Japan:

- GPS-observed deformation reflects interseismic processes on subduction zones bounding Japan as well as the dense crustal fault network
- Oblique convergence across the Nankai Trough is partitioned, with 3/4 accommodated by the subduction zone and the remaining 1/4 by right-lateral slip on the Median Tectonic Line
- Concentrations of strain accumulation correspond to rupture areas of recent M_W 8–9 class earthquakes

San Andreas fault stress rates

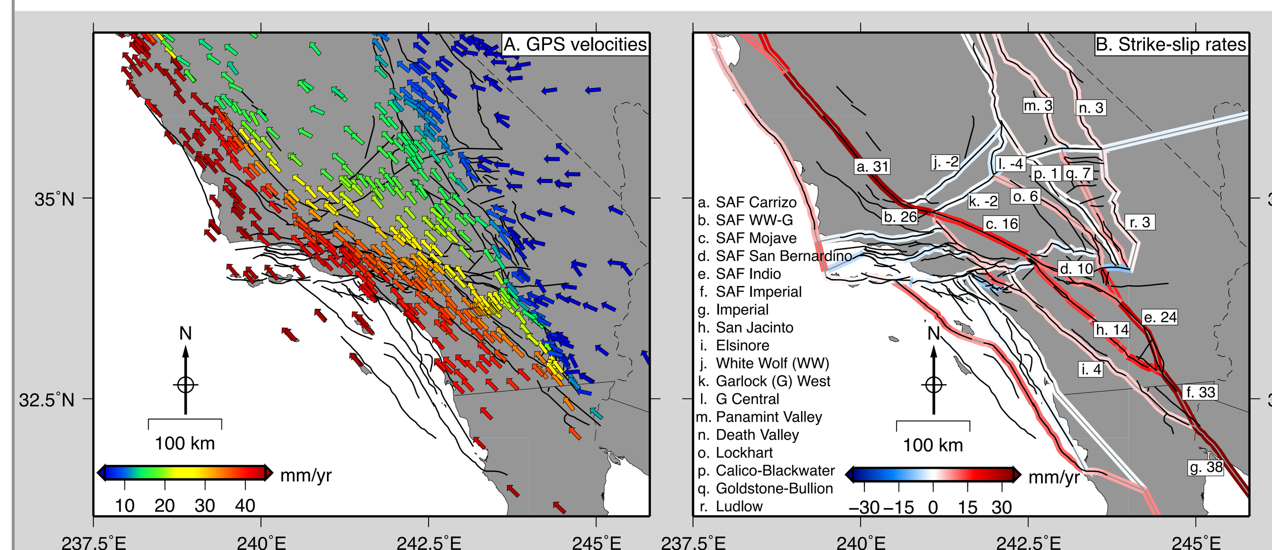
Description

We interpret interseismic deformation throughout southern California using an elastic block model that features:

- Incorporation of rectilinear Community Fault Model (CFM-R) geometry,
- Constraints from 6 combined GPS networks,
- Ability to resolve spatially variable slip by representing some faults with triangular dislocation elements,
- Estimation of homogeneous intrablock strain.

We use estimated fault slip rates to calculate the shear and normal stress on the San Andreas fault due to slip on all faults considered in the model.

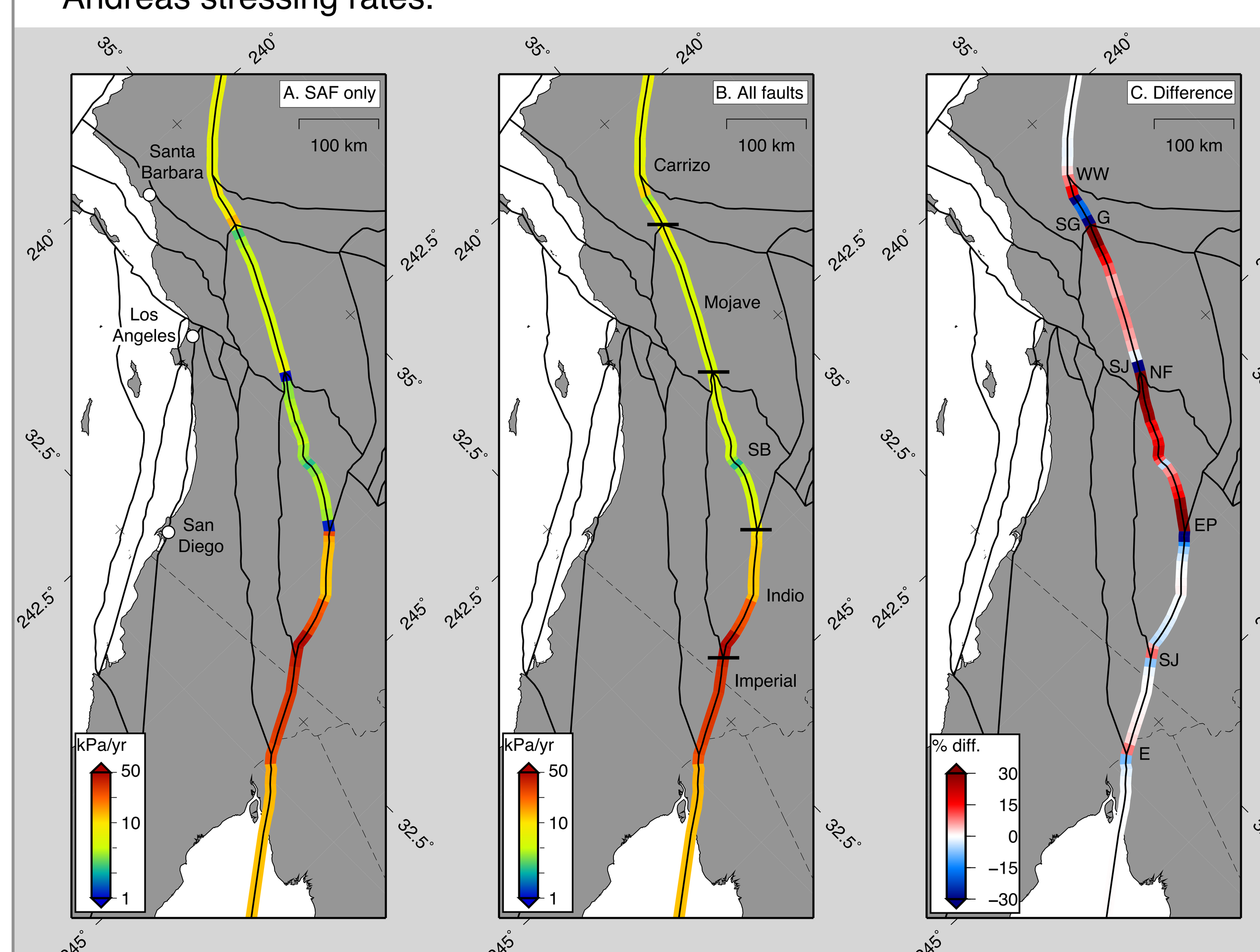
Results



GPS velocity field & estimated strike slip rates

Modulation of San Andreas stress accumulation rates

We compare the stress accumulation rate due to slip on the San Andreas alone ("self stress", A) to the rate due to slip on all southern California faults ("total stress", B) to investigate how interseismic fault interactions modulate San Andreas stressing rates.



San Andreas interseismic stress modulation

- Stress difference normalized by self stress gives stress amplification (C)
- Stress amplification is up to 30% along Big Bend segments
- Magnitude of interseismic stress amplification, integrated over the 150+ years since the 1857 Fort Tejon earthquake, exceeds co- and postseismic stress changes induced by 1992 Landers and 1999 Hector Mine earthquakes.

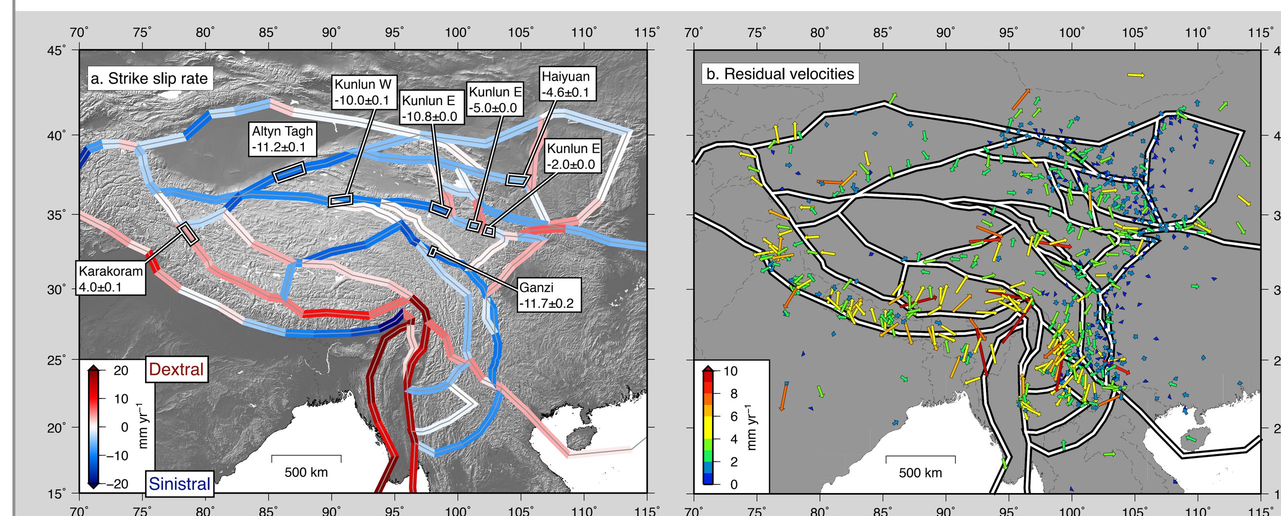
Deformation partitioning in Tibet

Description

We jointly invert 731 GPS velocities and 9 Holocene–Late Quaternary geologic fault slip rates for microplate Euler poles and hence fault slip rates.

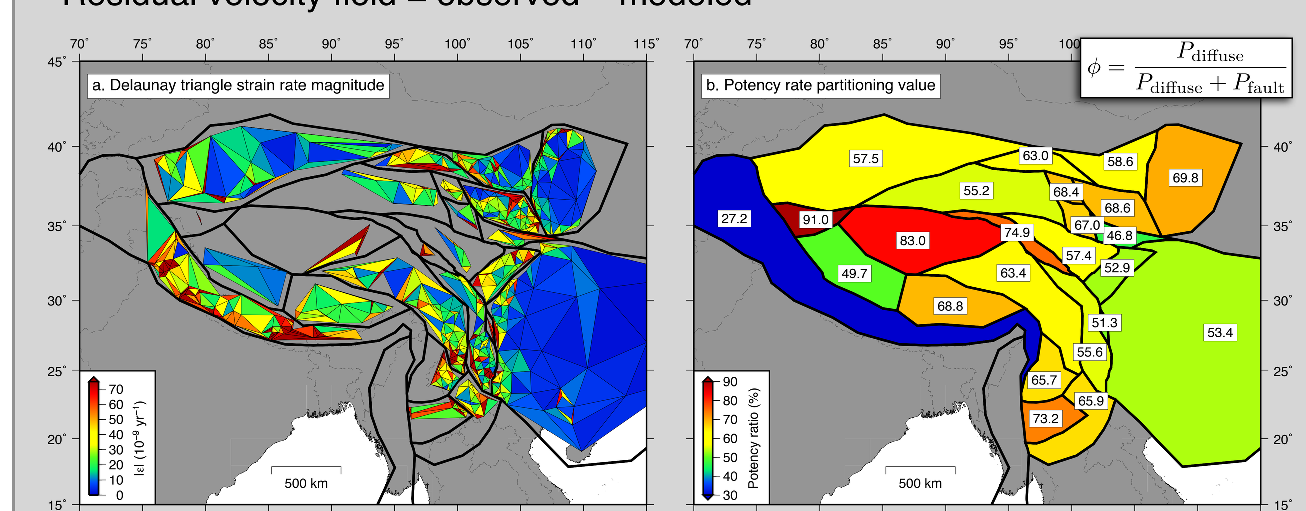
- Slip rates, multiplied by fault area, give an estimate of potency (geometric moment) rates accommodated by major faults.
- Residual velocity field reflects unmodeled deformation processes plus observational errors, and we use Monte Carlo simulations of these errors to isolate the moment rate representing deformation distributed within blocks.
- Ratio of intrablock to total potency rates give the potency rate partitioning value, which reflects the proportion of observed deformation taking place away from major faults.

Results



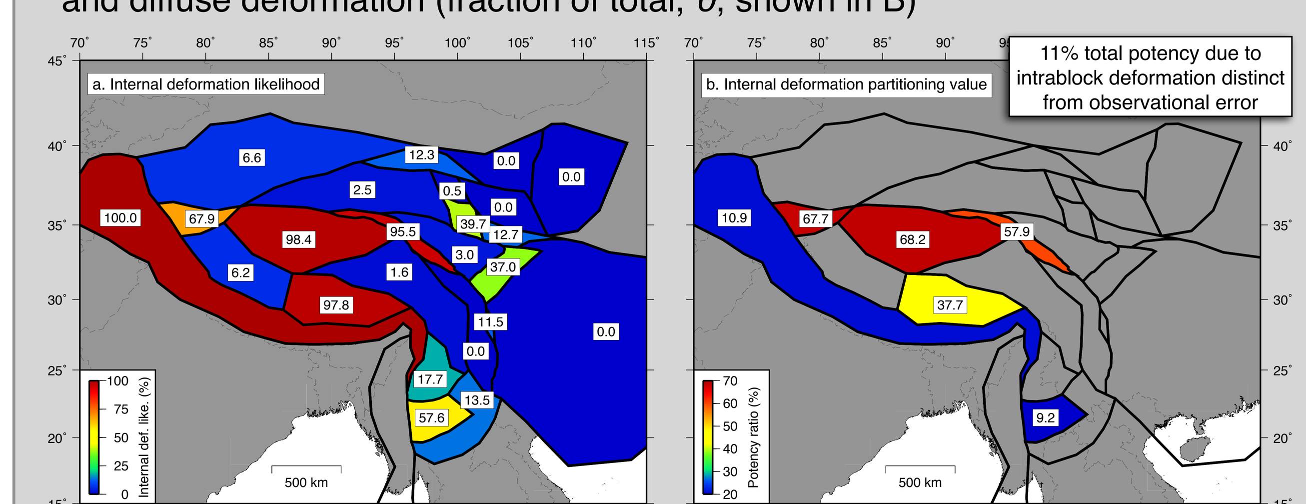
Estimated fault slip rates & residual velocities

- Strike-slip and fault-normal rates estimated on major faults; strike-slip shown
- Fault slip rates determine on-fault potency rates
- Residual velocity field = observed – modeled



Strain from residuals & potency partitioning

- Residual velocity gradient (A) gives potency rate comprising observational noise and diffuse deformation (fraction of total, θ, shown in B)



Internal Deformation Likelihood & adjusted partitioning

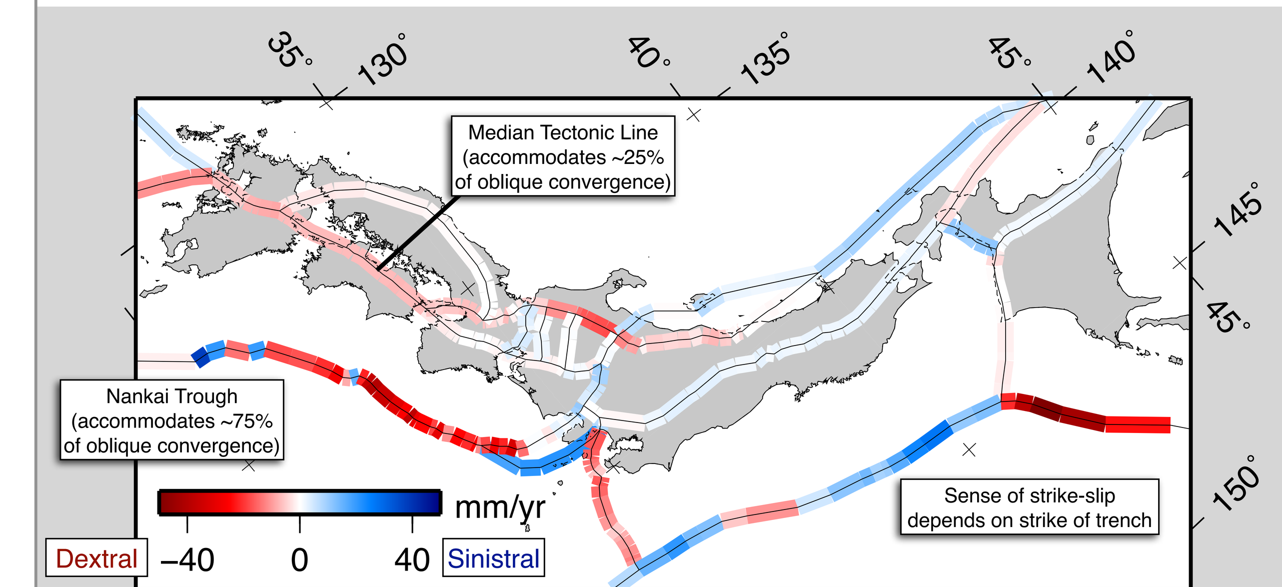
- IDL (A) is the likelihood that some part of the intrablock potency represents deformation, not just data noise
  - 100% = partly diffuse deformation; 0% = entirely noise
- Proportion of total potency accommodated by likely intrablock deformation considers the IDL correction; 11% total is intrablock, 89% is on major faults.

Earthquake cycle deformation in Japan

Description

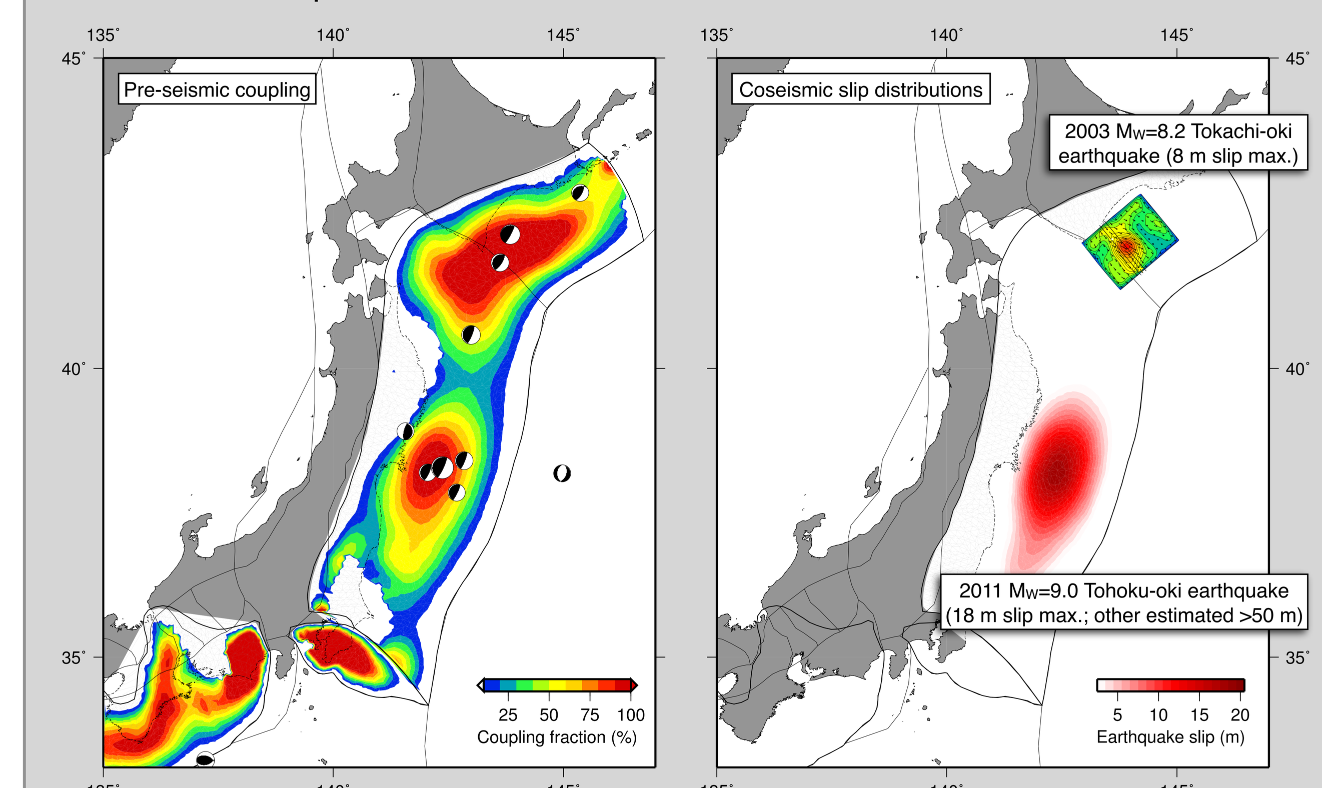
The densely spaced, continuously recording GEONET GPS network in Japan provides an ideal dataset for assessing the complicated deformation of Japan.

- Use interseismic GPS observations to estimate crustal fault slip rates and spatially variable coupling on subduction interfaces.
- Assess deformation distribution between crustal faults and subduction zones
- Compare subduction zone strain accumulation with coseismic slip models



Distribution of plate boundary deformation

- Strike-slip (shown) and fault-normal slip rates estimated on all faults in model
- Deformation partitioned between crustal faults and subduction zones, especially in southwest Japan



Comparing preseismic and coseismic deformation

- Interseismic locking on the Japan Trench interface (1997–2000) corresponds to rupture areas of 2003 M_W=8.2 Tokachi-oki and 2011 M_W=9.0 Tohoku-oki earthquakes.

Applications to multiple timescales

Should we expect fault slip rates constrained by geodesy to be consistent with those inferred from paleoseismology?

- Test directly through joint inversion of GPS velocities and fault slip rates. If a single model can provide adequate prediction of both datasets simultaneously, we can assume consistency in deformation rates over the time scales represented by the slip rates and geodesy.

What physical factors lead to temporal variation in deformation rates?

- The fault geometry of a block model is assumed fixed, which is unrealistic over geologic time scales. The interactions between one fault and its neighbors may lead to suppression or enhancement of slip. For example, if substantial clamping stress is induced on a fault, there may be insufficient shear stress to cause it to slip.

How can geologic studies provide insight into active deformation?

- Maps of active faults are used to inform the block geometry chosen for a particular model.
- We have found examples of faults not previously considered active being located at a strong gradient in GPS velocities, suggesting that fault activity may be rejuvenated.