Constraining the Static Deformation Process of the Great 2011 Tohoku Earthquake Using High Rate GPS

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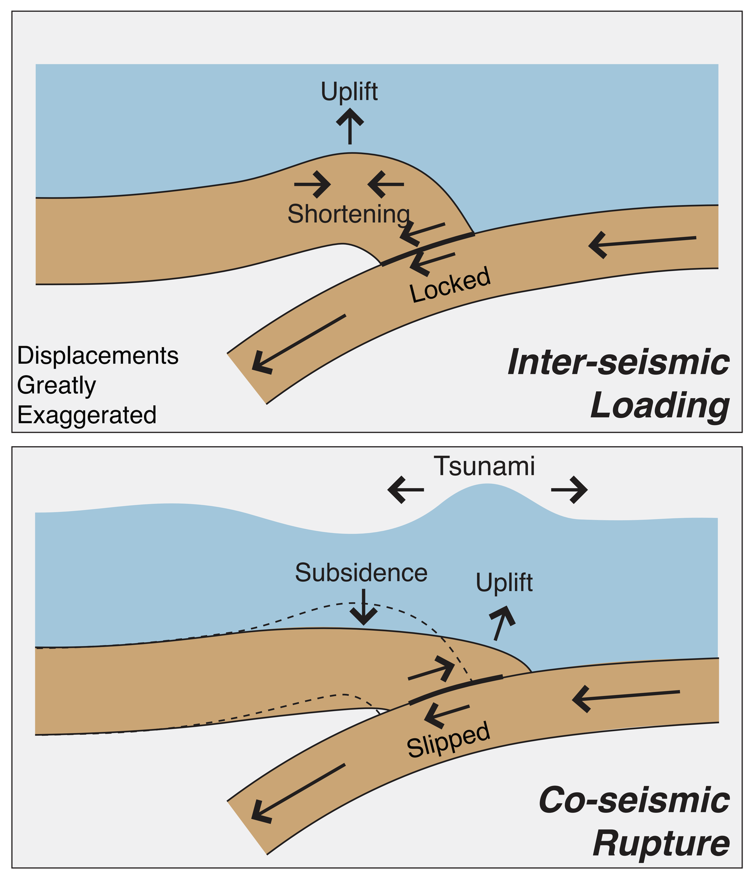
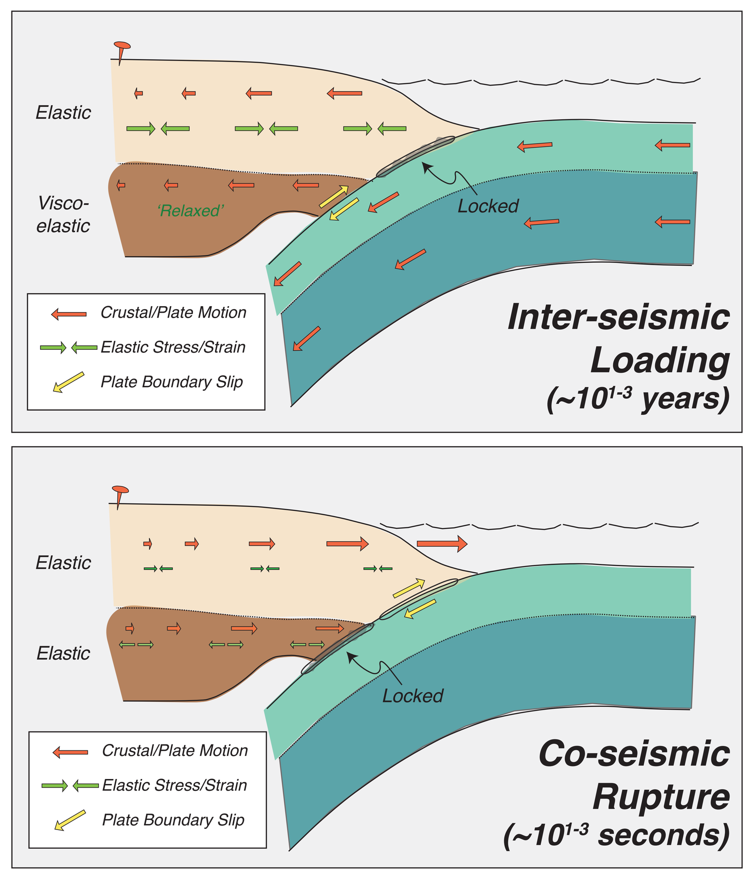
PENNSTATE GEODYNAMICS

Introduction

Classical textbook models for subduction zone earthquake cycles consist of purely elastic lithospheric plates (left). However, detailed observations of recent great (Mw > 8.0) megathrust subduction zone earthquakes demonstrate that simple elastic models are insufficient to anticipate megathrust magnitudes and kinematics. Updated models should incorporate more realistic rheological properties for the interacting lithospheres that depend on the time scales of deformation (right).

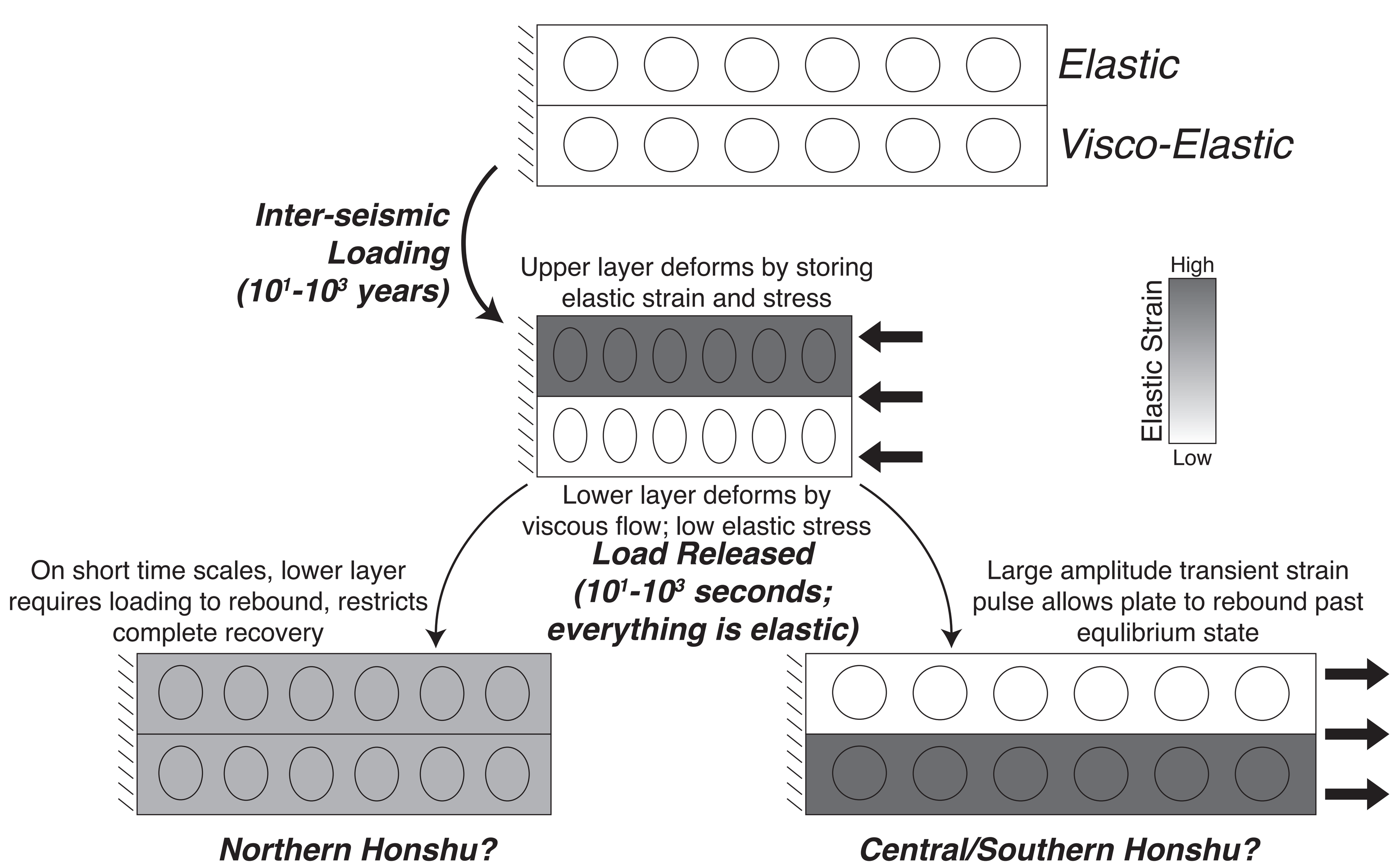


Subduction zone earthquake cycle framework: purely elastic, plates have same mechanical properties, upper plate passively records deformation



Updated models: differences in strain rate, friction on fault, rheology (viscosity), elastic heterogeneity, effect of transient strain signals

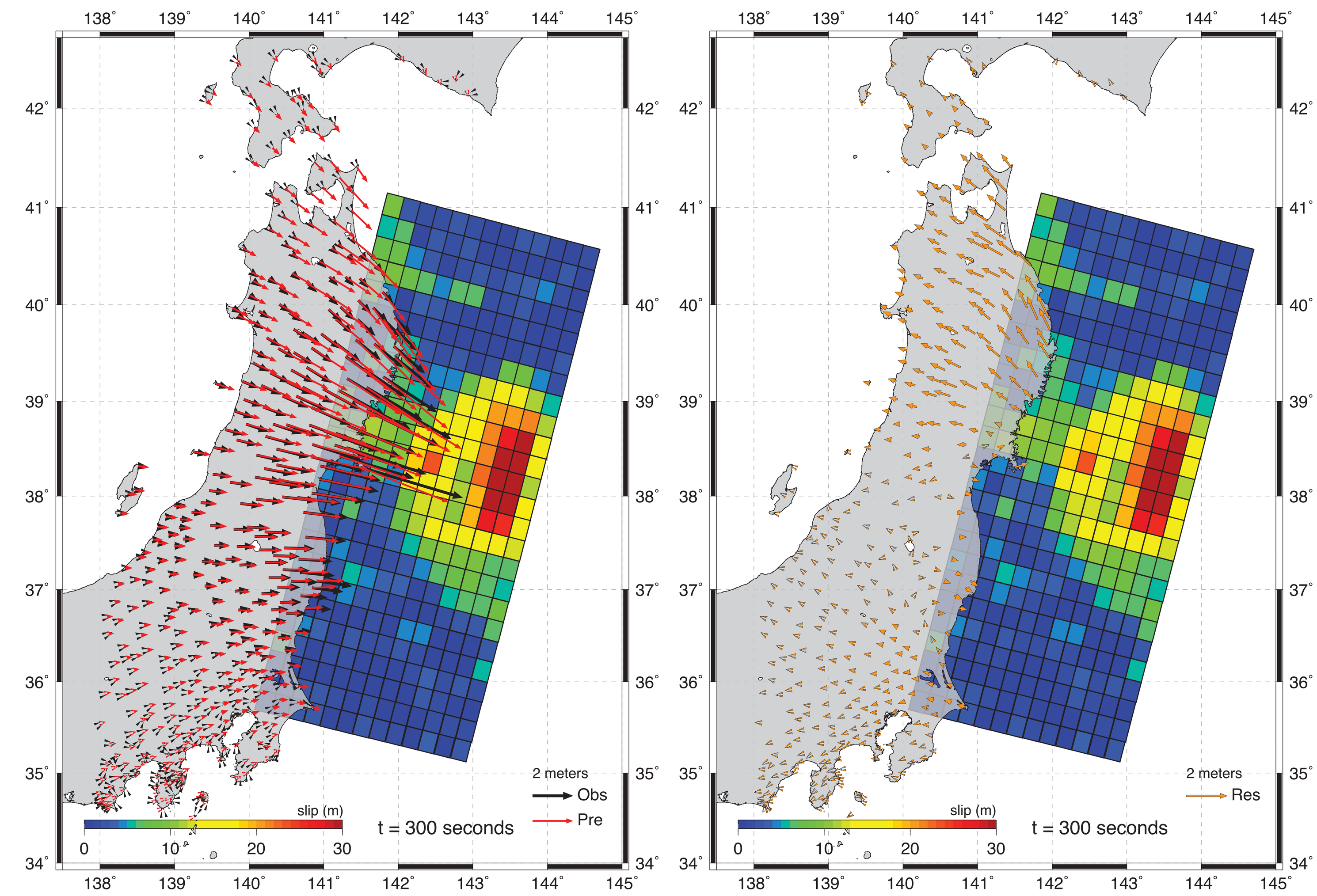
Conceptual Effect of Viscosity



Tohoku Earthquake

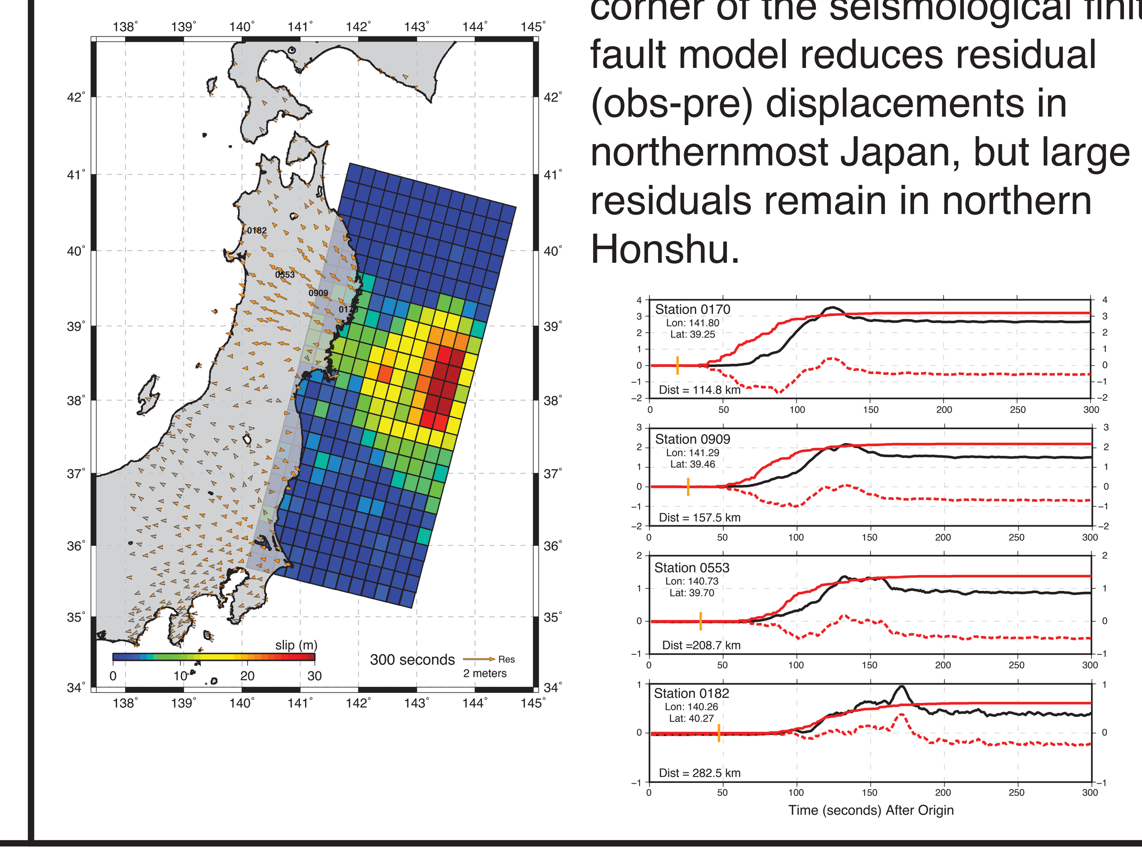
The 2011 Mw 9.0 Tohoku earthquake was recorded by a dense network of 1-Hz GPS stations in Honshu. These resolve the temporal evolution of the co-seismic rebound of the upper plate.

We use an Okada (1985) half-space solution with a seismological finite fault model (Hayes, 2011) to predict horizontal surface displacements. The agreement is reasonable in southern and central Honshu, However, we overpredict deformation in Northern Honshu: could this be an instance of incomplete upper plate rebound?



Are Residuals Artifacts?

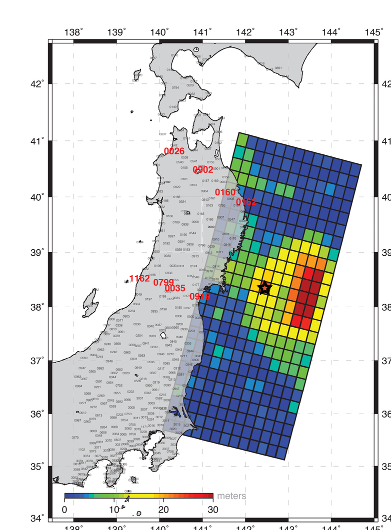
Removing the large slip (up to 9 meters) in the northwestern corner of the seismological finite fault model reduces residual (obs-pre) displacements in northernmost Japan, but large residuals remain in northern Honshu.

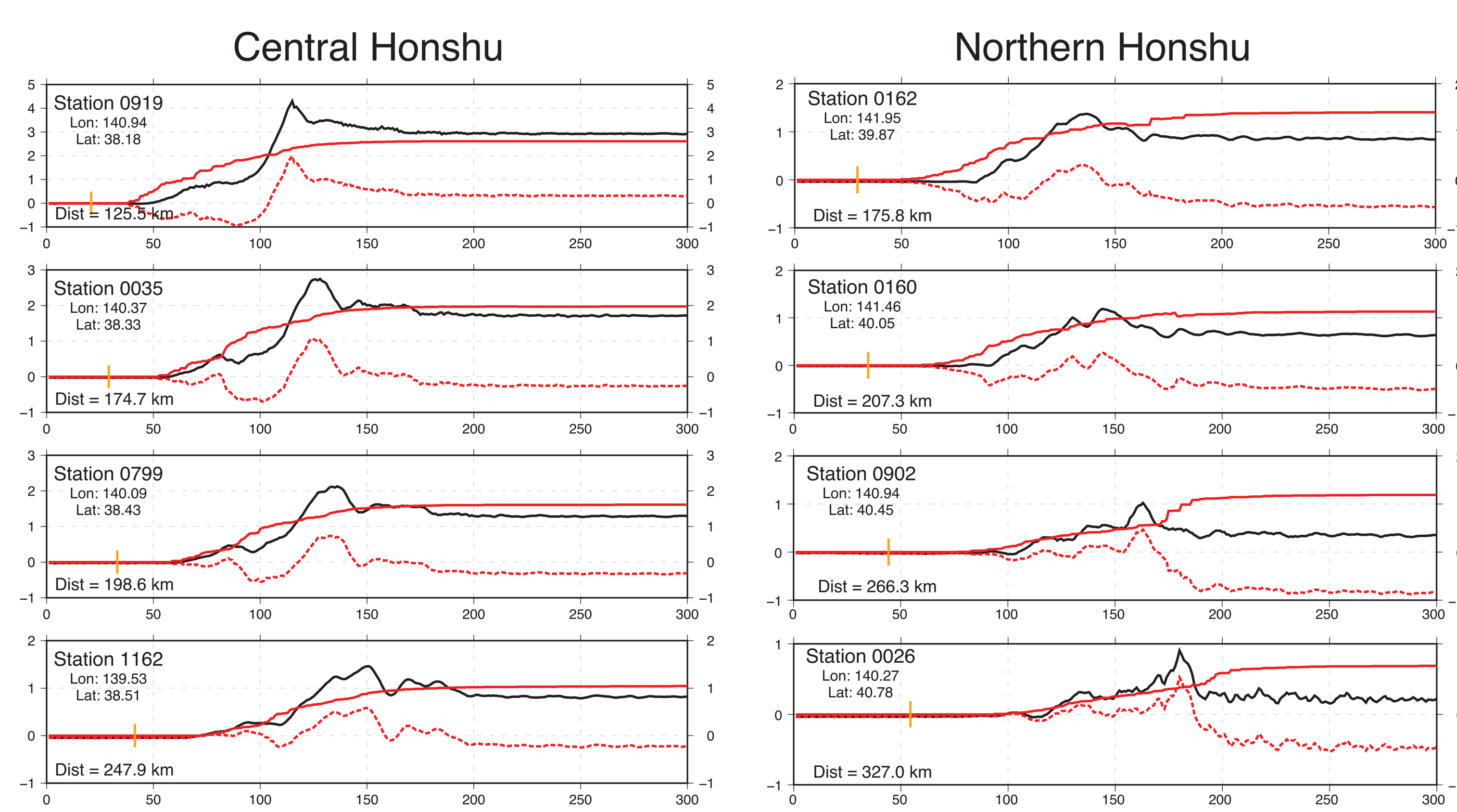


Evolution of Elastic Rebound

The GPS stations record the propagation of deformation resulting from fault displacements as well as strain release associated with elastic rebound of the upper plate. We attempt to model the latter effect (propagation of the elastic rebound across Japan) by assigning a constant moveout velocity for the Okada solution to each of the rupture patches. This allows us to create "static displacement time series" that we can directly compare to the observed GPS time series.

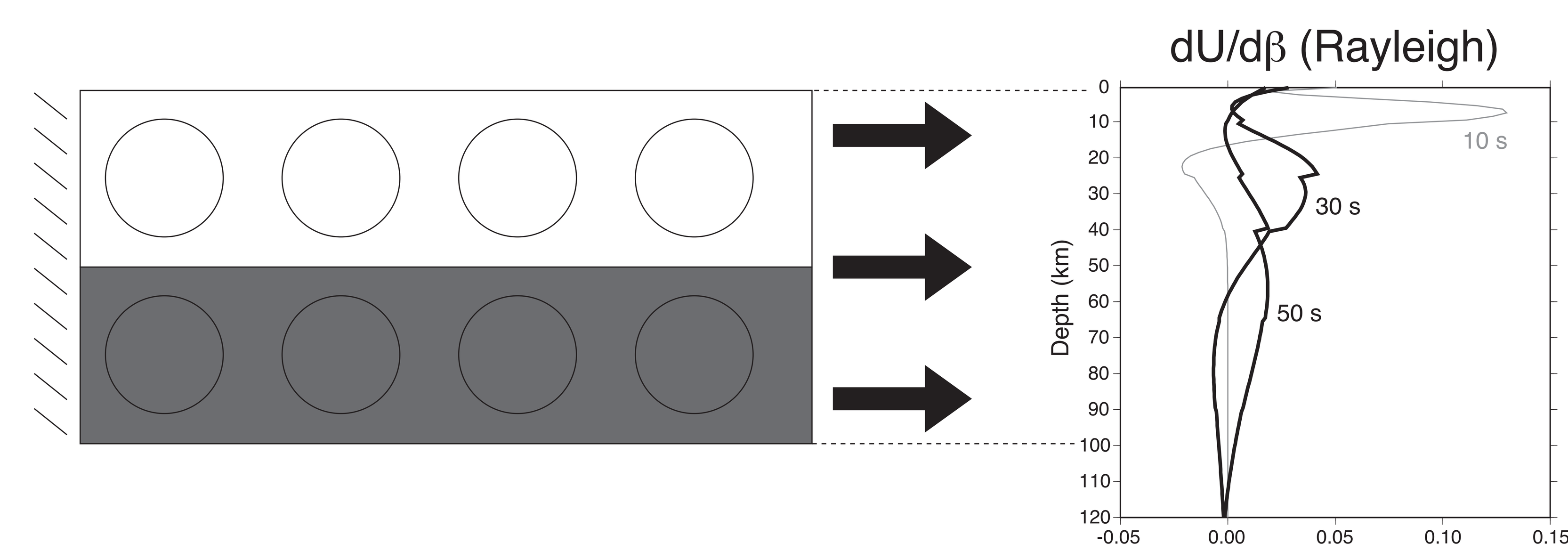
Growth of the static offset in Japan has a propagation velocity of ~3.5 km/s, consistent with 20-40 second period Rayleigh waves. This velocity is the same across regions with both good and poor agreement with the final displacements (right). In no case is there substantial offset associated with more rapid P-wave arrivals (~6.5 km/s).



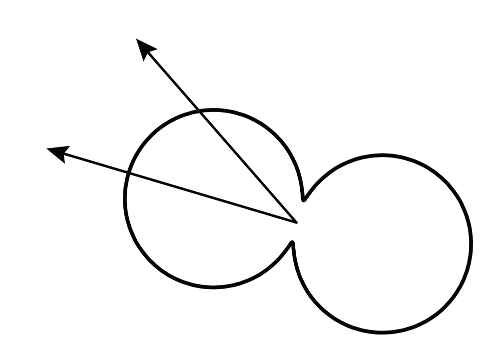


Rayleigh Waves Facilitating Rebound

The period of a surface wave determines its depth extent: long period waves sample deep structure, whereas short period waves sample shallow structure. Rayleigh waves sampling the lithosphere (30-50 second period) with sufficiently large amplitudes may supply the additional force needed for the upper plate to reach its complete rebound state.



Rayleigh Wave Radiation Pattern



Rayleigh wave radiation pattern for a shallowly dipping thrust fault. Note that the radiation amplitude is large in the direction that modeled displacements match observed, and small in direction of larger misfit.