Implications of loading/unloading a subduction zone with a heterogeneously coupled interface

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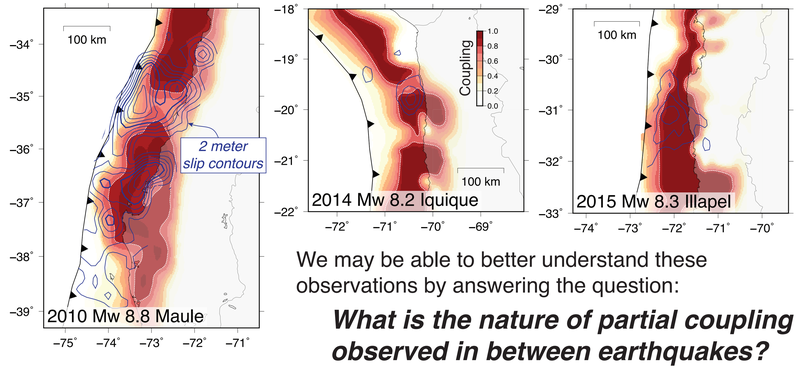
Introduction

Comparisons of co-seismic slip in three great earthquakes offshore Chile (2010 Maule, 2014 Iquique, and 2015 Illapel) to inter-seismic coupling inferred from onshore GPS prior to the events show:

- *Slip propagates outside the regions of highest coupling*
- *Events with greater slip areas also have larger slip magnitudes*
- *Tsunamigenic slip occurs despite low inferred coupling near the trench*



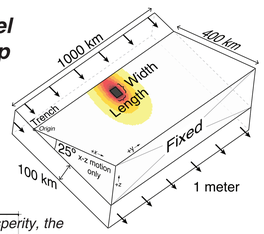
We may be able to better understand these observations by answering the question:

What is the nature of partial coupling observed in between earthquakes?

Pseudo-coupling Model

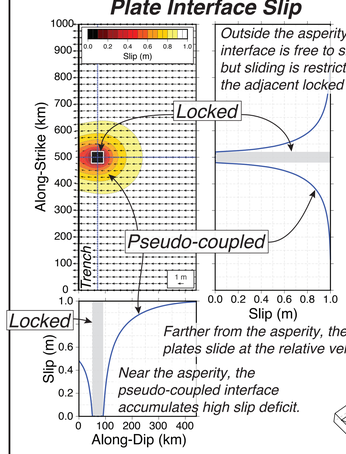
We assume that the plates are elastic bodies, so inter-seismic slip deficit must be continuous on the plate boundary. As a result, areas outside locked asperities can accumulate slip deficit even with no friction on the boundary. We call this "pseudo-coupling" to distinguish it from mechanical coupling and quantify its effect with a finite element model.

Model Setup



We displace the top and bottom of the subducting plate 1 meter while holding the backstop of the upper plate fixed. No slip is allowed in asperities, but the rest of the interface can slide freely. Increasing the dimensions of the locked zone increases the area of the effect.

Plate Interface Slip

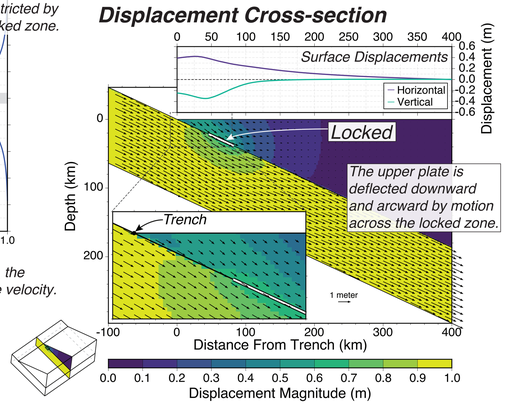


Outside the asperity, the interface is free to slide, but sliding is restricted by the adjacent locked zone.

Farther from the asperity, the plates slide at the relative velocity.

Near the asperity, the pseudo-coupled interface accumulates high slip deficit.

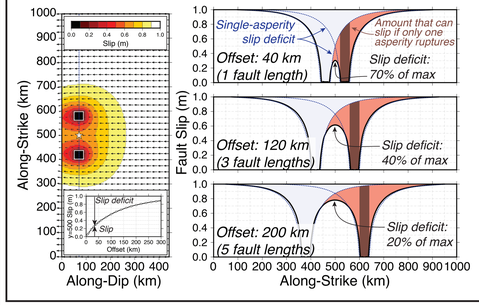
Displacement Cross-section



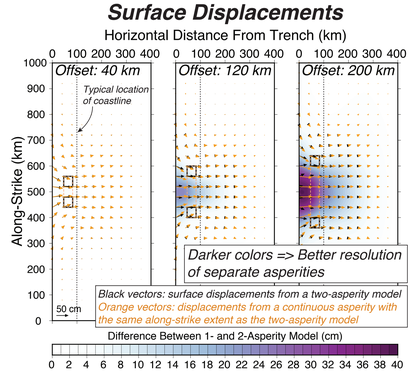
The upper plate is deflected downward and arcward by motion across the locked zone.

Interactions Between Asperities

The pseudo-coupling zones around asperities can overlap, increasing the slip deficit on the interface between them (despite the free-slip condition). With greater separation, the slip deficit between the asperities decreases.



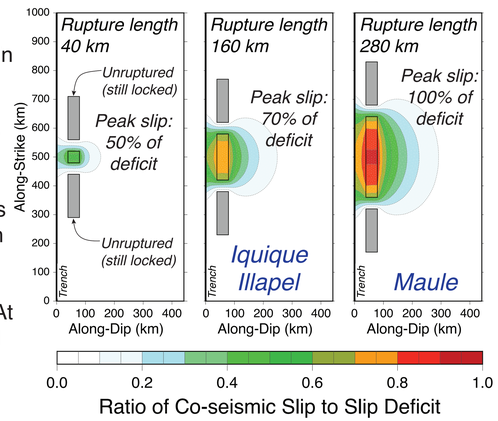
Surface Displacements



When asperities are close, they cannot be distinguished from a single, continuous asperity by their surface displacements.

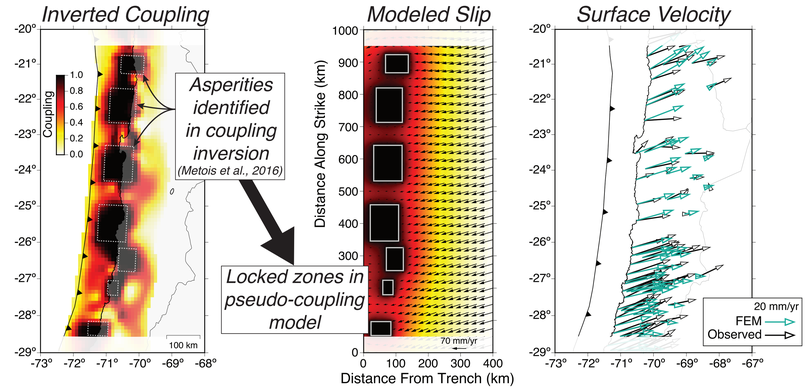
Pseudo-coupling around nearby, unruptured asperities limits the maximum available slip in an earthquake. A 40-km long event bounded by locked areas can slip up to only ~50% of the accumulated slip deficit. As the earthquake grows in length, it overlaps with a lower level of pseudo-coupling and can have greater co-seismic slip. At a length of ~250 km and larger, the earthquake can release the full accumulated slip deficit.

Co-seismic Interface Slip



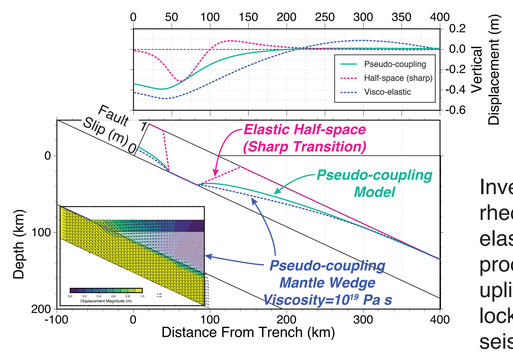
Imaging Plate Boundary Coupling

We fit observed horizontal GPS velocities from Chile reasonably well with a pseudo-coupling model (dip=17°, displacement=70 mm, 10° obliquity). This suggests that pseudo-coupling may provide a useful independent physical constraint for inferring the slip deficit distribution on the subduction interface.

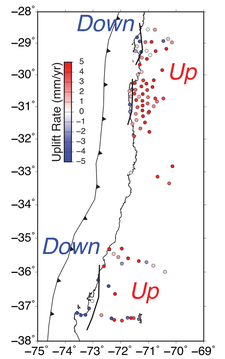


Elastic-only Models?

Vertical displacements in the upper plate are sensitive to the model rheology. Fully elastic pseudo-couping models have broad subsidence of the upper plate. In contrast, pseudo-coupling models with an elastic upper plate on top of a viscous mantle wedge result in a transition from subsidence to uplift due to flexure of the elastic region.



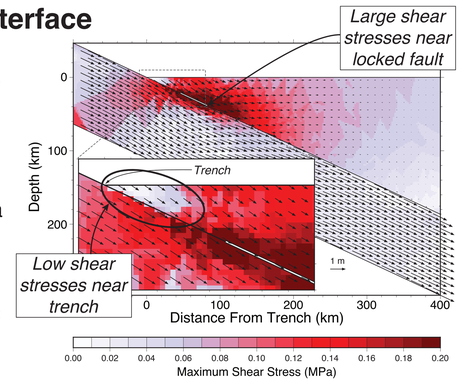
Vertical Motions in Chile



Inverting vertical motions from a rheologically layered Earth using elastic Green's functions may produce artifacts, such as mapping uplift to a sharp transition from locked to sliding at the base of the seismogenic zone.

Loading the Shallow Interface

The megathrust up-dip of the locked zone accumulates a large slip deficit and displacements near the trench. These displacements occur without accumulating significant elastic strain, i.e., the region moves as a block. During an earthquake, the shallow interface may have slip magnitudes comparable to the asperity, but without radiating the same characteristic seismic waves.

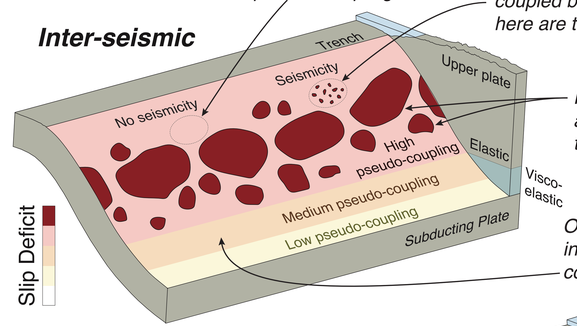


Summary

Some areas in the seismogenic zone appear partially coupled due to pseudo-coupling alone.

Other regions appear partially coupled because asperities here are too small to resolve.

Inter-seismic



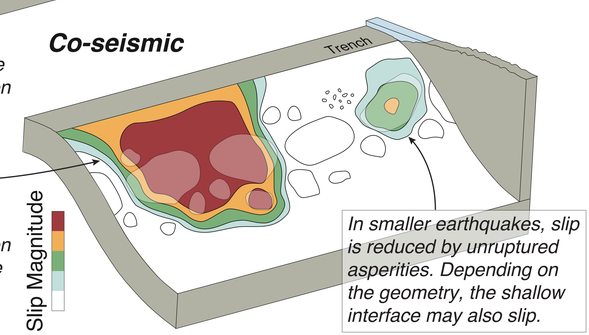
Fully locked asperities accumulate slip deficit at the convergence rate.

Outside asperities, the interface appears partially coupled over a large area.

Co-seismic

The eventual earthquake characteristics depend on the number and size of ruptured asperities.

Large, multi-asperity ruptures release the full accumulated slip deficit, allowing the up-dip region to slip in concert with the seismogenic zone.



In smaller earthquakes, slip is reduced by unruptured asperities. Depending on the geometry, the shallow interface may also slip.