Overprinting the signal of inter-seismic coupling on subduction megathrusts throughout the earthquake cycle

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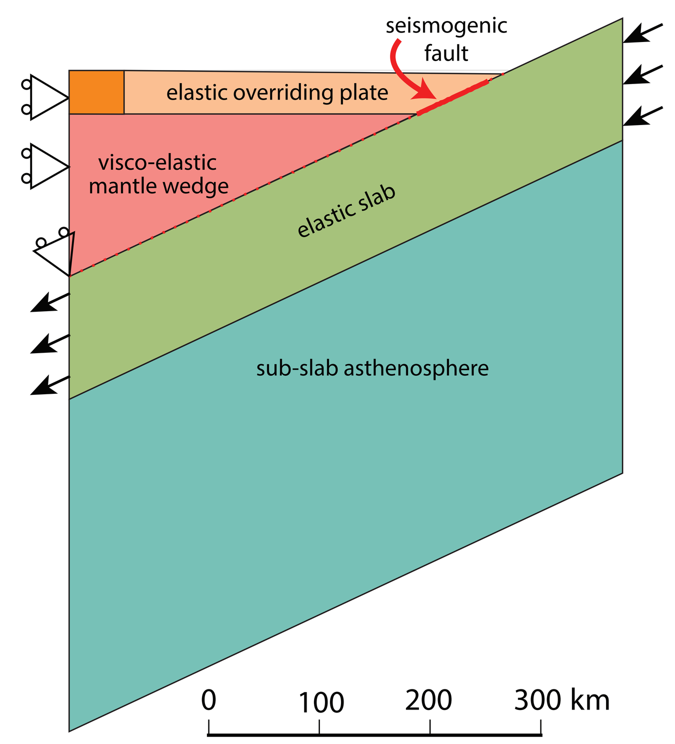
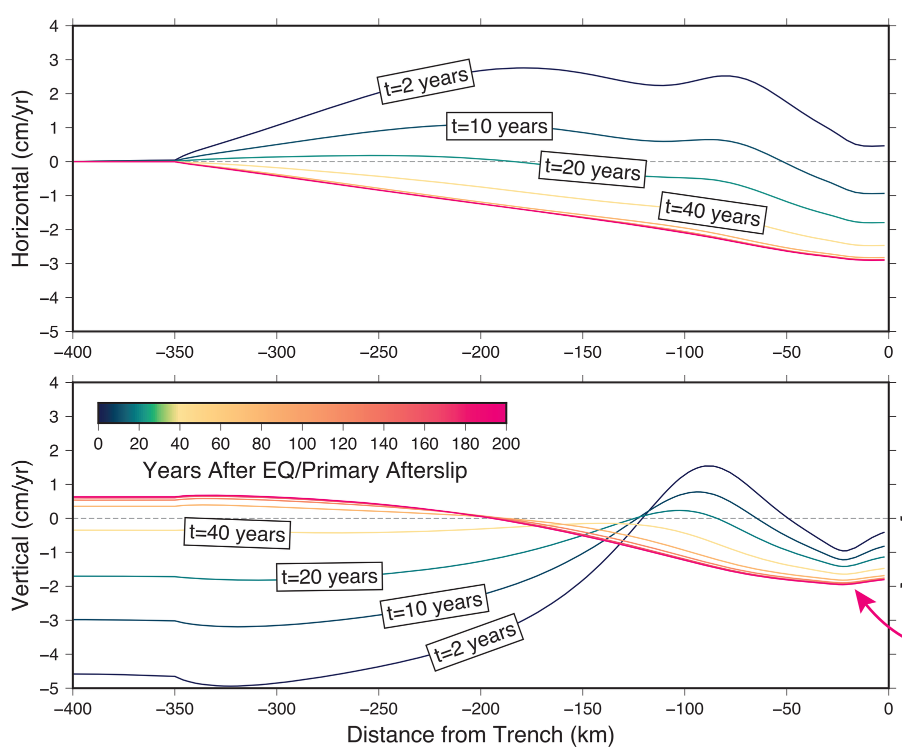
Intuition from 2D Modeling



Geodetic measurements of pre-earthquake surface motions in subduction zones provide important constraints on where the plate boundary is locked and building towards the next great (Mw 8.0+) earthquake. Govers et al. (2018) developed a suite of 2-D models to explore what processes are responsible for these observations.

An important model result consistent with geodetic observations is that following the co-seismic and rapid, primary afterslip stages, bulk relaxation of the visco-elastic regions produces surface velocities that obscure the effects of elastic loading. The duration of the effect depends on on the Maxwell relaxation time and the recurrence interval of the earthquake.



The surface velocities shown here correspond to a model with a Maxwell relaxation time of ~8 years and a recurrence interval of 200 years. The surface velocities reflect the effects of plate interface coupling while the visco-elastic region relaxes co-seismic stresses. The pattern for a completely relaxed viscous region is shown in red.

Surface velocities at times after co-seismic and primary afterslip.

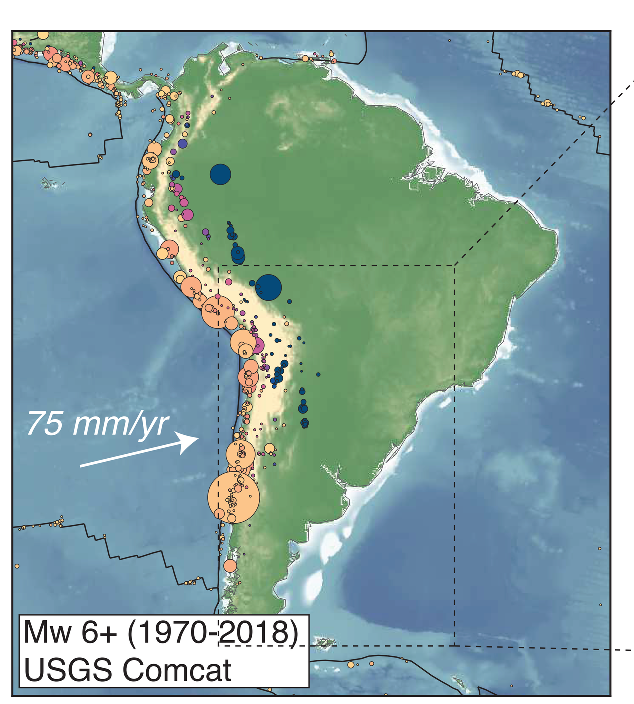
Surface velocity for fully relaxed visco-elastic region

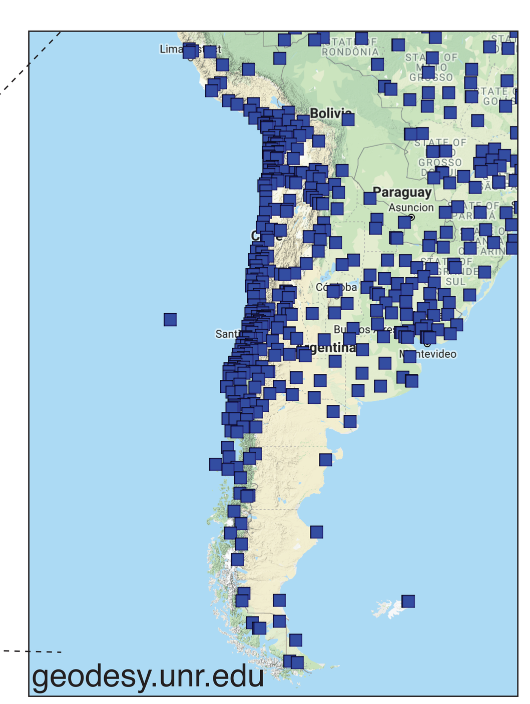
Check out our video discussing insights from these 2-D subduction earthquake cycle models on YouTube:

https://www.youtube.com/watch?v=V5b0SaouSpg

We test this hypothesis in South America for historical earthquakes because it has (a) a network of GPS instruments commonly used to infer plate interface coupling and (b) a history of large events.

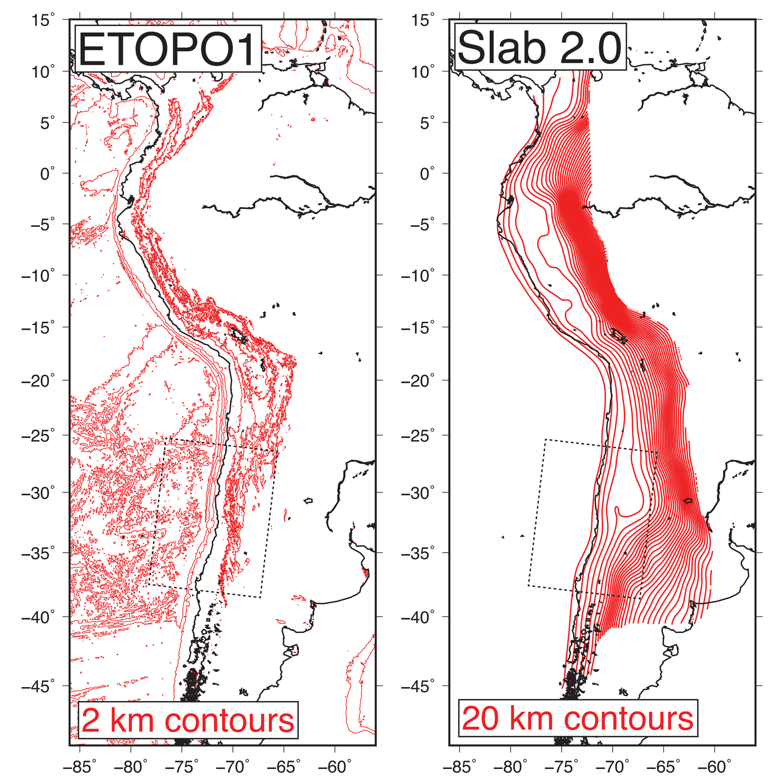
We model the subduction zone in 3-D to address the following question:



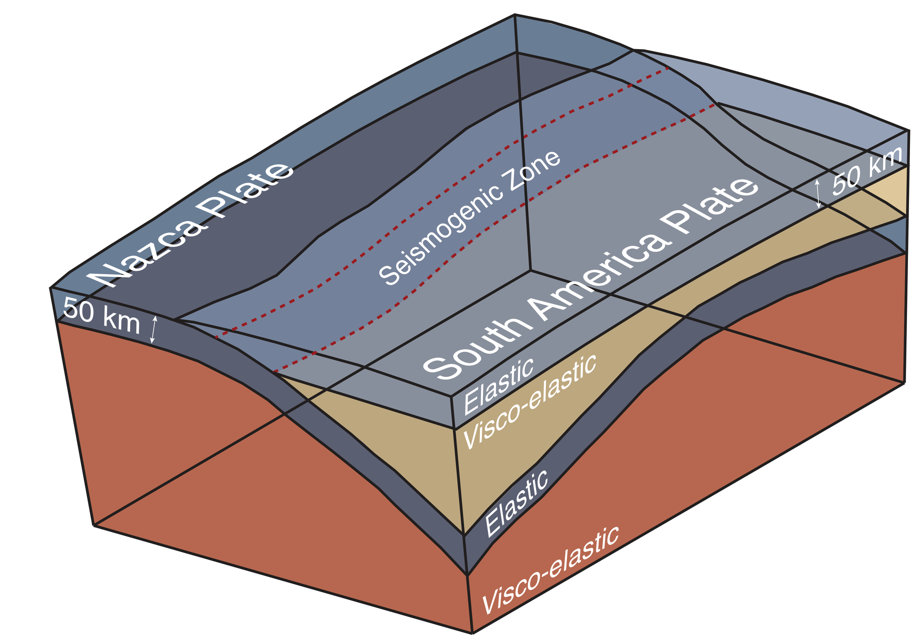


How long after an earthquake does it take for upper plate surface velocities to reflect purely interface coupling and not bulk relaxation?

South America 3D Model Setup

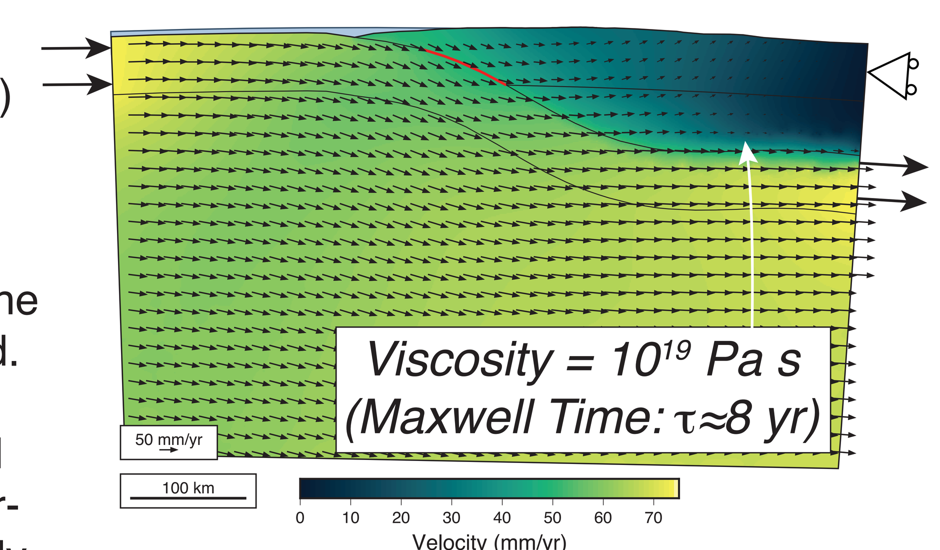


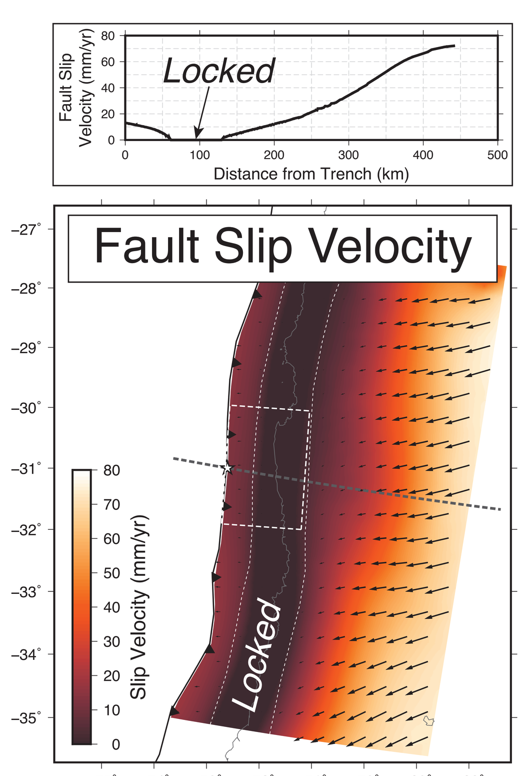
The surface topography and bathymetry are from ETOPO1 (Amante and Eakins, 2009). The geometry of the subducting plate is from Slab 2.0 (G. Hayes, personal communication).



Inter-seismic Loading

Plate motions (Argus et al., 2014) are applied at the up- and down-dip ends of the slab, while the back of the upper plate is fixed. The seismogenic zone is locked and the rest of the interface can slide freely.

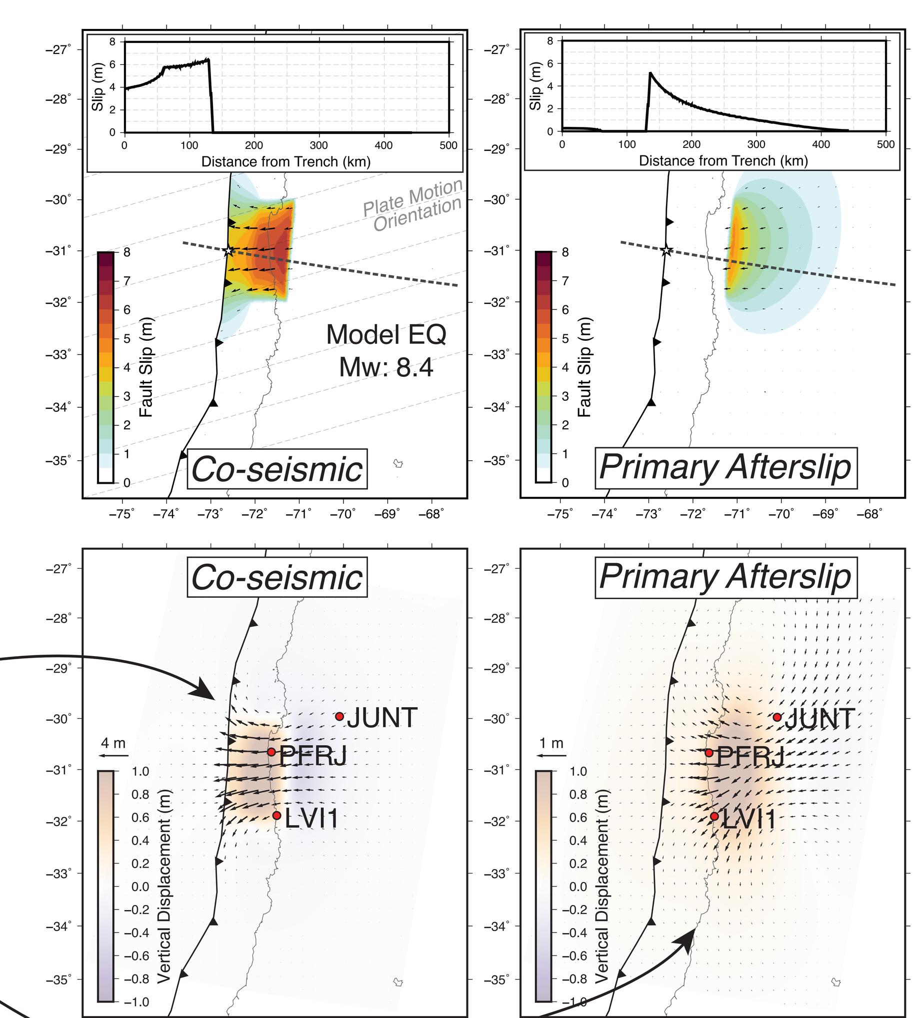




The locked zone restricts adjacent, freely sliding sections from moving at the full plate rate, making them appear partially coupled.

Earthquake/Primary Afterslip Simulation

After 15 earthquake cycles, we simulate the 2015 Mw 8.3 Illapel earthquake. First, we load the subduction zone for 72 years (the previous great earthquake in this section was in 1943), then release the previously locked interface from 30°S to 32°S. During the co-seismic stage, the down-dip region remains locked. After the earthquake, we allow the down-dip shear zone to begin relaxing. This simulates the relatively rapid primary afterslip that lasts up to several years.

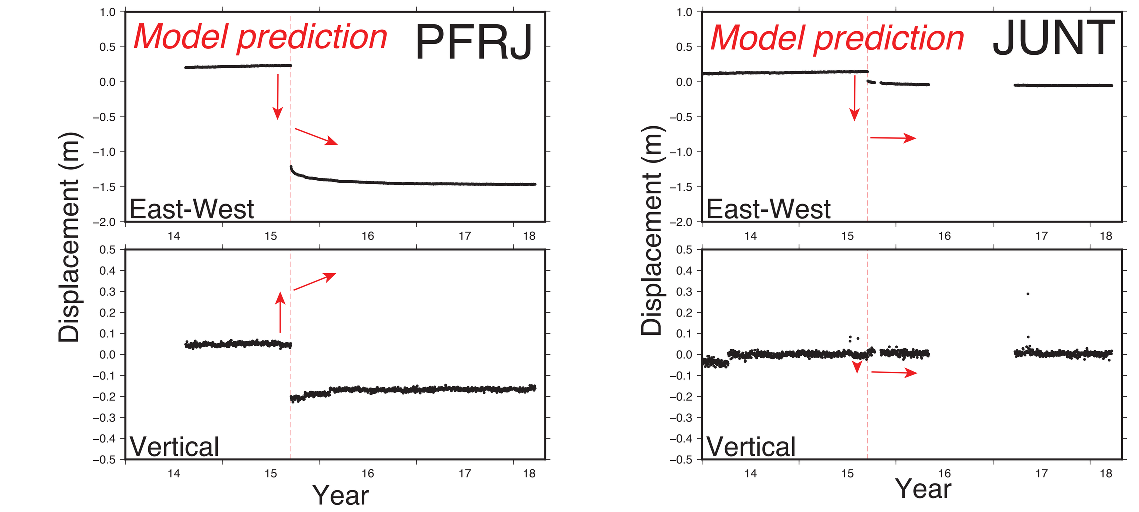


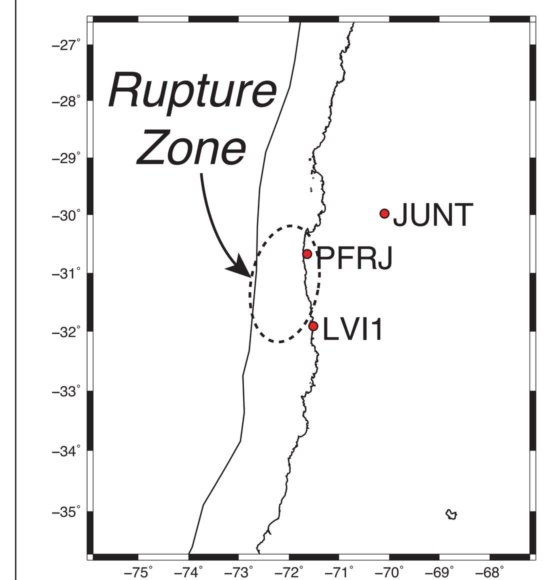
Co-seismic surface displacements are largest between the trench and the coast, and transition from uplift to subsidence occurs near coast.

Post-seismic displacements are concentrated onshore, have a broader footprint, generally result in uplift, and have smaller magnitudes in the horizontal component.

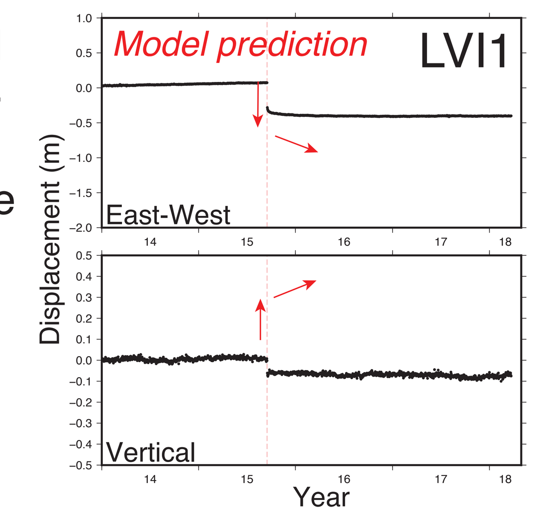
Comparison with Geodetic Observations

Here, we compare the results from our simulated earthquake to geodetic observations near the rupture zone. In this initial model, we are focused primarily on the orientations and relative magnitudes of displacements rather than trying to fit the GPS precisely.

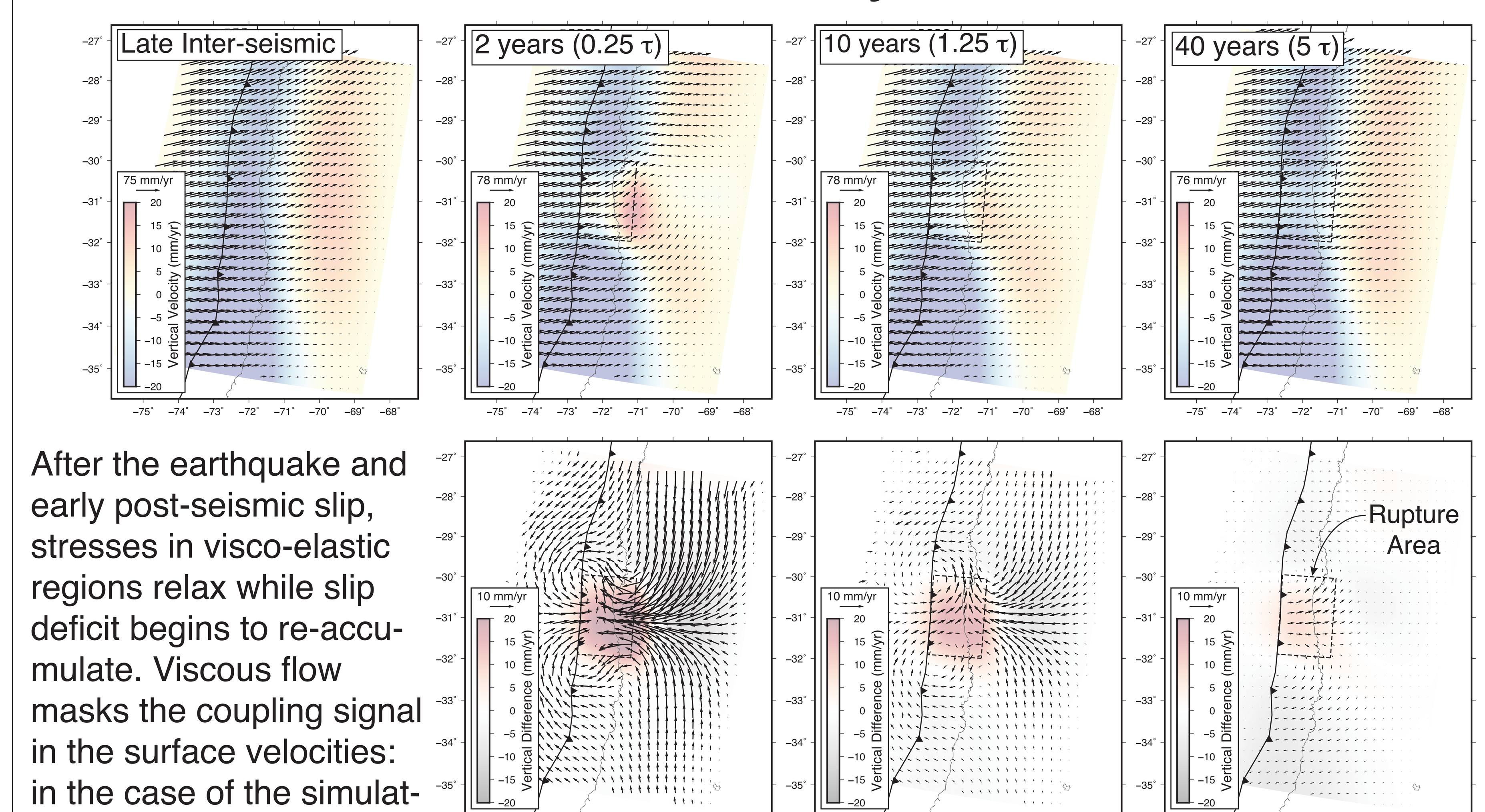




Our model predicts coastal stations will rise, then continue rising during the primary afterslip stage. However, the coastal stations PFRJ and LVI1 subside during the earthquake, suggesting our modeled rupture zone extends too far down-dip. Station JUNT is not strongly affected by co-seismic slip, but is predicted to move westward during the early post-seismic stage.



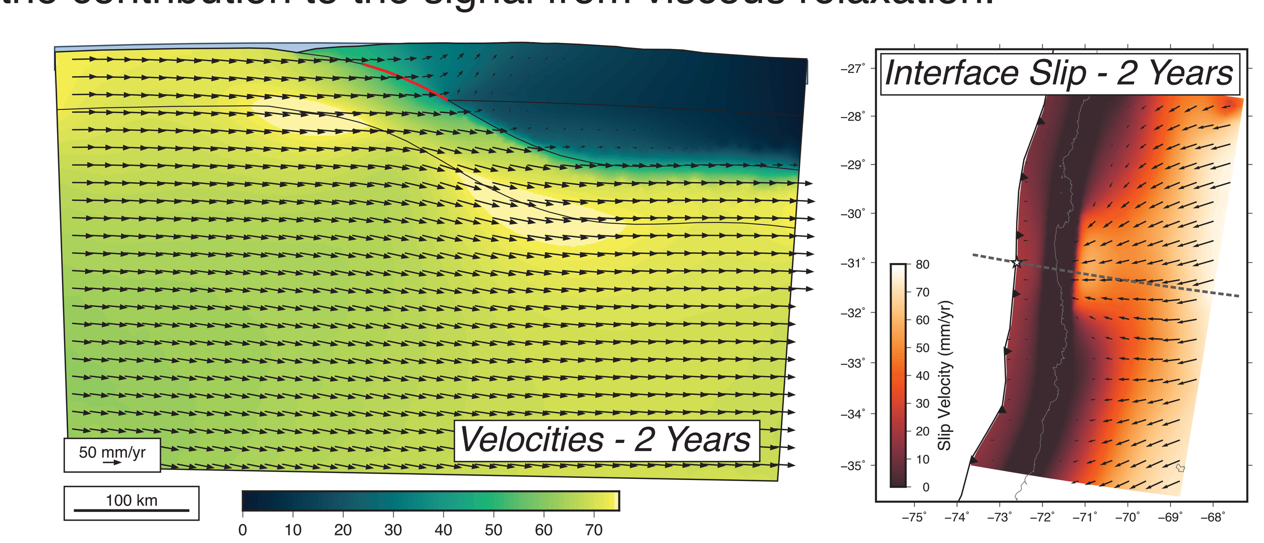
Modeled Post-seismic Velocity Field



After the earthquake and early post-seismic slip, stresses in visco-elastic regions relax while slip deficit begins to re-accumulate. Viscous flow masks the coupling signal in the surface velocities: in the case of the simulated 2015 Illapel earthquake, for 50+ years.

We subtract the modeled post-seismic surface velocities from the late inter-seismic velocities (when the viscous regions are relaxed) to isolate the contribution to the signal from viscous relaxation.

The effects of viscous flow can be seen in cross-section, slowing the upper plate and increasing the velocity of the subducting plate. In addition, the fault slip velocity is perturbed down-dip of the rupture.



Preliminary Conclusions

Our models show that viscous relaxation will affect the region of the 2015 Mw 8.3 Illapel earthquake for ~40 years (5 Maxwell relaxation times). This suggests that Mw 8+ events occurring within the past half century along the South America subduction zone may cause a relaxation signal that biases, if not entirely obscures, the plate interface coupling signal.