Effect of Rheology on Afterslip and Viscoelastic Patterns Following the 2010 Mw 8.8 Maule, Chile, Earthquake

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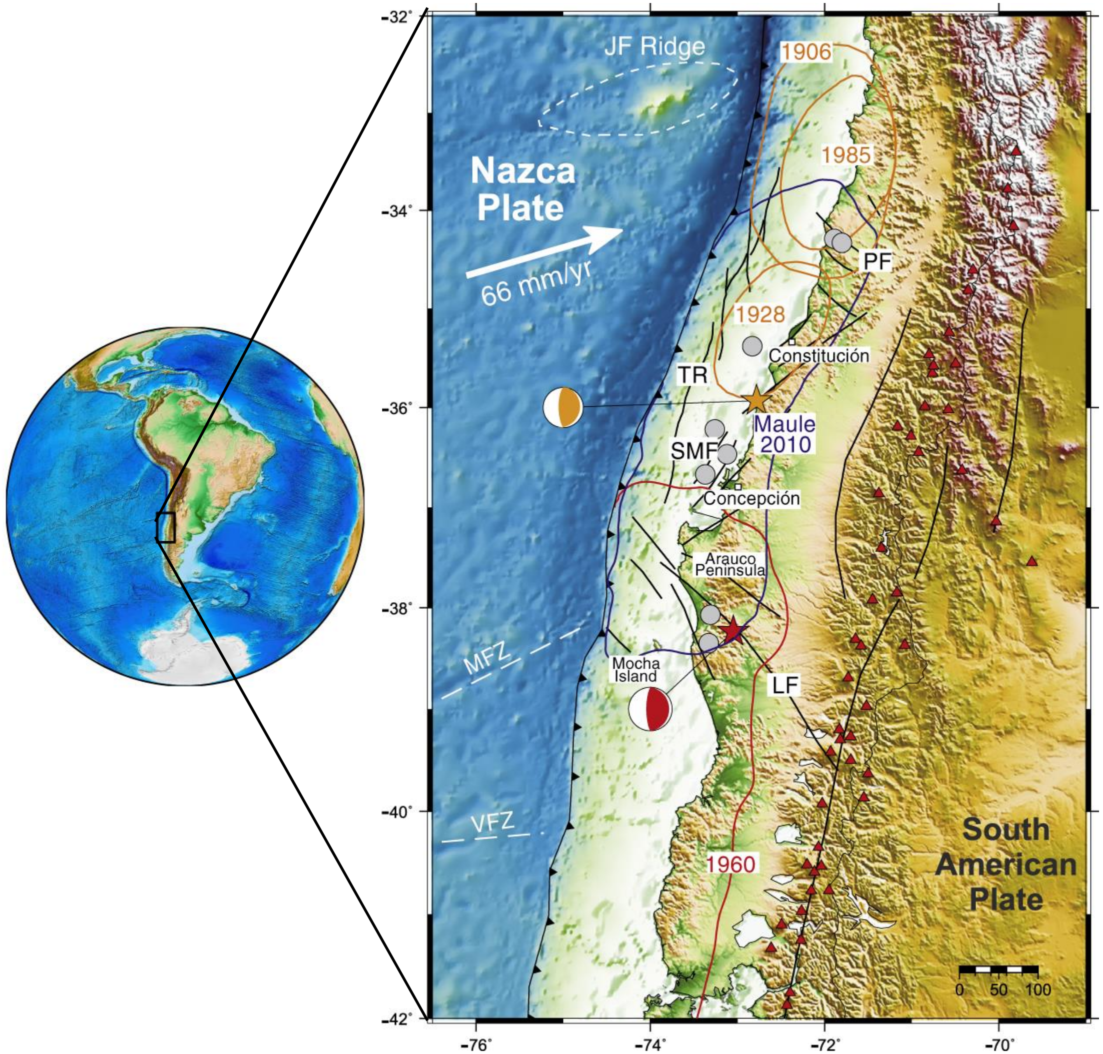
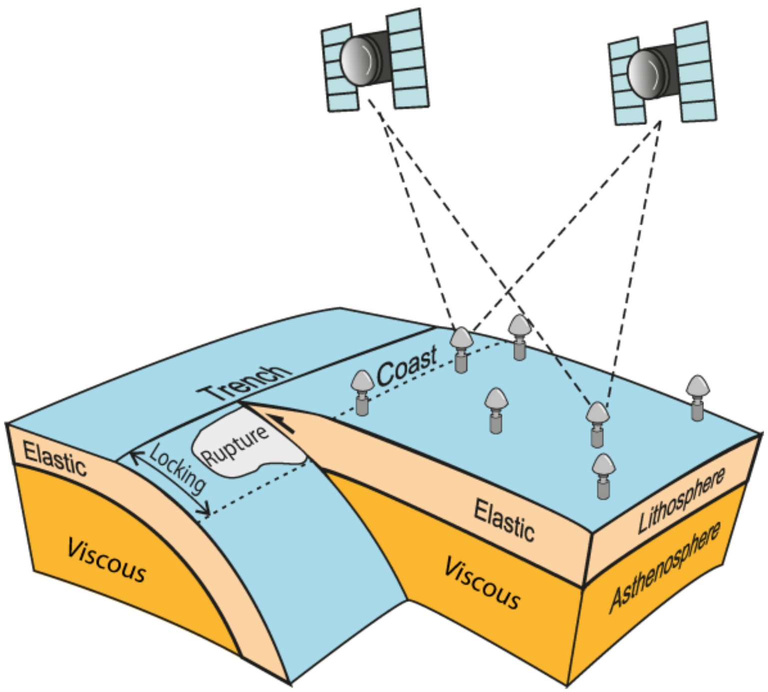
The seismic cycle constrained by GPS observations



Modified from Moreno et al. (2012)

GPS observations network



Modified from Wang et al. (2012)

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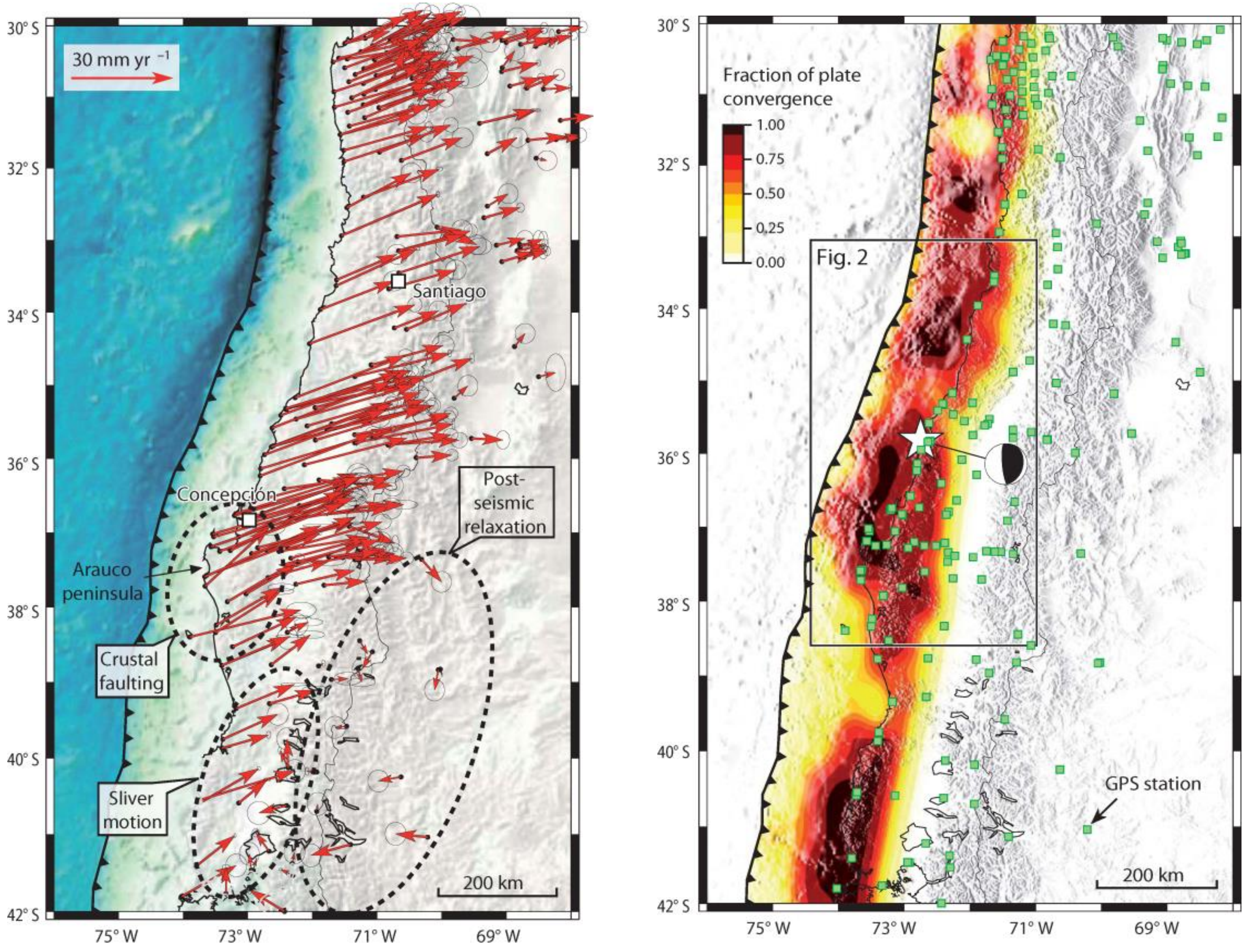
Interseismic GPS observations



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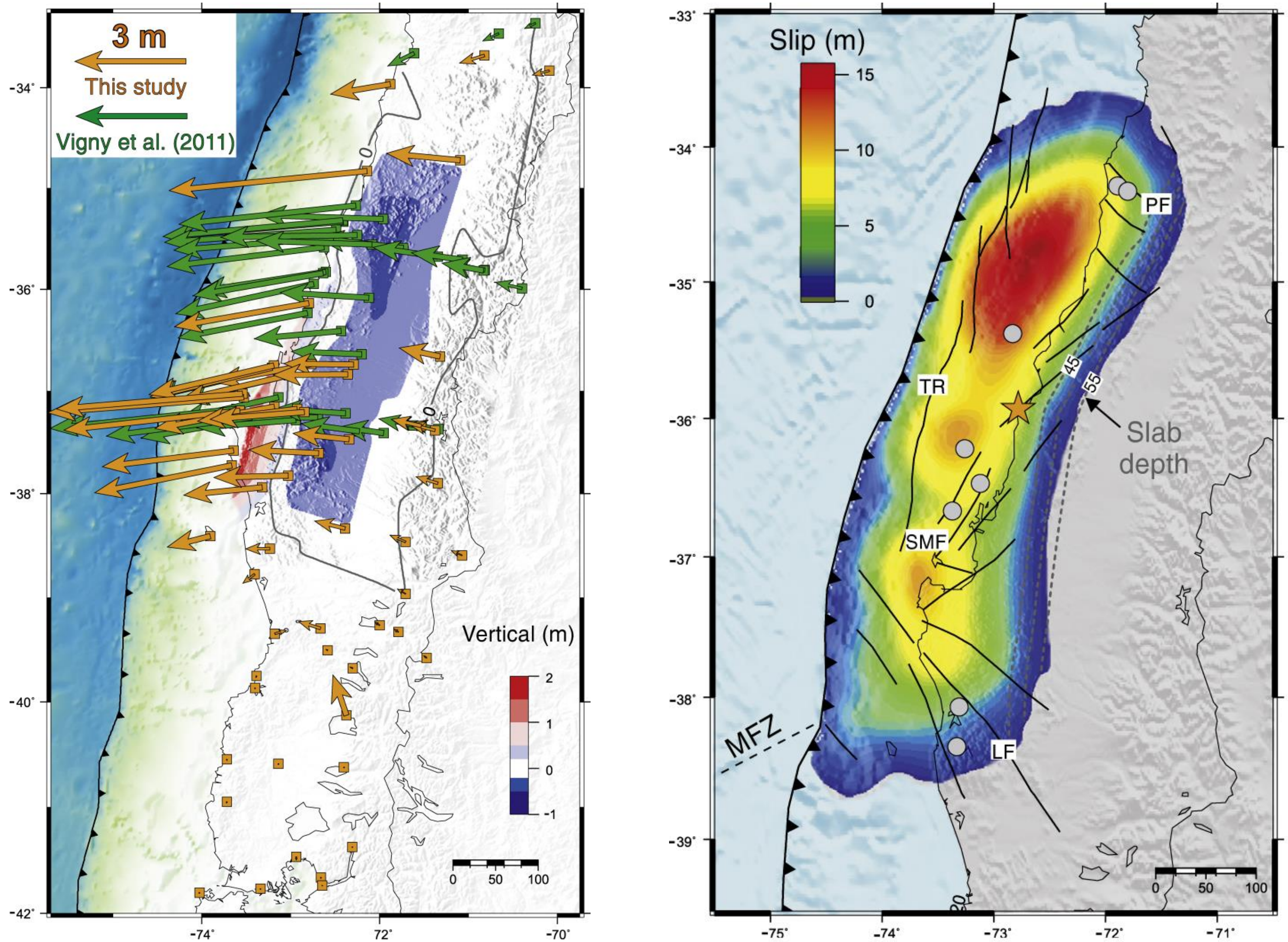
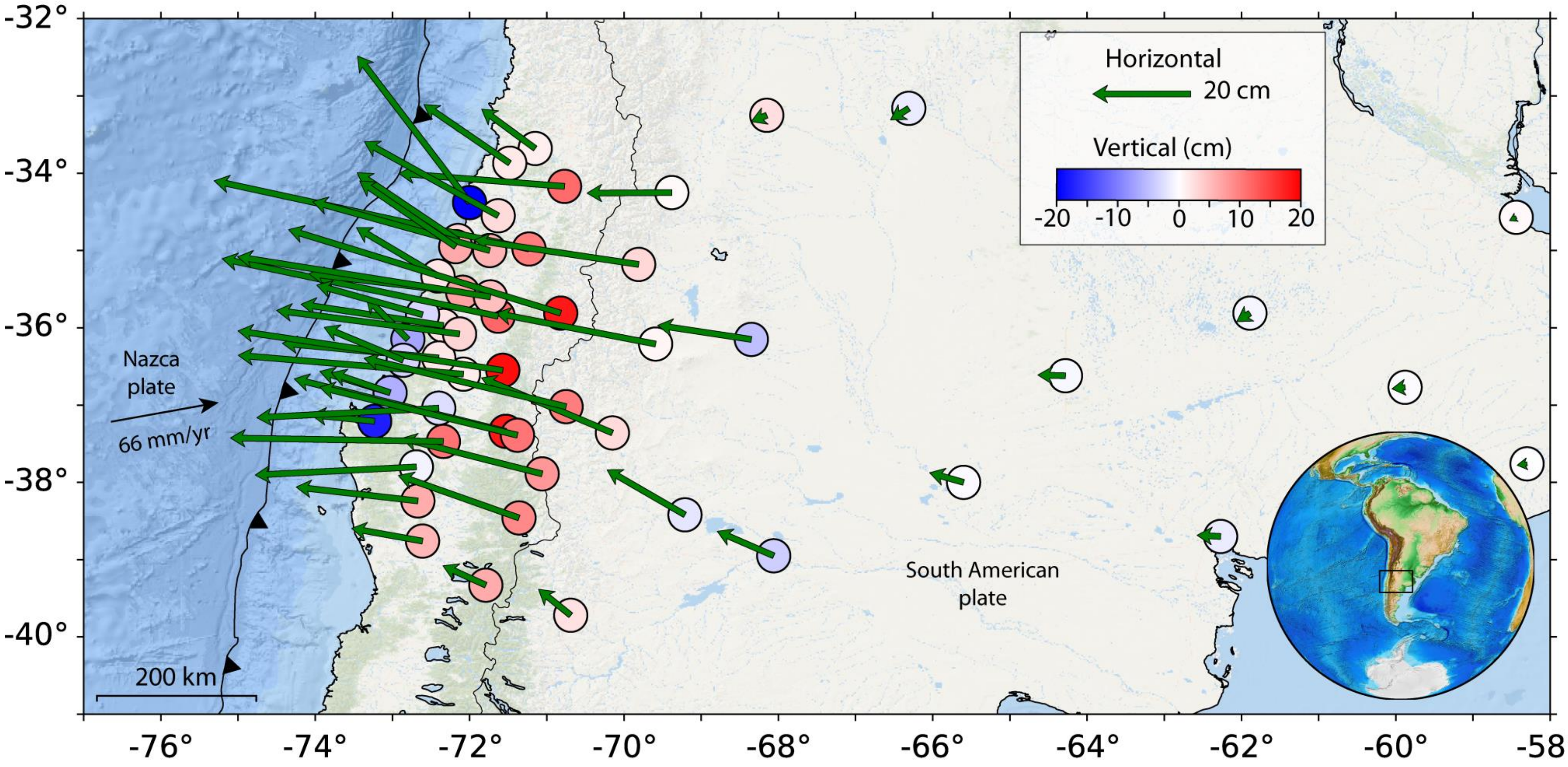
Coseismic GPS observations



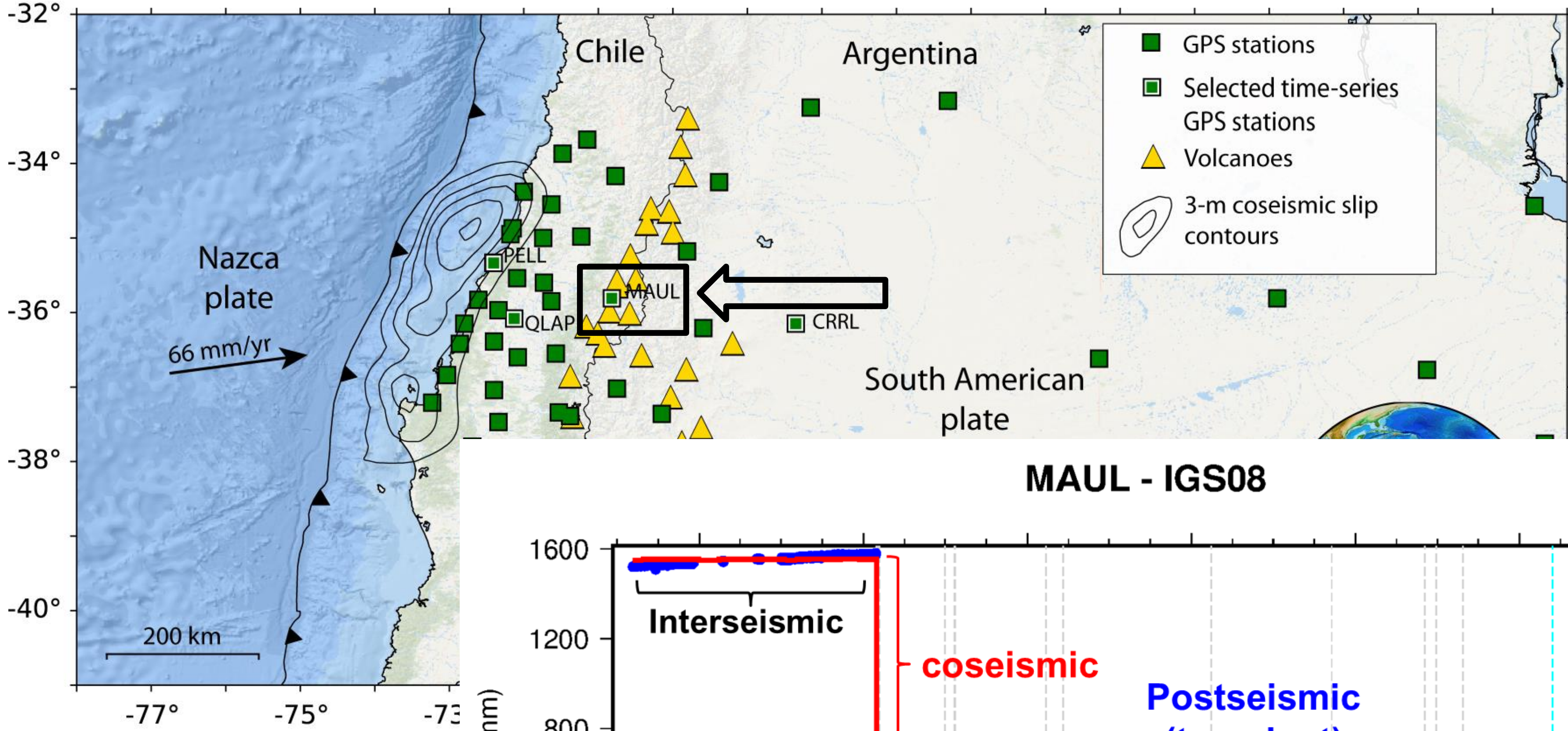
Modified from Moreno et al. (2012)

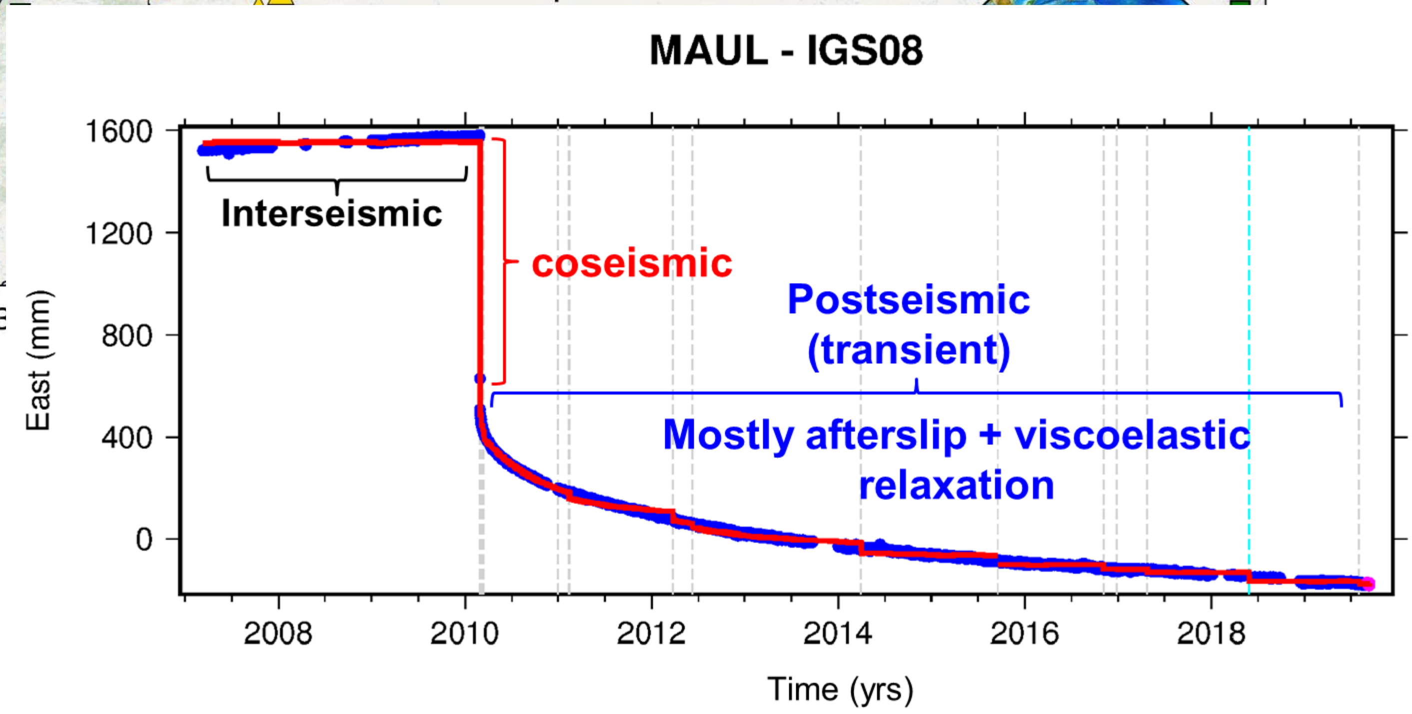
Postseismic GPS Observations



- Six years of cumulative postseismic displacements (Li et al., 2017)
- Aftershock and/or jumps, and secular were removed
- Stable South American frame

Postseismic GPS Observations





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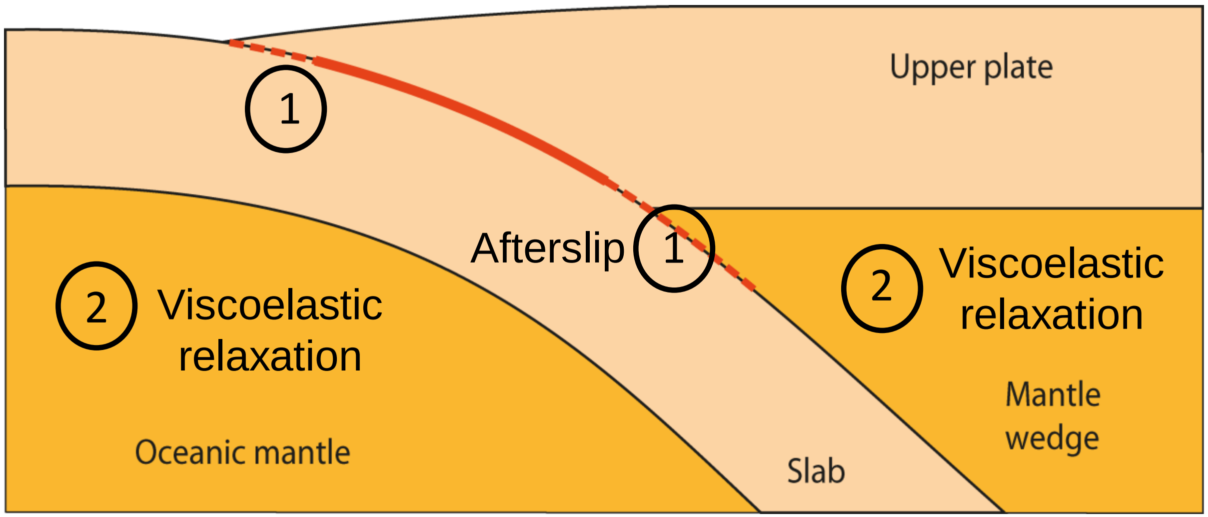
Afterslip inversions need a rheology model



Modified from Wang et al. (2012)

How different can afterslip distribution at the fault interface result from the choice of rheology?

Note: the following slides contain figures (model setup, workflow, results, and afterslip-aftershock correlation) modified from the original study of C. Peña et al. (2020), EPSL (in press), https://doi.org/10.1016/j.epsl.2020.116292

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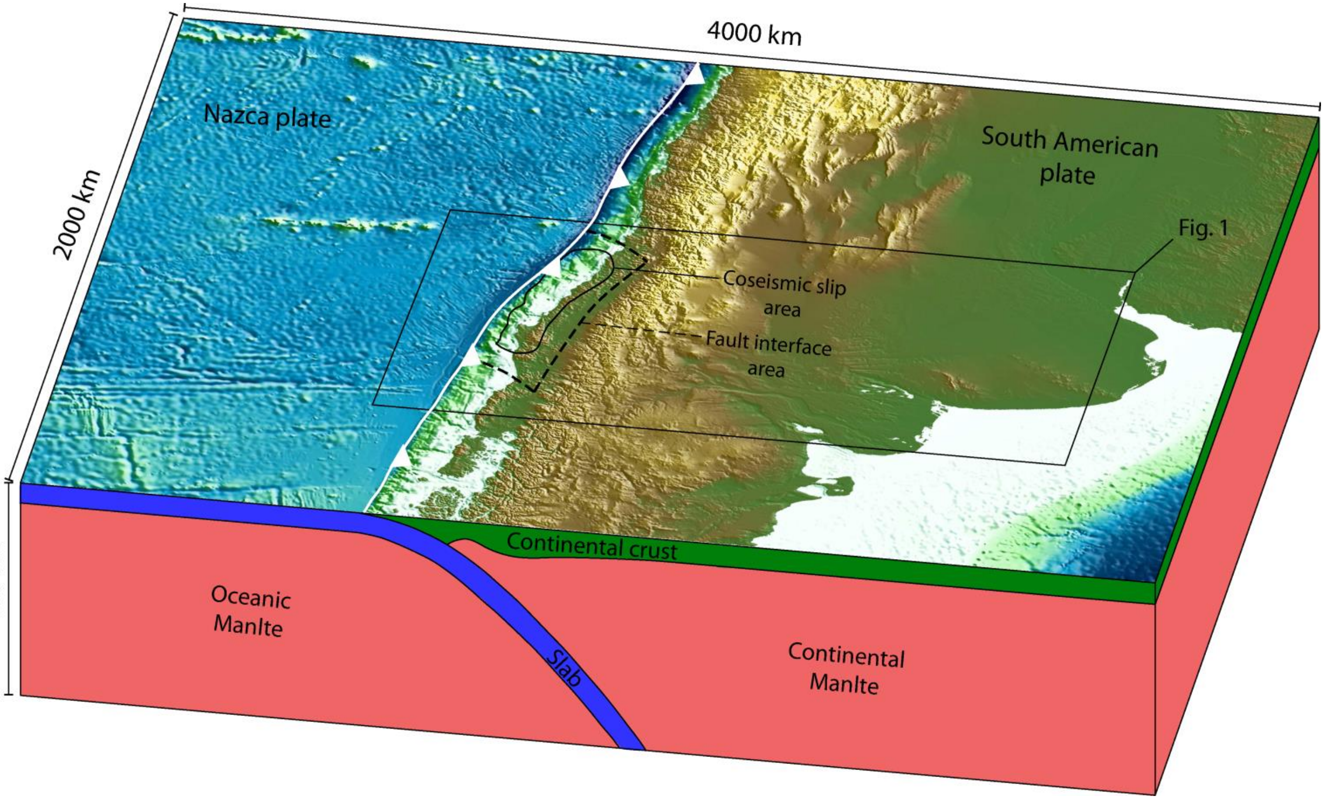
3D-FEM Model Setup



Discontinuities (geometry)

- Slab (Hayes et al., 2012)
- Moho (Tassara et al., 2006)

Boundary and initial conditions

- Coseismic slip model (Moreno et al., 2012)
- Temperature field (Völker et al., 2011)

Afterslip Inversion Workflow

Step 1: Viscoelastic forward modelling

Observed postseismic displacements at cGPS stations – Modelled postseismic displacements at cGPS stations

Input →

Step 2: Inversion

- Least square
- Non-negative rake
- Smoothing laplacian

→

Result

Afterslip distribution

$$\dot{\varepsilon} = A\sigma^n exp\left(\frac{-Q}{RT}\right) \quad (1)$$

→ **Power-law rheology (Dislocation creep)**

$$\dot{\varepsilon} = \frac{\sigma}{2\eta} \quad (2)$$

→ **Linear rheology (η = constant)**

- $\dot{\varepsilon}$ creep strain rate
- A material constant
- σ differential stress
- η effective viscosity
- Q activation enthalpy
- R gas constant
- T absolute temperature
  (from Völker et al., 2011)

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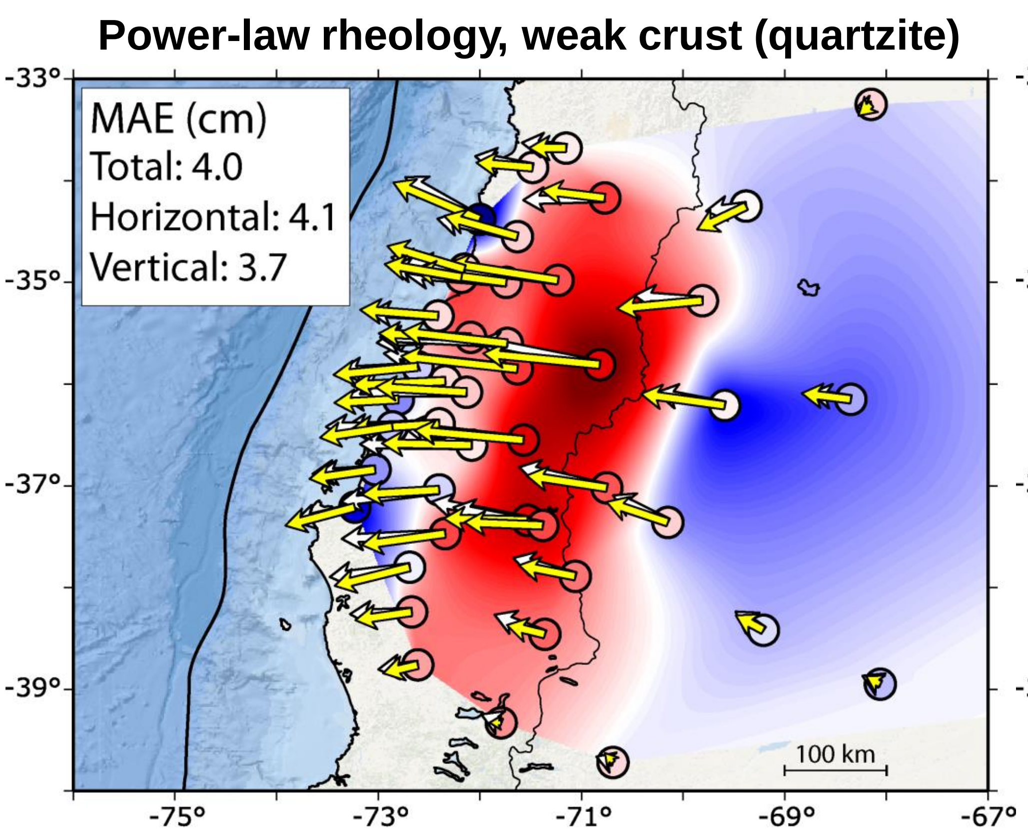
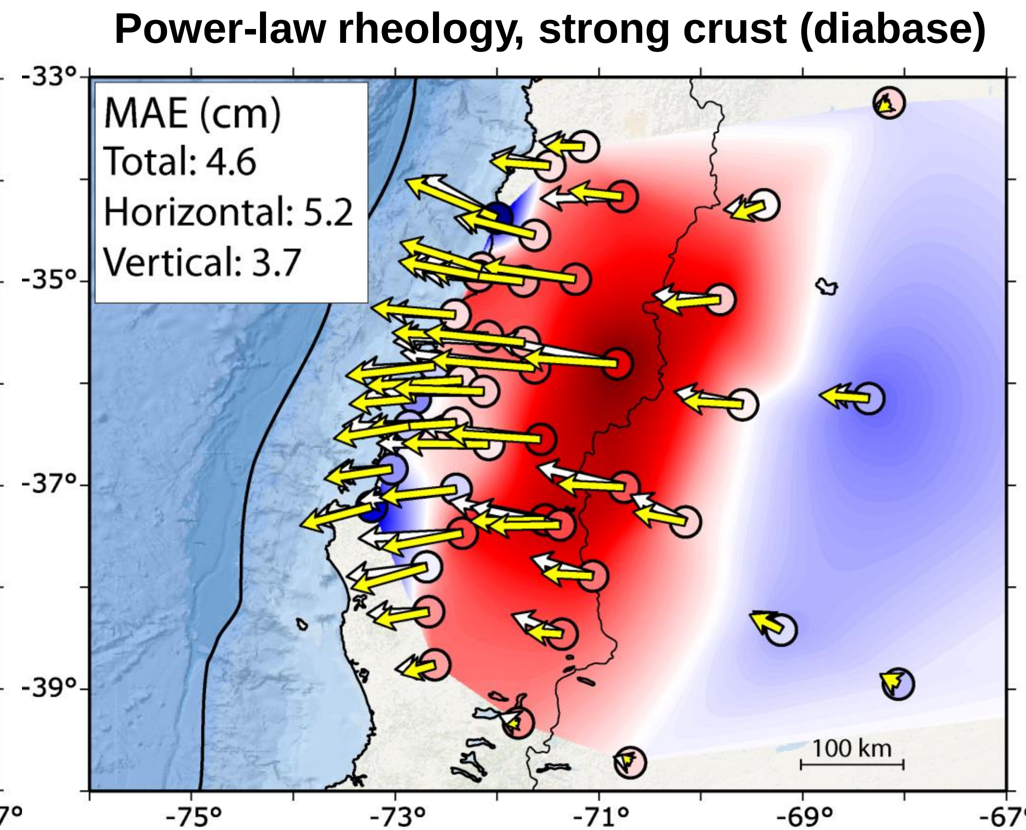
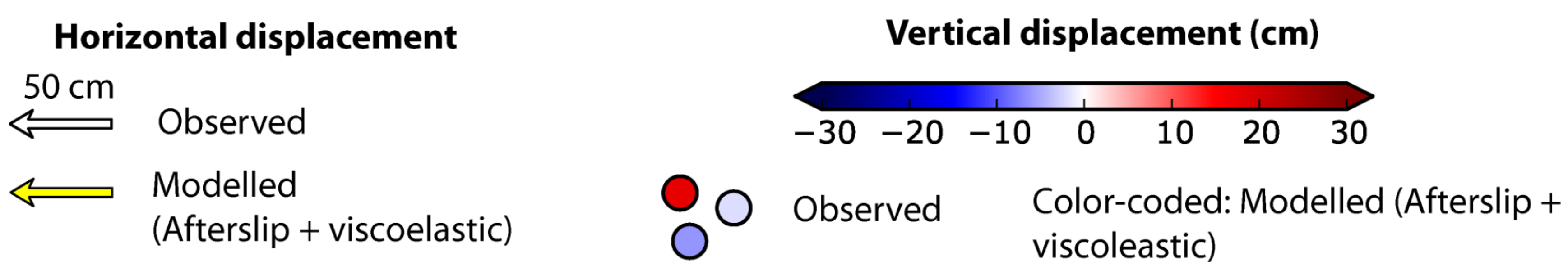
Results: Surface Displacements





Power-law simulations have same creep parameters for: Cont. mantle: Olivine 0.1 wt.% water, Slab: Diabase, Ocea. mantle: Olivine 0.005 wt.% water



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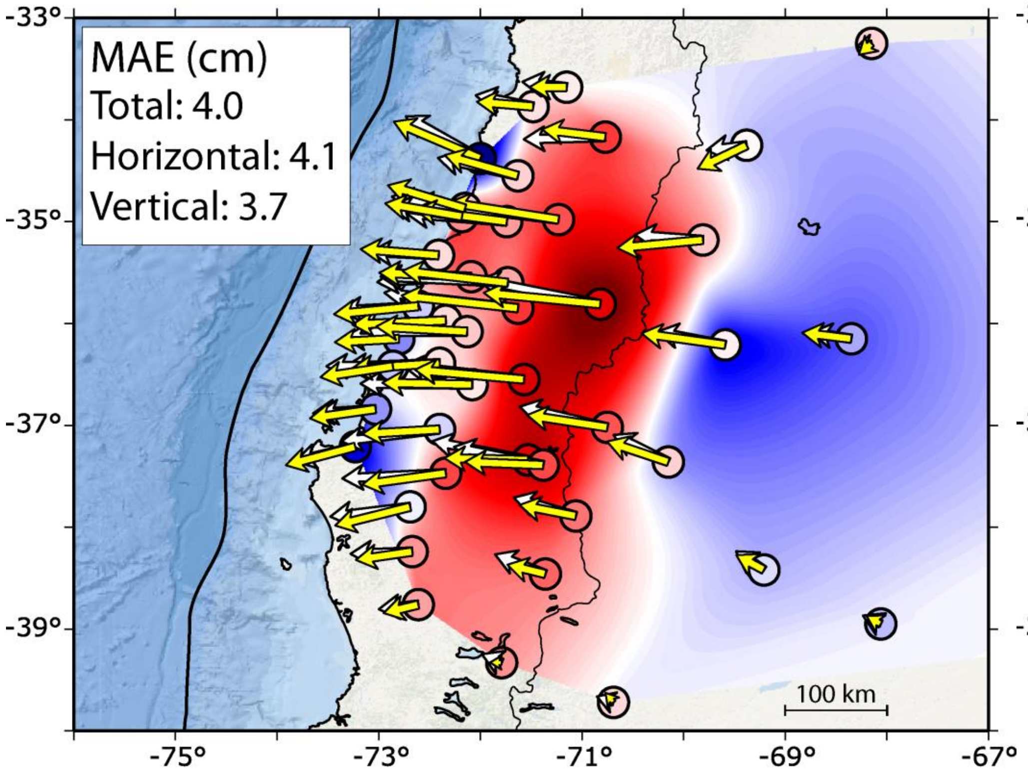
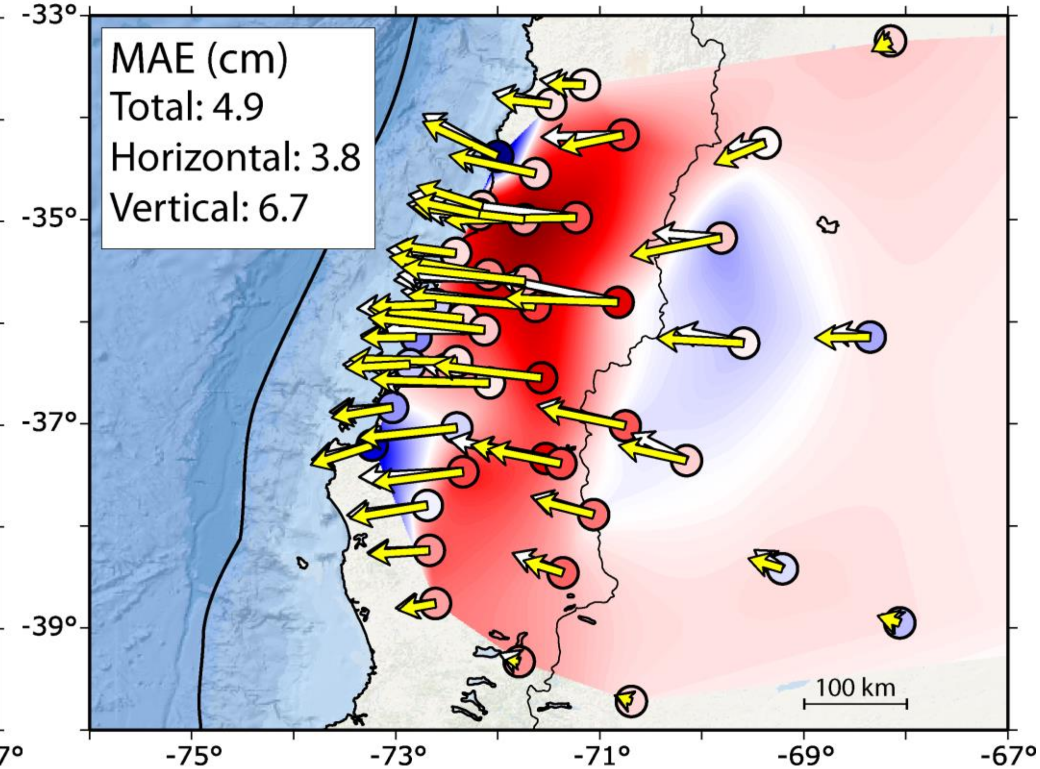
Results: Surface Displacements

Power-law rheology, weak crust (quartzite)



Linear rheology, elastic crust



Linear rheology simulation: Mantle: linear viscosity, slab: elastic

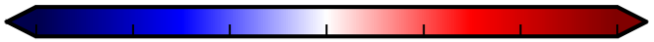
Horizontal displacement

50 cm

Observed

Modelled
(Afterslip + viscoelastic)

Vertical displacement (cm)



Observed

Color-coded: Modelled (Afterslip + viscoleastic)

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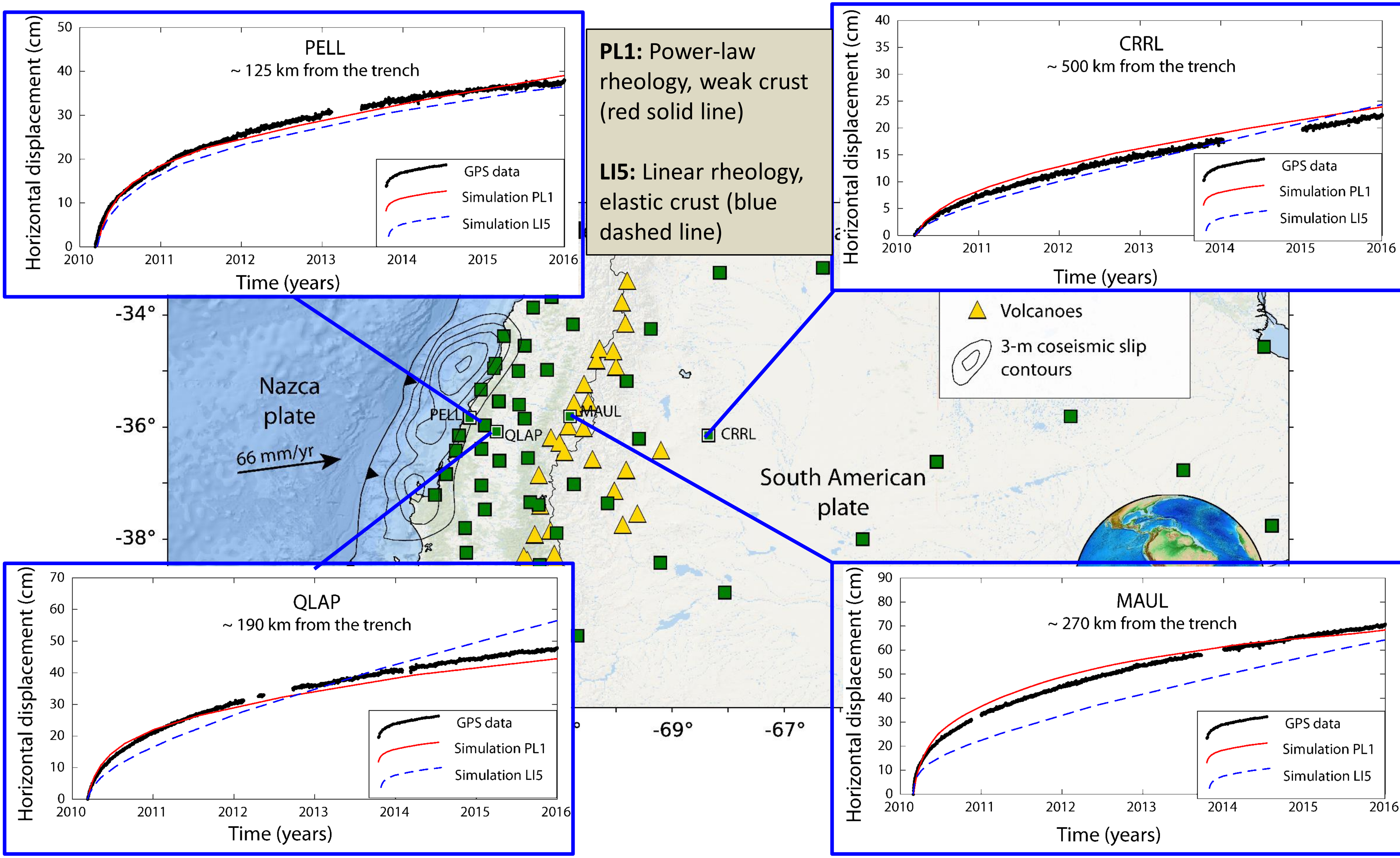
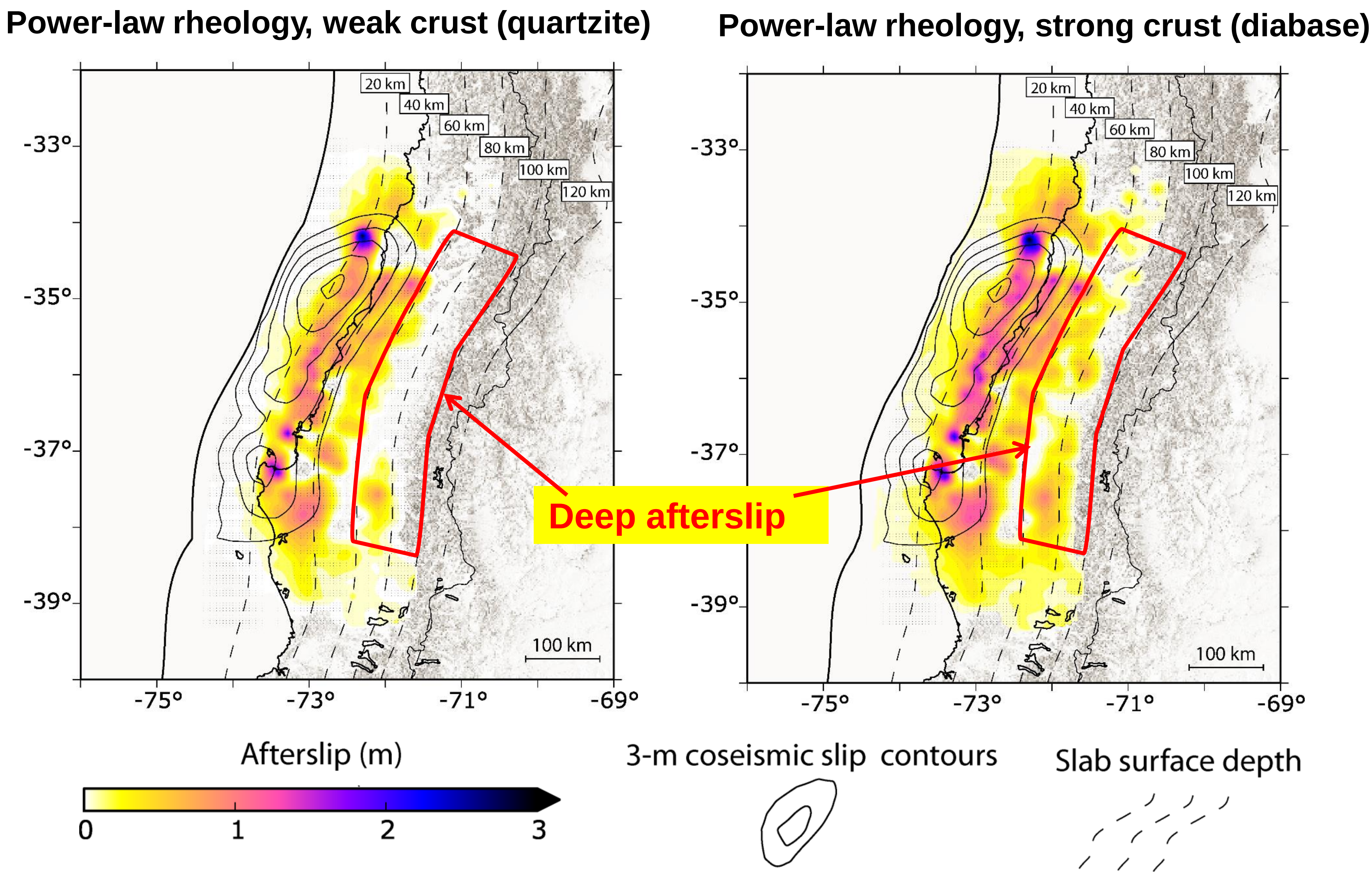
Results: Linear vs Power-law time series



PL1: Power-law rheology, weak crust (red solid line)

LI5: Linear rheology, elastic crust (blue dashed line)

Results: Afterslip Distributions



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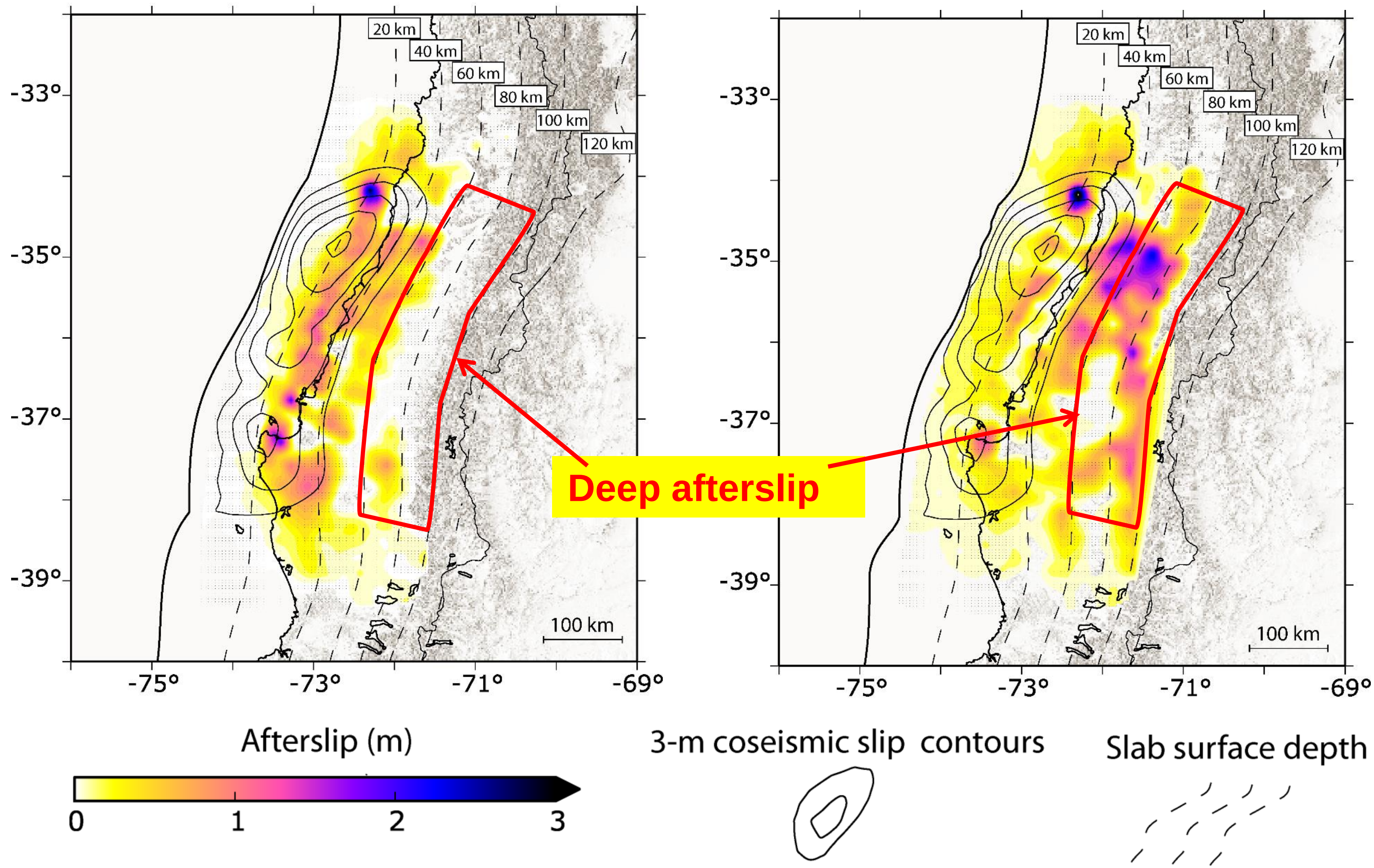
Results: Afterslip Distributions

Power-law rheology, weak crust (quartzite) | **Linear rheology, elastic crust**



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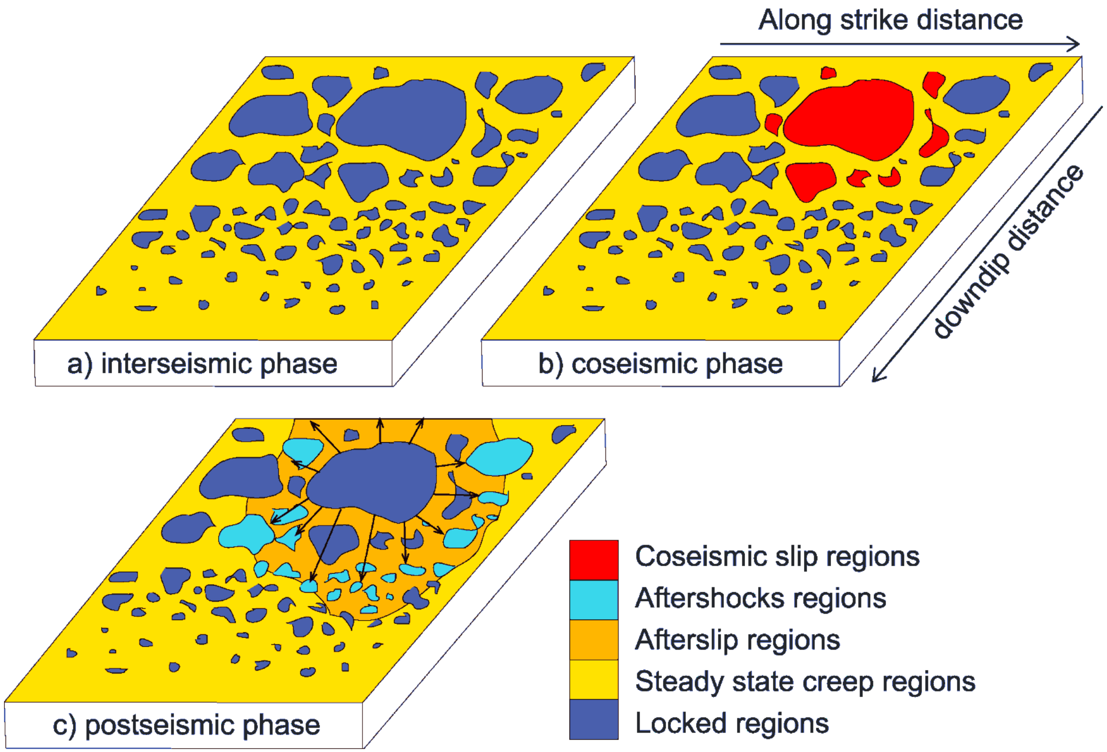
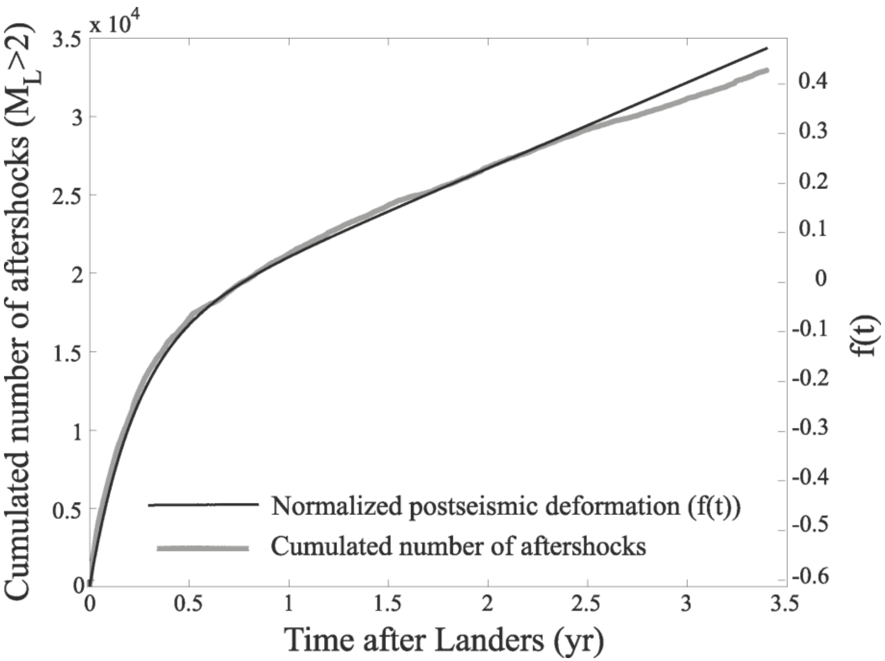
Afterslip generally drives aftershocks



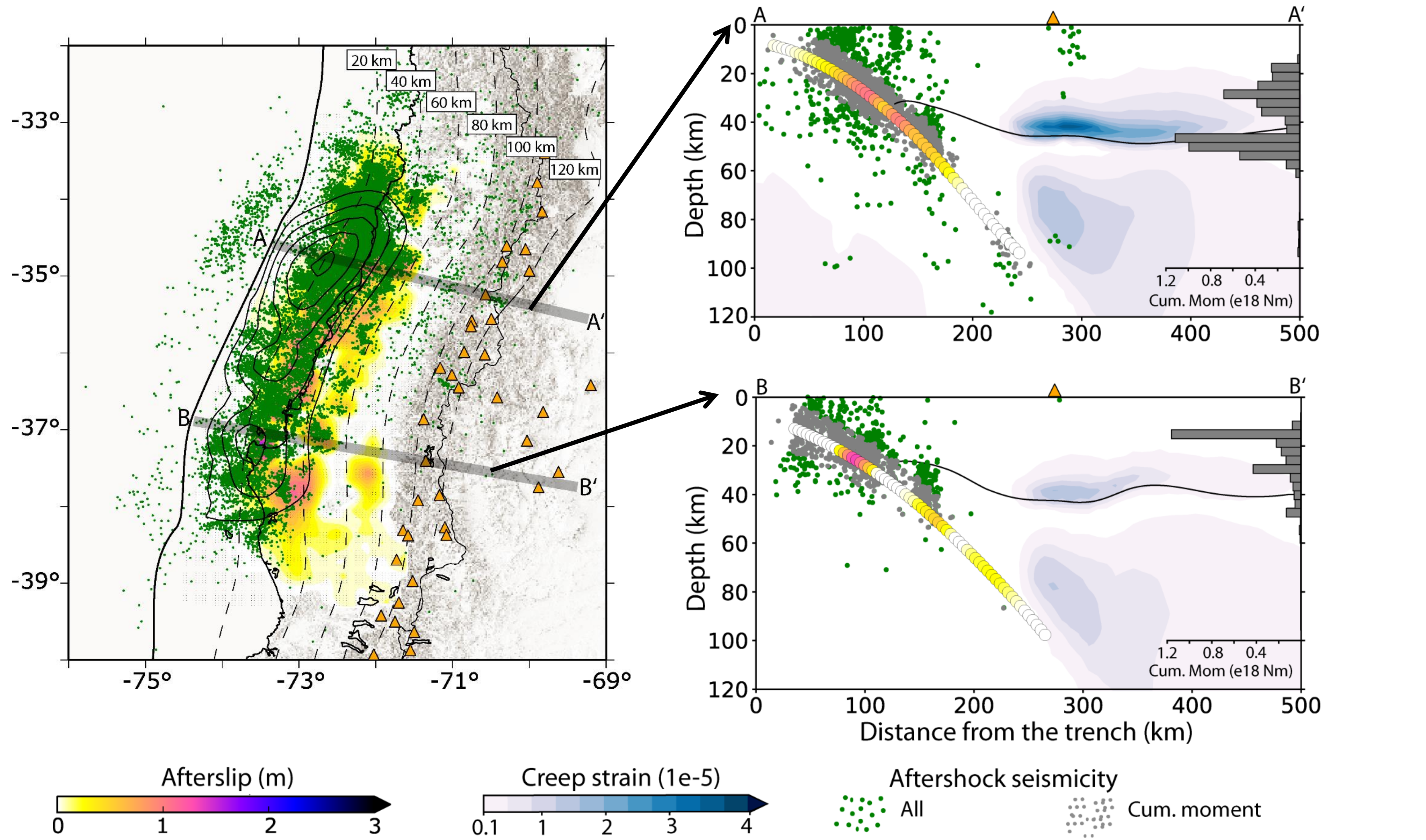


Perfettini and Avouac (2007)

Perfettini et al. (2018)

Further reading: Agurto et al. (2019), Avouac (2005), Bedford et al. (2016), Hsu et al. (2006), Peng and Zhao (2009), Lange et al (2014), Kato (2007)

Afterslip-aftershocks correlation: Power-Law Rheology, Weak Crust



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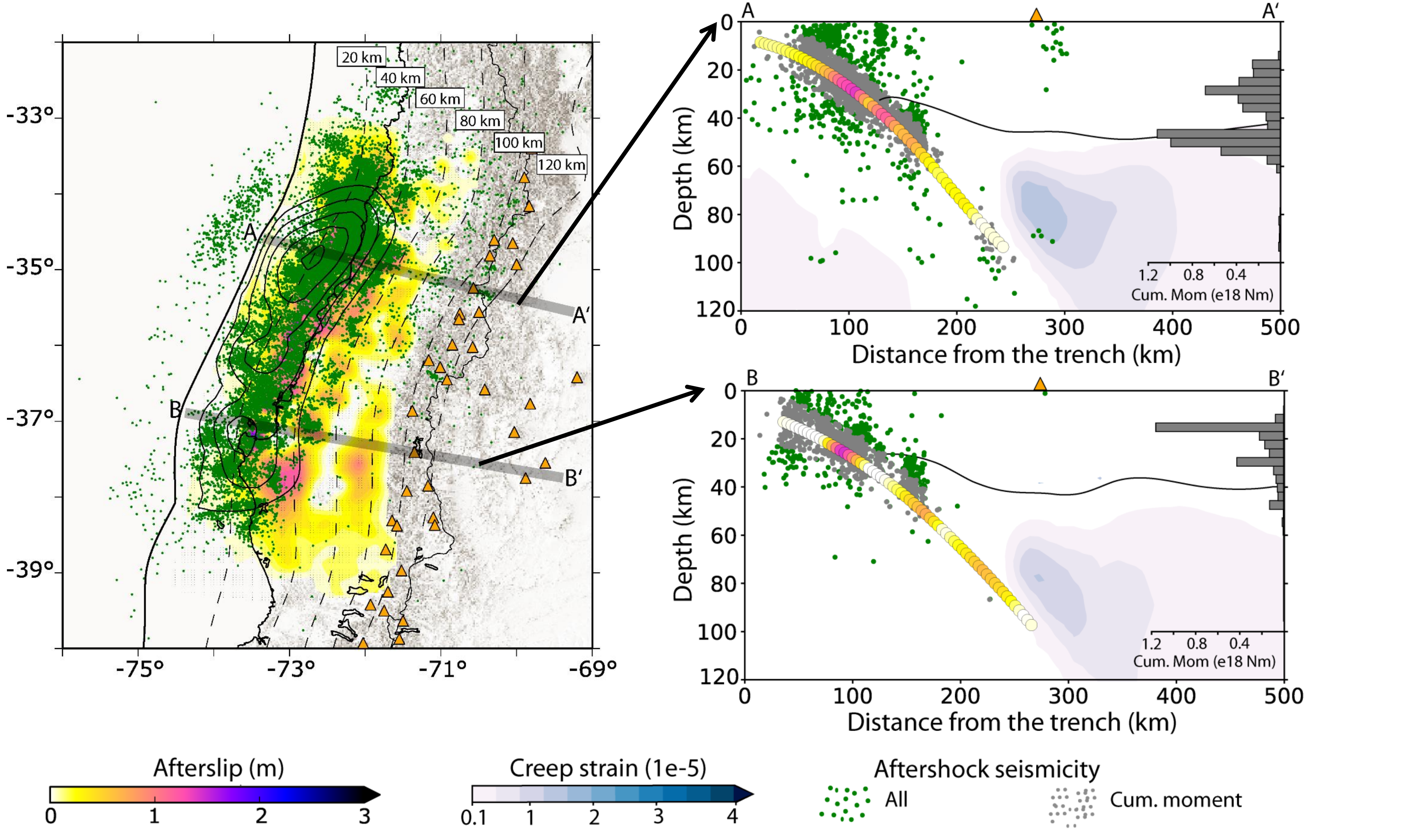
Afterslip-aftershocks correlation: Power-Law Rheology, Strong Crust



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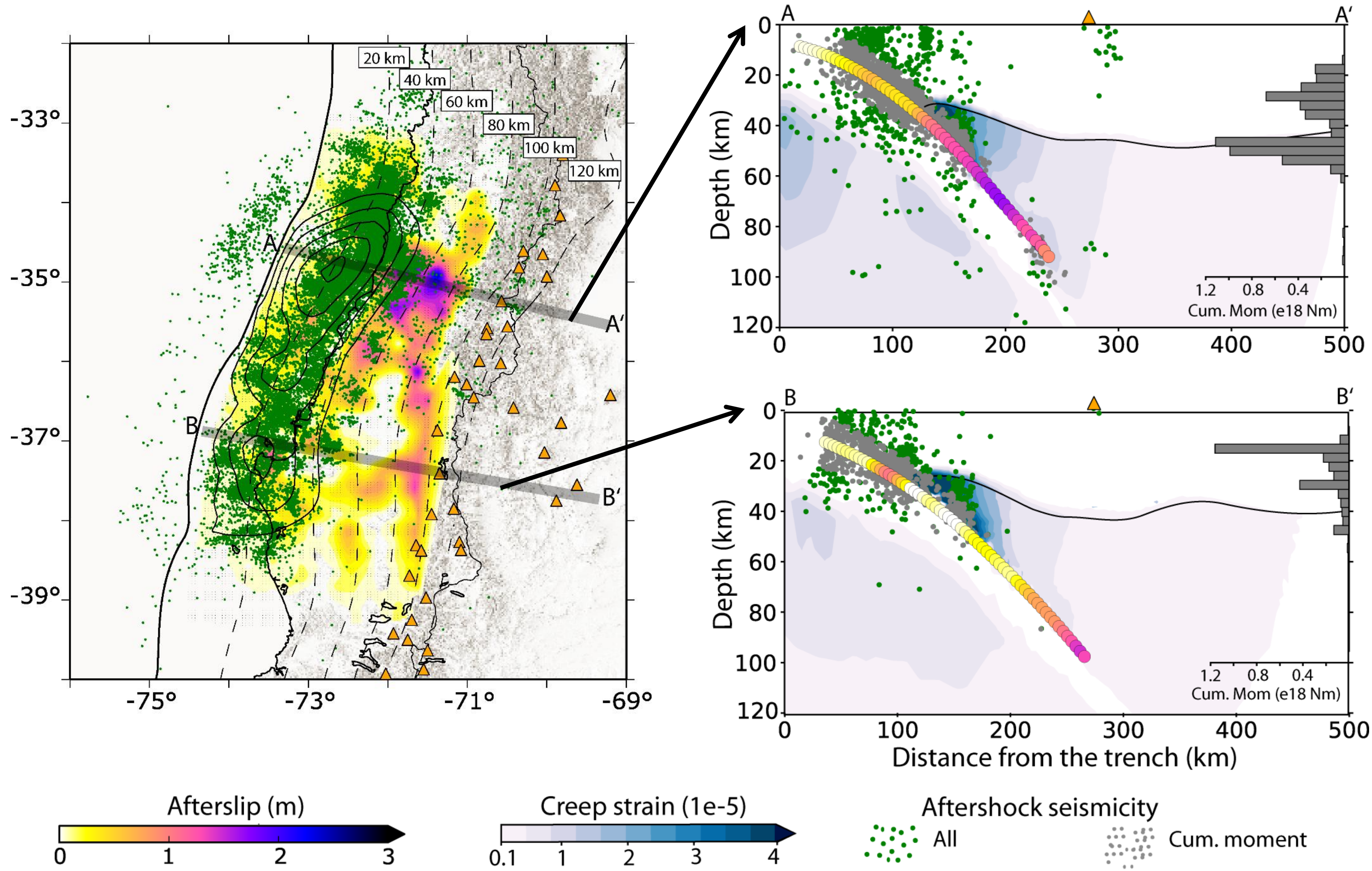
Afterslip-aftershocks correlation: Linear Rheology, Elastic Crust



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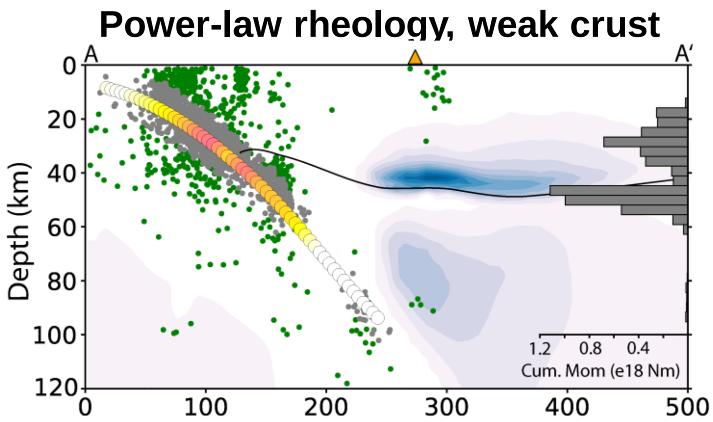
Concluding Remarks

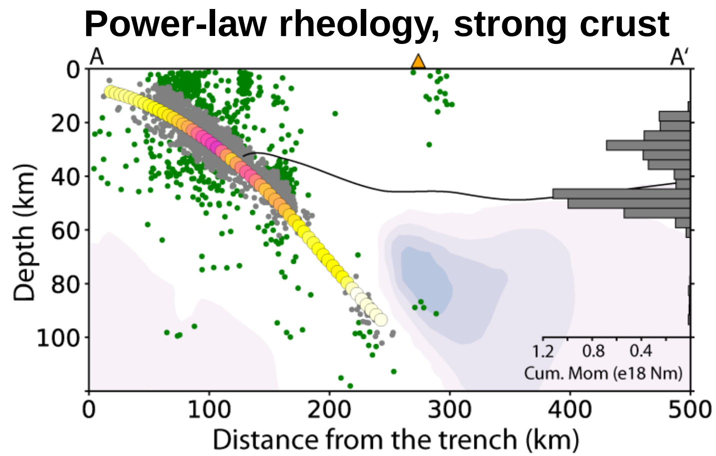
- ❑ **Inverted deep afterslip and viscoelastic patterns strongly depend on the choice of rheology (linear or power-law), as well as dislocation creep parameters.**

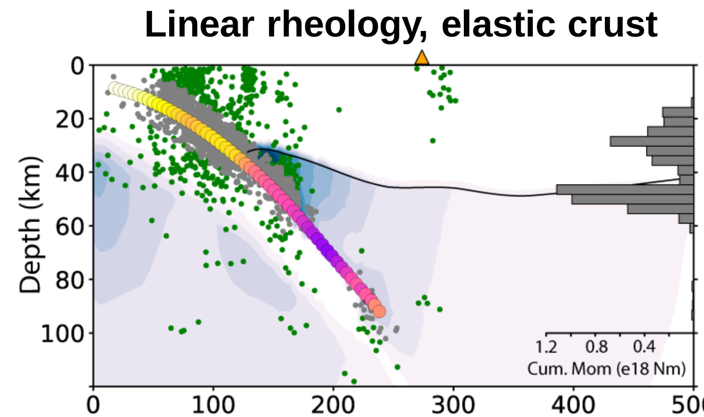
- ❑ **Election of a simulation that also allows non-linear viscoelastic relaxation in the continental lower crust reduces or eliminates the inverted afterslip distribution at the deeper segment (>60 km depth).**

- ❑ **Preferred simulation in the one with weak continental crust because of the best:**

  - ✓ **Fit to the cummulative GPS displacements.**
  - ✓ **Fit to the GPS time series.**
  - ✓ **Spatial correlation between afterslip and aftershock moment release at depths >60 km.**







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