Revisiting the North Chile seismic gap segmentation using GPS-derived interseismic coupling

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Abstract

No major earthquake occurred in North Chile since the 1877 Mw 8.6 subduction earthquake that produced a huge tsunami. However, geodetic measurements conducted over the last decade in this area show that the upper plate is actually deforming, which reveals some degree of locking on the subduction interface. This accumulation of elastic deformation is likely to be released in a future earthquake. Because of the long elapsed time since 1877 and the rapid accumulation of deformation (thought to be ~6-7 cm/yr), many consider this area is a mature seismic gap where a major earthquake is due and seismic hazar is high.

We present a new GPS velocity field, acquired between 2008 and 2012, that describes in some detail the interseismic deformation between 18°S and 24°S. We invert for coupling distribution on the Nazca-South America subduction interface using elastic modeling. Our measurements require that, at these latitudes, 10 to 12 mm/yr (i.e. 15% of the whole convergence rate) are accommodated by the clockwise rigid rotation of an Andean block bounded to the East by the subandean fold-and-thrust belt. This reduces the accumulation rate on the subduction interface to 56 mm/yr in this area. Coupling variations on the subduction interface both along-strike and along-dip are described.

We find that the North Chile seismic gap is segmented in at least two highly locked segments bounded by narrow areas of weak coupling. This coupling segmentation is consistent with our knowledge of the historical ruptures and of the instrumental seismicity of the region. Intersegment zones (Iquique, Mejillones) correlate with high background seismic rate and local tectonic complexities on the upper or downgoing plates.

The rupture of either the Paranal or the Loa segment alone could easily produce a Mw 8.0-8.3 rupture, and we proposethat the Loa segment (from 22.5◦S to 20.8◦S) may be the one that ruptured in 1877.

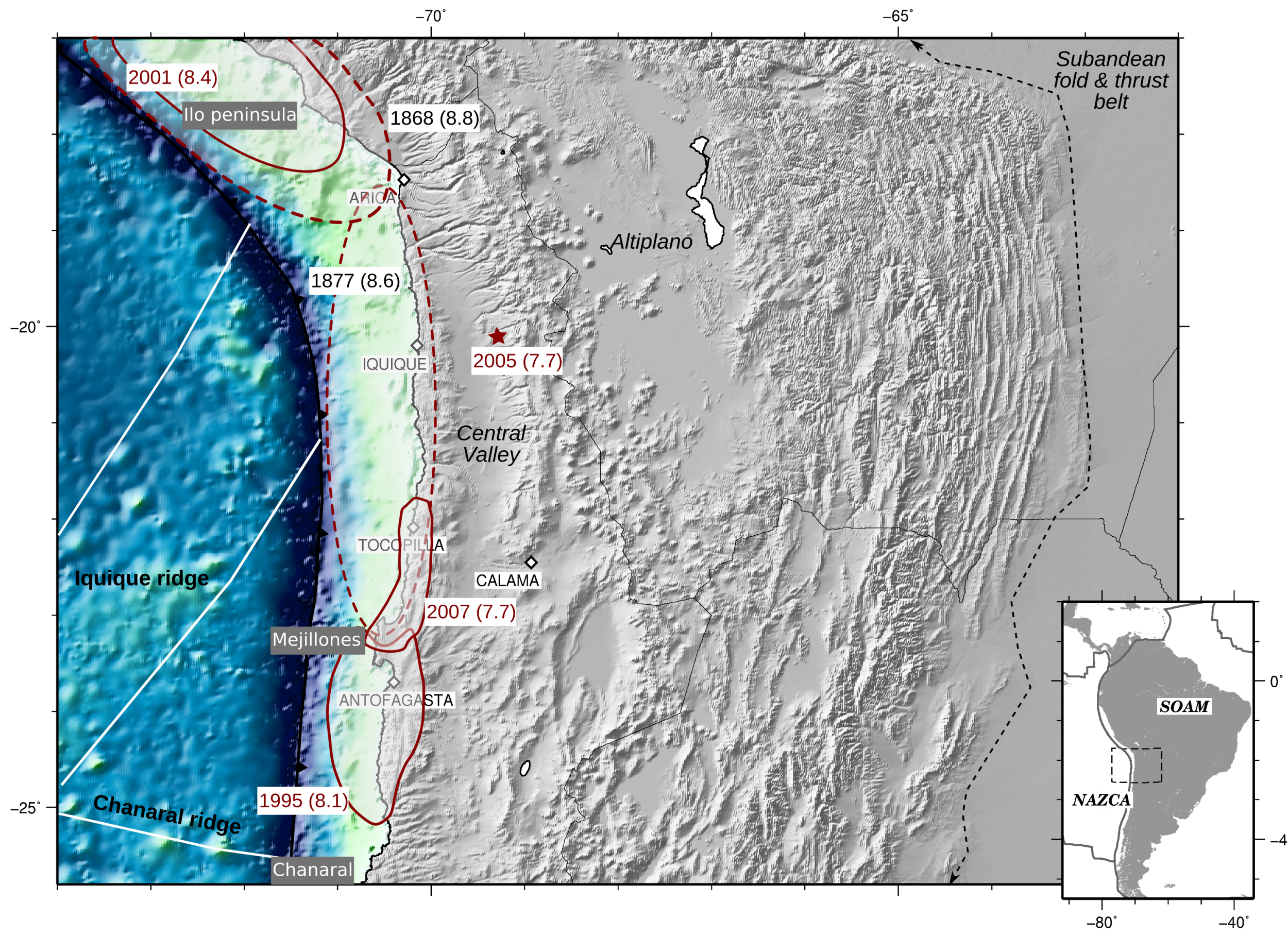
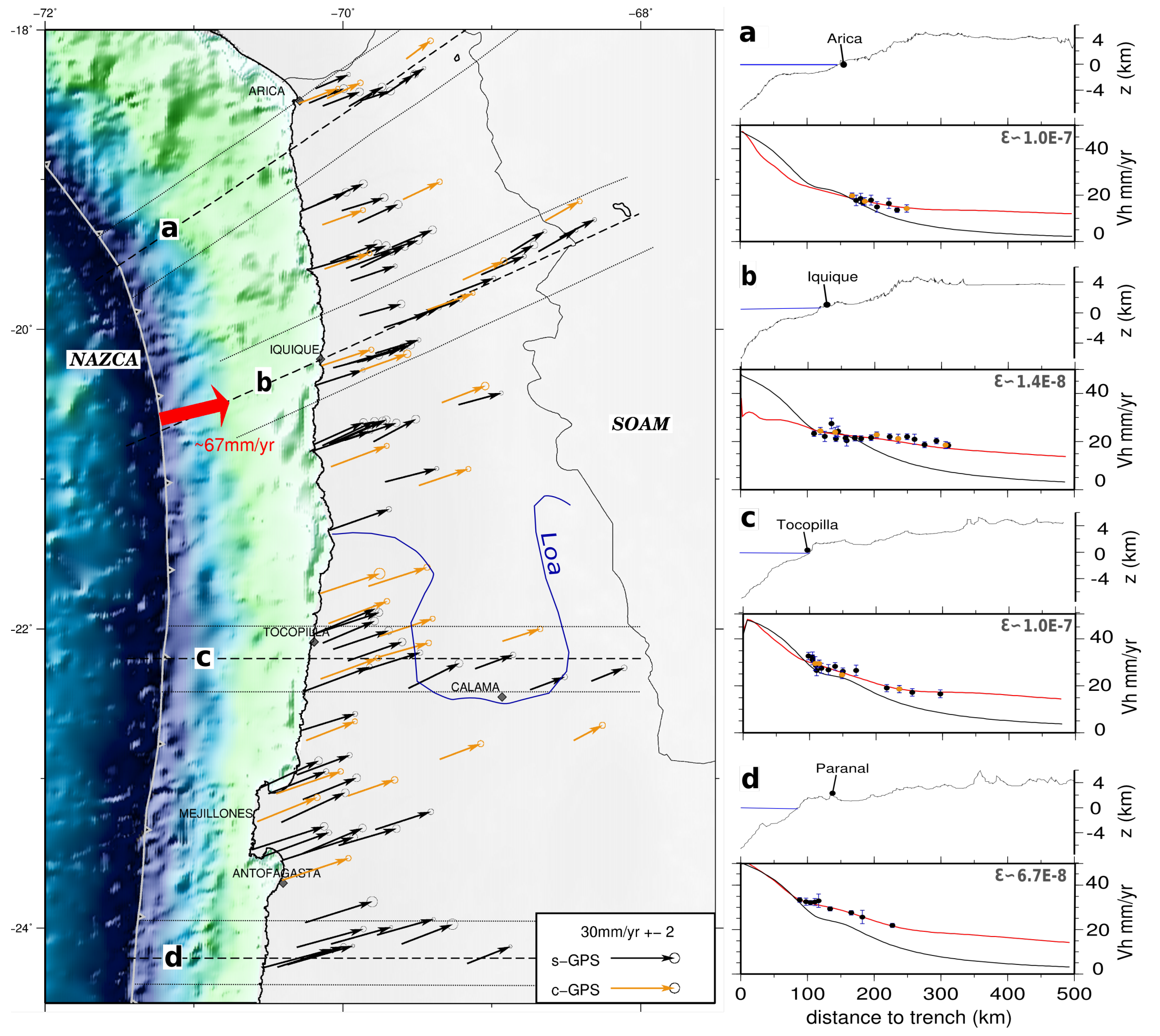


Fig. 1 : Seismotectonic framework of the North Chile area

1 - Data sets and modelling strategy



Data : Campaign measurements conducted on the old network from 2008 to 2010. New denser network installed in 2010 and measured 2-3 times up to 2012 (23 new benchmarks).

Process : GAMIT-GLOBK (10.4) standard process including 28 local and 33 regional cGPS stations. IGS antennae phase center and orbits tables are used.

Reference frame : We rotated our data in the ITRF 2008 by standard stabilization procedure and plot them relative to South America as defined by NNR-Nuvel1A (25.4°S, 124.6°W, 0.11°/My)

Fig. 2 : *Left : horizontal interseismic velocities calculated on the 2008-2012 time-span.*

Right : observed (dots) and predicted (curves) deformation along 30 km wide profile lines. Red curve : deformation predicted by our best model. Black curve : deformation predicted by a simple 2-plate model [Chlieh et al. 2001]

Software : DEFNODE code developped by *[Mc Caffrey, 2002]* and based on Okada's equations and on the backslip hypothesis *[Savage, 1983]*. We invert simultaneously for interseismic coupling and rigid motion of an Andean sliver. Nazca-SOAM convergence is fixed to (55.9°N, 95.2°W, 0.610°/My) *[Vigny et al. 2009]*.

Roughness : along-strike smoothing coefficient of 0.7/° of latitude increasing with depth

Geometry : simple planar slab geometry dipping 20°

Resolution : good from 10 km to 60 km depth all along the region, even shallower in front of Mejillones and deeper along the Iquique profile.

Constrains : no constrain is applied on the shallowest nodes. Coupling is not allowed to be positive below 80 km depth.

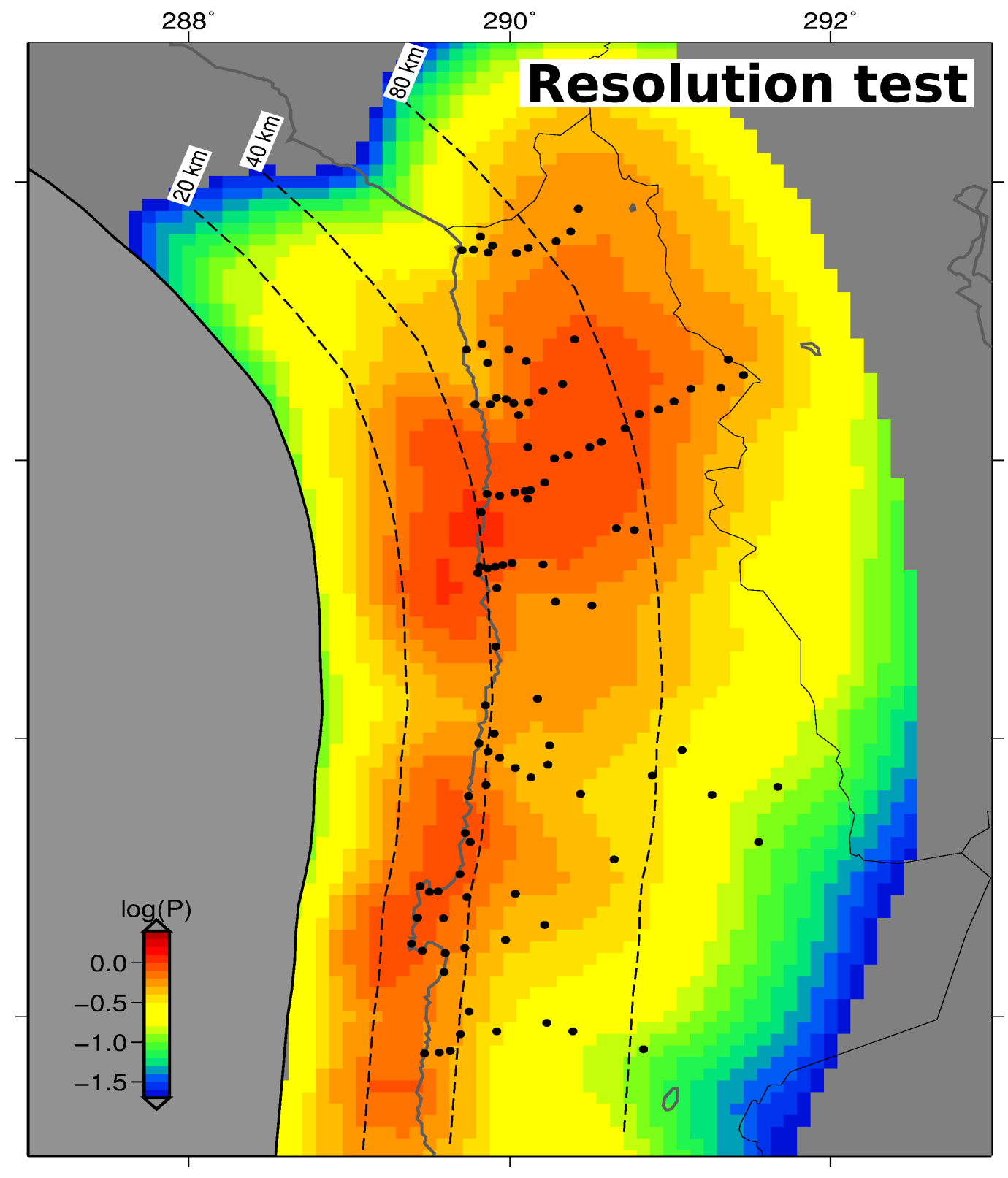


Fig. 3 : *Sensitivity of our inversion. We calculated the "Power" (in mm/yr) of our network (black dots) to resolve unit displacement on each nodes of the grid. (see e.g. [Loveless and Meade, 2011])*

2 - Preferred models : the need for an Andean sliver motion

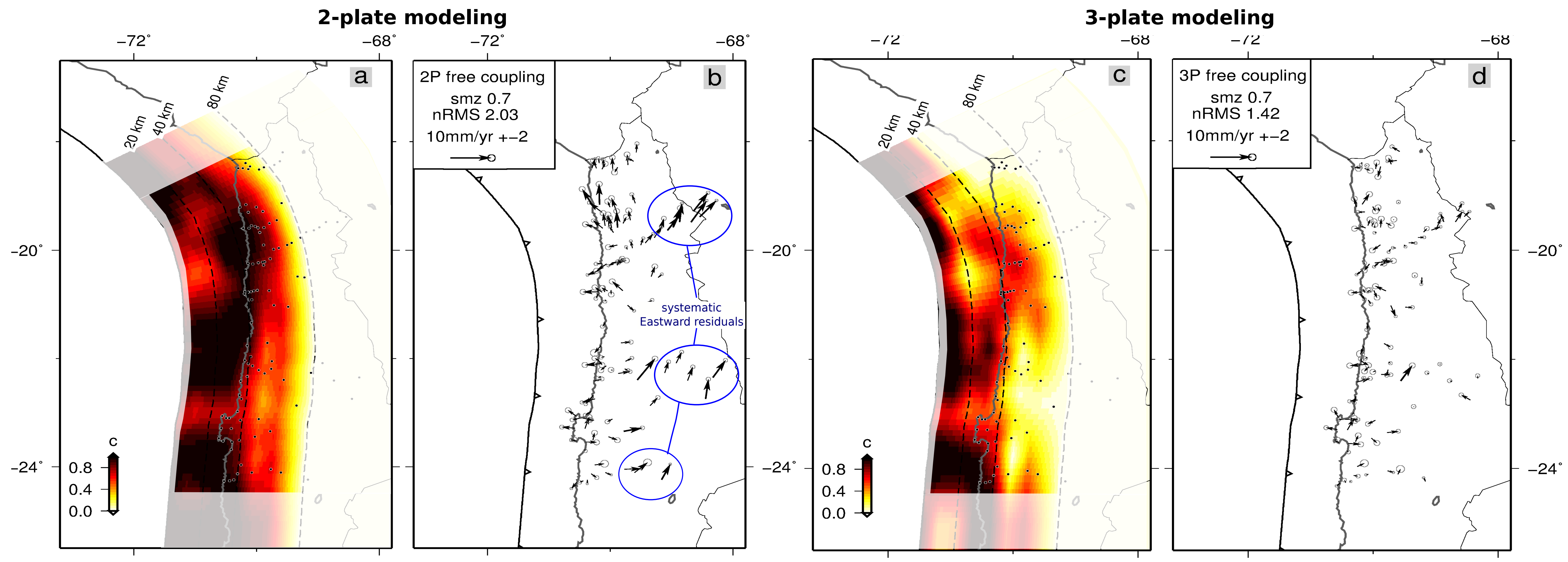


Fig. 4 : *Best coupling distribution inverted in a 2-plate configuration (a) and 3-plate configuration (c) with a 0.7/° smoothing constrain, and associated residuals (b-d).*

➜ Adding an **Andean sliver** bounded to the East by the subandean fold-and-thrust belt improves the fit to the data and significantly reduces the systematic eastward residuals. Deep coupling is also reduced, but lateral variations are very similar.

➜ The estimated rotation (**11 mm/yr toward North-East** in average on the entire network) is consistent with long-term geological observations *[Arriagada et al. 2008]* and present-day shortening on the Bolivian front. *[Brooks et al., 2011]*

3 - Coupling segmentation and interpretation : how far did the 1877 earthquake extend ?

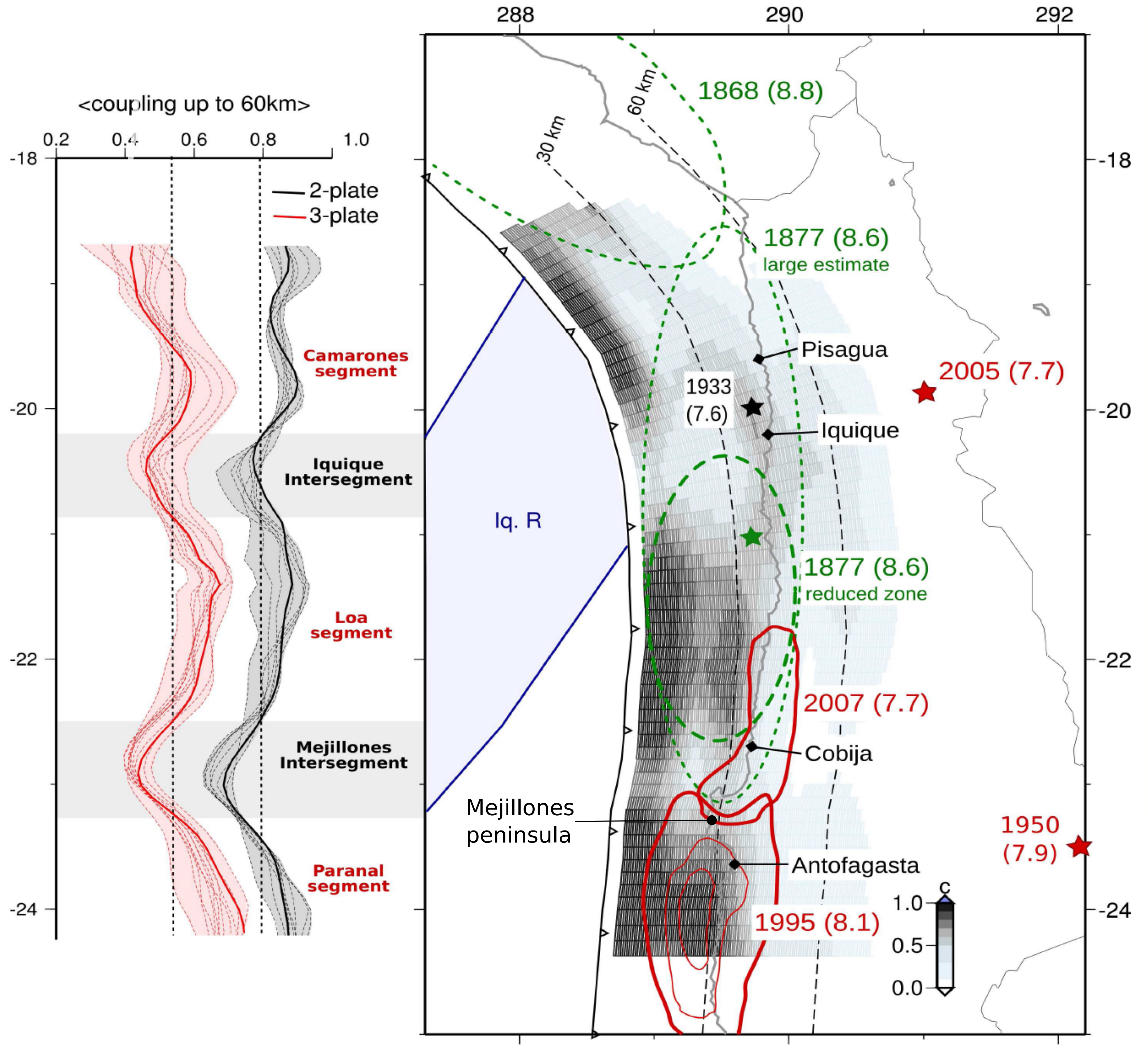


Fig. 5 : *Right - Interpretation of our "best" coupling distribution relative to historical seismicity and bathymetric features. Left - Average coupling variations with latitude for the first 60 km depth for the 2-plate (black curve) and 3-plate configurations (red curve). Grey and pink shaded area represent the variability of the model for both configuration.*

➜ The North Chile seismic gap is more complex than expected as it is composed of 3 **segments** (highly coupled : **Paranal, Loa and Camarones**) bounded by two well defined **intersegment** areas (where coupling is low : **Mejillones and Iquique**).

➜ The **Mejillones intersegment** seems to behave as a **barrier** to the propagation of the Tocopilla (2007), Antofagasta (1995) and 1877 megathrust earthquakes. Aseismic slip following the Antofagasta earthquake *[Pritchard et al., 2006]* and a large amount of aftershocks linked to the Tocopilla event occured there *[Contreras et al. 2011, Fuenzalida et al. 2011]*. This part of the subduction interface may be composed mainly of **velocity-strengthening patches.** Wether this structure is linked to the crustal fault network of the Mejillones peninsula is still an open question.

➜ The **Iquique intersegment** is associated to a relatively high level of background seismicity. A carefull reading of the testimonies used by *Kausel [1986]* to assess the 1877 rupture zone leads us to propose a shorter rupture (250 km long) rather than the larger estimate (500 km long) used up to now. The slip magnituded would have to be doubled to compensate for the shorter rupture and keep the magnitude close to 8.6.

➜ Therefore, the **1887 rupture** is consistent with the **rupture of the Loa segment only**. However, assuming a constant rate of 56 mm/yr since 1877, the seismic potential of this segment alone is only (but already) a magnitude 8.3. More time would be needed to accumulate the larger slip deficit requested by a shorter gap and reproduce the larger magnitude of the 1877 event. A possible alternative (to produce a larger magnitude) being a collective failure of several segments.

➜ The **Paranal segment** did not rupture since 1995 and very few megathrust tsunamigenic earthquakes are reported there. Since coupling is very high and since antofagasta did not produce a very large tsunami, it might not have ruptured the complete interface. Given its moderate magnitude and the corresponding modest amount of slip (1-2 m ?) it most probably only partially release the accumulation of deformation there.

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