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Earthquake source models to elucidate the seismic cycle
the recent contribution of geodesy

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Abstract (short version)

The study of aseismic slip and tremors is a great opportunity to decipher the behavior of seismic faults in the absence of large earthquakes. However, coseismic source models remain one of the simplest and most direct ways to understand earthquakes, and an essential piece of information to disentangle the contribution of each components of the seismic cycle. We use selected models of recent megathrust earthquakes to illustrate these points and outline the critical contribution of geodesy to the description of the coseismic models.

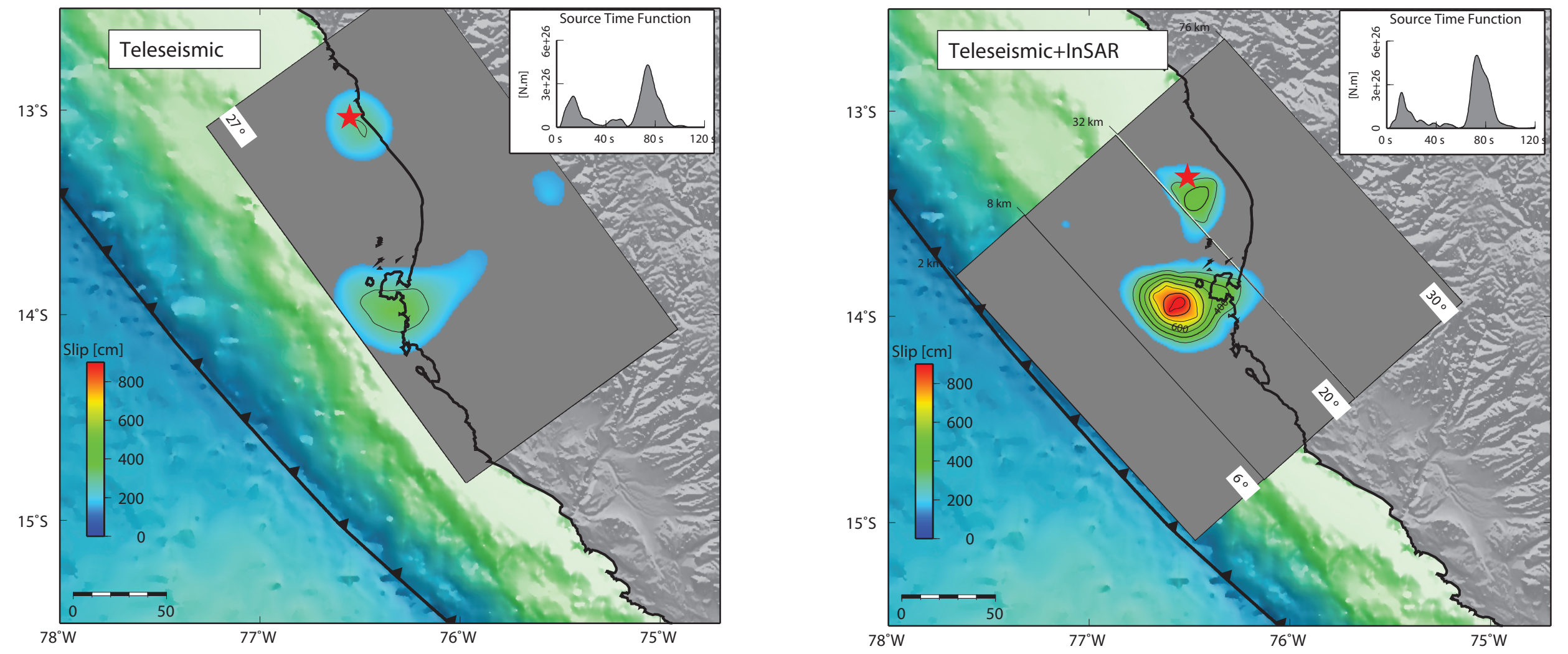
Influence of geodetic data in the inference of robust seismic source models

As a preamble of the discussion, we compare the teleseimic-only and geodetic-only solutions obtained for recent earthquakes in order to illustrate the critical role of geodesy in the problem of source inversion. This comparison serves as an argument to explain why previous studies relying on limited or no geodetic data were not able to converge on a coherent description of the seismic behavior of the megathrust.
In particular, we show that teleseismic-only inversions relying on bodywaves (P and SH) cannot properly resolve:

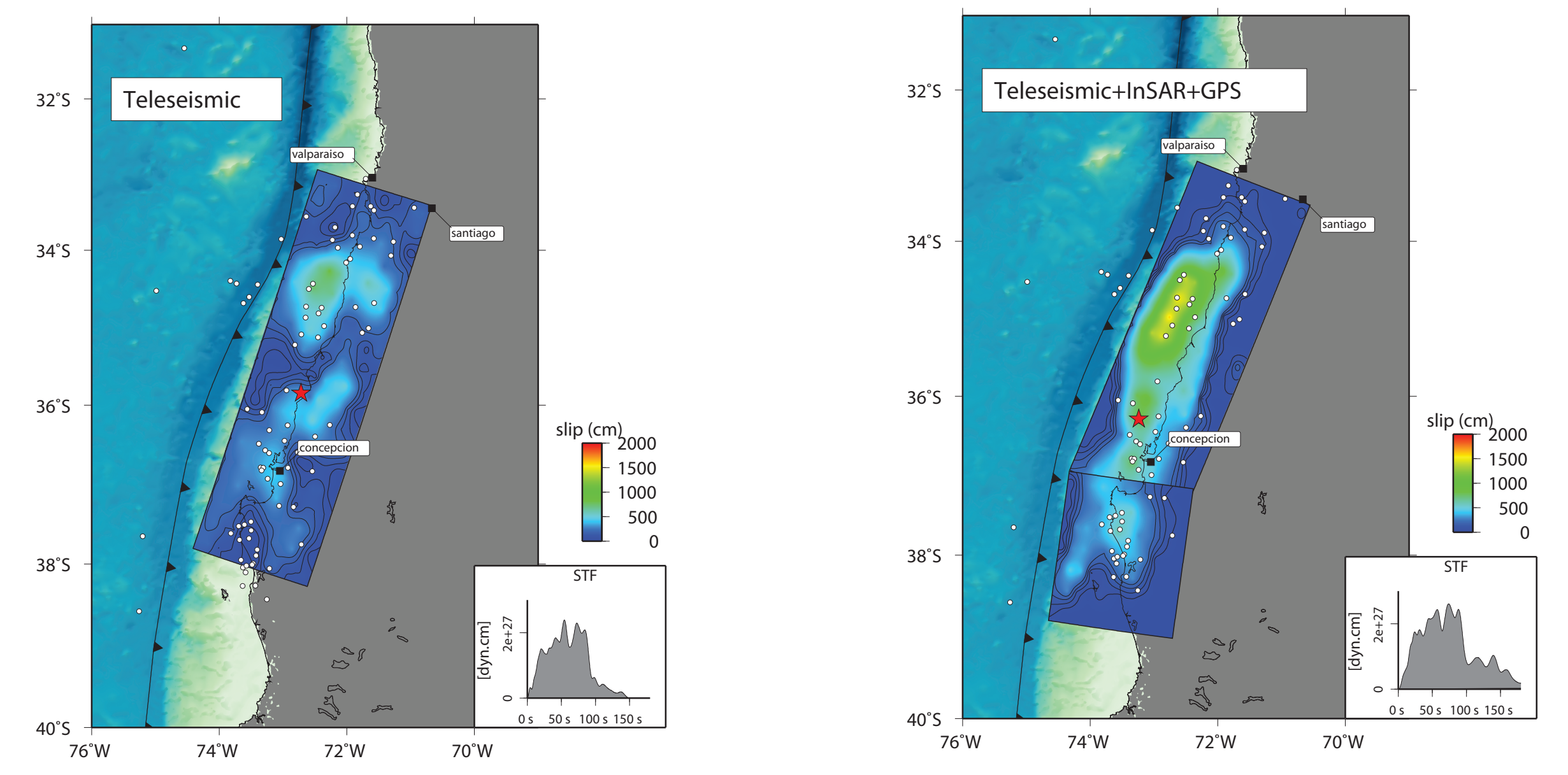
 * maximum slip,
 * average rupture velocity between asperities,
 * lateral location of the slip patches.

COSEISMIC

Pisco, Peru earthquake (Mw8.0), August 15, 2007

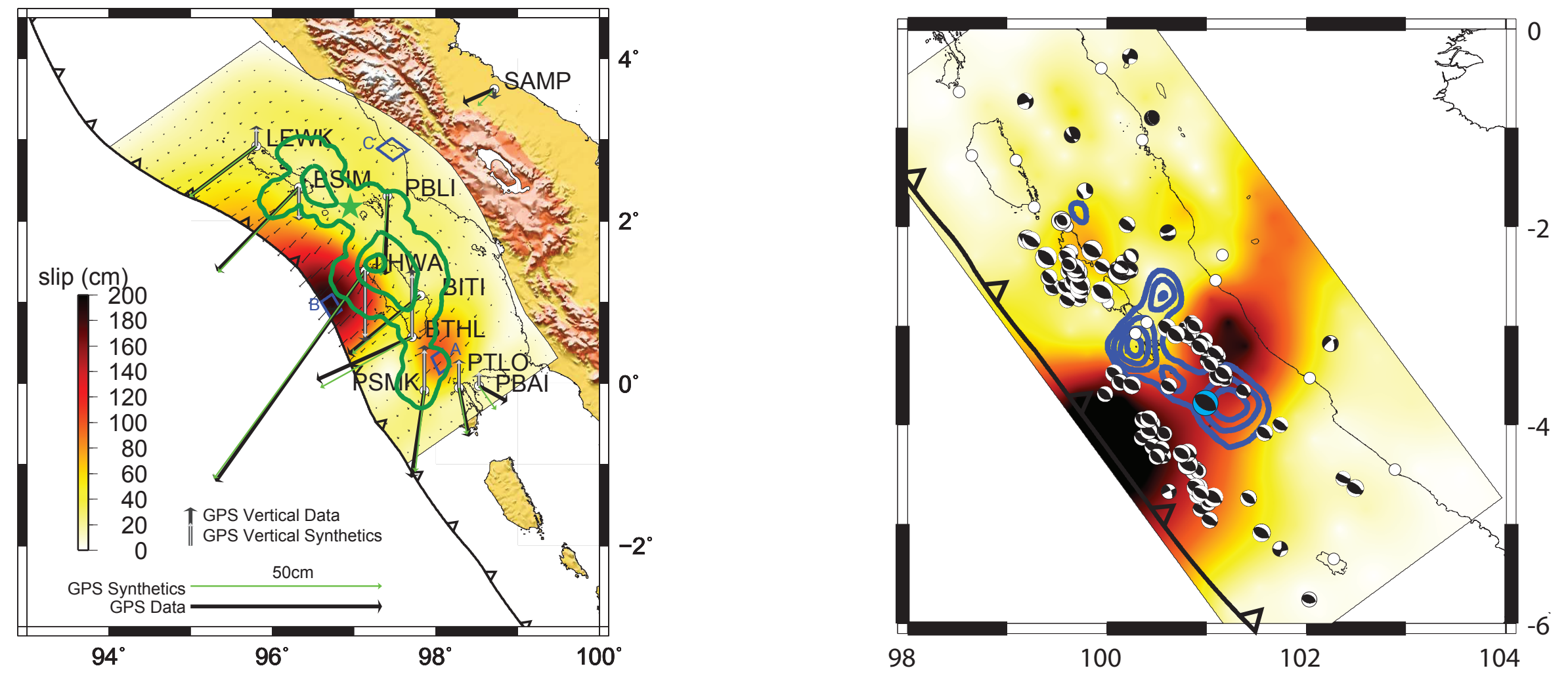

Teleseismic
Teleseismic+InSAR
Source Time Function
Slip [cm]
800
600
400
200
0
13°S
14°S
15°S
78°W
77°W
76°W
75°W

Maule, Chile earthquake (Mw8.7), February 27, 2010


Teleseismic
Teleseismic+InSAR+GPS
valparaiso
santiago
concepcion
slip (cm)
2000
1500
1000
500
0
STF
32°S
34°S
36°S
38°S
40°S
76°W
74°W
72°W
70°W

Examples from the Tectonics Observatory,Caltech, large earthquake database
http://www.tectonics.caltech.edu/slip_history

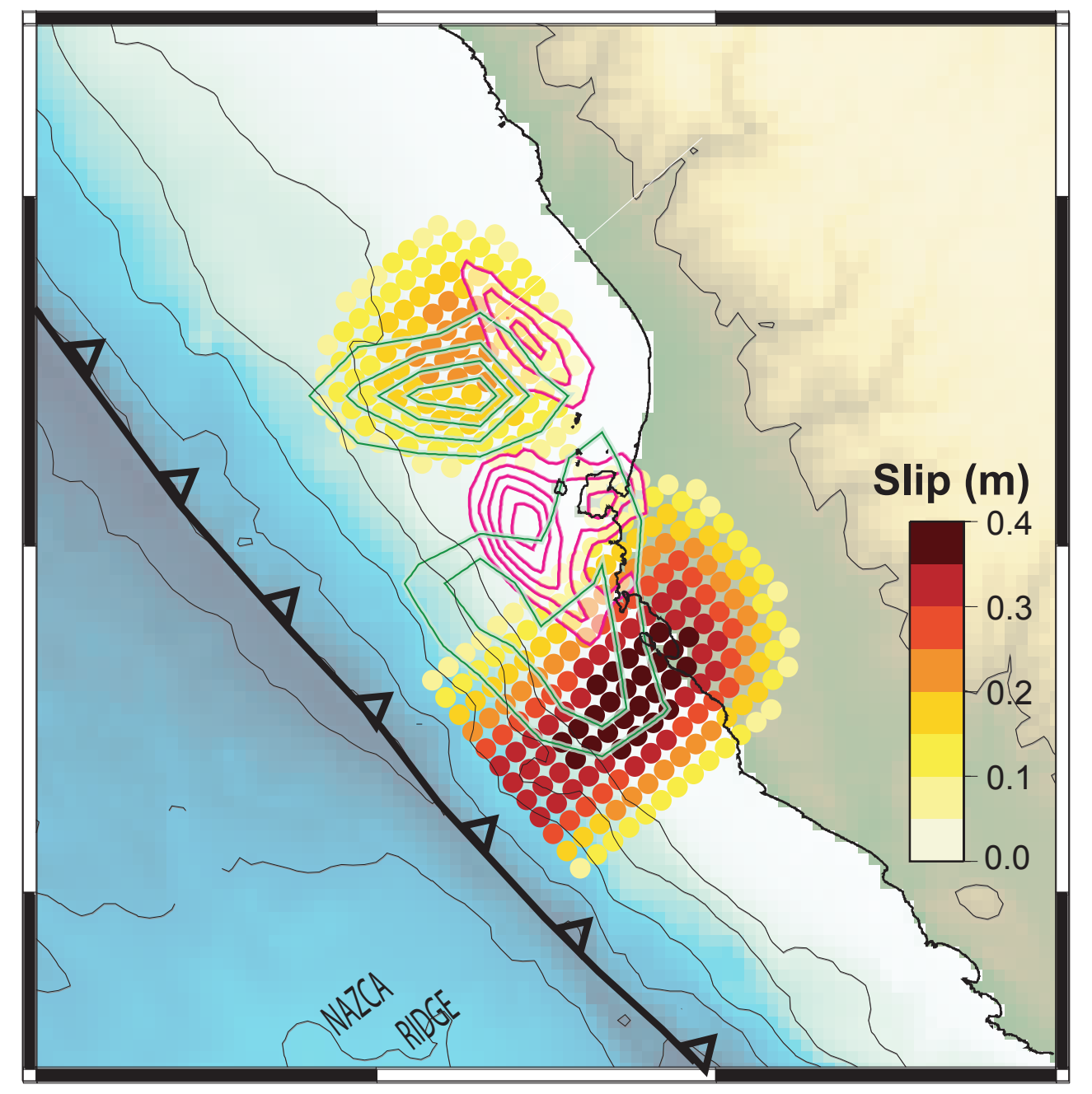
POST-SEISMIC


SAMP
LEWK
BSIM
PBLI
HWA
BITI
BTHL
PSMK
PTLO
PBAI
slip (cm)
GPS Vertical Data
GPS Vertical Synthetics
GPS Synthetics
GPS Data
50cm
94°
96°
98°
100°
98
100
102
104

Maps of the afterslip following the March 2005 Mw8.7 Nias earthquake (left) and the Mentawai earthquakes (Mw8.4, Mw7.9) (Kositsky and Avouac, 2010). The contours show the coseismic slip model (Konca et al., 2007 and 2009). The GPS data used to infer the post-seismic correspond to a period of 334 and 451 days after the Nias and Mentawai earthquakes.

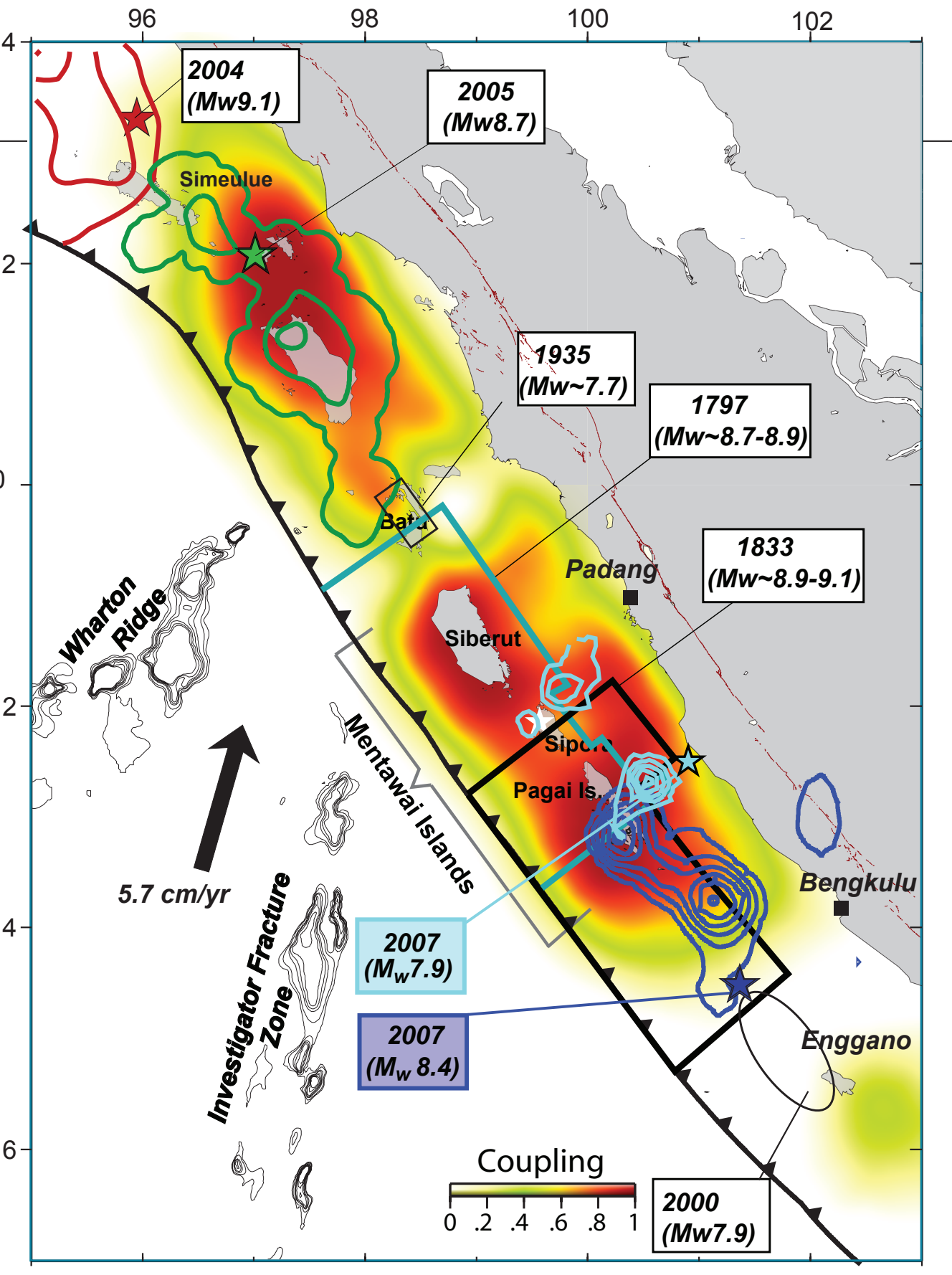
Recent inversions of source models involving high quality geodetic data strengthen the idea that the coseismic slip is anti-correlated with aftershocks and post-seismic slip.

The aftershocks equivalent displacement usually represents a small portion of the afterslip motion suggesting that afterslip drives the generation of aftershocks.


Slip (m)
0.4
0.3
0.2
0.1
0.0
NAZCA RIDGE

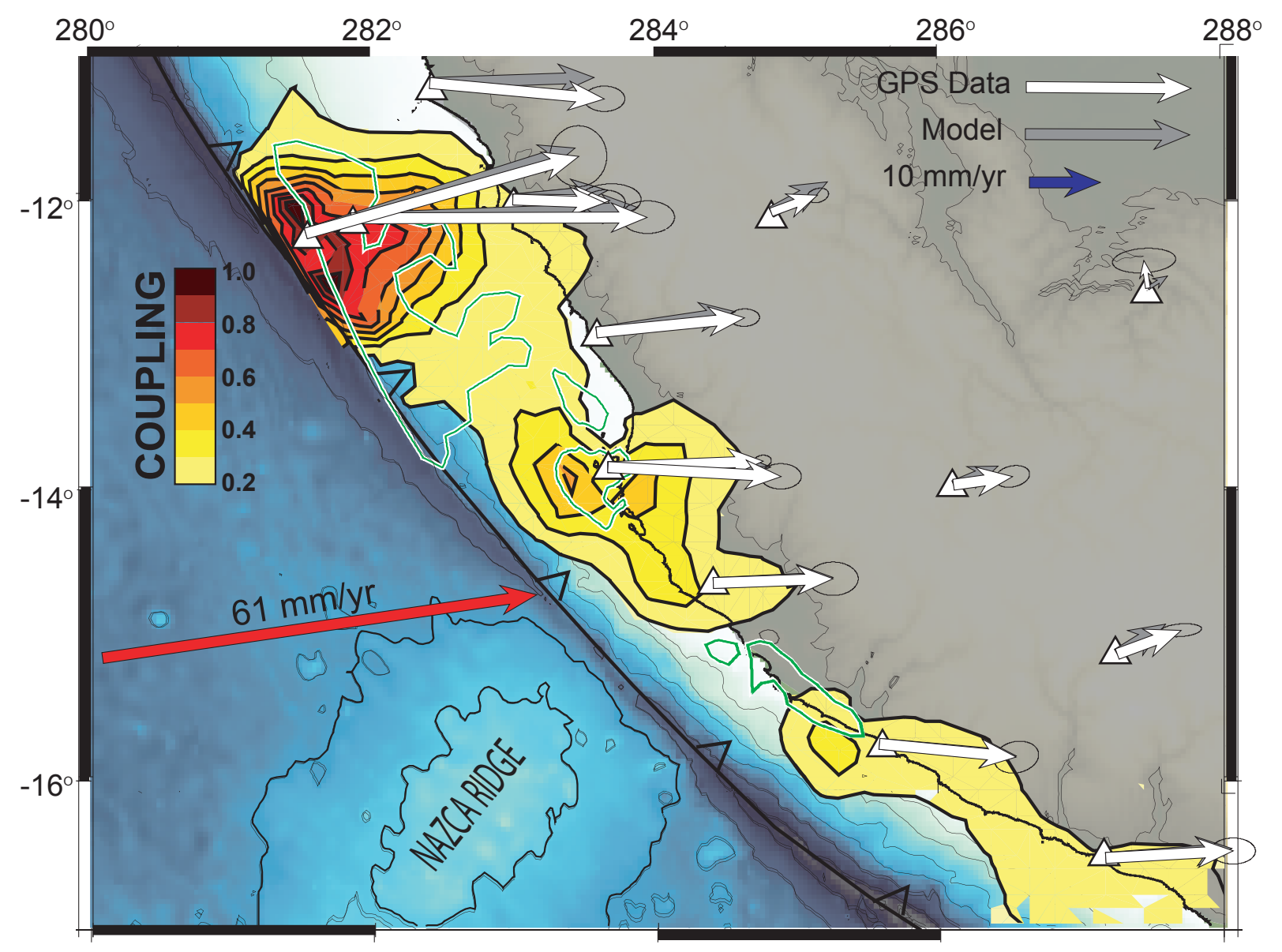
Map of the afterslip following the Pisco, Peru, earthquake (Mw8.0) of August 15, 2007 (Perfettini et al., 2010). The coseismic slip distribution and the aftershock density are outlined by the pink and green contours respectively (Sladen et al., 2010).

INTER-SEISMIC

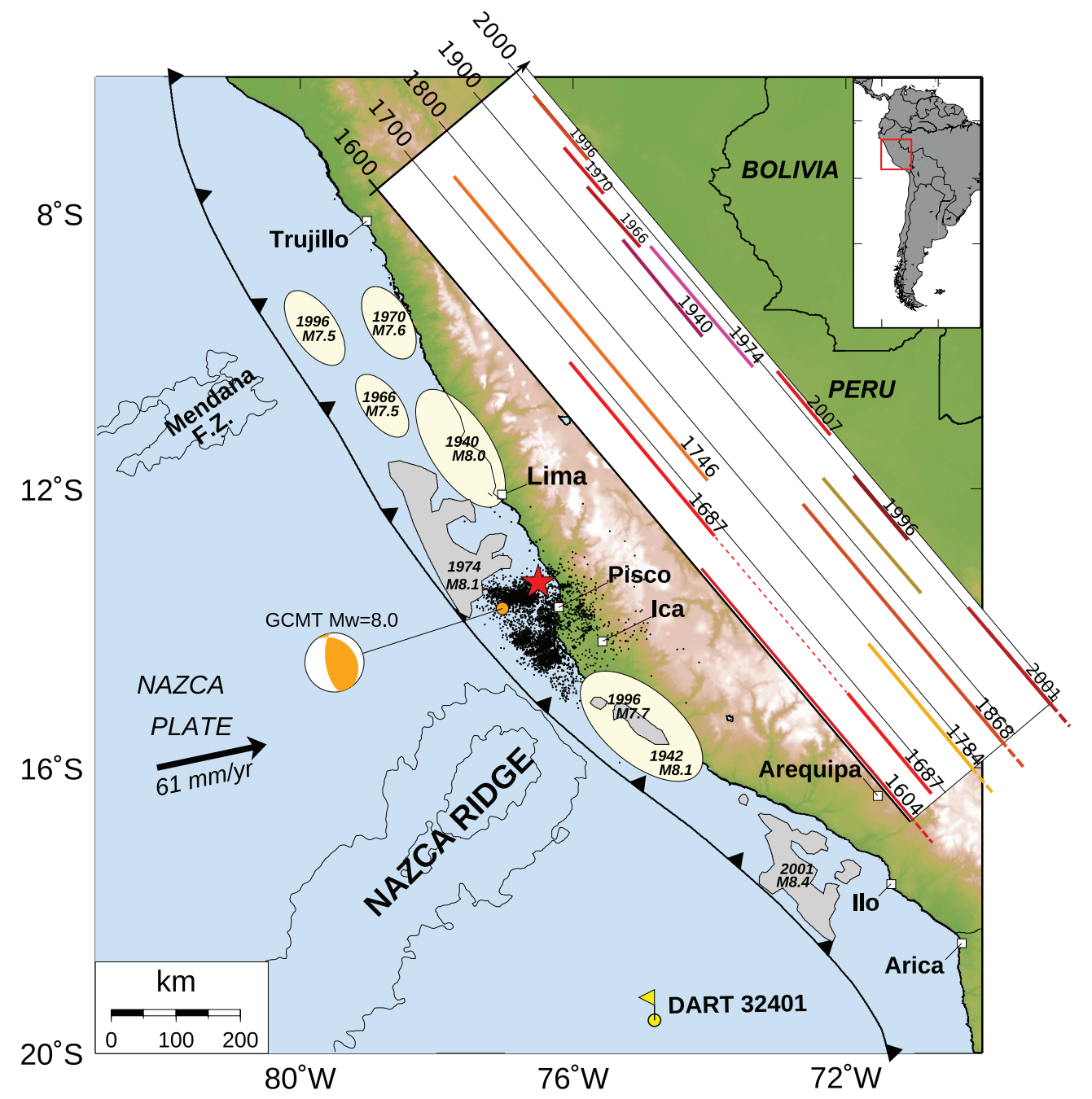

2004 (Mw9.1)
2005 (Mw8.7)
1935 (Mw~7.7)
1797 (Mw~8.7-8.9)
1833 (Mw~8.9-9.1)
2007 (Mw7.9)
2007 (Mw 8.4)
2000 (Mw7.9)
Simeulue
Padang
Siberut
Sipora
Pagai Is.
Bengkulu
Enggano
Wharton Ridge
Mentawai Islands
Investigator Fracture Zone
5.7 cm/yr
Coupling
0 .2 .4 .6 .8 1

Location of the large recent (contours) and historical earthquakes (boxes, infered from coral data) along the Sumatra subduction zone. The background colors represent the amount of interseismic coupling infered from GPS data (Chlieh et al., 2008).

Subduction zones seem segmented by permanent barriers (e.g. Nazca ridge, Simeulue island). This hypothesis is supported by strong concentration of aseismic afterslip, low interseismic coupling or absence of historical events straddling those barriers.


GPS Data
Model
10 mm/yr
COUPLING
61 mm/yr
NAZCA RIDGE
280°
282°
284°
286°
288°
-12°
-14°
-16°

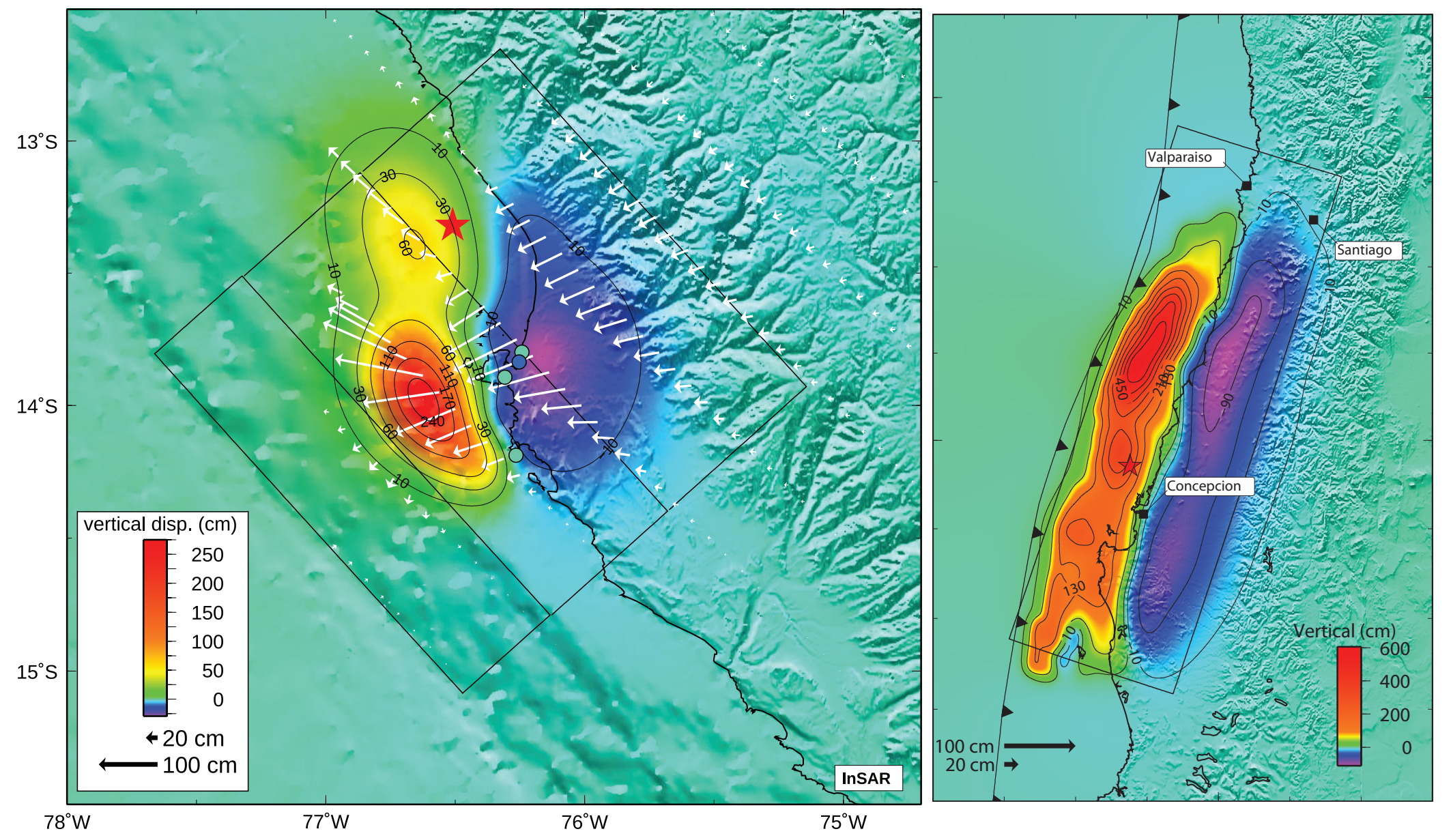
Map of seismic coupling infered from GPS data for the suduction zone of Central Peru (Perfettini et al., 2010). The green contours correspond to the recent large earthquakes (Mw>8.0).


BOLIVIA
PERU
Trujillo
Lima
Pisco
Ica
Arequipa
Ilo
Arica
Mendana F.Z.
NAZCA PLATE
61 mm/yr
NAZCA RIDGE
GCMT Mw=8.0
DART 32401
km
8°S
12°S
16°S
20°S
80°W
76°W
72°W

Historical earthquakes along the Peru subduction (timeline) and Mw>7.5 earthquakes (ellipses or grey contours) of the last 100 years (Sladen et al., 2010).

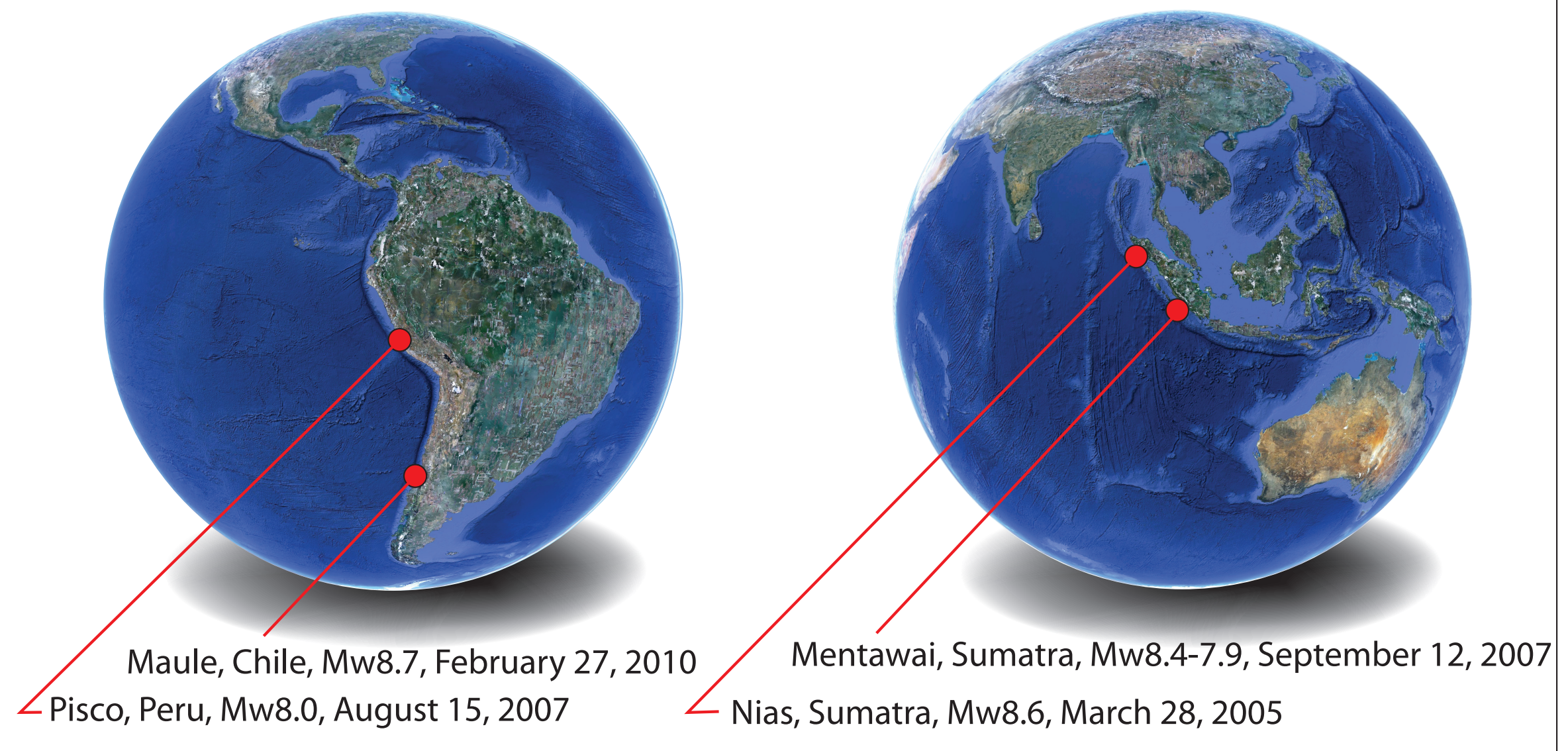
LONG-TERM

We find a strong anti-correlation between the surface deformation produced by large earthquakes and topography, at least for events in Japan and South America. This result might be interpreted as an indirect evidence that asperities are permanent features.


vertical disp. (cm)
250
200
150
100
50
0
20 cm
100 cm
InSAR
Valparaiso
Santiago
Concepcion
Vertical (cm)
600
400
200
0
13°S
14°S
15°S
78°W
77°W
76°W
75°W

Surface deformations computed from the source model of the Pisco (Sladen et al., 2010) (left) and Maule (right) earthquakes.

Events presented in this study


Maule, Chile, Mw8.7, February 27, 2010
Pisco, Peru, Mw8.0, August 15, 2007
Mentawai, Sumatra, Mw8.4-7.9, September 12, 2007
Nias, Sumatra, Mw8.6, March 28, 2005

References and acknowledgement

Chlieh, M., J.P. Avouac, K. Sieh, D.H. Natawidjaja, and J. Galetzka, Heterogeneous coupling of the Sumatran megathrust constrained by geodetic and paleogeodetic measurements, Journal of Geophysical Research, 113, B05305, doi: 10.1029/2007JB004981, 2008.

Konca, A.O., V. Hjorleifsdottir, T.R.A. Song, J.P. Avouac, D.V. Helmberger, C. Ji, K. Sieh, R. Briggs, and A. Meltzner, Rupture Kinematics of the 2005 Mw 8.6 Nias-Simeulue Earthquake from the Joint Inversion of Seismic and Geodetic Data, Bull. Seism. Soc Am., 97, 1A, pp. S307-S322, doi: 10.1785/0120050632.

Konca, AO, J.P. Avouac, A. Sladen, AJ Meltzner, K. Sieh, P. Fang, ZH Li, J. Galetzka, J. Genrich, M. Chlieh, DH Natawidjaja, Y. Bock, EJ Fielding, C. Ji, and DV Helmberger, Partial rupture of a locked patch of the Sumatra megathrust during the 2007 earthquake sequence, Nature, 456 (7222): 631-635, 2009.

Kositsky, A.P., and J.P. Avouac, Inverting geodetic time series with a principal component analysis-based inversion method, J. Geophys. Res., 115, B03401.

Hsu, Y., M. Simons, J.P. Avouac, J. Galetzka, K. Sieh, M. Chlieh, D. Natawidjaja, L. Prawirodirdjo, and Y. Bock, Frictional afterslip following the Mw 8.7, 2005 Nias-Simeulue earthquake, Sumatra, Science, 312, doi: 10.1126/science.1126960, 2006.

Perfettini, H., J.P. Avouac, H. Tavera, A. Kositsky, J.M. Nocquet, F. Bondoux, M. Chlieh, A. Sladen, L. Audin, D.L. Farber, and P. Soler, Seismic and aseismic slip on the Central Peru megathrust, Nature, 465, doi:10.1038/nature09062, 2010.

Sladen, A., H. Tavera, M. Simons, J. P. Avouac, A. O. Konca, H. Perfettini, L. Audin, E. J. Fielding, F. Ortega, and R. Cavagnoud, Source model of the 2007 Mw 8.0 Pisco, Peru earthquake: Implications for seismogenic behavior of subduction megathrusts, J. Geophys. Res., 115, B02405, doi:10.1029/2009JB006429, 2010.

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