The 2010 Maule, Chile Earthquake: Downdip rupture limit revealed by space geodesy G33A-0839

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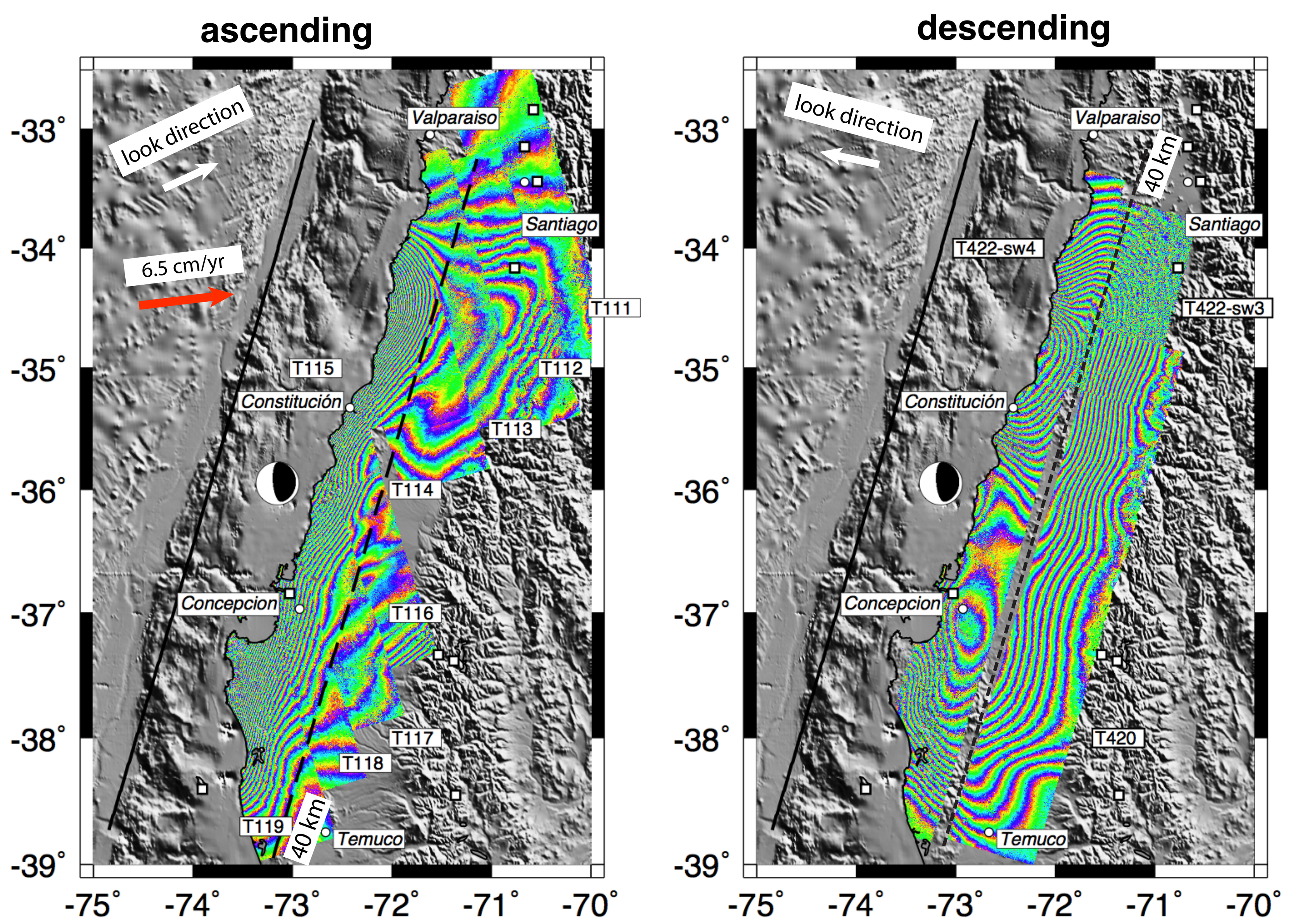
Abstract

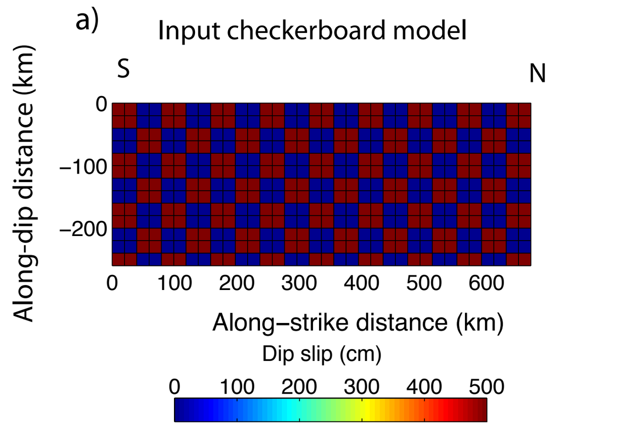
Radar interferometry from the ALOS satellite captured the coseismic ground deformation associated with the 2010 Mw 8.8 Maule, Chile earthquake. The ALOS interferograms along ascending tracks reveal a sharp transition from high fringe rate to low fringe rate at ~150 km from the trench axis. At a similar distance the descending interferograms exhibit a phase minimum. These fringe patterns are diagnostic of the downdip rupture limit of the Maule earthquake. An elastic dislocation model based on both ascending and descending ALOS interferograms and 13 near-field 3-component GPS measurements reveals that the coseismic slip decreases more or less linearly from a maximum of 17 m (along-strike average of 6.5 m) at 18 km depth to near zero at 43-48 km depth, quantitatively indicating the downdip limit of the seismogenic zone. The depth at which slip drops to near zero appears to be at the intersection of the subducting plate with the continental Moho. Our model also suggests that the depth where coseismic slip vanishes is nearly uniform along the strike direction for a rupture length of ~600 km. The average coseismic slip vector and the interseismic slip direction are not parellel, which suggests a possible deficit in strike-slip moment release.

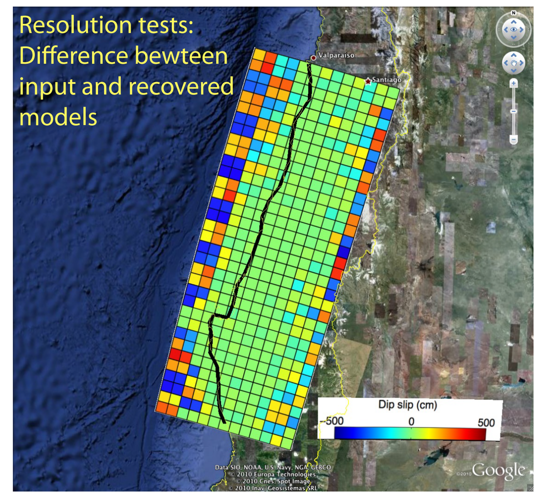
ALOS interferograms processed by GMTSAR (http://topex.ucsd.edu/gmtsar/)

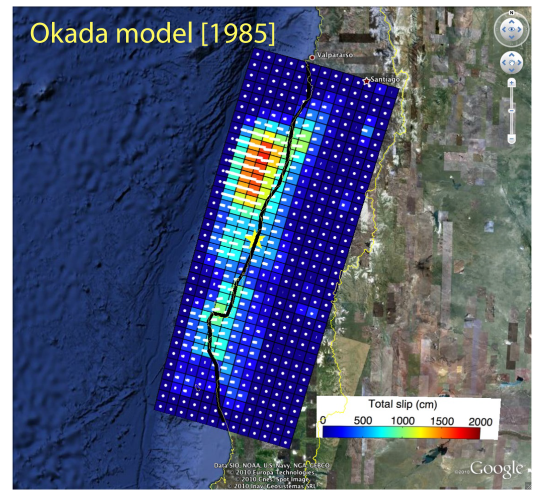


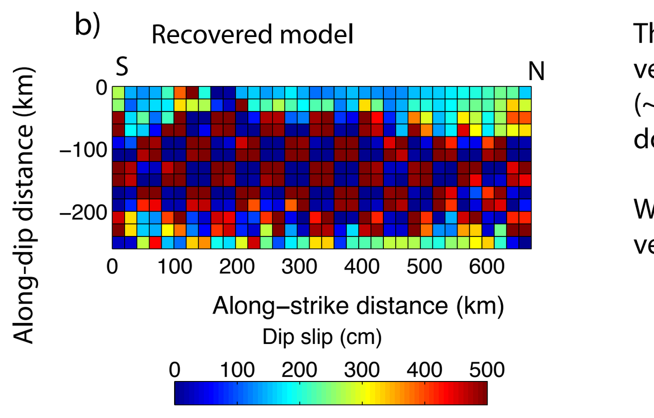
Nine tracks of ALOS ascending interferograms (FBS-FBS mode) and two tracks of ALOS descending interferograms (two subswaths of ScanSAR-ScanSAR mode and ScanSAR-FBS mode, and one track of FBS-FBS mode) cover a wide area from the coastline of central Chile to the foothills of the southern Andes. The earthquake epicenter is indicated by the CMT solution from global CMT. The black triangles indicate the location of the GPS sites used in the inversion. The surface trace of the simplified fault model used for the slip inversion is shown as a solid black line. The dashed black line in the interferograms marks a boundary where the phase gradient changes remarkably reflecting coseismic slip stopped at ~40 km depth (~150 km from trench axis).

Resolution tests and layered model



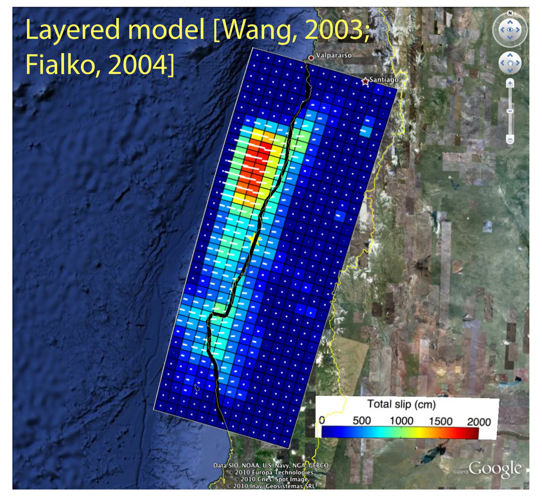






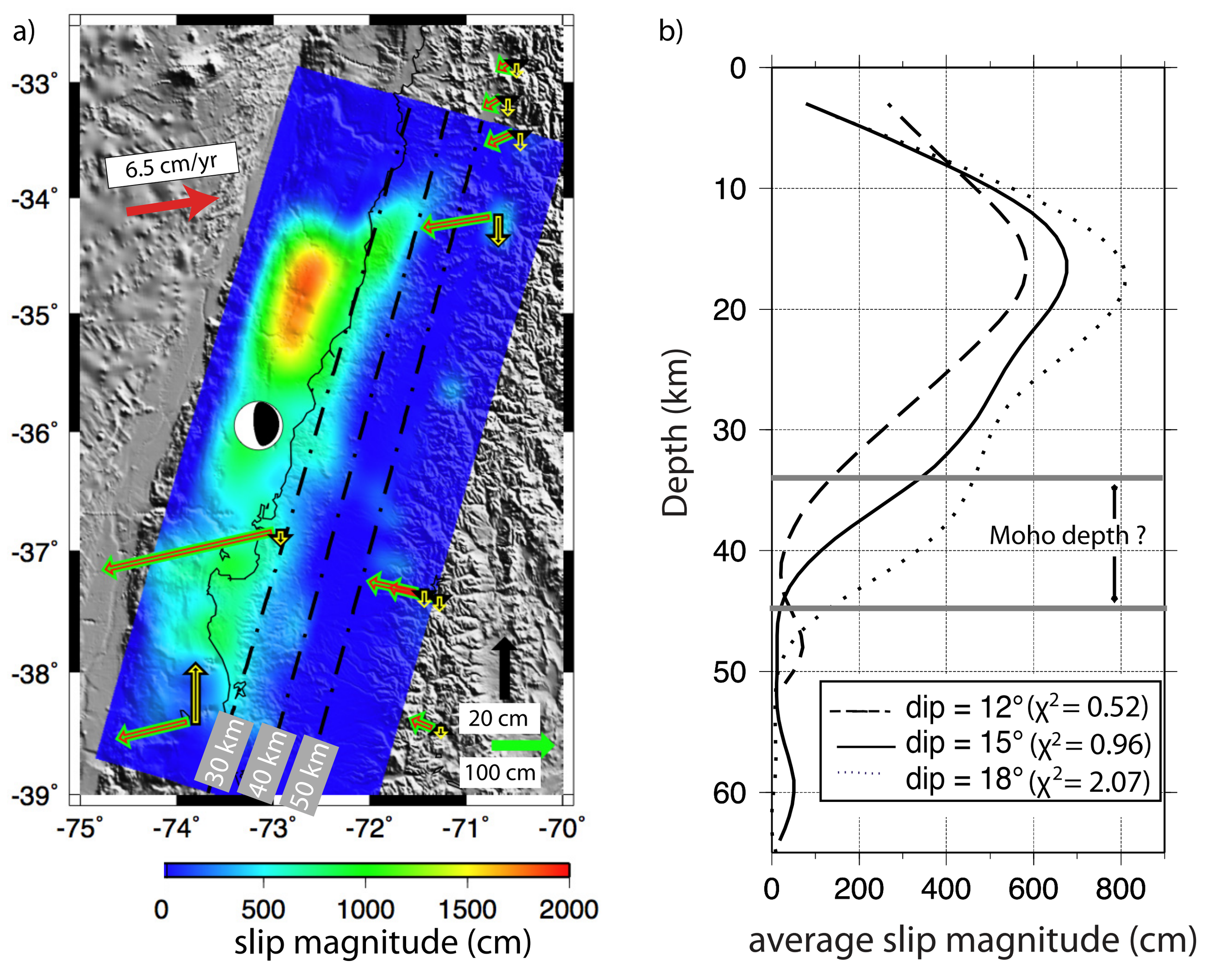
The checkerboard tests show that the in-version has resolution of 40 km (~ 10 km depth resolution) from 80-220 km down-dip distance.

We also investigated the effect of layered velocity structure [Bohm et al., 2002].



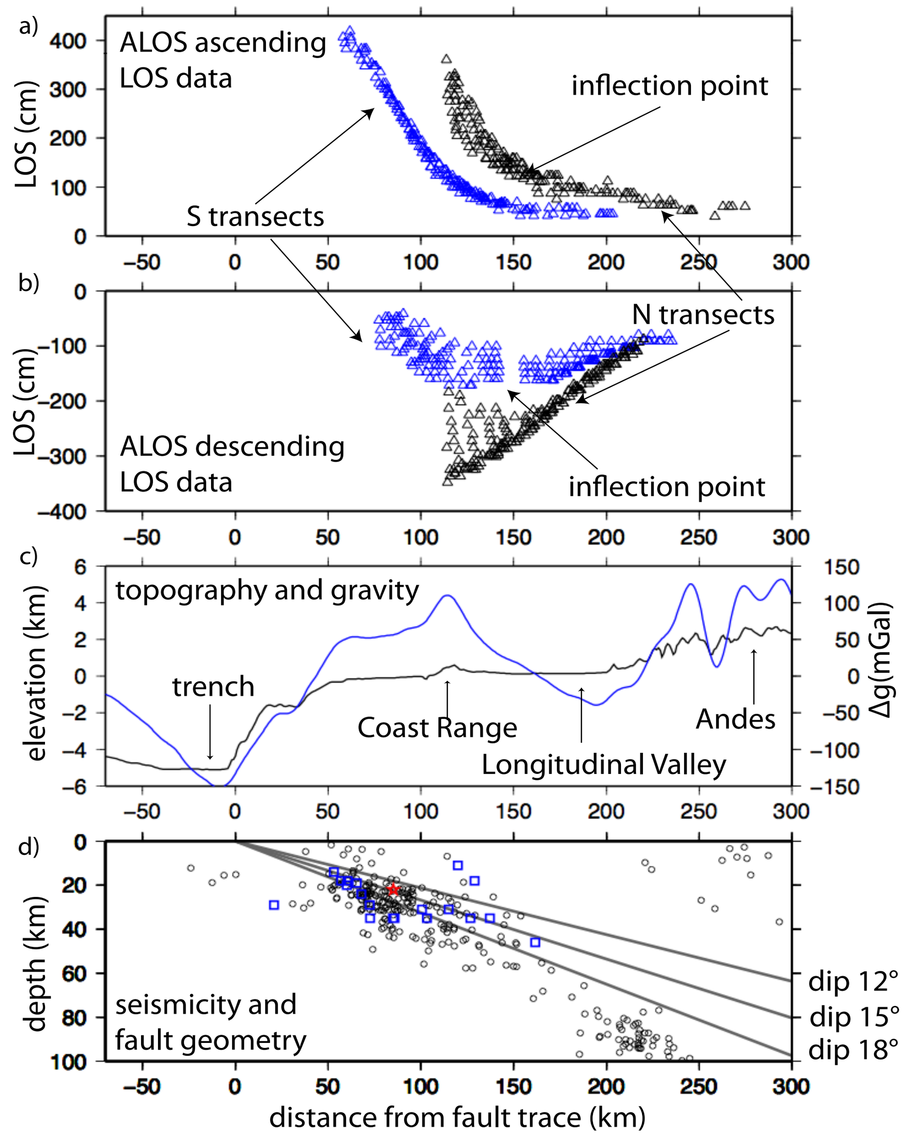
Coseismic slip model

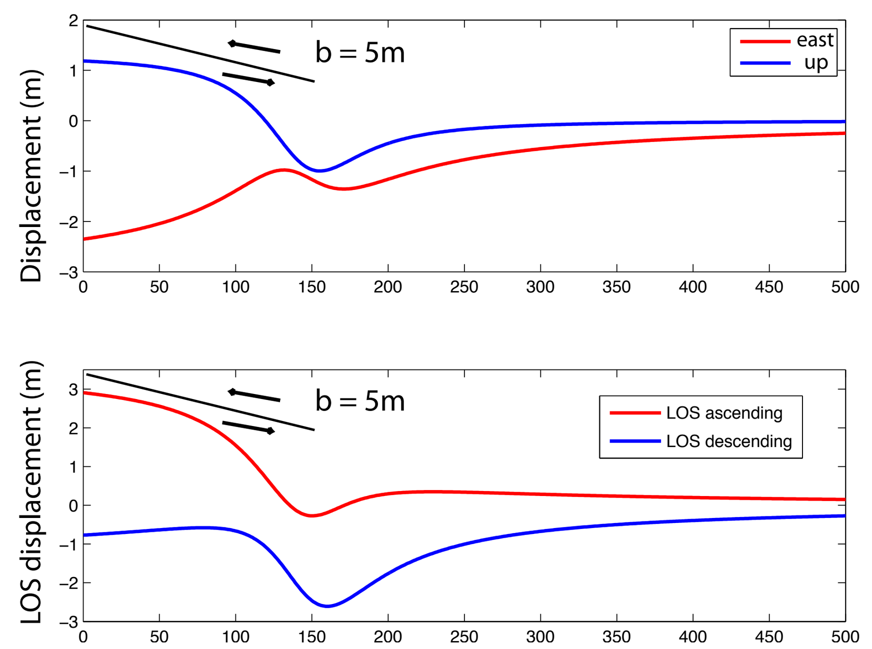
The InSAR Line-of-sight points, slip model and ALOS interferograms are available on ftp://topex.ucsd.edu/chile_eq/. This work is now online in Geophysical Research Letters (article in press).



a) coseismic slip model along a 15° dipping fault plane over shaded topography. Dashed lines show contours of fault depth. The fat green and black arrows show the observed horizontal and vertical displacement of the GPS vectors and the narrow red and yellow arrows show the predicted horizontal and vertical displacement from the coseismic slip model.
b) Along-strike averaged slip versus depth for different dip angles. Note the averaged slip magnitude decrease monotonically from its maximum at 18 km depth to near zero at 43-48 km depth. The slip-depth distribution for dip angle 12° and 18° is also shown for comparison.

Signature of the downdip rupture limit



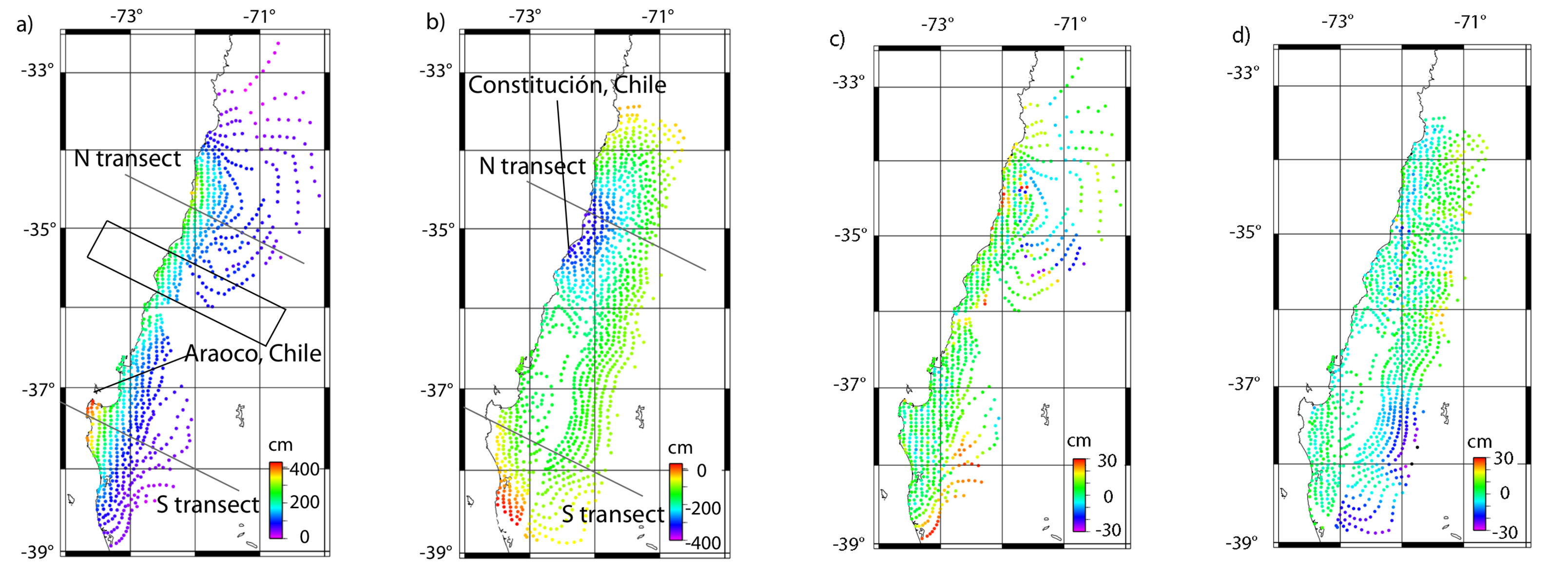


a) b) Transects of unwrapped ALOS ascending descending line-of-sight (LOS) displacements.
Notice the rapid change in ascending LOS displacement at distance 120-150 km from trench axis.

c) Topography (black line) and gravity (blue line) transects over Maule, Chile.

d) Seismicity and fault geometry beneath Maule, Chile. The black circles show the M>4 seismicity over Maule Chile,1960-2007, whose depth are well constrained (Courtesy of Zhitu Ma). The red star shows the location of the M8.8 Maule, Chile earthquake and the blue squares show the locations of the M>6 aftershocks (National Earthquake Information Center). The gray lines shows the fault plane in the slip models.

InSAR Line-Of-Sight displacement and model misfits



a) LOS data unwrapped from ALOS ascending interferograms.
b) LOS data unwrapped from ALOS descending interferograms.
c) Model residuals in ascending LOS data.
d) Model residuals in descending LOS data.

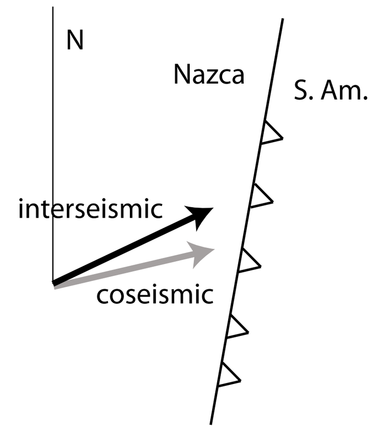
Compare interseismic slip vector and coseismic slip

Comparison of the interseismic velocity direction and coseismic slip direction suggests a deficit in strike-slip moment release. Interseismic velocity direction is from plate motion model [Kendrick et al., 2003]. Coseismic slip direction is derived from the ratio of the geodetic moment estimate:

dip moment = μ×A×Ddip

strike moment = μ×A×Dstrike

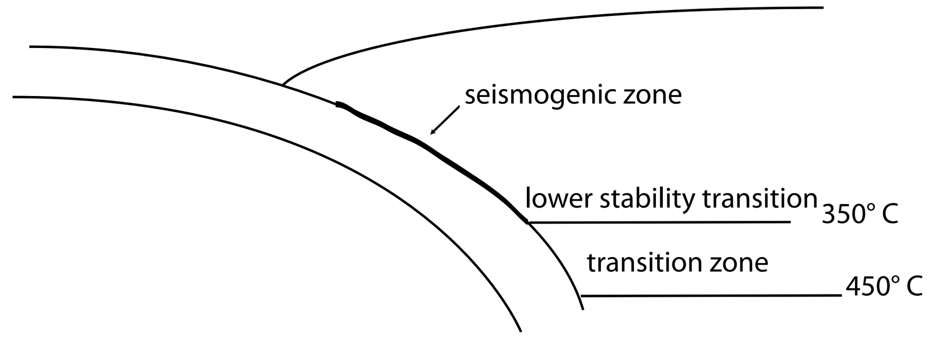
where,
μ is the shear modulus, A is the area of the locked part of the plate-interface.
Ddip and Dstrike are the mean dip-slip and strike-slip magnitude-averaged on the same fault rupture area.



Physical mechanisms of the downdip seismic limit

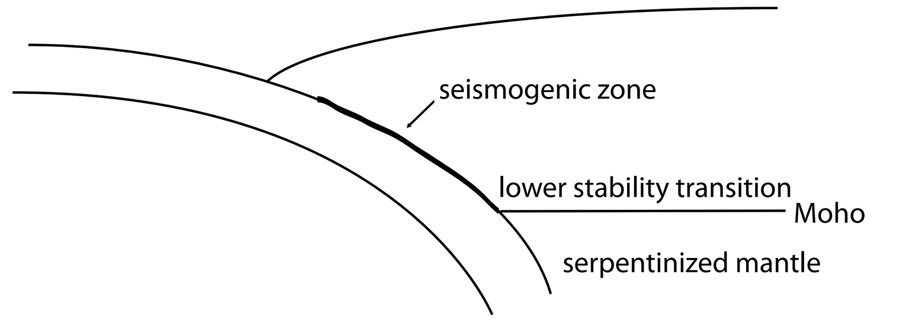
A. thermally controlled

As investigated by previous studies [e.g. Oleskevich et al., 1999], the fault friction transitions from stick-slip to stable-sliding at the depth of 350° C isotherm.



B. serpentinization in the fore-arc mantle wedge

Another possibility is that the fault friction transitions at the Moho depth because the contact material of the subducting plate with the hydrated mantle (i.e. serpentinization) is velocity strengthening [Bostock et al., 2002].



Conclusions

(1) The ALOS interferograms show pronounced changes in fringe pattern at a distance of ~150 km from the trench axis that are diagnostic of the downdip rupture limit of the Maule earthquake.

(2) An elastic dislocation model based on InSAR and GPS displacement measurements shows that the coseismic slip decreases more or less linearly from its maximum at ~18 km depth to near zero at ~43 km depth.

(3) The depth at which slip drops to near zero is almost uniform in the along-strike direction for a rupture length of ~600 km and it appears to be at the intersection of the subducting plate with the continental Moho.

(4) The average coseismic slip vector and the interseismic velocity vector are not parallel, suggesting a possible deficit in strike-slip moment release.

Acknowledgements

This research were supported by the National Science Foundation Geophysics Program (EAR 0811772) and the NASA Earthscope Program: the InSAR and Geodetic Imaging Component (NNX09AD12G).