Constraints on fault and lithosphere rheology from the coseismic slip and postseismic afterslip of the 2006 M_w 7.0 Mozambique earthquake

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The 2006 Mw 7.0 Mozambique earthquake

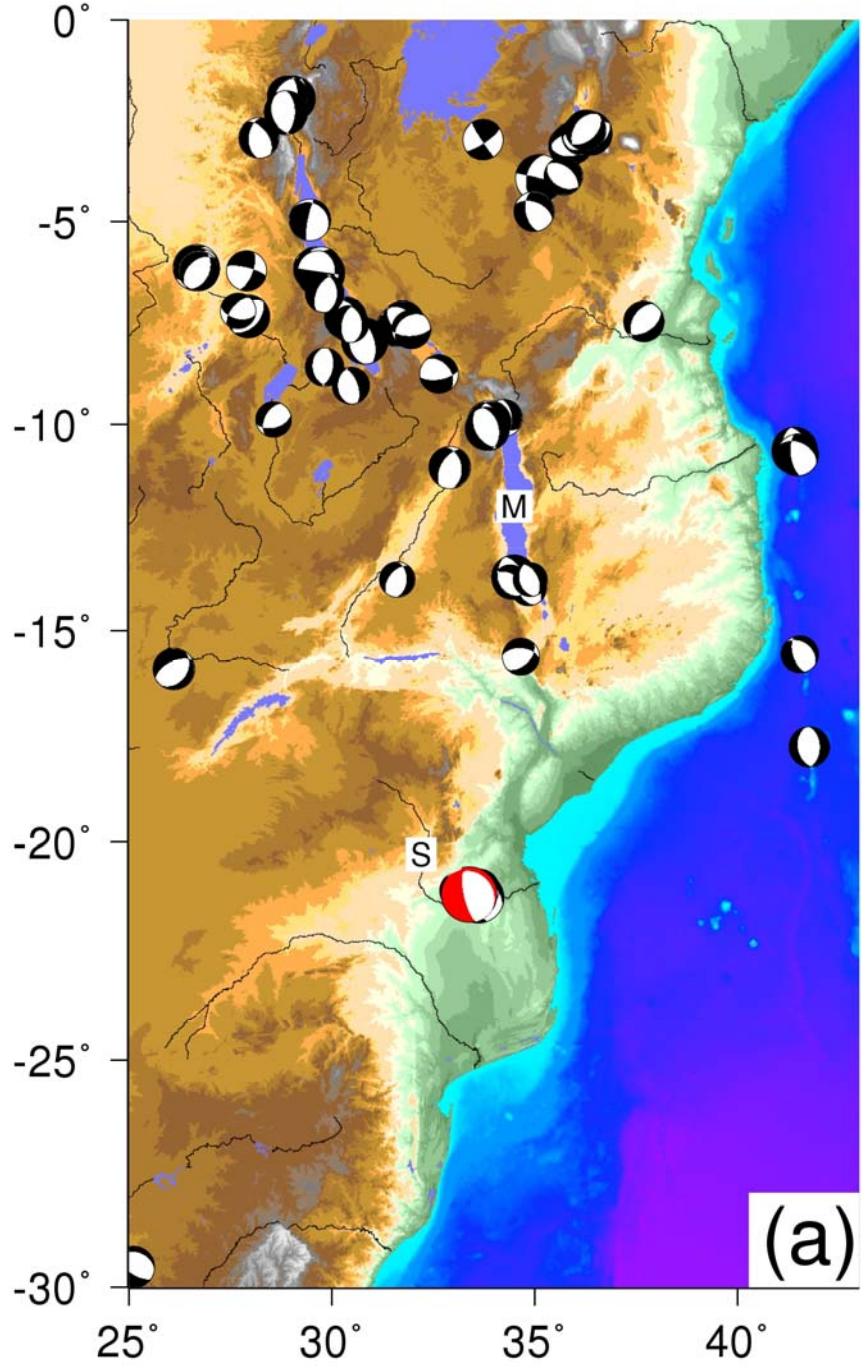
• Normal faulting at the S end of the East African Rift

• We have studied the event and the postseismic deformation using:

  • Teleseismic waveforms

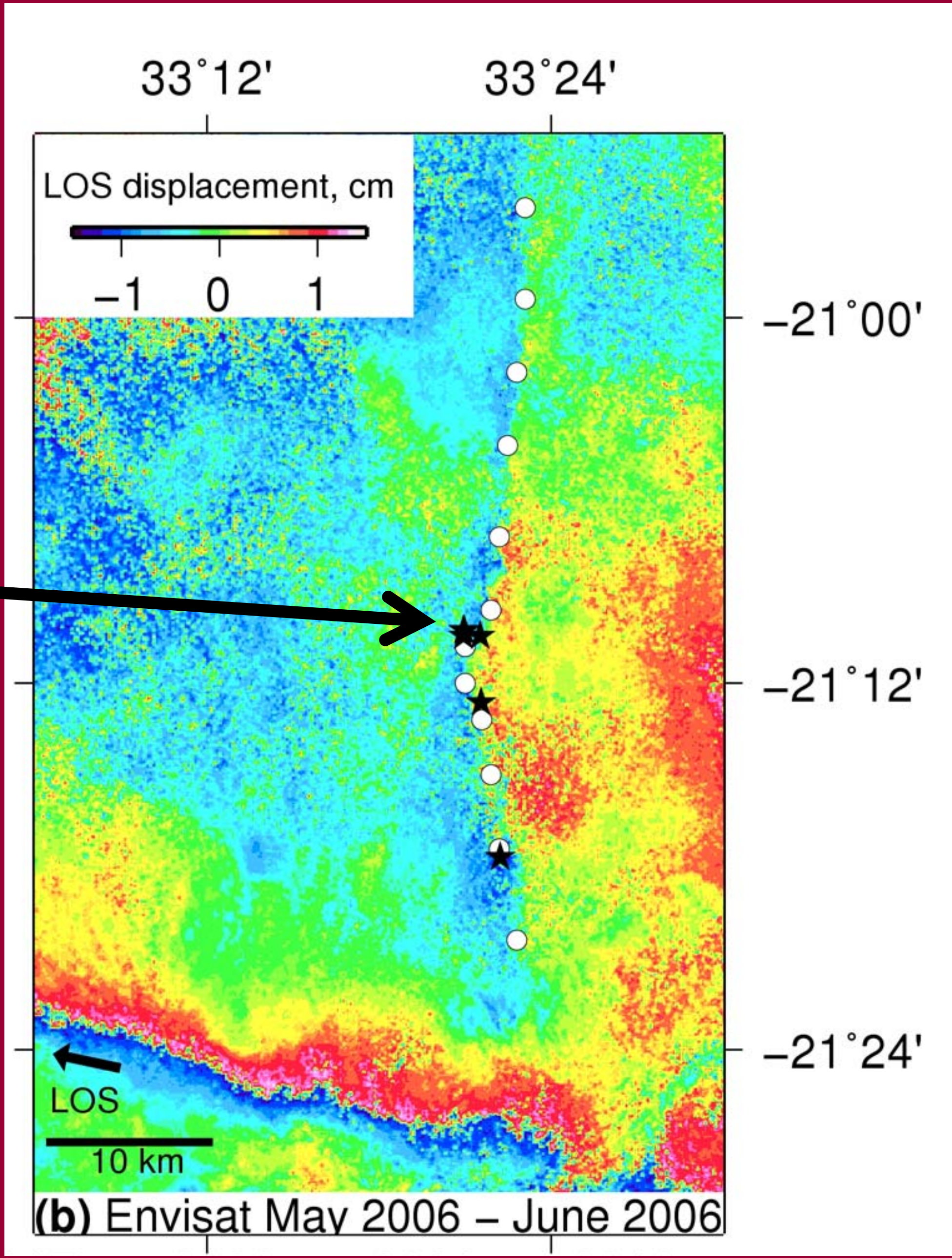
  • Envisat and ALOS SAR data

  • SPOT optical images



Postseismic Envisat descending-track interferogram

May 2006 – June 2006 (earthquake was in February 2006)

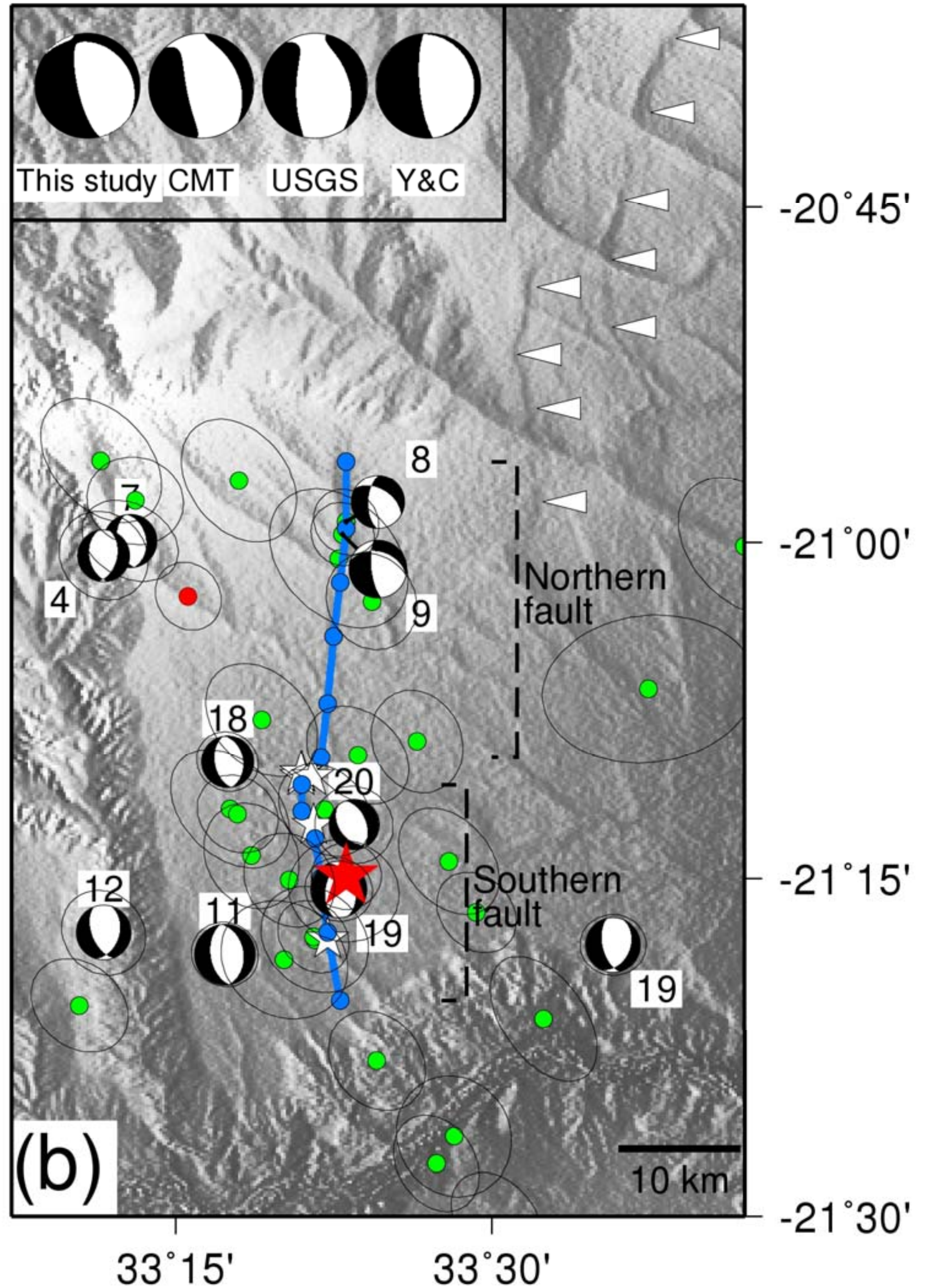


Sign convention used in this talk: negative LOS displacement -> increasing satellite-ground distance (i.e. subsidence if motion purely vertical)

Fault geometry, relocated hypocentre and aftershocks, and focal mechanisms

Relocated aftershocks and mainshock hypocentre using Hypocentraoidal decomposition [HDC, e.g. Jordan and Sverdrup 1981].

Focal mechanisms (depth labels in km) of large aftershocks from Yang and Chen [2008], Craig et al [2011], CMT.

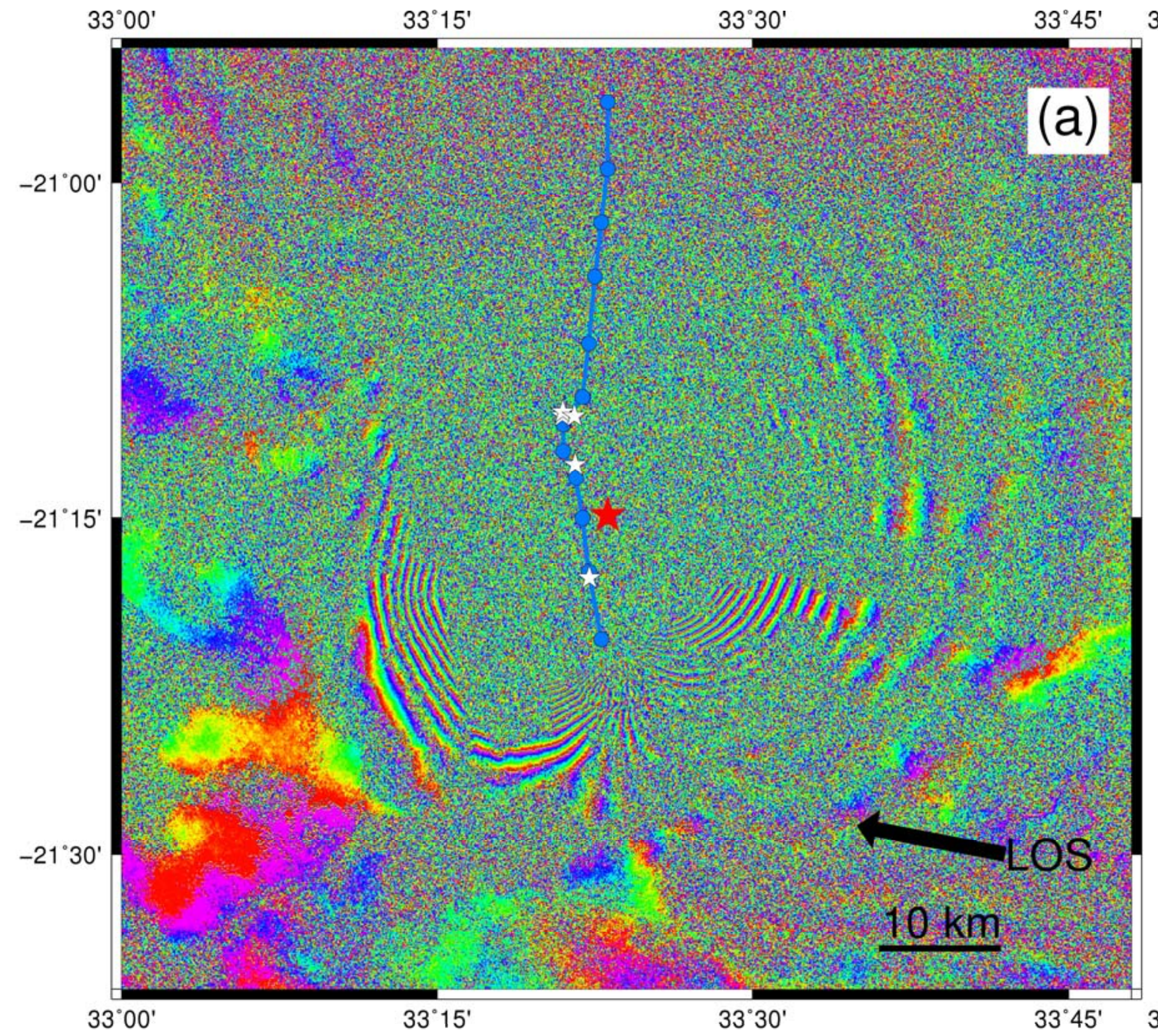


Coseismic Envisat descending-track interferogram

Blue lines -> surface trace from postseismic interferogram

Red star -> hypocentre

White stars -> surface breaks (Fenton and Bommer 2006)



Inversion details

Using the method of Ji et al [2002], Konca et al [2008,2010].

Simultaneous inversion of:

- 21 P waveforms
- 21 SH waveforms [e.g. Yang and Chen 2008]
- InSAR line-of-sight displacements [e.g. Raucoules et al 2010]
- Fenton and Bommer’s [2006] surface slip observations

Inversion method: ‘Simulated annealing’

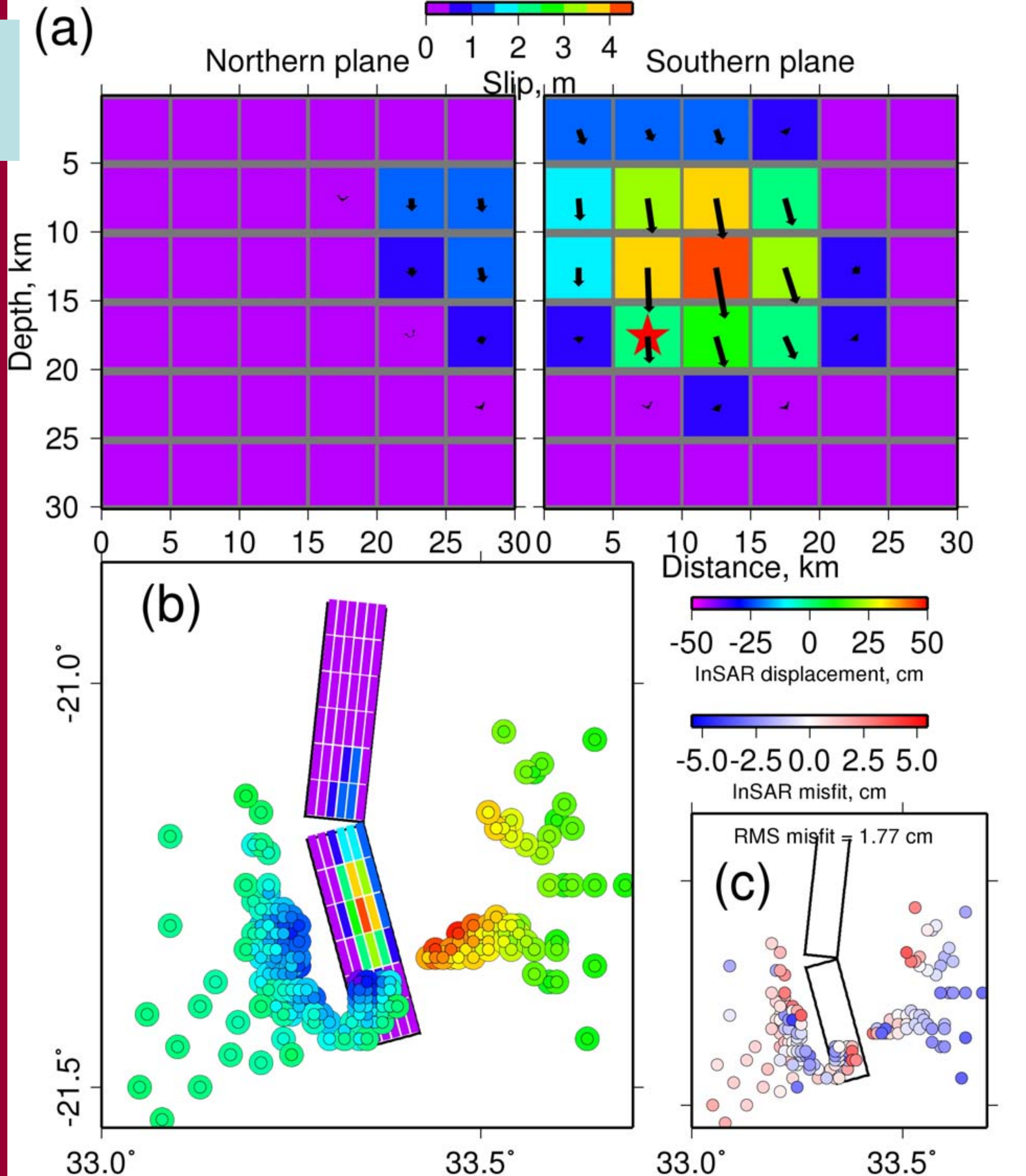
- iterative method, non-zero possibility of moving to a worse solution
- avoids being trapped in local minima

Fault rupture model:

- Rupture propagates as a pulse from the hypocentre
- Divide the fault into 5km x 5km patches, and solve for slip, rake, rise time, and rupture velocity for each patch

Moment constrained to be the CMT value

Results of coseismic slip inversion

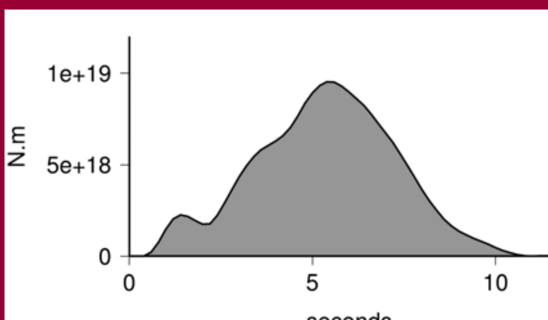


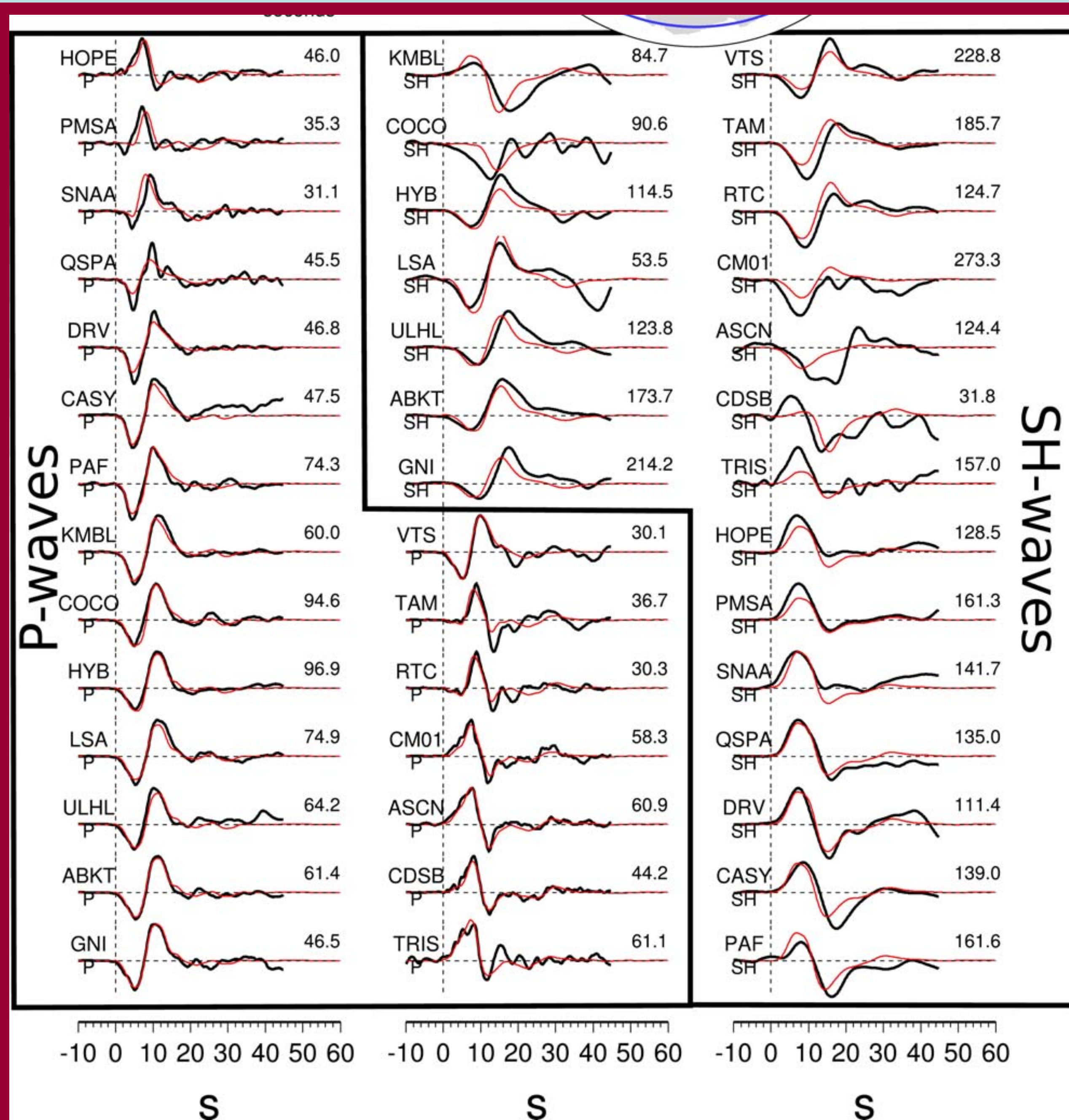
Features to note:

- The fault dip that best fits the data is 75º
- Decrease in slip from~10 km to the surface
- Only minor slip on the northern fault plane

Observed (black) and modelled (red) teleseismic waveforms

Source time function





Postseismic Envisat descending-track interferogram

May 2006 – June 2006 (earthquake was in February 2006)

Sharp discontinuity at the surface suggests afterslip on the shallow part of the fault plane.

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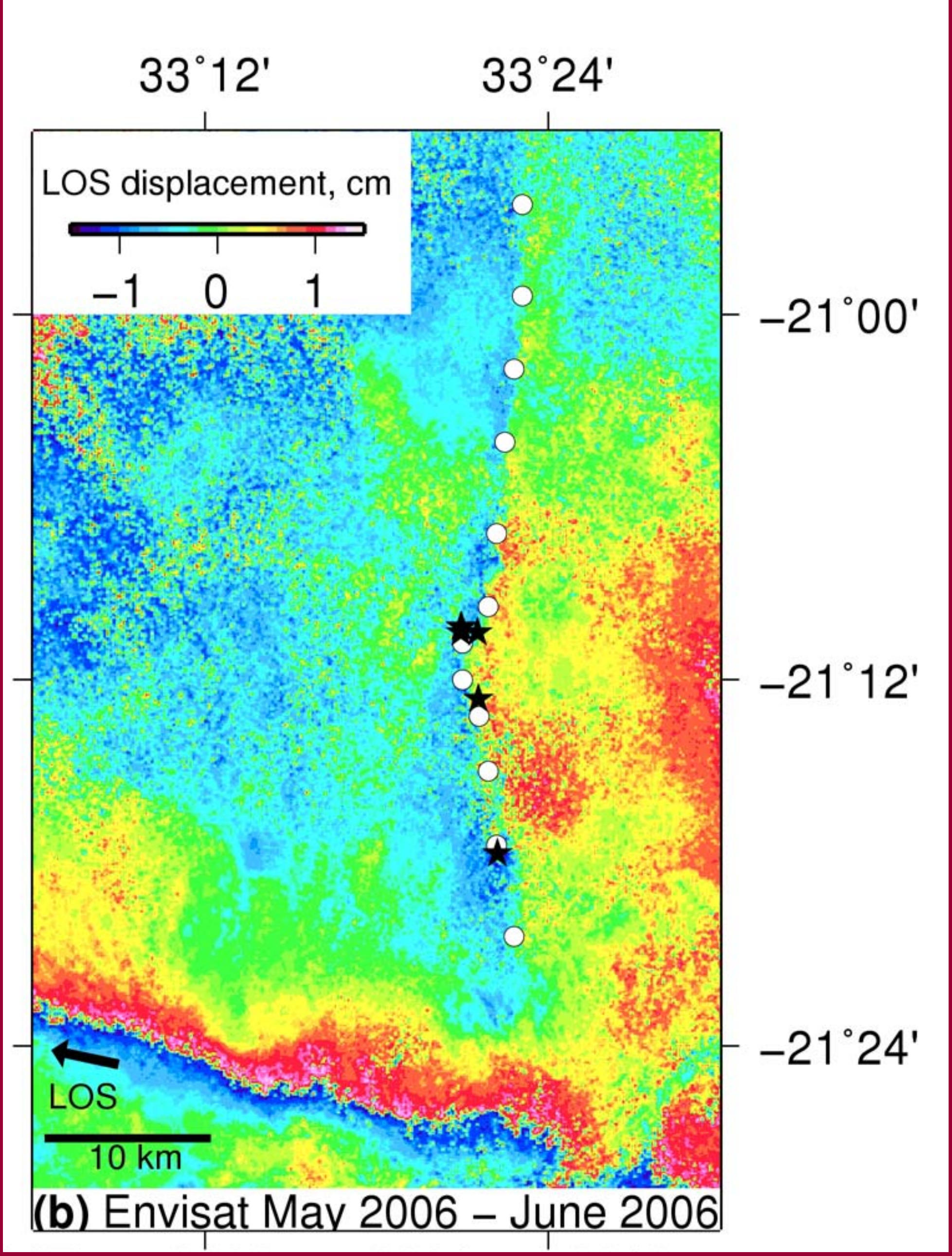
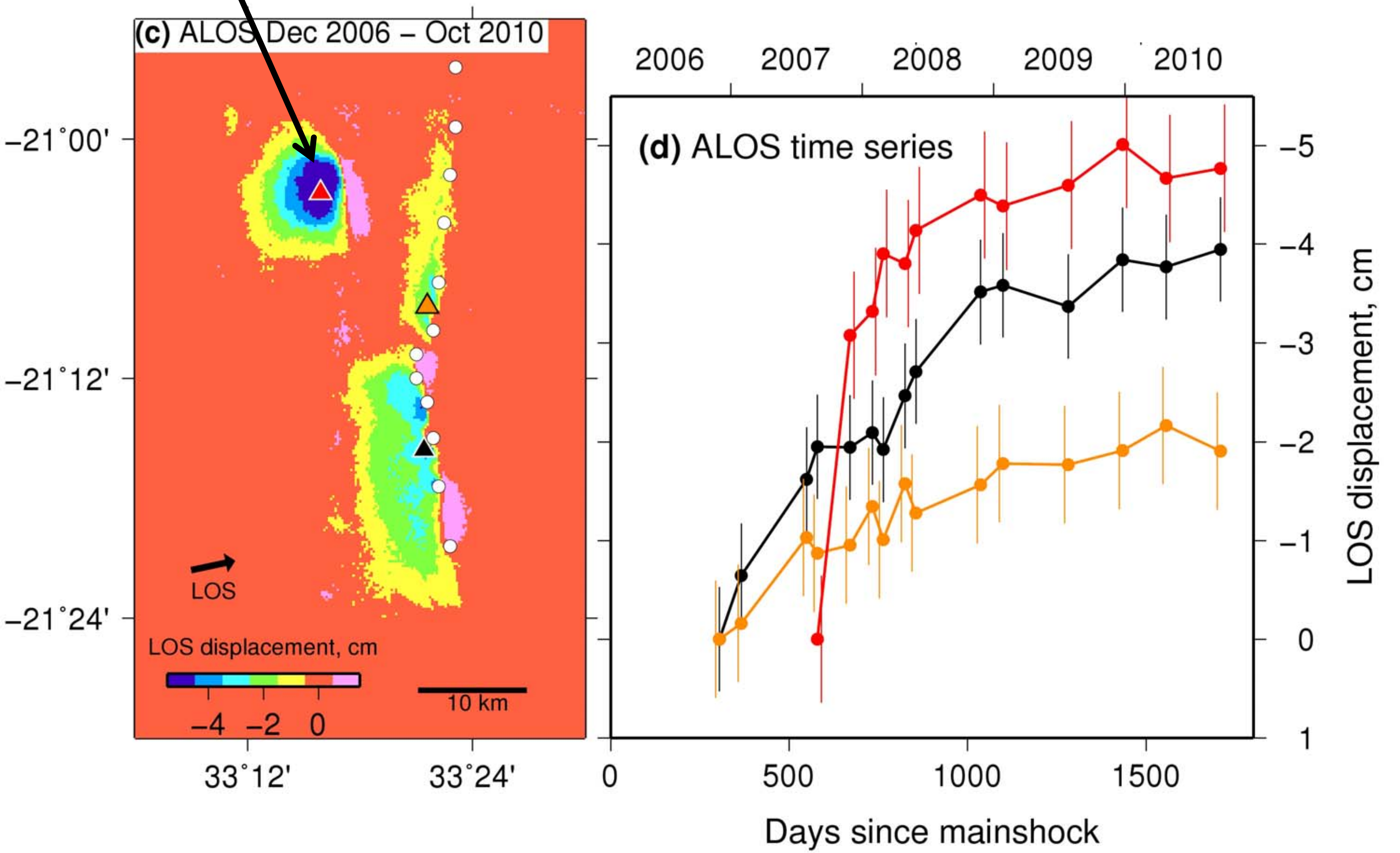


(b) Envisat May 2006 – June 2006

ALOS postseismic observations

Mw 5.2 aftershock

Data from December 2006 – October 2010



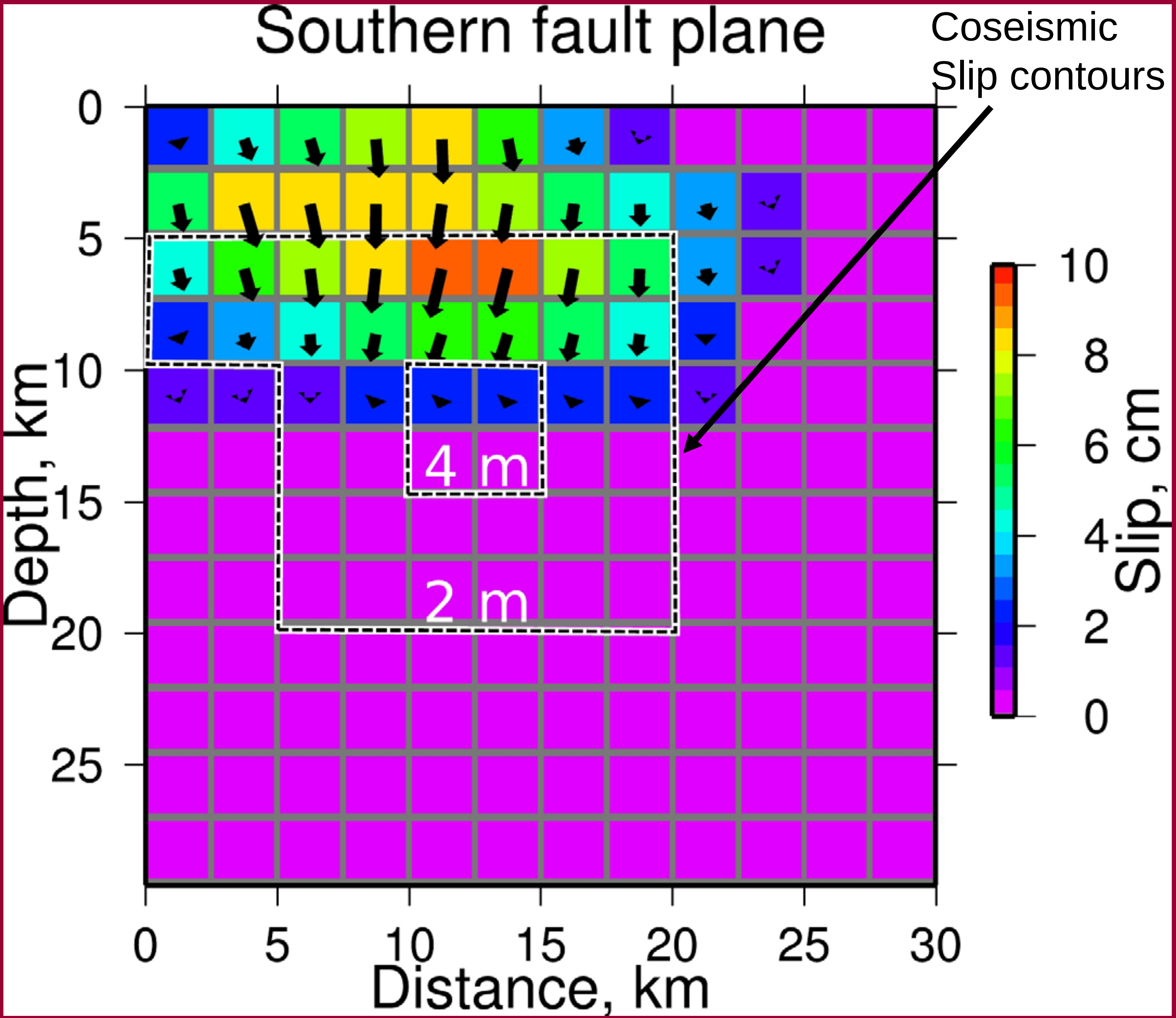
Afterslip on the southern fault plane

Afterslip observed in the ALOS data (~300 days post-event onwards)

Afterslip occurred in top 10 km.

Same as depth range of coseismic shallow slip deficit, and the sediment thickness in the region.

Suggests basement is velocity-weakening, and sedimentary sequence is velocity-strengthening (e.g. Marone et al 1991)

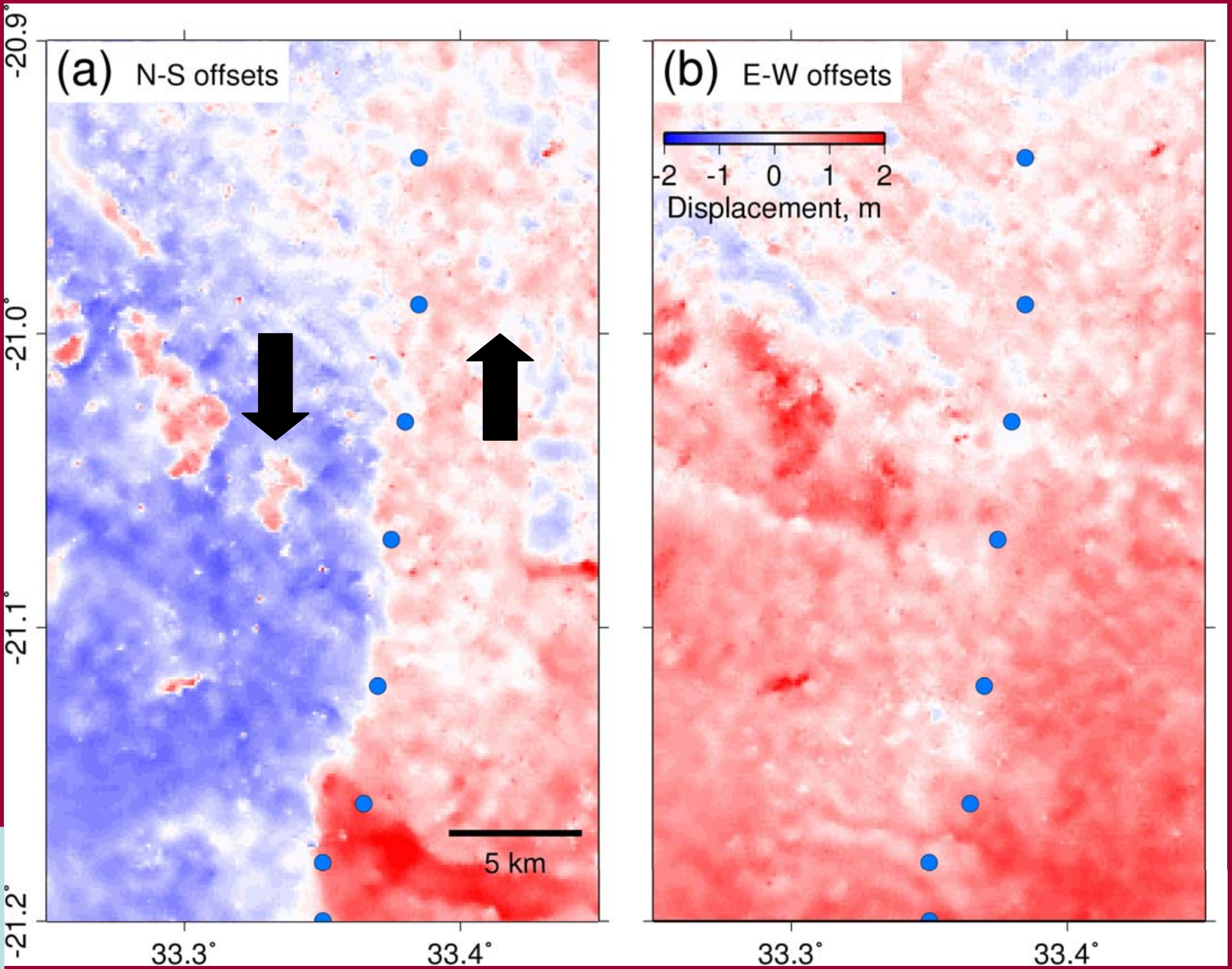


Strike-slip motion on the northern fault plane

Surface offsets from the cross-correlation of SPOT optical images (using the COSI-Corr program, Leprince et al 2007).

~1 metre of left-lateral strike-slip on the northern fault plane

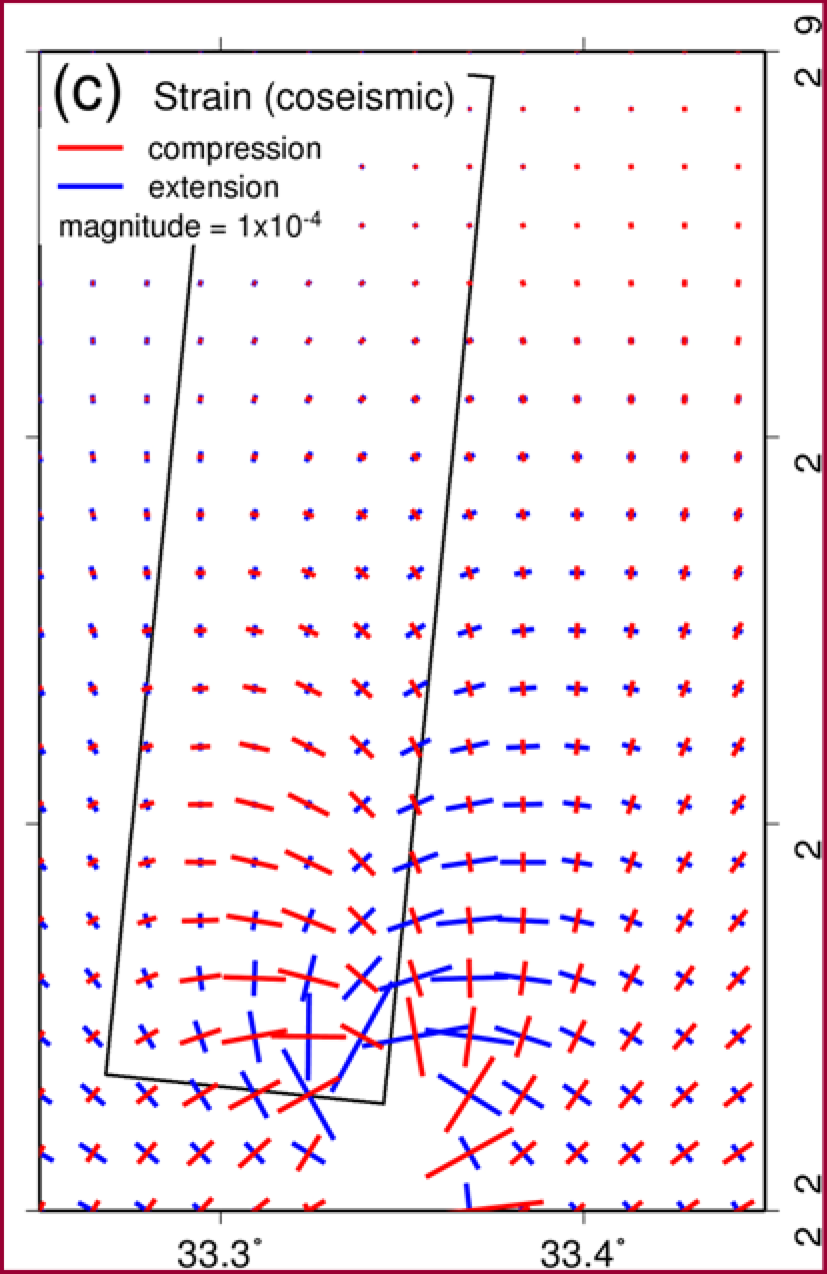
Uncertain proportions of postseismic and coseismic slip



Why the strike-slip component of slip?

Regional strain is E-W extension, so why is there strike-slip motion on the northern plane?

Stresses calculated from the coseismic slip model show a left-lateral strike-slip sense of stress in the region of the northern fault plane.

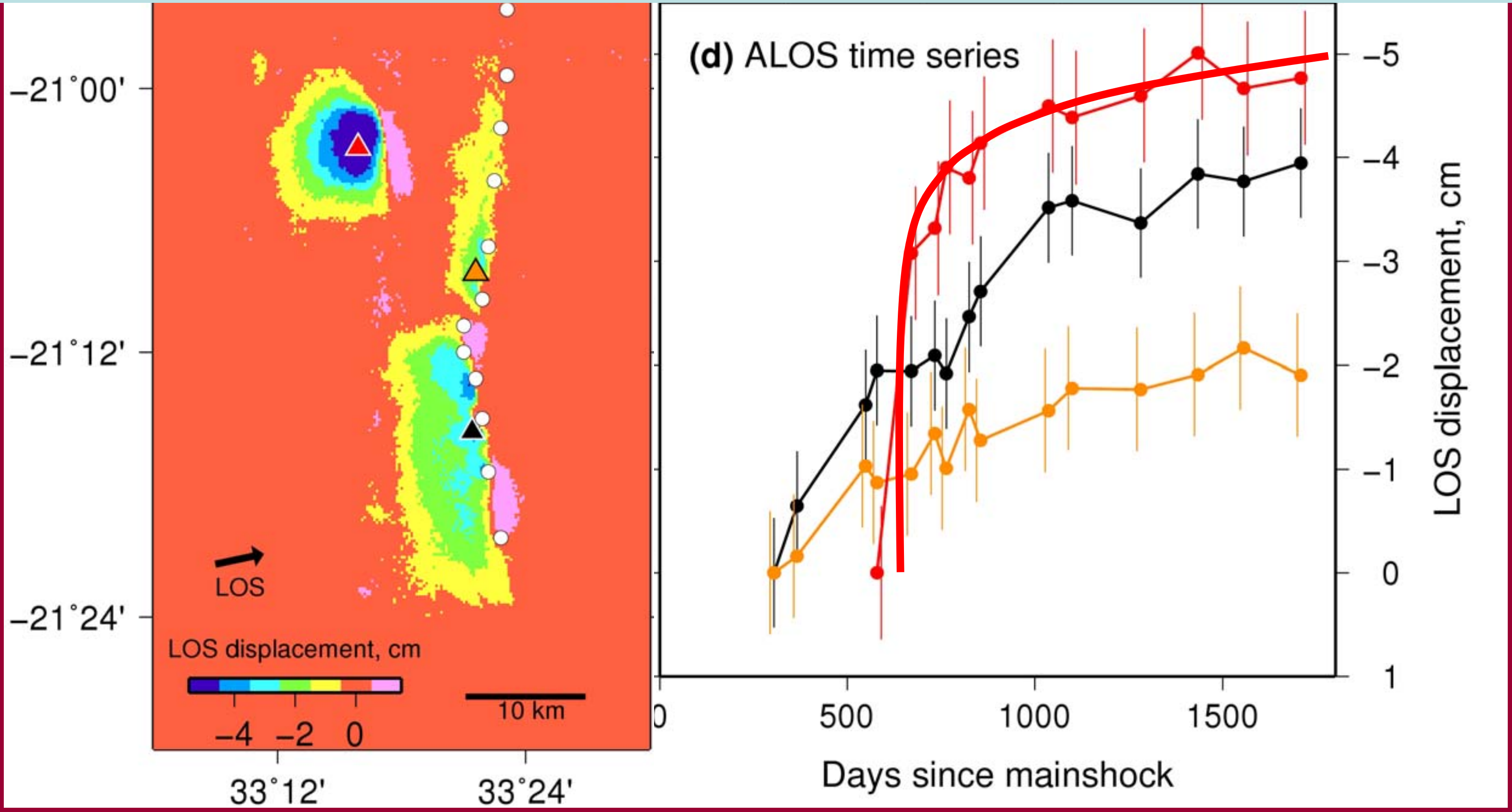


The Mw 5.2 Aftershock on 29 November 2007

We have fit the aftershock time series (red) with a coseismic offset plus a postseismic curve using the expressions of Perfettini and Avouac (2004) based on rate-dependent friction, i.e. $U(t) = U_c + \beta V_0 t_r log[1 + d(exp(t/t_r) - 1)]$

We estimate a to be 1×10^{-3} to 2×10^{-2} , where $a = \partial\mu/\partial \log(V)$

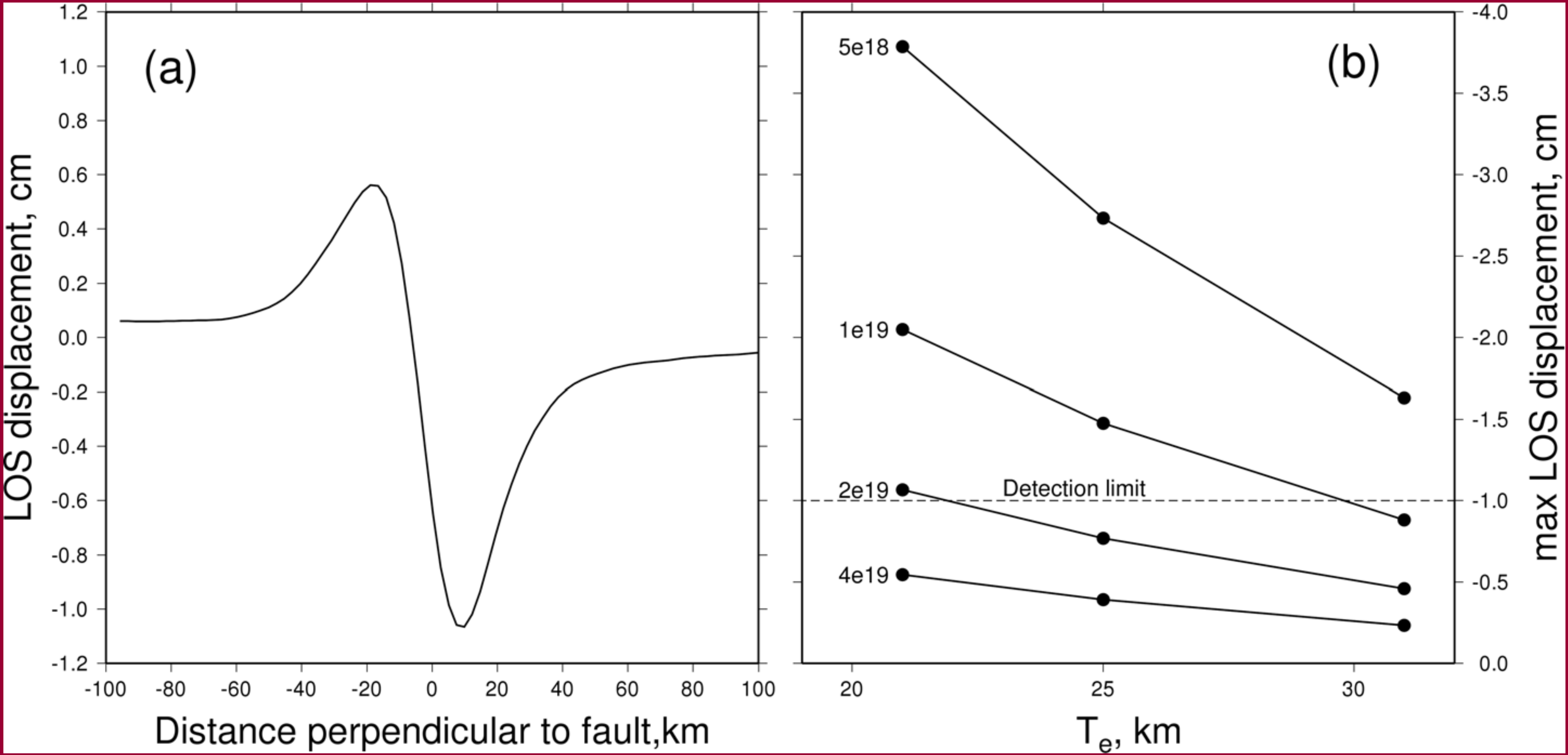
(similar to lab measurements and previous results, e.g. Dieterich & Kilgore 1994, Perfettini & Avouac 2004)



Constraints on lower lithospheric viscosities

No long-wavelength postseismic signal was observed in the ALOS data (300 days post-earthquake onwards), at our detection threshold above atmospheric noise of ~1 cm. (see also Fialko 2009, Raucoules et al 2010)

We used the VISCO-1d code (Pollitz 1992) to estimate that 2×10^{19} Pa s is the minimum lower crustal viscosity consistent with our lack of observed deformation



Summary

• The 2006 Mozambique earthquake occurred on a steeply-dipping normal fault, suggesting the re-activation of a pre-existing weakness.

• The slip decreased from depths of ~10 km towards the surface, and this shallow slip deficit was recovered to some extent by shallow afterslip on the fault plane. The depth range corresponds to the thickness of the sedimentary sequence in the region.

• Stresses generated by slip on the southern fault plane led to postseismic (and also possibly some coseismic) strike-slip motion on the northern fault plane.

• The value of '*a*' in the rate-dependent friction law is 1×10^{-3} to 2×10^{-2} , and the lack of visible long-wavelength postseismic deformation suggests that the viscosity of the viscous lower lithosphere is greater than 2×10^{19} Pa s.