Spatio-temporal evolution of seismic and aseismic slip on the Longitudinal Valley Fault, Taiwan

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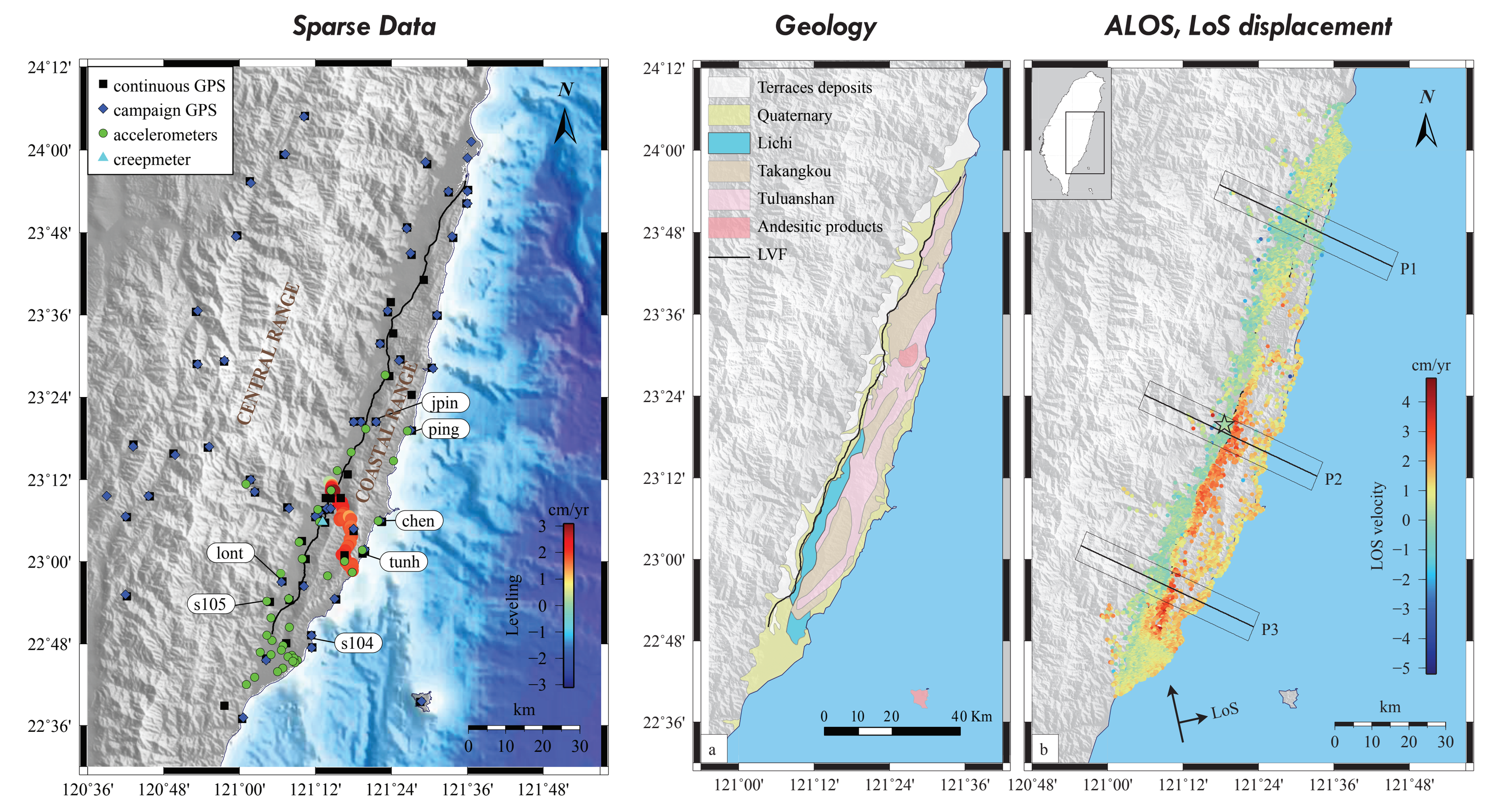
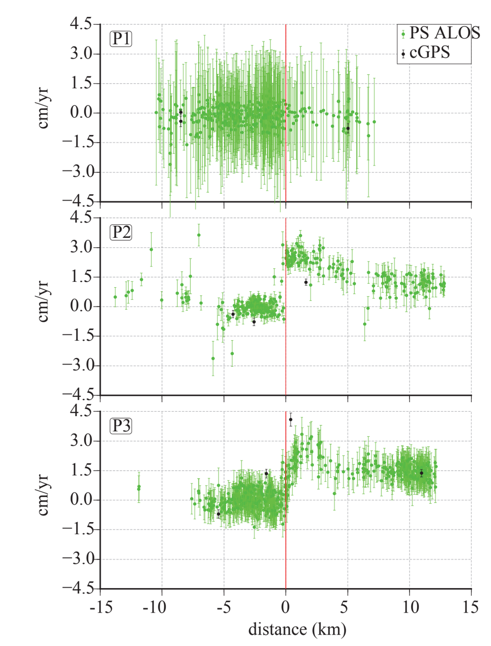
Abstract

The Longitudinal Valley Fault (LVF) in Eastern Taiwan is a high slip rate fault (about 5 cm/yr), which exhibits both seismic and aseismic slip. Deformation of anthropogenic features shows that aseismic creep accounts for a significant fraction of fault slip near the surface, whereas a fraction of the slip is also seismic, since this fault has produced large earthquakes with five Mw>6.8 events in 1951 and 2003. In this study, we analyze a dense set of geodetic and seismological data around the LVF, including campaign-mode Global Positionnig System(GPS) measurements, time series of daily solutions for continuous GPS stations (cGPS), leveling data, and accelerometric records of the 2003 Chenkung earthquake. To enhance the spatial resolution provided by these data, we complement them with Interferometric Synthetic Aperture Radar (InSAR) measurements produced from a series of Advanced Land Observing Satellite (ALOS) images processed using a persistent scatterer (PS) technique. The combined dataset covers the entire LVF and spans the period from 1992 to 2010. We invert this data to infer the temporal evolution of fault slip at depth using the Principal Component Analysis-based Inversion Method (PCAIM). This technique allows the joint inversion of diverse data, taking the advantage of the spatial resolution given by the InSAR measurements and the temporal resolution afforded by the cGPS data. We find that (1) seismic slip during the 2003 Chengkung earthquake occurred on a fault patch which had remained partially locked in the interseismic period; (2) the seismic rupture propagated partially into a zone of shallow aseismic interseismic creep but failed to reach the surface; (3) that aseismic afterslip occurred around the area that ruptured seismically. We find consistency between geodetic and seismological constraints on the partitioning between seismic and aseismic creep. About 80-90\% of slip on the LVF in the 0-26 km, seismogenic depth range is actually aseismic. We infer that the clay-rich Lichi Melange is the key factor promoting aseismic creep at shallow depth.

Data

A dense set of seismological and geodetic data is available on the longitudinal valley : PS ALOS, campaign GPS, Continuous GPS and creepmeter stations, accelerometers and leveling data. They have been conjointly inverse to get the temporal and spatial evolution of slip at depth





PS ALOS display a sharp discontinuity across the fault: it shows that the southern part of the longitudinal valley fault (LVF) creeps at surface, whereas the northern part remains locked.

Method

Principal Component Analysis based Inversion Method

Method based on the theory of dislocations in an elastic half space and Principal Component Analysis

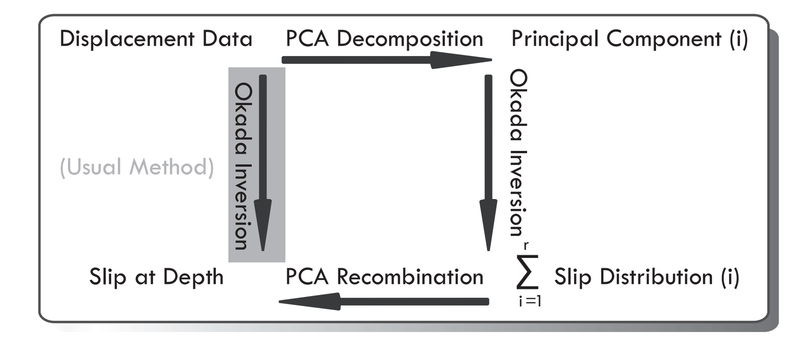
$X = USV^t$

$U = GG . L$

$X = (GG . L)\ SV^t$
$X = GG\ (LSV^t)$

Singular Value Decomposition of surface displacement series
+
Okada formulation
=
Slip decomposition

PCA and theory of dislocations are linear and associative and thus you can switch their ordering.



Kositsky & Avouac, JGR 2010

PCAIM can deal with any kind of time variation of fault-slip

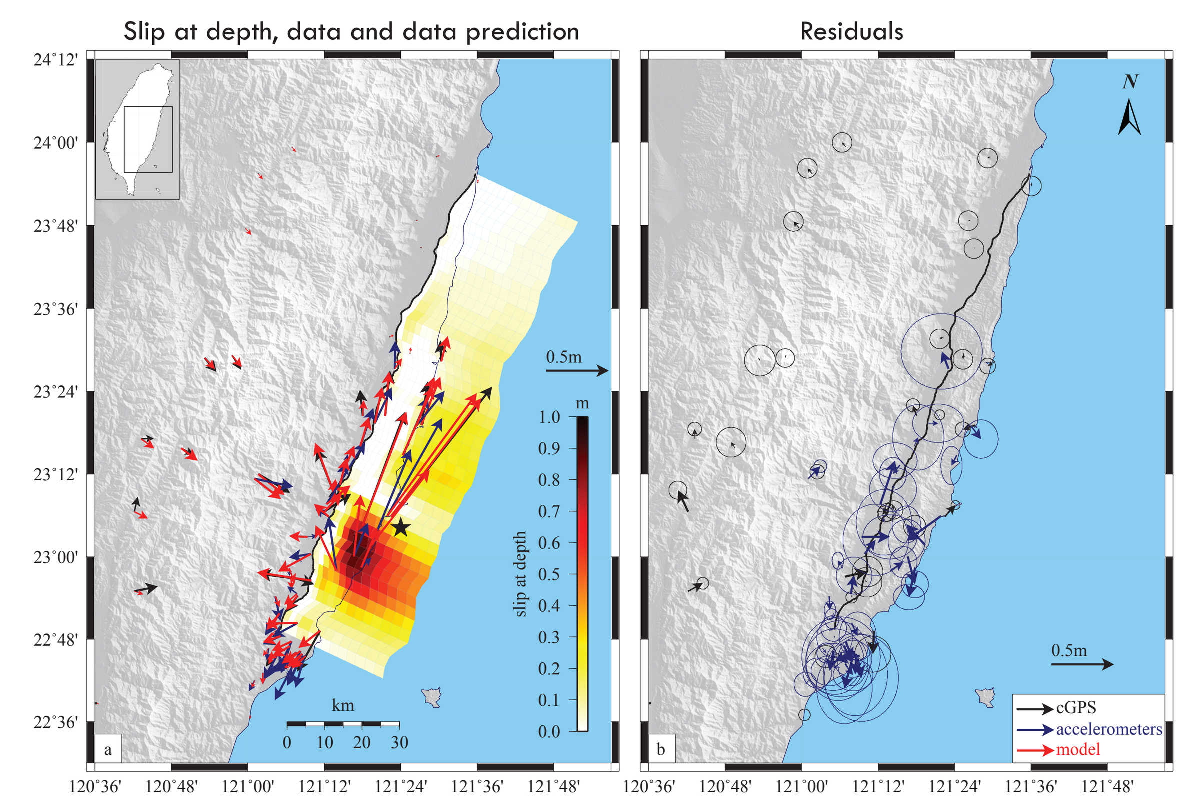
PCAIM can integrate simultaneously different geodetic measurement and remote sensing data.

This study was supported by the Gordon and Betty Moore foundation, the CNES and the Keck Institute.

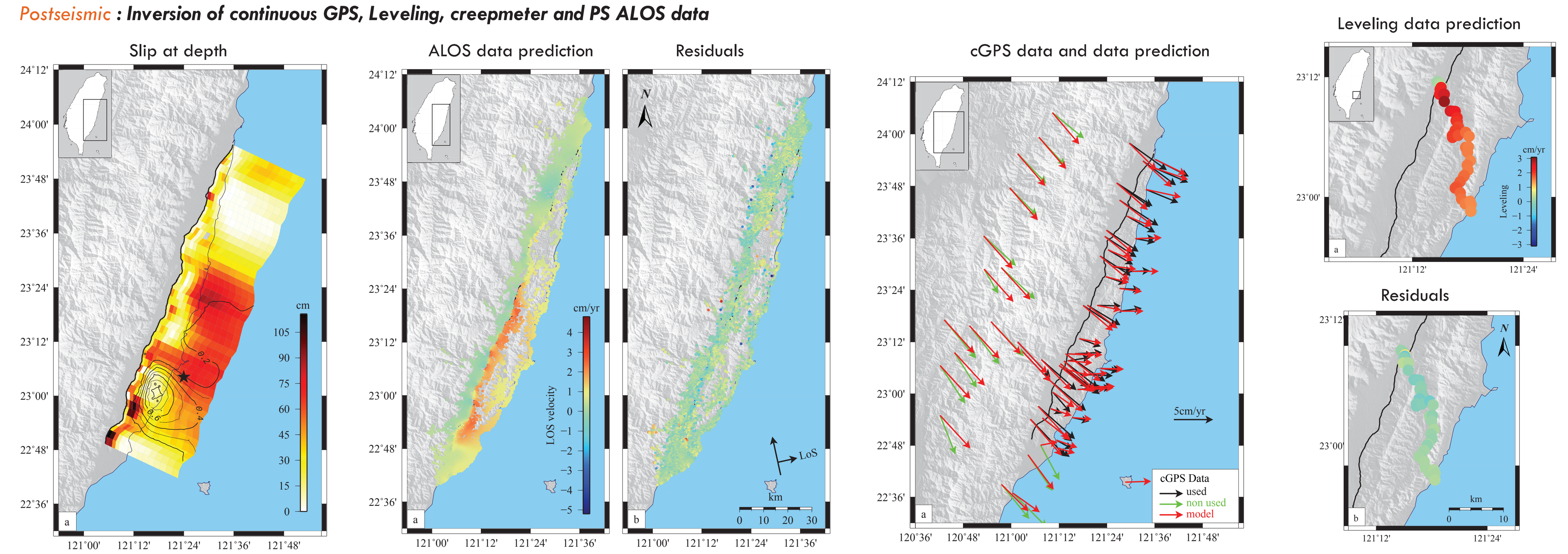
Inversion

Inversion models show that the 2003 Chengkung earthquake ruptured a zone that was locked before the event. Shallow creeping zone acted as a barrier during the 2003 earthquake and seems to cumulate less quantity of slip during the interseismic period, releasing the deficit of slip during the postseismic.

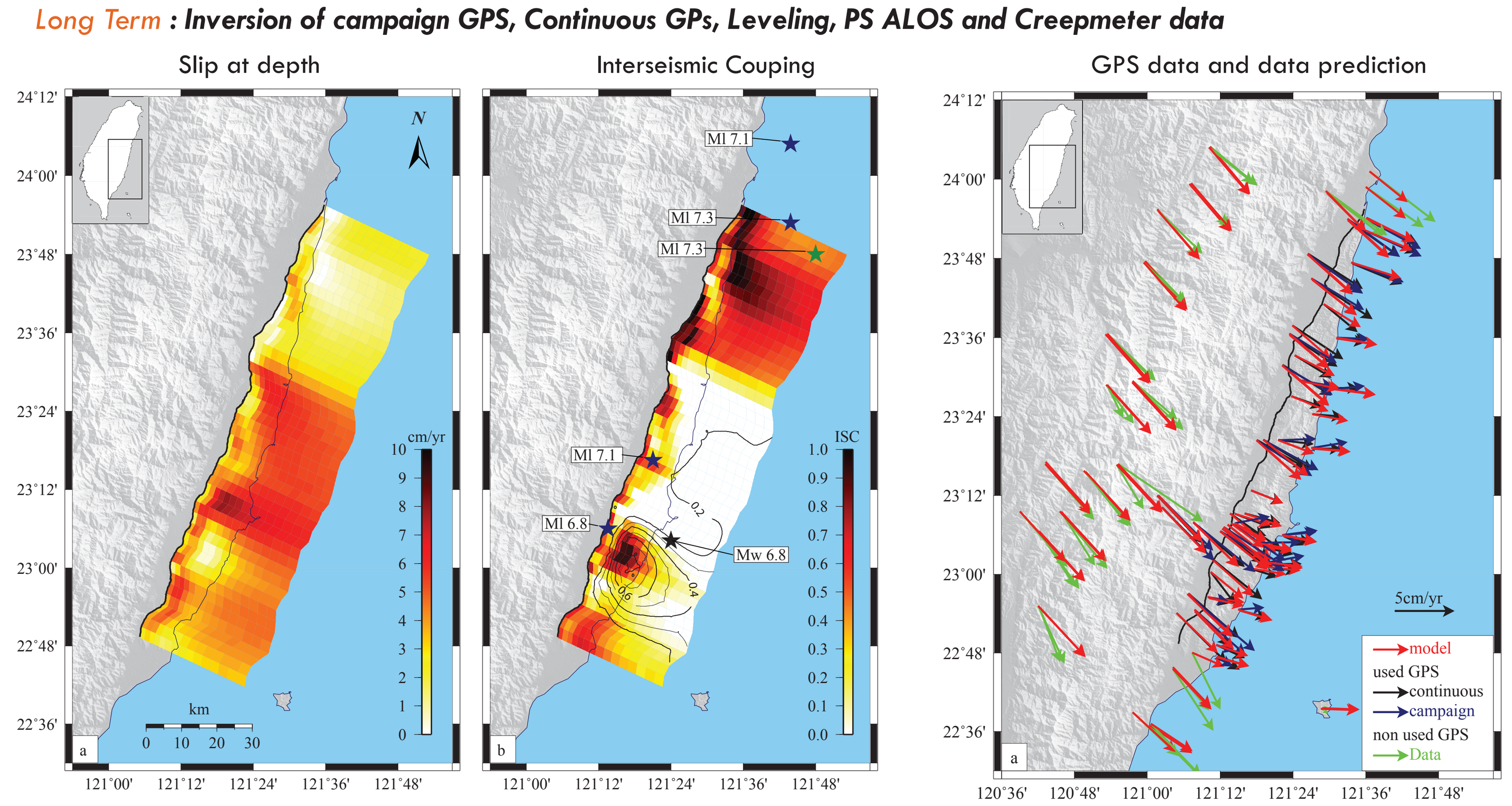
Coseismic **: Inversion of continuous GPS, Accelerometer and Creepmeter data**



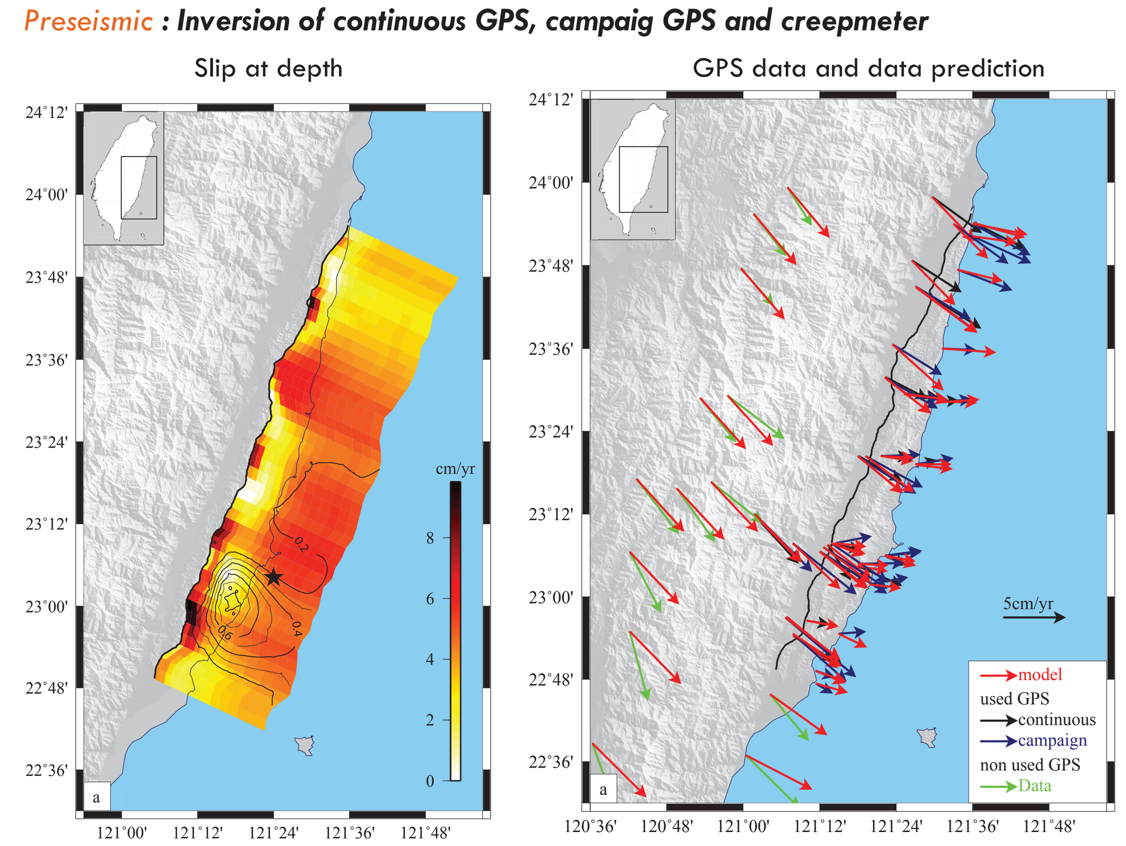
Postseismic **: Inversion of continuous GPS, Leveling, creepmeter and PS ALOS data**



Long Term **: Inversion of campaign GPS, Continuous GPs, Leveling, PS ALOS and Creepmeter data**

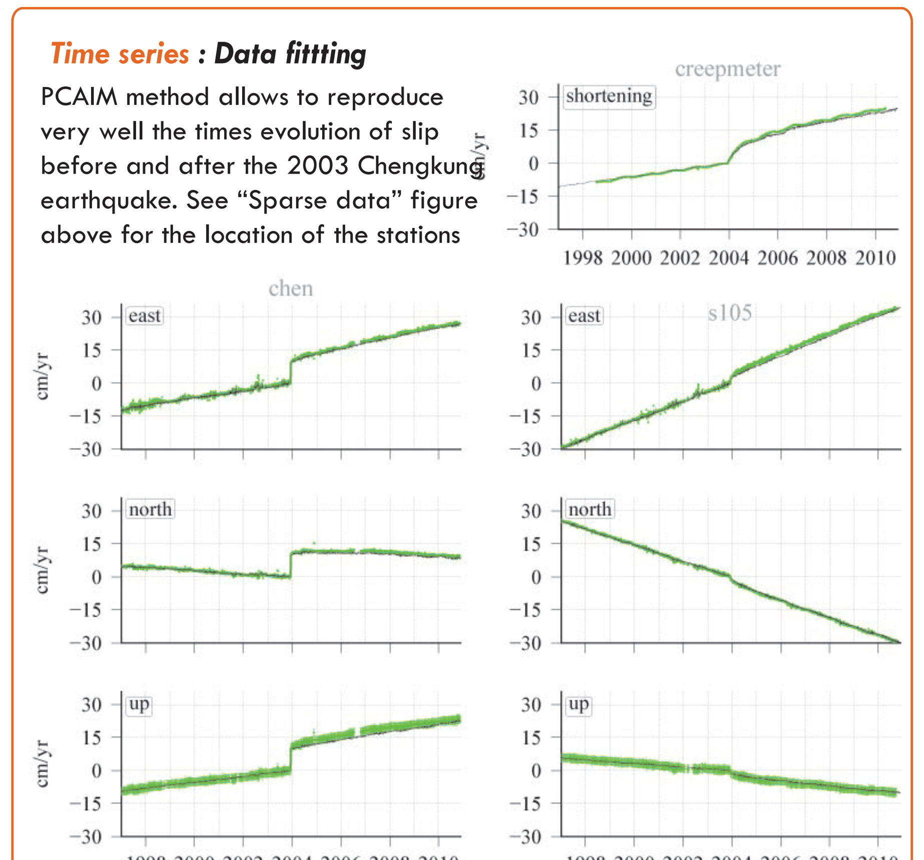


Preseismic **: Inversion of continuous GPS, campaig GPS and creepmeter**



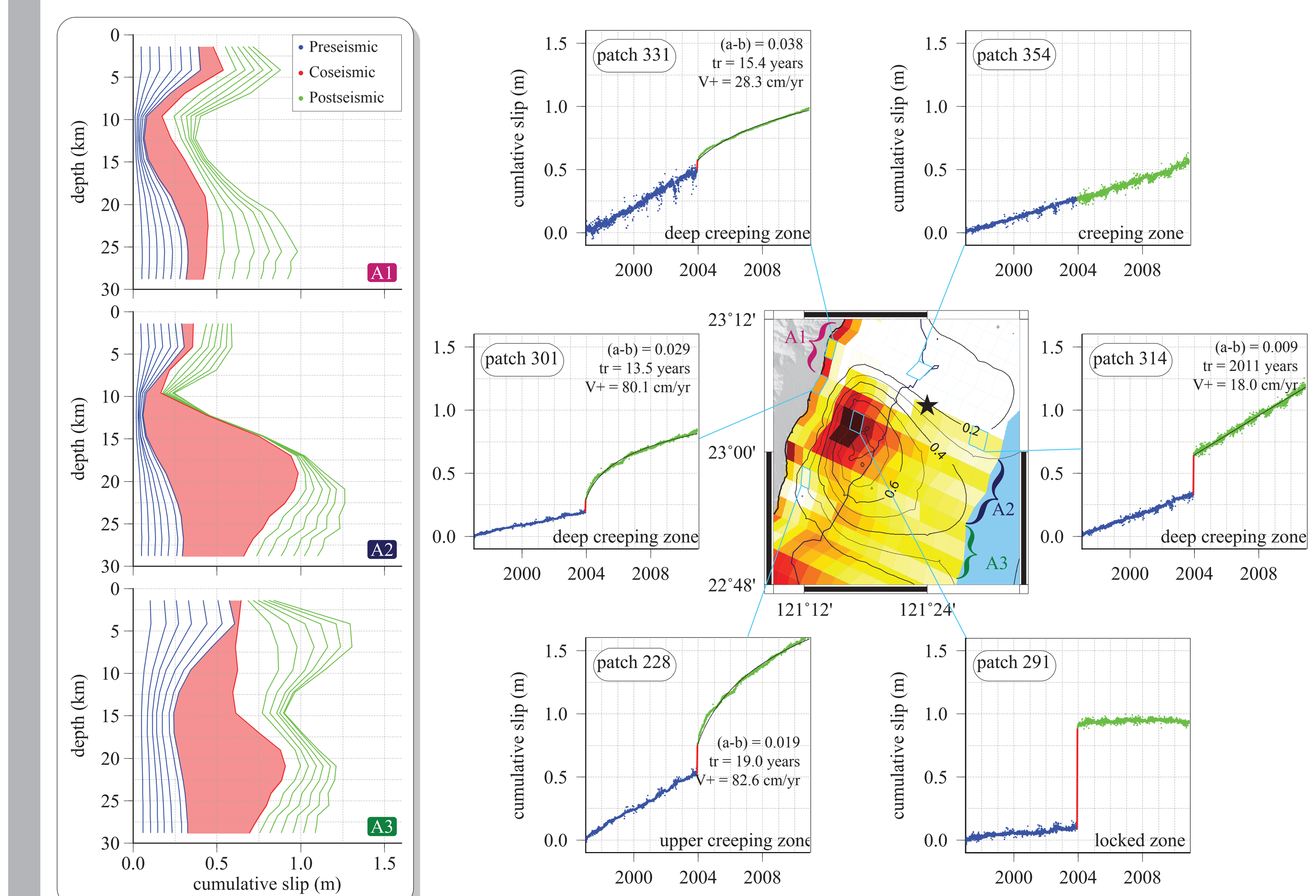
Time series **: Data fittting**

PCAIM method allows to reproduce very well the times evolution of slip before and after the 2003 Chengkung earthquake. See “Sparse data” figure above for the location of the stations



Insights on Frictional properties

Slip history at depth for six patches



Retrieving the (a-b) Frictional parameters

Knowing the evolution of slip at depth during the postseismic relaxation, the interseismic velocity, the normal stress and the stress drop of the 2003 chengkung earthquake, we can retrieve the frictional parameters (a-b)
.
(Perfettini et al., Nature 2010)

$$u(t) = V_0 \log\left(1 + \frac{V_+}{V_0 t_r}\right)$$

$$\frac{V_+}{V_0} = e^{\frac{\Delta\tau}{(a-b)\sigma}}$$

$$(a-b) = \frac{\Delta\tau}{\ln\frac{V_+}{V_0}\sigma}$$