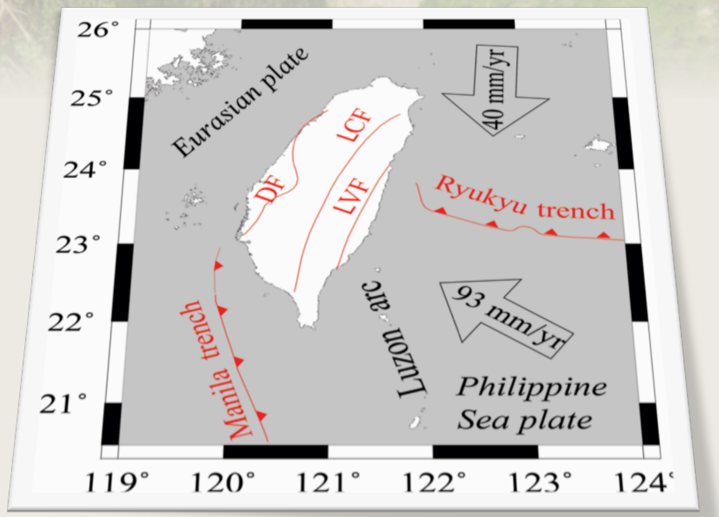
Longitudinal Valley, Taiwan



SEISMIC VS ASEISMIC BEHAVIOR ON THE LONGITUDINAL VALLEY FAULT : WHAT CONTROLS THE SLIP MODE?

Strasbourg
17/10/14

M. Thomas, J.-P. Avouac, N. Lapusta, J.-P. Gratier, J.-C. Lee

- **Motivation:**
  - Define the distribution of seismic/aseismic slip on fault
  - Document the factors that control this distribution
  - Develop physical model of the seismic cycle

Longitudinal Valley Fault, Taiwan

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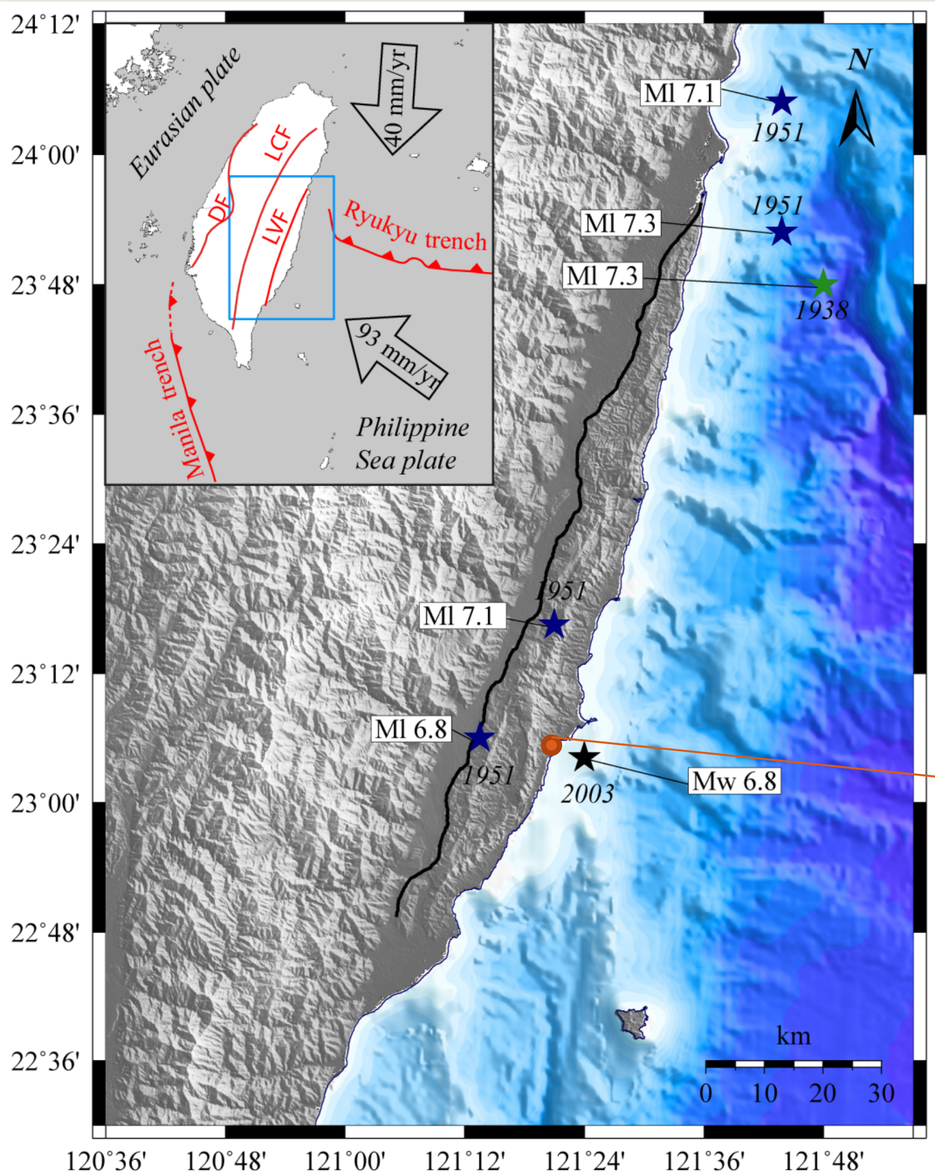
  - Define the distribution of seismic/aseismic slip on fault
  - Document the factors that control this distribution
  - Develop physical model of the seismic cycle

- **Approach:**
  - Target : Longitudinal Valley Fault, Taiwan
  - Data : geodesy, seismology
  - Inversion: temporal and spatial evolution of slip at depth
  - Implication for fault friction and the governing factors
  - 3D dynamic modeling
  - Deformation mechanisms that control the mode of slip

Longitudinal Valley Fault, Taiwan

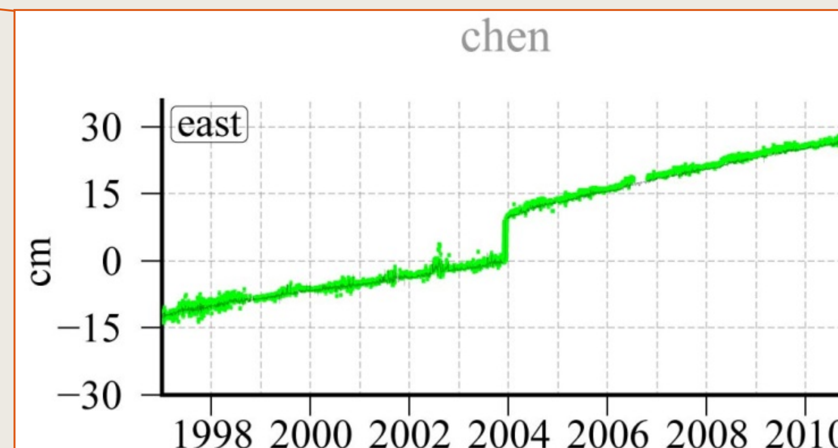
OUTLINE

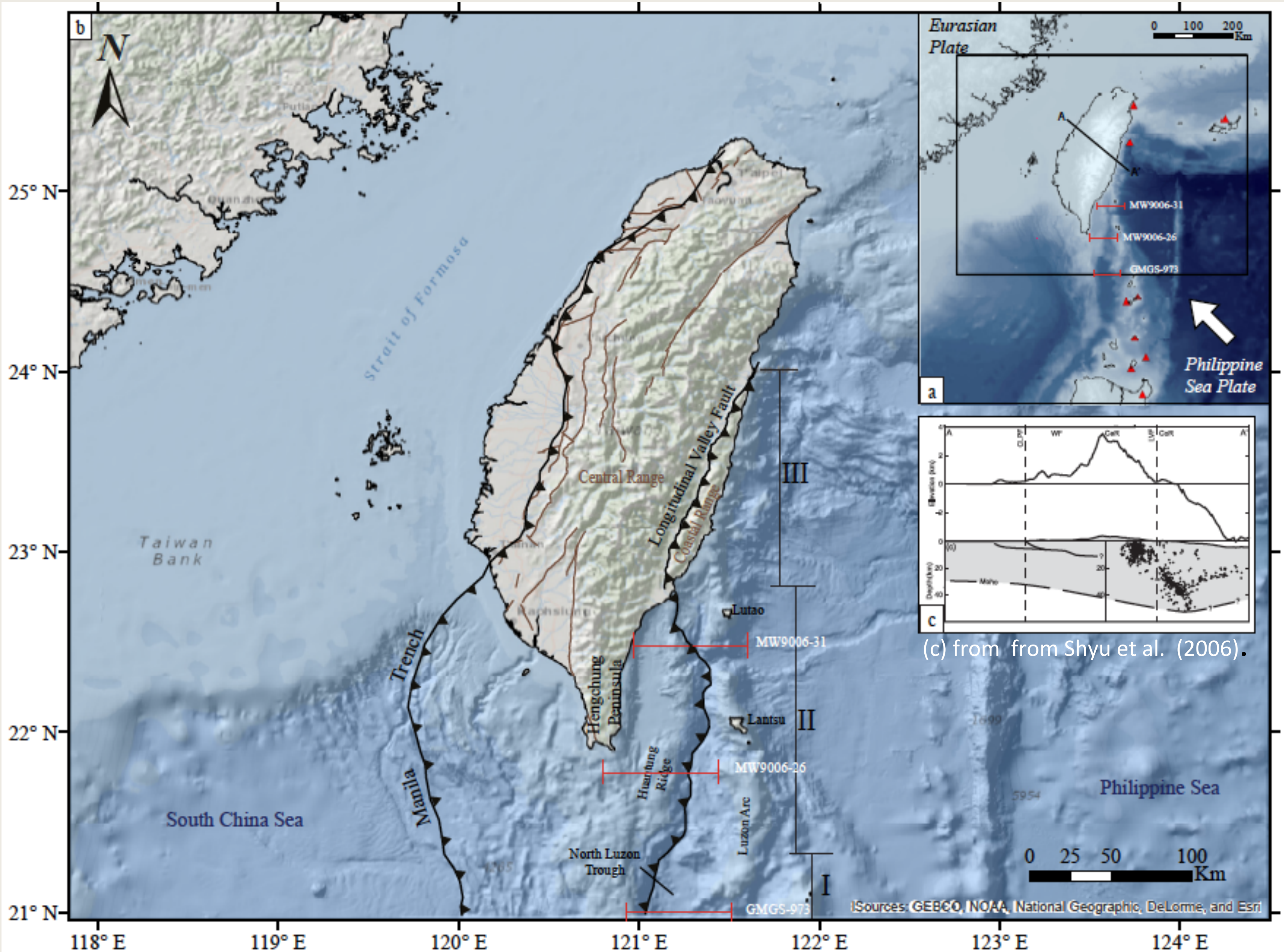
- PART 1: Geological and plate tectonic setting of the Longitudinal Valley fault
- PART 2: Spatio-temporal evolution of seismic and aseismic slip on the Longitudinal Valley Fault, Taiwan
- PART 3: Frictional properties derived for the geodetic analysis and Dynamic modeling of earthquakes sequences on the Longitudinal Valley Fault
- PART 4: Lithological control on the deformation mechanism and the mode of fault slip on the Longitudinal Valley Fault, Taiwan



The LVF is an exceptional laboratory to study the variations of frictional properties:

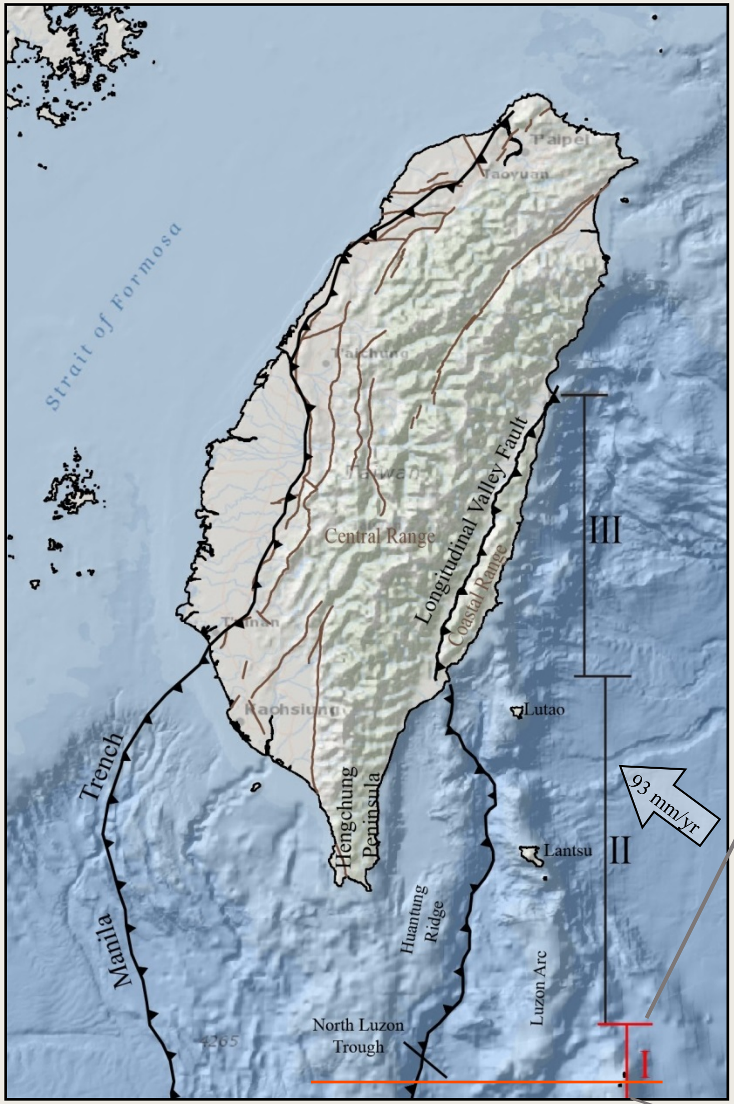
- LVF is part of very active plate boundary
- High slip rate: > 4 cm/yr
- Aseismic creep accounts for a significant fraction of the fault slip
- Large earthquakes : M>7 1951 ; Mw 6.8 2003
- Thrust fault: an access to the lithology
- Great data set that records interseismic, cosesmic postseismic periods.

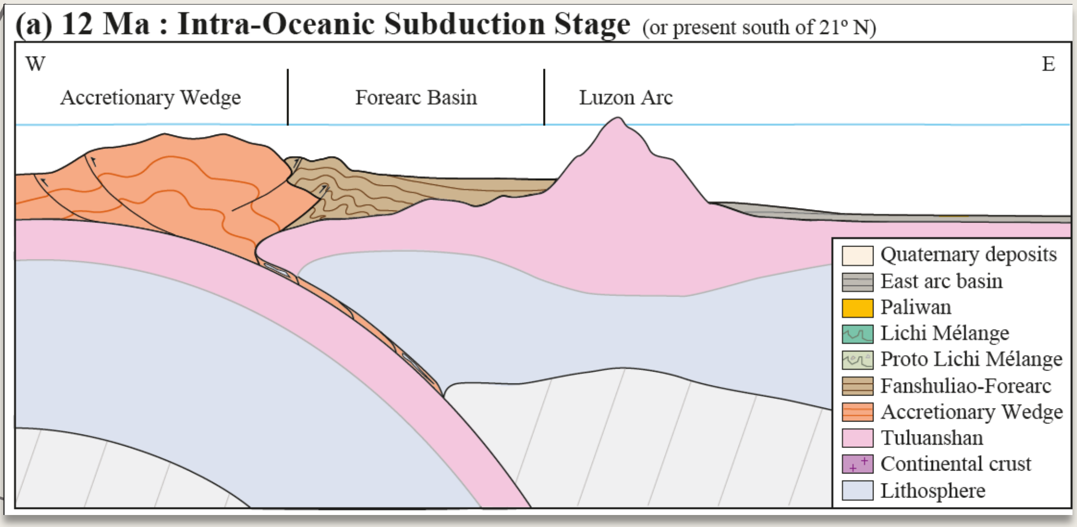




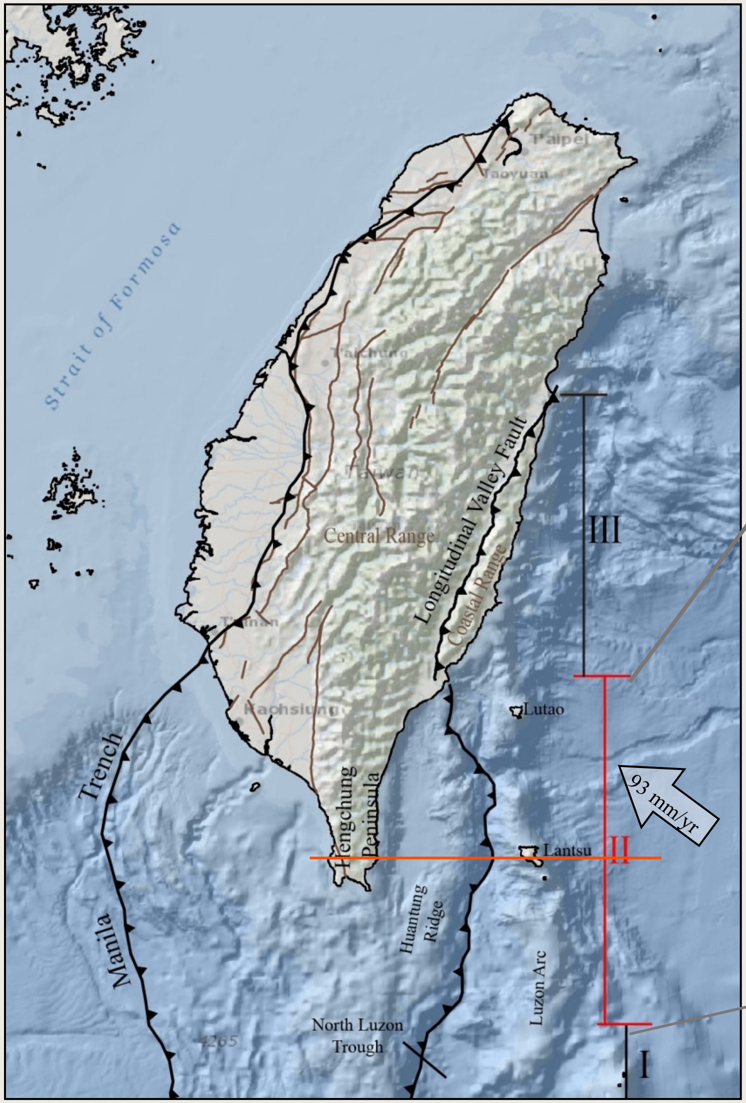
(c) from from Shyu et al. (2006).

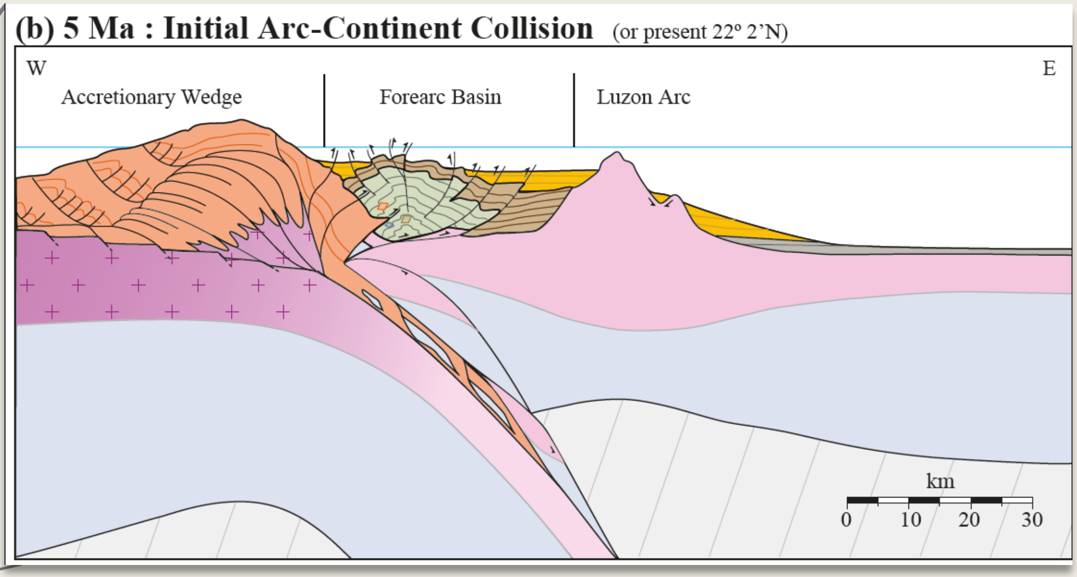
GEOLOGICAL SETTING : TECTONIC SCENARIO, early stage



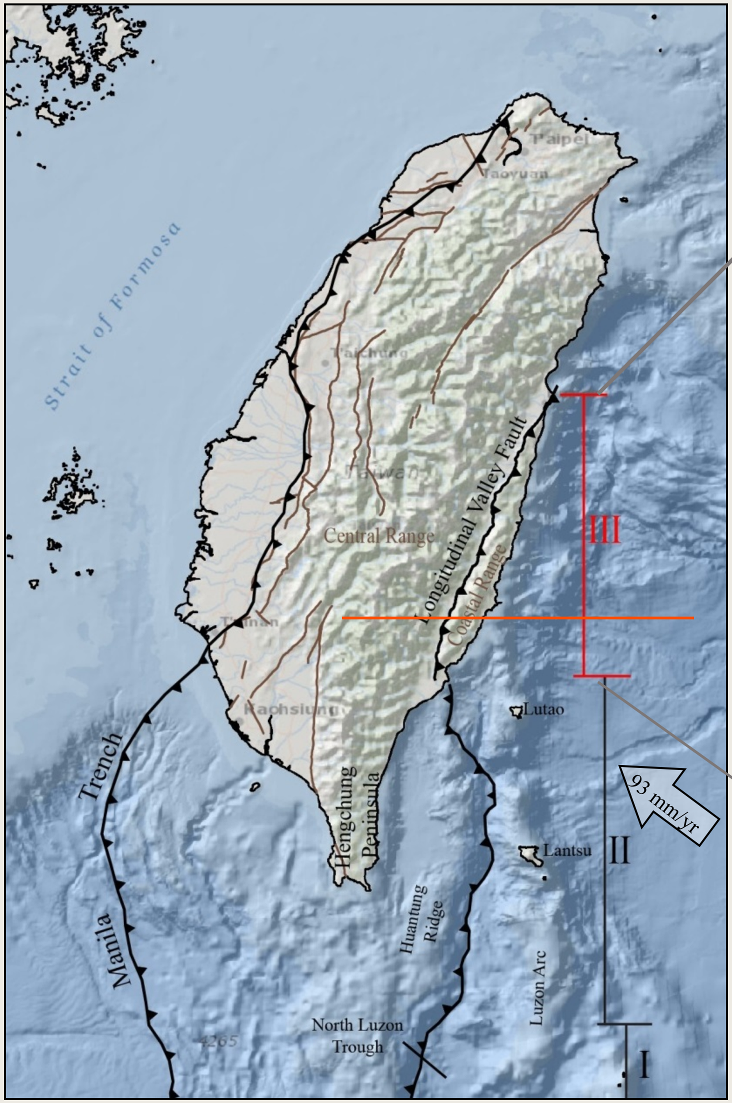


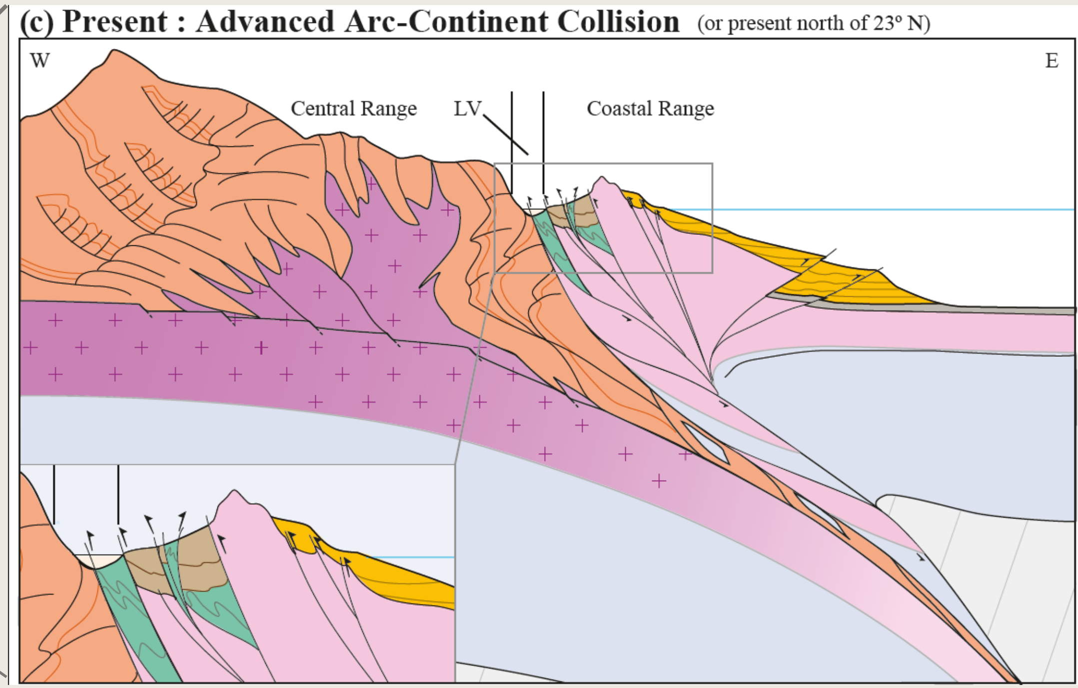
GEOLOGICAL SETTING : TECTONIC SCENARIO, initial collision



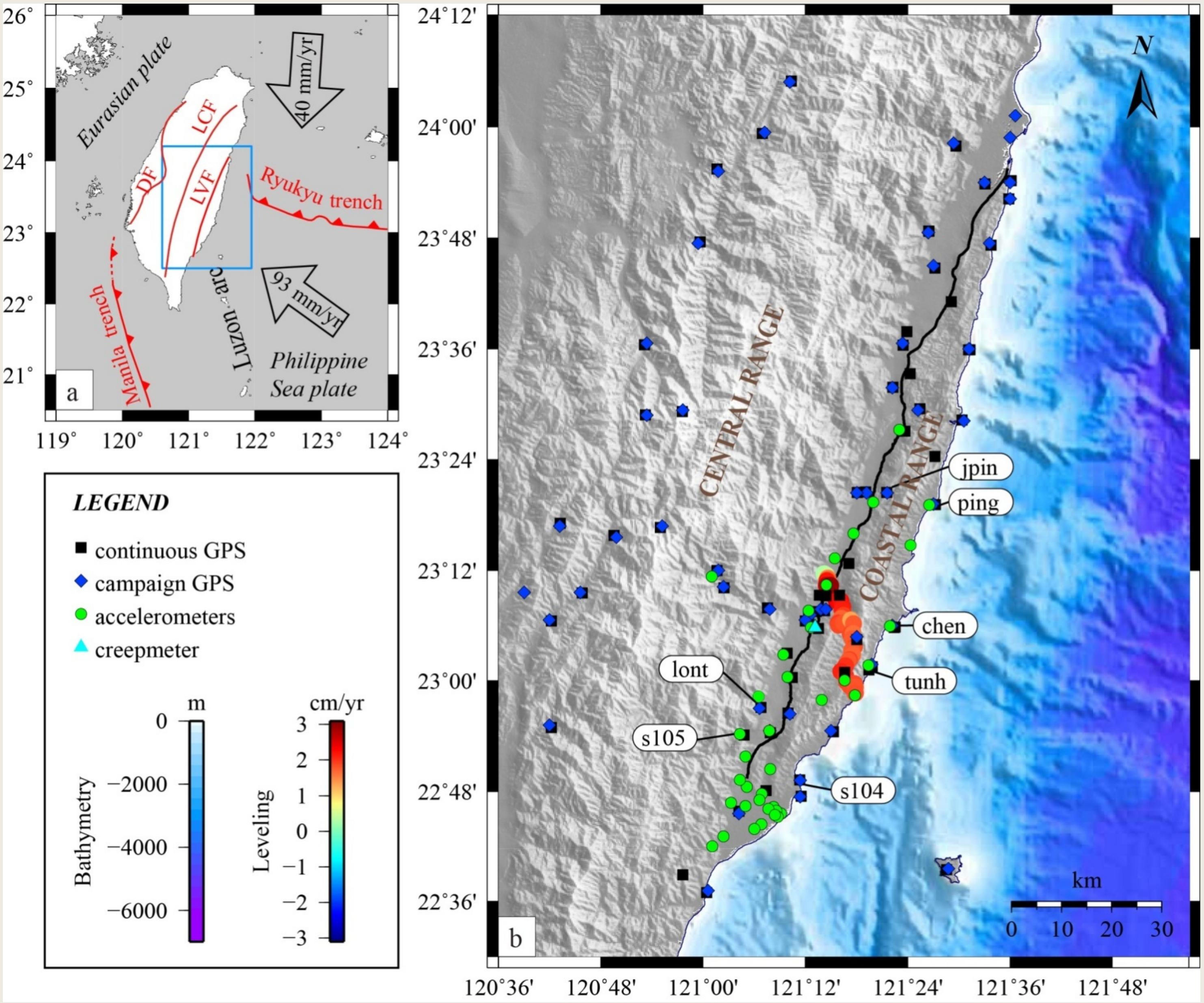


GEOLOGICAL SETTING : TECTONIC SCENARIO, advance collision





AVAILABLE DATA



GPS times series
From 1994 to 2011
Tec websites
67 stations

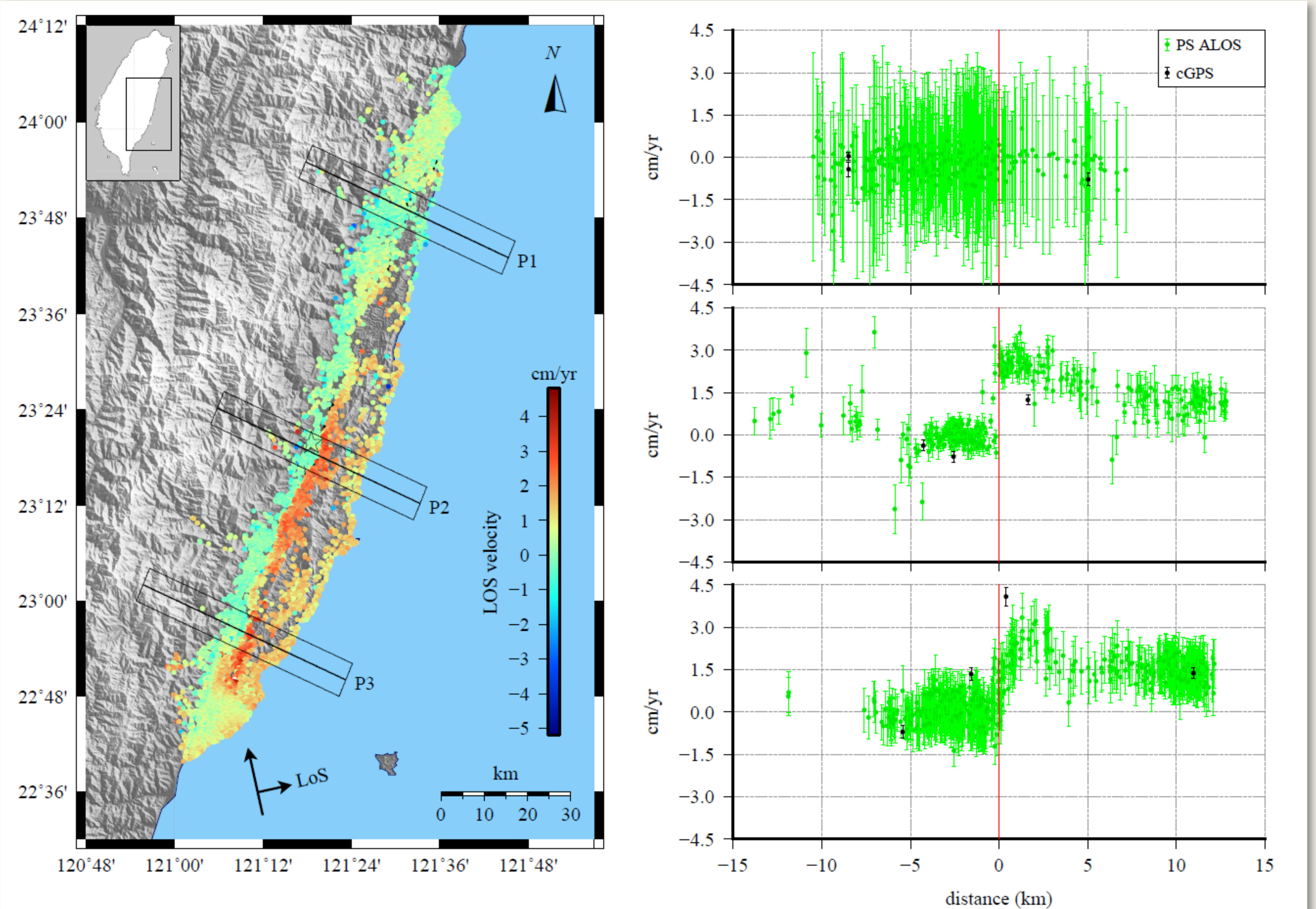
Campaign GPS
From 1992 to 1999
Yu et al, 2001
45 stations

Creepmeter
From 2009 to 2010
Lee et al, 2001

Accelerometers
2003 Chengkung EQ
Wu et al, 2006
38 stations

Leveling
From 2007 to 2010
Chen et al, 2012

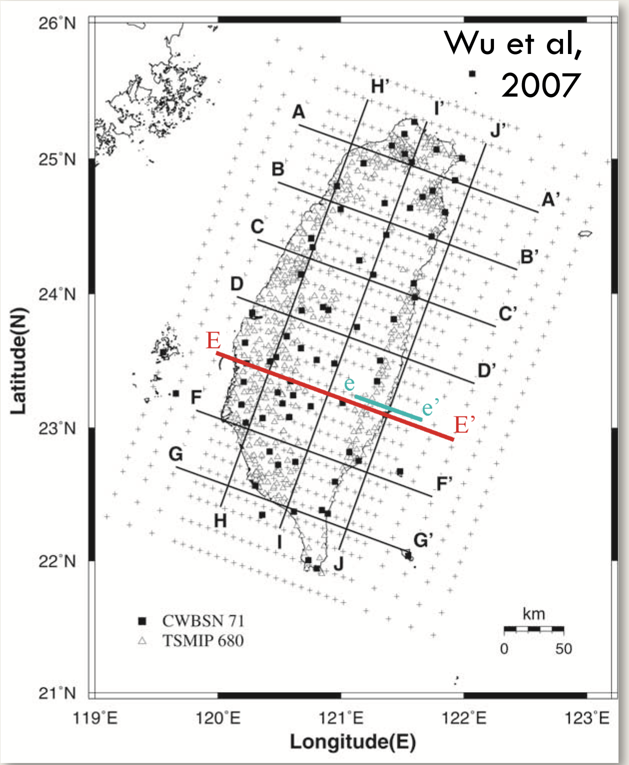
AVAILABLE DATA

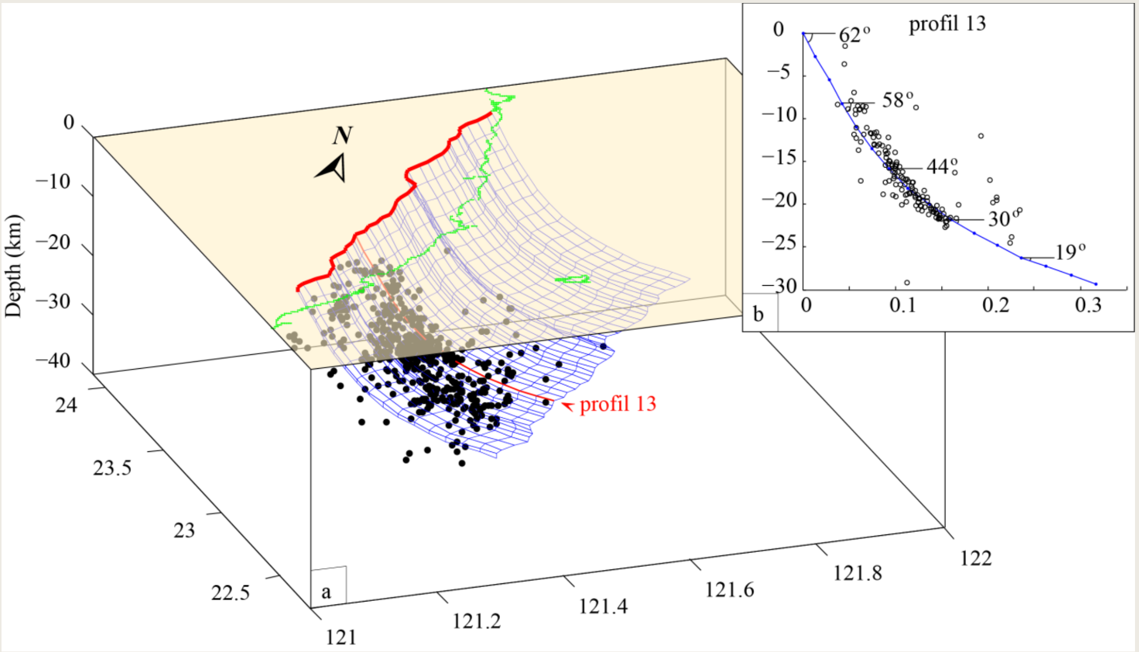


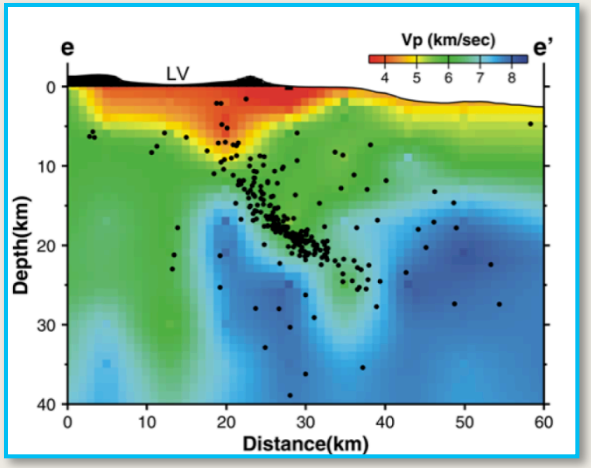
ALOS PS-InSAR mean velocities, From 2007 to 2010, Champenois et al, 2012

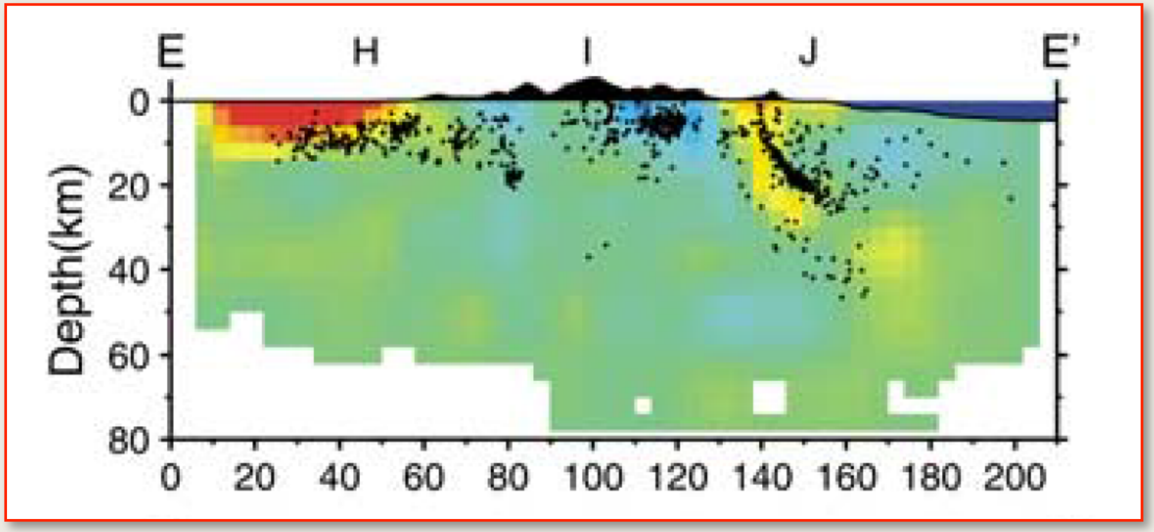
FAULT GEOMETRY

Seismicity catalog from Wu et al, 2008



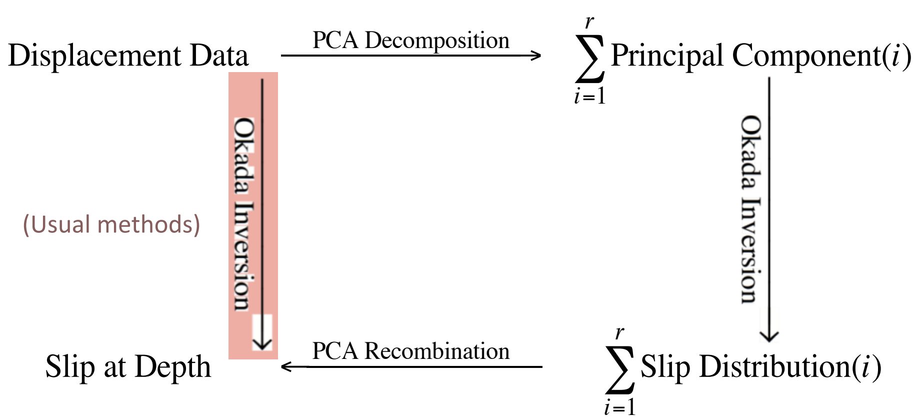






- Surface displacements is converted to slip based on theory of dislocation in elastic half-space (Okada 1985).
- Regularization: Laplacian proportional to resolution.
- Time - dependent inversion : PCAIM

PCAIM METHOD



$X = USV^{t}$

$U = GG \,.\, L$

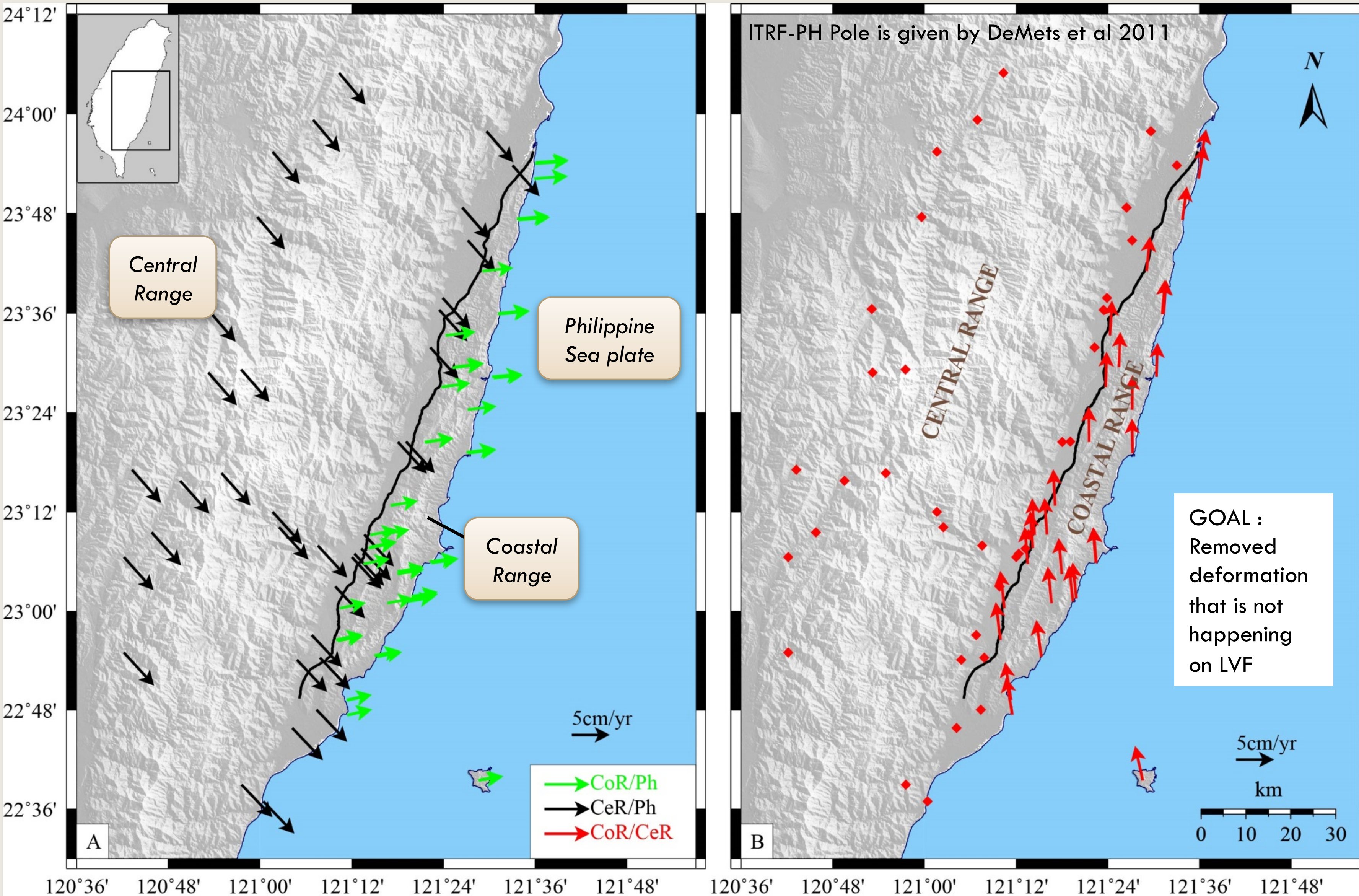
$X = (GG \,.\, L)\, SV^{t}$

$X = GG\,(LSV^{t})$

Singular Value Decomposition of surface displacement series
+
least-square inversion formulation
=
Slip decomposition

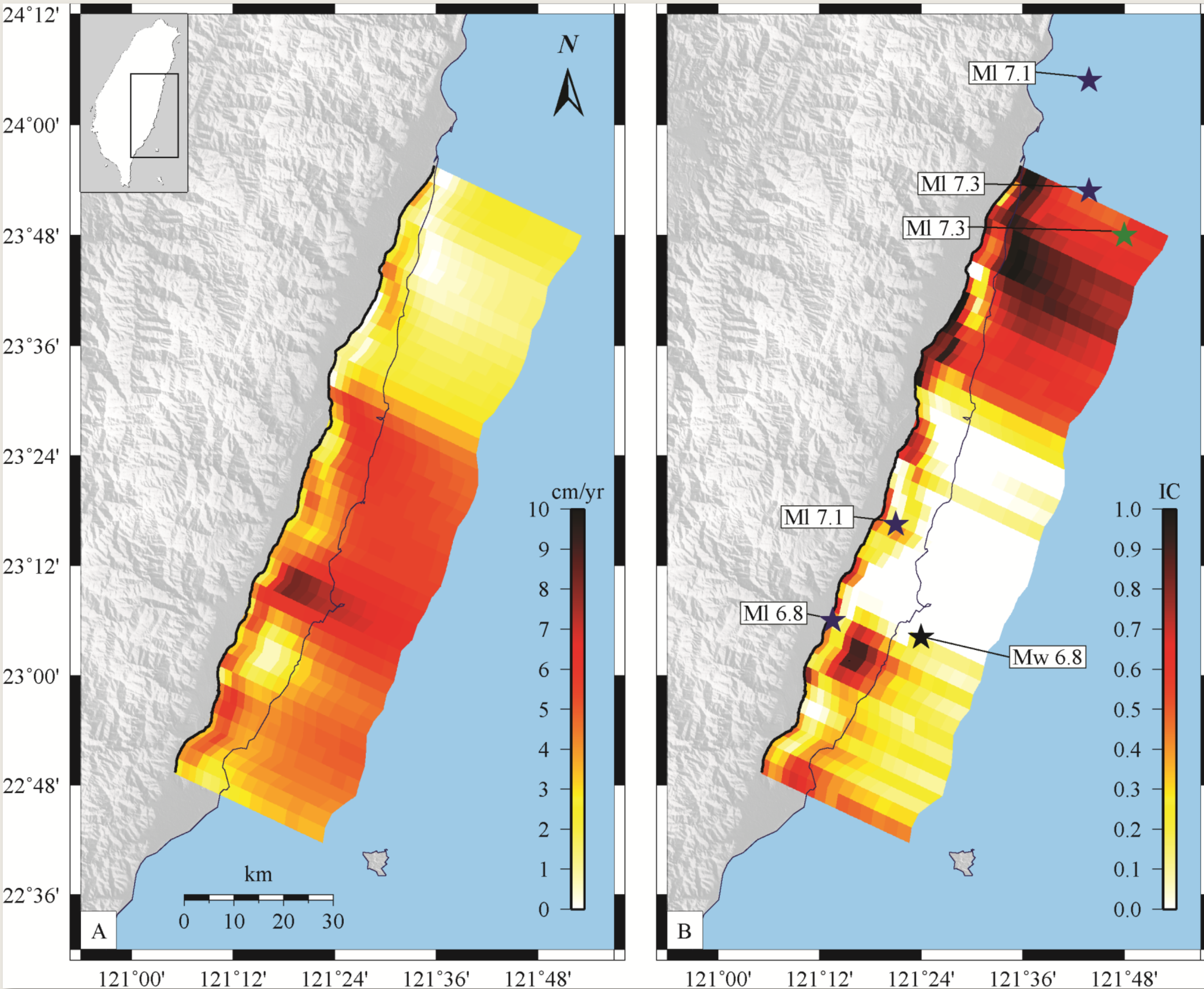
Kositsky and Avouac, JGR 2010

TIME-INDEPENDENT INVERSION: SECULAR MODEL, POLE CORRECTION



Eulerian poles computed with secular velocities inferred from continuous GPS (TEC) GPS campaign data (Yu et al, 2001)

TIME-INDEPENDENT INVERSION: SECULAR MODEL



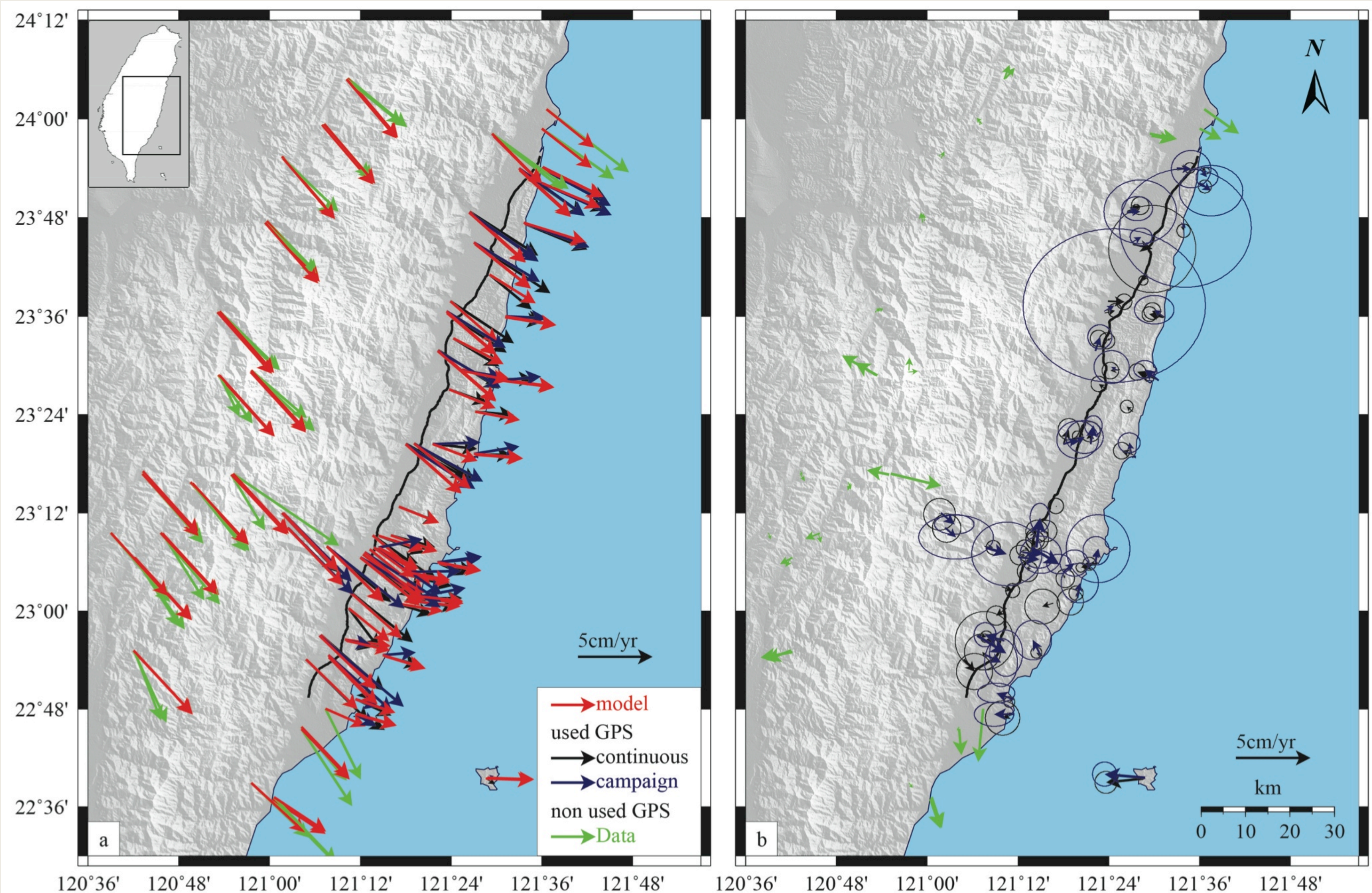
Figures :
A] = Slip at depth (mm/yr)

B]= Coupling

Inversion based on:

- campaign GPS (Yu, 2001),
- secular velocities from cGPS (TEC),
- PS ALOS (Champenois, 2012)
- leveling data (Chen, 2012)

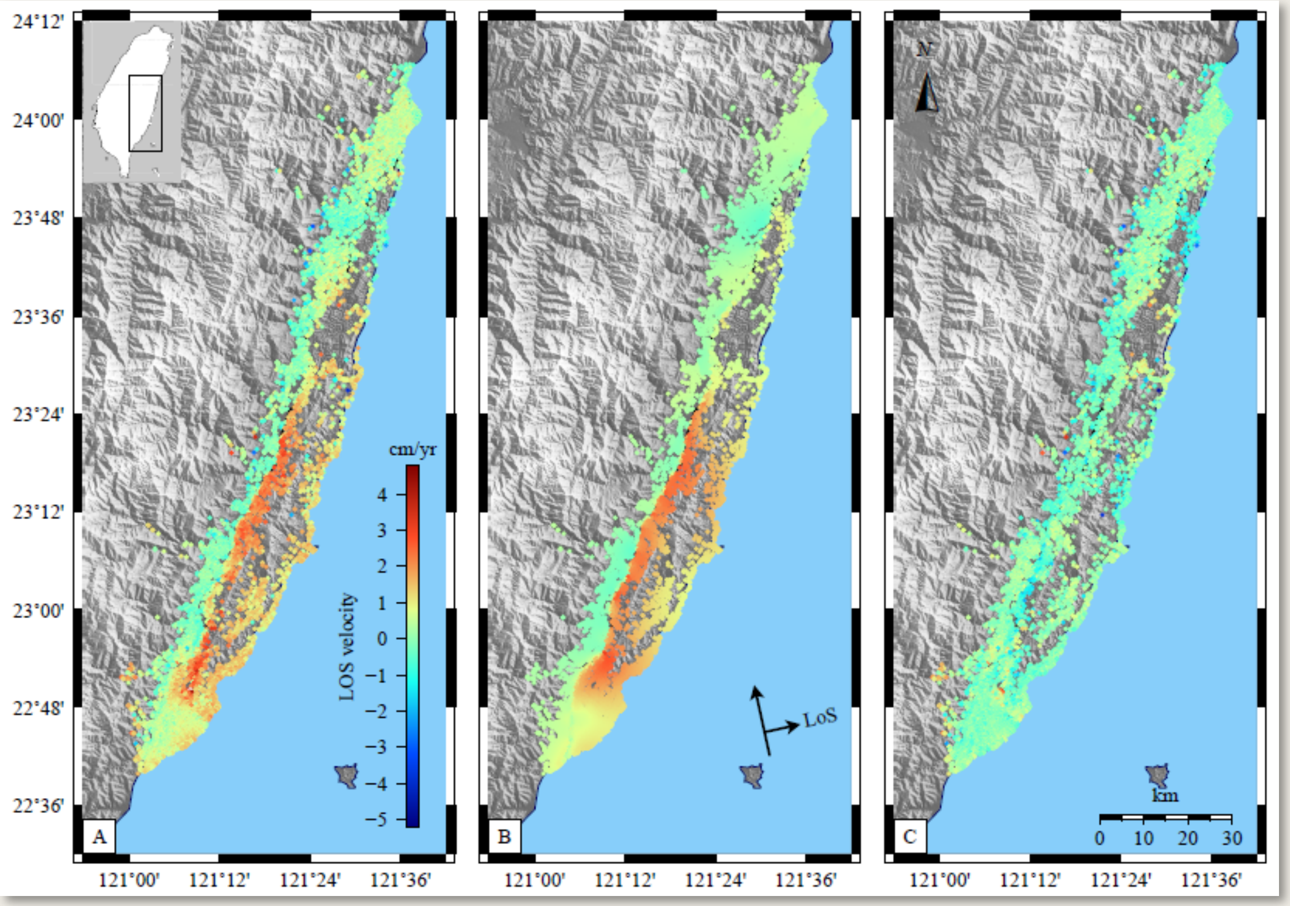
TIME-INDEPENDENT INVERSION: SECULAR GPS FIT



Data and model prediction of campaign GPS (Yu, 2001) and secular velocities from cGPS (TEC)

TIME-INDEPENDENT INVERSION: SECULAR PS ALOS AND LEVELING FIT

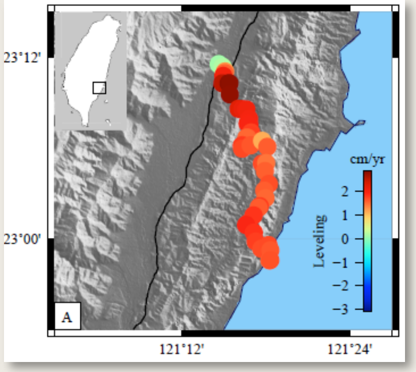
Data Model Residuals



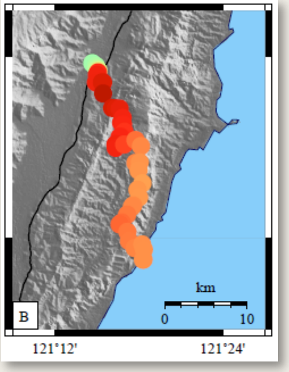
PS ALOS mean velocities (data from Champenois et al, 2012)

leveling measurements
(data from Chen, 2012)

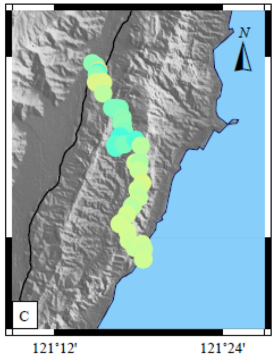
Data



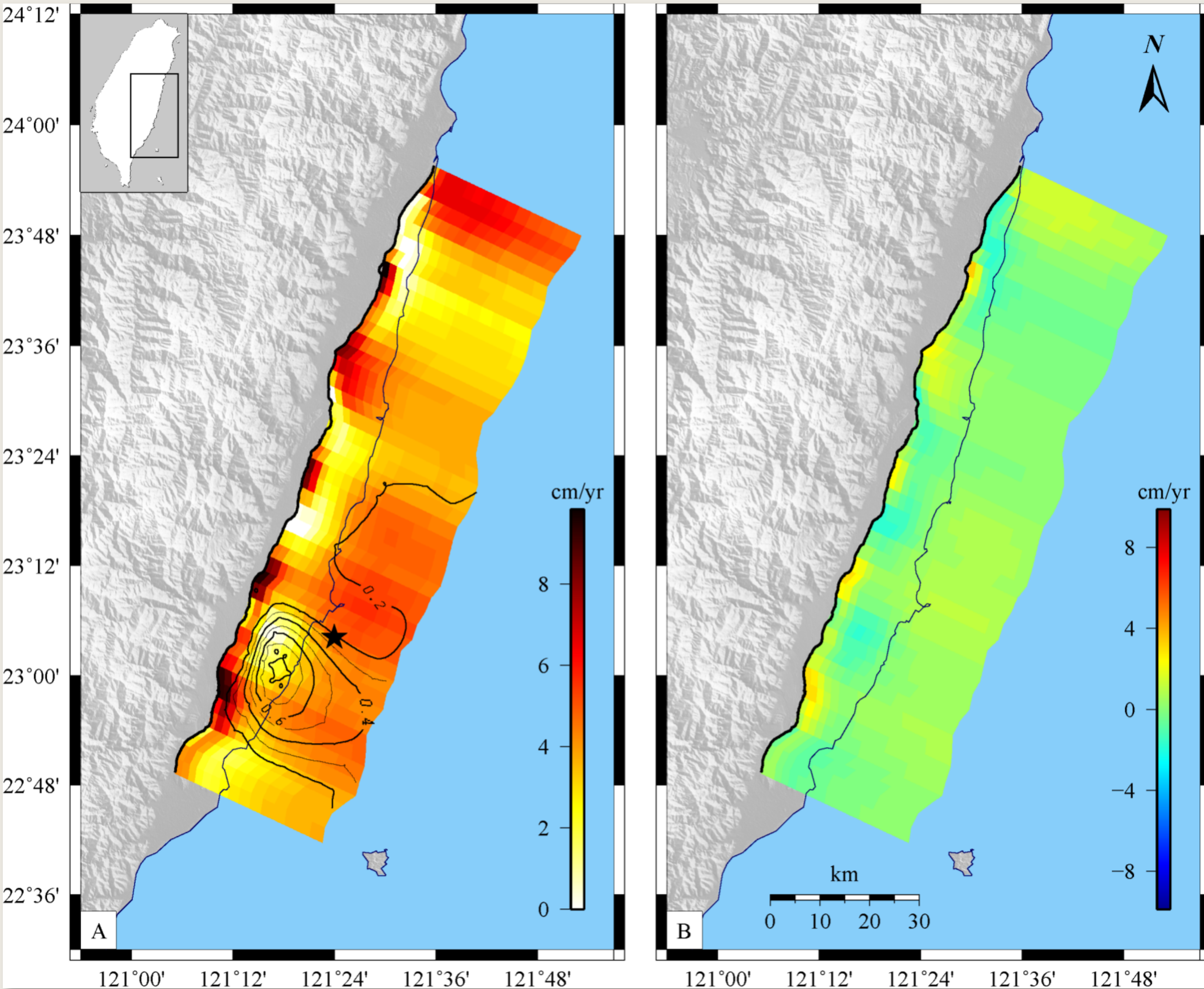
Model



Residuals



PCAIM: PRESEISMIC MODEL



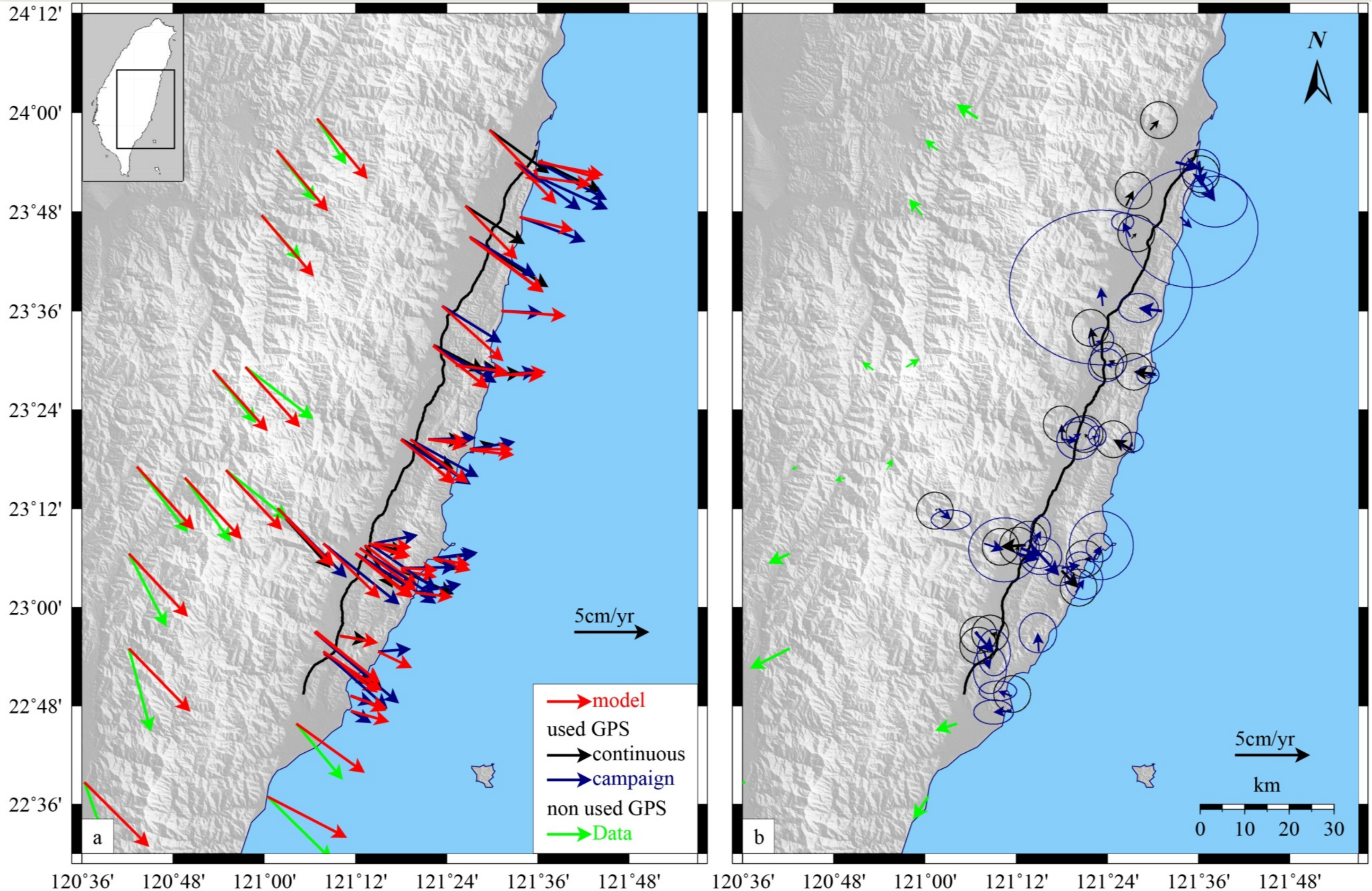
Figures :
A] = PCAIM inversion for Slip at depth (mm/yr)

B]= PCAIM inversion minus secular model

Inversion based on:

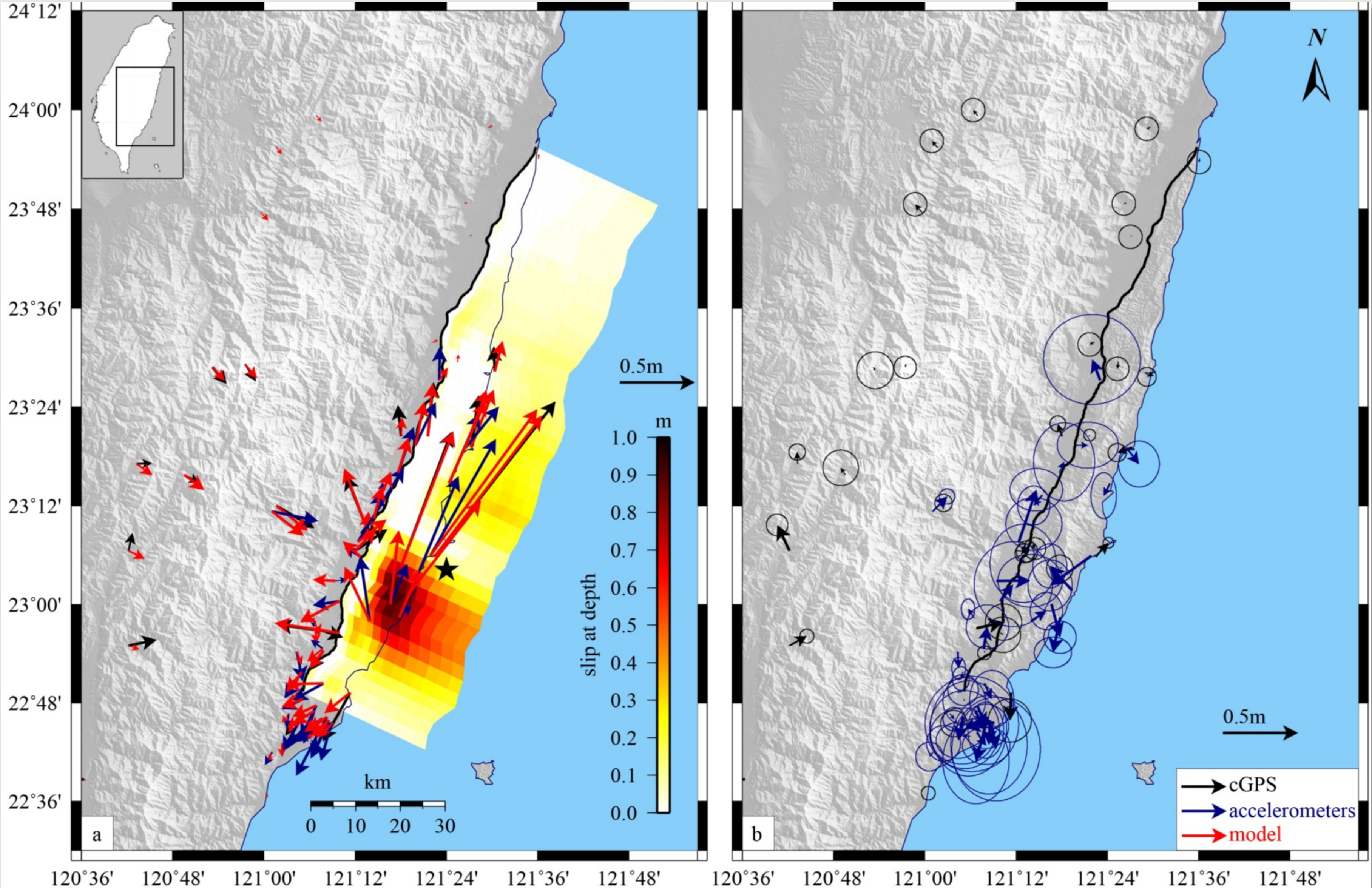
- campaign GPS (Yu, 2001),
- Continuous GPS (TEC),
- Creepmeter (Lee et al, 2001)

PCAIM: PRESEISMIC GPS FIT



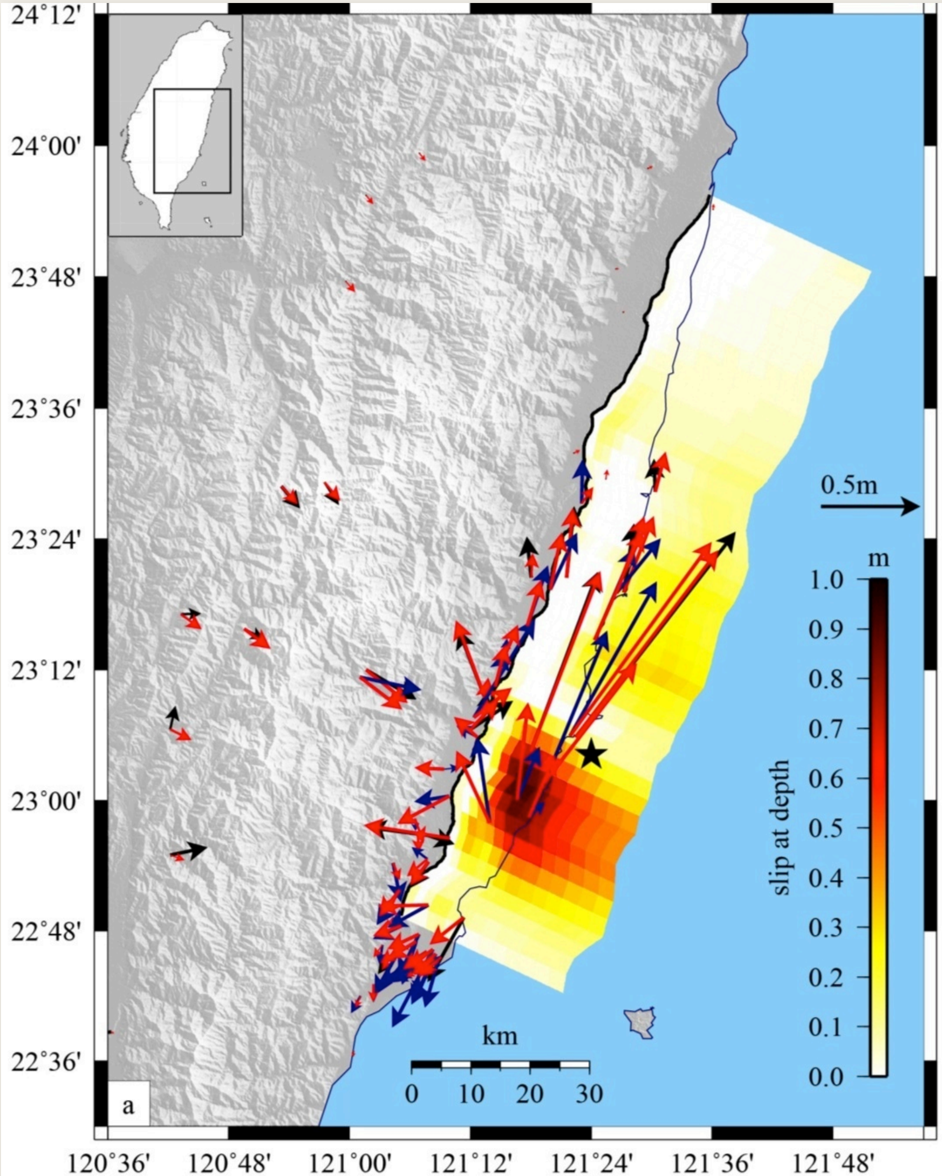
Data and model prediction of campaign GPS (Yu, 2001) and continuous GPS (TEC)

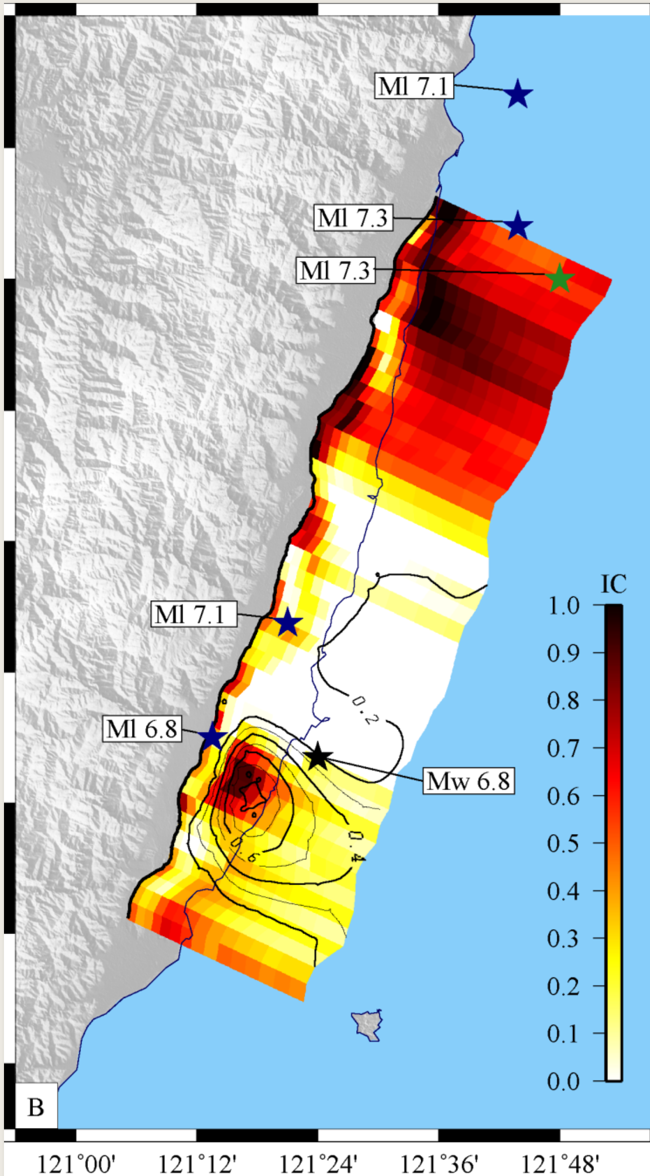
TIME-INDEPENDENT INVERSION: COSEISMIC, Mw 6.8 CHENGKUNG EQ (2003)



Model based on GPS (TEC), and accelerometers (Wu et al, 2006)

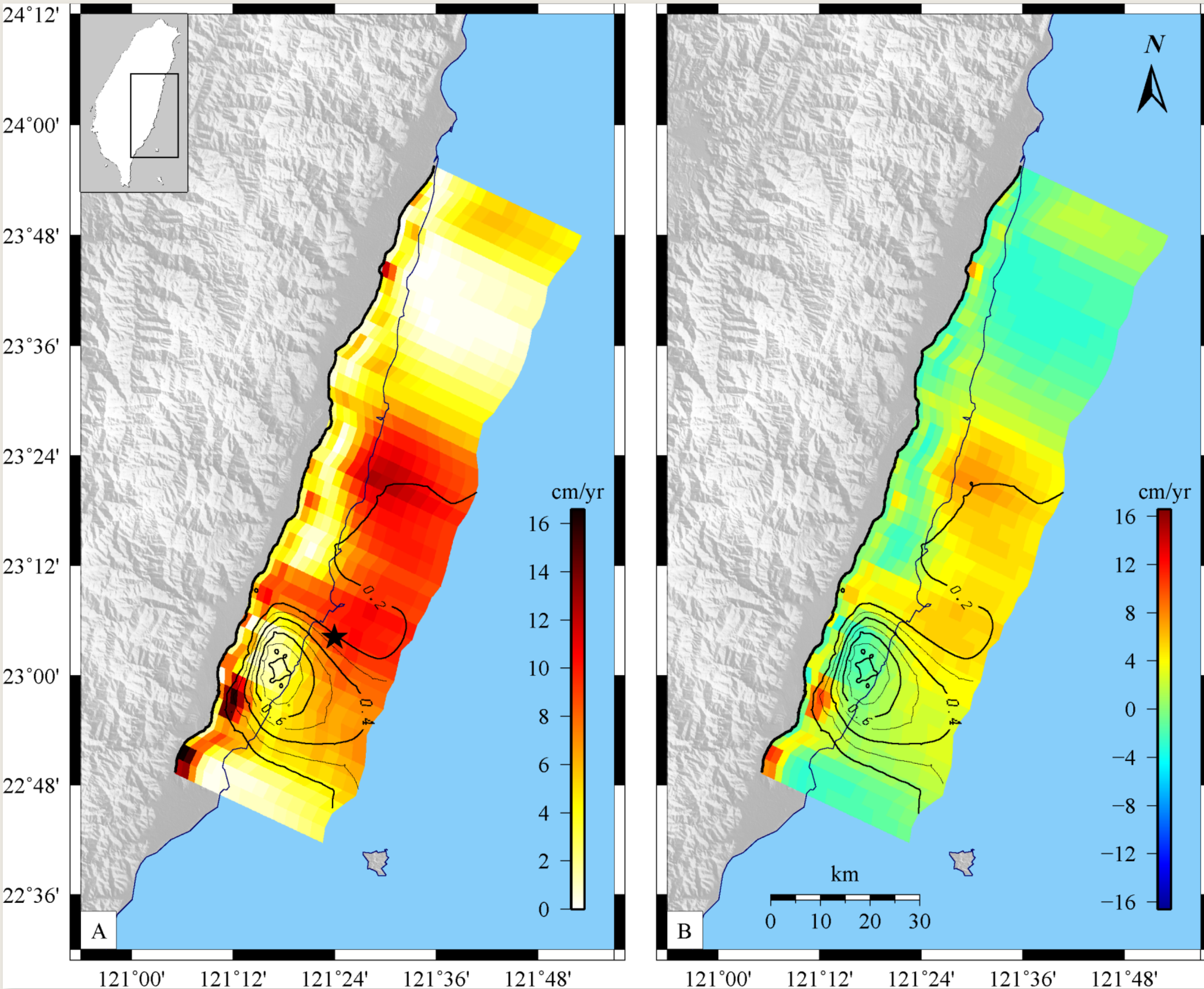
TIME-INDEPENDENT INVERSION: COSEISMIC & SECULAR MODEL





Model based on GPS (TEC), and accelerometers (Wu et al, 2006)

PCAIM: POSTSEISMIC MODEL, Mw 6.8 CHENGKUNG EARTHQUAKE (2003)



Figures :
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Inversion based on:

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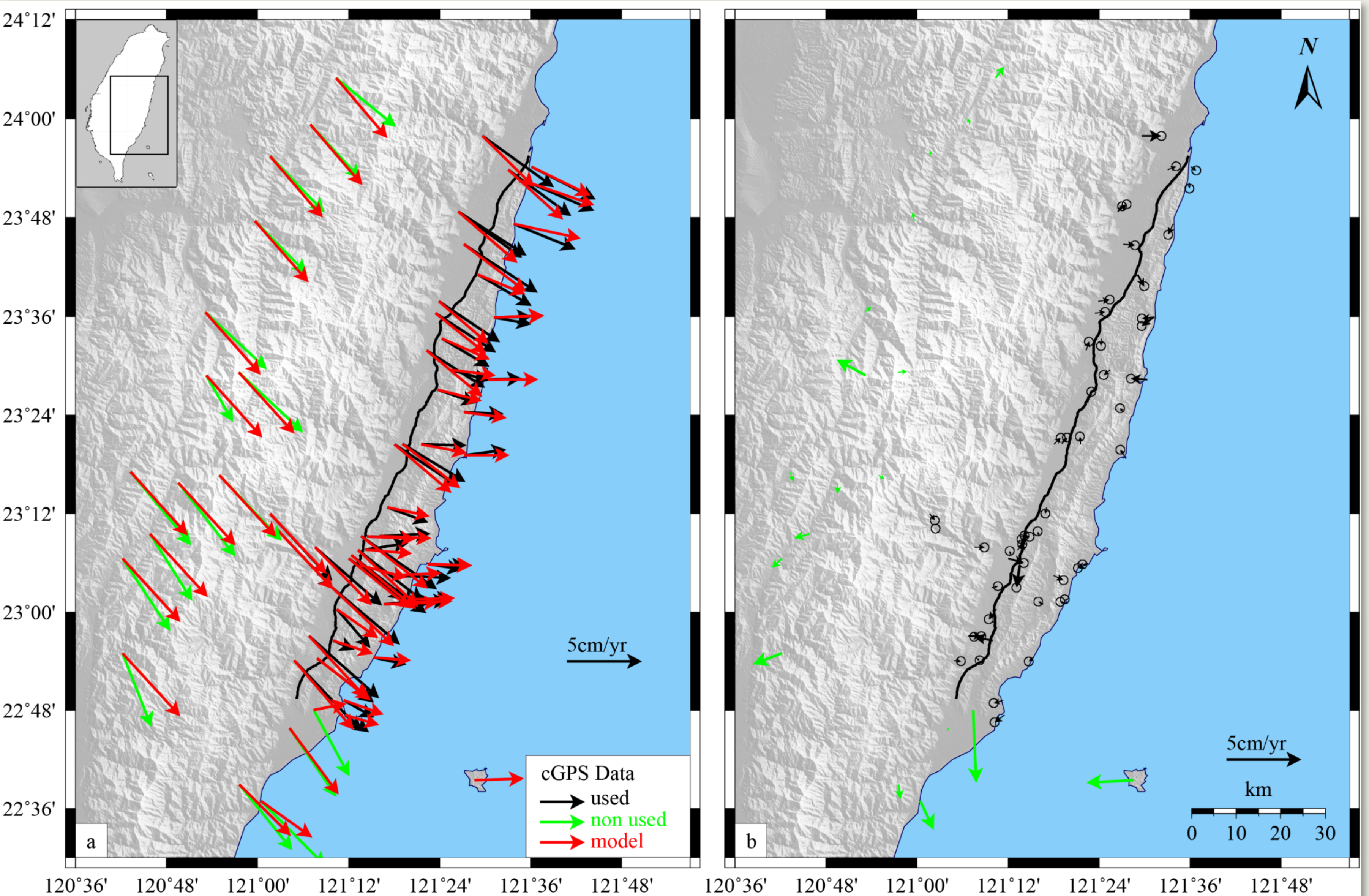
- PS ALOS (Champenois, 2012)
- Leveling data (Chen, 2012)
- Creepmeter (Lee et al, 2001)

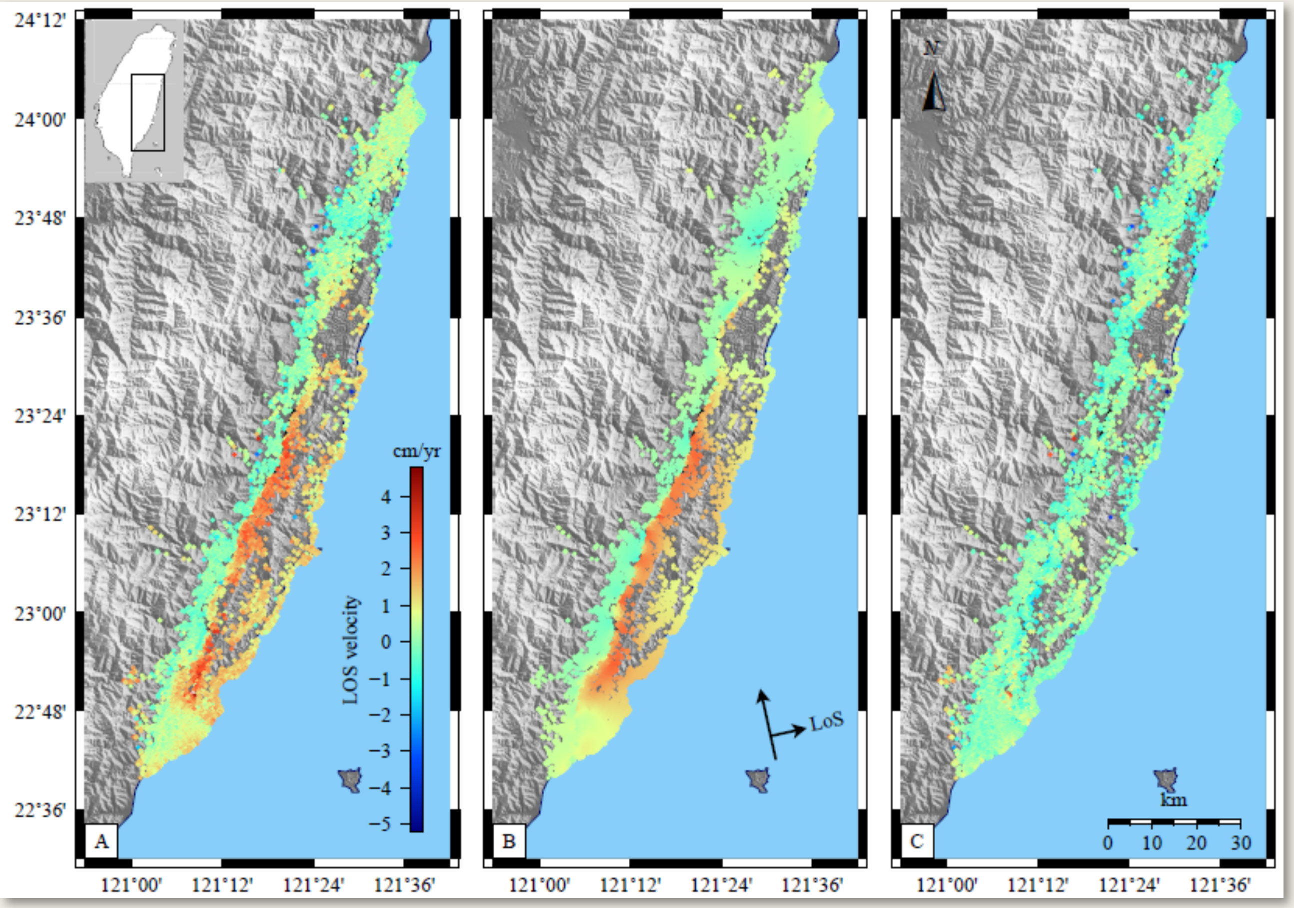
PCAIM: POSTSEISMIC GPS FIT, Mw 6.8 CHENGKUNG EARTHQUAKE (2003)



Data and model prediction of continuous GPS (TEC)

PCAIM: POSTSEISMIC ALOS FIT, Mw 6.8 CHENGKUNG EARTHQUAKE (2003)

Data Model Residuals



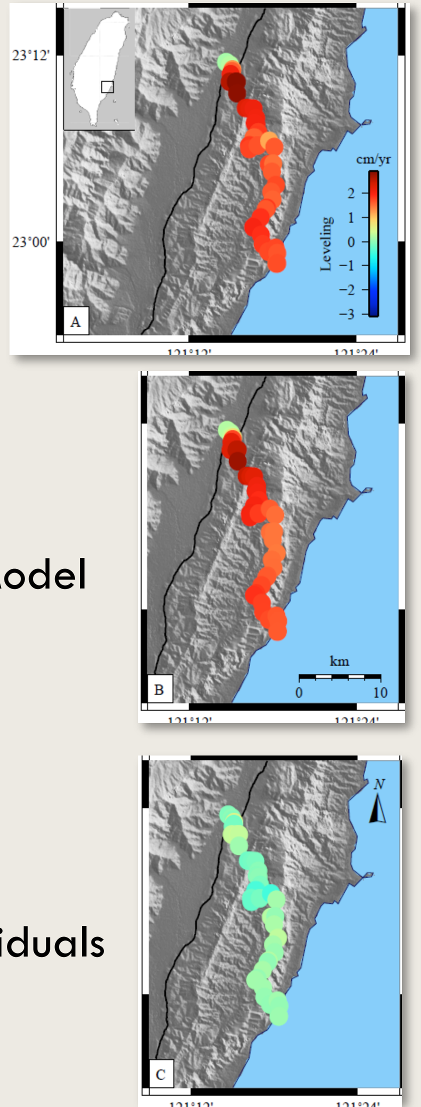
PS ALOS mean velocities (data from Champenois et al, 2012)

leveling measurements (data from Chen, 2012)

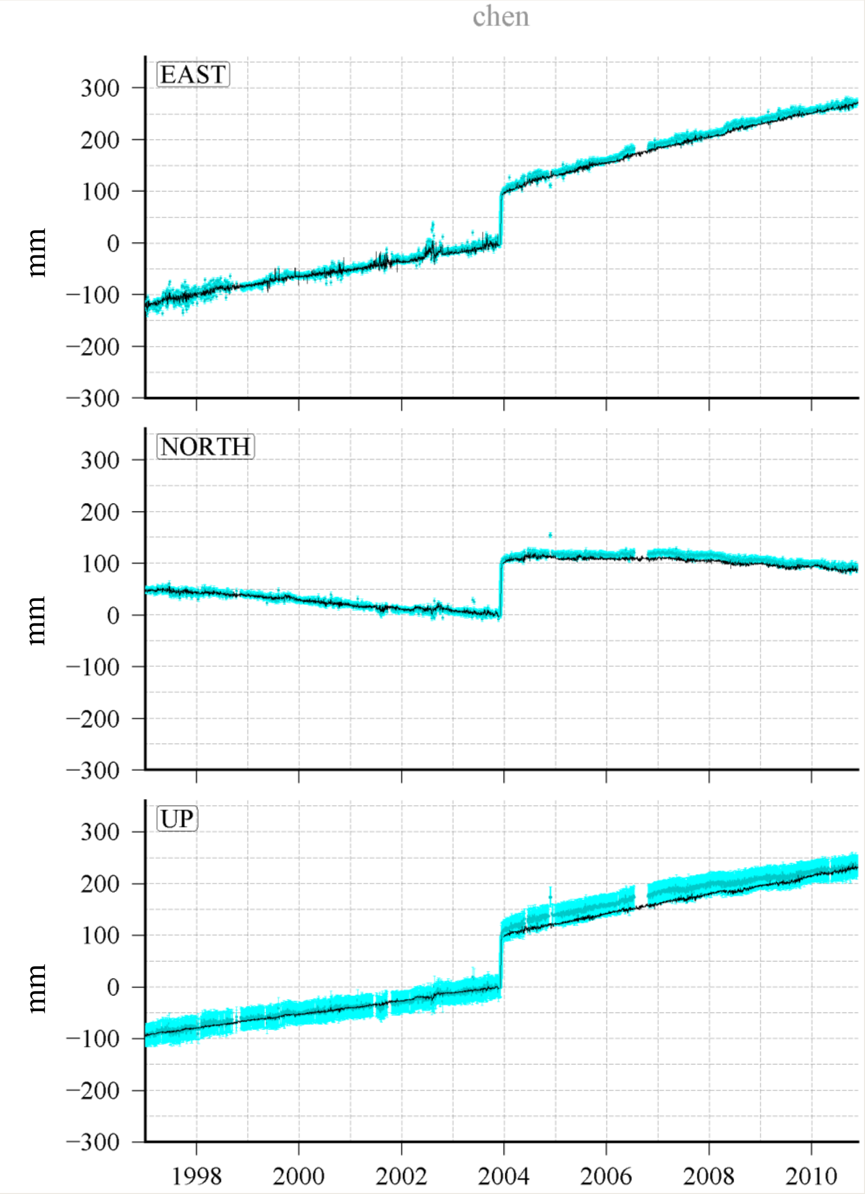
Data

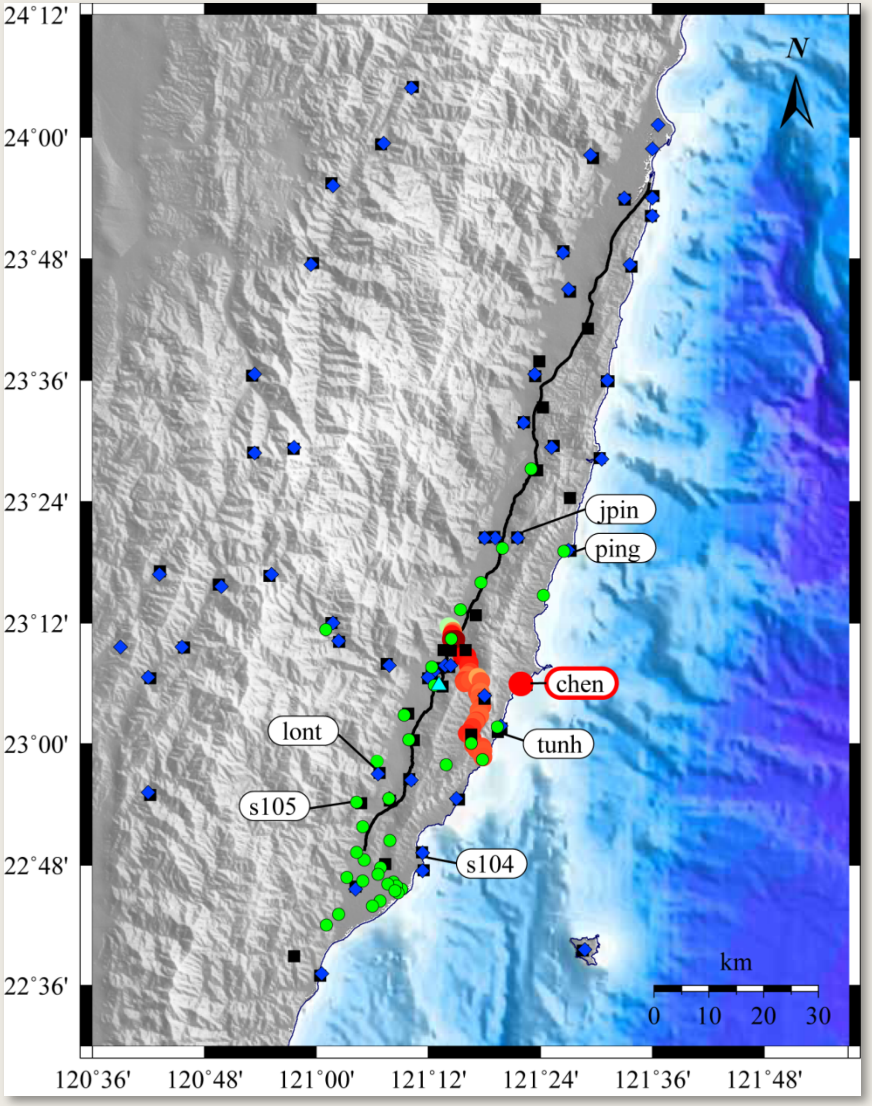
Model

Residuals

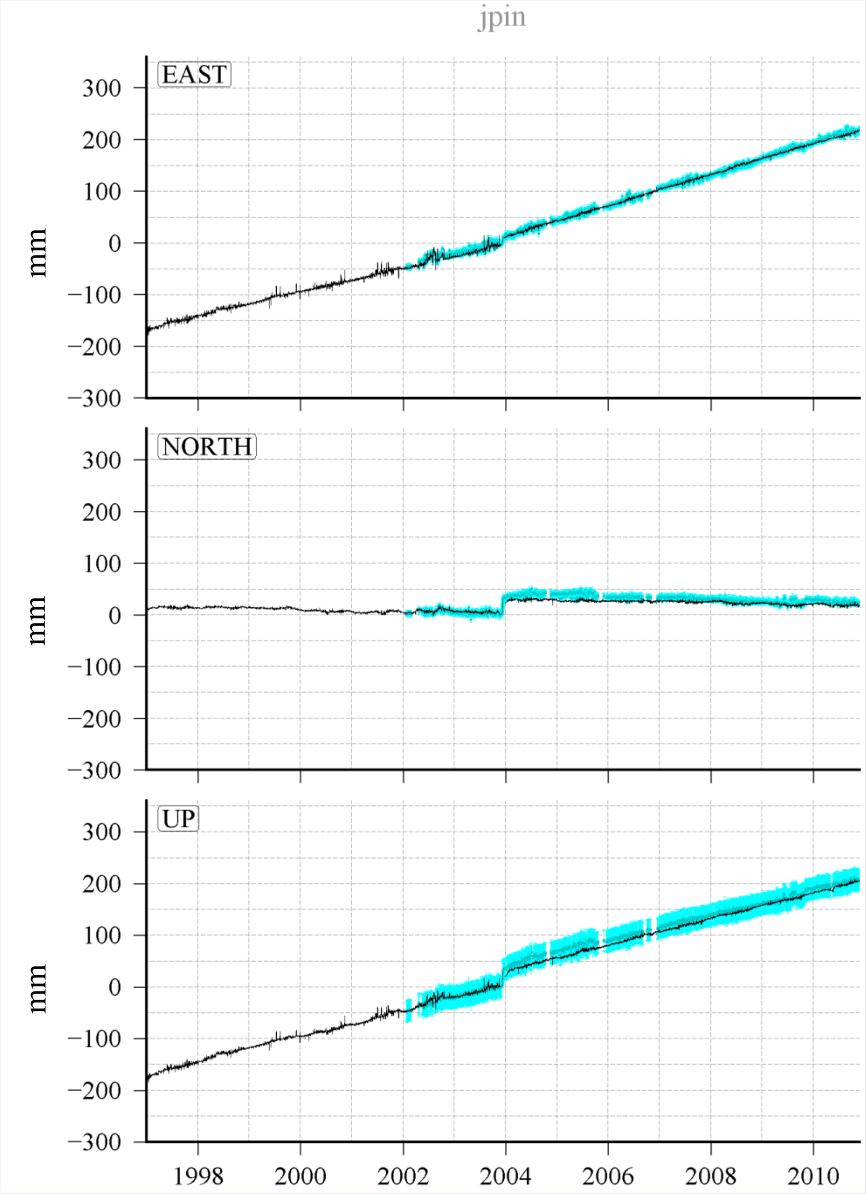


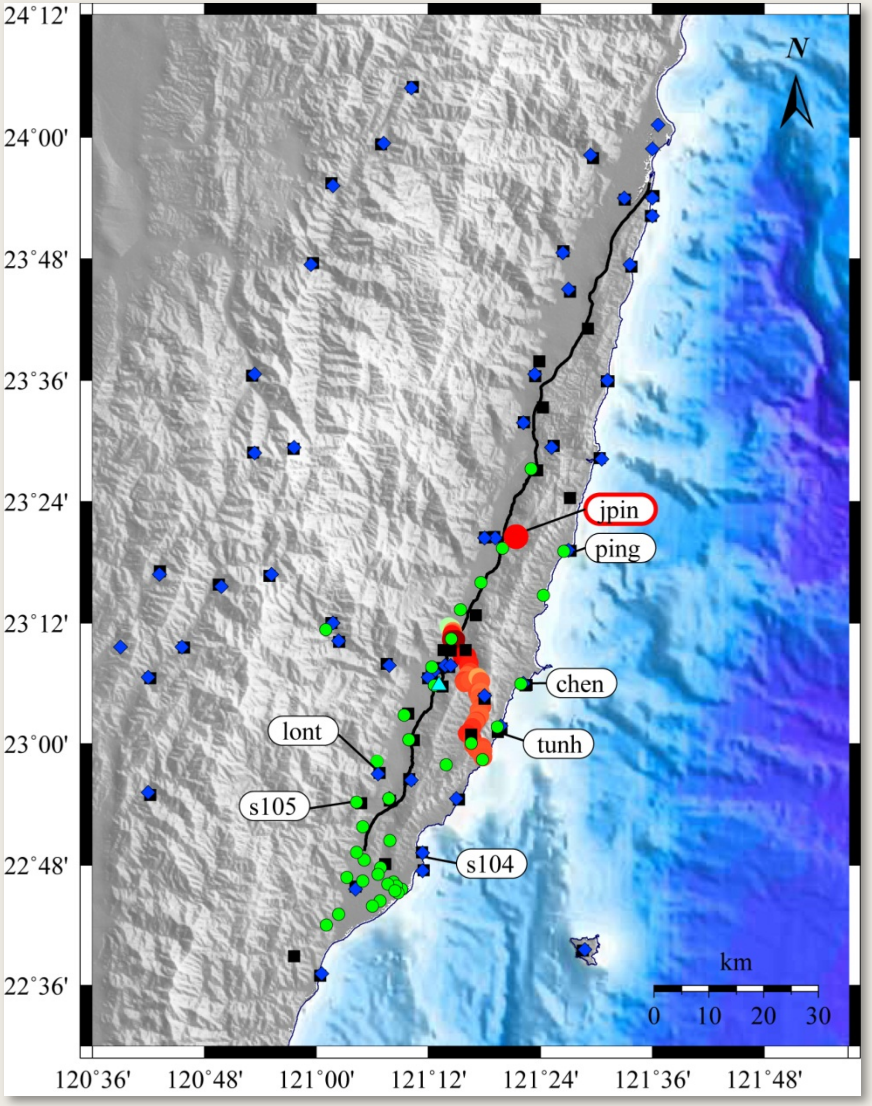
DATA FIT: GPS STATION "CHEN"



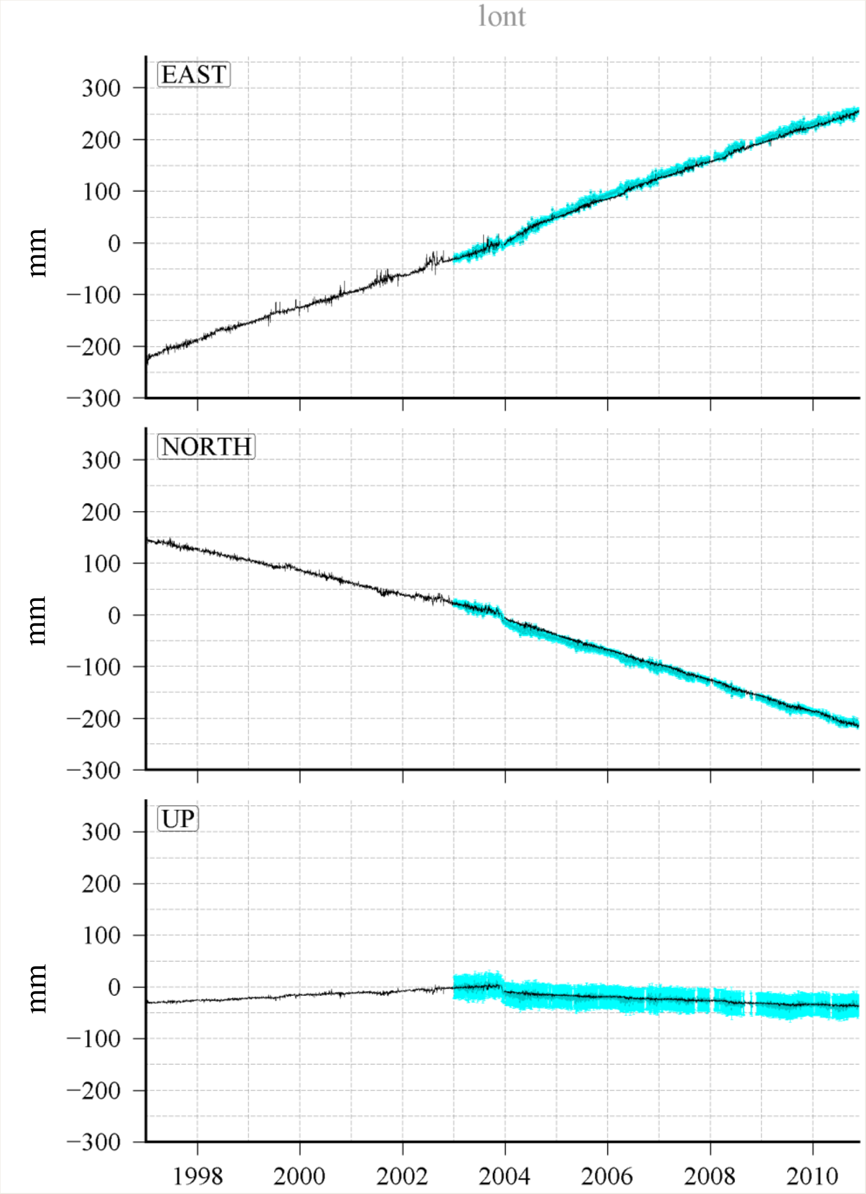


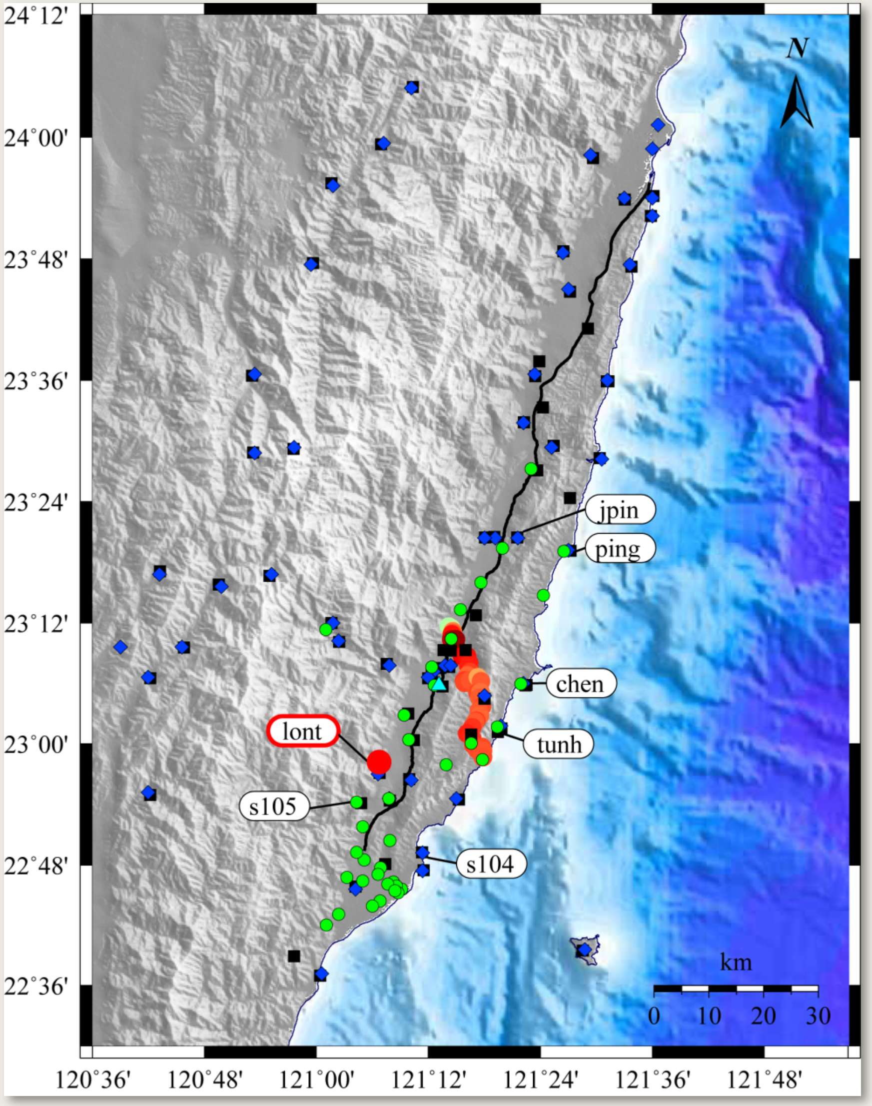
DATA FIT: GPS STATION "JPIN"



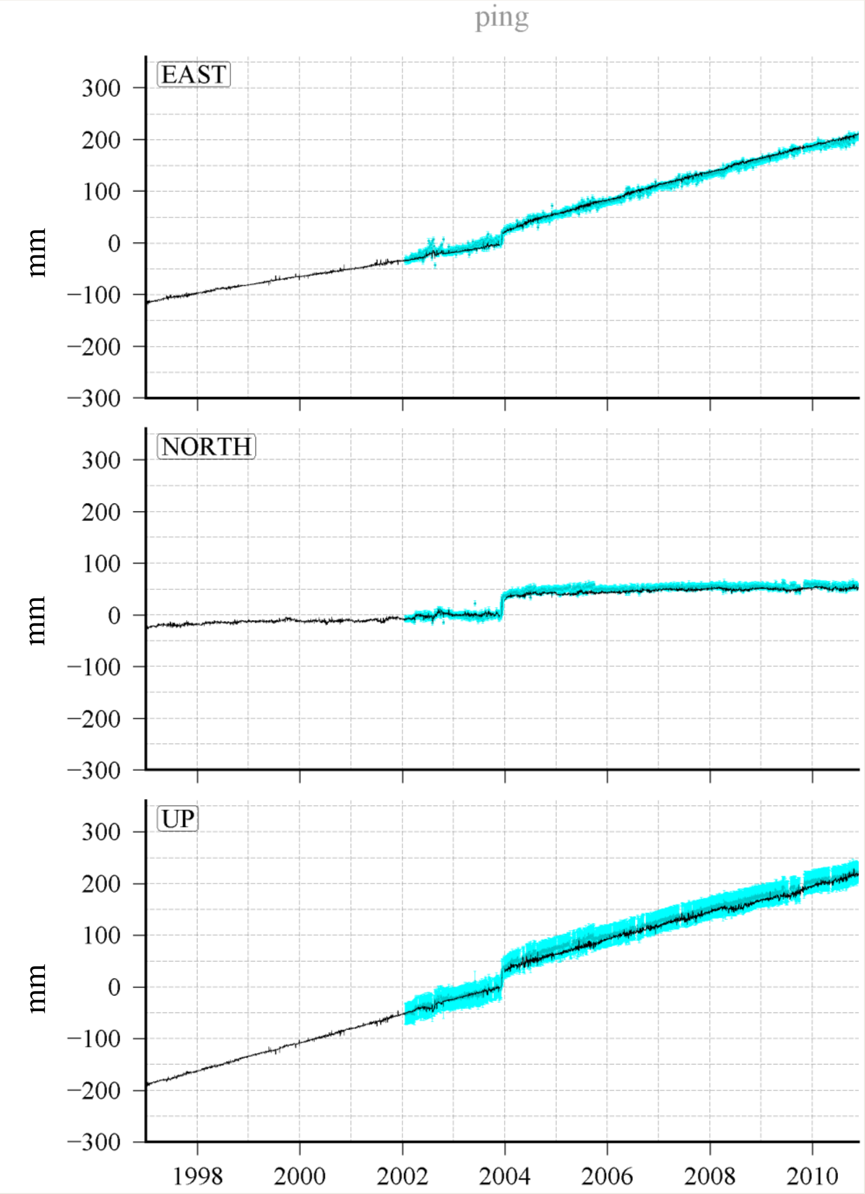


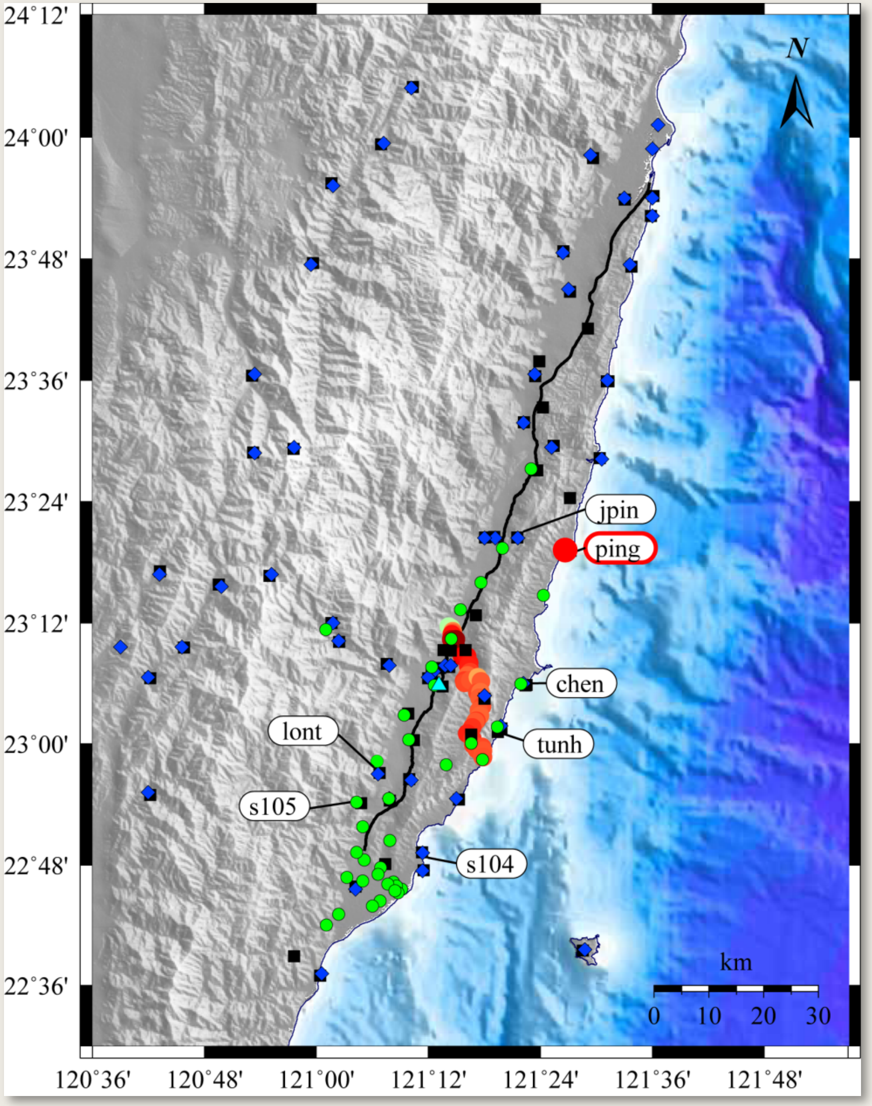
DATA FIT: GPS STATION "LONT"



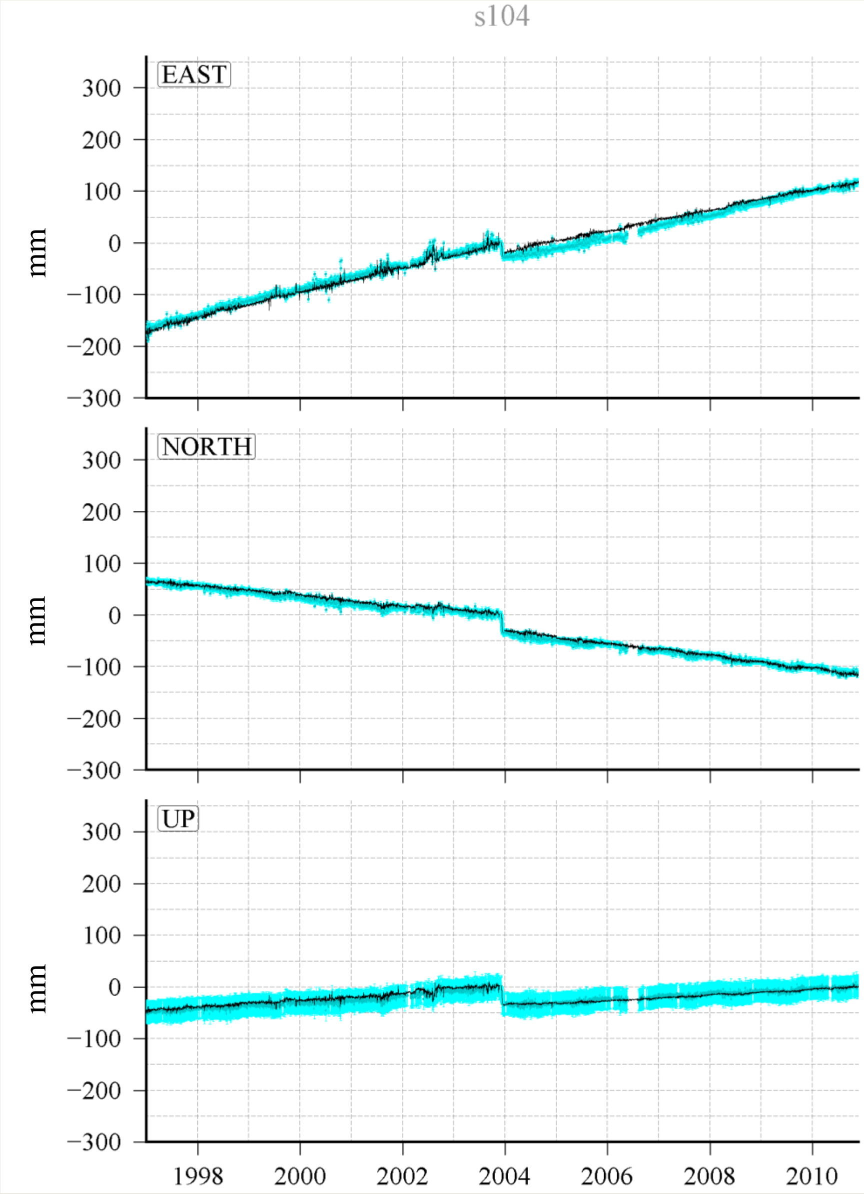


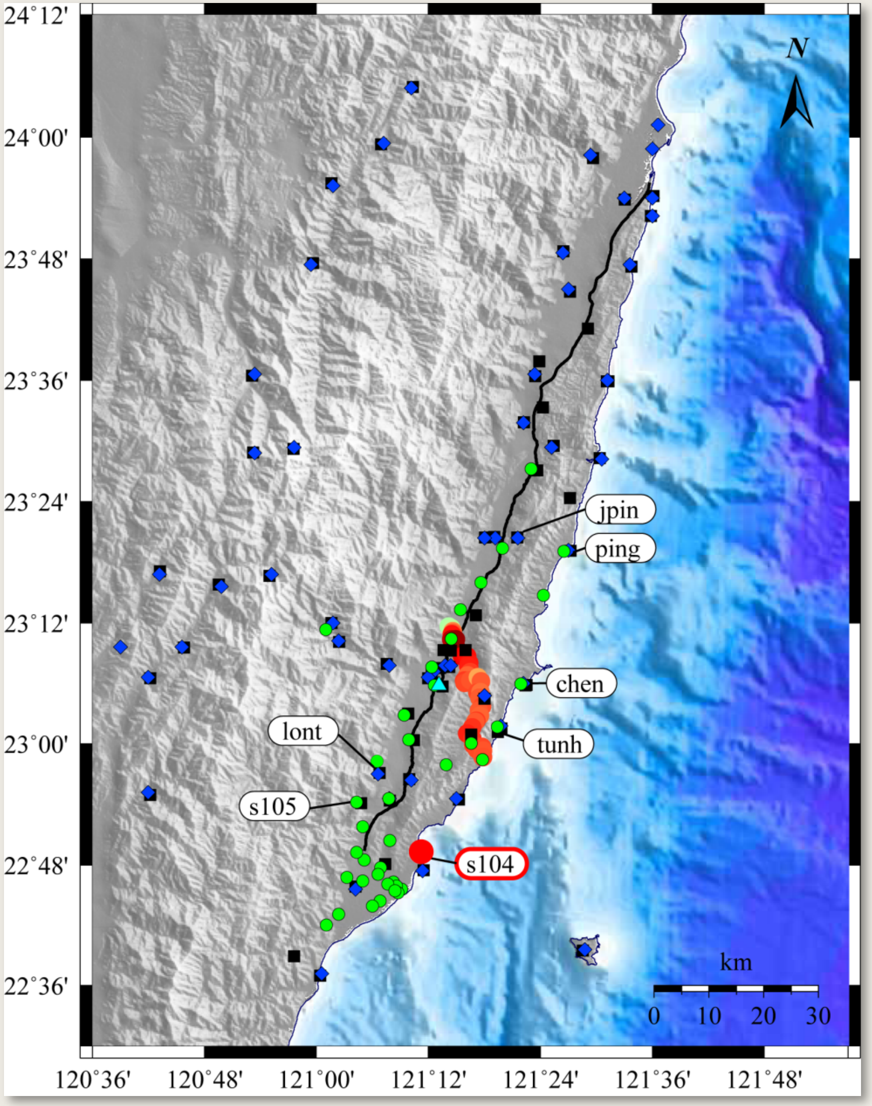
DATA FIT: GPS STATION "PING"



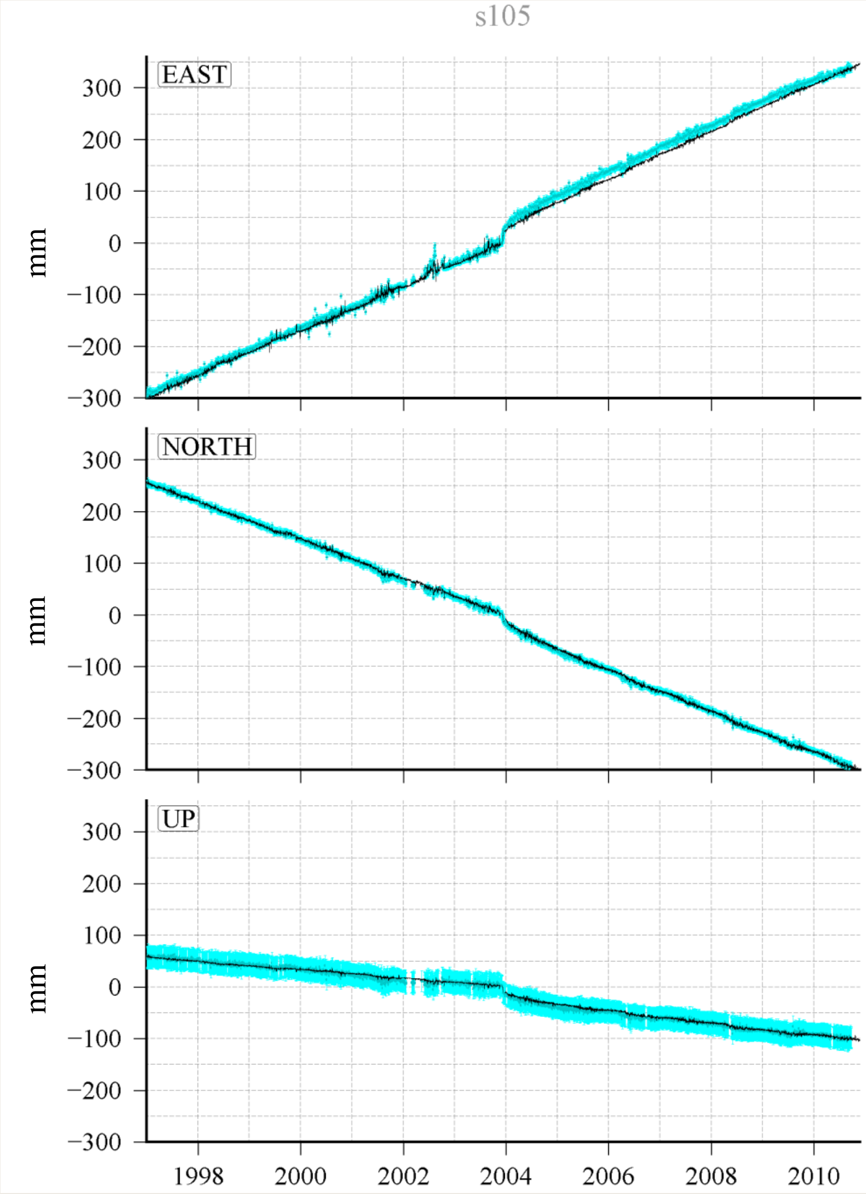


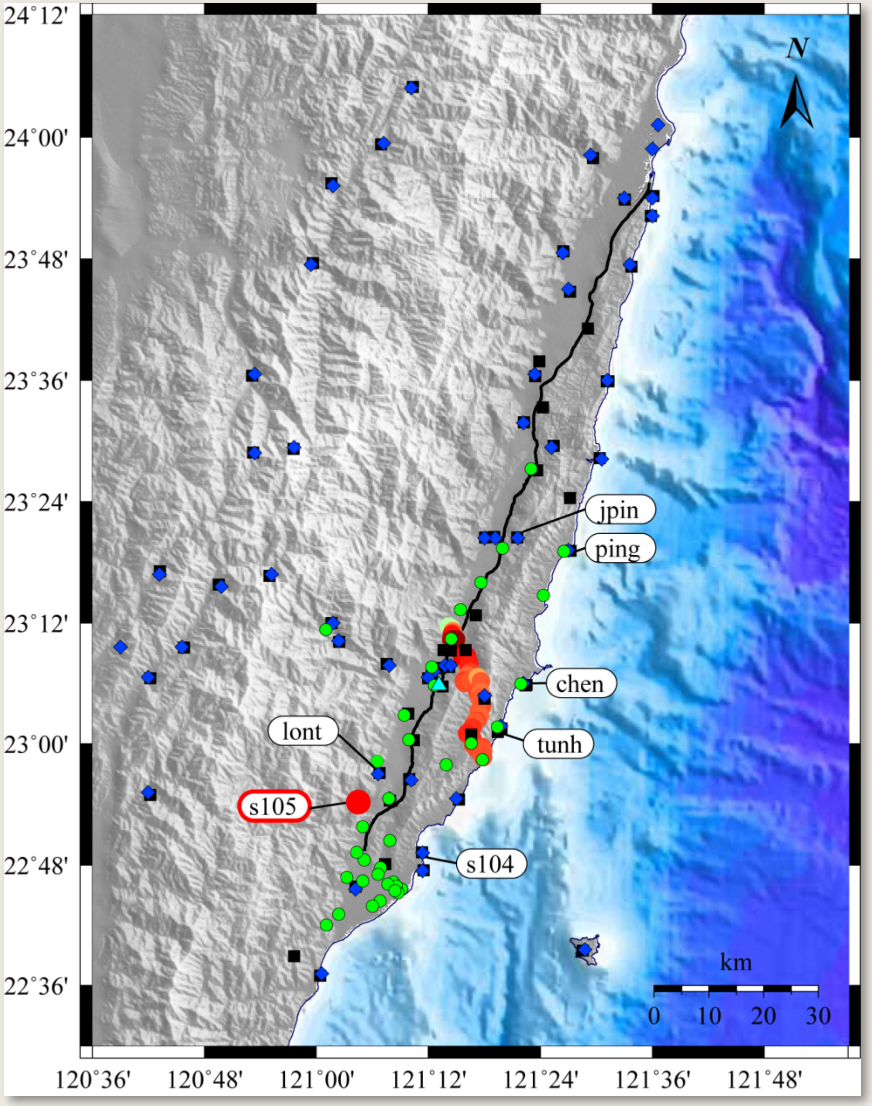
DATA FIT: GPS STATION "S104"



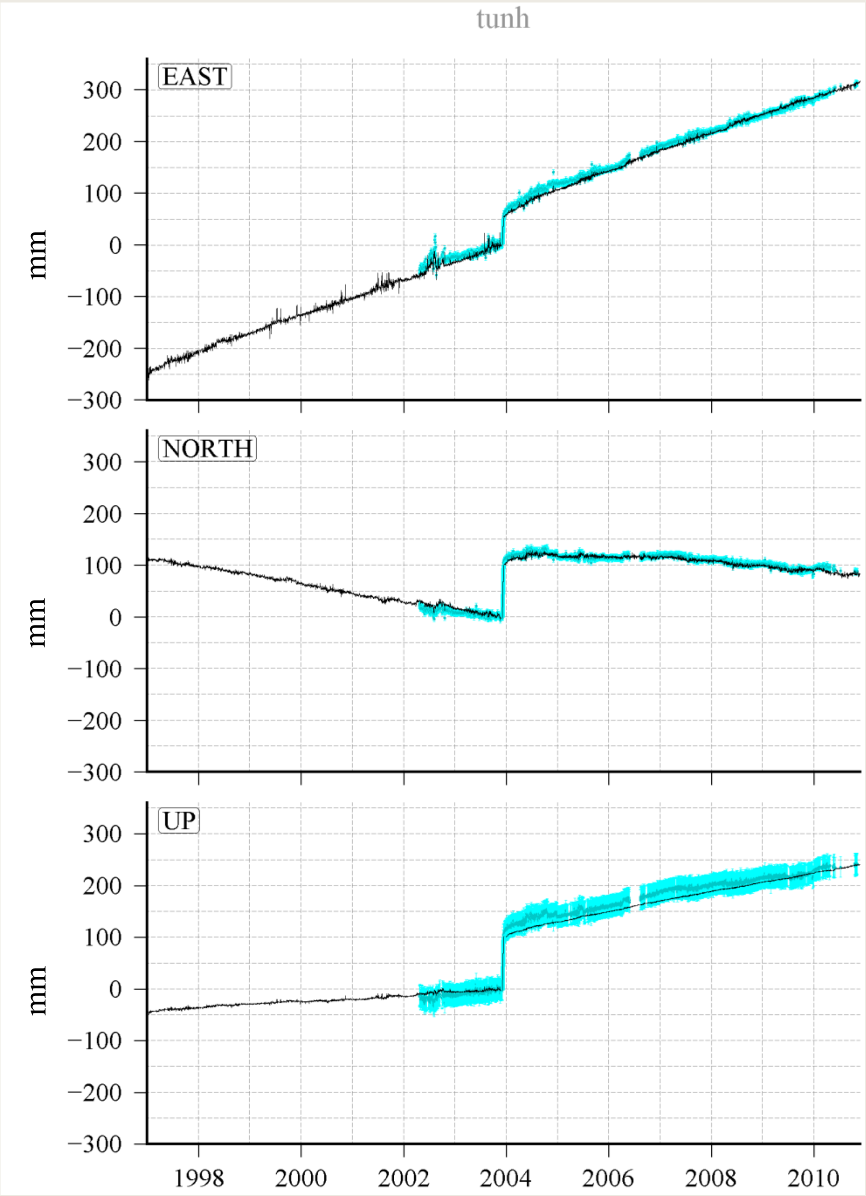


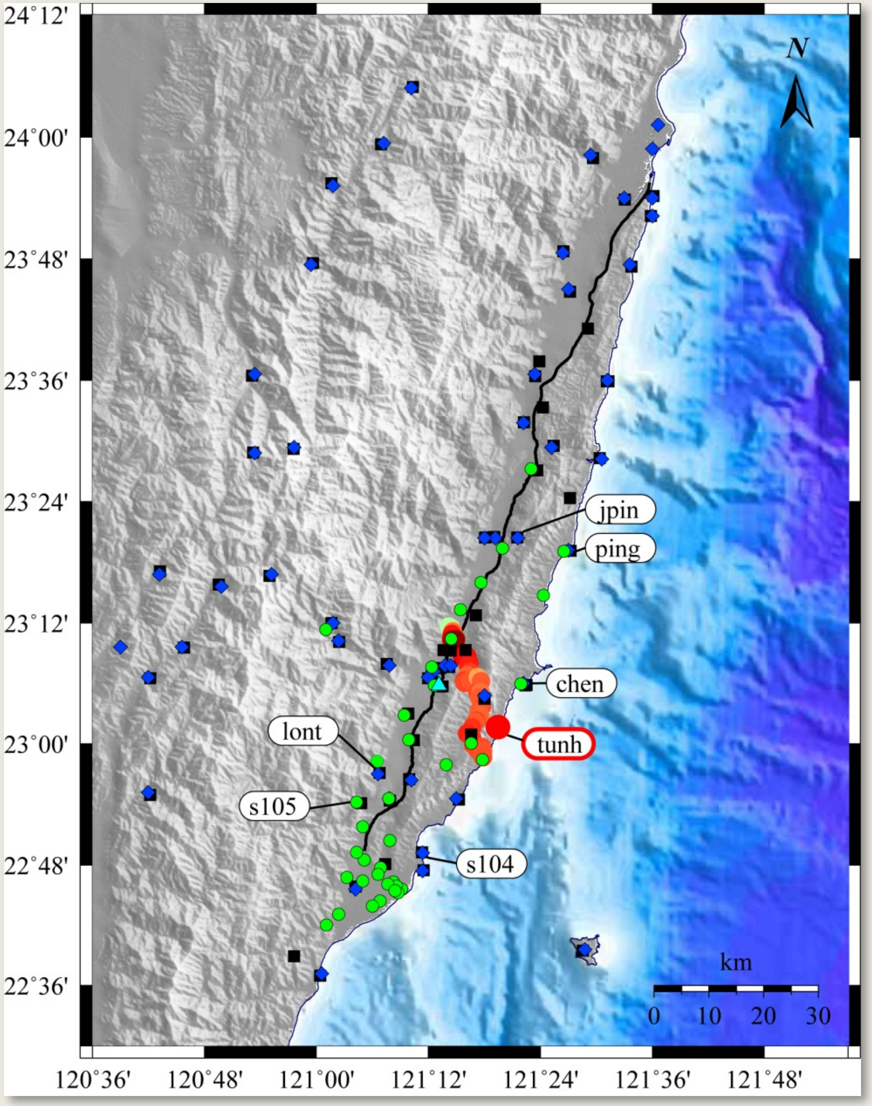
DATA FIT: GPS STATION "S105"



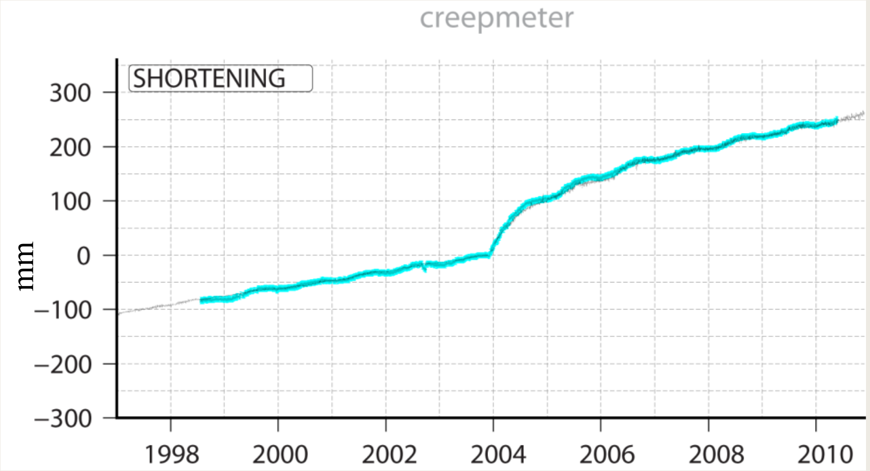


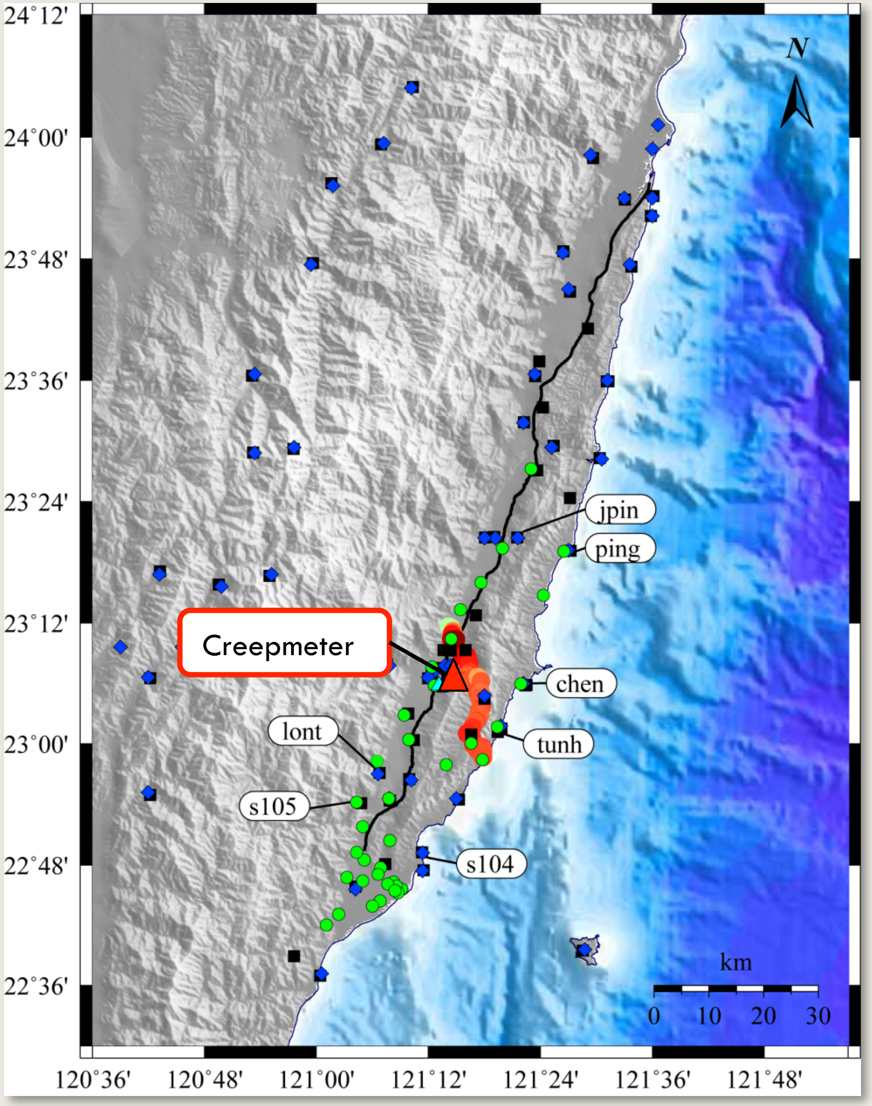
DATA FIT: GPS STATION "TUNH"





DATA FIT: CREEPMETER

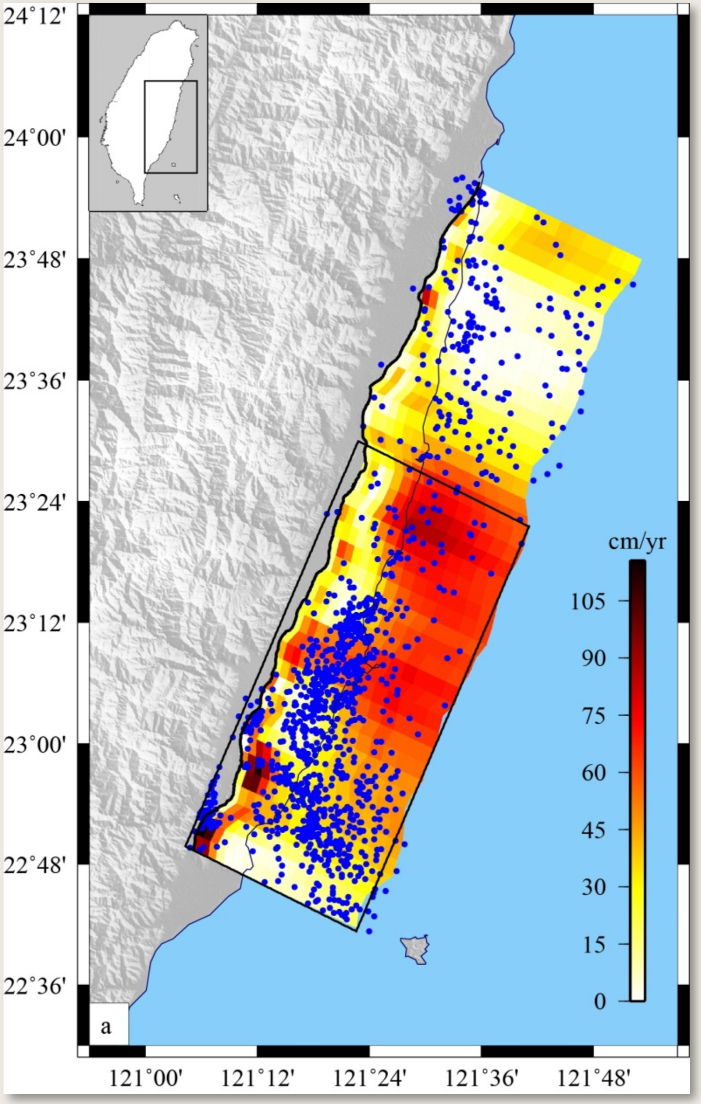




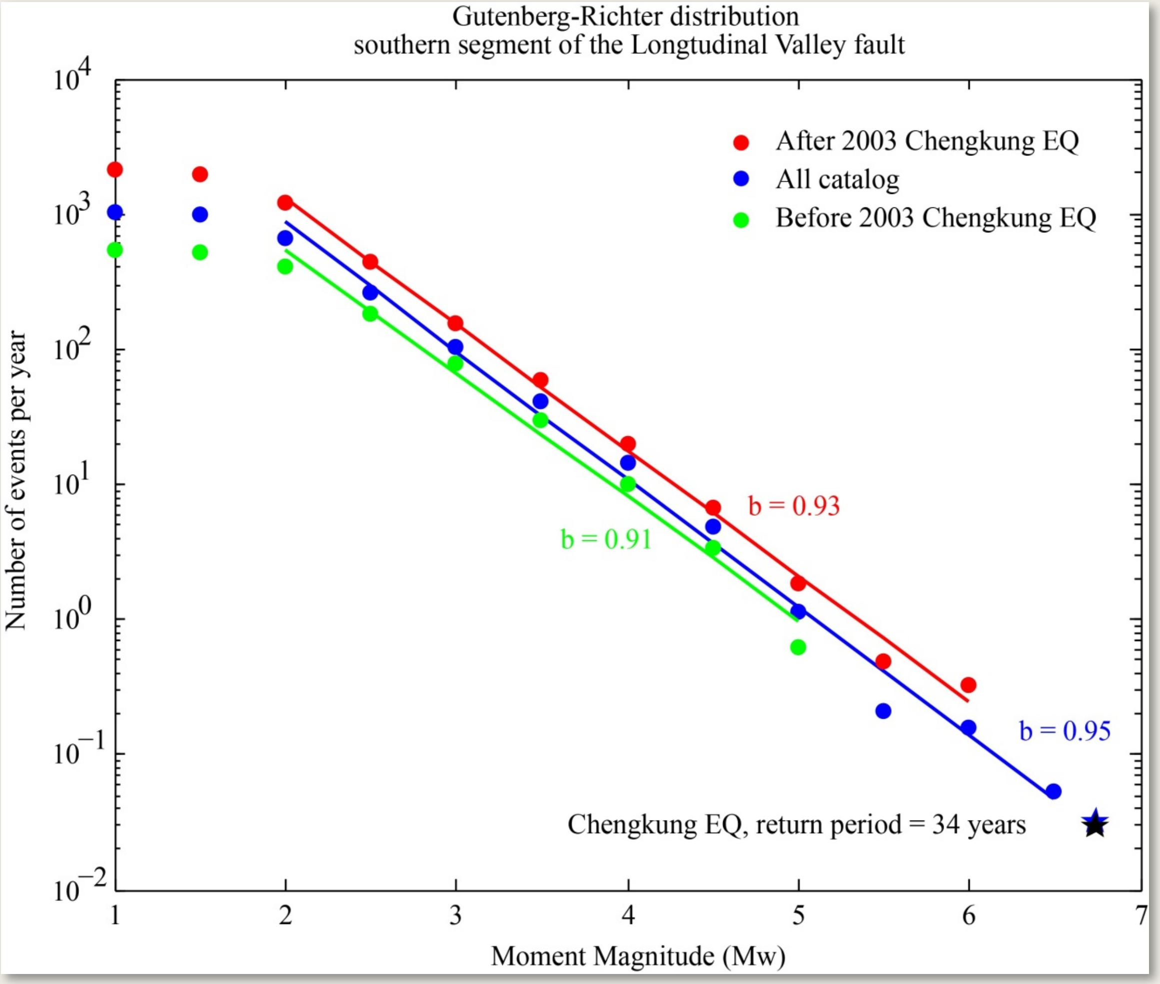
SEISMICITY

Return period:

$$T = \frac{M0_{coseismic} + M0_{postseismic}}{M0_{deficit}}$$



Seismicity (Mw>3) during 7 year after 2003 EQ



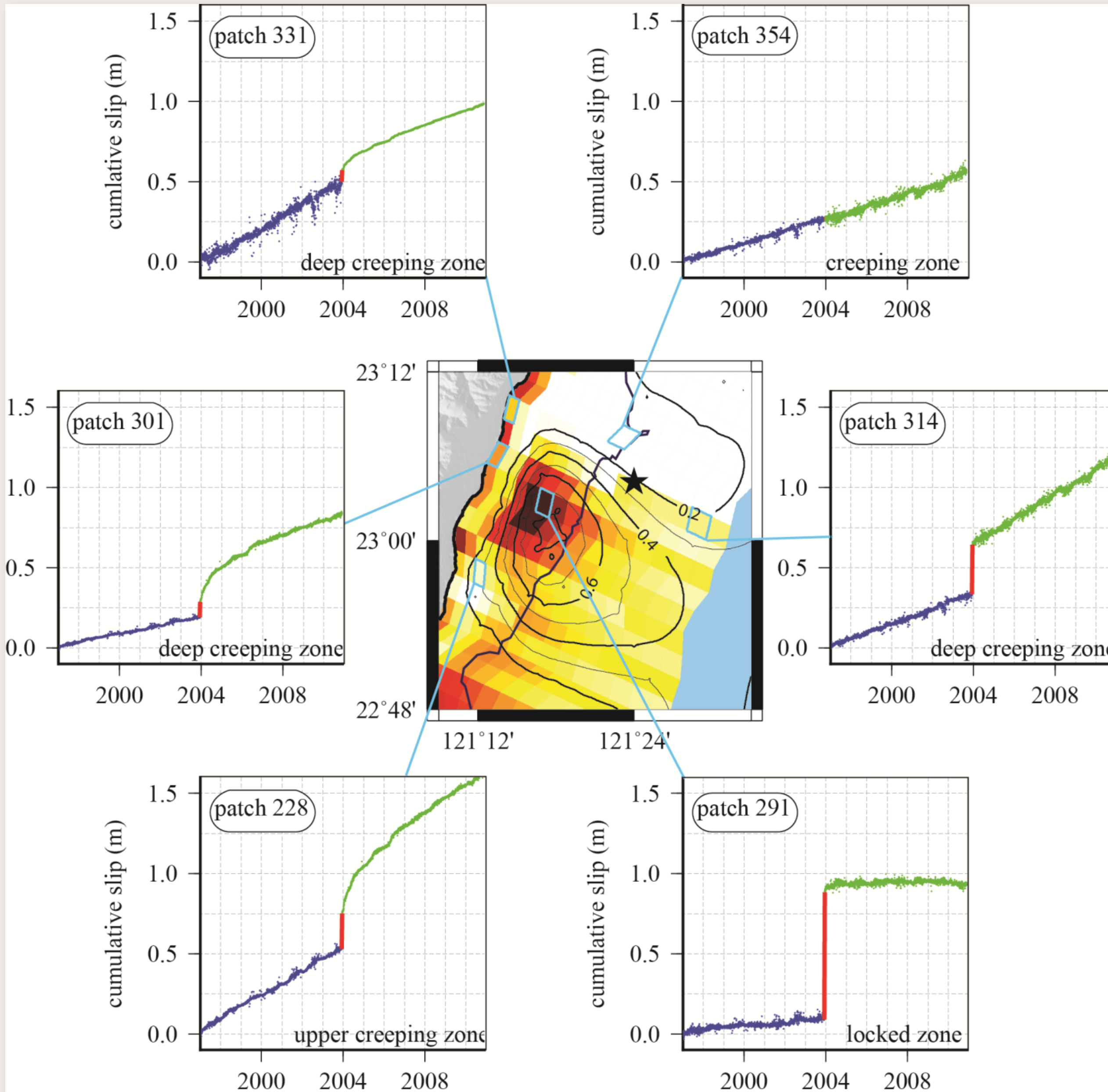
Seismicity catalog from Wu et al, 2008

SLIP AT DEPTH, TEMPORAL HISTORY

PCAIM inversion yields to a slip history at depth.

Upper patches creeps before and after the Chengkung events

Locked patch at ~10 to18 km depth, that only recorded seismic slip



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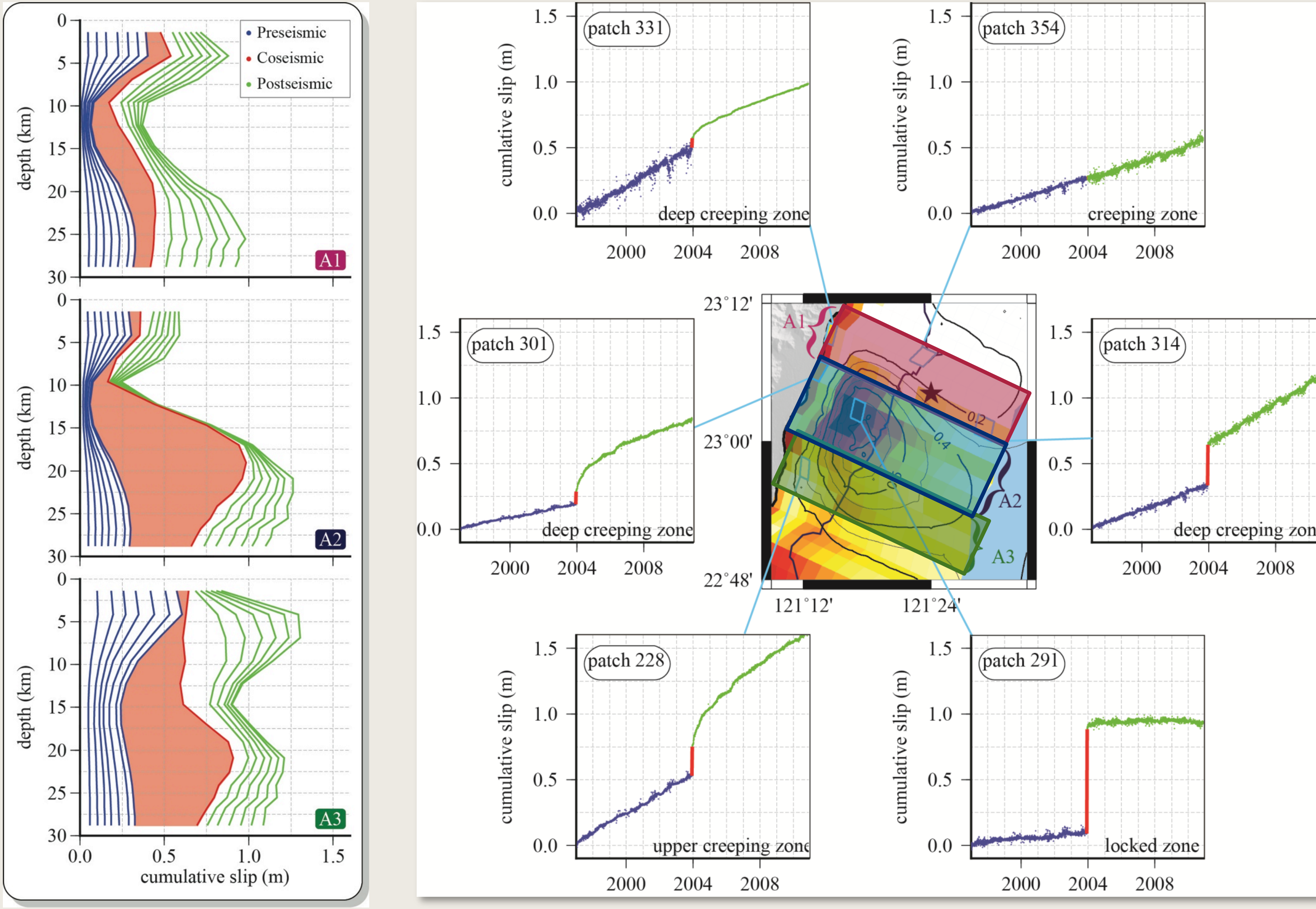


Rate-and-state law

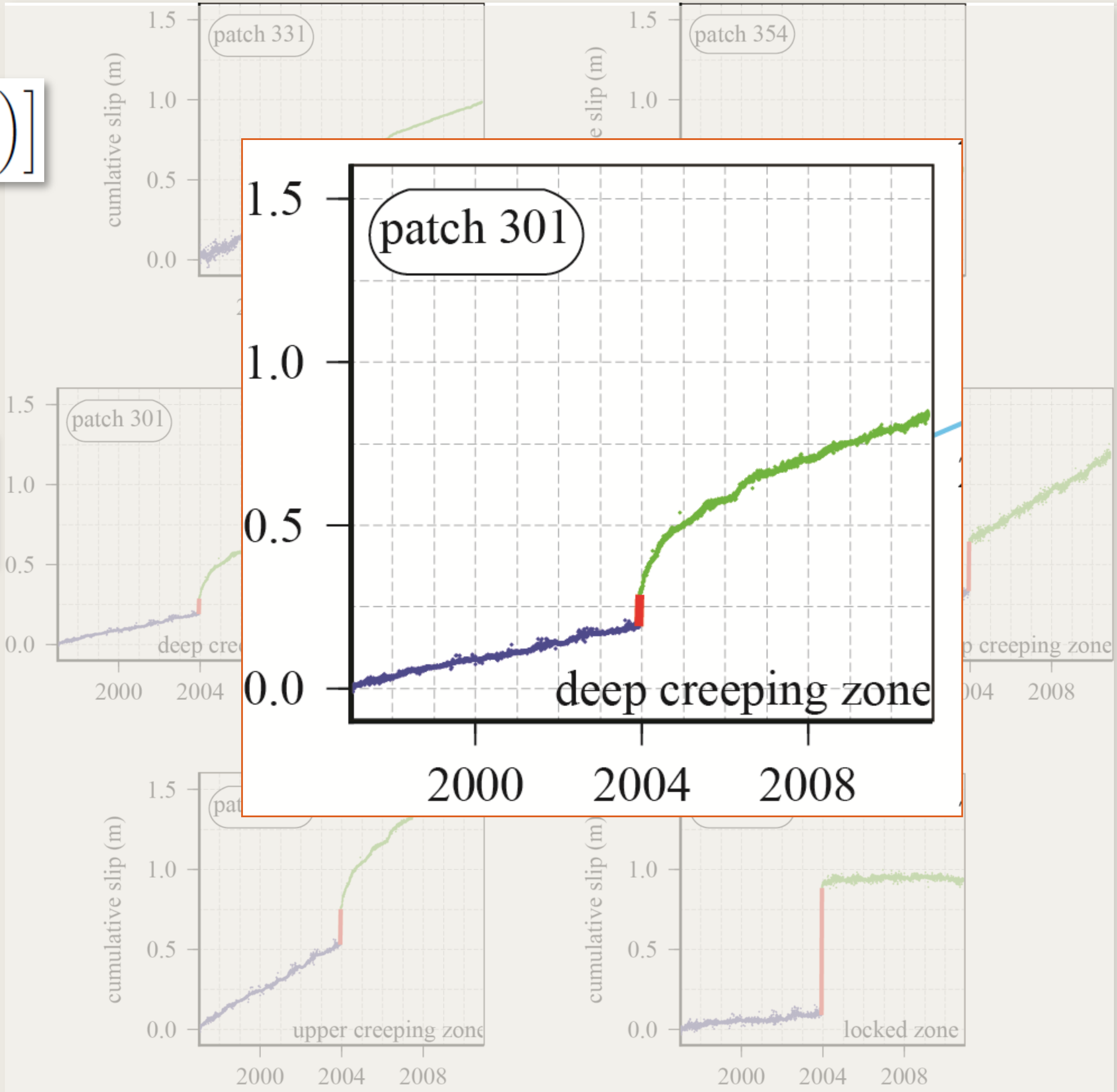
$$\tau_{ss} = (\sigma - p)\left[f_0 + (a-b)\ln\left(\frac{V}{V_0}\right)\right]$$

From Perfettini and Avouac., 2004

$$U(t) \approx V_{pl} t_r log\left[1 + \frac{V^+}{V_{pl} t_r} t\right]$$

$$(a-b) = \frac{\Delta CFF}{\bar{\sigma} log\left(\frac{V^+}{V_{pl}}\right)}$$

$$t_r = \frac{(a-b)\sigma}{\dot{\tau}}$$



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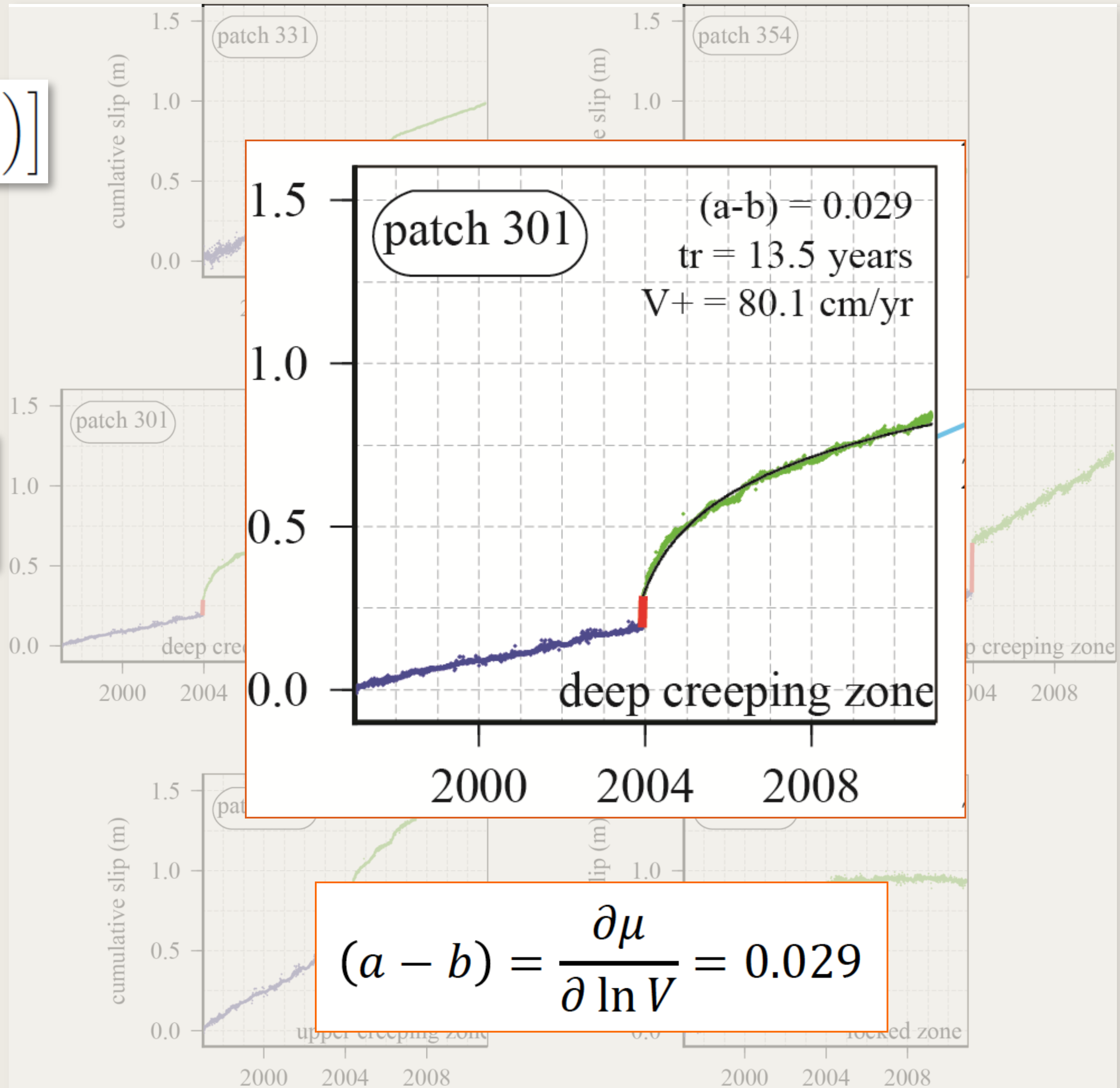
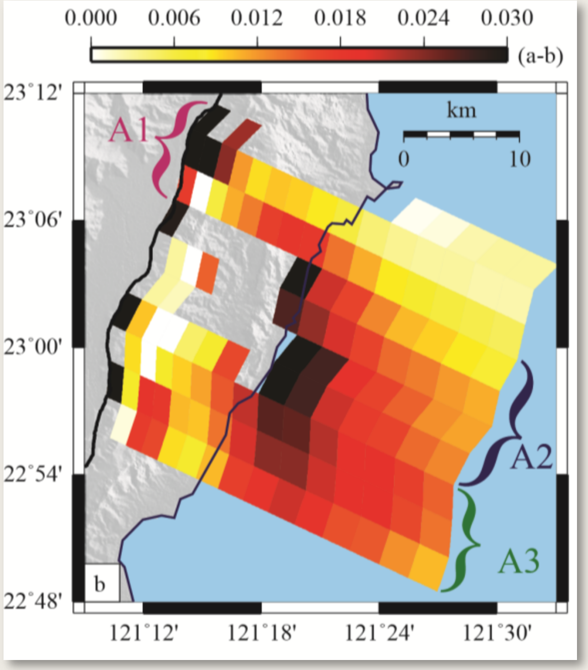


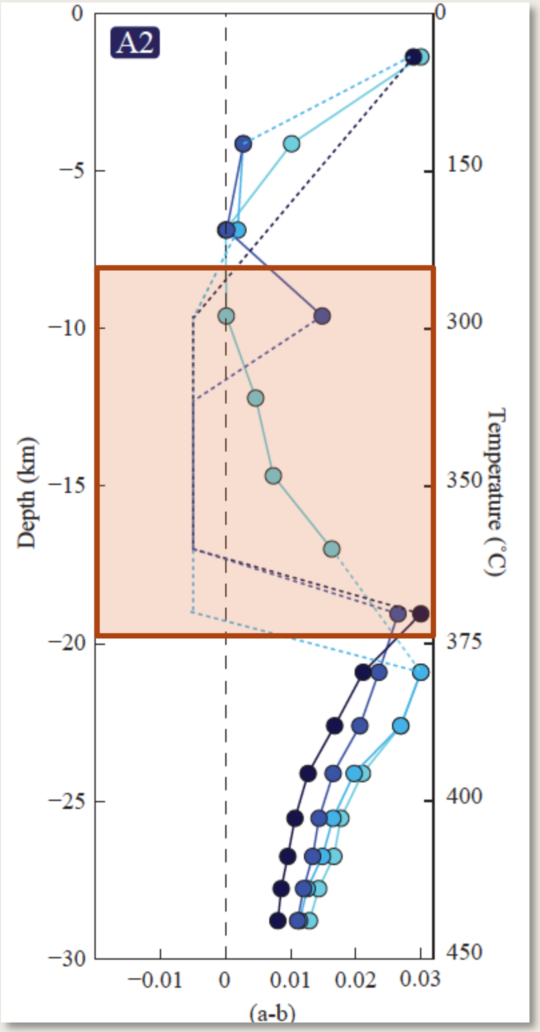
$$(a-b) = \frac{\partial \mu}{\partial \ln V} = 0.029$$

INSIGHTS ON FRICTIONAL PROPERTIES

(a-b) derived from inversion models, in function of depth

(a-b) derived from inversion models

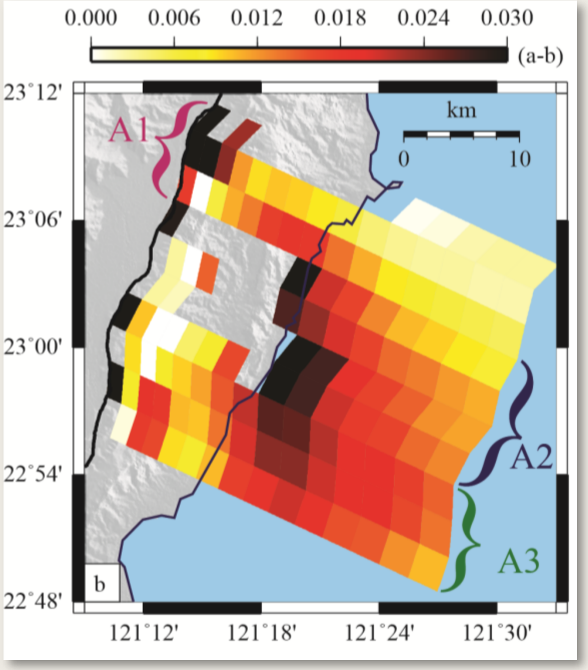


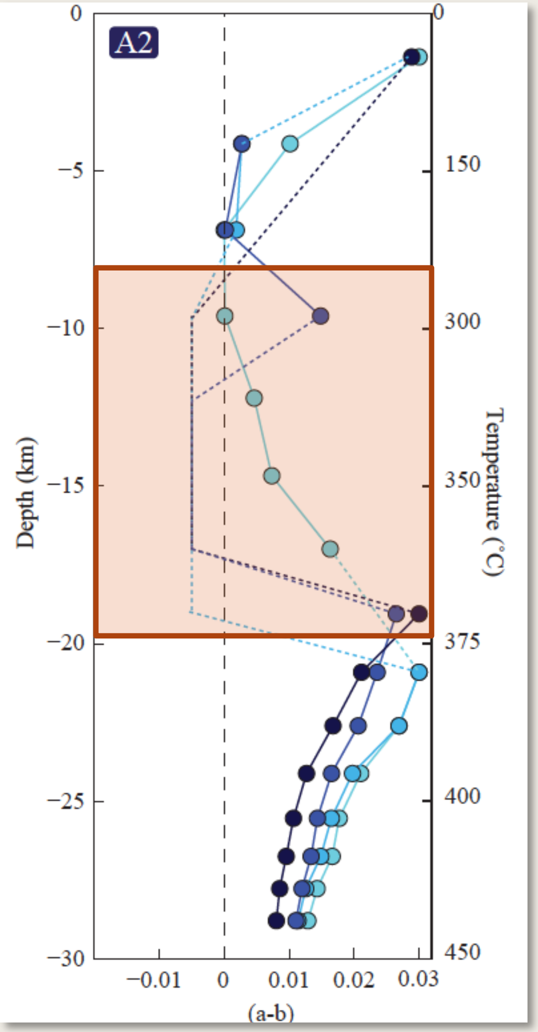


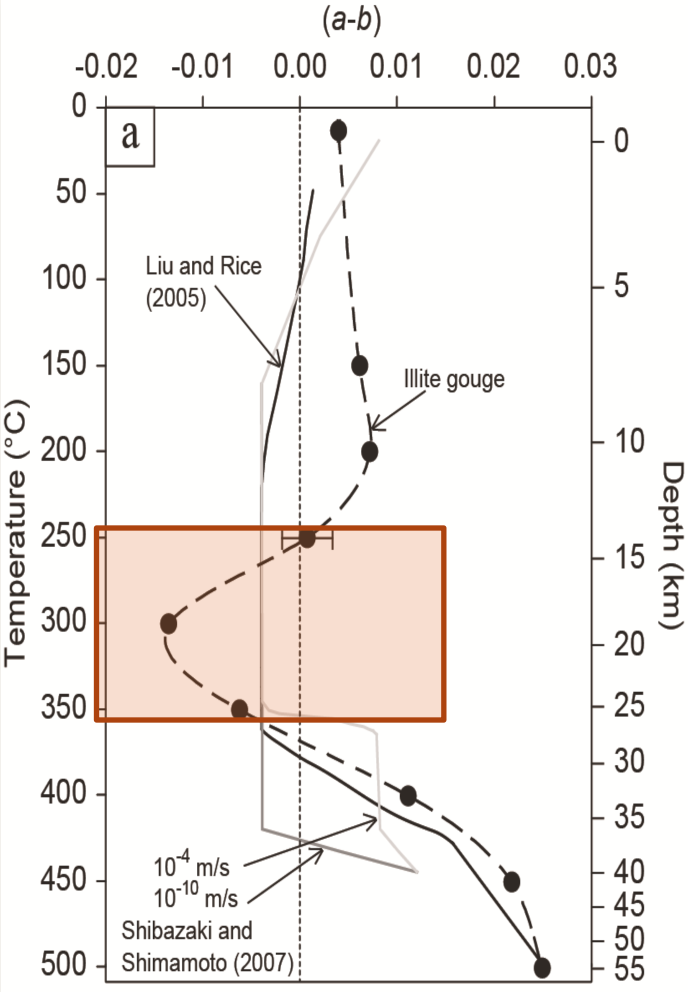
INSIGHTS ON FRICTIONAL PROPERTIES

(a-b) derived from inversion models, in function of depth

(a-b) derived from inversion models







Den Hartog, EPSL 2012

"BICycle" : Boundary Integration Cycle of Earthquakes

***Allows simulating earthquake** cycles* in their entirety,

from accelerating slip in slowly expanding nucleation zones

to dynamic rupture propagation

to post-seismic slip and interseismic creep

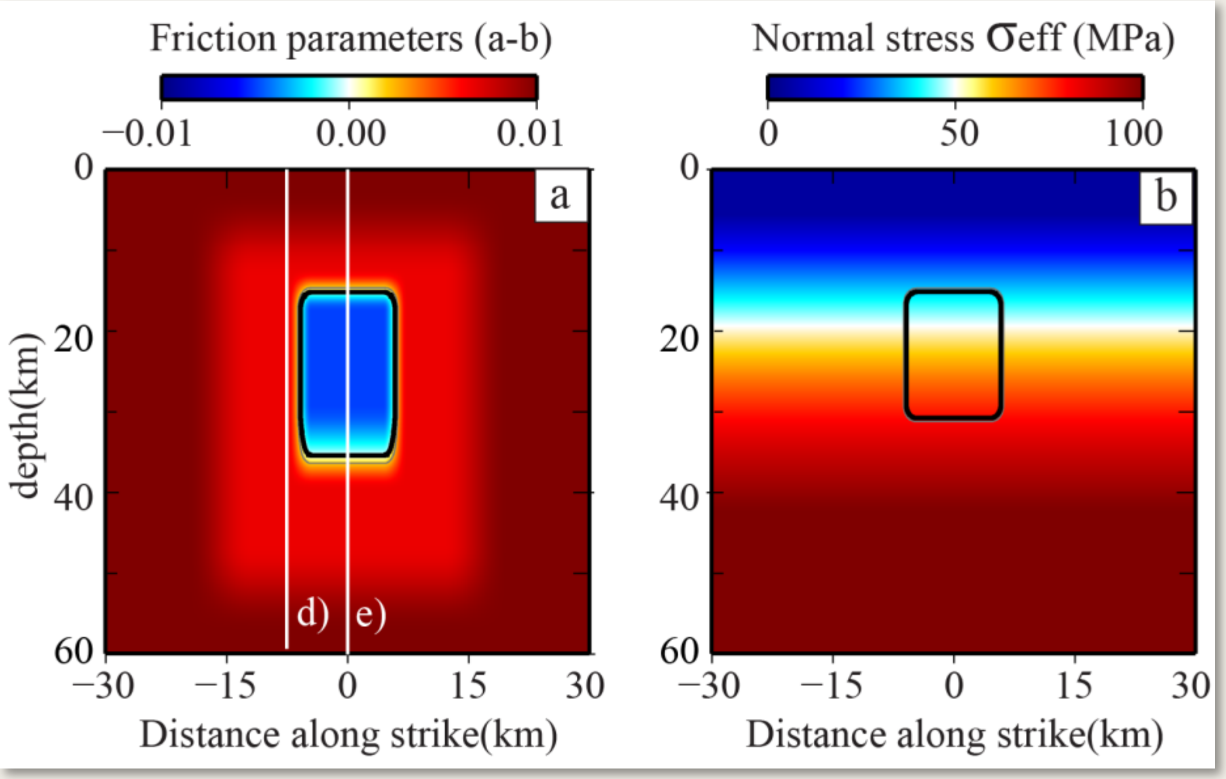
to fault re-strengthening between seismic events.

Rate and state law
(Dieterich 1981, Ruina 1983) :

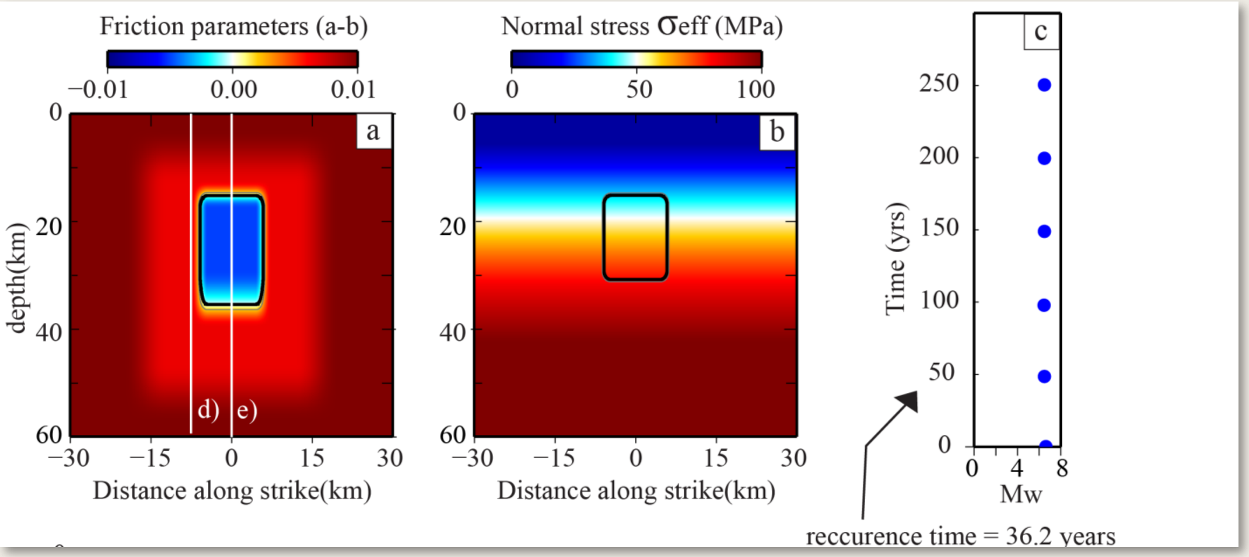
$$\tau = \bar{\sigma}\left(f_0 + a \ln\frac{V}{V_0} + b \ln\frac{V_0\theta}{L}\right)$$

with

$$\dot{\theta} = 1 - \frac{V\theta}{L}$$

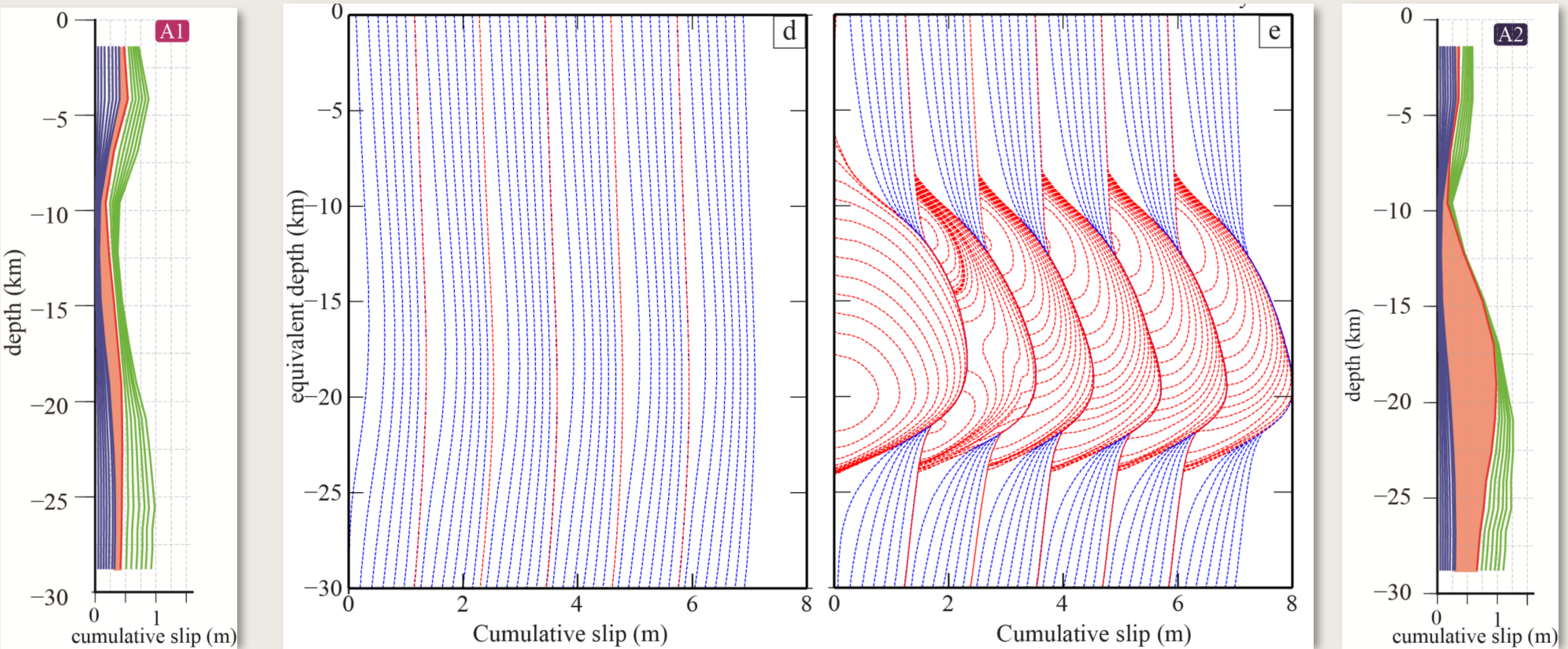


DYNAMIC MODELING ON THE LVF



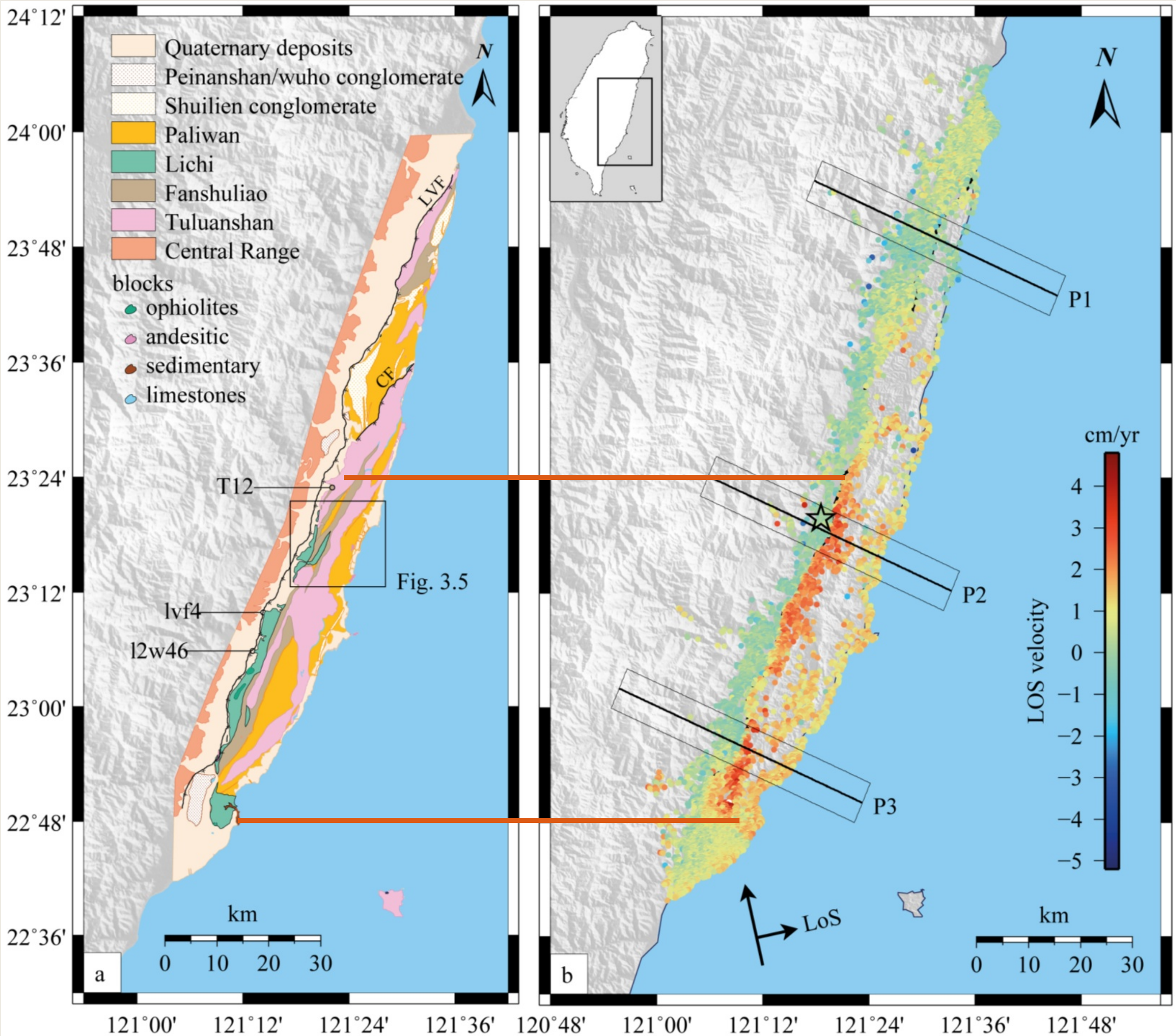
Output features :

- quasi periodic return of similar earthquakes rupturing the whole VW patch
- Mw 6.5 earthquakes
- Recurrence time = 36.2 years
- seismic ruptures do not reach the surface

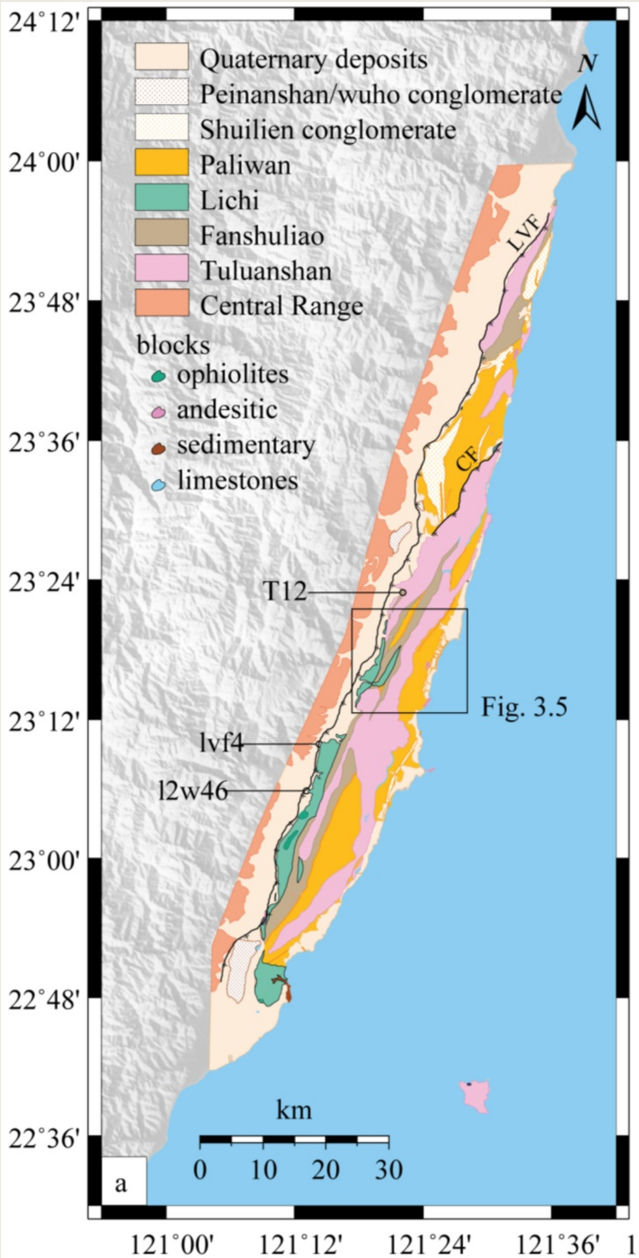


Section A3 from the static inversion of geodetic and remote sensing data

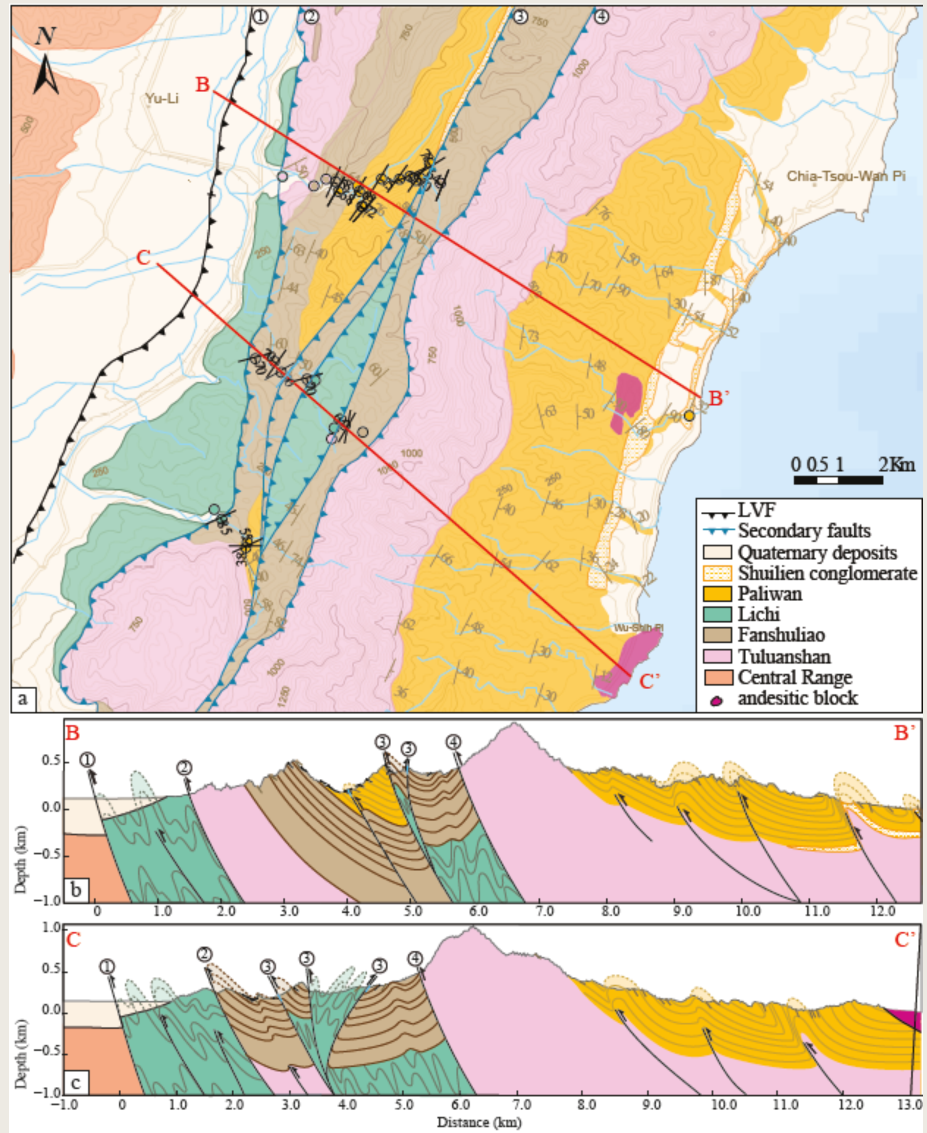
SPATIAL CORRELATION OF ASEISMIC SLIP WITH THE LICHI MELANGE



FIELD WORK: STRATIGRAPHIC RELATIONS



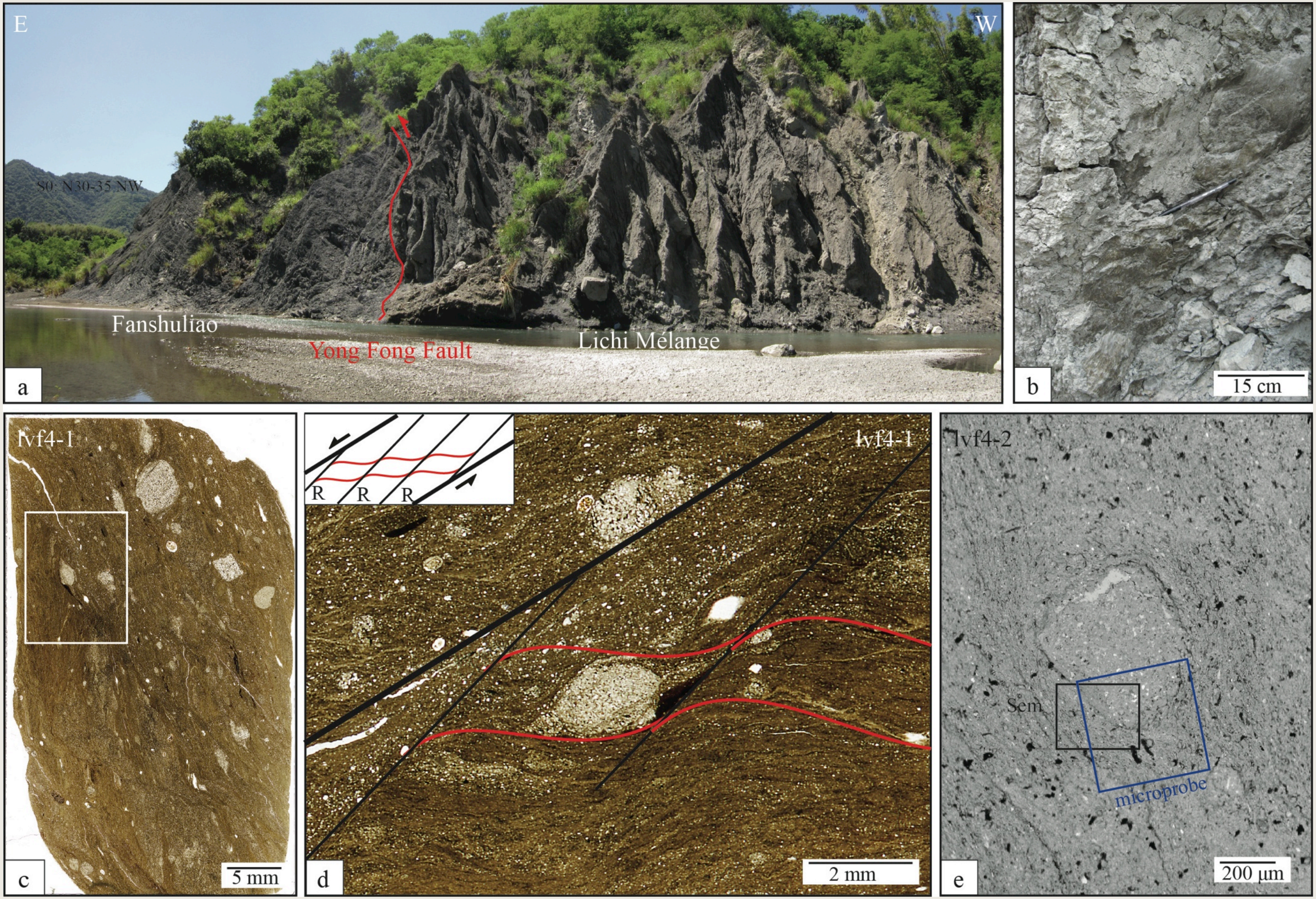
The Fanshuliao forearc deposits formation is the protolith of the Lichi Melange



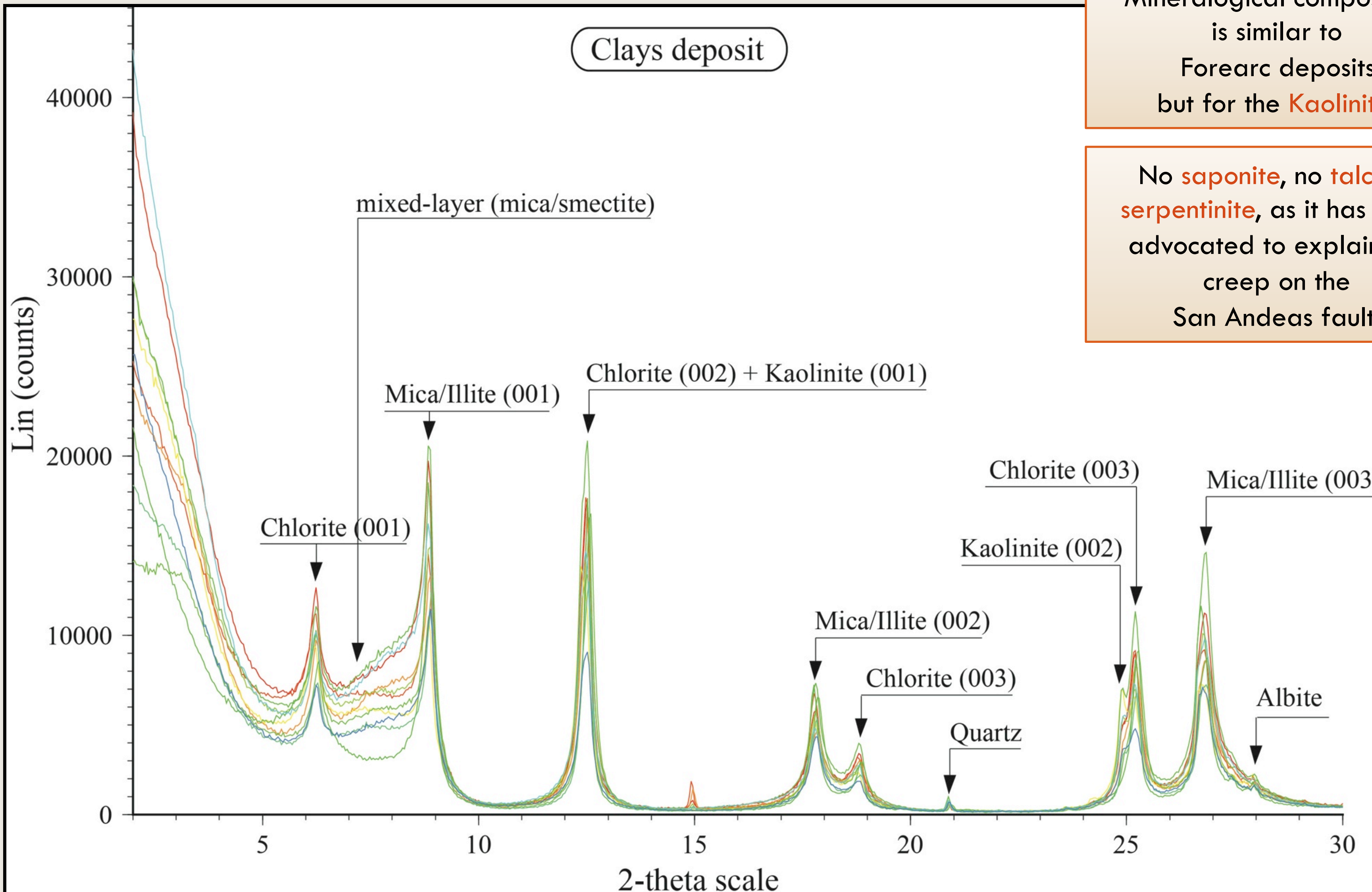
Lichi melange, a collision melange

Fanshuliao, forearc deposits

LICHI MELANGE: MICROSTRUCTURAL AND ANALYTICAL OBSERVATIONS



LICHI MELANGE: MINERALOGICAL COMPOSITION

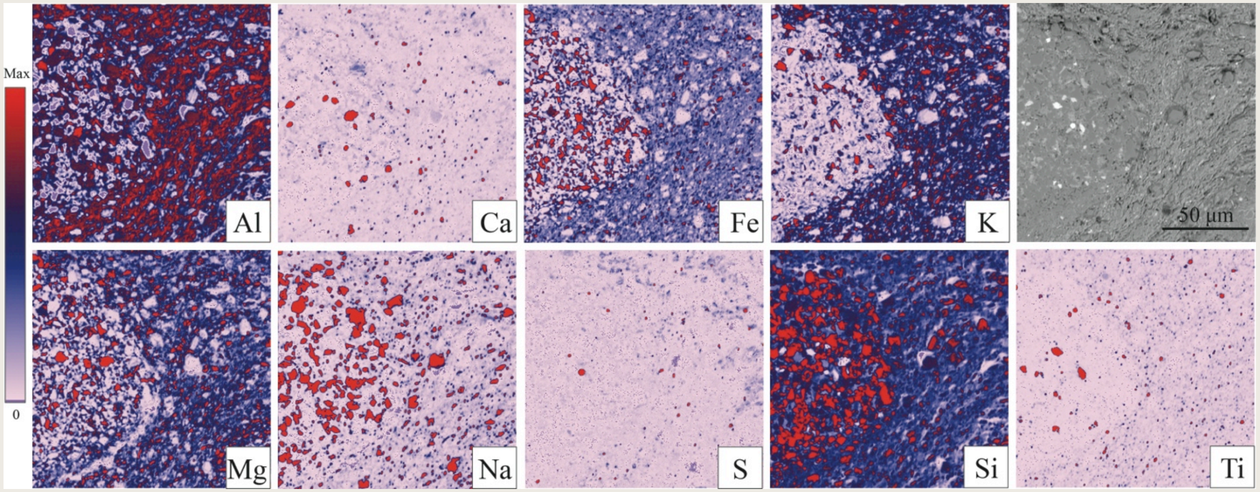


Mineralogical composition is similar to Forearc deposits, but for the Kaolinite.

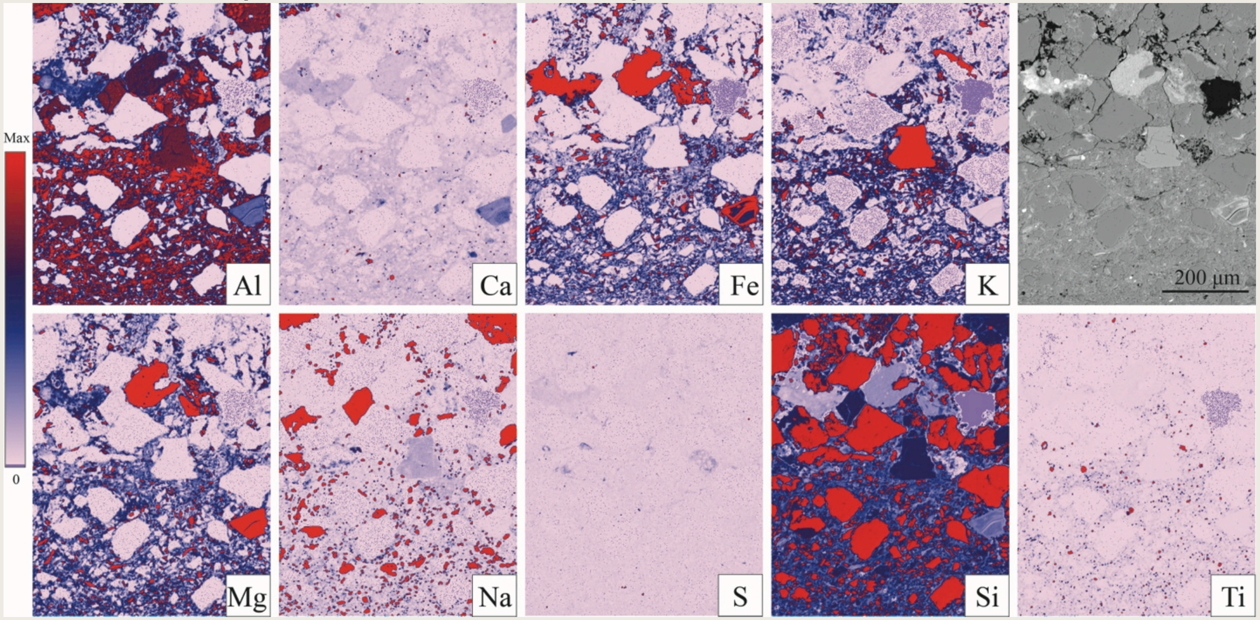
No saponite, no talc, no serpentinite, as it has been advocated to explain the creep on the San Andeas fault.

MICRO-ANALYZER COMPOSITIONAL MAP

Lichi melange, inside the LVF fault gouge



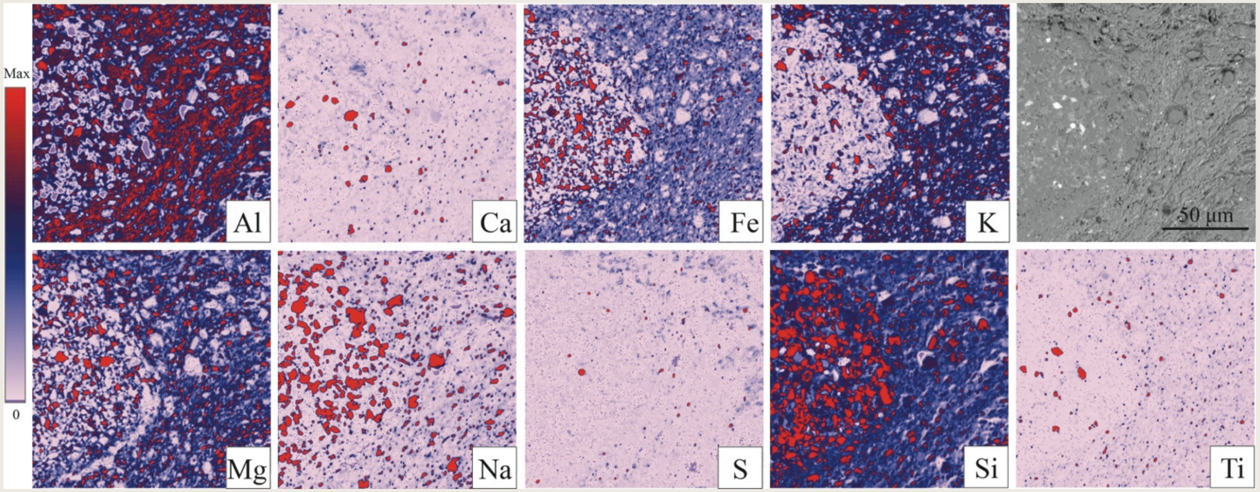
Fanshuliao, protolith of Lichi melange, near the fault zone



In the matrix, in comparison to the microlithons (initial state) or the protolith:

- **Depletion:**
  - Si
  - Na
  - Ca
- **Passive concentration:**
  - Al
  - K
  - Ti
  - S

Lichi melange, inside the LVF fault gouge



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For pressure-solution creep to develop, it requires:

- Soluble minerals
- Fluid phase

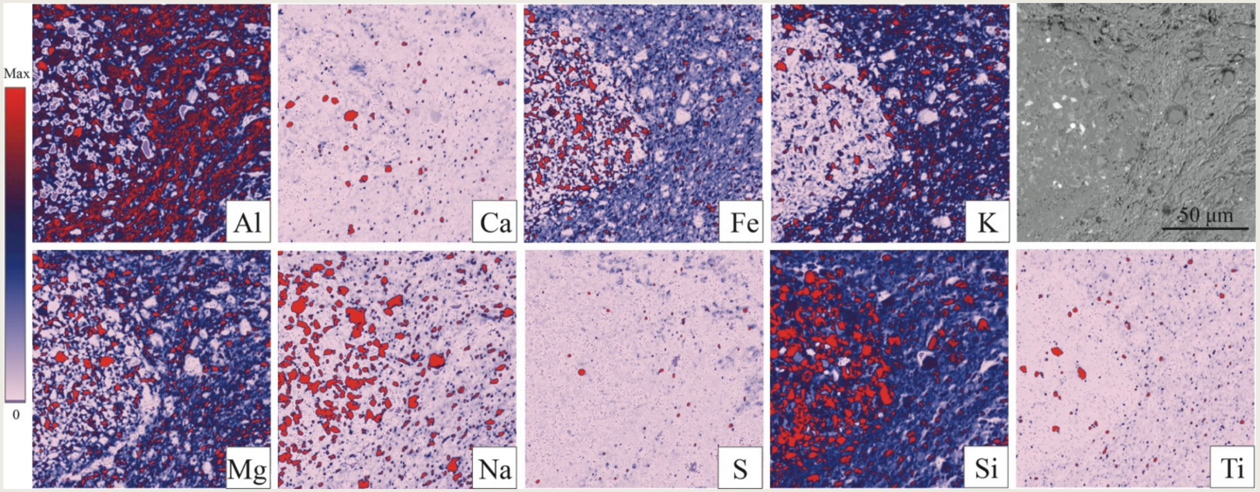
To accommodate large creep rate:

- Small grain size
- phylosilicates

Deficit in soluble minerals
=
Pressure solution creep

PRESSURE SOLUTION CREEP

Lichi melange, inside the LVF fault gouge



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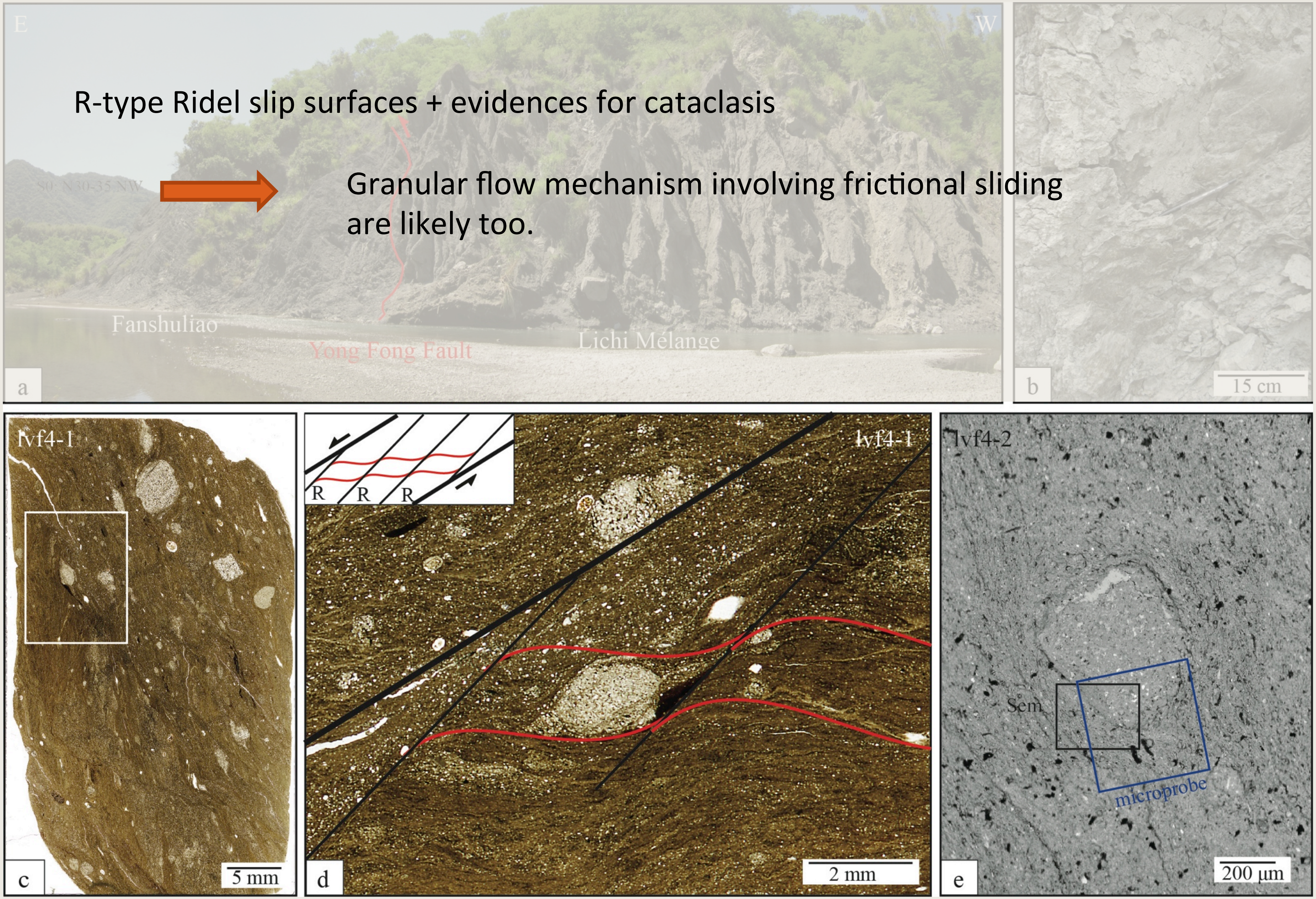
Lichi Melange gathers the specific conditions

Deficit in soluble minerals
=
Pressure solution creep

LICHI MELANGE: MICROSTRUCTURAL AND ANALYTICAL OBSERVATIONS

R-type Ridel slip surfaces + evidences for cataclasis

→ Granular flow mechanism involving frictional sliding are likely too.



Conclusion

- Map of seismic and aseismic segments on the LVF.
- Joint inversion of various dataset.
- Frictional properties of the fault retrieved from kinematic inversion.
- Cumulative slip history on the LVF is consistent with a simple model of a VW patch embedded in a VS area.
- Pressure-solution creep and Frictional sliding accommodate surface creep on the LVF.
- Tectonic fabric at the micro-scale is a key factors to control slip mode.

ACKNOWLEDGMENTS

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On-going work

- Dynamic modeling of earthquakes sequences on the LVF; implications for frictional properties.
- Effect of Damage on Earthquake rupture dynamic

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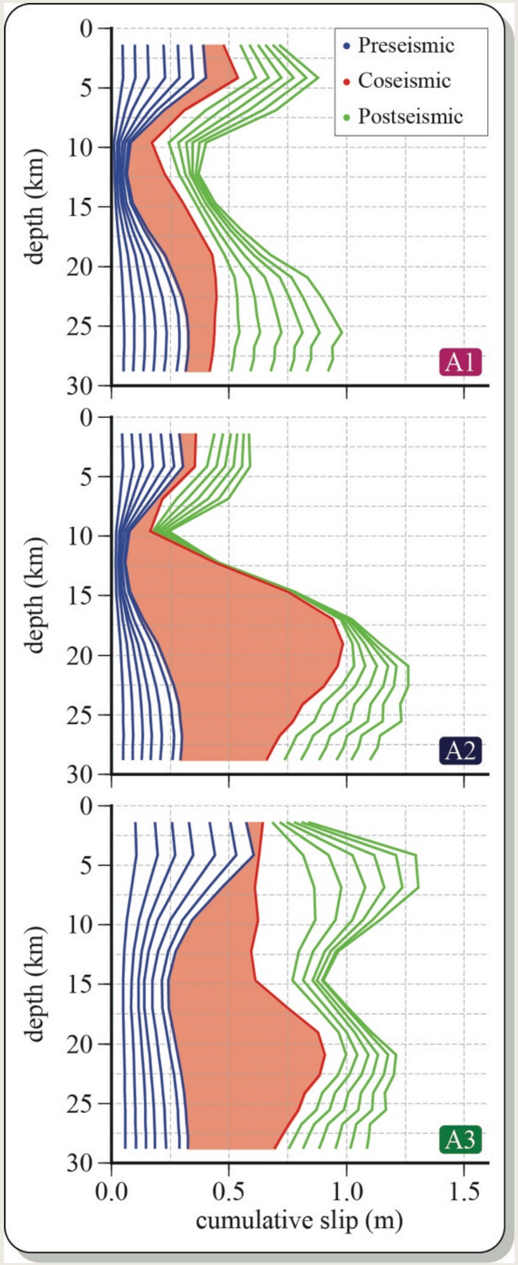
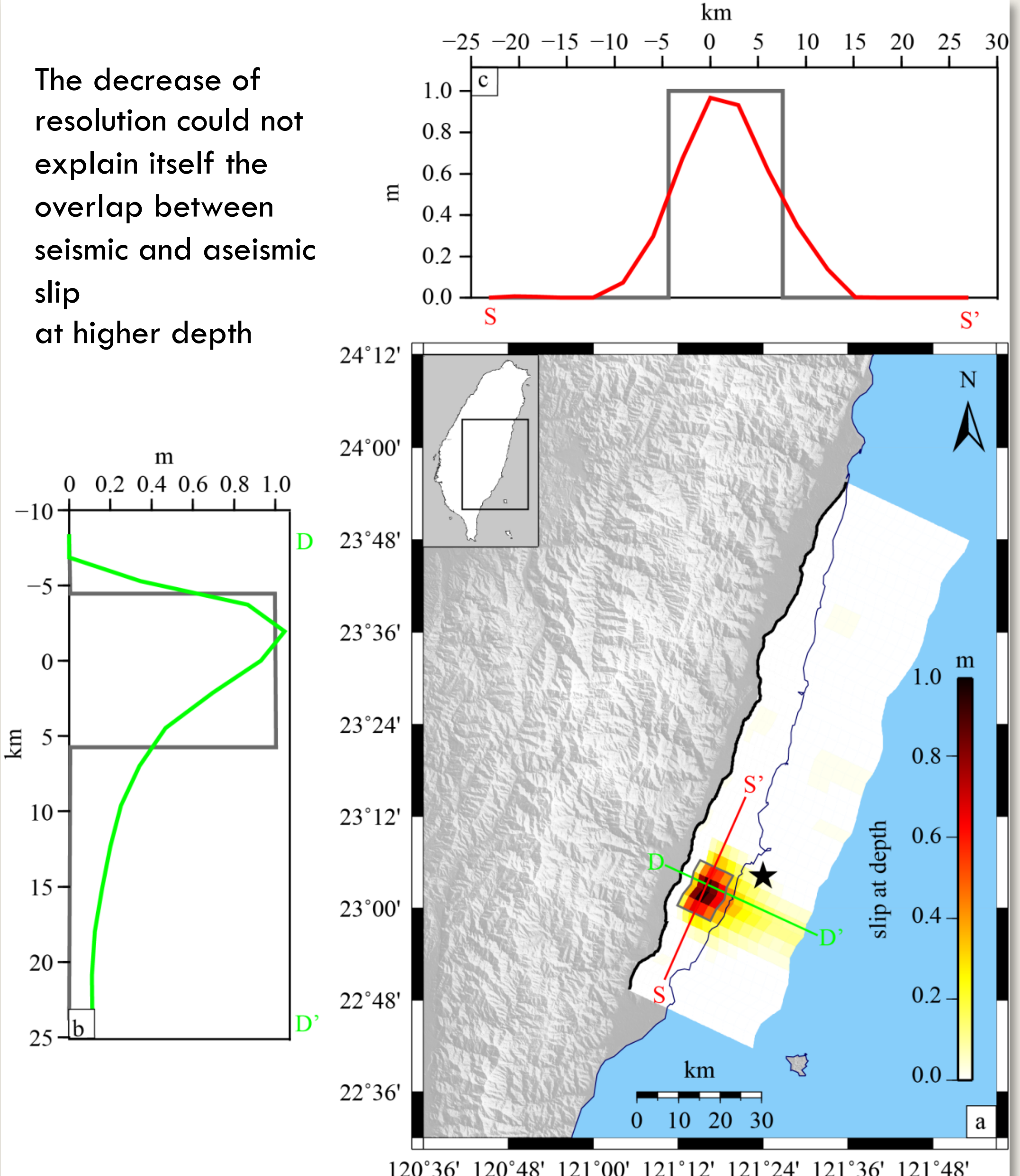
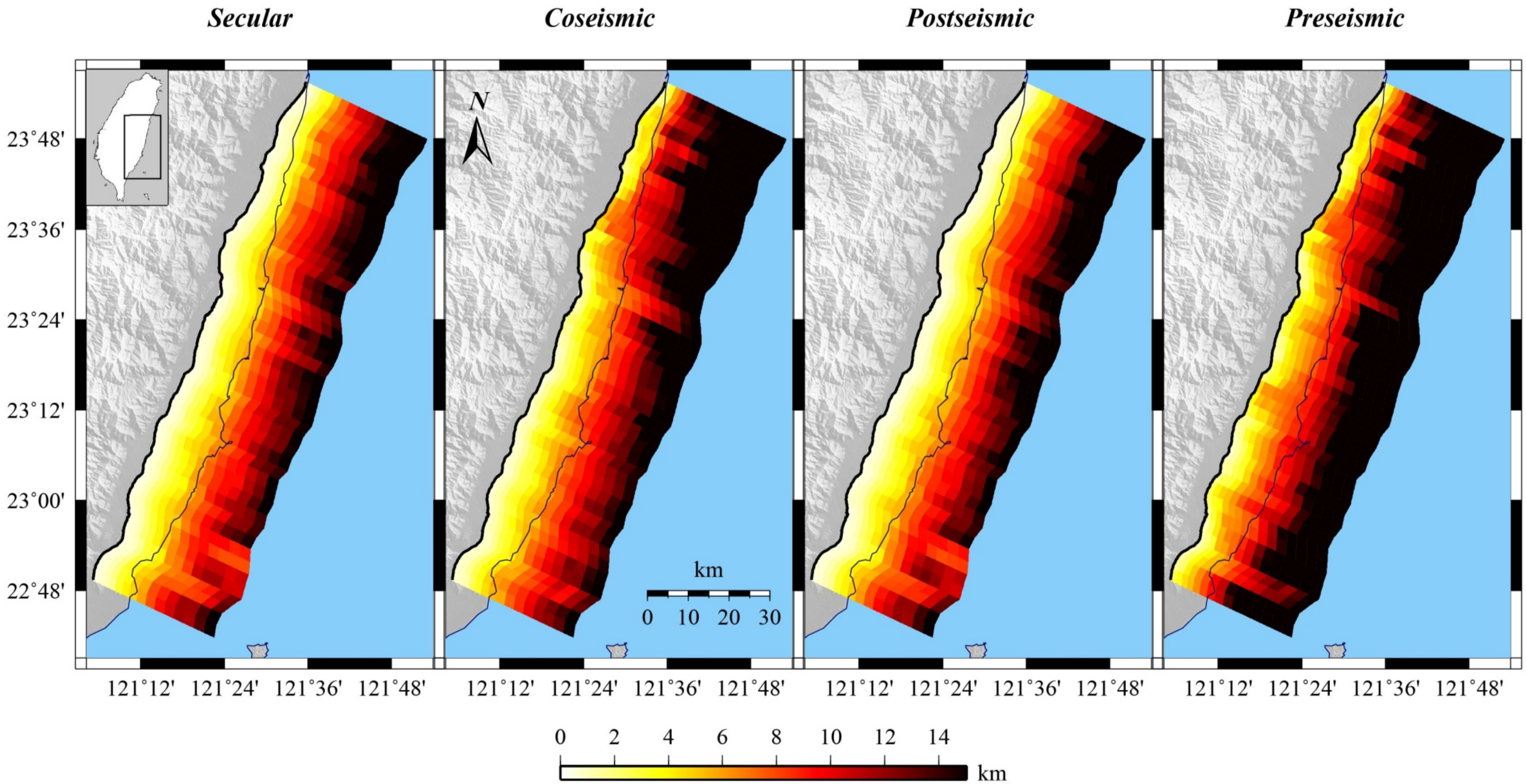
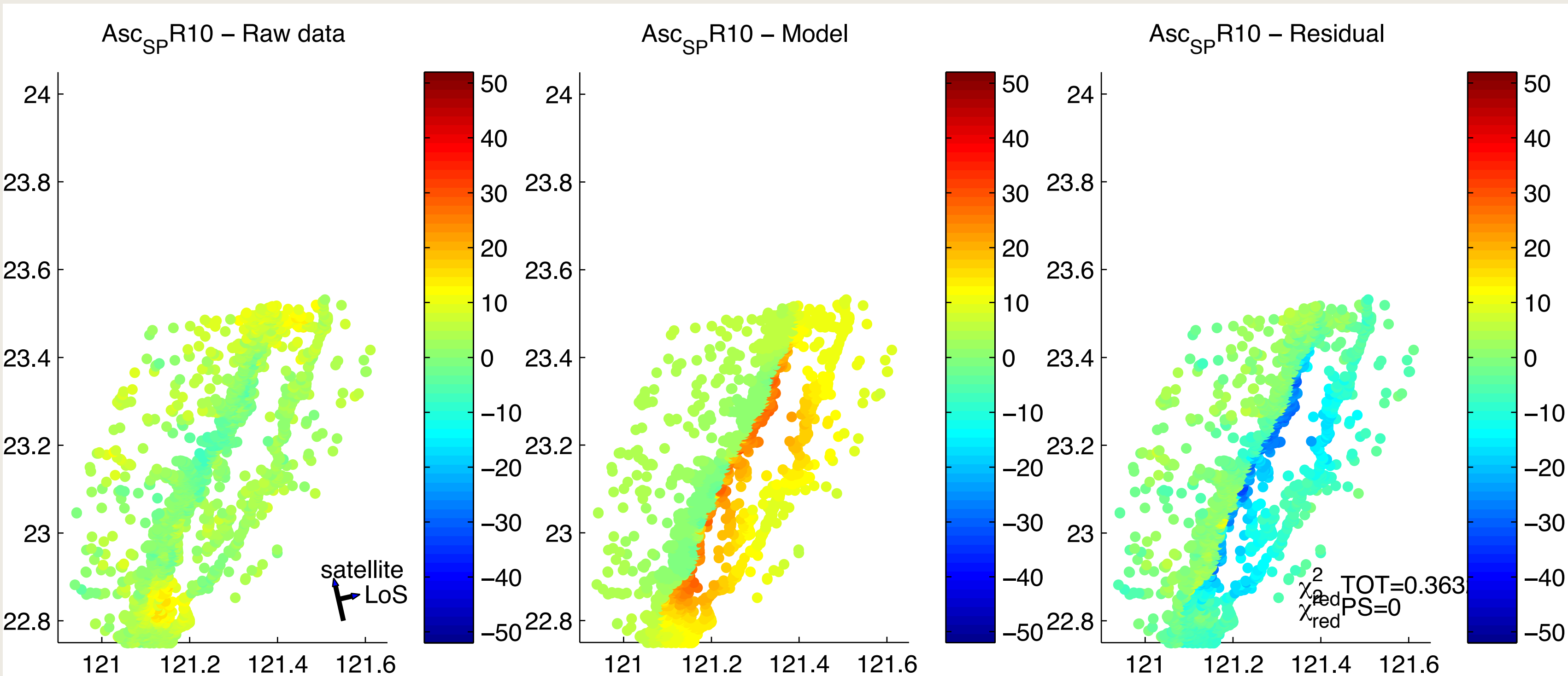
SLIP AT DEPTH, TEMPORAL HISTORY



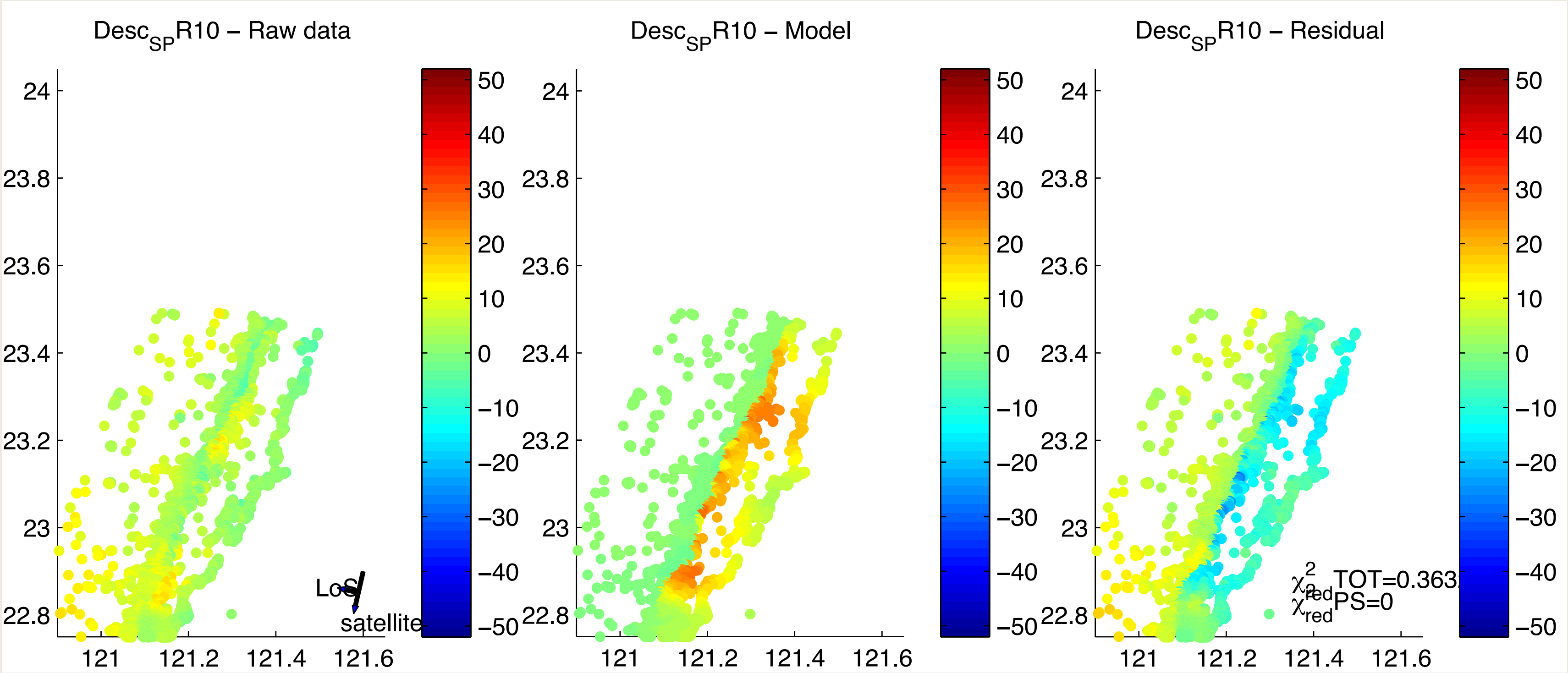
The decrease of resolution could not explain itself the overlap between seismic and aseismic slip
at higher depth




Secular
Coseismic
Postseismic
Preseismic
23°48'
23°36'
23°24'
23°12'
23°00'
22°48'
121°12'
121°24'
121°36'
121°48'
N
km
0
10
20
30
0
2
4
6
8
10
12
14
km



$Asc_{SP}R10$ – Raw data
$Asc_{SP}R10$ – Model
$Asc_{SP}R10$ – Residual
satellite
LoS
χ^2_{red}TOT=0.363
χ^2_{red}PS=0



Desc$_{SP}$R10 – Raw data
Desc$_{SP}$R10 – Model
Desc$_{SP}$R10 – Residual
LoS
satellite
χ^2_{red}TOT=0.363
χ^2_{red}PS=0
24
23.8
23.6
23.4
23.2
23
22.8
121
121.2
121.4
121.6
50
40
30
20
10
0
−10
−20
−30
−40
−50