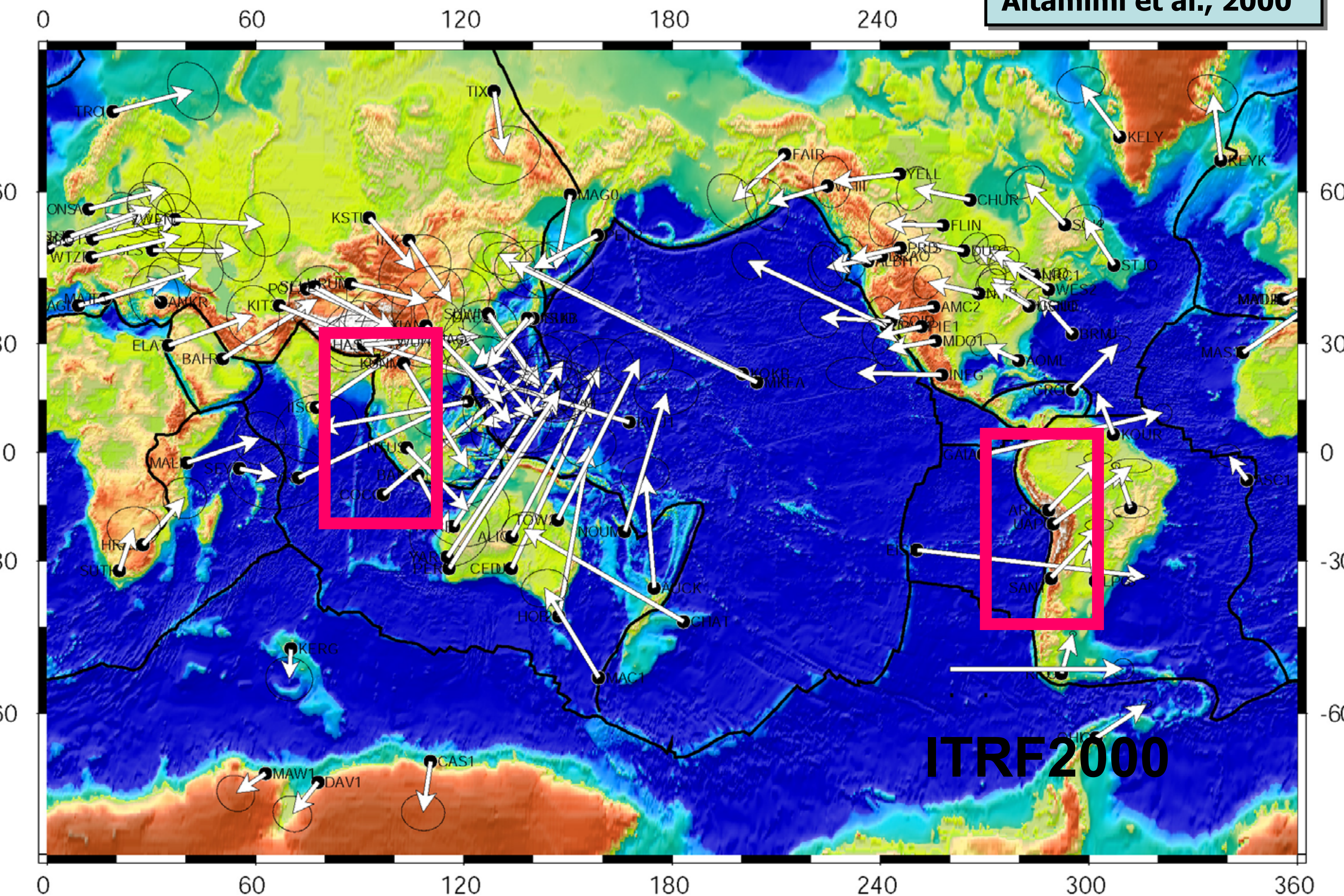
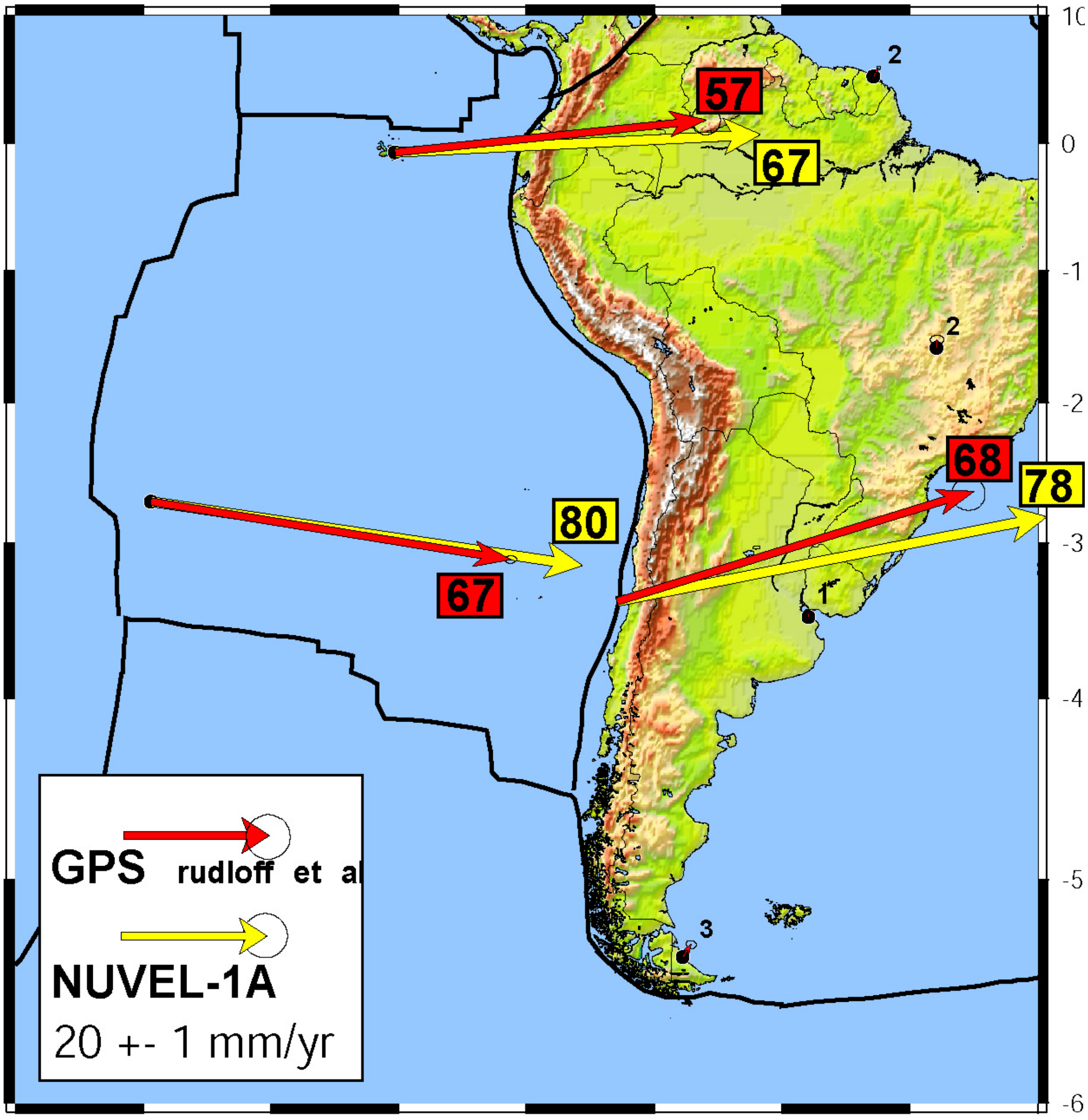
Subduction et Géodésie GPS

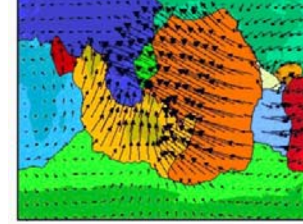
Large scale plate tectonics

Altamimi et al., 2000



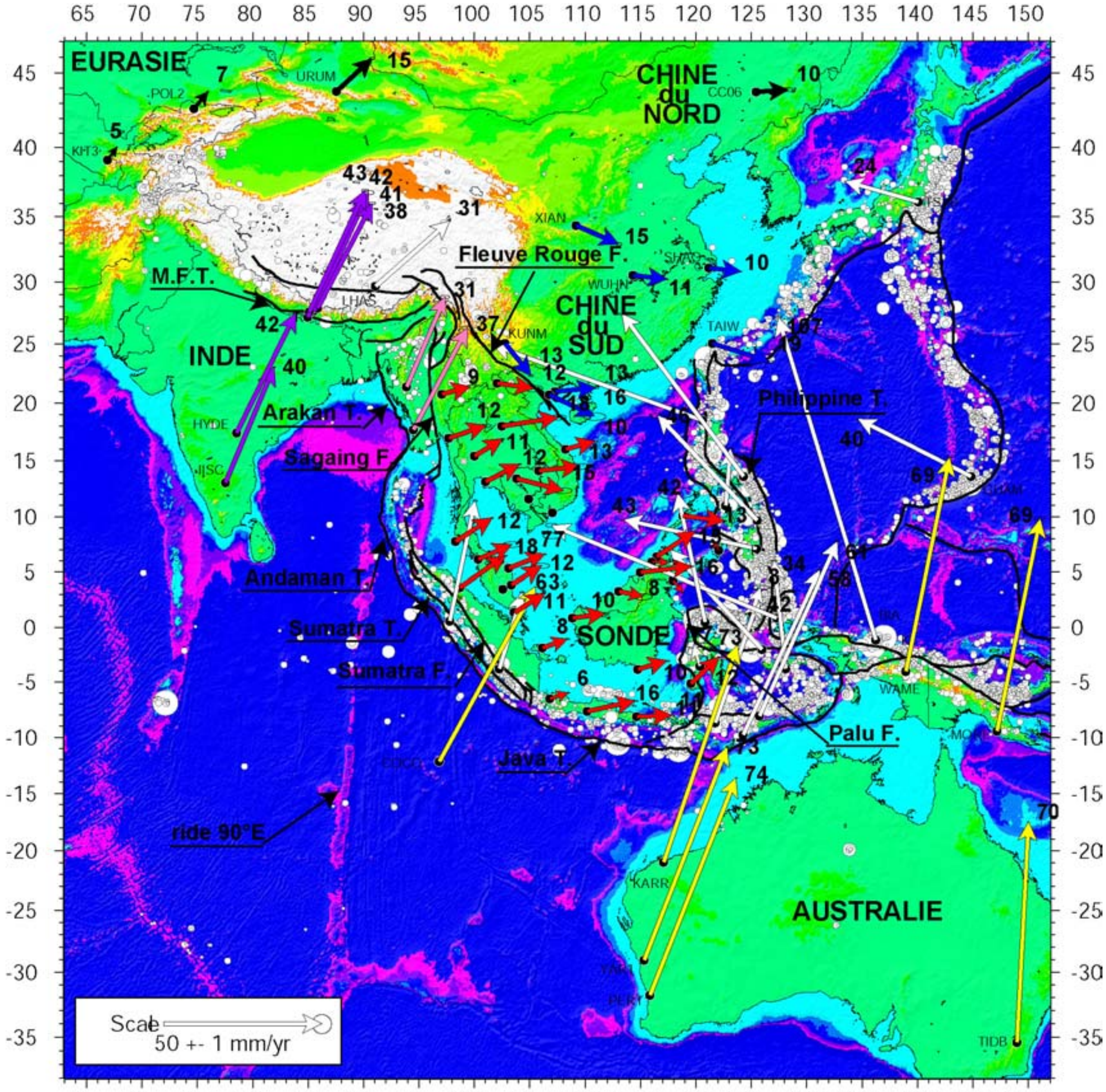
Nazca-SouthAmerica convergence





GPS : la tectonique des plaques

<u>À grande échelle: les micro-plaques ou blocs</u>



Le bloc de la sonde:
=> ce bloc est indépendant de l'Eurasie et s'en éloigne à ~1cm/an vers l'Est

La Chine du Sud:
=> est aussi indépendante de l'Eurasie et s'en éloigne à ~1cm/an vers l'Est également.

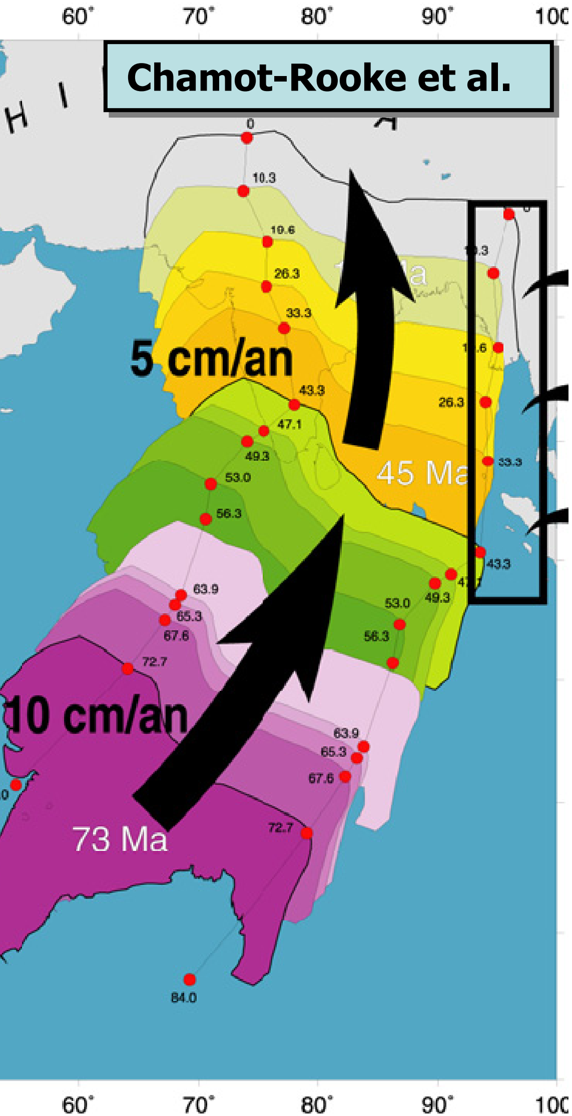
L'INDE:

=> Seulement 4 cm/a par rapport à l'Eurasie et seulemen 3.5 cm/an par rapport à Sunda

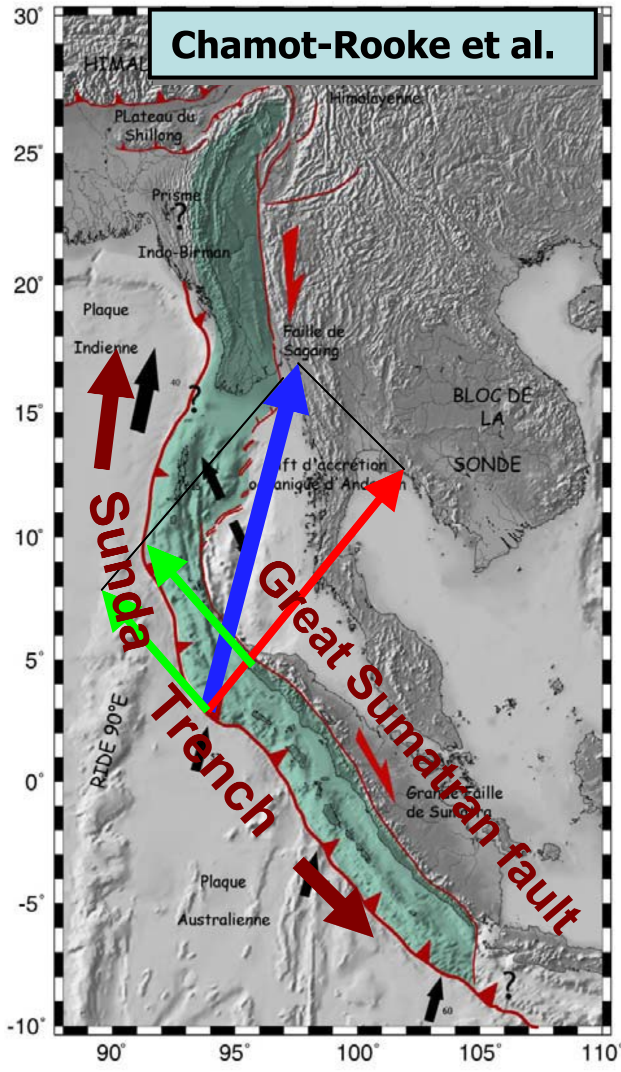
BURMA platelet (or sliver):

=> Ni Inde ni Sonde (encore moins Eurasie)

sismo-tectonic context



India Plate collision



Motion Partitioning

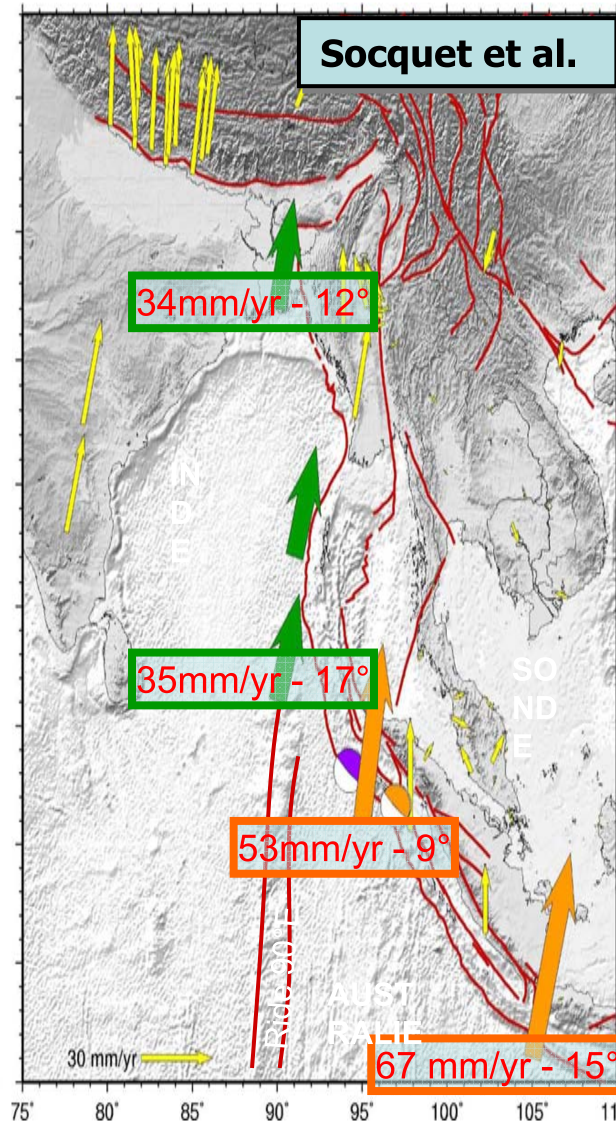
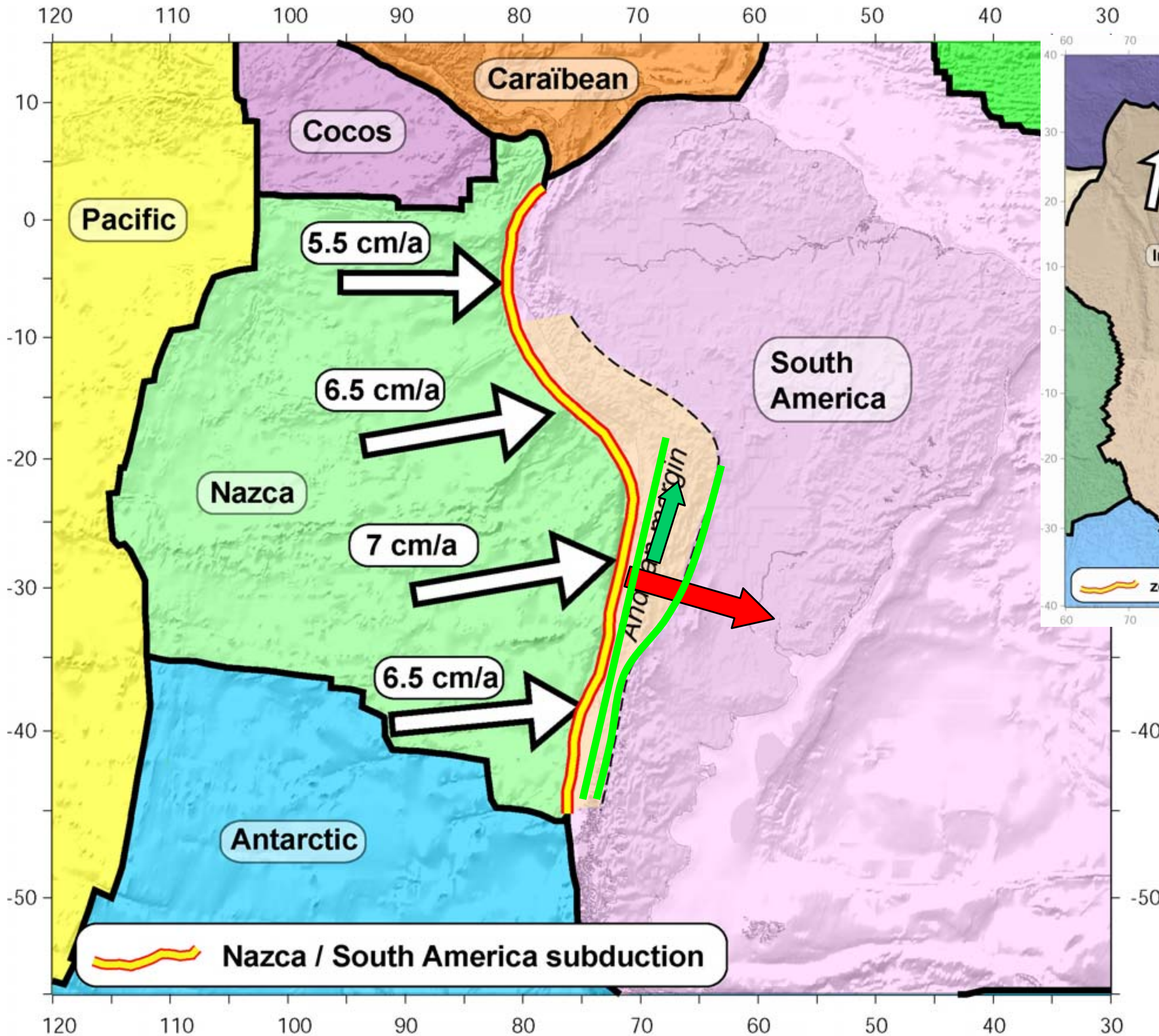
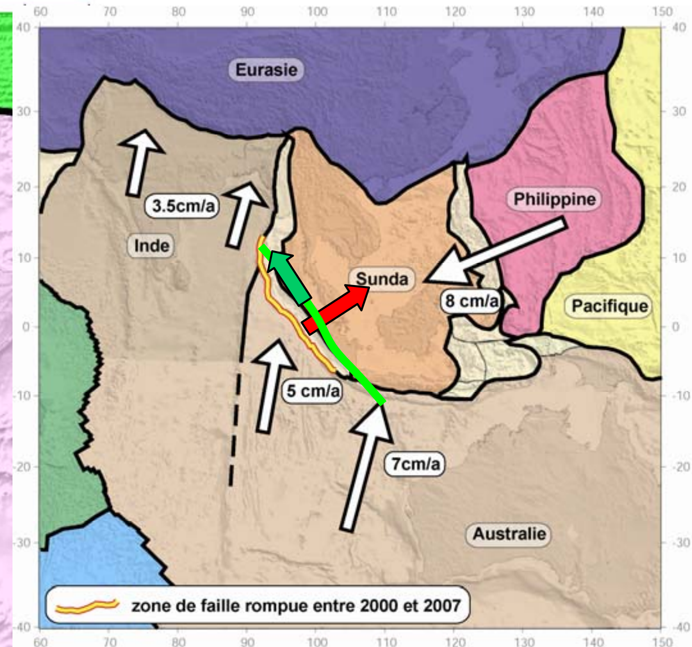


Plate boundaries

Problème 1: Relation obliquité/partitionnement ?



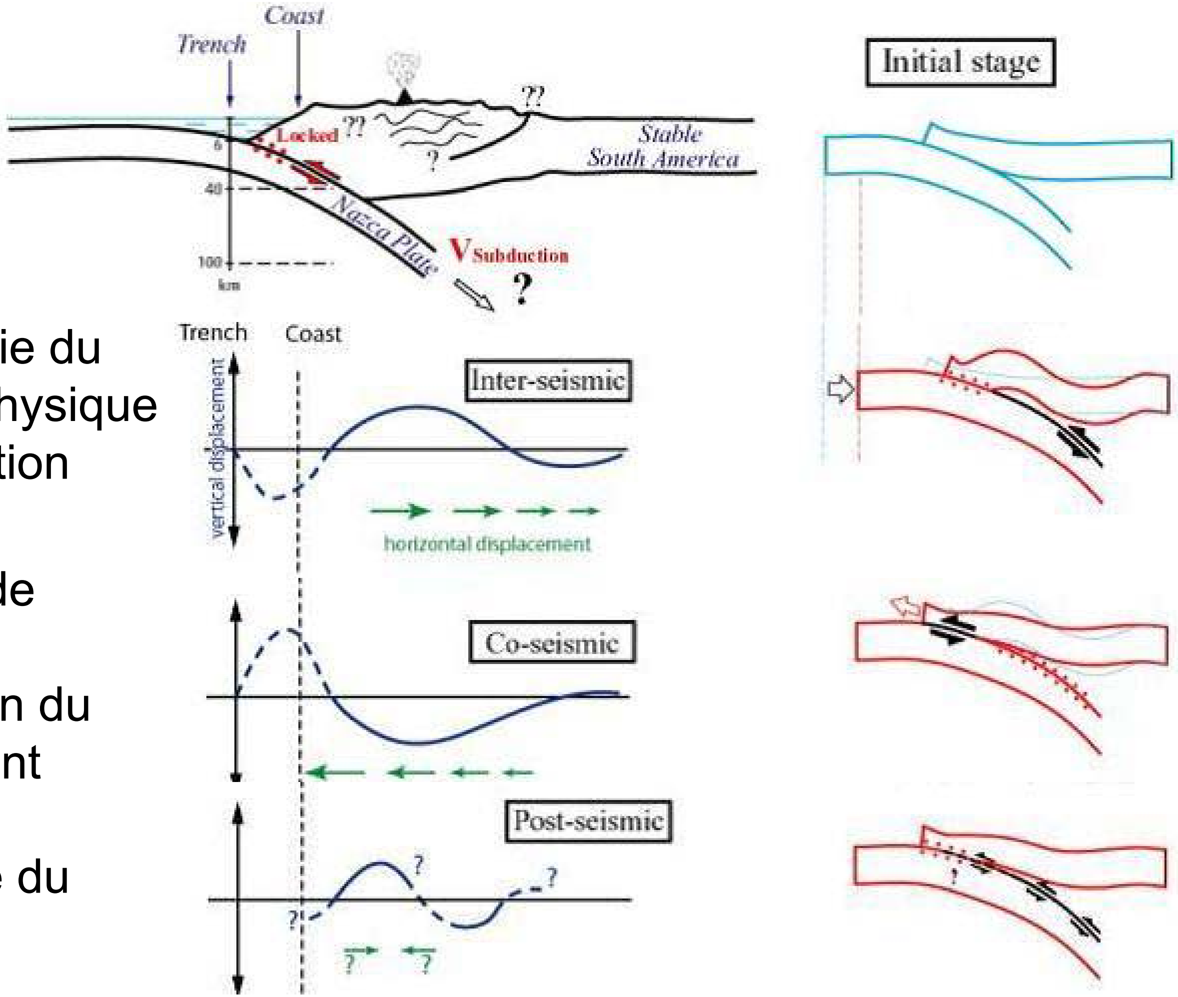


Seismic cycle in subduction context

éométrie du
ab et physique
e la friction

lodèle de
upture:
épartition du
issement

iscosité du
anteau

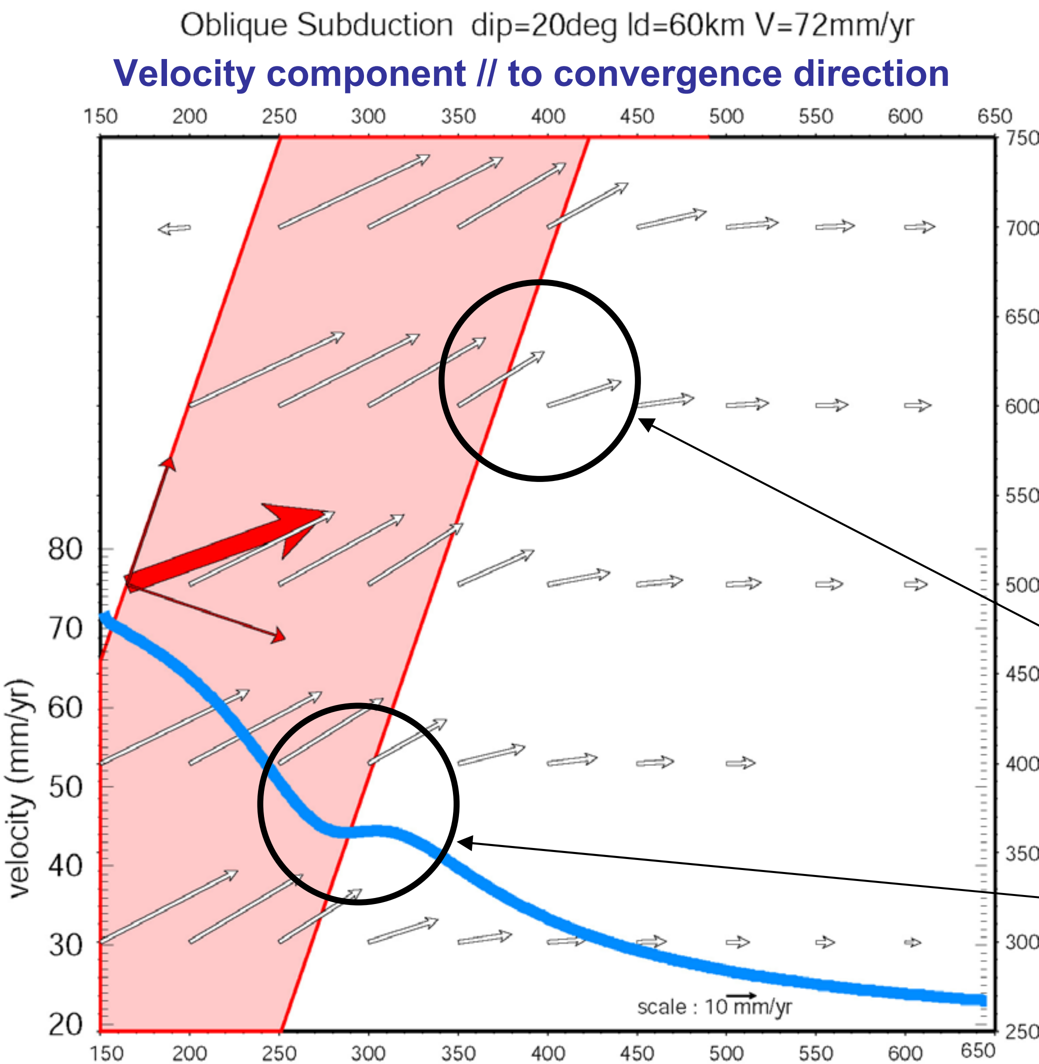


100^{s} years

seconds -> minutes

months- -> years

Subduction modeling



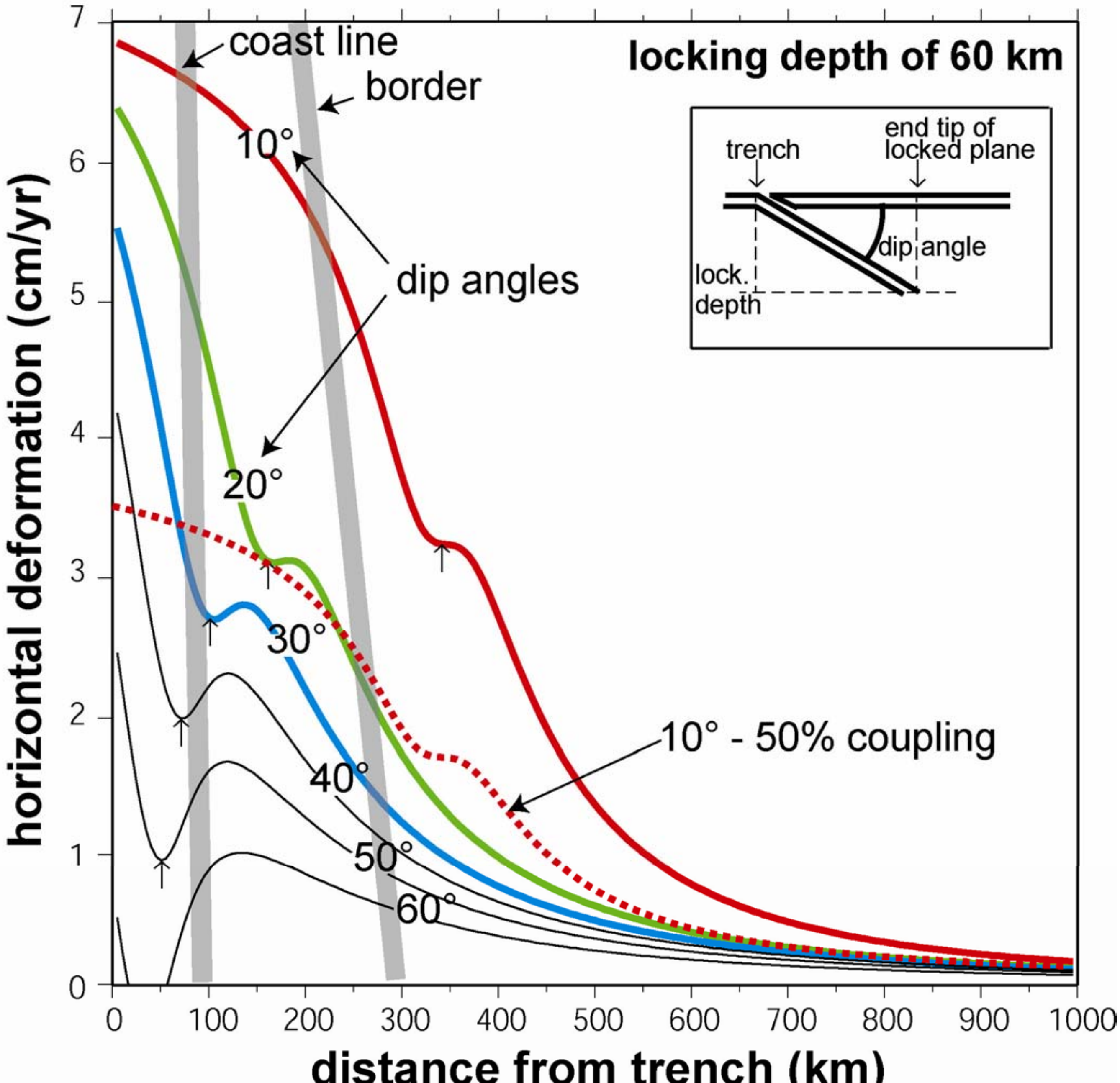
In the case of a subduction (dippping fault with downward slip) we use Okada's formulas.

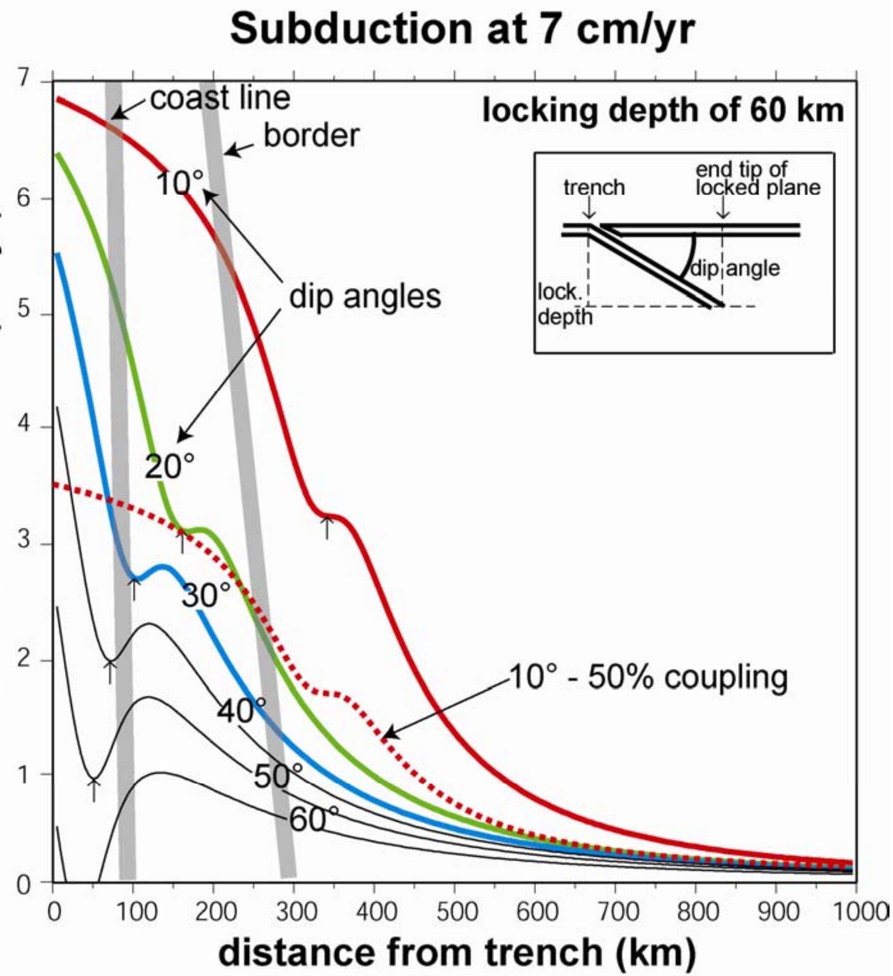
We find a very large deformation area (> 500 km) because the dipping angle is only 22°

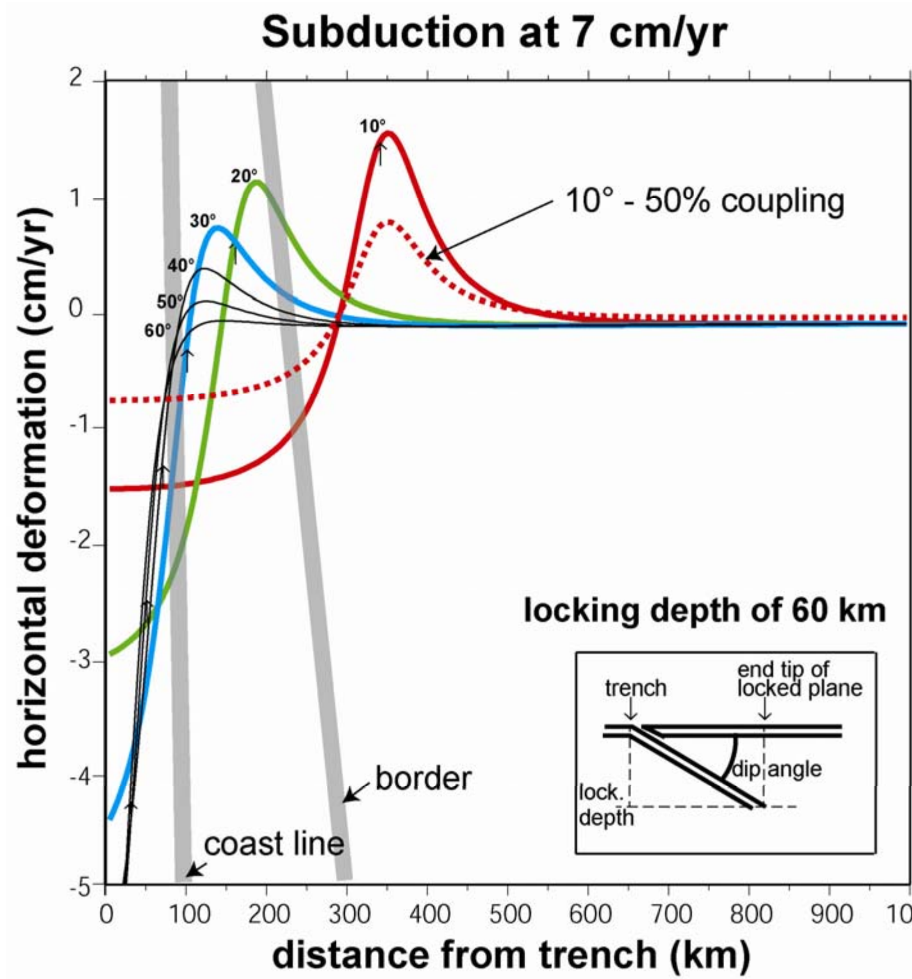
With oblique slip we predict the surface vector will start to rotate above the end-tip of the subduction plane

The profile of the velocity component // to the convergence shows a "plateau" at this location

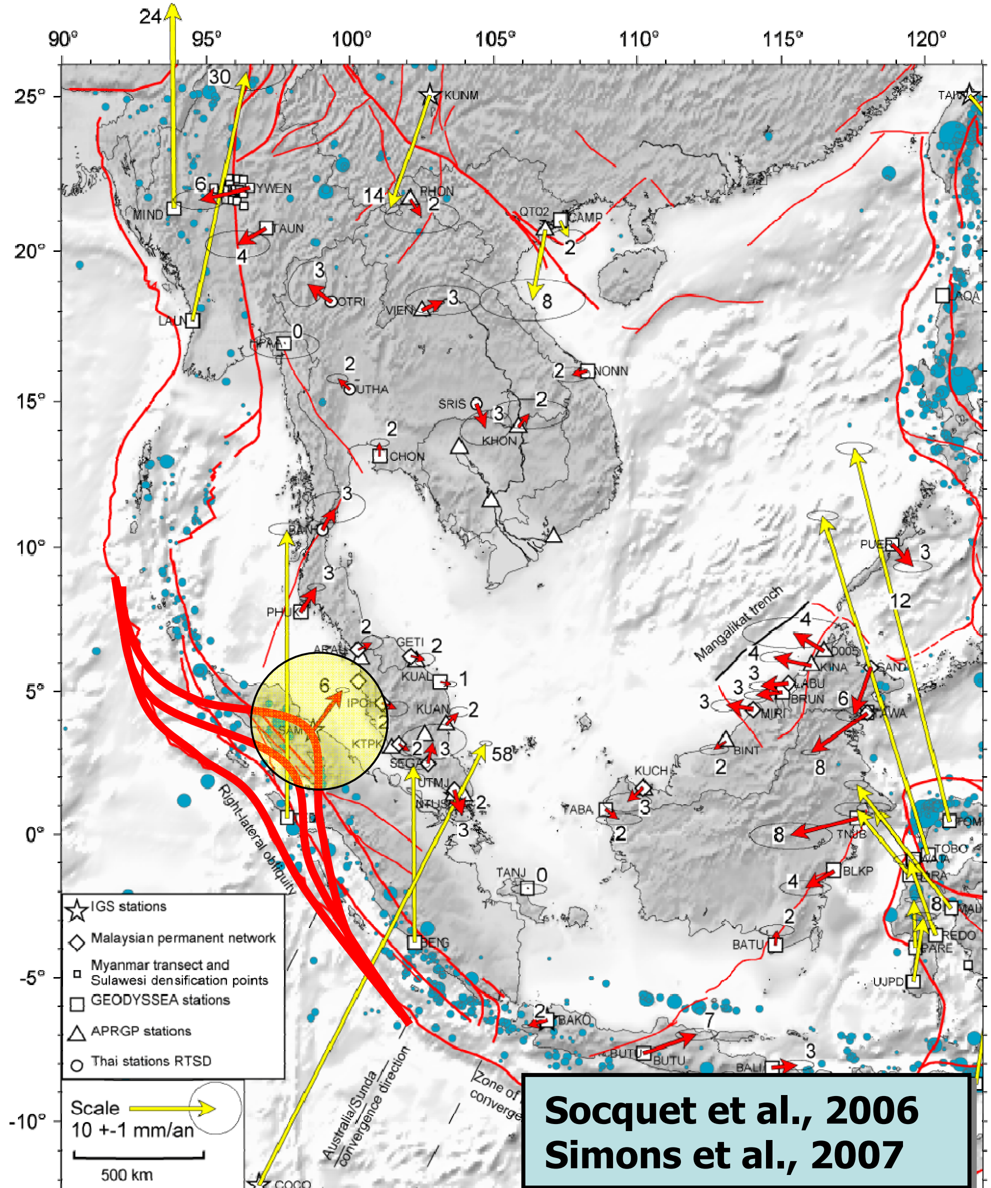
Subduction at 7 cm/yr




Subduction at 7 cm/yr
coast line
border
locking depth of 60 km
trench
end tip of locked plane
dip angle
lock. depth
10°
20°
30°
40°
50°
60°
dip angles
10° - 50% coupling
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
distance from trench (km)


Subduction at 7 cm/yr
10°
20°
30°
40°
50°
60°
10° - 50% coupling
locking depth of 60 km
trench
end tip of locked plane
dip angle
lock. depth
border
coast line
horizontal deformation (cm/yr)
2
1
0
-1
-2
-3
-4
-5
0
100
200
300
400
500
600
700
800
900
distance from trench (km)

Couplage elastique subduction Sumatra



An earthquake in this region was inevitable

GEODYSSEA

+

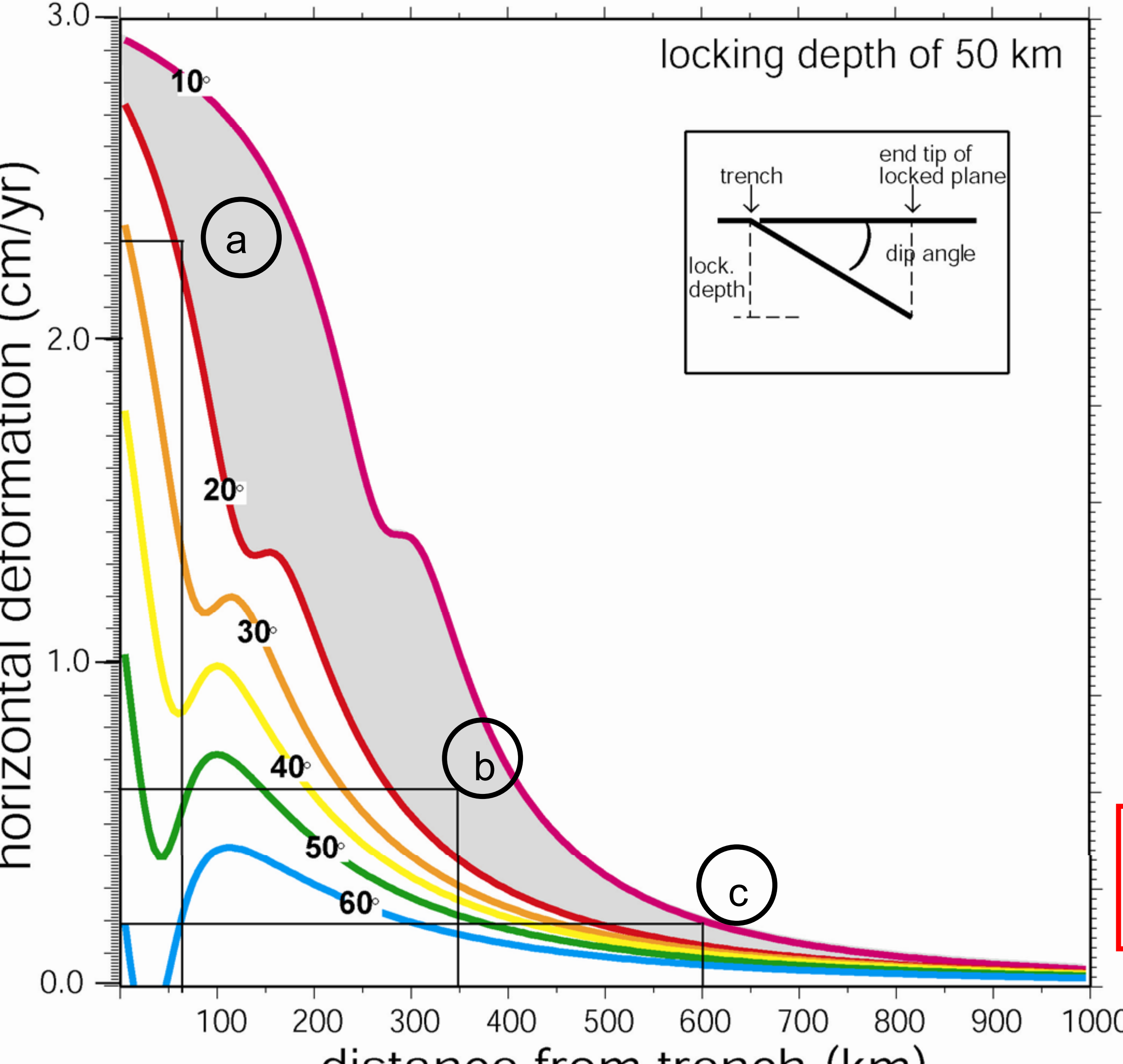
SEAMERGES

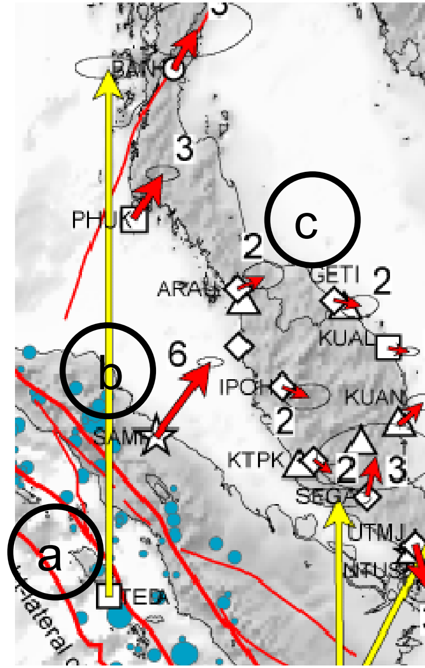
~100 sites

⇓

Deformation of Sundaland Platelet boundaries, in particular near Sumatra and Borneo

Subduction= 3 cm/yr





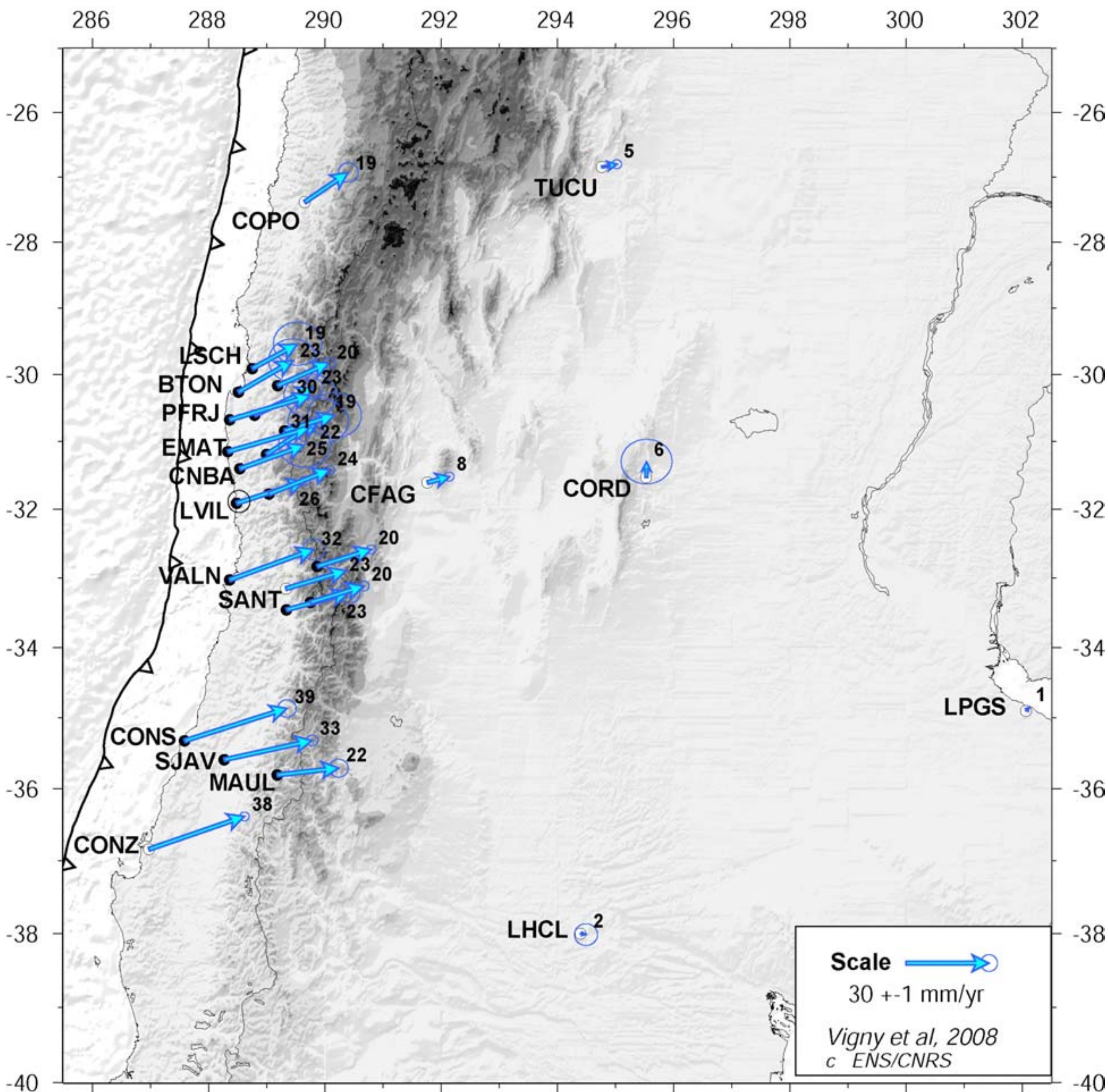
Dip ~15°

W ~200 km°

200km x 200km x 3m

= **Mw 8 every 100 yr**

GPS measures deformation of SAmerica

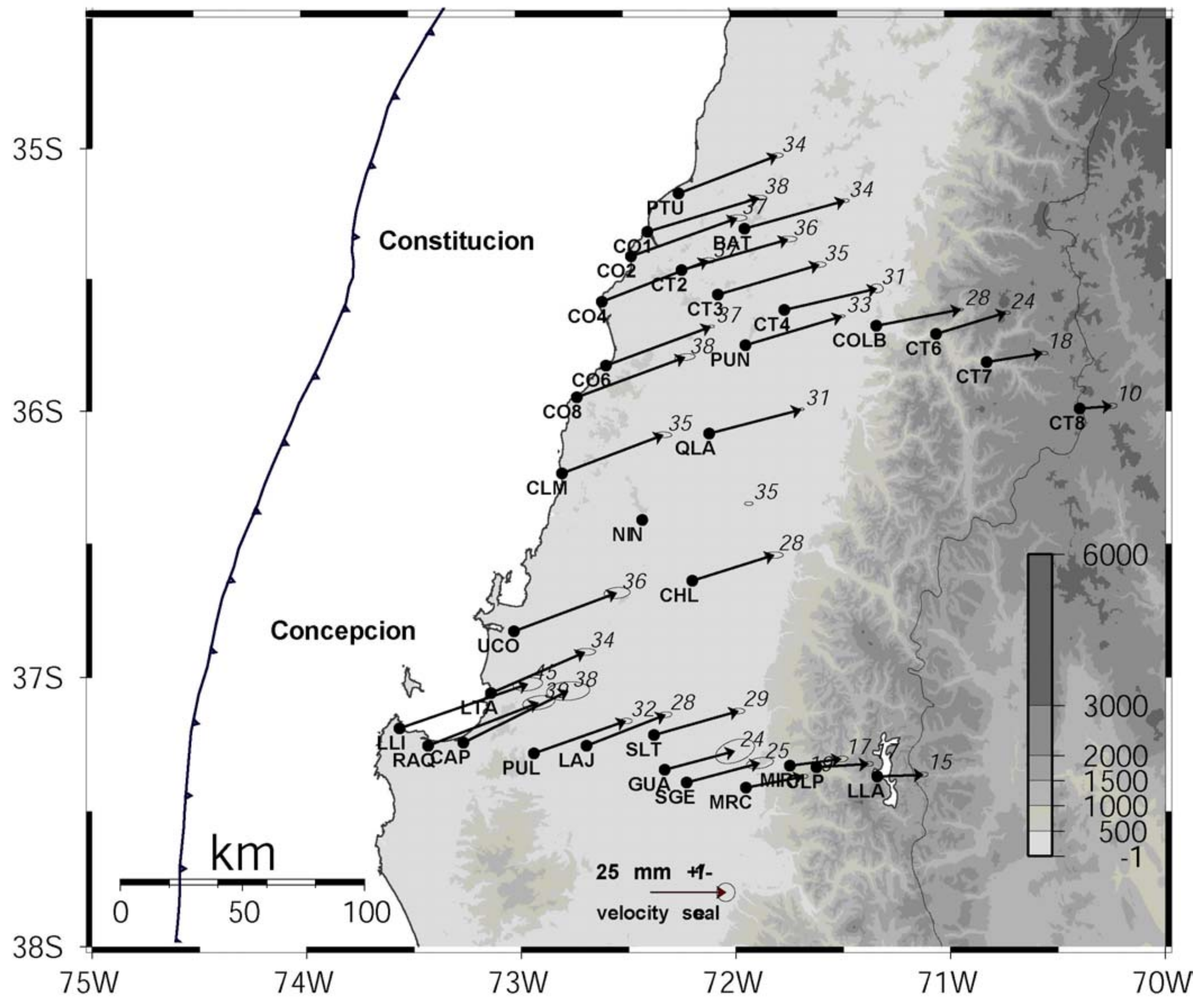


Deformation (elastic def. induced by coupling on the subduction) is visible in Chile

And

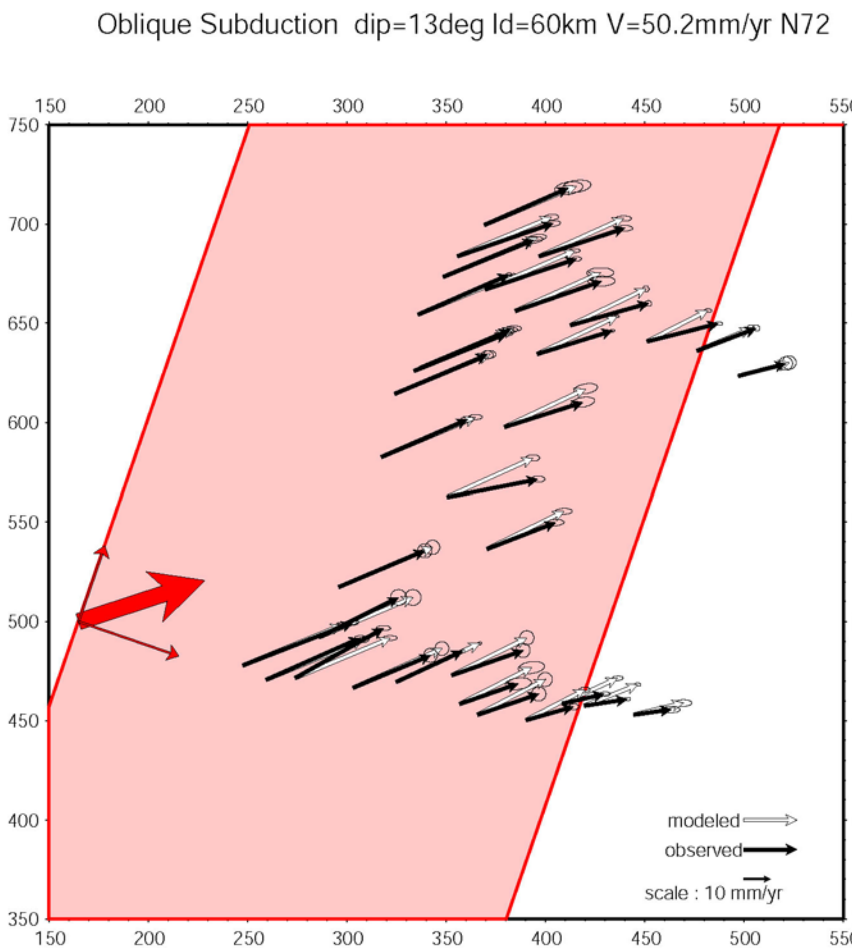
reaches far inland: TUCU (Tucuman) and CFAG (Coronel Fontana) in Argentina show deformation more than 400 km away from the trench

Zoom along high density profiles in Concepcion/Constitucion area

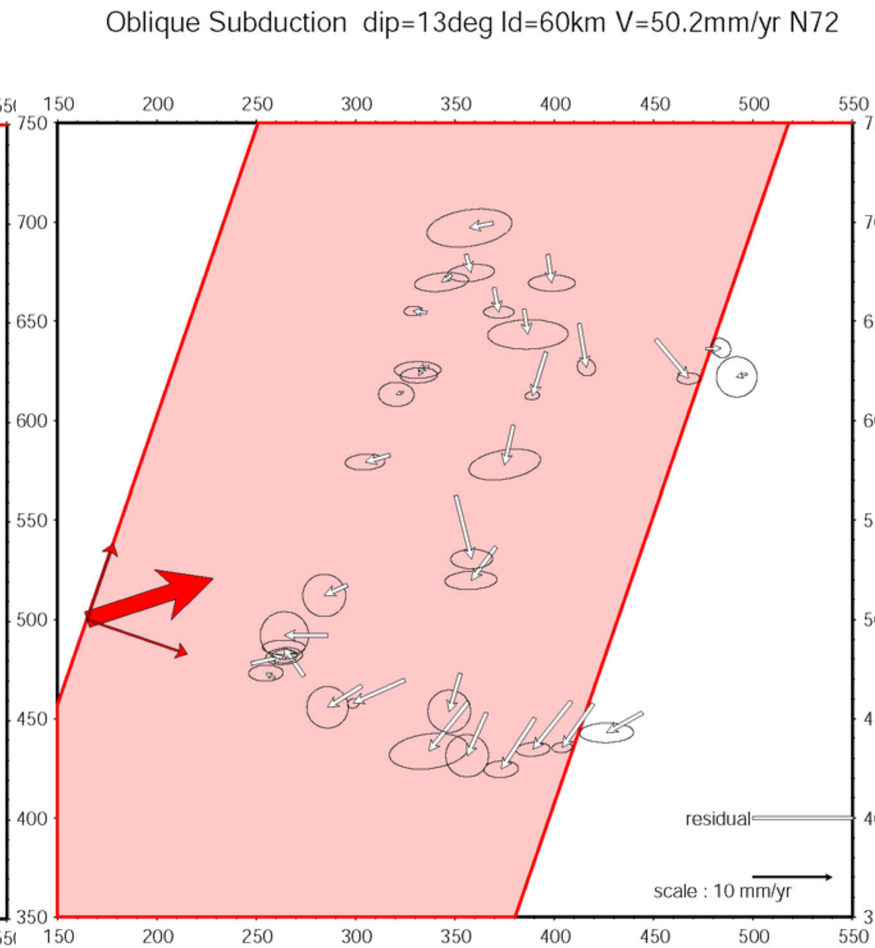


As expected from elastic coupling, velocities **decrease** Eastward (from 35-45 mm/yr along the coast to 10-15 mm/yr at the cordillera) and vector directions **rotate** from a direction // to plate convergence to East-West trending.

Subduction parameter adjustments

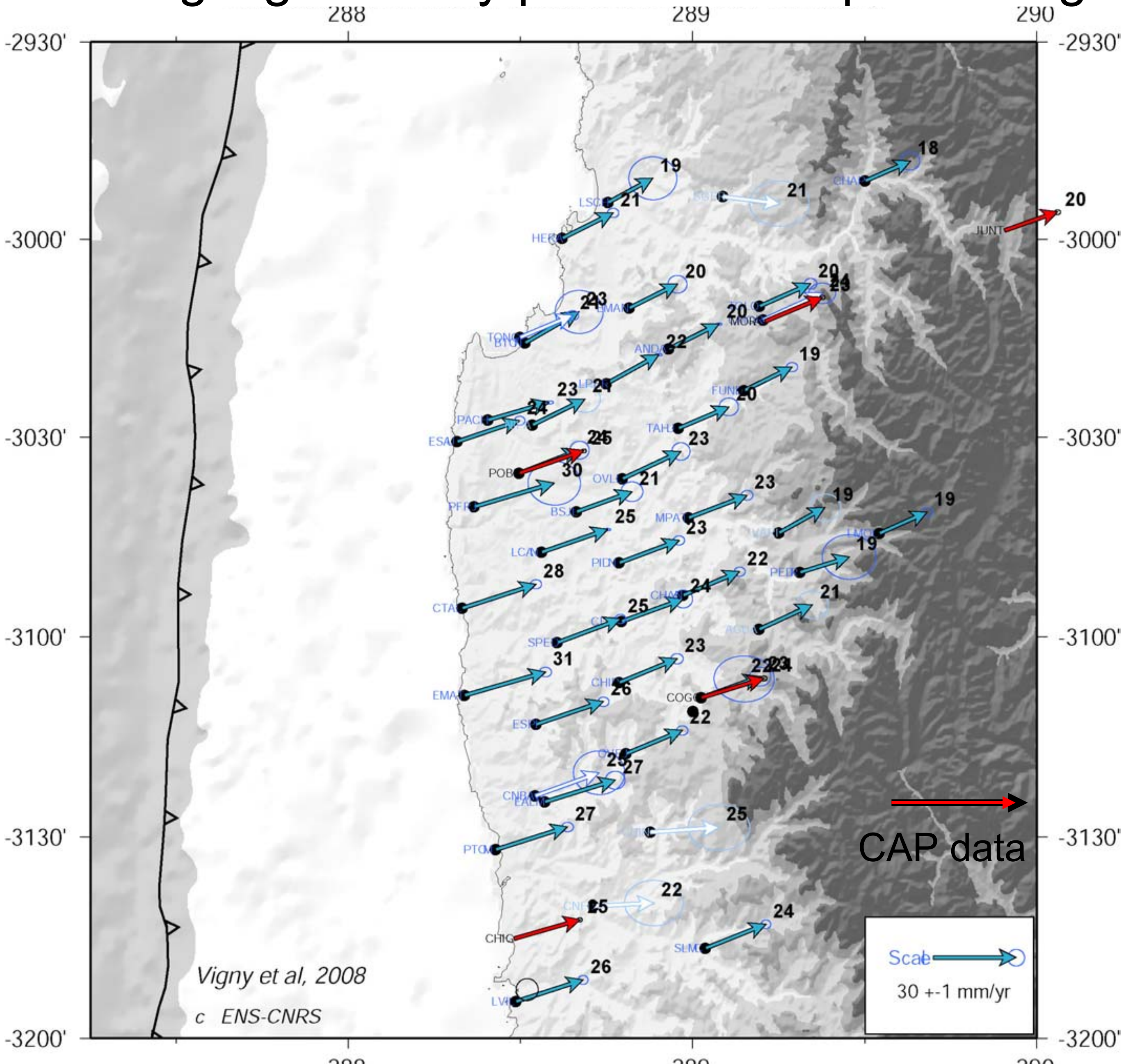


Model and data



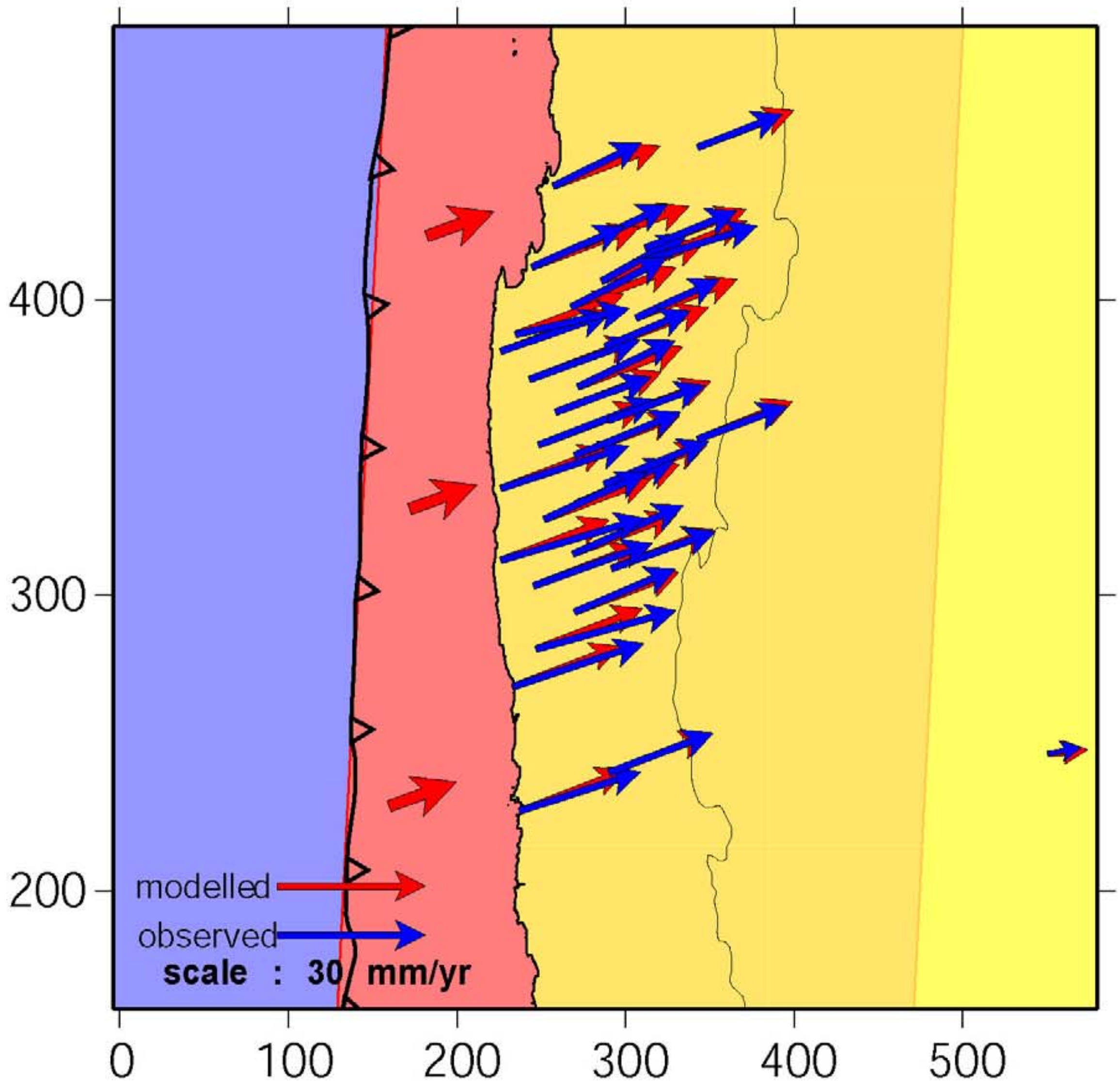
Residuals

Zoom along high density profiles in Coquimbo region



Patial coupling model

observed/modelled Velocities



model parameters

Subduction strike: 5°N

Dislocation strike: 71°N

Locking Depth: 60 km

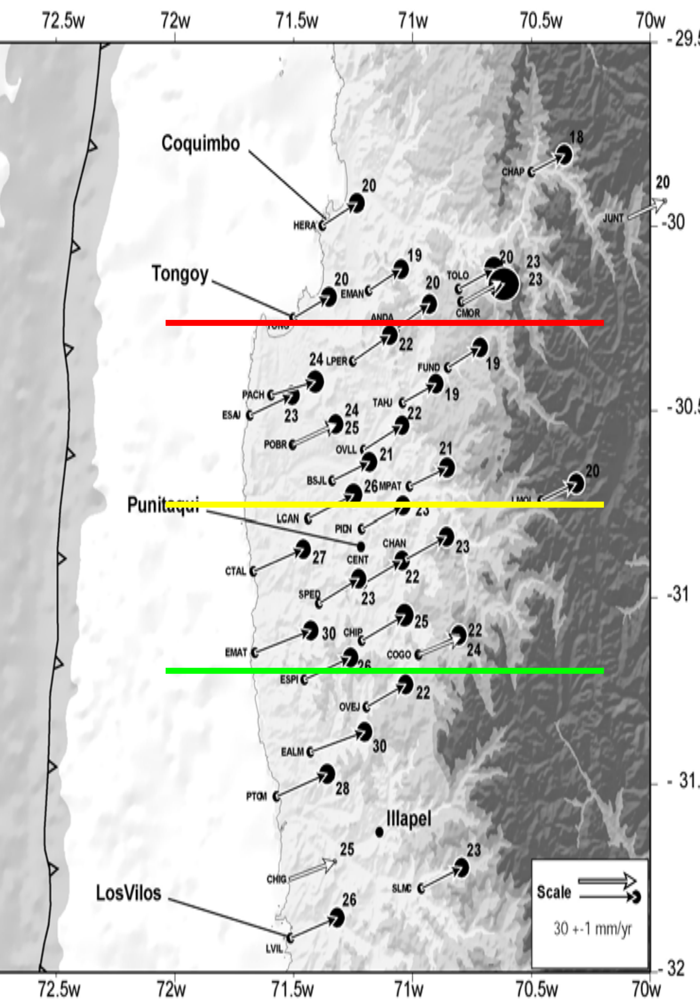
Plane Dip: 10°

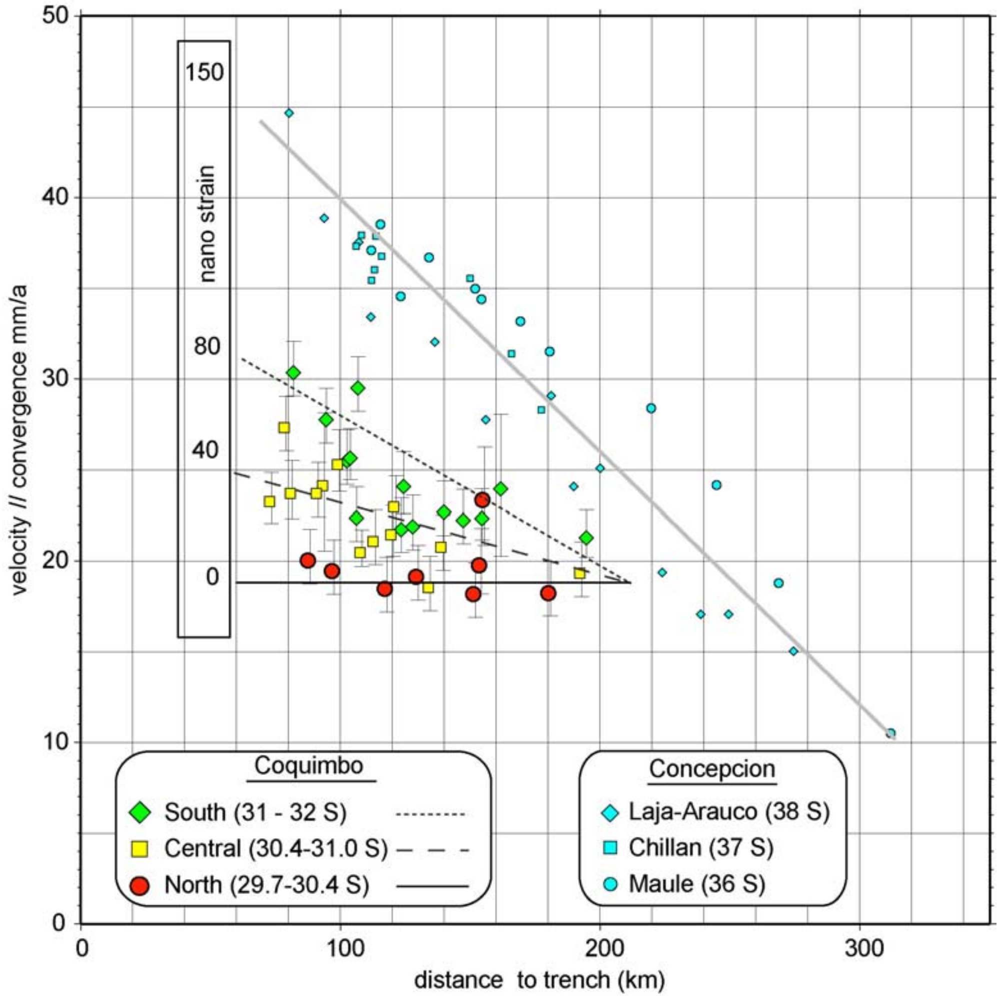
Slip: 27 mm/yr

(41% coupling)

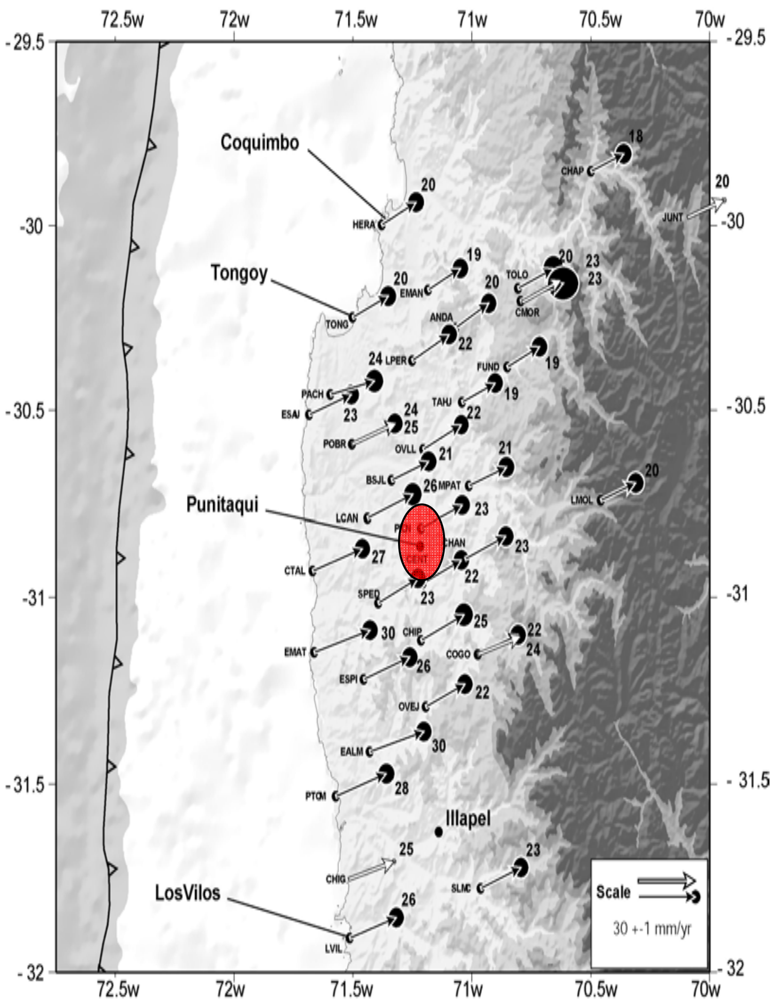
mean residual
2.6 mm/yr
over 34 points

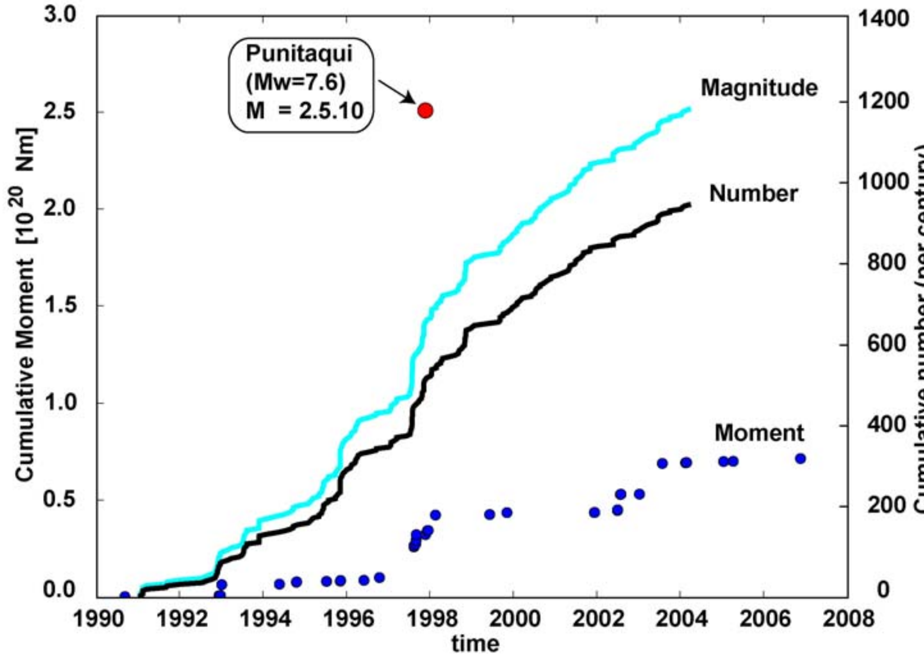
Along strike comparison

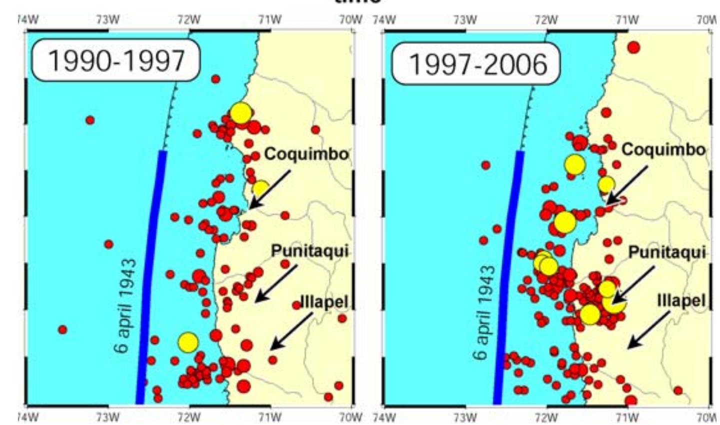




Seismicity after Punatiqui 15-oct-1997 Mw7.3 (**slab push**)

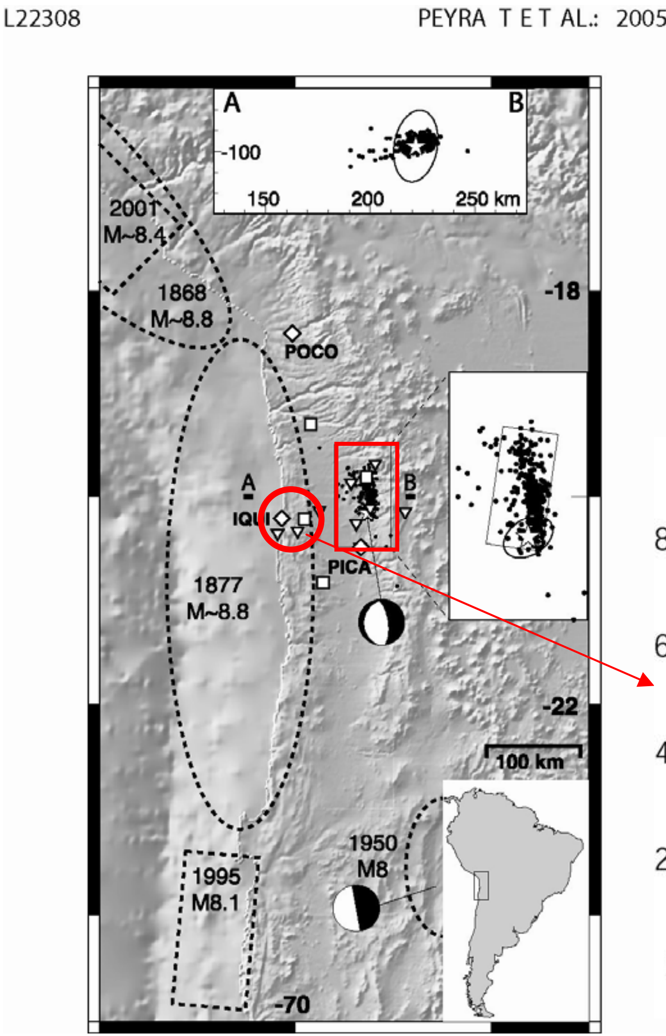


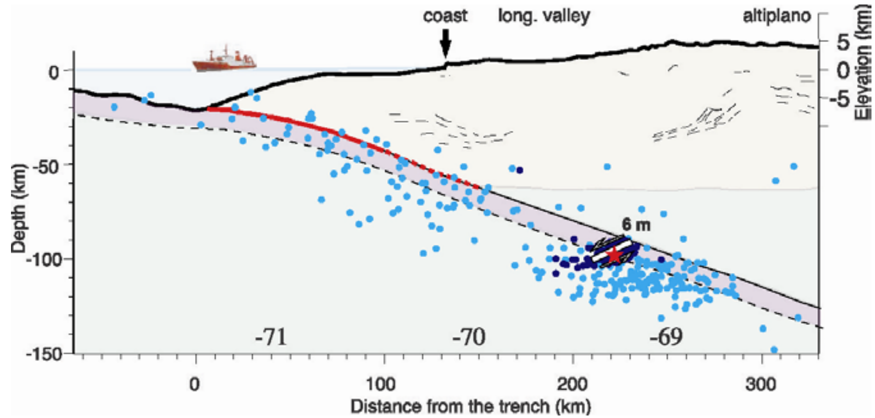


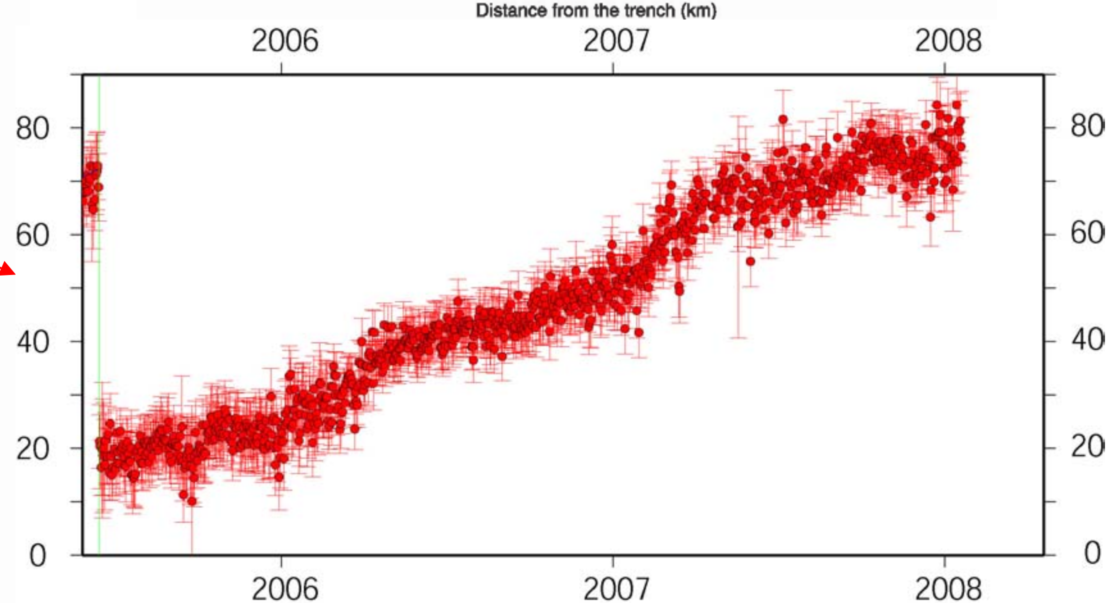


UAPF after Tarapaca Eq.   Mw7.7 13-june-2005 (**slab pull**)

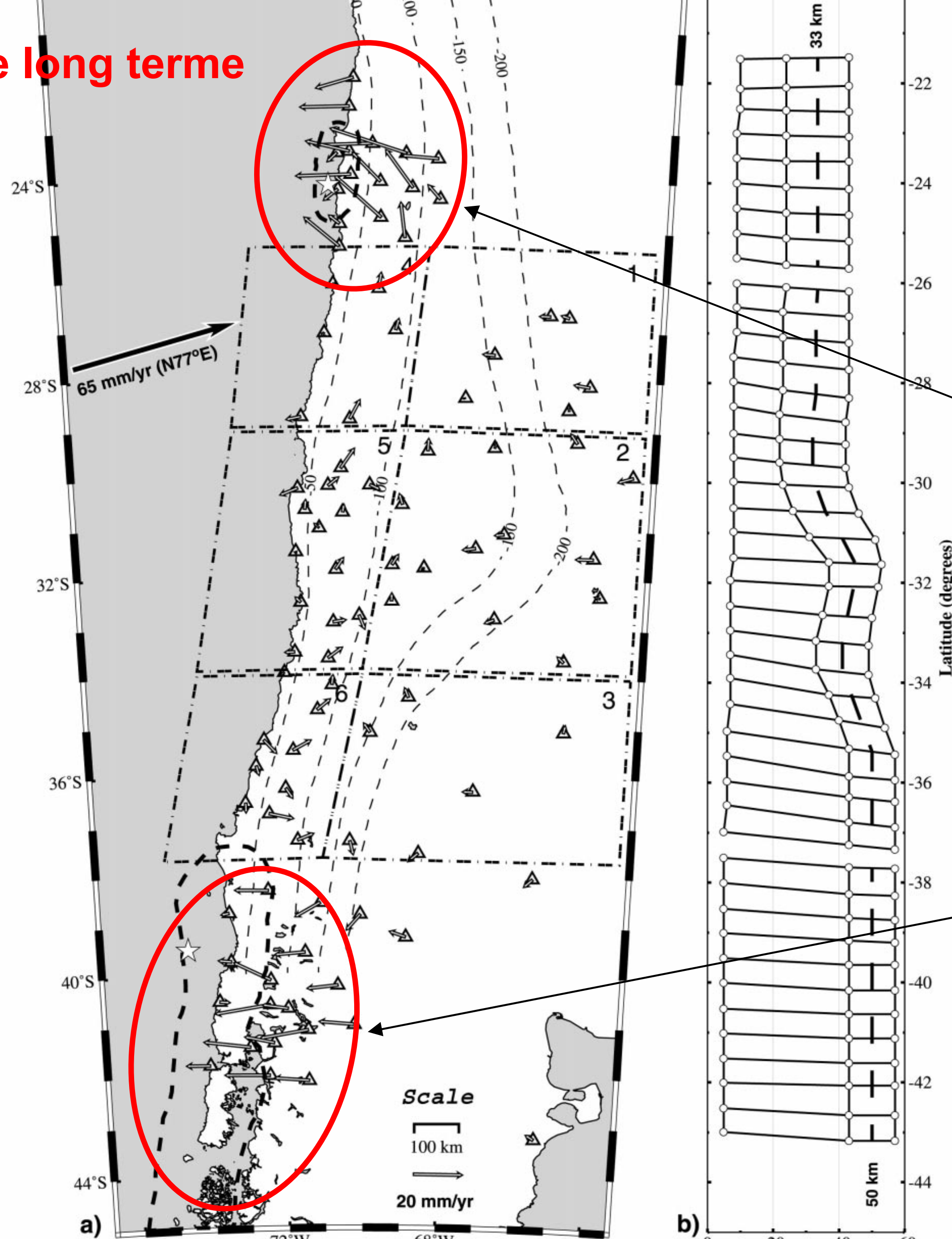
Peyrat et al., *GRL*, 2006







Post-sismique long terme



d'Antofagasta (Mw=8, 1995)

Post-seismic (10 years)

Valdivia (Mw=9.5, 1960)

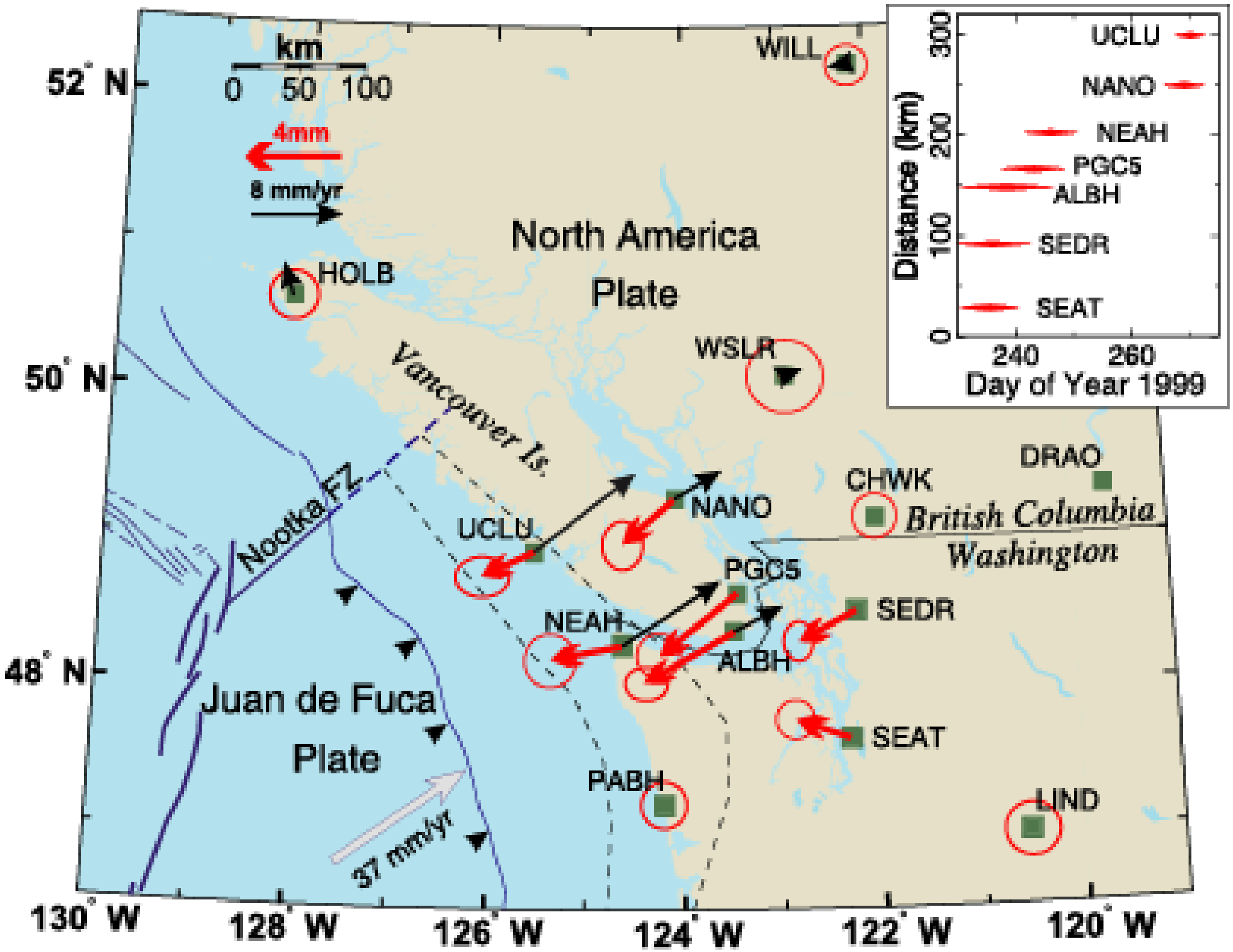
Post-seismic (50 years)

Klotz et al., 2001

Short term transients

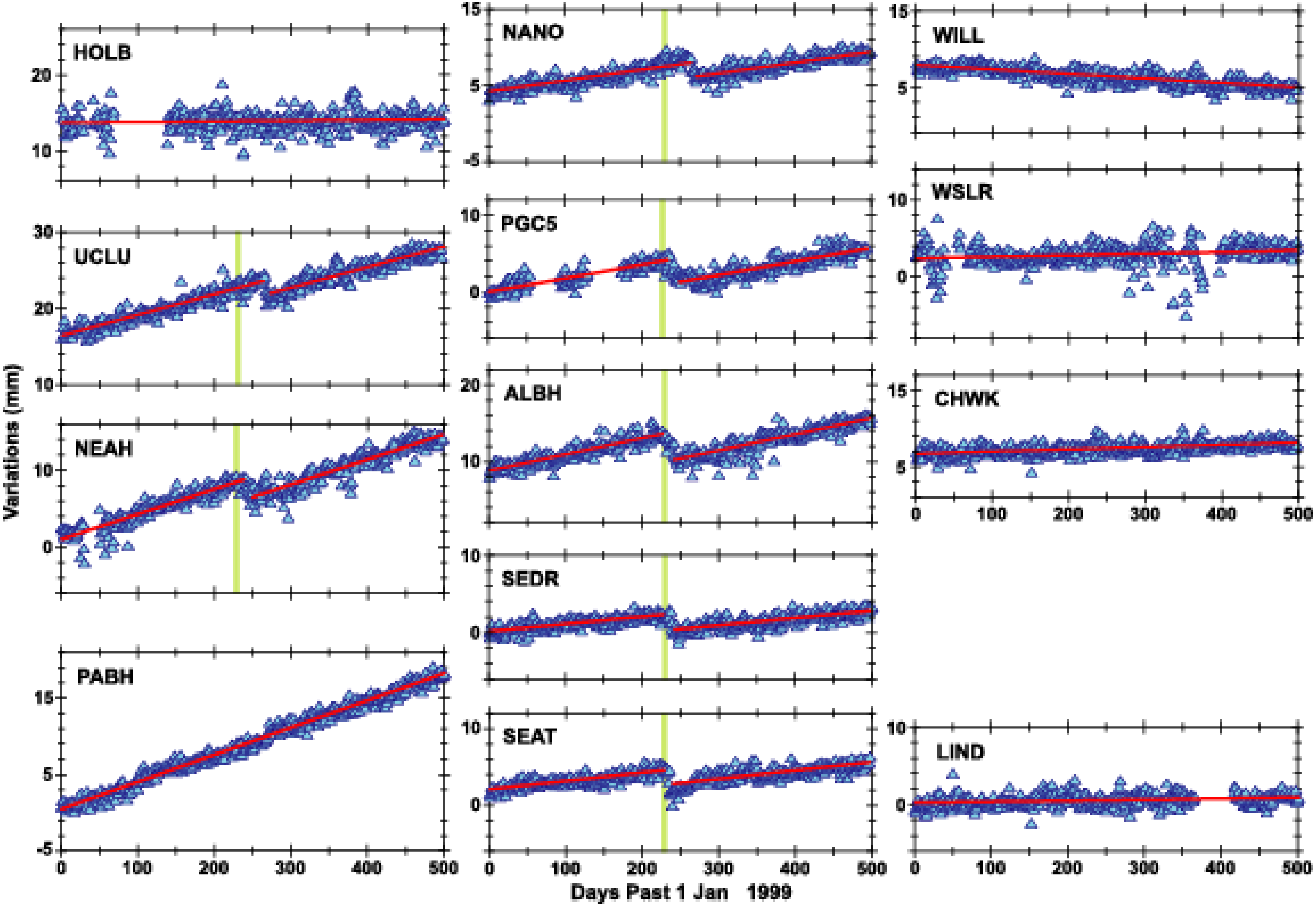
Silent slip on Cascadian subduction zone

Dragert et al., Science, 292, May 2001



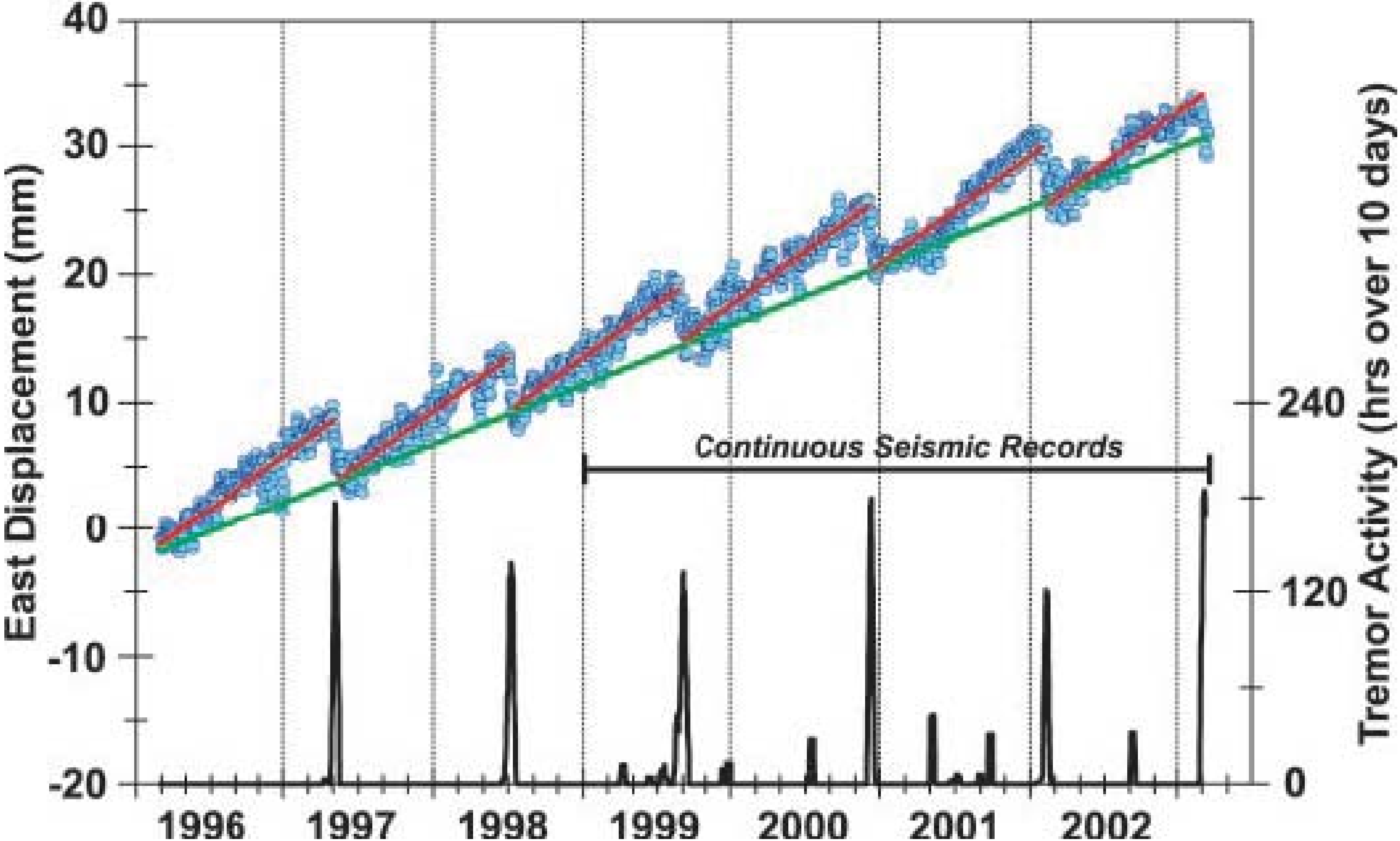
Jump in GPS stations time series

Dragert et al., Science, 292, May 2001

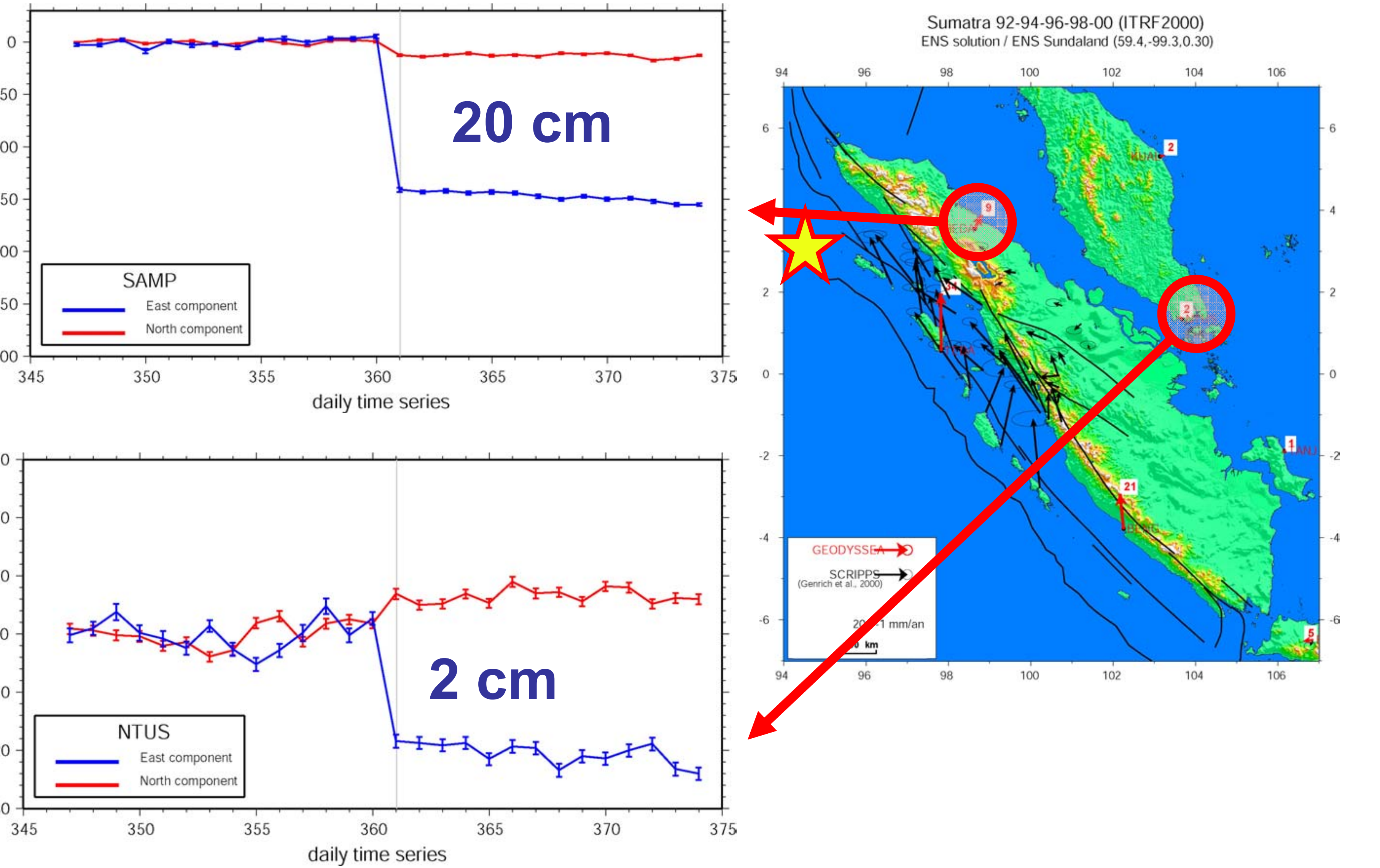


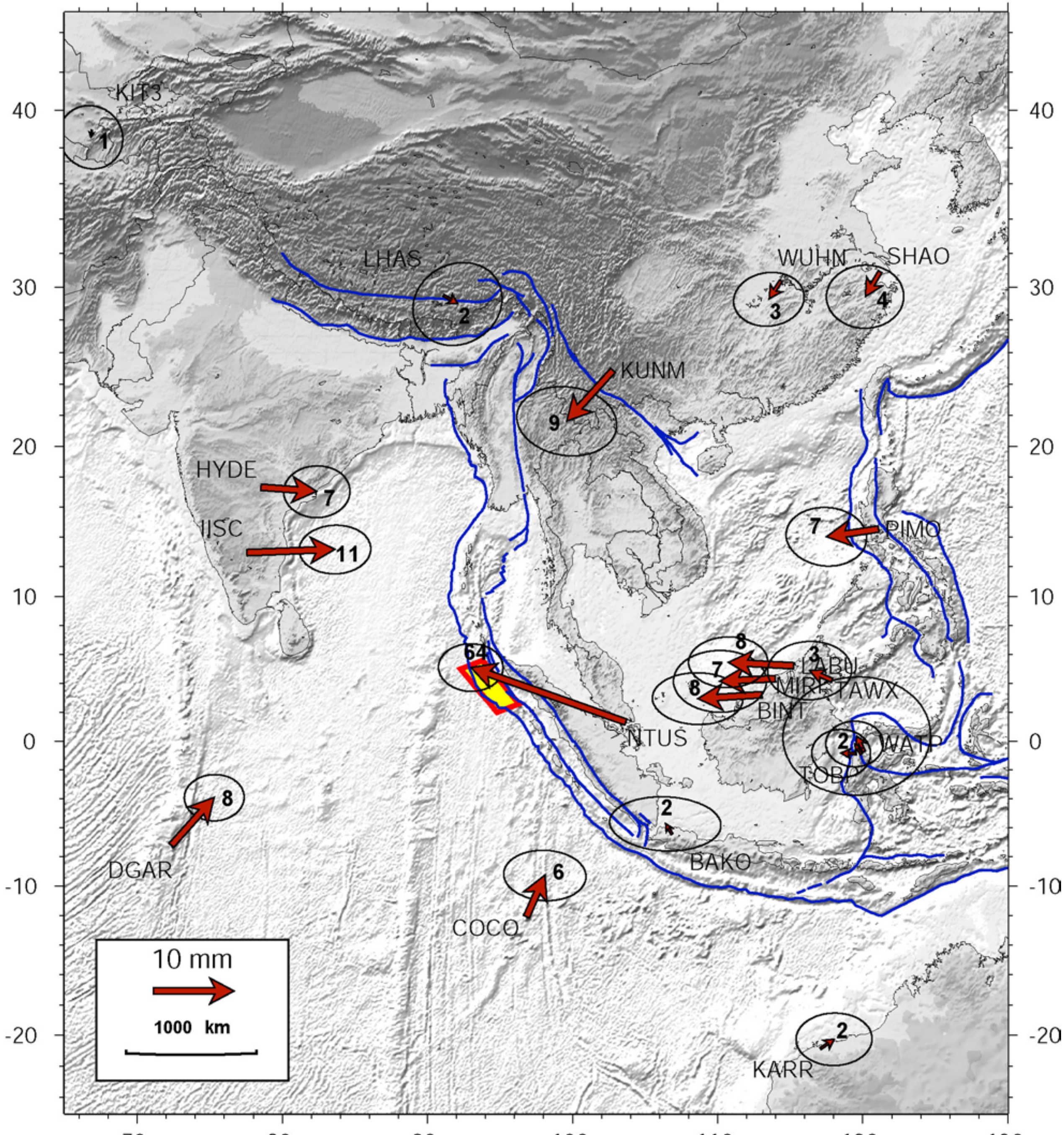
Repeated features, related to tremor

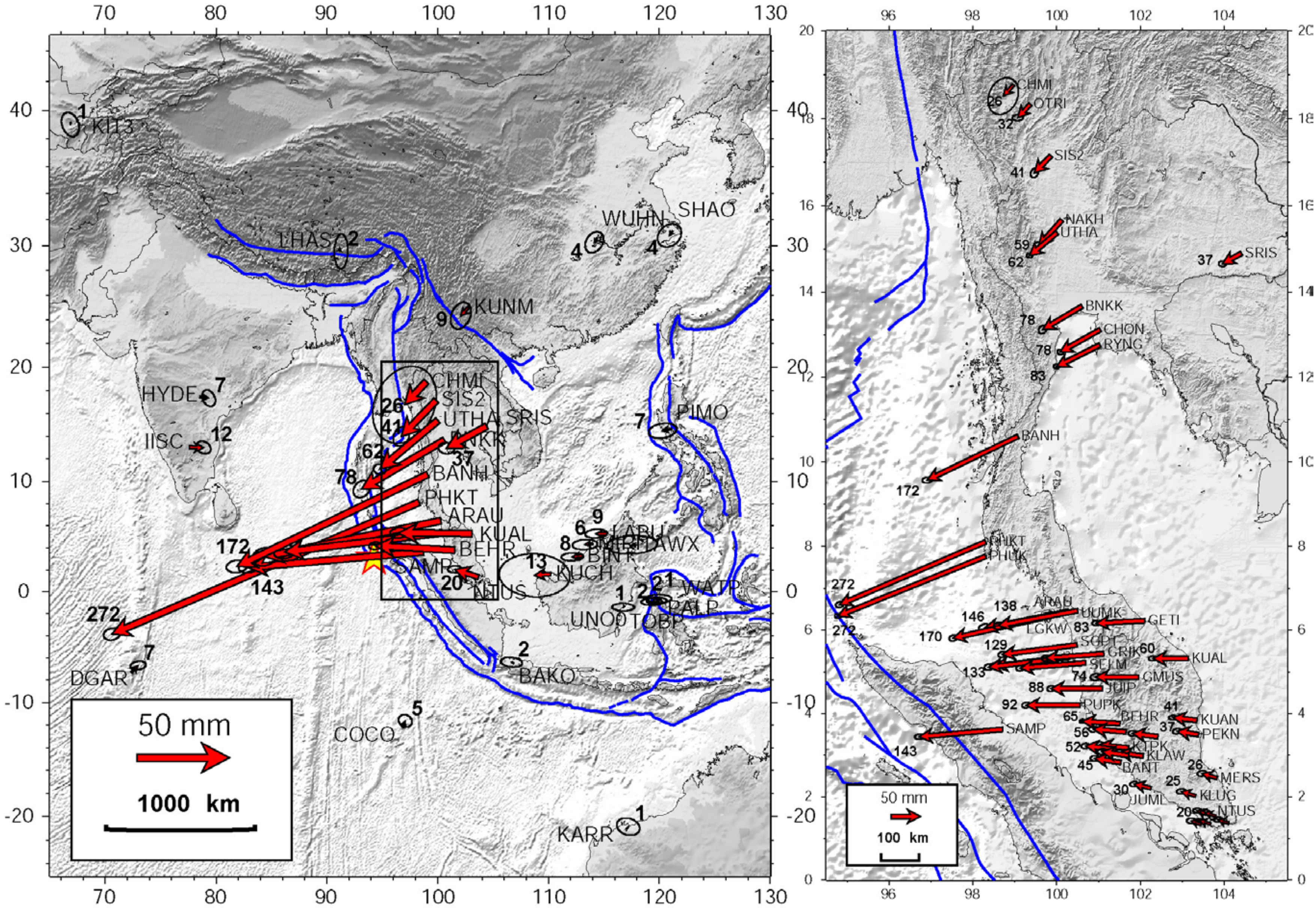
Rogers and Draggert, Science, 300, June 2003

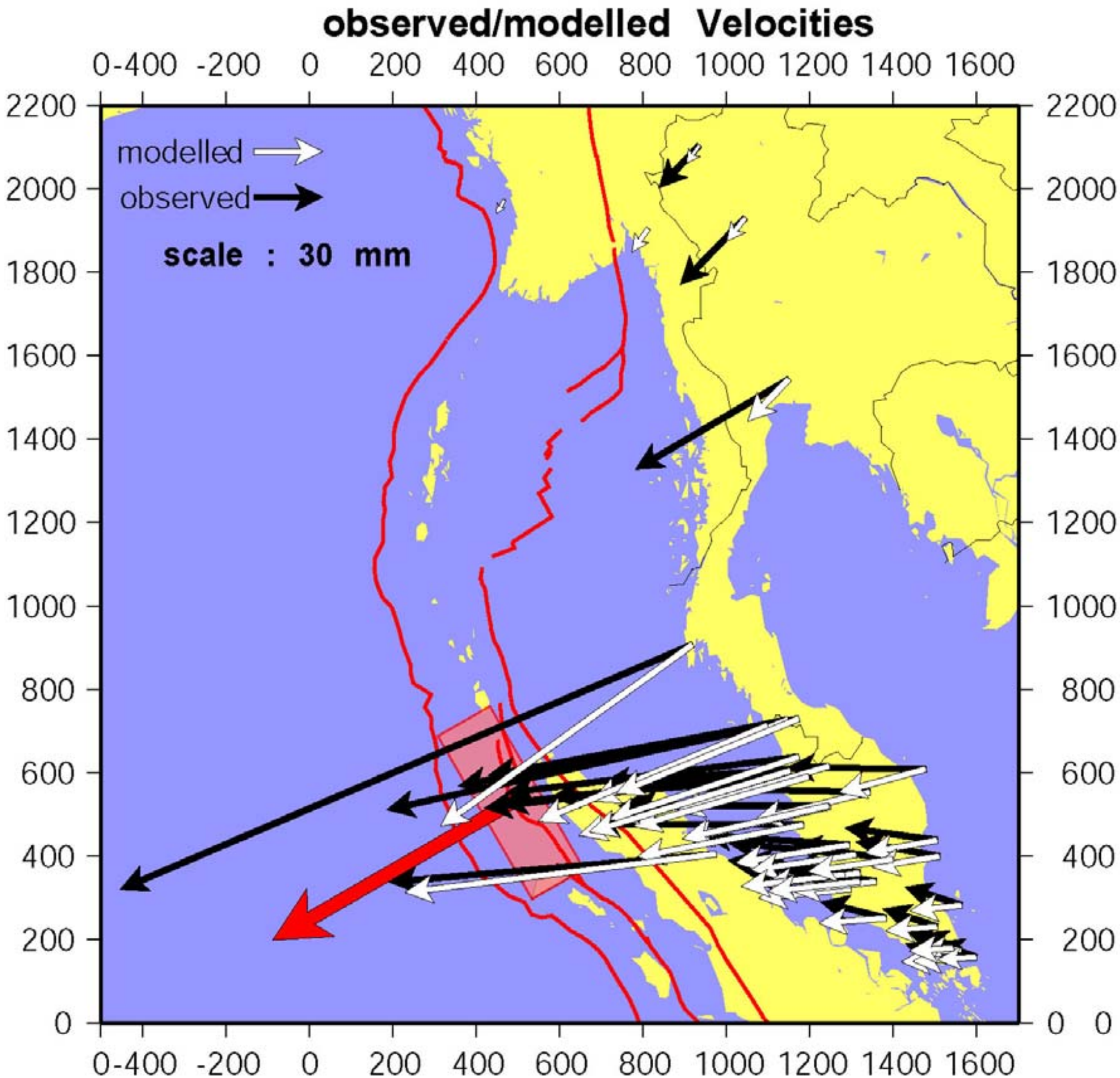


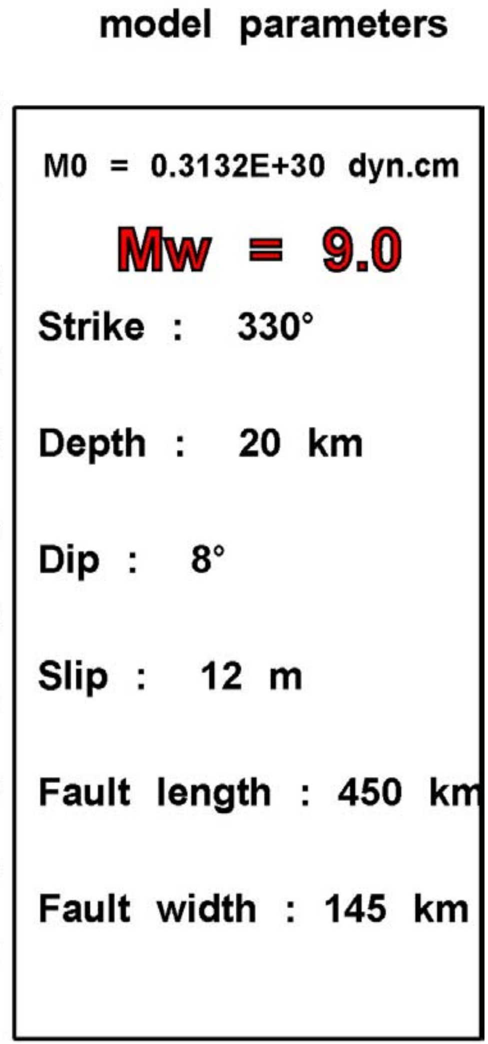
Le séisme de Sumatra du 25 décembre 2004



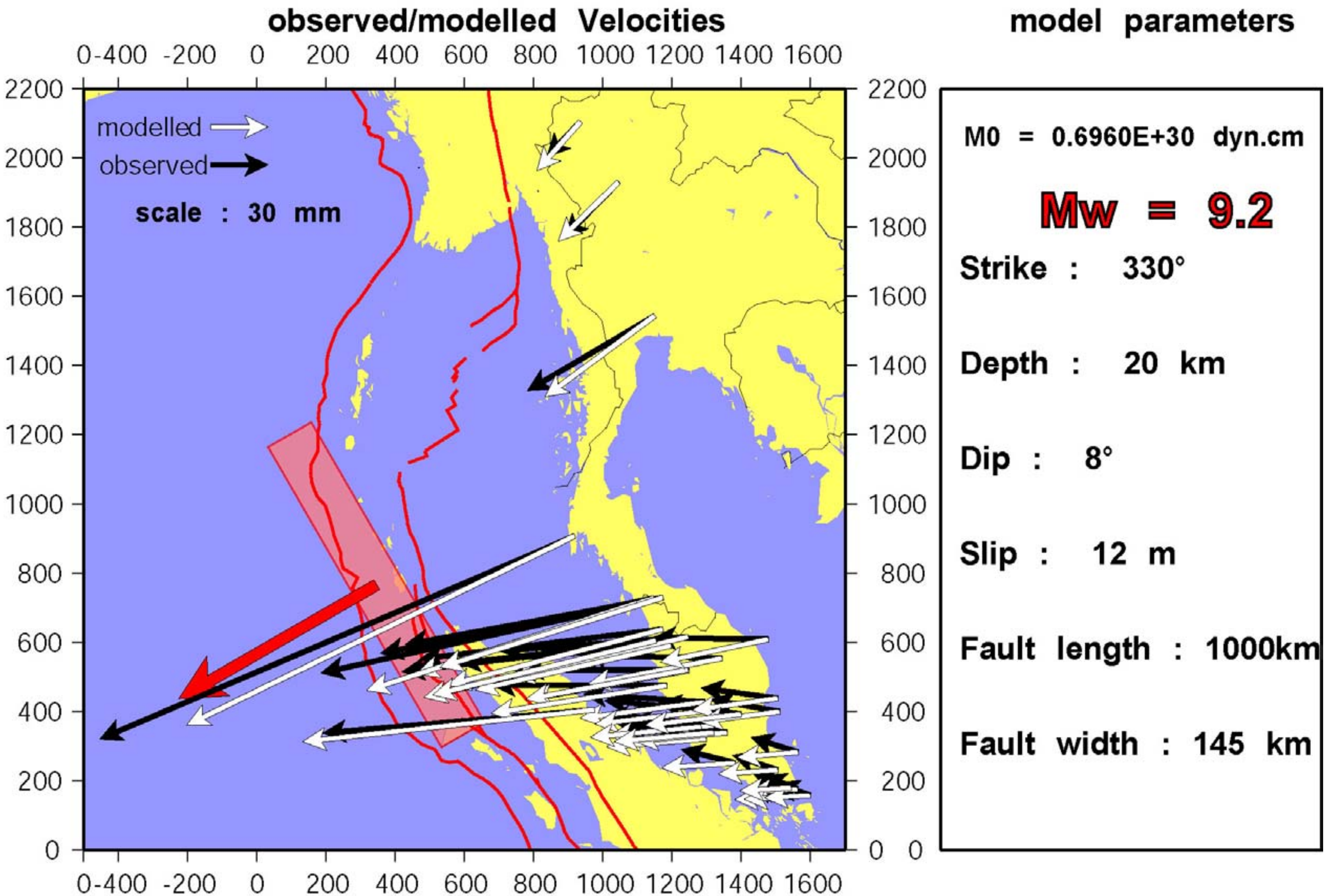

KIT3
LHAS
WUHN
SHAO
KUNM
HYDE
IISC
PIMO
LABU
MIRI
TAWX
BINT
NTUS
WATP
TOBI
BAKO
DGAR
COCO
KARR
10 mm
1000 km
40
30
20
10
0
-10
-20


KIT3
LHAS
WUHN
SHAO
KUNM
HYDE
IISC
CHMI
SIS2
UTHA
SRIS
BNKK
BANH
PHKT
ARAU
KUAL
BEHR
SAMP
NTUS
KUCH
LABU
BINT
TAWX
PIMO
WATP
PALP
UNOP
TOBP
BAKO
DGAR
COCO
KARR
50 mm
1000 km
OTRI
NAKH
CHON
RYNG
PHUK
UUMK
GETI
LGKW
SOPT
GRIK
SEKM
GMUS
JUIP
PUPK
KUAN
PEKN
KTPK
KLAW
BANT
MERS
KLUG
JUML
50 mm
100 km

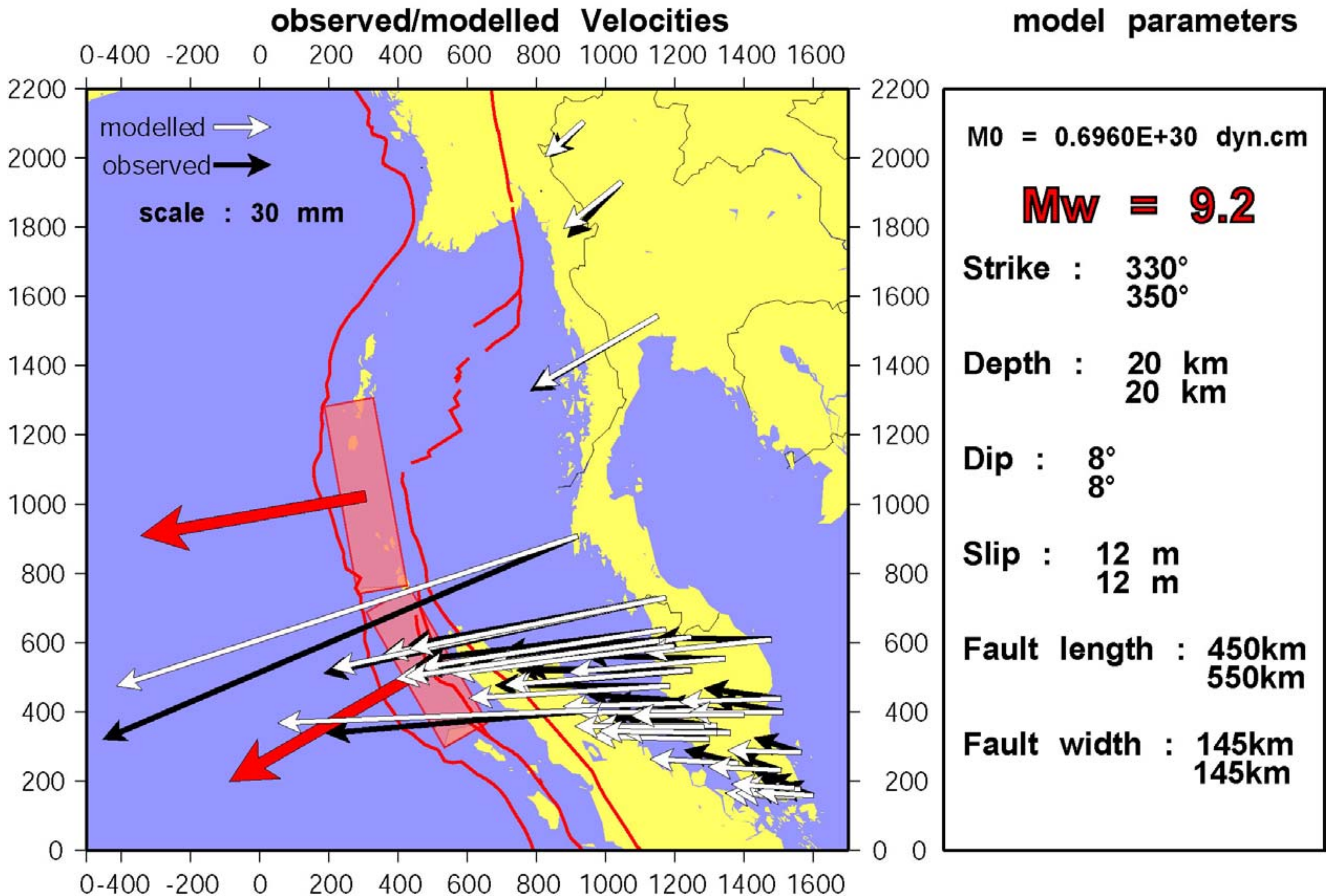




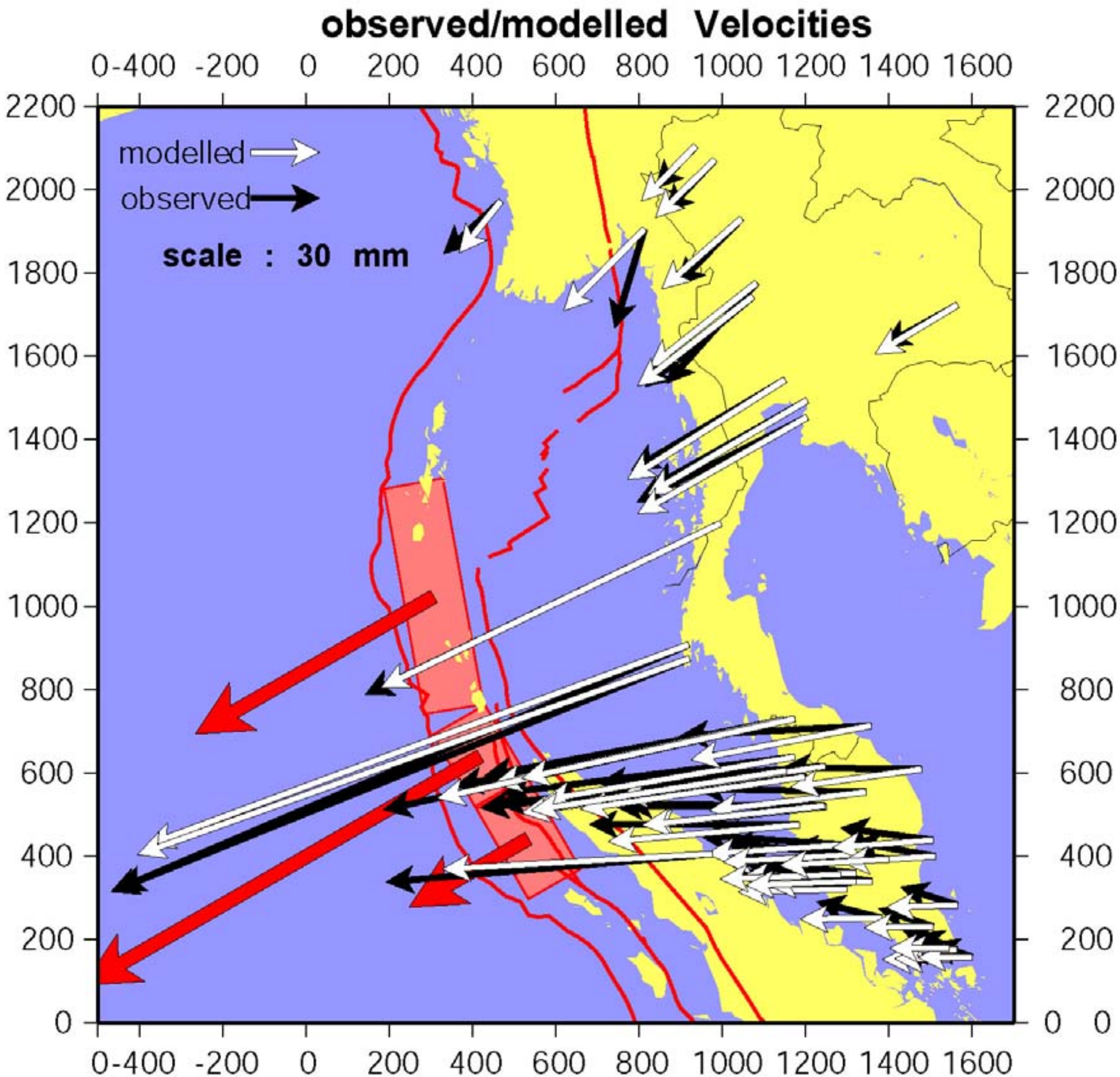
A rupture of 450 km length gives the reported magnitude (Mw=9.0) but it does not fit the observed deformation



A rupture of 1000 km length is required to fit far field deformation it corresponds to a larger magnitude Mw=9.2



Curvature of the trench must be taken into account to fit observed directions in Northern Malaysia



model parameters

M0=7.018E+29 dyn.cm

Mw = 9.2

Strike : 330° 330° 350°

Depth : 20 km 20 km 20 km

Dip : 8° 8° 8°

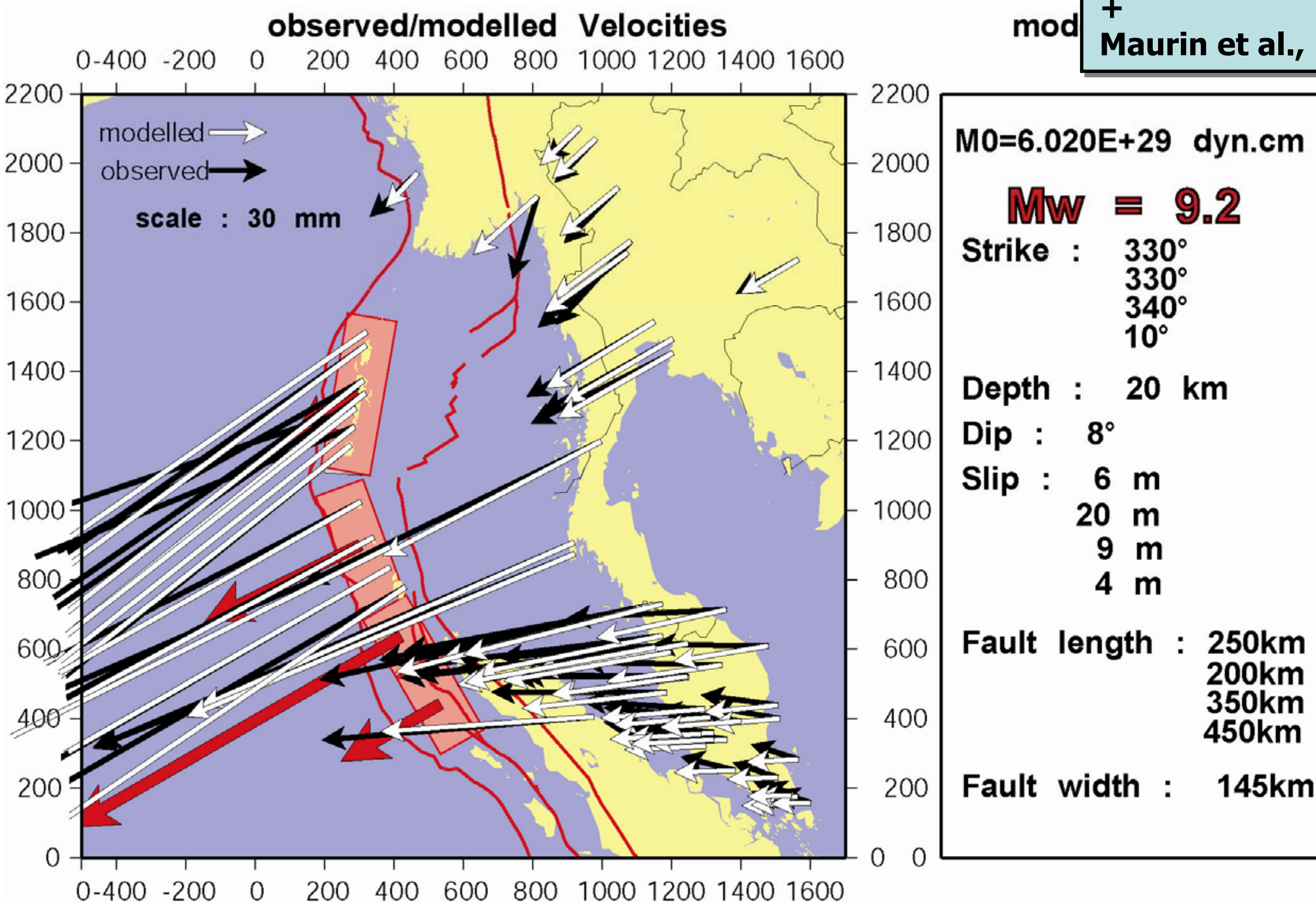
Slip : 6 m 20 m 12 m

Fault length : 250km 200km 550km

Fault width : 145km 145km 145km

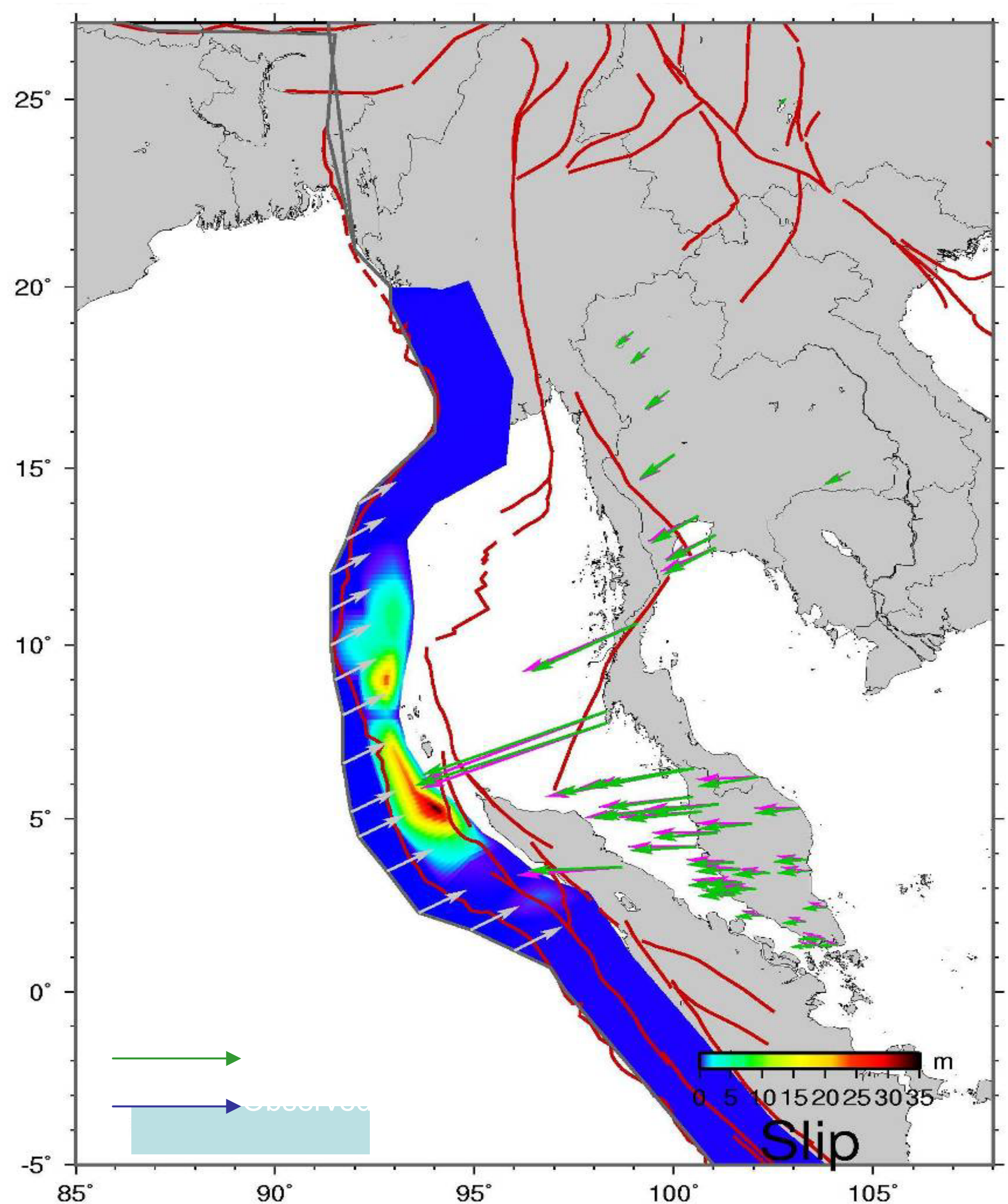
New Myanmar data can be fit with previous models, but…

Ganalaut et al., 2006
+
Maurin et al., 2006

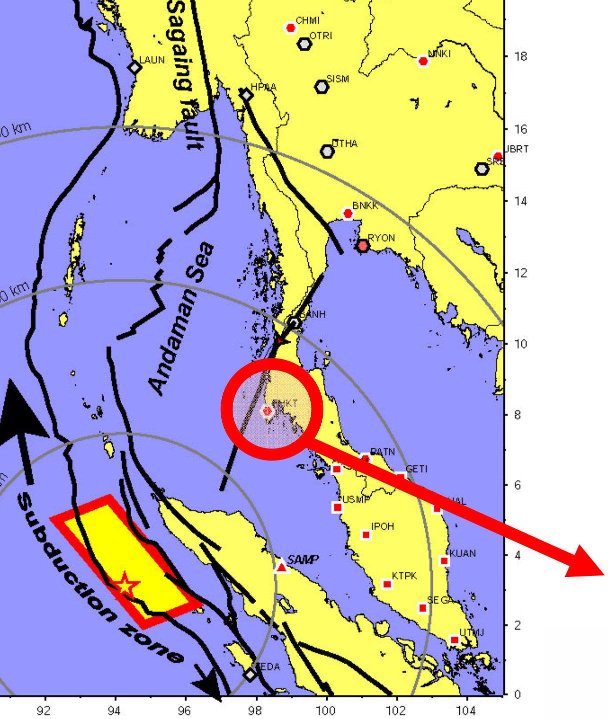


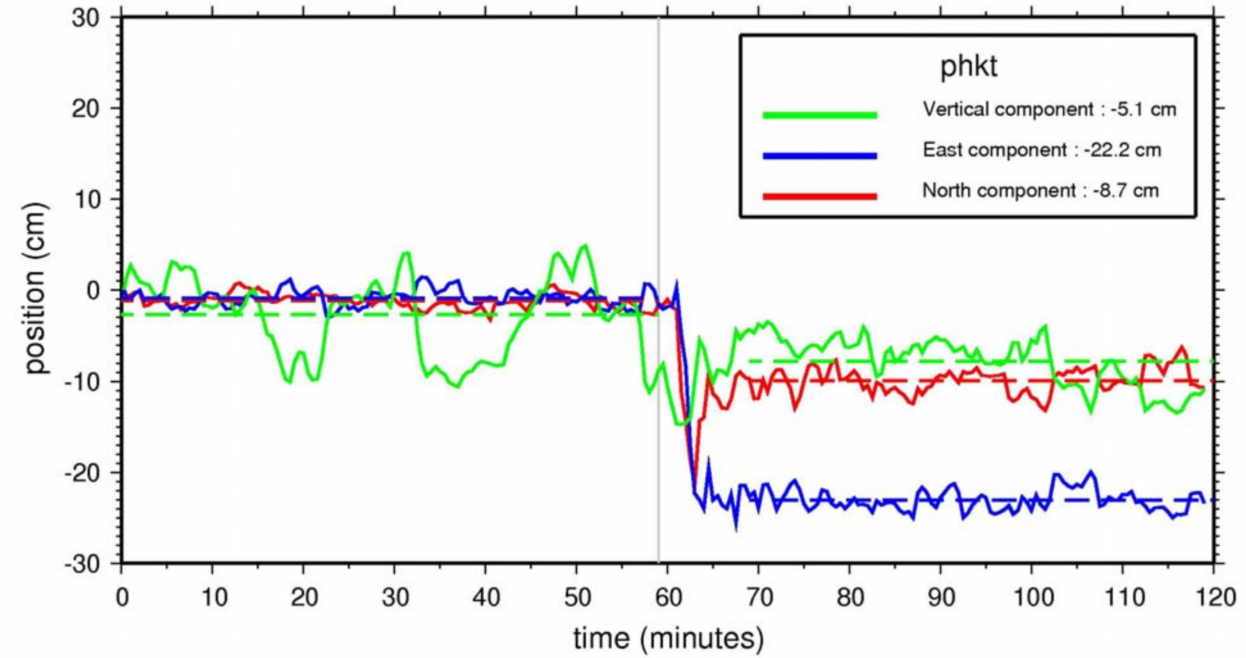
… Andaman data requires longer plane AND oblique slip

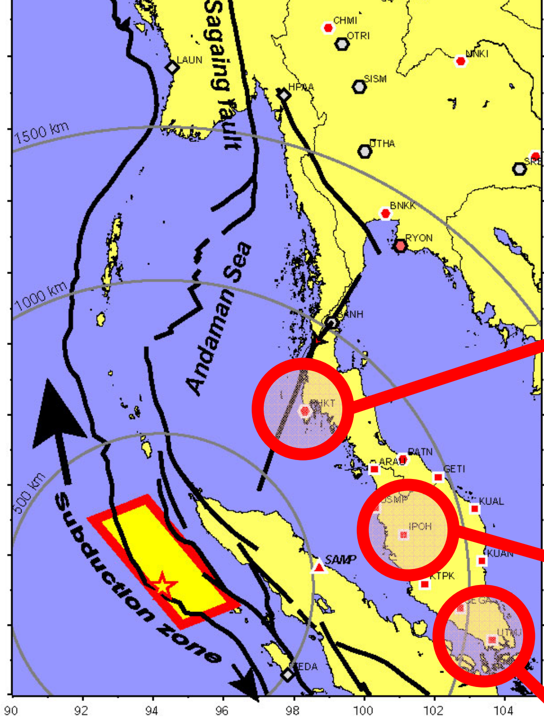
Full inversion of slip on fault

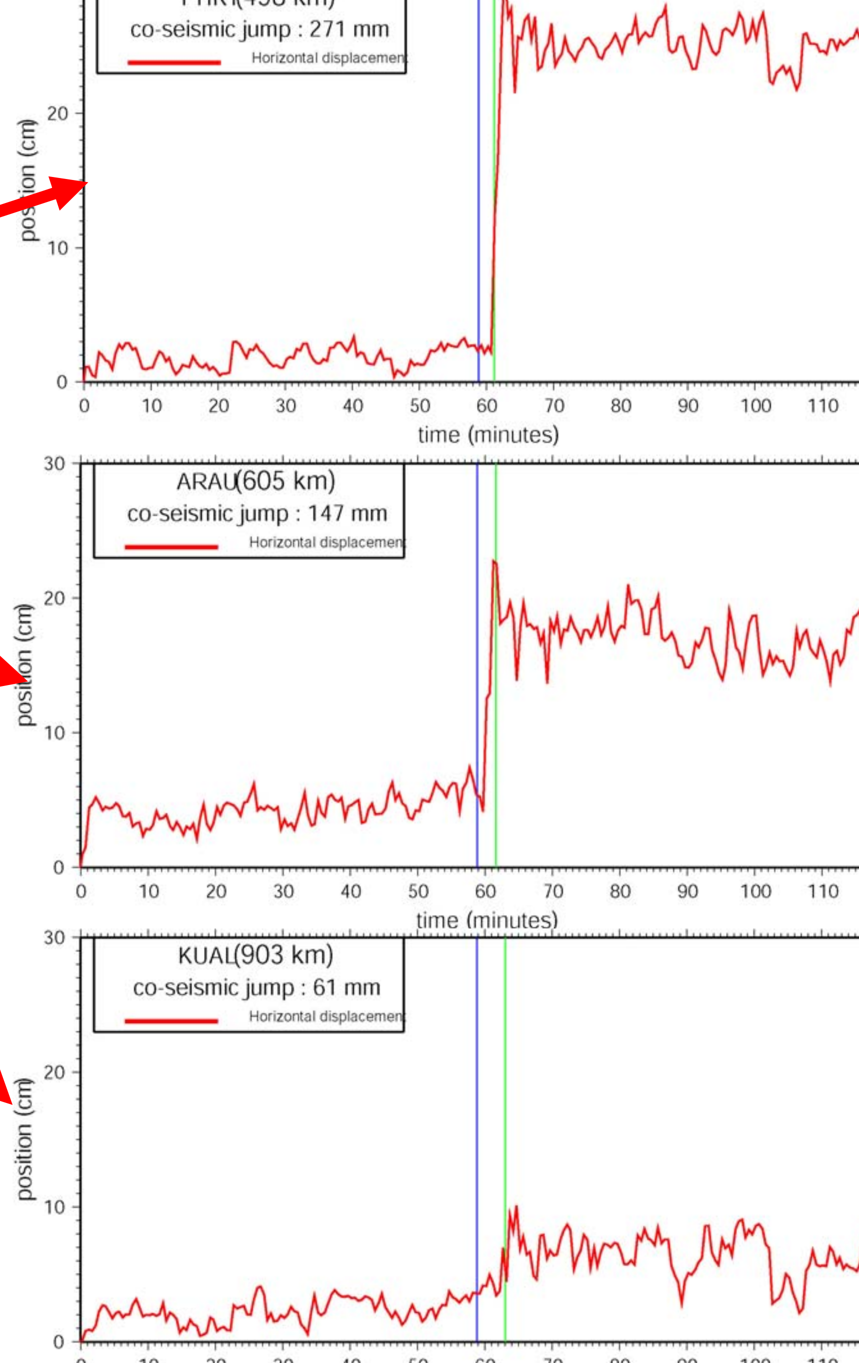


Kinematic solution at Phuket





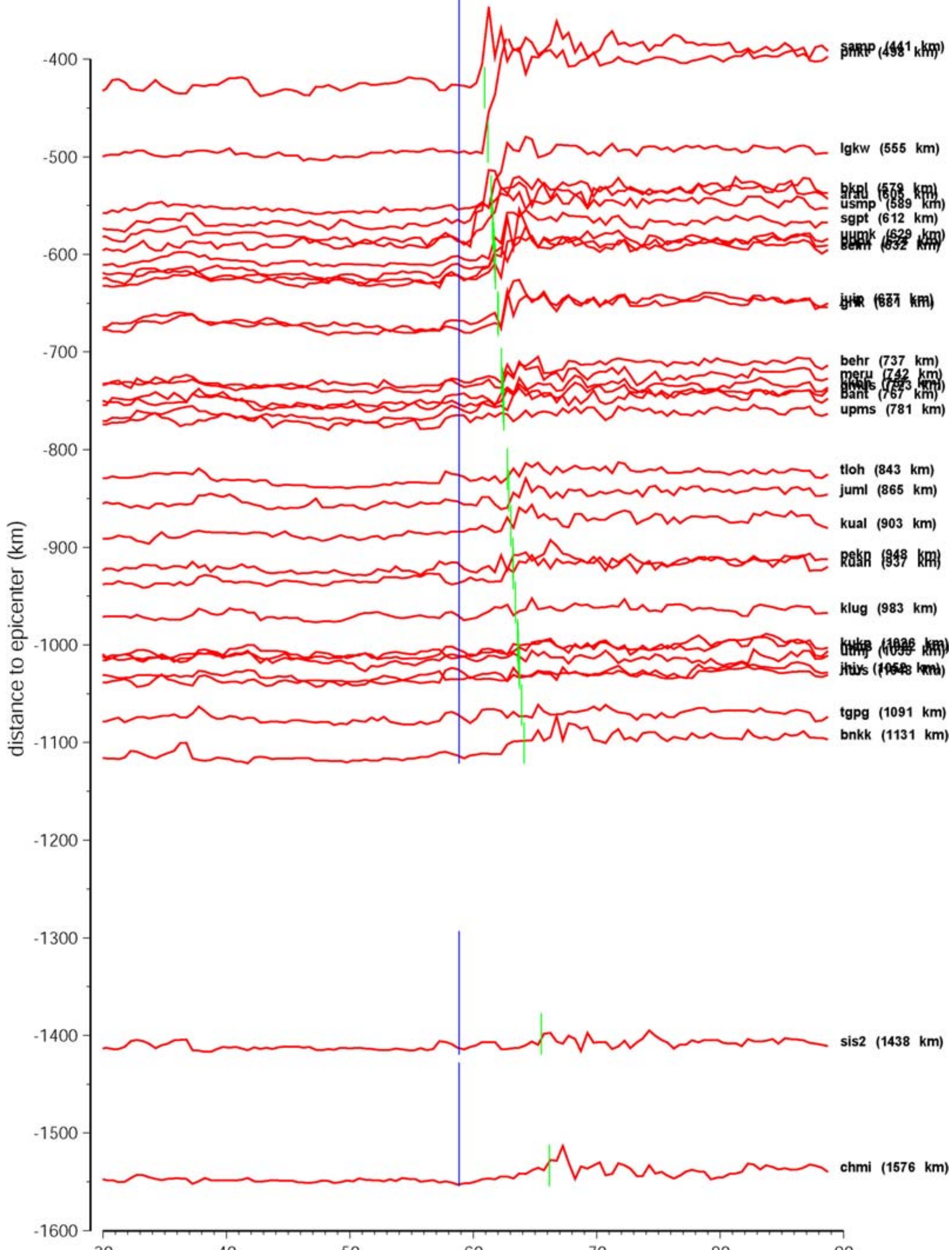




“Kinematic” (epoch-by-epoch) positioning of the GPS station show the co-seismic step…

…and allow to determine the displacement arrival time

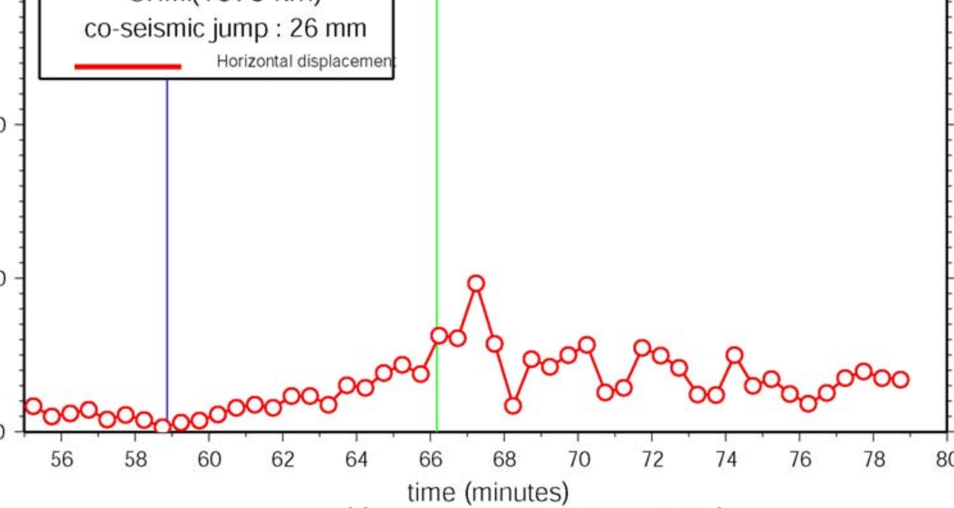
It seems related to surface waves rather than P or S wave……

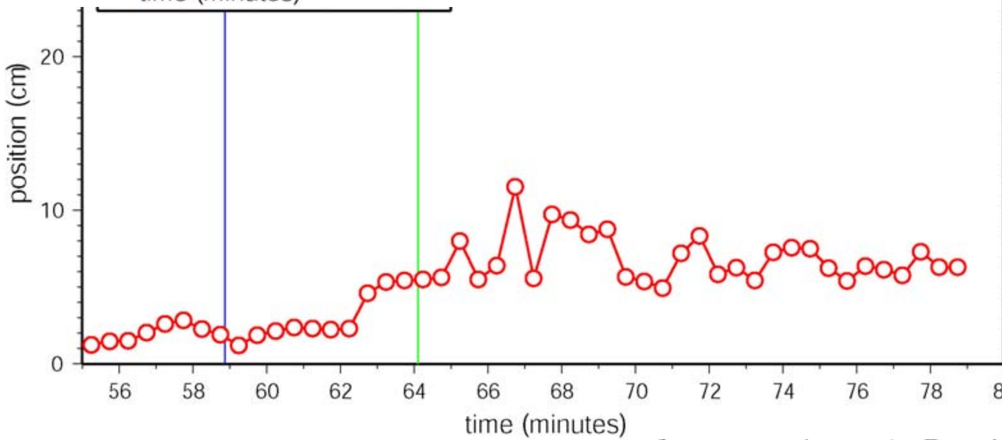


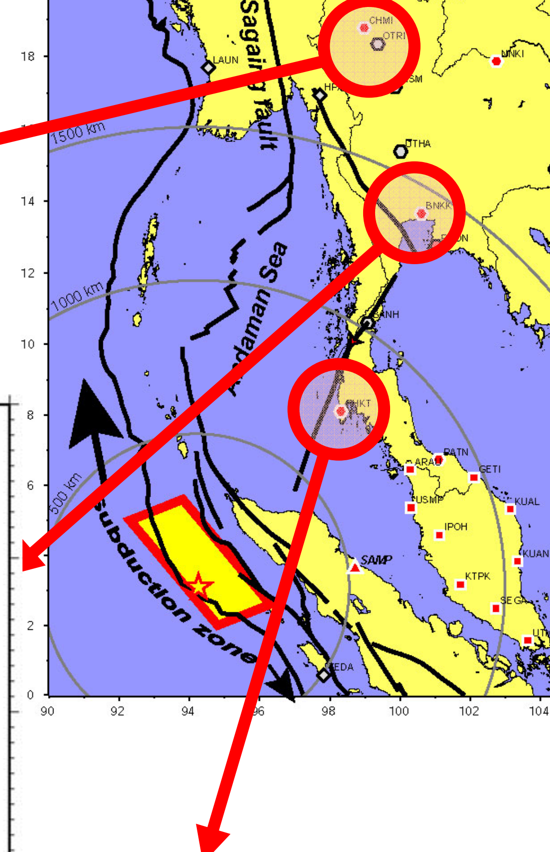
Assuming a velocity of 3.6 km/s for seismic waves

relocation of the source of the seismic energy is needed to match and sort arrival times at stations

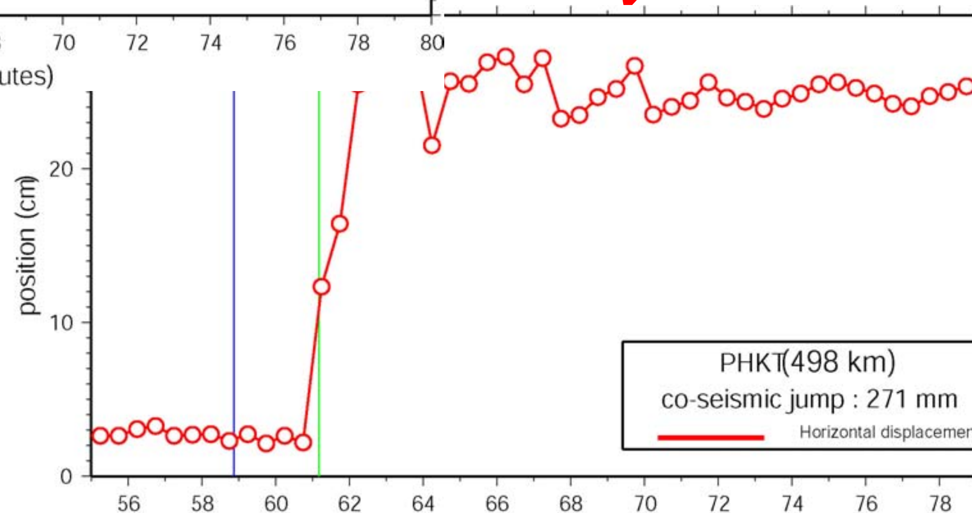
Again, a relocation of 200 km to the north is requested

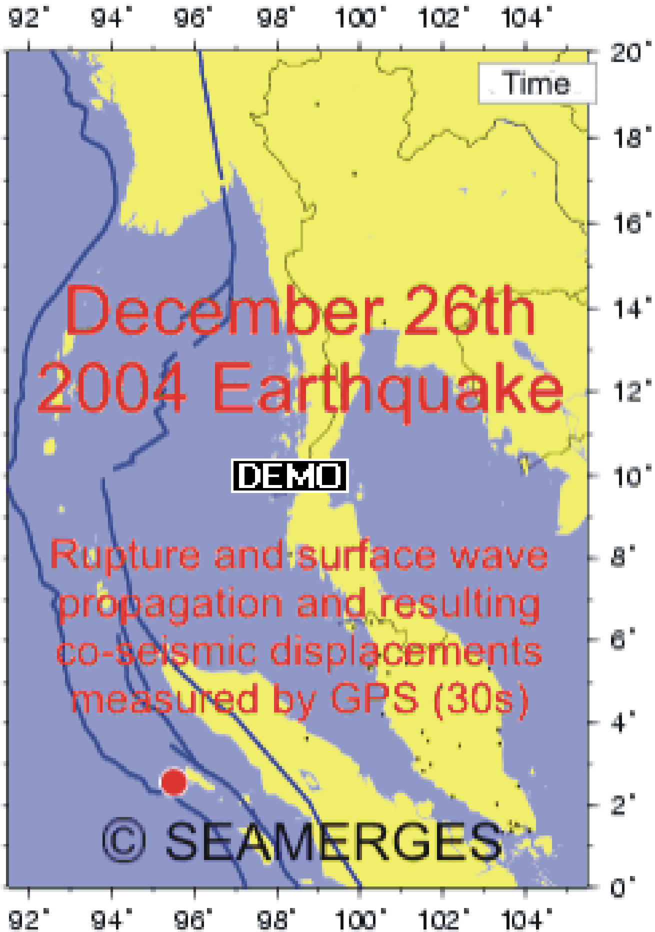






Indication of source directivity is pointed by larger "rise times" at northern stations





http://www.deos.tudelft.nl/seamerges

rupture

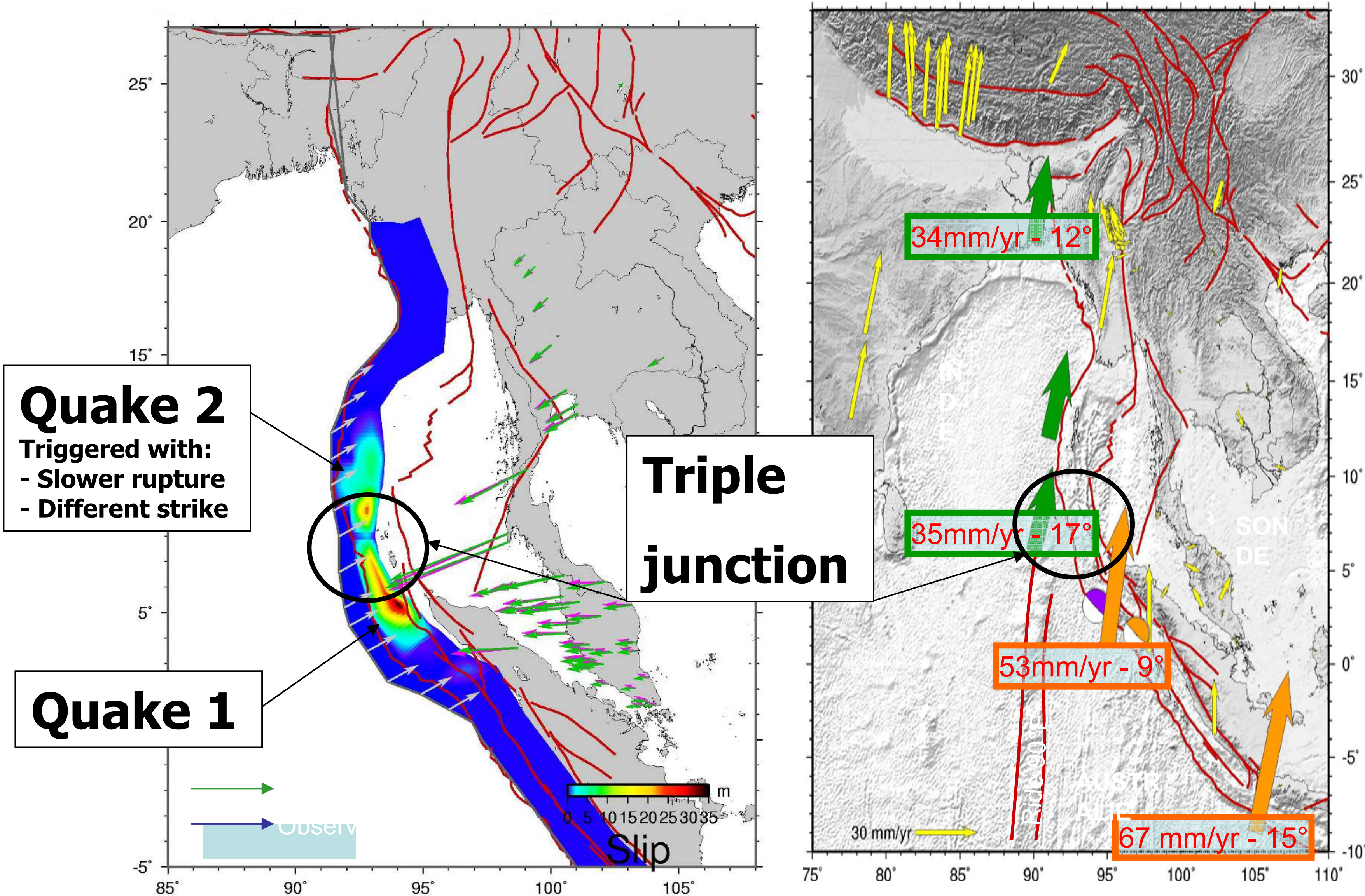
Seismic **surface**
waves propagati

(3.7 km/s)

GPS stations
displacements

Rupture Propagation:
3.7 km/s initially (South)
30s stop ~ 8° lat
1.8 km/s onward (North)

GPS cinématique => vitesse de rupture



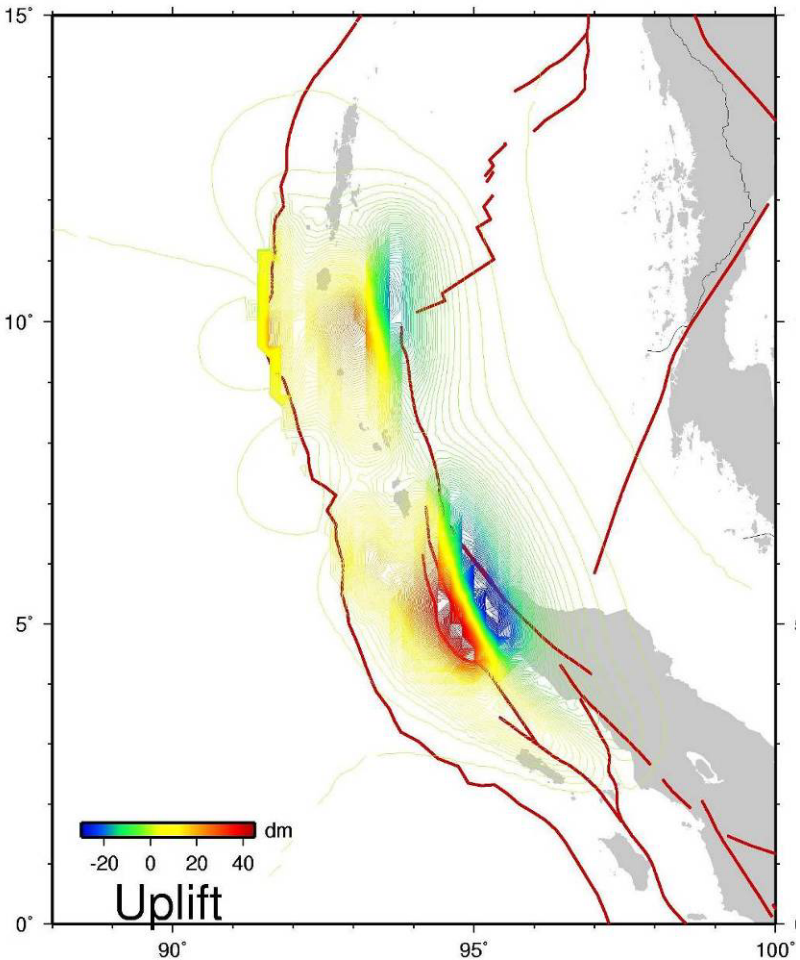
GPS cinématique+statique => 2 ruptures

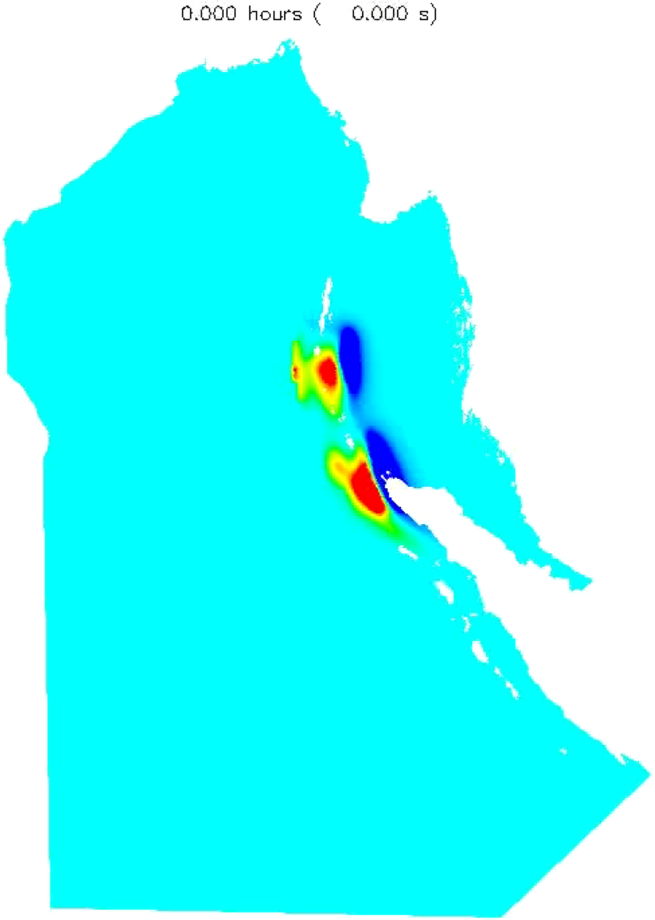
Vertical motions predicted by the models

- ➢**4 m of uplift**
- ➢**2 m of subsidence**

Tsunami modélisation

Pietrzack et al., 2007



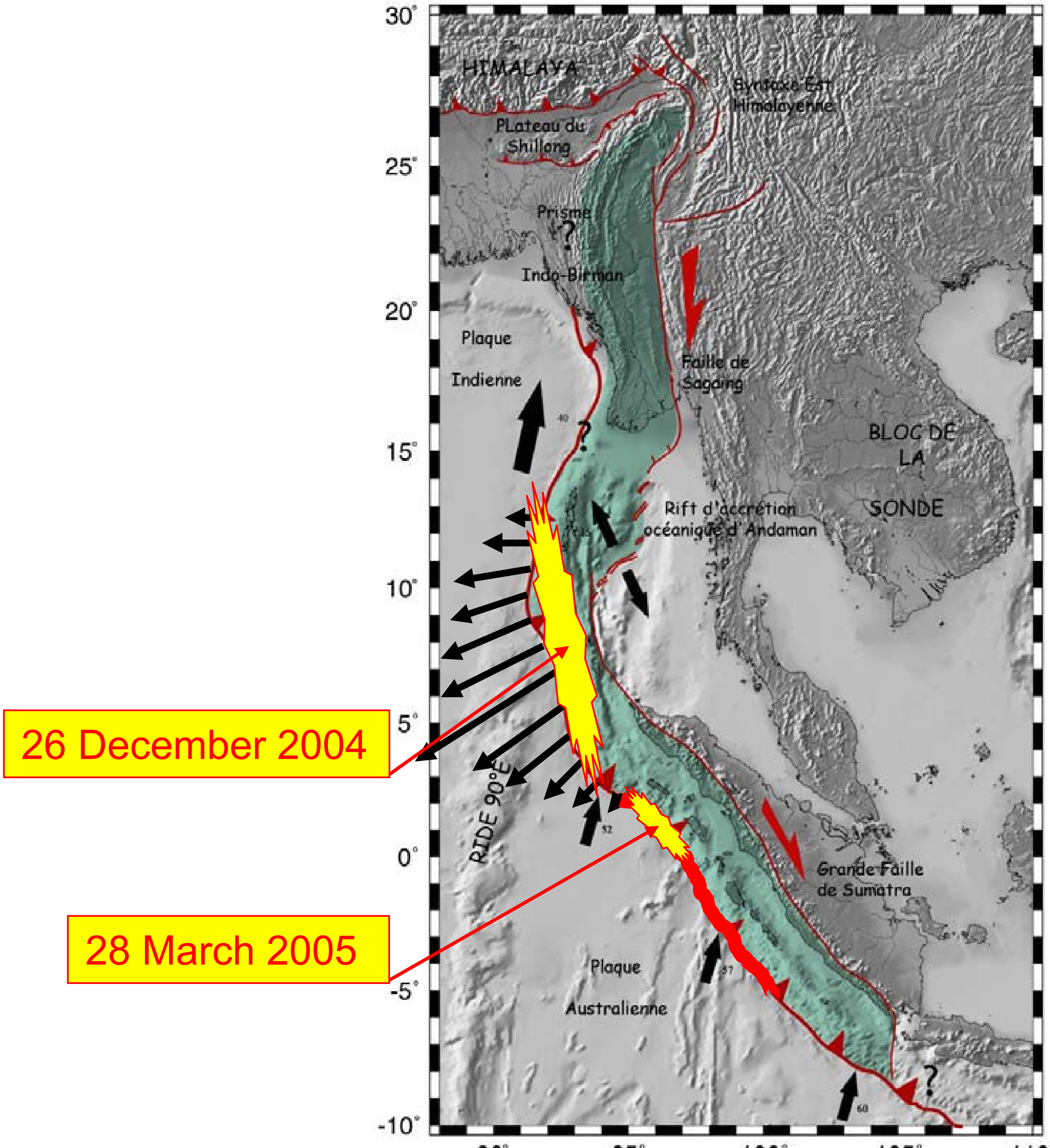


GPS cinématique+statique => modèle de Tsunami

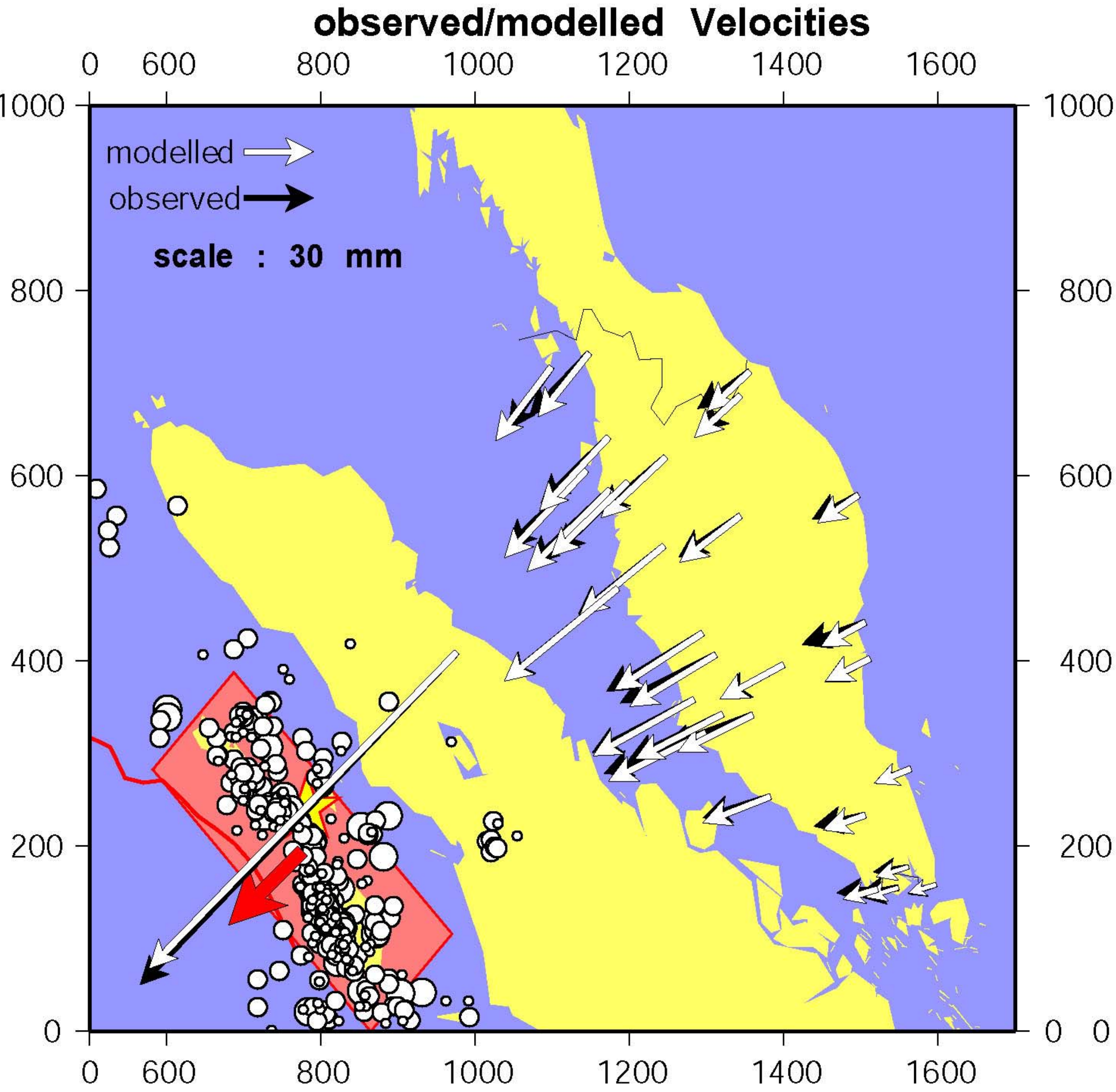
Modification of seismic hazard in the area

There is a higher risk of a near future events in the vicinity

1/ further South or the subduction



Nias Earthquake of March 28th



model parameters

M0 = 1.08E+29 dyn.cm

Mw = 8.7

Strike : 315.0

Depth : 25.0

Dip : 7.0

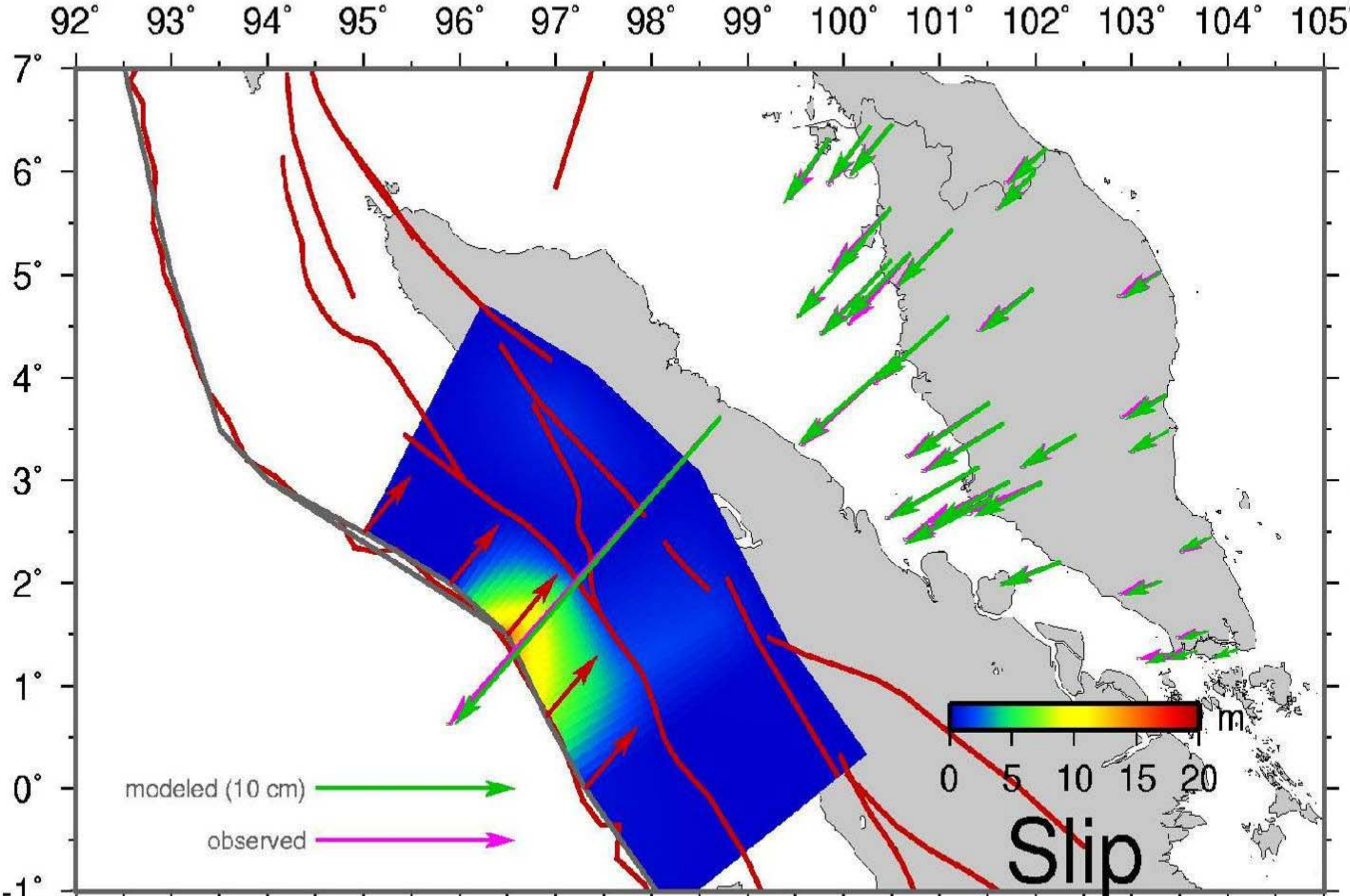
Slip : 450.0

Fault length : 400.0

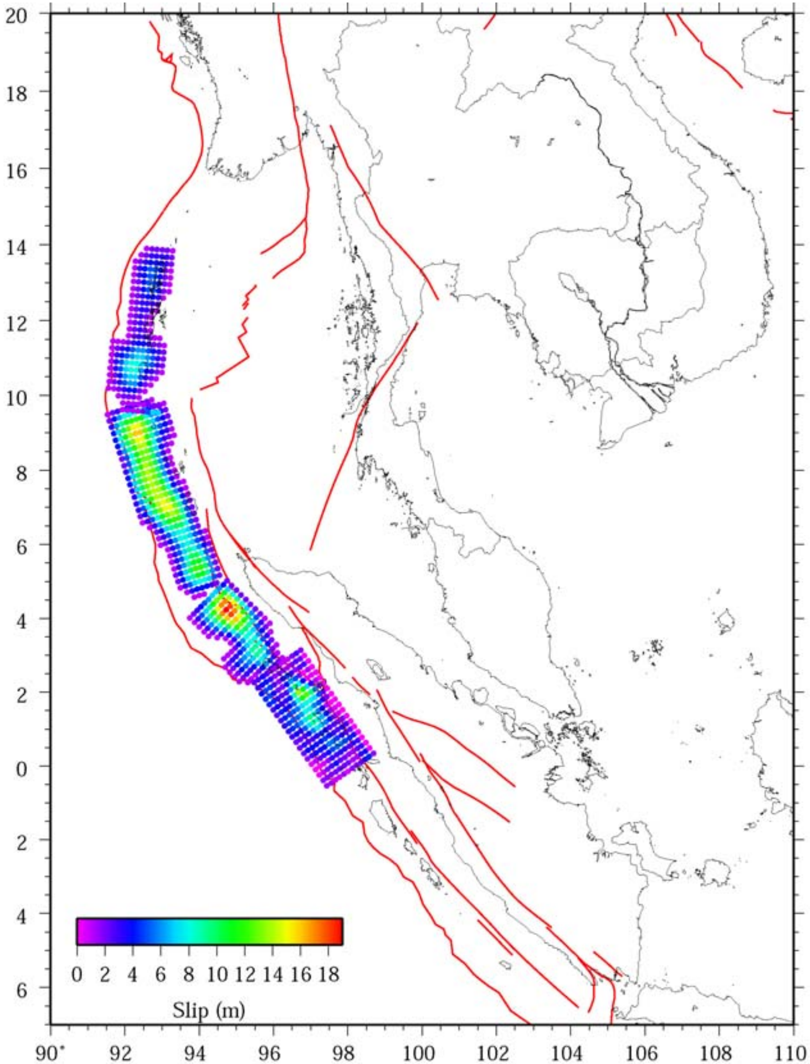
Fault width : 150.0

Vigny et al., 2005

Nias Earthquake: Quake 3 ? Triggered ?



istribution of slip by
hen et al., 2006



3 ruptures :

1 - Aceh

2 - Andaman

3- Nias

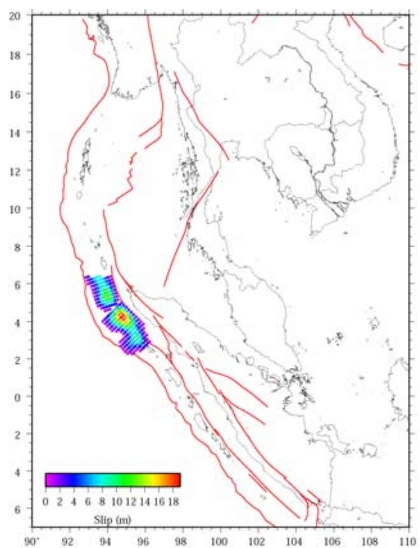
1 triggered 2 and 3 by increase of static stress

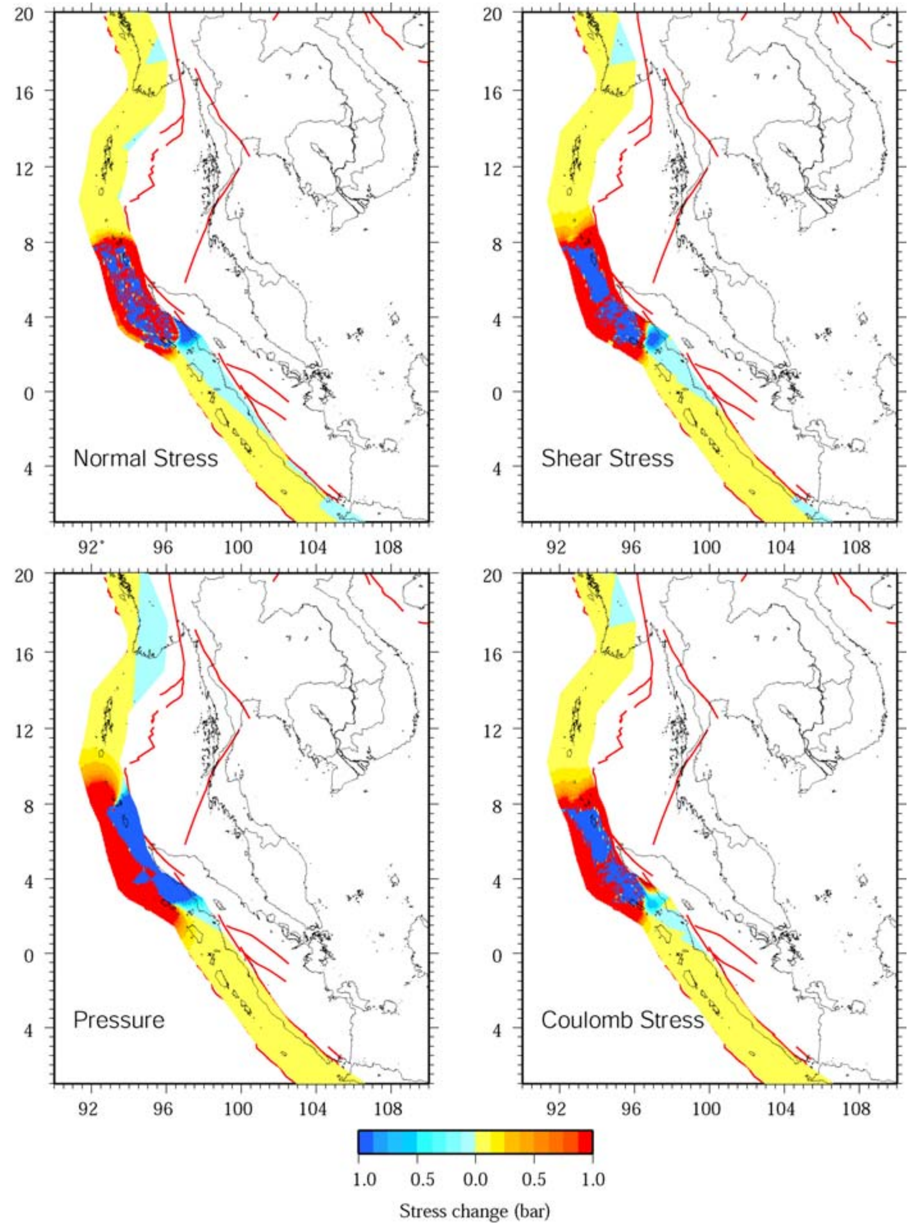
GPS cinématique+statique => modèle de glissement

=> calcul d'augmentation de contraintes

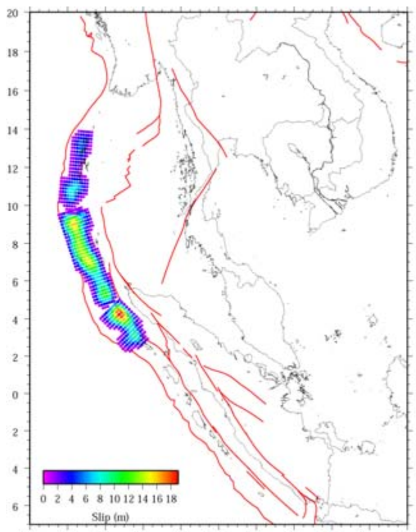
Coulomb stress increase on the trench

1 - Aceh



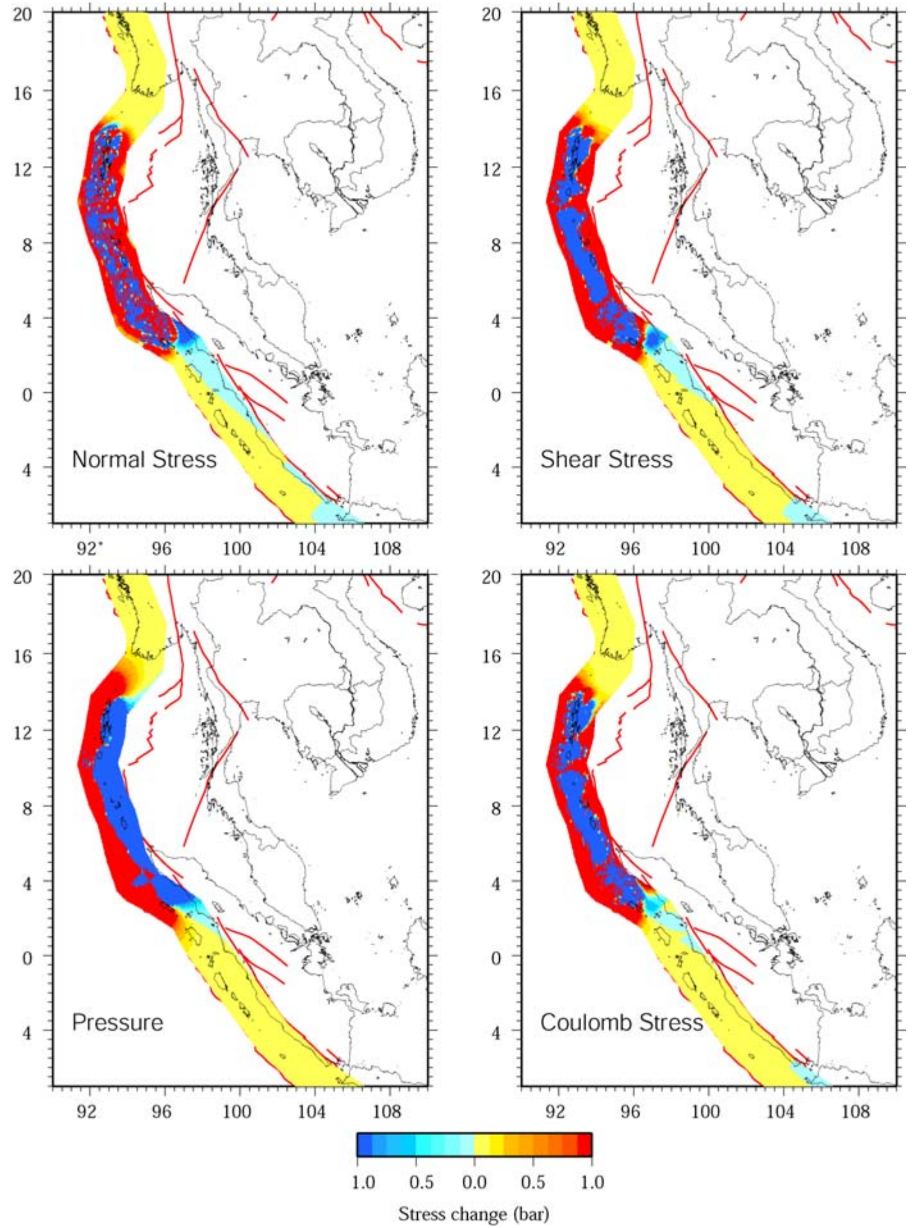


Coulomb stress increase on the trench



1 - Aceh

2 - Andaman



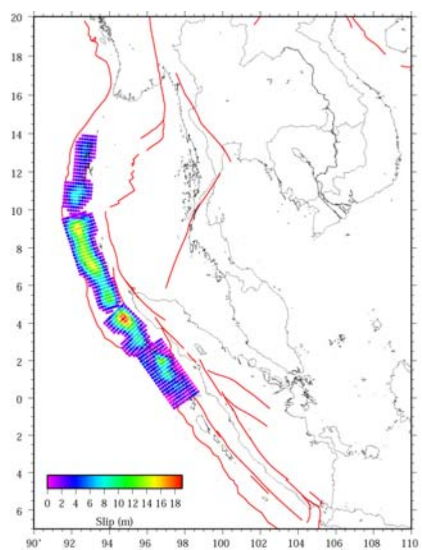
Coulomb stress increase

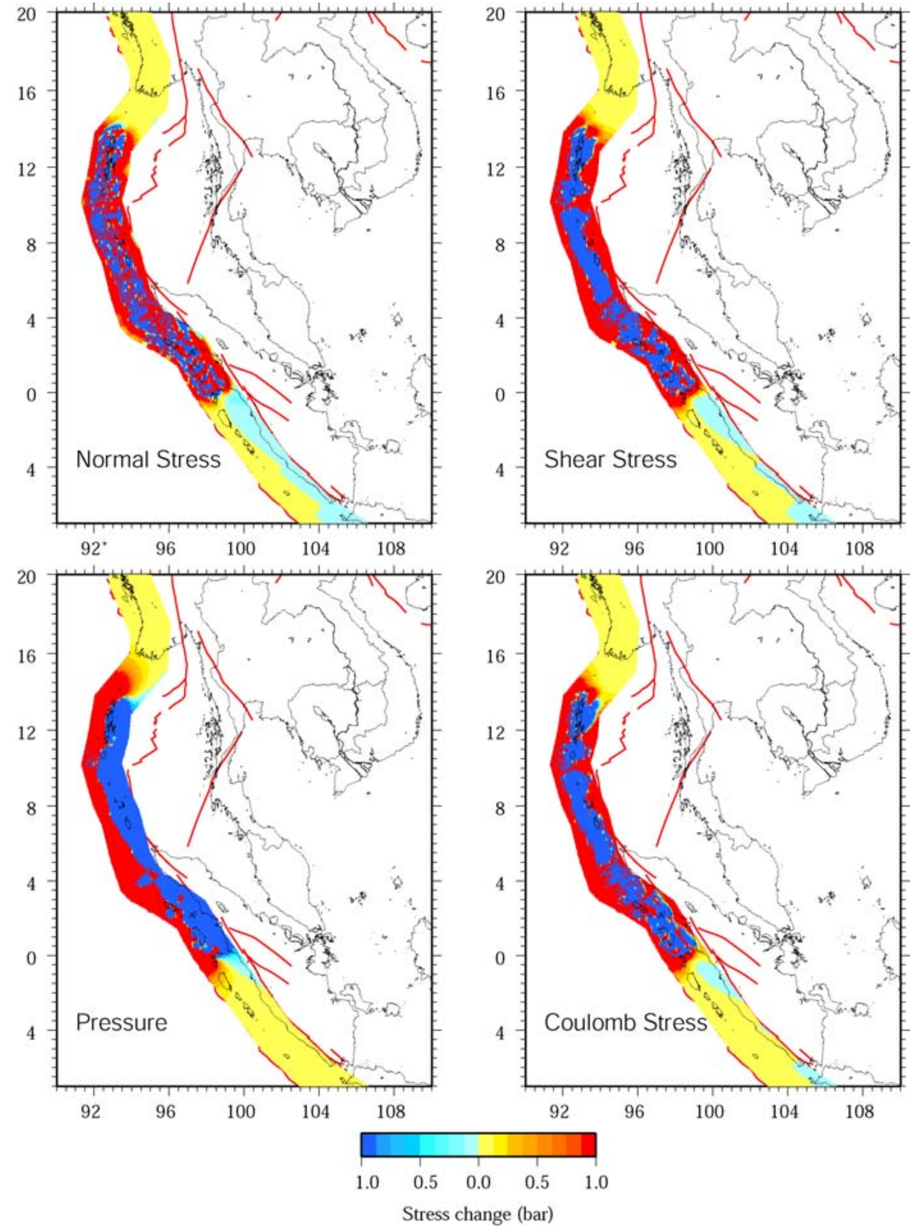
On the trench

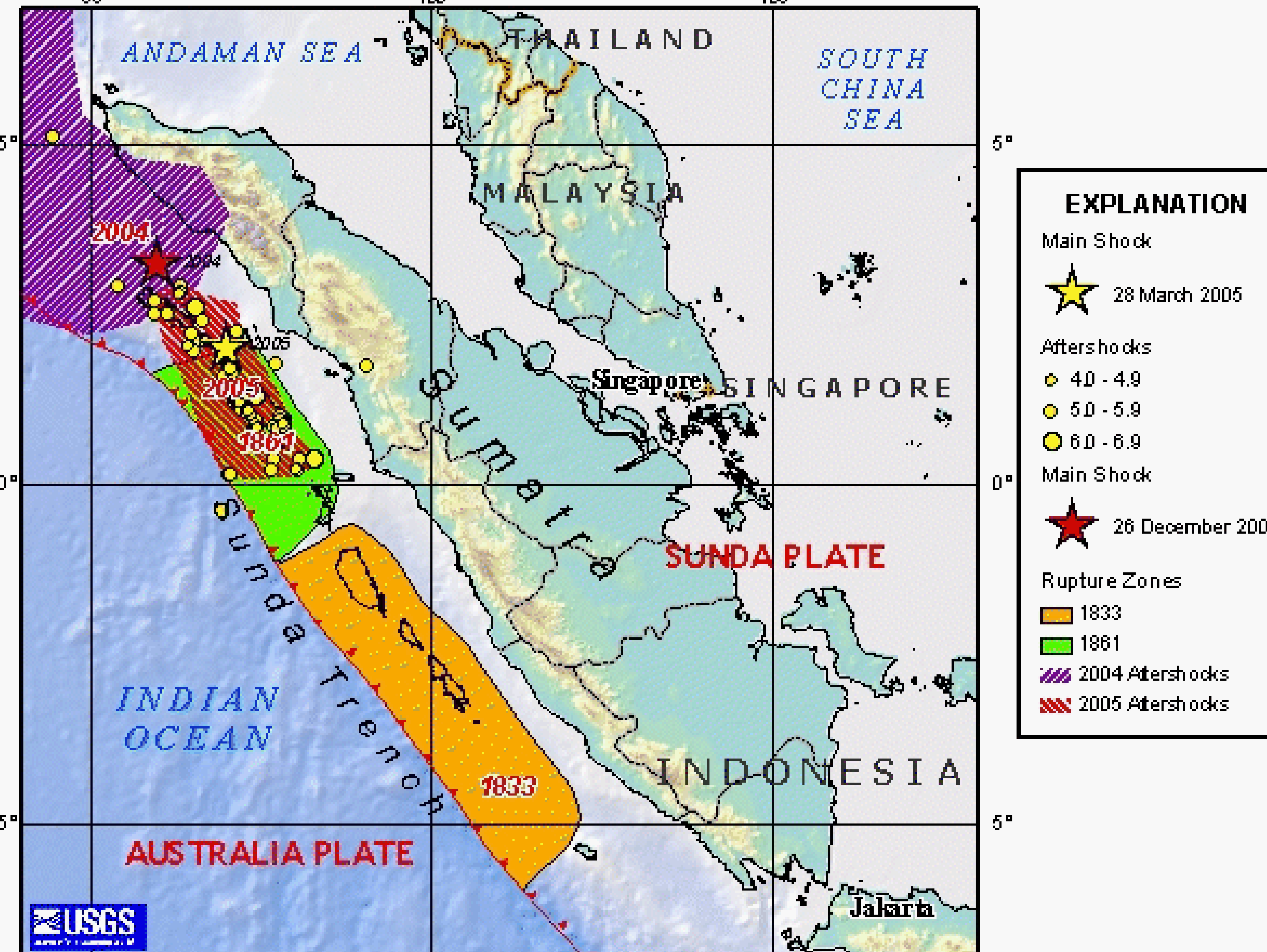
1 - Aceh

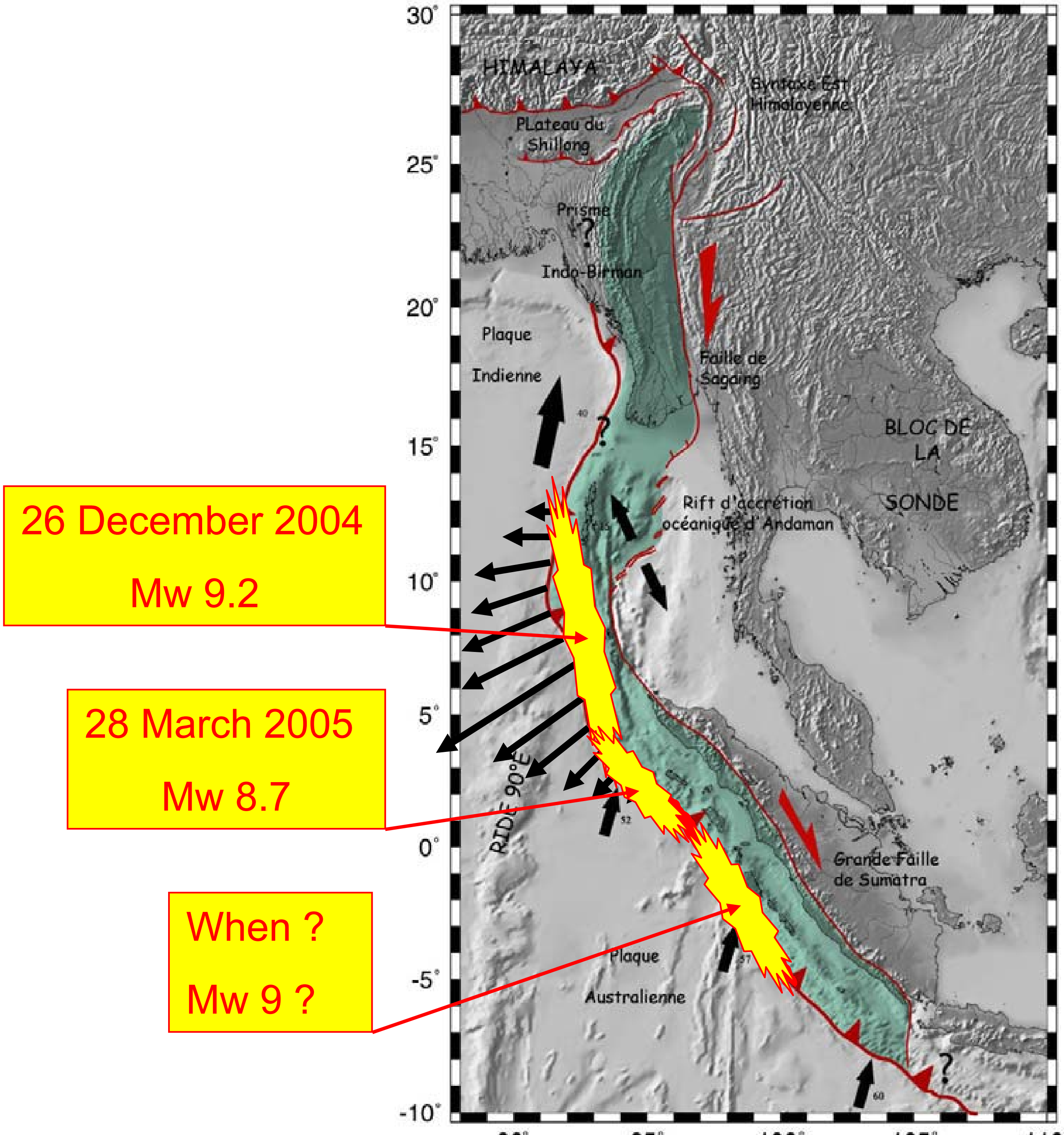
2 - Andaman

3 - Nias





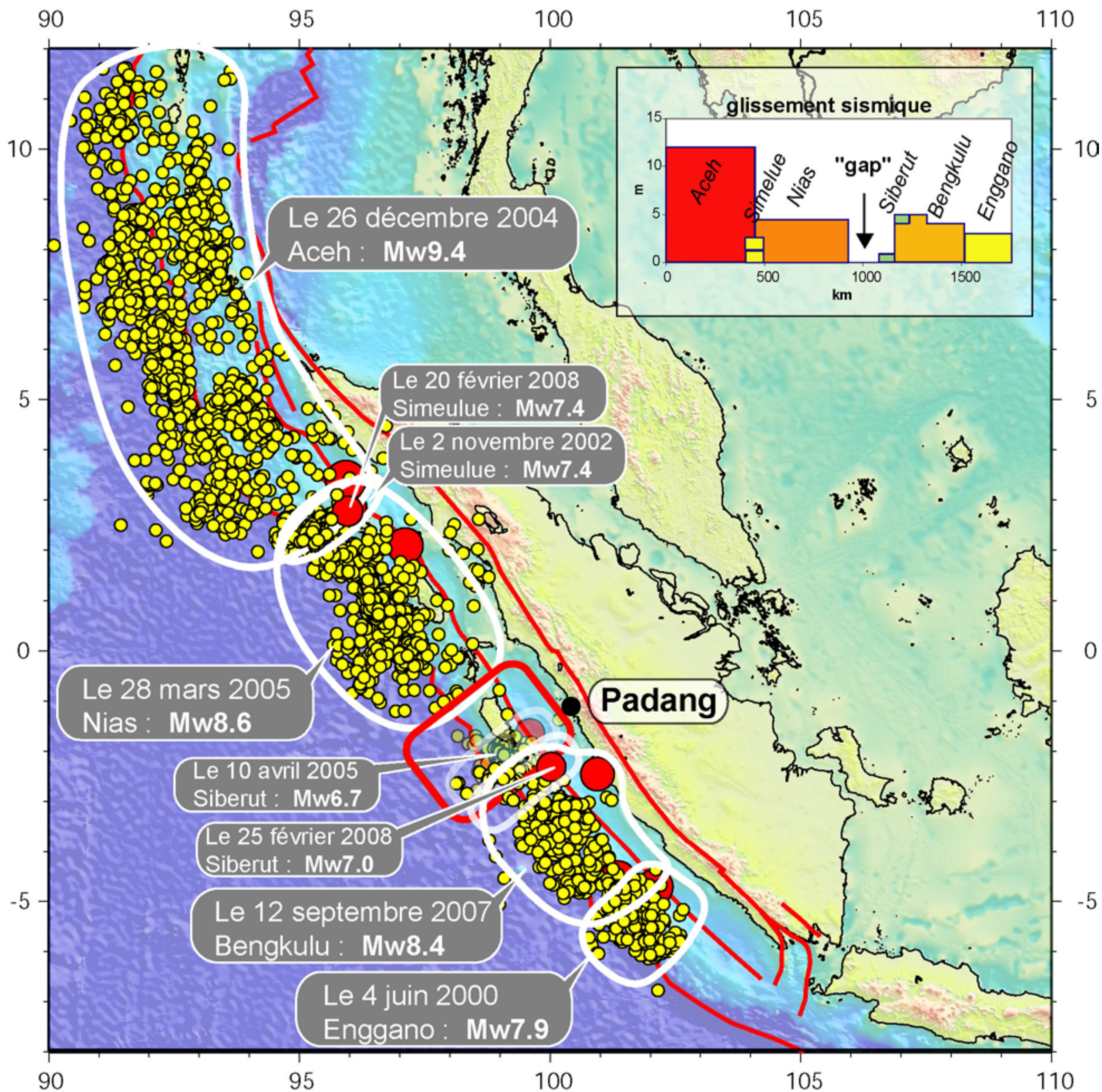

ANDAMAN SEA
THAILAND
SOUTH CHINA SEA
MALAYSIA
Singapore
SINGAPORE
Sumatra
SUNDA PLATE
INDONESIA
Jakarta
INDIAN OCEAN
AUSTRALIA PLATE
Sunda Trench
2004
2005
1861
1833
5°
0°
EXPLANATION
Main Shock
28 March 2005
Aftershocks
4.0 - 4.9
5.0 - 5.9
6.0 - 6.9
Main Shock
26 December 200
Rupture Zones
1833
1861
2004 Aftershocks
2005 Aftershocks
USGS



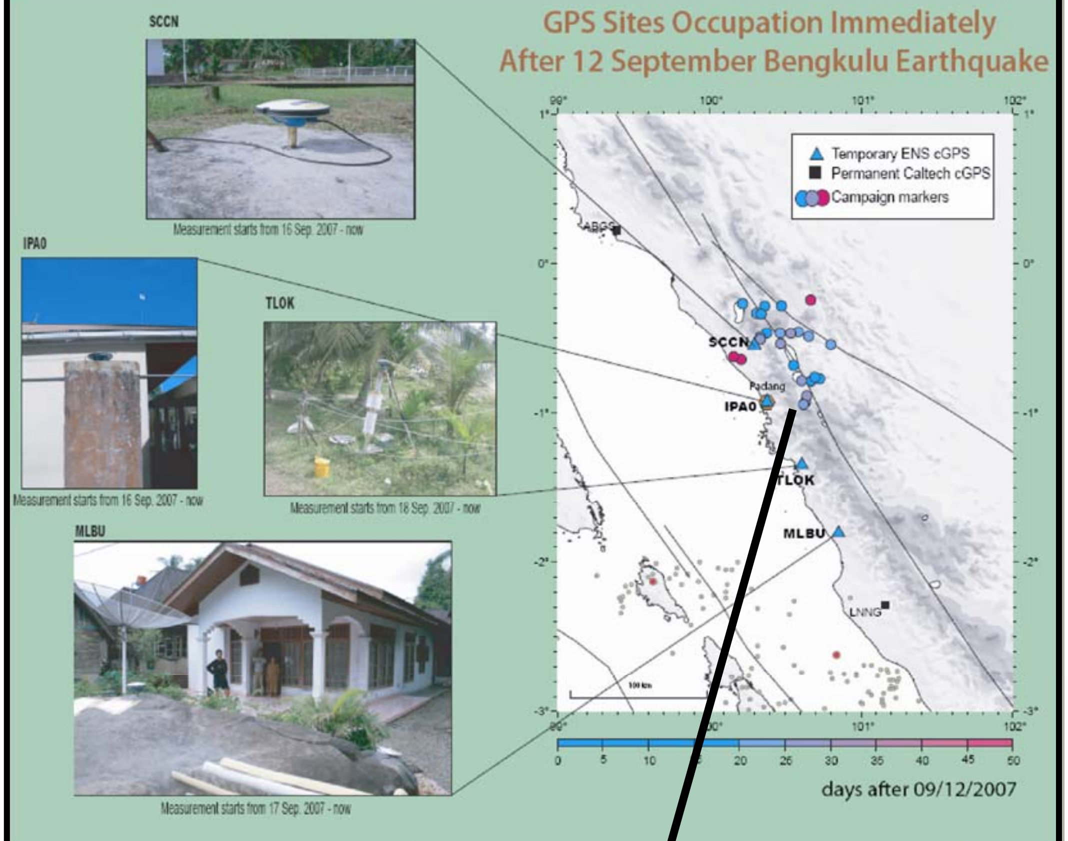
Modification of seismic hazard in the area

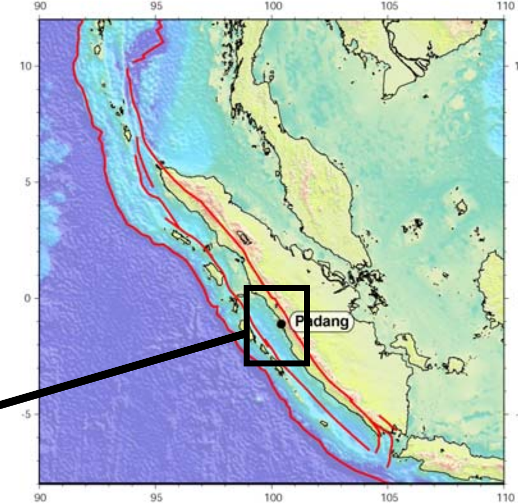
There is a higher risk of a near future event

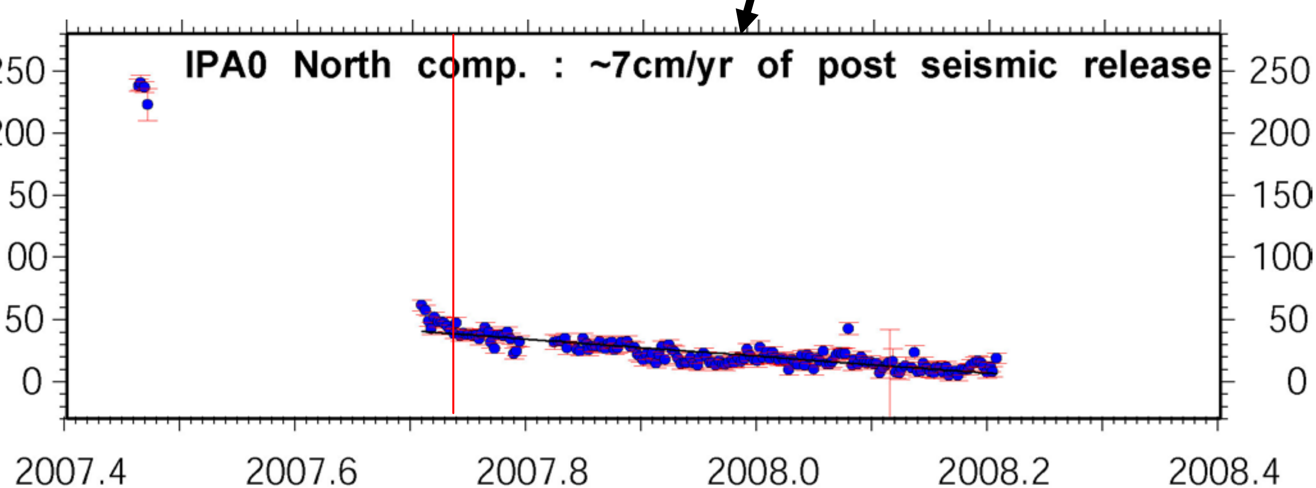
1/ further South on the subduction



glissement sismique
Aceh
Simelue
Nias
"gap"
Siberut
Bengkulu
Enggano
m
km
Le 26 décembre 2004
Aceh : Mw9.4
Le 20 février 2008
Simeulue : Mw7.4
Le 2 novembre 2002
Simeulue : Mw7.4
Le 28 mars 2005
Nias : Mw8.6
Padang
Le 10 avril 2005
Siberut : Mw6.7
Le 25 février 2008
Siberut : Mw7.0
Le 12 septembre 2007
Bengkulu : Mw8.4
Le 4 juin 2000
Enggano : Mw7.9

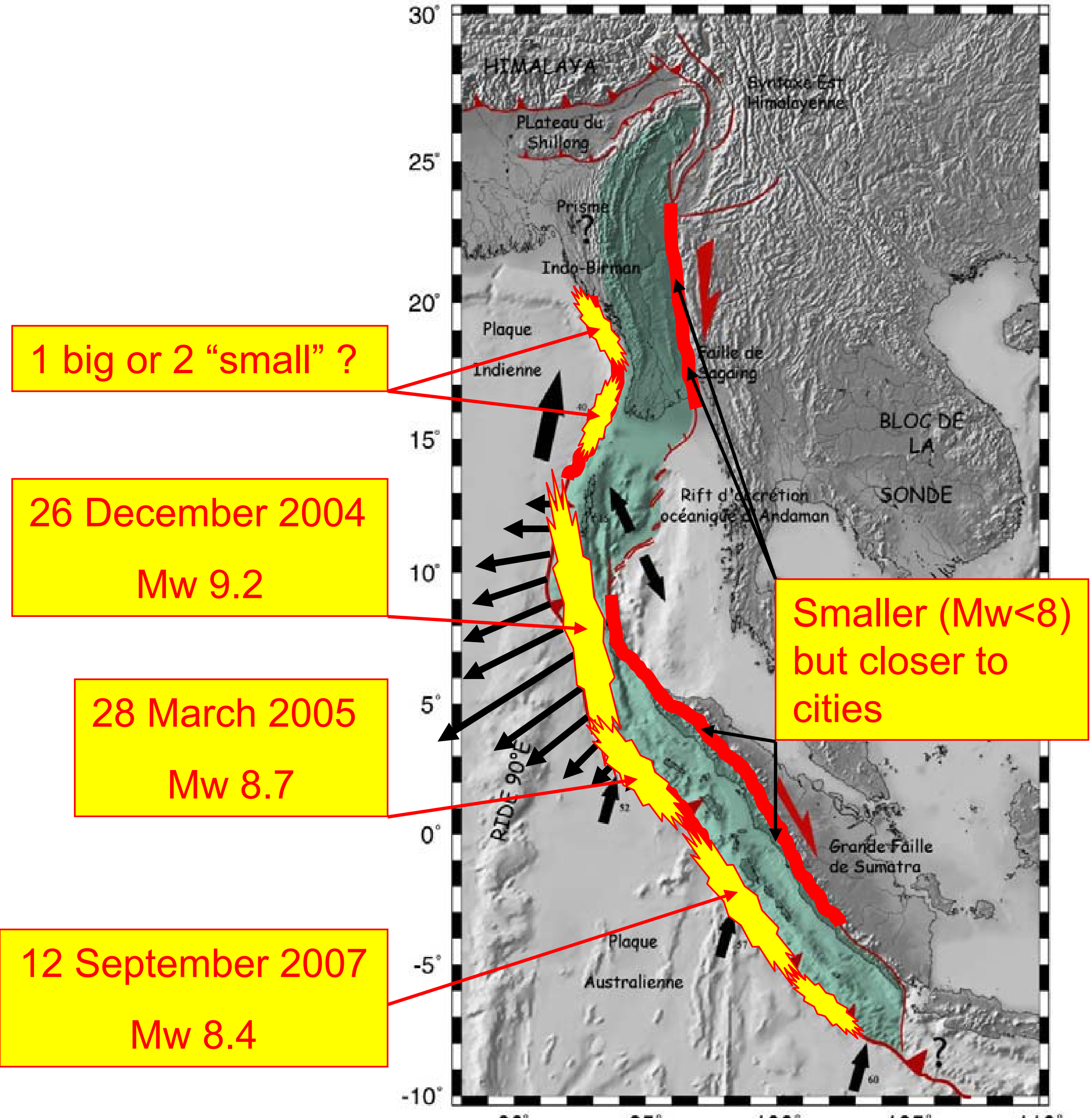






Deux scenarios:

1. post-sismique « normal » => ça va casser plus tard (et plus fort ?)
2. Post-sismique « plus que normal » => ça dissipe de la déformation silencieusement



Modification of seismic hazard in the area

There is a higher risk of a near future event

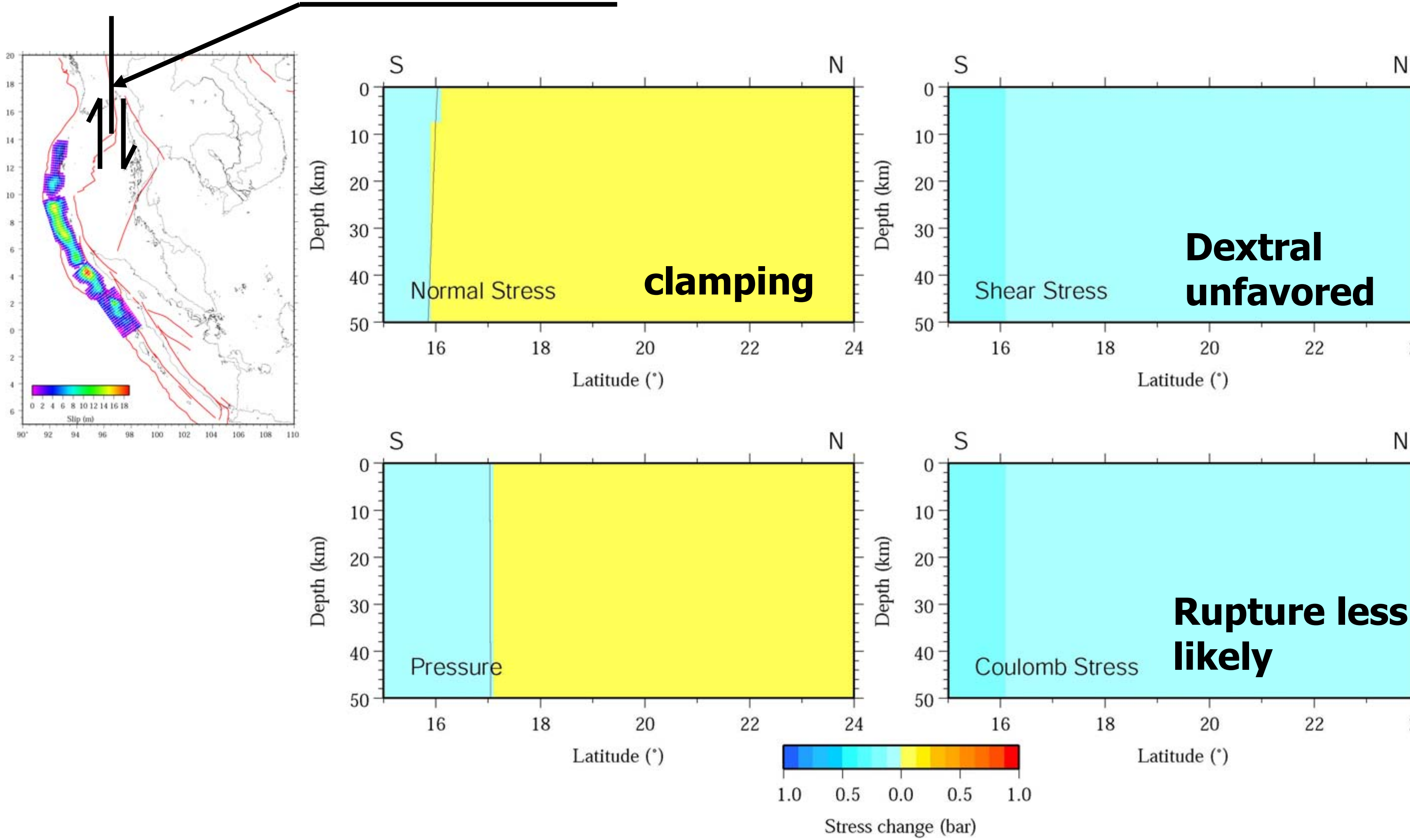
1/ further South on the subduction

2/ further North on the subduction

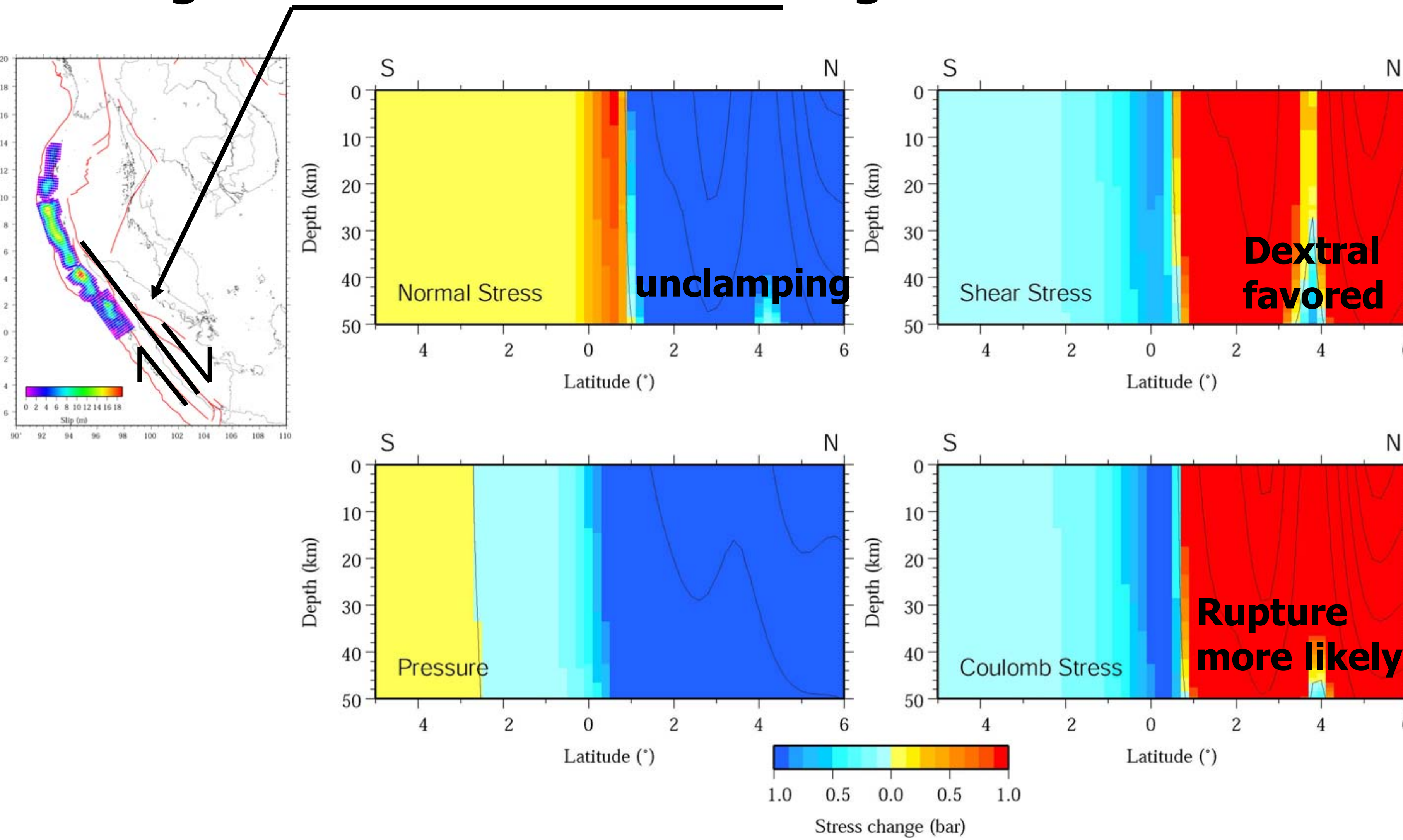
3/ on the Great Sumatran Fault

4/ on the Sagaing fault ?

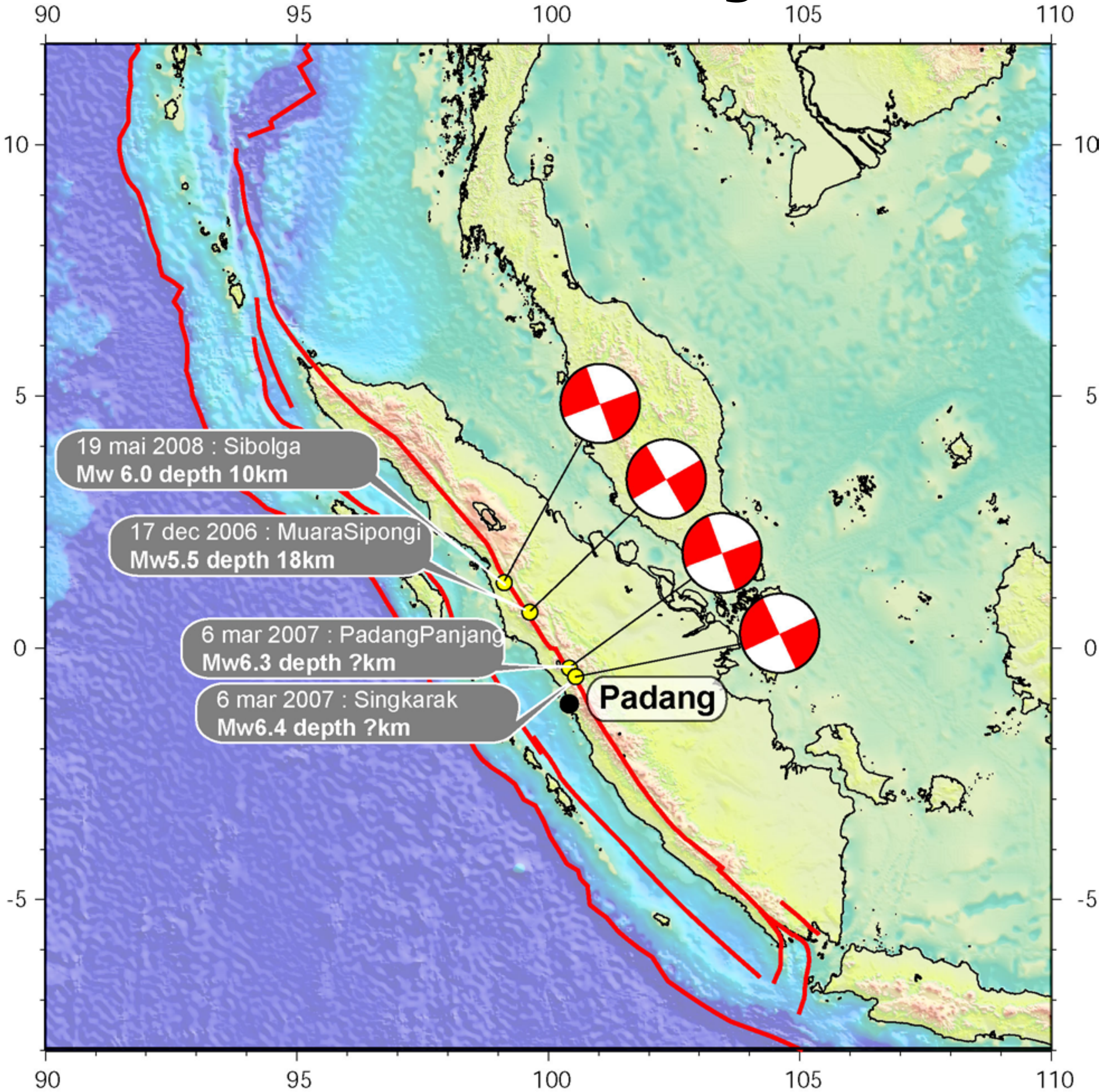
Loading of Sagaing fault: low everywhere and reverse!



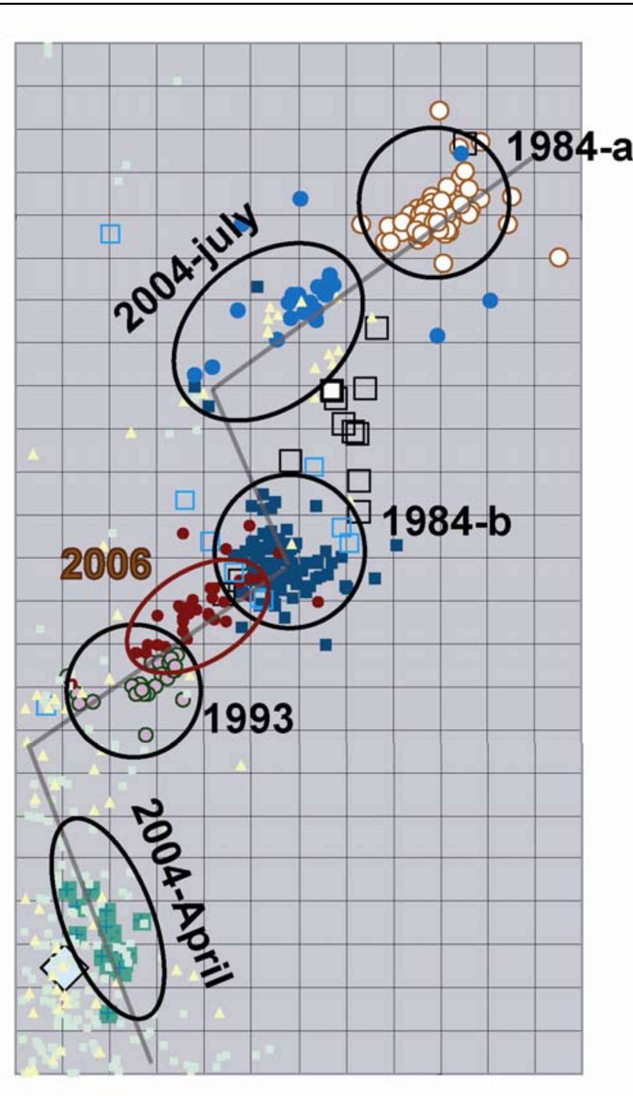
Loading of Great Sumatra fault: high above 0°N

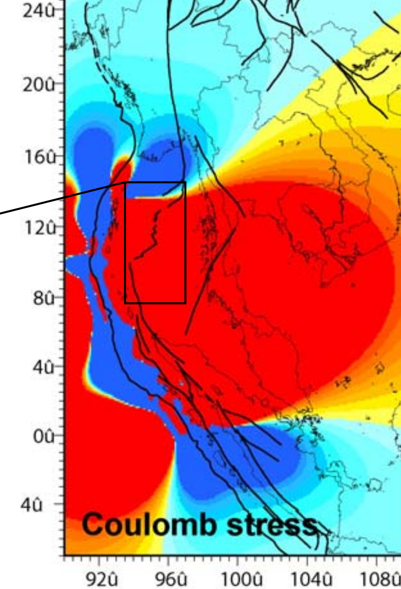


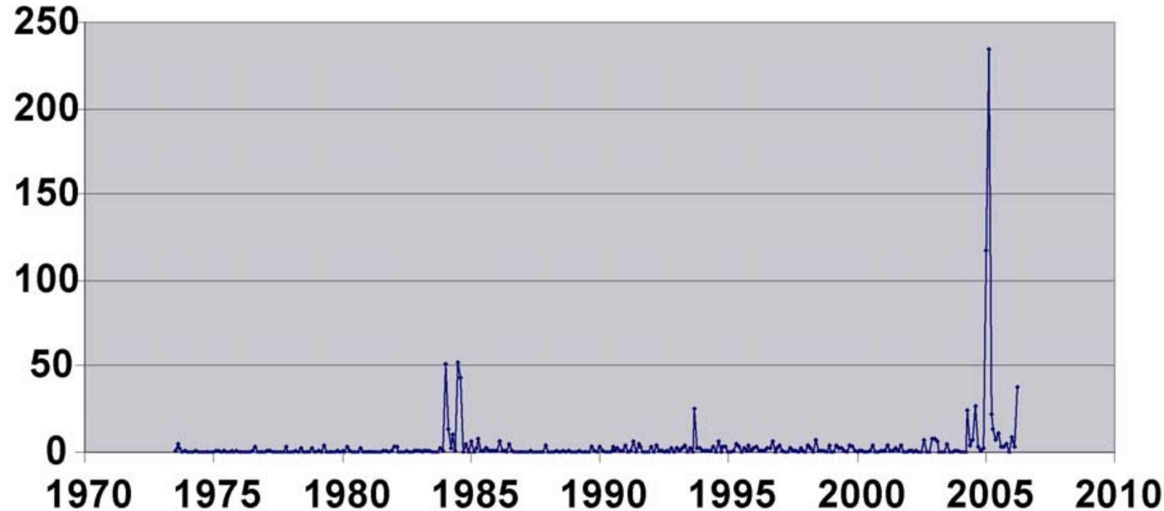
Loading of Great Sumatra fault: high above 0°N



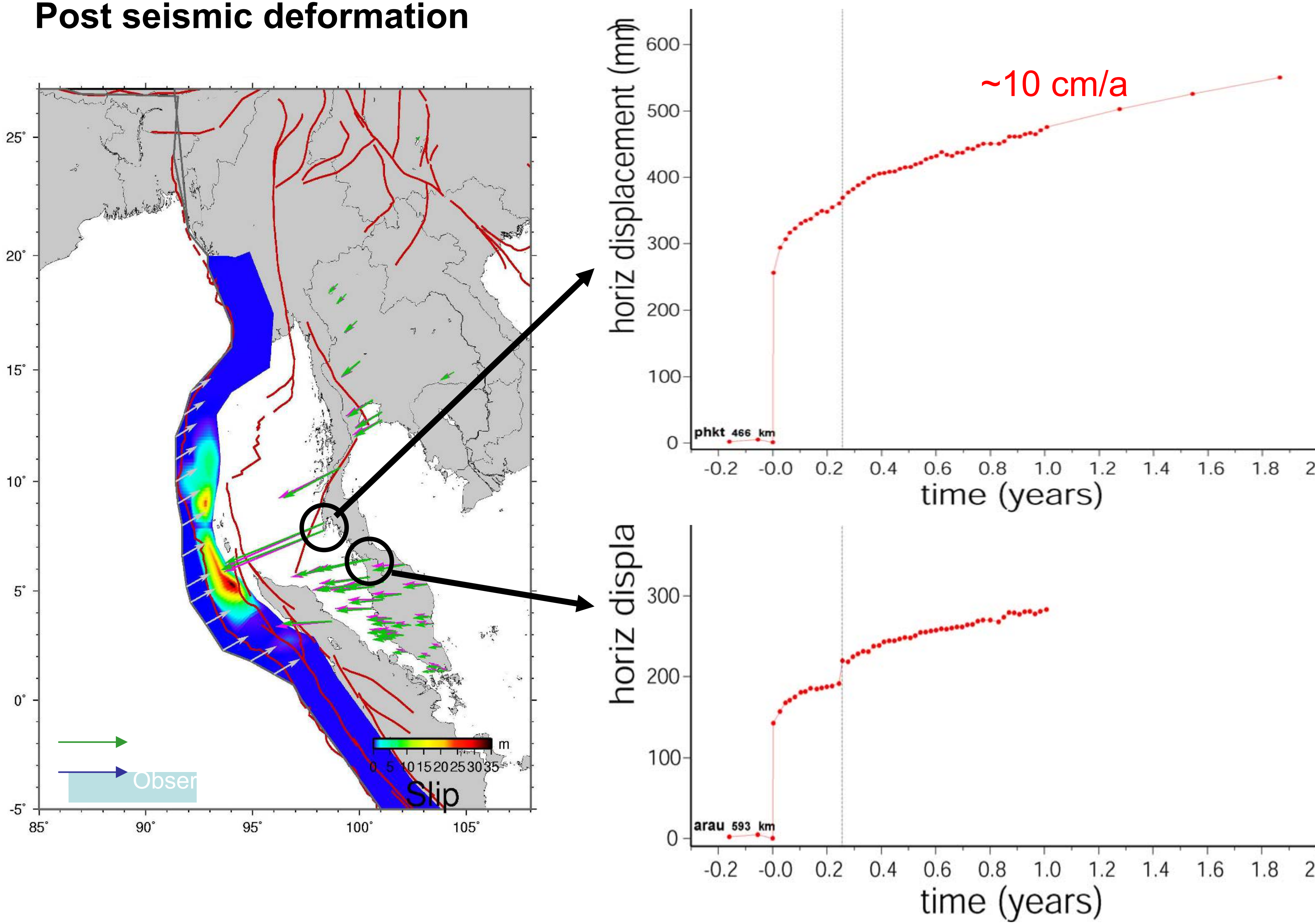
Andaman recent earthquakes swarm







Post seismic deformation



..encore du travail (difficile) en vue…….