Subduction et Géodésie GPS

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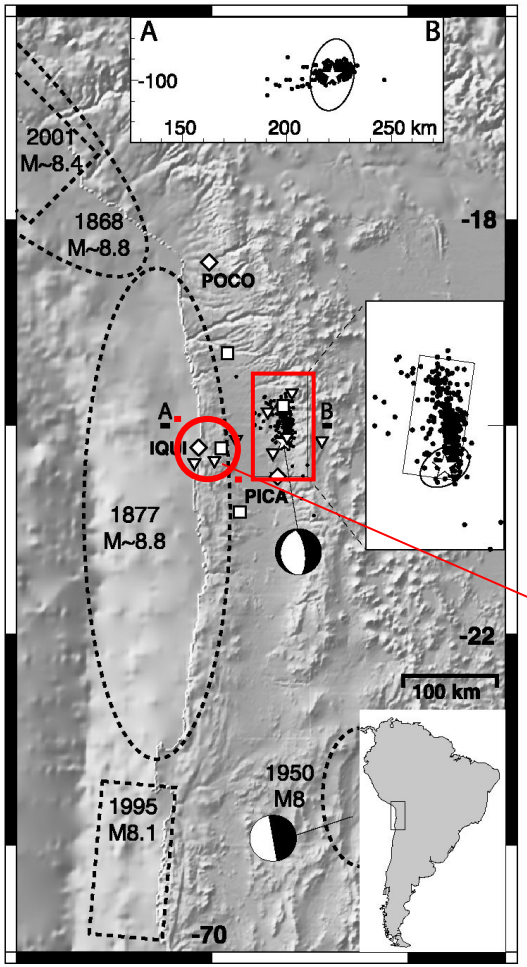
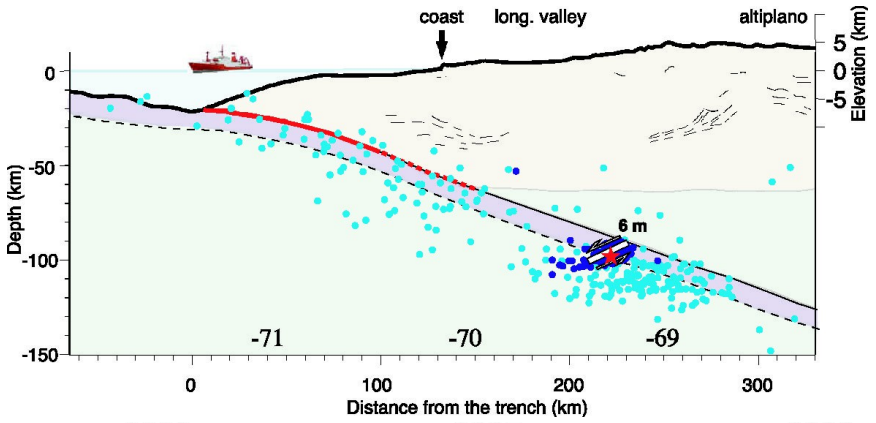
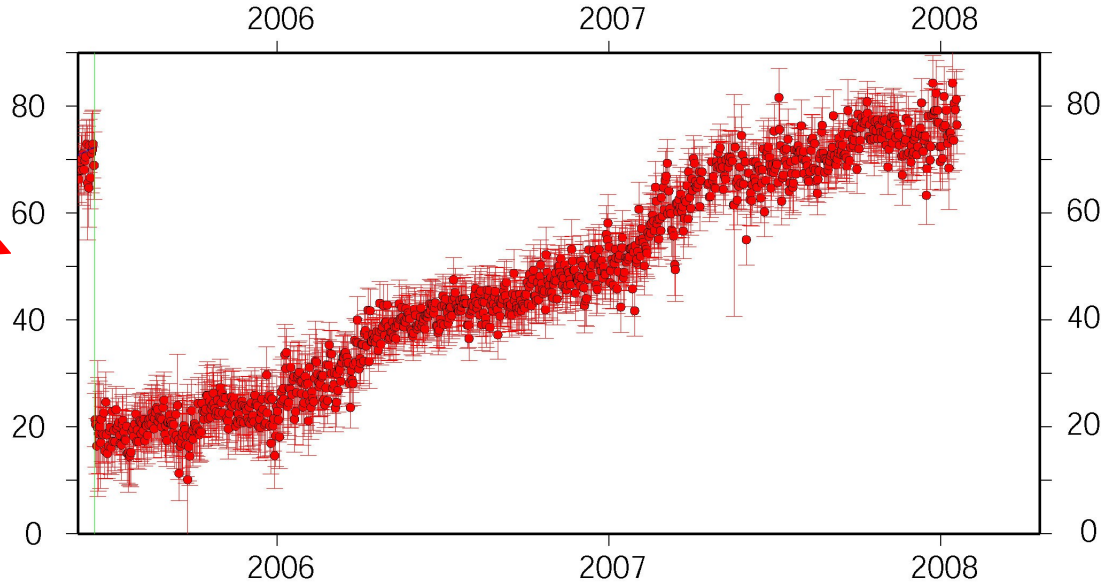
UAPF after Tarapaca Eq. Mw7.7 13-june-2005 (**slab pull**)

Peyrat et al., *GRL*, 2006



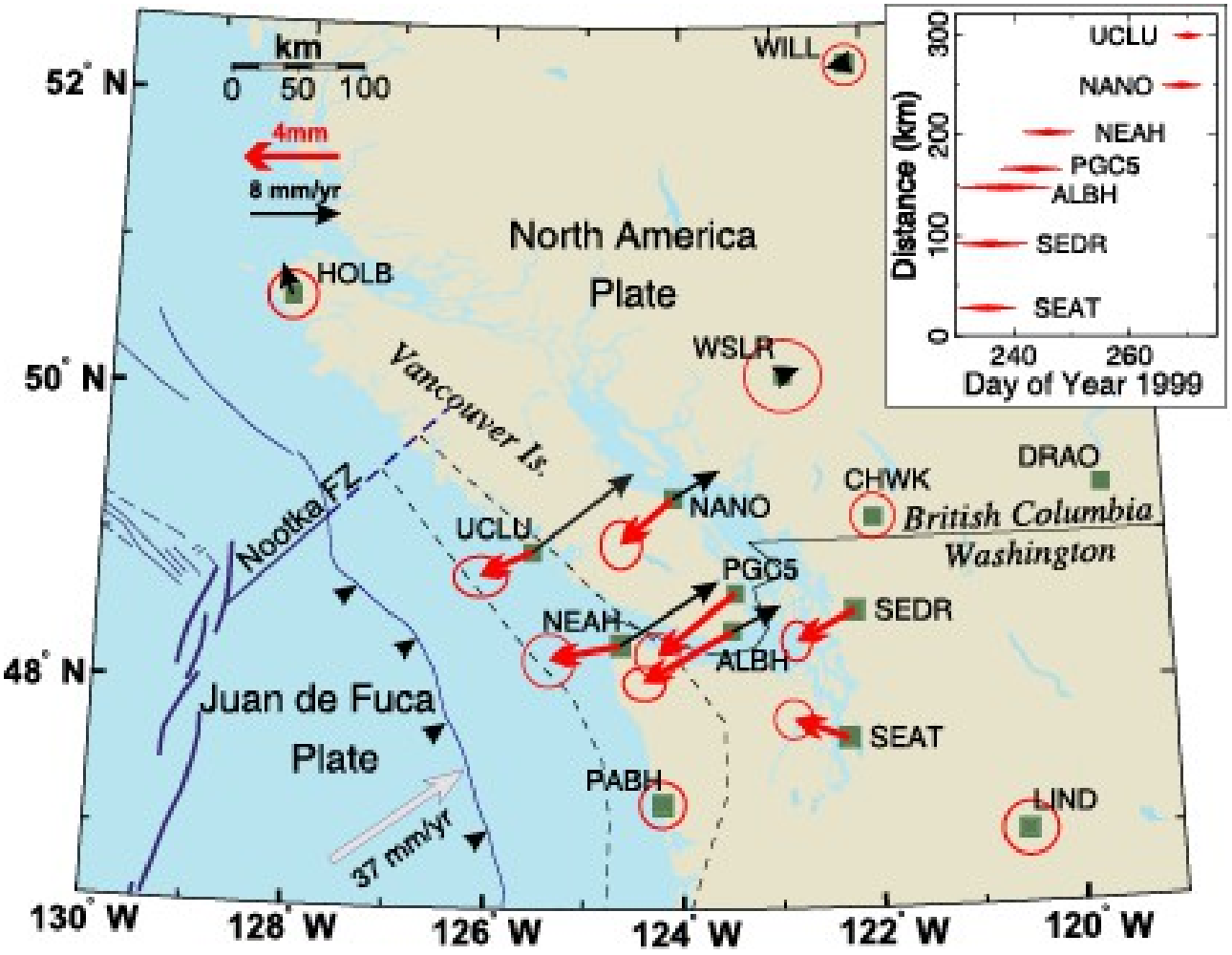




Short term transients

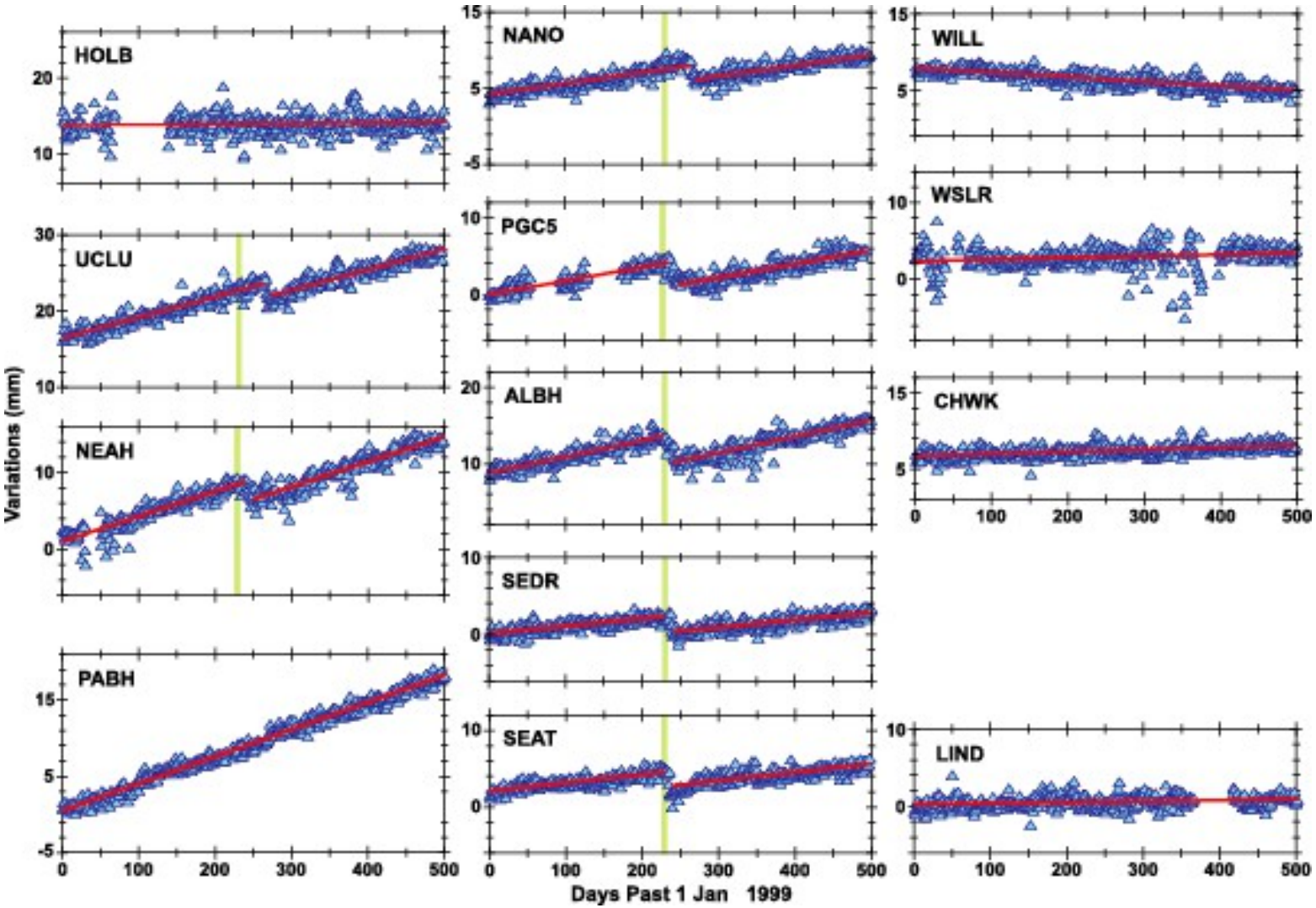
Silent slip on Cascadian subduction zone

Dragert et al., Science, 292, May 2001



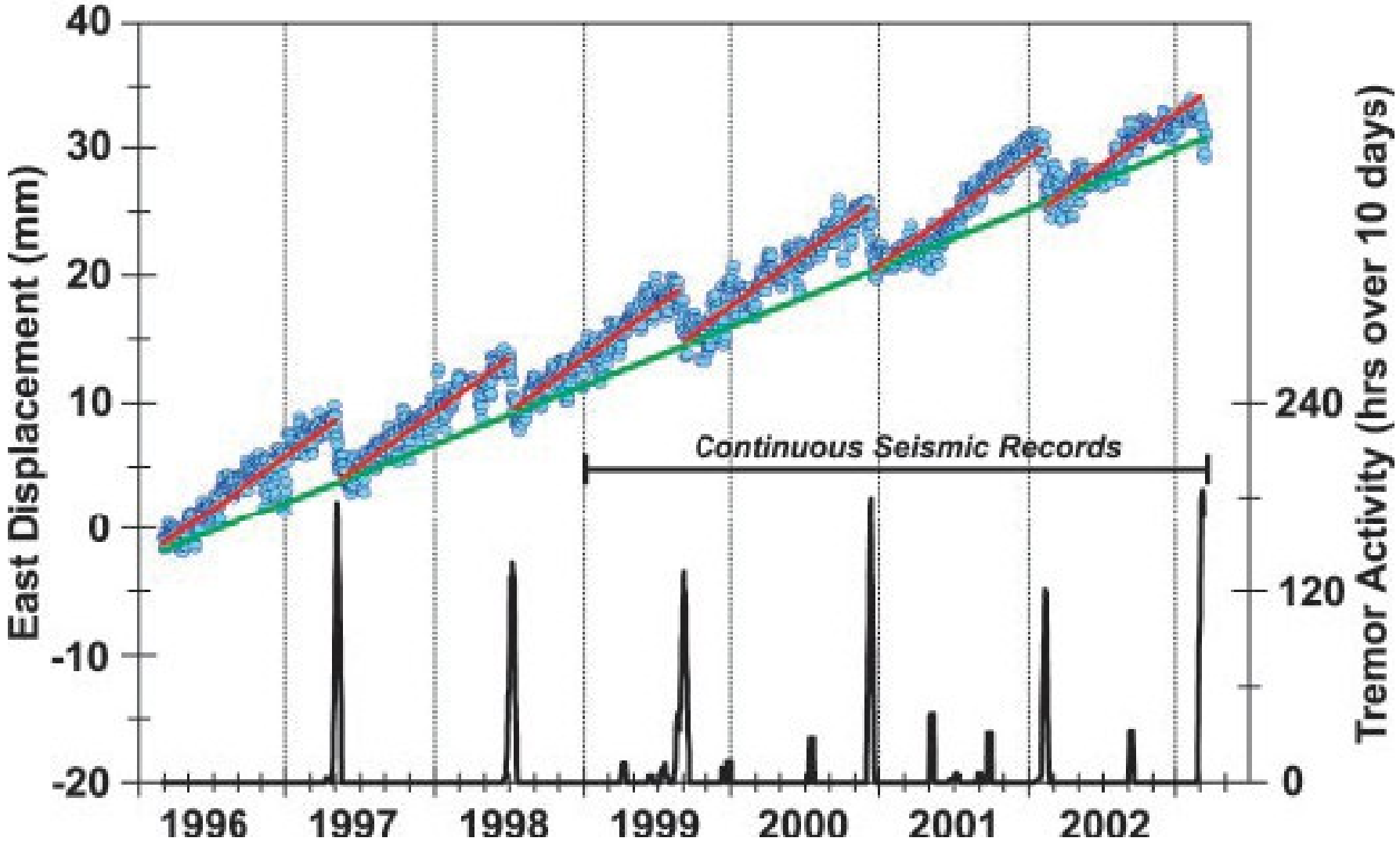
Jump in GPS stations time series

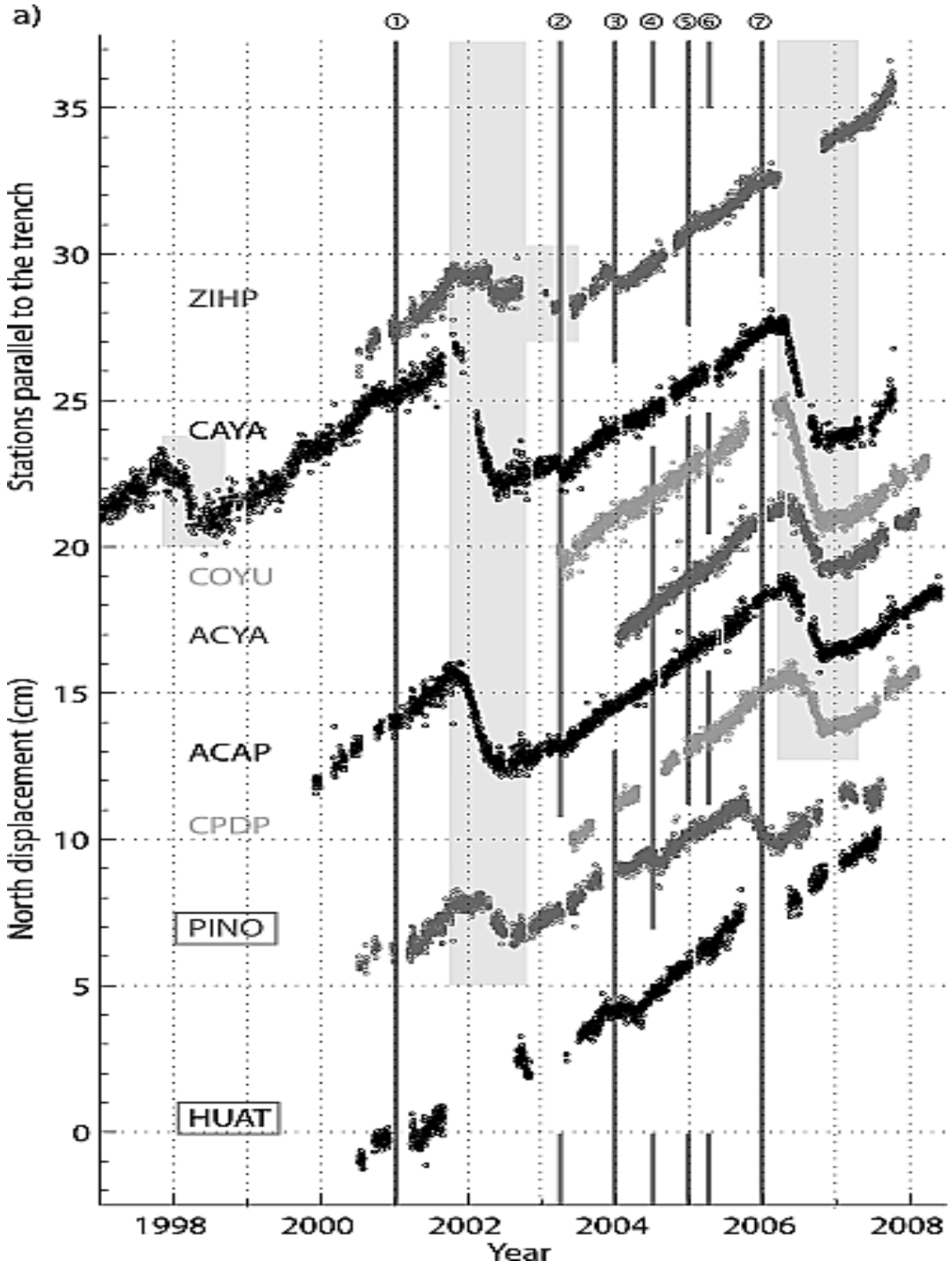
Dragert et al., Science, 292, May 2001



Repeated features, related to tremor

Rogers and Draggert, Science, 300, June 2003

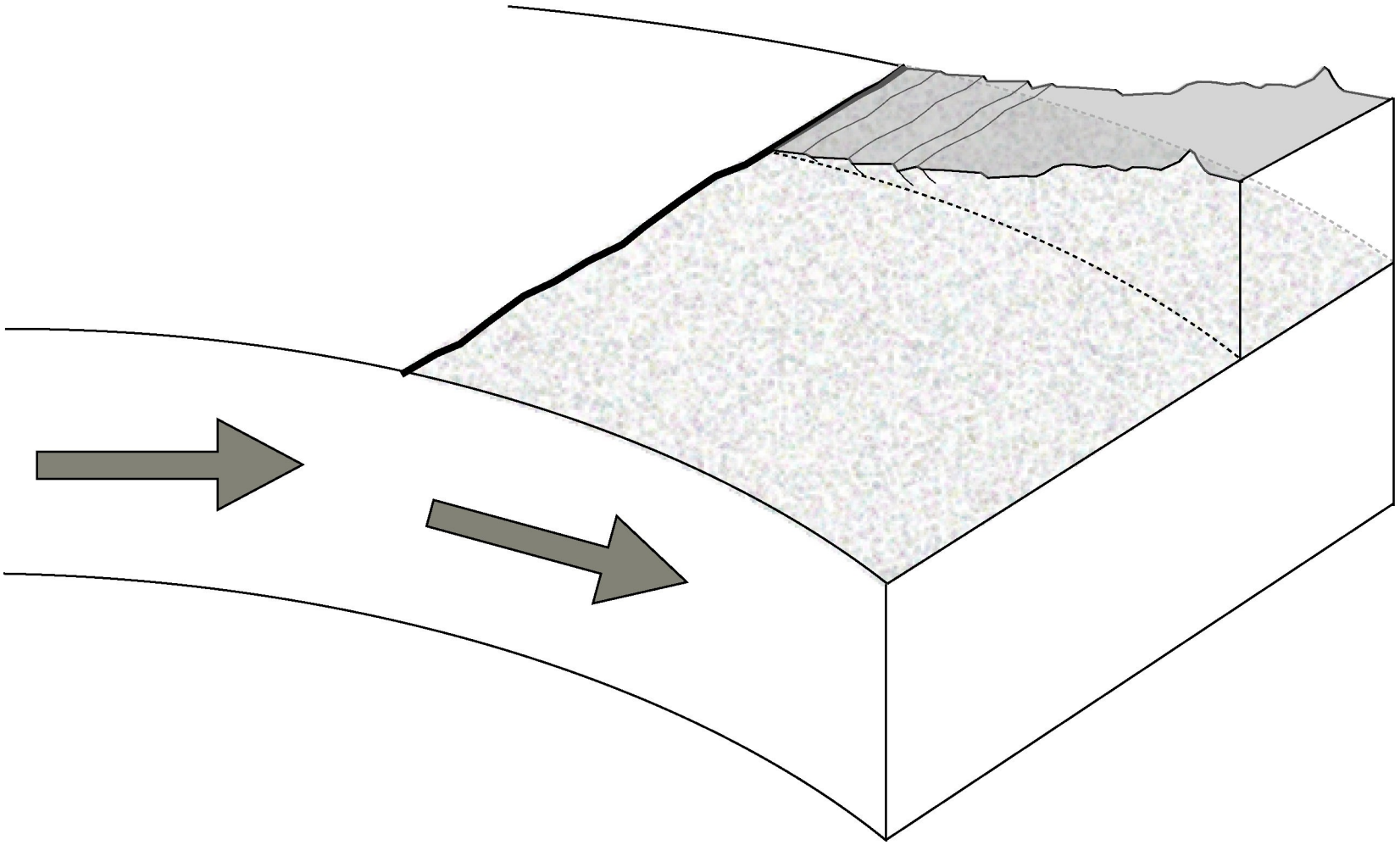




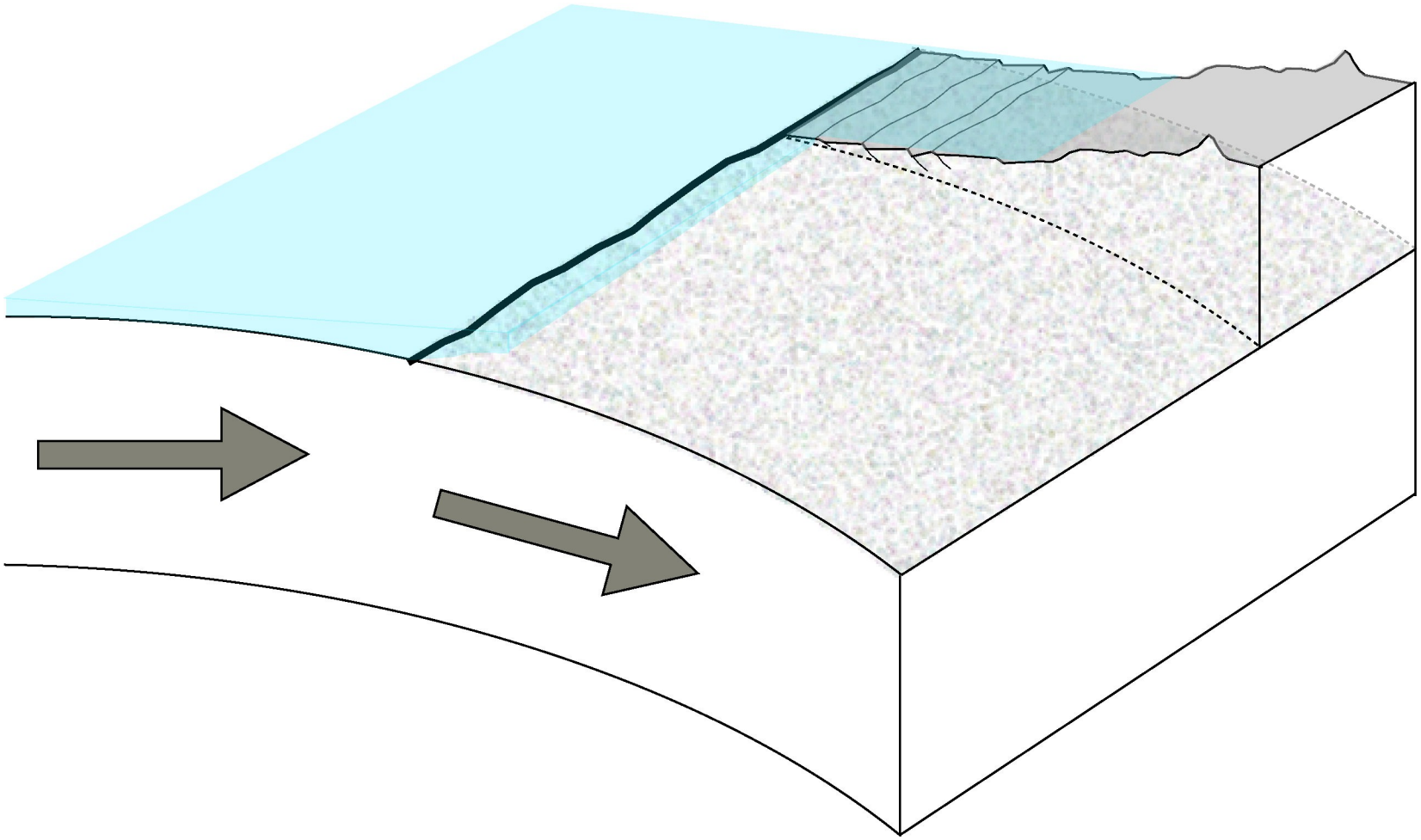
Au Mexique aussi

Vergnolle et al., JGR, 2009

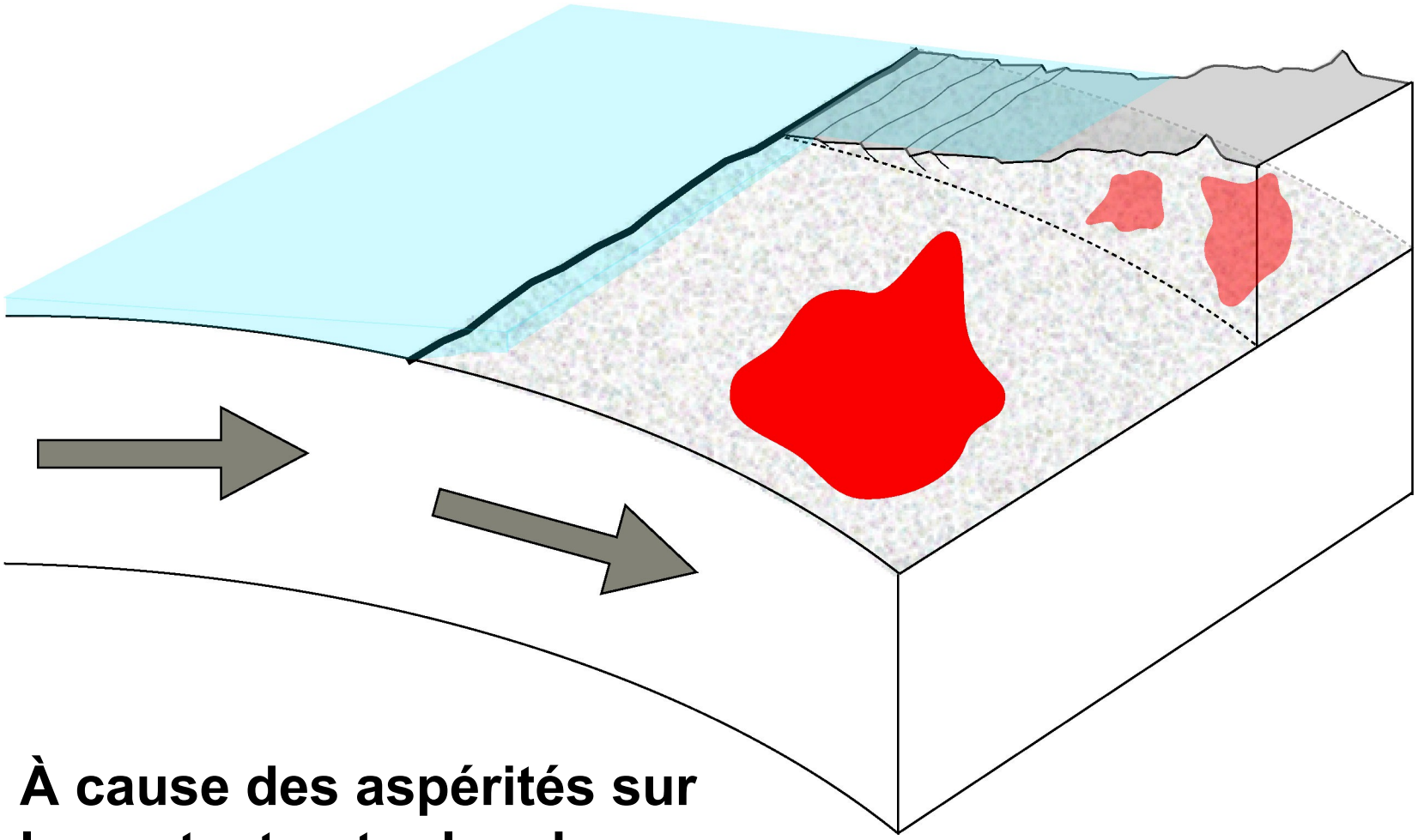
Pourquoi y a-t-il des séismes ?



Pourquoi y a-t-il des séismes ?

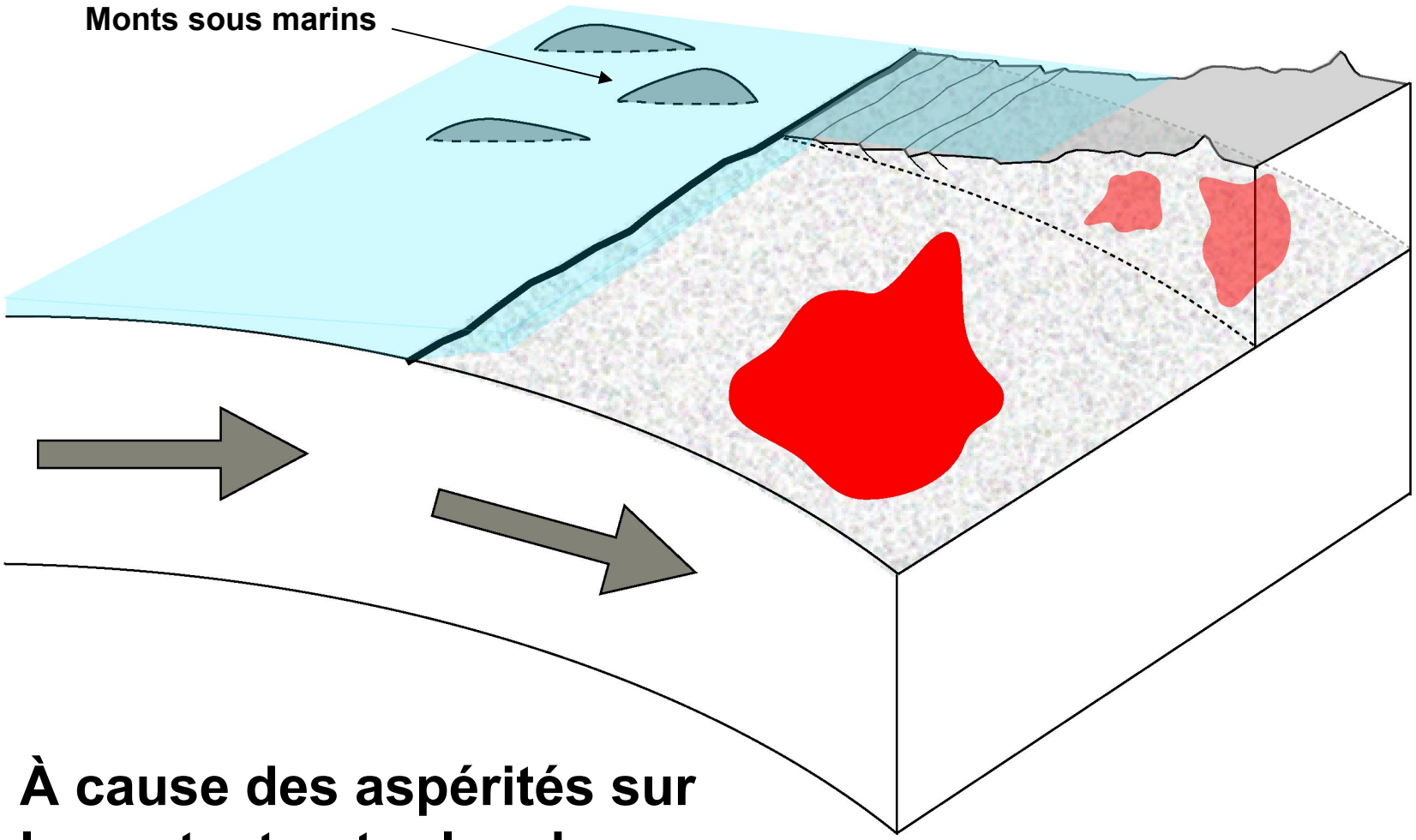


Pourquoi y a-t-il des séismes ?



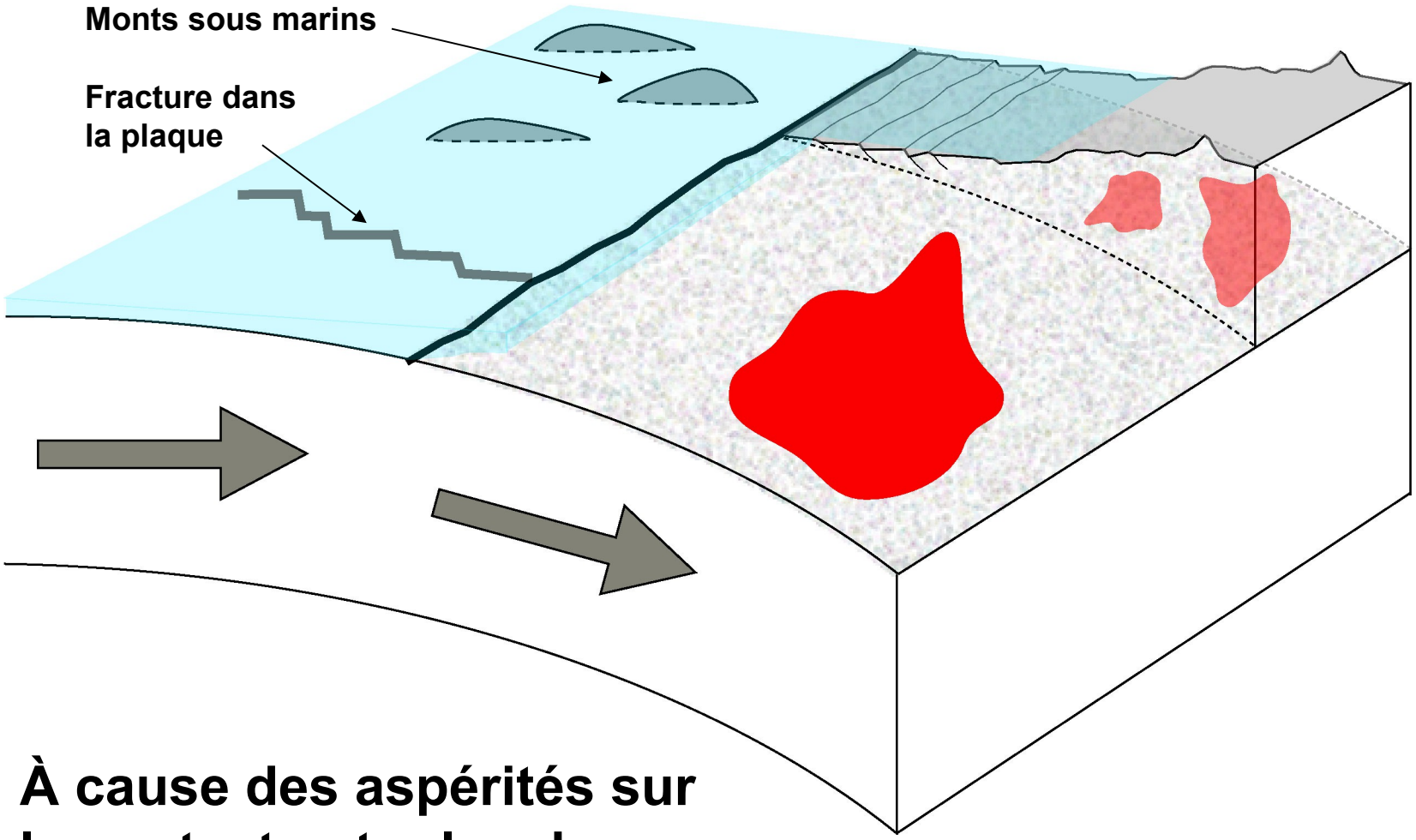
À cause des aspérités sur le contact entre les deux plaques

Pourquoi y a-t-il des séismes ?



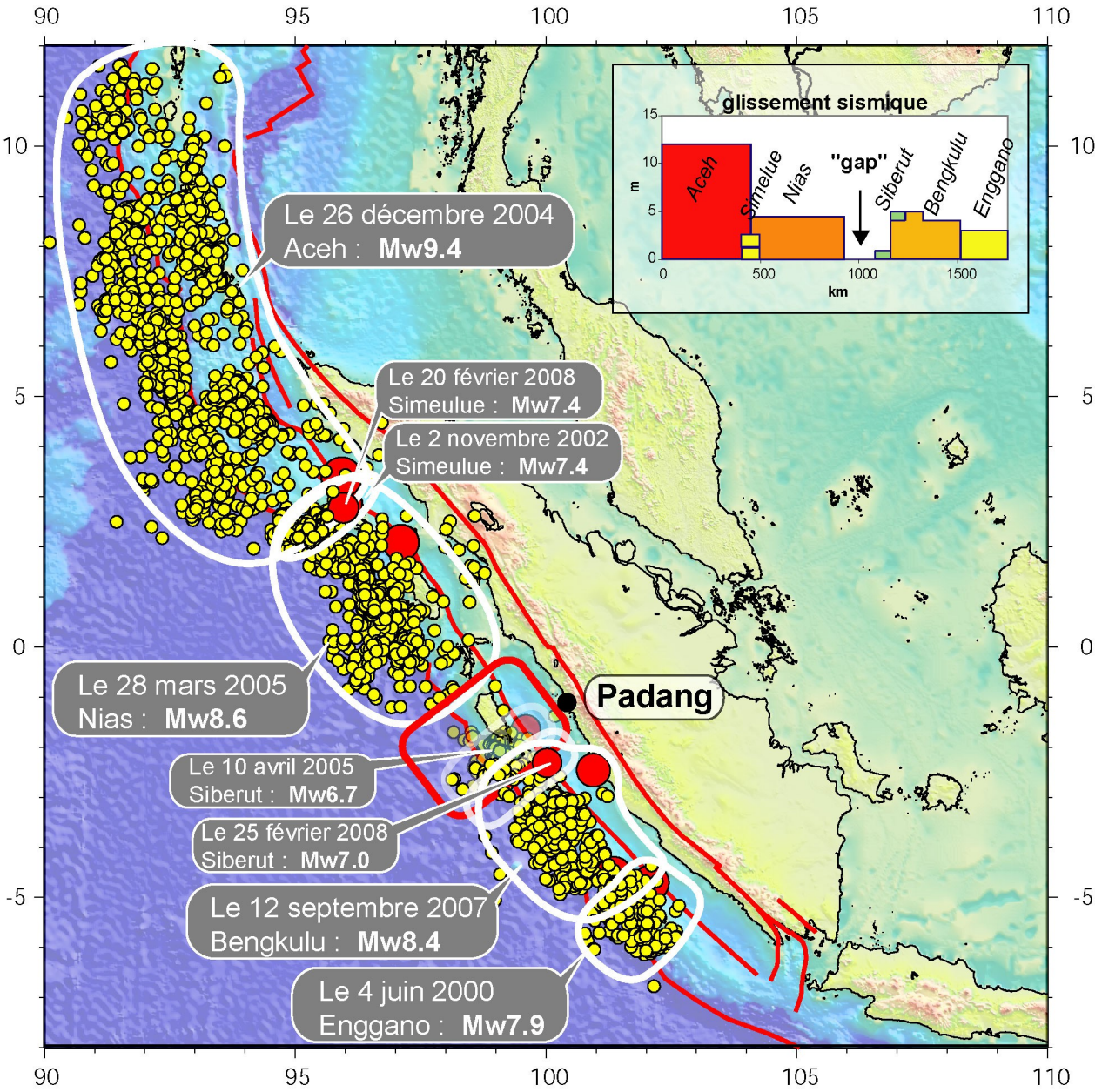
À cause des aspérités sur le contact entre les deux plaques

Pourquoi y a-t-il des séismes ?



À cause des aspérités sur le contact entre les deux plaques

Le(s) séisme(s) de Sumatra


90
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glissement sismique
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m
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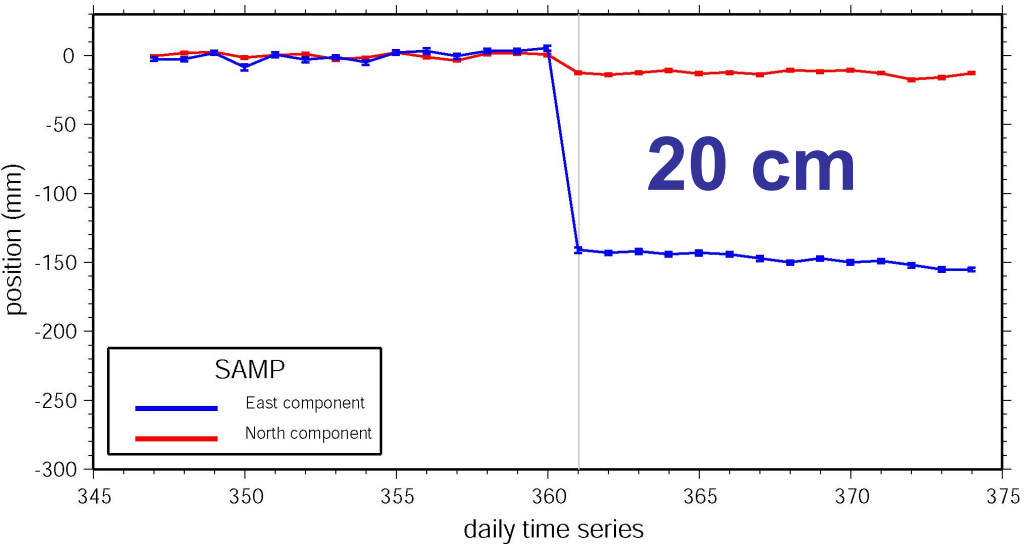
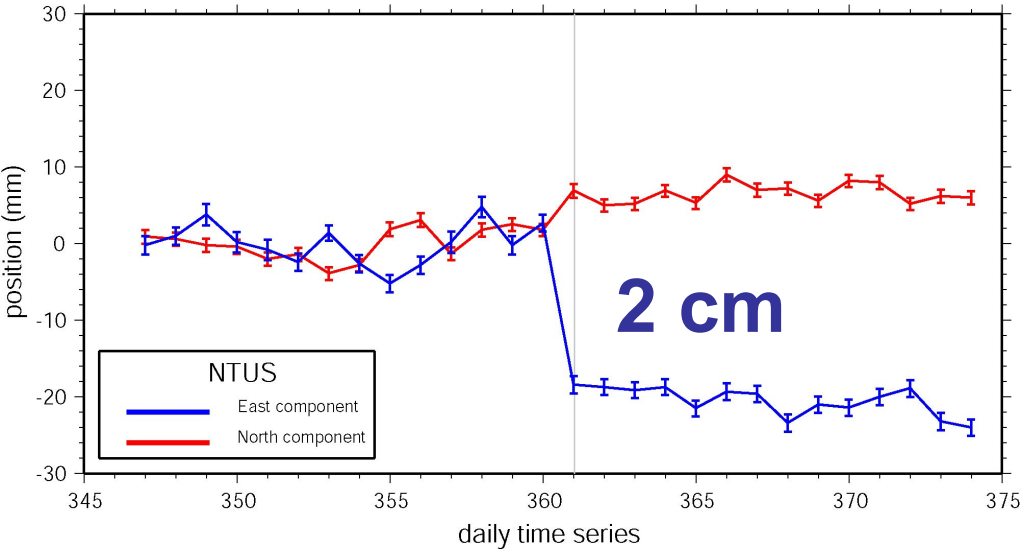
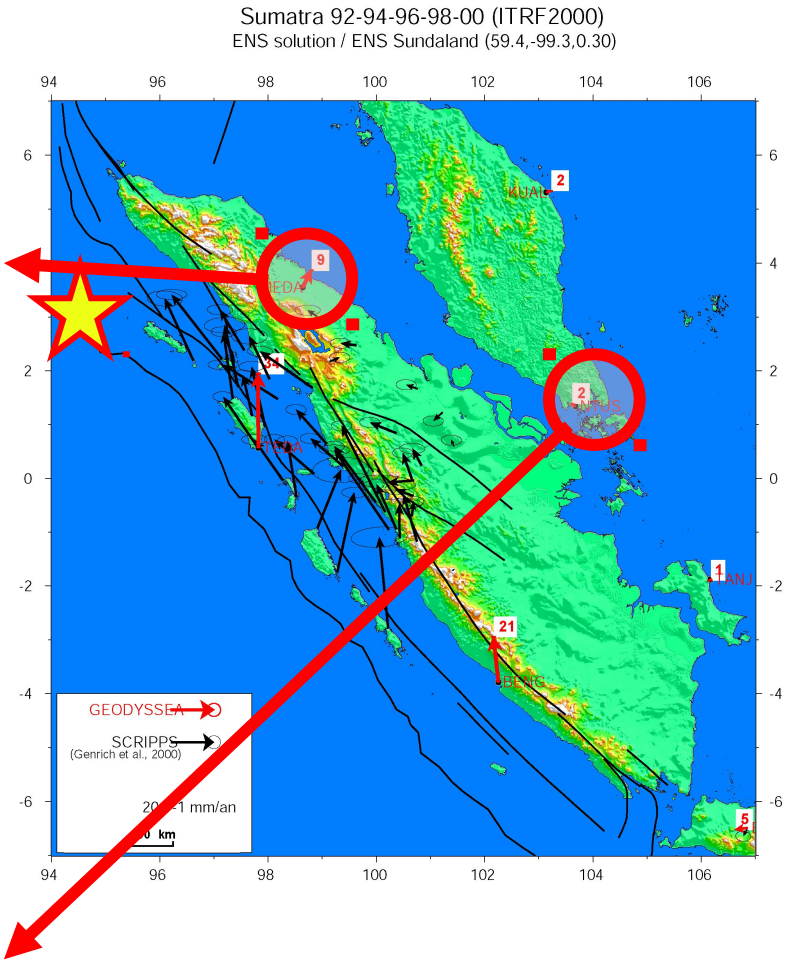
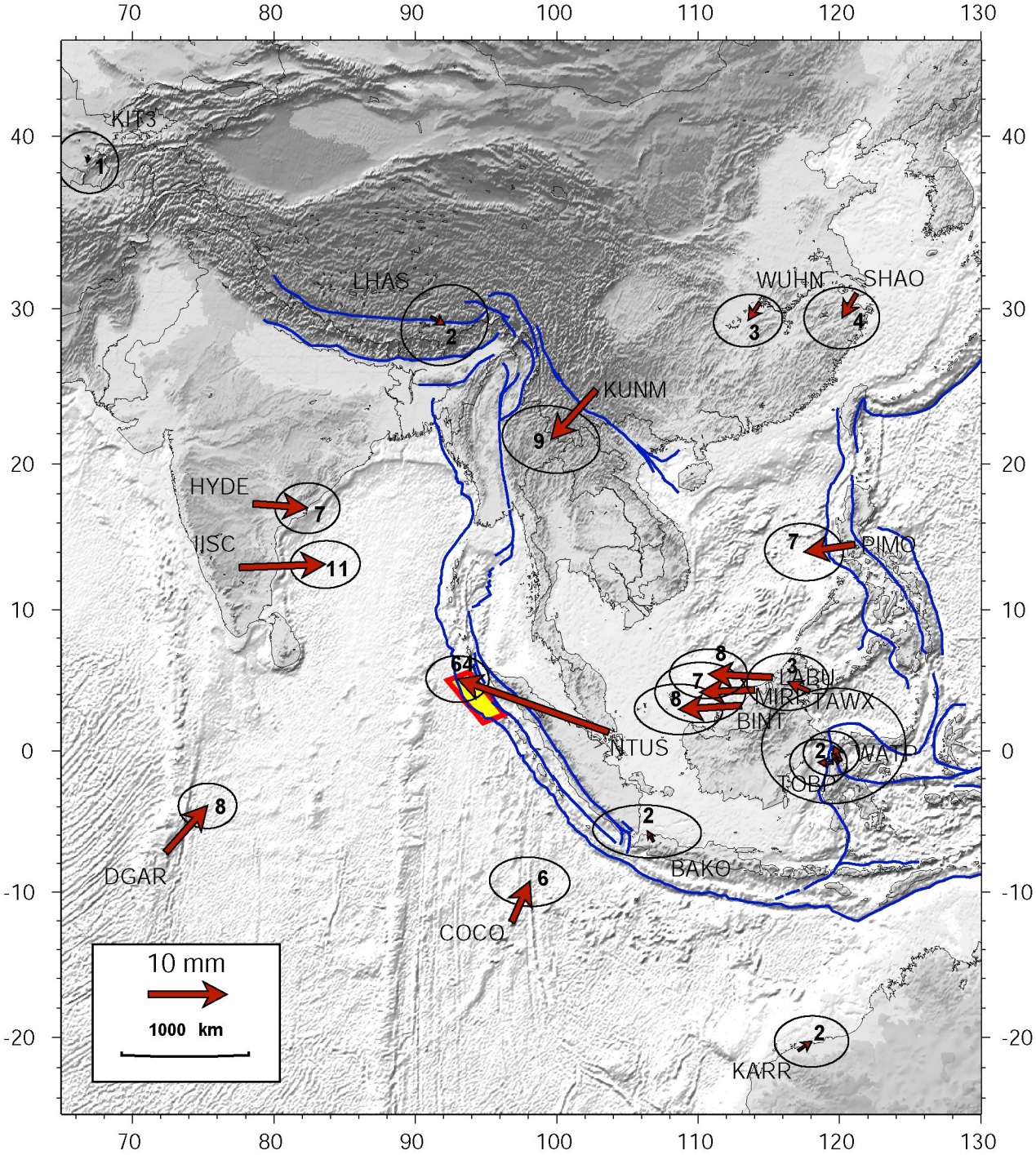
Nias
"gap"
Siberut
Bengkulu
Enggano
0
500
1000
1500
km
Le 26 décembre 2004
Aceh : Mw9.4
Le 20 février 2008
Simeulue : Mw7.4
Le 2 novembre 2002
Simeulue : Mw7.4
Le 28 mars 2005
Nias : Mw8.6
Padang
Le 10 avril 2005
Siberut : Mw6.7
Le 25 février 2008
Siberut : Mw7.0
Le 12 septembre 2007
Bengkulu : Mw8.4
Le 4 juin 2000
Enggano : Mw7.9

Le séisme de Sumatra du 25 décembre 2004








70
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30
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1
LHAS
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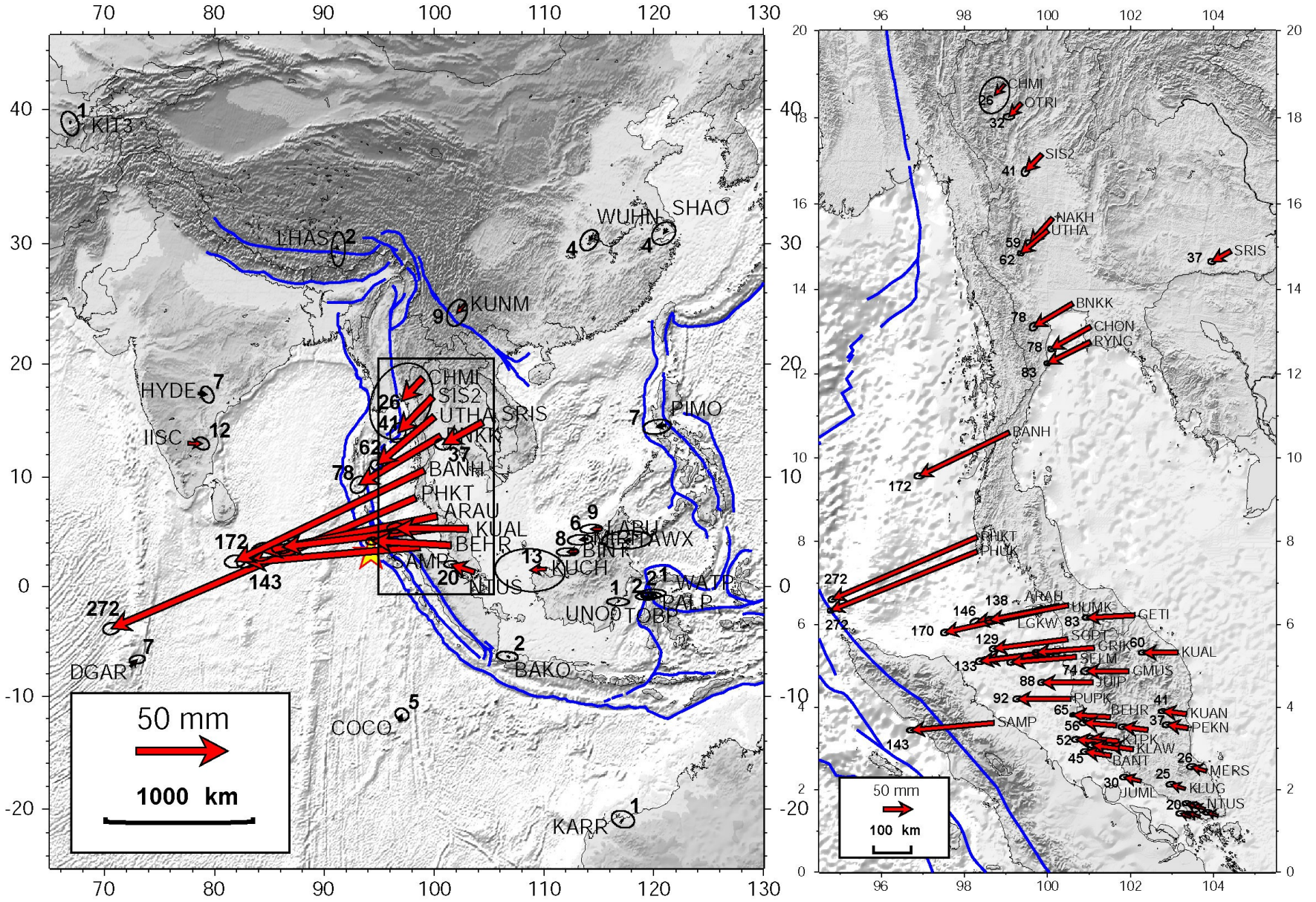
SHAO
4
KUNM
9
HYDE
7
IISC
11
PIMO
7
64
8
7
8
3
IRKU
MIRT
TAWX
BJNT
IITUS
2
WAIP
TOBI
2
BAKO
8
DGAR
6
COCO
2
KARR
10 mm
1000 km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IISC
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SIS2
UTHA
SRIS
BNKK
BANH
PHKT
ARAU
KUAL
BEHR
SAMP
NTUS
KUCH
BINT
LABU
MIDA
LAWX
PIMO
WATP
PALP
UNOO
TOBI
BAKO
DGAR
COCO
KARR
50 mm
1000 km
96
98
100
102
104
20
18
16
14
12
10
8
6
4
2
0
-20
OTRI
NAKH
UTHA
SRIS
BNKK
CHON
RYNG
PHUK
UUMK
GETI
LGKW
SGDT
GRIK
KUAL
SELM
GMUS
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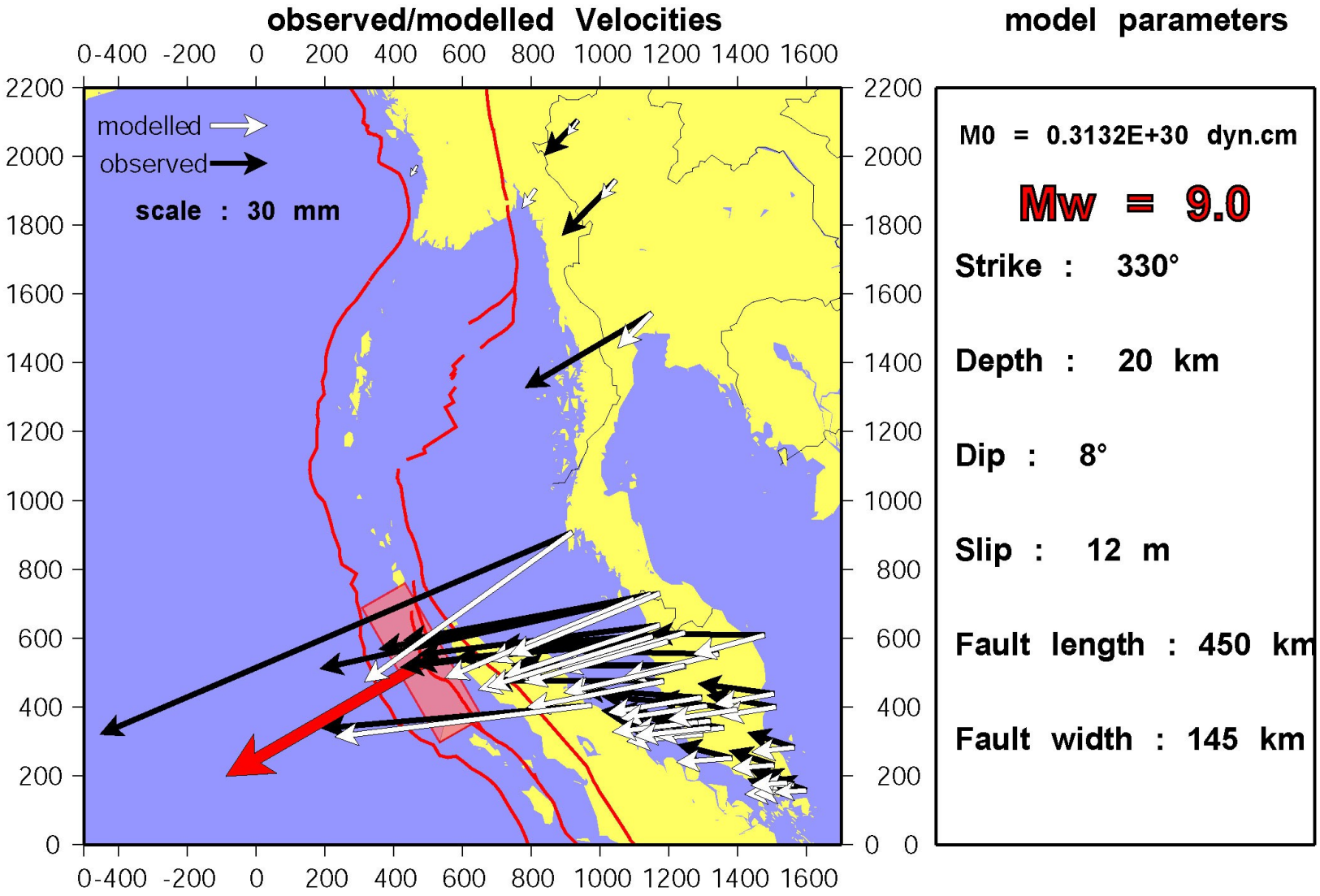
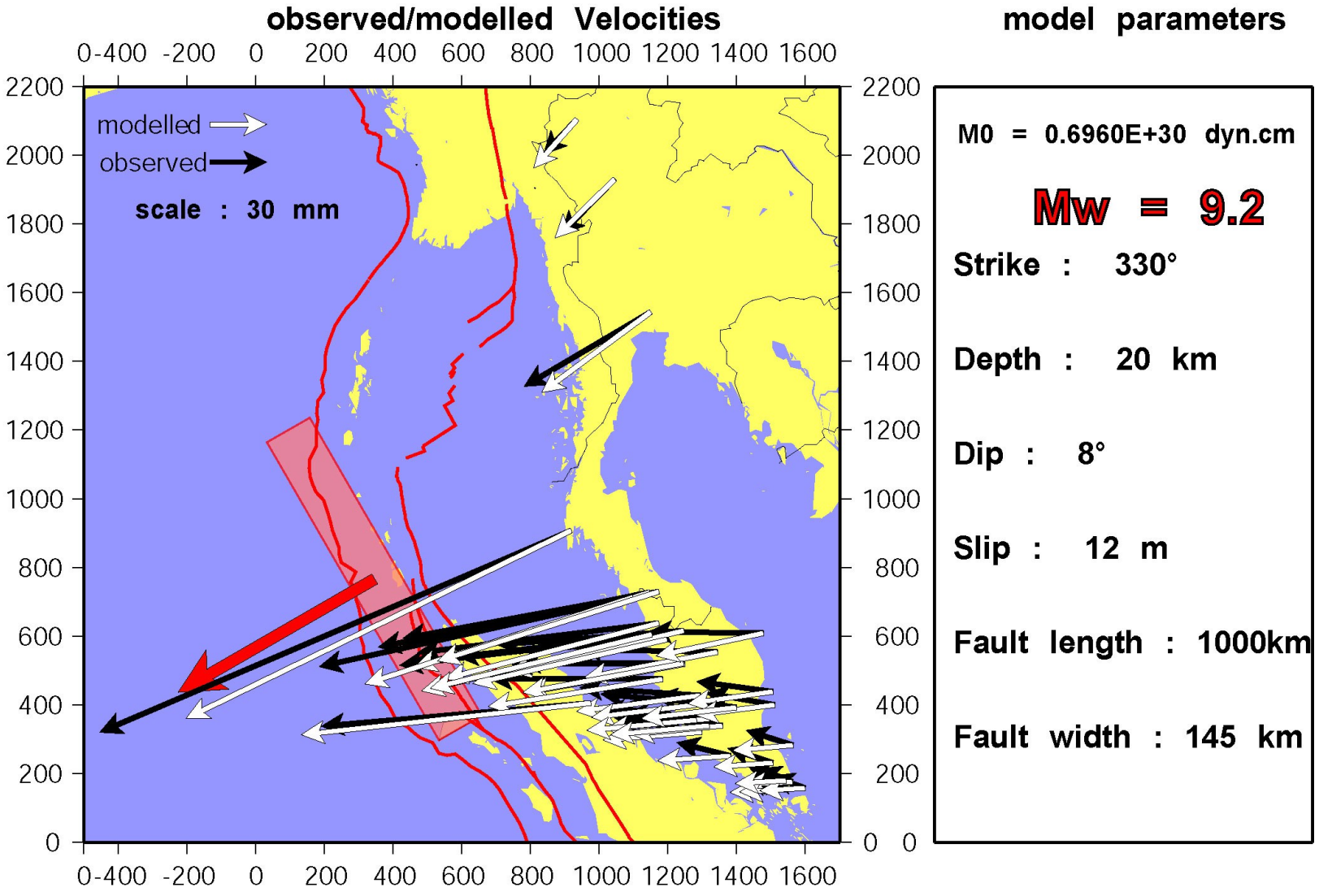
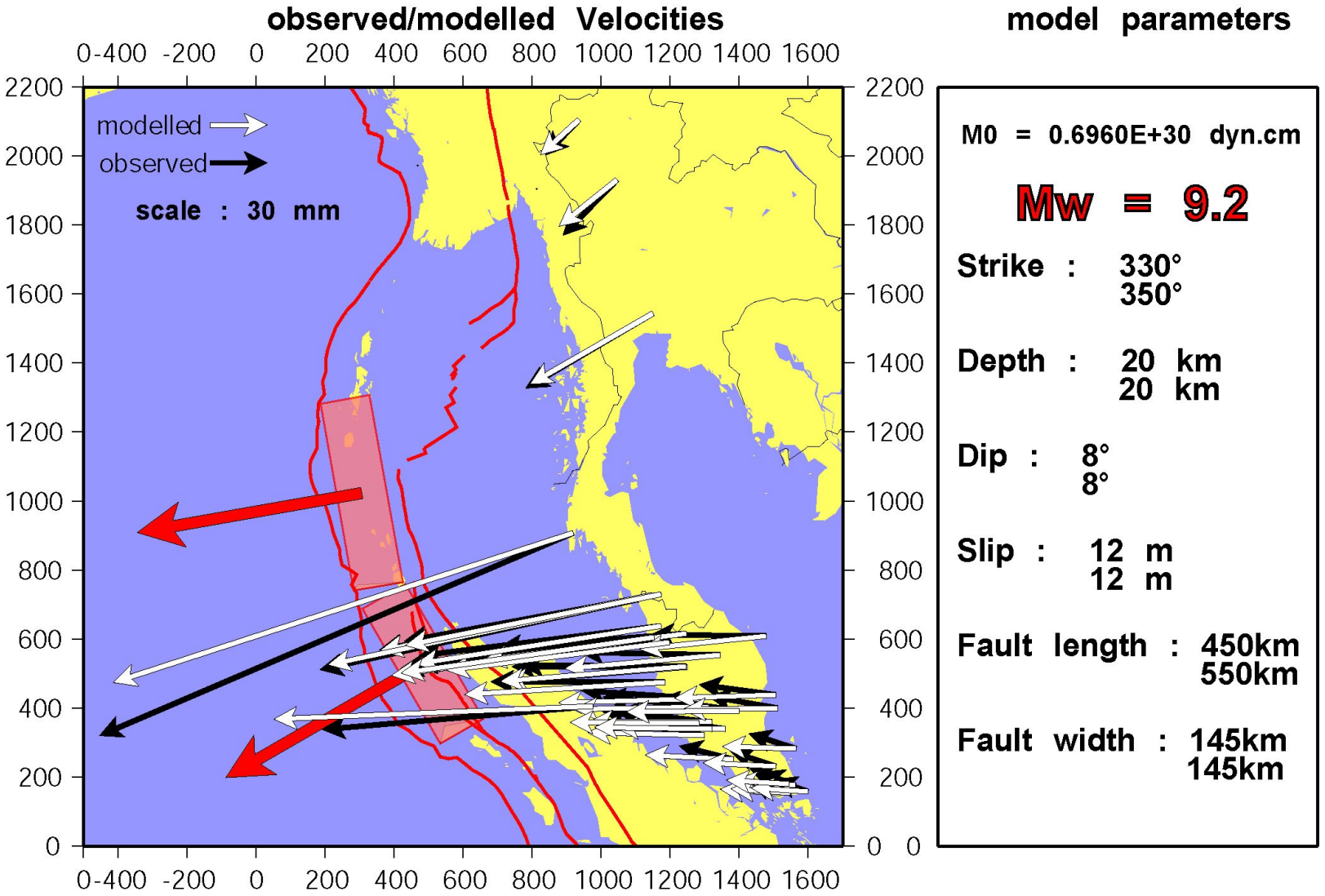
NTUS
50 mm
100 km



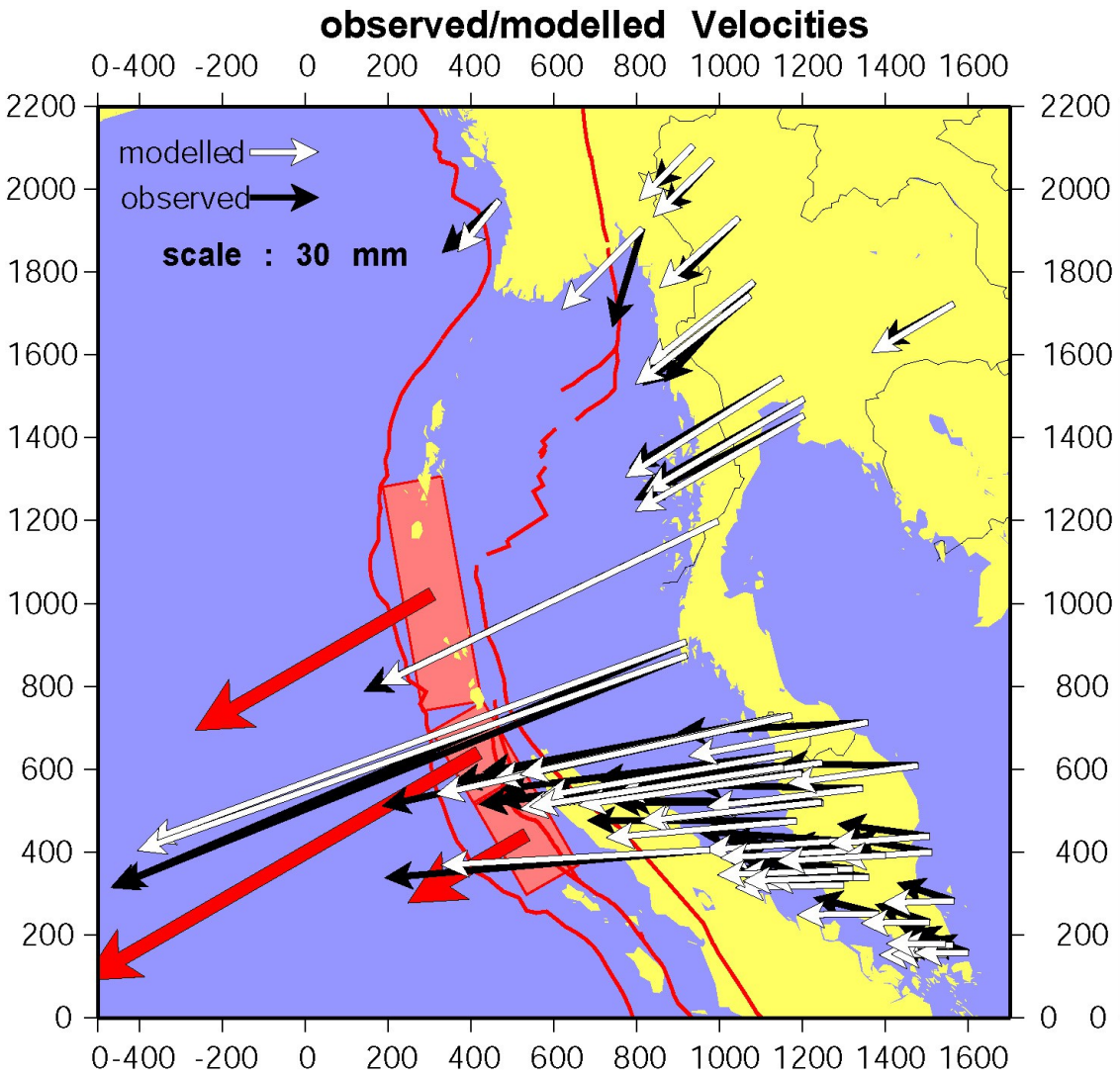
A rupture of 450 km length gives the reported magnitude (Mw=9.0) but it does not fit the observed deformation



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

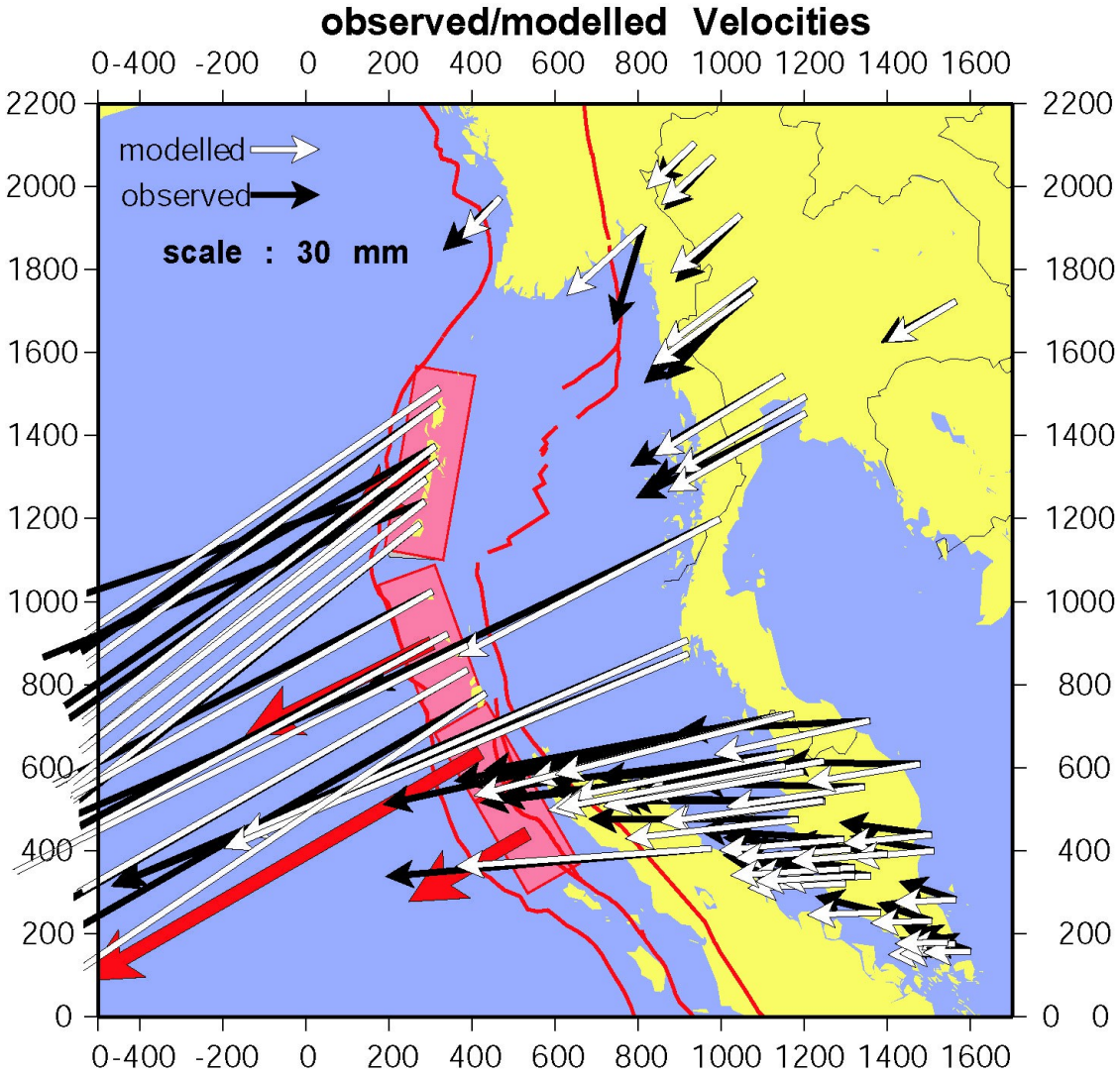
M0=7.018E+29 dyn.cm

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…

Gahalaut et al., 2006
+
Maurin et al., 2006



M0=6.020E+29 dyn.cm

Mw = 9.2

Strike : 330°
330°
340°
10°

Depth : 20 km

Dip : 8°

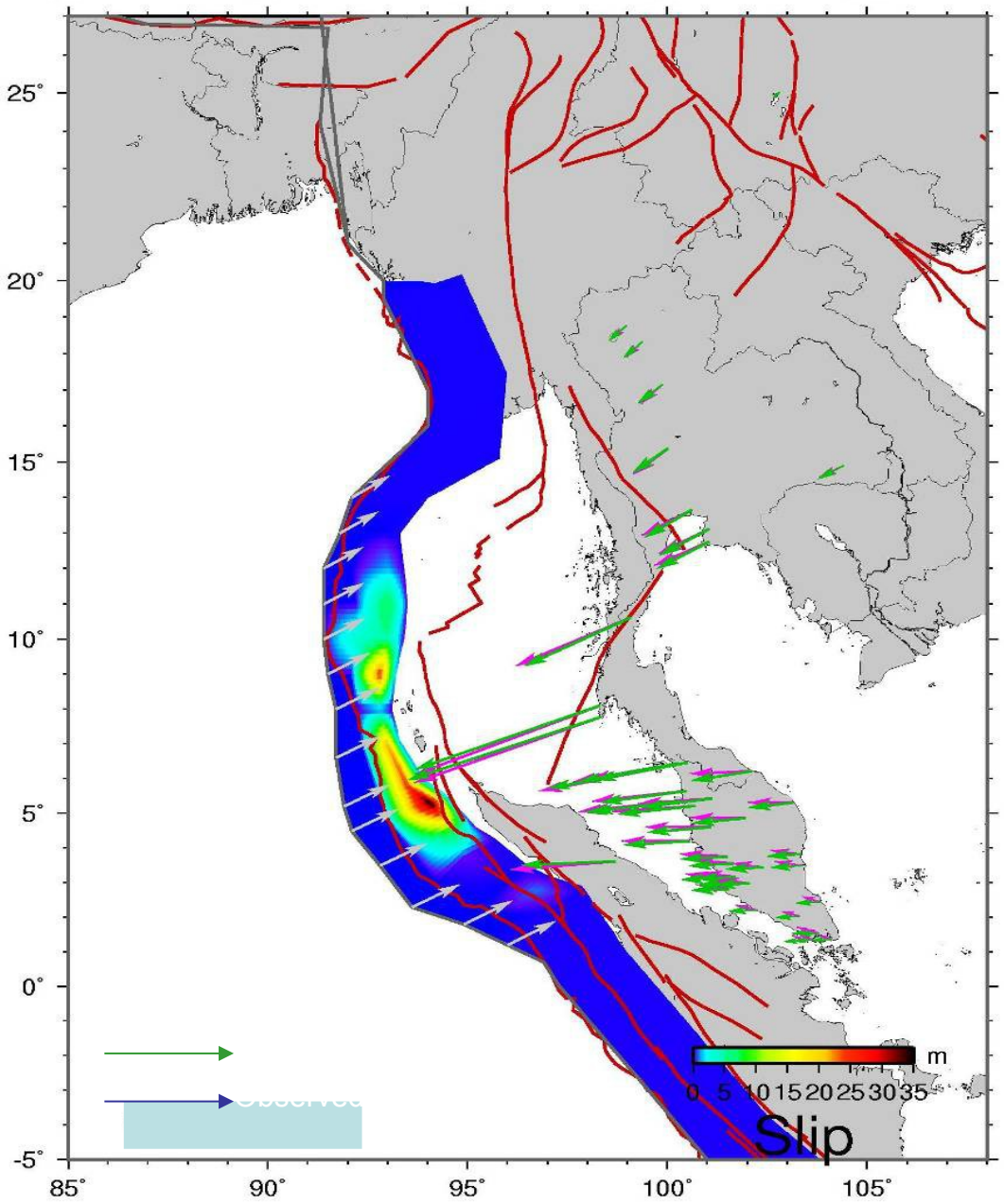
Slip : 6 m
20 m
9 m
4 m

Fault length : 250km
200km
350km
450km

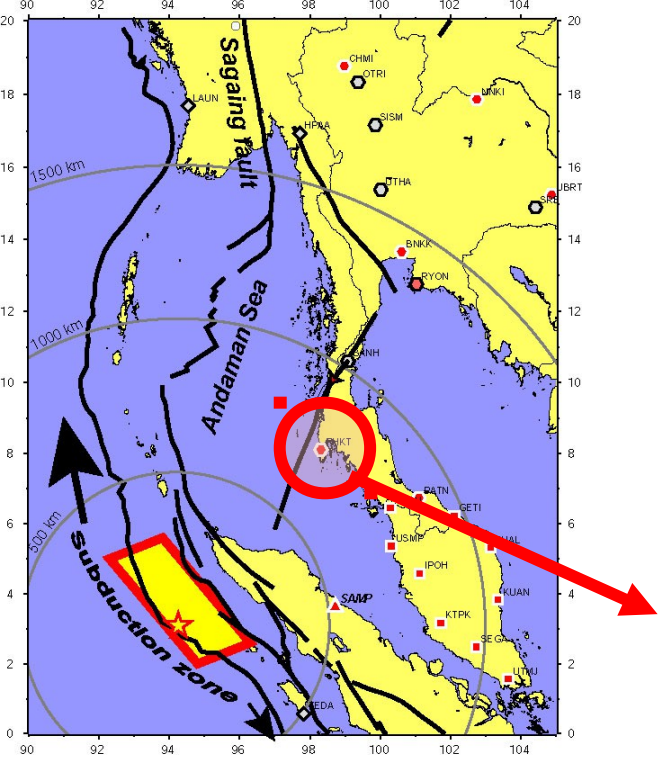
Fault width : 145km

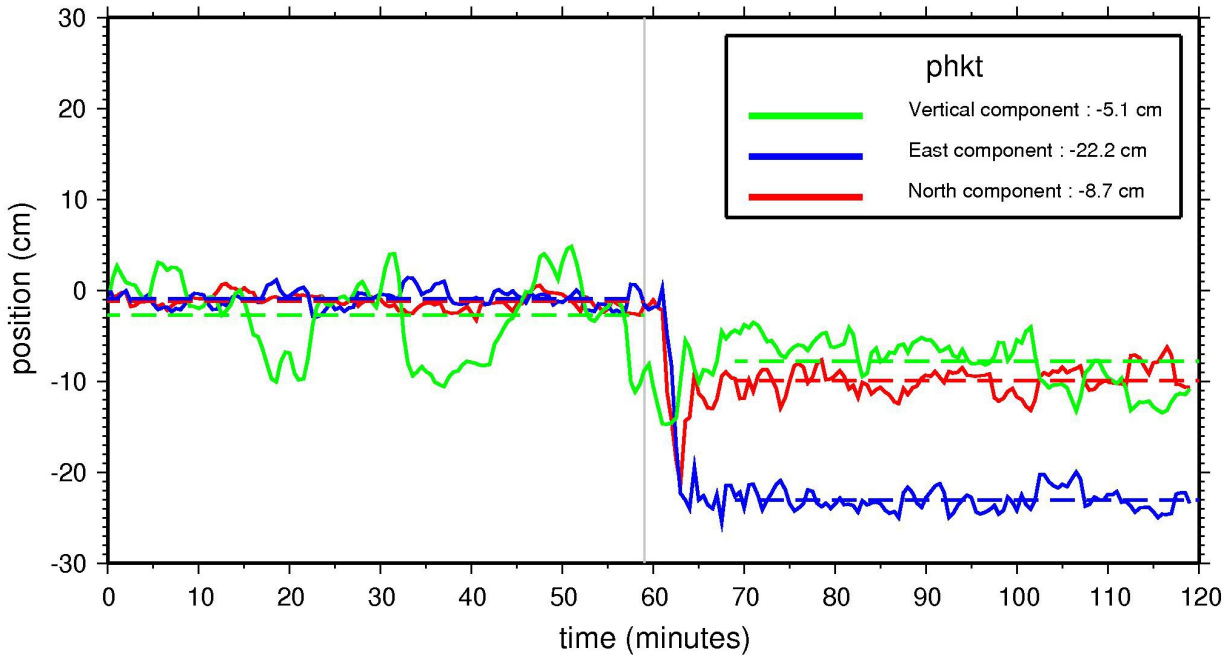
… Andaman data requires longer plane AND oblique slip

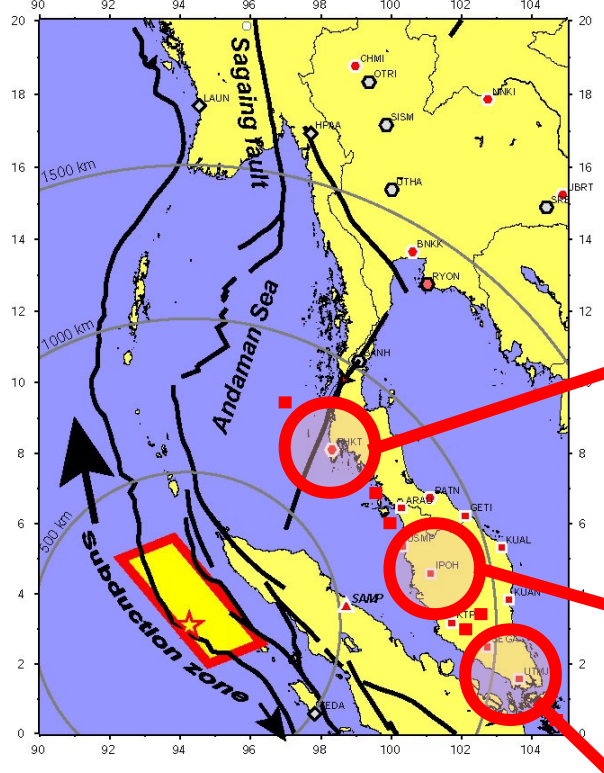
Full inversion of slip on fault

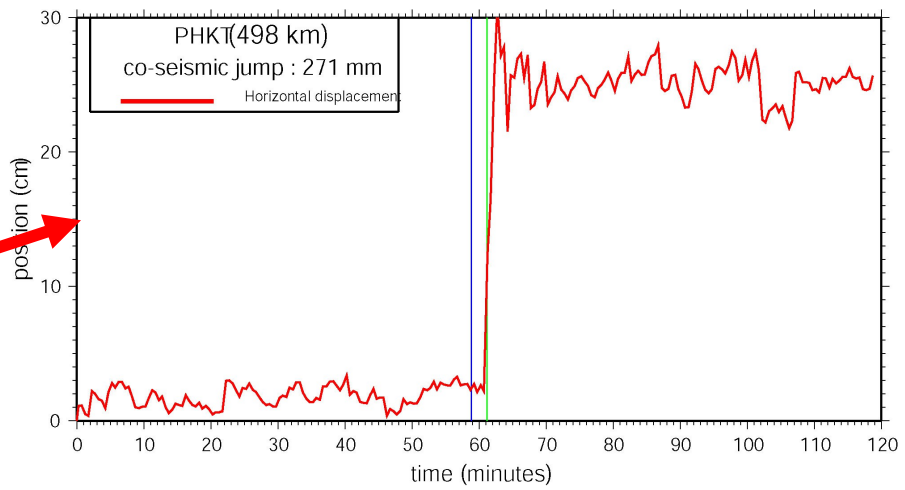


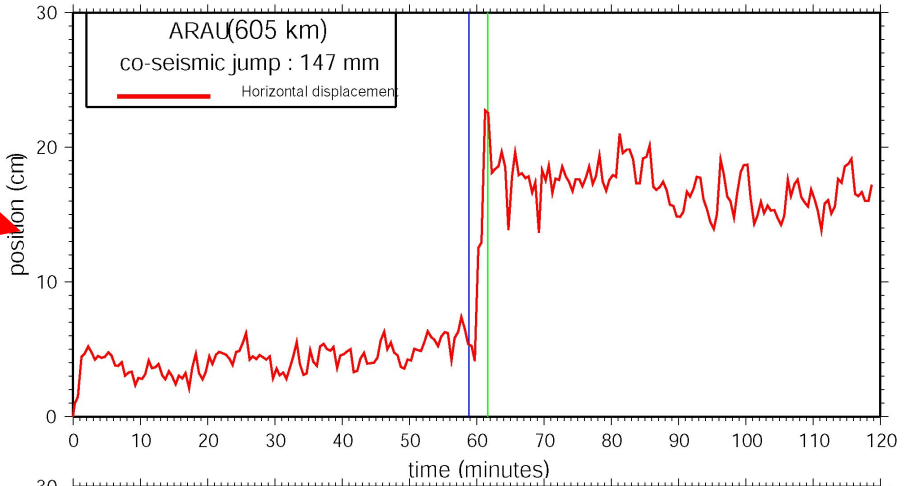
Kinematic solution at Phuket

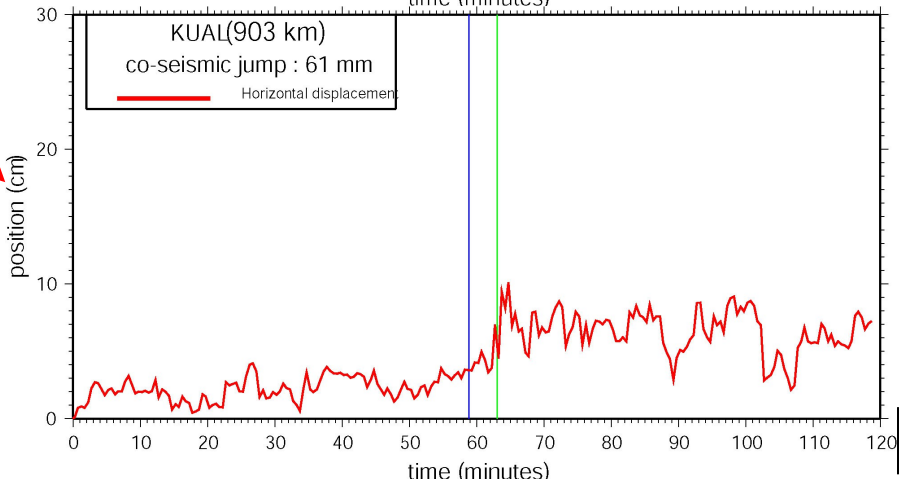








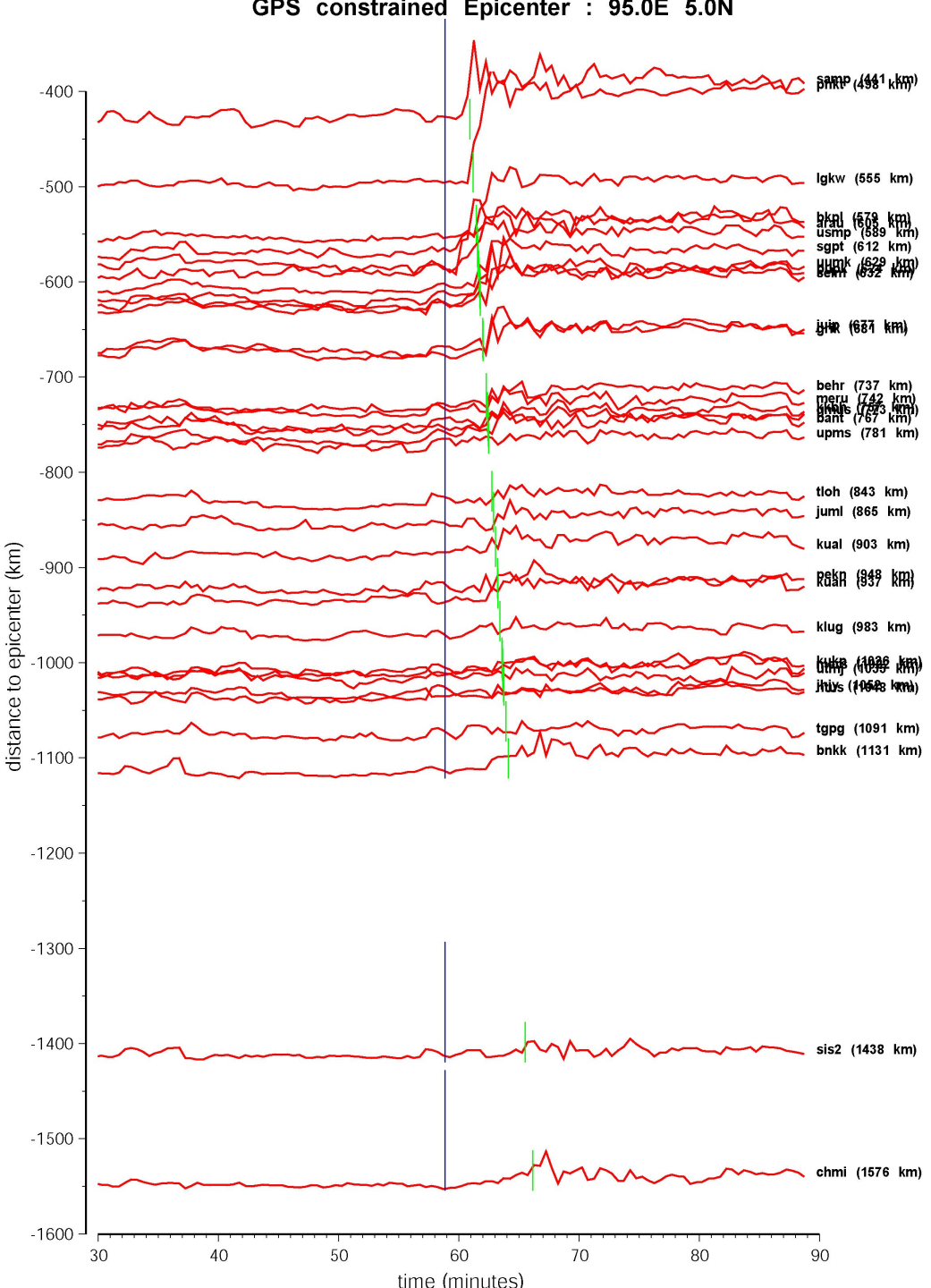




"Kinematic" (epoch-by-epoch) positioning of the GPS station show the co-seismic step…

…and allow to determine the displacement arrival time

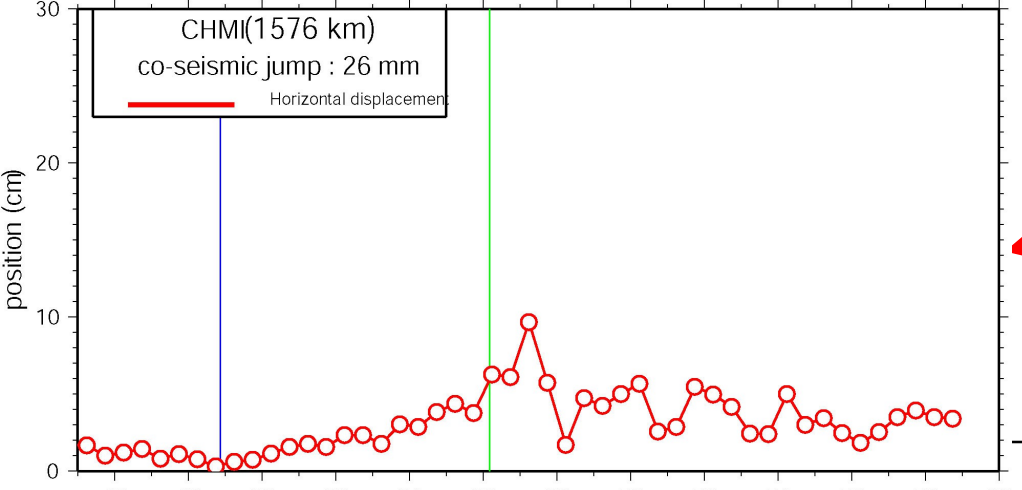
It seems related to surface waves rather than P or S wave……

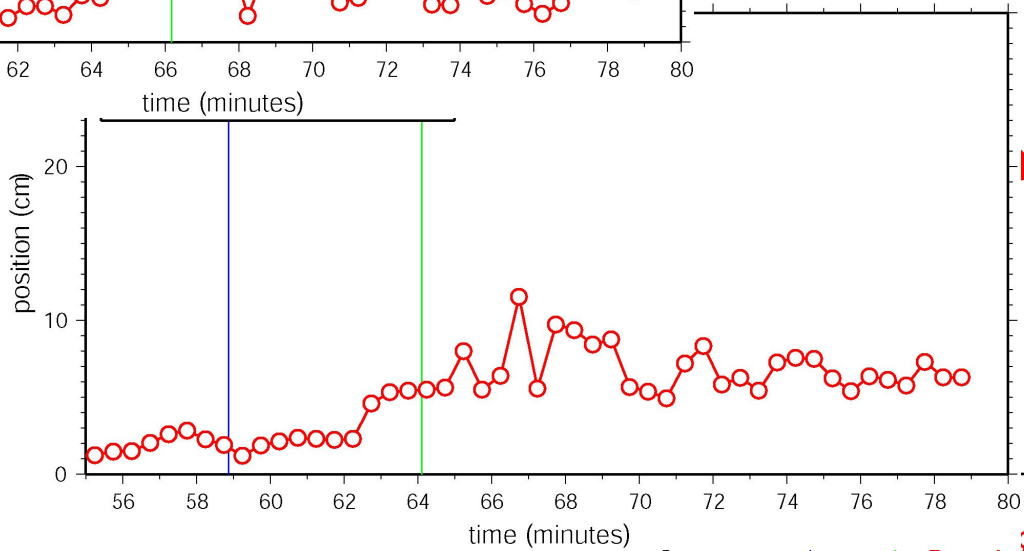


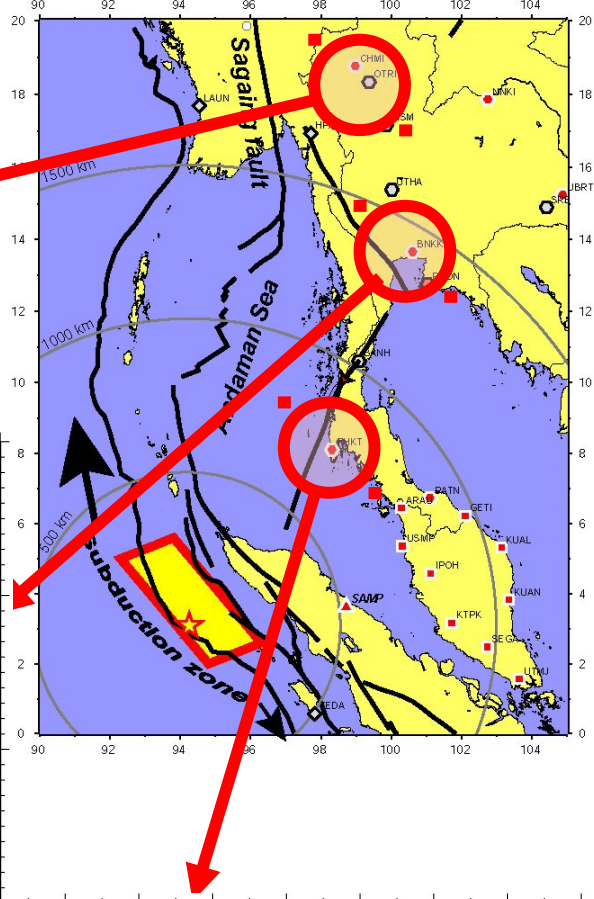
Assuming a velocity of 3.6 km/s for seismic waves

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

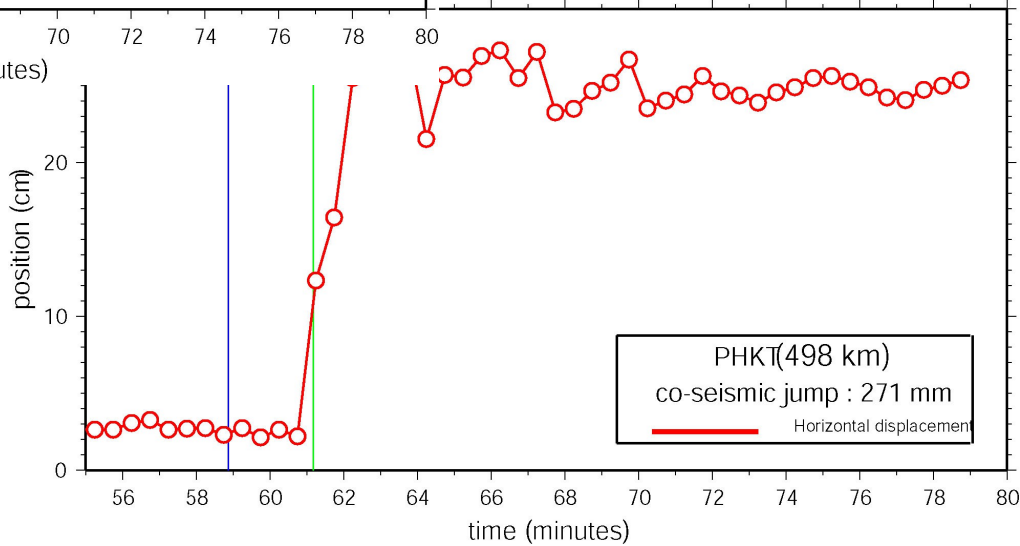
Again, a relocation of 200 km to the north is requested

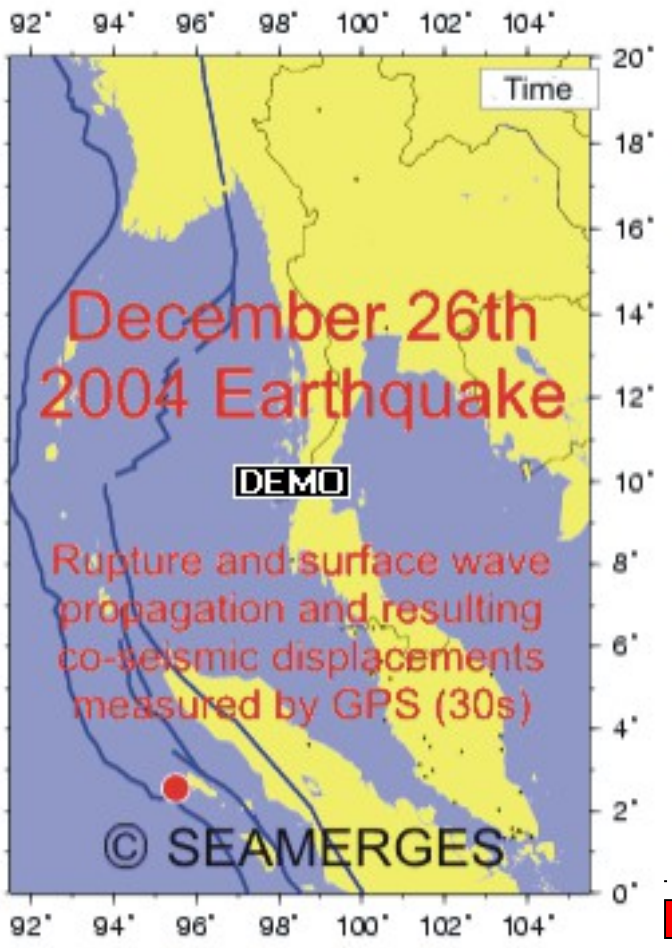






Indication of source directivity is pointed by larger “rise times” at northern stations





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

rupture

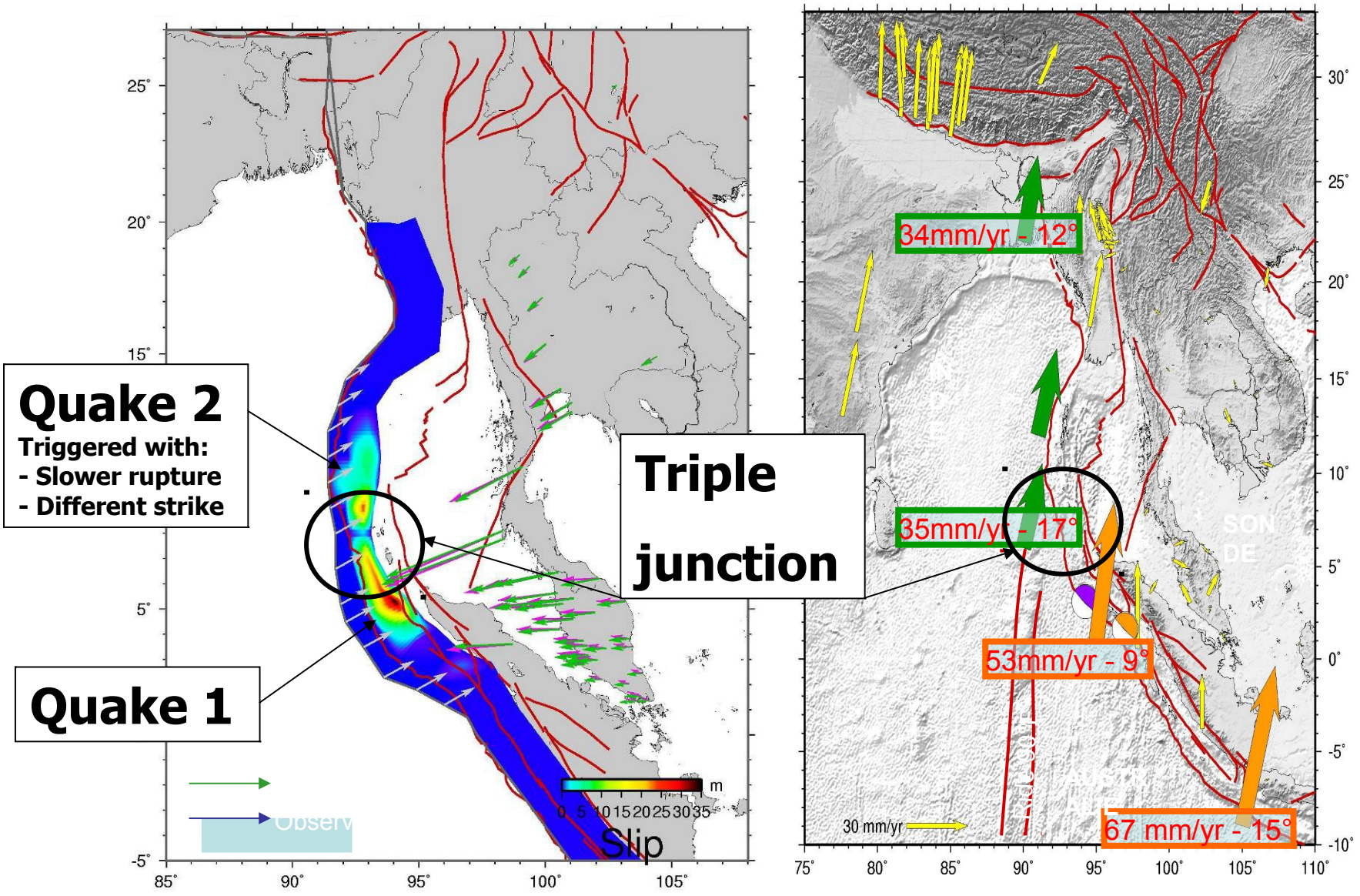
Seismic **surface** waves propagation

(3.7 km/s)

GPS stations displacements

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

GPS cinématique => vitesse de rupture



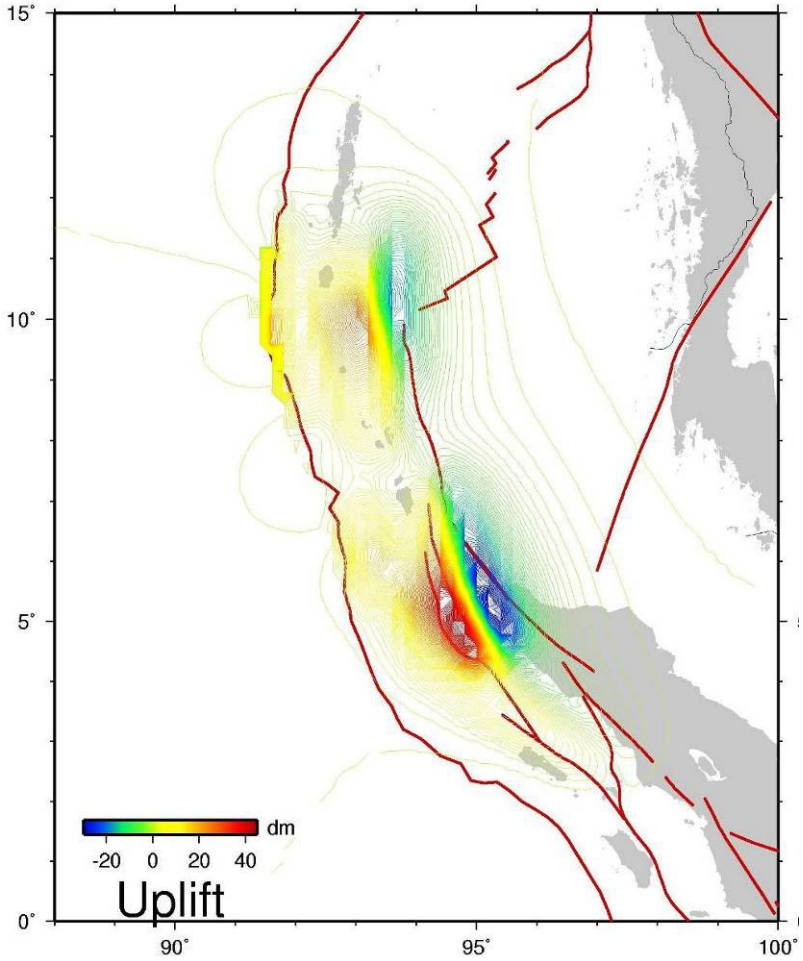
GPS cinématique+statique => 2 ruptures

Vertical motions predicted by the models

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

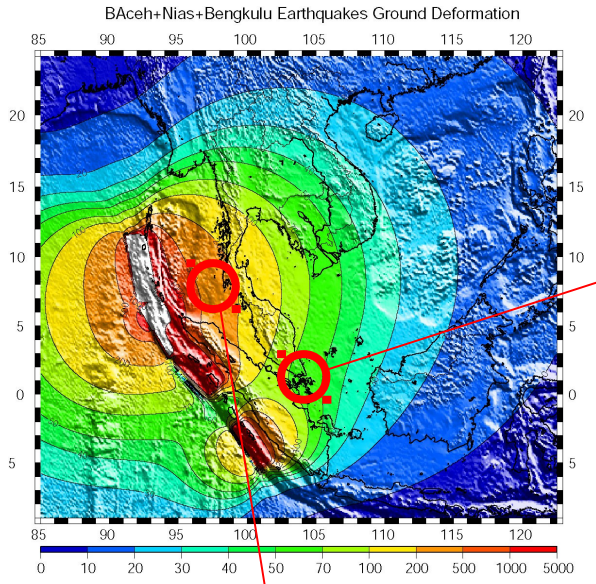
Tsunami modélisation

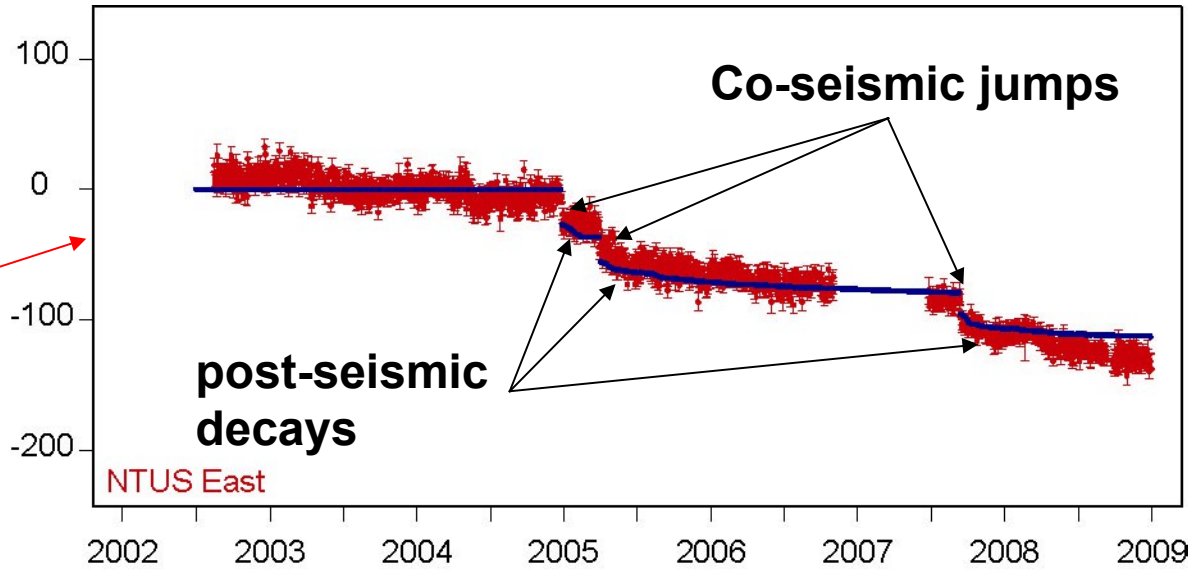
Pietrzack et al., 2007

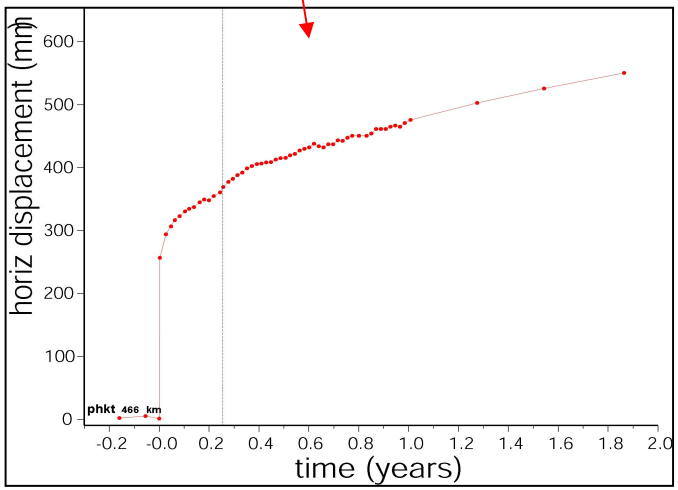


GPS cinématique+statique => modèle de Tsunami

post-seismic deformations



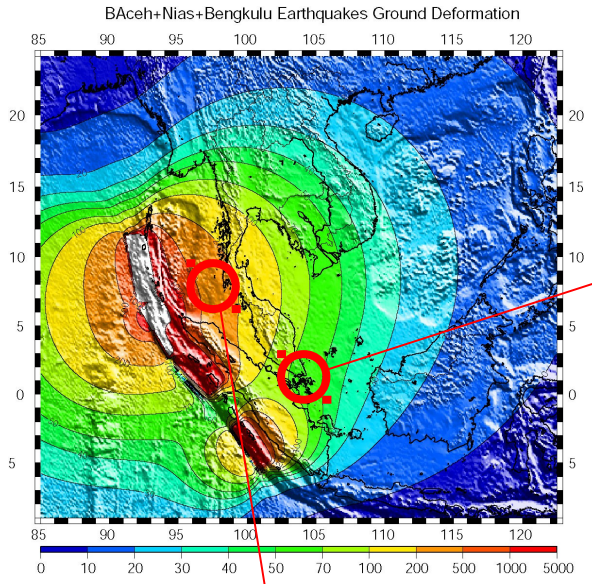


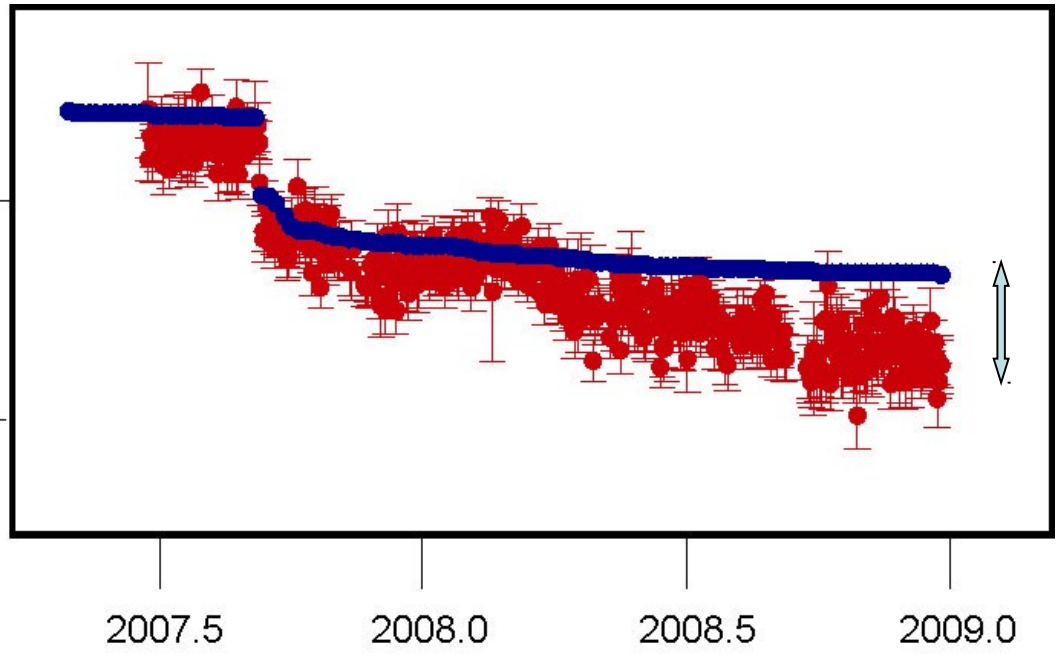


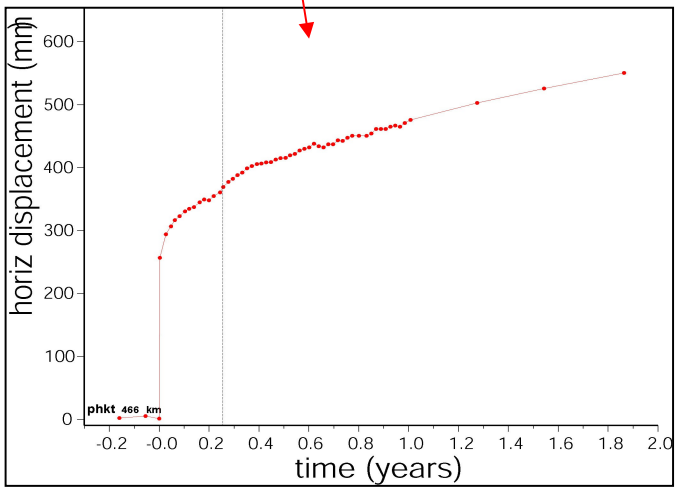
rates are different from what they were before… and they keep changing with time

Reference networks in these countries have to be redone… continuously !!

post-seismic deformations







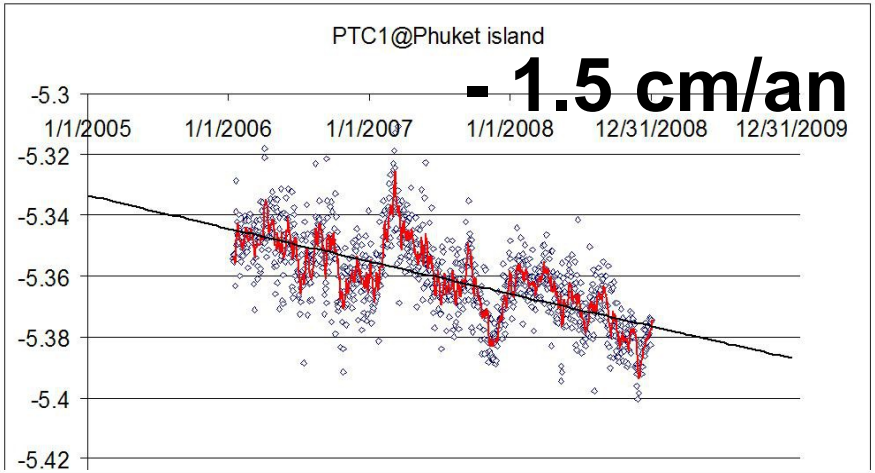
Models don't really match the data

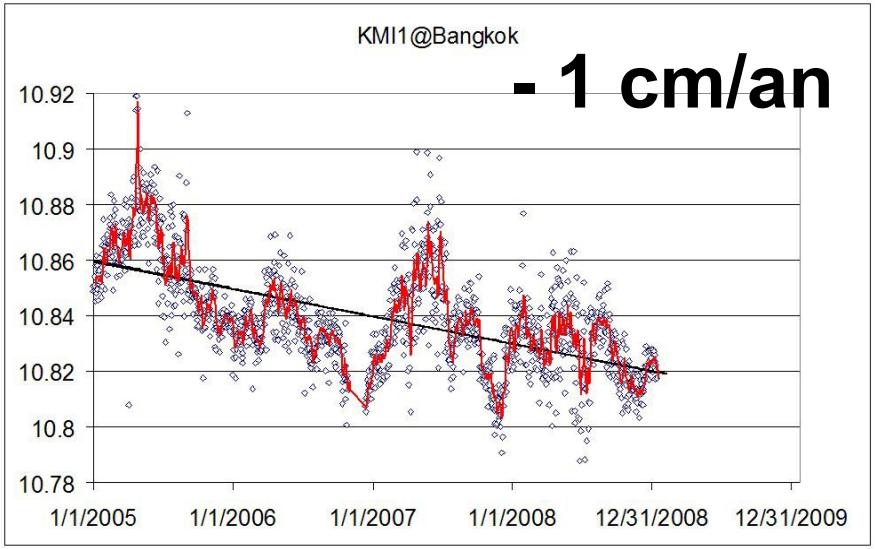
- **Unknown type of slip**
- **Unknown long term effects**

More continuous measurements are needed, most probably for much more than a decade

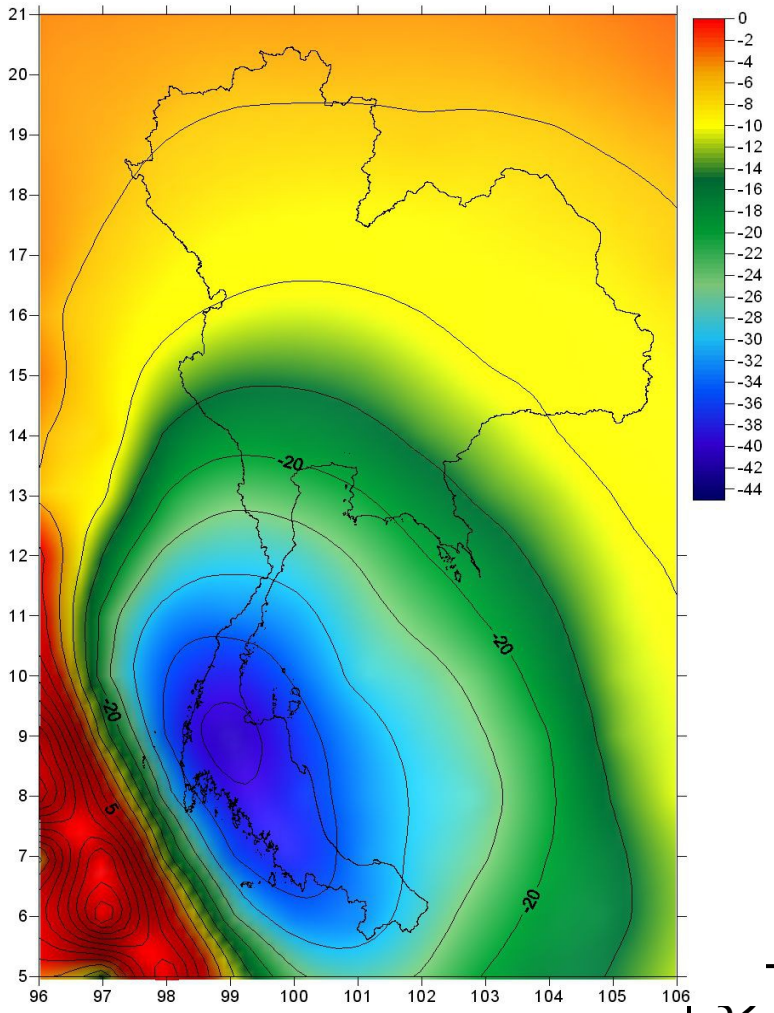
Subsidence en Thailande déclenchée par le séisme de Sumatra

Les Mesures

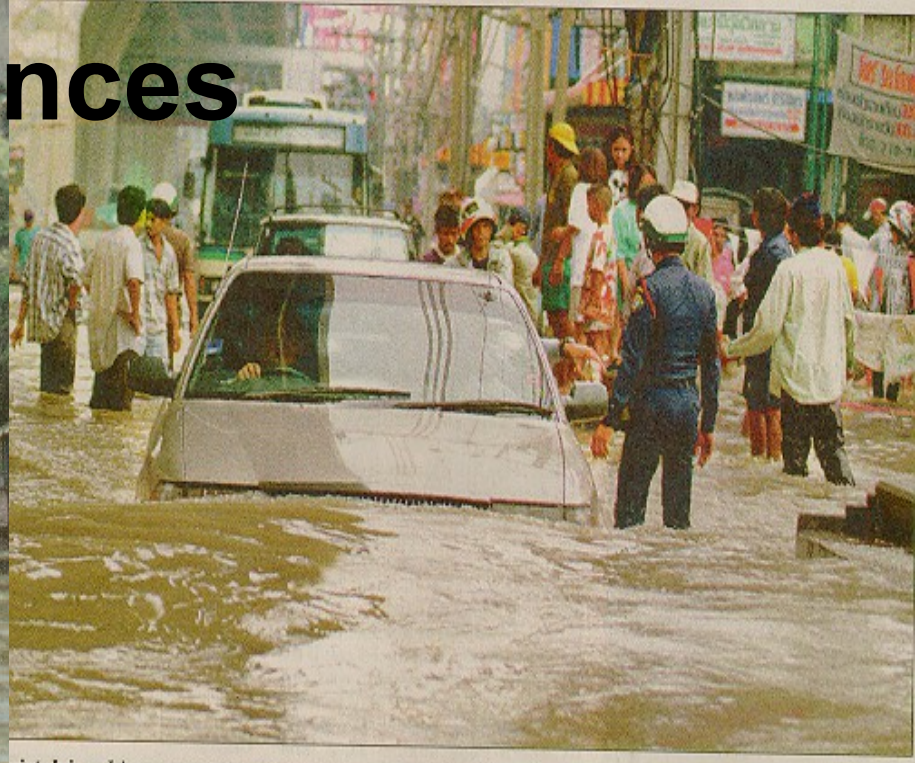




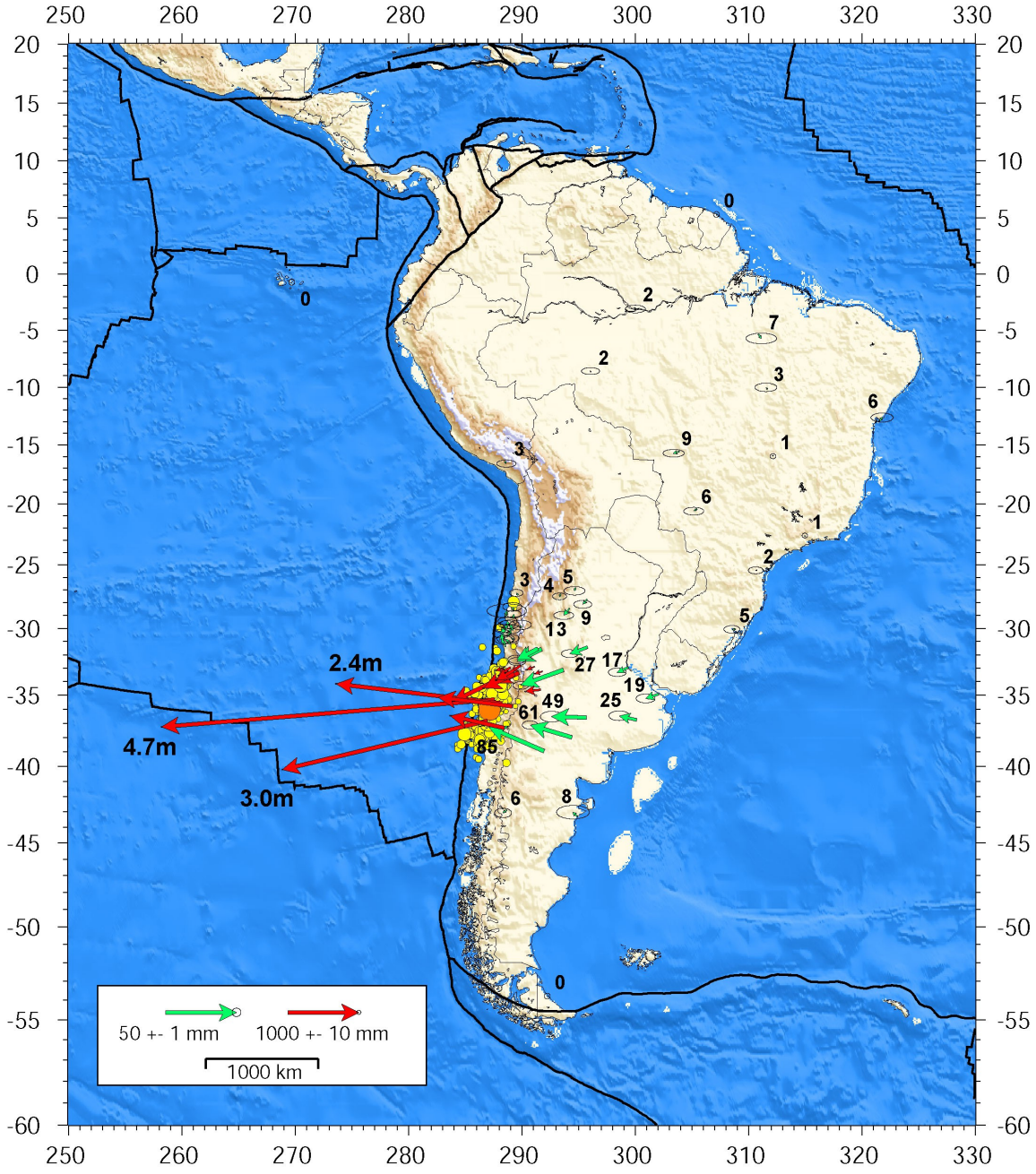
Le Modèle



Les conséquences



Le séisme du Chili – 27 fev. 2010



South America cGPS solution: 59 stations

IGS : 5

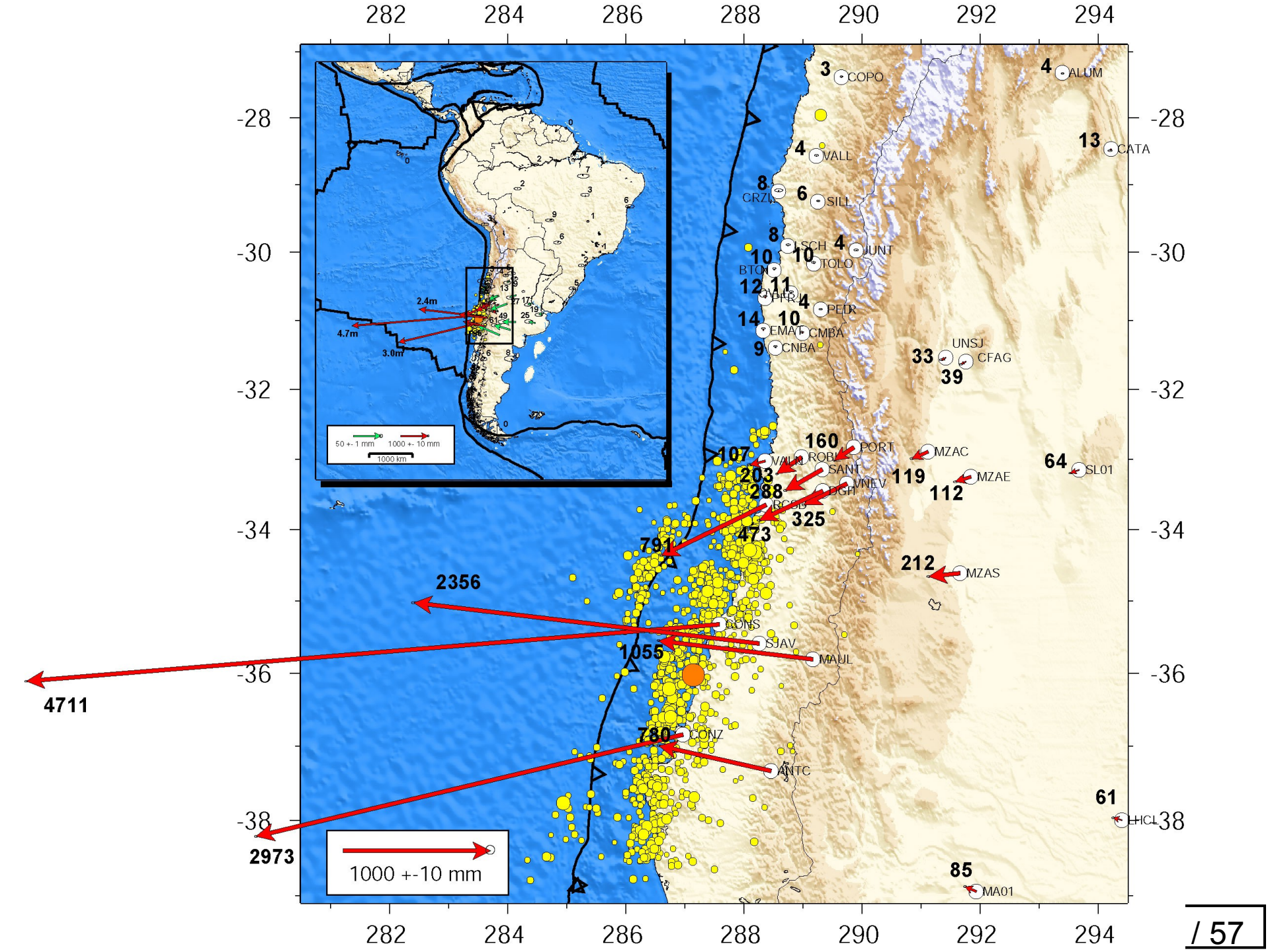
RAMSAC : 16

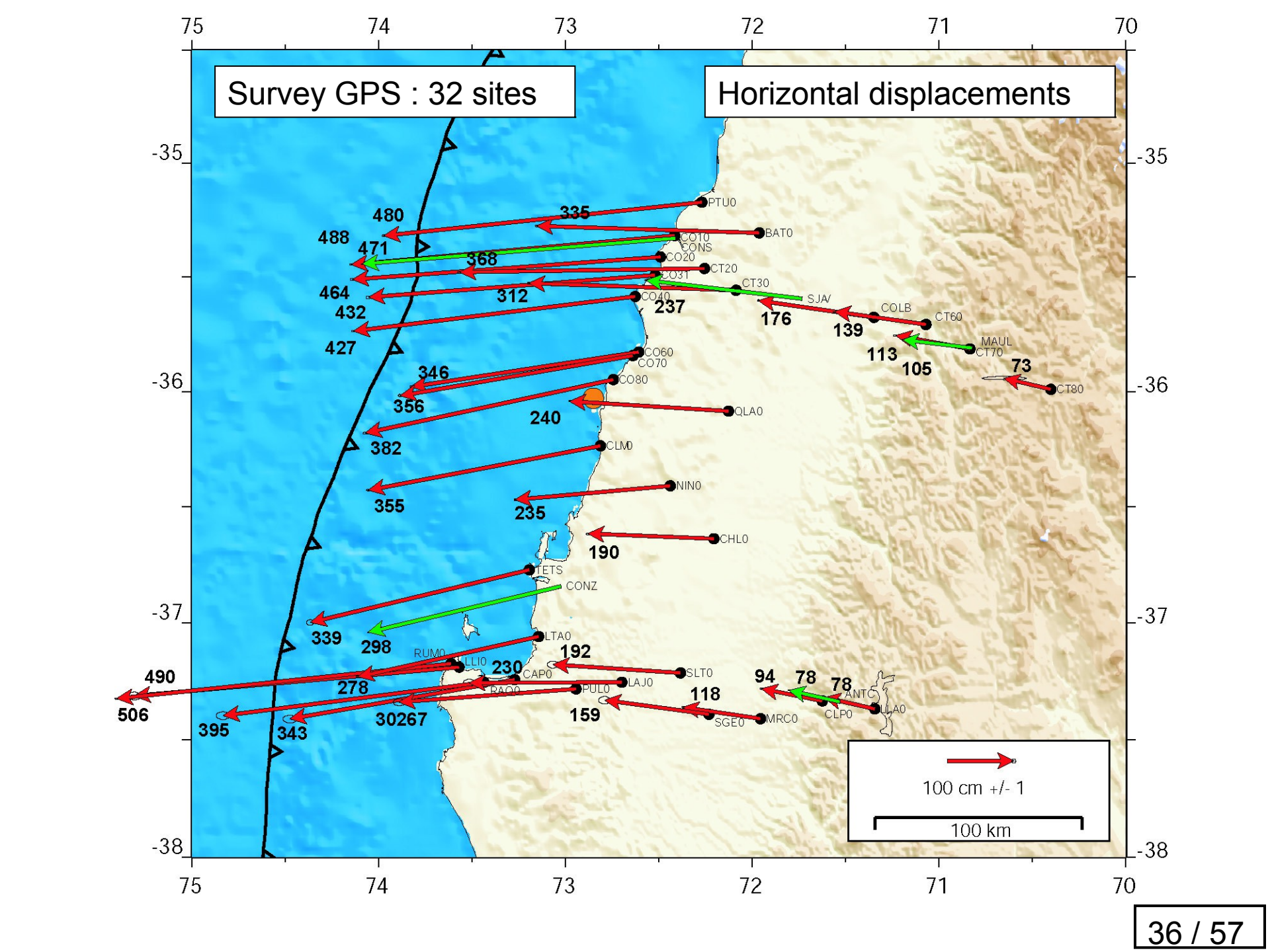
RBMC : 10

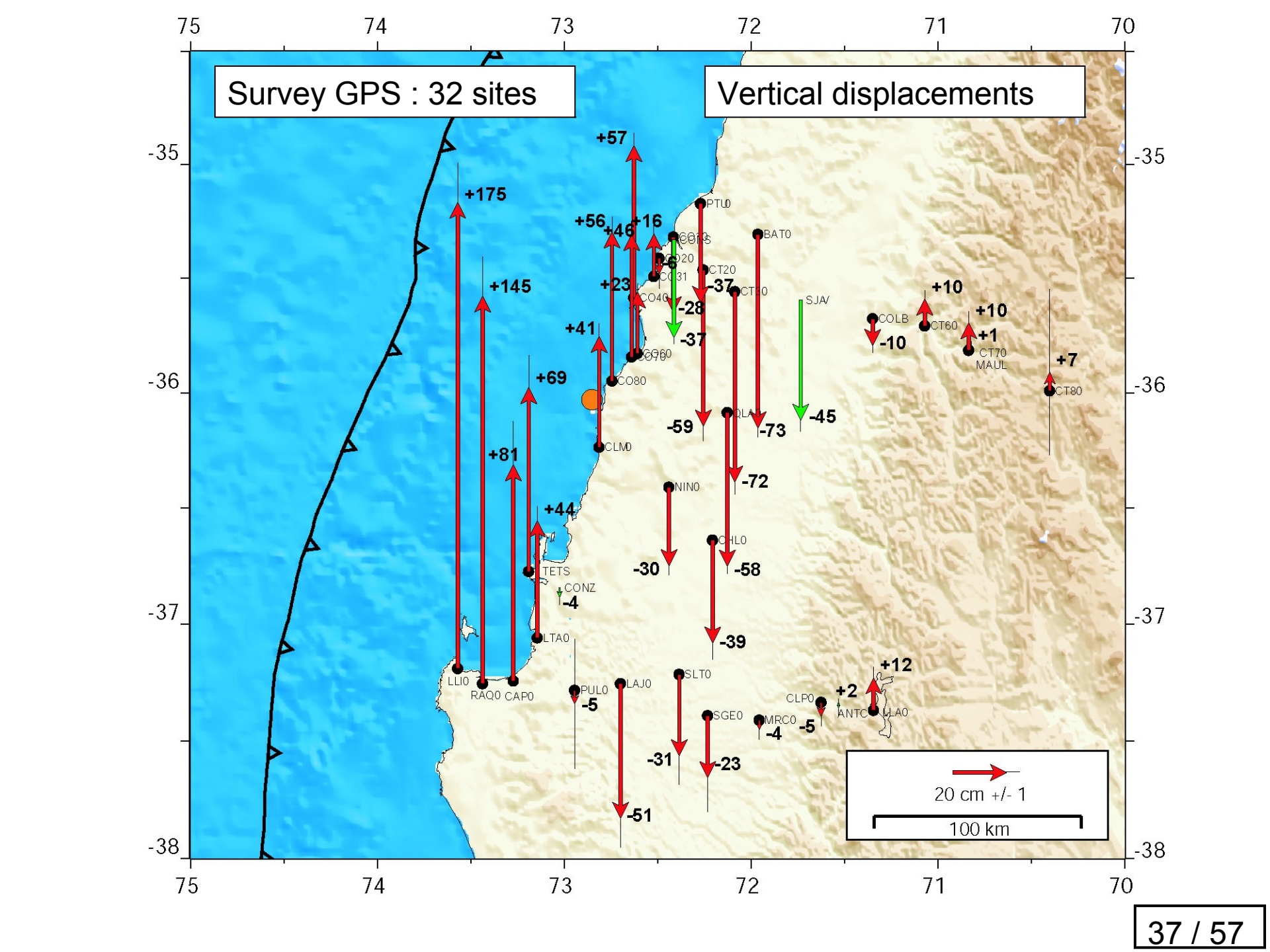
TIGO : 1

CAP : 5

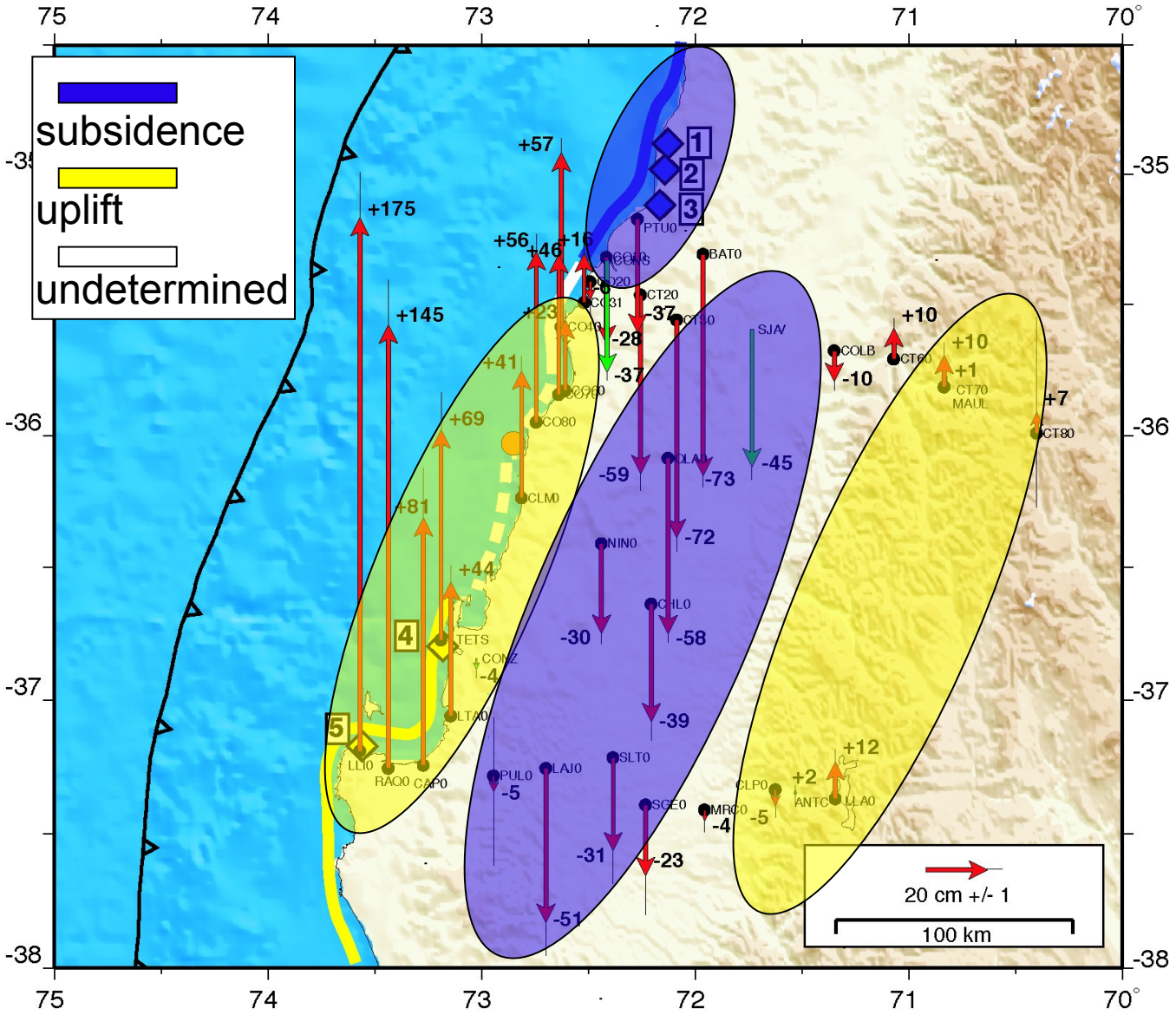
LIA-MdB : 22


282
284
286
288
290
292
294
-28
-30
-32
-34
-36
-38
COPO
ALUM
CATA
VALL
CRZL
SILL
SCH
JUNT
TOLO
BTON
PEDR
EMAT
CMBA
CNBA
UNSJ
CFAG
PORT
MZAC
ROBL
SANT
VNEV
DGH
MZAE
SL01
MZAS
GONS
SJAV
MAUL
CONZ
ANTC
HCL
MA01
3
4
13
4
8
6
8
4
10
10
12
11
4
14
10
9
33
39
160
107
203
288
325
119
112
64
473
791
212
2356
1055
4711
780
61
2973
85
1000 +-10 mm
50 +- 1 mm
1000 +- 10 mm
1000 km
2.4m
4.7m
3.0m


Survey GPS : 32 sites
Horizontal displacements
75
74
73
72
71
70
-35
-36
-37
-38
PTU0
BAT0
CO10
CONS
CO20
CT20
CO31
CT30
CO40
SJAV
COLB
CT60
MAUL
CT70
CT80
CO60
CO70
CO80
QLA0
CLM0
NIN0
CHL0
TETS
CONZ
LTA0
RUM0
LLI0
CAP0
RAO0
PUL0
LAJ0
SLT0
SGE0
MRC0
CLP0
ANTC
ULA0
480
488
471
368
464
432
427
335
312
237
176
139
113
105
73
346
356
382
355
240
235
190
339
298
192
230
278
490
506
395
343
30267
159
118
94
78
78
100 cm +/- 1
100 km


Survey GPS : 32 sites
Vertical displacements
75
74
73
72
71
70
-35
-36
-37
-38
+57
+175
+56
+46
+16
+145
+23
+41
+69
+81
+44
-6
-28
-37
-59
-73
-45
-72
-30
-58
-39
-4
+10
+10
+1
-10
+7
-5
-4
-5
-31
-23
-51
+12
+2
20 cm +/- 1
100 km
PTU0
BAT0
CT20
CT30
SJAV
COLB
CT60
CT70
MAUL
CT80
CO80
CLM0
QLA0
NIN0
CHL0
TETS
CONZ
LTA0
LLI0
RAQ0
CAP0
PUL0
LAJ0
SLT0
SGE0
MRC0
CLP0
ANTC
LLA0

Vertical displacements : comparison with field observations



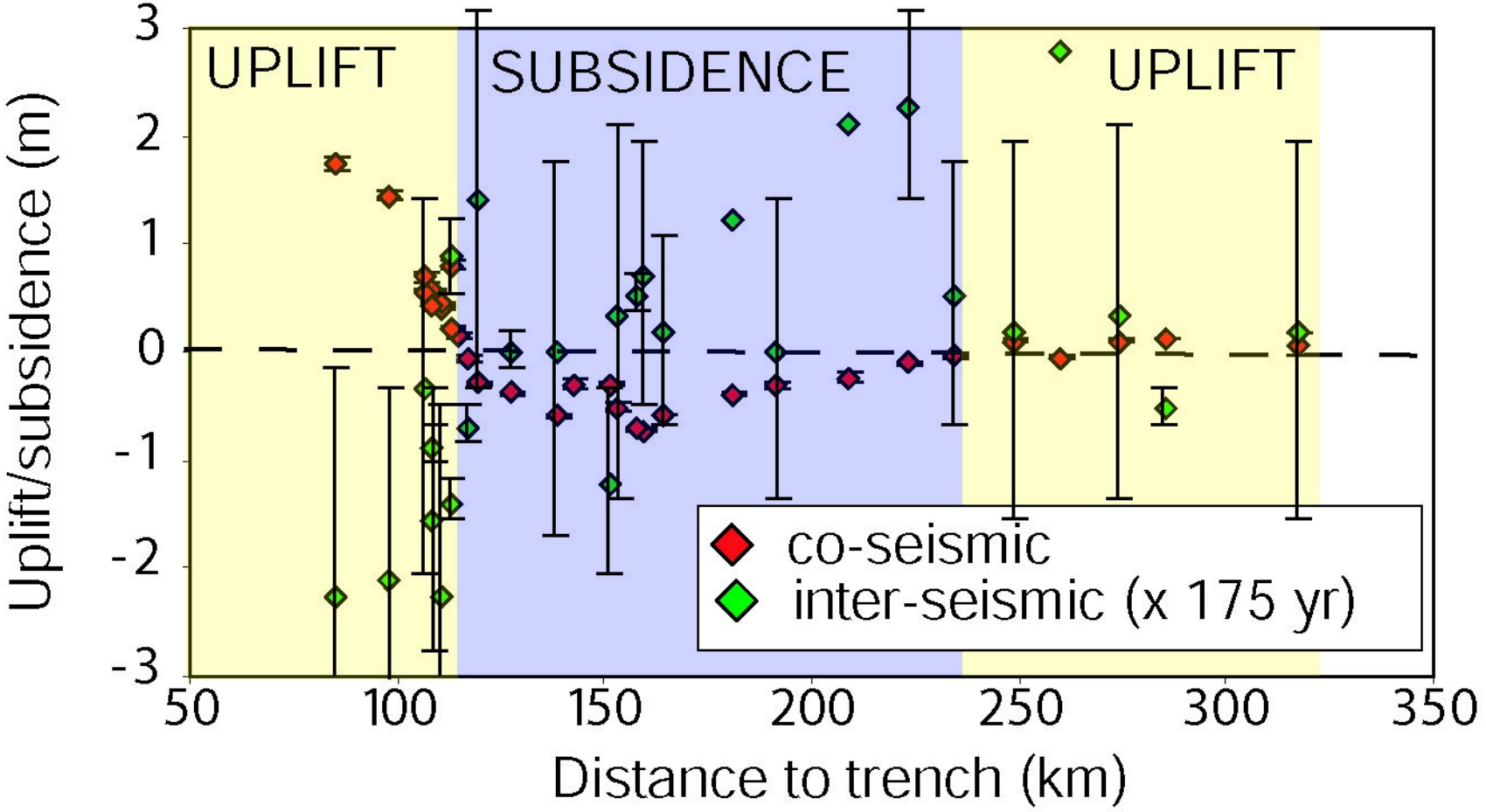
1- Caleta Duao
(high tide line)
-0.8m – -1.6m

2- Caleta La Pesca
(high tide lines)
-1m – -2m

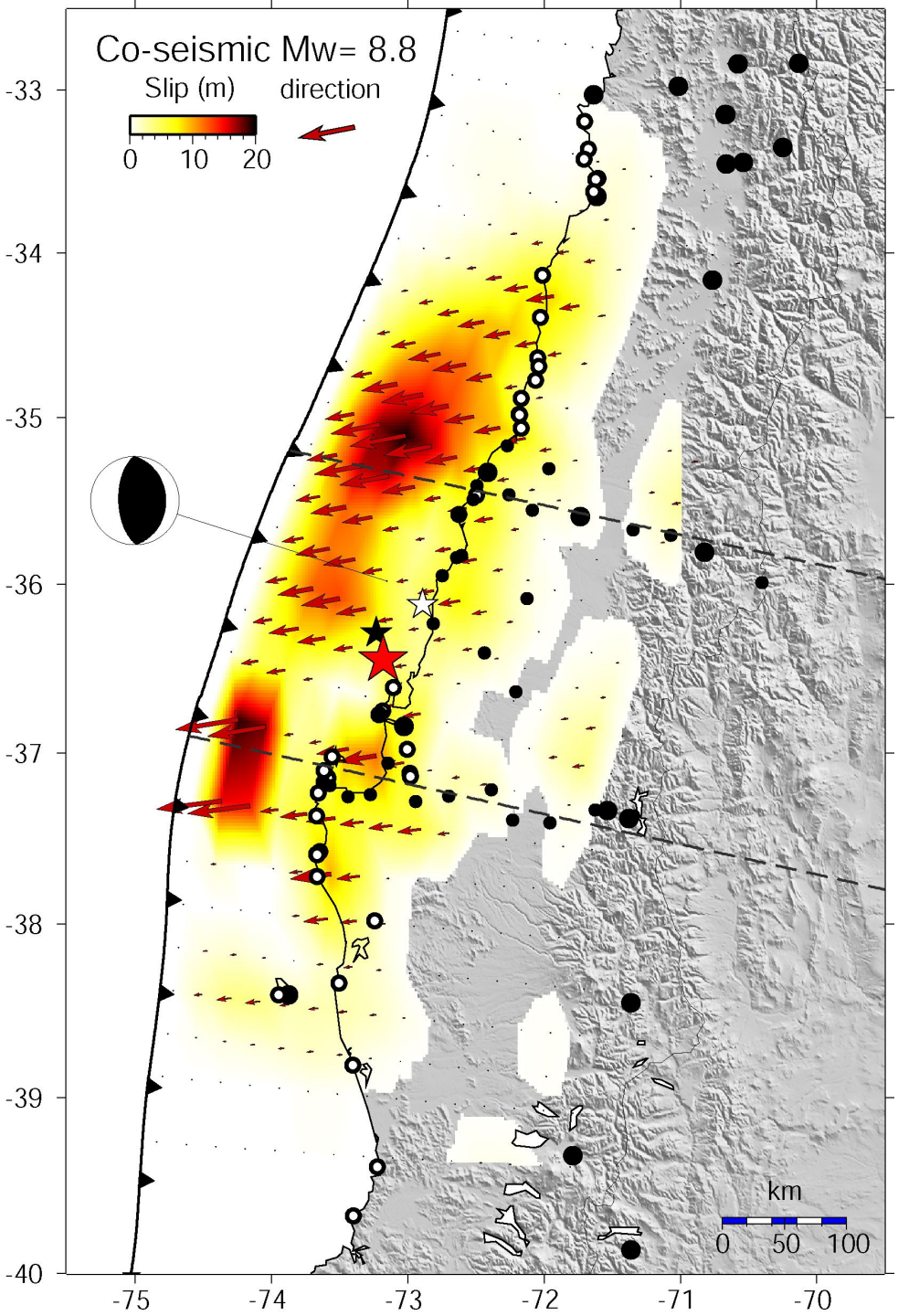
3- La Trinchera
(swimer testimony)
-1m – -1.5m

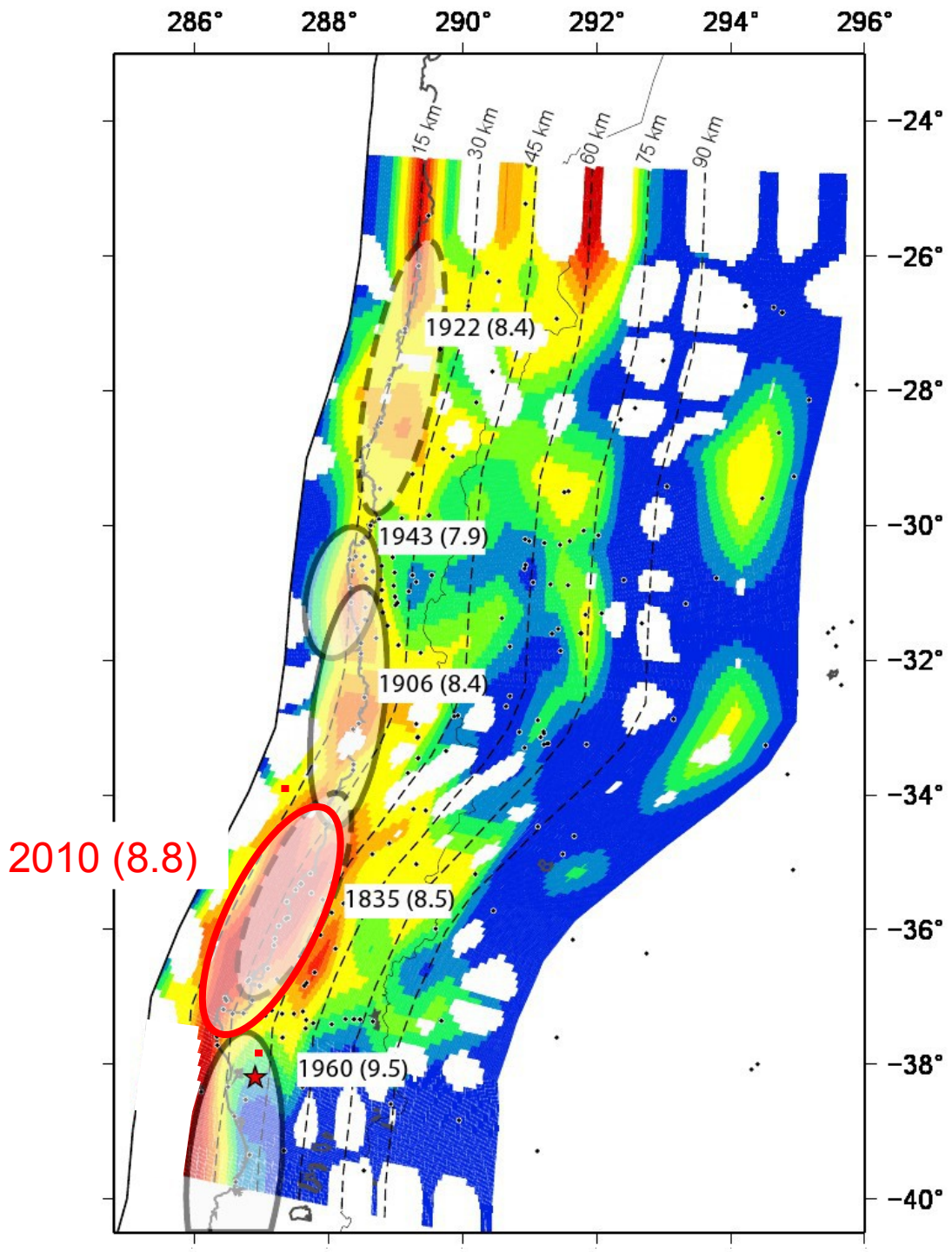
4- Caleta Chome
(high tide lines)
+0.6m – +0.8m

5- Caleta Lavapié
(high tide line)
~+2m


UPLIFT
SUBSIDENCE
UPLIFT
co-seismic
inter-seismic (x 175 yr)
Uplift/subsidence (m)
Distance to trench (km)
3
2
1
0
-1
-2
-3
50
100
150
200
250
300
350

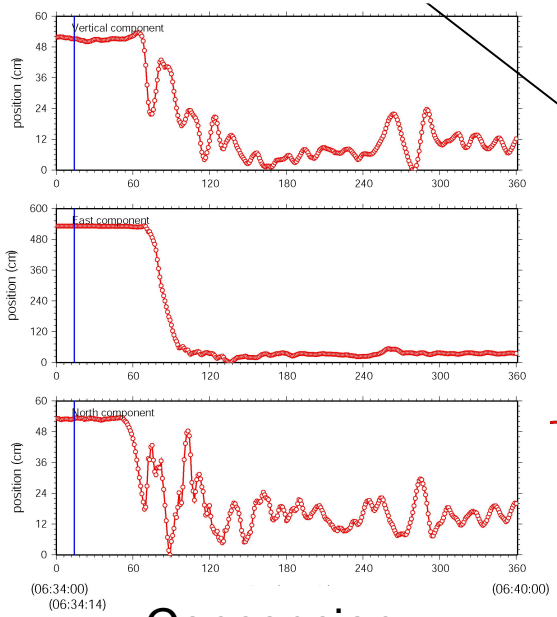
Le modèle de glissement sur la faille contraint par toutes les données: (GPS + INSAR + déplacement relatif du sol)



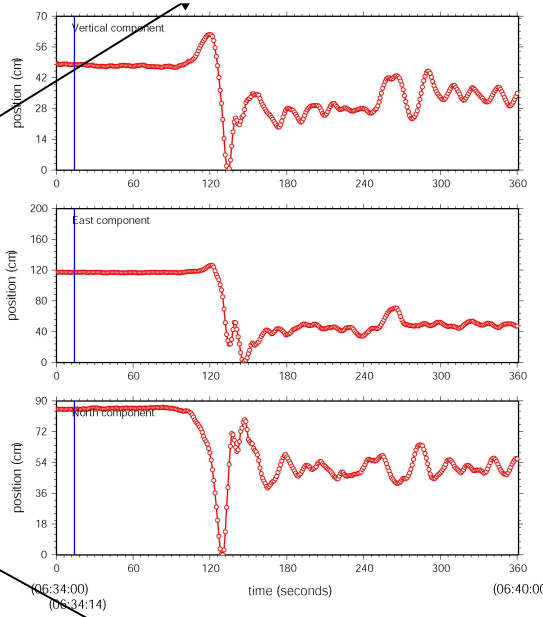


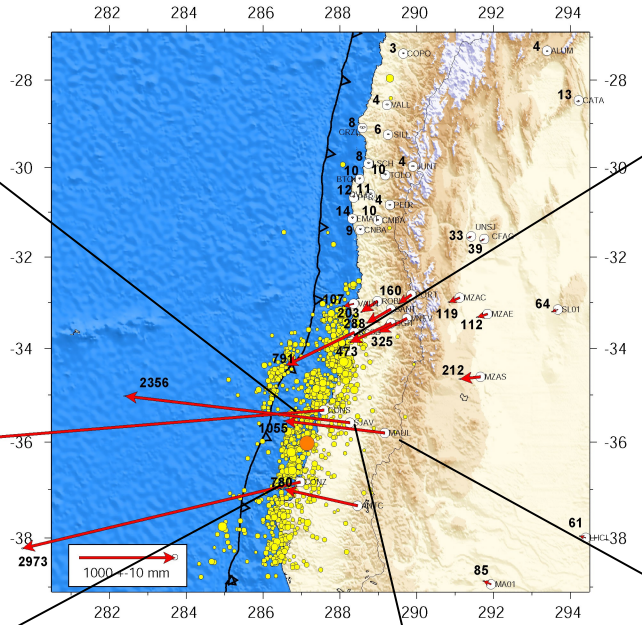
Très bonne Corrélation entre la zone couplée et les ruptures sismiques

Constitucion

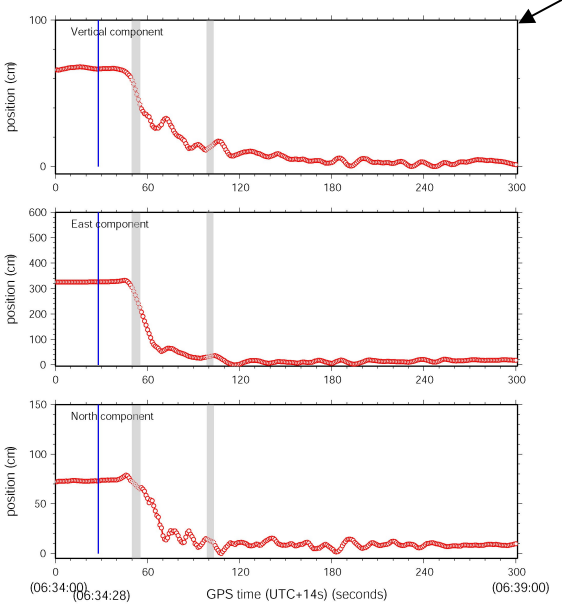


SantoDomingo

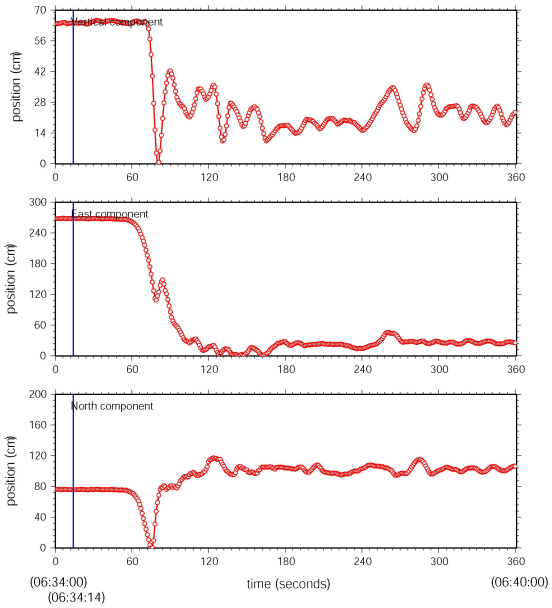




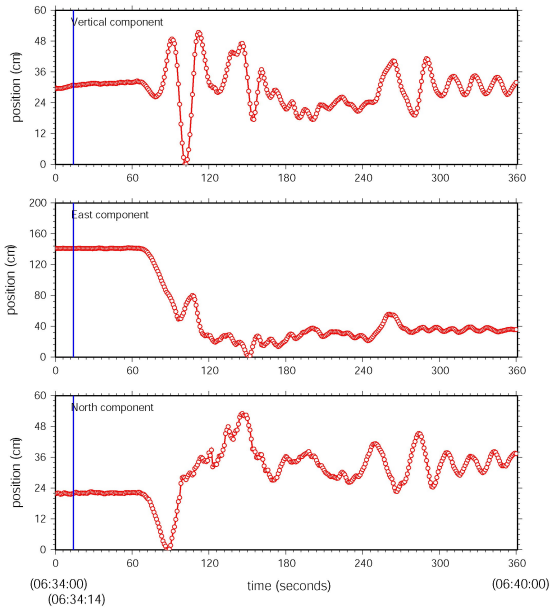
Concepcion

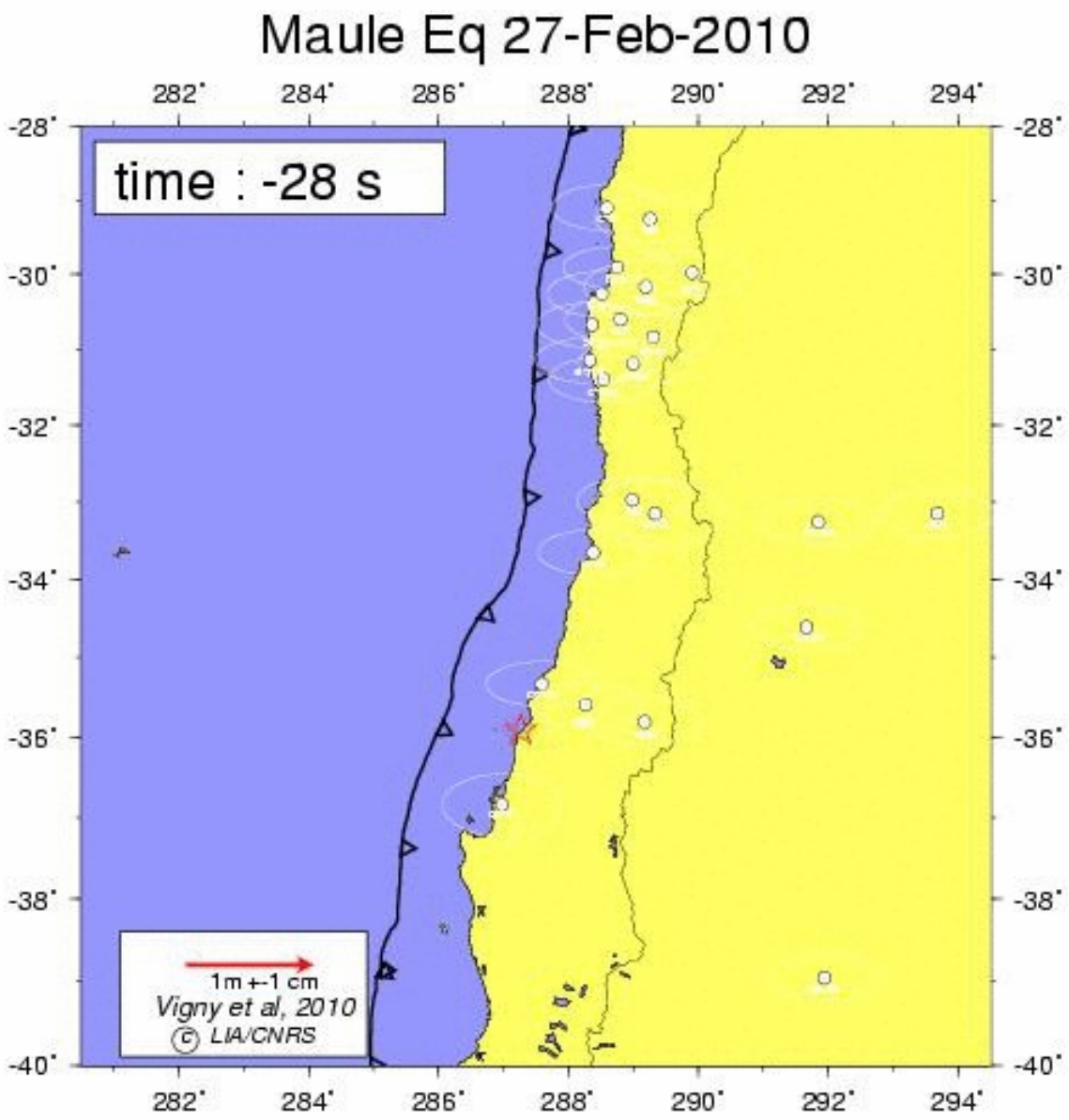


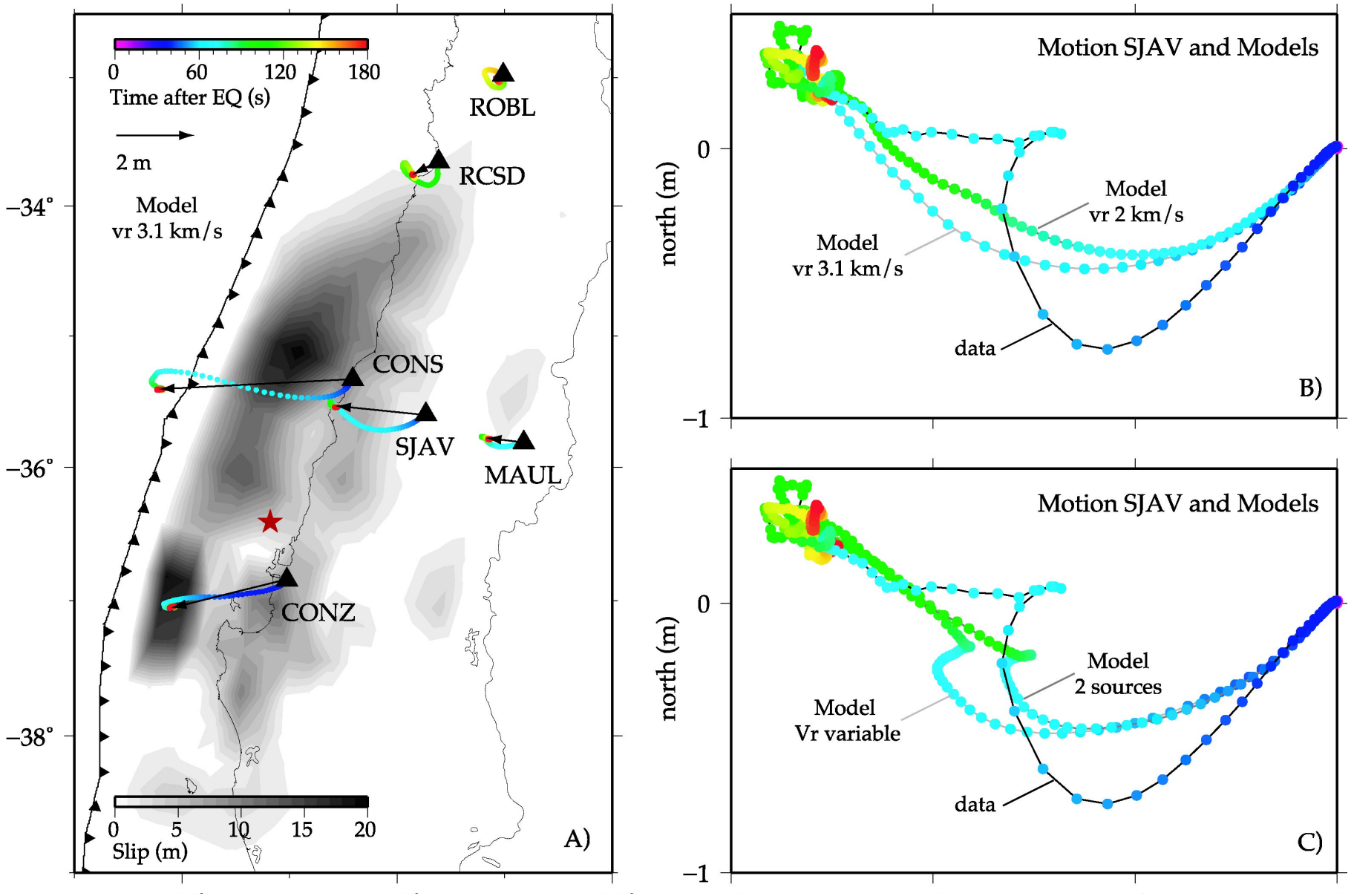
SanJavier



Colbun



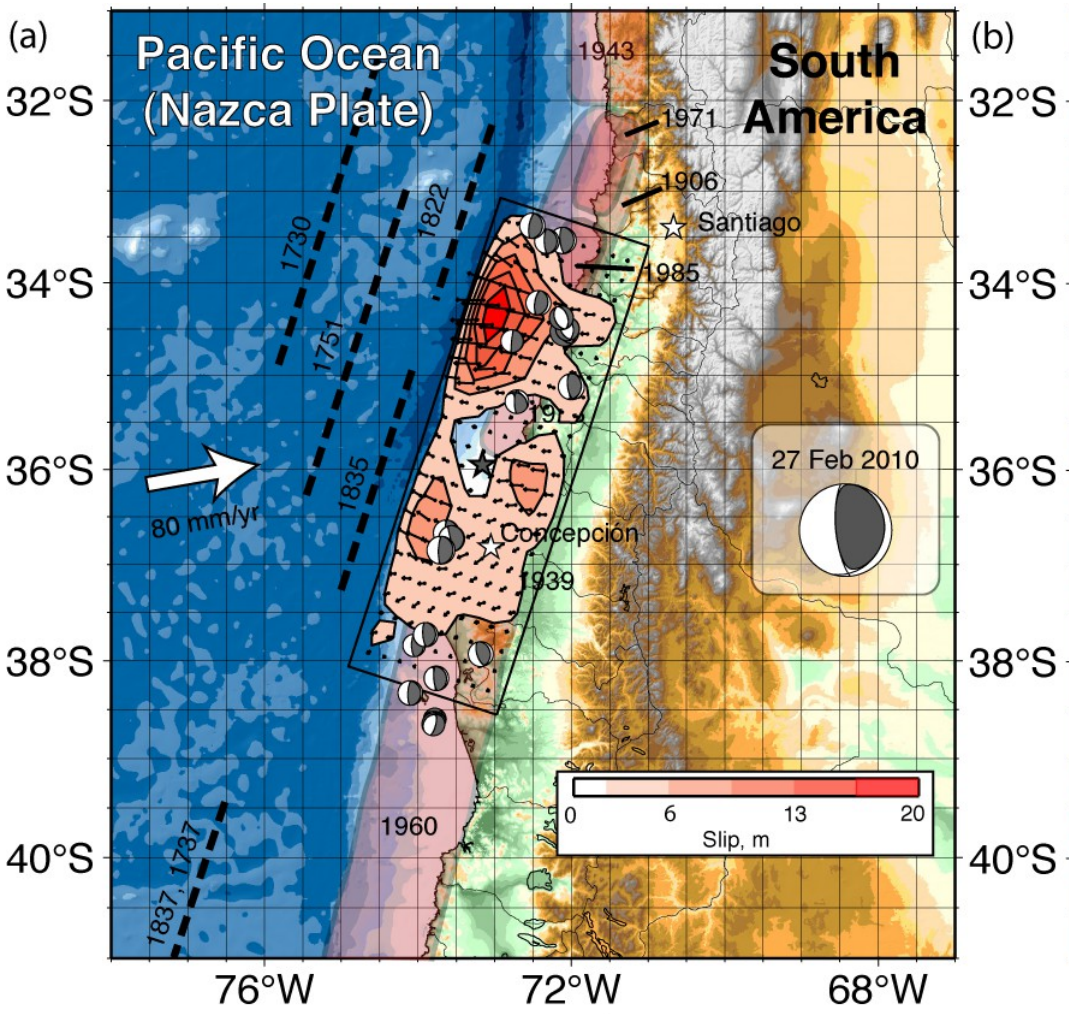

Maule Eq 27-Feb-2010
time : -28 s
282°
284°
286°
288°
290°
292°
294°
-28°
-30°
-32°
-34°
-36°
-38°
-40°
1m ←1 cm
Vigny et al, 2010
© LIA/CNRS



GPS haute fréquence: 1 point par seconde => trajectoire des stations pendant le séisme. Comparaisons avec modèles théoriques

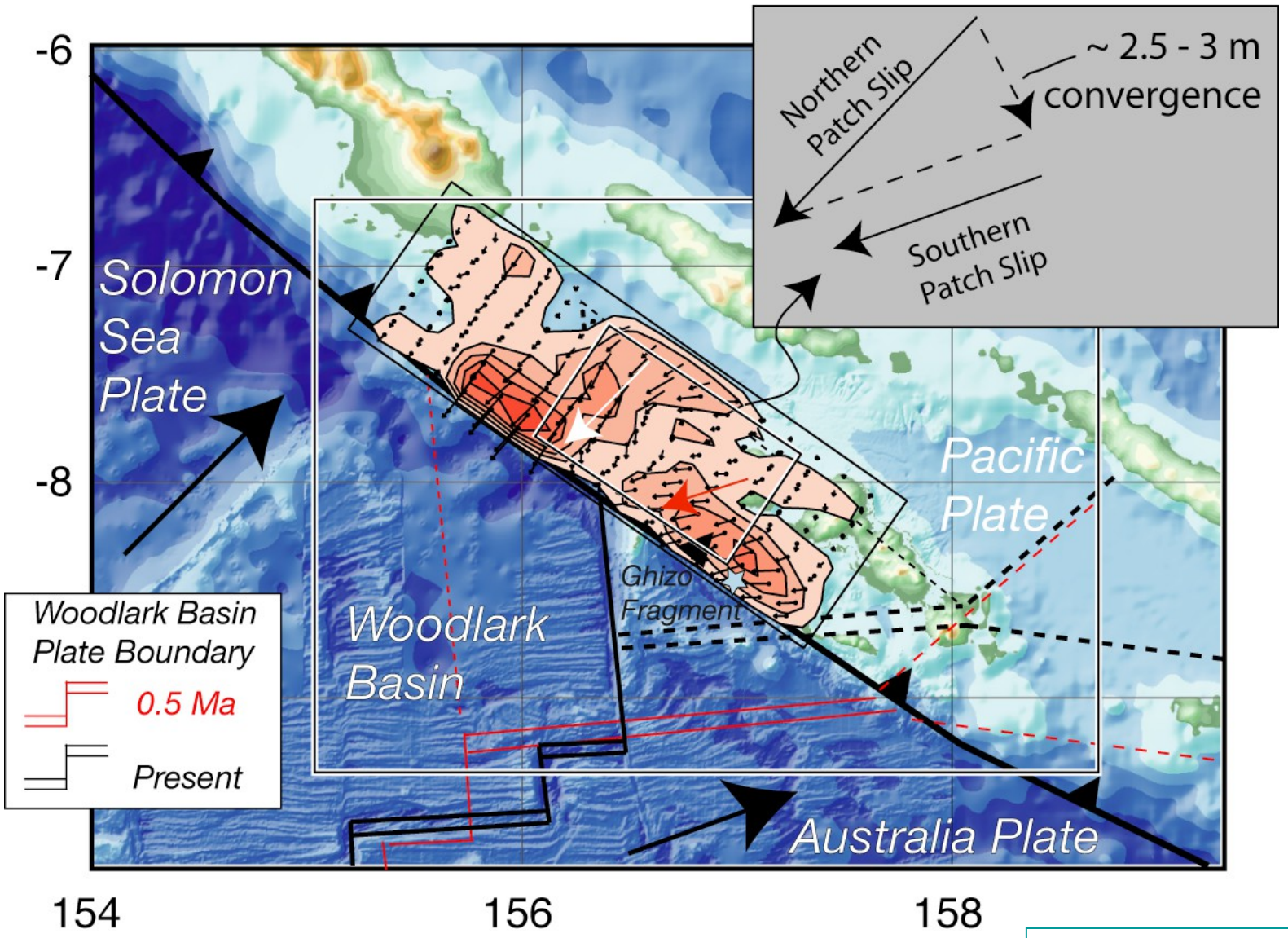
Ruptures superficielles ?

Chili (Maule) M_w=8.8, 27 Février 2010



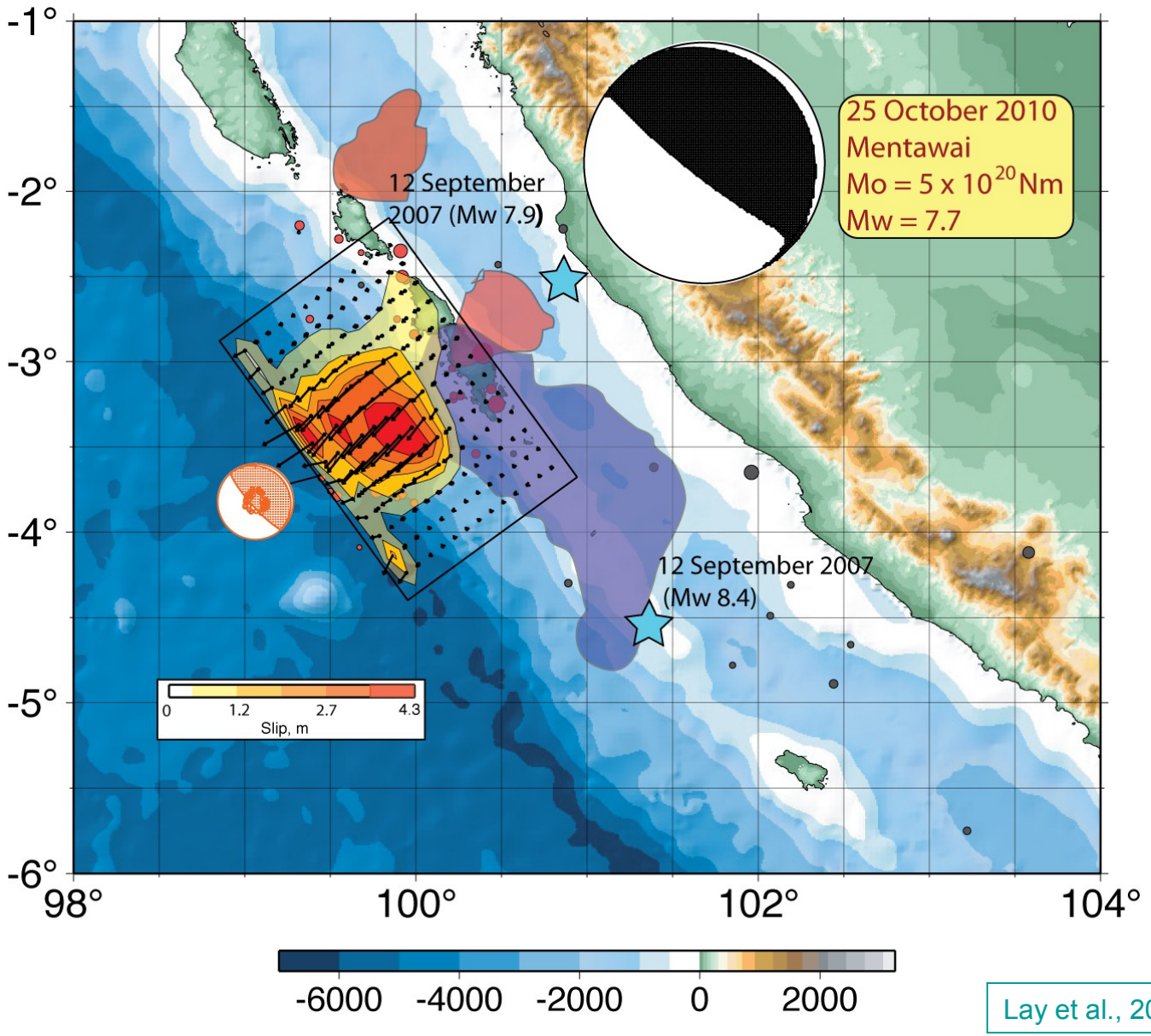
Lay et al., GRL, 2010

Iles Solomon M_w=8.1, 1 Avril 2007



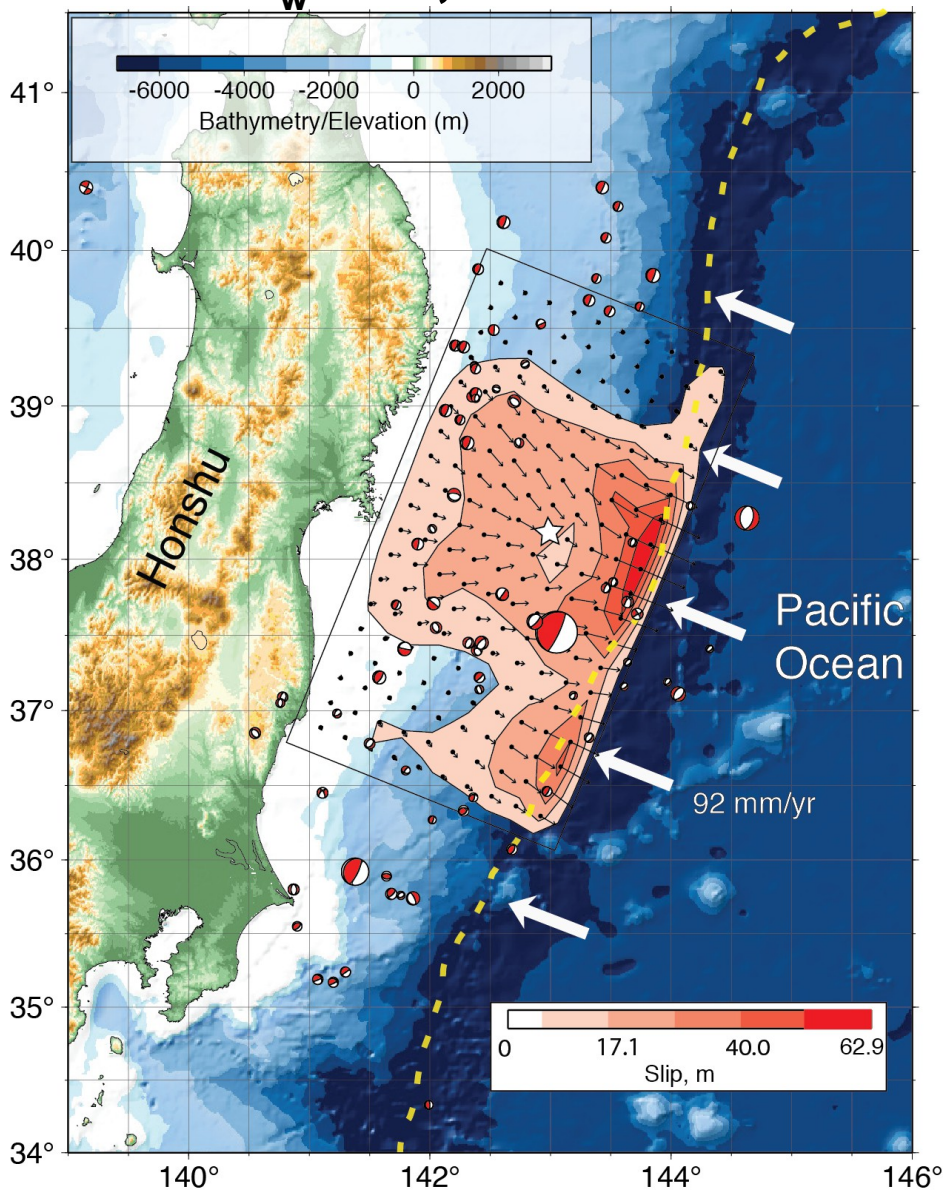
Furlong et al., Science (2009)

Iles Mentawai M_w=7.7, 25 Octobre 2010



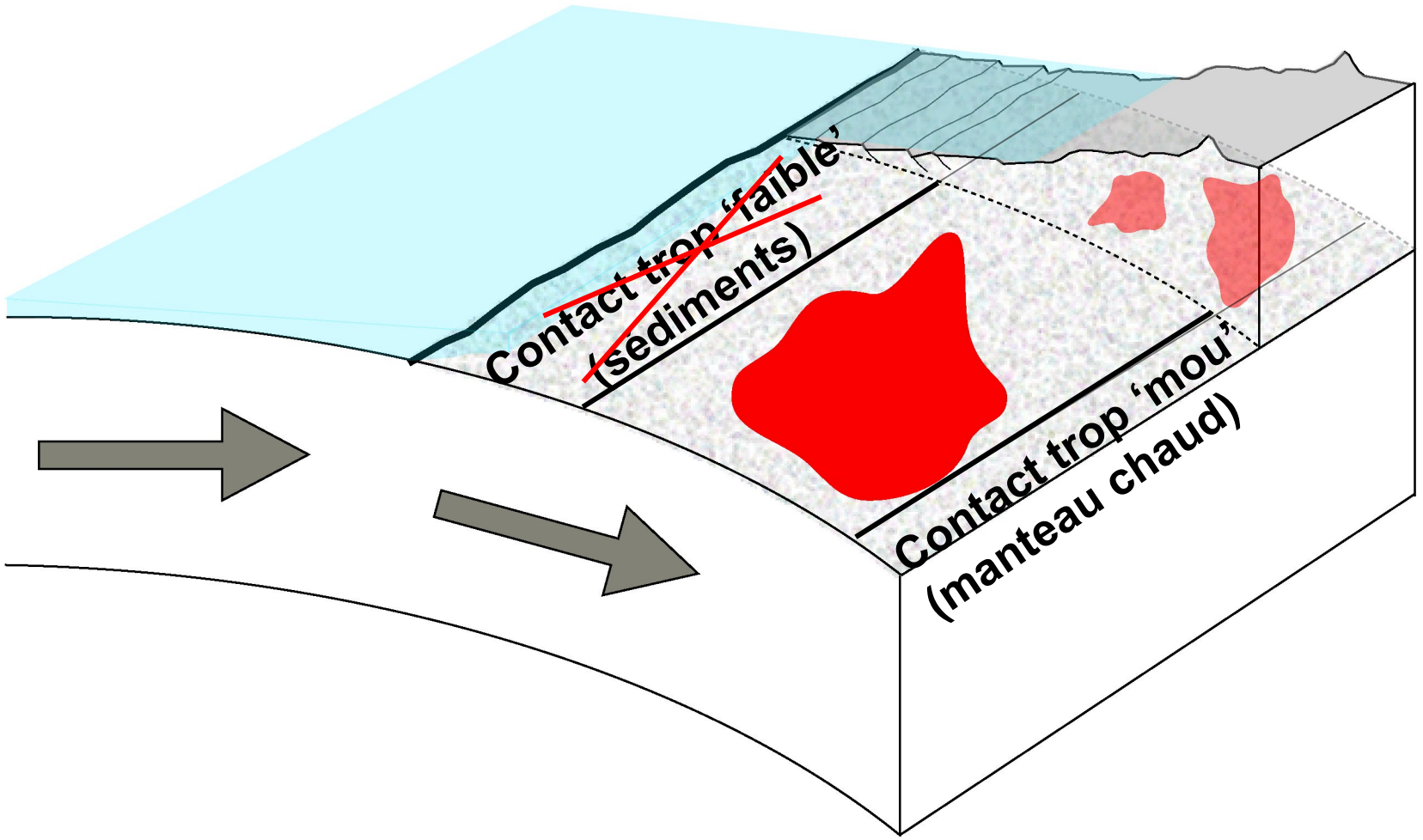
Lay et al., 2011; Hill et al., 2012

Tohoku M_w=9.0, 11 mars 2011



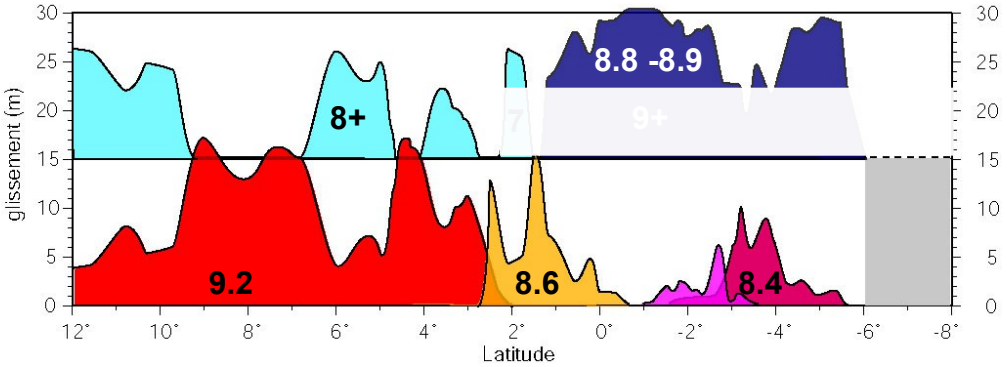
Lay et al., EPSL, 2011

Donc : la zone superficielle de contact casse aussi



Quantification de l'aléa sismique

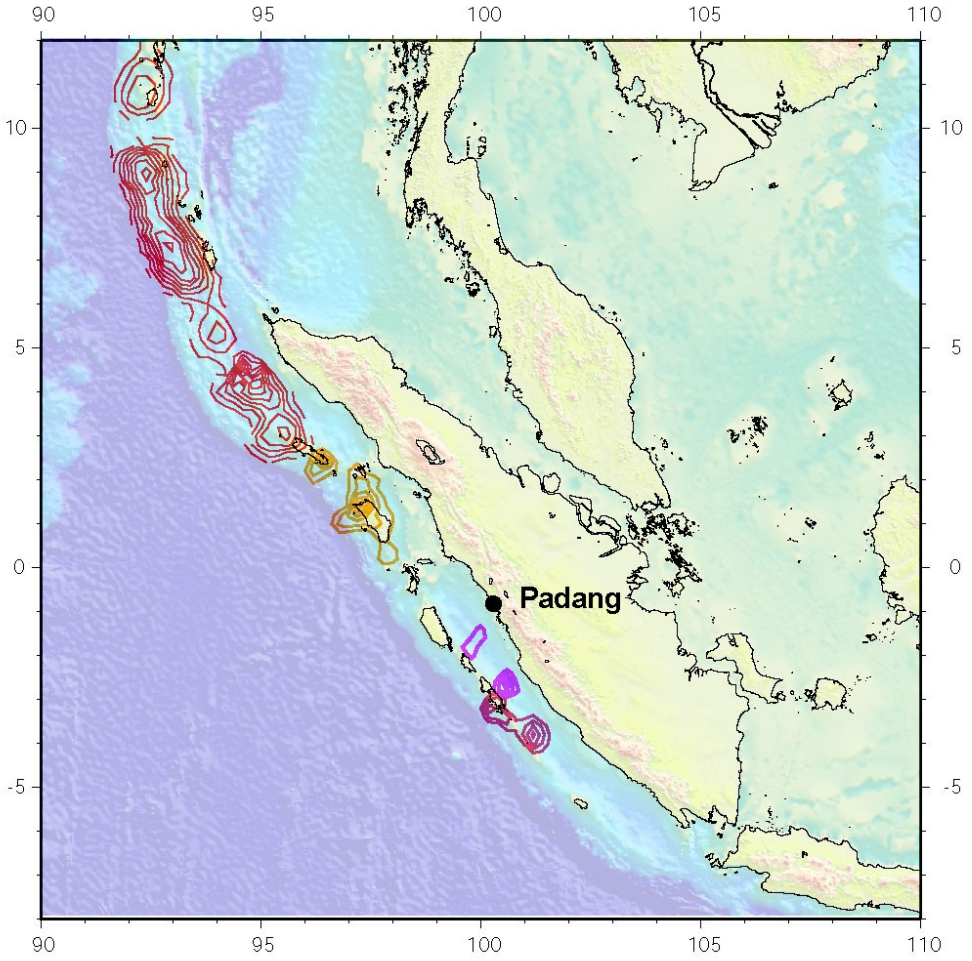
Où ?



7.5 m uniform slip

=

250 years at 3 cm/y

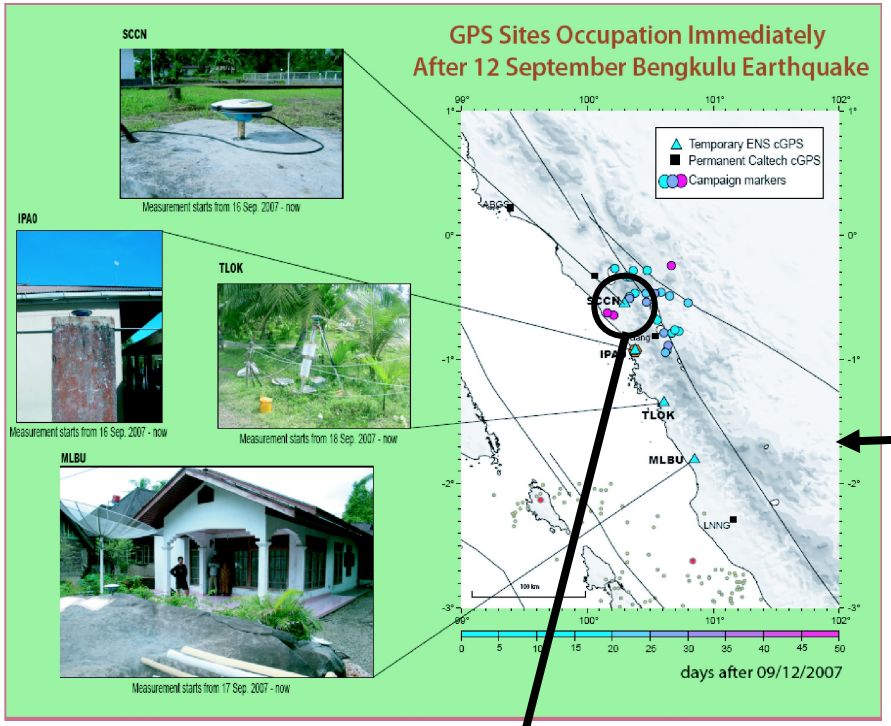


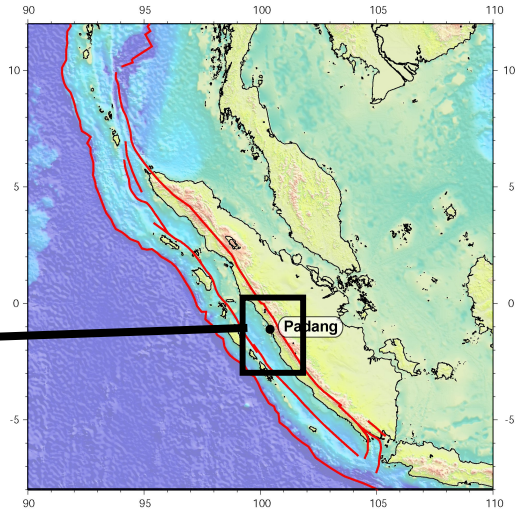
Chen Ji (Caltech)

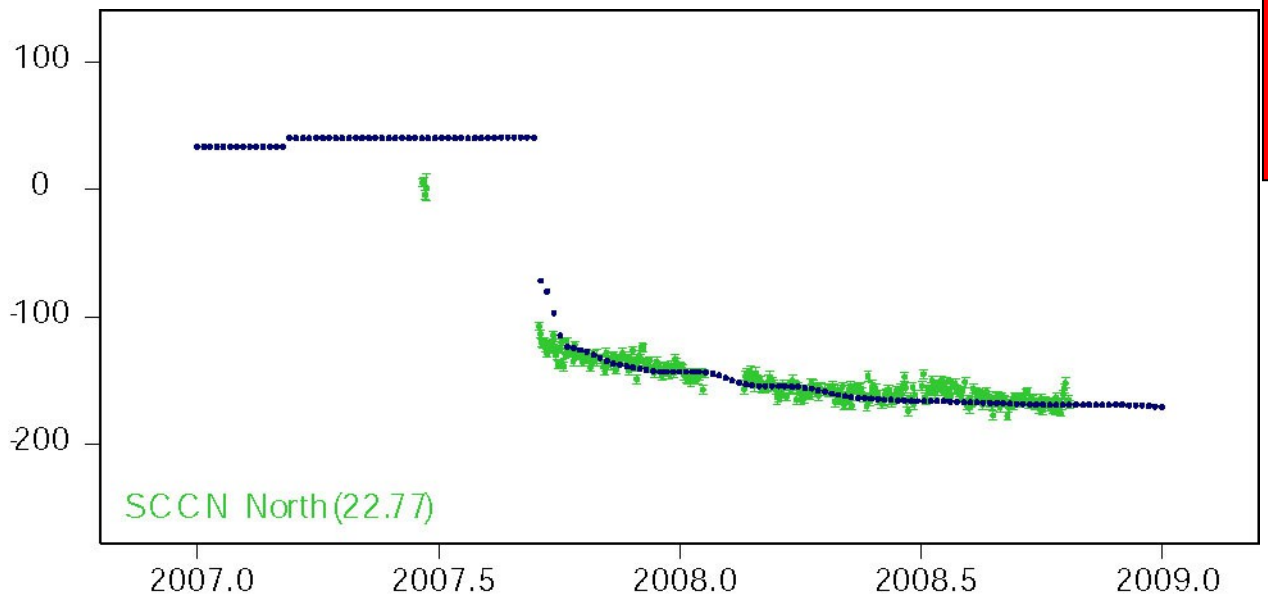
slip distribution

Inverted from seismic & GPS data

Padang still at risk





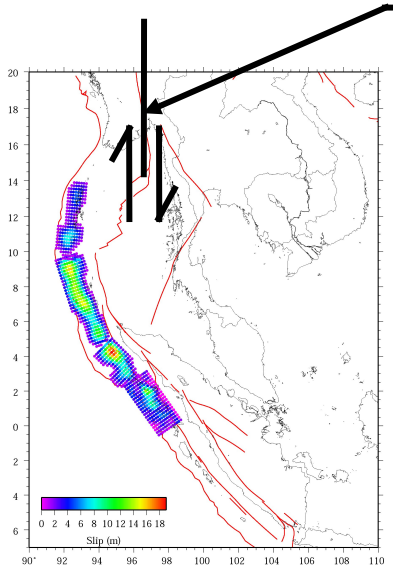


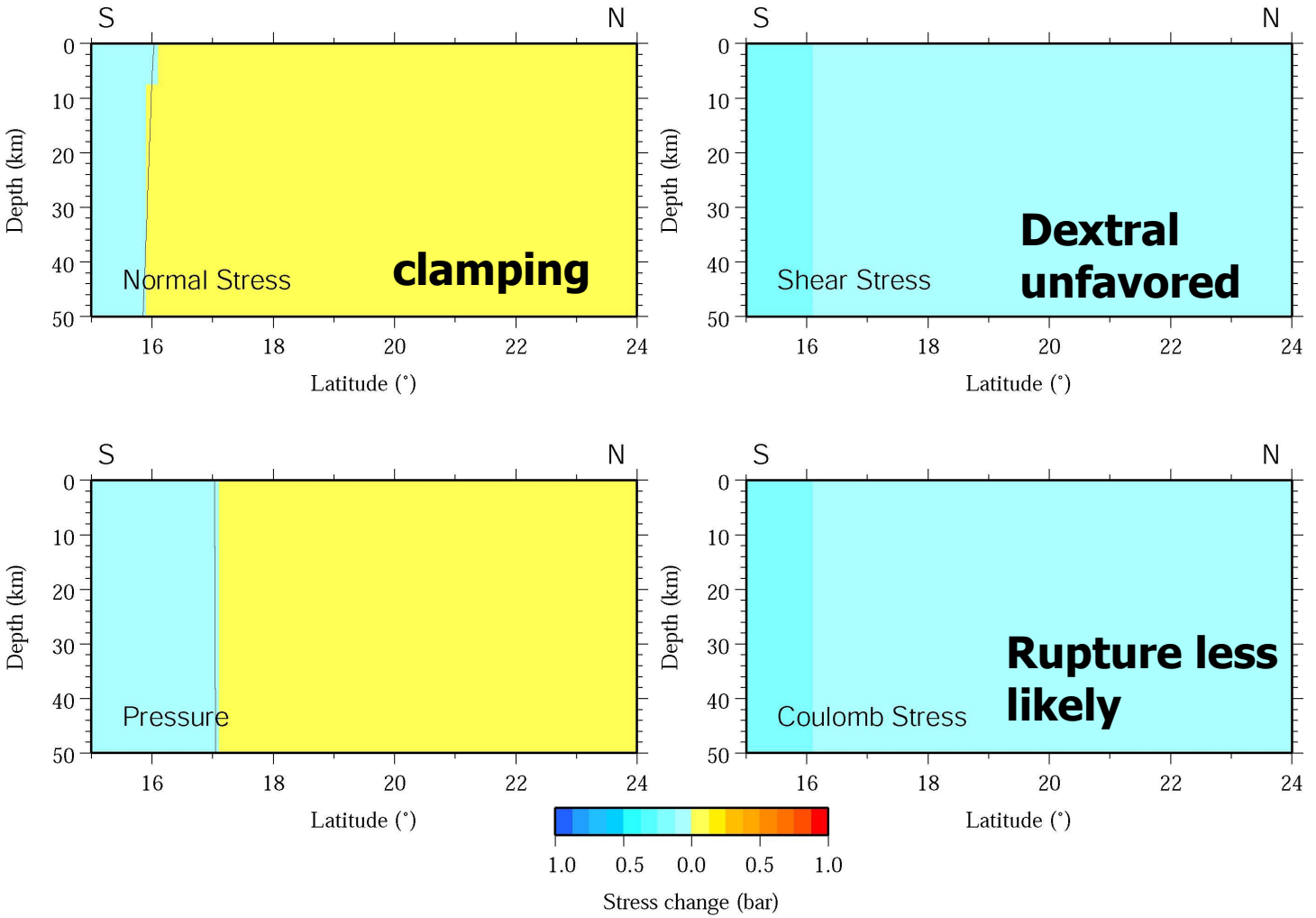
Two scenarios:

1. post-sismic « normal »
   => still locked
   => rupture later (the latest the biggest)

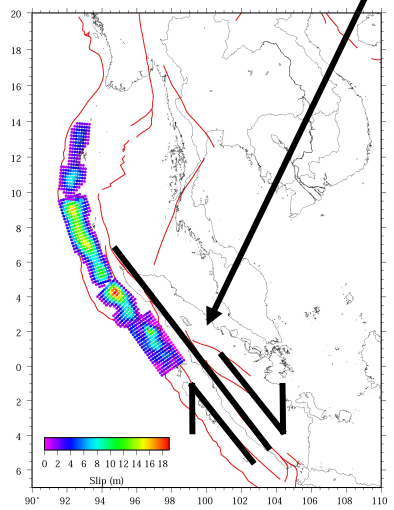
2. Post-sismic
   « more than normal »
   => silent dissipation of elastic deformation
   => smaller future rupture

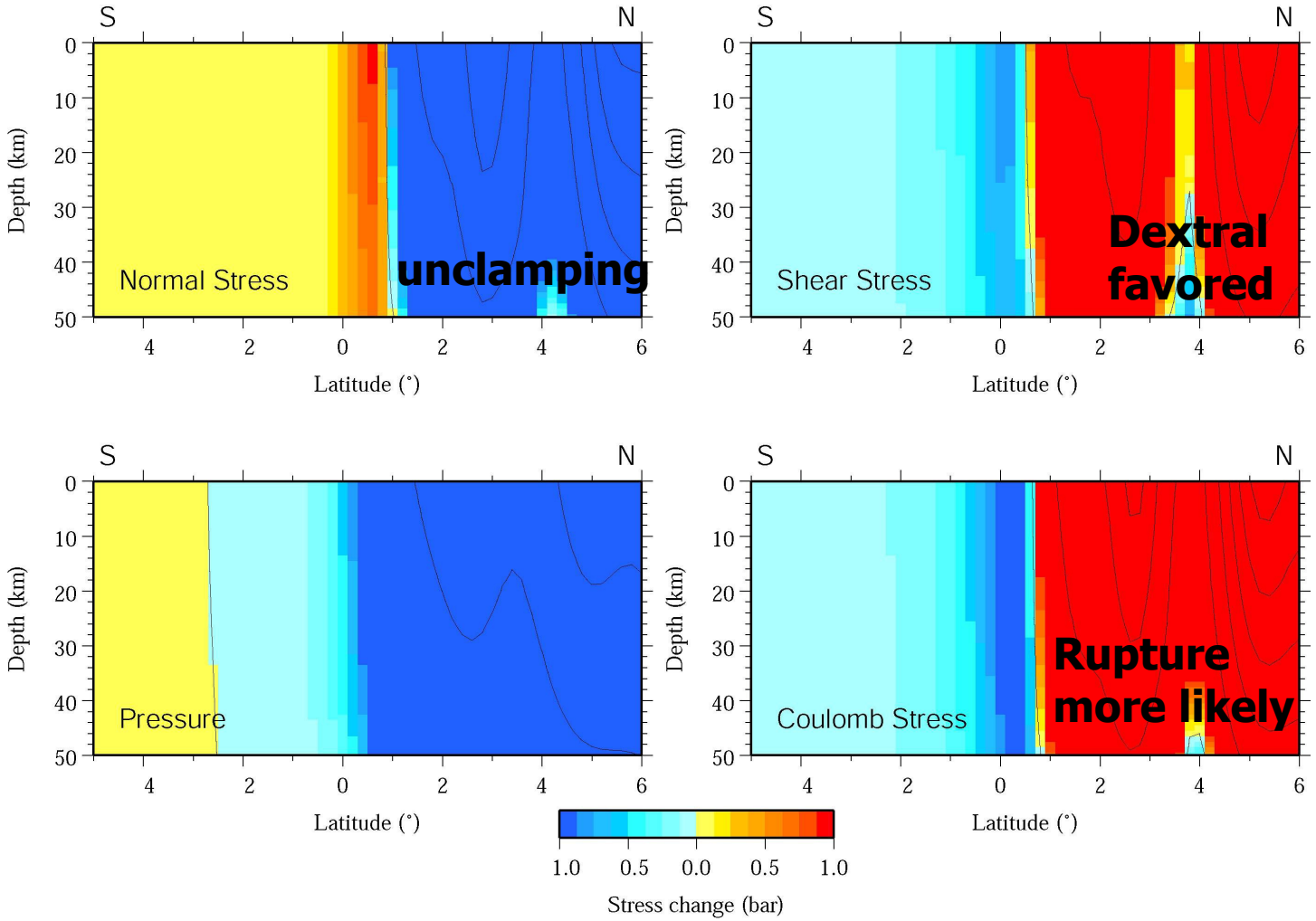
Loading of Sagaing fault: low everywhere and reverse!



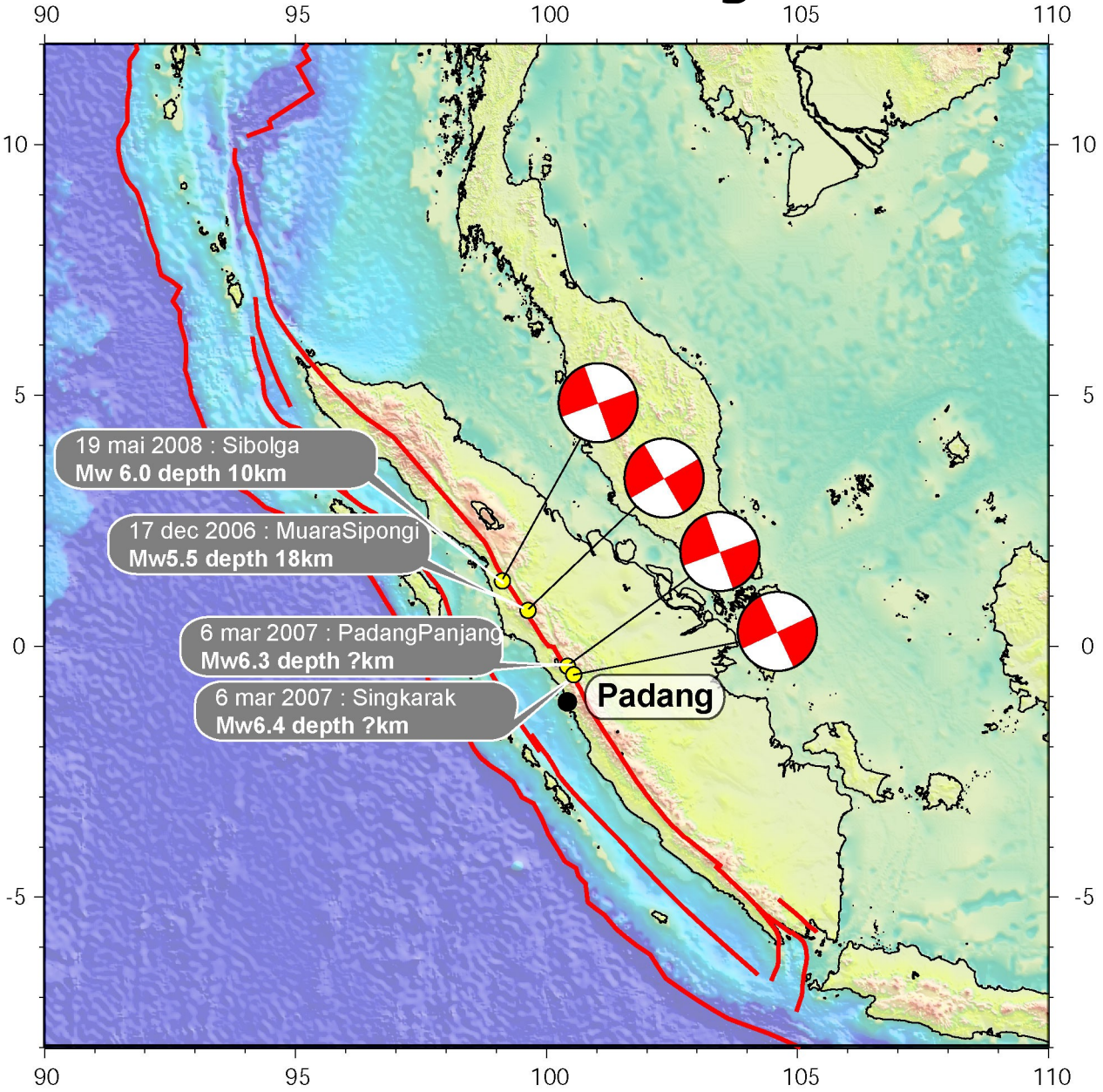


Loading of Great Sumatra fault: high above 0°N

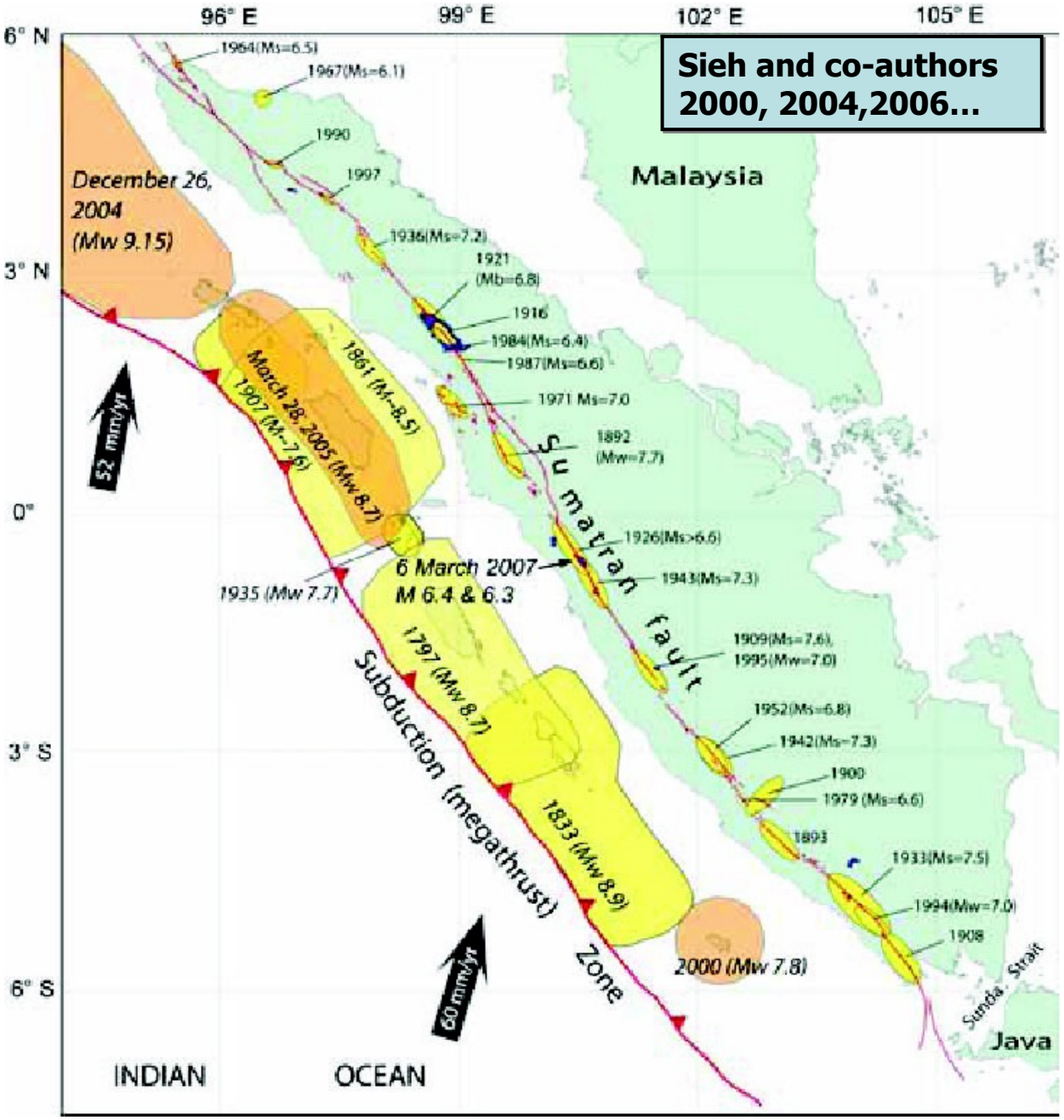




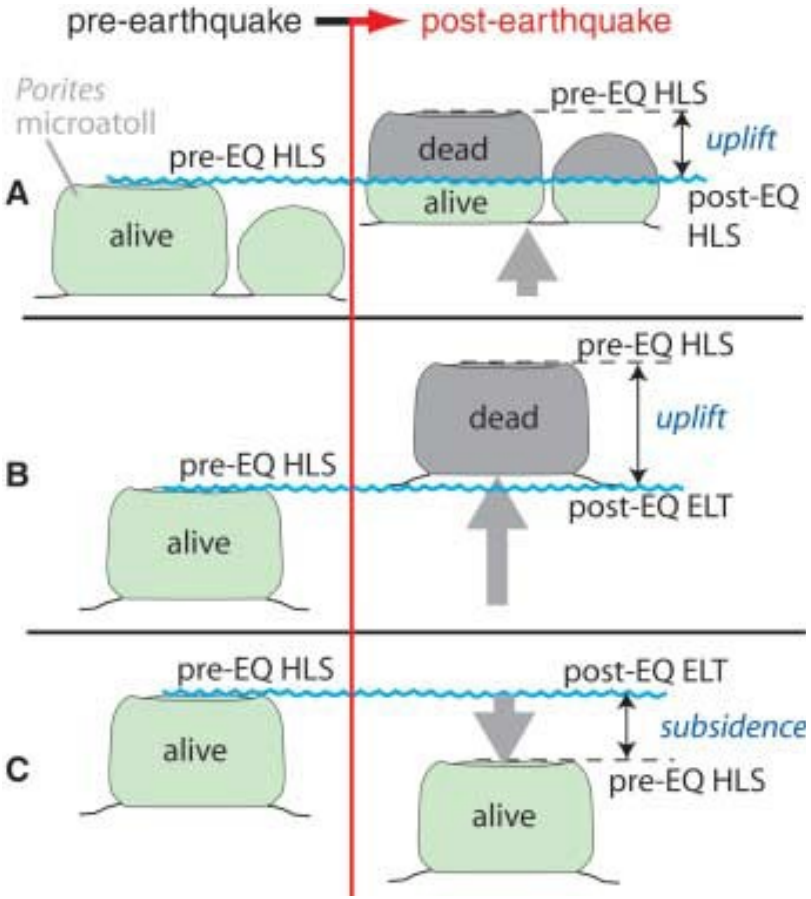
Loading of Great Sumatra fault: high above 0°N



QUAND ?


Sieh and co-authors
2000, 2004,2006…
96° E
99° E
102° E
105° E
6° N
3° N
0°
3° S
6° S
December 26,
2004
(Mw 9.15)
Malaysia
1964(Ms=6.5)
1967(Ms=6.1)
1990
1997
1936(Ms=7.2)
1921
(Mb=6.8)
1916
1984(Ms=6.4)
1987(Ms=6.6)
1971 Ms=7.0
1892
(Mw=7.7)
1861 (M=8.5)
March 28, 2005 (Mw 8.7)
1907 (M=7.6)
52 mm/yr
Su matran fault
1926(Ms>6.6)
1943(Ms=7.3)
6 March 2007
M 6.4 & 6.3
1935 (Mw 7.7)
1909(Ms=7.6),
1995(Mw=7.0)
1797 (Mw 8.7)
Subduction (megathrust) Zone
1952(Ms=6.8)
1942(Ms=7.3)
1900
1979 (Ms=6.6)
1833 (Mw 8.9)
1893
1933(Ms=7.5)
1994(Mw=7.0)
1908
2000 (Mw 7.8)
60 mm/yr
Sunda Strait
Java
INDIAN OCEAN

Coral reefs records



Three scenarios for measuring vertical deformation using Porites coral microatolls.
(A) Uplift recorded as the difference between pre- and post-earthquake highest level of survival (HLS).
(B) Uplift as separation between pre-earthquake HLS (pre-EQ HLS) and the model elevation of postearthquake extreme low tide (post-EQ ELT).
(C) Subsidence measured upward from pre-earthquake HLS to post-earthquake ELT.

Coral reefs records

Cross sections in vertical slabs of Goniastrea coral reef

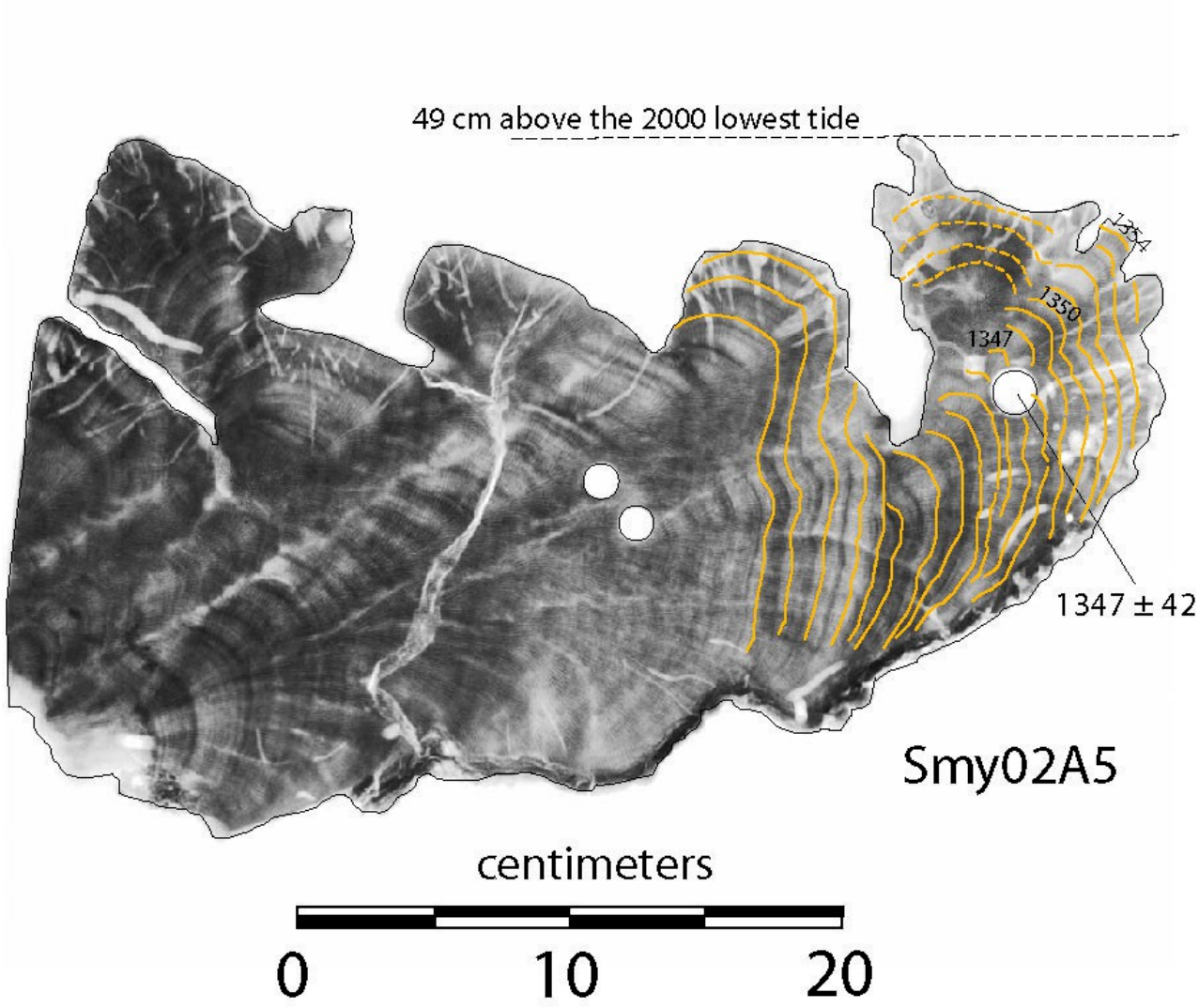
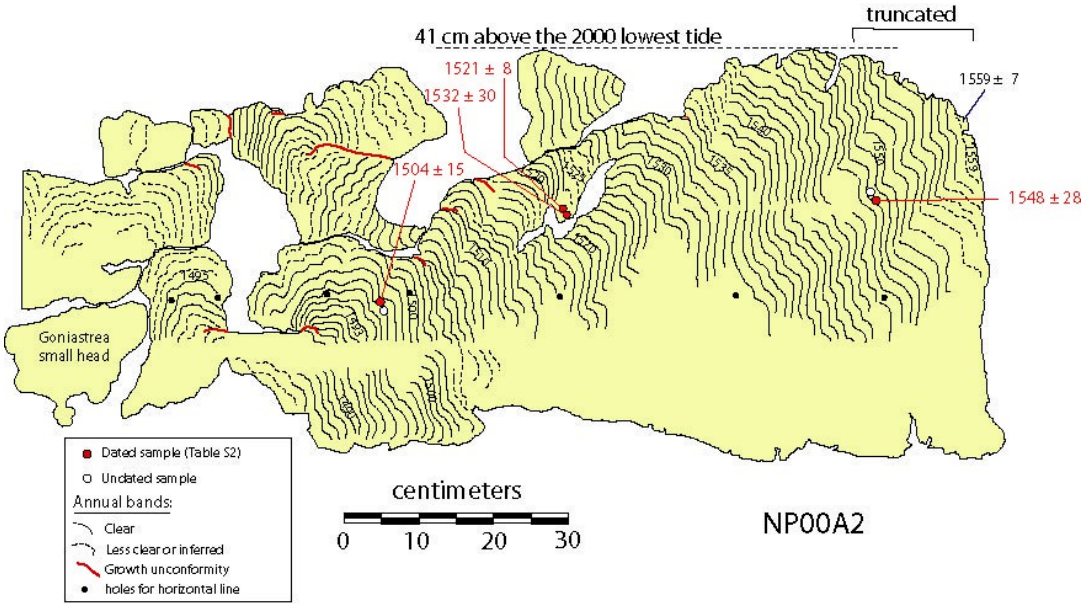


Figure S16. Cross-section of slab Smy02A5.

Sieh et al., 2008



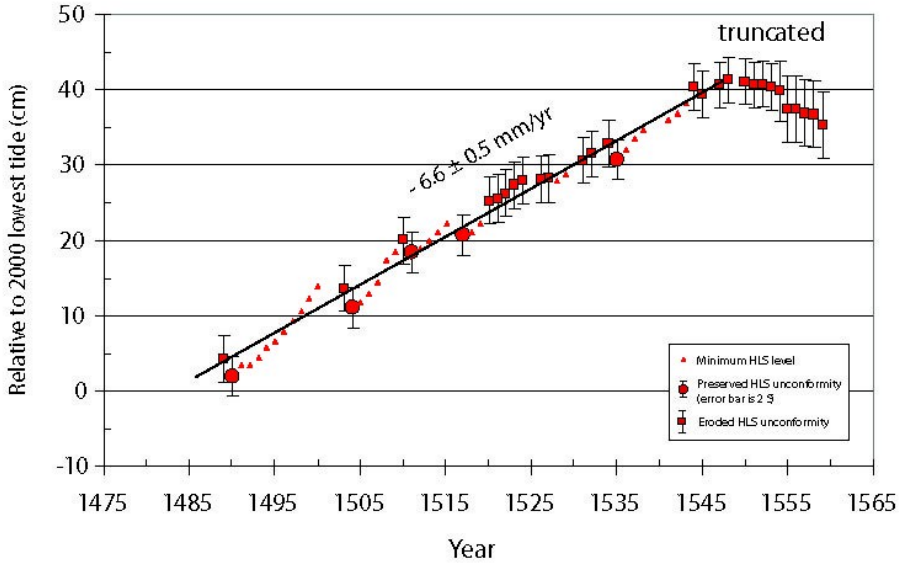
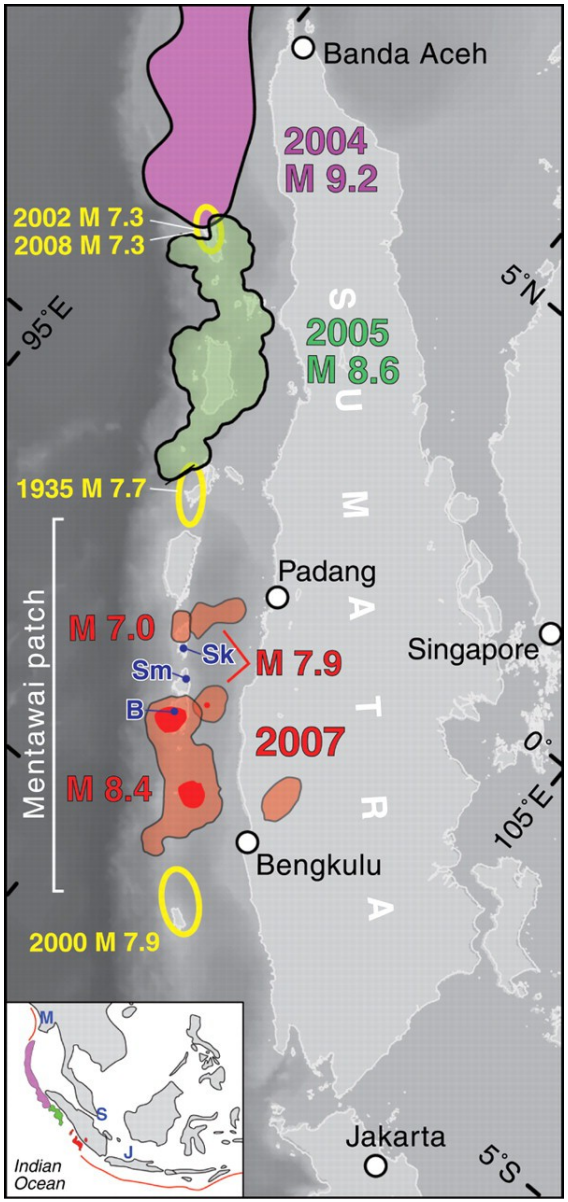


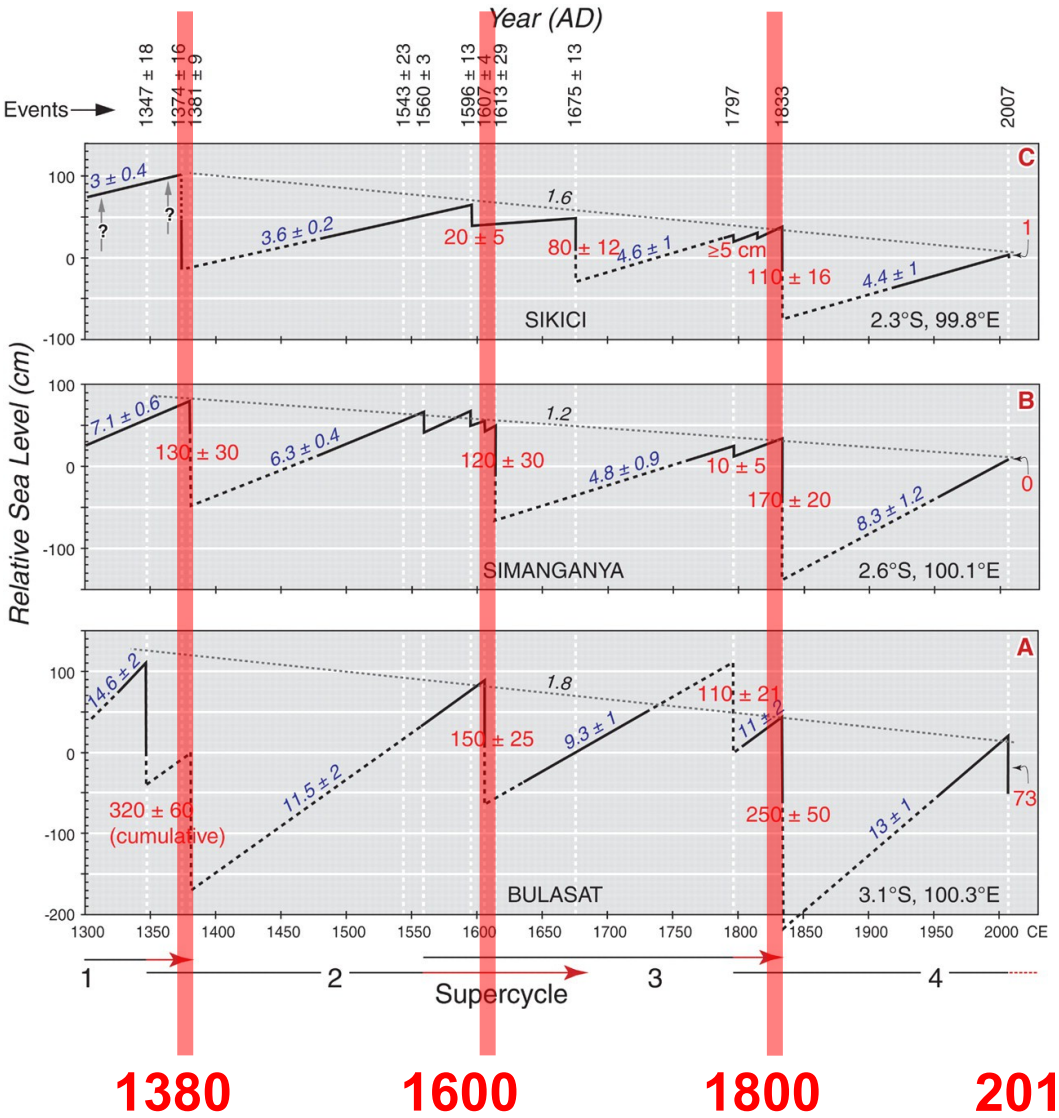
Figure S17. Cross-section of slab Np00A2 and graph of sea level history derived from the cross-section.

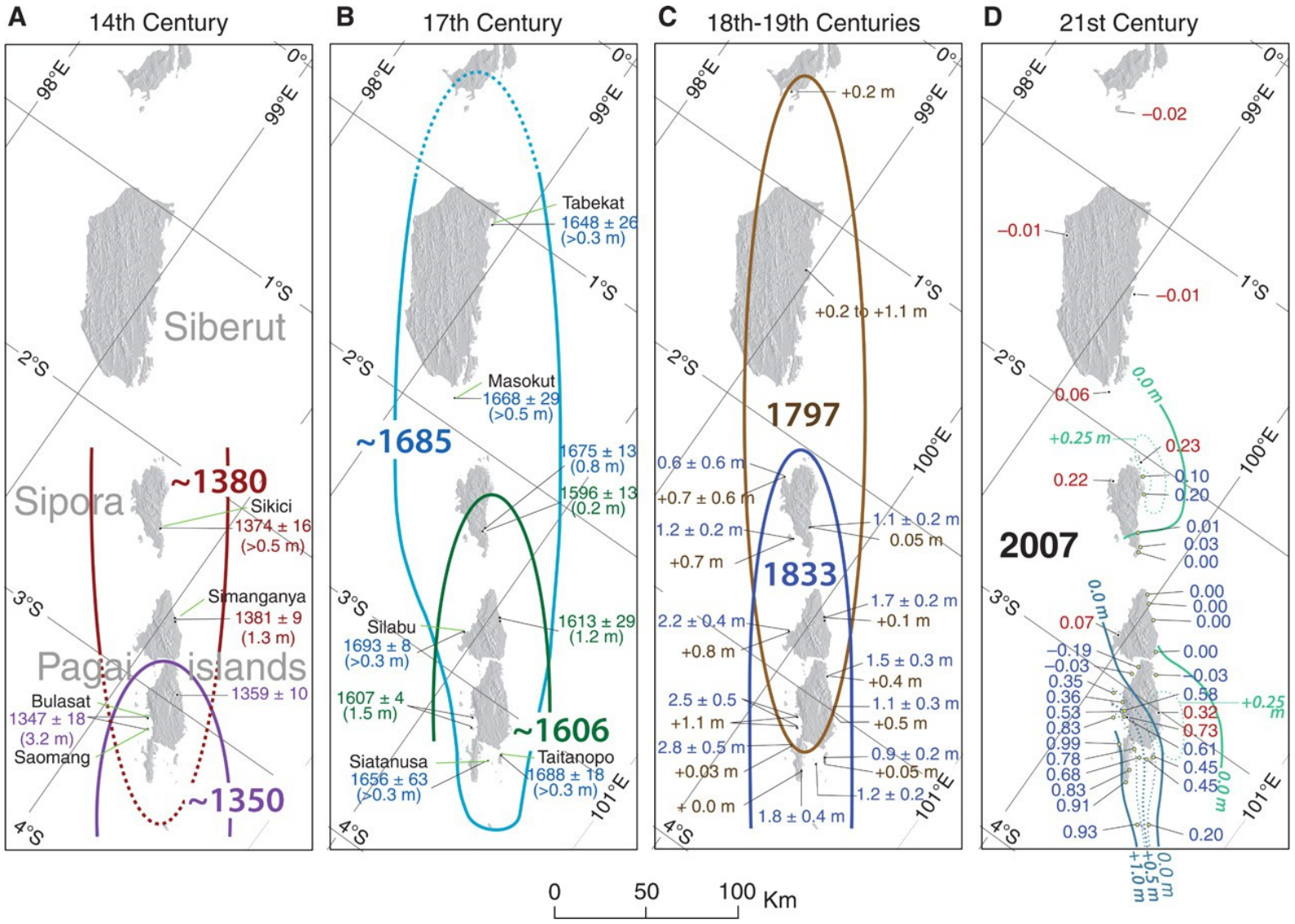
Sieh et al., 2008

Coral reefs records

Sieh et al., 2008







Sieh et al., 2008

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

21 4 2007