Geodesy-deduced thrust kinematics of large earthquakes in various tectonic environments

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2017/12/08

Outline

- **Introduction**
- **Case Study :**
  - –Wenchuan Earthquake
  - –Chi-Chi Earthquake at Tsaotun
  - –Western Solomon Islands
- **Conclusion**

Introduction

- **Earthquake :**

  Rupture, Deformation → Hazard

  Fault Slip → Asperity, Barrier

- **Geodetic Measurement, Seismic Observation**

- **Fault Geometry, Seismogenic Behavior**

Introduction

- **Co-seismic Displacement**
  - –Wenchuan Earthquake
  - –Chi-Chi Earthquake at Tsaotun
- **Inter-seismic Displacement**
  - –Western Solomon Islands

Fault behavior of the Longmenshan fault: deduced from the coseismic horizontal displacements derived from SPOT imagery for 2008 Wenchuan Earthquake

Yu-Ting Kuo[1], Kuang-Yin Lai[2], Yu Wang[3], Yu-Nung Nina Lin[4], Yue-Gau Chen[1], Chung-Pai Chang[5,6], John Suppe[1], Judith Hubbard[3], Ya-Ju Hsu[2], Jean-Philippe Avouac[7], Xi-Wei Xu[8], Bor-Shouh Huang[2]

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[5] Center for Space and Remote Sensing Research, National Central Univ., Jhongli, Taiwan

[6] Inst. of Geophysics, National Central Univ., Jhongli, Taiwan

[7] Division of Geological and Planetary Sciences, Caltech, California, U.S.A.

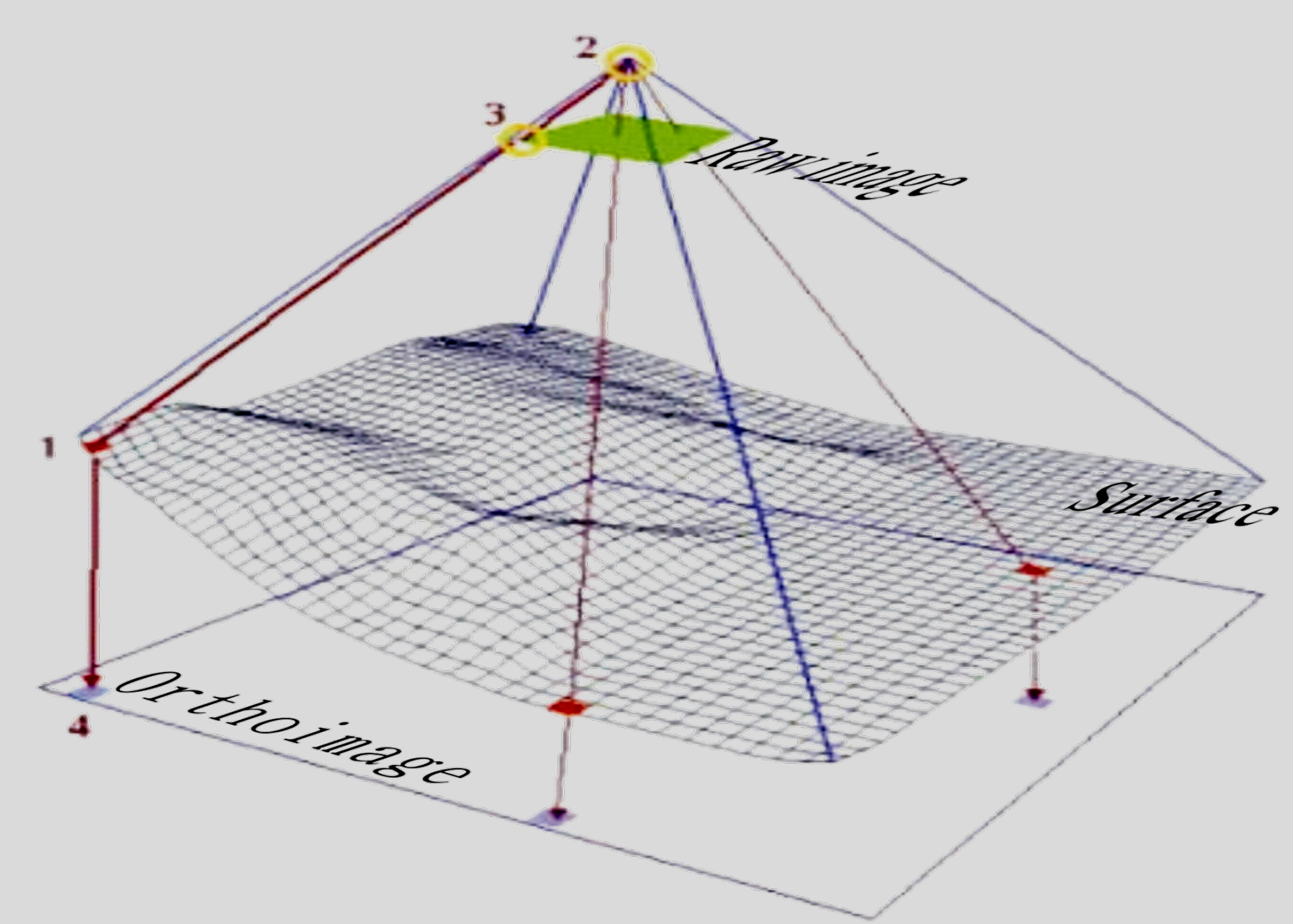
[8] Institute of Geology, China Earthquake Administration, Beijing, China

Cosi-Corr on SPOT Image

- **Wenchuan Earthquake**
- **Near-rupture Coseismic Displacement**
  - Cosi-Corr
    - Pre-EQ & Post-EQ SPOT images
- **Fault Slip Model**
  - Dislocation Model
    - Surface Displacement & Fault Geometry

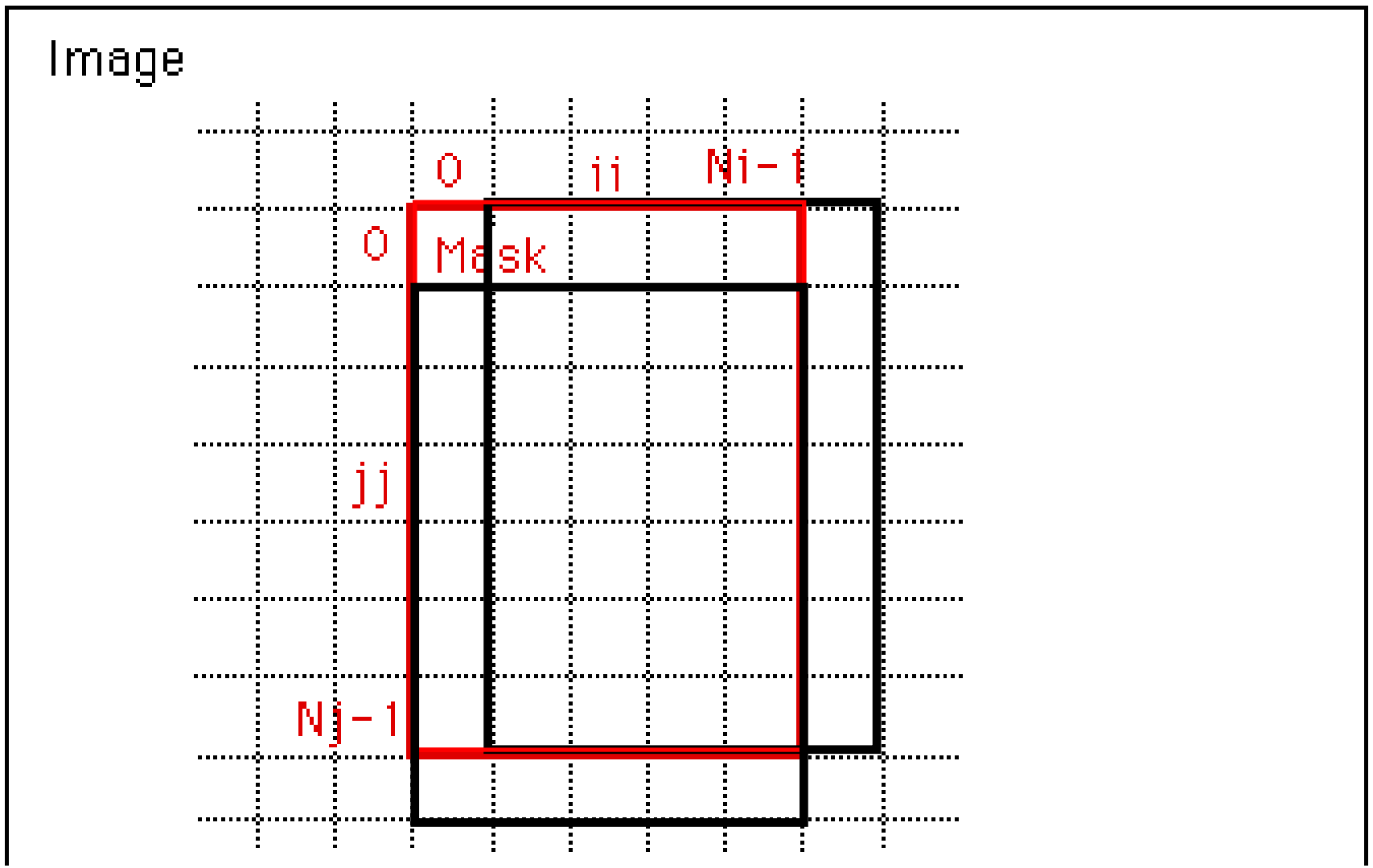
COSI-Corr

- **C**o-registration of **O**ptically **S**ensed **I**mages and **Corr**elation
- Measuring ground deformation using optical satellite and aerial images
- COSI-Corr is a software module developed at the California Institute of Technology and integrated in ENVI



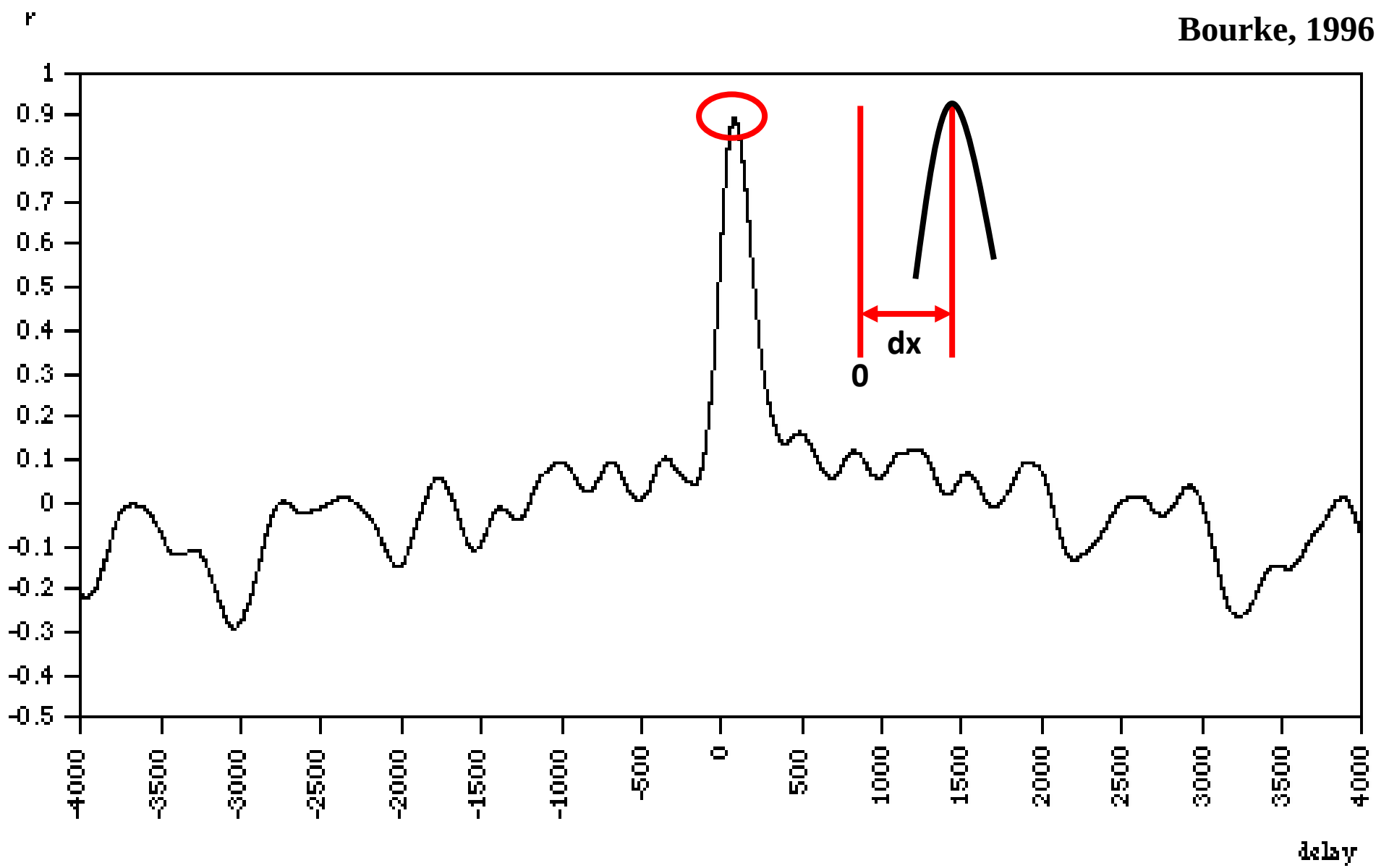
From https://www.satimagingcorp.com/

Bourke, 1996



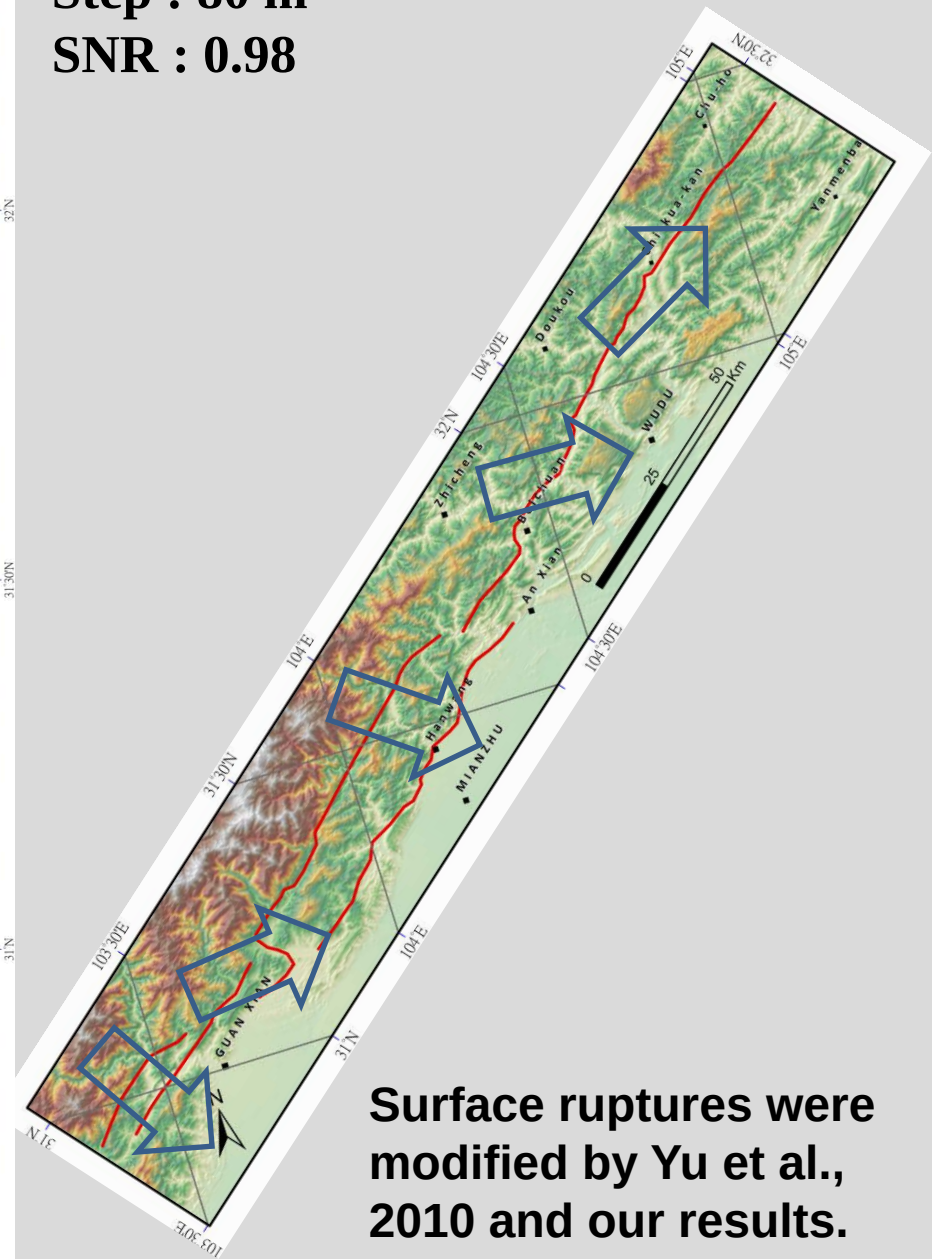
$$r[i][j] = \sum_{jj=-Nj/2}^{jj<Nj/2} \sum_{ii=-Ni/2}^{ii<Ni/2} (mask[ii+Ni/2][jj+Nj/2] - \overline{mask})(image[i+ii][j+jj] - \overline{image})$$

Bourke, 1996



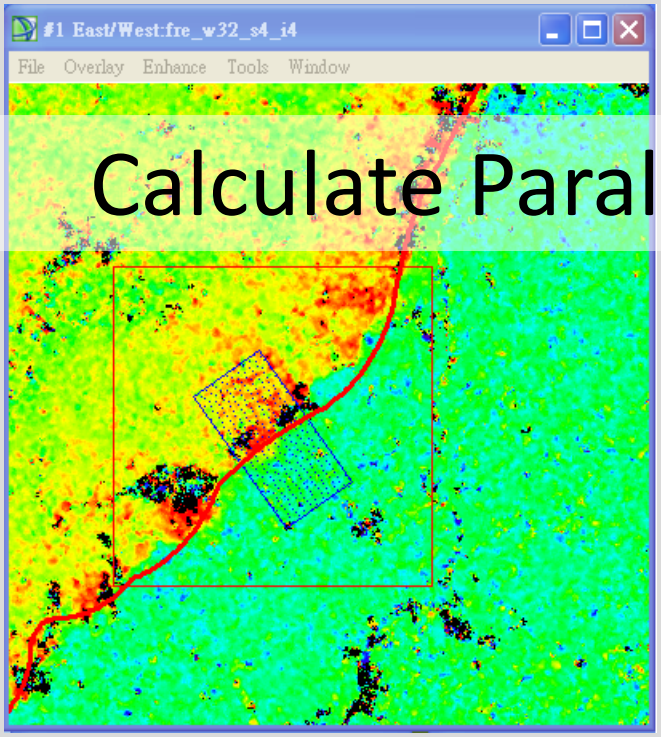
$$r[i][j] = \sum_{jj=-Nj/2}^{jj<Nj/2} \sum_{ii=-Ni/2}^{ii<Ni/2} (mask[ii+Ni/2][jj+Nj/2] - \overline{mask})\,(image[i+ii][j+jj] - \overline{image})$$

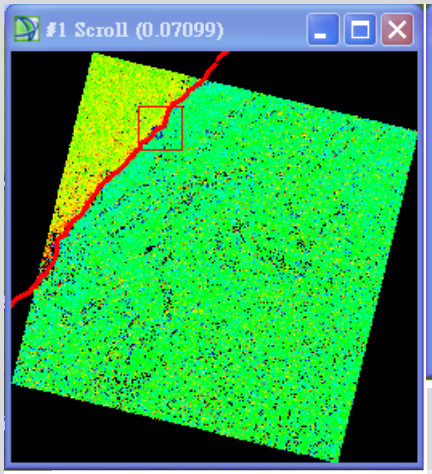
1 pixel : 5m
Window Size : 80 ~ 1280 m
Step : 80 m
SNR : 0.98

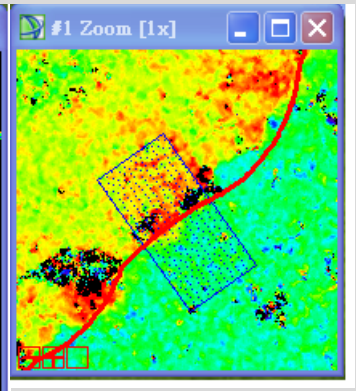


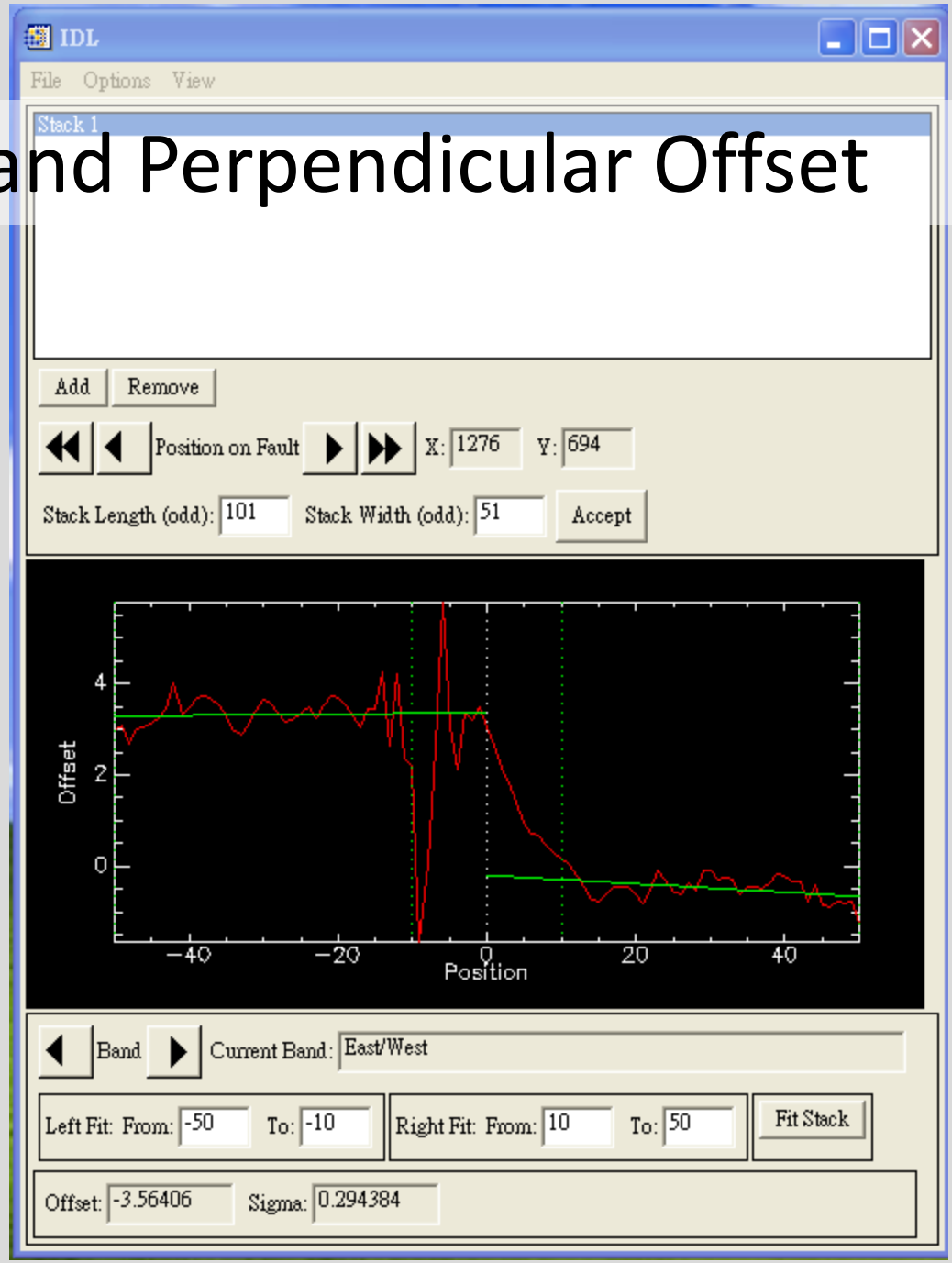
Surface ruptures were modified by Yu et al., 2010 and our results.

Calculate Parallel and Perpendicular Offset



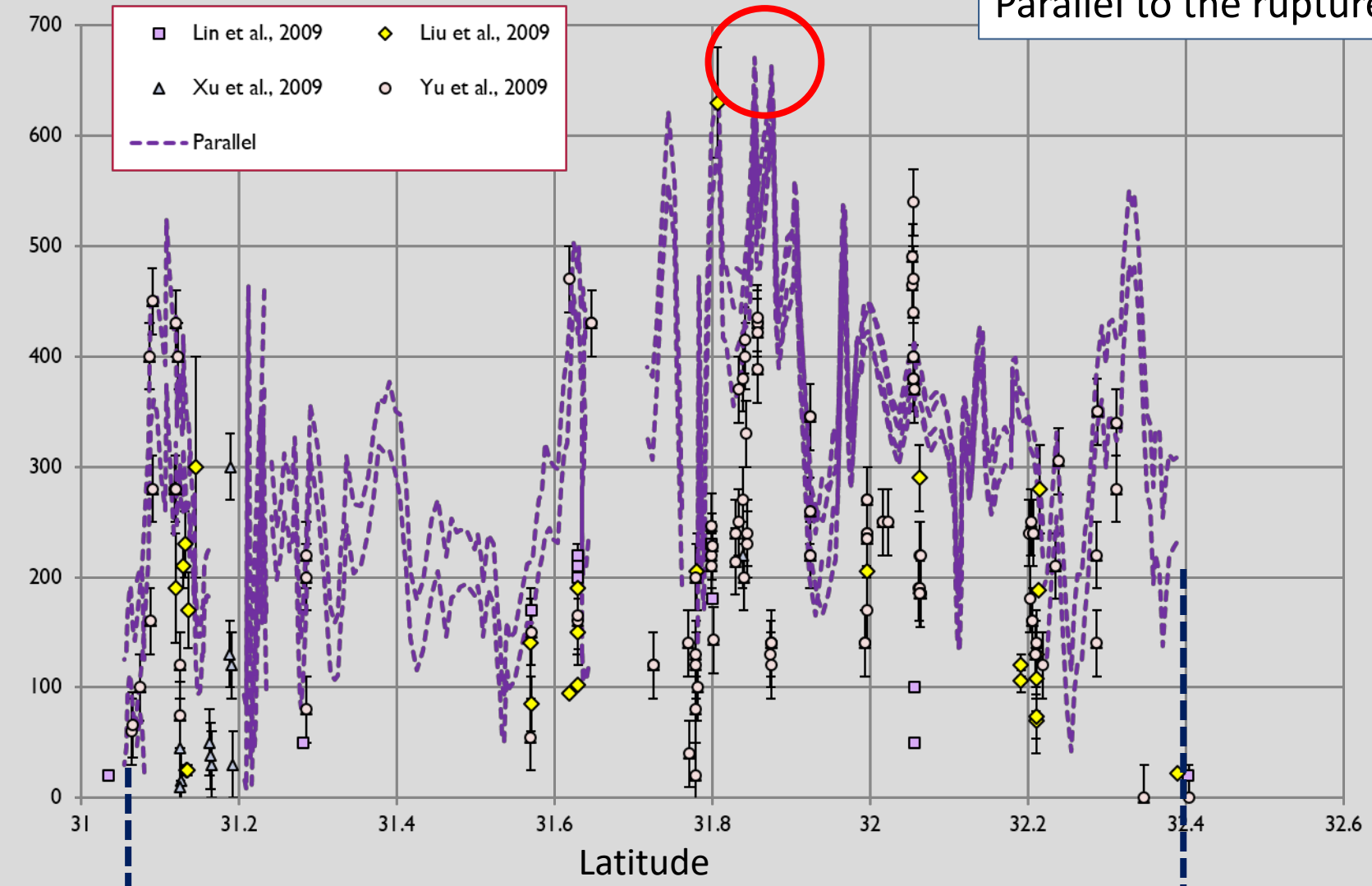




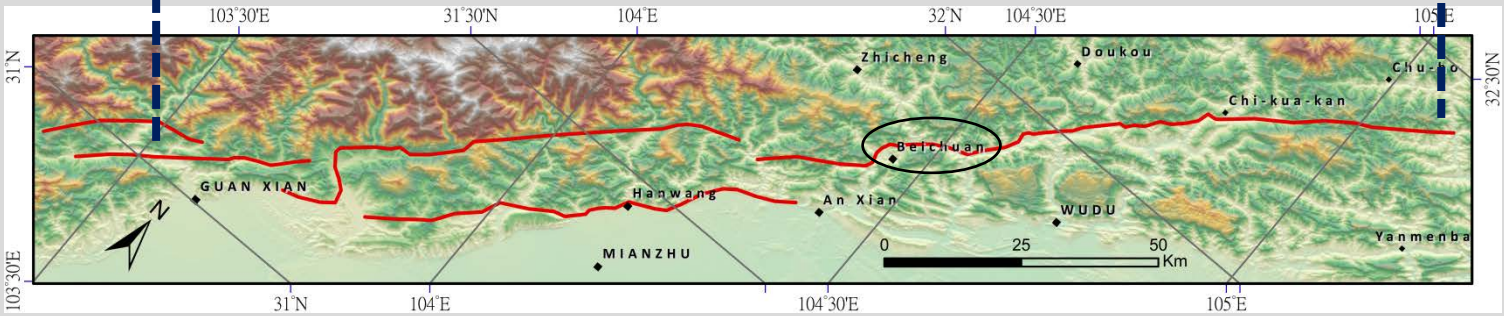


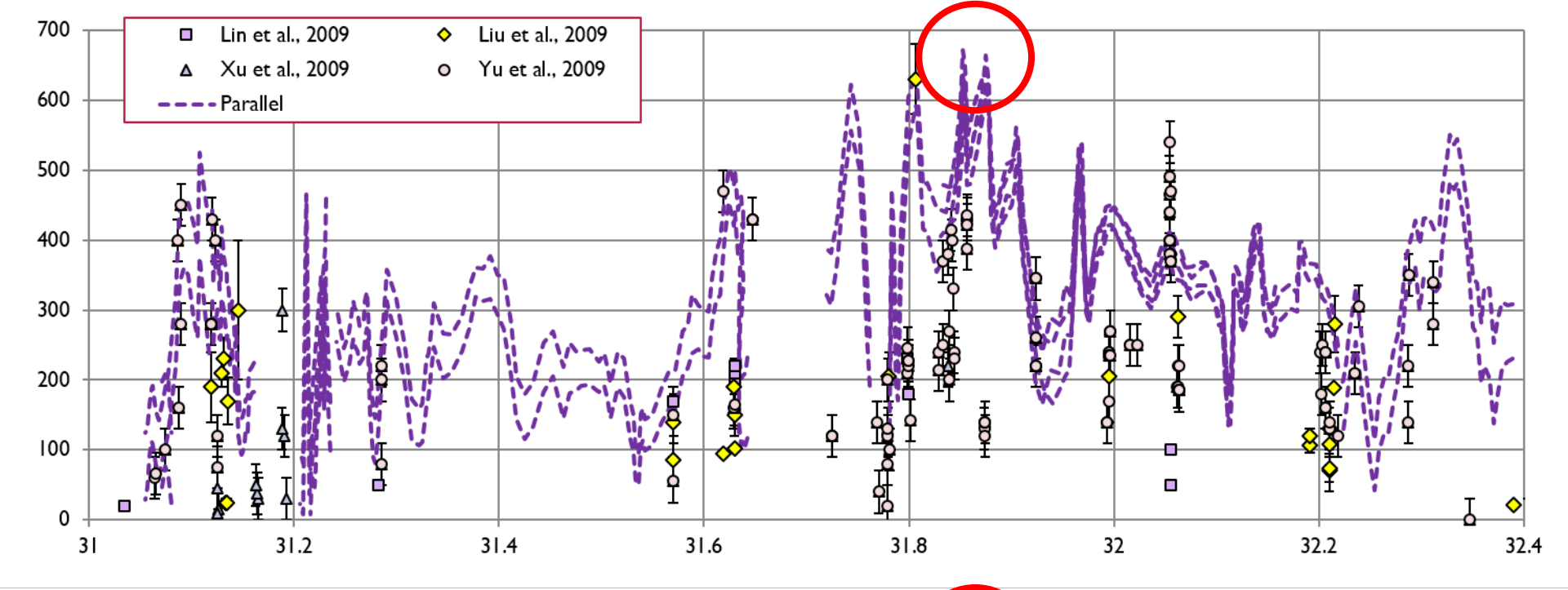
Stack Length : 12 Km
Stack Width : 4 km
Near-Fault Width : ~800 m

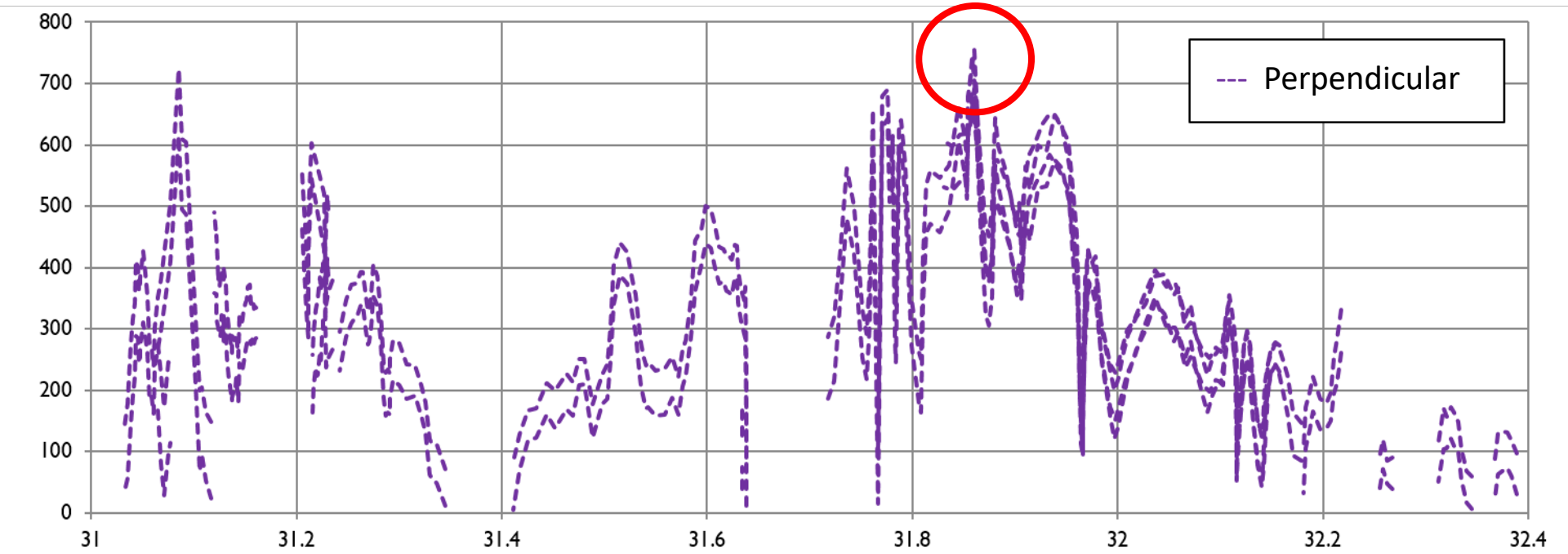
Parallel to the rupture



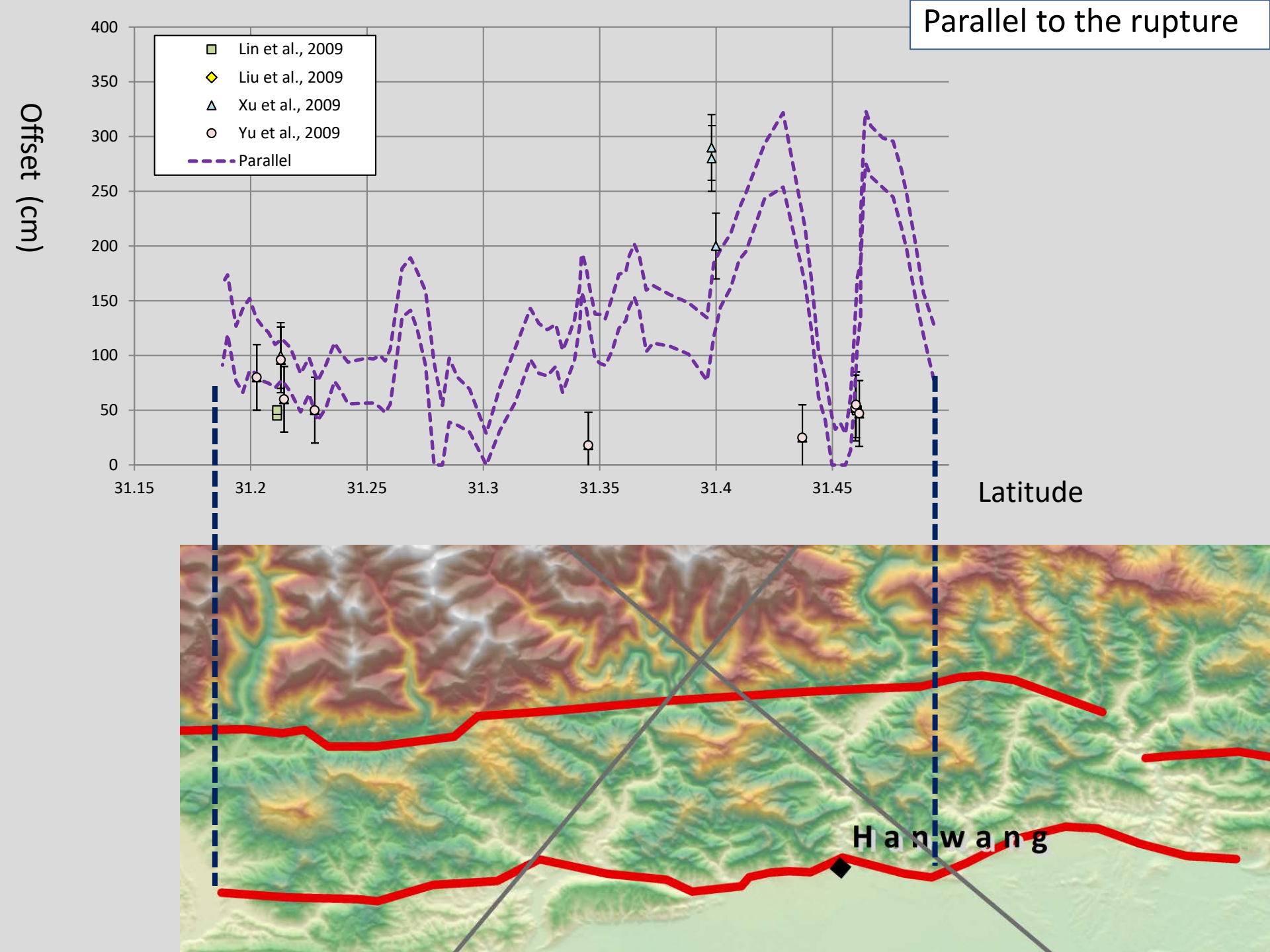
Beichuan

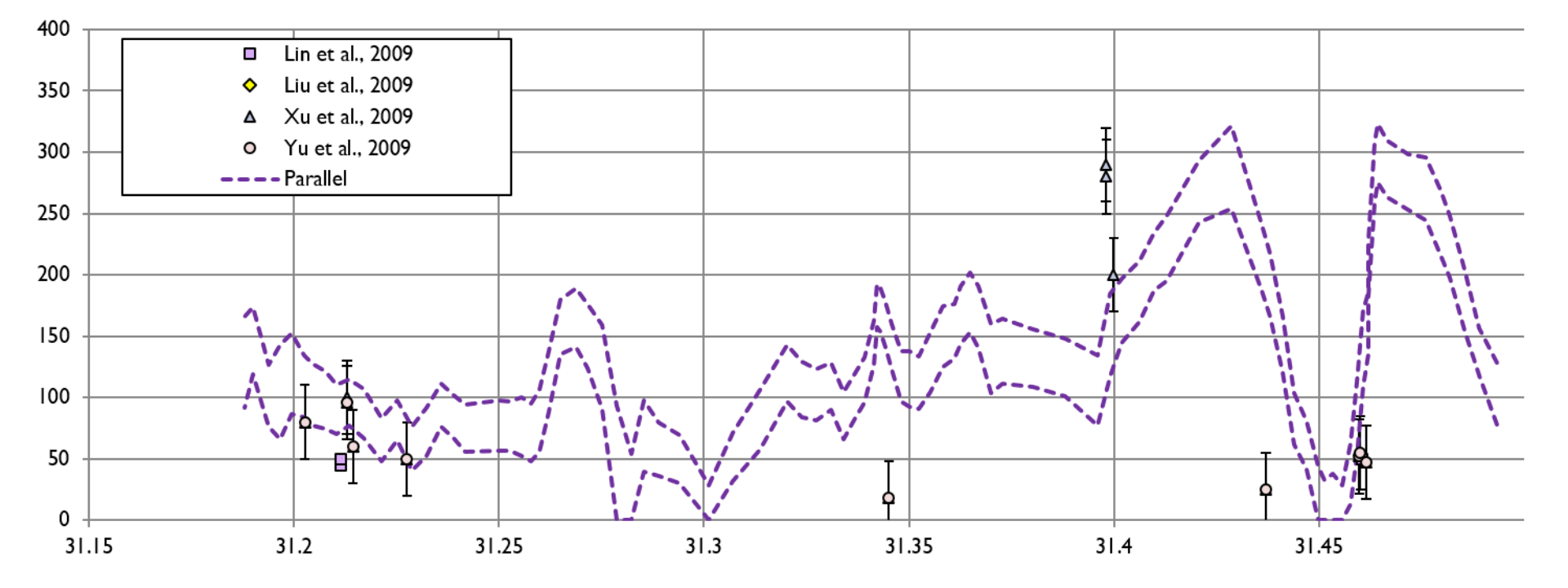


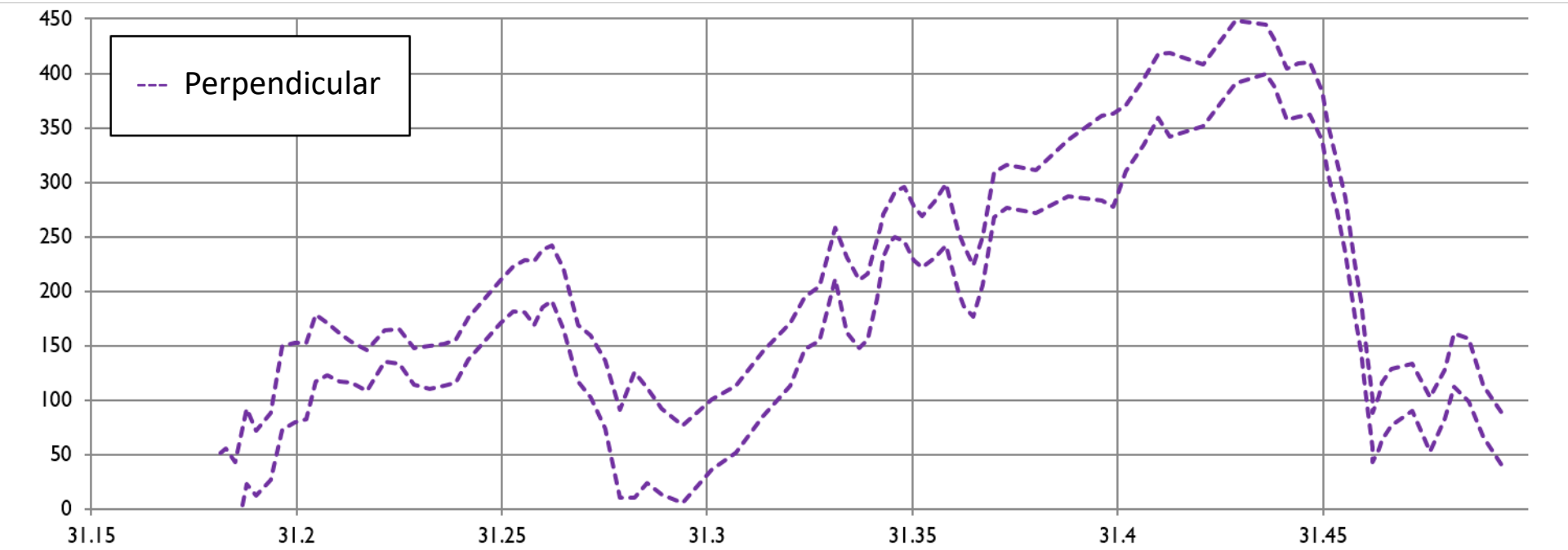

Lin et al., 2009
Liu et al., 2009
Xu et al., 2009
Yu et al., 2009
Parallel
700
600
500
400
300
200
100
0
31
31.2
31.4
31.6
31.8
32
32.2
32.4

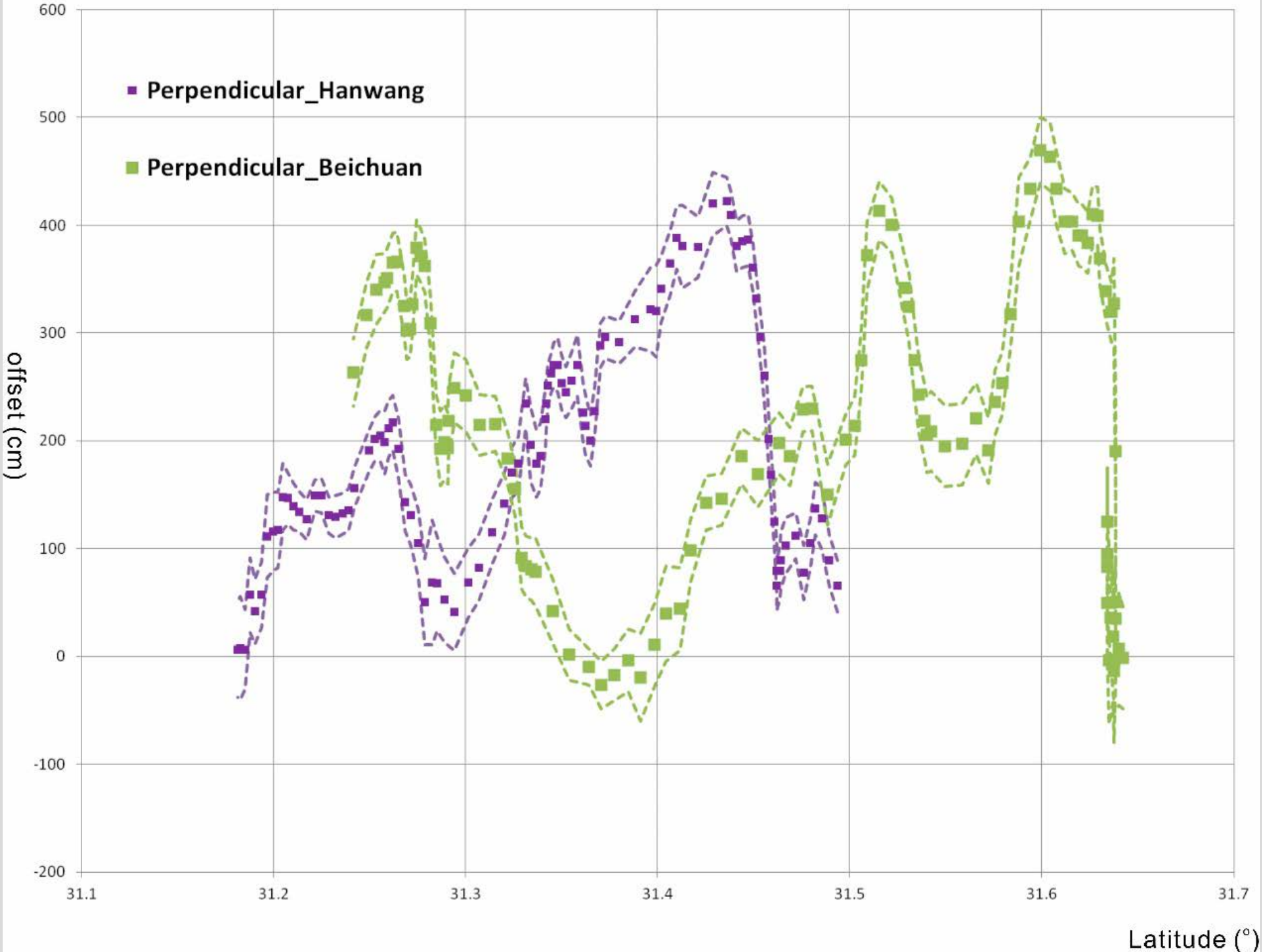

Perpendicular
800
700
600
500
400
300
200
100
0
31
31.2
31.4
31.6
31.8
32
32.2
32.4

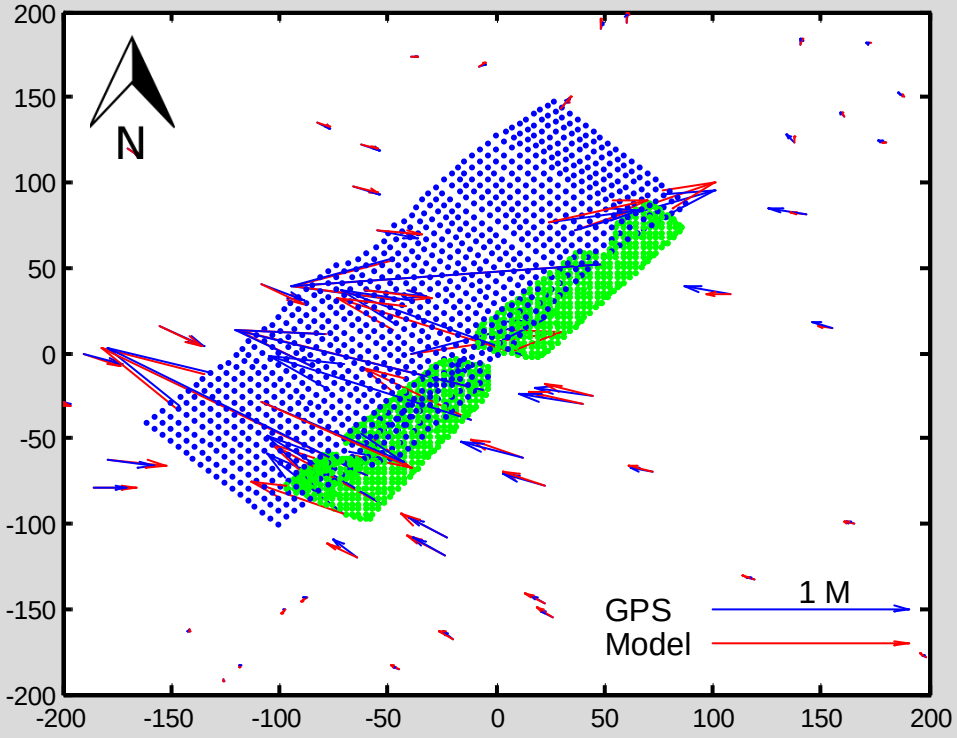
Parallel to the rupture



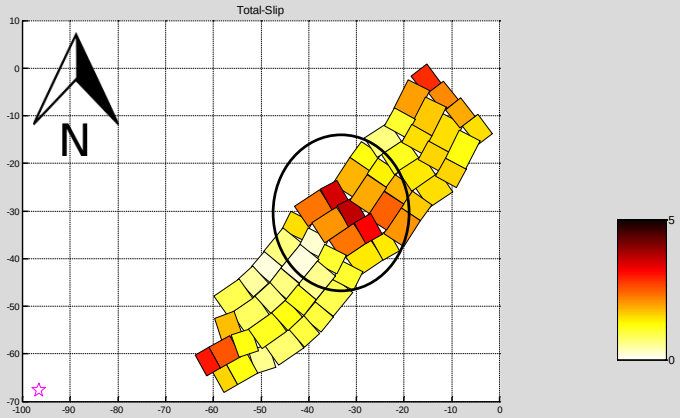

Lin et al., 2009
Liu et al., 2009
Xu et al., 2009
Yu et al., 2009
Parallel
400
350
300
250
200
150
100
50
0
31.15
31.2
31.25
31.3
31.35
31.4
31.45


Perpendicular
450
400
350
300
250
200
150
100
50
0
31.15
31.2
31.25
31.3
31.35
31.4
31.45


Perpendicular_Hanwang
Perpendicular_Beichuan
offset (cm)
600
500
400
300
200
100
0
-100
-200
31.1
31.2
31.3
31.4
31.5
31.6
31.7
Latitude (°)

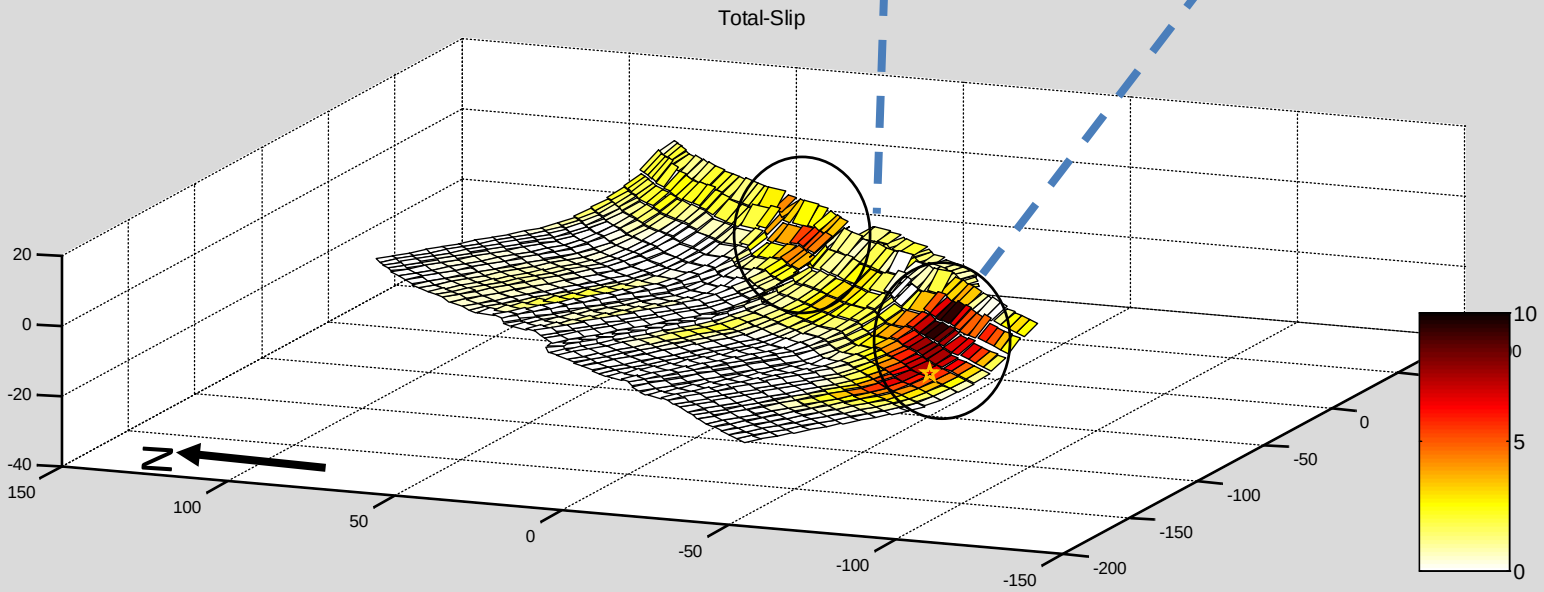


Pengguan Fault



Mw = 7.9

max net-slip = 9.5 m



Summary

- **Continuous Near-rupture Horizontal Displacement**
  - Parallel and Perpendicular Component
  - Distribution of Offset
  - Correlation between Beichuan and Hanwang Ruptures
- **Fault Slip Model**
  - Asperities on Beichuan and Pengguan Faults

Coseismic thrusting and folding in the 1999 Mw 7.6 Chi-Chi Earthquake: A high resolution approach by aerial photos taken from Tsaotun, Central Taiwan

Yu-Ting Kuo[1], Francois Ayoub[2], Sébastien Leprince[2], *Yue-Gau Chen[1], Jean-Philippe Avouac[2], J. Bruce H. Shyu[1], Kuang-Yin Lai[1], Yu-Ju Kuo[3]

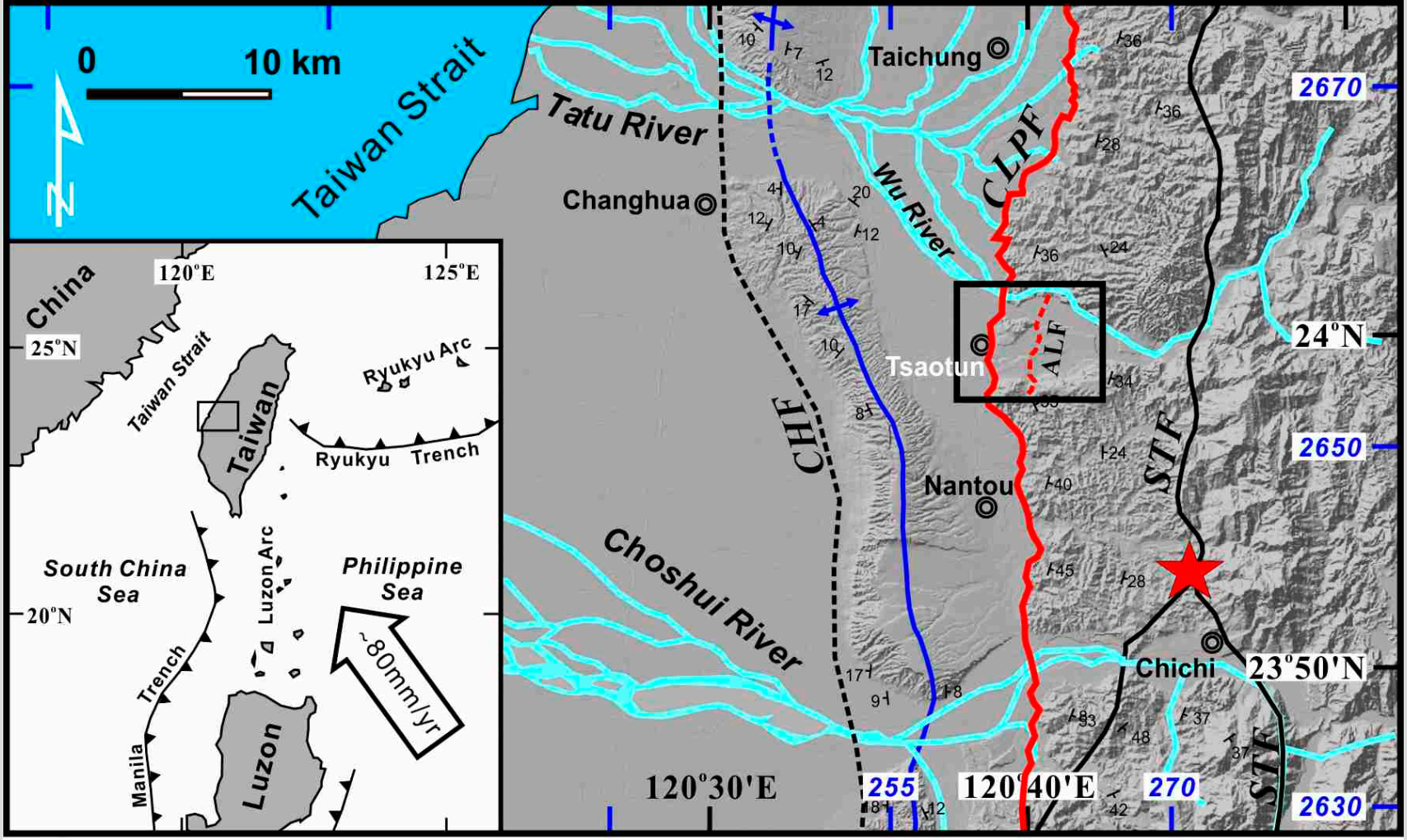
[1]Dept. of Geosciences, National Taiwan Univ., Taiwan, R.O.C.

[2]Division of Geological and Planetary Sciences, Caltech, California, U.S.A.

[3] Mathematics Dept., Indiana Univ. of Pennsylvania, U.S.A.

Cosi-Corr on Aerial Photo

- Chi-Chi Earthquake at Tsaotun
- High-resolution Surface Displacement
- Estimation of Vertical Displacement
- Fault Geometry



Anticline

Fault

Inferred fault

Fold scarp

1999 surface ruptures

ALF Ailiao fold scarp

CHF Changhua fault

CLPF Chelungpu fault

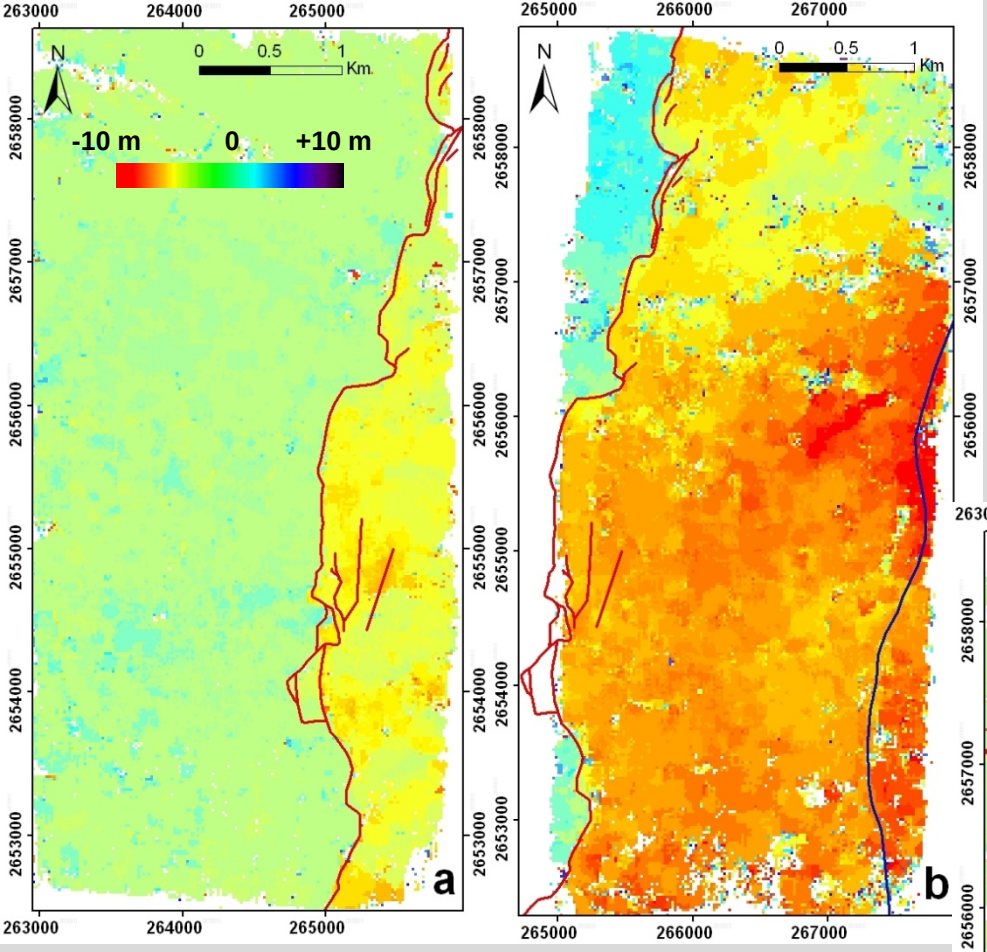
STF Shuangtung fault

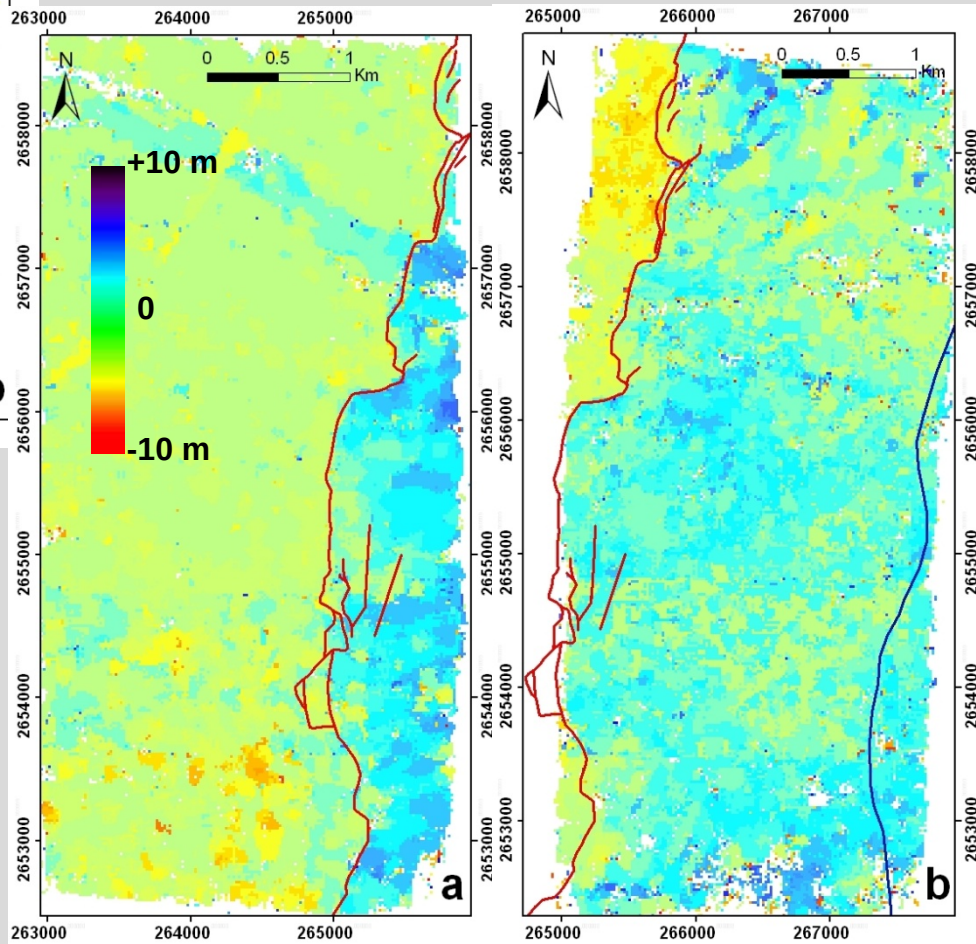
Study area

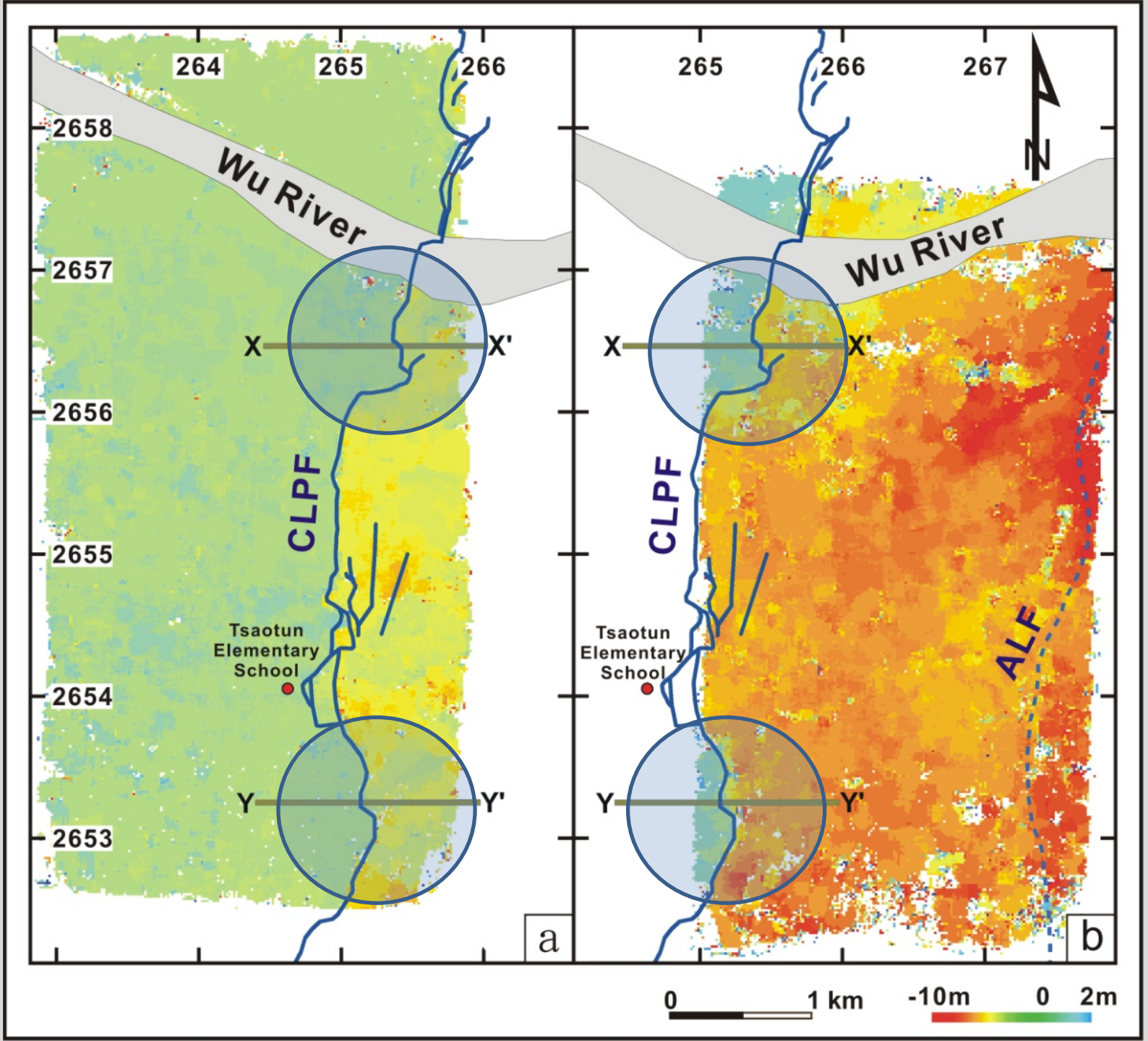
Epicenter of Chichi Earthquake

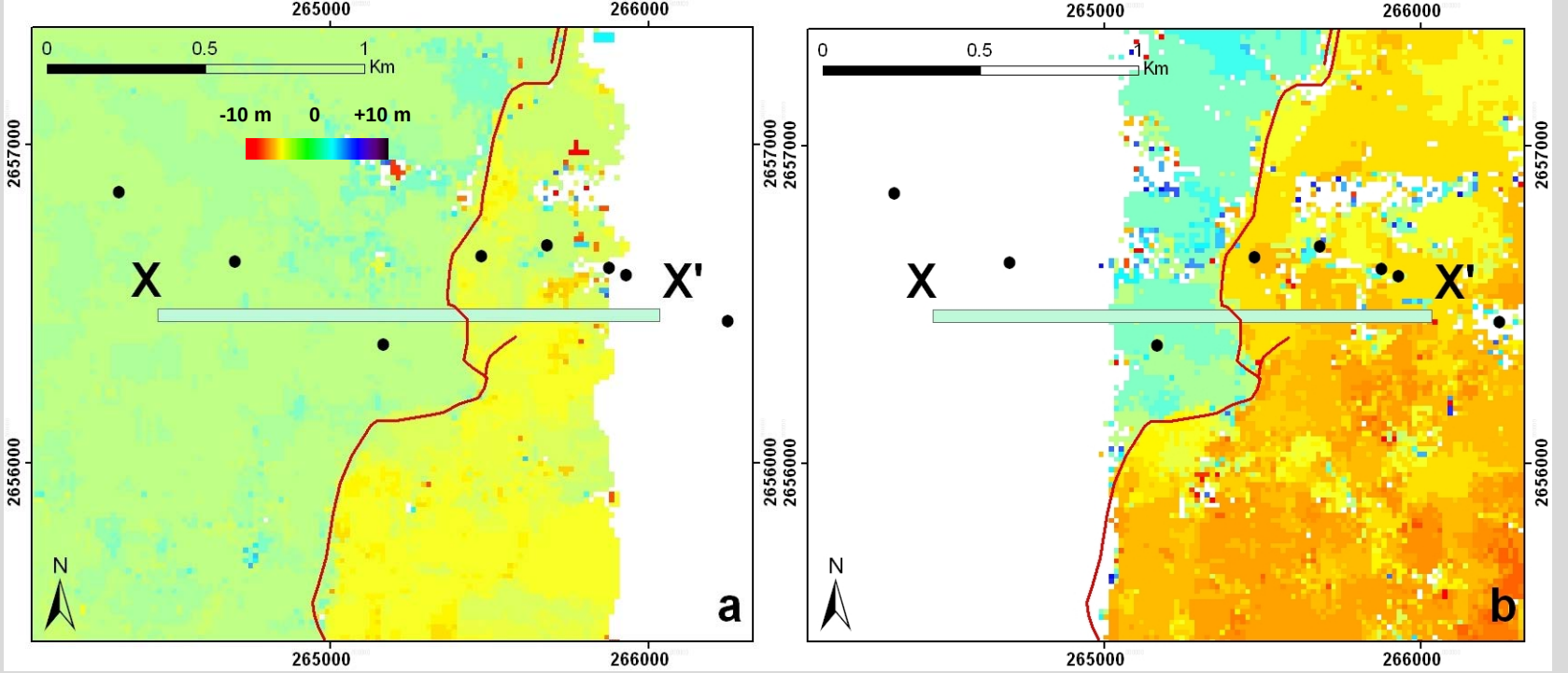
Result I

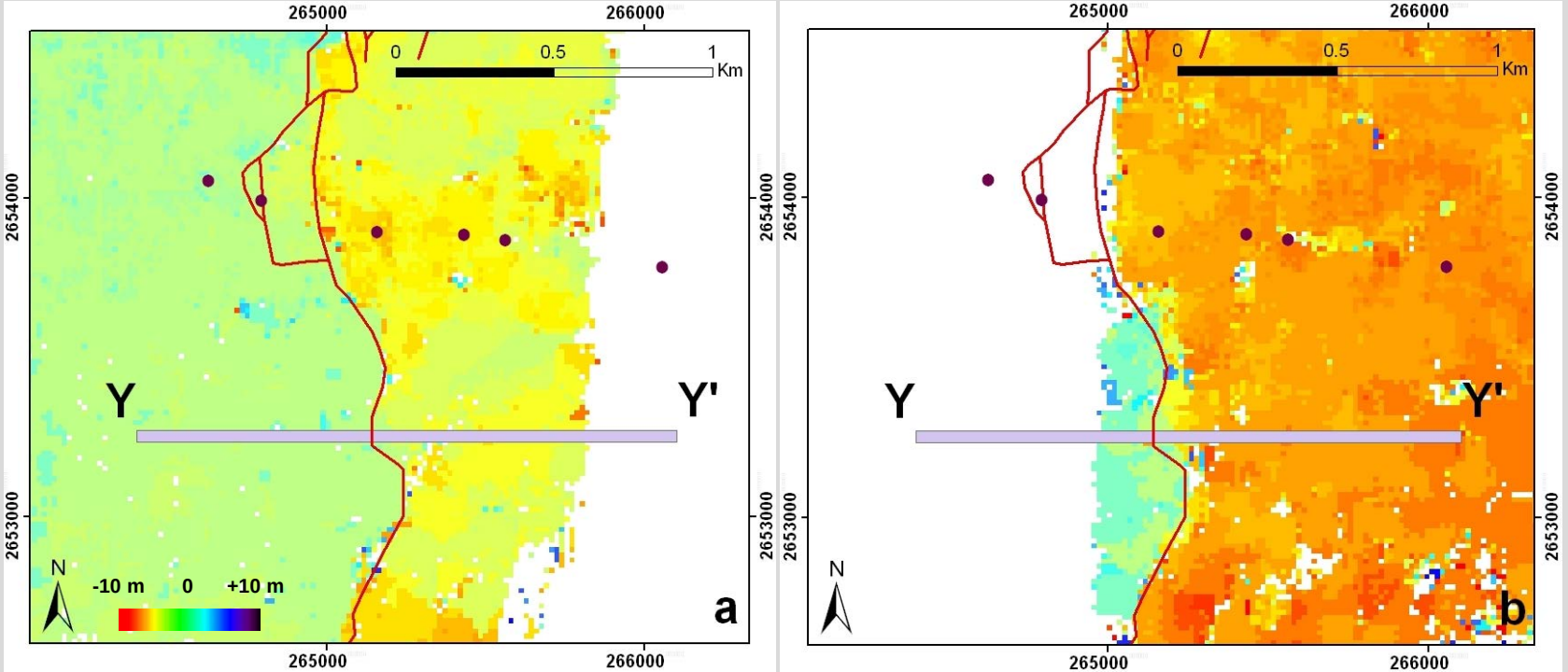
- **Orthorectification:**
  - **Pre-earthquake:**
    - **Pre-eq DEM**
    - **GCPs RMS ≈ 0.9 pixel**
  - **Post-earthquake:**
    - **Pre-eq DEM**
    - **GCPs RMS ≈ 0.6 pixel**
  - **Orthoimage : 1 m**
- **COSI-Corr**
  - **Window Size : 128 (m) *128 (m)**
  - **Step : 16 (m)**

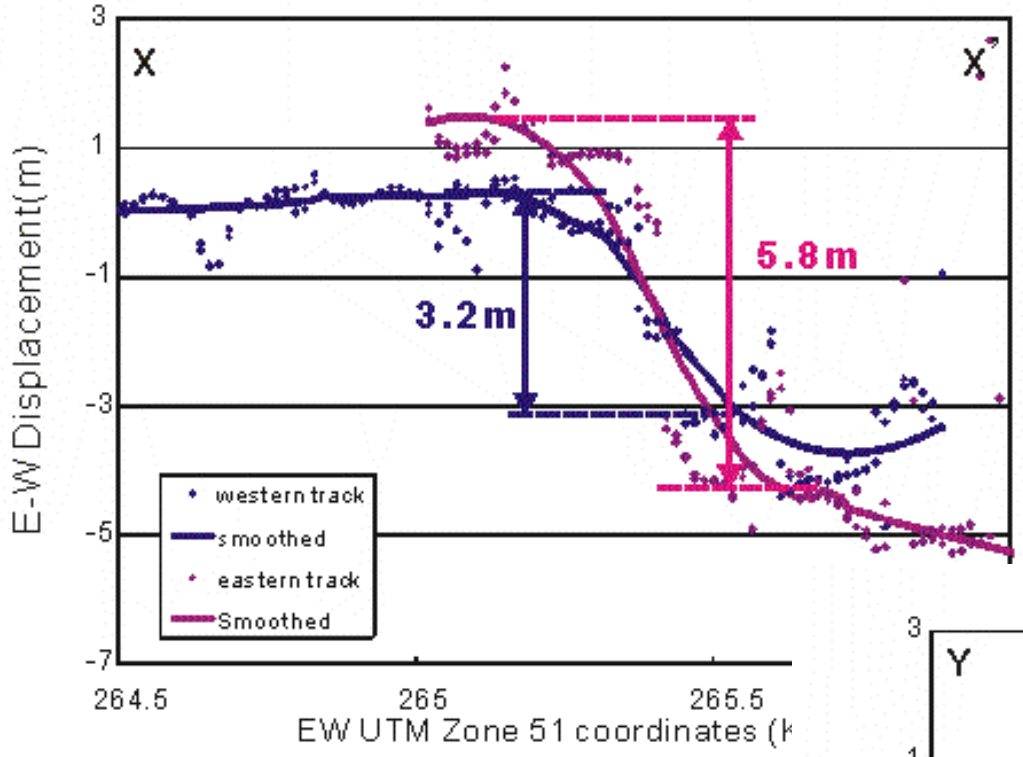

N
0 0.5 1 Km
-10 m 0 +10 m
a
b

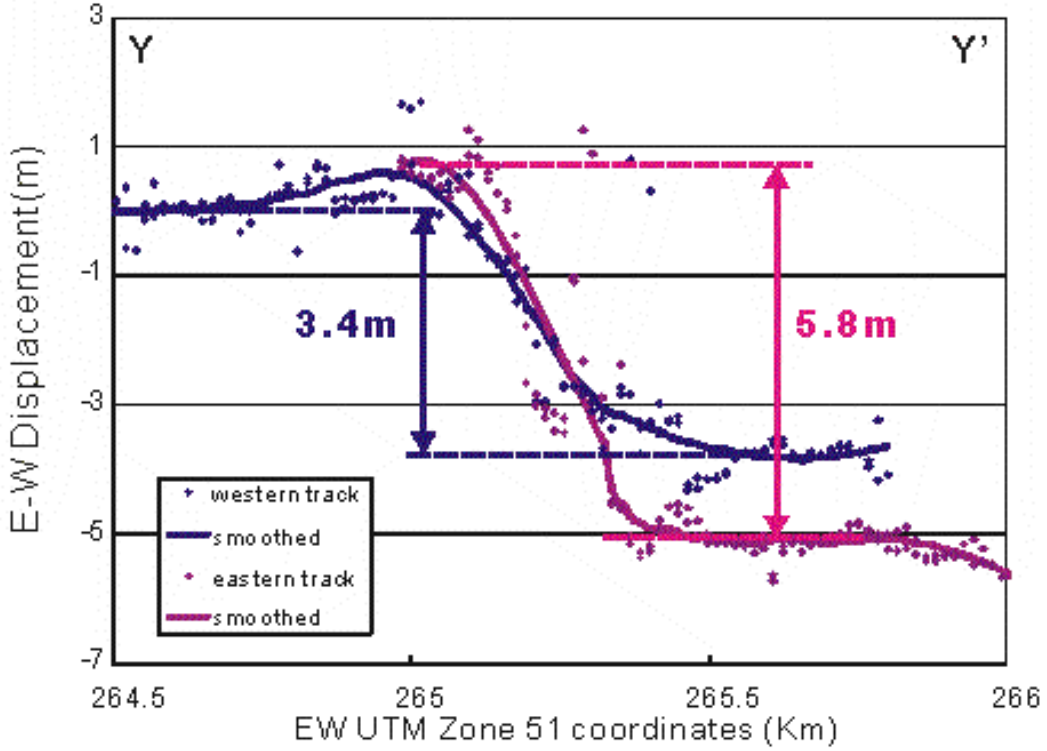

N
0 0.5 1 Km
+10 m
0
-10 m
a
b


264
265
266
2658
2657
2656
2655
2654
2653
Wu River
X
X'
Y
Y'
CLPF
Tsaotun
Elementary
School
a
265
266
267
N
Wu River
X
X'
Y
Y'
CLPF
ALF
Tsaotun
Elementary
School
b
0
1 km
-10m
0
2m

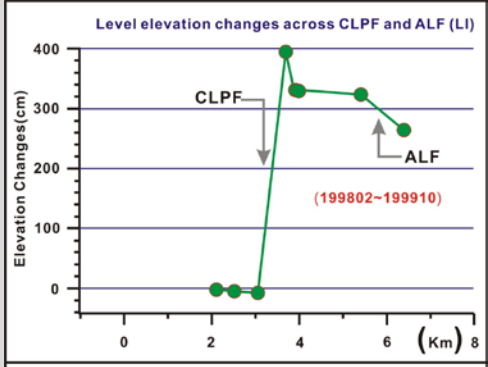

265000
266000
0
0.5
1
Km
-10 m
0
+10 m
2657000
2656000
X
X'
N
a
b

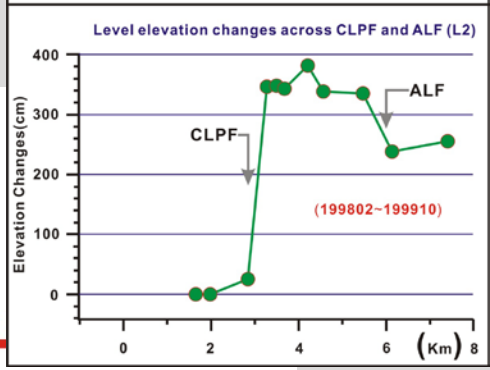

265000
266000
0
0.5
1
Km
2654000
2653000
Y
Y'
N
-10 m
0
+10 m
a
b


X
X'
3.2m
5.8m
western track
smoothed
eastern track
Smoothed
E-W Displacement(m)
3
1
-1
-3
-5
-7
264.5
265
265.5
EW UTM Zone 51 coordinates (K


Y
Y'
3.4m
5.8m
western track
smoothed
eastern track
smoothed
E-W Displacement(m)
3
1
-1
-3
-5
-7
264.5
265
265.5
266
EW UTM Zone 51 coordinates (Km)

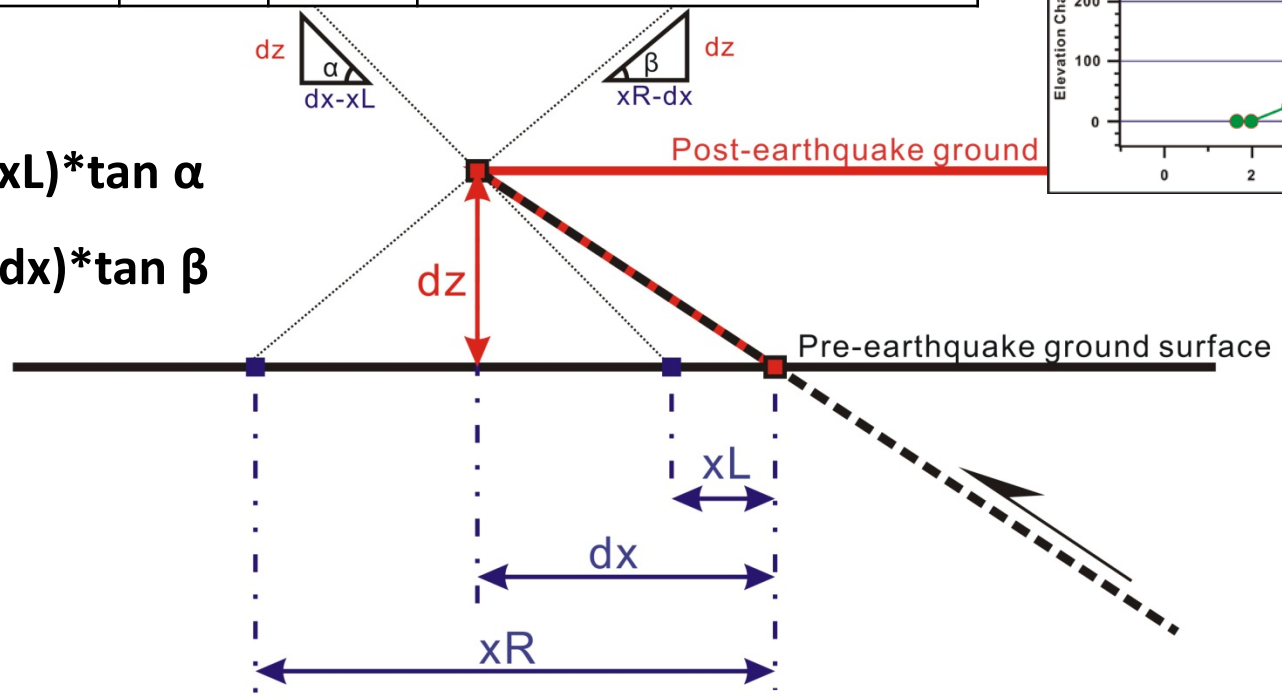
	α	β	xL	xR	dz	Leveling Measurement
X-X’	72°	72°	3.2m	5.8m	4m	3~4m
Y-Y’	71°	71°	3.4m	5.8m	3.5m	3~4m





$dz=(dx-xL)*\tan\alpha$

$dz=(xR-dx)*\tan\beta$



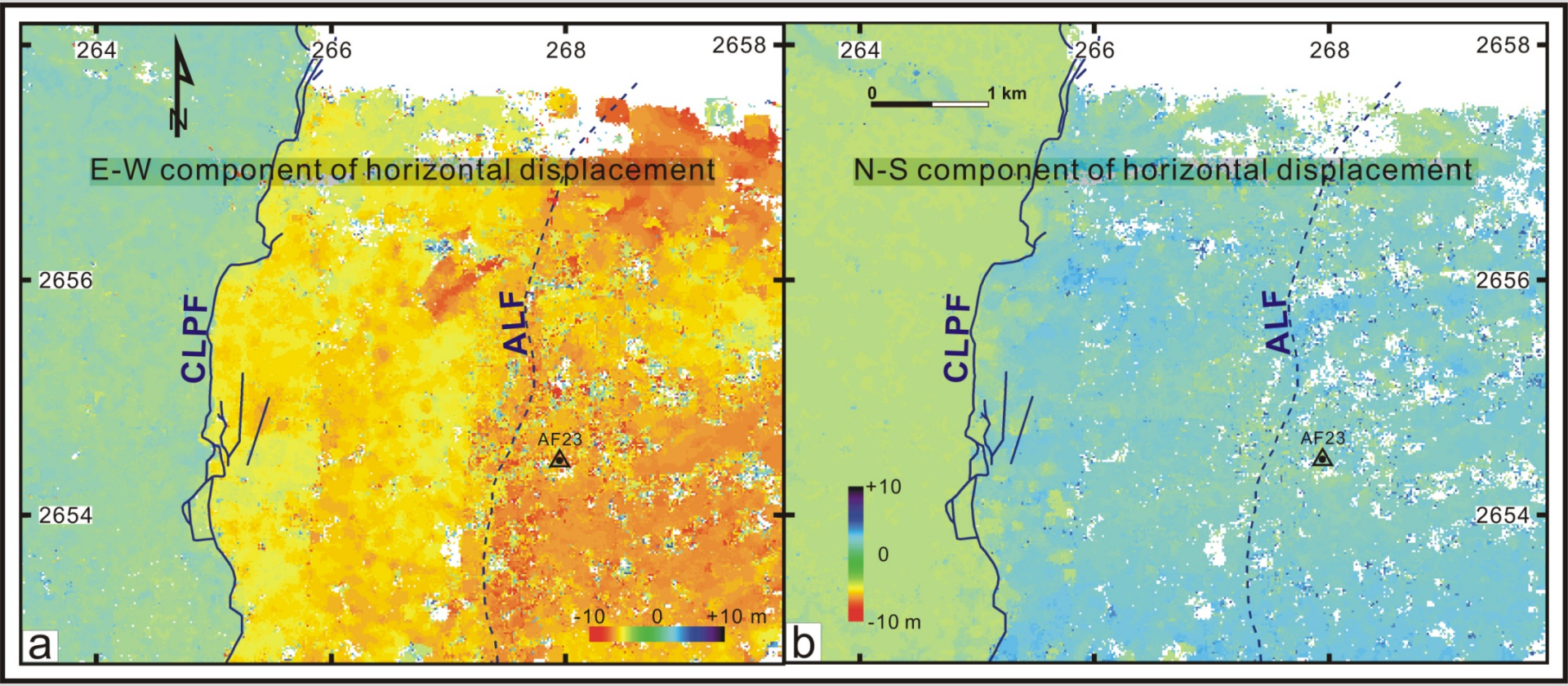
xL:The measured displacement from left flight channel
xR:The measured displacement from right flight channel
dx:The co-seismic horizontal displacement
dz: The co-seismic vertical displacement
α:The depression angle from left flight channel
β:The depression angle from right flight channel

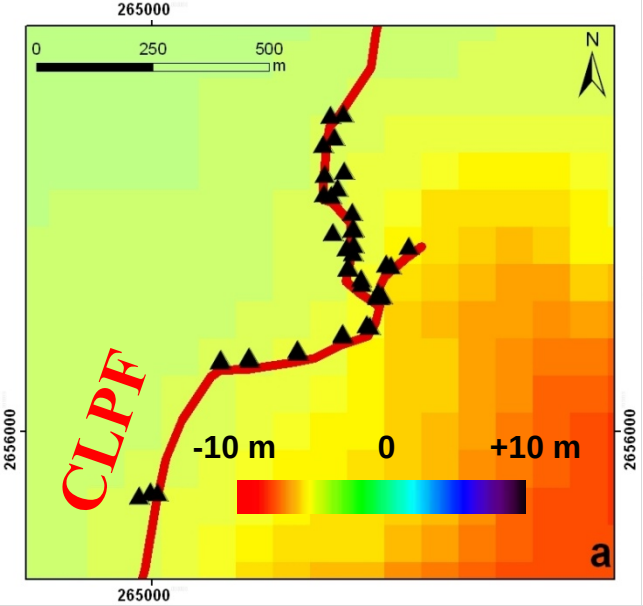
$$dx=(xL*\tan\alpha+xR*\tan\beta)/(\tan\alpha+\tan\beta)$$

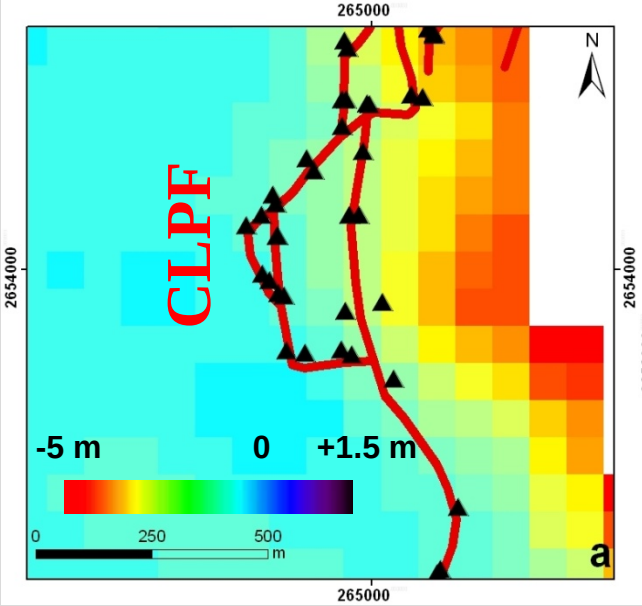
$$dz=(xR-xL)*(\tan\alpha*\tan\beta)/(\tan\alpha+\tan\beta)$$

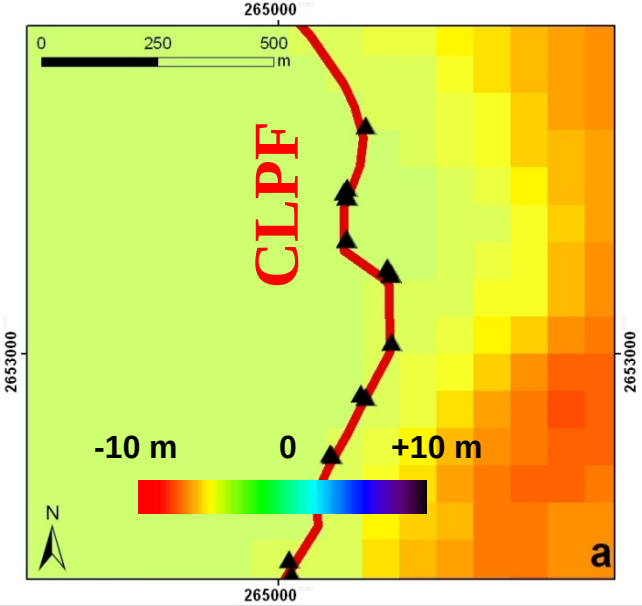
Result II

- **Orthorectification:**
  - **Pre-earthquake:**
    - **Pre-eq DEM**
    - **GCPs RMS ≈ 0.9 pixel**
  - **Post-earthquake:**
    - **Post-eq DEM**
    - **GCPs RMS ≈ 0.6 pixel**
  - **Orthoimage : 1 m**
- **COSI-Corr**
  - **Window Size : 128 (m) *128 (m)**
  - **Step : 16 (m)**

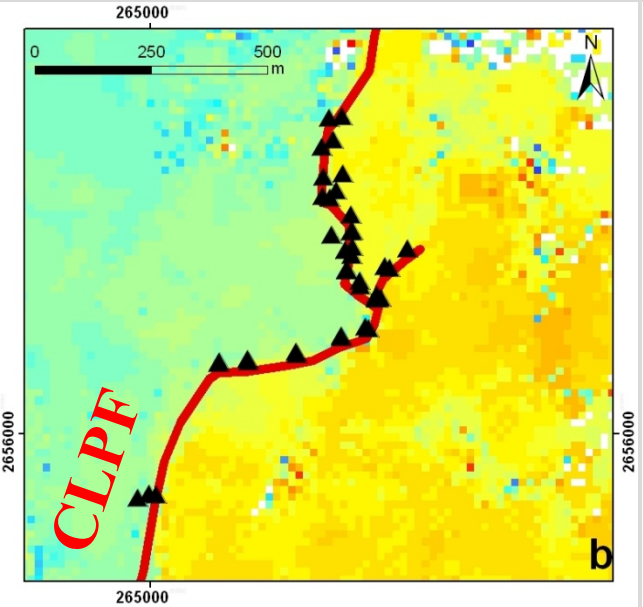

264
266
268
2658
2656
2654
E-W component of horizontal displacement
CLPF
ALF
AF23
-10
0
+10 m
a
0
1 km
N-S component of horizontal displacement
+10
0
-10 m
b

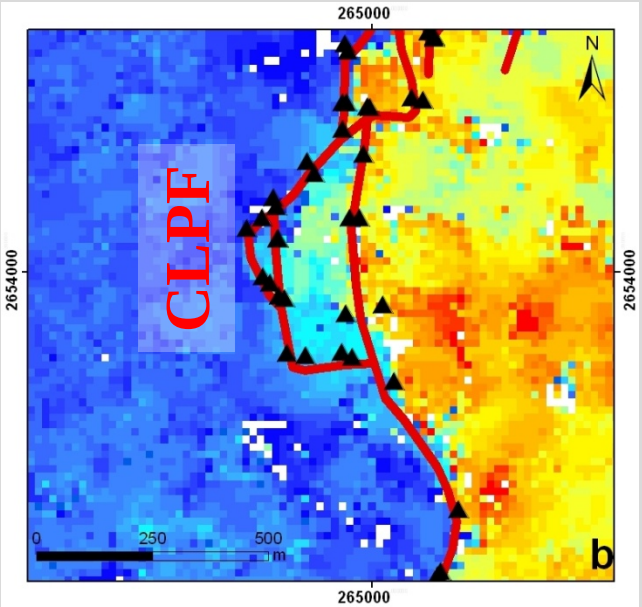


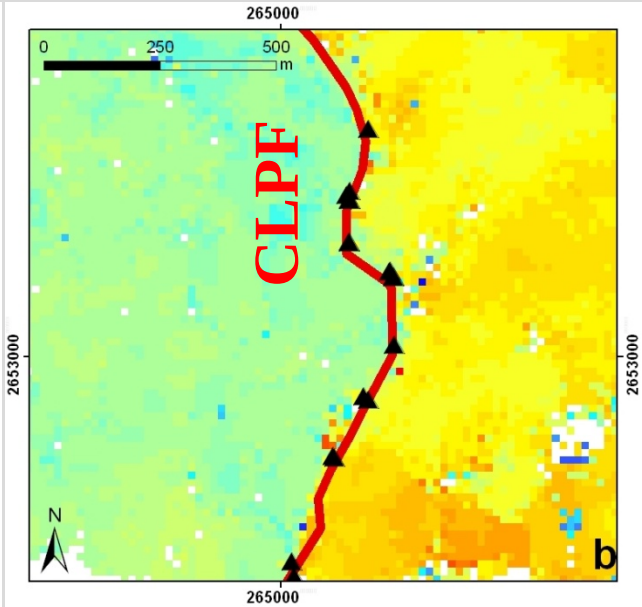


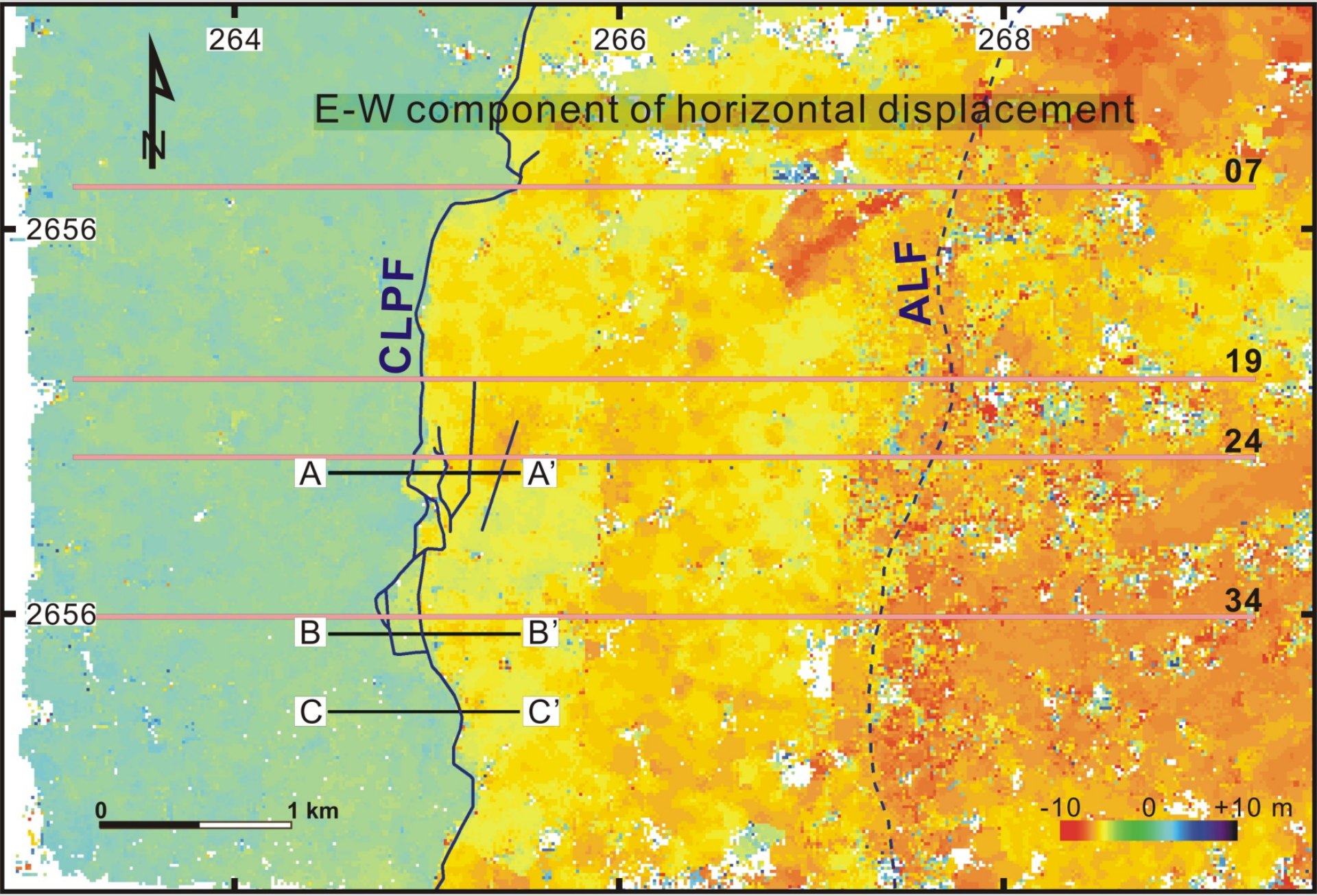


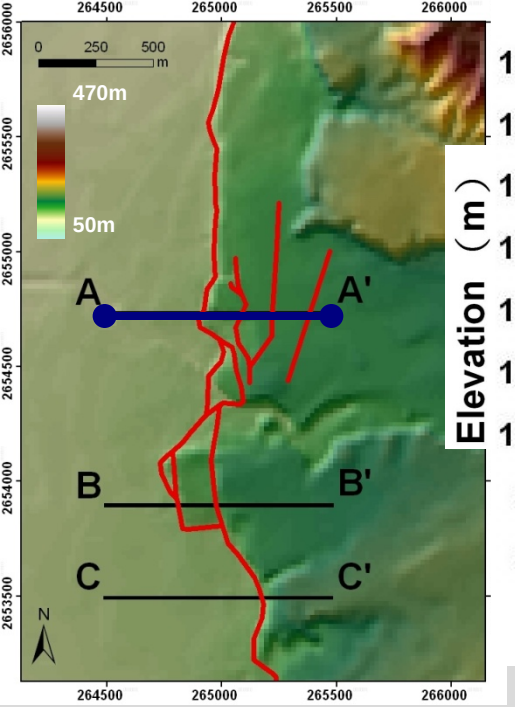
Dominguez et al., 2003

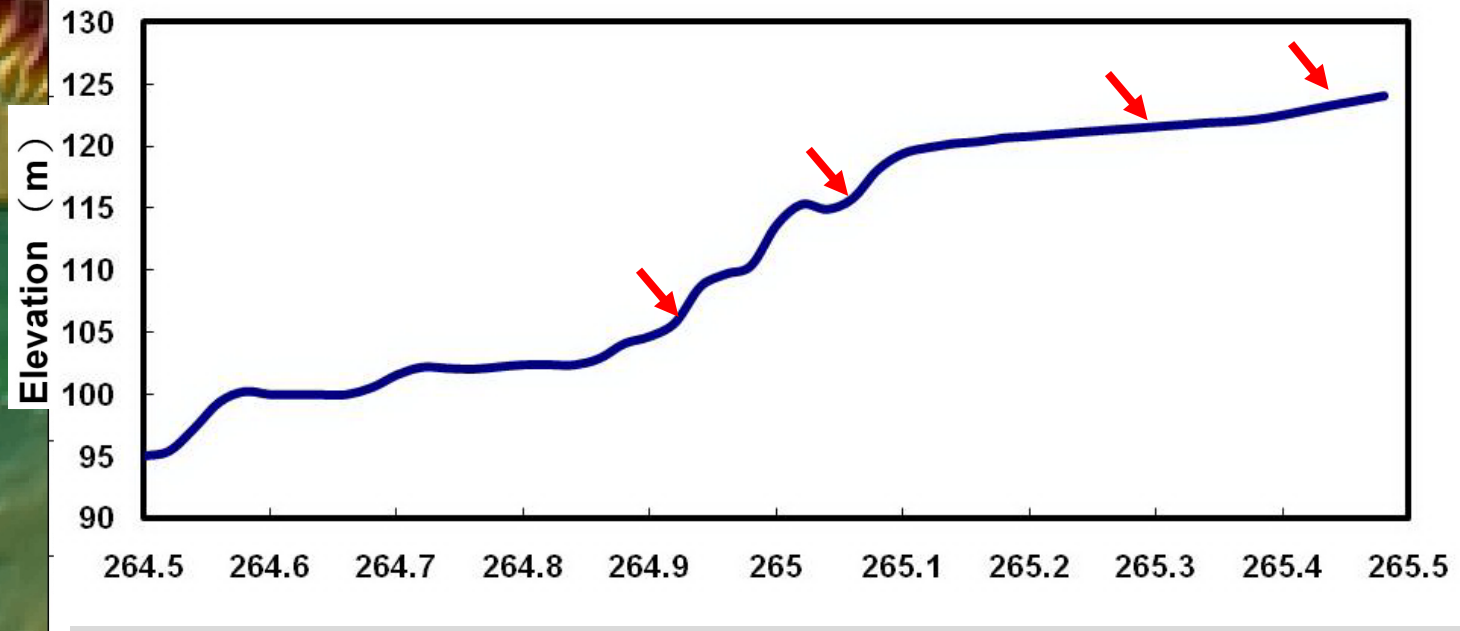


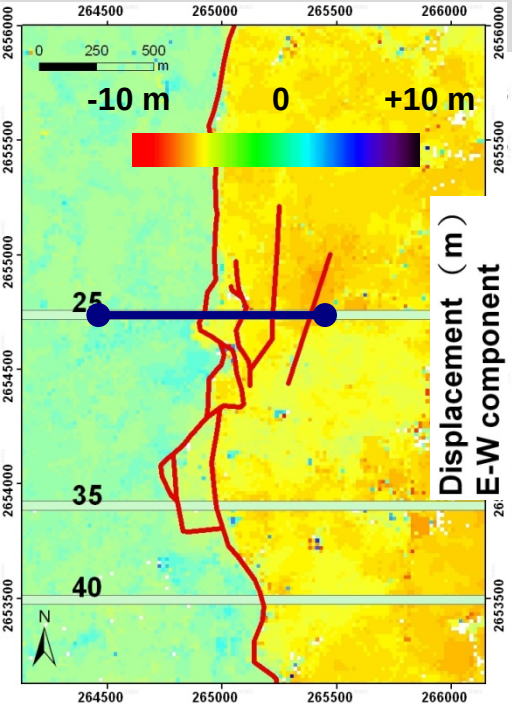


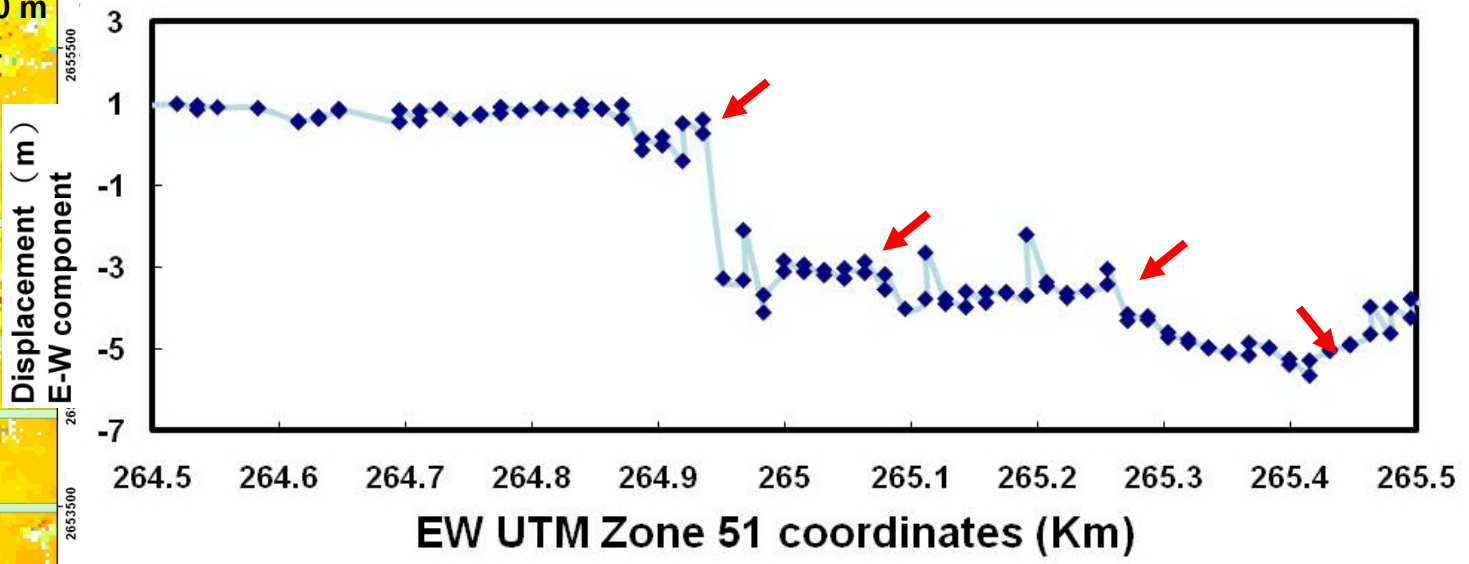


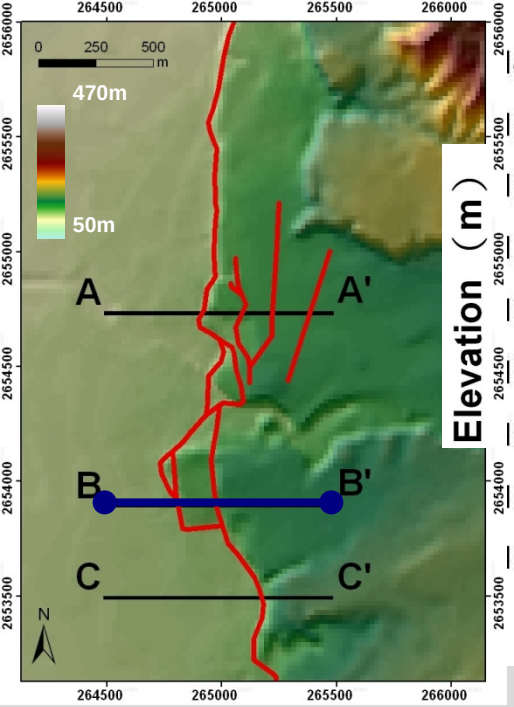

264
266
268
N
E-W component of horizontal displacement
07
19
24
34
2656
2656
CLPF
ALF
A
A'
B
B'
C
C'
0
1 km
-10
0
+10 m

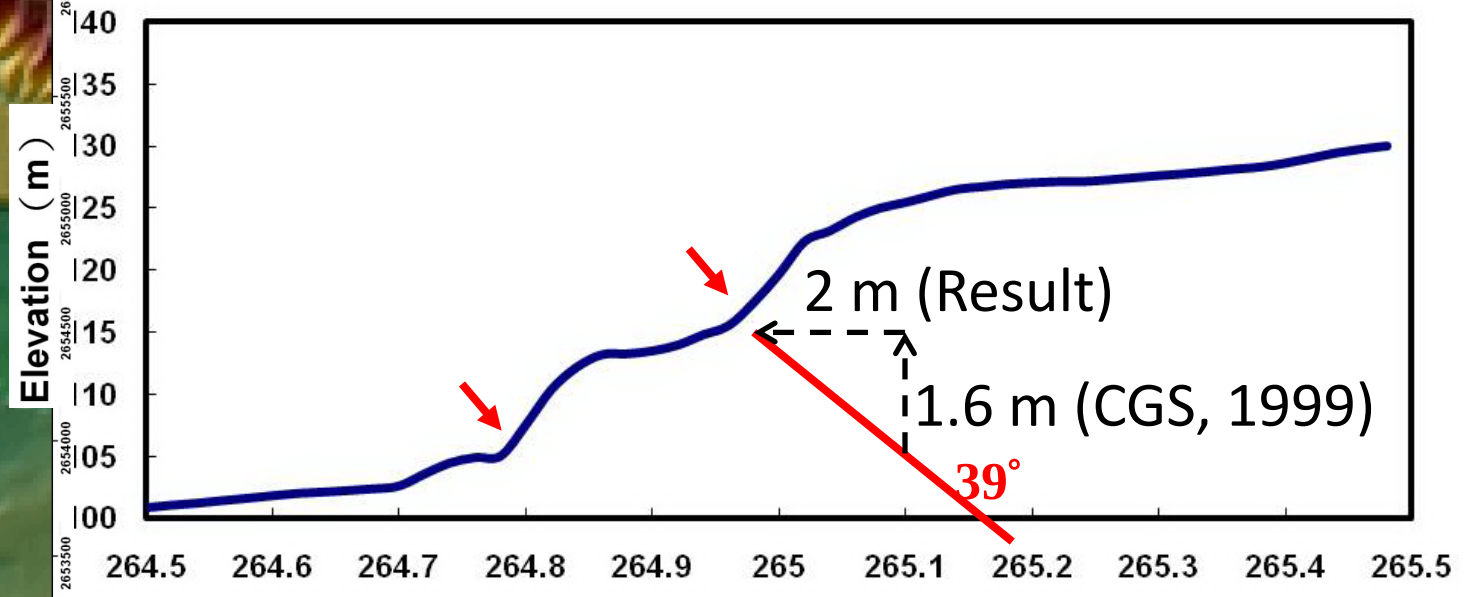

264500
265000
265500
266000
2656000
2655500
2655000
2654500
2654000
2653500
0
250
500
m
470m
50m
A
A'
B
B'
C
C'
N

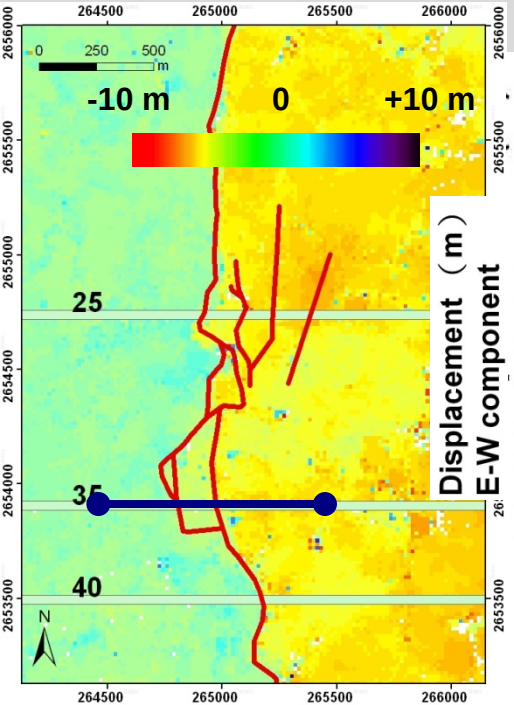

Elevation （m）
130
125
120
115
110
105
100
95
90
264.5
264.6
264.7
264.8
264.9
265
265.1
265.2
265.3
265.4
265.5

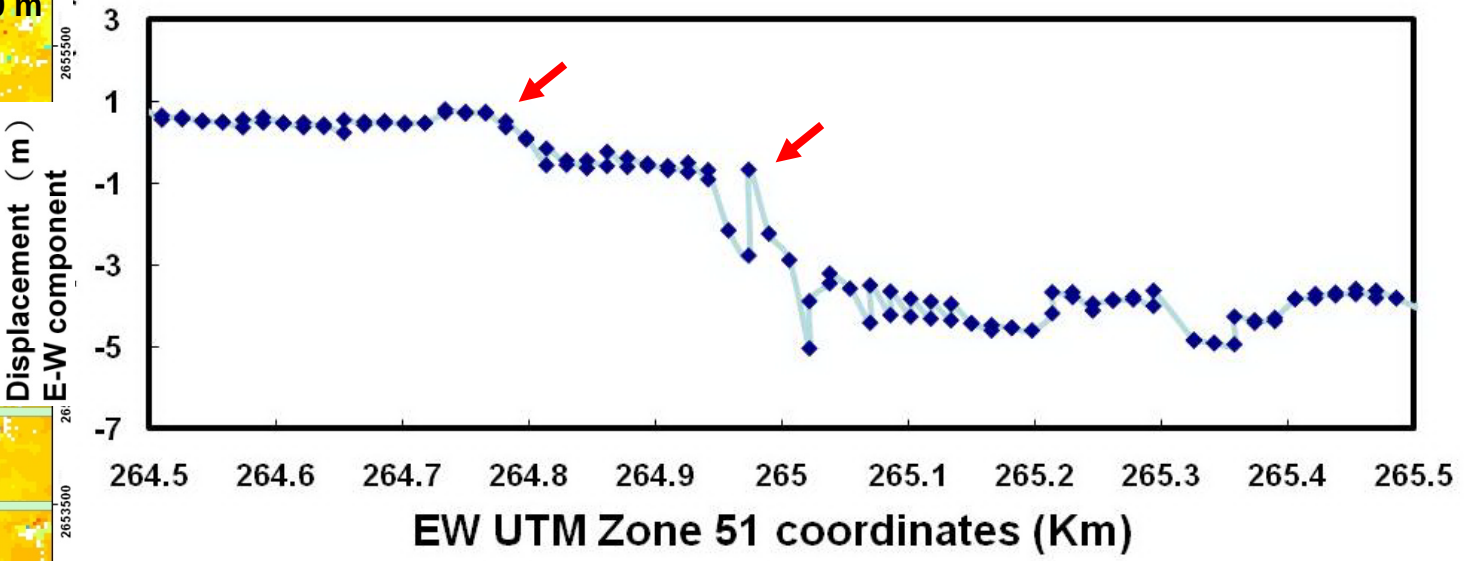

264500
265000
265500
266000
2656000
2655500
2655000
2654500
2654000
2653500
0
250
500
m
-10 m
0
+10 m
25
35
40
N

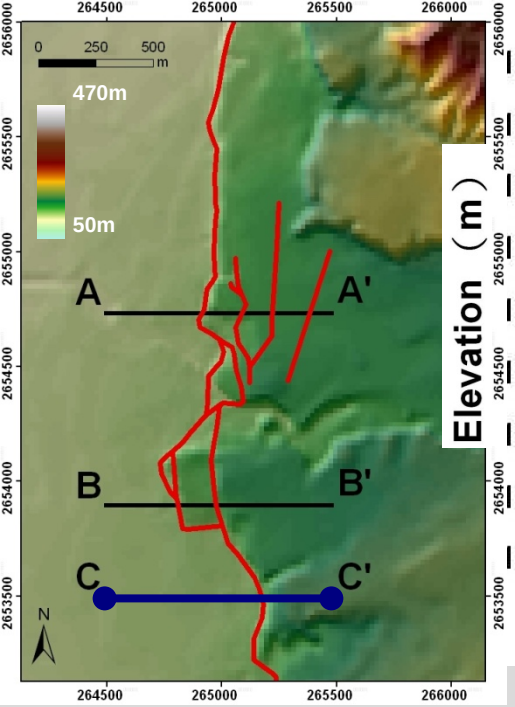

Displacement （m）
E-W component
3
1
-1
-3
-5
-7
264.5
264.6
264.7
264.8
264.9
265
265.1
265.2
265.3
265.4
265.5
EW UTM Zone 51 coordinates (Km)

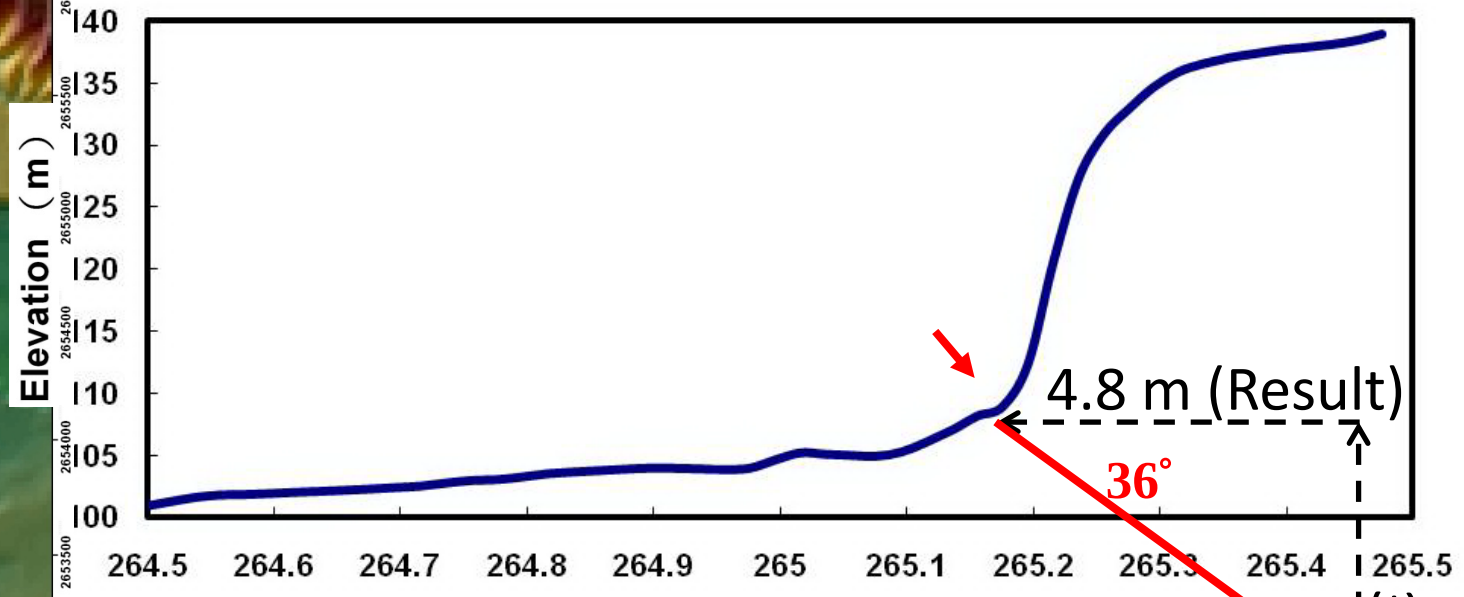

0 250 500 m
470m
50m
A
A'
B
B'
C
C'
N
264500
265000
265500
266000
2656000
2655500
2655000
2654500
2654000
2653500

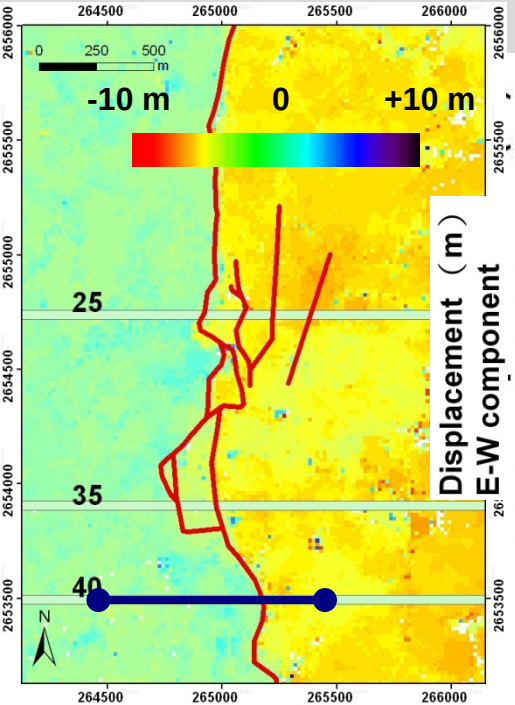

Elevation (m)
40
35
30
25
20
15
10
05
00
2 m (Result)
1.6 m (CGS, 1999)
39°
264.5
264.6
264.7
264.8
264.9
265
265.1
265.2
265.3
265.4
265.5

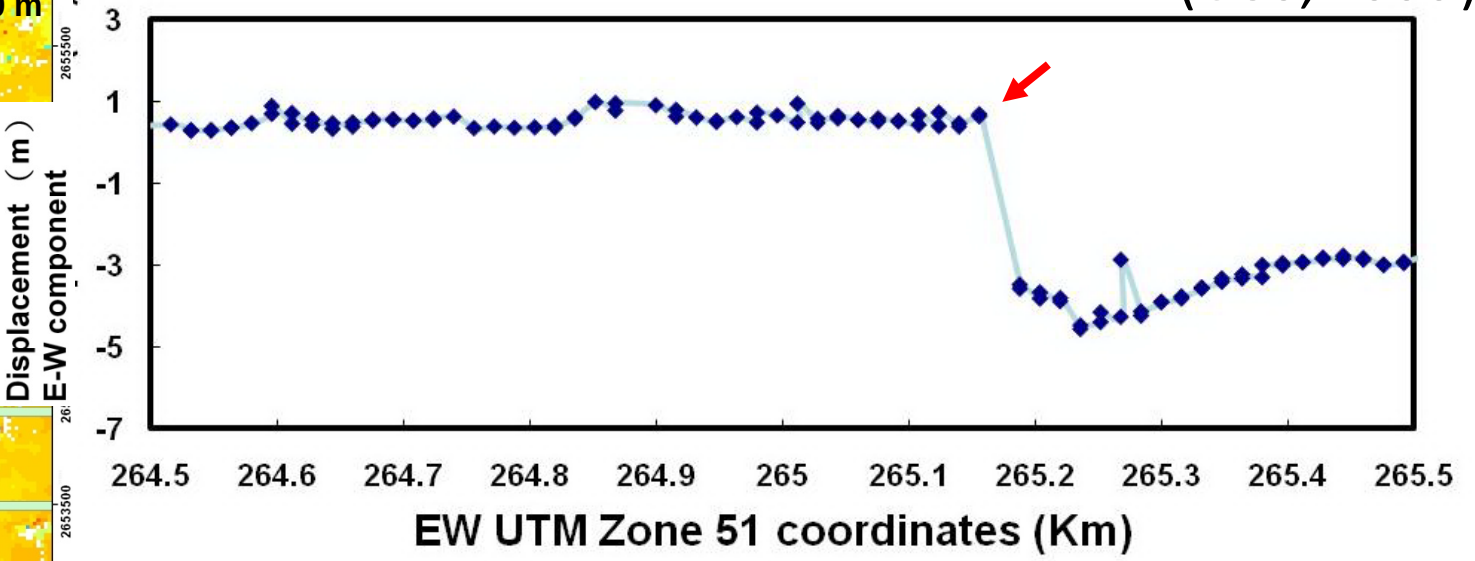

0 250 500 m
-10 m
0
+10 m
25
35
40
N
264500
265000
265500
266000
2656000
2655500
2655000
2654500
2654000
2653500

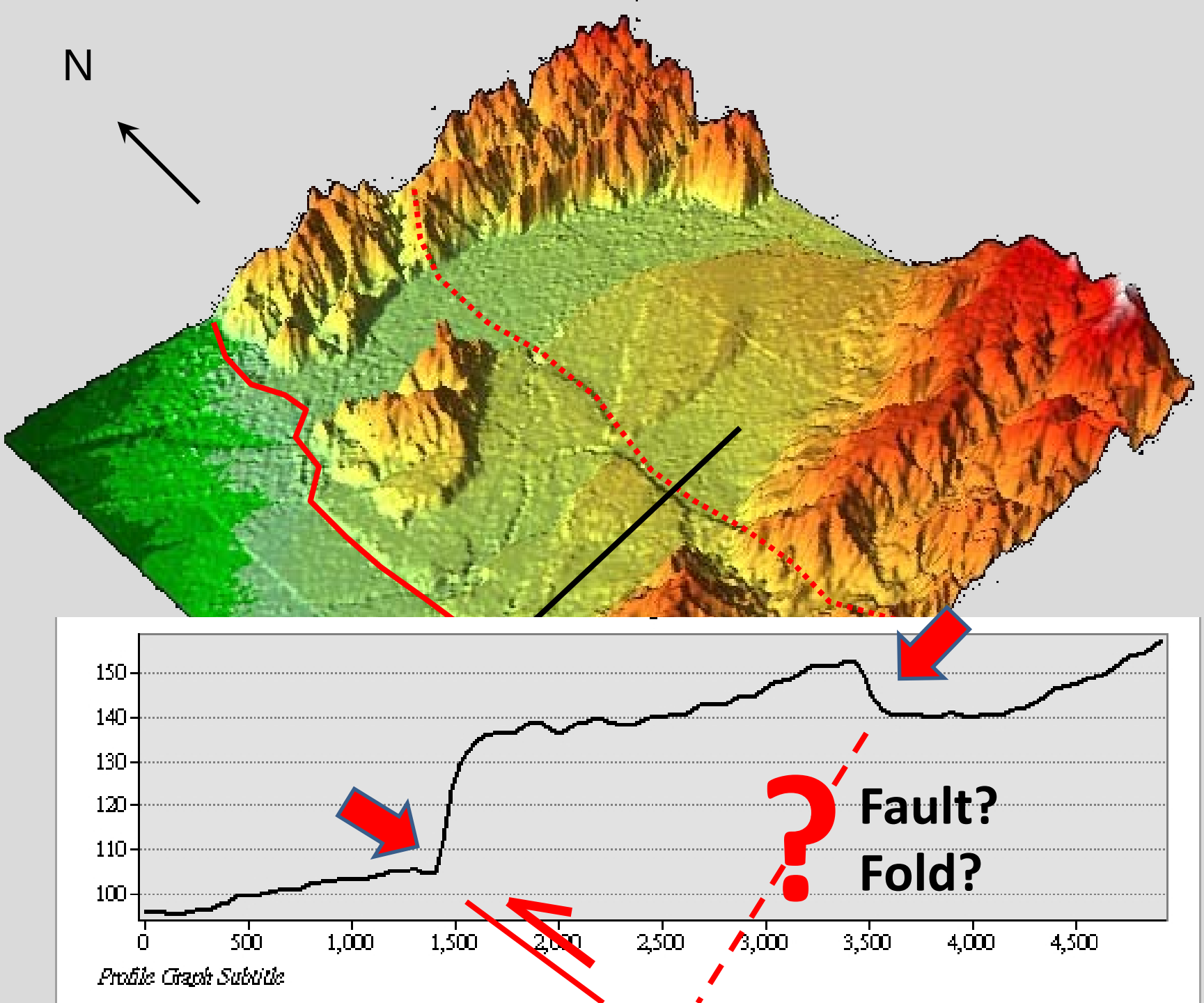

Displacement (m)
E-W component
3
1
-1
-3
-5
-7
264.5
264.6
264.7
264.8
264.9
265
265.1
265.2
265.3
265.4
265.5
EW UTM Zone 51 coordinates (Km)


0 250 500 m
470m
50m
A
A'
B
B'
C
C'
N
264500
265000
265500
266000
2656000
2655500
2655000
2654500
2654000
2653500

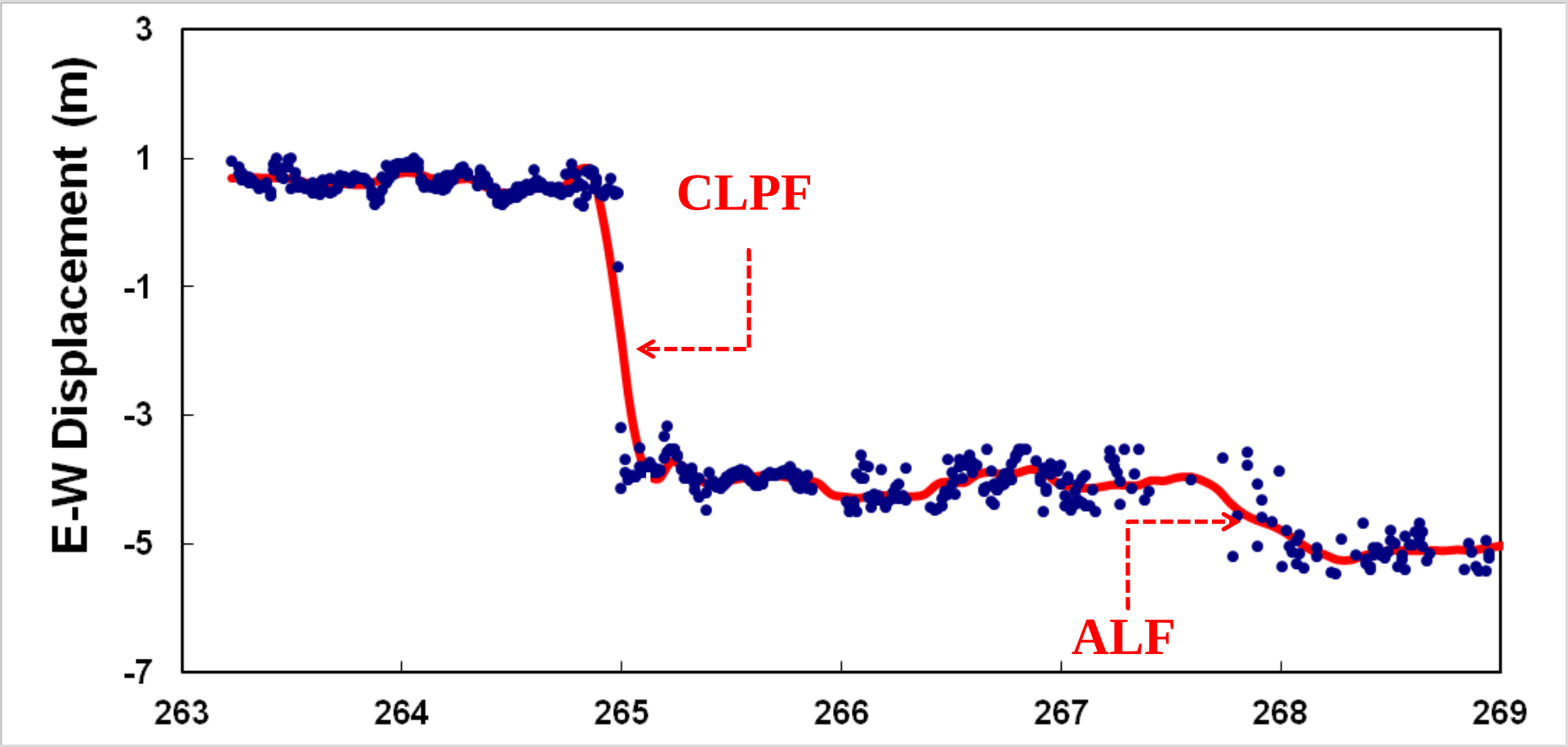

Elevation (m)
140
135
130
125
120
115
110
105
100
264.5
264.6
264.7
264.8
264.9
265
265.1
265.2
265.3
265.4
265.5
4.8 m (Result)
36°
3.5 m
(CGS, 1999)

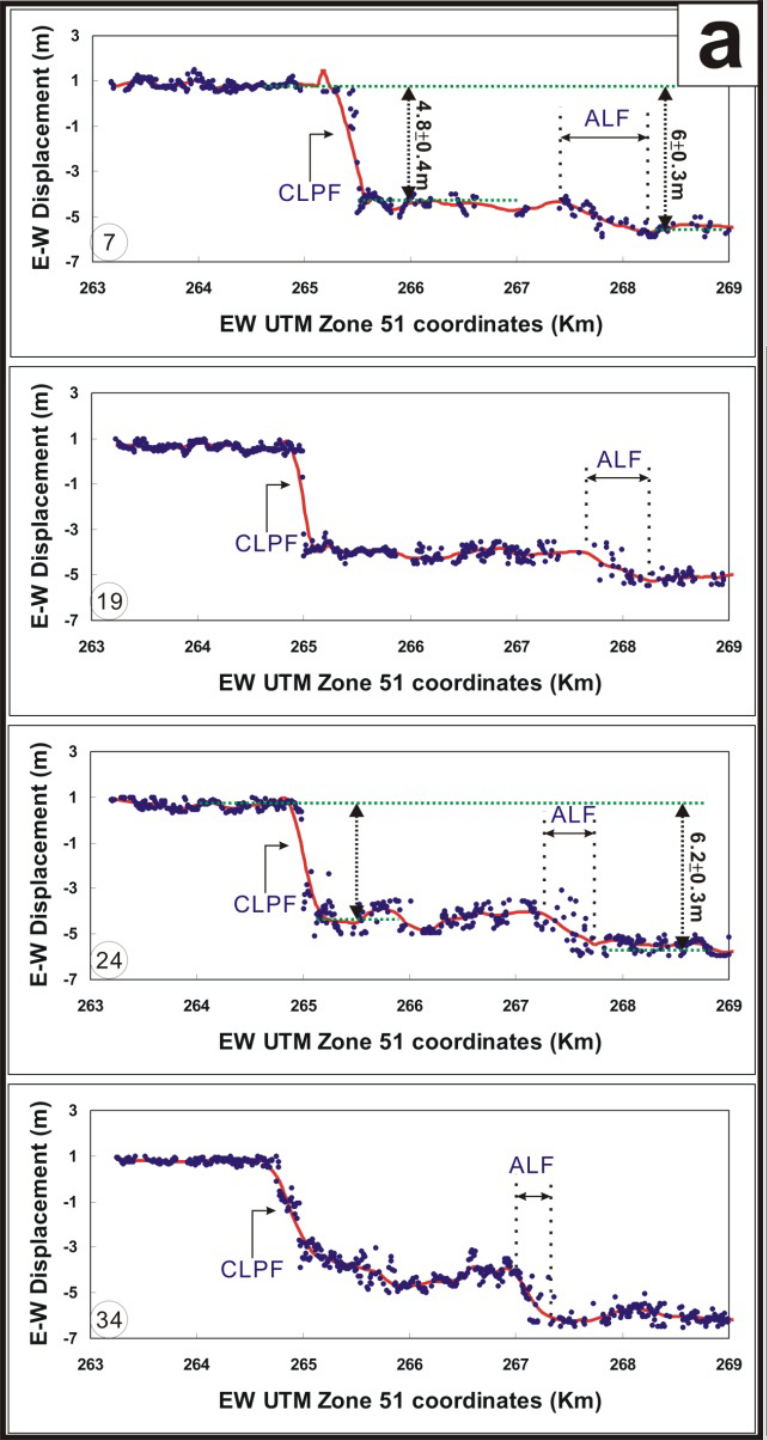

0 250 500 m
-10 m
0
+10 m
25
35
40
N
264500
265000
265500
266000
2656000
2655500
2655000
2654500
2654000
2653500

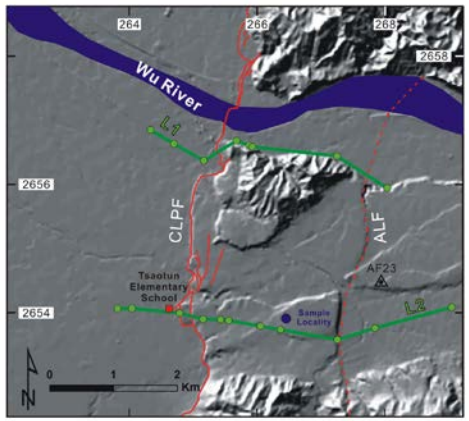

Displacement (m)
E-W component
3
1
-1
-3
-5
-7
264.5
264.6
264.7
264.8
264.9
265
265.1
265.2
265.3
265.4
265.5
EW UTM Zone 51 coordinates (Km)

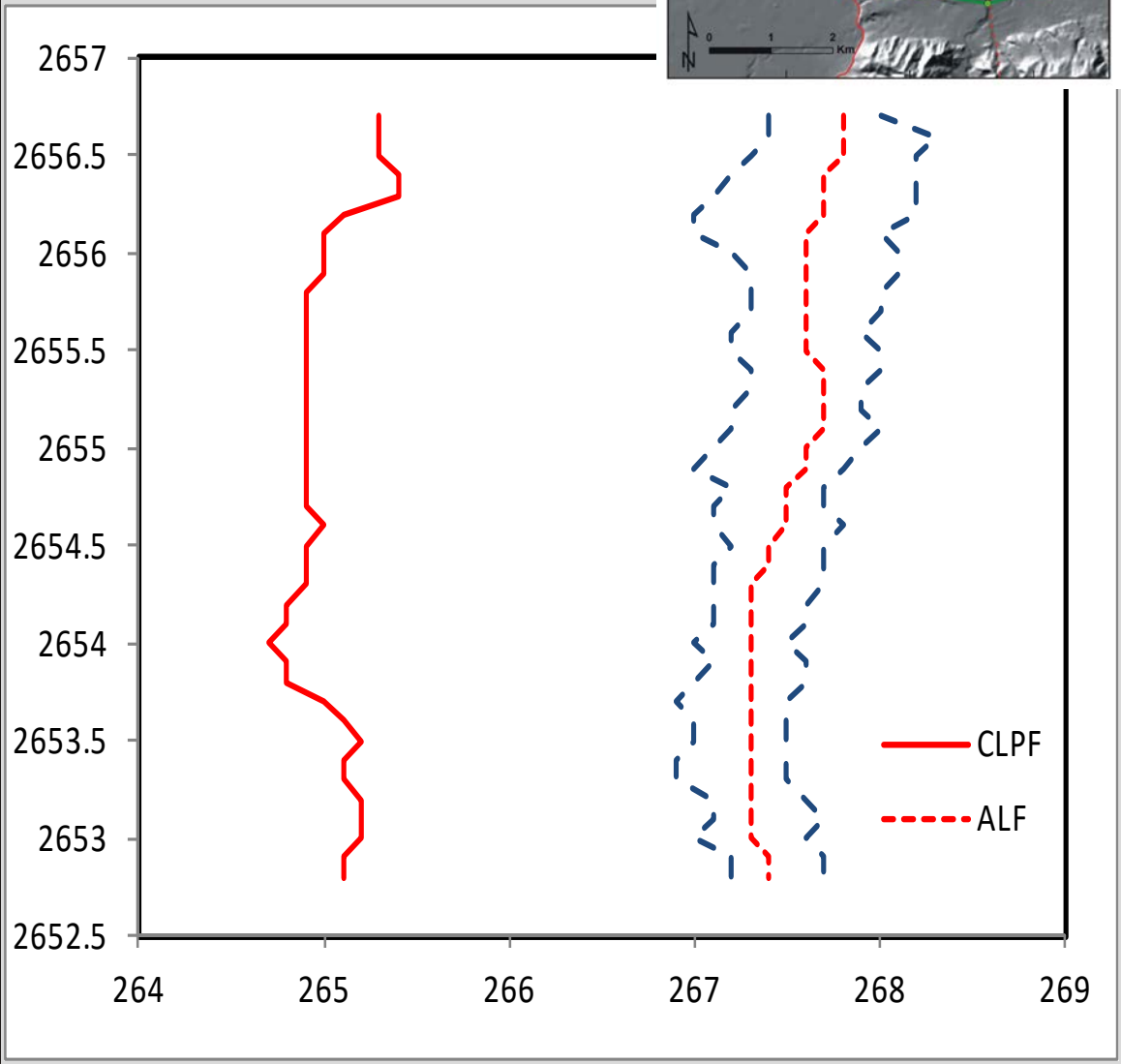

N
150
140
130
120
110
100
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
Profile Graph Subtitle
Fault?
Fold?

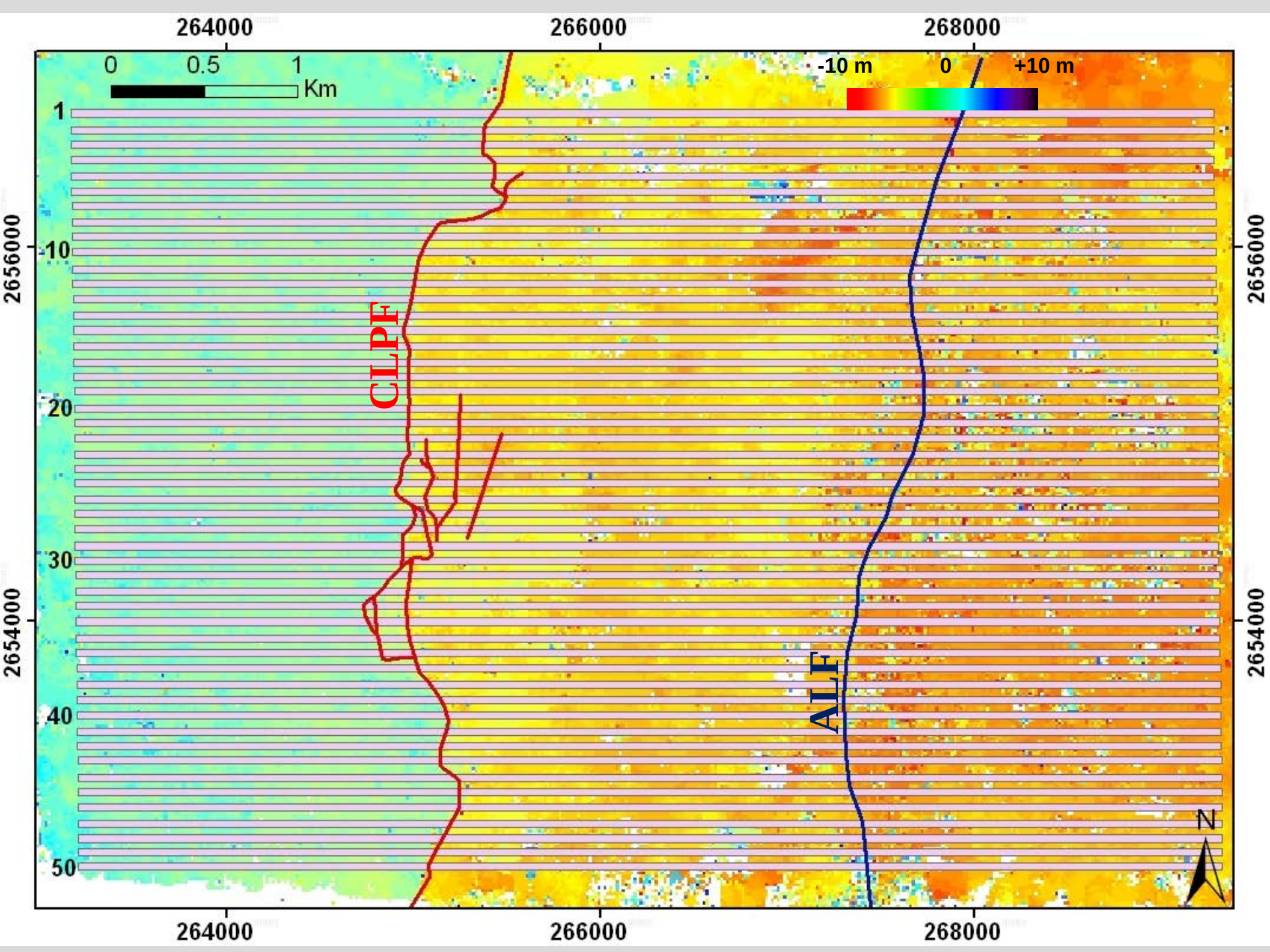
Fault? Fold?

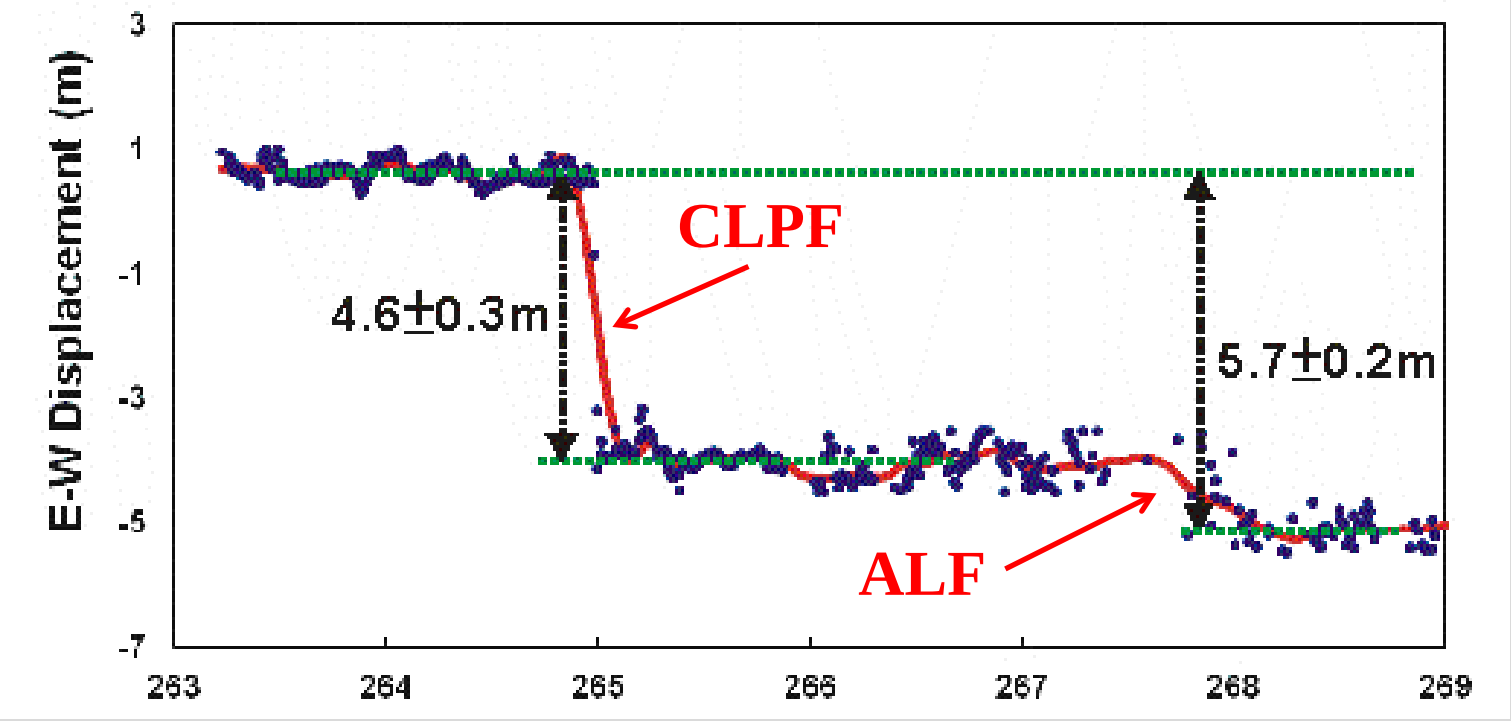


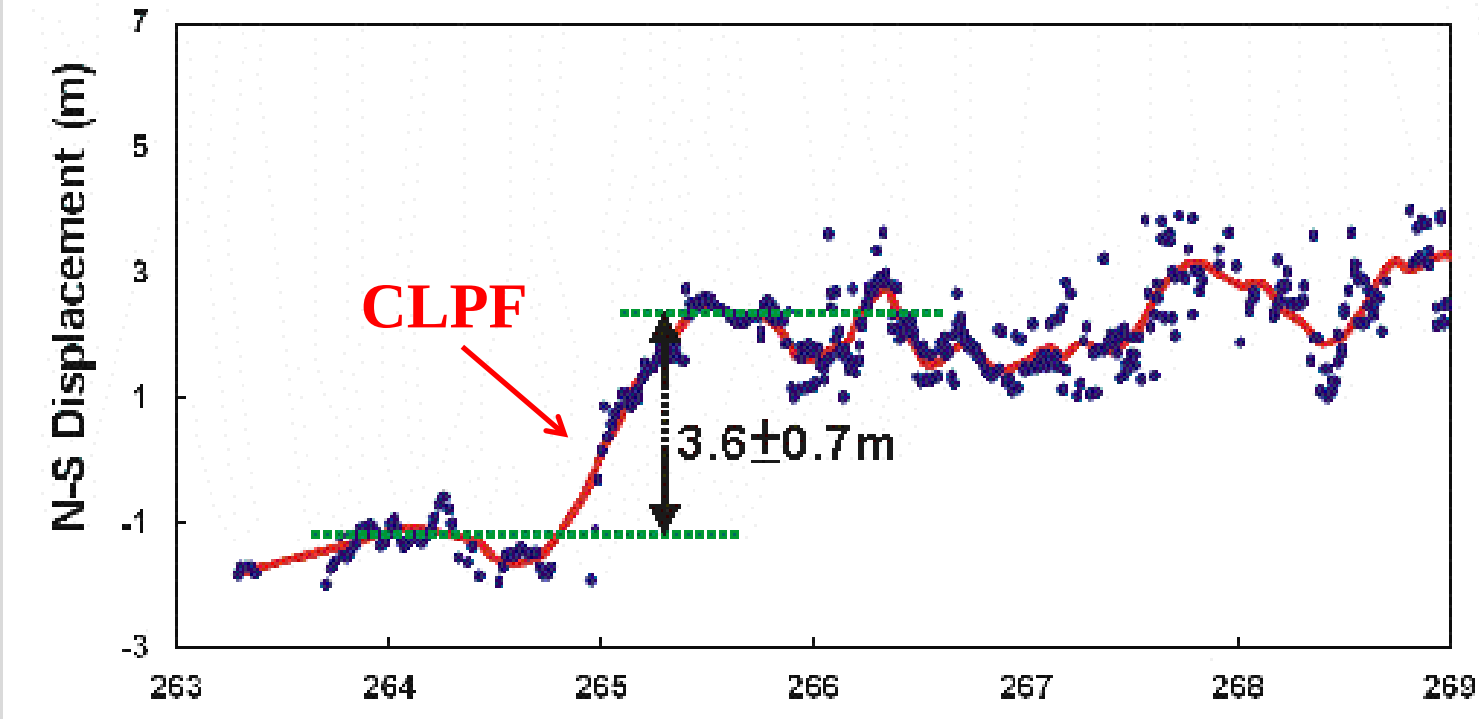

a
E-W Displacement (m)
EW UTM Zone 51 coordinates (Km)
CLPF
ALF
4.8±0.4m
6±0.3m
6.2±0.3m
7
19
24
34

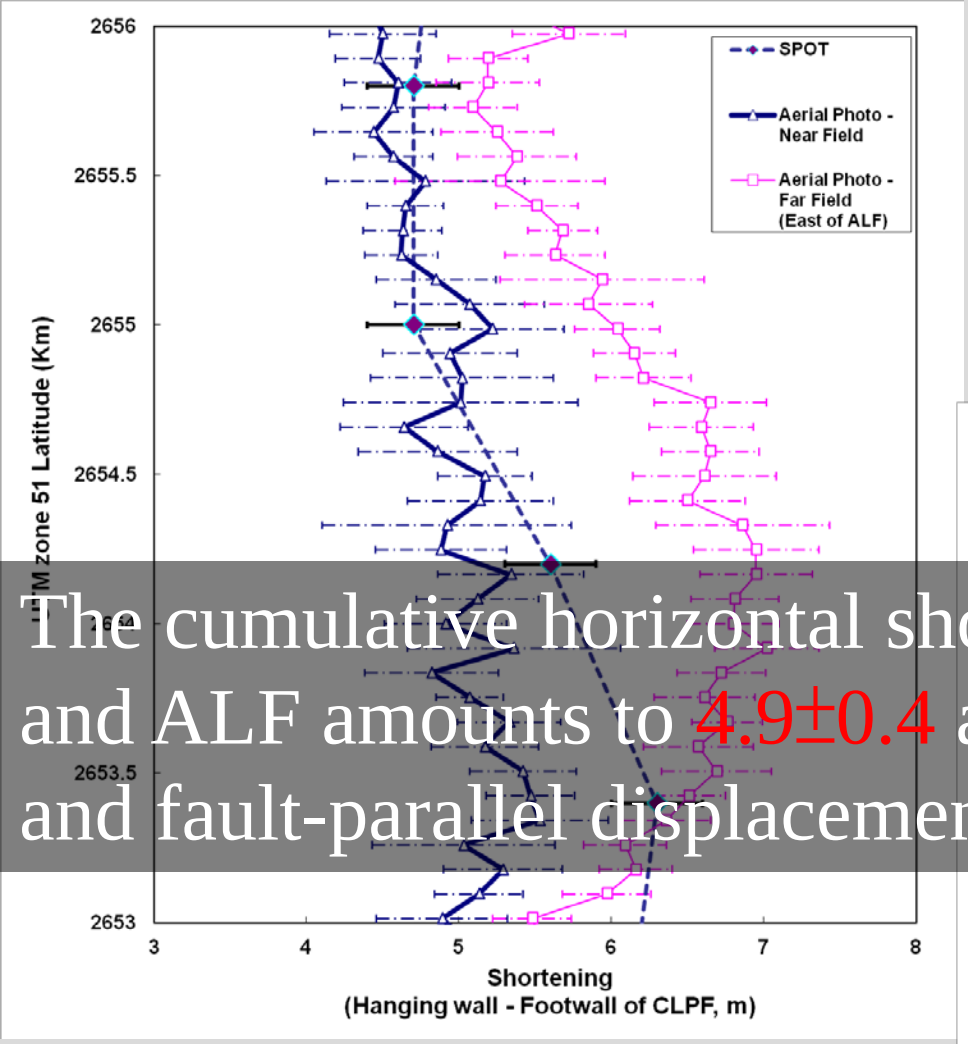

Wu River
CLPF
ALF
L1
L2
AF23
Tsaotun Elementary School
Sample Locality
N
Km

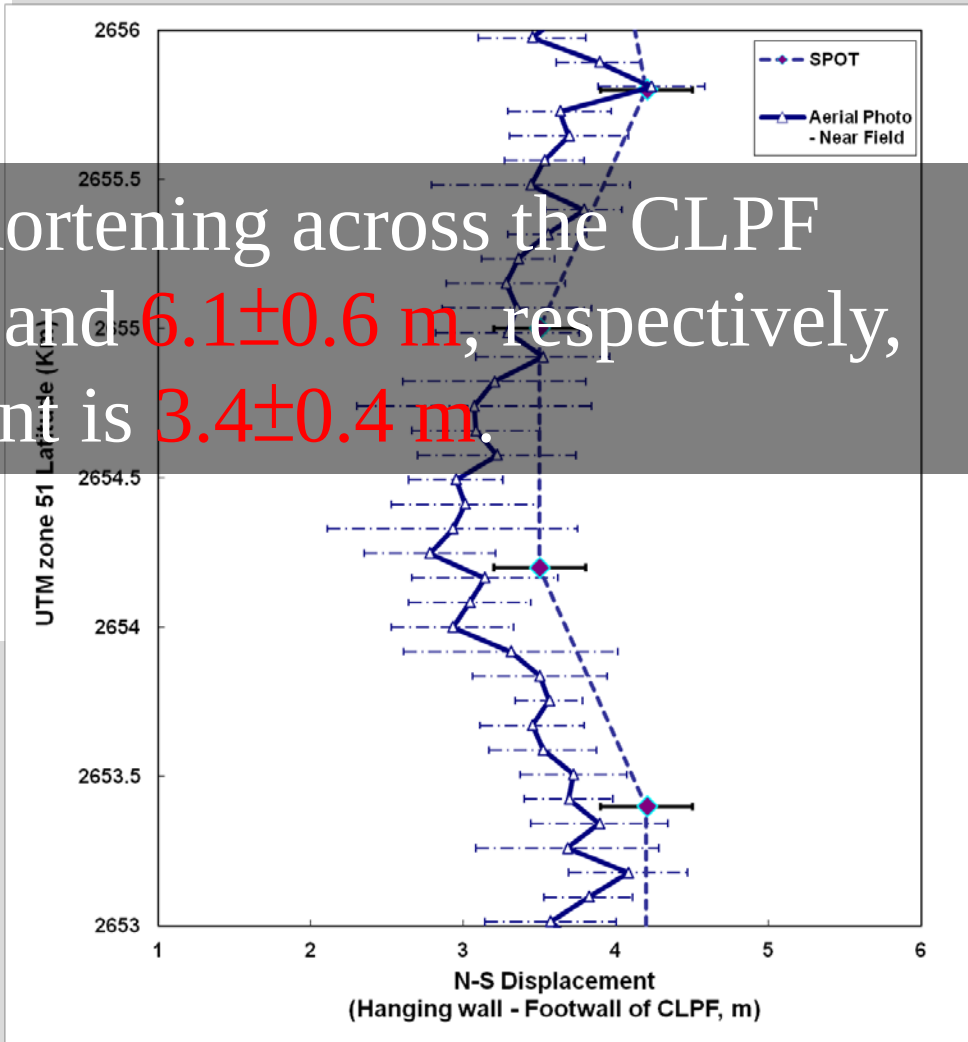

CLPF
ALF


264000
266000
268000
0
0.5
1
Km
-10 m
0
+10 m
1
10
20
30
40
50
2656000
2654000
CLPF
ALF
N

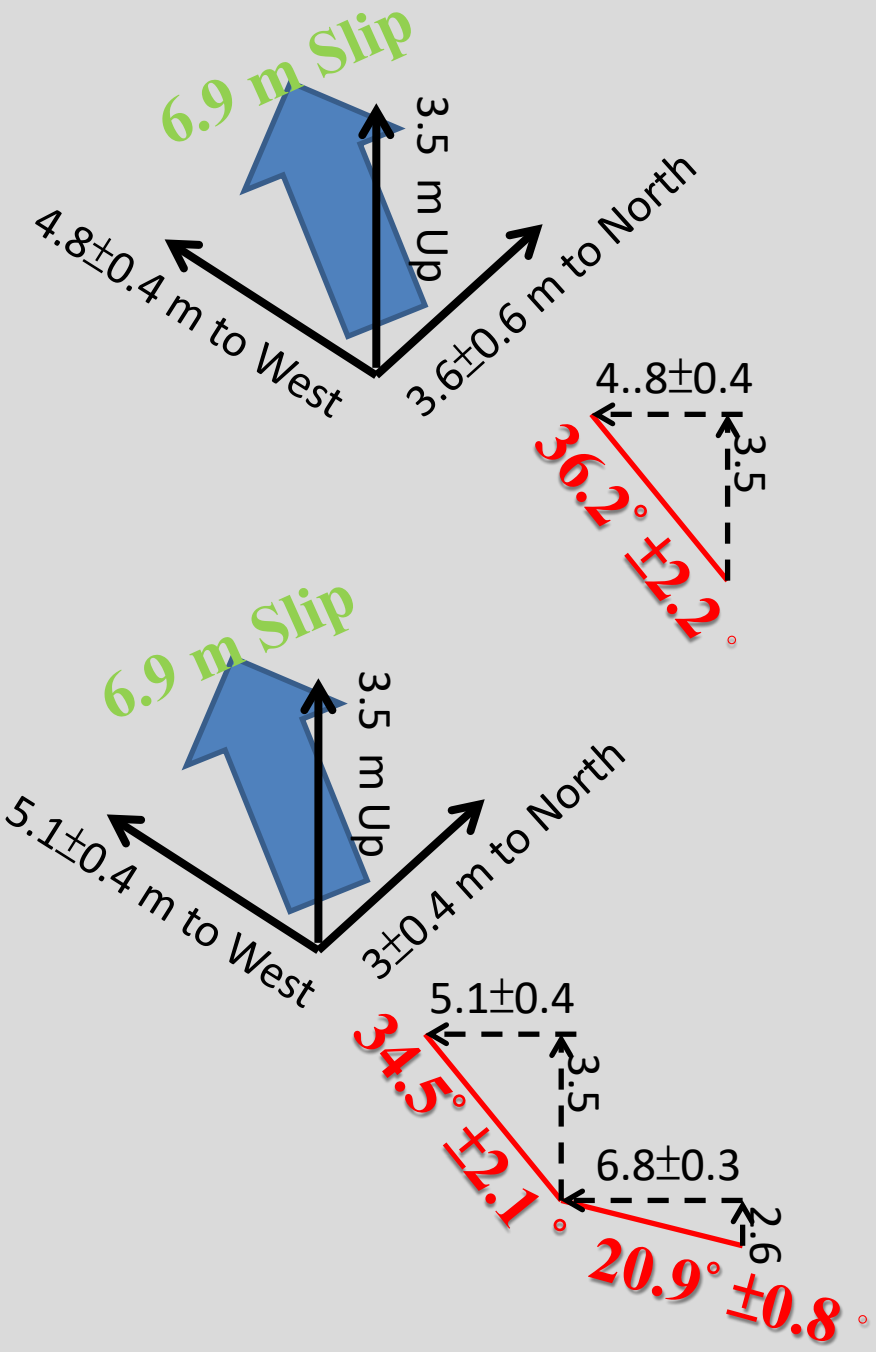

E-W Displacement (m)
3
1
-1
-3
-5
-7
263
264
265
266
267
268
269
CLPF
4.6±0.3m
5.7±0.2m
ALF

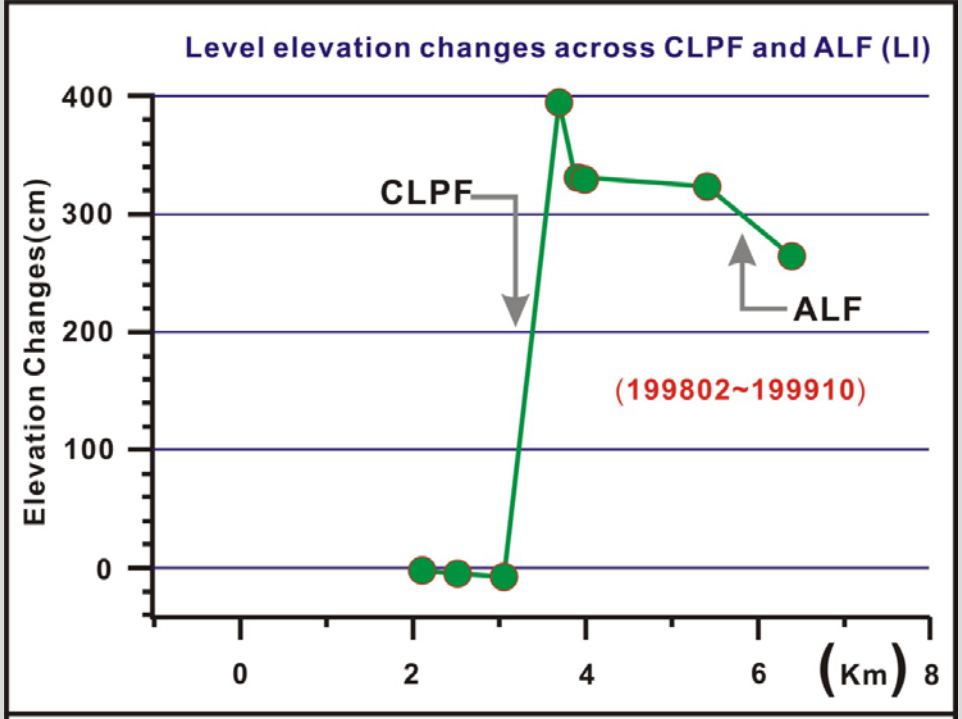

N-S Displacement (m)
7
5
3
1
-1
-3
263
264
265
266
267
268
269
CLPF
3.6±0.7m

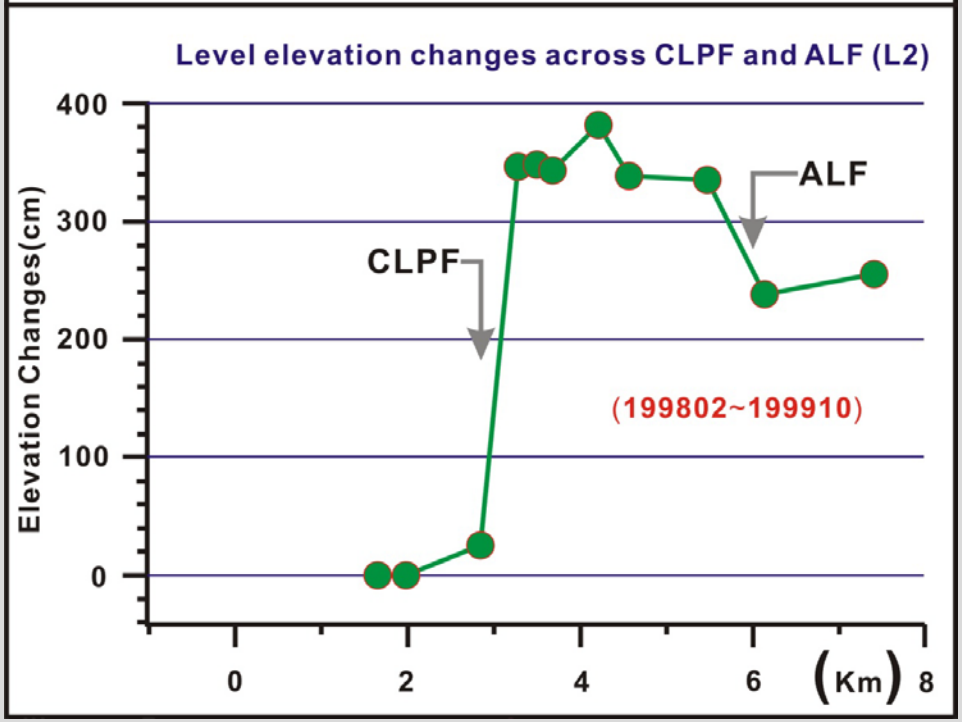


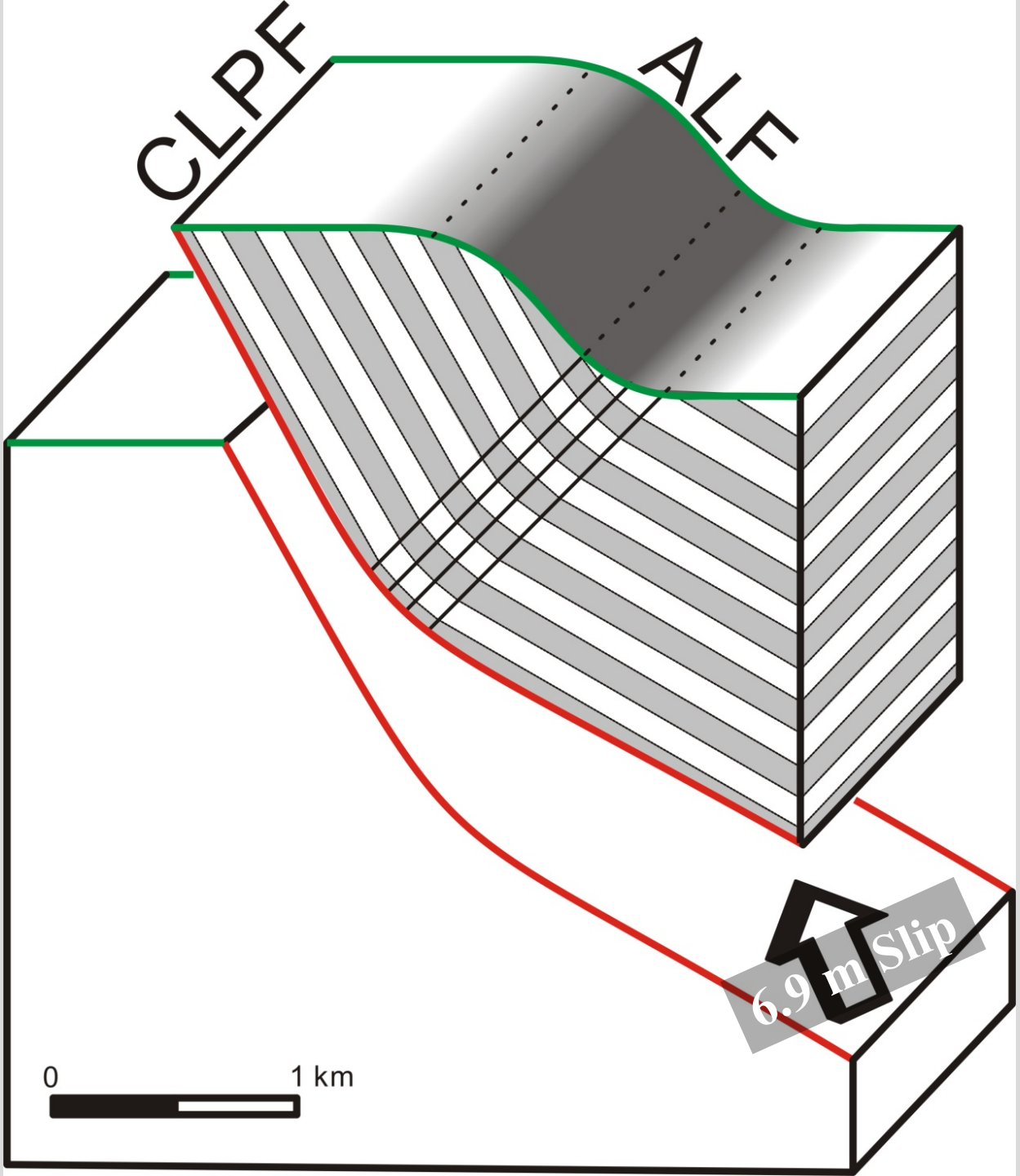


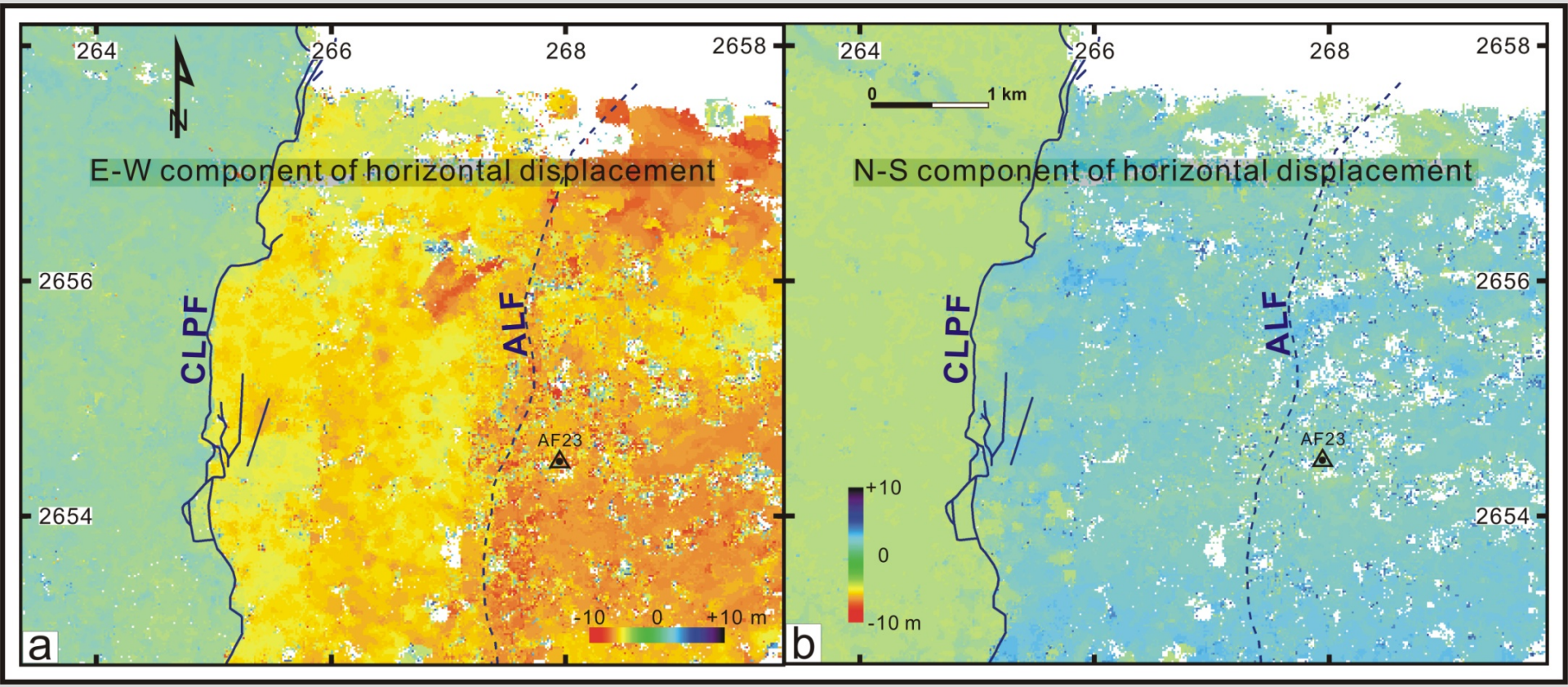
The cumulative horizontal shortening across the CLPF and ALF amounts to 4.9±0.4 and 6.1±0.6 m, respectively, and fault-parallel displacement is 3.4±0.4 m.

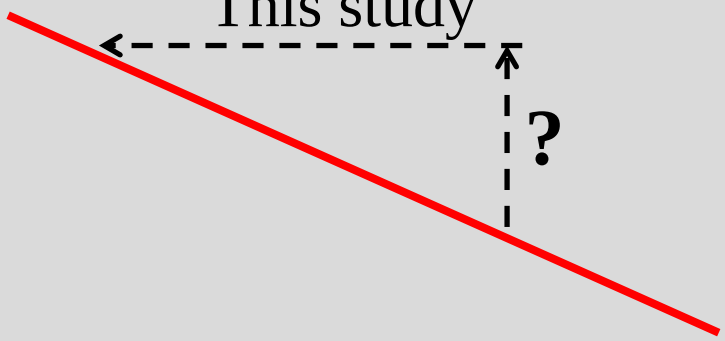

6.9 m Slip
3.5 m Up
4.8±0.4 m to West
3.6±0.6 m to North
4..8±0.4
3.5
36.2° ±2.2°
6.9 m Slip
3.5 m Up
5.1±0.4 m to West
3±0.4 m to North
5.1±0.4
3.5
6.8±0.3
2.6
34.5° ±2.1°
20.9° ±0.8°


Level elevation changes across CLPF and ALF (LI)
Elevation Changes(cm)
400
300
200
100
0
CLPF
ALF
(199802~199910)
0
2
4
6
(Km)
8

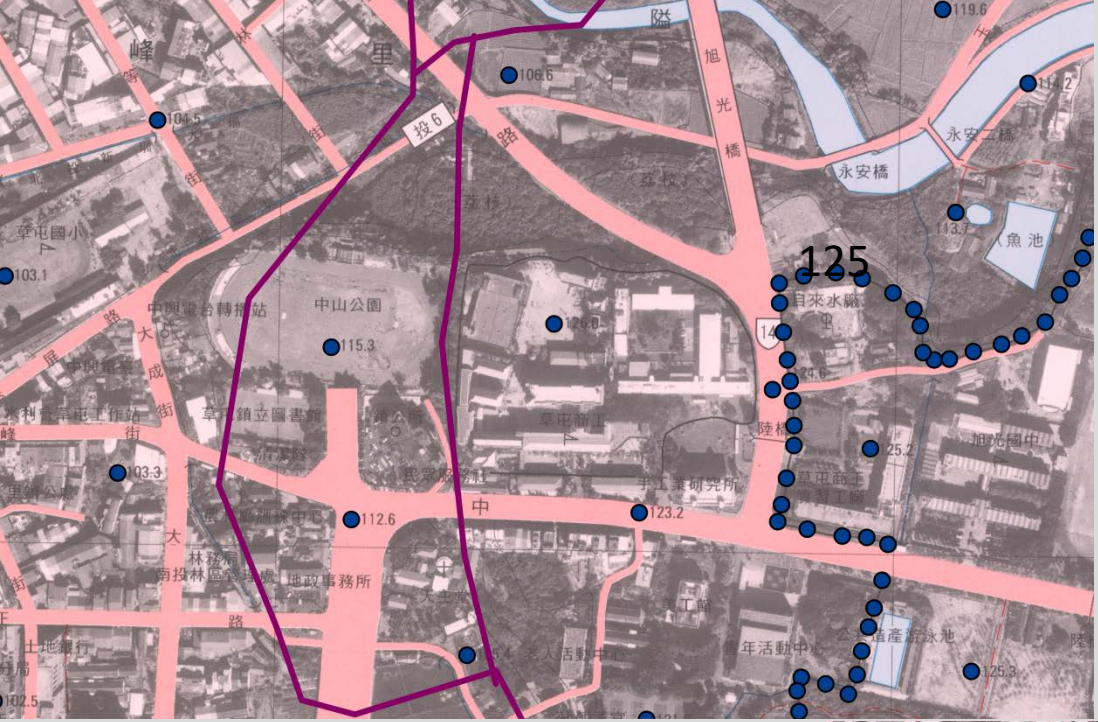

Level elevation changes across CLPF and ALF (L2)
Elevation Changes(cm)
400
300
200
100
0
ALF
CLPF
(199802~199910)
0
2
4
6
(Km)
8


CLPF
ALF
6.9 m Slip
0
1 km


264
266
268
2658
2656
2654
E-W component of horizontal displacement
CLPF
ALF
AF23
-10
0
+10 m
a
0
1 km
N-S component of horizontal displacement
+10
0
-10 m
b

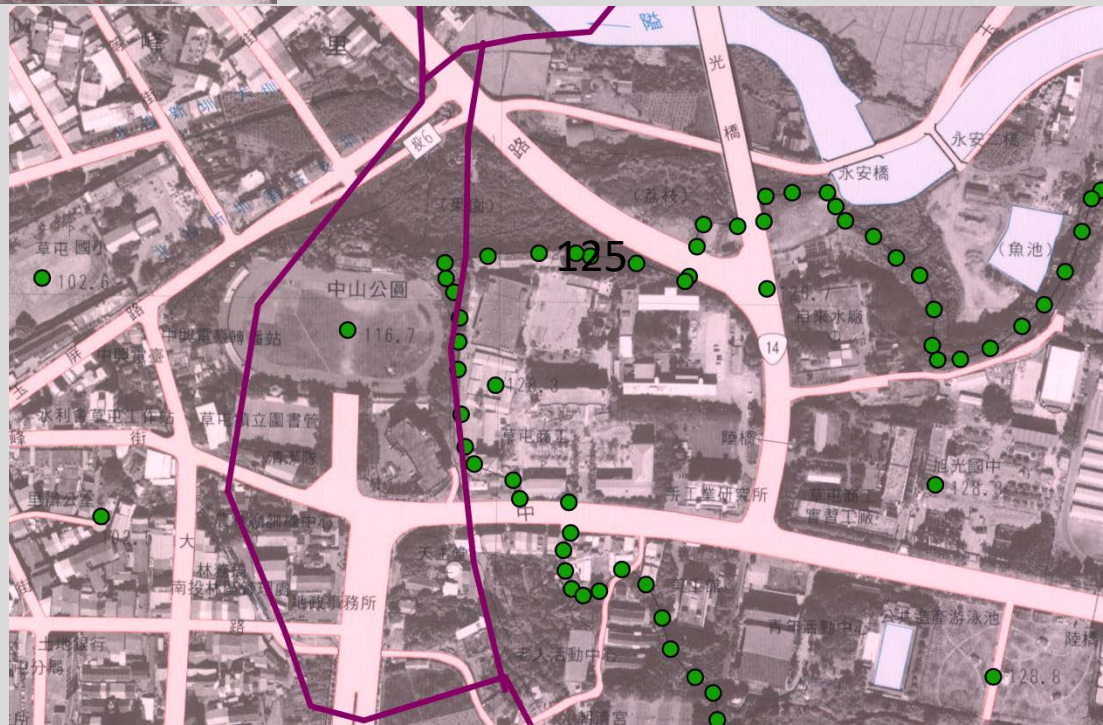

This study
?

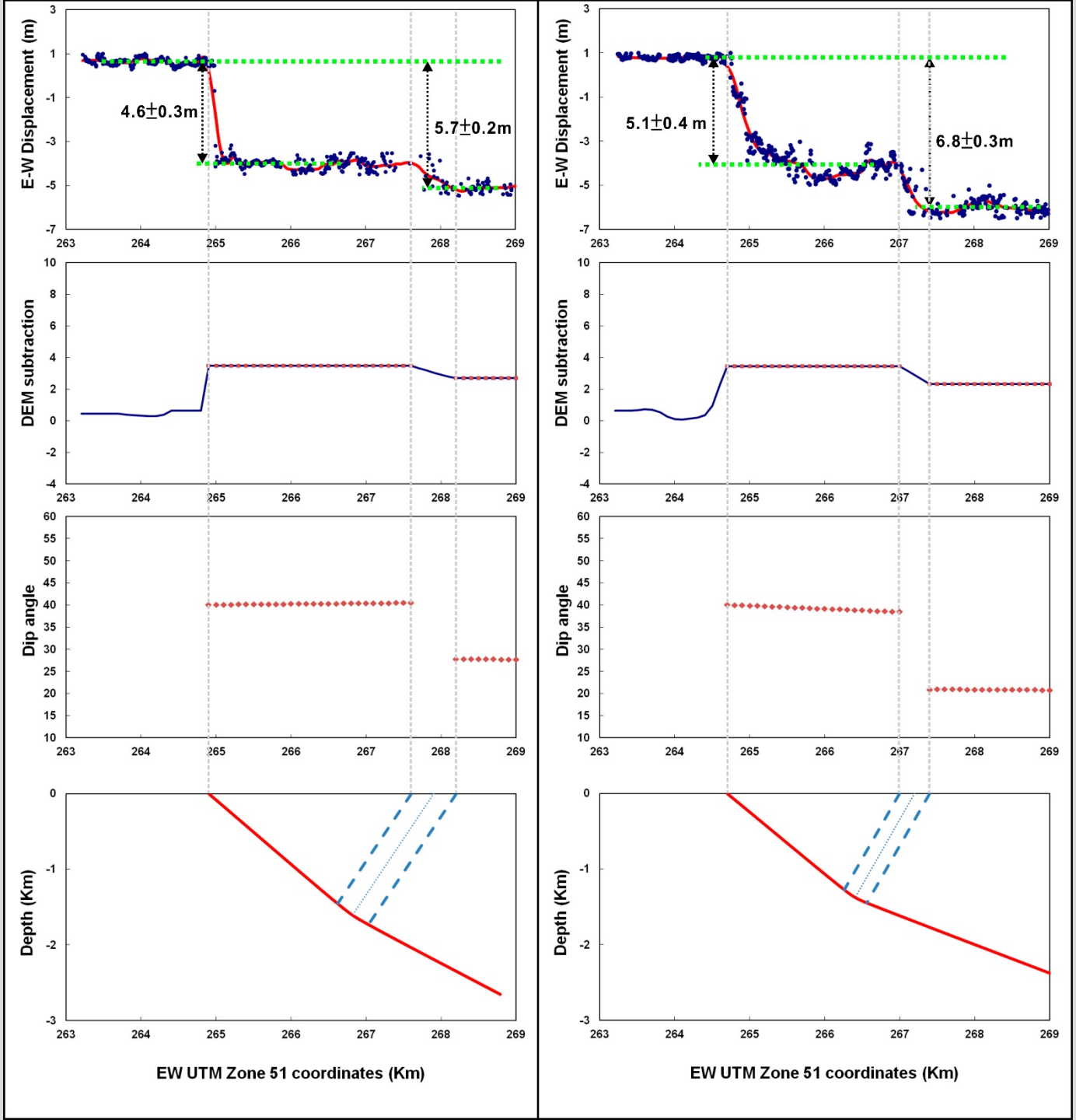
1/5000 Topo-map

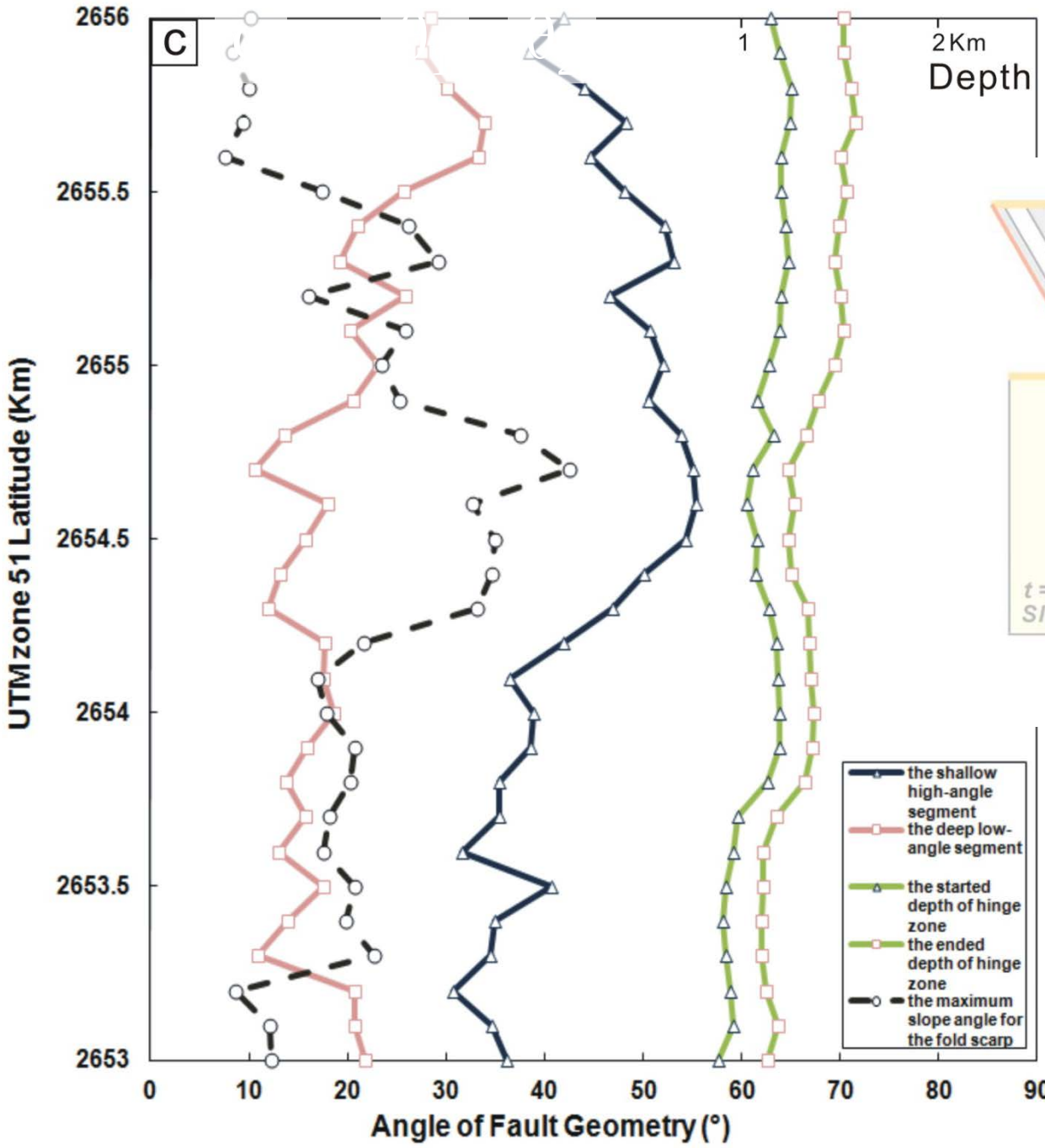


Pre-earthquake

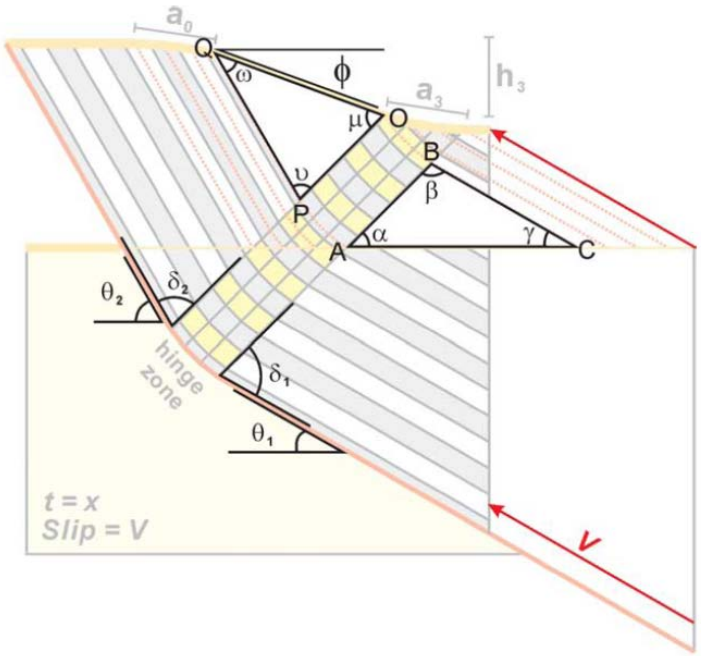
Post-earthquake




E-W Displacement (m)
4.6±0.3m
5.7±0.2m
DEM subtraction
Dip angle
Depth (Km)
EW UTM Zone 51 coordinates (Km)
E-W Displacement (m)
5.1±0.4 m
6.8±0.3m
DEM subtraction
Dip angle
Depth (Km)
EW UTM Zone 51 coordinates (Km)



Chen et al, 2007

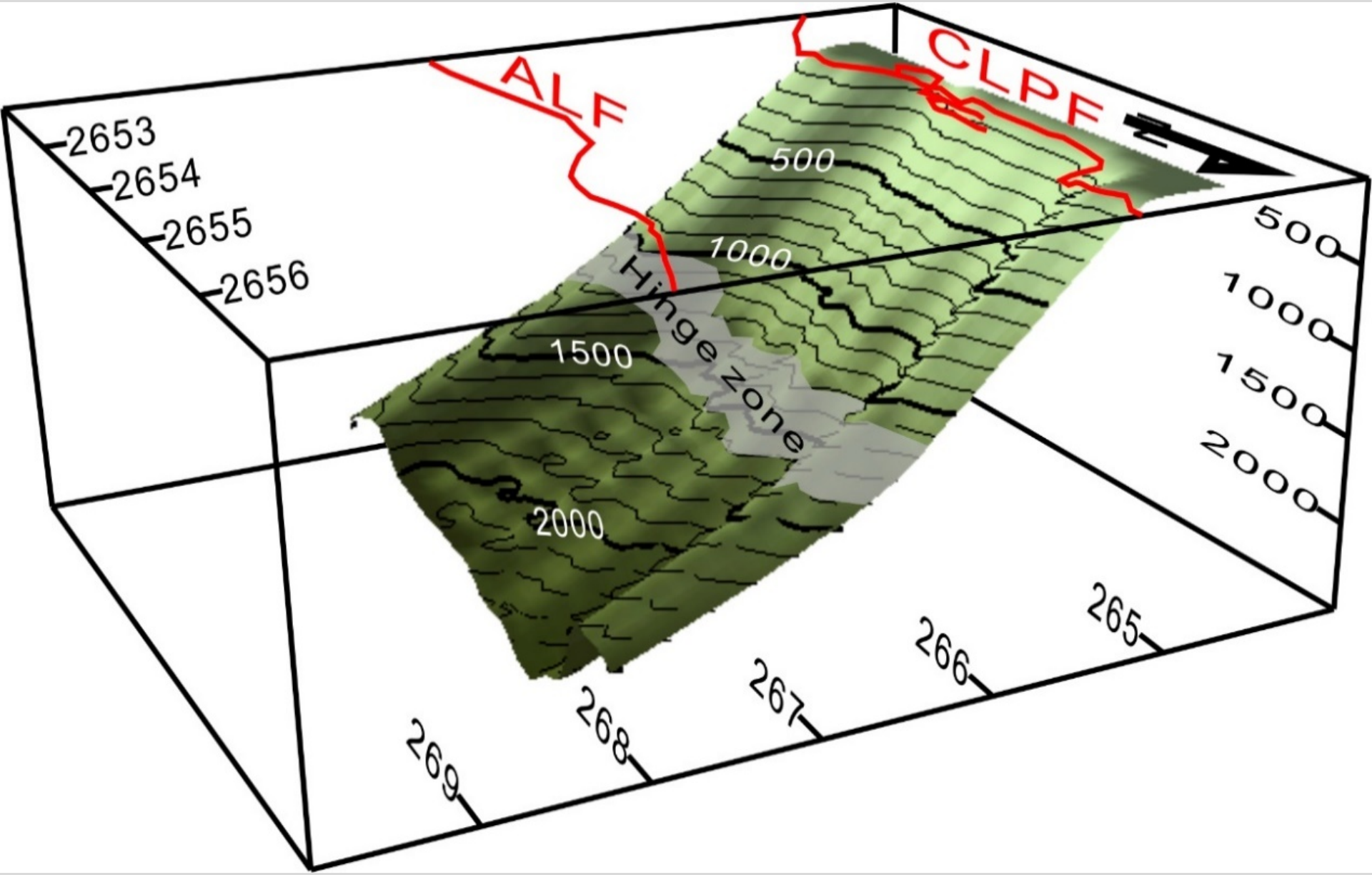


Average θ_2 : 42.9±7.1°

Average θ_1 : 20±5.7°

Average φ : 19.9±8.6°

Max φ : 42.6°



From Kuo et al., 2014

Summary

- Estimation of vertical displacements
- More detailed and accurate measurement
- Features of movement
- Various angles of fault plane
- The detailed fault geometry

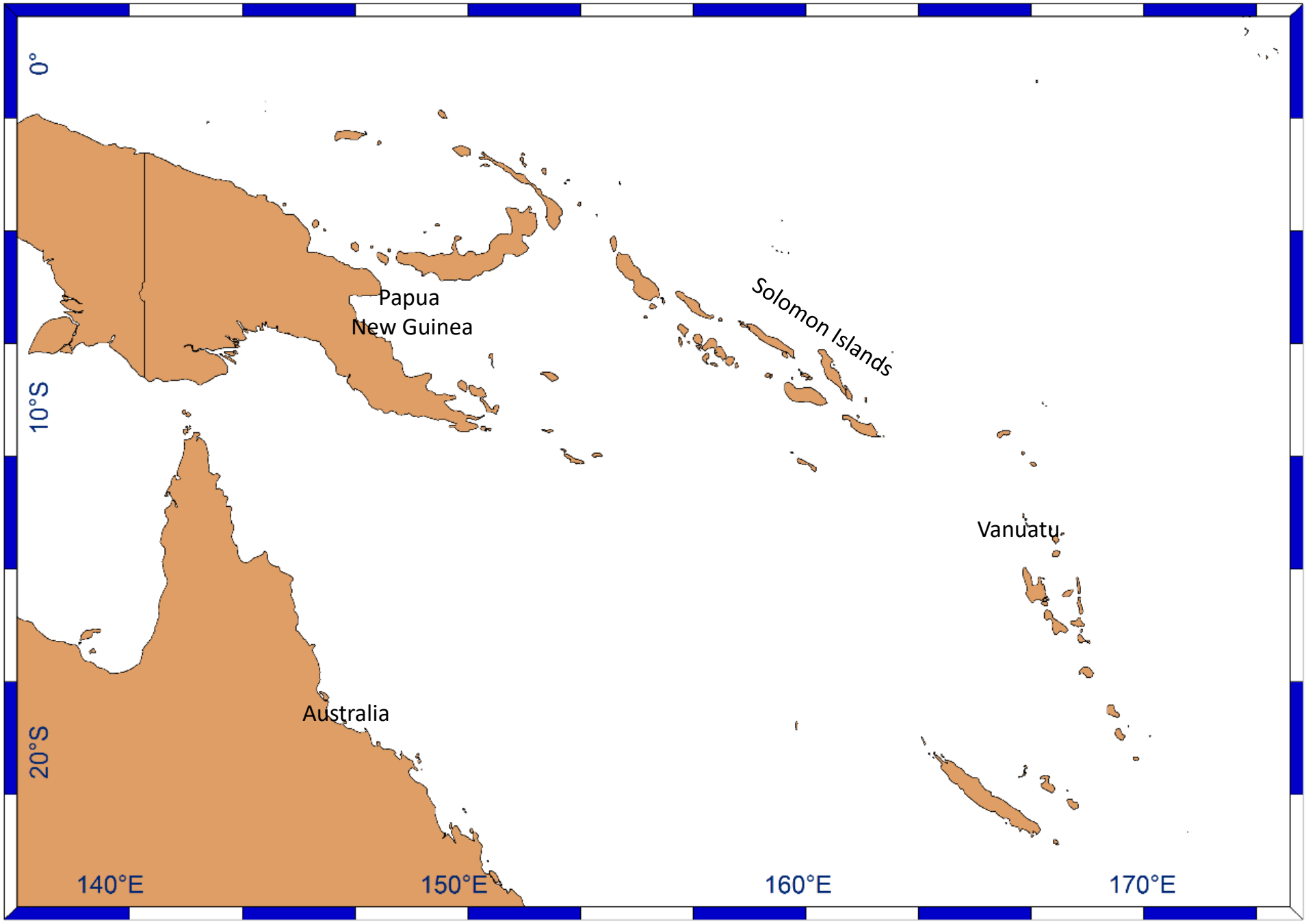
Characteristics on fault coupling along the Solomon megathrust based on GPS observations

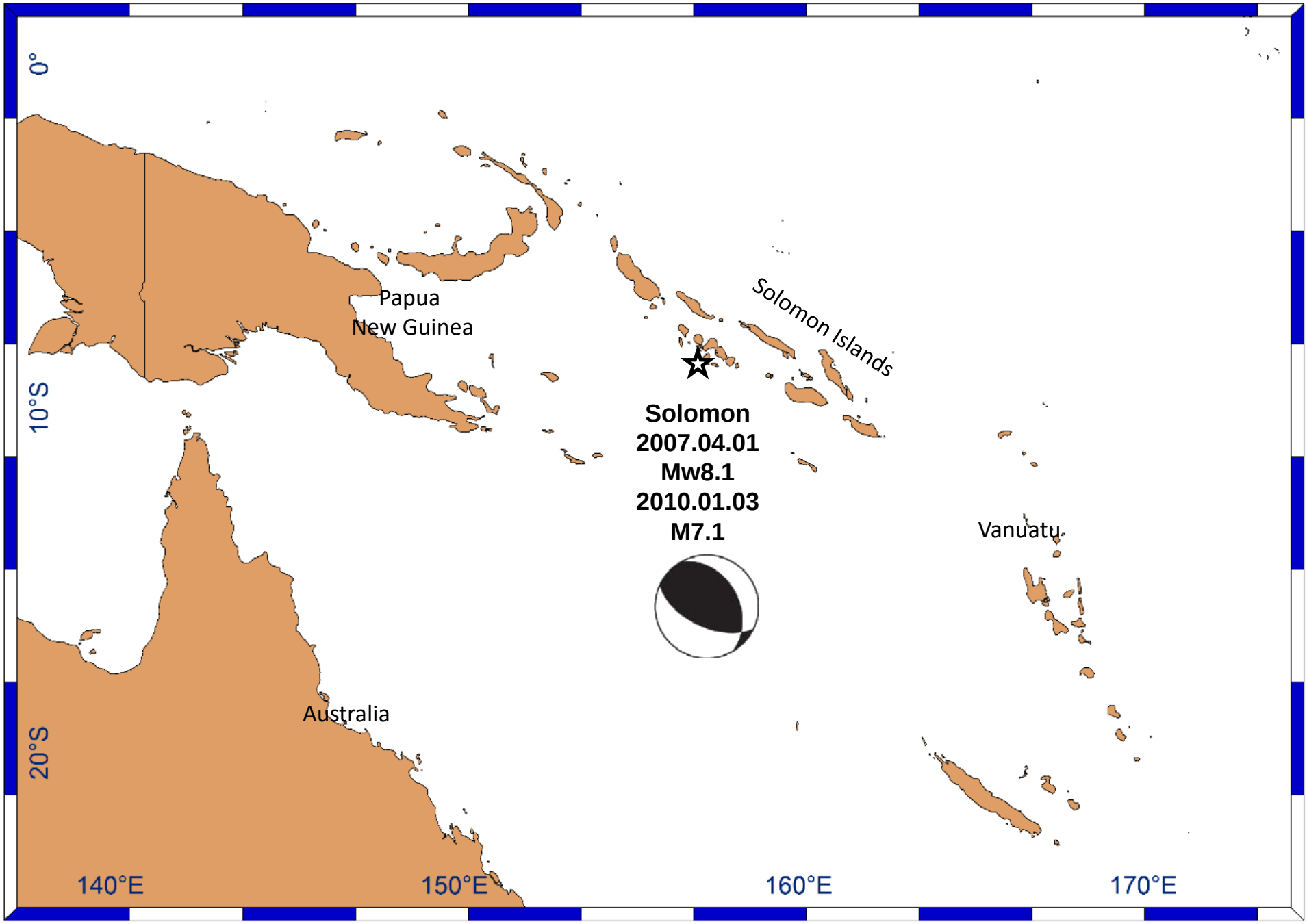
Yu-Ting Kuo[1], Chin-Shang Ku[1,2], Yue-Gau Chen[2], Yu Wang[3], Yu-Nung Nina Lin[4], Ray Y. Chuang[5], Ya-Ju Hsu[1], Frederick W. Taylor[6], Bor-Shouh Huang[1], and Hsin Tung[1,2]

[1]Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan.
[2]Department of Geosciences, National Taiwan University, Taipei, Taiwan.
[3]Earth Observatory of Singapore, Nanyang Technological University, Singapore.
[4]CGG, Singapore.
[5]Department of Geography, National Taiwan University, Taipei, Taiwan.
[6]Institute for Geophysics, University of Texas at Austin, Austin, Texas, USA.

GIPSY- OASIS on GPS

- **Wertern Solomon Islands**
- **Crust Deformation**
  - –GIPSY-OASIS
    - GPS data from 2011-2014
- **Back Slip Model**
  - –Dislocation Model


0°
10°S
20°S
140°E
150°E
160°E
170°E
Papua
New Guinea
Solomon Islands
Vanuatu
Australia


0°
10°S
20°S
140°E
150°E
160°E
170°E
Papua
New Guinea
Solomon Islands
Solomon
2007.04.01
Mw8.1
2010.01.03
M7.1
Vanuatu
Australia

Honiara

索羅門群島

9 Europa Technologies
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Data Sciences PtyLtd, PSMA
4'25.63" 東　海拔高度 -1457 公尺

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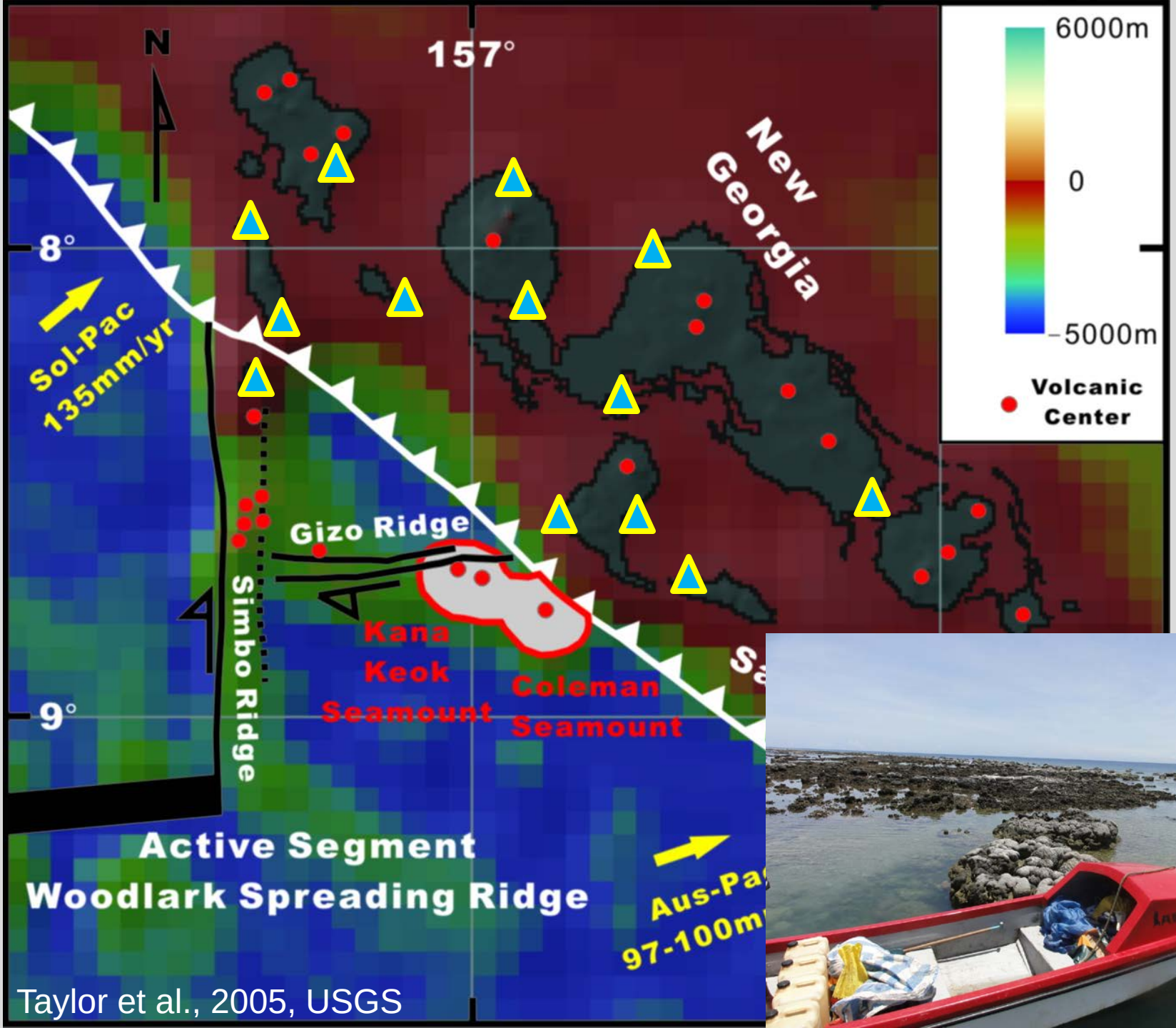
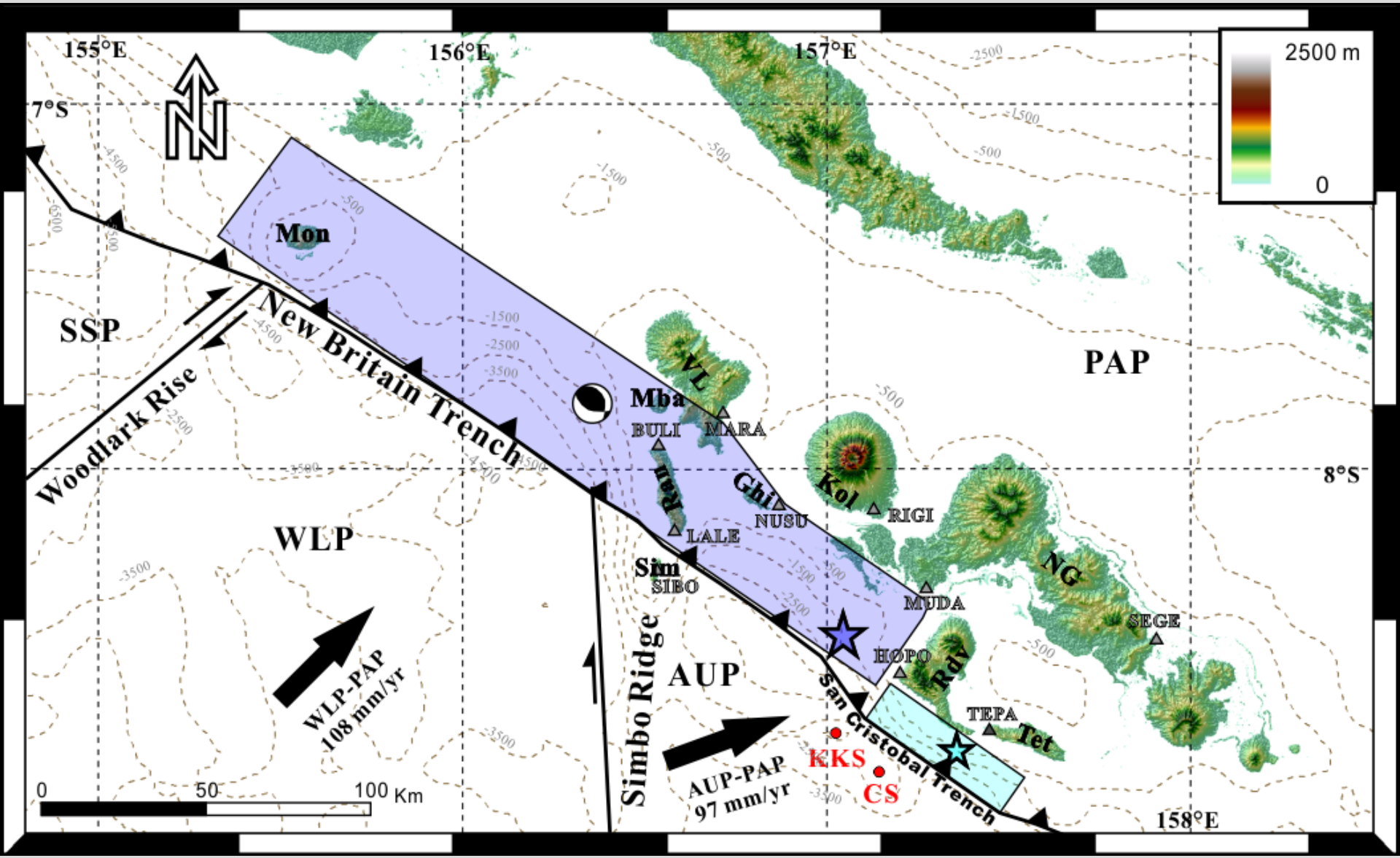
視角海拔高度　602.52 公里



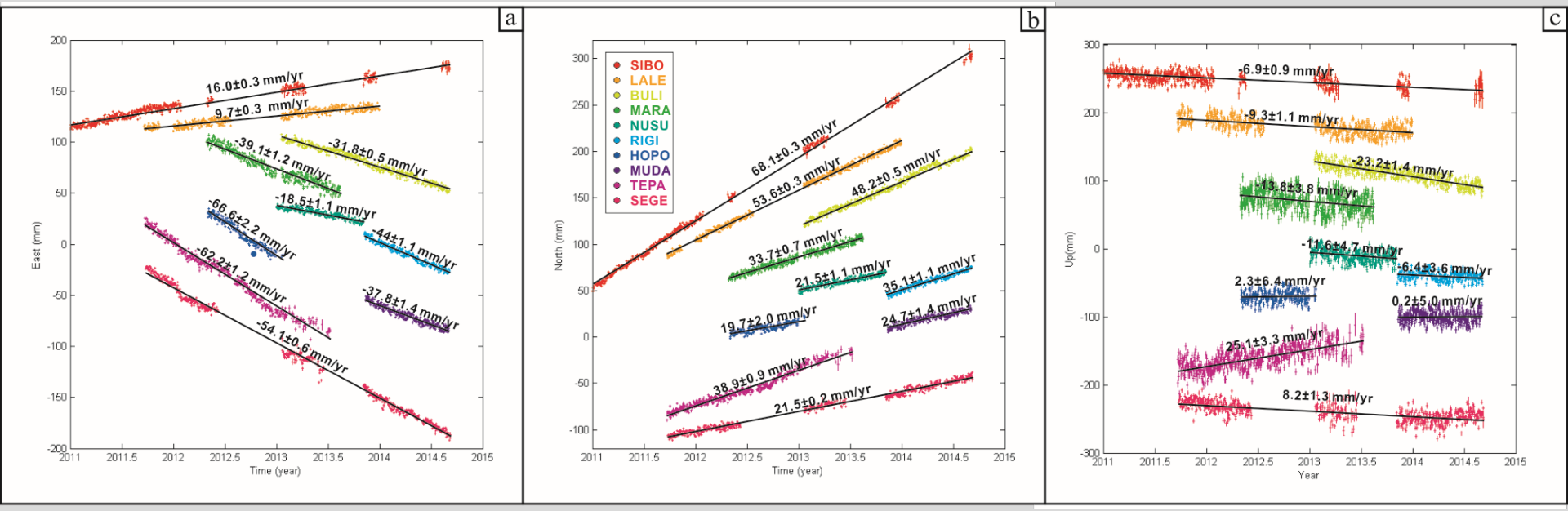
Taylor et al., 2005, USGS

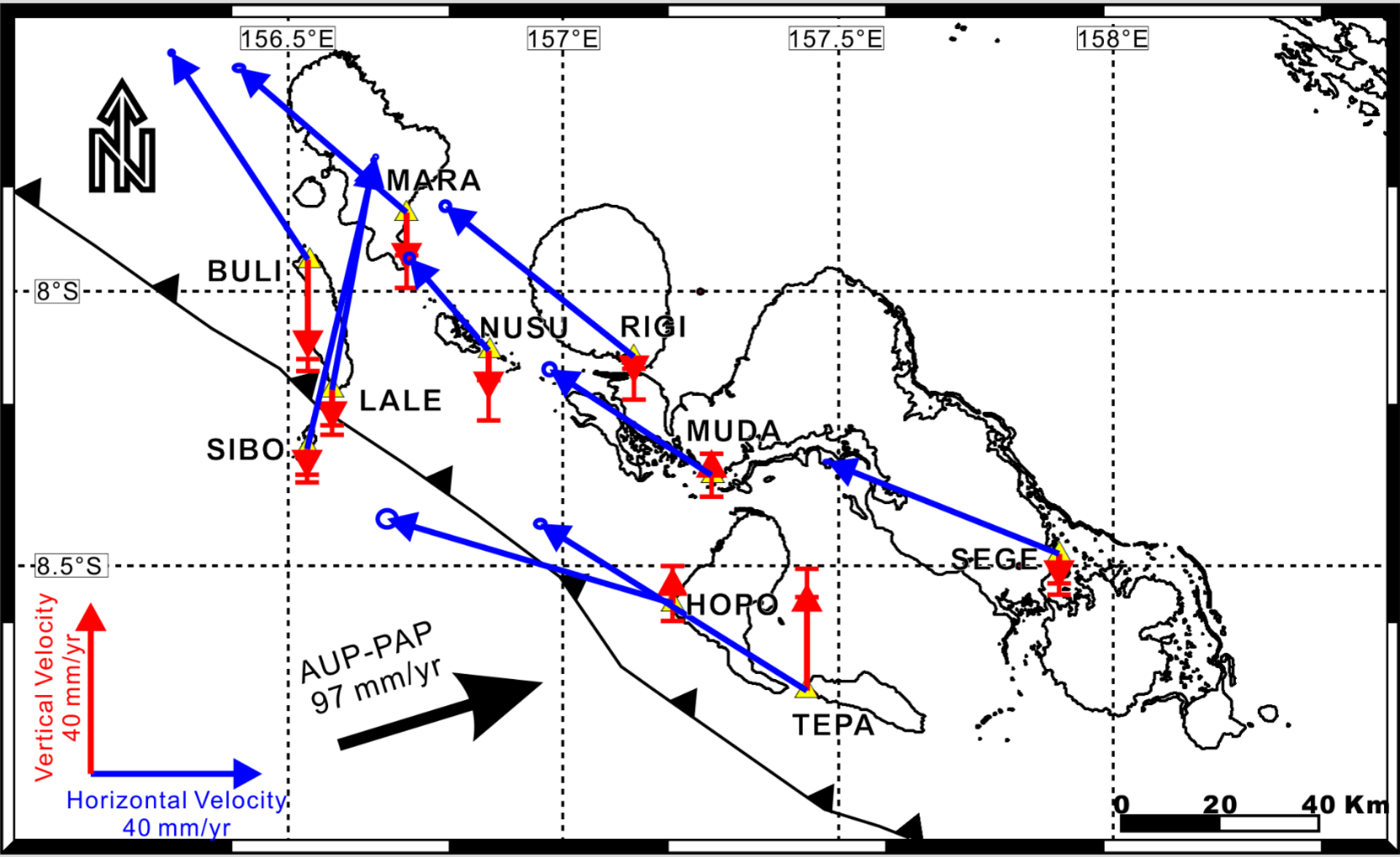

2009/08/21 11:18


2009/08/22 10:13

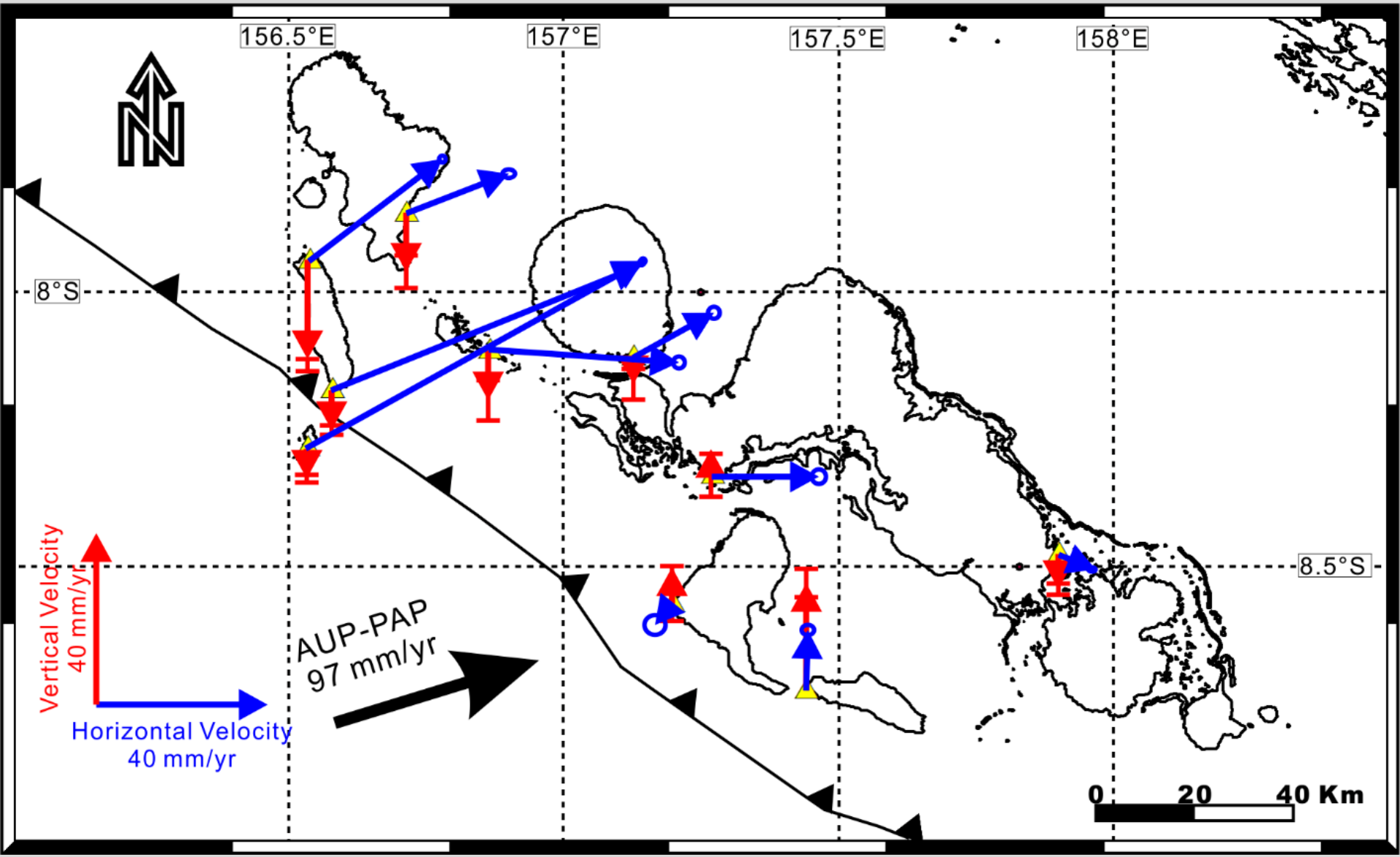

155°E
156°E
157°E
158°E
7°S
8°S
2500 m
0
Mon
SSP
New Britain Trench
Woodlark Rise
WLP
PAP
VL
Mba
BULI
MARA
Ghi
NUSU
Kol
RIGI
Ren
LALE
Sim
SIBO
NG
MUDA
SEGE
HOPO
RdV
AUP
Simbo Ridge
San Cristobal Trench
TEPA
Tet
KKS
CS
WLP-PAP
108 mm/yr
AUP-PAP
97 mm/yr
0
50
100 Km

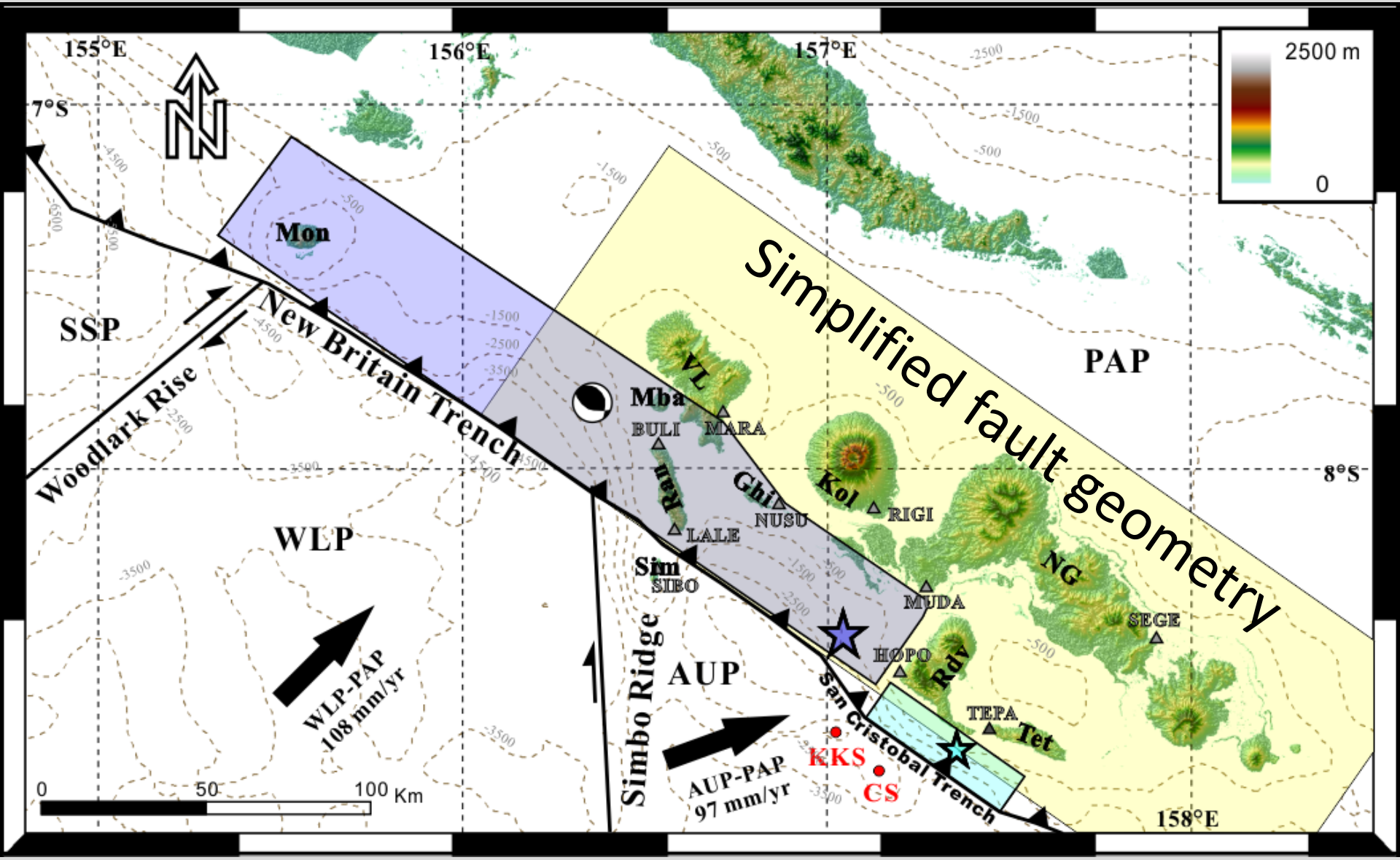
GPS Network and Processing

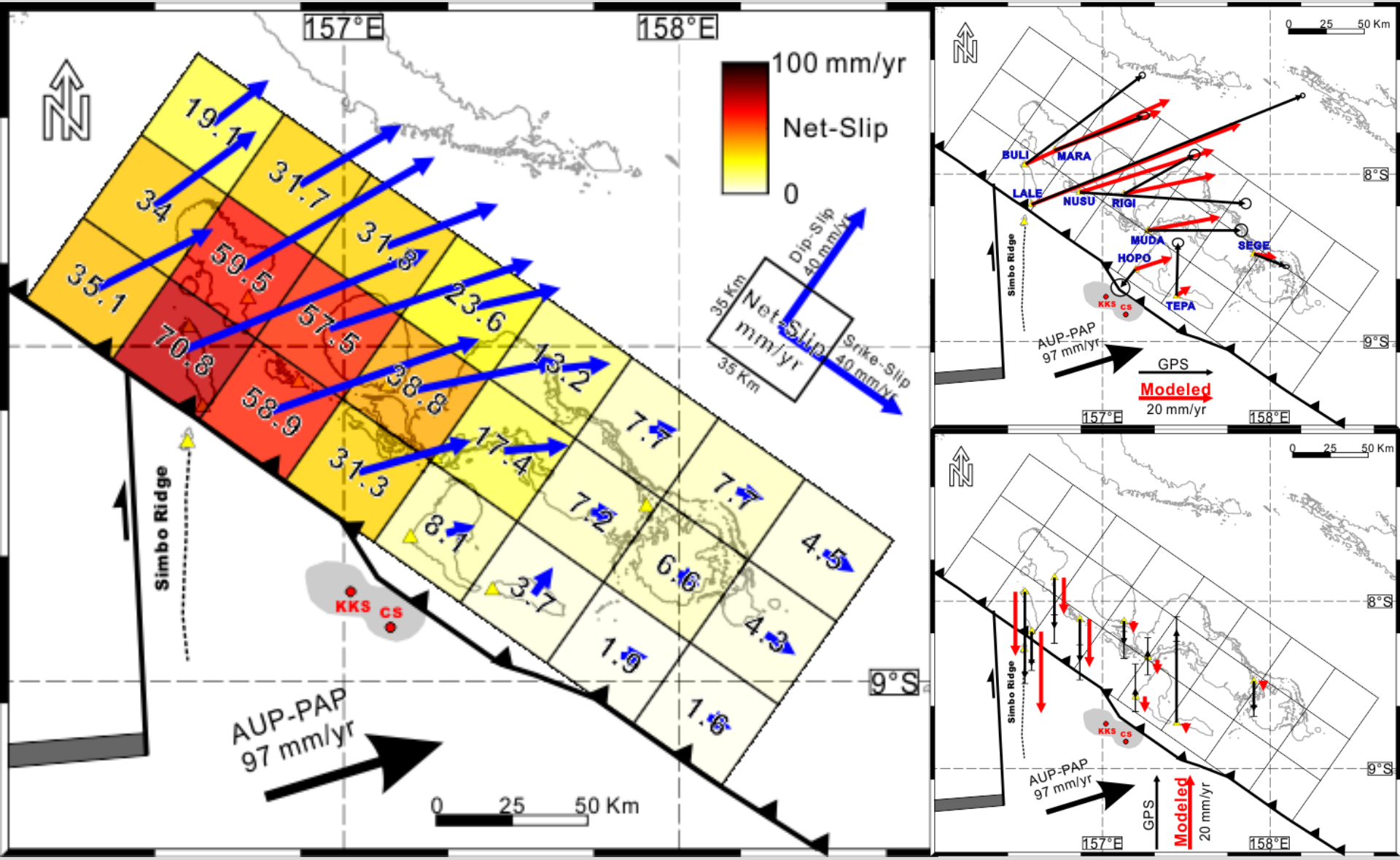



156.5°E
157°E
157.5°E
158°E
8°S
8.5°S
MARA
BULI
NUSU
RIGI
LALE
SIBO
MUDA
SEGE
HOPO
TEPA
AUP-PAP
97 mm/yr
Vertical Velocity
40 mm/yr
Horizontal Velocity
40 mm/yr
0
20
40 Km

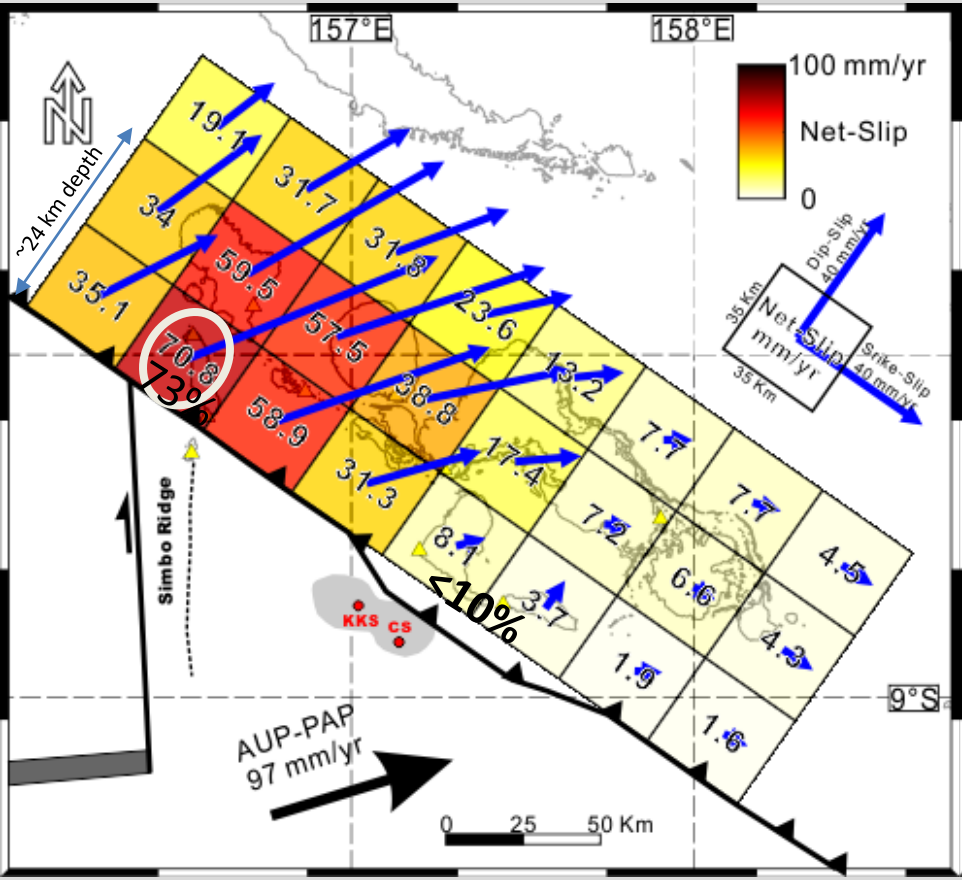
ITRF2008 - PAP

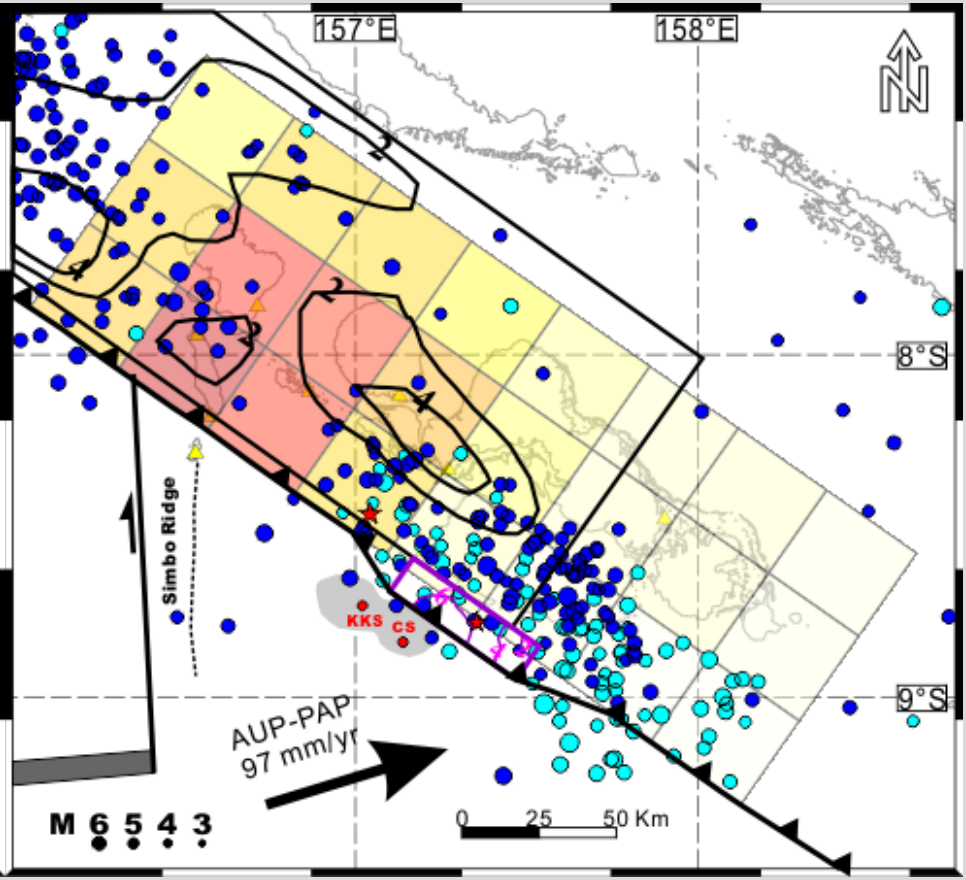



155°E
156°E
157°E
158°E
7°S
8°S
2500 m
0
Simplified fault geometry
Mon
SSP
New Britain Trench
Woodlark Rise
PAP
VL
Mba
BULI
MARA
Ran
Ghi
NUSU
Kol
RIGI
LALE
WLP
Sim
SIBO
NG
MUDA
SEGE
HOPO
Rdv
Simbo Ridge
AUP
San Cristobal Trench
TEPA
Tet
KKS
CS
WLP-PAP
108 mm/yr
AUP-PAP
97 mm/yr
0
50
100 Km


157°E
158°E
9°S
100 mm/yr
Net-Slip
0
Dip-Slip
40 mm/yr
35 Km
Net Slip
mm/yr
35 Km
Strike-Slip
40 mm/yr
19.1
34
31.7
35.1
59.5
31.9
23.6
70.8
57.5
38.8
13.2
58.9
31.3
17.4
7.7
8.1
7.2
7.7
4.5
3.7
6.6
4.3
1.9
1.6
Simbo Ridge
KKS
CS
AUP-PAP
97 mm/yr
0 25 50 Km
BULI
MARA
LALE
NUSU
RIGI
MUDA
SEGE
HOPO
TEPA
GPS
Modeled
20 mm/yr

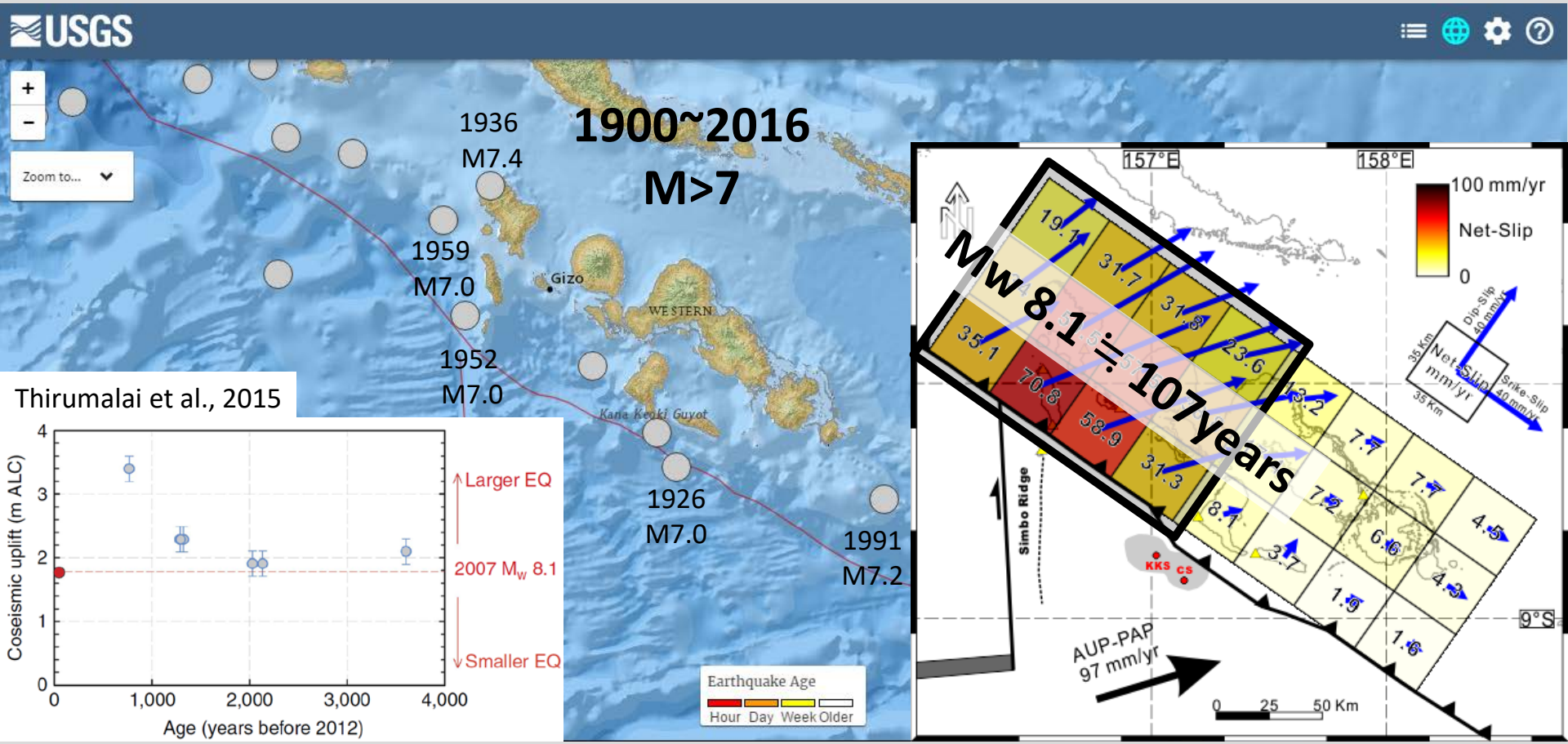
Asperity and Barrier on the Megathrust





Earthquake Scenario Estimation

From USGS



Summary

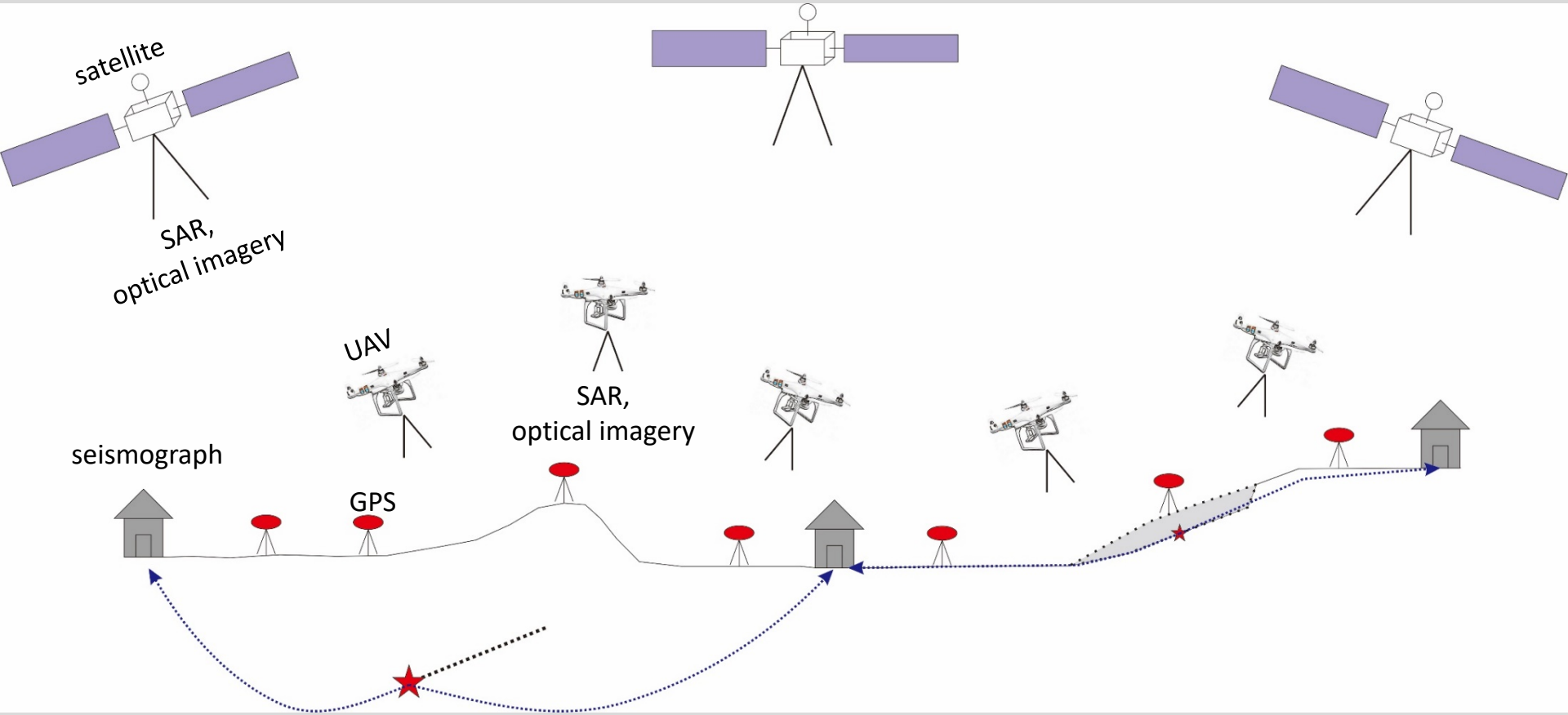
- Annual rate from GPS network
- Different Inter-seismic Coupling Ratios
- Asperity and Barrier
- Estimation of Earthquake Scenario

Conclusion

- **This study tested a few different methods to diagnose the fault kinematics and related rupture behaviors.**
- **It demonstrates utilizing the optical imageries, such as satellite and aerial photos, can provide continuous horizontal displacements in a large seismic event.**
- **The detailed fault geometry can be reconstructed by synthesized net slips from vertical and horizontal displacements.**
- **By the fault geometrical model, the characteristics of the rupture behavior can be simulated.**
- **The continuous-mode GPS data can be used to recognize the situations of the slip coupling on the fault plane beneath.**

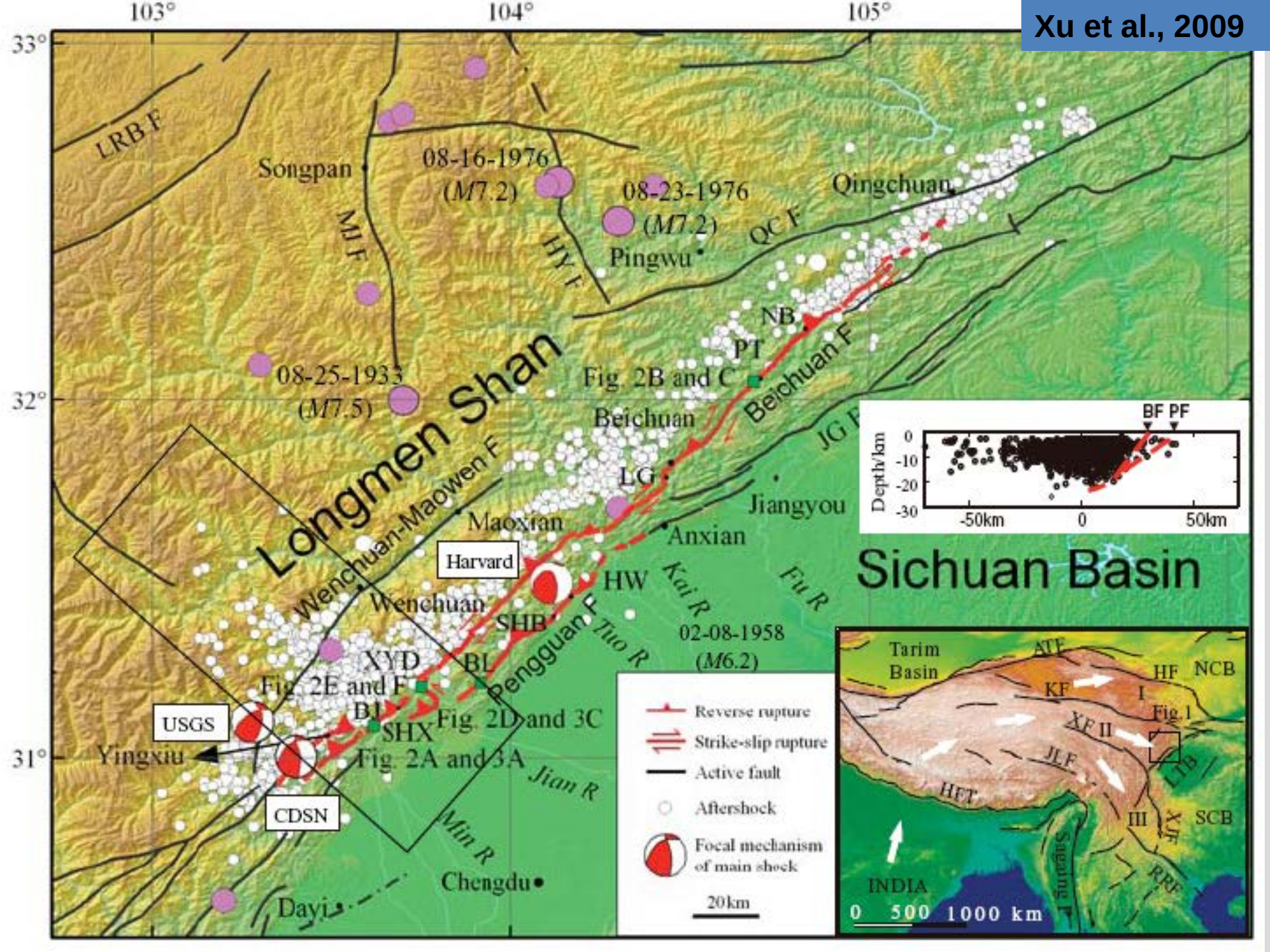
Thanks for your attention

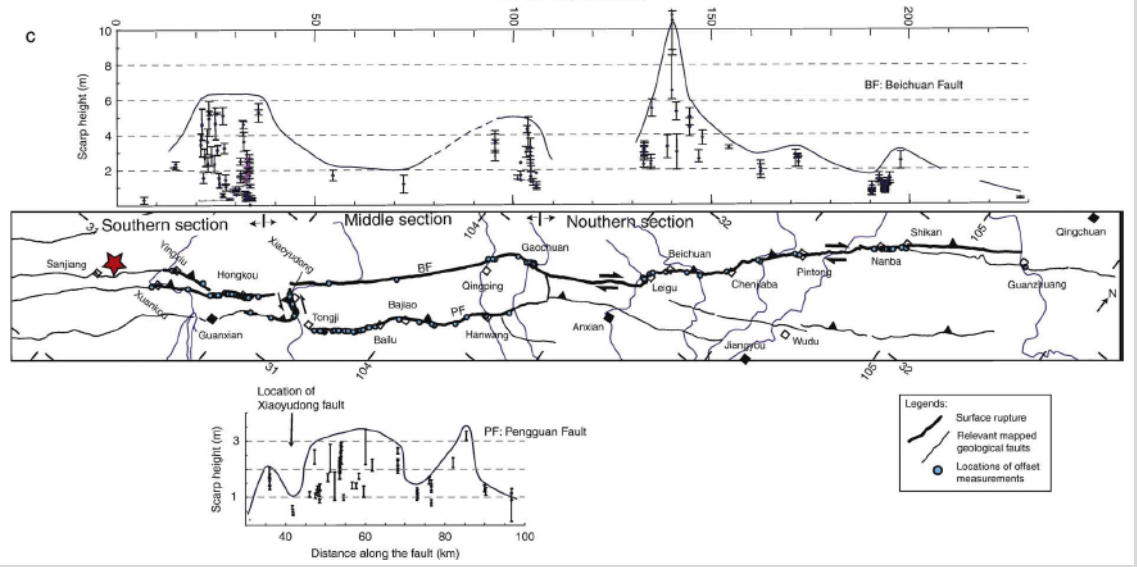
Future Study



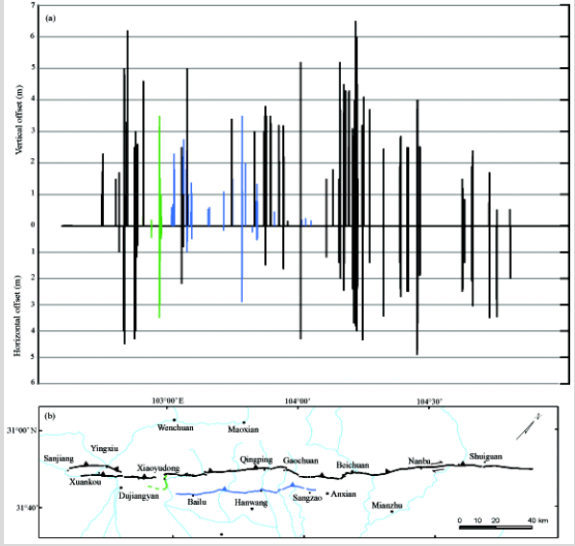
Future Study

- The behavior and geometry of seismogenic structure and landslide
- Location? Ground deformation? Area? Geometry? Behavior?
- Spatial : SAR, optical imagery
- Temporal : seismograph, GPS
- Joint inversion
- Automatic identification by system

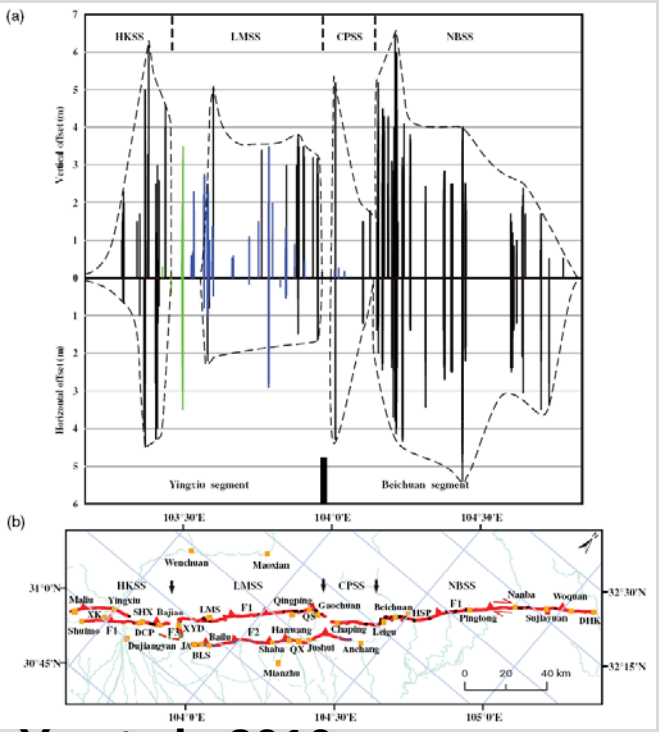

Xu et al., 2009
103°
104°
105°
33°
32°
31°
LRB F
Songpan
MJ F
08-16-1976
(M7.2)
08-23-1976
(M7.2)
HY F
Pingwu
QC F
Qingchuan
NB
PT
Beichuan F
08-25-1933
(M7.5)
Fig. 2B and C
Beichuan
Longmen Shan
Wenchuan-Maowen F
LG
Jiangyou
Maoxian
Anxian
Harvard
HW
Kai R
Fu R
Wenchuan
SHB
Pengguan F
Tuo R
02-08-1958
(M6.2)
XYD
BL
Fig. 2E and F
USGS
BL
SHX
Fig. 2D and 3C
Fig. 2A and 3A
Yingxiu
Jian R
CDSN
Min R
Chengdu
Dayi
Sichuan Basin
BF PF
Depth/km
0
-10
-20
-30
-50km
0
50km
Reverse rupture
Strike-slip rupture
Active fault
Aftershock
Focal mechanism of main shock
20km
Tarim Basin
ATF
KF
HF
NCB
I
Fig.1
XF II
JLF
LTB
HFT
III
XJF
SCB
Sagaing F
RRF
INDIA
0 500 1000 km



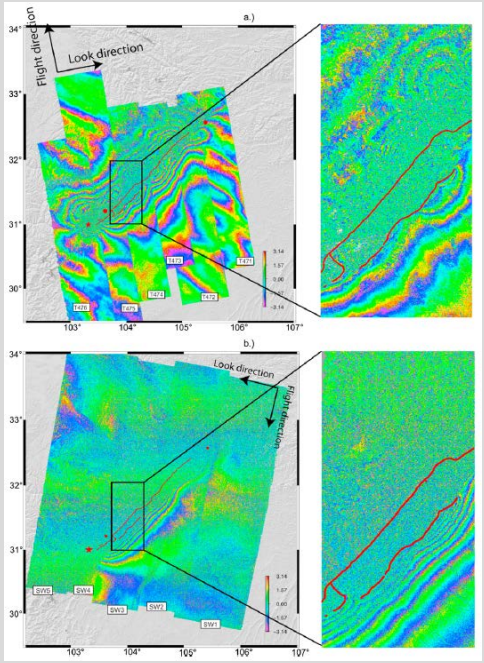
Liu-Zeng et al., 2009



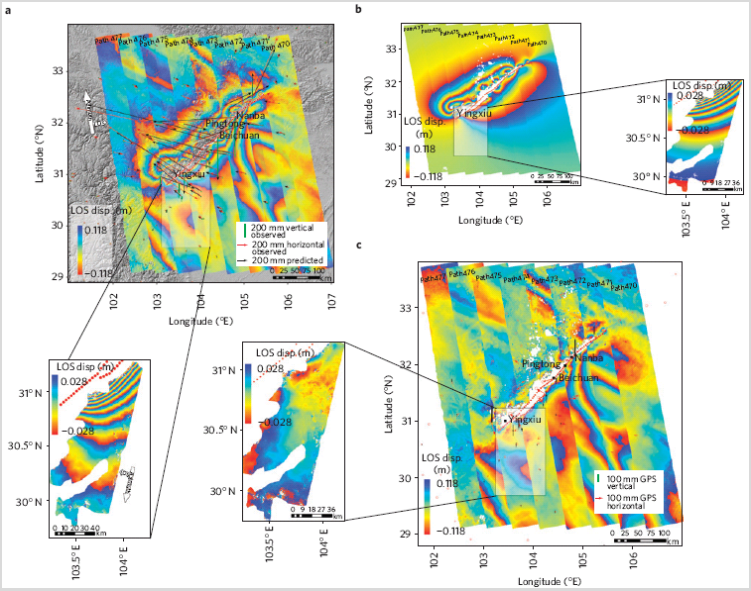
Xu et al., 2009



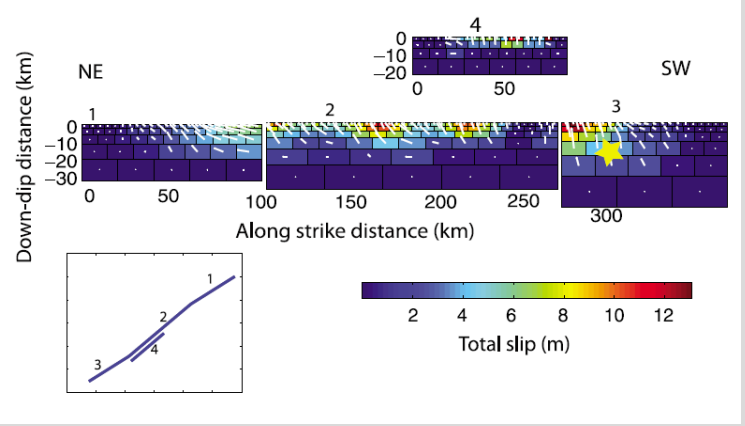
Yu et al., 2010



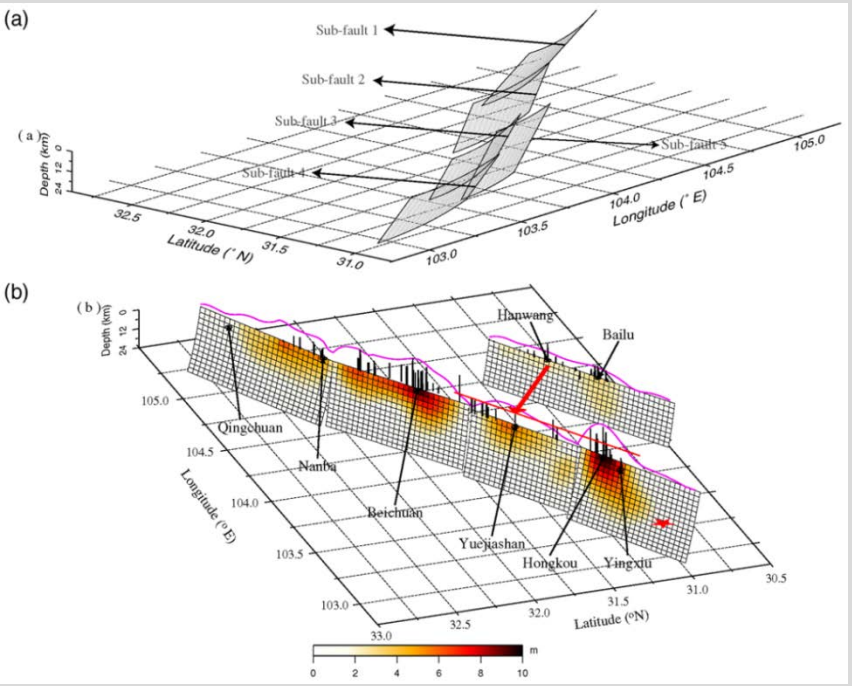
Tong et al., 2010



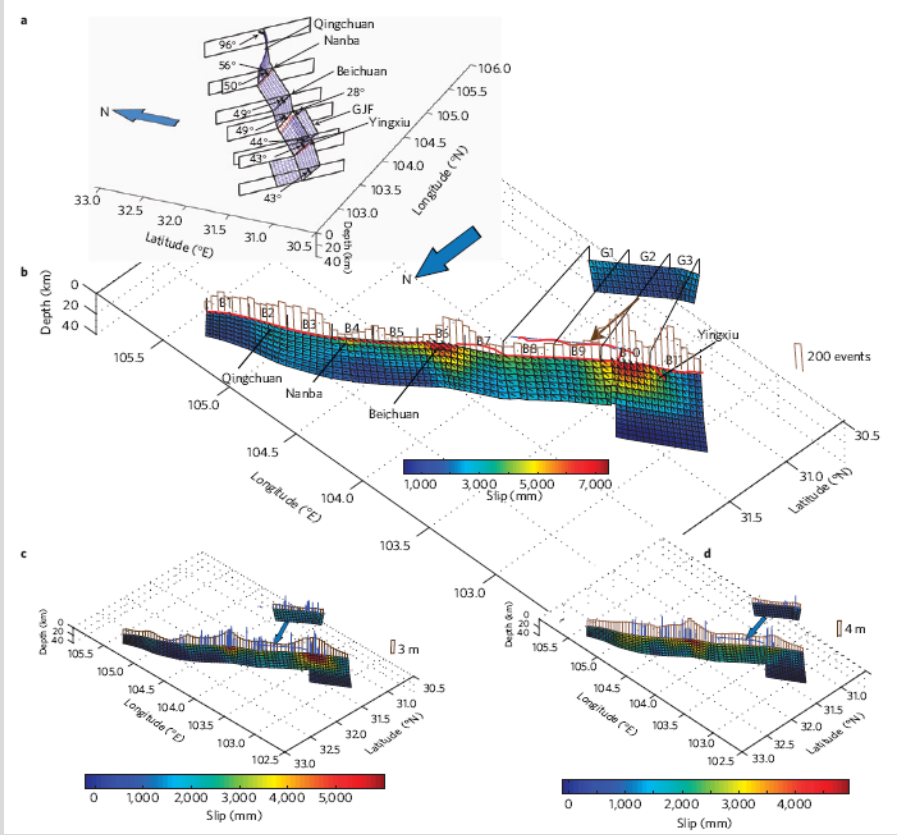
Shen et al., 2009



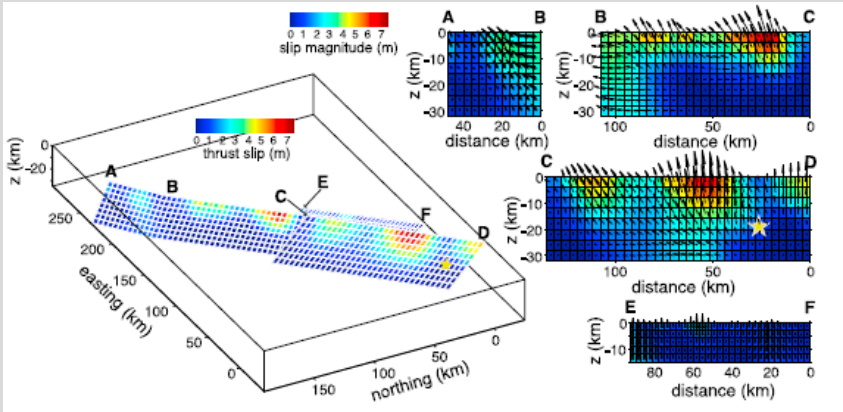
Tong et al., 2010



Xu et al., 2010



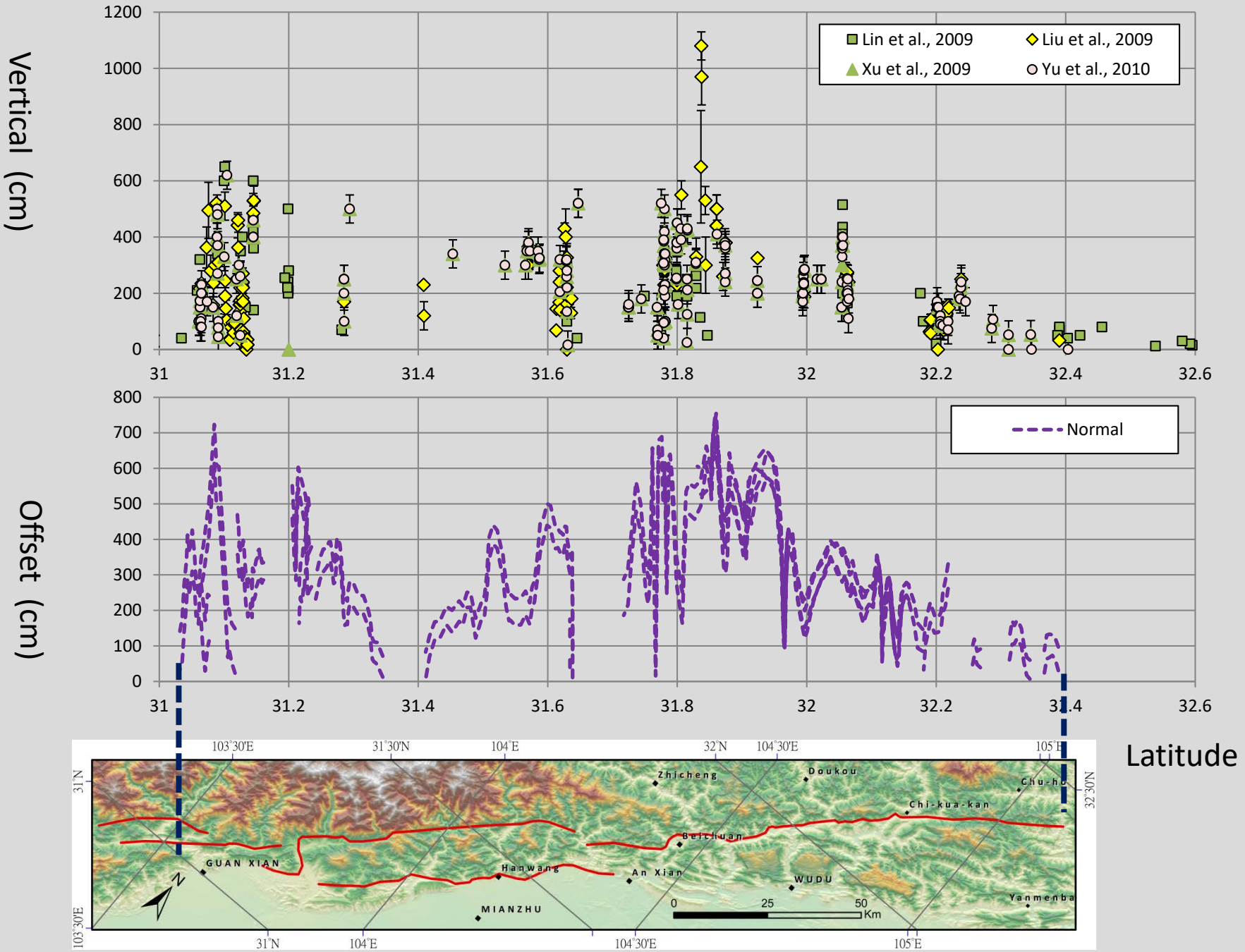
Shen et al., 2009

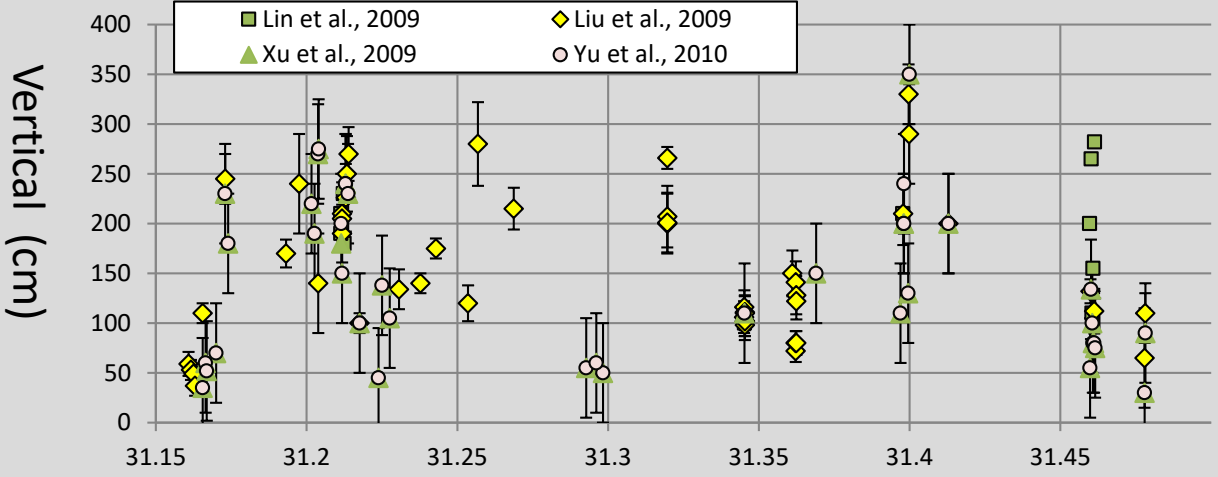


Feng et al., 2010

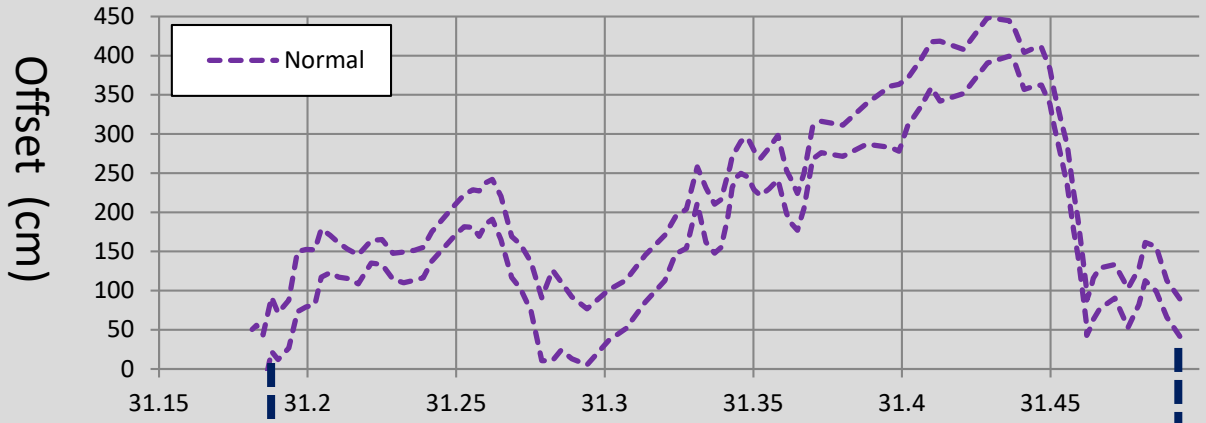
Question

- **Near-Fault Coseismic Displacements?**
- **Fault Geometry?**
- **Slips of Pengguan Fault?**

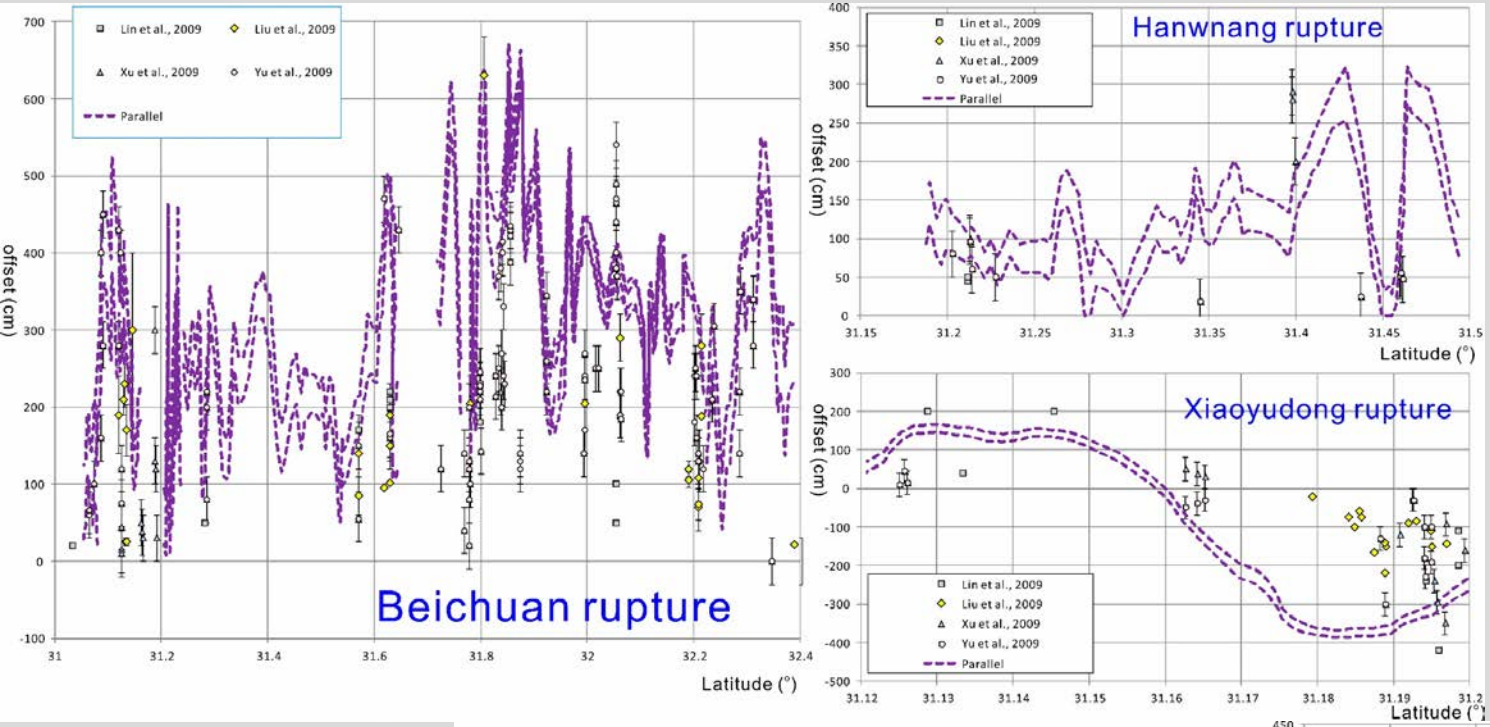

Vertical (cm)
Offset (cm)
Latitude
Lin et al., 2009
Liu et al., 2009
Xu et al., 2009
Yu et al., 2010
Normal
1200
1000
800
600
400
200
0
700
500
300
100
31
31.2
31.4
31.6
31.8
32
32.2
32.4
32.6
103°30'E
31°30'N
104°E
32°N
104°30'E
105°E
32°30'N
31°N
103°30'E
104°E
104°30'E
105°E
Zhicheng
Doukou
Chu-hu
Chi-kua-kan
Beichuan
GUAN XIAN
Hanwang
An Xian
WUDU
Yanmenba
MIANZHU
0
25
50
Km


Lin et al., 2009
Liu et al., 2009
Xu et al., 2009
Yu et al., 2010
Vertical (cm)
400
350
300
250
200
150
100
50
0
31.15
31.2
31.25
31.3
31.35
31.4
31.45

Latitude

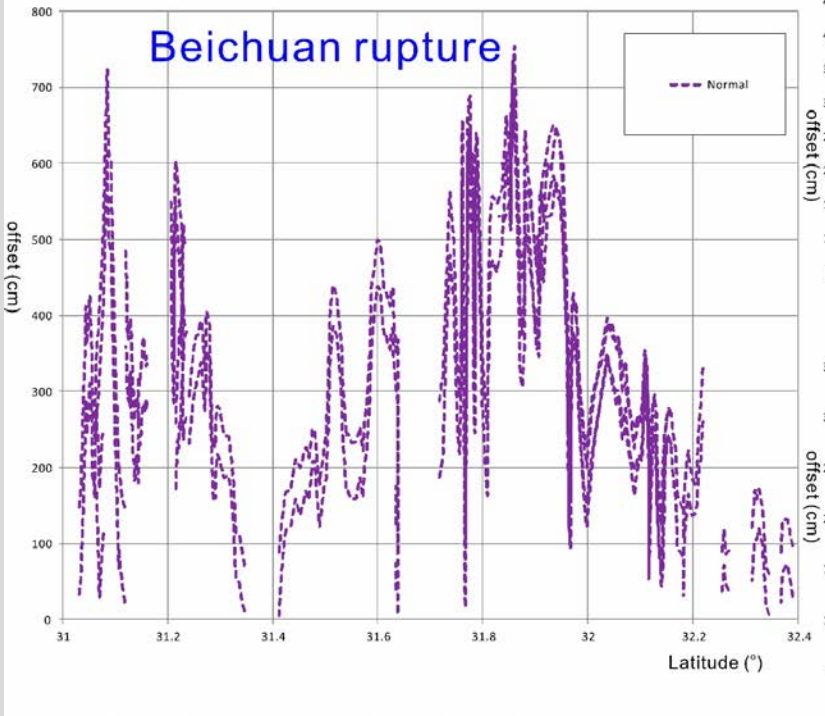

Normal
Offset (cm)
450
400
350
300
250
200
150
100
50
0
31.15
31.2
31.25
31.3
31.35
31.4
31.45

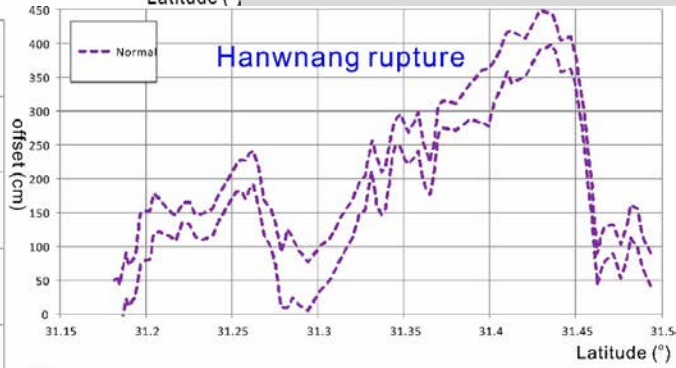

Hanwang


Lin et al., 2009
Liu et al., 2009
Xu et al., 2009
Yu et al., 2009
Parallel
Beichuan rupture
offset (cm)
Latitude (°)

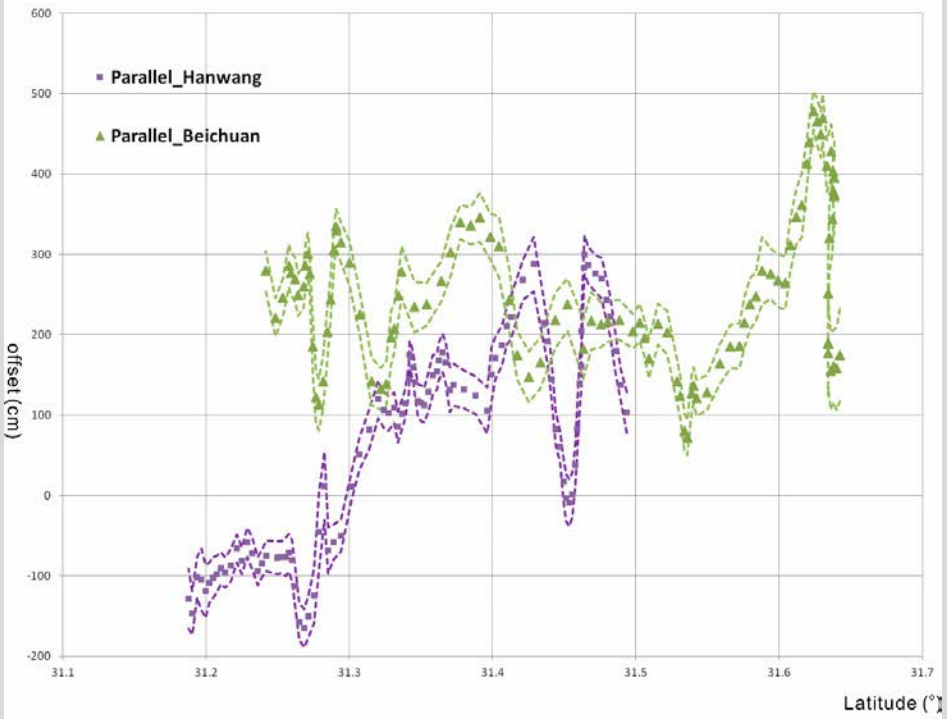
Lin et al., 2009
Liu et al., 2009
Xu et al., 2009
Yu et al., 2009
Parallel
Hanwnang rupture
offset (cm)
Latitude (°)

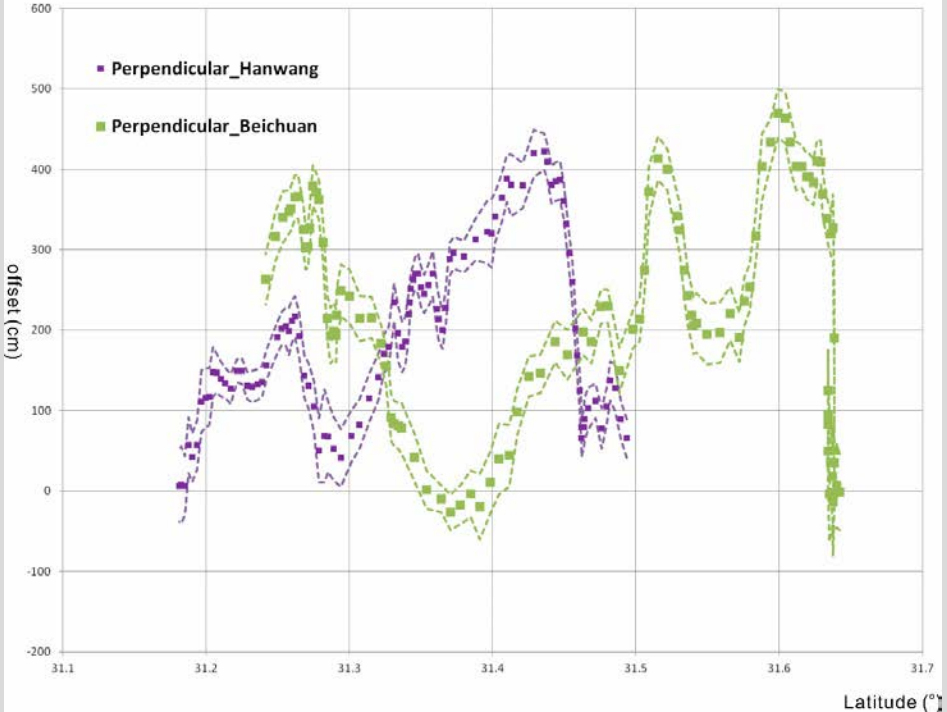
Xiaoyudong rupture
Lin et al., 2009
Liu et al., 2009
Xu et al., 2009
Yu et al., 2009
Parallel
offset (cm)
Latitude (°)

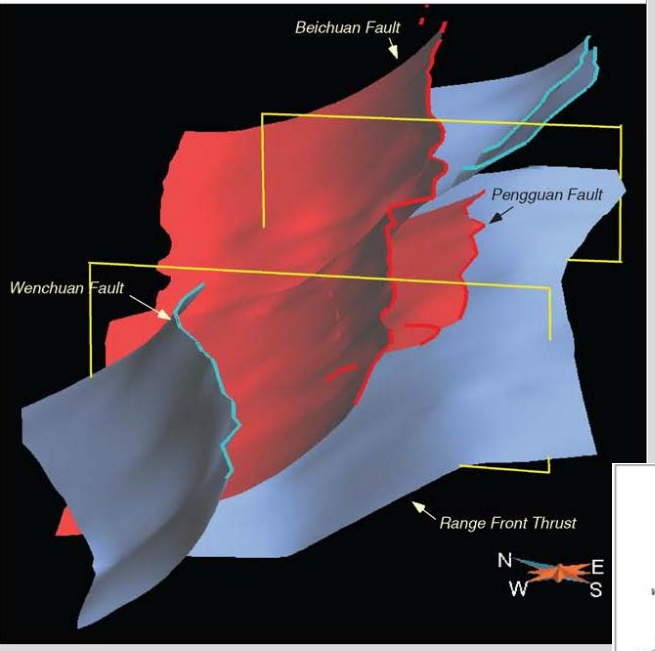

Beichuan rupture
Normal
offset (cm)
Latitude (°)


Normal
Hanwnang rupture
offset (cm)
Latitude (°)

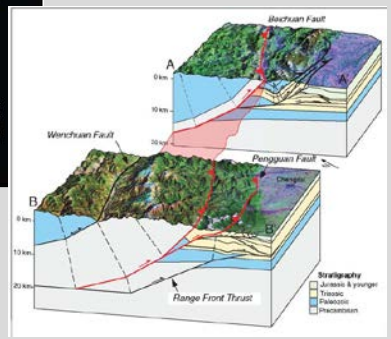

Normal
Xiaoyudong rupture
offset (cm)
Latitude (°)

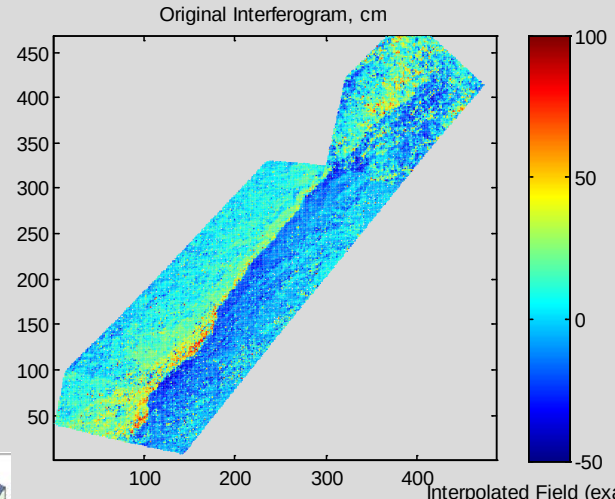

Parallel_Hanwang
Parallel_Beichuan
offset (cm)
600
500
400
300
200
100
0
-100
-200
31.1
31.2
31.3
31.4
31.5
31.6
31.7
Latitude (°)

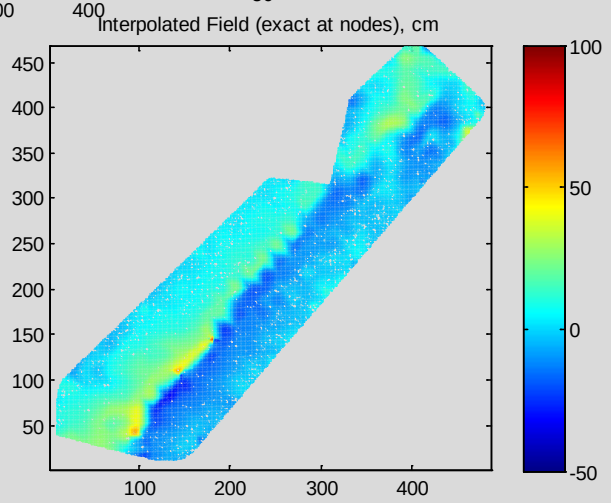

Perpendicular_Hanwang
Perpendicular_Beichuan
offset (cm)
600
500
400
300
200
100
0
-100
-200
31.1
31.2
31.3
31.4
31.5
31.6
31.7
Latitude (°)



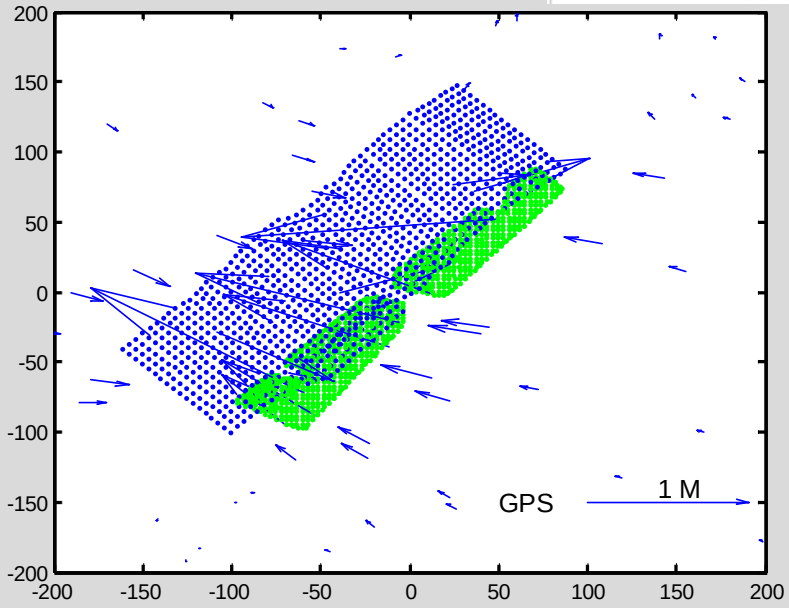
Hubbard et al., 2010





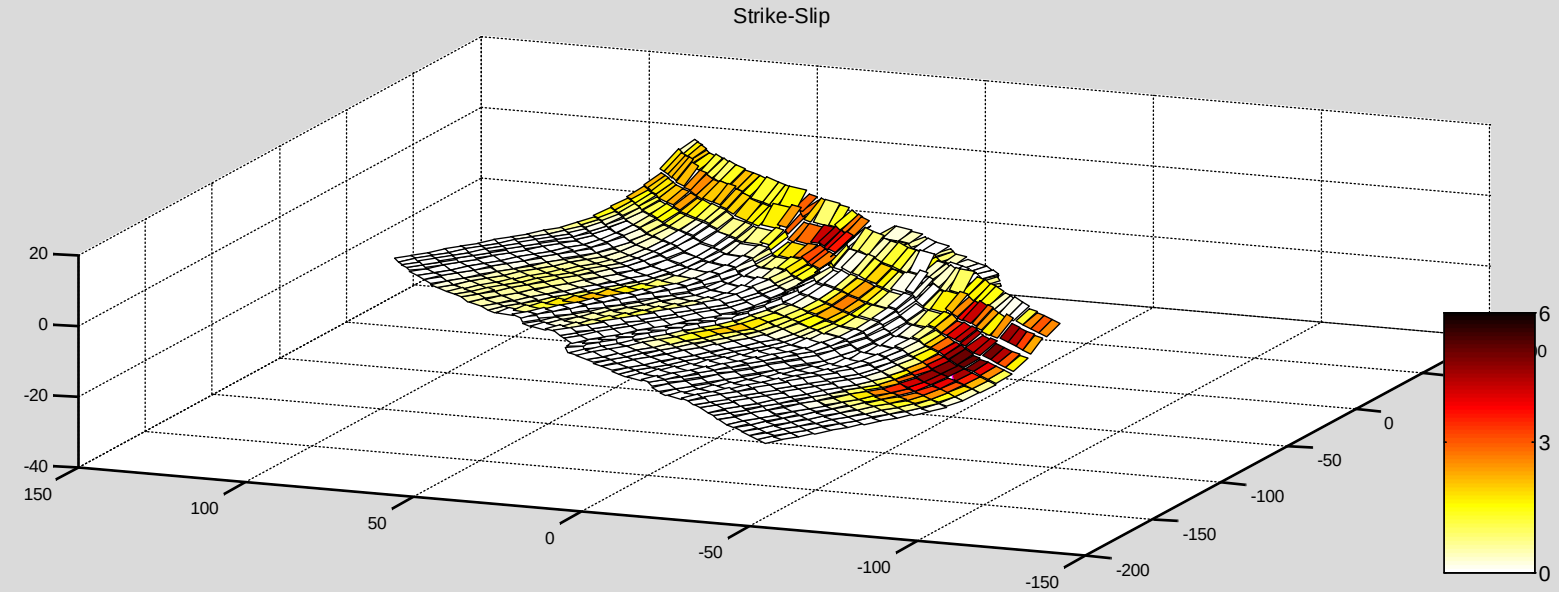


Lohman and Simons, 2005



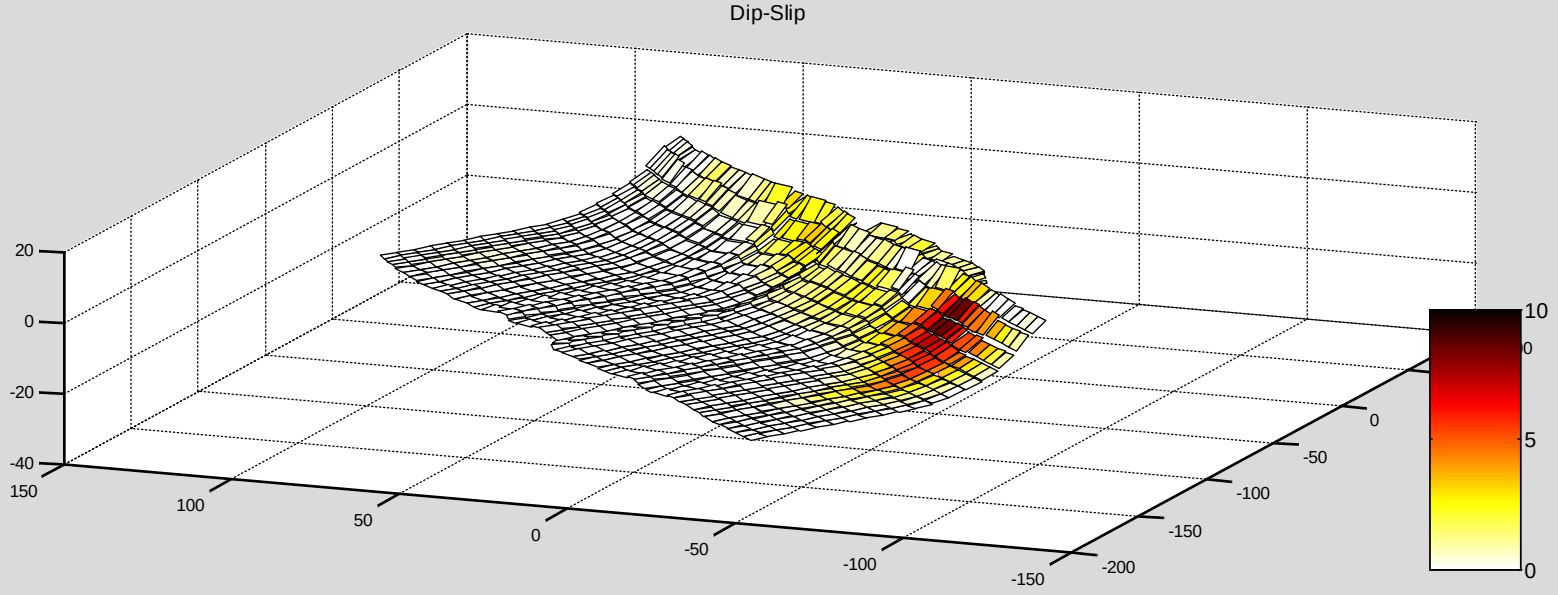
GPS E, N, U : 46*3
E, N : 112*2
Result E : 1030
N : 1047

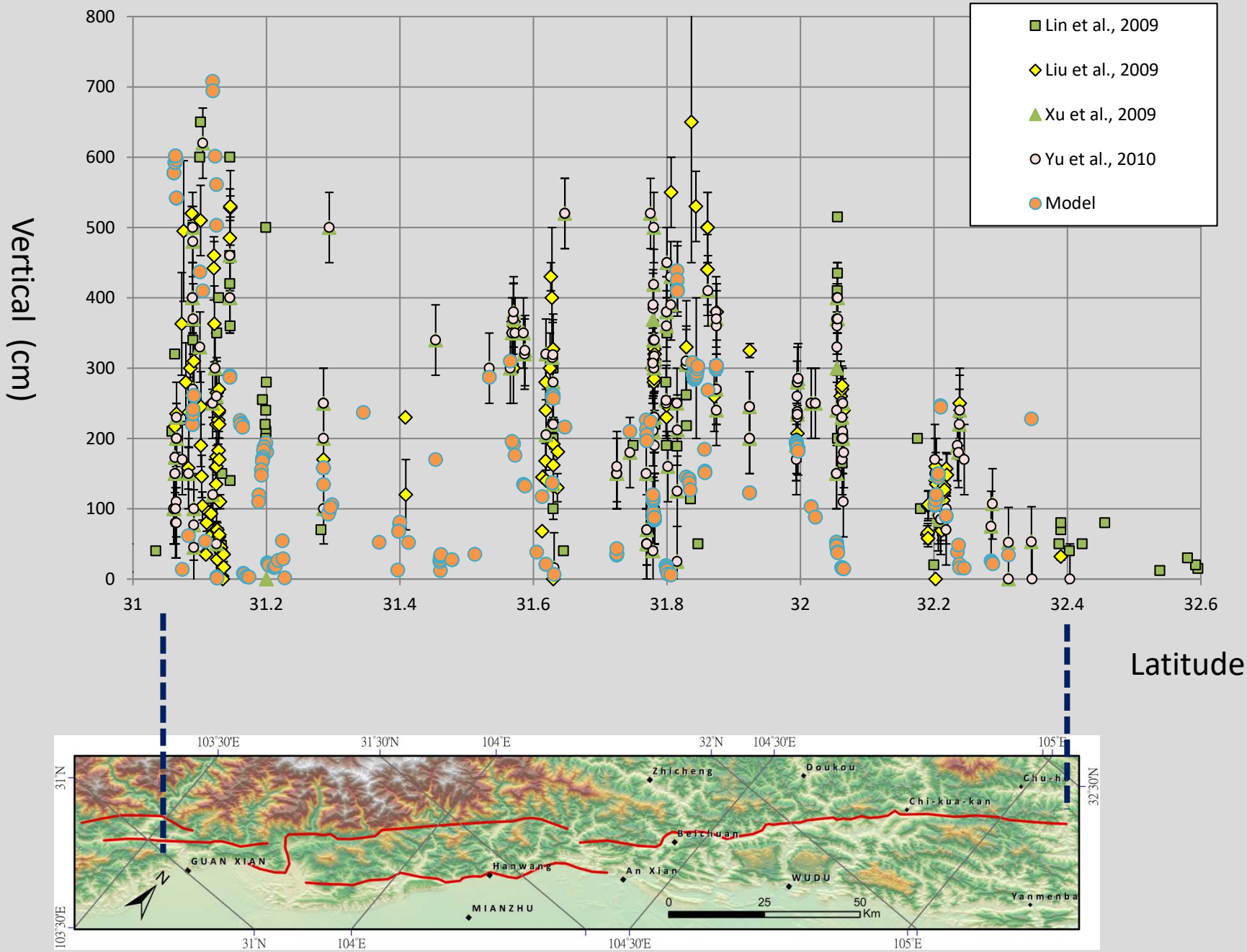
Total : 2439

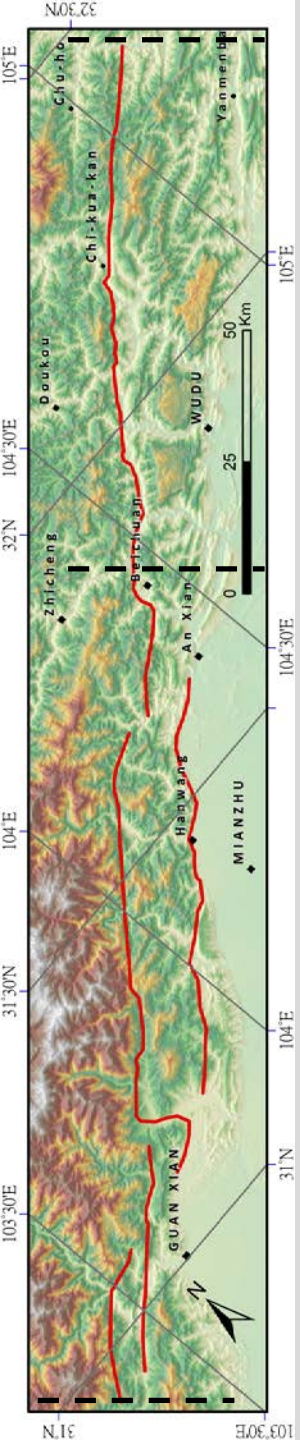


max strike-slip =5.1 m

max dip-slip = 8.6 m




Lin et al., 2009
Liu et al., 2009
Xu et al., 2009
Yu et al., 2010
Model
Vertical (cm)
Latitude
800
700
600
500
400
300
200
100
0
31
31.2
31.4
31.6
31.8
32
32.2
32.4
32.6
103°30'E
31°30'N
104°E
32°N
104°30'E
105°E
31°N
32°30'N
103°30'E
31°N
104°E
104°30'E
105°E
Zhicheng
Doukou
Chi-kua-kan
Beichuan
GUAN XIAN
Hanwang
An Xian
WUDU
MIANZHU
Yanmenba
0
25
50
Km



No.	Coseismic slip amplitude (m)	Secular rate (GPS) (mm/yr)	Secular rate (Geol) (mm/yr)	Recurrence time (GPS) 1000 years	Recurrence time (Geol) 1000 years
Northern	2.1	0.8		2.6	
Southern	2.8	2.2	1.2	1.3	2.3
Pengguan	1.5		0.2		7.5

Secular rate from Shen et al., 2009

Surface Rupture

Result from SPOT 4

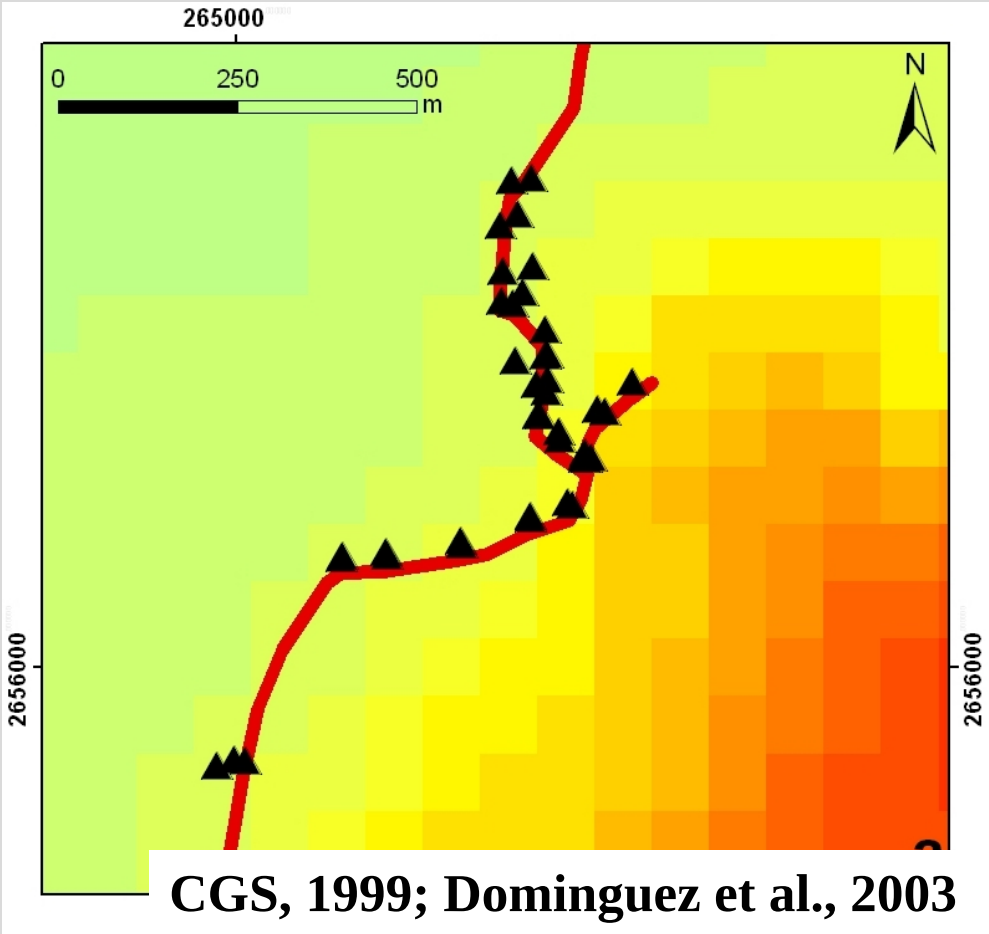
Pixel : 10m

Windows Size : 16*16 pixels

(If Error >3m) 32*32

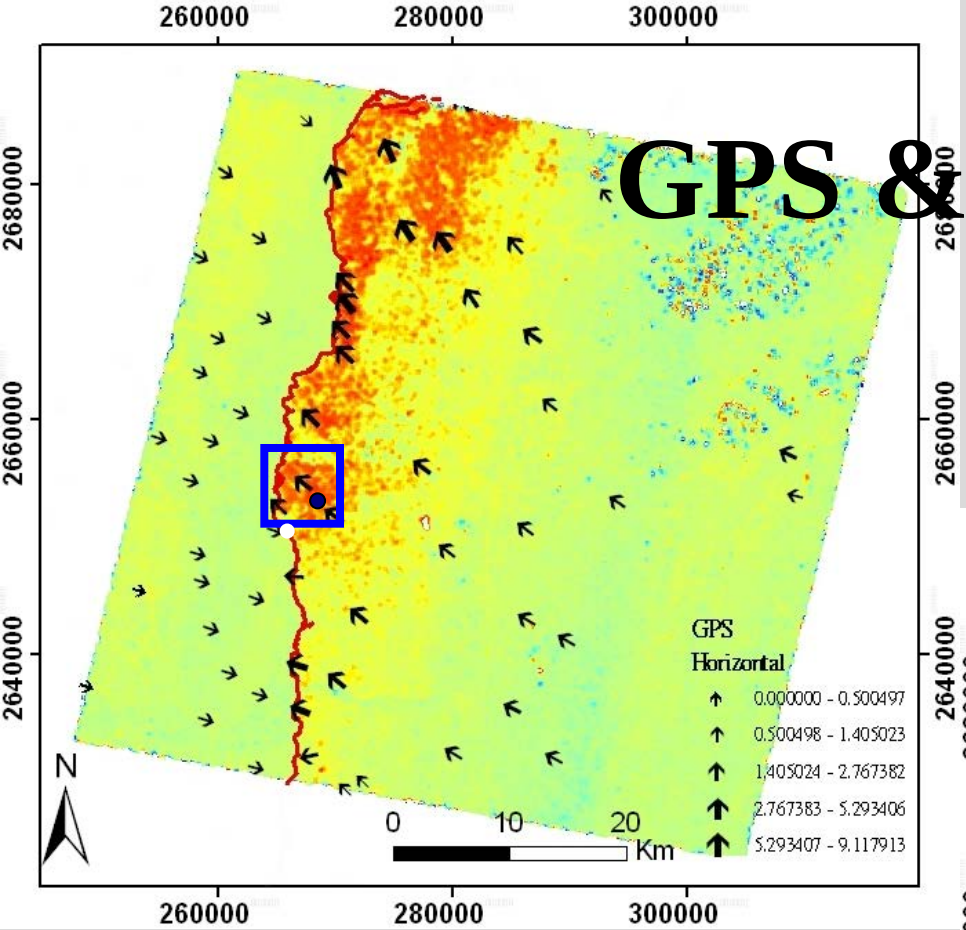
64*64

Step : 16 pixels



CGS, 1999; Dominguez et al., 2003

GPS & SPOT



Result from SPOT 4

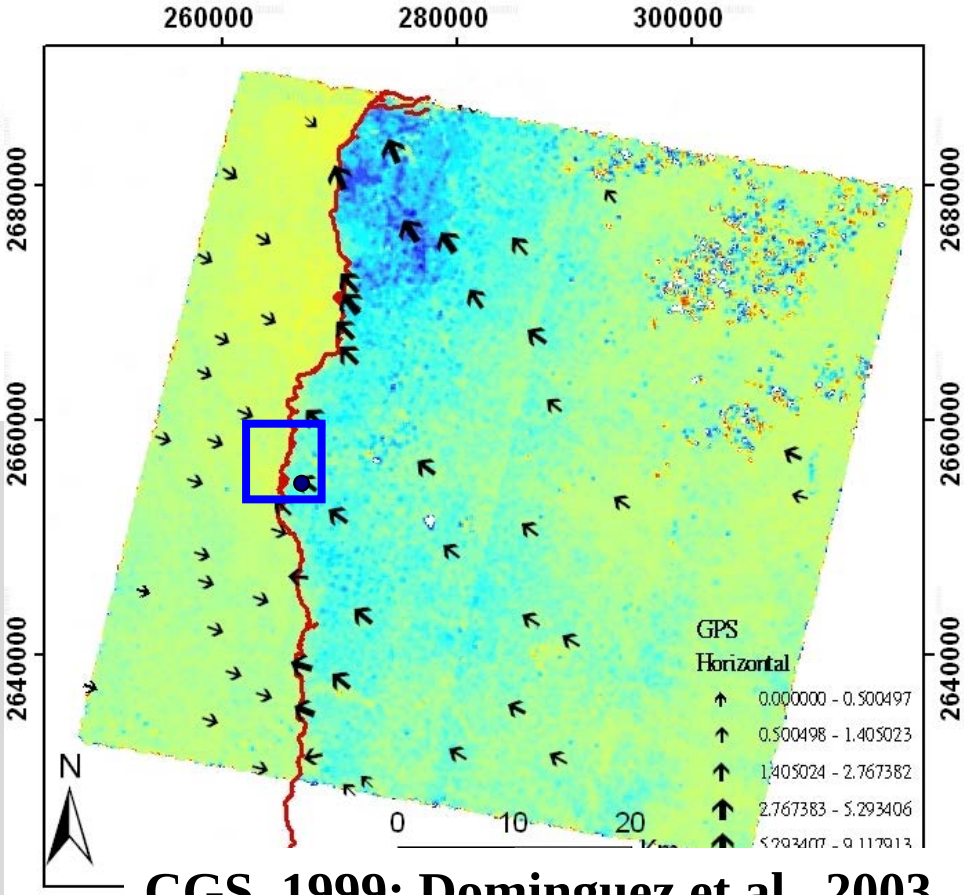
Pixel : 10m

Windows Size : 16*16 pixels

(If Error >3m) 32*32

64*64

Step : 16 pixels



AF23	SPOT
4.218m W	4~6m W
3.261m N	3~5m N
2.952m Up	

CGS, 1999; Dominguez et al., 2003

Key Points

- We deployed the first continuous GPS network at the Western Solomon Islands since 2011.
- GPS record reveals significantly different interseismic coupling ratios between two adjacent segments on the Solomon megathrust.
- We identify a semipermanent asperity and a potential barrier to rupture, each corresponding to the subduction of geological features.

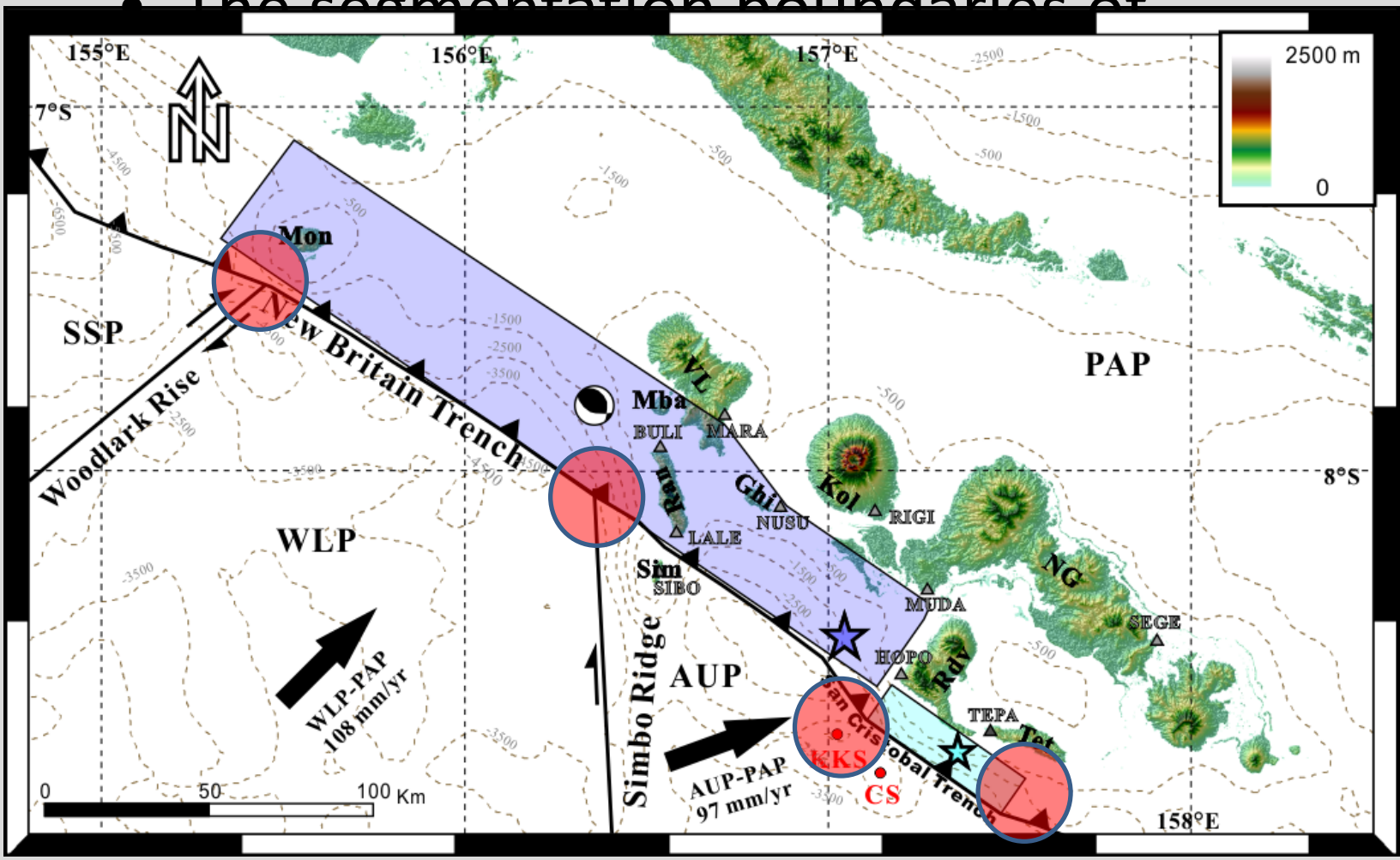
Outline

- Introduction
- Tectonic Setting
- The 2007 and 2010 Earthquakes
- GPS Network and Processing
- Back Slip Model
- Discussion
  - Asperity and Barrier on the Megathrust
  - Earthquake Scenario Estimation
- Conclusion

Introduction

- **Geological feature (ridge, seamount, etc.) <-> Segmentation boundary**
- **Not many studies in this area**
- **2007 & 2010 events**

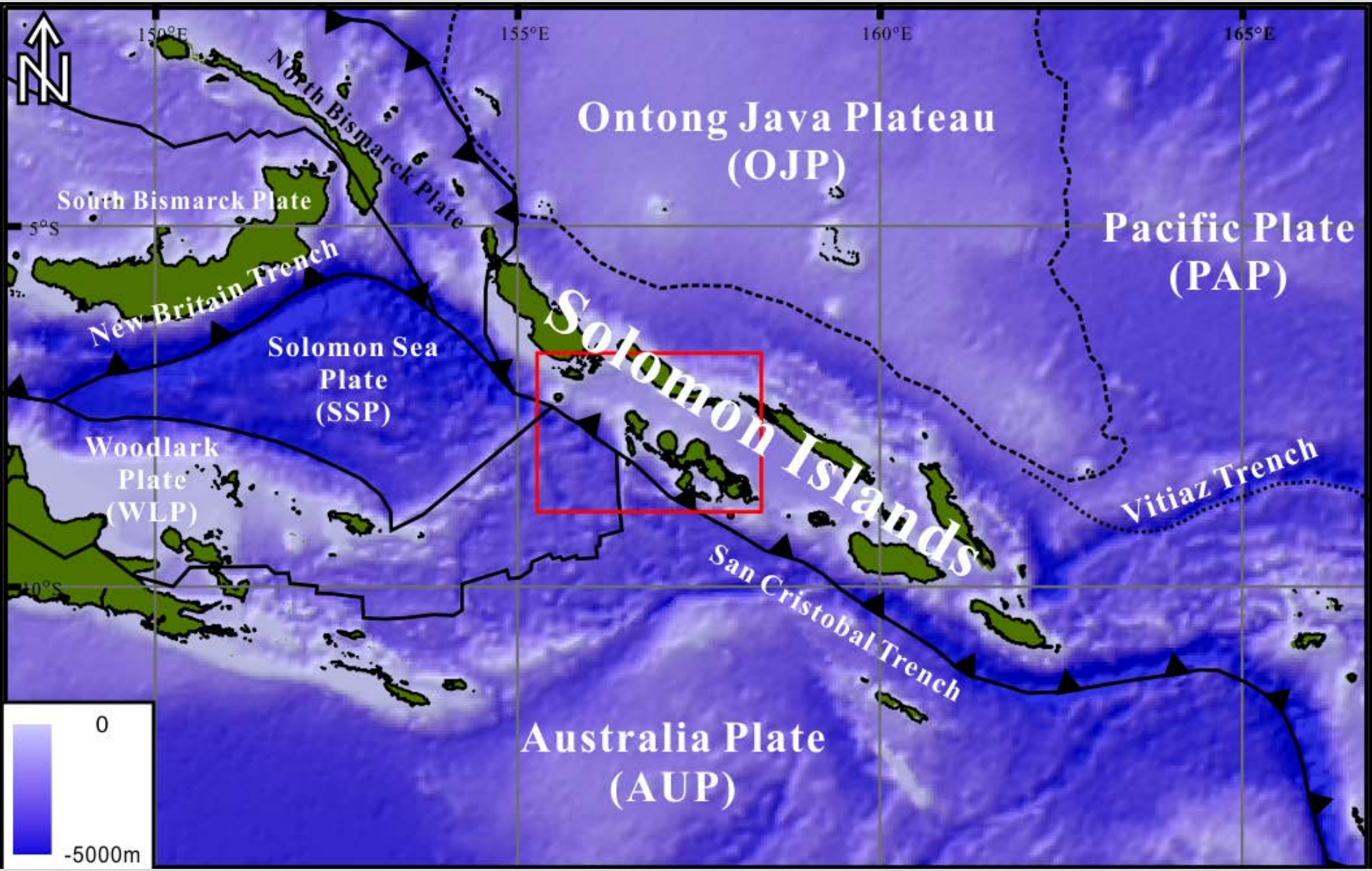
- The segmentation boundaries of



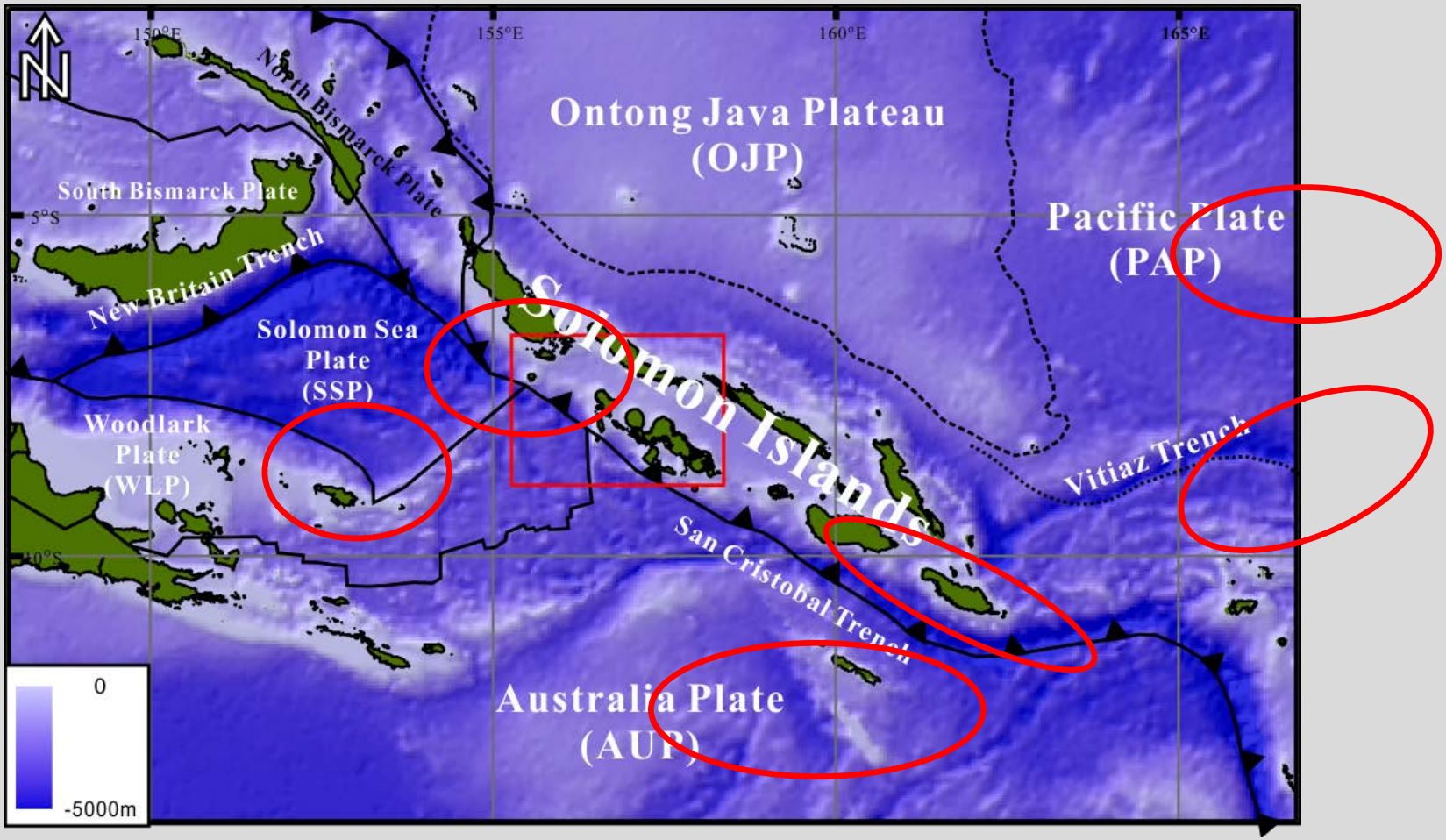
Introduction (Purpose)

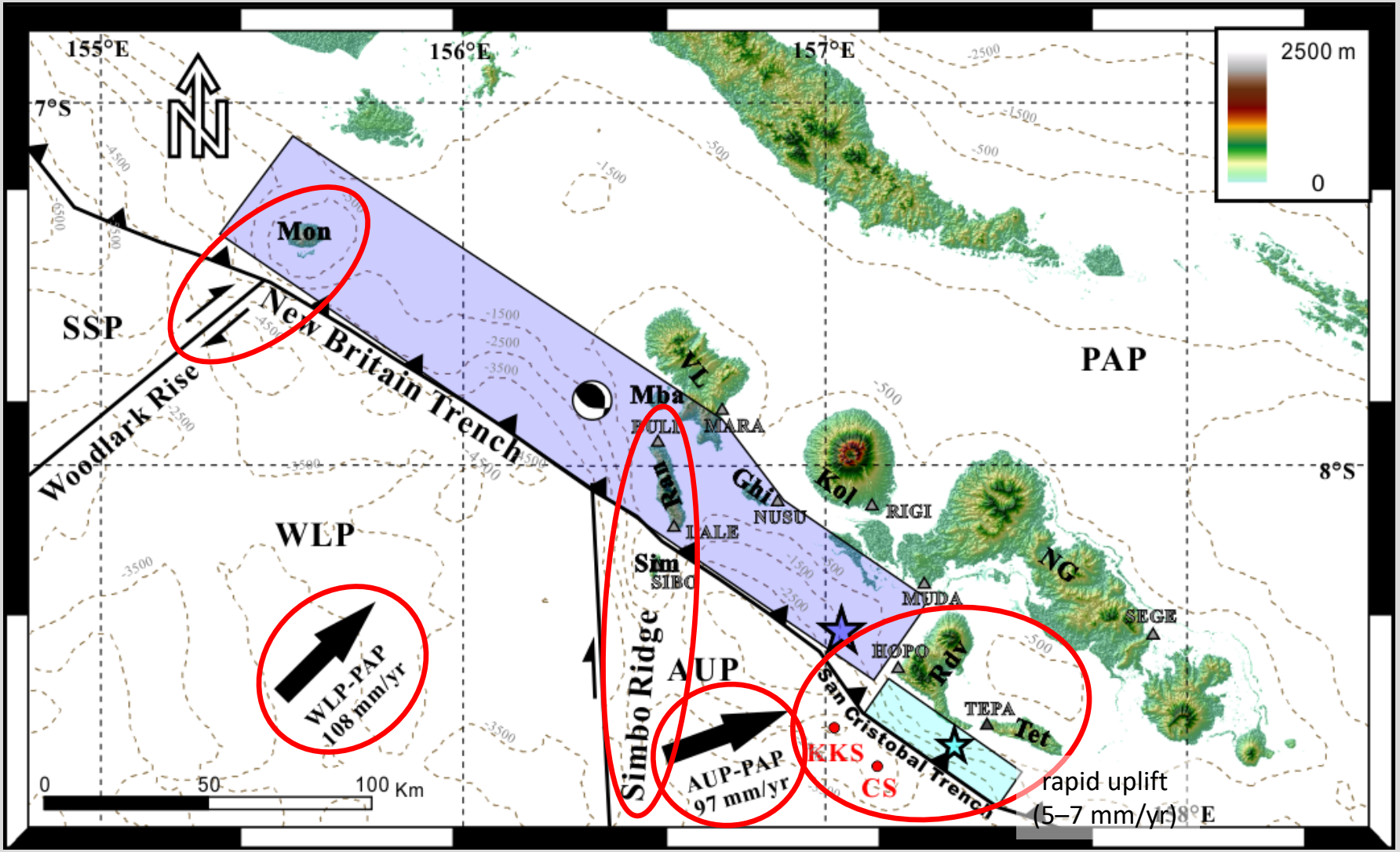
- To monitor the crust deformation associated with the postearthquake slip on the Solomon megathrust, we installed 10 continuous Global Positioning System stations on the Western Solomon Islands.
- In this paper, we present the GPS time series and secular velocities from 2011 to 2014 in the IGS08 reference frame with respect to the Pacific Plate.
- We compare our interseismic coupling pattern with the slip distribution and aftershocks of the 2007 and 2010 earthquakes and discuss the relationship between the current coupling pattern and the megathrust rupture patches.

From Kuo et al., 2016

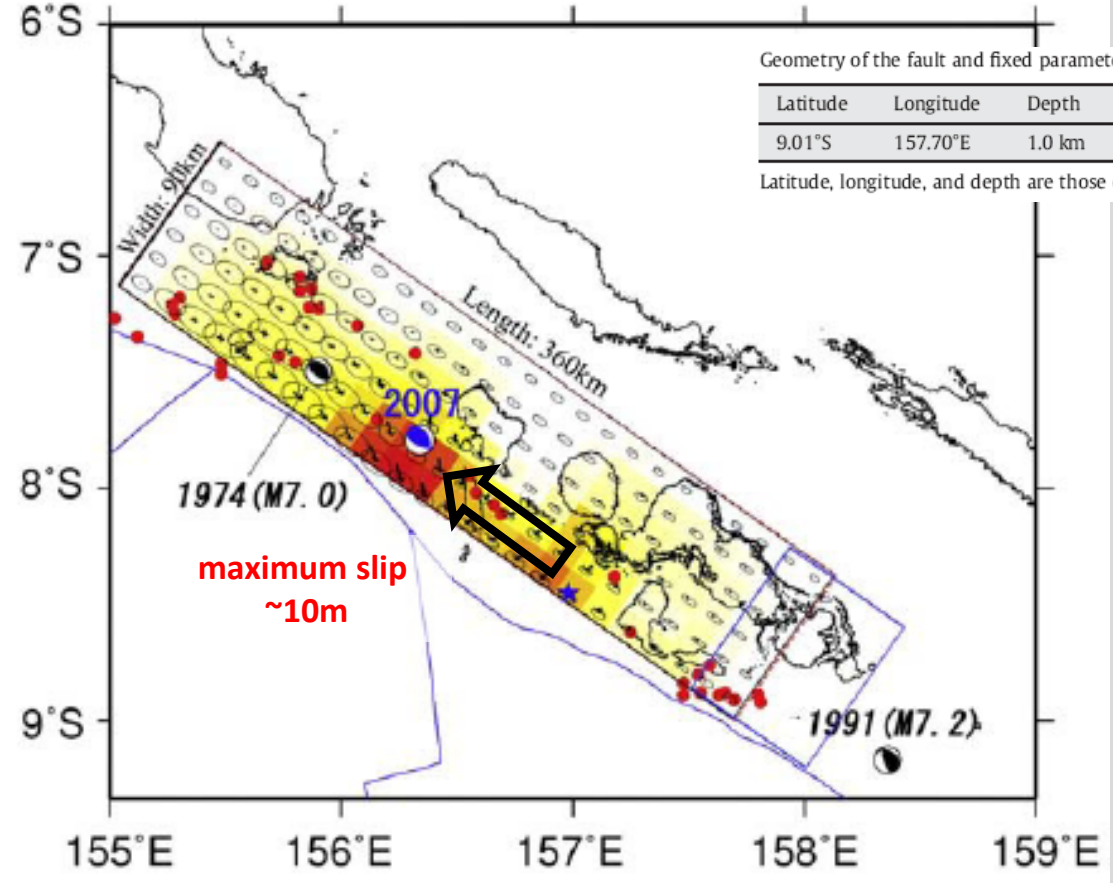


Tectonic Setting




155°E
156°E
157°E
7°S
8°S
2500 m
0
SSP
PAP
WLP
AUP
NG
Woodlark Rise
New Britain Trench
Simbo Ridge
San Cristobal Trench
Mon
Mba
VL
FULI
MARA
Ren
LALE
Ghi
NUSU
Kol
RIGI
Sim
SIBC
MUDA
SEGE
HOPO
Rdv
TEPA
Tet
KKS
CS
WLP-PAP
108 mm/yr
AUP-PAP
97 mm/yr
0
50
100 Km
rapid uplift
(5–7 mm/yr)

The 2007 and 2010 Earthquakes



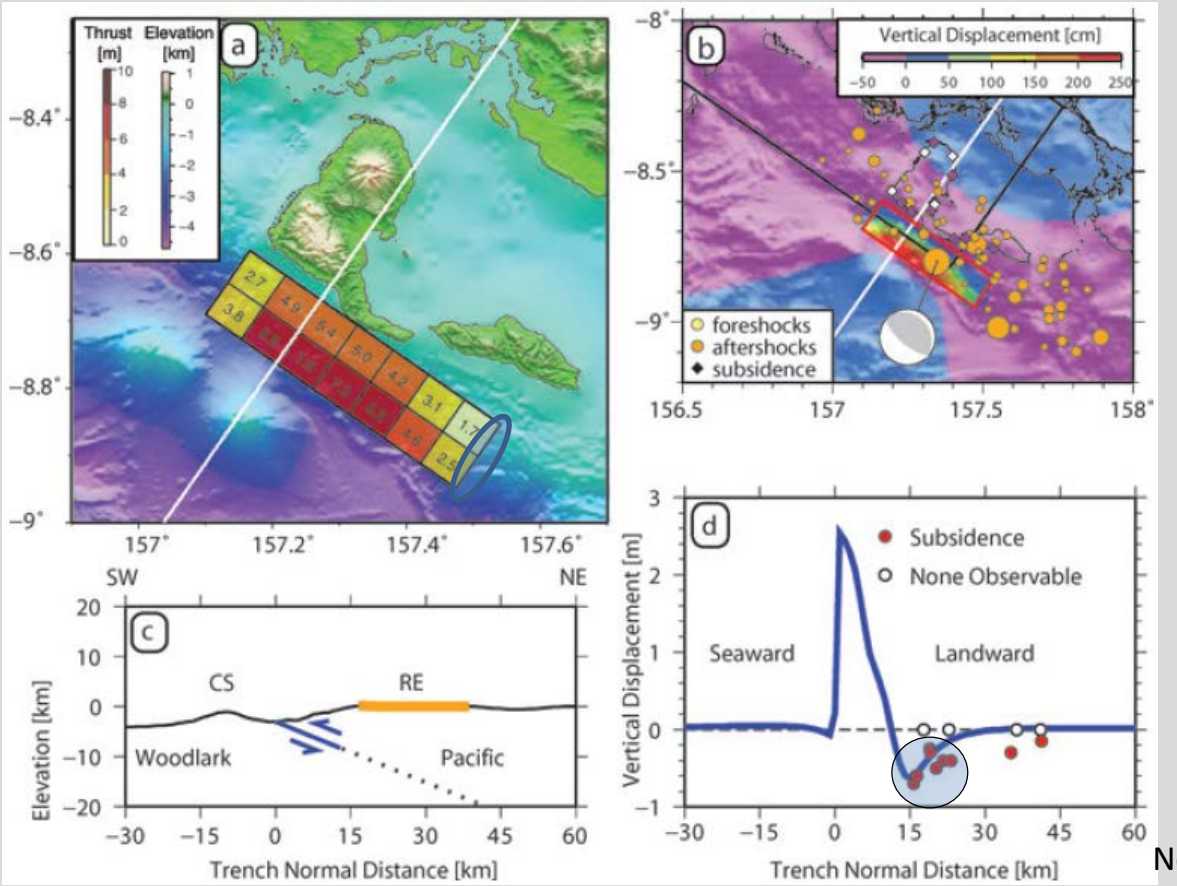
Geometry of the fault and fixed parameters for fault modeling.

Latitude	Longitude	Depth	Strike	Dip	Length	Width
9.01°S	157.70°E	1.0 km	N305°E	20°	360 km	90 km

Latitude, longitude, and depth are those of the upper southwest corner of the fault.

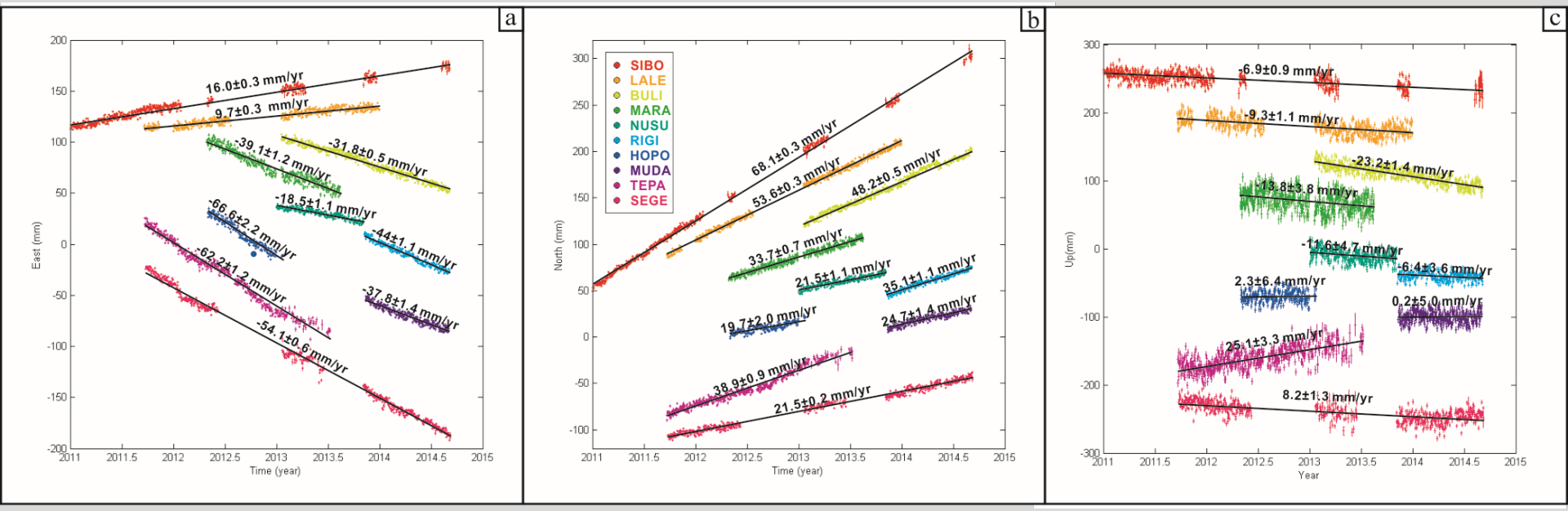
Miyagi et al., 2009

The 2007 and 2010 Earthquakes



Newman et al., 2011

GPS Network and Processing

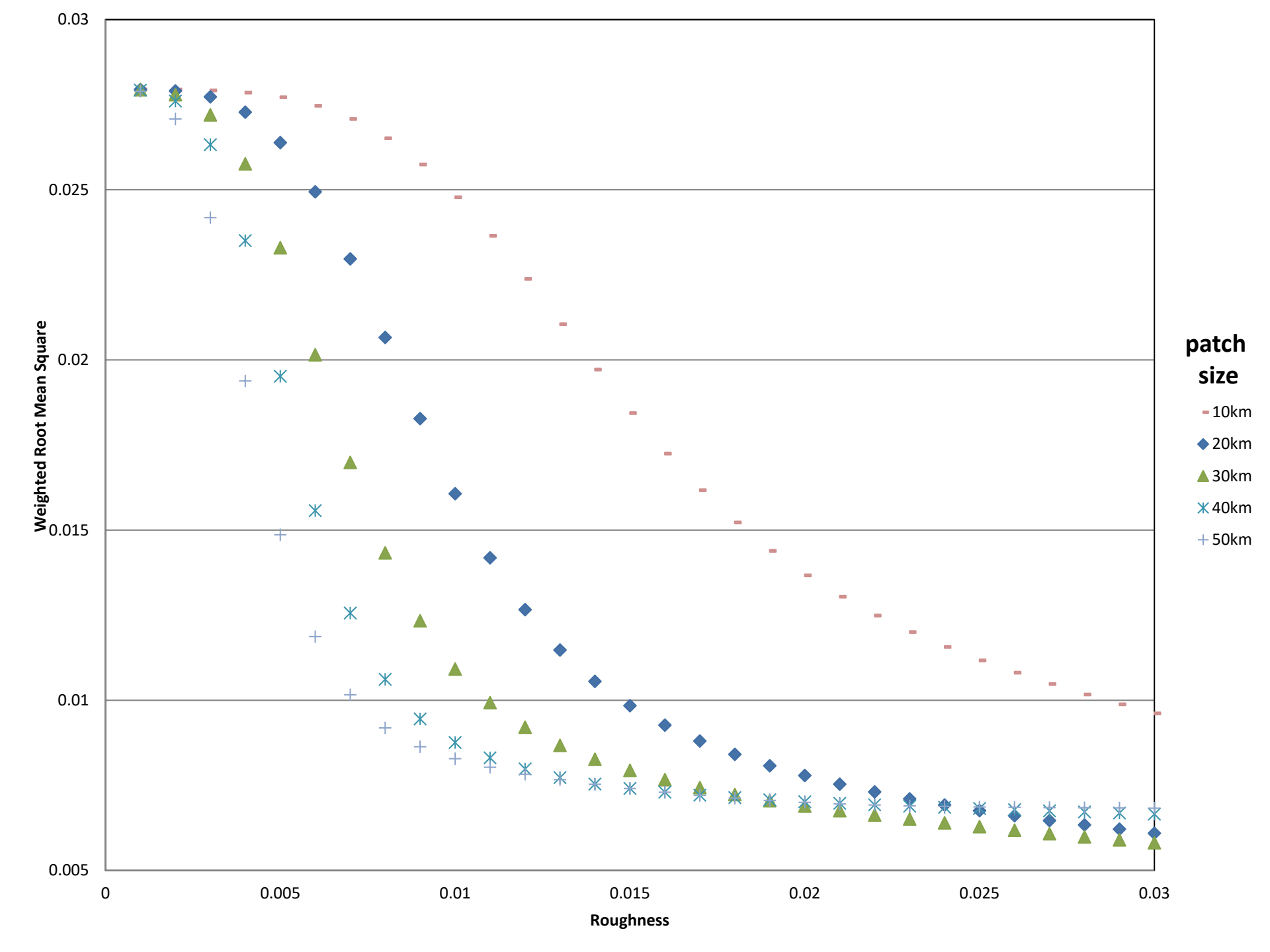


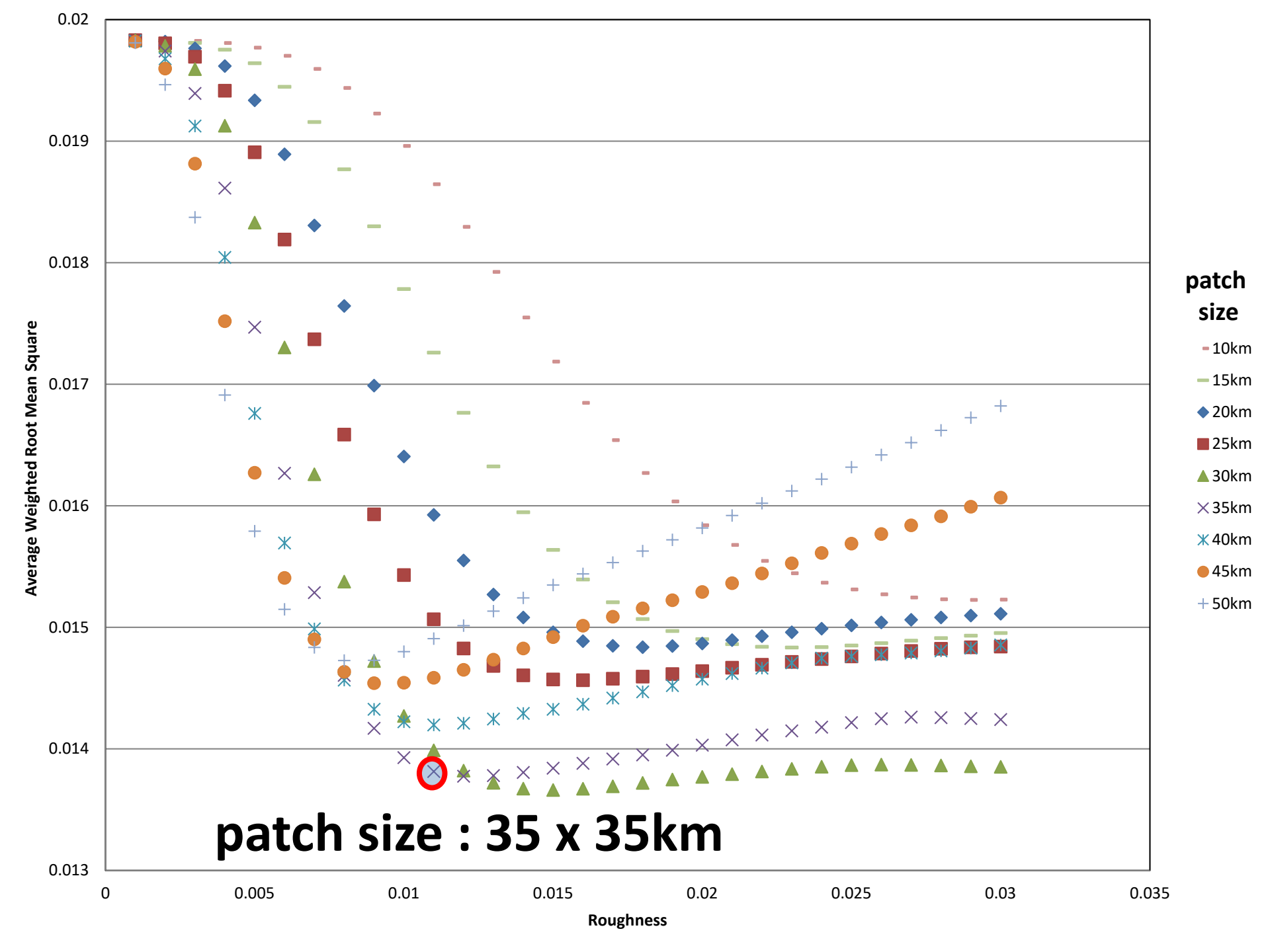
Discussion

- Asperity and Barrier on the Megathrust
- Earthquake Scenario Estimation

Key Points

- We deployed the first continuous GPS network at the Western Solomon Islands since 2011.
- GPS record reveals significantly different interseismic coupling ratios between two adjacent segments on the Solomon megathrust.
- We identify a semipermanent asperity and a potential barrier to rupture, each corresponding to the subduction of geological features.


0.03
0.025
0.02
0.015
0.01
0.005
Weighted Root Mean Square
0
0.005
0.01
0.015
0.02
0.025
0.03
Roughness
patch size
10km
20km
30km
40km
50km


0.02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
Average Weighted Root Mean Square
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
Roughness
patch size
10km
15km
20km
25km
30km
35km
40km
45km
50km
patch size : 35 x 35km

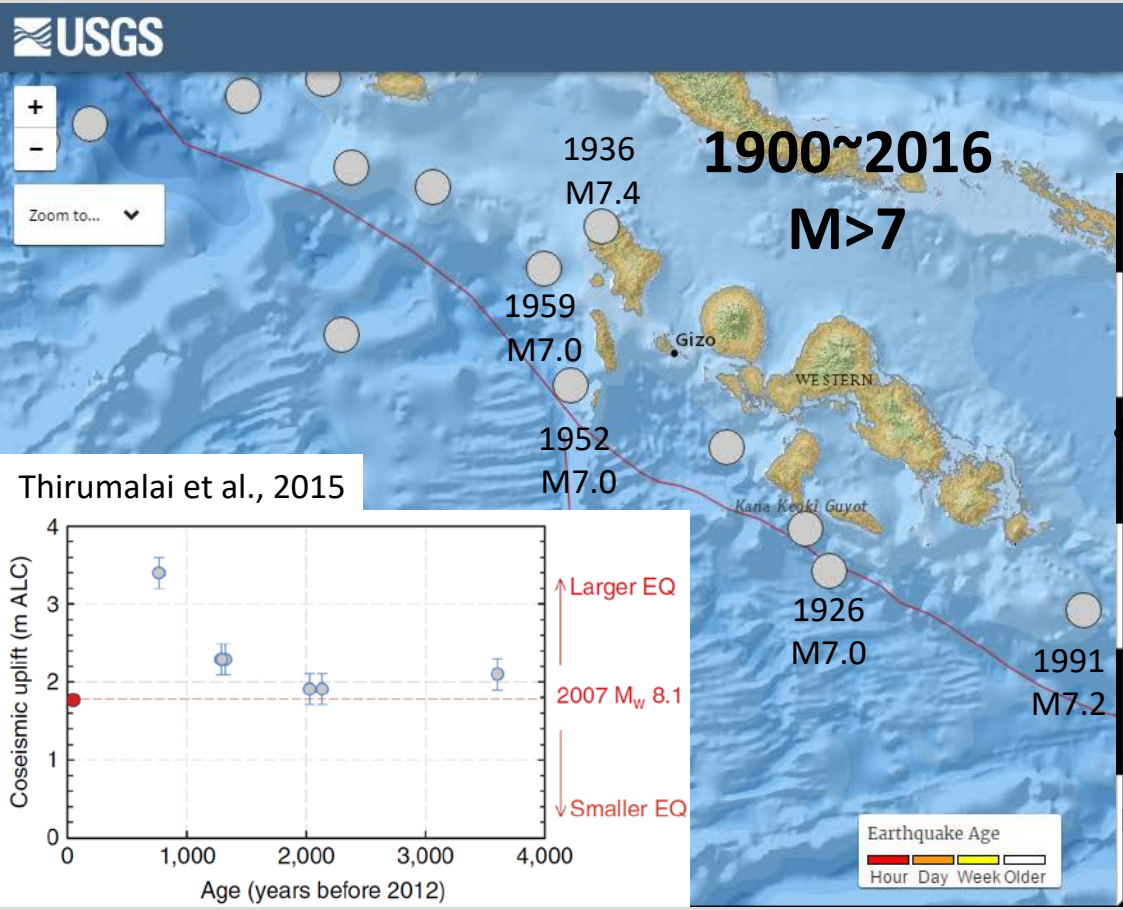
Conclusion

- Our GPS measurements from 2011 to 2014 reveal a spatially variant slip-coupling pattern for the 2007 and 2010 earthquake corresponding megathrust segment.
- After synthesizing the prominent coseismic slip patch, aftershock distribution and even paleogeodetic records, we conclude that the high coupling patch on the 2007 rupture related segment probably represents a semipermanent asperity developed on the megathrust, whereas the currently low coupling patch on the 2010 rupture related segment perhaps shows only the signal of a seismic barrier.
- The location of the asperity and the barrier correlate with subducting oceanic crust bathymetric features, while the exact controlling mechanism remains unknown.
- The inferred characteristic earthquake scenario for the study area can be hypothesized as a single or doublet earthquake with magnitude no less than Mw 8 in a recurrence interval of 100 or more years.

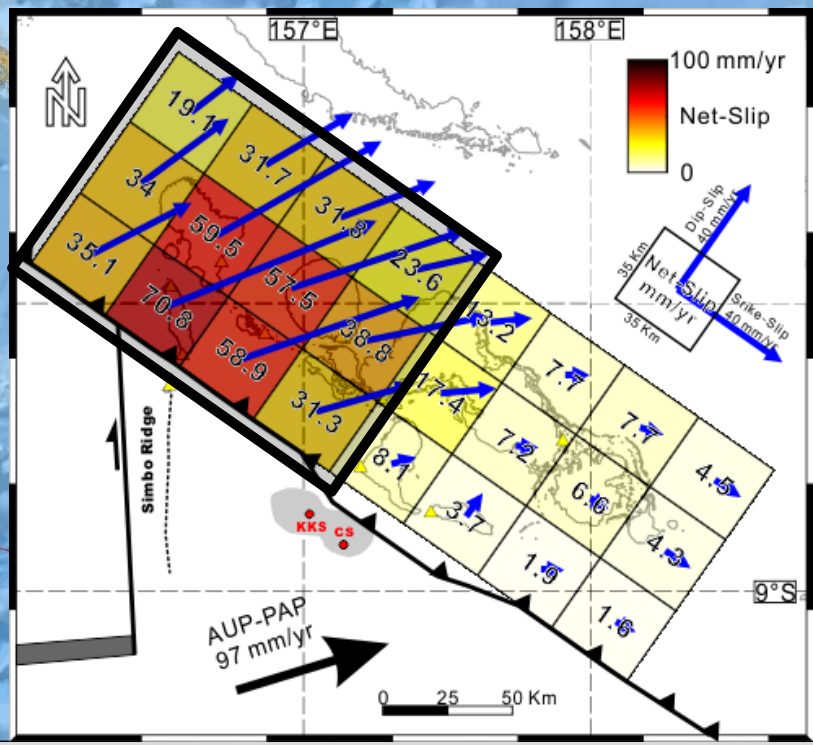
$M_0 = \mu AD$ (Aki, 1966)

$M_w = 2 * \log_{10}(M_0)/3 - 10.7$ (Kanamori, 1977)

From USGS



Thirumalai et al., 2015



From Kuo et al., 2016

Asperity and Barrier

It is generally observed that large earthquakes consist of subevents, relatively compact patches with locally large slip, known as ‘asperities’. The term “seismic asperity” was first defined by *Kanamori* [1978] to explain “geometrical asperities, heterogeneities from the frictional strength or a mixture (of both)” on the fault plane. A complementary idea is that of a “barrier” defined as the region that will not fail during the main shock [*Das and Aki*, 1977; *Kanamori*, 1986].


Solomon
2009/08/23 10:54


2009/08/19 04:28