# 1-7

## SAR で見えてきた地震断層の実態：非平面地震断層モデリング

## Realistic Image of Earthquake Fault Detected by SAR: Nonplanar Fault Source Modeling

古屋正人（北大院理）

Masato Furuya (Hokkaido University)

When any moderate to large earthquakes take place, we can now promptly learn their origin time, location, and preliminary reports on the focal mechanisms. However, since those seismic data are acquired at “far-field” from epicenters, they assume a point source despite the actual earthquake rupture occurs in a finite domain. Also, the hypocenter location inferred from seismic observation is often distant from and deeper than the actual hypocenter. To overcome such issues, near-field observations are critical, and satellite-based SAR observations do play a critical role, revealing complex nature of actual earthquake rupture processes. Here, we review our studies on co-seismic deformation observation and modeling derived mainly from ALOS/PALSAR data with particular emphasis on the complex geometry of real earthquake faults.

中規模以上の地震が発生した場合，その発生時刻，場所，震源メカニズムに関する予備的な報告までをも数分以内に知ることができる．しかしこれらの情報は遠地で得られる地震波データの解析から点震源を仮定して得られるため，正確な位置から外れる等の問題がある．震源近傍での観測はその意味で重要であり，SAR 画像の解析から地震断層のより現実的で複雑な実態が明らかになってきた．ここでは主に ALOS/PALSAR データの解析から得られた近年発生した内陸地震の断層運動の実態についてレビューし，特に現実の地震断層の幾何学的な複雑性に基づいた非平面形状を持った断層モデルについて紹介する．

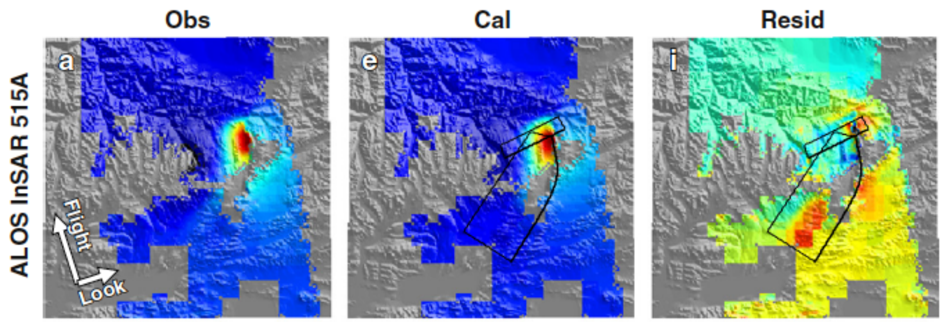



図 1. Yutian 地震(M7.1/March 2008)に伴う地殻変動(Furuya & Yasuda 2011).

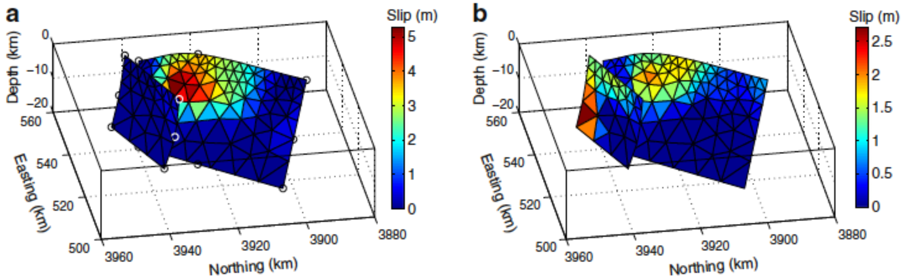



図 2. 図 1 の Cal の断層滑りモデル(Furuya & Yasuda 2011). a:正断層, b:左横ずれ

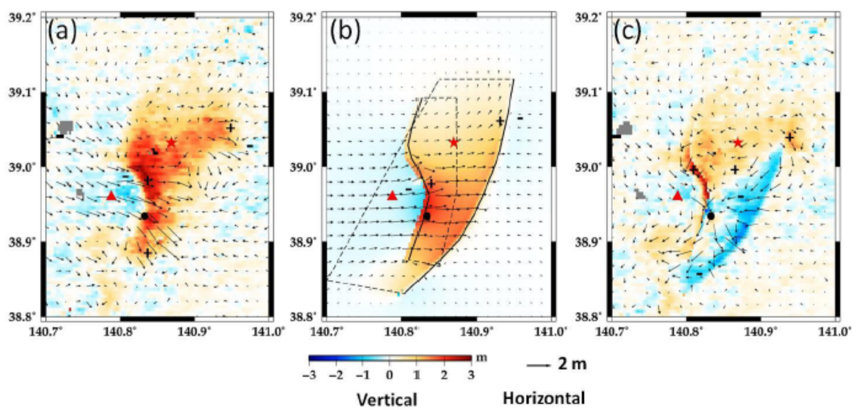



図 3. 岩手宮城内陸地震の(a)三次元地殻変動(Ando & Okuyama, 2010), (b)Abe et al (2012)による計算値. (c) (a)と(b)の残差.

# SARで見えてきた地震断層の実態: 非平面地震断層モデリング

# Reality of Earthquake-fault Rupture Revealed by SAR: non-planar fault modeling

- ✓ Importance of pixel-offset data
- ✓ Geometric complexity
- ✓ Multiple/conjugate rupture

古屋正人

高田陽一郎, 小林知勝, 松尾功二, 木下陽平, 安田貴俊,
阿部隆博, 武藤みなみ, 孫碩帥, 村上亮

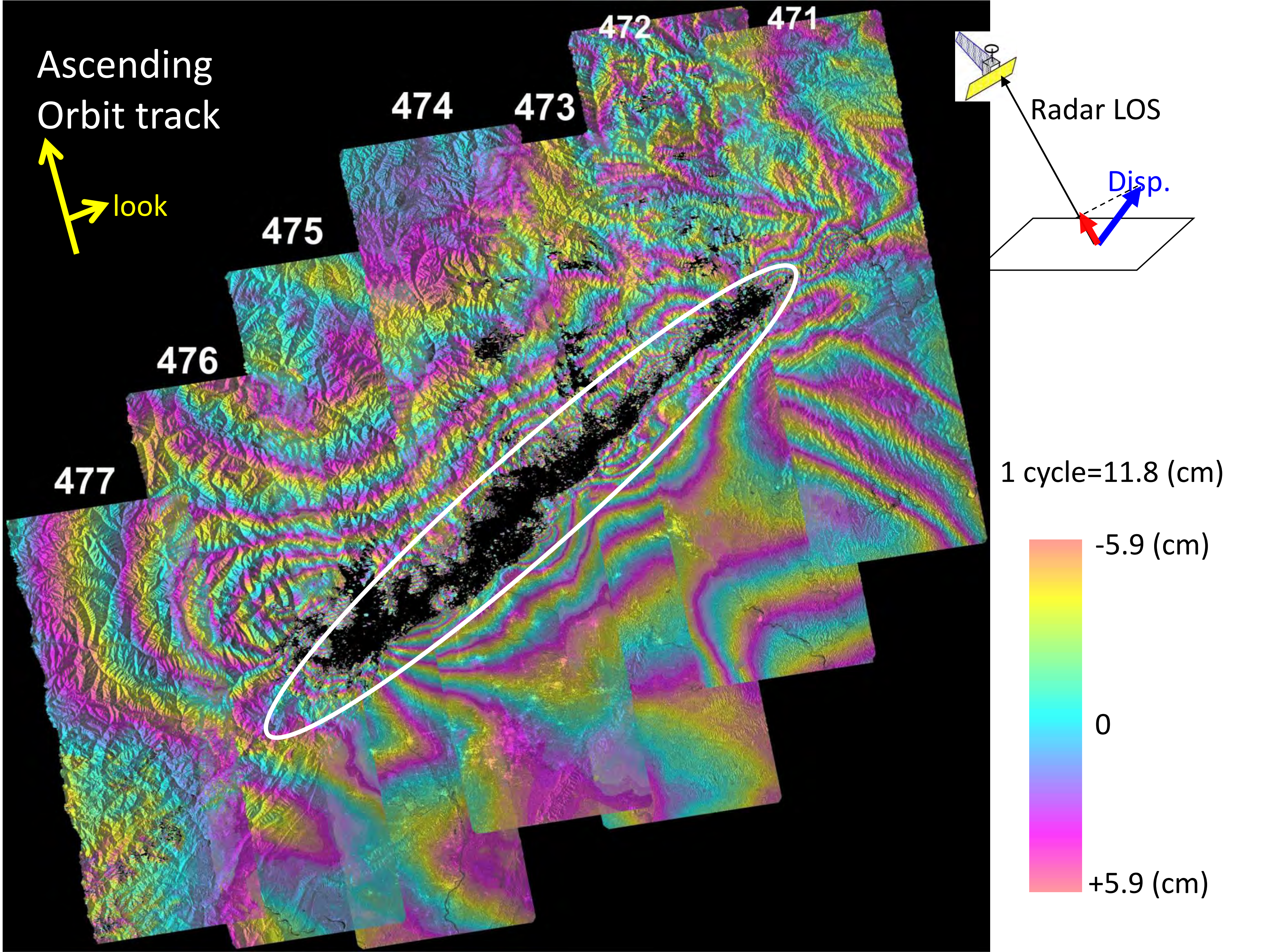
Hokkaido University
SPACE GEODESY

# Earthquakes we studied with PALSAR

- 2007 Noto
- 2007 Laos, Yunnan
- 2007 Kyrgyztan
- 2007 Chuetsu-oki
- 2008 Iwate-Miyagi
- 2008 Wenchuan
- 2008 Yutian
- 2008 Dumxiang

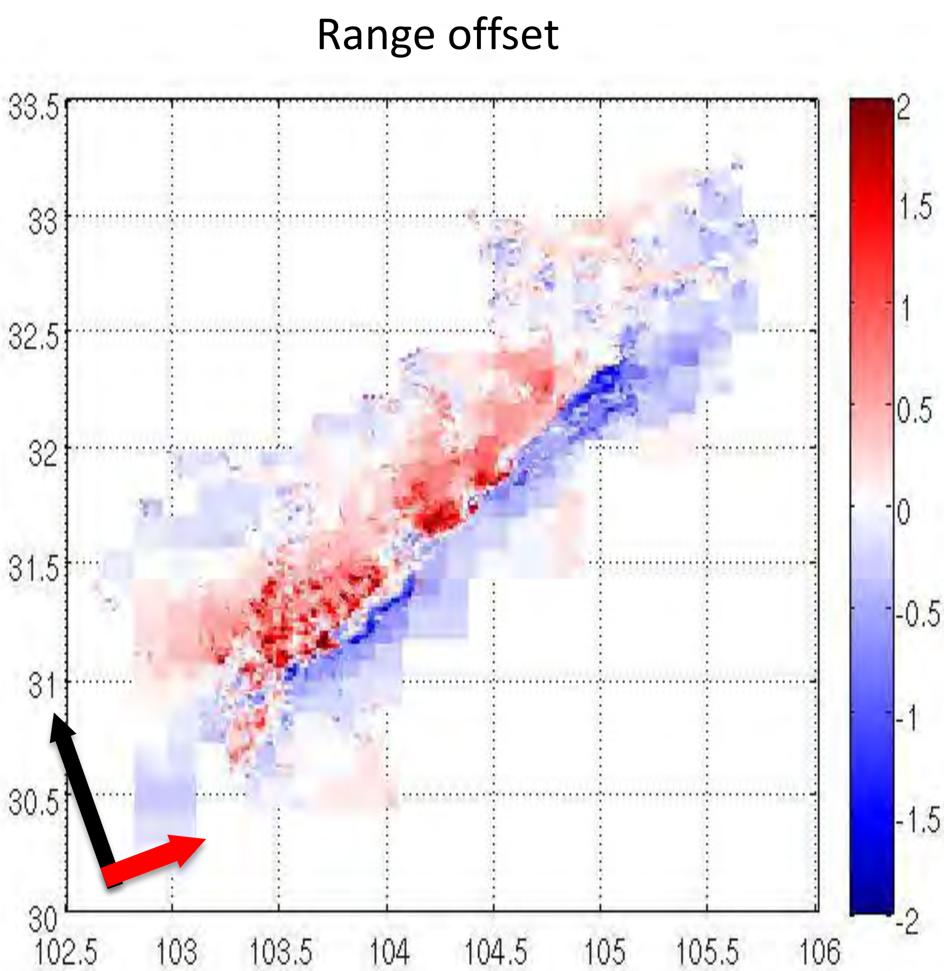
…

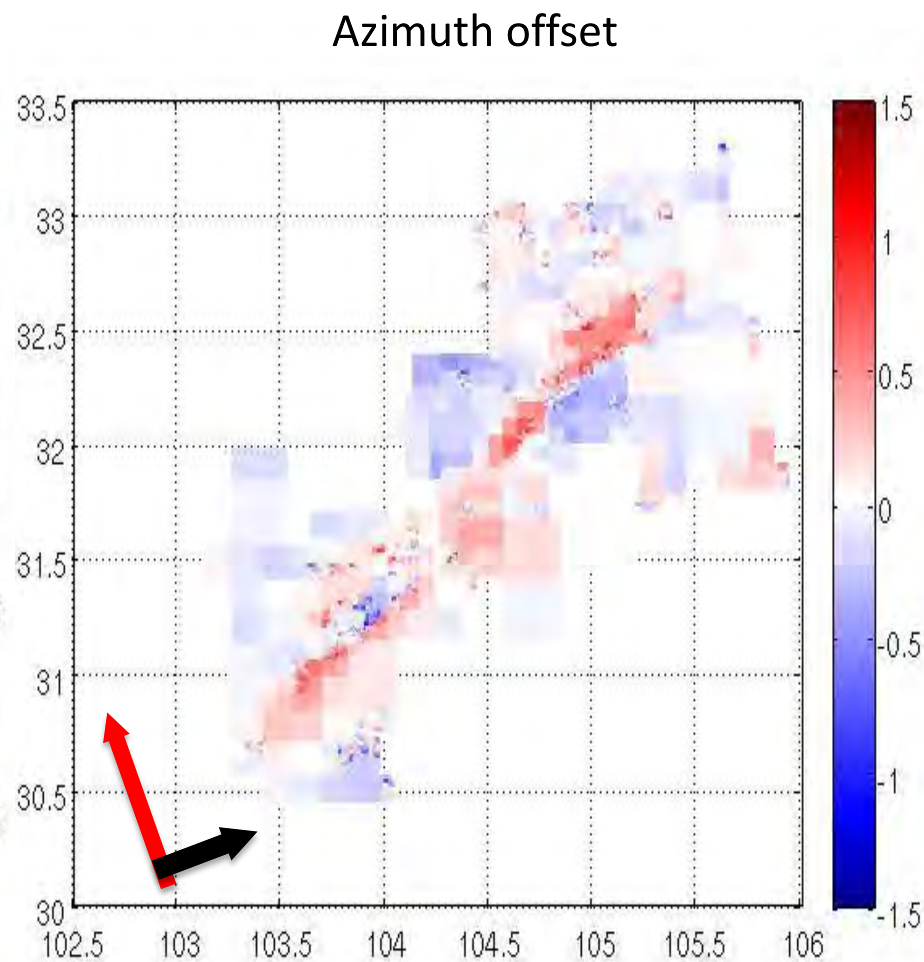
# Importance of pixel-offset data



Ascending
Orbit track
look
477
476
475
474
473
472
471
Radar LOS
Disp.
1 cycle=11.8 (cm)
-5.9 (cm)
0
+5.9 (cm)

# Pixel-offset data: Range & Azimuth data

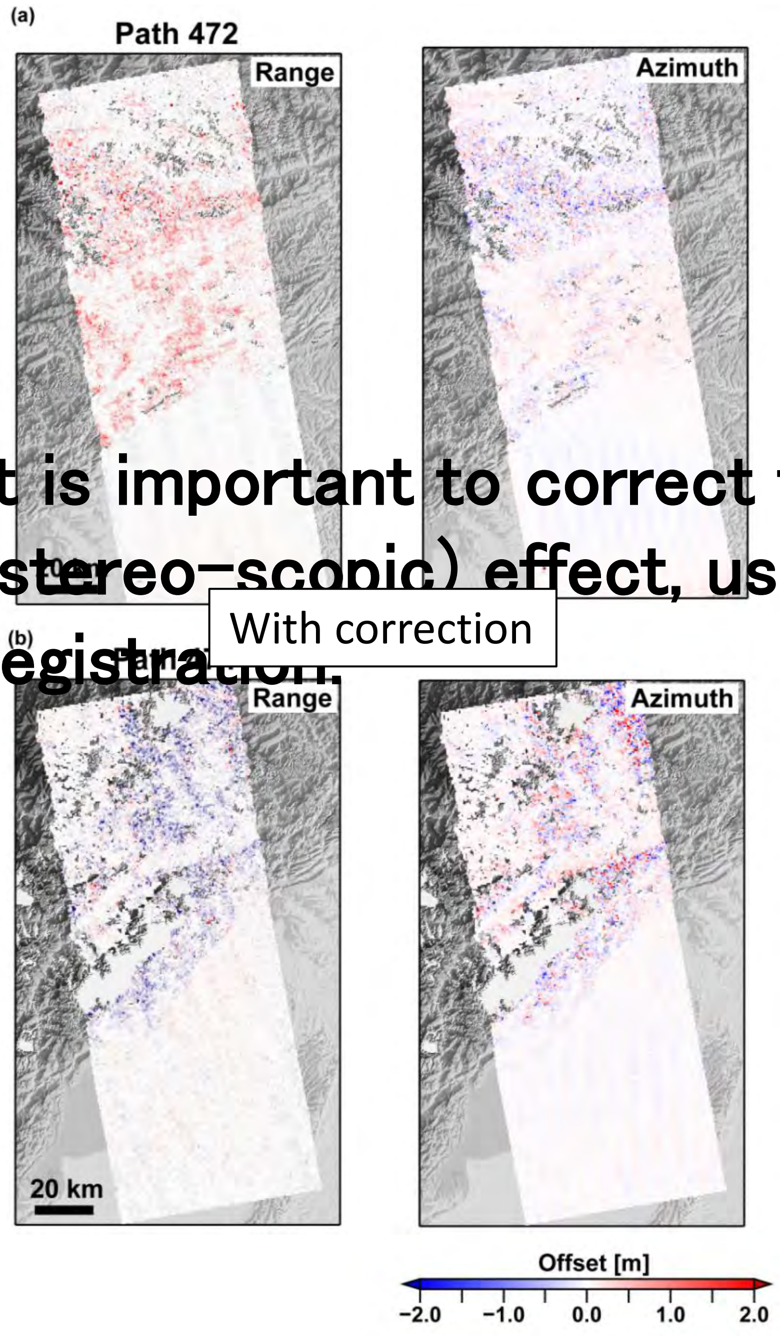


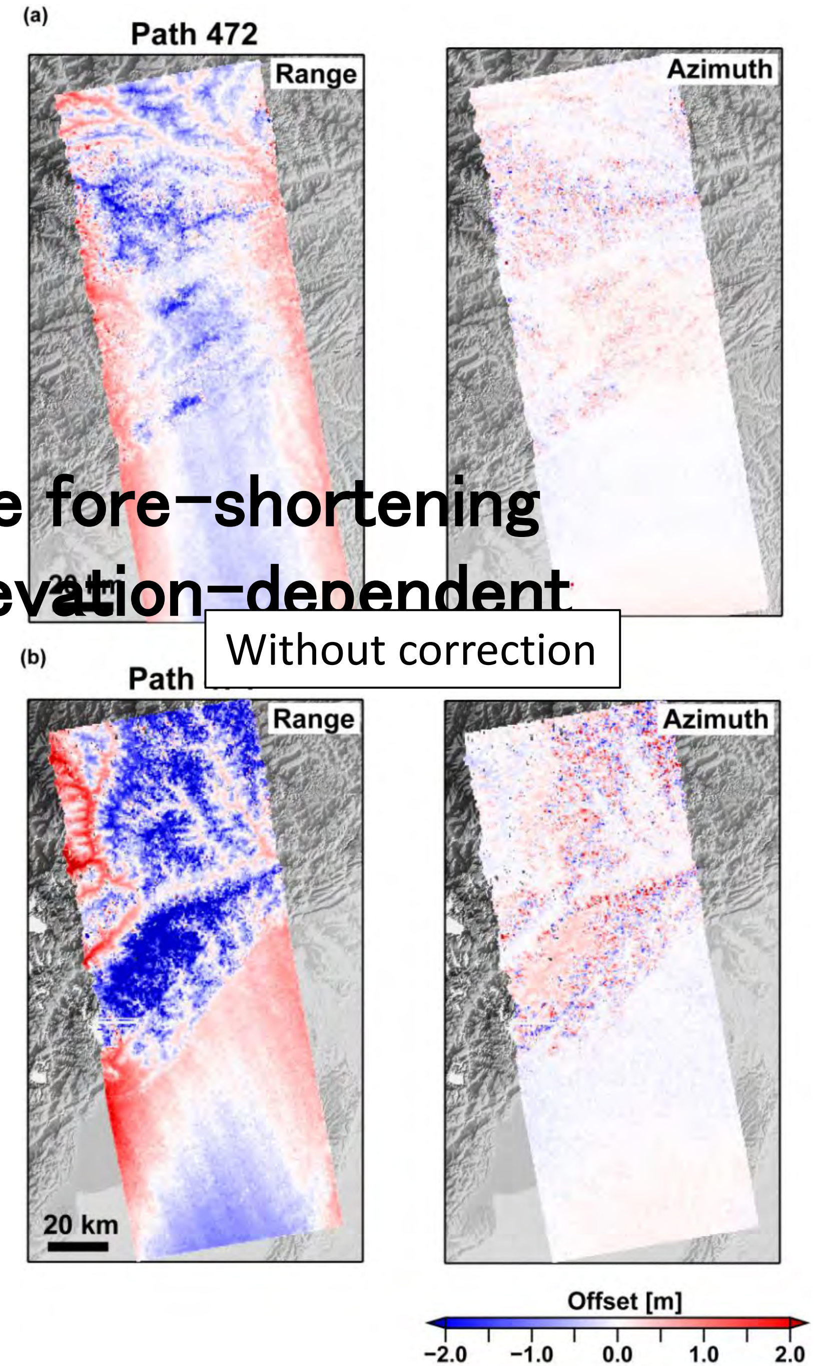

2008 Wenchuan earthquake (Kobayashi et al. 2009; Furuya et al. 2010)

It is important to correct for the fore-shortening (stereo-scopic) effect, using elevation-dependent registration.

With correction




Without correction



# Case study 1: 2008 Yutian (M7.1)

Tectonophysics 511 (2011) 125–133

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Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

# The 2008 Yutian normal faulting earthquake (Mw 7.1), NW Tibet: Non-planar fault modeling and implications for the Karakax Fault

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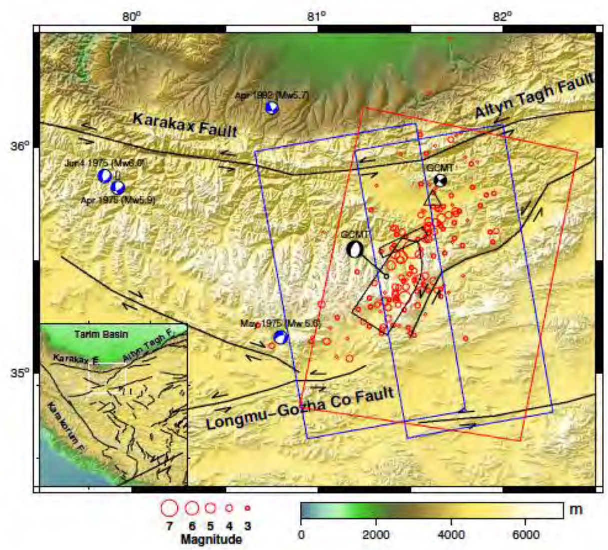
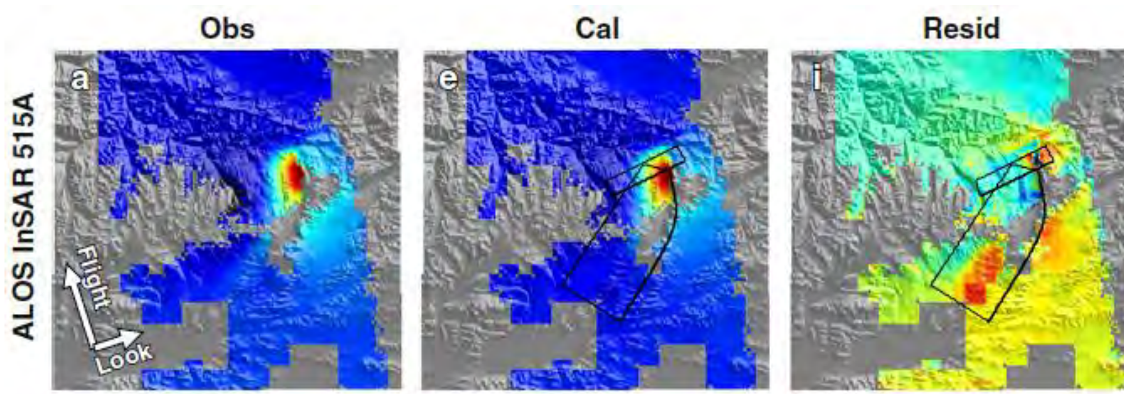
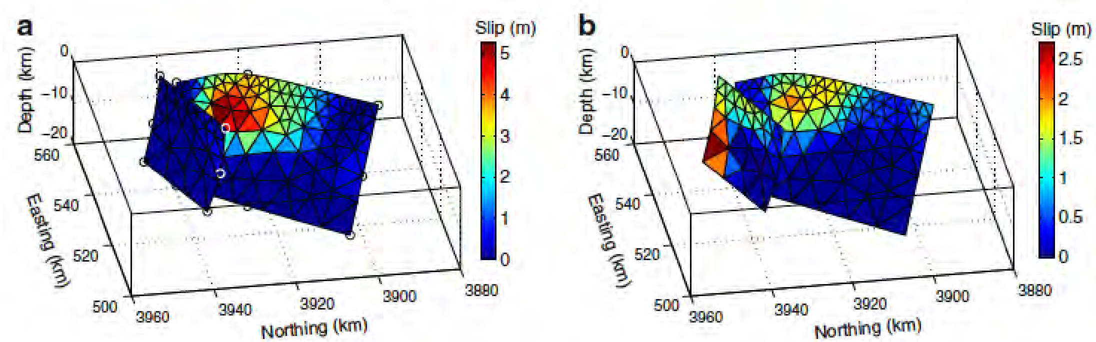
*Department of Natural History Sciences, Graduate School of Science, Hokkaido University, N10W8, Kita-ku, Sapporo 060-0810, Japan*

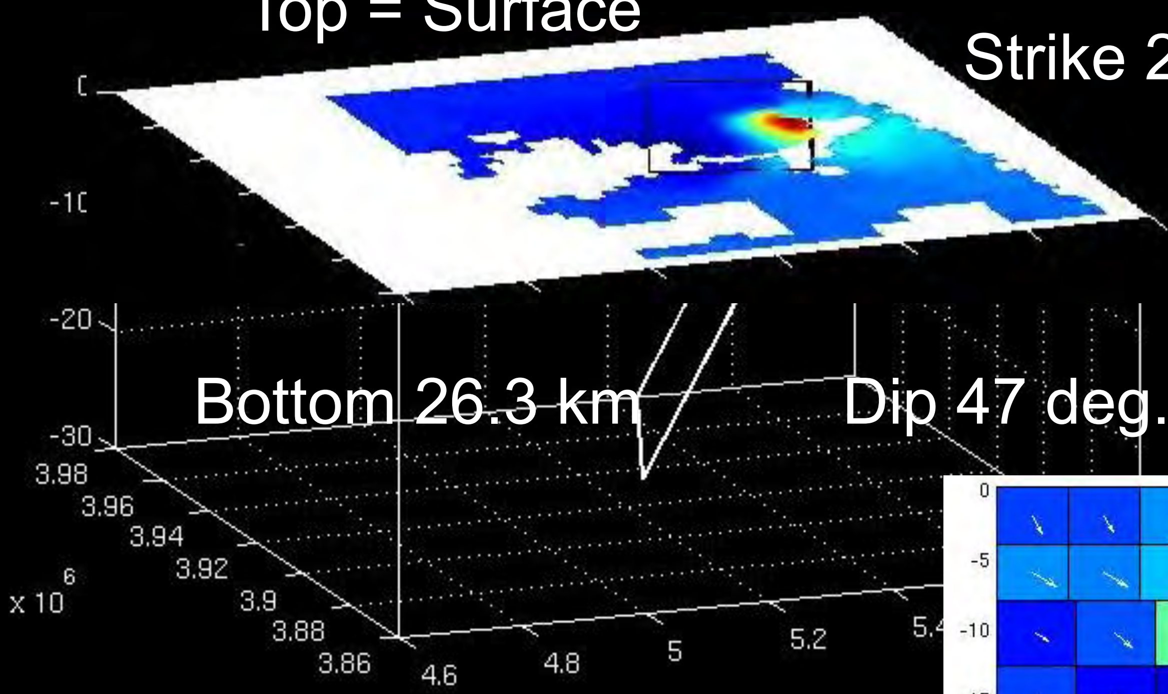


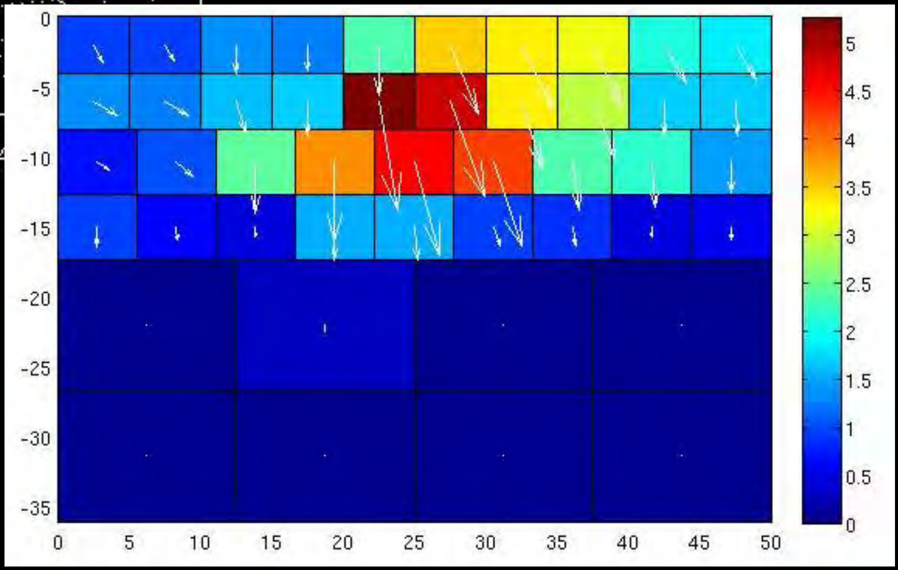



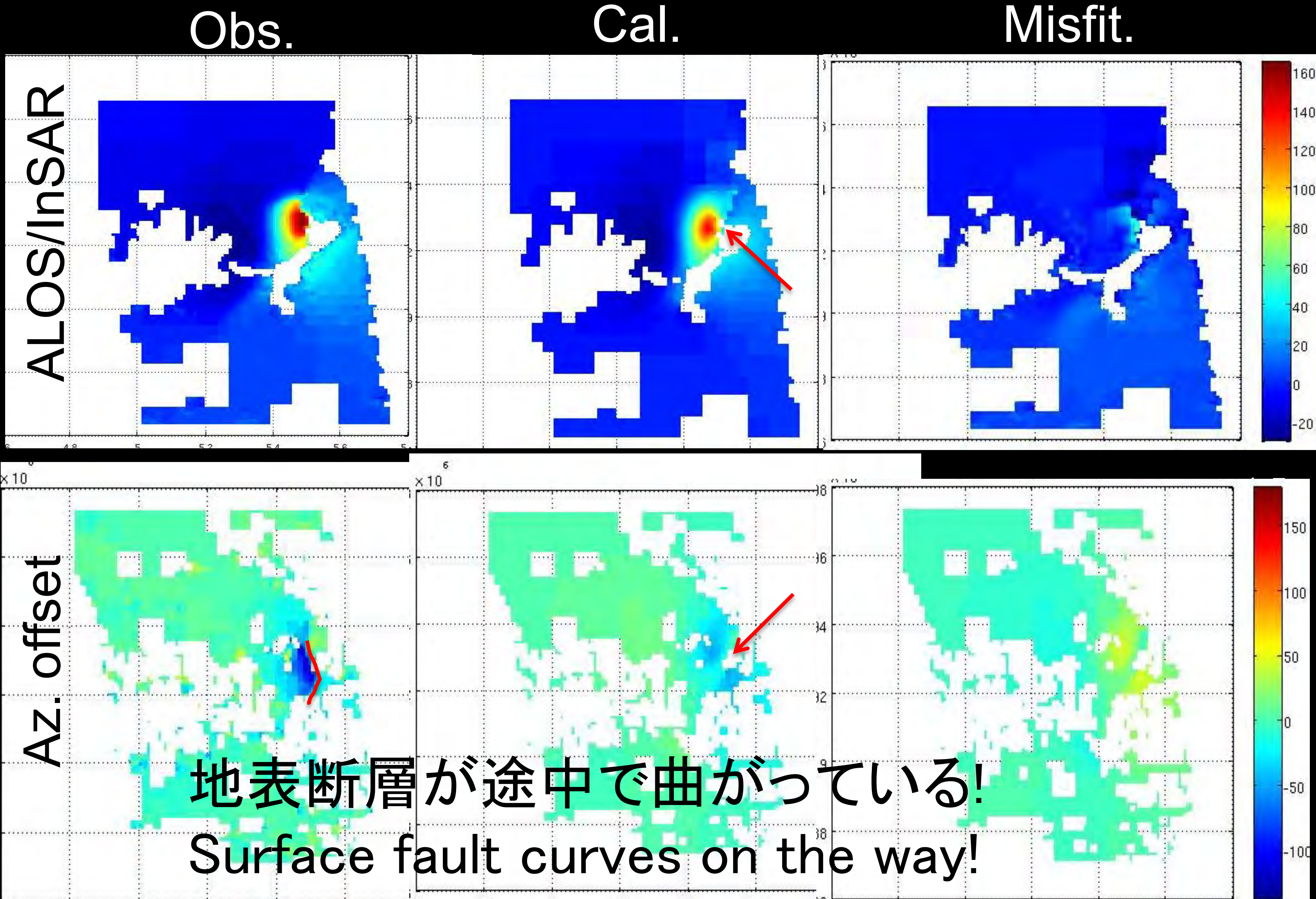

Furuya & Yasuda (2011)

# 1st Preliminary Fault model:



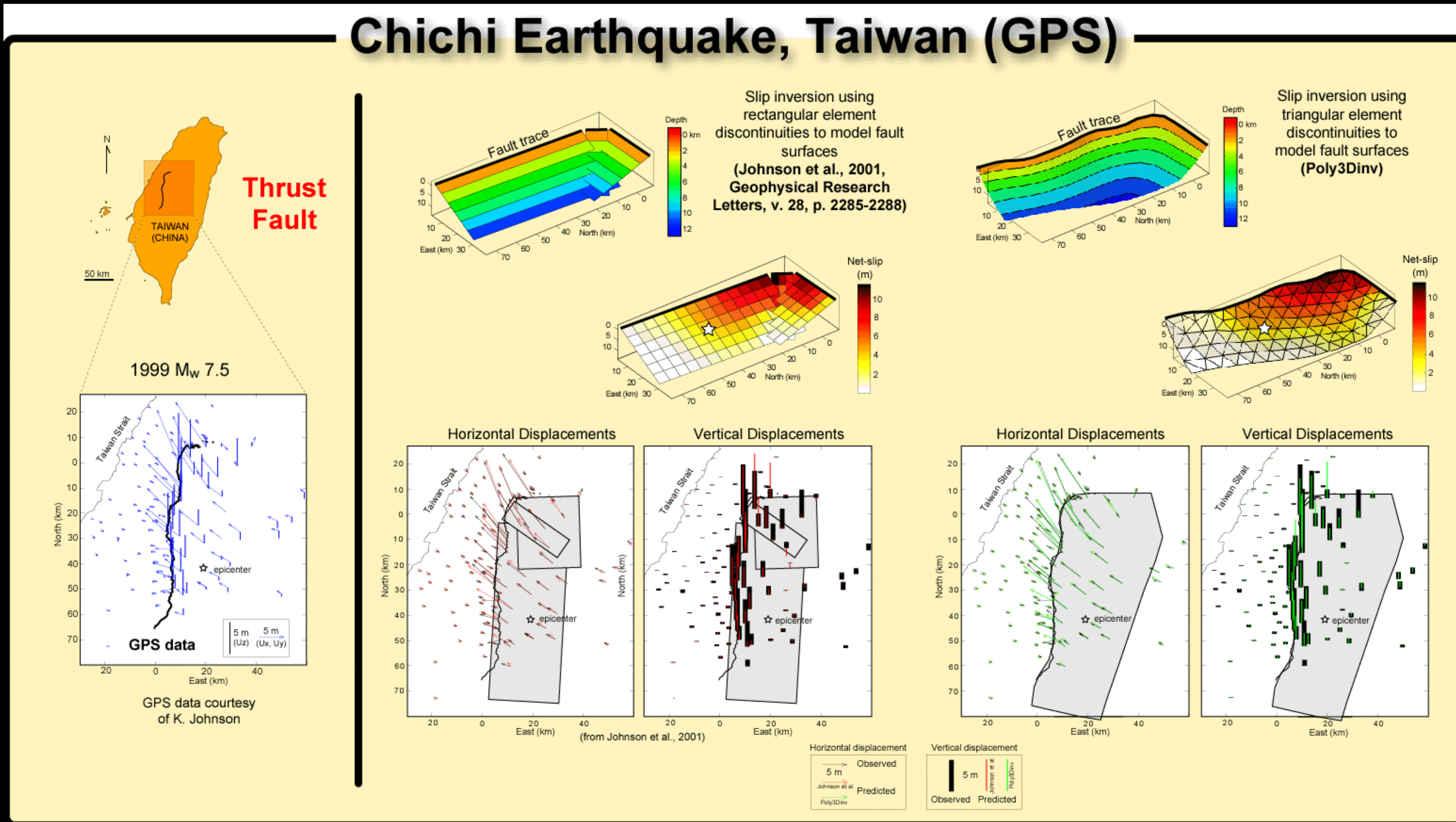




Mw=7.1 (Mo=5.38 x 10^19 Nm, rigidity=30 GPa)




地表断層が途中で曲がっている!
Surface fault curves on the way!

# 断層が曲がっているときの処方箋:
# Triangular dislocation element




Poly3D/Poly3Dinv が有名ではあるが…(Maerten et al., BSSA 2005)
http://pangea.stanford.edu/research/geomech/Software/Software.htm

# Another approach

- Meade, B. J., (2007).

"…Despite these contributions, the applications of TDEs has not been widespread due to the fact that their construction has remained opaque."

Appendix A. Supplementary material
Doi:10.1016/j.cageo.2006.12.003

Matlab's M-file is available.

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Computers & Geosciences 33 (2007) 1064–1075

COMPUTERS & GEOSCIENCES

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## Algorithms for the calculation of exact displacements, strains, and stresses for triangular dislocation elements in a uniform elastic half space ☆

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Received 5 August 2006; received in revised form 6 December 2006; accepted 10 December 2006

**Abstract**

We present algorithms for analytically calculating the displacements, strains, and stresses associated with slip on a triangular dislocation element (TDE) in a homogeneous elastic half space. Following previous efforts, the solution is constructed as a dislocation loop where the deformation fields for each of the three triangle legs are calculated by the superposition of two angular dislocations. In addition to the displacements at the surface we derive the displacements and strains at arbitrary depth. We give explicit formulas for the strains due to slip on an angular dislocation, the calculation of angular dislocation slip components, a method for identifying observation coordinates affected by a solid body translation, and rules for internally consistent vertex ordering allowing for the superposition of multiple TDEs. Examples of surface displacements and internal stresses are given and compared with rectangular representations of geometrically complex fault surfaces.



*Keywords:* Elastic dislocation; Faulting; Seismotectonics

**1. Introduction**

Elastic dislocation theory is widely used for calculating the displacements, strains, and stresses associated with faulting from earthquake rupture to interseismic time scales (e.g., Burgmann et al., 2002; McGuire and Segall, 2003; Savage and Burford, 1973). Fault surfaces are often parameterized as a collection of point or rectangular sources due to the availability of analytic solutions for the deformation due to slip on dislocation elements of these shapes (e.g., Okada, 1985, 1992). However, some faults, such as those at subduction zones, may have geometries with substantial variations in both strike and dip. Rectangular parameterizations of complex fault surfaces exhibit geometric gaps due to the fact that it is often impossible to mesh non-planar surfaces exactly using rectangular elements. The effect of these gaps is to complicate the accurate calculation of displacements and stresses due to the effects of strain singularities at the edge of every dislocation element. These effects vanish, except exactly at element edges, with gap-free parameterizations of fault surfaces. With gap-free representations of fault surfaces these effects vanish

☆Code available from server at http://www.iamg.org/CGEditor/index.htm

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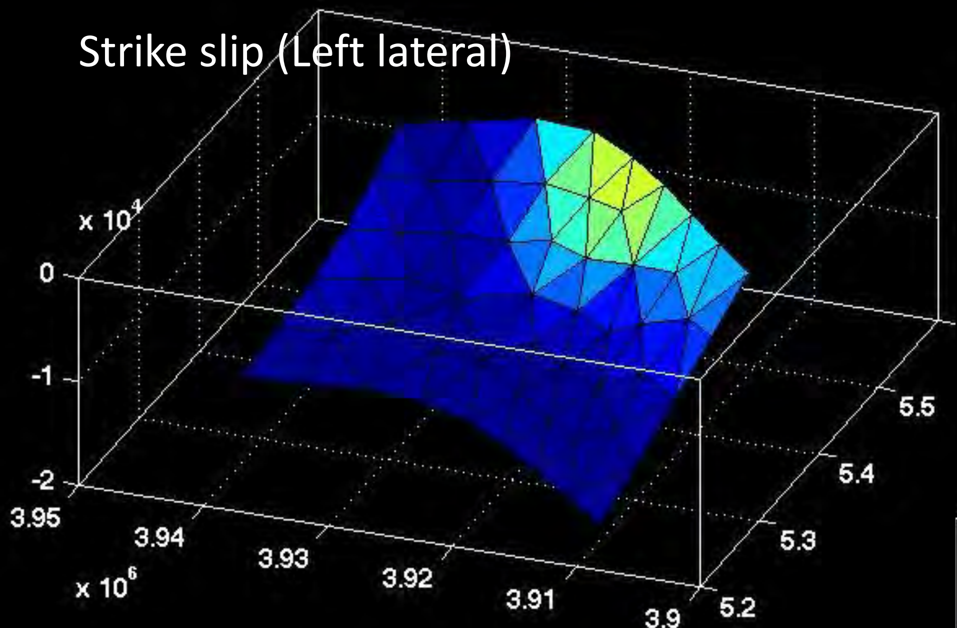
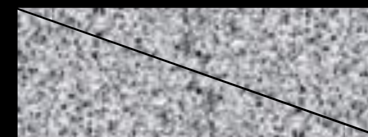
*E-mail address:* meade@fas.harvard.edu.

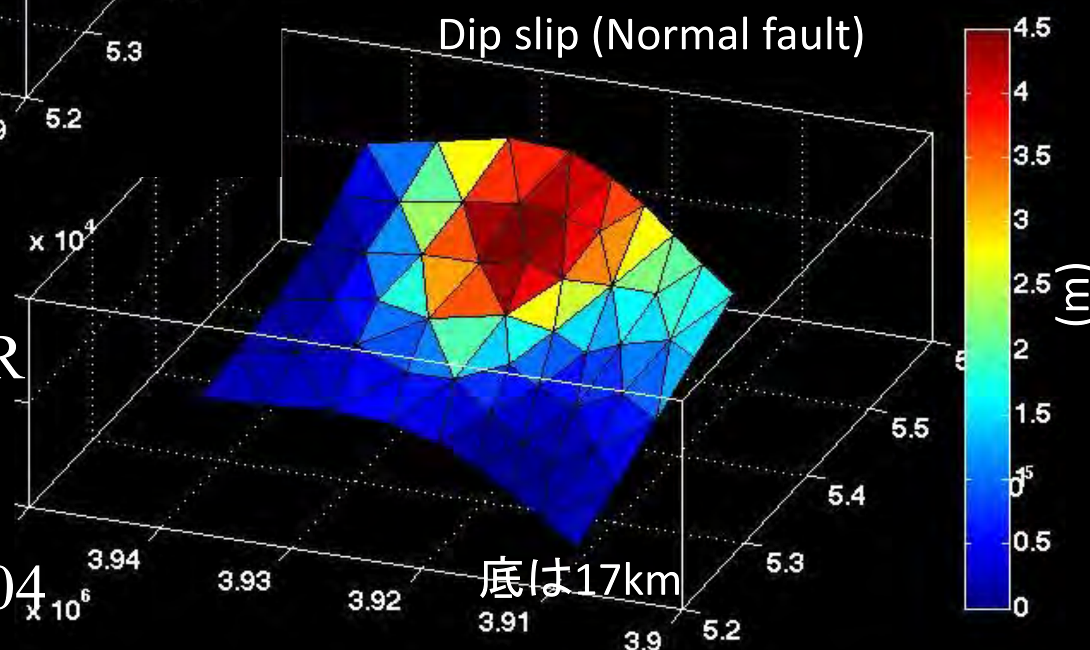
0098-3004/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cageo.2006.12.003

# Fault Model ver. May 2010 (JpGU)



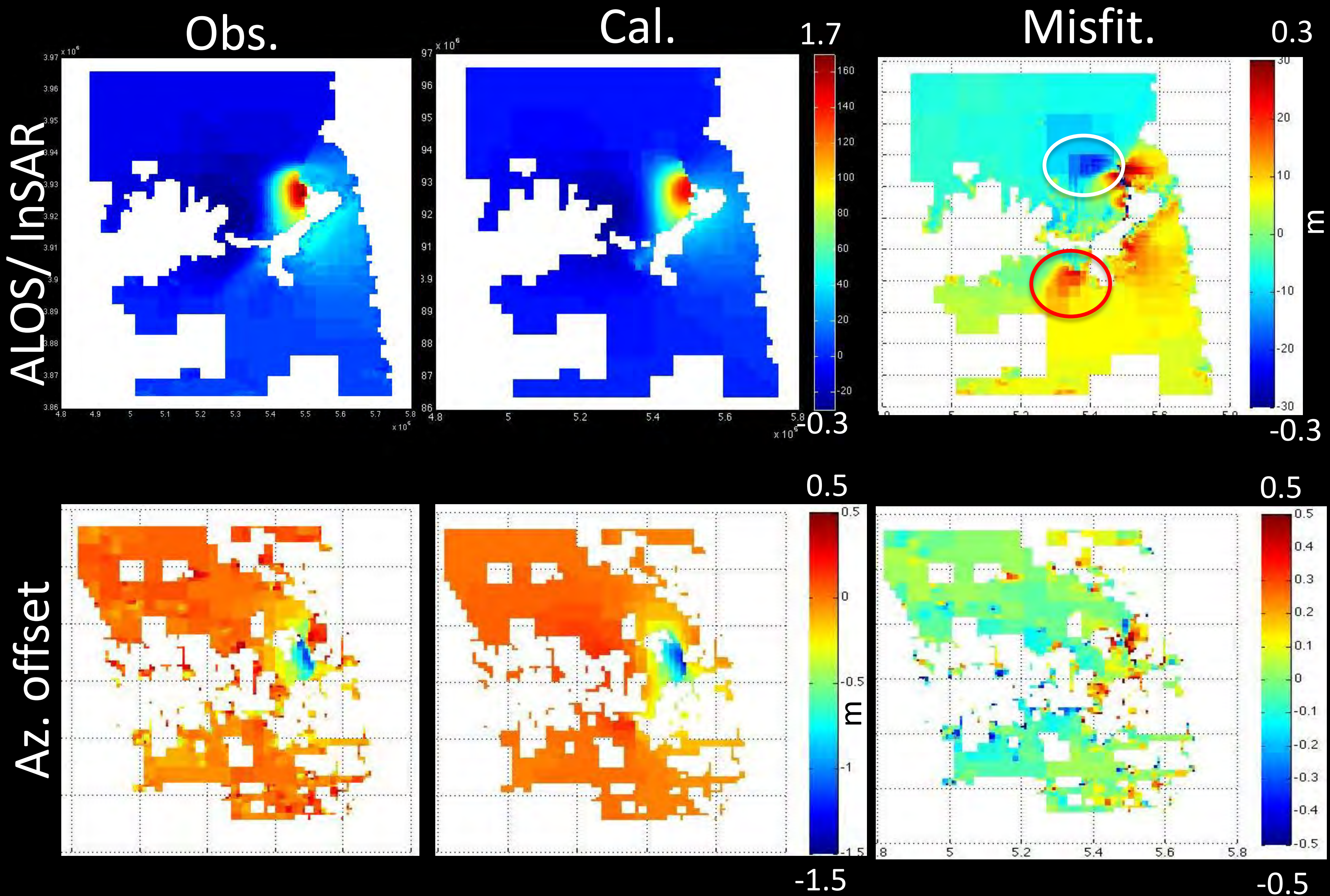



正断層型の地震

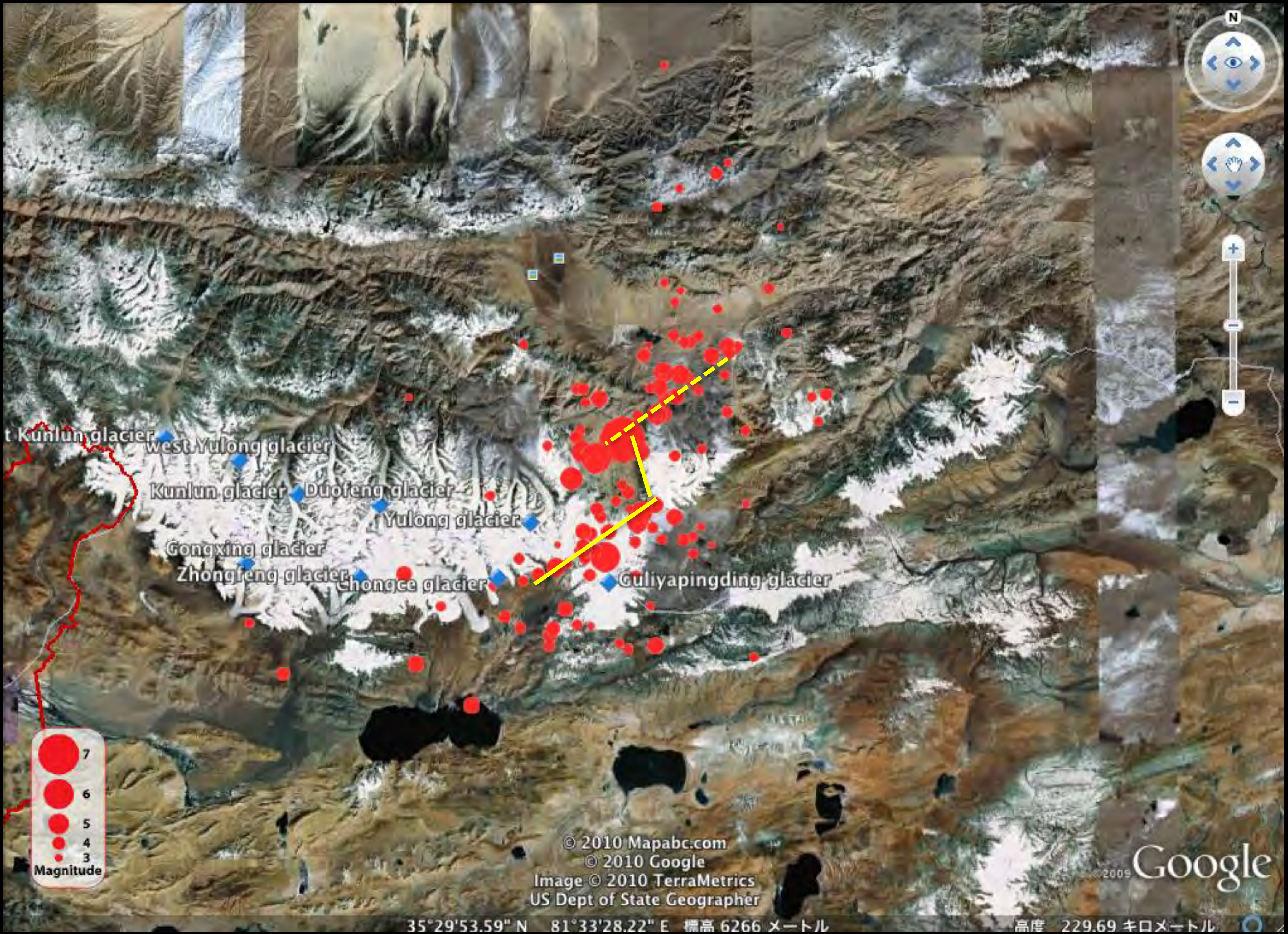



Inverted from ALOS InSAR (515) and Az. Offset data.

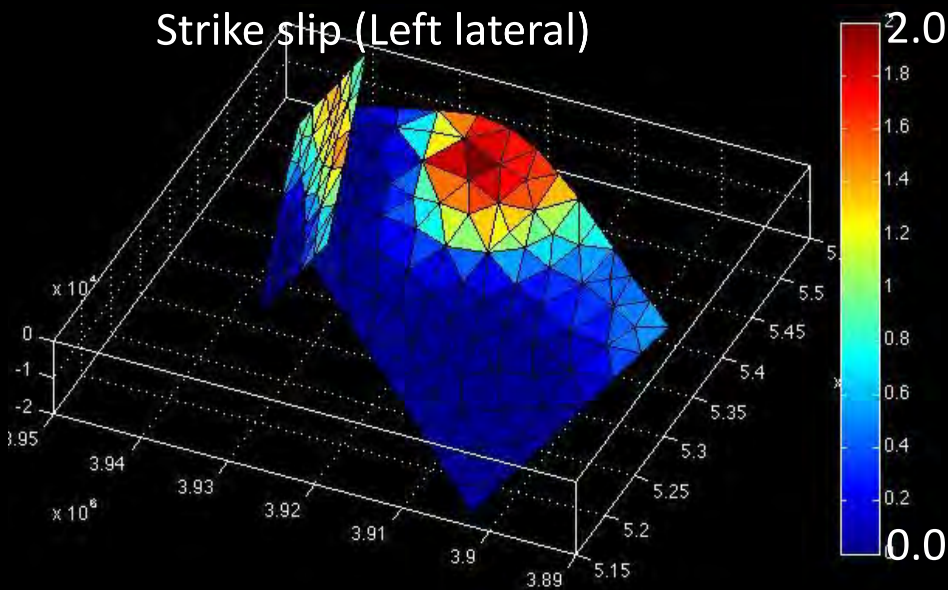
Moment magnitude Mw 7.04


Obs.
Cal.
Misfit.
ALOS/ InSAR
Az. offset
1.7
-0.3
0.3
-0.3
m
0.5
-1.5
0.5
-0.5
m

# Aftershock distribution (ISC)

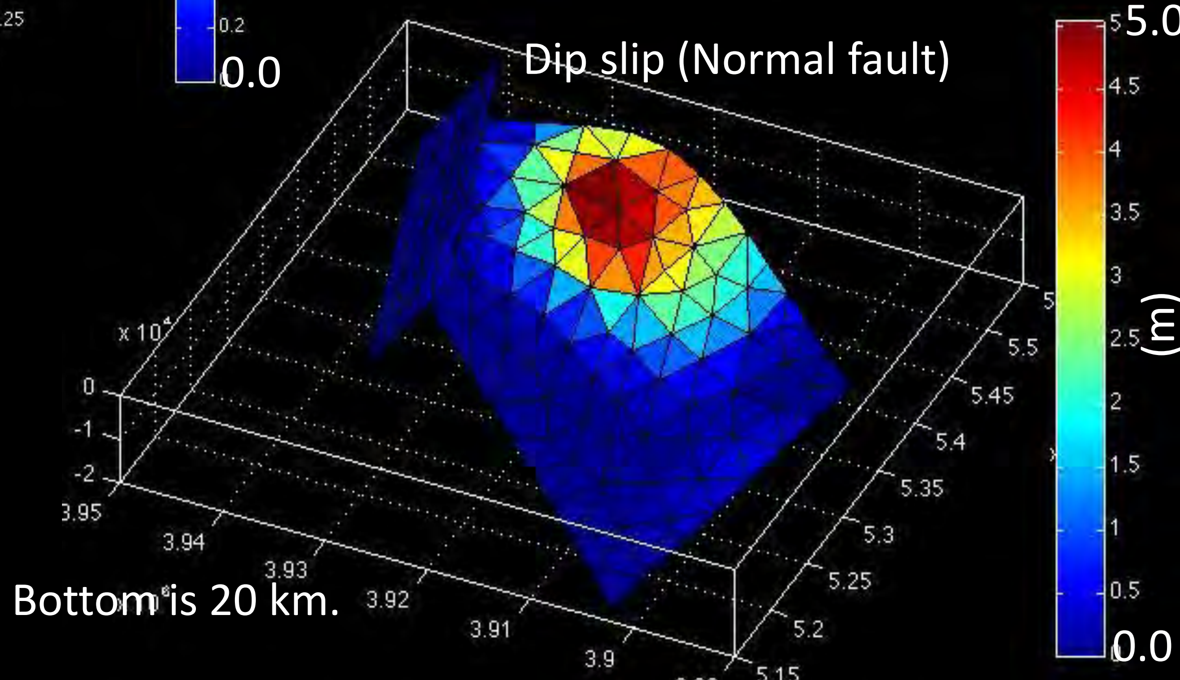


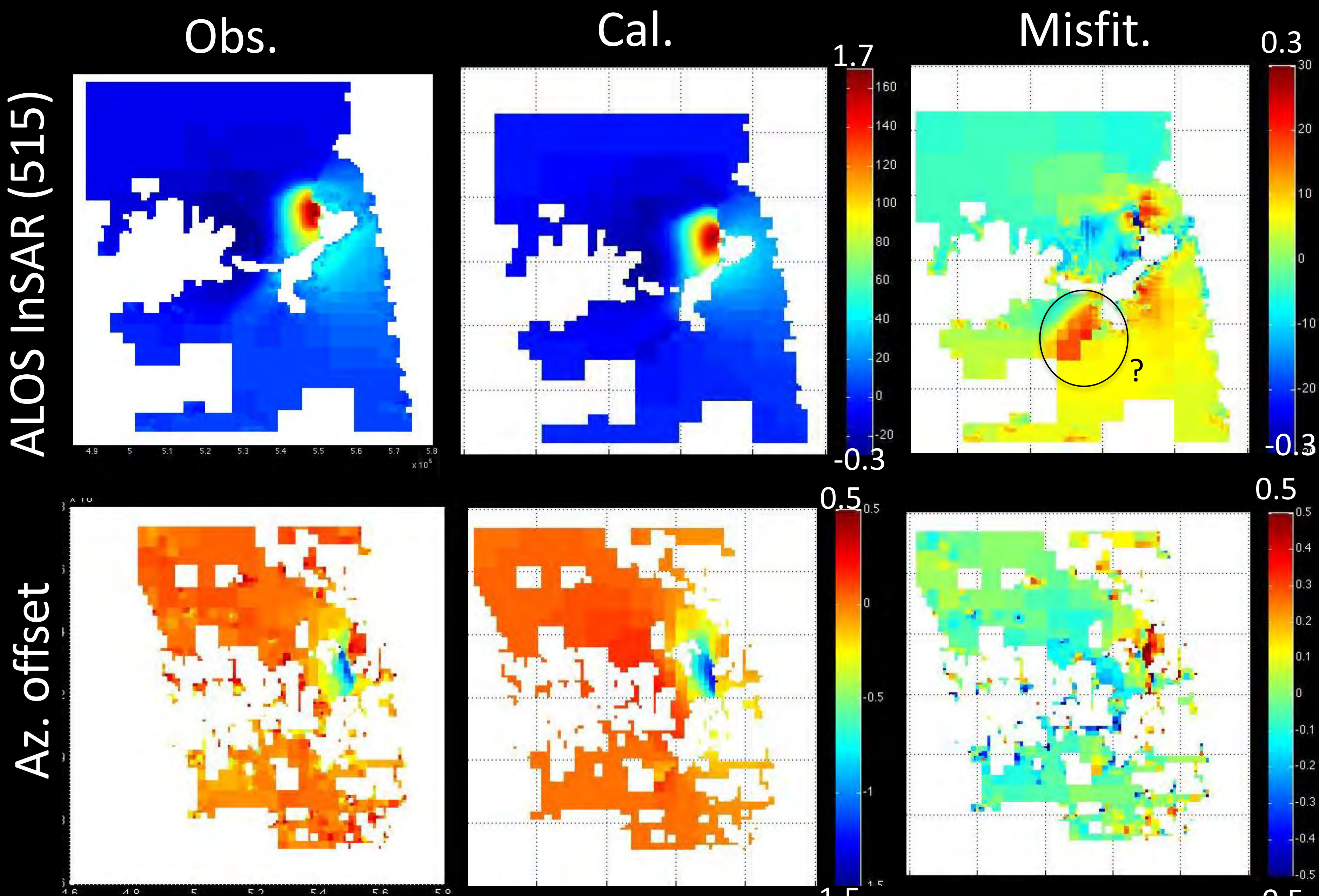
# Fault Model: Furuya & Yasuda (2011)




Inverted from ALOS InSAR (514, 515) , Az. Offset data and Envisat InSAR.

Moment magnitude Mw 7.1




Obs.
Cal.
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ALOS InSAR (515)
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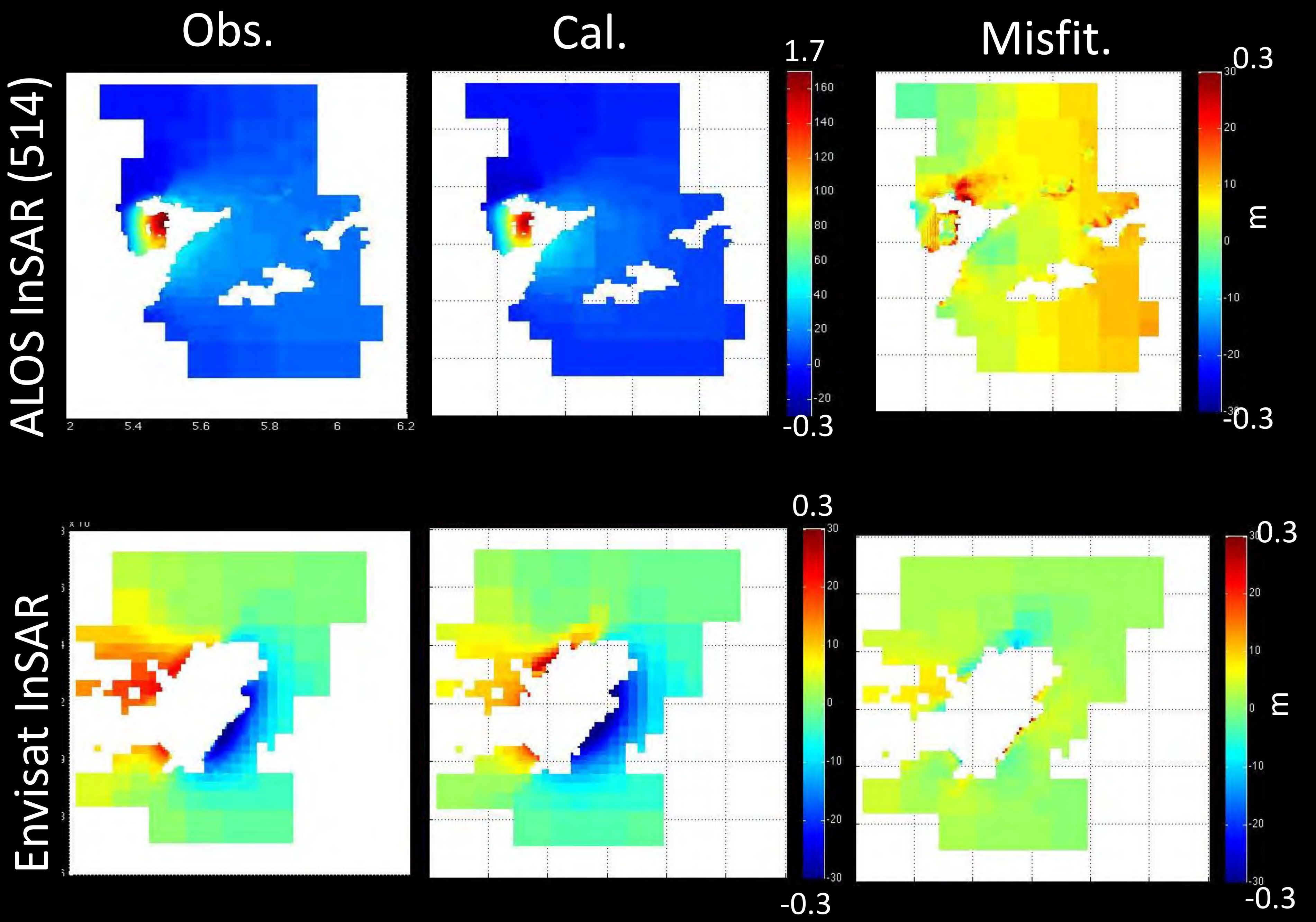
0.3
-0.3
0.5
-1.5
0.5
-0.5
?



Obs.
Cal.
Misfit.
ALOS InSAR (514)
Envisat InSAR
1.7
-0.3
0.3
-0.3
0.3
-0.3
0.3
-0.3
m
m
160
140
120
100
80
60
40
20
0
-20
30
20
10
0
-10
-20
-30
5.4
5.6
5.8
6
6.2

# Case study 2: 2008 Iwate-Miyagi

*E-LETTER* — *Earth Planets Space*, **61**, e9–e12, 2009

# Coseismic displacement due to the 2008 Iwate-Miyagi Nairiku earthquake detected by ALOS/PALSAR: preliminary results

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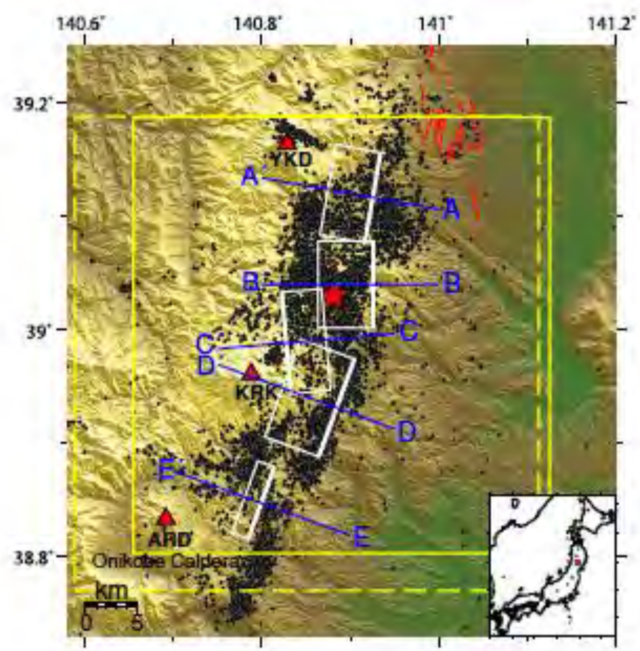
[1]*Department of Natural History Sciences, Hokkaido University, Sapporo, Japan*
[2]*Institute of Seismology and Volcanology, Hokkaido University, Sapporo, Japan*

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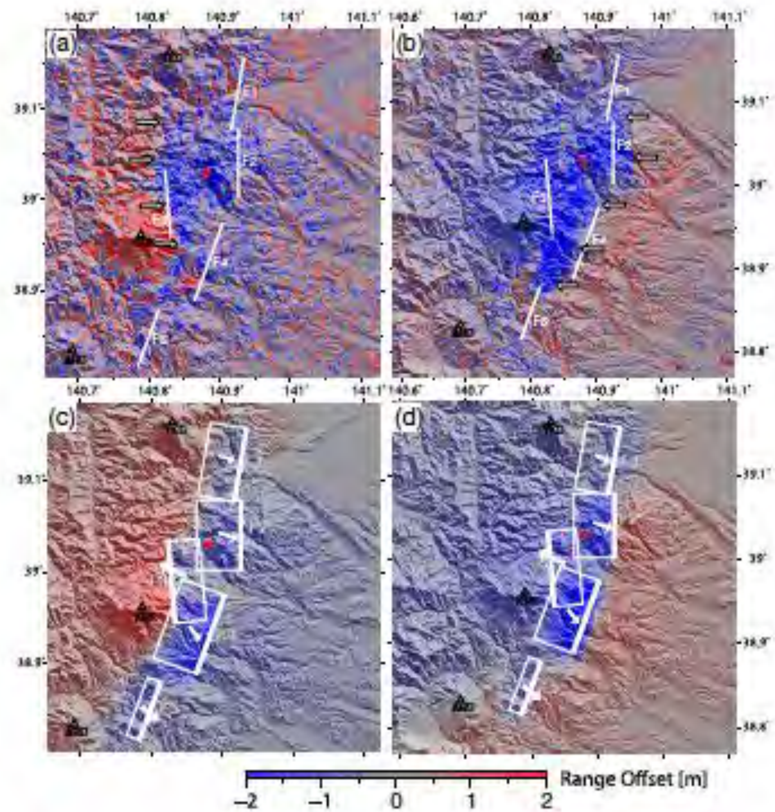
irthquake, p



*Accepted for publication in BSSA*

# Nonplanar Fault Source Modeling of the 2008 Mw6.9 Iwate-Miyagi Inland Earthquake in Northeast Japan


Takahiro Abe[1], Masato Furuya[1#] and Youichiro Takada[2]

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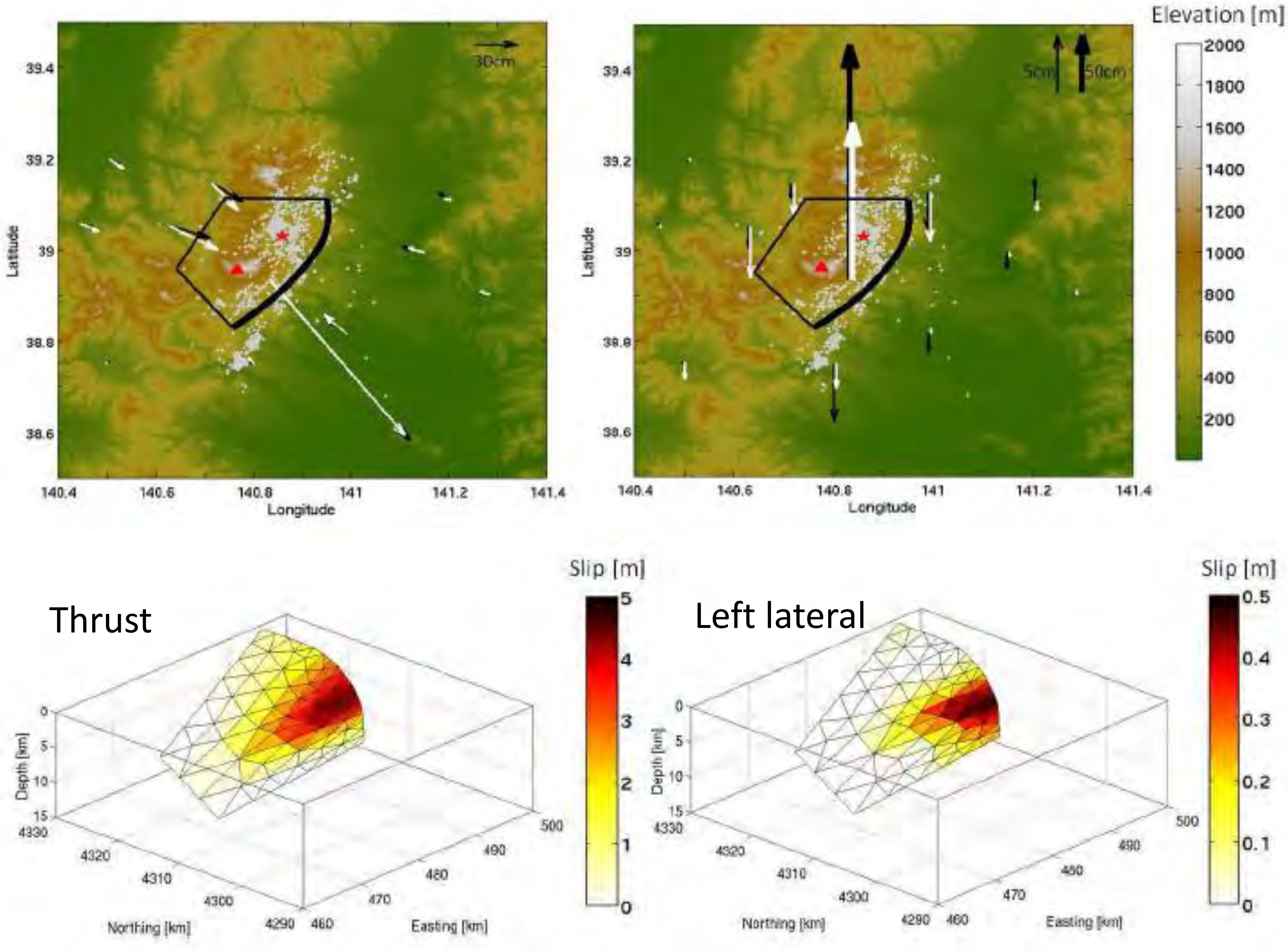
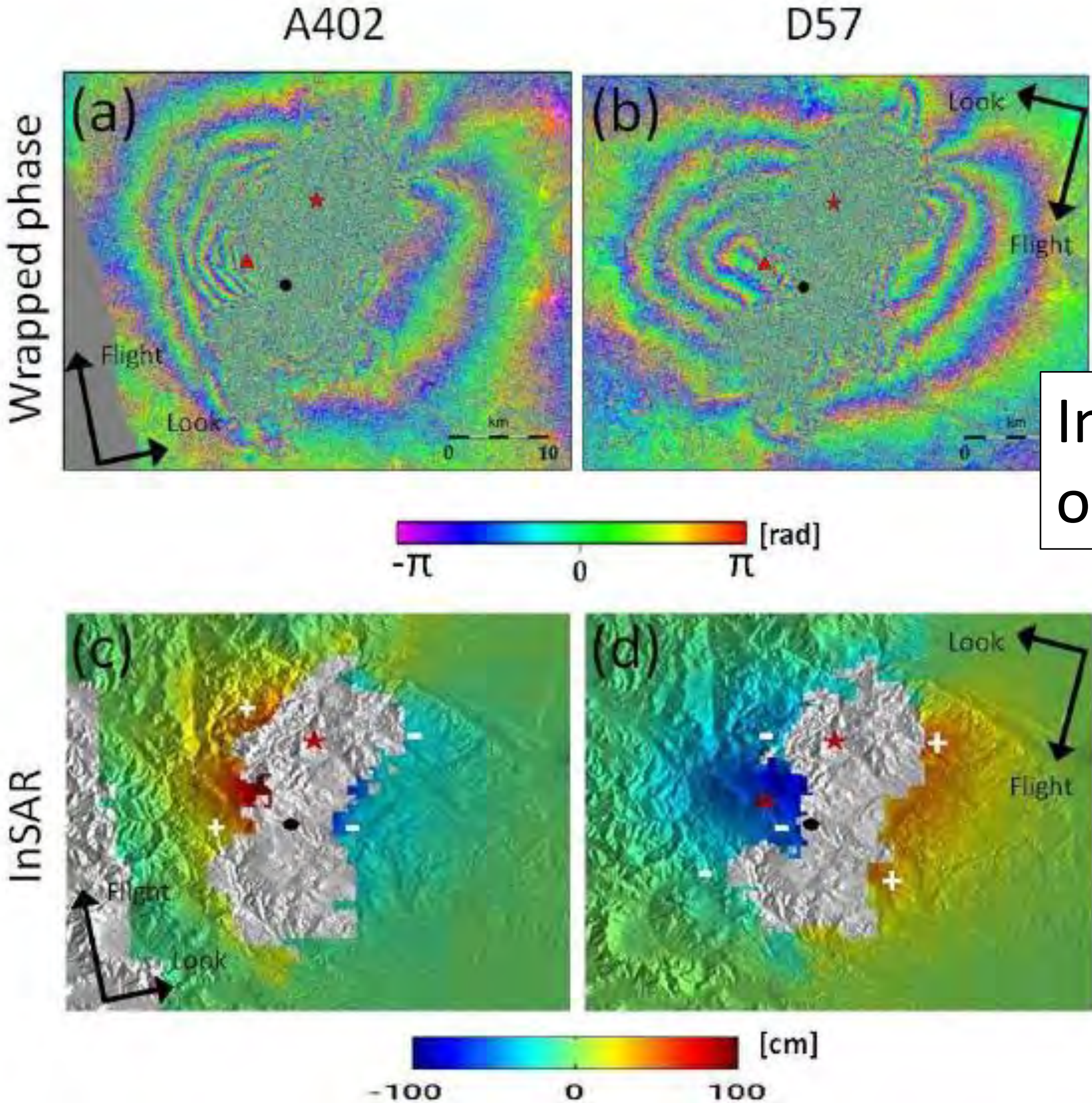
2. *Kamitakara Observatory, Disaster Prevention Research Institute, Kyoto University, 2296-2 Hongo, Kamitakara, Takayama, Gifu 506-1317, Japan*

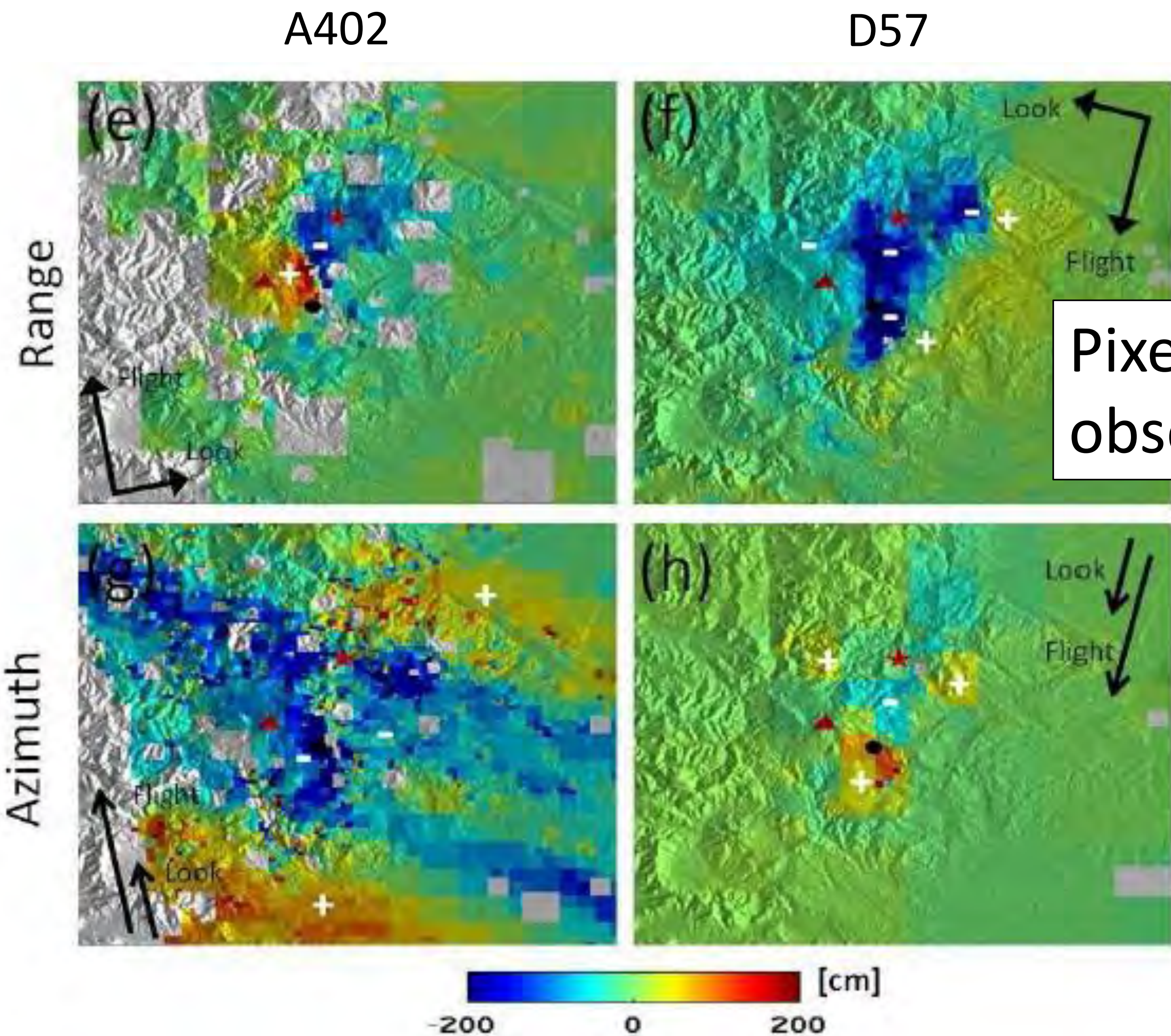

GPS, InSAR, range- and azimuth offset data were inverted.

# Observed (black) and Calculated GPS (white) from GPS-based single-segment fault model



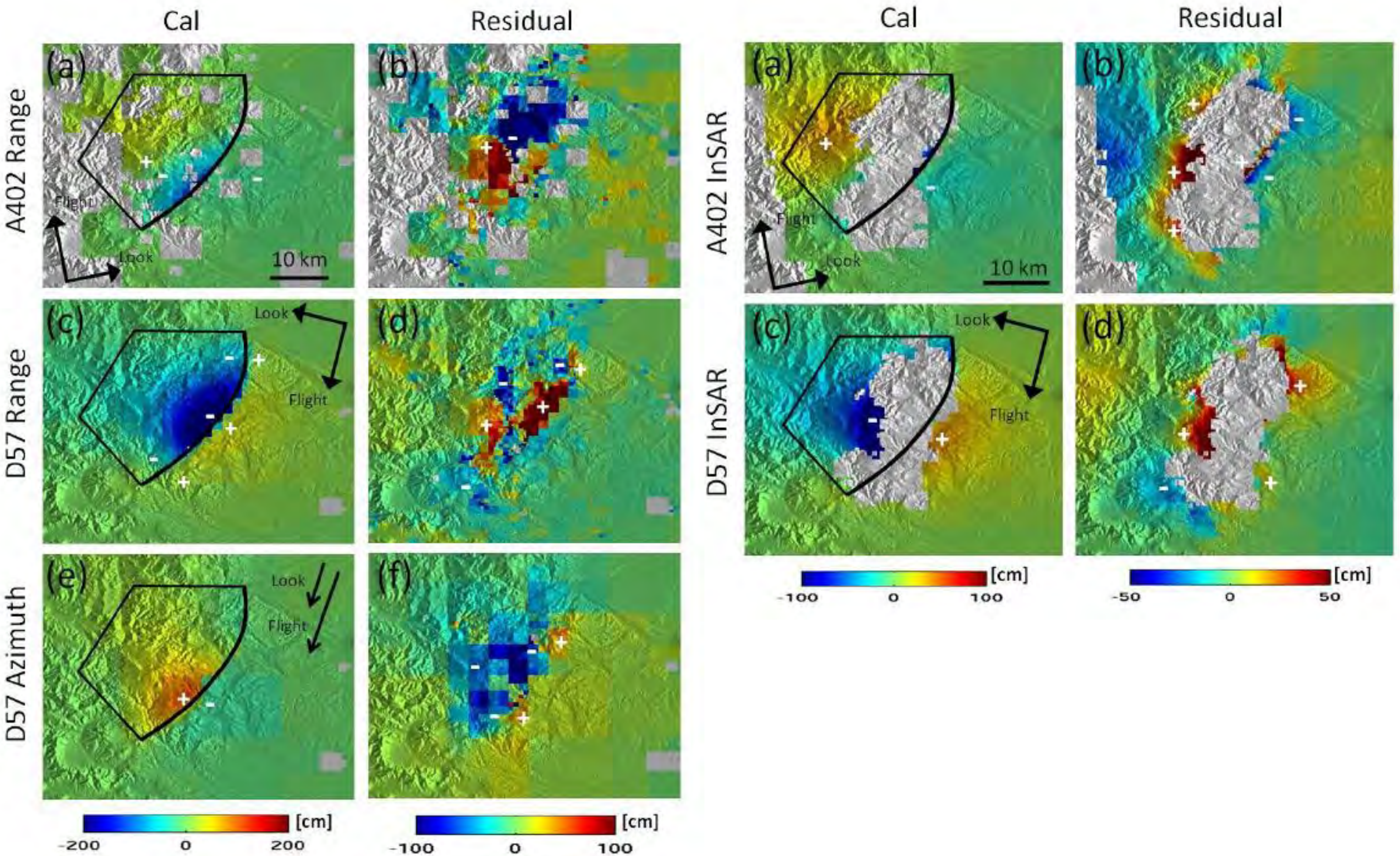


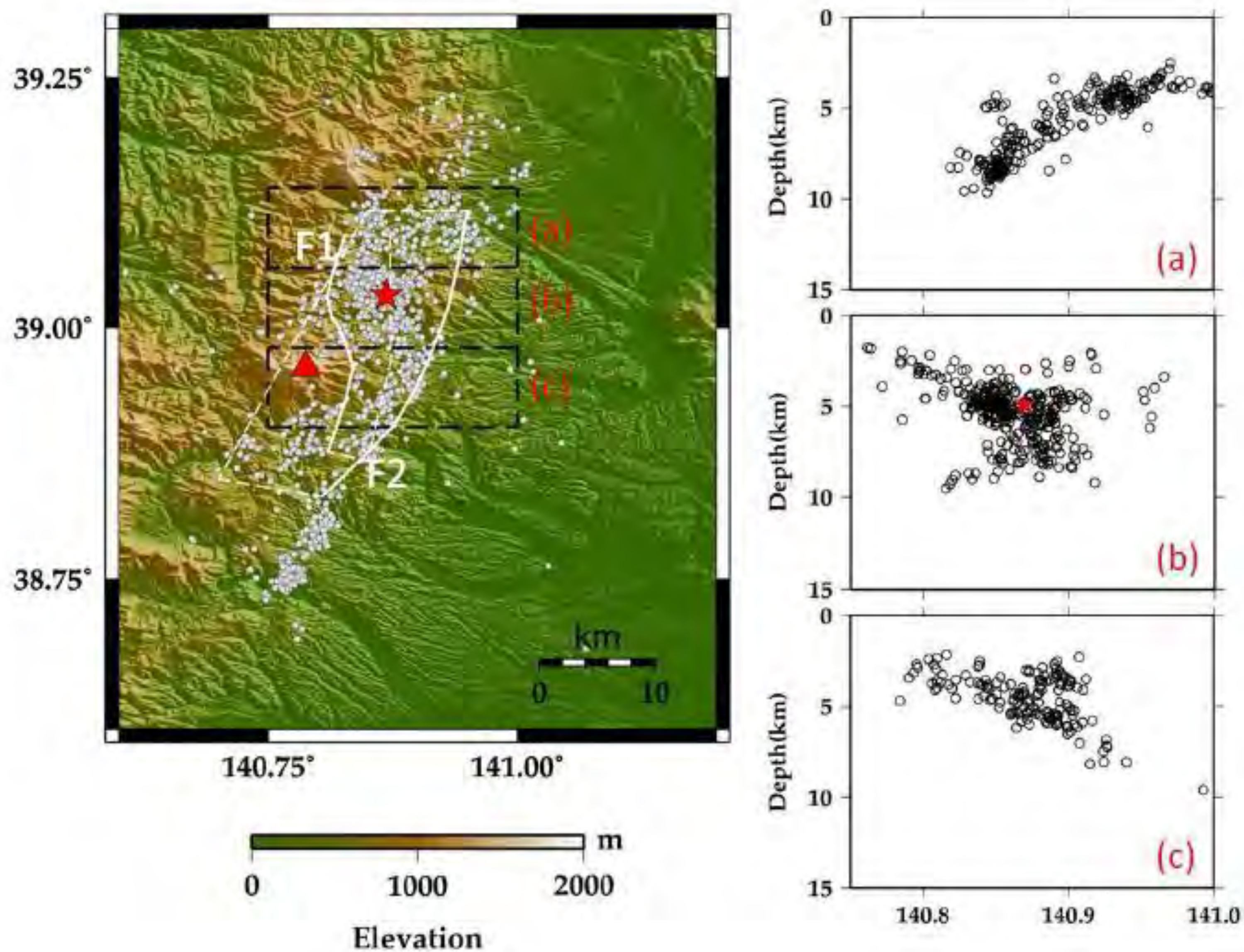

InSAR observations




Pixel-offset observations

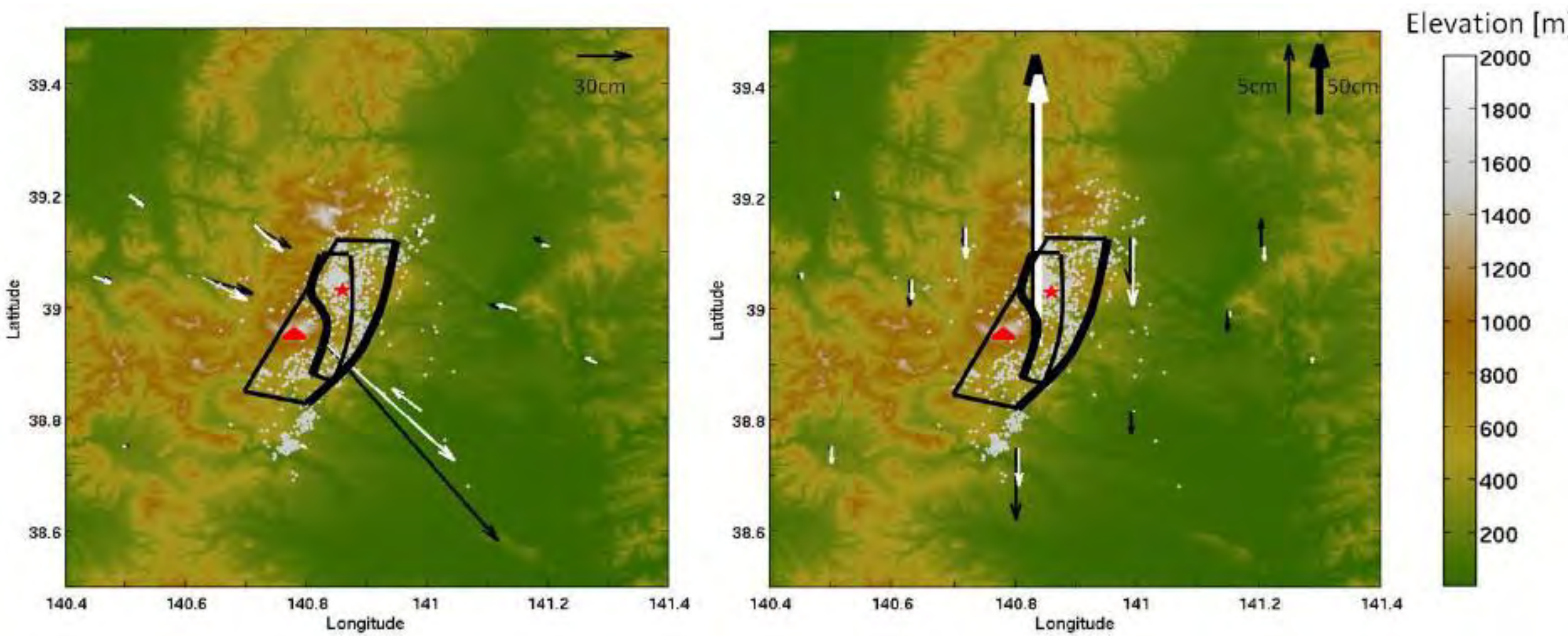
# Significant misfit residuals from GPS-based fault model

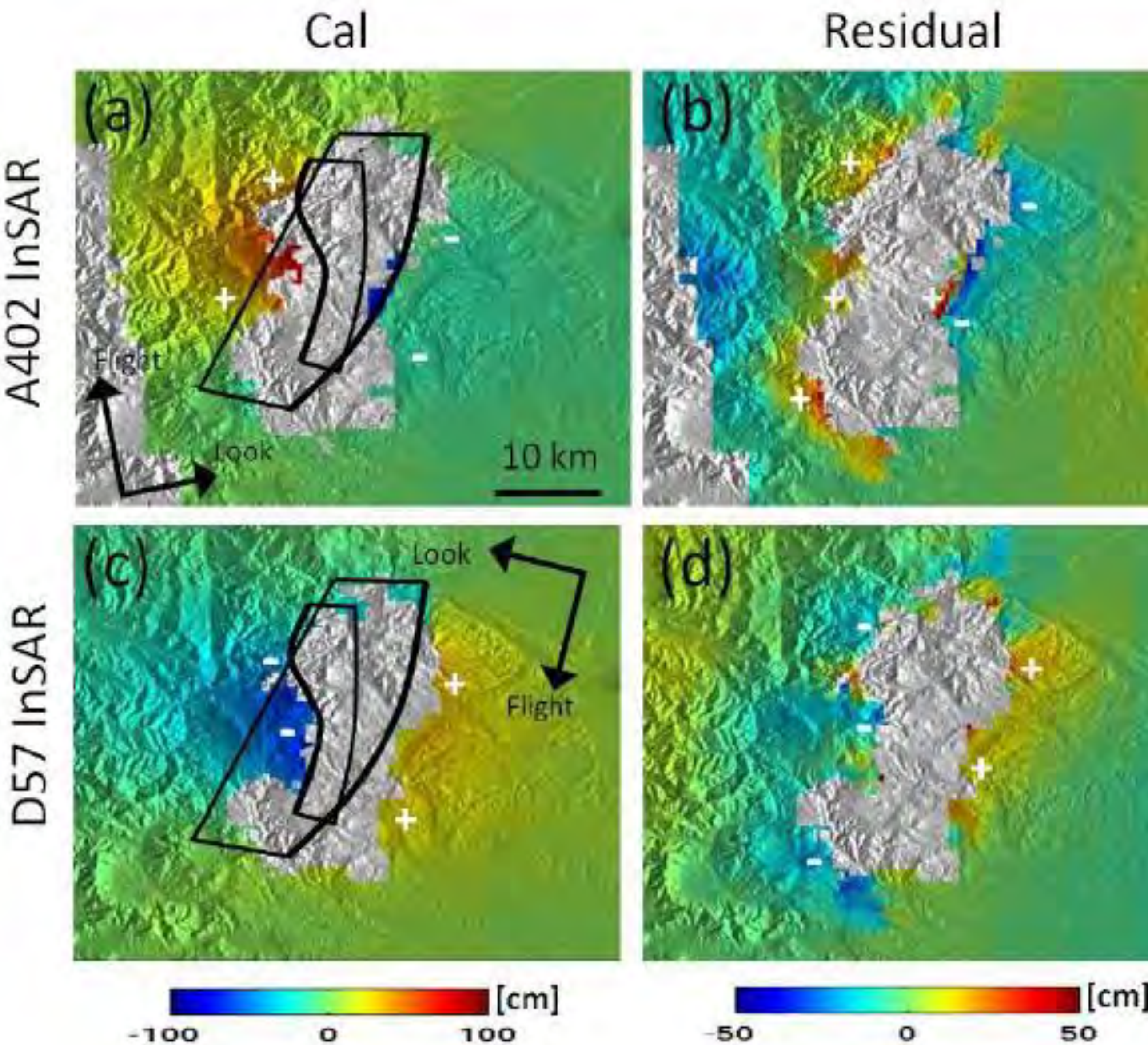


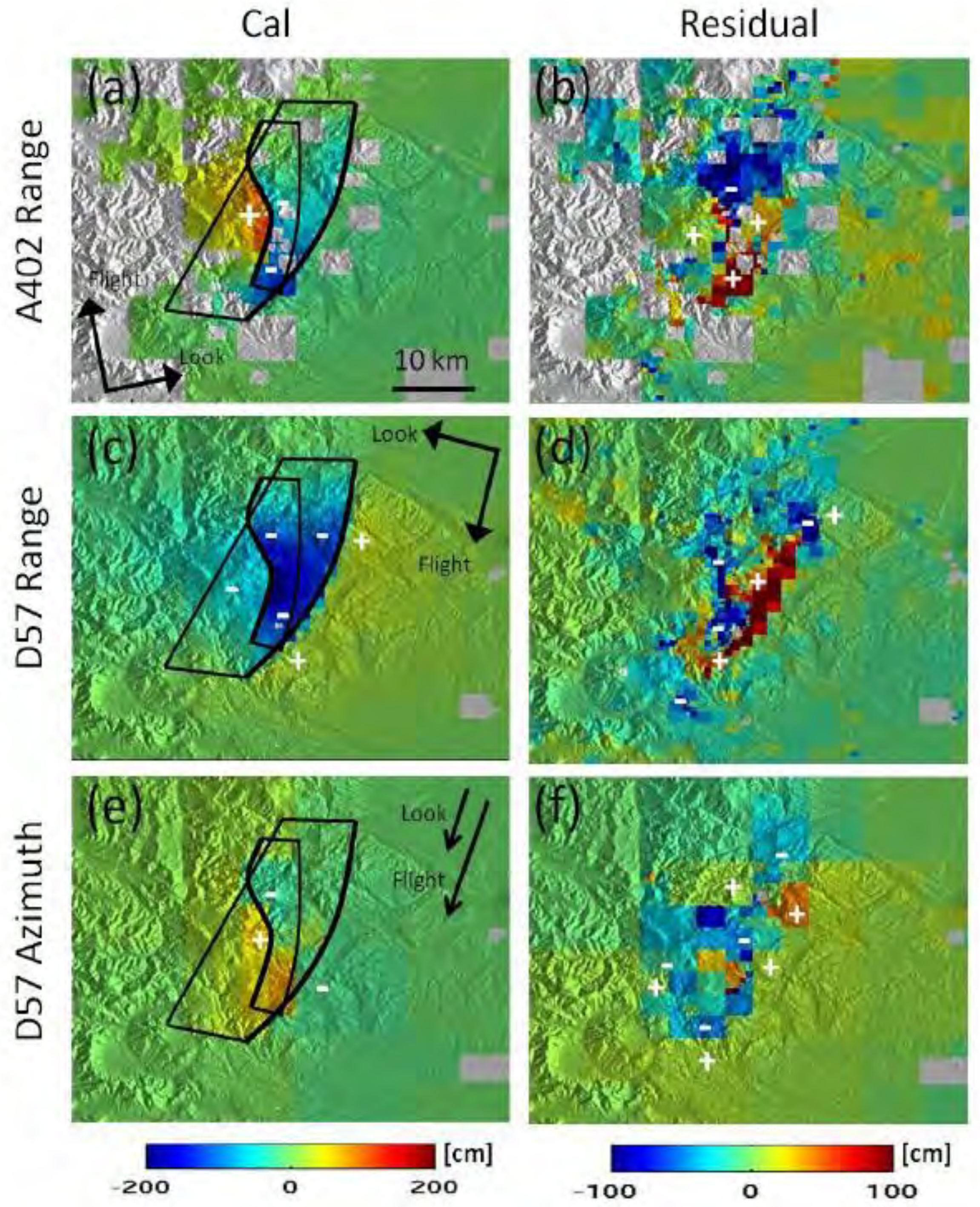


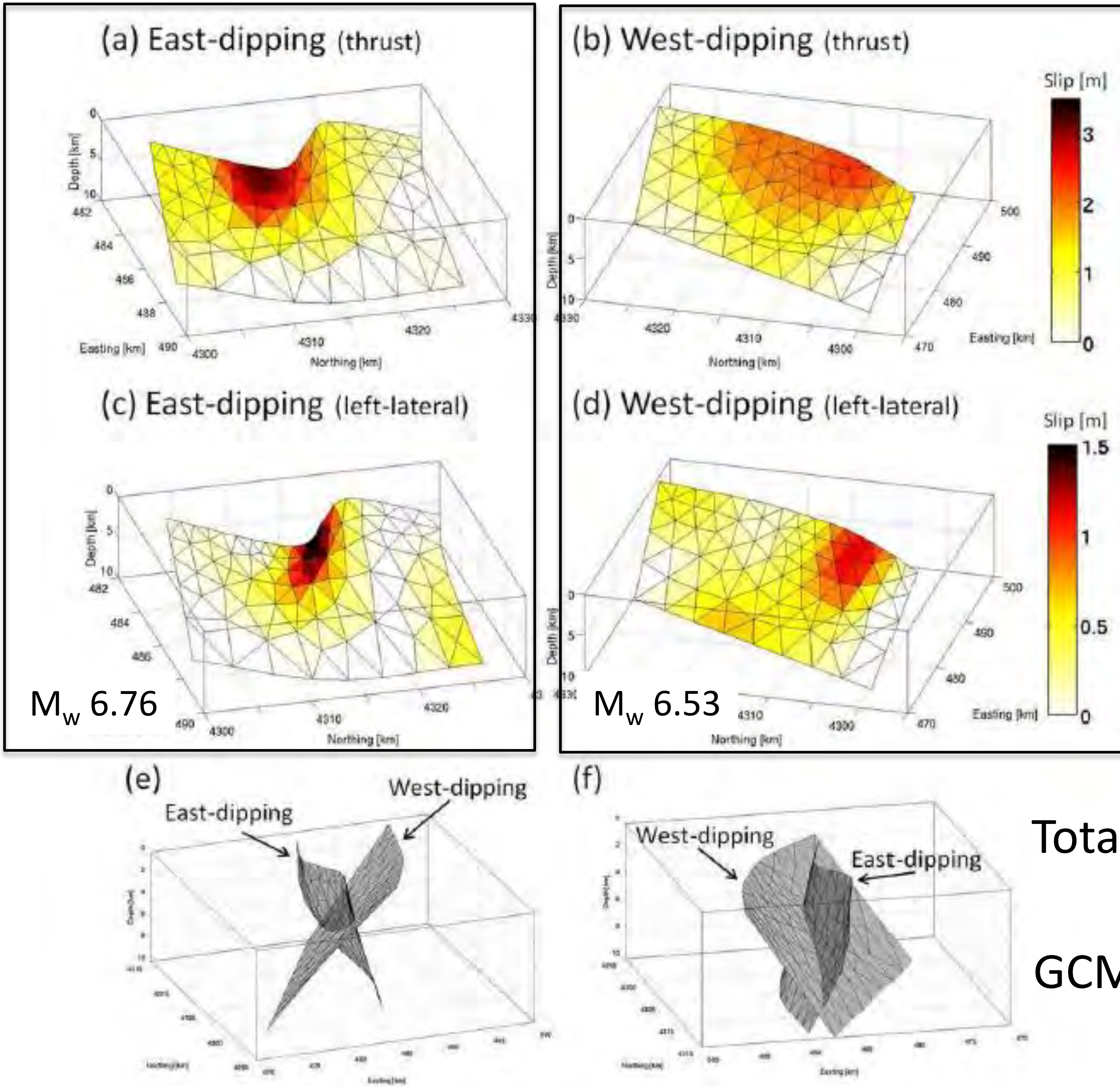

Aftershock data: Courtesy of Group for the aftershock observations of the Iwate-Miyagi Nairiku Earthquake 2008 (see also, Okada et al. 2012)

# Observed (black) and Calculated GPS (white) from GPS-based double-segment fault model




Cal
Residual
A402 InSAR
D57 InSAR
(a)
(b)
(c)
(d)
Flight
Look
10 km
Look
Flight
[cm]
-100
0
100
[cm]
-50
0
50

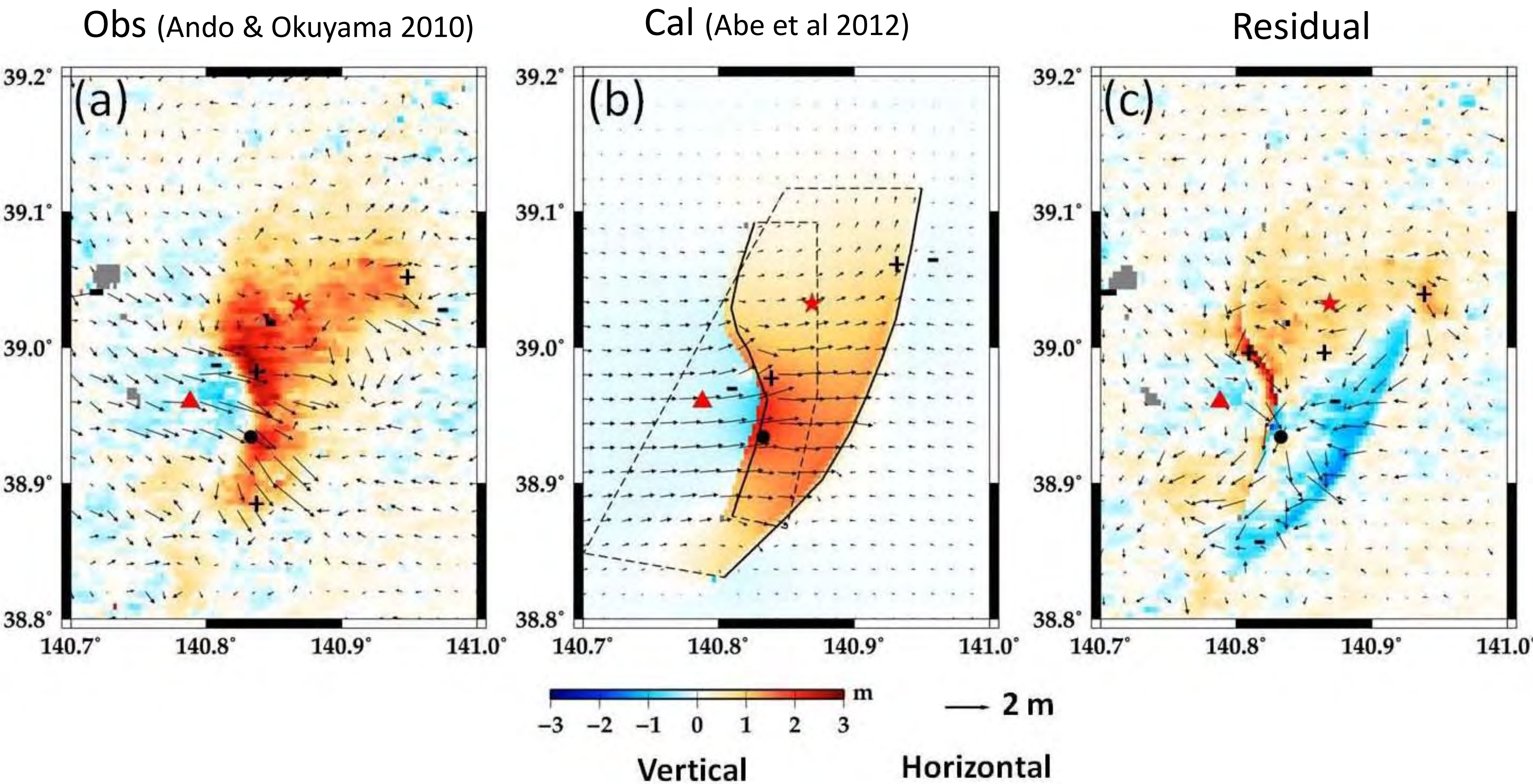

Cal
Residual
A402 Range
D57 Range
D57 Azimuth
(a)
(b)
(c)
(d)
(e)
(f)
Flight
Look
10 km
[cm]
-200
0
200
-100
0
100




Total $M_w$ 6.87

GCMT $M_w$ 6.9

# Observed (left) and Calculated (middle) 3-D displacements



# Summary

✓ Pixel-offset tracking plays an even more important role than InSAR in order to map co-seismic deformation of large earthquakes.

✓ We have to correct for the artifact caused by fore-shortening over rugged terrain.

✓ Geometric complexity

✓ Multiple/conjugate rupture planes

✓ We're looking forward to the ALOS-2!


- Acknowledgement: PALSAR level 1.0 data are provided from PIXEL under a cooperative research contract between JAXA and ERI/Univ Tokyo as well as the Earthquake working group. The PALSAR data belongs to METI and JAXA.