Inversion of Earthquake Rupture

The fundamental tool to explore the mechanics of earthquakes

The North Anatolian Fault

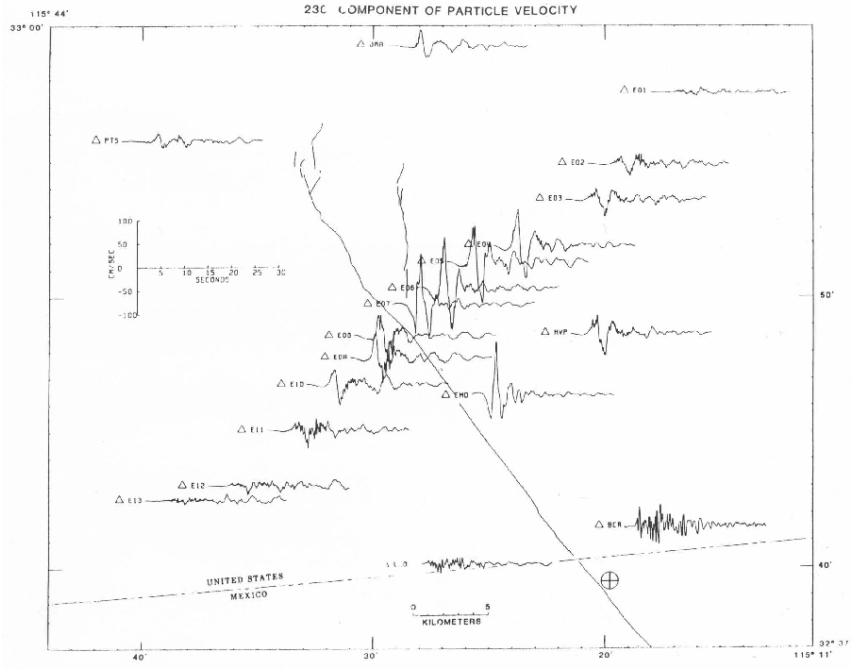
- **The goal of source inversion is not to fit the data**
- **Any computer can do that**

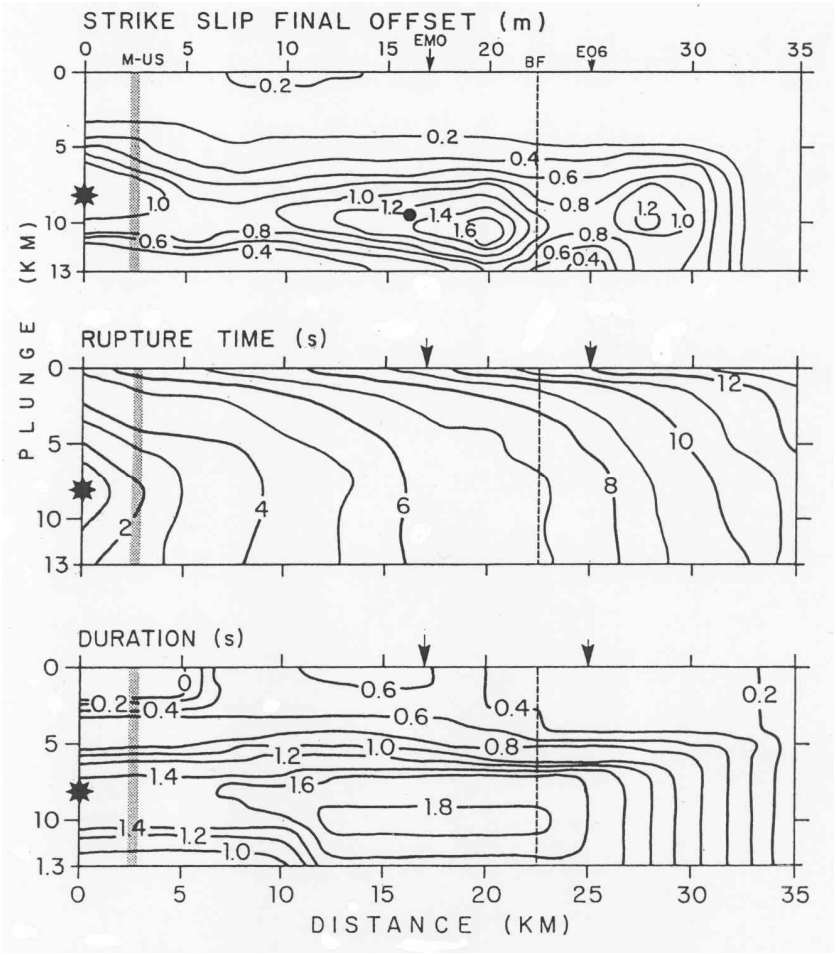
- The goal of source inversion is not to fit the data
- Any computer can do that because the number of model parameters generally far exceeds the number of observations

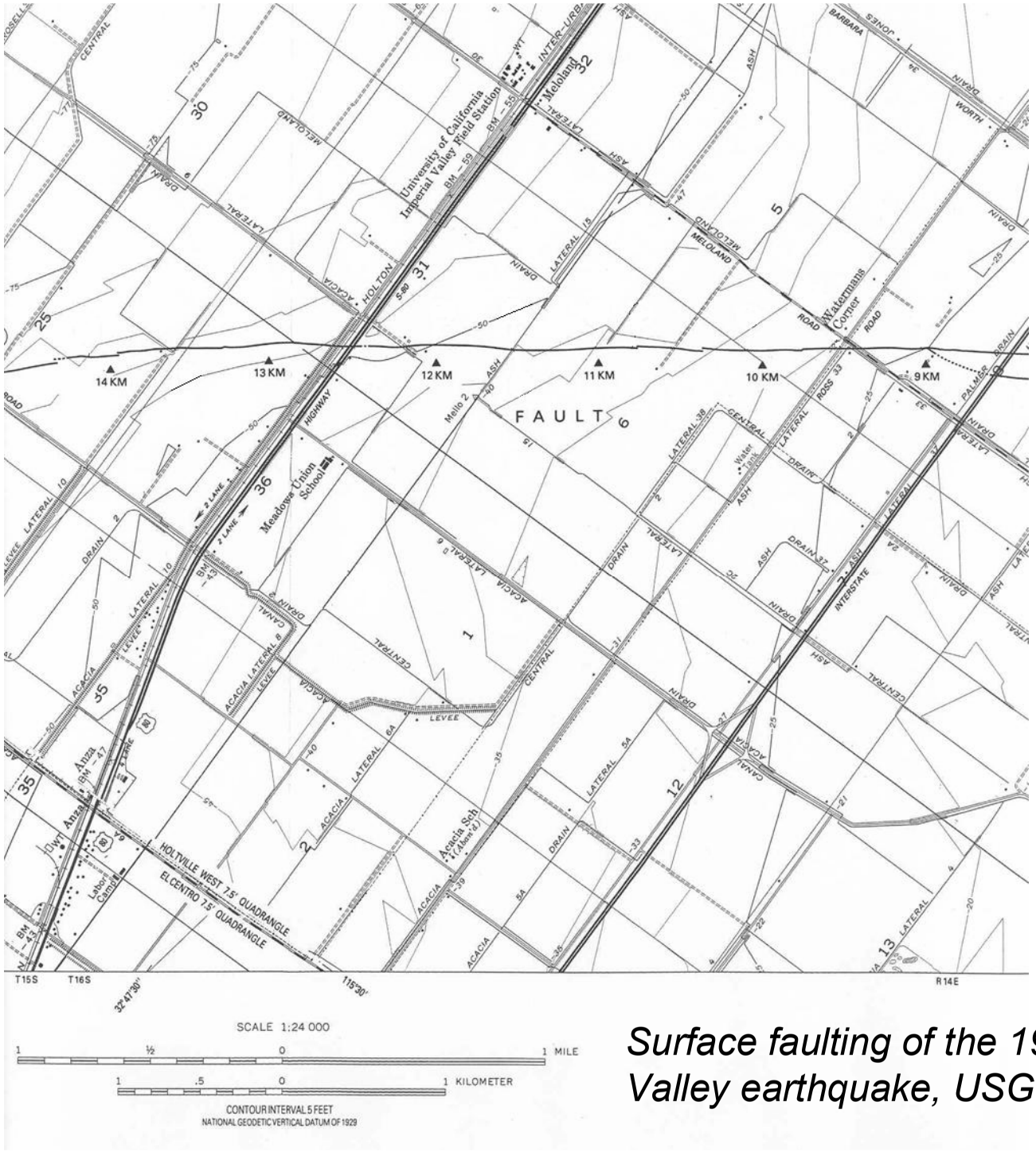
- The goal of source inversion is not to fit the data
- Any computer can do that
- The goal of source inversion is to fit the robust information present in the data with a restricted number of physically meaningful source parameters

The most important part of source inversion is understanding the forward problem

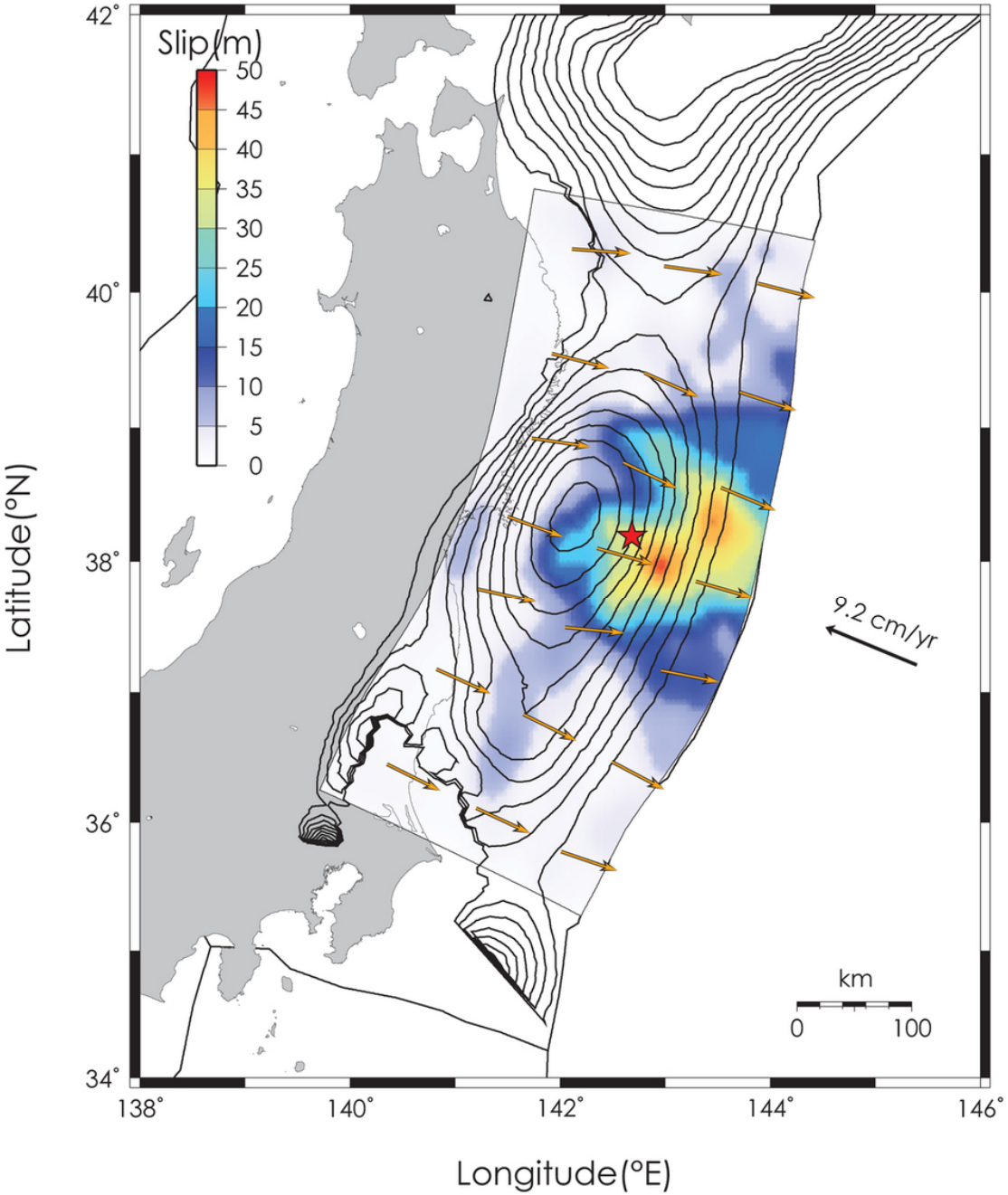
1979 *ML=6.6* Imperial Valley Earthquake (Archuleta, 1984)



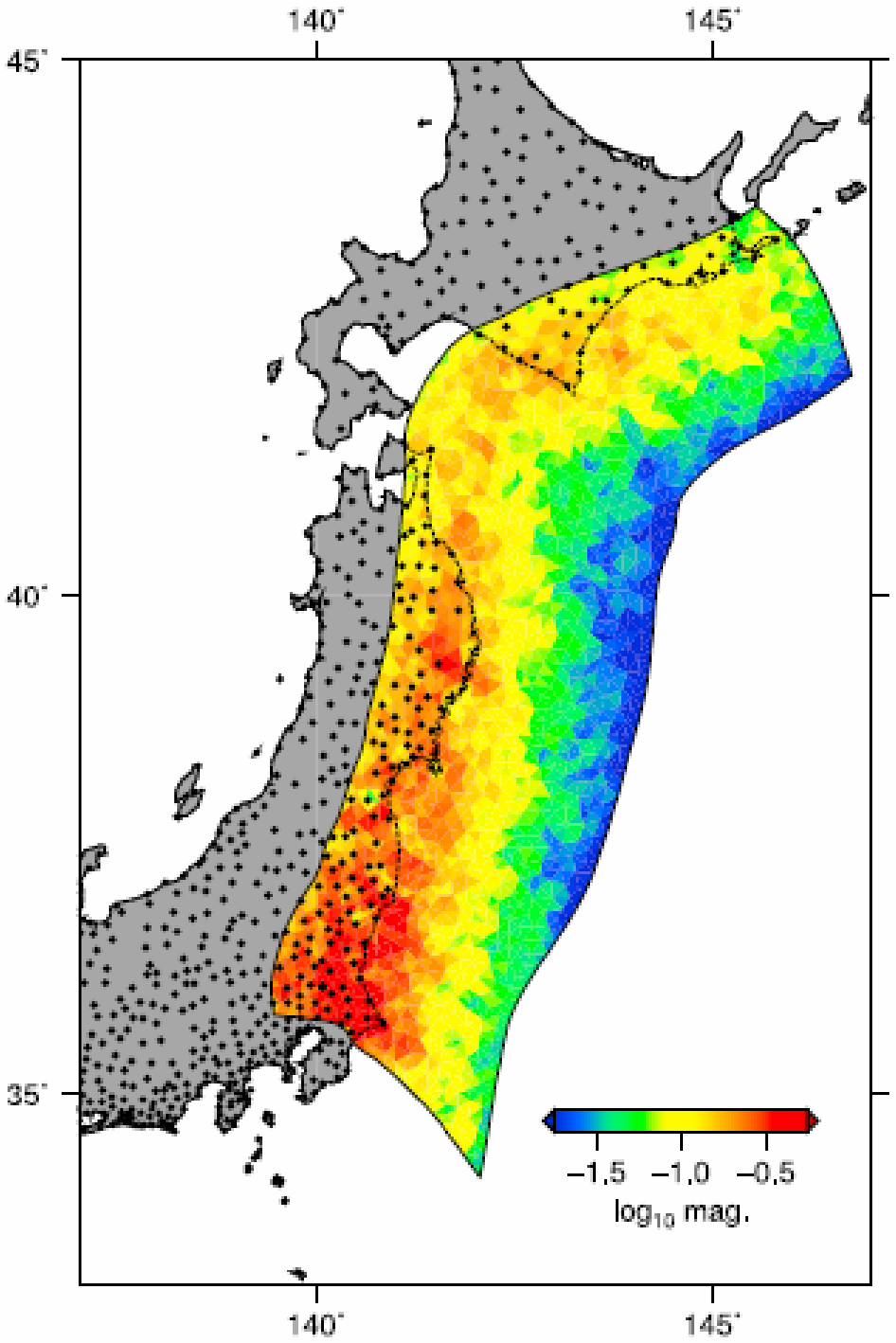




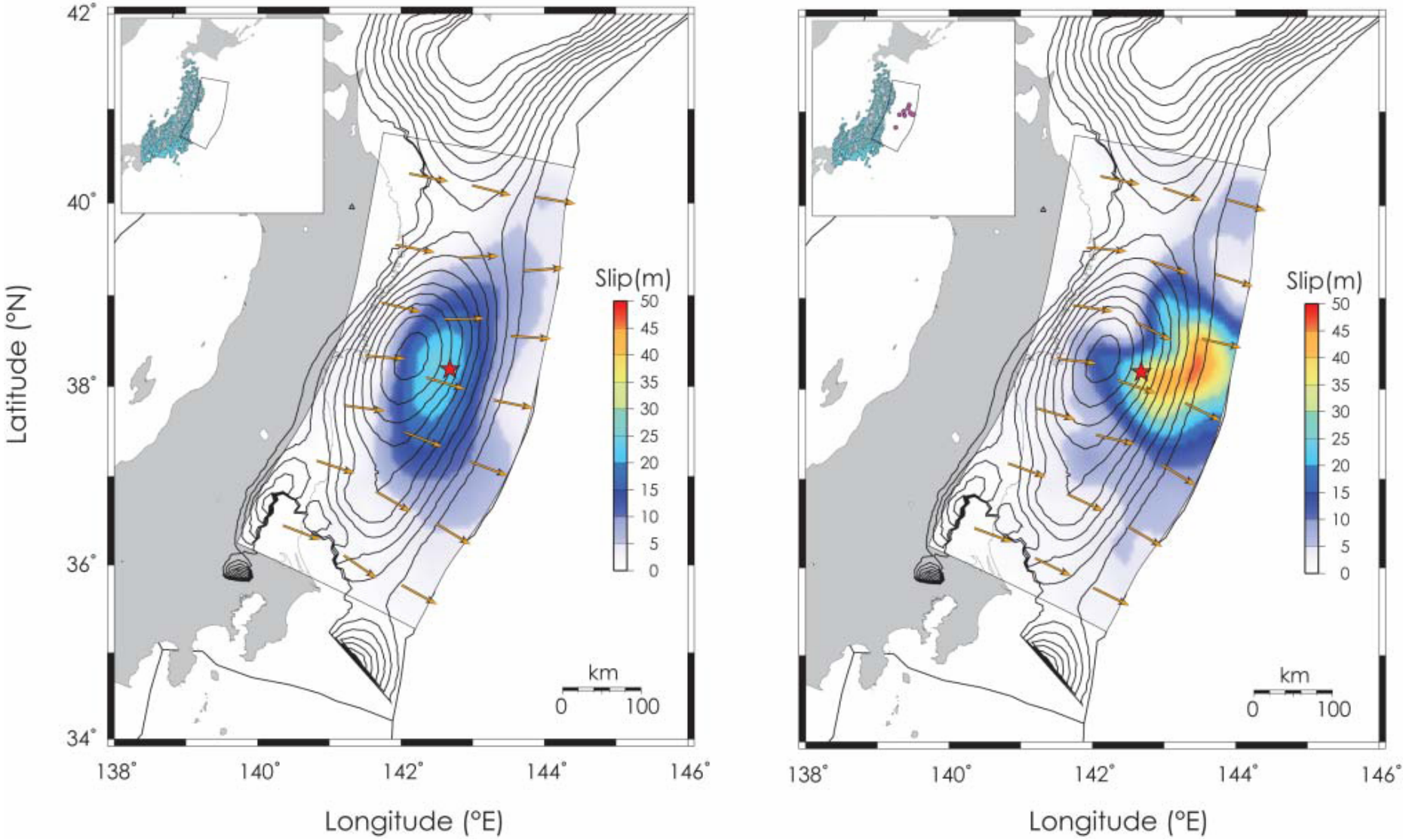
Surface faulting of the 1979 Imperial Valley earthquake, USGS 1982



Romano et al., 2012



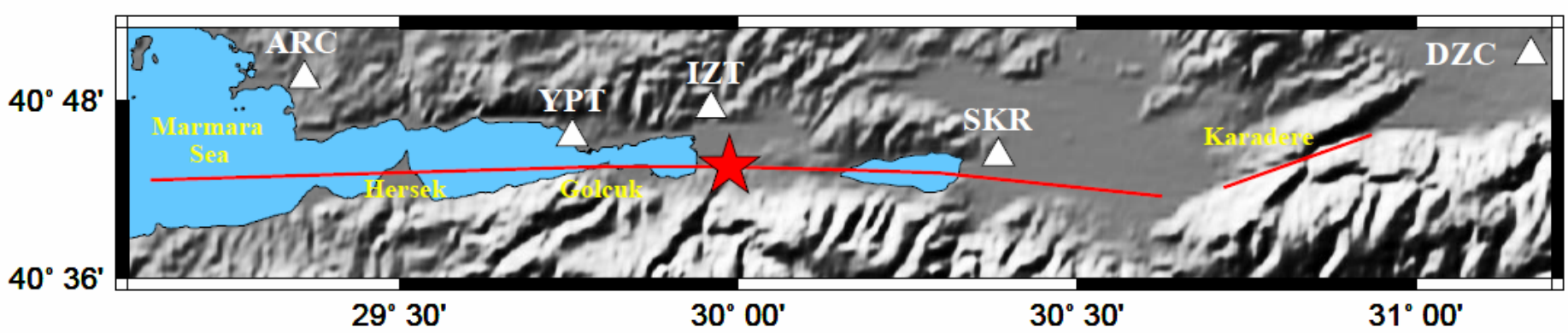
Loveless and Meade, 2011

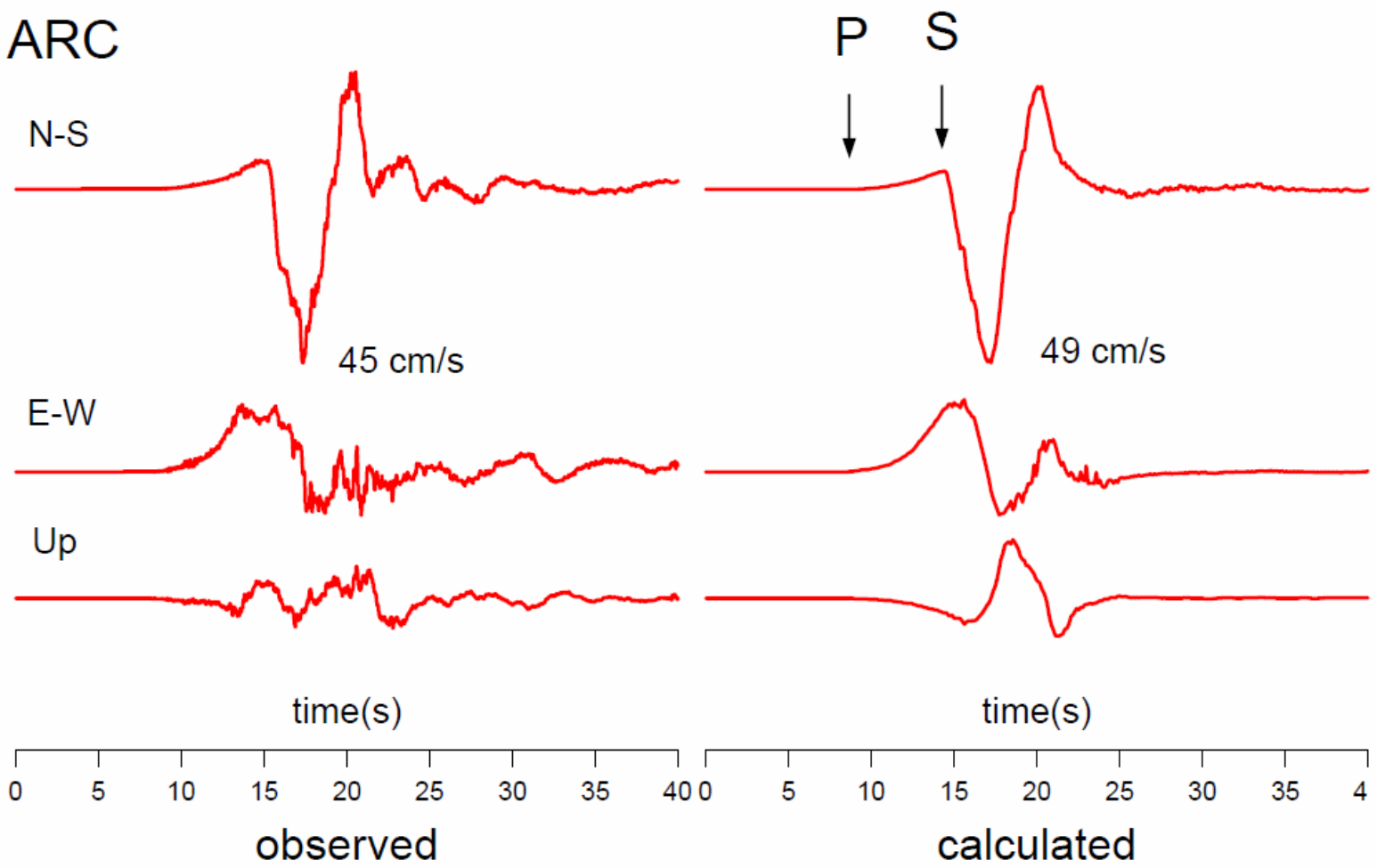


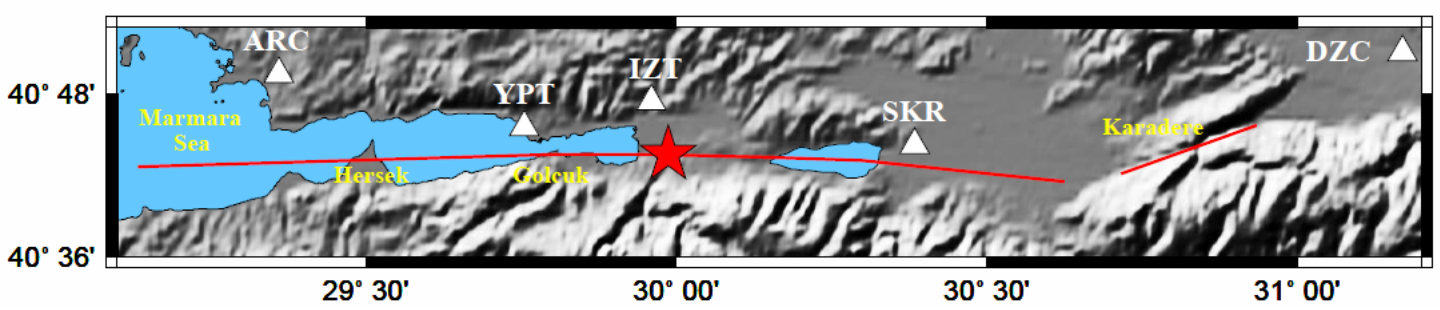
Romano et al, 2012

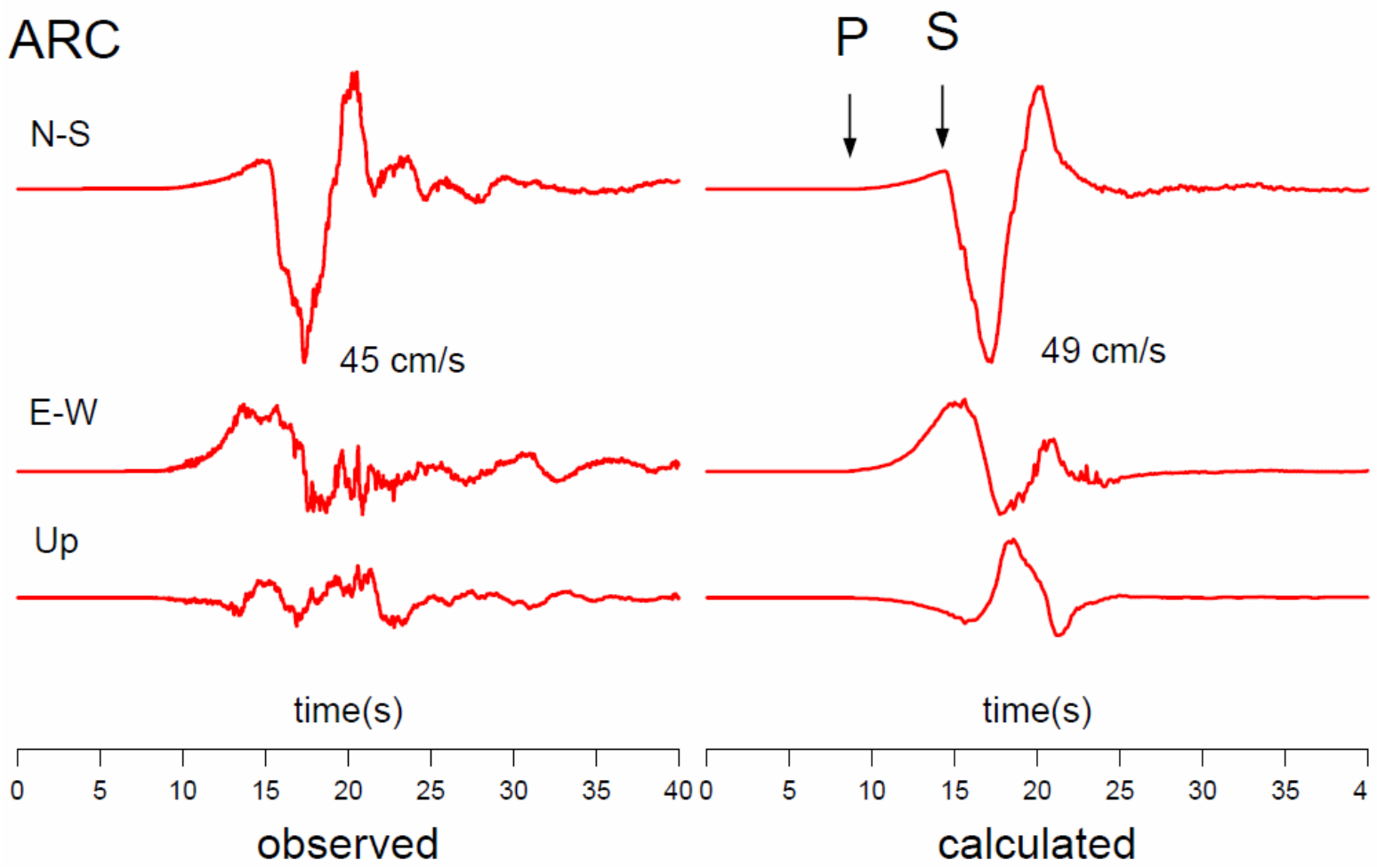
- Adapt the model parameters to the observations
- Do not invert data for information which is not in the data

Let us look at one of the best recorded large earthquake: The Mw 7.6 Izmit earthquake




ARC
P
S
N-S
45 cm/s
49 cm/s
E-W
Up
time(s)
time(s)
0 5 10 15 20 25 30 35 40
0 5 10 15 20 25 30 35 4
observed
calculated

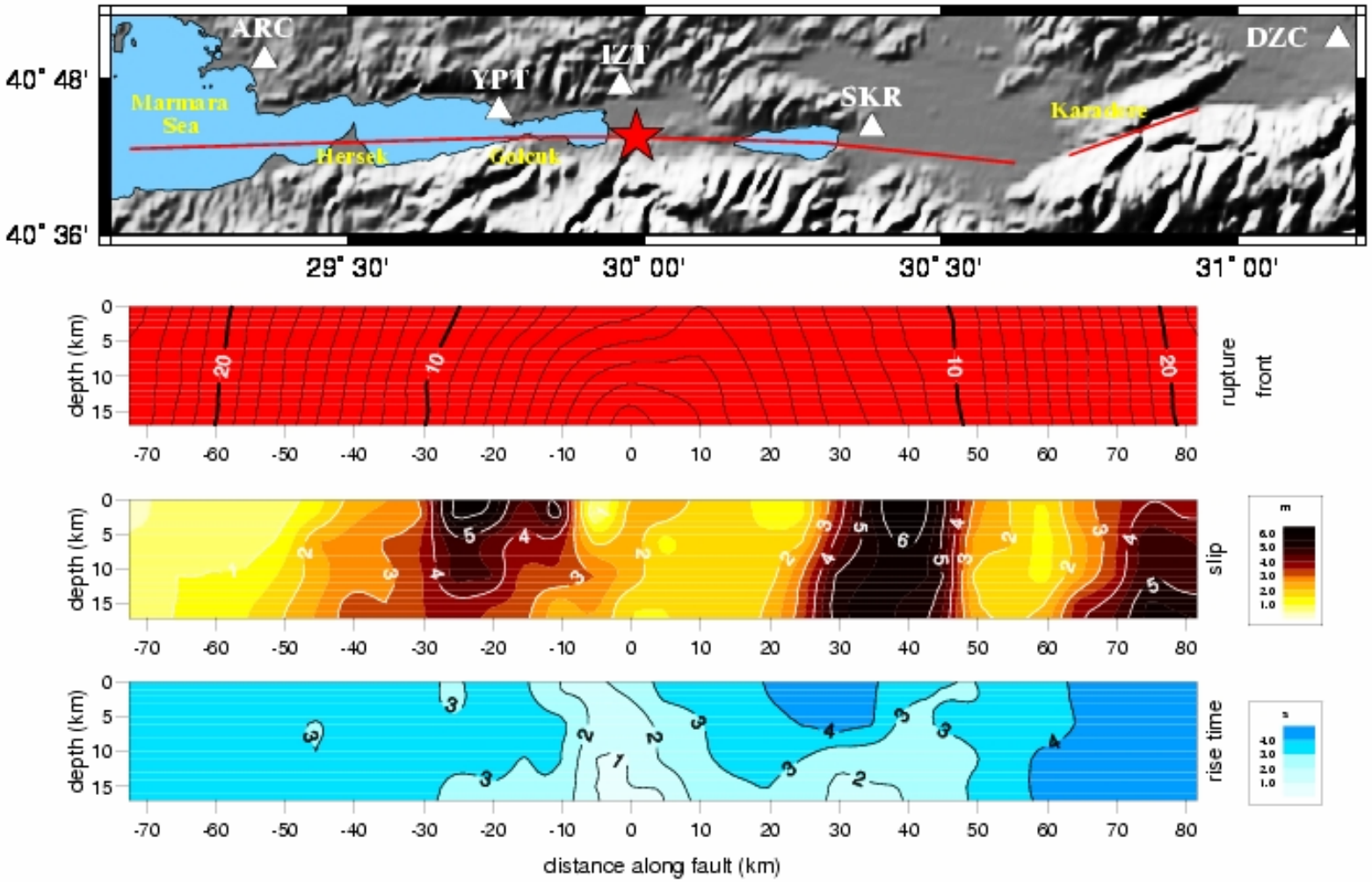

ARC
YPT
IZT
SKR
DZC
Marmara Sea
Hersek
Golcuk
Karadere
40° 48'
40° 36'
29° 30'
30° 00'
30° 30'
31° 00'

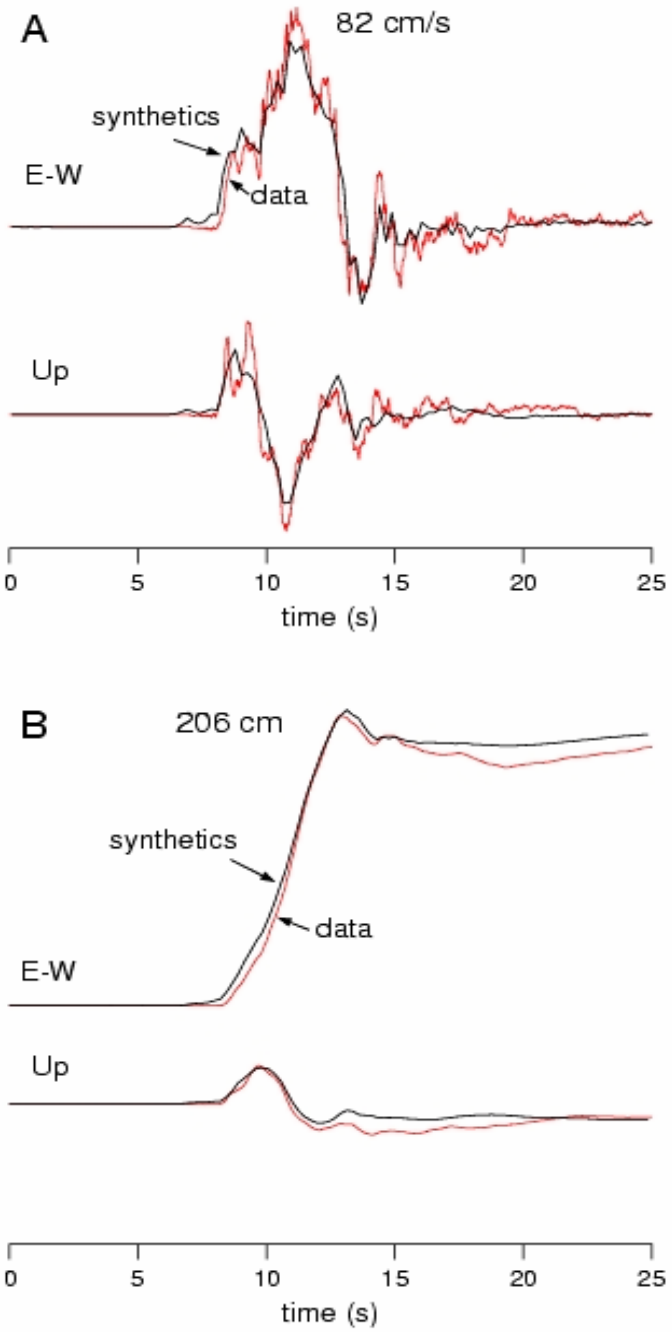


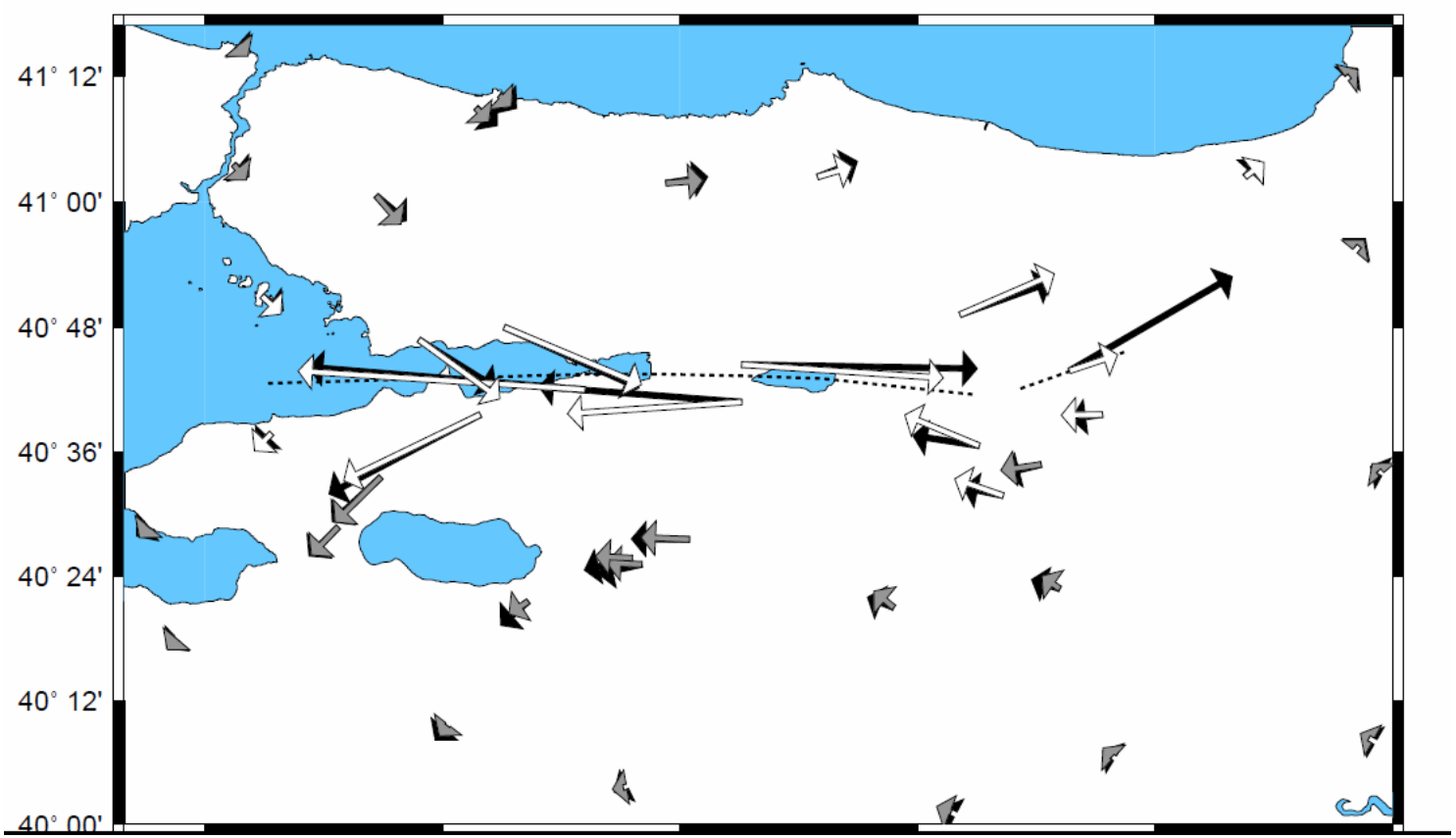
The calculation is made with only 3 model parameters: SLIP=3m, RISE-TIME=3s, RUPTURE VELOCITY=3km/s.

Inverting this record with 1000 model parameters will not give us more information, but may instead degrade the information, because of trade-off between so many unresolvable parameters.

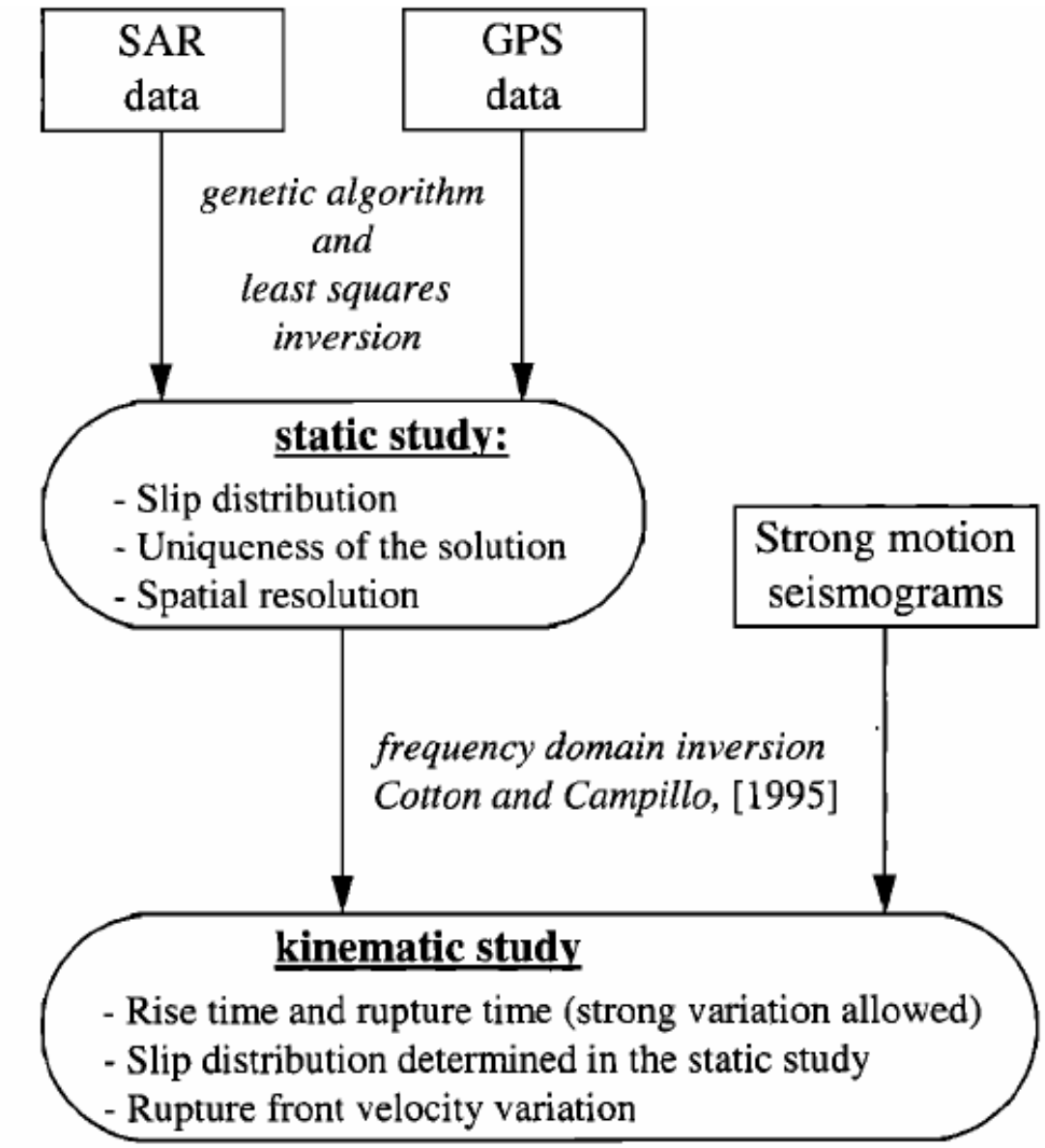
The Mw 7.6 Izmit earthquake




A
82 cm/s
synthetics
E-W
data
Up
0
5
10
15
20
25
time (s)
B
206 cm
synthetics
data
E-W
Up
0
5
10
15
20
25
time (s)


41° 12'
41° 00'
40° 48'
40° 36'
40° 24'
40° 12'
40° 00'

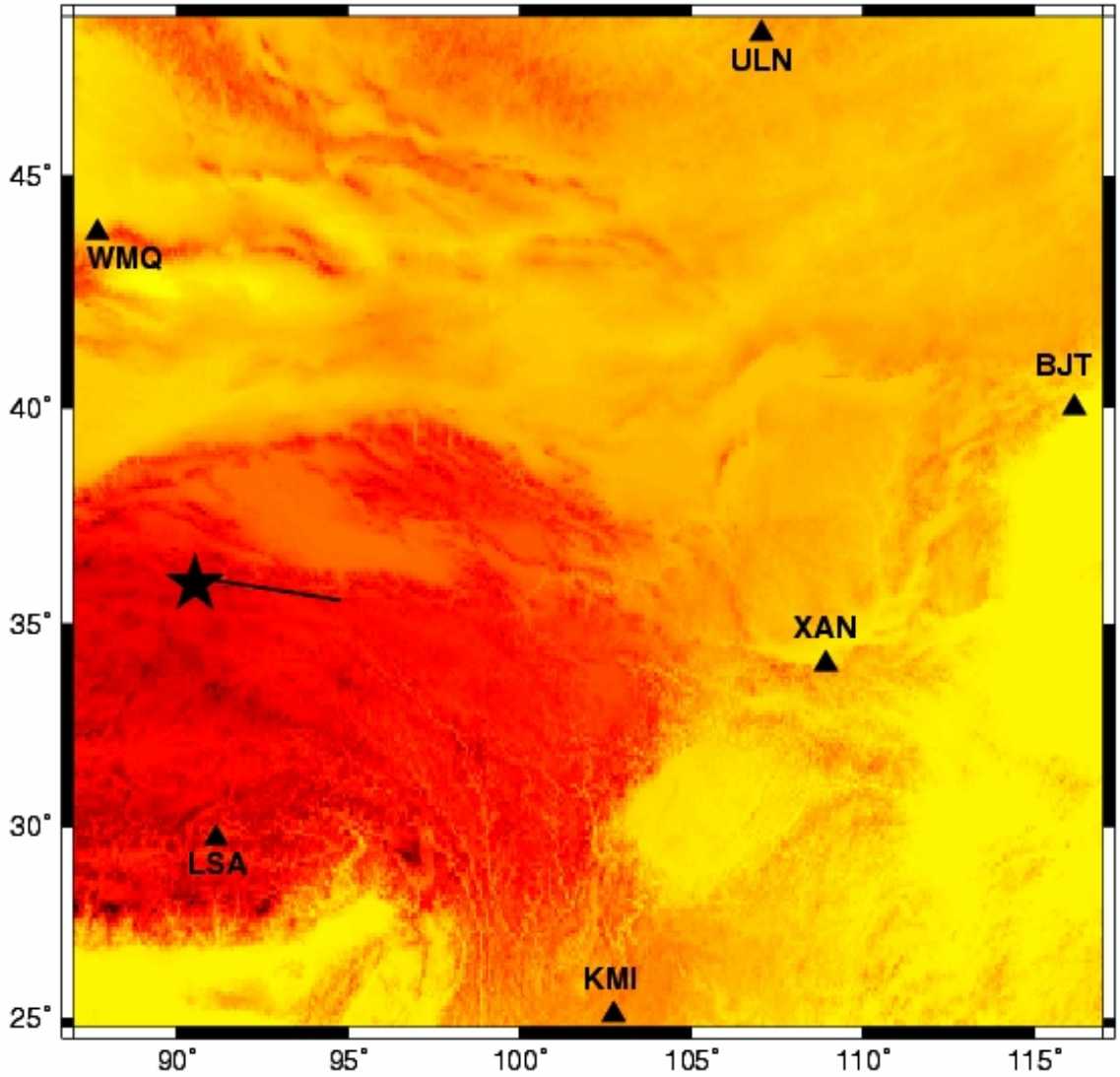
If you have different types of data (the usual case), a hierarchy of the data is necessary



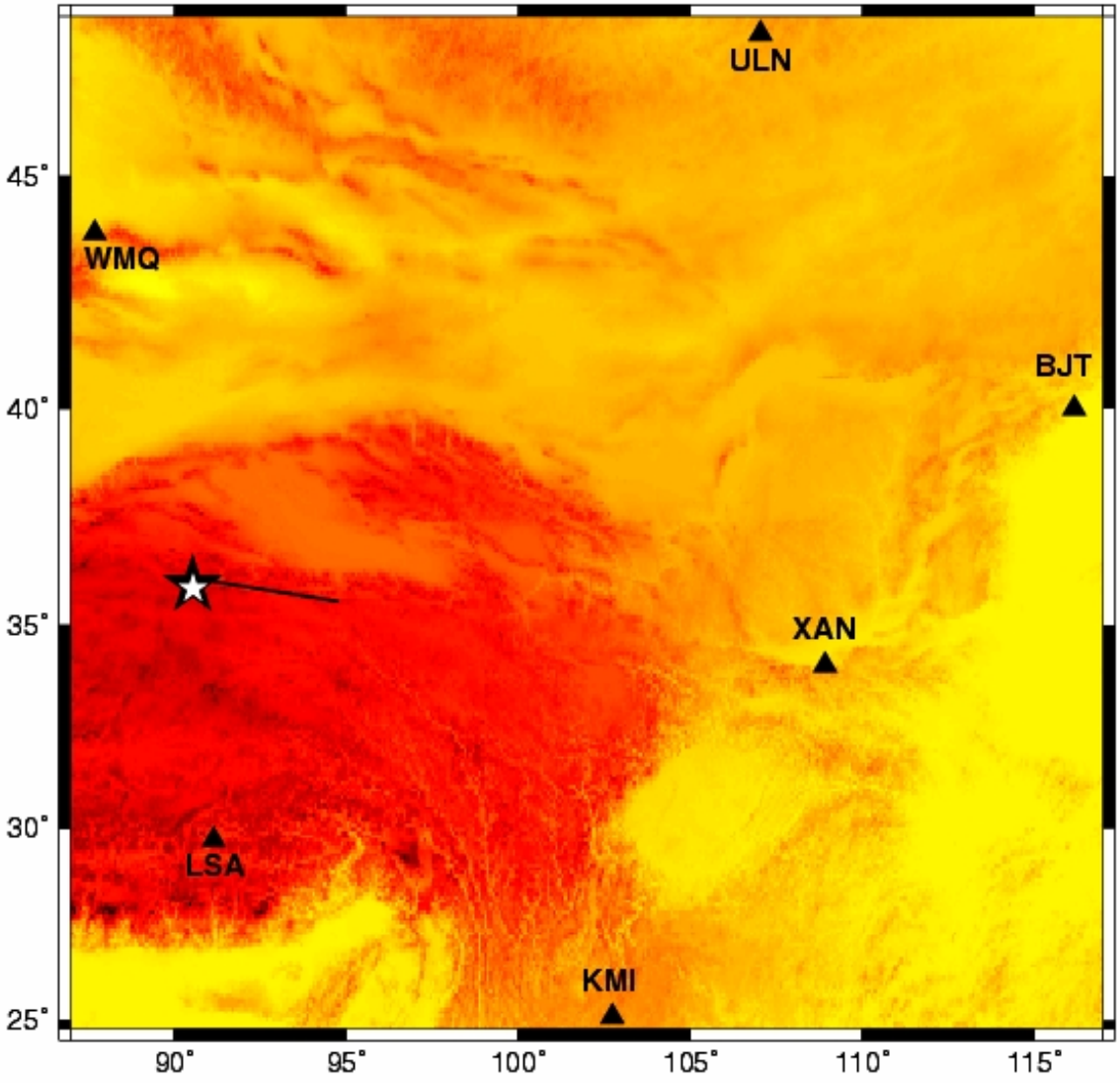
Hernandez, Cotton & Campillo, 1999

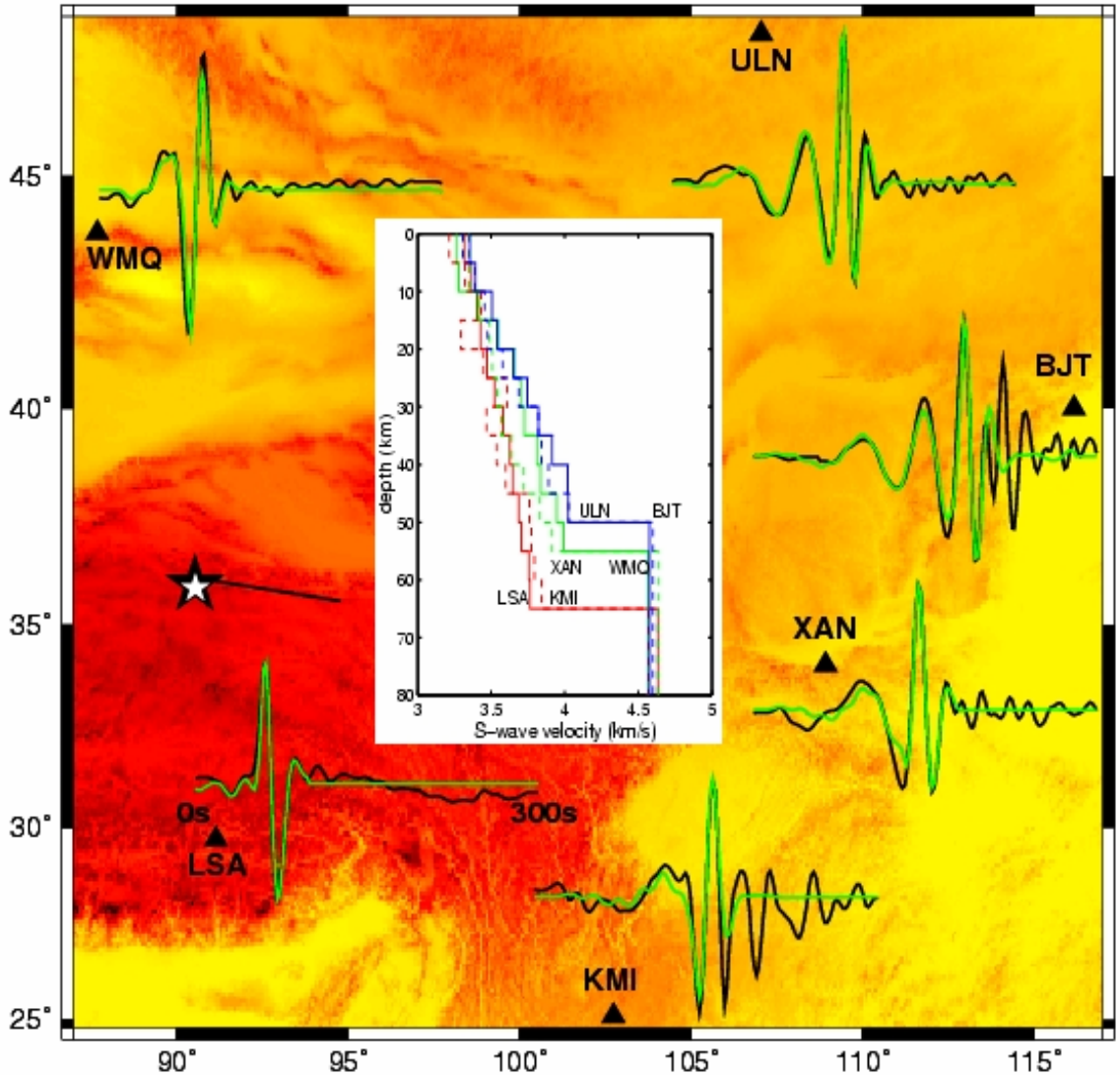
2001 Ms=8.1 Kunlun

Xinhua news agency

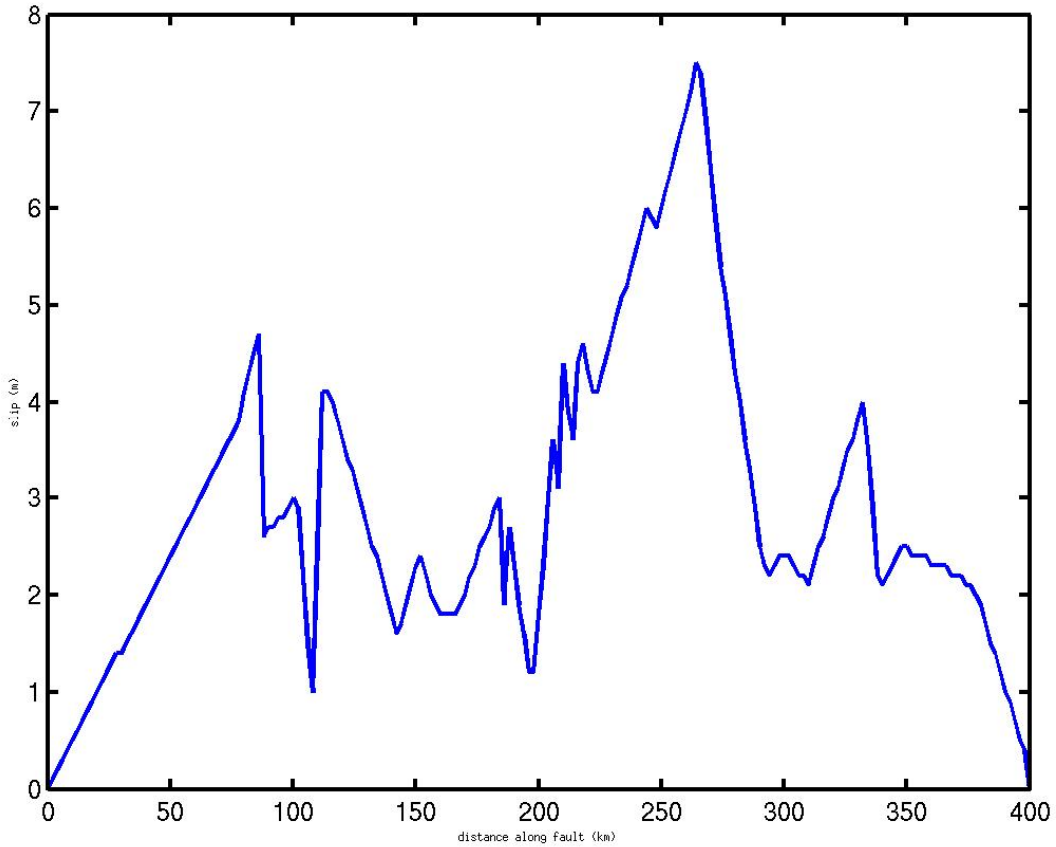

ULN
WMQ
BJT
XAN
LSA
KMI
45°
40°
35°
30°
25°
90°
95°
100°
105°
110°
115°

Look for complementary information:

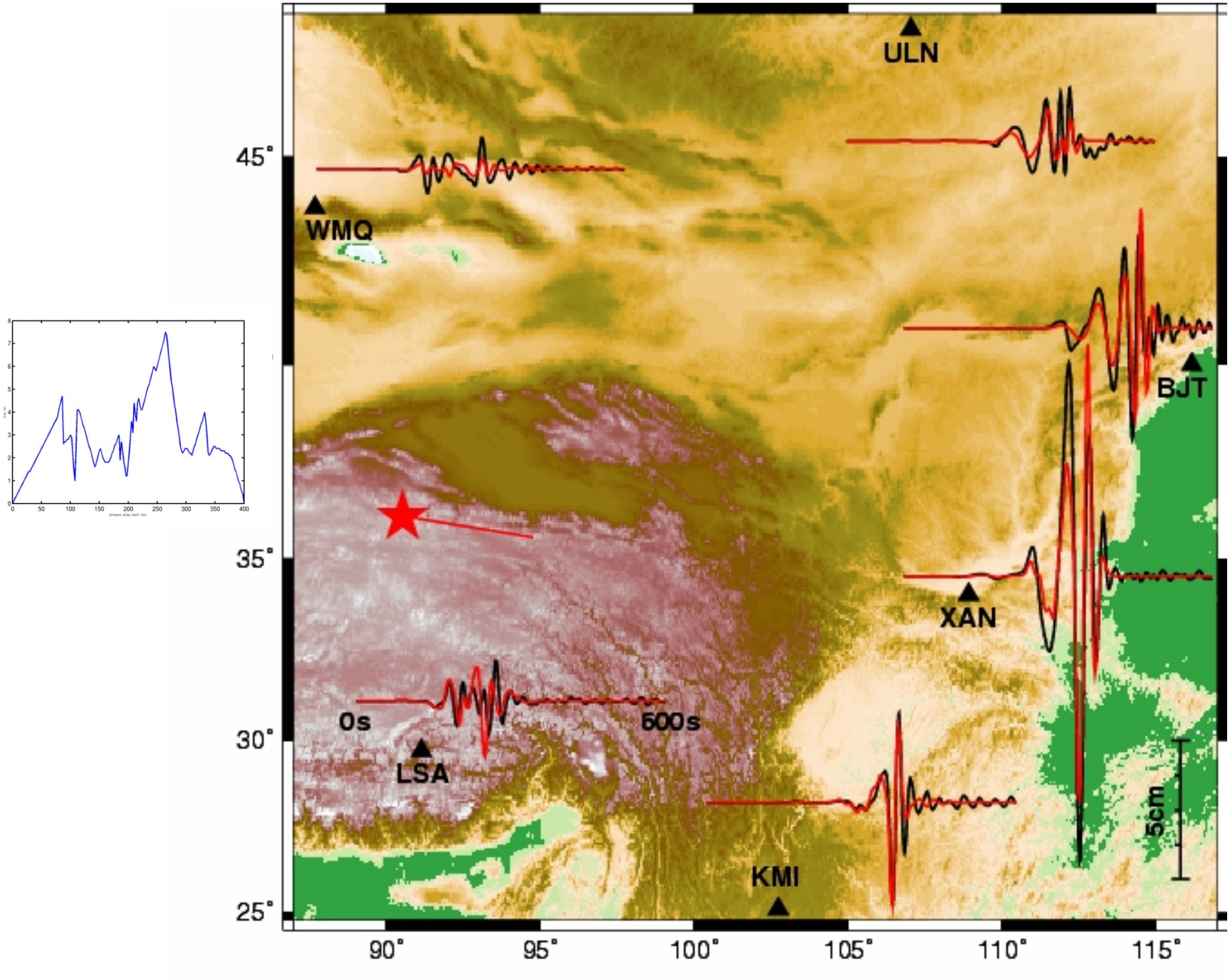


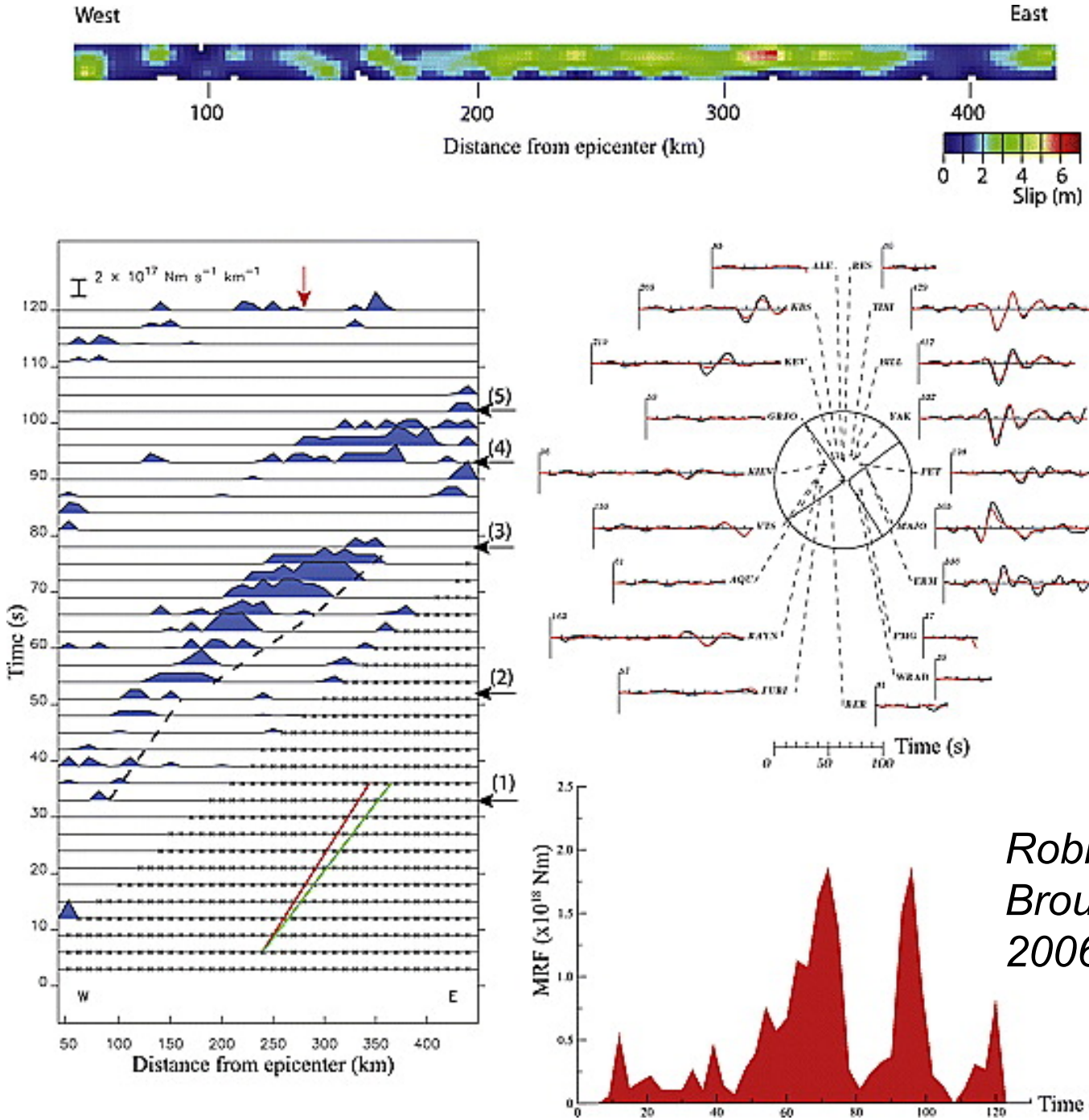

ULN
WMQ
BJT
XAN
LSA
KMI
0s
300s
45°
40°
35°
30°
25°
90°
95°
100°
105°
110°
115°
depth (km)
S–wave velocity (km/s)
ULN
BJT
XAN
WMQ
LSA
KMI

Measured Surface slip

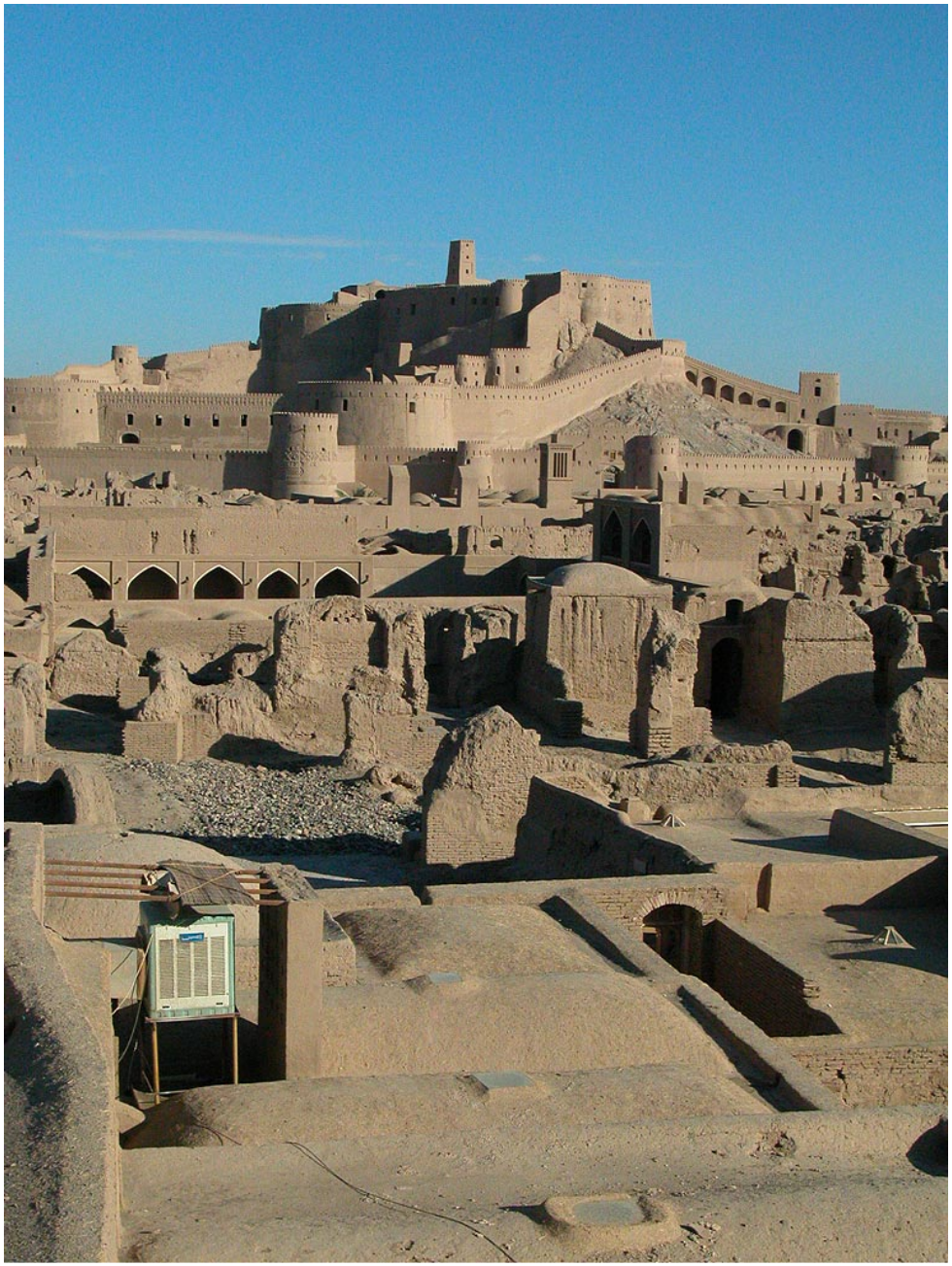


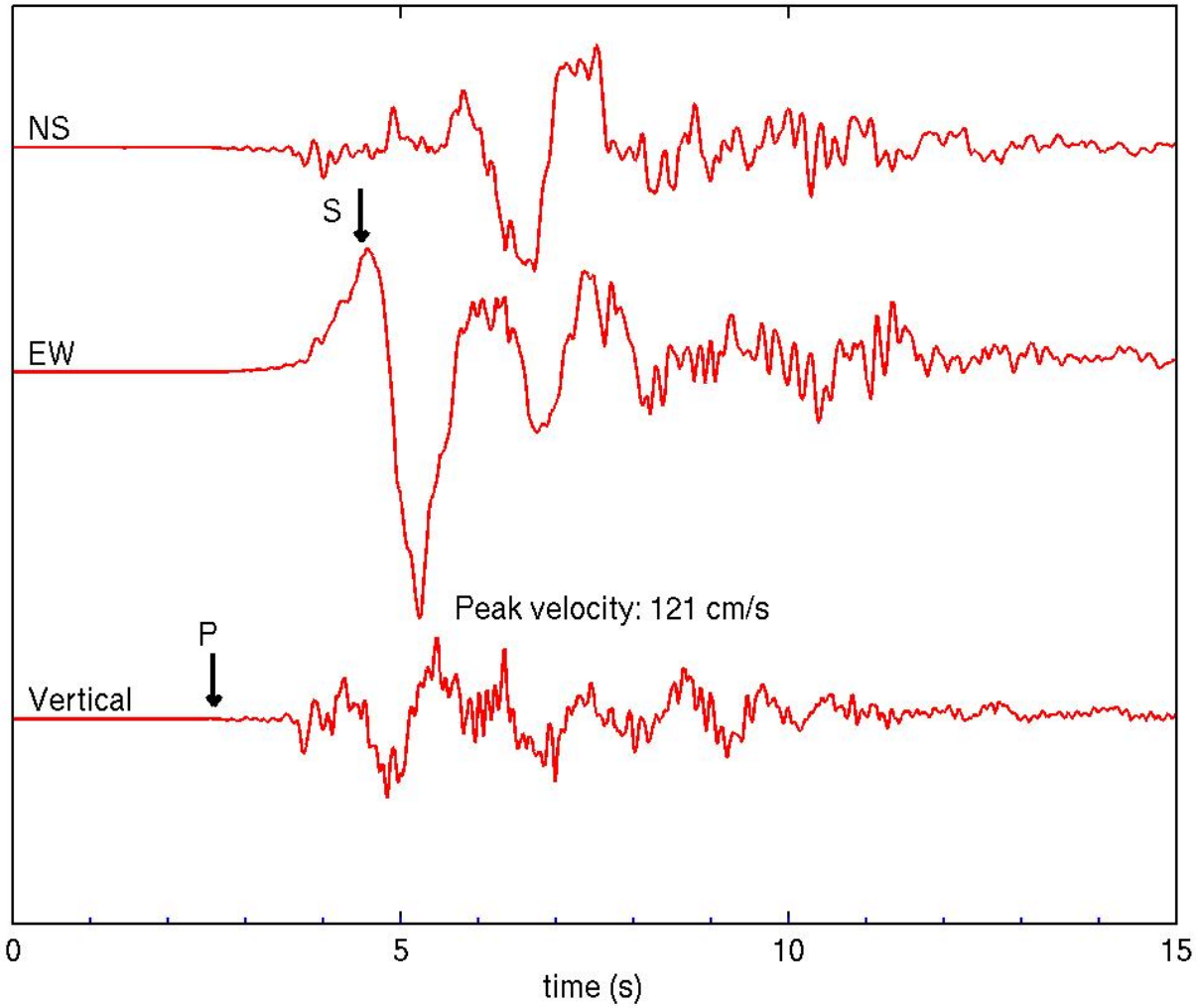
Distance along the fault

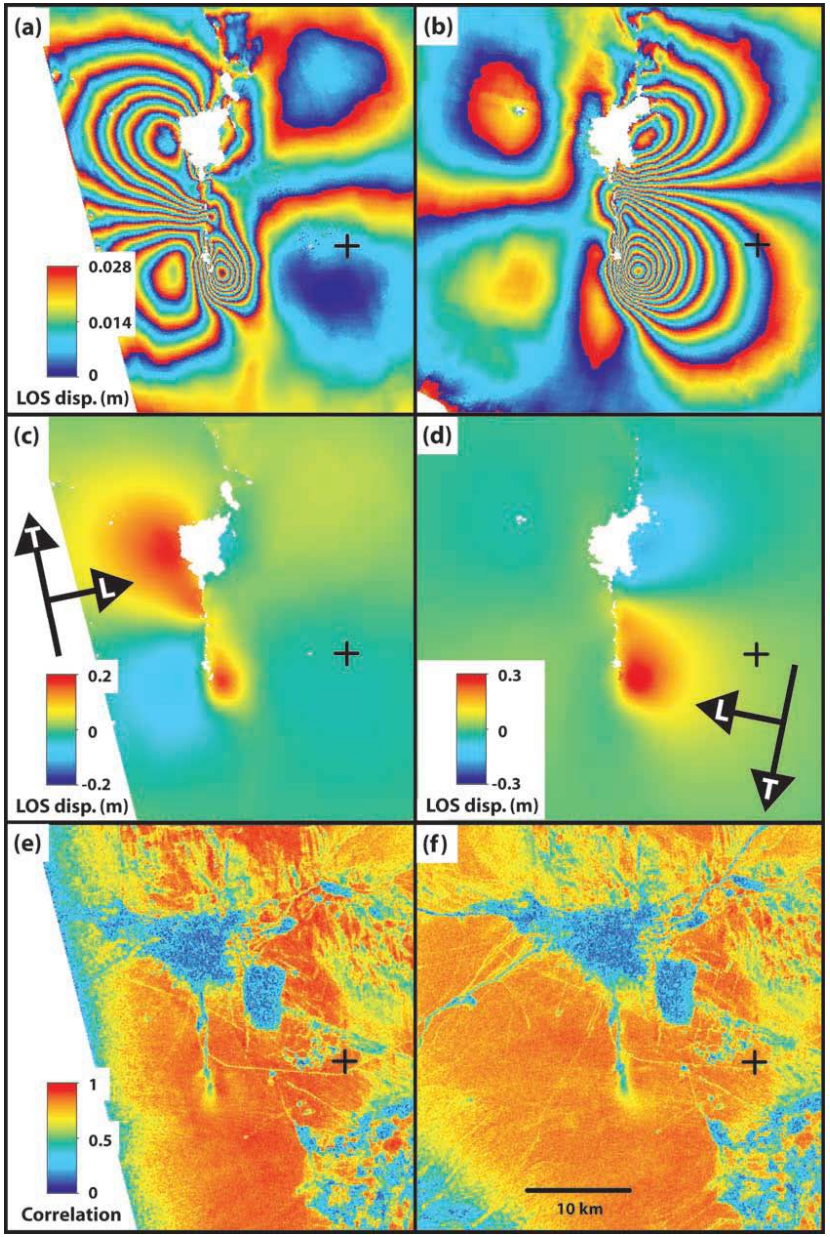

ULN
WMQ
BJT
XAN
LSA
KMI
0s
600s
5cm
45°
35°
30°
25°
90°
95°
100°
105°
110°
115°



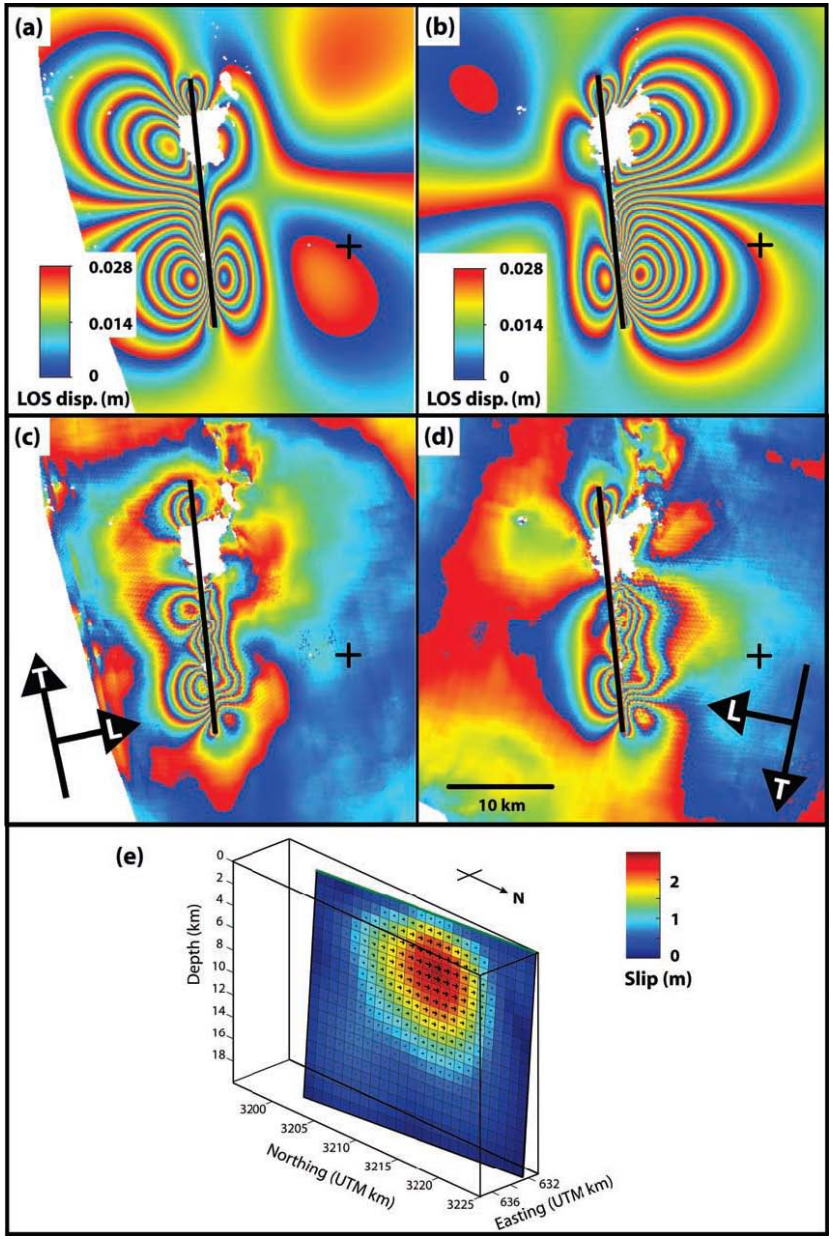
Robinson, Brough and Das, 2006



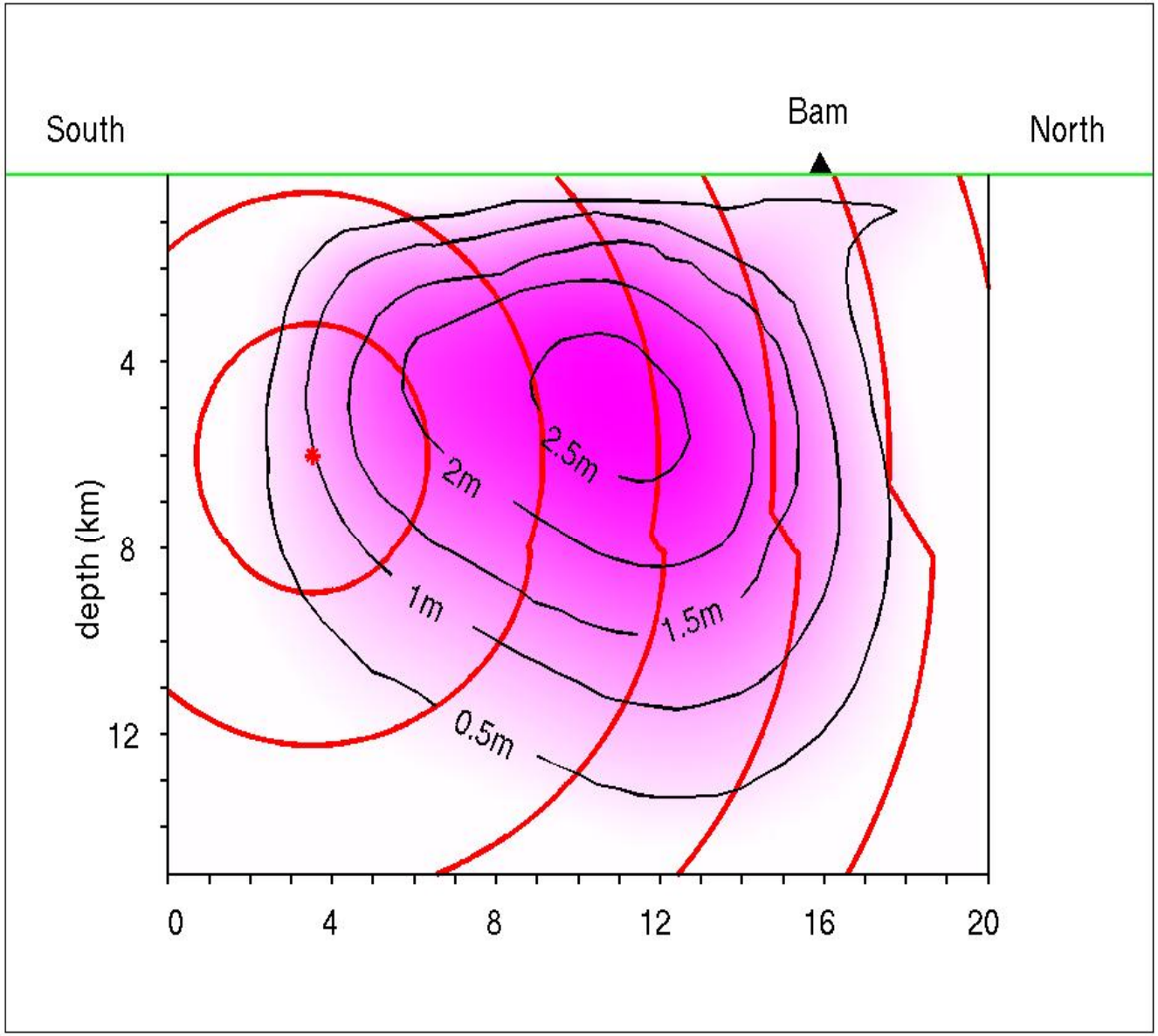

NS
S
EW
Peak velocity: 121 cm/s
P
Vertical
0
5
10
15
time (s)

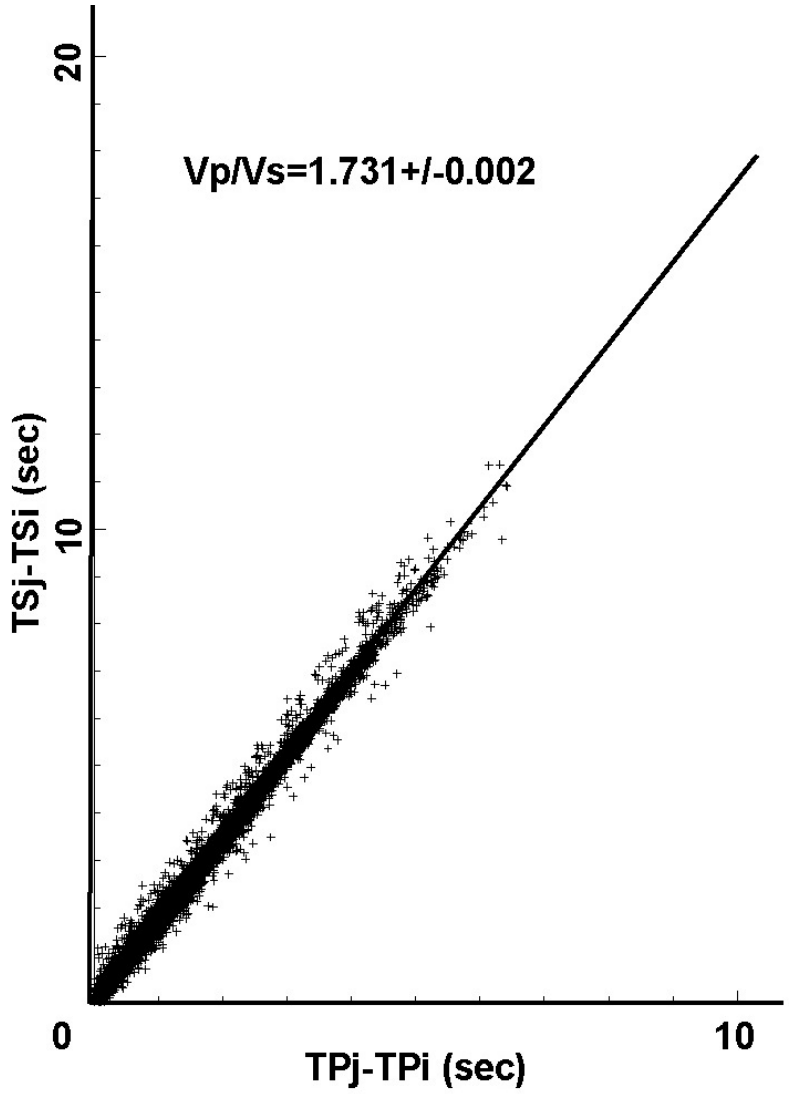


Funning et al. (2005)

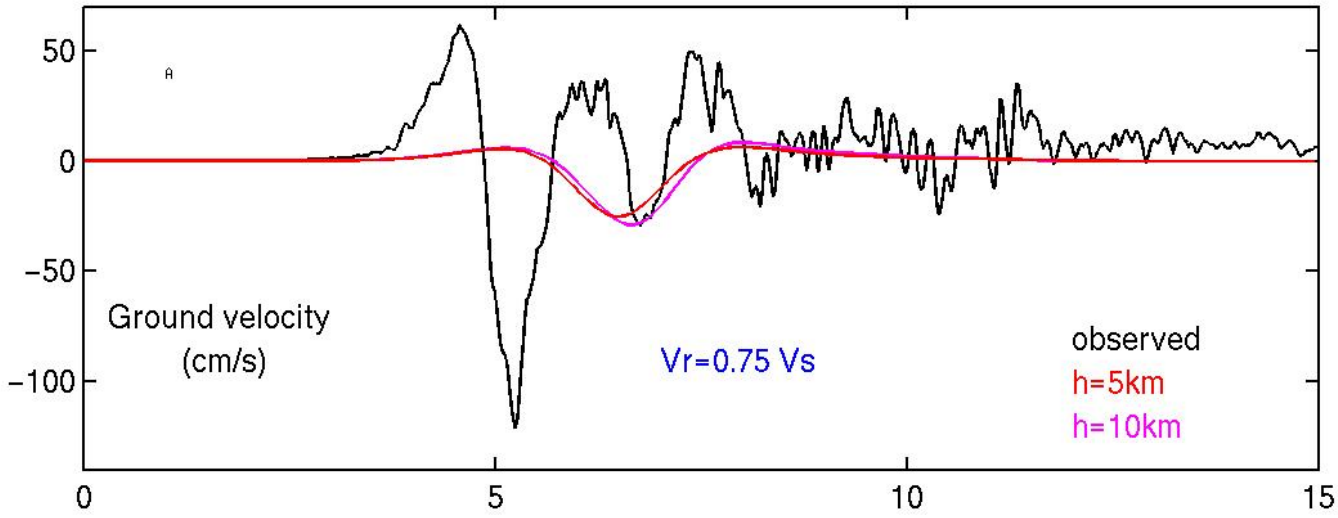


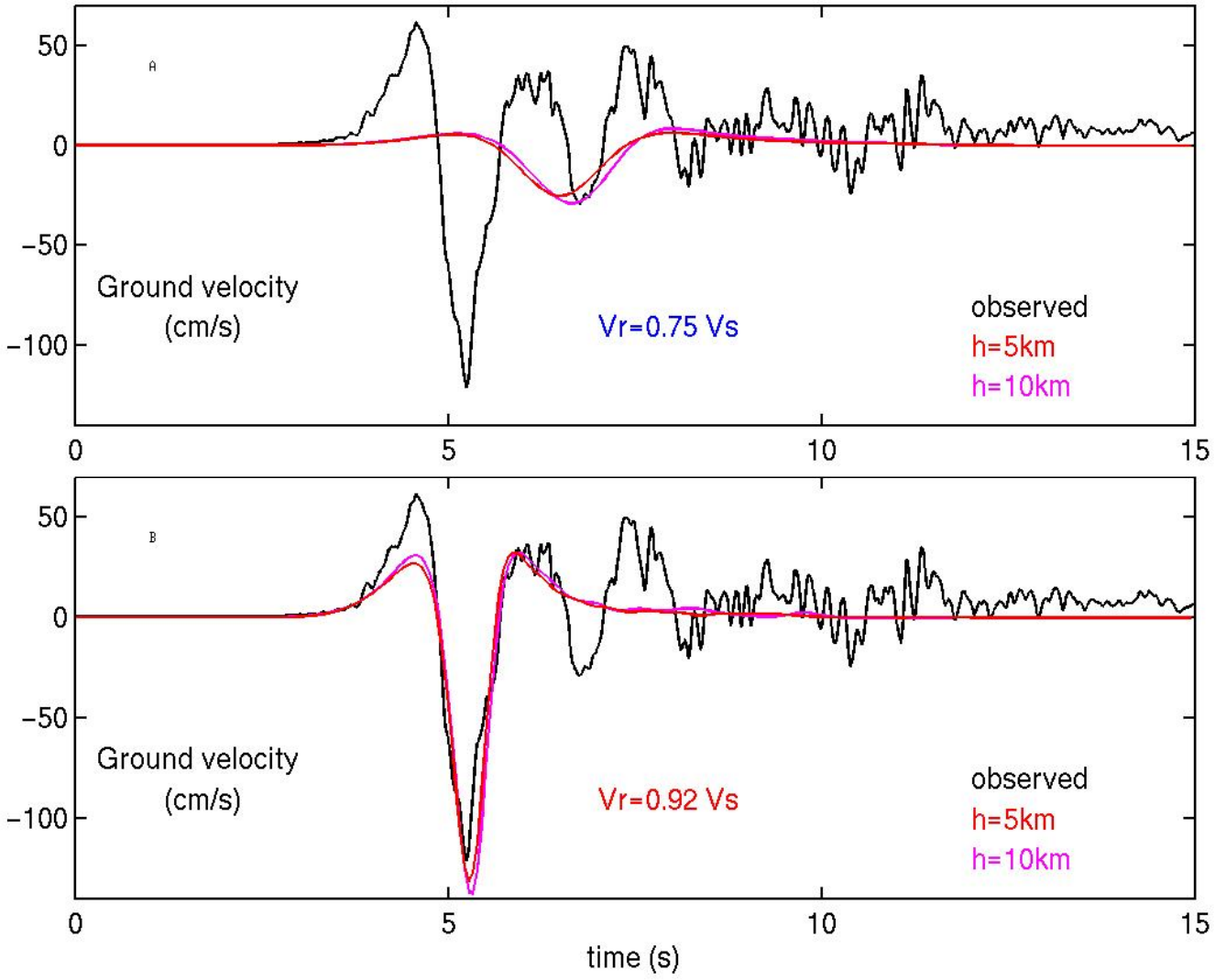
Funning et al. (2005)

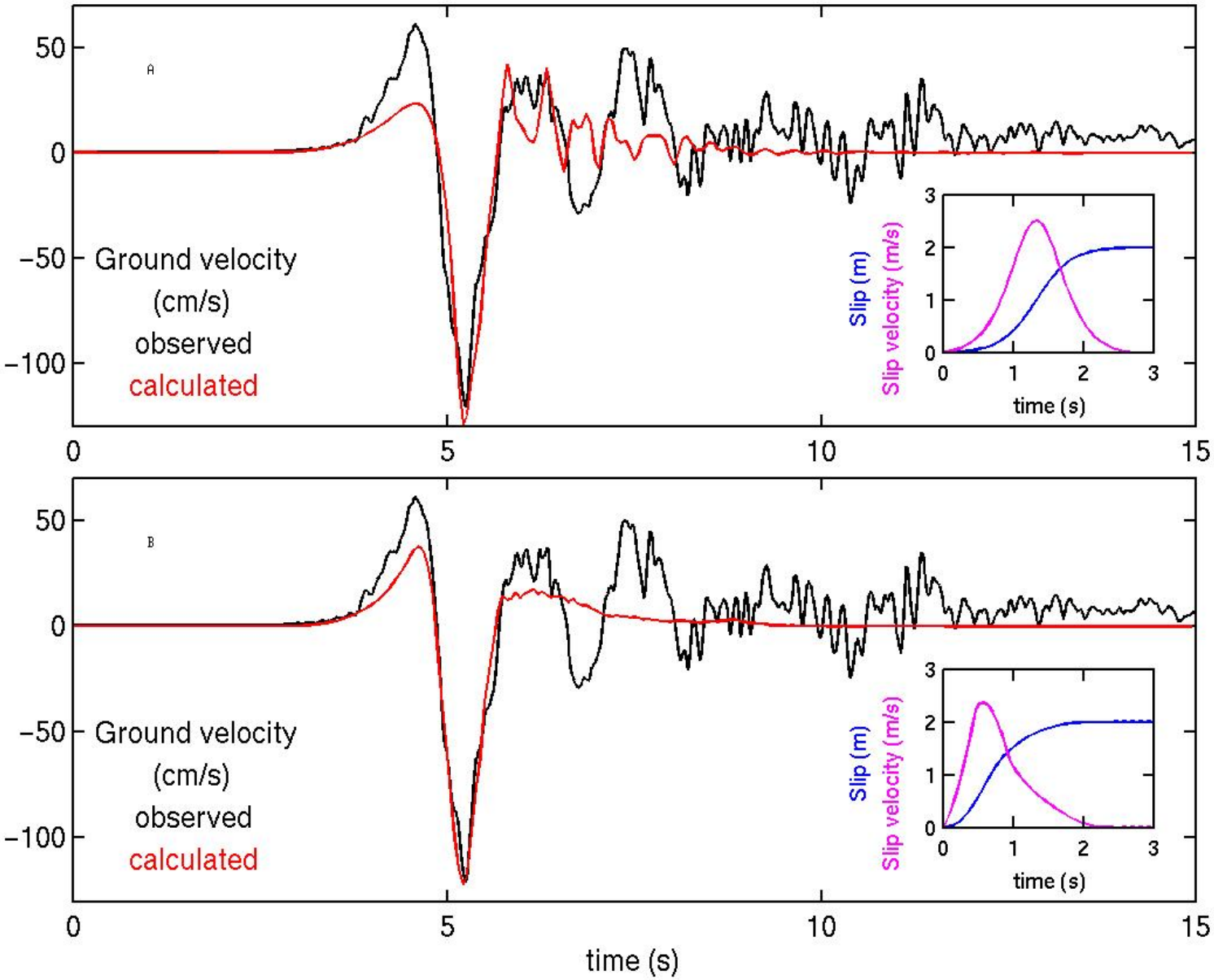

South
Bam
North
depth (km)
4
8
12
0
4
8
12
16
20
2m
2.5m
1m
1.5m
0.5m

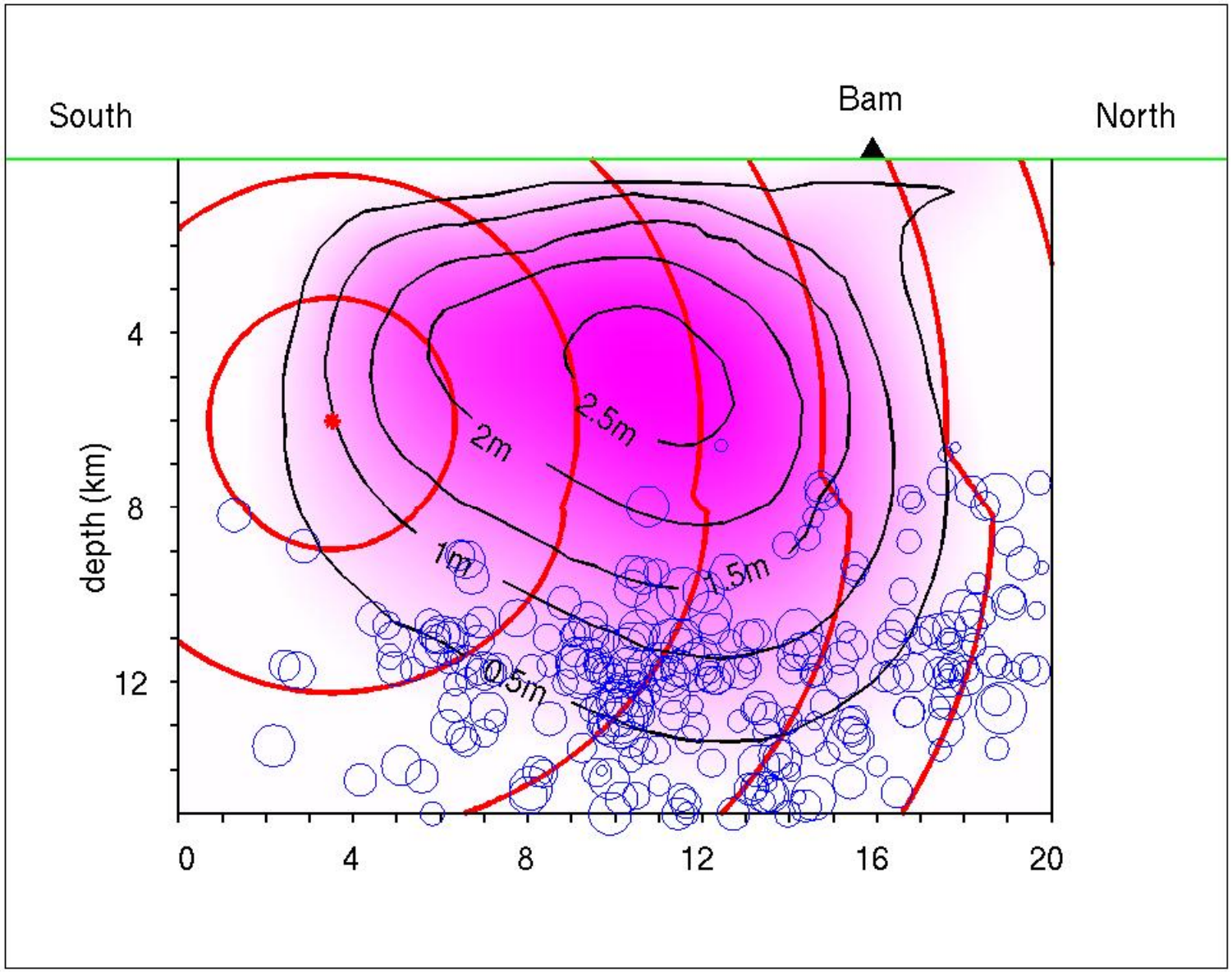


Tatar et al. (2005)


A
50
0
−50
−100
0
5
10
15
Ground velocity
(cm/s)
Vr=0.75 Vs
observed
h=5km
h=10km

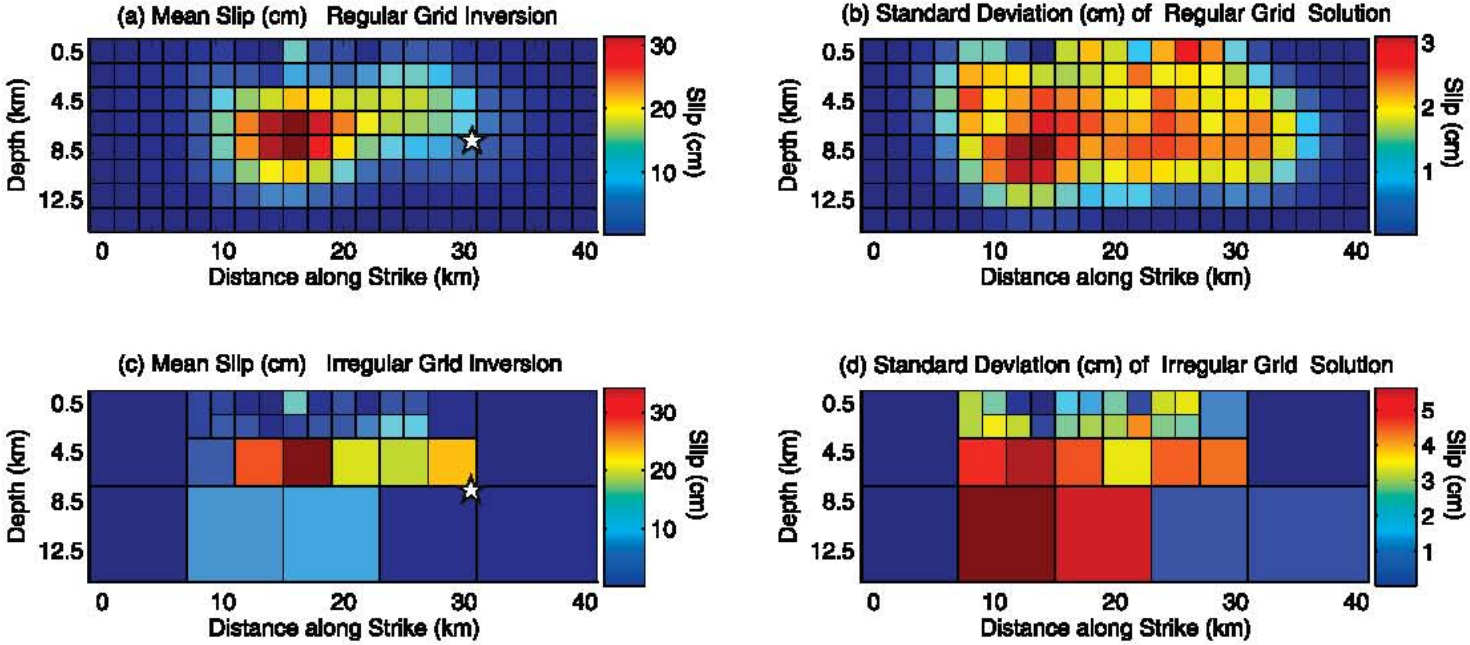

A
50
0
−50
−100
Ground velocity
(cm/s)
Vr=0.75 Vs
observed
h=5km
h=10km
0
5
10
15
B
50
0
−50
−100
Ground velocity
(cm/s)
Vr=0.92 Vs
observed
h=5km
h=10km
0
5
10
15
time (s)


A
B
50
0
−50
−100
Ground velocity
(cm/s)
observed
calculated
0
5
10
15
time (s)
Slip (m)
Slip velocity (m/s)
3
2
1
0
0
1
2
3
time (s)

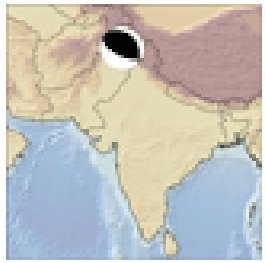

South
Bam
North
depth (km)
4
8
12
0
4
8
12
16
20
2m
2.5m
1m
1.5m
0.5m

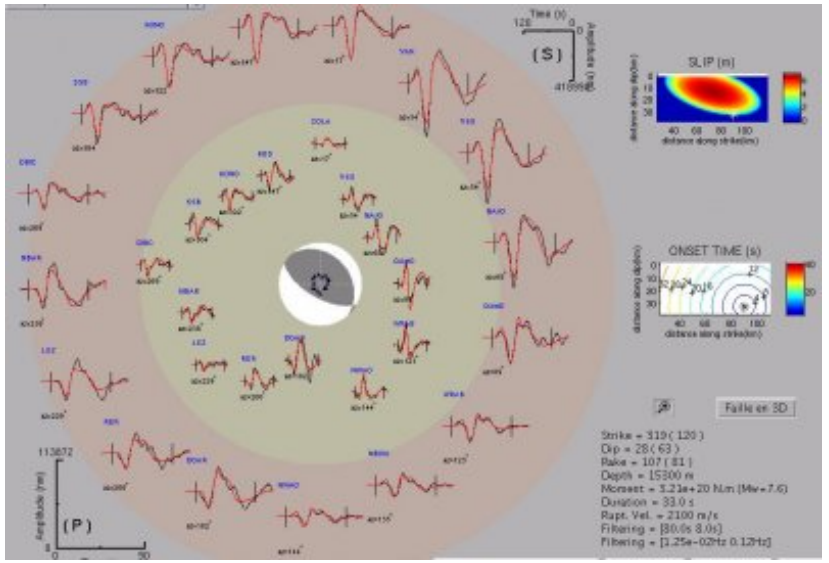
Limit the number of model parameters

2004 Mw 6.0 Parkfield

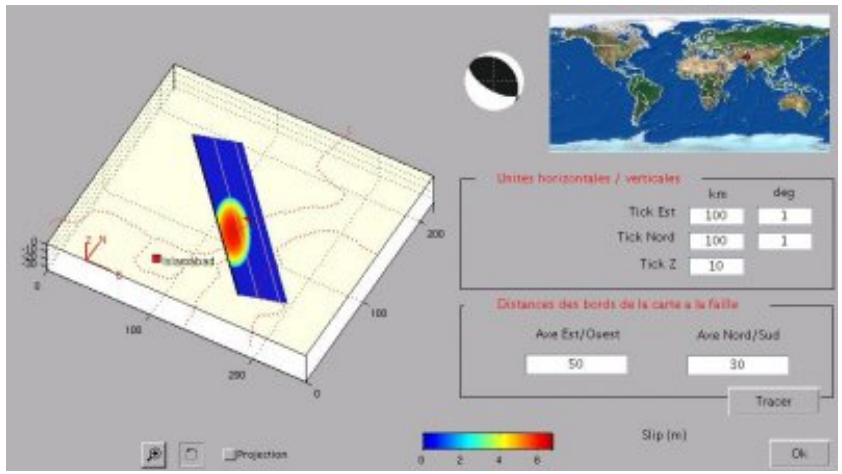


Page et al., 2009



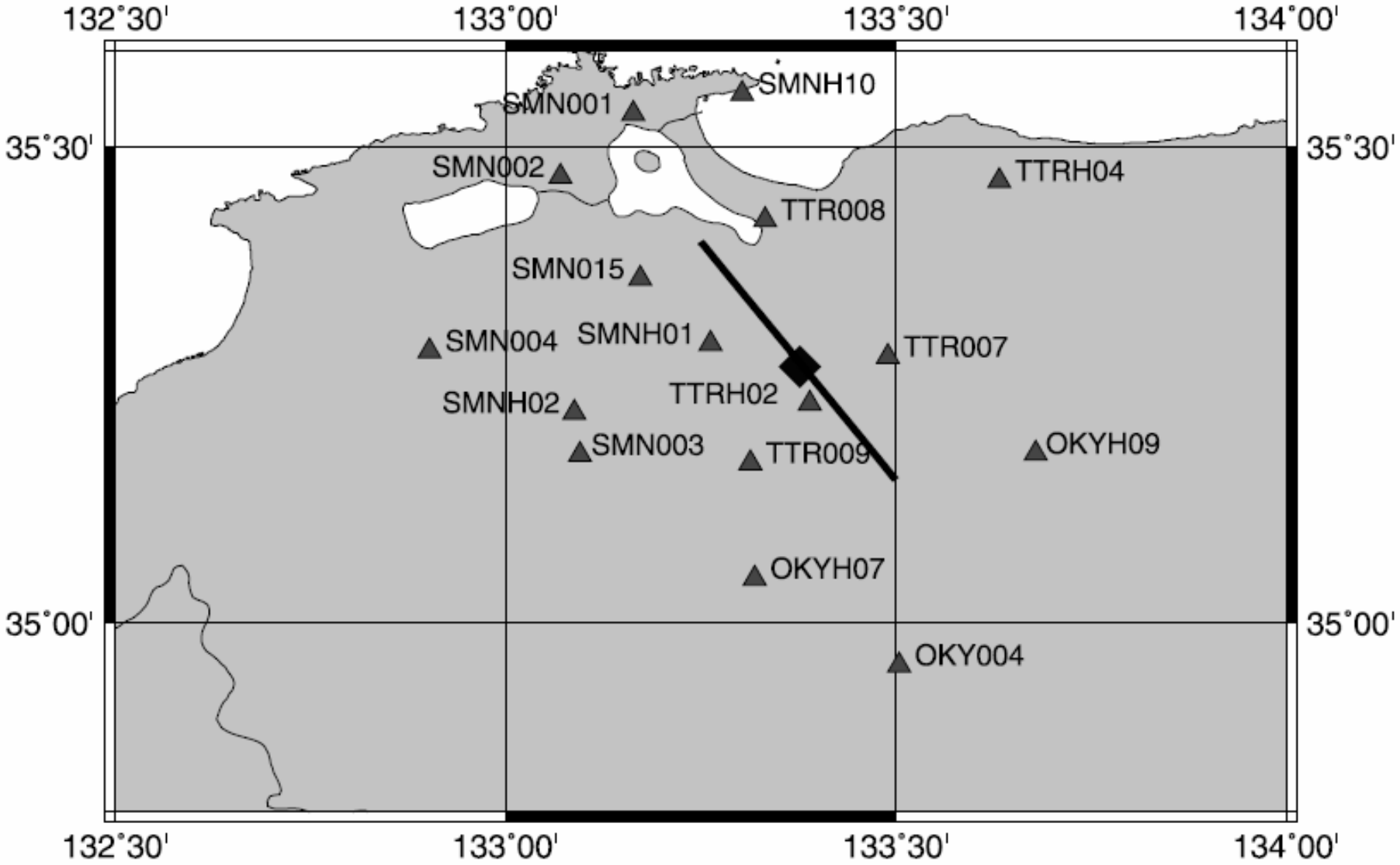


M 7.7 Pakistan earthquake (2005)
Near Real Time Inversion of Broadband Records

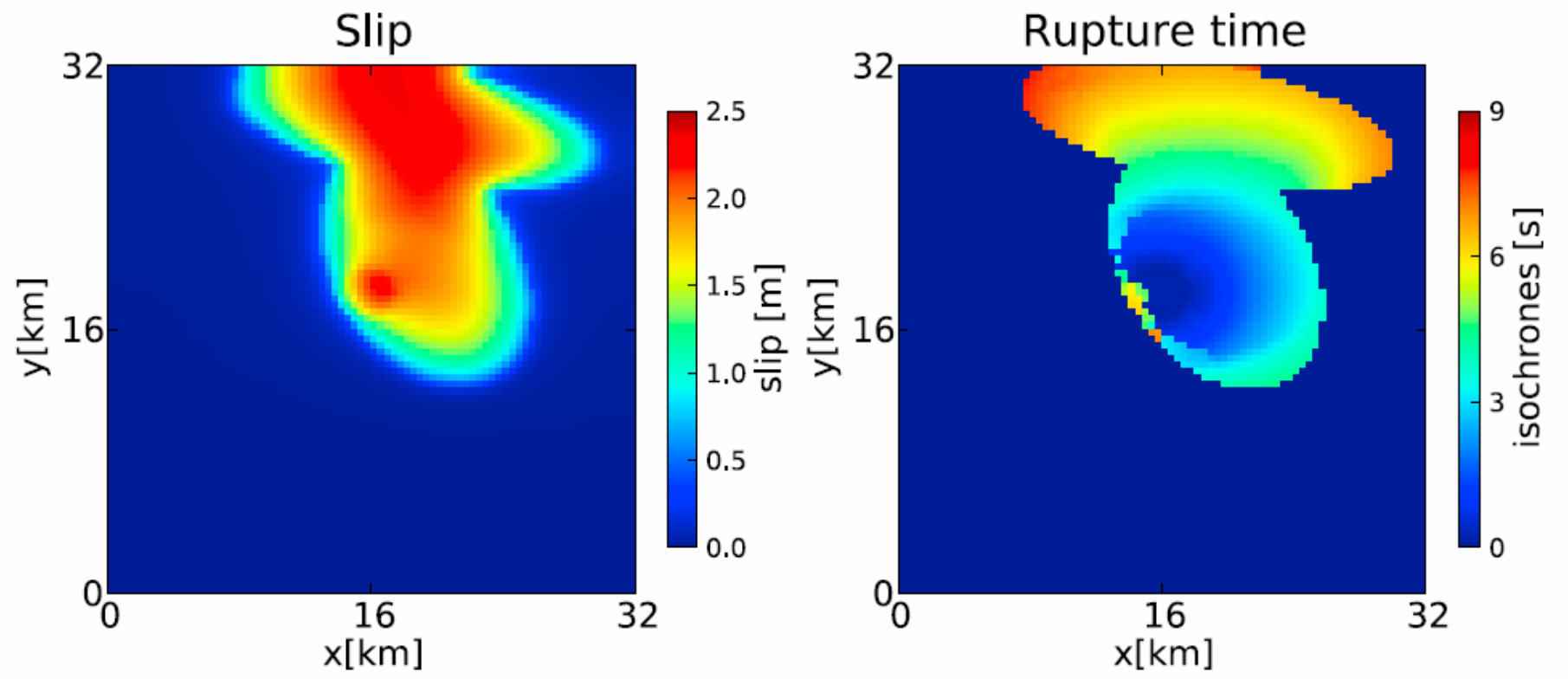


Vallée (geoazur)

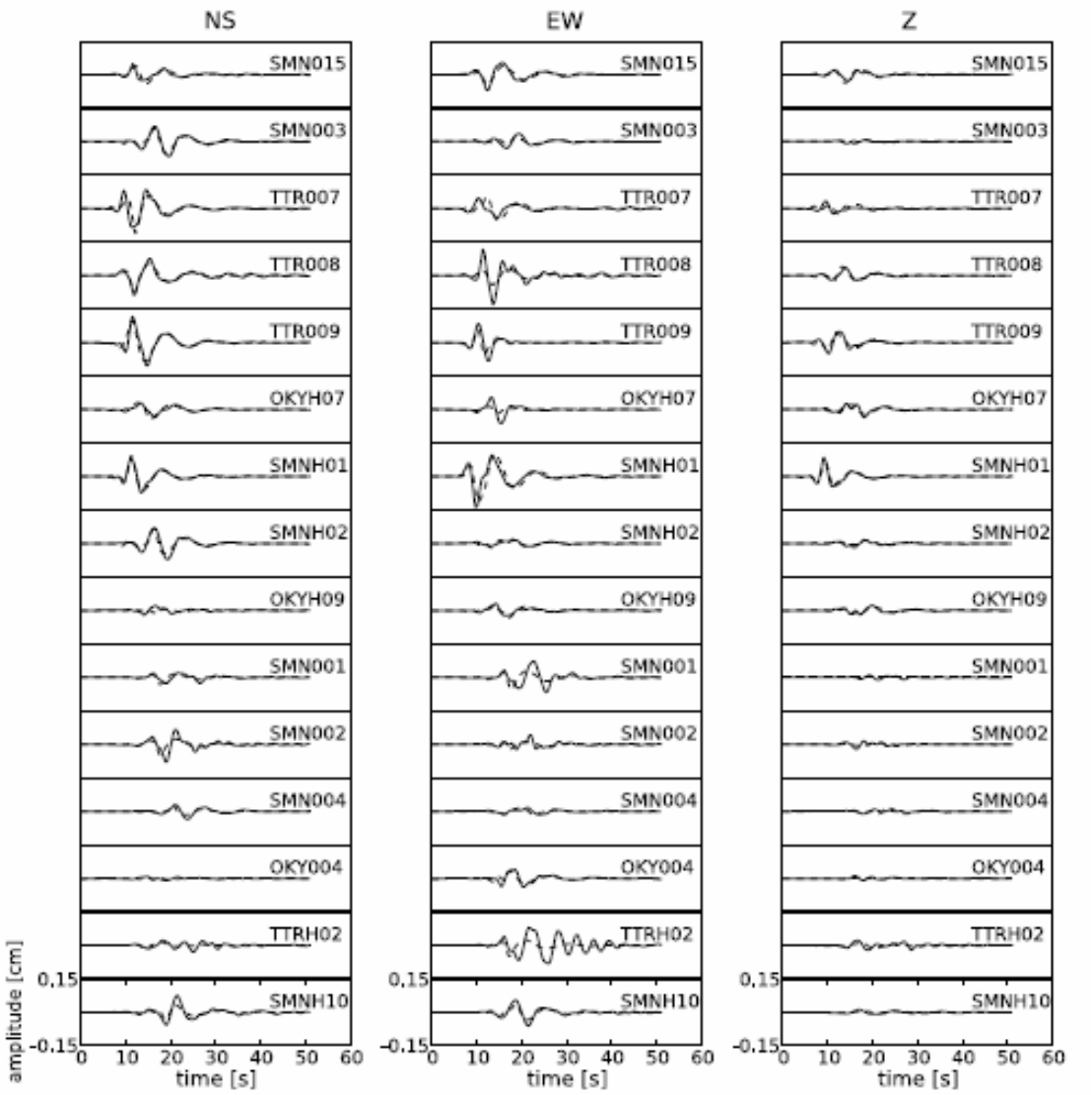
Mw 6.8 Tottori earthquake



Di Carli et al, 2009



Di Carli et al, 2009



Di Carli et al, 2009

- The most « robust » characteristics of the source are generally contained in the early low-frequency low-amplitude part of the accelerometric or seismic records. This part contains the near-field and intermediate-field terms (close to the fault) or the W phase (at teleseismic distance).

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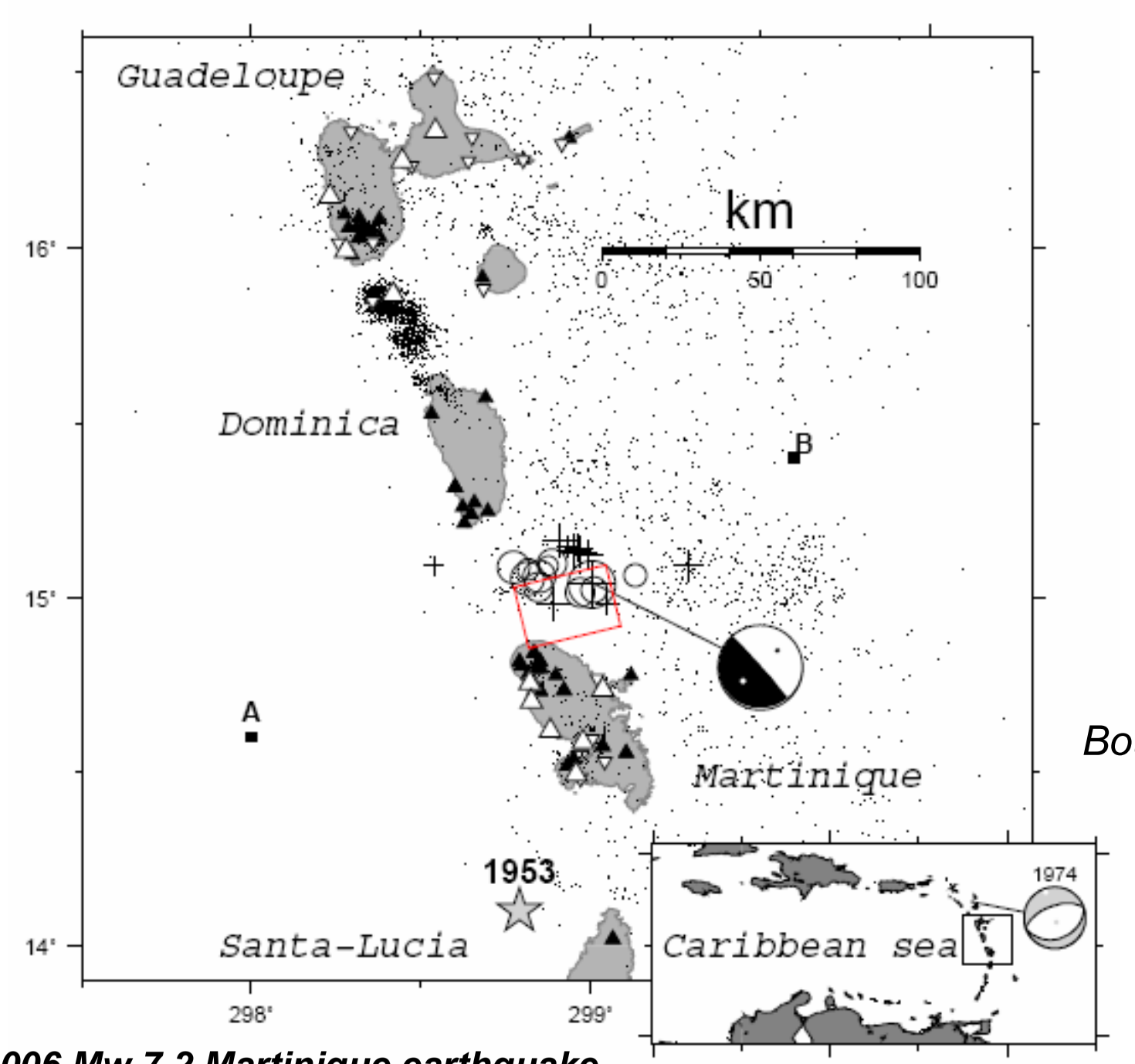
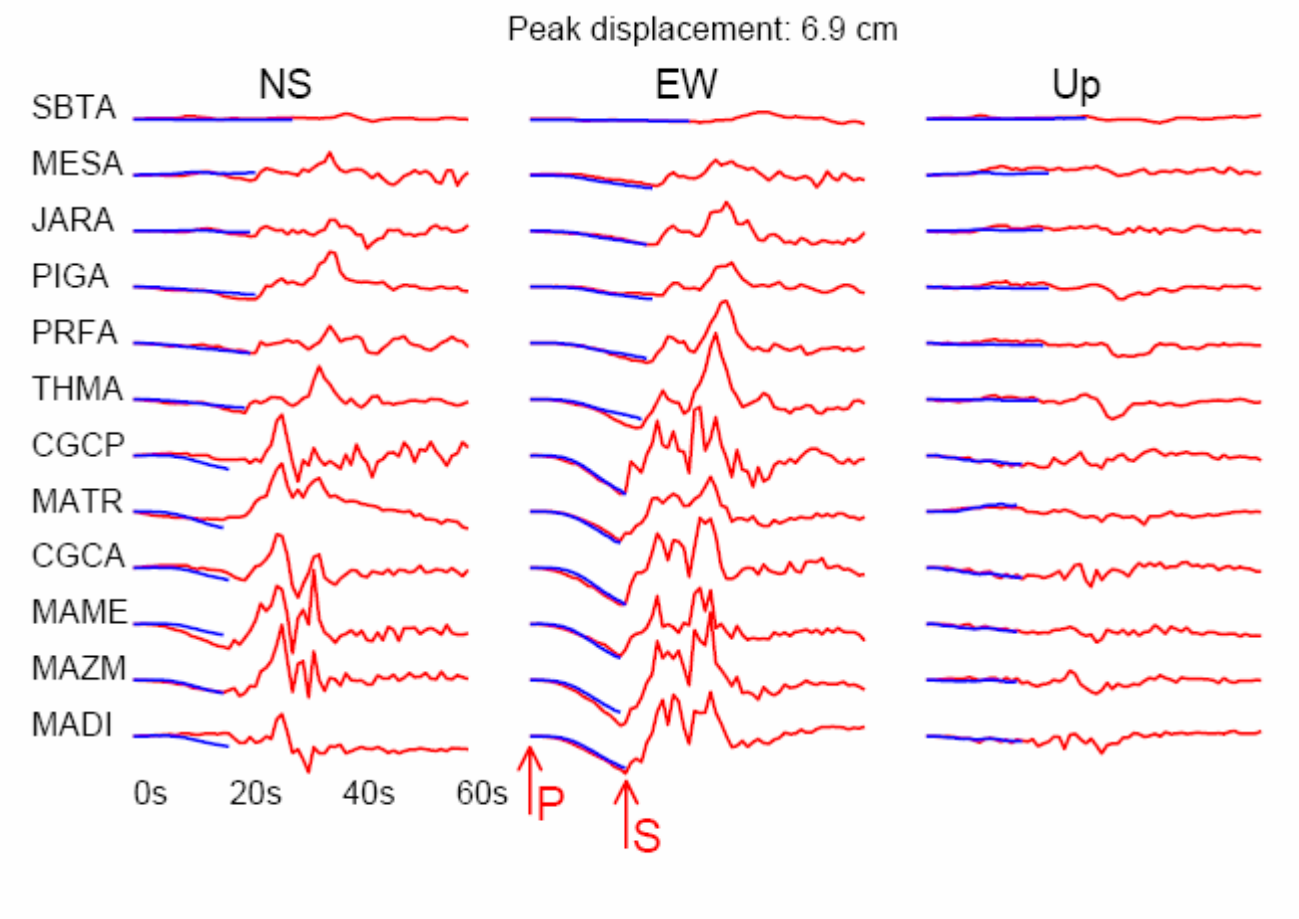
- A blind inversion may poorly resolve the fundamental characteristics of the source, and instead provide apparent details of the rupture which are meaningless.

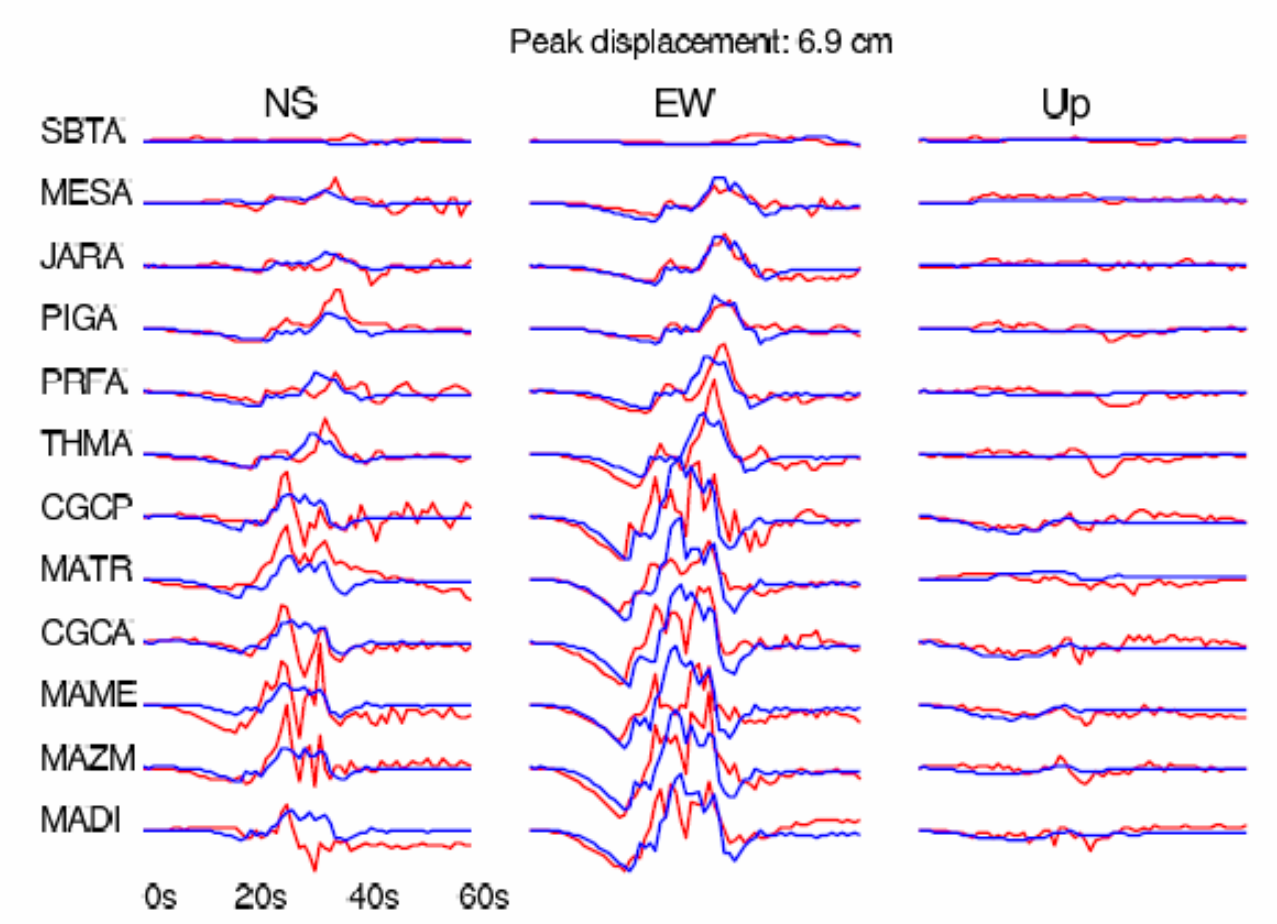


Bouin et al.

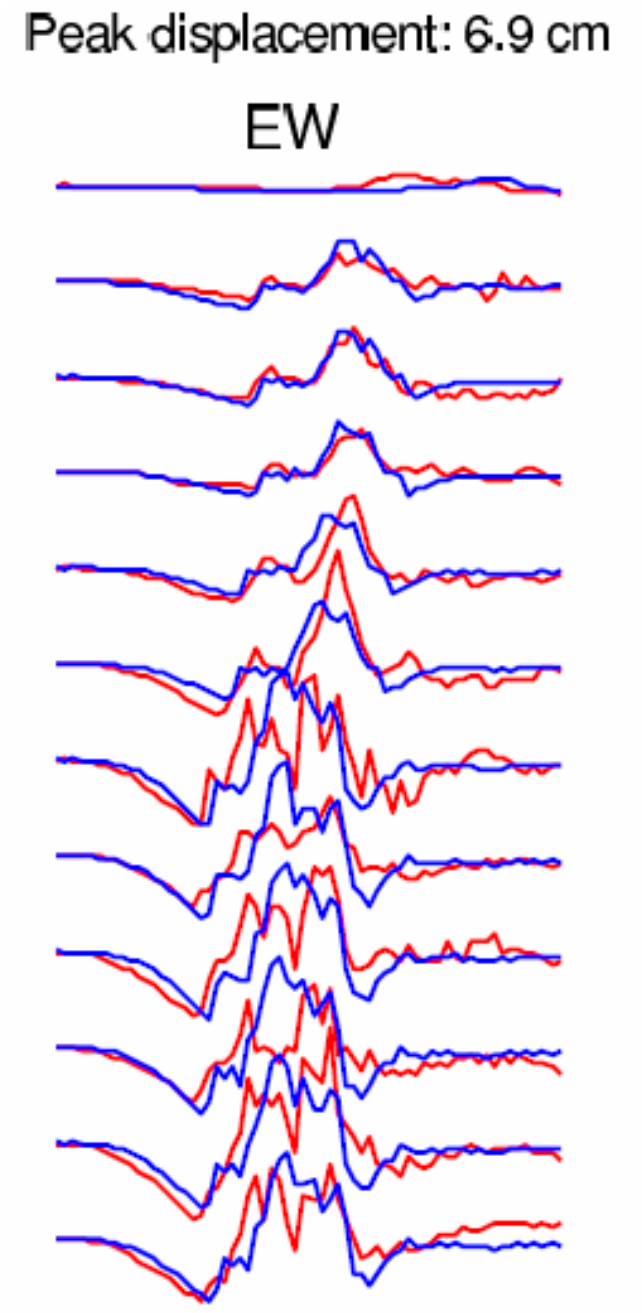
The 2006 Mw 7.2 Martinique earthquake



We first invert the near and intermediate field which contains the robust characteristics of the source: Strike, Dip, Rake, Seismic Moment.

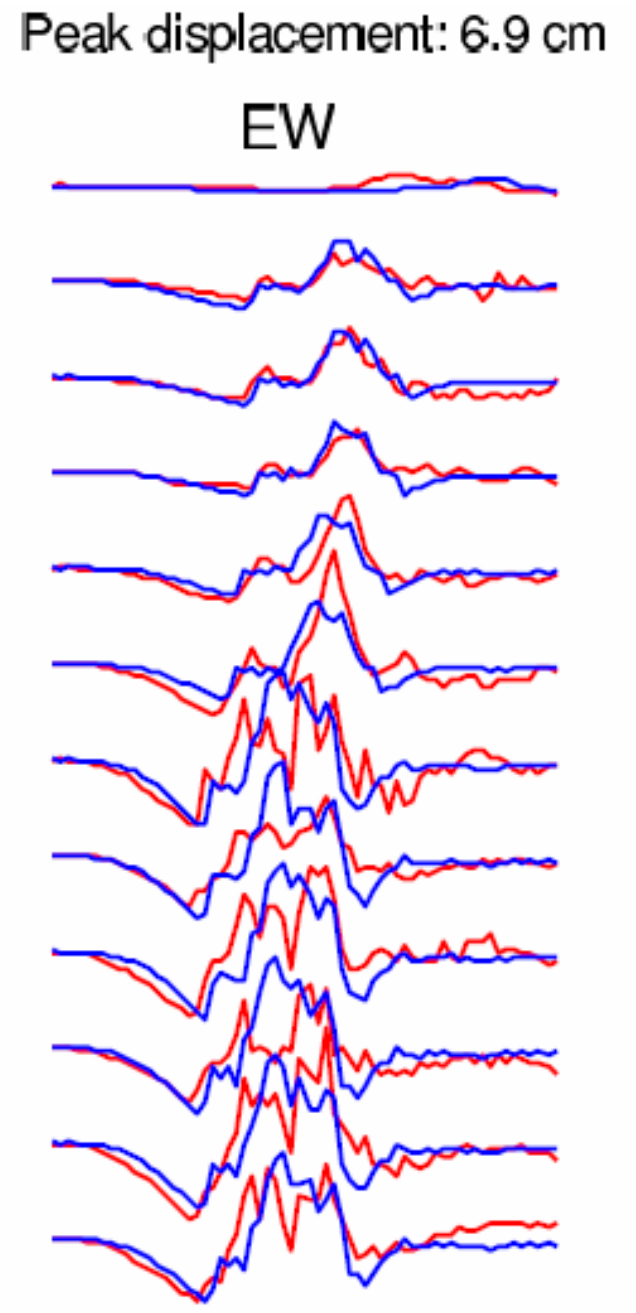


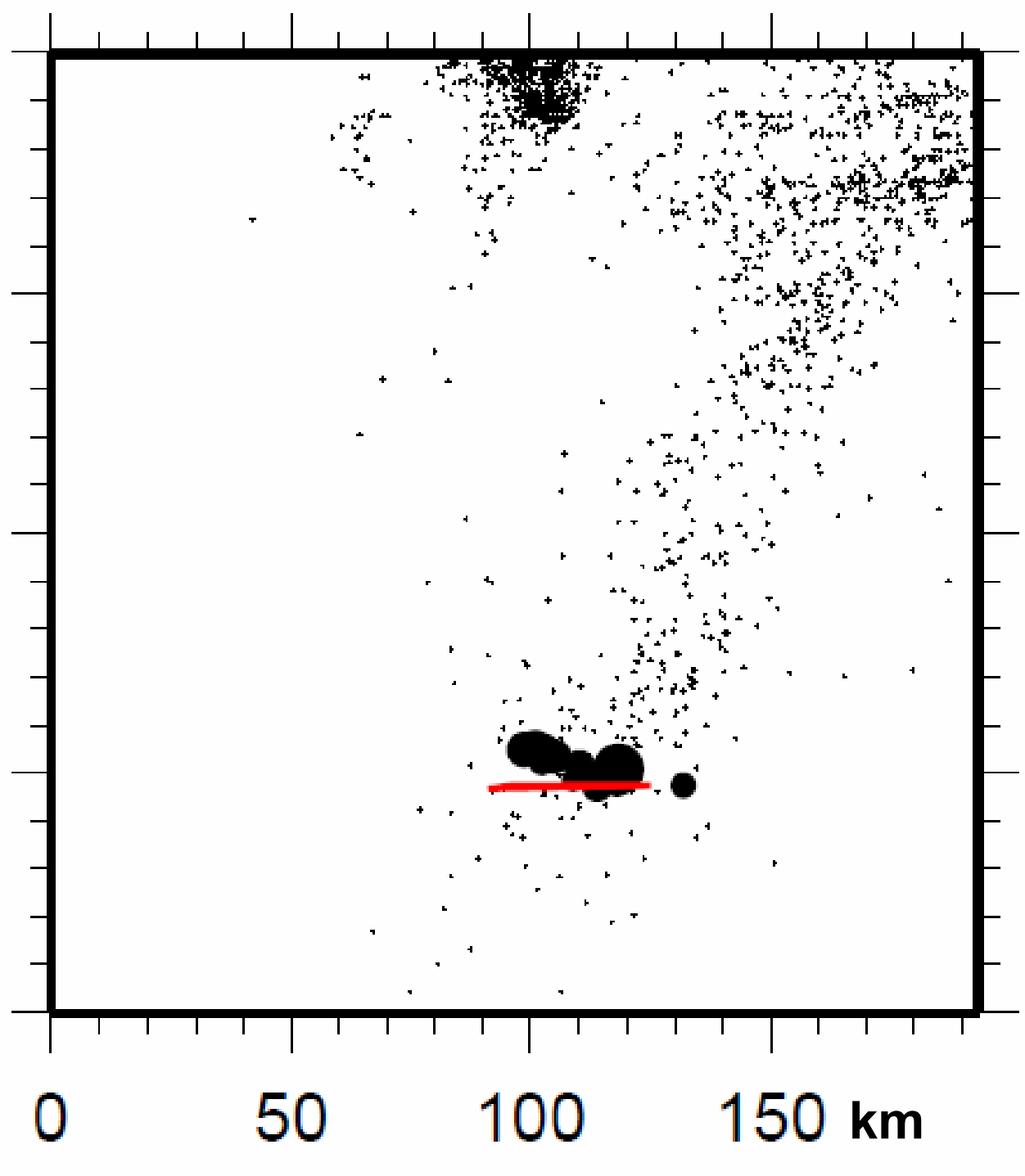
We then determine the Fault Length, Fault Width, Rupture Velocity and Rise Time, which best fit the records.


Peak displacement: 6.9 cm
EW

Inverting for more model parameters could eventually yield a perfect fit

but the details of the model would be highly non-unique





Bouin et al.