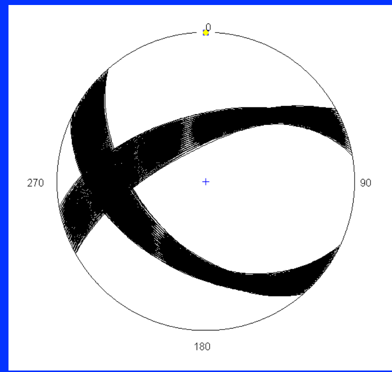
Can OBS networks help constrain moment tensor inversions? Examples from Portugal.



S. Custódio[1] and J. Zahradník[2]

(1) University of Coimbra, Portugal
(2) Charles University in Prague, Czech Republic

Introduction

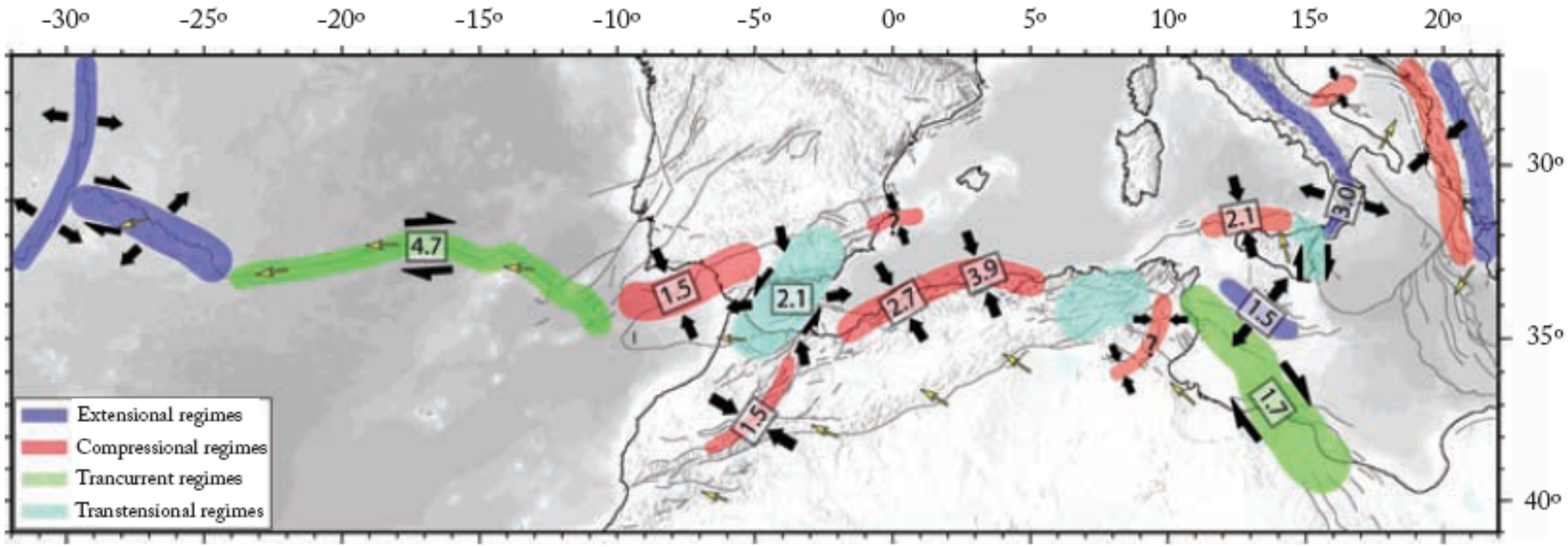
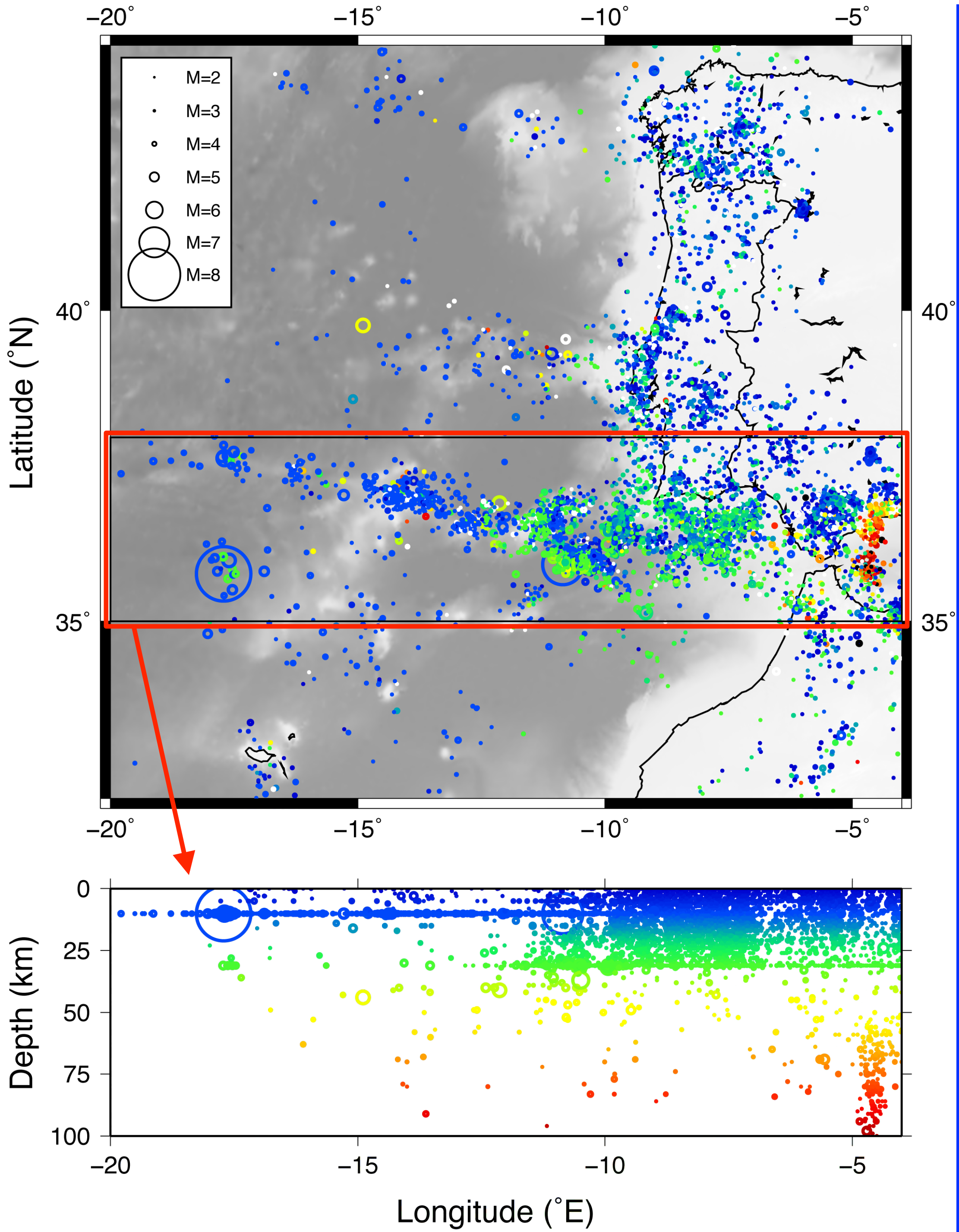


Figure 3.1: Present-day tectonic sketch of the Nubia-Eurasia boundary. Deformation rates are in mm/year. Figure from *Serpelloni et al.* [2007].

Instrumental Seismicity (post 1960)

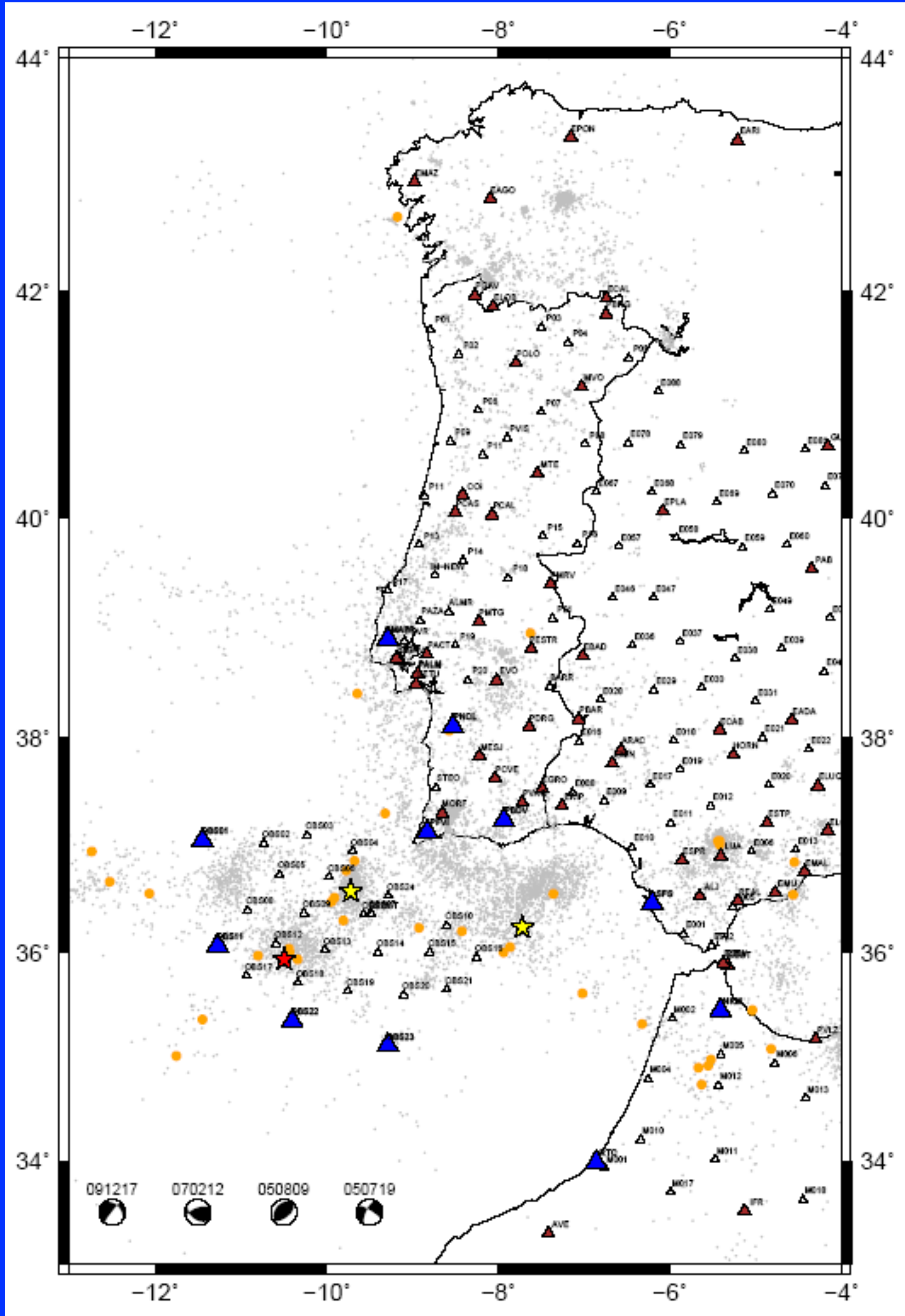
Portuguese IM catalog

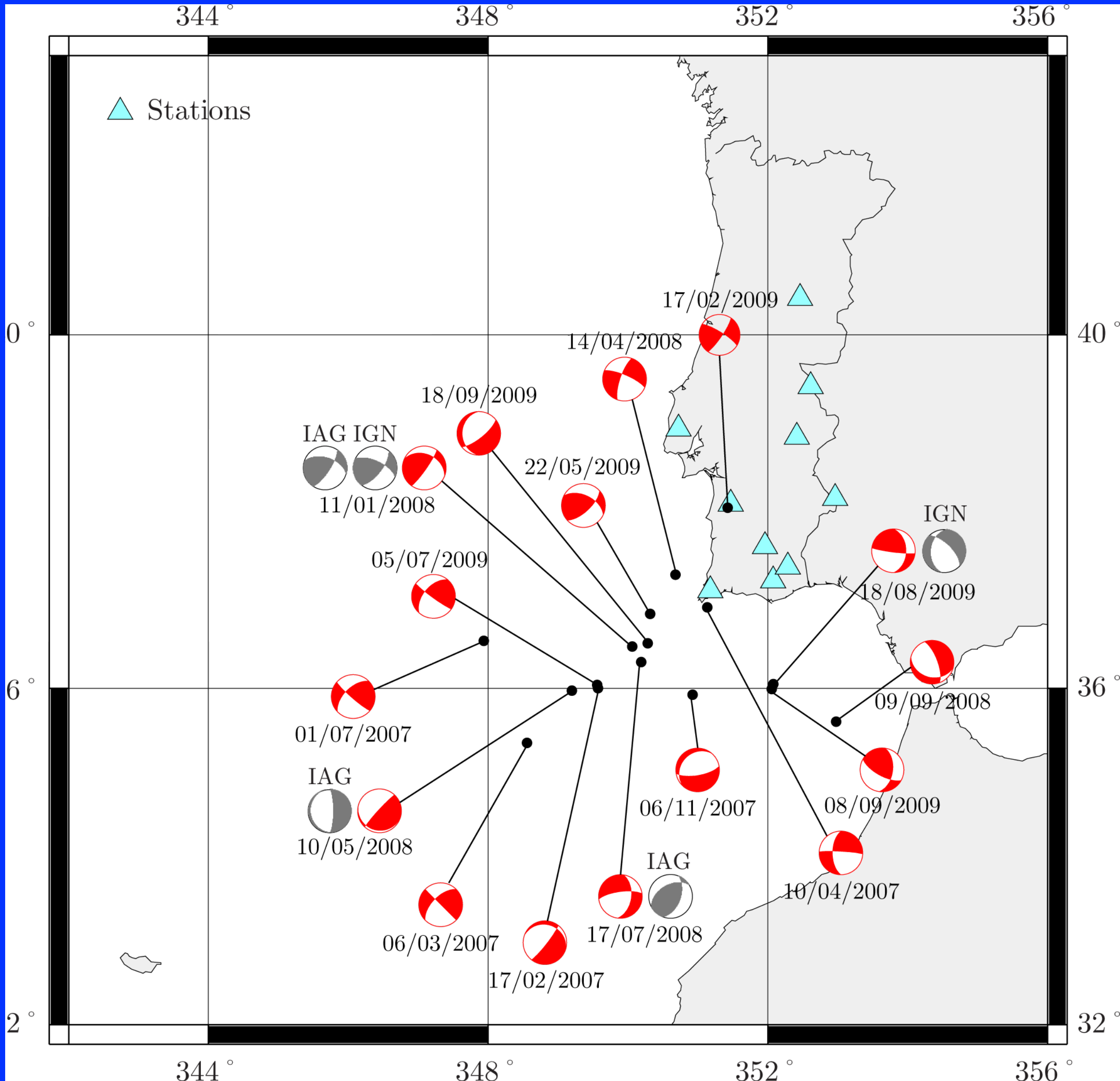


Setting:

BB Station Coverage (Permanent + Temporary)

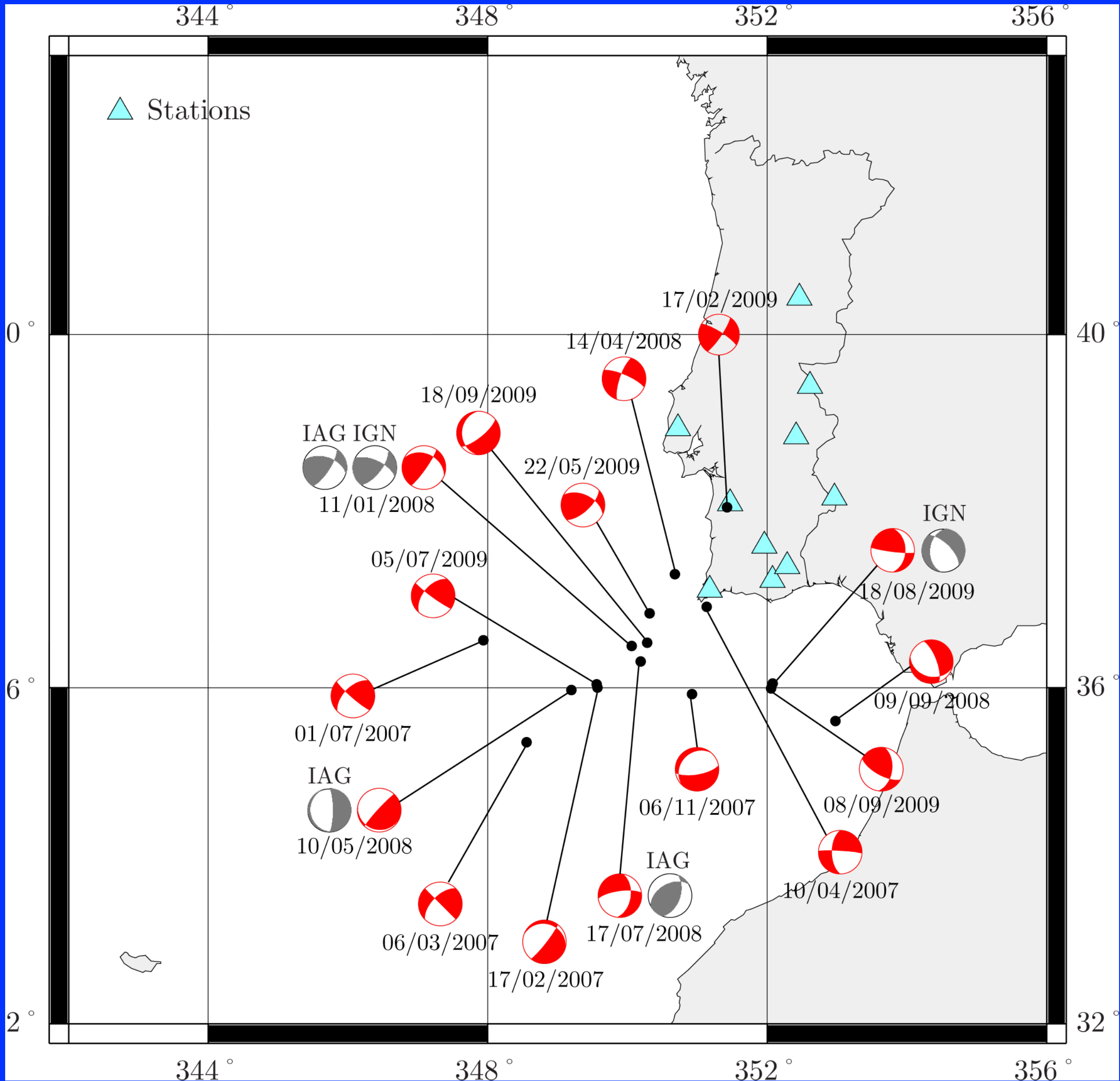
Background Seismicity





[Talk today at 12:20 Domingues et al.]

Domingues, MSc Thesis 2010



[Talk today at 12:20 Domingues et al.]

Domingues, MSc Thesis 2010

How good are these MTs? How resolvable?

Method

Linear inverse problems:

$$b = A\, a$$

data **parameters to be found**

Numerical Recipes by Press et al.,

chap. 2.6, 15.4, 15.6.

Waveform inversion of MT

Linear problem (if the source position and time are known)

parameters to be found = moment tensor components

Green's functions **data**

$$\chi^2 = |\mathbf{A} \cdot \mathbf{a} - \mathbf{b}|^2$$

(Solution by means of least squares)

ISOLA:

$$M_{pq} = a_i M^i_{pq}$$

a1, a2, … a6 =?

M1 M2 … M6

Singular Value Decomposition

Singular Vectors

$$\mathbf{A}^{-1} = \mathbf{V} \cdot [\mathrm{diag}\,(1/w_j)] \cdot \mathbf{U}^T$$

➔ Solution by means of SVD

Singular Values

$$\mathbf{a} = \sum_{i=1}^{M} \left(\frac{\mathbf{U}_{(i)} \cdot \mathbf{b}}{w_i} \right) \mathbf{V}_{(i)}$$

Singular Values Singular Vectors

$$\mathbf{a} = \left[\sum_{i=1}^{M} \left(\frac{\mathbf{U}_{(i)} \cdot \mathbf{b}}{w_i} \right) \mathbf{V}_{(i)} \right] \pm \frac{1}{w_1}\mathbf{V}_{(1)} \pm \cdots \pm \frac{1}{w_M}\mathbf{V}_{(M)}$$

$$\sigma^2(a_j) = \sum_{i=1}^{M} \frac{1}{w_i^2} [\mathbf{V}_{(i)}]_j^2 = \sum_{i=1}^{M} \left(\frac{V_{ji}}{w_i} \right)^2$$

$$\mathrm{Cov}(a_j, a_k) = \sum_{i=1}^{M} \left(\frac{V_{ji} V_{ki}}{w_i^2} \right)$$

Advantage:

SVD expresses the uncertainty through singular vectors in a transparent way.

Confidence Region Ellipse

Singular Values

Singular Vectors

Model Parameter

$$\Delta\chi^2 = w_1^2(\mathbf{V}_{(1)} \cdot \delta\mathbf{a})^2 + \cdots + w_M^2(\mathbf{V}_{(M)} \cdot \delta\mathbf{a})^2$$

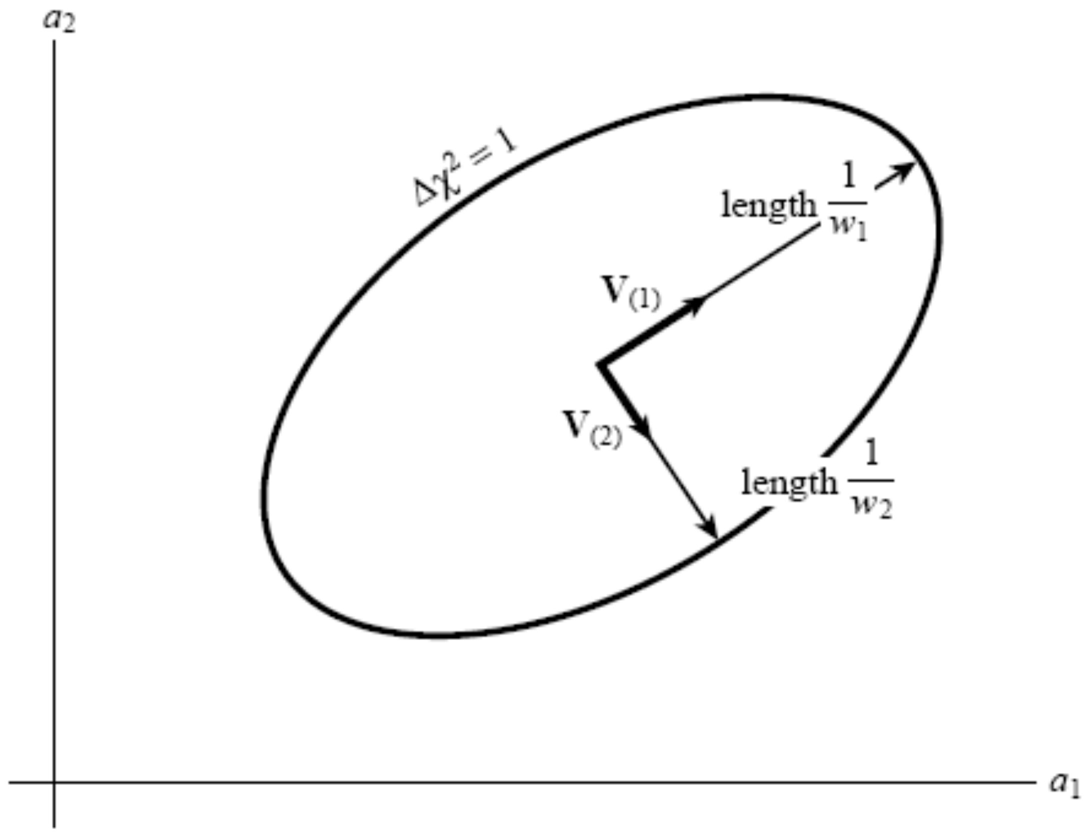


Figure 15.6.5. Relation of the confidence region ellipse $\Delta\chi^2 = 1$ to quantities computed by singular value decomposition. The vectors $\mathbf{V}_{(i)}$ are unit vectors along the principal axes of the confidence region. The semi-axes have lengths equal to the reciprocal of the singular values w_i. If the axes are all scaled by some constant factor α, $\Delta\chi^2$ is scaled by the factor α^2.

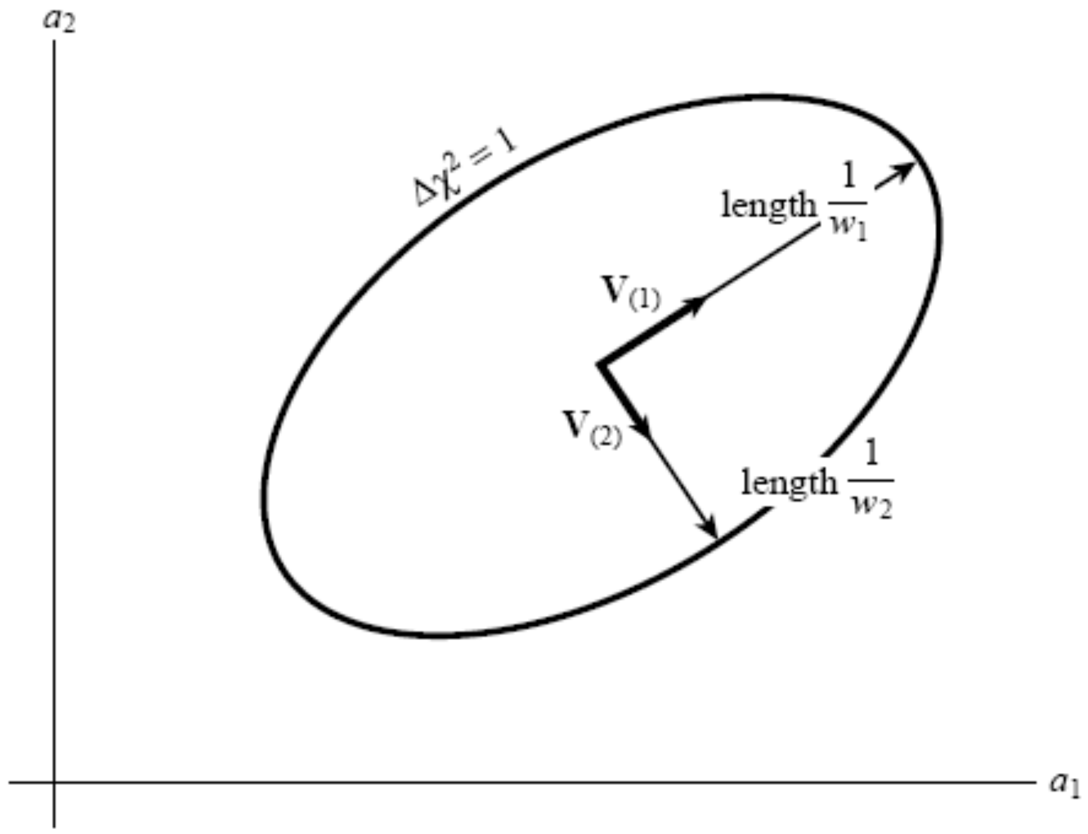
Confidence Region Ellipse

Singular Values

Singular Vectors

Model Parameter

$$\Delta\chi^2 = w_1^2(\mathbf{V}_{(1)} \cdot \delta\mathbf{a})^2 + \cdots + w_M^2(\mathbf{V}_{(M)} \cdot \delta\mathbf{a})^2$$



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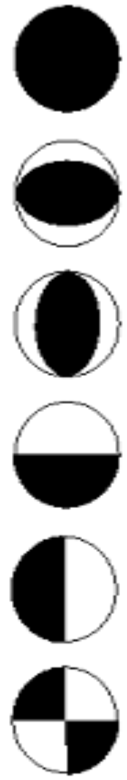


A 2-D cross-section of the 6D error ellipsoid

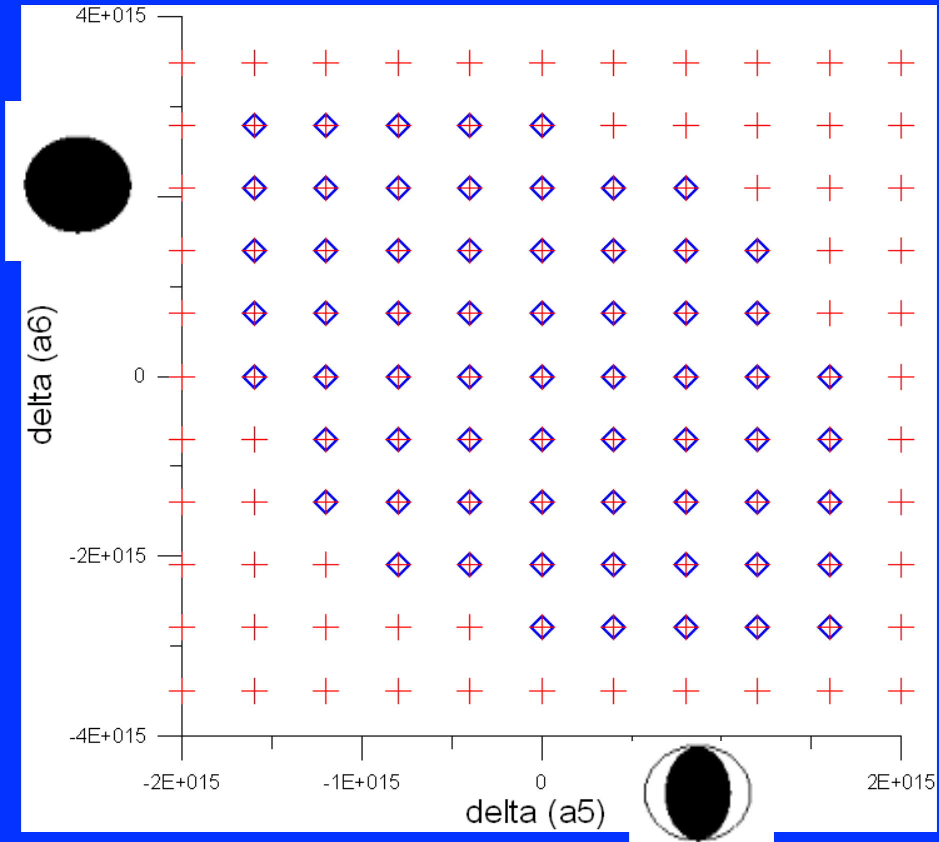
Confidence Region Ellipse

Singular Values

Singular Vectors

Model Parameter

$$\Delta\chi^2 = w_1^2(\mathbf{V}_{(1)} \cdot \delta\mathbf{a})^2 + \cdots + w_M^2(\mathbf{V}_{(M)} \cdot \delta\mathbf{a})^2$$

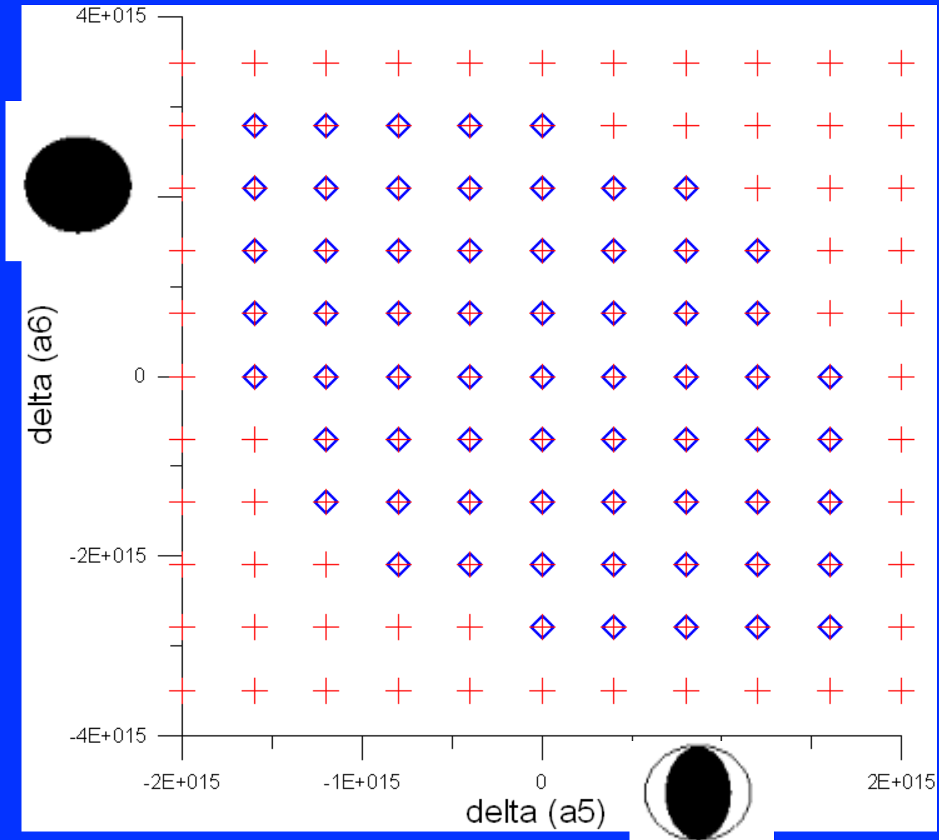


Not shown
MT components

A 2-D cross-section of the 6D error ellipsoid

Confidence Region Ellipse — **Singular Values** — **Singular Vectors** — **Model Parameter**

$$\Delta\chi^2 = w_1^2(\mathbf{V}_{(1)} \cdot \delta\mathbf{a})^2 + \cdots + w_M^2(\mathbf{V}_{(M)} \cdot \delta\mathbf{a})^2$$



<u>We need:</u>

• Green's functions
(epicenter, depth, crustal model, frequency range, stations location)

• Estimate of data error

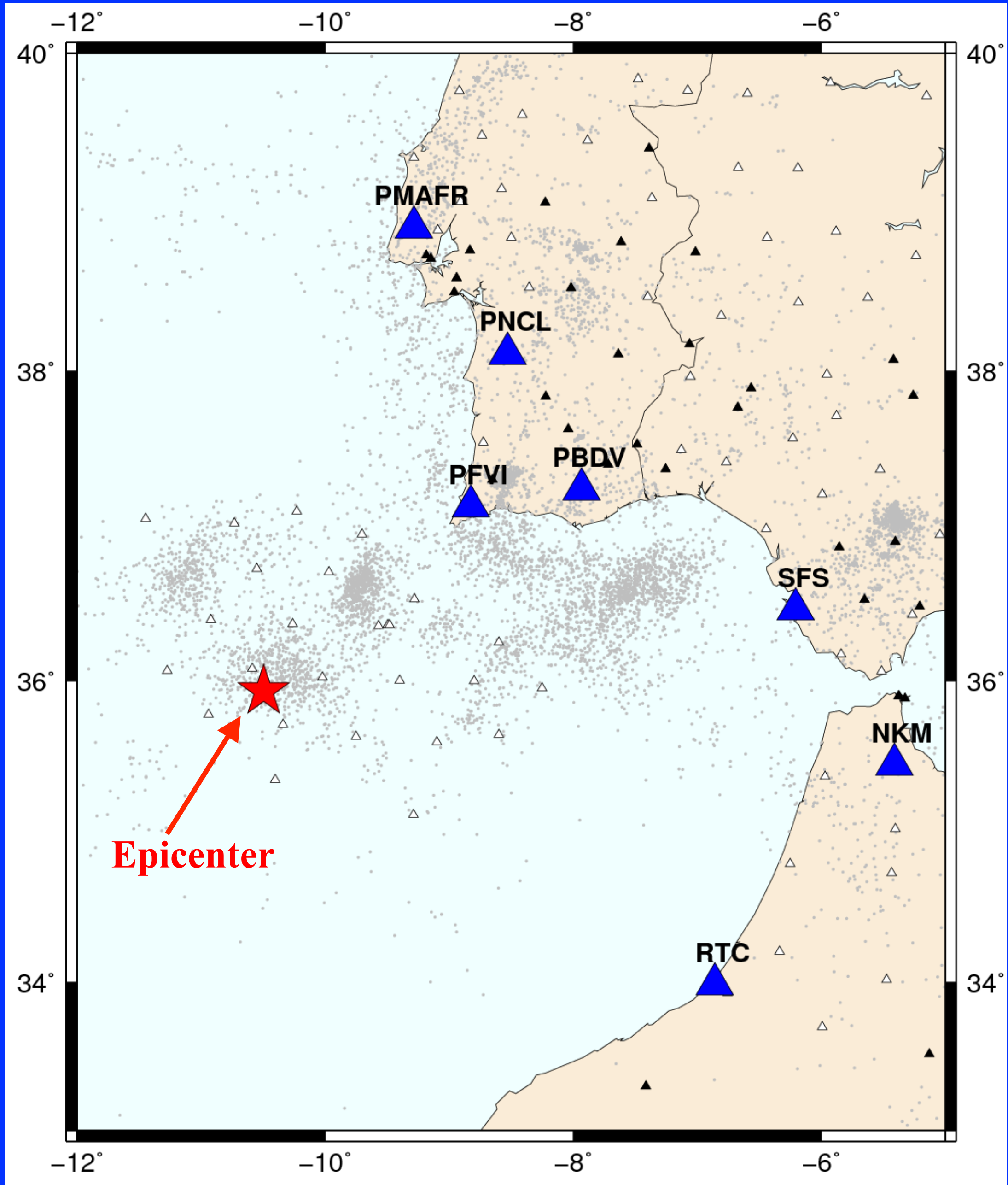
(Errors are assumed to be Gaussian)

<u>We do not need:</u>

• Real data

Application

Reference Study Parameters



Epicenter:
35.9330 N, 10.4950 W

Depth:
40 km

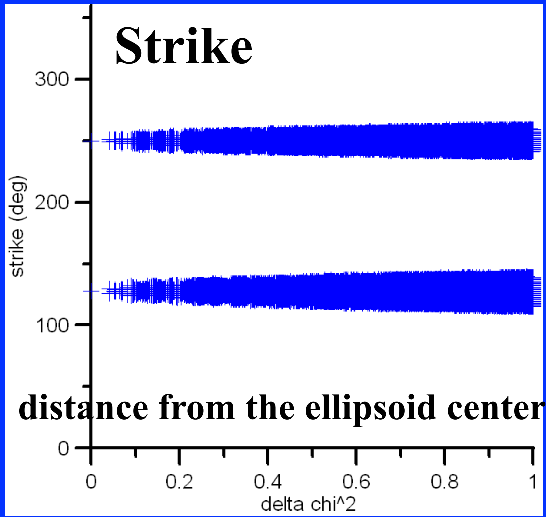
Frequency Range:
0.028 – 0.08 Hz

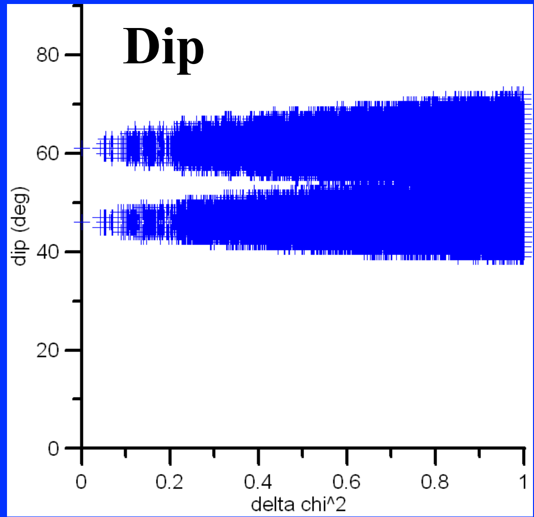
Velocity Model:
1D regional model of Stich et al. (JGR 2003), 7 layers

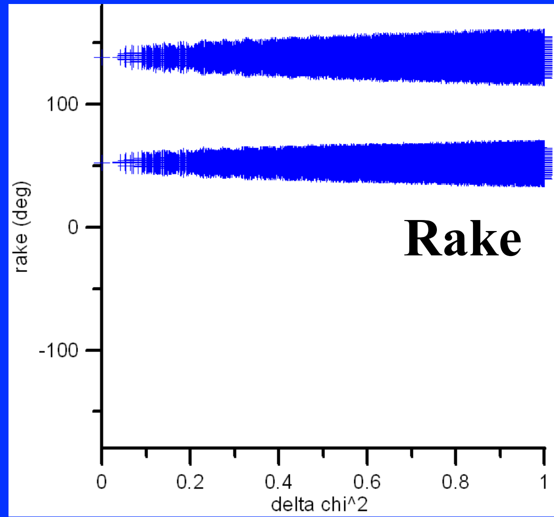
Station Network:
IB (7 land stations)

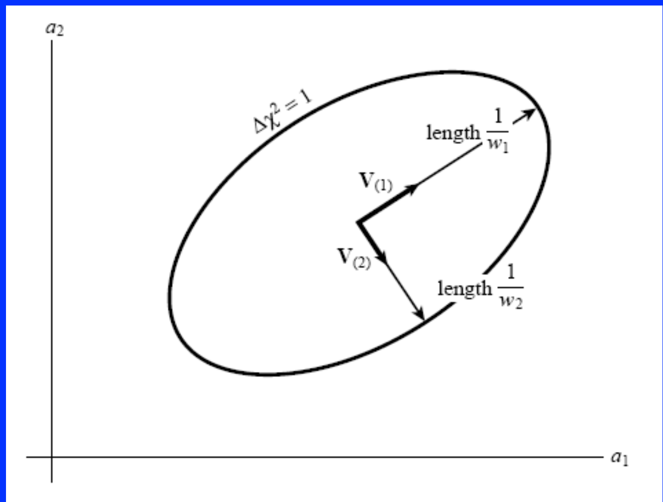
Focal Mechanism:

Strike, dip, and rake can be computed for each point of the 6D ellipsoid, and expressed as a function of the distance from the ellipsoid center:

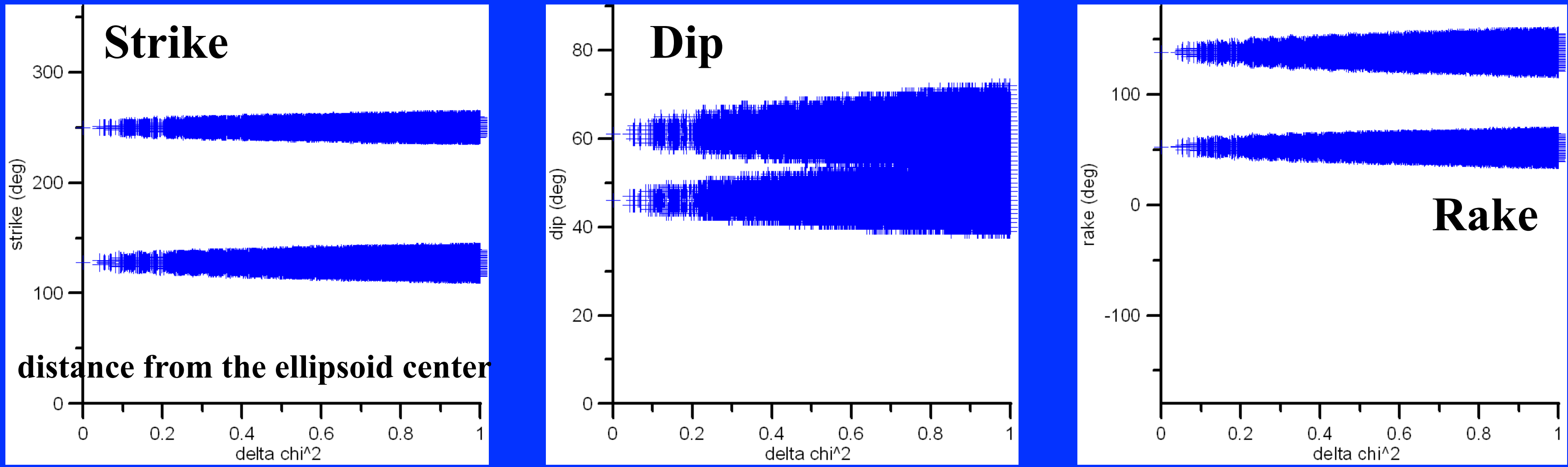


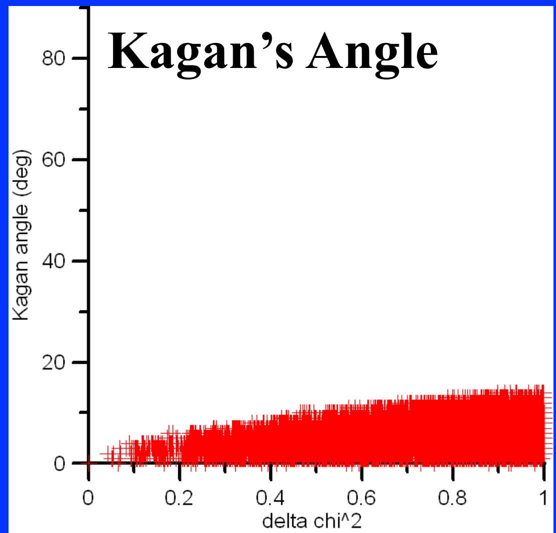






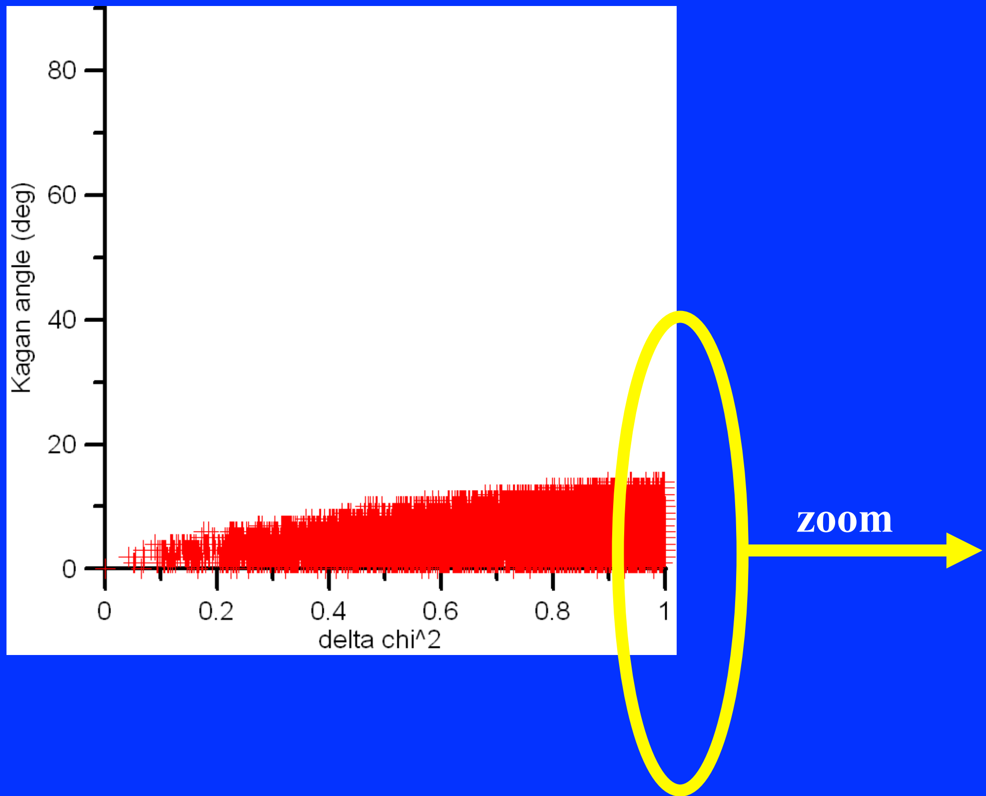
Kagan's Angle

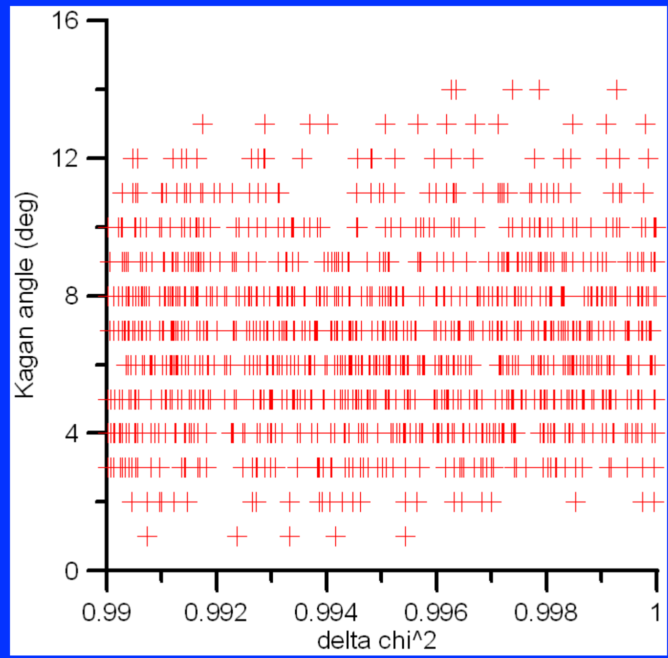


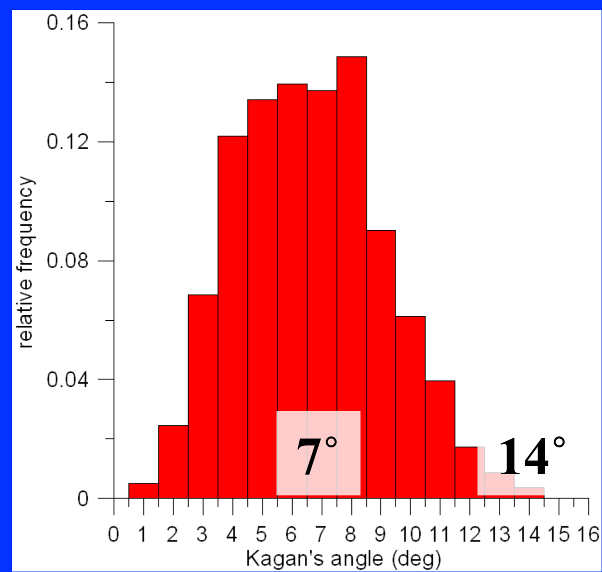


<u>Kagan's Angle:</u>
quantifies the difference between two DC solutions
=
smallest angle between the slip vectors of two double couples

Kagan's angle near the ellipsoid surface.

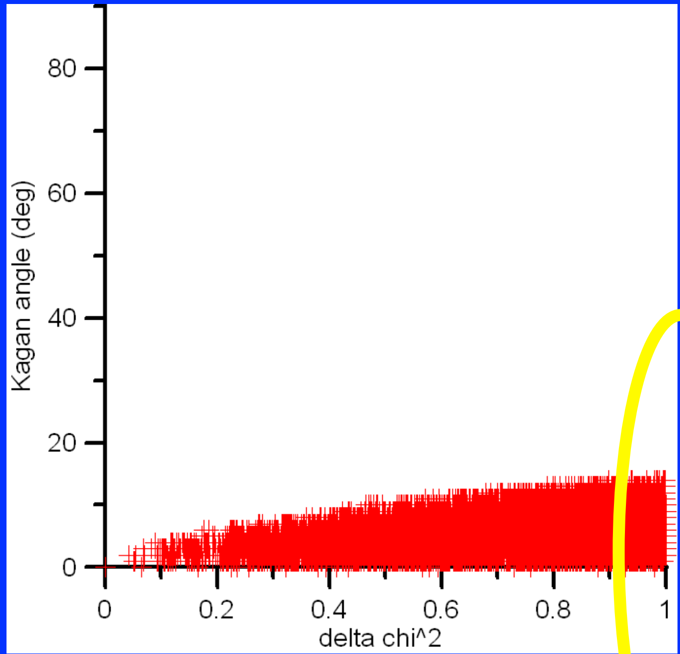




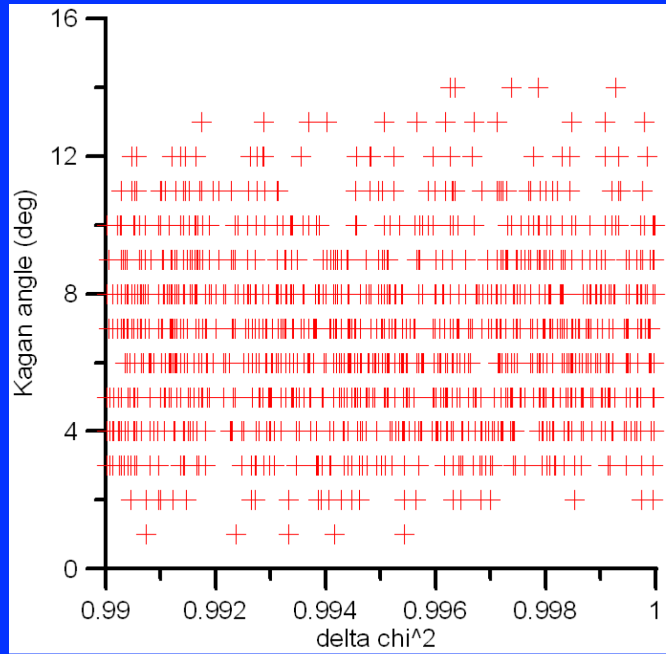


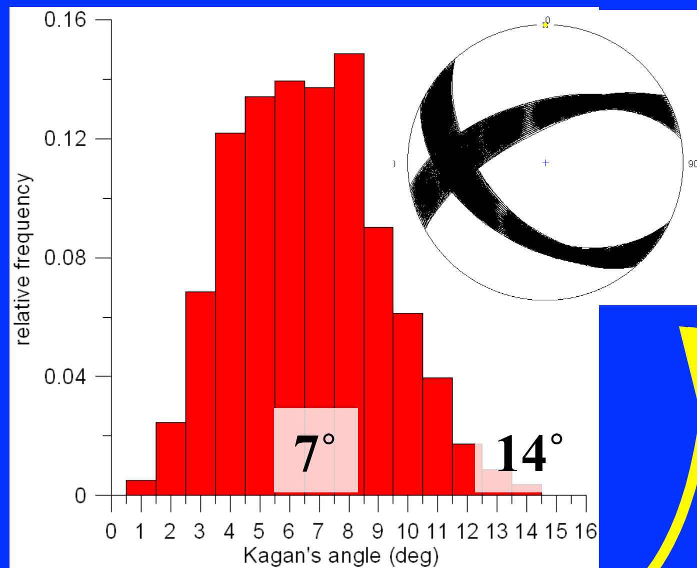
Histogram of Kagan's angle near the $\chi^2 = 1$ ellipsoid surface: a simple representation of the MT uncertainty. Only DC part is treated in this way.

Kagan's angle near the ellipsoid surface.



zoom



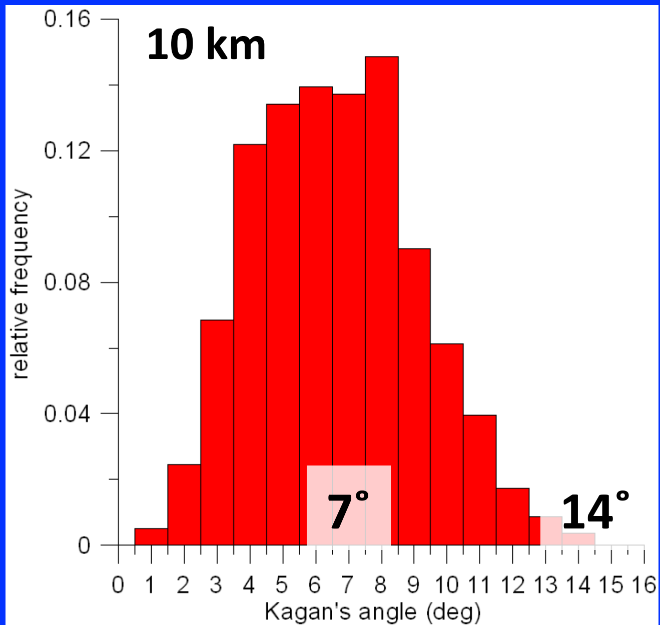


Histogram of Kagan's angle
near the χ^2 = 1 ellipsoid surface:
a <u>simple</u> representation of the MT uncertainty.
Only DC part is treated in this way.

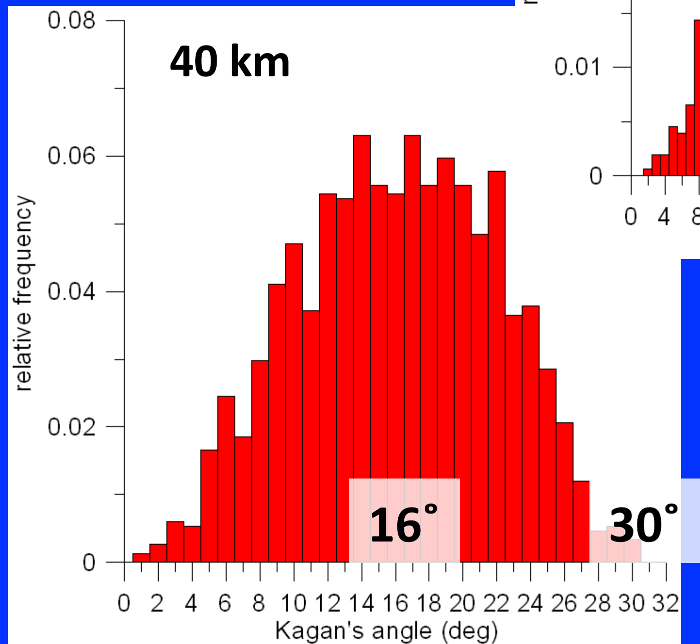
Different Scenarios

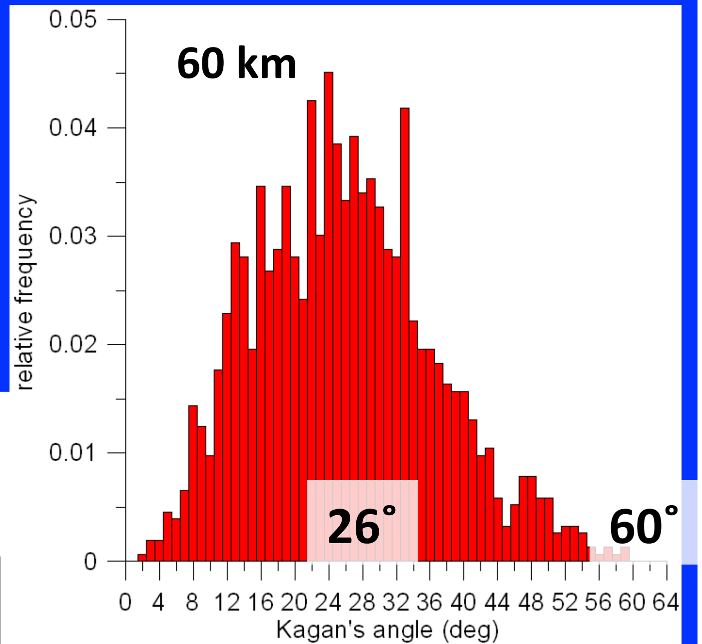
Variation of Kagan's angle with source depth

IB network (land stations)



At the source depth of 10 km the resolvability is excellent.

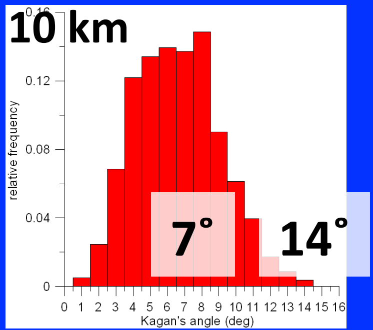


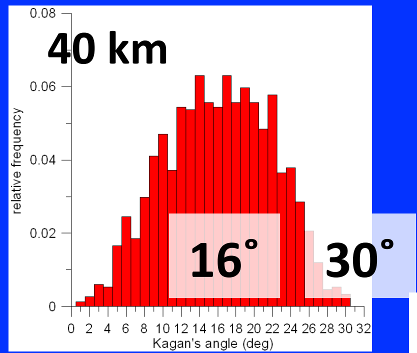


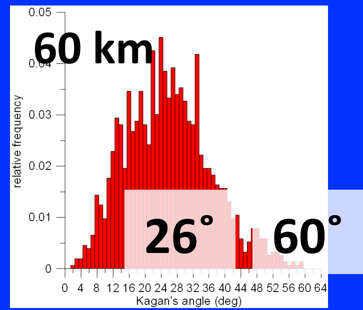
The same variation with the <u>source depth</u>

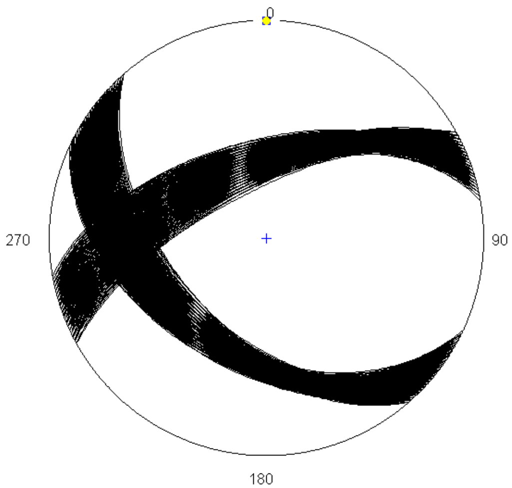
IB network (land stations)

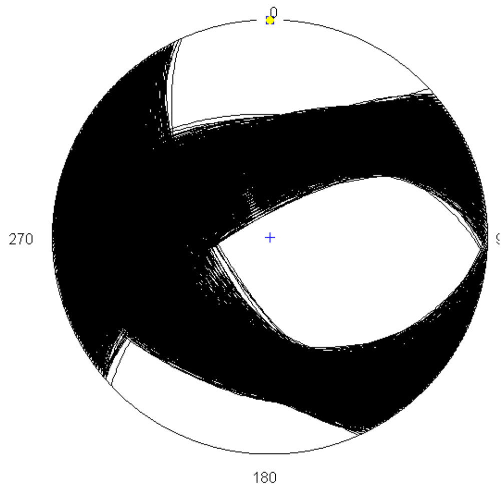
but also expressed by means of nodal lines

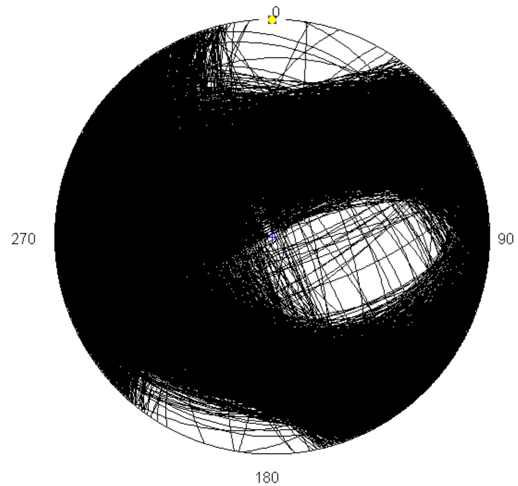




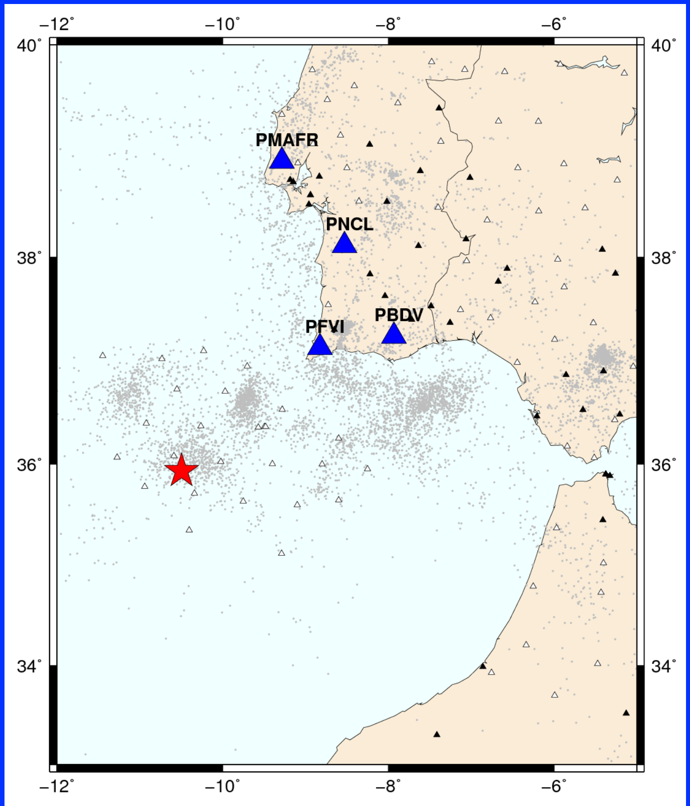


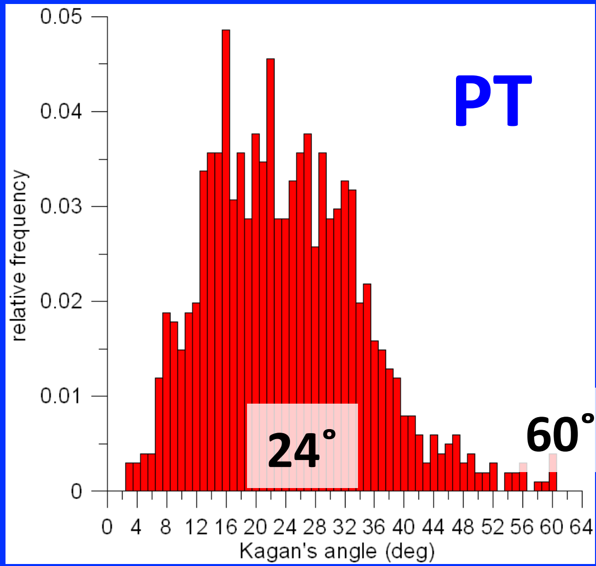






Variation of Kagan's angle with station distribution (source depth of 40 km)





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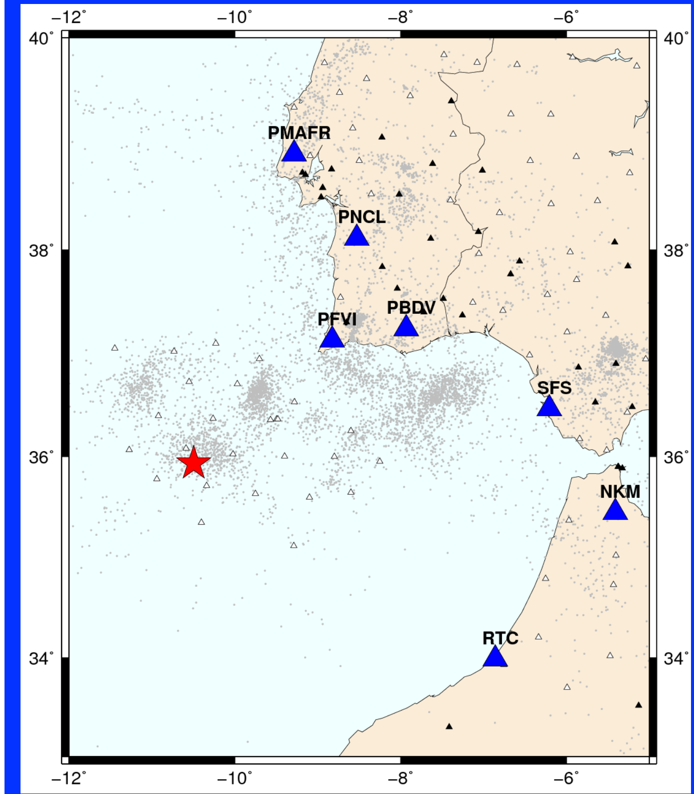

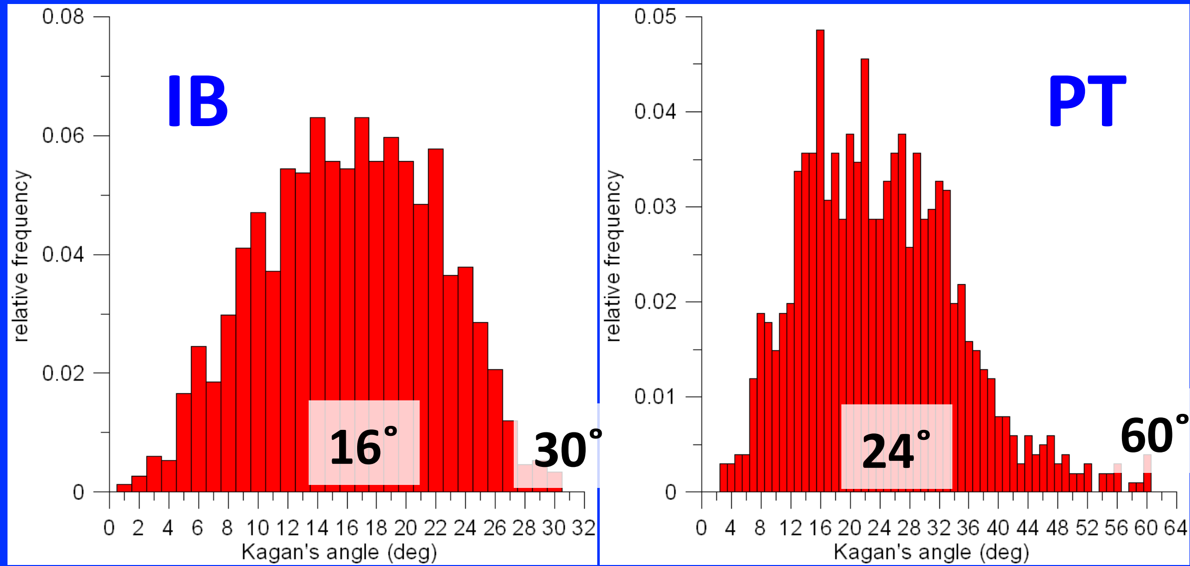

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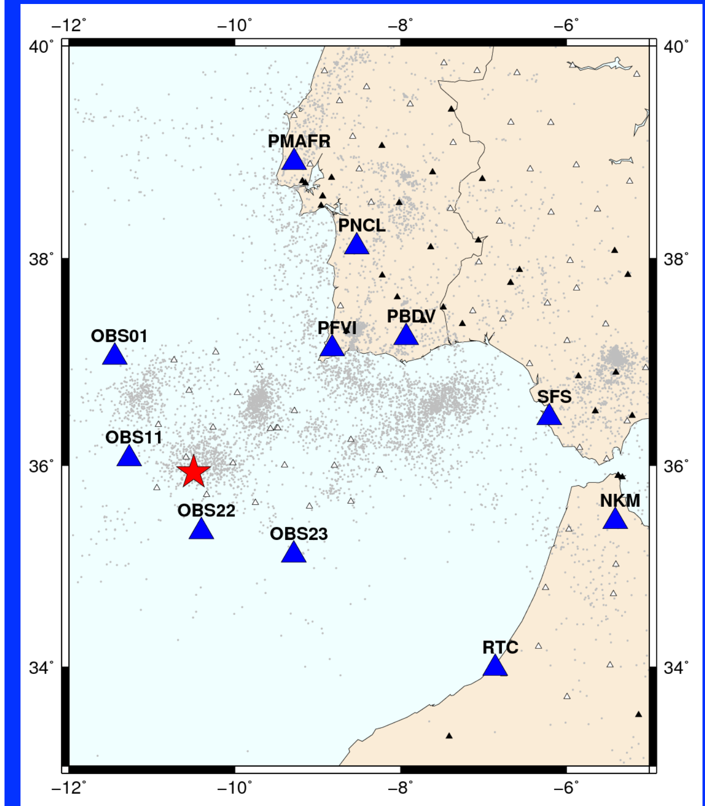
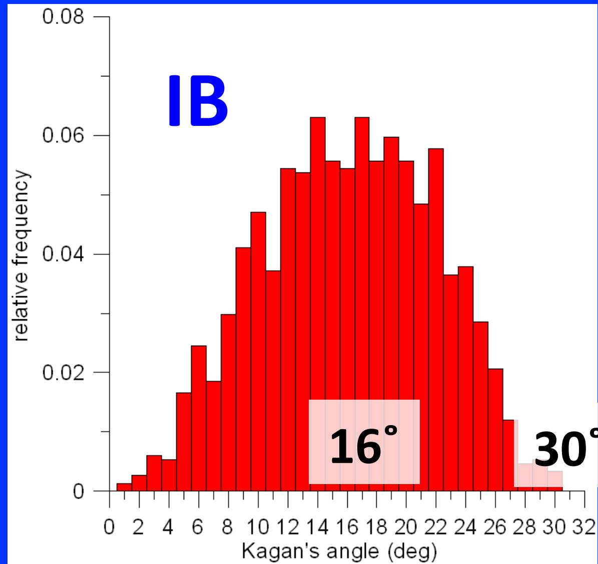
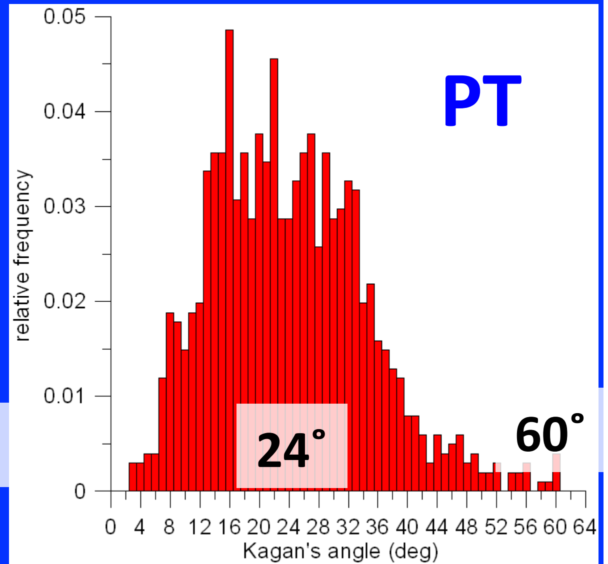
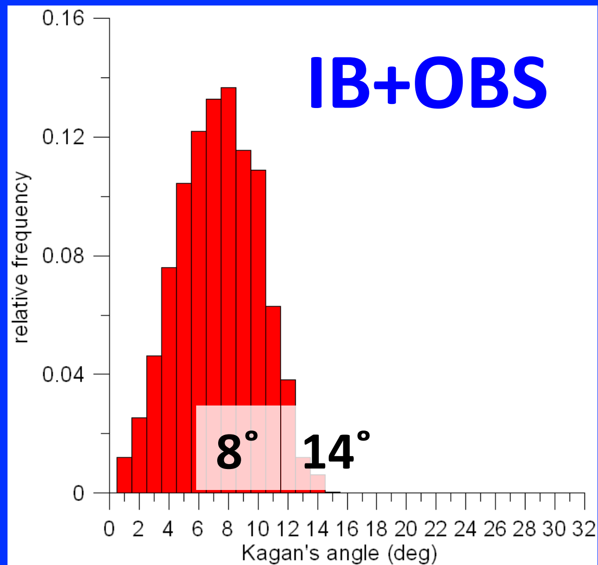








The improvement by OBS for the 40-km depth would be significant!

(Resolvability as good as in the 10-km case !)

Also Studied
(not shown here, please see “poster” outside)

- Frequency range:
  - better resolvability when using higher frequencies
- Focal mechanism:
  - no significant difference for 4 tested focal mechanisms
- Velocity Structure:
  - no significant difference between different 1D layered models;
  - better resolvability of the crust is slow
- Different configurations and density of land stations
  - more land stations improve the resolvability
  - 4 OBSs improve the resolvability more than 14 land stations

OBS Data

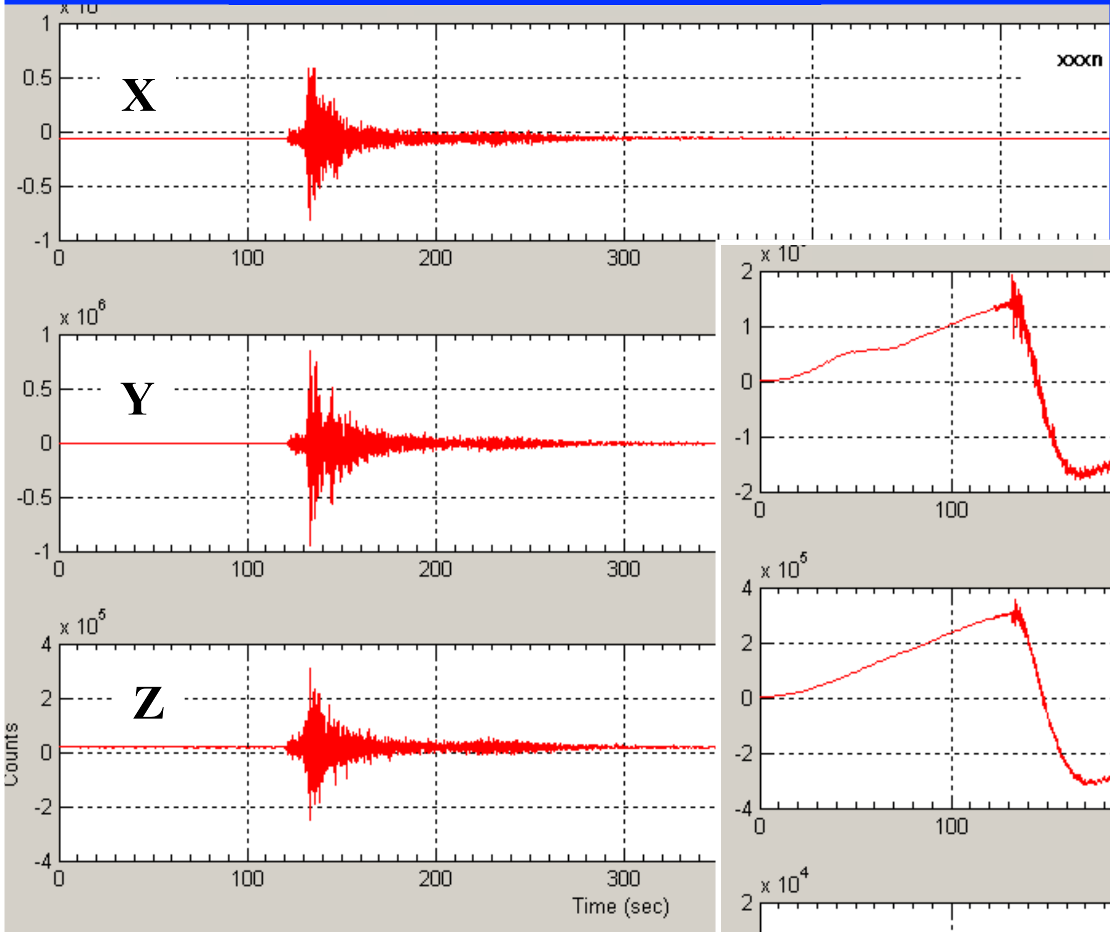
Real OBS data (NEAREST project, Geissler et al., GRL 2010)

[Talk tomorrow at 9:30 Matias et al.]

Can MT's be calculated from waveforms?

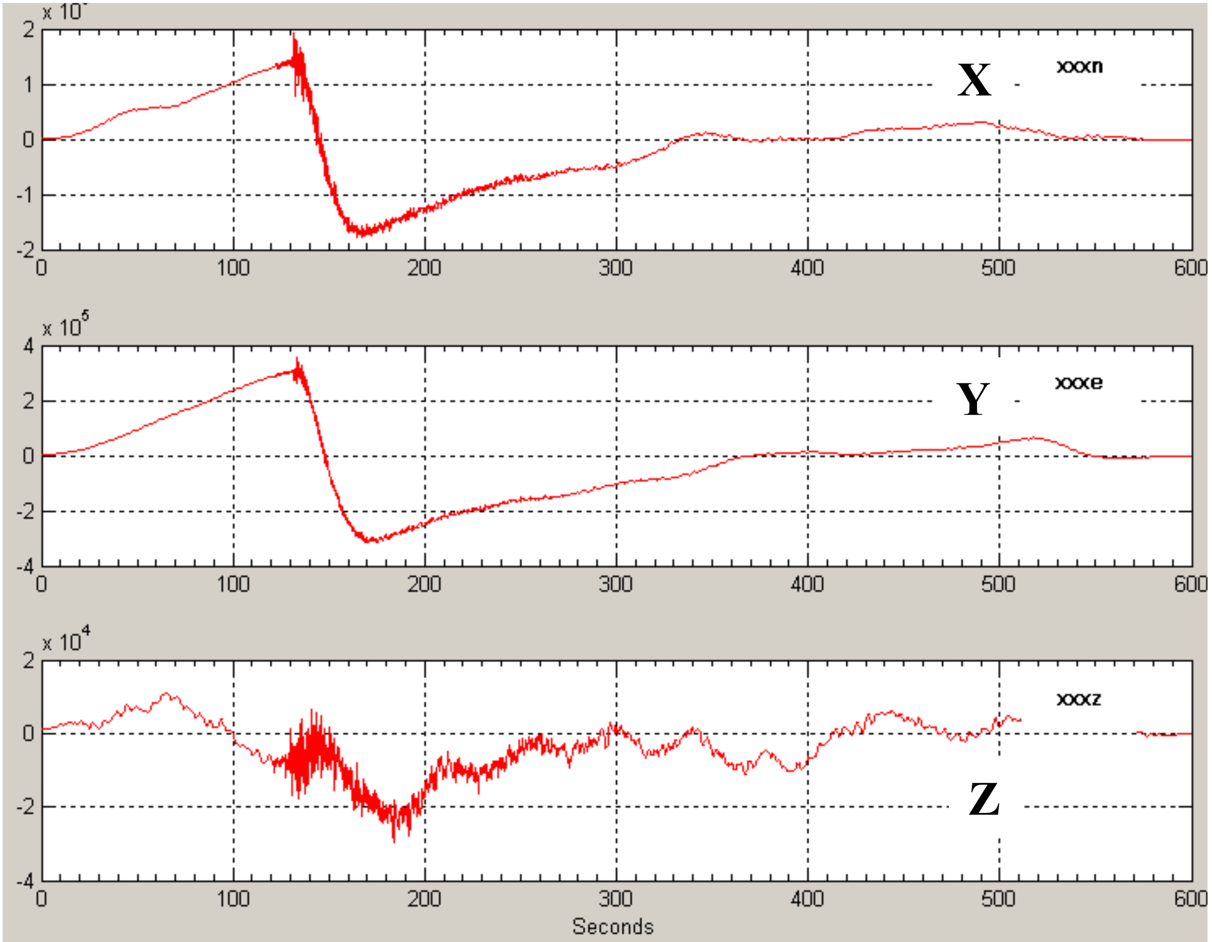
Real OBS data : Jan 11, 2008, Mw 4.5, depth = 49 km

raw velocity (counts)

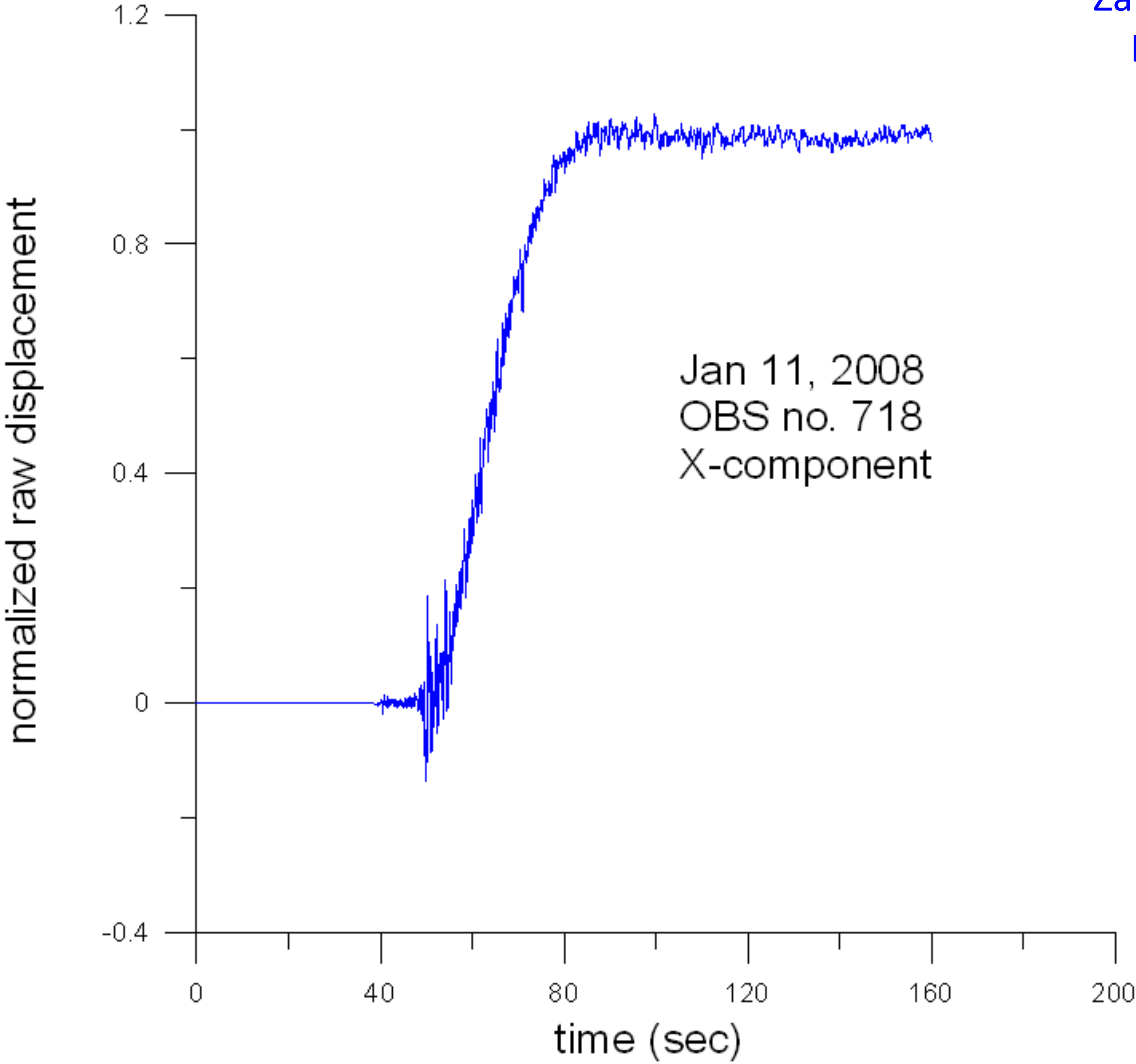


station No. 18
no clip !

raw displacement (counts*s) – integrated



Correction procedure of Zahradnik and Plesinger, BSSA 2005 and 2010



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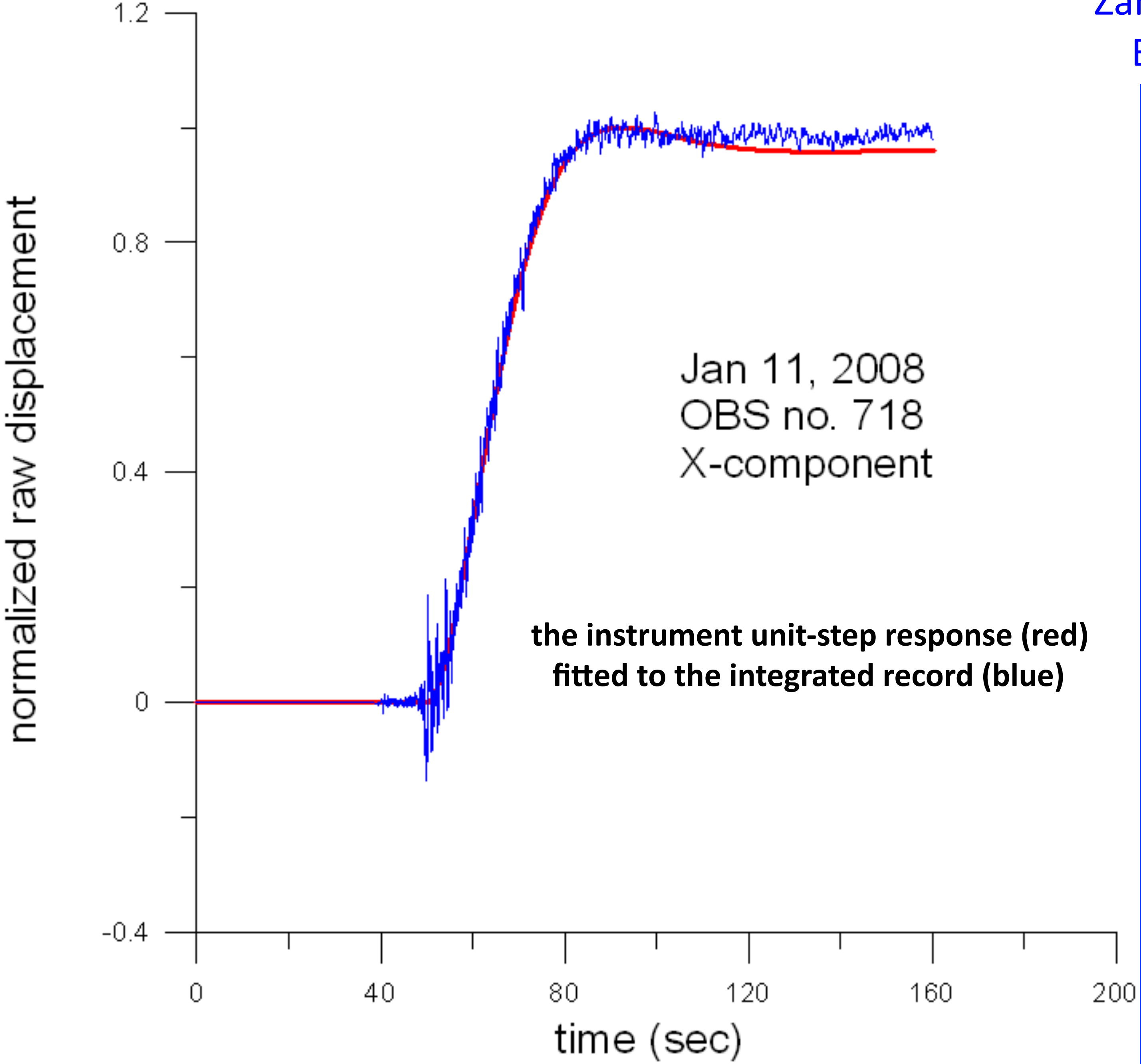
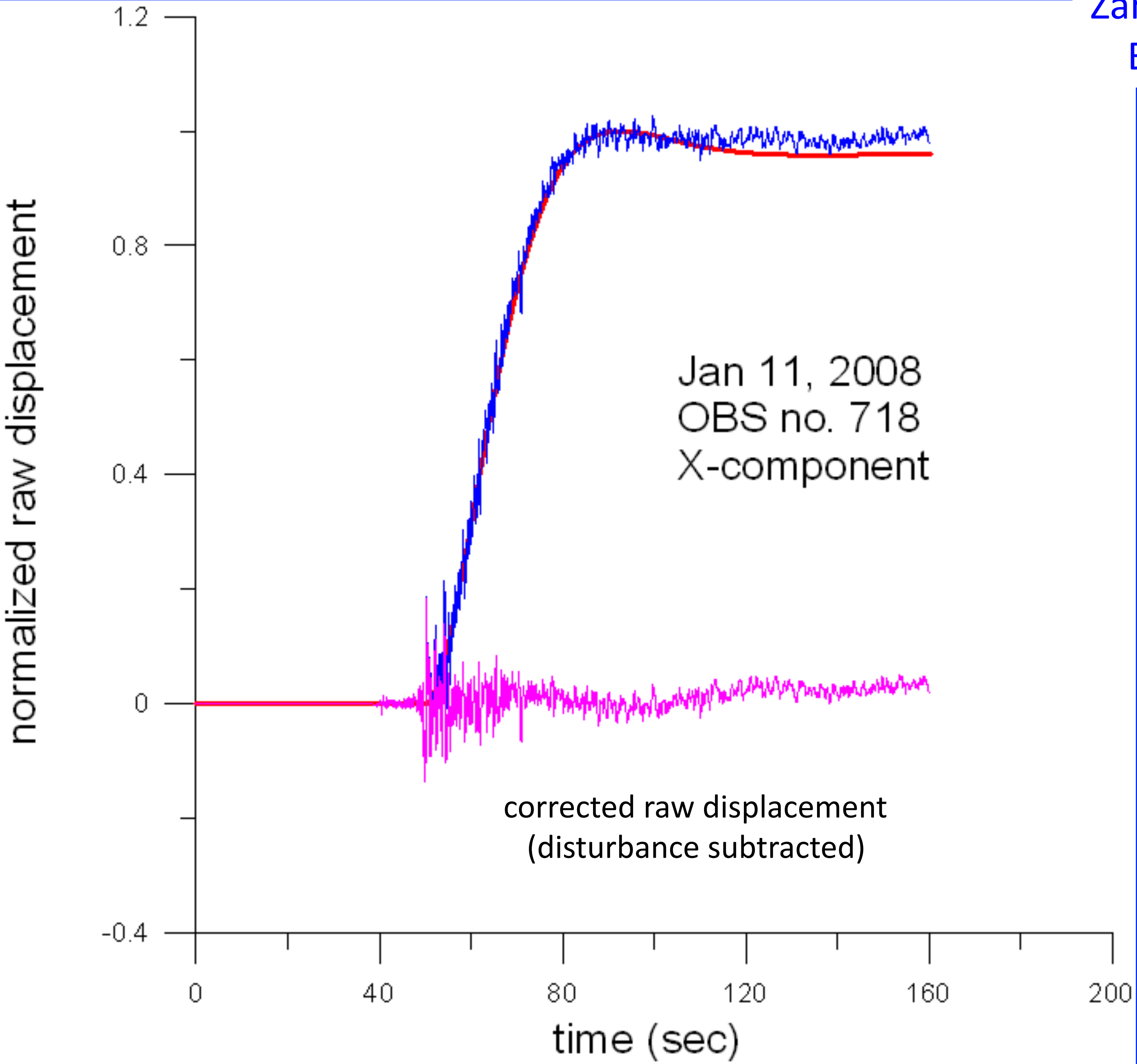
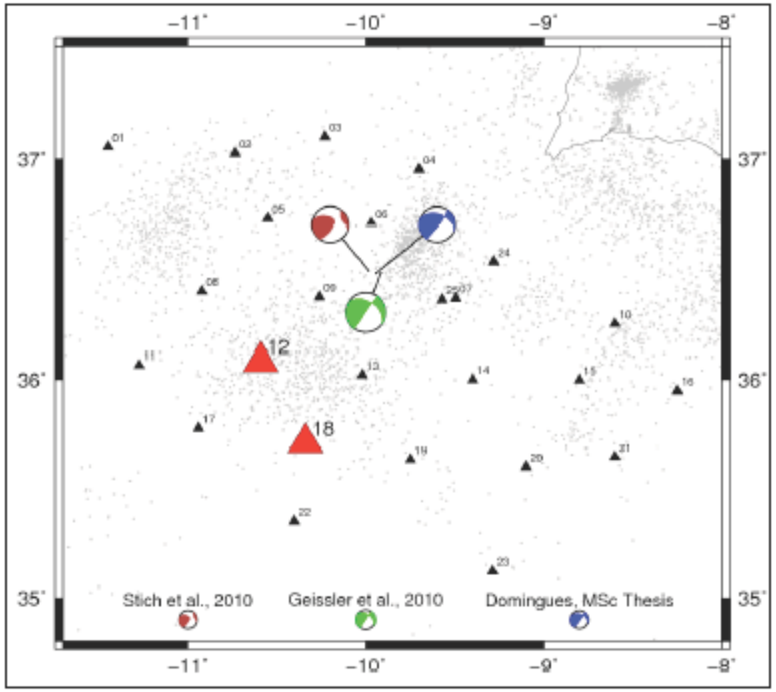


the instrument unit-step response (red) fitted to the integrated record (blue)

Correction procedure of Zahradnik and Plesinger, BSSA 2005 and 2010

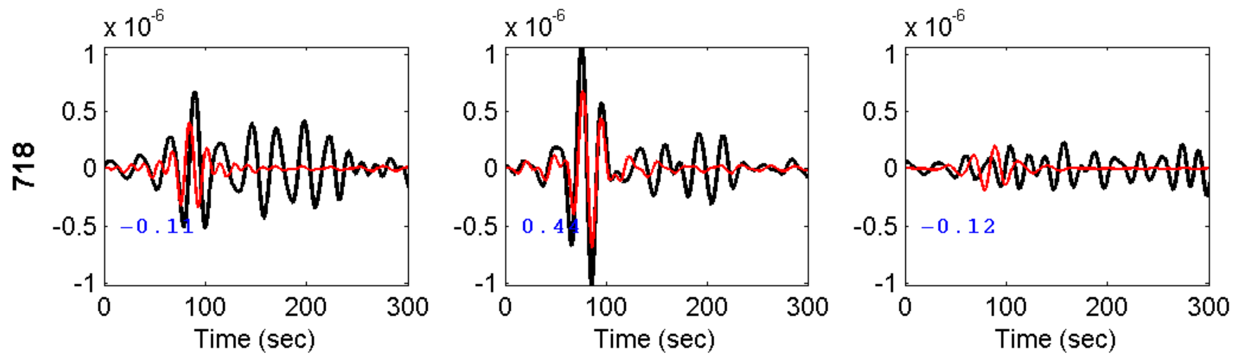


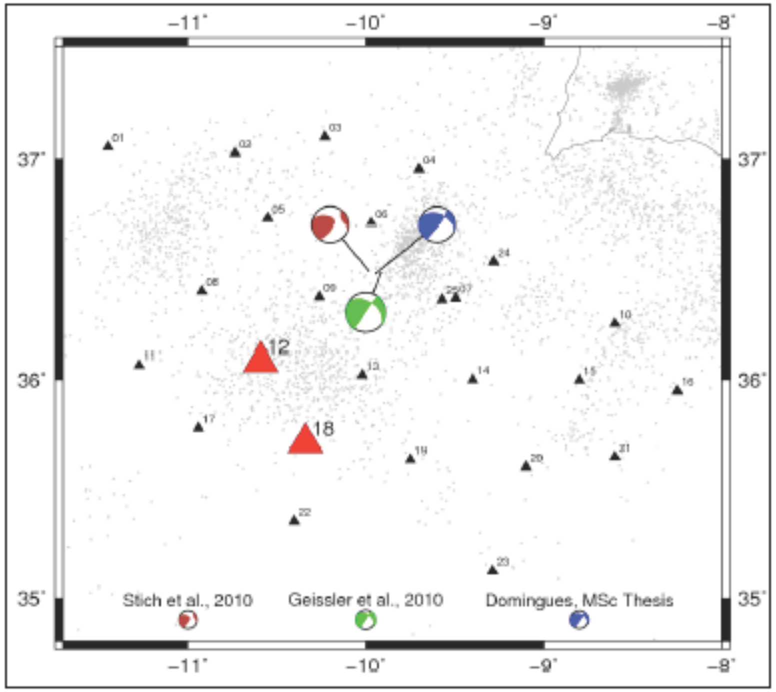


Forward modeling: Jan 11, 2008, M 4.5
frequency band 0.03 – 0.08 Hz

station no. 18:
the disturbance was successfully removed

black: observed
red: synthetic

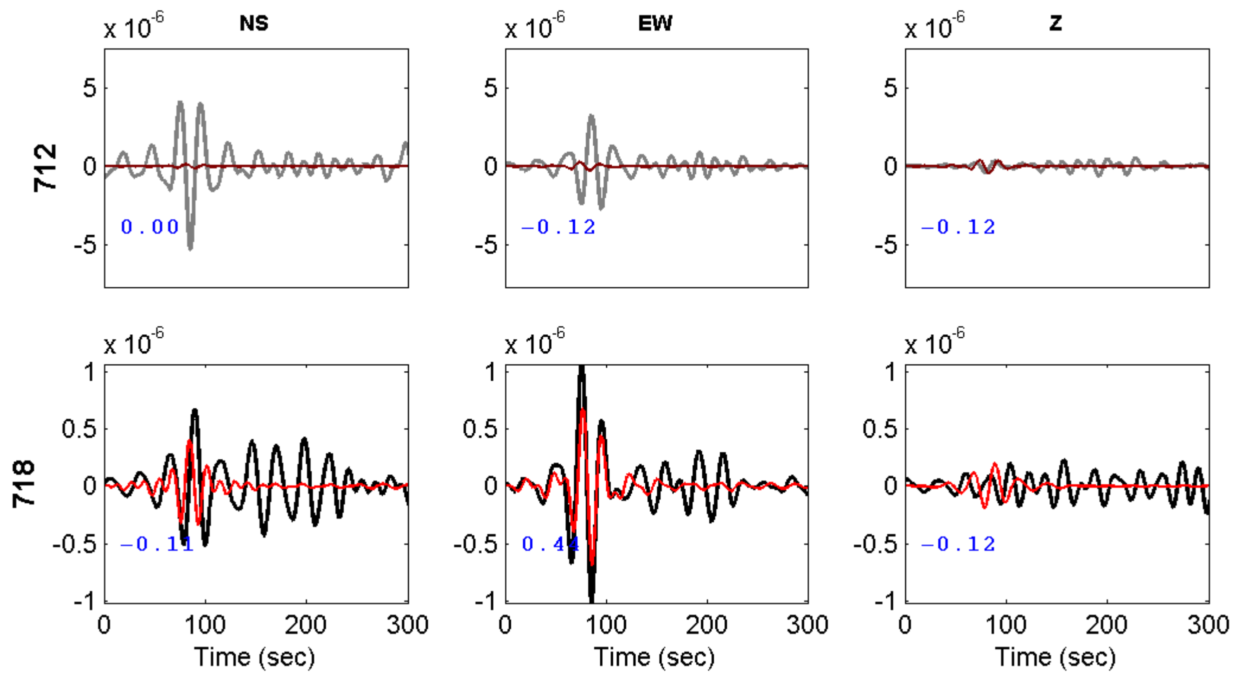




Forward modeling: Jan 11, 2008, M 4.5
frequency band 0.03 – 0.08 Hz

station no. 12:
the disturbance removal was not successful

black: observed
red: synthetic



Conclusions

- The MT resolvability can be studied without data (network design), this capability is now added to ISOLA.
- This type of study has a relative meaning due to poor estimates of the data errors.
- Effects of the frequency range, source depth, and network configuration are significant.
- MT's of the shallow sources (10 km) are easy to resolve well.
- MT's of the 40- and 60-km depth should profit from dense land networks and/or OBS.
- Use of regional OBS waveforms is a challenging task.