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Shear-wave splitting and mantle anisotropy in the Alpine Area

Luděk Vecsey, Jaroslava Plomerová, Vladislav Babuška
and the AlpArray working groups

INSTITUTE OF GEOPHYSICS
OF THE CZECH ACADEMY OF SCIENCES

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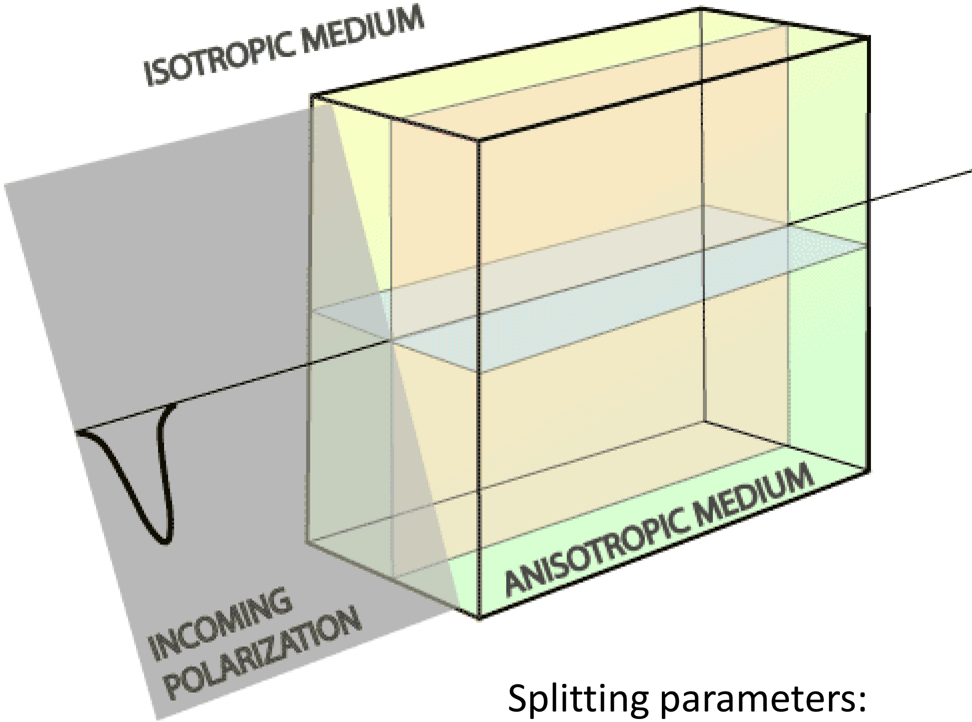
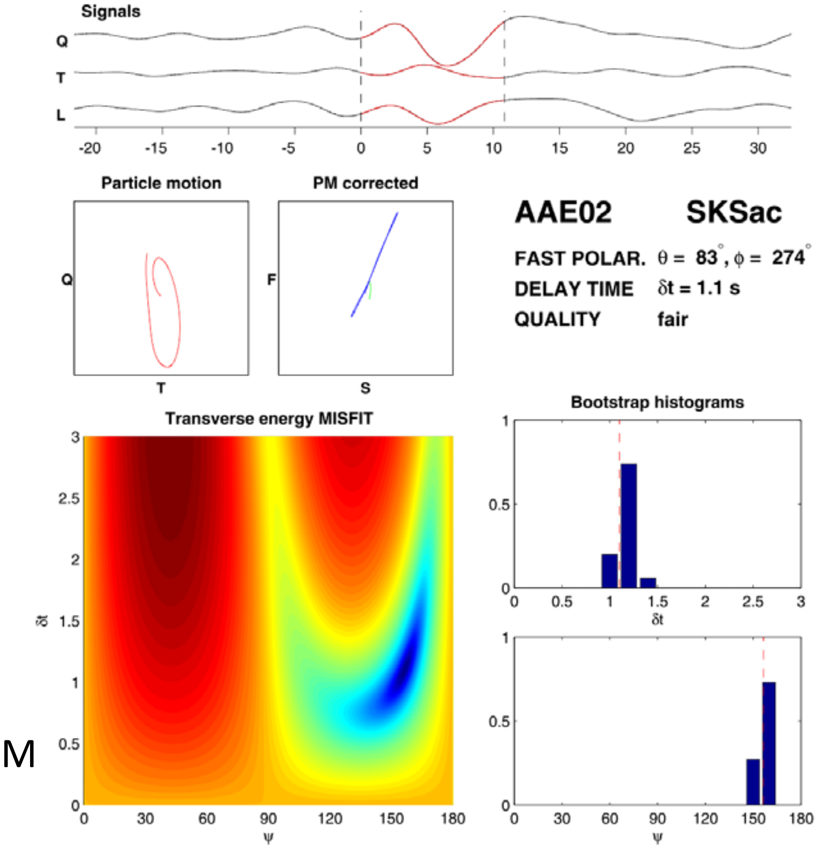
Overview

- Automatic XKS waveform selector
- Pitfalls of splitting methods
  - Noise
  - Orientation of horizontal components
- Sensor misorientation
- Dynamic back-azimuth
- Splitting evaluation
- Particle motion
- Conclusions

Shear-wave splitting in an anisotropy medium



Shear wave splits into two polarized shear waves



Splitting parameters:

- delay time
- polarization direction of the fast split wave

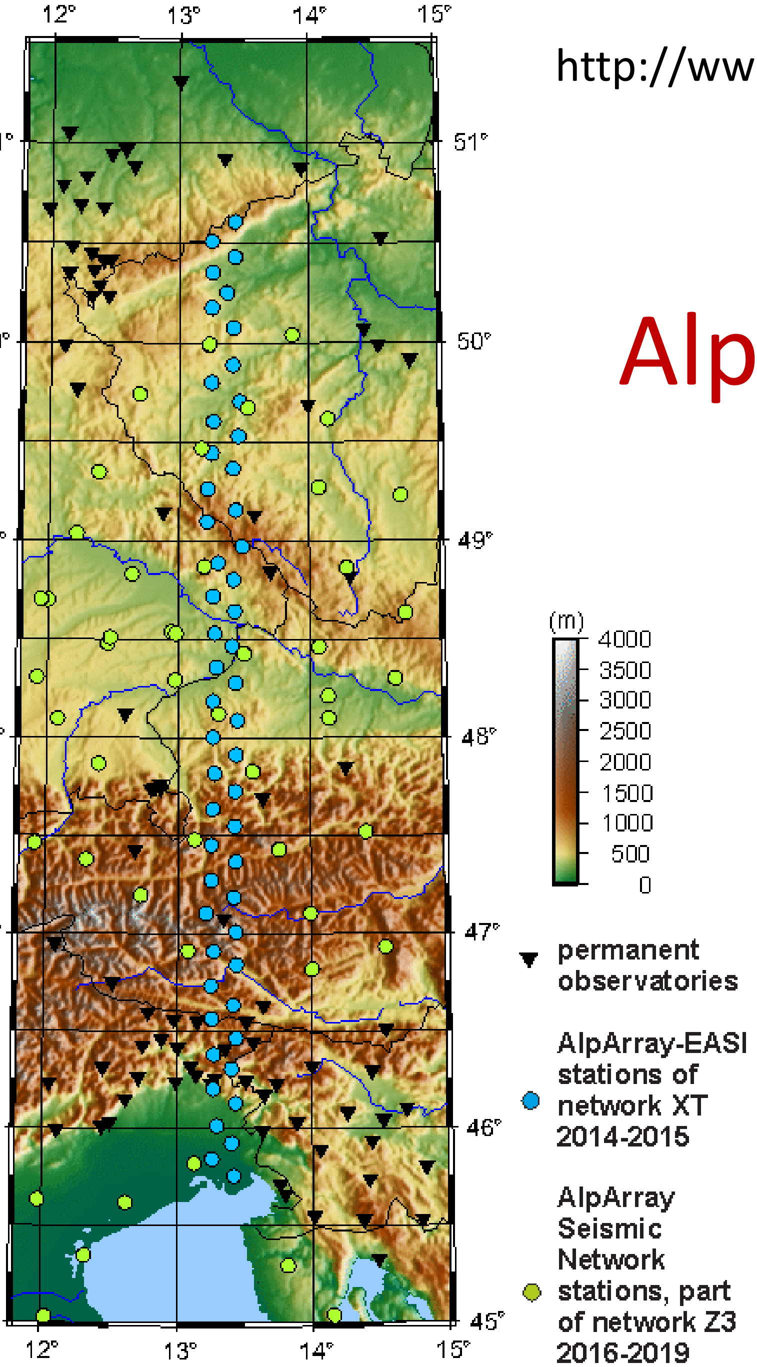
Eigenvalue method – for shear waves with a linear PM

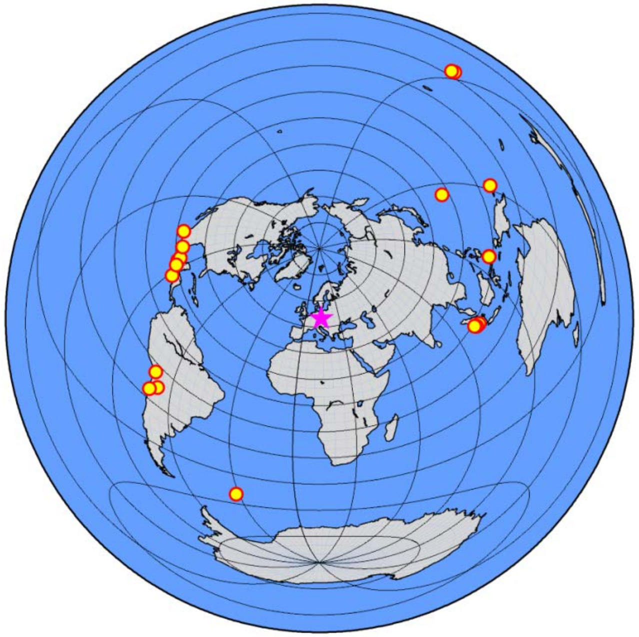
Transverse energy method – for XKS waves http://www.alparray.ethz.ch

AlpArray-EASI dataset

High number of stations (~200)

Lower number of good quality SKS events





Automated XKS waveform selector

Main tasks:

Preprocess signal: demean, resample, response and sensor orientation corrections according to station metadata

Find and select XKS waves:

- with high SNRs
- not influenced by nearby seismic phases
- correctly filtered (Butterworth bandpass filter there and back)
- with their particle motions of elliptical or linear shape, without edges and/or rapid changes

Keywords: ObsPy/Python, GCMT, IRIS-Syngine, EIDA

Automated script for selection of XKS waves.

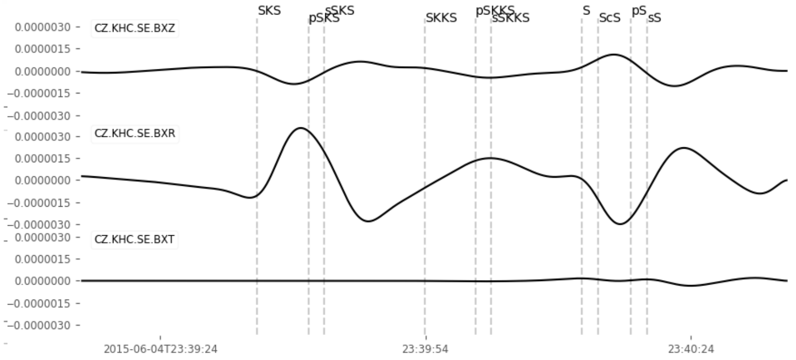
INPUT:
GCMT catalog - list of teleseismic events, their locations and moment tensors
EIDA - signal data and metadata
IRIS-Syngine - synthetic seismograms (used model: prem_a_2s)

OUTPUT:
Selections of XKS waves

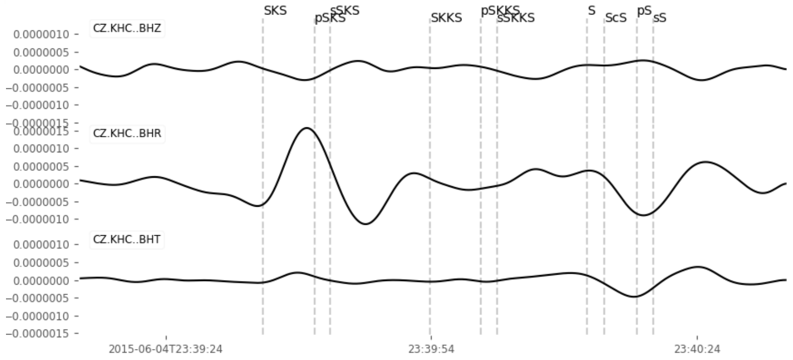
PROCEDURE STEPS:
Synthetic signal #1: theoretical arrivals and amplitudes, Gaussian-like source time function; included effects: source radiation, reflection or transmission on interfaces, geometrical ray spreading, attenuation
Synthetic signal #2: 3 component signal for a given moment tensor and velocity model (we use anelastic anisotropic PREM and resolution 2-100 s)
Measured signal: demean, resample, response and sensor orientation corrections according to station metadata

Automated XKS waveform selector

Synthetic signal (BP filter 7-30 s)

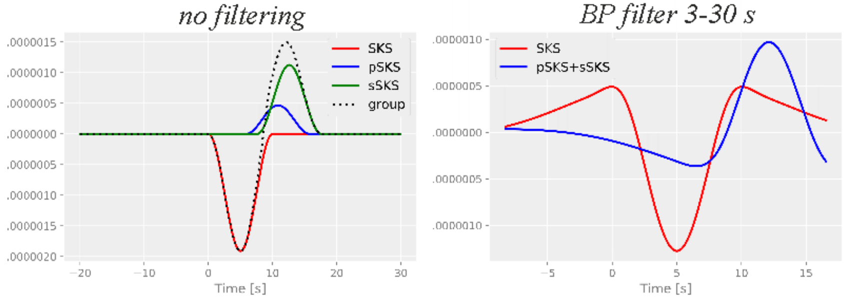


Measured signal (BP filter 7-30 s)

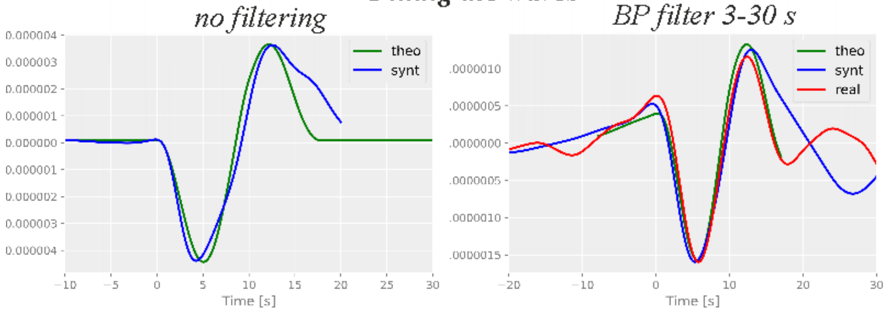


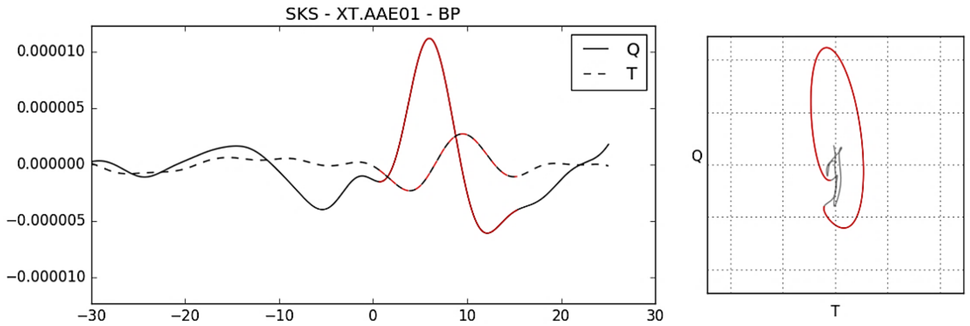
2015-06-04T23:15:43.90 lat: 5.99° long: 116.54° depth: 10.0 km magn: 6.0 BORNEO moment tensor: [-6.40e+24, -7.60e+23, 7.16e+24, 7.68e+24, 5.91e+24, 2.74e+24] dyne cm

Theoretical waves



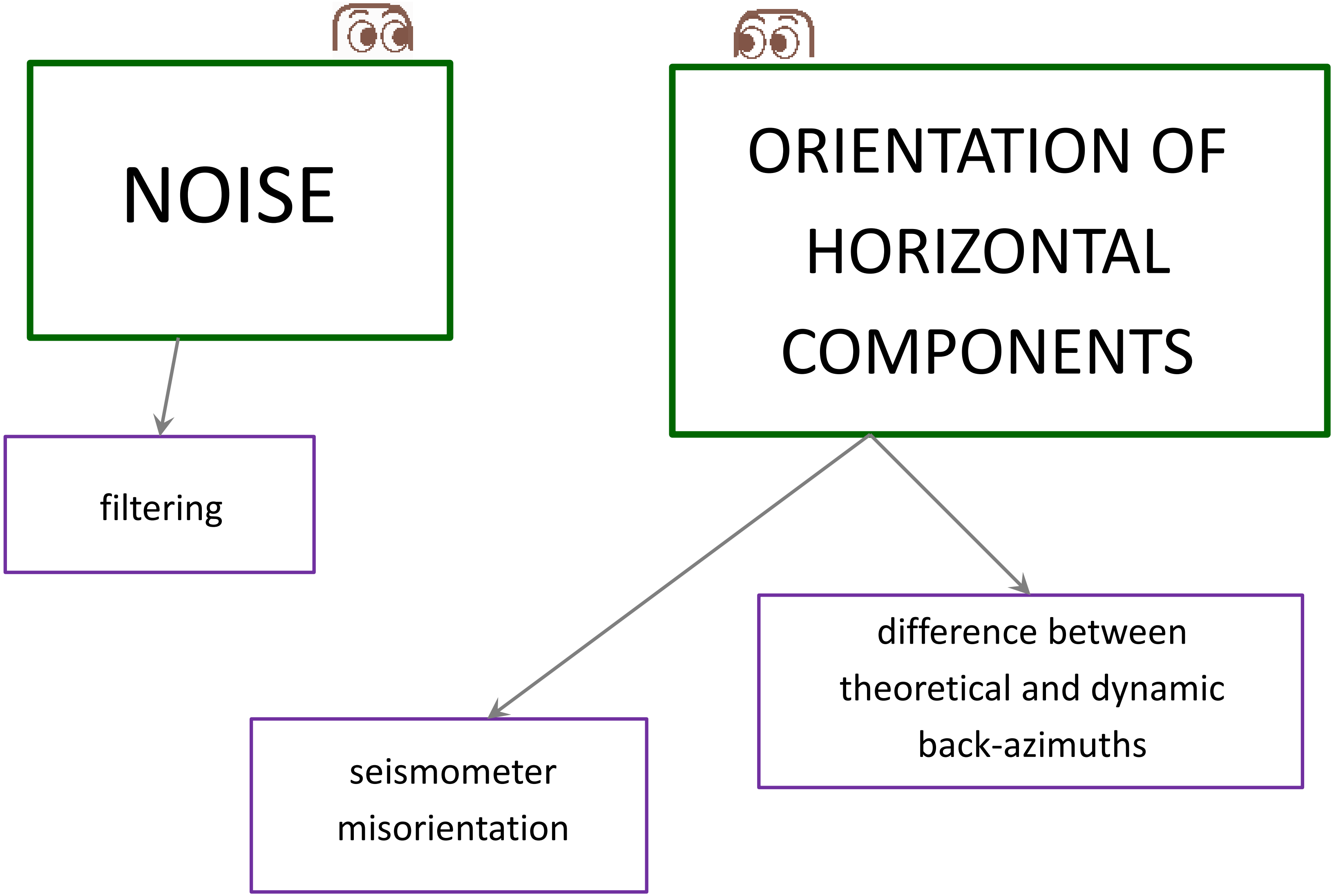
Fitting the waves





Automated selection of SKS wave

Pitfalls of splitting methods (eigenvalue, transverse)



NOISE

filtering

ORIENTATION OF HORIZONTAL COMPONENTS

seismometer misorientation

difference between theoretical and dynamic back-azimuths

Effects of seismic noise on splitting

Synthetic test:

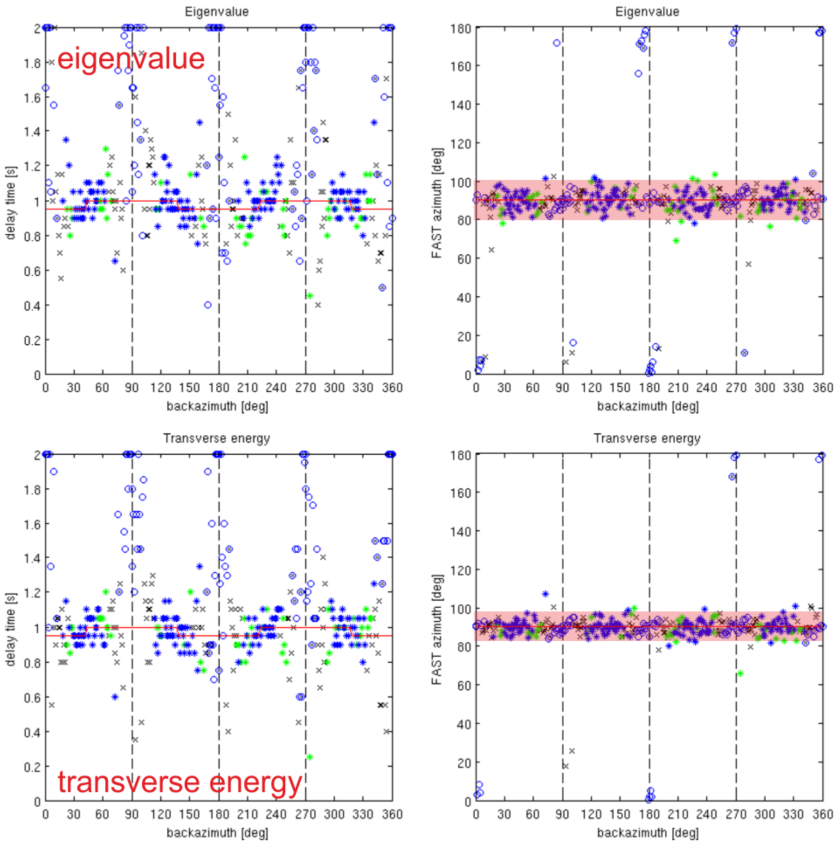
SKS wave
T = 8 s
incidence angle 8°
backazimuths 0°-360°

Anisotropic layer
thickness 100 km
S anisotropy 4.8 %
hexagonal anisotropy with horizontal (θ=90°) FAST symmetry axis at azimuth ϕ=90°

Splitting champion fighters
eigenvalue method
transverse energy method

Quality conditions (by Wuestefeld & Bokelmann, 2007)

*	good splitting	o	good null
*	fair splitting	o	near null
x	poor splitting		



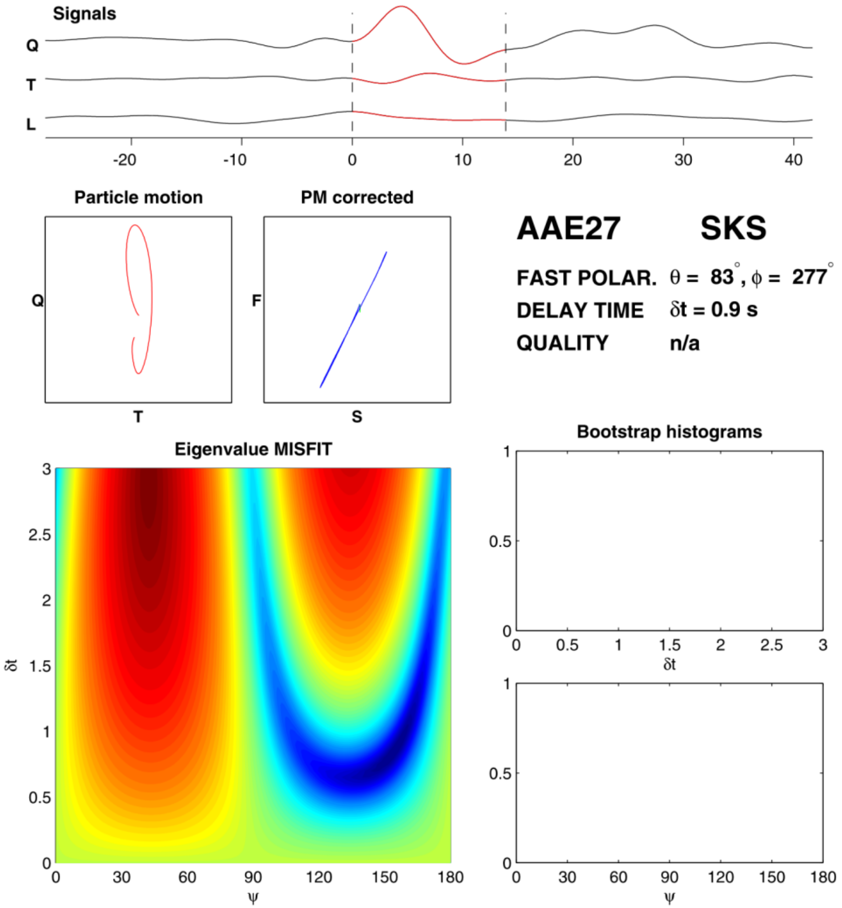
noise in signal
SNR = 10

eigenvalue method ✗
transverse energy ✓

Vecsey et al., 2008

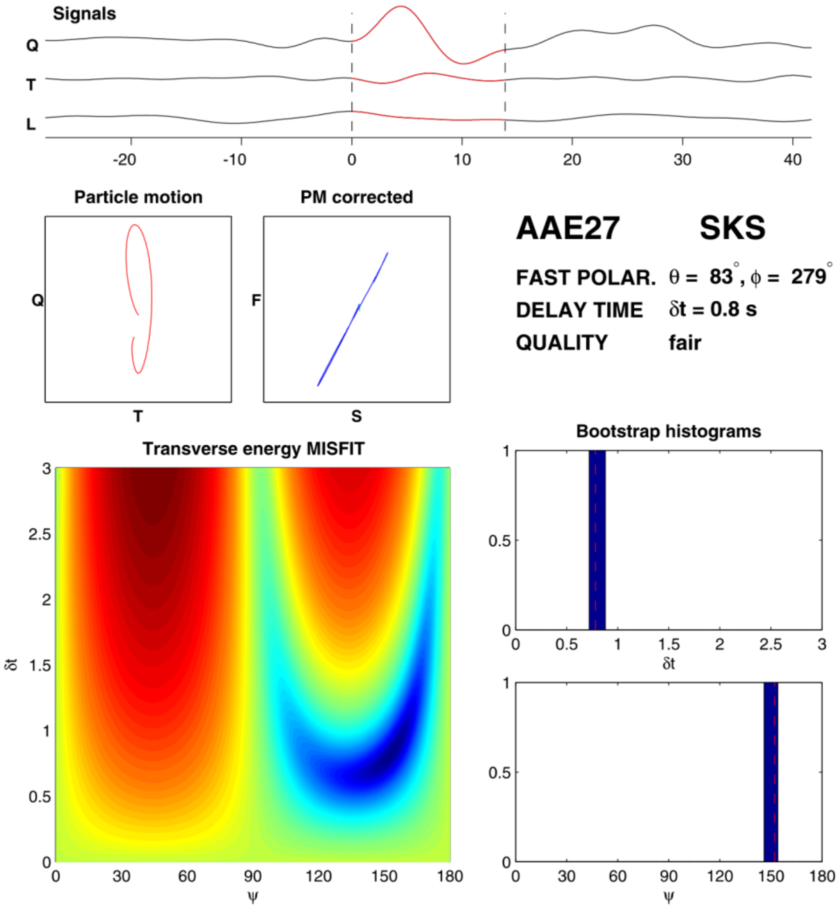
Stability of eigenvalue and transverse energy methods

Eigenvalue method


AAE27 SKS

FAST POLAR. θ = 83°, ϕ = 277°
DELAY TIME δt = 0.9 s
QUALITY n/a

Transverse energy method


AAE27 SKS

FAST POLAR. θ = 83°, ϕ = 279°
DELAY TIME δt = 0.8 s
QUALITY fair

Effects of sensor mis-orientation on splitting

Synthetic test:

SKS wave
T = 8 s
incidence angle 8°
backazimuths 0°-360°

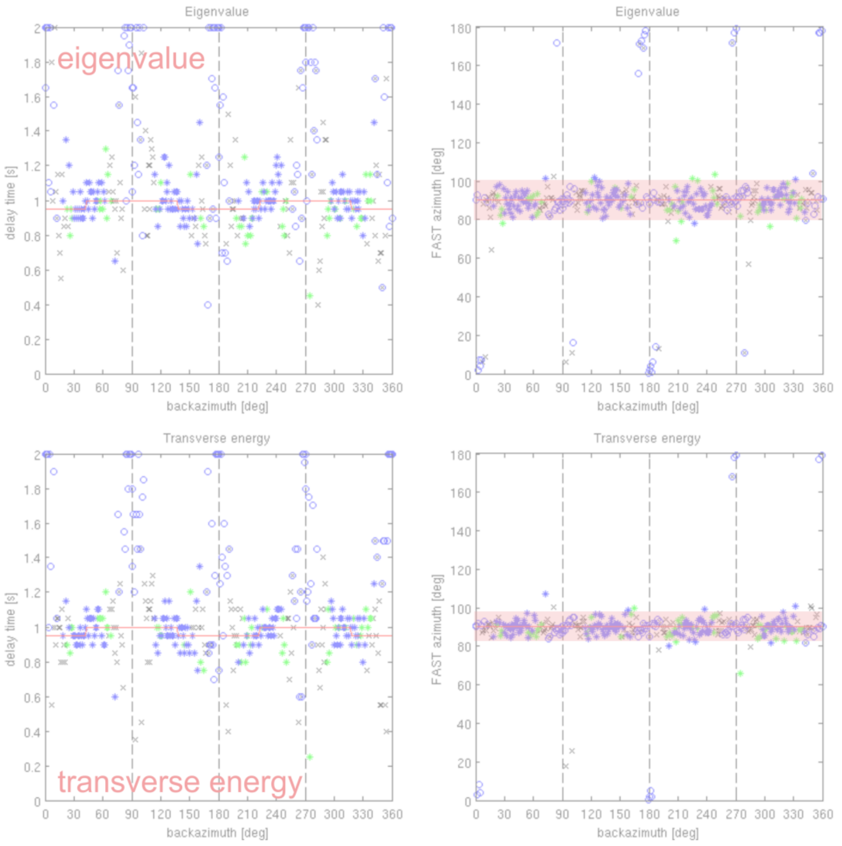
Anisotropic layer
thickness 100 km
S anisotropy 4.8 %
hexagonal anisotropy with horizontal (θ=90°) FAST symmetry axis at azimuth ϕ=90°

Splitting champion fighters
eigenvalue method
transverse energy method

Quality conditions (by Wuestefeld & Bokelmann, 2007)

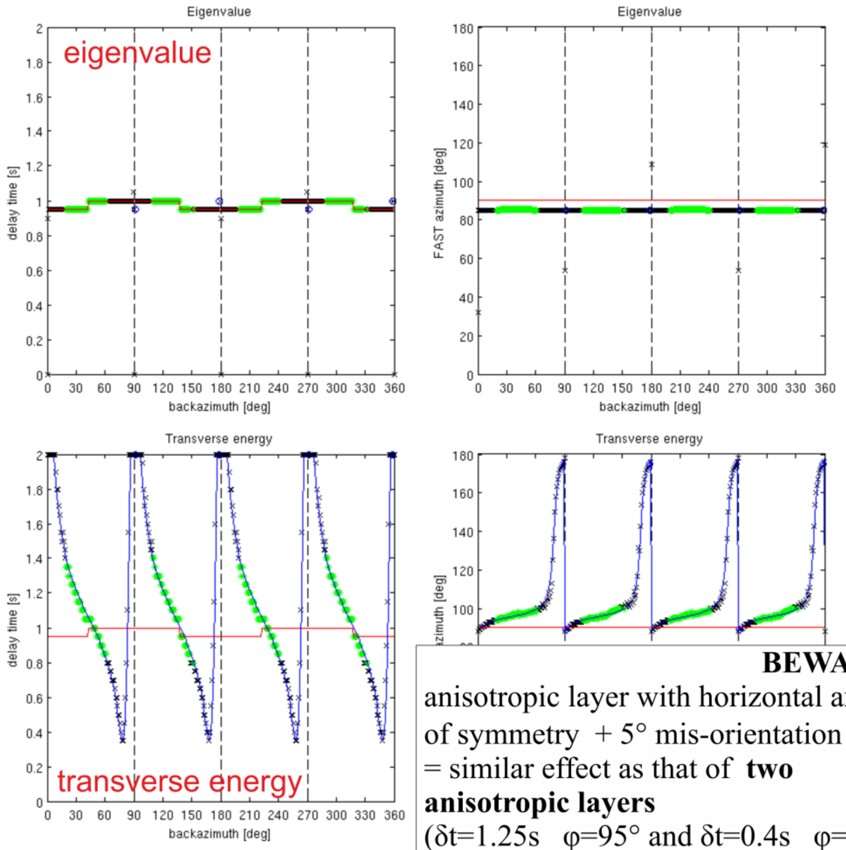
* good splitting
* fair splitting
x poor splitting

o good null
o near null



noise in signal
SNR = 10

eigenvalue method ✗
transverse energy ✓



BEWARE!
anisotropic layer with horizontal axis of symmetry + 5° mis-orientation = similar effect as that of **two anisotropic layers** (δt=1.25s φ=95° and δt=0.4s φ=28°) see blue lines

misorientation 5°

eigenvalue method ✓
transverse energy ✗

Vecsey et al., 2008

Sensor mis-orientation

How to measure:

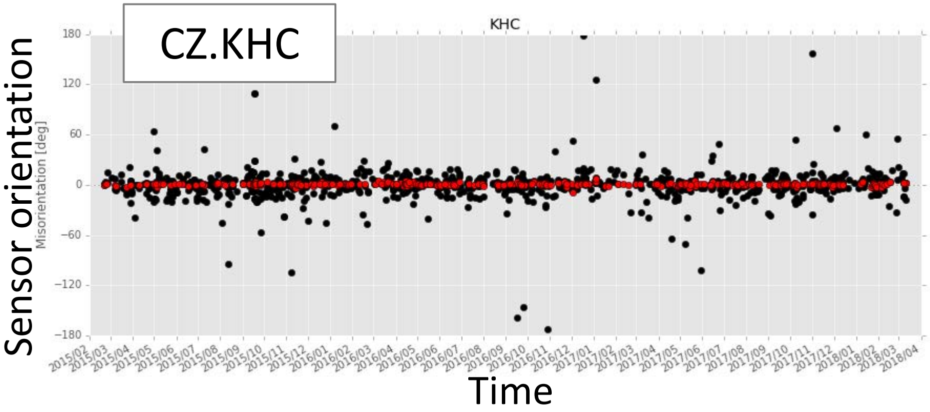
Gyrocompass: very accurate, not very frequent usage (if ever)

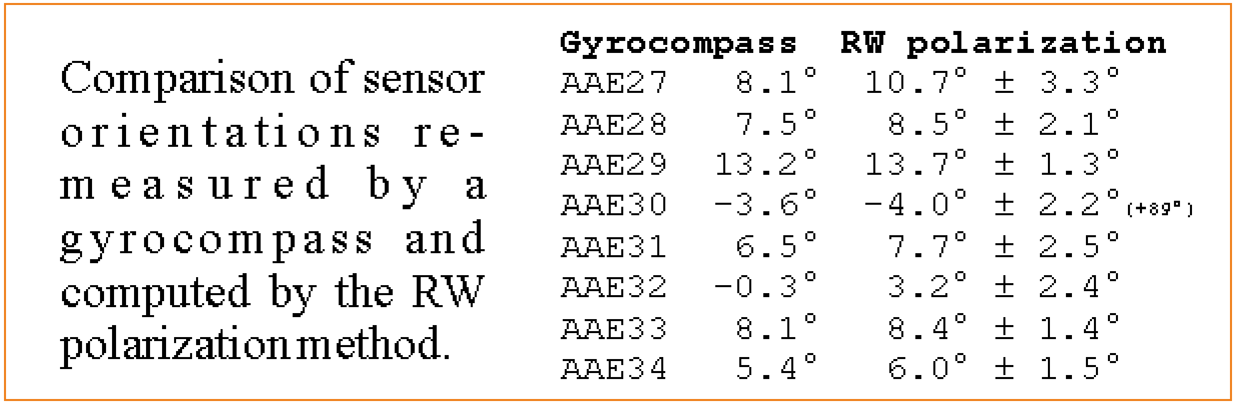
Polarization of Rayleigh waves: not so accurate, better detection of temporal changes (see black dots)

-> Improved Rayleigh wave method : corrected for dynamic back-azimuths, best precision 1-2° (see red dots)

How to correct:

Change values in station metadata (easy!)



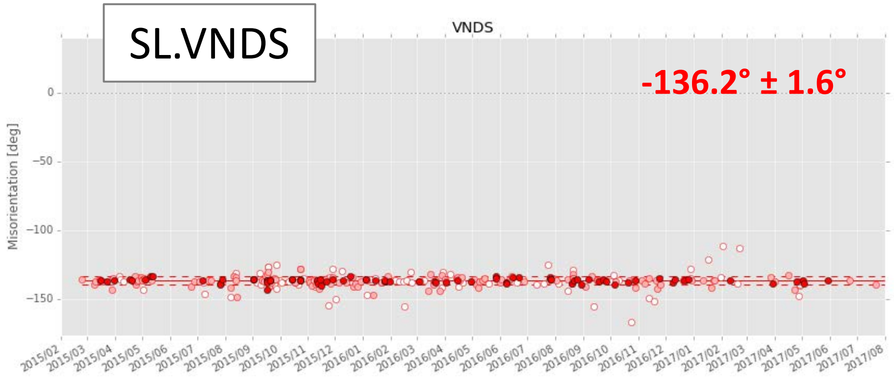


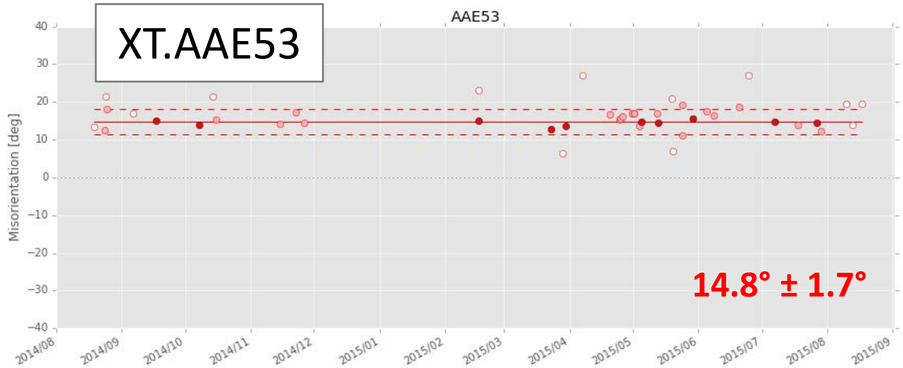
Comparison of sensor orientations re-measured by a gyrocompass and computed by the RW polarization method.

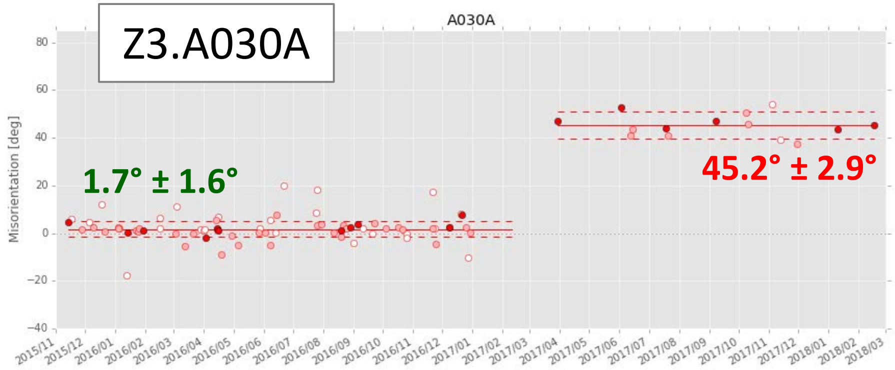
	Gyrocompass	RW polarization
AAE27	8.1°	10.7° ± 3.3°
AAE28	7.5°	8.5° ± 2.1°
AAE29	13.2°	13.7° ± 1.3°
AAE30	-3.6°	-4.0° ± 2.2° (+89°)
AAE31	6.5°	7.7° ± 2.5°
AAE32	-0.3°	3.2° ± 2.4°
AAE33	8.1°	8.4° ± 1.4°
AAE34	5.4°	6.0° ± 1.5°

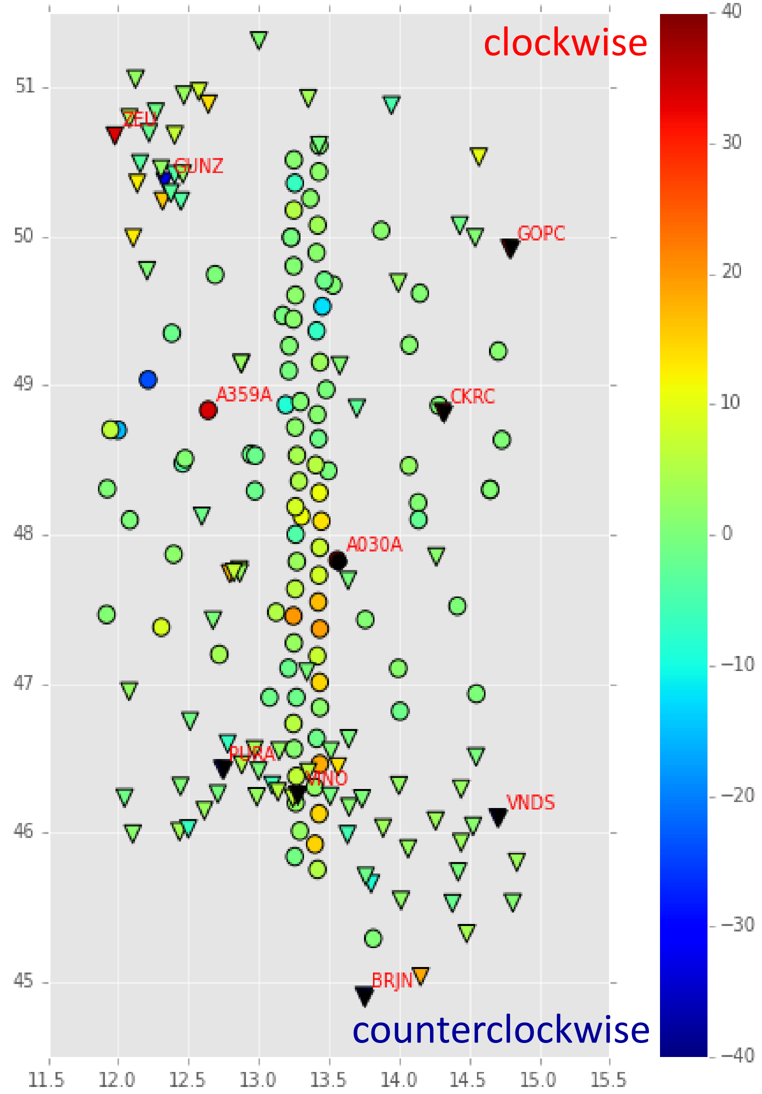
Sensor mis-orientations

by the improved Rayleigh wave method



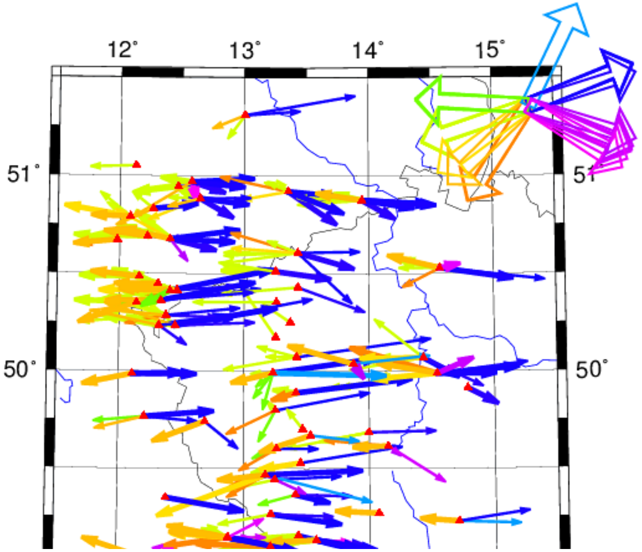


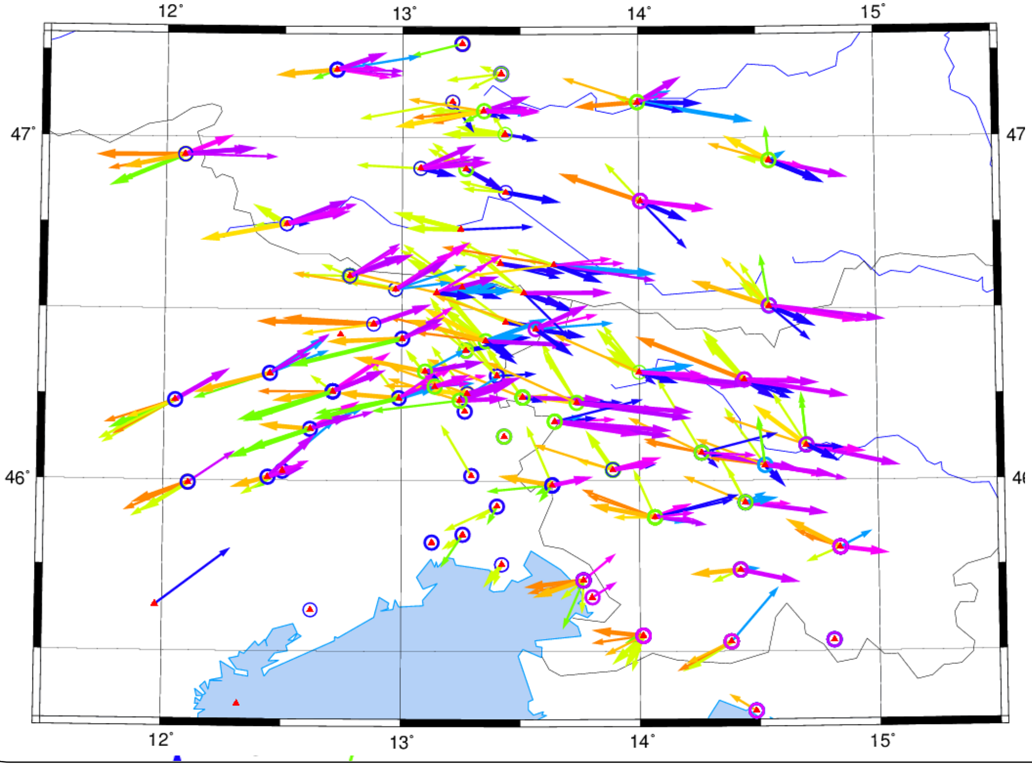


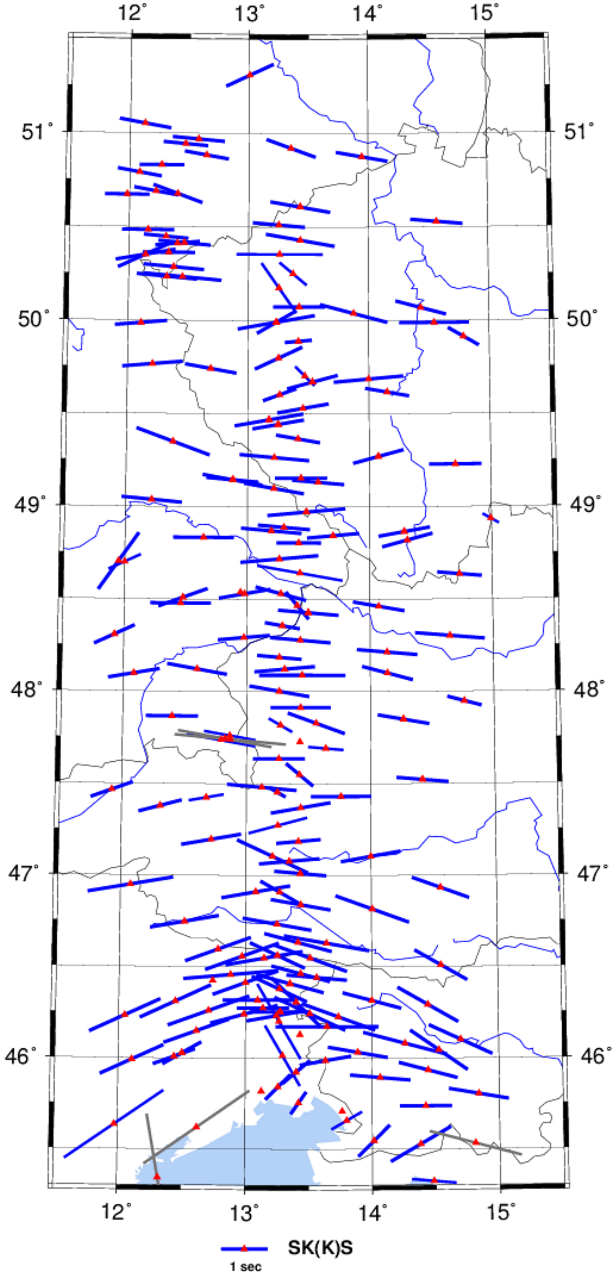


Mis-orientations colored from **blue** (-40°) to **red** (+40°), larger deviations are in **black**. Stations with their mis-orientations exceeding 30° are named. Triangles mark permanent stations, circles temporary ones.

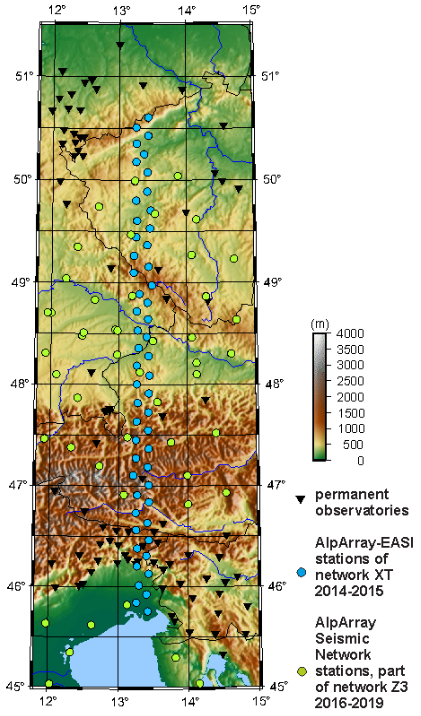
SKS splitting corrected for sensor mis-orientations

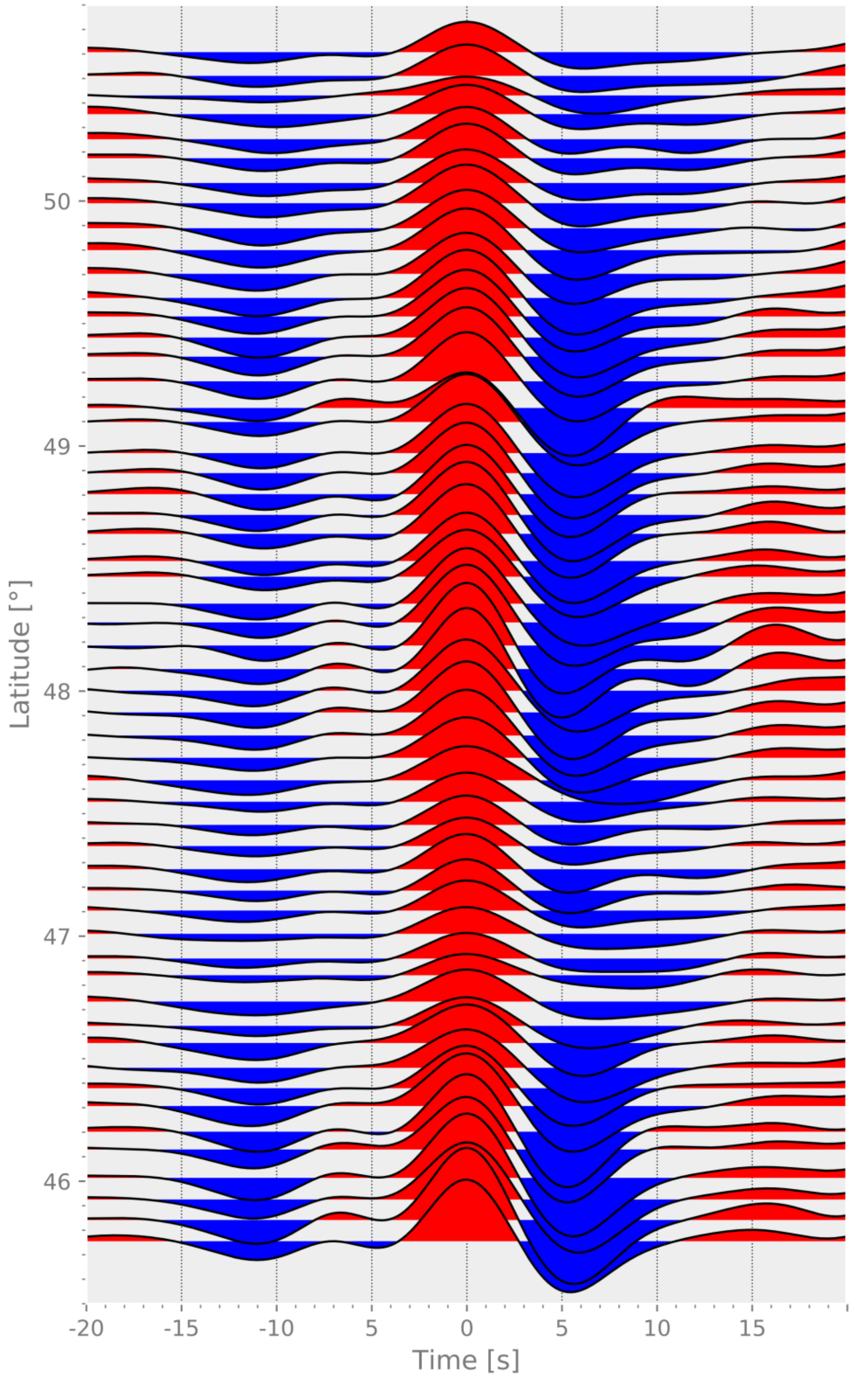






SKS waveform (Q component) for one event:

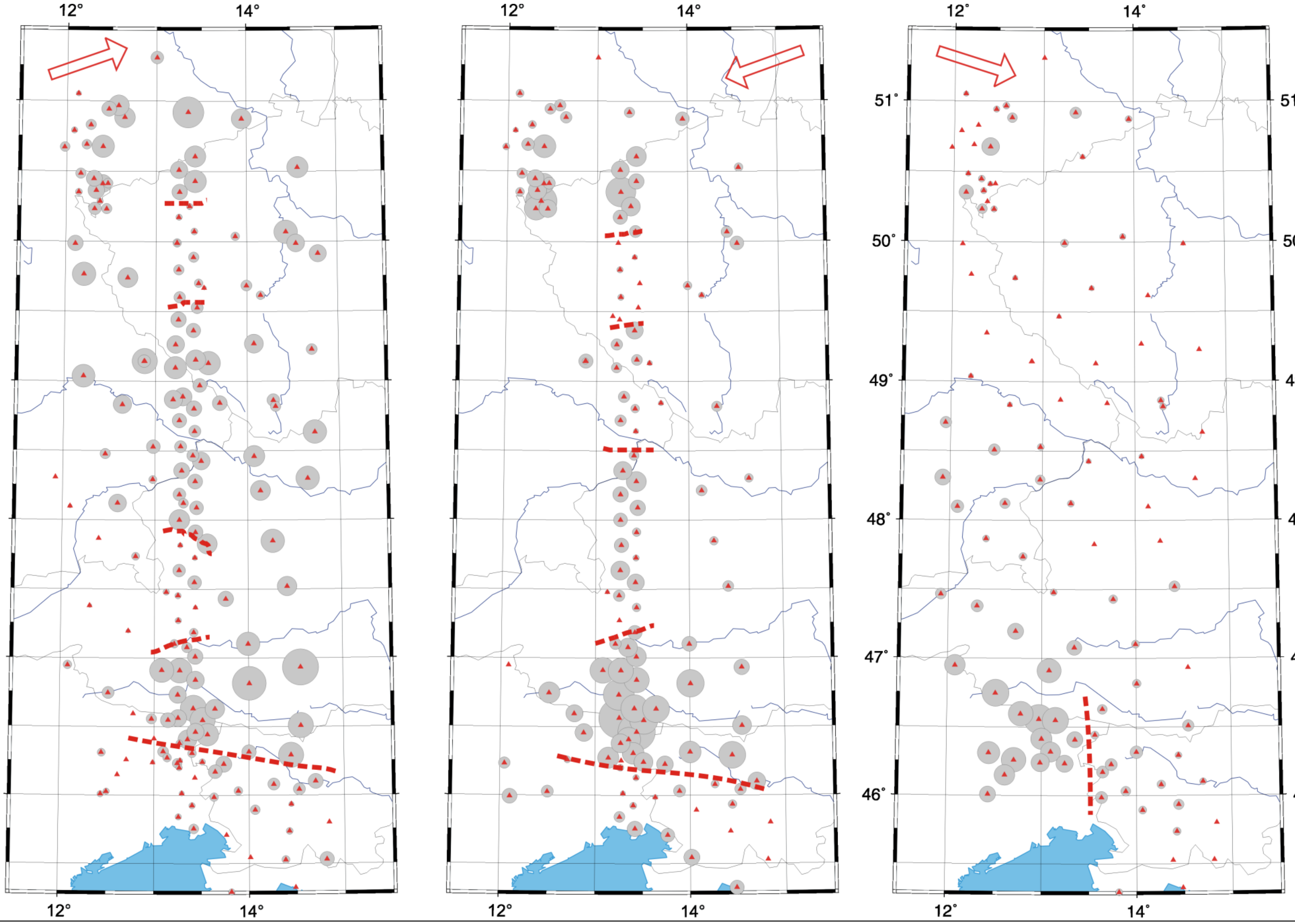




SKS wave on Q component centered around a main peak. Displacement signals corrected for a seismometer response and filtered by 7-30 s bandpass Butterworth filter.

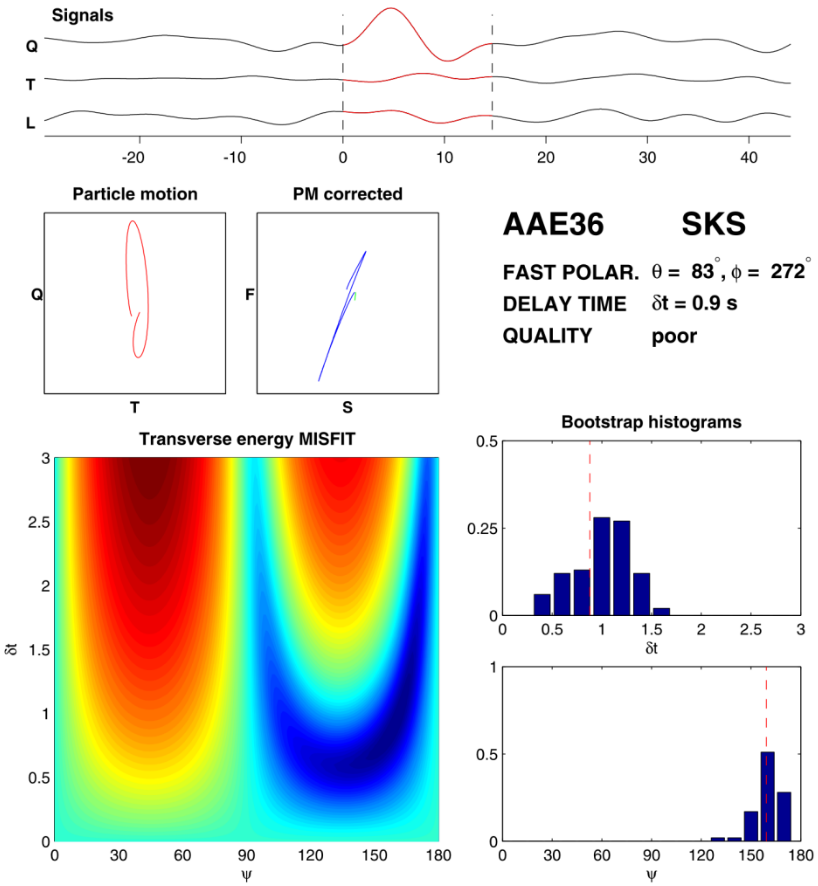
Metrics invariant to a rotation of horizontal components:

Particle motion thickness



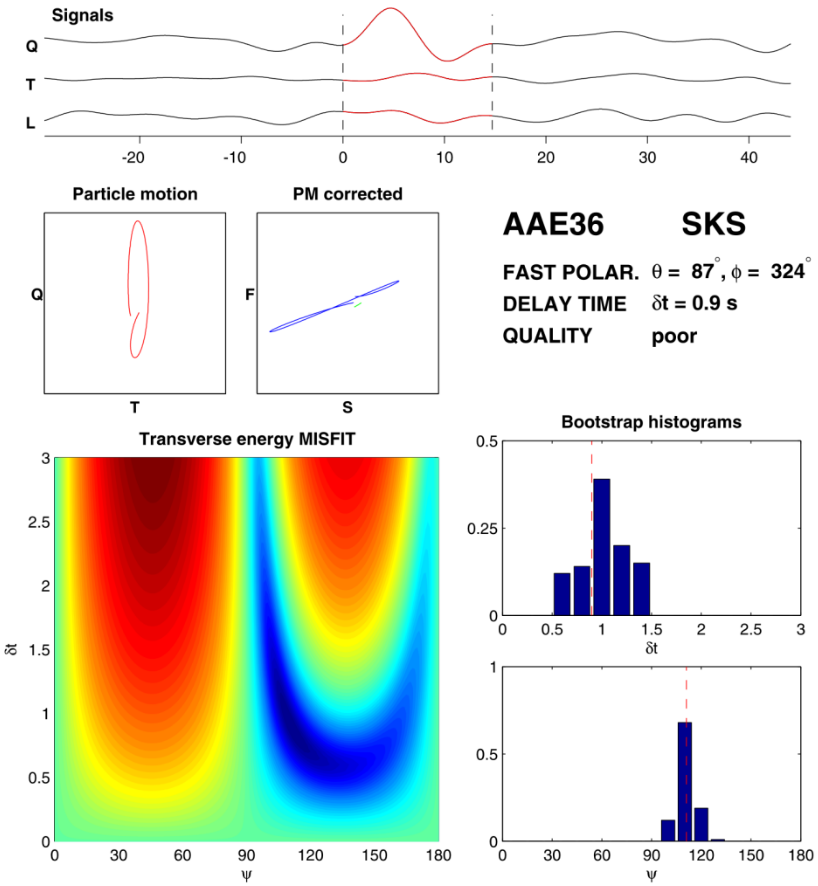
Dynamic versus theoretical azimuth

THEORETICAL BAZ 71.3°



Fast S azimuth **272°**

DYNAMIC BAZ 75.1°



Fast S azimuth **324°**

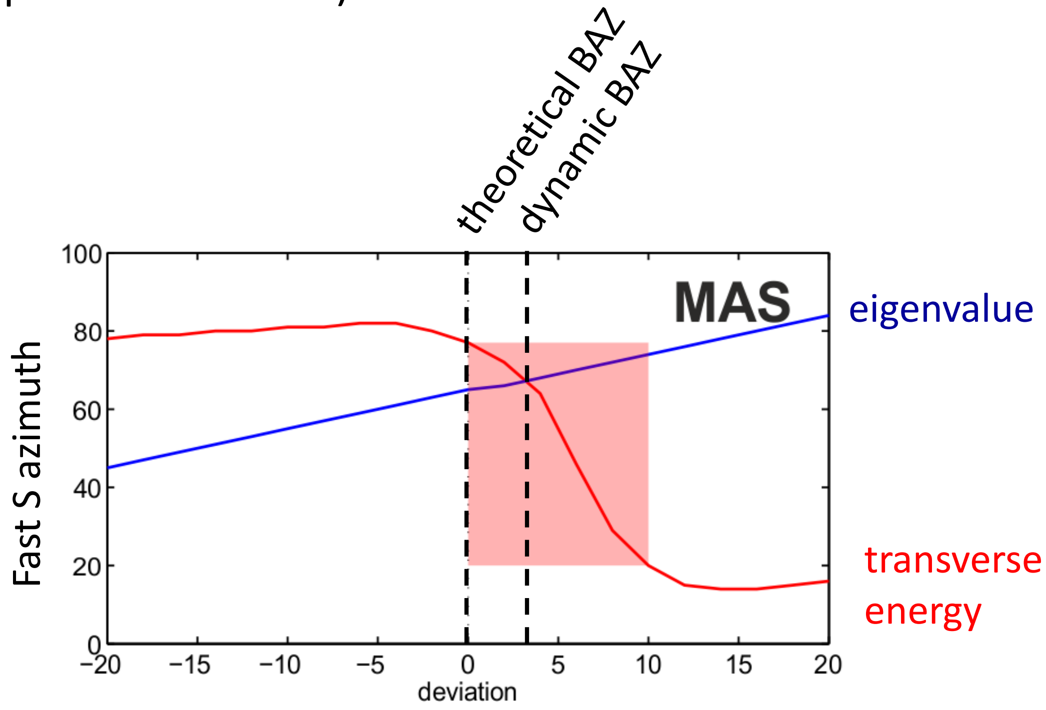
Dynamic back-azimuth

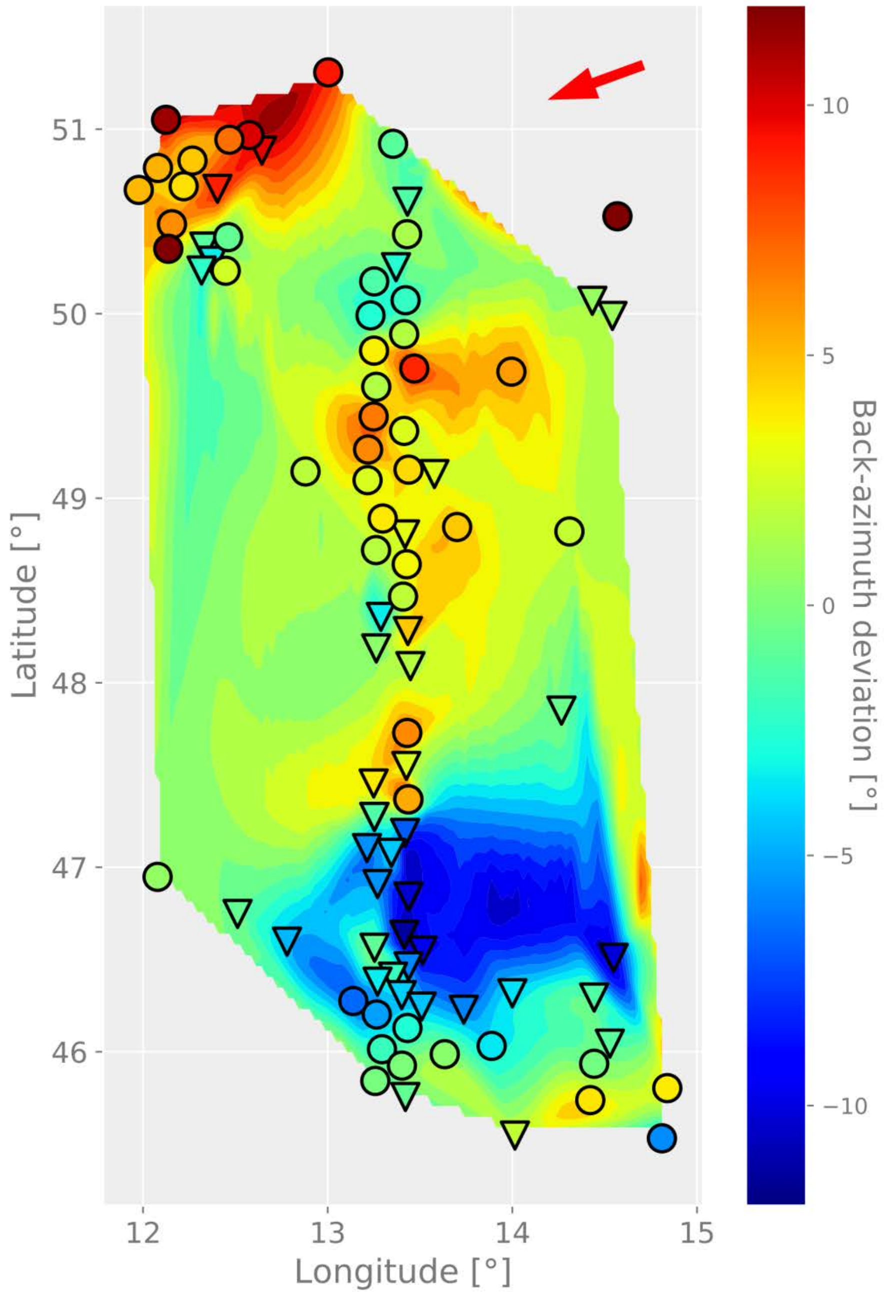
…first, do corrections for mis-orientations!

How to measure:

- if PM is linear – PM should be polarized directly in Q direction
- if PM is elliptical (and wide) – by comparison of eigenvalue and transverse energy methods
- (if PM is elliptical but narrow – problem as usual)

Comparison of the eigenvalue and transverse energy methods





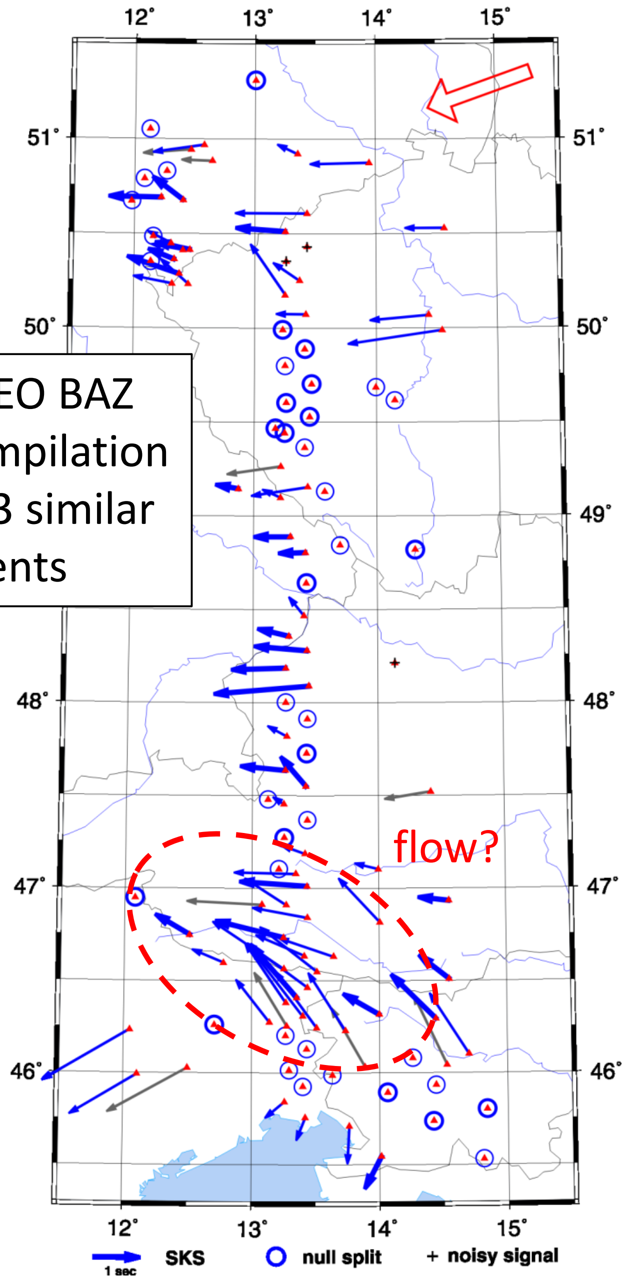
Differences between dynamic and theoretical back-azimuths

EVENT 2015-06-04T23:15:43.90
lat: 5.99° long: 116.54° depth: 10.0 km
magn: 6.0 BORNEO

▽ from an elliptical PM

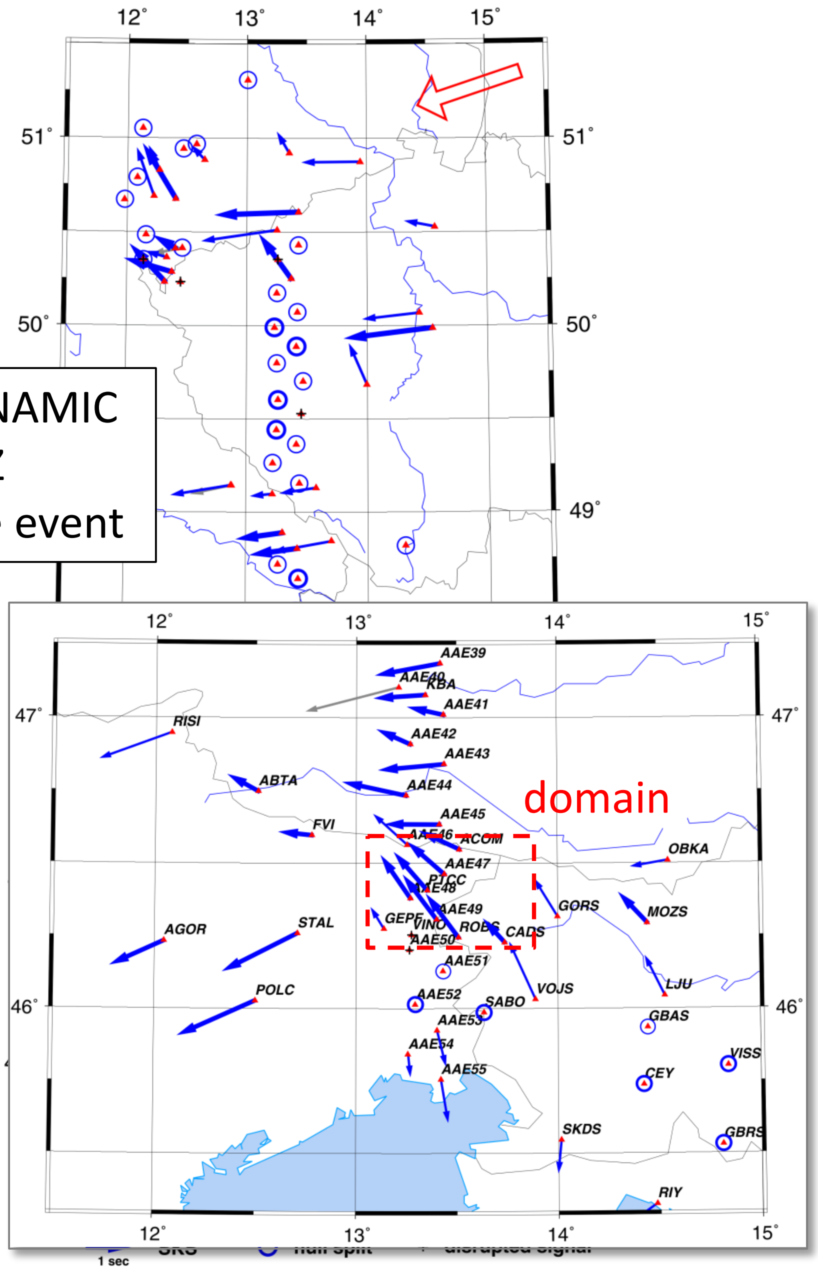
○ from a linear PM

SKS splitting corrected for dynamic back-azimuths



THEO BAZ
compilation
of 3 similar
events

DYNAMIC
BAZ
one event



Conclusions

To obtain larger number of good quality XKS splittings, we prepared an **automatic waveform selector for core-mantle refracted shear waves**. The procedure includes a signal pre-processing, detection and qualification of near seismic phases and a careful wave selection itself with respect to edges and rapid changes in a wave's particle motion (PM).

We demonstrate that methods used for shear-wave splitting evaluation are sensitive to noise in signals and can be **extremely sensitive** to **incorrect sensor orientations** and to **differences between dynamic and theoretical back-azimuths**.

We **improved a method for determination of sensor orientations** from Rayleigh-wave polarizations. Automatic procedures were tested on data from 187 permanent and temporary stations located in the area of the AlpArray project. Accuracy of the method attains 1°, in case of sufficient number of Rayleigh waves and up to about 2° is comparable with the gyrocompass measurements.

PM of shear-wave allows to follow regional variations of mantle structure even for waves with weak signals on the T component (narrow PM). Moreover, it is **invariant** to sensor mis-orientations and effects connected with dynamic back-azimuths.

Corrections for sensor mis-orientations and differences between dynamic and theoretical back-azimuths enhance **resolution** of evaluated splitting parameters.

Distinct regional variations along the AlpArray-EASI line imply **complex domain-like architecture** of the south-central part of the European plate.