35 Years of Global Broadband Array Seismology in Germany and Perspectives

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WORKSHOP on ARRAYS in GLOBAL SEISMOLOGY

Overview

- Seismological Arrays in Germany
- Structural Imaging
- Imaging of Quasi- Continuous Sources
- Arrays and the Seismic Source
- 3-d Array
- Polarisation and Anisotropy
- Deep Ocean Test Array (DOCTAR)

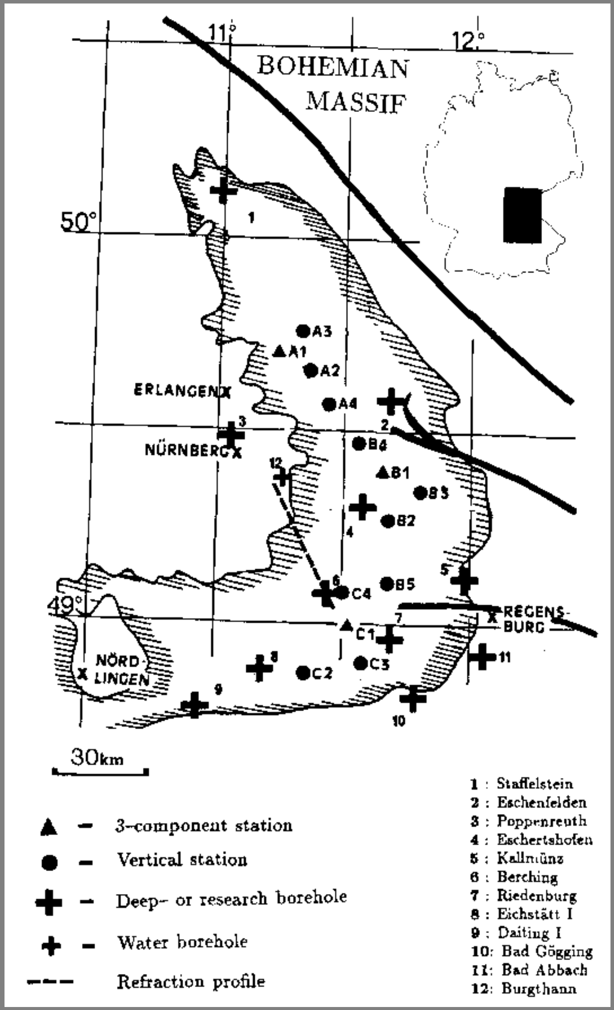
The Gräfenberg Array (GRF)

- Broadband data since 1975. Continuous data since 1977. 12 vertical, 3 3-C Streckeisen STS1 (20 s) stations since 1979.

- Organized by University Consortium (Hilfseinrichtung of German Research Council)

- Scientific objective

- Upgrade to 12 3-C STS2 instruments in 2006

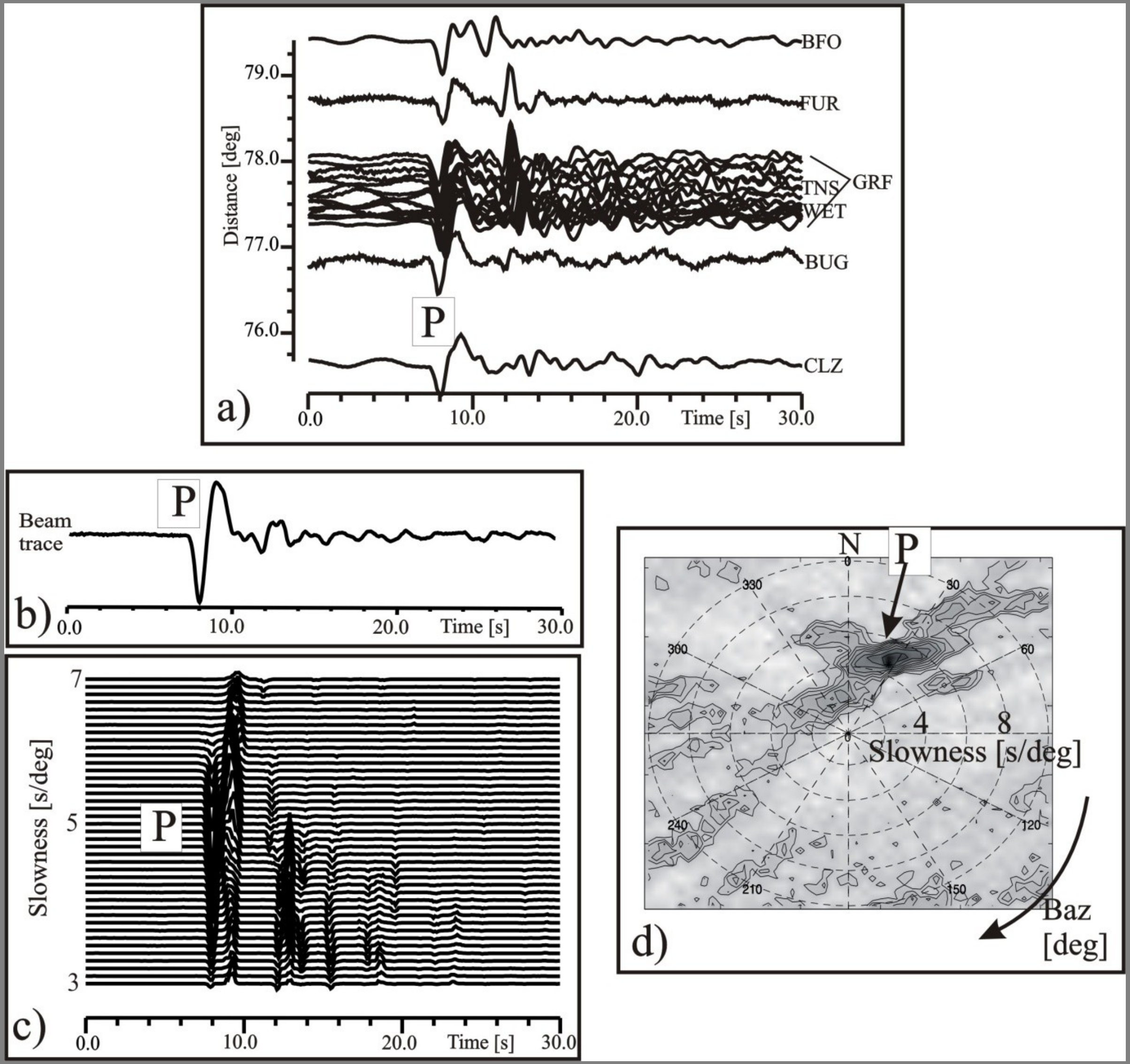


Array Methods

Aligned seismograms (distance dependent)

beam

vespa



F-k

Thomas 08

Depth Determination by Pn-sPn

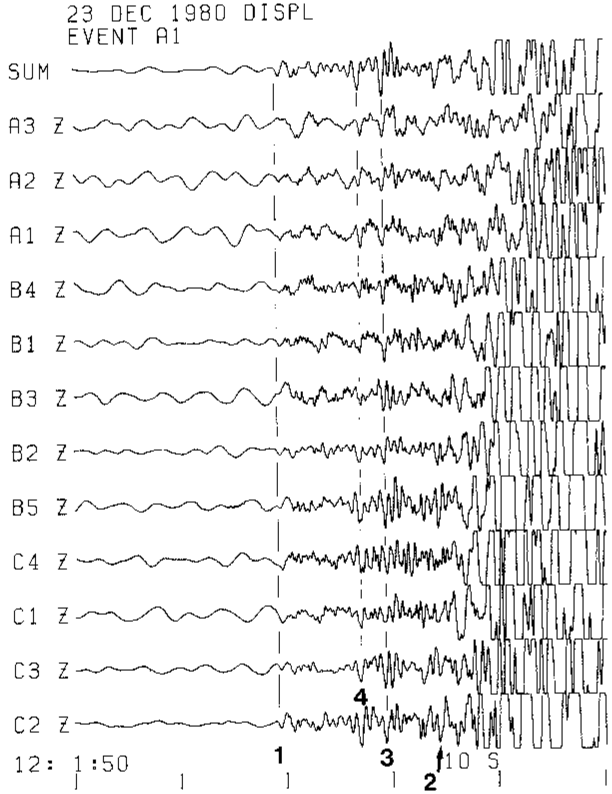


FIG. 7. The same as in Figure 2 for event A1. Again the displacement proportional bandpass is used as in Figure 4.

Zonno and Kind, 1983

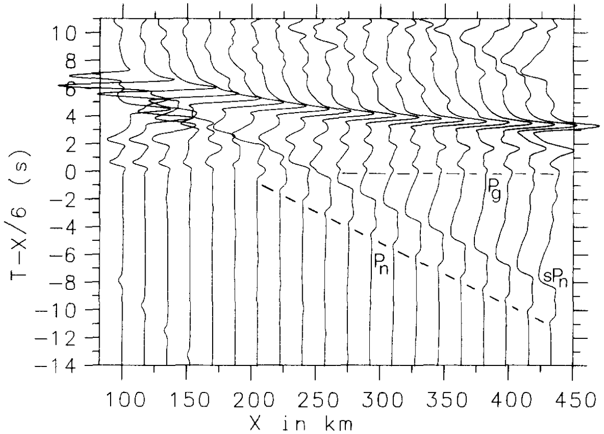


FIG. 10. Theoretical seismogram section. The ray paths of the marked phases are shown in Figure 11. The source orientation of the large Friuli event in May 1976 is used.

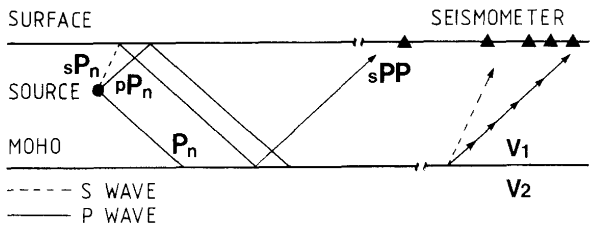
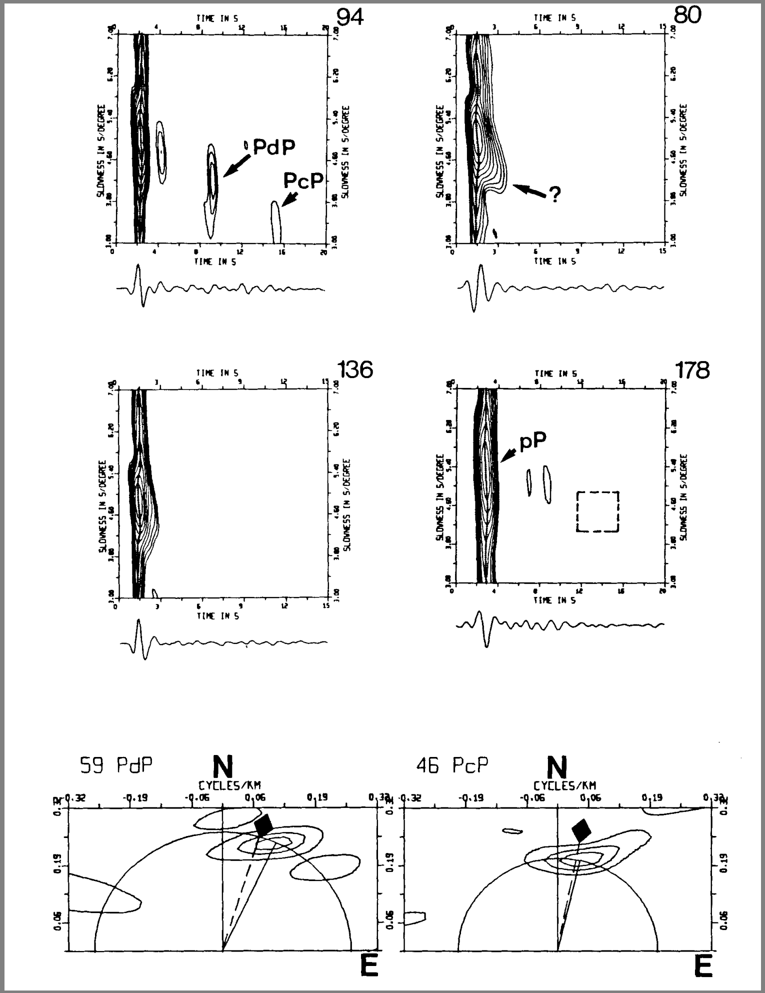


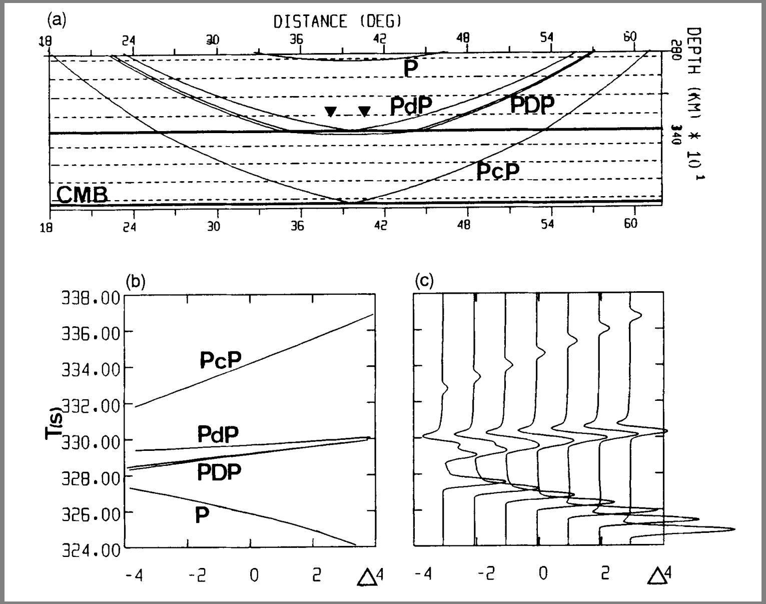
FIG. 11. Ray paths of the strongest phases shown in Figure 10.

Full wavefield synthetics
(reflectivity method)

P-Reflections from D''



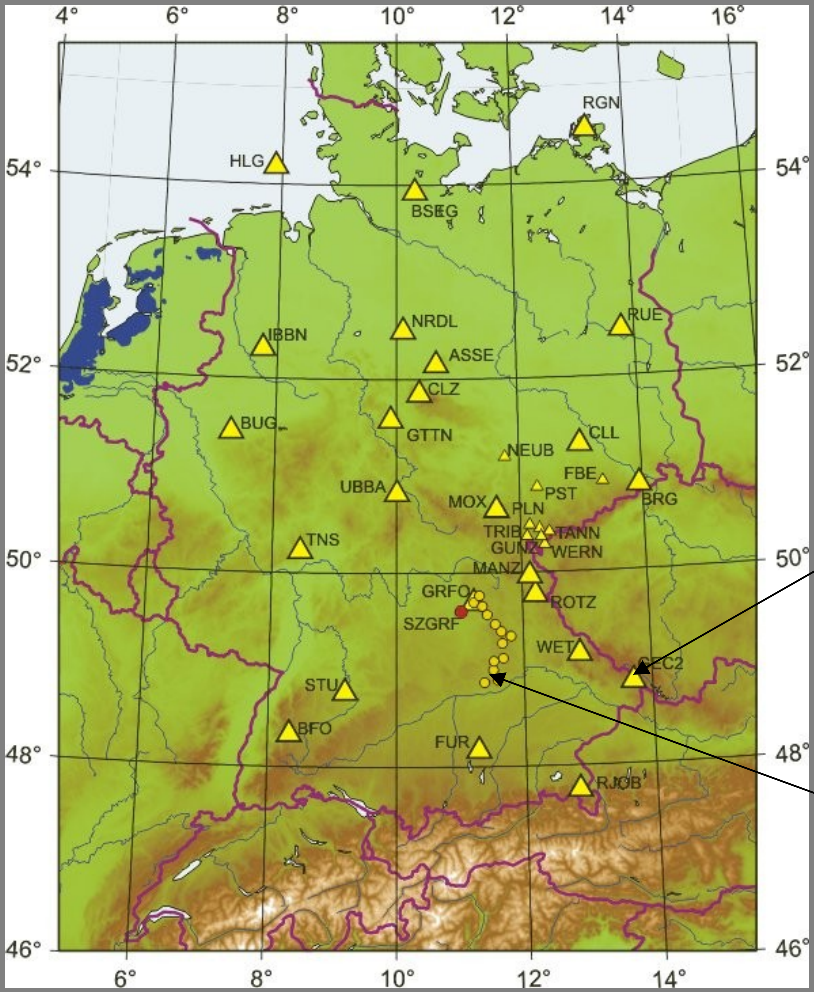
Kurile earthquakes recorded at GRF.

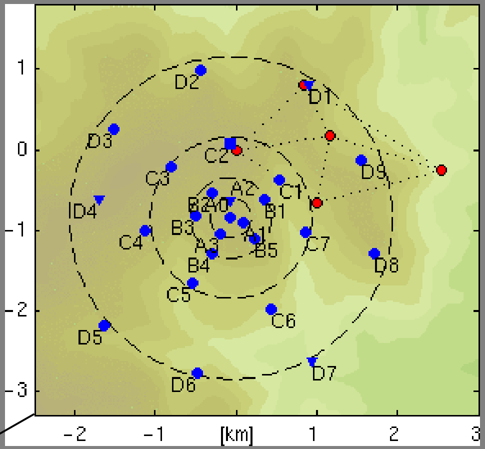


Weber, 1993

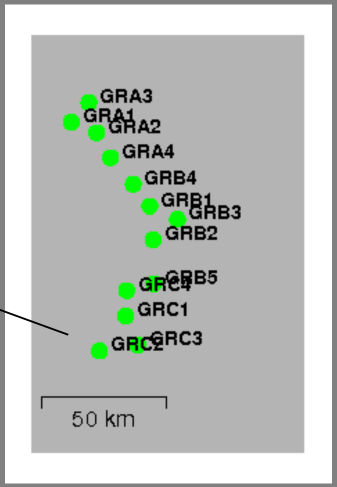
Seismological Arrays in Germany

GERES Array (mainly shortperiod, detection array)





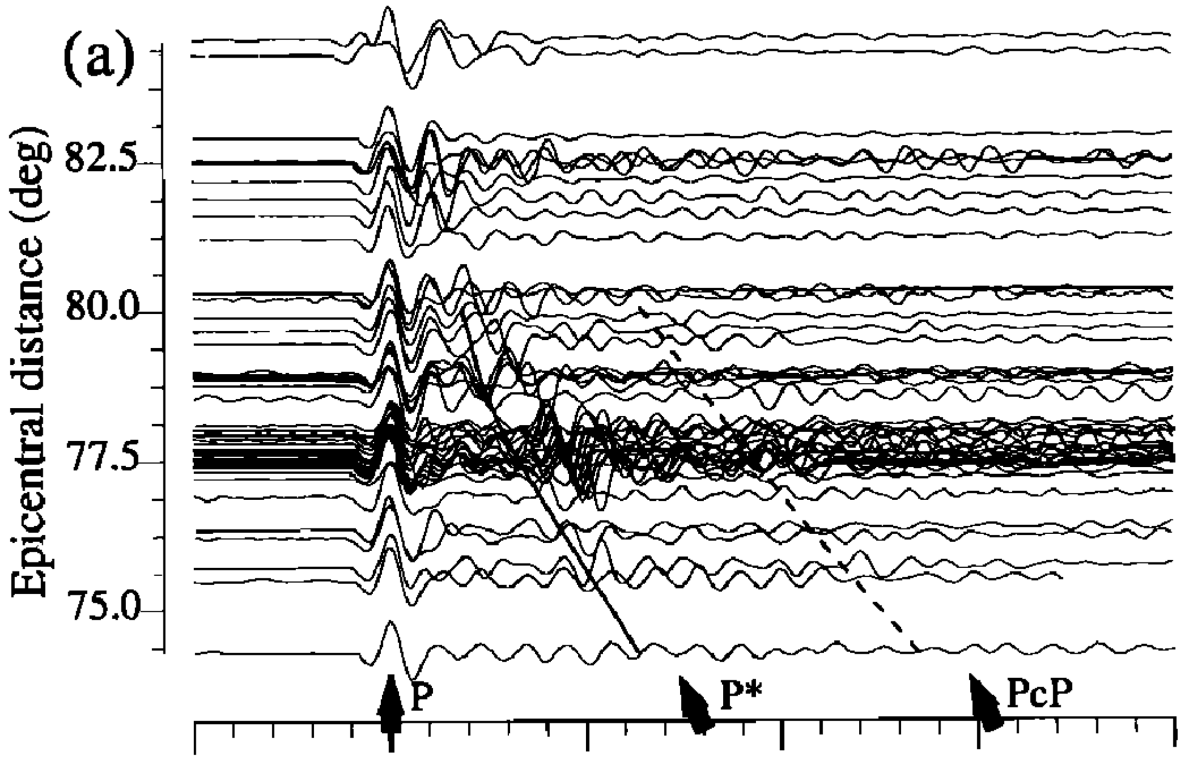
GRF Array



GRSN (broadband STS2 since 1992)

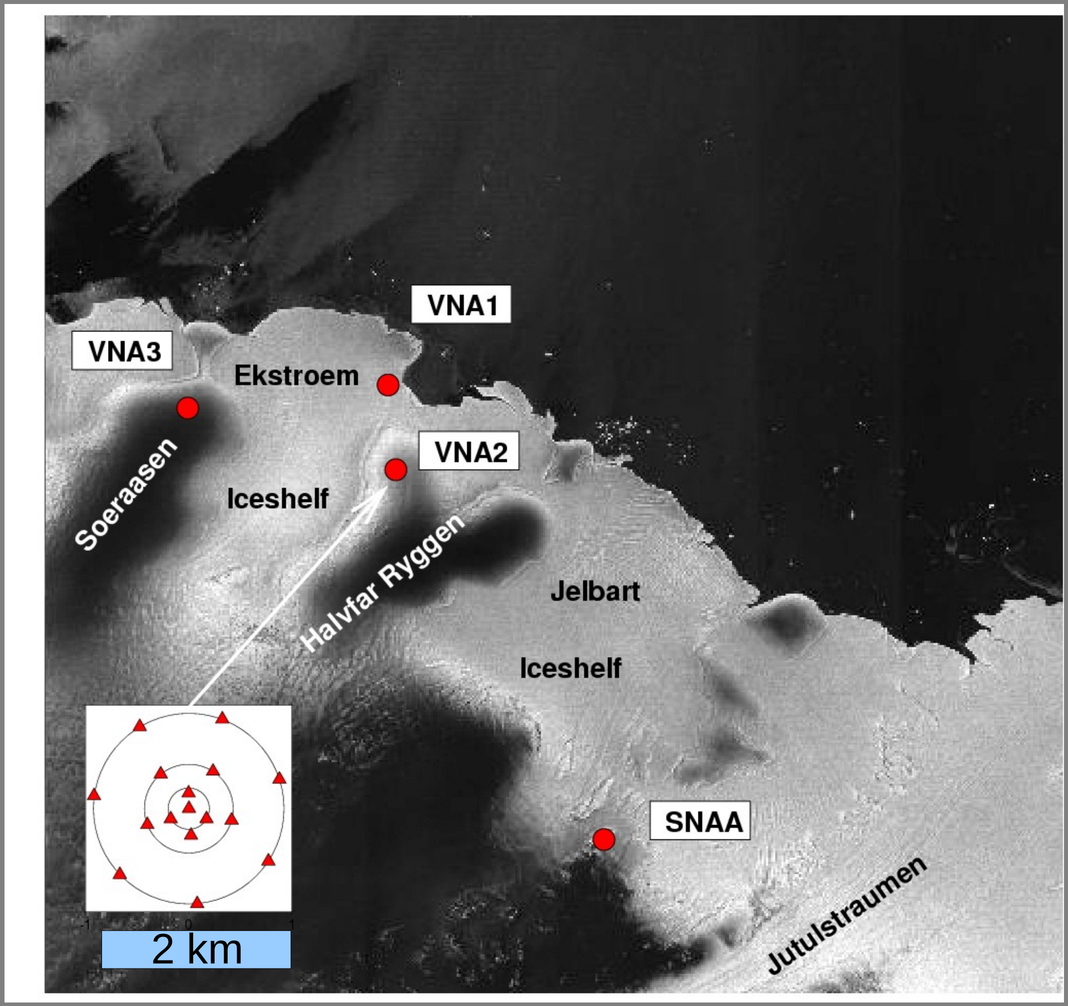
P-Reflections from D''

Kurile Earthquake (17.12.1991) recorded at GRSN



Freybourger et al., 2000

Neumayer Array, Antarctica (Alfred Wegener Institute AWI)

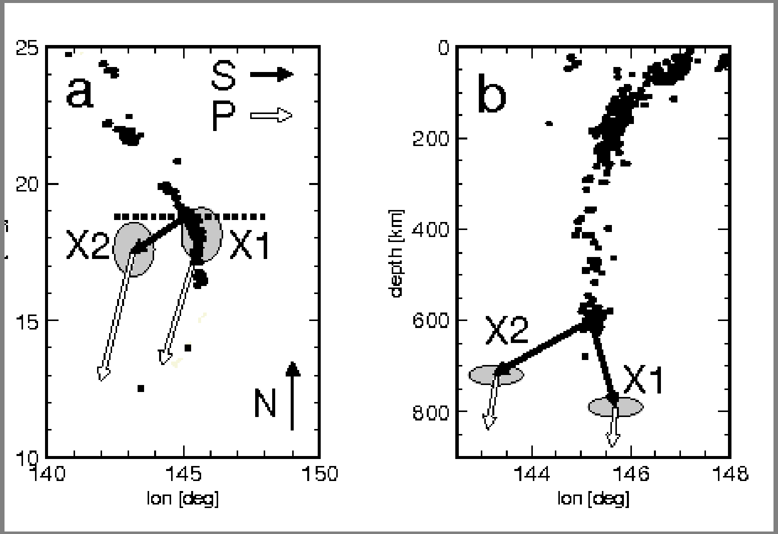


1 broadband
3 Cand
15 vertical
1 Hz sensors.

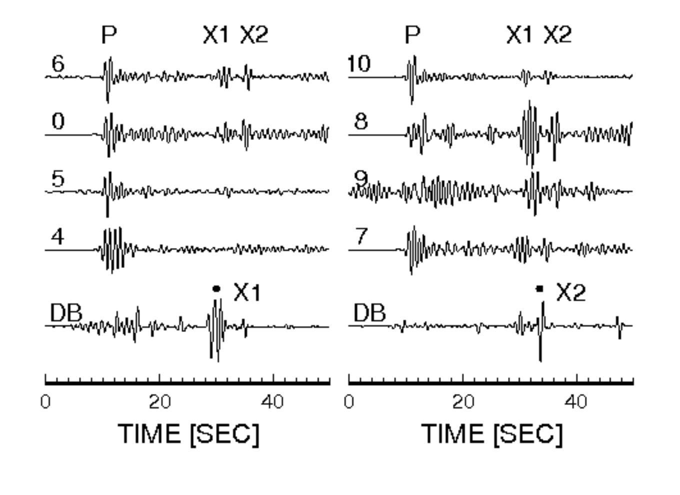
Since 2000 continous data, realtime data transmission.

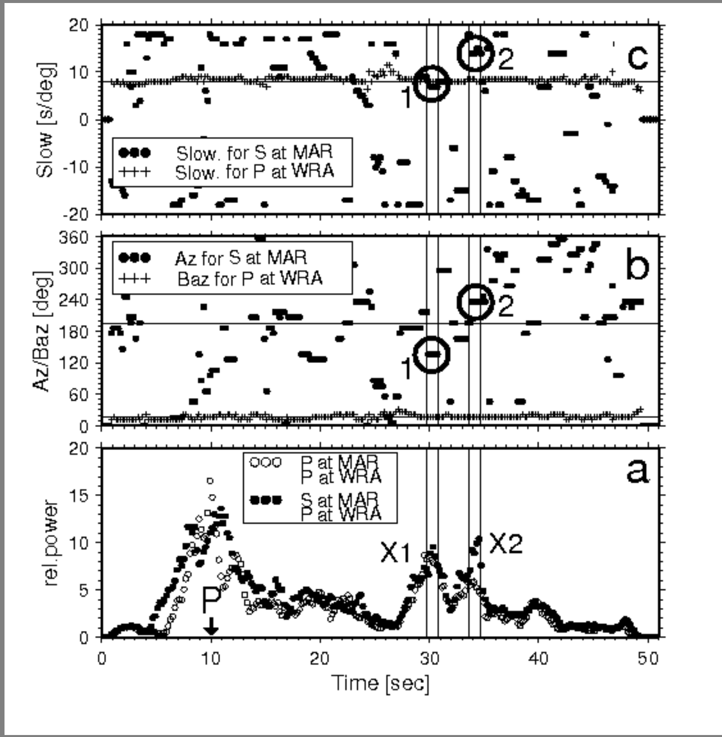
(A. Eckstaller, AWI)

Double Beamforming – Simultaneous Use of Source and Receiver Arrays



Source Array: Deep Cluster beneath Mariana Trench
Receiver Arrays: GRF and WRA
-Australia

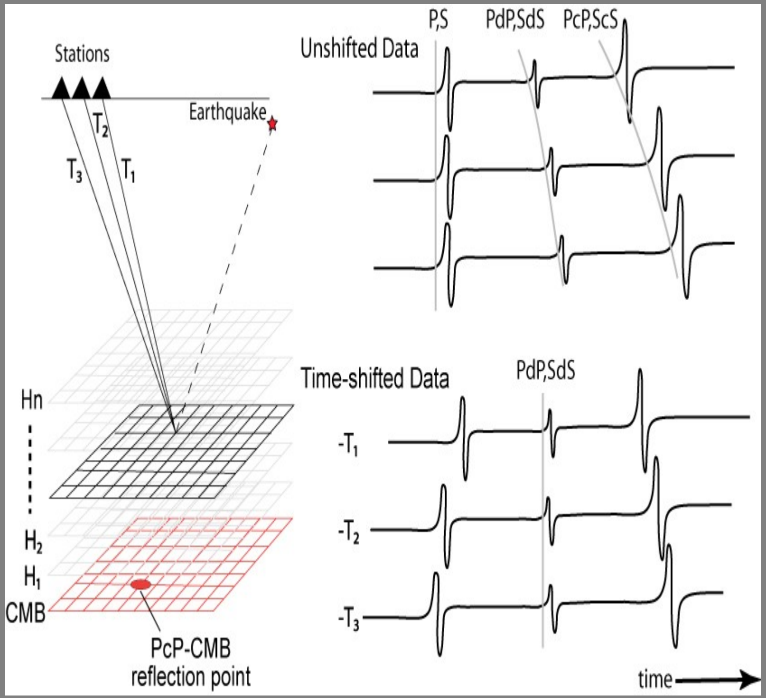


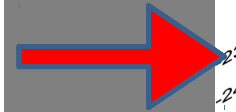


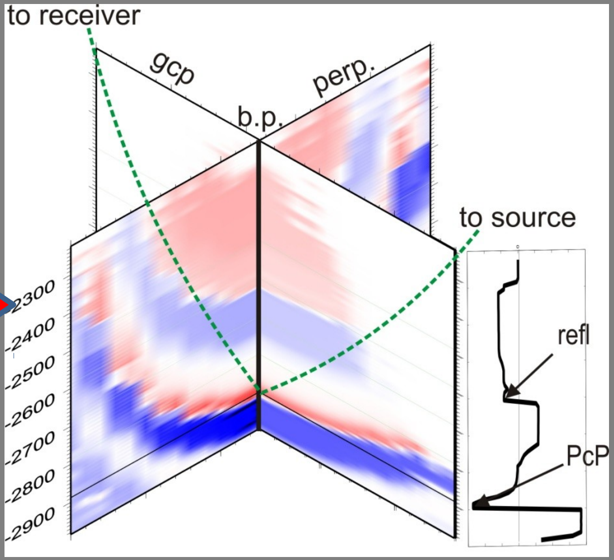
Krüger et al., 2001

Array methods

Migration



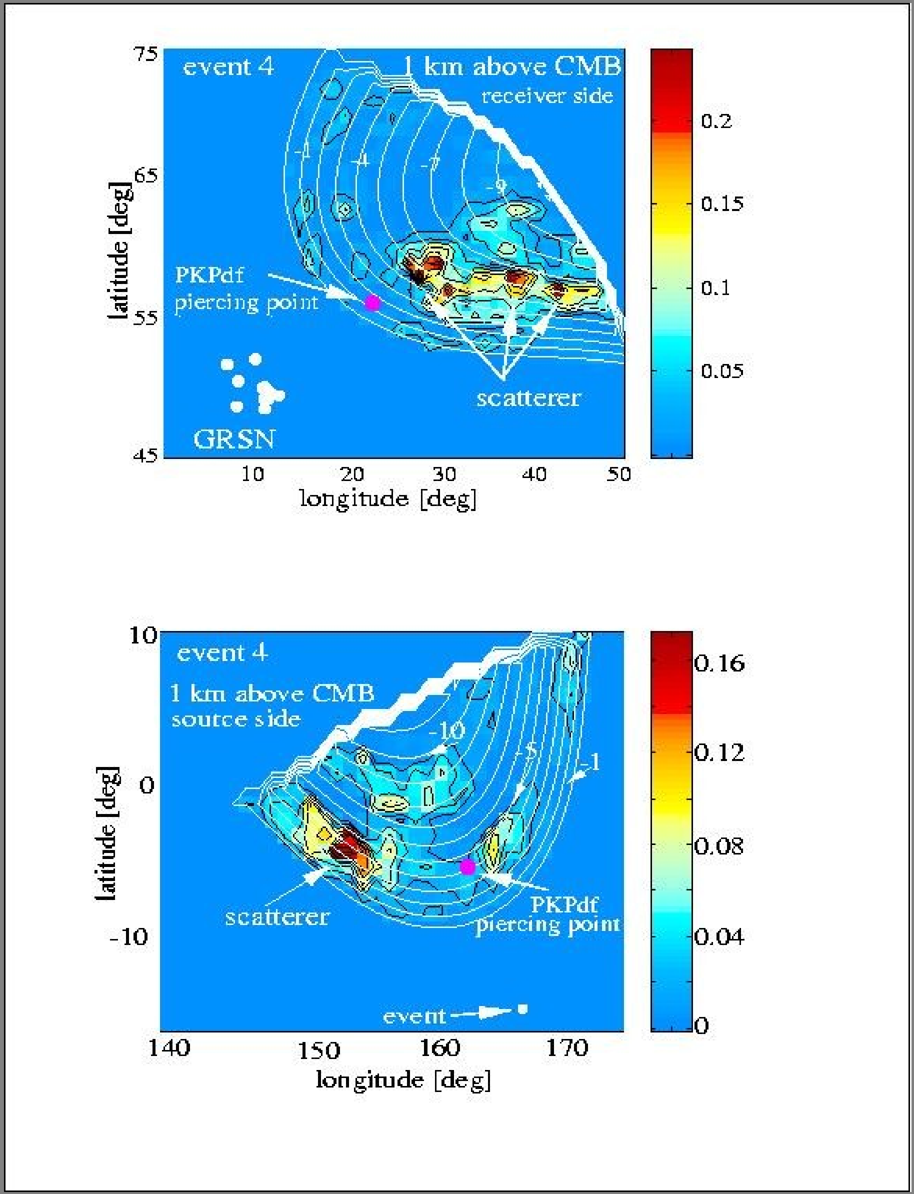




Ampl. at b.p.

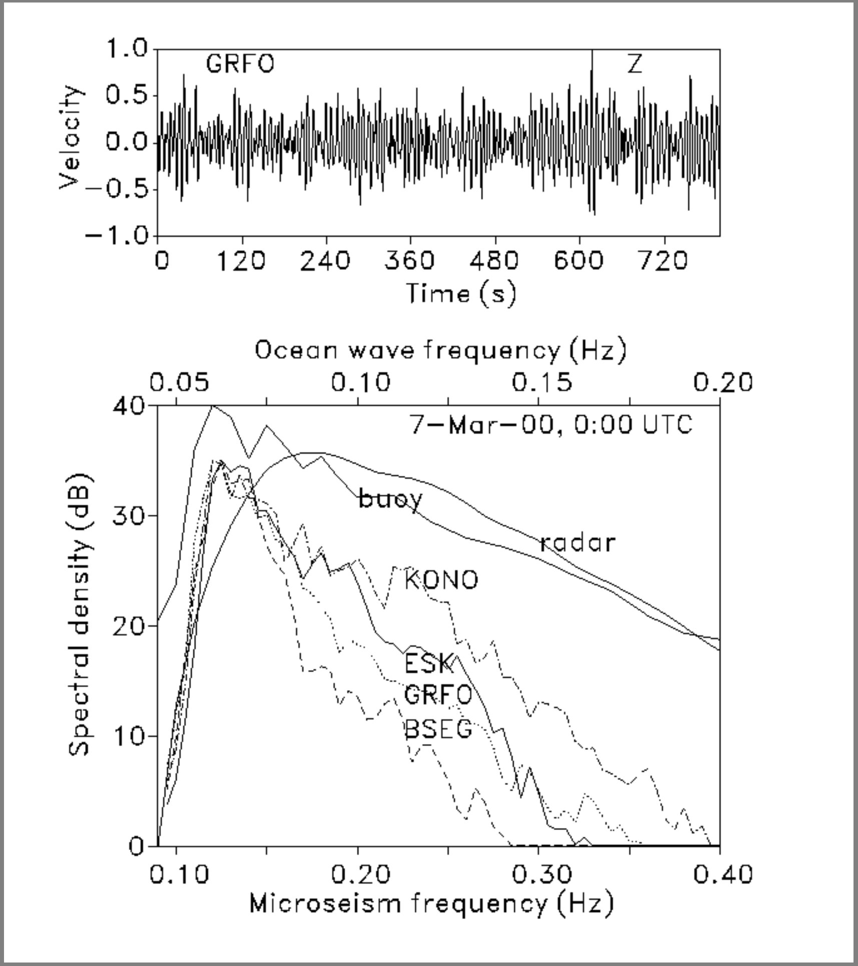
Scattering above the CMB from PKP recordings at GRSN

red: high amplitude (abs)
white lines: isochrones



Thomas et al 1999

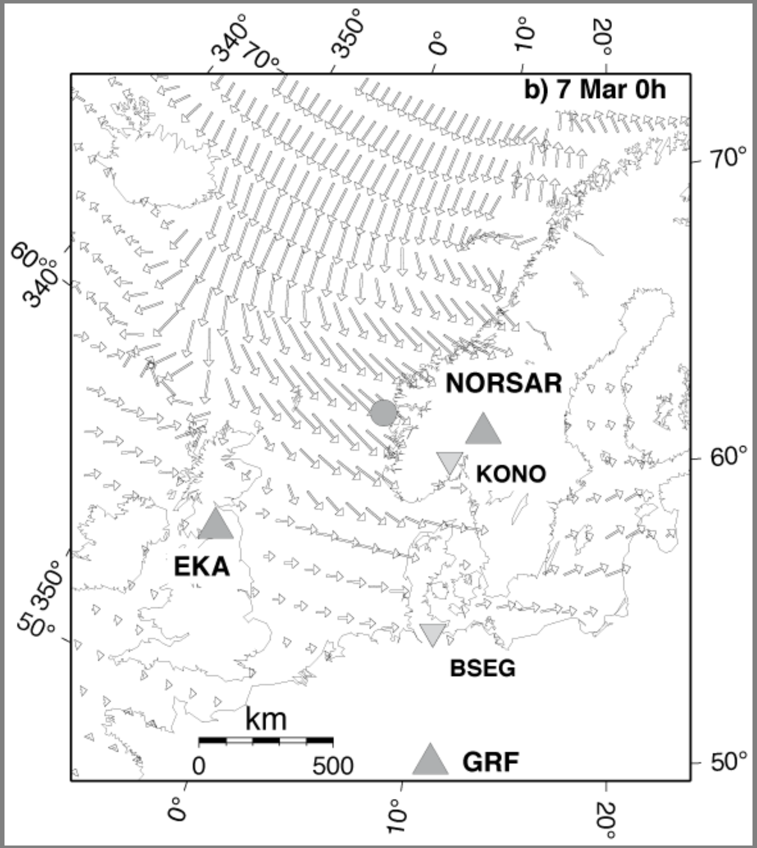
Imaging of quasi-continuous Sources: Oceanic Microseisms



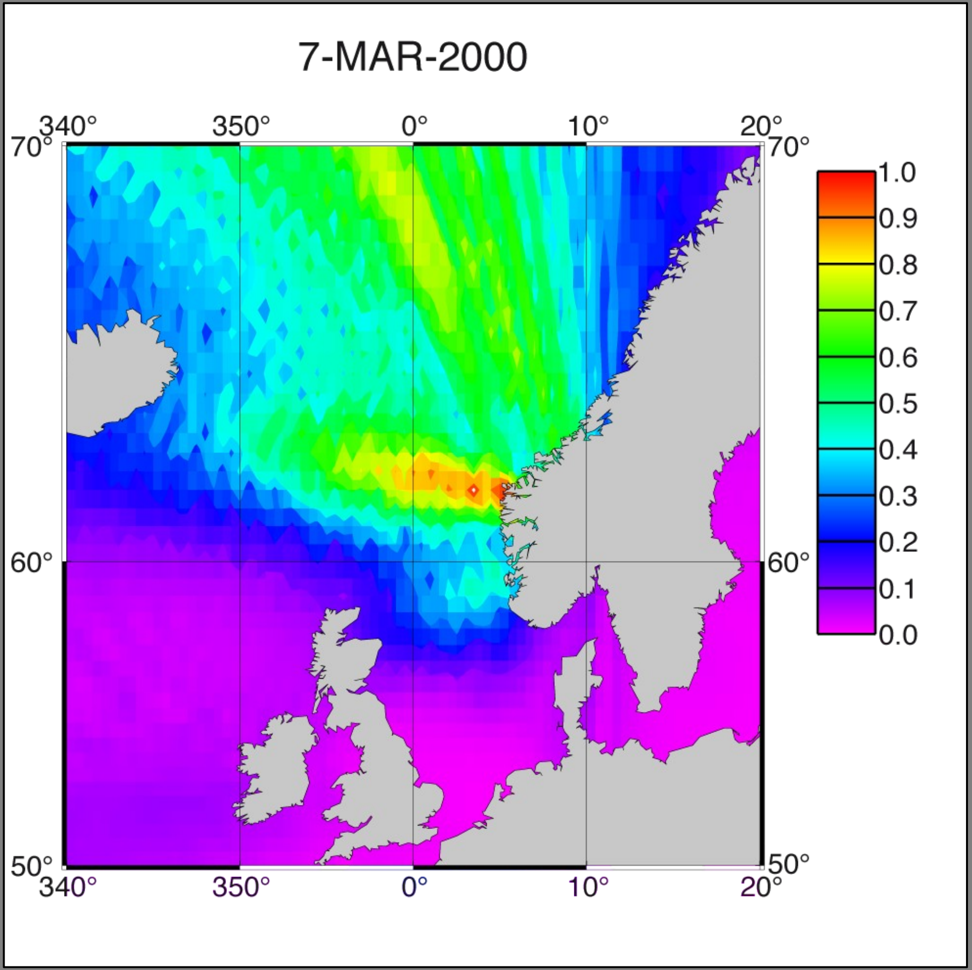
Essen et al., 2003

Dominant Source Regions of Oceanic Microseisms in the Northern Atlantic

WAM Model



Combined Azimuth Estimation by 3 Arrays



Dominant Source Regions of Oceanic Microseisms in the Northern Atlantic

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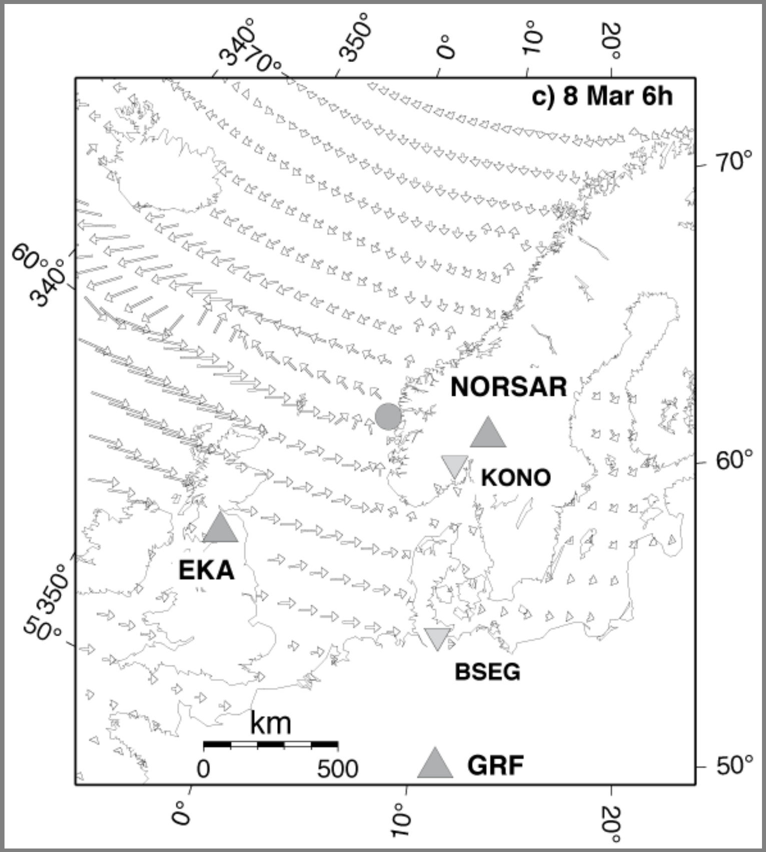
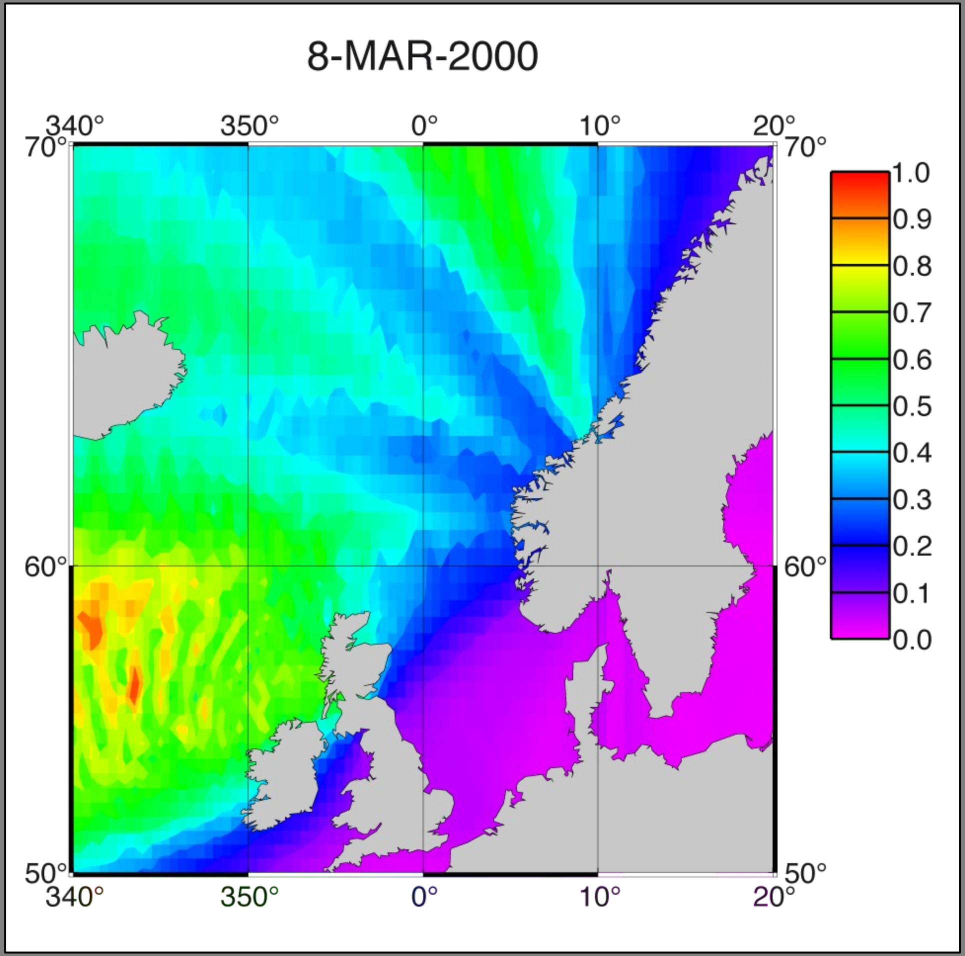
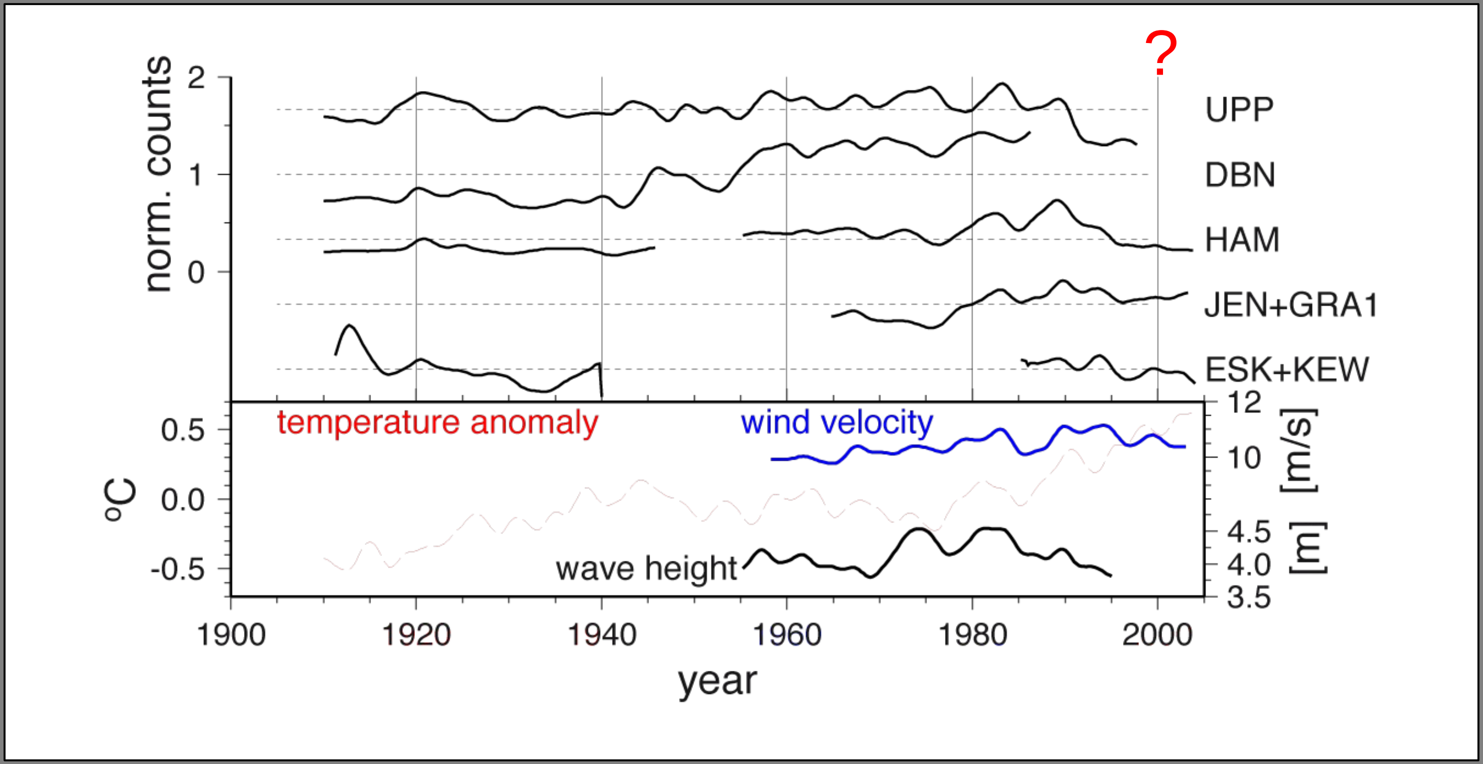


Combined Azimuth Estimation by 3 Arrays

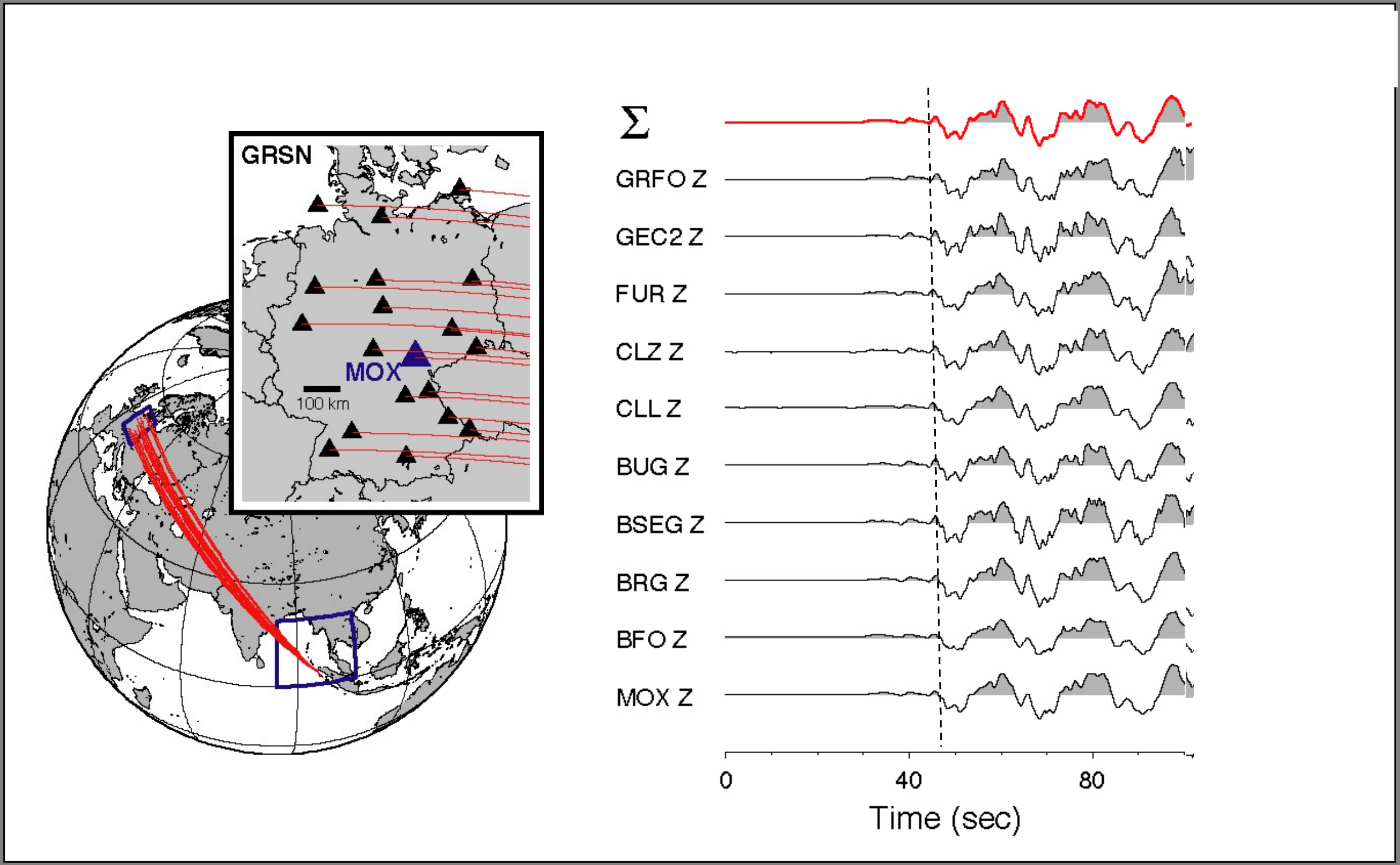


Ocean Microseisms as Climate-Proxy? Analysis of Historical and Digital Data



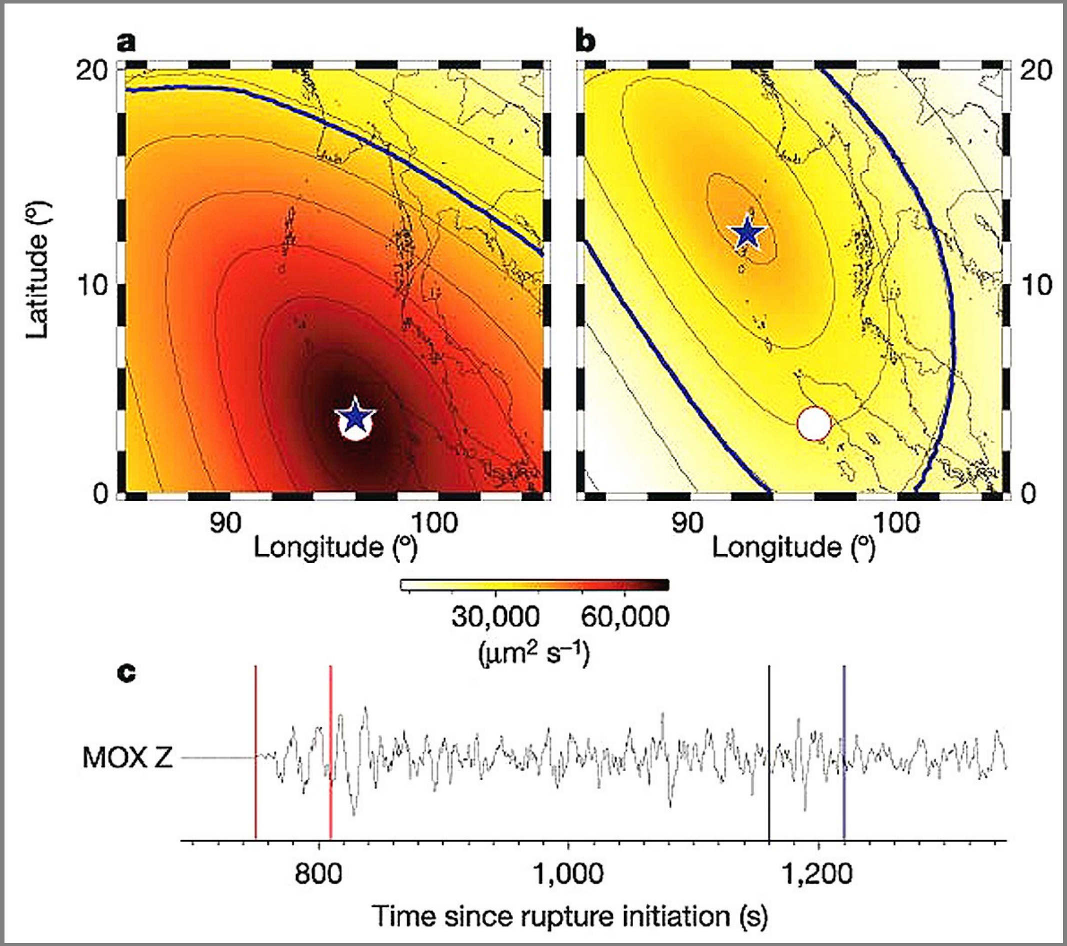
Dahm et al. 2003

Dec 26, 2004, M9.2 Sumatra Andaman Earthquake Backprojection of P-waves recorded at GRSN



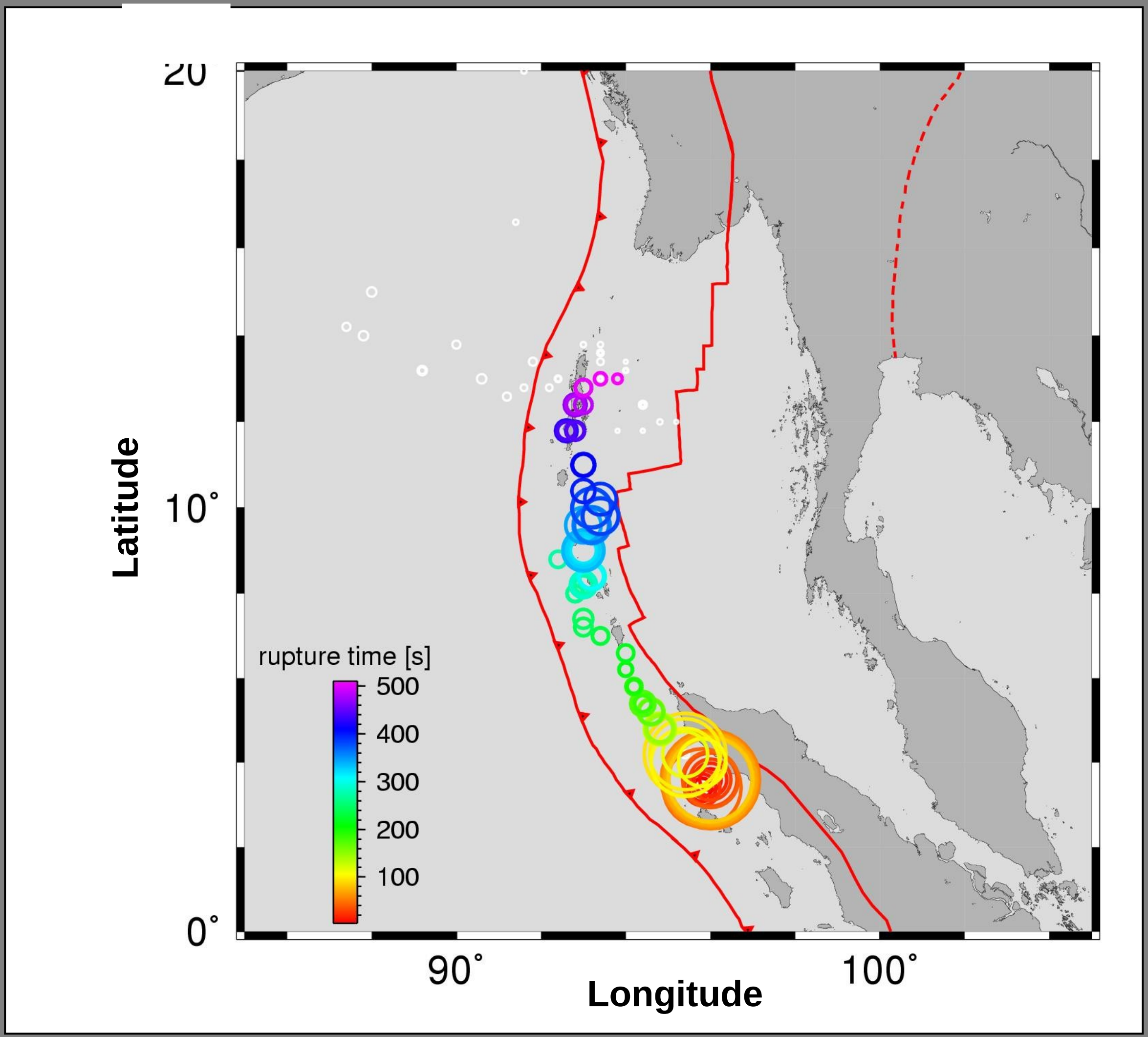
Krüger and Ohrnberger, 2005

Systematic Scanning of the Source Region



Krüger and Ohrnberger, 2005

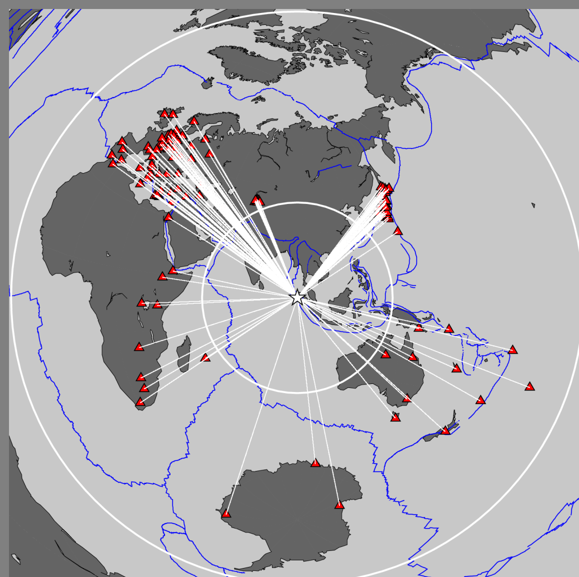
Spatio-temporal Rupture Evolution as imaged by GRSN

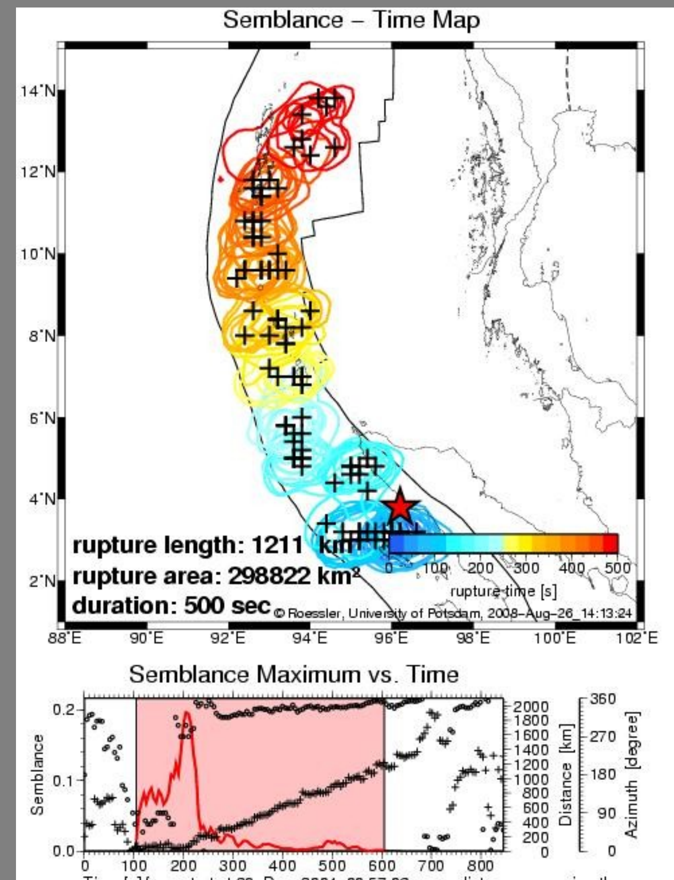


Improved Resolution by Simultaneous Use of Several Arrays

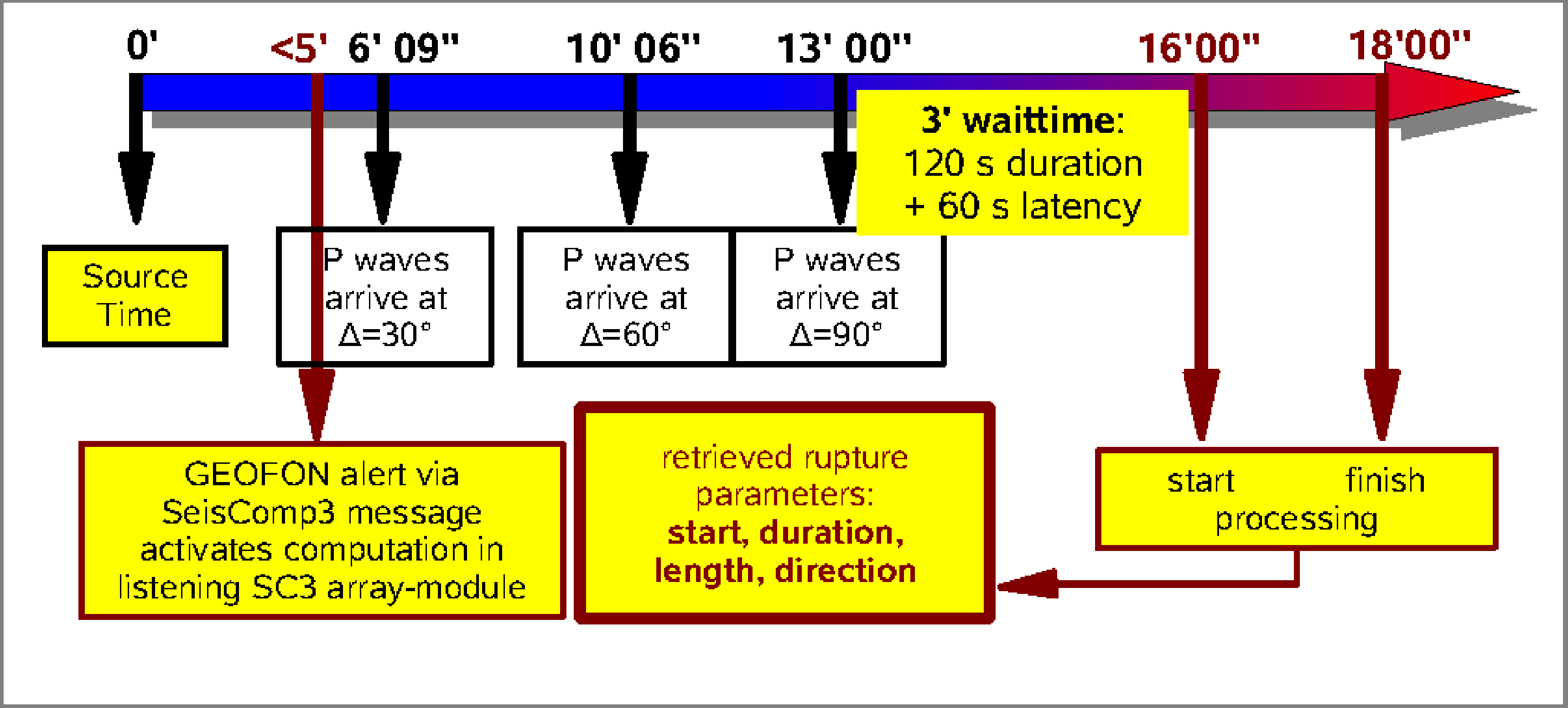
142 global stations:

Germany 19
Europe 46
Central Asia 10
Japan 43
Australia/ 12
Oceania
Antarctica 3
Africa 9



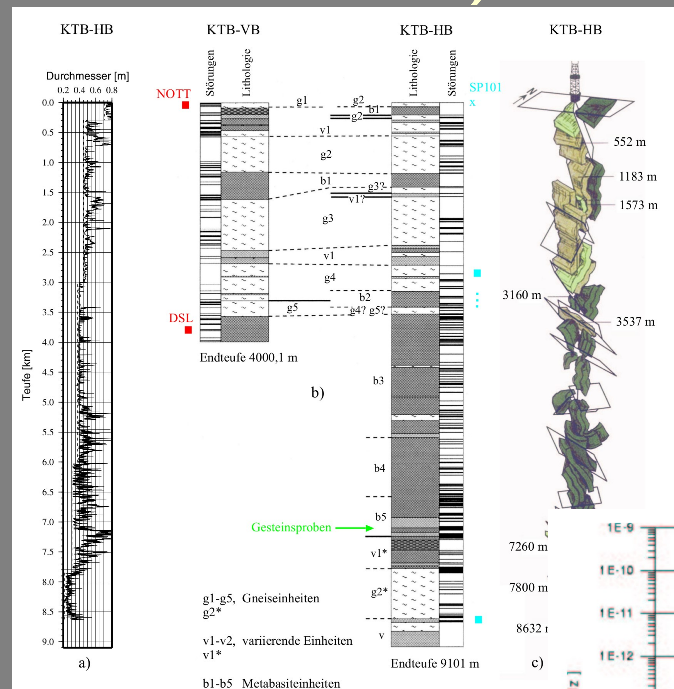


Implementation as additional Component in GITEWS (German Indonesian Tsunami Early Warning System)

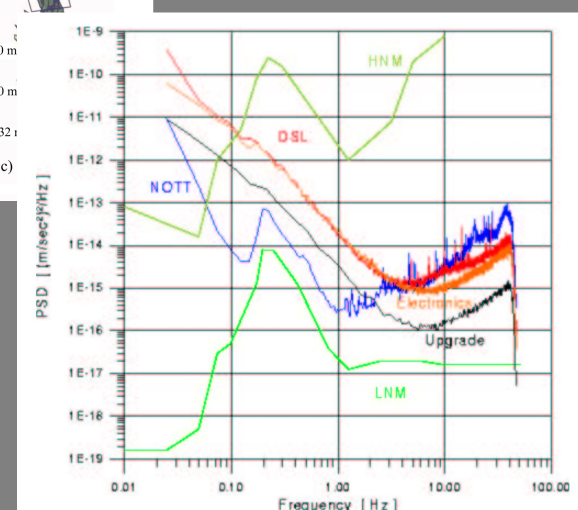


Ehlert & Rößler, 2009

Not (only) a Success: 3-d Array at KTB site (9000 m deep research borehole in crystalline basement)



Plan:
Installation of seismometers in the „Kontinentale Tiefbohrung" in Northern Bavaria in addition to a surface array.



Hope: Less attenuation, less noise, less scattering.
Outcome: Sensor could not survive 275 °C for long, data transmission difficult.

Trela, 2003

What about Anisotropy?
P -wave Polarization Results at GRF and GRSN

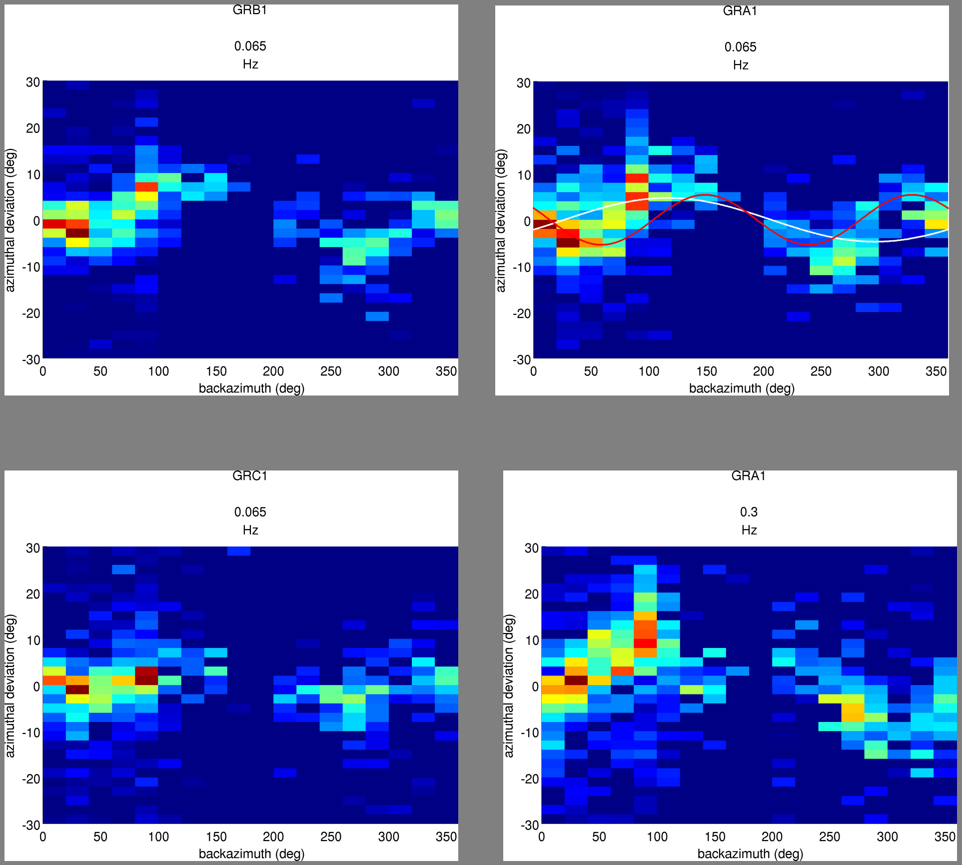
P wave polarization: sensitive to azimuthal anisotropy and local heterogeneity

Application to 20 years of GRF and GRSN data resulting in about 1000 high qualtiy P-waveforms

Frequency dependence of measurements

Harmonic analysis of dependence on backazimuth

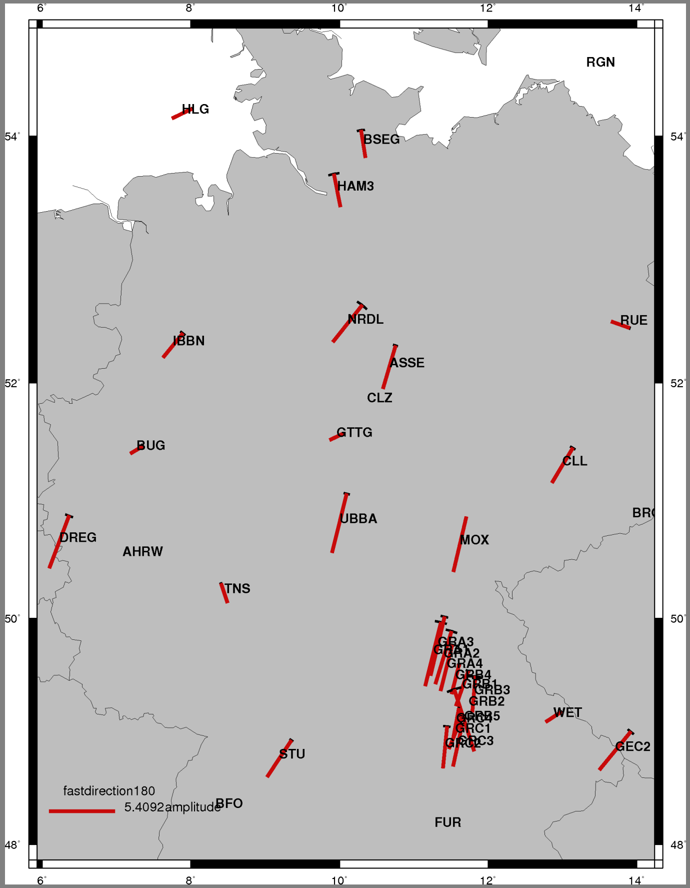
Azimuthal deviations as function of backazimuth



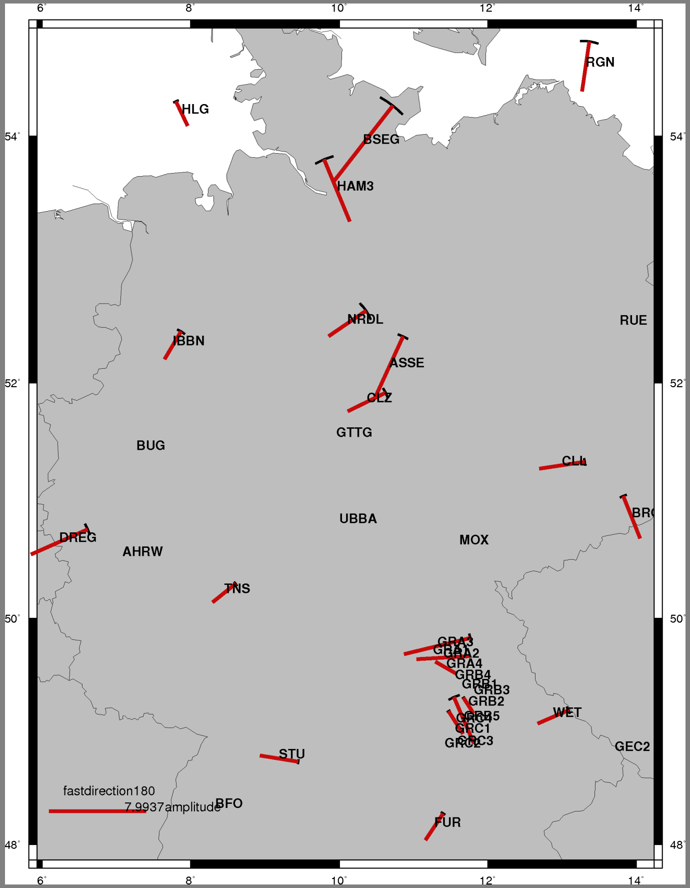
Cristiano et al. 2013

P -wave Polarization Analysis at GRSN
Direction of Fast Axis (harm. analysis)

f = 0.065 Hz

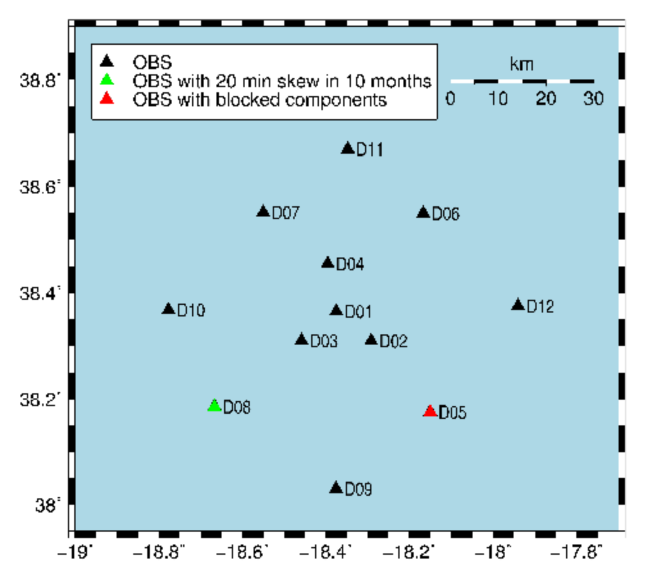


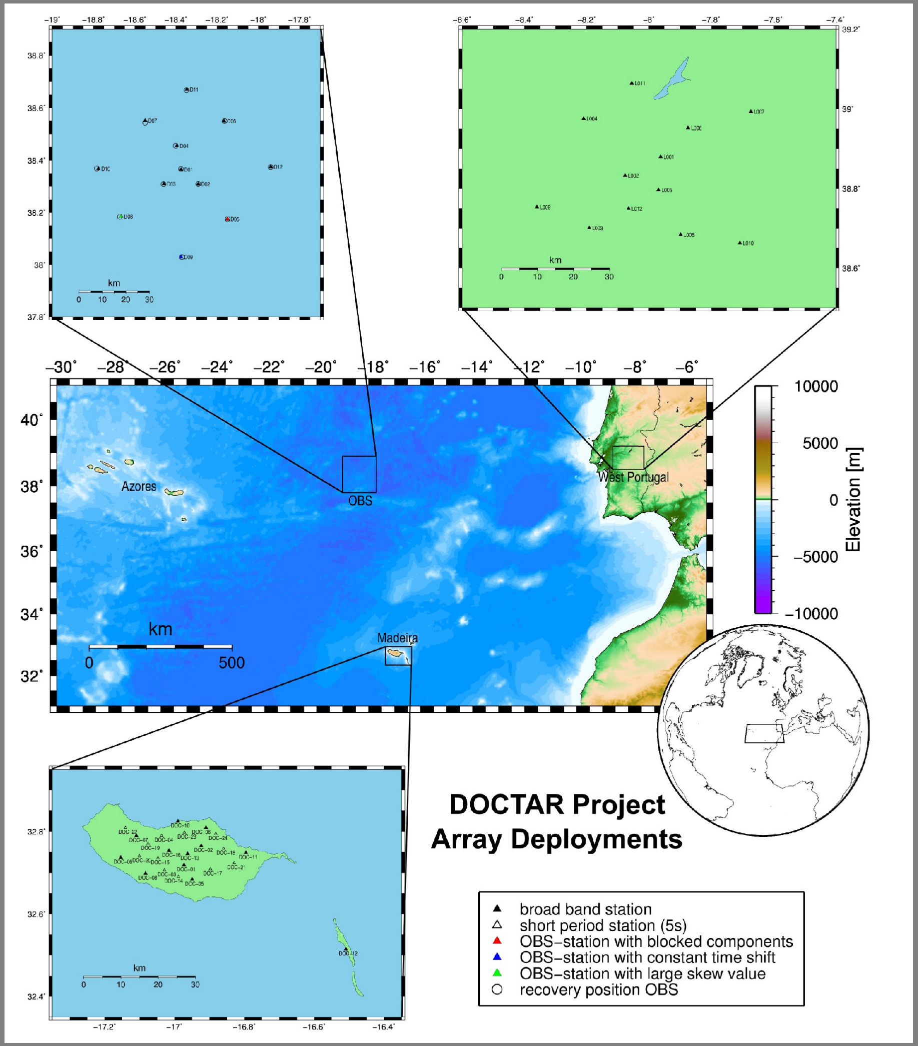
f = 0.3 Hz



Cristiano et al., 2013

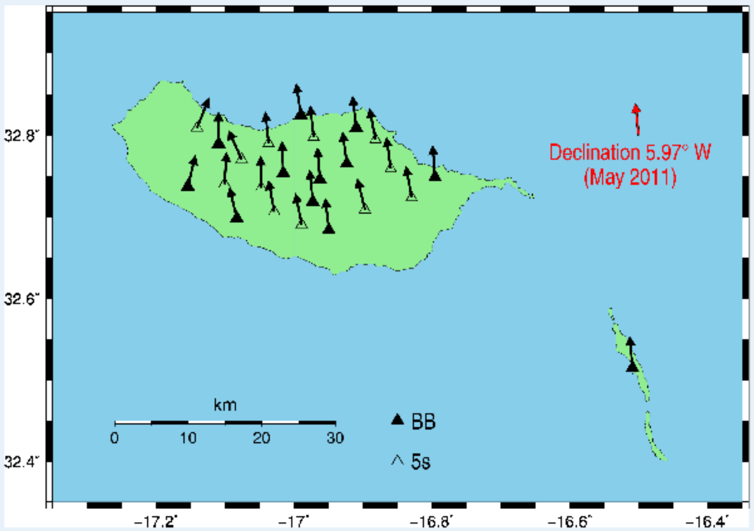
DOCTAR Project Array Deployments



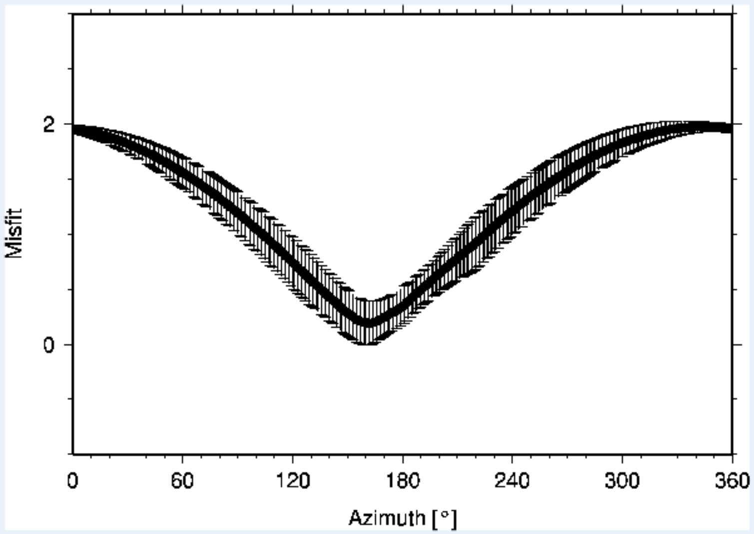


12 3-C broadband (Guralp 60 s) seismometers and HTI hydrofones in 5000 m water depth.
Madeira Array: 12 broadband and 12 shortperiod seismometers.
Portugal: 12 broadband seismometers

DOCTAR: Orientation of 3-C Stations



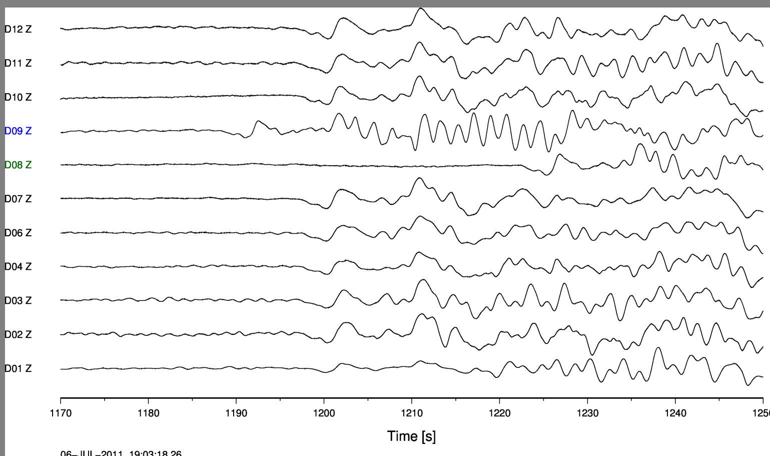
seismometer orientation compared to true North direction as measured with a portable gyrocompass (GIPP)
declination calculated using the current International Geomagnetic Reference Field (IGRF) model
(http://www.ngdc.noaa.gov/geomag-web/#declination)

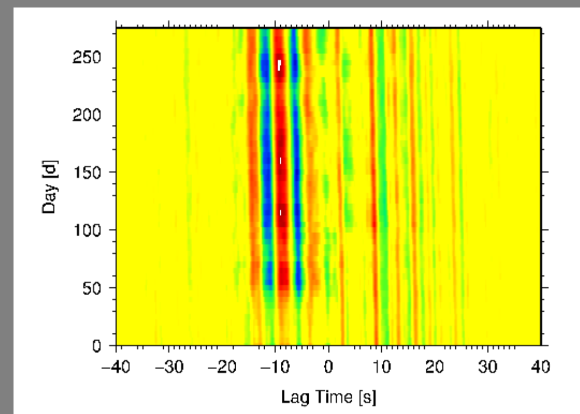


weighted average misfit between observed P-phase amplitudes of several teleseismic events on horizontal components and amplitudes as expected from corresponding P-phase polarization on vertical component for all tested azimuths, the error bars give the first standard deviation

Still problematic for OBS.

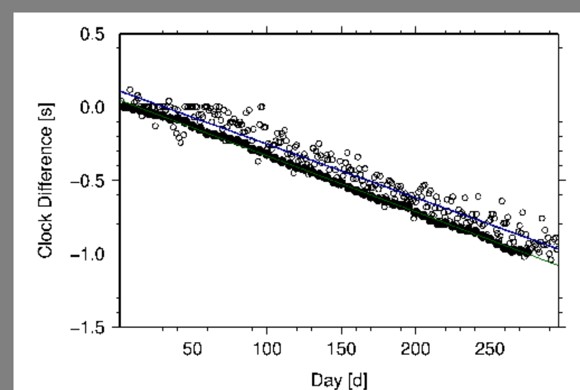
OBS: Clock Drift Correction using Ambient Noise





Correlation traces for station pair D01 and D02.

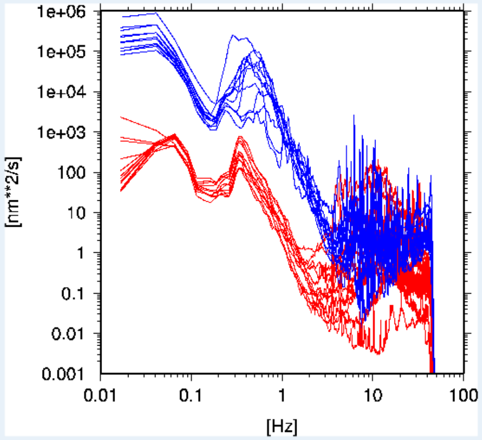
Jul 6, 2011, Mw 7.6, S29.54 W176.34, h=17 km



Extracted clock differences for station pair D01 and D02 for one day stack (open circles) and 20 days stack.

Hannemann et al., 2013

Array Processing Examples

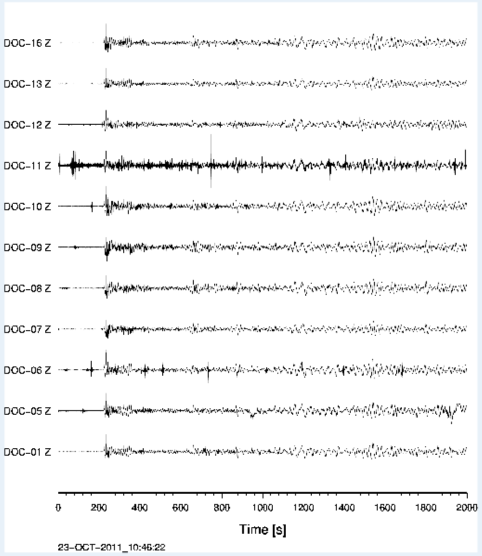


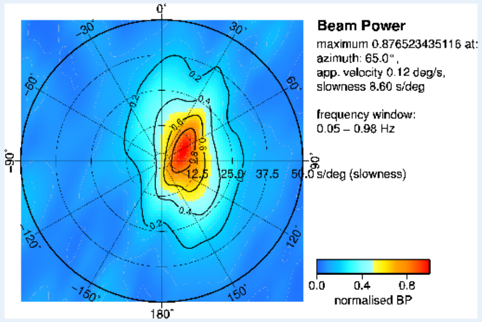
Spectra of vertical component for OBS stations (blue) and Madeira broadband stations (red) for one day of data (01. August 2011)

- upper panels: broadband recordings of Madeira and OBS array for 23. October 2011, Van Merkez, Turkey, Mw 7.1 earthquake
- lower panels: result of fk-analysis of P-wave for Madeira and OBS array
- theoretical values:

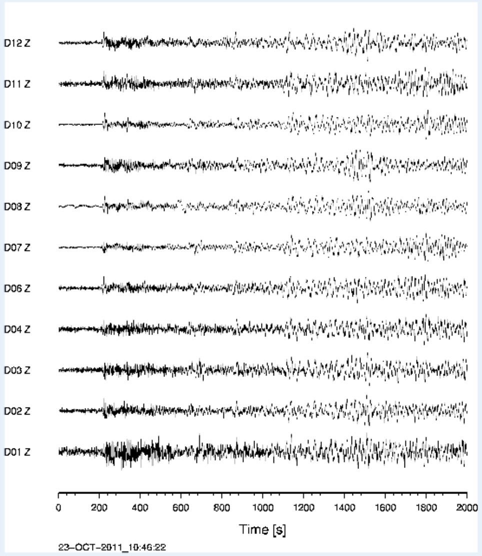
array	azimuth [°]	P-slowness [$\frac{s}{\circ}$]
Madeira	65.00	7.7
OBS	69.22	7.8

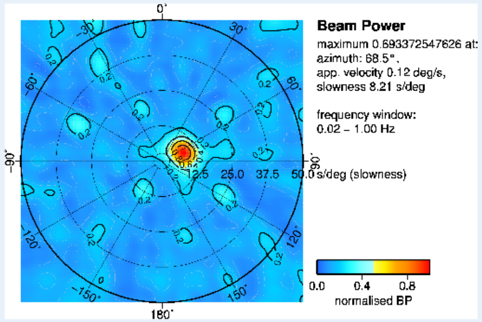
Madeira





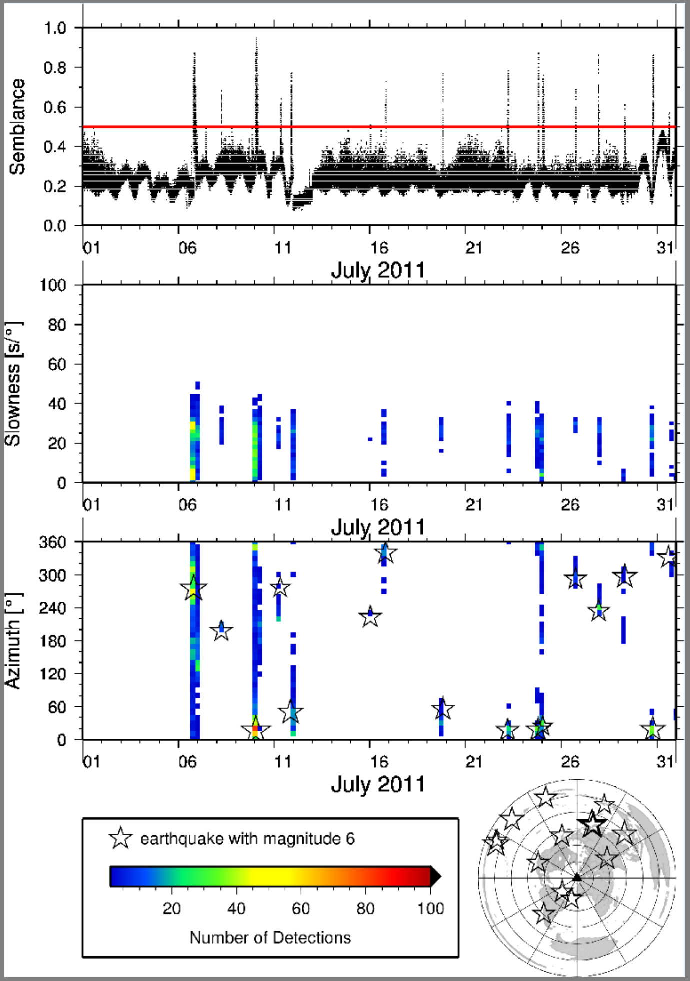
OBS



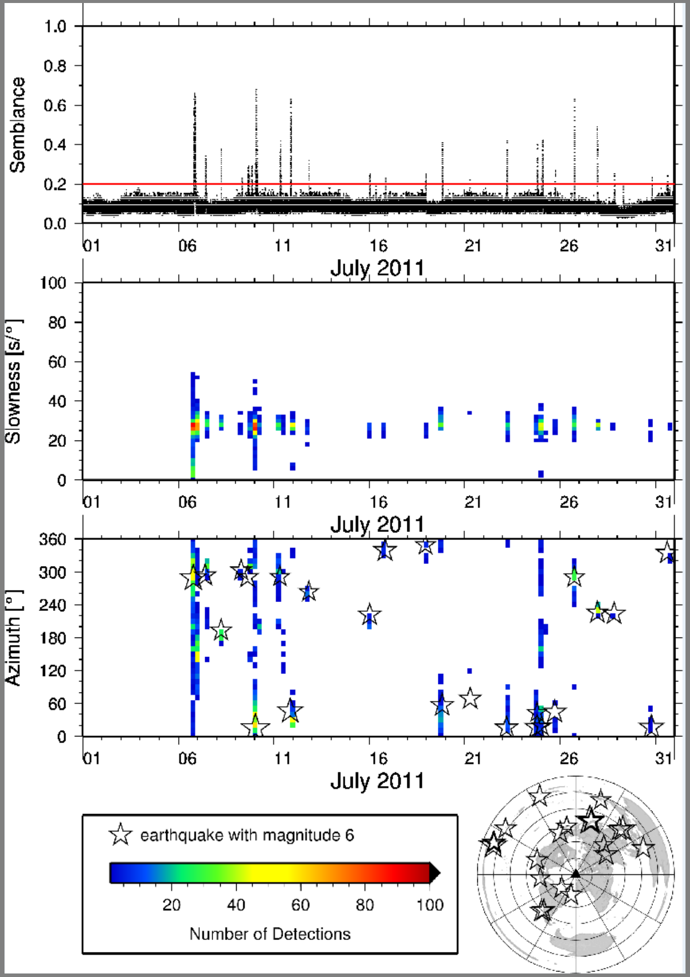


Moving window f-k analysis detection results

Madeira

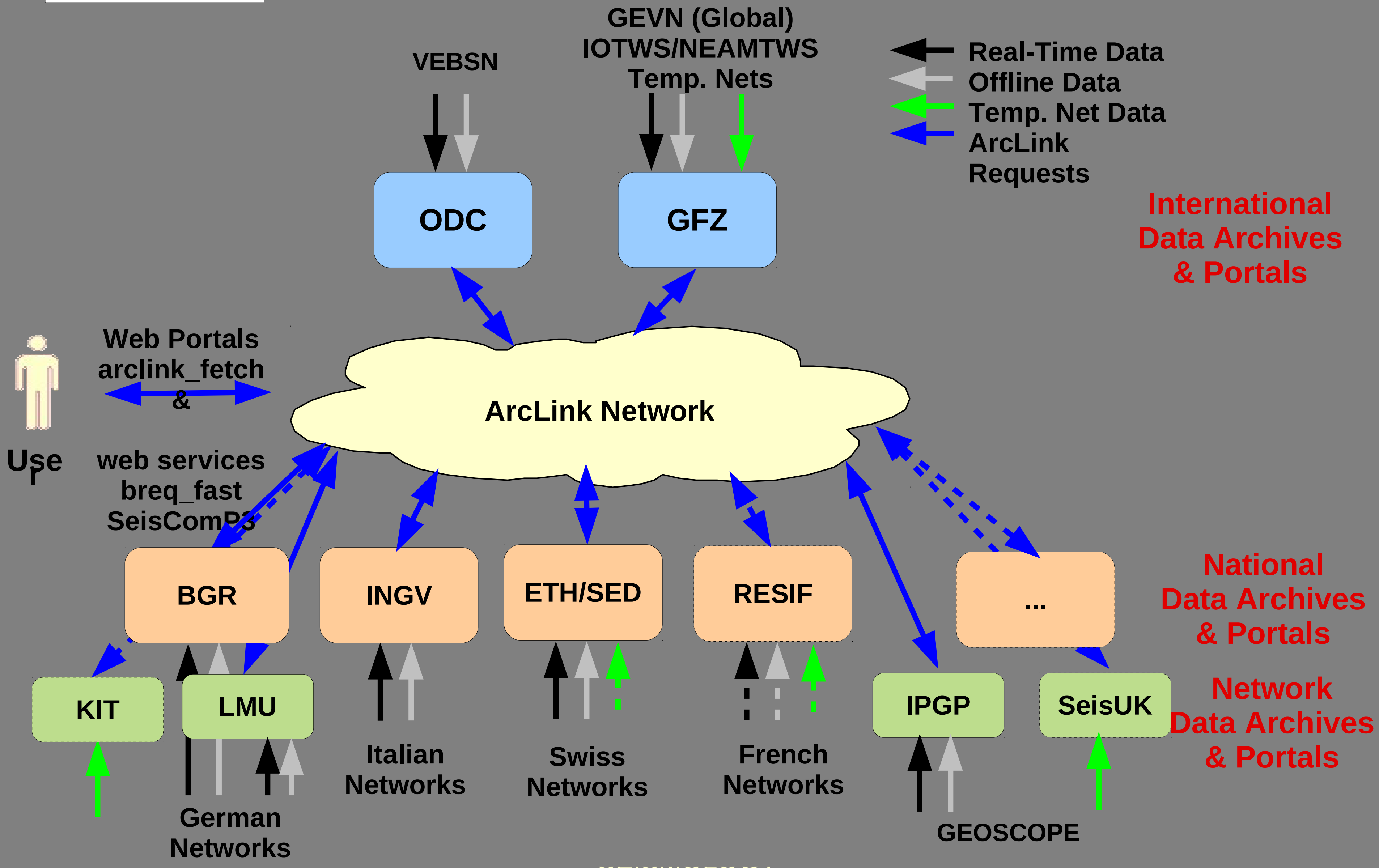


OBS



40 s time window length, 10 s time step, bandpass 7-25 s.

EIDA European Integrated Data Archives



Some Conclusions

In 1975 several important developments merged:

- Broadband, high gain, high dynamic range instruments
- Continuous recording of digital data
- Full wavefield modelling methods (1d media)

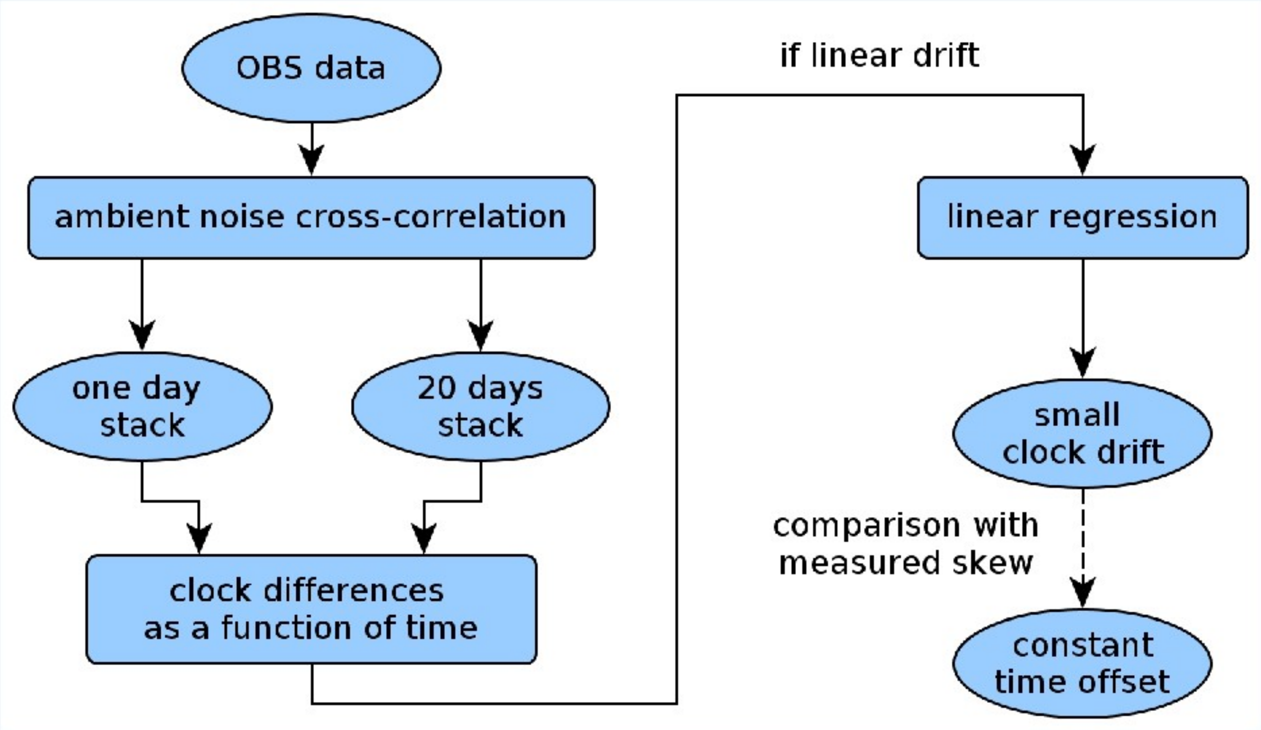
Challenges

- Multi scale arrays
- Multi array methods
- Full use of 3-C information
- Recording of high(er) frequencies
- Arrays in the ocean

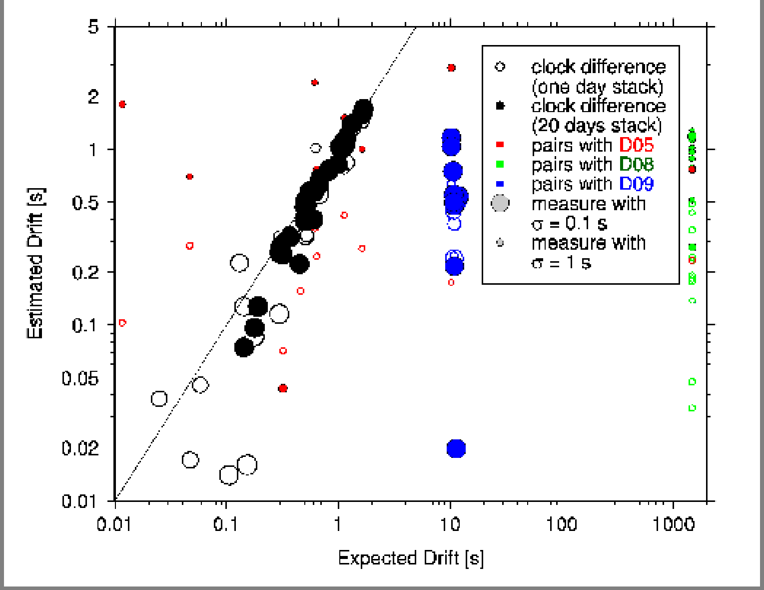
DOCTAR: Clock Drift Correction

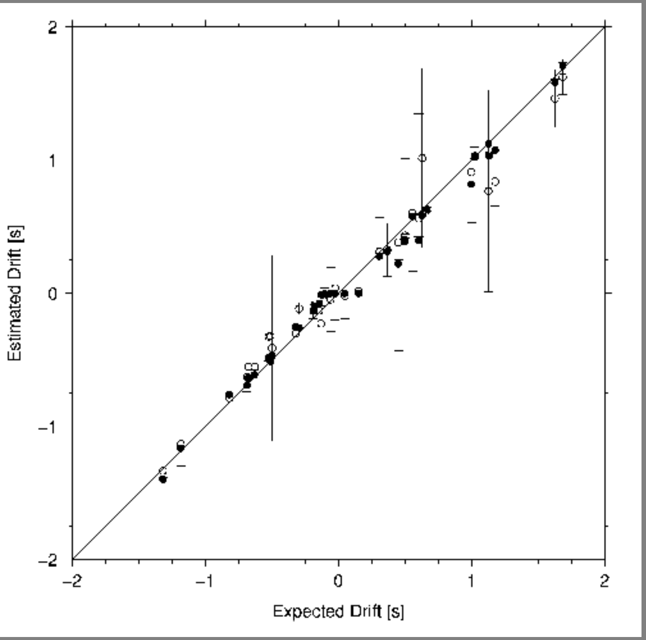
Work-Flow for Clock Drift Measurement with Ambient Noise Cross-Correlation

- based on method by [Sens-Schönfelder(2008)]
- ambient noise processing options chosen after [Bensen et al.(2007)]

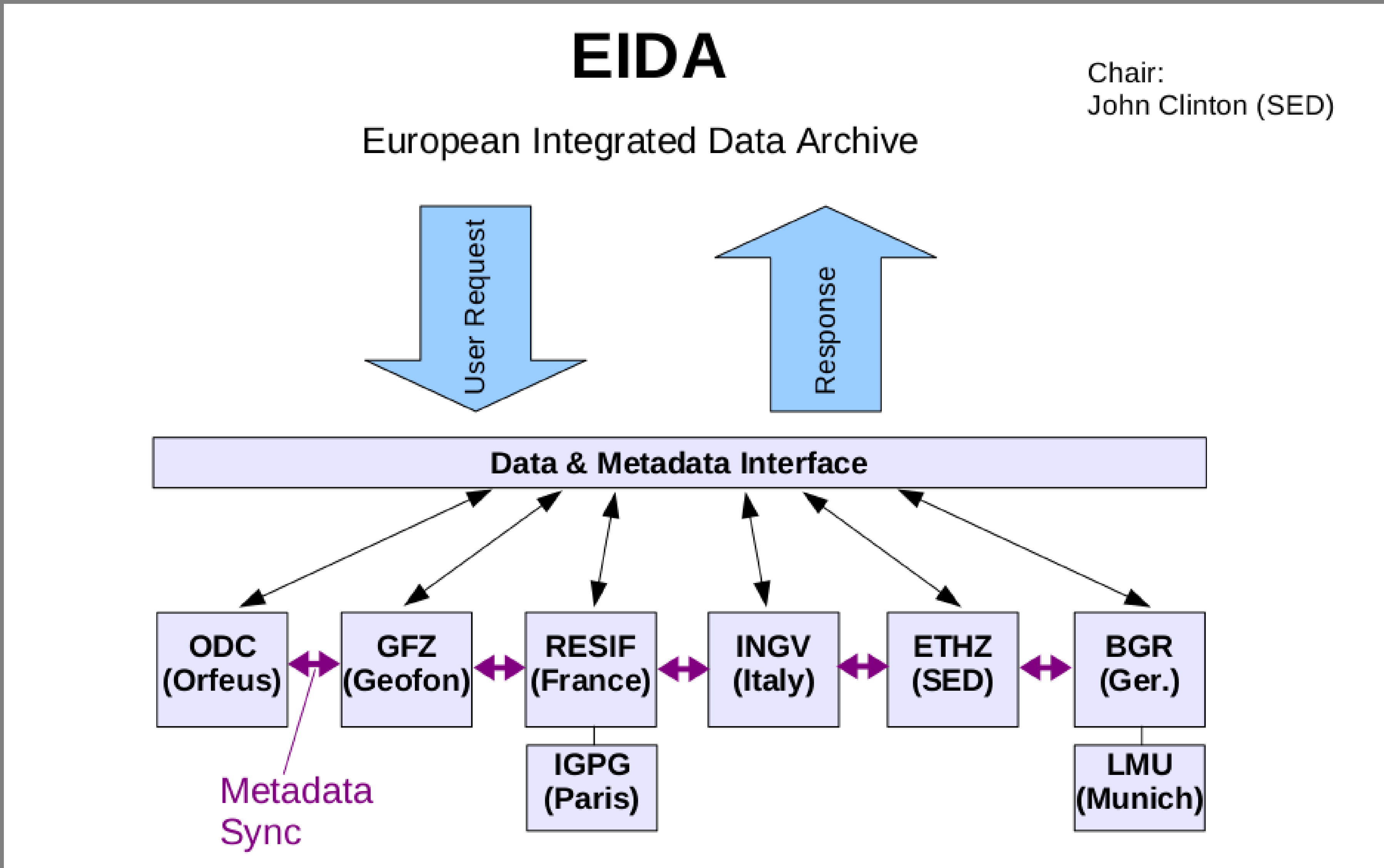


DOCTAR: Clock Drift Correction, Results for Vertical Seismometer Components



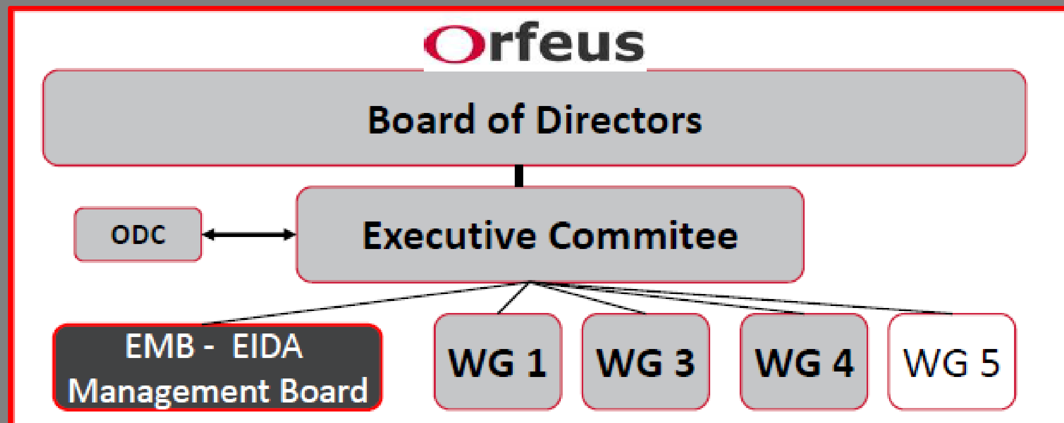


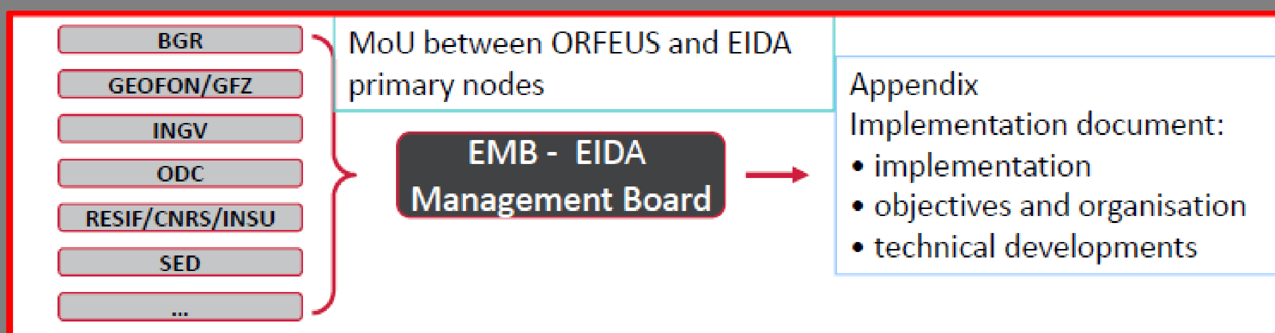
Clock drift is linear, large skew values and constant offsets are real!



Stammler 2013

European Integrated
Data Archives





Hanka 2013