Global Broadband Arrays – a View from NORSAR

Johannes Schweitzer

and NORSAR's Array Seismology Group

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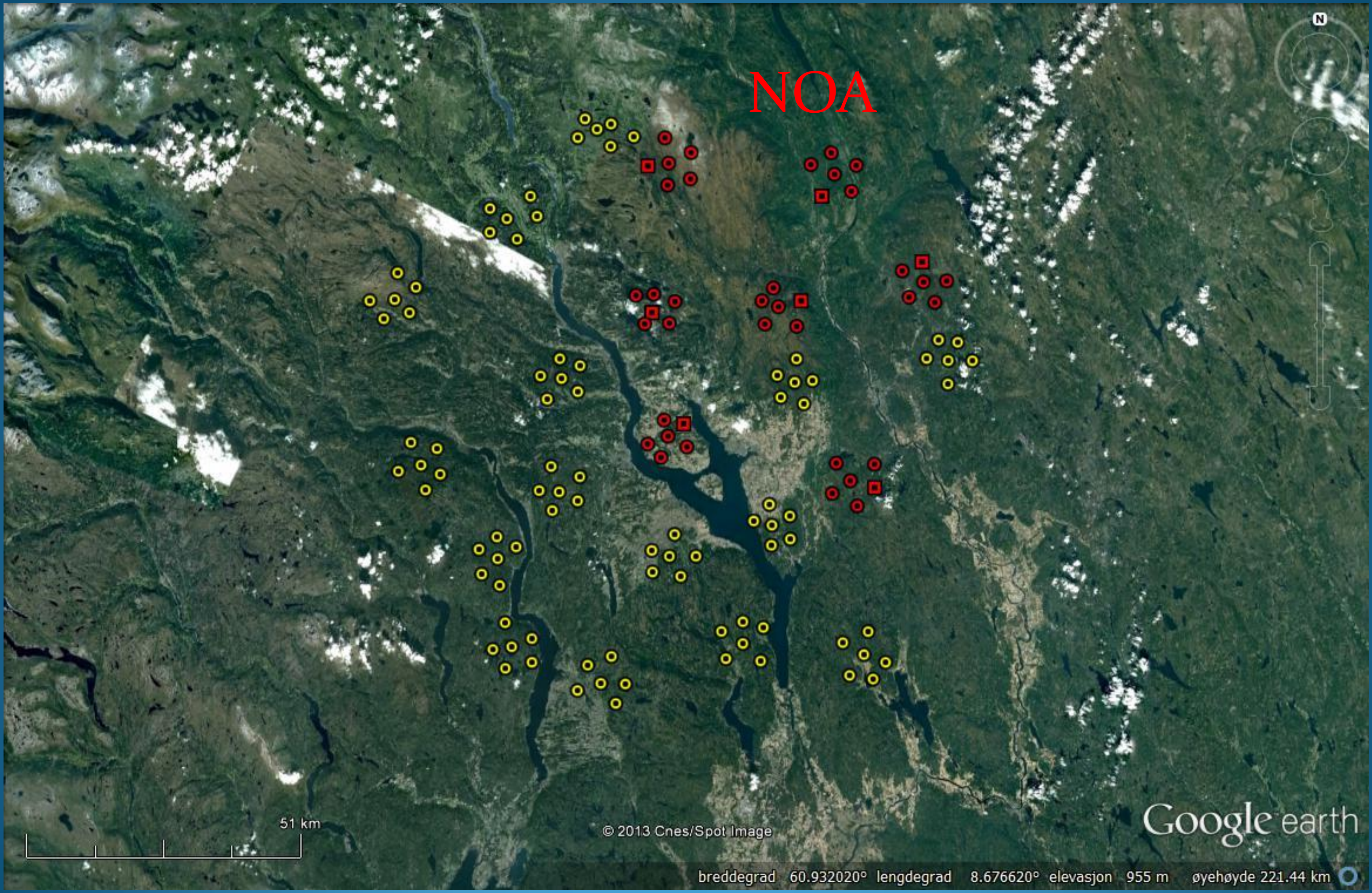
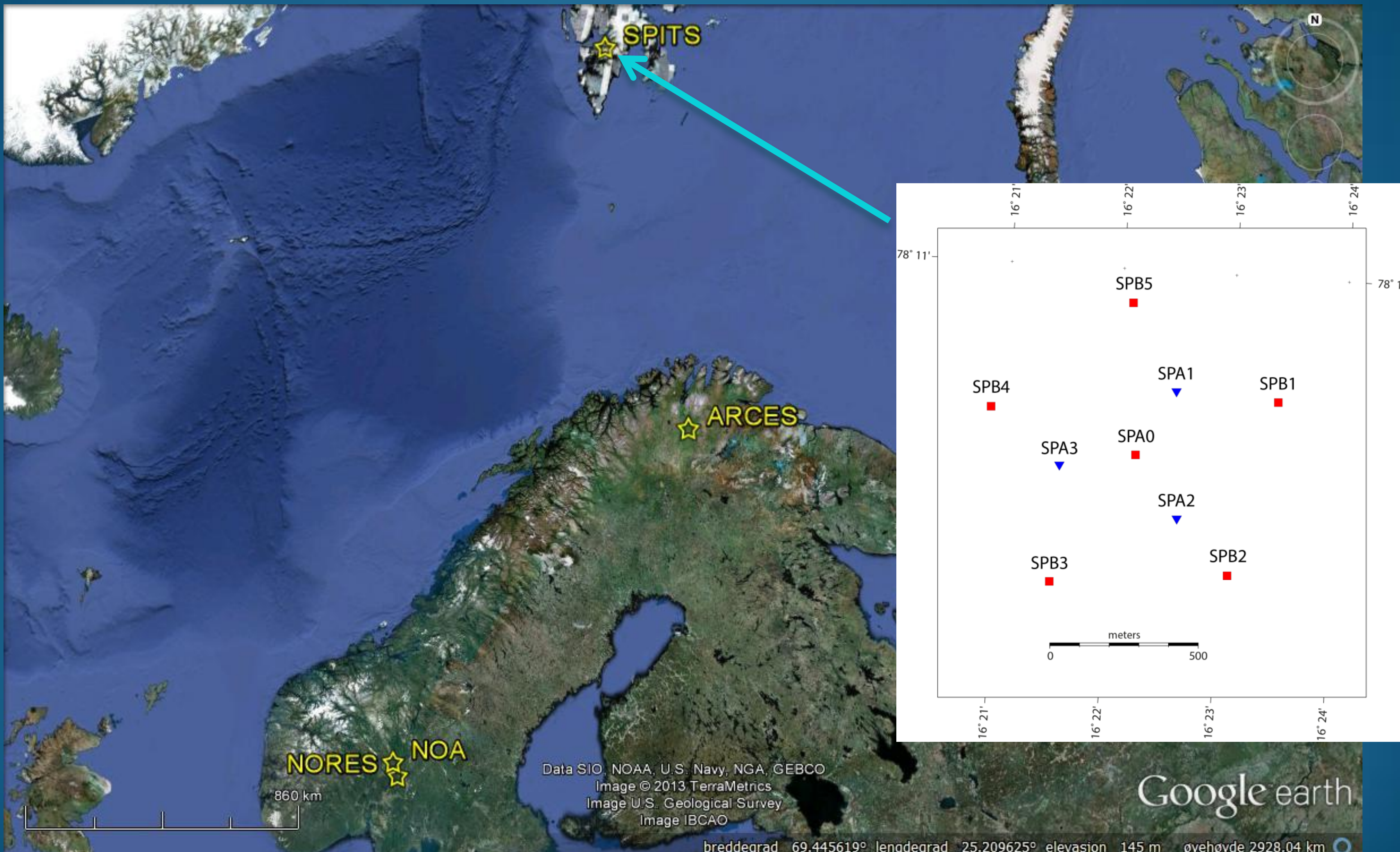
Raleigh, North Carolina

NORSAR Array – Until 1976 (NAO)

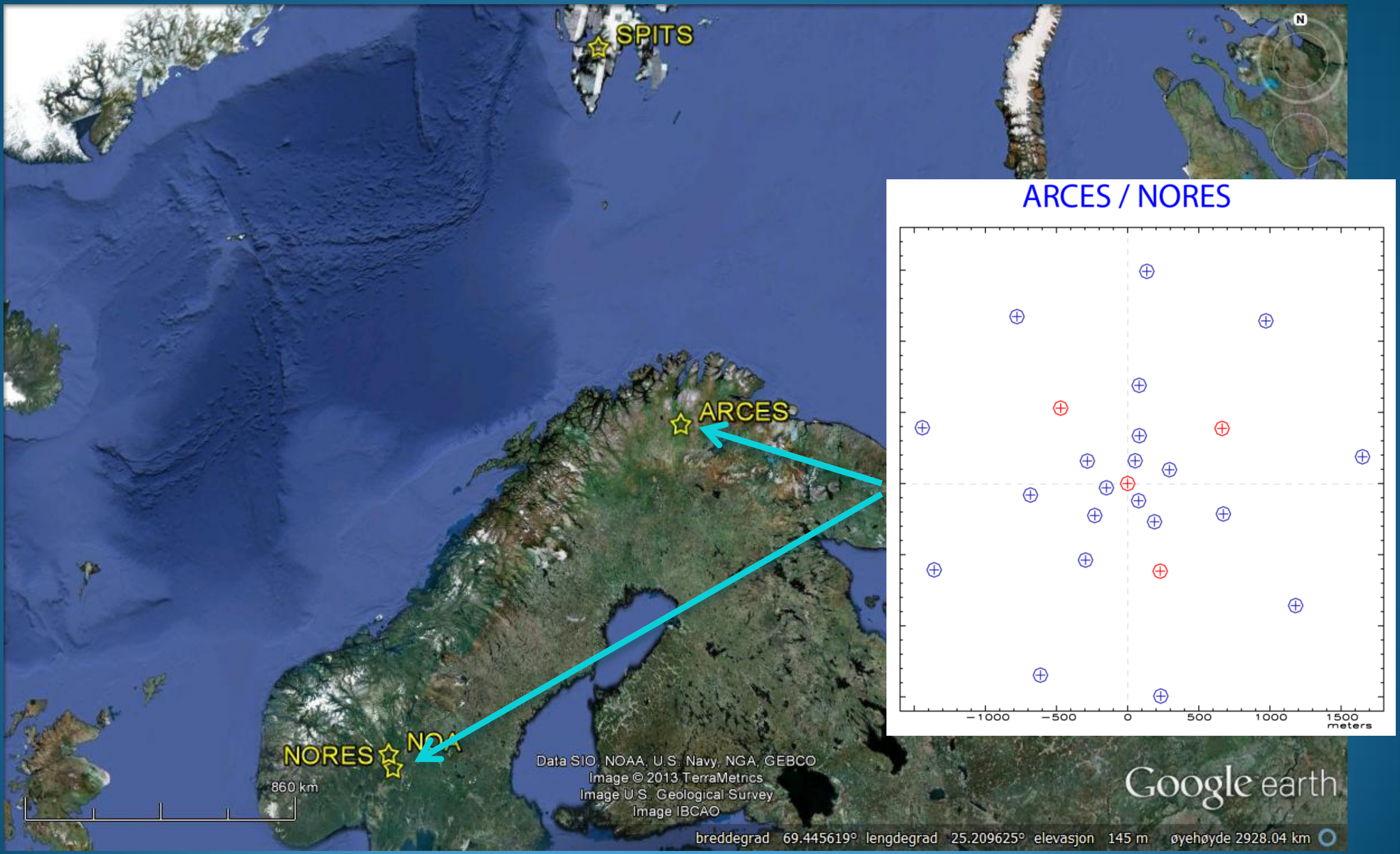


NORSAR Arrays

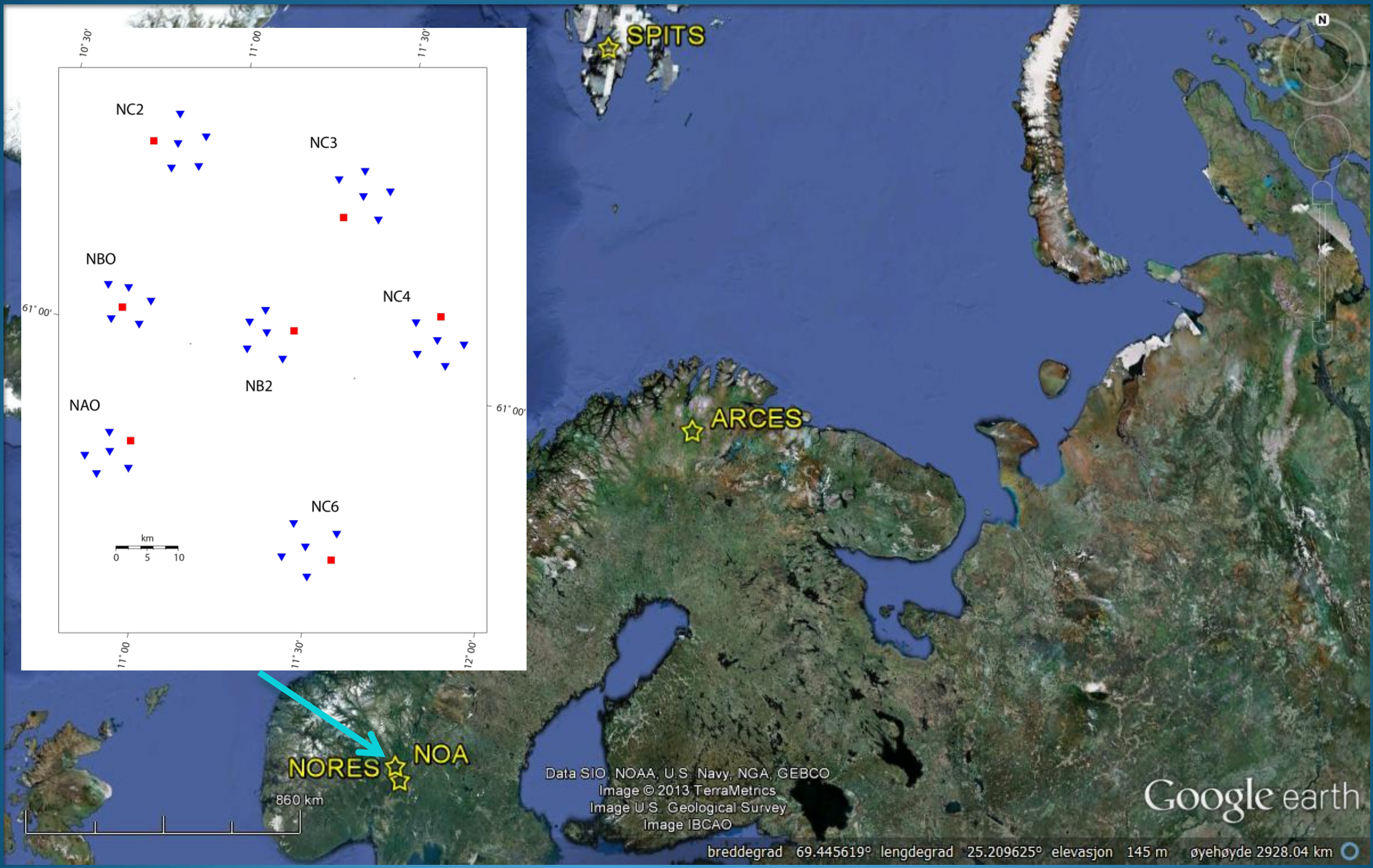
NORSAR Arrays – SPITS



NORSAR Arrays – ARCES/NORES



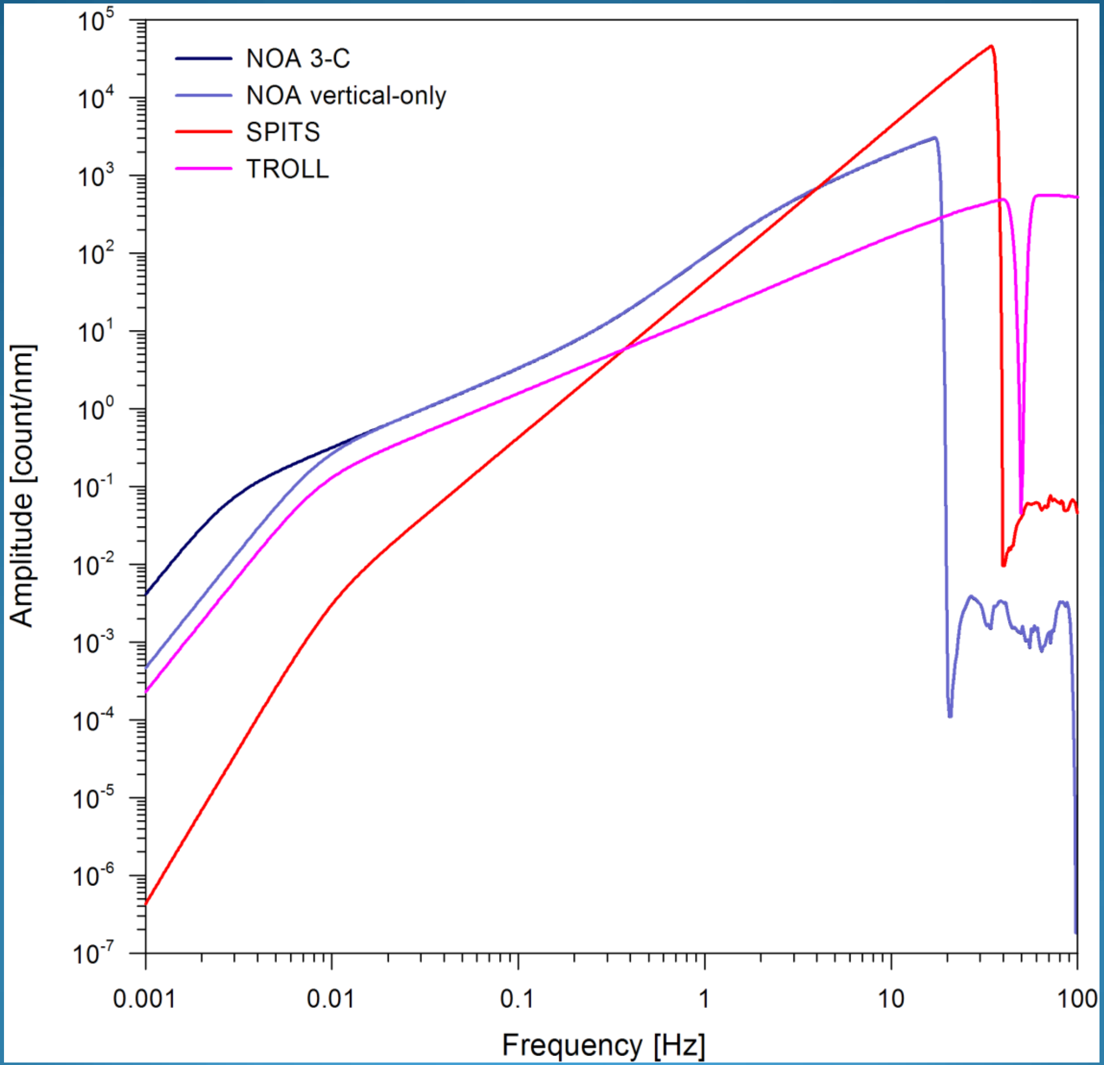
NORSAR Arrays – NOA



NORSAR Array Data (non-SP)

- 1971 -> 1976 triggered LP NAO data (22 sites, one per subarray)
- 1976 -> 1984 triggered LP NOA data (7 sites, one per subarray)
- 1984 -> 1995 continuous LP NOA data (7 sites, one per subarray)
- 1996 -> 2012 continuous BB NOA data (7 sites, one per subarray)
- 2004 -> continuous BB SPITS data (all 9 sites vertical + 6 sites horizontal)
- 2012 -> continuous BB NOA data (all 42 sites vertical + 7 sites horizontal)
- 2014 -> continuous BB ARCES data (all 25 sites as 3C)

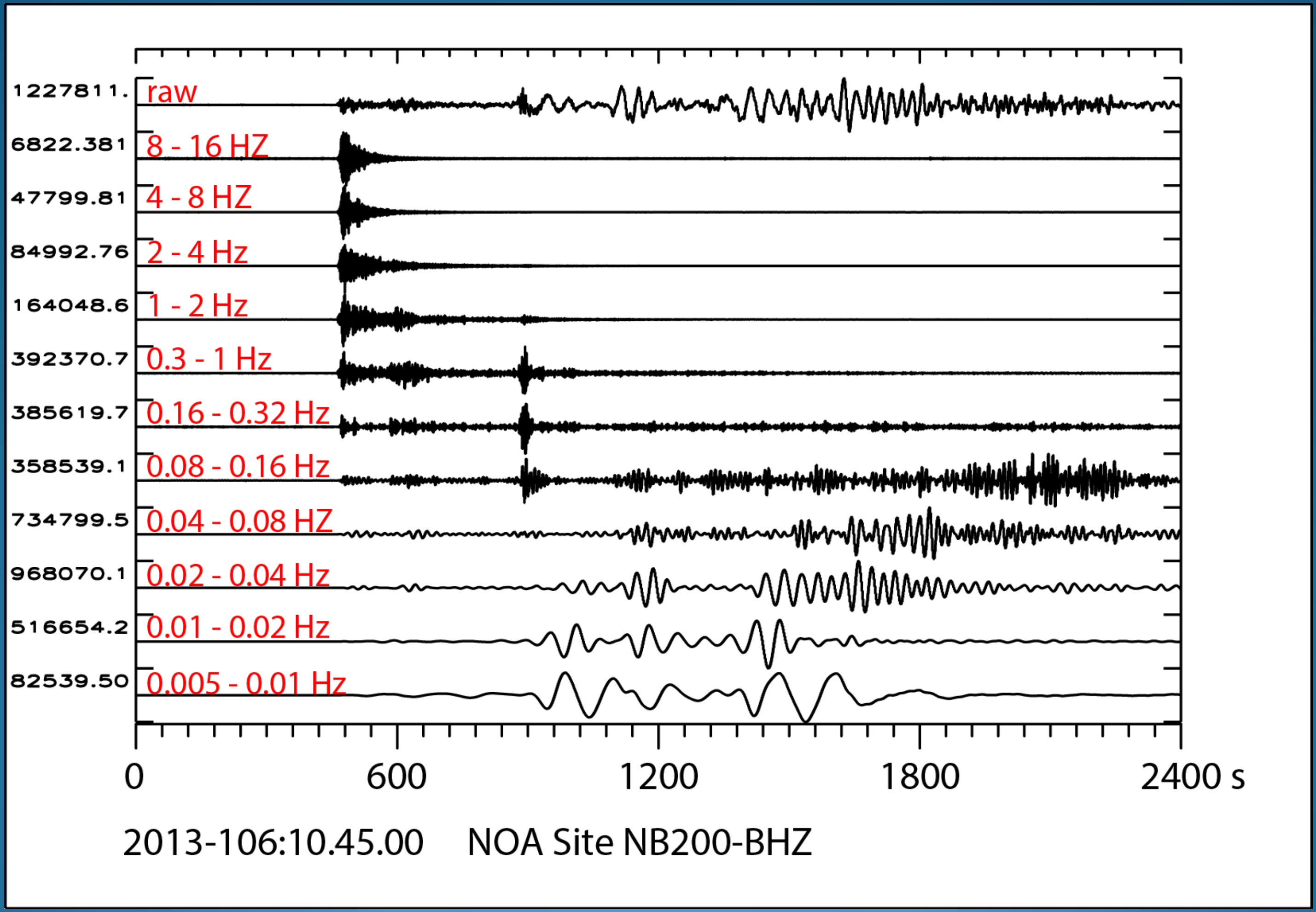
NORSAR – new BB Instruments



Broadband Arrays

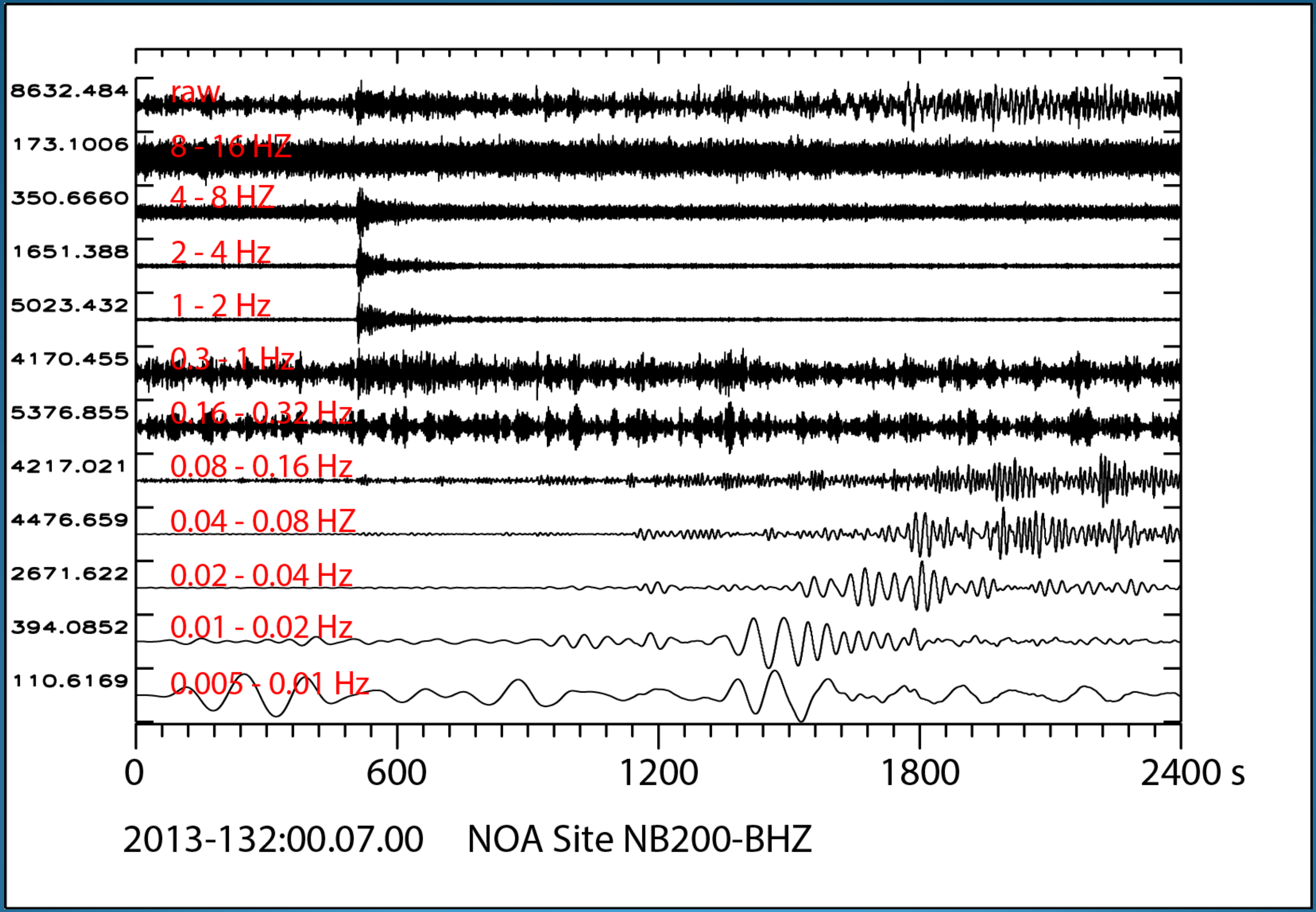
- Wide range of possible seismic signals (local - regional – teleseisms)
- Wide range of signal frequencies
- Considerations about aperture
- Considerations about geometry

Iran 16 April 2013 10:44:20 Mw 7.8



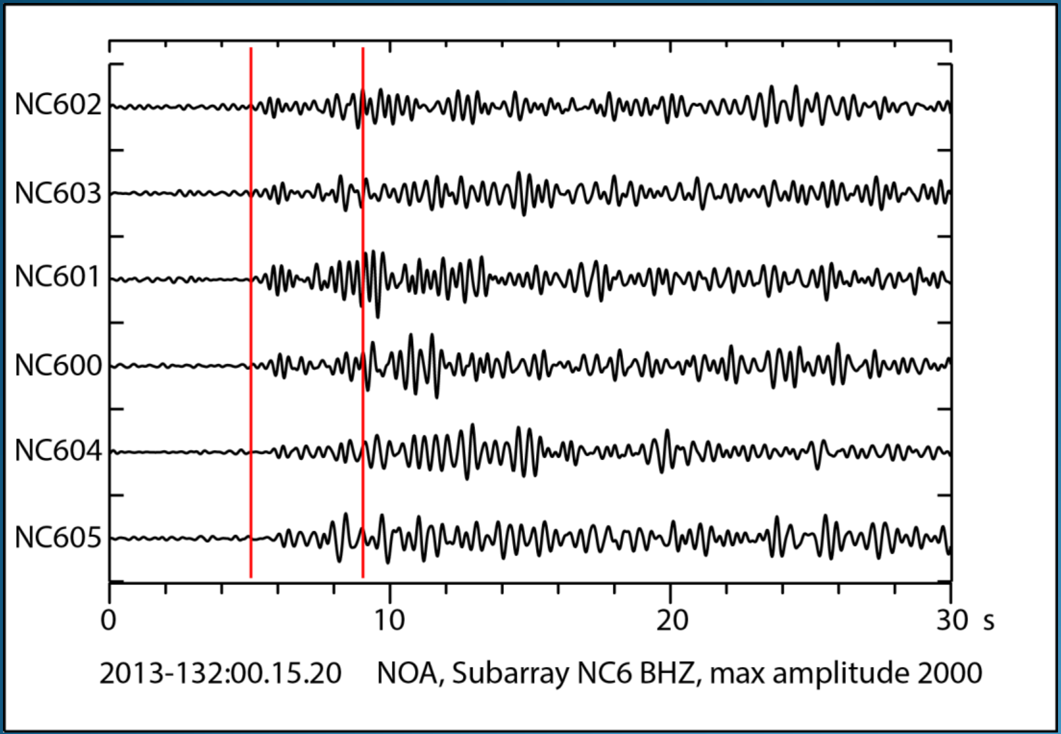
NOA: $\Delta = 47.1°$, theoretical backazimuth = 110.68° & v_{app} = 14.29 km/s

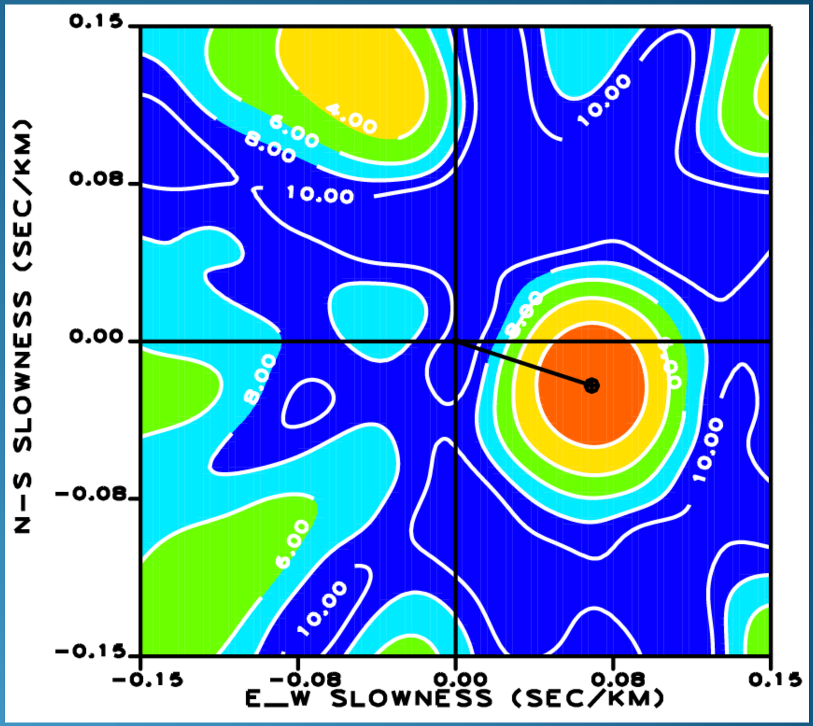
Iran 12 May 2013 00:07:04 M 5.6



NOA: $\Delta = 46.3°$, theoretical backazimuth = 116.77° & v_{app} = 14.15 km/s

Iran 12 May 2013 00:07:04 M 5.6



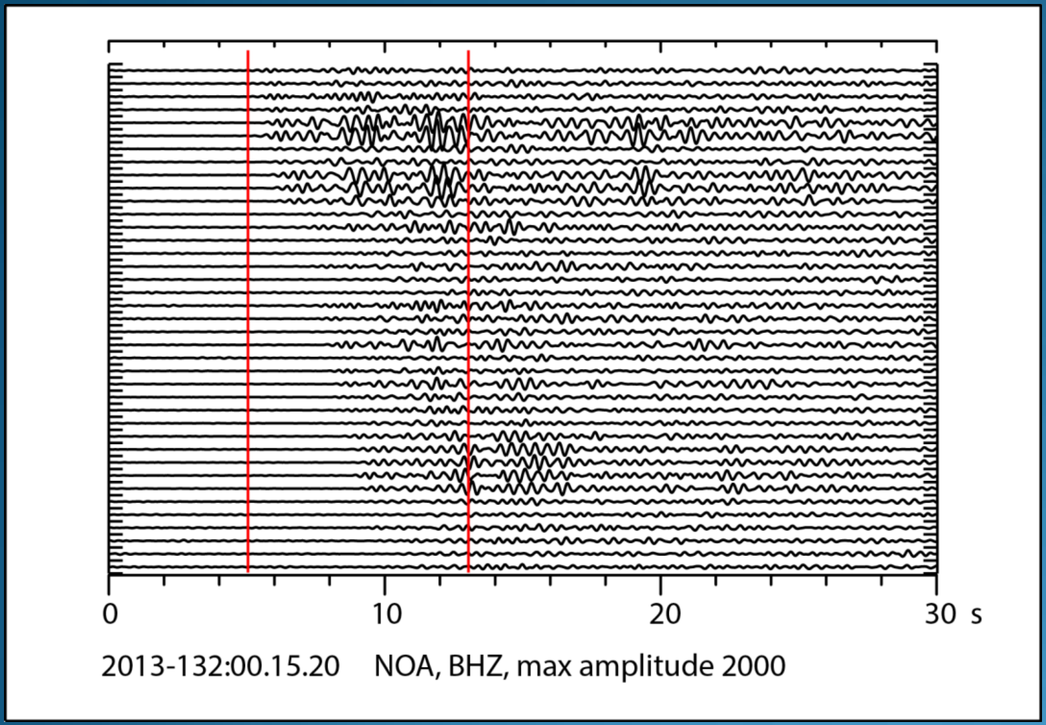


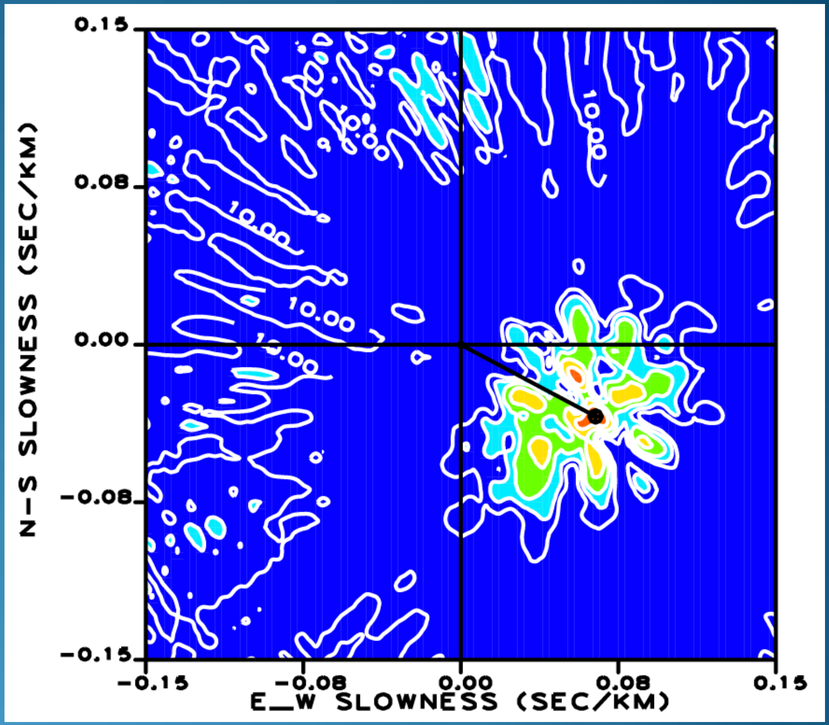
FK – analysis
Bandpass filter: 1 – 4 Hz
Window length: red lines
Channels:
Subarray NC6

Results
Apparent velocity: 14.68 km/s
Backazimuth: 108.02 degrees
Coherence: 0.86
Contours db below maximum

(theoretical backazimuth = 116.77° & v_{app} = 14.15 km/s)

Iran 12 May 2013 00:07:04 M 5.6



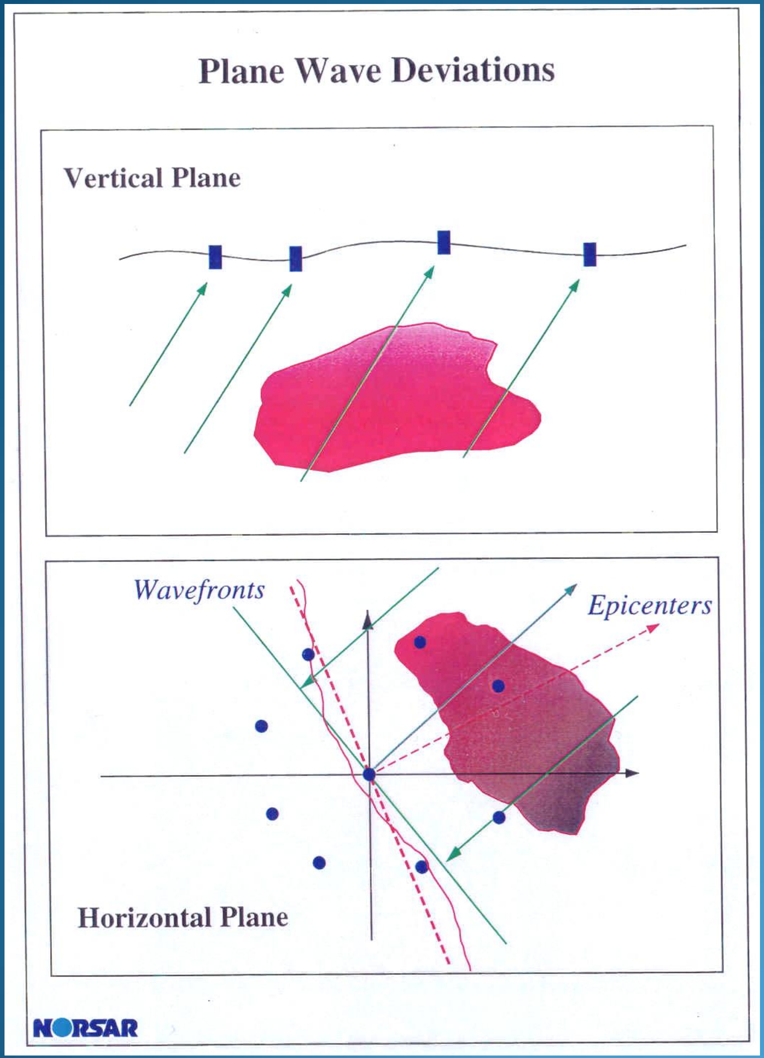


FK – analysis
Bandpass filter: 1 – 4 Hz
Window length: red lines
Channels:
All channels shown

Results
Apparent velocity: 13.76 km/s
Backazimuth: 118.01 degrees
Coherence: 0.26
Contours db below maximum

(theoretical backazimuth = 116.77° & v_{app} = 14.15 km/s)

Time Delay / Slowness Corrections

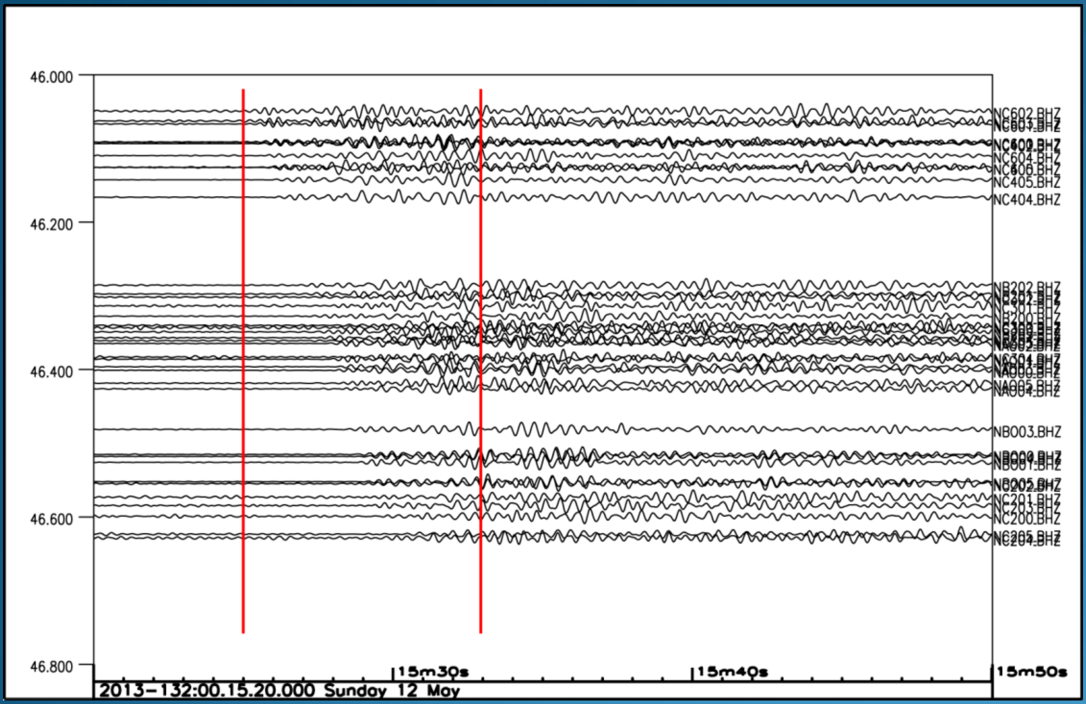


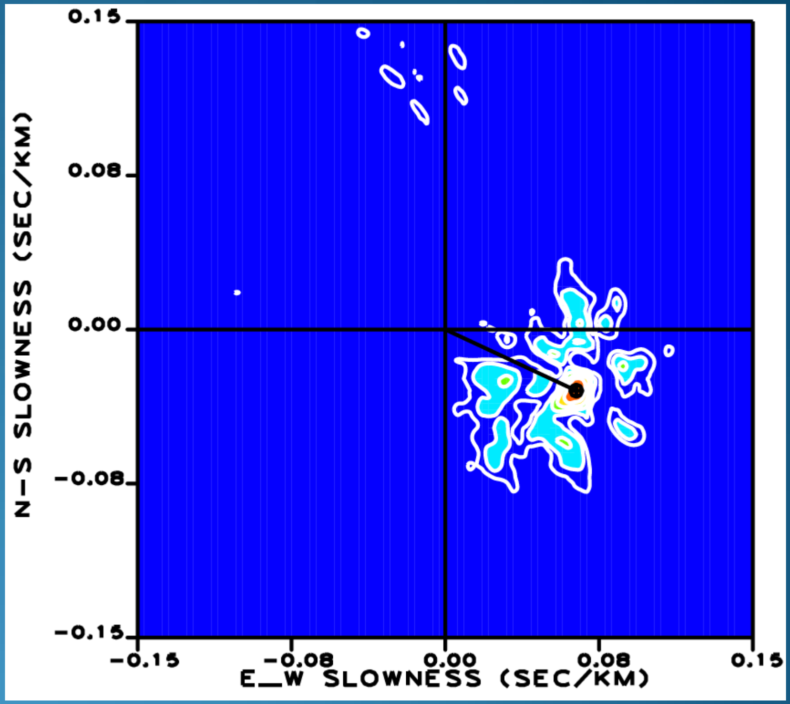
Since the Earth is not homogeneous, ray paths deviate from theory.

As a consequence, the observed slowness vector may differ from the one predicted according to event location and velocity model.

For arrays, statistics may be used to find systematic deviations, and then use these for calibration **before** any fk-analysis or location.

Iran 12 May 2013 00:07:04 M 5.6



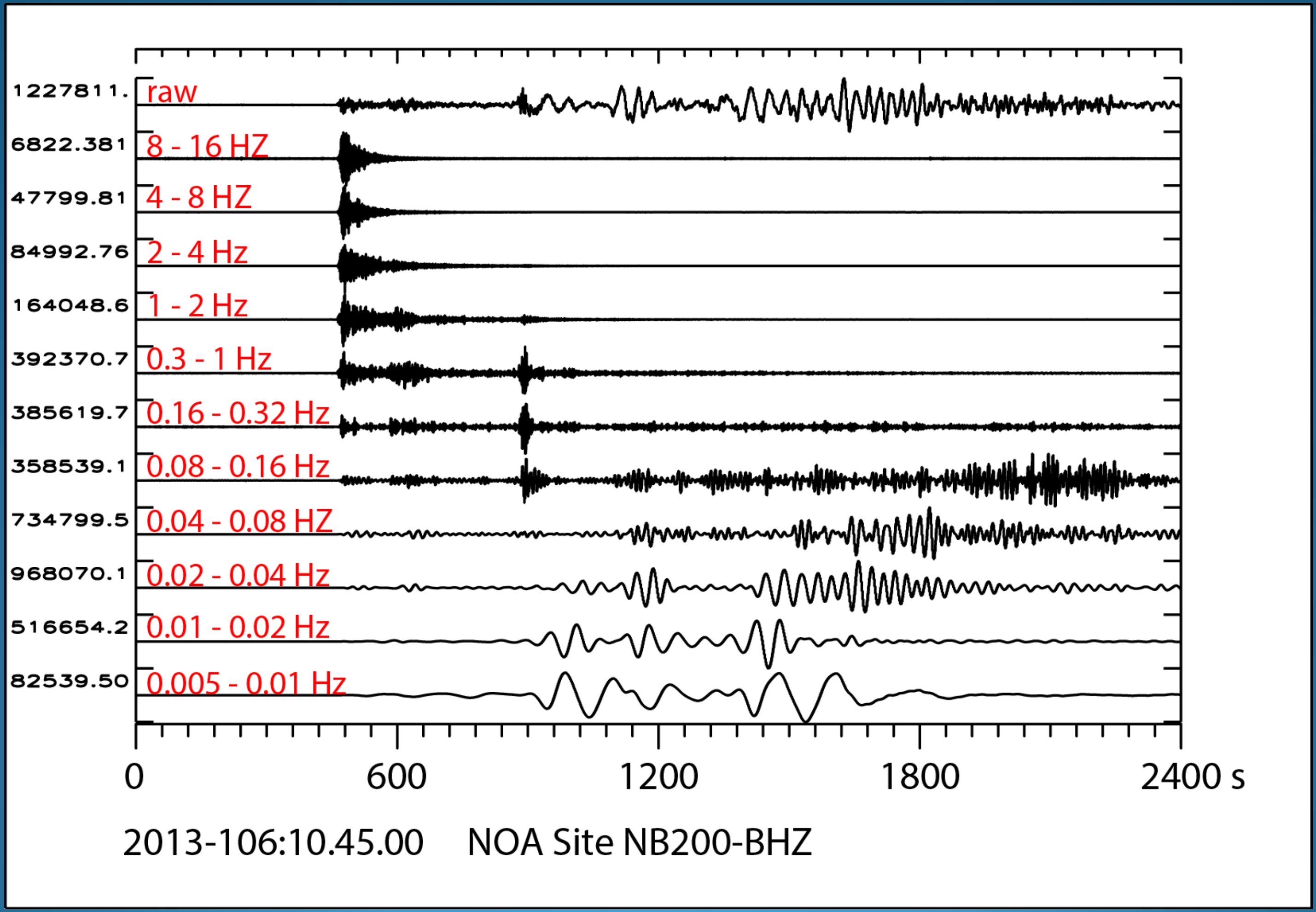


FK – analysis
Bandpass filter: 1 – 4 Hz
Window length: red lines
Channels:
Full NOA - Corrected

Results
Apparent velocity: 14.19 km/s
Backazimuth: 115.01 degrees
Coherence: 0.51
Contours db below maximum

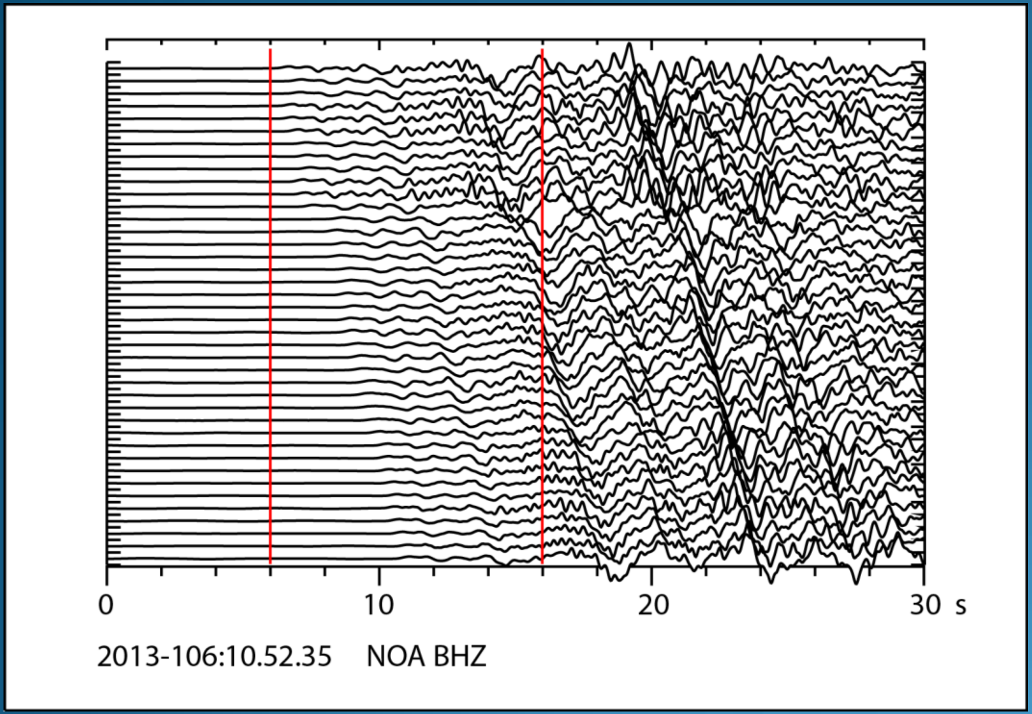
(theoretical backazimuth = 116.77° & v_{app} = 14.15 km/s)

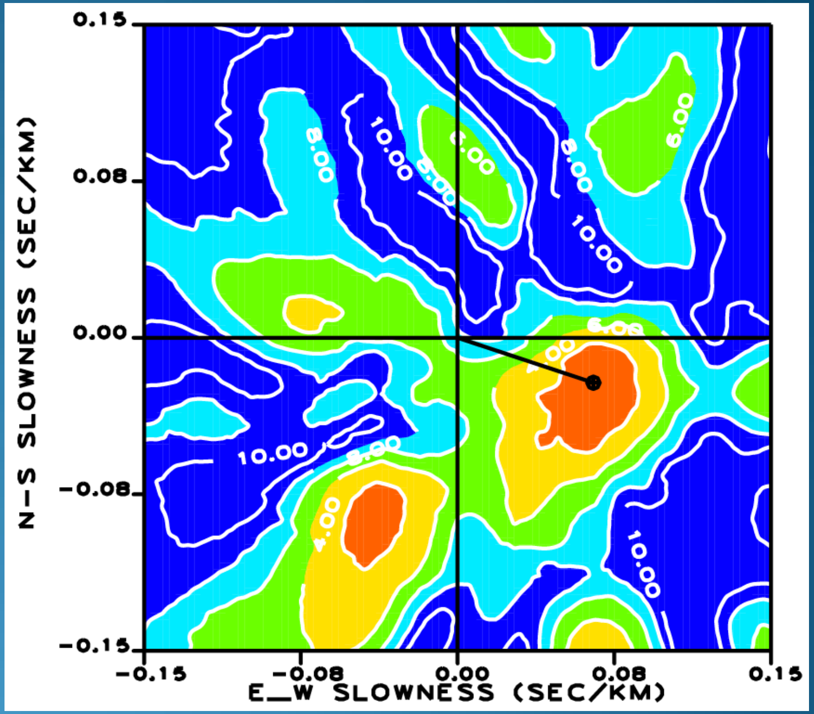
Iran 16 April 2013 10:44:20 Mw 7.8



NOA: Δ = 47.1°, theoretical backazimuth = 110.68° & v_{app} = 14.29 km/s

Iran 16 April 2013 10:44:20 Mw 7.8



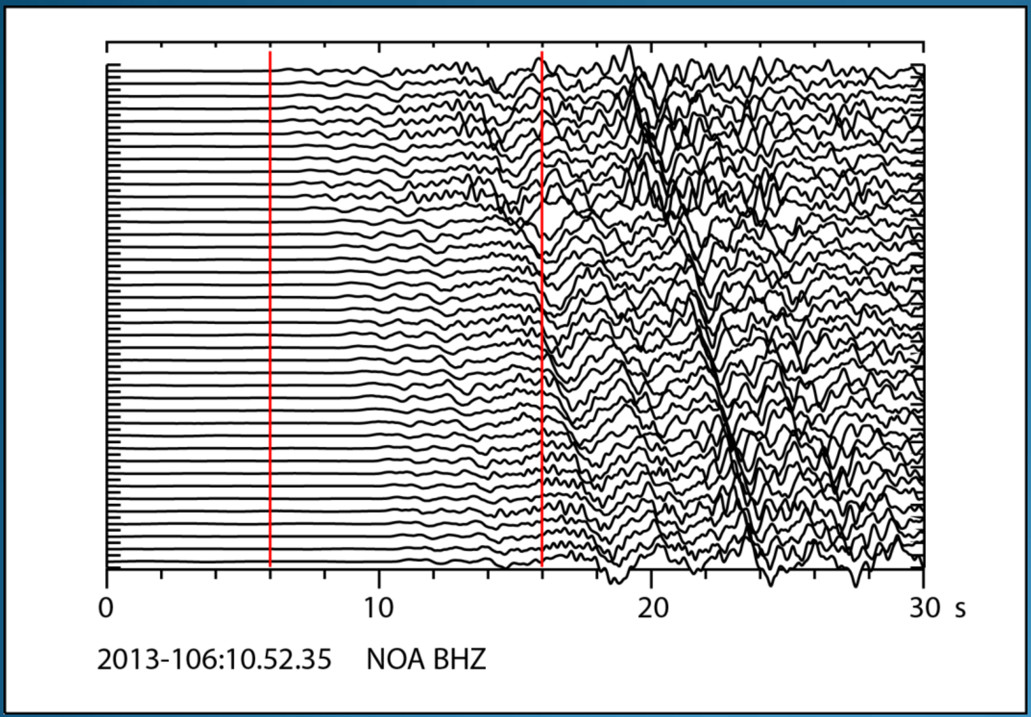


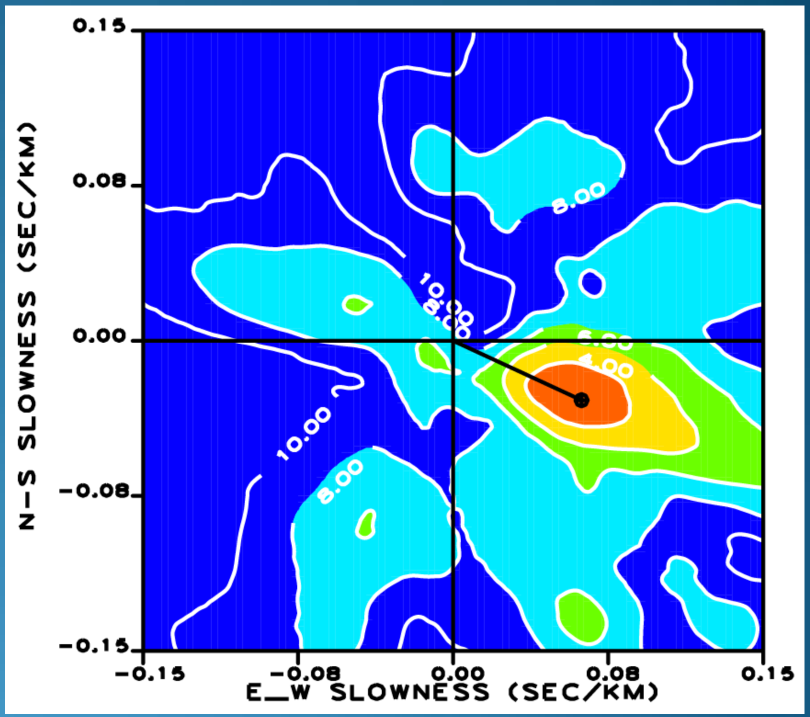
FK – analysis
Bandpass filter: 0.08 – 4 Hz
Window length: red lines
Channels:
Full NOA - Corrected

Results
Apparent velocity: 14.60 km/s
Backazimuth: 108.34 degrees
Coherence: 0.38
Contours db below maximum

(theoretical backazimuth = 110.68° & v_{app} = 14.29 km/s)

Iran 16 April 2013 10:44:20 Mw 7.8





FK – analysis
Bandpass filter: 0.08 – 4 Hz
Window length: red lines
Channels:
Full NOA – Uncorrected !

Results
Apparent velocity: 14.62 km/s
Backazimuth: 114.82 degrees
Coherence: 0.43
Contours db below maximum

(theoretical backazimuth = 110.68° & v_{app} = 14.29 km/s)

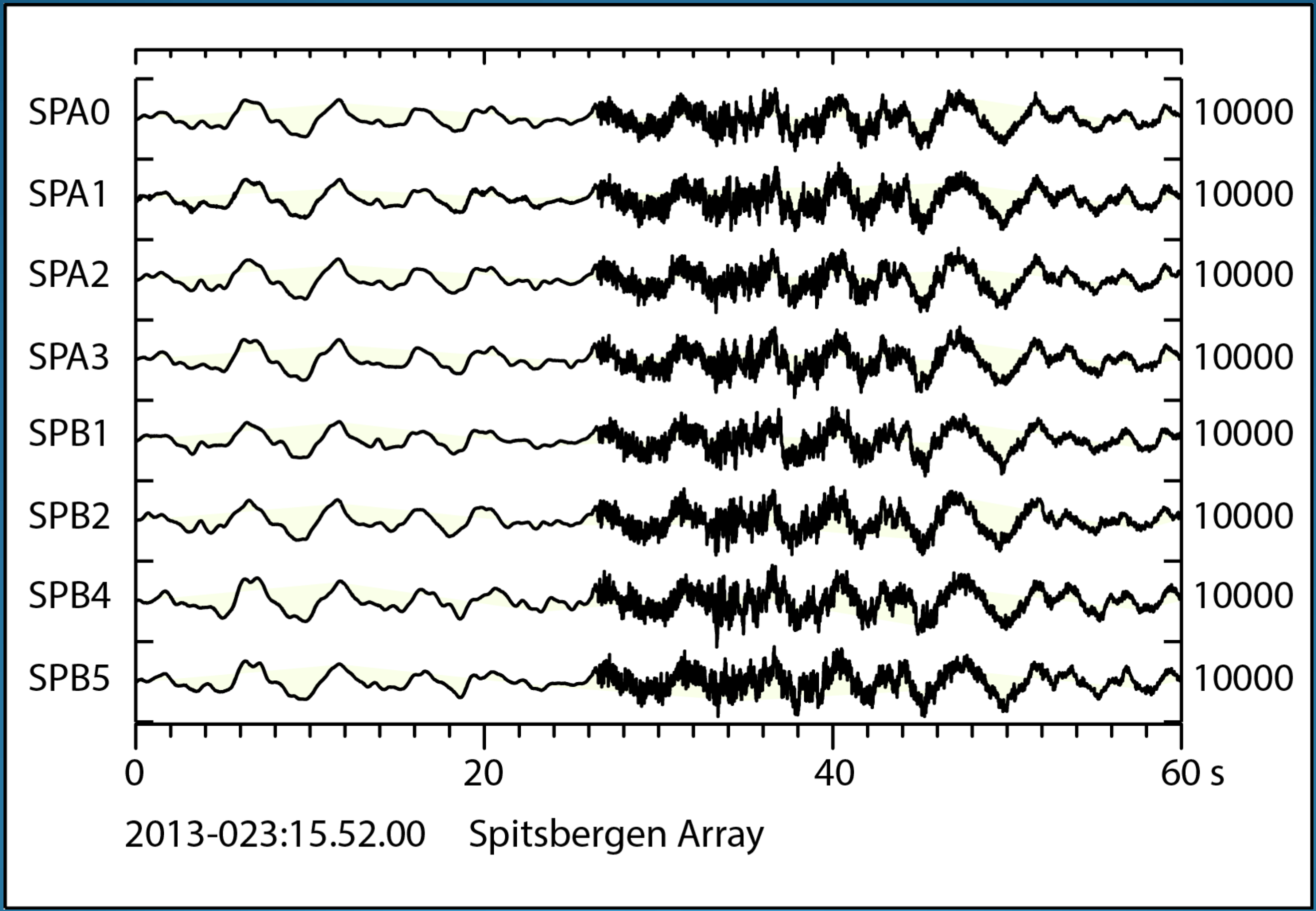
Broadband Arrays – Aperture

- Slowness resolution -> the larger the better
- Change of $dt/d\Delta$ -> small array
- Signal coherence -> signal frequency / wavelength dependent
- Plane wave approach -> array aperture < - > source distance
- Similar site conditions (site response, RF) -> small array

Broadband Arrays – Geometry

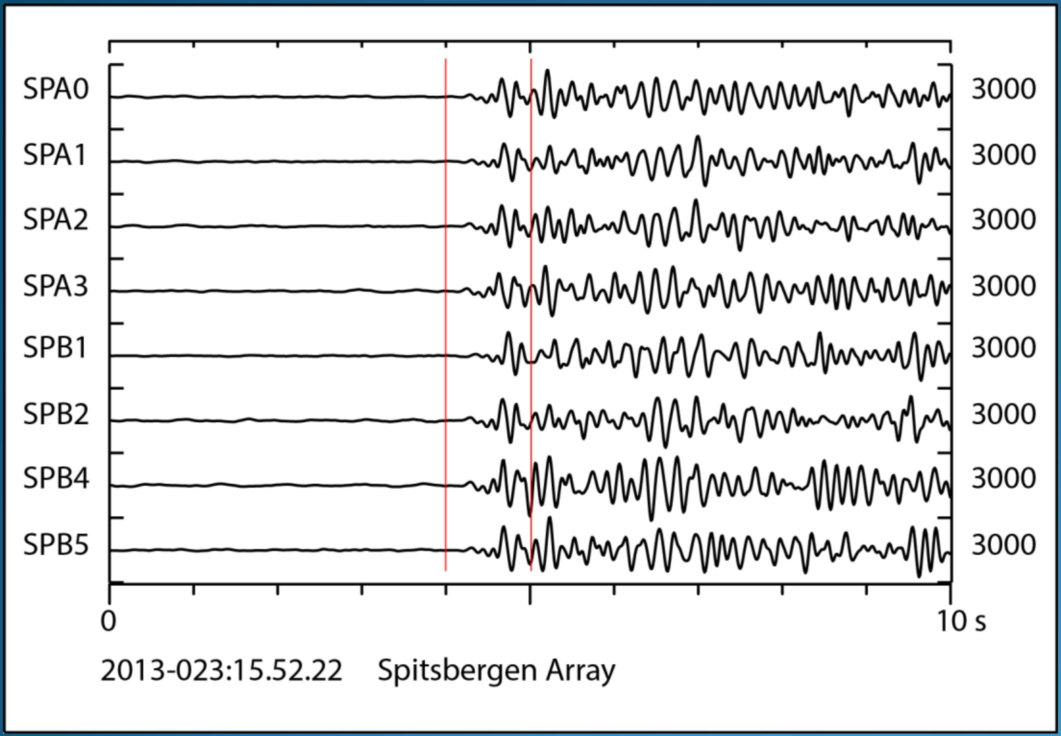
• Sidelobe suppression	->	number & position of array sites, not aligned
• Noise suppression	->	number of sites (SNR increase: $\sqrt{N}$)
• Equal azimuthal resolution	->	circular geometries
• Preferred geometry	->	maximum aperture about 100 km with 7 - 10 ARCES-like subarrays

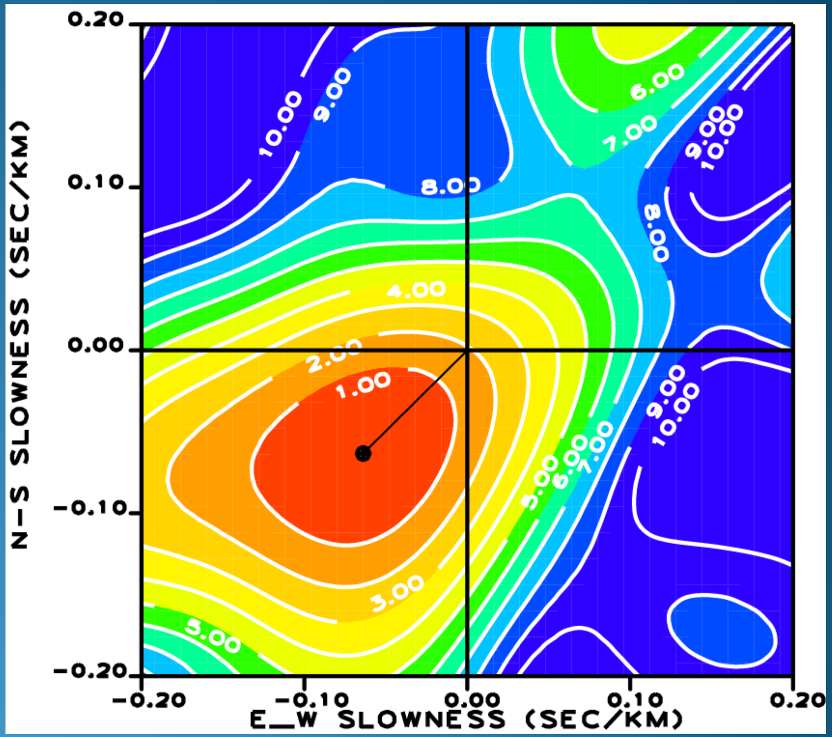
Barentsburg: Mining Related Event – 1



Distance ~80 km from SPITS

Barentsburg: Mining Related Event – 2

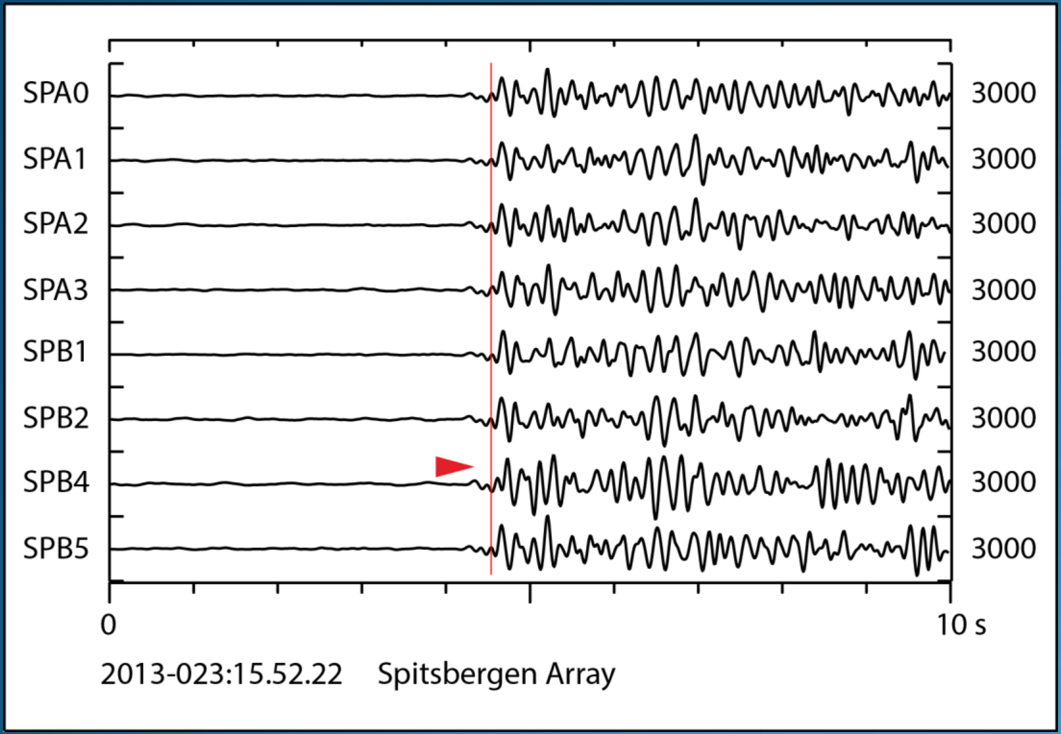


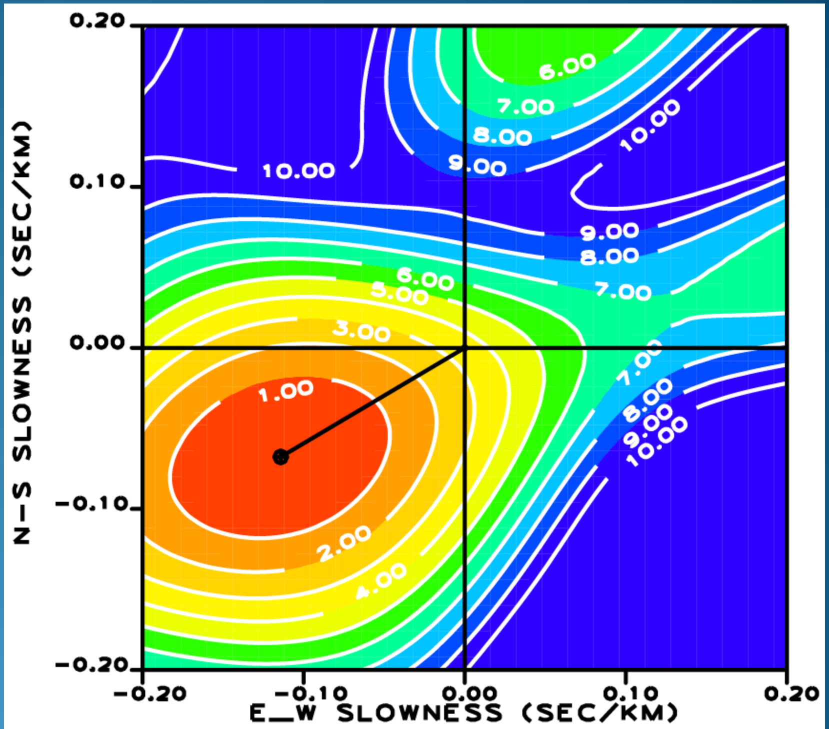


FK – analysis
Bandpass filter: 2 – 8 Hz
Window length: red lines
Channels:
All channels shown

Results
Apparent velocity: 11.11 km/s
Backazimuth: 225.27 degrees
Coherence: 0.73
Contours db below maximum

Barentsburg: Mining Related Event – 4





FK – analysis
Bandpass filter: 2 – 8 Hz
Window length: as before
Channels:
As before but without SPB4

Results
Apparent velocity: 7.53 km/s
Backazimuth: 239.34 degrees
Coherence: 0.93
Contours db below maximum

Conclusions – 1

- NORSAR operates arrays of different aperture, fully equipped with broadband sensors:

  since 2004 SPITS (1 km)

  since 2012 NOA (aperture 60 km) with subarrays of 5 km aperture

  from 2014 on ARCES (3 km)

- Data from these installations are open to test different broadband array scenarios and analysis algorithms.

- Also the concept of networks of arrays can be tested with NORSAR's data.

Conclusions – 2

- Signal coherence is a function of frequency content and inter-site distances.
- New broadband array installations should allow for event observations from regional to teleseismic distances.
- Data redundancy is needed for cases of equipment malfunction or local noise bursts.
- Permanent data quality control is needed (automatic).
- Correct timing is crucial, central timing would be the best solution.

Conclusions – 3

- Arrays have to be calibrated before any backazimuth or slowness observations can be used for more sophisticated interpretations.

- Array calibrations are depending on the local heterogeneous velocity structure below the array (frequency and incidence angle dependent, different for S- and P-type onsets).

- Array calibration needs long term operation to record a sufficient amount of calibration data.

New Manual of Observatory Practice (NMOSP)

Edited by Peter Bormann and published for IASPEI with open access:

nmsop.gfz-potsdam.de

Chapter 9

Seismic Arrays

(Version December 2011; DOI: 10.2312/GFZ.NMSOP-2_ch9)

Johannes Schweitzer, Jan Fyen, Svein Mykkeltveit,
Steven J. Gibbons, Myrto Pirli, Daniela Kühn, and Tormod Kværna[1)]

[1)] All: NORSAR, Gunnar Randers vei 15, P.O. Box 53, N-2027 Kjeller, Norway; contact via:
Phone: +47-63805900, E-mail: johannes.schweitzer@norsar.no

Thank You