A sea-floor and land-based network to study the Western Barents Sea continental margin: experiences, observations, limitations & results

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& the IPY Project Consortium

NORSAR

INTERNATIONAL 2007 2008 POLAR YEAR

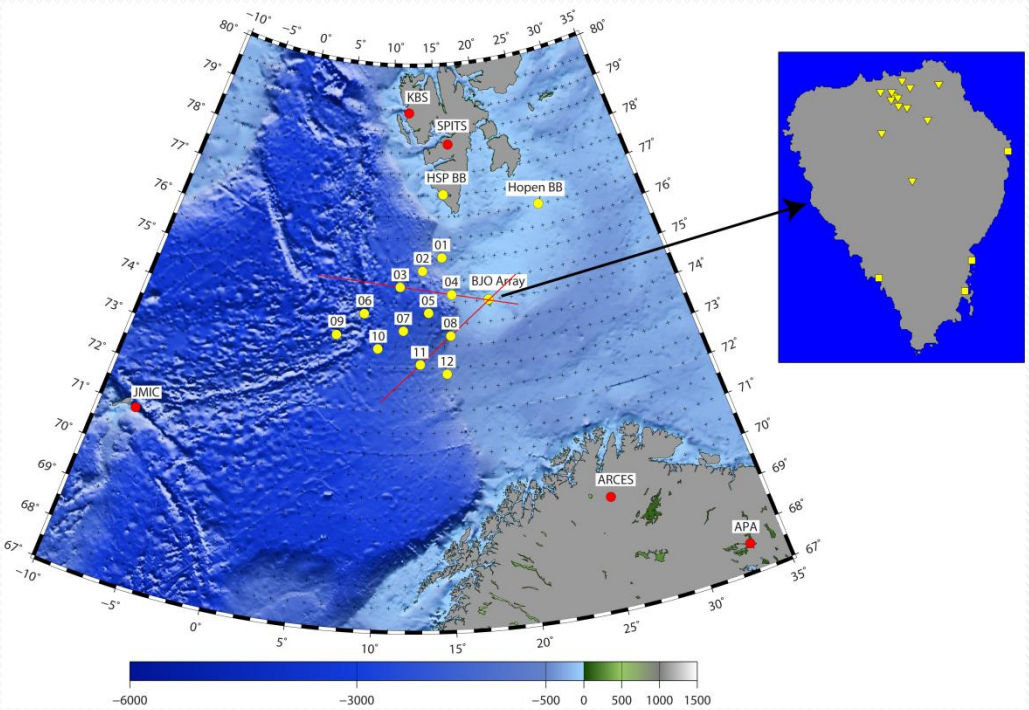
Introduction & Outline

- This presentation:
  - OBS/H data analysis: first time at NORSAR
  - Focus on the study of local/near-regional seismicity
  - No description of active experiments, structural studies within the project

- Presentation of the project
  - Scientific consortium
  - Research goals
  - Field-work and seismic network
  - Instrumentation
- Challenges
  - Actual data availability
  - Achieved data quality
  - Data examples
- Limitations in event location
  - Network capability
  - Examples
- Results
  - General
  - Overview of more specialised studies
- Outlook
- Summary
- Future considerations

The project & its network

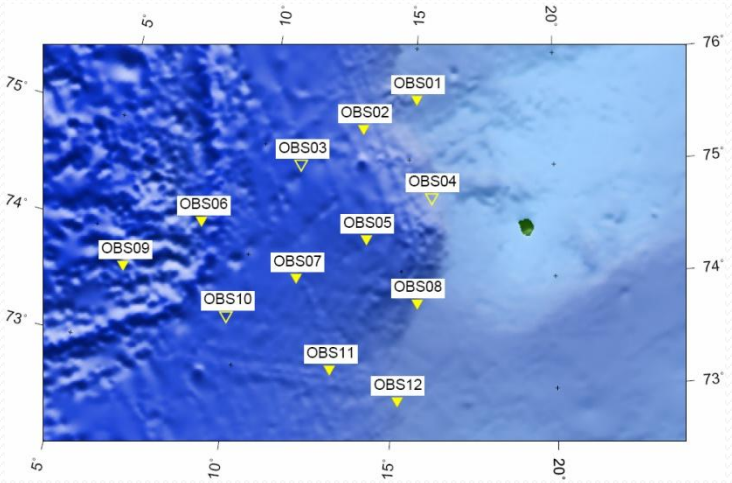
«The dynamic continental margin between the Mid-Atlantic-Ridge system (Mohns Ridge, Knipovich Ridge) and Bear Island»



- Project focused on:
  - Observation of seismicity on the sedimentary wedge between the ridges and the continental margin
  - Structure of the sedimentary wedge
  - Structure of the uppermost mantle in the region
  - Kinematics (plate motions, large-scale tectonic structures, *e.g.*, Senja fracture zone)

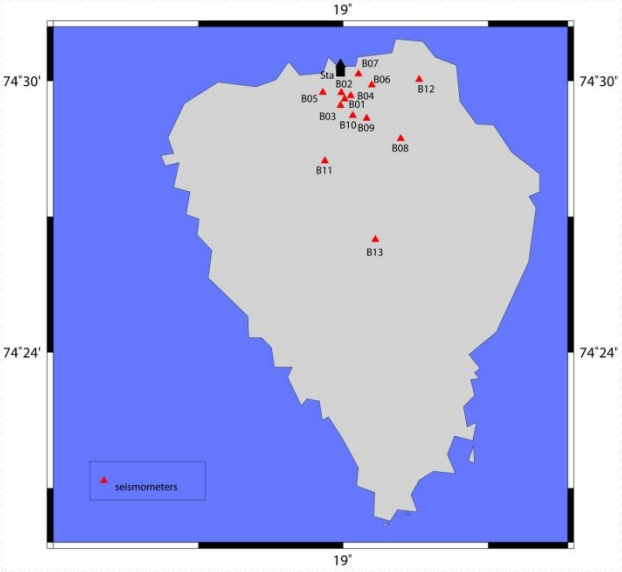
OBS/OBH

- 12 OBS/OBH from DEPAS
  - LOBSTER
  - CMG-40T 60 s – 50 Hz
  - HTI-04-PCA/ULF 100 s – 8 kHz
  - Send Geolon MCS 24-bit recorder
  - 50 sps
  - September 2007 – August 2008
- Some instrument/data loss
  - OBS04: fished out by a Russian trawler in April 2008
  - OBS03: lost after hitting on ship's propeller during recovery
  - OBS10: not recovered; found on Iceland in April 2009; no data



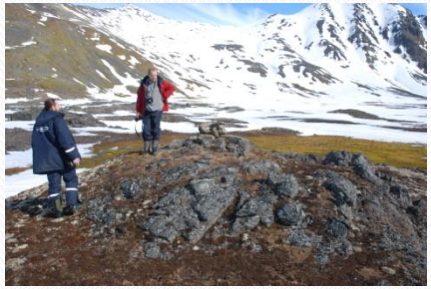
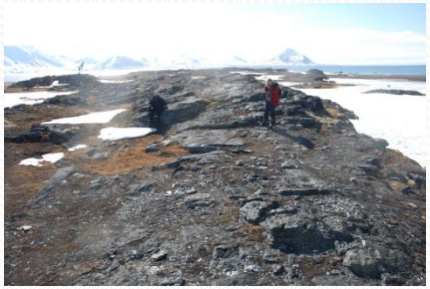
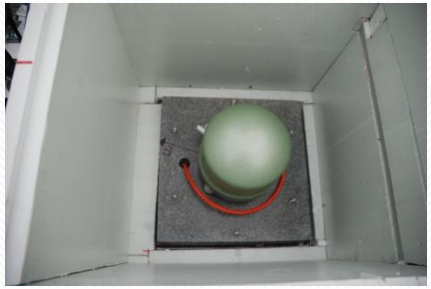
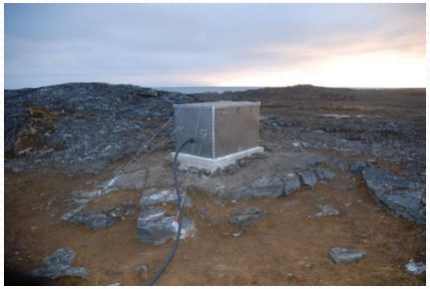
BJOA – the Bear Island array

- Small-aperture, short-period seismic array
  - 13 elements
  - 3-component
  - LE3D-5s
  - May 2008 – end of September 2008



HSPB – broadband station at Hornsund

- New, broadband station at Hornsund, Spitsbergen
  - Site survey in June 2007
  - Installation September 2007
  - Polish Polar Station Hornsund
  - STS-2 with CMG-DM24 & later MK-6 26-bit digitizer
  - Now: permanent, high quality station

Data availability & quality

- OBS/H 9.5/12 for ~11 months
- BJOA ✓ for ~4.5 months
- HSPB ✓
- HOPEN off almost for entire project duration
- Permanent, regional network:
  - Several arrays (SPITS, ARCES, NORSAR , APA, FINES, HFS)
  - Single, 3-C stations (JMIC, KBS, BJO1, TRO, LOF, KEV)

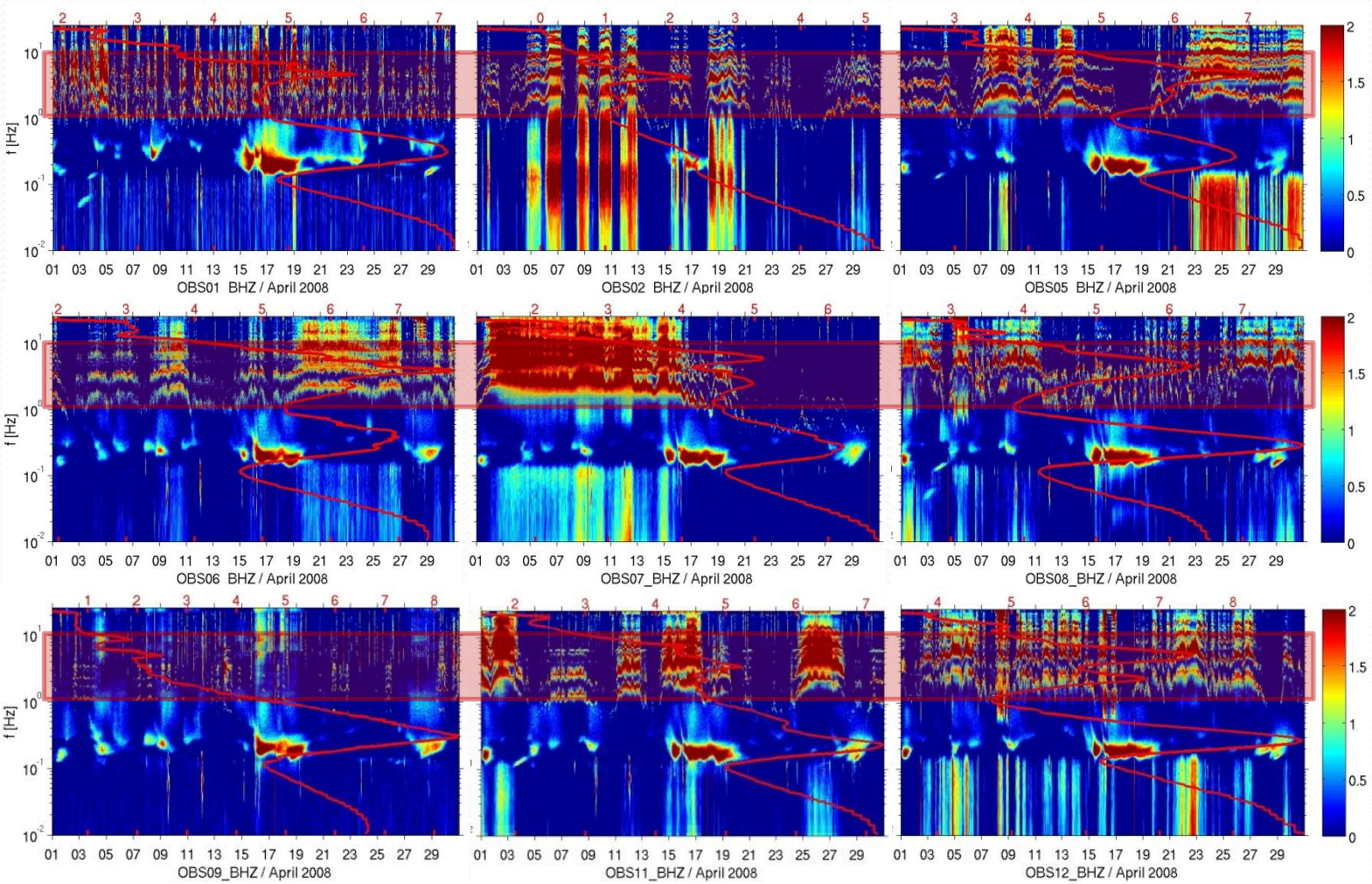
- Project land-station data quality:
  - HSPB: high quality data
  - BJOA: better SNR than permanent station on Bear Island; SNR gain due to beamforming; stations close to shoreline more noisy

- OBS/H channel status:
  - OBS02: stopped recording a week before recovery , no skew
  - OBS02: bad signal on vertical component
  - OBS04: fished out, no skew; suspicions of bad coupling on seafloor
  - OBS04: horizontals often clipping
  - OBS07: very low amplification on Y-component until end November 2007
  - OBS12: bad signal on X-component
  - Hydrophones ✓

- OBS/H data quality:
  - Bad noise conditions, extreme in cases
  - Worse for shallower stations
  - Various noise sources (traffic, weather related, marine life, ocean currents *etc*.)
  - Best conditions: OBS09 (& OBS06)

Power spectral density plots – I

Frequency range interesting for body-waves



Colour-scale shows positive deviation from average noise level (red line)

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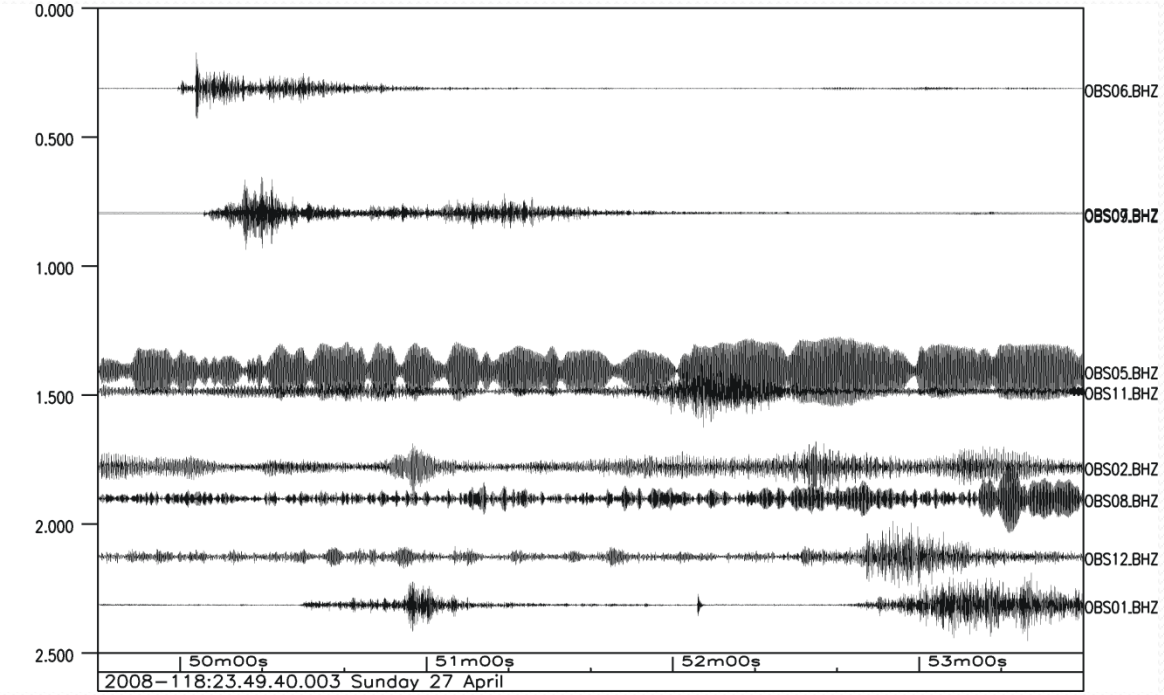
OBS SNR conditions & analysis – an example

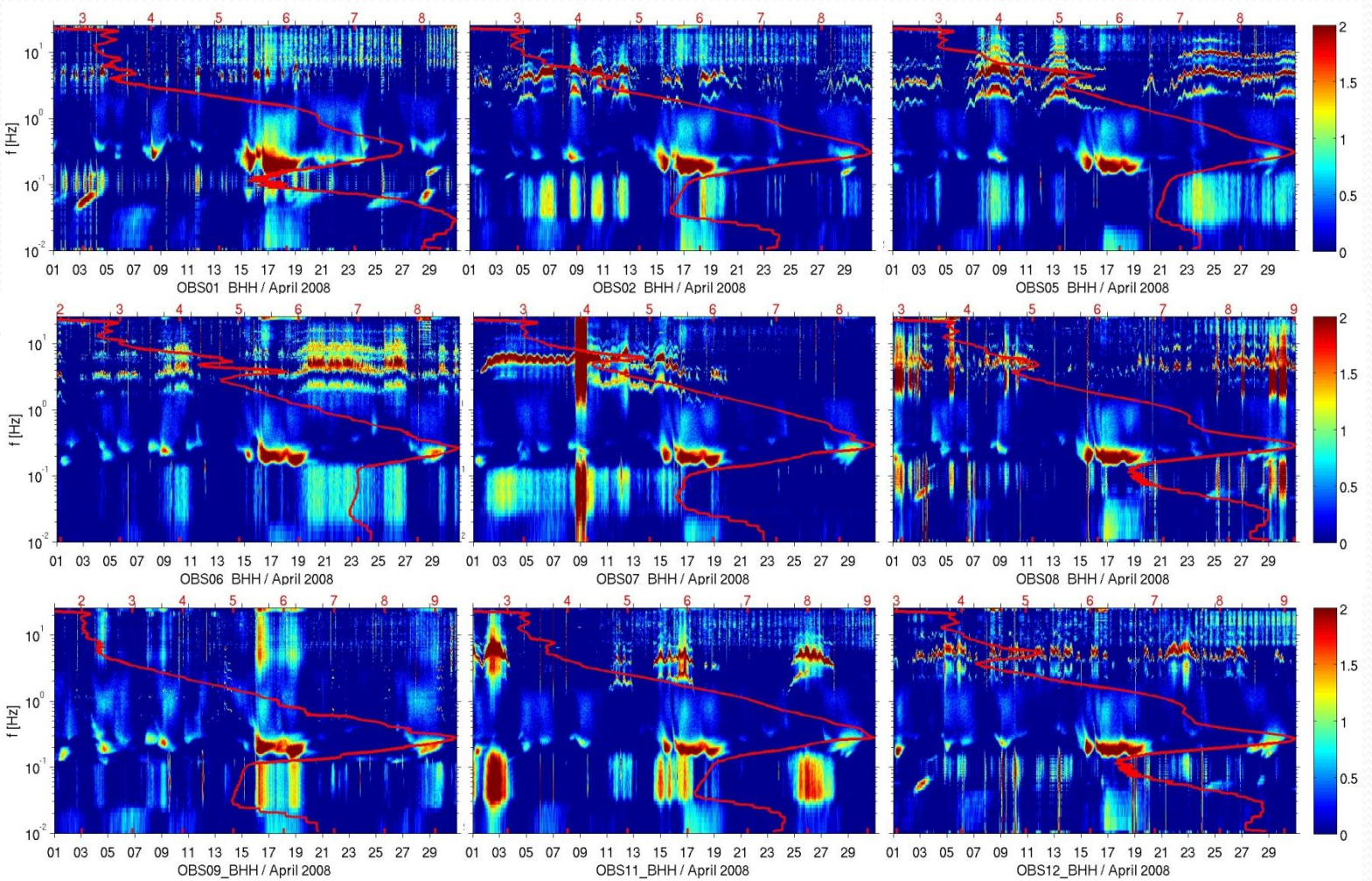
- 27/04/08 23:49:52.6
- 73.952°N, 8.819°E
- Mohns – Knipovich Bend
- M ~ 3

- Distance plot in (°) from epicentre
- Filtered between 3.5 – 12 Hz
- Clear picks on 4 OBSs: OBS06, OBS07, OBS09 & OBS01
- One of the better examples!



Power spectral density plots – II

Better conditions on the hydrophone; sometimes, alternative for picking first arriving P-phases!



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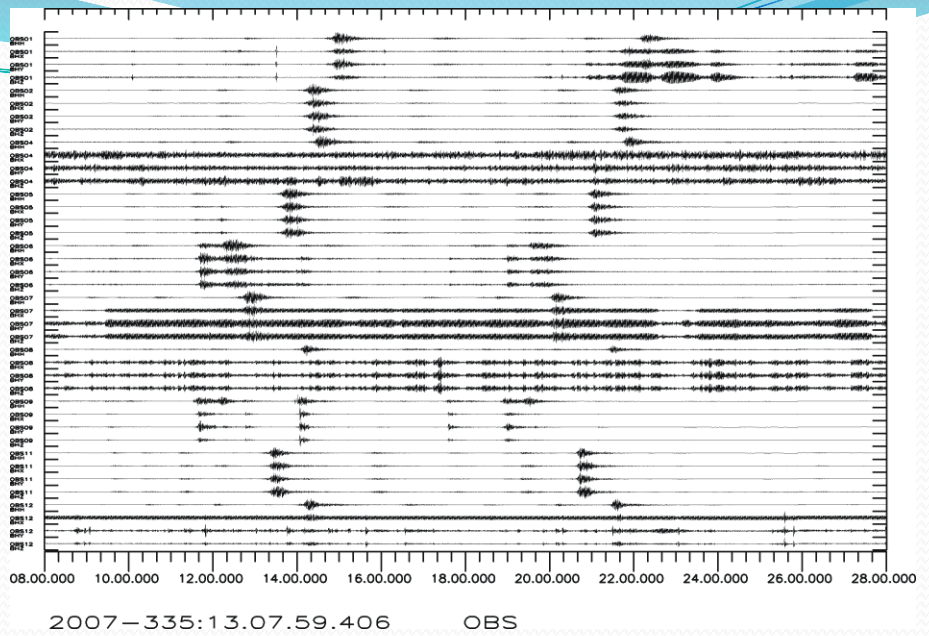
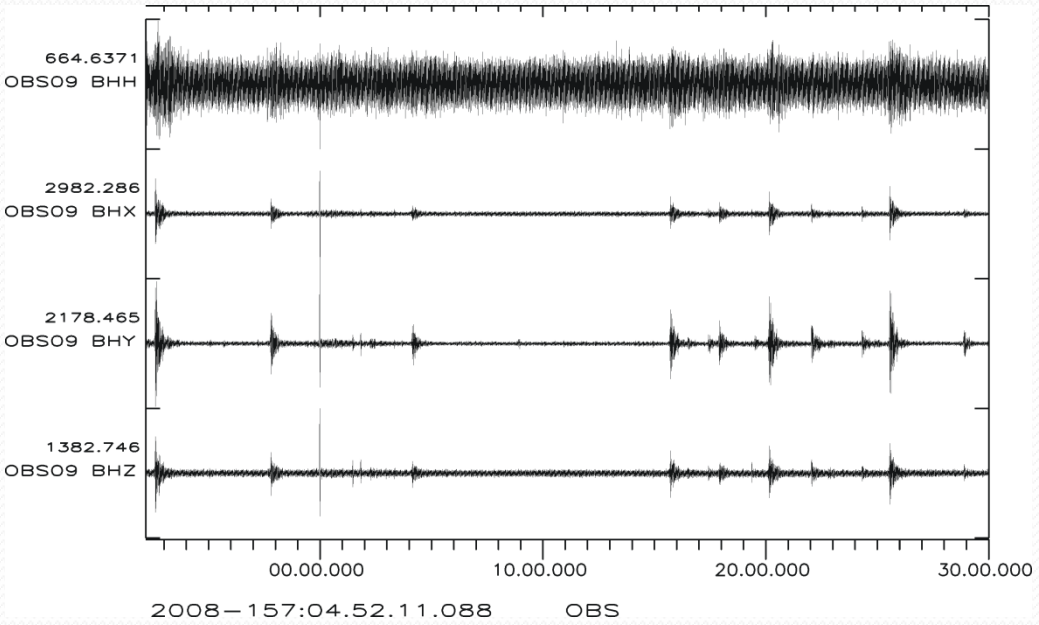
Record examples – I

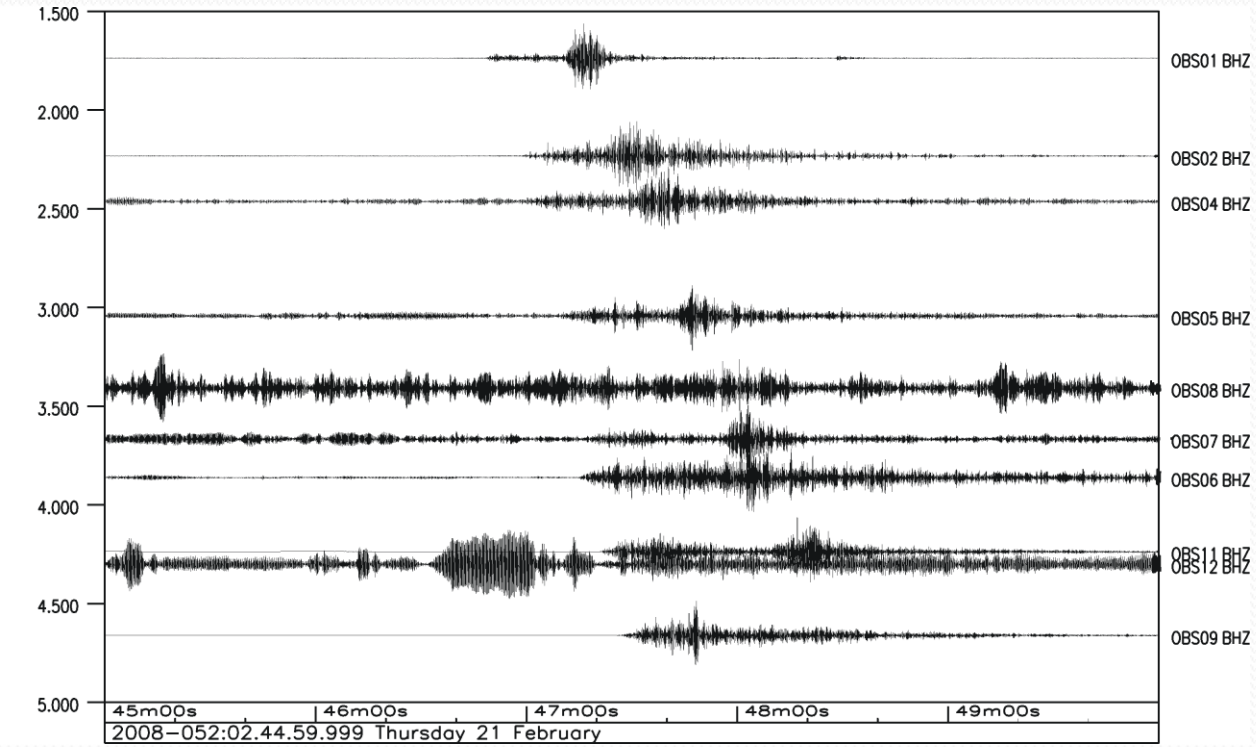
- Local seismicity examples:
  - 01/12/2007 swarm activity sample
  - Mohns – Knipovich Bend
  - Larger events ~ M 4.5
  - Bandpass filtered 3.5 – 12 Hz
  - 05/06/2008 swarm activity sample
  - Northern Mohns Ridge
  - Larger event ~ M 2.7
  - Bandpass filtered 3.5 – 12 Hz
  - Useful records only on OBS09





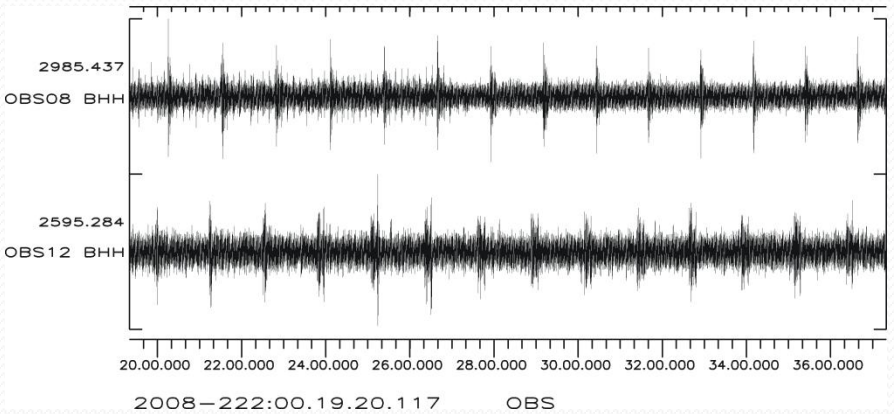
Record examples – II

- Large, regional event
  - 21/02/2008, Mw 6.1 Storfjorden mainshock
  - Bandpass filtered 3.5 – 12 Hz
  - Epicentral distance [°] plot

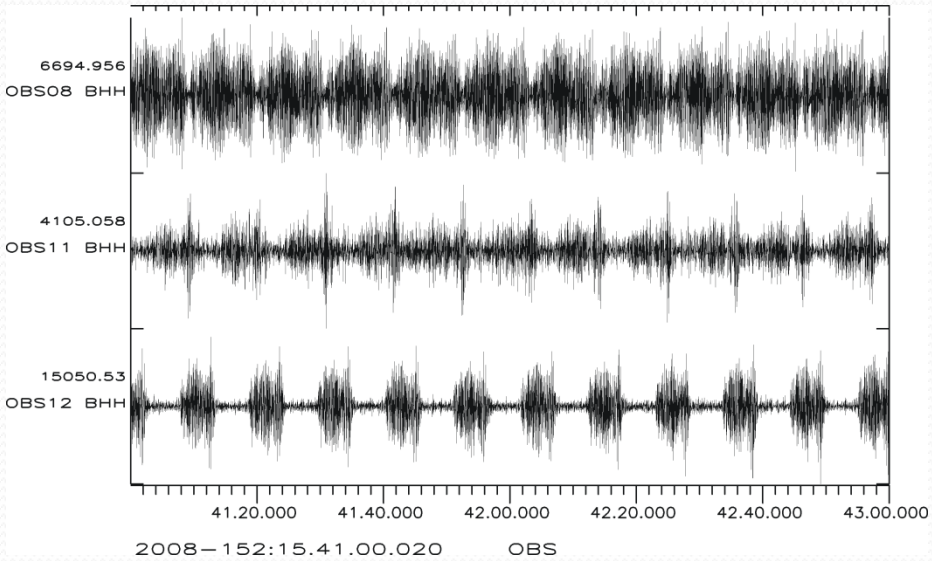


Record examples – III

- Man-made sources
  - Airgun shots
  - Project profile
  - Bandpass filtered 3.5 – 16 Hz



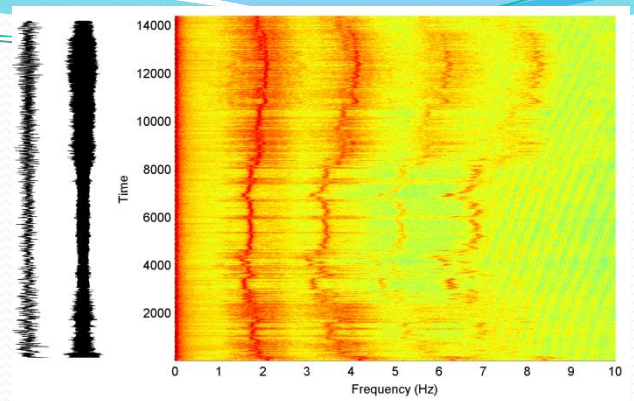
- High resolution seismic profiling?
- Bandpass filtered 3 – 16 Hz



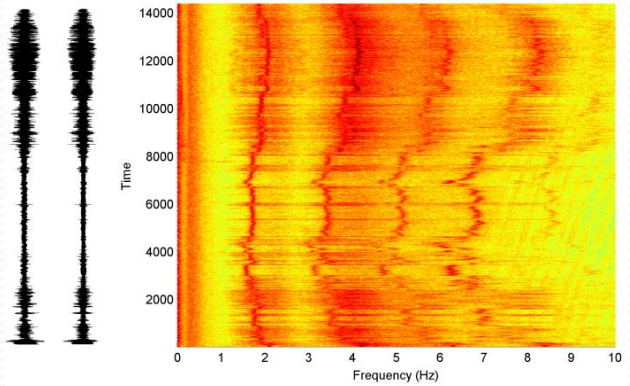
Record examples – IV

- 4-hour signal & spectrogram
  - OBS12: BHY, BHZ, BHH
  - Left: unfiltered record
  - Right: bandpass 1 – 10 Hz
  - Spectrogram up to 10 Hz
- Sub-harmonics on OBS channels, almost completely absent on OBH
- Same observed at several stations
  - Long duration
  - Resonance frequencies changing over time
- Shear resonances in upper sediment layer?

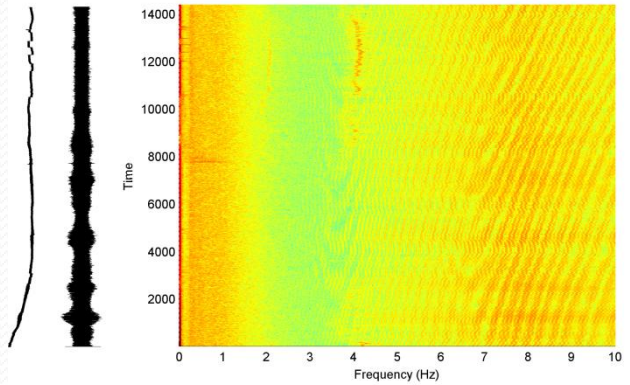
  (Godin & Chapman, 1999)



BHY



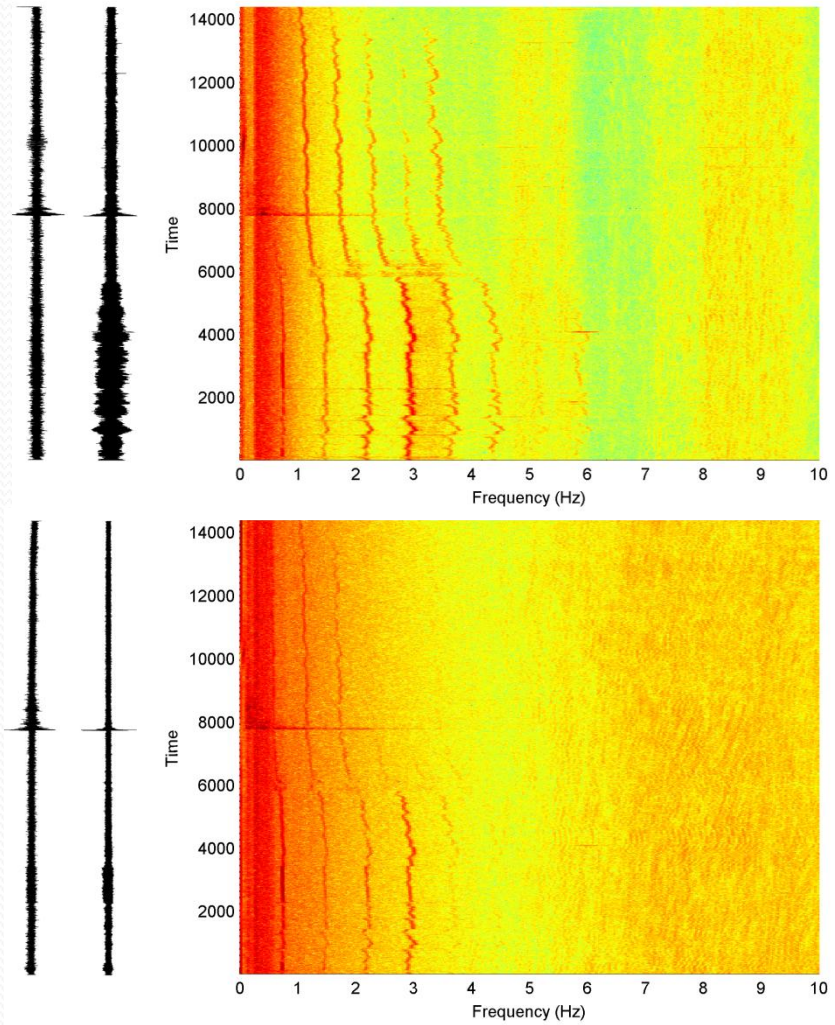
BHZ



BHH

Record examples – V

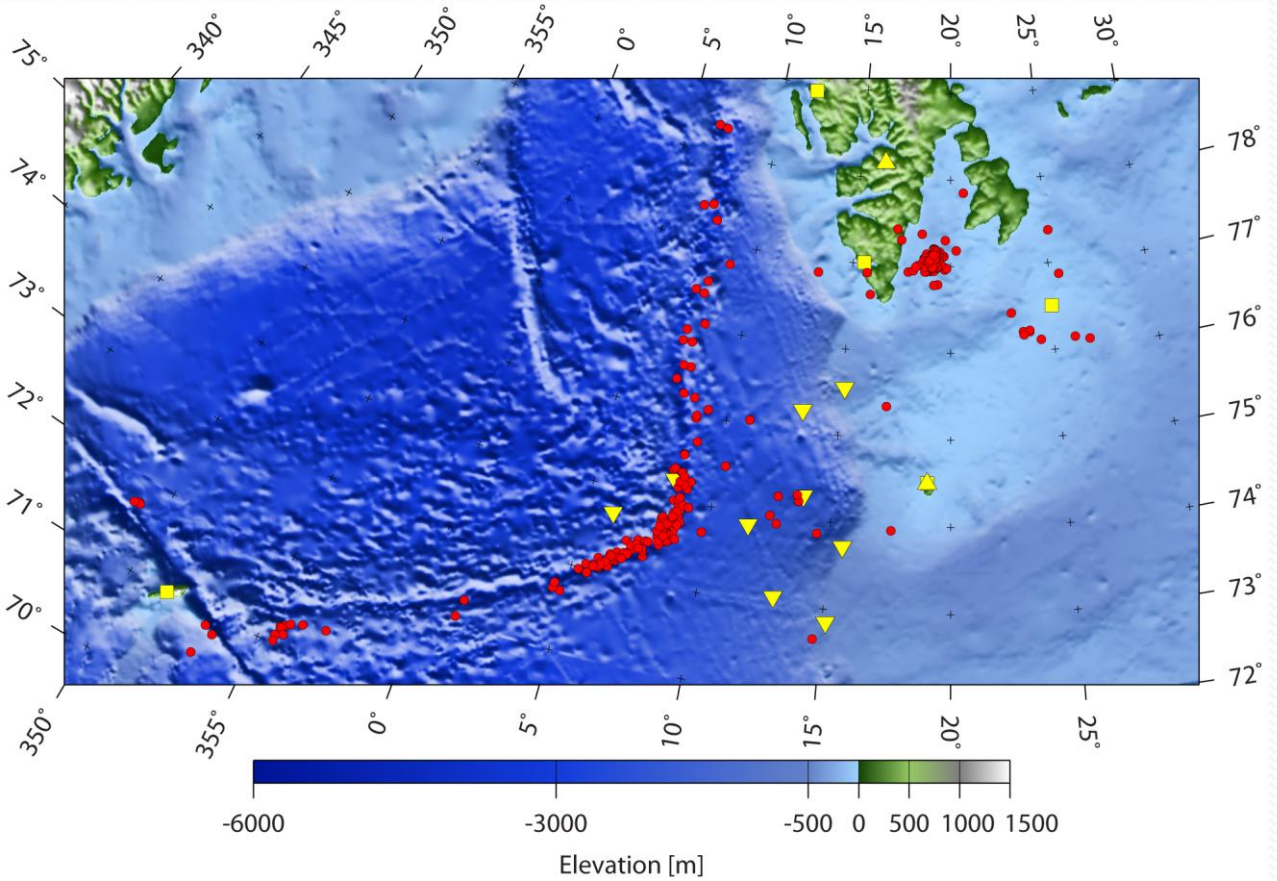
- 4-hour signal & spectrogram
  - OBS09: BHZ, BHH
  - Left: unfiltered record
  - Right: bandpass 1 – 10 Hz
  - Spectrogram up to 10 Hz
- Strong sub-harmonics on vertical OBS channel (also horizontals; not shown), weaker on OBH
- Local earthquake
- As mentioned previously:
  - Long duration
  - Resonance frequencies changing over time
- Shear resonances in upper sediment layer? Theoretically, thin sedimentary layer at OBS09



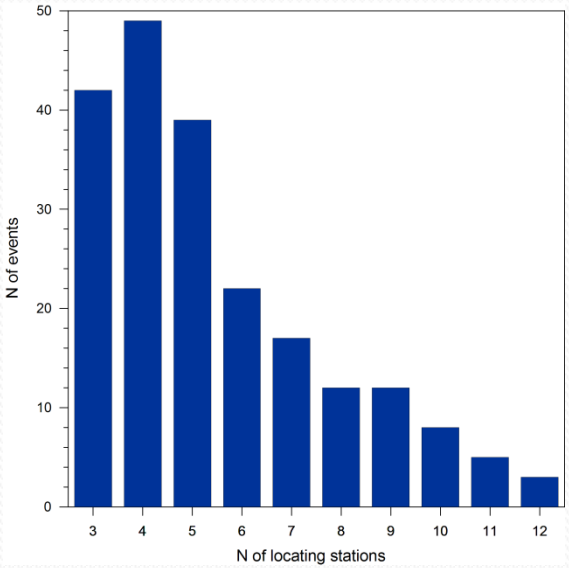
Located seismicity

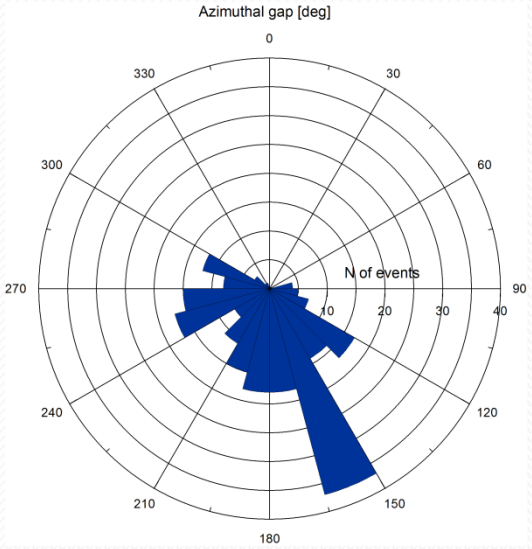
- 210 events
  - Mid-ocean ridges
  - Sedimentary wedge
- 256 events
  - Svalbard Archipelago
    (Pirli *et al.*, 2010: SRL, 81(1))

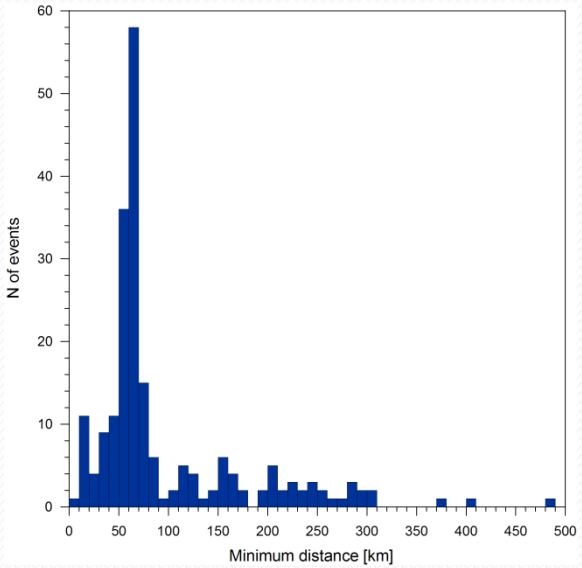
- Relocation of NORSAR's reviewed bulletin entries
- Relocation of automatic GBF algorithm results
- Location of events detected by STA/LTA detector on OBSs



Network performance

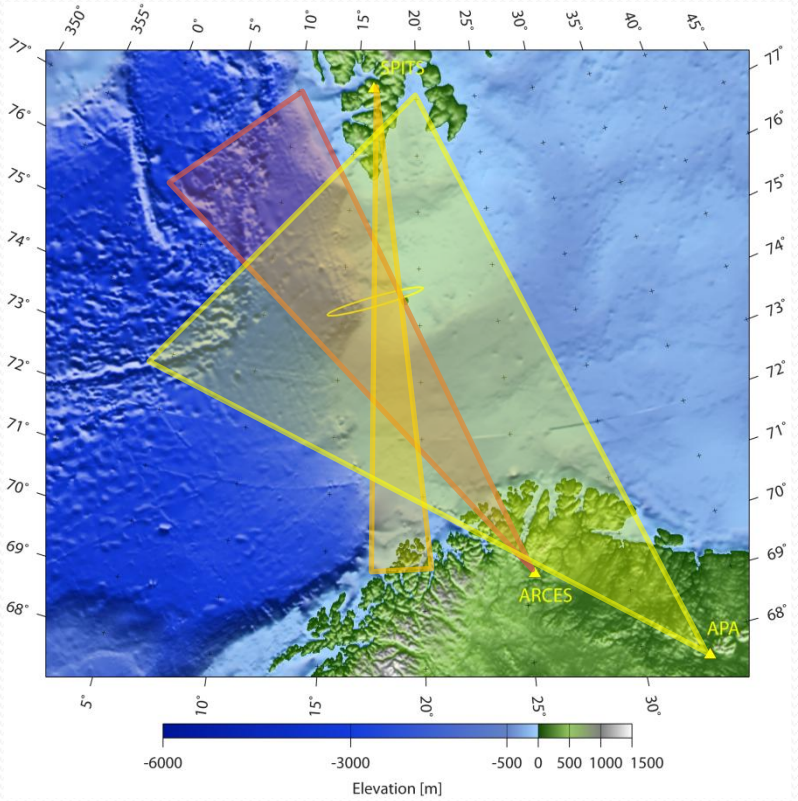


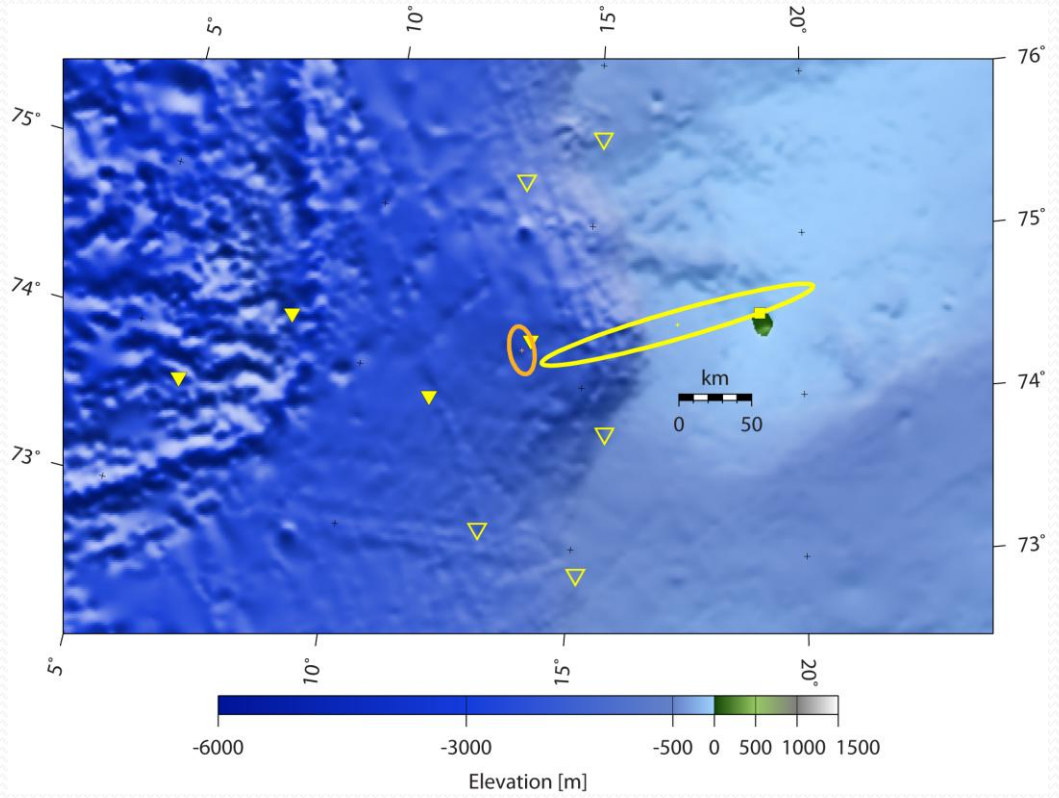




- Network still rather sparse (*e.g.*, OBS inter-station minimum distance ~ 60 km)
  - Large epicentral distances, high noise conditions, mostly events of low M → events located by few stations
- Very few solutions with gap < 100°
- No resolution for focal depth determination (2xdepth epicentral distance criterion)
- 3-D velocity model required

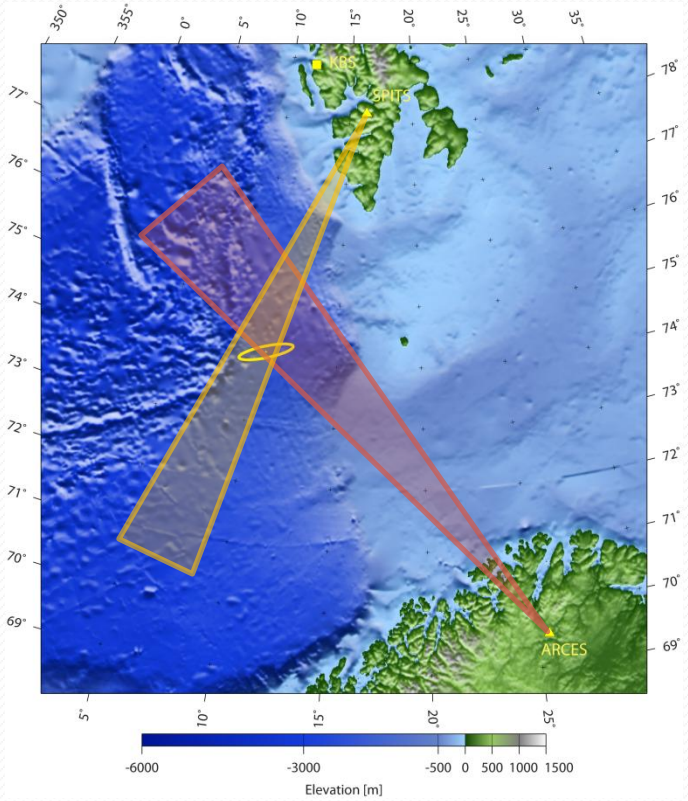
Example I

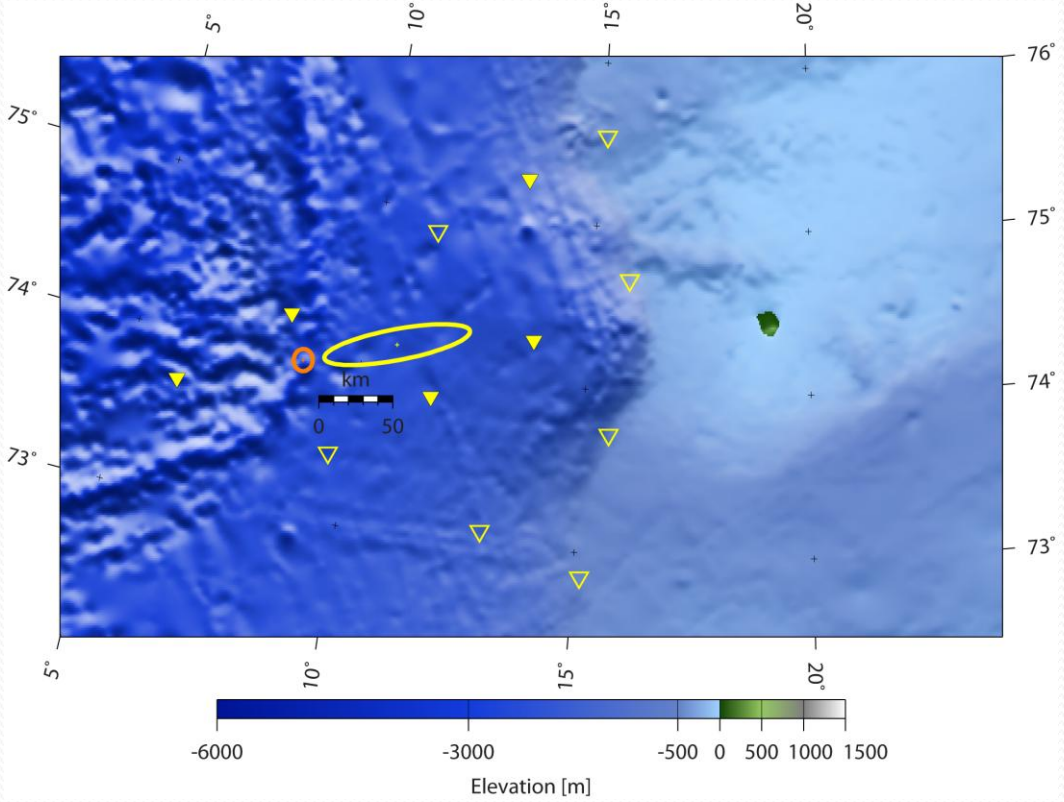




- 21/01/2008 19:31:50, M 3.0
  - Initial location (yellow) only with SPITS, ARCES, APA, KBS
  - Influenced mostly by array observations (triangles show resolved backazimuth & its uncertainty)
  - Introduction of BJO1 arrival picks moves location ~ 130 km to the W (orange)
  - Refinement of location using OBSs (filled symbols)

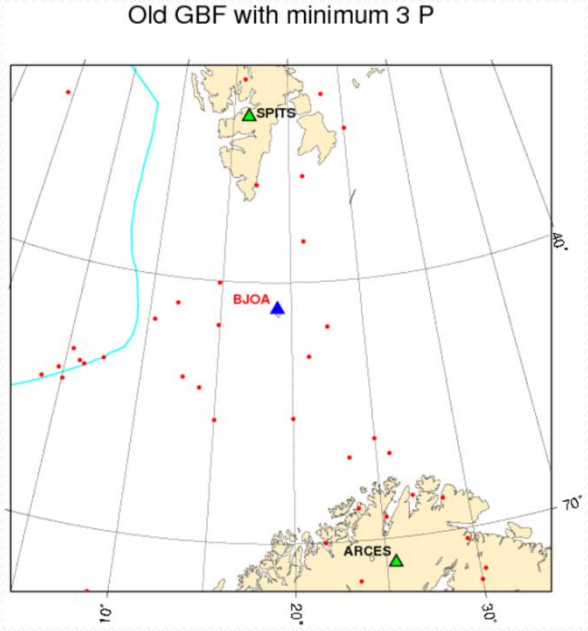
Example II

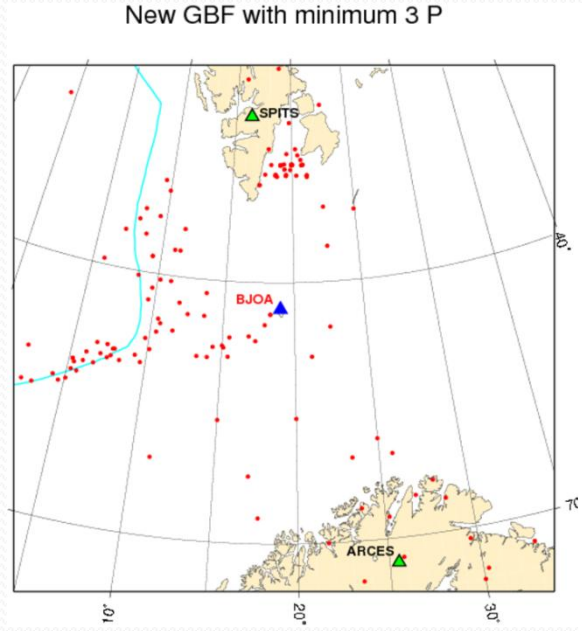


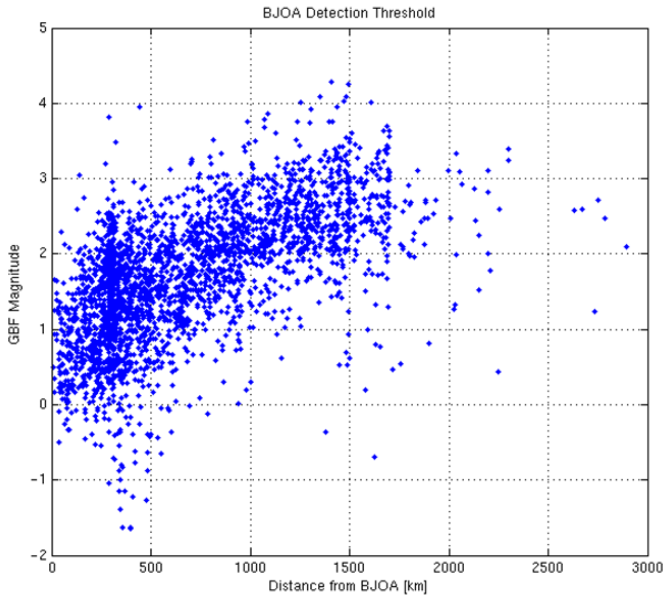


- 03/01/2008 21:17:27, M 3.0
  - Initial location (yellow) only with SPITS, ARCES, KBS
  - OBS picks move the location to the ridge (orange)

BJOA contribution

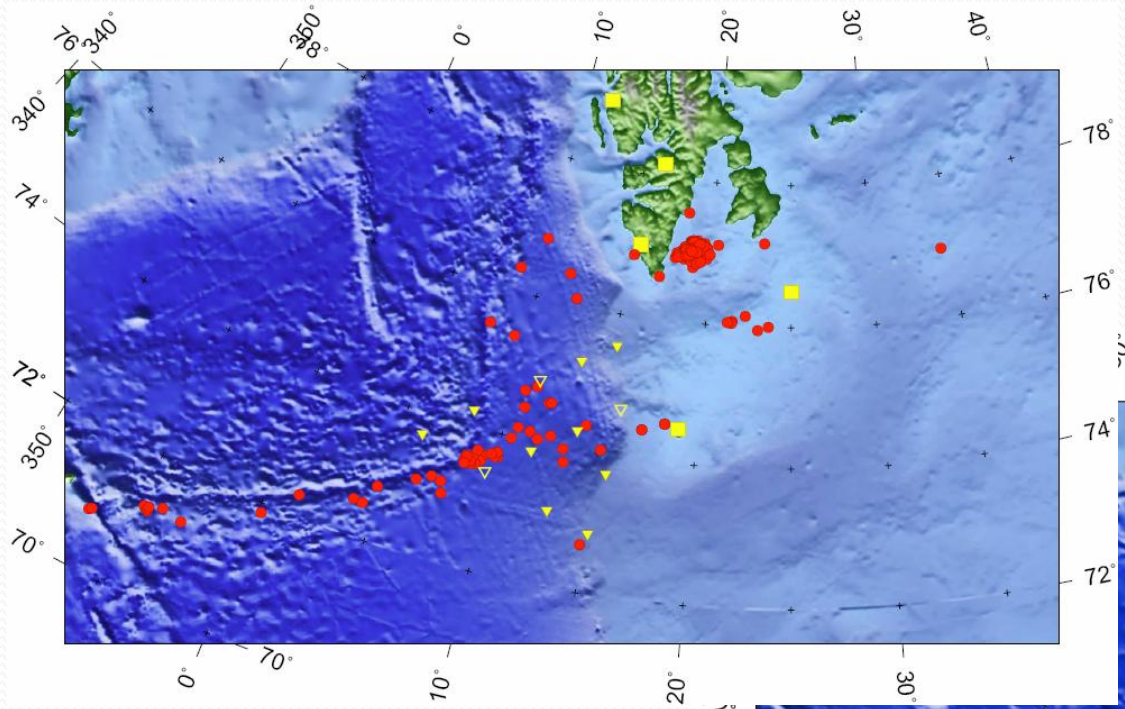




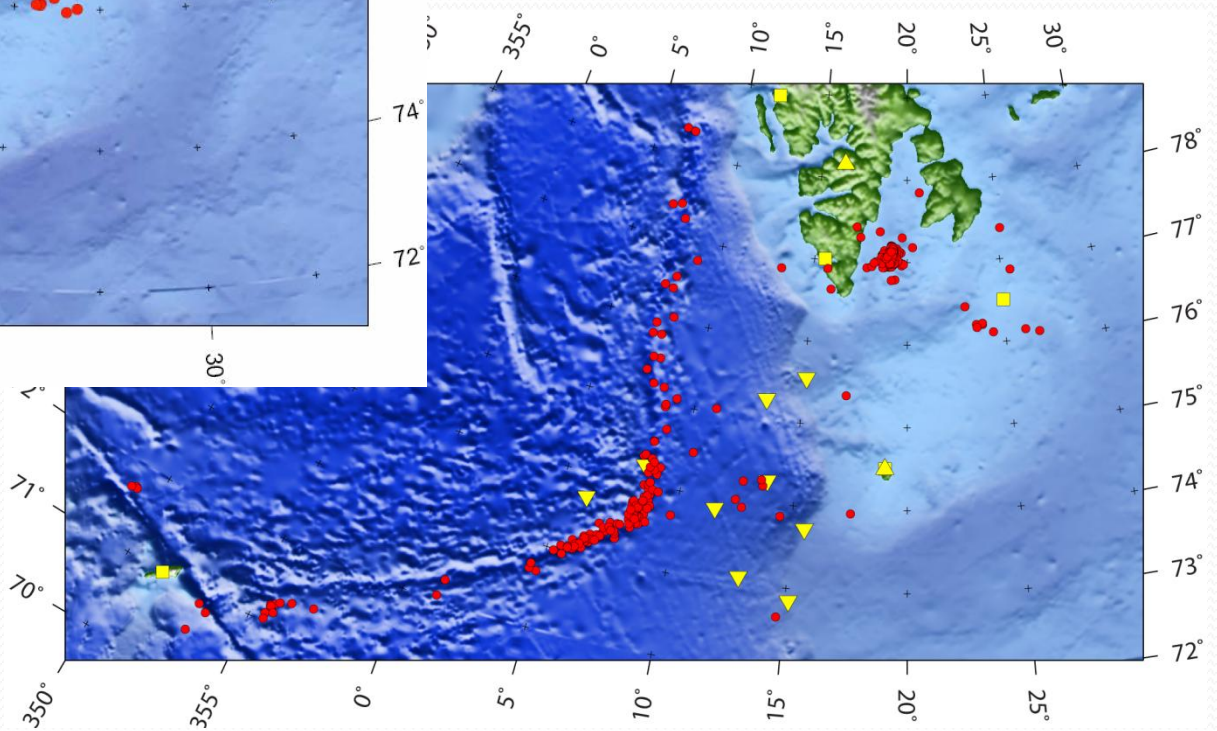


- May – September 2008
- GBF: automatic, grid-search-based, event location algorithm, utilizing array analysis results
- BJOA very useful, particularly for the project area
- On the wish-list: a permanent array on Bear Island

Overall IPY network contribution



NORSAR Regional Reviewed Bulletin
September 2007 – September 2008

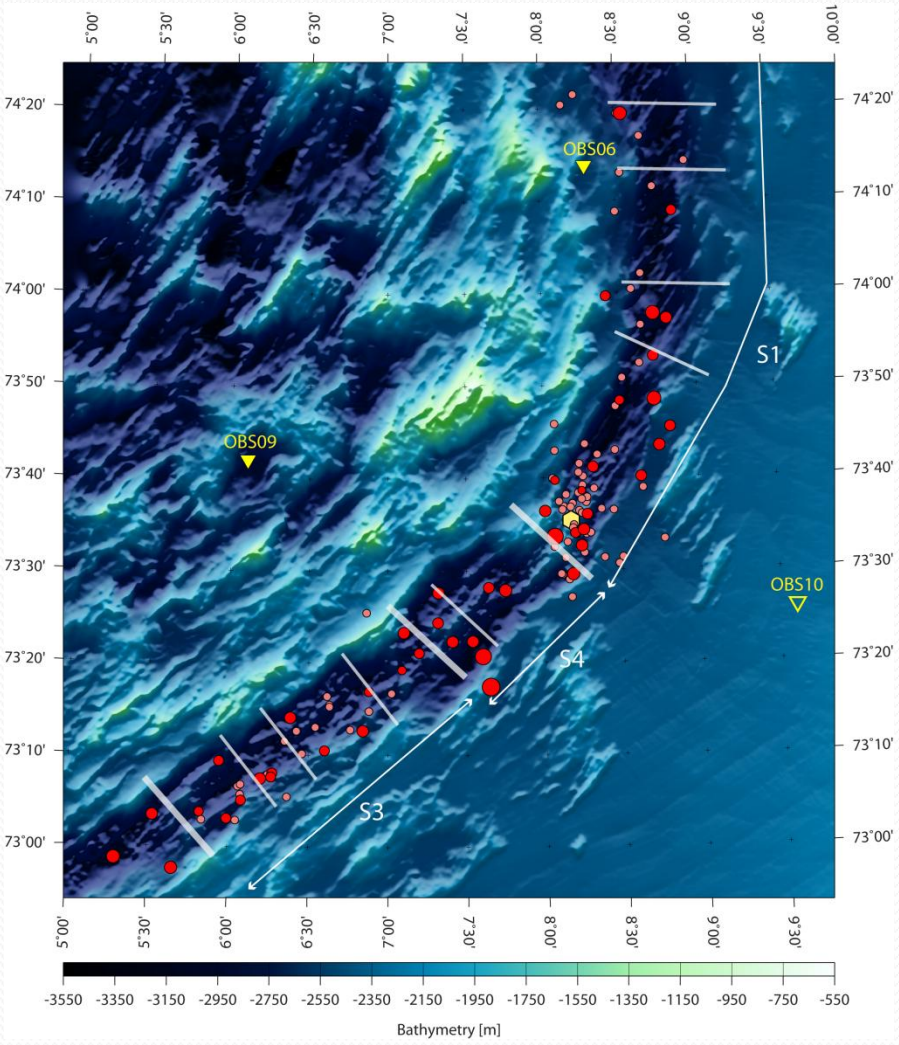


IPY (re)located events
September 2007 – September 2008

Project results: ridge swarm activity

- Thousands of events on the Mohns – Knipovich Bend
  - Organised in smaller or larger swarms
  - Larger of them (M > 2) located
  - Main volume of seismicity discovered and associated by means of waveform similarity
  - Volcano-tectonic character and association to hydrothermal activity

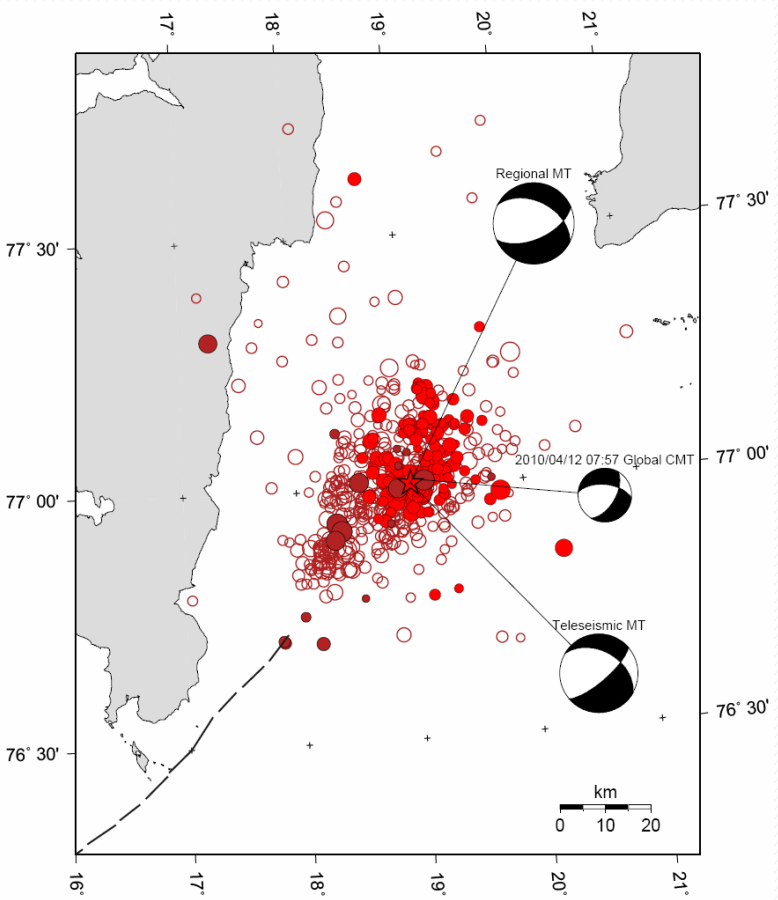
- Figure:
  - All located events; master events in red
  - Ridge segmentation level 2 & 3 (Crane *et al.*, 1999; 2001)
  - Yellow symbol: Loki's Castle hydrothermal vent field (Pedersen *et al.*, 2010)
  - Bathymetry: Norwegian Petroleum Directorate



Project results: the Storfjorden sequence

- 21/02/2008 earthquake, Mw 6.1
  - Storfjorden, Svalbard Archipelago
  - Nicely recorded on IPY-project network
  - Rupture on an unmapped oblique-normal fault of NE-SW trend, steep SSE dip
  - Relative location of early aftershocks; until September 2008
    (Pirli *et al.*, 2010)

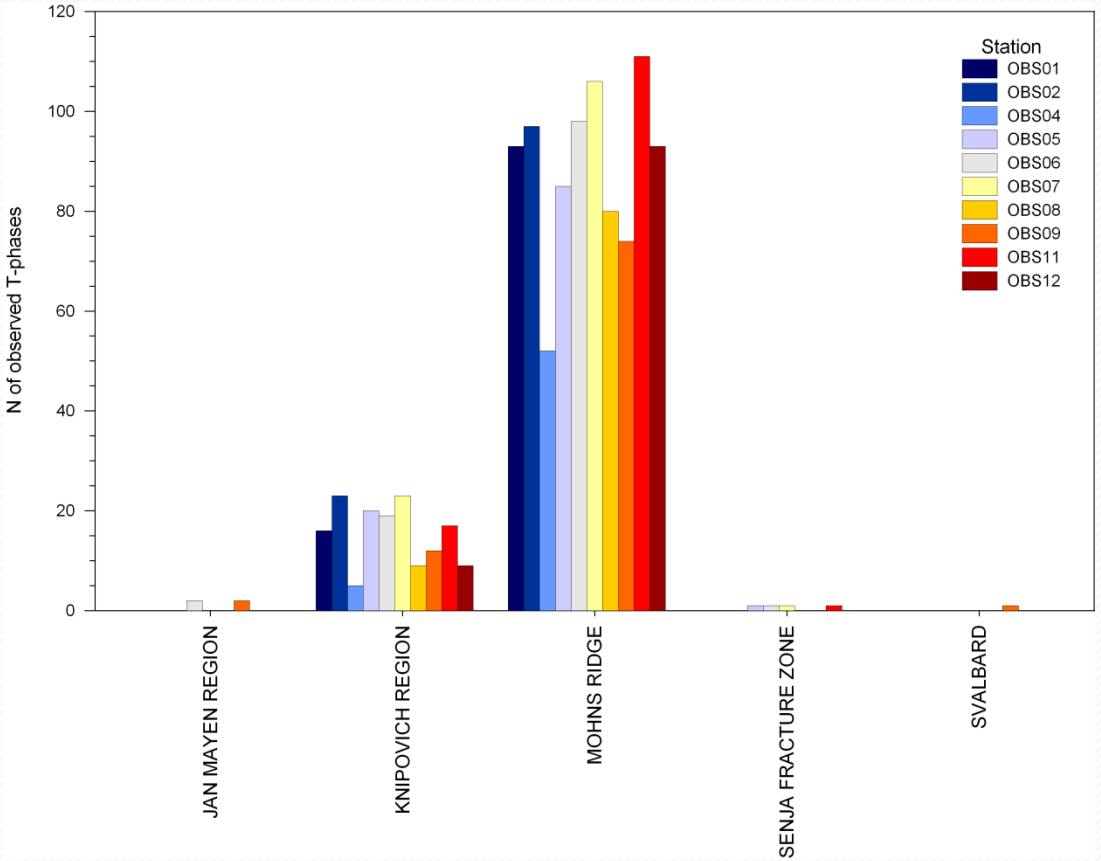
- Persisting activity:
  - Still ongoing sequence
  - Migration of epicentres to the SW of original volume
  - Same geometry with seismogenic fault
  - Matching structure suggested by Bergh and Grogan, 2003 (dashed, black line)



Open circles: NORSAR's reviewed bulletin
Filled circles: red = Pirli *et al.*, 2010; dark red = relocation using Pirli *et al.*, 2010 parameterisation

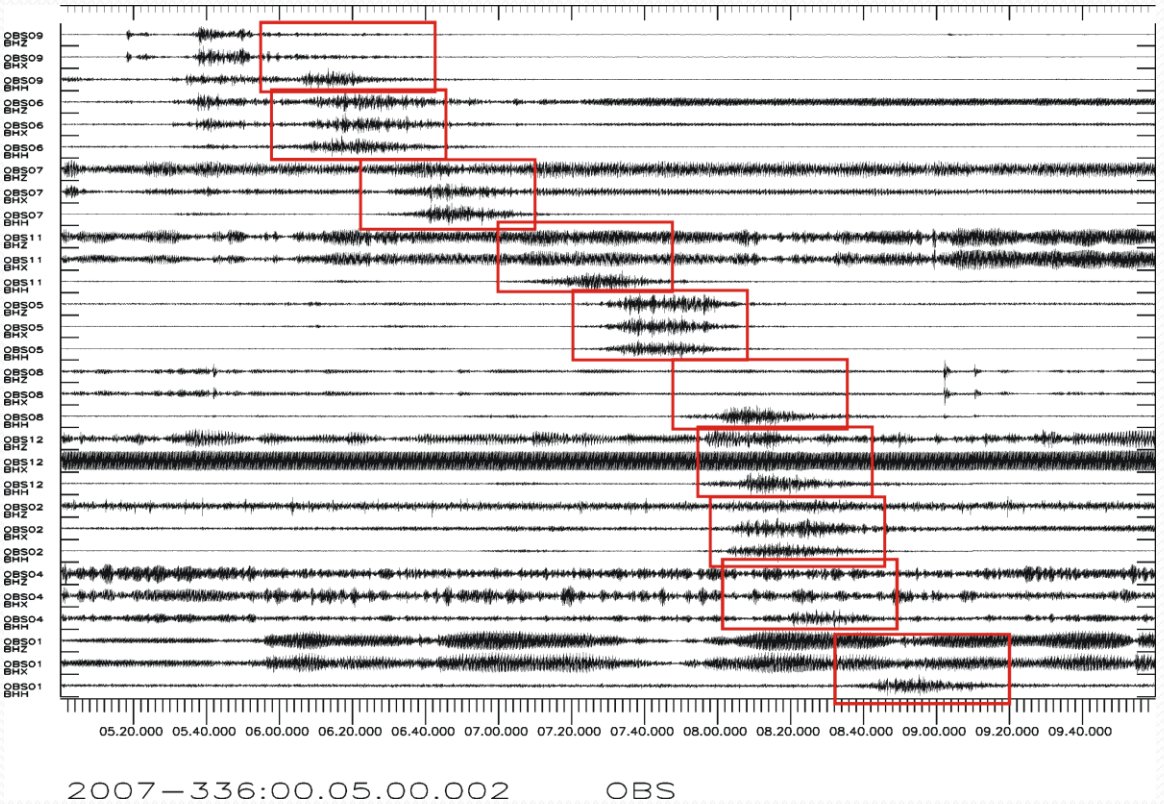
Outlook: T-phases (I)

- Abundant T-phase records on all OBS/H stations
- Source regions: mostly Mohns Ridge, also Knipovich Ridge
- Useful to constrain locations



Outlook: T-phases (II)

- Possibility to locate events, where no information on body-waves can be obtained
- Example: 02/12/2007 00:05:20 event
  - Mohns – Knipovich Bend region
  - High noise on several vertical components; impossible to pick first arrivals
  - T-phases with good SNR almost on all hydrophones



Summary

- A regional, land- & seafloor-based network to study the western Barents Sea margin
- Local & regional seismicity study
  - Enhanced image of seismicity within project duration
  - Detailed information about the Mohns – Knipovich bend (not all events located; no focal depth)
  - Increased coverage of the coinciding Storfjorden series
  - Not enough resolution for events on the sedimentary wedge (no focal depth)
- Reasons behind network performance
  - Network still too sparse
  - Bad noise conditions on most OBS stations
  - Nature of seismicity: small magnitudes, rather sparse occurrence along the wedge
- Outlook
  - Taking advantage of T-phase records
  - Further work on special studies (ridge seismicity, Storfjorden sequence)

Considerations for the future

- Long data series very important
- A smaller geographic region as target
  - How to select? Based on seismicity potential? How much «gambling» is there involved, especially with seismicity of transient character?
- Better coverage by the local network
  - Number of stations, network dimensions, inter-station distances, total extent of region that can be covered
- Combination of land- & seafloor-based stations is important for the location of small-moderate magnitude events (between M 2 and 4)
- Careful preparation to lay the foundations for better OBS/H data
  - OBS data: better quality in deeper environments
  - Boat equipped to assess seafloor (*e.g.*, echo sounding); ensuring favourable coupling conditions
  - Burial of stations?

- Considerations for our future project
  - Same consortium already planning new research project (Knipovich Ridge)
  - Different concept; more focused research; examining possible synergy with other sciences
  - Permanent seismic array on Bear Island