Research activities in underwater acoustics at NTNU

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Acoustics

NTNU

Underwater Acoustics

Study sound propagation in water column and sea bottom, and interaction with sea surface and sea bottom for

- Detection and localization of target and object in underwater or buried in the seabed
- Seabed characterization
- Underwater acoustic communication
- Underwater positioning and navigation

Underwater Acoustics Research

- **Acoustic Remote Sensing**
  - Numerical modeling of sound propagation in fluid, elastic and pore elastic media
  - Seabed characterization by model-based geoacoustic inversion
  - Passive acoustics: ocean ambient noise, ship & seismic noise
- **Underwater Acoustic Communication**
  - Algorithm and acoustic modem design for effective and reliable acoustic communication
  - Channel modeling, optimal sensor node positioning and reliable wireless communication between sensor nodes
  - Instrumentation and underwater acoustic experiments

Acoustic Remote Sensing for seabed properties

- **Shear wave velocity in the sediments**
  - Interface waves and ocean ambient noise by horizontal array on/close to the seafloor
- **Seismic velocities in the basalt**
  - Reflection data by towed horizontal array in the water column
- **P-wave velocity & attenuation in the sediment**
  - Pressure data by vertical hydrophone array in the water column

Inversion methods

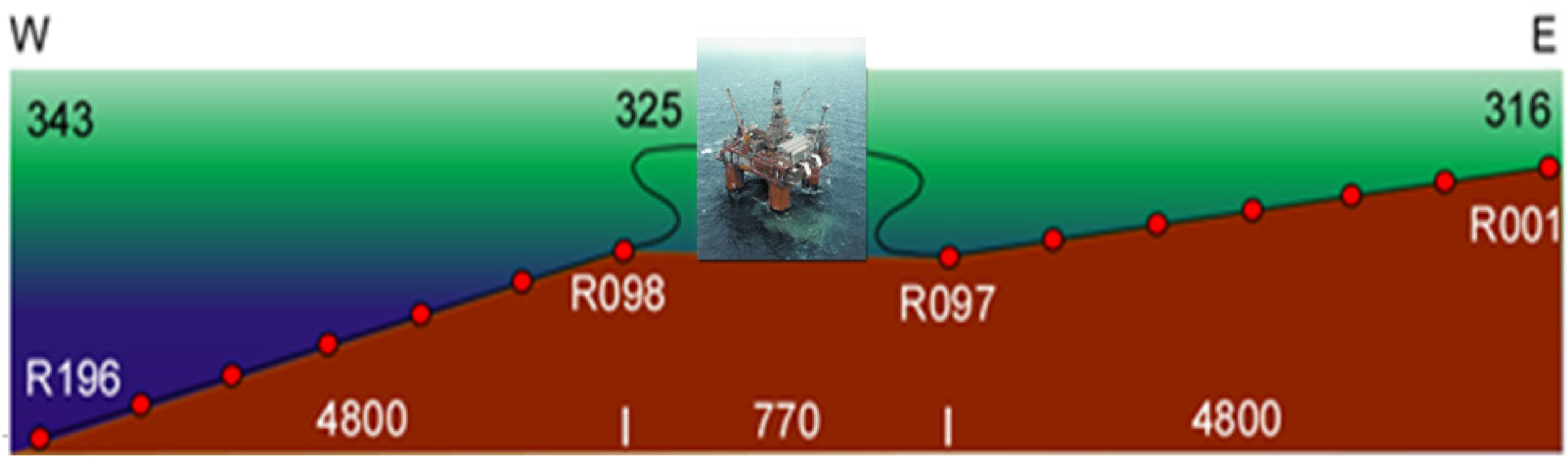
- Linearized inversion
  - Singular value decomposition
- Nonlinear inversion
  - Optimization
    - ASSA (adaptive simplex simulated annealing
    - DE (differential evolution)
    - GA (genetic algorithms)
  - Bayesian approach

Bayesian Inversion

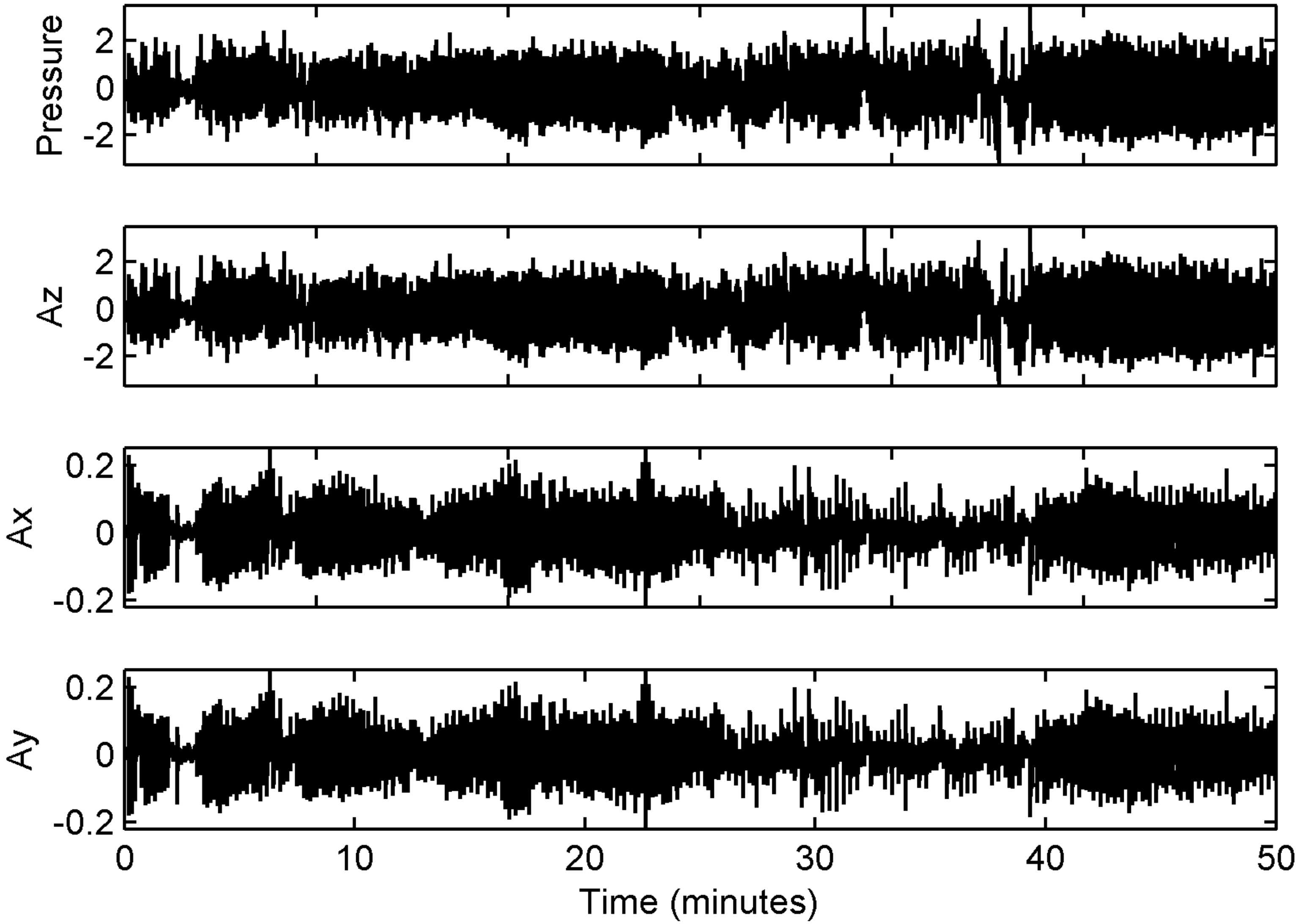
- Bayes' rule: $P(\mathbf{m}|\mathbf{d})P(\mathbf{d}) = P(\mathbf{d}|\mathbf{m})P(\mathbf{m})$
- MAP (maximum a *posteriori*) values
- Marginal probability distribution
- Uncertainty
- Optimal parameterization: $\mathrm{BIC} = 2E(\hat{\mathbf{m}}) + M \log_e N$

Ocean ambient noise recording

- 196 fiber-optical sensors with 50m spacing
- 2.38 hours recording
- Water depth of 316m – 343m

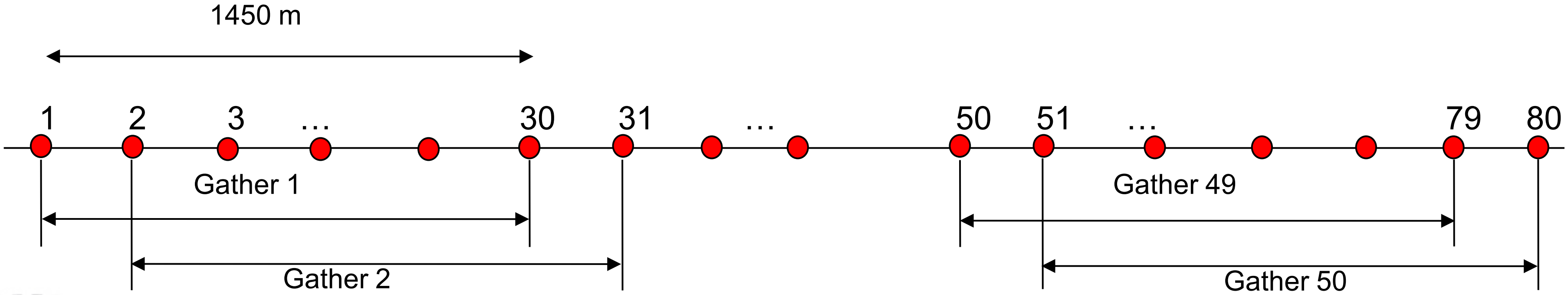


Multi-component noise data

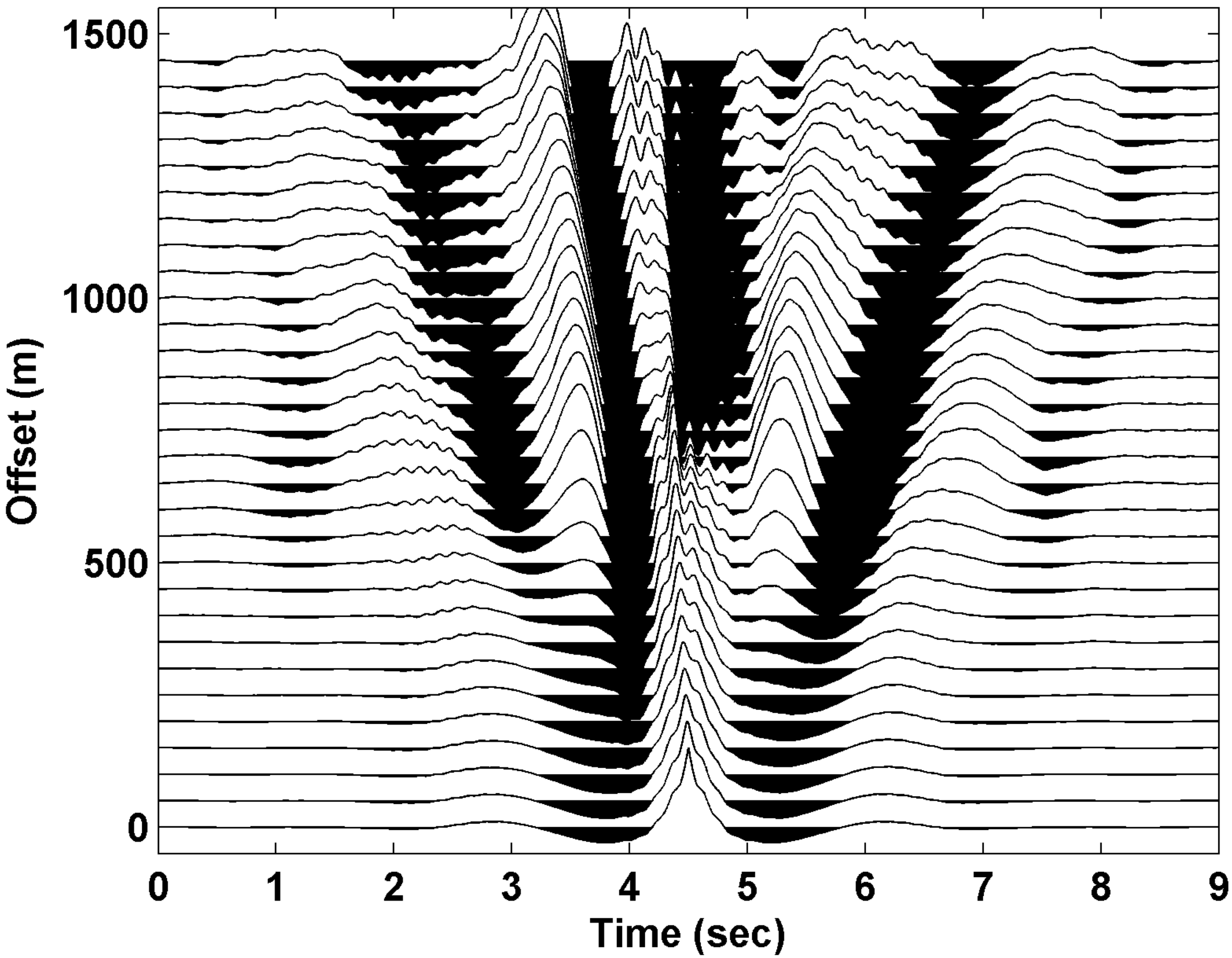


Data processing

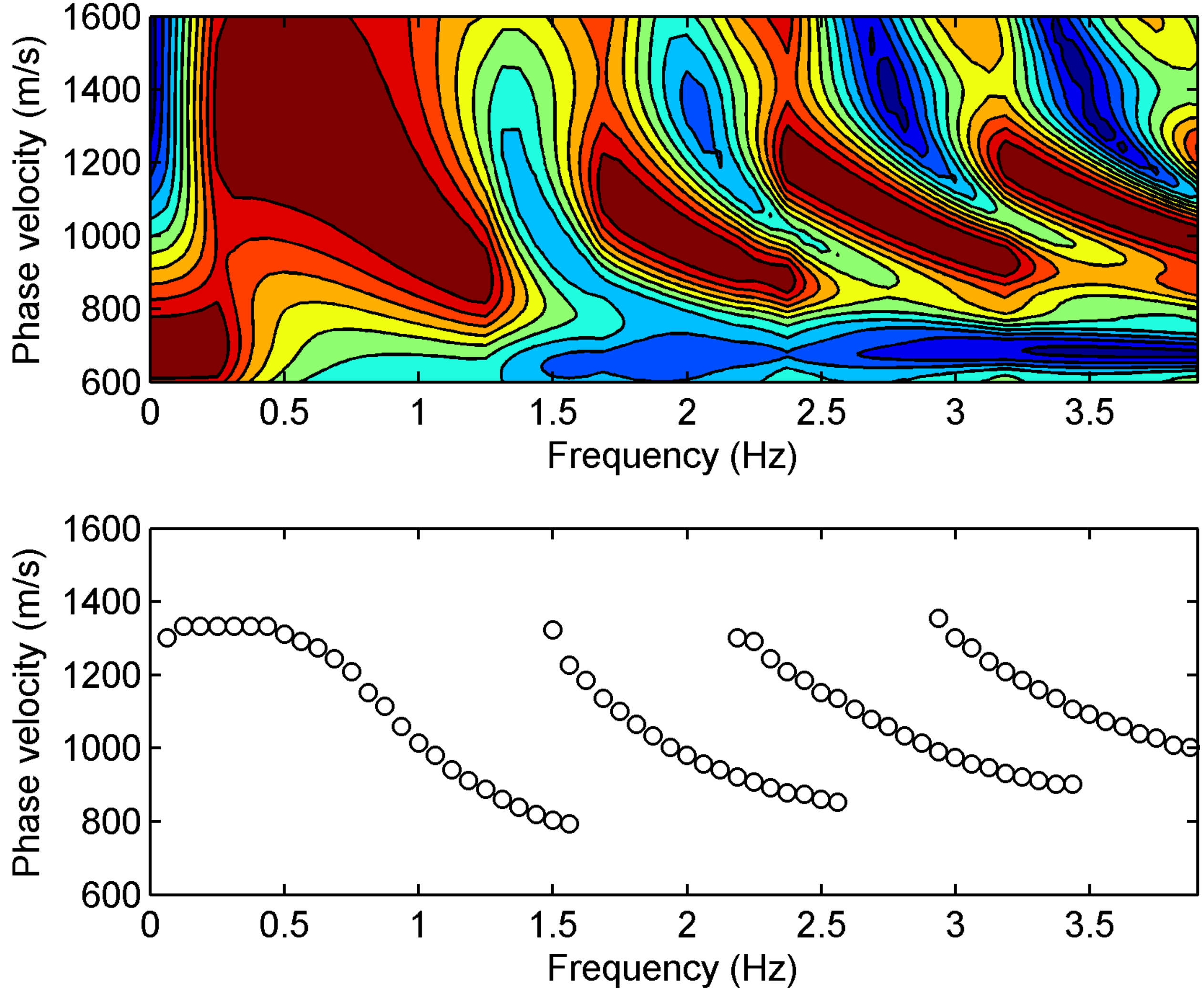
- Low-pass filtering (0.68-6 Hz)
- One-bit normalization
- Segmentation (4.5s each segment)
- Cross-correlation and stacking (1720 segments)
- Gathers (30 Green’s functions each gather)



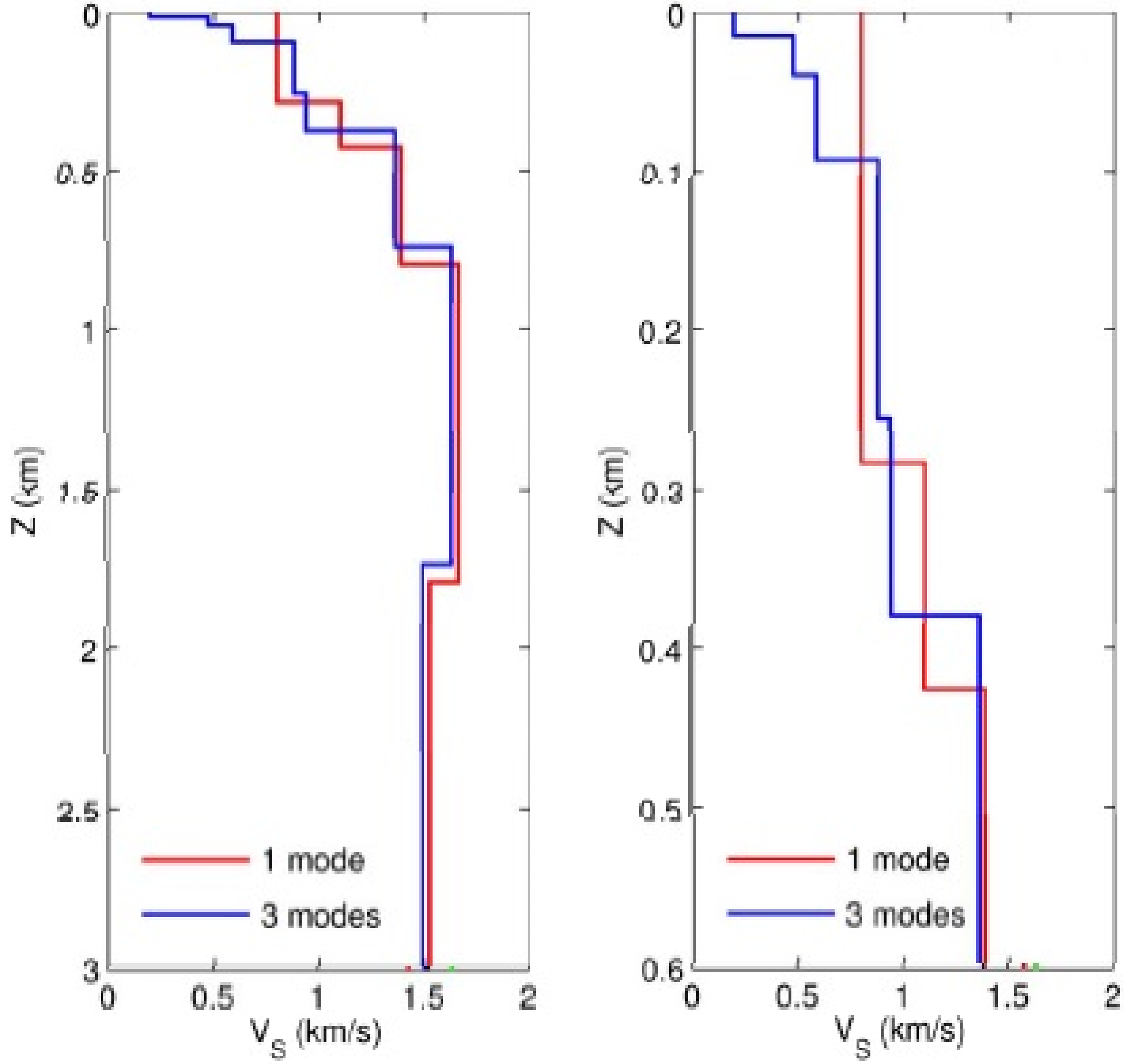
Green functions - pressure



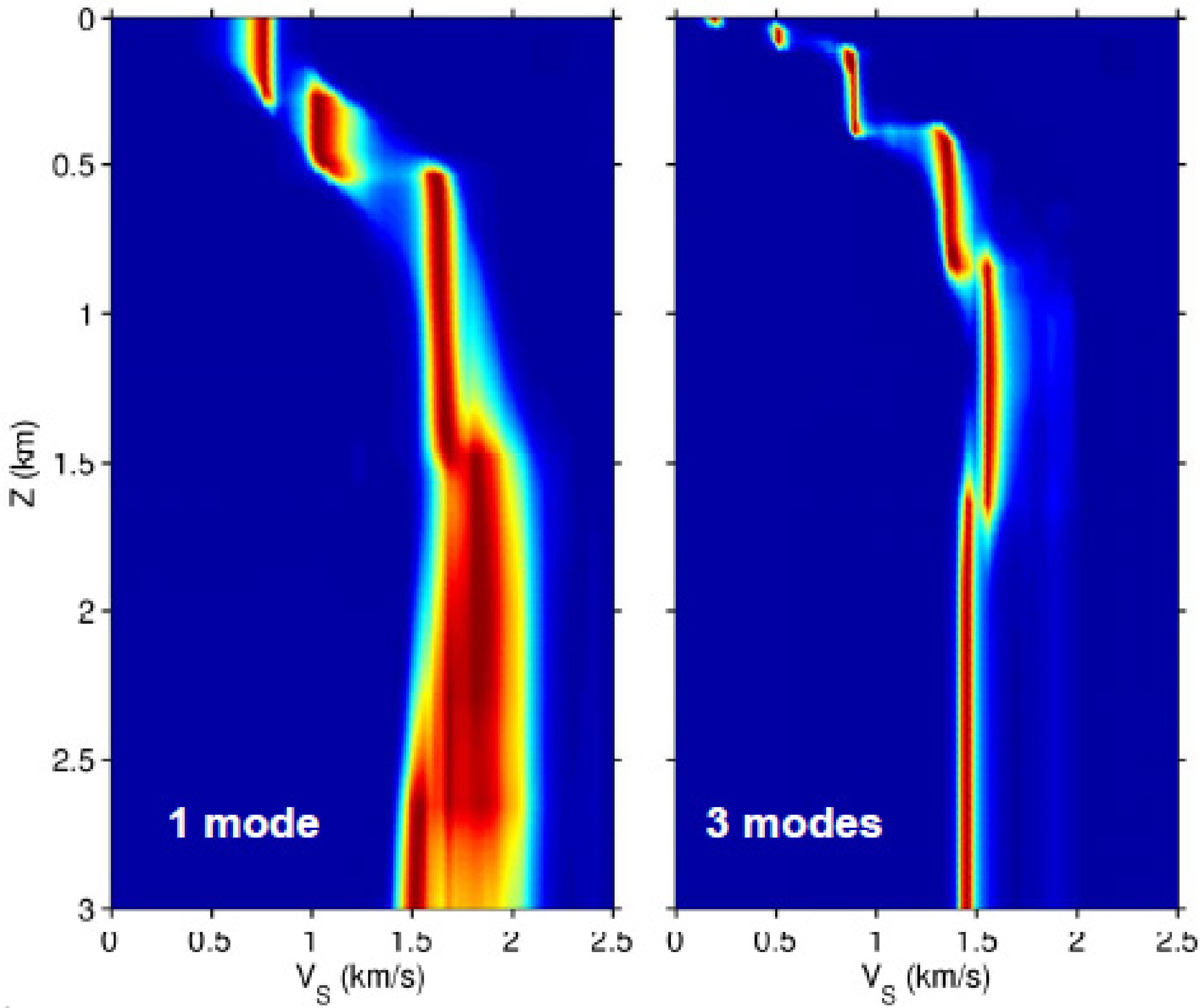
Phase-velocity dispersion



Inversion results

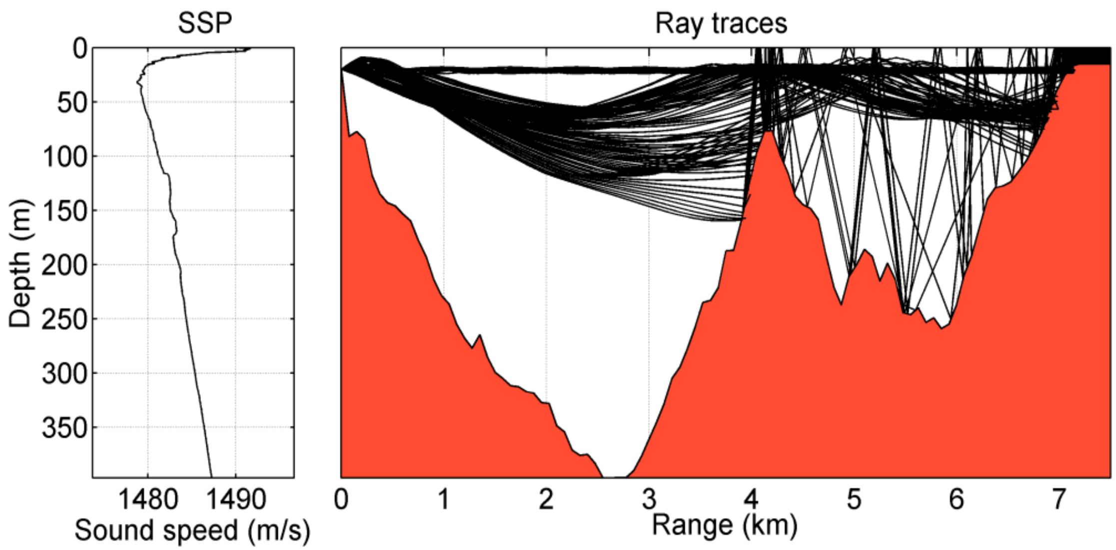


Marginal probability profile



Underwater Acoustic Communication

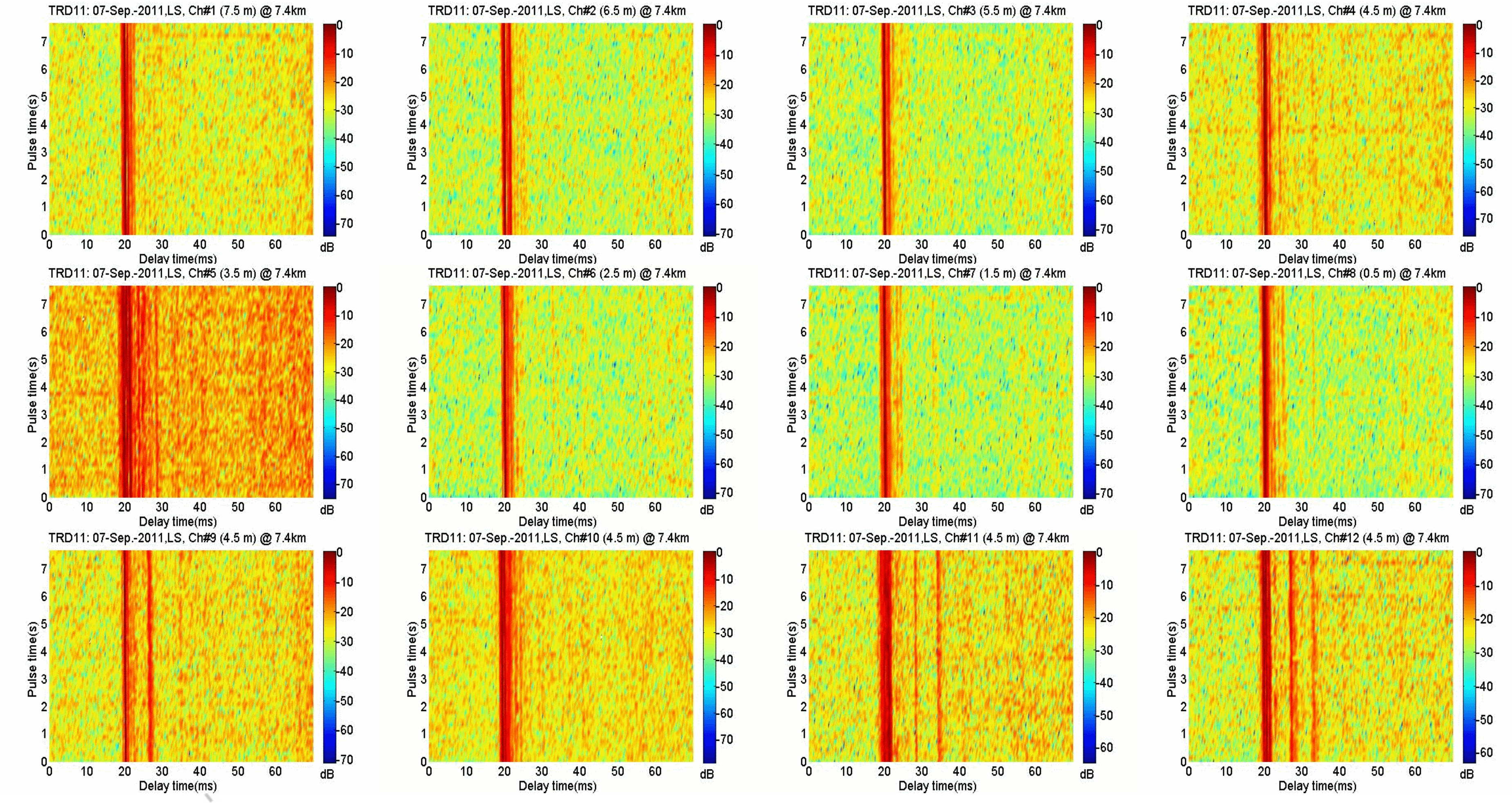
Limitations on underwater communication channel:



- Time-varying
- High dispersive
- Extended multipath
- Bandwidth limited
- Complex bathymetry
- Ambient noise

Channel measurements

Impulse response 202.044 s/frame



Development of real-time single carrier frequency domain Turbo Equalizer

- Low computational complexity
- Suitable for quasi-static channel
- Overall data rate 4 ks/s

Development of underwater OFDM acoustic communication system

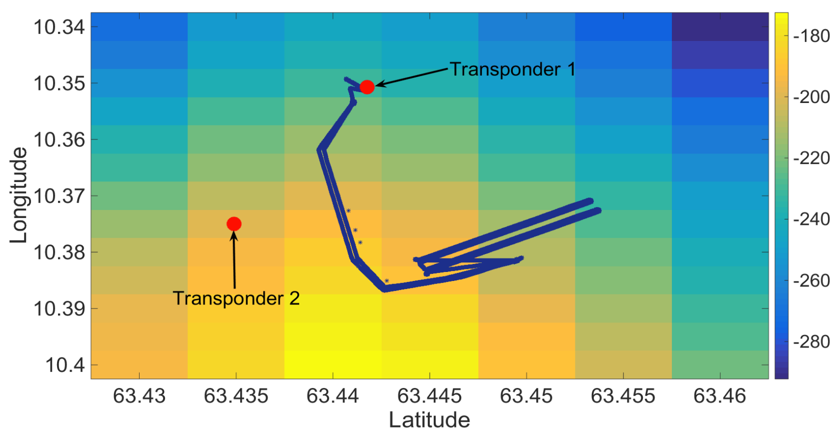
- Time-domain oversampled technique to explore potential Doppler and delay diversity
- Iterative ICI equalizer and channel estimation to further improve performance
- OMP sparse channel estimator to explore channel inherent sparsity
- Real-time system implemented on Multi-core DSP

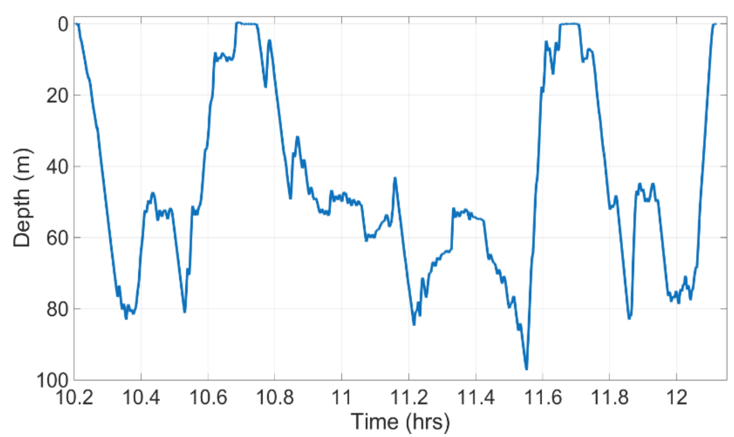
CPU PROCESSING TIME

Function	Processing time
CFO compensation	0.76 ms
Vector norm calculation	0.101 ms
OMP channel estimation	87.7 ms
ICI equalization & Soft demapper	5.25 ms
SISO decoder	6.77 ms
Soft mapper	0.347 ms
Total time per iteration	101 ms

Channel modeling and optimization

- Underwater acoustic channel modeling for underwater network and vehicle navigation
- Optimization of channel condition for Long Base-Line localization (AUVs)
- Prediction of channel conditions for path planning of underwater vehicles (AUVs)



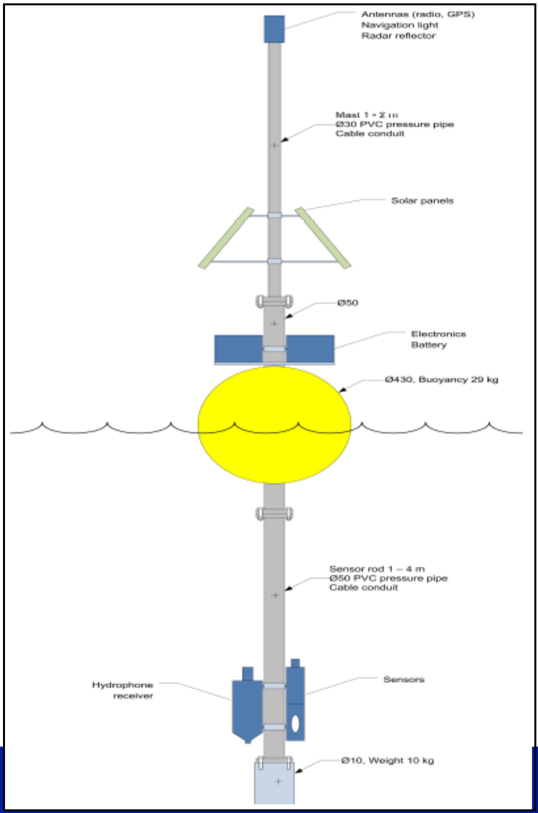


Underwater Acoustic Communication between nodes

- Underwater communication between different nodes in underwater networks
- Studying different algorithms to optimize the communication performance
- Sea experiments in Trondheim fjord for testing the algorithms

Acoustic Underwater Laboratory – (AUL)

- Low-high freq. transmitters (850Hz, 12kHz & 40 kHz)
- Power amplifier
- 3 broadband vertical hydrophone arrays (8-element for each)
- 32-channel filter
- 24-channel amplifier
- 32-channel data acquisition system
- Autonomous acquisition (stand-alone hydrophones in Spring 2016)
- NTNU research vessel – R/V Gunnerus



Instruments

Underwater Communication experiments in Trondheim fjord

Sea experiments performed in Trondheim fjord in the past 6 years with different configurations to test different algorithms for supporting the research and educational program.

Courses in Underwater Acoustics

- Marine Acoustics (Master)
- Acoustic Remote Sensing (Specialization)
- Marine Acoustics II (Specialization, PhD)
- Geoacoustic Modeling and Inversion (PhD)

Acknowledgement

Thanks PhD candidates

- Bo Peng
- Slaman Ijaz Siddiqui

for their contributions to this presentation.