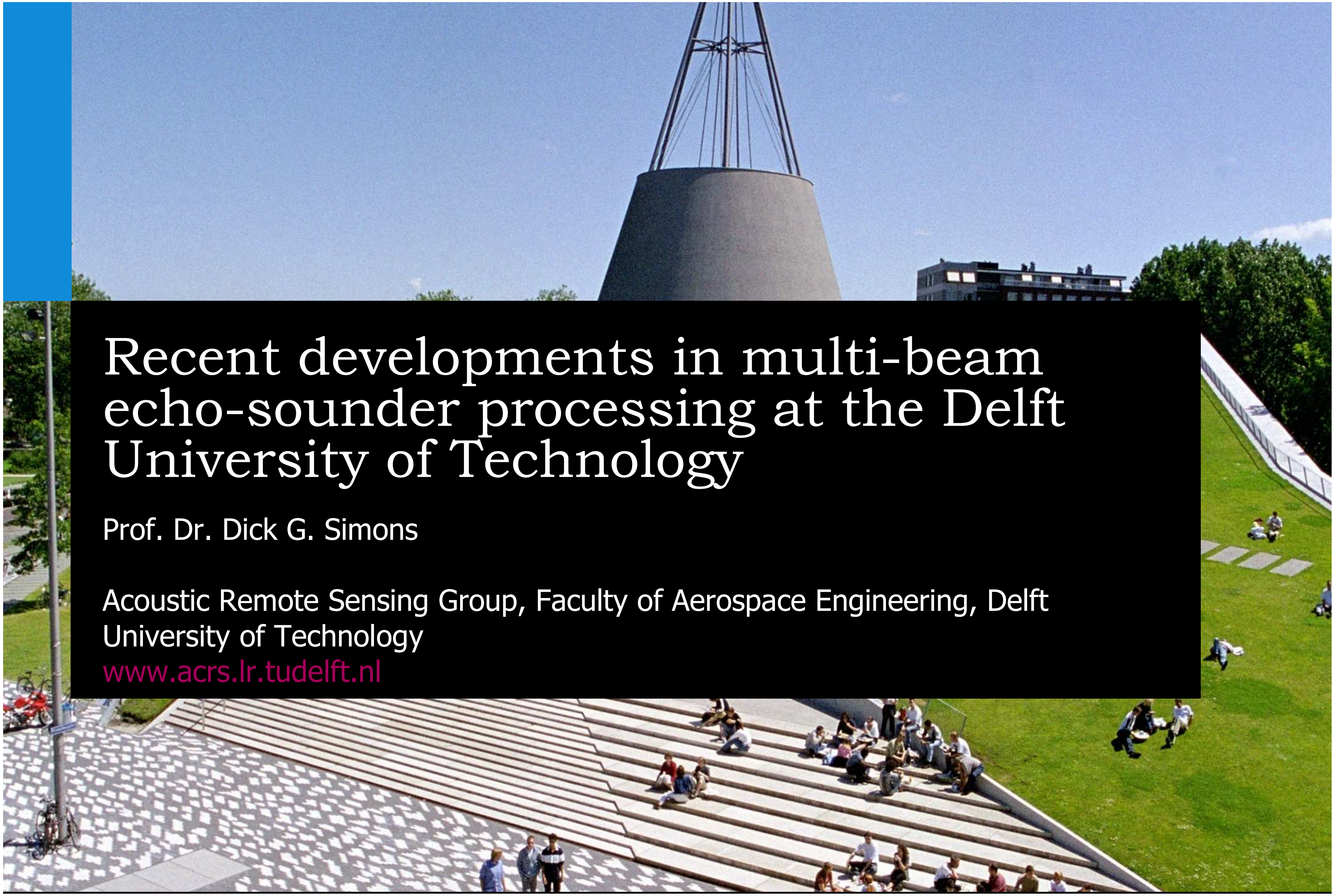

Recent developments in multi-beam echo-sounder processing at the Delft University of Technology

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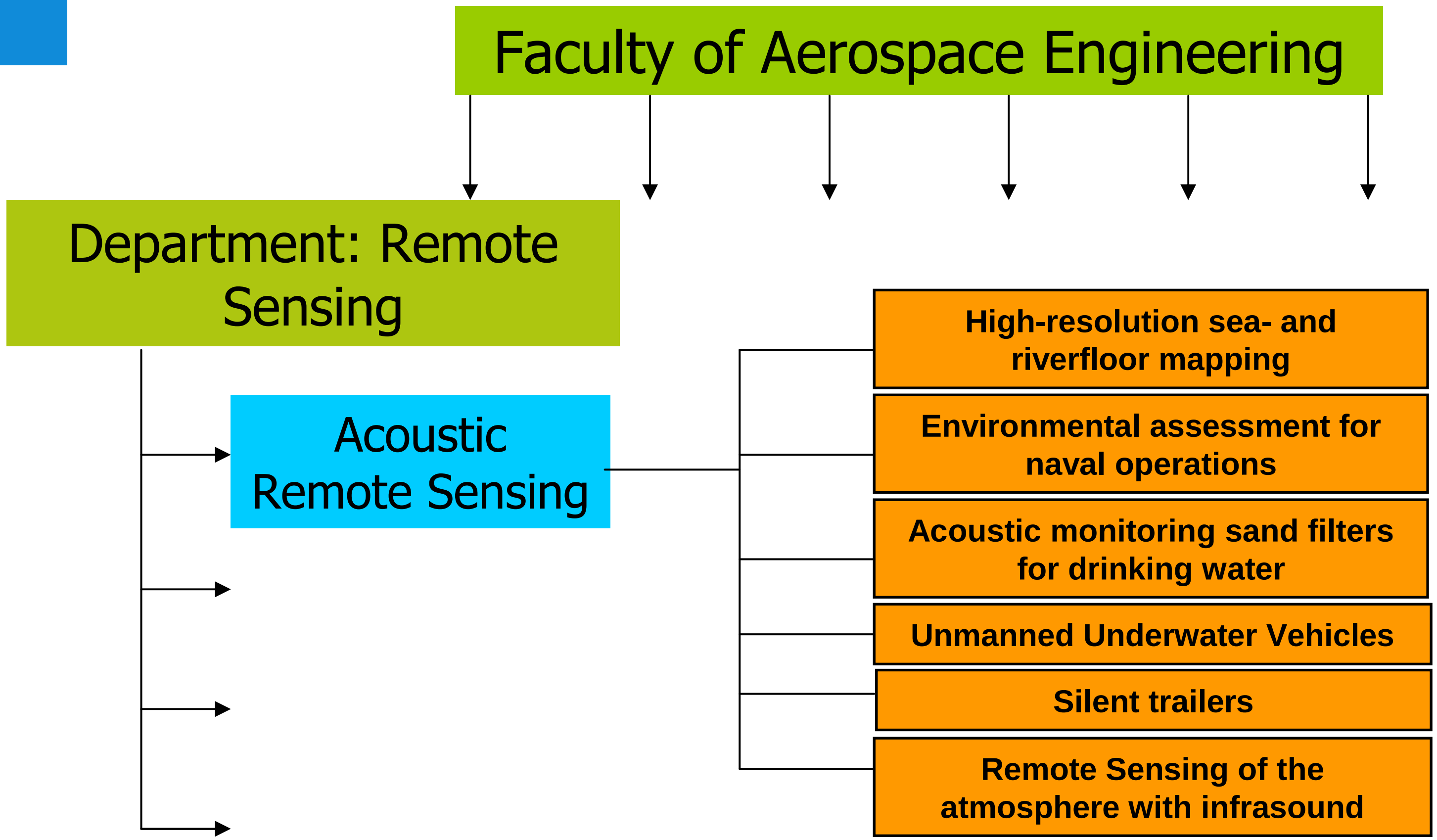
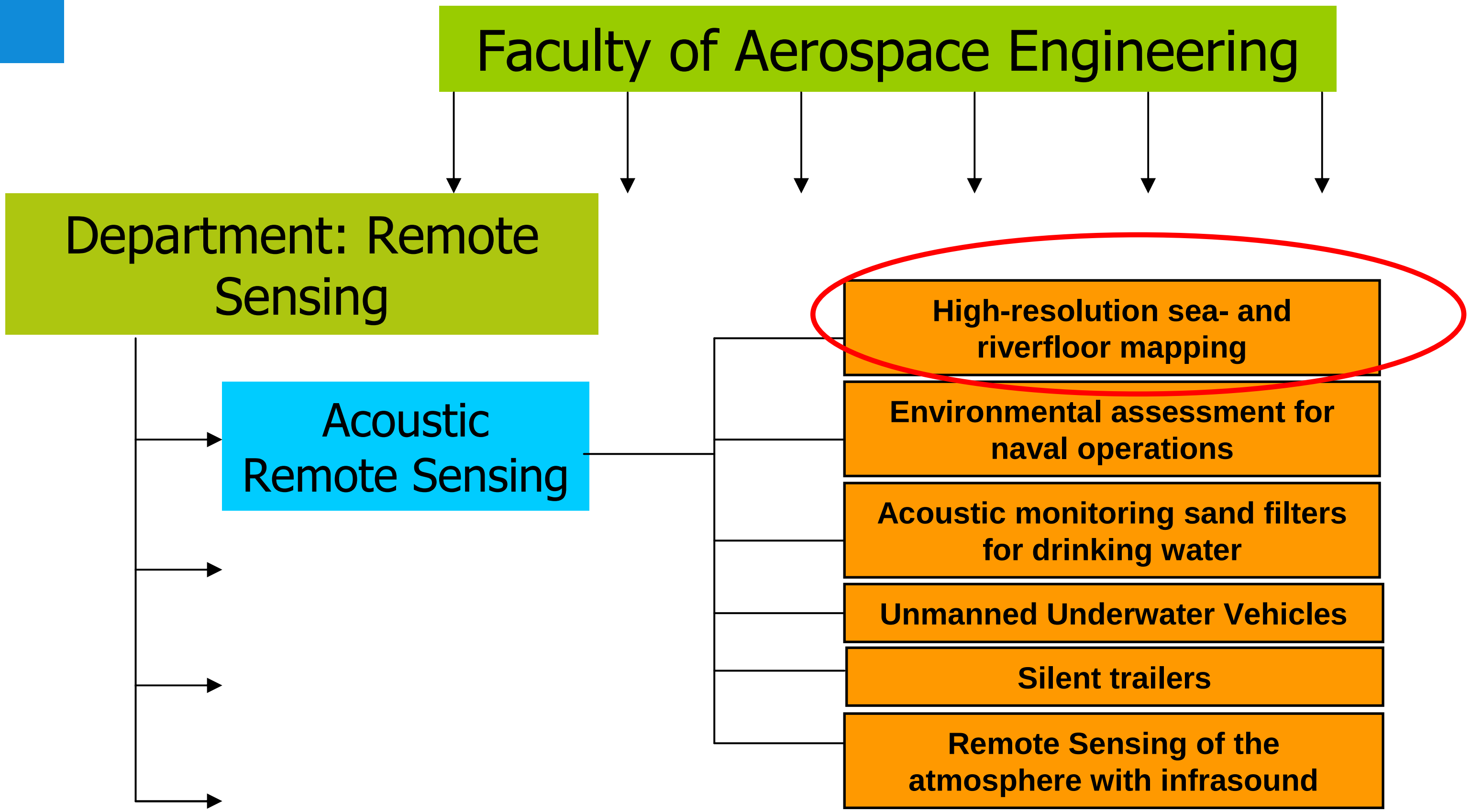
Outline

- Introduction to the Acoustic Remote Sensing group
- The multi-beam echo-sounder
- Compensation of multi-beam echo-sounder (MBES) bathymetric measurements for errors due to the unknown water column sound speed
    - The importance of sound speed information for MBES surveys
    - Approach for eliminating the sound speed induced errors
    - The dataset considered
    - Application of the method to MBES data
    - Challenges and future development
- Sediment classification with the MBES
    - A Bayesian approach for seafloor classification using (MBES) data
    - Examples of applying the method:
        - The Cleaver Bank area (Mine hunting, coarse sand extraction, marine geology)
        - The river Waal (Sediment engineering measures)
        - A coastal region (Rapid Environmental Assessment)
    - Challenges and future developments
- Conclusions

Overview of research at the Acoustic Remote Sensing Group



Overview of research at the Acoustic Remote Sensing Group



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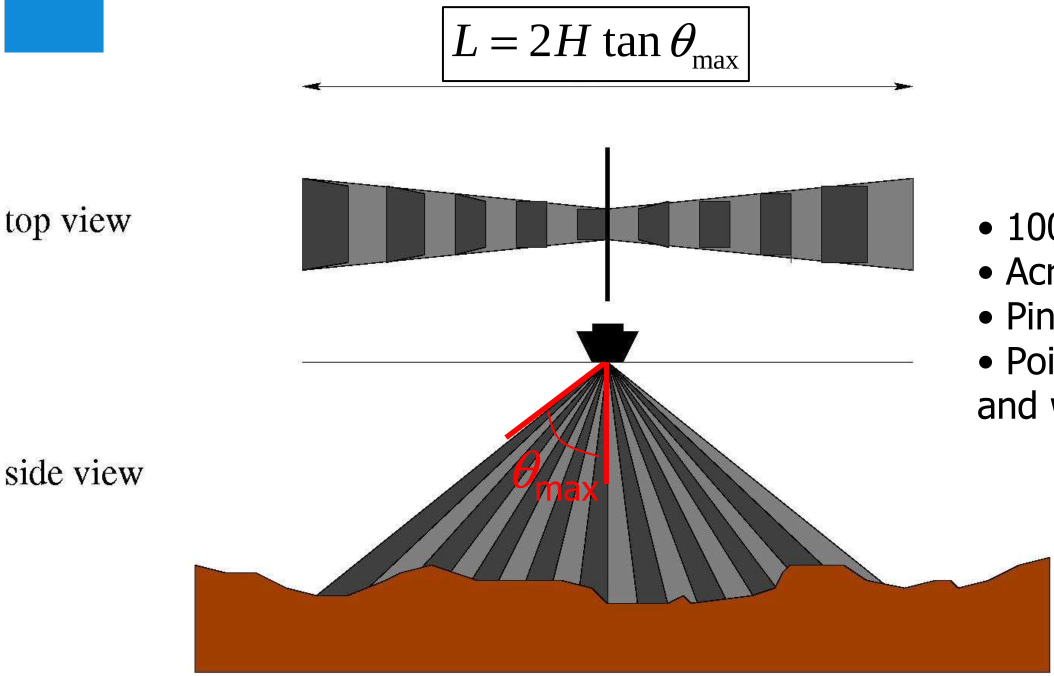
The multi-beam echo-sounder

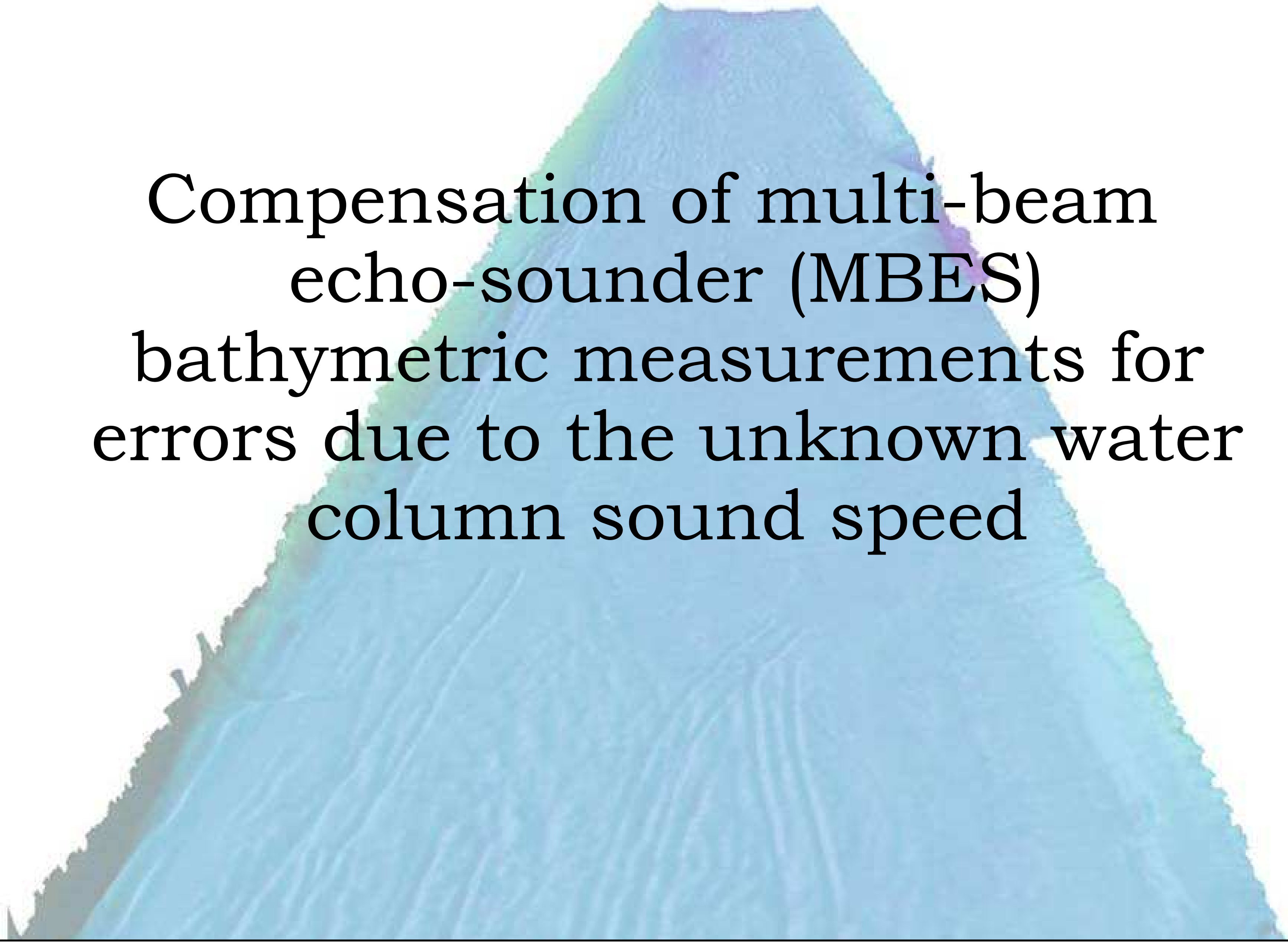


- 100-500 beams
- Across- & along-track beam opening angle: ~1°
- Ping rate: 5-40 Hz
- Point density dependent on measurement geometry and water depth

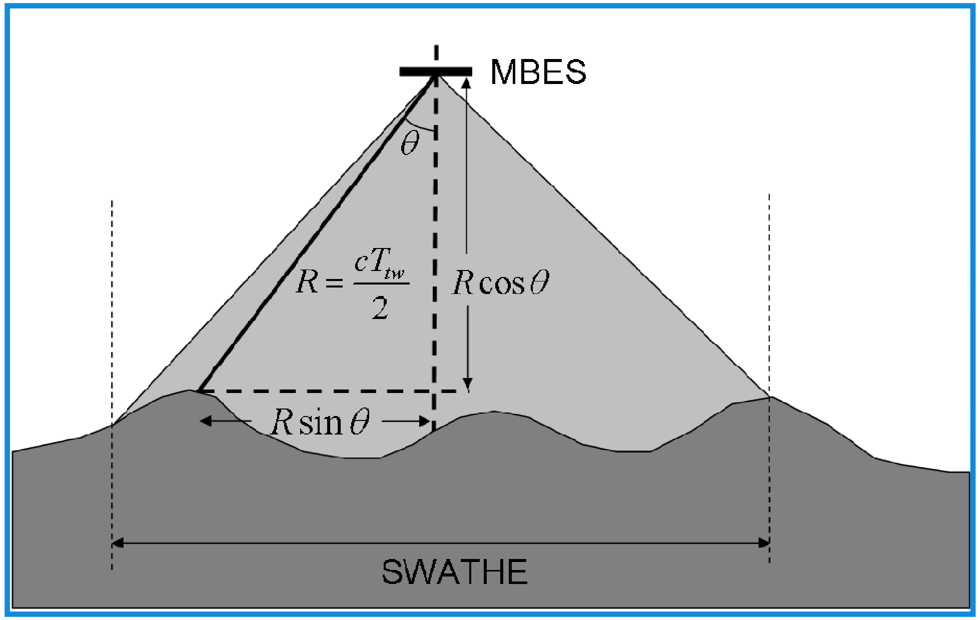
Ping rate: 30 Hz
254 soundings, spanning 160°
Sailing speed: ~5 m/s →

Water depth (m)	Beams/m^2	L (m)
5	26	57
10	13	113
20	7	227
50	3	567
100	1	1134

Compensation of multi-beam echo-sounder (MBES) bathymetric measurements for errors due to the unknown water column sound speed



The importance of sound speed information for multi-beam echo-sounder surveys



Water column sound speeds:

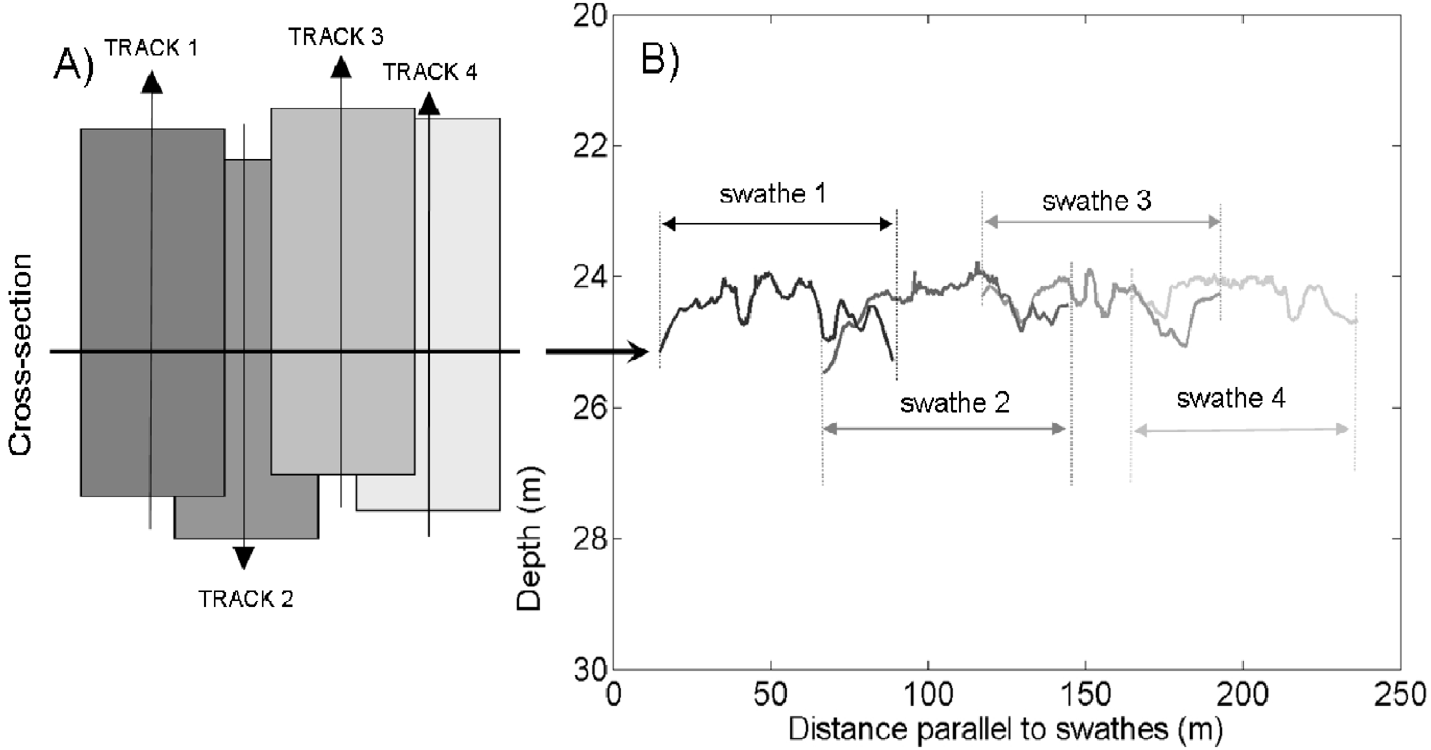
- *Effect on sound propagation*

$R = \frac{cT_{tw}}{2}$ when assuming straight rays. Additional effects for refracted rays.

- *Effect on the beamsteering angles*

The delay for steering at angle θ behaves as $\tau \sim \frac{d \sin(\theta)}{c}$

Example of sound speed induced bathymetric errors



Approach for eliminating sound speed induced errors

Principle

- Along overlapping parts of adjacent swathes there is a redundancy in measurements
- Detectable seafloor bathymetric variation does not occur on time scales of the survey
- Define an energy function that quantifies the difference in water depths at equal points along adjacent swathes
- Search for those sound speed profiles that minimize the energy function

Approach for eliminating sound speed induced errors

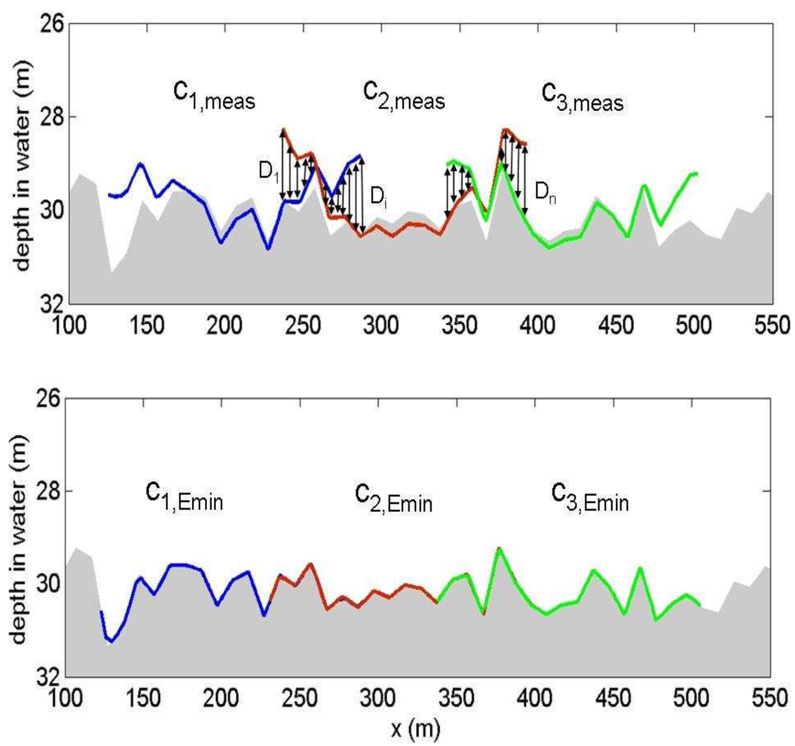
Optimization method

- Take *E*, e.g., as:

$$E(\mathbf{x}) = \sqrt{\sum_{i=1}^{n} \left| D_i(\mathbf{x}) \right|^2}$$

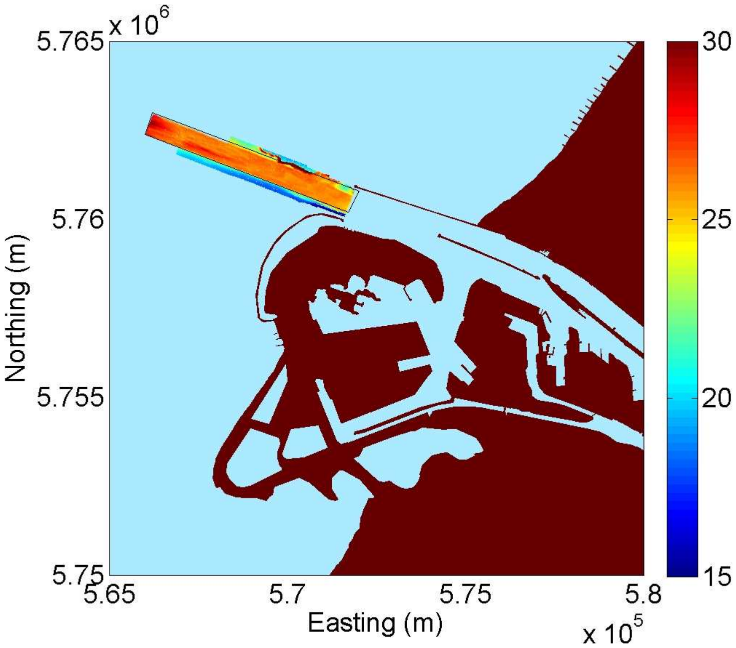
Vector of unknowns

- **x** is the vector containing the unknown sound speed profiles
- Search for those sound speeds that provide maximum agreement in bathymetry along overlapping swathes, i.e., minimize *E*
- Two minimization approaches
  - Method of Differential Evolution
  - Gauss-Newton method



The dataset considered

Measurement area

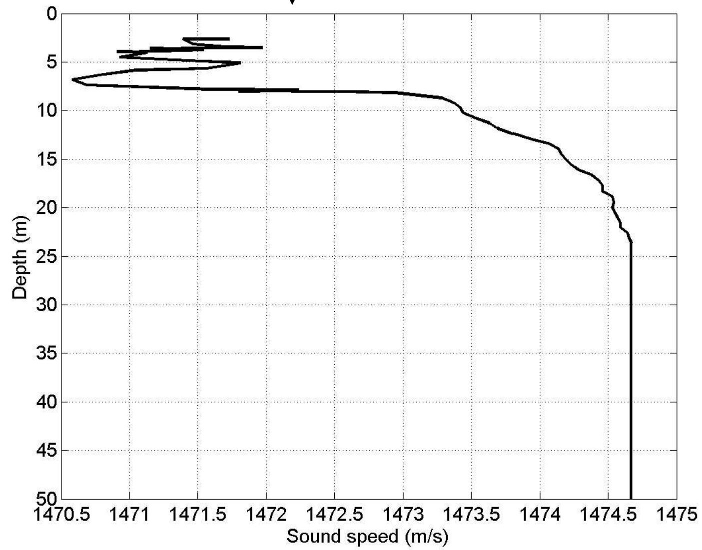


- Data taken in February 2007 in the Maasgeul (North Sea)
- EM3000 single head multibeam echosounder
- 127 beams spanning ~120 degrees
- Area: 6 km^2
- 15 tracks sailed parallel
- Swath widths of ~70-80 m, overlap of ~20 to 30 m
- Ping rate ~4 Hz
- Ship speed ~ 4 m/s
- 7-hour survey: 0.2 GB data
- ~2 soundings/m^2

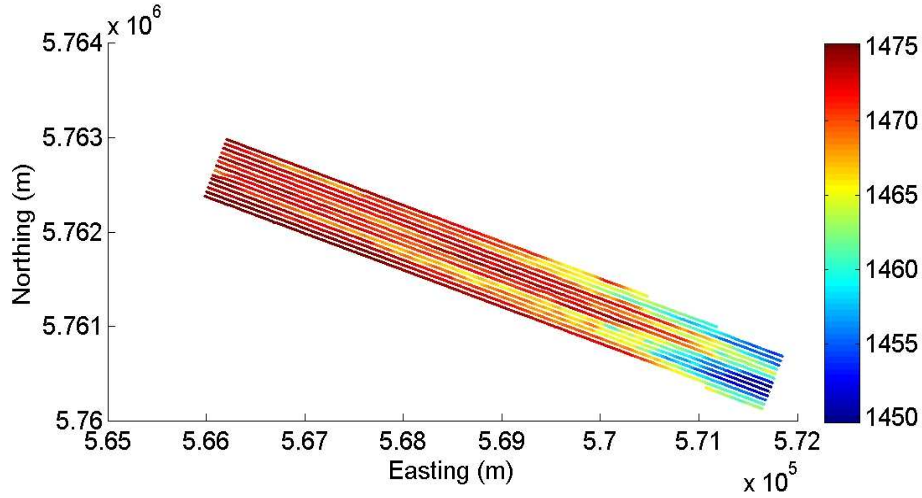
The dataset considered

Sound speed measurements during the survey

Sound speed profile measured at the start of the survey (only one available)

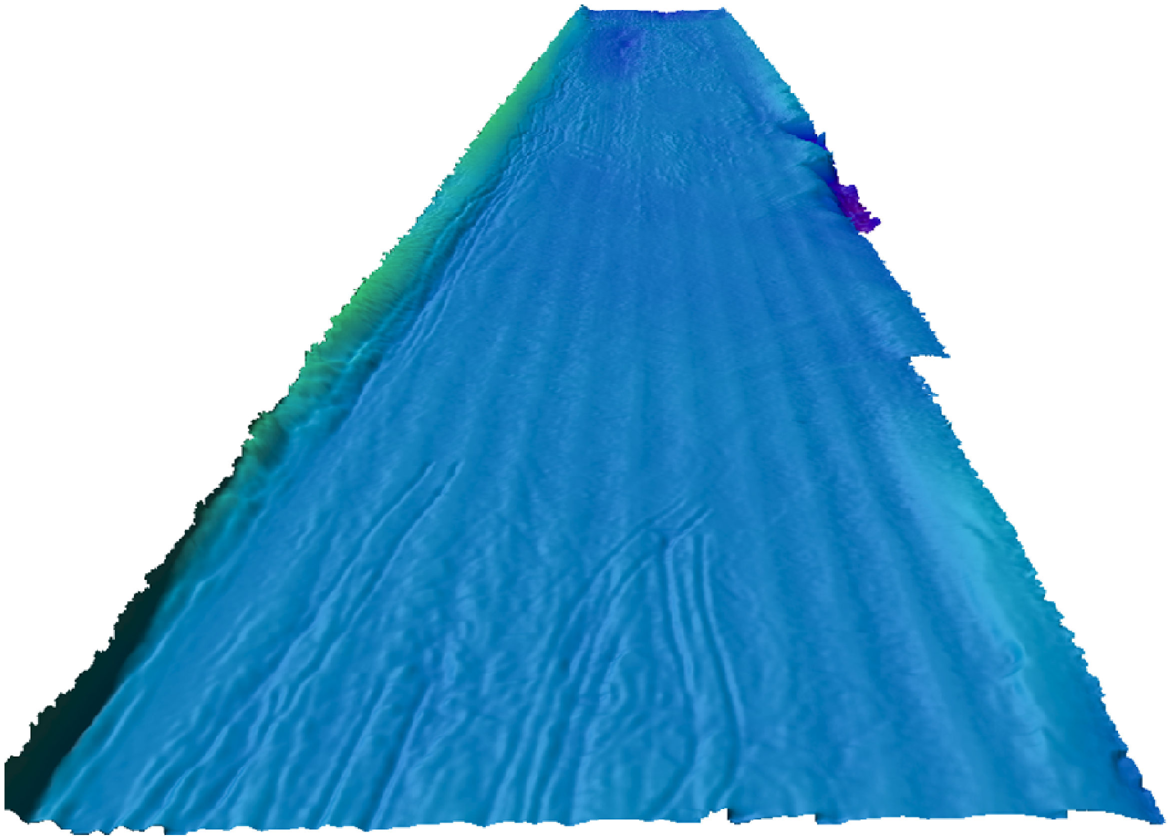


Sound speed measurements at the transducer head



The dataset considered

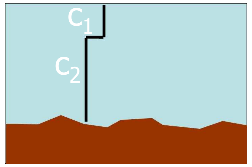
Uncorrected bathymetry

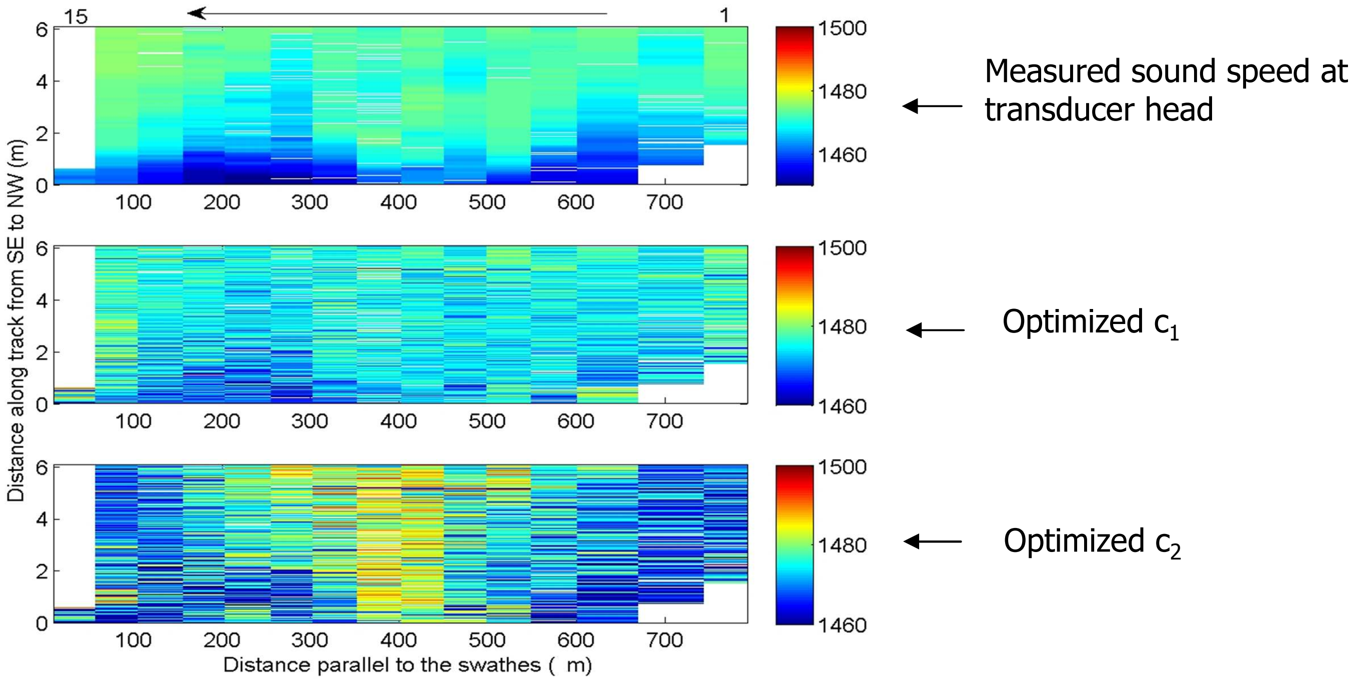


Application of the method to multi-beam echo-sounder data

Sound speed estimates

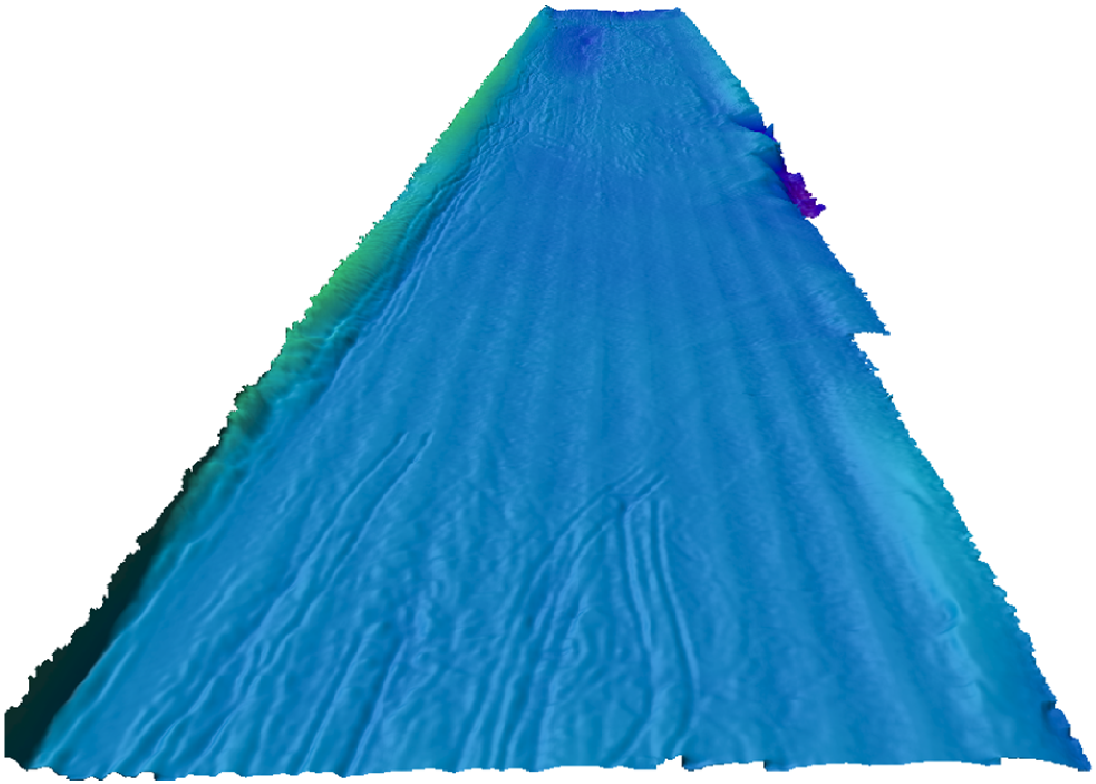
Two sound speeds per swathe
Differential Evolution for the optimization





Application of the method to multi-beam echo-sounder data

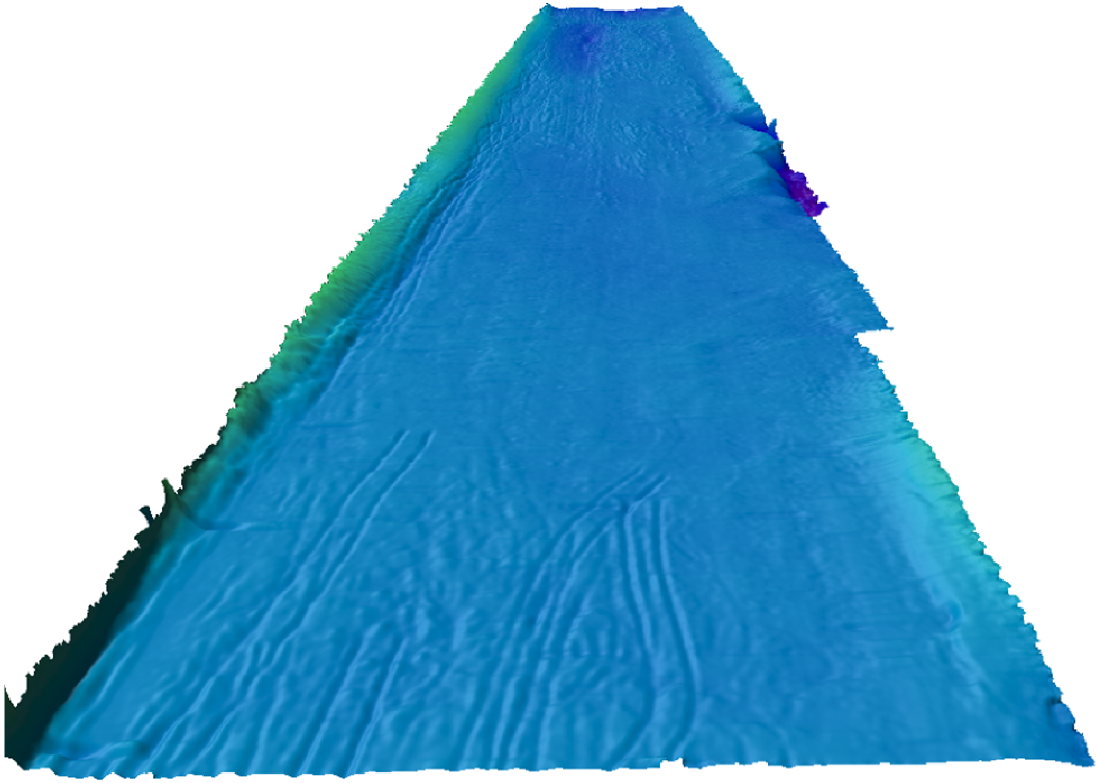
Uncorrected bathymetry



Before

Application of the method to multi-beam echo-sounder data

Corrected bathymetry



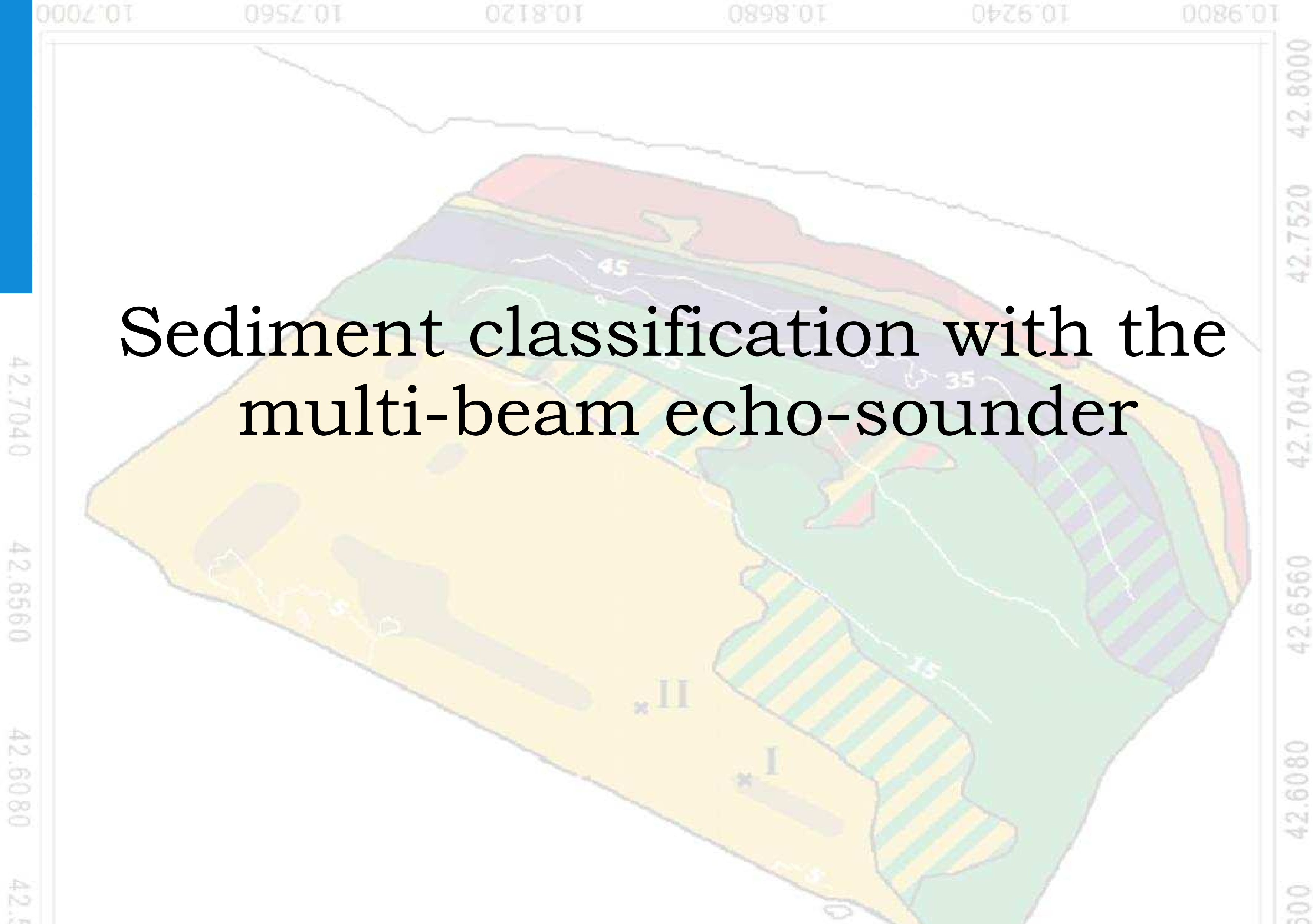
After

Method and results are documented in: Mirjam Snellen, Kerstin Siemes and Dick G. Simons, *Compensating MBES errors through simultaneous estimation of bathymetry and water column sound speed,* submitted to the IEEE Journal of Oceanic Engineering

Challenges and future developments

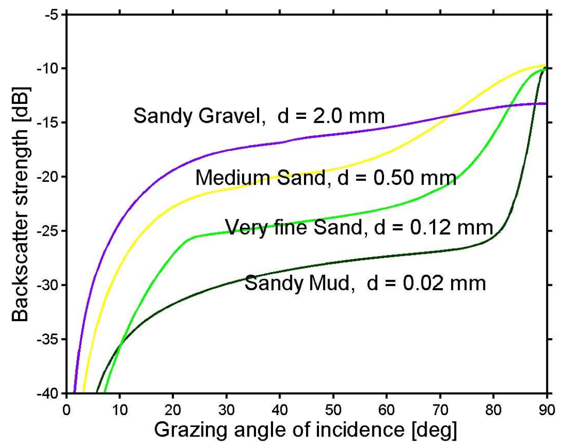
- An efficient search through the data for overlapping measurements
- An fast optimization approach for a range of sound speed profile shapes, e.g. using empirical orthogonal functions
- Semi-online application, thereby also functioning as a tool for assessing the sound speed information quality

Sediment classification with the multi-beam echo-sounder



A Bayesian approach to seafloor classification using MBES backscatter data

- The method uses the averaged backscatter measurements *per beam* with corrections for propagation losses and footprint applied
  - No corrections for angle-dependence of the backscatter strength needed
  - Variations of seafloor type along the swath are accounted for
  - Errors in transducer calibration do not pose a problem
- Method accounts for the ping-to-ping variability of the backscatter strength *in the most optimal way*



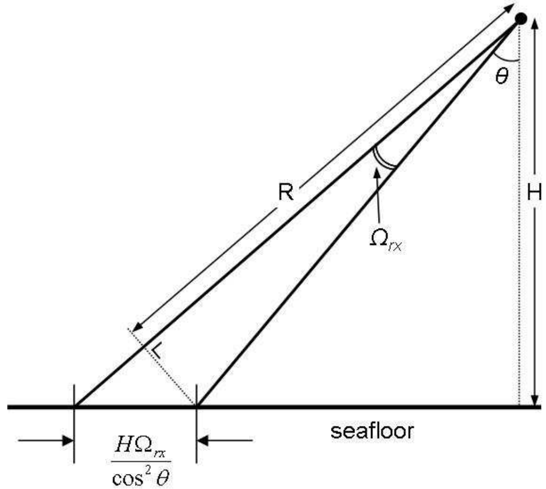
MBES backscatter data

The data employed

- We consider averaged backscatter measurements per beam

- Beam footprint :

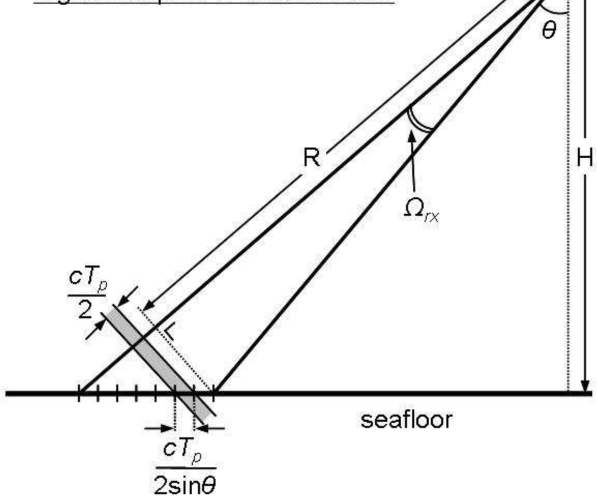
$$A_B = \Omega_{tx} R \frac{H\Omega_{rx}}{\cos^2\theta}$$



- Signal footprint :

$$A_S = \Omega_{tx} R \frac{cT_p}{2\sin\theta}$$

Signal footprint in receive beam



MBES backscatter data

The data employed, continued

- Number of signal footprints per beam footprint:

$$N_s(\theta) = \frac{\dfrac{H\Omega_{rx}}{\cos^2\theta}}{\dfrac{cT_p}{2\sin\theta}}$$

- For N_s large: averaged beam backscatter values (y) normally distributed, i.e., $y = N(\bar{y}, \sigma_y^{\ 2})$

$$\sigma_y = \frac{5.57}{\sqrt{N_s}} \quad \text{(dB)}$$

- For shallow water areas (small N_s) averaging over pings and beams

- Corrections needed for the effect of slopes on the backscatter strengths

MBES seafloor classification

Step 1: Nonlinear curve fitting

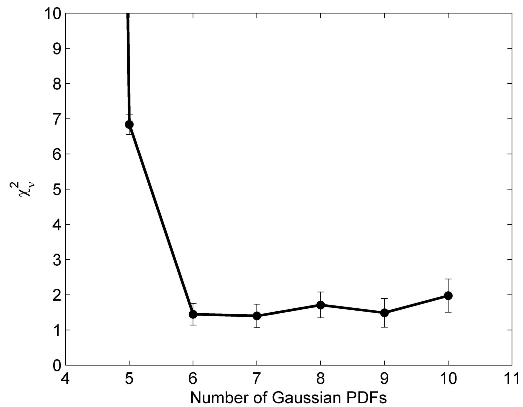
- Fit a model to the histogram of selected measured backscatter strengths:

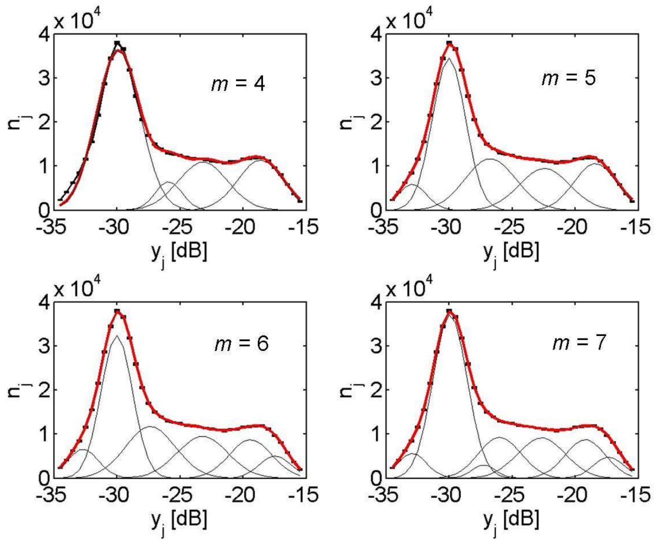
$$f(y_j \mid x) = \sum_{k=1}^{m} c_k \exp\left(-\frac{(y_j - \bar{y}_k)^2}{2\sigma_{y_k}^2} \right)$$

$$x = (\bar{y}_1, \ldots, \bar{y}_m, \sigma_{y_1}, \ldots, \sigma_{y_m}, c_1, \ldots, c_m)^T$$

- Employ goodness-of-fit criterion to decide upon the number of seafloor types:

$$\chi_\nu^2 = \frac{1}{M - 3m} \sum_{j=1}^{M} \frac{\left(n_j - f(y_j \mid x)\right)^2}{\sigma_j^2}$$

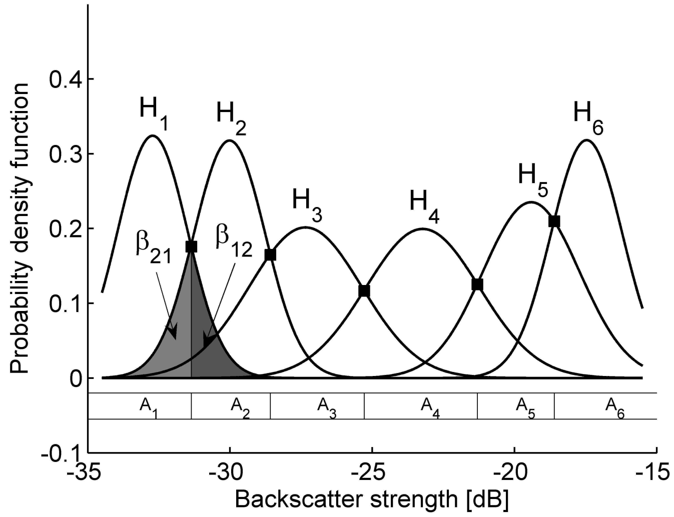




MBES seafloor classification, continued

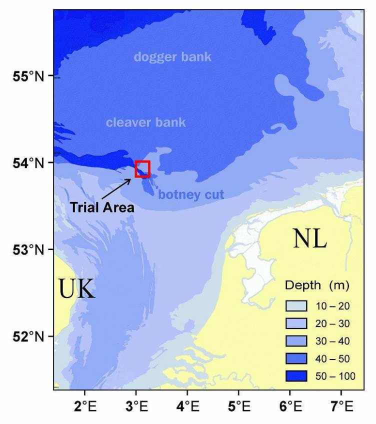
- Step 2: Acoustic classes identification
  Assign a seafloor type to each of the measurements according to:

  accept H_k if $$\underbrace{\max}_{H_i} f(y_j \mid H_i) = f(y_j \mid H_k)$$



- Step 3: Assign seafloor type to the acoustic classes using available cores and models
- Step 4: Quality assessment
  Determine the β values and corresponding decision matrix
- Step 5: mapping the classification results

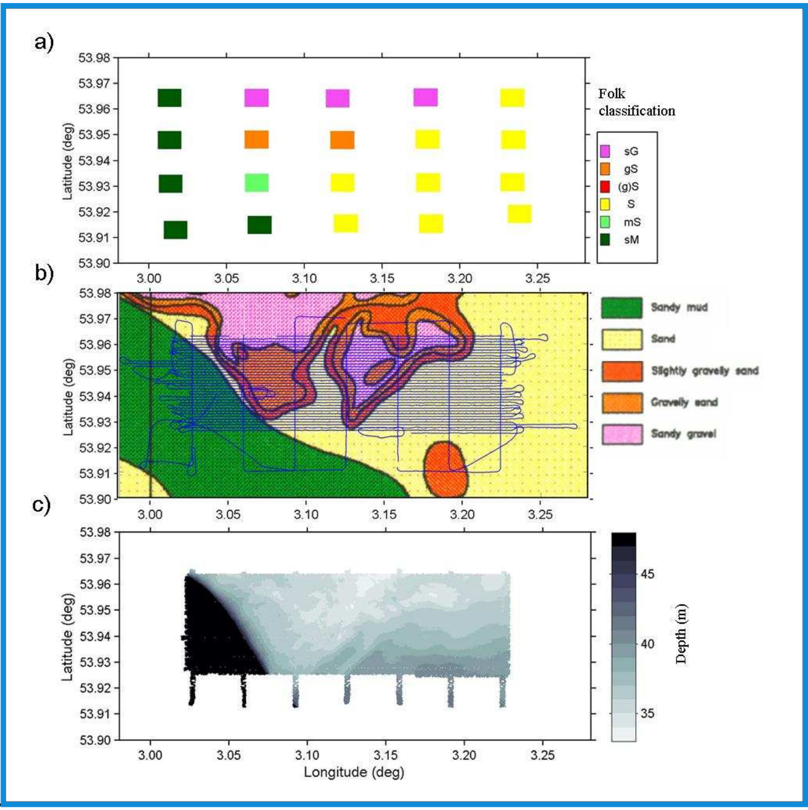
The Cleaver Bank area



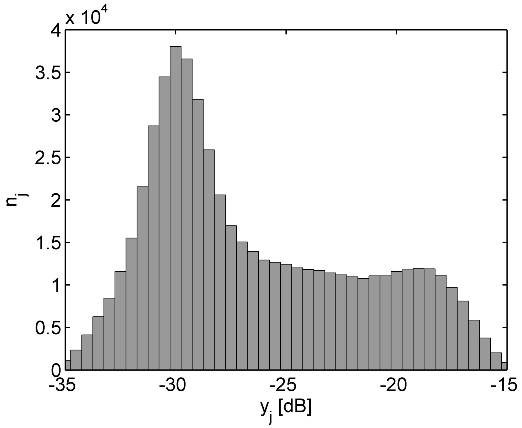
- Area characterized by a range of bottom types (-1 < M_z < 6)

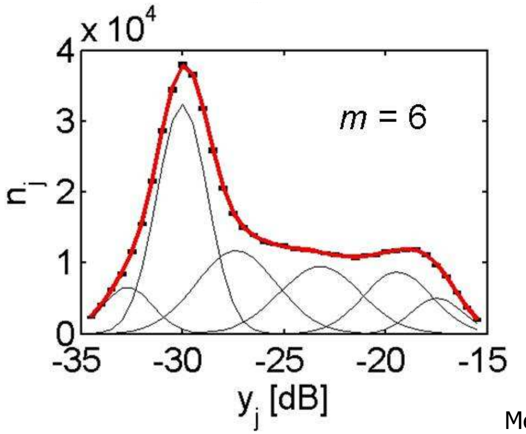
$$M_z = -\log_2 \left(d \text{ (mm)} \right)$$

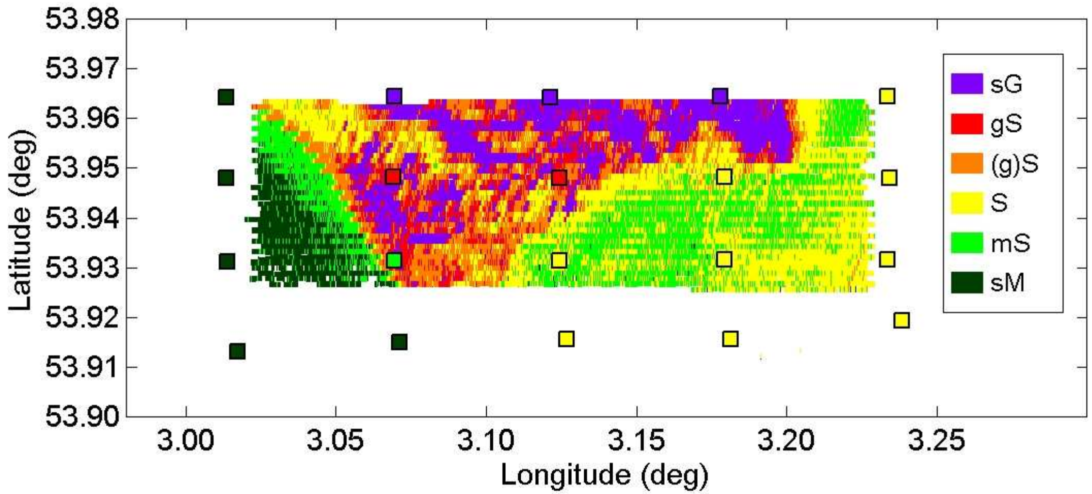
- Depths: 30-60 m
- Backscatter measurements taken with a 300 kHz MBES system
- A large number of cores were taken to get up-to-date ground truth



Application of the method to MBES data collected at the Cleaver Bank area





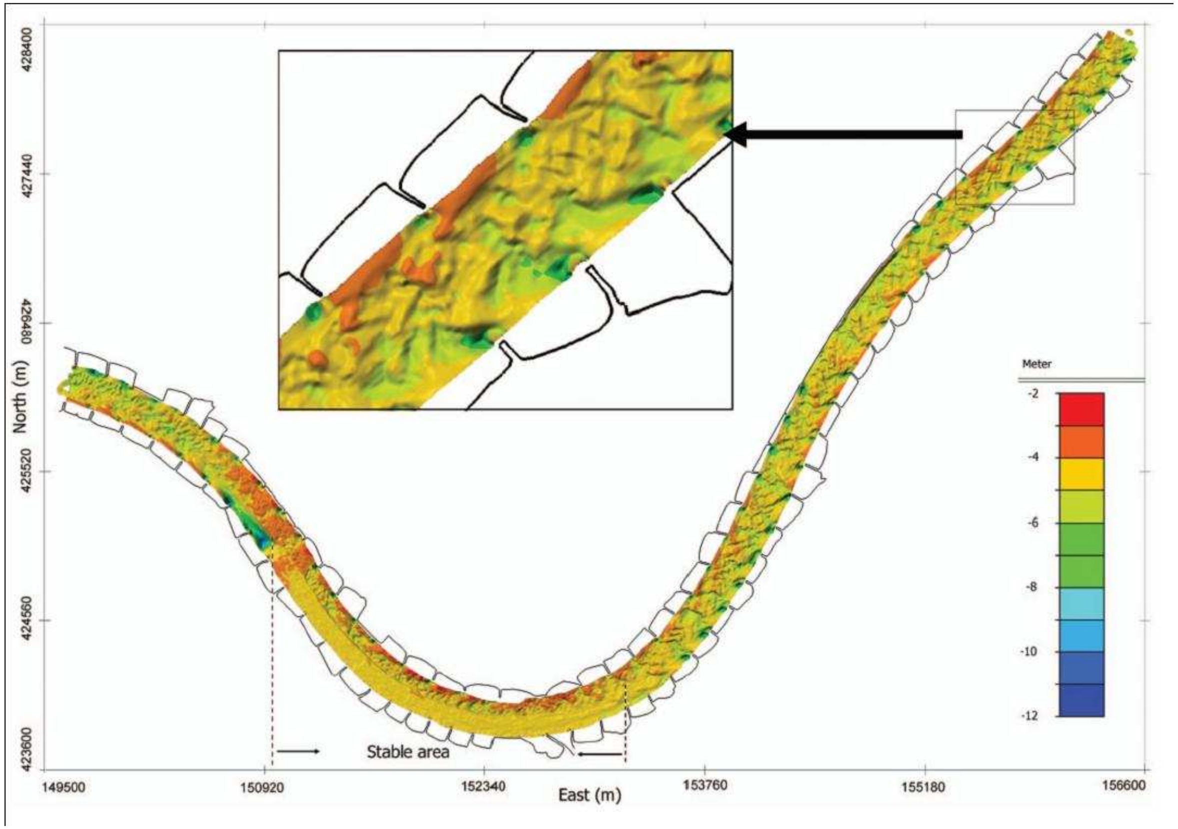


Methods and results are documented in: Dick G. Simons and Mirjam Snellen, *A Bayesian approach to seafloor classification using multi-beam backscatter data*, Applied Acoustics 70 (2009) 1258–1268

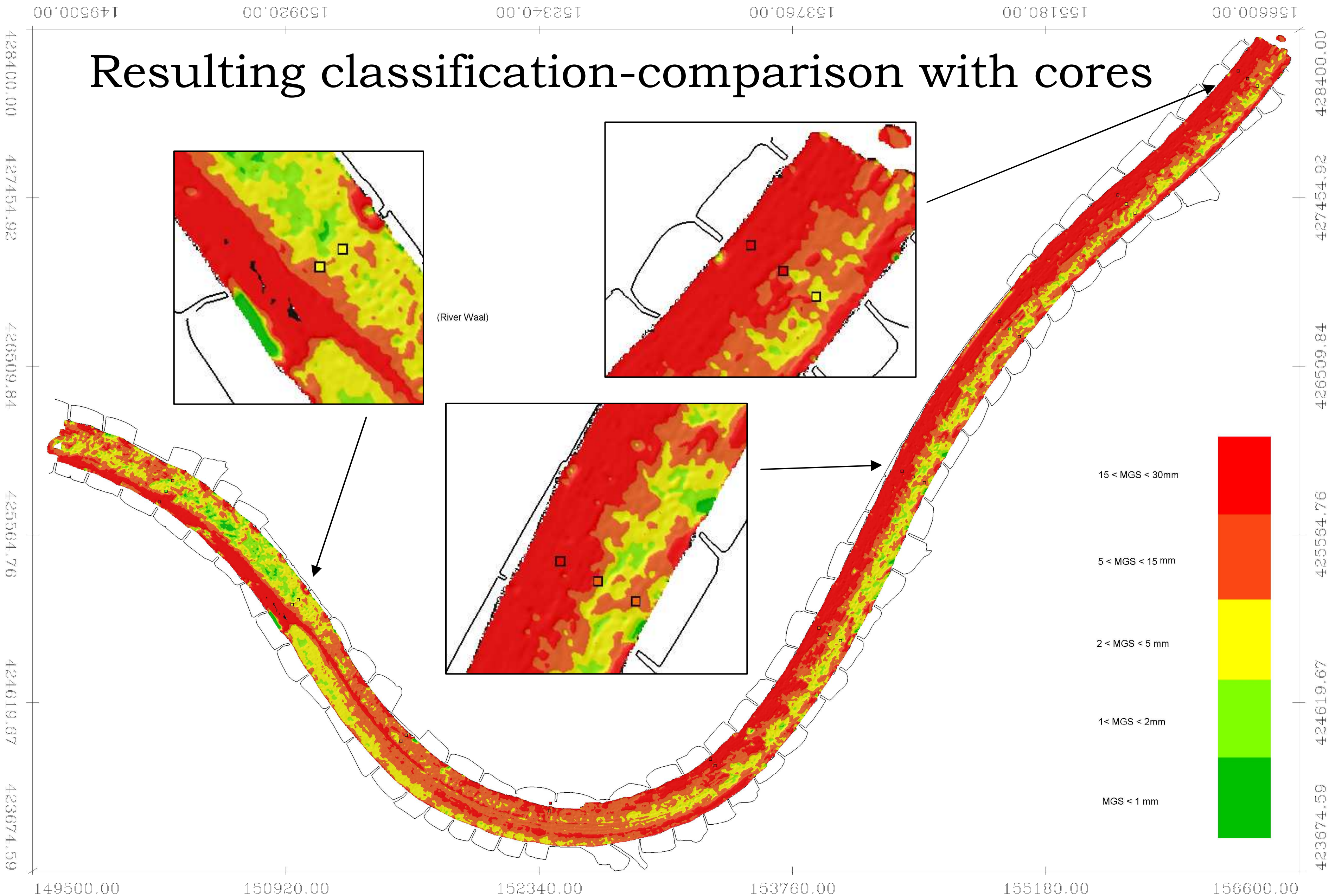
Classification of Riverbed Sediments

- Measurements taken in part of the Waal
- Very shallow water
- Backscatter measurements taken with a 300 kHz MBES system
- Samples taken at various positions along the river: <u>coarse</u> sediments(-5 < *Mz* < 0)

River Waal, the Netherlands
(Bathymetry Map)



Resulting classification-comparison with cores



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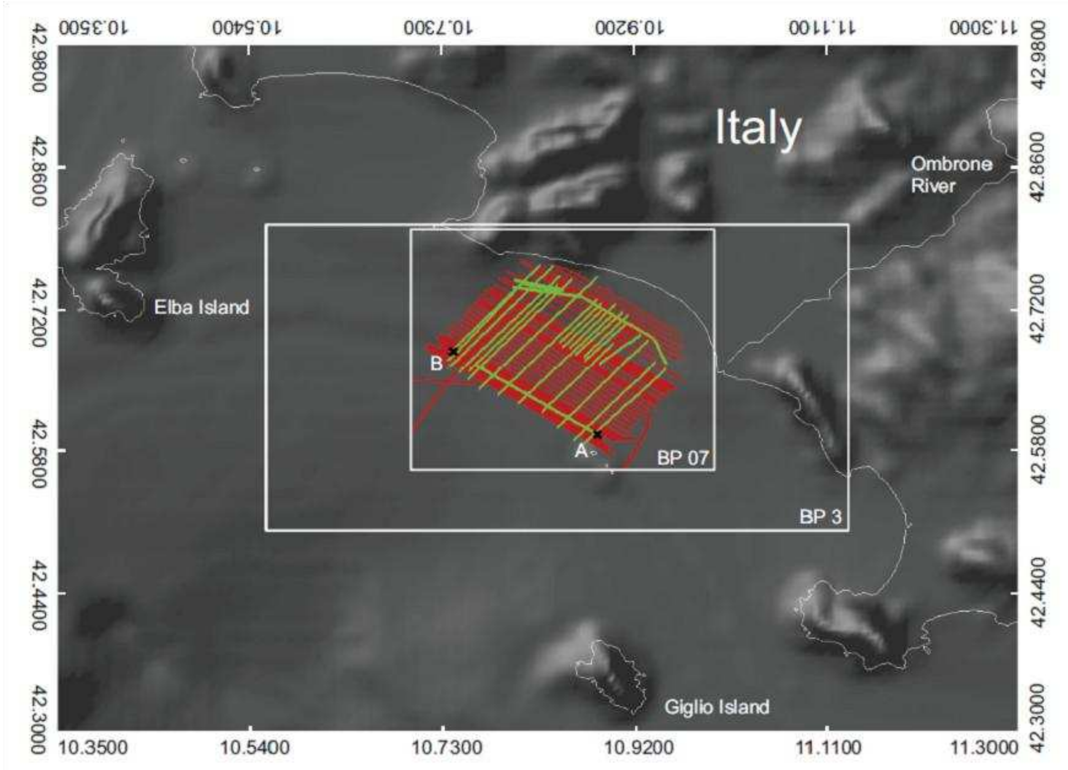
Methods and results are documented in: A.R. Amiri-Simkooei, M. Snellen and D.G. Simons, *Riverbed sediment classification using MBES backscatter data*, J. Acoust. Soc. Am. 126 (4), October 2009, pp. 1724-1738

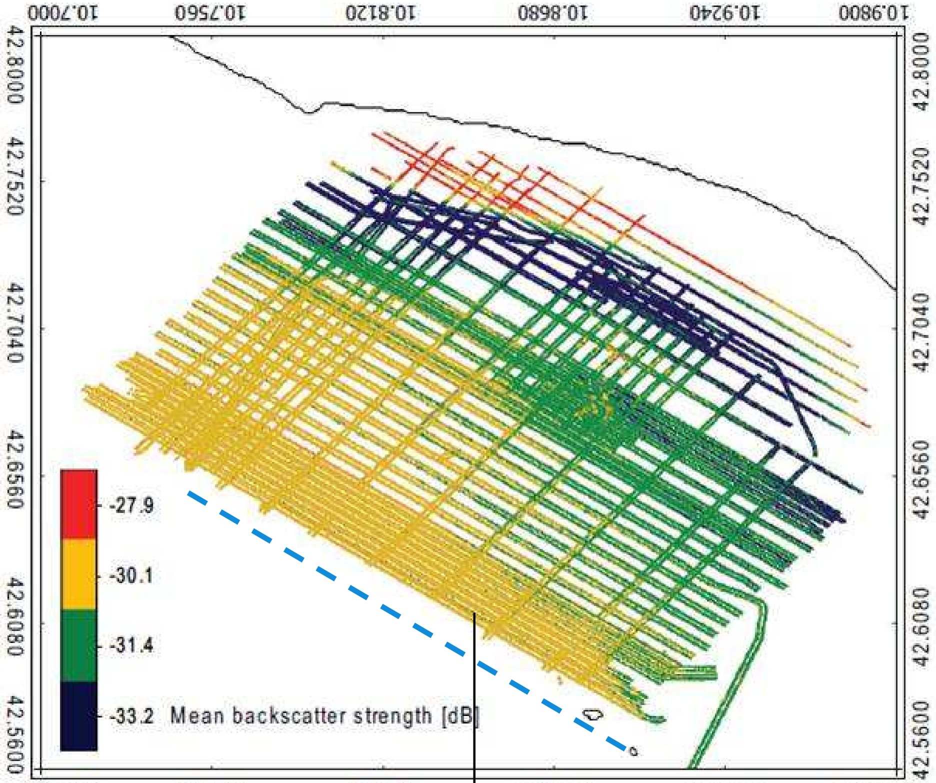
Application of the method to a coastal region

- Measurements taken South of Elba island in the Mediterranean Sea
- Water depths: 10-160 m
- Backscatter measurements taken with a 300 kHz MBES system
- Samples taken at various positions in the area: soft sediments ($7 < M_z < 11$)

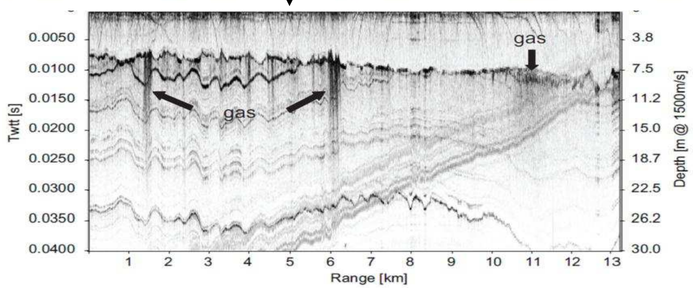


Data from the Netherlands Hydrographic Service
Work funded by TNO Defence, Security & Safety
Cooperation with University of Brussels

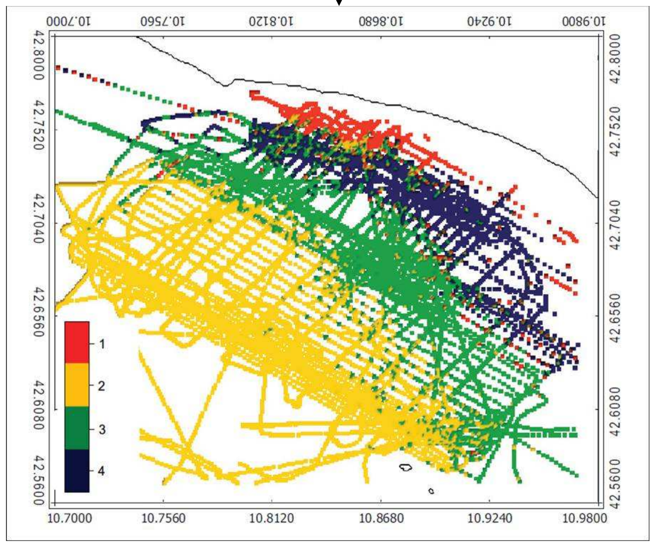
Resulting classification



MBES classes



SBES classes (200 kHz)



Methods and results are documented in: Kerstin Siemes, Mirjam Snellen, Dick G. Simons, Jean-Claude le Gac, Jean-Pierre Hermand, *Predicting spatial variability of sediment properties from hydrographic data for geoacoustic inversion*, submitted to the IEEE Journal of Oceanic Engineering

Challenges and future developments

- Allowing for processing real-time, building up and refining the classification map and automatic updating the fitting procedure

- Employing the complete signal per beam, resulting in improved classification at the cost of increased data rates

- Combining high-resolution bathymetry and high-resolution classification

Conclusions

- Multi-beam measurement systems are a powerful means for imaging sea- and river-floor bathymetry
- The redundancy in measurements allows for correcting bathyemtric errors (and simulteneously estimation of water column sound speeds)
- MBES classification method is available that discriminates between sediment types in the most optimal way
  - Method adopted for application in a range of water depths
  - Method shows good classification results for a large span in bottom types
    - Cleaver Bank: $-1 < M_z < 6$
    - River Waal: $-5 < M_z < 0$
    - Coastal area: $7 < M_z < 11$
- Real-time classification and refraction correction feasible but not yet established

Thanks for your attention!