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Innomar

High-Resolution 3D Sub-Bottom Profiling: Principles and Case Study Results

Master's Thesis Defense by
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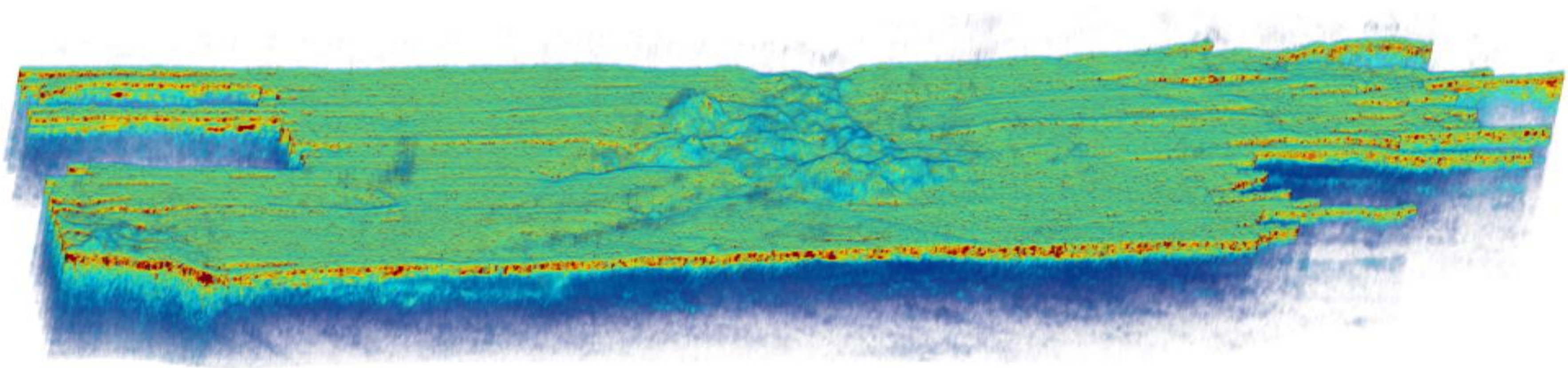
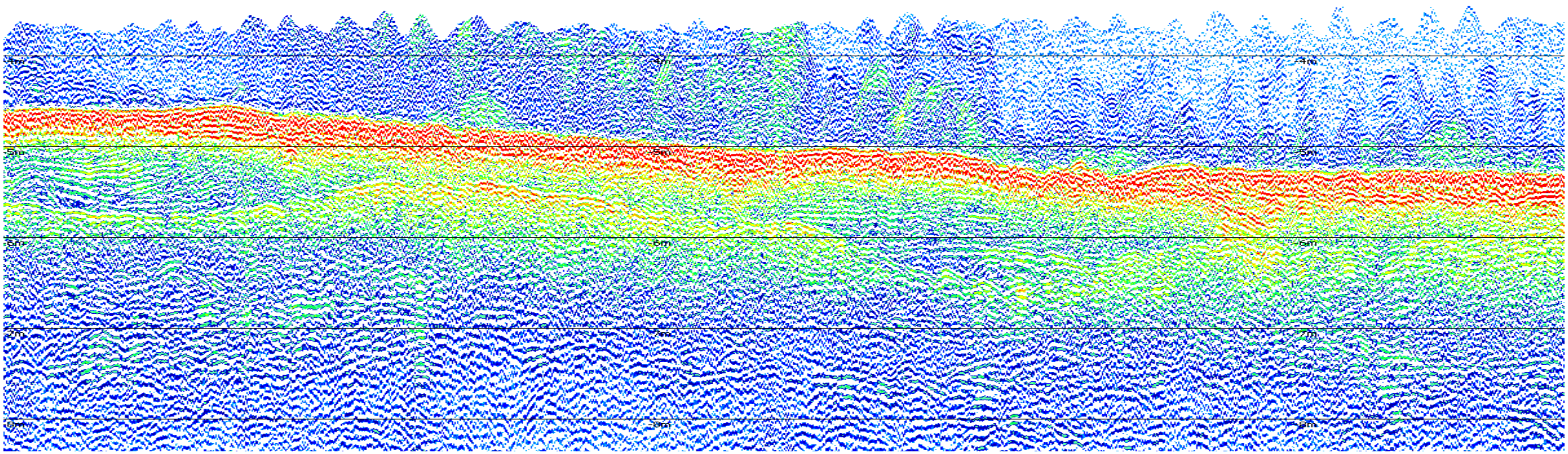


Source: own research

1. Motivation and Introduction

- Detailed interest in sediment layers
- Detection of ammunition, boulders, cables or pipelines
- Undisturbing alternatives to excavation for arachaeological sites
- Mostly only individual depth slices (echoplots)
- Demand for high resolution 3D imaging



Source: own research

1. Motivation and Introduction

Source: Rose, D. (2015)

- Multitransducer systems by Innomar Technologie GmbH as one example for 3D sub-bottom profiling
- SES-2000 sixpack as most recent development
- Six adjacent SES-2000 smart transducers combined in one line array
- Acquisition of three datasets with different frequencies and system modes

1. Motivation and Introduction

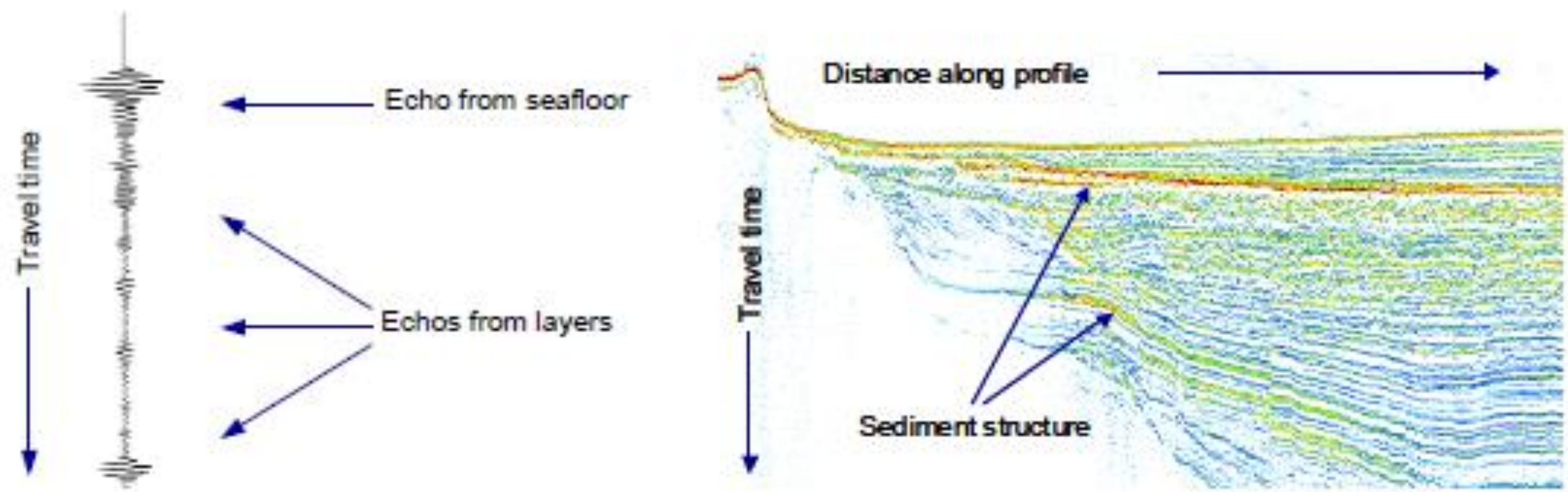
Research questions:

- How do signal frequencies and array configurations affect the penetration depth and the resolving capacity ?

- Is the derived data convenient for 3D modelling and the reconstruction of features in the subseabed ?

2. Theoretical Backround

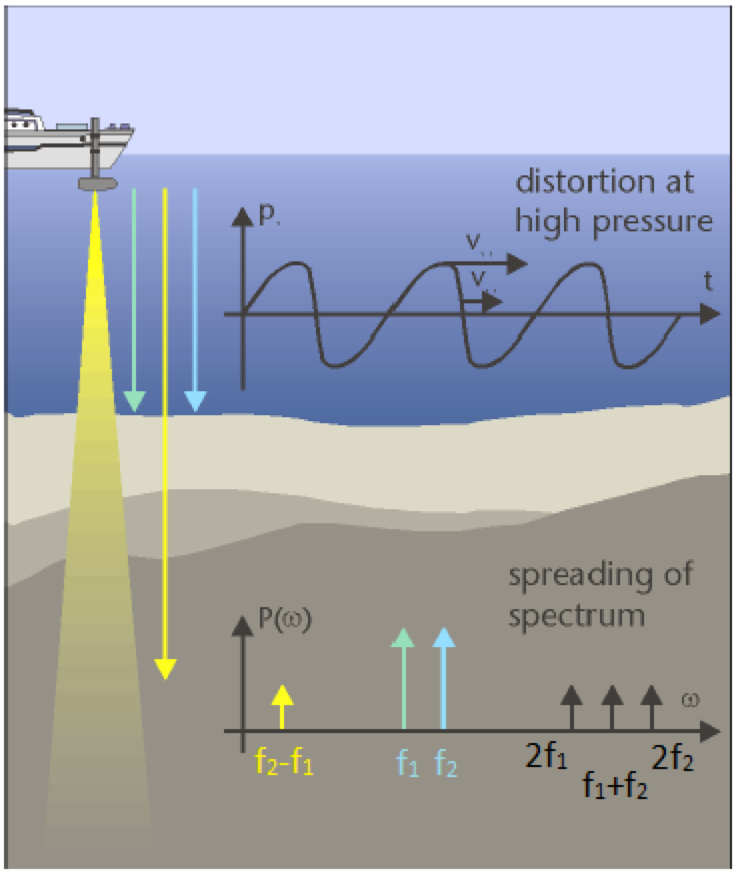
- Echoes of low frequent sound pulses are recorded
- Survey platform moves and corresponding echoes are juxtaposed
- dilemma between vertical resolution and penetration depth
- Sound pulse creation either by conventional or by parametric means



Source: Innomar Technologie GmbH (2012)

2.1 Parametric Sub-bottom profiling

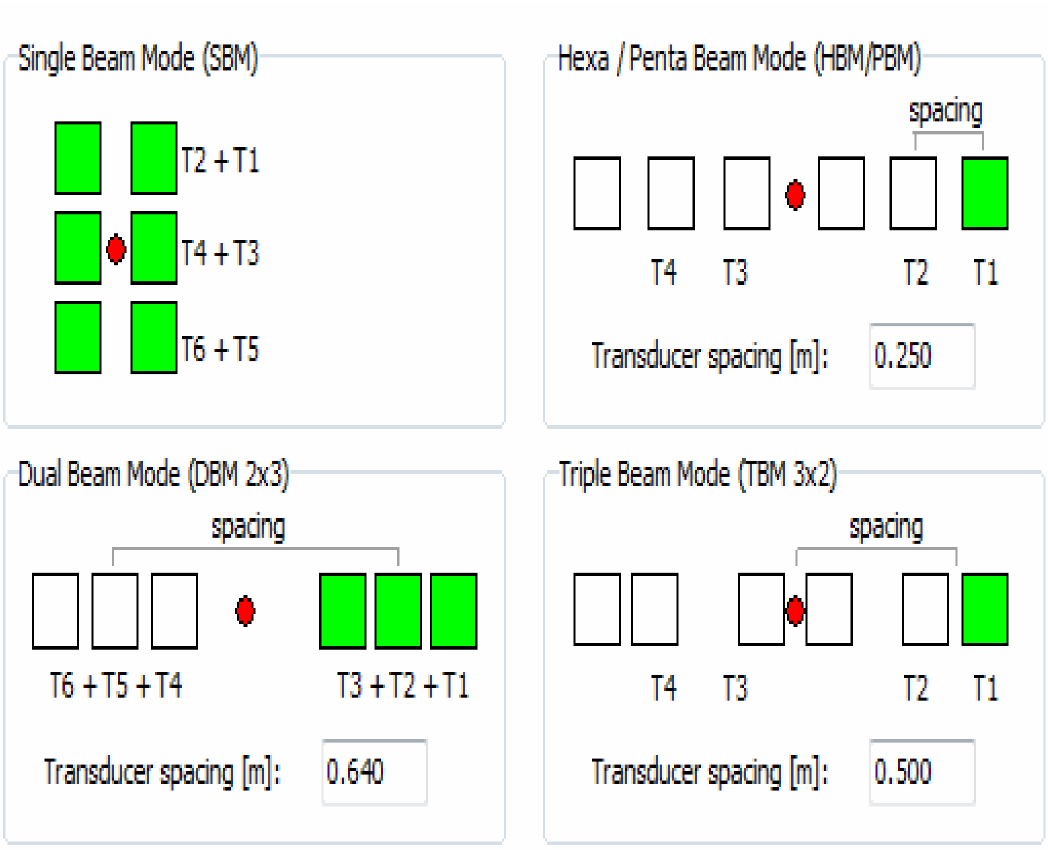
- Superposition of 2 waves with slightly different frequency



Source: Innomar Technologie GmbH (2012)

- constructive and destructive superposition
- creation of difference frequency
- further the sum frequency and harmonics are created
- difference frequency can penetrate the seafloor
- sharper sound pulses due to nonlinearity of water
- better vertical resolution and narrower beams than conventional systems

3. Data Acquisition

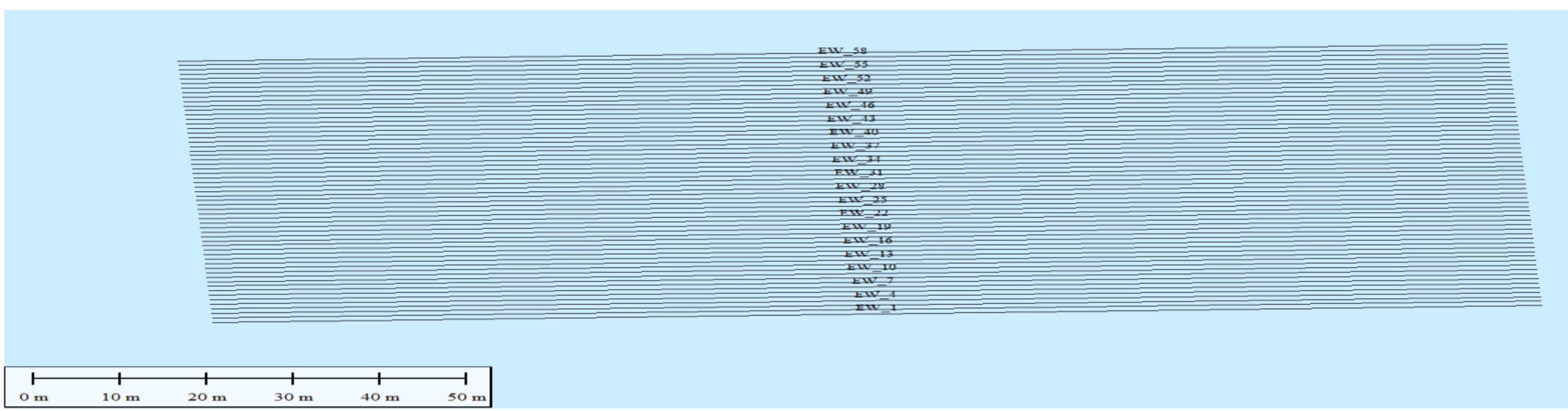


Source: Menu of SESWIN by Innomar (2018)

- SES-2000 sixpack as newest development among Innomar's product range
- 6 adjacent transducers can be operated in different system modes and with secondary low frequencies ranging from 4 kHz to 15 kHz

- 3 datasets with different setting were acquired
- 59 planned survey lines parallel to the prevailing wind and wave direction

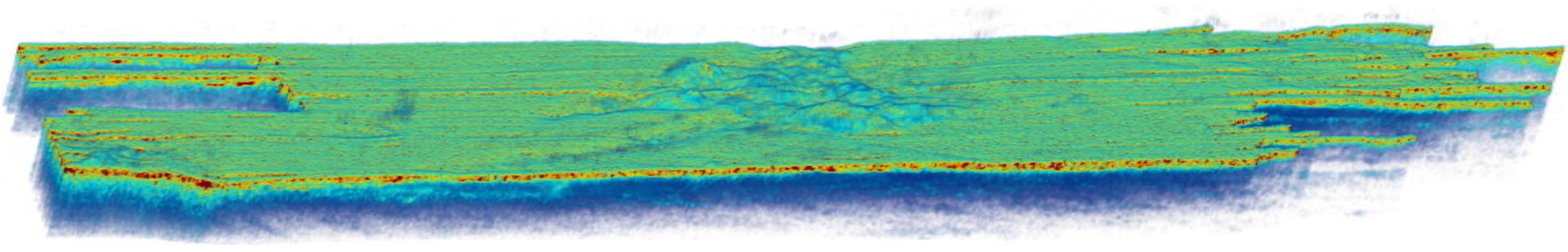
Measurement	expected resolving capacity alongtrack	expected resolving capacity acrosstrack	expected vertical resolving capacity
July, 10 kHz, HBM	29.3 cm	25 cm	7.7 cm
August, 12 kHz, PBM	17.2 cm - 21.6 cm	25 cm	6.2 cm
November, 6 kHz, PBM	21.5 cm	25 cm	9.2 cm



Source: own research

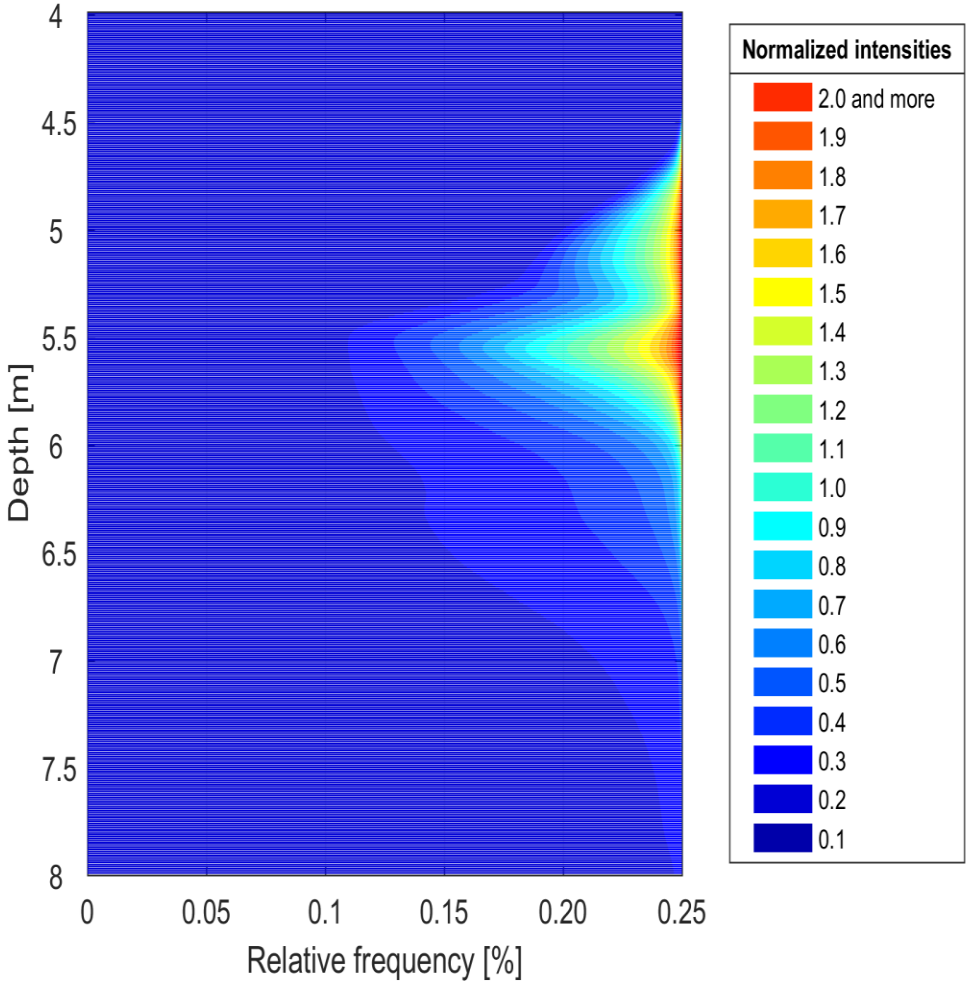
4. Data Processing

- low and high frequency were stored in different chanels
- .ses3 format needed to be converted to .raw and .bin format
- .bin format could be gridded in SESGridder software package
- grids with same boundary limits, voxel numbers and voxel spacings were created for all 3 measurements
- voxel = volume pixel; spatial coordinates not encoded, but can rather be concluded from voxel number -> much smaller datasets, that are easier to edit



Source: own research (Voxler 3D)

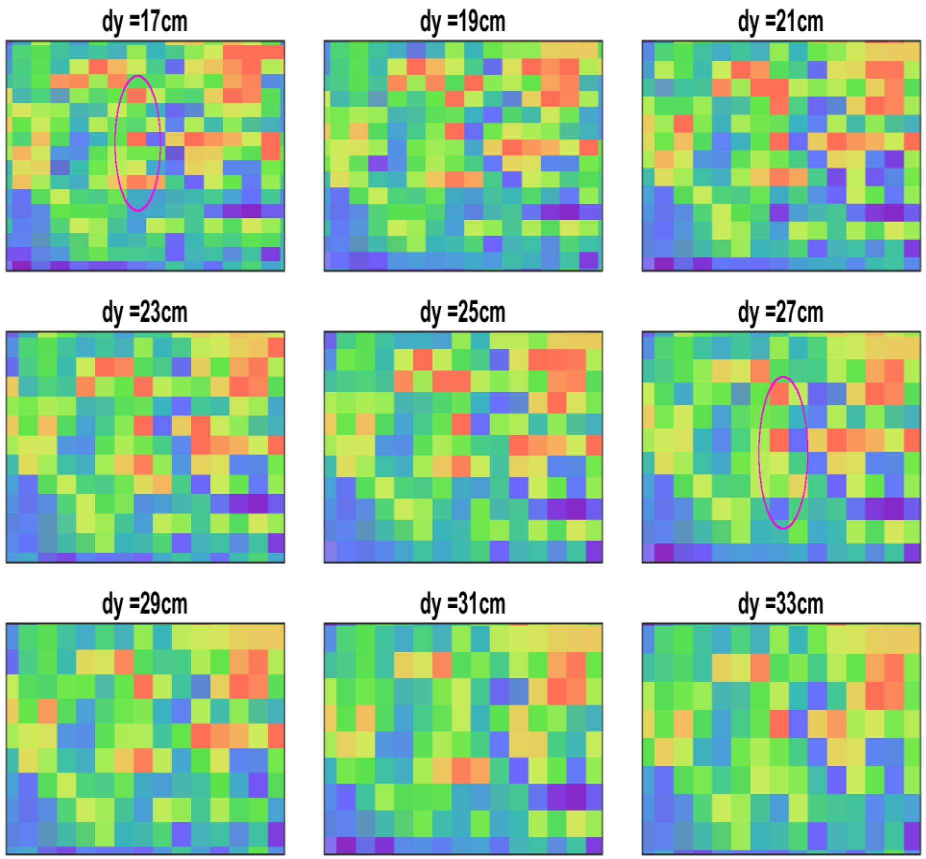
4.1 Penetration Depth



Source: own research (Matlab)

- set range limits recorded depth (8m Aug and Nov; 10m Jul)
- intensity values sorted as a function of depth
- different gain factors and source levels -> normalization necessary
- seafloor as strongest reflector chosen to be reference level for intensity values
- whole survey area, but also smaller features were compared

4.2 Resolving Capacity



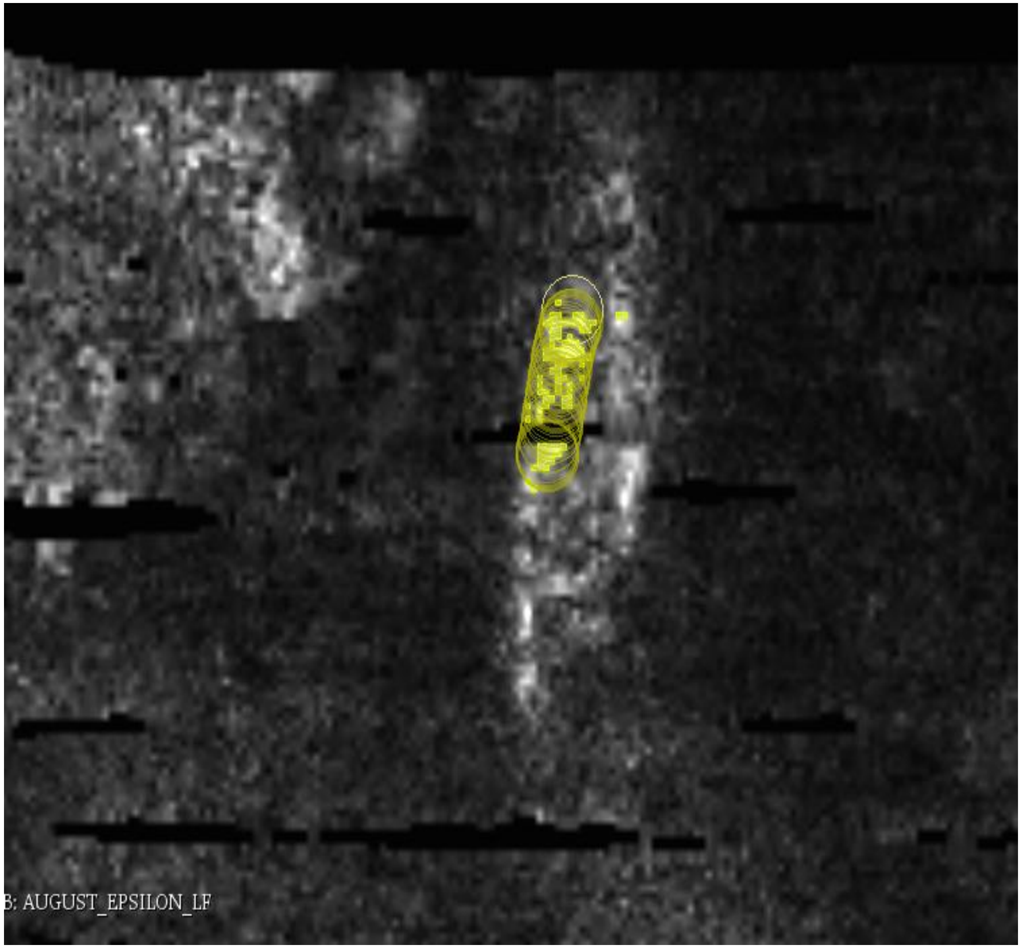
November - 6 kHz, PBM - acrosstrack

Source: own research (Matlab)

- 3 self conceived methods were applied
- resolution was altered along one dimension to find limit of resolution of adjacent features
- comparison of autocorrelation function of sample data
- comparison of mean differences of sample data
- visual detection of limit of resolution
- all methods are empirical and subjective

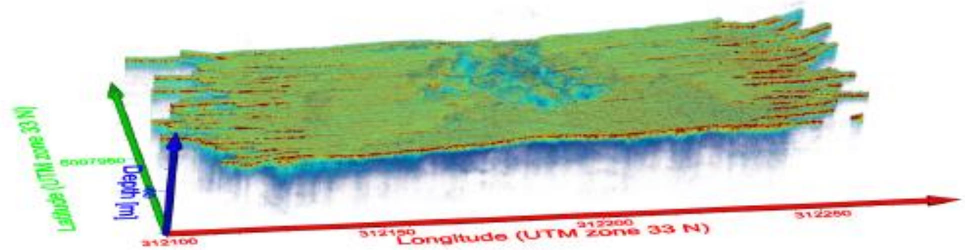
4.3 3D Modeling

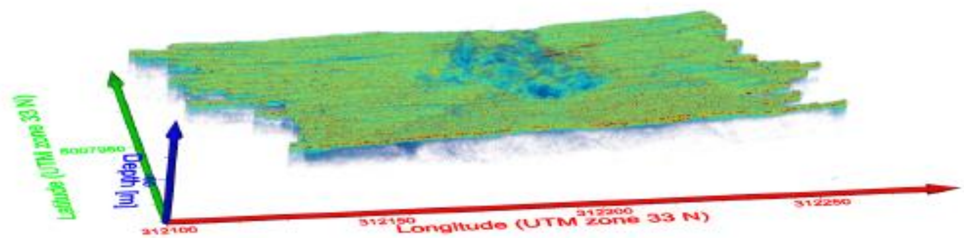
- exemplary modeling of presumed wreck
- extraction of wreck from 3D voxel data set by 3D Slicer
- applied intensity filter
- further conversion and editting of 3D point cloud with Voxler 3D, Geomagic, AutoCAD, Cloud Compare and Blender
- Combination of acquired datasets with 3D modelled features at the seafloor (provided by GfS e.V.)

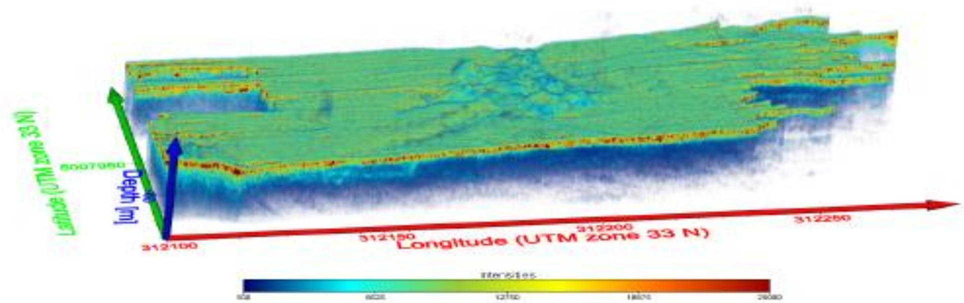


Source: own research (3D Slicer)

5. Results



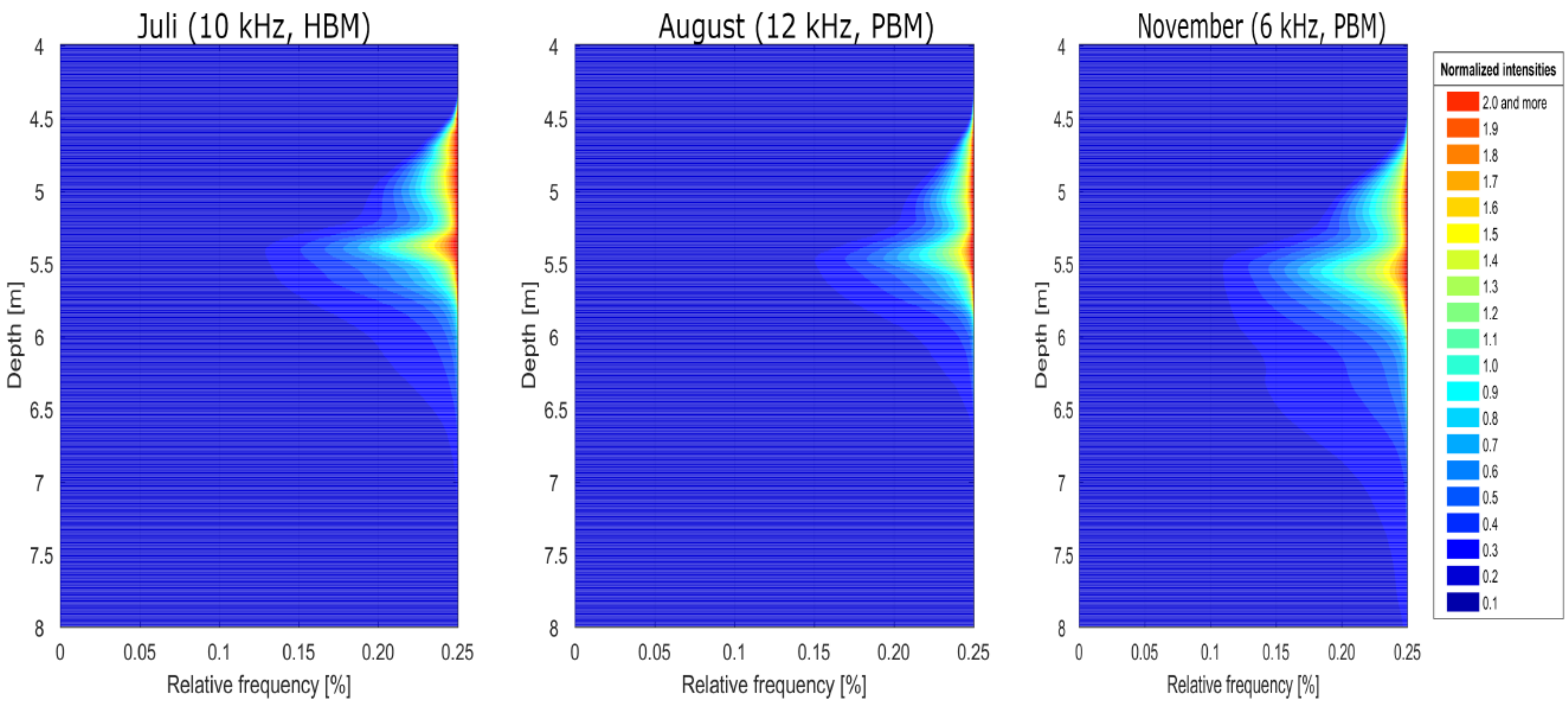




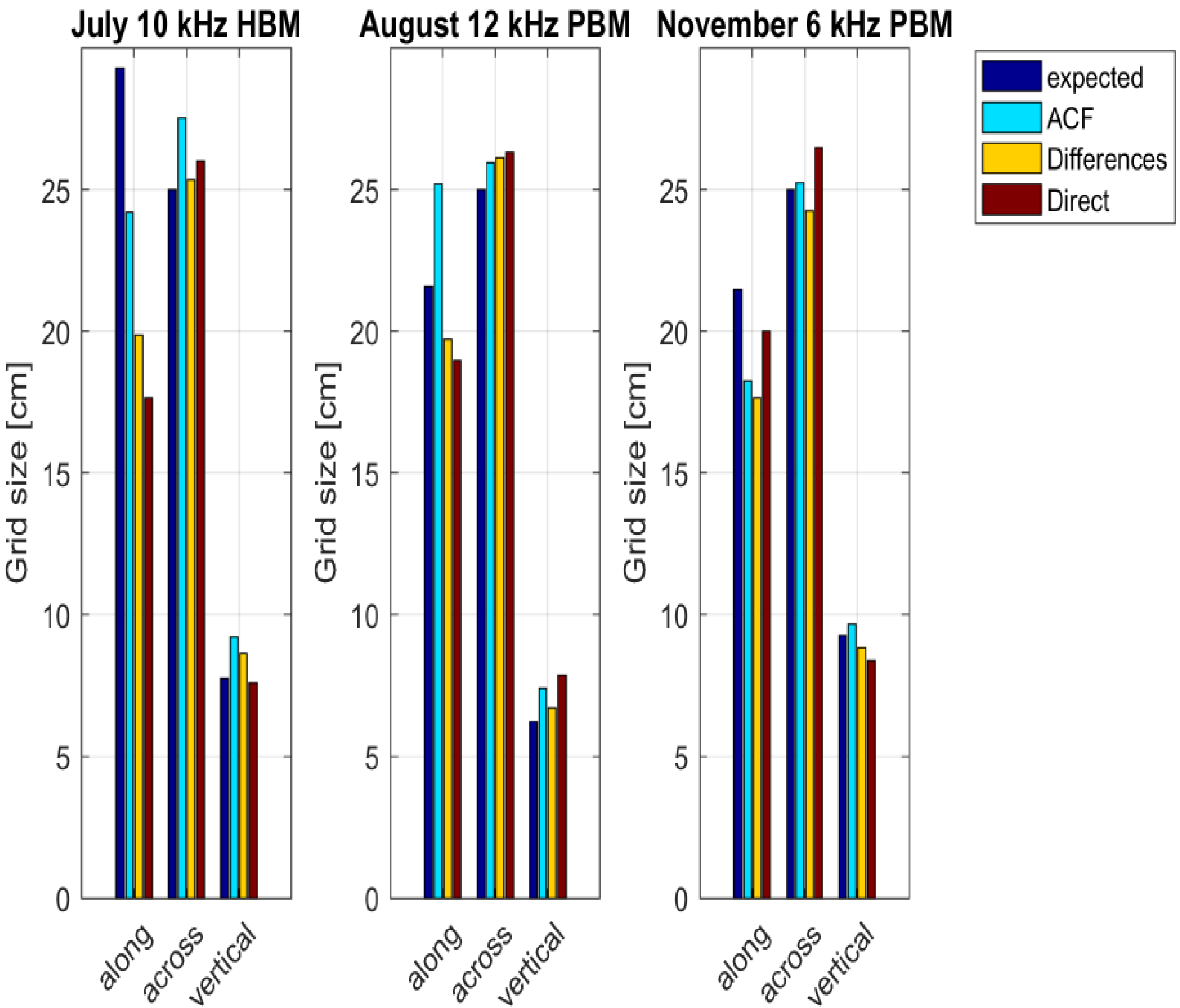
- varying expanse of survey lines
- intensity differences are not representive, but rather display the effect of different gain settings
- penetration depth is corresponding with the used frequency
- perspective cannot serve as qualitative comparison
- horizontal slicing yields to further insight

Source: own research (Voxler 3D)

- 6 kHz PBM measurement (Nov) with best penetration qualities
- 10 kHz can only penetrate marginally more than 12 kHz
- apparently PBM can compensate partly for frequency difference
- mean seafloor depth of 5.5 m can be identified in all datasets
- investigation of smaller subareas was confirming findings

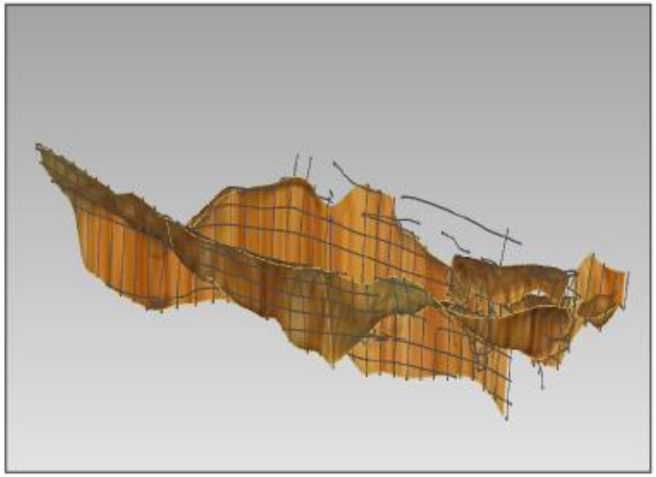
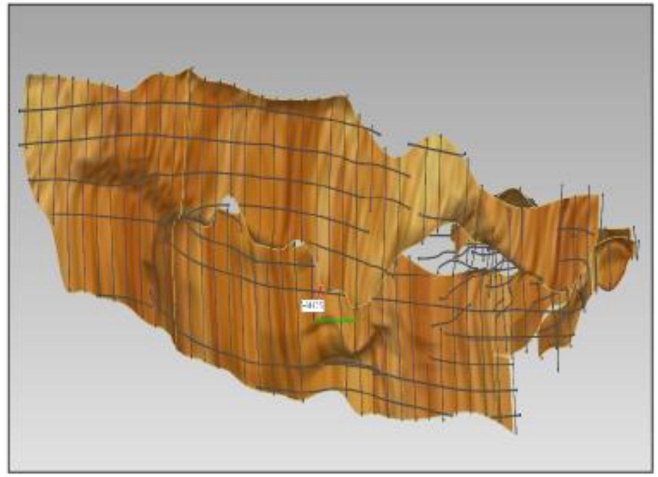
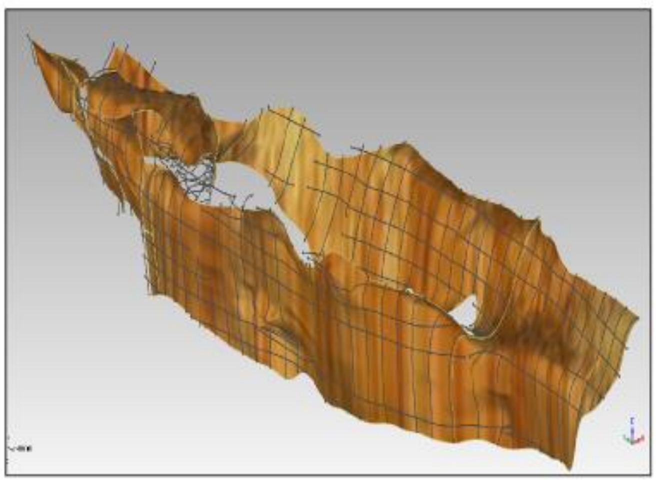
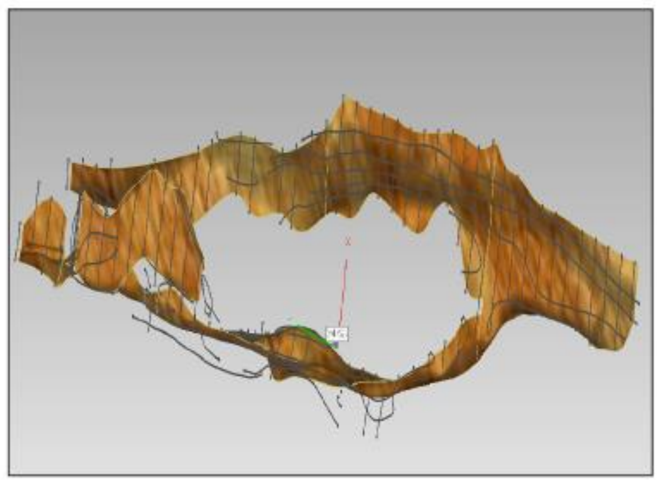


Source: own research (Matlab)



- expectations were mostly met quite well
- highest deviations in alongtrack direction
- vertical resolving capacity as function of frequency
- lateral resolving capacity as function of sounding distances

Source: own research

Source: own research

- extraction of ribs and horizontal waterlines
- adaption of surfaces to the created lines plan
- speed of sound is higher in longitudinal direction of wood

5. Results

• objects lying on deeper layer indicate theory of sealing of breach in coastline – by this answer applied archaeological questions
• used frequency and system mode are determining penetration depth
•system mode can partly compensate frequency differences
• lateral resolving capacity is determined by sounding distance
• no evidence for other effects, that could improve resolving capacity
• vertical resolving capacity as function of pulse length

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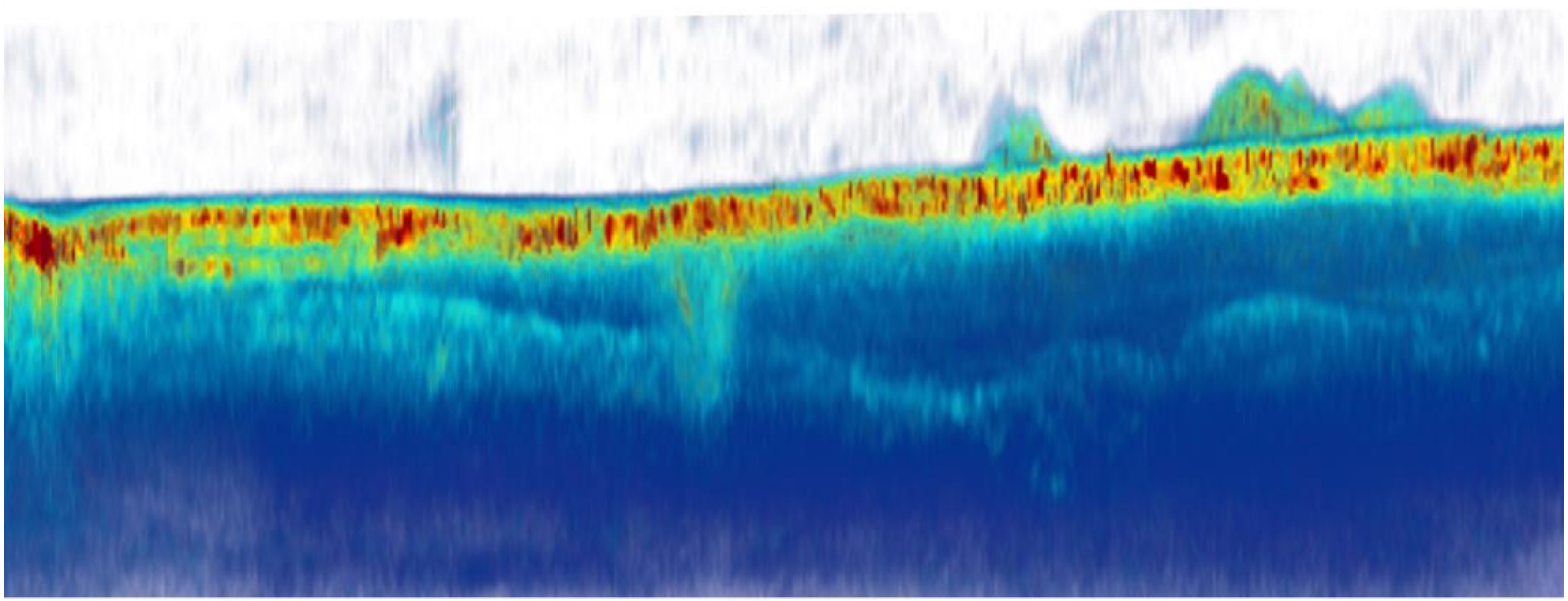
Thank you for your attention

Source: Martin Siegel GfS e.V.

Sources

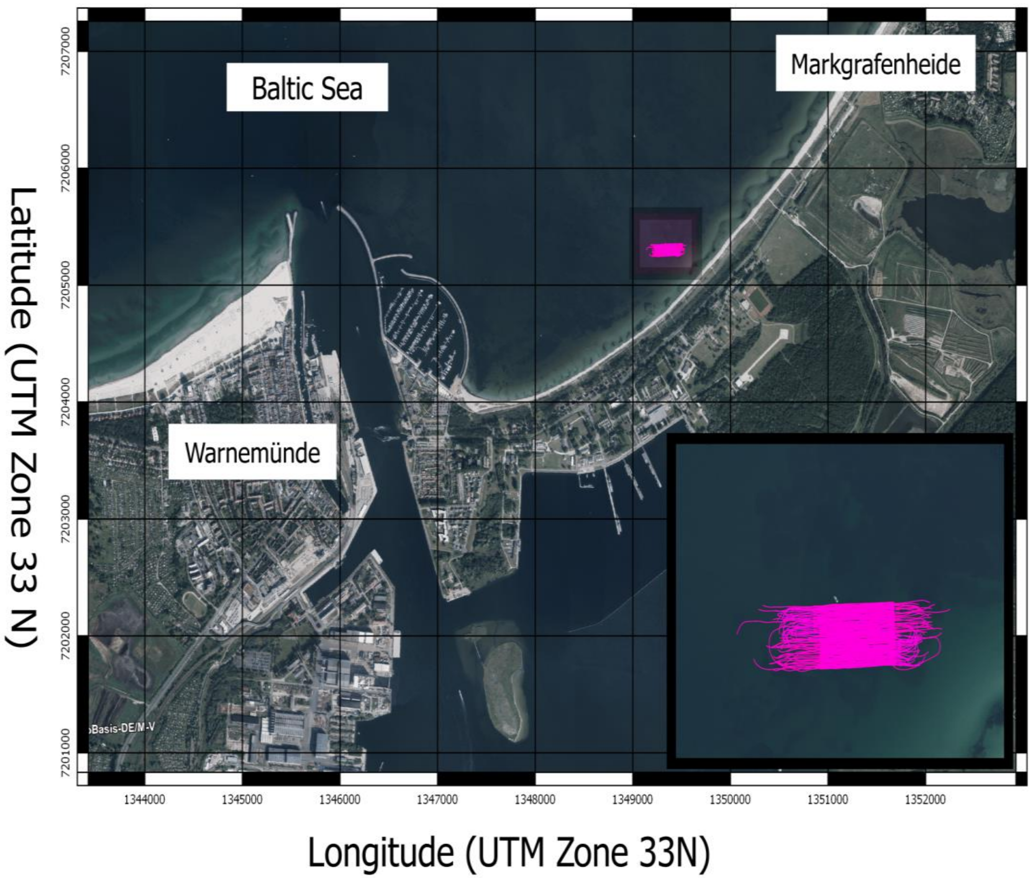
- Rose,D. Jans, W.; Lowag J. and Wunderlich J. (2015) „Acoustic Detection of buried objects- tests and results using a parametric sub-bottom profiler“.
- Langhof, A.S. (2000) „Küstenentwicklung im Warnowmündungsbereich vom Postglazial bis zur Gegenwart“. Universität Rostock
- Material provided by GfS e.V. (2018) – Gesellschaft für Schiffsarchäologie Rostock e.V. by Martin Siegel
- Innomar Technologie GmbH (2012) „SES-2000 Narrow-Beam Parametric Sub-Bottom Profilers Technical Background“
- Plets, R. M. ; Dix, J. K. ; Adams, J. R. and Best, A.I. (2007) „3D reconstruction of a shallow archaeological site from high resolution acoustic imagery: The Grace Dieu“ In: applied acoustics, Elsevier BV
- Gutowski, M. ; Malgorn, J. and Vardy, M. E. (2015) „3D sub-bottom profiling – High resolution 3D imaging of shallow subsurface structures and buried objects“ In: OCEANS 2015 – Genova, IEEE

5. Results



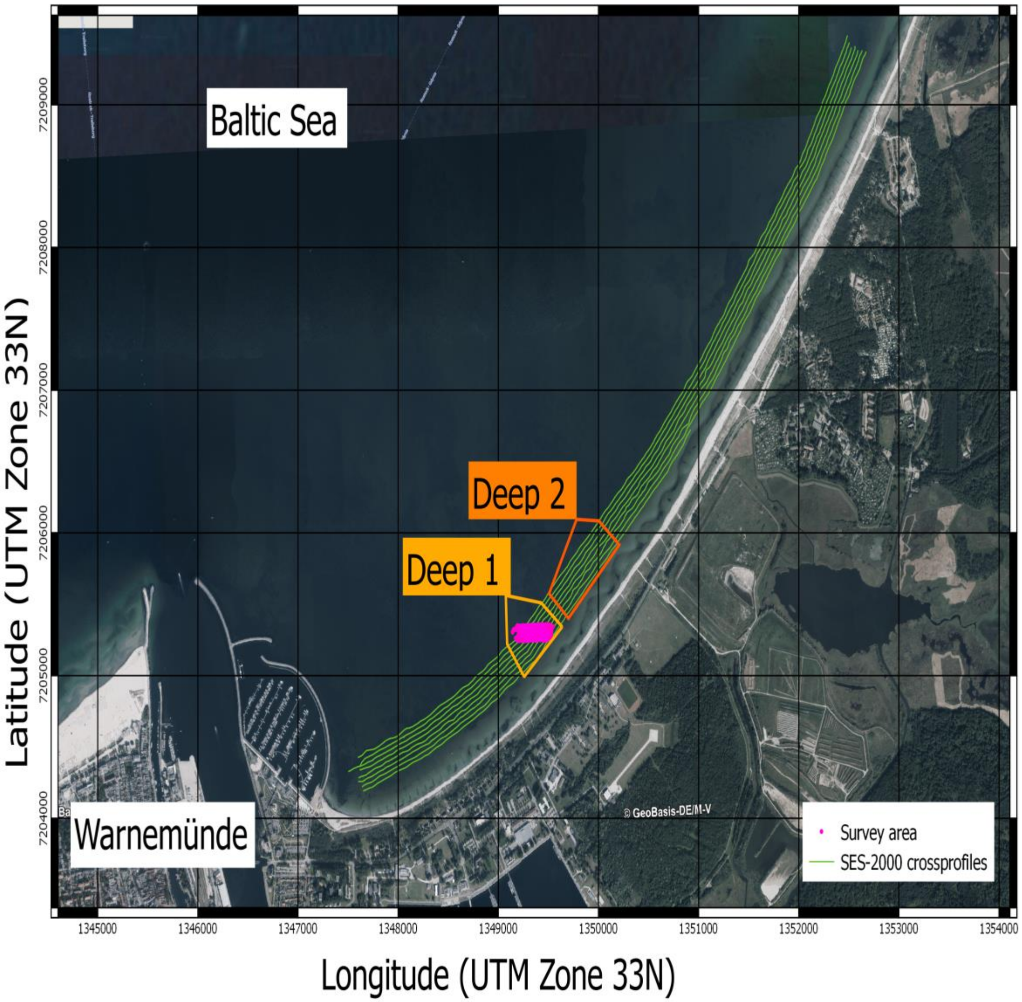
Source: own research (Voxler 3D)

1.1 Survey area



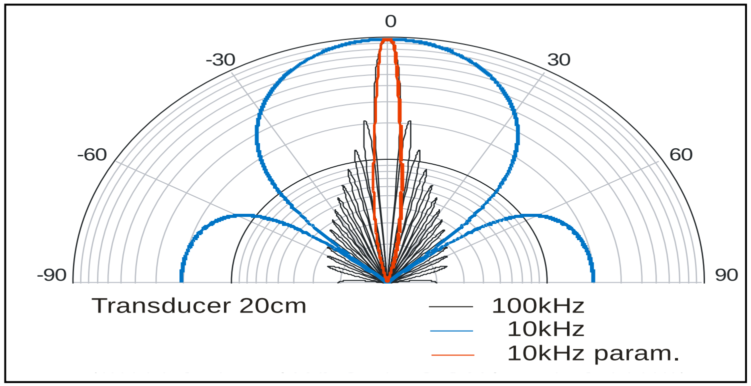
Source: Own research

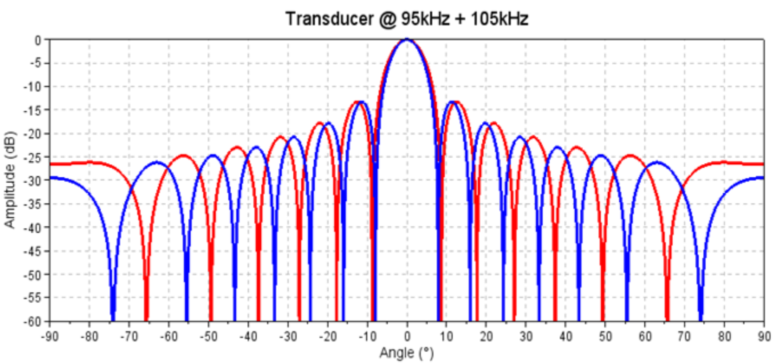
- Many archaeological sites parallel to coastline
- Wooden poles, boulders, fascines and one wreck found in survey area by GfS e.V.
- Pose rather measure of coastal protection than remains of early harbour structures
- 3D representation of subseafloor can promote archaeological understanding

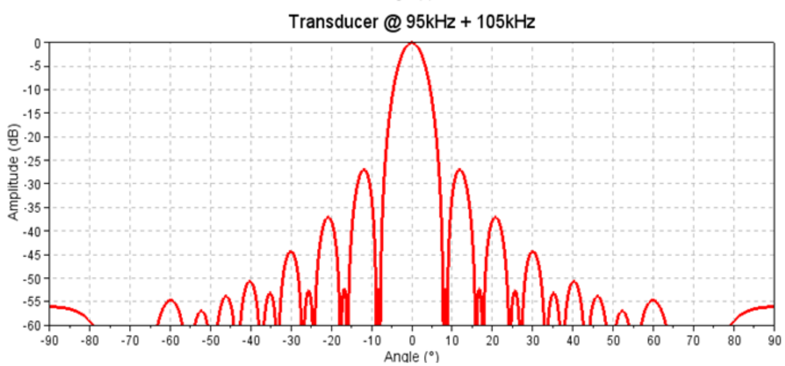


Source: Material provided by GfS e.V. (2018)

- breaches in coastline posing threat to vital trading of the hanseatic city of Rostock
- 8 crossprofiles to detect former breaches in sediment layers
- 2 „Deeps“ clearly identified
- „Deep 1“ coincides with survey area and findings on the seafloor
- Kuno Voß (1928) described sealing of breaches







- side lobes are unwanted
- more and narrower side lobes the higher the frequency
- difference frequency has narrow sound beam
- has virtually no side lobes
- slightly different position of sidelobes of primary frequencies leads to destructive superposition
- amplitude of secondary frequency depends on product of the two primary high frequent waves
- high lateral resolution possible

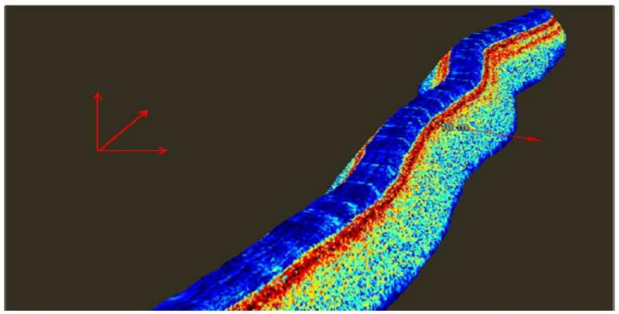
Source: Innomar Technologie GmbH (2012)

- difference frequency is created for all frequency components
- bandwidth of primary signal is determined by construction type of transducer
- absolute bandwidth stays the same for primary and secondary frequencies – the bandwidth is inherited
- low frequencies with high bandwidths can be emitted

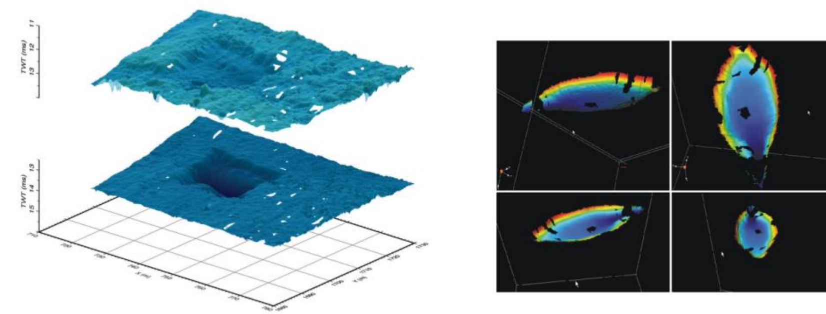
$$\tau_{eff} = \frac{1}{B} \longrightarrow \Delta R = \frac{c * \tau_{eff}}{2} \longrightarrow \Delta R = \frac{c}{2 * B}$$

- created sound pulses can be relatively short
- low frequencies with short pulses can be emitted
- vertical resolution is much better than for conventional systems

- demand for comprehensive datasets of the subseafloor rather than exemplary depth slices – urge for 3D systems
- development of different approaches



Source: Plets et al. (2007)

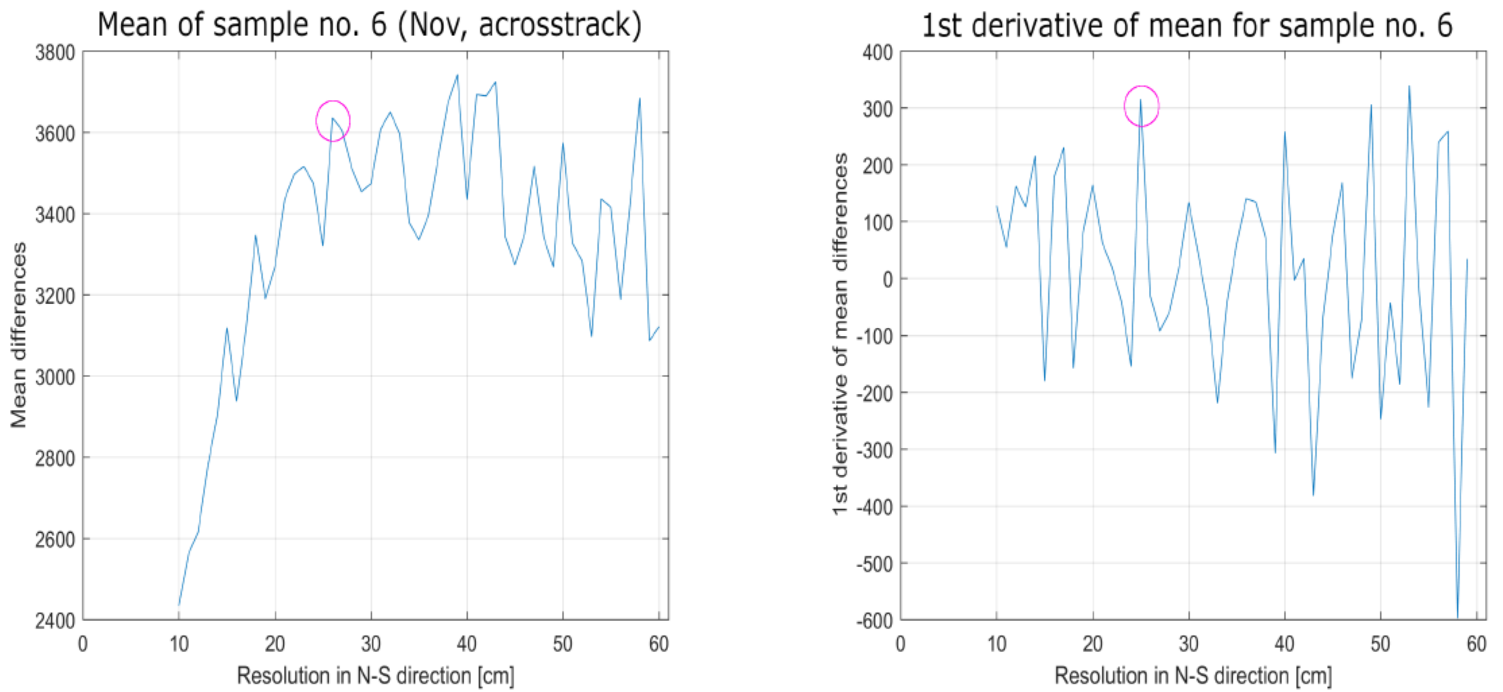


Source: Gutowski et al. (2015)

- Sub-bottom imager by Pangeosubsea
- combines conventional transducers and SAS technology
- high system requirements (96 GB RAM; 120 Mb/s dataflow)

- GeoChirp 3D by Kongsberg
- combines seismic data processing and chirp sonar technology
- towed system
- sophisticated data processing

• presented 3D illustrations turned out to be difficult to interprete



Source: own research (Matlab)

• Mean and Standard deviation for Autocorrelation function per grid size
• Mean and 1st derivative for differences per grid size
•still highly subjective, but easier to interprete 2D representations

6. Discussion and Outlook

- ease of data acquisition and fast data processing as advantage
- presented methods need to be elaborated and objectified
- for comprehensive analysis more datasets with different settings would be usefull
- reference measurements, reference objects, reference positions like poles would further be advantageous
- perspectively combination with material detection by reflection coefficients
- combination of different sensor types and measurements (divers, MBES, Side-Scan Sonar)