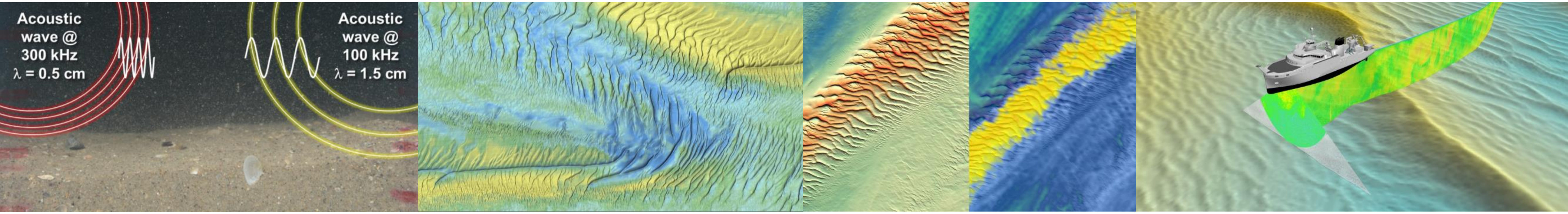
economie

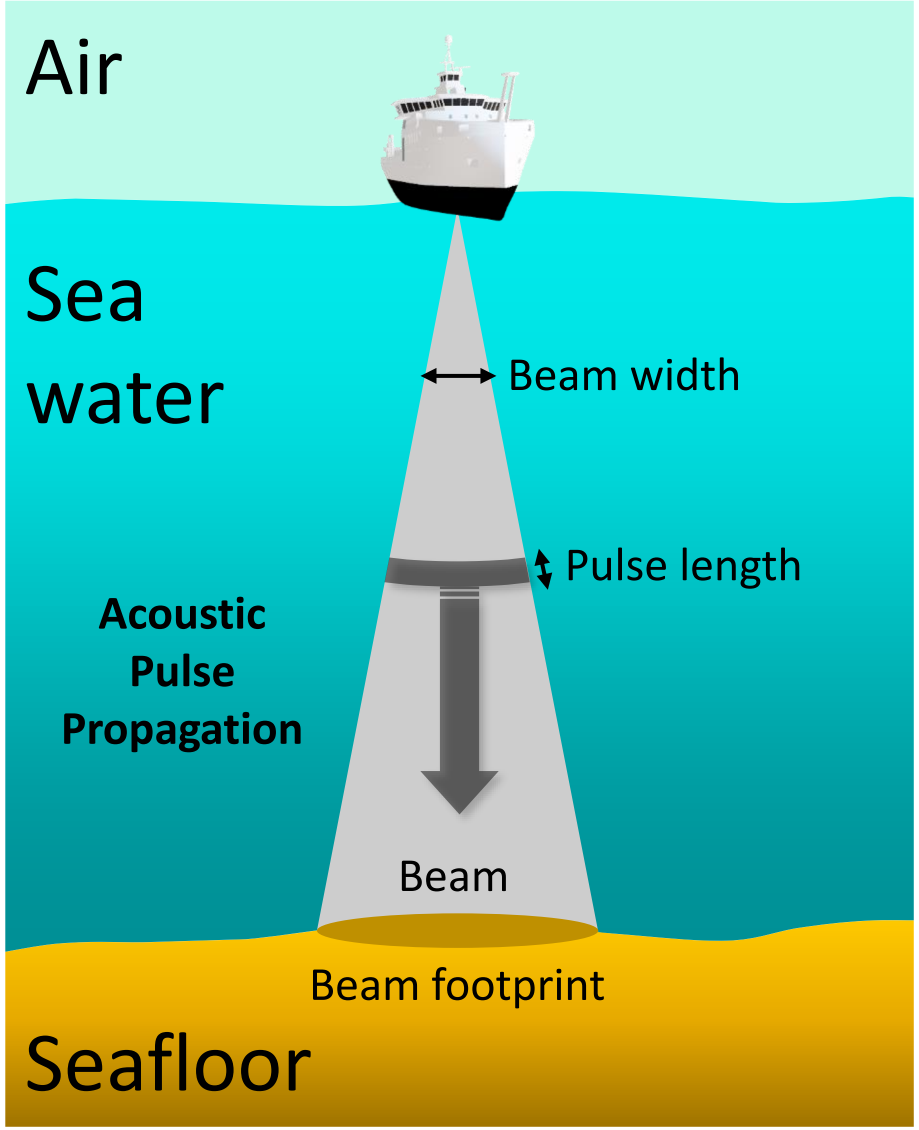
FPS Economy, S.M.E.s, Self-employed and Energy

Unveiling the Wonders of Backscatter

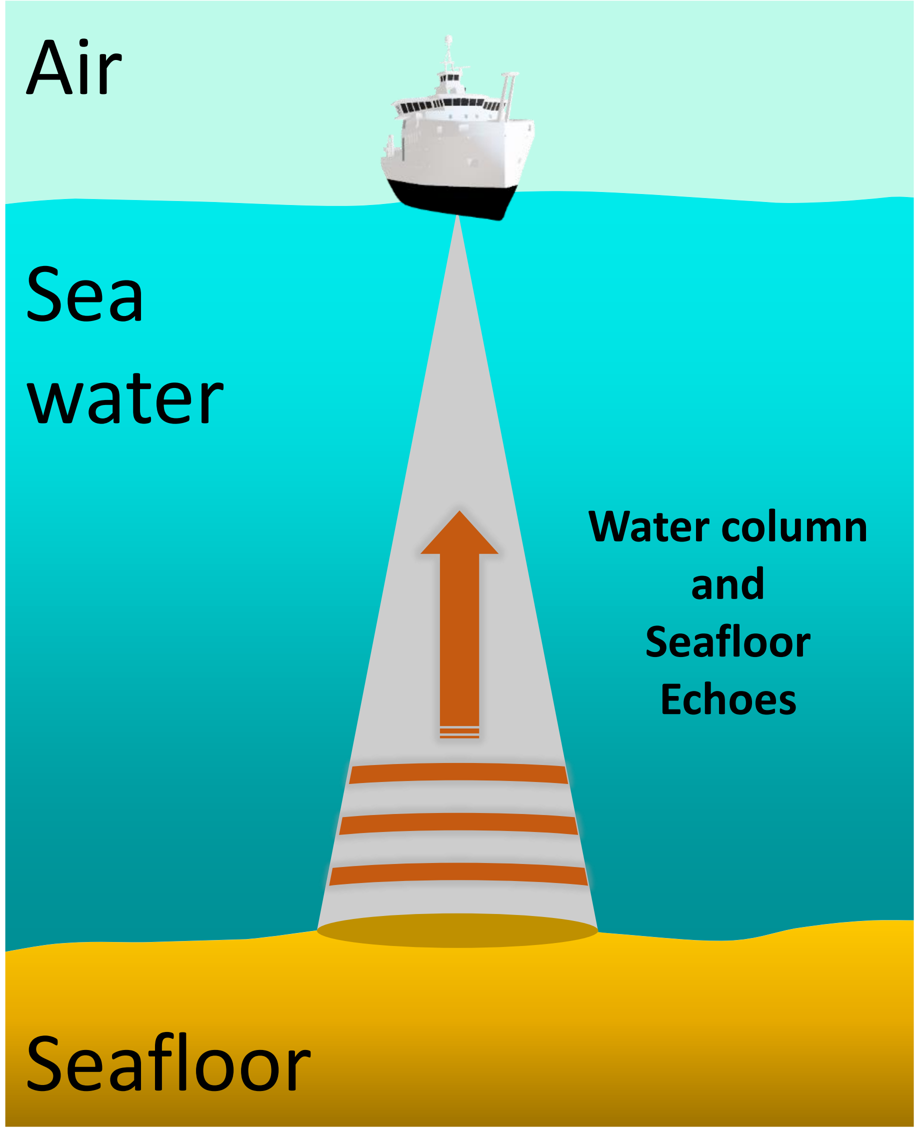


Marc Roche
Study Day 2024

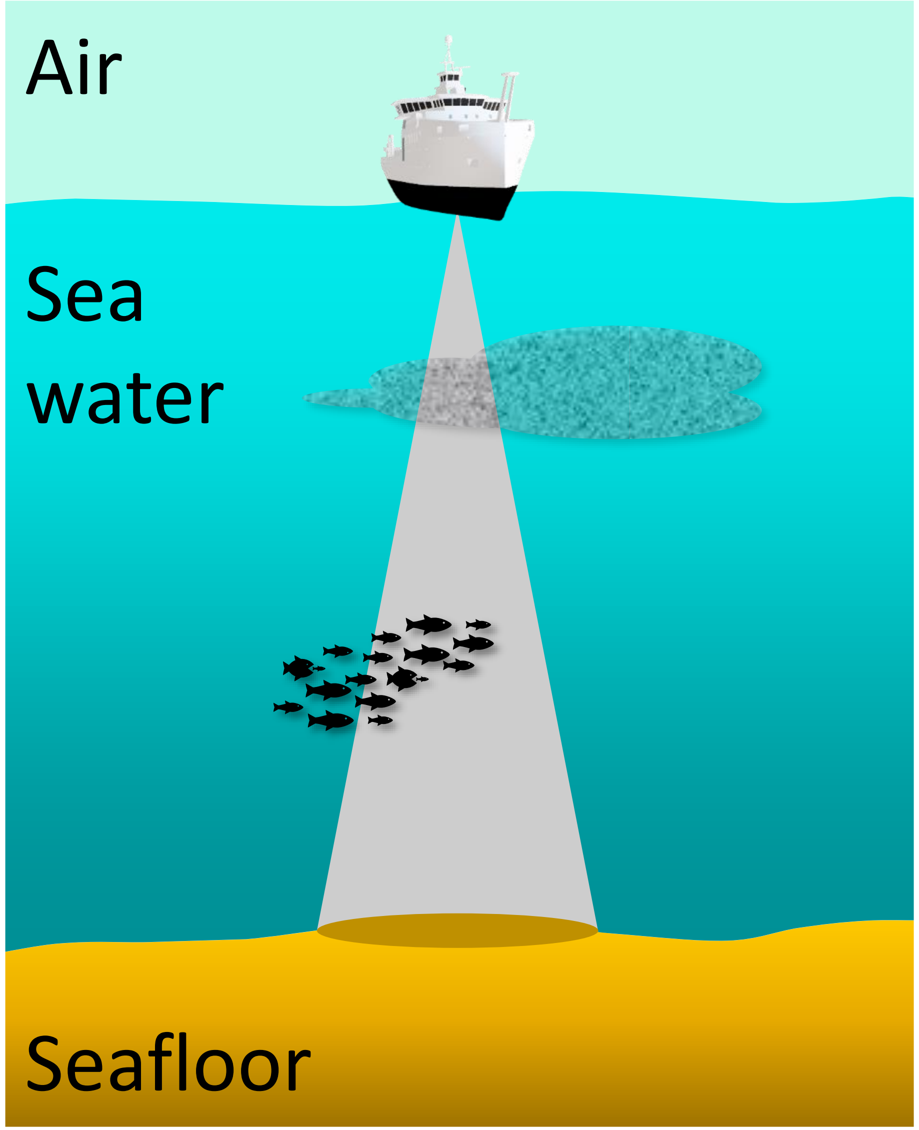
What are we talking about?

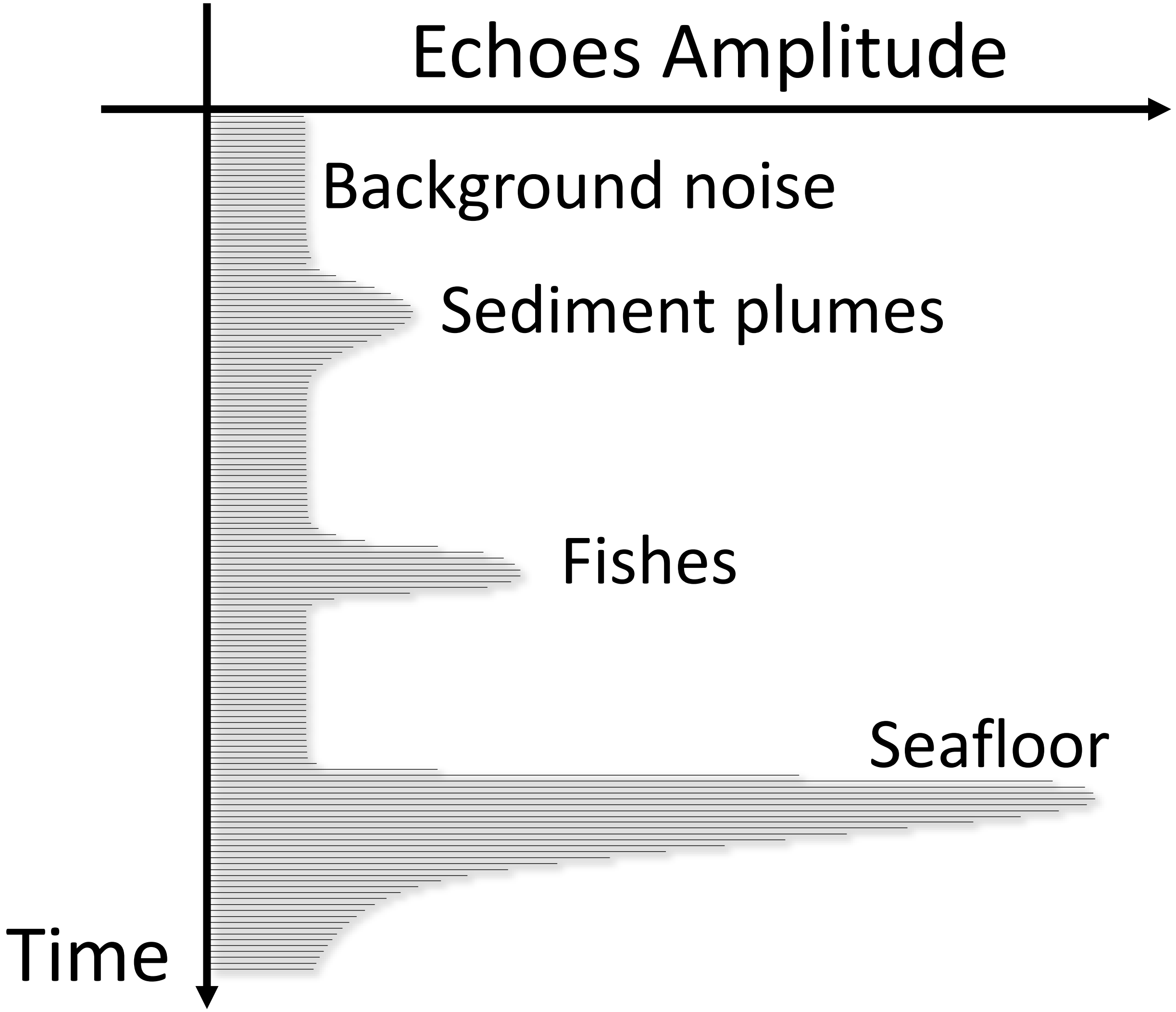


What are we talking about?

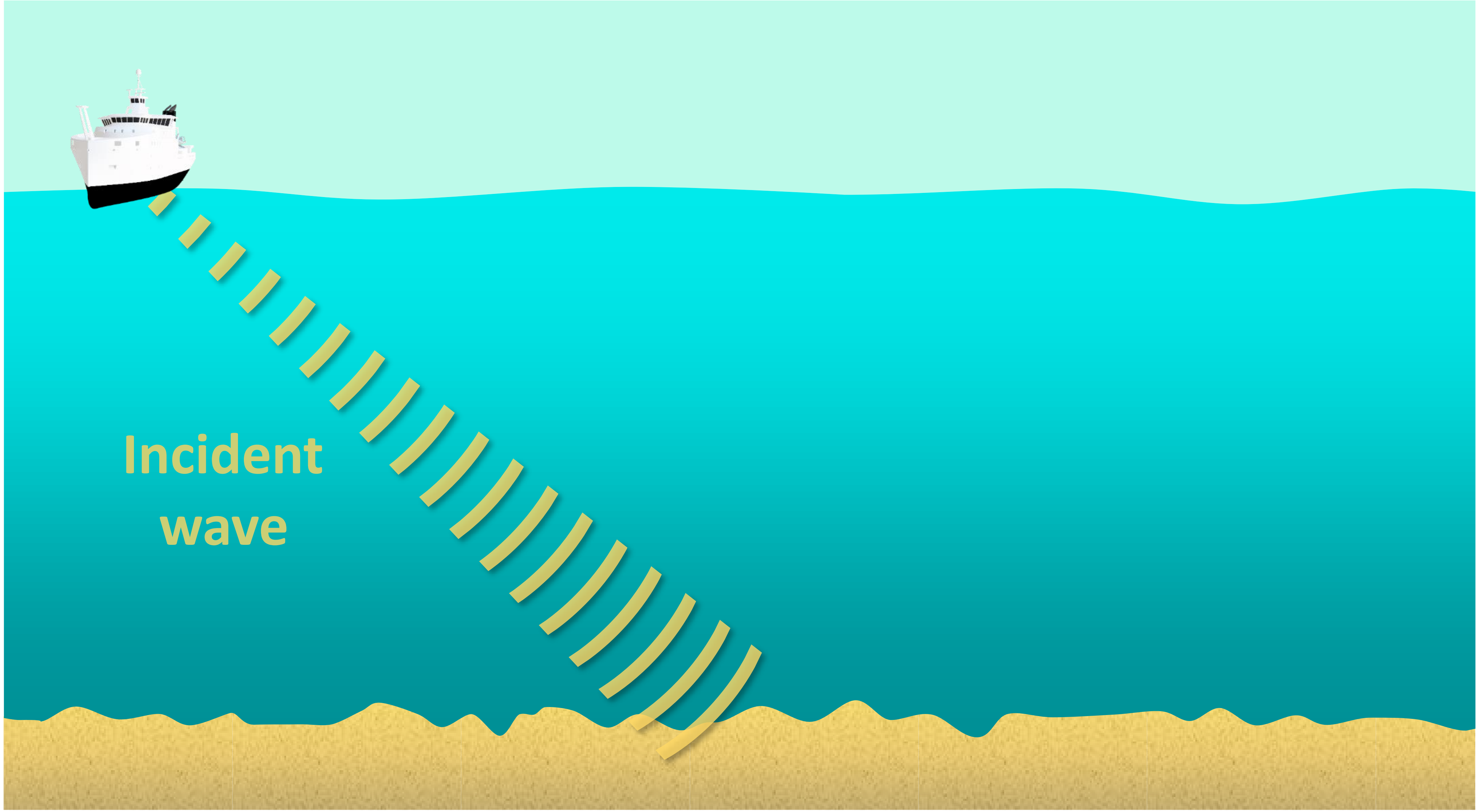


What are we talking about?

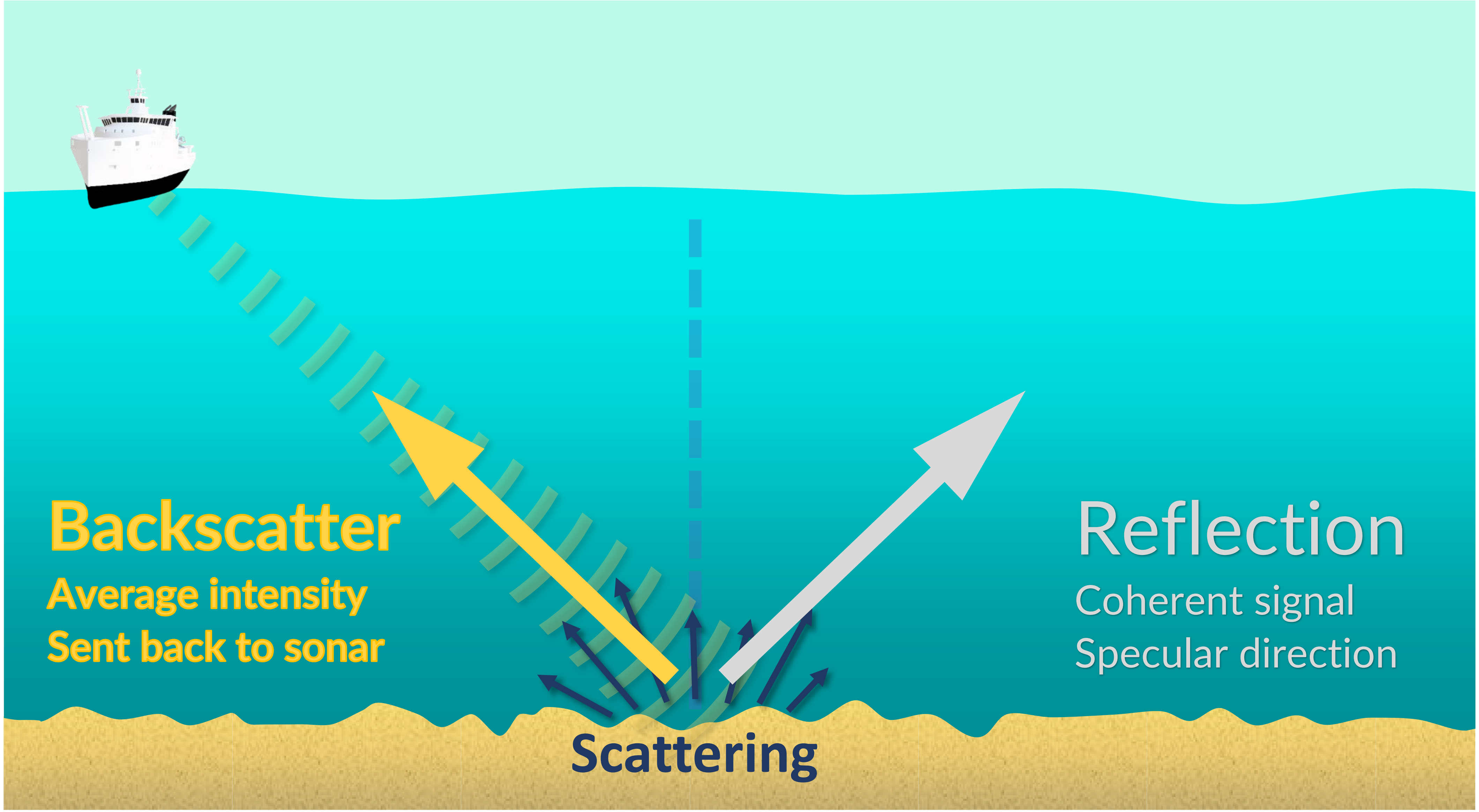




Terminology



Terminology



Backscatter

Average intensity

Sent back to sonar

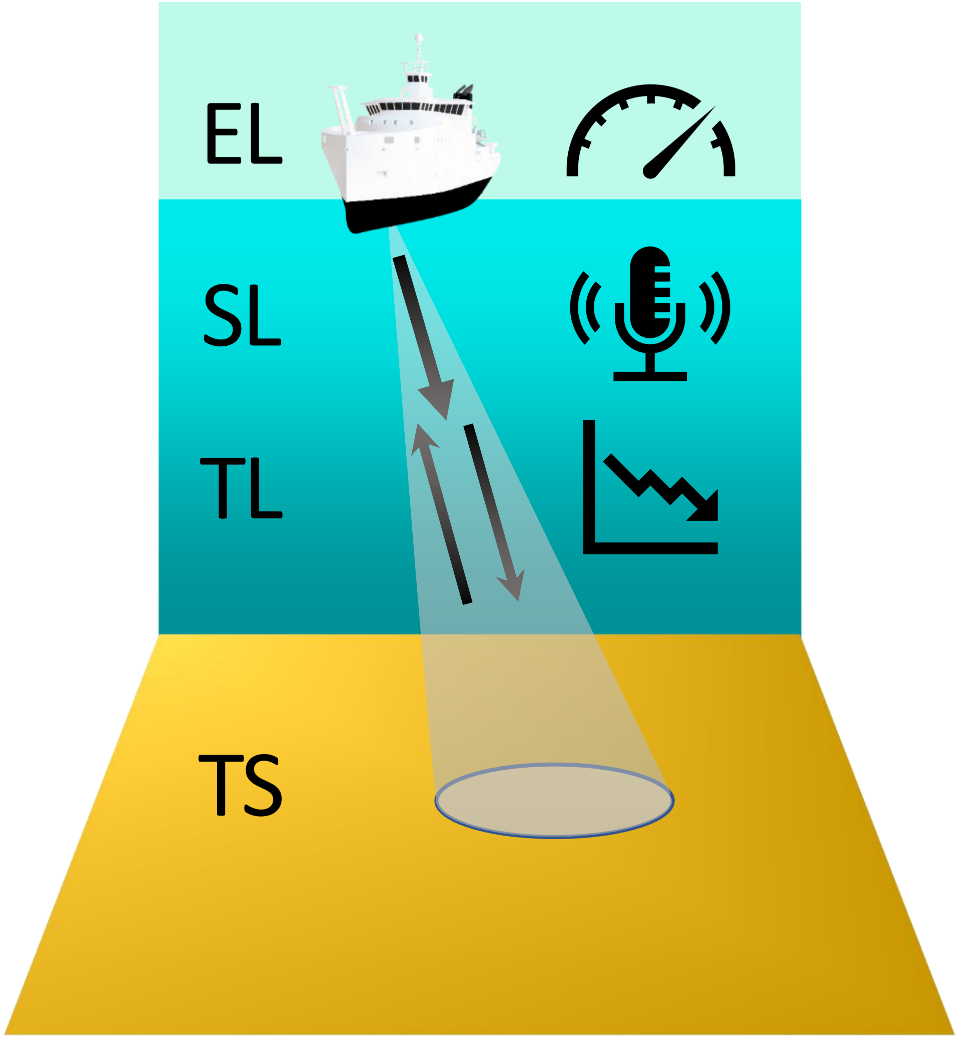
Reflection

Coherent signal

Specular direction

Scattering

The Sonar Equation (in dB): EL = SL - 2 TL + TS



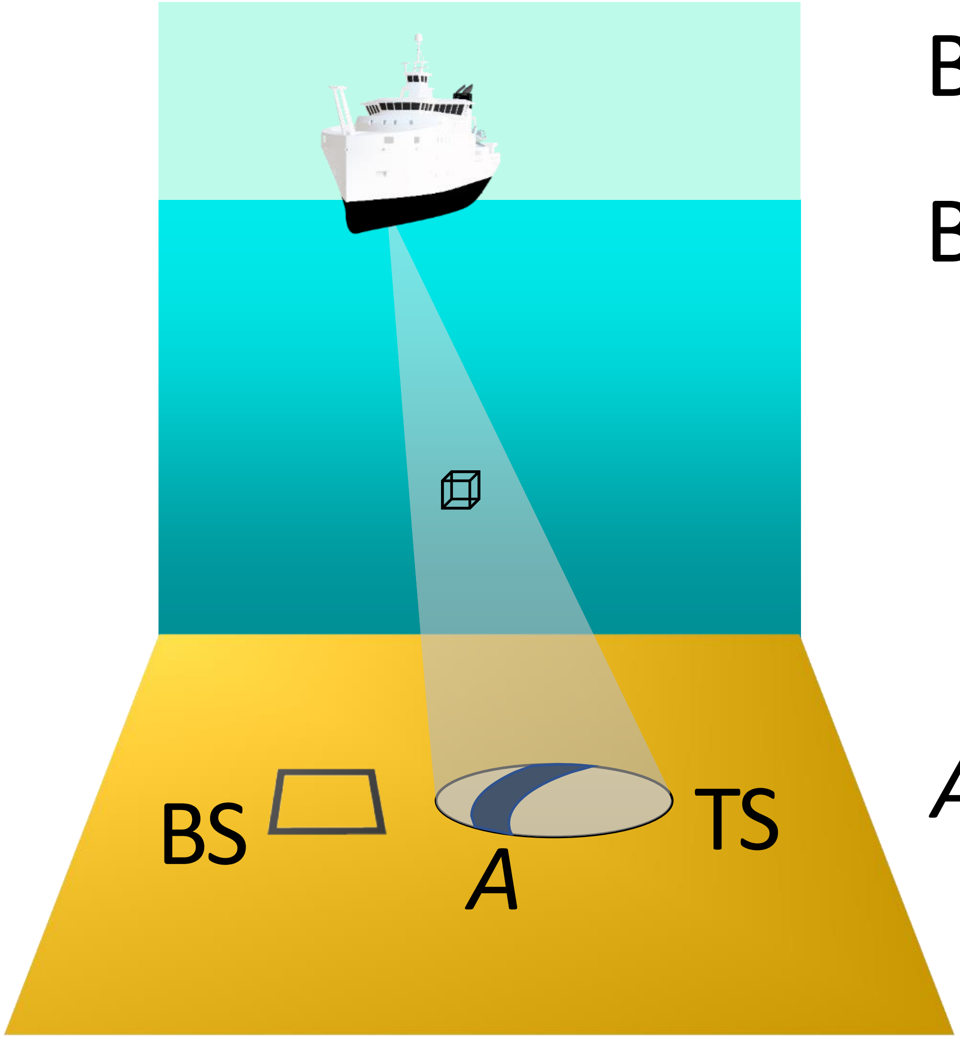
EL = Echo Level

SL = Source Level

TL = Transmission loss

TS = Target Strength = $\frac{\text{Backscatter intensity}}{\text{Incident intensity}}$

Backscatter Strength - BS



BS = TS - 10 log *A*

BS = Backscatter Strength (dB)

Target Strength (dB) of 1 m² seafloor

- Seafloor type & caracteristics
- Incident angle
- Frequency

A = Instantaneous ensonified area (m²)

- Sonar aperture ; signal duration
- Sonar configuration (range, angle…)

In Water Column: Sv = Volume Backscattering Strength (dB/m³)

Backscatter Strength - BS - dB

$$\text{BS in dB} \sim \log_{10}\left\{\frac{\text{backscatter intensity}}{\text{Incident intensity}}\right\}$$

Negative values:
backscatter intensity < incident intensity

Indicative values

Sediment Type	Typical BS (dB)
Mud - Silt	-30 dB to -20 dB
Fine - Medium sand	-20 dB to -15 dB
Medium - Coarse sand	-15 dB to -10 dB
Coarse sand - Gravel	-10 dB to -5 dB
Gravel	-5 dB to 0 dB

dB is not a linear scale!

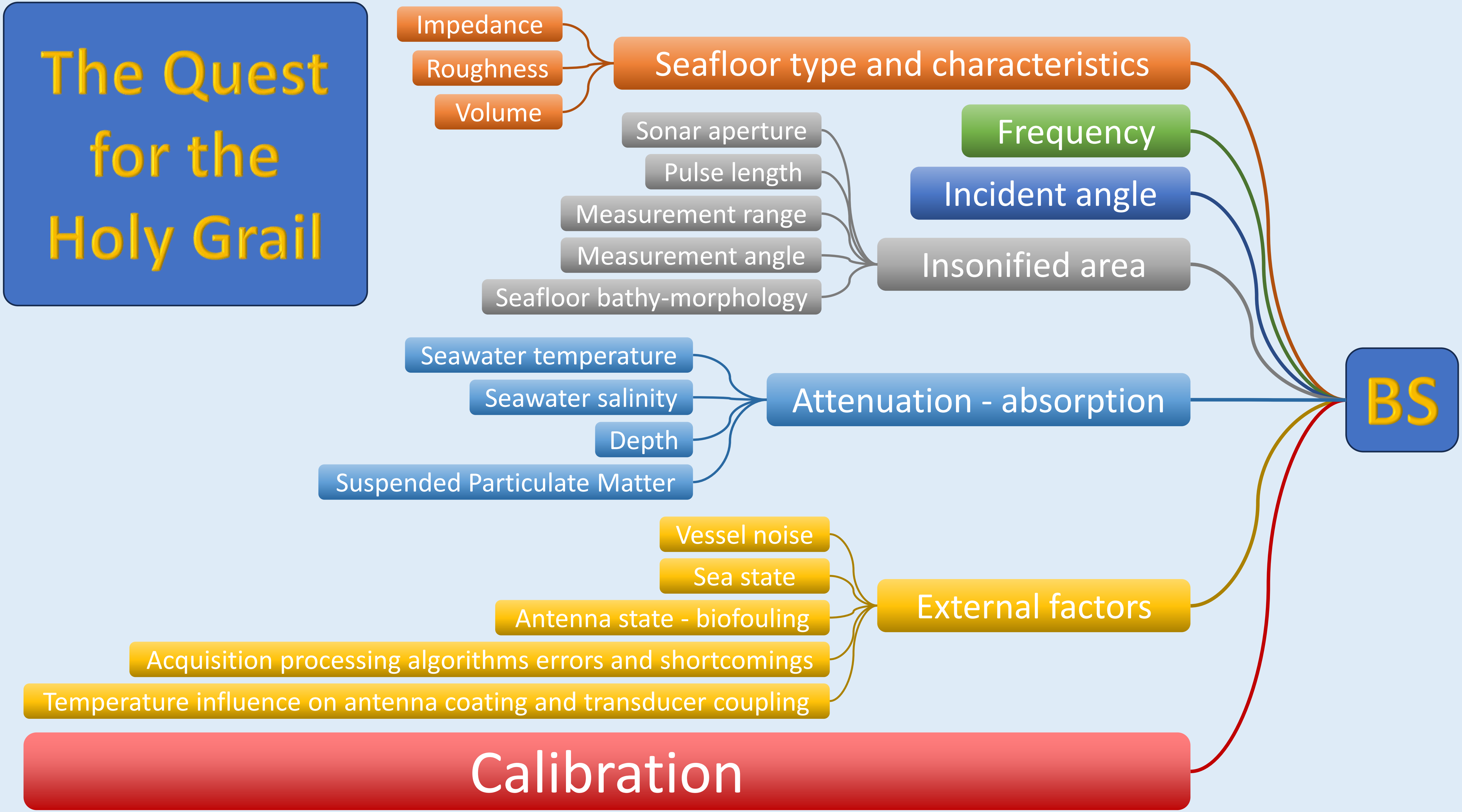
Δ dB	Equivalent x Intensity
1	1.3
2	1.6
3	2.0
4	2.5
5	3.2
10	10
20	100
30	1000

Coarse sand (-15 dB) generates an echo 100 times more intense than a Silt (-25 dB)!

The Quest for the Holy Grail

- BS
  - Seafloor type and characteristics
    - Impedance
    - Roughness
    - Volume
  - Frequency
  - Incident angle
  - Insonified area
    - Sonar aperture
    - Pulse length
    - Measurement range
    - Measurement angle
    - Seafloor bathy-morphology
  - Attenuation - absorption
    - Seawater temperature
    - Seawater salinity
    - Depth
    - Suspended Particulate Matter
  - External factors
    - Vessel noise
    - Sea state
    - Antenna state - biofouling
    - Acquisition processing algorithms errors and shortcomings
    - Temperature influence on antenna coating and transducer coupling
  - Calibration

The Quest for the Holy Grail



- Seafloor type and characteristics
  - Impedance
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  - Volume
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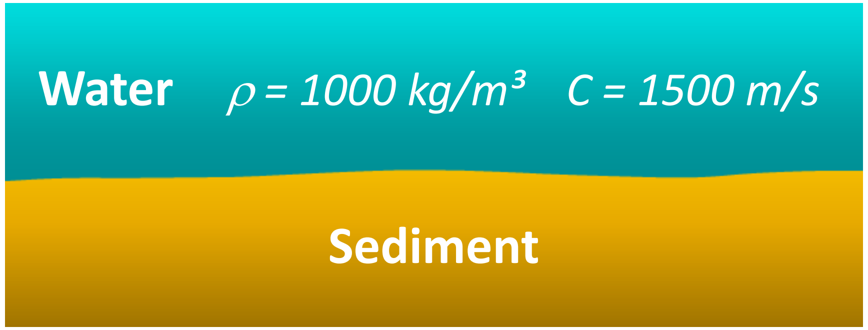
Acoustic impedance

- Acoustic impedance = $Z = \rho . c$

ρ = density kg/m³

c = acoustic velocity m/s

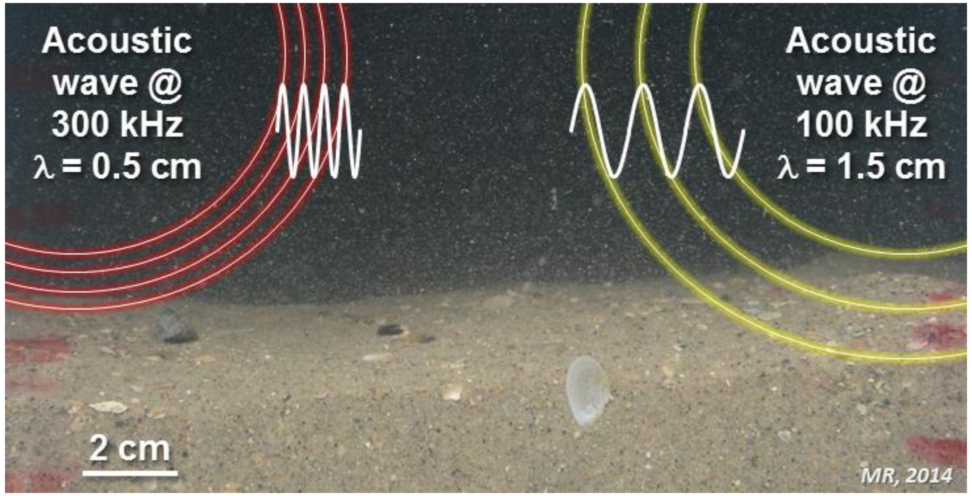


- Impedance contrast sediment – water = $V = \dfrac{Zwater - Zsed}{Zwater + Zsed}$

	ρ kg/m³	C m/s	Z_{sed}	V	V dB
Clay	1200	1470	$1.76\ 10^6$	0.081	-21,8
Clayey silt	1500	1515	$2.27\ 10^6$	0.204	-13,8
Sand + silt	1700	1600	$2.72\ 10^6$	0.290	-10,7
Coarse sand	2000	1800	$3.60\ 10^6$	0.411	-7,7

Roughness and Frequency

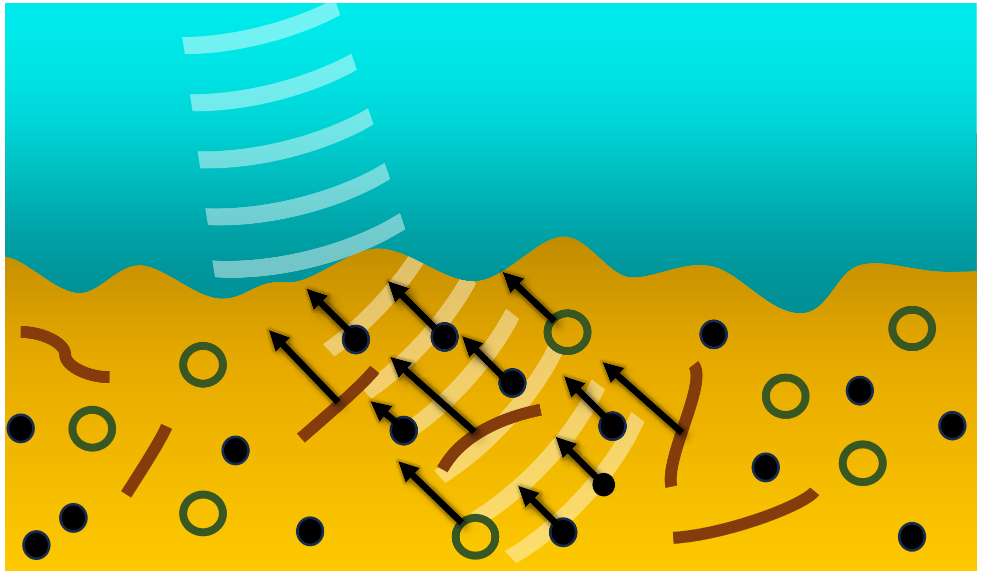
- Roughness is the ratio of average micro-relief to wavelength λ (= $\frac{V}{F}$)
- Relative notion:

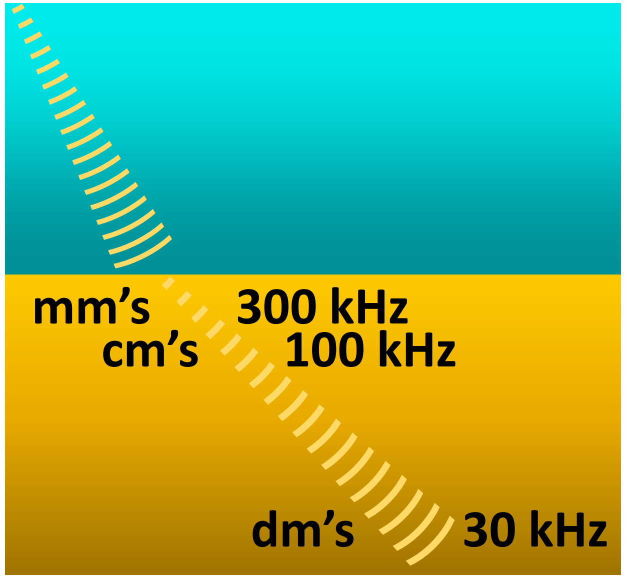


- The rougher the sediment interface, higher the backscatter
- Roughness strongly correlated with sediment impedance

Volume contribution

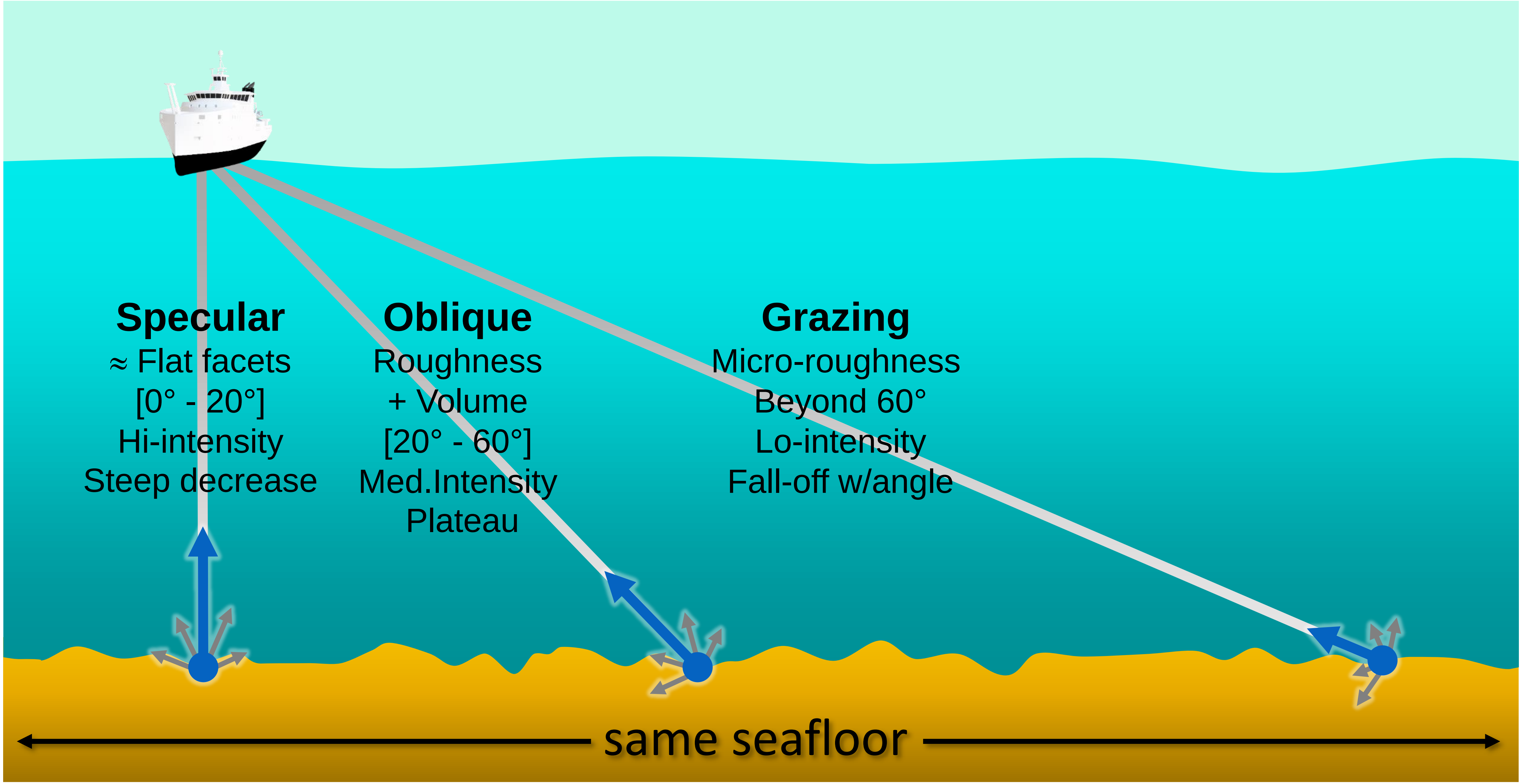
- Some of the incident acoustic energy may penetrate the sediment and be scattered by heterogeneities such as :
  - mineral inclusions
  - Biological diffusers
  - Gas bubbles
  - …





- Often prevalent at intermediate oblique incidence
- Relies on the acoustic wave penetration in the sediment
- Very strong influence of frequency (Low F <> High F)

Angular dependence: scattering regimes vs Angle



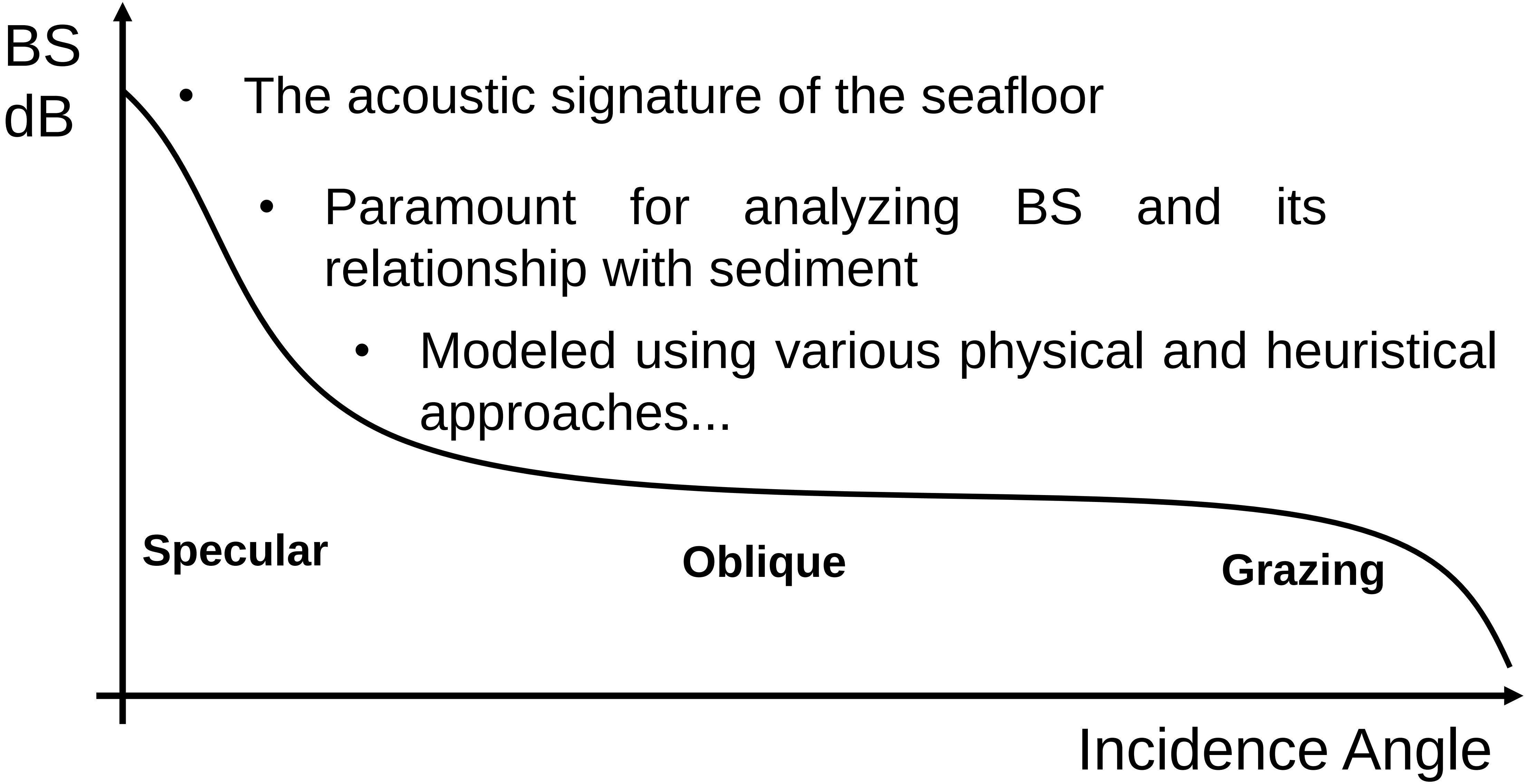
Specular
≈ Flat facets
[0° - 20°]
Hi-intensity
Steep decrease

Oblique
Roughness
+ Volume
[20° - 60°]
Med.Intensity
Plateau

Grazing
Micro-roughness
Beyond 60°
Lo-intensity
Fall-off w/angle

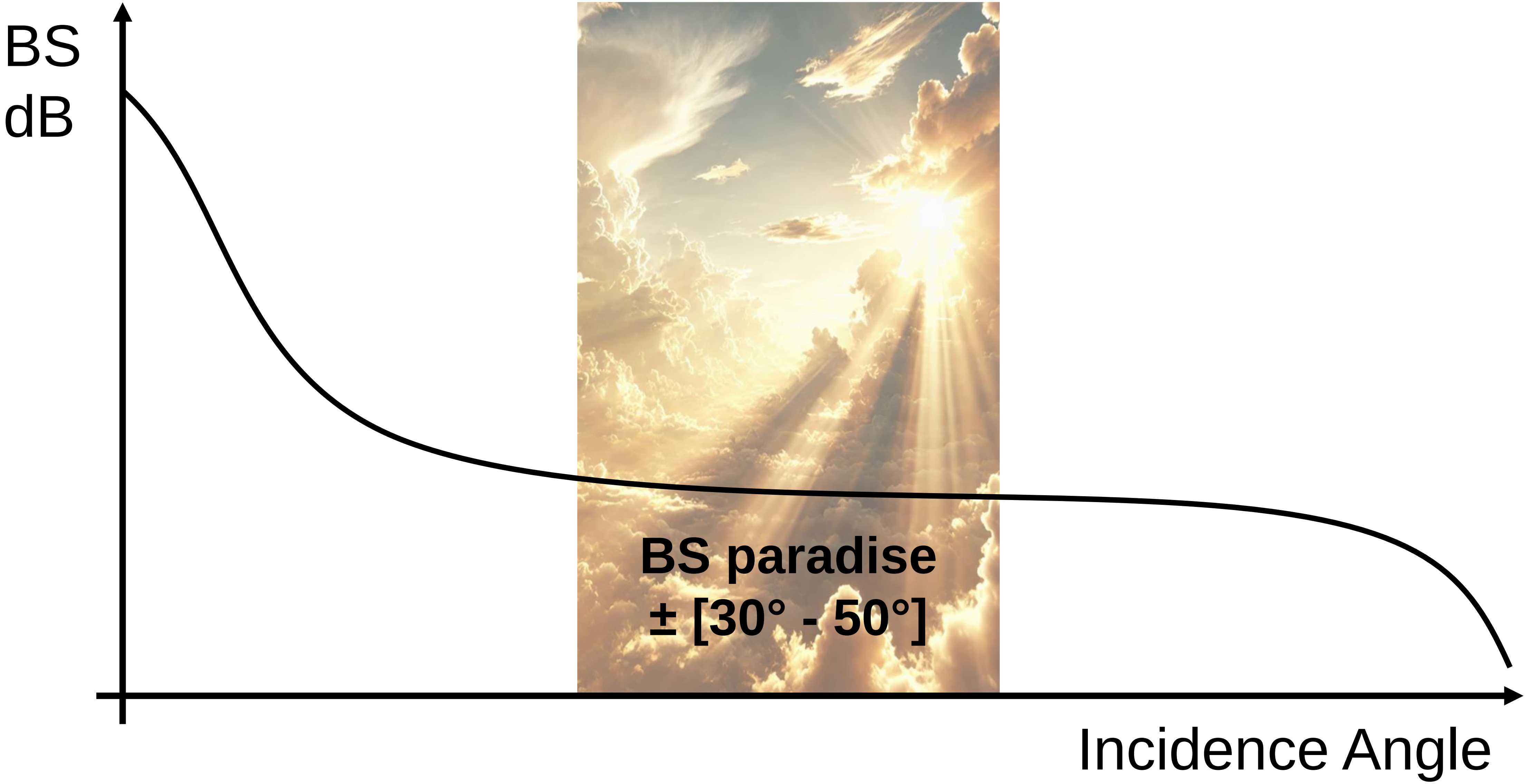
same seafloor

BS Angular Response



- The acoustic signature of the seafloor
- Paramount for analyzing BS and its relationship with sediment
- Modeled using various physical and heuristical approaches...

BS Angular Response

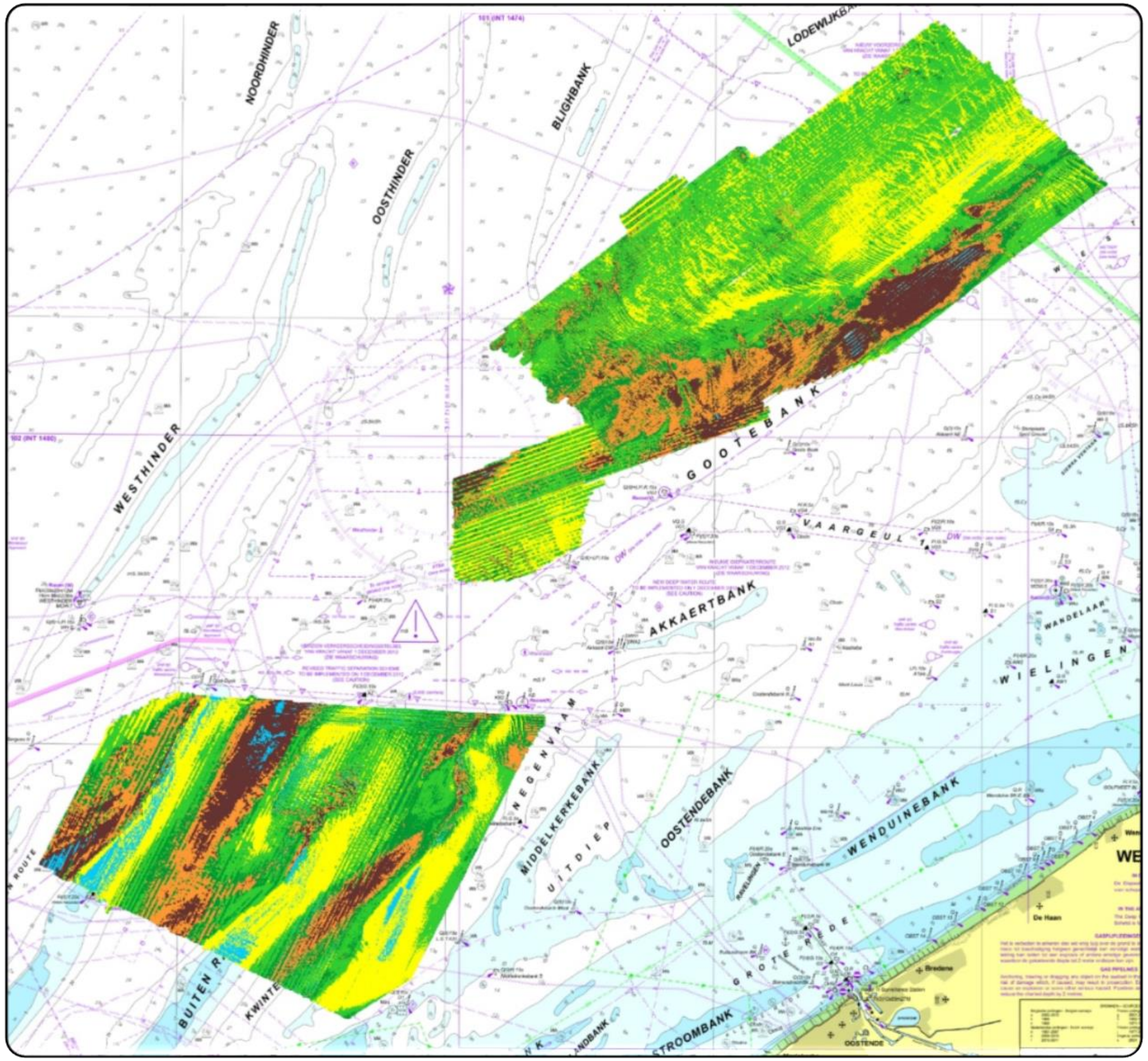


Using BS in relation to sand extraction

Illustrated by case studies

1. For surface sediment mapping
2. As a proxy for assessing the impact of extraction on the nature of the sediment
3. For tracking the sediment plumes
4. A few amusing anecdotes anecdotes on BS…

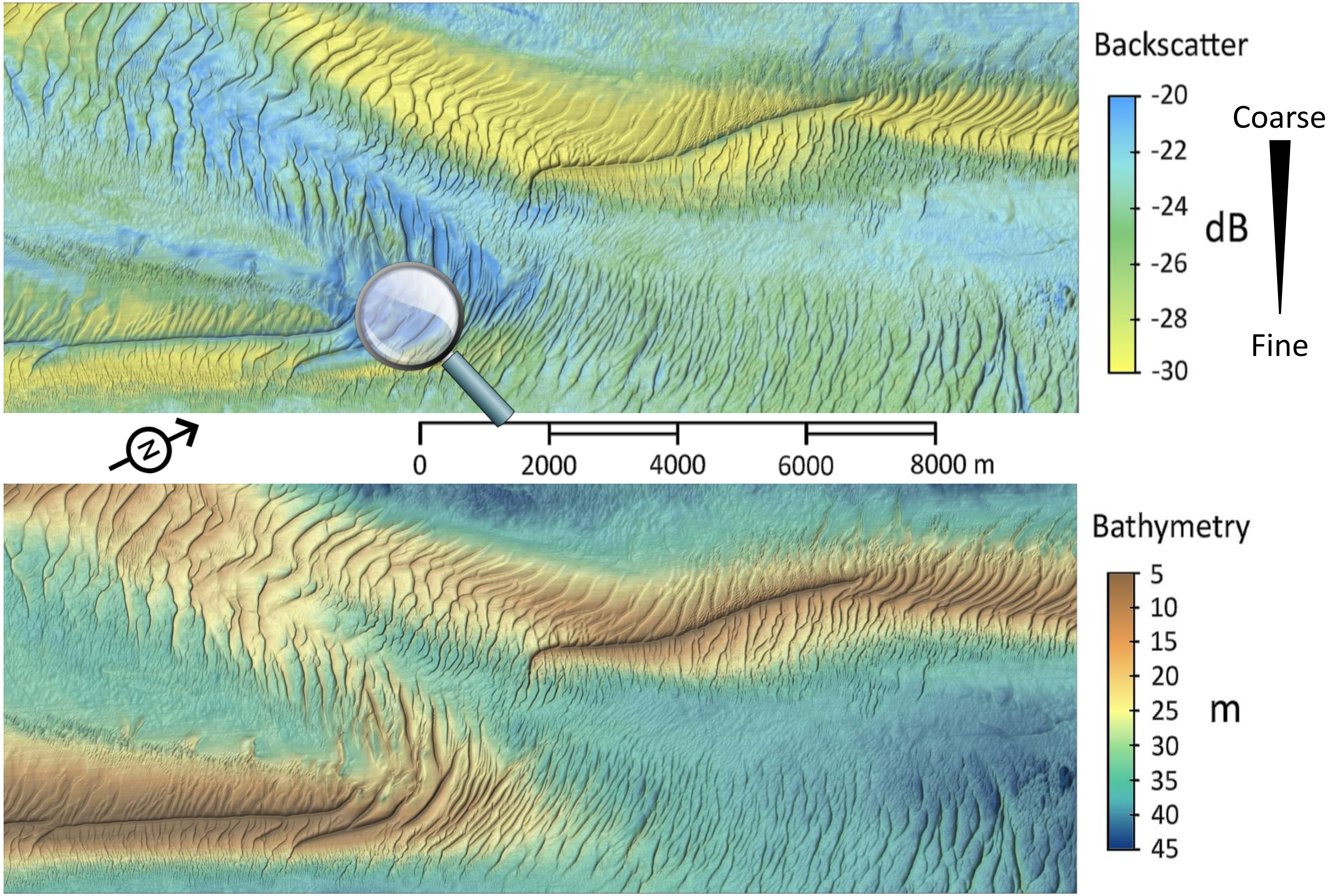
Surface sediment mapping



Old RV Belgica
EM1002 100 kHz - 2005

Class 1	🟫	· Highest BS · Clastic gravel in a sandy or muddy matrix, sandy gravel · Gravel fields in the swale · Typical " hillhocky " morphology	
Class 2	🟩	· Moderate BS · Gravely bioclastic sands (shells or shell debris) · Sand dune fields in the swale and on the bank · Most exploited granulate	
Class 5	🟩		
Class 3	🟧	· High BS · Fine muddy sand, few shells, Lagis koreni bioturbation · Flat area in the swales	
Class 4	🟨	· Lowest BS · Fine homogeneous sand · Shalowest areas	
Outlier	🟦		

Surface sediment mapping

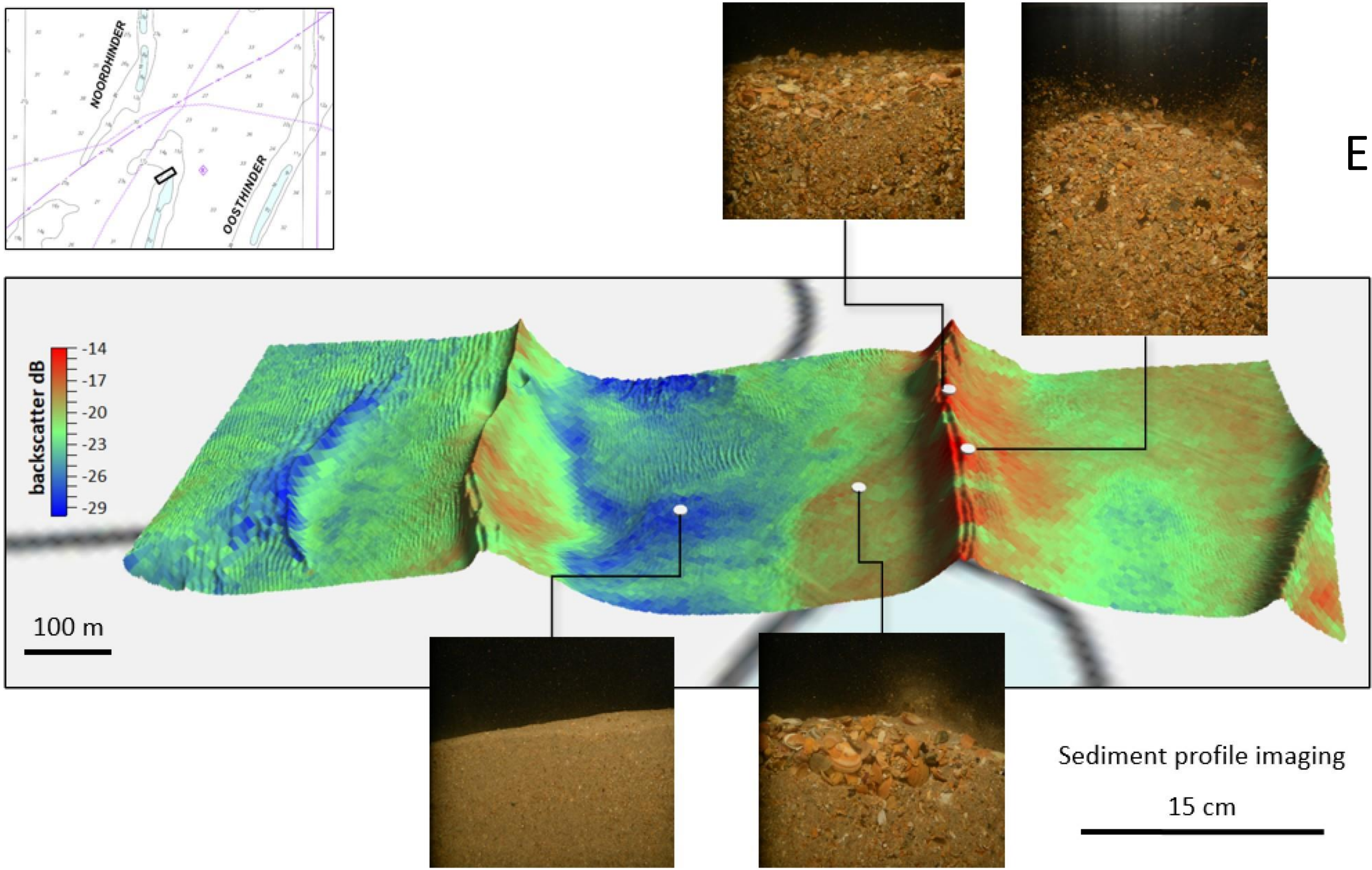


Westhinder and
Noordhinder

Old RV Belgica
EM3002D 300 kHz
2012

Surface sediment mapping

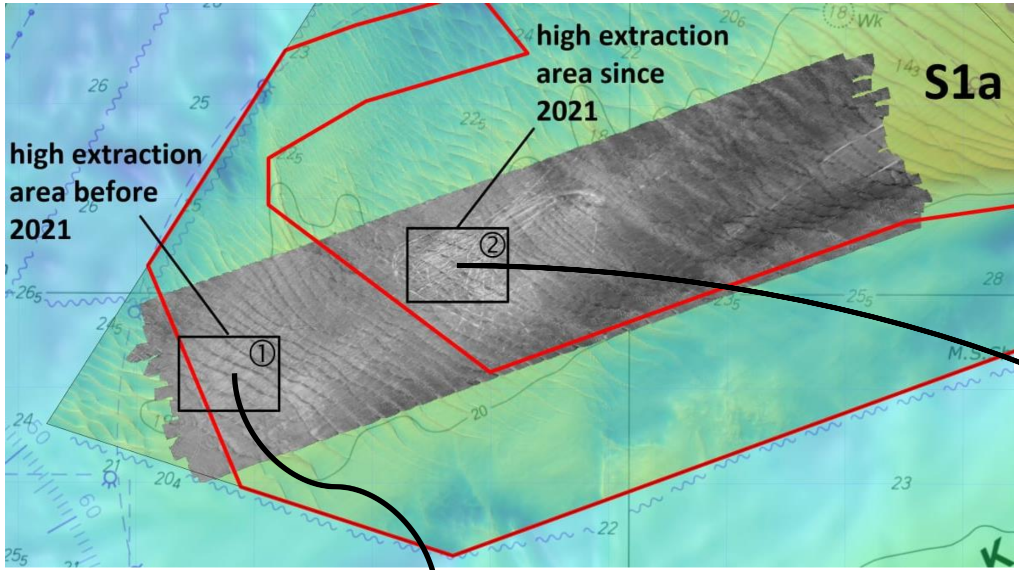
Westhinder
RV Simon Stevin
EM2040D 300 kHz
2022



Sediment profile imaging

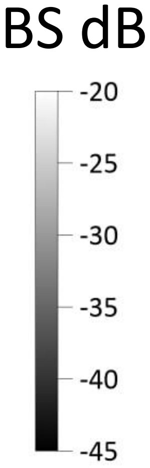
15 cm

Surface seafloor mapping

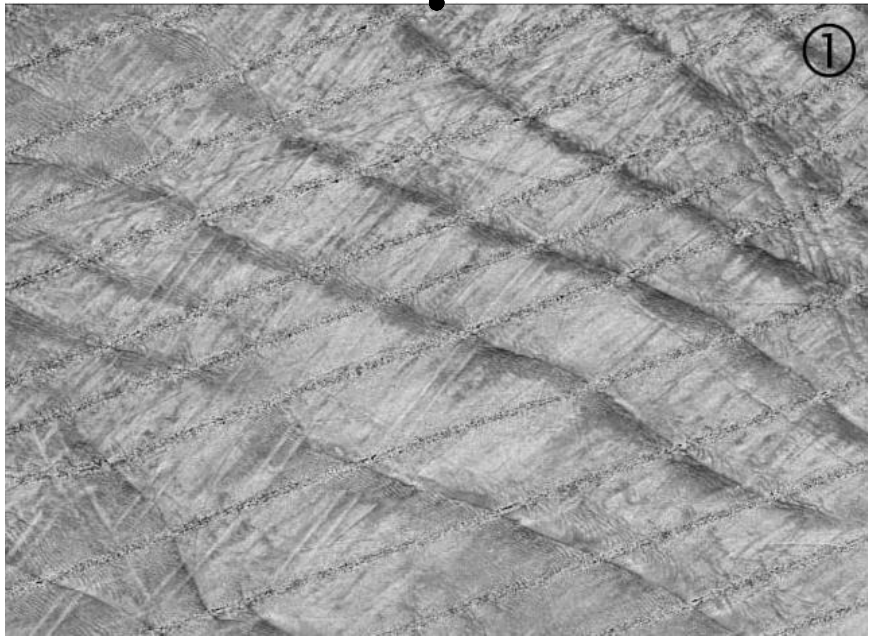


closed to sand extraction since 01/01/2021

□

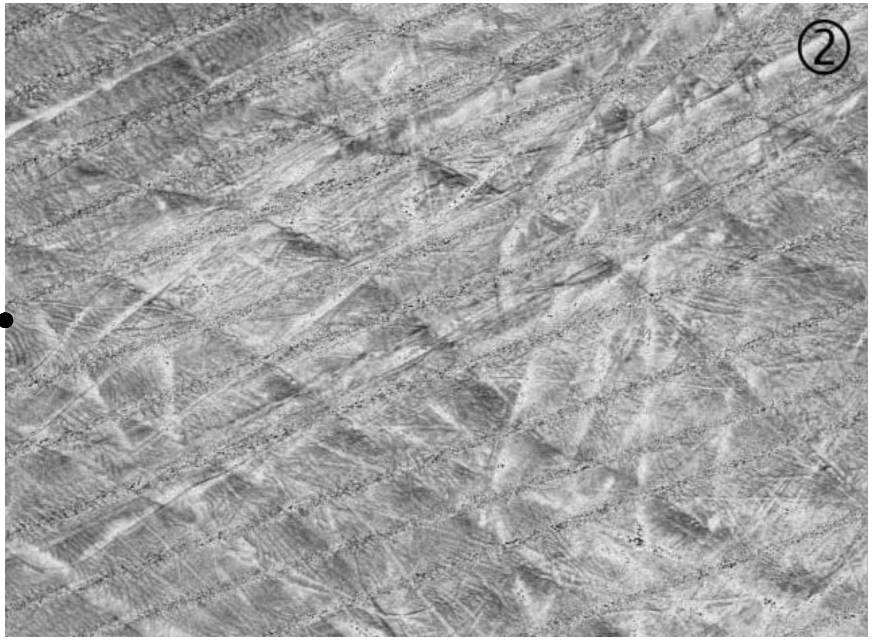


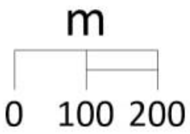
Thorntonbank
Old RV Belgica
EM3002D
300 kHz
2021



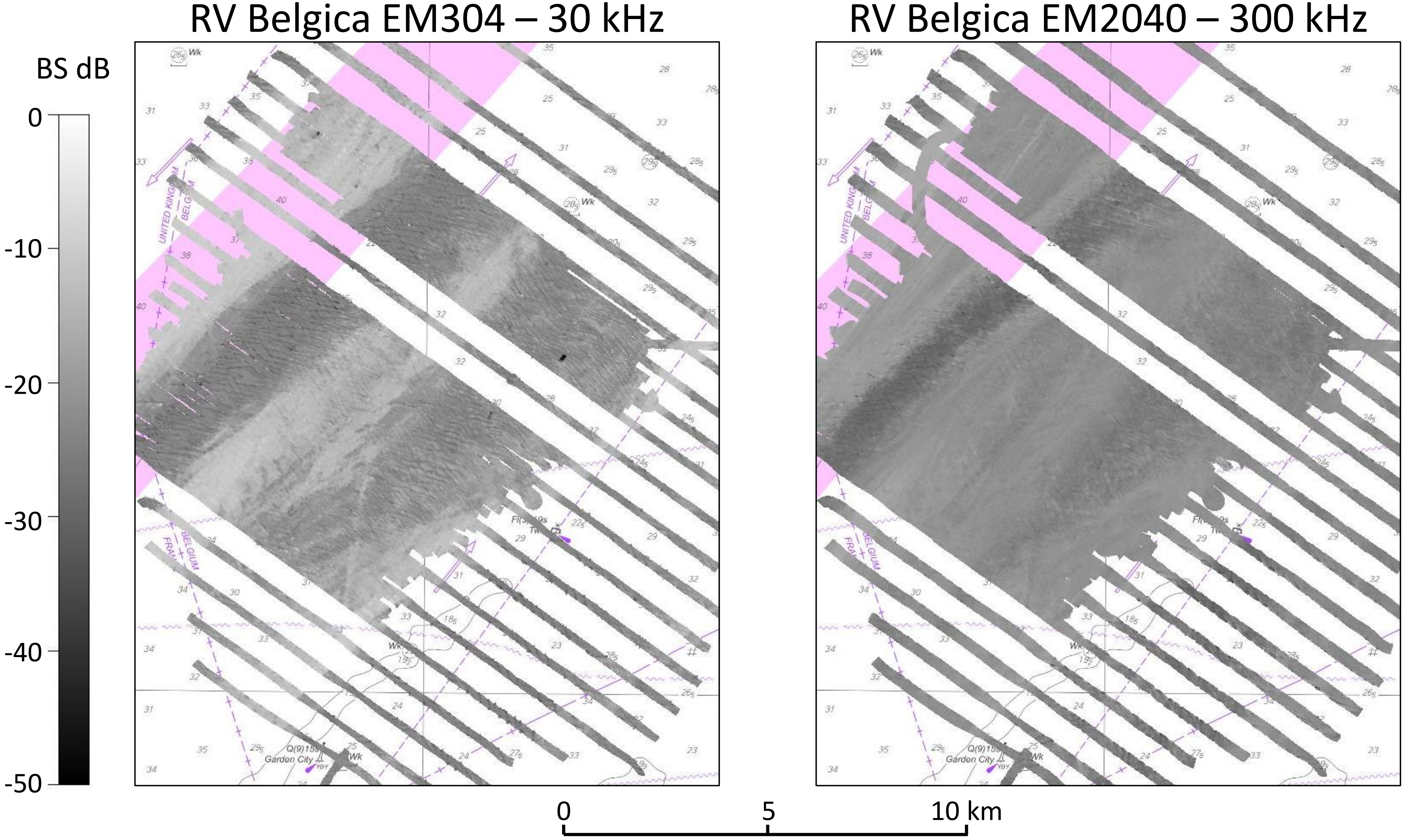
Intensive trawling

Intensive dredging





Surface sediment mapping



RV Belgica EM304 – 30 kHz

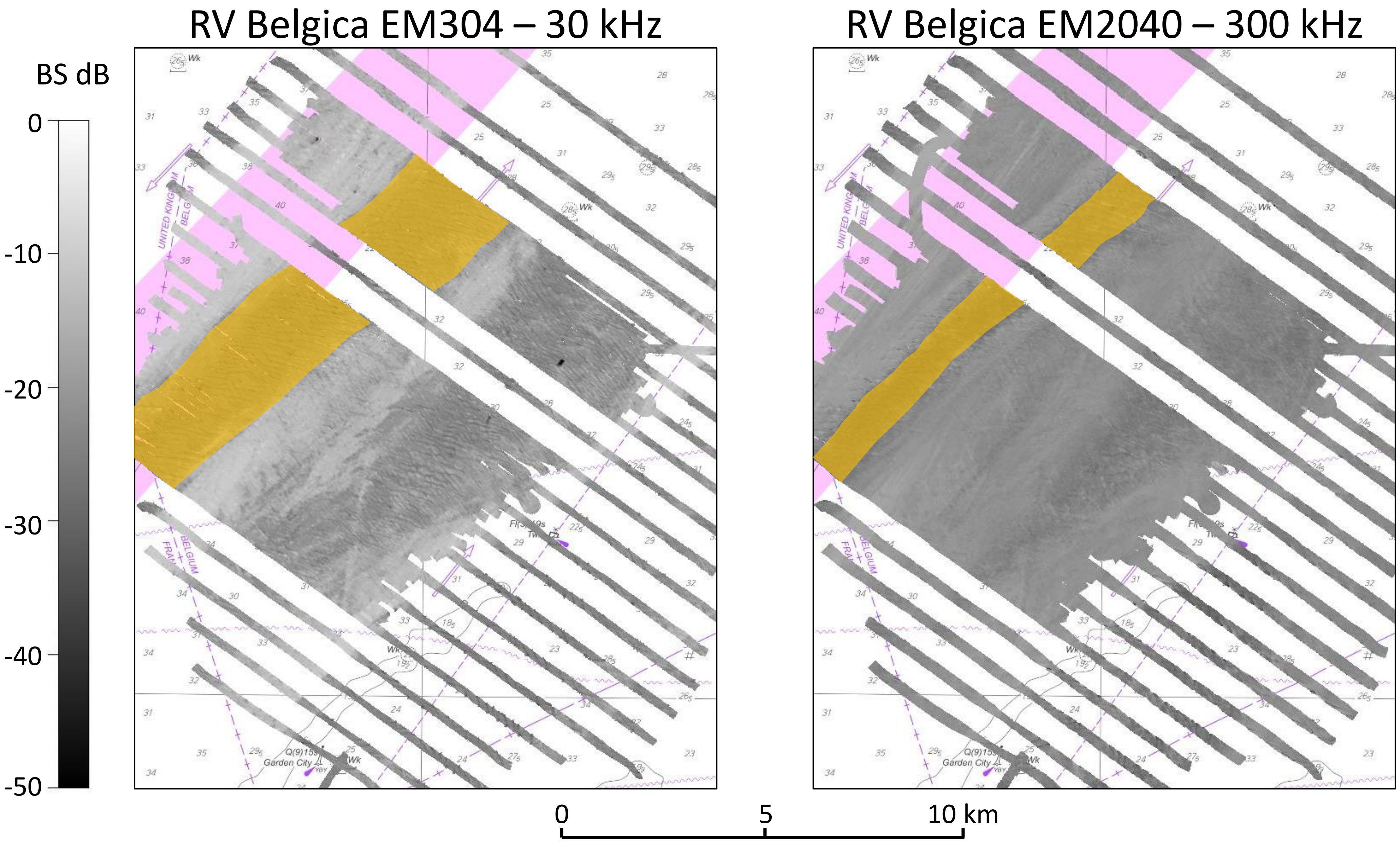
RV Belgica EM2040 – 300 kHz

Exploration area

2022

Δ Octave = 3.32

Surface sediment mapping


RV Belgica EM304 – 30 kHz

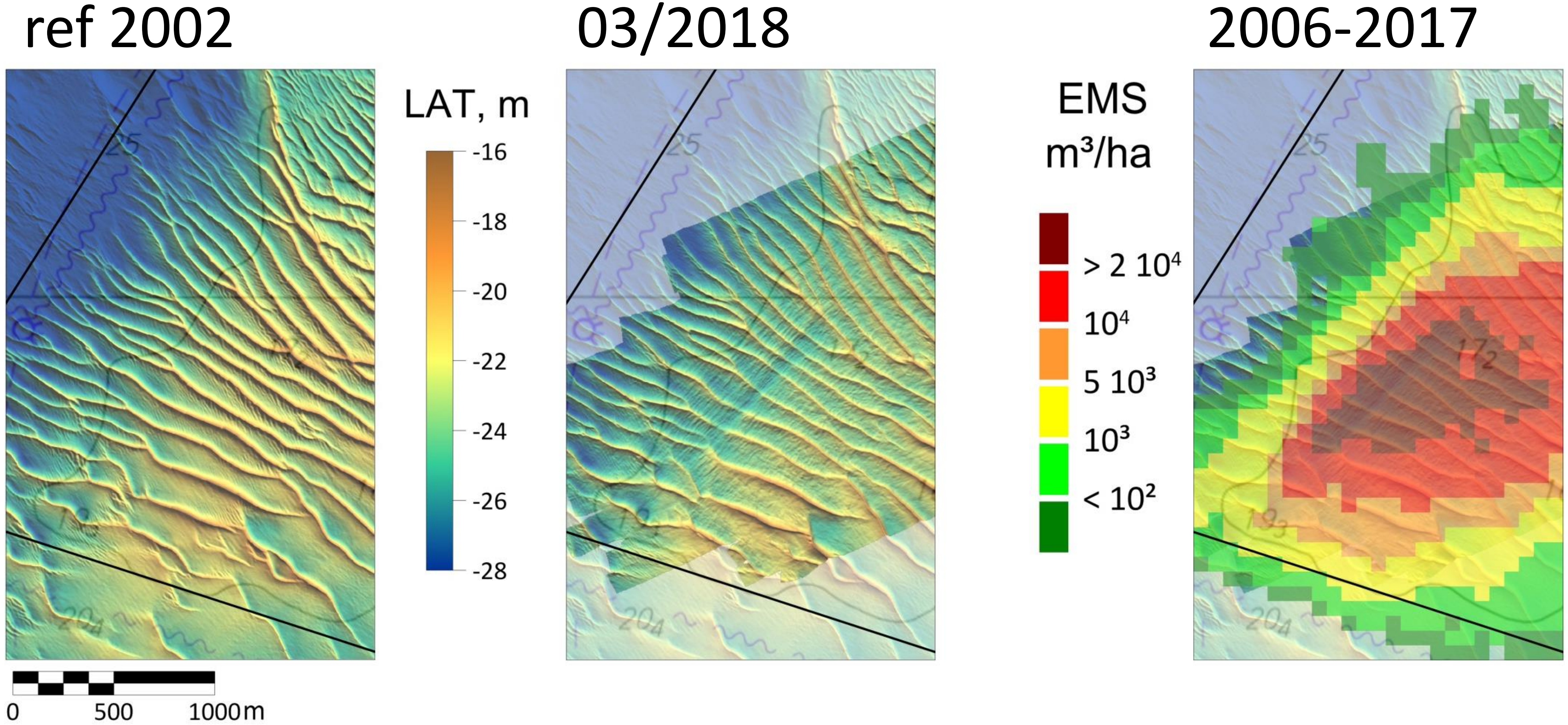
RV Belgica EM2040 – 300 kHz

Exploration area

2022

Δ Octave = 3.32

BS for monitoring the seabed: *Case study 1 - Thorton bank SW*



ref 2002

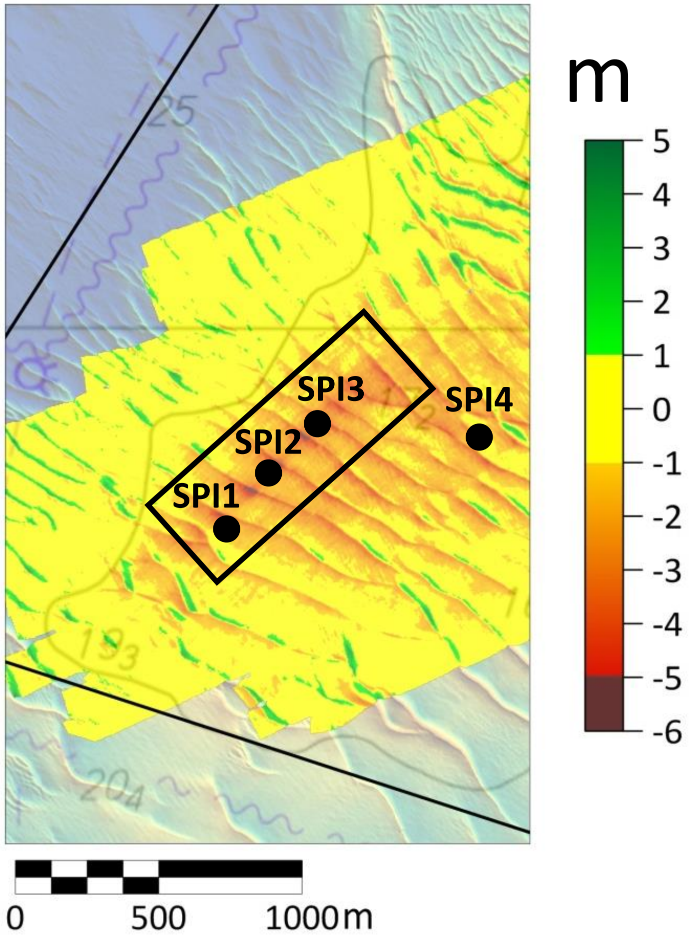
03/2018

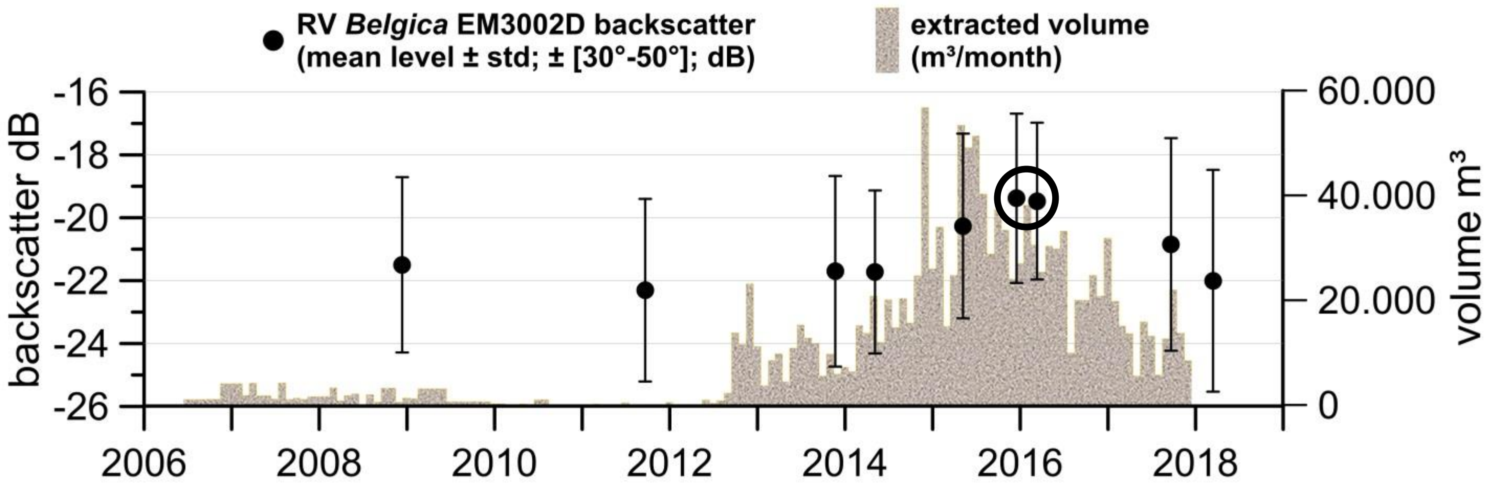
2006-2017

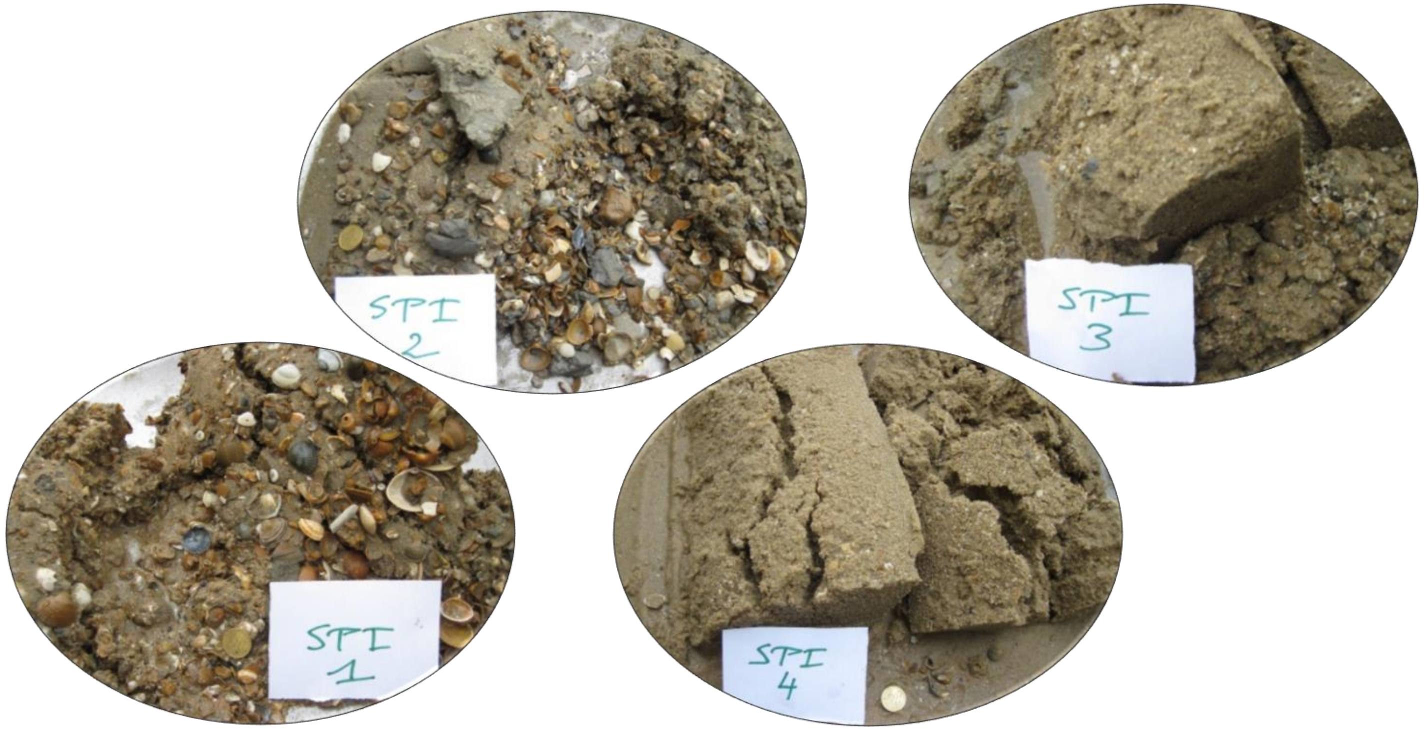
BS for monitoring the seabed: *Case study 1 - Thorton bank SW*

Δ

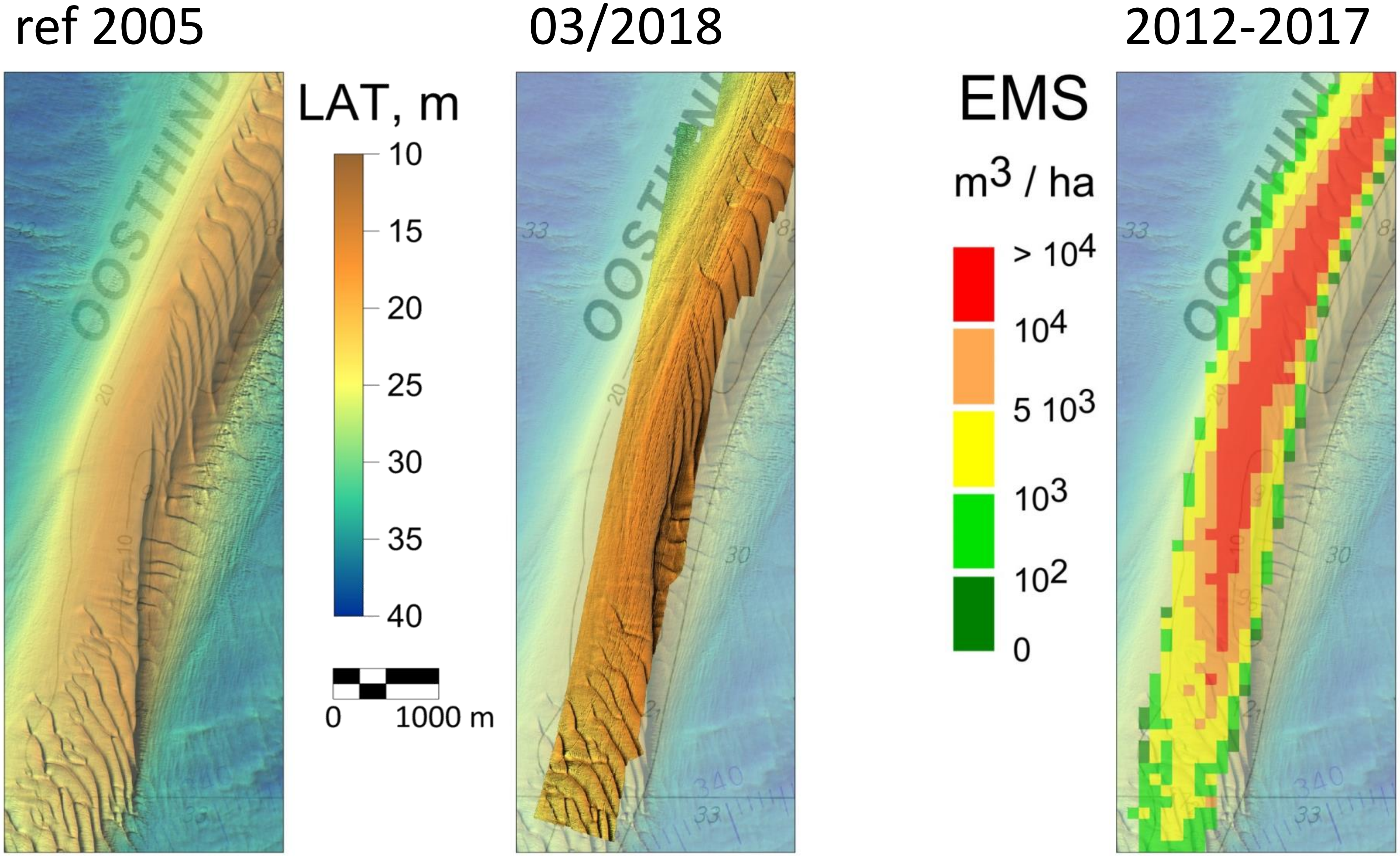
ref 2002 – 03/2018







BS for monitoring the seabed: *Case study 2 – Oosthinder Bank*

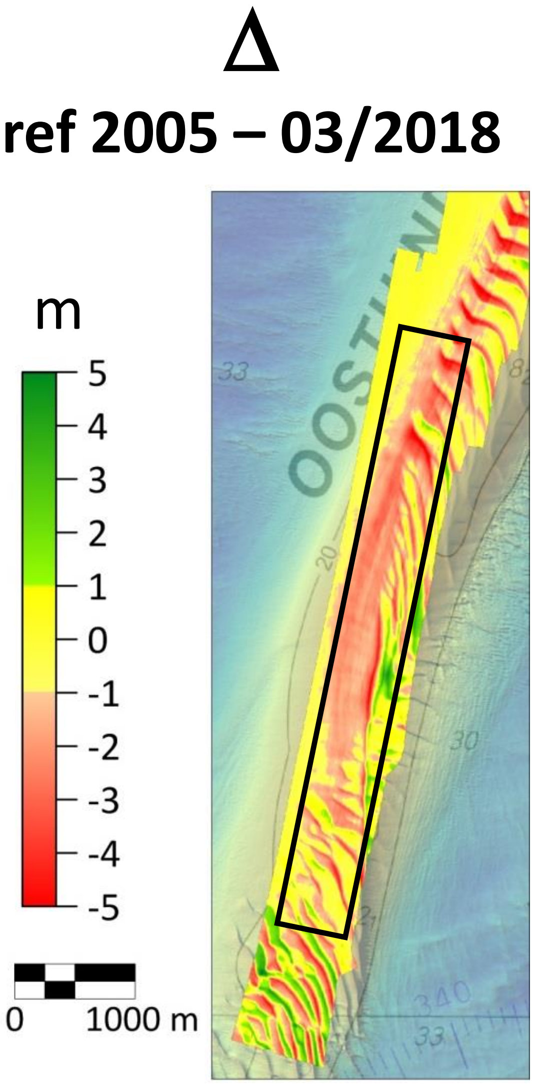


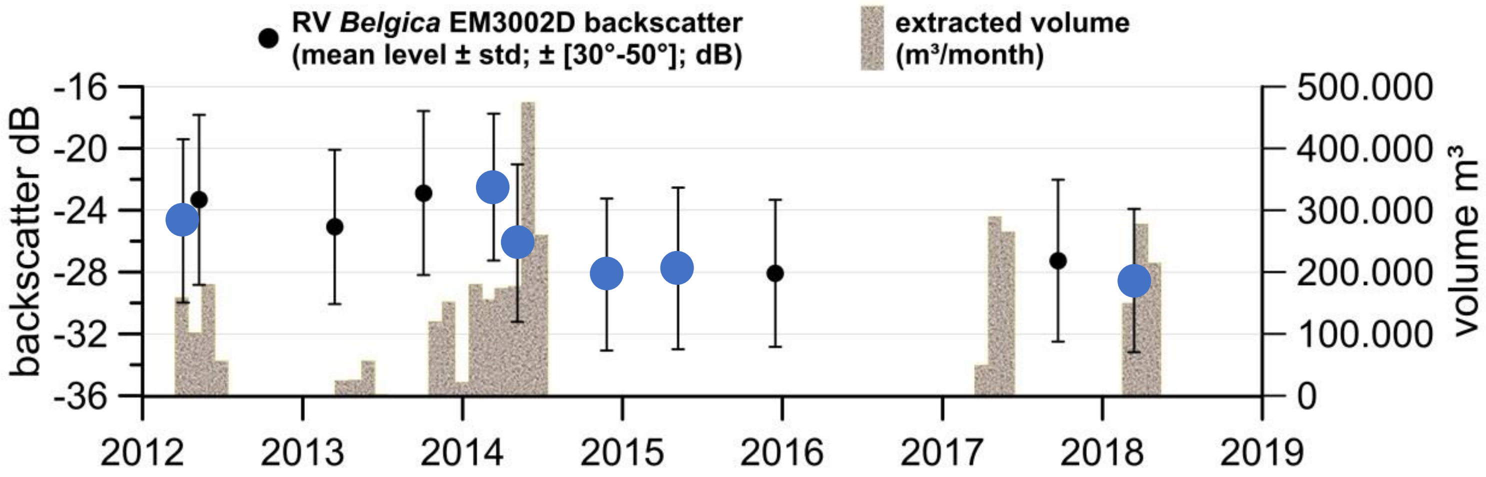
ref 2005

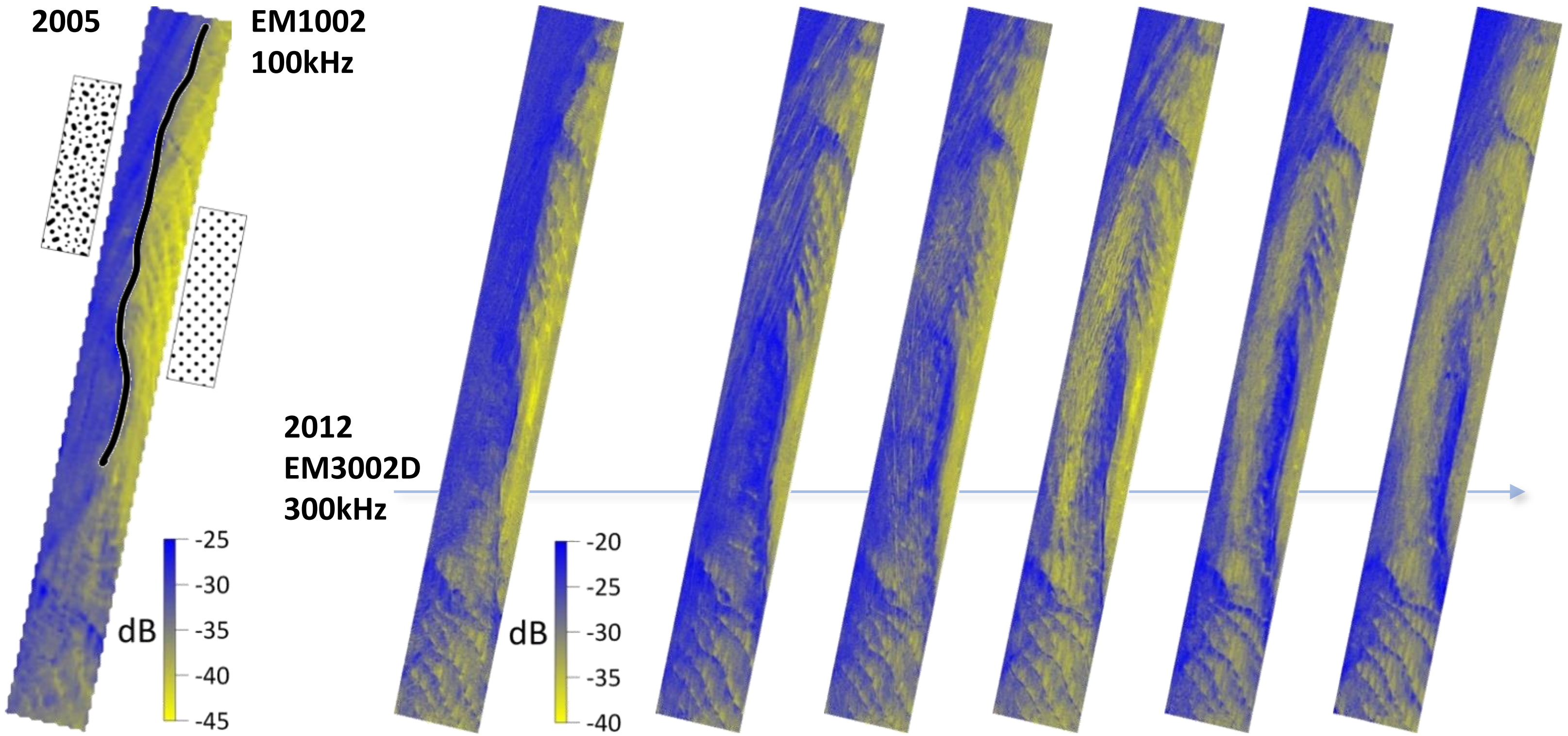
03/2018

2012-2017

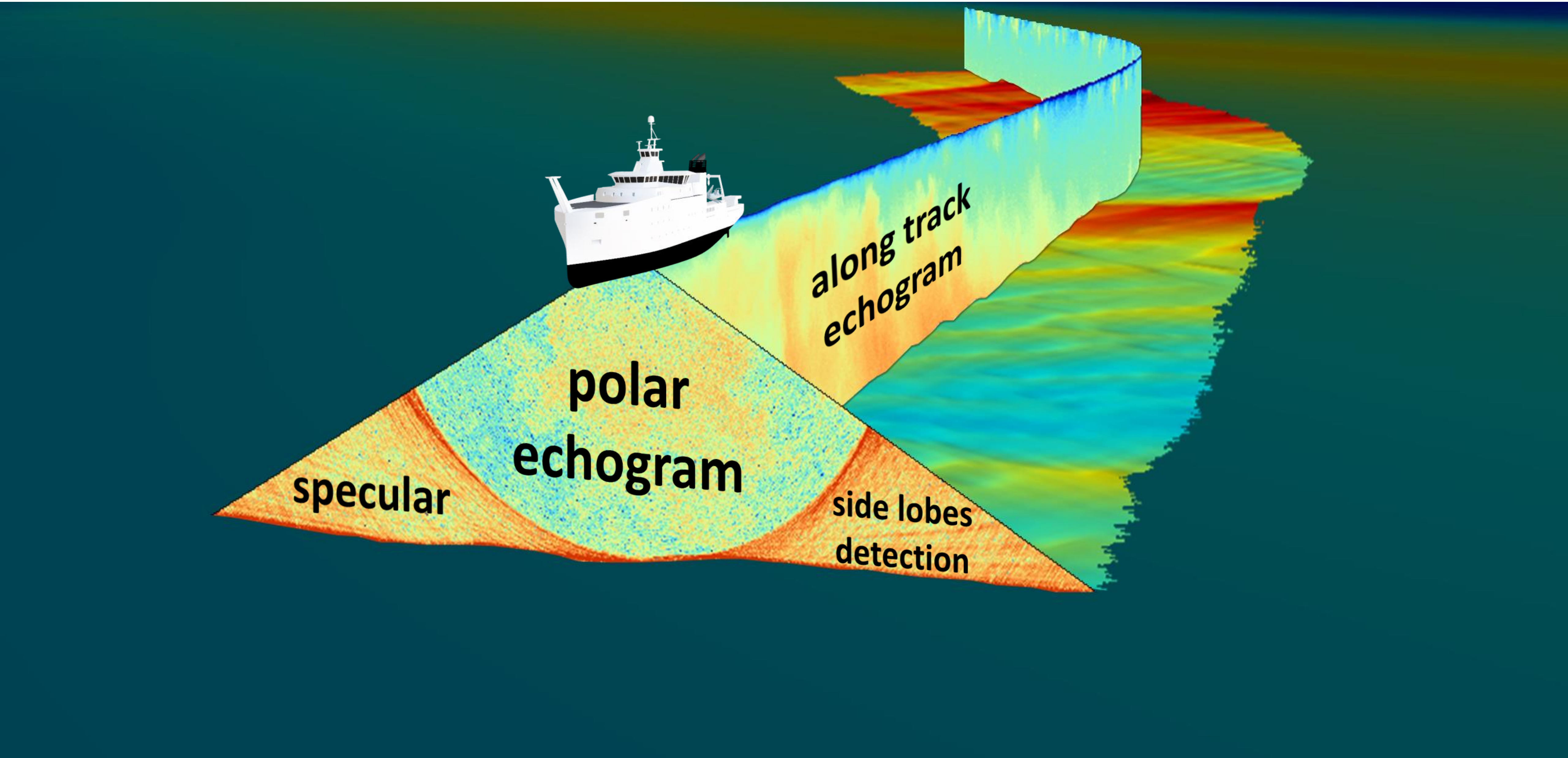
BS for monitoring the seabed: *Case study 2 – Oosthinder Bank*



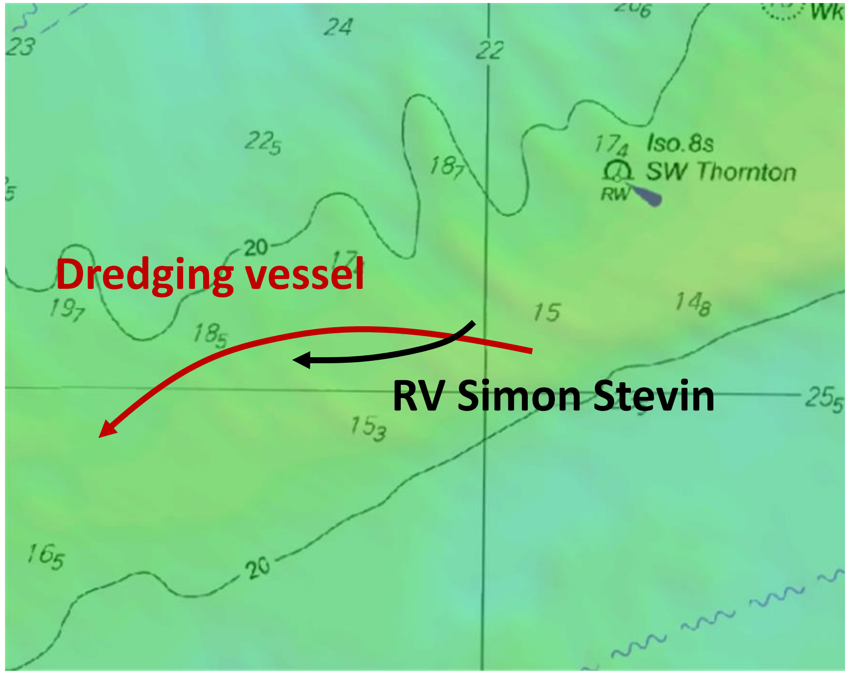


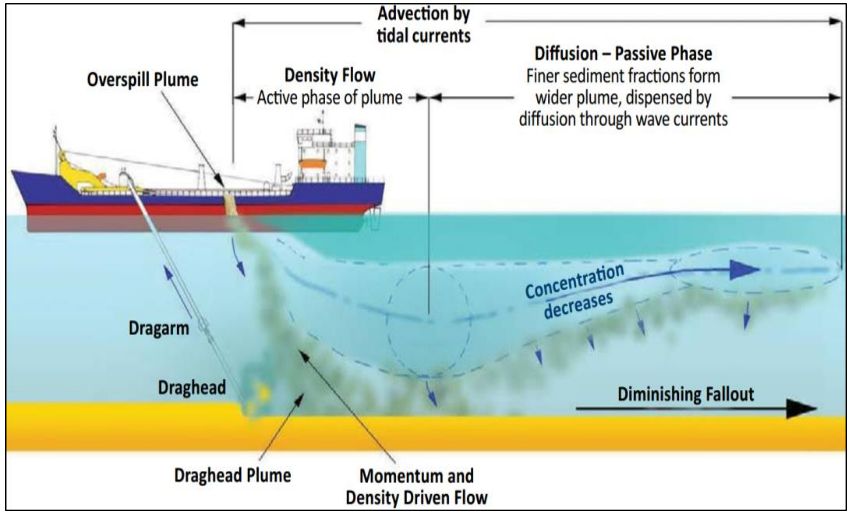


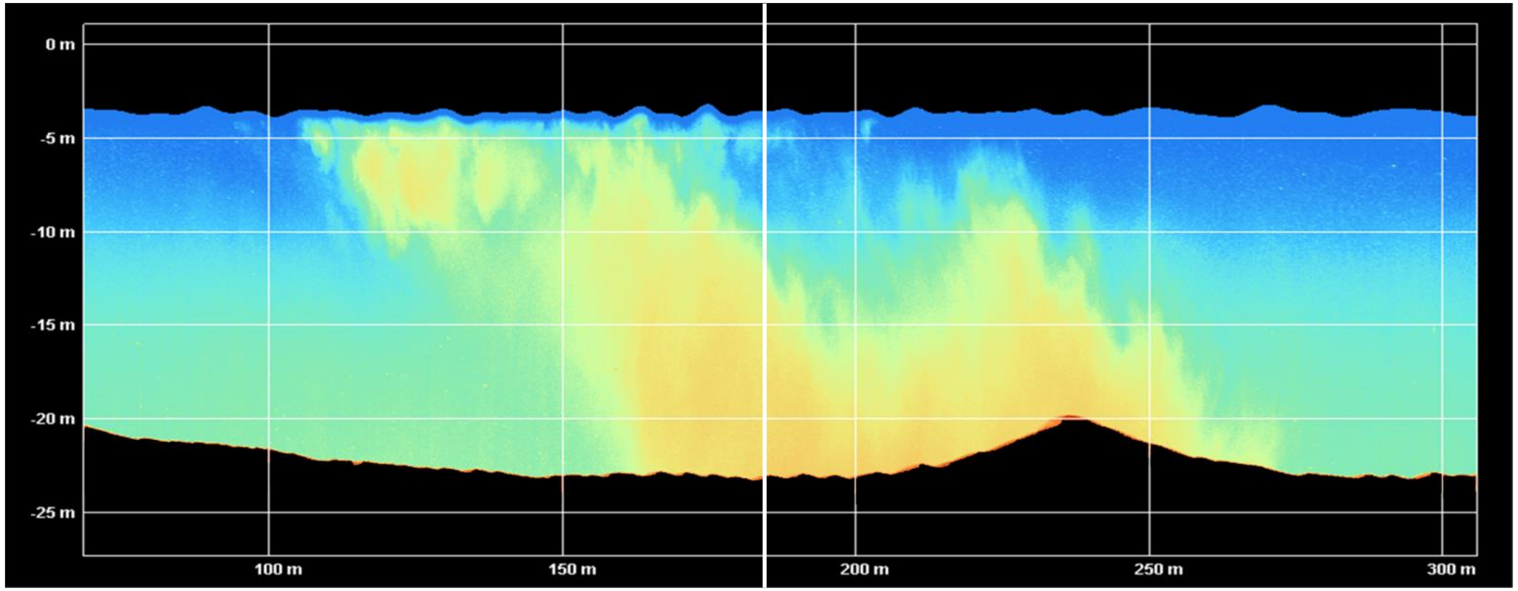
Water column BS

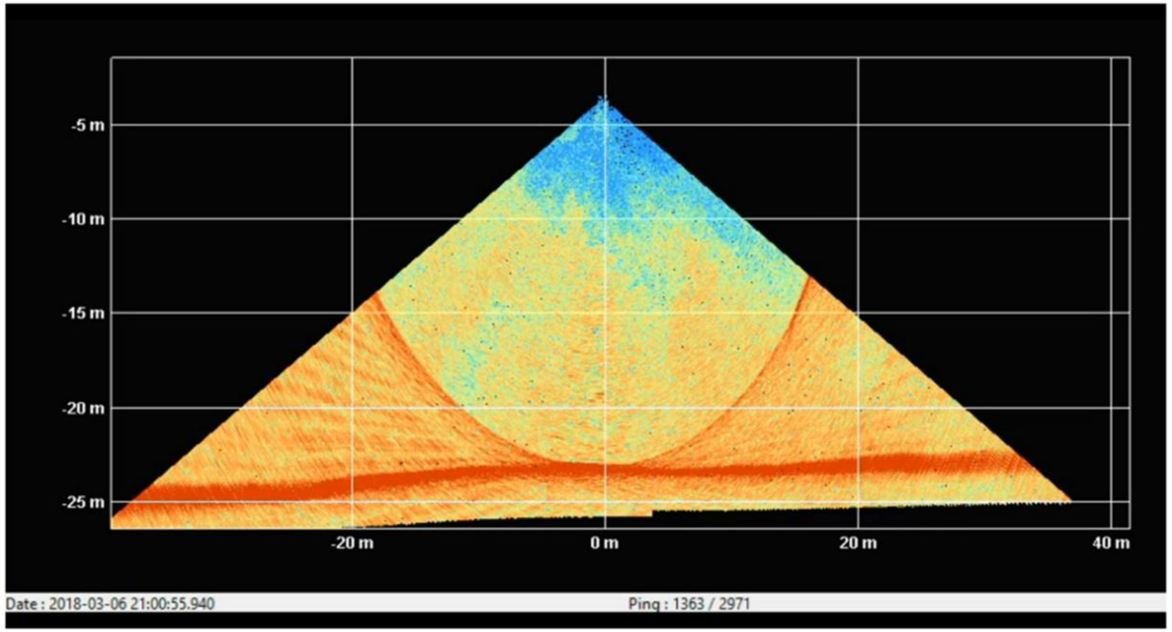


Water column BS for tracking the sediment plumes







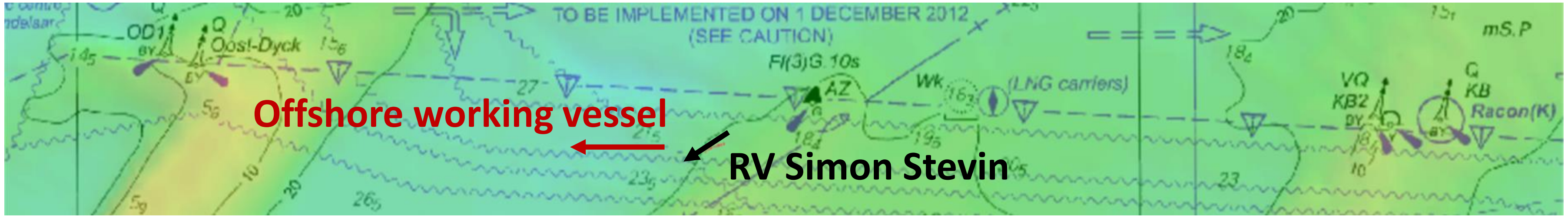


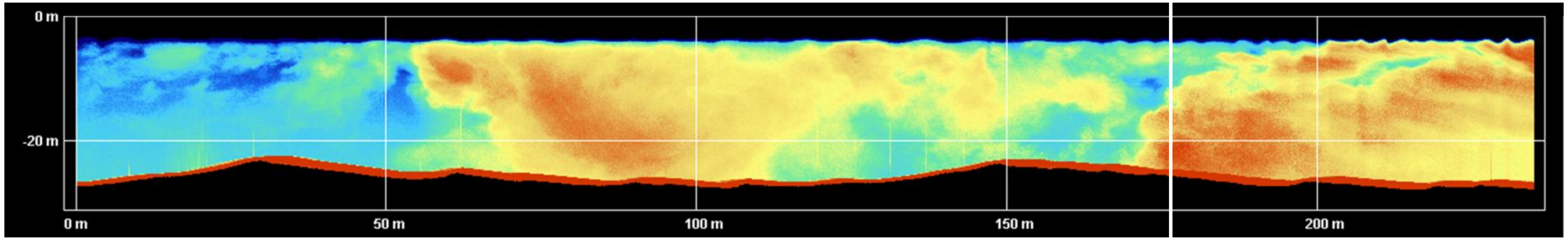
Sv dB

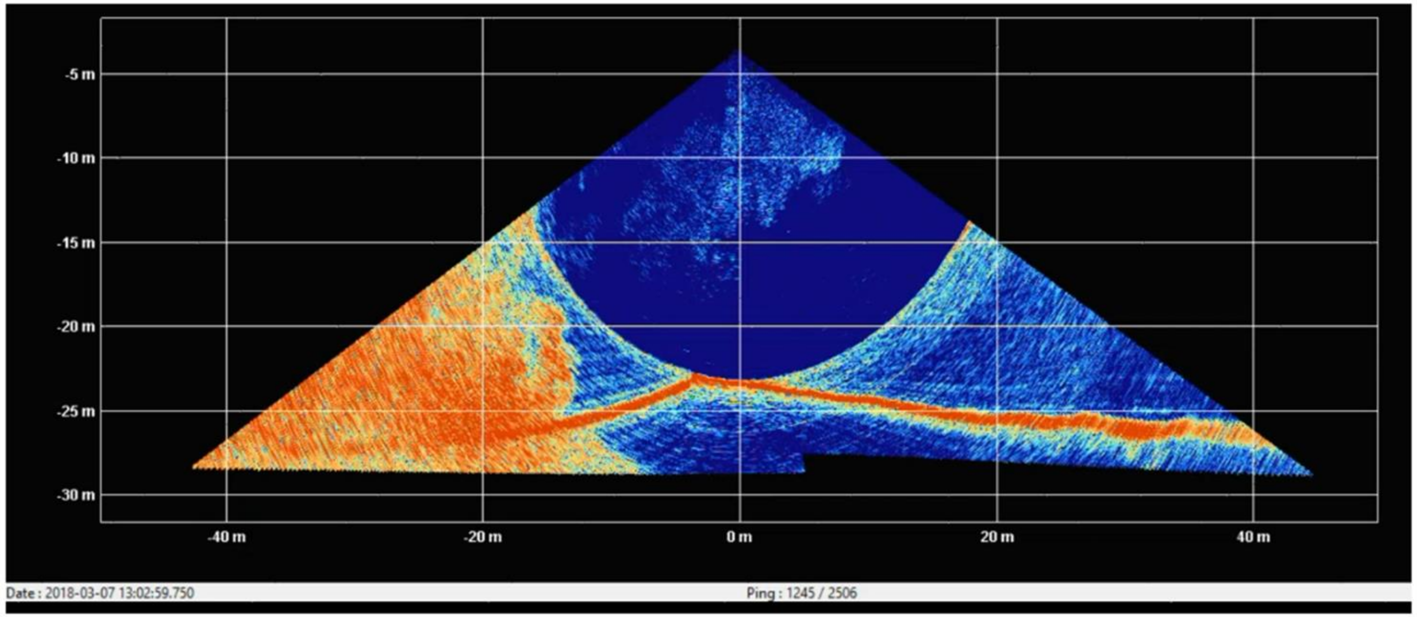
RV Simon Stevin
EM2040 300 kHz
19/03/2023

Water column BS for tracking the sediment plumes

A colossal plume generated by offshore work

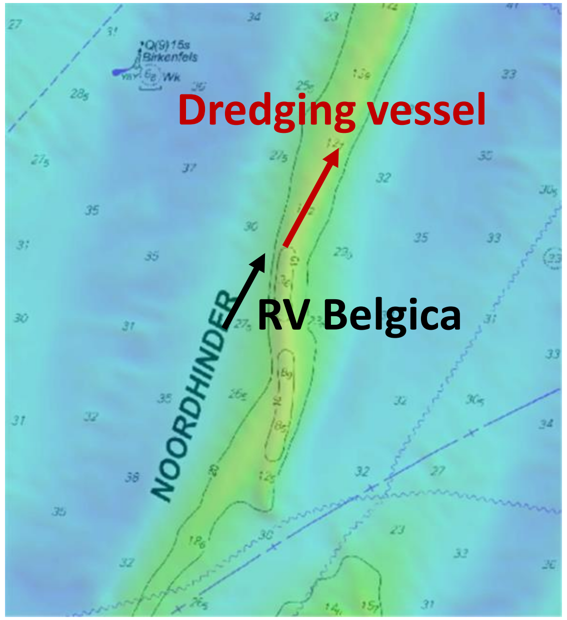


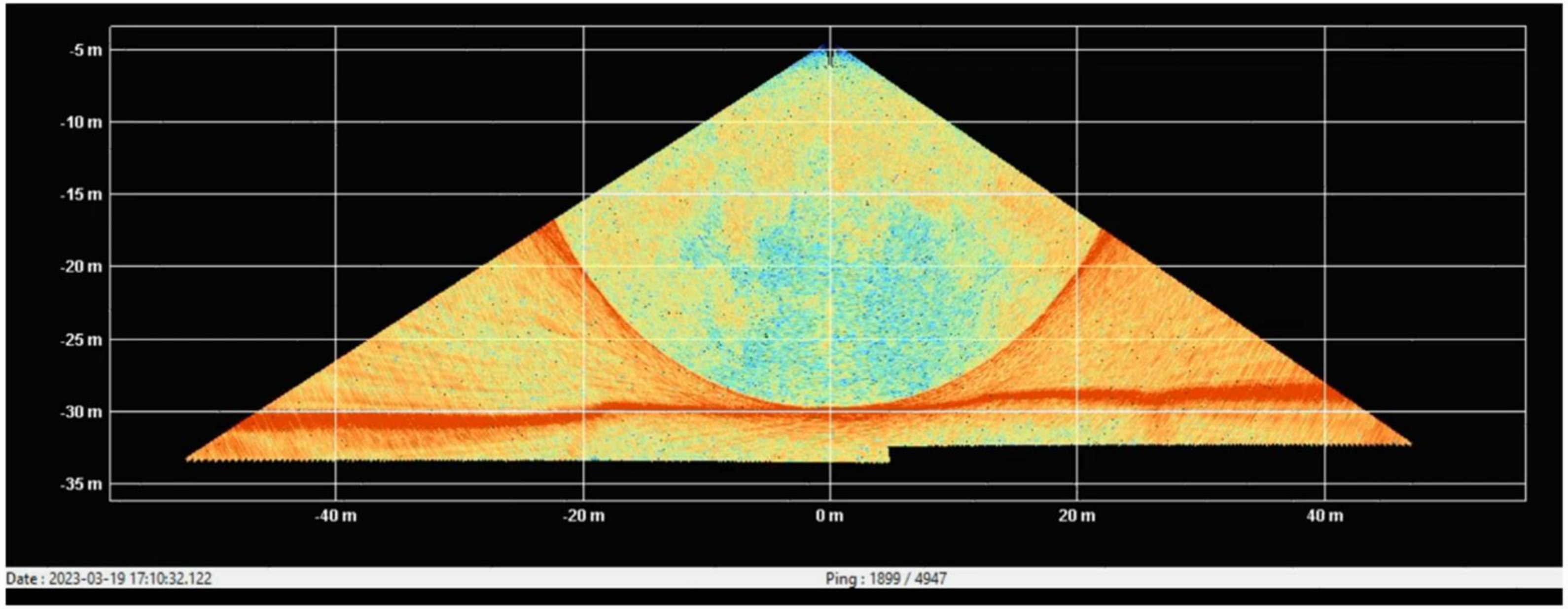




RV Simon Stevin
EM2040 400 kHz
07/03/2018

Water column BS for tracking the sediment plumes





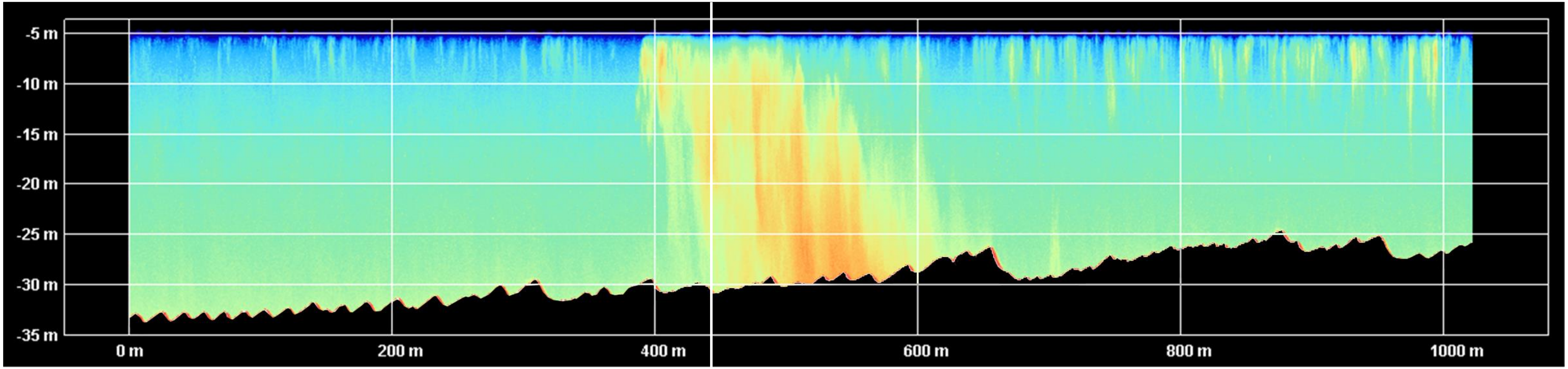
Date : 2023-03-19 17:10:32.122

Ping : 1899 / 4947

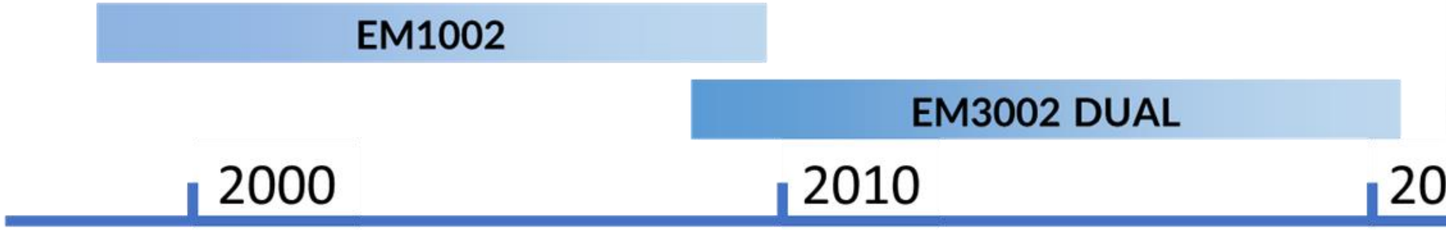
Sv dB

-40 -5

RV Belgica
EM2040 300 kHz
19/03/2023



BS Calibration is now absolutely necessary!



RV Belgica A962

belspo

EM2040 DUAL RX

New RV Belgica

belspo Genavir

EM2040 DUAL RX

RV Simon Stevin

VLIZ VLOOT

EM2040 DUAL SWATH

HV
Sirius

AGENCY FOR
MARITIME &
COASTAL SERVICES

Flanders
State of
the Art

Optimal sharing of BS data

≠ MBES

≠ Acquisition mode

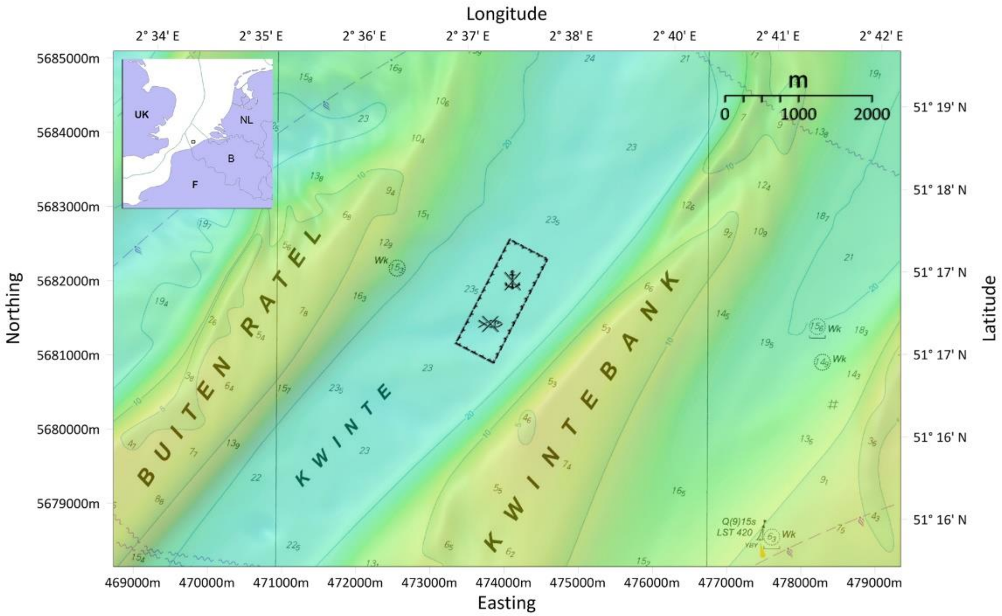
For integration in seabed sediment mapping and monitoring

➢ **Calibration**

BS calibration on reference area:

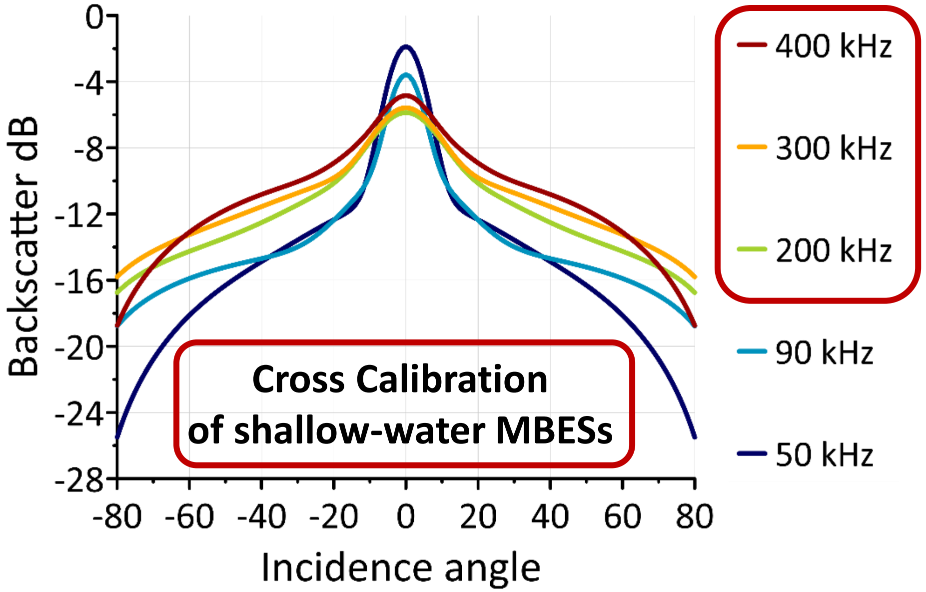
A reference area, e.g. Kwinte area (B)

- Mean backscatter level **stability = foundation**
- Flat morphology
- Homogenous sediment cover
- Open-Science compliant!



A reference angular response model

- Measured on reference area
- Using a fully calibrated Single Beam Echosounder
- One angular response per frequency



Cross Calibration
of shallow-water MBESs

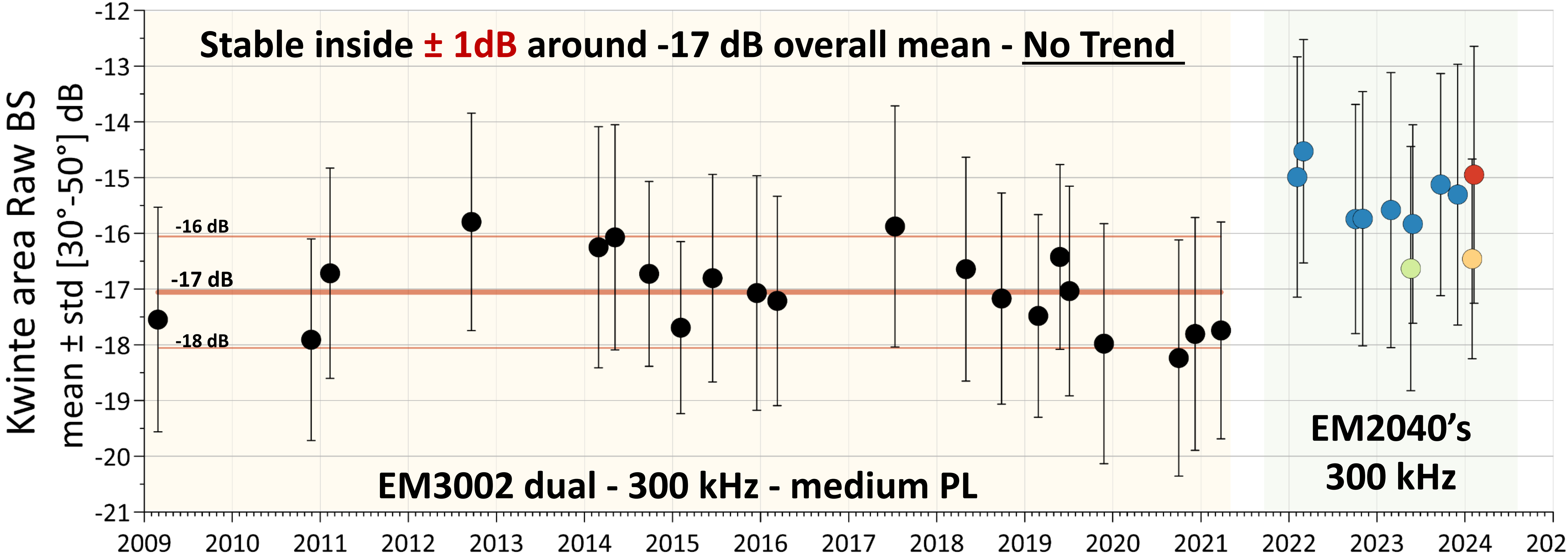
economie

FPS Economy, S.M.E.s, Self-employed and Energy

AGENCY FOR
MARITIME &
COASTAL SERVICES

Ifremer

Stability must be demonstrated by time-series



Stable inside ± 1dB around -17 dB overall mean - No Trend

EM3002 dual - 300 kHz - medium PL

EM2040's 300 kHz

The old time series

● **RV Belgica A962**

The new time series

● **New RV Belgica**

● **RV Simon Stevin**

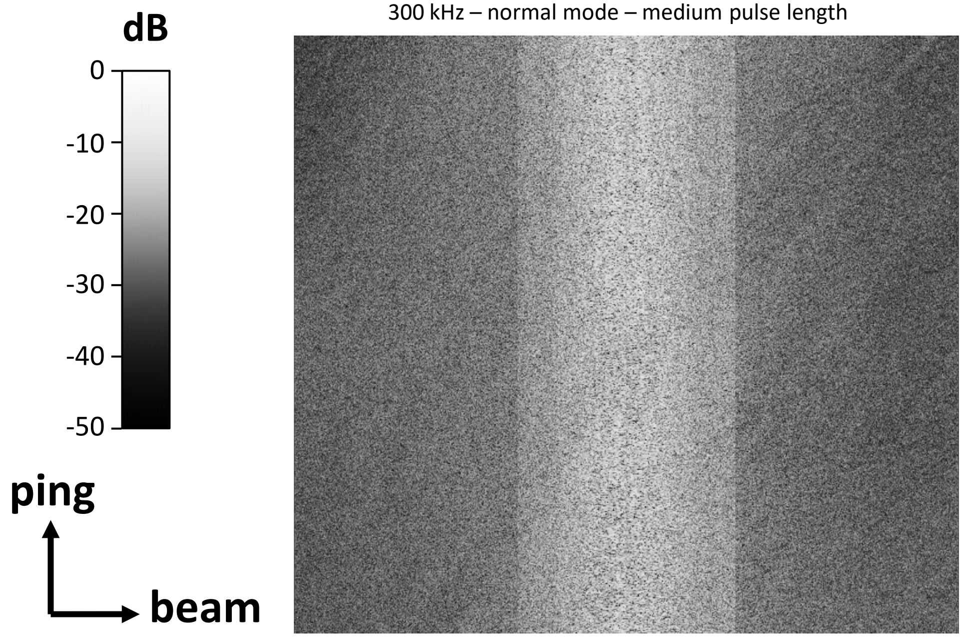
● **HV Sirius**

● **RV Zirfaea**

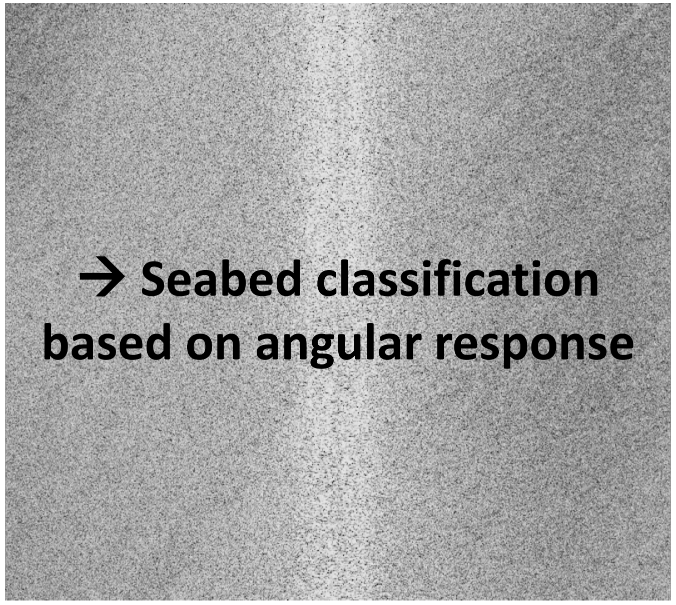
Recipe of BS calibration on reference area:

Raw BS

0004_20220204_052559_Belgica.all
300 kHz – normal mode – medium pulse length

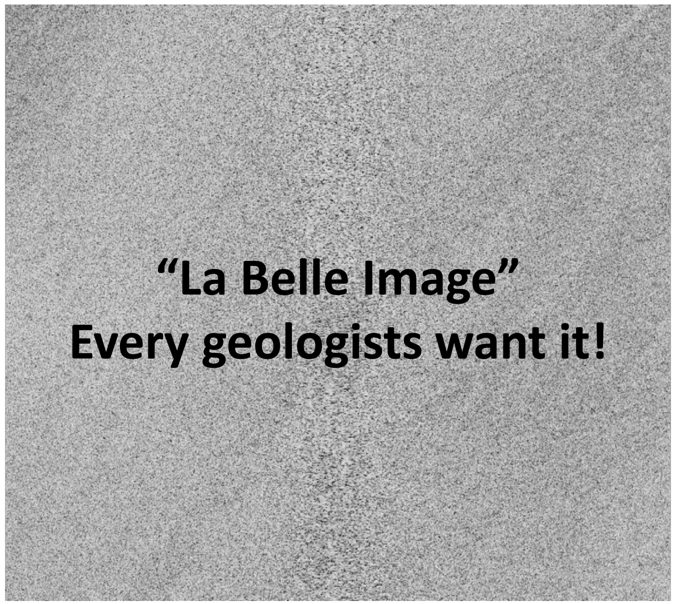


Calibrated BS
+ beam pattern correction



→ Seabed classification based on angular response

Calibrated BS
+ beam pattern correction
+ flattening – angular compensation

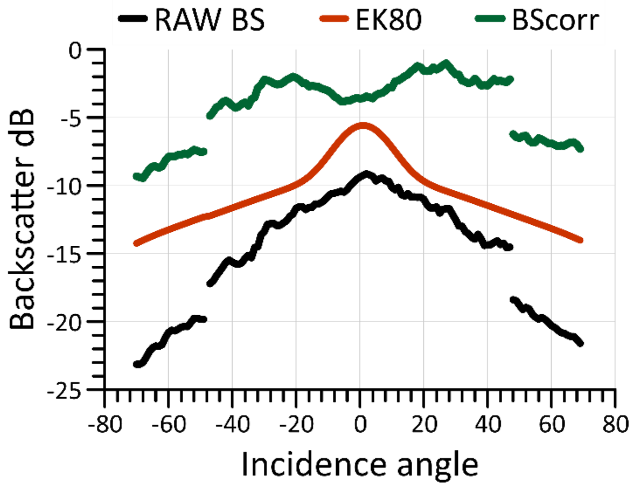


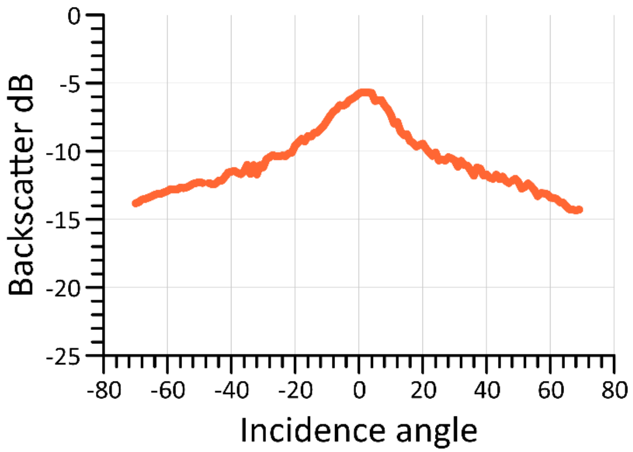
“La Belle Image”
Every geologists want it!

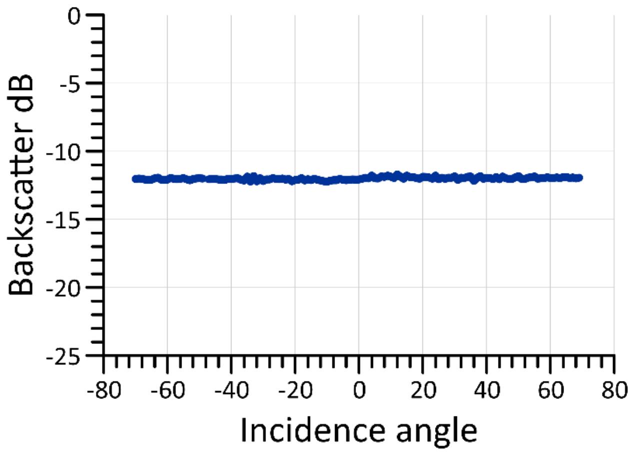
Raw BS

Calibrated SBES
= Reference

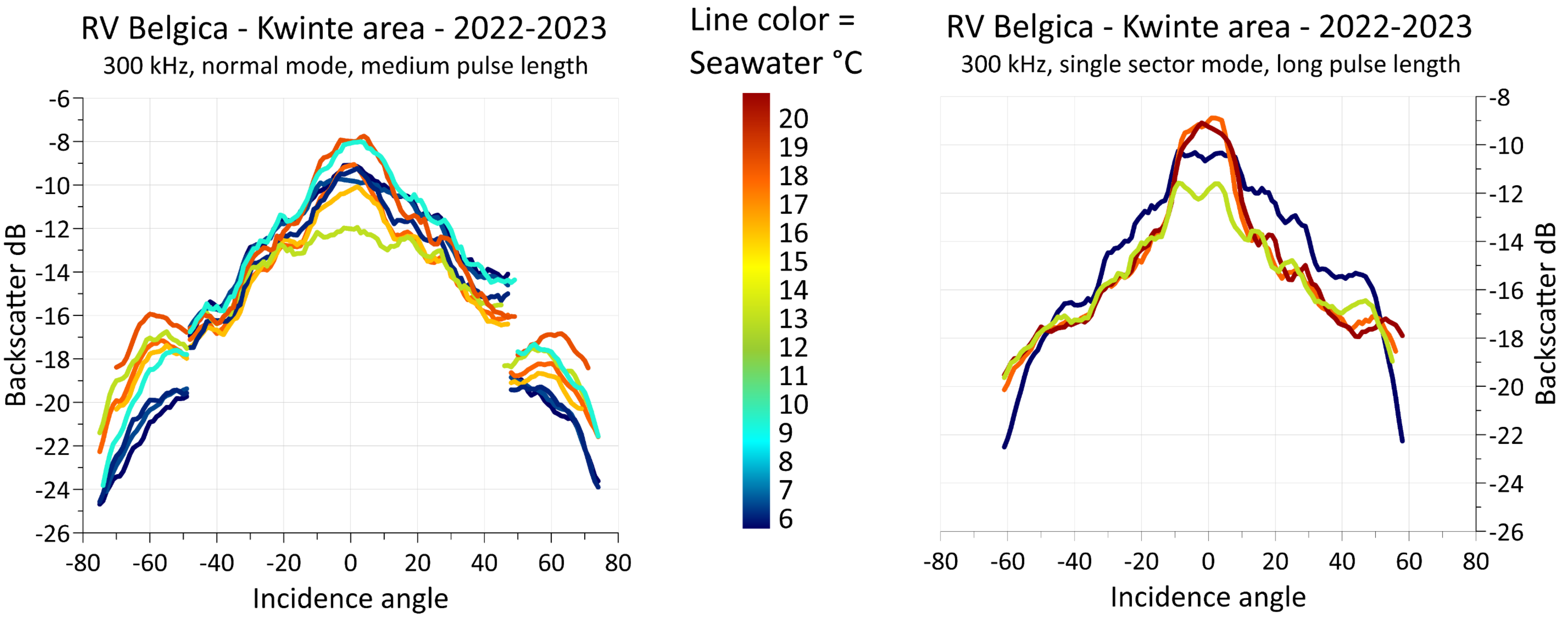
BS correction
= Reference - Raw







T° dependence of BS



RV Belgica - Kwinte area - 2022-2023
300 kHz, normal mode, medium pulse length

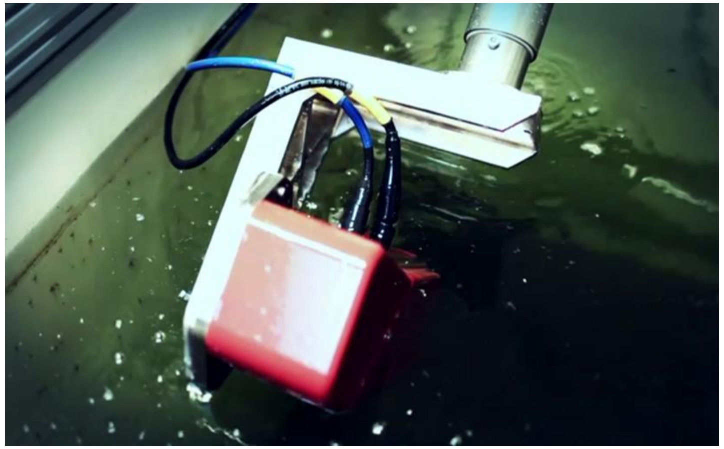
Line color =
Seawater °C

RV Belgica - Kwinte area - 2022-2023
300 kHz, single sector mode, long pulse length

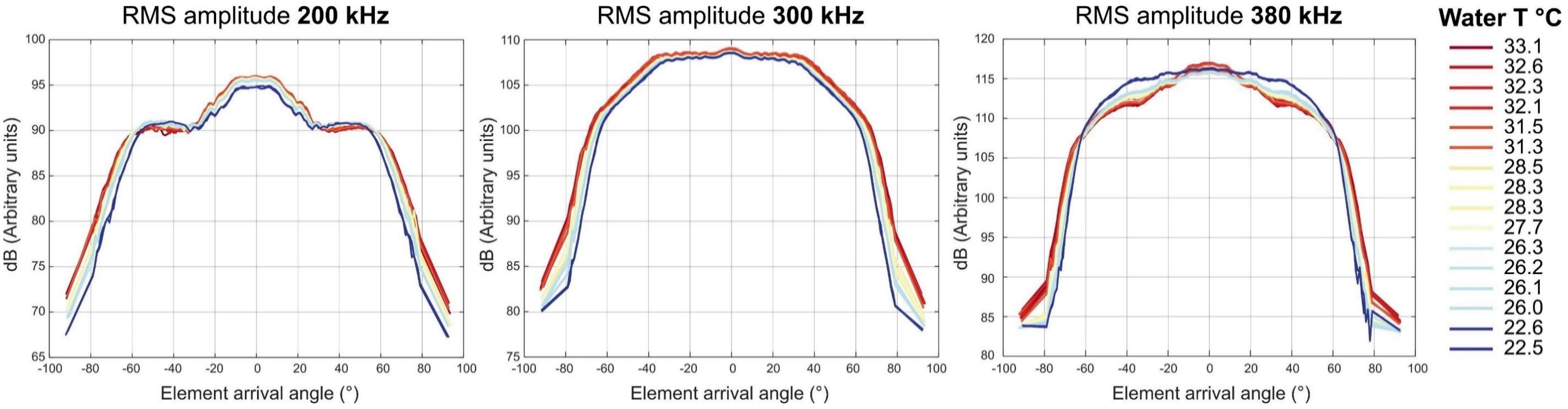
- BS angular response correlated with sea water temperature
- As high as 4.5 dB between “cold” and “warm” water

In-tank measurements confirm the T° dependence

Kongsberg Discovery



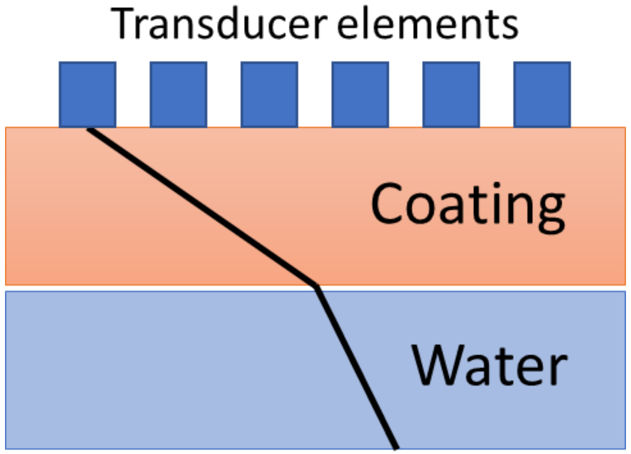
- With one of the earliest EM2040 RX units
- RX directivity change with T °C
- Complex, changes with frequency



T° dependence causes? Hypotheses:

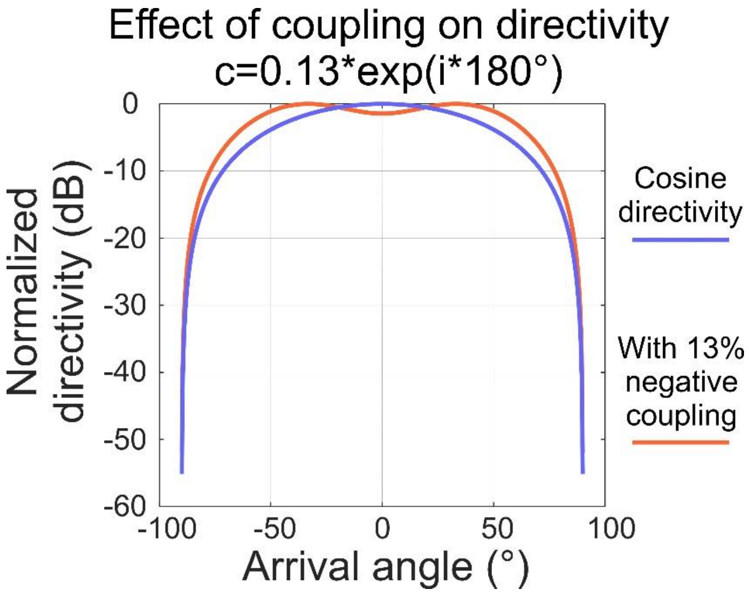
1. Snell law – Refraction

- Coating sound speed change with T°
- Leads to a change in refraction
- Not sufficiently taken into account?
- But should only cause a scaled directivity



2. Coupling

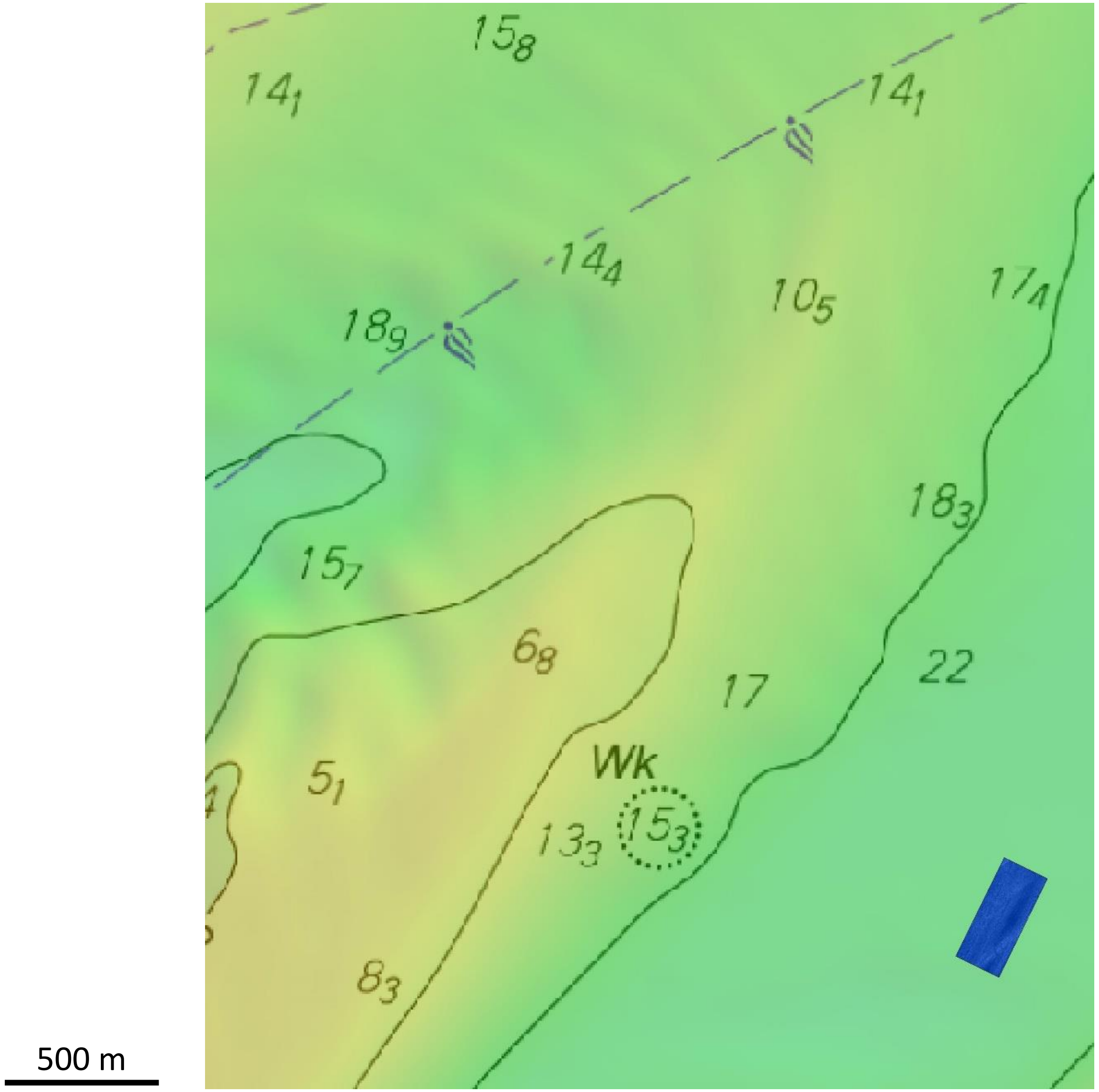
- Interaction between neighboring transducer elements
- Can produce various effects
- Complex relation to material parameters
- A probable cause of significant directivity variations
- Hard to model for real-time compensation



3. Other phenomena that can give non-symmetric effects must be considered

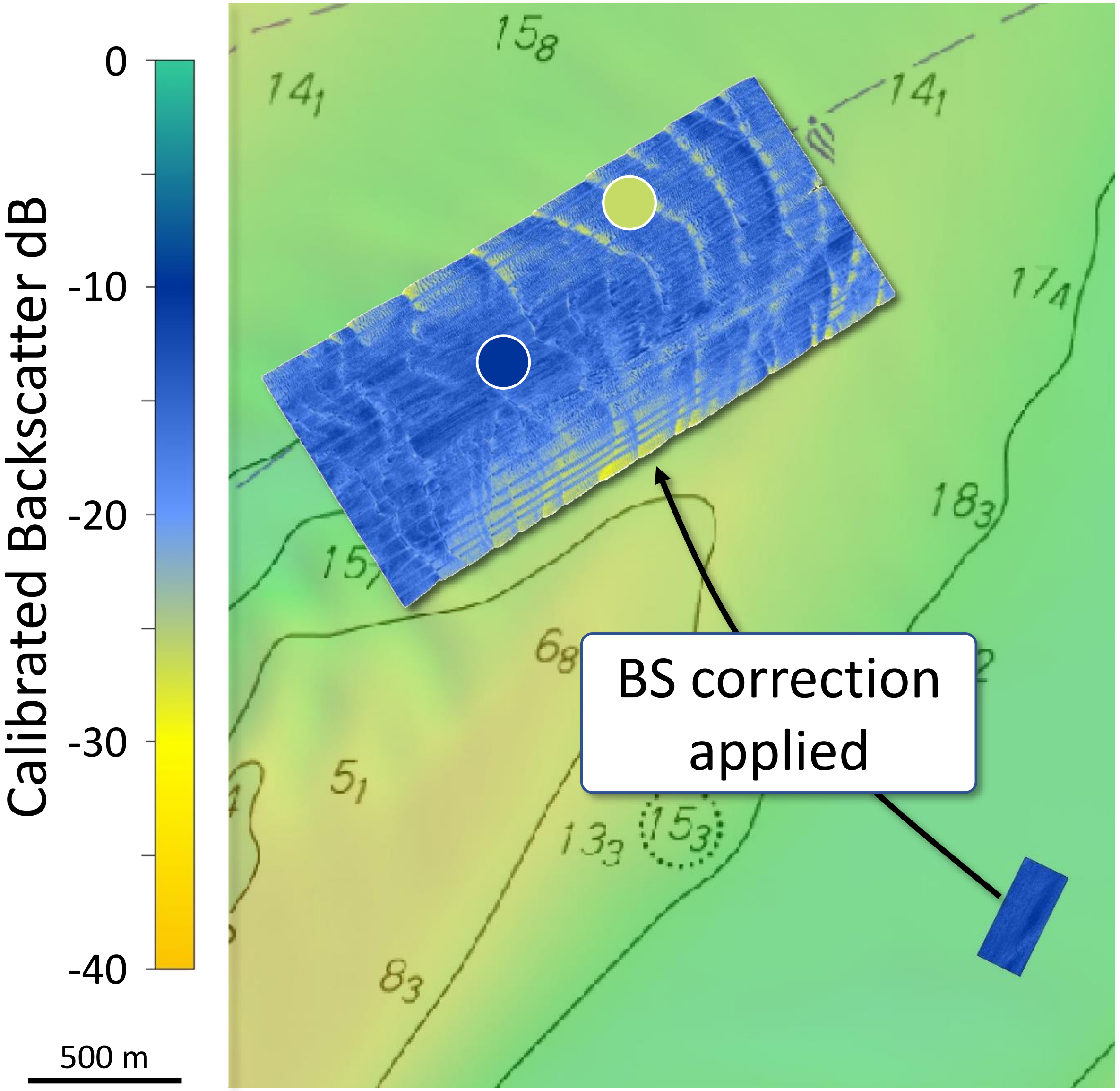
Solution: Survey of the Kwinte area always!

Using our usual monitoring mode (300 kHz, normal mode, medium pulse length)



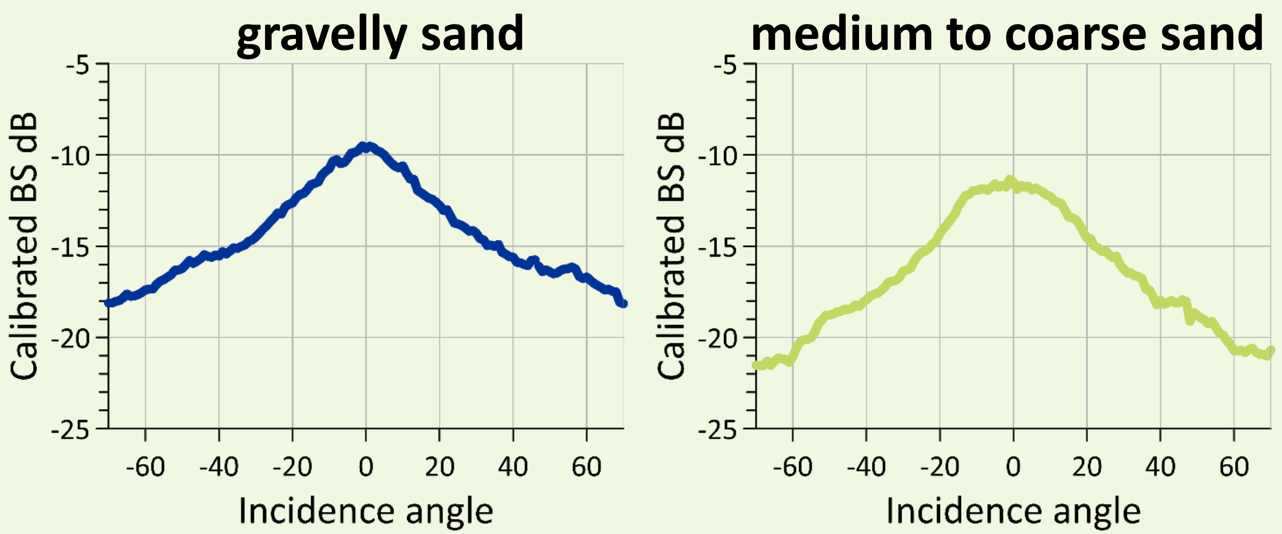
Solution: Survey of the Kwinte area always!

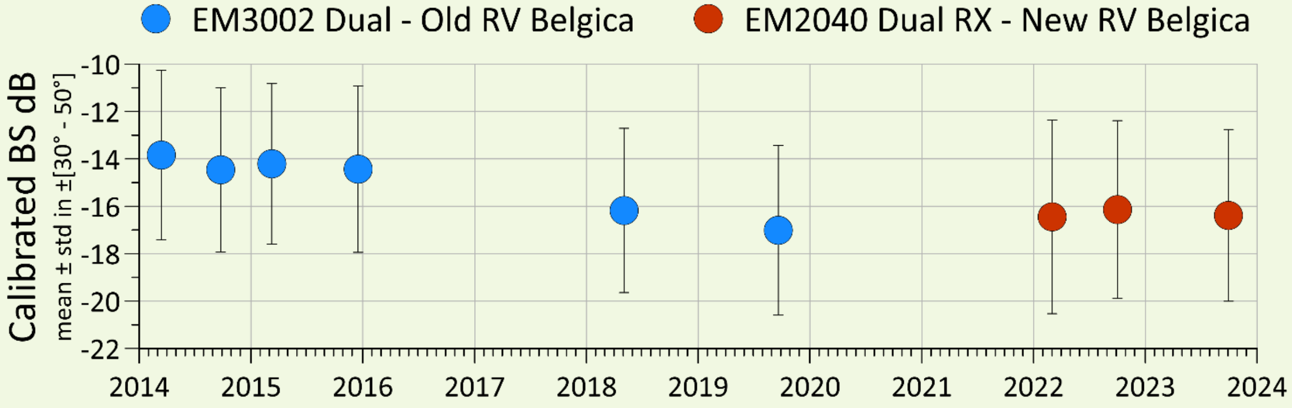
☑ One calibration per measurement campaign applied to all data



BS correction applied

Calibrated BS angular responses and time series





Thank you!
Question?