HYDRO 2024
Hydrographic Conference

Seafloor Backscatter Measurements by Hydrographic Multibeam Echosounders

Toward Incorporation of Backscatter Measurements in Hydrography Protocols & Standards ?

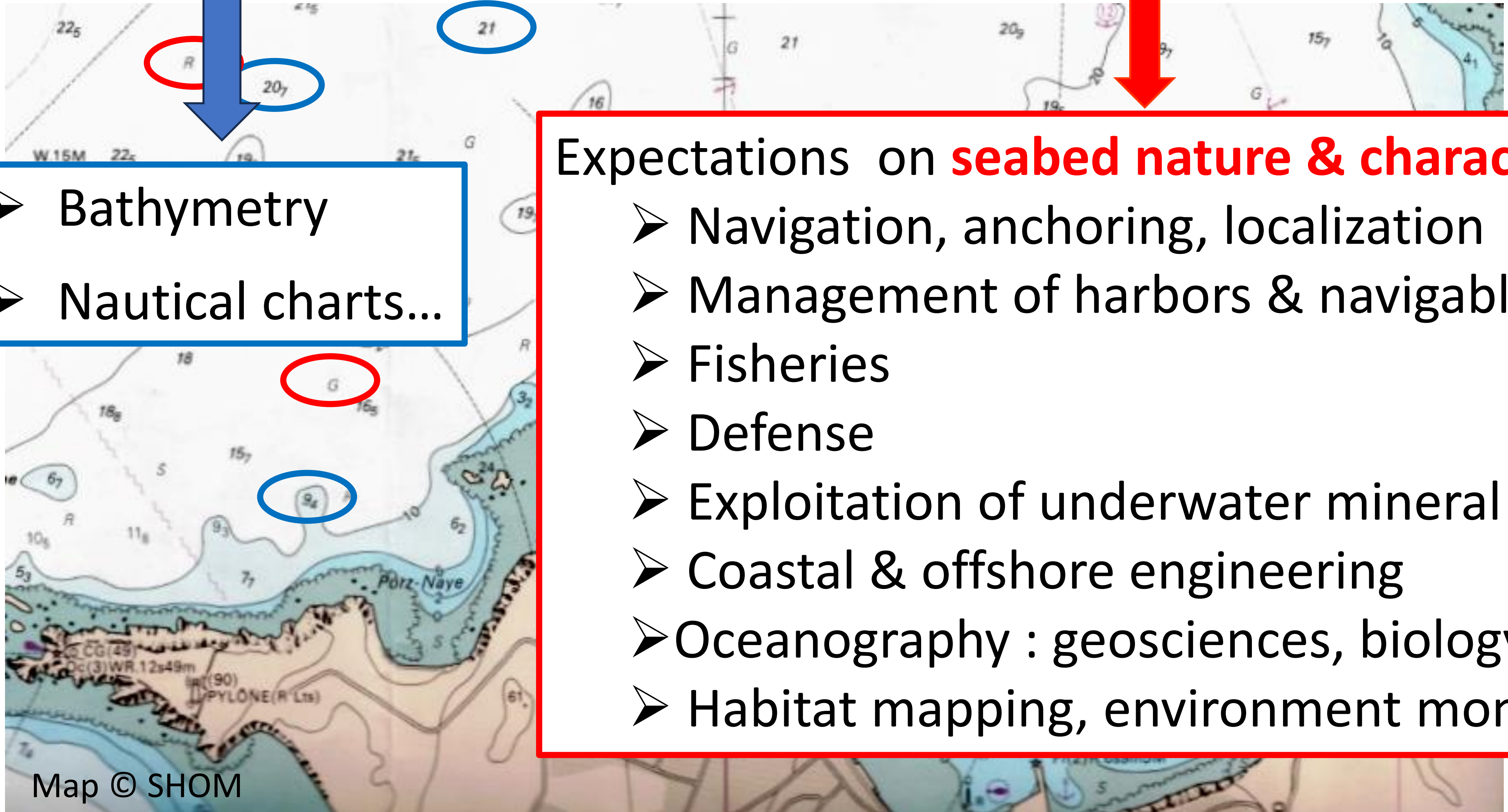
Xavier Lurton

Consultant in Underwater Acoustics

xavier.lurton@orange.fr

Hydrography's Two Major Issues:

"How deep ?" **AND** ***"What's below ?"***



Map © SHOM

- Bathymetry
- Nautical charts…

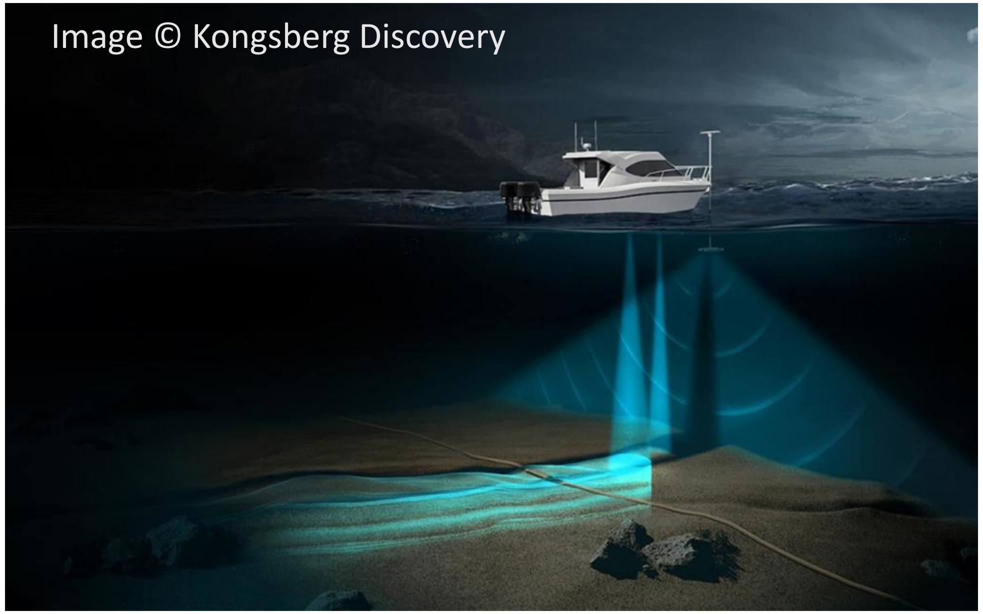
Expectations on **seabed nature & characteristics**

- Navigation, anchoring, localization
- Management of harbors & navigable ways
- Fisheries
- Defense
- Exploitation of underwater mineral resources
- Coastal & offshore engineering
- Oceanography : geosciences, biology…
- Habitat mapping, environment monitoring...

Seabed identification approaches

- Historical: **direct sampling & observation**
  - Greased lead line
  - Sediment grab
  - Camera

Still (forever?) the Ground Truth!



- Today: **remote sensing**
  - *Airborne Lidar, satellite optical images…*
  - **ECHOSOUNDING !**
    - THE TOOL for bathymetry and seafloor mapping for more than one century
    - A decisive evolution : the **multibeam echosounder (MBES)**
    - An accurate & practical sensor – prevalent today (*and still for long*)

A key potential beyond bathymetry : Seafloor reflectivity measurement

Echosounding: from one same echo…

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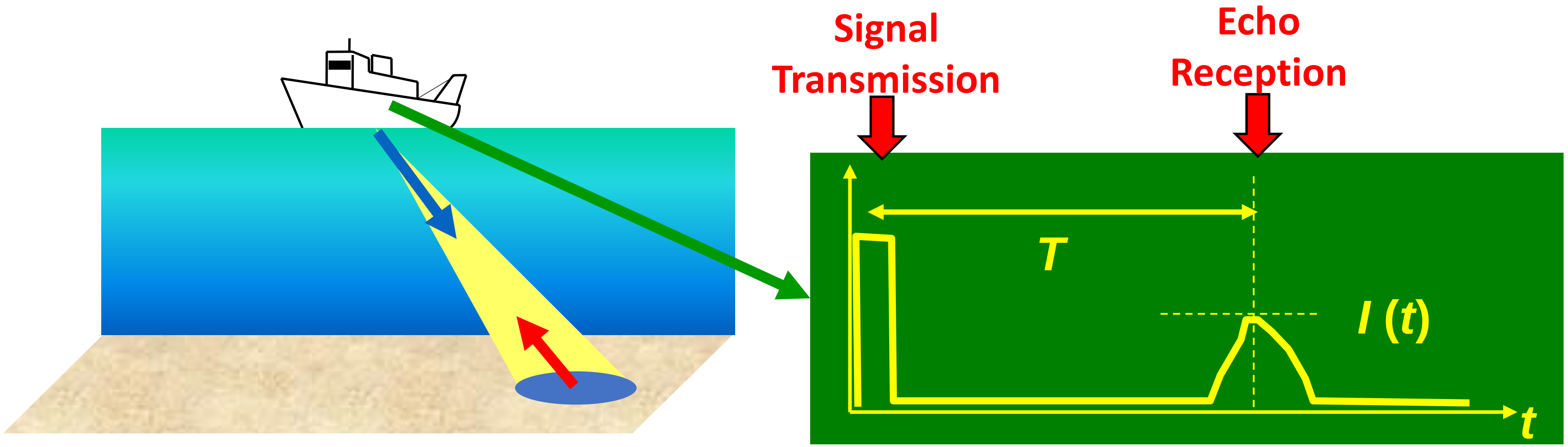


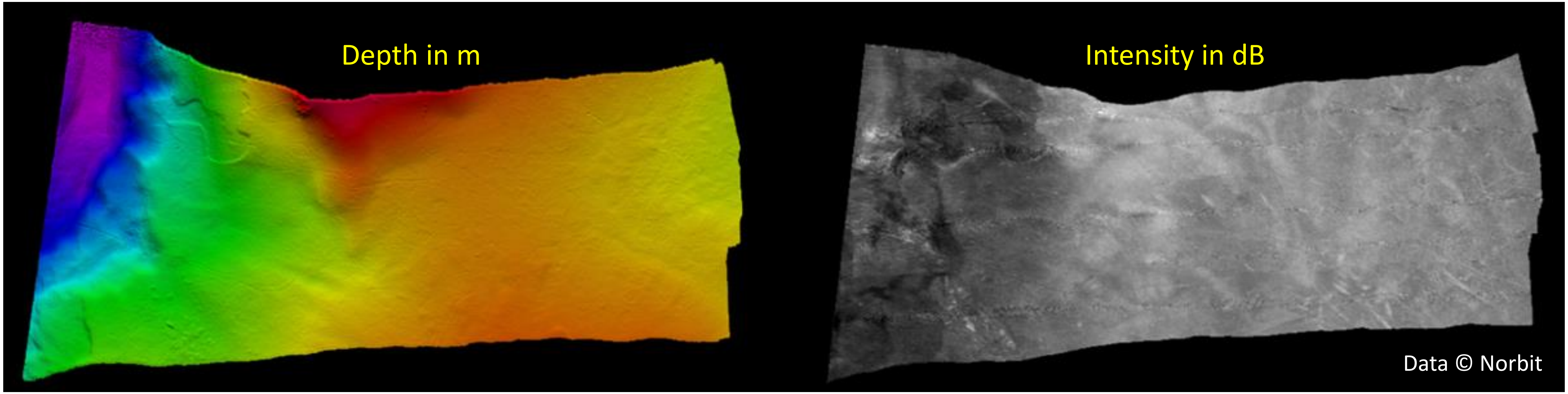
Time, Phase + Geometry

- Echo Delay ***T*** ➔ Range & Angle
  - Target localisation
  - **Bathymetry**, mapping…

Amplitude + Geometry

- Echo Intensity ***I*** ➔ *Target Strength*
  - Target nature / structure
  - **Seafloor characterization**…

One sensor ➔ Two information levels



- Seabed reflectivity = an intrinsic **by-product of echosounding**
- **Echosounding answers to both “How deep?” and “What’s below?”**

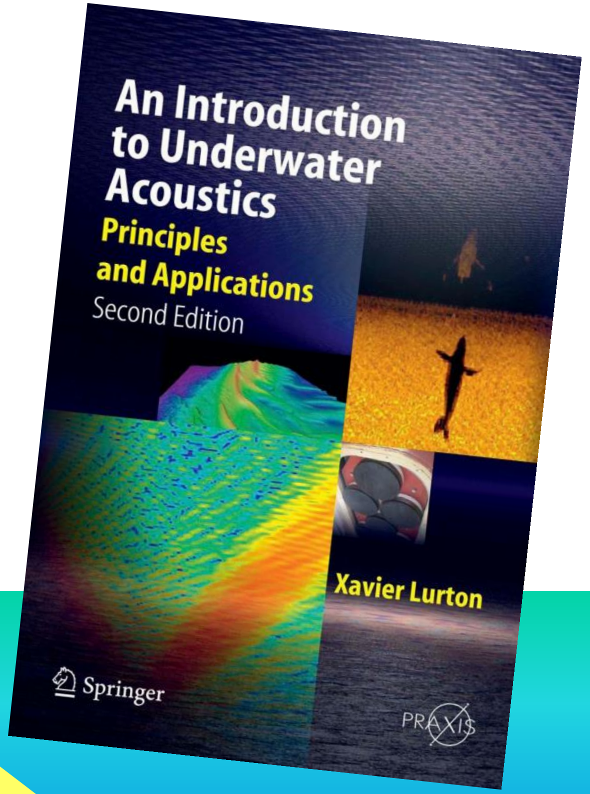
QVOD ERAT DEMONSTRANDVM … ***Not so simple !!!***

- Echo time delay is extremely robust – echo amplitude is not
- Relations between reflectivity and seafloor properties are very complex
- **Reflectivity = far more challenging than bathymetry to record, process & interpret**

How can Backscatter be *objectively* quantified?

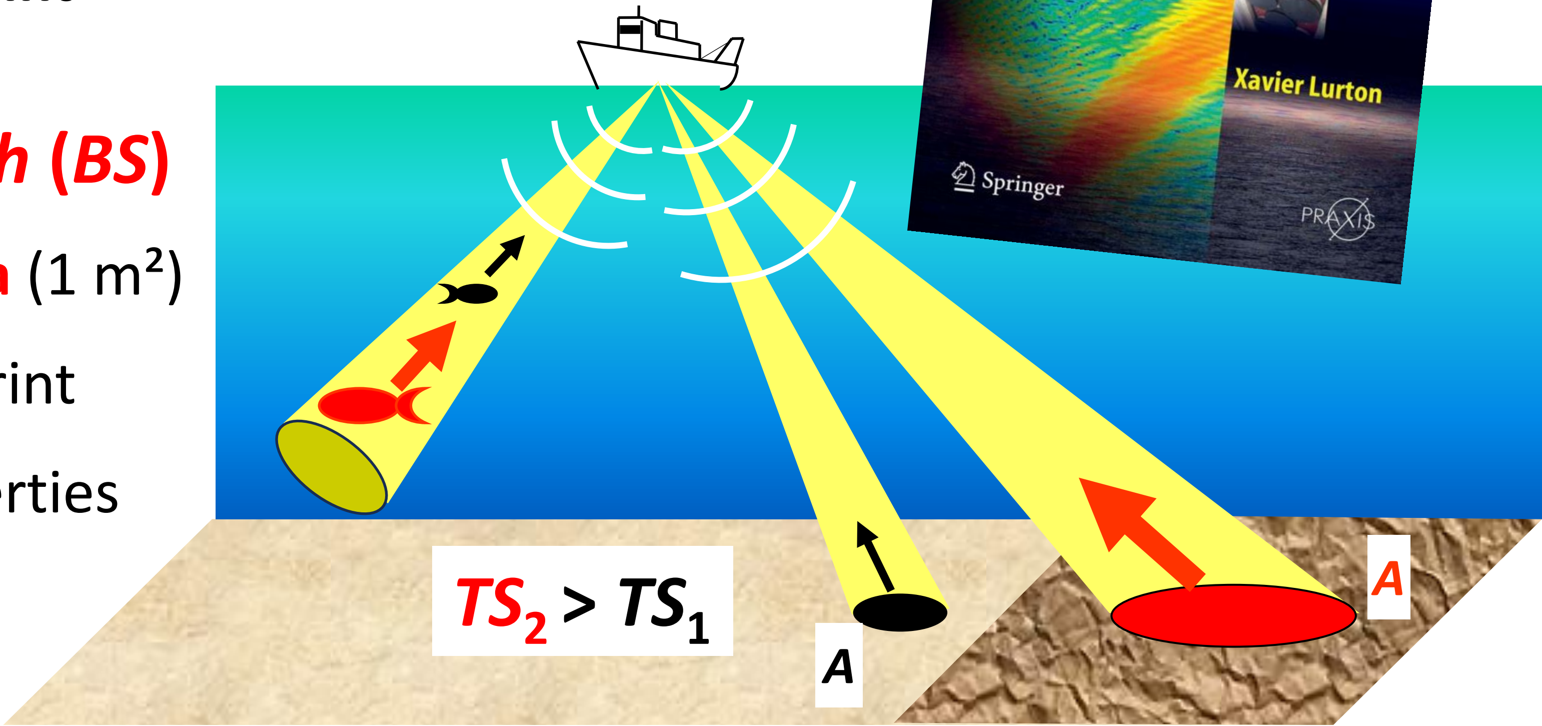
Fundamental concepts in sonar: the ***Target Strength* (*TS*)…**

- Expressed simply: the **relative intensity level sent back** by a target
- The **larger/harder** the target, the **higher the TS**
- For an extended interface (seafloor…), the actual target extent is the sonar's beam/signal « **footprint** »



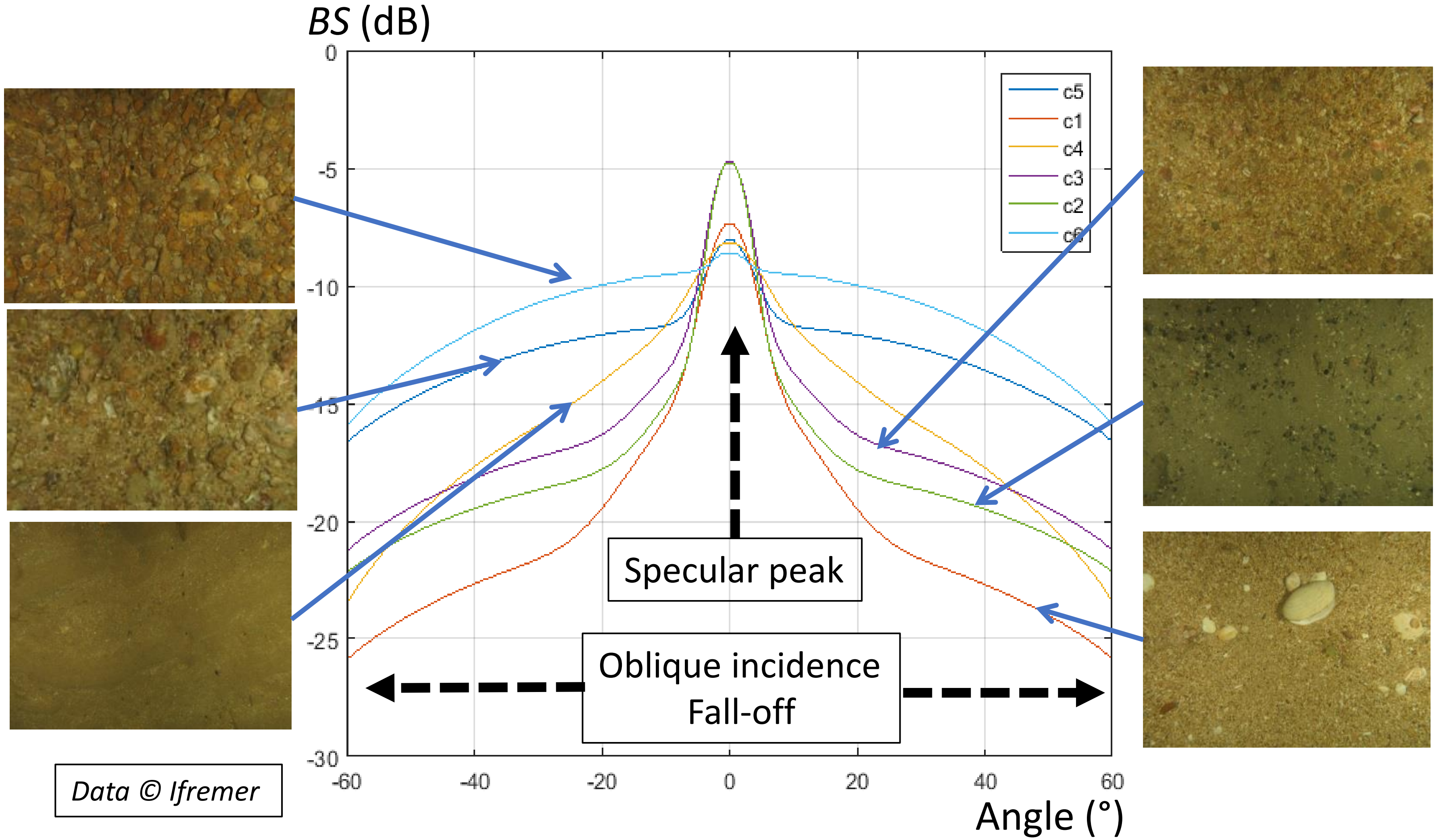
… & the ***Backscattering Strength* (*BS*)**

- ➢ = ***TS*** expressed for **a unit area** ($1\ m^2$)
- ➢ to be corrected by sonar footprint
- ➢ characteristic of seafloor properties
- ➢ $$BS = TS - 10 \log A$$

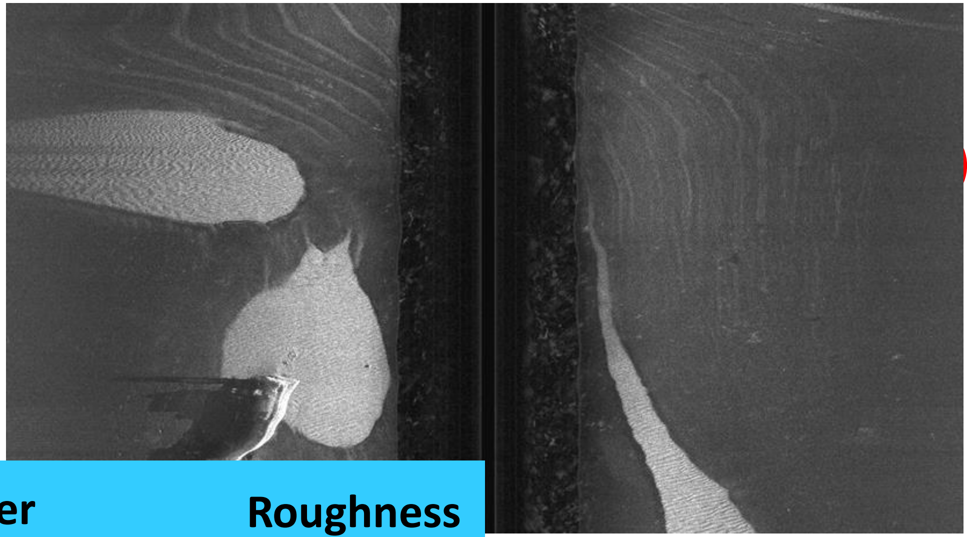


Examples of measured angular *BS vs* Ground Truth

- Continental Shelf, Bay of Biscay
- Simrad ME70 MBES
- Around 70 kHz
- Data fit with a heuristic law ➔ smoothing
- 10 dB dynamics between these sediments

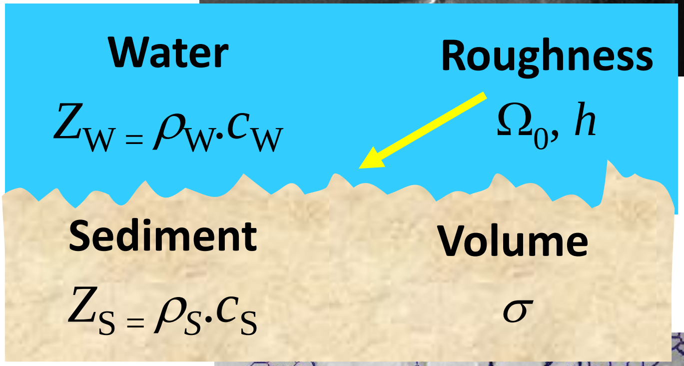


What could Backscatter Strength *ideally* provide?



1. **A proxy for local seabed types**
   - A few seabed « classes » : R, G, S, M…
   - An exhaustive calibrated « sonar image »

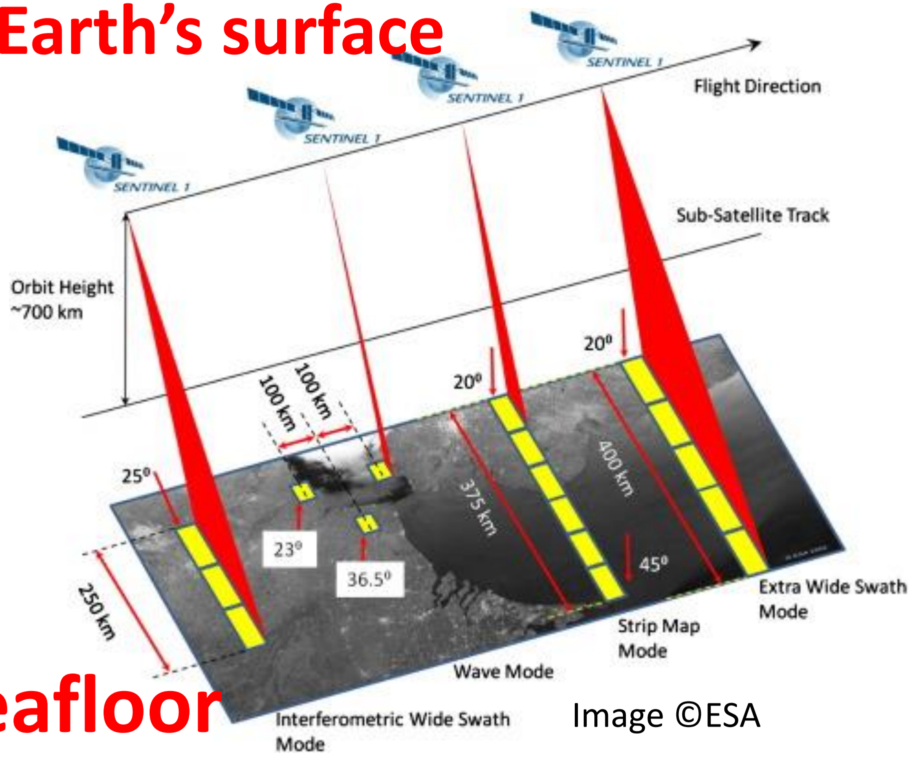
2. Seabed **acoustical** properties
   - Impedance contrast Z_s / Z_w
   - Surface roughness, sediment volume
   - (Local scatterers, layering…)



3. **Geological** properties
   - Density, velocity, shear…
   - Porosity, grain-size distribution

An analogy w/ Space: Satellite-borne Radar

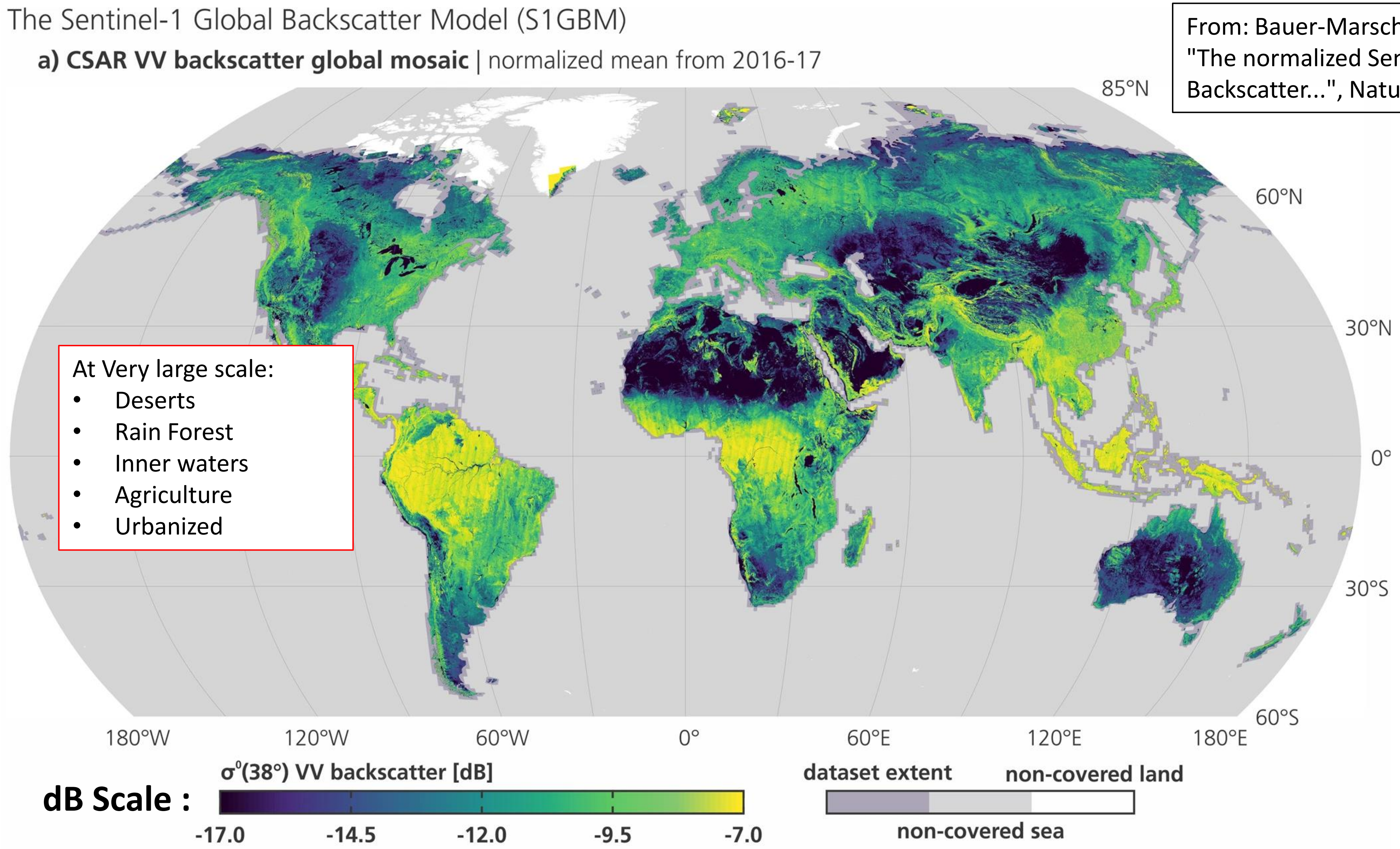
- Example: ESA's **Sentinel-1 CSAR**
  - C-band imaging & hi-res topography
  - Launched in 2014
  - 2 satellites ➔ complete Earth coverage in 6 days !
- **Mission: *Radiometry*** (=BS measurement) of **the Earth's surface**
  - 25° to 45° incidence - Resolution = 10 m
  - Independent of day/night, clouds…
- Numerous **applications**
  - **Land** mapping & monitoring
  - Agriculture, vegetation…
  - **Sea**-state; ice mapping…



➔ Extremely **similar to MBES mapping of seafloor**

The Earth's BS from satellite radar: overview…

From: Bauer-Marschallinger et al "The normalized Sentinel-1 Global Backscatter...", Nature (2021)



At Very large scale:

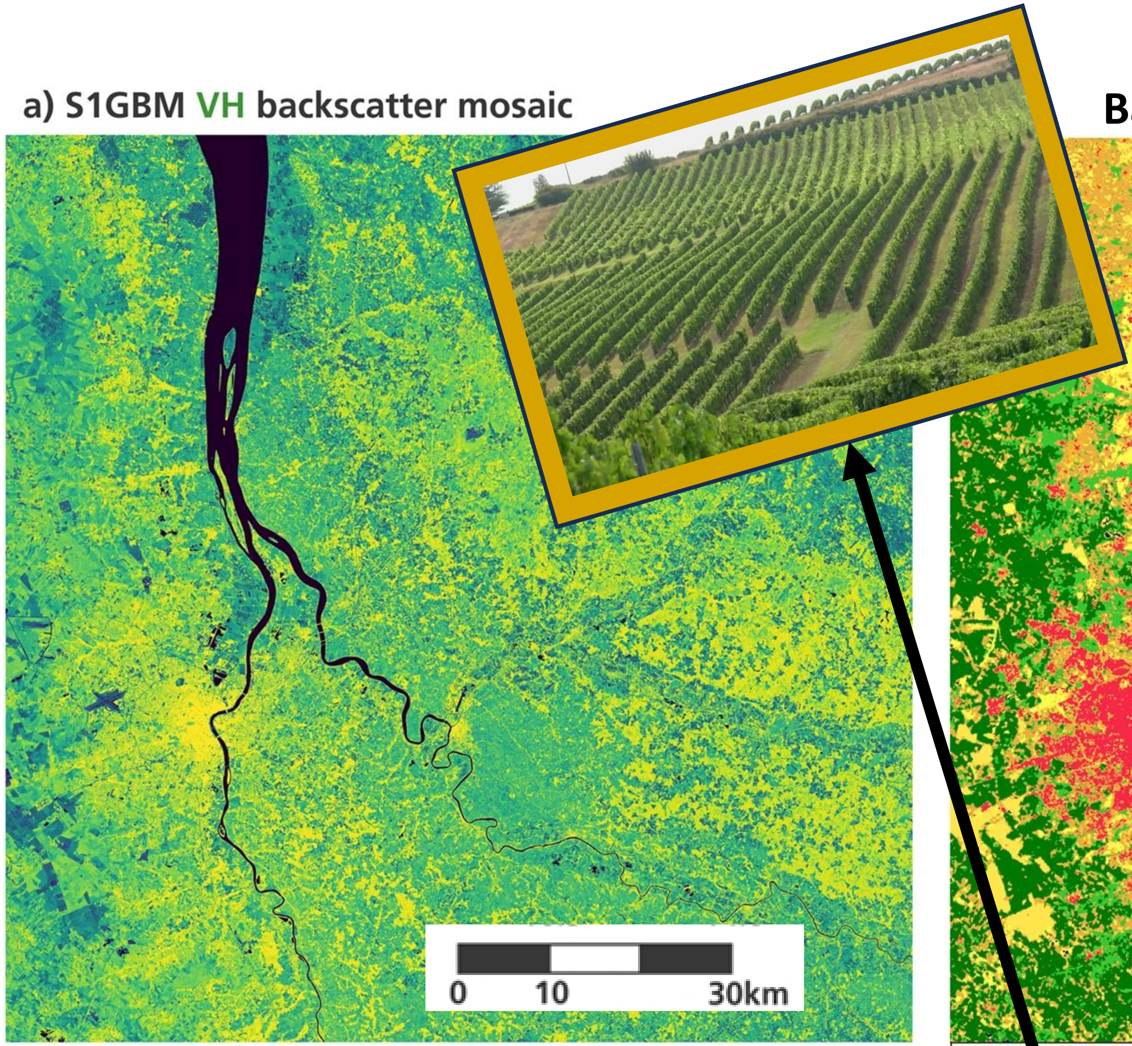
- Deserts
- Rain Forest
- Inner waters
- Agriculture
- Urbanized

dB Scale :

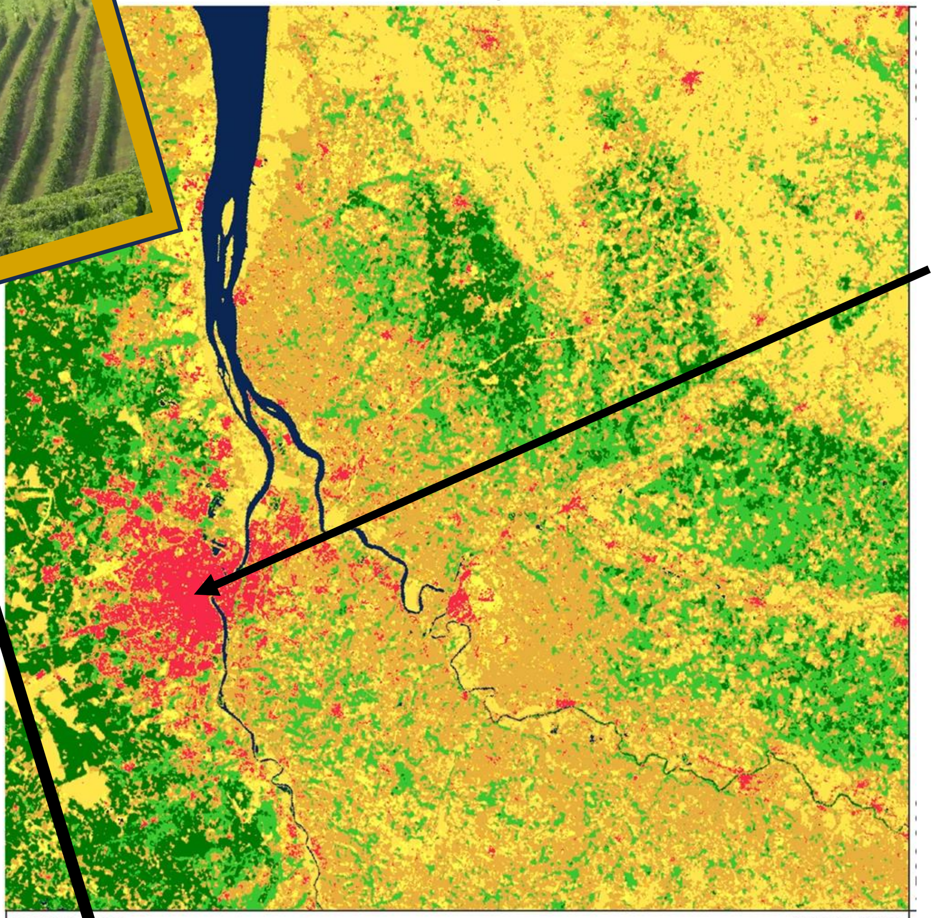
… or at local scale

From: Bauer-Marschallinger et al "The normalized Sentinel-1 Global Backscatter...", Nature (2021)

a) S1GBM VH backscatter mosaic



Backscatter Interpretation



Bordeaux (City)

σ⁰ VH backscatter [dB]

dB Scale : -24.0 -21.5 -19.0 -16.5 -14.0

C100 | major local classes

agricultural forest urban open water

Radar or Sonar : expected sensor's capabilities

- **Quantitative** estimates of (1) **transmitted** signals (2) **recorded** echo waveforms
- An appropriate (= exhaustive) **coverage** and **sampling** of the seabed
- A practical analysis of incidence **angle dependence**
- … & ideally : add **frequency** dependence/ **azimuth** variation/ sediment **penetration**...

Today's Hydrography Sonars Can Do It All !!!

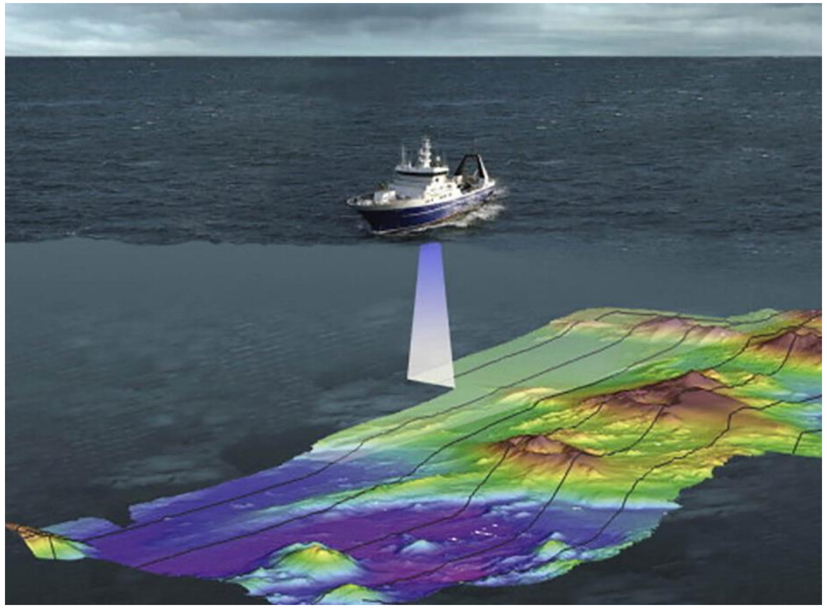
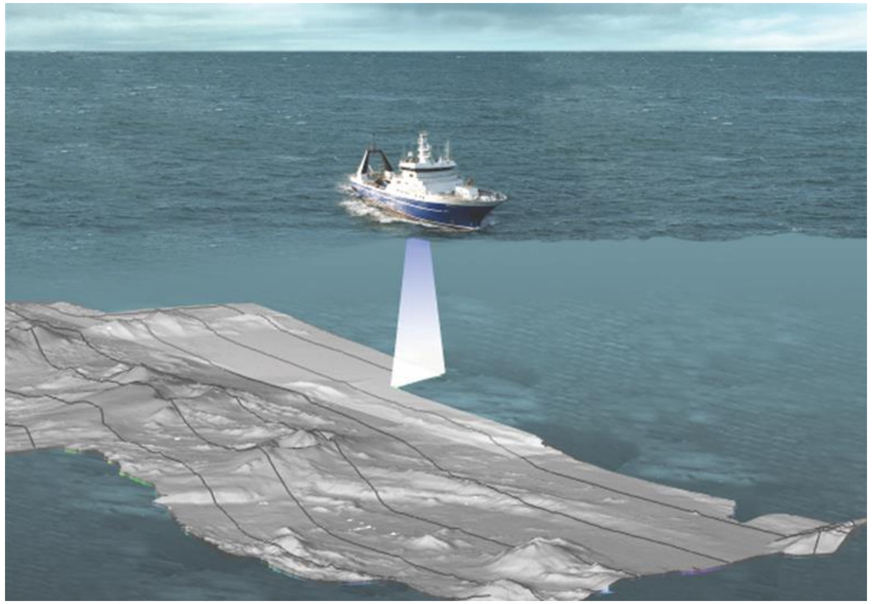
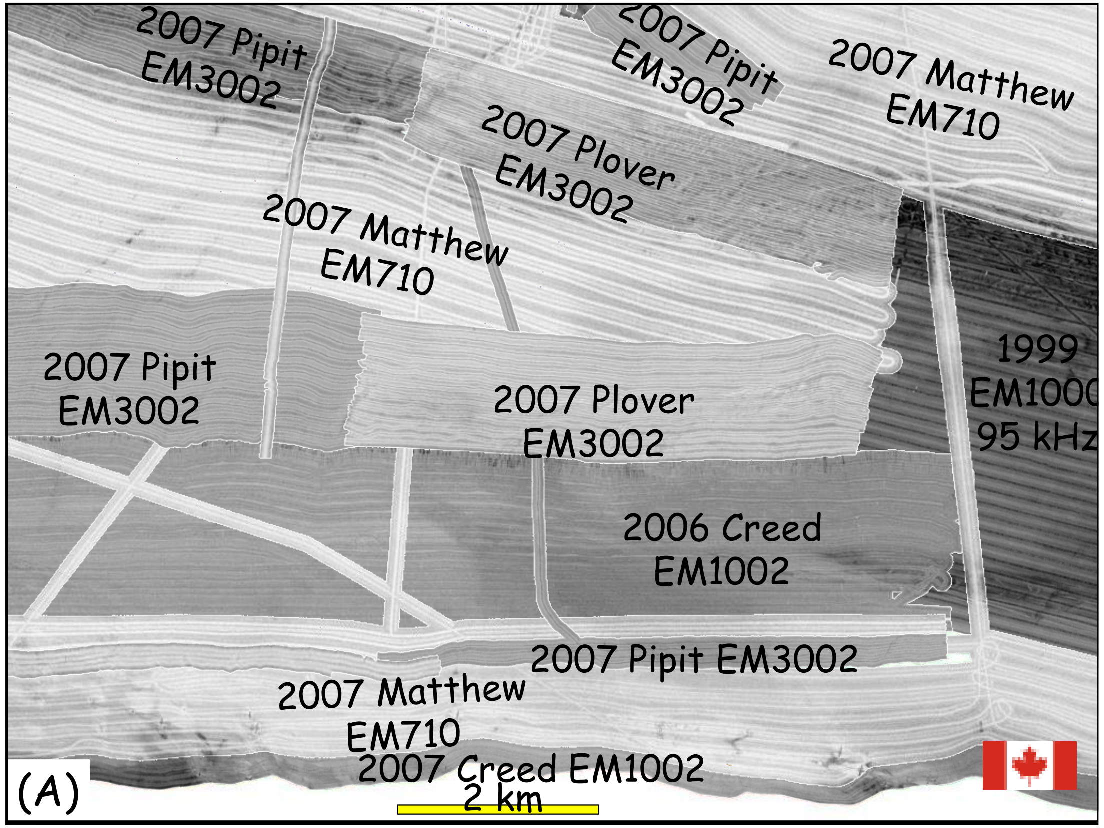


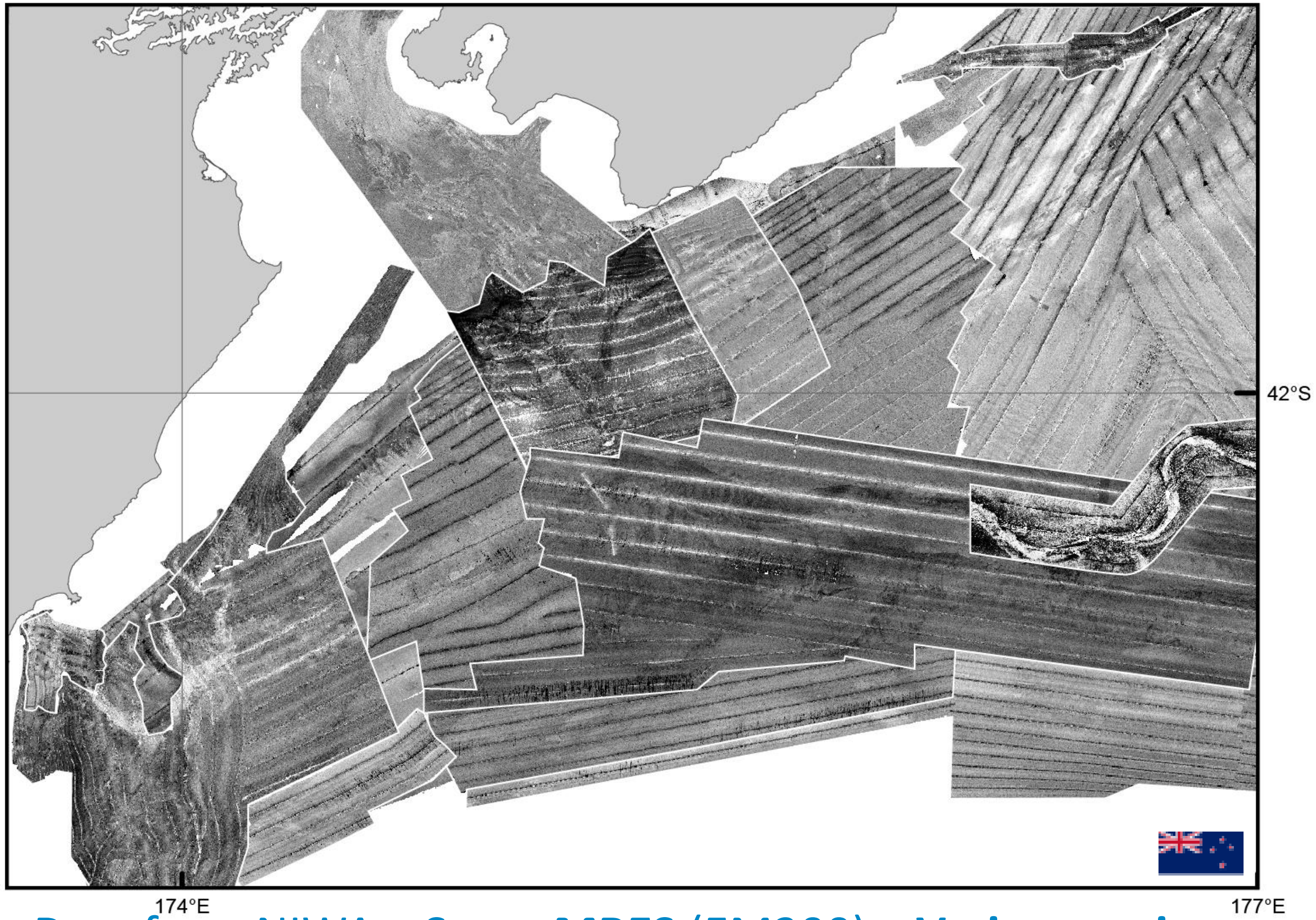
Image © NIWA



Backscatter calibration = not an option!



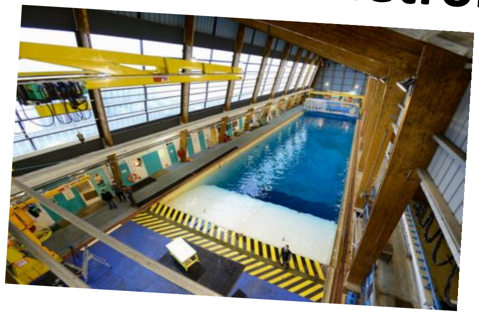
Data from UNB & CHS – **Various MBES & cruises**

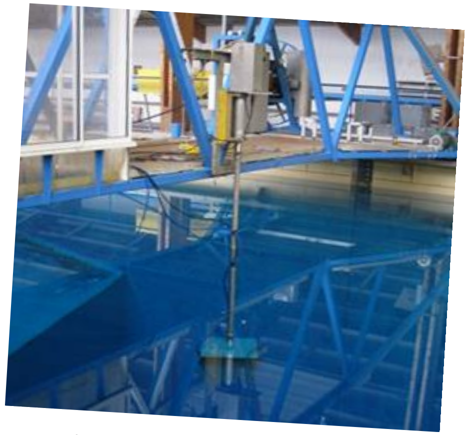


Data from NIWA – **Same MBES** (EM300) – **Various cruises**

MBES Backscatter Calibration Methods

Metrological





In factory, or test tank

Electroacoustical data:

➔ Source Level / Signal / Receiver sensitivity / Gains / Directivity…

➔ Practical for Hi-frequency systems

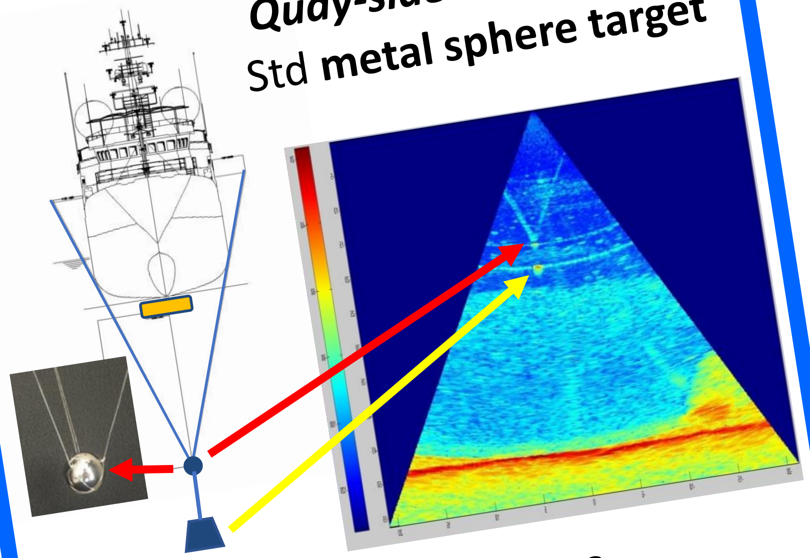
➔ Implies **facilities, equipment** & availability

- *Lanzoni & Weber, JASA 2012*

Reference Target

Quay-side or test-tank

Std **metal sphere target**



➔ Classical for fisheries SBES

➔ Practical difficulties for MBES

- *Foote, Mayer et al. JASA (2005)*
- *Ongoing works : CCOM, Ifremer…*

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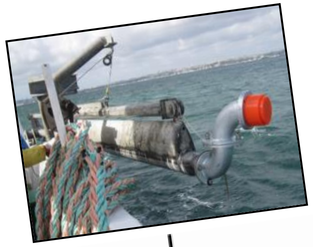
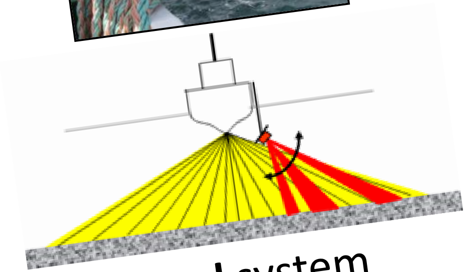
MBES Backscatter Calibration Methods

Cross-calibration





Under survey conditions

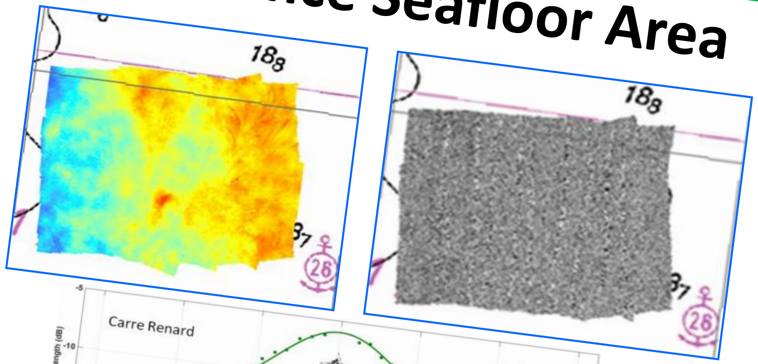
➔ Adjust data w/**another calibrated** system

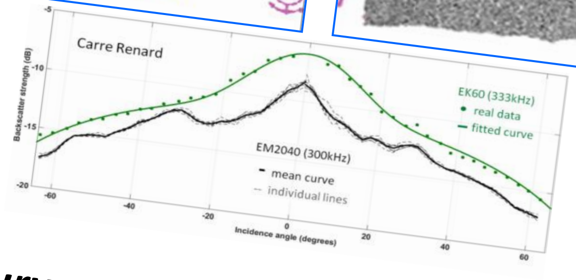
➔ Practically a **tilted Single-beam Echosounder**

➔ No specific area needed

- *Ladroit et al., MGR (2018)*
- *Eleftherakis et al. MGR (2018)*

Reference Seafloor Area





Under survey conditions

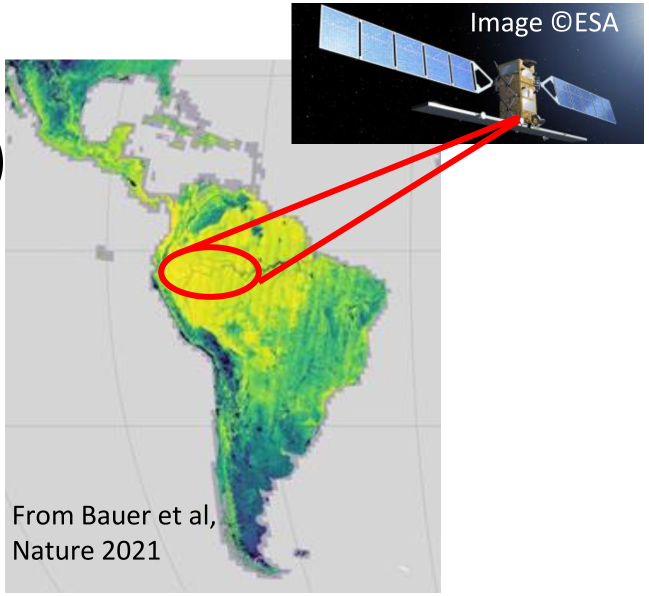
➔ Direct comparison w/ **local reference data**

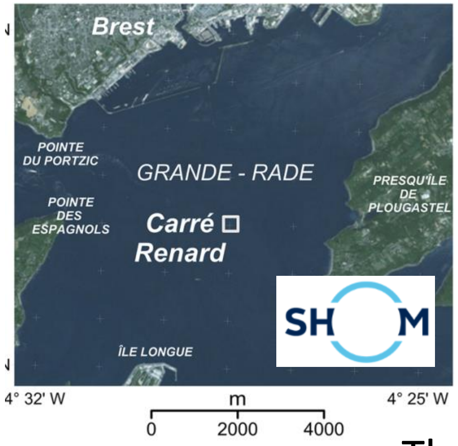
➔ Find, validate & monitor specific areas

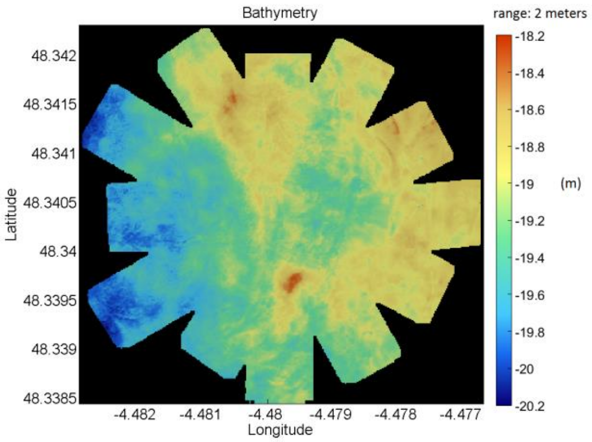
- *Lurton et al. MGR (2018)*
- *Roche et al. IHO 2024*

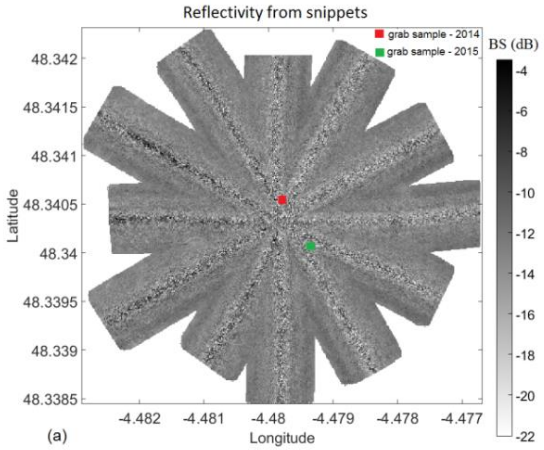
MBES Calibration / Seafloor Reference Areas

- **The most practical method today**
- Inspired (*again!*) by **satellite-borne radar** (South Am. rainforest)
- A number of **strong conditions** to fulfill :
  - **Low-relief** topography / Significant extent / Accessibility
  - **High reflectivity** level / Low angle dependence
  - Space **homogeneity** & Time **stability**
- **Compatibility with hydrography** methods
- *See papers by Deleu et al. & Roche et al. (this conference)*









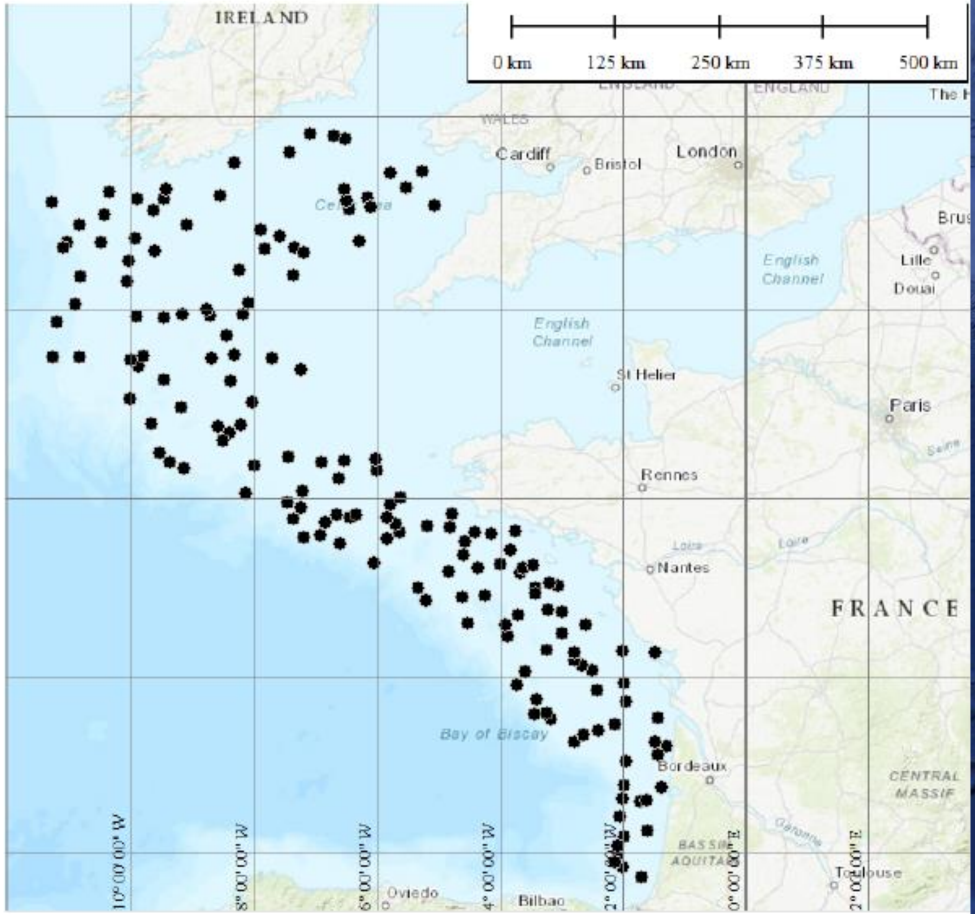
The *Carré Renard* reference area – Bay of Brest (France) – Depth 20 m – *Data © Ifremer*

An example of BS mapping at regional scale

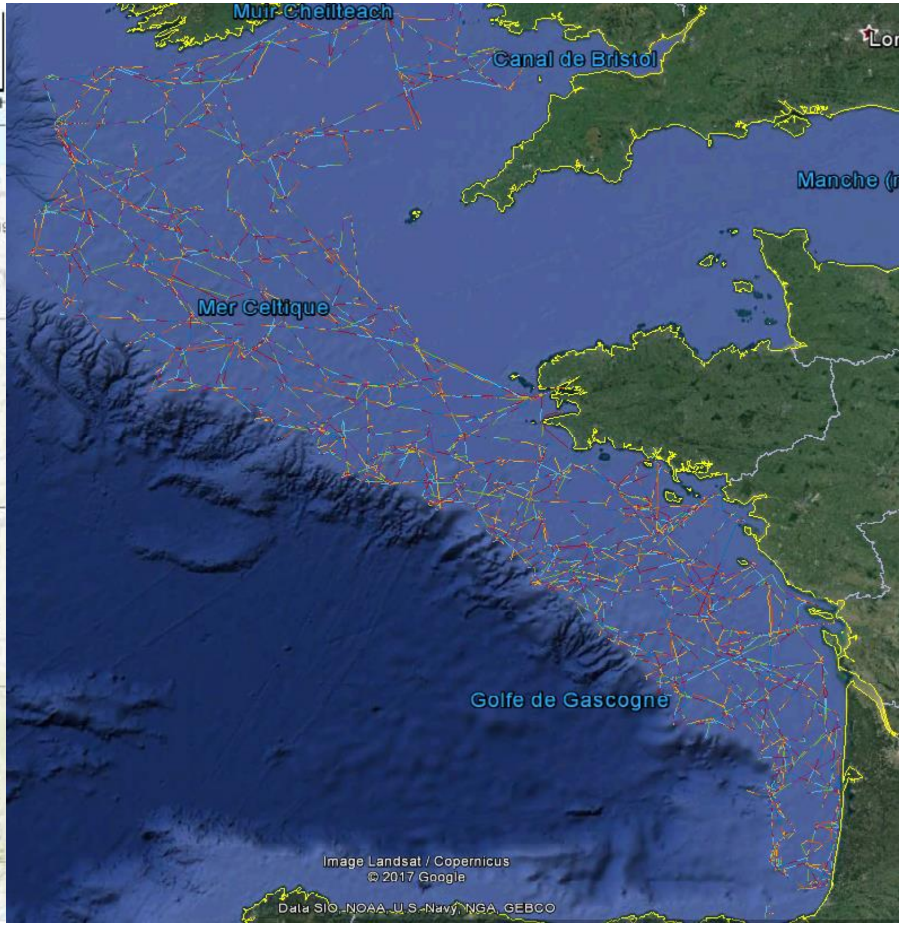
Data from a systematical effort of seabed mapping over several years

One same MBES : Simrad ME 70 (calibrated – Fisheries specialized)

- 169 « Boxes »
- 213 surveys
- Inter-box lines
- Ground-truthing



169 boxes



Data: © Ifremer

All survey lines over 4 years

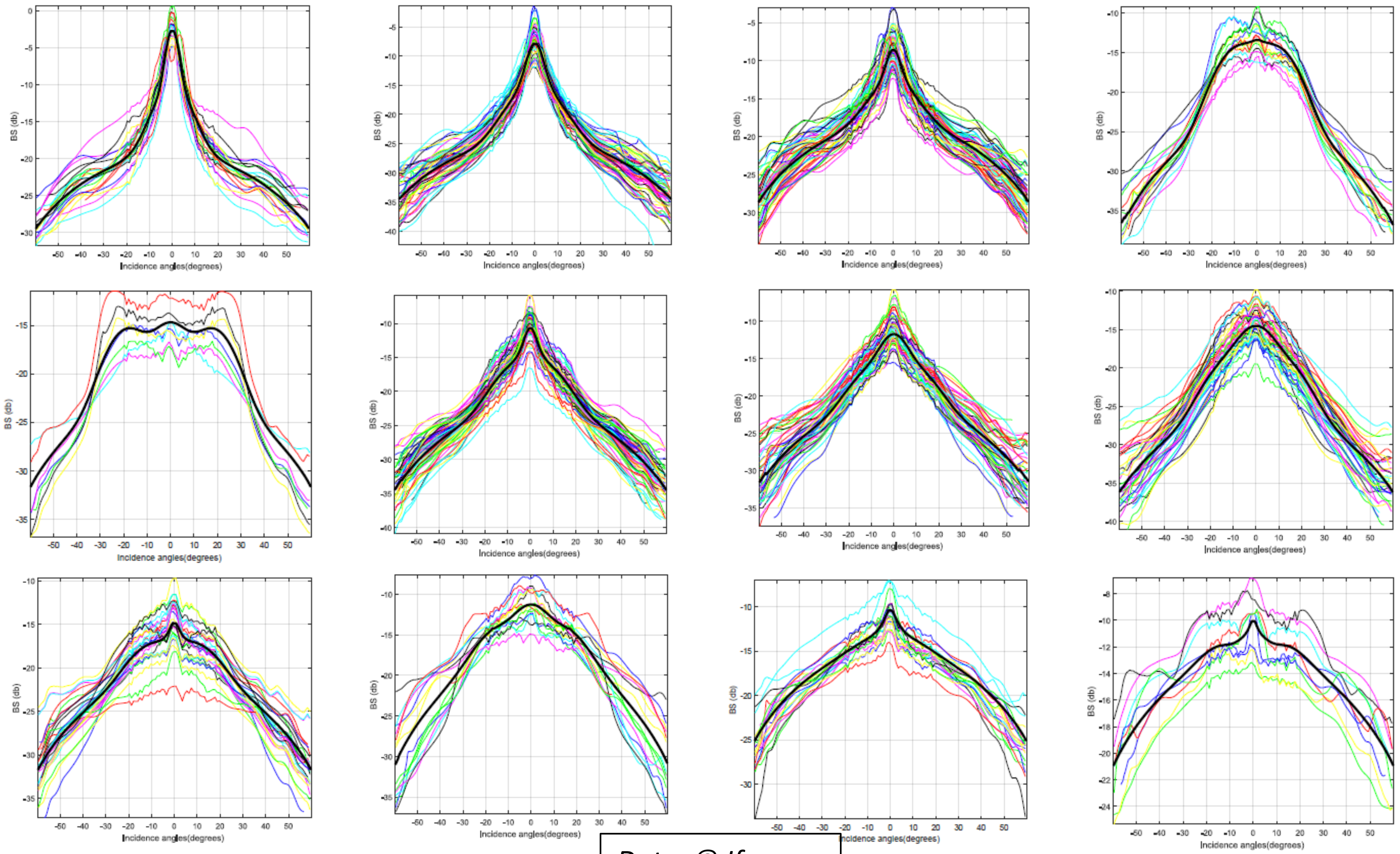
Processing of angular backscatter measurements

➔ **Classification** of all angular BS curves (shape, level…)

213 Surveys

$\approx 400\ BS(\theta)$

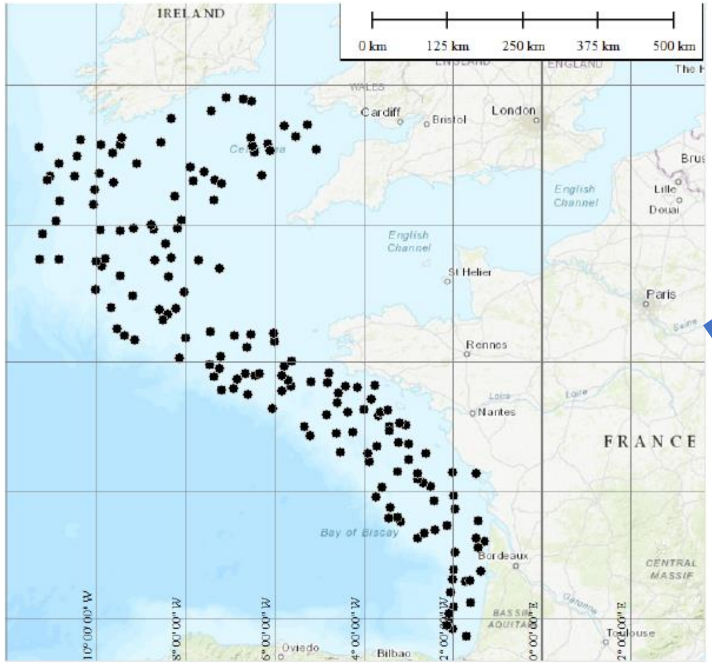
12 Classes



Data: © Ifremer

Final « Acoustical facies » mapping at region scale

- After classification / **12 *BS*(θ) classes**
- Interpolation between the 169 boxes, using the connecting lines
- A **map of the « acoustical facies » classes** (at 70 kHz)



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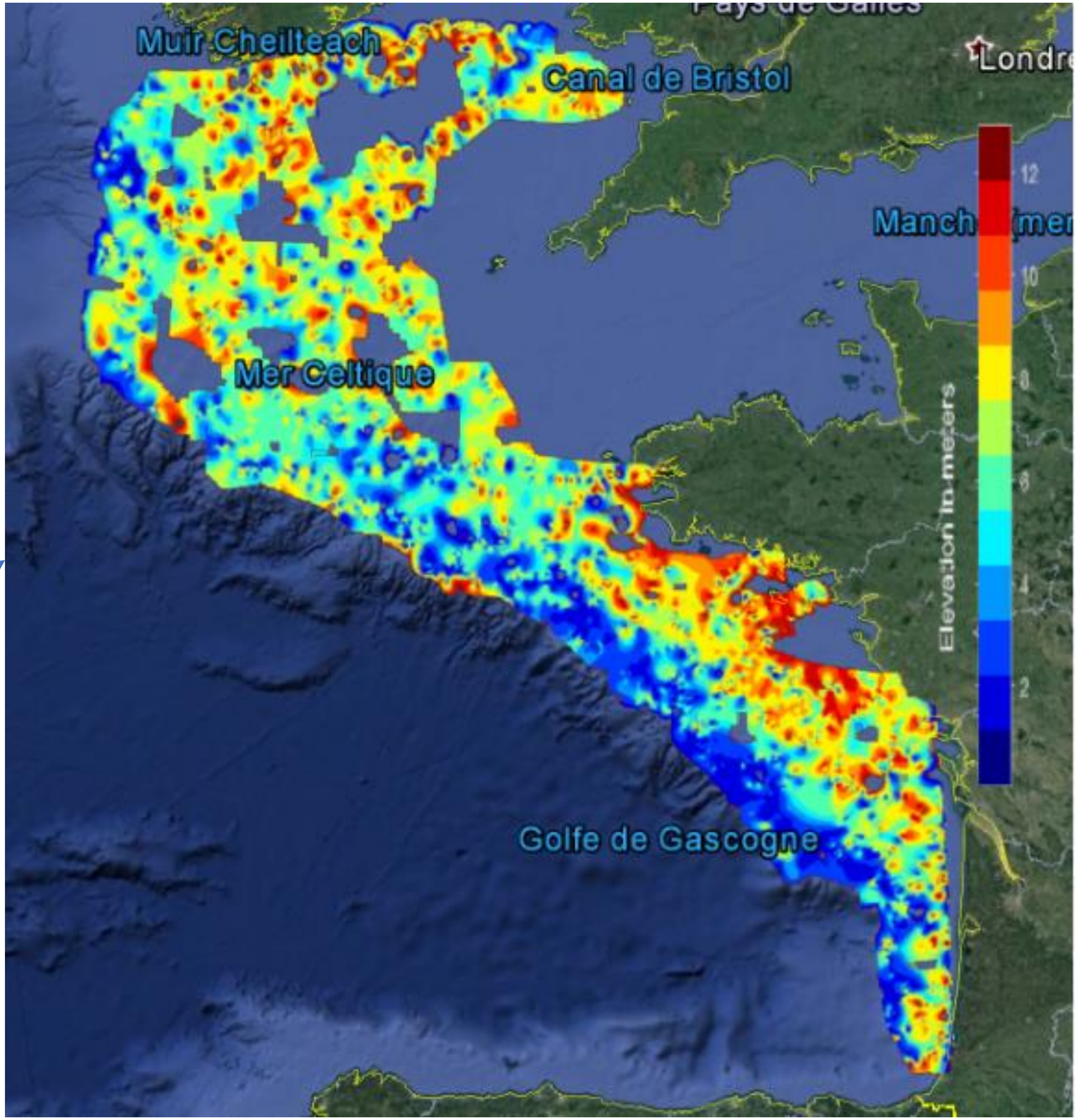
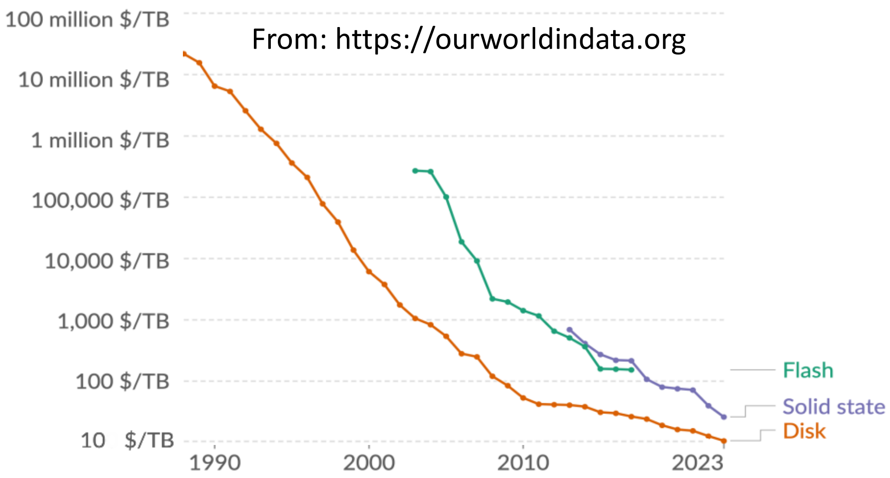


Backscatter Data Recording ➔ Large data volumes

- **Magnitude 1 TB/day** – 100x to 1000x more than just bathymetry
- **Optional ➔** often (not always!) **not recorded**



Why this is a shame :

- The **cost of storage** media (HD…) has decreased **very low**
- A **systematic recording of backscatter** is desirable in the context of a policy of global seafloor mapping (Oceans 2030)
- **Potential tools for processing** huge data amounts now available

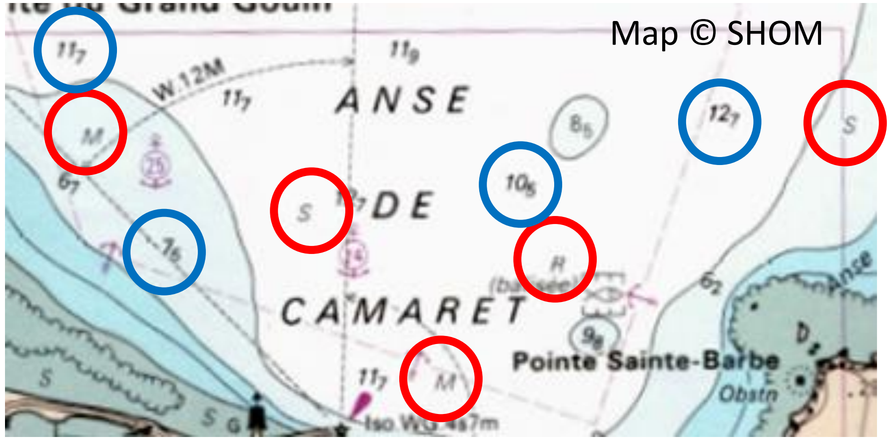
A.I. = The Future for BS data processing

- Automated processing of large data volumes
- New capabilities for specific operations
  - **Quality Control & Filtering**
  - **Seabed classification w/ machine learning**
- Already used today in hydrographic mapping

Typical daily cost of survey vessels

10 - 40 k€

Backscatter / Bathymetry compatibility?



Map © SHOM

1. **Sensors**
   - Same echosounders
2. **Survey** strategies
   - Coverage & sampling scale: possibly different- can be made consistent
3. Data **processing** tools
   - Complementary methods
   - BS processing = incorporated today in most MBES processing SW suites
4. **Calibration**
   - Common operational protocols ? Reference seafloor areas ?
5. Data **quality** standards
   - Still to be defined for BS

Towards BS incorporation in hydrography standards

A first step: latest version of S-44

(ed. 6.2.0 - 2024)

Chapter 3 - DEPTH, BATHYMETRIC COVERAGE, FEATURES, AND NATURE OF THE BOTTOM

(…)

3.8. Nature of the bottom

3.8.1. Acoustic Backscatter

3.8.2. Optical Backscatter

The Backscatter Working Group (BSWG)

GEOHAB
BSWG

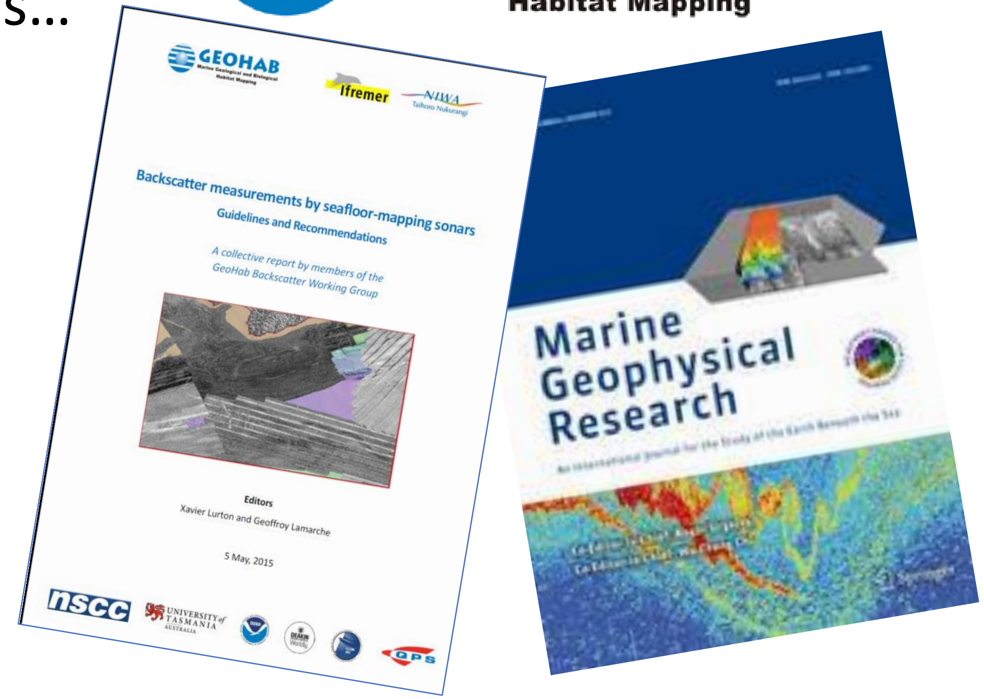
- A framework for methodology definition and recommendations already exists : ***BSWG !!!***
    - ➢ Started in 2013 – In the **GeoHab** context (habitat mapping community)
    - ➢ Gathers scientists, engineers, industrialists, operators…
    - ➢ Suggests guidelines, research topics, cooperations…
    - ➢ **Guideline document** in 2015 (available on line)
    - ➢ MGR “**Backscatter Special Issue**” in 2017
- BSWG II was launched Fall 2022

⬇

First contacts BSWG- IHO / Late 2023

(➔ IHO S-44 ed. 6.2.0 2024)

GEOHAB
Marine Geological and Biological
Habitat Mapping



A few takeaway messages

- **Sonar backscatter** is a key component of today's seafloor mapping
- **Hydrographic bathymetry & backscatter share**:
  - ➢ complementary **needs** – *for exploration, mapping & monitoring*
  - ➢ common **tools** – *echosounders, SW packages*
  - ➢ compatible **methodologies** – *calibration, survey strategies*

  … and **miss**:
  - ➢ a common **framework of standards** and protocols
- A first attempt = undertaken in latest **IHO S-44** – *To be continued !!!*
- Two possible (& realistic) short-term common objectives :
  - A **Quality Scale** for Backscatter ?
  - **Reference seafloor areas** for calibration ?

Data © Ifremer