Hydrographic data from survey design to final habitat products in the Norwegian seabed mapping programme MAREANO

Terje Thorsnes, Margaret Dolan, Lilja R. Bjarnadóttir, Markus Diesing, Alexandre Schimel, Valérie Bellec & Daniel Wiberg - Geological Survey of Norway

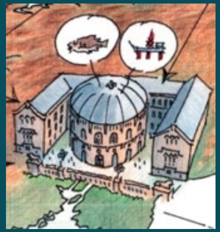
Start 2005
Budget 2005-2024: 1.65 billion NOK (140 million Euro)

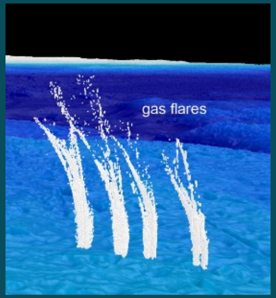
Kartverket · Norges Geologiske Undersøkelse · Havforskningsinstituttet

MAREANO — collecting marine knowledge

- Knowledge for ecosystem-based ocean management
- Science
- SDG 14
- Industry
- Innovation

MAREANO






Source: Øyvind Hagen


Source: NTNU/AMOS

Mareano organisation

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MAREANO inter-ministerial steering group

DET KONGELEGE NÆRINGS- OG FISKERIDEPARTEMENT

$

DET KONGELEGE KLIMA- OG MILJØDEPARTEMENT

DET KONGELEGE OLJE- OG ENERGIDEPARTEMENT

DET KONGELEGE KOMMUNAL- OG DISTRIKTSDEPARTEMENT

MAREANO programme group – all relevant management and research institutions

NORSK POLARINSTITUTT

MILJØ-DIREKTORATET

Kartverket

NORGES GEOLOGISKE UNDERSØKELSE - NGU -

HAVFORSKNINGSINSTITUTTET

NORWEGIAN OFFSHORE DIRECTORATE

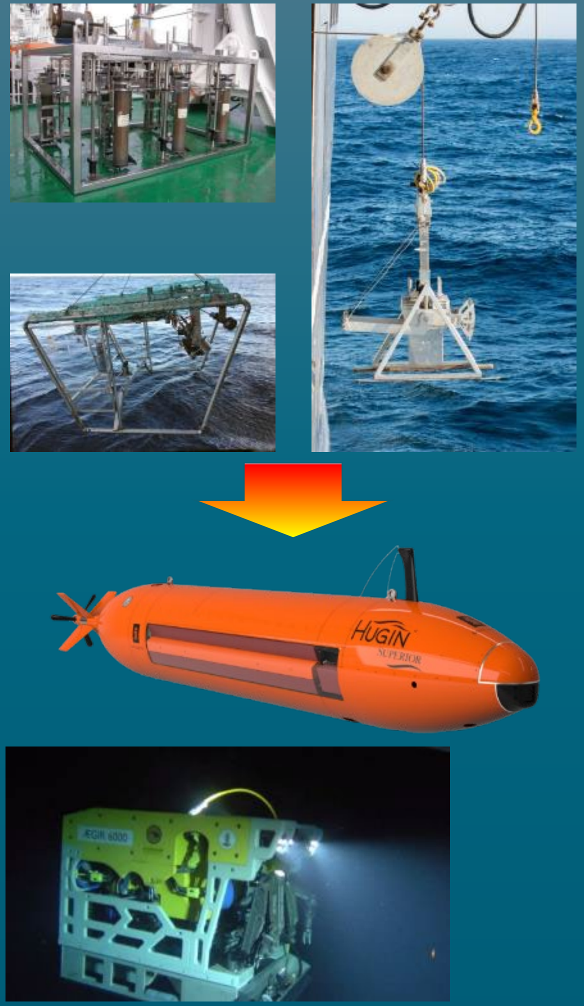
KYSTVERKET

NVE

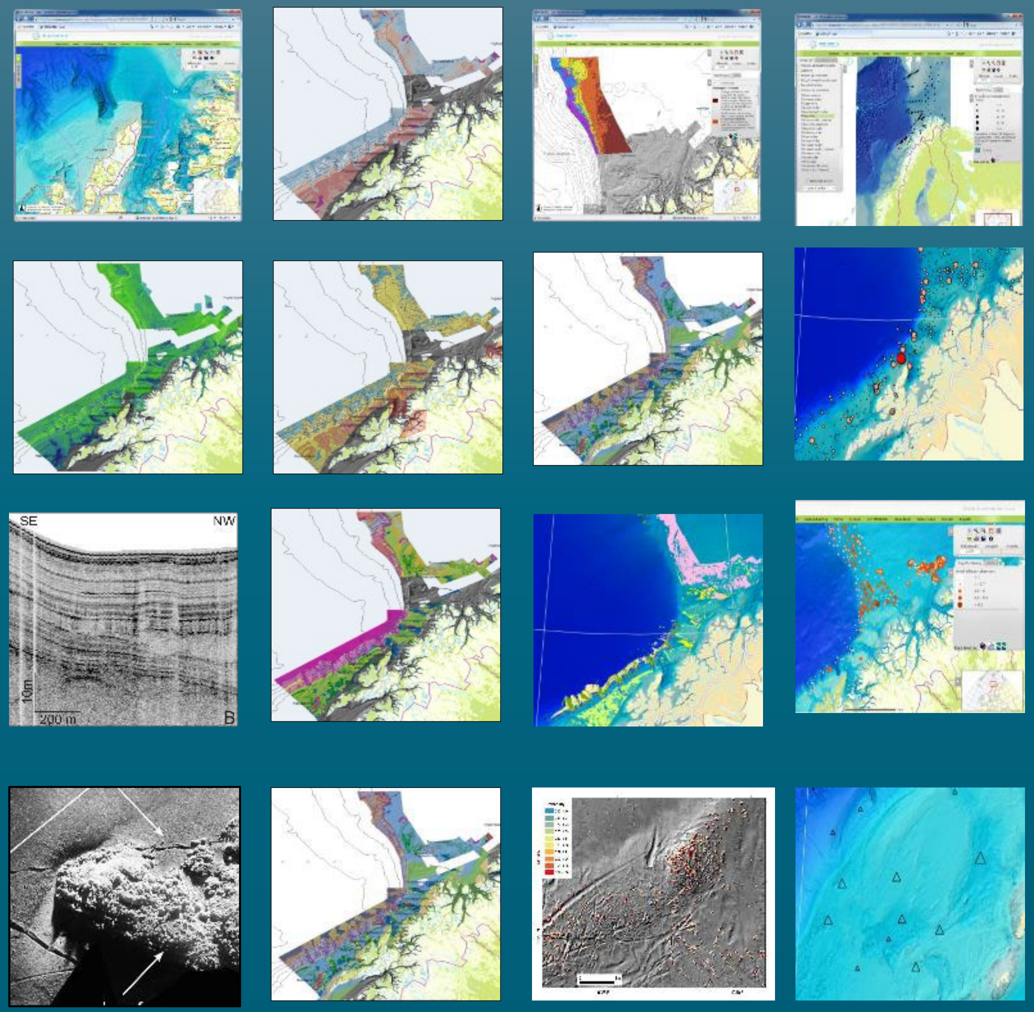
Main steps for seabed mapping

MBES bathymetry, backscatter, water column, subbottom profiler

Geology, biology and chemistry data acquisition – images and samples



Products



Coverage – bathymetry, geology and habitats

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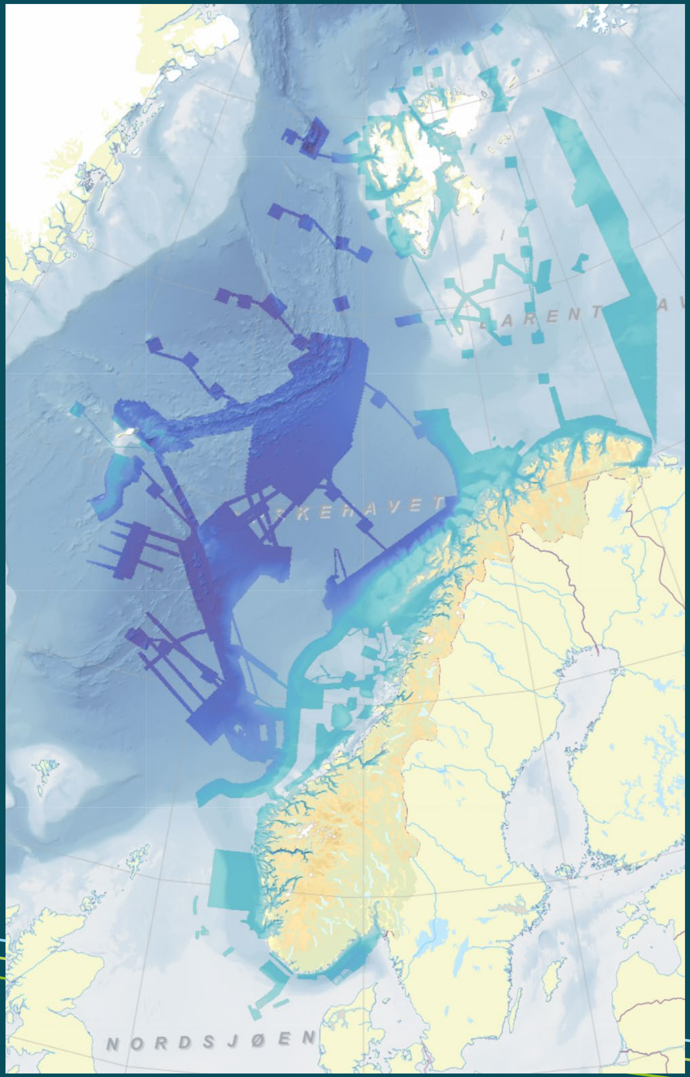
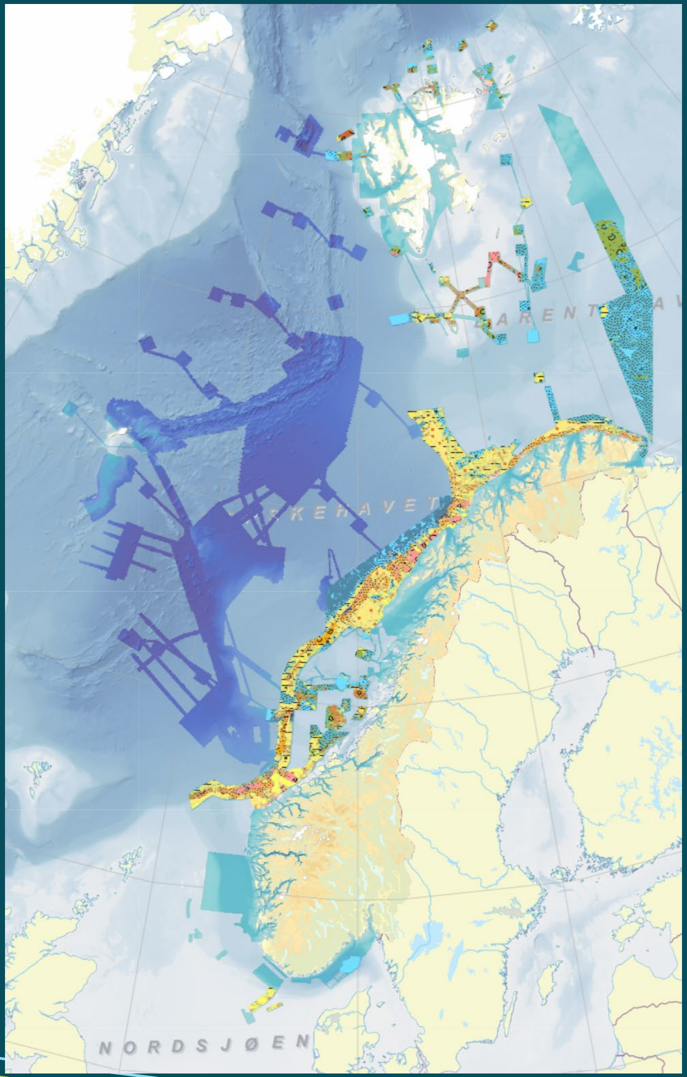
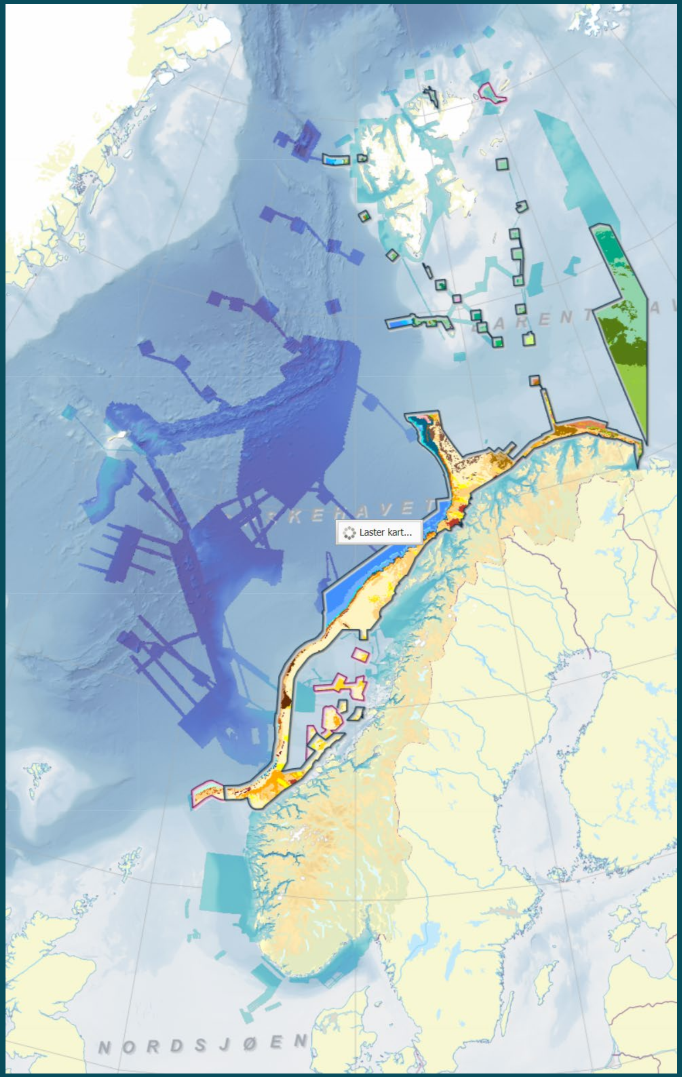
Bathymetry – 300 000 sq km



G-B-C field work – 280 000 sq km



Habitats – 245 000 sq km



Bathymetry – collect once, use many times

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Norwegian Mapping Authority Hydrographic Service
MAREANO programme

Norwegian Hydrographic Service

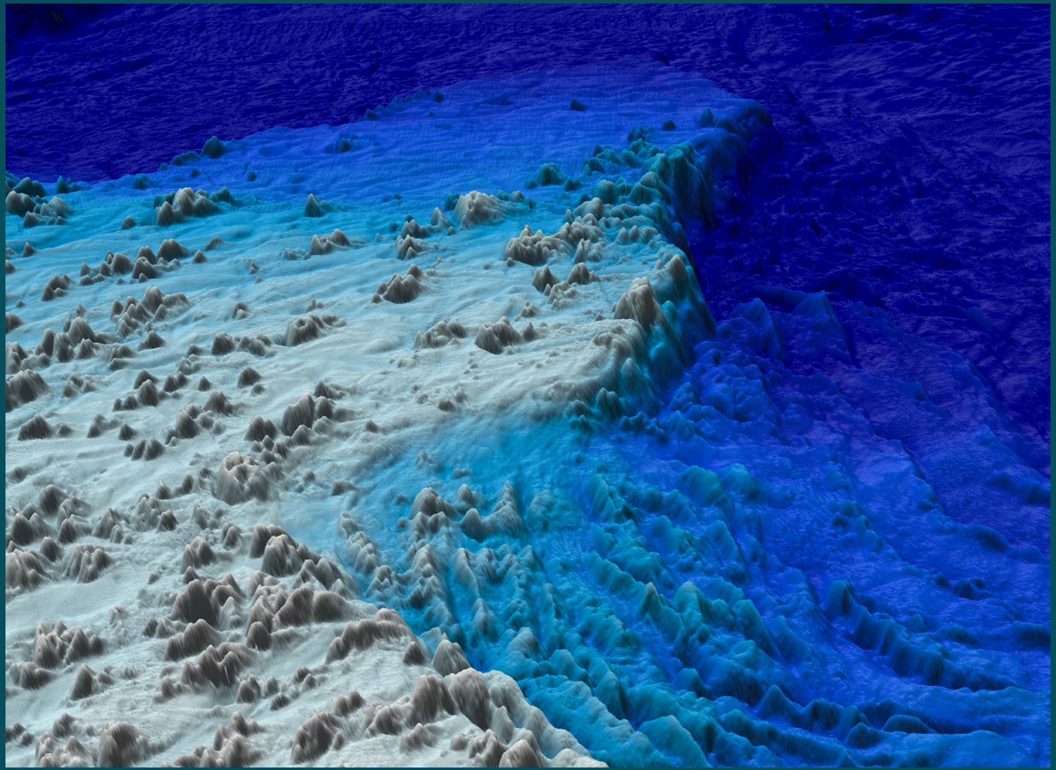
and

…

APPENDIX B

Technical Specifications

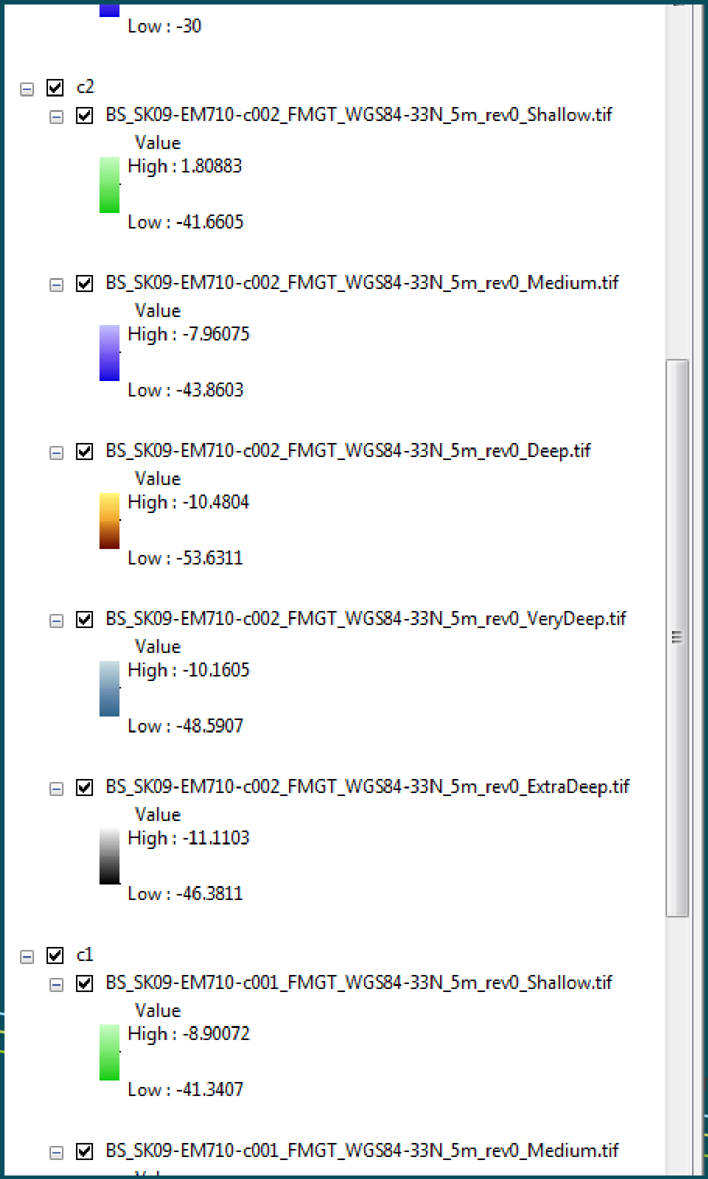
MAREANO Programme

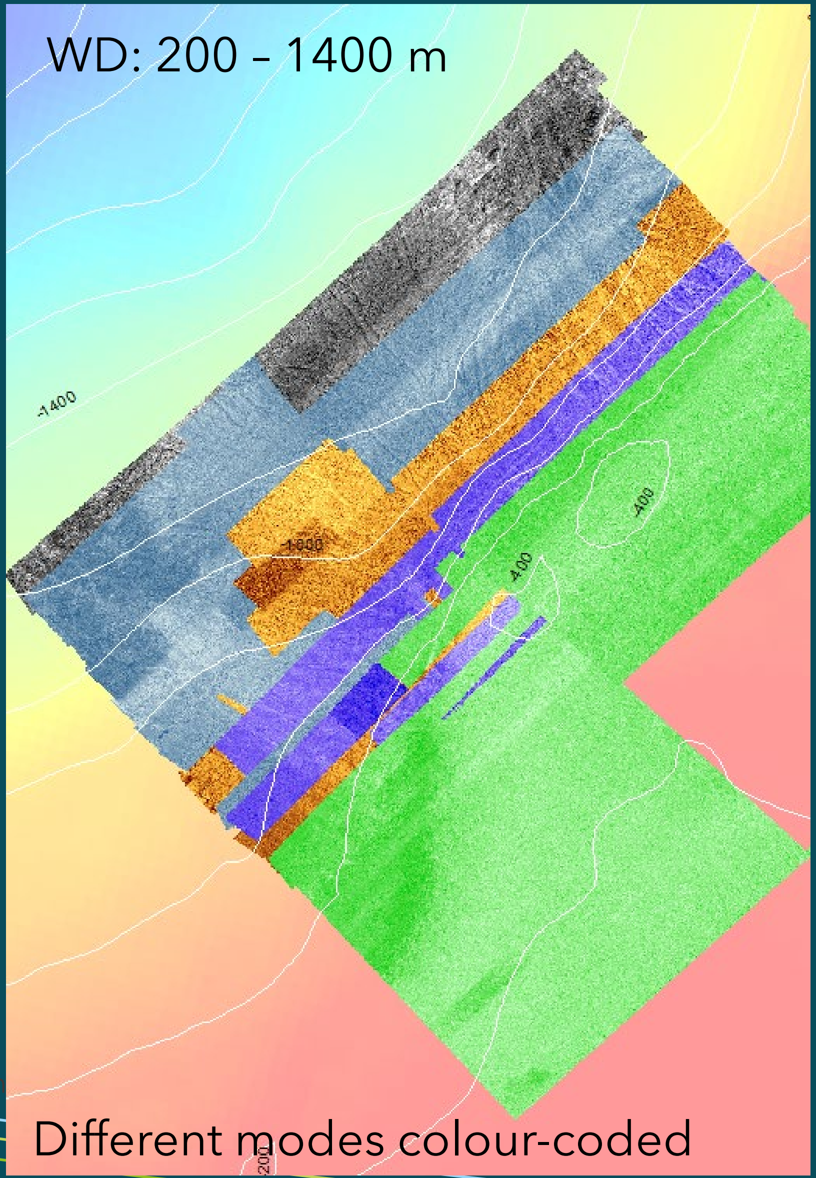


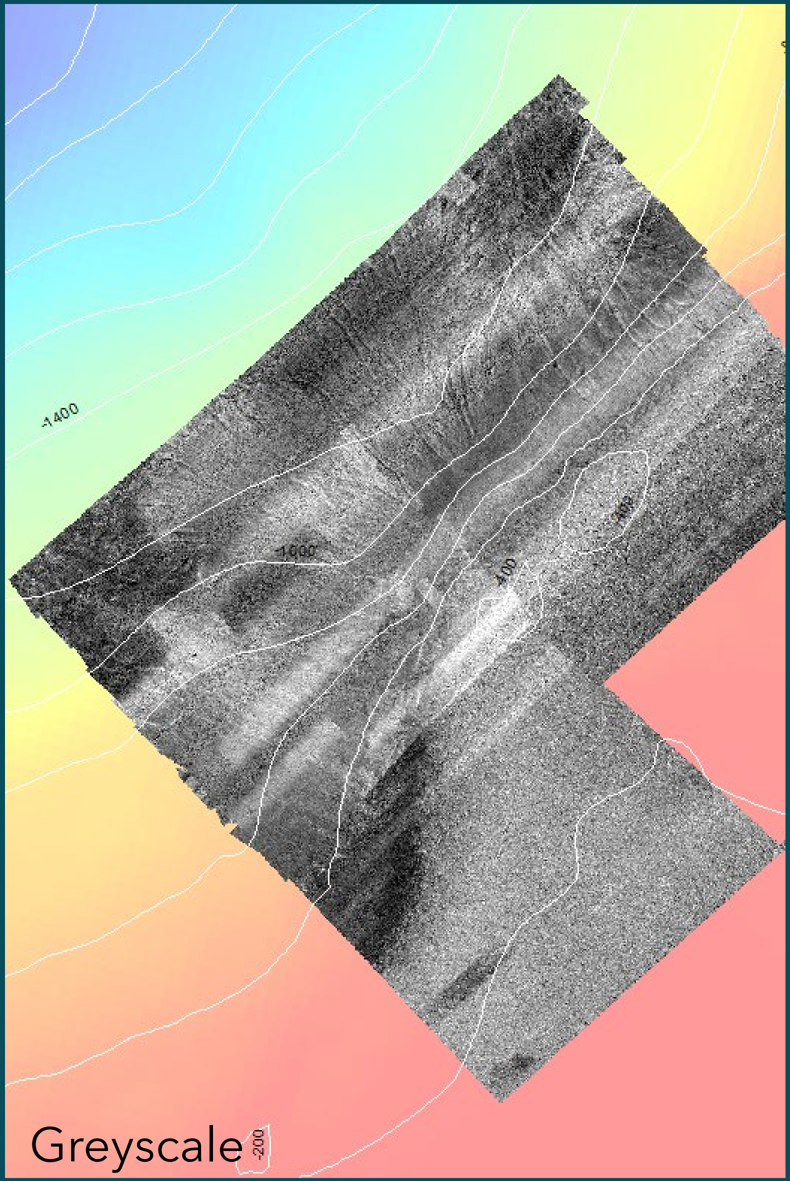
In addition to the general seabed topography, all seabed features (like iceberg scour marks, coral reefs, pockmarks, sand waves and boulders, etc.) are very important to the MAREANO programme. Both the survey and the processing shall be carefully done to preserve all the seabed feature information and removing all the faulty soundings. Seabed features shall not be camouflaged by artefacts and artefacts must not appear as seabed features. No smoothing of the XYZ data shall be applied. Backscatter data are equally important as bathymetry data for the MAREANO programme. The multibeam backscatter data shall provide a representative view of natural variations in seabed acoustic reflectivity within the survey area, such that they are suitable for geological mapping.

How backscatter should not be....

Real example – delivery from West Svalbard continental slope…







Backscatter – important data for sediment classification

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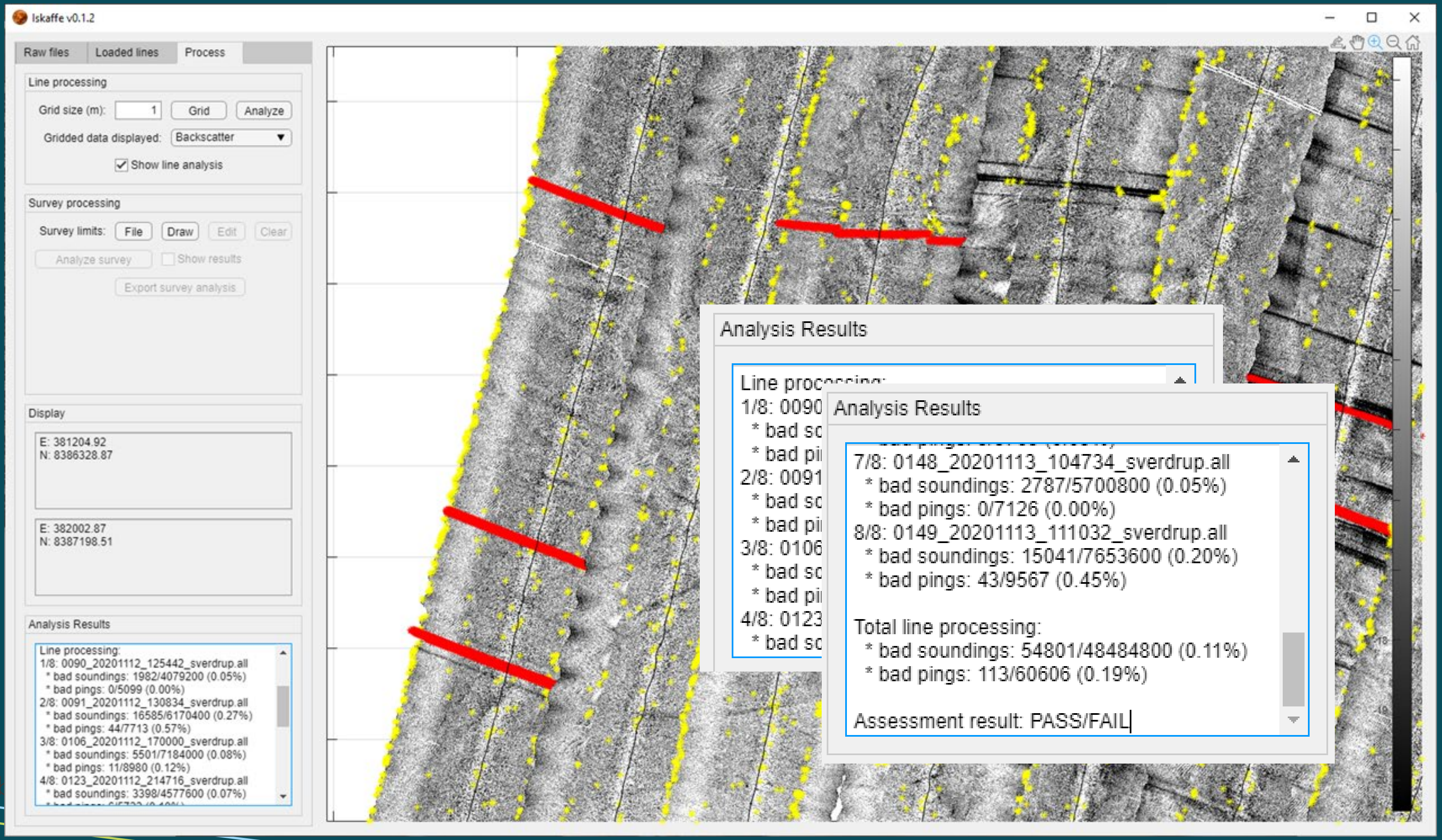
Iskaffe - tool for quality assessment of backscatter data

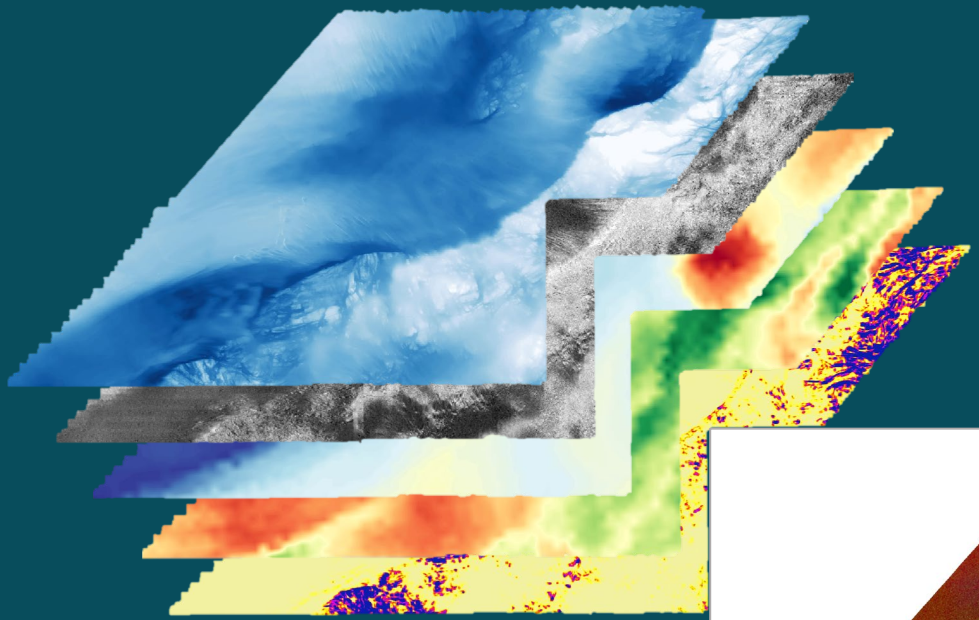
- App built on CoFFee to visualize and assess the quality of Multibeam seafloor backscatter data
- Built at NGU (open-source)
- Support .all
- In development…



iskaffe
multibeam backscatter quality control

Source: Alexandre Schimel

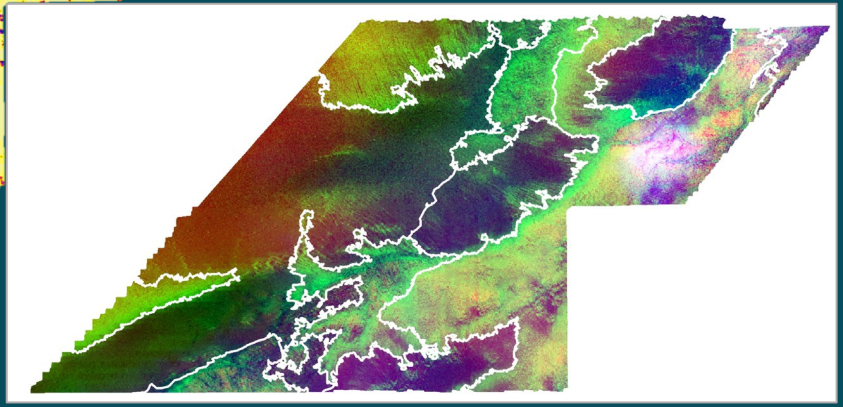
Survey planning

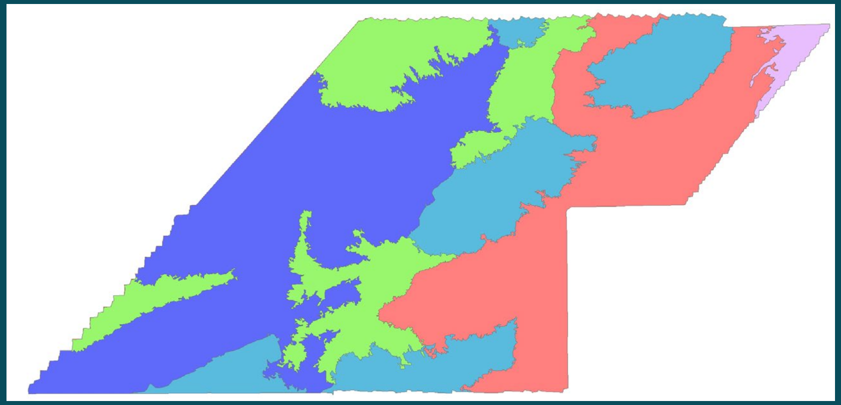


Environmental variables

- Bathymetry
- Backscatter
- Temperature
- Current velocity
- Terrain rugosity++

RSOBIA segmentation and stratification





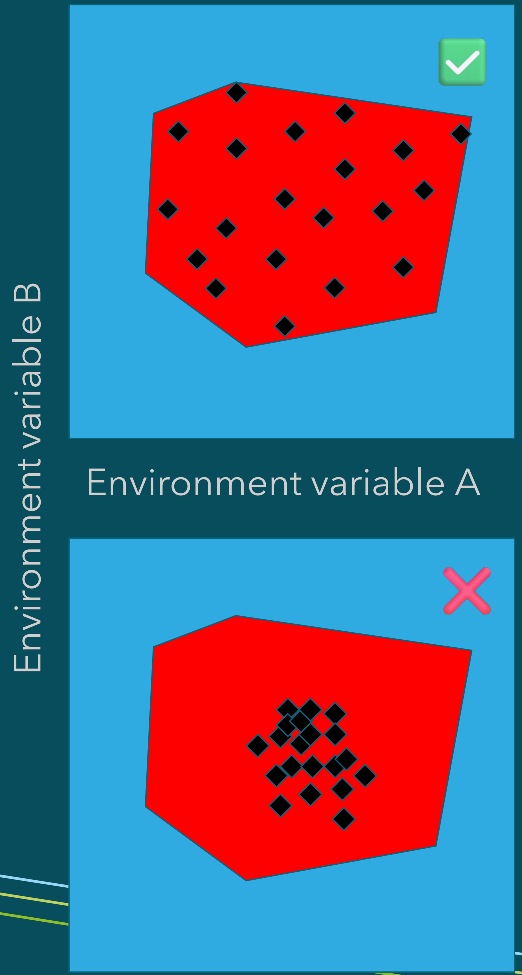
- Multi layer raster (shown as RGB)
- Segmentation using OBIA – spatially aware
- Weighting possible

- Automatic computation of strata number (Calinski-Harabasz criterion)
- Classes have c. similar environmental properties in terms of combination of environmental variables
- Classes have diffferent variability and areas

Source: Margaret Dolan

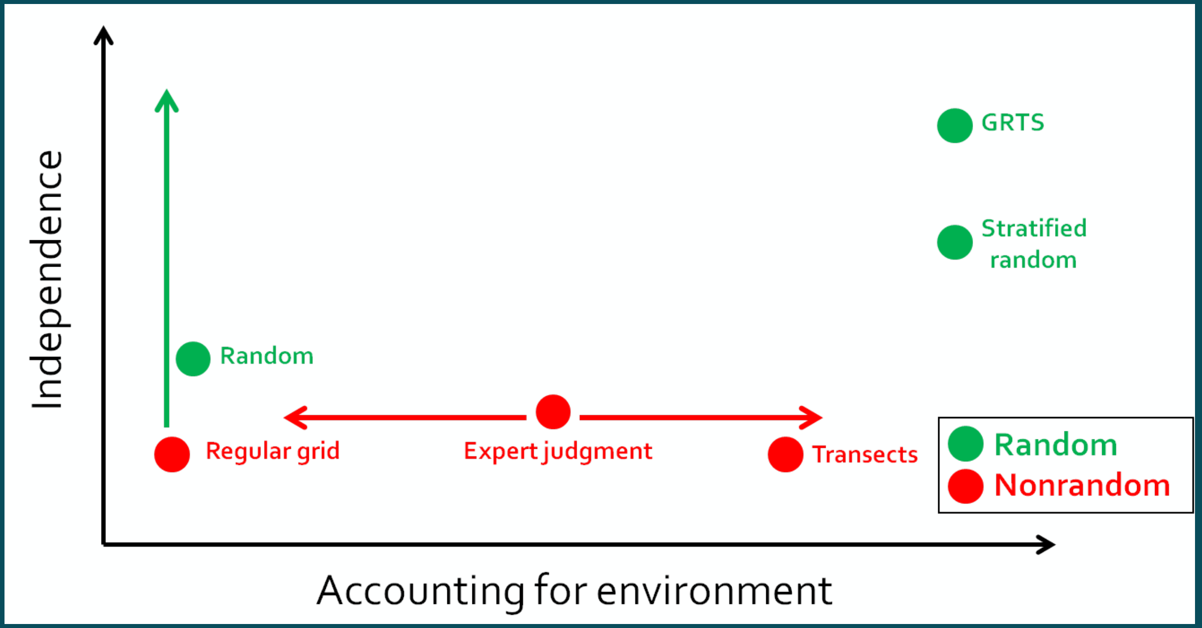
Important factors for modelling and interpretation

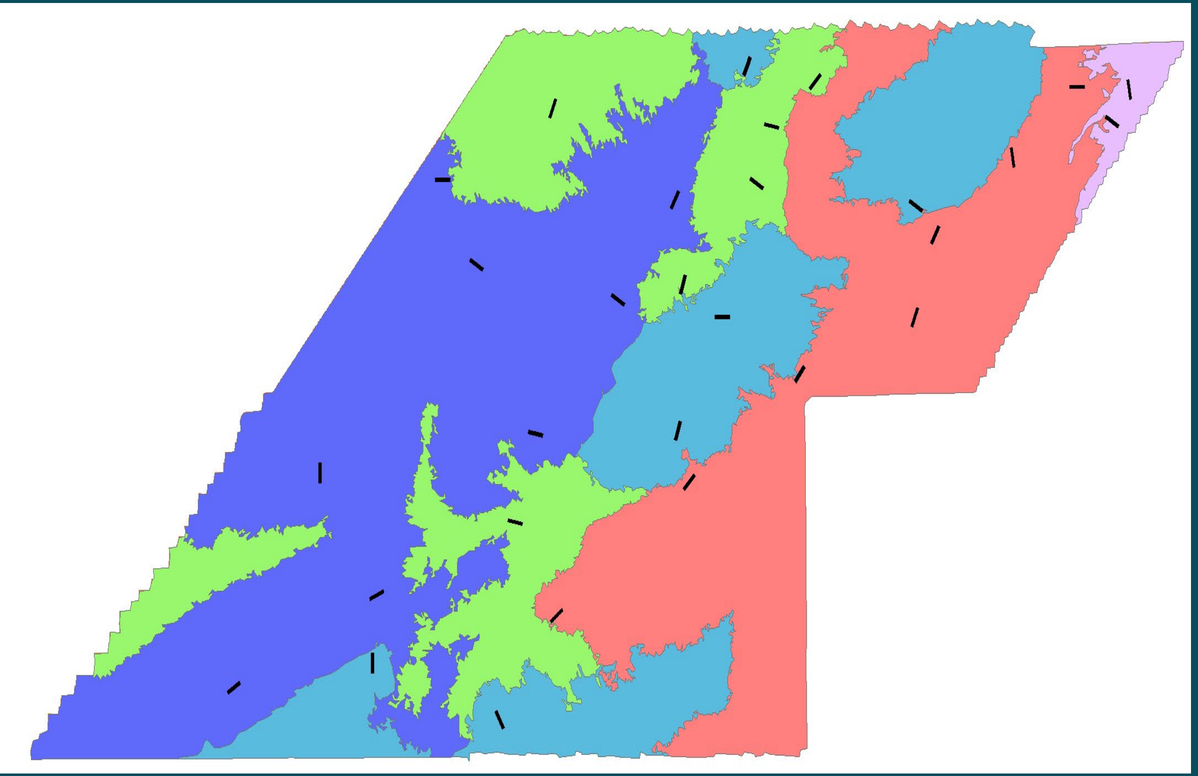
- Good coverage of environmental space
- Objective, statistically independant stations
- Option for supplementing automatically chosen stations with targeted stations (special features, or minor scale variation within one stratum)



GRTS – Generalized Random Tessalation Stratified

- Gives spatially balanced stations
- Accounts for variation within strata
- Accounts for area of strata
- Can produce reserve stations
- Can include rules – e.g. distance between stations





Source: Margaret Dolan

Data acquisition for geology, biology and chemistry

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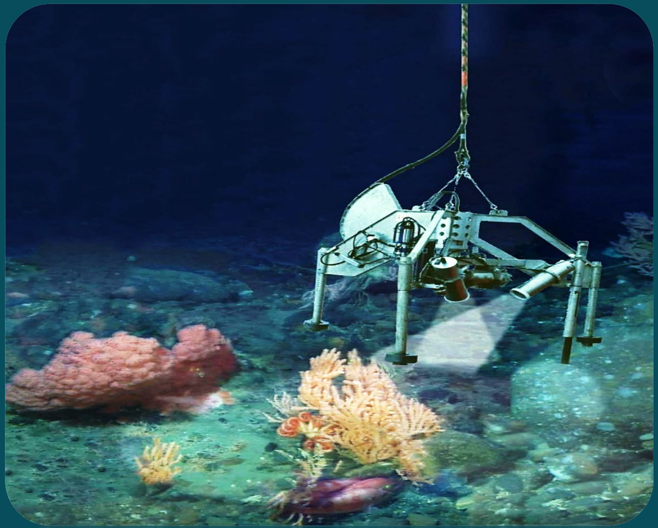
G.O. Sars or similar

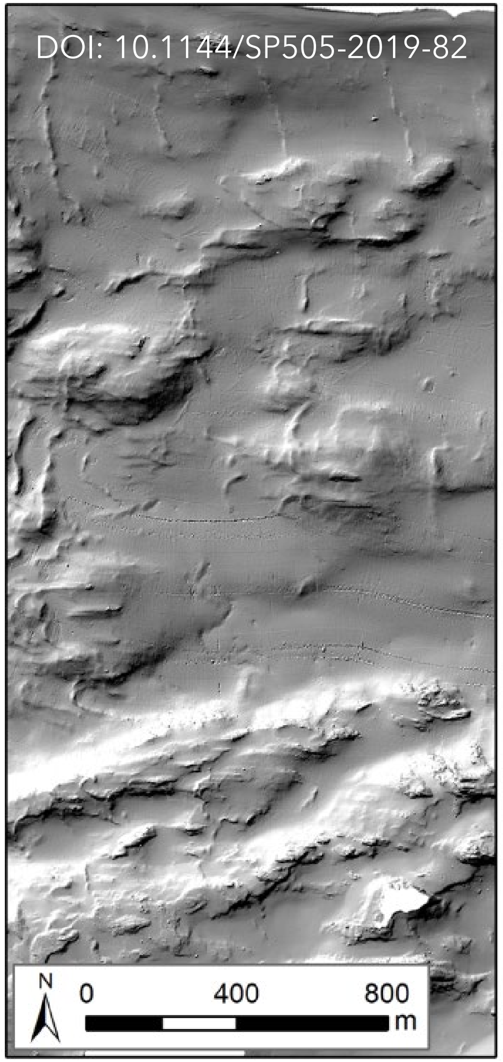
Towed video platform or ROV



Grab sampling and coring

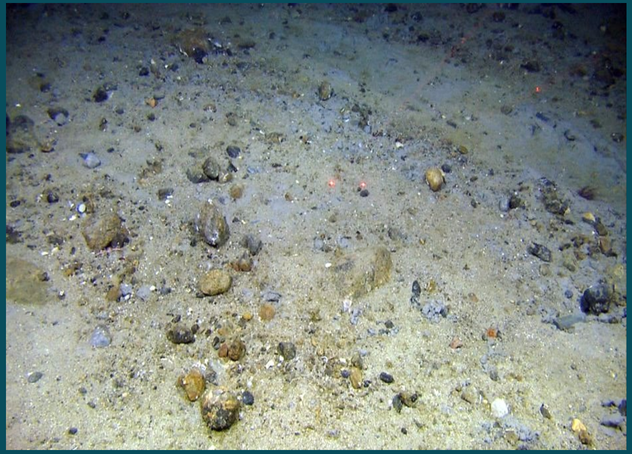
Trawling and sledge

Production line – sediment maps

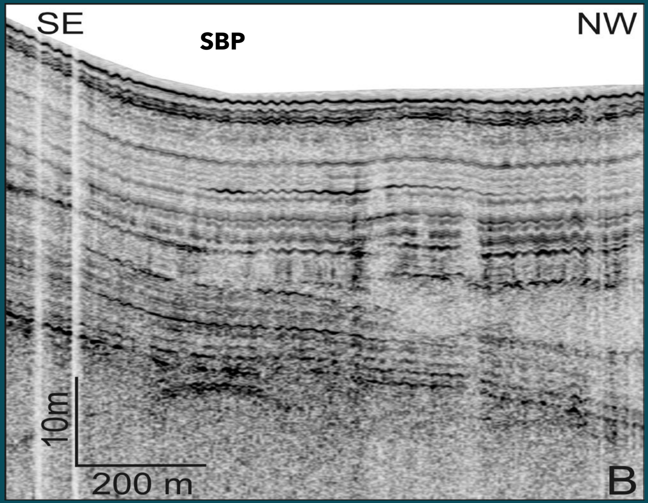


Bathymetry, terrain derivatives

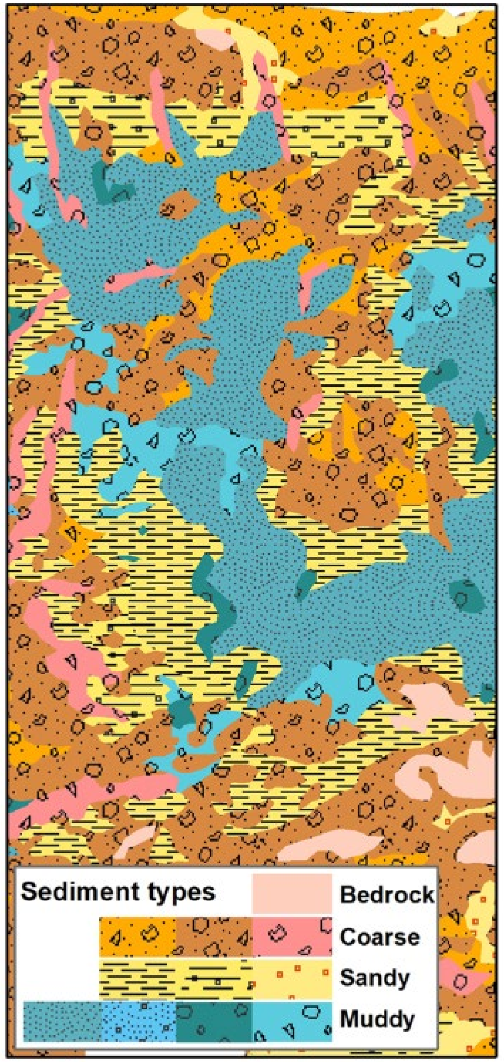
Backscatter



Photos, grab samples



Subbottom profiler



Expert interpretation, digitisation

Production line – habitat maps

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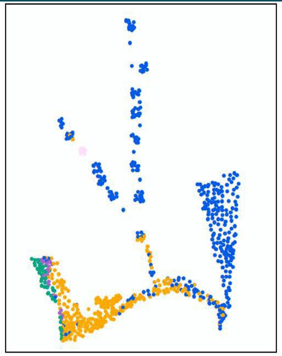
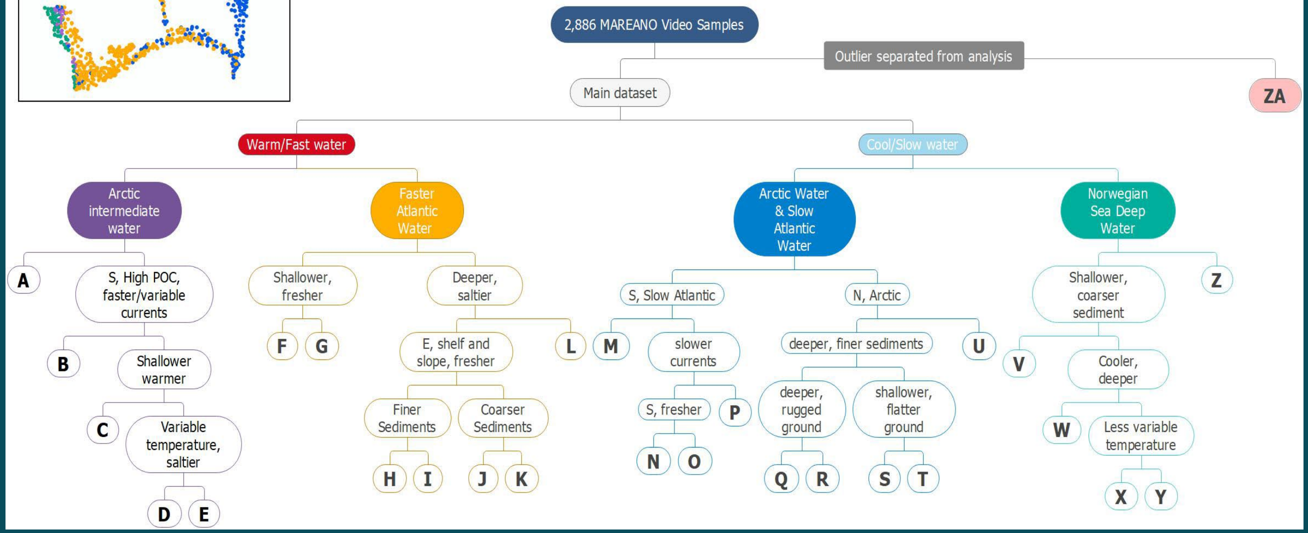
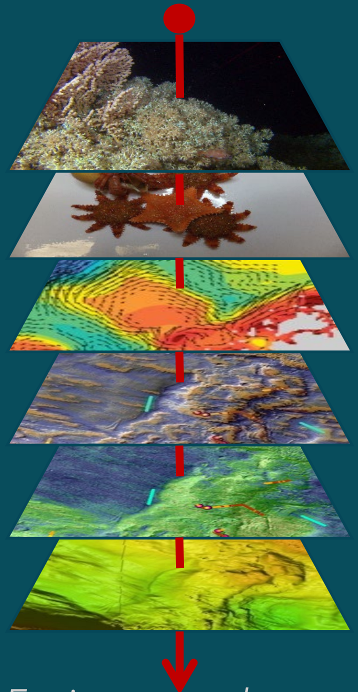


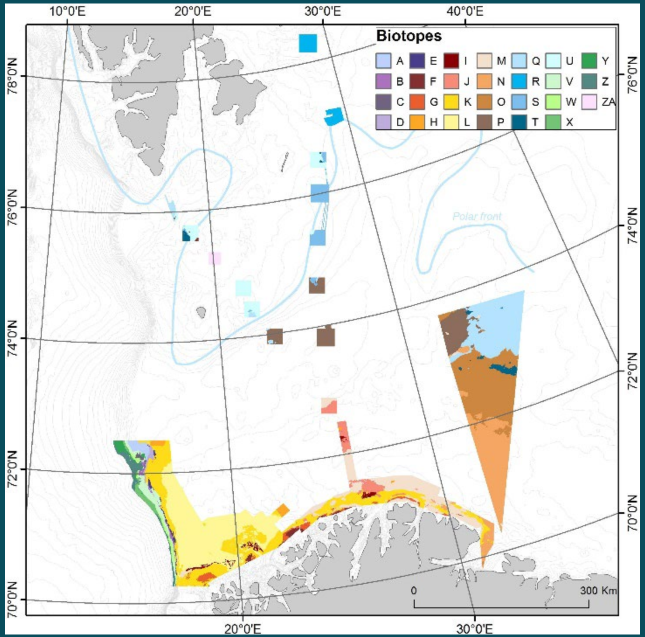
1. Classification of videos, using multivariate statistics



Buhl-Mortensen et al. 2020. Frontiers in Marine Science

2. Modelling and prediction of habitat maps using ML





Environmental variables incl. geological map products

Maps and data types

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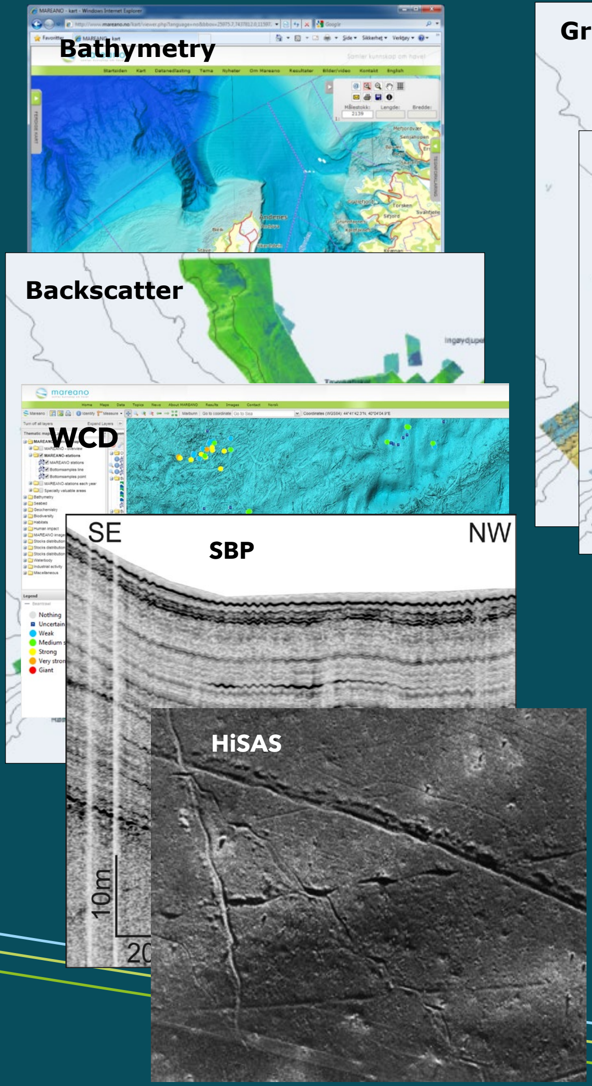
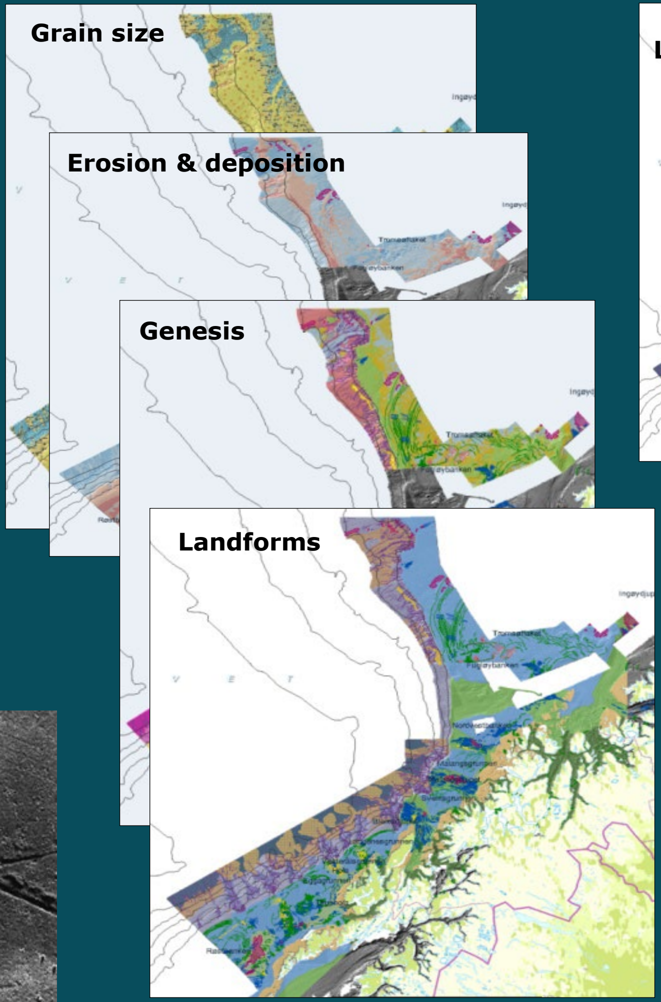
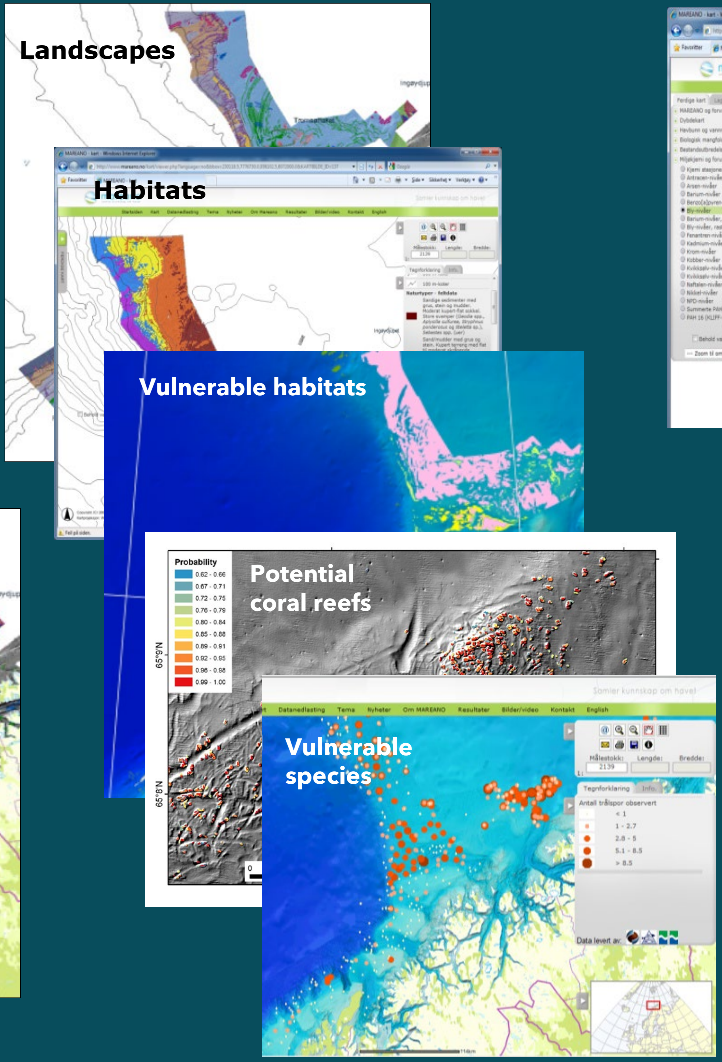
Acoustic data



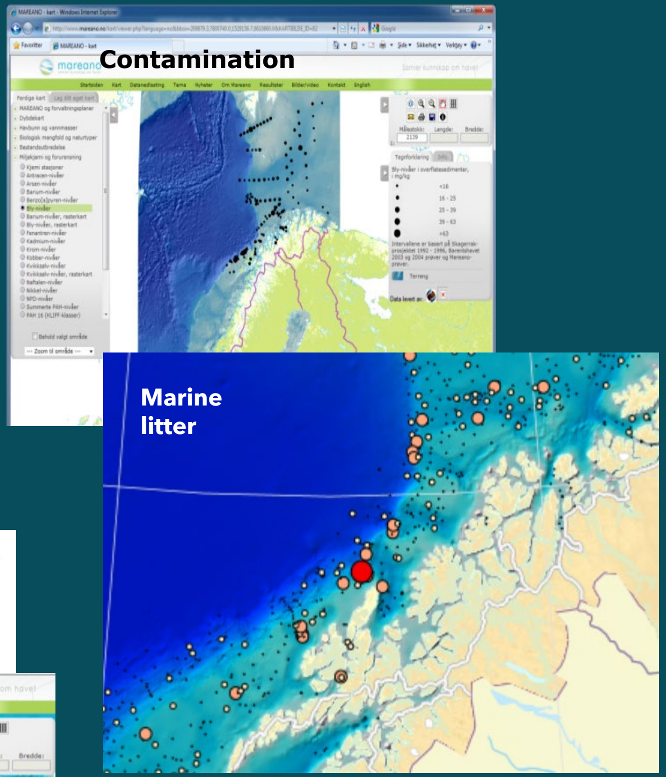
Sediment maps



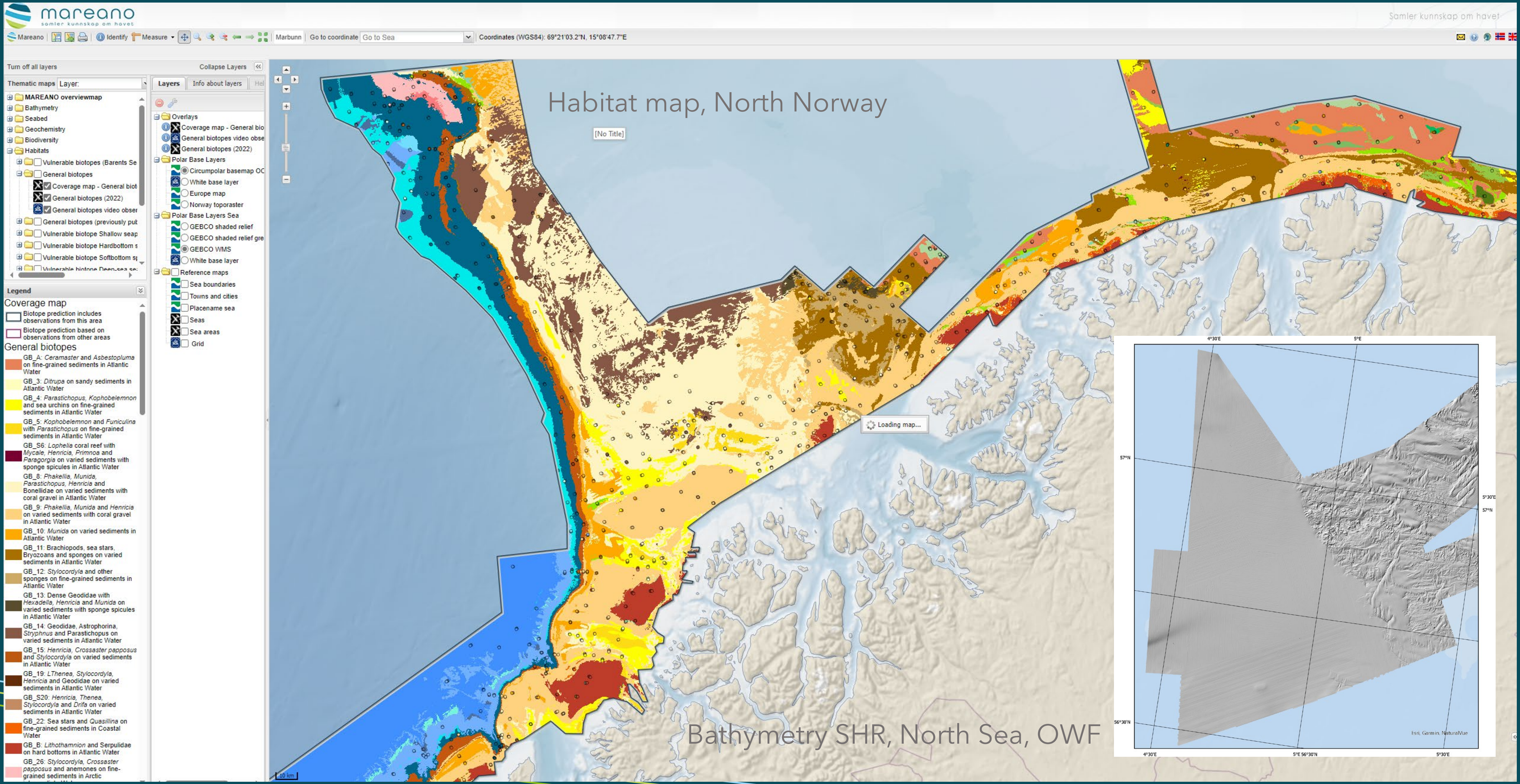
Modelled maps



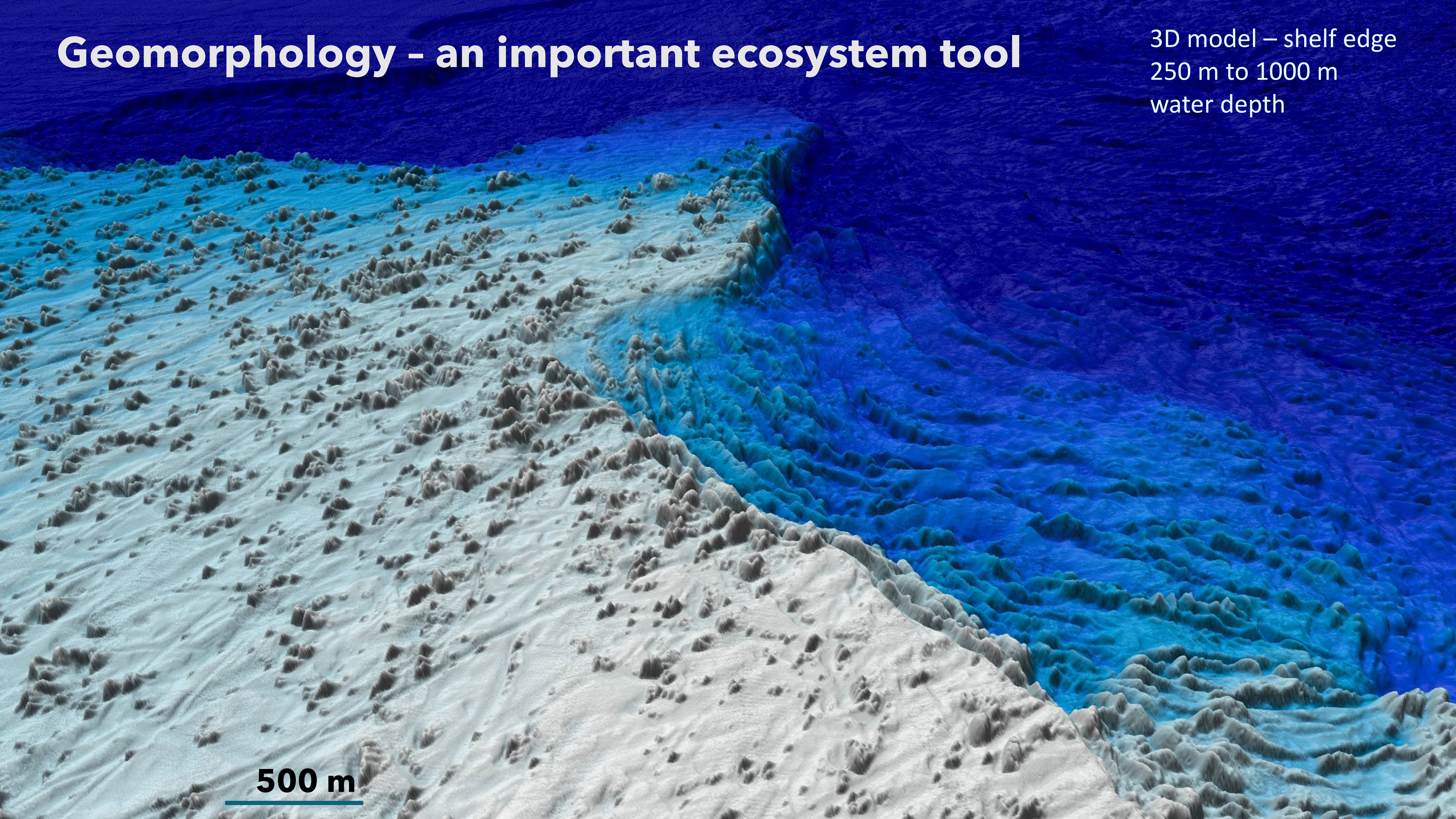
Human impact maps



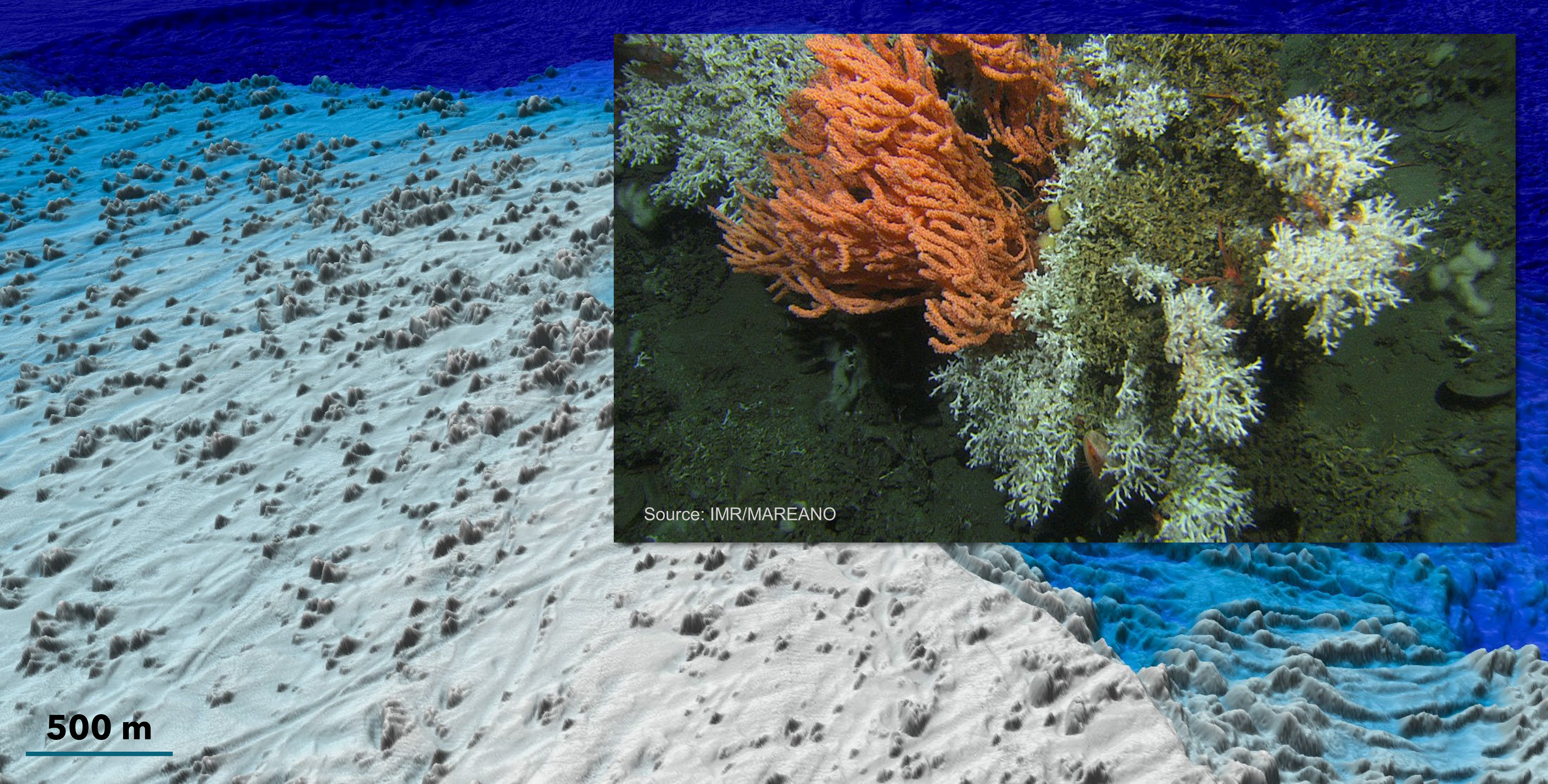
Mareano web site – all data free and public*



Geomorphology – an important ecosystem tool



The mounds are Lophelia pertusa cold water coral reefs



Semi-automatic classification of cold-water coral mounds

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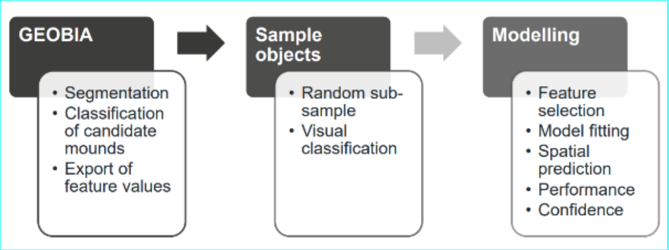
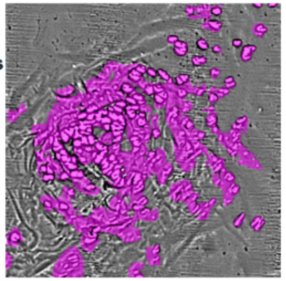
200 000+ probable coral reefs



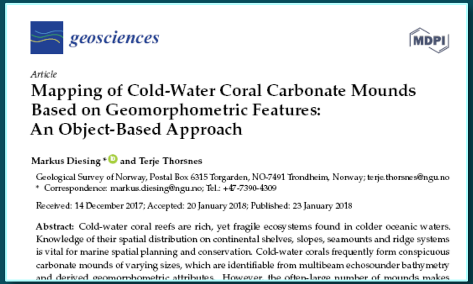
GEOBIA

1. **Multi-resolution segmentation**
   - BPI3 (8 bit)
2. **Classification of candidate mounds**
   - Positive elevation (0mean)
   - Pre-existing information
3. **Export of feature values**

Feature Type	Features
Object mean value	slope, rgh, vrm3, curv, curvPL, curvPR, bpi3, bpi5, bpi10, bpi25, 0mean
Maximum pixel value	slope, rgh, vrm3, curvPL, bpi3, 0mean
Extent	area, border length, length-width ratio,
Shape	asymmetry, compactness, elliptic fit, main direction



GEOLOGICAL SURVEY OF NORWAY



geosciences MDPI

Article

Mapping of Cold-Water Coral Carbonate Mounds Based on Geomorphometric Features: An Object-Based Approach

Markus Diesing * and Terje Thorsnes

Geological Survey of Norway, Postal Box 6315 Torgarden, NO-7491 Trondheim, Norway; terje.thorsnes@ngu.no
* Correspondence: markus.diesing@ngu.no; Tel.: +47-7390-4309

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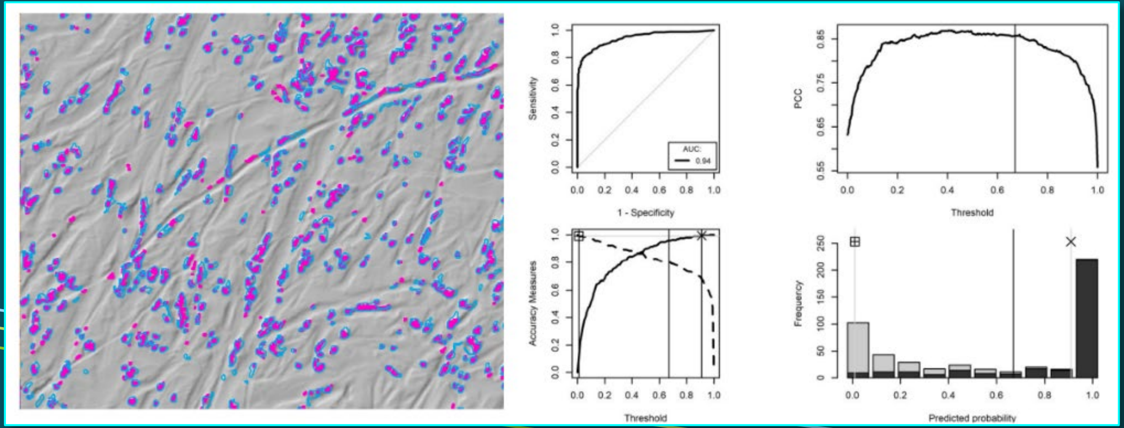
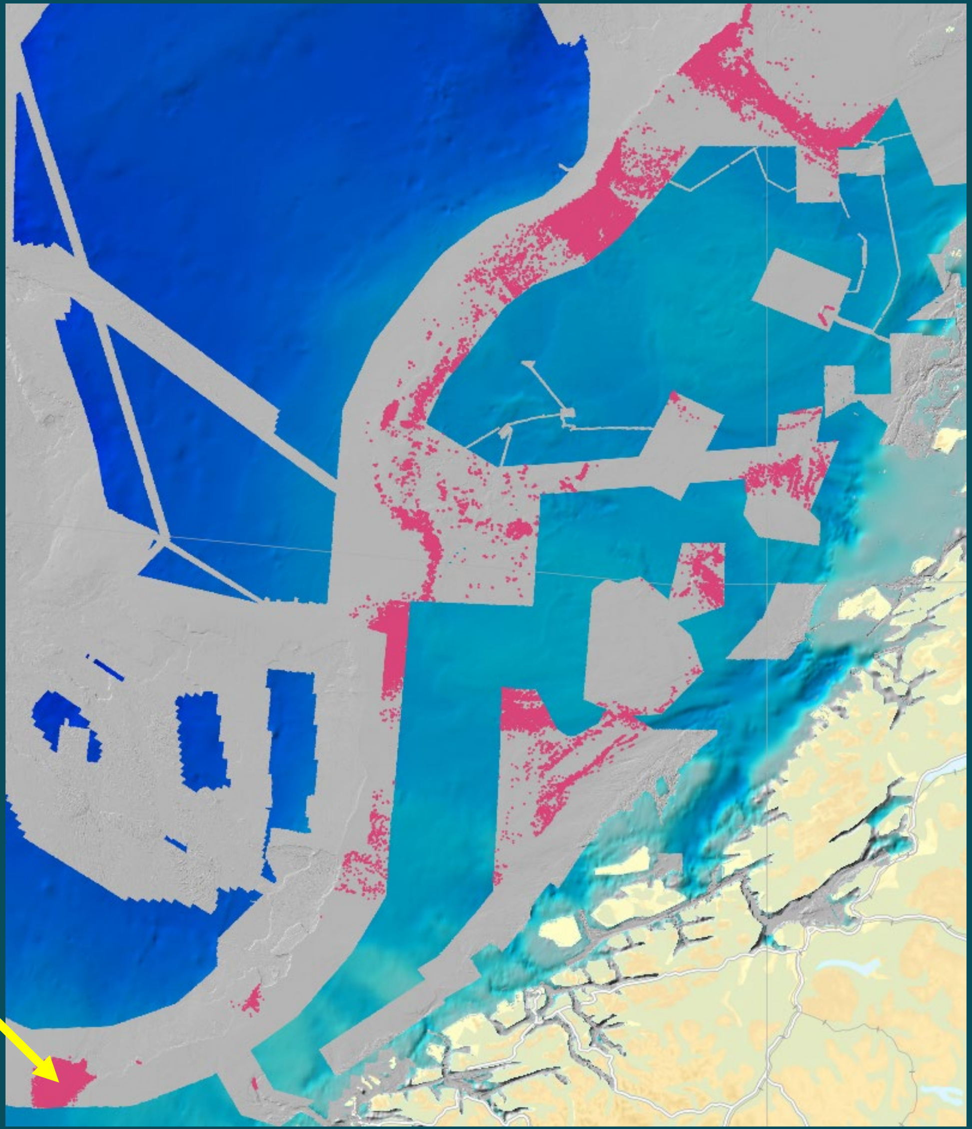
Abstract: Cold-water coral reefs are rich, yet fragile ecosystems found in colder oceanic waters. Knowledge of their spatial distribution on continental shelves, slopes, seamounts and ridge systems is vital for marine spatial planning and conservation. Cold-water corals frequently form conspicuous carbonate mounds of varying sizes, which are identifiable from multibeam echosounder bathymetry and derived geomorphometric attributes. However, the often-large number of mounds makes





«New» needs, tools, platforms and sensors

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- Offshore wind farms
- Deep sea minerals
- Autonomous underwater vehicles
- Synthetic aperture sonar – SAS
- Water column data
- Multispectral backscatter
- Artificial intelligence

Generally – huge amounts of data – very little patience…

Offshore wind power

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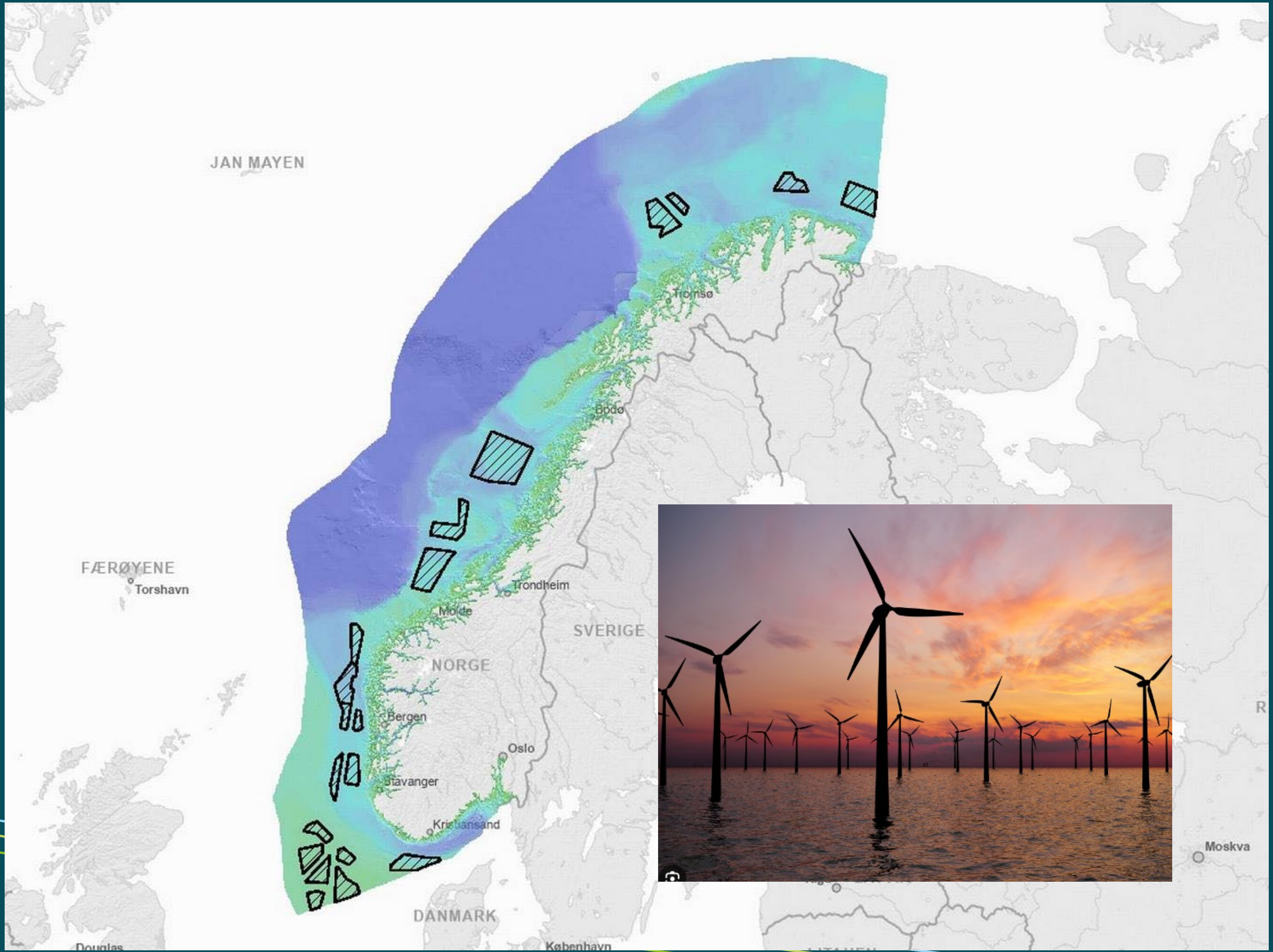
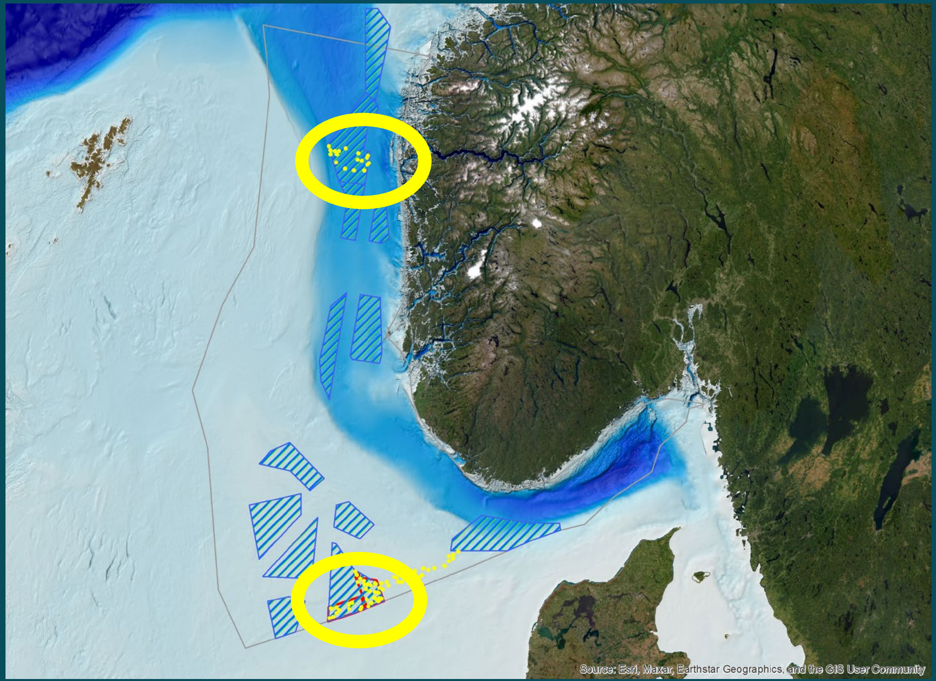


Cruise March 2024



Deep-sea mining

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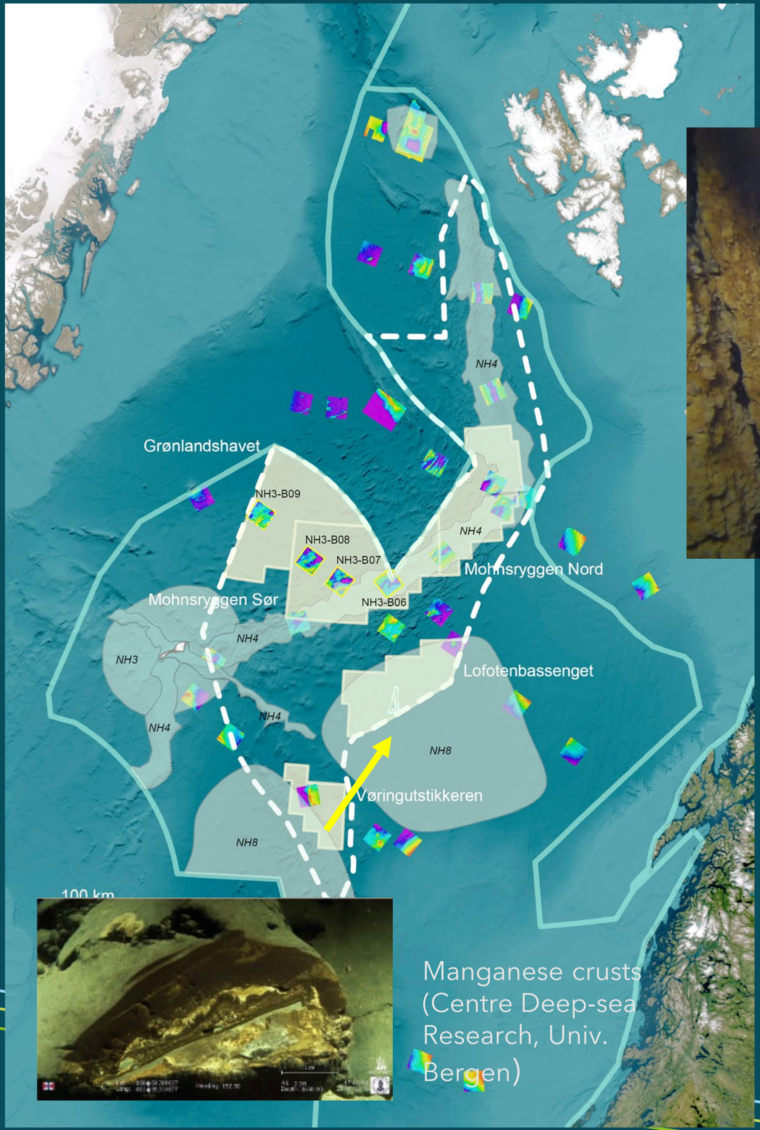
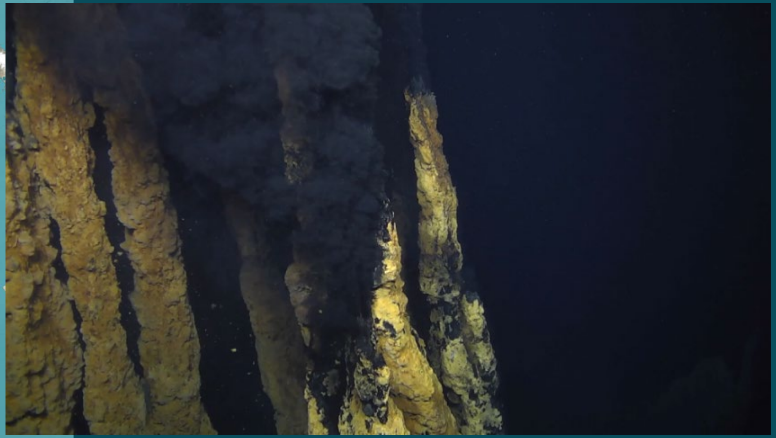
Opening area, and suggested first round

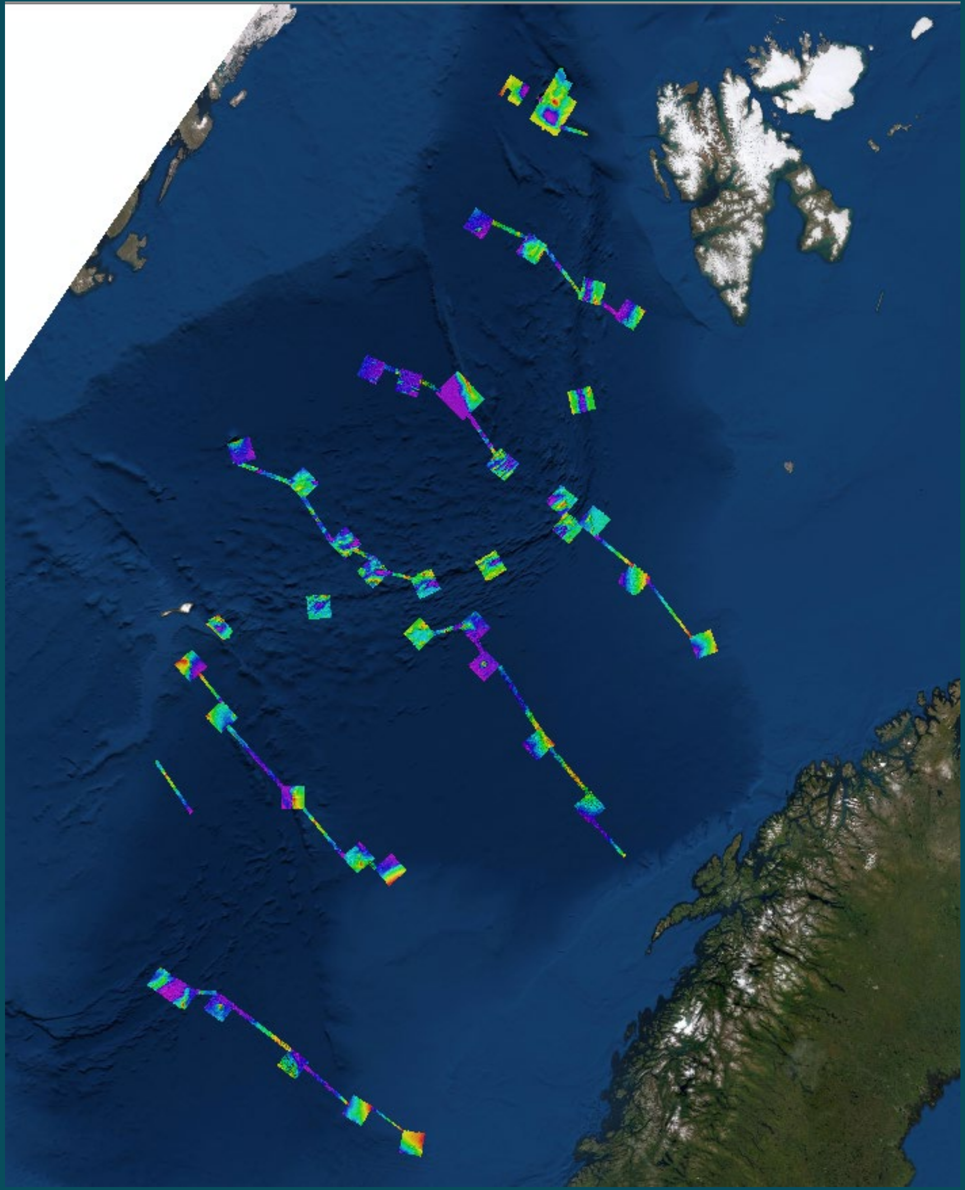


Manganese crusts (Centre Deep-sea Research, Univ. Bergen)



Black smokers (Centre Deep-sea Research, Univ. Bergen)

MAREANO MBES data acquired in 2019



Management of seabed areas with high carbon content

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Smithsonian
MAGAZINE

New Research

Seafloor Trawl Fishing May Release as Much Carbon as Air Travel

A new study finds the carbon released when bottom trawlers stir up the seafloor is equal to the emissions of the entire aviation industry

Alex Fox
Correspondent
March 22, 2021

Eos Science News by AGU

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Getting to the Bottom of Trawling's Carbon Emissions

A new model shows that bottom trawling, which stirs up marine sediments as weighted nets scrape the ocean floor, may be releasing more than a billion metric tons of carbon every year.

Search The Guardian International

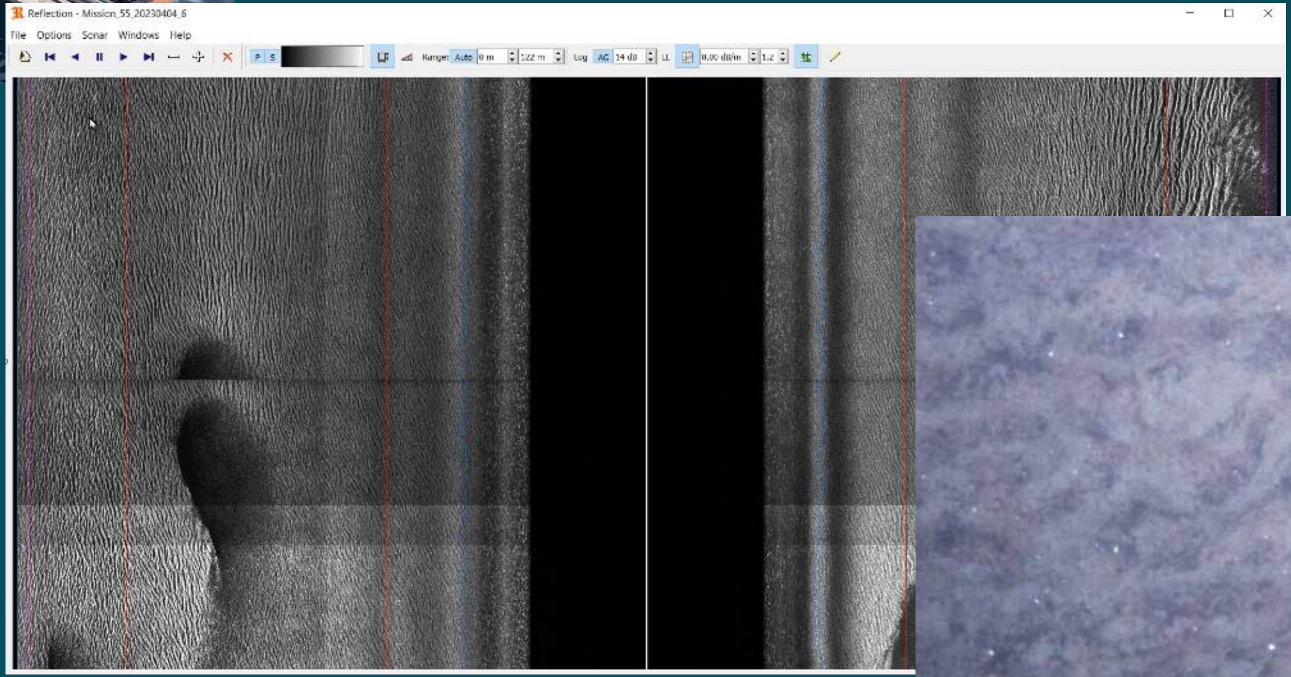
Bottom trawling releases as much carbon as air travel, landmark study finds

Dragging heavy nets across seabed disturbs marine sediments, world's largest carbon sink, scientists report

An area of seabed damaged by trawling. Bottom trawling by fishing boats pumps out 1 gigaton of carbon every year. Photograph: Howard Wood/COAST

AUV for seabed mapping

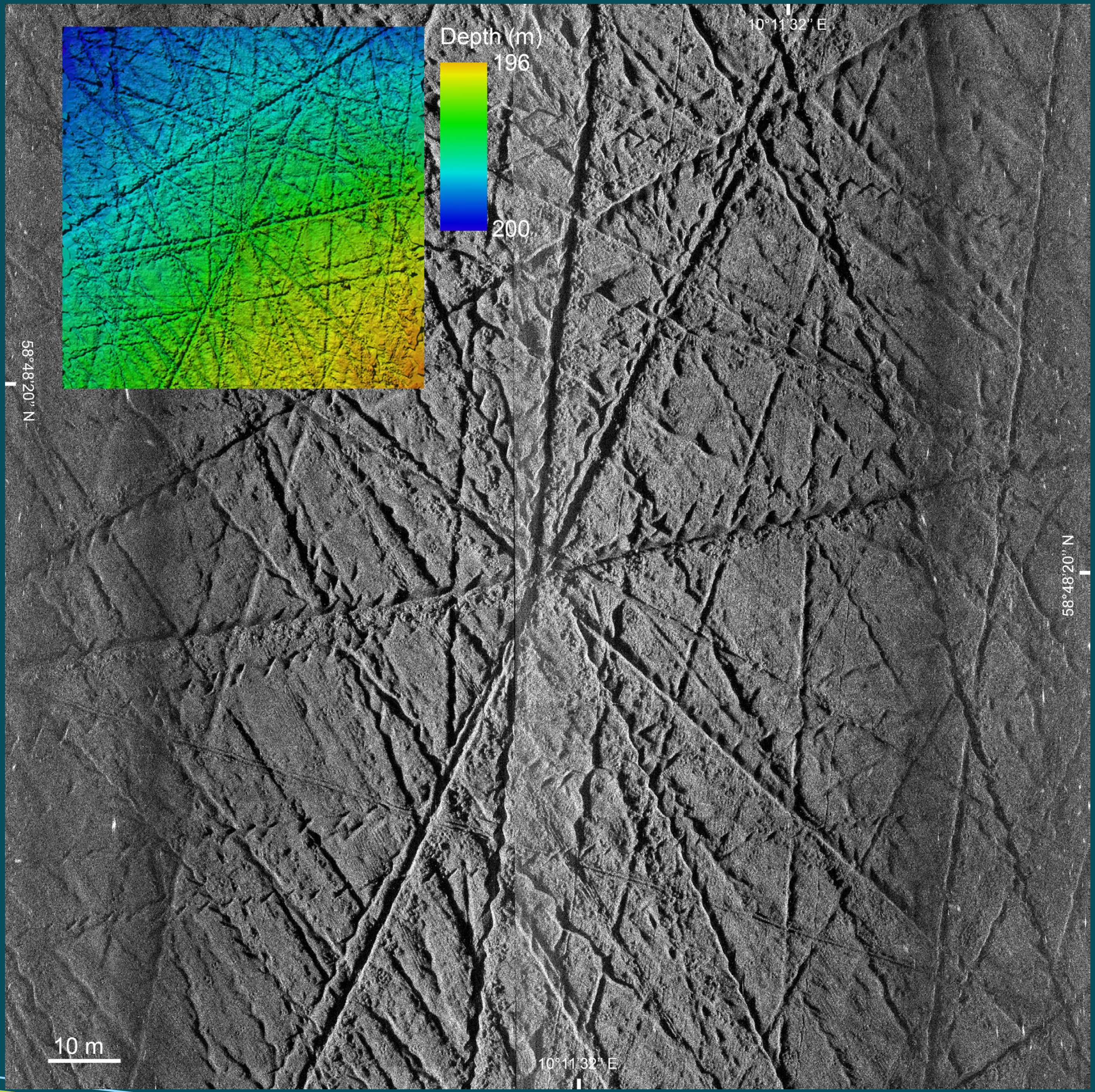
Sonar (HiSAS), sand megaripples



Photos – sea stars, shells and sand ripples

Trawl marks in high carbon muddy sediments

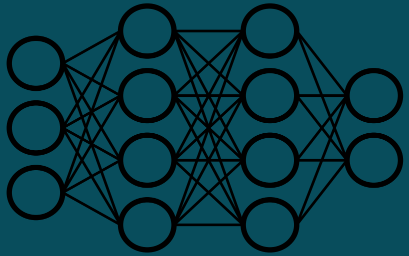
Synthetic aperture sonar imagery (2 cm) and shaded relief bathymetry (inset, 25 cm). AUV flight height 20 m.



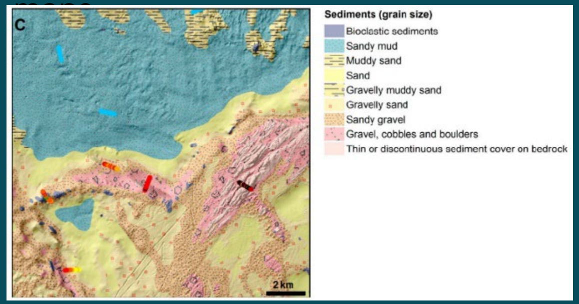
AI for automatic classification of sediments and fauna

Video frames with expert labelling:
- Seabed geology type (NGU)
- Relevant biology species (IMR)

Model training
(neural network)



Ground-truth data for sediment



Cooperation with Ocean Frontiers Institute (Canada) project "Benthic Ecosystem Mapping and Engagement" (BEcoME)

Fast & automated predictions
on new acquired videos

Scientists to use predictions for their assessment (confirmation)

Natural gas seeps, using water column data

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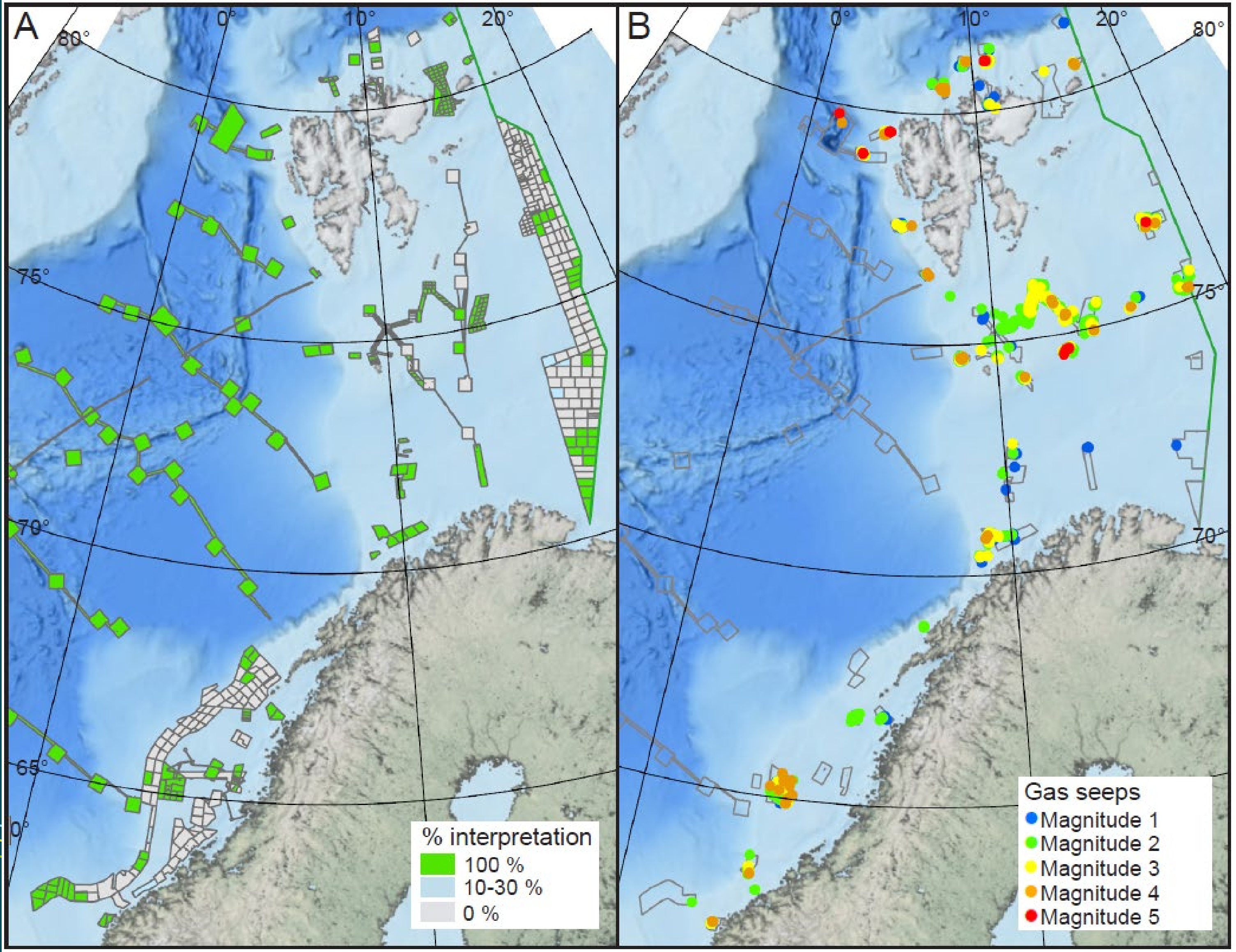
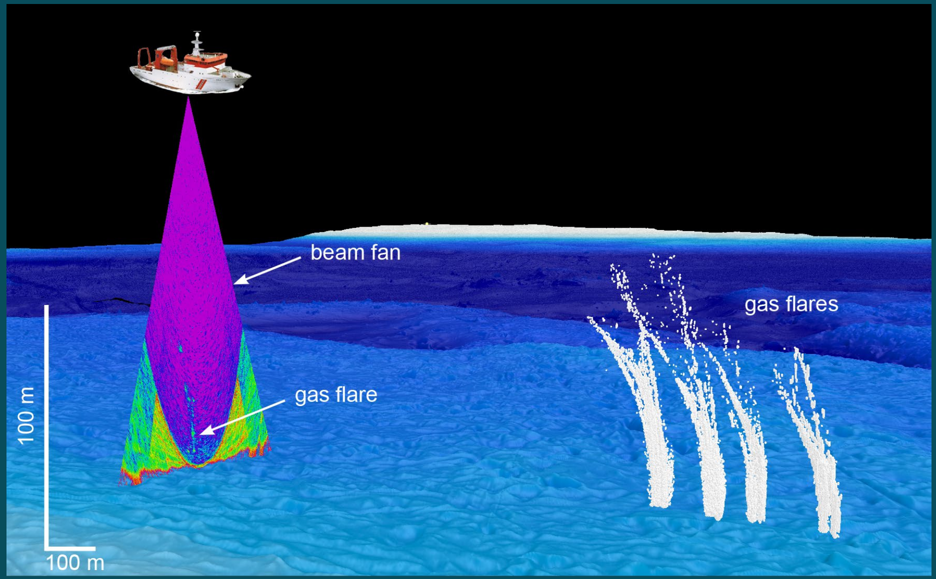




NORWEGIAN JOURNAL OF GEOLOGY
https://dx.doi.org/10.17850/njg103-2-4
GEOLOGICAL SOCIETY OF NORWAY

Gas seeps in Norwegian waters – distribution and mechanisms

Terje Thorsnes[1,2*], Shyam Chand[1,2], Valerie Bellec[1], F. Chantel Nixon[3], Harald Brunstad[4], Aave Lepland[1], Sigrun Melve Aarrestad[5]

Software for water column data interpretation

Issue 3 2024
Volume 28

Innovative tool for seabed data exploration

Espresso: Open source software for the visualization of multibeam water column data

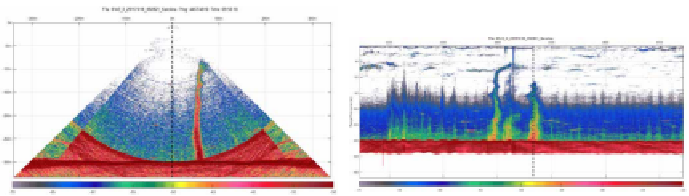
By Alexandre Schimel, Yoann Ladroit and Sally Watson

Espresso is a free and open source software to visualize and analyse multibeam water column data. Its core feature is the capability to echo-integrate water column data vertically, allowing for the visualization 'from above' of georeferenced water column acoustic anomalies across multiple files. Originally developed at NIWA, Espresso is now open source, licensed under MIT, maintained internationally and available on GitHub. The software is coded in MATLAB and a compiled version is available for Windows.

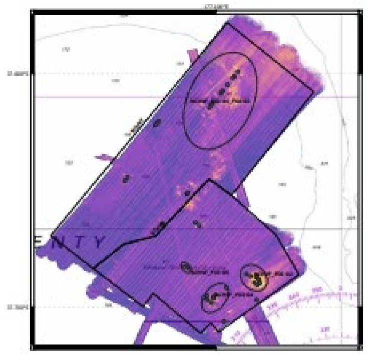
Modern multibeam echosounders can record the acoustic echo returned by objects in the water column between the sonar and the seafloor. This 'water column data' can provide useful information about the presence, density, shape and temporal nature of features in the water column such as fish, gas seeps, aquatic vegetation, turbidity, shipwrecks or human-made structures. As a result, water column data is increasingly requested as an additional output of hydrographic surveys carried out under the guiding principle of 'collect once, use many times'.

However, water column data comes with challenges. In particular, the data is difficult to store and dispatch due to its size, which is typically several orders of magnitude larger than bathymetry and backscatter data. The cause of this size disparity is that for any given ping and beam, there is one bathymetry value and one (or several) backscatter data value(s), but hundreds to thousands of water column data values, each corresponding to a different range from the sonar head to the seafloor and beyond. In other words, water column data is essentially a 3D dataset – varying in pings, beams and range – and this additional dimension leads to another challenge: to visualize and interpret multidimensional data, a visualization method must be chosen that eliminates some dimensionality, at the cost of introducing some inconvenience and/or ambiguity.

For example, water column data is most naturally visualized as a 'wedge view', where the values for each beam and each range of a single ping are displayed in the across-track plane (Figure 1a). This method effectively eliminates the ping dimension, so its inherent issue is that to visualize the entire dataset, one would need to go through every ping, one at a time, for every file. A less inconvenient visualization method is the 'range-stack view', where the signal for any given ping at a given range is averaged over all beams, which allows the visualization of many pings' worth of data varying in range, as a single image akin to that of a single-beam echosounder (Figure 1b). This method effectively eliminates the beam dimension, at the cost of causing acoustic anomalies to appear distorted and ambiguous. For example, two horizontal echoes on separate sides of the vessel would appear as a single vertical mark in this view. Moreover, to visualize an entire dataset, it is still necessary to go through many such range-stack images.



▲ *Figure 1: Example of water column data containing echoes from gas seeps, visualized as a wedge view (a) and as a range-stack view (b). (Data courtesy: Kongsberg EM710 data from the FOSAE-2015-BH03 survey in the Barents Sea, acquired as part of the Norwegian seafloor mapping programme MAREANO (Bøe et al., 2020))*



▲ *Figure 2: Example of vertically echo-integrated view of water column data containing echoes from gas seeps, created and annotated with Espresso and exported to ArcGIS. The strong acoustic echoes produced by gas seeps are visible from above as 'hot spots' (bright yellow) relative to their empty water column surroundings (purple). (Data courtesy: Kongsberg EM302 data acquired from NIWA vessel RV Tangaroa over the Calypso Hydrothermal Vent fields in the Bay of Plenty, New Zealand (Lamarche et al., 2019; Spain et al., 2022))*

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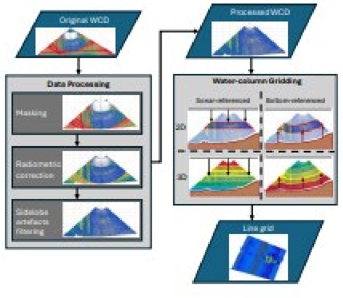
A powerful but little-known visualization method is the 'vertically echo-integrated view', in which the 3D dataset is georeferenced, gridded and averaged vertically, which enables a 2D visualization 'from above' in the manner of bathymetry grids or backscatter mosaics (Figure 2). This method has the enormous advantage of allowing the display of several files' worth of data in a single image, for efficient scanning and interpretation of broad regions of data. This approach essentially sacrifices the vertical dimension, for which the cost is ambiguity about the depth of an acoustic anomaly, but this is mitigated if the interval of depth, range or height above seafloor of the data to be vertically echo-integrated can be specified. Vertical echo integration has already proven useful for applications such as bubble vent localization (Urban et al., 2017; Mitchell et al., 2022) and mapping kelp density (Lucieer et al., 2023) but, to date and to our knowledge, it is not implemented in any of the few examples of commercial software available to visualize multibeam water column data.

Presentation and workflow overview

Espresso is a research software developed at NIWA between 2018 and 2021 to scrutinize multibeam water column data, including a capability for vertical echo-integration (Figure 3). Espresso is now open source and free to use under MIT licence, and available for download at https://github.com/alexschimel/Espresso. Espresso is coded in MATLAB, but releases are also compiled for Windows, which allows installation of the software as any standard Windows application without the need for a MATLAB licence. In this article, we summarize some of Espresso's core features. For more information on its capabilities, please see its growing wiki at https://github.com/alexschimel/Espresso/wiki, which currently includes a quick start guide and a user guide (in development).

An Espresso session starts with converting and loading the desired raw data files. The raw data can be visualized, but Espresso offers a range of pre-processing options to remove or filter unwanted noise that may otherwise dominate the picture, especially in



▲ *Figure 4: Overview of the core workflow of Espresso, from loaded raw data to the vertical echo-integration of individual files.*

column data, by marine biologists for fish school shape analysis, by marine conservationists for location of leaking offshore pipelines, by coastal scientists for turbidity plume tracking, or by marine engineers for examination of the footprint of submerged infrastructure.

Espresso was developed by researchers as a research tool, and thus has more limitations than a software created and maintained by professional developers for commercial use. First, it supports a limited number of multibeam data formats: mostly the Kongsberg .all/.wcd and .kmall/.kmwcd formats, with some support for the Teledyne .s7k format (SeaBat, Norbit systems). Moreover, the data processing in Espresso is often highly simplified, meaning that processed data does not have the same level of quality and positional accuracy as that of professional hydrographic software. More importantly, Espresso was coded in MATLAB and thus faces significant limitations in memory and speed, although considerable efforts were made to optimize the software for large-data handling (e.g. water column data is accessed via memory mapping) and computing speed (some processing steps use parallel computing on machines equipped with a compatible GPU).

Conclusion

Vertical echo-integration is a novel and useful visualization method for multibeam water column data, with a high potential for routine data examination and research. The open source Espresso software provides this visualization capability (and other features) to everyone and for free (under the terms of the MIT licence), thereby constituting a powerful complement to commercial software for the scrutinization and processing of multibeam water column data. The authors hope that the hydrographic community finds this tool useful. If you use Espresso in your work, please acknowledge the authors of this article. For citations, a peer-reviewed article is in preparation. ■

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Conclusions

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- Bathymetry QC important
- Collect once – use many times
- Backscatter QC and standard protocols – should be developed
- Need for reference areas for backscatter
- Geomorphology – important tool for ecosystem analysis
- New platforms and sensors like AUVs and SAS provide entirely new possibilities
- Generally – huge amounts of data – very little patience…

Hydrographic data is the fundament for all Mareano seabed and ecosystem mapping mareano

collecting marine knowledge