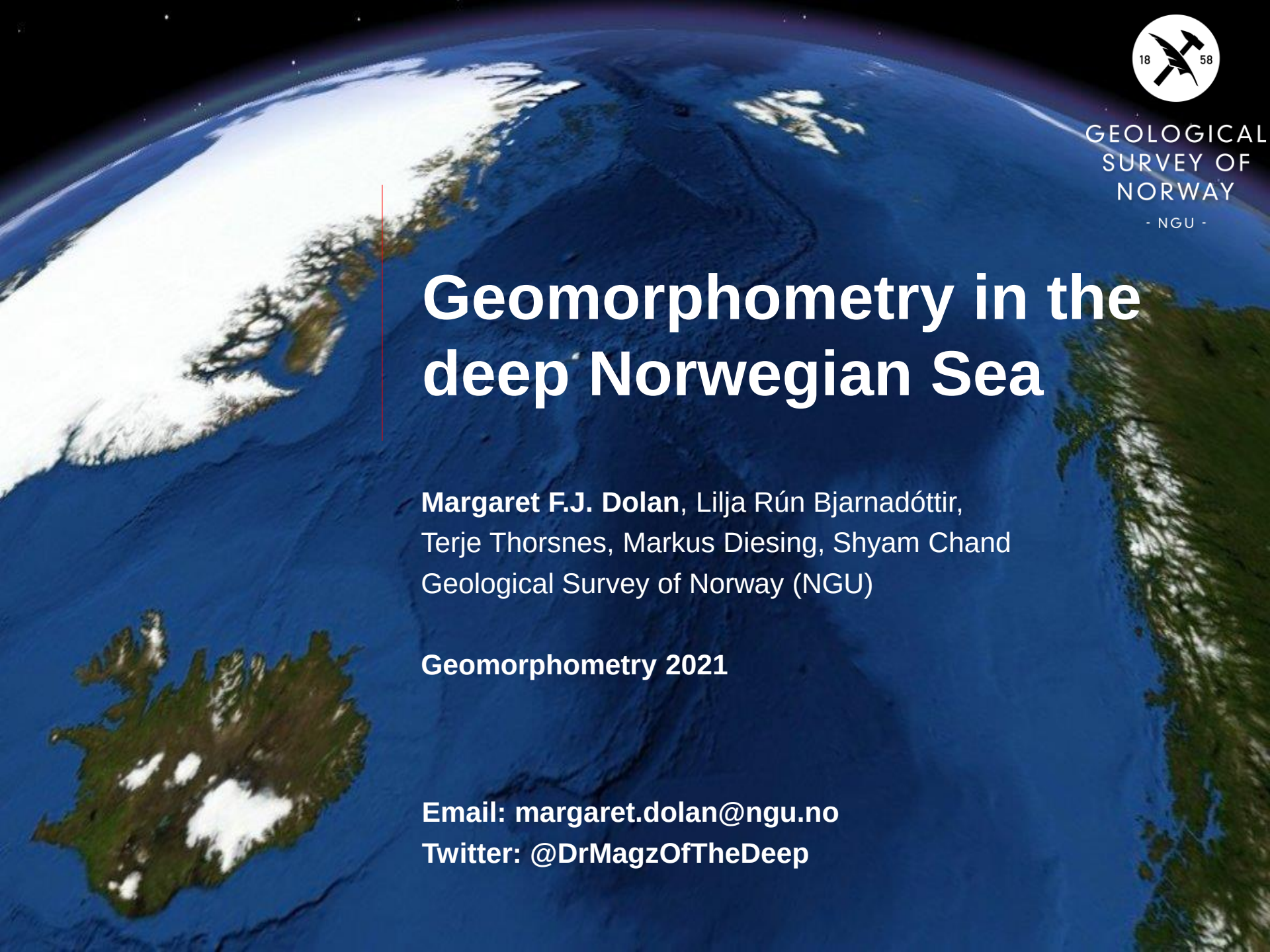

GEOLOGICAL SURVEY OF NORWAY
- NGU -

Geomorphometry in the deep Norwegian Sea

Margaret F.J. Dolan, Lilja Rún Bjarnadóttir, Terje Thorsnes, Markus Diesing, Shyam Chand
Geological Survey of Norway (NGU)

Geomorphometry 2021

Email: margaret.dolan@ngu.no
Twitter: @DrMagzOfTheDeep

MAREANO seabed mapping programme, Norway

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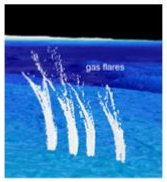
Ecosystem based advice



Science

MAREANO

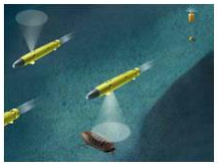
SDG 14

SUSTAINABLE DEVELOPMENT GOAL 14
Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Industry

Innovation

Source: Øyvind Hagen



Source: NTNU/AMOS

Kartverket

GEOLOGICAL SURVEY OF NORWAY
- NGU -

INSTITUTE OF MARINE RESEARCH

Data and maps

- Bathymetry
- Geology
- Biology
- Environmental status

MAREANO – into the deep Norwegian Sea

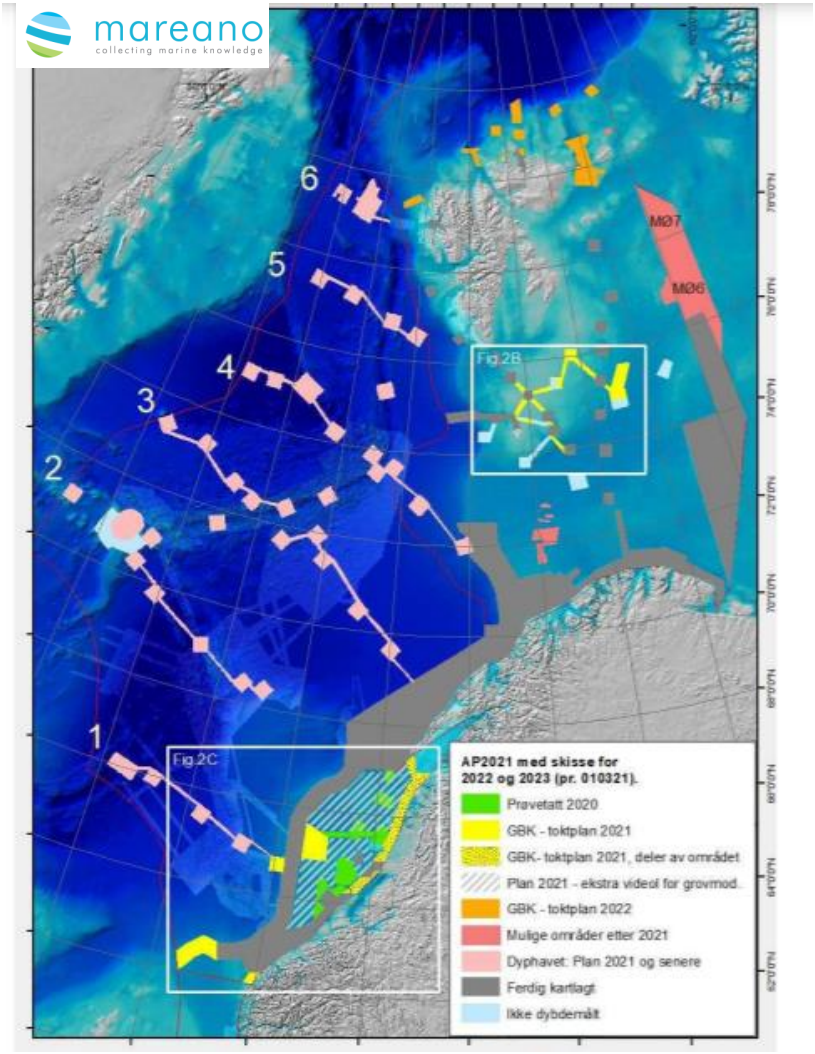


Figure from MAREANO activity plan 2021 (Norwegian)

Shift focus from shelf/slope to deep sea

Varied terrain, environment and seabed habitats

- abyssal plain
- Mid-Atlantic Ridge
- Molloy Deep
- seamounts
- etc.

Knowledge needed for update to management plan

- rich minerals
- unique and vulnerable ecosystems
- geo/bio diversity
- the unknown…

<< 100% mapping

Pre-survey characterisation the deep Norwegian Sea

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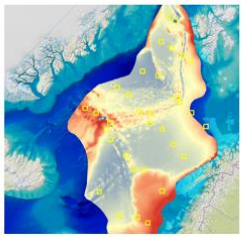
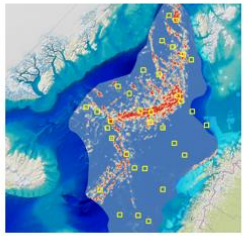
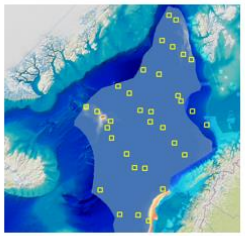
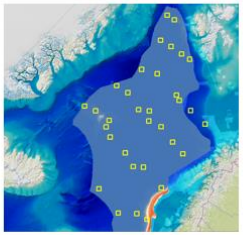
Survey strategy based on statistical analysis and expert assessments

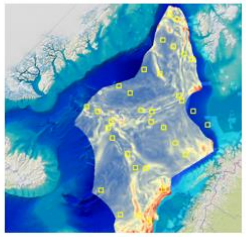
Continuous and categorical data from Emodnet, IMR, NGU and other sources were combined with expert advice from UiB (K.G. Jebsen Centre), HI and NGU

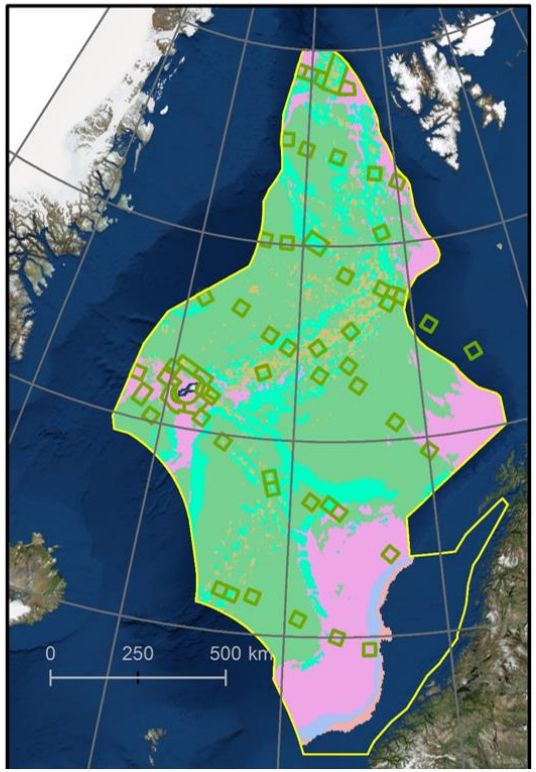

Bathymetry


Terrain variation

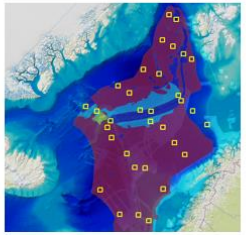

Salinity


Temperature

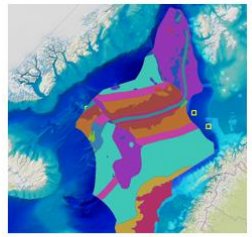

Current velocity

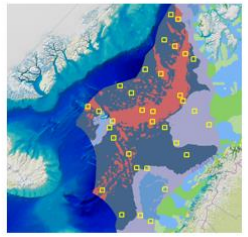


~40 'representative' boxes


Lithology, Emodnet

Biogeographical regions, OSPAR

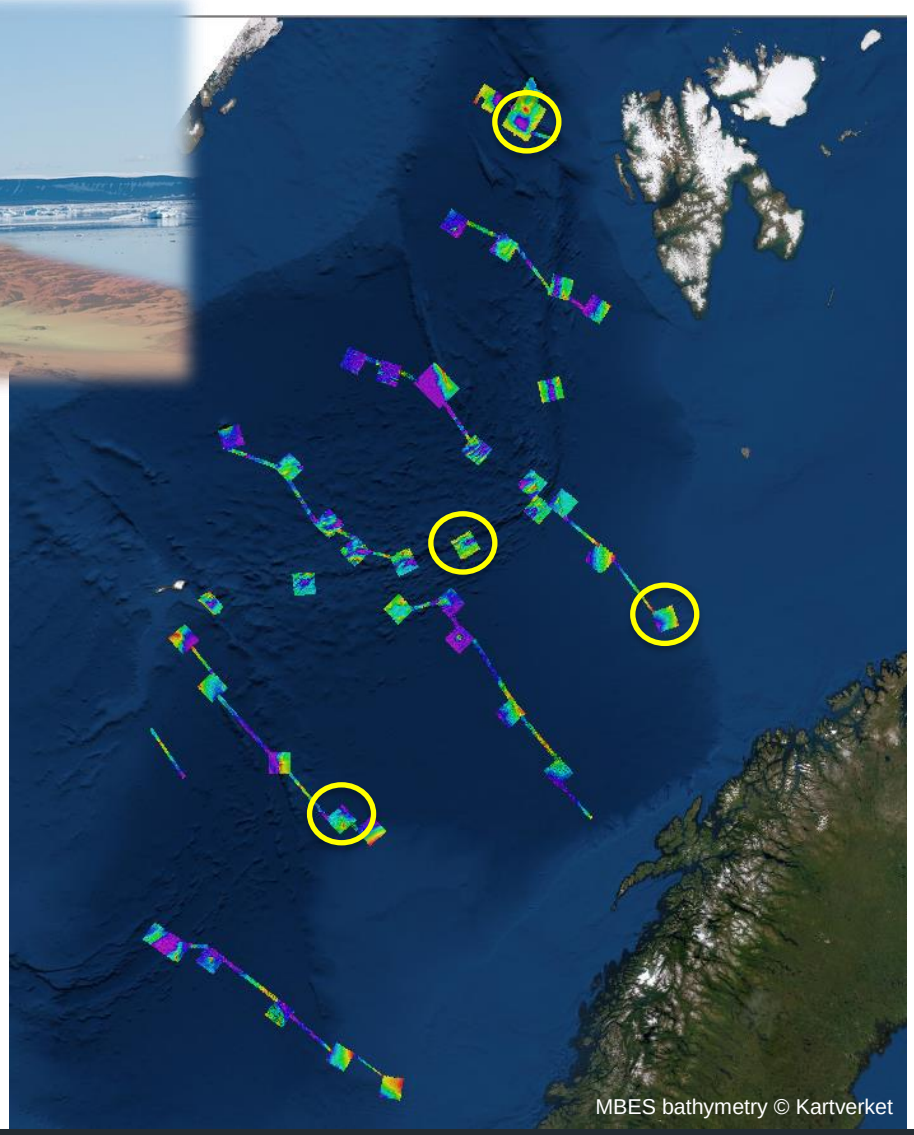

Age, Emodnet

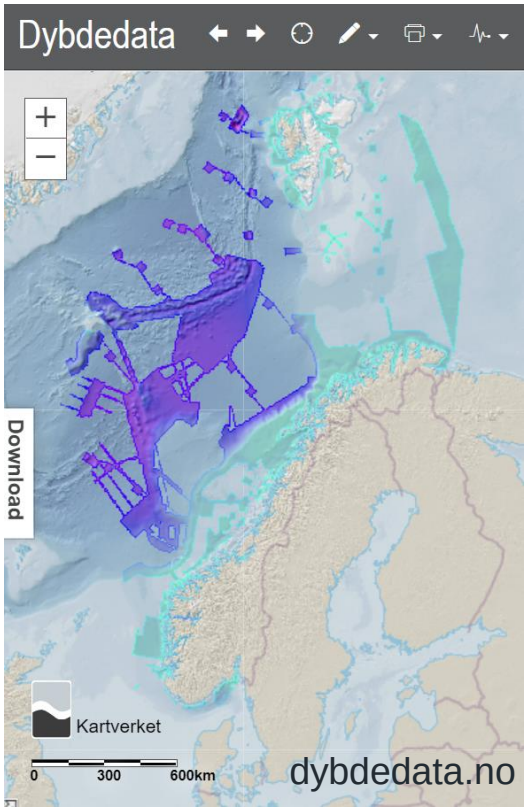

Landscape, MAREANO

MAREANO in the deep sea


Image: Kartverket

- Surface-based multibeam echosounder mapping 2019
- 64 000 km^2 mapped across ~40 boxes (~35 x 35 km)


MBES bathymetry © Kartverket



EMODnet GEBCO SEABED 2030

Example bathymetry data quality

MBES bathymetry © Kartverket

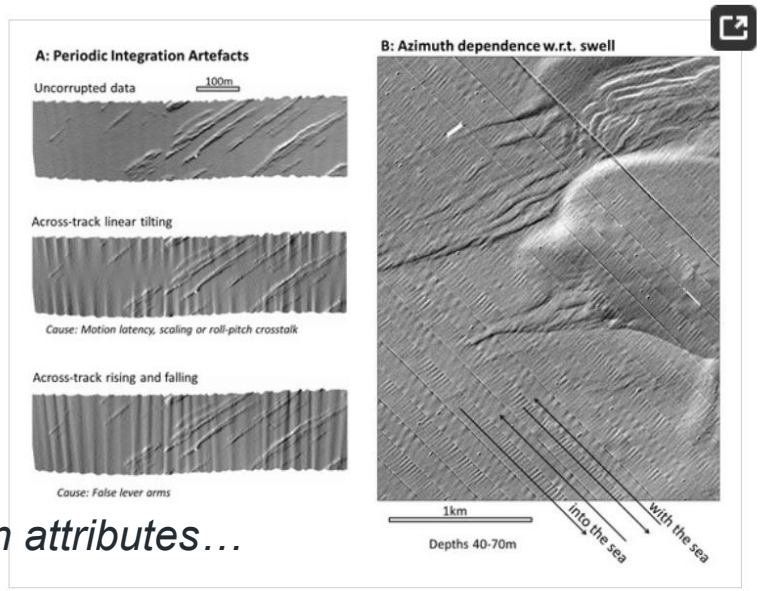
-880
-960
-1040
-1120
-1200
-1280
-1360
-1440

Håkon Mosby Mud Volcano

Image: Kartverket

Motion related artefacts
c.f. Hughes Clarke (2018)
Geosciences Special Issue
Marine Geomorphometry

- *Consequences for terrain attributes…*



Extreme depths!

Molloy Deep (5 569 m deep) vs. Stetind (1 395 m high)

Image produced by Kartverket

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Relative relief

- Common metric in nature-type mapping
- Depth range within 1 km^2
- Overview & context cf. mainland based on 100 m bathymetry

Jotunheimen

Adapting tools & methods for deep sea surveys (acoustic, video, sampling)

Towed video

Image: MAREANO

Image: MAREANO

Grabs and other sampling gear

Image: MAREANO

Image: T.Thorsnes

AUV

Image: UiB

ROV

Image: MAREANO

'VAMS'

Shallow → Deep

fast → slow

€ → €

➢ ***Cost effective survey suited to terrain and info needs***

How can terrain attributes help plan underwater seabed mapping and sampling surveys?

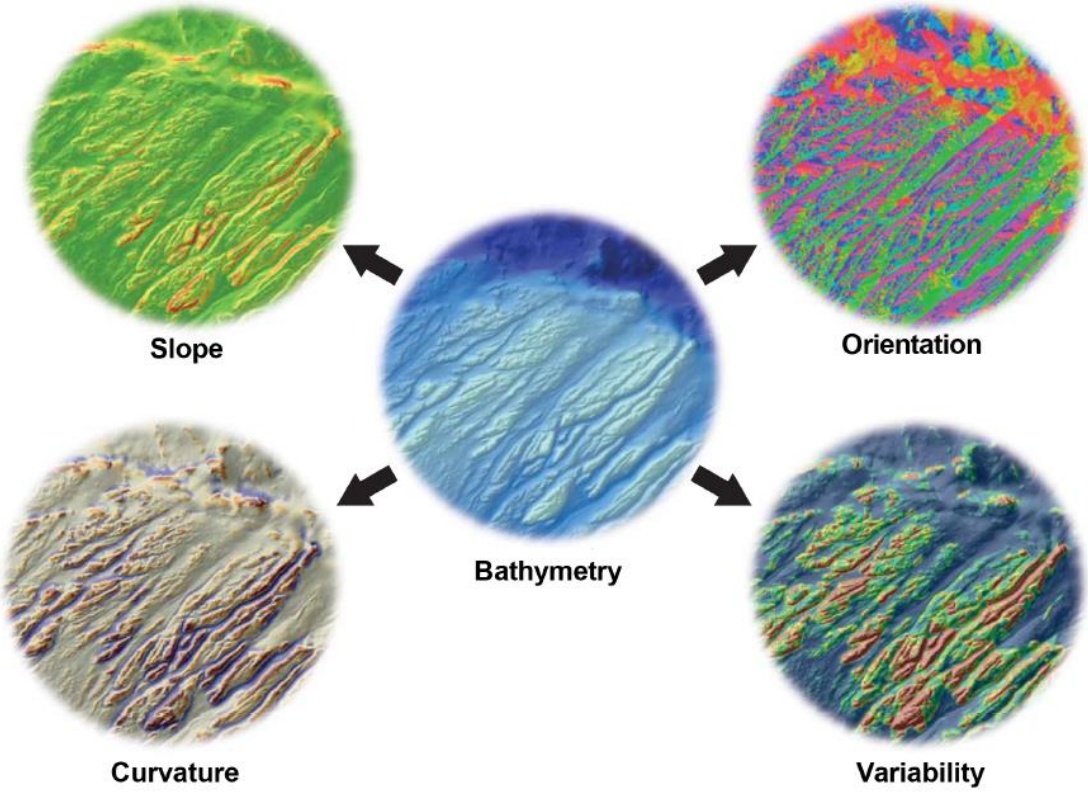


Figure: Lecours et al. 2016

Image: Kongsberg Maritime

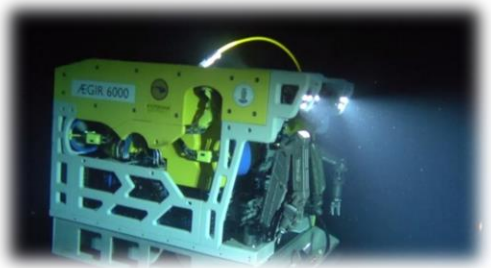


Image: UiB

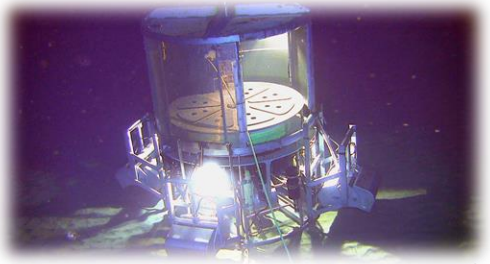
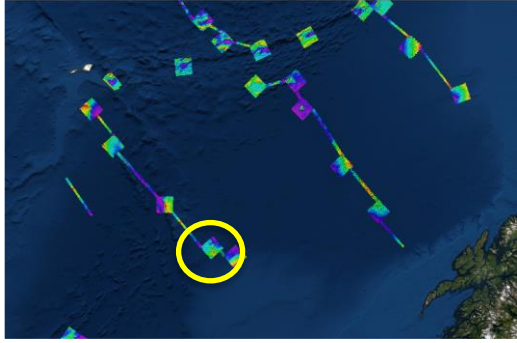
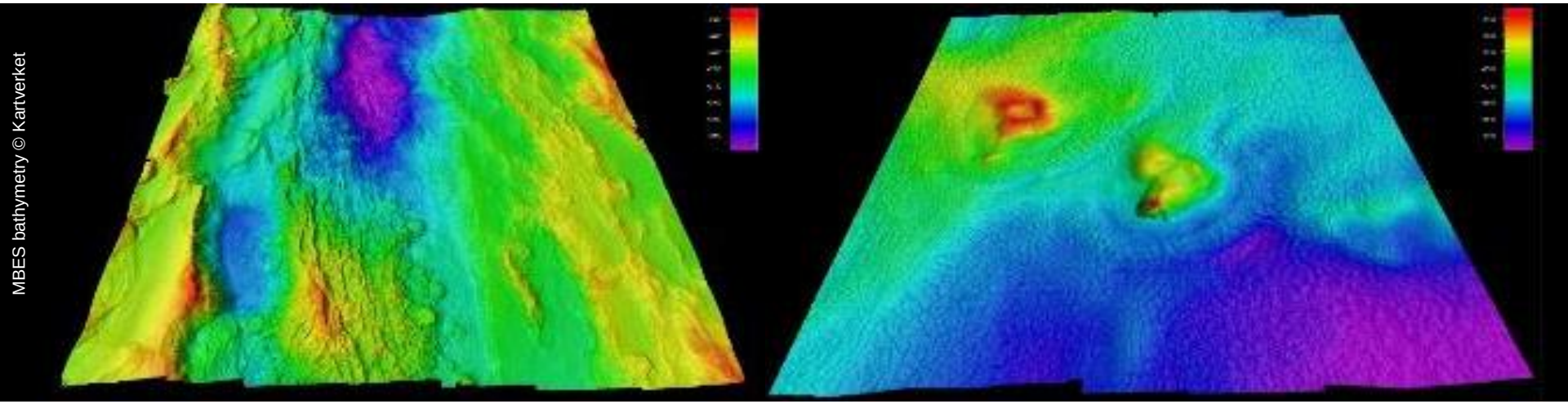


Image: MAREANO

- Intuitive terrain attributes that will help assess accessibility with underwater vehicles etc.
- Which attributes are helpful? At what scales?

Survey planning examples
Rugged vs. flat box

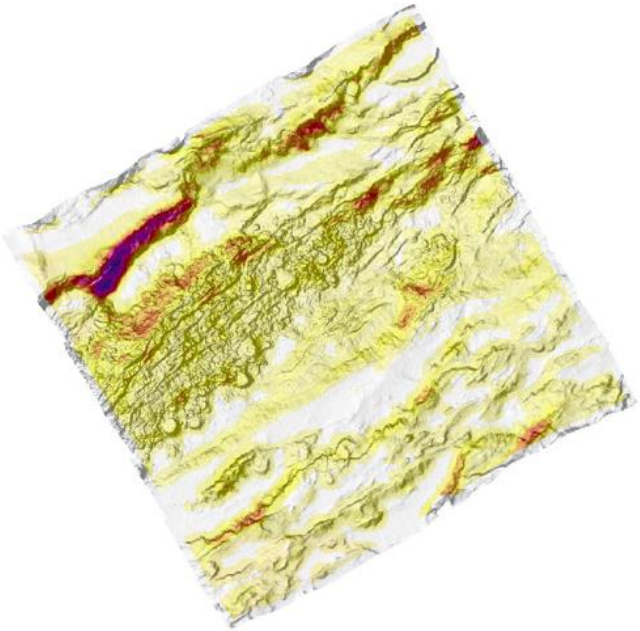




MBES bathymetry © Kartverket

	Complex rugged site at MAR	'Flat' site with mounds/craters
min	1579	2564
max	3564	2996
mean	2457	2822
s.d.	355	76
median	2386	2829
mode	2186	2839

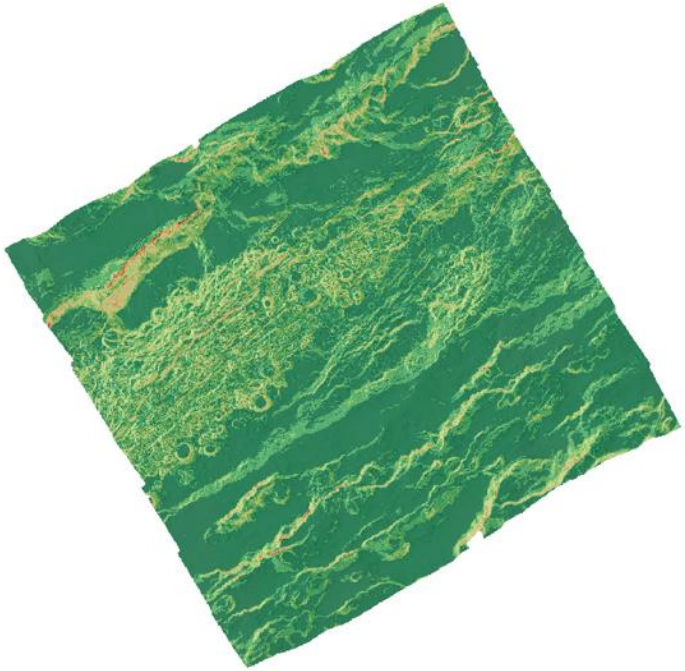
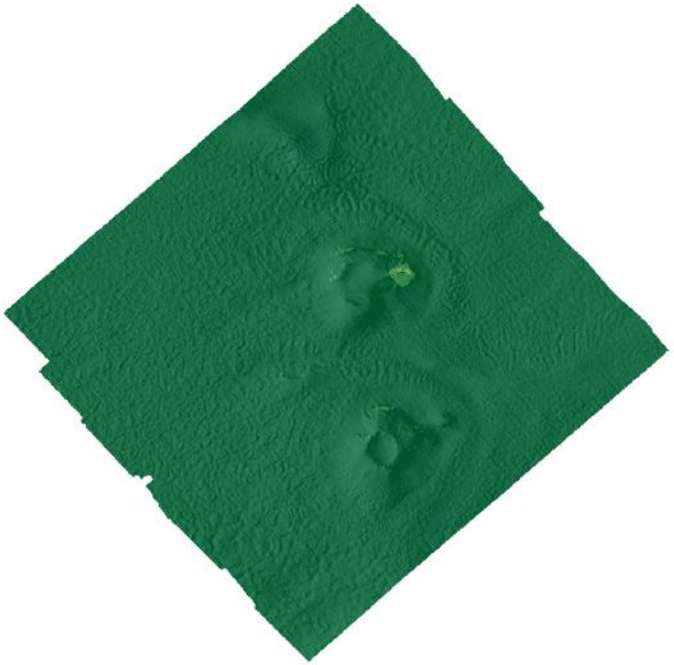
Rugged vs. flat box : Relative Relief

NH0-B03		NH2-B03
	Relative relief (m) within 1km^2 < 100 100 - 200 200 - 300 300 - 400 400 - 500 500 - 600 600 - 700 700 - 800 800 - 900 900 - 1000 1000 - 1100 1100 - 1200 1200 - 1300	
Min 15.67578125 Max 1185.5590820313 Mean 215.09741717535 Std dev. 133.29989328384		Min 8.31005859375 Max 288.45263671875 Mean 29.335922658924 Std dev. 20.647297766231

Bathymetry grid: 20 m
Method: focal statistics

Flat vs. rugged box: Slope

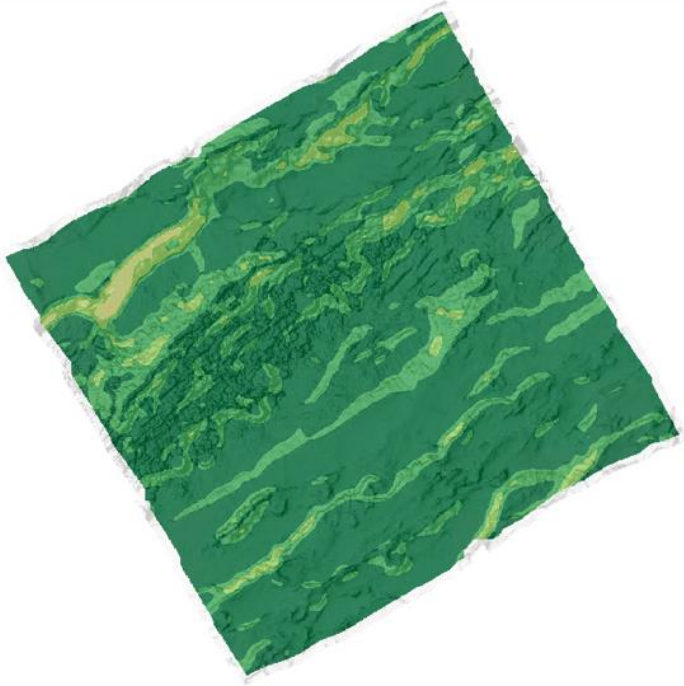
Bathymetry grid: 20 m
Method: r.param.scale

NH0-B03		NH2-B03
	**Local slope (degrees)** analysis distance 100 m *5x5cells* 0- 10 10 - 20 20 - 30 30 - 40 40 - 50 50 - 60 60 - 70 70 - 80	
Min 0.003583853746234565 Max 74.97022782541367 Mean 11.61179306959016 Std dev. 10.11112662615443		Min 0.0007295366866981664 Max 28.32241500969228 Mean 1.942384845805645 Std dev. 1.396008847819817

Flat vs. rugged box: Slope

Bathymetry grid: 20 m
Method: r.param.scale

NH0-B03

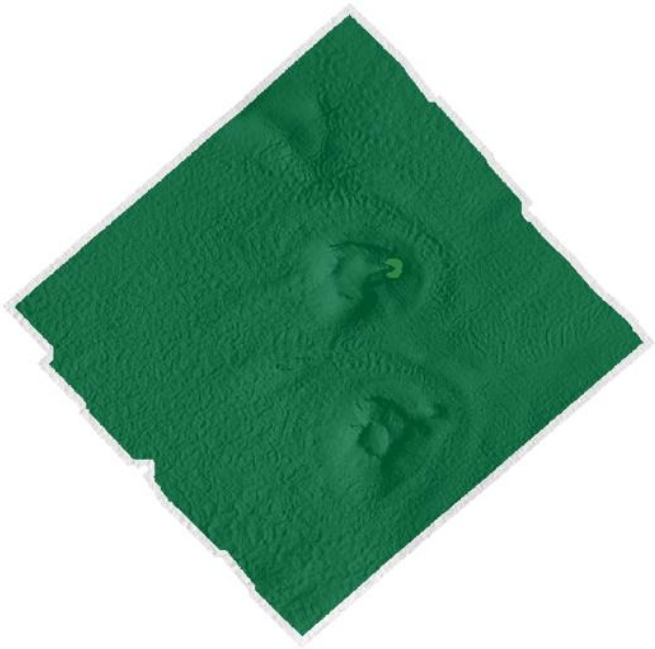


Min	0.005330115743774398
Max	41.81793128395108
Mean	7.734973923295072
Std dev.	6.003191637588627

Broadscale slope (degrees)
analysis distance
1 km *49x49cells*

- 0- 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80

NH2-B03

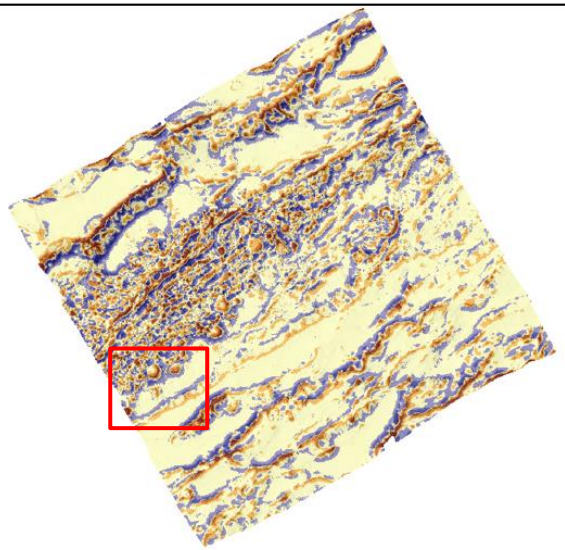
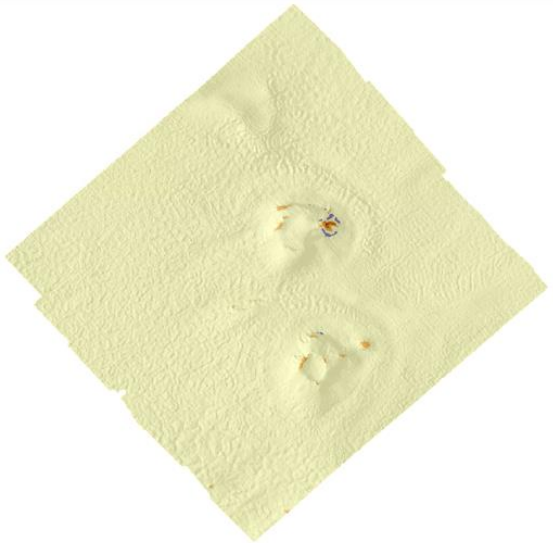


Min	0.0009278240731720338
Max	14.64297526278237
Mean	0.9556217360983562
Std dev.	1.02966292685382

Flat vs. rugged box: Local Topographic Position

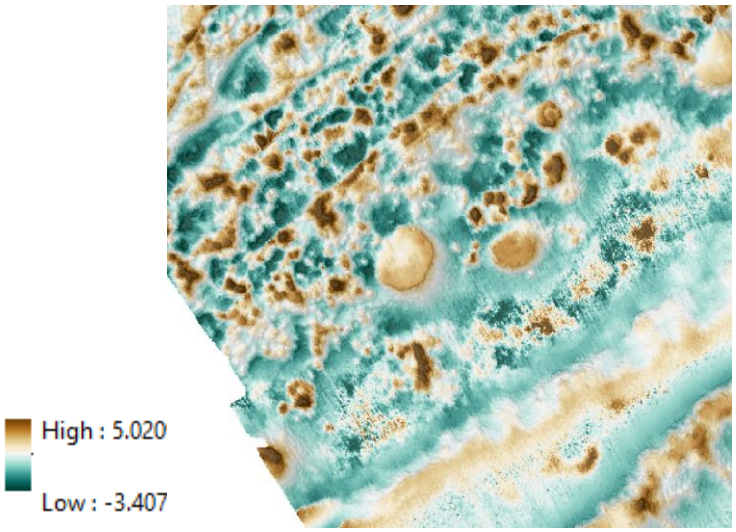
Bathymetry grid: 20 m

Difference from mean elevation – WhiteboxTools – *absolute LTP*

NH0-B03		NH2-B03
	**Difference from mean elevation** over analysis distances up to ~ 1 km *49 x 49 cells* -146 < -70 -70 - -40 -40 - -15 -15 - 15 15 - 40 40 - 70 70 - 248	
Min -146.2998352050781 Max 248.0702819824219 Mean 0.0498044468832697 Std dev. 27.47927442476264		Min -32.65765762329102 Max 79.55190277099609 Mean -0.002232184911547427 Std dev. 3.435996416394245

- ~BPI common in marine applications [BTM toolbox for ArcGIS (Wallbridge et al. 2018)]
- Finer scale analysis captures mostly noise/artefacts – multiscale analysis options important. *Alternatives…?*

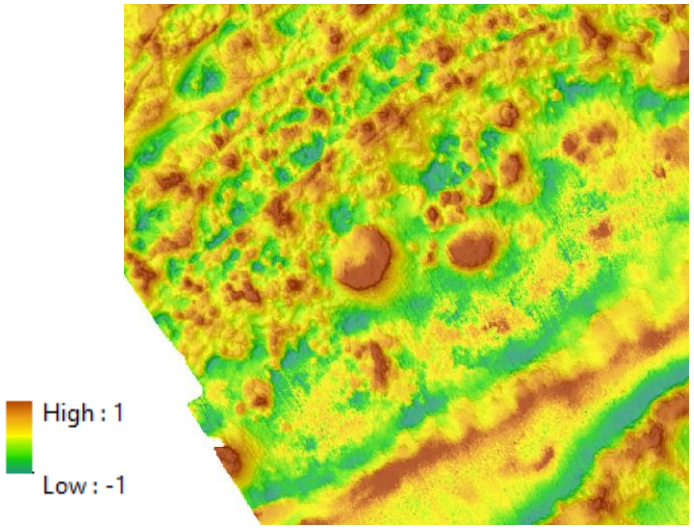
Alternative metrics – use relative LTP? e.g. Newman et al. 2018



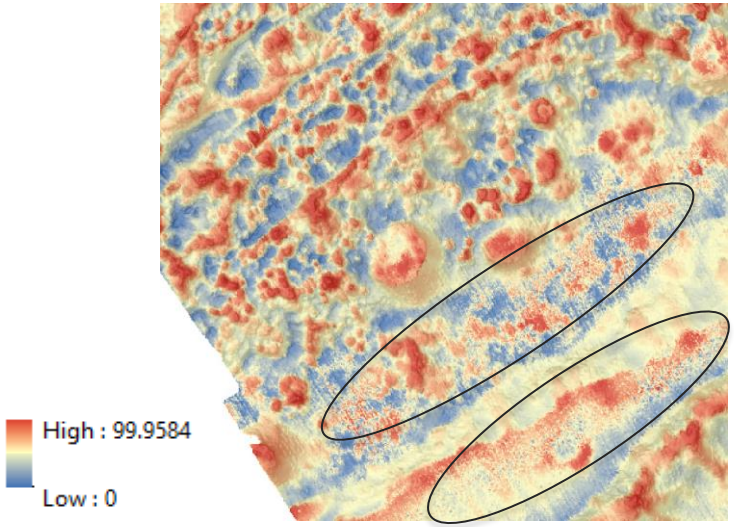
Deviation from mean elevation *relative LTP*

WhiteboxTools™

~1 km analysis
49 x 49 cells



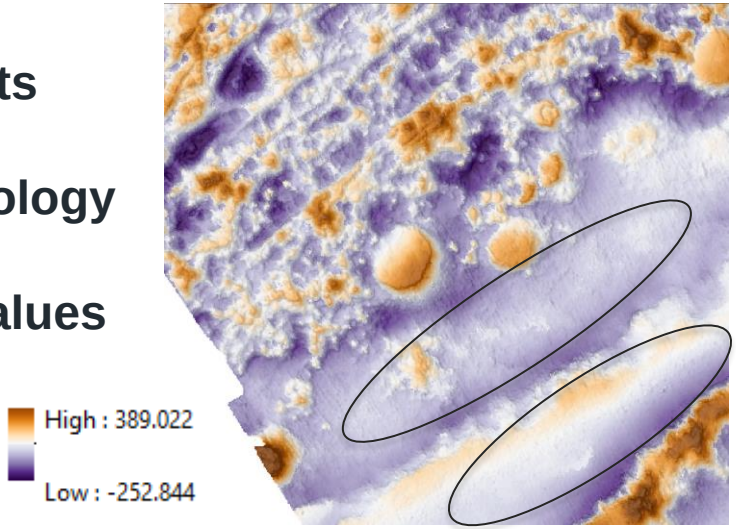
Relative topographic position *relative LTP*



Elevation percentile *relative LTP*

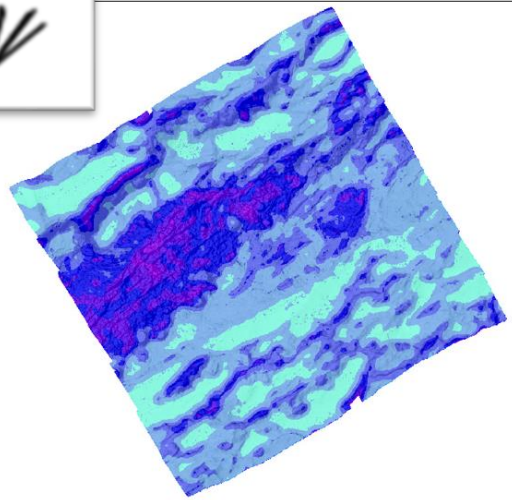
Artefacts vs. geomorphology

Intuitive values



Difference from mean elevation ☺ *absolute LTP*

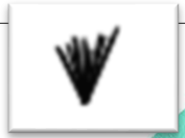
Flat vs. rugged box: Roughness/ruggedness



Min	2.108821153640747
Max	32.15636825561523
Mean	10.51933101845606
Std dev.	5.582087150841384

Magnitude of maximum multiscale roughness (degrees)
over distances of up to 1 km

- < 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35

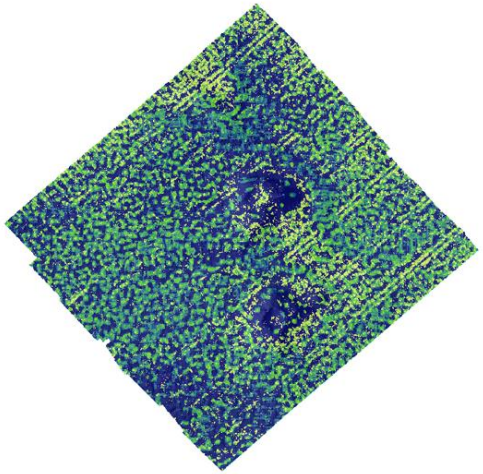


Min	1.578232169151306
Max	10.61559581756592
Mean	2.471979528344201
Std dev.	0.4405687744265555

Scale of maximum multiscale roughness

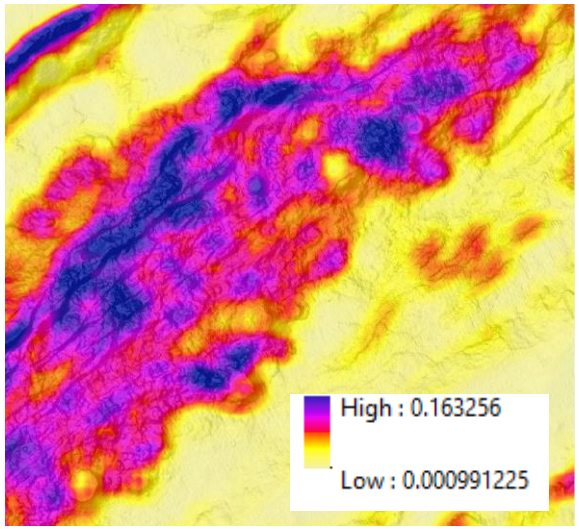
- 1 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25

Filter radius in cells



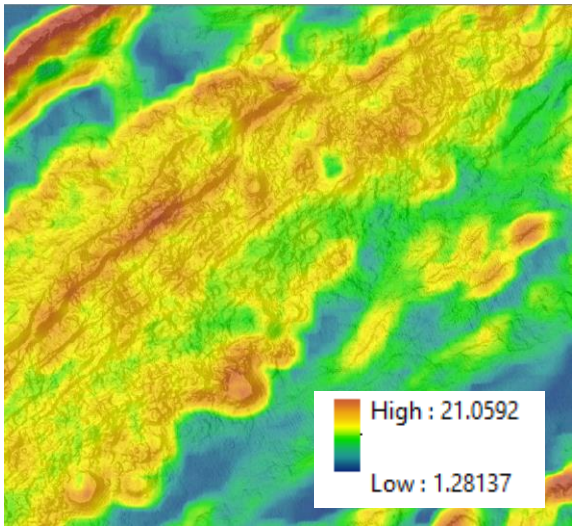
- Lindsay et al. (2019) multiscale roughness based on dispersion of surface normal
- Magnitude and scale ouputs
- Max scale ~1km – relevant to AUV/ROV operations
- Bathy grid 20m

Alternative roughness/ruggedness metrics…



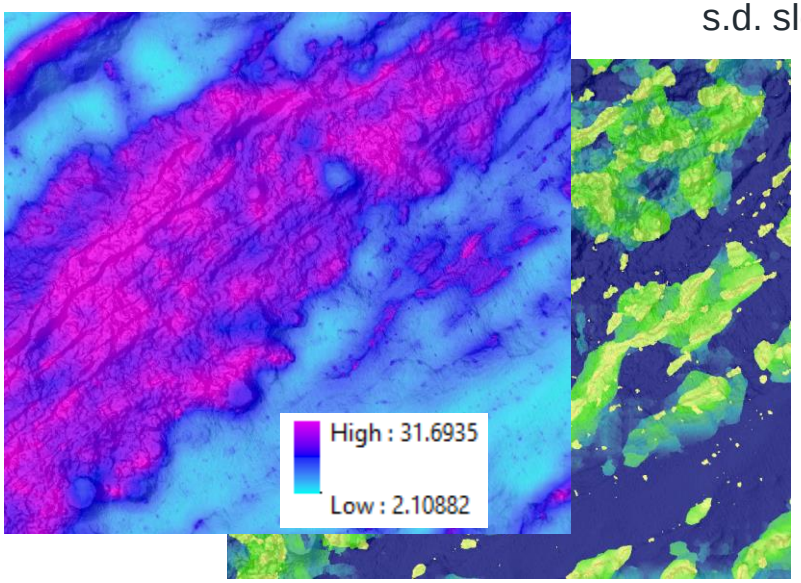
Vector ruggedness measure ~1km
Sappington et al. 2007
(BTM toolbox ++)

Neighbourhood effects
vs. intuitive values
vs. interpretability



s.d. slope (WhiteboxTools) ~1km

e,g, Grohmann et al. 2010



Multiscale roughness (magnitude & scale) – combine?

Conclusions and further work

- Terrain attributes useful for **quantitative characterisation**
- **Intuitive metrics** preferred for survey planning
- Find **thresholds** for safe operation of different gear
- Improve multibeam DTMs for geomorphometric analysis & fuse with regional data?

➢ Follow up surveys and characterisation of seabed geo/bio/environmental status

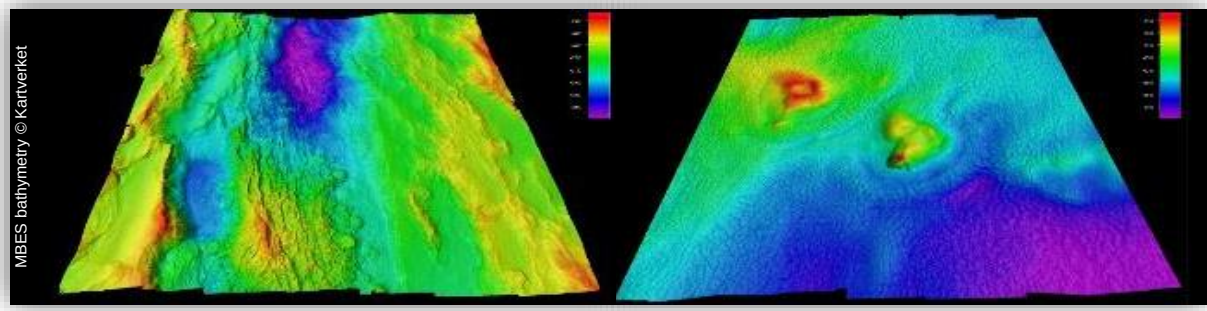


Image: Kongsberg Maritime

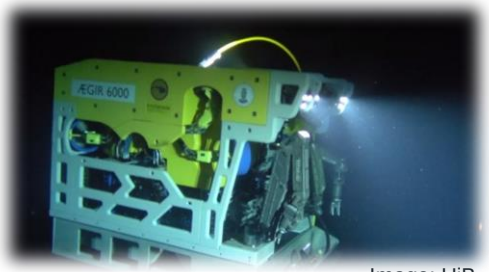


Image: UiB

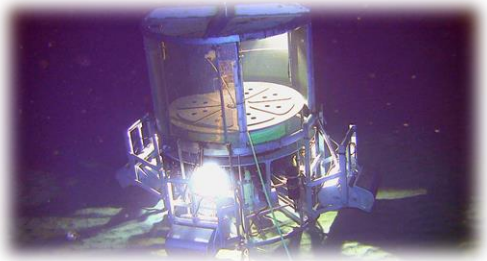
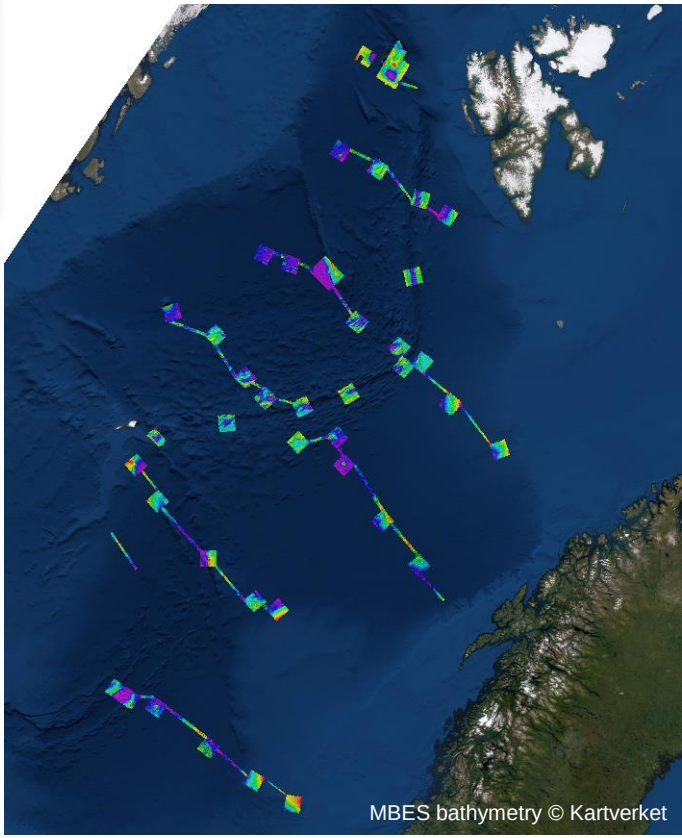


Image: MAREANO



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