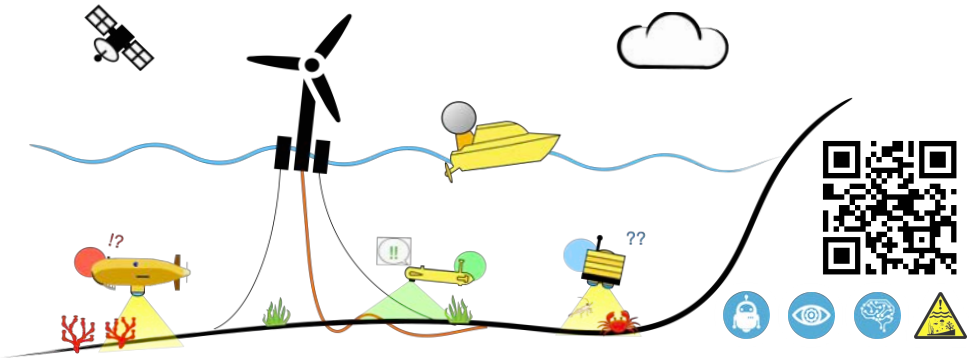
Geospatial data and tools for environmental sensing
~ Ocean Case Study ~

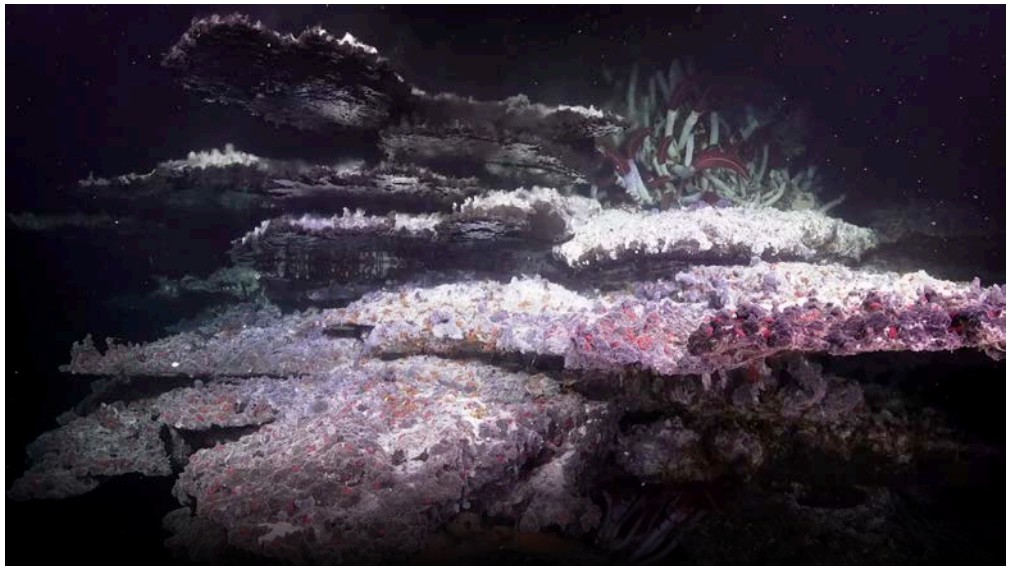


Blair Thornton
Professor of Marine Autonomy

University of Southampton

Ship Science, 1999-2002 (B. Eng)
PhD Marine Robotics at Uni. Tokyo/UoS, Japan 2002-2006
Staff at Uni. Tokyo, Japan 2006-2016
Staff at Uni. Southampton, 2016-present with a cross appointment at Uni. Tokyo

500+ days at sea 60 expeditions deploying robots in the ocean

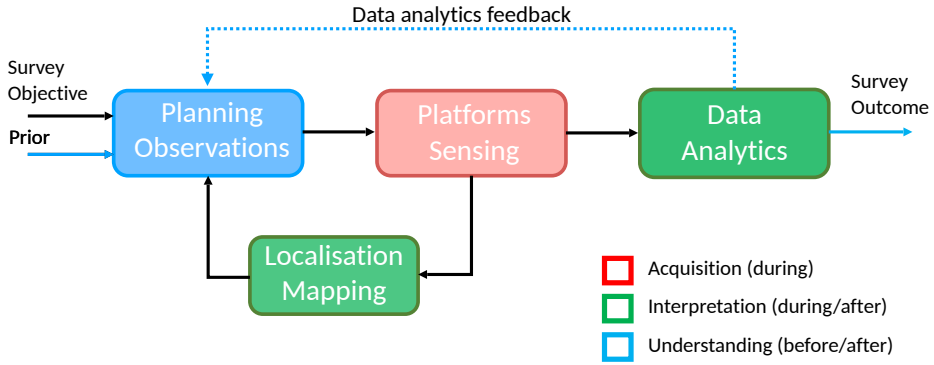


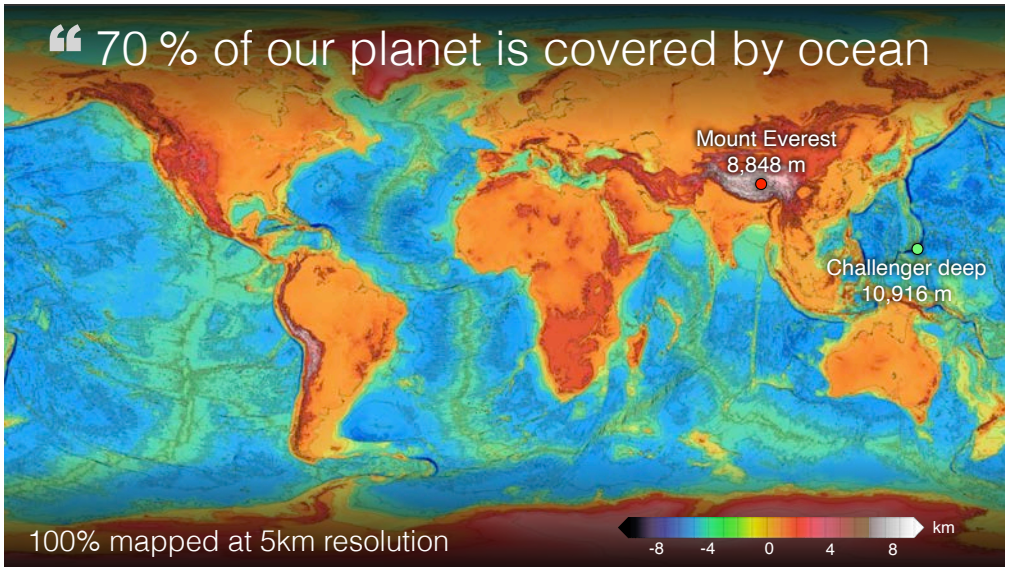
Challenges

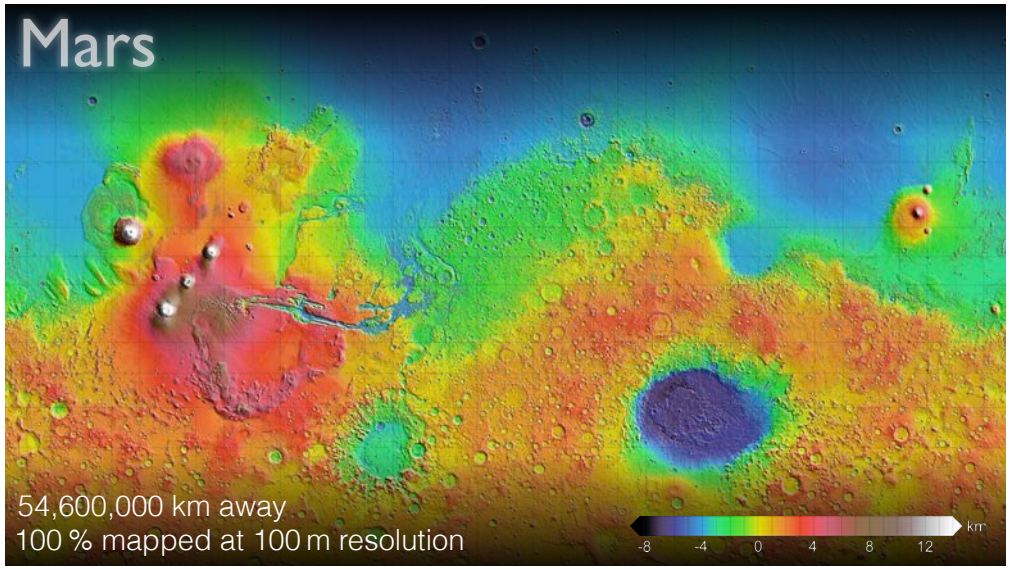
Solutions (?)

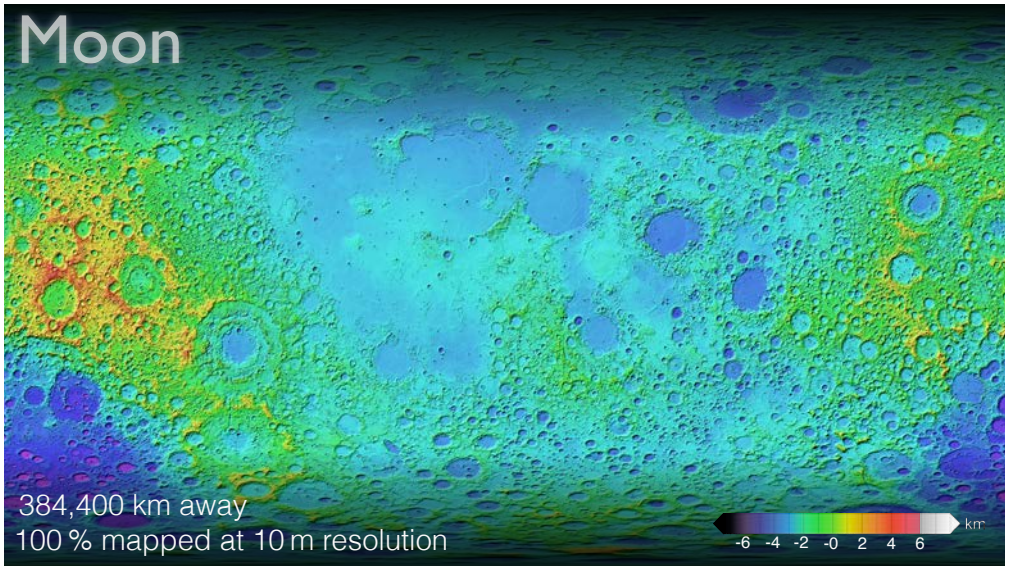
Input → **Machine Learning??** → Output

Solutions

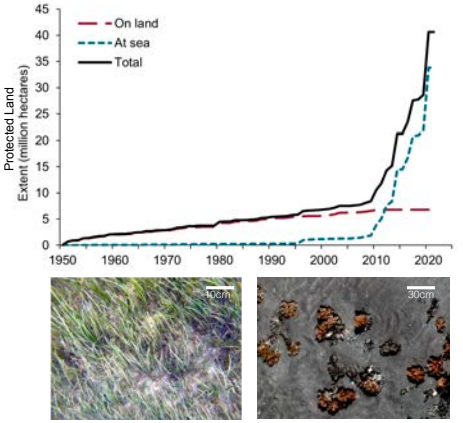


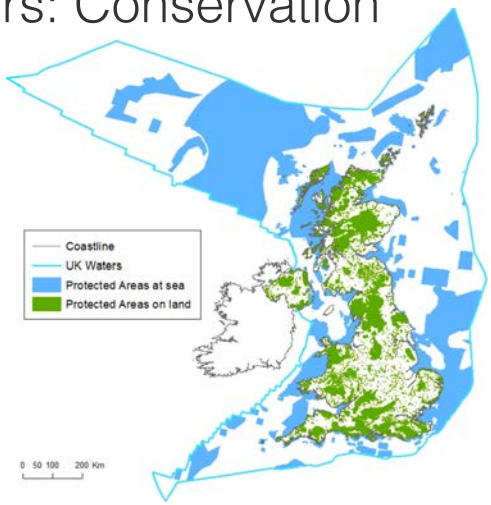






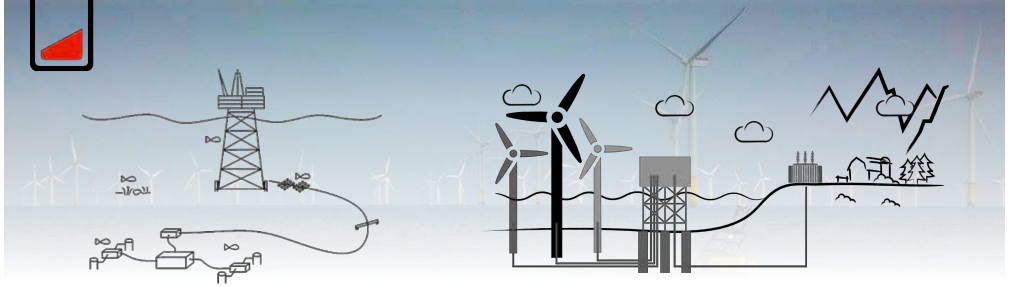
Capability drivers: Conservation





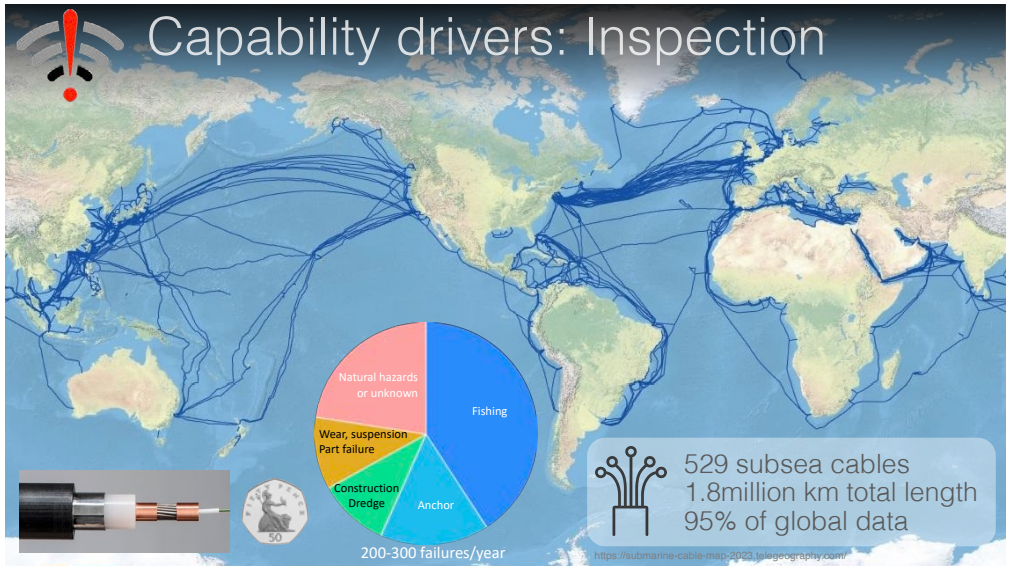
Capability drivers: Inspection

Infrastructure details are on cm to m scales

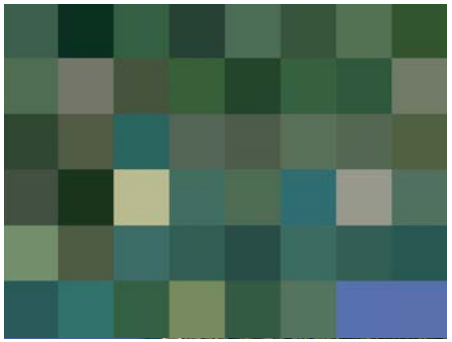


×180 (UK 2015)
↳ ×0 (UK 2050 target)

×2,600 (UK 2022)
↳ ×15,000 (UK 2050 target)



Seafloor mapping **5km**



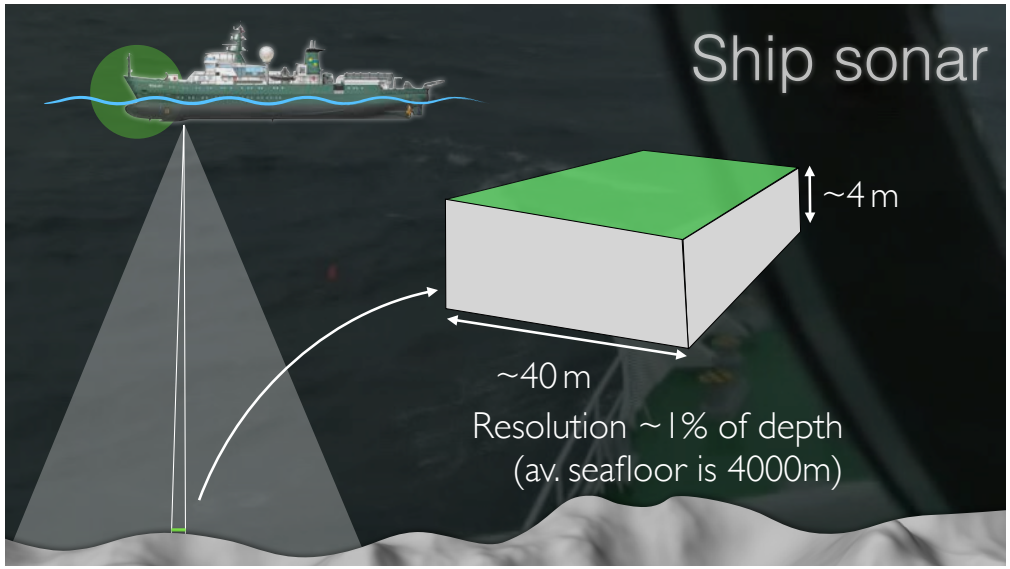
❝ 100% of the seafloor mapped

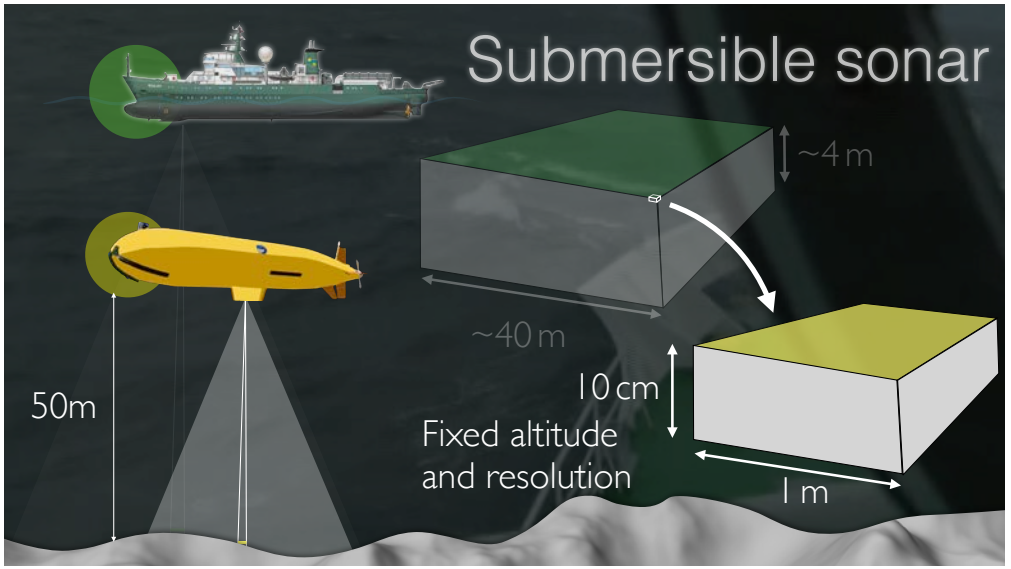
Seafloor mapping **100m**

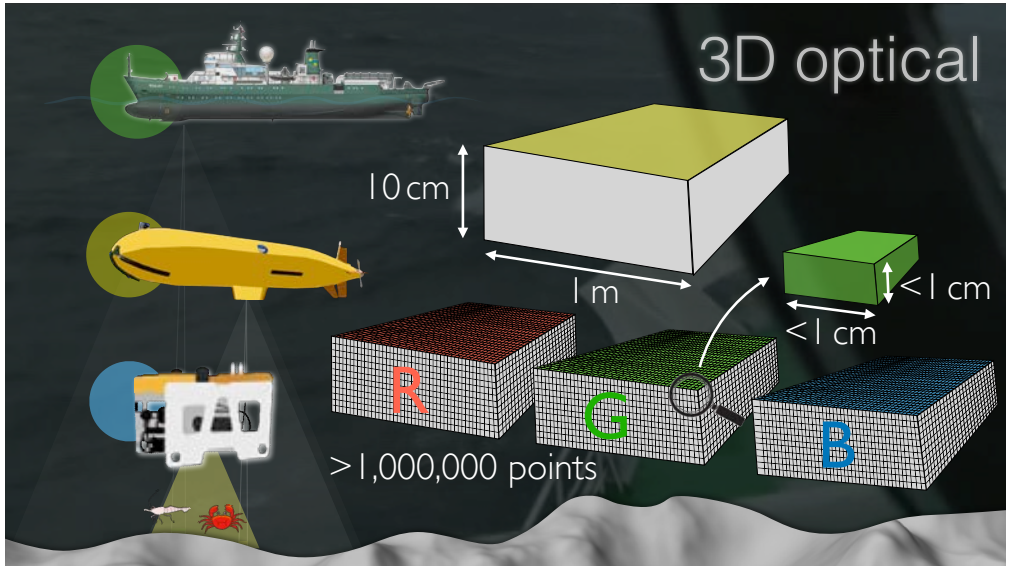
❝ Less than 10% mapped

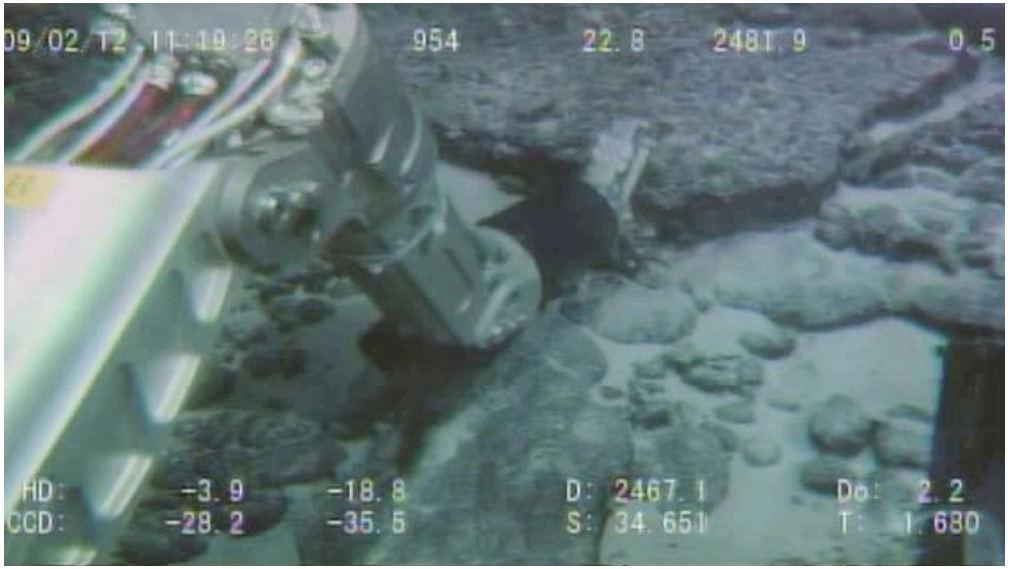
Seafloor mapping **10m**

❝ Less than 0.01% mapped

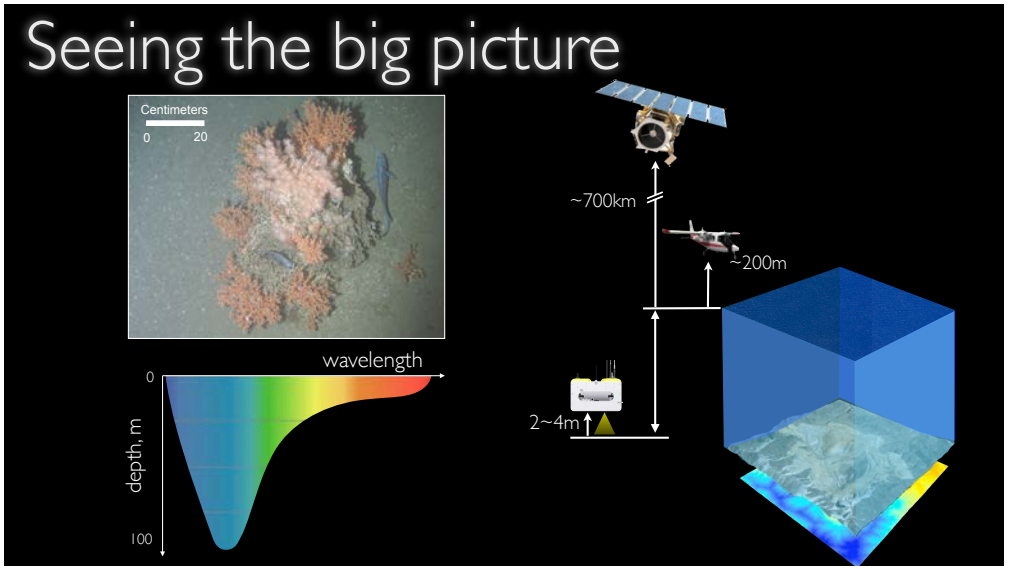

Ship sonar
~4 m
~40 m
Resolution ~1% of depth
(av. seafloor is 4000m)

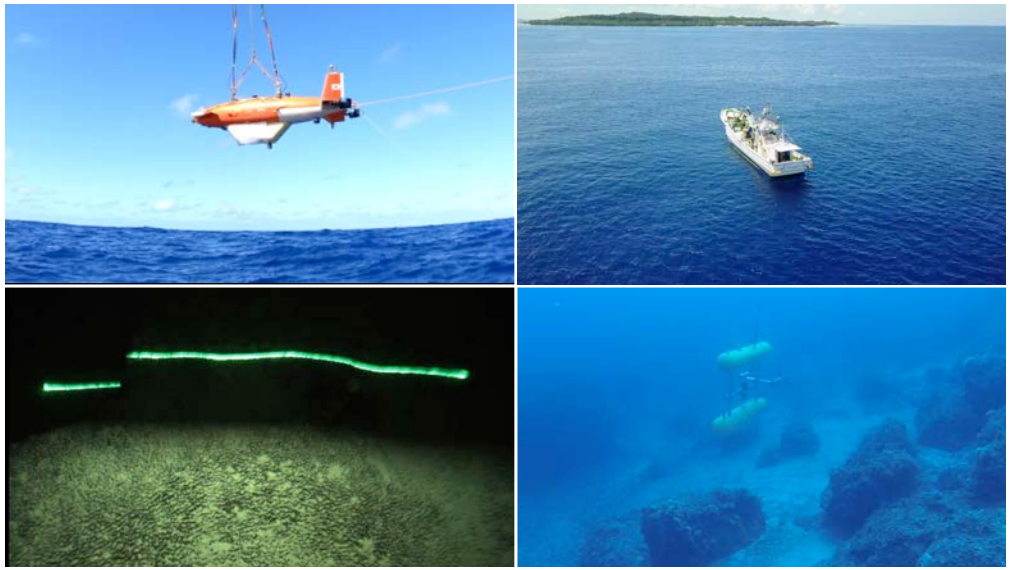

Submersible sonar
~4 m
~40 m
50m
10 cm
Fixed altitude
and resolution
1 m


3D optical
10 cm
1 m
<1 cm
<1 cm
R
G
B
>1,000,000 points

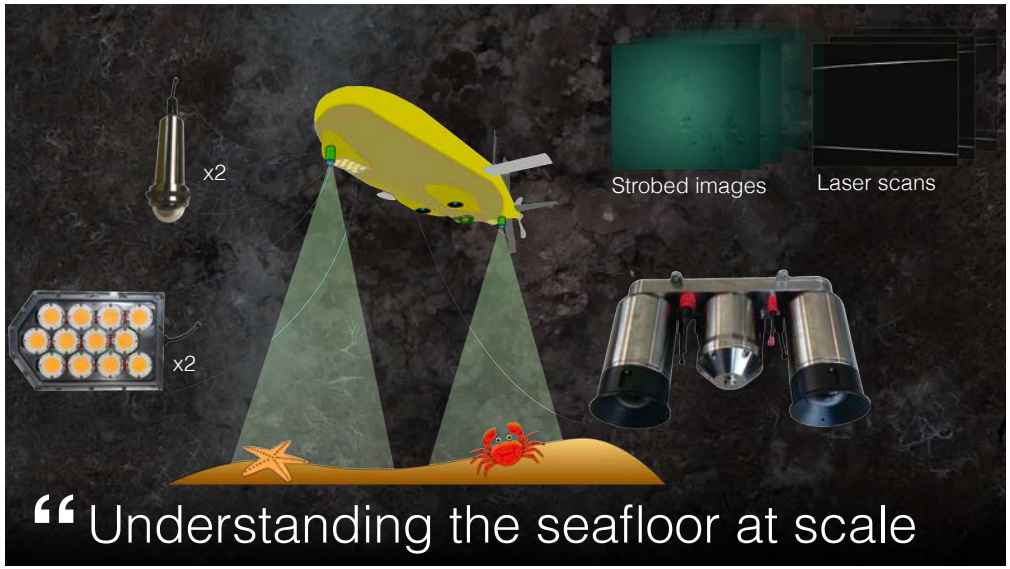

09/02/T2 11:19:26
954
22.8
2481.9
0.5
HD: -3.9 -18.8
CCD: -28.2 -35.5
D: 2467.1
S: 34.651
Do: 2.2
T: 1.680

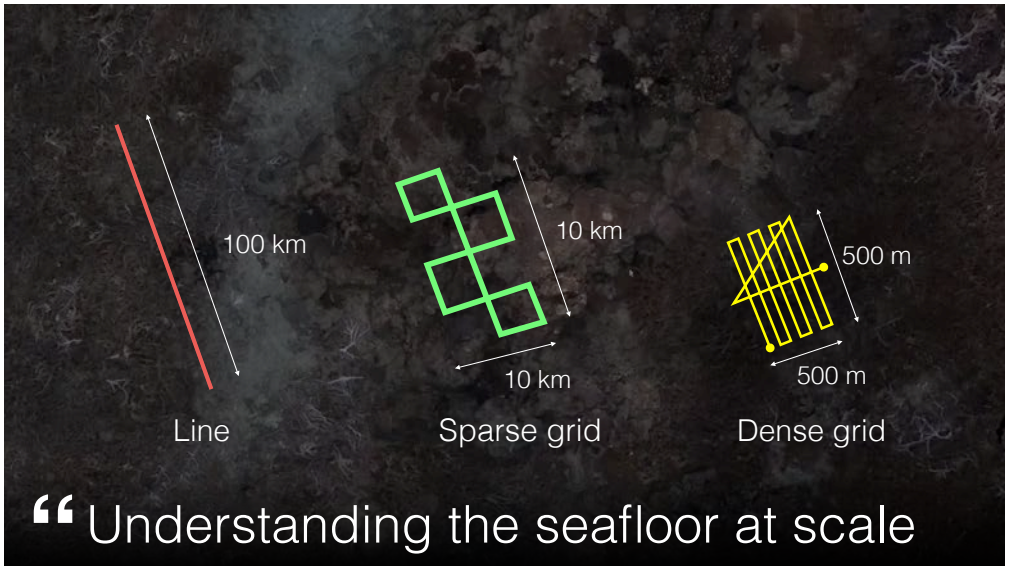

14/12/21 15:08:06
HD: 195.6 -16.3
CCD: -44.6 -46.6


Seeing the big picture
Centimeters
0 20
wavelength
0
depth, m
100
~700km
~200m
2~4m

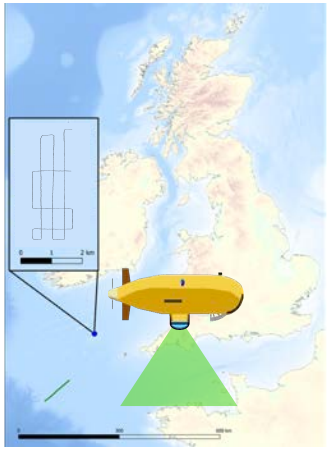


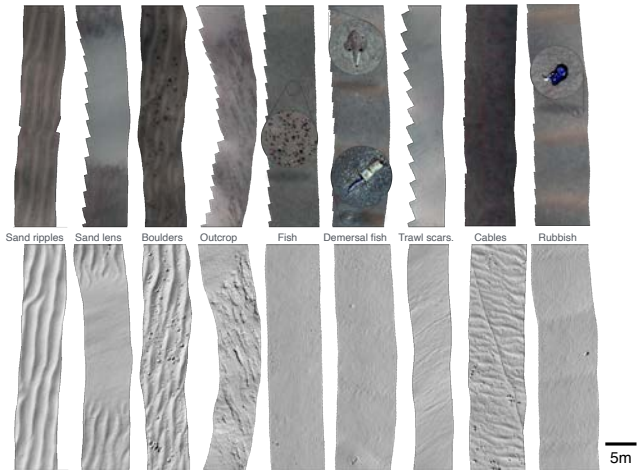

“Understanding the seafloor at scale

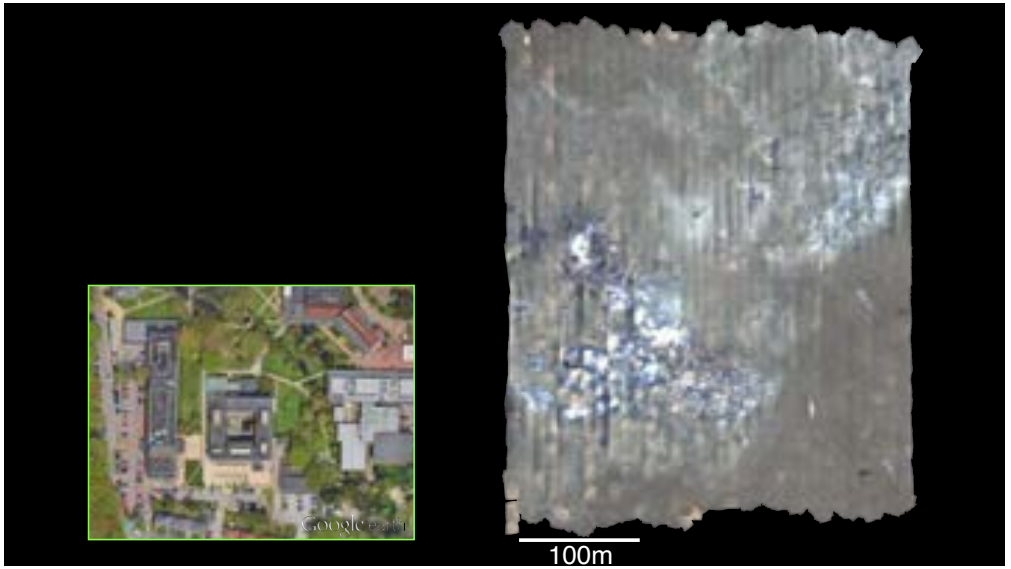


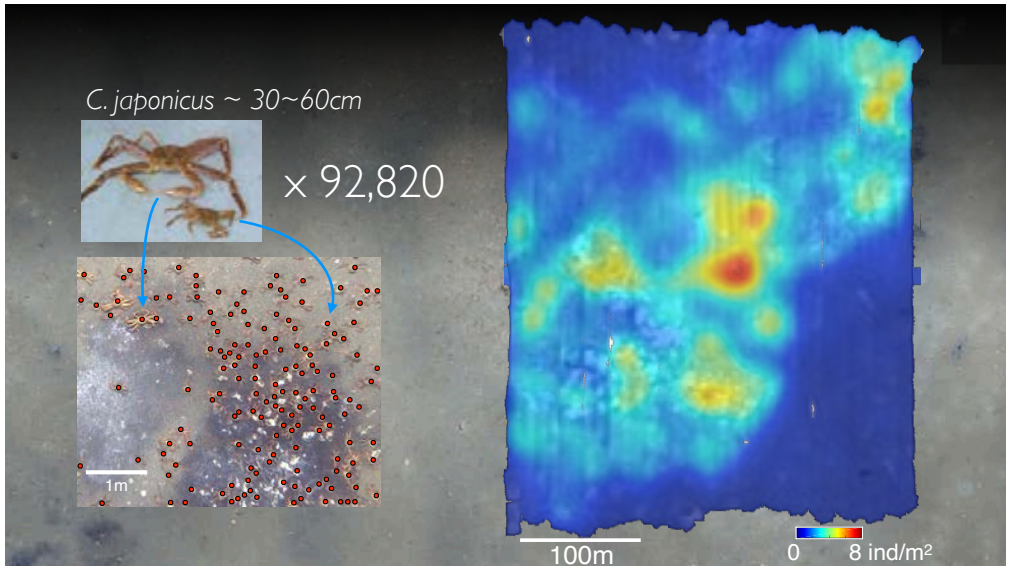


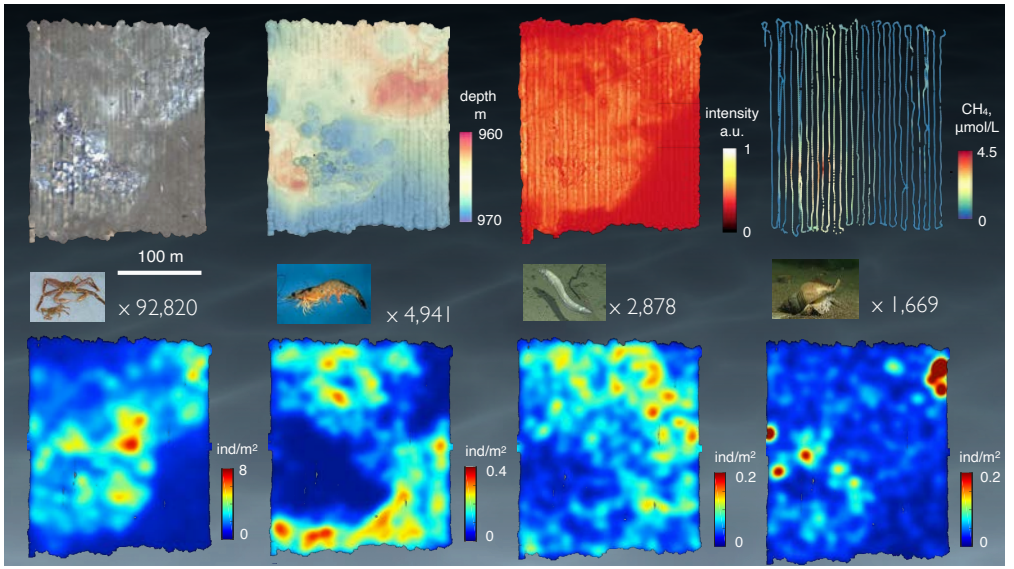
mm-resolution over km-extents

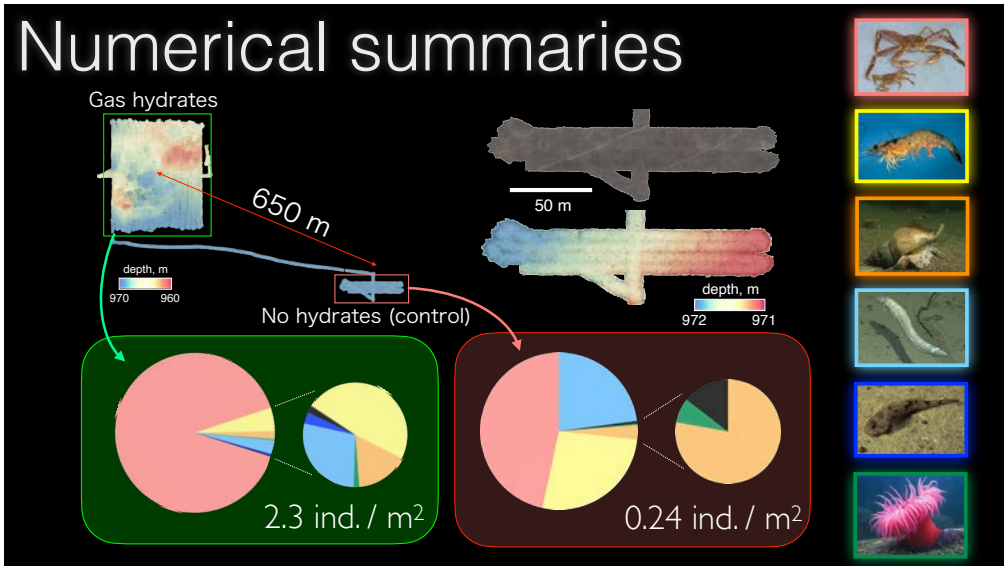


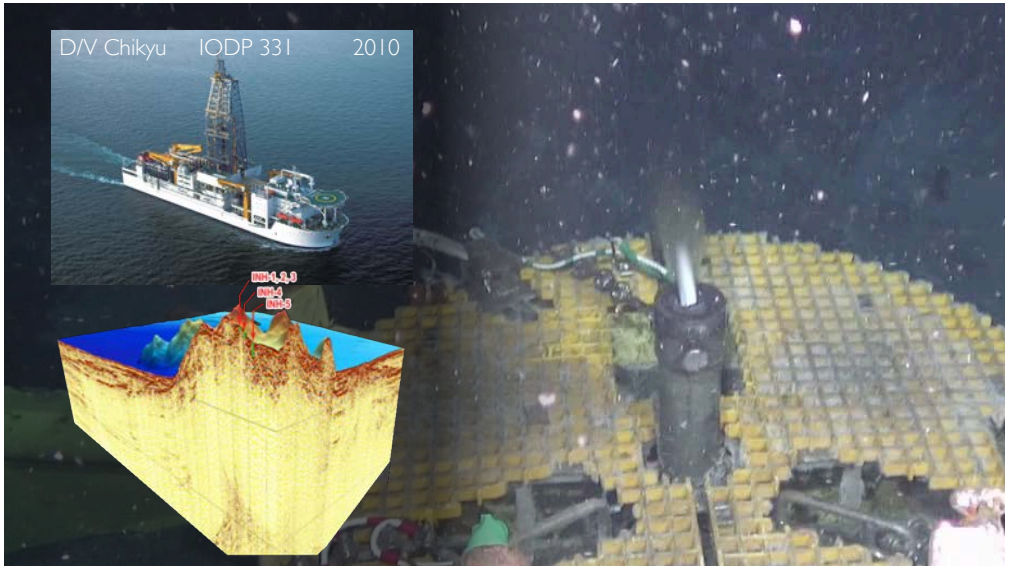


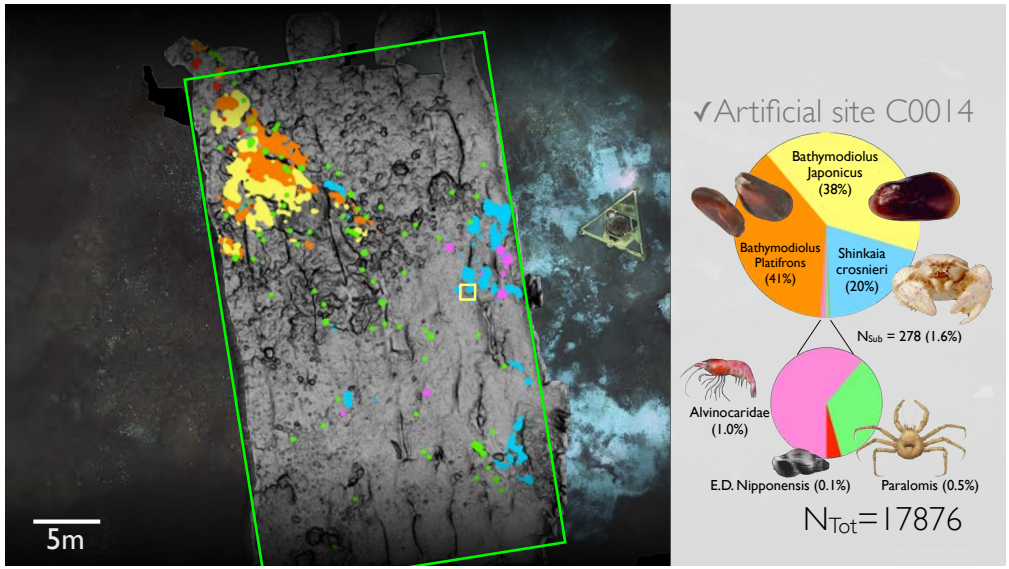



C. japonicus ~ 30~60cm
x 92,820
1m²
100m
0
8 ind/m²


depth
m
960
970
intensity
a.u.
1
0
CH4,
µmol/L
4.5
0
100 m
x 92,820
x 4,941
x 2,878
x 1,669
ind/m²
8
0
ind/m²
0.4
0
ind/m²
0.2
0
ind/m²
0.2
0


Numerical summaries
Gas hydrates
650 m
depth, m
970
960
No hydrates (control)
50 m
depth, m
972
971
2.3 ind. / m²
0.24 ind. / m²

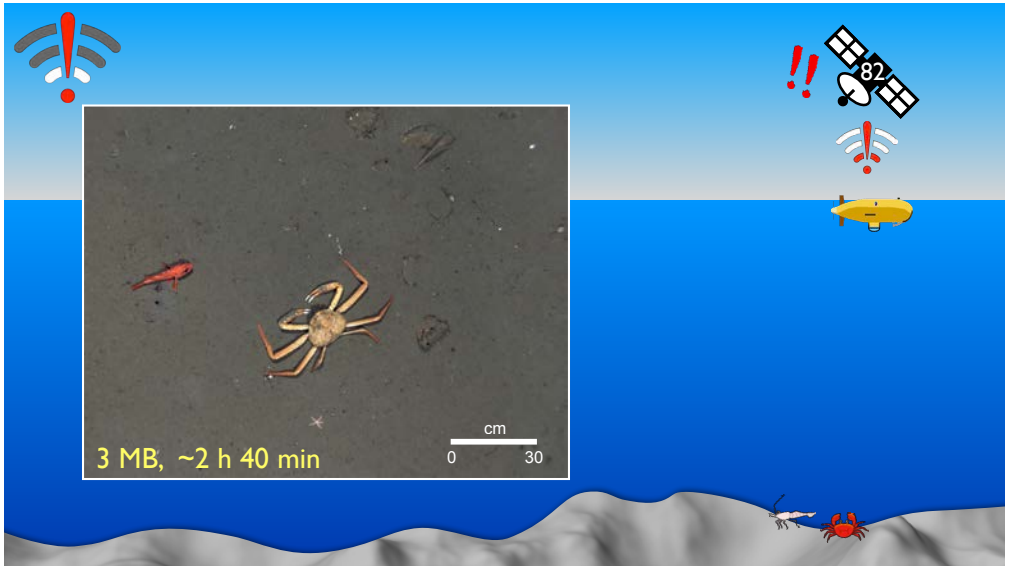

D/V Chikyu
IODP 331
2010

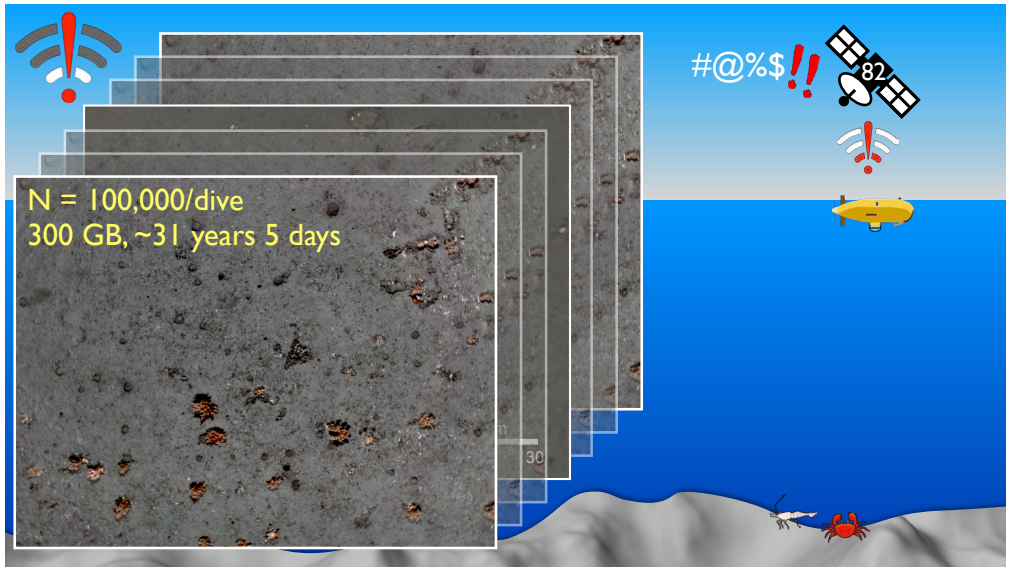


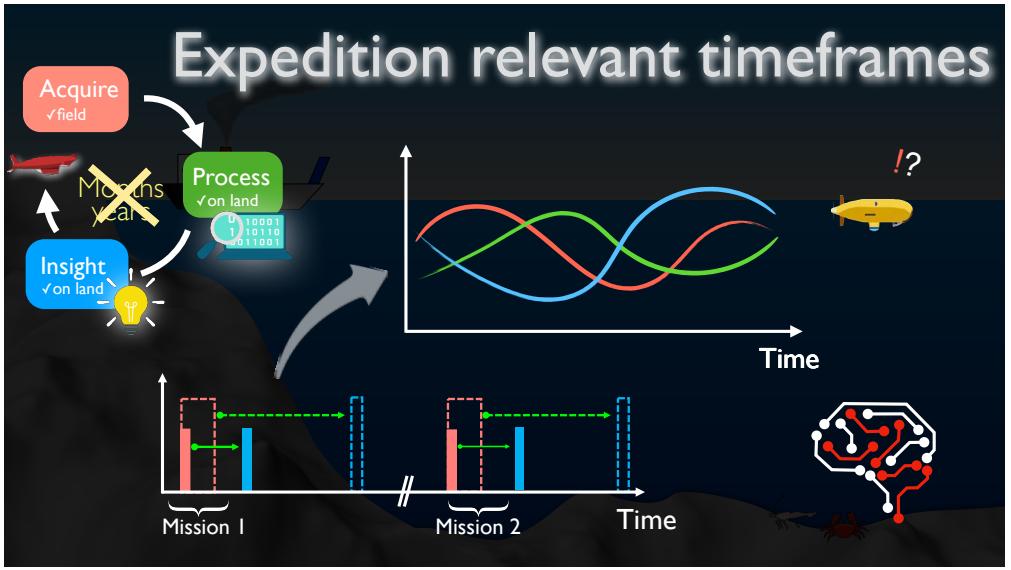
✓Artificial site C0014

N_{Tot}=17876

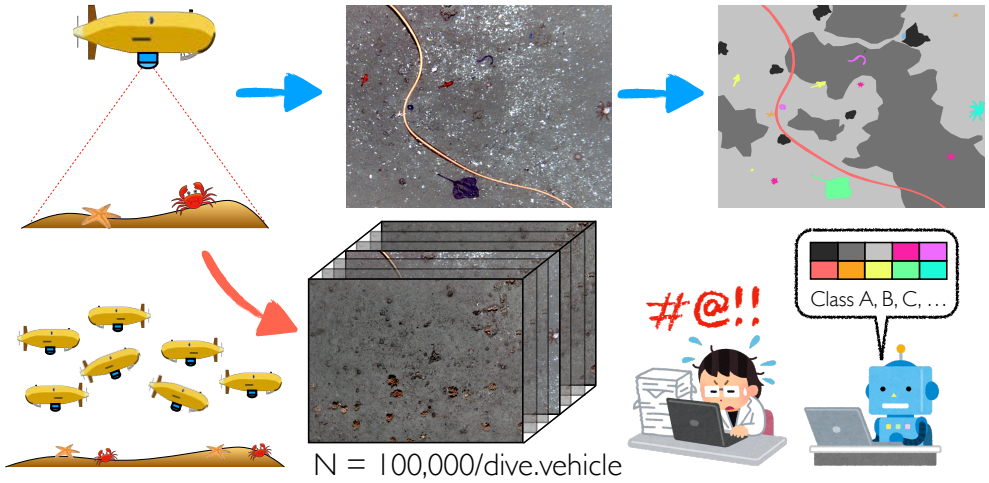
Feeding back data analytics

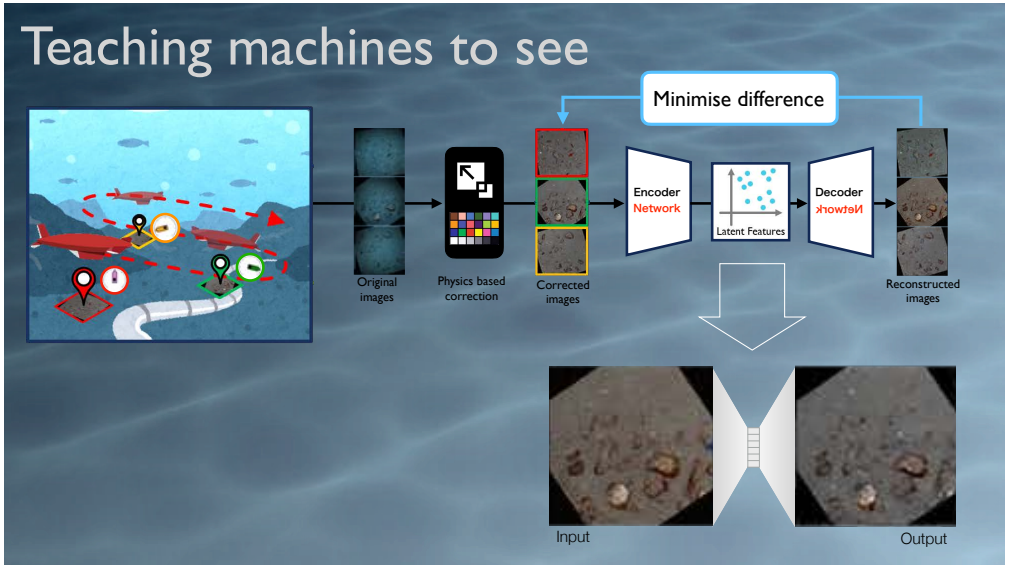




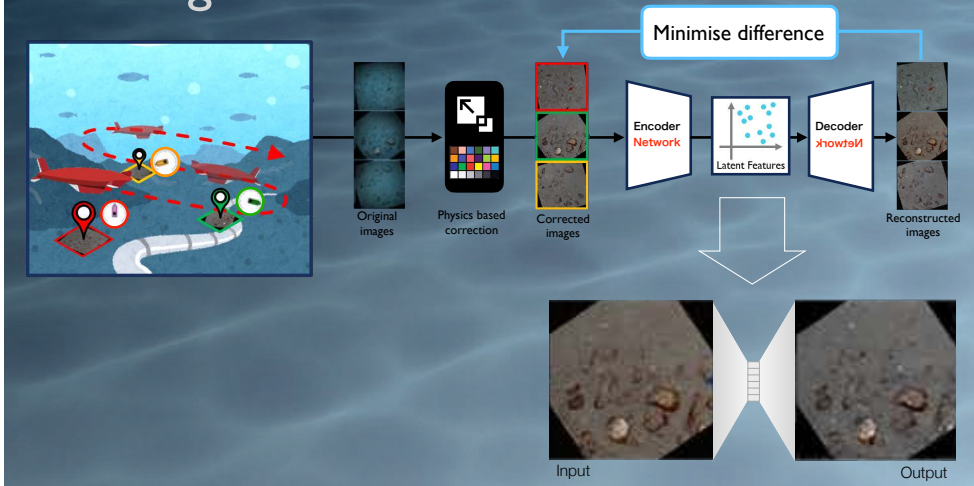


Human-Machine value alignment

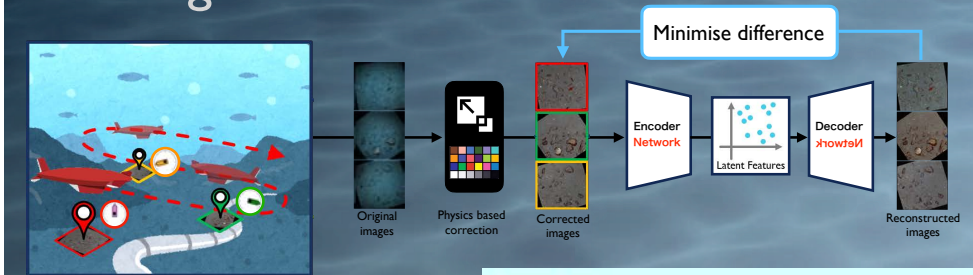




Teaching machines to see

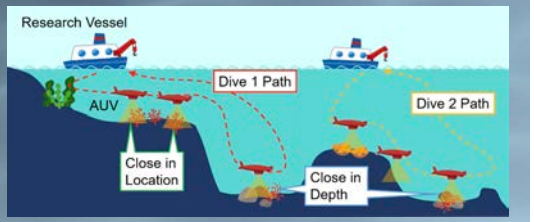


Teaching machines to see

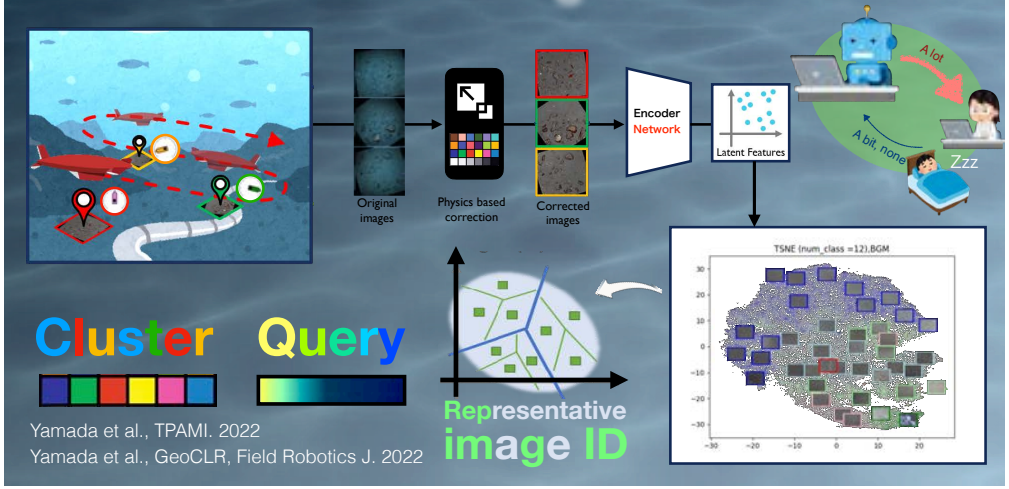


"Features can occur on patterns larger than a single image footprint

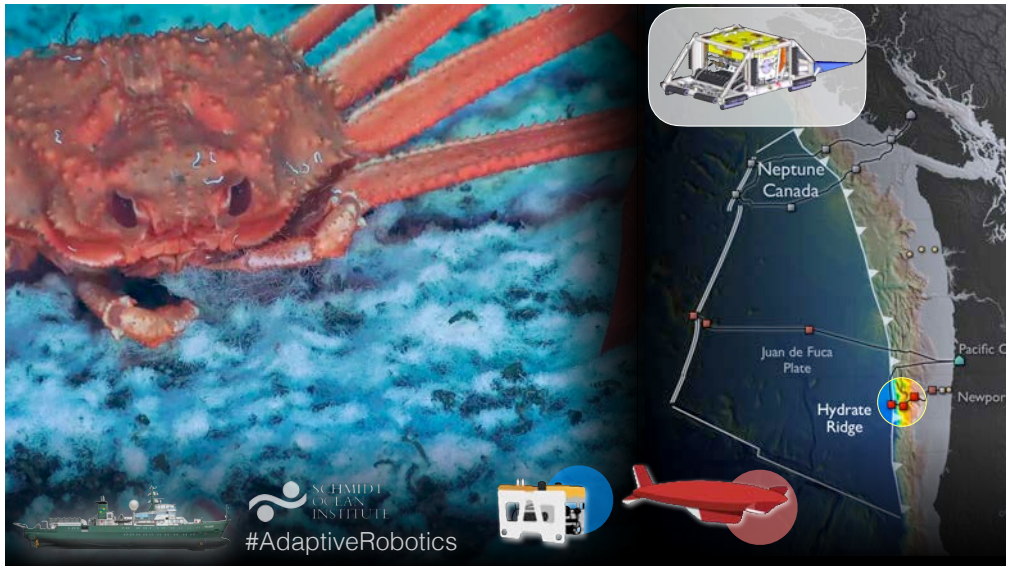
"Features can occur along a depth gradient

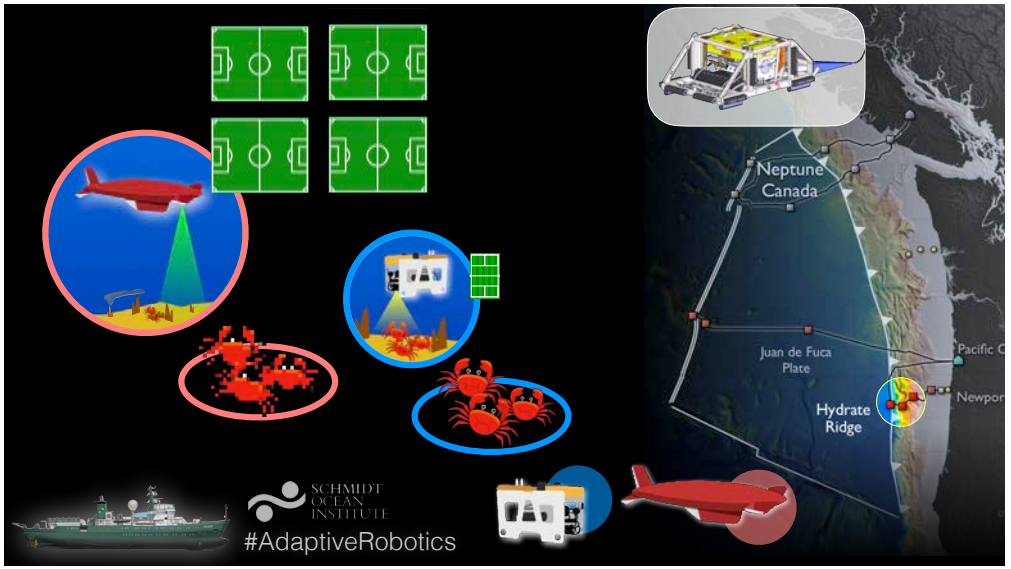


Eliminate, minimise and guide human effort

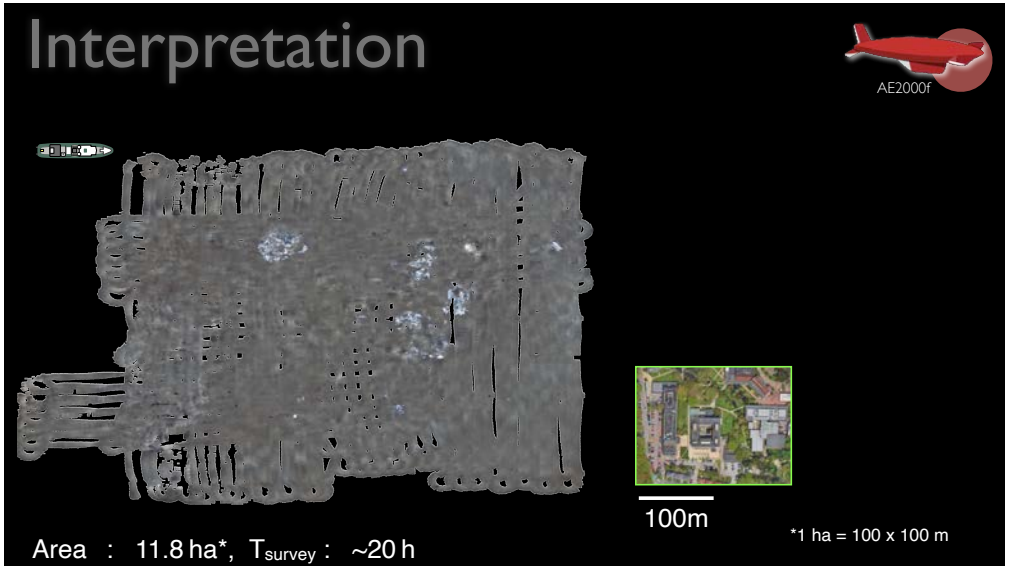


Yamada et al., TPAMI. 2022
Yamada et al., GeoCLR, Field Robotics J. 2022

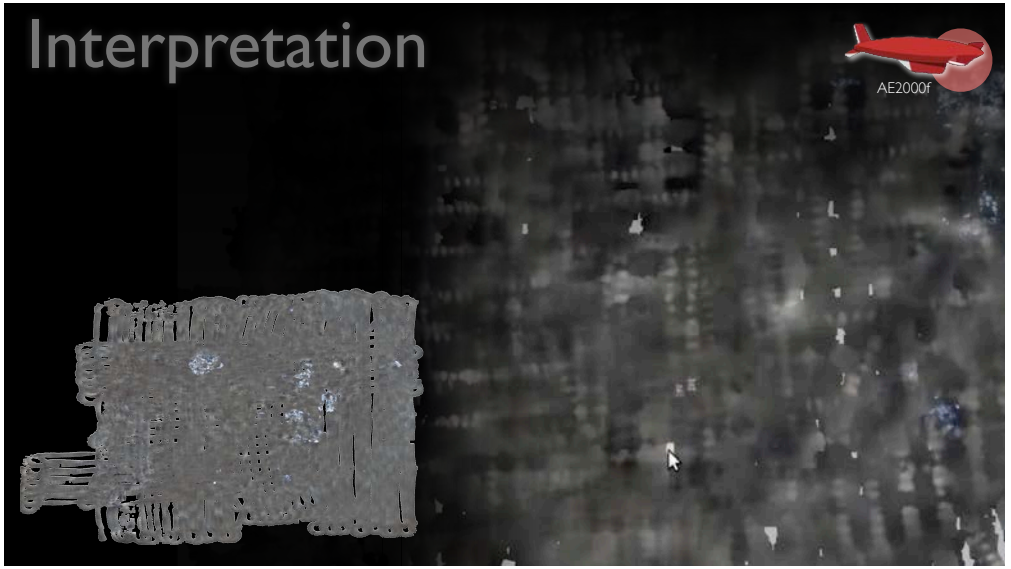


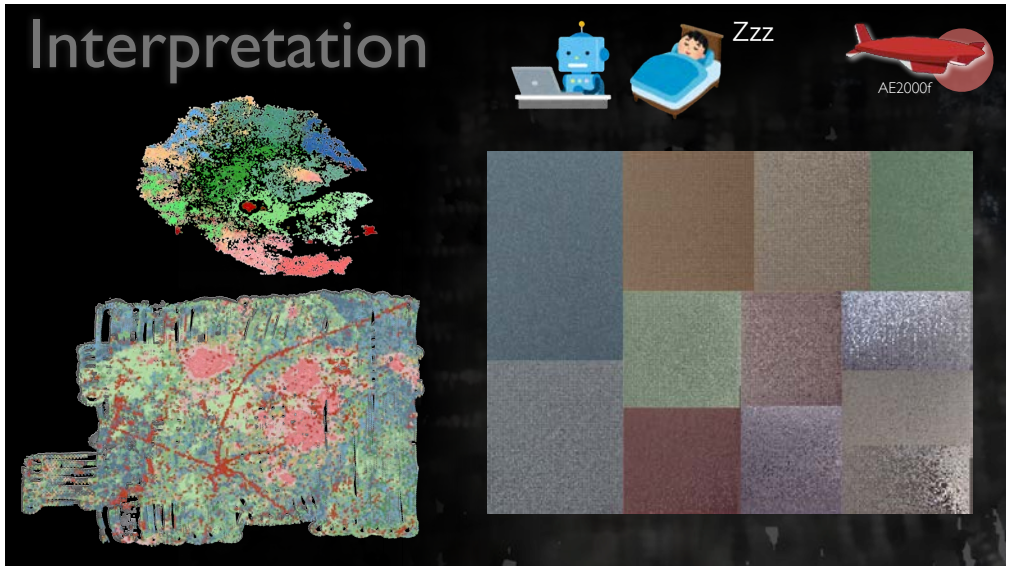


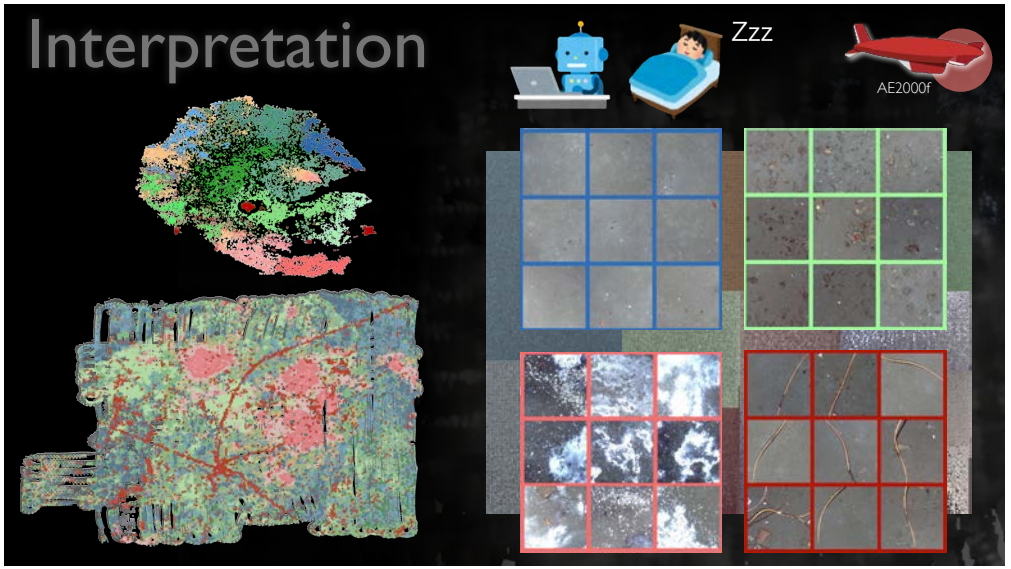
Interpretation

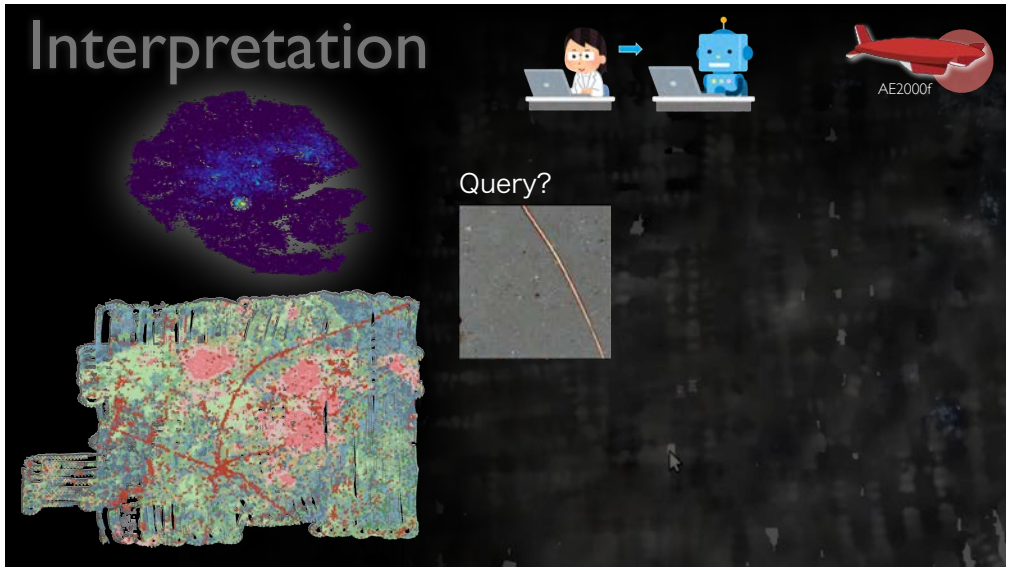


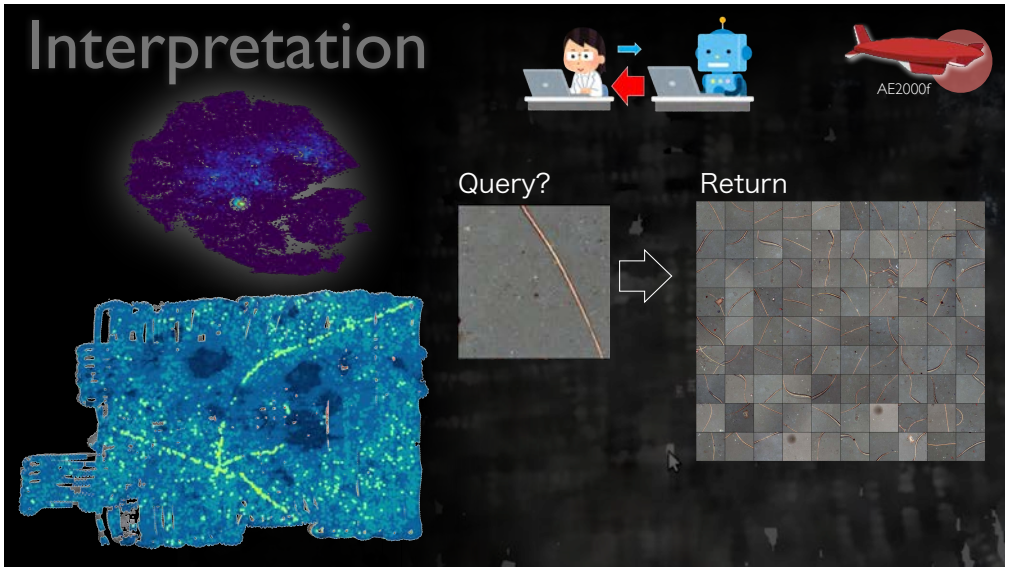
Interpretation



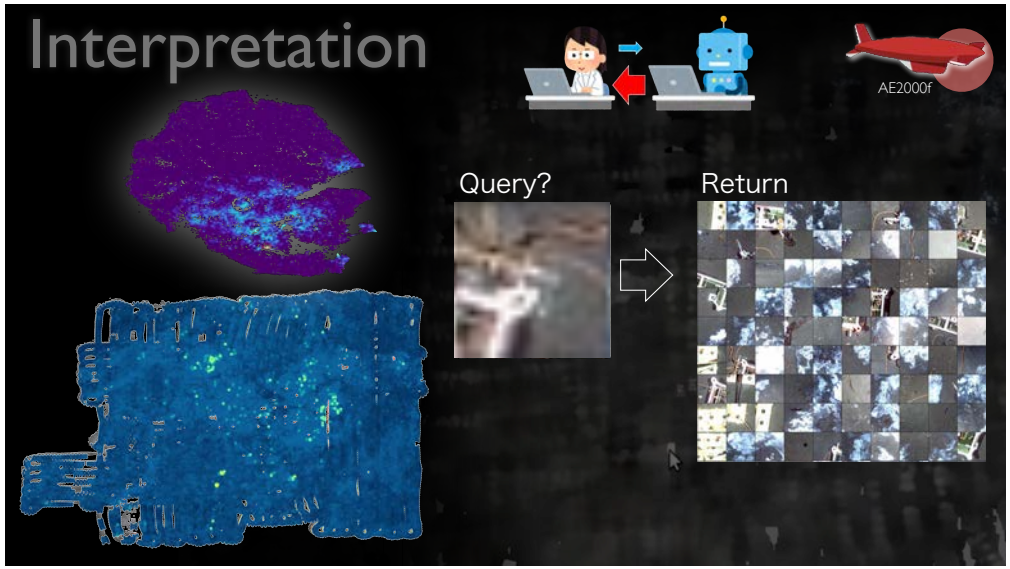

Interpretation
Zzz
AE2000f


Interpretation
Zzz
AE2000f

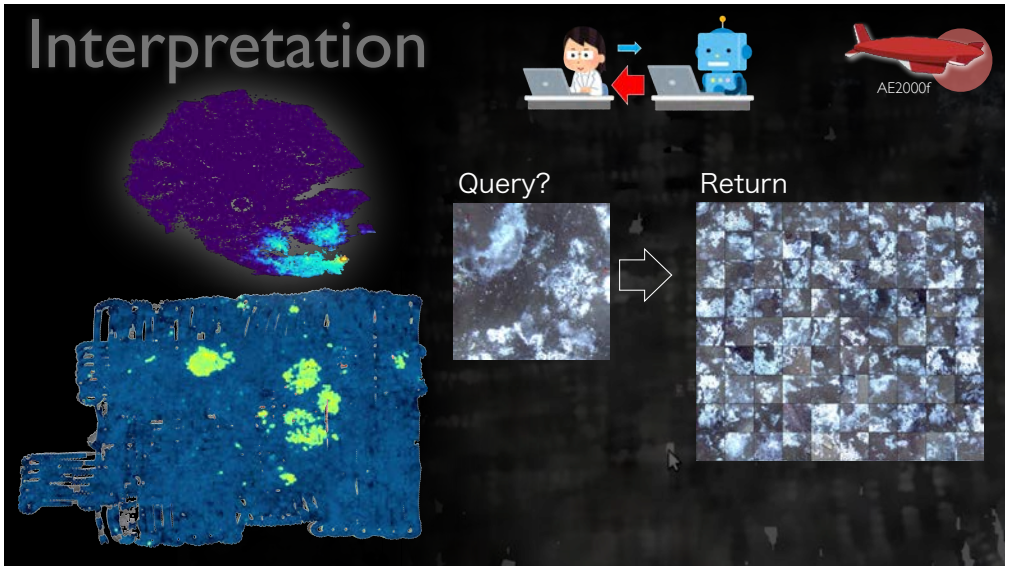

Interpretation
AE2000f
Query?


Interpretation
AE2000f
Query?
Return

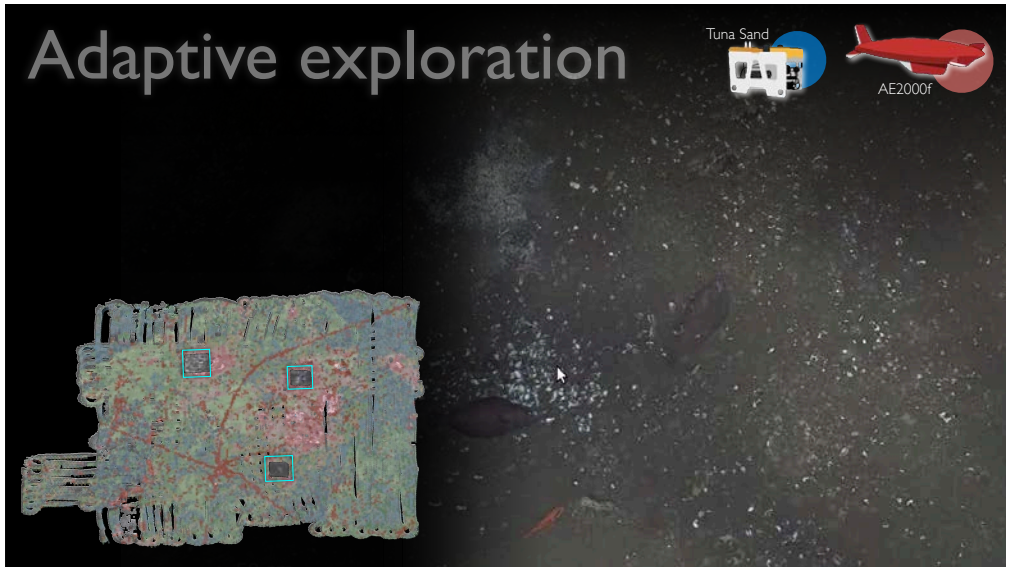
Interpretation



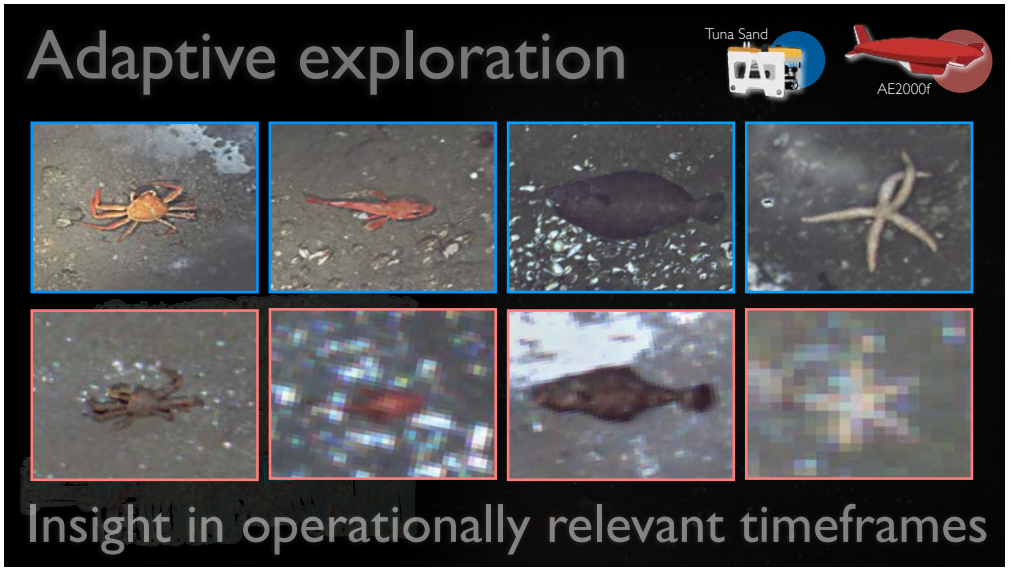
Interpretation

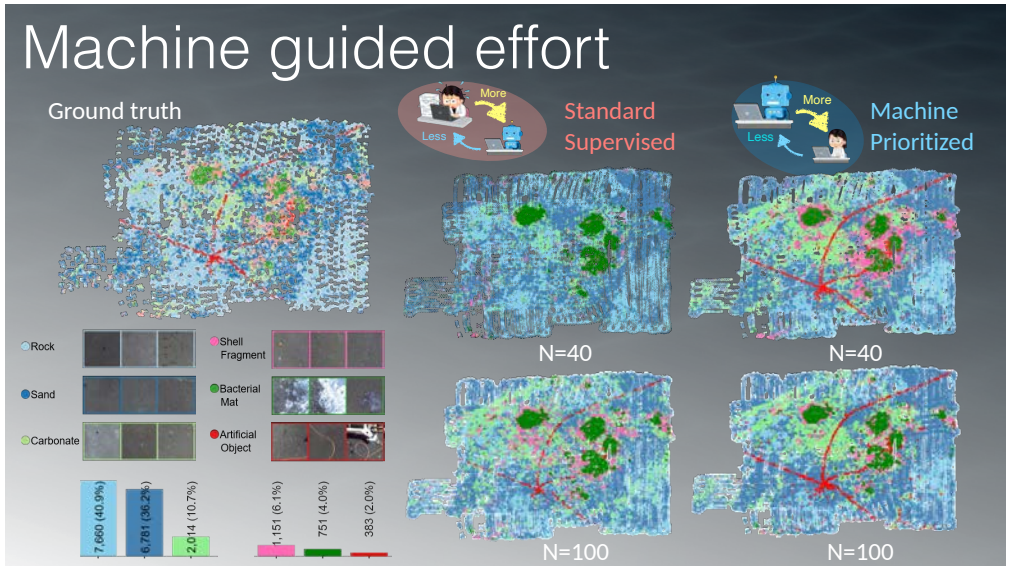


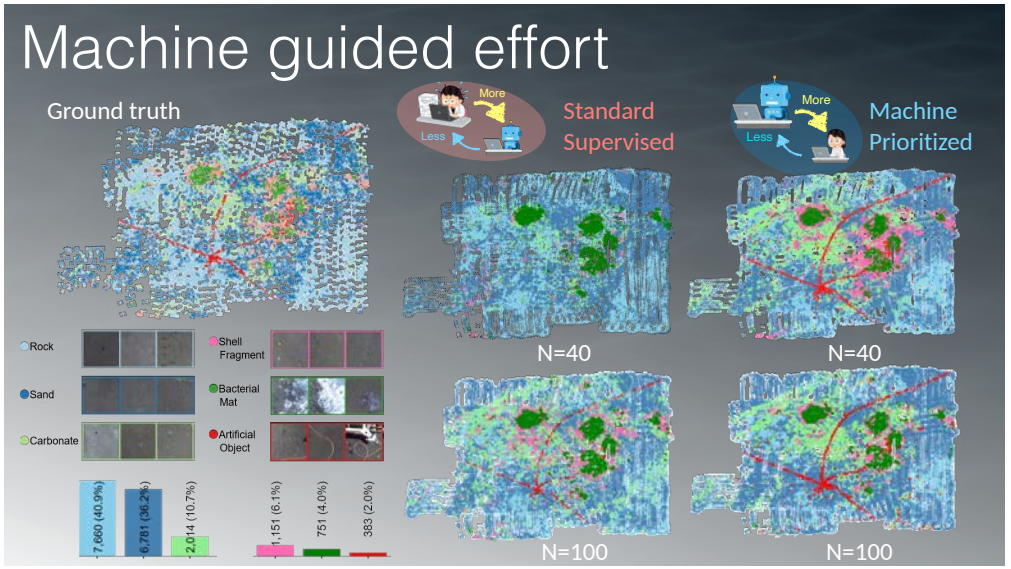
Adaptive exploration



Adaptive exploration




Machine guided effort
Ground truth
More
Less
Standard
Supervised
Machine
Prioritized
N=40
N=40
N=100
N=100
Rock
Sand
Carbonate
Shell Fragment
Bacterial Mat
Artificial Object
7,660 (40.9%)
6,781 (36.2%)
2,014 (10.7%)
1,151 (6.1%)
751 (4.0%)
383 (2.0%)


Machine guided effort
Ground truth
More
Less
Standard
Supervised
Machine
Prioritized
N=40
N=40
N=100
N=100
Rock
Sand
Carbonate
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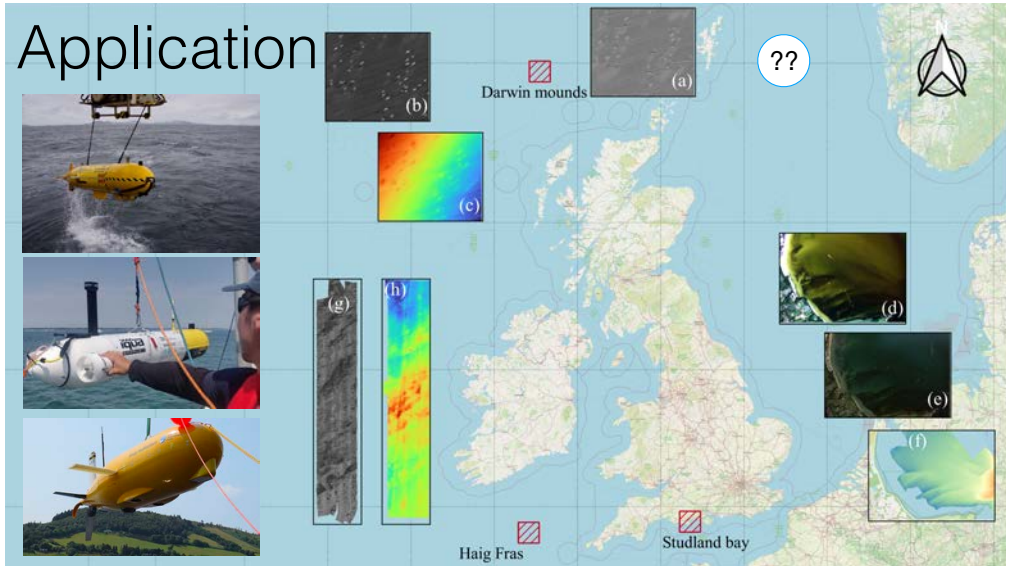
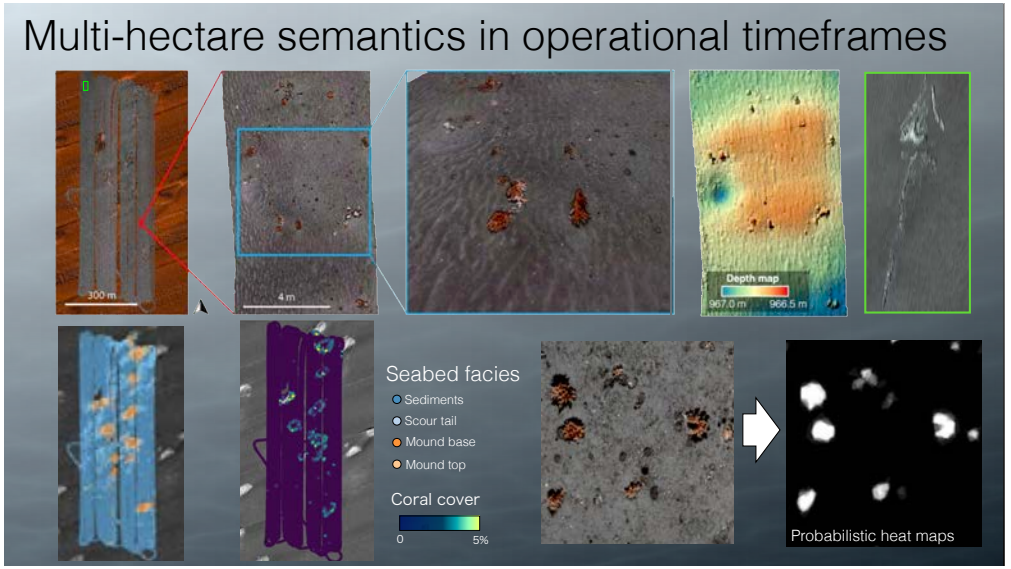
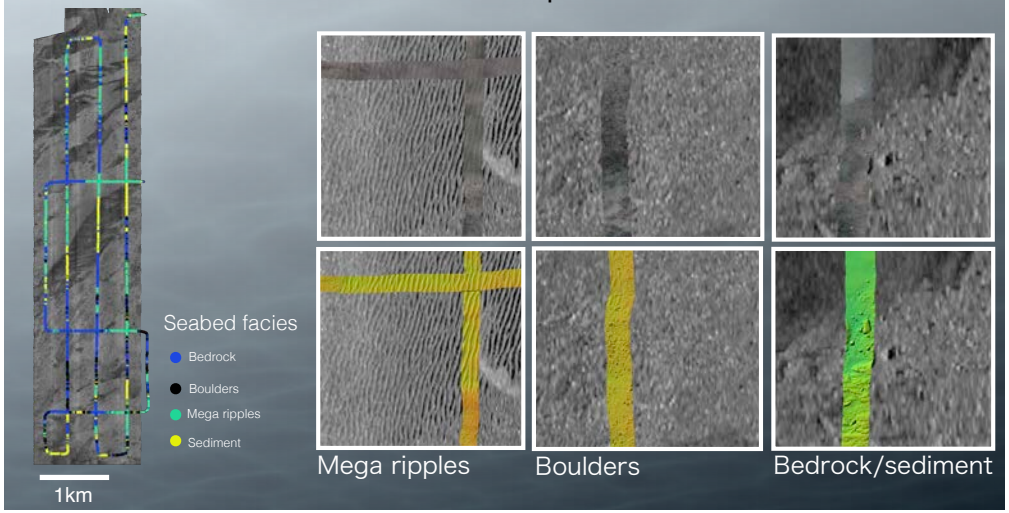
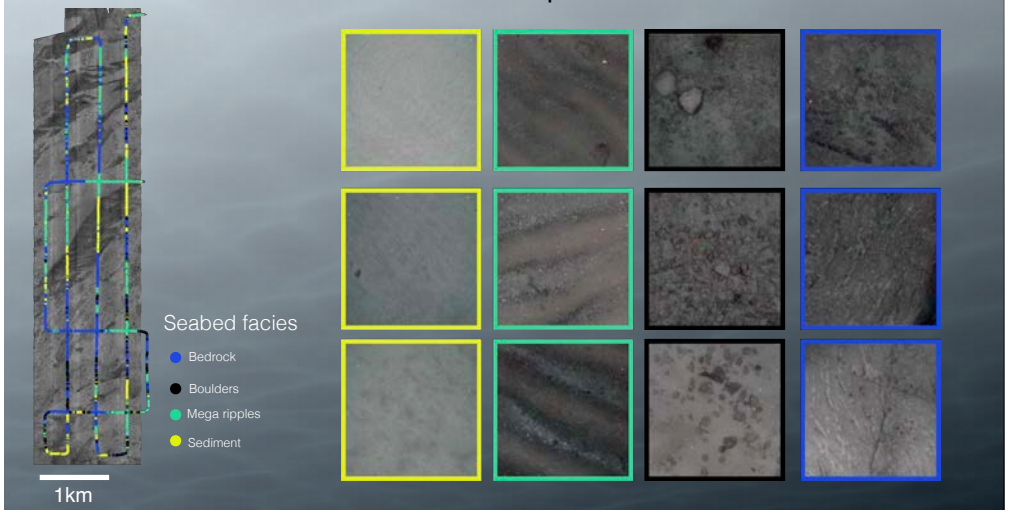

Application
??
Darwin mounds
Haig Fras
Studland bay
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)

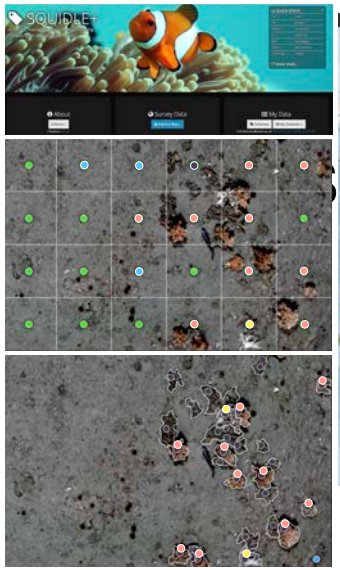

Multi-hectare semantics in operational timeframes
300 m
4 m
Depth map
967.0 m
966.5 m
Seabed facies
Sediments
Scour tail
Mound base
Mound top
Coral cover
0
5%
Probabilistic heat maps

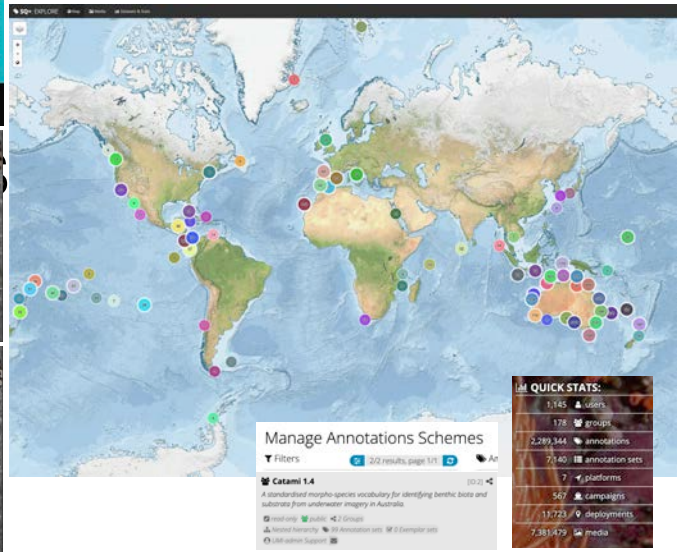
Multi-hectare semantics in operational timeframes

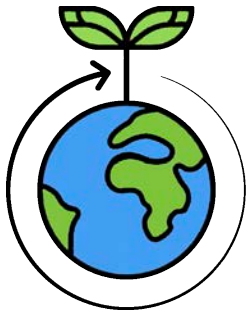


Multi-hectare semantics in operational timeframes



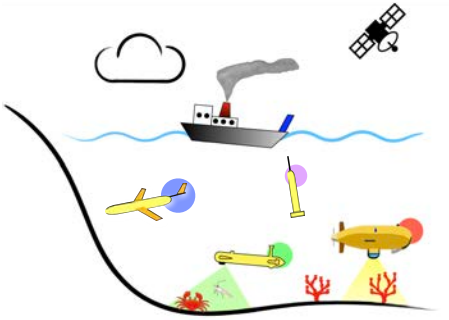




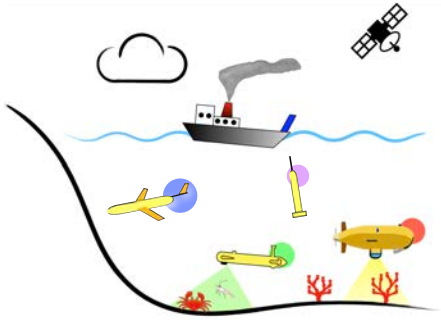


Scalable and Sustainable Surveys

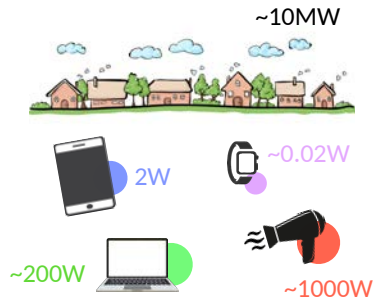
“Can we **decouple** autonomous system operations **from crewed ships**?



“Can we **decouple** autonomous system operations **from crewed ships**?

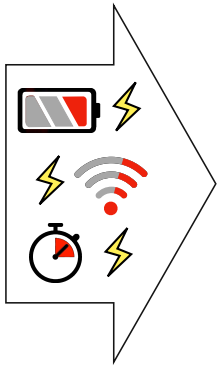


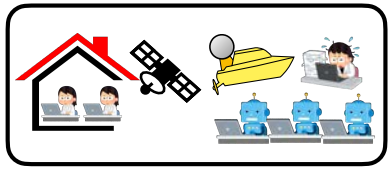
Energetic Equivalent



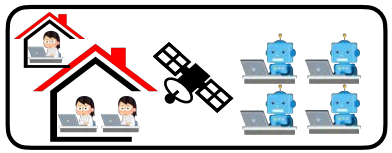
Scalability and sustainability

In person



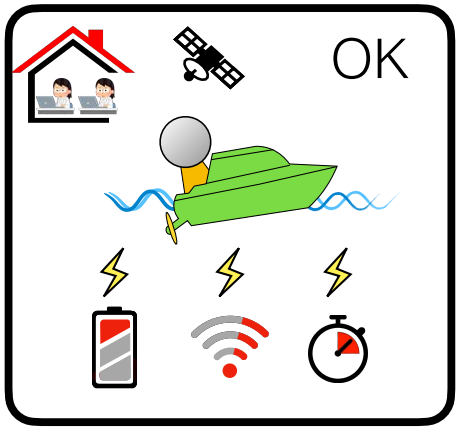


Hybrid

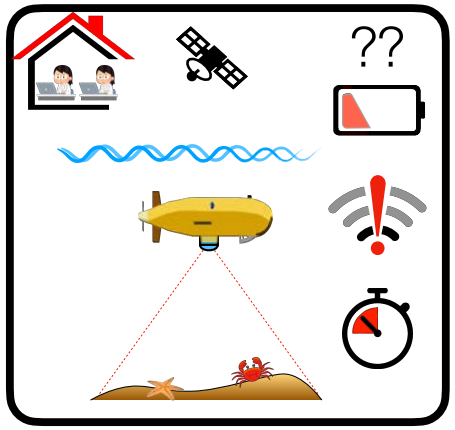


Online (remote)

Scalable operations under constraints?

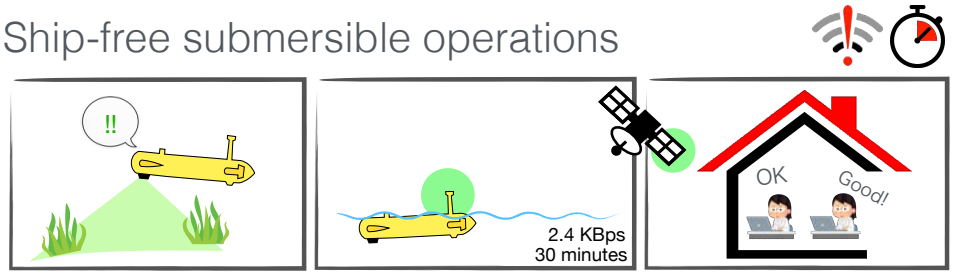


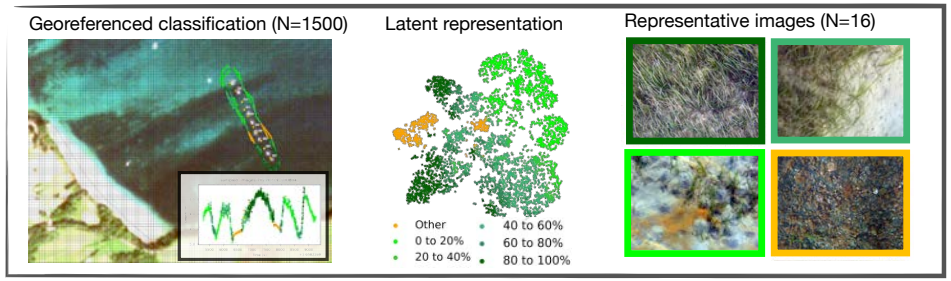
Surface: Established



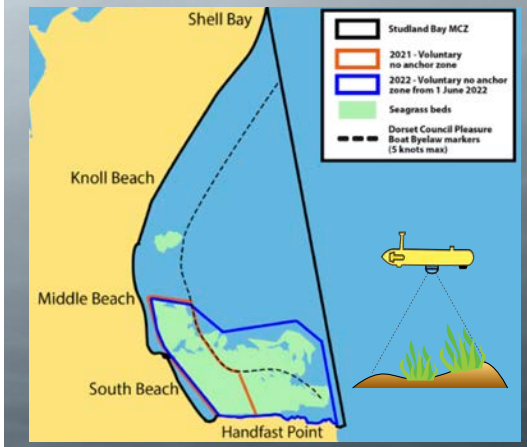
Underwater: Challenges

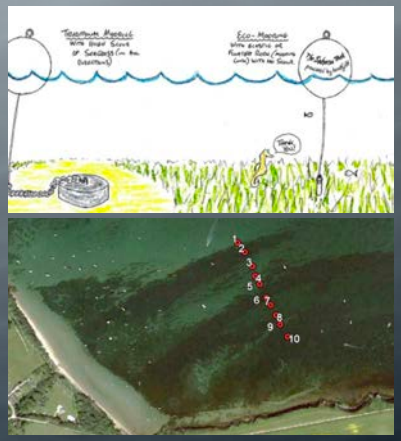
Ship-free submersible operations





Remote awareness over satellite bandwidths

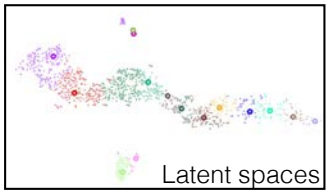


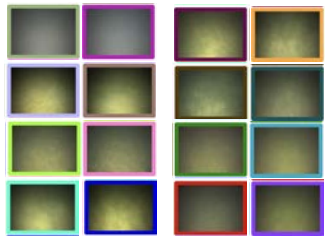


Remote awareness over satellite

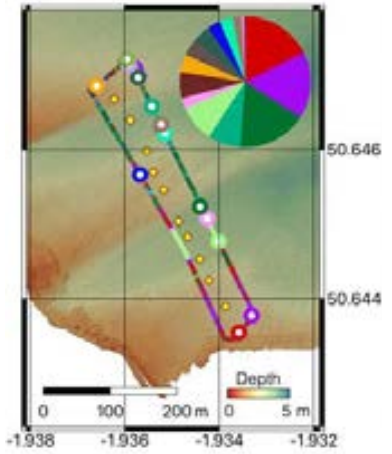
140GB summerised into 102kB (8min at 1.9kBit/s)

Imaging Survey	
Images acquired	4,007
Distance travelled	1.04 km
Duration	1 h 7 min
Raw image dataset size	140 GBytes
On-line Summary Generation	
Latent representations	1500
Pre-processing & encoding	10 min 33 s (0.42 s/image)
Representative images	16
Rep. image ID & BPG compression	48 s (3 s/image)
Total time to generate summary	11 min 20 s
Summary Transmission	
Iridium SBDs (Latents: Rep. images)	51 (35:16)
Time to transmit summaries	~17 min
Transmitted data size	102 kBytes





Representative images



Remote awareness over satellite

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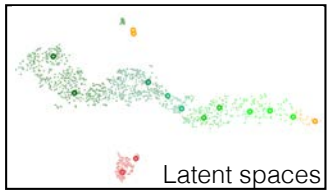
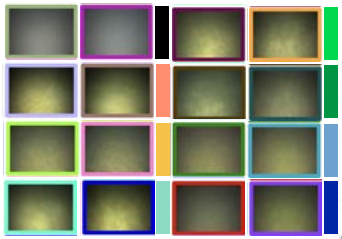
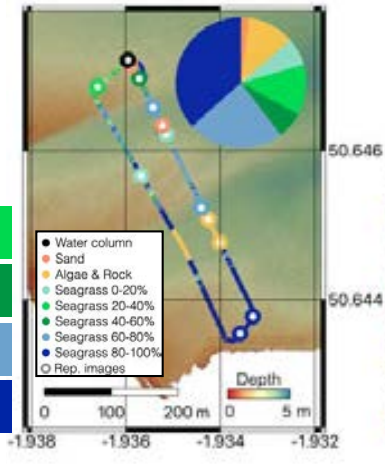




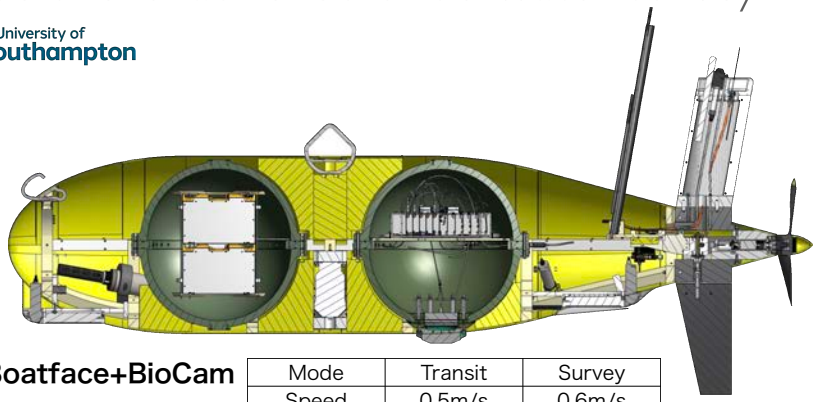
Representative images



Ship-free shore launched underwater survey

National Oceanography Centre

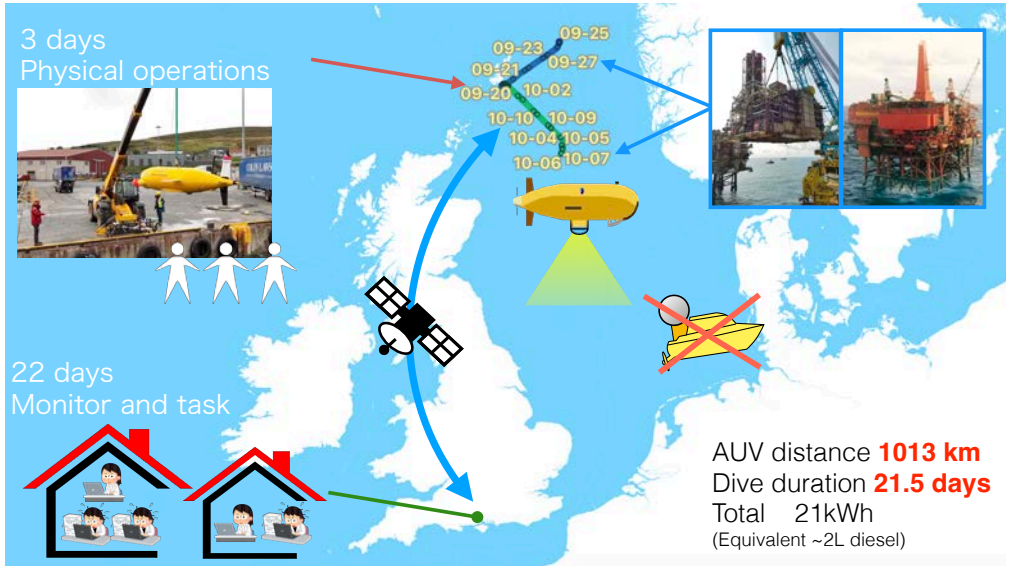
University of Southampton



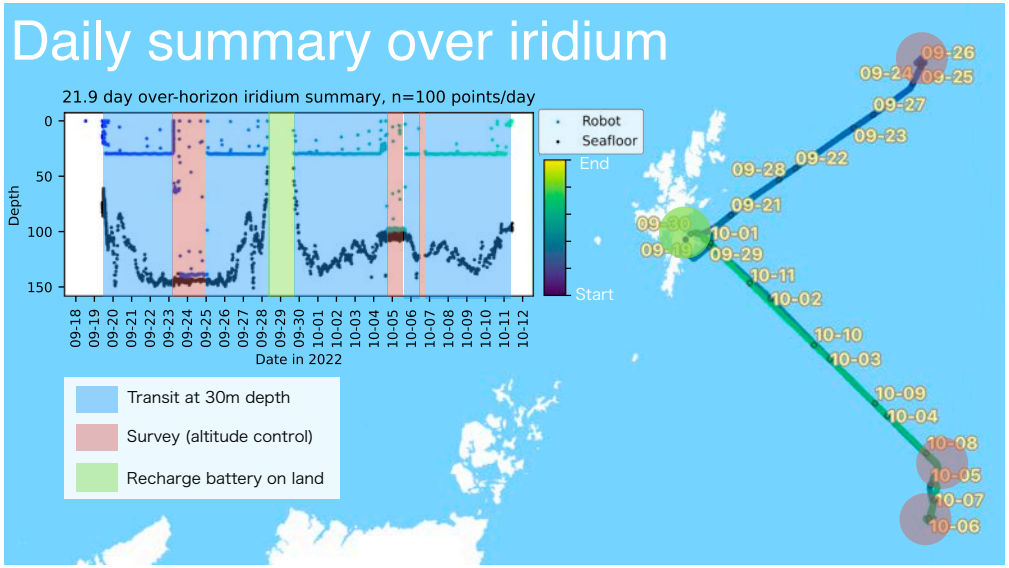
Boaty McBoatface+BioCam

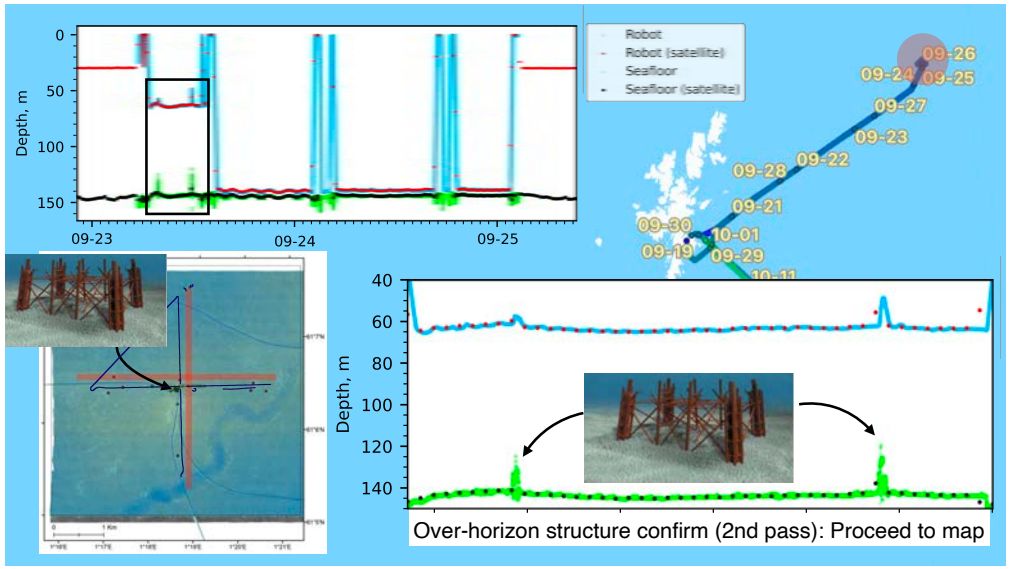
Mass: 770kg
Depth: 4500m
Energy: 13.8 kWh
Forward Avoidance

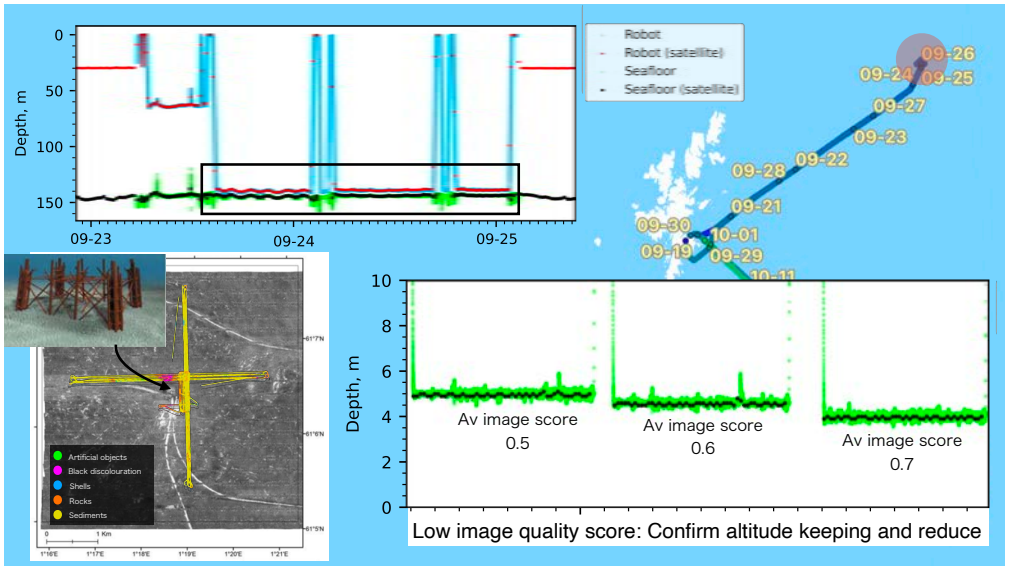
Mode	Transit	Survey
Speed	0.5m/s	0.6m/s
Range	880km	290km
Endurance	21days	6days
Vertical	30m depth	5m altitude

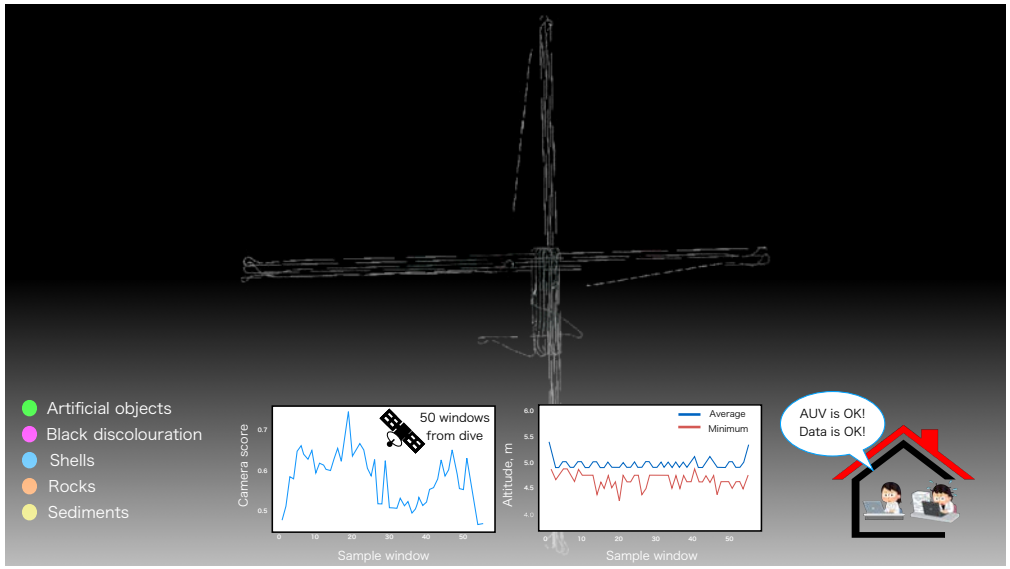


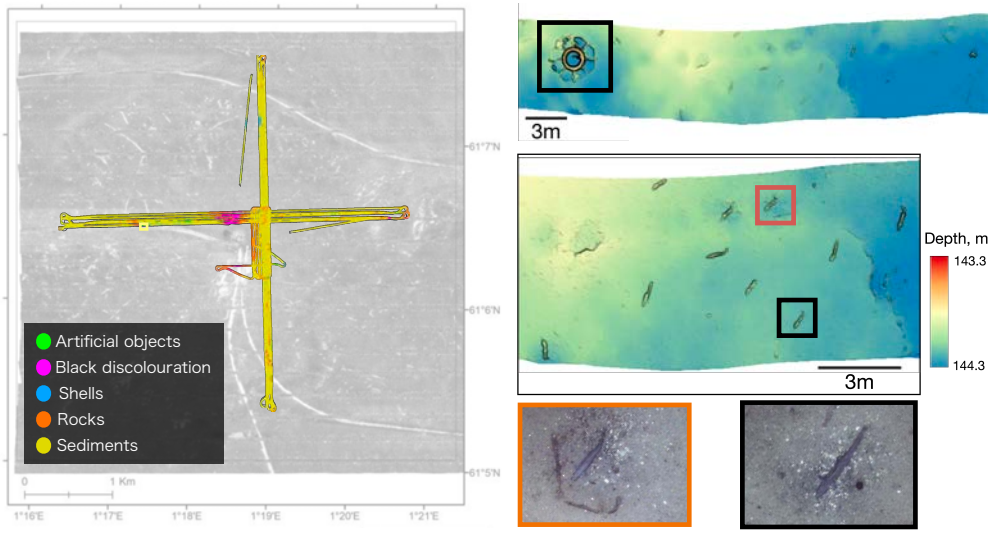
Daily summary over iridium

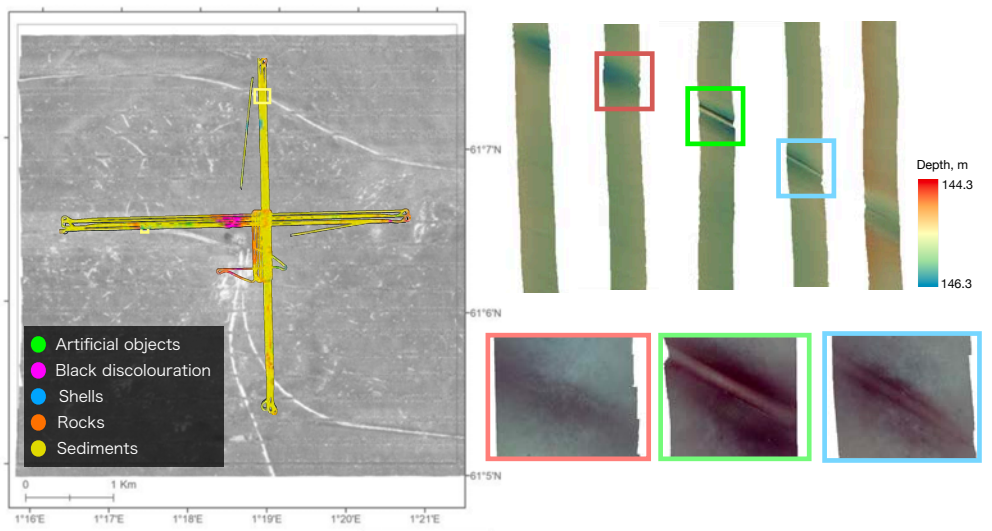



Depth, m
0
50
100
150
09-23
09-24
09-25
Robot
Robot (satellite)
Seafloor
Seafloor (satellite)
09-26
09-24
09-25
09-27
09-23
09-28
09-22
09-21
09-30
10-01
09-19
09-29
10-11
Depth, m
40
60
80
100
120
140
Over-horizon structure confirm (2nd pass): Proceed to map

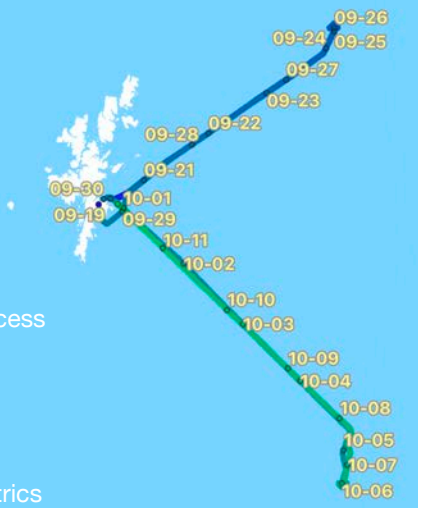

Depth, m
0
50
100
150
09-23
09-24
09-25
Robot
Robot (satellite)
Seafloor
Seafloor (satellite)
09-26
09-24
09-25
09-27
09-23
09-28
09-22
09-21
09-30
10-01
09-19
09-29
10-11
Artificial objects
Black discolouration
Shells
Rocks
Sediments
Depth, m
10
8
6
4
2
0
Av image score
0.5
Av image score
0.6
Av image score
0.7
Low image quality score: Confirm altitude keeping and reduce


Artificial objects
Black discolouration
Shells
Rocks
Sediments
50 windows
from dive
Camera score
Sample window
Average
Minimum
Altitude, m
Sample window
AUV is OK!
Data is OK!

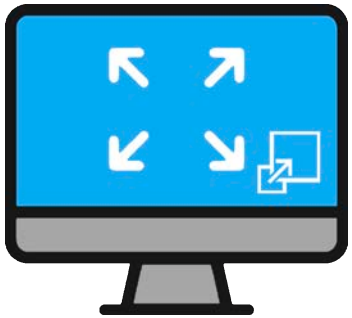

Artificial objects
Black discolouration
Shells
Rocks
Sediments
3m
3m
Depth, m
143.3
144.3

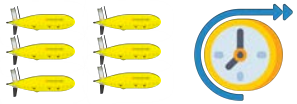


Ship-free operations



- 21+day, 1013km shore launch AUV mission success
- Total 21.4 kWh (~2L diesel) instead of 60,000L
  - ➡ 813km transit (14days, 15.0kWh 70% tot.)
  - ➡ 200km survey (4days, 6.4kWh 30% tot.)
- Over-horizon awareness and re-tasking demonstrated based on data quality control metrics



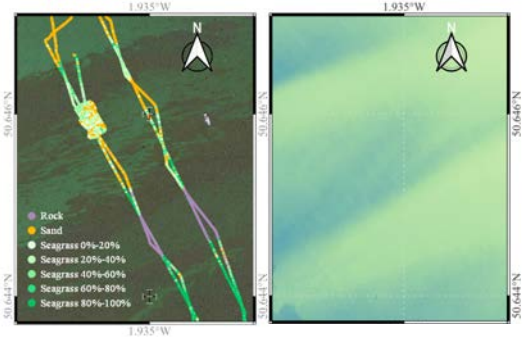


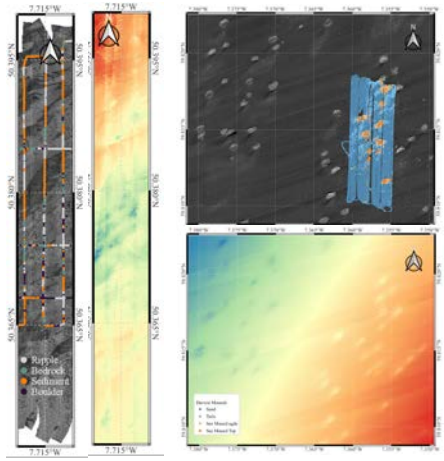
Still talking about

- small numbers of slow robots
- in a big ocean

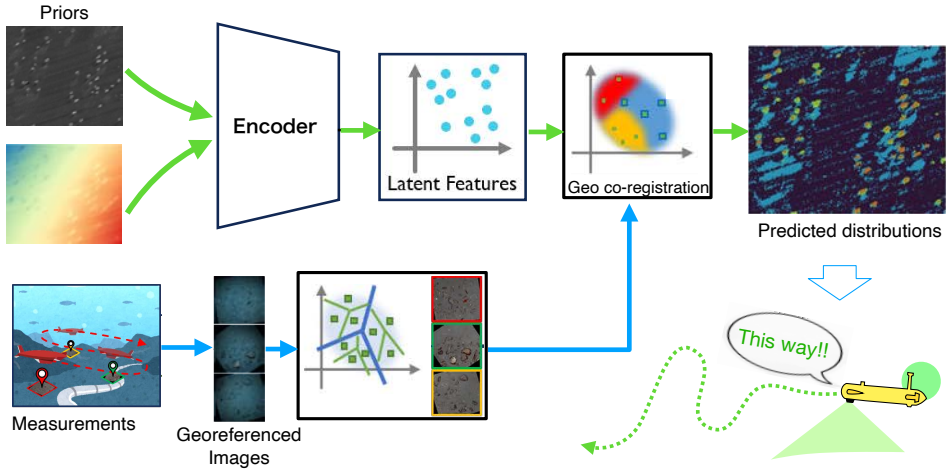
Resolution and cover tradeoffs between modalities

	Darwin Mounds	Studland Bay	Haig Fras
SSS	0.2	/	0.2
MBS	1	/	/
Bathymetry	1	2	4
Satellite images	/	3	/
Aerial images	/	0.34	/

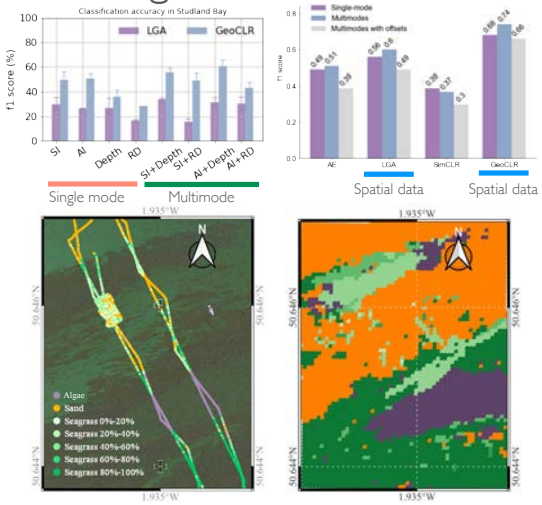


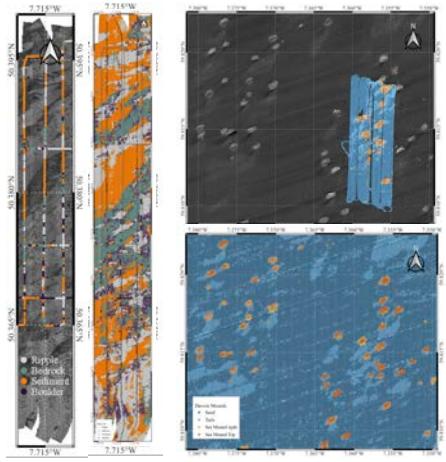


Inferring visual classes onto multimodal priors



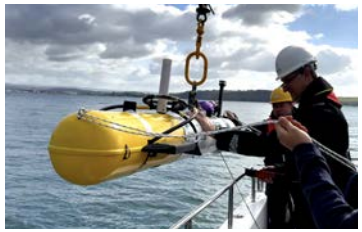
Inferring visual classes onto multimodal priors

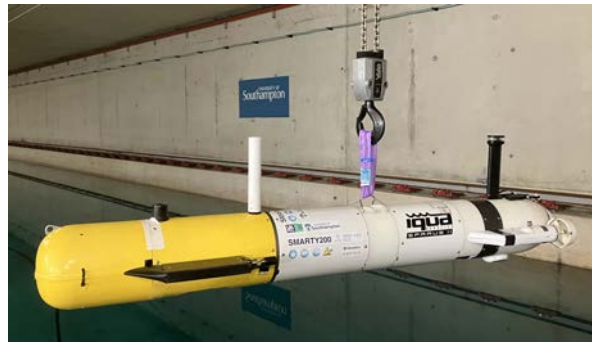




Analytics into observation feedback

- Machine assisted data interaction for rapid, flexible summary and interpretation for quality control & planning
- Robust intelligence together with platform endurance scalable and sustainable acquisition
- Predicting observations onto priors for intelligent route planning and wide area understanding





https://oceanperception.com