The Rise of Satellite-Derived Bathymetry

International SDB Day

Mooloolaba Beach, May 14th, 2019

EOMAP
Germany, Australia

Let there be light

Aquatic parameters modulate the sunlight reflected from a water body.

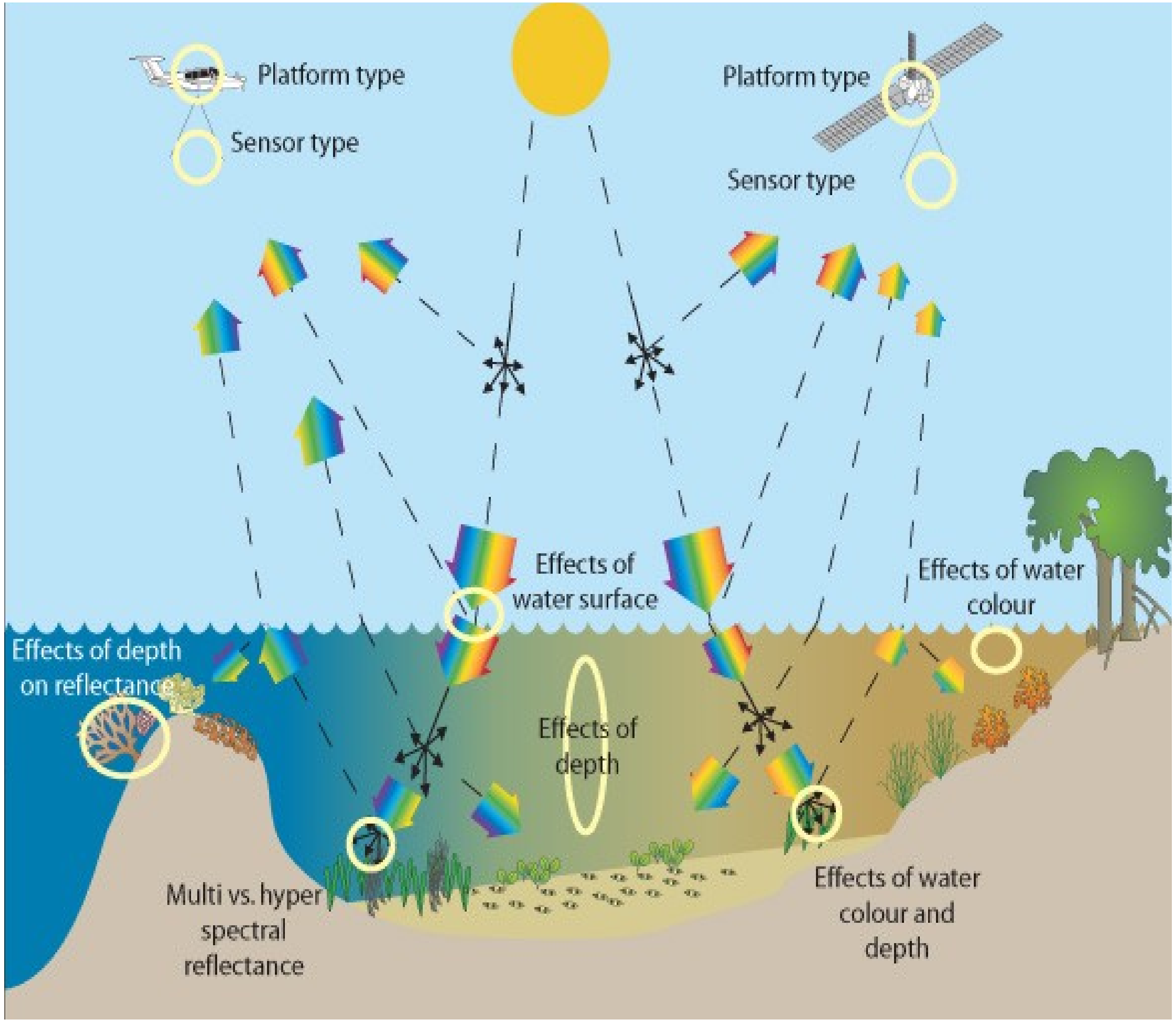
Describe the modulation correctly and you can estimate the parameters.

Let there be light

Aquatic parameters modulate the sunlight reflected from a water body.

Describe the modulation correctly and you can estimate the parameters.

Simple.



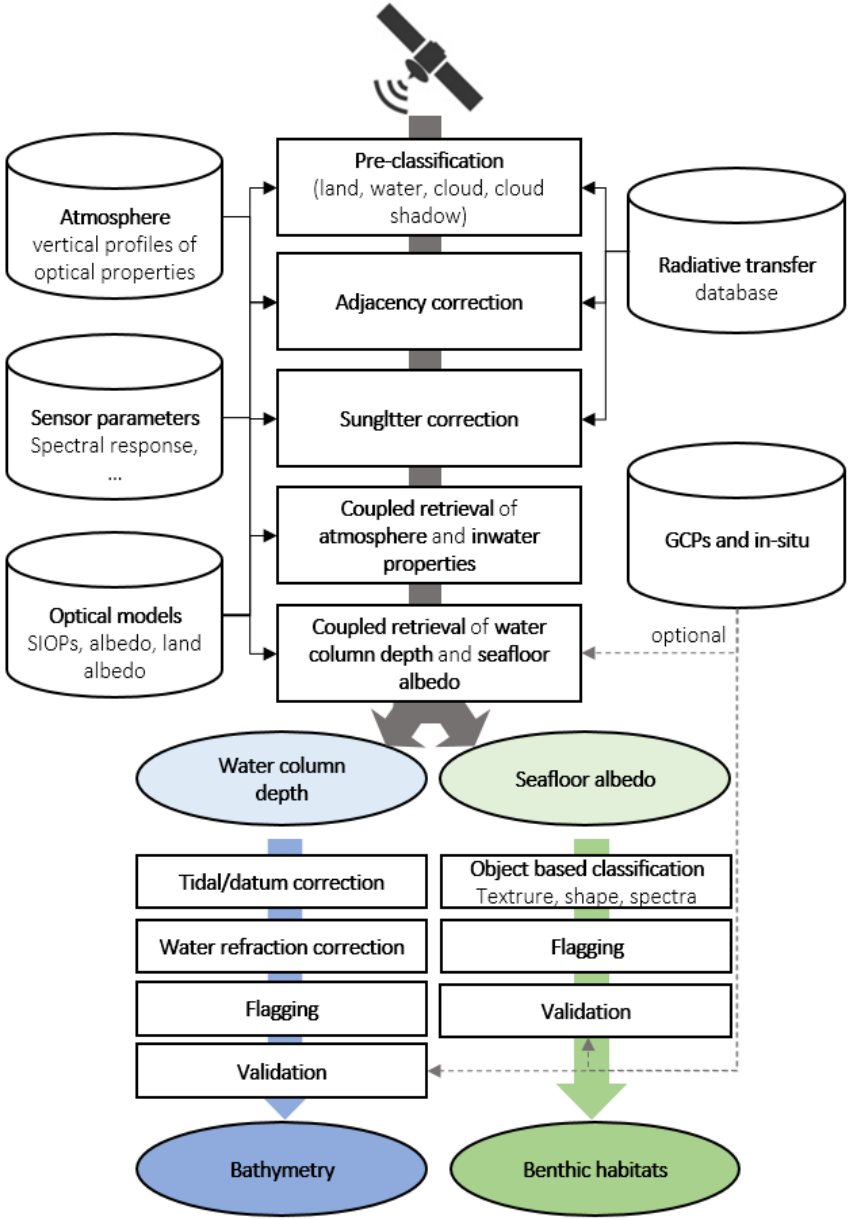
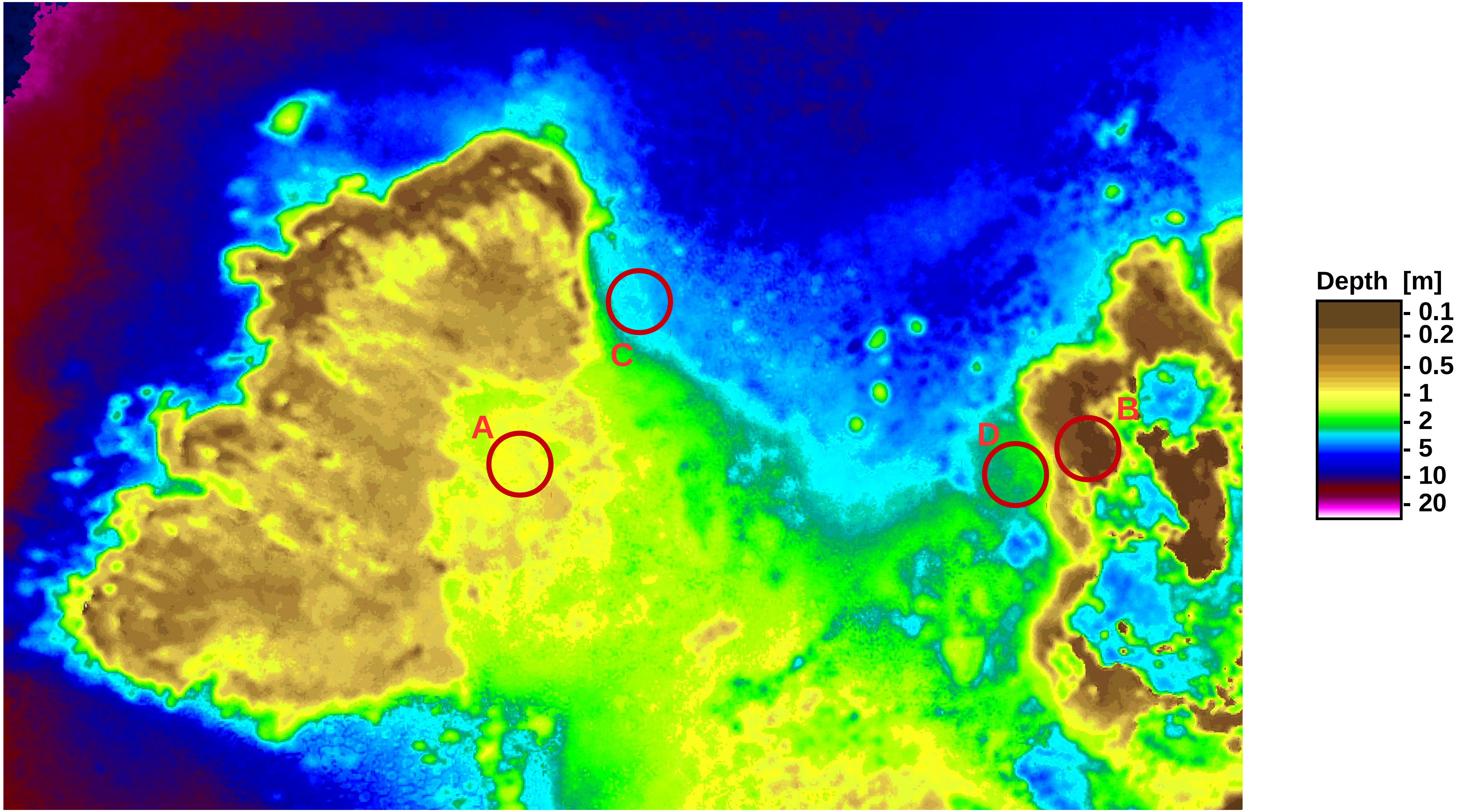


 Image courtesy of the Centre for Spatial Environmental Research, University of Queensland

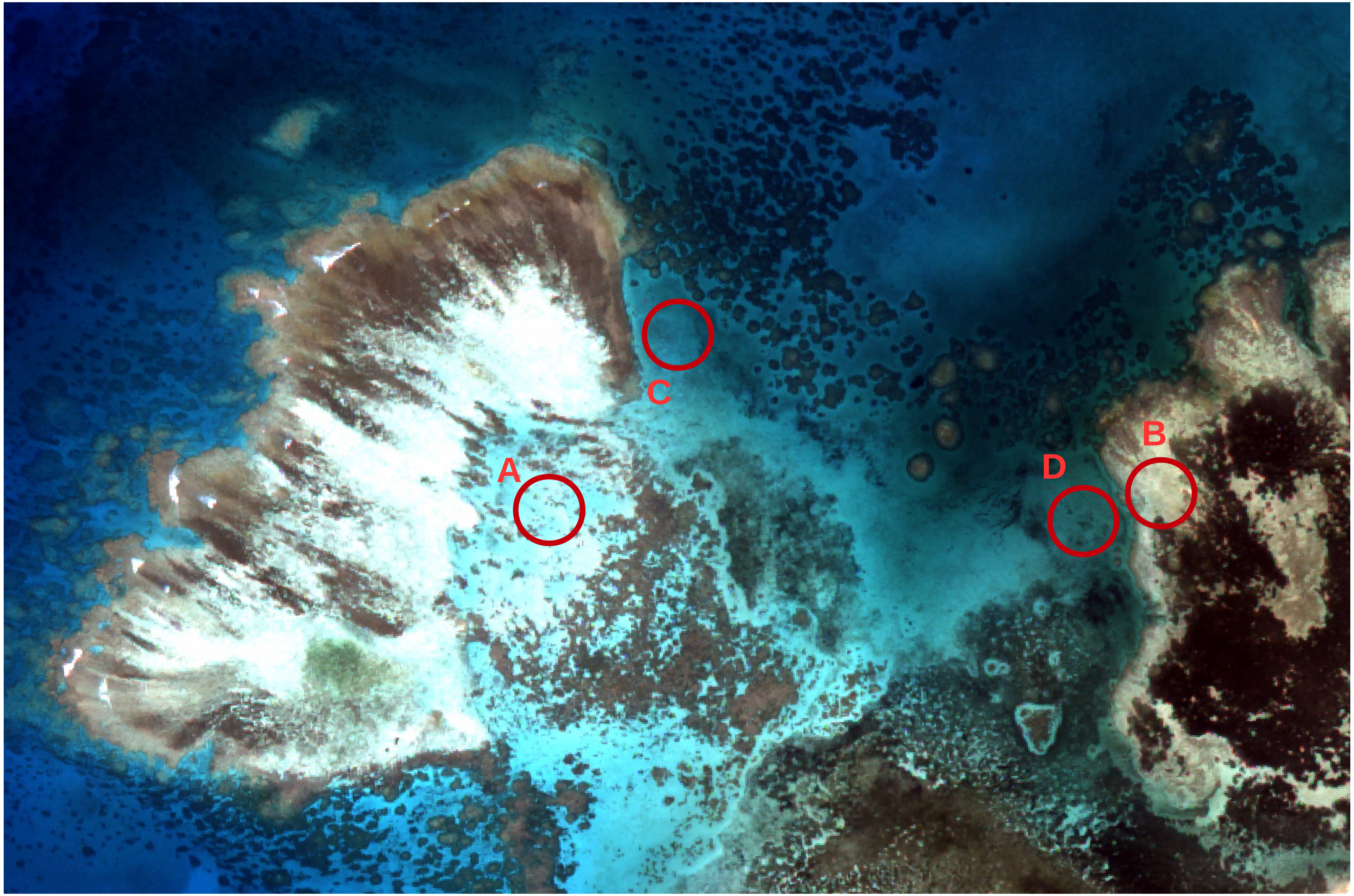

C
A
B
D

B
A
D
C



EOMAP

B
A
D
C



Origins of SDB - 1

Empirical methods

Lyzenga (1985), Clark et al (1987), Jupp (1988), Philpot (1989), Luczkovich et a1 (1993), Dustan et al, (2001), Stumpf et al (2003), …

1) Depth data <u>required</u> a priori
2) Works for given sensor and given scene
3) Most popular: multiple linear regression

Modern implementations:
GEBCO Cookbook, Beaman et al, Fugro

Origins of SDB -2

Radiative Transfer in the water column

Gordon et al (1975), Jerlov (1976), Morel and Prieur (1977), Aas (1987), Philpot 1987, Kirk (1983), Walker (1994), Mobley (1994)………. Dekker et al 2001

$$\mu\frac{dL(\mathbf{s})}{dz} = -cL(\mathbf{s}) + b\int_{\Xi} L(\mathbf{s}')\tilde{\beta}(\mathbf{s},\mathbf{s}')d\Omega$$

$$K_d = \frac{a}{\overline{\mu}_d}\left(1 + r_d\frac{b_b}{a}\left(1 - \frac{r_u\overline{\mu}_d}{\overline{\mu}_u + \overline{\mu}_d}\frac{b_b}{a + kb_b}\right)\right), k = \frac{r_d\overline{\mu}_u + r_u\overline{\mu}_d}{\overline{\mu}_u + \overline{\mu}_d}$$

$$R(0-) = \frac{r_d\overline{\mu}_u}{\overline{\mu}_u + \overline{\mu}_d}\frac{b_b}{a + kb_b}, k = \frac{r_d\overline{\mu}_u + r_u\overline{\mu}_d}{\overline{\mu}_u + \overline{\mu}_d}$$

$$E_d(z) = E_d(0)e^{-K_d z}$$

$$R(0-, H) = R_\infty + (A - R_\infty)e^{-(K_d+\kappa)H}$$

$$E_u(0-) = E_u(0-)_C + E_u(0-)_B$$

$$E_u(0-) = R_\infty E_d(0-)\left(1 - e^{-(\kappa_C + K_d)H}\right) + AE_d(0-)e^{-(\kappa_B + K_d)H}$$

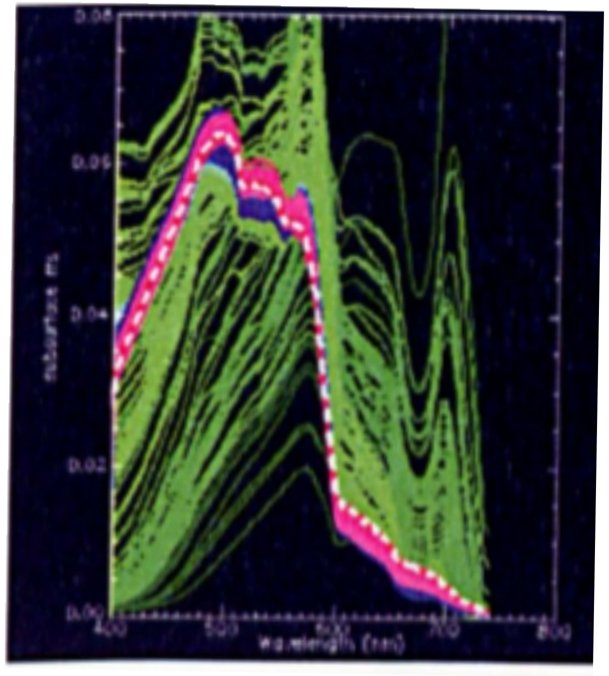
Origins of SDB - 3

Physics-based methods

Maritorena et al (1994), Lee et al, (1998-2001), Mobley (2005), ...

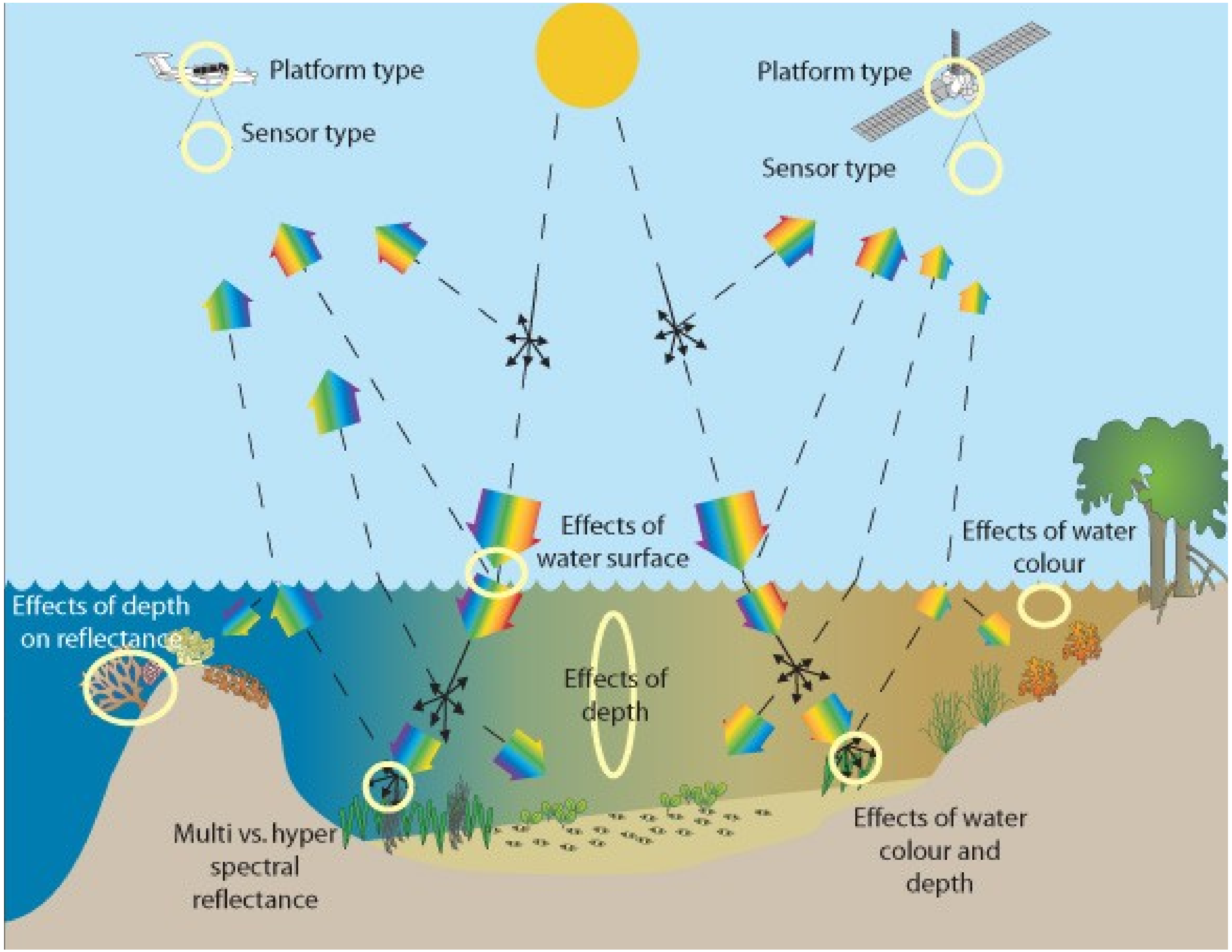
1) No data required a priori
2) Sensor agnostic, location independent
3) (semi-)analytical solutions*, Look-up-Tables**, fully physical solutions***

Modern implementations:
HOPE (Lee)*, SAMBUCA (Brando & Wettle)*, SMLUT (Mobley)**, WATCOR (EOMAP)***



A tale of two methods

	(Semi-) Empirical	Physical
Setup & investment	Easy	Sophisticated
Location independent (In situ data not necessary)	No	Yes
Uncertainties traceable (independent of in-situ data)	No	Yes
Production capability	Dependent on in-situ data	Highly automatable
Methods	Relating brightness or log-ratios to depth (e.g. Lyzenga et al. , Stumpf….)	Resolving the light transfer equation (CSIRO SAMBUCA, EOMAP WATCOR,)



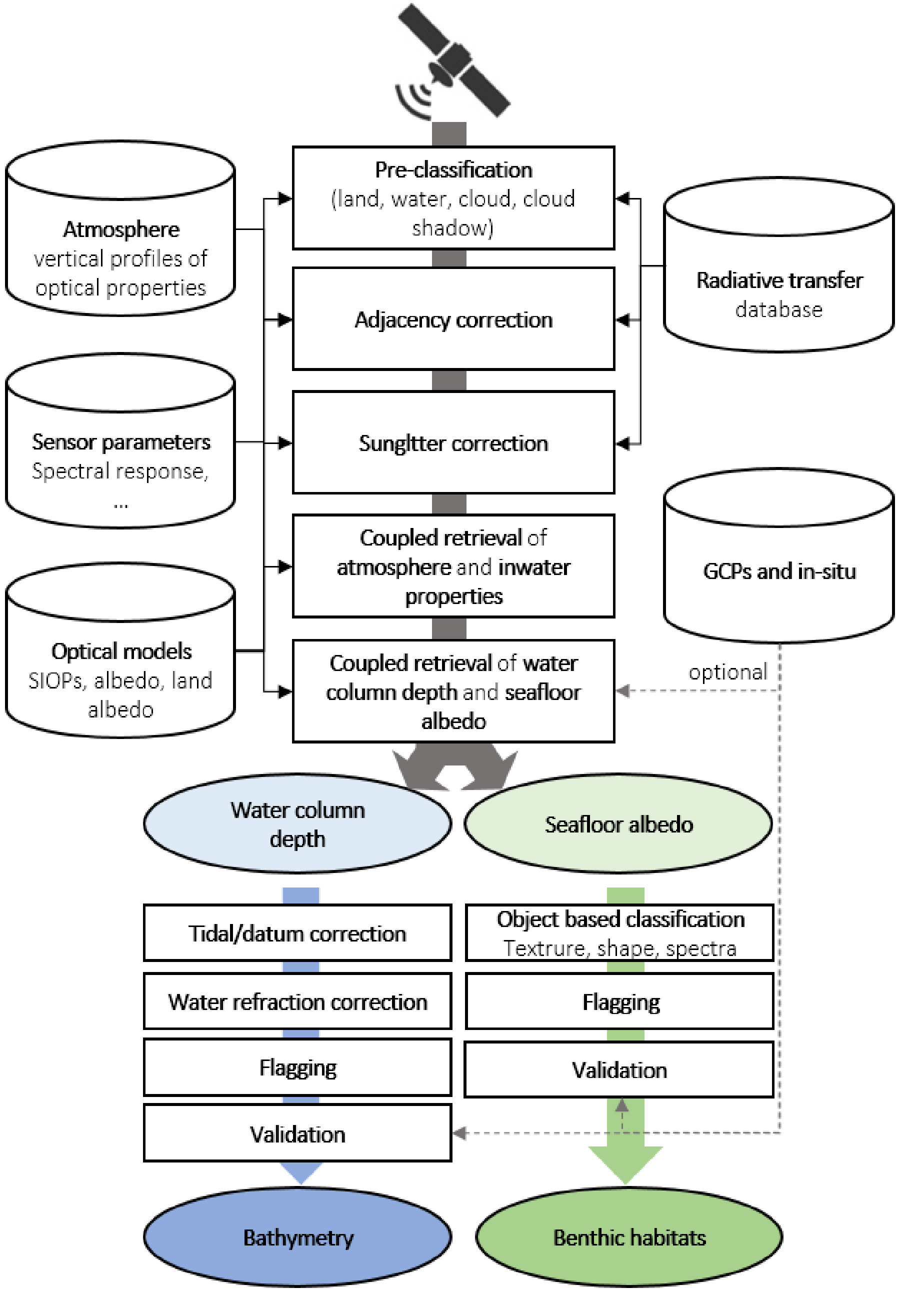
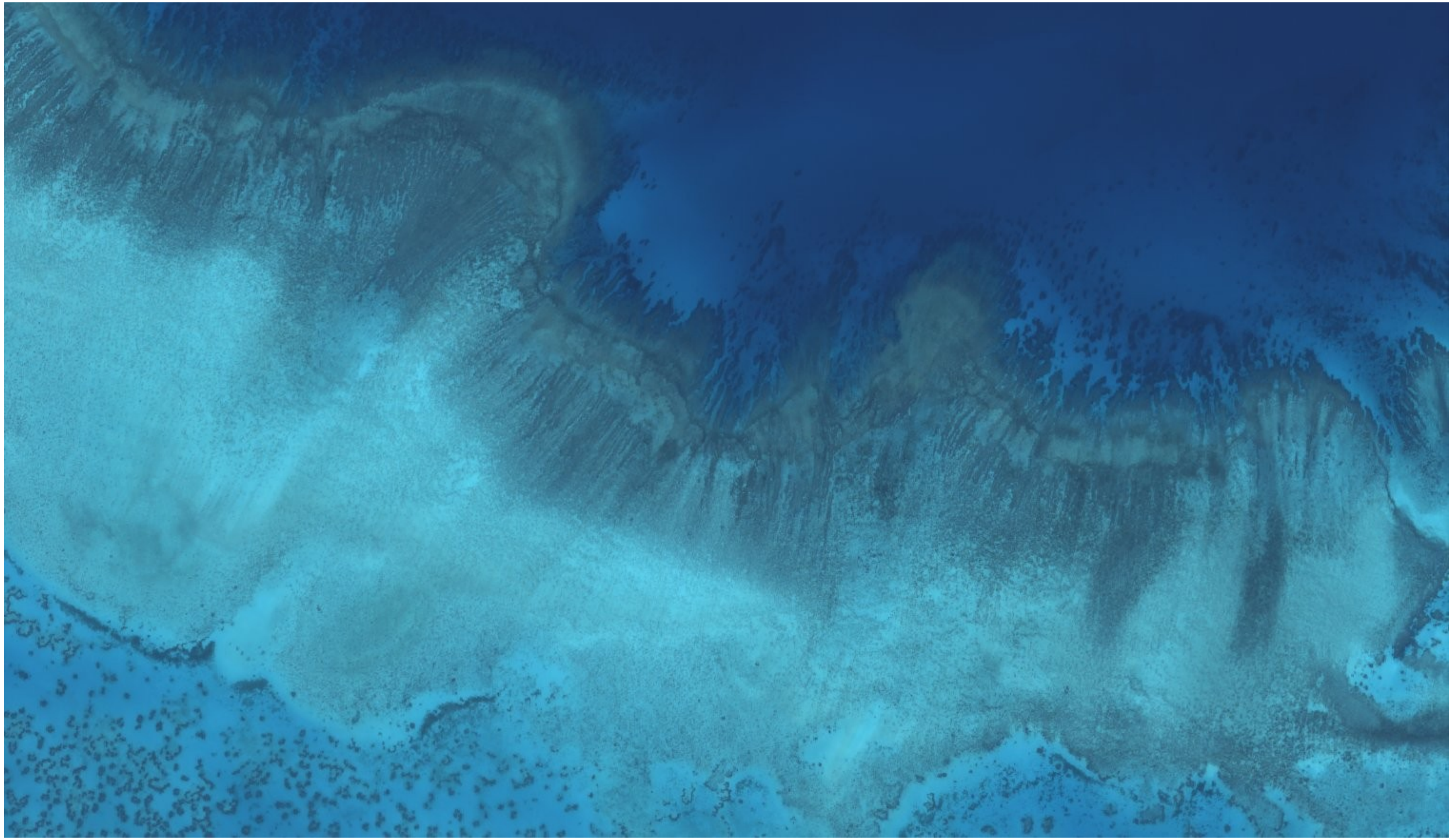


 Image courtesy of the Centre for Spatial Environmental Research, University of Queensland)

At-sensor radiance

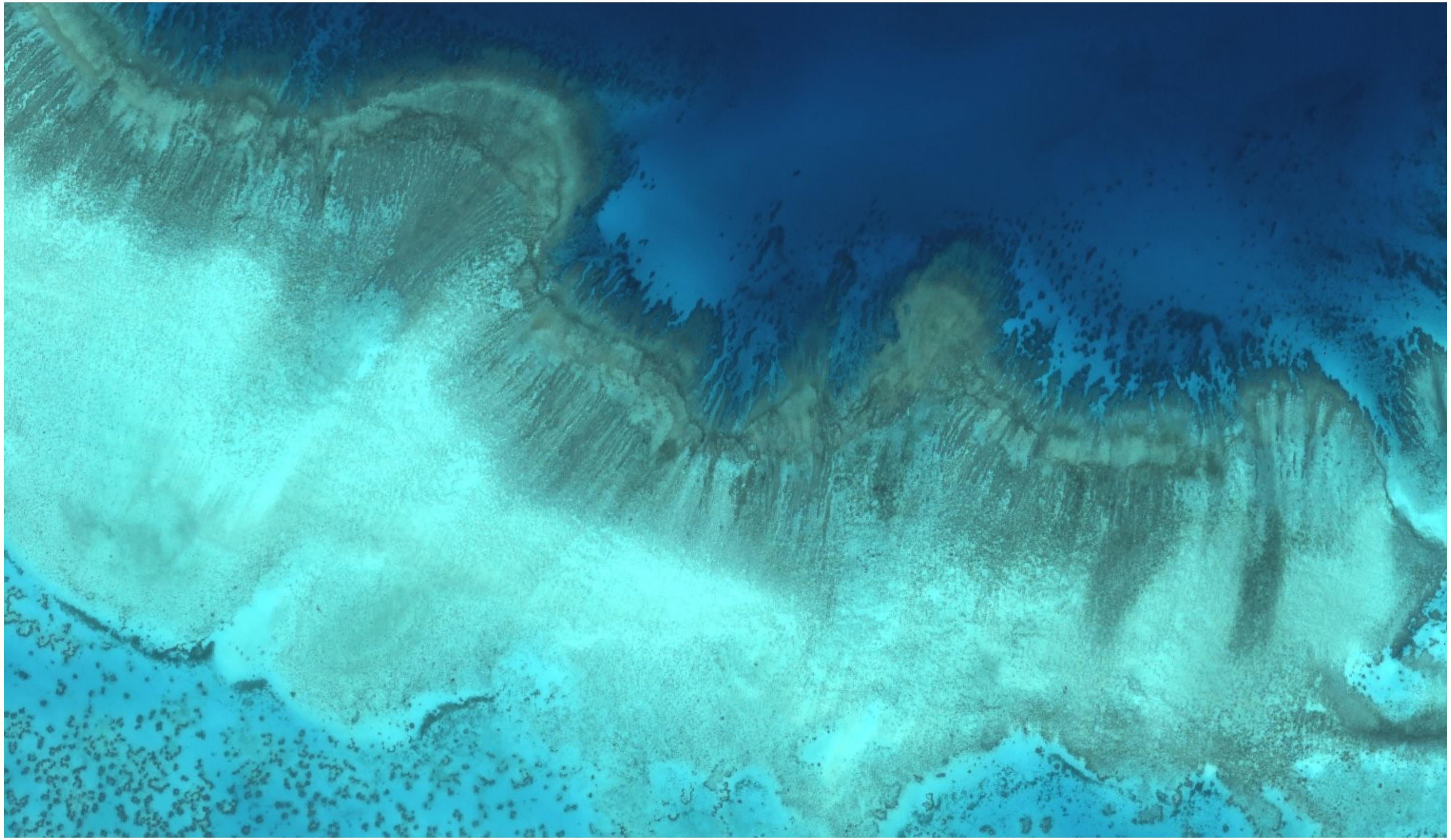


Heron Reef
Great Barrier Reef
Australia

DigitalGlobe
WorldView-2

2m resolution

Sub-surface reflectance

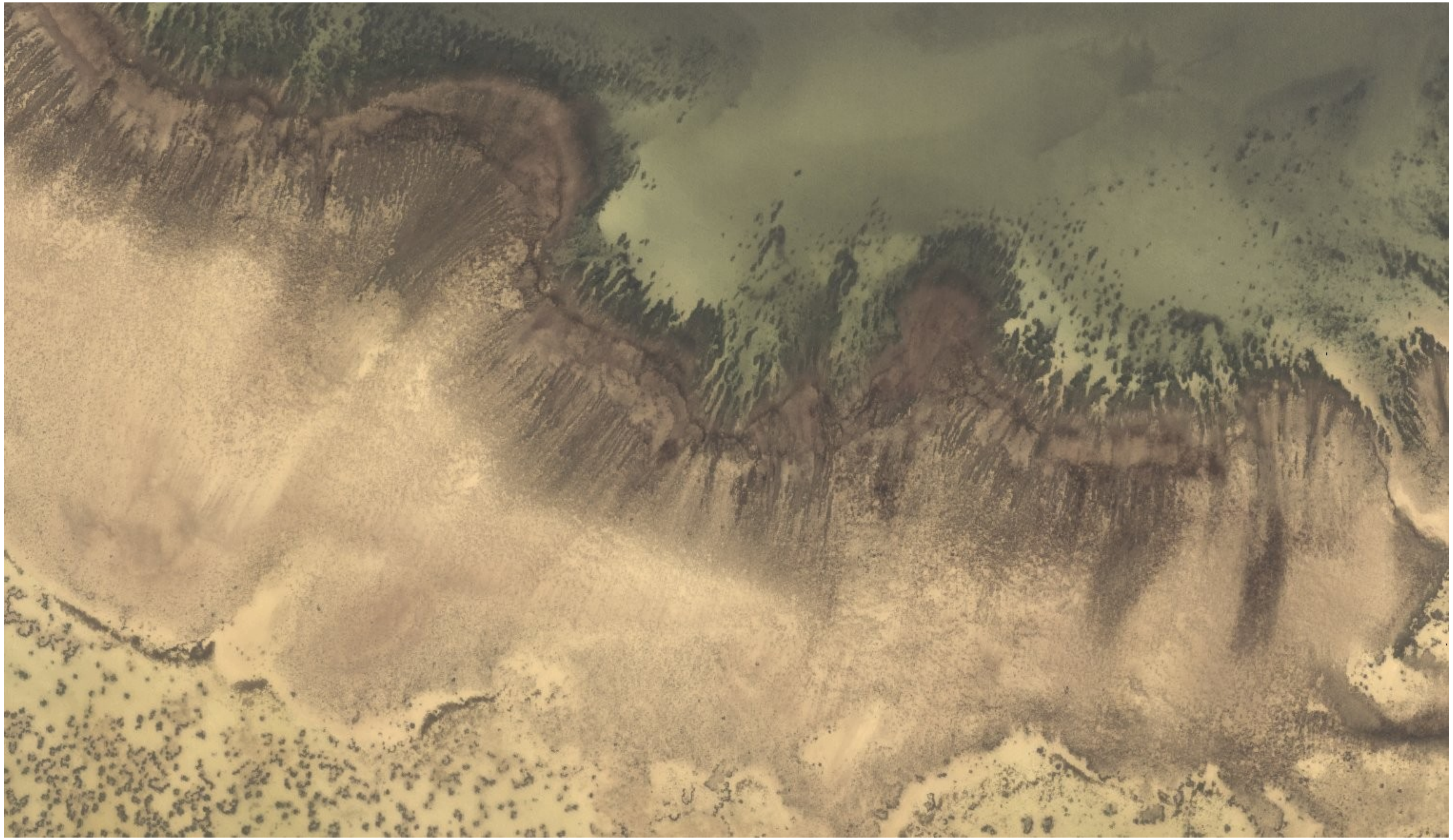


Heron Reef
Great Barrier Reef
Australia

DigitalGlobe
WorldView-2

2m resolution

Seafloor reflectance

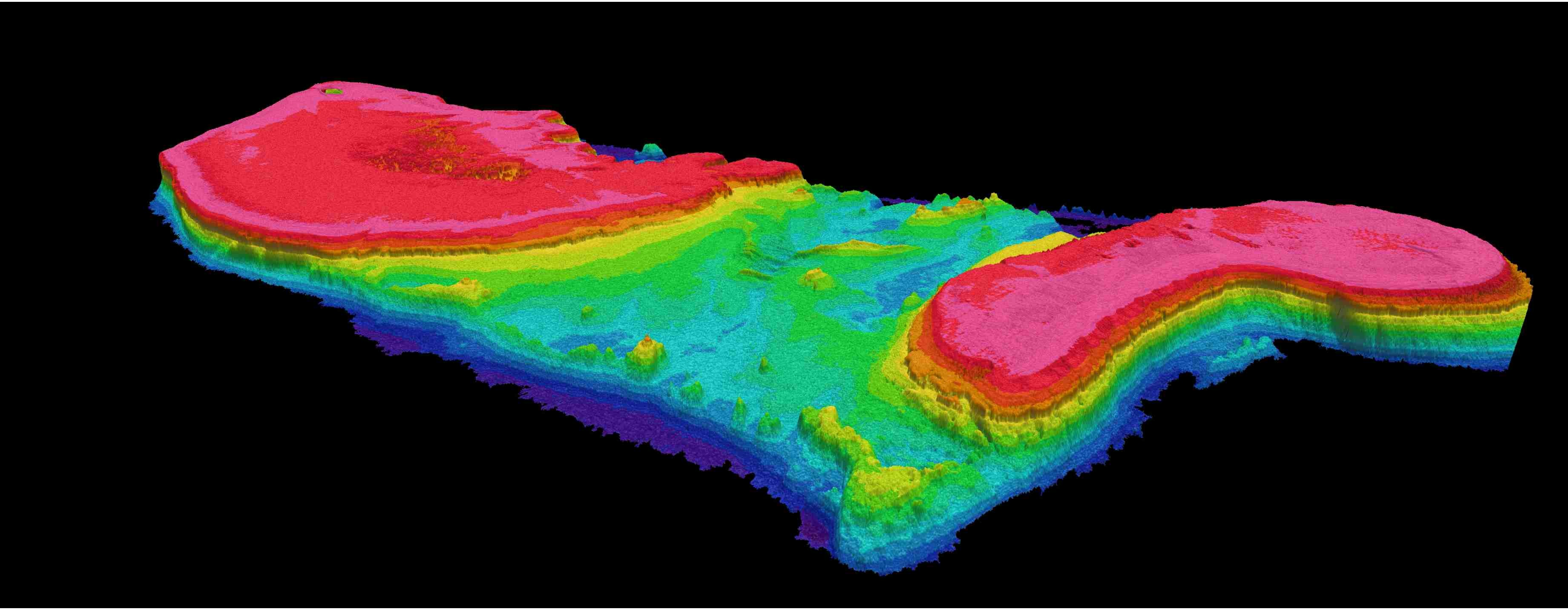


Heron Reef
Great Barrier Reef
Australia

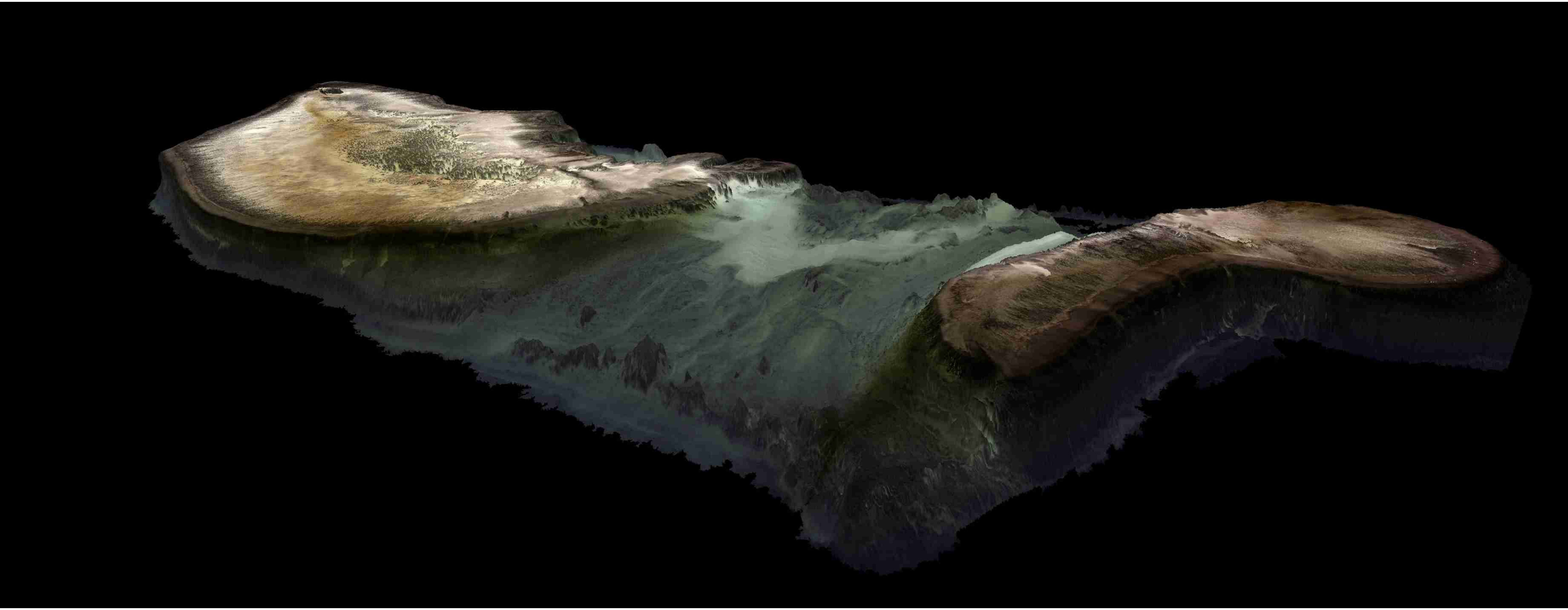
DigitalGlobe
WorldView-2

2m resolution

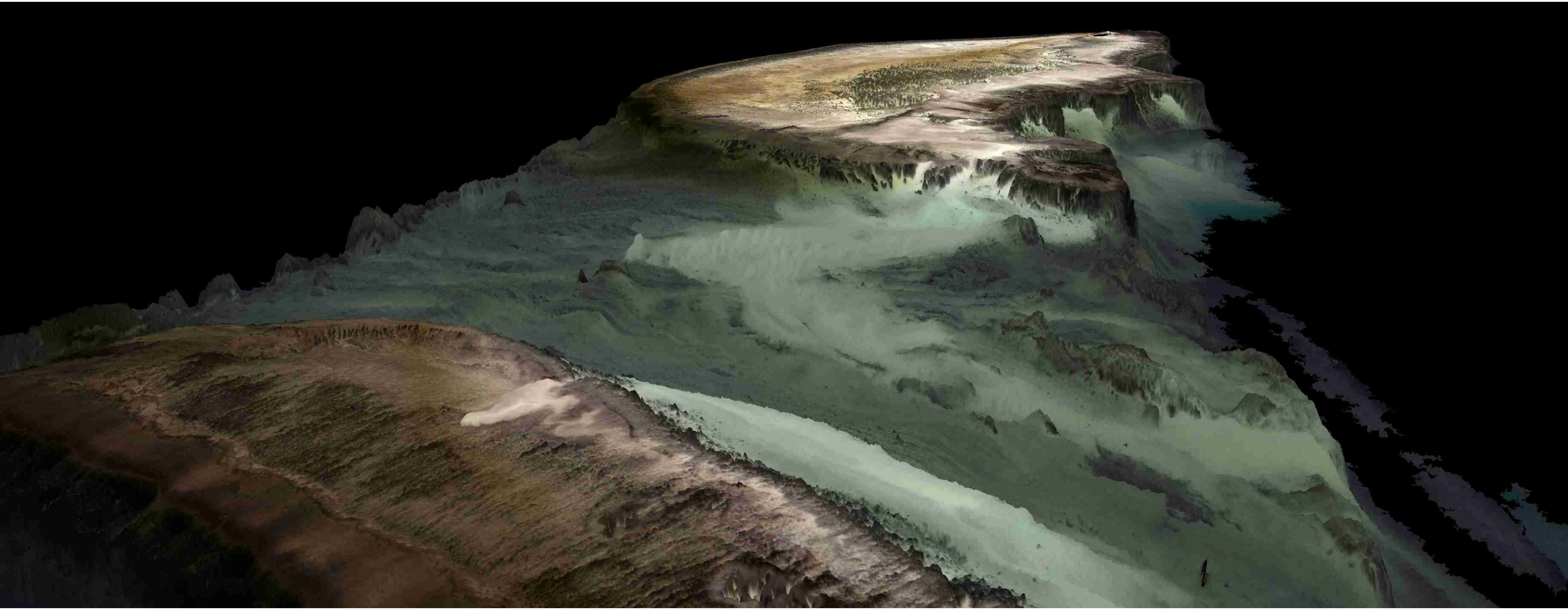
SDB of Heron and Sykes Reef, 2m resolution



Seafloor reflectance draped on SDB

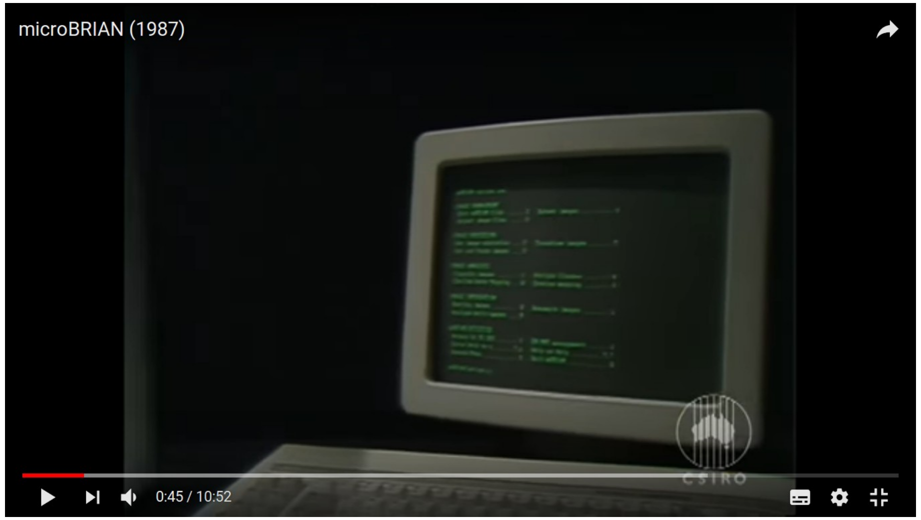


Seafloor reflectance draped on SDB



Evolution of SDB

- Empirical methods (1980’s): R&D, localised sites
MicroBRIAN: Mapping the Great Barrier Reef: depth-of-penetration

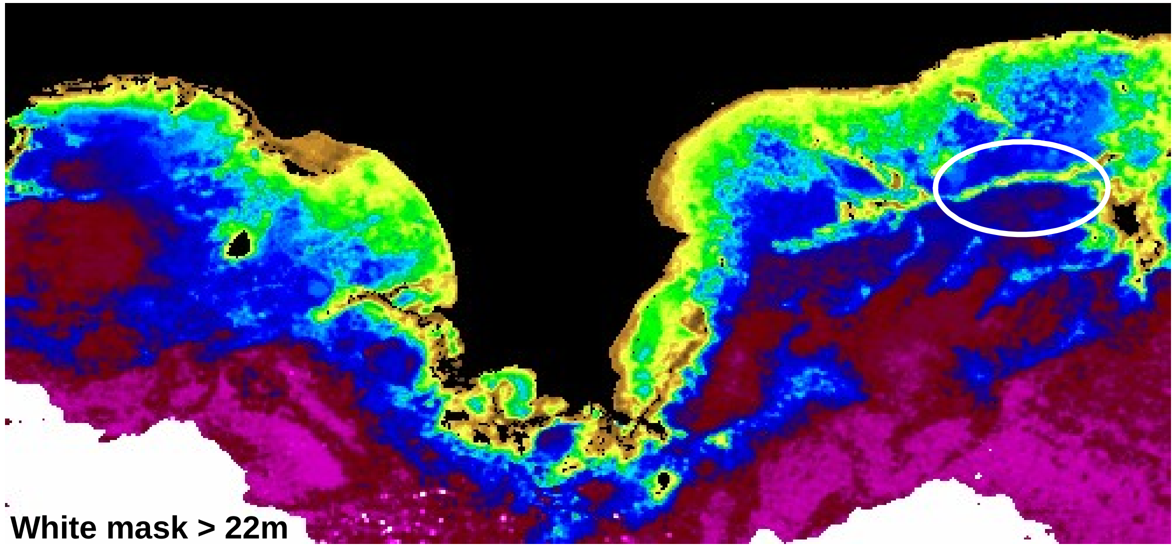


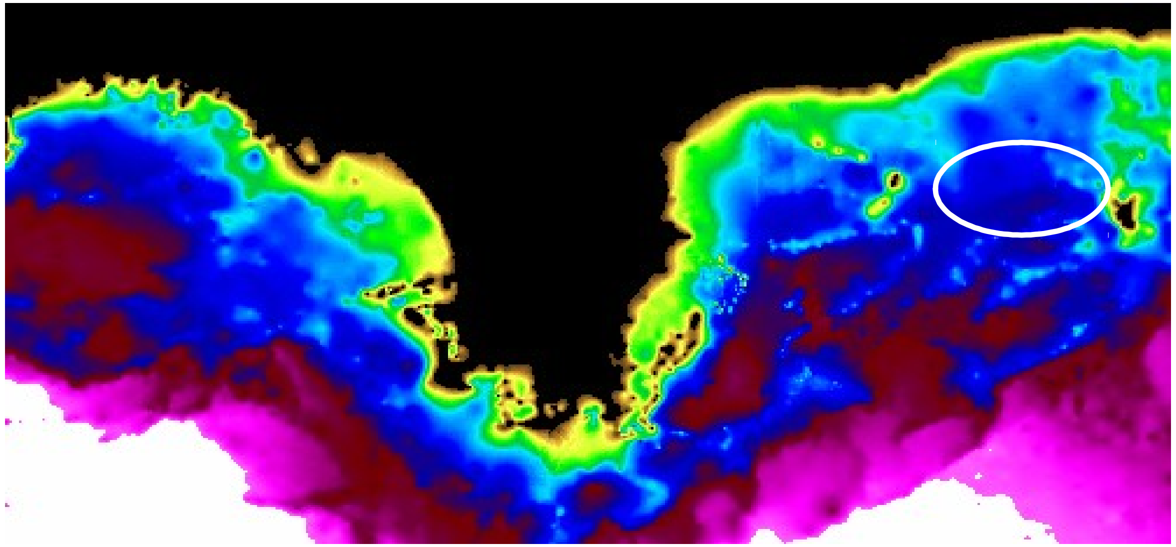
- Decades of R&D (physics-based), some over-promising, gradual uptake

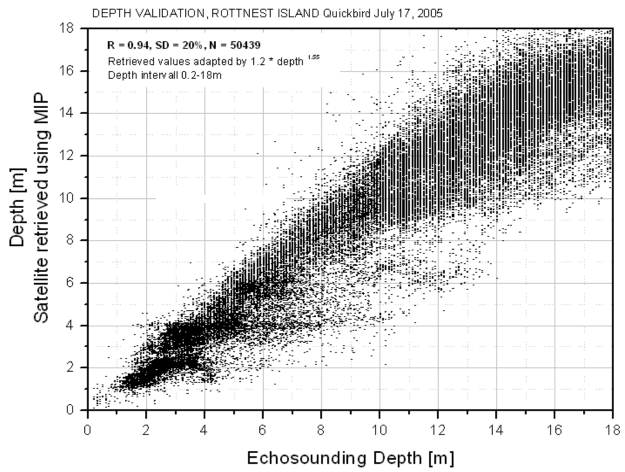
- Commercial deployments around 2005, environmental mapping applications

Evolution of SDB

Rottnest Island
QuickBird
2005

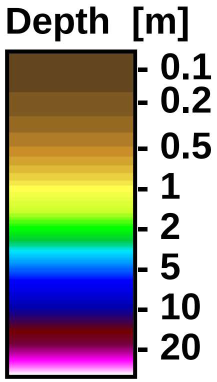






VALIDATION:
0-18m

R=0.94
SD=20%
N=50439 points

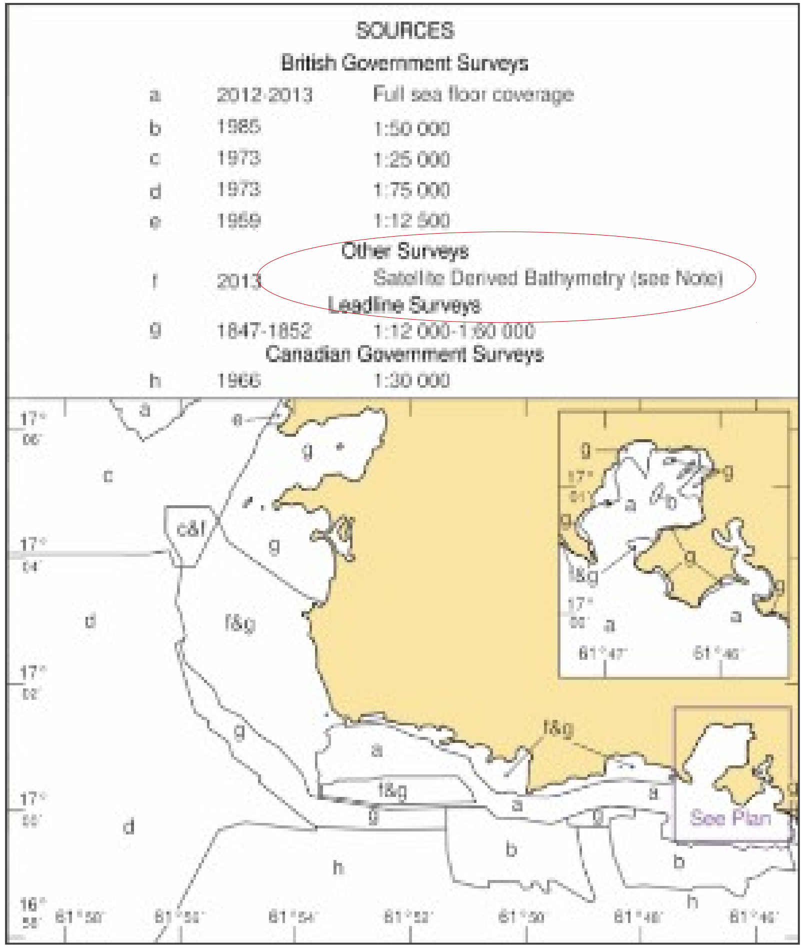


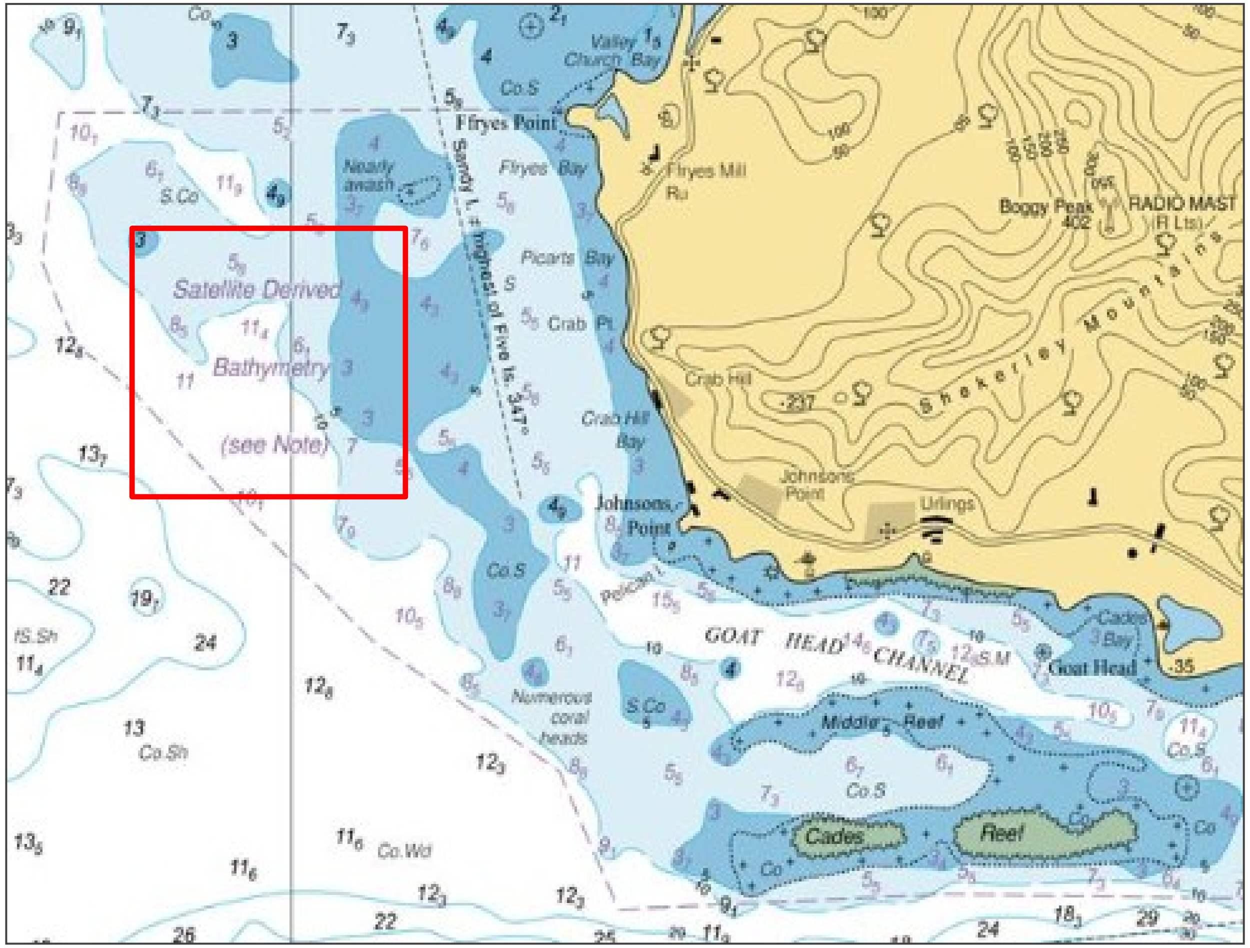
Areas deeper than 22m: white
Ellipsoid: Existing reef/shelf not detected by echo sounding measurement

Evolution of SDB

EOMAP’s SDB in chart BA2066, the first (UKHO) chart which includes SDB data

Antigua
WV-2
2015





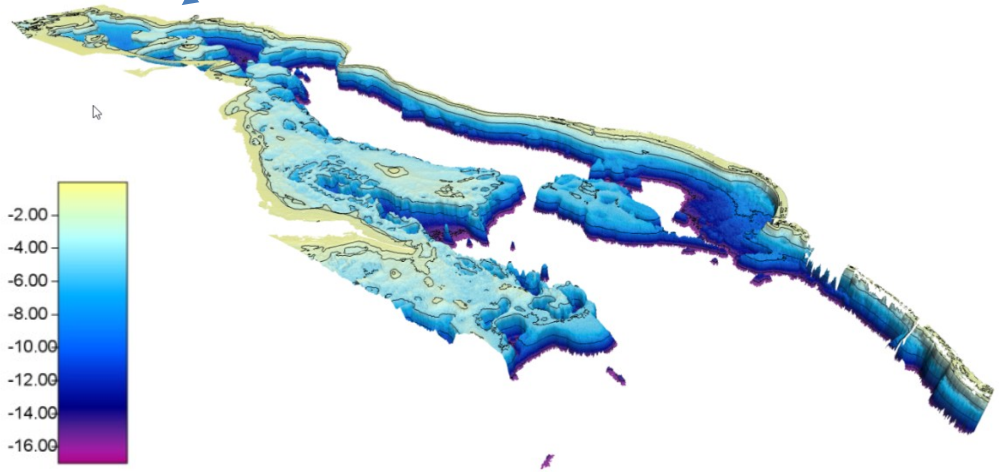
Worldwide validated Satellite Derived Bathymetry

> 75 mapping projects in more than 25 countries in the last 2 years

Example SDB – Satellite-Derived Bathymetry

Van Oord
Marine ingenuity

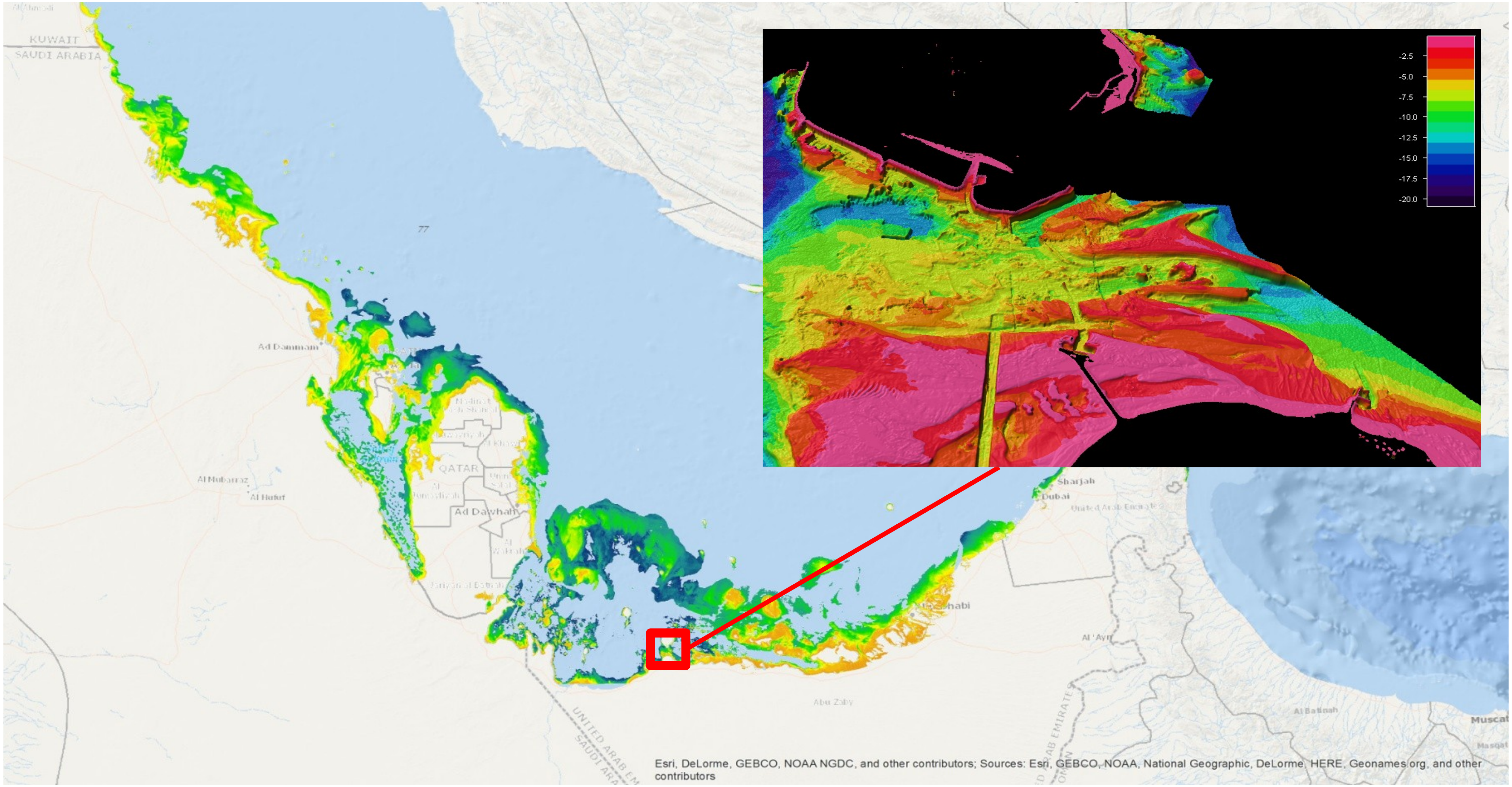
Can our csd Athena enter the area safely?



DIMENSIONS

Length over all	: 135.80 m
Breadth over all	: 27.82 m (without fendering)
Length between perpendiculars	: 108.00 m
Breadth moulded	: 27.80 m
Depth moulded	: 9.00 m
Draught - Light ship weight	: 5.62 m
Draught - International freeboard	: 6.60 m

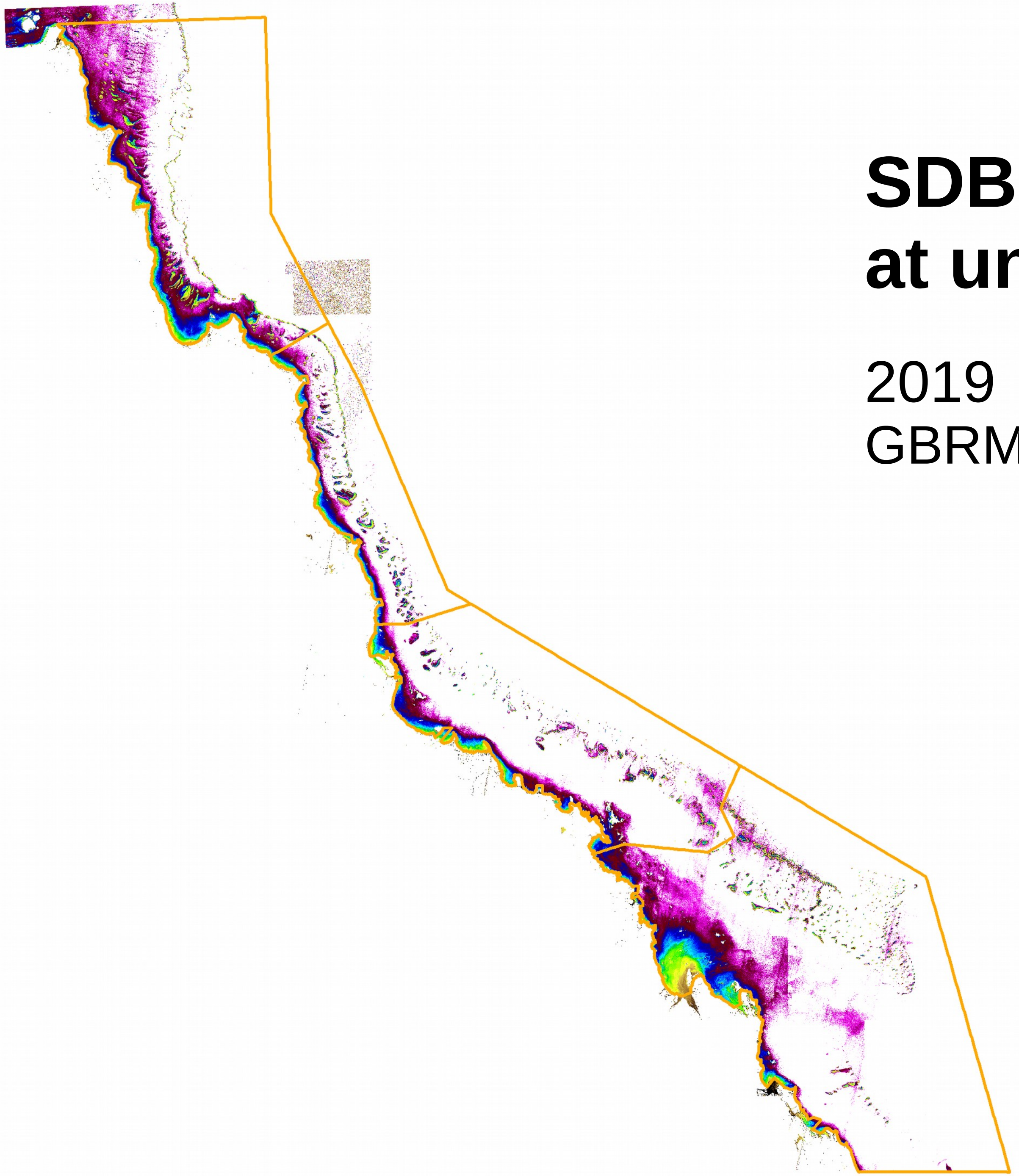
Self-propelled cutter suction dredger Athena:


KUWAIT
SAUDI ARABIA
Ad Dammam
Al Mubarraz
Al Hufuf
QATAR
Ad Dawhah
Sharjah
Dubai
Abu Zaby
Al 'Ayn
Muscat
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors; Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Rapid bathymetry and seafloor mapping on regional and national scale

EMODnet

EMODnet Bathymetry: European program of 40 hydrographic entities to provide bathymetric survey data for a European harmonized dataset



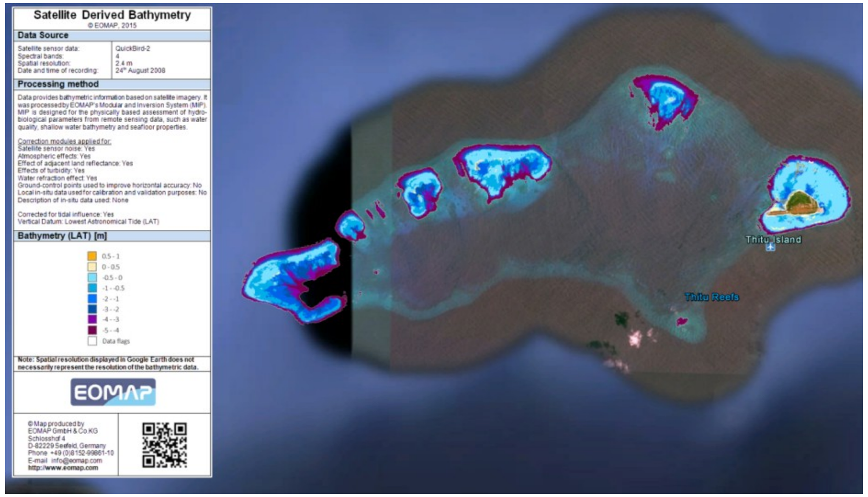
SDB of entire Great Barrier Reef at unprecedented 10m resolution

2019

GBRMPA, UQ, AIMS, EOMAP

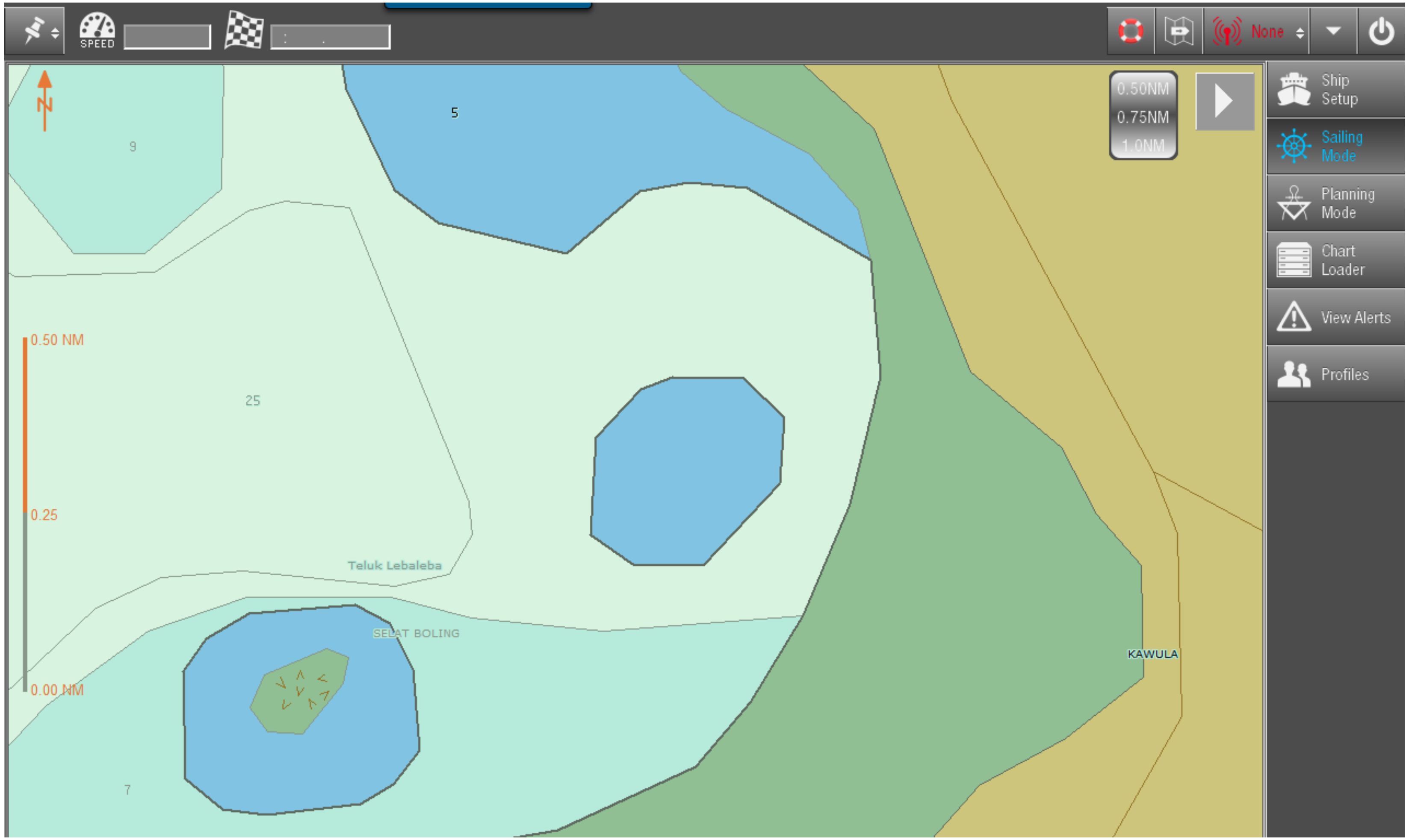
Application: Legal Evidence

South China Sea: Den Haag court case
Using Very High resolution Satellite Images for Den Haag court case



Reconnaissance survey: South Feydhoo atoll

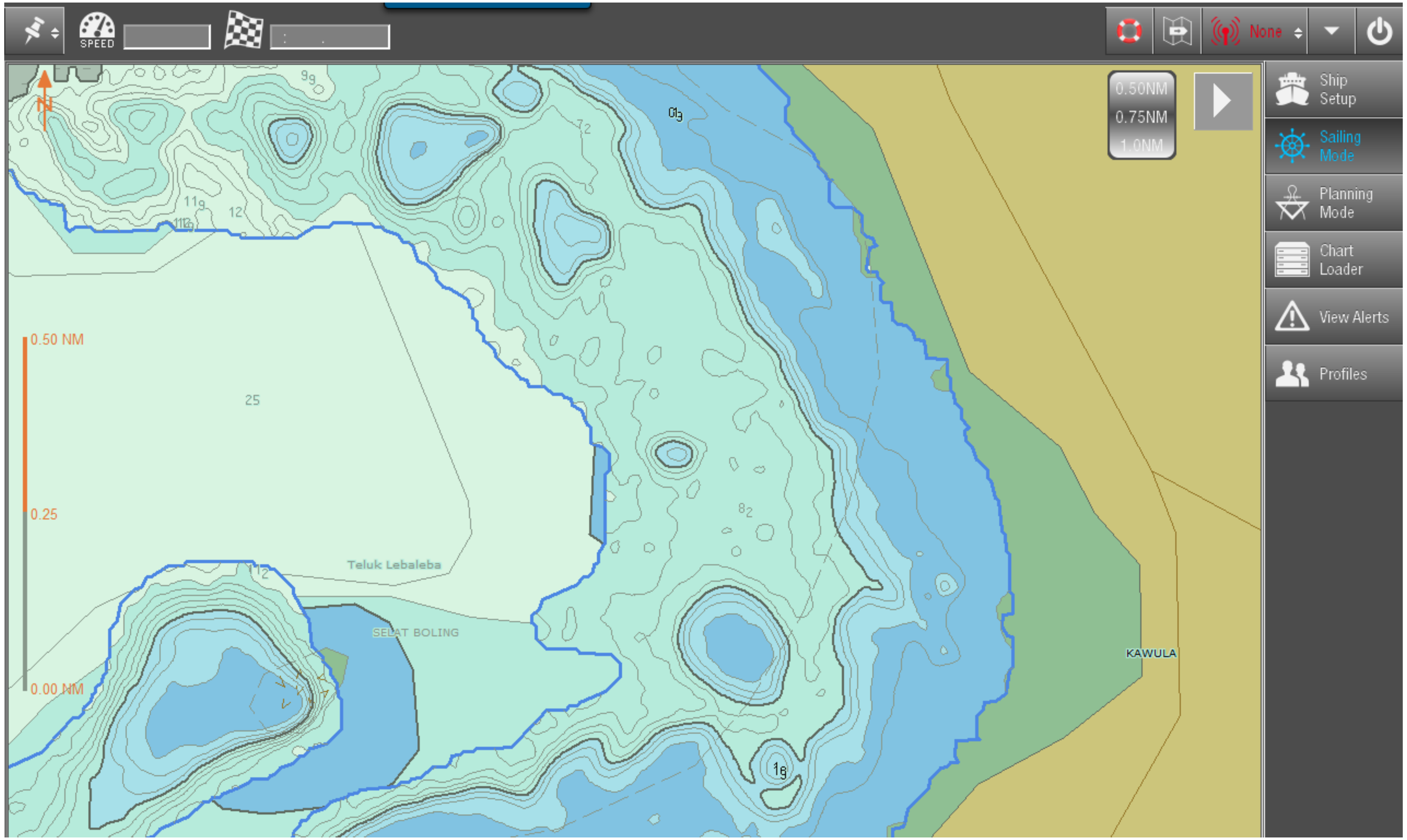
Edition 5, Update 2, Issues Date 20160310 ENC
Indonesia, Pulau L.



standard ENC

Reconnaissance survey: South Feydhoo atoll

ENC creation: ChartPlotter, 7Cs
Satellite Derived Bathymetry: 10m grid



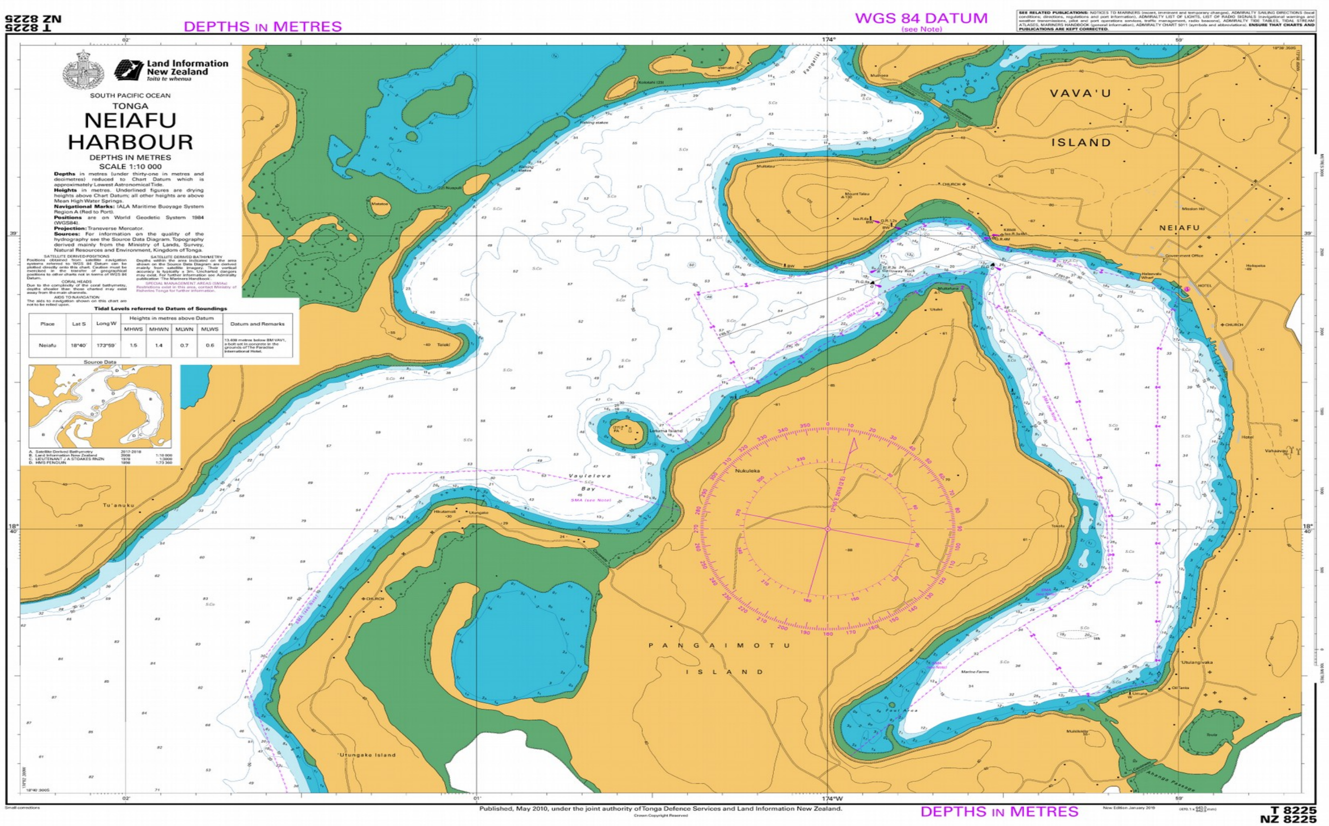
SDB overlay
current ENC

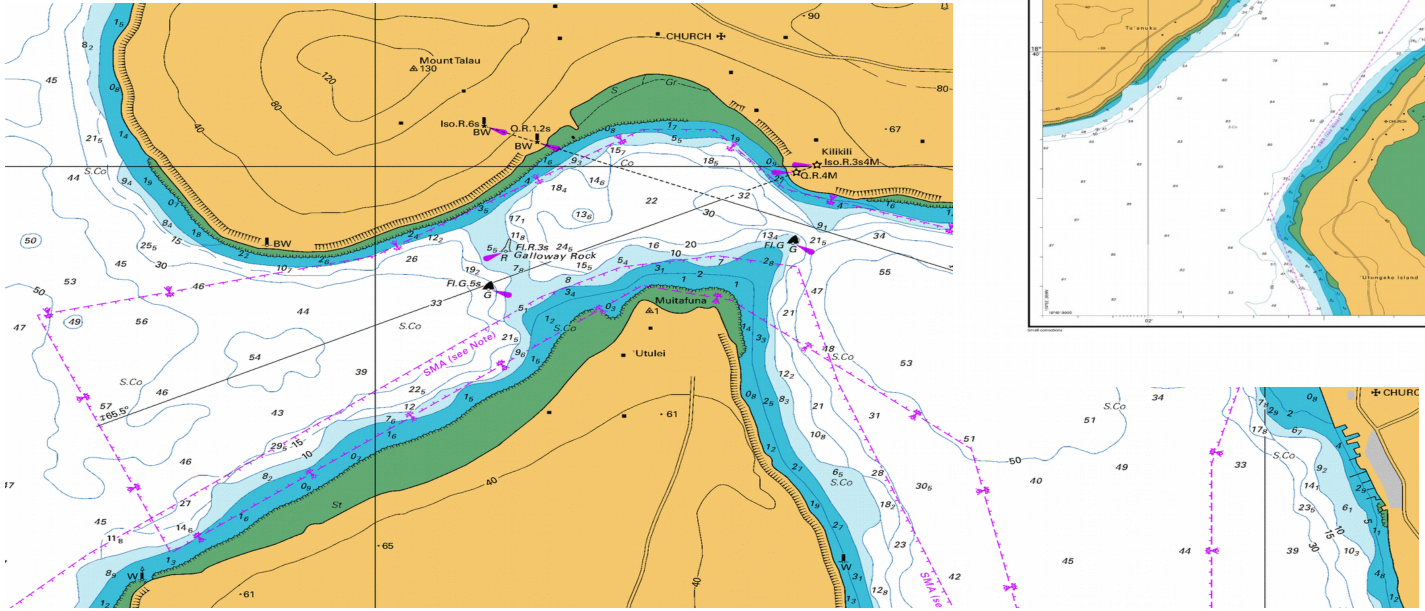
Evolution of SDB

LINZ PRNI Project (2018):

Multiple technologies

‘Best available data’





SATELLITE DERIVED BATHYMETRY
Depths within the area indicated on the area shown on the Source Data Diagram are derived mainly from satellite imagery. Their vertical accuracy is typically ± 3m. Uncharted dangers may exist. For further information see Admiralty publication 'The Mariners Handbook'.

Charting standards

ZOC [1]	Position Accuracy [2]	Depth Accuracy [3]	Seafloor Coverage	Typical Survey Characteristics [5]
A1	± 5 m + 5% depth	=0.50 + 1%d Depth (m) / Accuracy (m) 10 / ± 0.6 30 / ± 0.8 100 / ± 1.5 1000 / ± 10.5	Full area search undertaken. Significant seafloor features detected [4] and depths measured.	Controlled, systematic survey [6] high position and depth accuracy achieved using DGPS or a minimum three high quality lines of position (LOP) and a multibeam, channel or mechanical sweep system.
A2	± 20 m	= 1.00 + 2%d Depth (m) / Accuracy (m) 10 / ± 1.2 30 / ± 1.6 100 / ± 3.0 1000 / ± 21.0	Full area search undertaken. Significant seafloor features detected [4] and depths measured.	Controlled, systematic survey [6] achieving position and depth accuracy less than ZOC A1 and using a modern survey echosounder [7] and a sonar or mechanical sweep system.
B	± 50 m	= 1.00 + 2%d Depth (m) / Accuracy (m) 10 / ± 1.2 30 / ± 1.6 100 / ± 3.0 1000 / ± 21.0	Full area search not achieved; uncharted features, hazardous to surface navigation are not expected but may exist.	Controlled, systematic survey achieving similar depth but lesser position accuracies than ZOC A2, using a modern survey echosounder [5], but no sonar or mechanical sweep system.
C	± 500 m	= 2.00 + 5%d Depth (m) / Accuracy (m) 10 / ± 2.5 30 / ± 3.5 100 / ± 7.0 1000 / ± 52.0	Full area search not achieved, depth anomalies may be expected.	Low accuracy survey or data collected on an opportunity basis such as soundings on passage.
D	*Worse than ZOC C*	Worse than ZOC C	Full search not achieved, large depth anomalies expected.	Poor quality data or data that cannot be quality assessed due to lack of information.

Can be fullfilled with SDB

Survey standards

IHO S-44

HSPT3

IHO STANDARDS FOR HYDROGRAPHIC SURVEYS (S-44)
6th Edition draft 1.0 February 2019

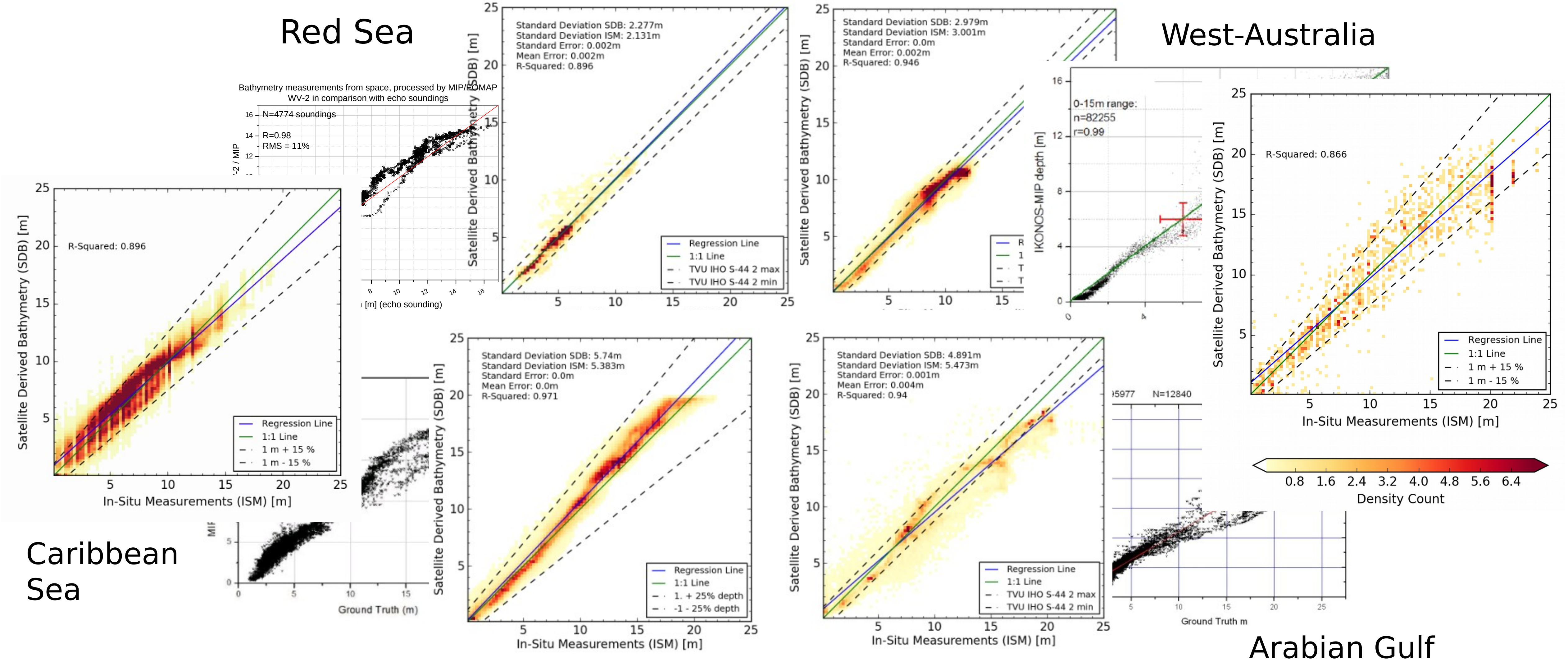
Matrix
Specifications for the Collection of Hydrographic Data
(To be read in conjunction with the full text set out in this document.)

	MATRIX Proposal 2, Standards Only	Ver. 5	CAN	Italy	does someone need / use this now			Section 6.5 uncertainties		Table2	USA	AUS	GBR	Fugro		
	Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
D	**Depth of water**															
a	**THU (Constant)**	---	>50m	50m	20m	10m	5m	2m	1m	0.5	0.1					
b	**THU (Variable, Depth Dependent)**	0	>20%	20%	10%	5%	2%	1%								
c	**TVU (Constant)**	---	>2m	2m	1m	0.5m	0.25	0.2m	0.15m	0.1	0.05					
d	**TVU (Variable, Depth Dependent)**	0	>20%	20%	10%	5%	2.30 %	2%	1.3%	1%	0.75 %	0				
e.1	**Bathymetry ~~Density~~Coverage**	---	1%	1.70 %	2.30%	3%	5%	100% (0% overlap)	120% (10% overlap)	150 % (25 % overlap)	200 % (50 % overlap)					
e.1	**Bottom Feature Search**	---	<10%	10%	20%	30%	50%	100% (0% overlap)	120% (10% overlap)	150 % (25 % overlap)	200 % (50 % overlap)					
e.1	**Seafloor Search (combined OPTION for coverage and line spacing)**	---	1%	1.70 %	2.30%	3%	5%	100% (0% overlap)	120% (10% overlap)	150 % (25 % overlap)	200 % (50 % overlap)					
e	**Seafloor Search**	---	>= 5 x average depth	4 x average depth	3 x average depth or 25m (whichever is greater); bathymetric lidar 5x5 spot spacing	100 % Search	120 % Search (10 % overlap)	150% Search (25% overlap)	200% Search (50% overlap)							
g	**Feature Size Detection (Constant)**	---	>5	5	2	1	0.5	0.25	0.1							
	Feature Detection (Variable, Depth Dependent)	0	>25% (or 20 - MAGNUS)	25% (or 20 - MAGN	10%	10% (beyond 50m										

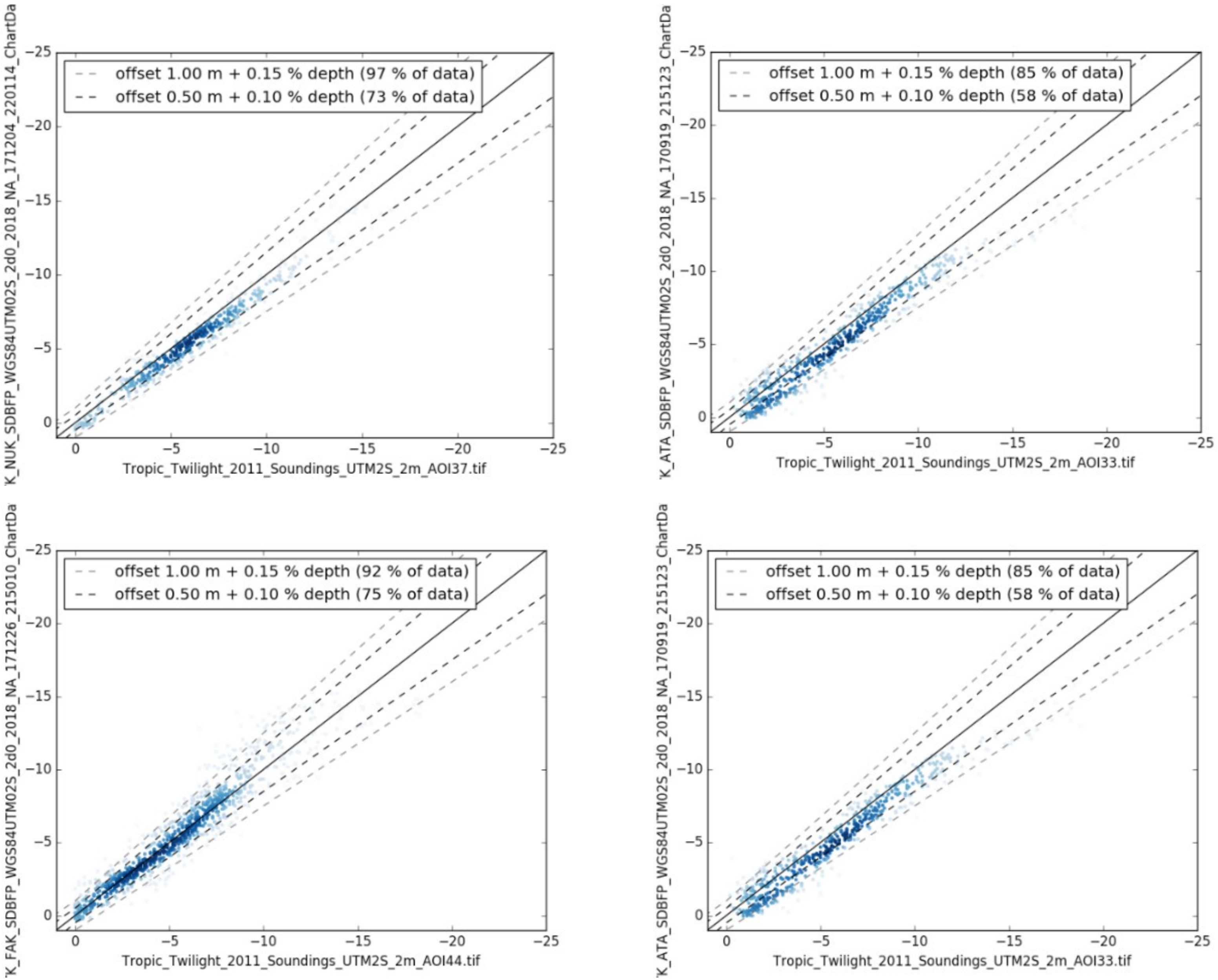
Evolution of SDB

EOMAP

Accuracies



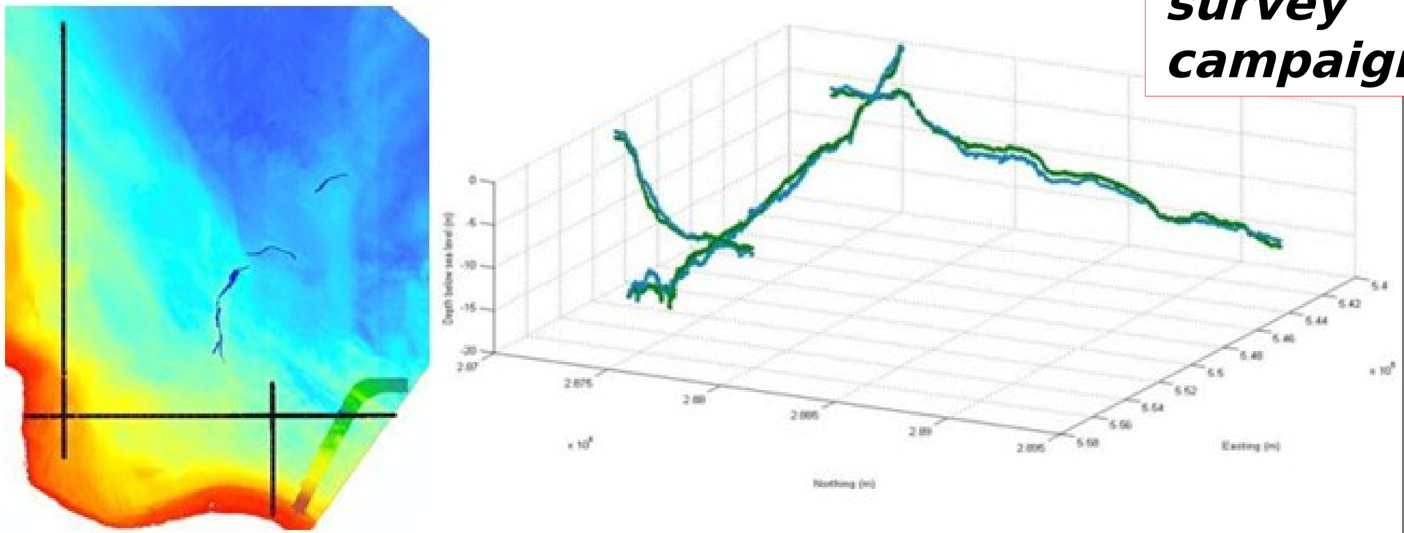
Without in situ calibration data: up to 10% ± 0.5m CE90


offset 1.00 m + 0.15 % depth (97 % of data)
offset 0.50 m + 0.10 % depth (73 % of data)
Tropic_Twilight_2011_Soundings_UTM2S_2m_AOI37.tif
K_NUK_SDBFP_WGS84UTM02S_2d0_2018_NA_171204_220114_ChartDa
offset 1.00 m + 0.15 % depth (85 % of data)
offset 0.50 m + 0.10 % depth (58 % of data)
Tropic_Twilight_2011_Soundings_UTM2S_2m_AOI33.tif
K_ATA_SDBFP_WGS84UTM02S_2d0_2018_NA_170919_215123_ChartDa
offset 1.00 m + 0.15 % depth (92 % of data)
offset 0.50 m + 0.10 % depth (75 % of data)
Tropic_Twilight_2011_Soundings_UTM2S_2m_AOI44.tif
K_FAK_SDBFP_WGS84UTM02S_2d0_2018_NA_171226_215010_ChartDa
offset 1.00 m + 0.15 % depth (85 % of data)
offset 0.50 m + 0.10 % depth (58 % of data)
Tropic_Twilight_2011_Soundings_UTM2S_2m_AOI33.tif
K_ATA_SDBFP_WGS84UTM02S_2d0_2018_NA_170919_215123_ChartDa

Use Case: Shell Qatar survey

VERIFICATION - BATHYMETRY

Support seismic survey campaigns



Comparison for bathymetry from satellite (in blue) against LIDAR bathymetry (in green) along 3 calibration lines

Average absolute error: 60cm

Sounding vs. Satellite (meter)	
Mean Diff	0.25
Mean Abs Diff	0.60
RMSQE	0.73

November 2013 10

Presented during the IPTC meeting in Doha, Qatar, 2014

NOAA Bathymetry surveys 2012

Locations:

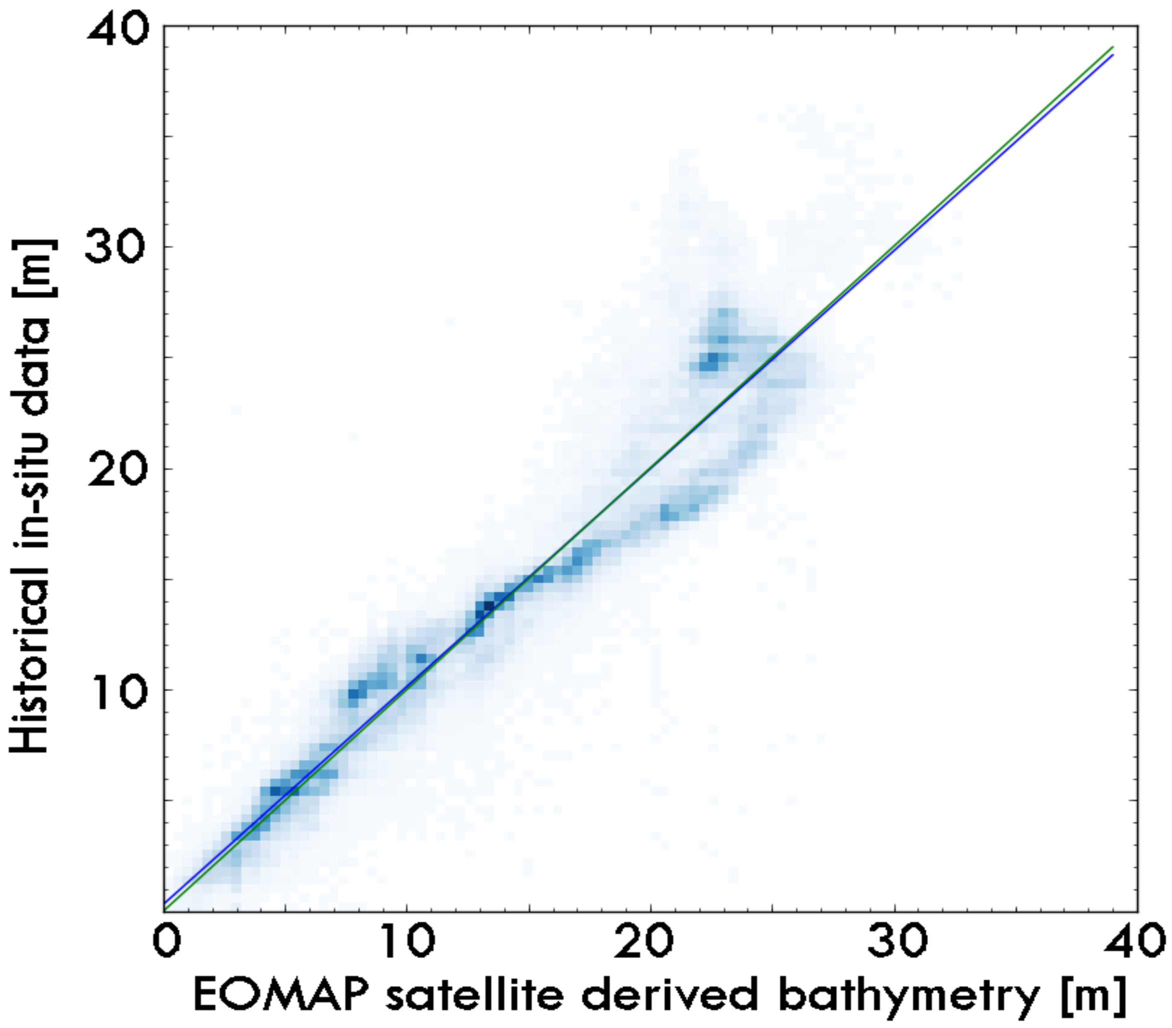
- U.S. Virgin Islands
- Northern Mariana
- Simeonof Islands

Validation:

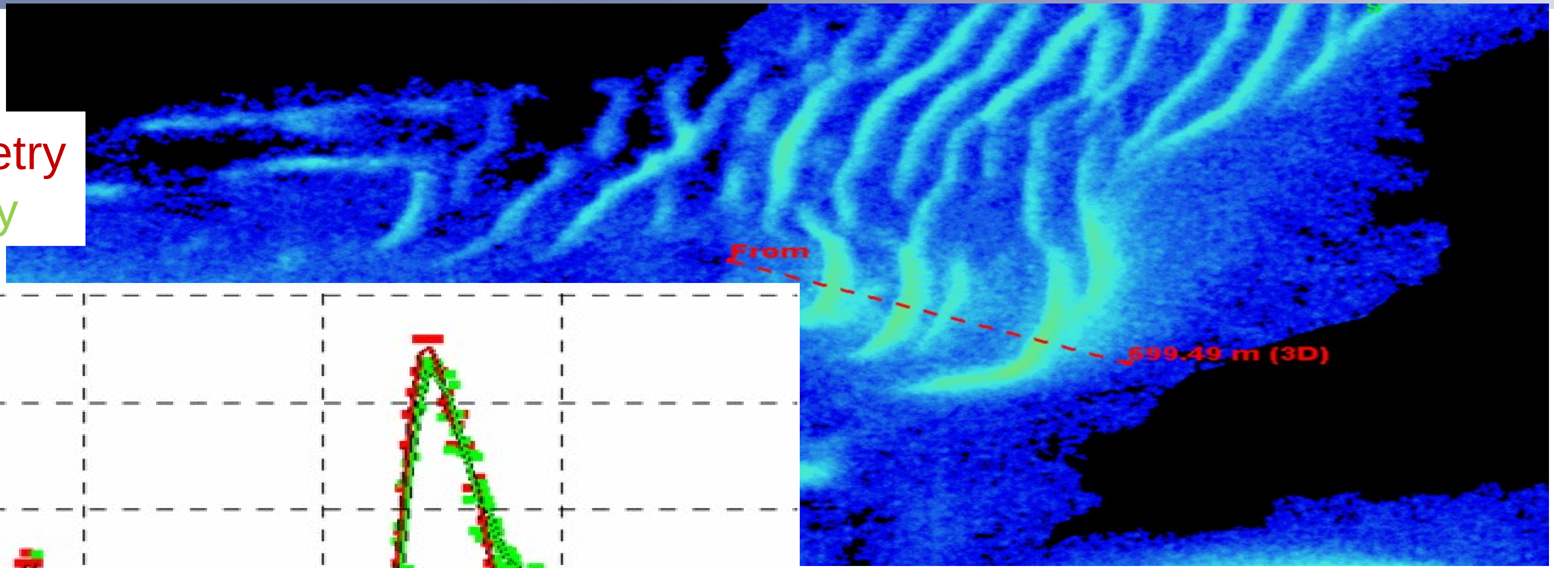
Bathymetry ~10-15%
CE90 for all AOIs.

Commercial pilot project:

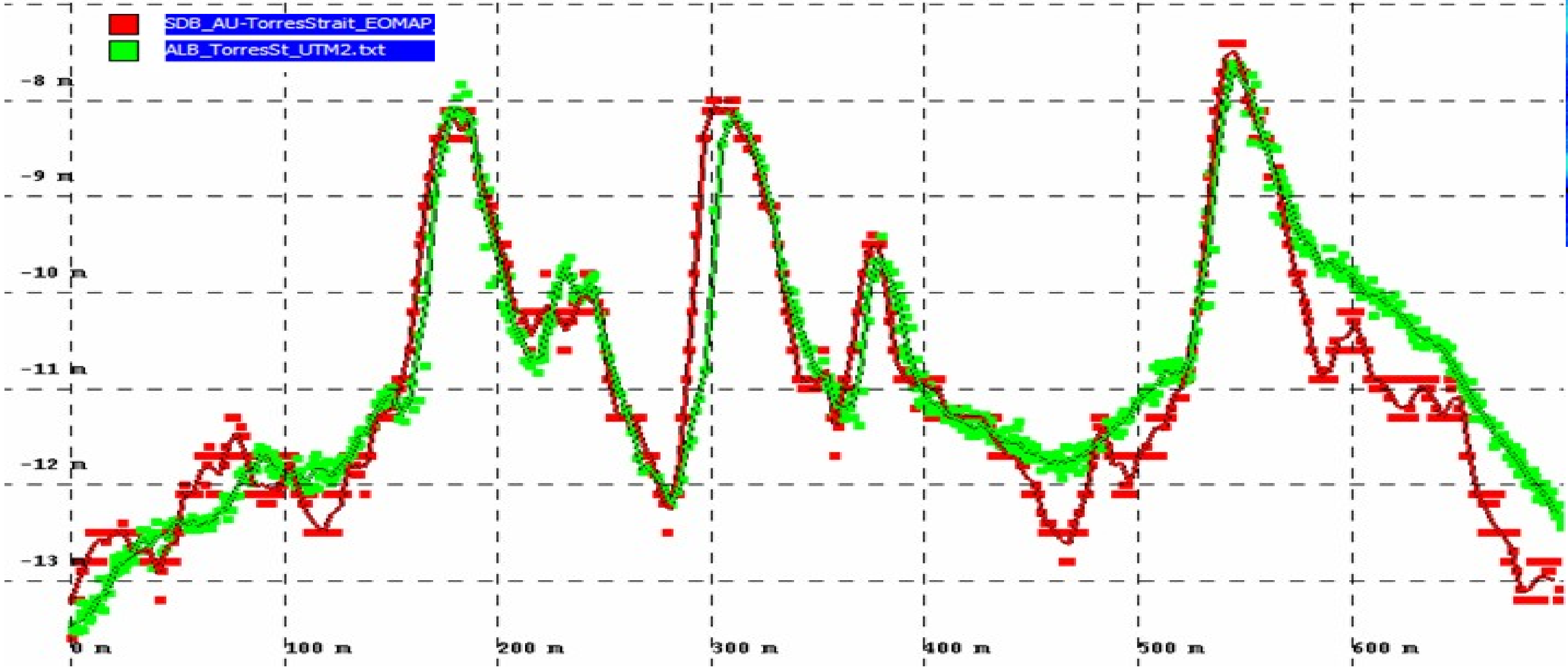
- Rapid
- Cost effective
- Robust



Independent validation by Fugro



Satellite Derived Bathymetry
Airborne Lidar Bathymetry



Torres Strait, Queensland

Courtesy of Don Ventura, © FUGRO

UKHO MEDITERRANEN SURVEYS, 2013

Pilot project, WV-2 data:
Bathymetry + seabed classification

Vertical accuracies: 10–15% of depth
Positional accuracy: 10 m CEP 90%

Four seabed types identified:

- Sand
- Debris
- Vegetation
- Mixed seafloor

Conventional methods have 4-8 times the costs of satellite-derived products.
- United Kingdom Hydrographic Office

NEEDHAM H, HARTMANN K, MIMPRISS G. 2013. Imagery-derived Bathymetry and Seabed Classification Validated. Hydro International 17(1).

Mimpriss G. 2013. Remote Sensing in the Maritime Environment (Feb. 11, 2013). The United Kingdom Hydrographic Office, Taunton, UK

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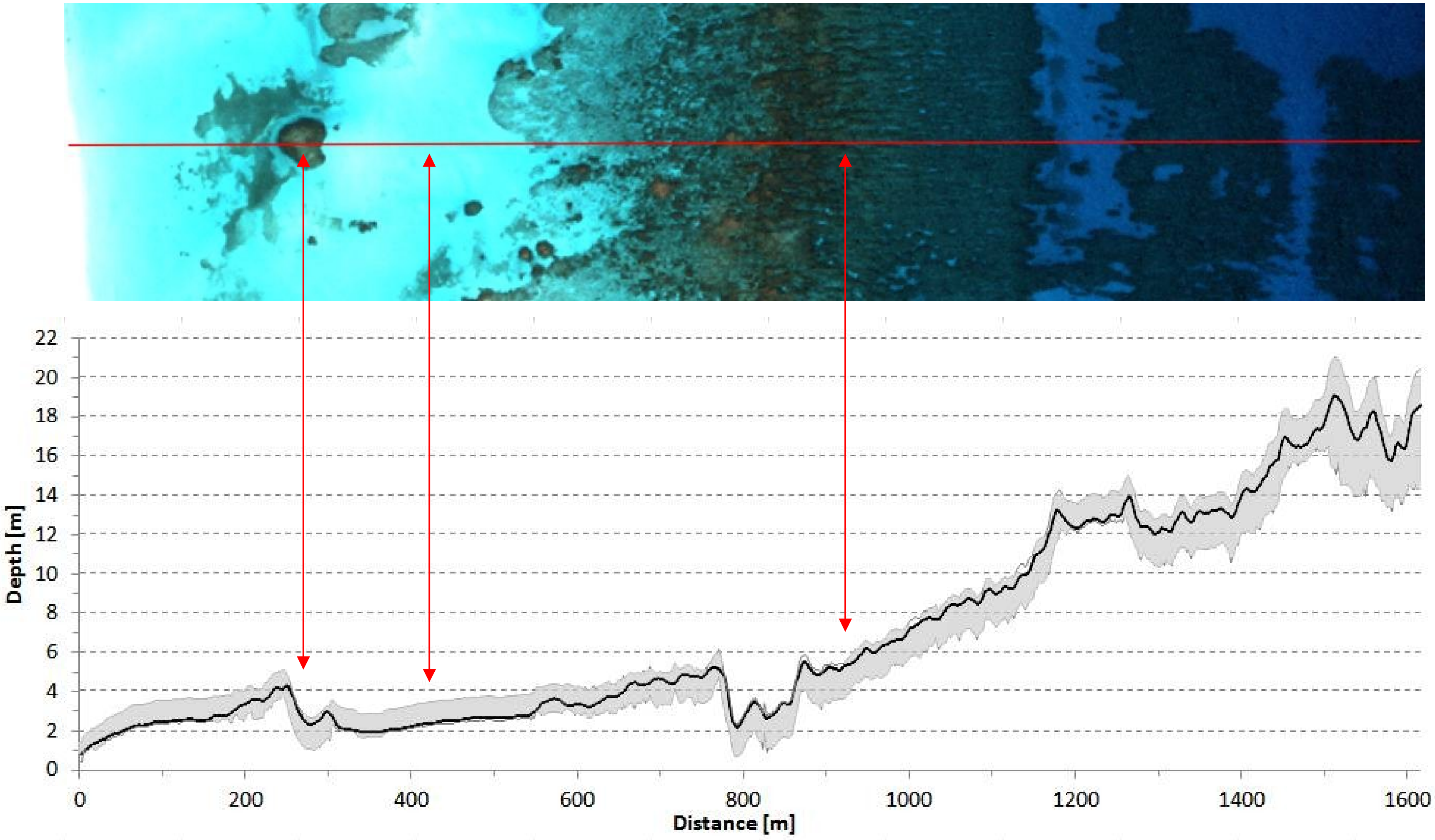
Uncertainties



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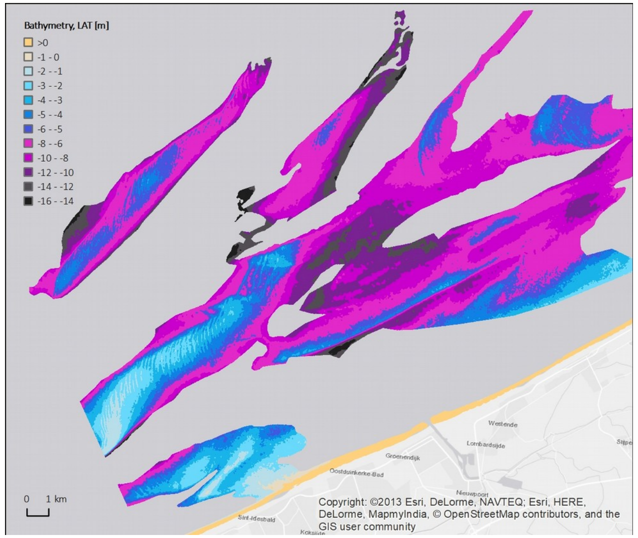

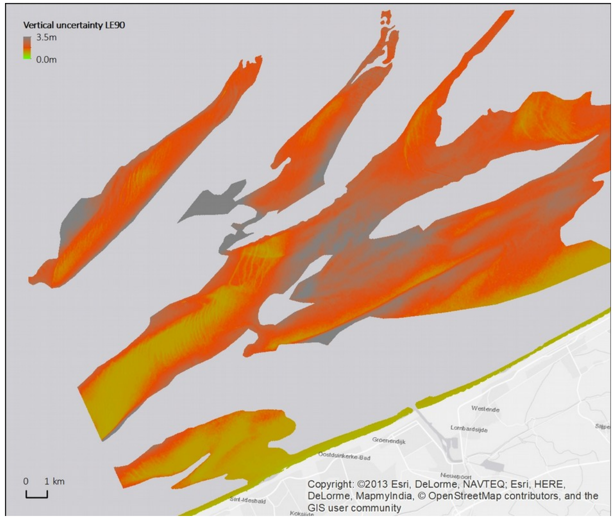

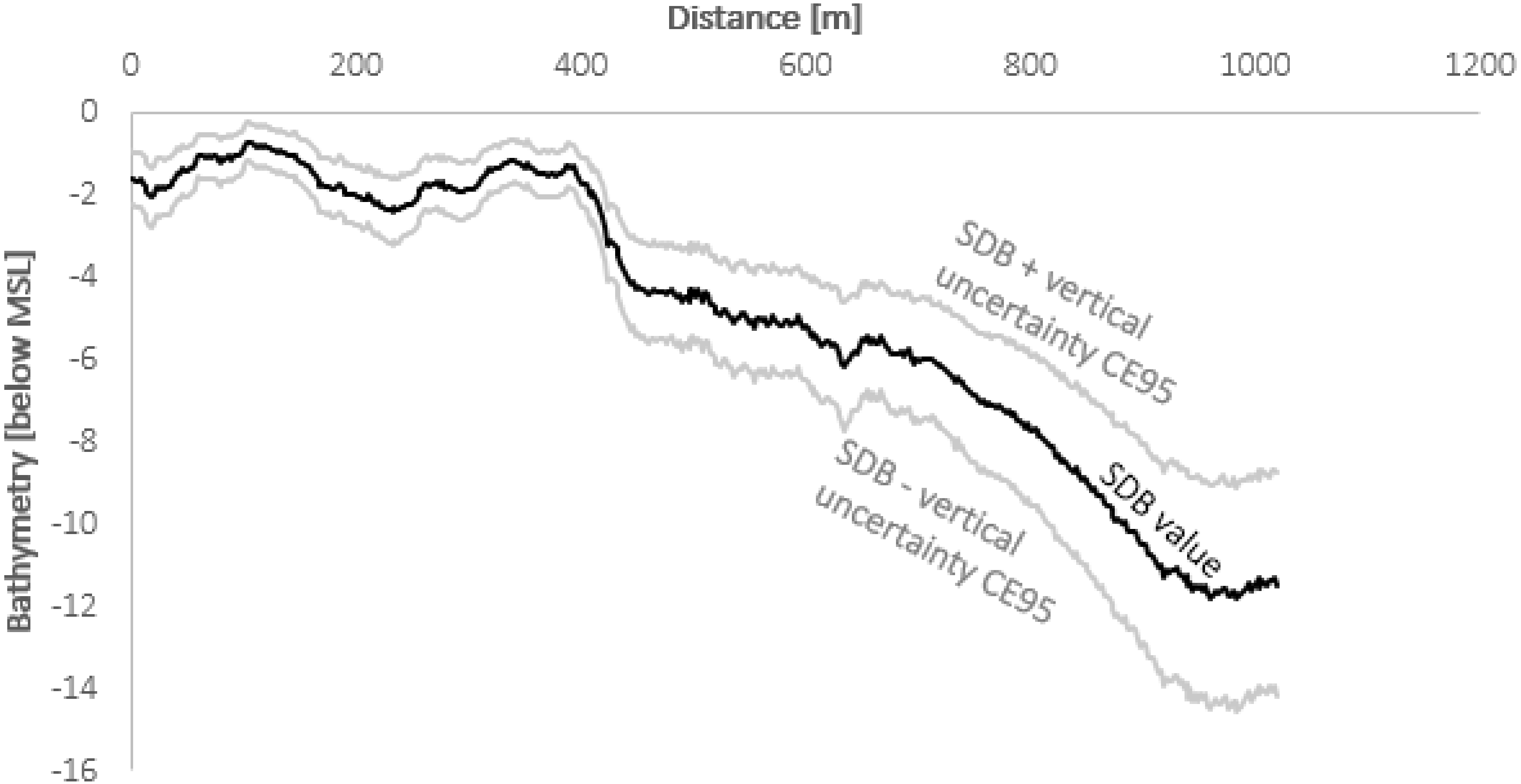

Building blocks of SDB

Sensors and platforms
spatial resolution, radiometric calibration/stability, signal-to-noise, re-visit frequency

Algorithms
implementation of physics, speed, assumptions

Production workflows (including QC procedures)
manual vs. automation, robustness, speed, accuracy assessment, quality control

Future of SDB

Sensors and platforms
Options and capabilities will only increase
Dedicated shallow water sensors?
UAVs

Algorithms
Aquatic RT physics is essentially fully understood
Ongoing development retrieval procedures, uncertainty forecast
Layering methods: physics-based, empirical, even photogrammetry

Production workflows (including QC procedures)

Increasing automation	>	stand-alone software
Accuracy and uncertainty	>	defining standards
Processing speed	>	near real time processing

The Roles of SDB

Planning, Mapping and Monitoring
Optimising multi-disciplinary campaigns
Fit-for-purpose as stand alone: budget, speed, remoteness, extent

Complementary
SDB less accurate than MBES and ALB
Shallow zone is highly problematic for MBES
Mobilisation trivial vs. ALB and MBES
SDB and ALB will not work in turbid waters

Otherwise in-accessible areas
Rapid, worldwide mapping from the comfort of your computer

Uptake and stewardship of SDB

Complementary role of SDB further embraced by other technologies (and driven by users, e.g. LINZ and NIWA)

R&D ongoing, engagement with research community

Uptake and stewardship of SDB

Providers: when and how to leverage SDB, objectivity

Providers and Users: consider making SDB
(or at least location/extent) available to AusSeabed or
Seabed 2030.

Uptake and stewardship of SDB

Charting and survey standards: continue developing with IHO and AusSeabed

Acquiring SDB software in-house involves educational process, e.g. pre- and post- Quality Control

Uptake and stewardship of SDB

Providers: transparent and collaborative … SDB forum.

Users: feedback, requests, collaboration … SDB forum.

Uptake and stewardship of SDB

Welcome.