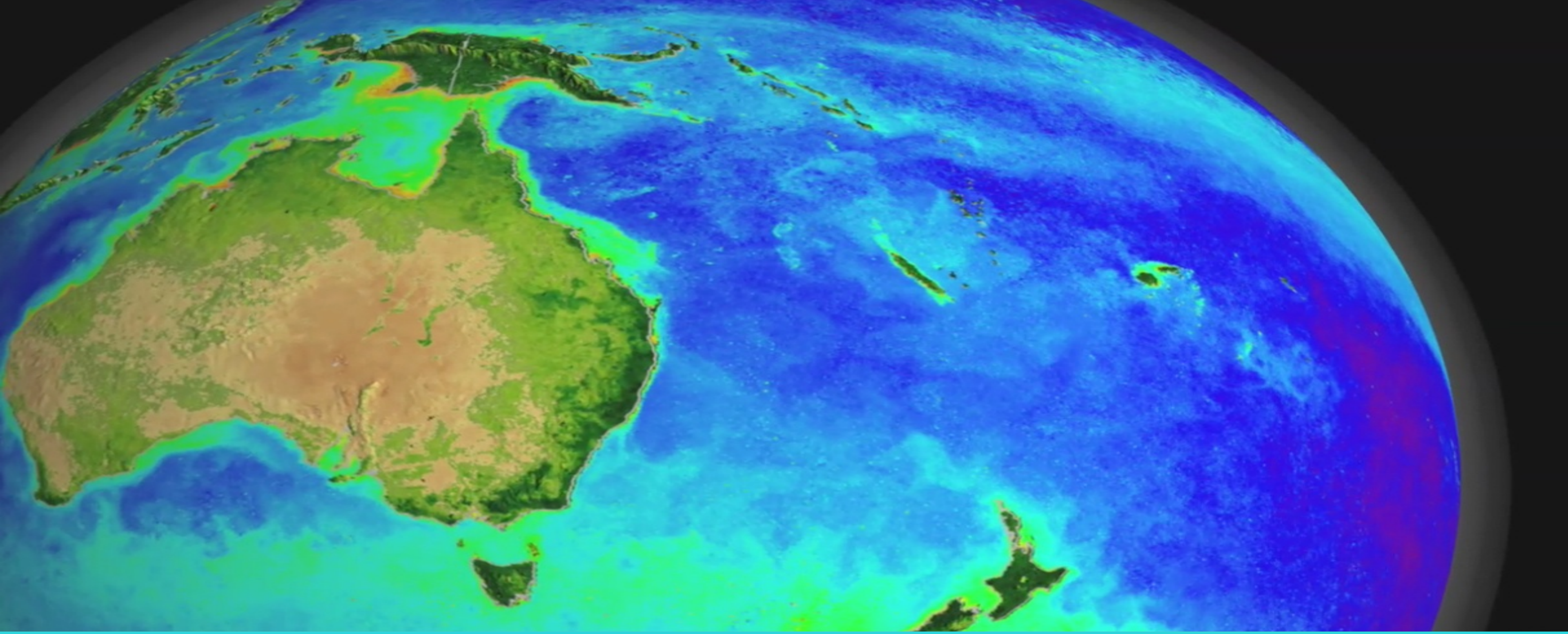


Assessing bio-optical variability of ocean waters and adjacent coral reefs using hyperspectral satellites

Arnold Dekker, Nagur Cherukuru, Elizabeth Botha, Kadija Oubelkheir and Vittorio Brando

2012 HyspIRI Workshop, Washington 16-18 October 2012

BY THE ENVIRONMENTAL EARTH OBSERVATION PROGRAM IN CSIRO LAND & WATER

www.csiro.au *THROUGH WEALTH FROM OCEANS*

Based on work by: Young Je Park, Magnus Wettle, David Blondeau-Patissier, Paul Daniel, Stuart Phinn, Ch Roelfsema, &*Collaboration with Department Sustainability, Environment, Water, Population, Community and the Arts.*

Introduction

To assess the validity of the often published sentence:

……we assumed the ocean water optical properties to be the same over the coral reefs………for:

1.Optically significant water column concentrations

2.IOPS (spectral light absorption and backscattering)

3.SIOPS(concentration-specific light absorption and backscattering)

..for the purpose of:

•Remote sensing inversion algorithm parameterisation

•Bio-optical/underwater light climate modelling

And building forth on excellent work done by:

Boss, E. , Zaneveld, J.R.V. (2003). The effect of bottom substrate on inherent optical properties: Evidence of biogeochemical processes. *Limnology and Oceanography* 48(1): 346-354

Goodman, J.A., Lee, Z.P., and Ustin, S.L. (2008) Influence of atmospheric and sea-surface corrections on retrieval of bottom depth and reflectance using a semi-analytical model: a case study in Kaneohe Bay, Hawaii. *Applied Optics* (47),28: p F1-F12.

Hedley, J., Roelfsema, C., Koetz, B. And Phinn, S. (2012) Capability of the Sentinel-2 mission for tropical coral reef mapping and coral beaching detection. *Remote Sensing of Environment* (120): p 145 – 155.

Hochberg, E.J., & Atkinson, M.J., (2003). Capabilities of remote sensors to classify coral, algae, and sand as pure and mixed spectra. *Remote Sensing of Environment*, 85, 174-189

Klonowski, W. M., P. R. C. S. Fearns, and M. J. Lynch. 2007. Retrieving key benthic cover types and bathymetry from hyperspectral imagery. Journal of Applied Remote Sensing **1:** 011505.

Maritorena, S. and Guillocheau (1996) Optical properties of water and spectral light absorption by living and non-living particles and by yellow substances in coral reef waters of French Polynesia. *Marine Ecology Progress Series*, (131): p 245-255.

A specific driver for our research: CSIRO - Optically Shallow and Optically Deep Water -Remote Sensing based on 3 methods

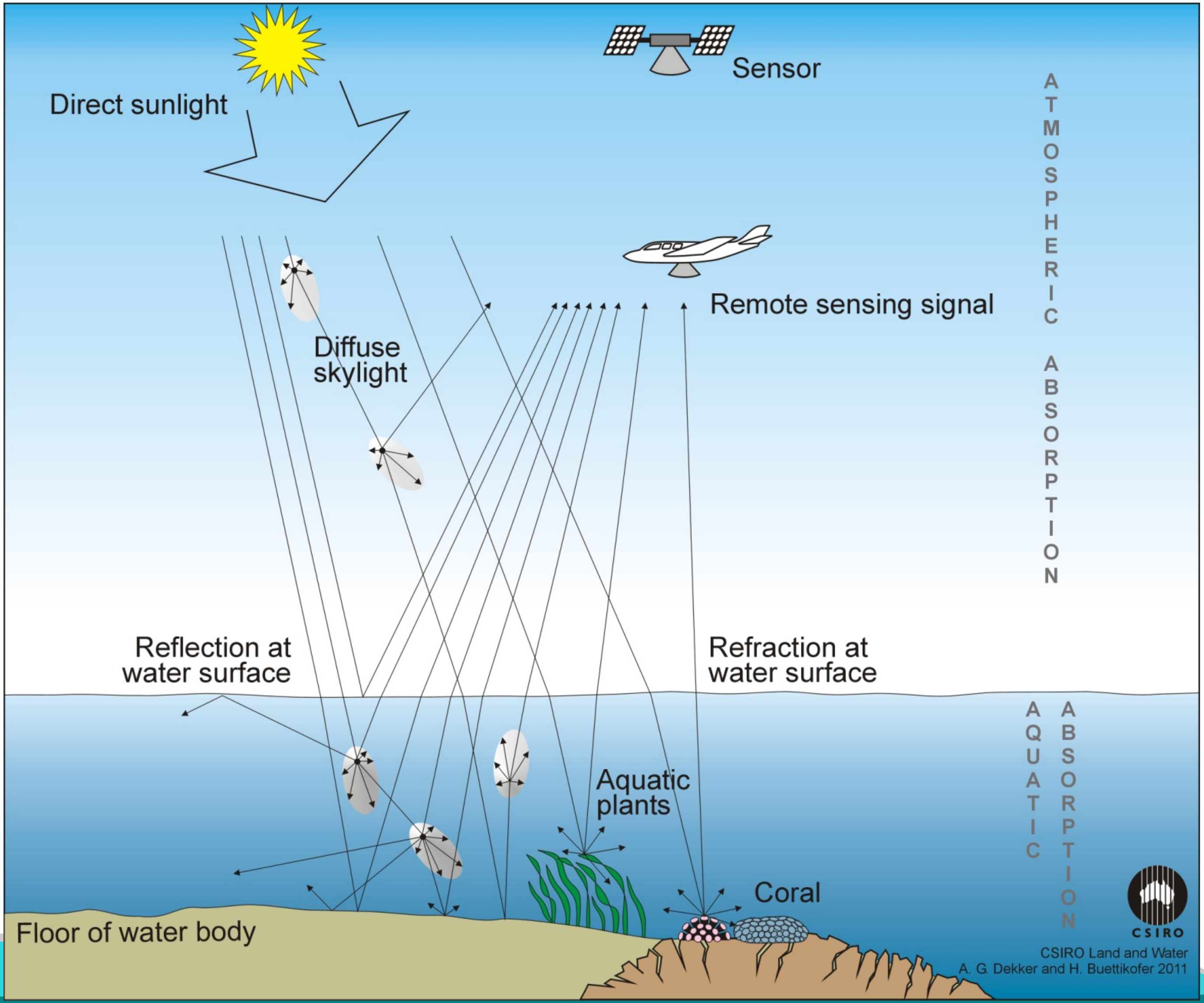
1. Atmospheric correction and air-water interface effects removal (RT physics-based and increasingly relying on ANN for fast processing)

2. For optically deep waters: adaptive linear matrix inversion method (aLMI) ***using variable sets of SIOPS*** (concentration Specific Inherent Optical Properties) to ***allow for varying water types*** within one image

3. For optically shallow waters: enhancement of aLMI (including optimisation) by including ***multiple substratum types*** (= SAMBUCA)

The conceptual physics-based model for optically shallow waters

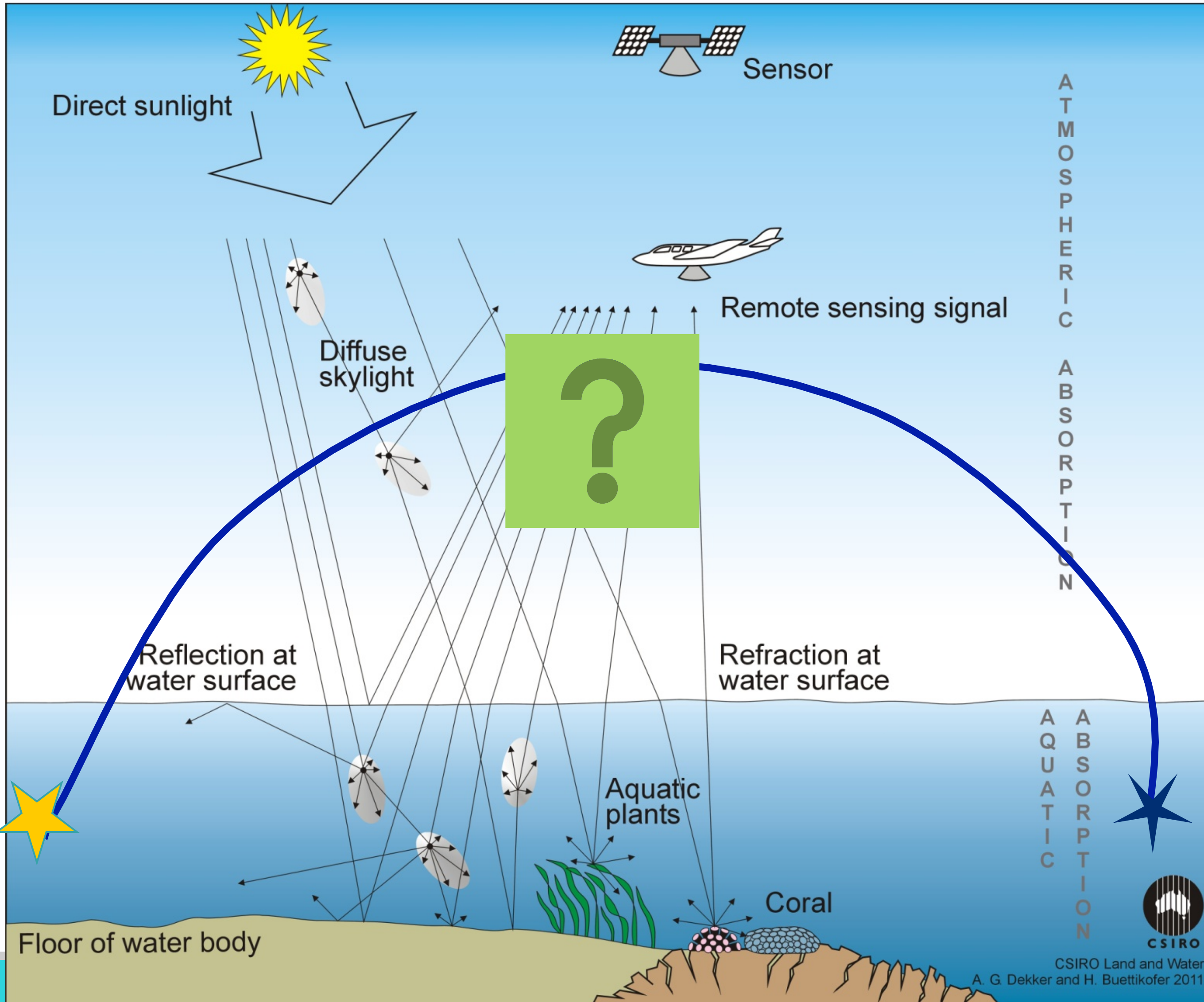
optically shallow



optically deep

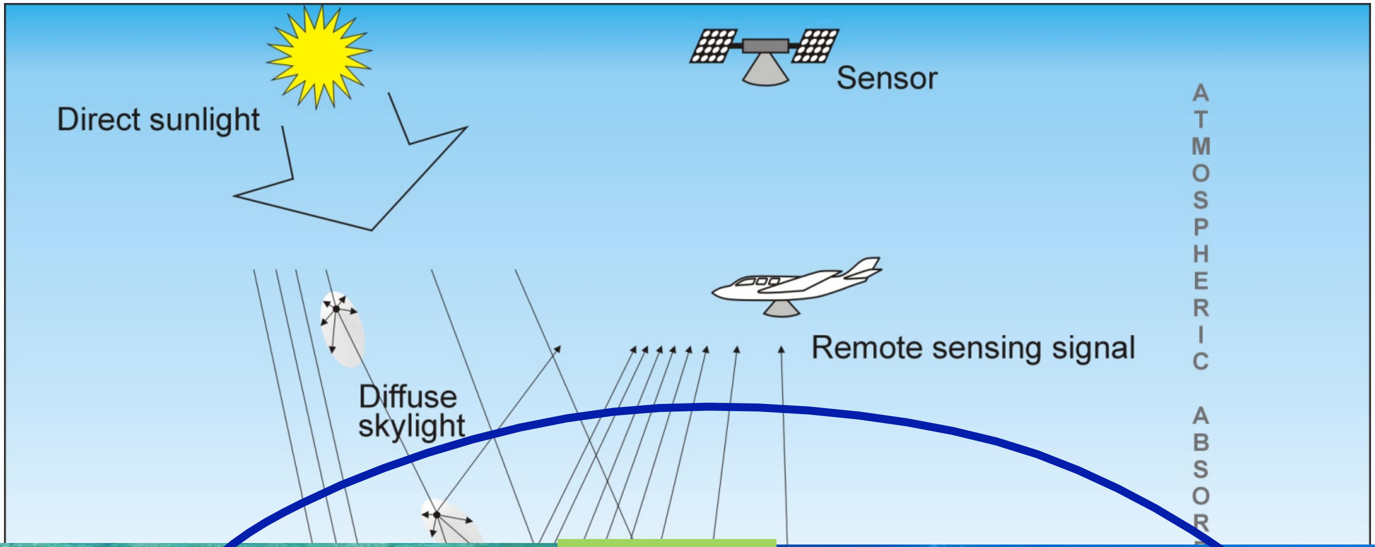
The conceptual physics-based model for optically shallow waters

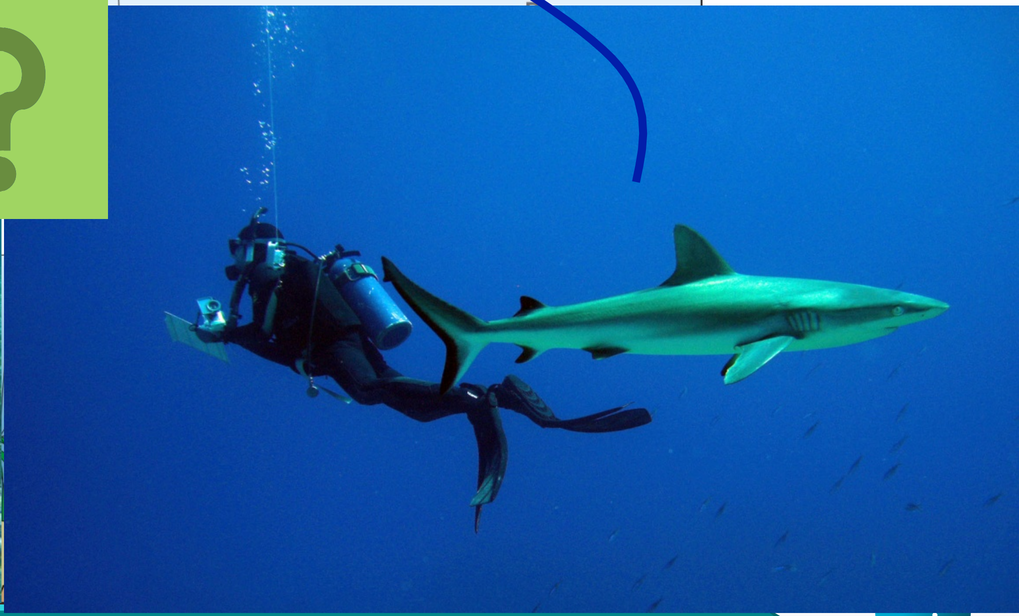
optically shallow



optically deep

The conceptual physics-based model for optically shallow waters





Study Areas and Fieldwork

- Heron Island in the southern Capricorn Bunker Group of the Great Barrier Reef:(23°27' S, 151°55' E)
  - 19th May 2004 to the 24th May 2004
  - Aim: Coral bleaching, substratum mapping, bathymetry
- Herald Cays in the Coral Sea The Coringa Herald Cays (17°00'S 149°10'E
  - 29th November 2006 to 6th December 2006
  - Aim: substratum mapping, bathymetry
- Lihou Reef system farther out into the Coral Sea). The Lihou Reefs (ranging from 18°00' S to 17°10' S and from 151°20' E to 152°10' E)
  - 5th December 2008 to the 16th December 2008.
  - Aim: substratum mapping, bathymetry

Study Area - Reef Locations

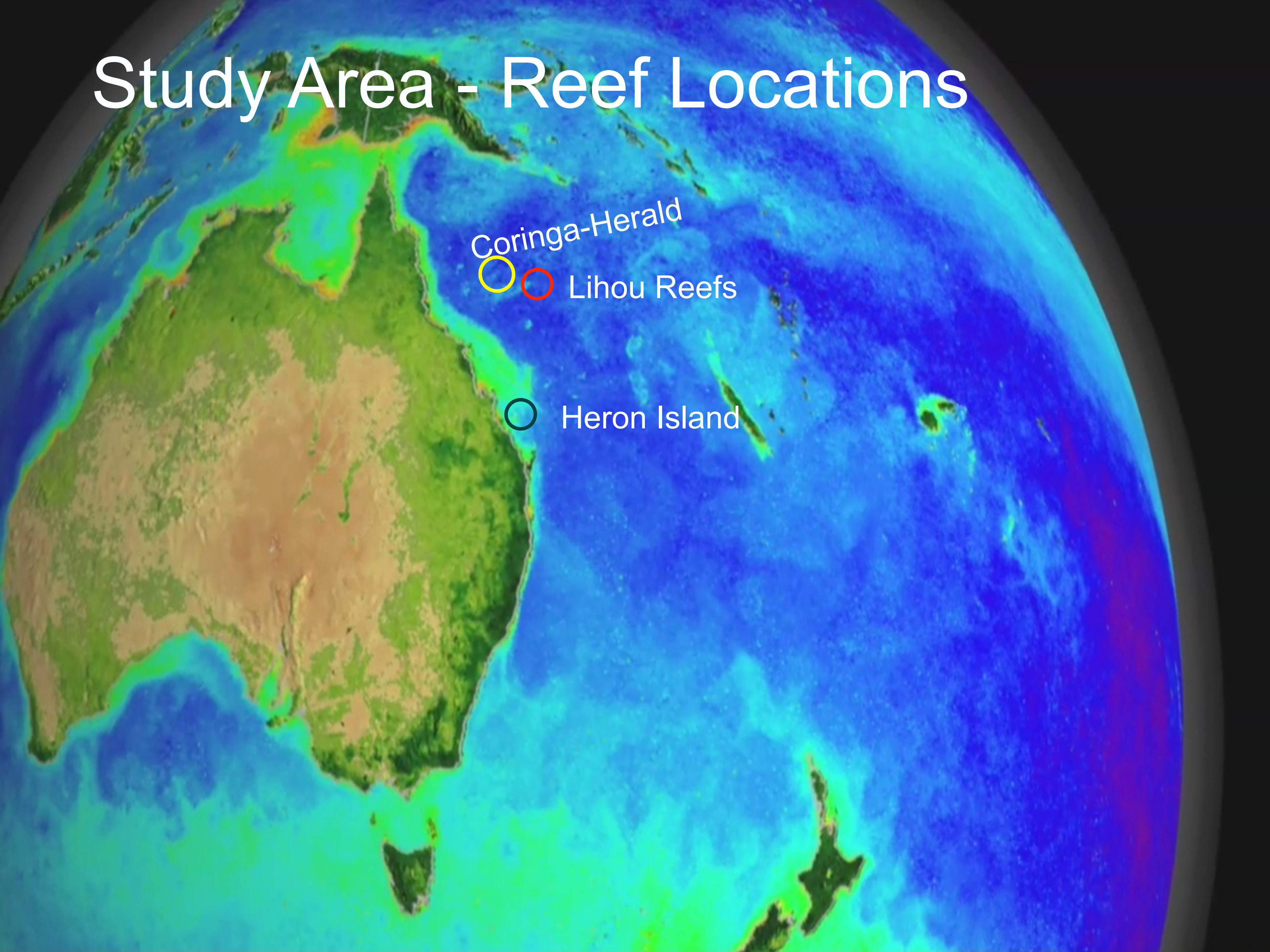
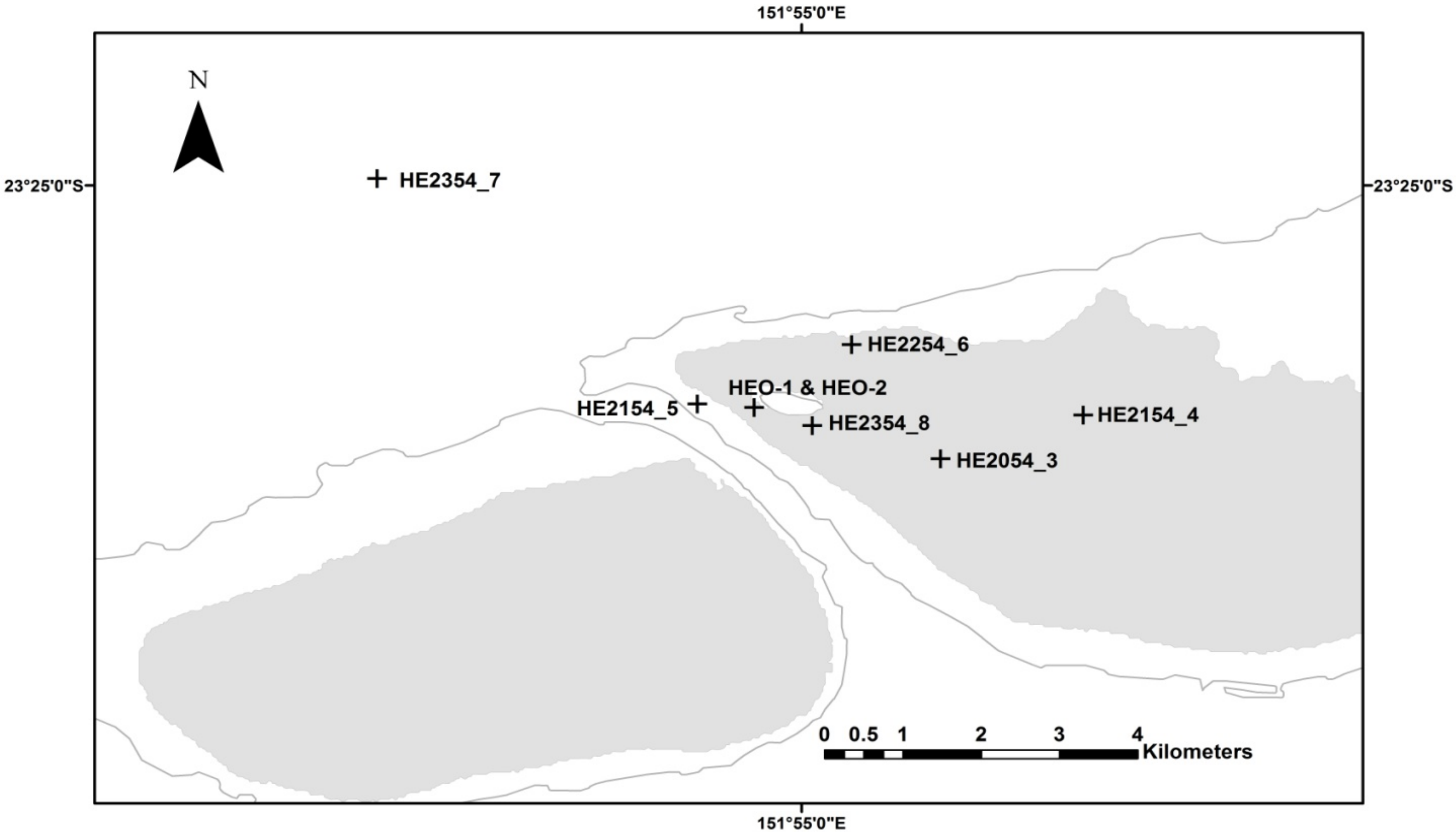
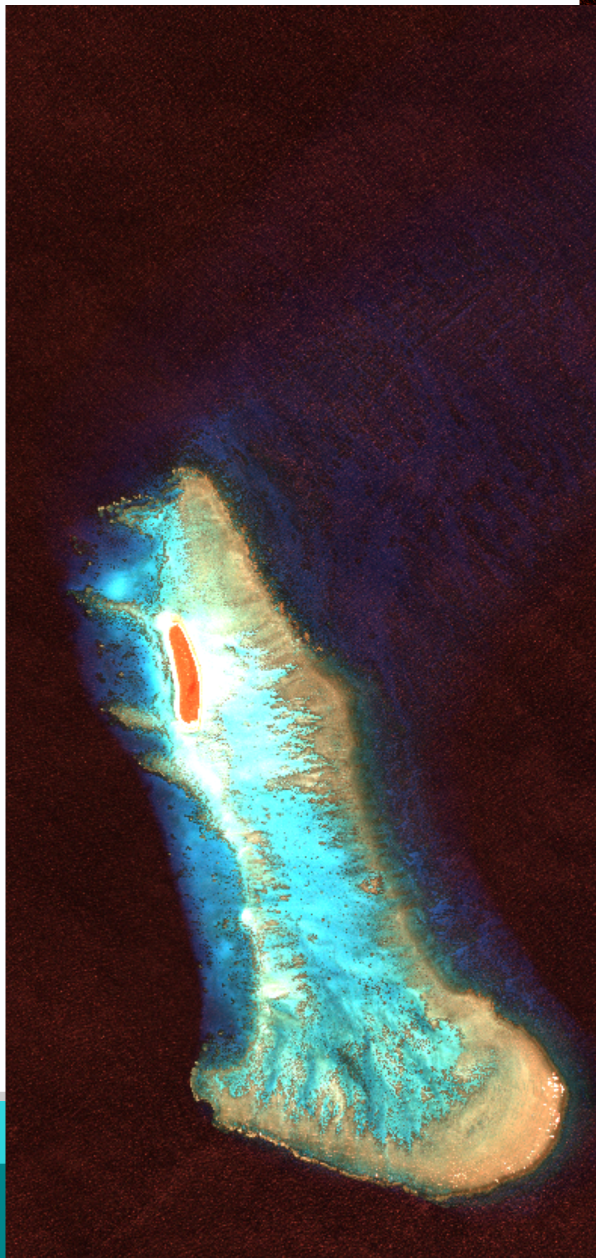


Image: Heron Island reef

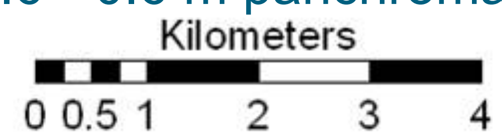

151°55'0"E
N
23°25'0"S
23°25'0"S
HE2354_7
HE2254_6
HEO-1 & HEO-2
HE2154_5
HE2354_8
HE2154_4
HE2054_3
0 0.5 1 2 3 4
Kilometers
151°55'0"E

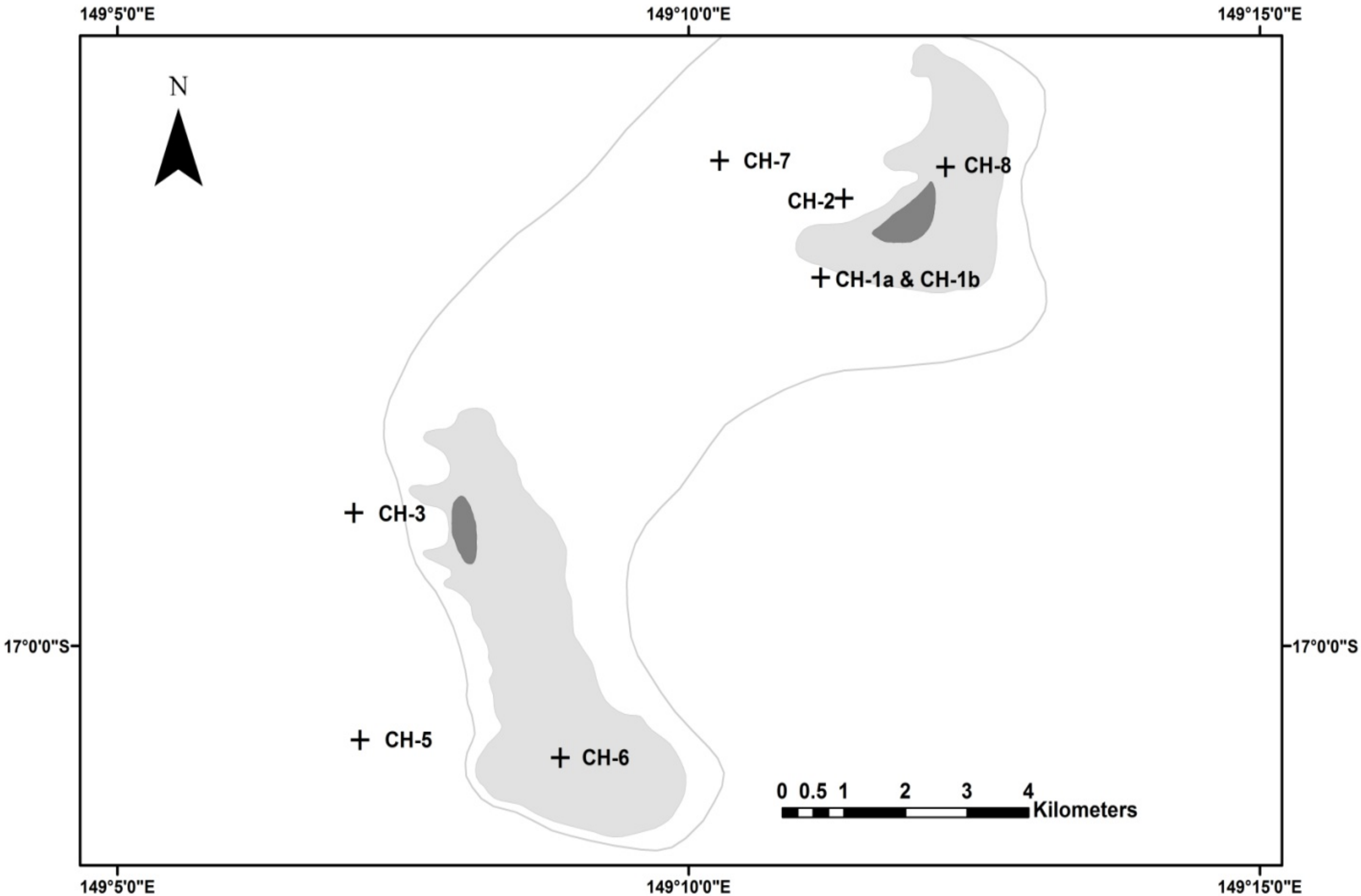


Un-corrected pseudo-true colour Quickbird data (2006) of North East Herald (Oct 06) and South West Herald Cays (Sep 06): spatial resolution

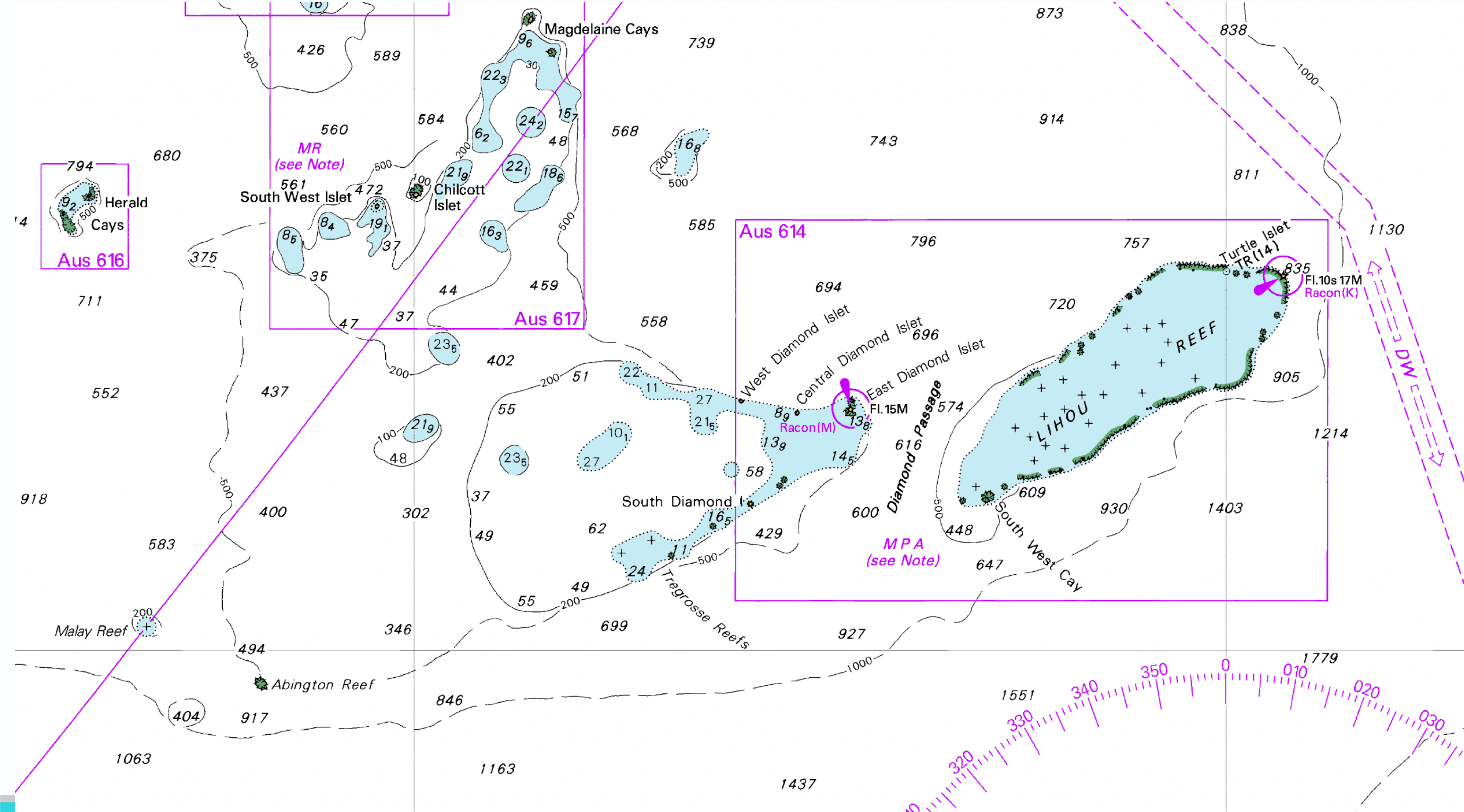
2.6 * 2.6 m in colour bands (Bl-Gr-Re-NIR);

0.6 * 0.6 m panchromatic (Grey Scale)



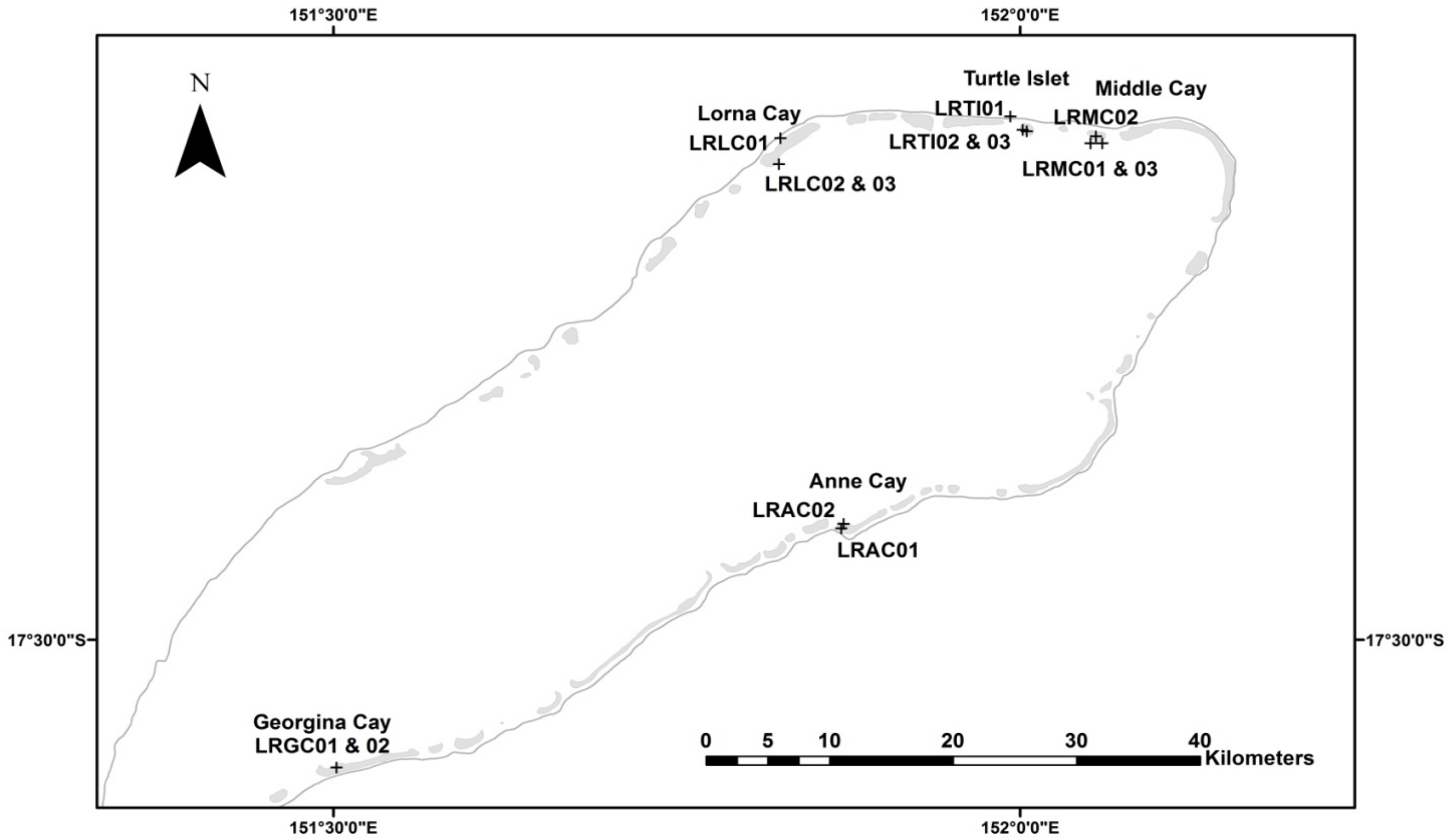

149°5'0"E
149°10'0"E
149°15'0"E
N
CH-7
CH-8
CH-2
CH-1a & CH-1b
CH-3
17°0'0"S
17°0'0"S
CH-5
CH-6
0 0.5 1 2 3 4
Kilometers
149°5'0"E
149°10'0"E
149°15'0"E

Bathymetry Coringa-Herald and Lihou Reefs



CSIRO

Fieldwork Sites LihouReefs



Field survey conducted during December 2008.
Stations are marked on the map where water samples were collected.


Fieldwork on Coral Reefs:
Small boats – no infrastructure

In:

LIMNOLOGY
and
OCEANOGRAPHY: METHODS

Limnol. Oceanogr.: Methods 9, 2011, 396–425

Intercomparison of shallow water bathymetry, hydro-optics, and benthos mapping techniques in Australian and Caribbean coastal environments

Arnold G. Dekker[1,2], Stuart R. Phinn[2]*, Janet Anstee [1], Paul Bissett[3], Vittorio E. Brando[1,2], Brandon Casey[4], Peter Fearns[6], John Hedley[7,8], Wojciech Klonowski[6], Zhong P. Lee[5], Merv Lynch[6], Mitchell Lyons[2], Curtis Mobley[9], and Chris Roelfsema[2]*

We compared 5 physics-based inversion models and one empirical inversion model on two airborne imaging spectrometry datasets in Caribbean (coral reef) and Australia (coastal embayment with seagrasses)

The CSIRO model tested was SAMBUCA:

SAMBUCA: Semi Analytical Model for Bathymetry, Unmixing and Concentration Assessment

$$r_{rs}(\lambda)_{modelled} = f\left(P, G, X, B, H, S, Y\right)$$ Lee et al (1998, 1999, 2001)

is replaced by

$$r_{rs}^{\text{model}} = f\begin{pmatrix} C_{CHL}, C_{CDOM}, C_{NAP}, H, q_{ij}, A_i(\lambda), A_j(\lambda), S_{CDOM}, S_{NAP}, \\ Y_{PHY}, Y_{NAP}, a^*_{\text{PHY}}(\lambda), a^*_{\text{NAP}}(\lambda_0), b^*_{b\text{PHY}}(\lambda_0), b^*_{b\text{NAP}}(\lambda_0) \end{pmatrix}$$

- C_{CHL} is the concentration of chlorophyll a
- C_{CDOM} is the concentration of CDOM, ie $a^*_{\text{CDOM}}(\lambda_{\text{CDOM}})$ is set to 1
- S_C is the slope of the CDOM absorption
- C_{NAP} is the concentration of NonAlgalParticulate matter
- S_{NAP} is the slope of NonAlgalParticulate absorption
- $a^*_{NAP}(\lambda_{\text{NAP}})$ is specific absorption of NonAlgalParticulate at λ_{tr}
- $b_b{}^*_{NAP}(\lambda_0)$ is the specific backscattering due to NonAlgalParticulate matter
- $a^*_{PHY}(\lambda_{\text{ph}})$ is specific absorption of phytoplankton
- $b_b{}^*_{PHY}(\lambda_0)$ is the specific backscattering due to phytoplankton
- A_i, A_j are the reflectances of substrate i & j [selected from a spectral library of *n* spectra]
- q_{ij} is the ratio of substrate i to substrate j within each pixel

Chlorophyll and NAP

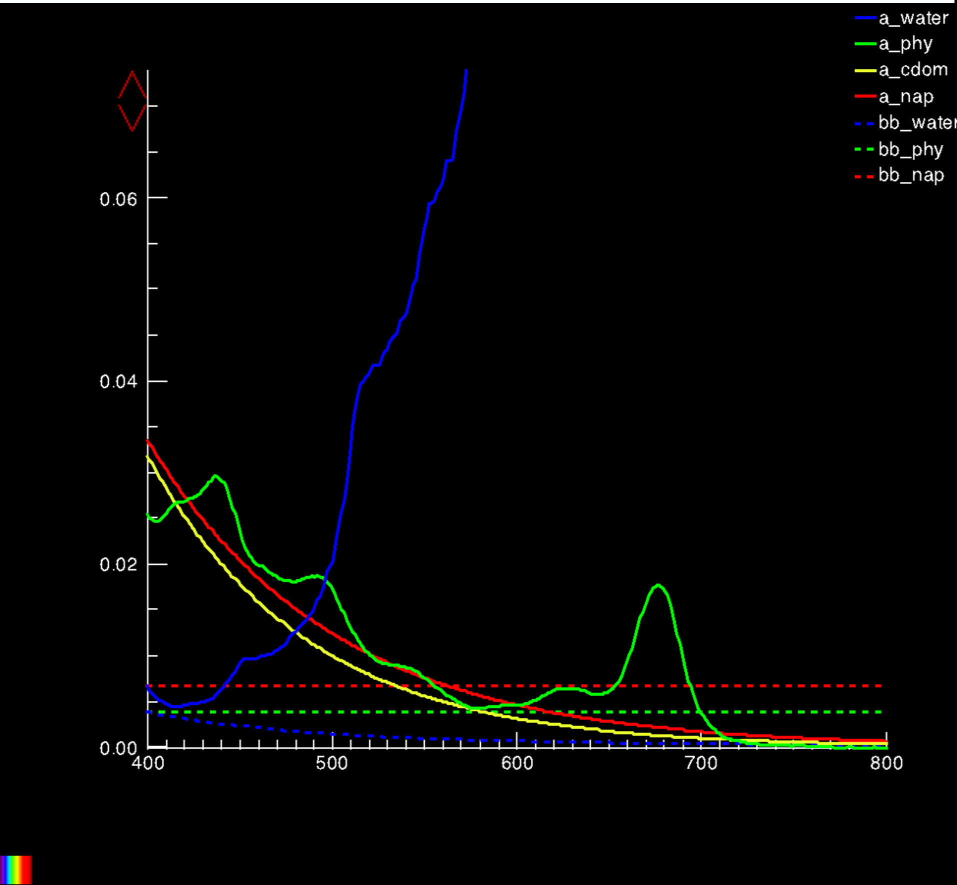
	Reef	Ocean	Ratio
	Mea	Mean	Mean R:O
Chlorophyll (µg L^{-1})			
Heron Island	0.113	0.386	0.294
Coringa Herald	0.039	0.101	0.389
Lihou Reefs	0.053	0.106	0.498
Non Algal Particulate (mg L^{-1})			
Heron Island	1.232	1.106	1.114
Coringa Herald	0.276	0.233	1.183
Lihou Reefs	1.470	1.152	1.276

Ratio's Reef to Ocean IOPS and SIOPs

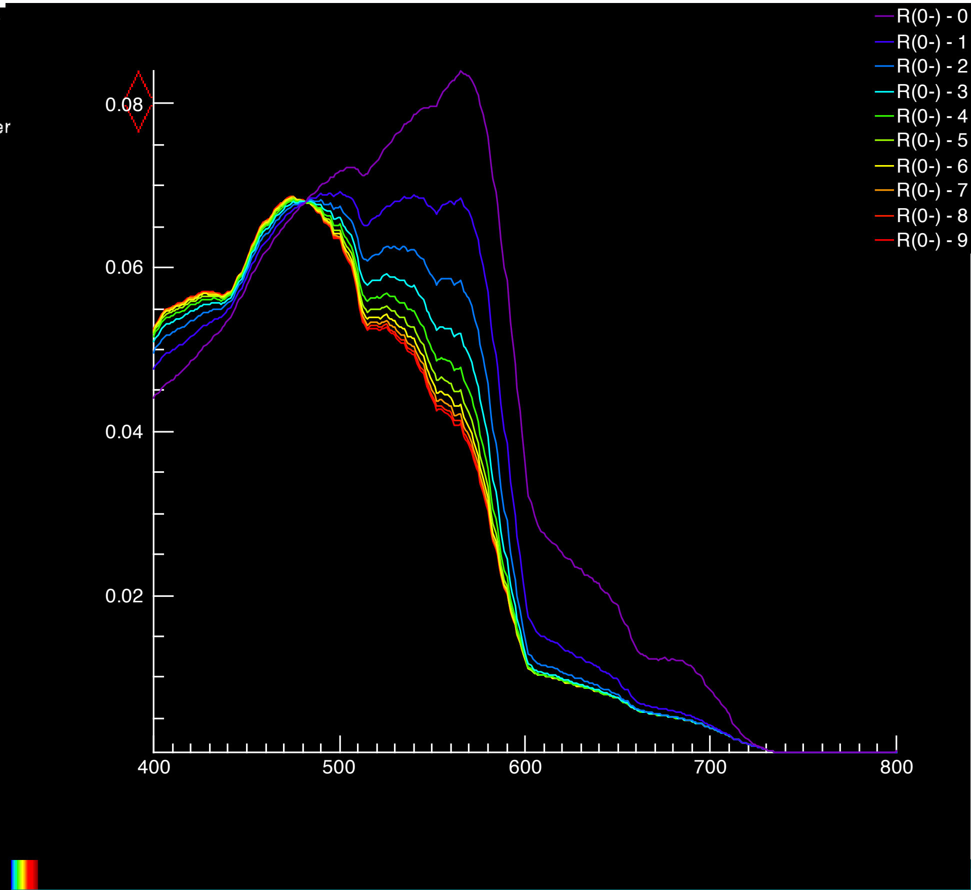
Ratio's	Heron Island	Herald Cays	Lihou Reefs
Heron Island	Mean Reef:Ocean	Mean Reef:Ocean	Mean Reef:Ocean
$a_{(NAP)440}$	1.274	1.589	1.113
$a_{(NAP)*440}$	0.458	1.001	0.824
$a_{(CDOM)440}$	0.925	2.055	1.052
$a_{(phy)440}$	0.342	0.608	0.988
$a_{(phy)*440}$	1.345	1.650	0.703

Ocean IOP parameterisation
2,4,6,…..20 m depth simulations

IOPS

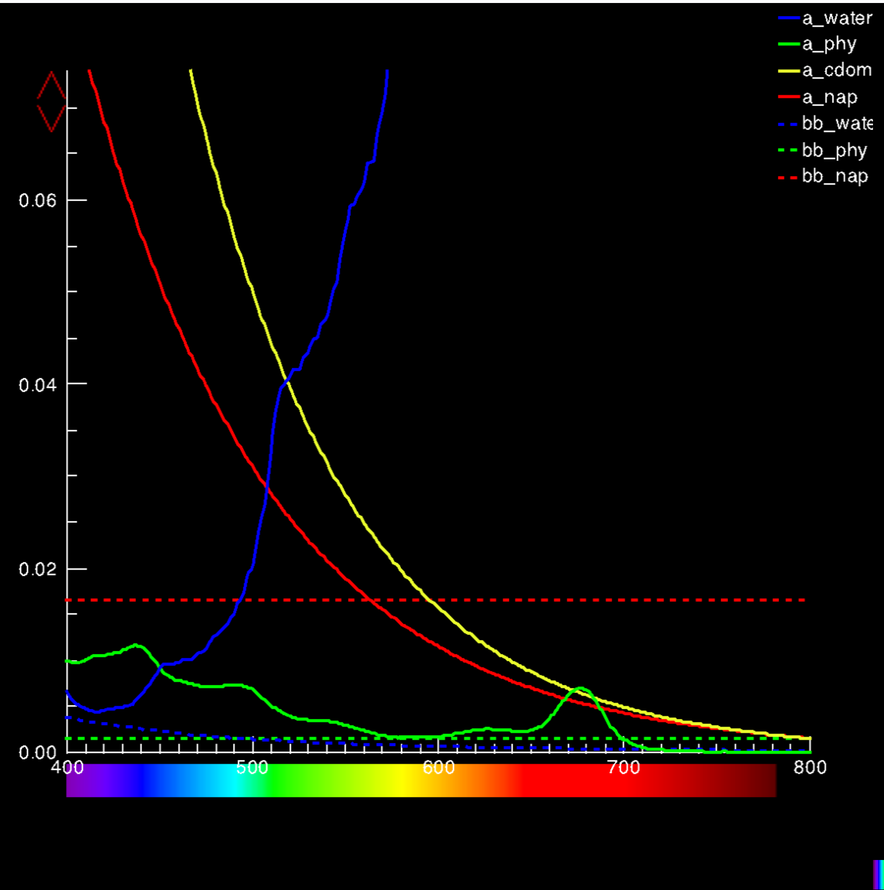


R(0-)



Coral Reef IOP parameterisation 2,4,6,…..20 m depth simulations

IOPS



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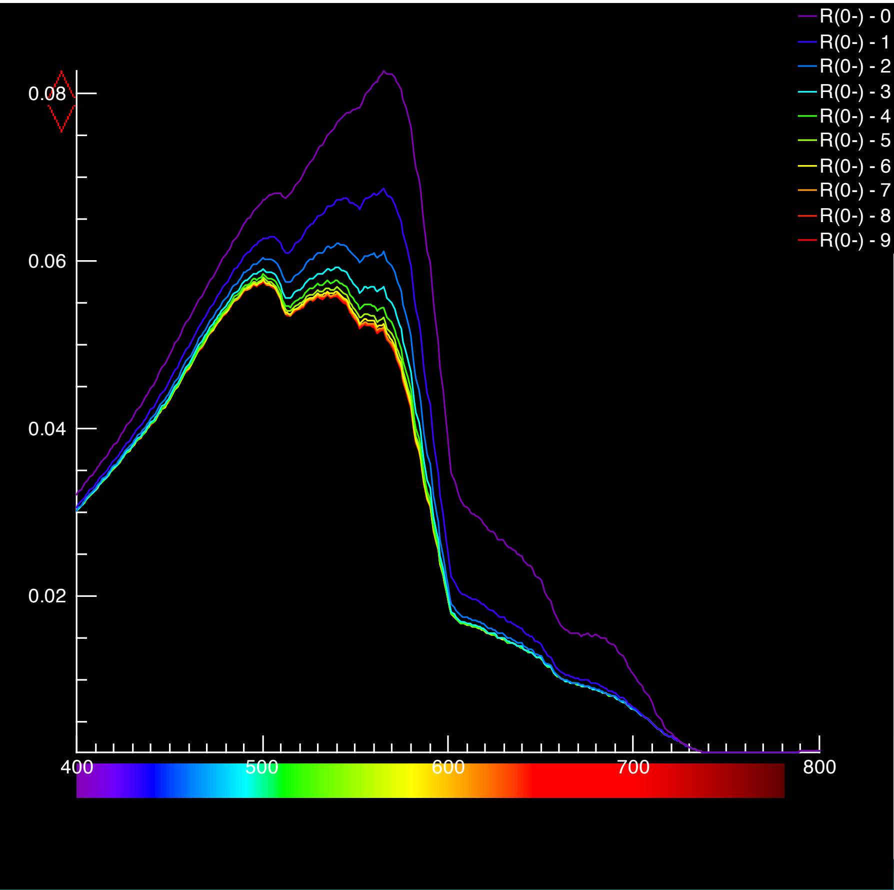
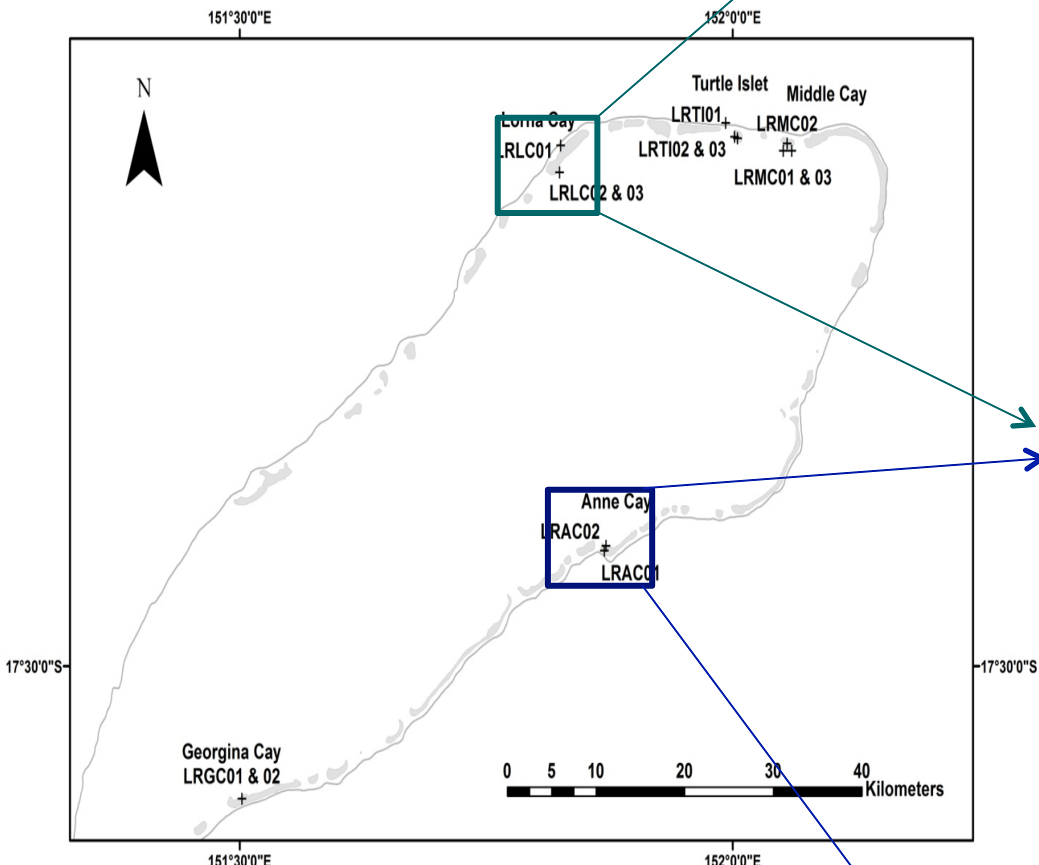


Fieldwork Sites Lihou Reefs



Conclusion optical variability surrounding ocean waters and coral reef waters:

The often published sentence:

……we assumed the ocean water optical properties to be the same over the coral reefs………for: is invalid.

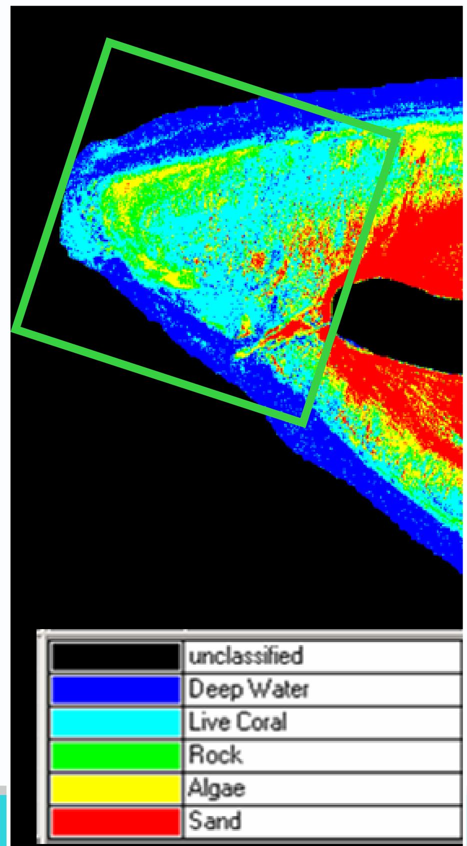
Optical variability of ocean water surrounding coral reefs is variable

Optical variability of coral reef waters is variable

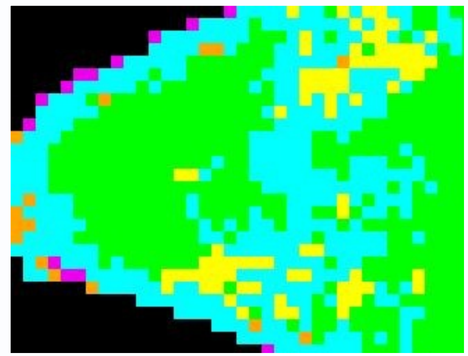
Ocean waters are biogeochemical transformed by coral reefs

SAMBUCA bathymetry map from Hyperion

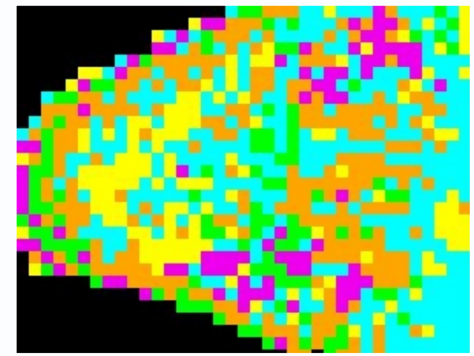
supervised IKONOS classification



SAMBUCA-generated substrate maps using Hyperion data



substrate 1



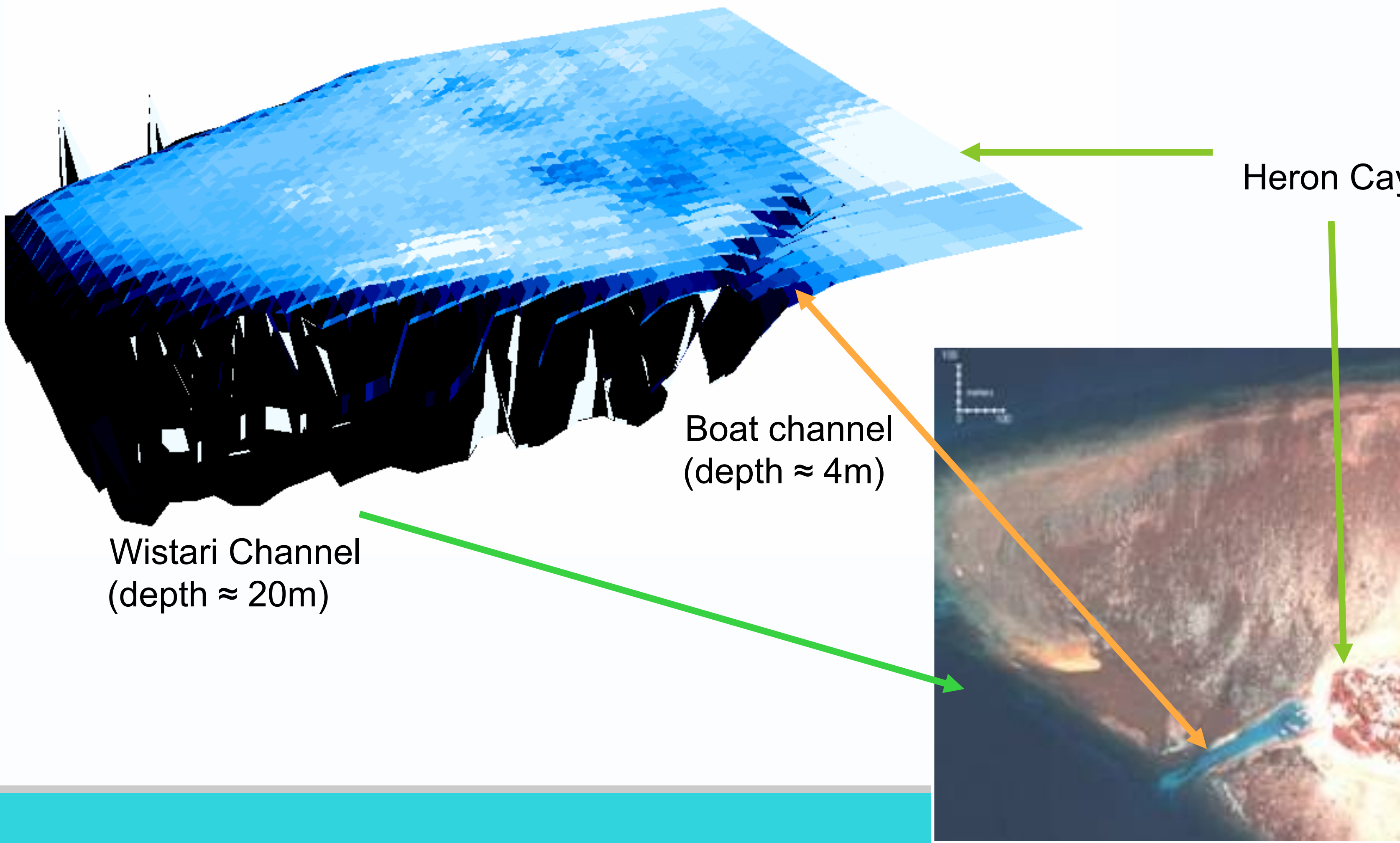
substrate 2

Averaged reflectance library:

- Coral
- Rock
- Algae
- Partially bleached *Acropora sp.*
- Bleached *Acropora sp.*

CSIRO

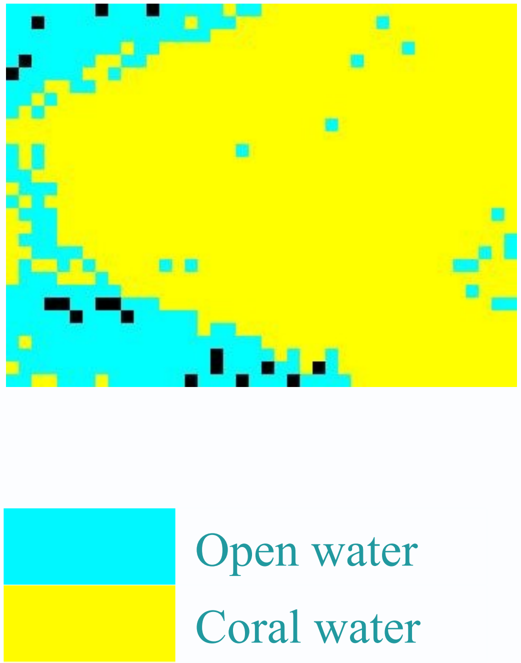
Results SAMBUCA bathymetry map from Hyperion data



Results: optical domain map

IKONOS reference image

SAMBUCA-generated optical domain map using Hyperion data



Recommendations/future work

- Analyse for these three studies:
  - the b_b measurements
  - The HPLC measurements
- Use these results to model the error caused in output of simulations of bio-optical models (using RTF or SA models) and assess the resultant error in:
  - Remote sensing algorithms for simultaneous retrieval of water column IOPS, bathymetry and substratum cover
  - Assessments of primary productivity
  - Assessment of biogeochemical transformations of surrounding (ocean) waters by coral reefs
- For a complex reef platform system such as Lihou Reefs: design a sophisticated field study based on hydrodynamical measurements and modelling and related biogeochemical measurements and modelling

The role of HyspIRI for global assessment of biogeochemical transformations of ocean water by coral reefs (and seagrasses, macro-algae etc.)

- HyspIRI is a key sensor for this purpose:
  - 19 day global revisit; 60 m spatial resolution; Hyperspectral VSNIR and TIR capability;High S:N

This is essential information to understand primary productivity and carbon budgets of coral reef systems

We need to make sure that all coral reefs to 50 m deep are included in HyspIRI data collection

Excellent synergy with ocean colour sensors

- Sentinel-3 and PACE capable of assessing concentrations, IOPS and SIOPS around reef systems
- Sentinel-2 with its 5 day revisit 10, 20 and 60 m multispectral resolution)

Spectral library: if to include sea grass, macro-algae, corals, benthic micro-algae, sand, mud, rubble, detritus ….then metadata fields significantly different from terrestrial, vegetation and mineral spectra!

Acknowledgements:
My co-authors and special recognition to:
Magnus Wettle for doing significant parts of the fieldwork, measurements and analysis for Heron Island and Herald Cays and Young Je Park for Lihou Reefs

Thank you

CSIRO Land & Water: Environmental Earth Observation
Arnold Dekker (BSc., MSc., PhD)

t +61 2 62465821
e arnold.dekker&csiro.au
w www.csiro.au

Adjunct-Professor: Centre for Spatial Environmental Research, University of Queensland