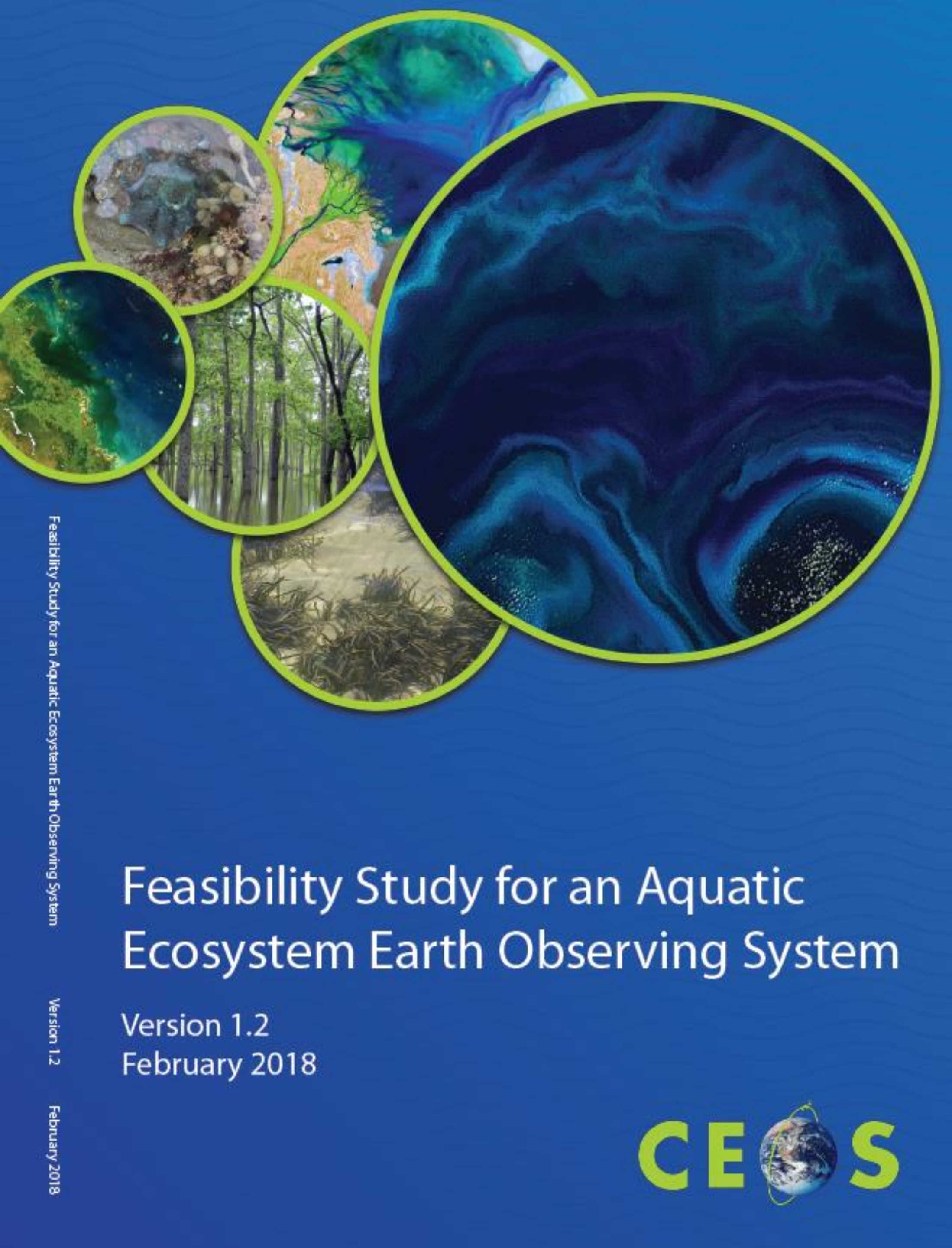

There are (a lot of) terrestrial, ocean and atmospheric sensors….. but none specifically for where ~60% of global population lives and ~60 Trillion U$ of GDP is produced……….

Opportunities for the SA Space Sector

Scope of the Feasibility Study Imaging Spectrometer for (non-Ocean) Aquatic Ecosystems

- One of the GEO Water Strategy recommendations to CEOS was : a feasibility assessment to determine **the benefits and technological difficulties of designing a hyperspectral satellite mission focused on inland water quality measurements**:
- The GEO AquaWatch community proposed to extend the scope to: **(i) a dedicated imaging spectrometer or (ii) augmenting designs of planned spaceborne sensors for terrestrial and ocean colour, to allow improved inland, near coastal waters, benthic and shallow water bathymetry applications**.
- CEOS agencies also requested : augmenting designs of spaceborne sensors for terrestrial and ocean colour applications as**a cost-effective pathway to addressing the same science and societal benefit applications**
- Focus is on a **global mapping mission**

CEOS Team "Feasibility Study Imaging Spectrometer":

Lead: CSIRO - Arnold Dekker; Coordinator: DLR - Nicole Pinnel

Members:

CNES	Marie-Jose Lefevre & Xavier Briottet (France)
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EOMAP	Thomas Heege (Germany)
CNR	Federica Braga, Claudia Giardino & Vittorio Brando (Italy)
NASA	Kevin Turpie & Nima Pahlevan (USA)
CSA	Martin Bergeron & Maycira Costa (Canada)
USGS	Thomas Cecere (USA)
WaterInsight	Steef Peters (Netherlands)
TNO	Andy Court (Netherlands)
CSIRO	Hannelie Botha & Antonio Robles-Kelly (Australia)

Supporting sponsors:

(NSO)	Mark Loos & Joost Carpaaij (Netherlands)
(EC)	Astrid-Christine Koch & Catharina Bamps (European Commission)

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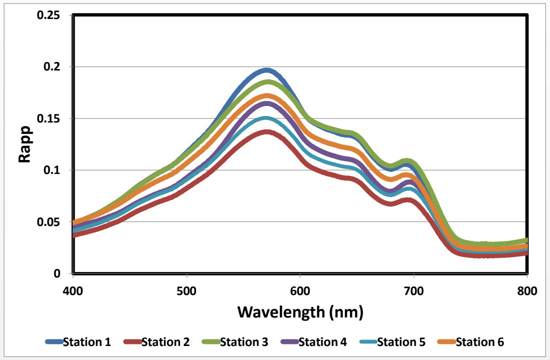
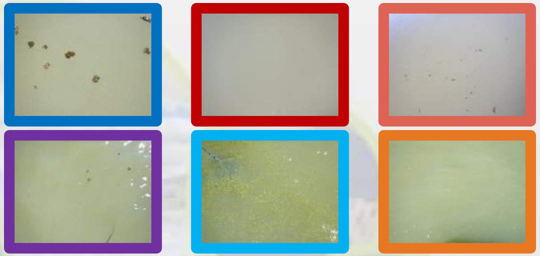
Feasibility Study for an Aquatic Ecosystem Earth Observation System

Available from:http://ceos.org/about-ceos/publications-2/

Inland waters: not so simple: land-water boundaries; lakes at -140 to 4500 m altitude

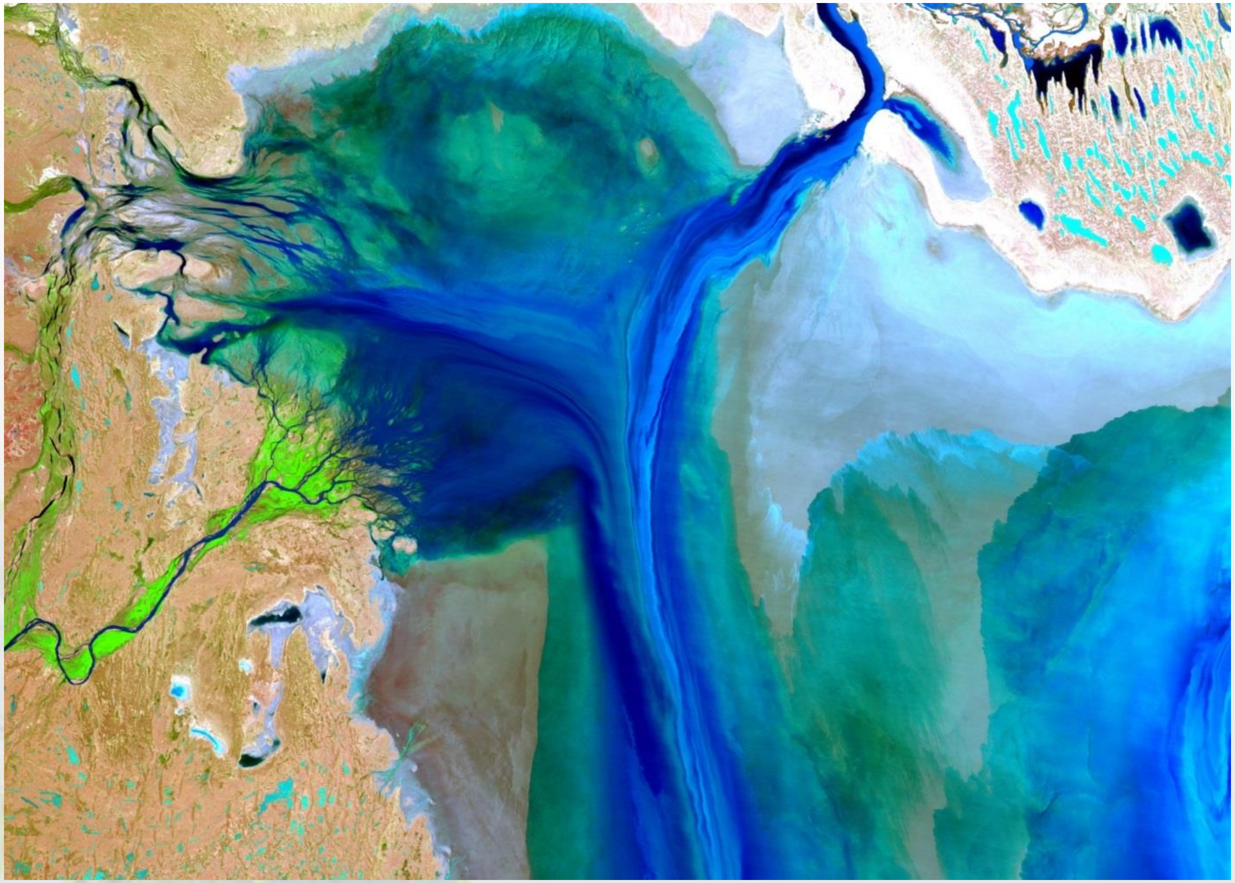
- Reflectance





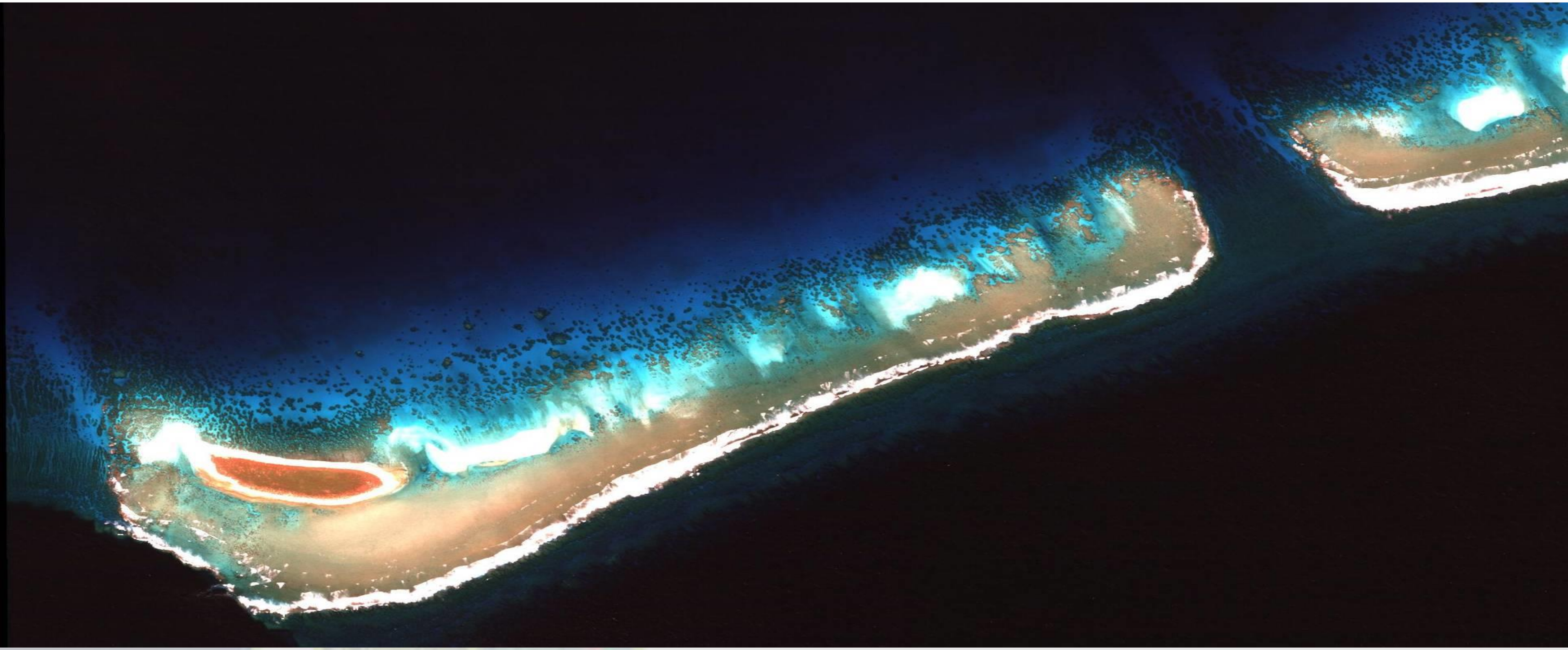
CSIRO

Salt lakes- not so simple (Lake Eyre- Australia after floods)



THE COLOUR OF COASTAL WATERS

Coral reefs: not so simple:
Examples of coral reef habitat and sampling



Seagrass and intertidal: not so simple:

End User Requirements

What do Managers Need from Optical Remote Sensing in Aquatic Ecosystems?

- Status, Condition and Trend & Anomalies:
  - Status (survey, classify and map)
    - o what is where? (=99%of current remote sensing effort)
      - (is it absent when it should be present) or
      - (is it present when it should be absent?)
  - Condition:
    - o is it healthy?, is it stable?
    - o Is it stressed?
  - Trend:
    - o Is it getting worse or is it improving?
      - Remote Sensing can do hind casting and now casting
      - Model data fusion and data assimilation needed for forecasting
  - Anomalies:
    - o Normal (to be expected) or exceptional (indicating exceptional change from before? E.g. climate change indication?)

Variables that can be measured directly using EO in aquatic ecosystems

- Water Column Properties:
  - Chlorophyll-a, Phaeophytin (all photosynthesizing orgs)
  - Cyanophycocyanin & CP-erythrin=>Cyanobacteria
  - Total Suspended Matter
  - Coloured Dissolved Organic Matter
  - Transparency/Turbidity/Vertical Attenuation of Light
- 3-D Information (if the bottom is visible)
  - Bathymetry (depth of substrate)
  - Bottom Relief (topography)

R&D:

- Water Column Properties:
  - Phytoplankton functional types
  - Particle size distributions

Variables that can be measured directly using EO in aquatic ecosystems

- **Benthic substratum**
  - **Coastal: Seagrasses, macro-algae and associated substrates & freshwater: macrophytes and associated substrates**
    - **Extent**
    - **Main species differentiation:** ***if spectrally & spatially discriminable!***
    - **Density of cover; biomass**
  - **Coral Reef and associated substrates**
    - **Extent**
    - **Bleaching**
    - **Main substratum types (Live coral ,dead coral , seagrasses, macro-algae)-main species :** ***if spectrally & spatially discriminable!***

Variables that can be measured directly using EO in supra-to intertidal ecosystems

Intertidal rock platforms and beaches and mudflats

- **Seagrasses, macro-algae, benthic micro-algae and associated substrates & freshwater: macrophytes and associated substrates**
  - **Extent**
  - **Main species differentiation: *if spectrally & spatially discriminable!***
  - **Density of cover; biomass**
- **Inter to Supratidal: saltmarsh, mangroves, floodplains**
  - **Extent**
  - **Main species differentiation: *if spectrally & spatially discriminable!***
  - **Density of cover; biomass**

- Shoreline erosion and flooding
  - Supratidal: from mangrove and saltmarsh via intertidal to subtidal
  - Intertidal zone extent (HAT to LAT)
  - Shallow water bathymetry
- Emergency management
  - Oil & Chemical Spill Response
  - Floods
- Erosion Budgets
  - Effect of land-use changes on run-off
- Eutrophication- Nutrients Fluxes & Budgets
  - Inland waters, bays and estuaries to coral reefs
  - Habitat, water quality, algal blooms
- Carbon Fluxes & Budgets
  - Land to sea fluxes and reservoirs (incl. mangroves, saltmarsh, seagrasses)
- National Environmental Accounts
  - Habitats, State of Environment reporting
  - Reporting on progress towards UN SDG (Sustainable Development Goals)
- Aquaculture
  - Environmental site awareness; long term effects.

Sensor Specifications

From science and applications requirements to design specifications for an EO sensor

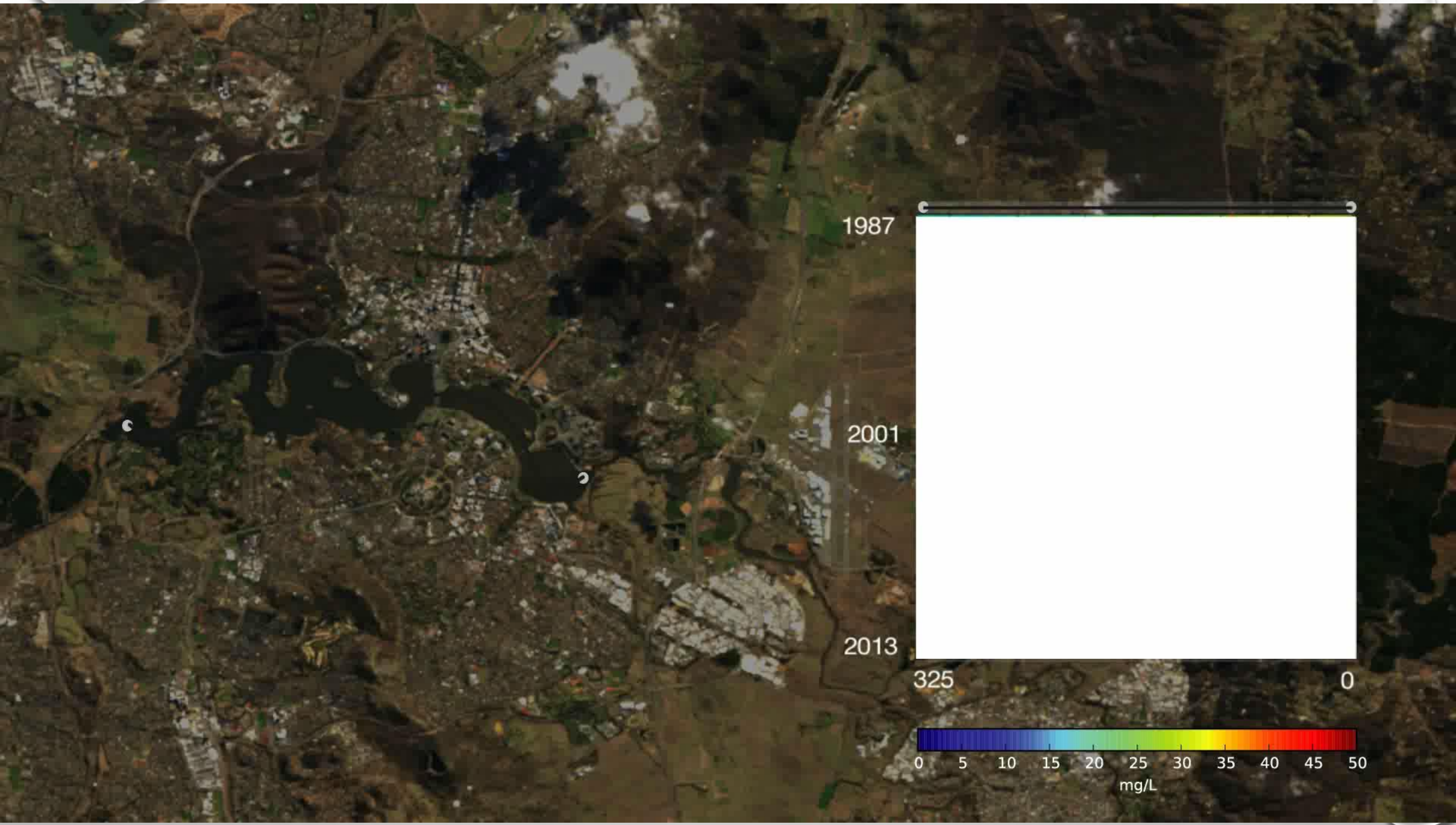
Measurement requirement (B= Baseline, T=Threshold)

- Levels/ranges of the desired aquatic ecosystem variable (e.g. concentration, spatial cover etc.)

- Temporal resolution
- Spatial resolution
- Spectral resolution
- Radiometric resolution

- Geolocational accuracy
- Sunglint avoidance
- Polarisation sensitivity

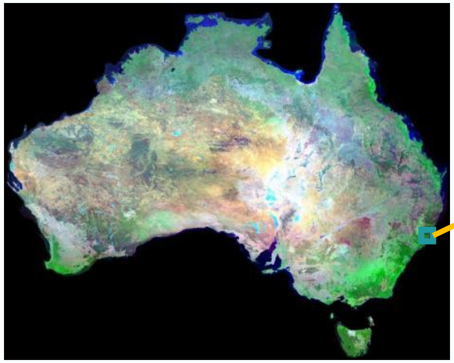
Temporal resolution

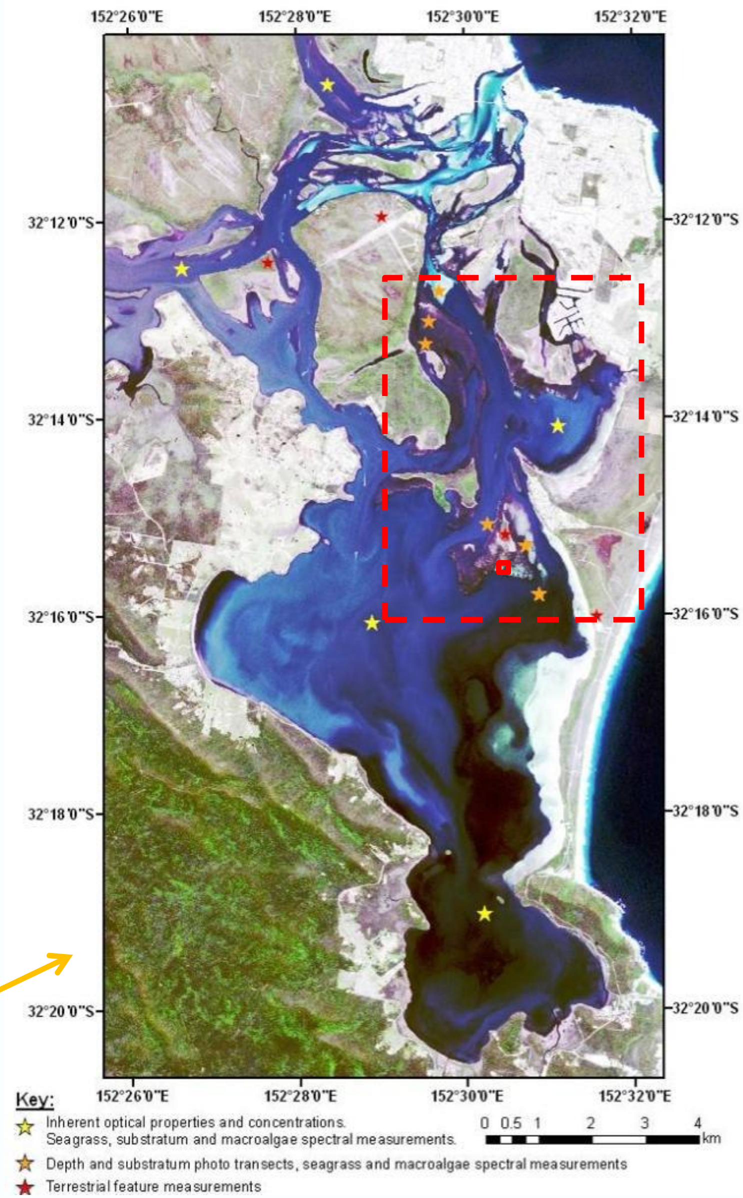

1987
2001
2013
325
0
0 5 10 15 20 25 30 35 40 45 50
mg/L

Spatial resolution

Study area

Wallis Lake, NSW central coast

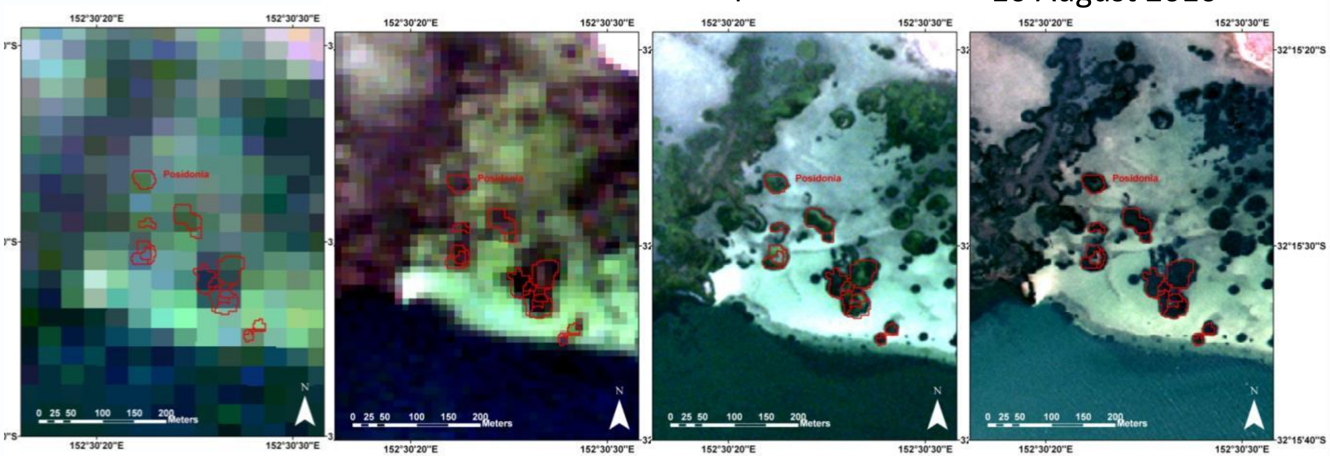




Effects of spatial resolution on feature discrimination:
Question: which most suitable for a global mapping mission?

Low cost → **Higher cost**
Coarse detail → **Fine detail**

Landsat TM5 20 September 2008	ALOS 5 January 2007	QuickBird-2 20 September 2008	WorldView-2 10 August 2010



Spatial resolution:	**30m**	**10m**	**2.6m**	**1.6m**
Spectral Bands:	**4 VIS/NIR, 2 SWIR, 1 ThIR**	**4 VIS/NIR**	**4 VIS/NIR**	**8 VIS/NIR**

Intertidal and supratidal vegetation:

Effects of spatial and spectral resolution on classification

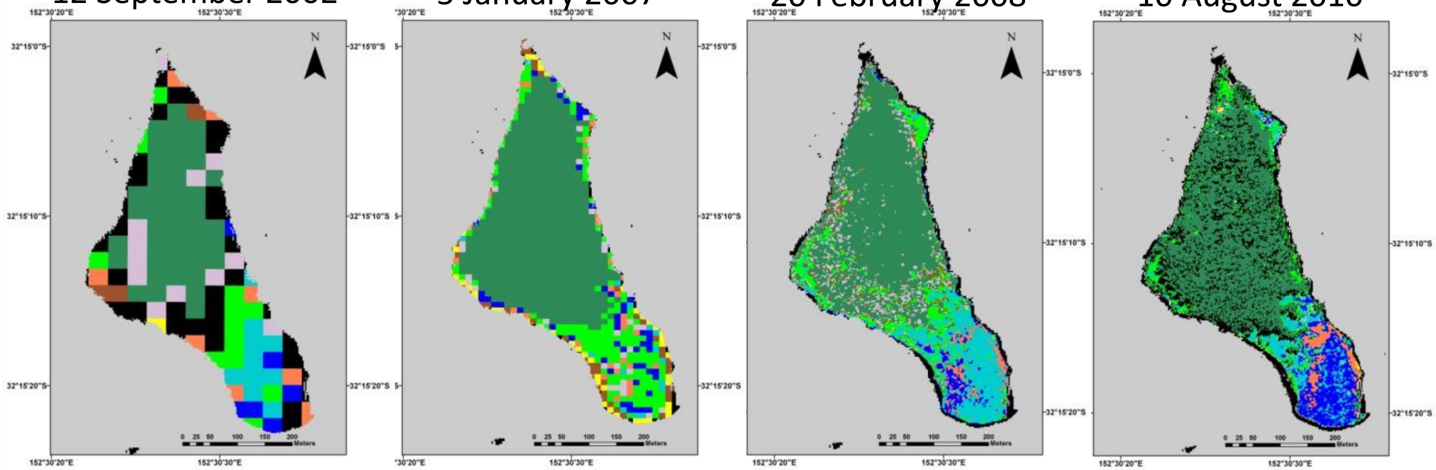
Saltmarsh and Mangrove vegetation classification: Snake Island, Wallis Lake NSW

Landsat ETM 7 — 12 September 2002

ALOS — 5 January 2007

QuickBird-2 — 20 February 2008

WorldView-2 — 10 August 2010



- Seagrass Wrack
- Sand
- *Juncus krausii*
- Water mask
- Mangrove
- Casuarina
- *Sporobolus virginicus*
- Unclassified
- *Suadea australia*
- Succulent salt marsh vegetation

Spatial resolution for inland waters is a key driver for specifications

Table 6.2.

Ground sampling distance requirements showing resolvable size class and total cumulative number and area coverage of the world's lakes (based on assumptions using Verpoorter et al. (2014) dataset). (Courtesy E.L. Hestir & Mark Matthews)

Size Class	Required GSD*	% Total Area	Total number	
≥ 10 km^2	1054 m	44	25,976	Focus of current and future OC sensors
≥ 1 km^2	333 m	60	353,552	
≥ 0.1 km^2	105 m	80	4,123,552	
≥ 0.01 km^2	33 m	90	27,523,552	Focus of this study
≥ 0.002 km^2	15 m	100	117,423,552	

*Calculated using a box of 3 x 3 pixels sufficient to resolve the specified lake size

Ground sampling distance requirements showing the resolvable river width class and cumulative number of total river reaches of the world's rivers from Pavelsky et al. (2012) dataset.

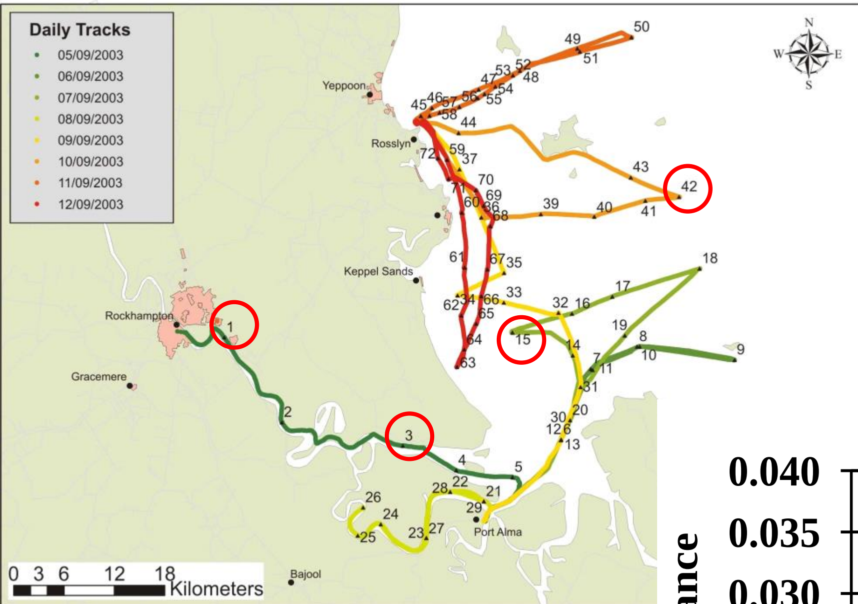
River Reach Size Class (width)	Required GSD*	Total number of reaches	Percent of total reaches	
1.5 km	500	2,877	< 0.1%	
≥ 1 km	333	8,483	<1%	
≥ 0.5 km	167	35,420	1%	Focus of current and future OC sensors
≥ 0.1 km	33	382,466	12%	Focus of this study
≥ 0.05 km	17	766,303	24%	
≥ 0.01 km	3	2,576,452	81%	

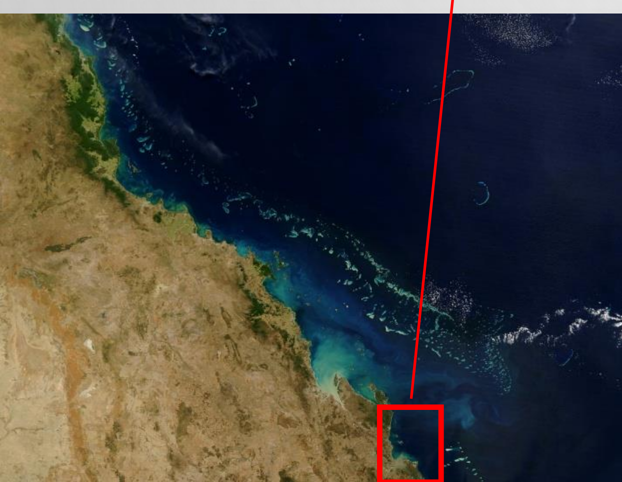
*Calculated using a box of 3 x 1 pixels sufficient to resolve the width of the river reach

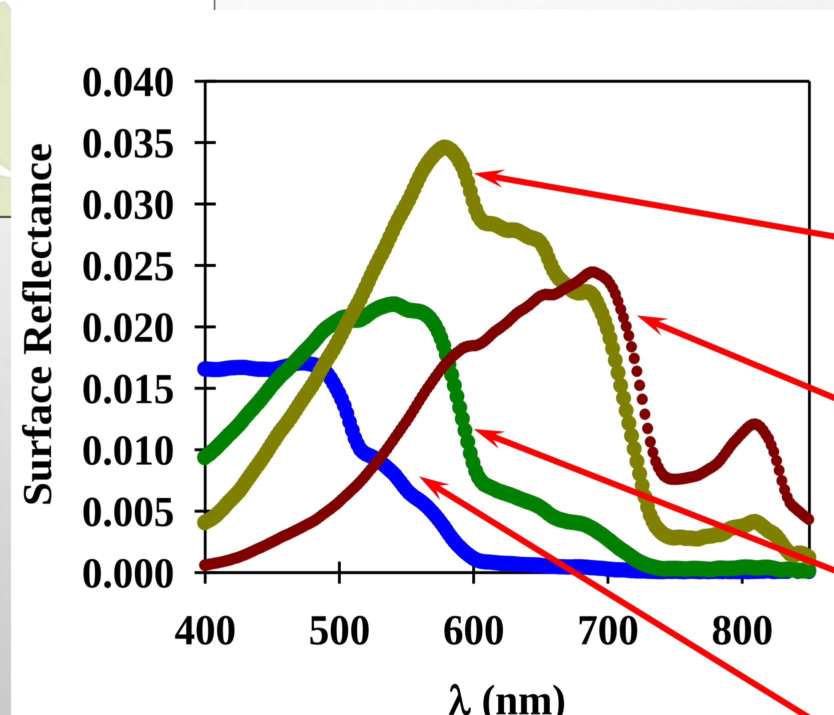
Spectral resolution

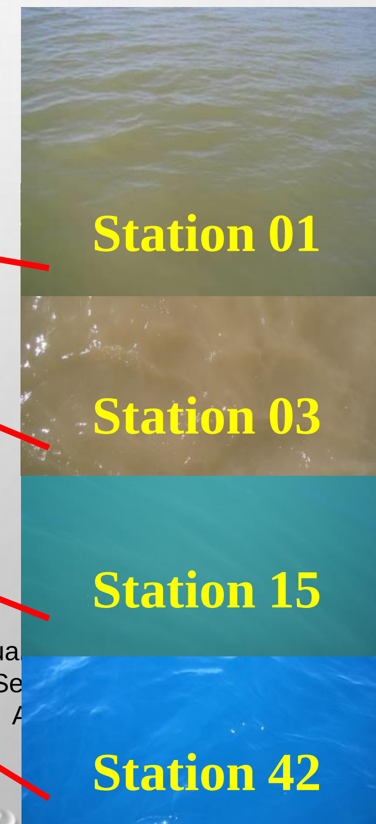
September 03:
Extensive spatial sampling of
IOP and AOP during a 8-day cruise

→ **a system of high variable water types**

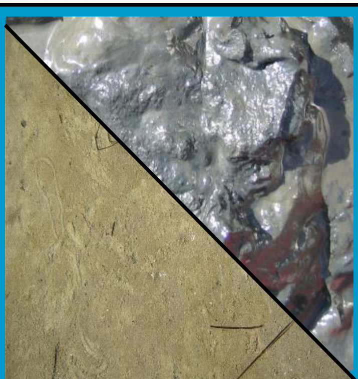






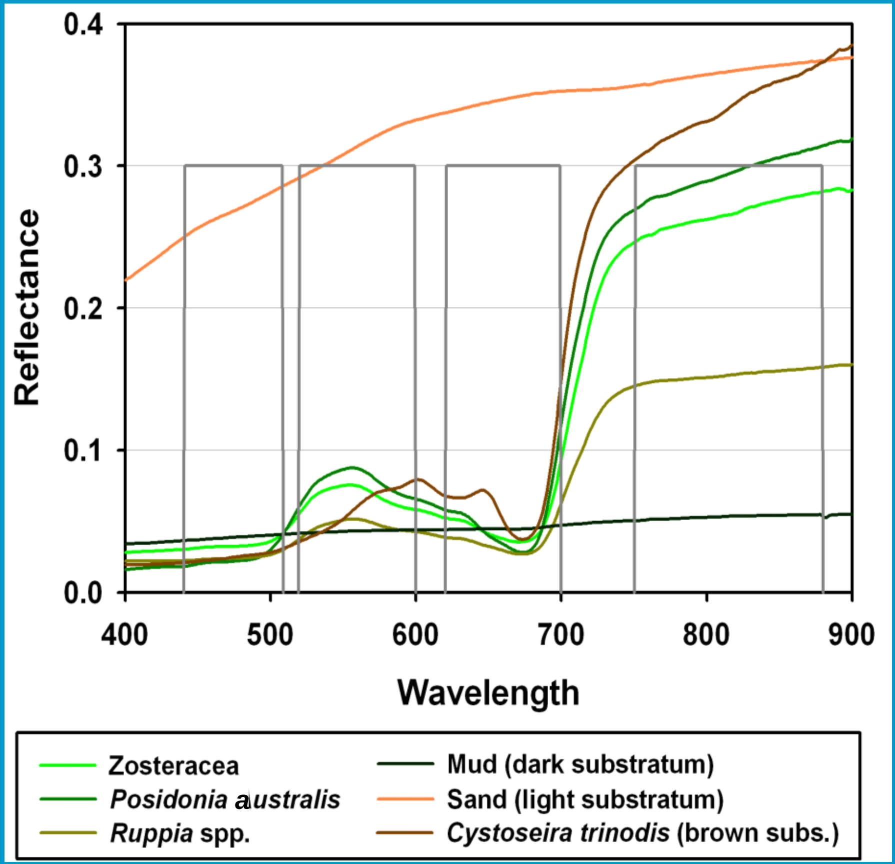


Optical properties of the benthic substratum in Wallis Lake NSW



Sand and mud

Zosteraceae

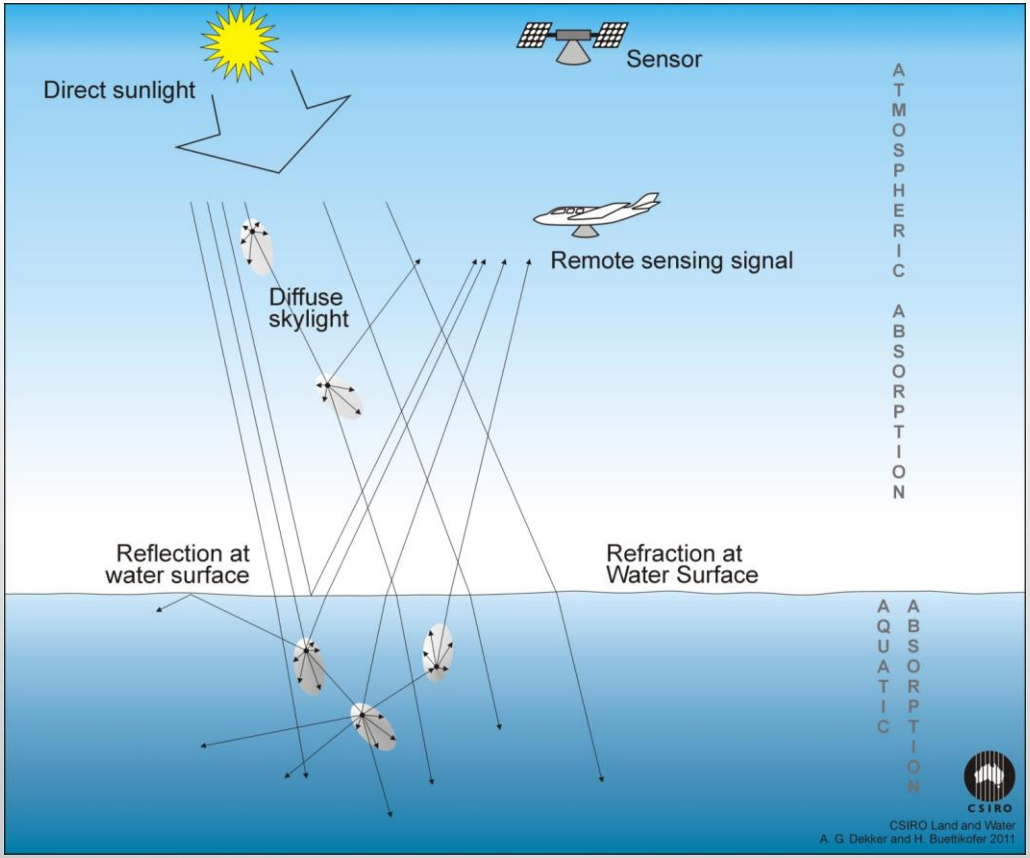


Posidonia australis

Ruppia megacarpa

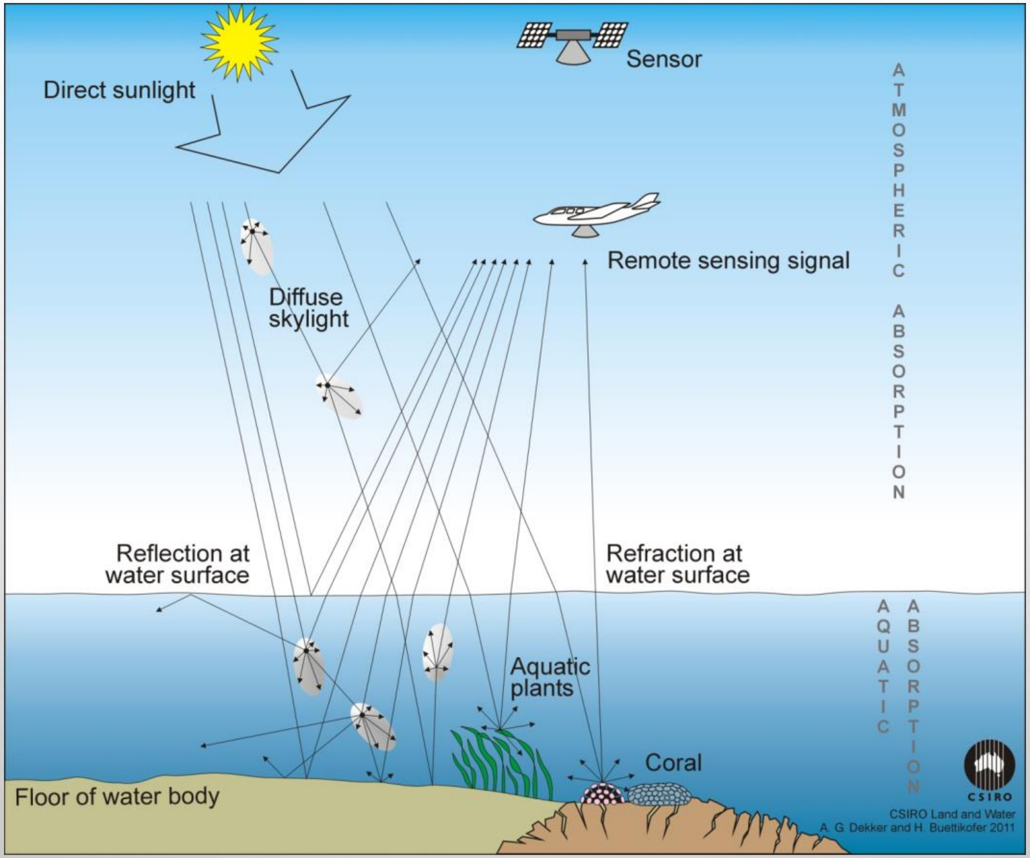
Using Bio-optical modelling across coral reef/seagrass/macro-algae/estuarine/freshwater ecosystems

THE CONCEPTUAL PHYSICS-BASED MODEL FOR OPTICALLY DEEP WATERS



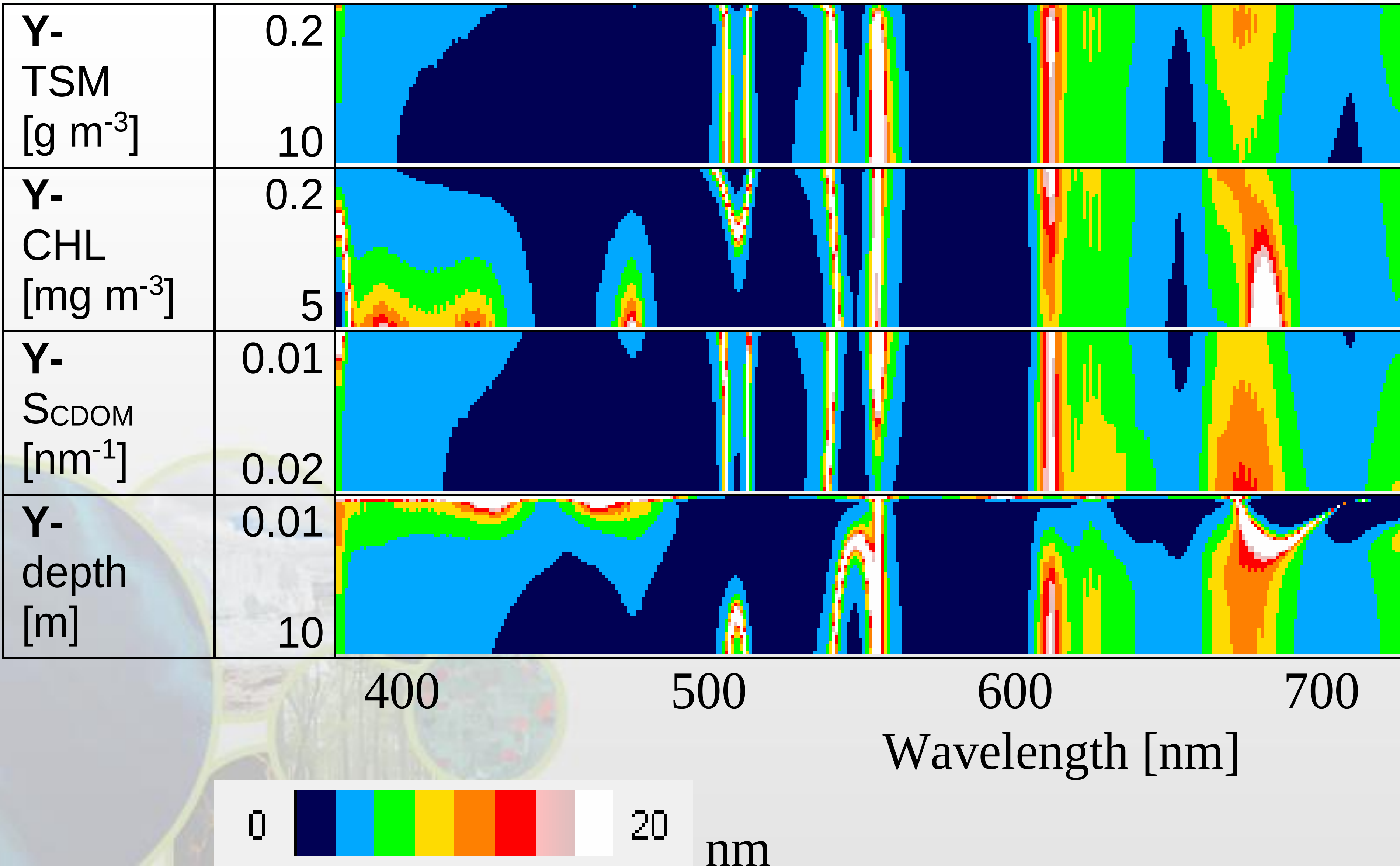
CSIRO

THE CONCEPTUAL PHYSICS-BASED MODEL FOR OPTICALLY SHALLOW WATERS (......OPTICALLY DEEP ON THE RIGHT)



CSIRO

Spectral resolution (in 2.5 nm steps) required to resolve change at low to high variable concentration (standard OAC scenario-optically shallow water)



Summary spectral bands & resolution from: (i) multiple types of simulations, (2) spectral pigment features (from phytoplankton, macrophytes and other benthos), and algorithm requirements

Centre	FWHM	Water quality and benthic characterisation related application	
[nm]	[nm]		
+/-380	15	CDOM (Mannino et al., 2014) ; NAP; PFT (Wolanin et al., 2016); mycosporin-like amino acids (Dupuoy et al., (2008)	1
+/-412	5 to 8	CDOM (Mannino et al., 2014); PFT (Wolanin et al., 2016)	2
+/-425	5 to 8	CDOM ; Blue Chl-a absorption reference band ; NAP; PFT (Wolanin et al., 2016)	3
+/-440	5 to 8	CDOM (Mannino et al., 2014); Blue Chl-a absorption maximum; PFT (Wolanin et al., 2016)	4
467	5 to 8	Band required to separate Pheaocystis from diatoms (Astoreca et al., 2009); Blue Chl-a absorption band reference band; Accessory pigments	5
+/-475	5 to 8	Accessory pigments ; Blue Chl-a absorption band reference band ; PFT (Wolanin et al., 2016), NAP;	6
+/-490	5 to 8	Blue Chl band-ratio algorithm; PFT (Wolanin et al., 2016), Accessory pigments	7
+/-510	5 to 8	Blue Chl band-ratio algorithm ; NAP ;	8
+/-532	5 to 8	PFT & carotenoids (Wolanin et al., 2016); NAP	9
+/-542	5 to 8	NAP	10
555	5 to 8	NAP (as most algal pigments absorptions are low); Cyanophycoerythrin reference band PFT (Wolanin et al., 2016)	11
565	5 to 8	CPE in vivo absorption maximum and possibly fluorescence (Dierssen et al., 2015)	12

		reference band PFT (Wolanin et al., 2016)	
565	5 to 8	CPE in vivo absorption maximum and possibly fluorescence (Dierssen et al., 2015)	12
+/-583	5 to 8	CPE and CPC reference band; chlorophylls a,b and c (Johnsen et al., 1994); CPE fluorescence (Dierssen et al., 2015)	13
+/-594	5 to 8	PFT (Wolanin et al., 2016)	14
+/-615	5 to 8	CPC in vivo absorption maximum (Hunter et al., 2010) -avoiding chlorophyll- c	15
624	5 to 8	CPC in vivo absorption maximum (Dekker, 1993; Simis 2007), suspended sediment, PFT(Wolanin et al., 2016); chlorophyll c (Johnsen et al., 1994)	16
631	5 to 8	PFT (Wolanin et al., 2016)	17
+/-640	5 to 8	NAP, CPC reference band	18
649	5 to 8	Chl-b in vivo absorption maximum (Johnsen et al., 1994)	19
665	5 to 8	FLH baseline (Gower et al., 1999; Gilerson et al., 2008)	20
676	5 to 8	Red Chl-a in vivo absorption maximum (Johnsen et al., 1994)	21
683	5	Chlorophyll fluorescence (FLH) band (Gower et al., 1999; Gilerson et al., 2008)	22
+/-700	5 to 8	HABs detection; NAP in highly turbid water; reference band for 2 or 3 band Chl-a algorithms	23
+/-710	5 to 8	FLH baseline (Gower et al., 2005); HABs detection; NAP in highly turbid water; reference band for 2 or 3 band Chl-a algorithms	24
+/-748	15	NAP in highly turbid water (Ruddick et al., 2006) ; FLH baseline band (Gilerson et al., 2008)	25
+/-775	15	NAP in highly turbid water (Ruddick et al., 2006);	26

Recommended spectral bands for atmospheric correction purposes as well as Non Algal Particulate matter concentration estimation.

centre [nm]	FWHM [nm]	Atmospheric characterisation and air-water interface effect removal bands	
+/- 360	8	To constrain the SWIR-based aerosol model over turbid waters	1
+/- 368	8	To constrain the SWIR-based aerosol model over turbid waters	2
+/-412	8	NO2	
+/-520	8	Aerosol retrieval	3
+/-575	8	Chappuis band for O3 absorption(Gorshelev et al.(2014)	4
+/-605	8	Chappuis band for O3 absorption (Gorshelev et al.(2014)	5
+/-620	8	Aerosol retrieval	
+/-709	8	Aerosol retrieval	
+/-740	8	Sun glint removal	
+/- 761	3	Sun glint removal	6
+/-775	16	Aerosol retrieval; water vapour reference band	7
+/-820	16	Water vapour absorption	8
+/-865	16	Aerosol retrieval; water vapour reference band; sunglint removal; (Dogliotti et al., 2015)	9
+/-940	16	Water vapour absorption	10
+/-1020	16	water vapour reference band	11
+/-1050	16	water vapour reference band	12
+/-1130	16	Water vapour absorption	13
+/-1135	16	Water vapour reference band	14
+/- 1380	16	Cirrus clouds	15

CEOS Report : “Feasibility Study for an Aquatic Ecosystem Earth Observation System: Summary

1. Spectral and spatial resolution are the core sensor priorities

- Spectral
  - ~26 bands in the 380-780 nm wavelength range for retrieving the aquatic ecosystem variables
  - ~15 spectral bands between 360-380 nm and 780-1400 nm for removing atmospheric and air-water interface effects.
  - These requirements are very close to defining an imaging spectrometer with spectral bands between 360 and 1000 nm (suitable for Si based detectors), possibly augmented by a SWIR imaging spectrometer.
- Spatial-
  - ~17 m pixels resolves ~25% of river reaches globally
  - ~33 m pixels resolves the vast majority of water bodies (lakes, reservoirs, lagoons, estuaries etc.) large than 0.2 ha
  - Still maintains radiometric sensitivity

2. Radiometric resolution and range and temporal resolution need to be as high as is technologically and financially possible.
3. A high temporal resolution could be obtained by a constellation of Earth observing sensors e.g. in a various low earth orbits augmented by high spatial resolution geostationary sensors.

The Market

- How large is the market: massive (10's billion $'s) (monitoring (local, regional, state, nation, continent, global), assessment, state of environment, SDG reporting etc)
- How fragmented is the market: highly
- Are there any big players: possibly: WorldBank, Asian Development Bank etc., UN organisations, large NGO's, philantrophic foundations etc.,
- Will they invest up front:?????? Not likely
- National governments, defence, space agencies, aerospace companies
- Will they invest up front:?????? possibly

This is a niche area where Australia has (a significant amount of) expertise: SA space industry opportunity (…in partnership with national and international partners?) Discussion welcome

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