Algorithms for water quality

A view from down under

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DIVISION OF LAND AND WATER & WATER FOR A HEALTHY COUNTRY
www.csiro.au

1st GloboLakes Scientific Workshop | Stirling, UK

Reef

Estuaries

Reservoirs

Rivers

Remote sensing of water colour

Retrieval algorithms exploit the relationship between water colour and biological or optical parameters

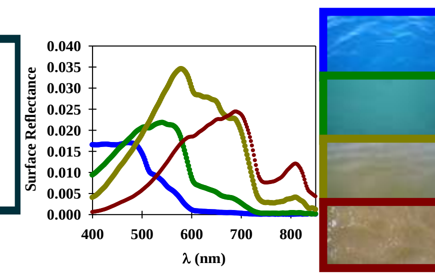
Optically Active Constituents
- Phytoplankton
- Suspended matter
- Coloured dissolved organic matter
- Water itself

Empirical approaches

(statistical methods)

Physics-based approaches

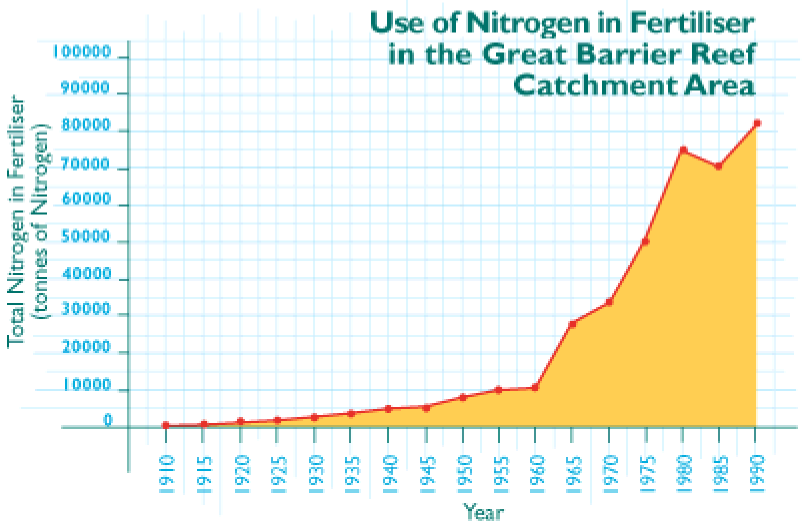
(model inversions)

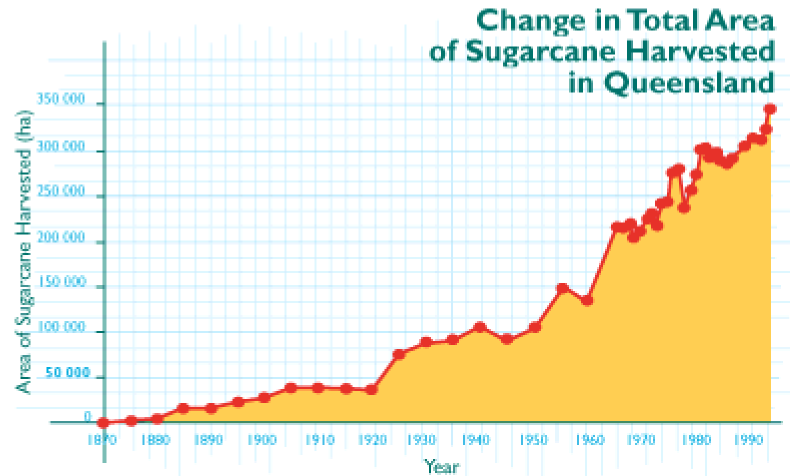


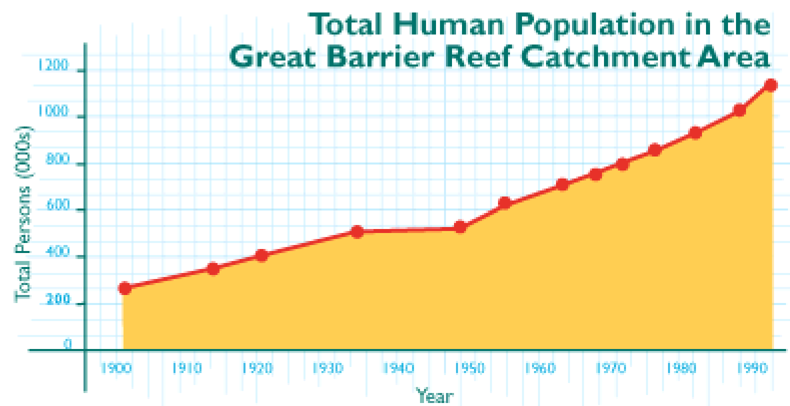
Inherent optical properties
- Absorption (a)
- Scattering (b)
- Beam attenuation (c)
- Volume scattering [β(0)]

Apparent optical properties
- Colour
- Reflectance [$R(0-)$]
- Attenuation (K_d)
- Transparency (Z_{SD})

The Great Barrier Reef: An ecosystem in trouble







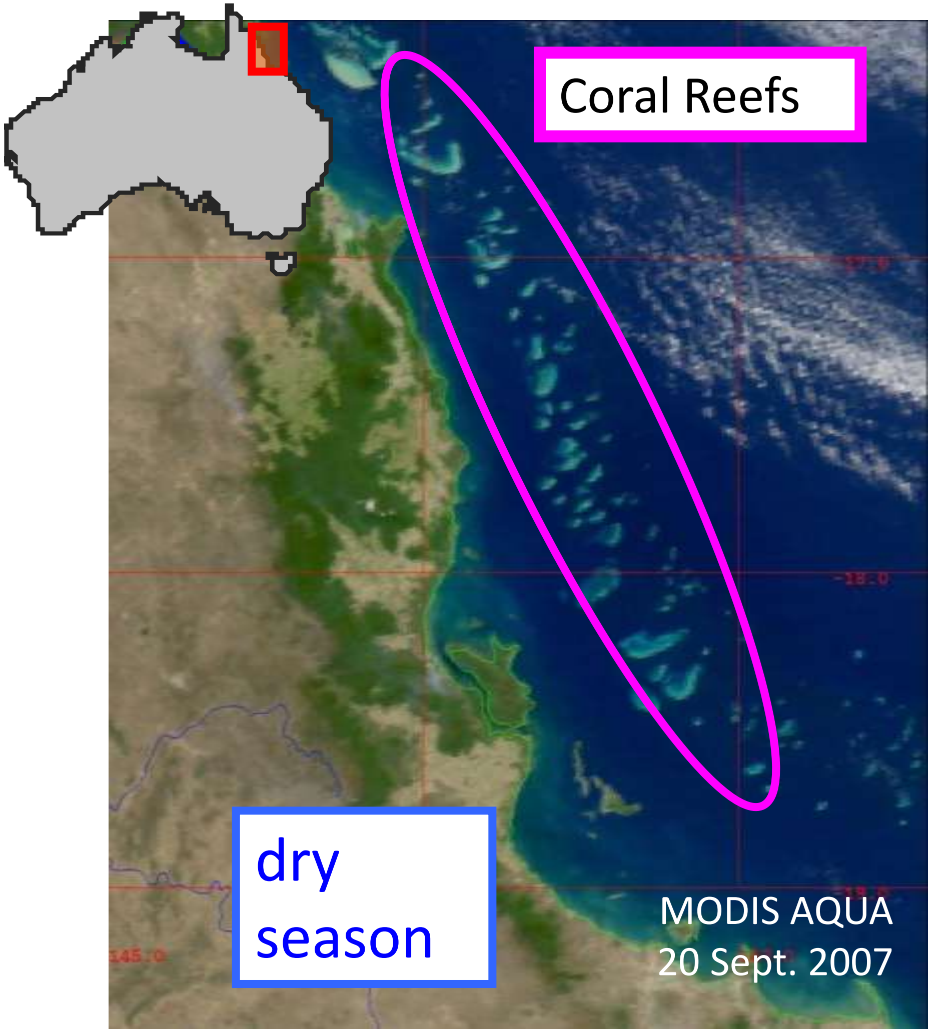
State of the Great Barrier Reef World Heritage Area 1998

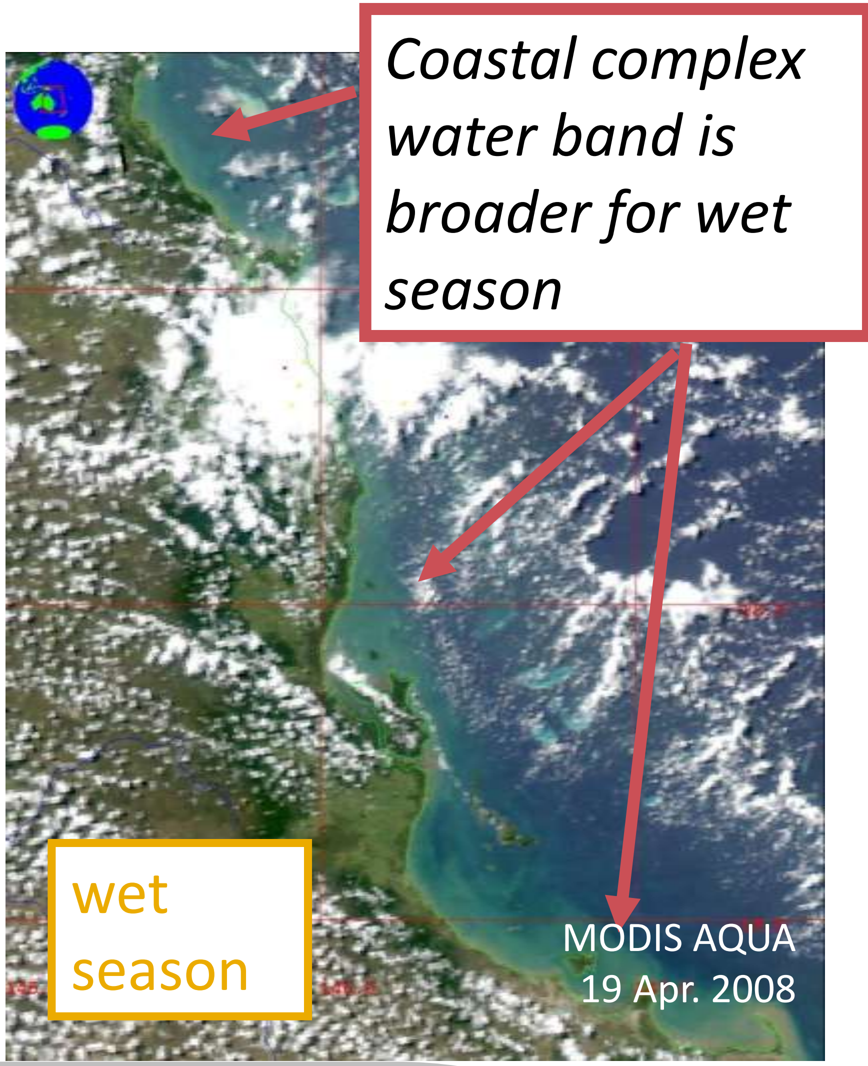
EDITED BY D R Wachenfeld, J K Oliver, J I Morrissey

Optical water quality retrieval for complex waters: application to the Great Barrier Reef

- A physics-based approach
  - Characterize the optical properties of GBR coastal waters
  - Assess validity of NASA's global algorithms
  - Develop regionally valid algorithm
- Translation into management relevant information
  - Engage with stakeholders to understand end-user needs
  - Process 11 years of daily MODIS images at 1 km resolution
  - Deliver water quality data to GBR monitoring programs

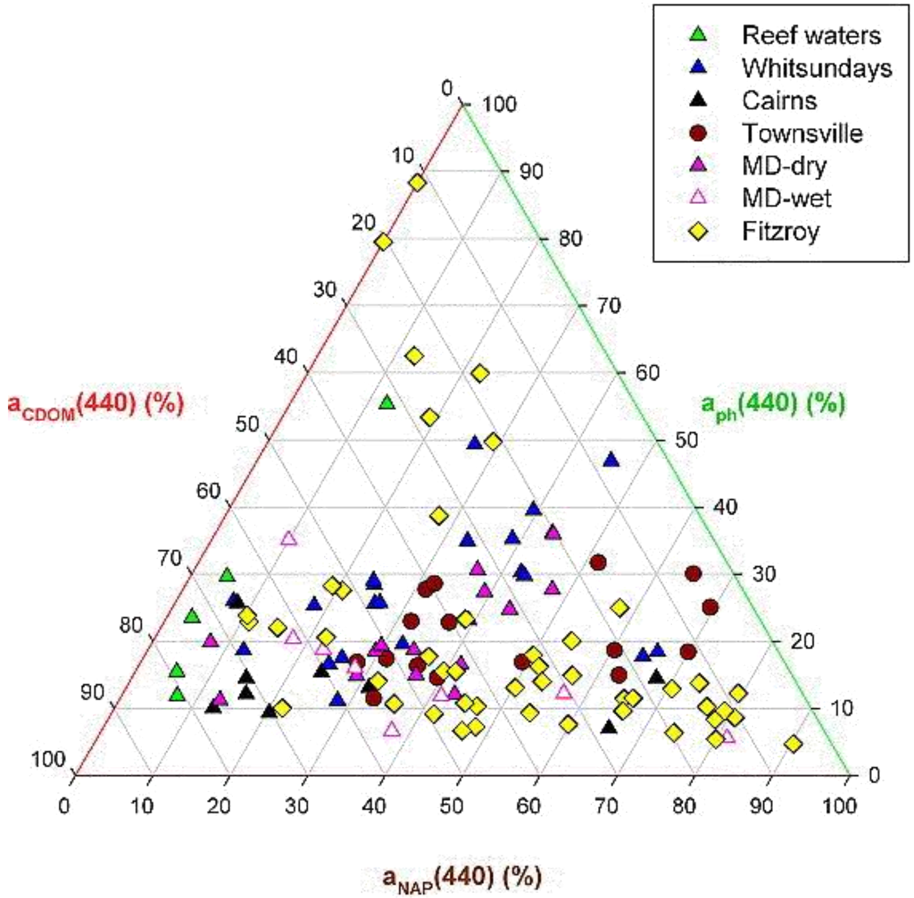
Problem:
Optical complexity spatial & seasonal differences

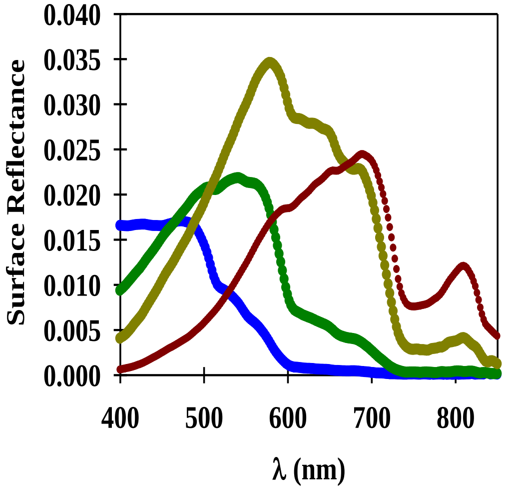


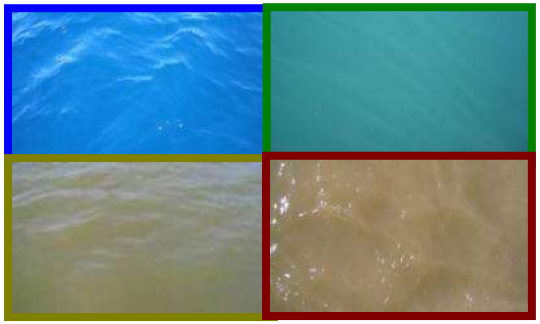


Slide courtesy of Vittorio Brando, CSIRO

Problem:
Optical complexity spatial & seasonal differences







Blondeau-Patissier et al., 2009 JGR

Solution: The adaptive Linear Matrix inversion (a-LMI)

Loop RTE inversion over candidate model parameter sets

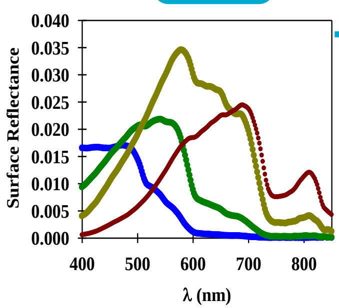
$SIOP_k$ = Candidate model parameter set k

$[a^*_{phy}(\lambda), S_{CDOM}, a^*_{NAP}(440), S_{NAP}, b^*_{bphy}(555), Y_{phy}, b^*_{NAP}(555), Y_{NAP}]_k$

$[C_{CHL}, C_{CDOM}, C_{NAP}]_k = f(r_{rs}^{input}, SIOP_k)$

$\Delta k = \Delta(r_{rs}^{input}, r_{rs}^{model}{}_k)$

r_{rs}

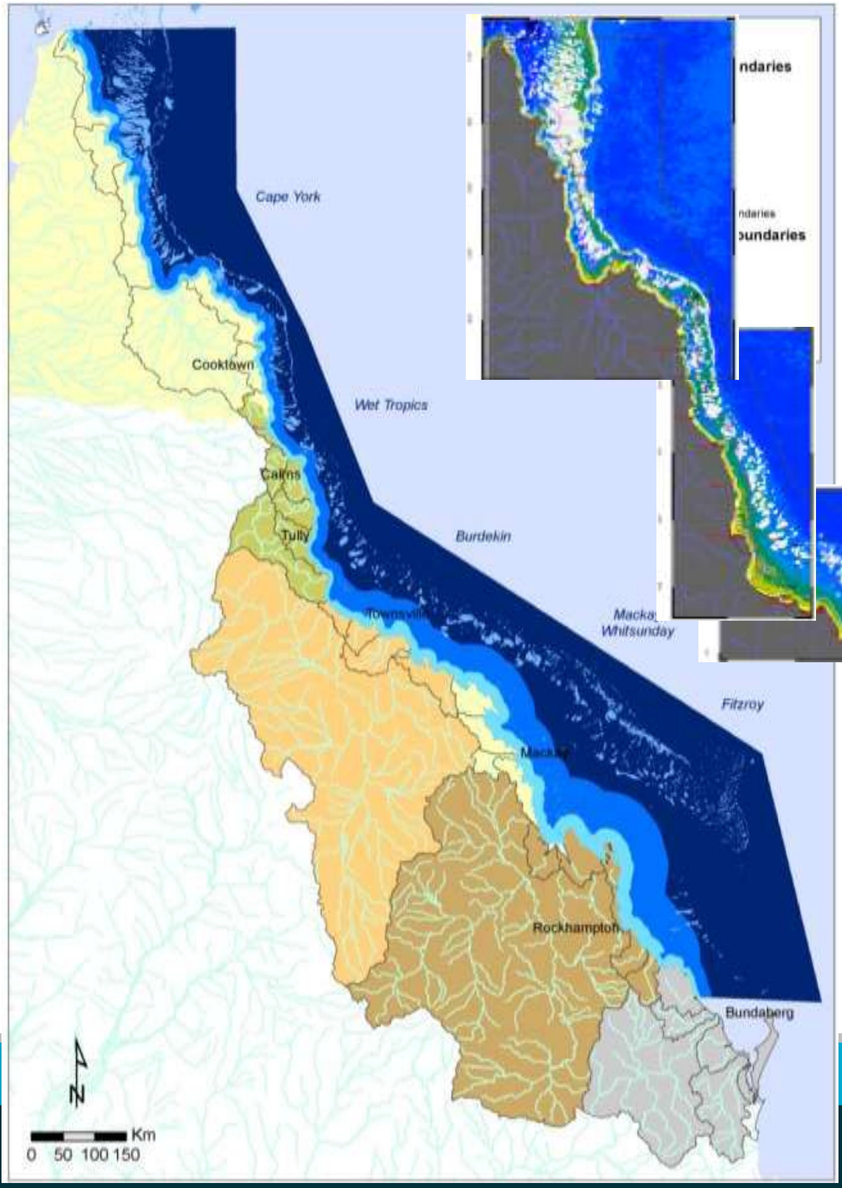


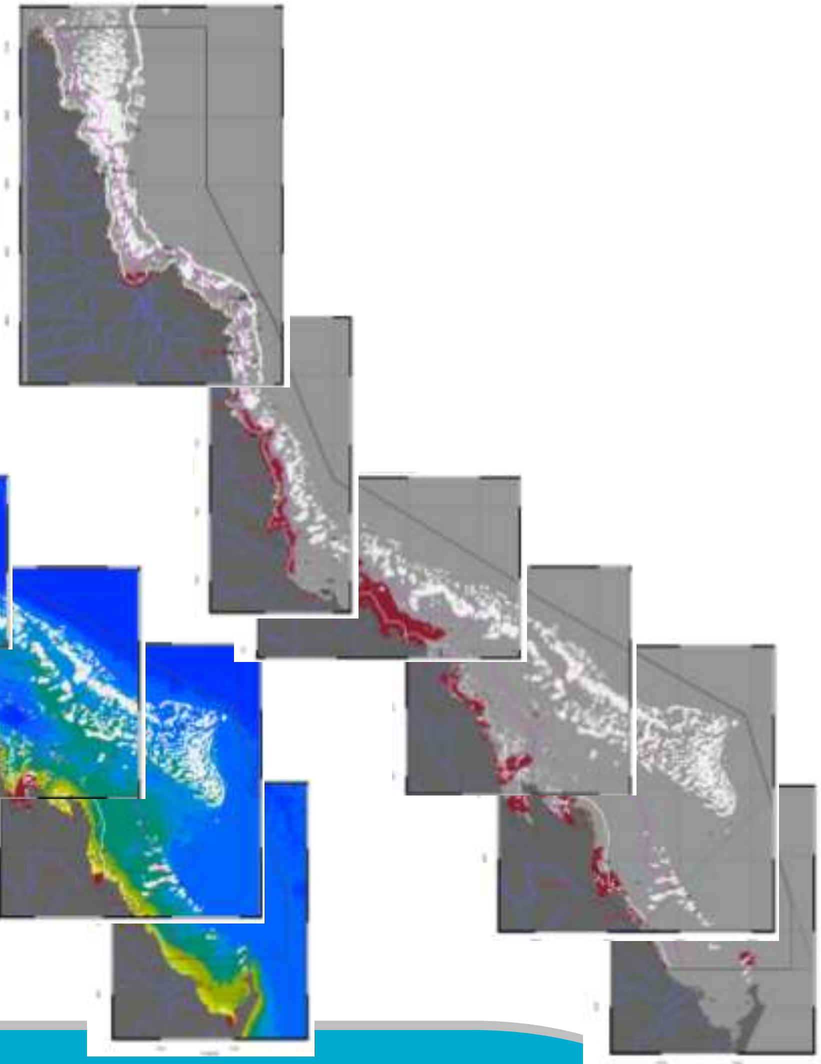
C_{CHL}
C_{CDOM}
C_{NAP}

a_{phy}
a_{CDOM}
a_{NAP}
b_{bphy}
b_{bNAP}

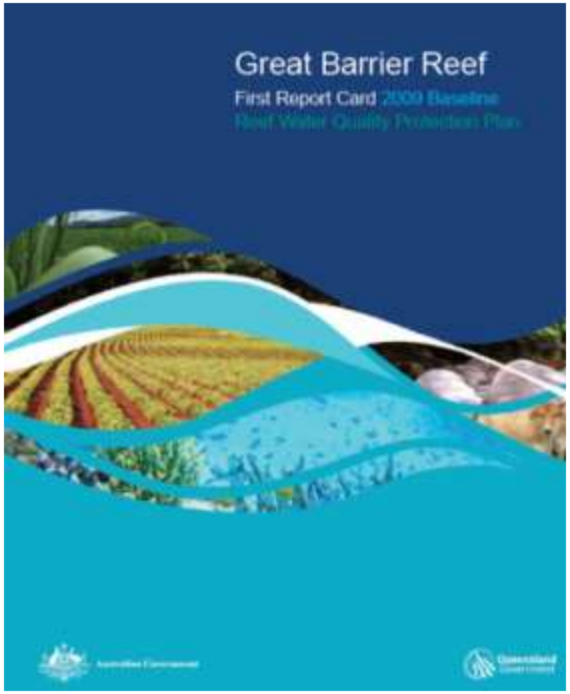
Brando et al, 2012, Applied Optics

MODIS-based wq products





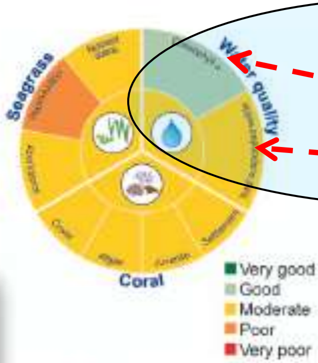
GBR Report card



Marine results

The effects of river discharge into the Great Barrier Reef are largely concentrated into inshore areas up to 20 kilometres from shore. Higher than average wet season rainfall in the Great Barrier Reef catchment occurred between 2007 and 2009, particularly in the Burdekin River catchment. Marine results for 2008–2009 are presented for seagrass, water quality and coral.

Seagrass: Inshore seagrasses are in moderate condition. Seagrass abundance is moderate and has declined over the past five to 10 years, associated with excess nutrients. The number of reproductive structures is poor or very poor in four of the six regions, indicating limited resilience to disturbance.



Water quality: Inshore water quality is moderate overall. Concentrations of total suspended solids range from poor (Burdekin and Mackay Whitsunday regions) to very good (Burnett Mary region).

Pesticides: Pesticides, even at low concentrations, are a significant cause for concern. Of particular concern is the potential for compounding effects that these chemicals have on the health of the inshore reef ecosystem, especially when delivered with other water quality pollutants during flood events.

Waters within 20 kilometres of the shore are at highest risk of degraded water quality. These waters are only approximately eight per cent of the Great Barrier Reef Marine Park, but support significant ecosystems as well as recreation, tourism and fisheries.

Coral: Most inshore reefs are in good or moderate condition, based on coral cover, macroalgal abundance, settlement of larval corals and numbers of juvenile corals. Most inshore reefs have either high or increasing coral cover; however, corals in the Burdekin region are mostly in poor condition.

Water quality: chlorophyll *a* and suspended solids

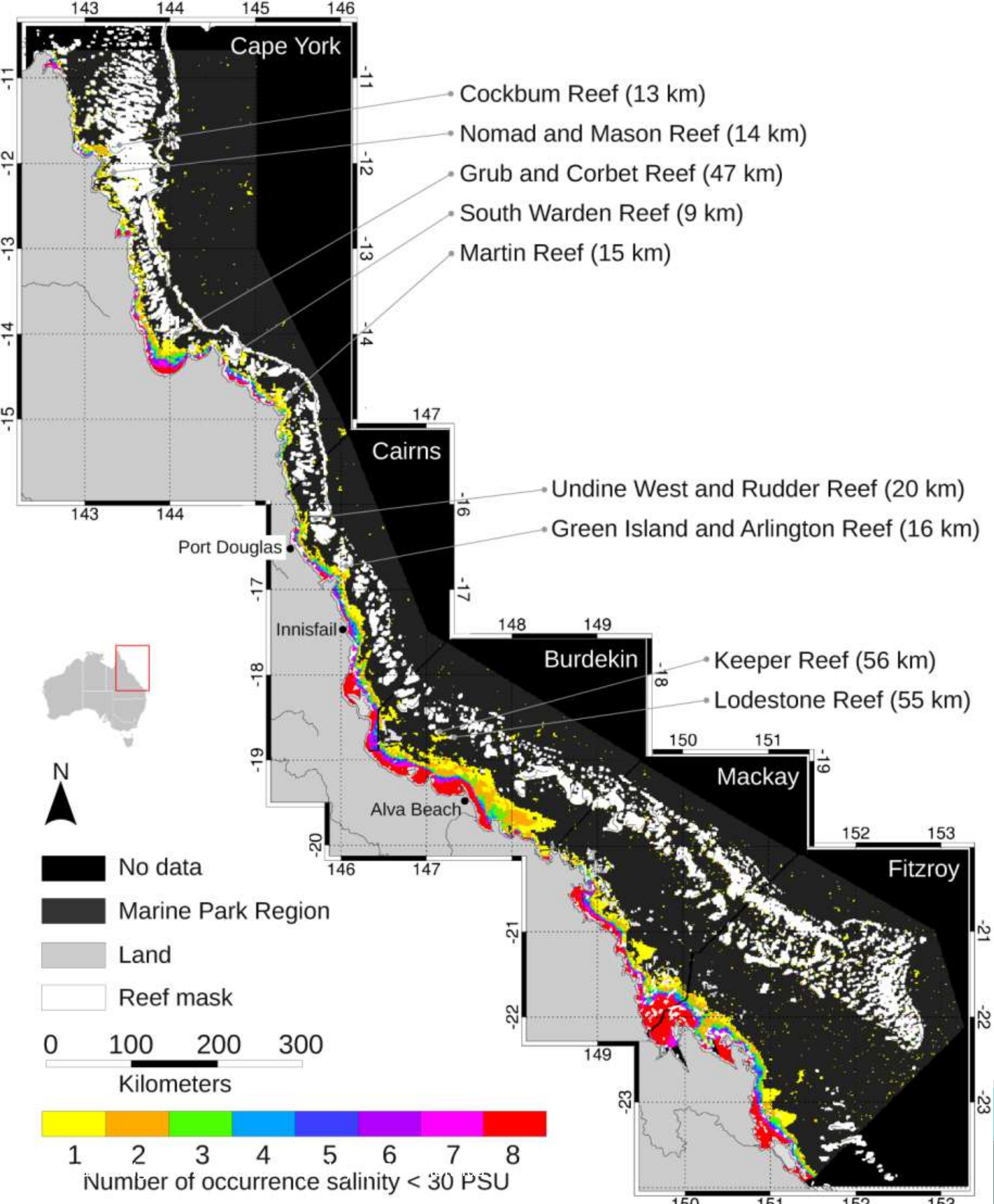
Chlorophyll *a* is used as an indicator of nutrient loads in the marine system. Data analysed from satellite imagery showed that inshore waters in the Wet Tropics and Burdekin regions had elevated concentrations of chlorophyll *a* over the monitoring period (Table 5.9).

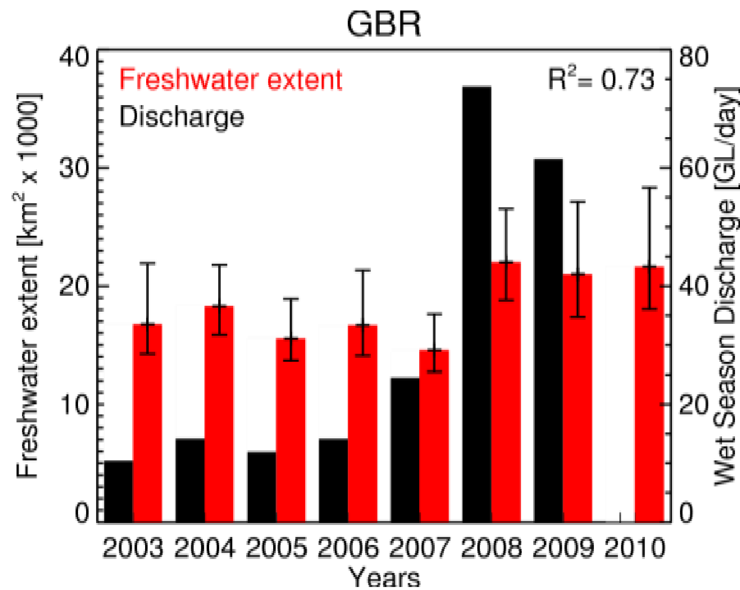
The satellite data also showed that highest concentrations of suspended solids were recorded at inshore areas of the Cape York, Burdekin and Mackay Whitsunday regions. High concentrations of suspended solids were also recorded in midshelf and offshore waters in the Mackay Whitsunday region. It should be noted that the Cape York remote sensed water quality data requires further validation.

Table 5.9 – Summary of the exceedance of mean annual chlorophyll *a* and non-algal particulate matter as a measure of suspended solids using remote sensing data (retrieved from MODIS AQUA) for the inshore, midshelf and offshore waterbodies (1 May 2008–30 April 2009).

	Chlorophyll *a*: relative area (%) of the waterbody where the annual mean value exceeds the water quality guideline value			Suspended solids: relative area (%) of the waterbody where annual mean value exceeds the water quality guideline value		
Region	Inshore	Midshelf	Offshore	Inshore	Midshelf	Offshore
Cape York	41	2	0	55	39	13
Wet Tropics	57	9	0	41	13	12
Burdekin	54	1	0	65	5	3
Mackay Whitsunday	24	3	0	74	42	50
Fitzroy	35	2	0	35	2	0
Burnett Mary	27	2	0	13	2	3

Whole GBR: 2002/03-2009/10



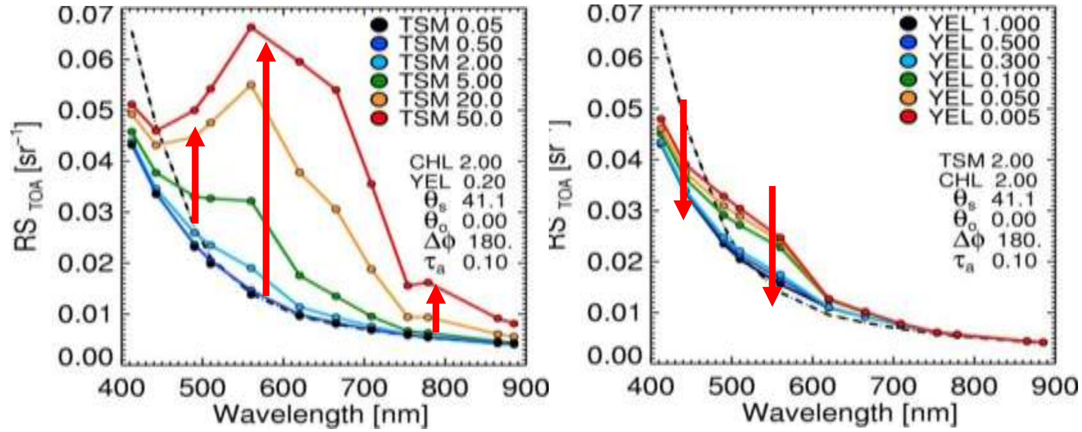


Schroeder et al. 2012, Mar. Poll. Bull.

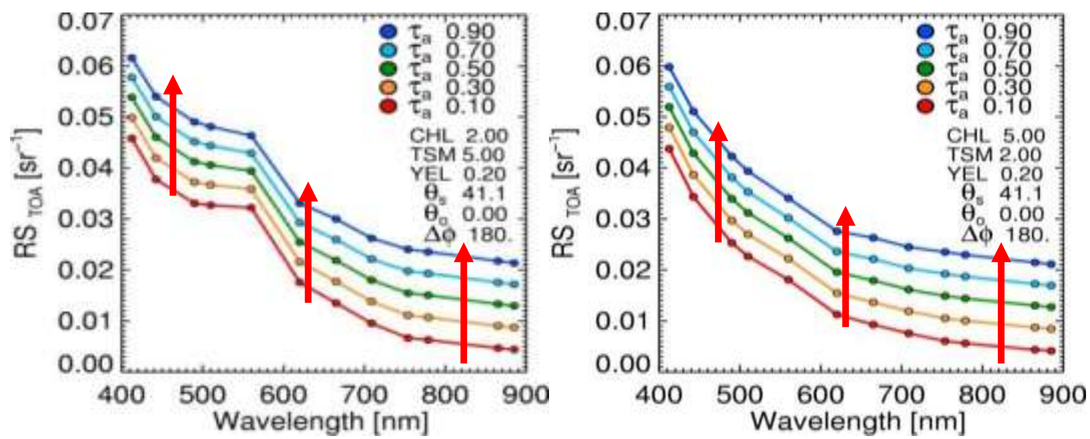
Problem: atmospheric correction over optically complex waters

Simulated top-of-atmosphere spectra over coastal waters

... depending on variations of the water constituents



... depending on variations of the type and concentration of the aerosol



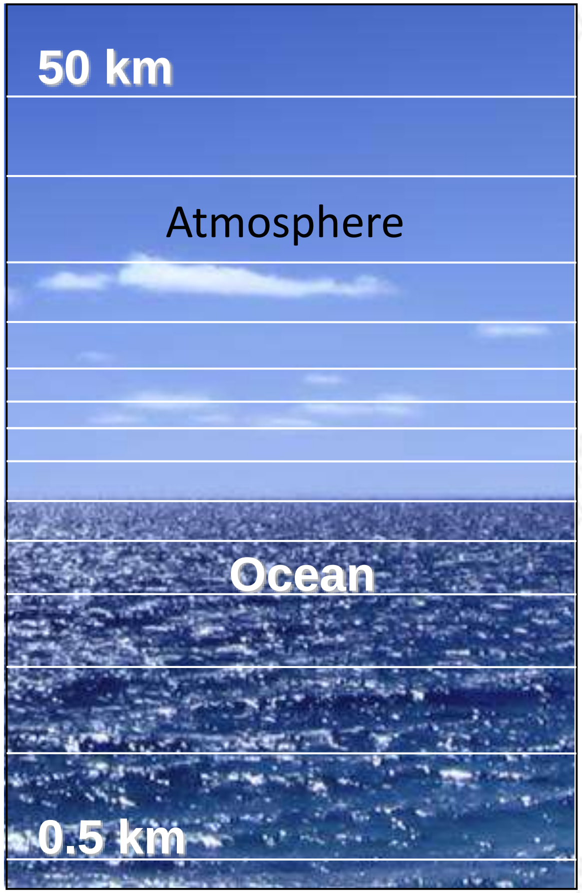
Schroeder et al. 2007. IJRS

Solution: Integrated inverse RT

Forward model parameterisation

Coupled radiative transfer model based on matrix-operator method (FUB)

Simulates the upward azimuthally resolved radiance field



- Vertical profile (US-Standard)
- Ozone (344 DU)
- Rayleigh (980hPa, 1040hPa)
- Aerosols (8-Types)
- Optical depths (5)
- Single scattering albedos
- Phase functions

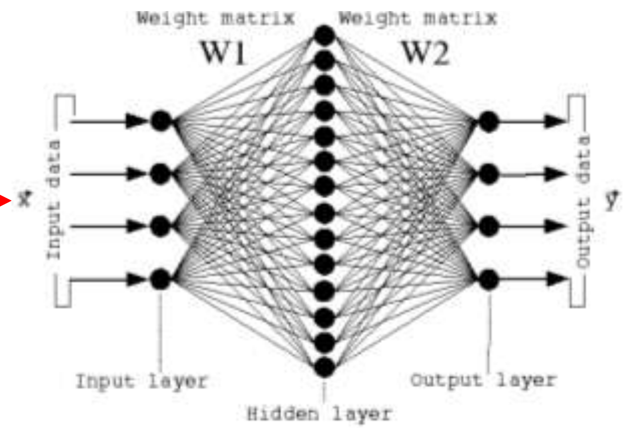
- Vertical homogenous mixing of CHL, TSM, YEL
- No bottom-up effects (optically deep water)
- Phase functions
- $a=a_w+a_{p1}(CHL)+a_{p2}(TSM)+a_y(YEL)$
- $b=b_w+b_{p1+p2}(TSM)$

Slide courtesy of Thomas Schroeder, CSIRO

Solution: Integrated inverse RT

Inverse model (Atmospheric correction)

$$\vec{y} = S_2 \times \left\{ \mathbf{W}_2 \times S_1 \left(\mathbf{W}_1 \times \vec{x} \right) \right\}$$



$$x = \sin(\theta_o)\,\cos(\Delta\phi)$$
$$y = \sin(\theta_o)\,\sin(\Delta\phi)$$
$$z = \cos(\theta_o)$$

Input: Top-Of-Atmosphere (TOA)

$$[illegible] = [RS_{\mathrm{TOA}}(\lambda_{[412.5-869.5\,\mathrm{nm}]}),\ x,\ y,\ z,\ \cos(\theta_{\mathrm{SUN}}),\ P\,]^{\mathrm{T}}$$

TOA reflectance bands 8-16 | Sun/Obs geometry | Surface pressure

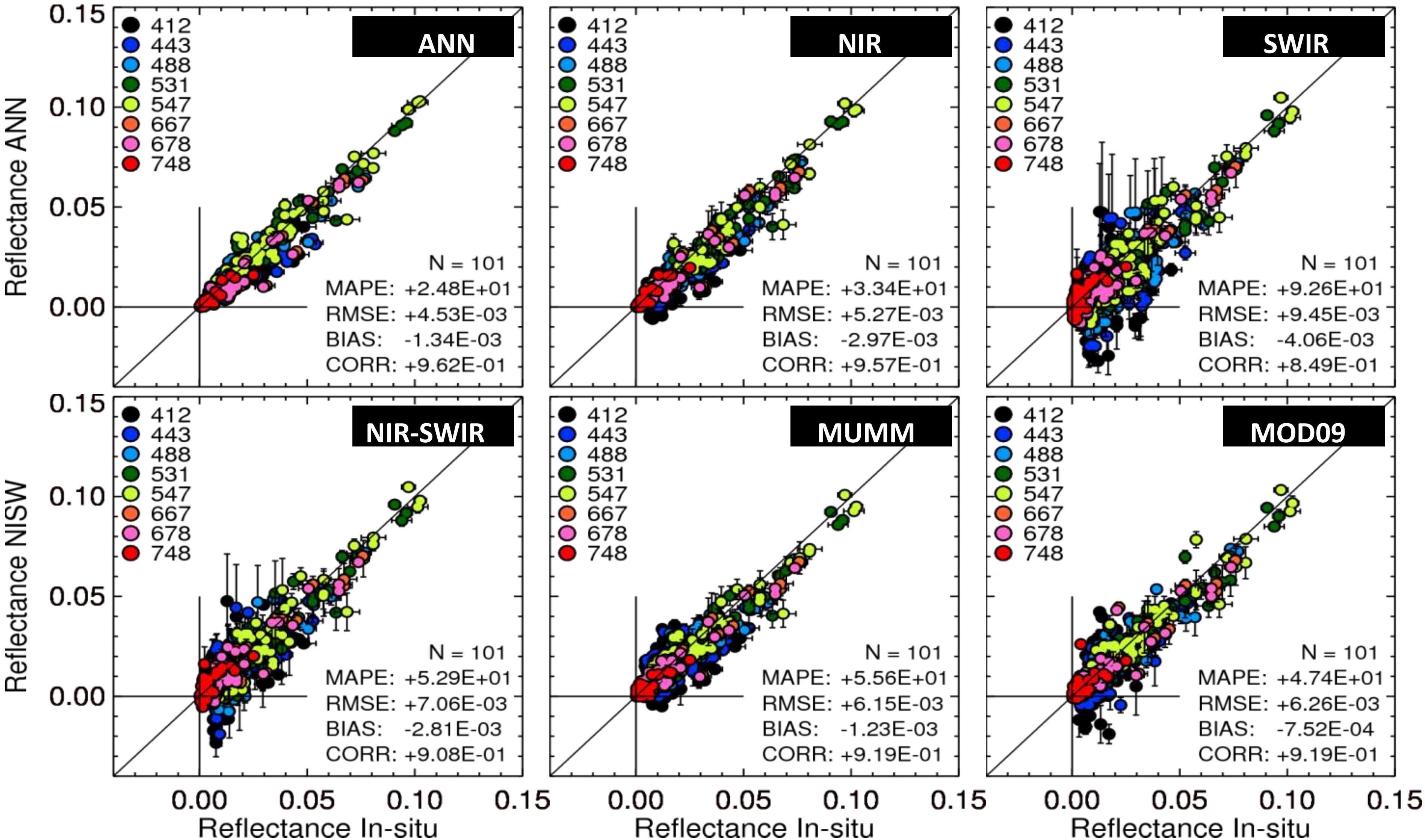
Output: Bottom-Of-Atmosphere (BOA)

$$[illegible] = [\ \log_{10}\{RS_{\mathrm{BOA}}(\lambda_{[412.5-748\,\mathrm{nm}]})\},\ \tau_{\mathrm{a}\,[440,550,670,870\,\mathrm{nm}]}\ ]^{\mathrm{T}}$$

BOA reflectance bands 8-15 | Aerosol optical thickness

Slide courtesy of Thomas Schroeder, CSIRO

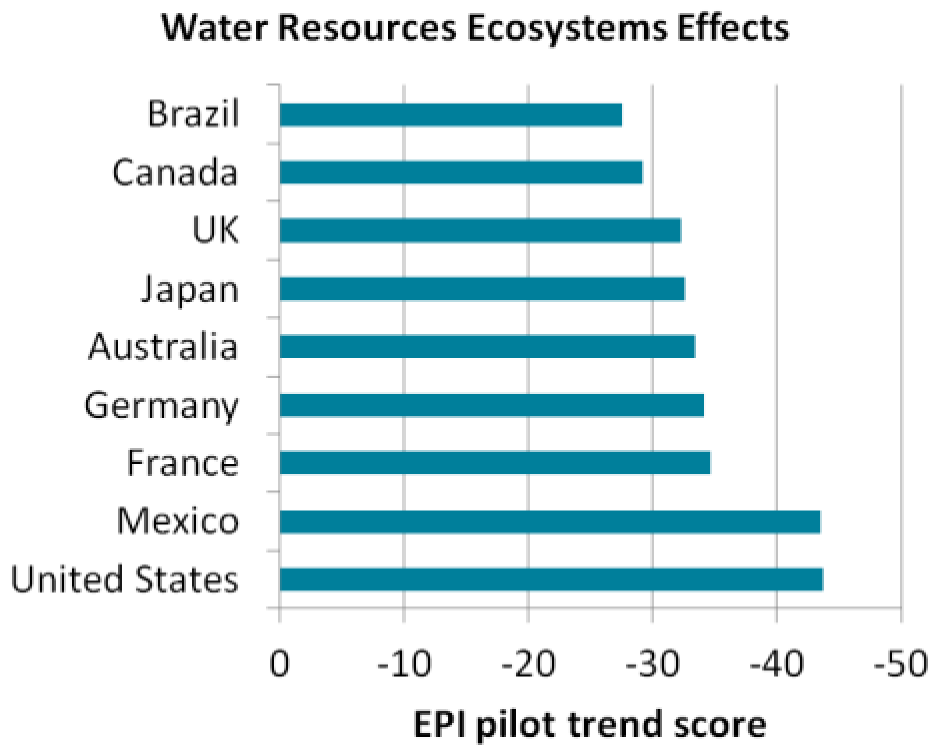
Band averaged performance Terra/Aqua combined ΔT=±3 h, 3x3 pixel



Slide courtesy of Thomas Schroeder, CSIRO

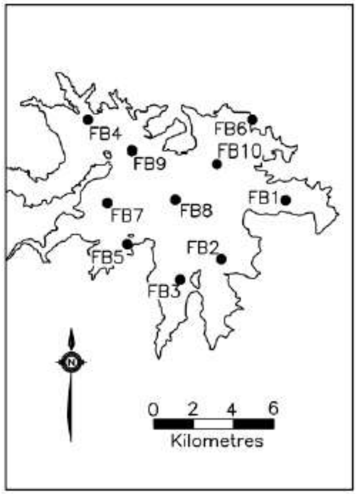
Need: regional and continental assessment of freshwater quality

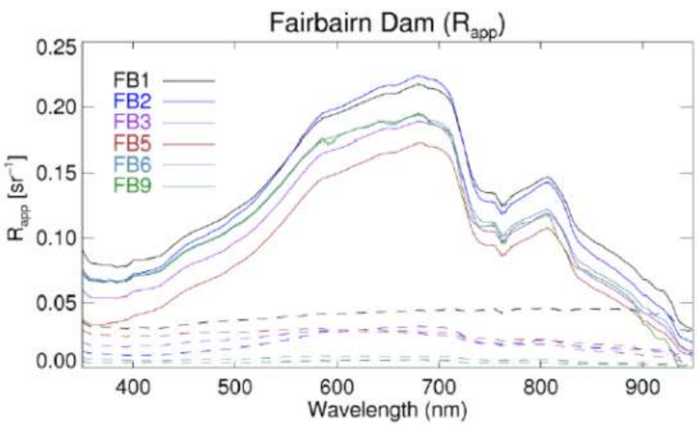
- Disparate and declining sampling networks
- Poor temporal coverage
- Accuracy

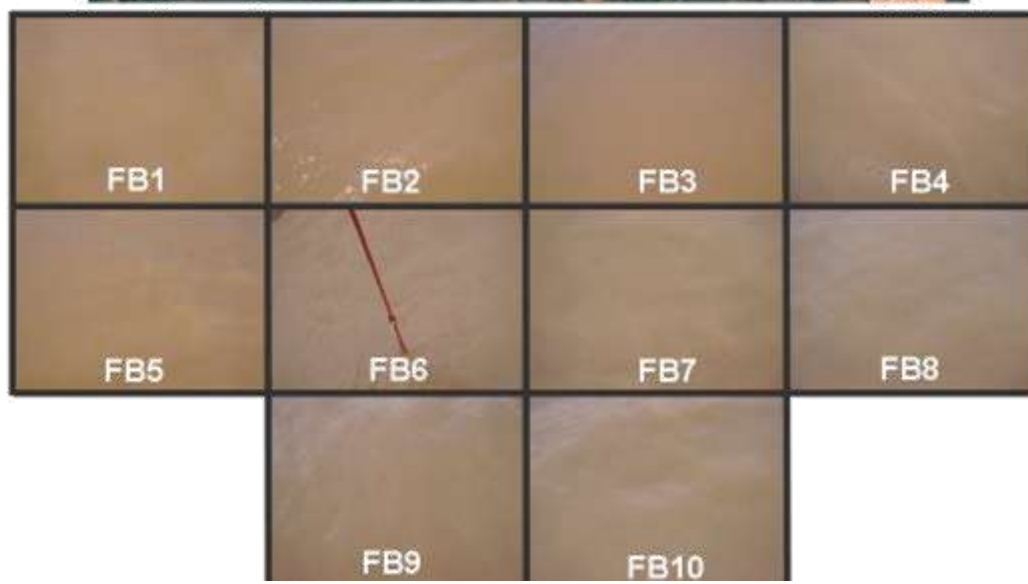


Malthus et al. IGARSS'12

Problem: atmospheric correction over optically complex waters

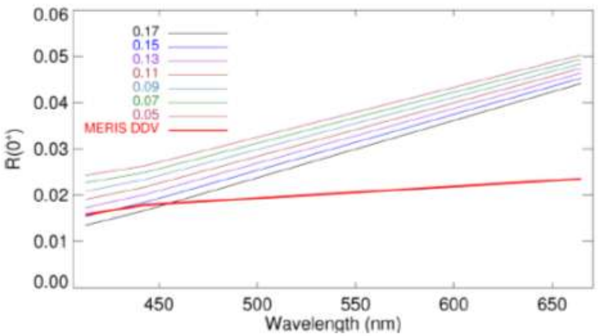


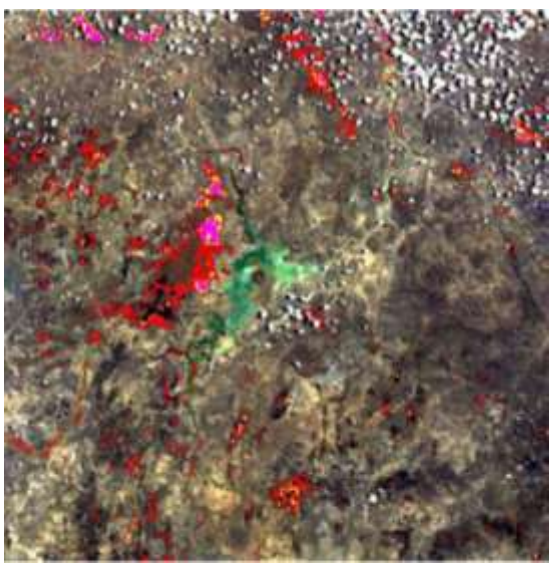




Campbell, 2010 UQ

Solution: understanding local conditions





= Dense dark vegetation

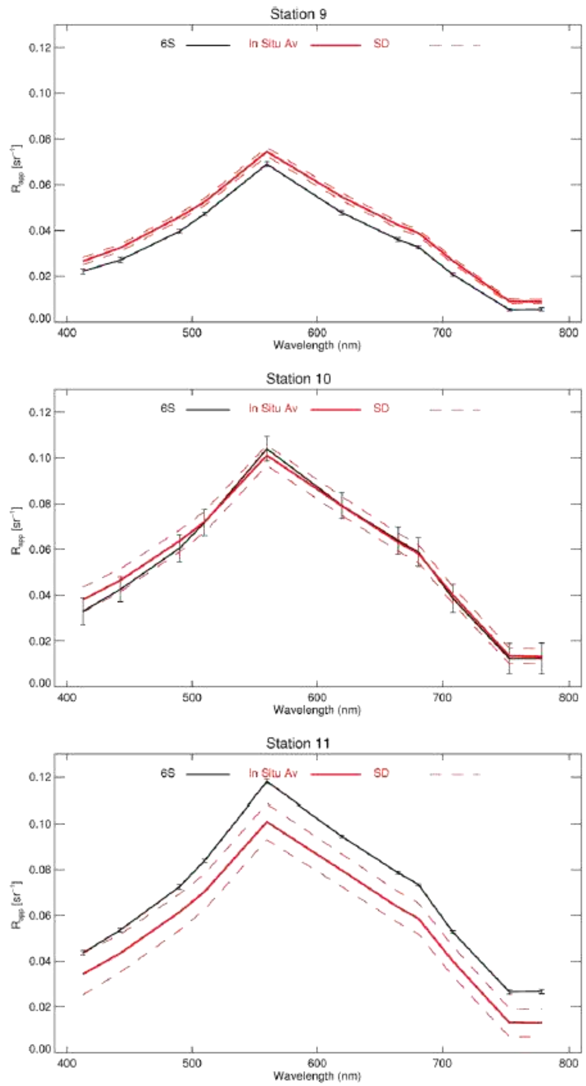


Image based image correction

Requires no *in situ* radiometric measurements

Campbell, 2010 UQ

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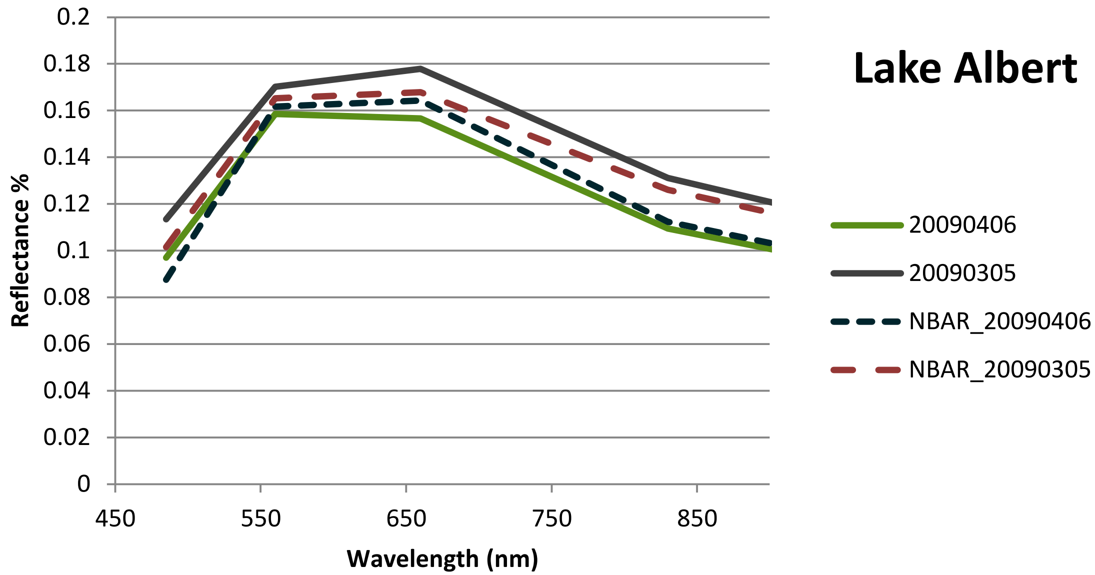
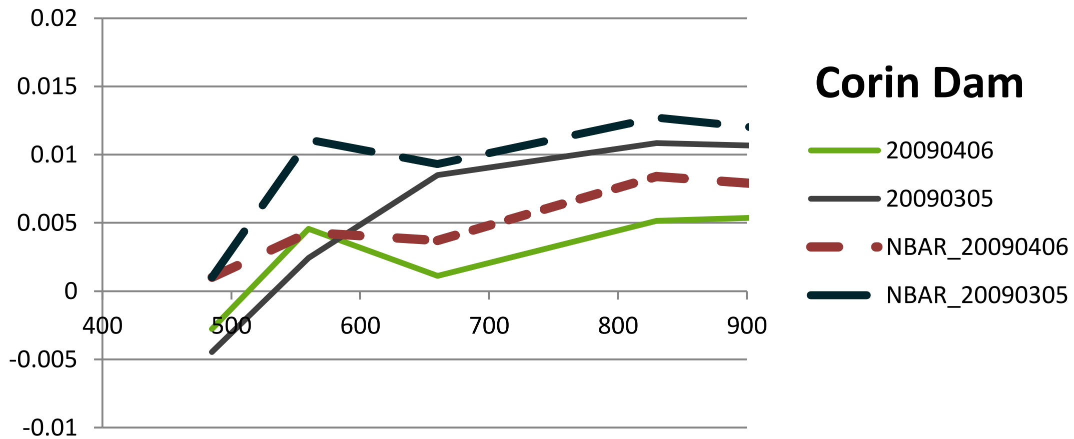
Problem: topography effects





Slide courtesy of Janet Anstee, CSIRO

Need: a better solution to atmospheric correction

- Generic methods or sensor-specific methods?
- Generalized global algorithms, region specific algorithms, or hybrids?
- Integrated / assimilated solutions
- Calibration & validation
- Do we need local knowledge? *In situ* data?
- Adjacency effects: Do they? Do we correct for them?
- Bottom effects

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Remote sensing in inland waters: Optical complexity and seasonal differences

Inland waters seasonal variations

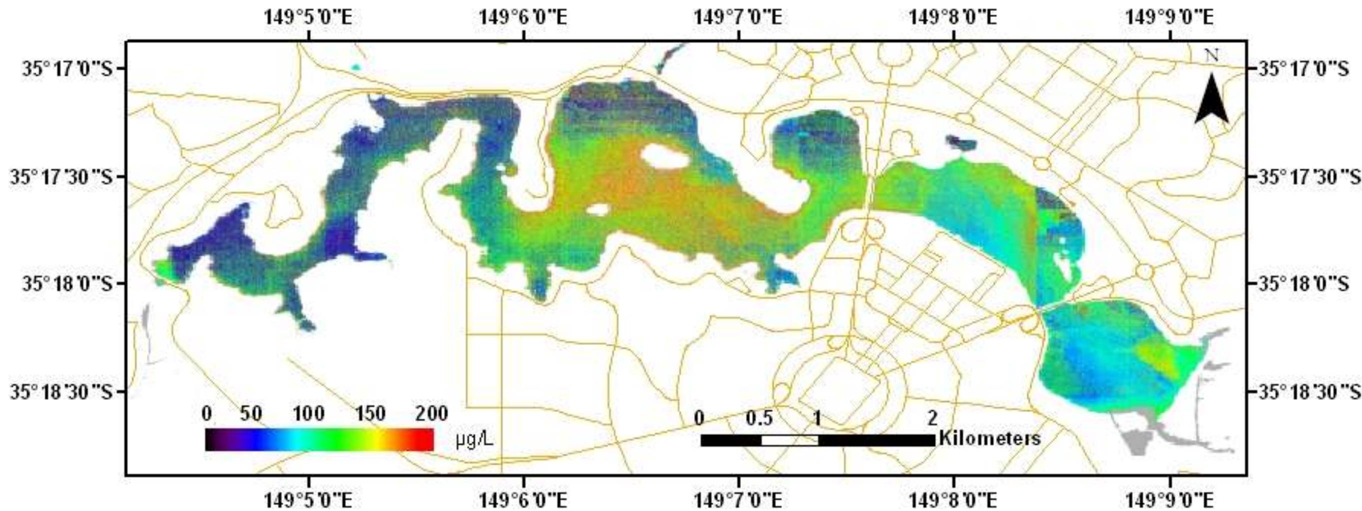
Worldview 2

Slide courtesy of Janet Anstee, CSIRO

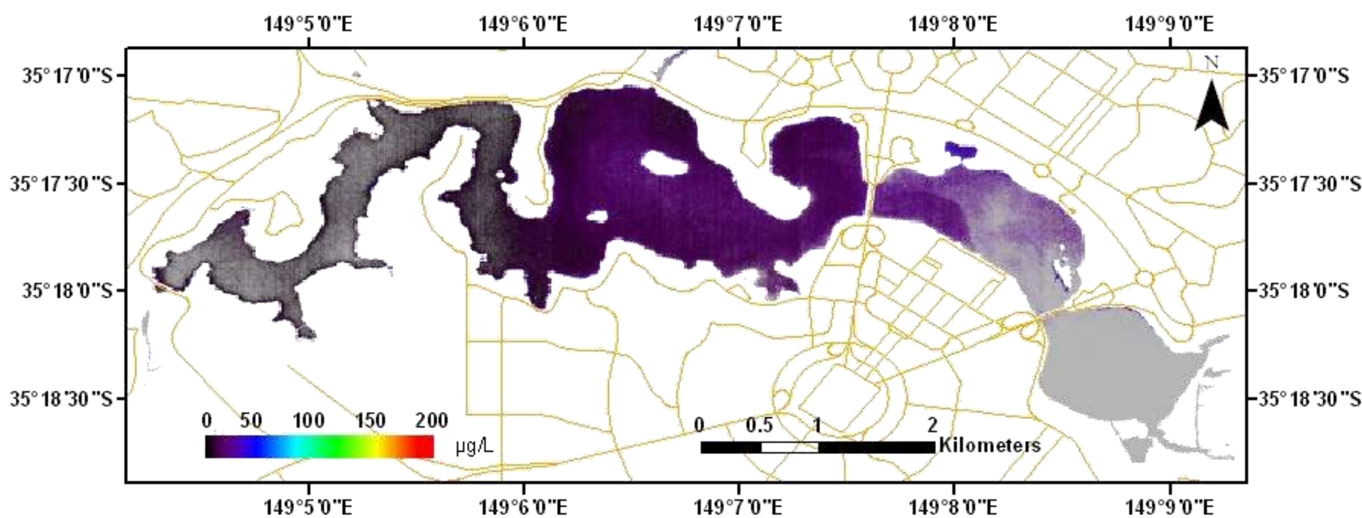
aLMI: C_{CHL}

NCA Issue
Extreme Blue-Green Algae Alert
8 February 2010

17 March 2010



21 July 2010



Grey areas indicate model did not retrieve a result or were excluded in the QA

Slide courtesy of Janet Anstee, CSIRO

Water quality variables from remote sensing

Chlorophyll

Colored dissolved organic matter

Cyano-pigments

Total suspended matter

Water column optically active components

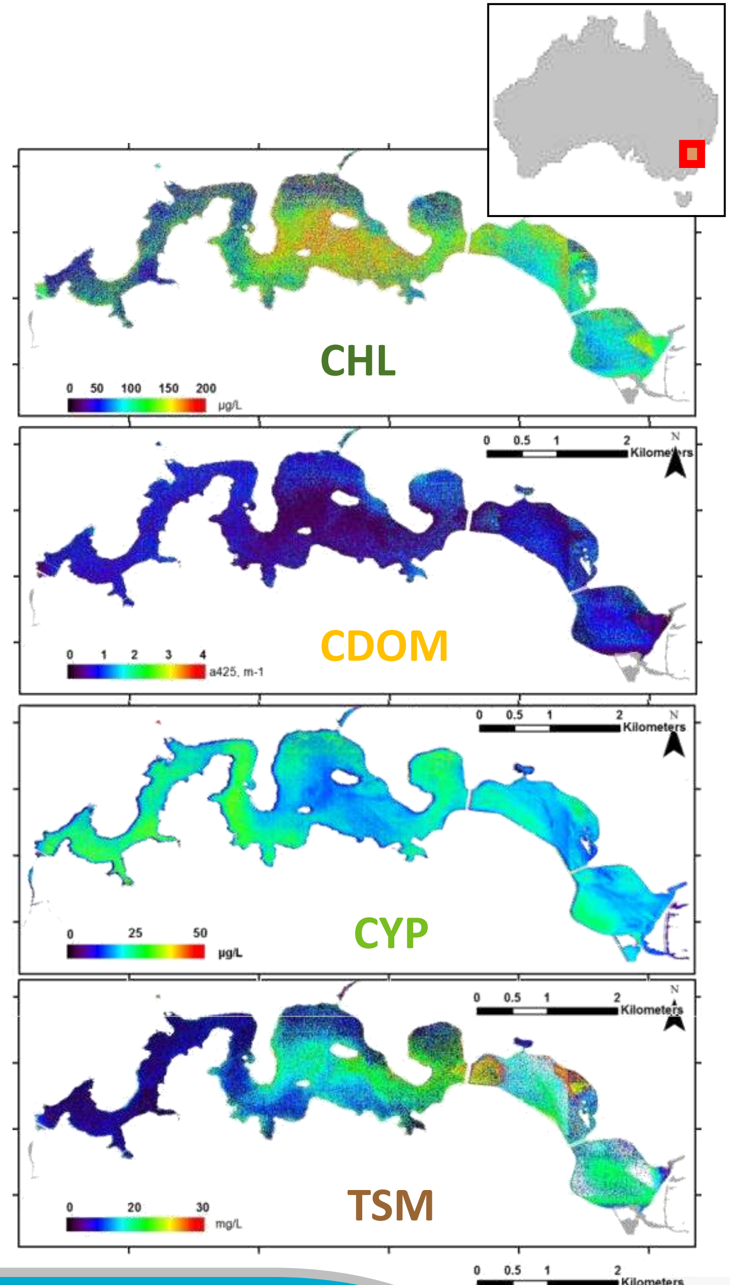
Vertical attenuation of light

Secchi depth

Bathymetry

Vegetation

Estimated from water column properties



Problem: issues of scale

EO data now available at pixel sizes of 2 to 300 metres

- 149 thousand water bodies in Australia

- 2% can be imaged by MODIS (250 m) and MERIS (300m)
- = ~ **2,300** water bodies (11% of the total area)

- 42%   can be imaged by Landsat and LDCM (30m)
- = **~ 63,000** water bodies (32% of the total area)

- Many more by Sentinel-2 (2014)

Dekker & Hestir 2012, CSIRO

Relative sensor capability for wq retrieval

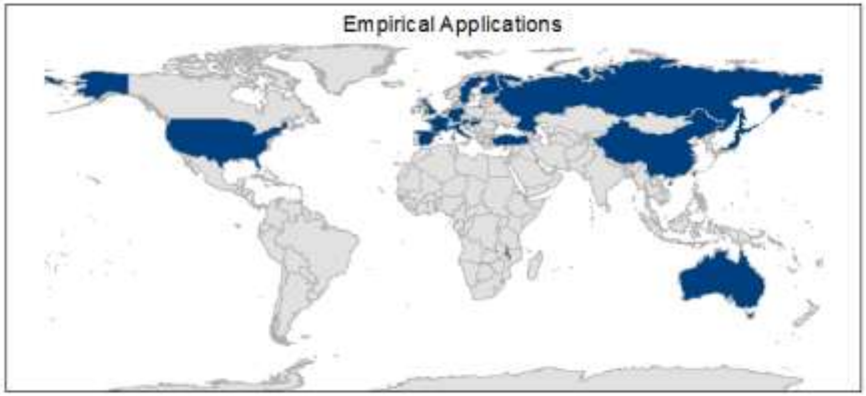
	Pixel Size (m)	Bands (400-900 nm)	Revisit cycle	CHL	CYP	TSM	CDOM	SD	K_d
Low res.									
MODIS	1000	9	Daily	Highly suited	Potential	Highly suited	Highly suited	Highly suited	Highly suited
MODIS	500	2	Daily	Not suited	Not suited	Potential	Potential	Potential	Potential
MODIS	250	2	Daily	Not suited	Not suited	Potential	Not suited	Potential	Potential
MERIS & OCM2	300	15	2-3 days	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited
VIIRS	750	7	2x/day	Suited	Potential	Potential	Suited	Suited	Suited
Med res.									
Landsat	30	4	16	Potential	Potential	Suited	Suited	Suited	Suited
Future									
Sentinel-3	300	21	Daily	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited
LDCM	30	5	16	Suited	Potential	Suited	Suited	Suited	Suited
Sentinel-2	10-60	10	3-5 days	Highly suited	Suited	Highly suited	Suited	Highly suited	Highly suited
HySpIRI	60	60	19 days	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited

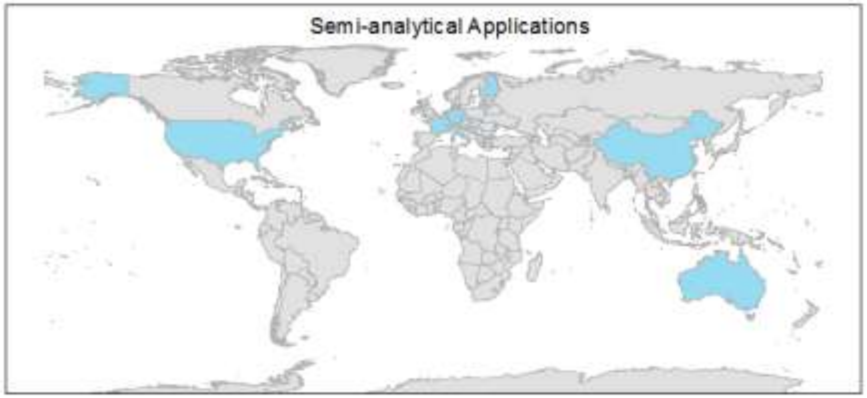
● **Highly suited,** ● **Suited,** ● **Potential,** ● **Not suited**

Dekker & Hestir 2012, CSIRO

Algorithms

- Only localized and a few regional case studies exist
- State of the science needs to be far better progressed
- Generic methods or sensor-specific methods?
- Generalized global algorithms, region specific algorithms, or hybrids?
- Do we need local knowledge? *In situ* data?





Malthus et al. IGARSS ; Odermatt et al. 2012 RSE; Matthews 2011 IJRS

Needs

- A better understanding of inland optical conditions
  - Inland bio-optical databases, open source
  - Understanding optical variability
  - Range of conditions for parameterization
  - Calibration and validation
  - Substratum/bottom effects

- **Cloudiness** may impart temporal biases in the data record in some areas
- Rigorous **validation** and error reporting are needed to achieve end-user confidence

Current

- Chlorophyll
- Colored dissolved organic matter
- Cyano-pigments
- Total suspended matter

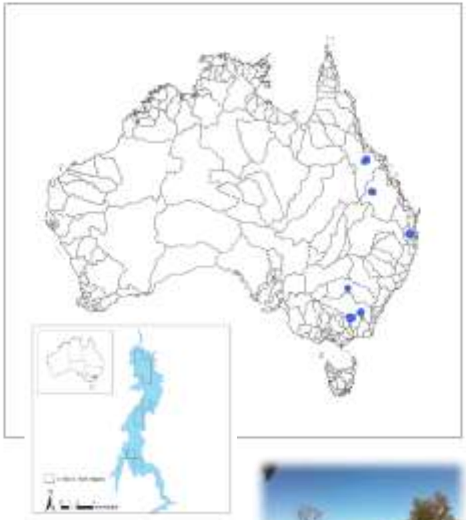
Future

- Phytoplankton functional types
- Sources of coloured dissolved organic matter
- Particle size distributions
- Fraction inorganic to organic matter

+

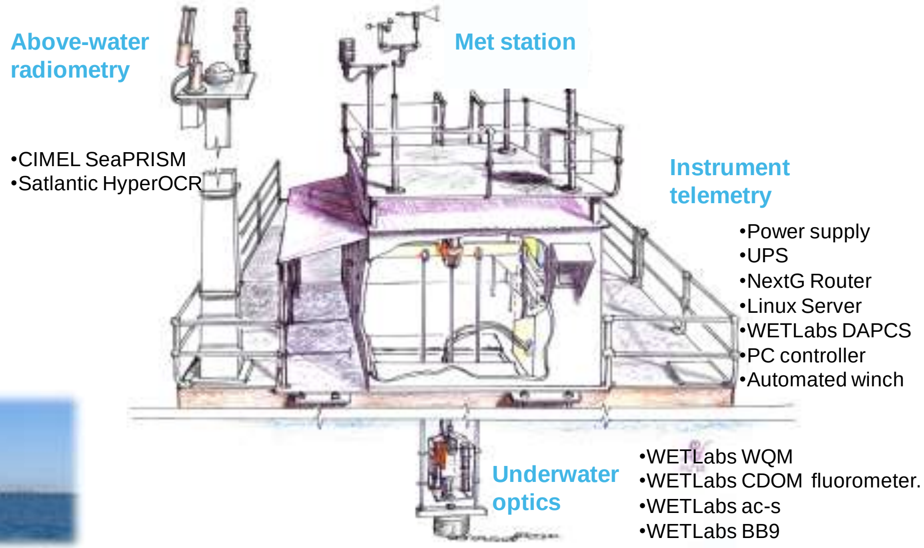
- Climate change
- Run off loads
- Catchment sources
- Nutrient dynamics
- Net primary production
- Emergency management

Ways forward



IMOS Integrated **Marine Observing** System

Lucinda Jetty Coastal Observatory (LJCO)
imos.org.au/ljco.html



Thank you

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