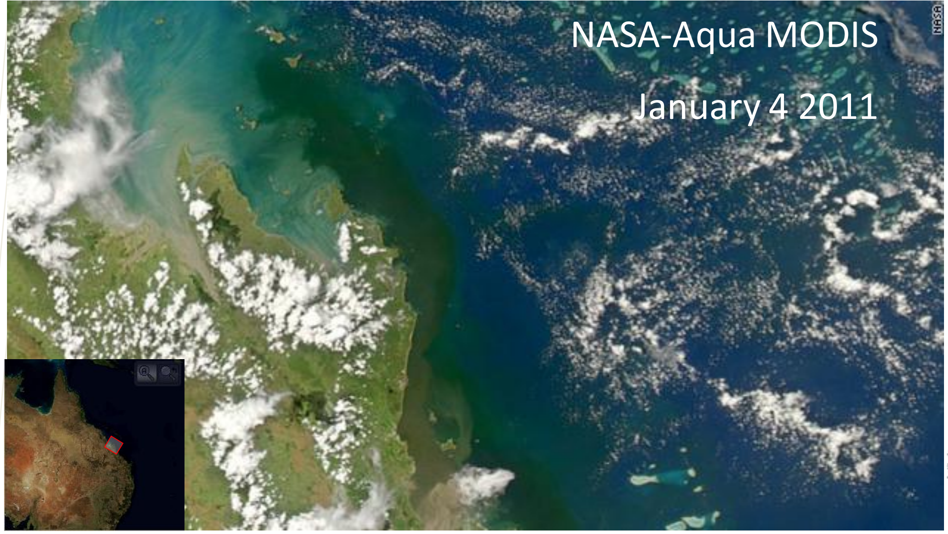
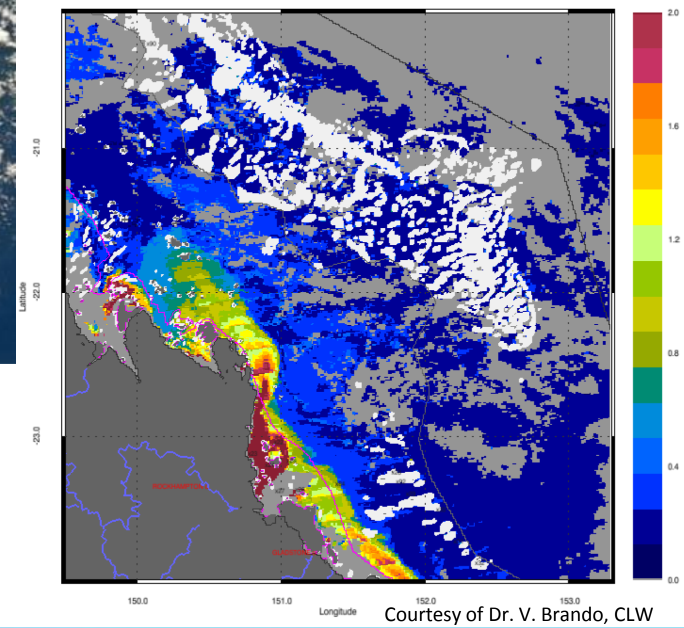


Satellite Chlorophyll estimate



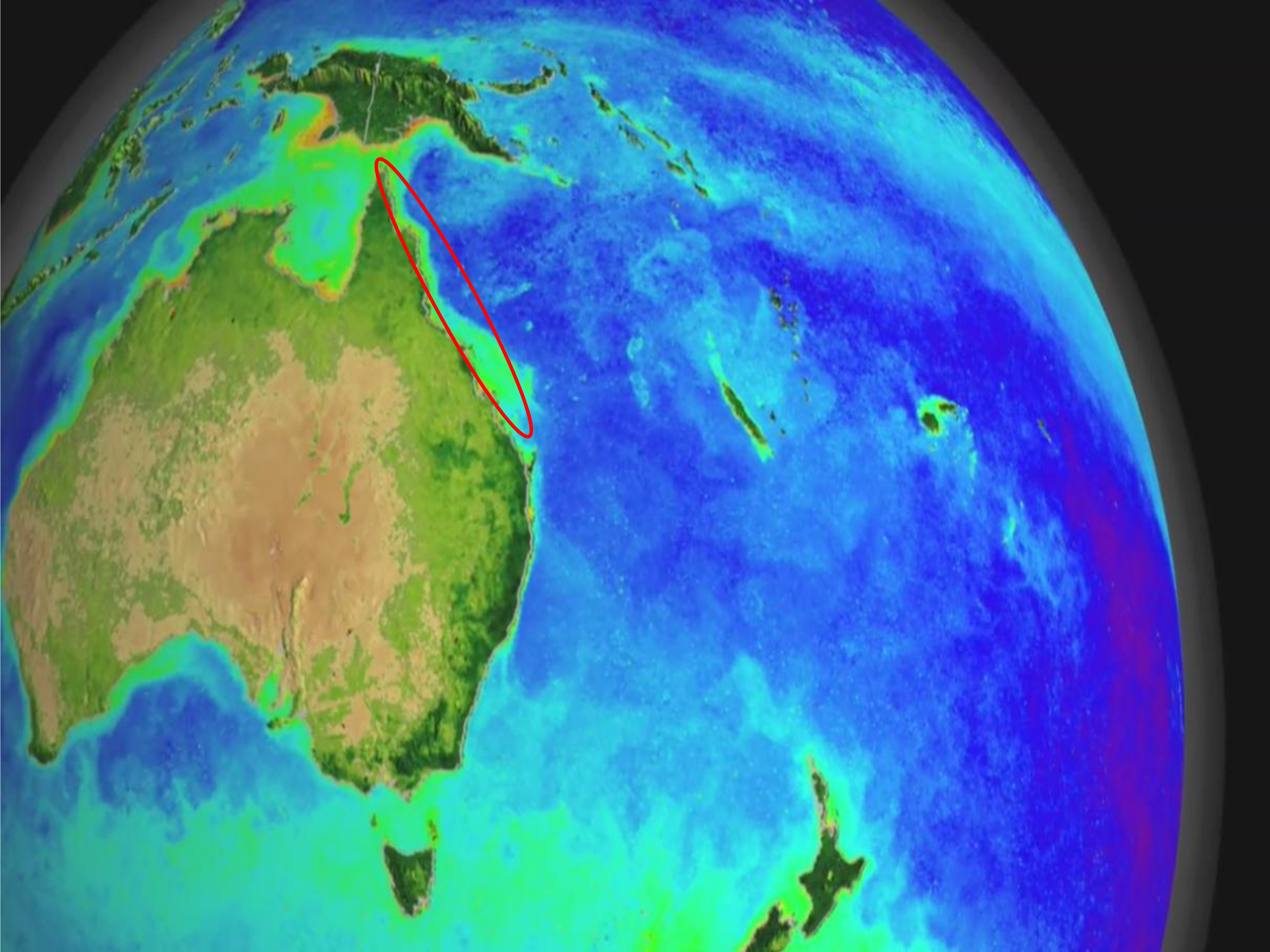
Courtesy of Dr. V. Brando, CLW

www.csiro.au

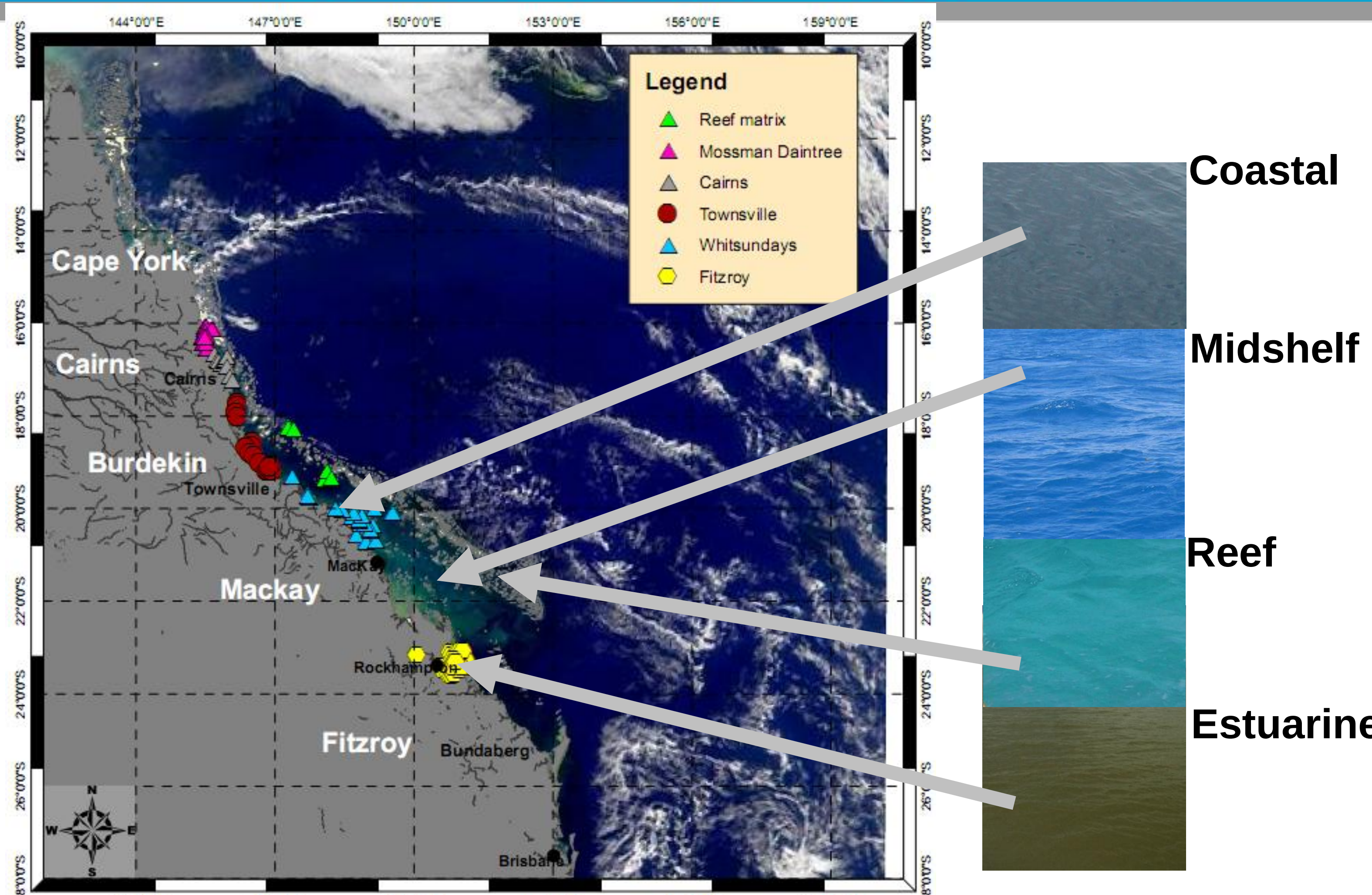
Adaptive SIOP parameterisation algorithm for complex waters

Dekker A. G., Brando V. E., Schroeder T., Boldeau-Patissier, D, Oubelkheir, K., Cherukuru, N., Clementson, L.

CSIRO Land & Water, Canberra



The Great Barrier Reef – a complex system



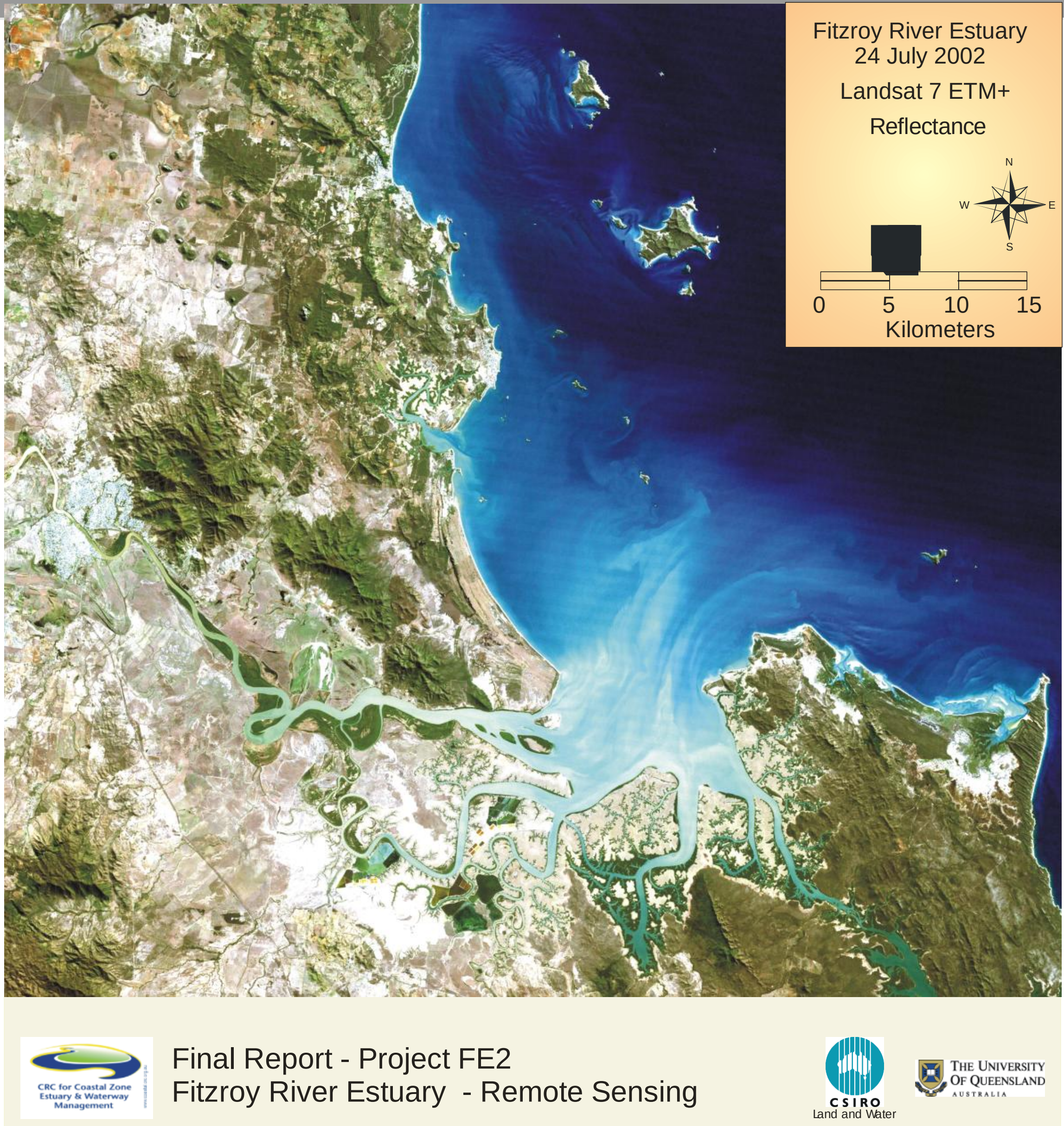
Blondeau-Patissier, Brando, Dekker et al. (2009), *Bio-optical variability of the absorption and scattering properties of the Queensland inshore and reef waters*, Australia, *JGR, 114*

Fitzroy River Estuary – Keppel Bay:

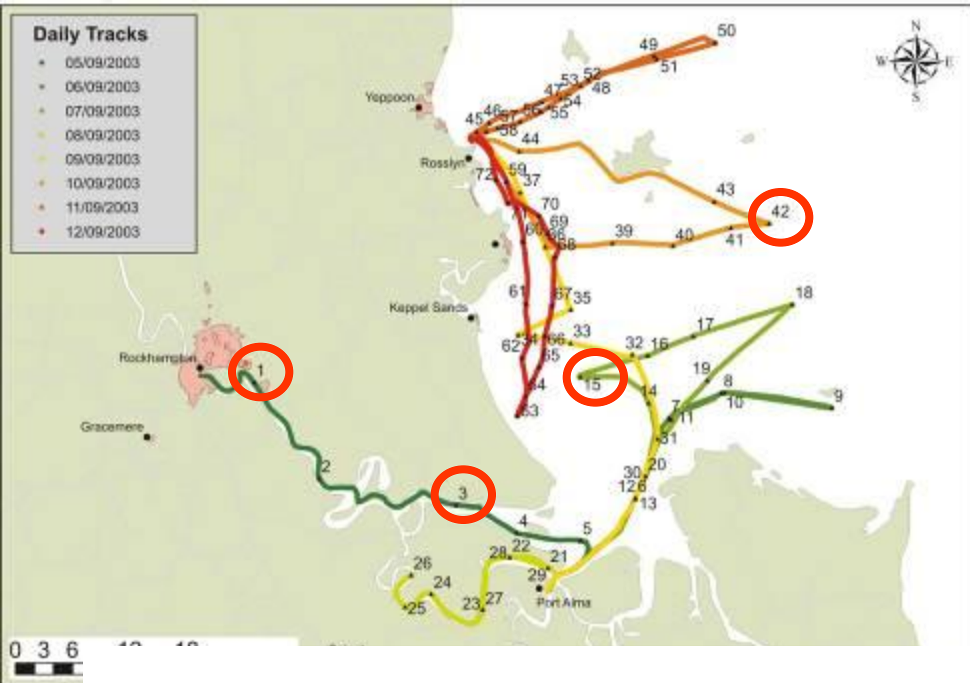
- **Turbid macrotidal estuary**
- **Highly dynamics system**

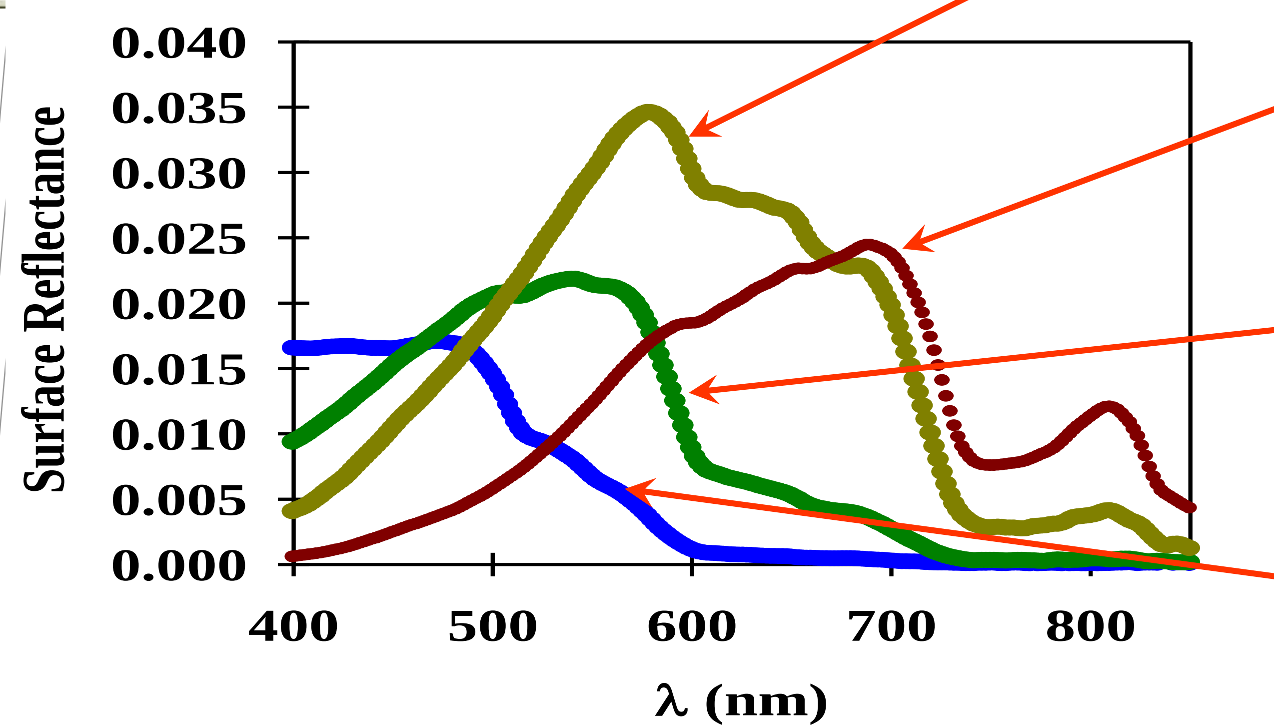
  (space & time)
- **Highly varying Specific Inherent Optical Properties**

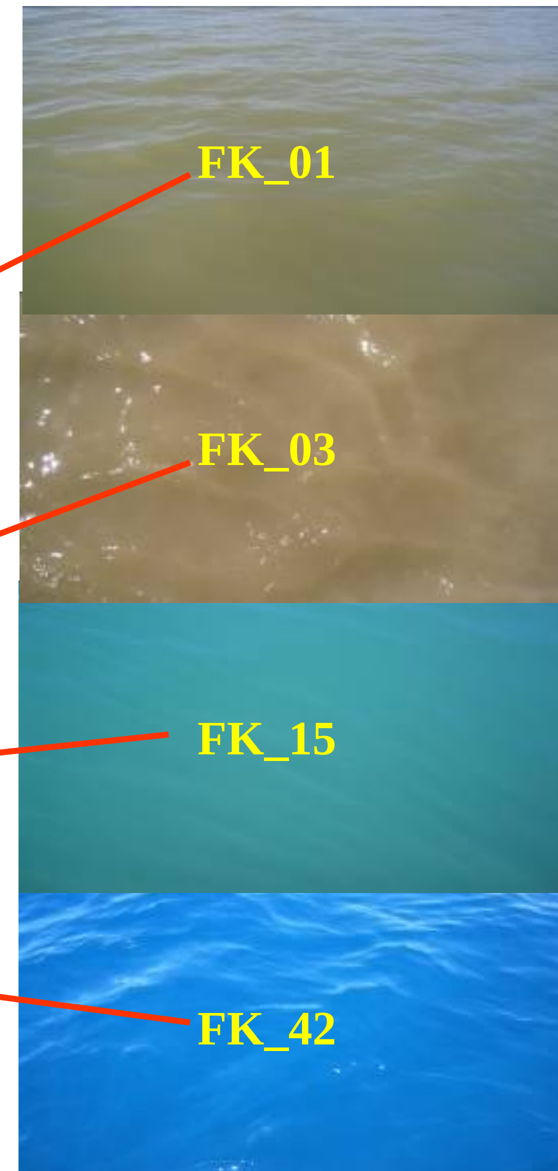
  (a, b_b & b_b/b))



Examples of reflectance spectra, Fitzroy River-Keppel Bay Sep '03

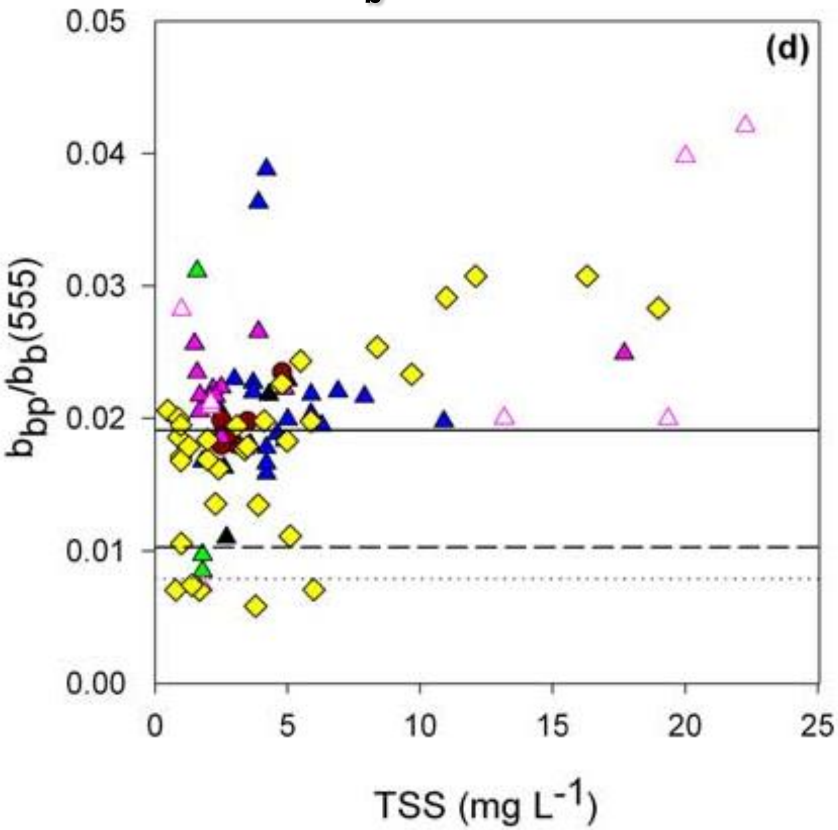




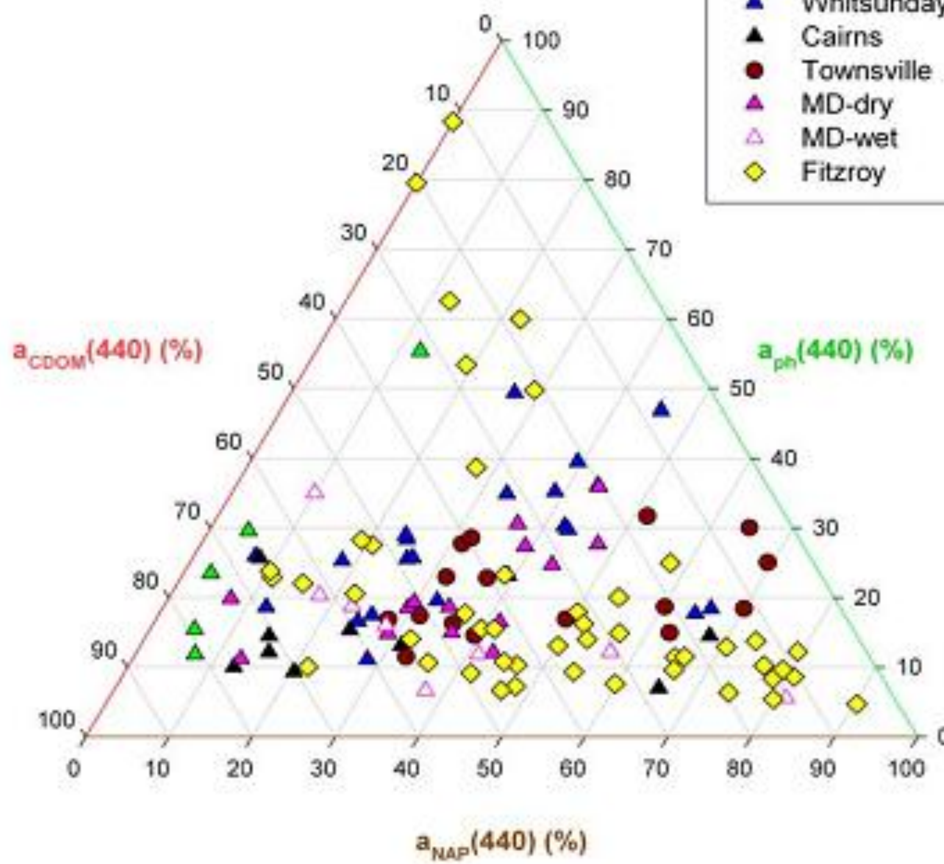


Variability:
b_b:b ratio and absorption budget (a_{ph}~a_{NAP}~$a_{cdom440}$)

b_b:b ratio

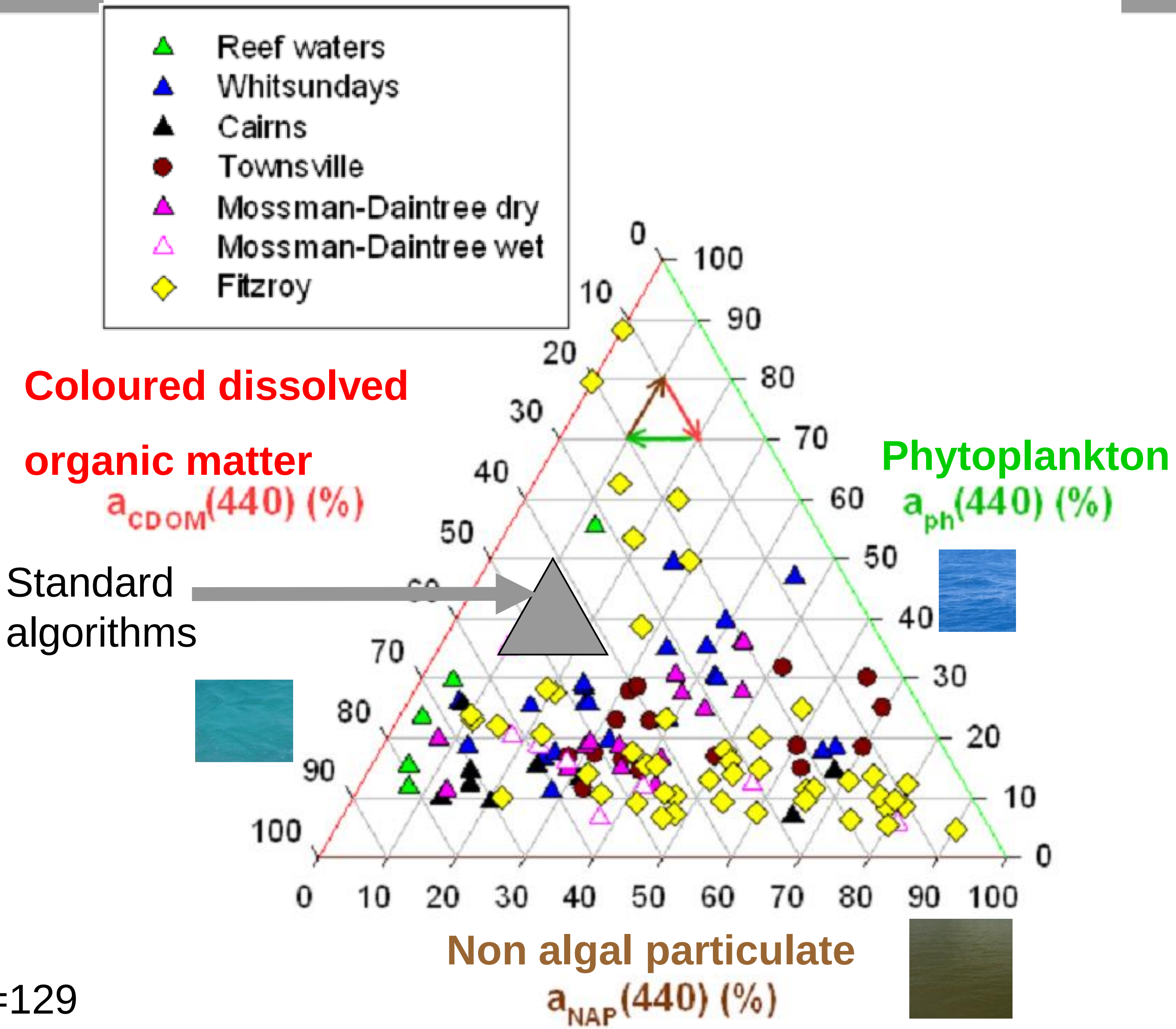


absorption budget



From Blondeau-Patissier, Brando et al., (2009), Bio-optical variability of the absorption and scattering properties of the Queensland inshore and reef waters, Australia, *JGR, 114*

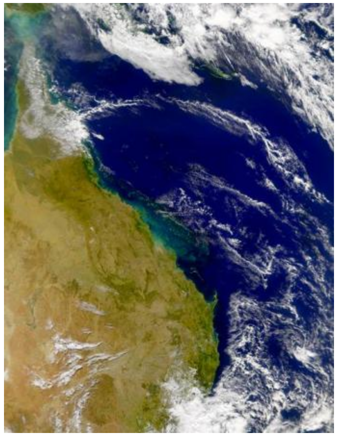
The Great Barrier Reef – a complex system



N=129

Standard algorithms and the GBR

"(…) For the coastal waters of the Great Barrier Reef, the accuracy of in water constituent retrievals from remote sensing is poor if regional and seasonal knowledge of specific IOPs is not incorporated."



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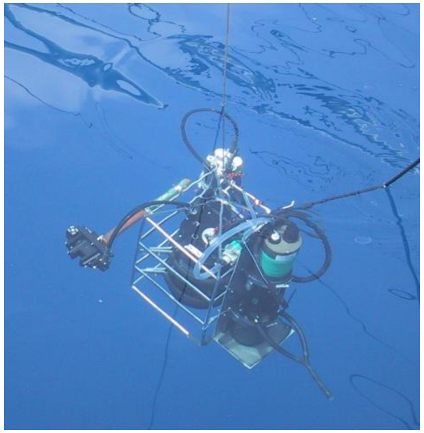

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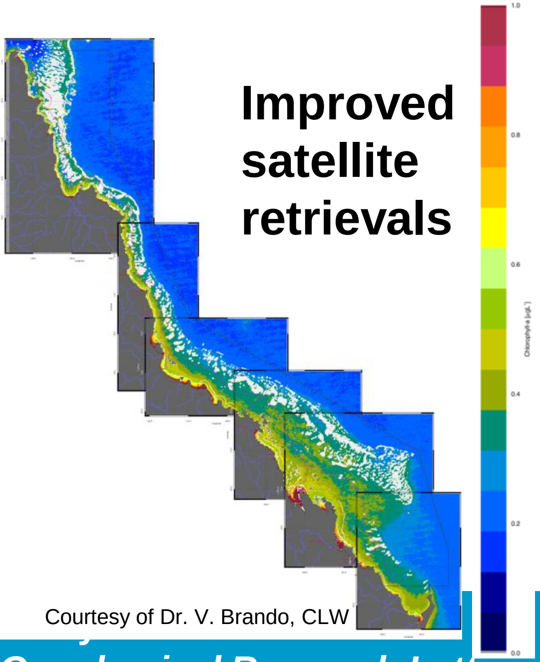


Improved satellite retrievals

Courtesy of Dr. V. Brando, CLW

Qin, Y., V. E. Brando, A. G. Dekker, and D. Blondeau-Patissier (2007), Va… **constituents retrieval algorithms in Australian tropical coastal waters, *Geophysical Research Letters*, *34***

An adaptive semi-analytical inversion of ocean colour radiometry in optically complex waters

Vittorio E. Brando, Arnold G. Dekker, Young Je Park and Thomas Schroeder
CSIRO Land & Water, Environmental Earth Observation Program, GPO Box 1666, Canberra,ACT, Australia;
(Young Je Park now is at Korea Ocean Satellite Center, Korea Ocean Reseach and Development Institute, 1270 Sadong, Ansa 426-744, Korea)

The algorithm for MODIS: Linear Matrix Inversion (LMI) for concentrations retrieval

- **LMI (Hoge and Lyon, 1996) has been already successfully applied to retrieve the concentrations of the optically active constituents in inland and coastal waters with hyperspectral data (Hoogenboom et al., 1998; Brando and Dekker, 2003; Giardino et al., 2007).**

$$r_{rs}(\lambda) = g_0 u(\lambda) + g_1[u(\lambda)]^2$$

(Gordon et al 1998)

$$u = \frac{b_b}{a + b_b}$$

$$a = a_w + \sum_{j=1}^{N} a_j^* C_j$$

$$b_b = b_{bw} + \sum_{j=1}^{N} b_{bj}^* C_j$$

Direct inversion of the analytical model using a linear matrix inversion (LMI)

$$u = \frac{a_w + \sum_{j=1}^{N} a_j^* C_j}{a_w + \sum_{j=1}^{N} a_j^* C_j + b_{bw} + \sum_{j=1}^{N} b_{bj}^* C_j}$$

The algorithm for MODIS: LMI parameterized with variable SIOP sets

$$-a_w(\lambda_i)u(\lambda_i)+b_{bw}(\lambda_i)\left(1-u(\lambda_i)\right)=\sum_{j=1}^{N}\left[a_j^*(\lambda_i)u(\lambda_i)-b_{bj}^*(\lambda_i)\left(1-u(\lambda_i)\right)\right]C_j$$

$$\mathbf{y}=\mathbf{A}\mathbf{x}$$

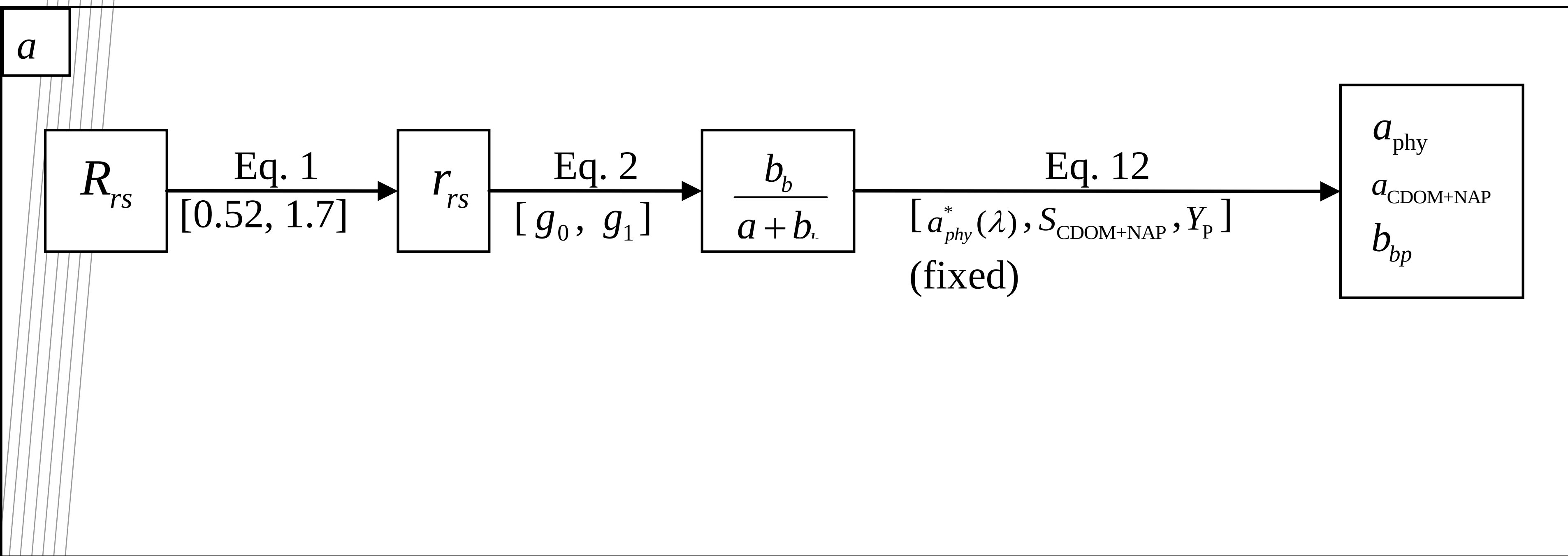
$$A_{ij}=a_j^*(\lambda_i)u(\lambda_i)-b_{bj}^*(\lambda_i)\left(1-u(\lambda_i)\right), \qquad i=1,\ldots,M \quad j=1,\ldots,N$$

$$y_i=-a_w(\lambda_i)u(\lambda_i)+b_{bw}(\lambda_i)\left(1-u(\lambda_i)\right),$$

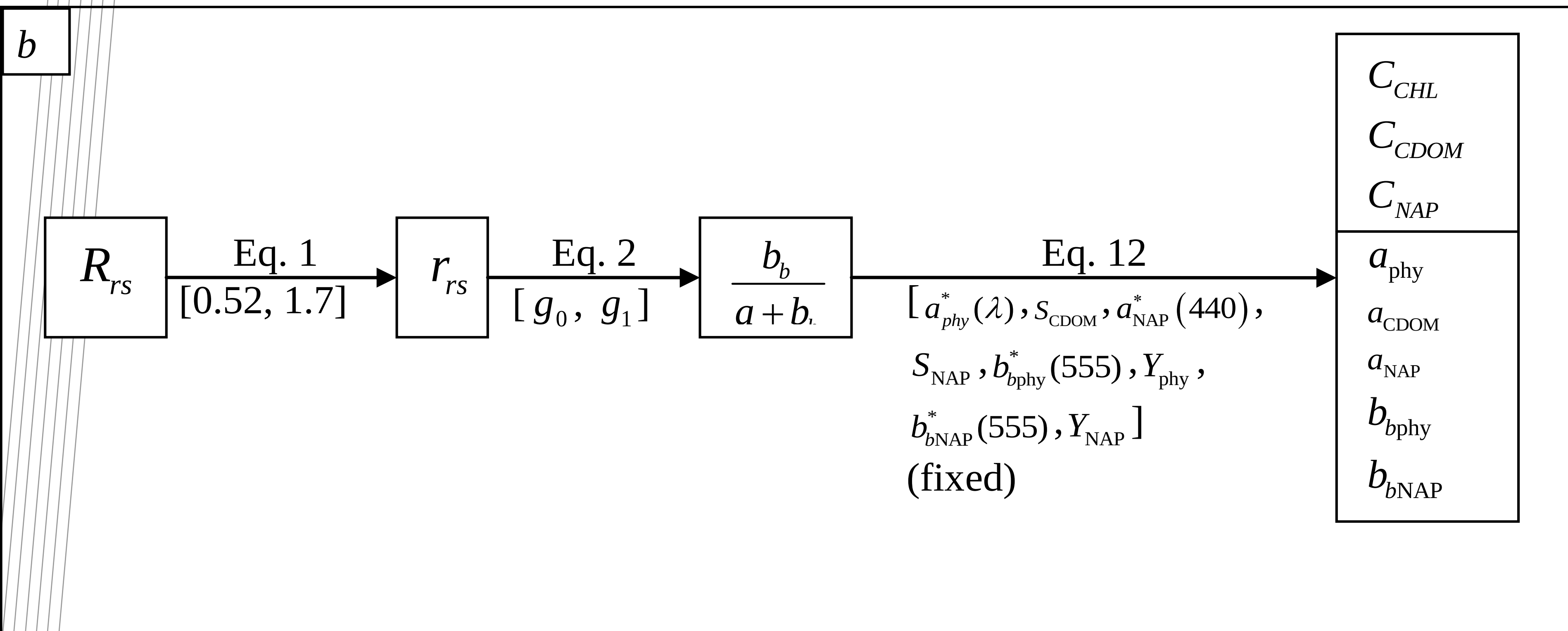
$$x_j=C_j\ ,$$

- **3 constituents and 7 MODIS bands lead to an over-determined LMI system.**
- **The Singular Value Decomposition (SVD) method has the property of minimizing the residual error in a least squares sense.**

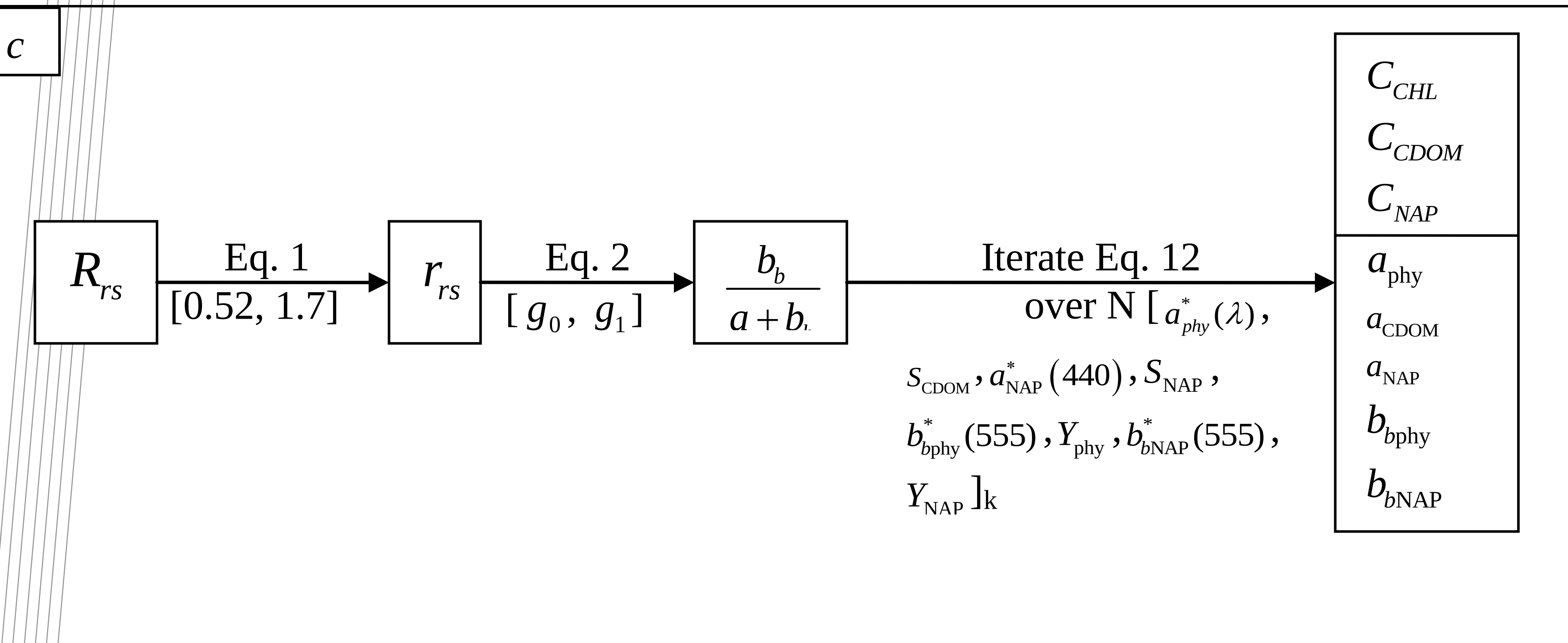
Single SIOP parameterisation to derive IOPs



Single SIOP parameterisation to derive IOPs and concentrations



Adaptive multiple SIOP parameterisation to derive IOPs and concentrations



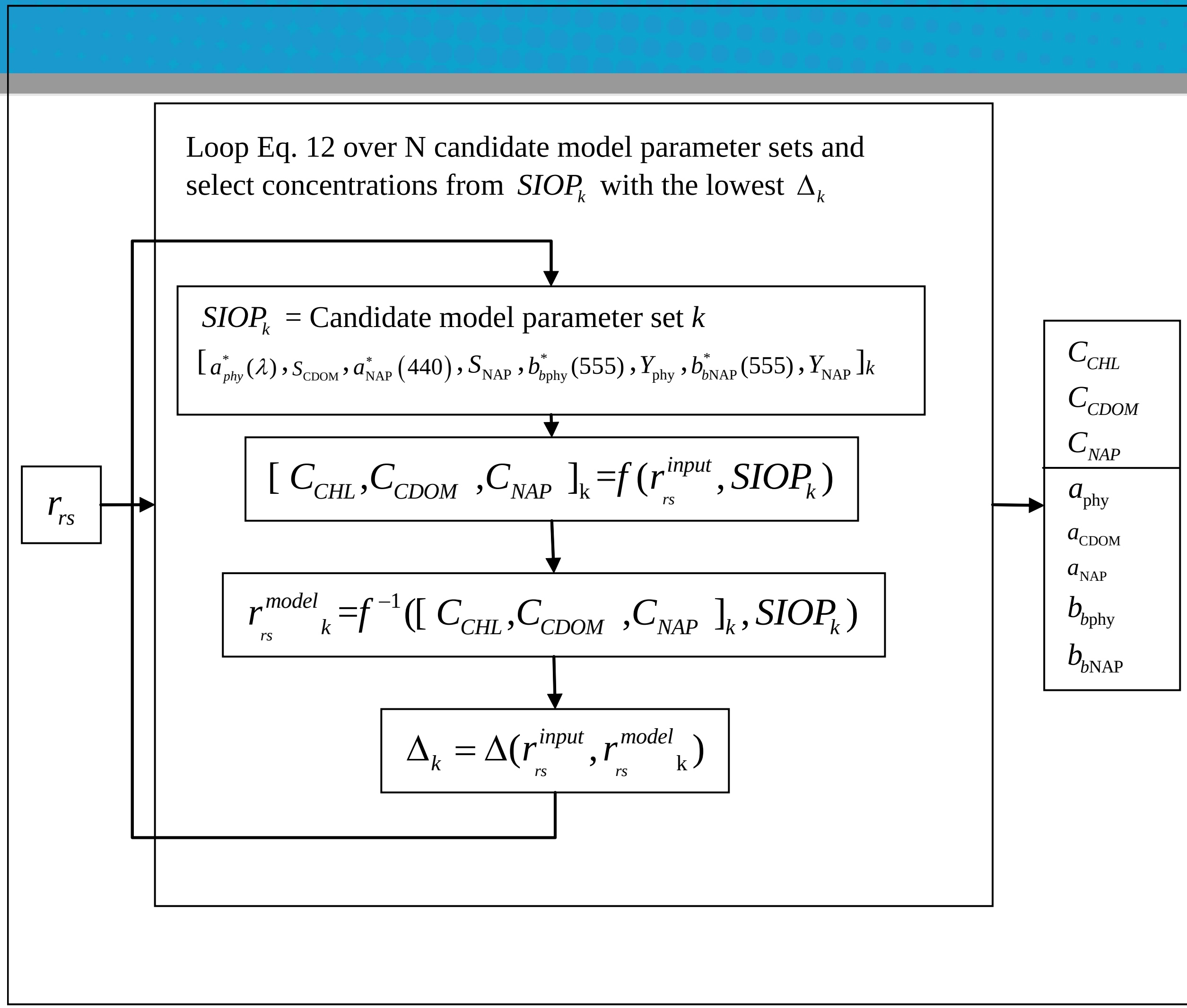
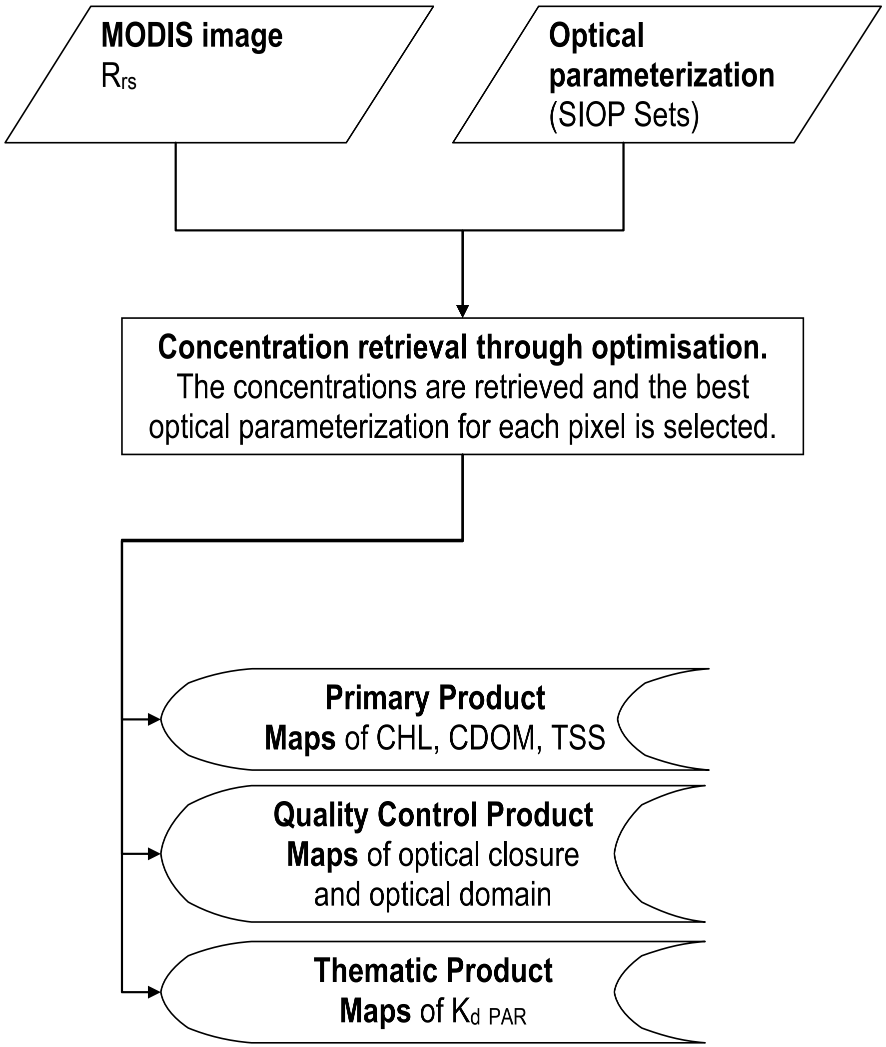


Figure 1. Outline of the a-LMI for the retrieval of C_{CHL}, C_{CDOM} and C_{NAP} and IOPs. The resultant concentrations and IOPs are selected from the model parameter set with the best optical closure (i.e. the lowest Δ_k).

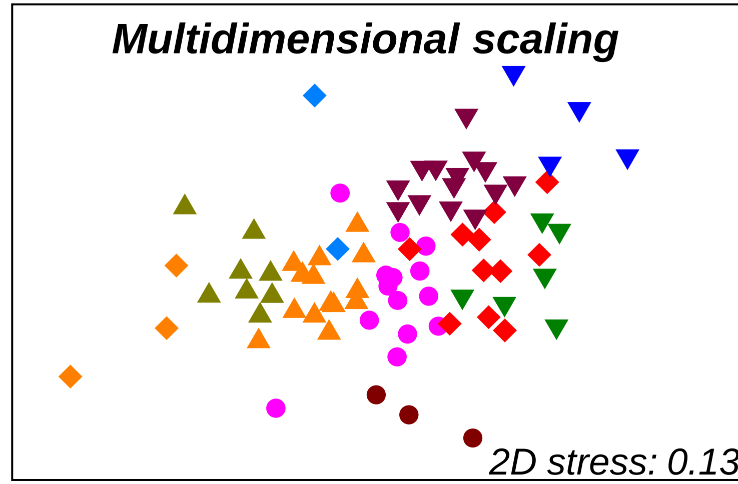
The CSIRO MODIS regional algorithm: Matrix Inversion Method (MIM) parameterized with regional SIOP sets

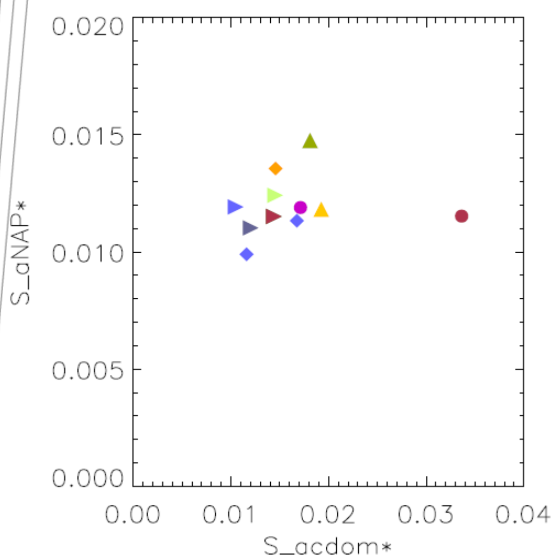
- The concentration retrieval selects the best optical parameterization for each pixel through optimization.
- 3 constituents and 7 MODIS bands lead to an over-determined MIM system.
- The Singular Value Decomposition (SVD) method has the property of minimizing the residual error.
- The MIM-SVD inversion was applied iteratively to each pixel while varying the optical parameterization (i.e. of the 10 water types identified as being representative) to minimize RMSE.



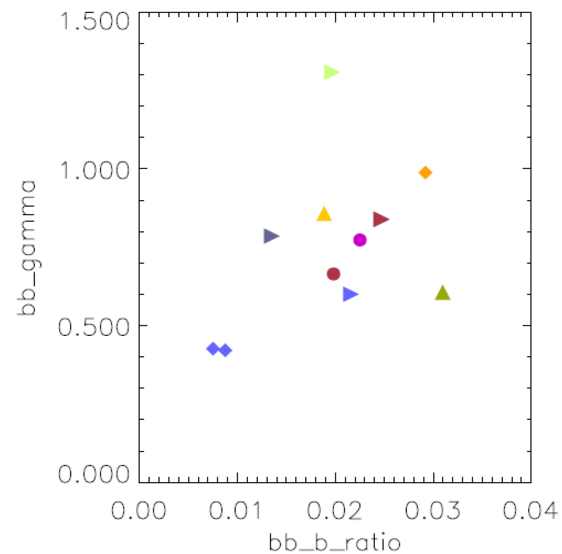
Method: Select the minimum number of SIOP sets to adequately represent these water types (i.e. optical domains of sets of a_{phy}*440, a_{phy}*440/ a_{phy}*676, a_{NAP}*440, b_{bp}*555, $b_{bp}555/b_p555$ and the slopes of a_{CDOM}, a_{NAP} and b_{bp})

- **The 83 sites were** classified **with multivariate statistics:**
  - *Hierarchical clustering*
  - *Principal component analysis*
  - *Multidimensional scaling*





The centroids **of these 10** classes **were used to parameterize the optical model for the MODIS inversion**



CSIRO's algorithm approach optically deep waters

Step 1: Atmospheric correction approach

emphasis on coastal waters - based on inverse modelling of radiative transfer simulations and Artificial Neural Network (ANN) inversion

(Schroeder et al., 2007a, 2007b, IJRS)

Step 2: Water constituent retrieval algorithm

based on Linear Matrix Inversion (LMI) of a semi-analytical model with a variable Specific Inherent Optical Property (SIOP) parameterization

(Brando et al., 2008, OO XIX; 2012 AO)

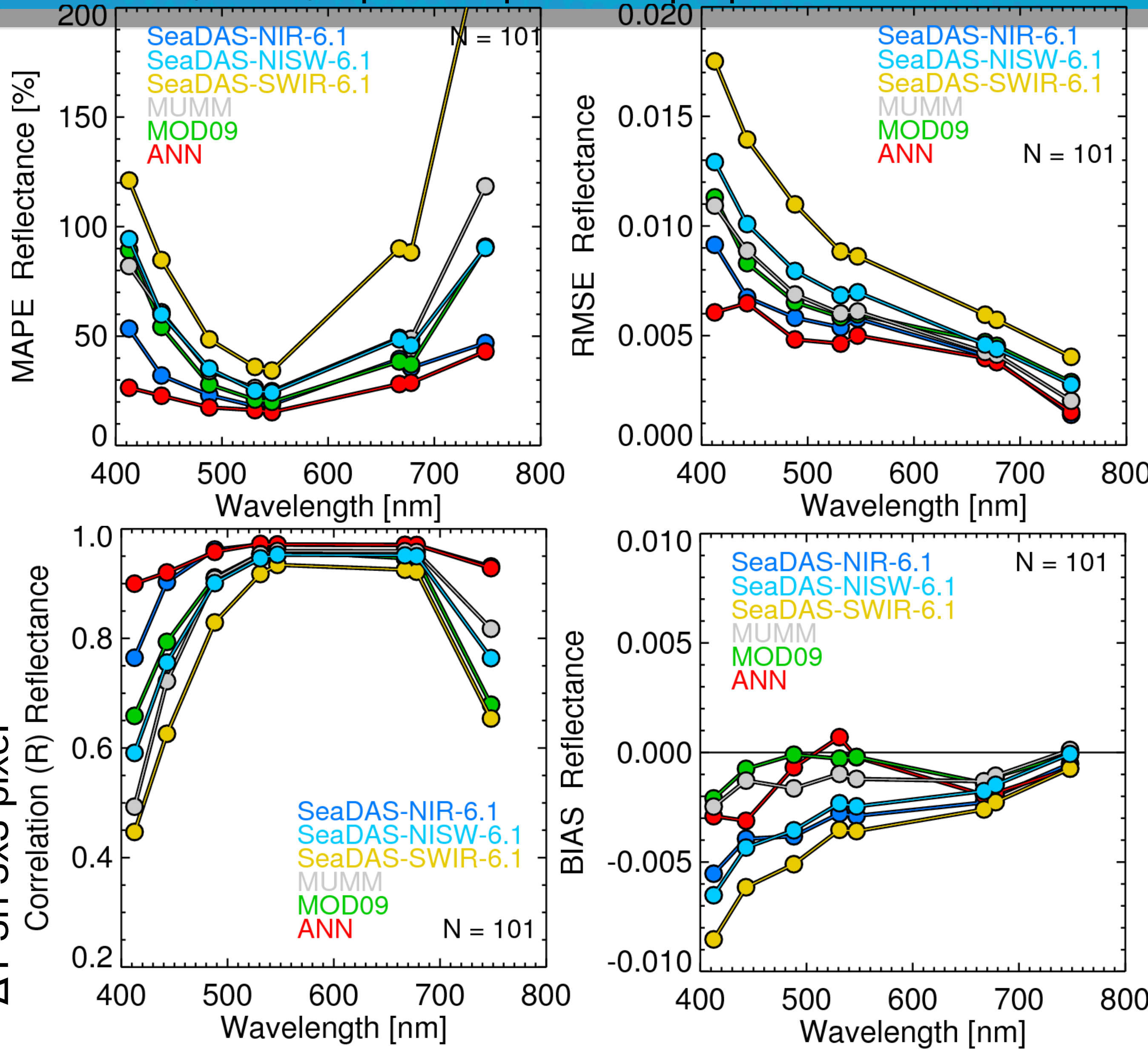
CSIRO

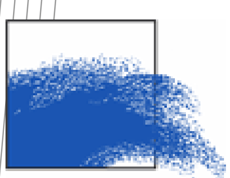
Evaluation of MODIS atmospheric correction algorithms with emphasis on coastal waters

Schroeder et al., 2012, Optics Express in prep.

Match-up results Terra/Aqua combined

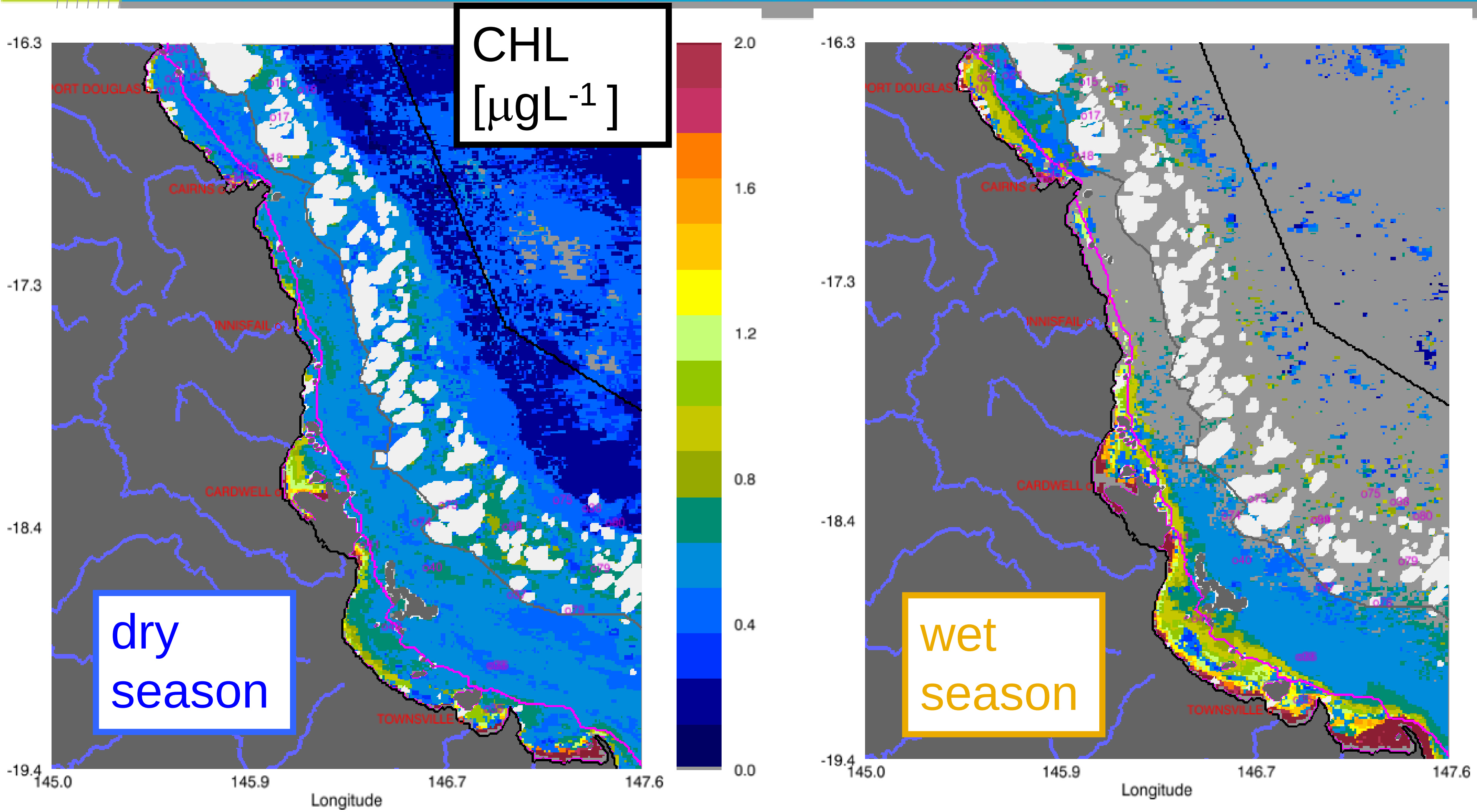
ΔT 3h 3x3 pixel





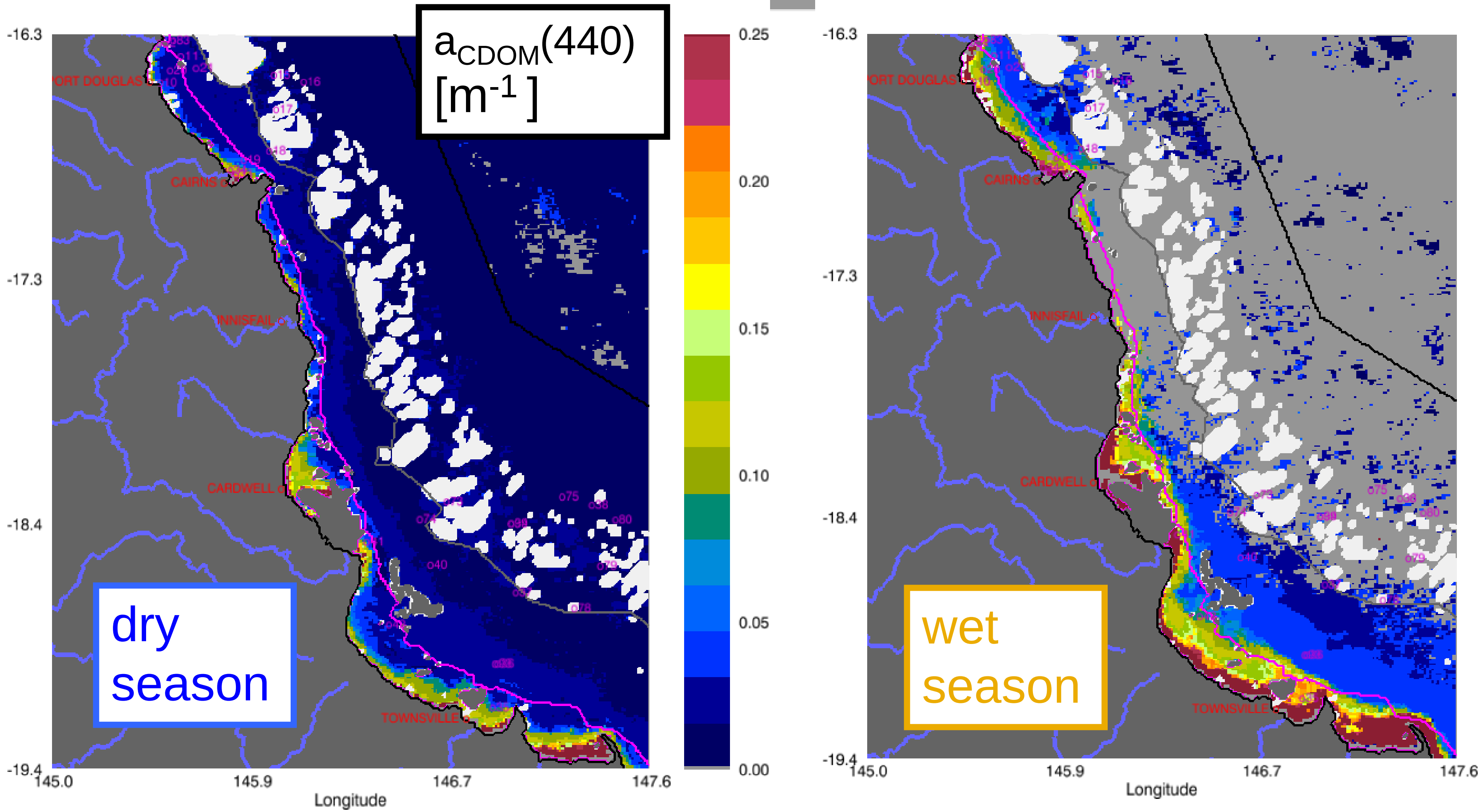
Composites of aLMI AQUA retrievals for dry and wet season

CHL



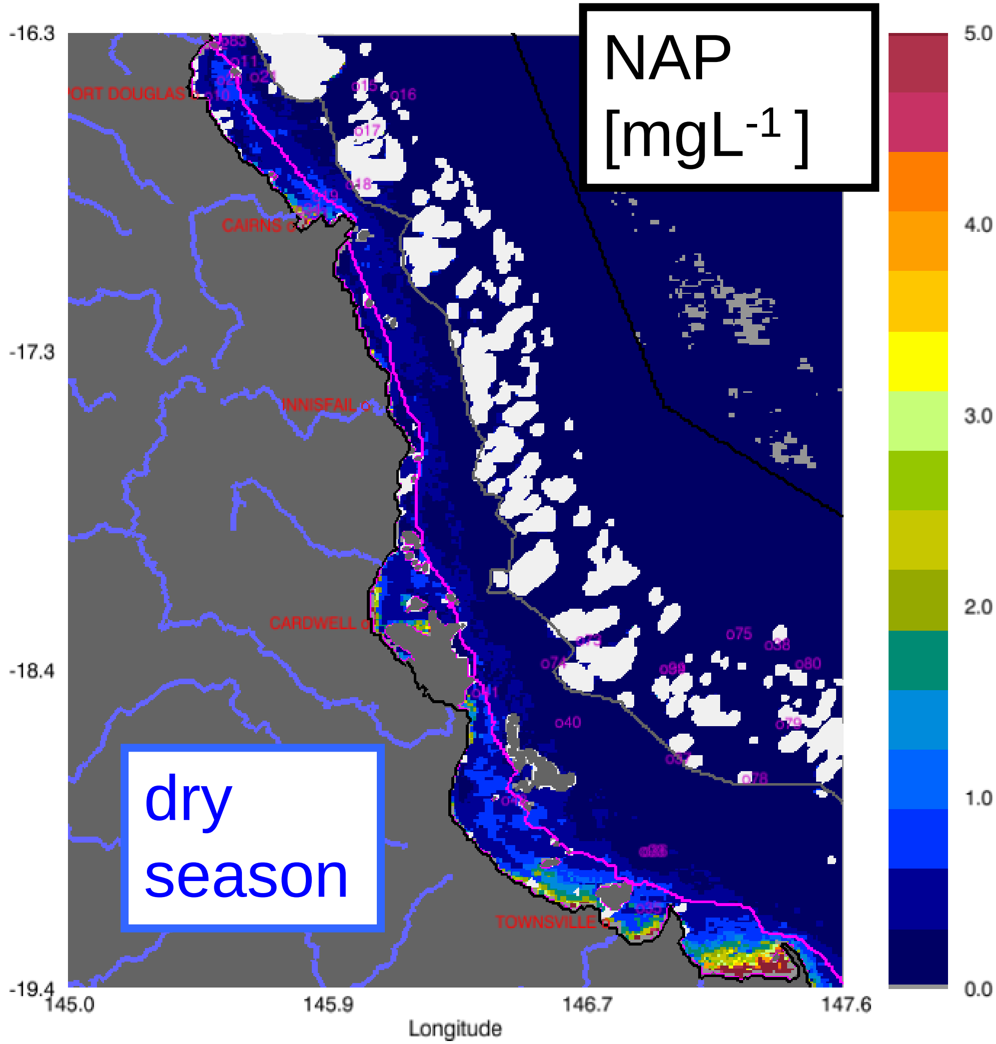
Composites of aLMI AQUA retrievals for dry and wet season

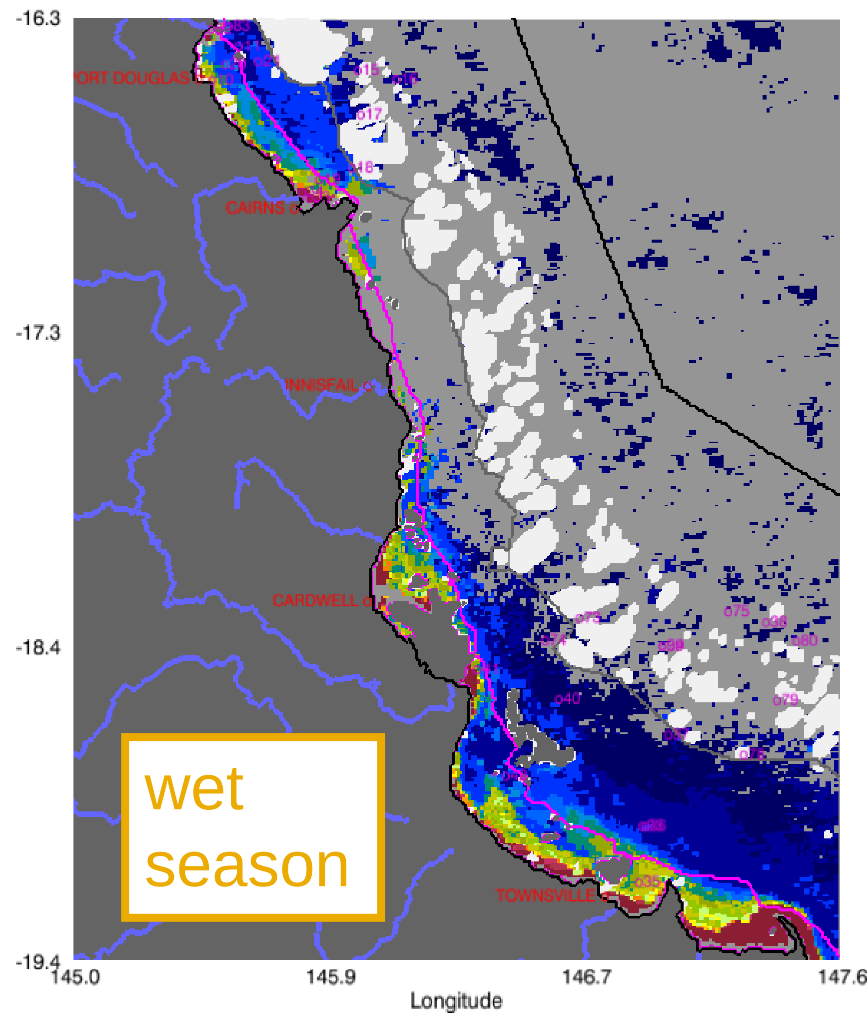
CDOM



Composites of aLMI AQUA retrievals for dry and wet season

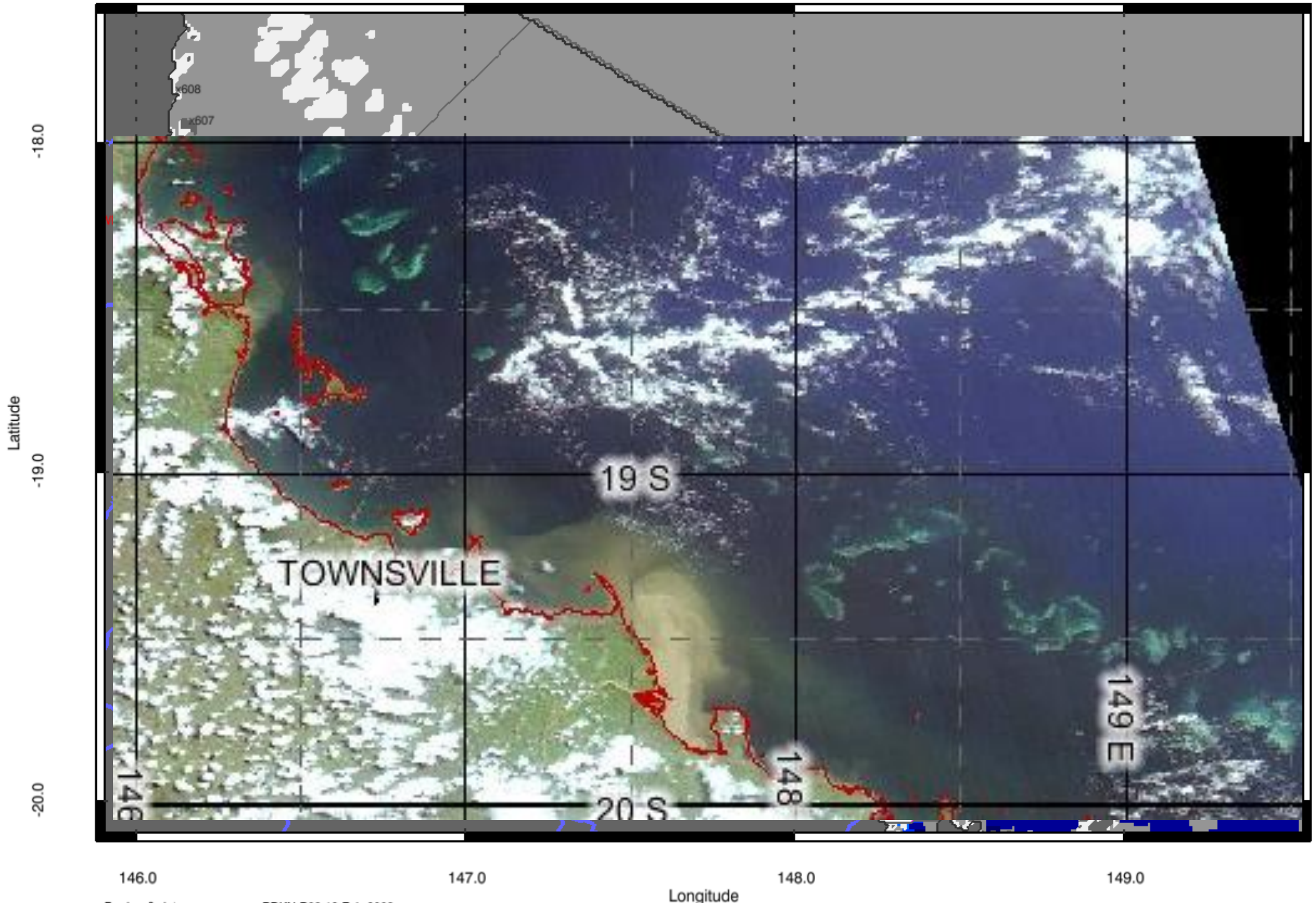
NAP



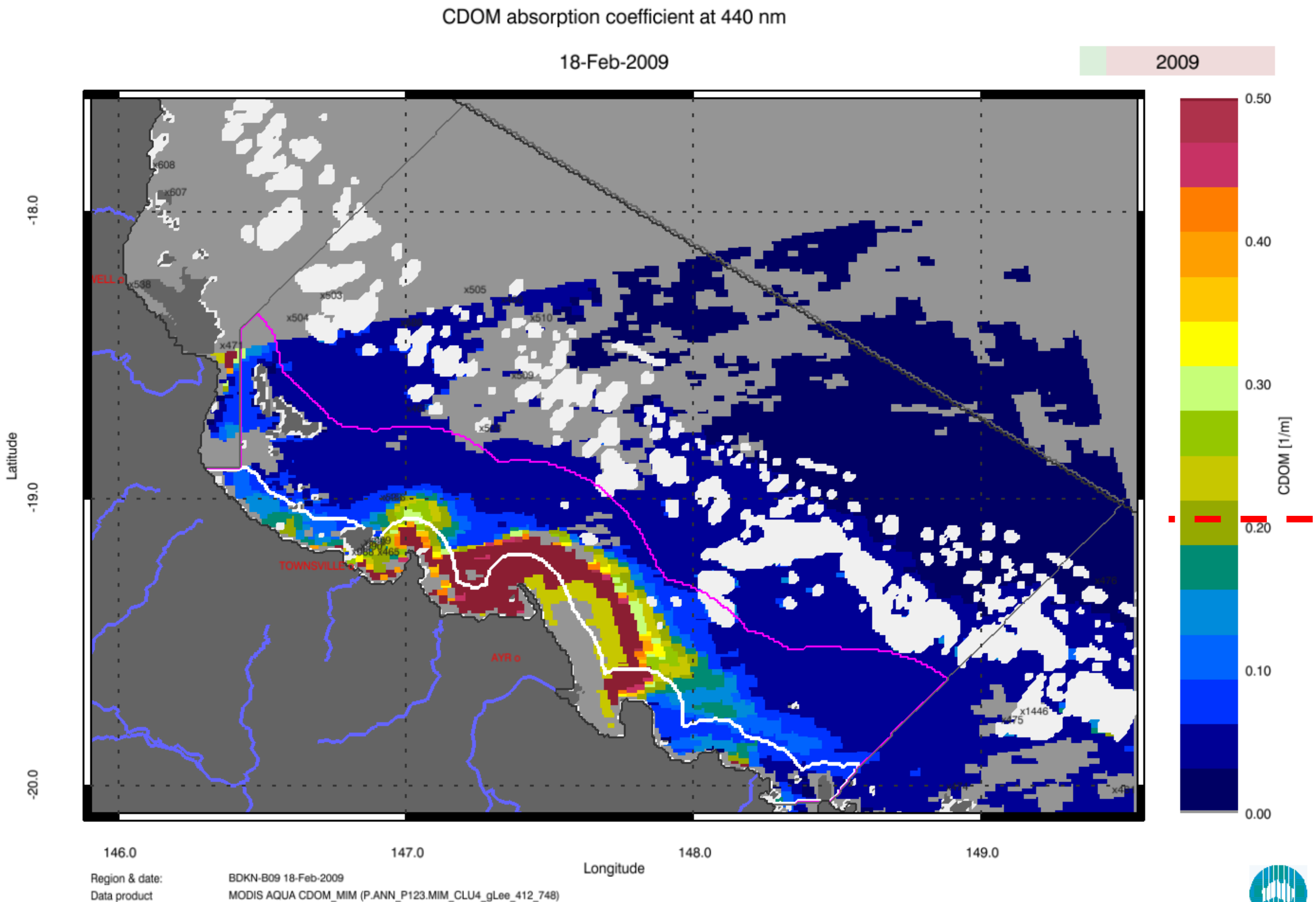


Mapping flood plume extent: true colour imagery

MODIS AQUA 18 February 2009



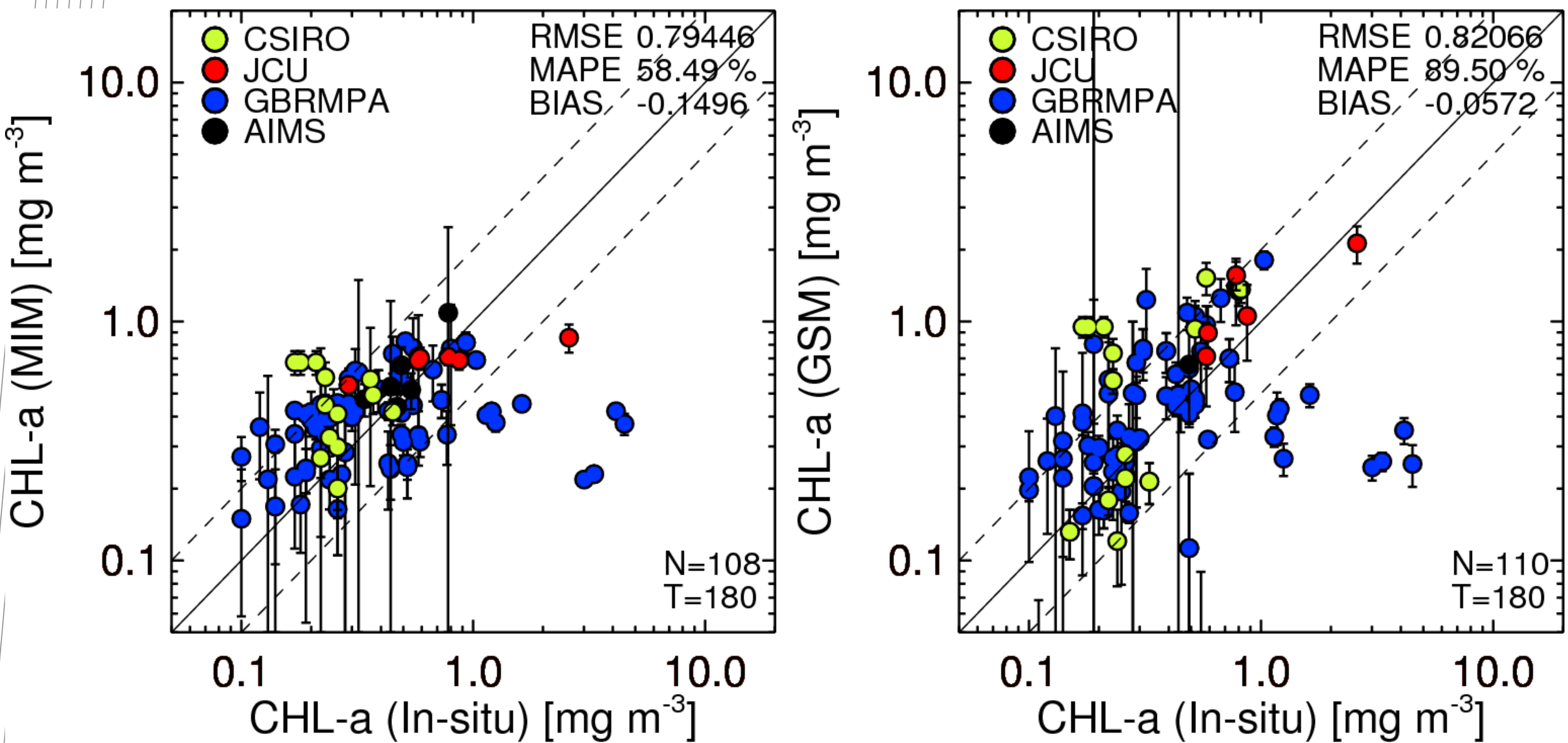
Mapping flood plume extent: daily CDOM map



Retrieval of Chlorophyll-a: (till 2007) Validation results for Great Barrier Reef Waters

CSIRO

NASA



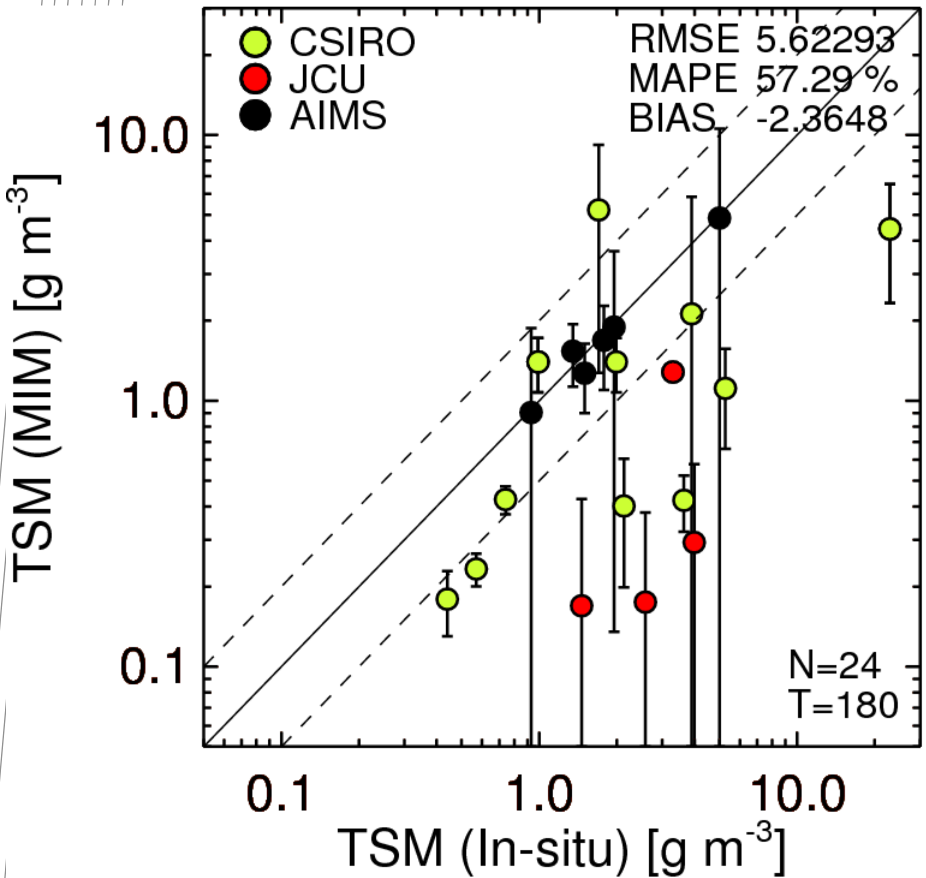
59%

90%

CSIRO

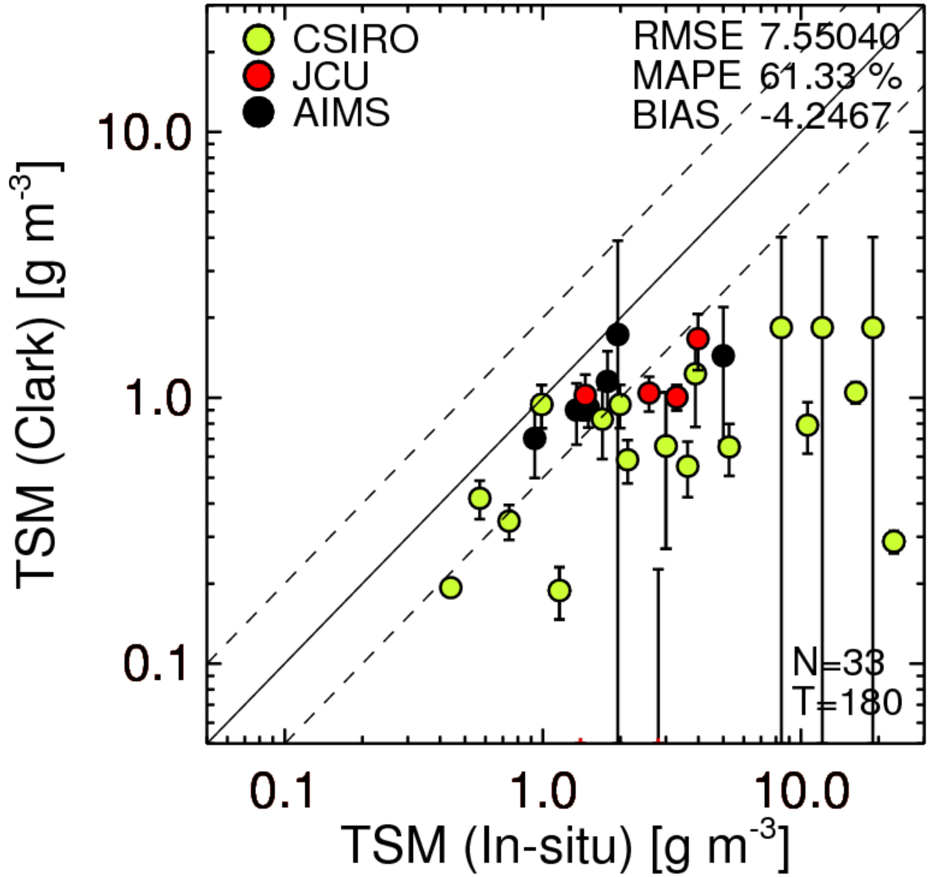
Retrieval of Total Suspended Matter (till 2007) Validation results for Great Barrier Reef Waters

CSIRO



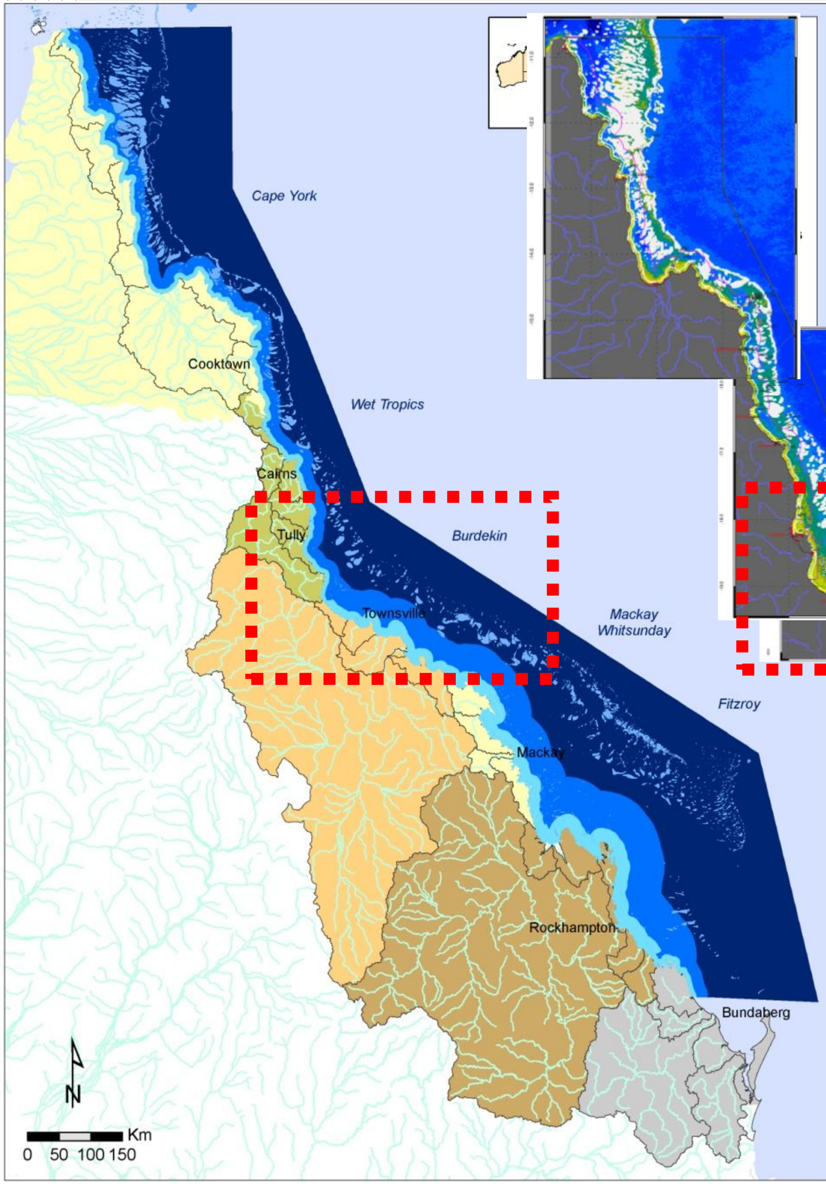
57%

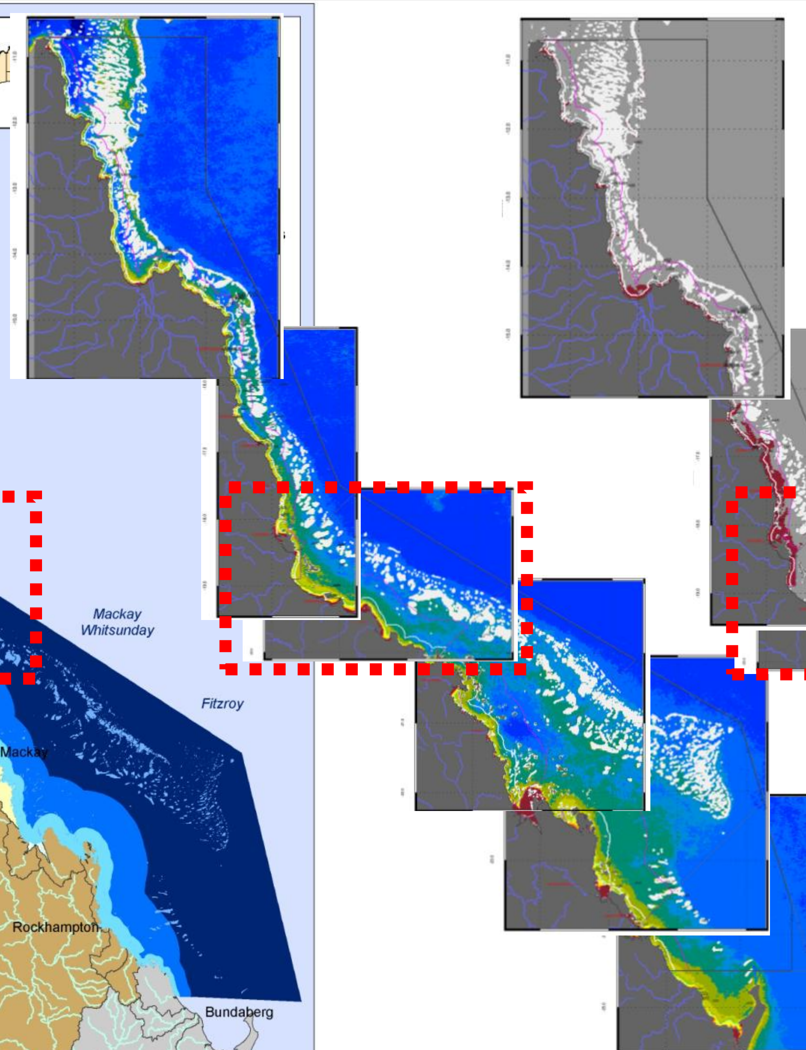
NASA

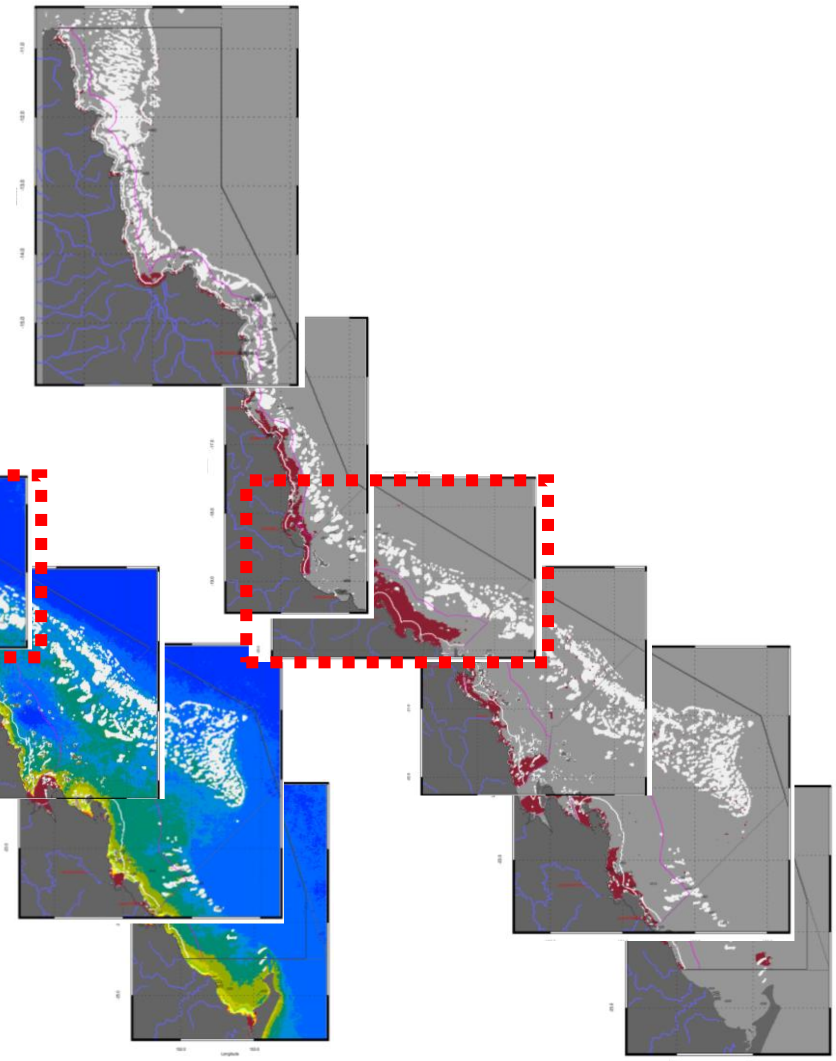


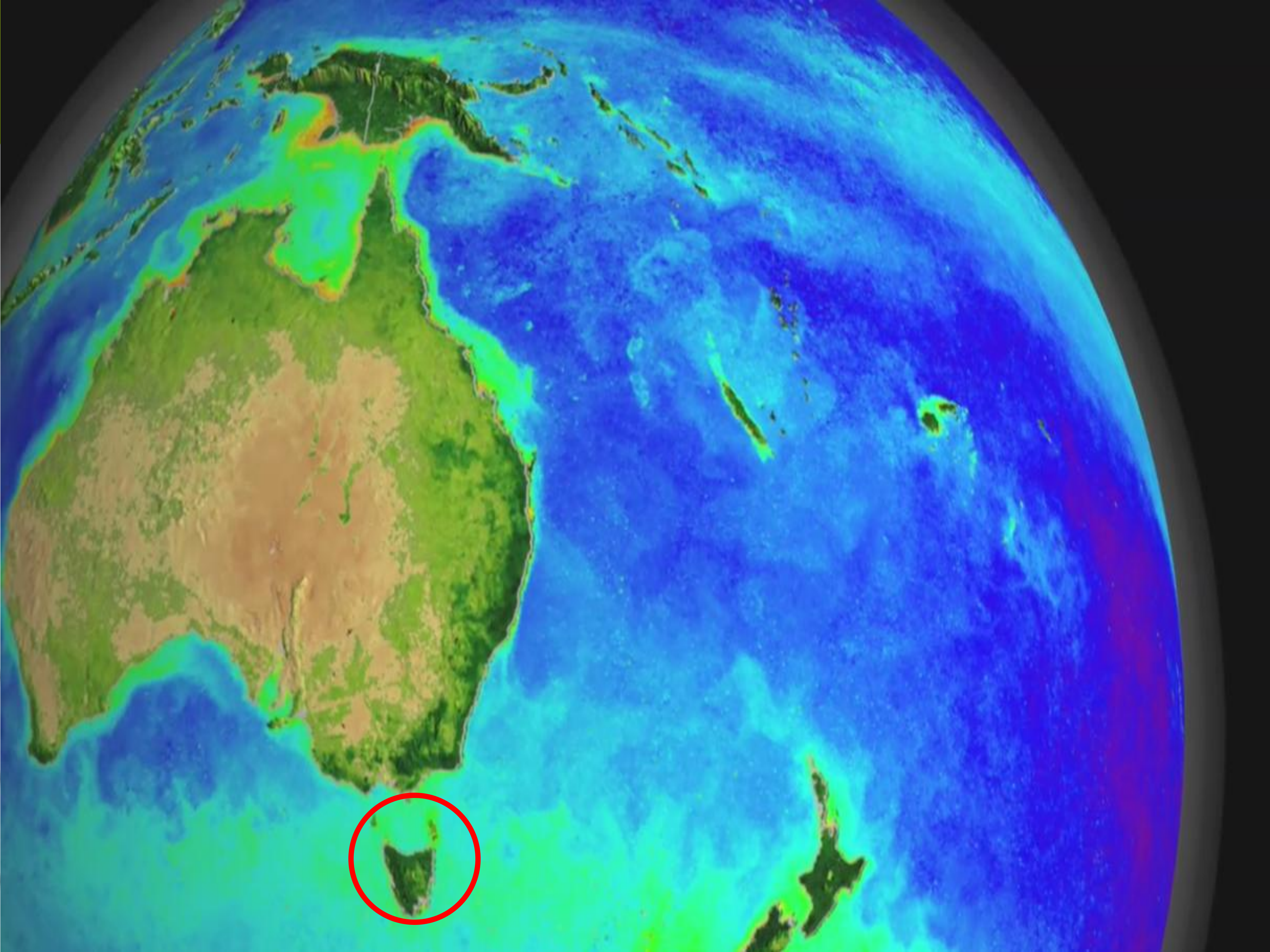
61%

Implementing the GBRMPA Water quality guidelines – Compliance Assessment







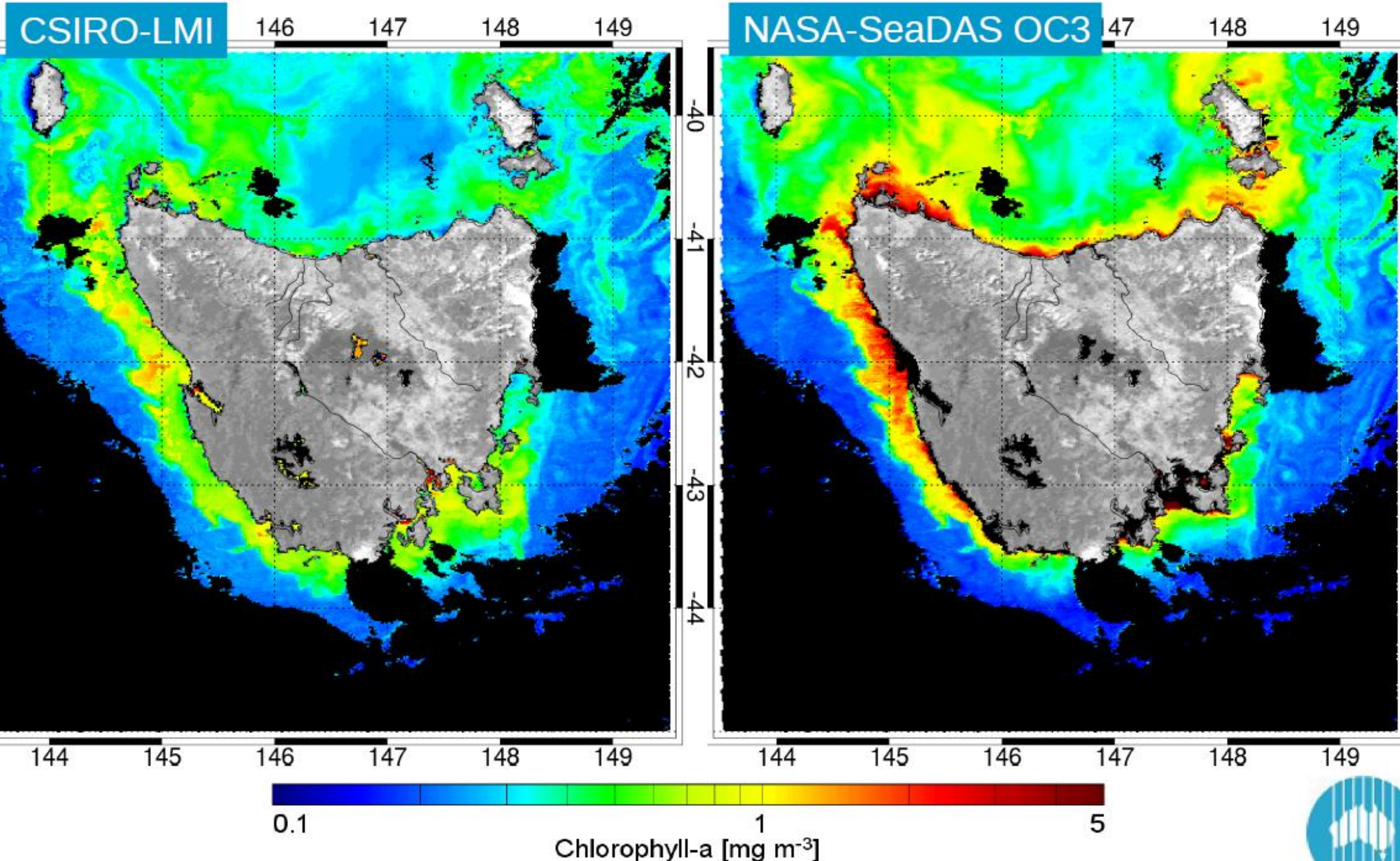


- CDOM dominates the absorption properties of Tasmania's coastal waters

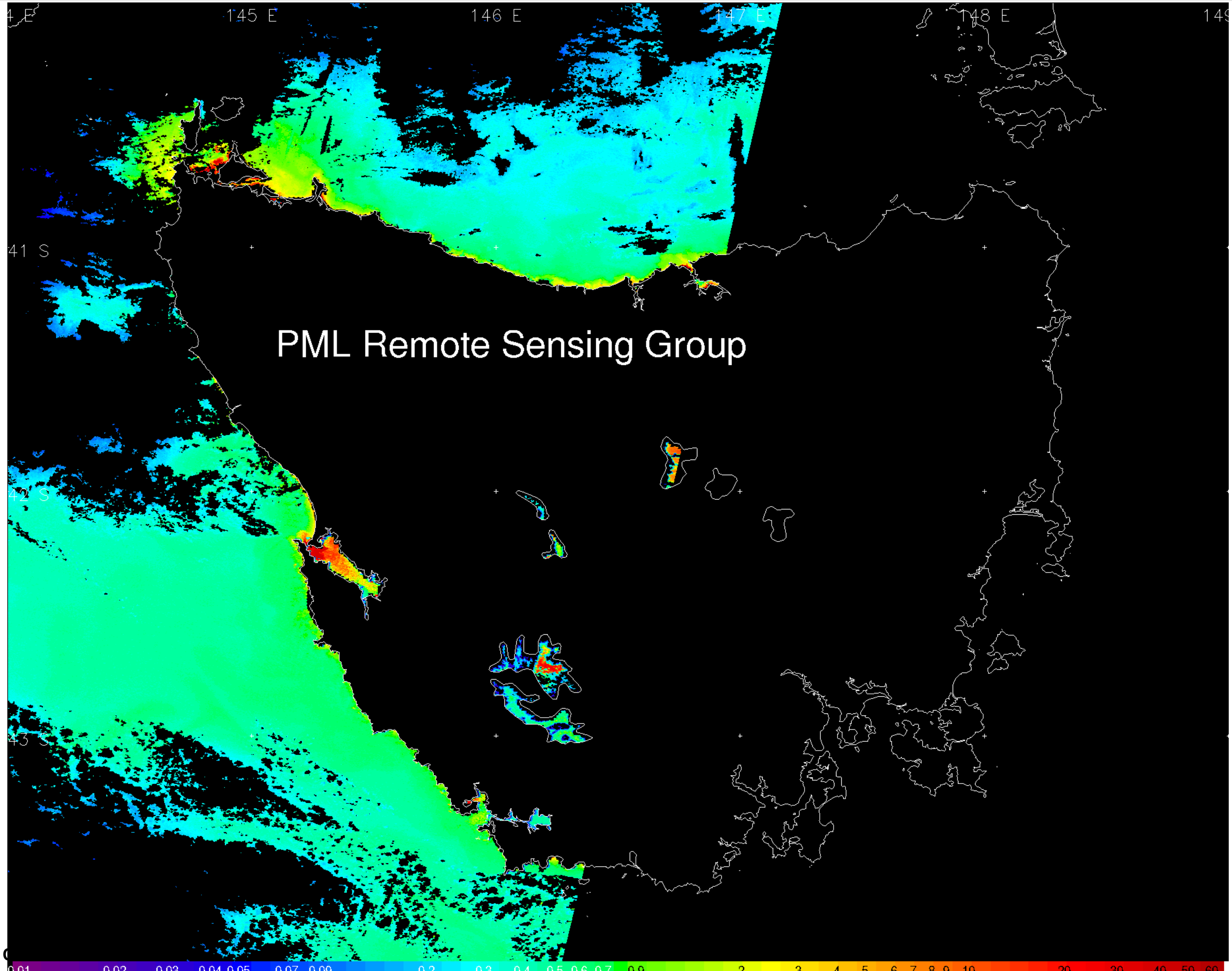
- 2007 field work: Absorption coefficients of up to 5.2 m^{-1} at 440 nm within several meters thick surface layers

CSIRO regional vs NASA global chlorophyll-a

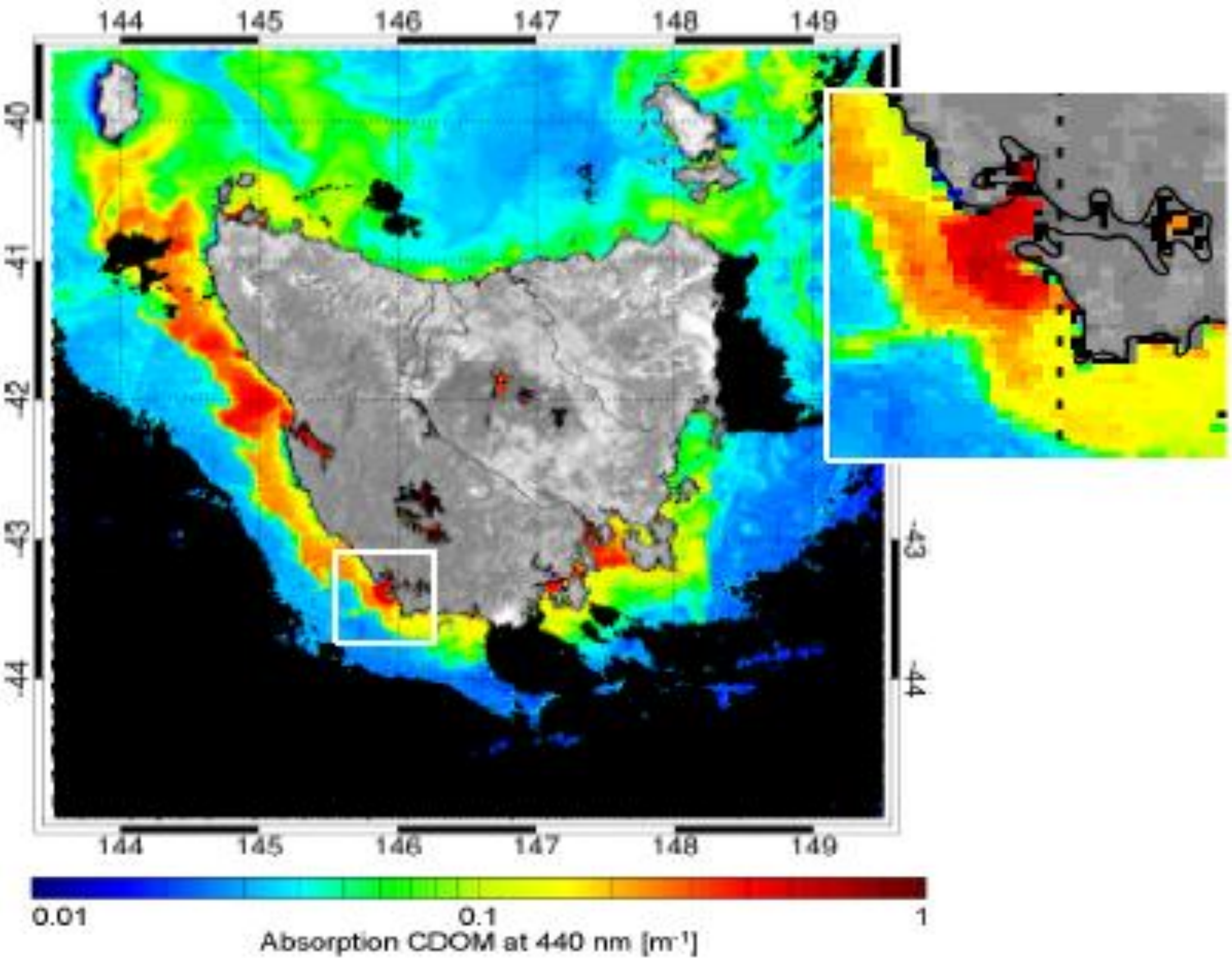
Example: Tasmania – 13 October 2003



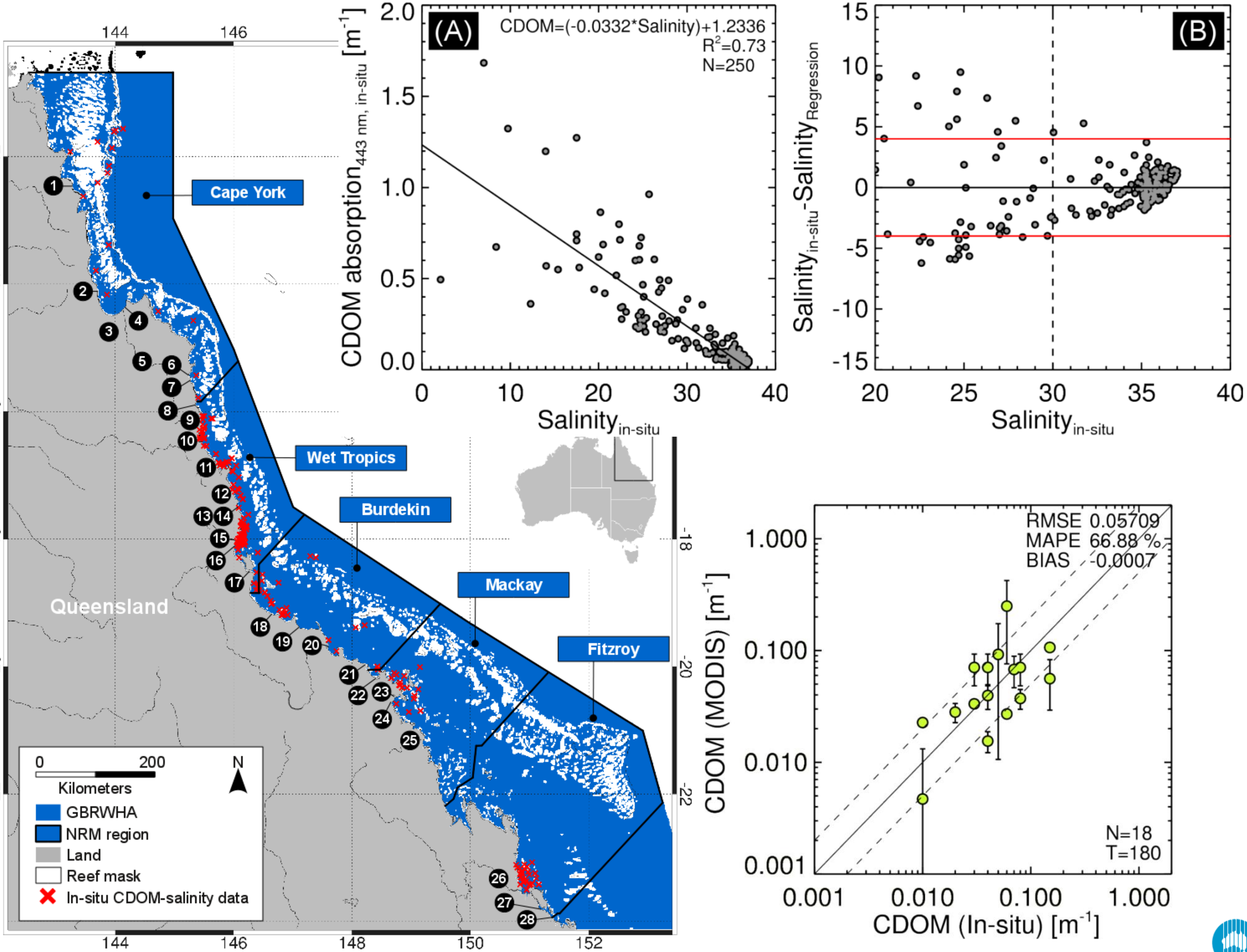
ChloroGIN Lakes MERIS Algal2
29Feb2012



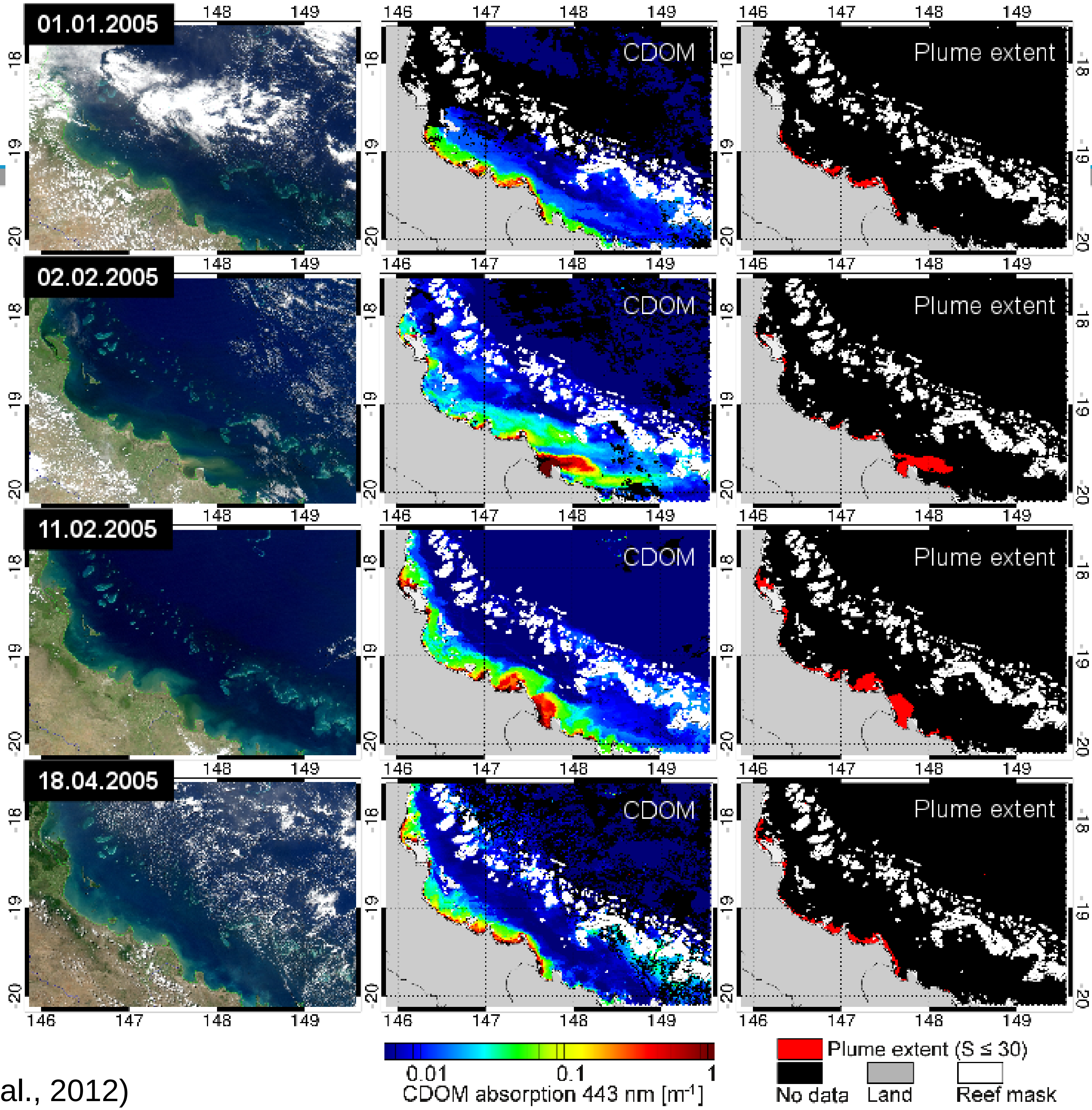
Now CDOM is imaged as CDOM(=validity)



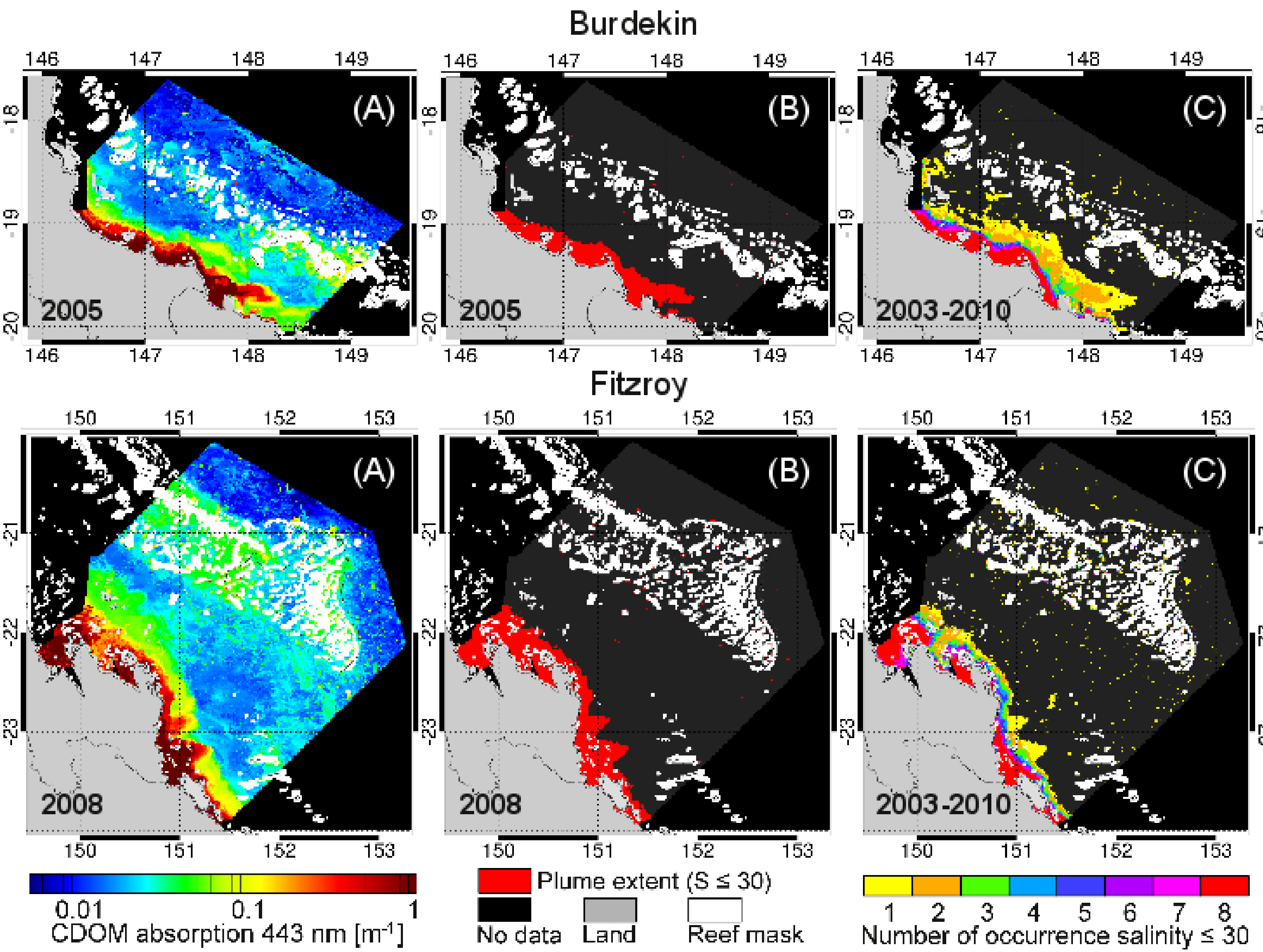
Devlin et al. (2012)



(Schroeder et al., 2012)

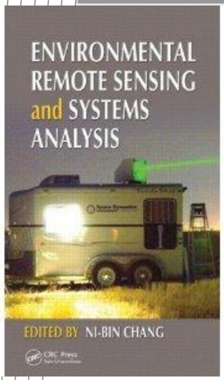


(Schroeder et al., 2012)



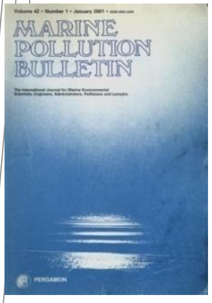
(Schroeder et al., 2012)

Recent flood plume related publications GBR



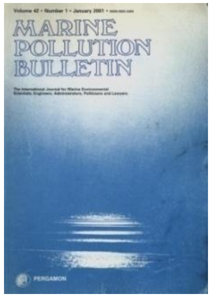
Monitoring and mapping of flood plumes in the Great Barrier Reef based on in-situ and remote sensing observations

Devlin, M., **Schroeder, T**., McKinna, L., Brodie, J., **Brando, V., Dekker, A.,** In:
Advances of Environmental Remote Sensing to Monitor Global Changes,
Chapter 8, pp 147-190, CRC Press, Boca Raton, Florida, USA,
ISBN: 978-1-4398-7743-2, in press **(2012)**



Inter-annual variability of wet season freshwater plume extent into the Great Barrier Reef lagoon based on coastal ocean colour observations

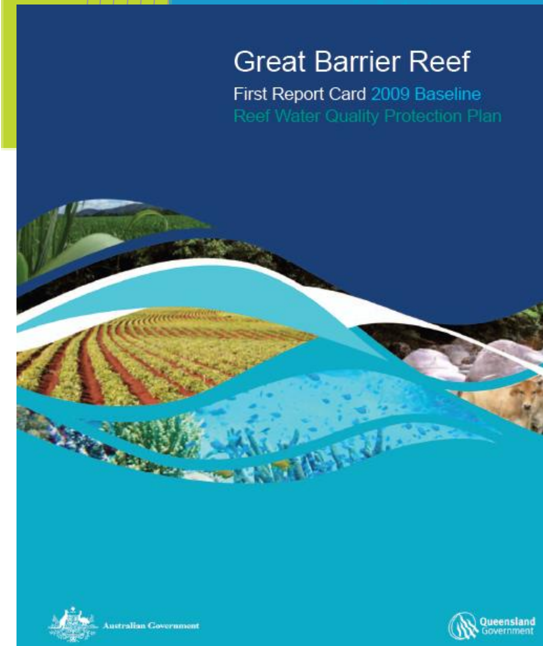
Schroeder T., Devlin M., **Brando V., Dekker A.,** Brodie J., Clementson L., McKinna L.;
Marine Pollution Bulletin, in press **(2012)**



Long term monitoring of photosystem II herbicides - Correlation with remotely sensed freshwater extent to monitor changes in the quality of water entering the Great Barrier Reef

Kennedy K., **Schroeder T.,** Shaw M., Haynes D., Lewis S., Bentley C.,
Paxman C., Carter S., **Brando V.**, Bartkow M., Hearn L., Mueller J.F.;
Marine Pollution Bulletin, in press **(2011)**

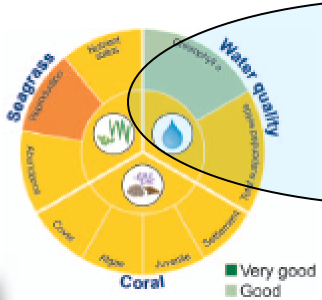
GBR Report card based on MODIS (CLW)
Brando V., Dekker A. et al.



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).

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.

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.

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

…asin Authority 27th

Conclusions aLMI for complex waters

The Applied Optics paper focused on MODIS based LMI inversions, the results and method are easily transferable to other sensors such as SeaWiFS, MERIS, OCM-2, GOCI, VIIRS, Landsat, WordView-2 etc., since all spectral information is used.

The retrieval accuracy will vary for each sensor and it will need adequate quantification.

The accuracy of the retrieval is likely to be similar or slightly degraded for sensors that have less spectral bands such as SeaWiFS and VIIRS [52].

For sensors with increased spectral bands (e.g. MERIS, OLCI) the retrieval accuracy can be expected to improve as additional wavelengths provide additional constraints, reducing the uncertainties on both amplitudes and spectral shapes

Also works in inland waters

Conclusions aLMI for complex waters

Strengths:
•Sensor agnostic
•Water type agnostic

Need to incorporate Kimberley and NSW (S)IOP and GBR 2008-2011 (S)IOPs and do match-up MERIS V3 FR and RR Dataset

Question/Challenge:

how to parameterise with SIOPs when going from regional (=100's to 1000's kms) to continental (3000*4000 km across temperate-subtropical and tropical) to global?

ESA-CoastColour type activities very important for further comparisons of EO approaches to complex waters

CSIRO