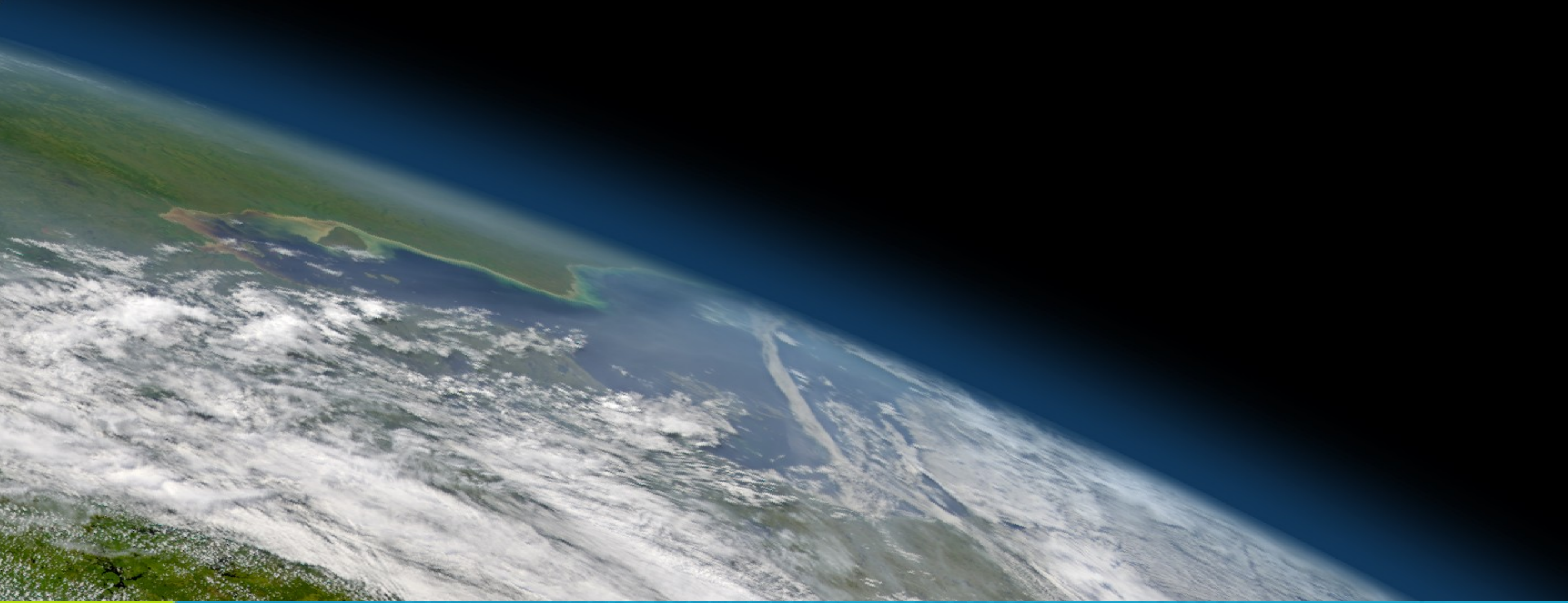

Remote sensing & mapping of water quality in optically complex waters

SeaHARRE-5 Workshop 13-16 April 2010, Hobart, Tasmania

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This presentation

Introduction – water quality from remote sensing

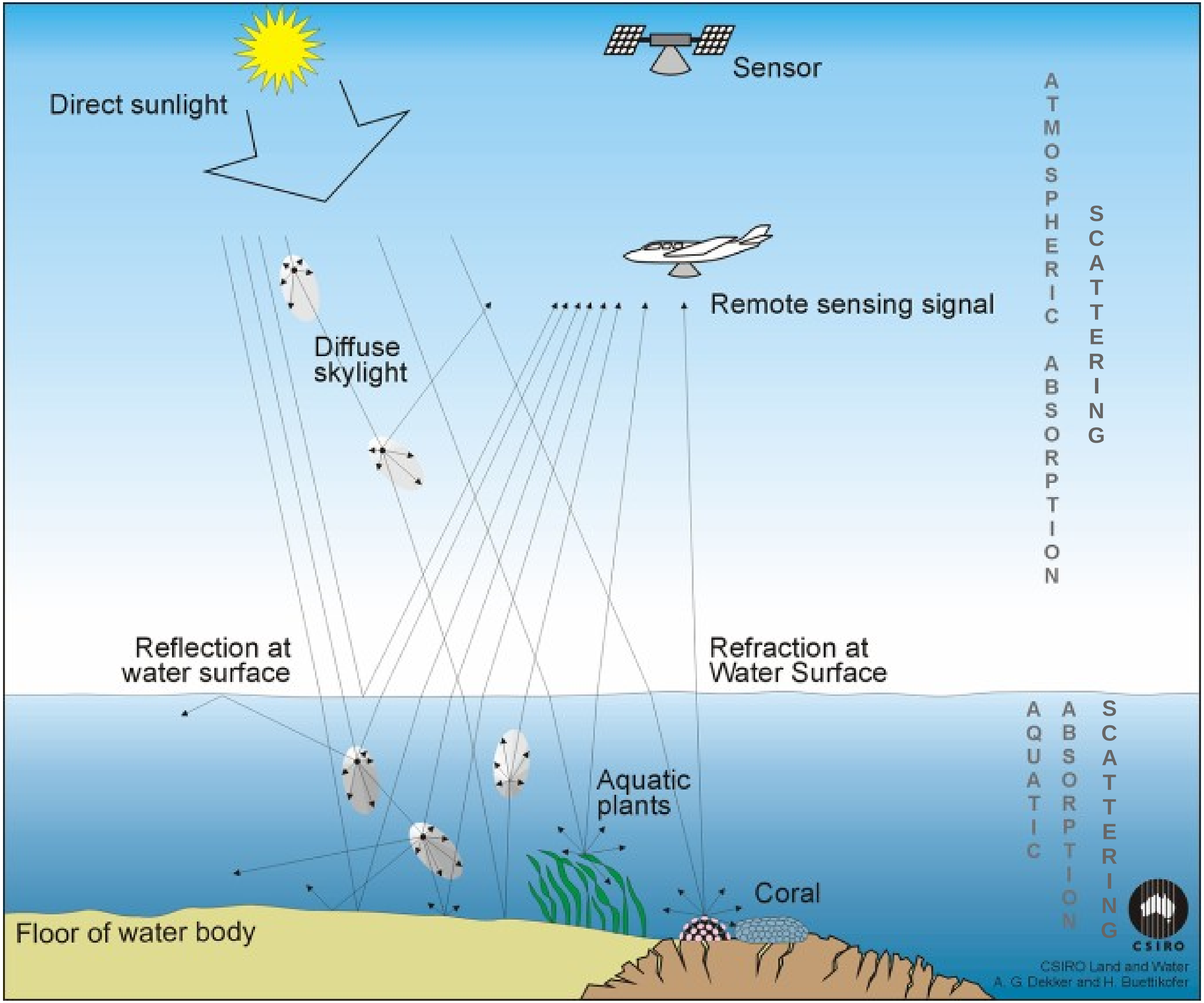
Challenges in Australian coastal waters

CSIRO's algorithm methodology for optically deep waters

Validation (opportunities)

Application – Flood plume mapping

$$L_{\mathrm{TOA}}(\lambda) = L_{\mathrm{Rayleigh}}(\lambda) + L_{\mathrm{Aerosol}}(\lambda) + L_{\mathrm{Rayleigh+Aerosol}}(\lambda) + t(\lambda)\, L_{\mathrm{Water}}(\lambda)$$



Standard atmospheric correction approach
The "black pixel" (BP) assumption

NIR (>700 nm) open ocean is assumed to be "black" with Lw=0

For turbid (coastal) waters black ocean assumption often invalid

Various approaches try to re-establish the BP assumption by removing the NIR contribution from the TOA NIR signal eg:

- Siegel et al. (2000) via CHL estimate
- Ruddick et al. (2000) via fixed aerosol and backscatter type
- Lavender et al. (2005) via sediment estimate
- Wang et al. (2007) SWIR correction 1240, 1640, 2130 nm MODIS only
- Aiken and Moore (2000) use iterative approach for bright pixels

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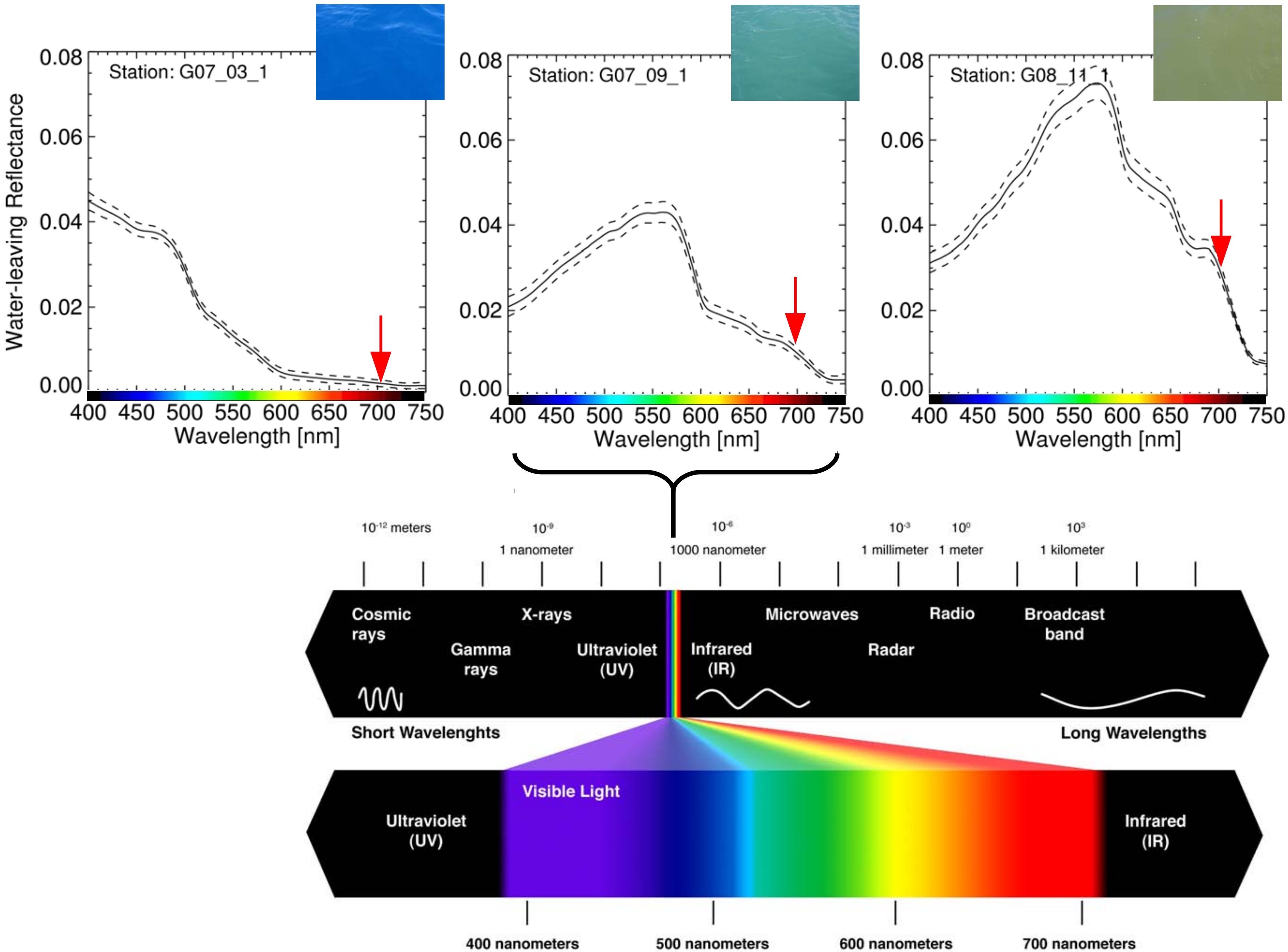
Ocean Colour - Reflectance
Intro II



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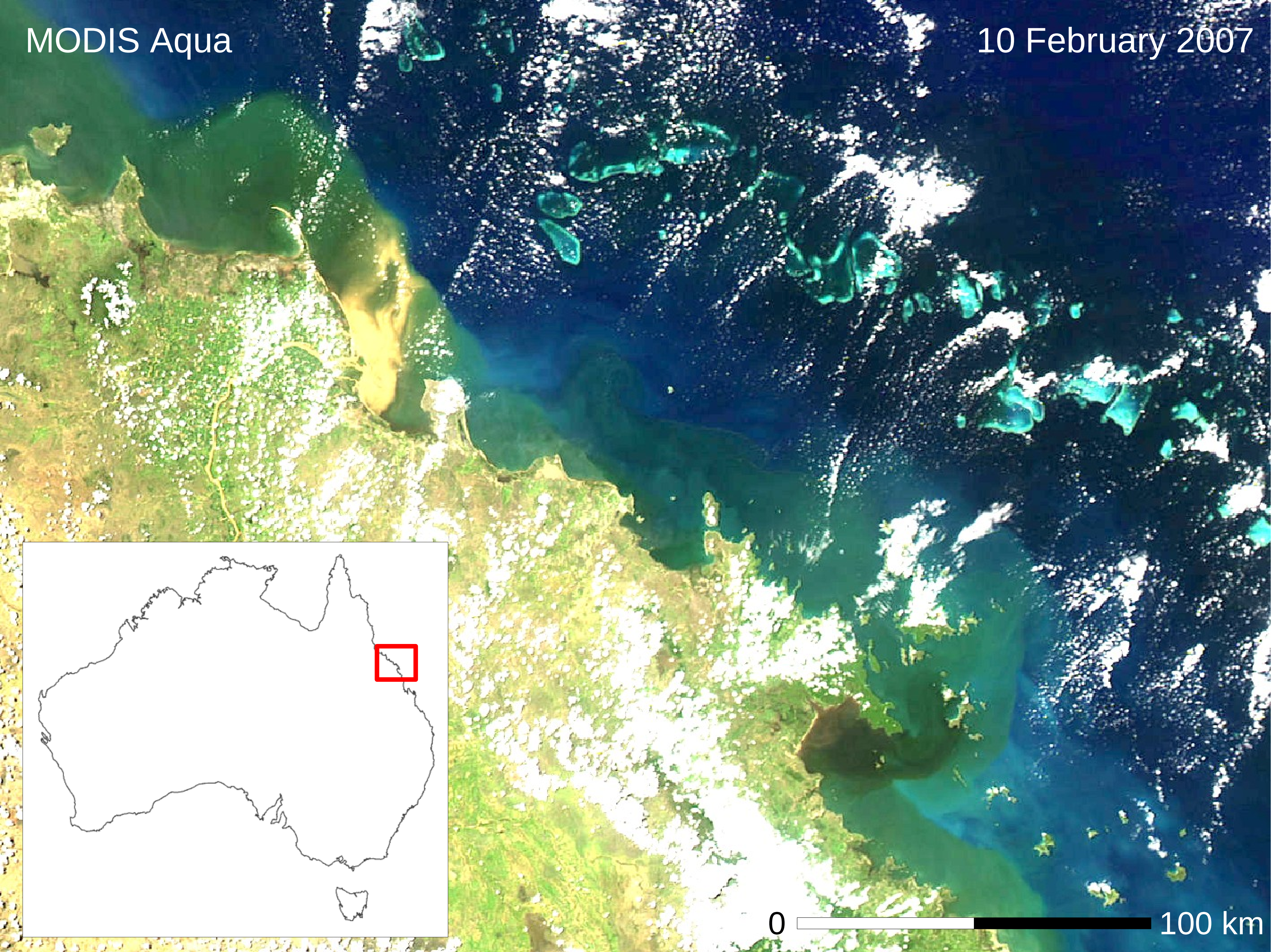
MODIS Aqua
10 February 2007
0
100 km

Gobal algorithms & Australian coastal waters

Problem 1

Global (empirical) algorithms are designed for open ocean (blue) waters and frequently fail when applied to optically complex coastal waters as previously shown for the Great Barrier Reef

(Qin et al. 2007, GRL)

Problem 2

Standard atmospheric correction algorithms systematically fail for CDOM and TSS dominated coastal waters

Image credit: http://www.lib.utexas.edu

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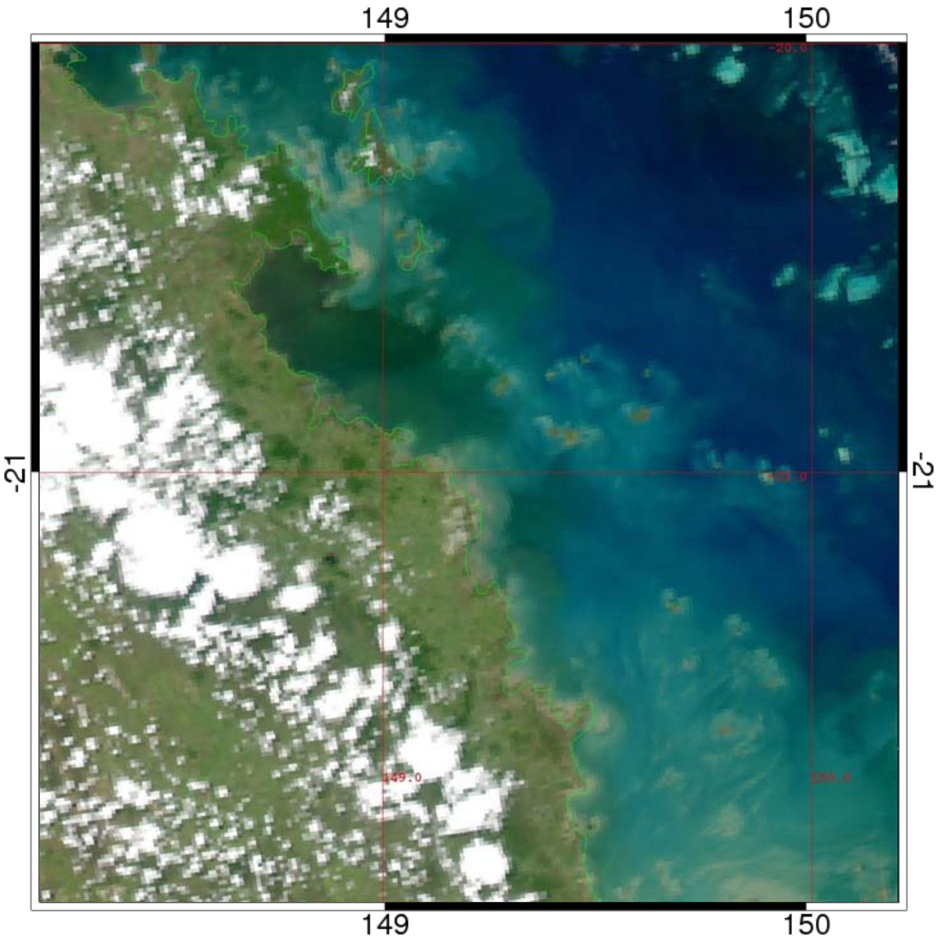
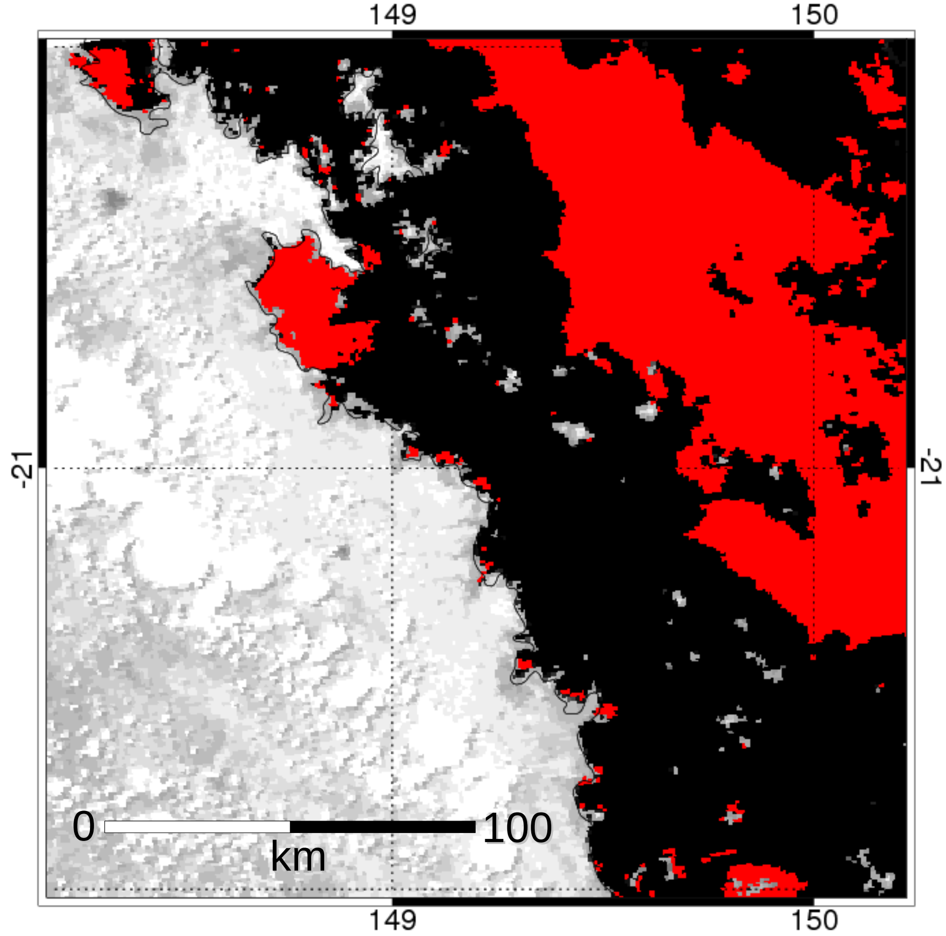
NIR atmospheric correction failure MODIS-Aqua

Extreme 1: Mackay – Whitsundays, QLD – 22 February 2008



Spectral range 412 – 748 nm



= Atmospheric correction failure

Image credit: http://www.lib.utexas.edu

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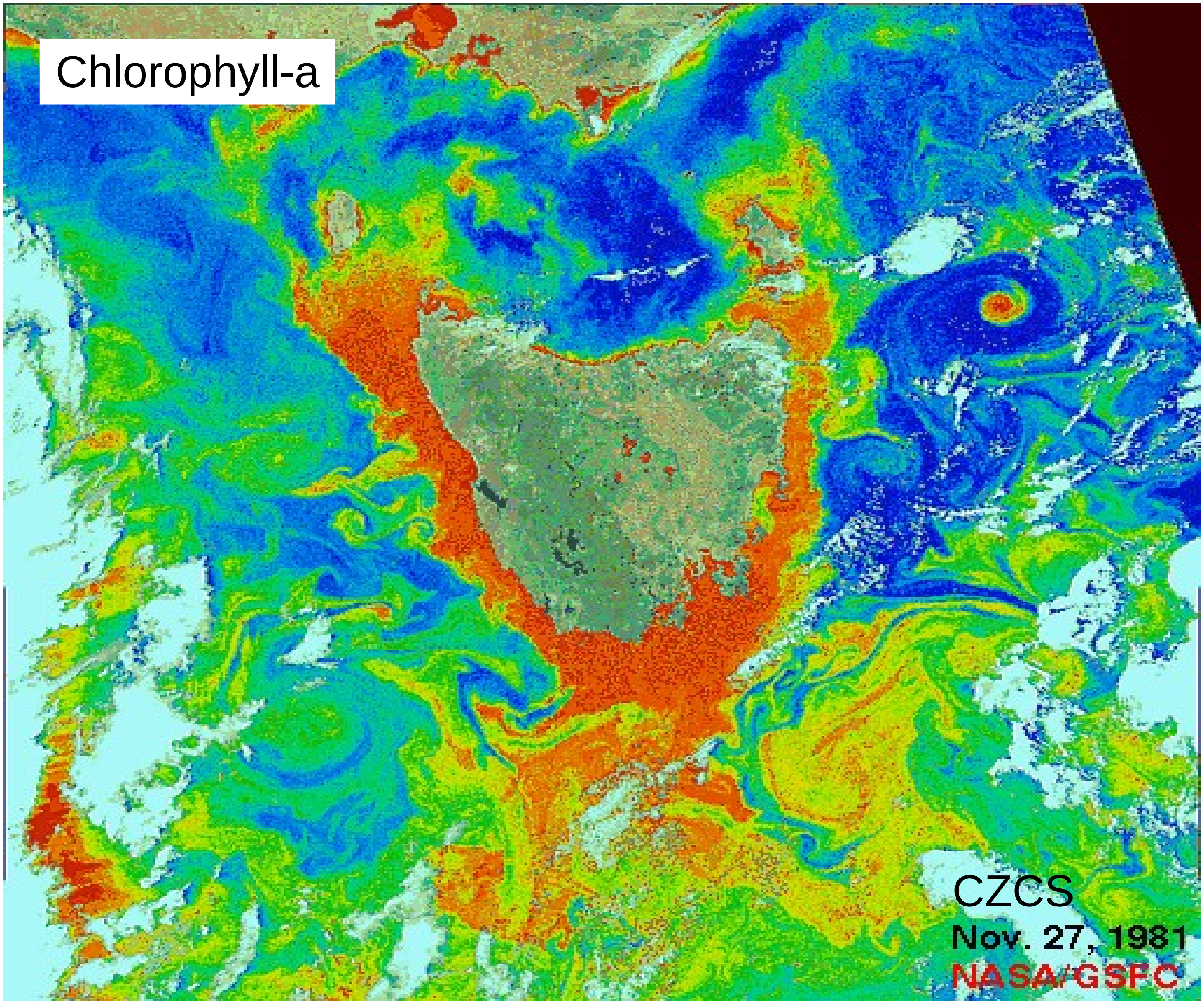
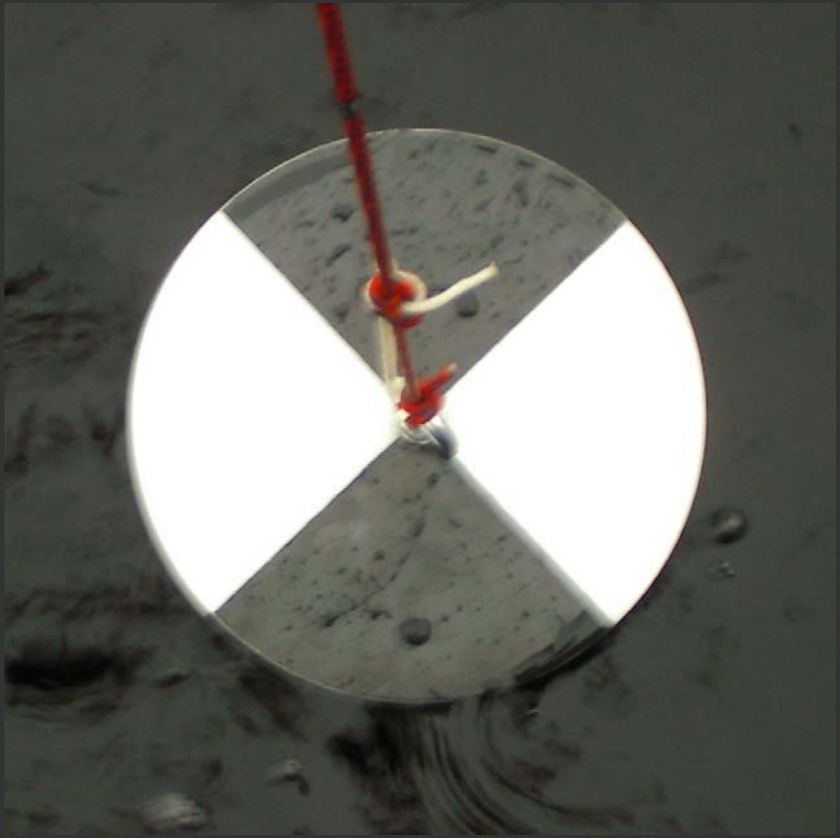
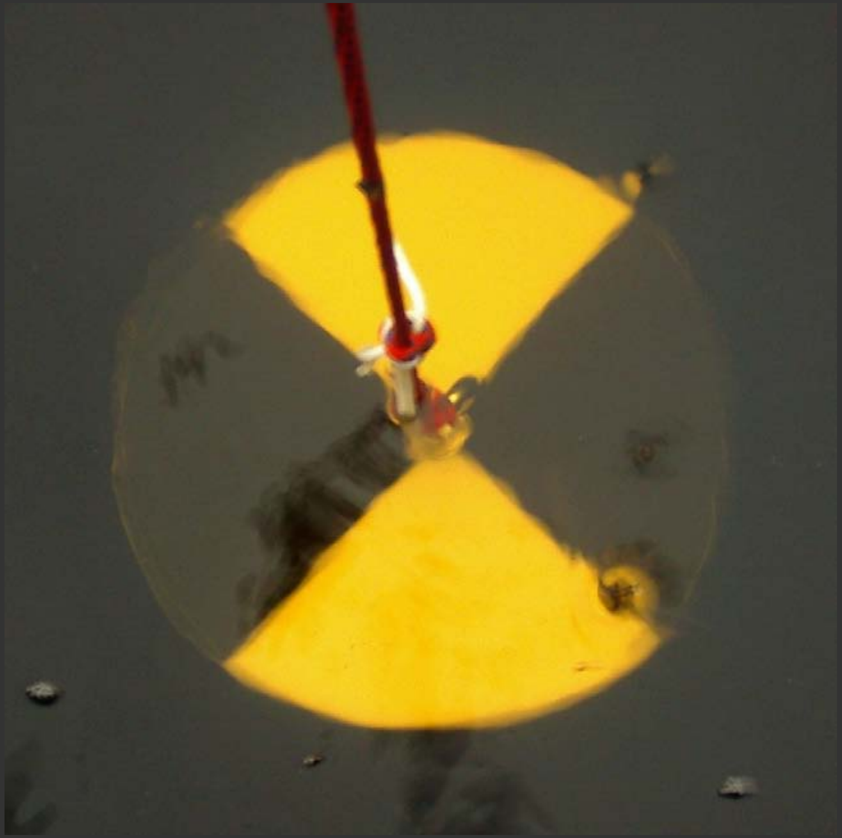
(Global) Ocean Colour Products



CDOM dominates the absorption properties of Tasmania's coastal waters

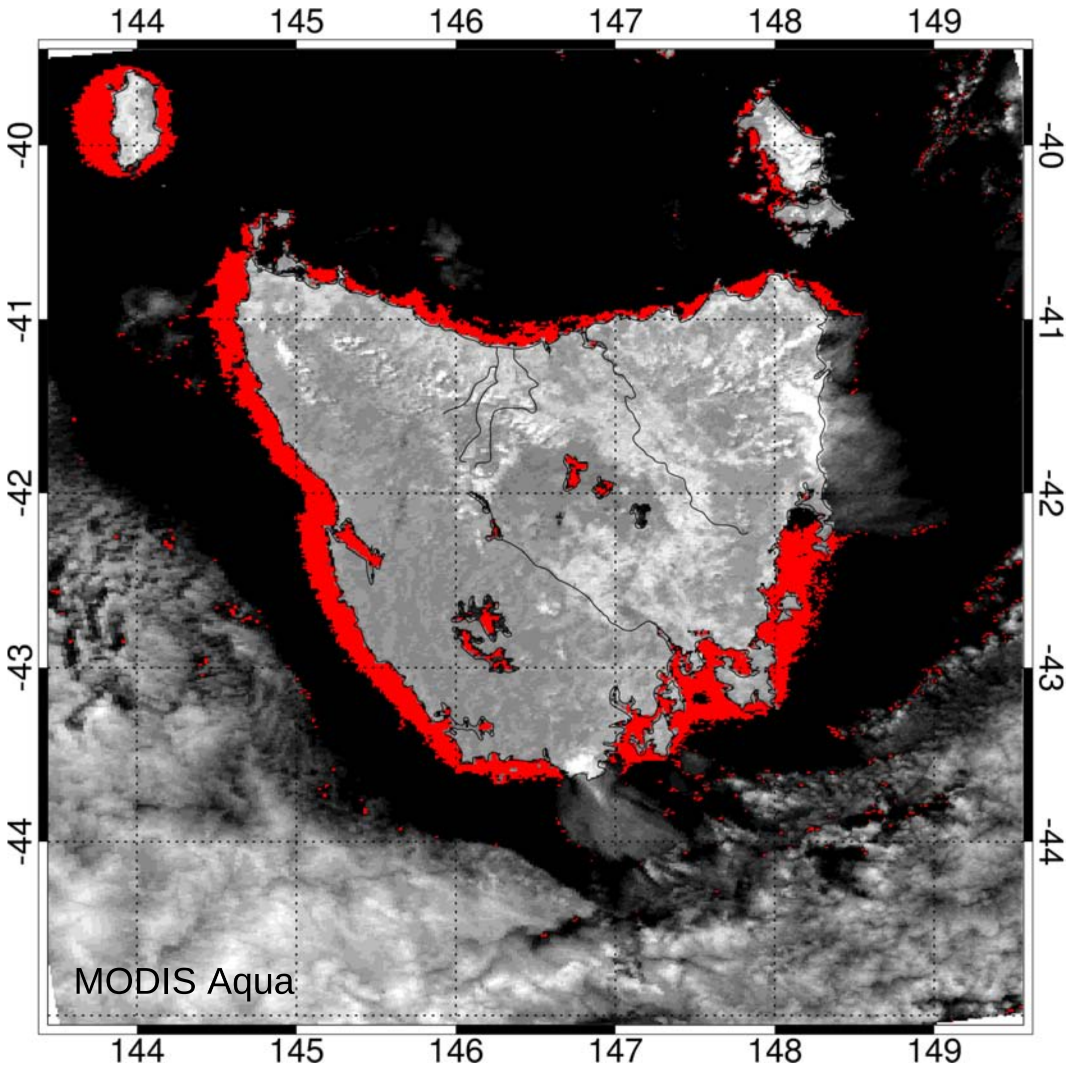



2007 field work: Absorption coefficients of up to 5.2 m^{-1} at 440 nm within several meters thick surface layers

NIR algorithm failure for Tasmanian region

Example: Tasmania – 13 October 2003

412 – 678 nm



= Atmospheric correction failure

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, Ocean Optics XIX)

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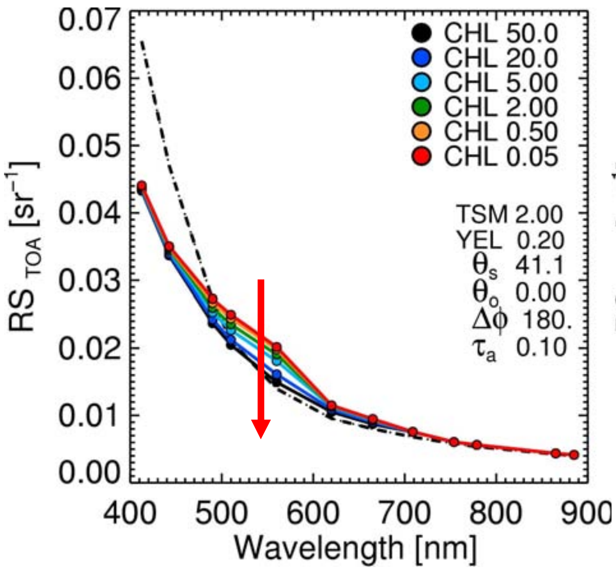
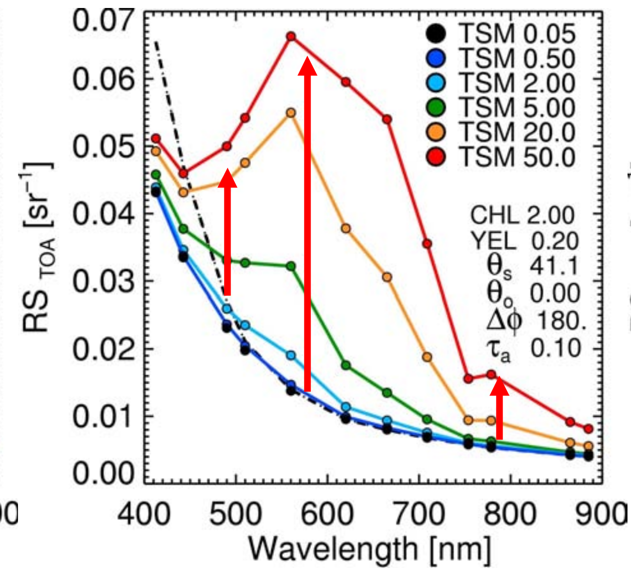
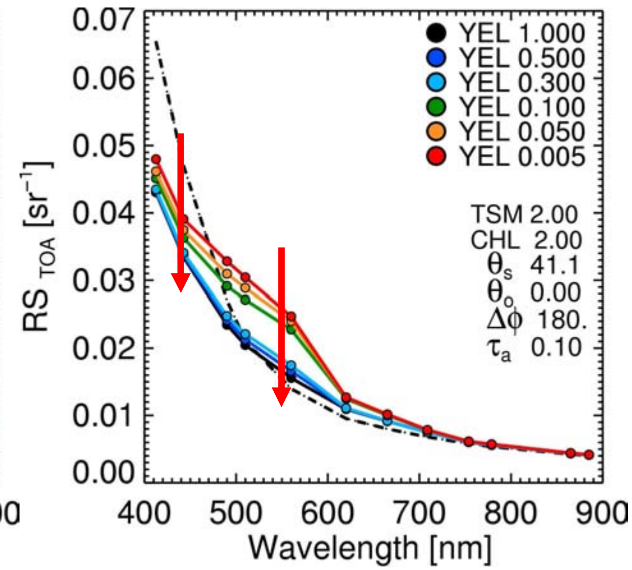
Simulated Top-of-Atmosphere Spectra

Coastal waters

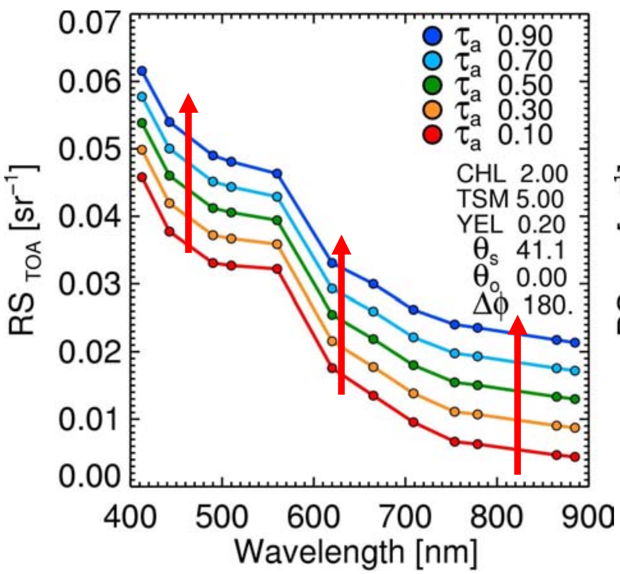
... depending on variations of the water constituents

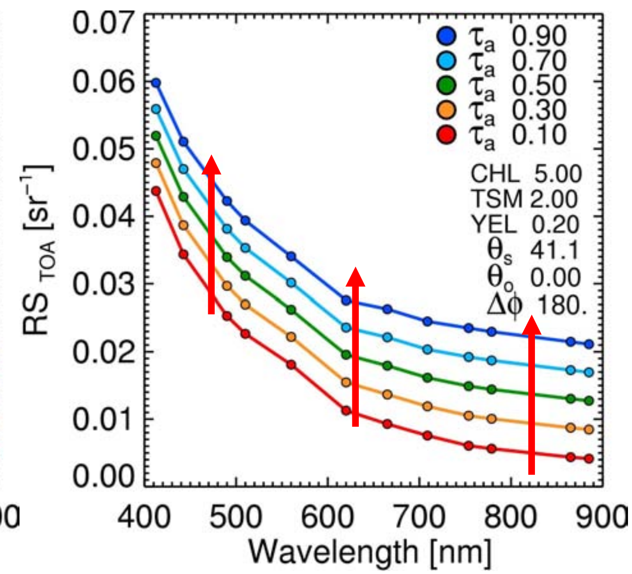






... depending on variations of the type and concentration of the aerosol





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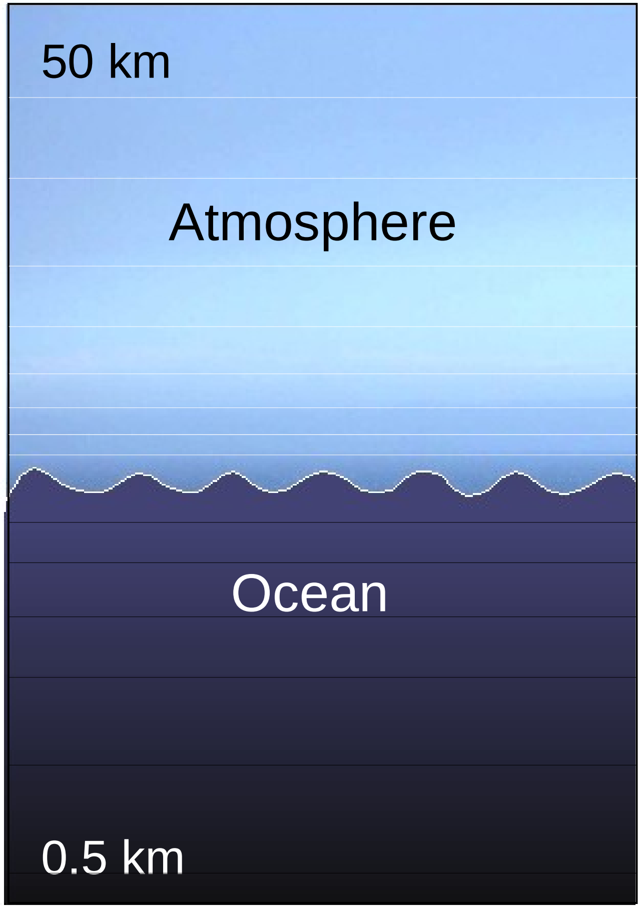
Atmospheric correction – Forward model

- Coupled radiative transfer model based on matrix-operator method (FUB)
- Simulates the upward azimuthally resolved radiance field (TOA & BOA)
- Variety of different sun and observing geometries and as well as different types of atmospheric and oceanic constituents

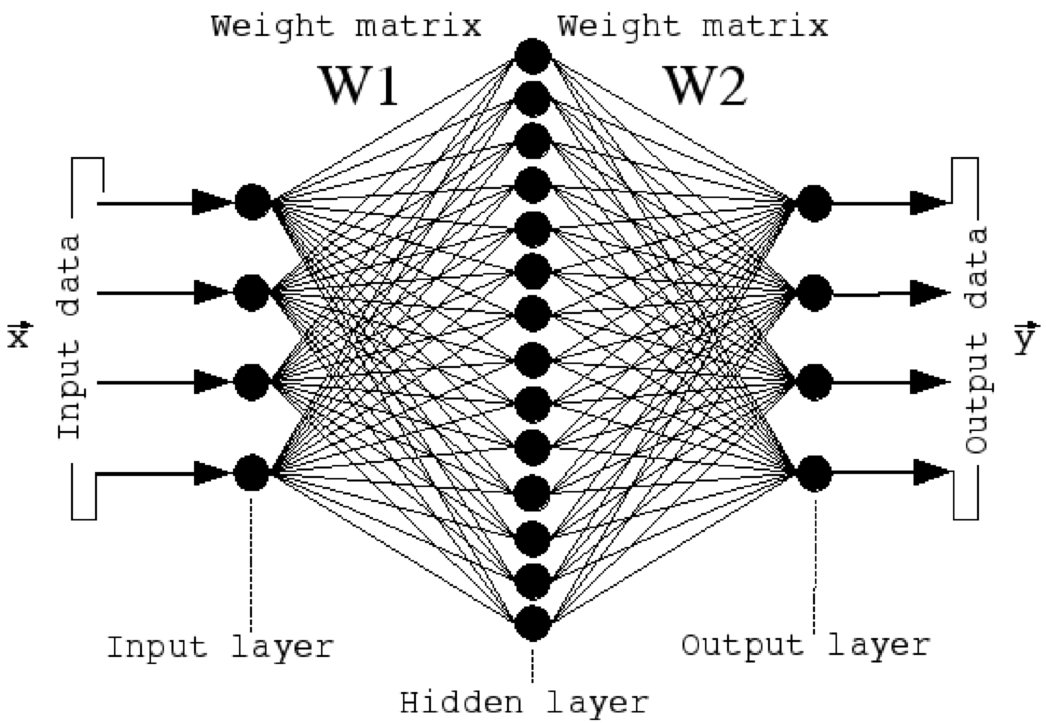


- Vertical profile (US-Standard)
- Ozone (344 DU)
- Rayleigh (980hPa, 1040hPa)
- Aerosols (8-Types)
- Optical depths
- Single scattering albedos
- Phase functions

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

Atmospheric correction – Inverse model

- ANN: multi-layer perceptron



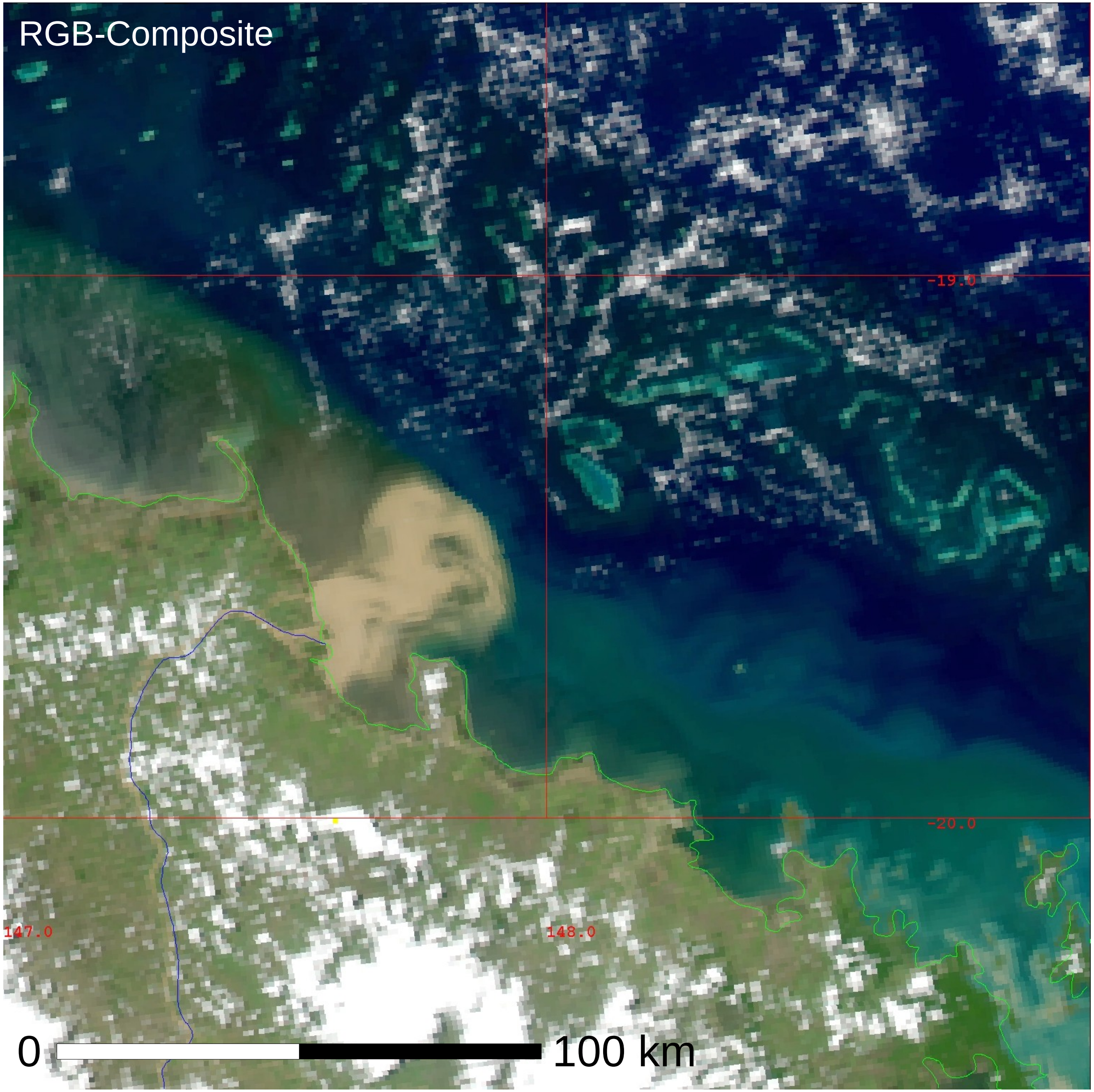
$$\vec{y} = S\left\{ W2 \cdot S(W1 \cdot \vec{x}) \right\}$$

$$S(x) = (1+e^{-x})^{-1}$$

- The network's free parameters (weights) are adapted during a supervised learning procedure
- Training data set: 200.000 randomly selected vectors from the simulated data base (Gaussian signal-dependent noise, PCA)

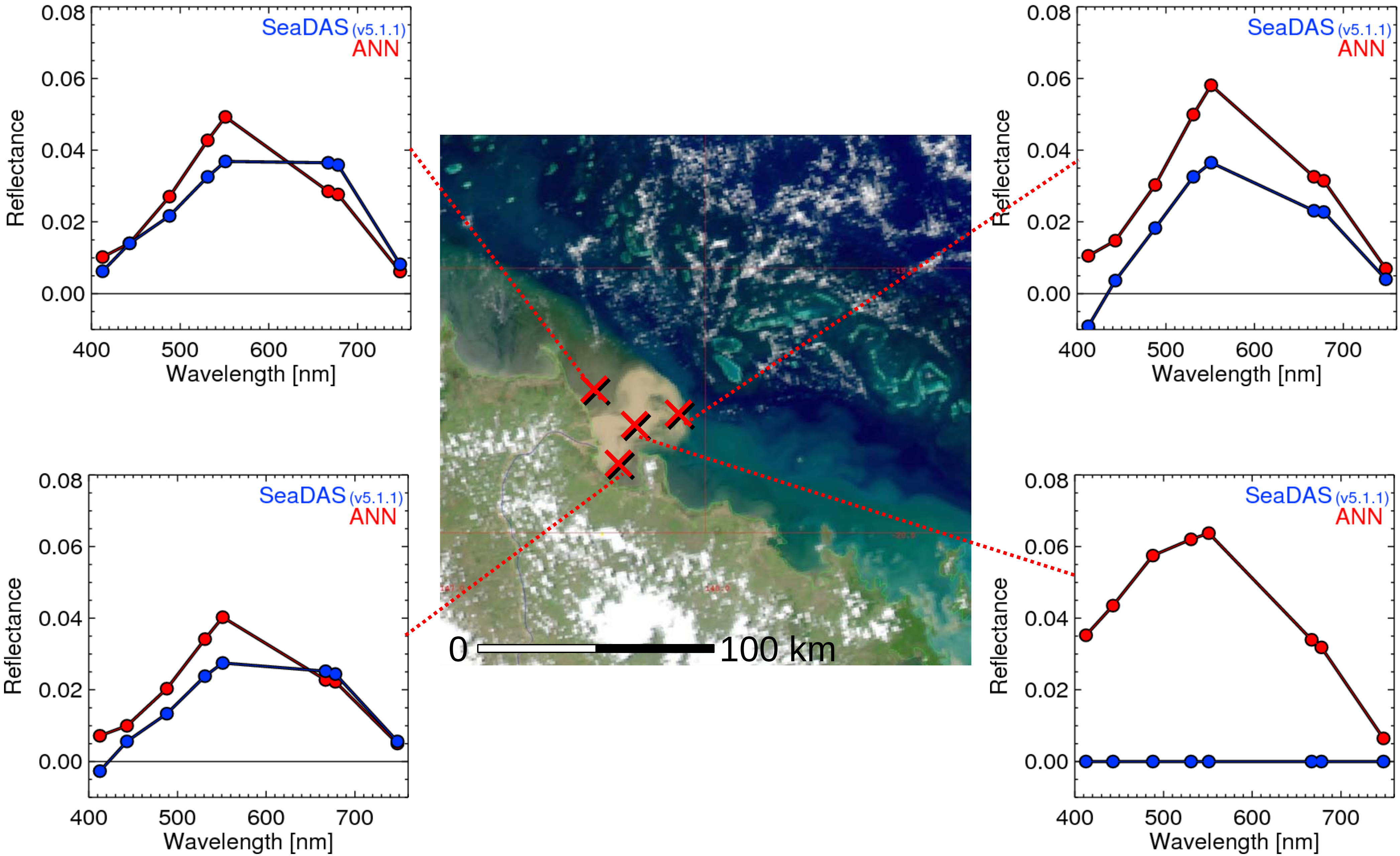
Application atmospheric correction – MODIS-Aqua

Extreme 1: Burdekin, QLD – 22 February 2008



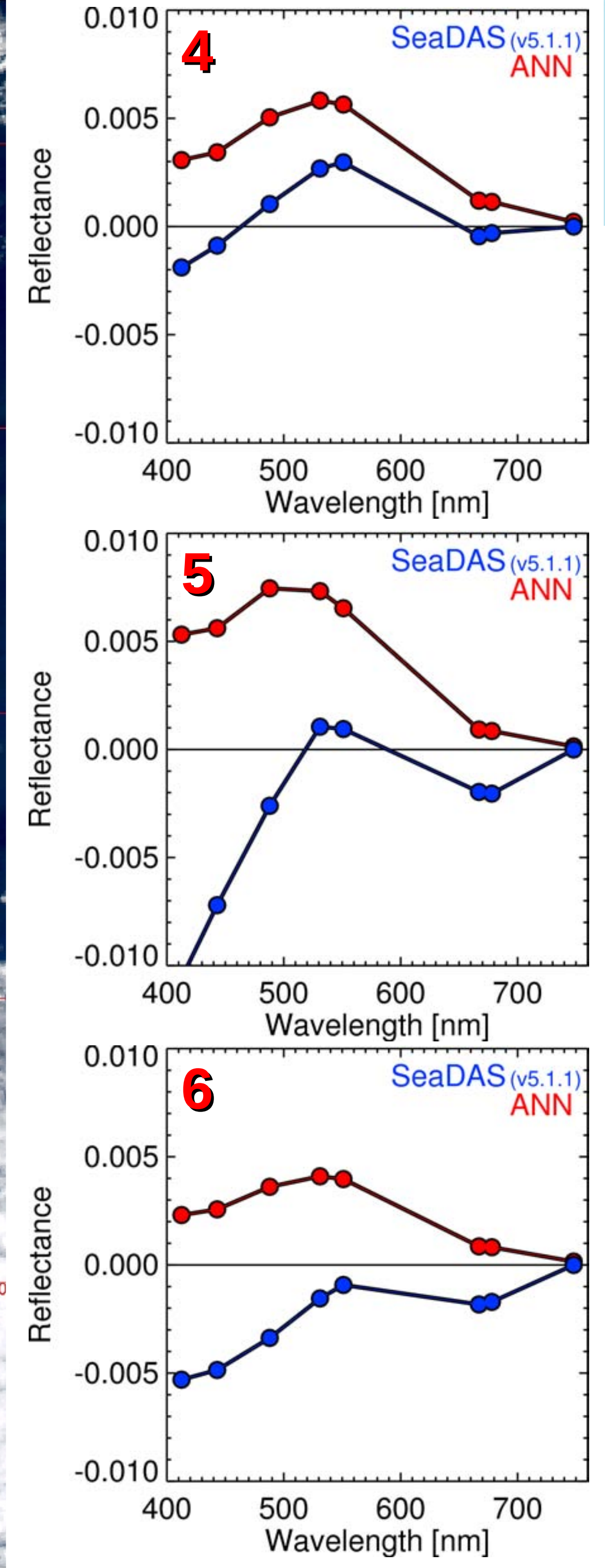
Application atmospheric correction MODIS

Extreme 1: Burdekin, QLD – 22 February 2008



Reflectance spectra

Example: Tasmania – 13 October 2003



MODIS-Aqua 13 October 2003
Created with HDFLook

Atmospheric correction validation MODIS

Match-up data base with more than 130 in-situ reflectance measurements (Trios RAMSES, Simbada)

Image: Revamp protocols

Image: LOA Université de Lille

CSIRO, GKSS, MUMM – mainly coastal waters

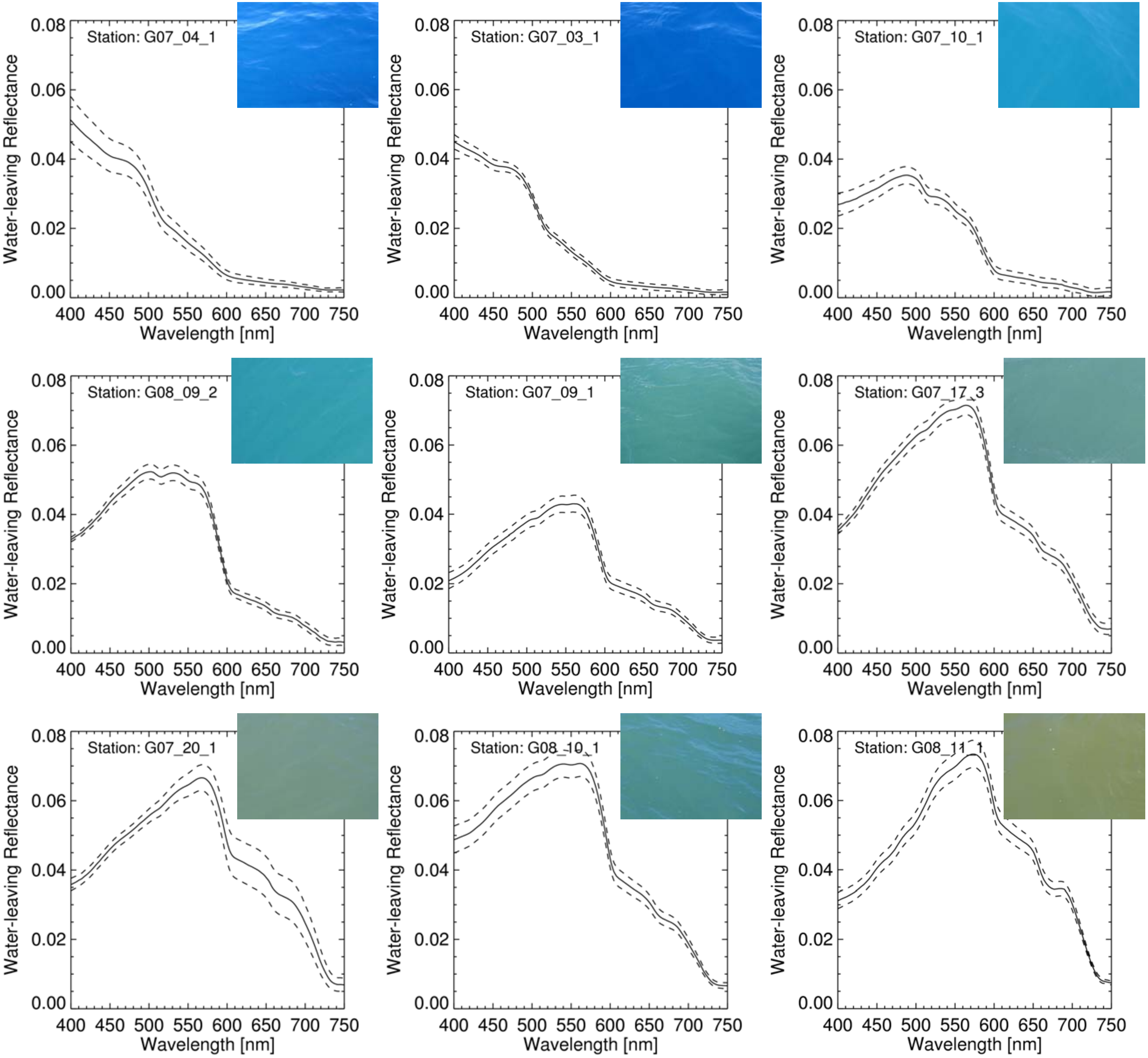
Data quality requirements:

Maximum of ±60 min to satellite over pass

Median from an unflagged (land, sun glint, cloud) 3x3 pixel box

Inputs checked with respect to simulation ranges

Reflectance Spectra Fieldwork GBR 2007/08



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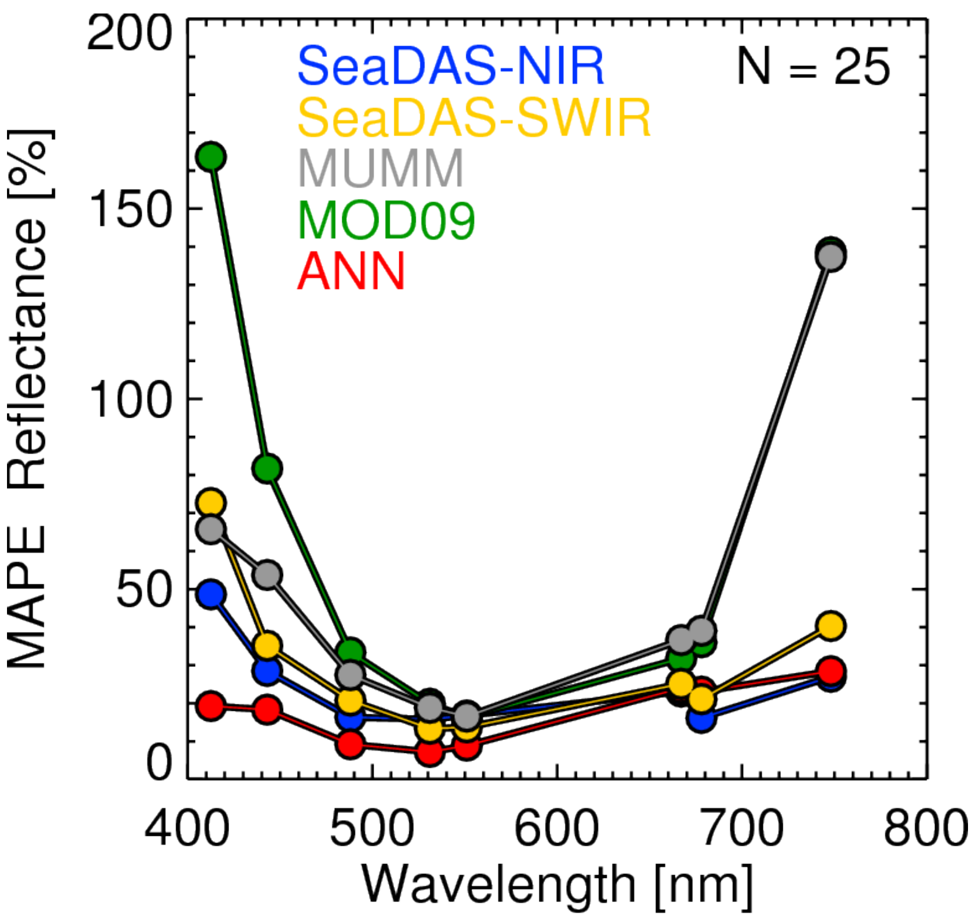
Atmospheric correction inter-comparison vs in-situ
SeaDAS-NIR, -SWIR, MOD09, ANN, MUMM

Relative error



	Spectral range [nm] [412]	[412-748]
MOD09	163%	65%
MUMM	73%	49%
SeaDAS-SWIR	66%	30%
SeaDAS-NIR	48%	24%
ANN	19%	17%

Analysis ongoing of MUMM's full reflectance data base >750 spectra
Match-ups: 71 ± 60 min, 50 ±30 min

(Schroeder et al, 2010 in prep.)

Overview water constituents retrieval
Linear Matrix Inversion (LMI)

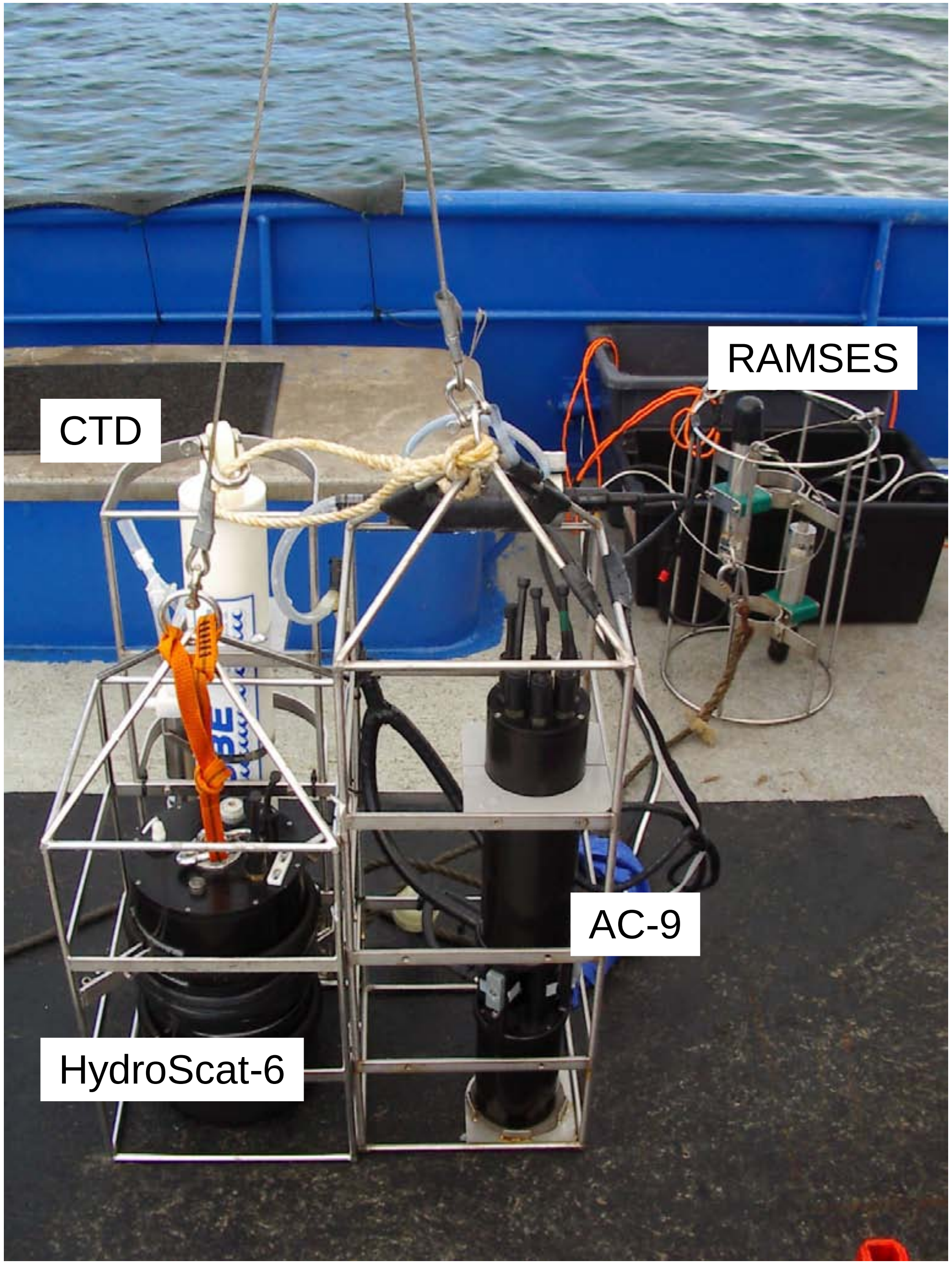
$$R \simeq g_1 \left(\frac{b_\mathrm{b}}{(b_\mathrm{b}+a)}\right) + g_2 \left(\frac{b_\mathrm{b}}{(b_\mathrm{b}+a)}\right)^2$$

(Gordon 1988)

$$\begin{aligned} a_\mathrm{tot}(\lambda) &= a_\mathrm{w}(\lambda) + a_\mathrm{PHY}(\lambda) + a_\mathrm{NAP}(\lambda) + a_\mathrm{CDOM}(\lambda) \\ &= a_\mathrm{w}(\lambda) + \Sigma a_j^*(\lambda)\, C_j \end{aligned}$$

$$\begin{aligned} b_{b,\,\mathrm{tot}}(\lambda) &= b_{b,\,\mathrm{w}}(\lambda) + b_{b,\,\mathrm{PHY}}(\lambda) + b_{b,\,\mathrm{NAP}}(\lambda) \\ &= b_{b,\,\mathrm{w}}(\lambda) + \Sigma b_{\mathrm{b},\,j}^*(\lambda)\, C_j \end{aligned}$$

In-situ collection of optical properties



Absorption of phytoplankton (Lab CMAR)

Absorption of non-algal particulate matter (Lab CMAR)

Absorption of CDOM (Lab CMAR)

TSM, CHL (Lab CMAR)

Particulate back-scattering (HydroScat-6)

Dissolved plus particulate absorption and attenuation (AC-9)

Temperature, salinity (CTD)

Optics (RAMSES-Trios)

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Principle water constituents retrieval

Linear Matrix Inversion (LMI)

Loop over selected SIOP sets

In-situ SIOP set

$$[a^*_{\text{PHY}},\ S_{a,CDOM},\ a^*_{\text{NAP}},\ S_{a,\text{NAP}},\ b^*_{b,\text{PHY}},\ S_{b,\text{PHY}},\ b^*_{b,\text{NAP}},\ S_{b,\text{NAP}}]$$

MODIS data

$$R_{\text{MEAS}}$$

$$C = f(R_{\text{MEAS}},\ SIOPs)$$

$$R_{\text{MODEL}} = f^{-1}(C,\ SIOPs)$$

$$\Delta R = (R_{\text{MODEL}} - R_{\text{MEAS}})$$

Select concentrations from SIOP set with best optical closure

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Validation summary in-water algorithm

CHL	CSIRO-LMI	59%	vs	SeaDAS-GSM	90%	N=110
TSM	CSIRO-LMI	57%	vs	SeaDAS-Clark	61%	N= 33
CDOM	CSIRO-LMI	67%	vs	SeaDAS-QAA (Incl. detritus)	216%	N= 27

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Error sources

- Mixing ratio of the water constituents
- Temporal difference between sampling and satellite overpass
- Inhomogenous horizontal und vertical distribution of the water constituents within a satellite pixel (Comparison ~1km^2 pixel with a sample of a few liters)
- Remaining errors of the atmospheric correction ~20%
- Errors associated with the in-situ measurements
- Reproduction of measurements, differences between the Labs. (Revamp Inter-Calibration Report, 2002)
  CHL 10%, TSM 50%, YEL 50%
- Not considered physical effects
- Natural variability of the water constituents in the framework of an average bio-optical model

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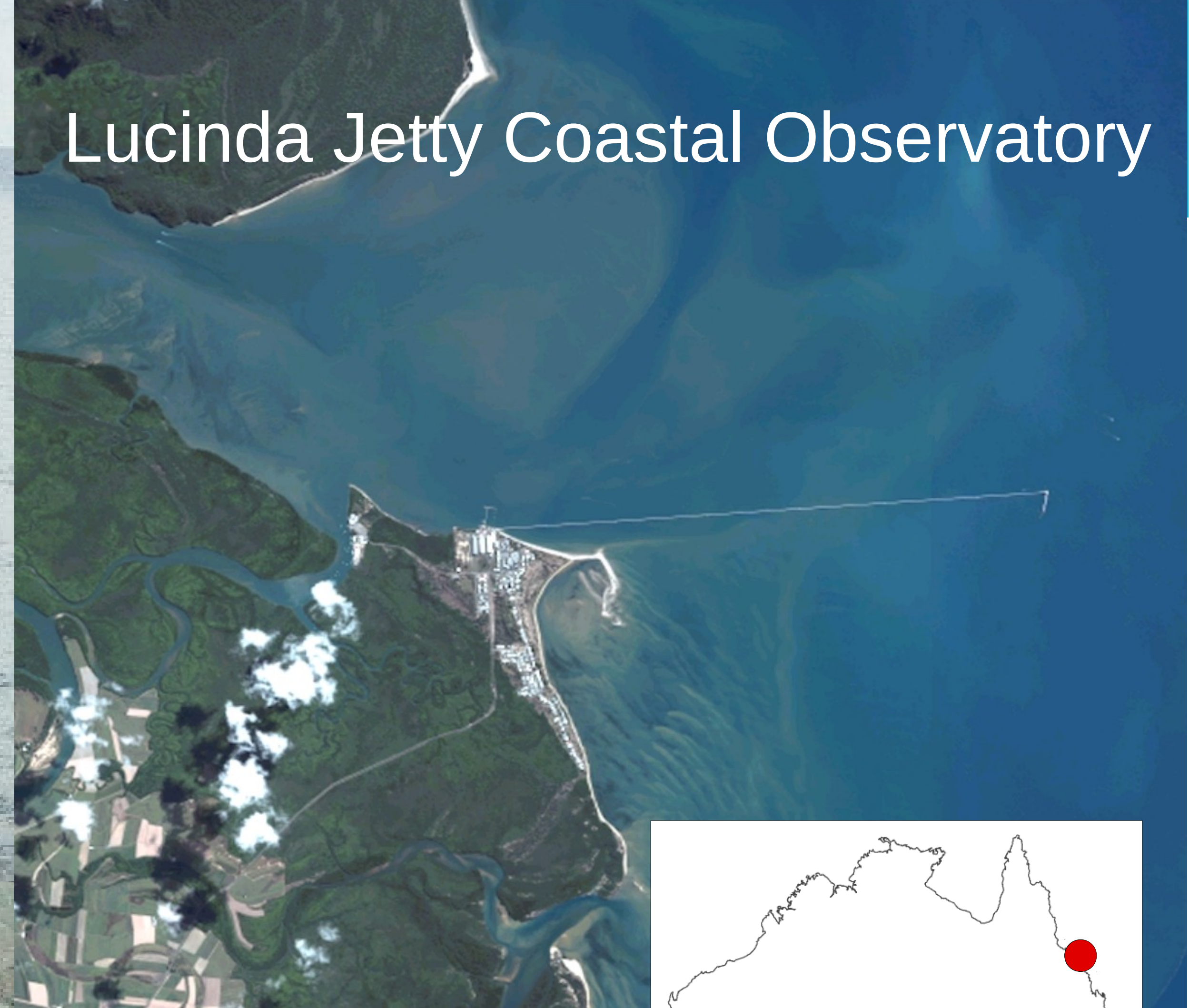
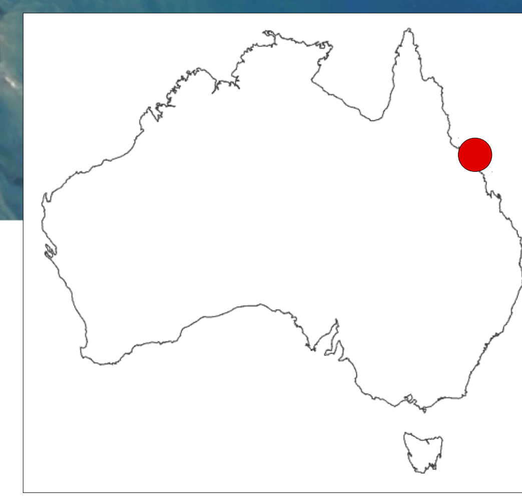
Lucinda Jetty Coastal Observatory





(PI Vittorio Brando)

IMOS

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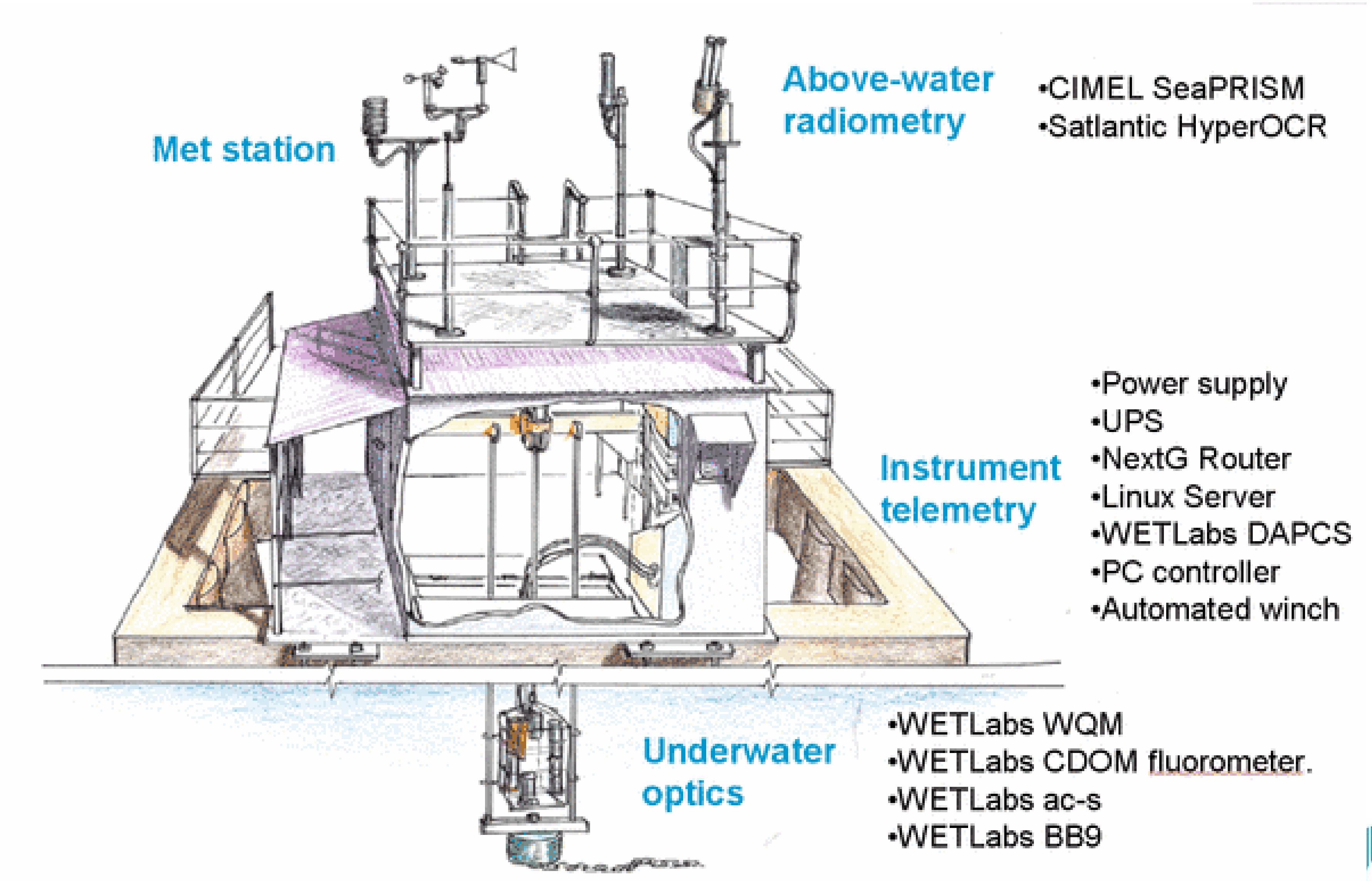
Lucinda Jetty Coastal Observatory



(PI Vittorio Brando)

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Remote sensing applications

Water quality monitoring, trend analysis & reporting

Compliance monitoring (Marine Monitoring Program)

Algal bloom detection

Provide data assimilation inputs bio-geochemical models

Flood (fresh water) plume mapping

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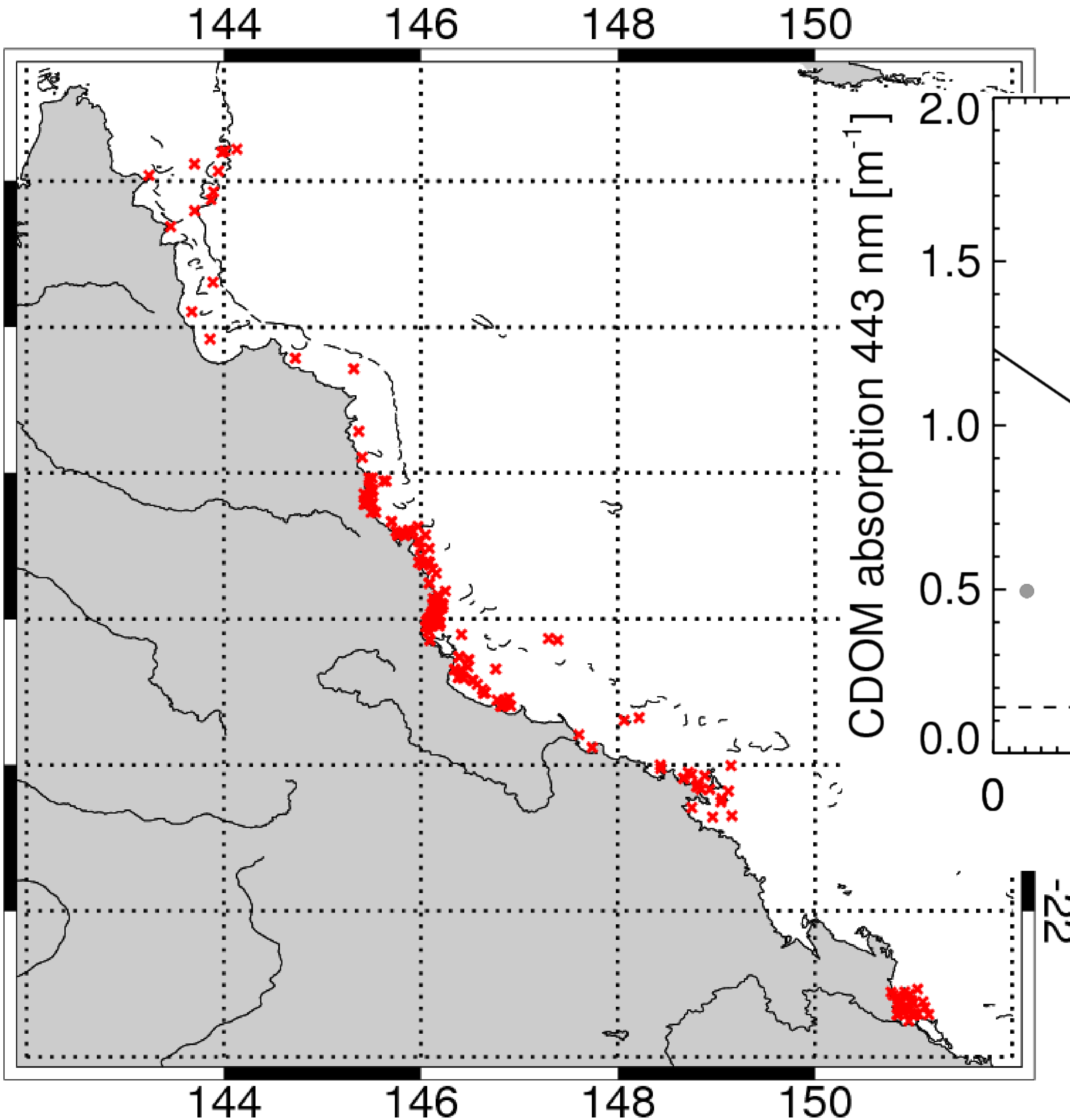
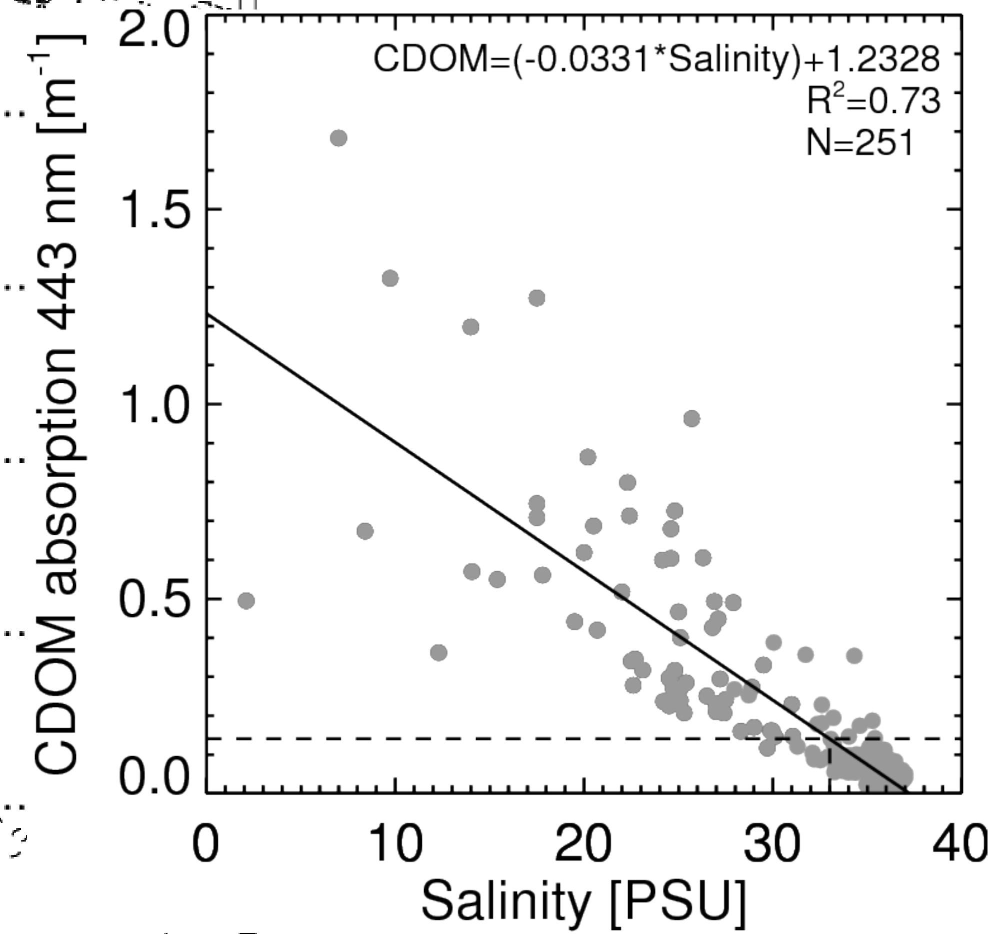
Application – mapping fresh water plumes GBR





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Photos courtesy Dr Michelle Devlin

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Image credit: http://www.lib.utexas.edu

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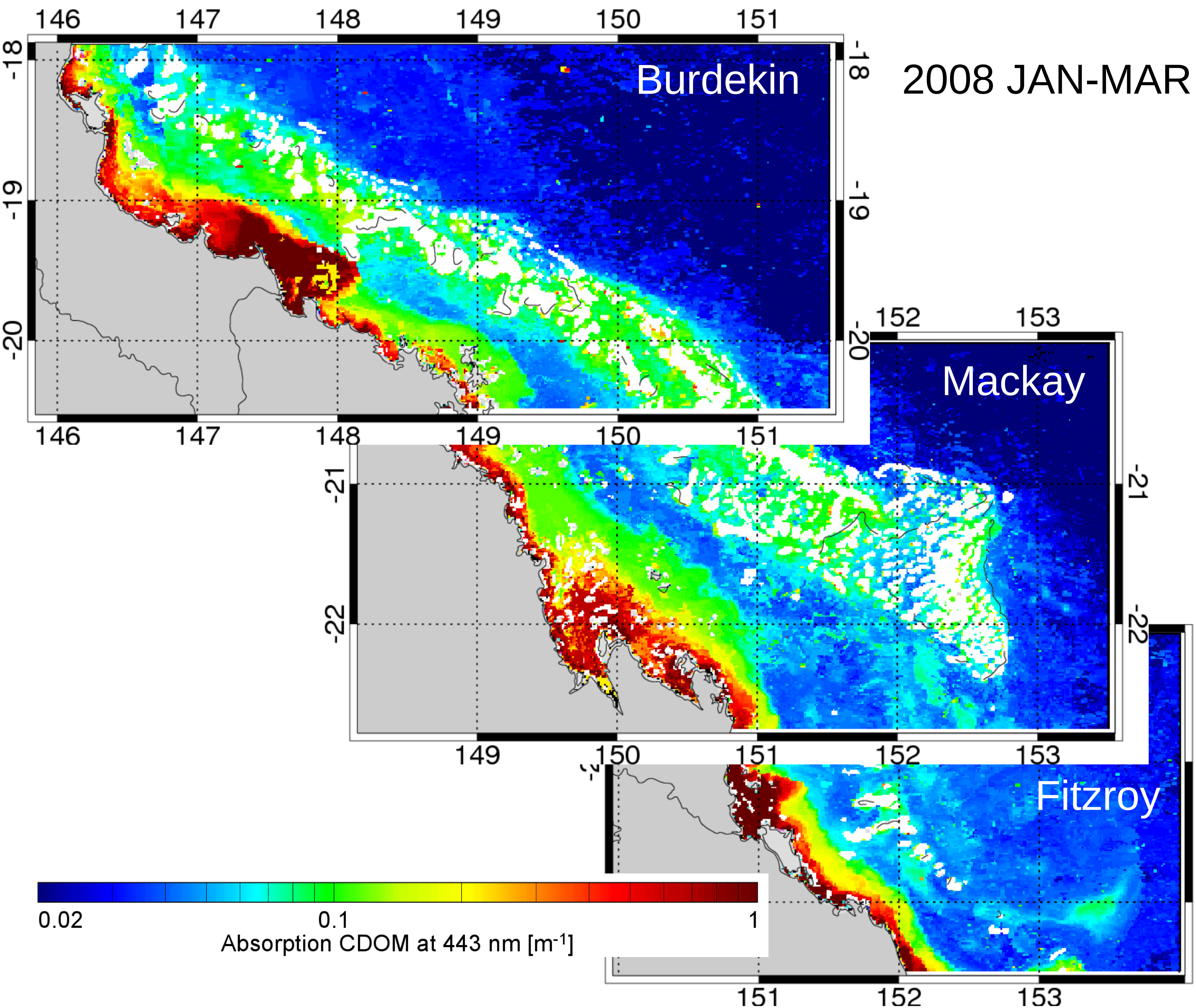
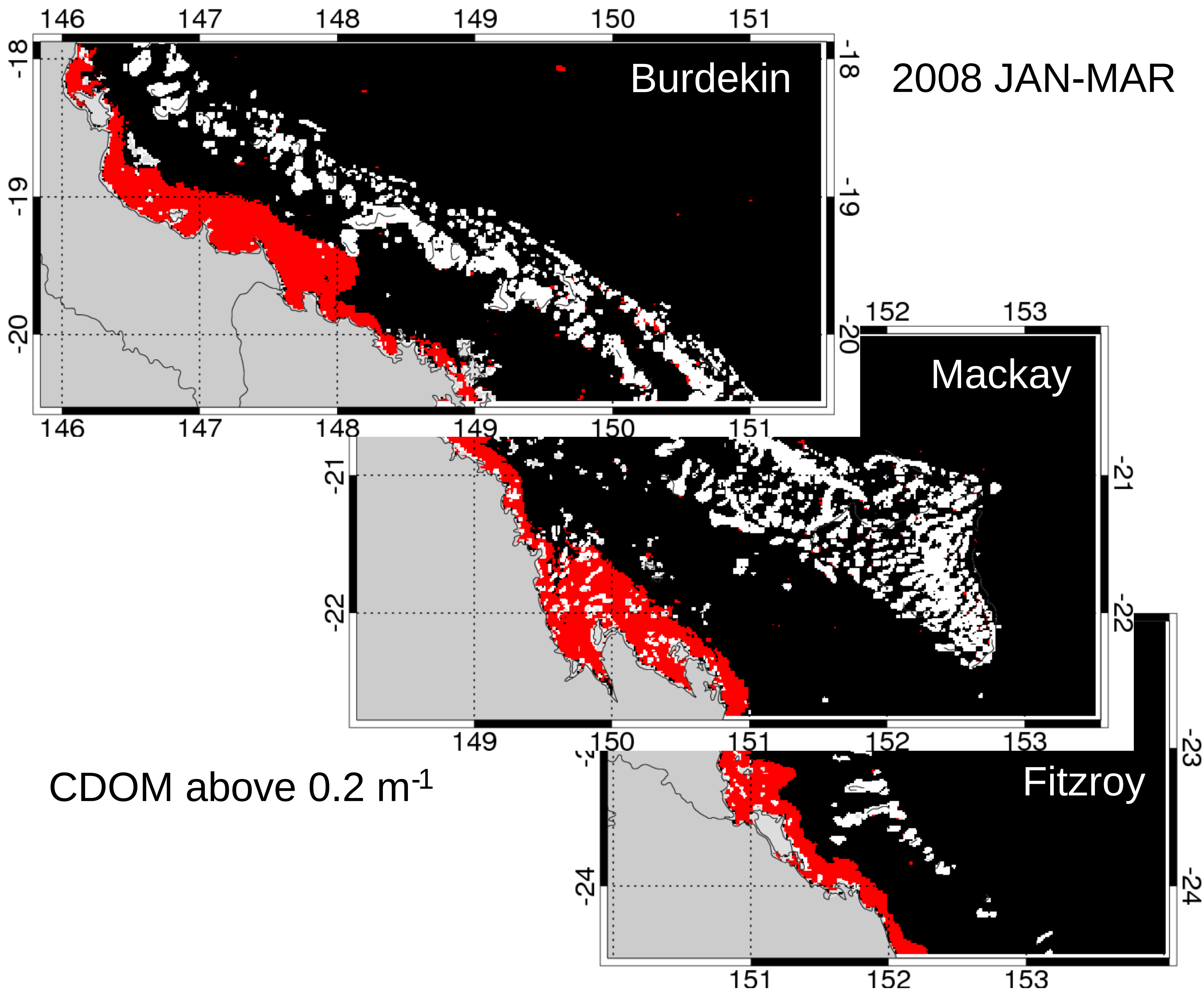
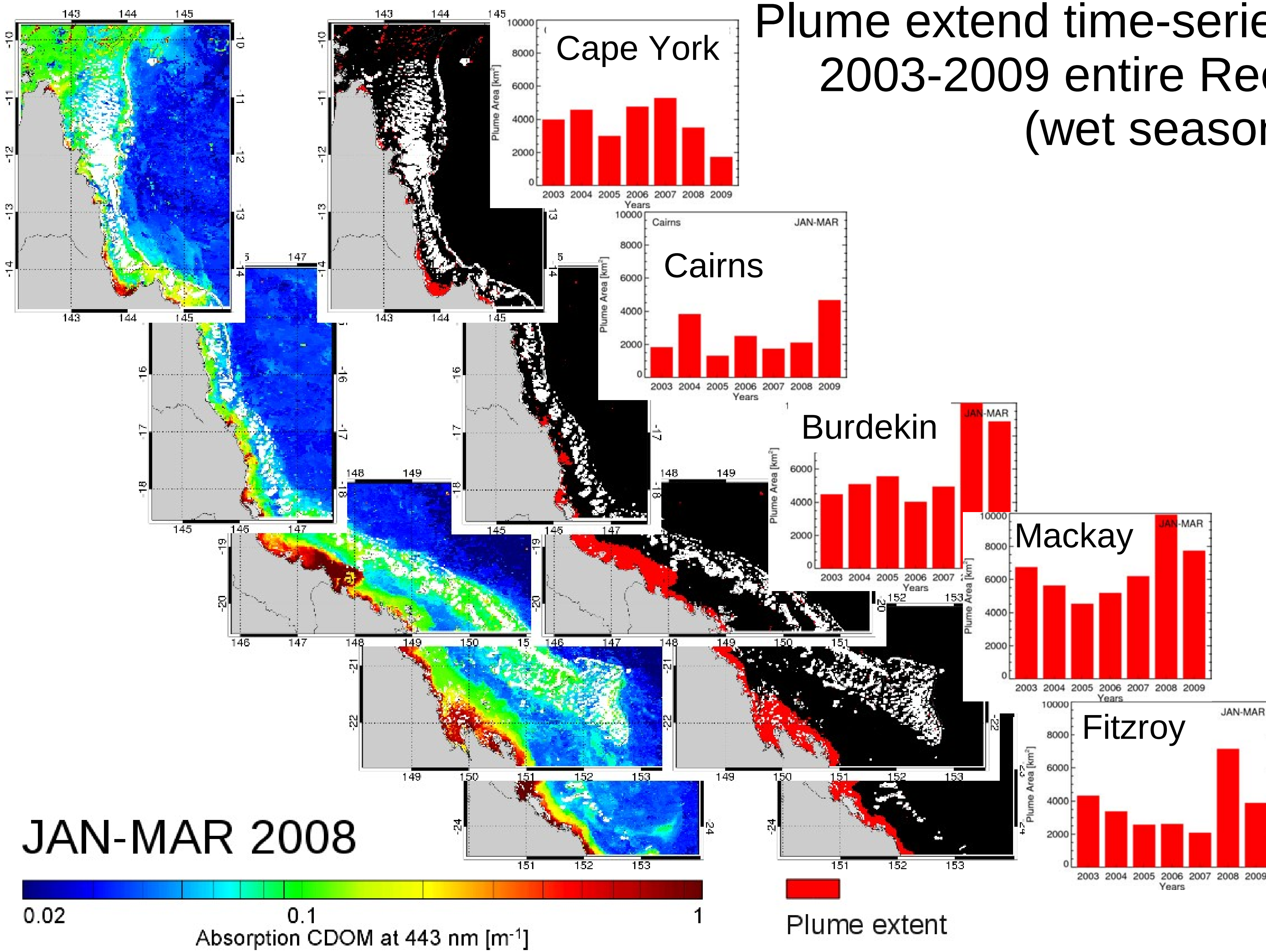


2008 JAN-MAR
Burdekin
Mackay
Fitzroy
0.02
0.1
1
Absorption CDOM at 443 nm [m-1]


2008 JAN-MAR
Burdekin
Mackay
Fitzroy
CDOM above 0.2 m-1
146
147
148
149
150
151
152
153
-18
-19
-20
-21
-22
-23
-24

Plume extend time-series 2003-2009 entire Reef (wet season)



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Prof Juergen Fischer, Free University Berlin, Germany

Integrated Marine Observing System (IMOS)

CSIRO Wealth from Oceans Flagship

NASA & ESA

CSIRO

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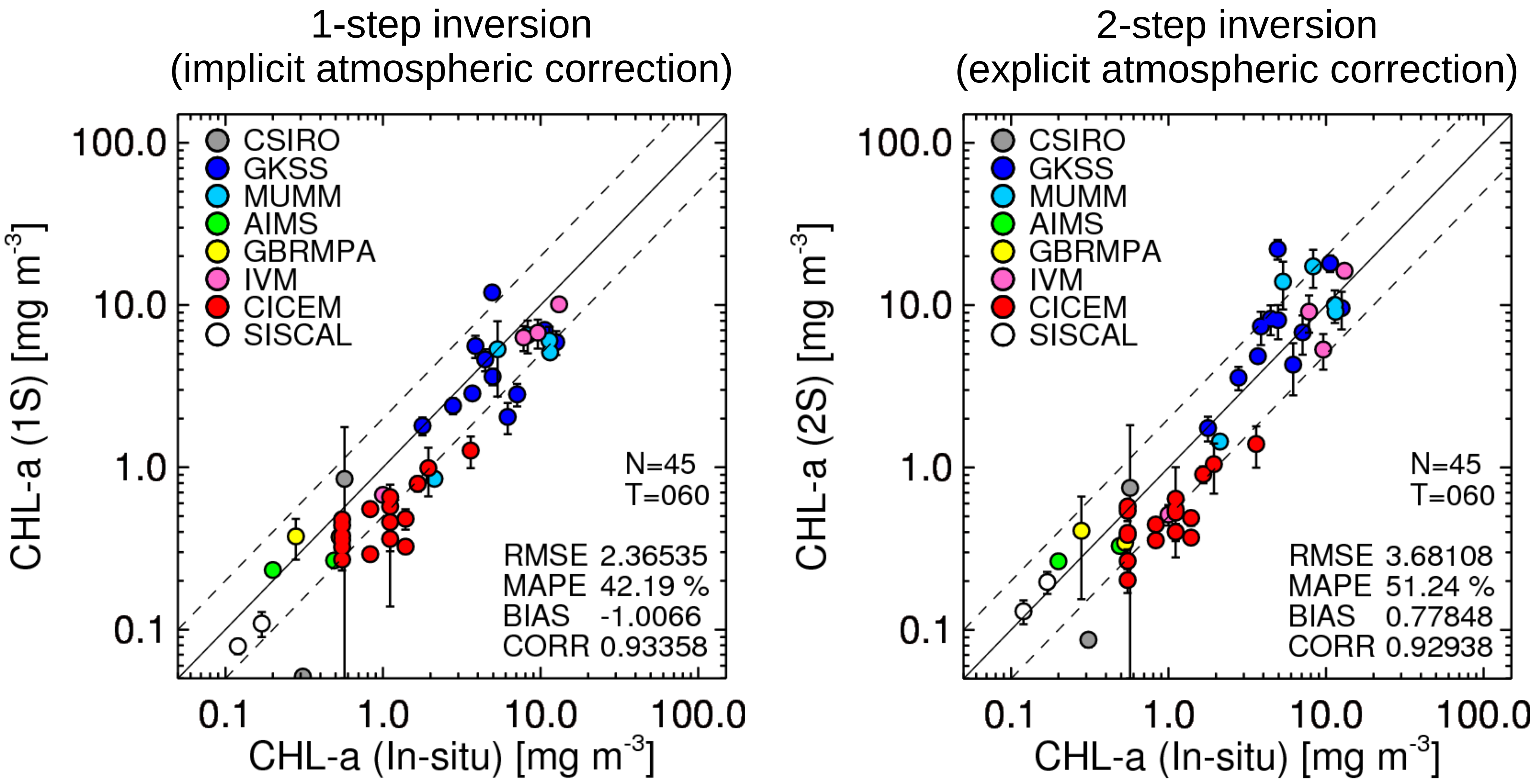
Email: Thomas.Schroeder@csiro.au

Thank you

CSIRO

Chlorophyll-a retrieval - MERIS

Data quality IPF 5.05 (MEGS 7.4.1)



MODIS match-up examples North Sea