Perspectives on remote sensing from some South African waters: applications for global lakes

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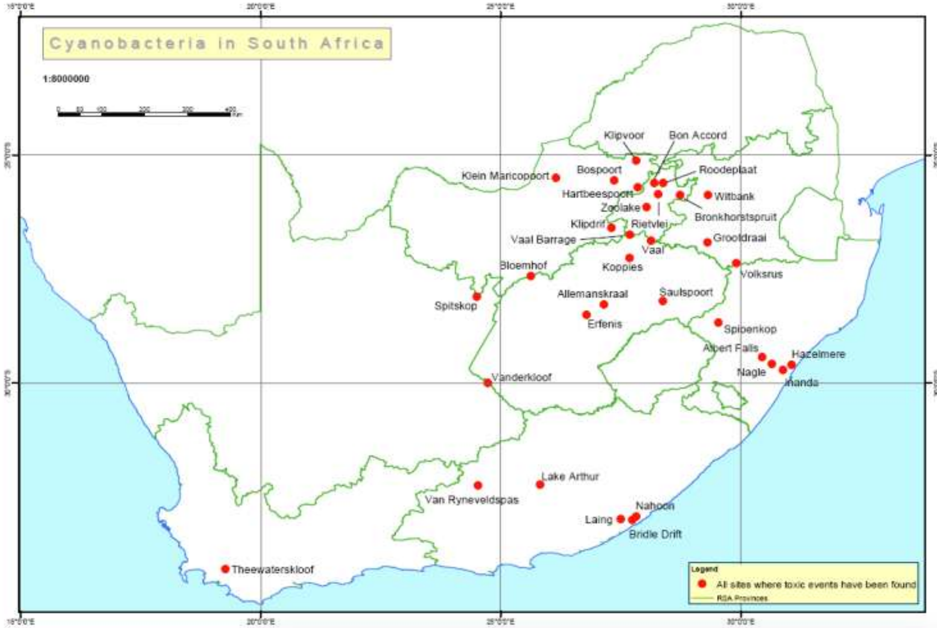
Who are we? South African Context



- Societal growth and demand on water resources have resulted in ***increased eutrophication and pollution***, often resulting in ***harmful algal blooms***
- ***Toxins produced by cyanobacterial algal blooms*** are found in many of South Africa's freshwater systems, and are ***a threat to public and ecosystem health.***
- There is an increasing need for routine observations of water quality, allowing improvement of ***knowledge*** and ***risk management*** and ***quantitative assessment of the extent of eutrophication***.
- There is currently ***insufficient knowledge*** and information on the ***status and trends of water quality and eutrophication*** and substantial gaps in available data archives
- ***Remote sensing*** can play a crucial role in determining water quality status across many water bodies in a ***cost-effective*** and ***routine*** manner; with an ability to make a considerable contribution to both ***operational monitoring systems***, and ***ecosystem research***.

Who are we? The Marine Remote Sensing Unit

MRSU
MARINE REMOTE SENSING UNIT

University of Cape Town • iYunivesithi yaseKapa • Universiteit van Kaapstad

CSIR
our future through science

www.afro-sea.org.za

CHPC
CENTRE FOR HIGH PERFORMANCE COMPUTING

ACTIVITIES

Research and development

Data processing and storage

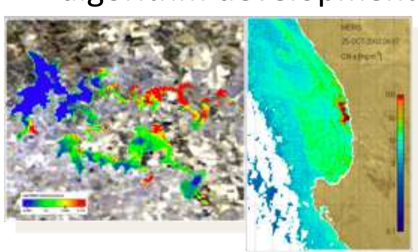
Dissemination

CORE SCIENCE → IMPLEMENTATION → USERS

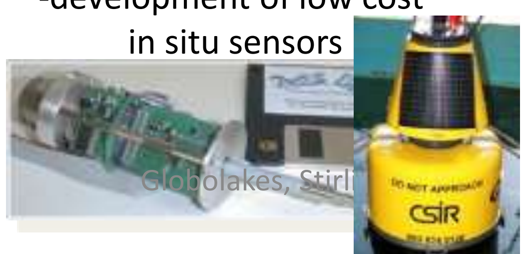
RELATED PROJECTS

Safe Waters Earth Observation Systems (SWEOS, CSIR)

Earth Observation R&D
- algorithm development



In situ R&D
-development of low cost in situ sensors

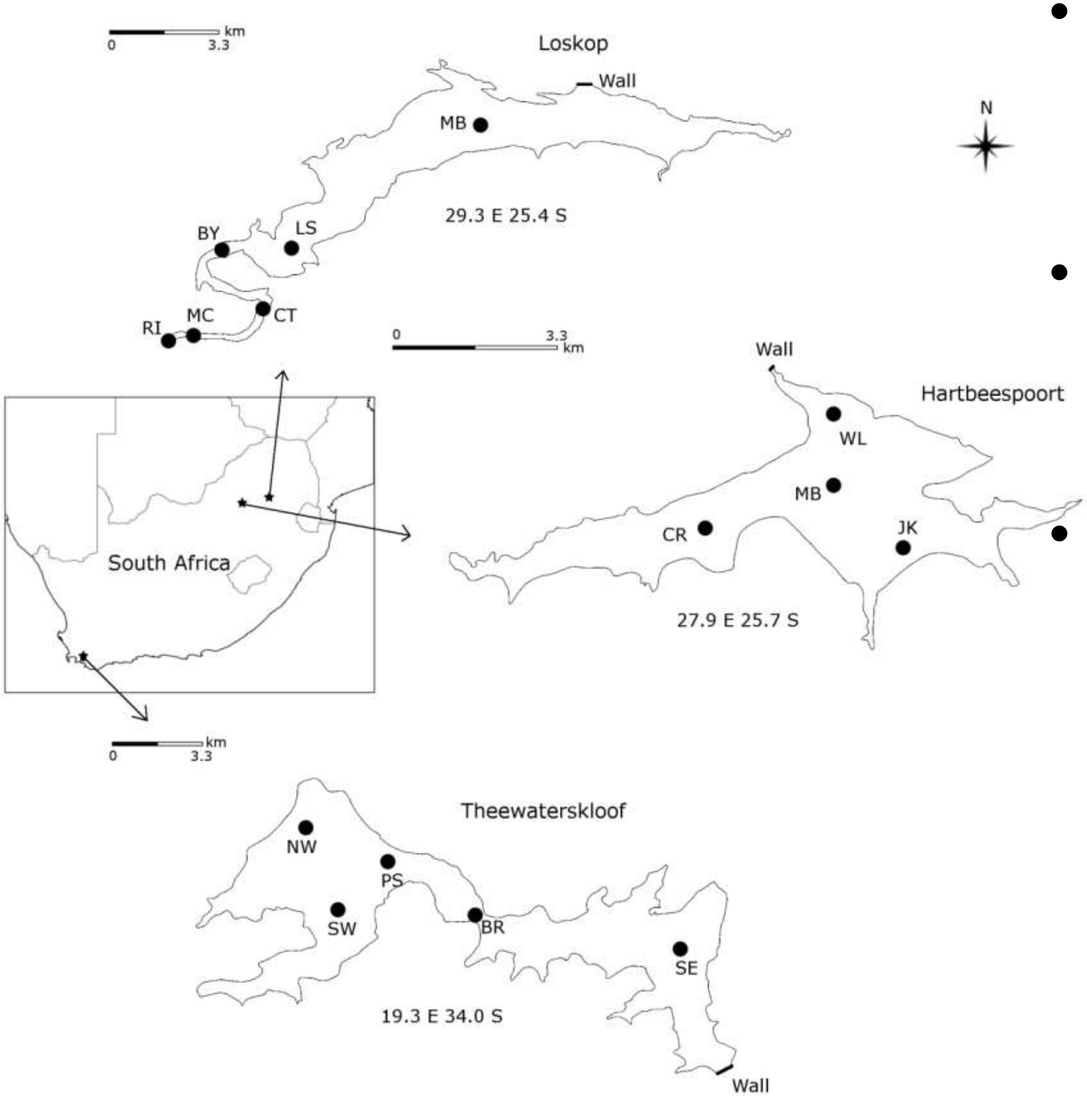


EAMNet
Europe-Africa Marine EO Network

GEONETCAST
DELIVERING OPERATIONAL SERVICES TO USERS

Inland Maritime Safety Programme

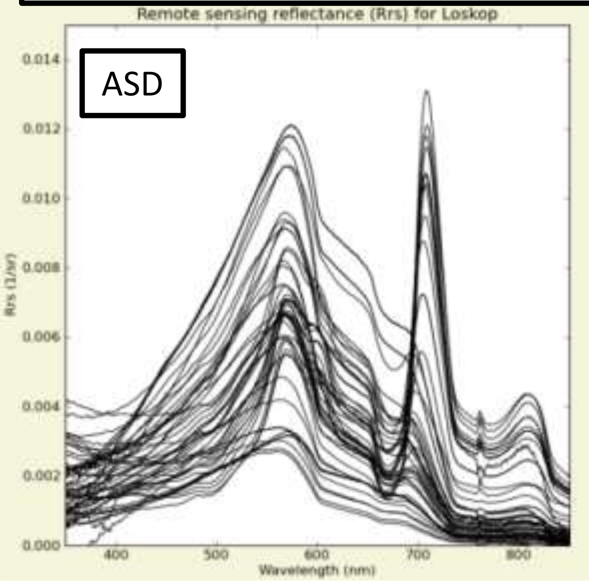
In situ observations in South African waters



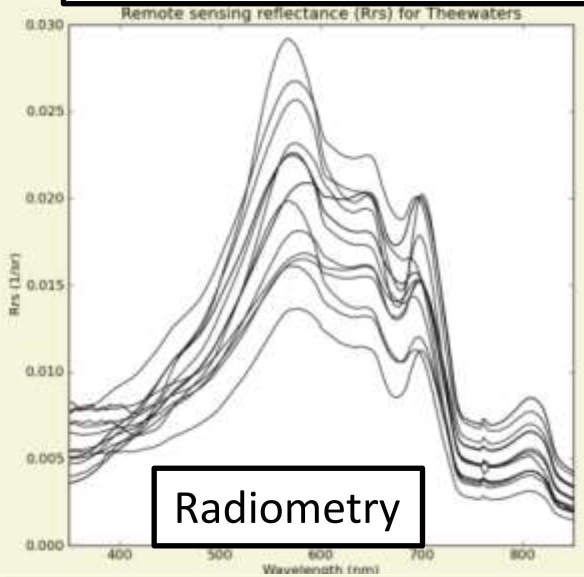
- In situ campaigns at three reservoirs between 2010-2012 undertaken as part of PhD work
- Collection of **full-suite** of radiometry, IOPs, atmospheric, bio-geophysical parameters
- **Wide range of water types** from oligotrophic case 1, *gelbstoff* dominated, sediment dominated, eutrophic *dinoflagellate* blooms, to hypertrophic *Microcystis* scums, *Dolichospermum* cyanobacteria

In situ observations in South African waters

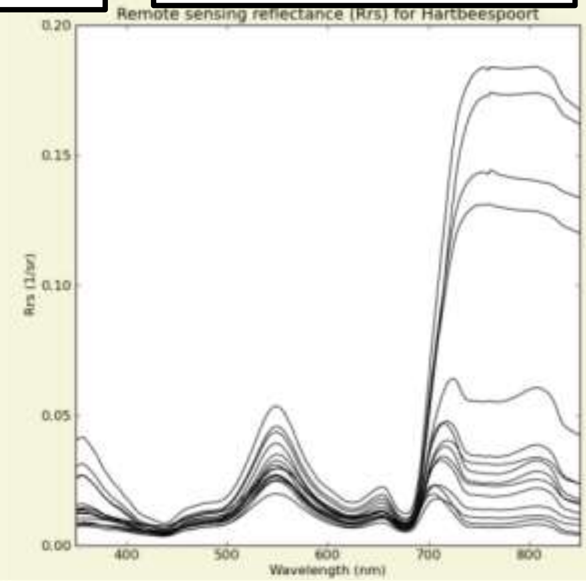
Oligo-Hypertrophic Dinoflagellate/Diatoms

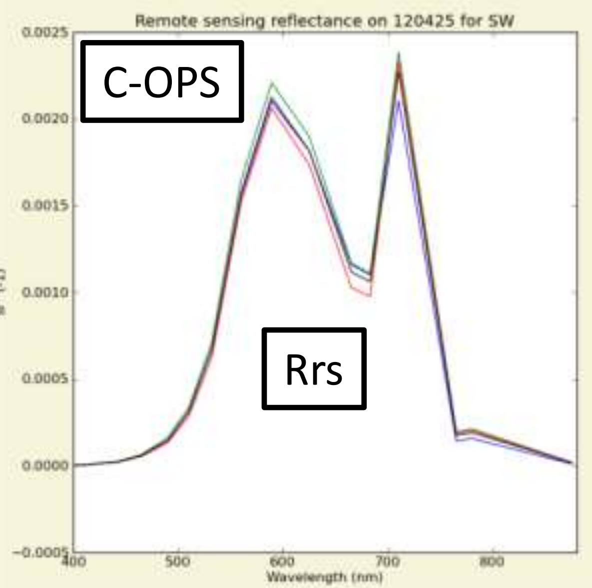


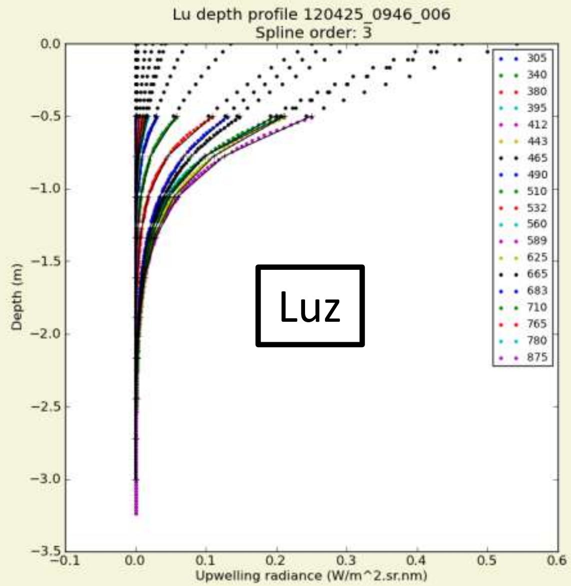
Meso-eutrophic mixed/dolichospermum

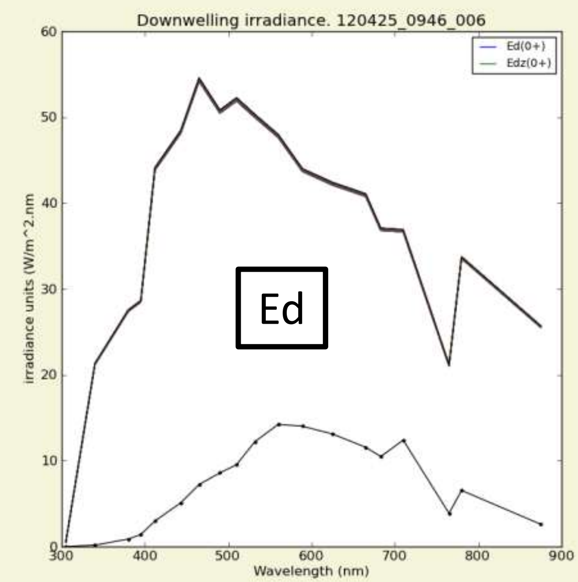


Hypertrophic Microcystis



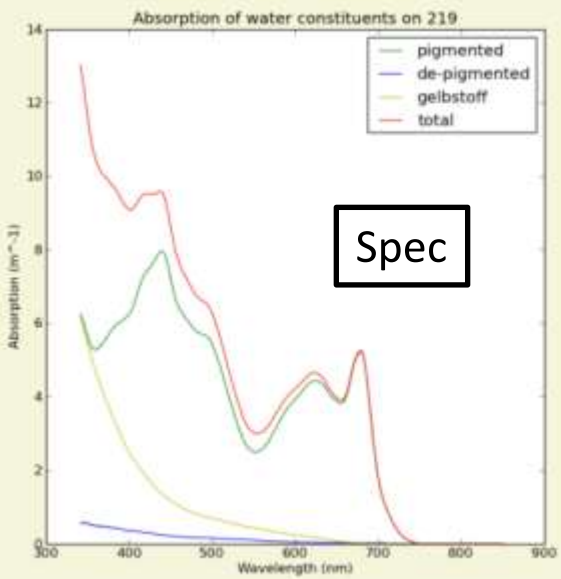


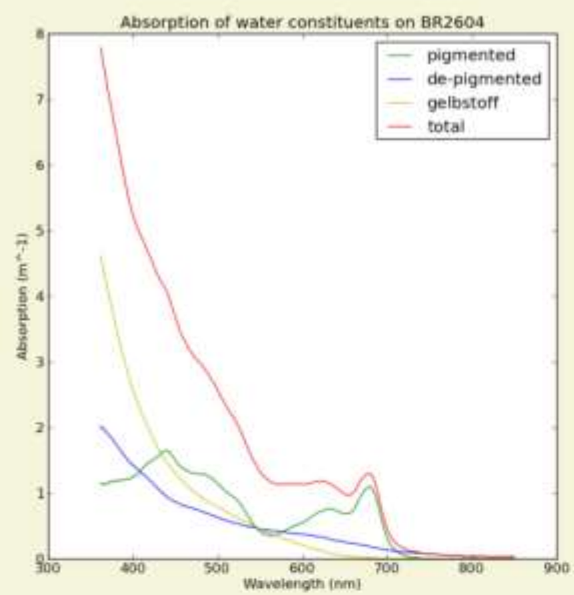




In situ observations in South African waters

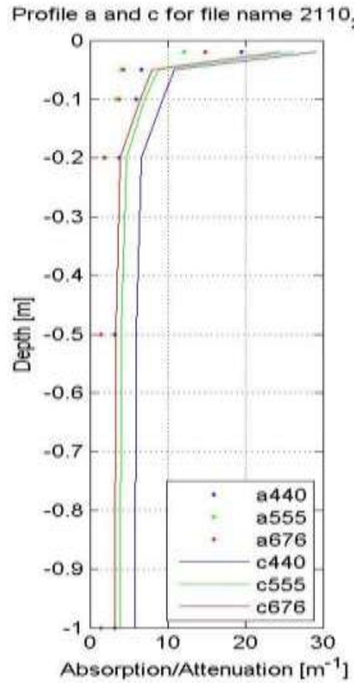
Spec

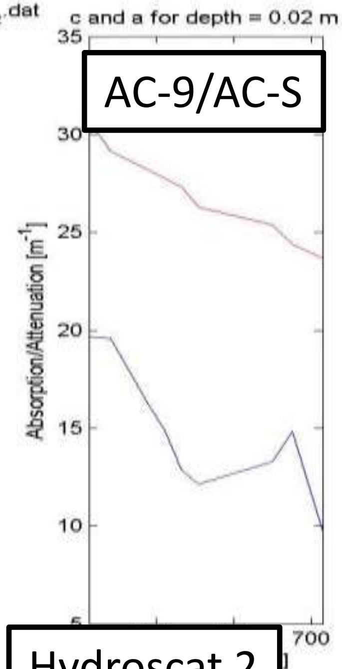


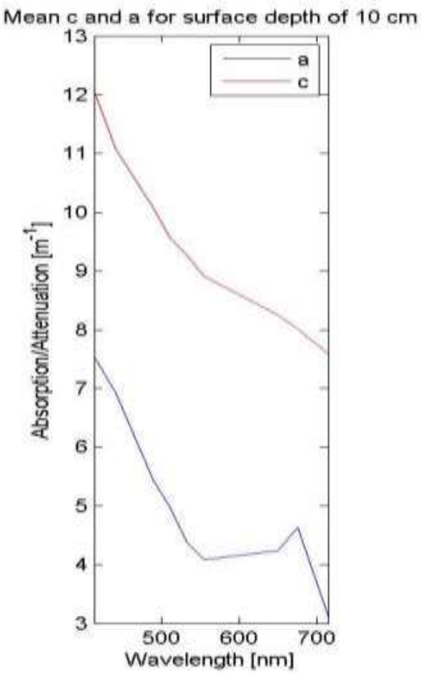


Inherent Optical Properties

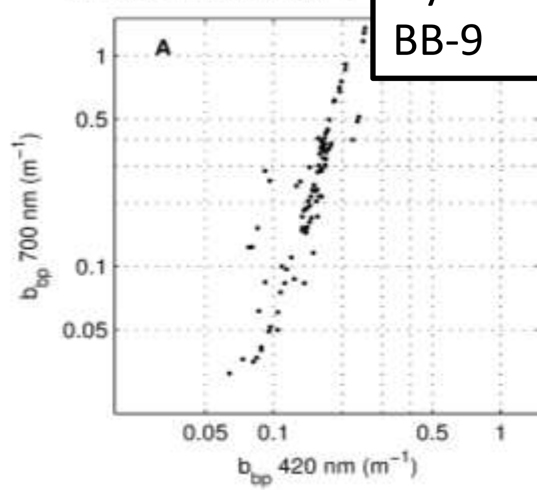
AC-9/AC-S

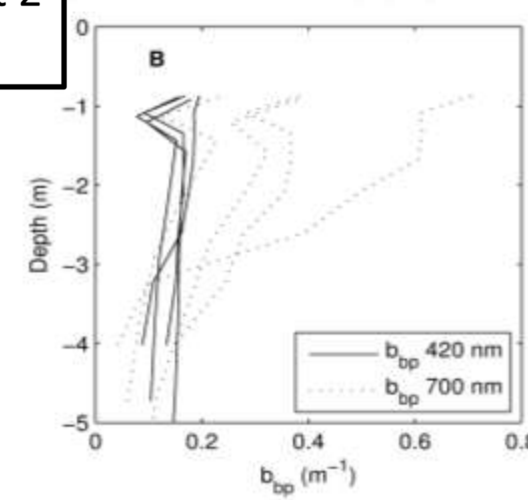






Hydroscat 2
BB-9



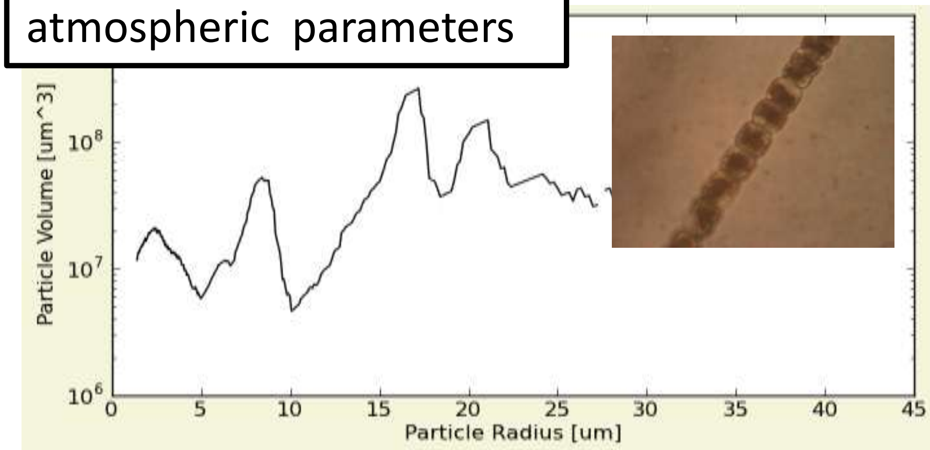


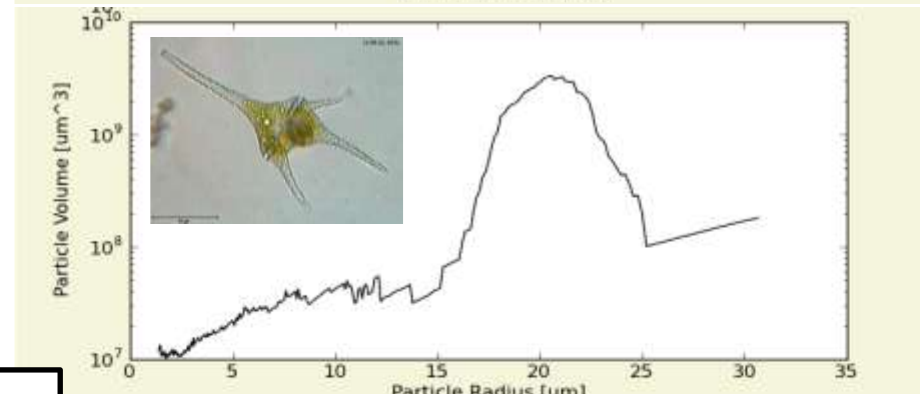
In situ observations in South African waters

Autonomous near-real time platforms

Payload: radiometers, fluorometers, temperature, wind,

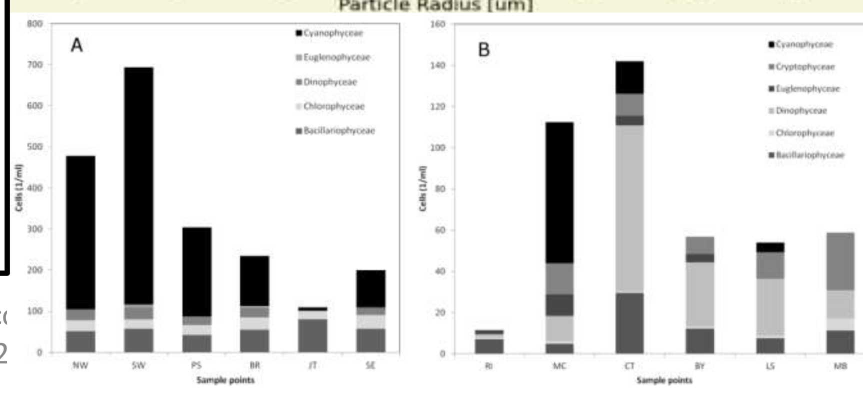
Type, size, biogeophysical, atmospheric parameters





Chl-a
Phycocyanin
TSM
Secchi Disk
AOT
Chemical

Stirling Sc
2012



The MPH algorithm

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An algorithm for detecting trophic status (chlorophyll-*a*), cyanobacterial-dominance, surface scums and floating vegetation in inland and coastal waters

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Surface scums
Floating vegetation

ABSTRACT

A novel algorithm is presented for detecting trophic status (chlorophyll-*a*), cyanobacterial blooms, surface scum and floating vegetation in coastal and inland waters using top-of-atmosphere data from the Medium Resolution Imaging Spectrometer (MERIS). The maximum peak-height algorithm (MPH) uses a baseline subtraction procedure to calculate the height of the dominant peak across the red and near-infrared MERIS bands between 664 and 885 nm caused by sun-induced chlorophyll fluorescence (SICF) and particulate backscatter. Atmospheric correction of the MERIS TOA reflectance data for gaseous absorption and Rayleigh scattering proved adequate given the spectral proximity of the relevant bands and the sufficiently large differential spectral signal. This avoided the need to correct for atmospheric aerosols, a procedure which is typically prone to large errors in turbid and high-biomass waters. A combination of switching algorithms for estimating chl-*a* were derived from coincident *in situ* chl-*a* and MERIS bottom-of-Rayleigh reflectance measurements. These algorithms are designed to cover a wide trophic range, from oligotrophic/mesotrophic waters (chl-*a*$<20\,\mathrm{mg\,m^{-3}}$), to eutrophic/hypertrophic waters (chl-*a*$>20\,\mathrm{mg\,m^{-3}}$) and surface scums or dry floating algae or vegetation. Cyanobacteria-dominant waters were differentiated from those dominated by eukaryote algal species (dinoflagellates/diatoms) on the basis of the magnitude of the MPH variable. This is supported by evidence that vacuolate cyanobacteria (*Microcystis aeruginosa*) possess enhanced chl-*a* specific backscat-

The MPH algorithm

- Chlorophyll-*a* empirically based algorithm designed for trophic state / cyanobacteria detection in inland and near-coastal phytoplankton-dominant waters
- Based on the *Maximum Peak Height (MPH)* in the MERIS red bands at 681, 709 and 753 nm
- **Derived from data from 4 systems:**
  1. Benguela (2003-2010)
  2. Zeekoevlei lake (2008)
  3. Hartbeespoort lake (2010)
  4. Loskop lake (2011)

  → 74 *in situ* Chl-a observations with matching MERIS reflectance spectra (P/O time < 2 hours)
- Utilizes **MERIS BRR** (not Rrs) to normalize for atmospheric Rayleigh effects because of problems with atmospheric correctons

The MPH algorithm

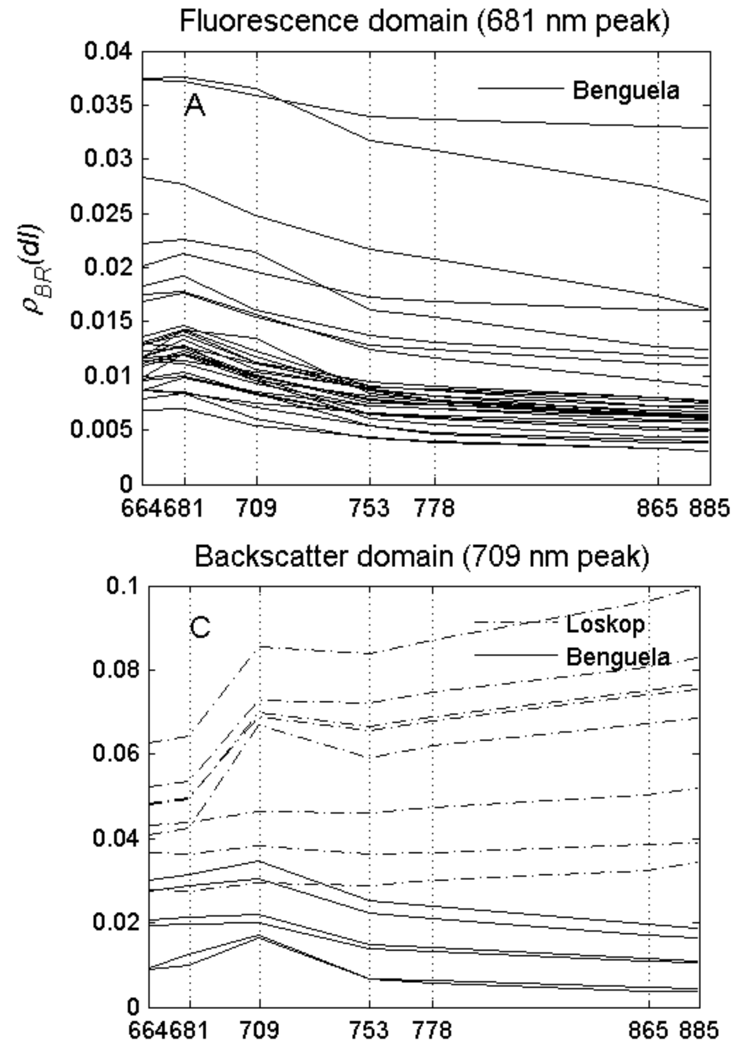
Simultaneously handles 3 primary cases:

1. **Mixed oligotrophic/mesotrophic low to medium biomass** conditions with Chl-a less than 30 mg.m-3 → 681 fluorescence
   a) 1.a eukaryote species SICF signal
   b) 1.b special case: low biomass cyanobacterial blooms (no SICF)
2. **High biomass or eutrophic/hypertrophic water** with Chl-a concentrations greater than 30 mg.m-3 → 709 backscatter
   a) 2.a eukaryote species (Diatoms/Dinoflagellates)
   b) 2.b vacuolate cyanobacterial species
3. **Extremely high biomass conditions** associated with surface scums, or hyperscums, and 'dry' floating algae or vegetation (Chl-a > 500 $mg.m^{-3}$)
   a) Cyanobacterial scums (chl-a > 500 mg.m^(-3))
   b) Floating aquatic macrophytes

The MPH algorithm

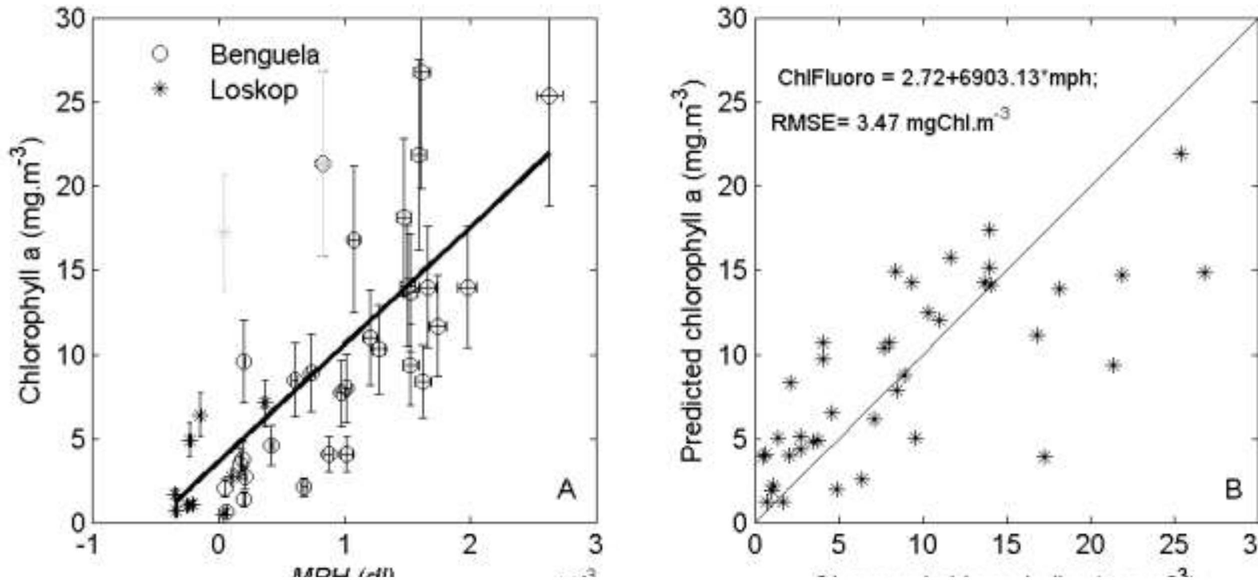
$$MPH = \rho_{BRmax} - \rho_{BR664} - ((\rho_{BR885} - \rho_{BR664}) * (\lambda_{max} - 664)/(885 - 664))$$

- where λ_{max} and $\rho_{BR\,max}$ are respectively the position and magnitude of the highest peak in the MERIS bands at 681, 709 and 753 nm.
- **Fluorescence domain:** maxpeakpos == 681 nm
- **Backscatter domain:** maxpeakpos == 709 nm
- **'Dry' domain:** maxpeakpos == 753 nm.

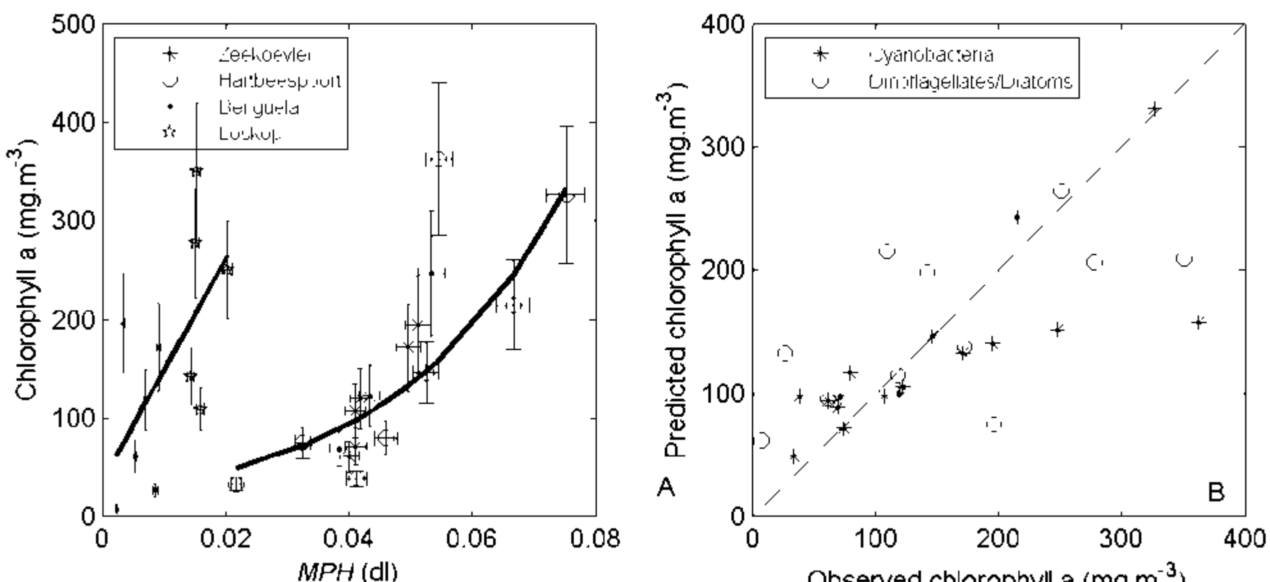


The MPH algorithm

- ‘Fluorescence‘ domain



- ‘Backscatter’ domain
- Note large difference in MPH magnitude between dinoflagellate and cyanobacteria dominant blooms



The MPH algorithm

Method for cyanobacteria detection:

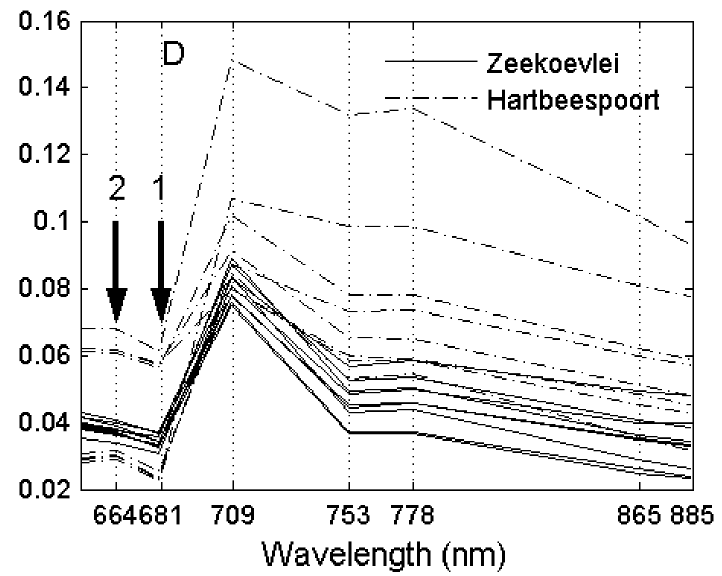
1. Cyanobacteria dominant waters possess no **observable** SICF peak at 681 nm (arrow 1, Fig1.D), and;
2. Cyanobacteria dominant waters possess a 664 sun induced **absorption** / phycocyanin fluorescence (SIPF) peak

This leads to:

1. An observable trough between the two wavelengths either side of the 681 nm band
2. An observable SIPF peak between the two wavelengths either side of the 664 nm band

$$SICF\_peak = \rho_{BR681} - \rho_{BR664} - ((\rho_{BR709} - \rho_{BR664}) * (681 - 664)/(709 - 664))$$

$$SIPF\_peak = \rho_{BR664} - \rho_{BR619} - ((\rho_{BR681} - \rho_{BR619}) * (664 - 619)/(681 - 619))$$



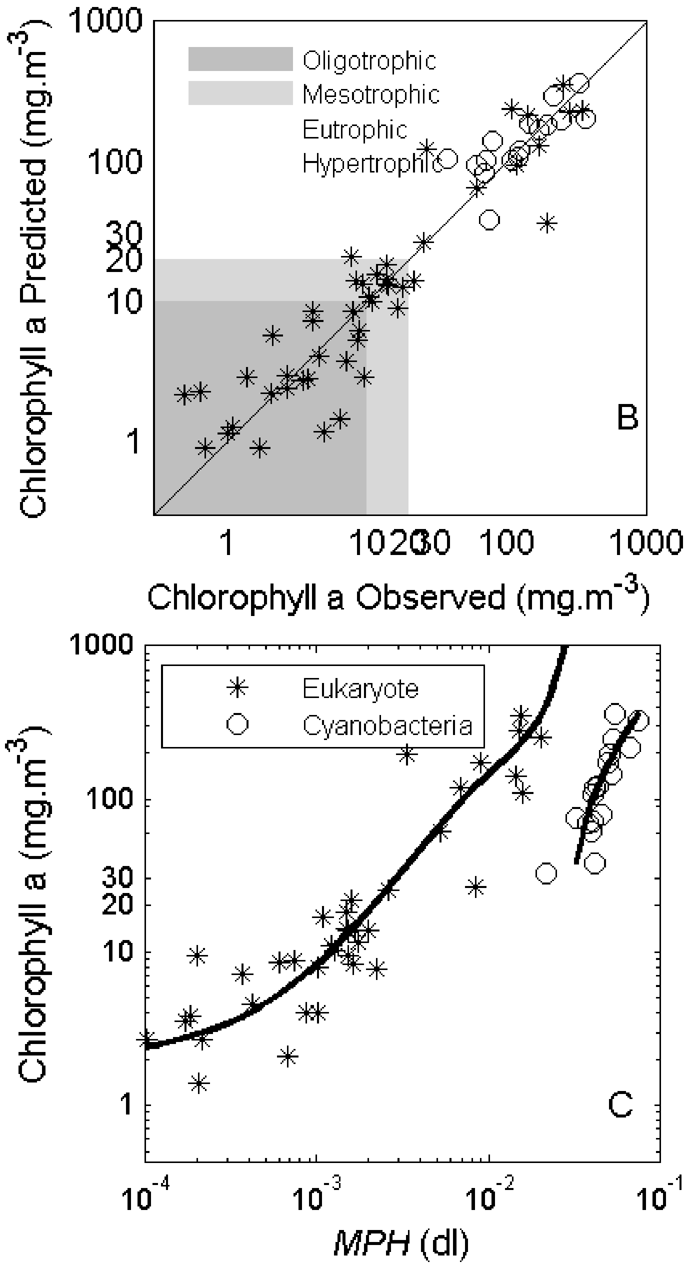
If *SICF_peak* < 0 **and** *SIPF_peak* > 0 **and** maxpeakposition == 709: Cyanobacteria = **True**

If cyanobacteria **and** (chla> 500 **or** maxpeakpos==754): Cyanobacterial scum = **True**

If cyanobacteria == False **and** maxpeakpos == 754: Vegetation == **True**

The MPH algorithm

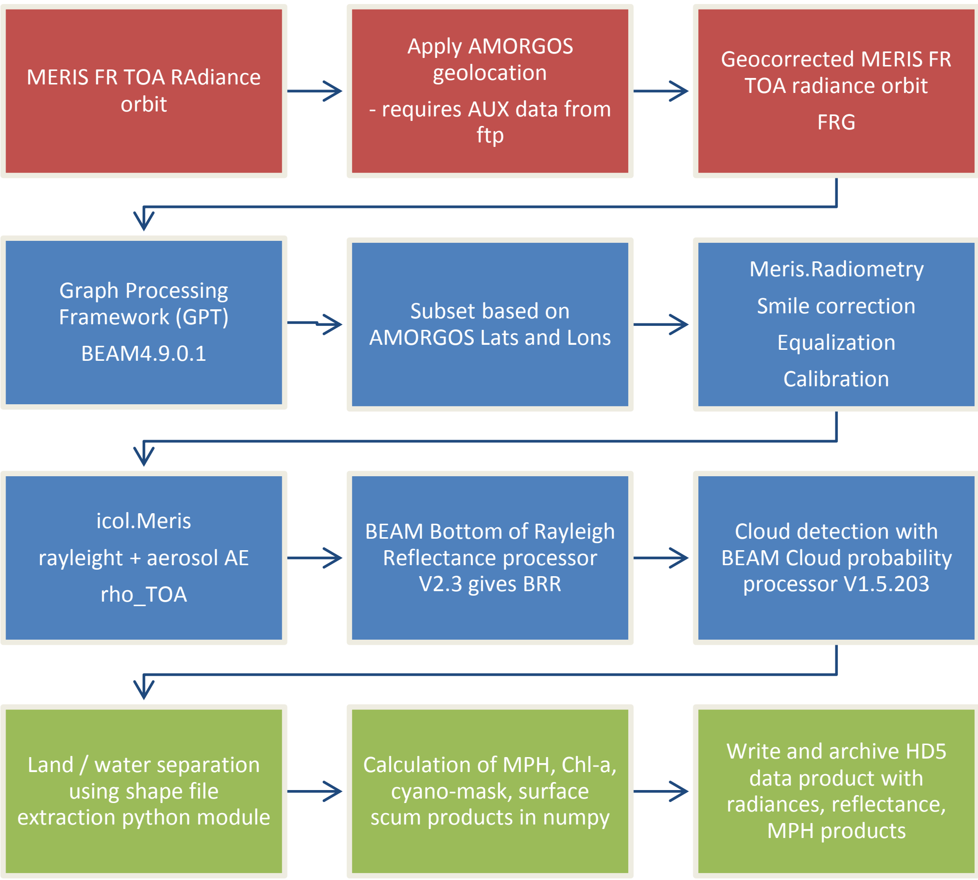
- Chl-a determined with range of 0.5 – 300 mg m^{-3} with and expected error of 30% and a sensitivity down to at least 3.5 mg m^{-3}
- Trophic status determined from Top-of-Atmosphere type reflectance normalised for Rayleigh effects only – no aerosol correction
- Discrimination between eukaryote and cyanobacteria (*Microcystis*) species from space based on magnitude of reflectance in 709 nm band
- Novel flag based on pigmentation, backscatter magnitude, for detecting cyanobacteria for chl-*a* > 30 based on absence of *SICF* and presence of *SIPF*
- Further detection of floating vegetation and surface scums



The MPH algorithm

- Coded in python programming language
- Calls database with full archive of African MERIS FR data
- Uses geo-correction L1 FRG lat/lon bands produced by **AMORGOS** which does not alter radiometry
- Uses available **BEAM processors**
  - Bottom-of-Rayleigh-Reflectance processor;
  - Level 1 radiometry processor including SMILE correction;
  - Cloud processor for cloud detection;
  - ICOL tested but gives errors – suggestion is to implement with Rayleigh corrections ONLY
- Uses shape file extraction procedure for land-water discrimination
- Could easily be made into **a beam module** – any takers?
  - MPH variable with **regional parameterisations** – preliminary validation work in the Baltic sea looks promising, although there are some challenges
  - **Flag for the presence of cyanobacteria** – already partially validated in global systems

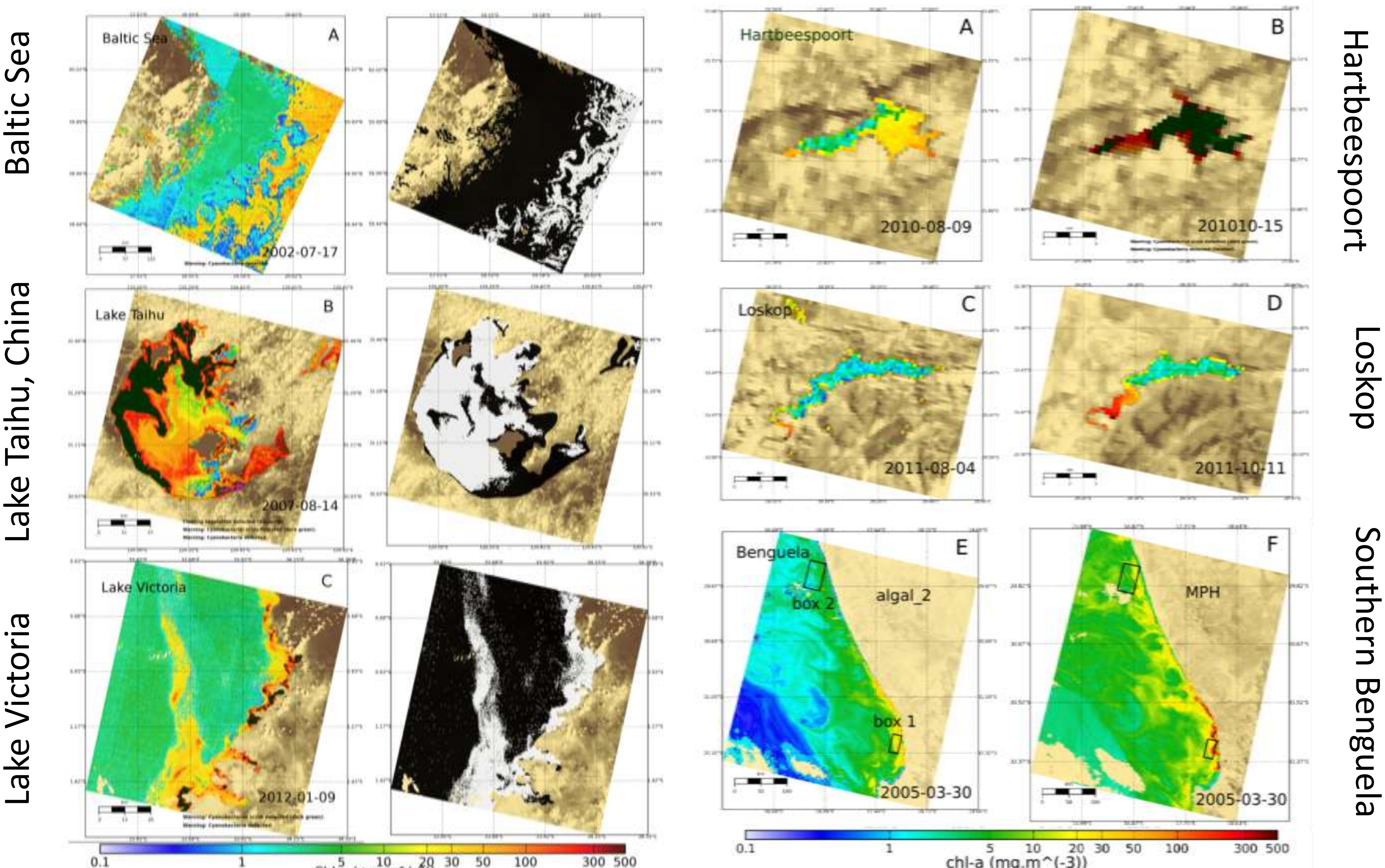
Operational data processing chain



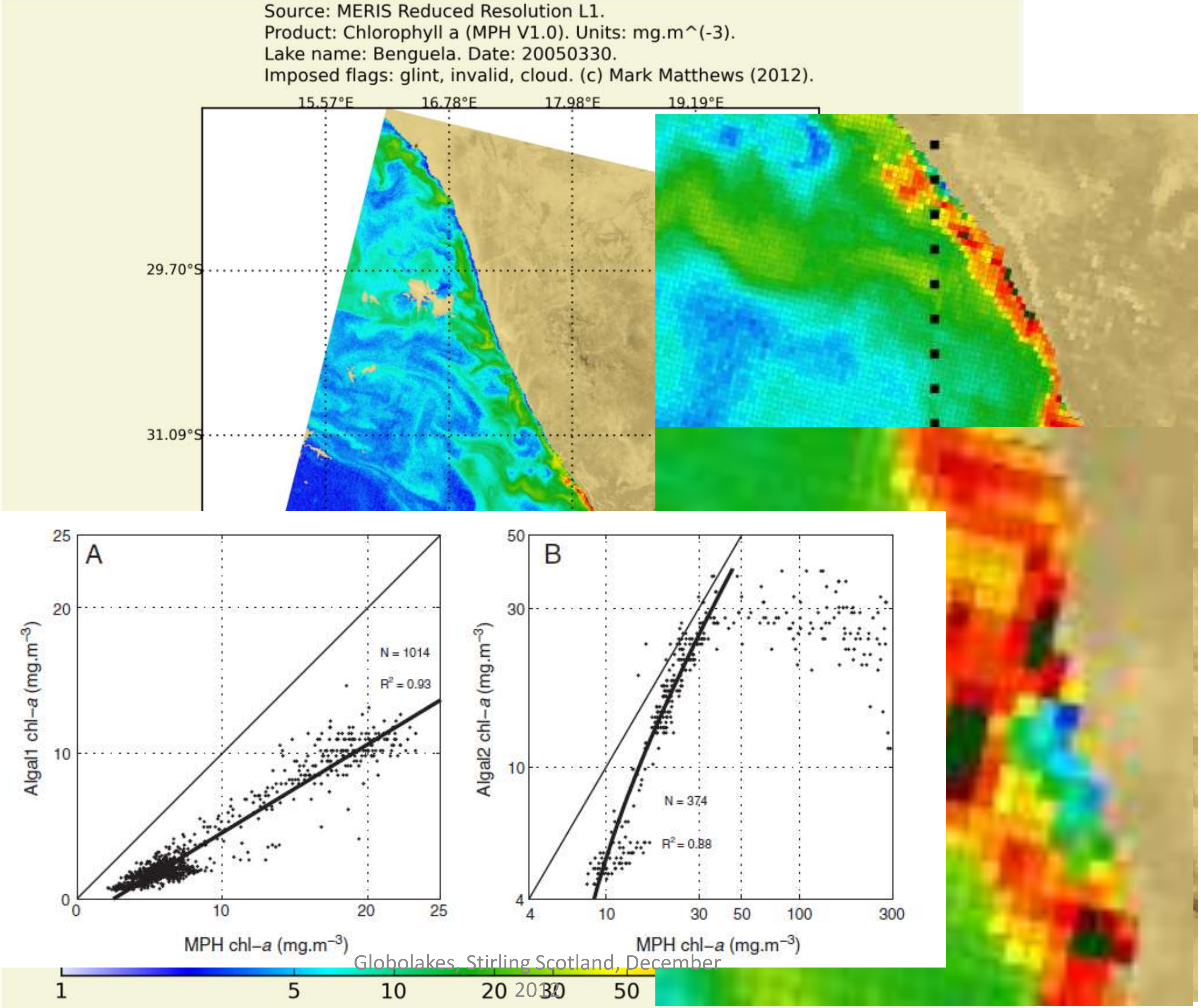
The MPH algorithm

Global examples

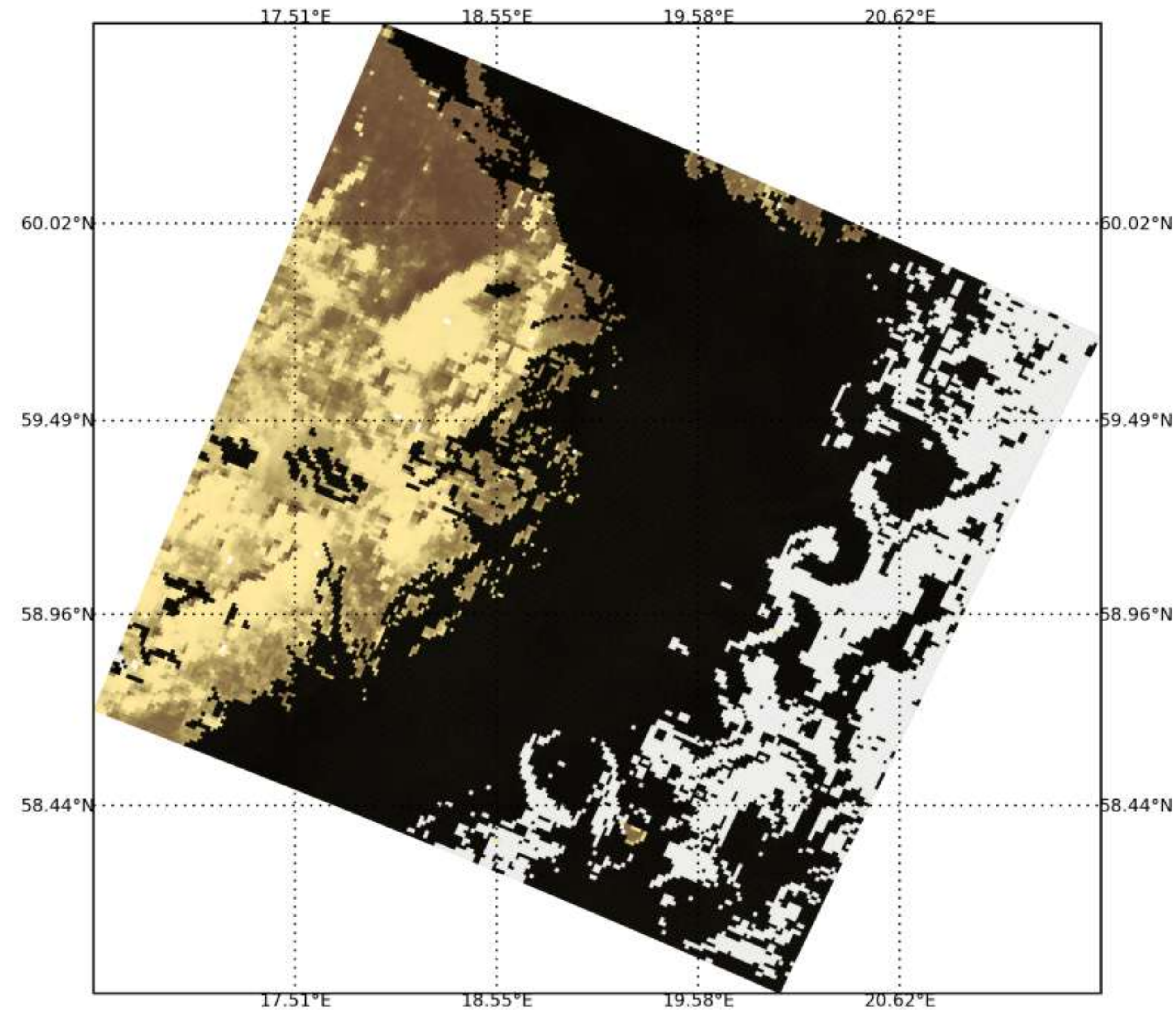
Local examples



Southern Bengula



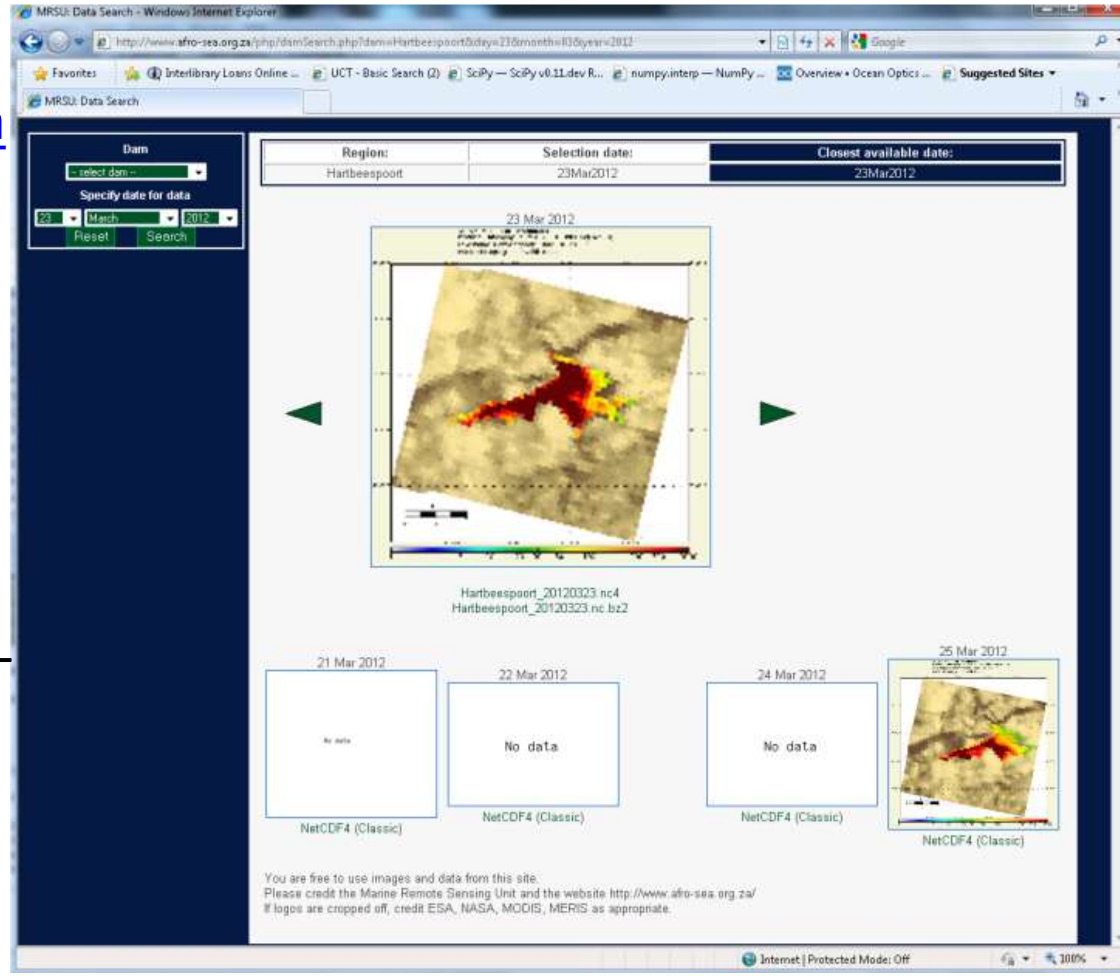
Baltic Sea, Europe



Warning: Cyanobacteria detected (white).

Time series observations of eutrophication and cyanobacteria

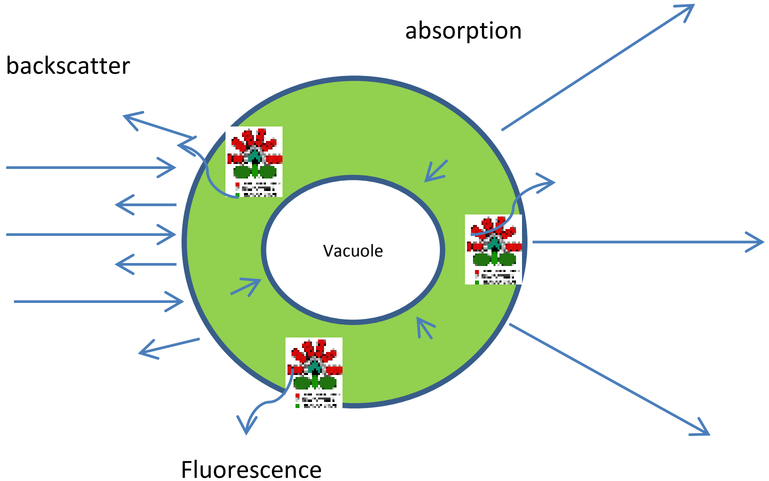
- Pilot demonstration product dissemination portal www.afro-sea.org.za for 8 inland waters was operational until MERIS went offline
- Continuous global observation of surface water quality, cyanobacterial blooms, algal blooms
- Utilizing the power of near-real time processing and visualization
- Full MERIS archive for Africa stored at CHPC and backprocessed for 10 year time series



Investigating impact of gas vacuoles using a two-layered sphere model

- *M. aeruginosa* modelled as a two layered sphere
- Shell = chromatoplasm, core = gas vacuole
- Facilitated by prokaryotic cellular arrangement
- Derivation of real and imaginary refractive indices from absorption data using inverse ADA model (Bricaud&Morel'86

M. aeruginosa



Matthews et al. In Press

Some thoughts... algorithm selection

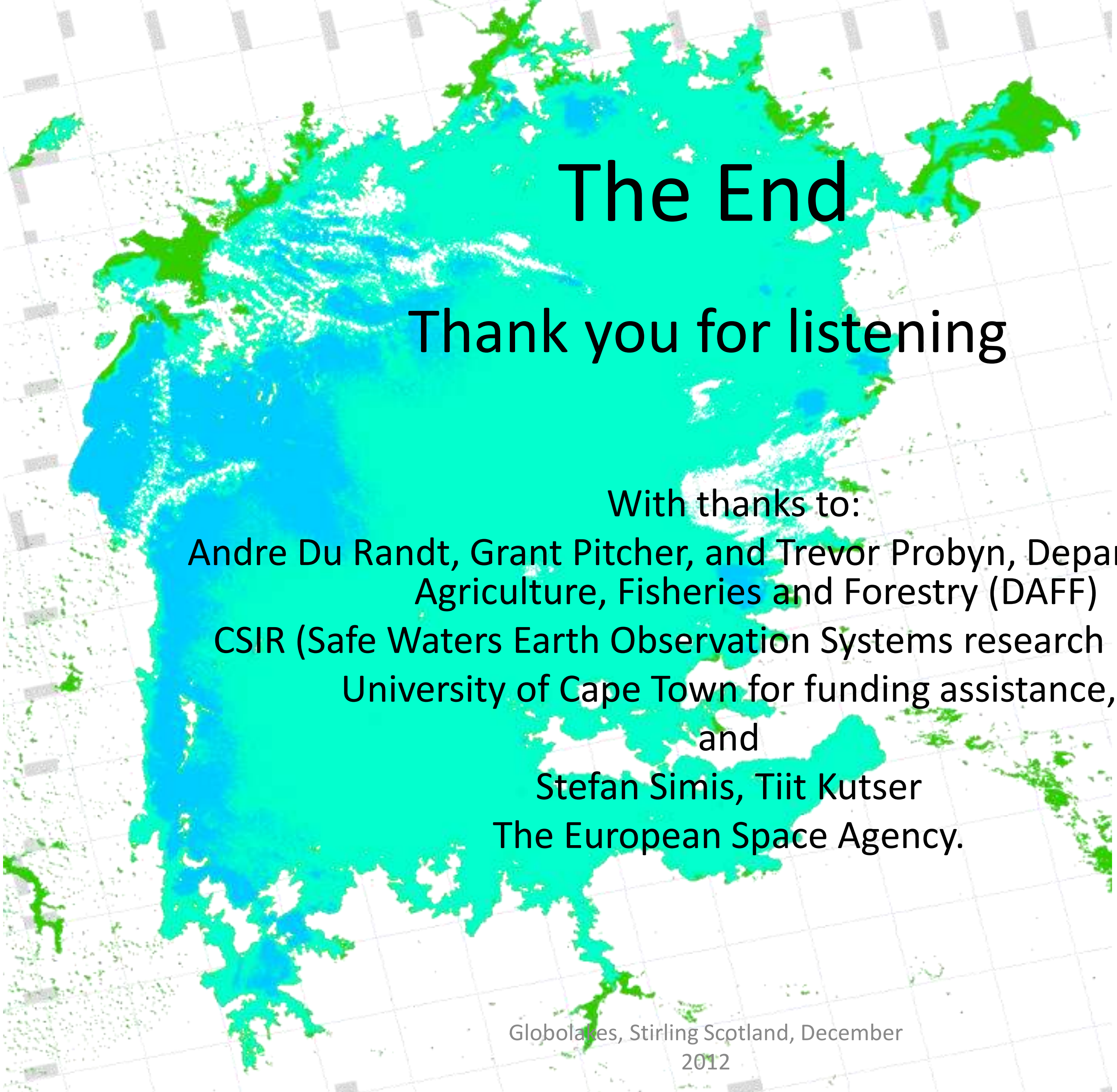
- Suggested empirical algorithms for various parameters (Matthews 2011)
- Different algorithms work in different **concentration ranges** and **sensor sensitivities/bands**
- There is often a significant **bio-optical basis for 'empirical' algorithms** : empirical algorithms from bio-optical models
- Definitions for trophic status classes important up front

Table 3. Suggested band(s), band ratios and/or band arithmetic for the detection of water-quality parameters in inland and transitional waters using broad-band or narrow-band sensors based on review of current literature.

	Sensor spectral resolution		
Parameter	Broad bands	Narrow bands (nm)	Bio-optical basis
z_{SD}	Red band or red/blue ratio, e.g. TM3/TM1 + TM1	Red band or blue/red ratio, e.g. 512/620	Reflectance in red $\propto b_{bp}$. The blue band dominated by a_Φ and a_{CDOM} serves to normalize
TSS	<10 g m^{-3}: Red/green ratio or (green + red)/2	<30 g m^{-3}: (560–520)/(560 + 520) or single red band, e.g. 700	The a_Φ minimum at 560 nm is sensitive to TSS, whereas the 520 nm band serves to normalize
	>10 g m^{-3}: Red or NIR band or (green + red)/2	>30 g m^{-3}: NIR ratio, e.g. 850/550	Reflectance in red and NIR $\propto b_{bp}$ and b_{bm}. Band ratios normalize for variations in particle refractive indices and grain sizes
	>30 g m^{-3}: NIR/red or NIR/green ratio		
Chl-*a*	<20 mg m^{-3}: Green/blue ratio or (blue – red)/green	<30 mg m^{-3}: 560 or FLH algorithm	Chl-*a* $\propto$ reflectance in red due to b_{bp}, and inversely related to reflectance in blue due to a_Φ
	>20 mg m^{-3}: Red/blue or red/NIR ratio	>30 mg m^{-3}: 700/670 ratio or three-band model 750(1/670–1/710) or RLH or SUM algorithms	Reflectance at 700 nm sensitive to $b_{b\Phi}$ normalized by the a_Φ maximum near 665 nm
a_{CDOM}	Green/red ratio	Red/blue ratio, e.g. 670/412, or 'decoding index' [490–(700/675)–520]/[490 + (700/675)+ 520]	Relatively insensitive sensors: Reflectance in green inversely related to a_{CDOM} normalized by reflectance in red
			Sensitive sensors: Reflectance in blue inversely related to a_{CDOM} normalized by the reflectance in the red
Turbidity	Red band	Red or NIR band	Reflectance in red and NIR $\propto b_{bp}$ and b_{bm}
SPIM	Red or NIR band	Red or NIR band	Reflectance in red and NIR $\propto b_{bp}$ and b_{bm}
PC	–	(620/650) or (709/620) ratio or (600 + 648)/2–624	Reflectance at 620 nm inversely related to PC due to absorption maximum

Some thoughts...

- Phycocyanin retrievals sceptical/impossible < 50 mg m^{-3} due to SNR issues, Chla:PC ratios not predictable, ONLY possible if cyanobacteria dominant and chl-a>20-30 mg m-3
- Algorithm derivation/validation protocols:
  - difference between measurement and pass over time
  - errors for in situ estimates (e.g. chl-a), differences in methodologies (e.g. extraction efficiencies)
- Atmospheric correction:
  - 6S/SCAPE-M most likely to be best candidates
- ... for what its worth



The End

Thank you for listening

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