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“Shallow benthic habitat mapping opportunities in both continental nearshore and remote marine park islands; spatial-spectral and temporal scale issues of benthic health and processes -

Arnold Dekker, Young Je Park, Janet Anstee, Hannelie Botha, Vittorio Brando, Paul Daniel, Rebecca Edwards, Magnus Wettle now at @GeoScience Australia

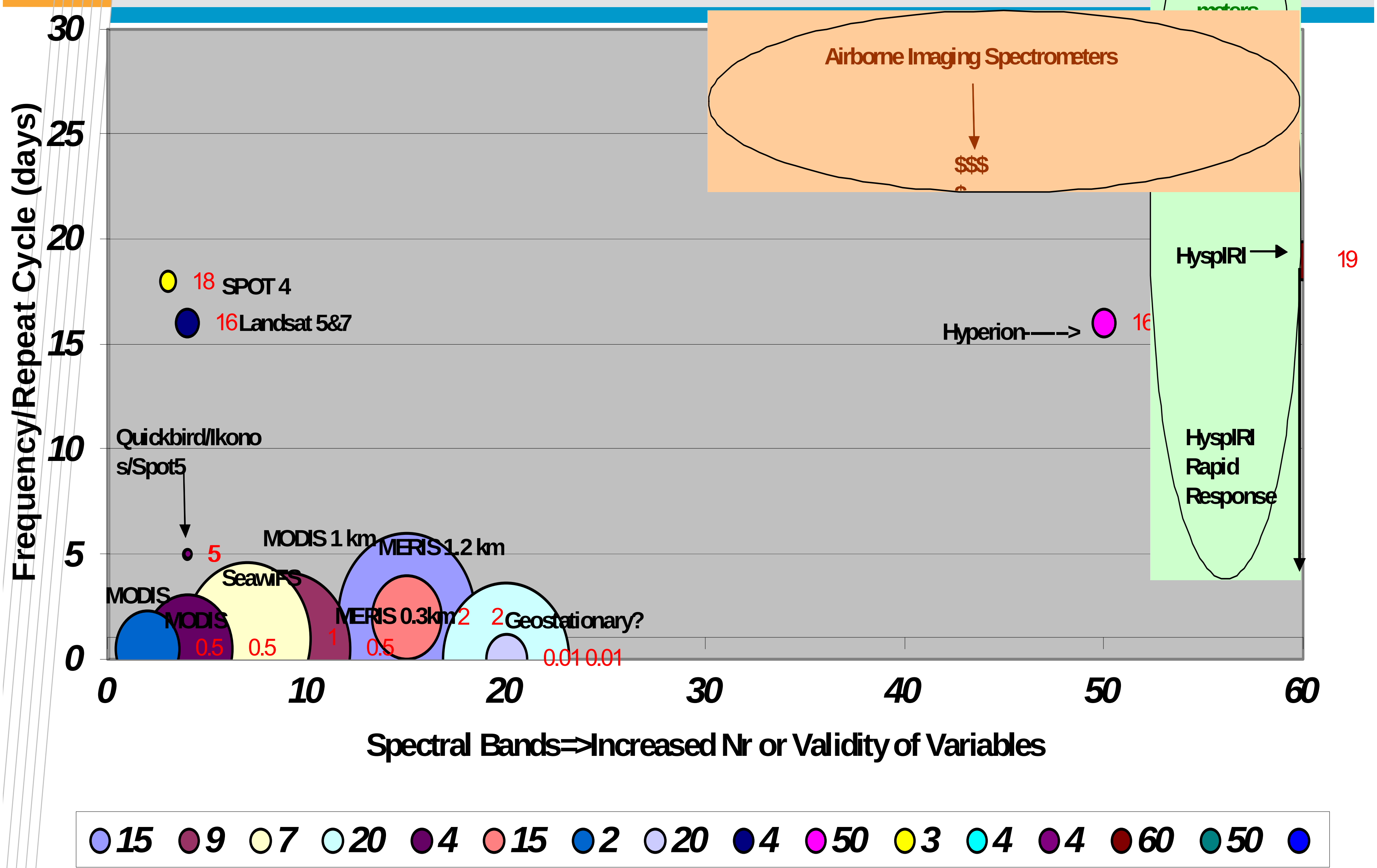
HyspIRI Workshop 12th August 2009 , Pasadena, Ca, USA

CSIRO

Earth observation is essential for Australian environmental management

Spatial and Spectral Resolution vs Frequency

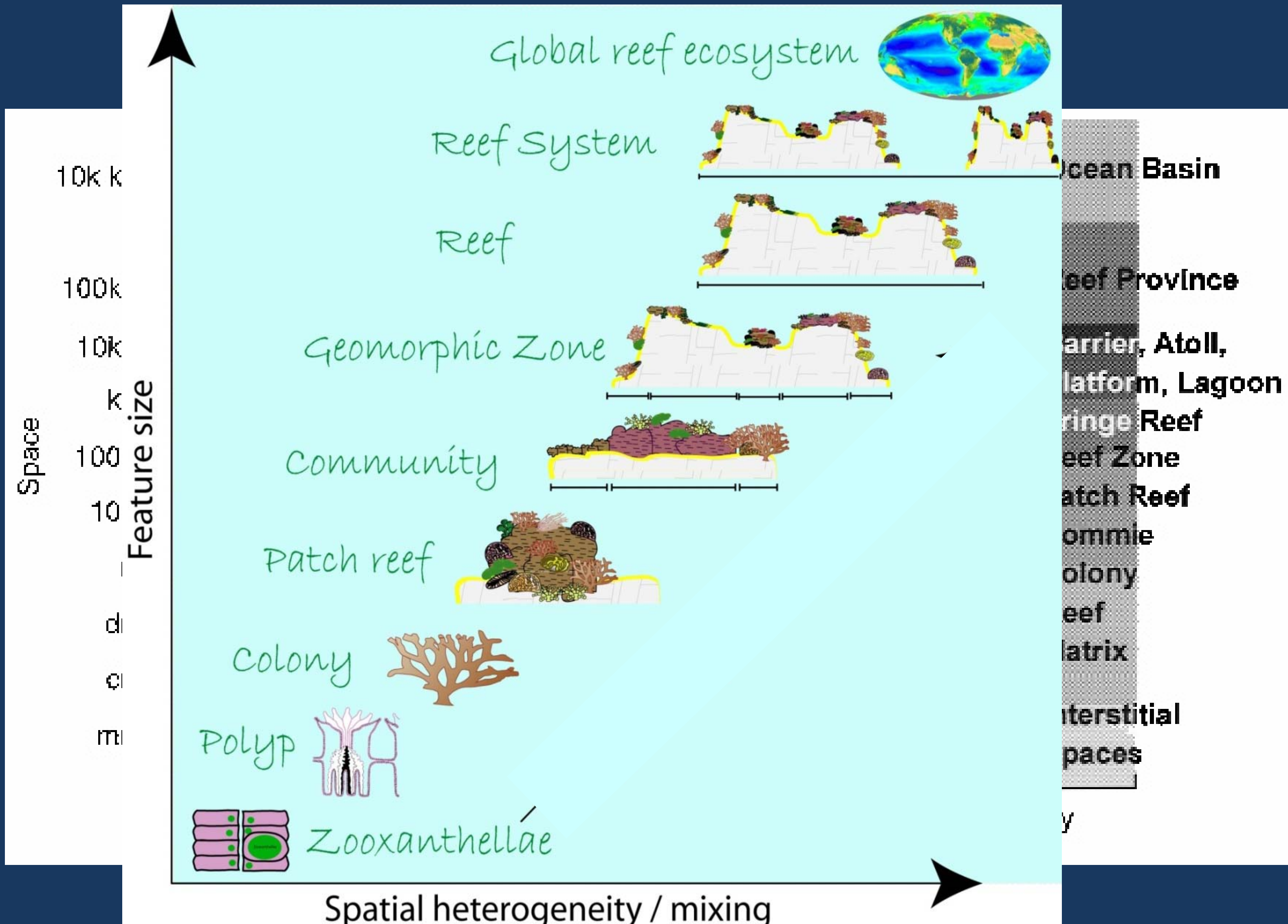
(red numbers= revisit time; size of circle= spatial resolution)



Contents

- Sun Glint Issue
- Coral Bleaching
- Cyanobacteria
- Conclusions and Discussion Points

- Previous spatial-temporal analyses – coral reefs



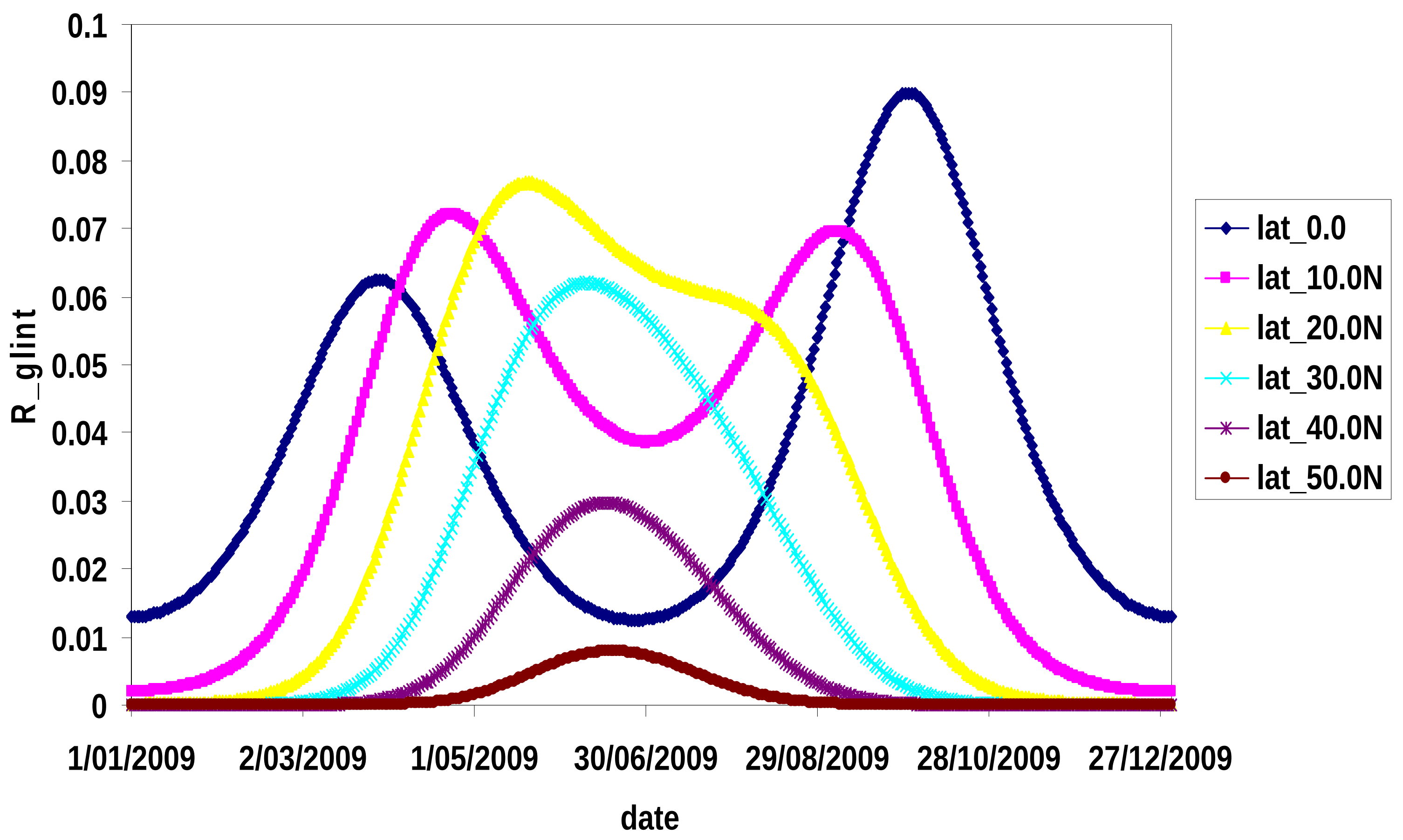
B.G. Hatcher. "Coral reef ecosystems: how much greater is the whole than the sum of the parts?" *Coral Reefs*, vol. 16, pp. 77-91, 1997.

Simulation of the HyspIRI Sun Glint Reflectance

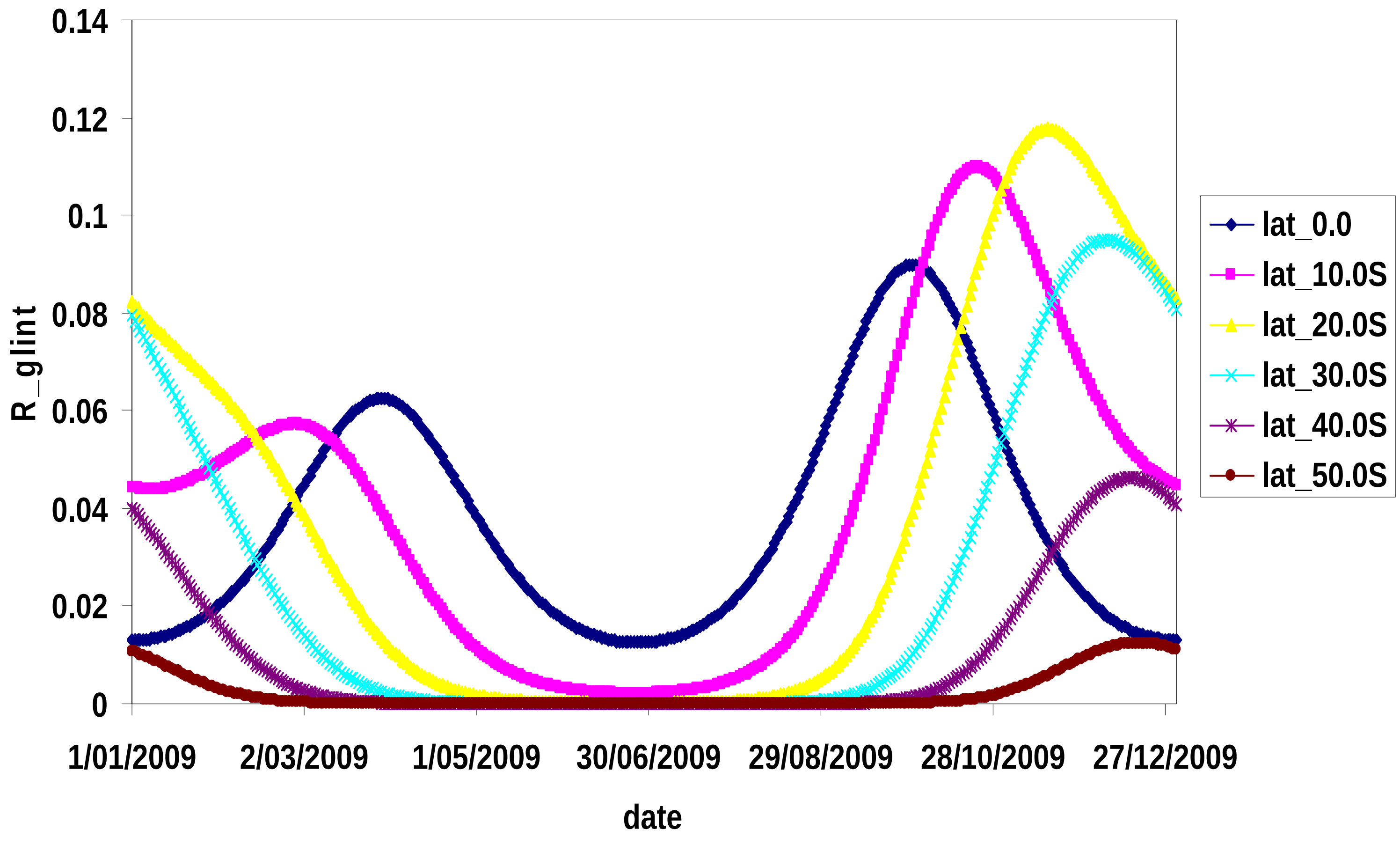
- 11:00 local time equator crossing (assuming orbit period = 98minutes)
- 4 degree tilt in backscatter direction
- Cox-Munk model of the isotropic surface slope distribution
- wind speed 5 m/s assumed (if not specified)

- Local time correction
  - Δtime = - 98.*latitude/360. (descending)
- Due to overpass time difference, the glint reflectance is slightly weaker in the northern hemisphere than in the southern hemisphere

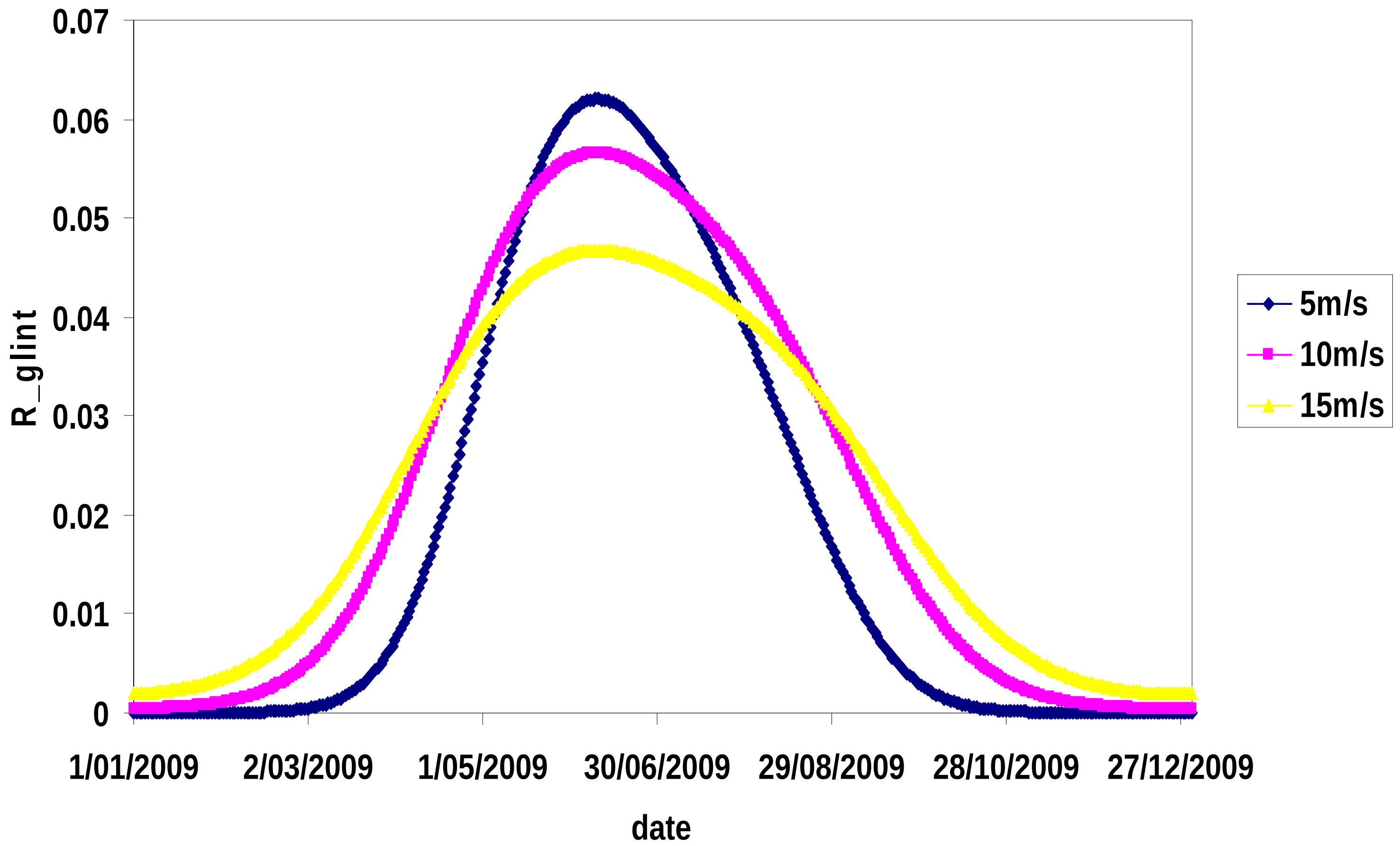
Glint reflectance: seasonal variation in Northern hemisphere



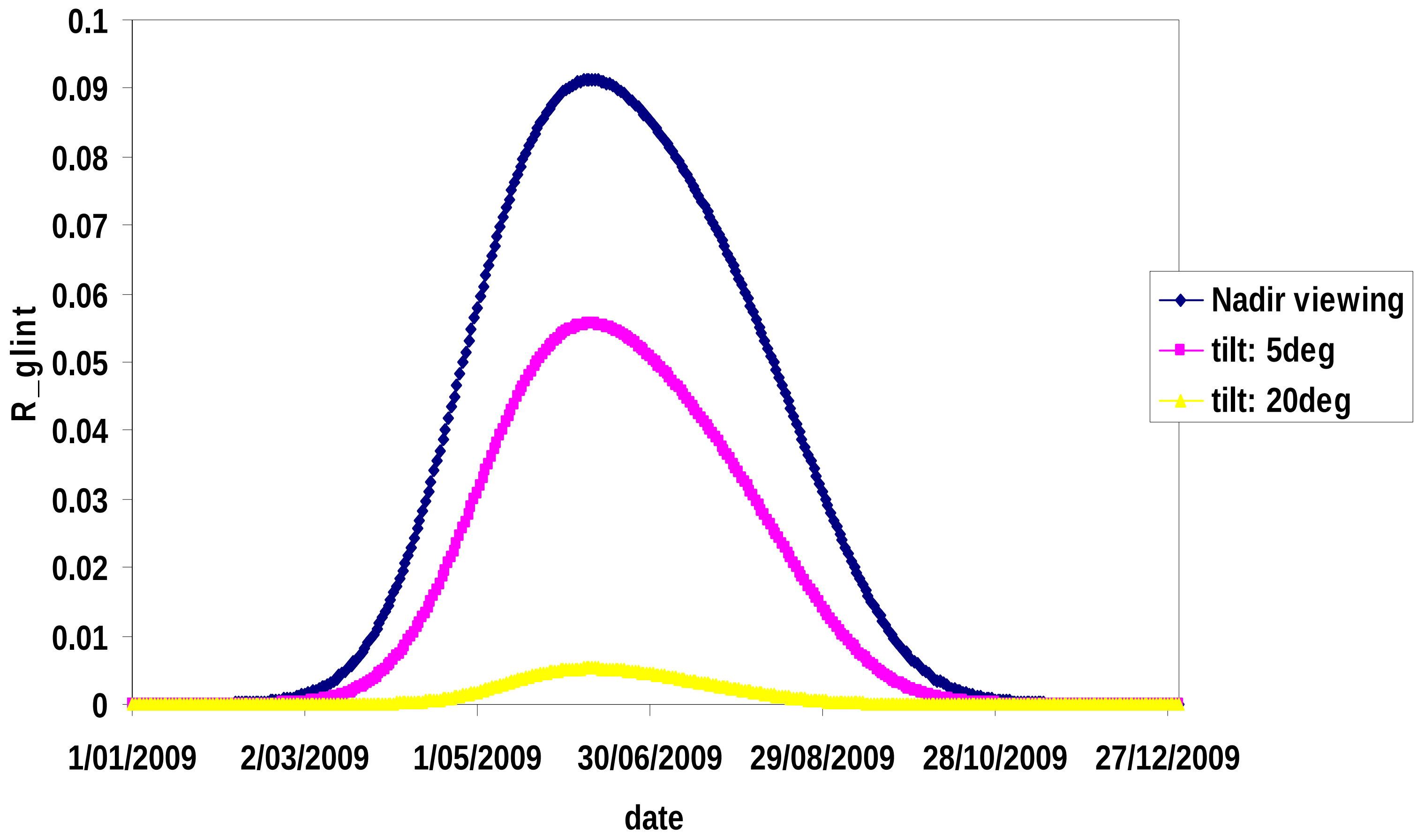
Glint reflectance: seasonal variation in Southern hemisphere



Glint reflectance: wind speed effect at latitude 30°N



Glint reflectance: effect of tilt in backscatter direction



Equations etc.

- R_glint =π*Lg(0+)/Ed(0+) where Lg is radiance due to glint = glint reflectance at surface
- R_glint formula with the Cox-munk slope model

$$R_{glint} = \frac{\pi \rho_F(\omega) P_s(\theta_0, \phi_0, \theta, \phi; W)}{4 \cos\theta \cos\theta_0 \cos^4 \theta_n}$$

$\theta_0, \phi_0, \theta, \phi$: solar zenith, azimuth, sensor zenith and azimuth

$\rho_F(\omega)$: Fresnel reflectance

$P_s(\theta_0, \phi_0, \theta, \phi, W)$: probability of surface slope with that the incident ray from direction θ_0, ϕ_0 is reflected to direc

ω : half of the angle between the vectors of the surface to sun and the surface to the sensor

θ_n : zenith angle of the vector normal to surface slope

W : wind speed at 10m above sea surface

$$P_s(\theta_0, \phi_0, \theta, \phi, W) = \frac{1}{\pi \sigma^2} \exp\left(\frac{-\tan^2 \theta_n}{\sigma^2} \right)$$

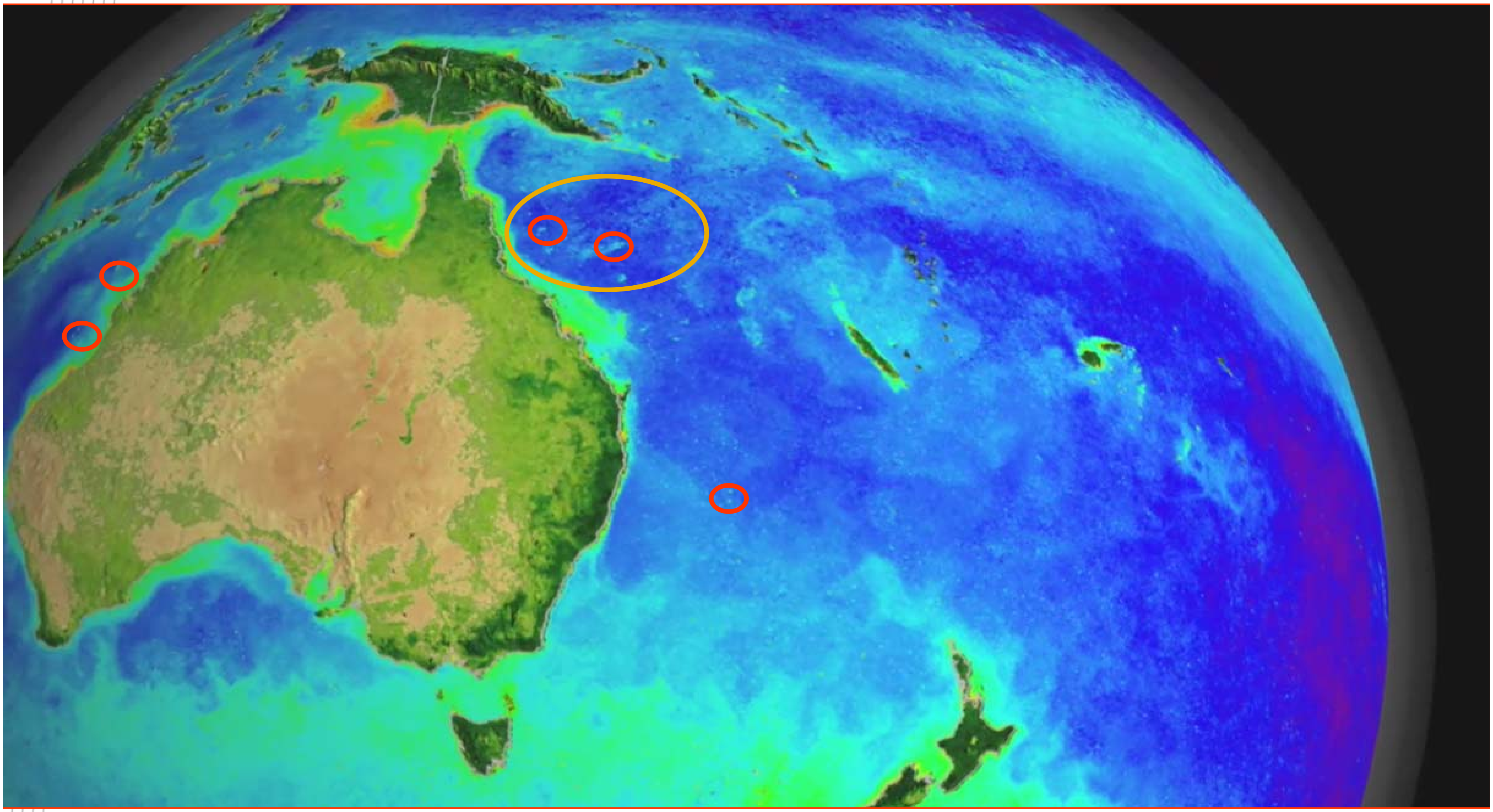
$$\sigma^2 = 0.003 + 0.00512W$$

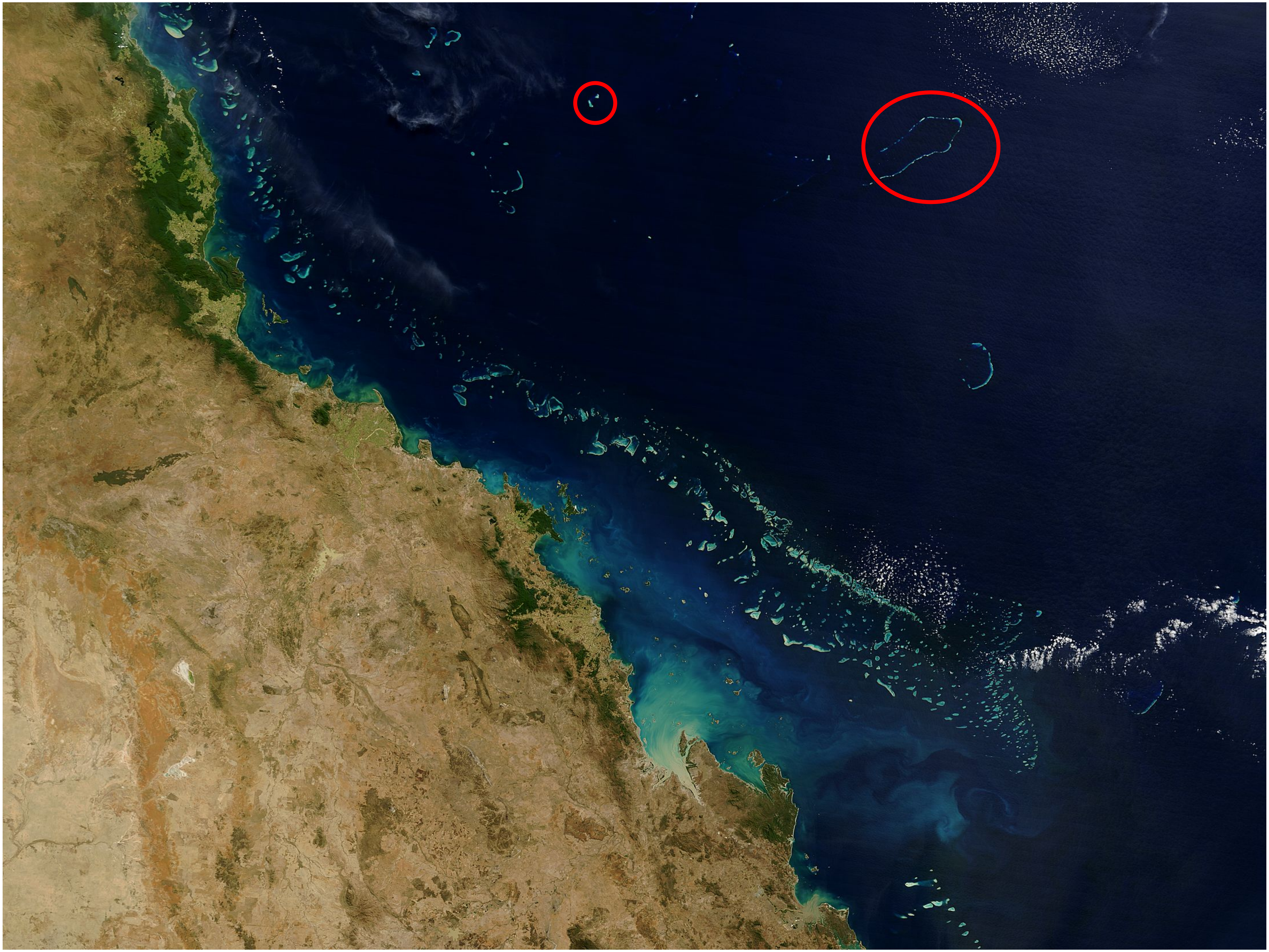
- In SeaWiFS L2 processing, the glint flag applied if glint reflectance exceeds 0.01

Glint correction using spatial variability

- Assumption:
  - High spatial variable reflectance at the NIR is due to the sun glint
  - This method allows non-negligible NIR reflectance and can be applied either before or after the atmospheric correction

The Commonwealth Tropical Marine Reserves

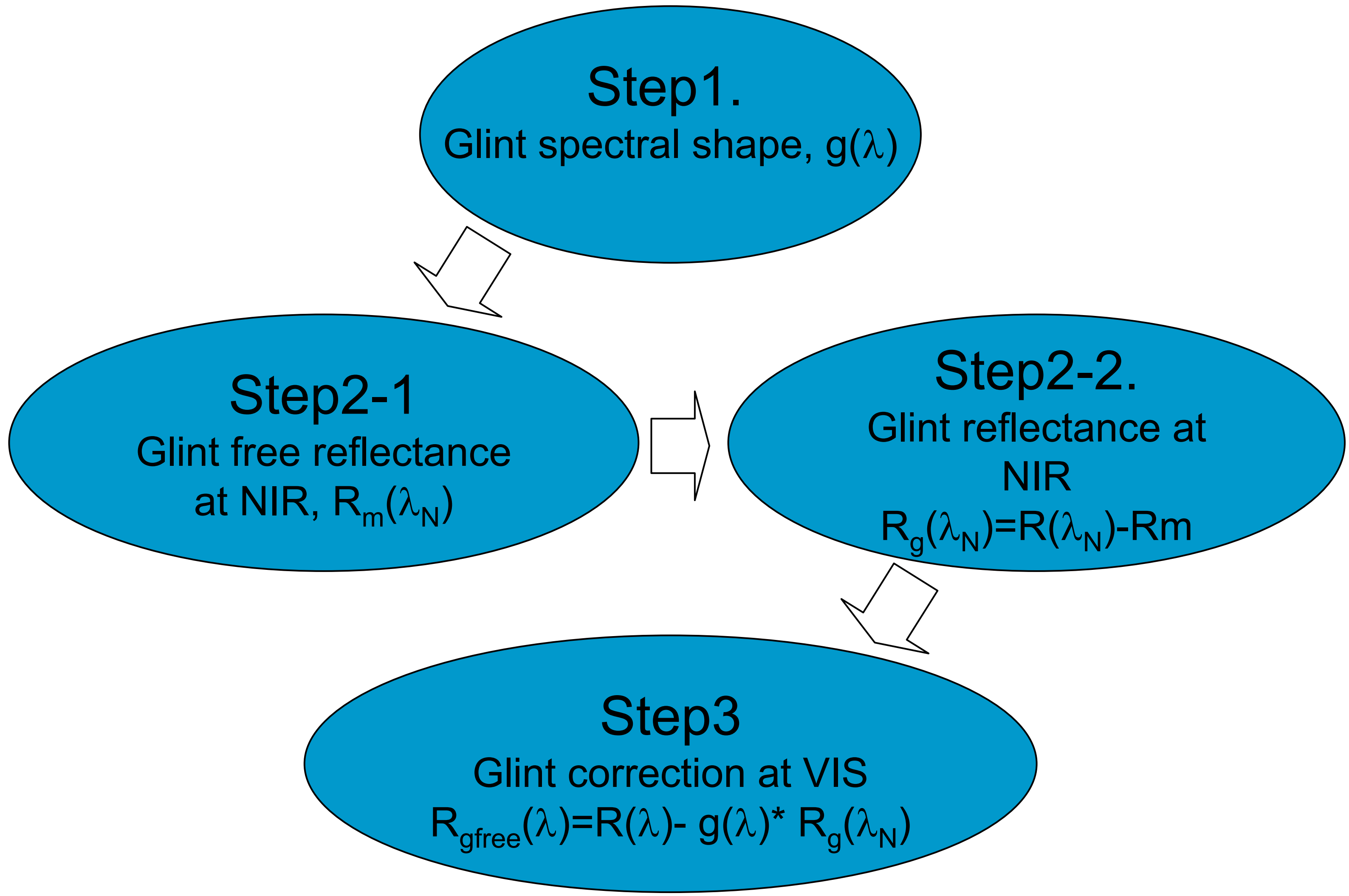




Un-corrected pseudo-true colour Quickbird data (2006) of North East Herald (Oct 06) and South West Herald Cays (Sep 06): spatial resolution

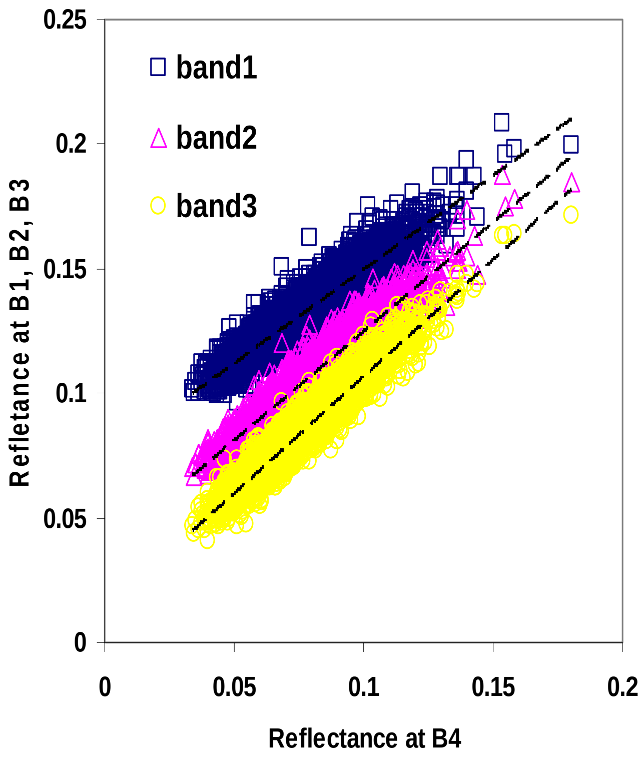
2.6 * 2.6 m in colour bands (Bl-Gr-Re-NIR);

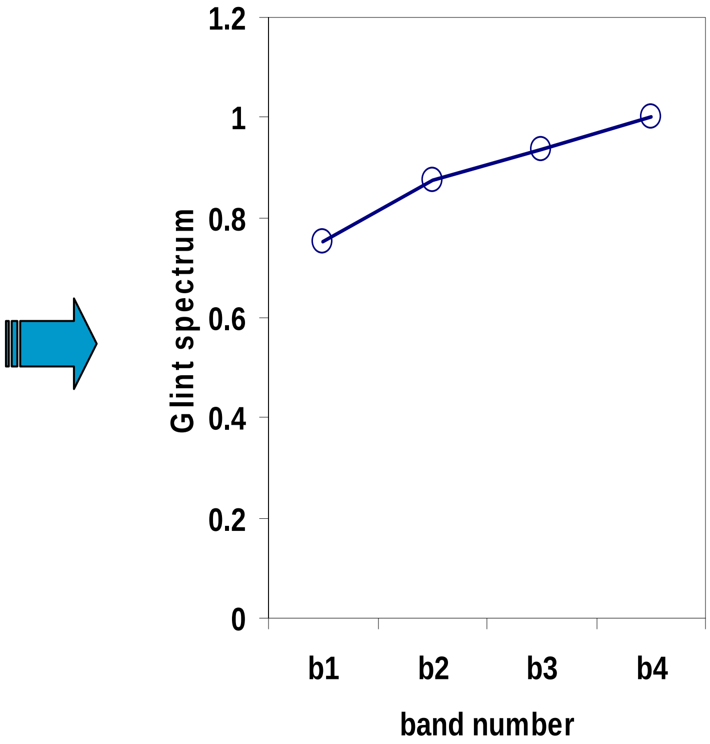
Steps


Step1.
Glint spectral shape, $g(\lambda)$
Step2-1
Glint free reflectance
at NIR, $R_m(\lambda_N)$
Step2-2.
Glint reflectance at
NIR
$R_g(\lambda_N)=R(\lambda_N)$-Rm
Step3
Glint correction at VIS
$R_{gfree}(\lambda)=R(\lambda)- g(\lambda)^* R_g(\lambda_N)$

Glint spectral shape: image based approach (Hochberg et al. 2003 & Hedley et al. 2005)

- Glint spectral shape is derived from the slope of the linear regression of each waveband against a NIR band





Glint reflectance estimation at NIR allowing for benthic reflectance at surface

1. First estimation of glint-free NIR reflectance as local minima in 3x3 boxes

R_m for box center pixels

↓

2. Spatial smoothing and interpolate to each pixel, *which eliminates extremely low reflectance (possibly shade)*

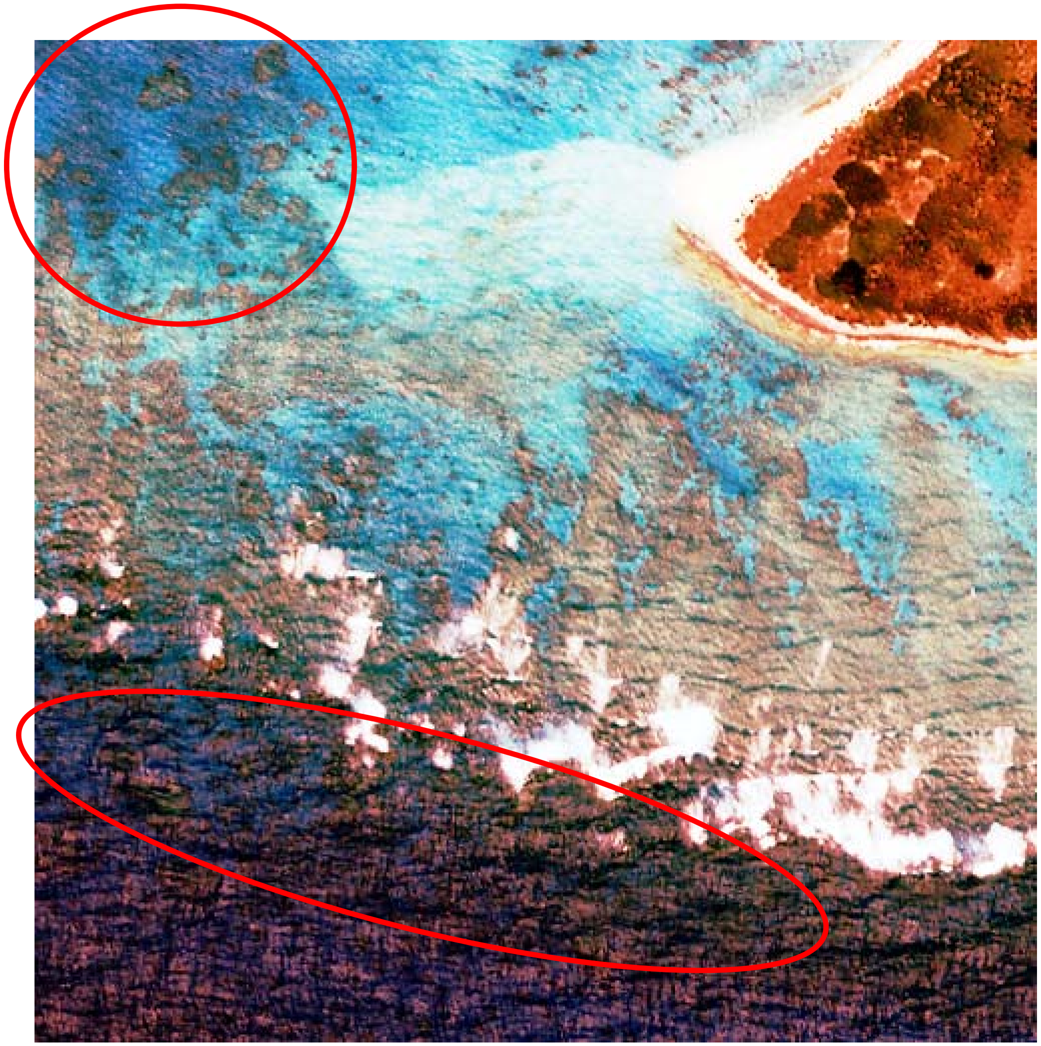
R_m for each pixel

↓

3. Estimate the glint reflectance for each pixel

$R_g = R - R_m$

NE Coringa Herald QB image: before glint correction
Note glint on and shading in waves!



NE Coringa Herald QB image: after glint correction

Simulation HyspIRI from a QB image of North-east Coringa Herald

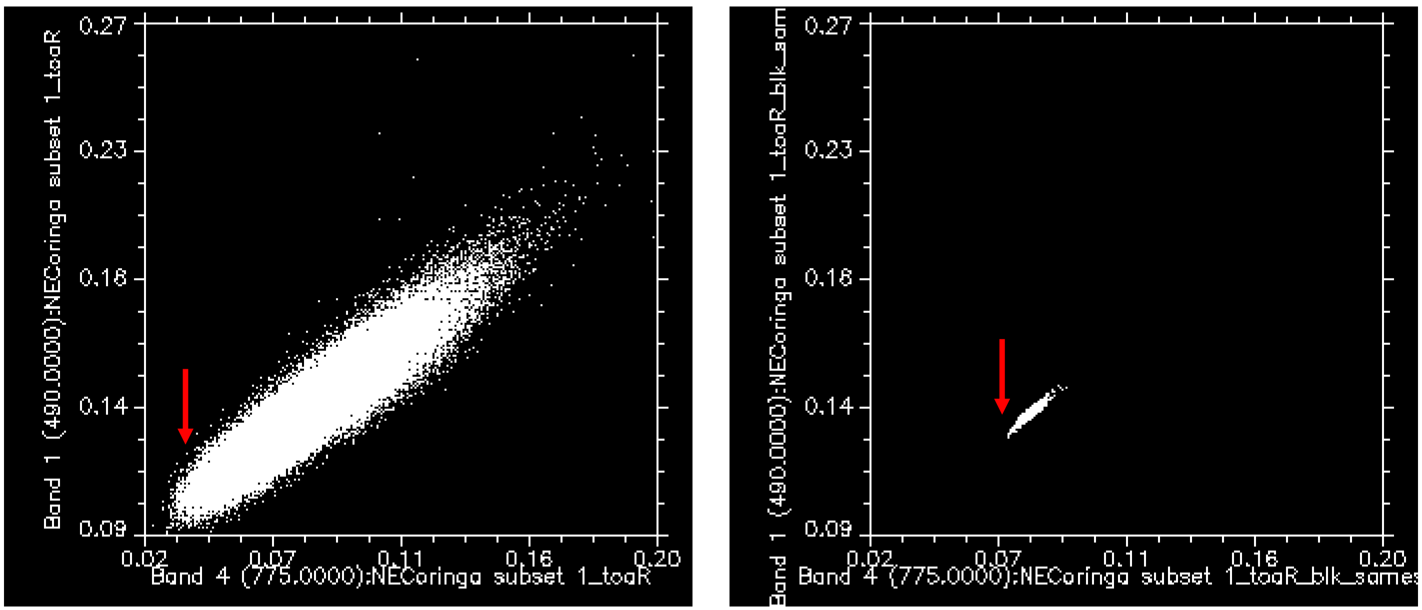
QB raw: 2.6m

Simulation: 60m

- Sunglint feature becomes obscured.

inter-band scatter plot of deep water pixels

- inter-band scatter plot of deep water pixels (left: 2.6m image, right:60m image)



•Due to the average effects, glint variability is reduced in the 60m image.

•A possible glint correction issue is that unaffected pixels not found in the 60m image, i.e. difficulty to estimate the glint signal per pixel

Recommendation

- Increased Tilt *or Sophisticated* Glint correction that maintains spectral integrity over optically deep and optically shallow waters!
- Glint correction would be:
  - Combination of both a statistical model (e.g. Cox & Munk for ocean and improved coastal model) and scene based techniques (Hochberg et al. 2003 or Kutser et al. 2009)

CORAL REEF HABITAT MAPPING USING MERIS: CAN MERIS DETECT CORAL BLEACHING?

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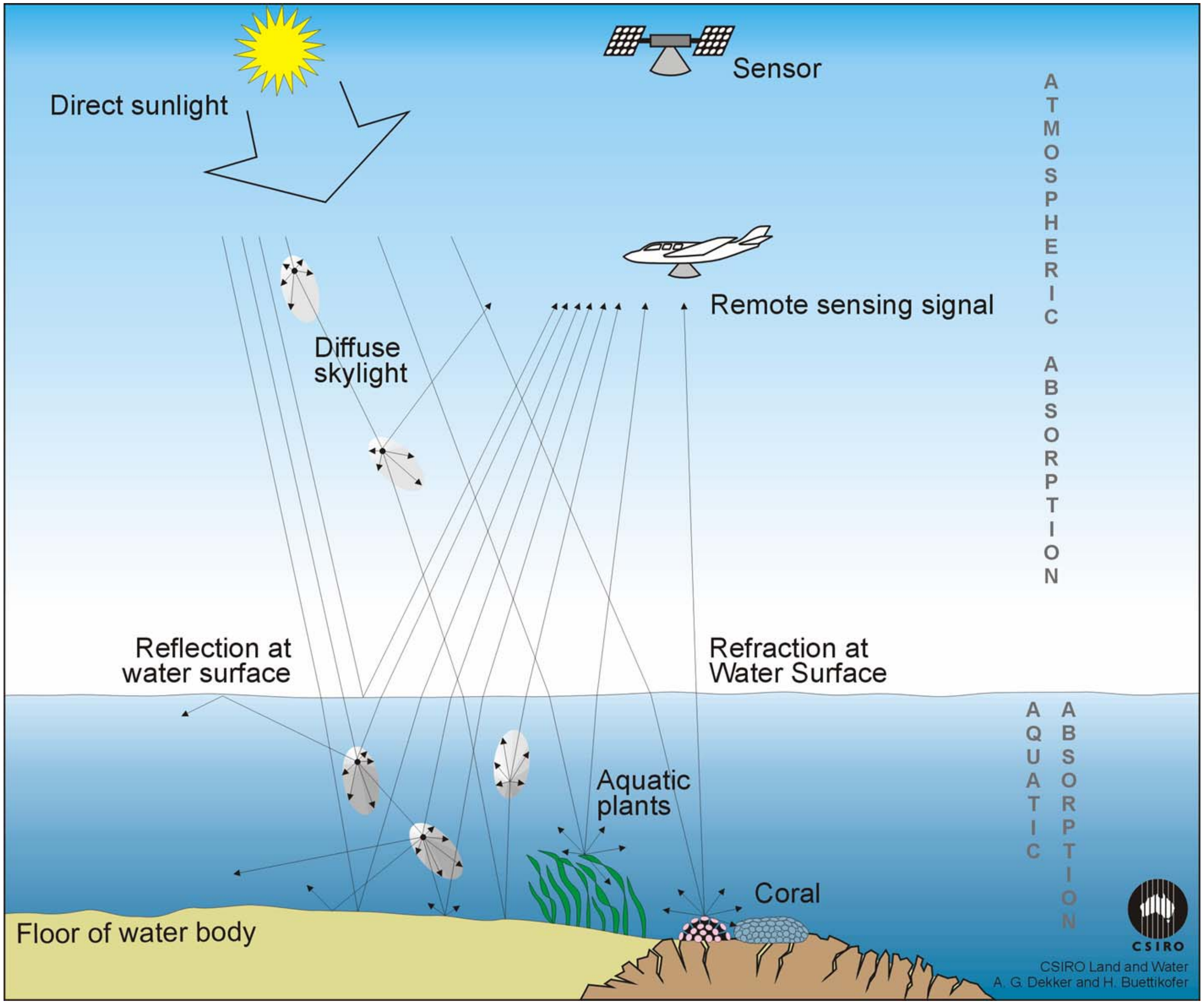
Lesley Clementson
Marine Bio-optical Research, CSIRO Marine and Atmospheric Research

Optical complexity of inland and coastal waters

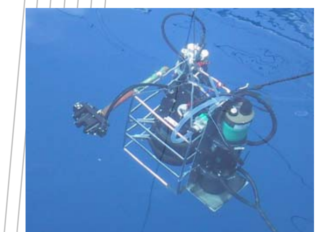
Optically shallow water



Optically deep water

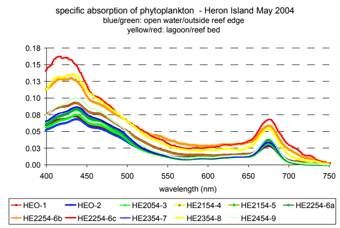
Overview

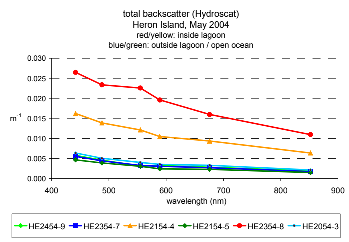
water measurements

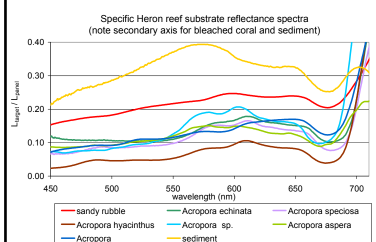


substrate measurements

spectral absorption and backscattering of water







spectral reflectance of substrates

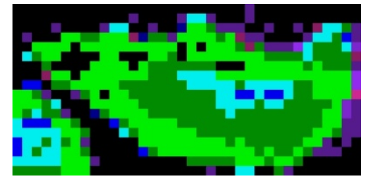
SAMBUCA

$$r_{rs}(\lambda)_{modelled} = f\left(C_{CHL}, C_{CDOM}, C_{TR}, X_{PHY}, X_{TR}, q1, H, S_{CDOM}, S_{TR}, a^*_{TR}(\lambda_{TR}), Y\right)$$

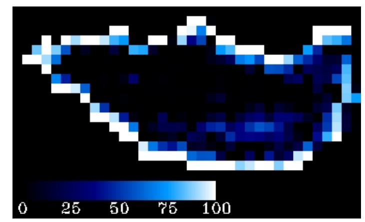
- C_{CHL} is the concentration of chlorophyll a
- C_{CDOM} is the concentration of CDOM, i.e. a^*_{CDOM} (λ_{CDOM}) is set to 1
- S_C is the slope of the CDOM absorption
- C_{TR} is the concentration of tripton
- S_{TR} is the slope of tripton absorption
- $a^*_{TR}(\lambda_{tr})$ is specific absorption of tripton at λ_{tr}, which is sample dependent
- X_{PHY} is the specific backscattering due to phytoplankton
- X_{TR} is the specific backscattering due to tripton
- q1 is the ratio of substrate 1 to substrate 2 within each pixel

MERIS image

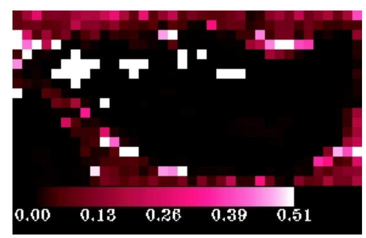
SAMBUCA output:



bathymetry map



substrate map



accuracy map

SAMBUCA

$$r_{rs}(\lambda)_{modelled} = f\left(P, G, X, B, H, S, Y\right)$$ *(Lee et al, 1999; 2000; 2001)*

is replaced by

$$r_{rs}(\lambda)_{modelled} = f\left(C_{CHL}, C_{CDOM}, C_{TR}, X_{PHY}, X_{TR}, q1, H, S_{CDOM}, S_{TR}, a^{*}_{TR}\left(\lambda_{TR}\right), Y\right)$$

- C_{CHL} is the concentration of chlorophyll a
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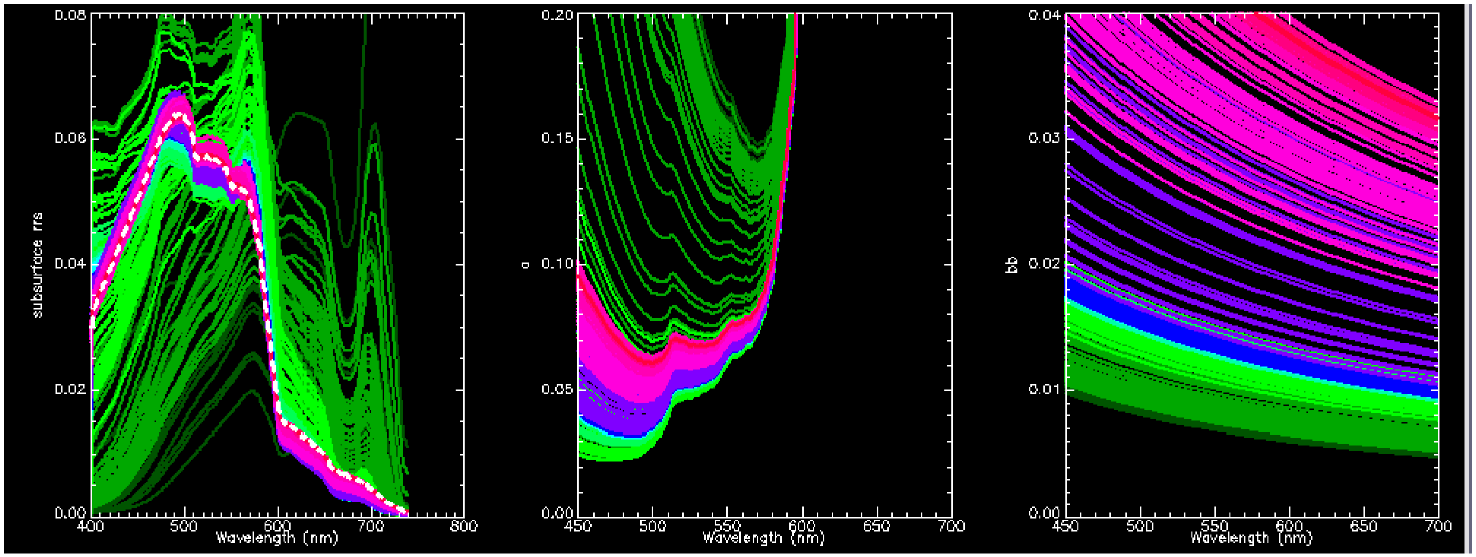
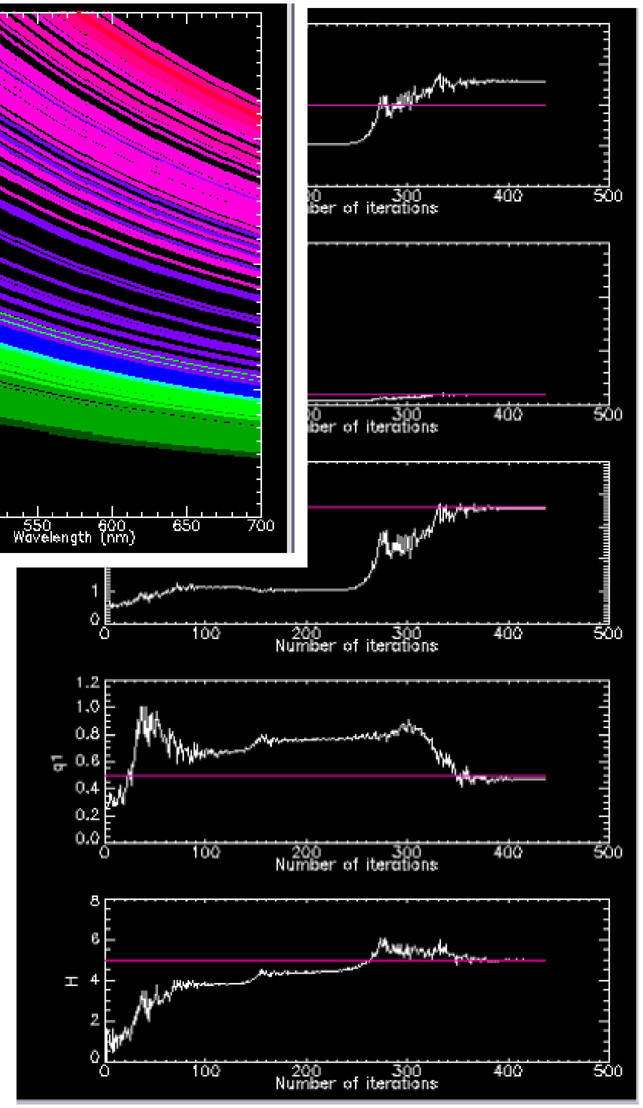
SAMBUCA





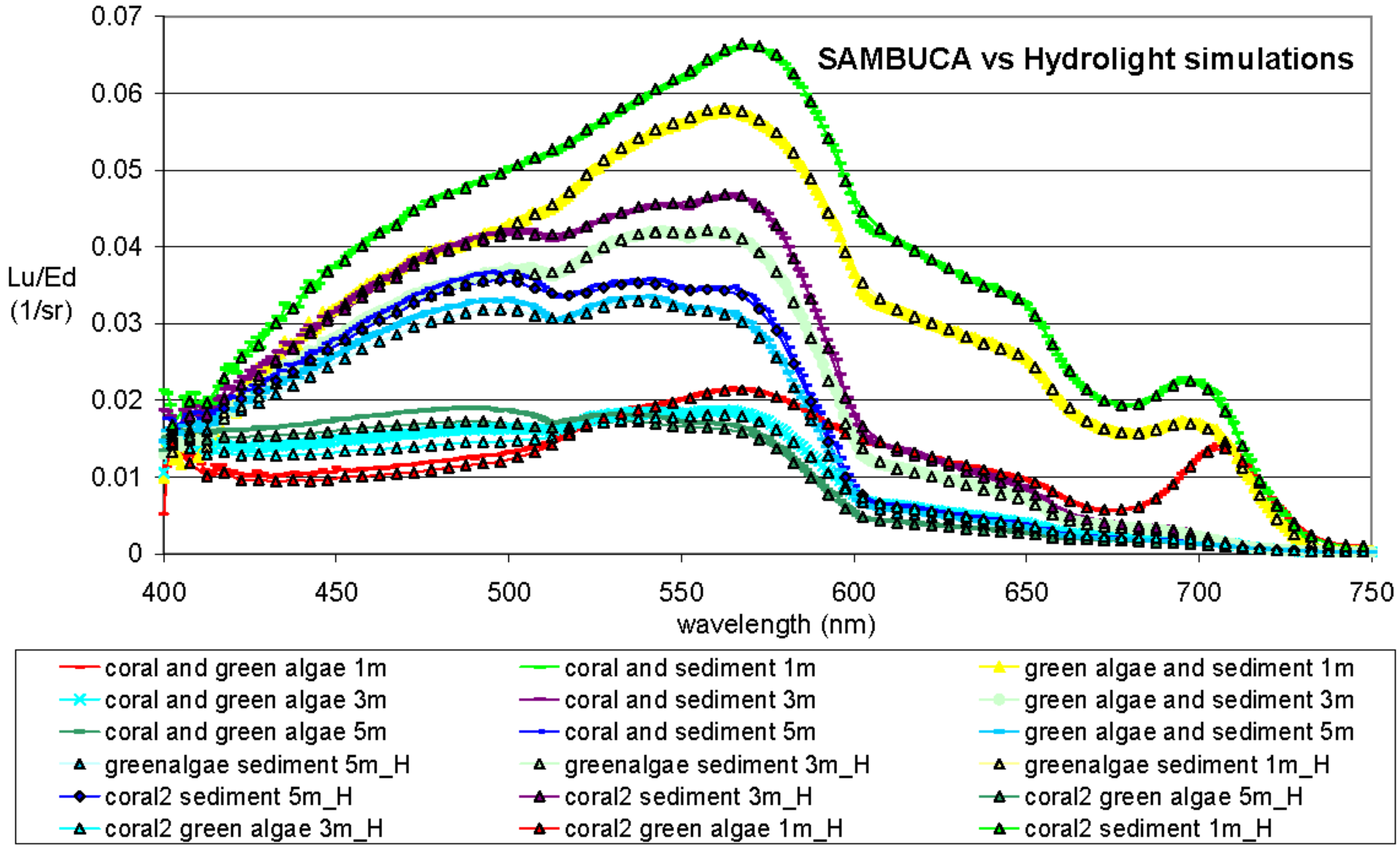
Optimisation - customized simplex method

$$error = r_{rs}(\lambda)_{measured} - r_{rs}(\lambda)_{modelled}$$

Minimising error solves for:

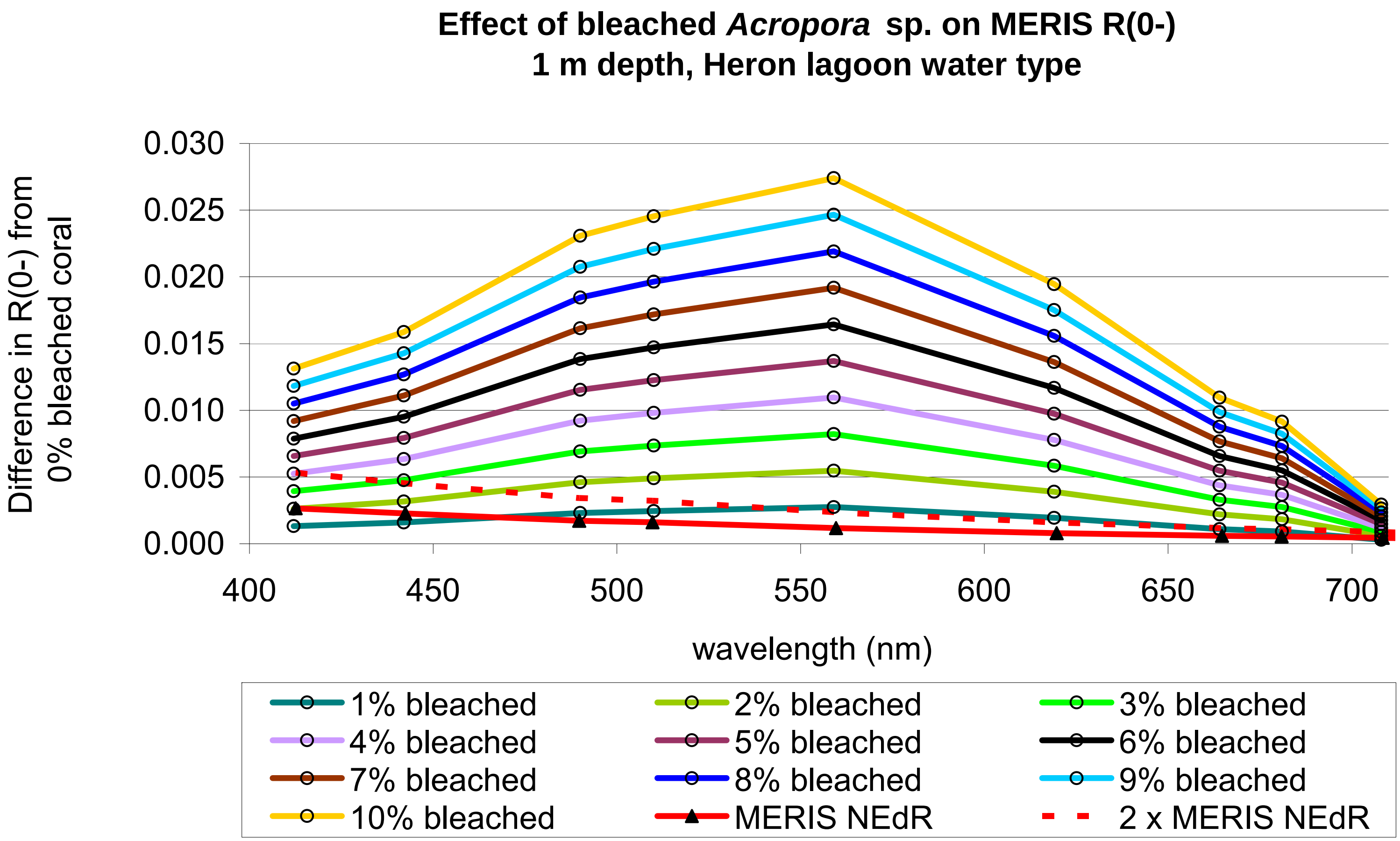
C_{CHL}, C_{CDOM}, C_{TR}, q1 (substrate ratio), H (depth)

SAMBUCA



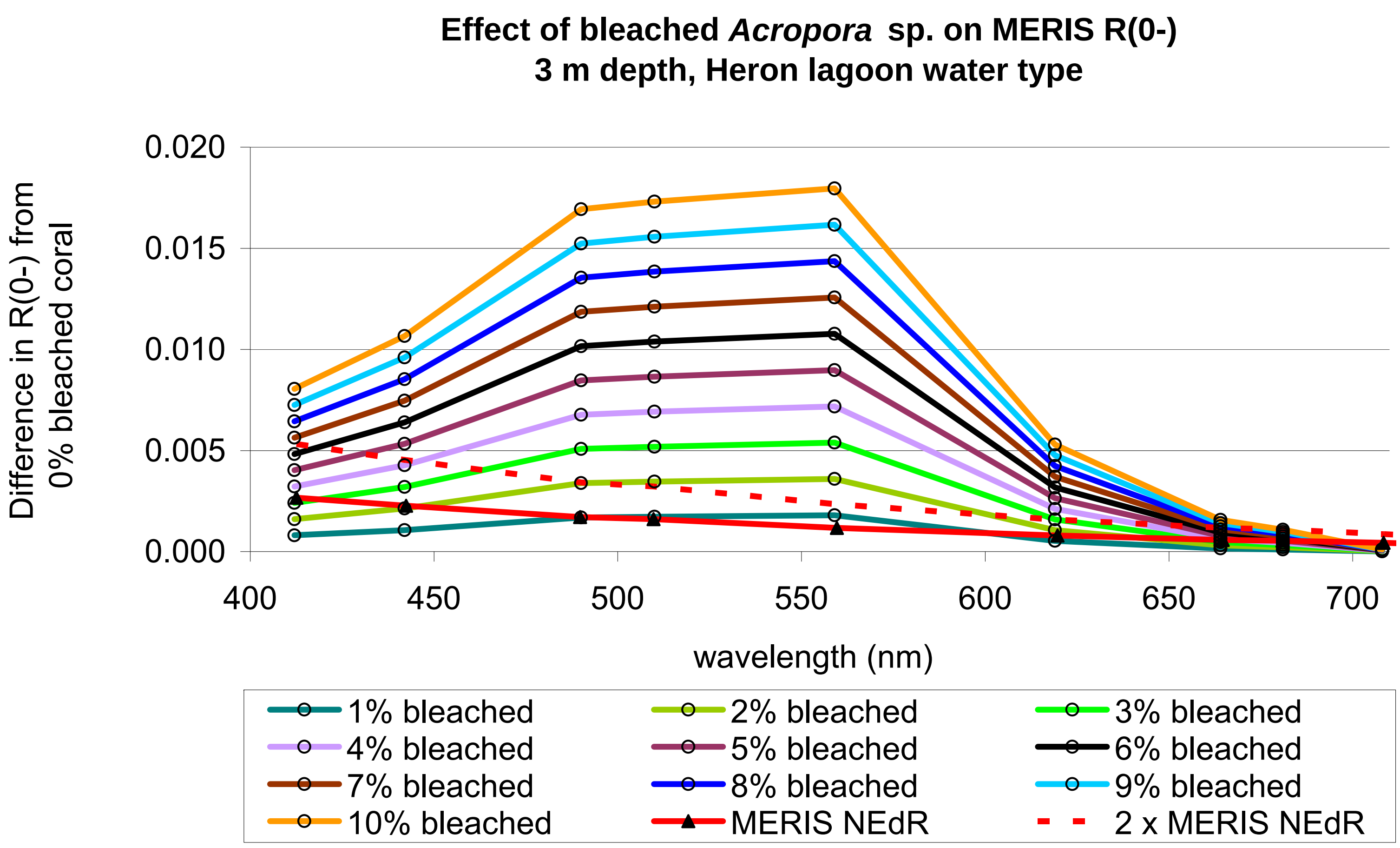
- Hydrolight: industry-standard numerical model for underwater RT
- Parameterisation: coral water type, 3 depths, 3 coral reef substrates

Coral bleaching detection sensitivity analysis:

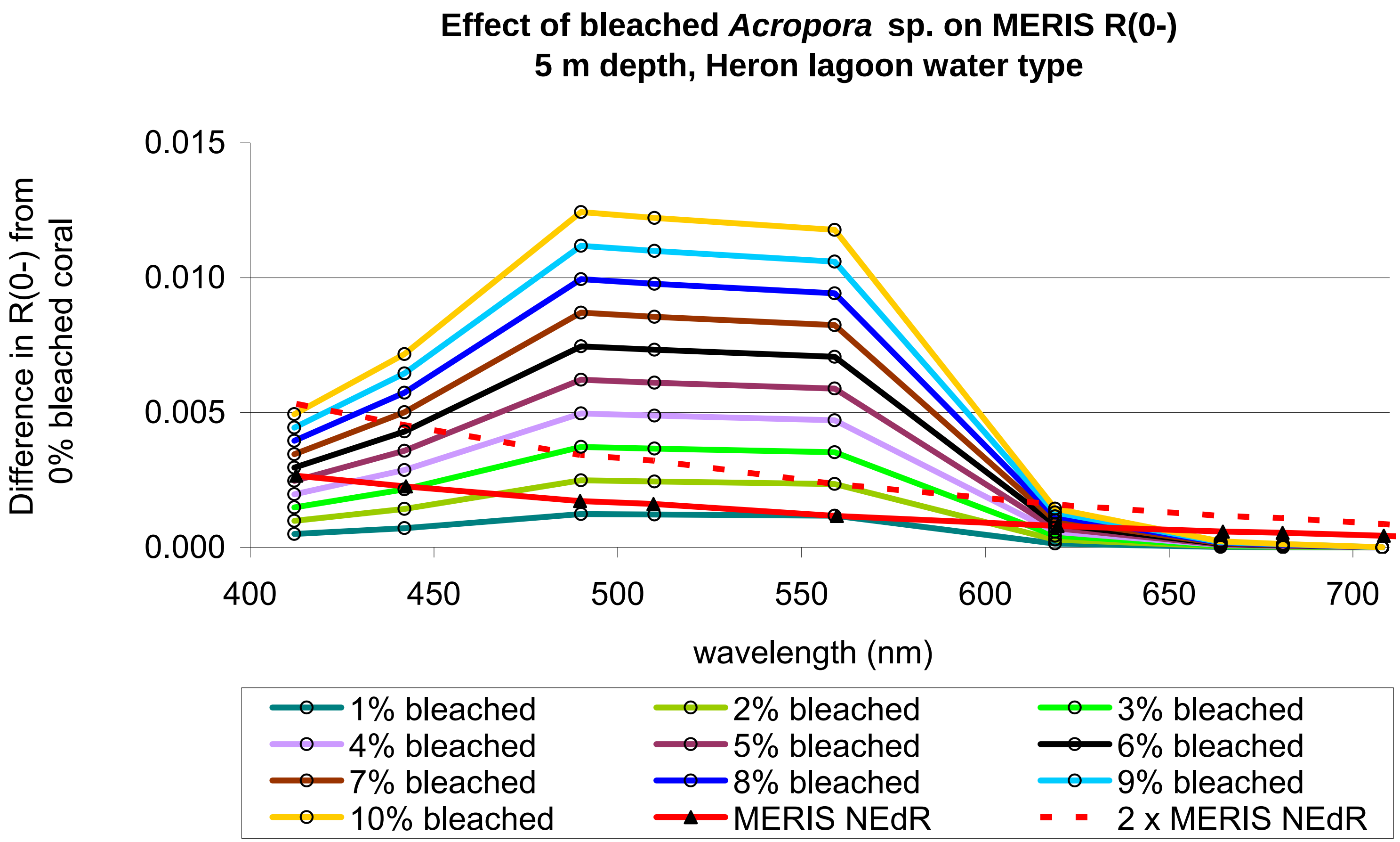


MERIS NedR based on: Wettle, M., Brando, V. E., Dekker, A.G. (2004)
A methodology for retrieval of environmental noise equivalent spectra applied to four Hyperion scenes of the same tropical coral reef. Rem. Sens. Environm. (93): p 188 – 197

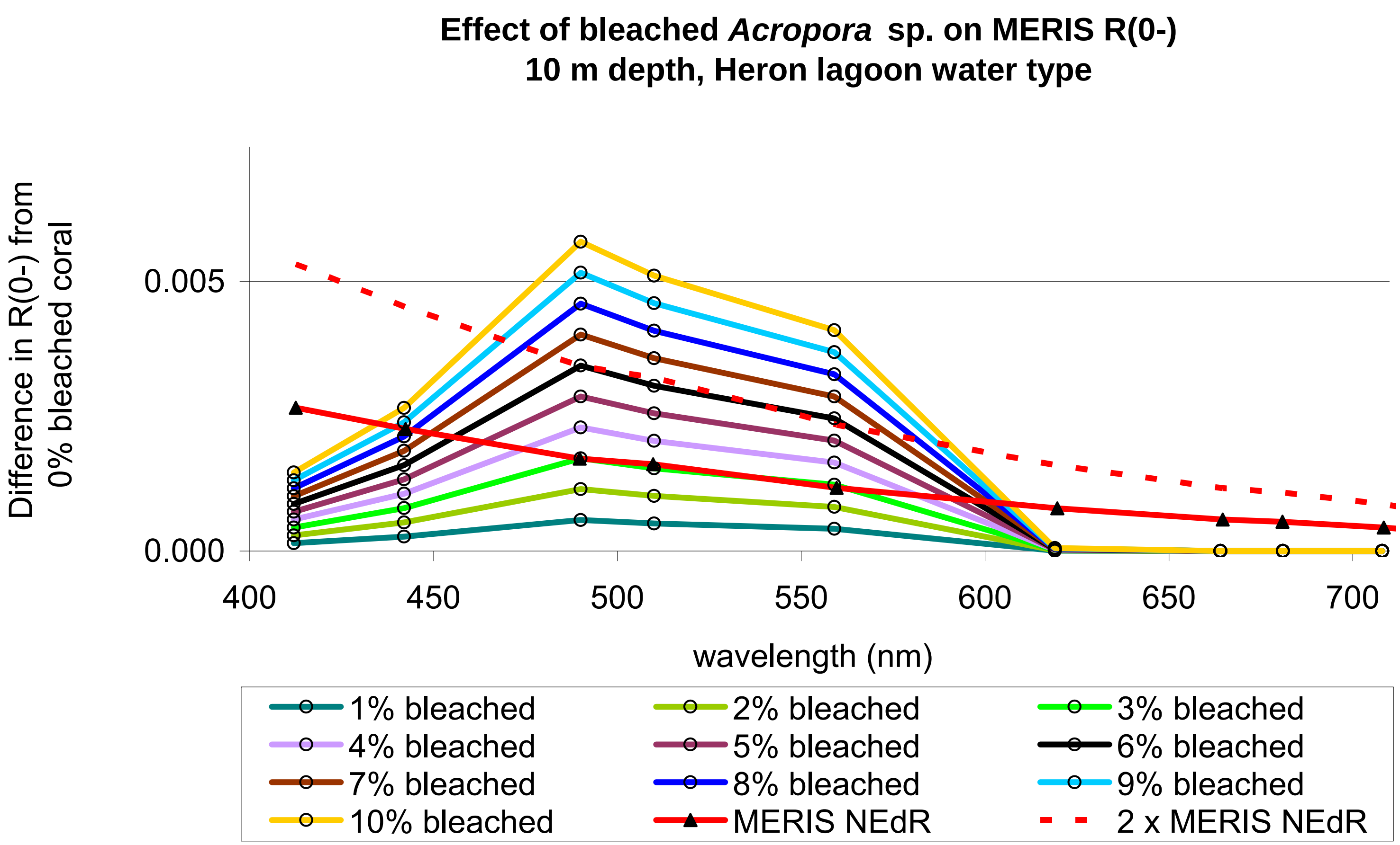
•Coral bleaching detection sensitivity analysis



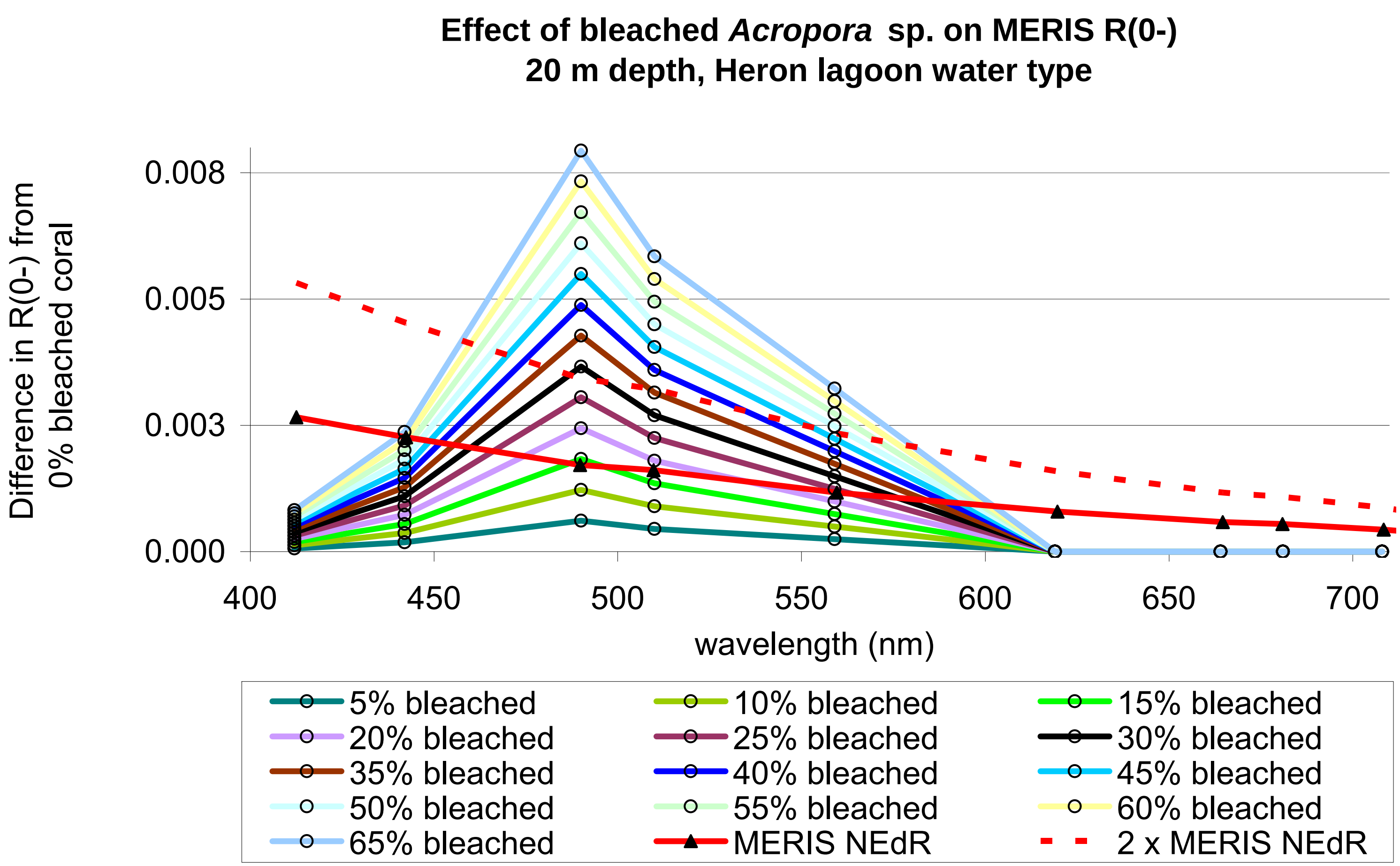
•Coral bleaching detection sensitivity analysis



•Coral bleaching detection sensitivity analysis



•Coral bleaching detection sensitivity analysis

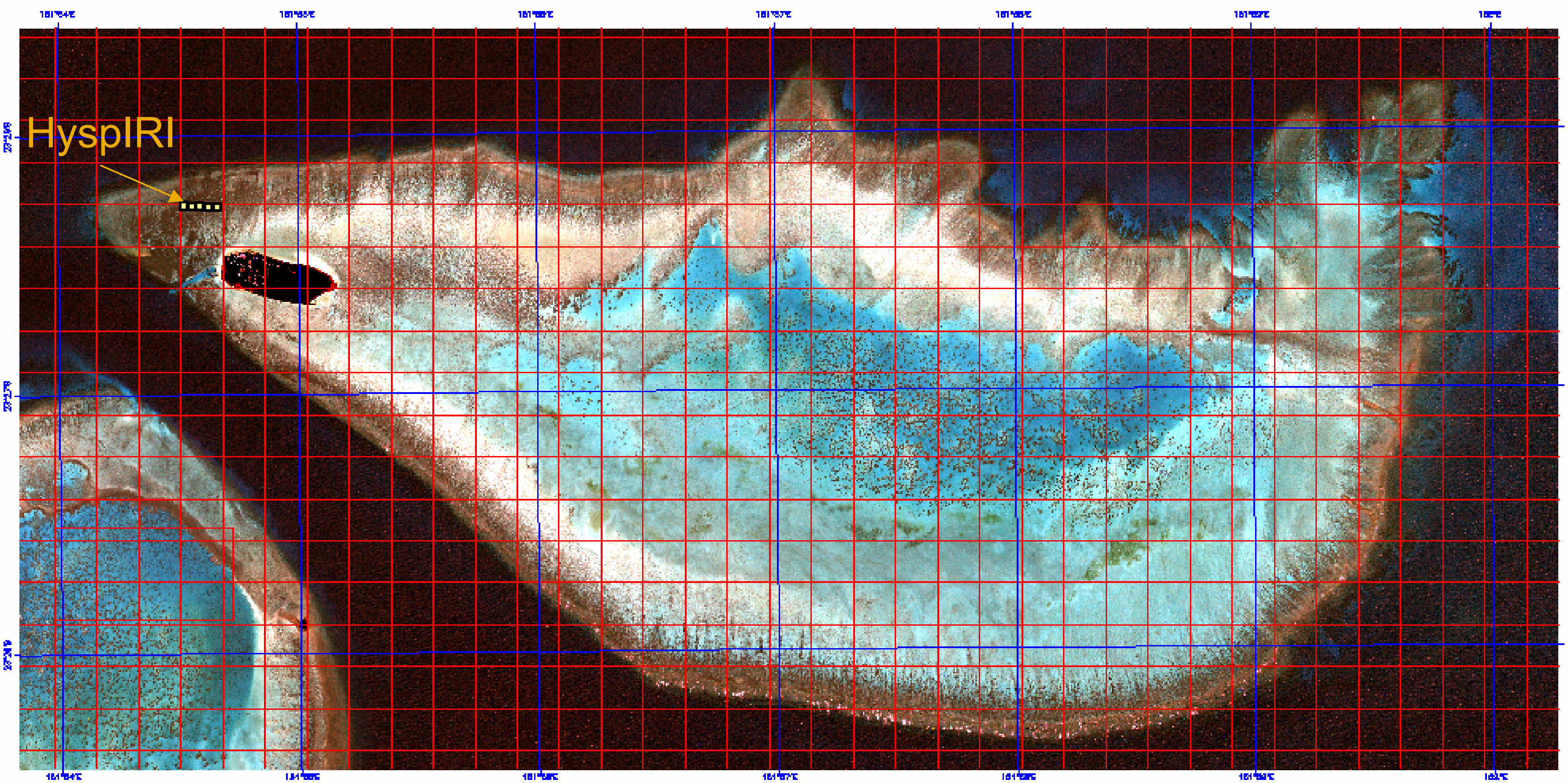


•Coral bleaching detection sensitivity analysis: summary

depth (m)	minimum bleaching measurable (%)	total bleached surface needed within a 300 x 300 m pixel (m x m)	Number of bands available
1 m	2 %	≈ 40 x 40 m	6
2 m	2 %	≈ 40 x 40 m	4
3 m	3 %	≈ 50 x 50 m	3
4 m	3 %	≈ 50 x 50 m	3
5 m	4 %	≈ 60 x 60 m	3
10 m	7 %	≈ 80 x 80 m	3
15 m	20 %	≈ 134 x 134 m	3
20 m	50 %	≈ 210 x 210 m	3

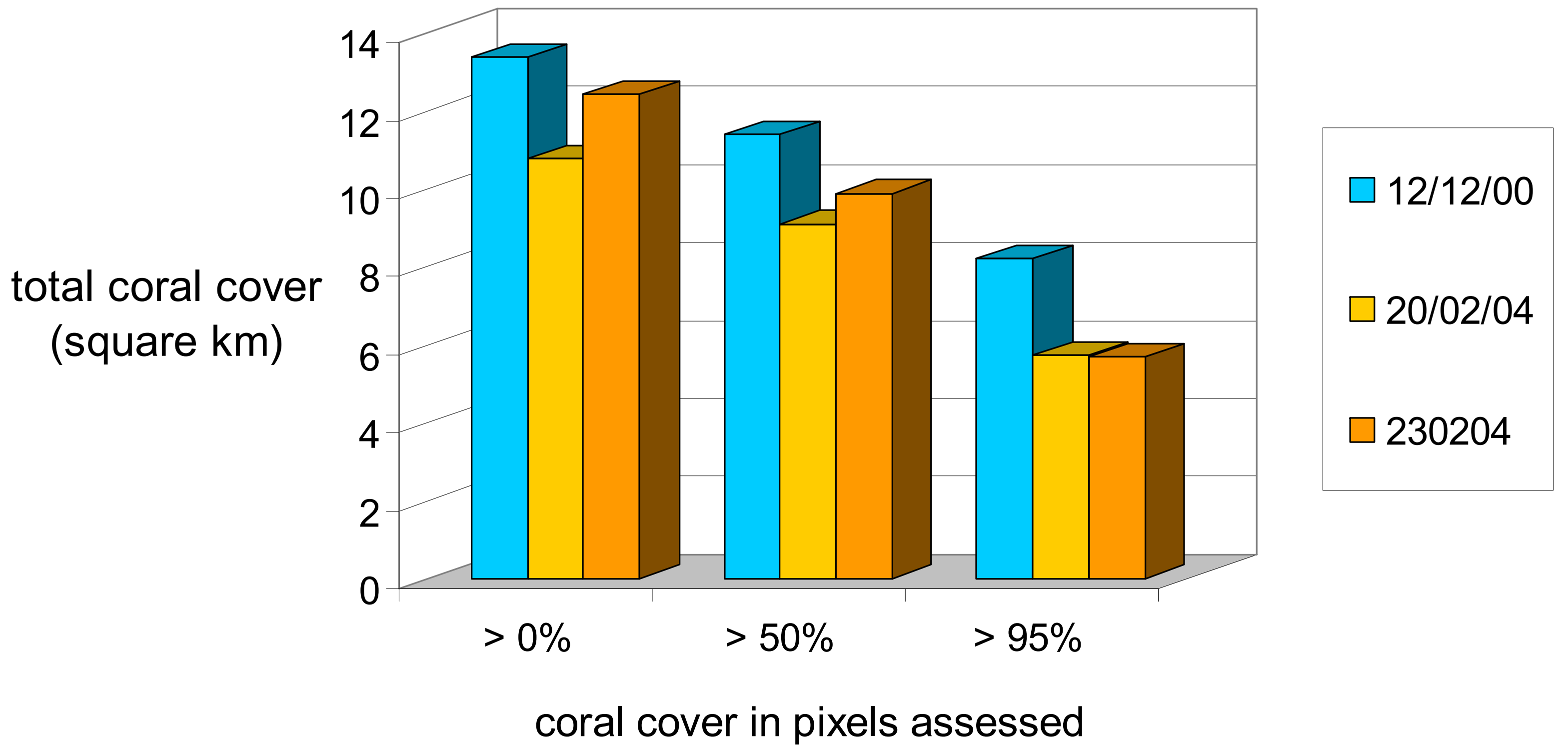
- e.g. at 5 m depth, a 4% bleached area is detectable in3 MERIS bands
- MERIS applicable down to 10m of water column depth?
- MERIS spectral characteristics not a limitation (in theory)
- HyspIRI higher spectral & spatial res. & lower S:N – very suitable!

MERIS pixel size (300 m in red) on IKONOS (4 m) over Heron Reef: HyspIRI 60 m will be excellent for whole of GBR scale



Results: MERIS bleaching detection

Total surface area (km^2) mapped as live coral for pixels with more than 0%, 50% and 95% cover of coral for the three MERIS scenes.



- **From non-bleached image (blue) to two bleached images: decrease in cumulative surface area mapped as containing coral (dark substrate)**
- **MERIS FR can map coarse bleaching over entire GBR: 2500 x 300 km**
- **HyspIRI more suited (probably) due to higher spatial and spectral resol.**

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Quantitative remote sensing for detection and monitoring of cyanobacterial blooms

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Introduction

- Significant benefits to adopt remote sensing of inland and coastal waters:
  - Quantitative & provides spatial and temporal coverage
  - At effectively lower cost than traditional field-based methods

- From 2012 onwards, our ability to map cyanobacterial concentrations from space will take a significant step forward with the new generation of spaceborne imaging spectrometers:
- HyspIRI is the main sensor with a sufficient global coverage frequency to be a prototype operational system for inland and coastal water bodies

Relationships

There is a need to understand the relationship between water-leaving radiances and other biological or optical parameters

Optically Active Components (OACs)
- Phytoplankton
- Suspended matter
- Coloured dissolved organic matter
- Water itself

Conclusion: optical complexity of inland and coastal waters requires a physics based approach (as opposed to an empirical one)

Empirical approaches

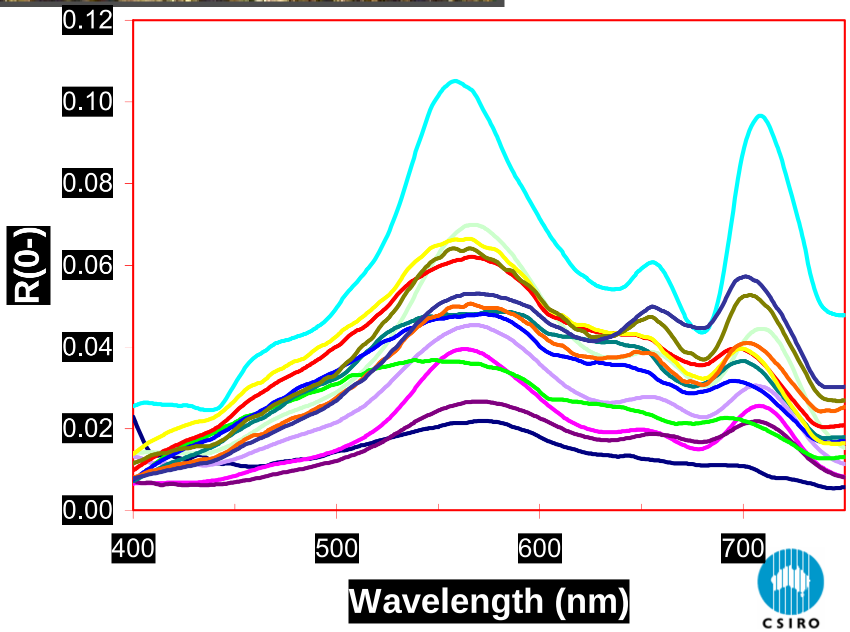
(Semi) analytical approaches

Inherent optical properties
- Beam attenuation (*c*)
- Absorption (*a*)
- Scattering (*b*)
- Volume Scattering [$\beta(0)$]

$$c = a + b$$

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

Colour of cyanobacterial dominated waters in Australia



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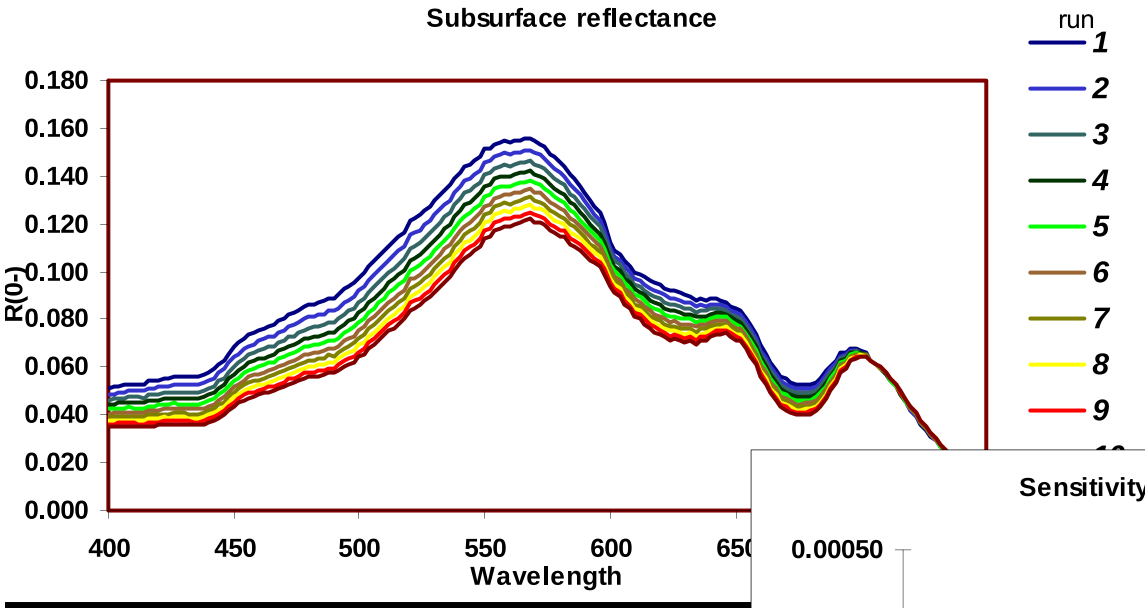
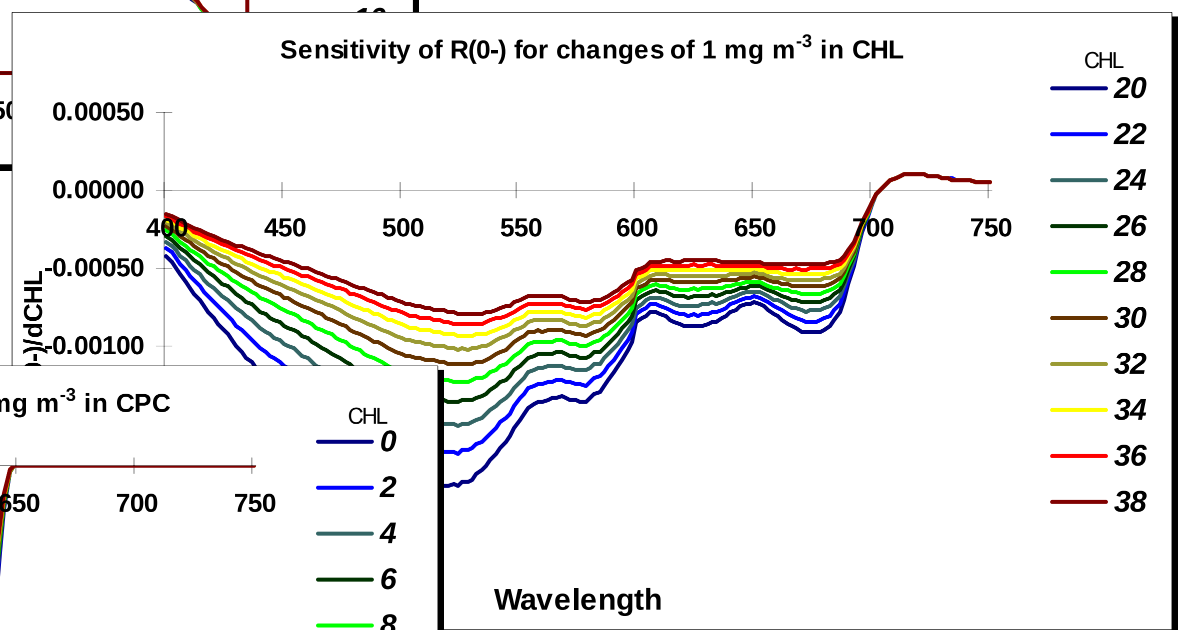
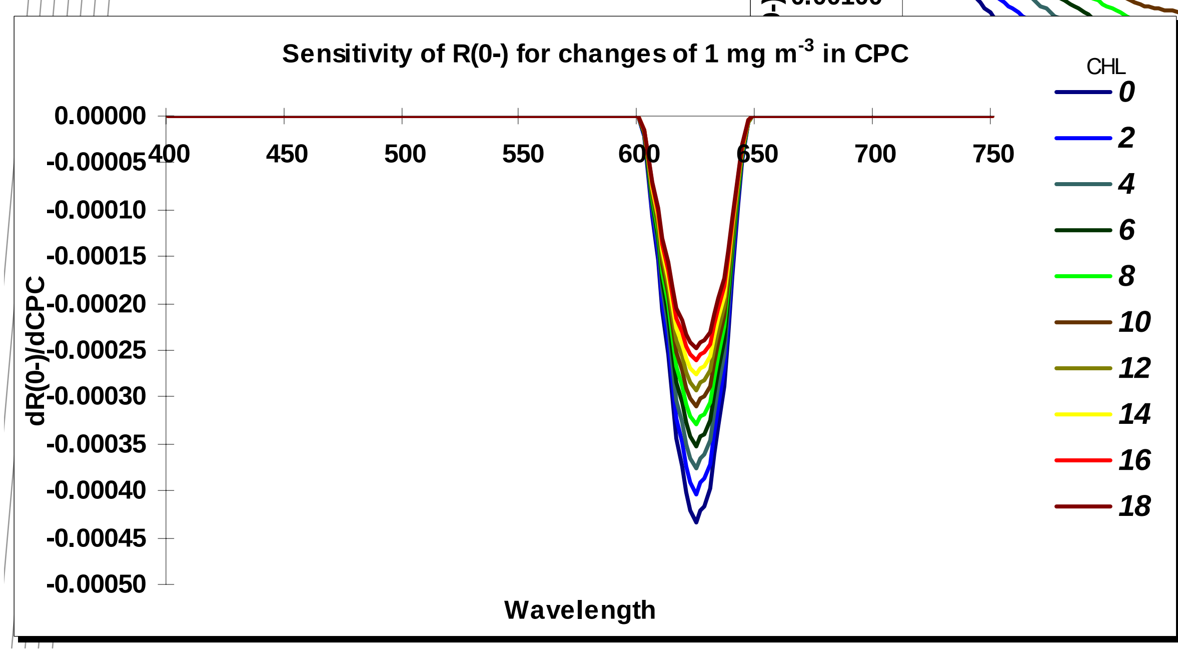
Shallow Lake Simulation

Chl 20 - 30 mg m^{-3}

CPC 0 - 20 mg m^{-3}







Needs imaging spectrometry

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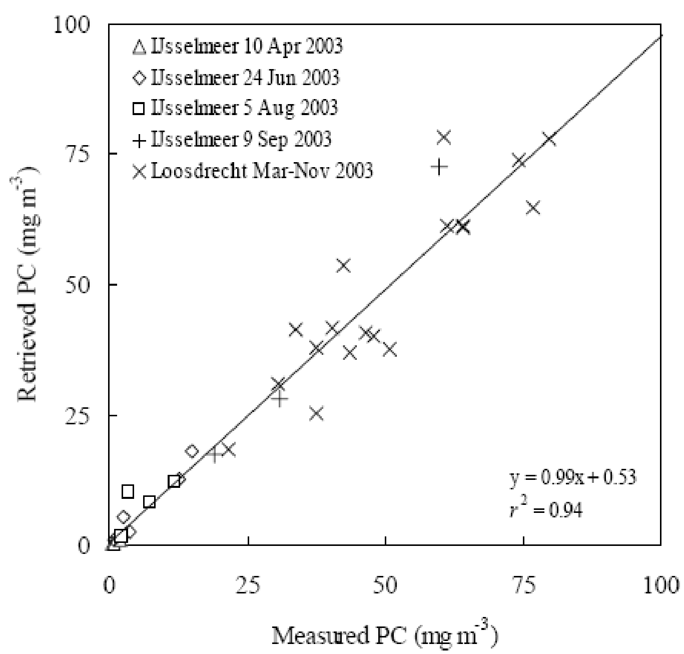
Some Semi-Analytical Algorithms with validation- requires 10 nm spectral bands in the 620 to 710 area

- Dekker (1992,1993,1997) -Casi sensor

$$PC = -28.1 + 15904\left(0.5\left(R_{600} + R_{648}\right) - R_{630}\right),\ R^2 = 0.99$$

- Jupp et al. (1994) -Casi sensor
- Simis et al. (2005) -based on field reflectance data

$$a_{pc}(620) = \left[\frac{R(709)\times\left(a_w(709)+b_b\right)}{R(620)} - b_b - a_w(620)\right]\times\delta^{-1} - \left[\varepsilon\times a_{chl}(665)\right]$$



Implications

- Requires *high spectral resolution* sensors
- Requires *sufficient spatial resolution* to map lakes & large rivers & lagoons
- Requires *sufficient temporal resolution*
- The challenge is robustness of the algorithms under varying:
  - (In)organic matter concentrations
  - CDOM concentrations
  - other phytoplankton functional types
- Provides only a surface view (90% of signal from 1/Kd depth), but overcomes the limitations in ship-board sampling of near surface concentrations (see “Influence of the vertical distribution of cyanobacteria in the water column on the remote sensing signal by T. Kutser, et al., Estuarine, Coastal and Shelf Science 78 (2008) 649-654)

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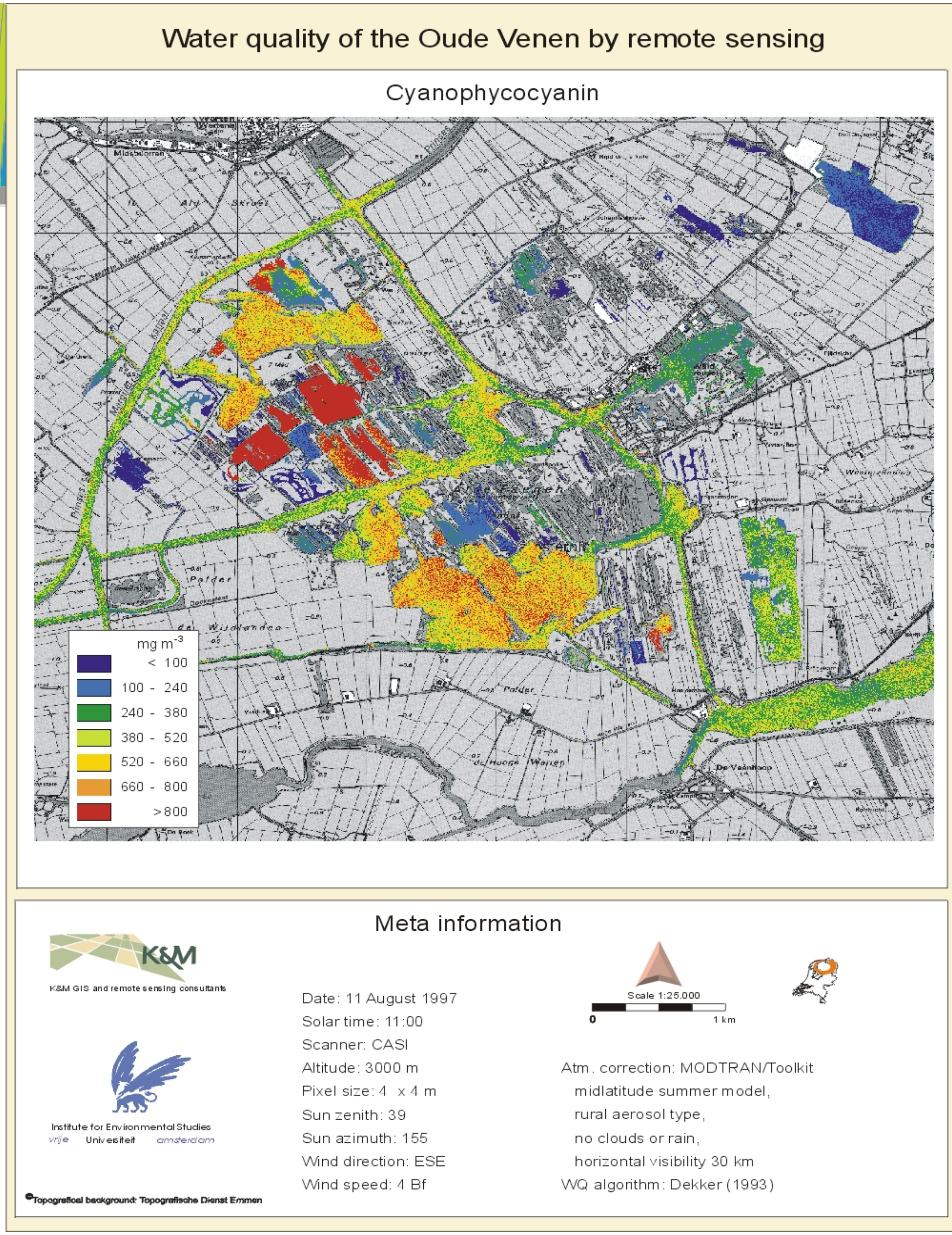

CASI Airborne imaging spectrometry derived cyanophycocyanin image over Dutch lakes indicating concentration of potentially toxic cyanobacteria

Dekker et al. (1997)

Lakes area = 24 km²

HyspIRI @ 60 m =6600 pixels

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Conclusions and Discussion Points

- HyspIRI will enable quantitative estimation of Chlorophyll, Cyanobacterial pigments, CDOM, Suspended matter, $k_{d,}$ Secchi Transparency and Turbidity from Inland to Coastal Waters (optically deep systems)
- In optically shallow systems HyspIRI will allow accurate bathymetry, substratum (groups & communities) & water column composition assessment as well as coral bleaching and other substratum change detection
- Sun Glint vs S:N trade-off (pointing, earlier orbit) : needs proper modelling effort vs variable retrieval specifications: Glint avoidance has preference. BUT: high latitudes applications e.g. Baltic Sea will be affected;
- Modelling effort needs international effort of groups that have complete (in situ, lab and image) data sets covering wide range of habitats
- Requires *a priori* physics-based image preprocessing and processing techniques (analytical forward-inverse approach) augmented subsequently by other image processing methods

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Thank you