An introduction to marine optics and ocean colour products/algorithms

Dr Samantha Lavender

SEOES & Marine Institute,
University of Plymouth

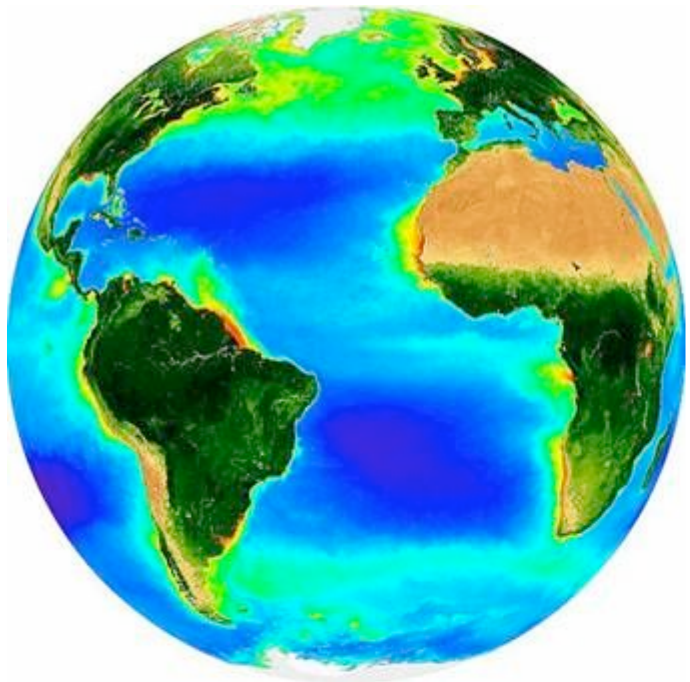
ARGANS Limited
Tamar Science Park, Plymouth

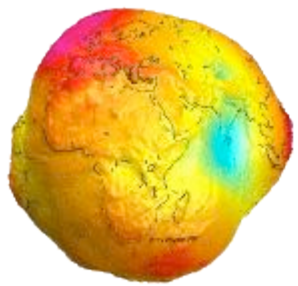
s.lavender@plymouth.ac.uk
samantha.lavender@argans.co.uk
http://www.research.plymouth.ac.uk/geomatics/

ESA Observation Summer School (4-14 August 2008)

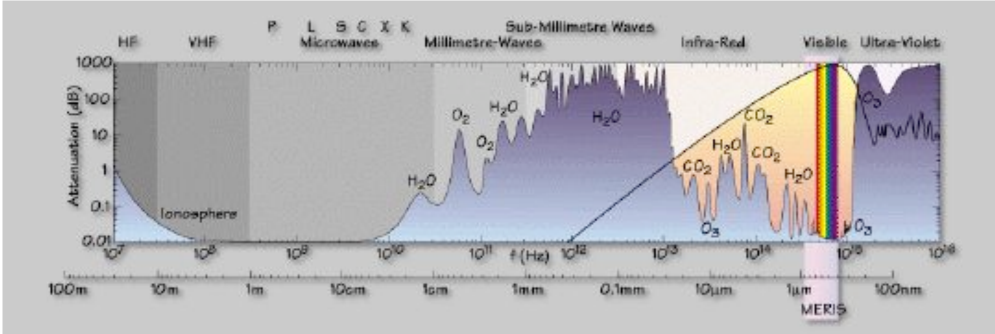
Satellites can be used to measure:

- sea surface temperature
- optical properties (ocean colour)
- sea surface roughness
- height of the sea surface and waves
- salinity
- gravity
- ……

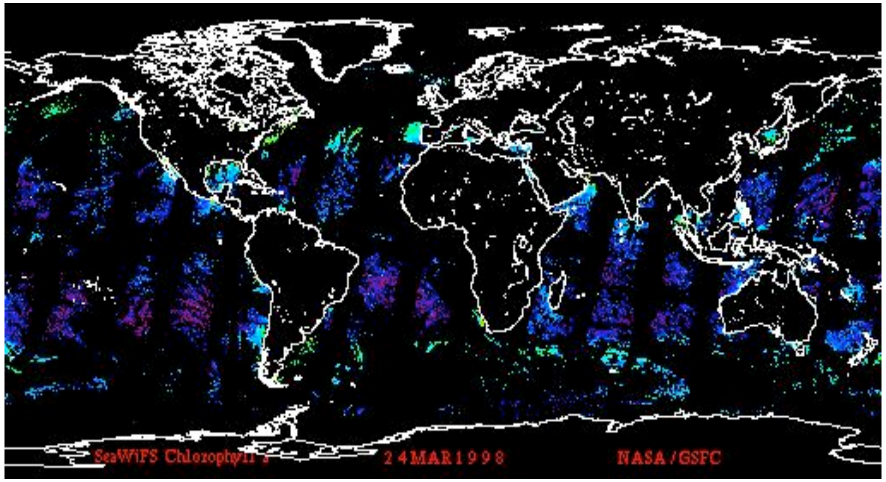


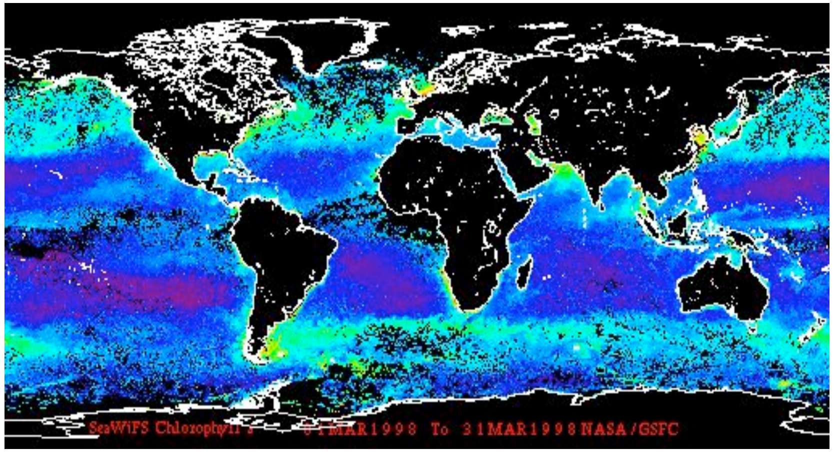


Ocean colour is the spectral variation of water-leaving radiance, L_w, that can be related to the concentrations of optically active materials e.g. phytoplankton pigments.



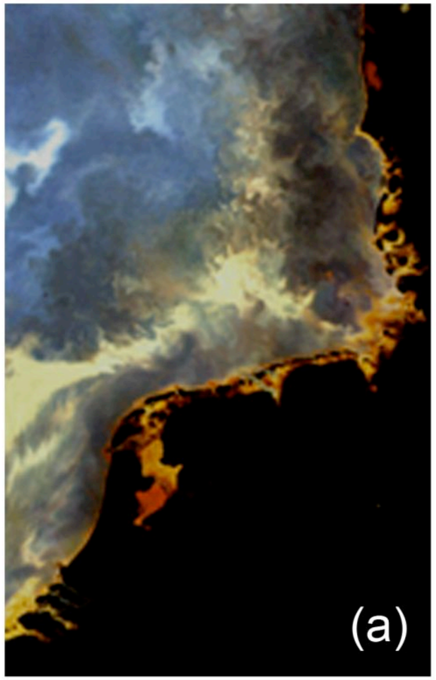
The satellites orbit the earth several times a day, and by combining the strips from several days we can start to fill in the gaps caused by clouds.

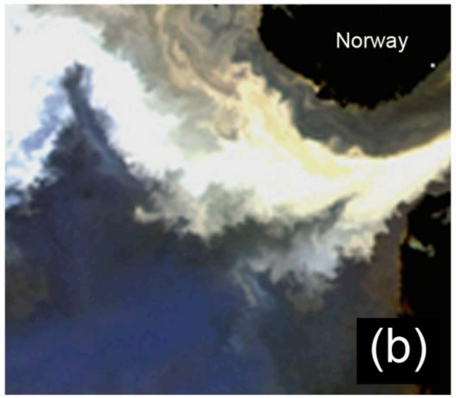




The First Satellite Ocean Colour Sensor

The first truly marine sensor was launched in October 1978 on the Nimbus-7 satellite. The Coastal Zone Color Scanner (CZCS) had several objectives, such as defining requirements for future ocean monitoring instruments, but was only a research and development sensor. The next marine sensor was not launched until 1996.….

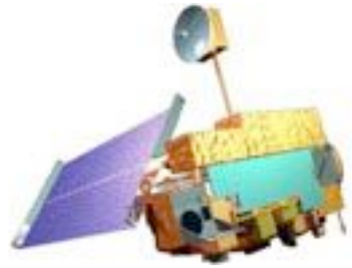




Handbook of Remote Sensing (In Press), Chapter 27 Figure 1.

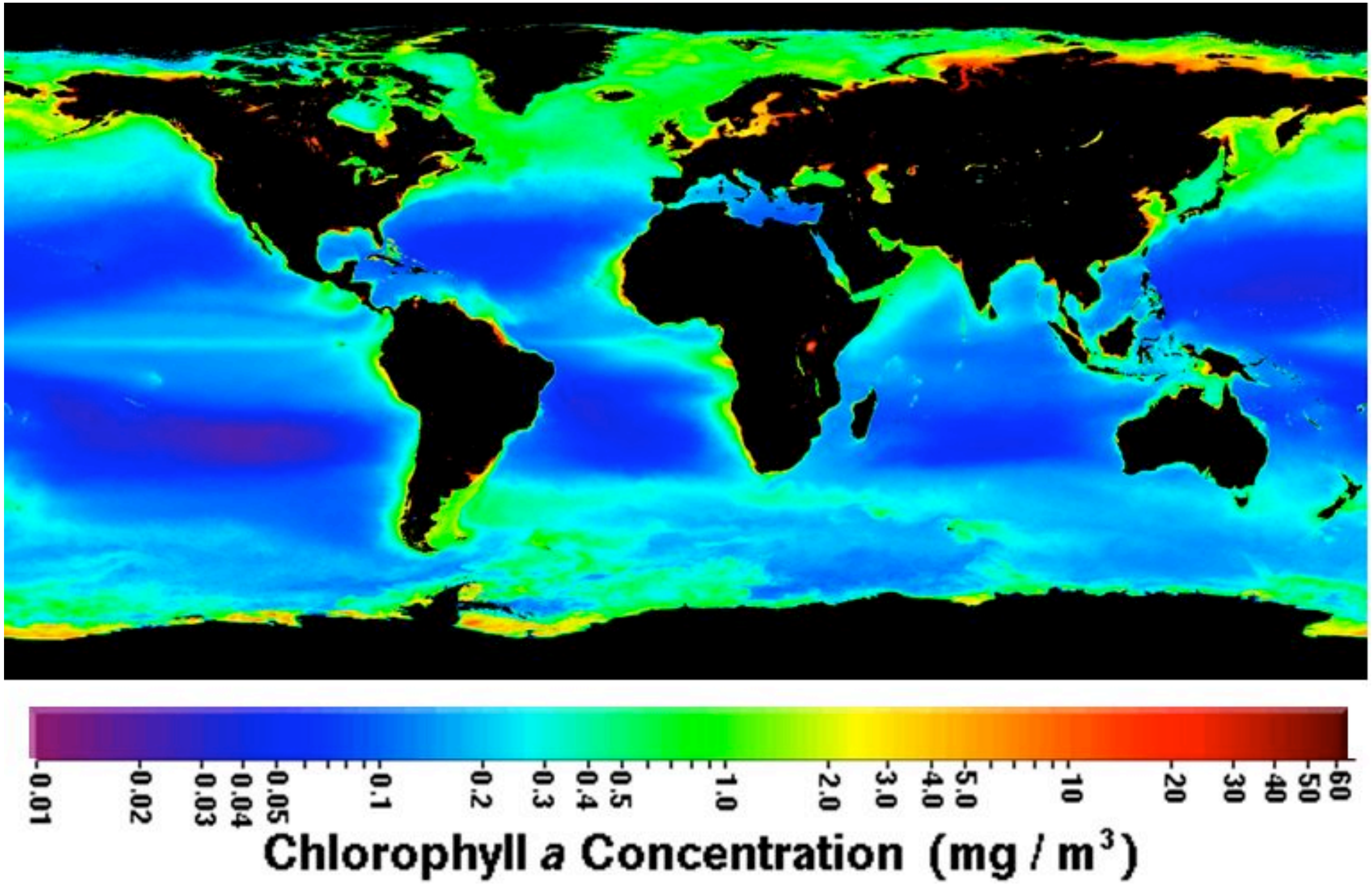
What global data is available today? via NASA

• Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was launched in August 1997 and provides daily imagery globally. Spatial resolution of 1km (now primarily only commercially available) and 4km. There have been large data gaps in 2008.



• Moderate Resolution Imaging Spectrometer (MODIS) was launched on the Terra platform in December 1999 and Aqua platform in May 2002. Spatial resolutions of 250m (UV wavebands), 500m (visible waveband in the red) & 1km (ocean colour wavebands). Has standard ocean colour products as well as and atmosphere products.

SeaWiFS climatological images



Courtesy of GeoEYE, the NASA SeaWiFS Project (Code 970.2) and Ocean Biology Processing Group.

What global data is available today? via ESA

Medium Resolution Imaging Spectrometer (MERIS) launched on the ENVISAT platform (carrying 9 instruments) in March 2002.

- Primary scientific goal is ocean colour, but can also be used for determining atmospheric and land surface information.
- Spatial resolutions of 1km and 300m.
- Other instruments include AATSR (thermal) and ASAR.

MERIS (Courtesy of ESA)

Placing Ocean Colour Wavebands in the Electromagnetic Spectrum

Below 400 nm a combination of different factors make it increasing difficult: increasing ozone absorption, Rayleigh scattering in the atmosphere and a drop in the charge coupled device (CCD) performance.

Beyond 700 nm the water absorption becomes a significant factor. So without strongly scattering particulates, present in high suspended particulate matter concentrations, we get very little water-leaving radiance.

The strong atmospheric absorption bands should also be avoided and the sensor needs to have specific wavebands to separate the in-water constituents.

Passive Optical Imagery: Number of Wavebands

Panchromatic: measures energy in one wide portion of the electromagnetic spectrum. It usually spans the visible to near-infrared regions and is represented as black-and-white imagery.

Multispectral: measures reflectance in many bands. The different bands can be combined to create colour images. It can also include separate detector arrays measuring different parts of the spectrum.

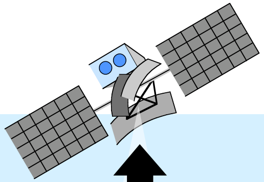
Hyperspectral: measures reflectance in many individual bands, often hundreds that are only a few nanometers wide. The theory is that narrow bands will detect narrow features such as chlorophyll fluorescence.

Ocean Colour Sensor Characteristics

Sensor	Spatial Resolution at Nadir (km)	Ocean Colour Wavebands (nm)
CZCS	0.825	430-450, 510 -530, 540 -560, 660 -680 and 700 -800
OCTS	0.700	402-422, 433 -453, 480 -500, 510 -530, 555 -575, 655 -675, 745 - 785 and 845 -885
SeaWiFS	1.130	402-422, 433 -453, 480 -500, 500 -520, 545 -565, 660 -680, 745 - 785 and 845 -885
MODIS	1.000	405-420, 438 -448, 483 -493, 526 -536, 546 -556, 662 -672, 673 - 683, 743-753 and 862 -877
MERIS	1.20/0.300	407.5 -417.5, 437.5 -447.7, 485 -495, 505 -515, 555 -565, 615 - 625, 660 -670, 677.5 -685, 700 -710, 750.0 -707.5, 758.75 - 761.25, 770 -780, 855 -875, 885 -895 and 895 -905

Spatial resolution and waveband characteristics of selected global ocean colour sensors; data taken from IOCCG Report 1 (1998)

Summary of processing



Satellite (TOA ~7/800km)

L_{toa}

(Spectral domain = 400 - 900nm)

E_d

L_w

Method

Atmospheric correction:

$L_{toa} \Rightarrow L_w$

Remote sensing reflectance: $R_{rs} = L_w / E_d$ [sr^{-1}]

Quantification:

$R_{rs} \Rightarrow$ water constituents concentrations

Pixel size: 350 to 1000m

Coverage: daily / weekly / yearly

Water constituents:

- *Suspended Particulate Matter (SPM)*
- *Coloured dissolved organic material (CDOM)*
- *Phytoplankton (Chlorophyll, Chl)*

Atmospheric Correction, Simplified Main Equation

The main equation can be written as a sum of the contributions:

$$L_{toa}(\lambda) = L_p(\lambda) + L_{sky-g}(\lambda) + L_{sun-g}(\lambda) + L_{ws}(\lambda)$$

λ - wavelength,

$L_p(\lambda)$ - path radiance generated by scattering in the atmosphere – Rayleigh & aerosols,

$L_{sky-g}(\lambda)$ - sky-glitter radiance originating from the specular reflection of atmospherically scattered light (skylight) by the sea surface,

$L_{sun-g}(\lambda)$ - sun-glitter radiance originating from the specular reflection of direct sunlight from the sea surface,

$L_{ws}(\lambda)$ - water-leaving radiance entering the sensor.

Atmospheric Correction of CHRIS-PROBA

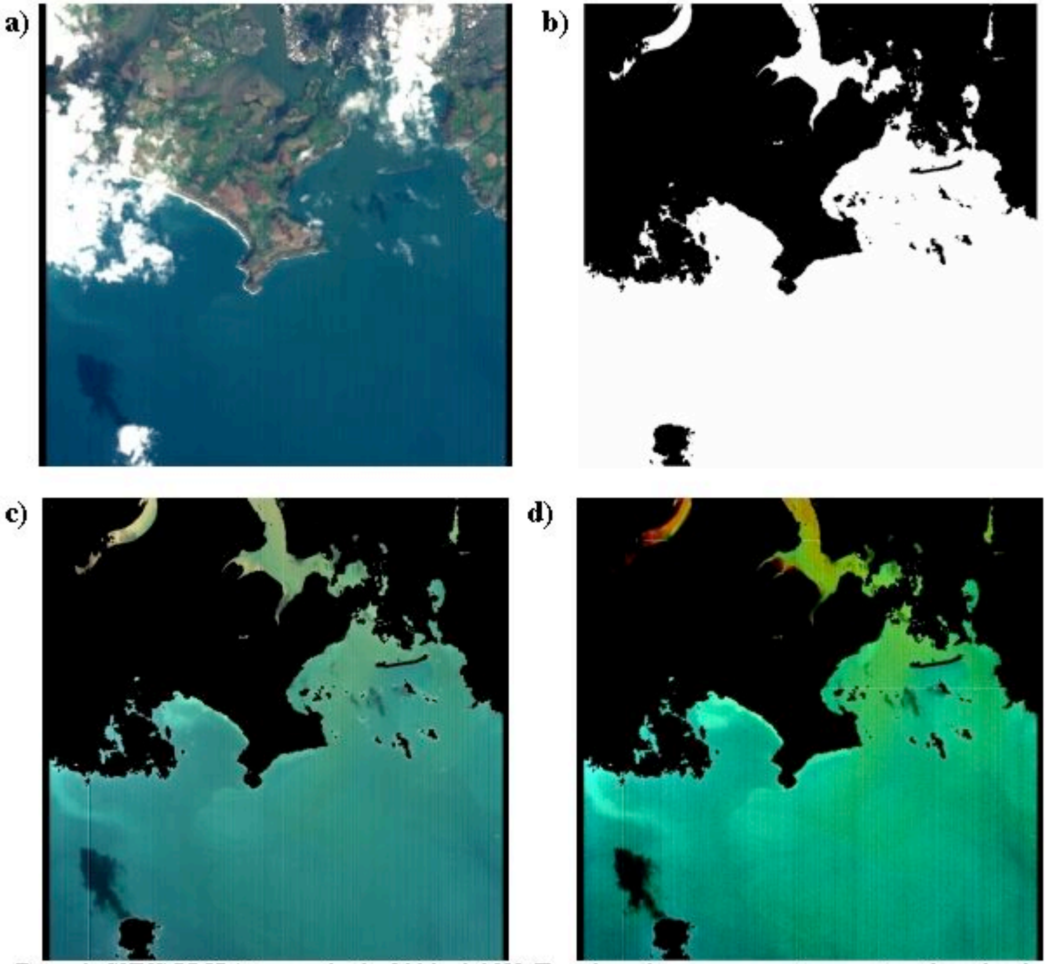
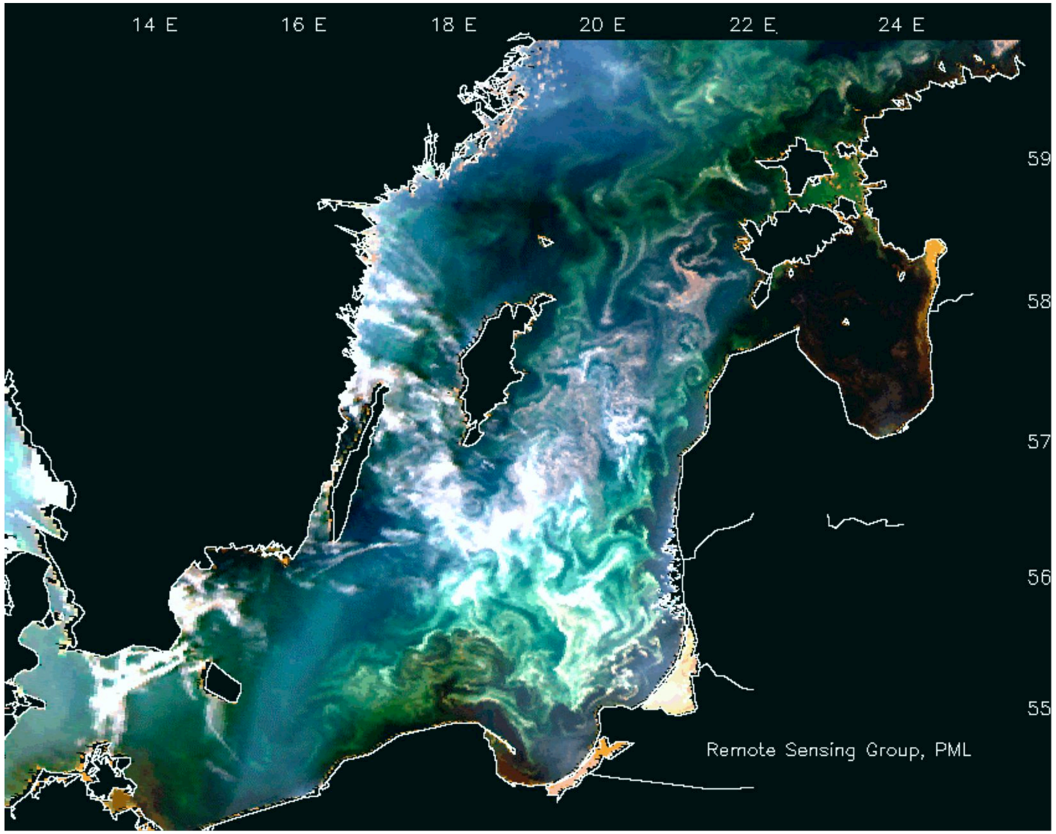


Figure 2. CHRIS-PROBA imagery for the 06 March 2003. The coloured images represent composites of wavebands 11, 6 and 3 as red, green and blue. The images are (a) uncorrected image, (b) non-water mask, (c) Rayleigh corrected image and (d) aerosol corrected image.

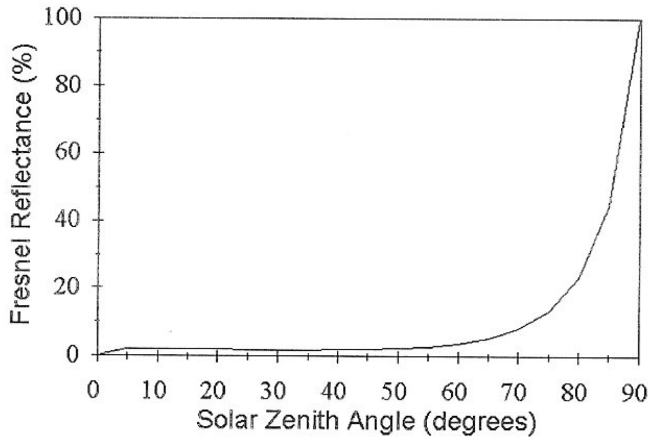
Lavender et al. (2005) RSPSoc 2004: Mapping and Resource Management, Aberdeen.

SeaWiFS Rayleigh corrected colour composite (the 670, 510 and 412 nm bands as red, green and blue) for 01 August 1999 showing *cynobacteria* in the eastern Baltic.



Lavender & Groom (2000)

Transmission across the sea surface

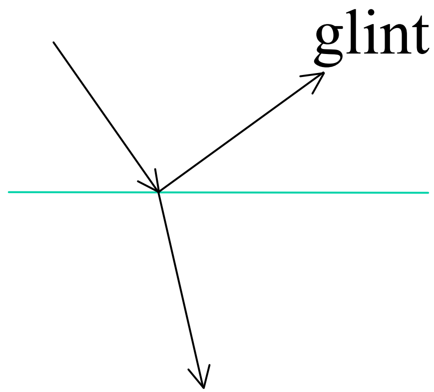


- refraction ... Snell's Law

$$\frac{\sin\theta}{\sin\theta_r} = \frac{1}{n_w} = 1.33$$

- partial reflection, partial transmission

The relative proportions of the transmitted and reflected parts vary according to the Fresnel equation i.e. the viewing geometry:



$$\rho(\theta) = 0.5\left(\frac{\sin^2(\theta - \theta_r)}{\sin^2(\theta + \theta_r)}\right) + 0.5\left(\frac{\tan^2(\theta - \theta_r)}{\tan^2(\theta + \theta_r)}\right)$$

where $\rho(\theta)$ is the Fresnel reflectance (fraction reflected)

If the sea surface interface is assumed to be:

• Lambertian i.e. the backscattered radiation only carries the properties of the material with which it last interacted and is not effected by the angle of the incident radiation.
• specular i.e. smooth with respect to wavelength.

The relationship between the sub-surface and above-surface reflectances can be paramaterised as:

$$R_{rs}(\lambda) \approx f/Q \cdot R_{-0}(\lambda)$$

For Case II waters (Lavender, 1996): $R_{rs}(\lambda) \approx \frac{0.529 \cdot R_{-0}(\lambda)}{(1 - 2.16 \cdot R_{-0}(\lambda))}$

f is an approximation of air–water transmission effects
Q as the underwater irradiance-to-radiance ratio

Approaches to the extraction of water colour parameters.

Empirical: statistical relationships are sought between the measured spectral values and water quality parameters.

Semi-analytical: inherent and apparent optical properties are used to model the reflectance and vice versa. The water constituents are expressed as their specific absorption and backscattering coefficients..

See Morel et al. (2007, Remote Sensing of Environment) for a good review of this.

Development of algorithms (empirical).

• SeaWiFS aims to measure global chlorophyll concentrations to 30% accuracy.

• The SeaWiFS chlorophyll algorithms uses a reflectance ratio (O’Reilly et al. 1998):

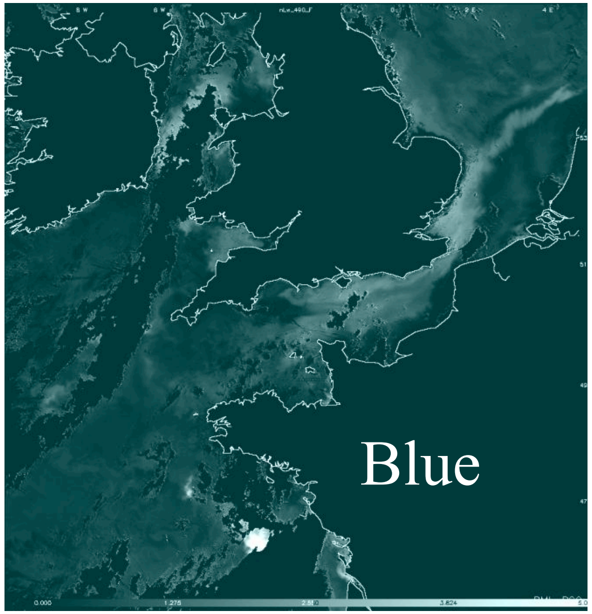
$$\mathrm{chl} = 10^{(0.366\text{-}3.067x + 1.930x^{2} + 0.649x^{3}\ \ 1.532x^{3})}$$

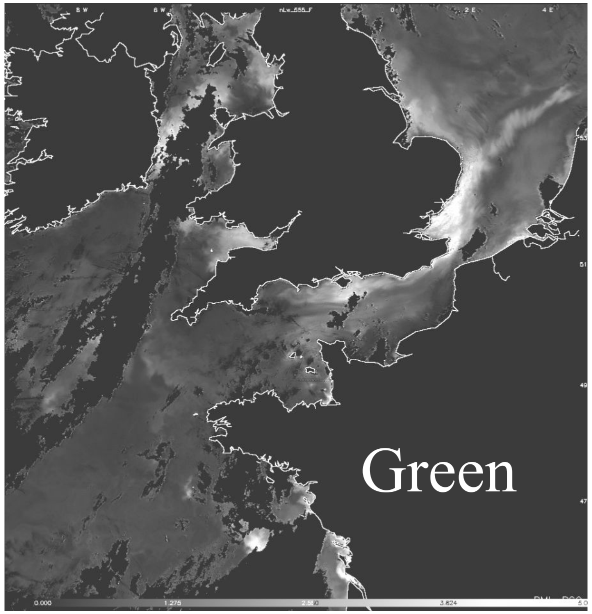
$$x = \log_{10}\left(\left(R_{rs}443 > R_{rs}490 > R_{rs}510\right)/R_{rs}555\right)$$

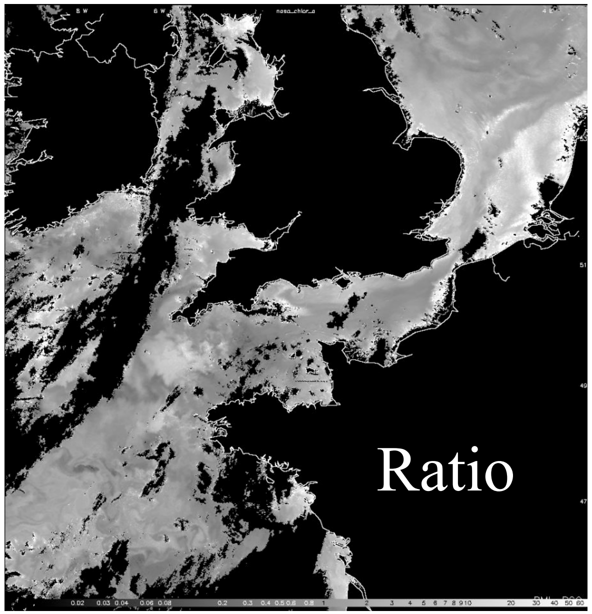
• The main chlorophyll *a* absorption band is 400 - 470 nm, so the algorithm also works because accessory pigments, mostly carotenoids, co-exist and co-vary with chlorophyll *a* over most ocean provinces.

Deriving the concentration of chlorophyll.

As phytoplankton concentration increases the reflectance in the blue decreases and in the green it increases slightly. Thus a ratio of blue to green water reflectance can be used to derive quantitative estimates of pigment concentration.







Inherent Optical Properties & Semi-Analytical Algorithms

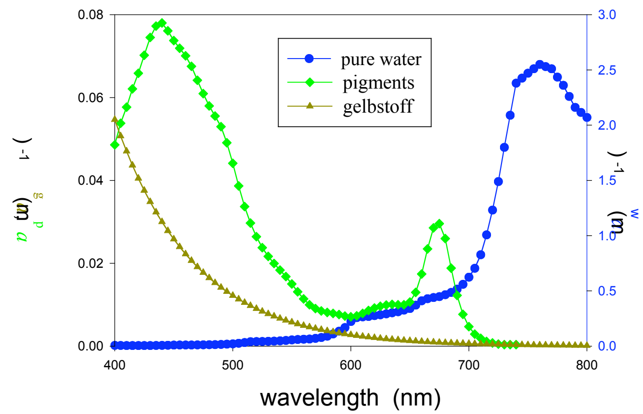
Specific inherent optical properties: attributed to the individual scattering and absorption components e.g. a^*_{CDOM}.

Bulk inherent optical properties: water column is considered as a composite entity with no regard as to specific component contributions e.g.

$$a = a_w + chl \cdot a^*{}_{chl} + CDOM \cdot a^*{}_{CDOM} + SPM \cdot a^*{}_{SPM}$$

$$b_b = b_{bw} + chl \cdot b^*{}_{bchl} + SPM \cdot b^*{}_{bSPM}$$

$$R_{rs} \cong \int \left(\frac{b_b}{a + b_b} \right)$$



The Difficulties in Modelling…

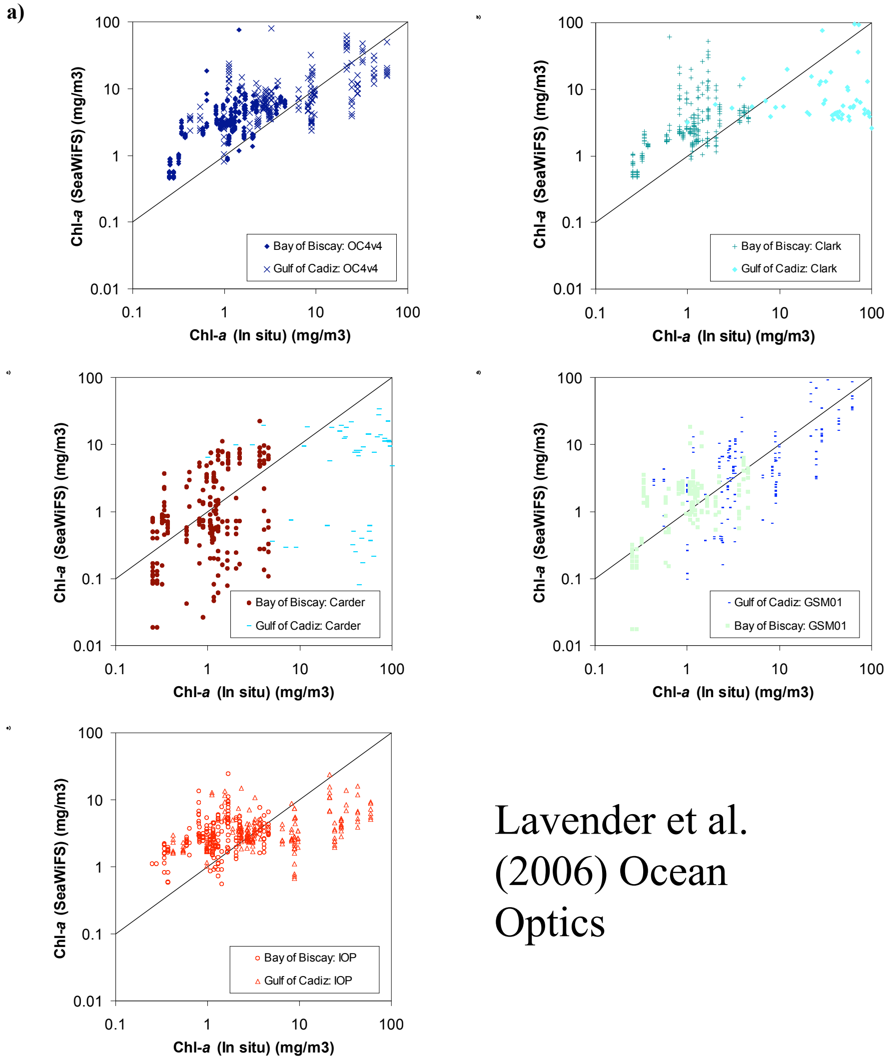


Figure 3: Comparisons of chlorophyll-a estimates from SeaDAS version 5.0 against the Bay of Biscay and Gulf of Cadiz in-situ data for (a) OC4v4 algorithm, (b) Clark algorithm, (c) Carder model, (d) GSM01 model and (e) IOP, epsilon model.

Lavender et al. (2006) Ocean Optics

The difficulty in running an IOP model is that assumptions must be made….

Each model will do this differently and be developed using different *in situ data* (it may be a regional rather than globally designed approach).

See IOCCG Report 5

Challenges for the future….

• Creating a long (multi-sensor) time-series using all the available data – SL2

• Making data available to (EO non-expert) end-users with Quality Assurance (e.g. CEOS QA4EO) – SL2 & SL3

• Improvement of the processing (atmospheric correction, land adjacency affect and algorithms/models) in coastal waters – SL3

• Having the satellites / sensors available to do the research / activities we want:

  • ESA: Sentinel-3 OLCI
  • NASA: Geo-CAPE and HyspIRI
  • NOAA: VIIRS

Suggested information sources

• The IOCCG reports available at http://www.ioccg.org/

• Challenger Society for Marine Science (CSMS) / Remote Sensing and Photogrammetry Society (RSPSoc) Ocean Colour SIG:
http://www.research.plymouth.ac.uk/geomatics/csms_ocolour/

• ESA Cal/Val Portal: http://calvalportal.ceos.org/

• NASA Oceancolor Portal: http://oceancolor.gsfc.nasa.gov/