→ 4th ESA ADVANCED TRAINING ON OCEAN REMOTE SENSING

Principles of Ocean Colour remote sensing

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Funded by Prof. **André Morel** (teaching, research, observation)

Outline

1. **Ocean colour historical background**
2. **Radiative transfer – Modelling**
3. **Ocean colour remote sensing**
   Basic principles
   Sensors
   Calibration and validation
4. **Marine optics & Biogeochemistry**
   - Case 1 & Case 2 waters
   - Apparent & inherent optical properties
5. **Introducing ocean colour algorithms and products**
   - Atmospheric corrections
   - Inversion algorithms
   - Processing software and ocean colour products
6. **Applications**
7. **References**

1. Ocean colour historical background

Poseidon's paintbox: Historical archives of ocean colour in global change perspective, by Dr. Marcel R. Wernand, ISBN: 97890-6464-509-9.

• Describes the gradual understanding of the transparency (clarity) and degrees of coloration of natural waters from H. Hudson (~1600) to C. Raman (1970),

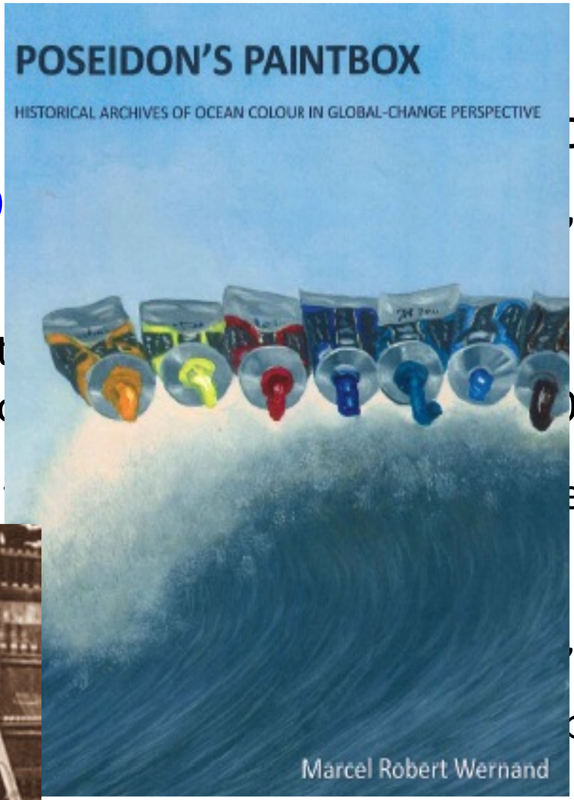
• Highlights reports of explorers and scientists (how is it related to water quality and contents?),

• Explains the development of instruments (Secchi disc, Forel-Ule scale, etc.)

• Relates Raman (1922) discoveries on light (blue) scattering and absorption (long visible wavelengths) by water molecules.

1. Ocean colour historical background

Poseidon's paintbox: Historical ... our in global change perspective, by D... , ISBN: 97890-6464-509-9.



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- Relates Raman (1922)... ption (long visible wavelengths) by


Secchi, Pietro Angelo
Inventor of the Secchi Disk

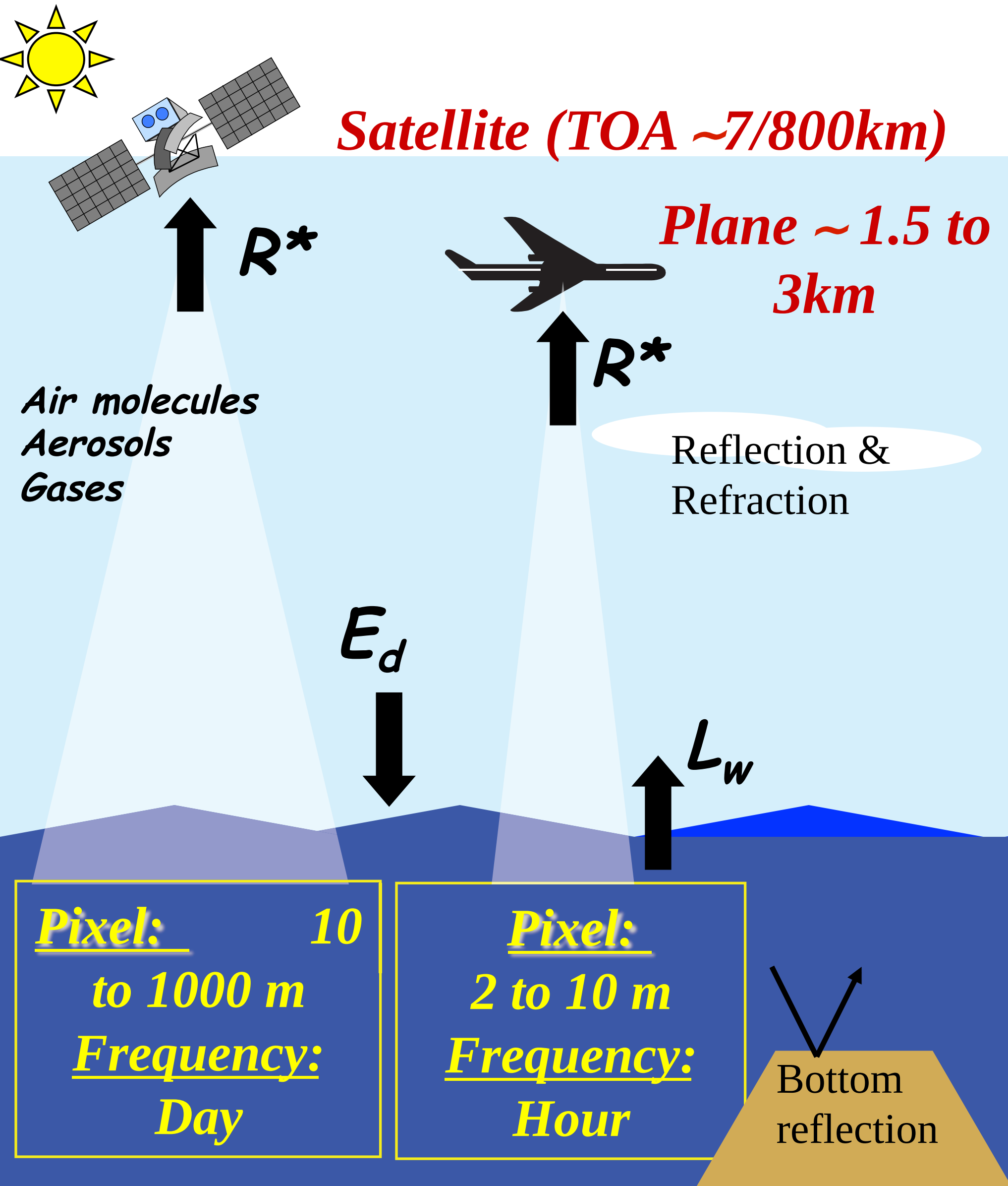
Various colours of natural waters

Water colour = water reflectance

➔ Identification / quantification of the coloured water constituents

= non-algal particles, CDOM, Chla (+ phyto.species)

Overview



Method

- **Atmospheric correction**:

$$R^* \Rightarrow R_{rs}$$

- **Water reflectance**:

$$R_{rs} = L_w / E_d$$

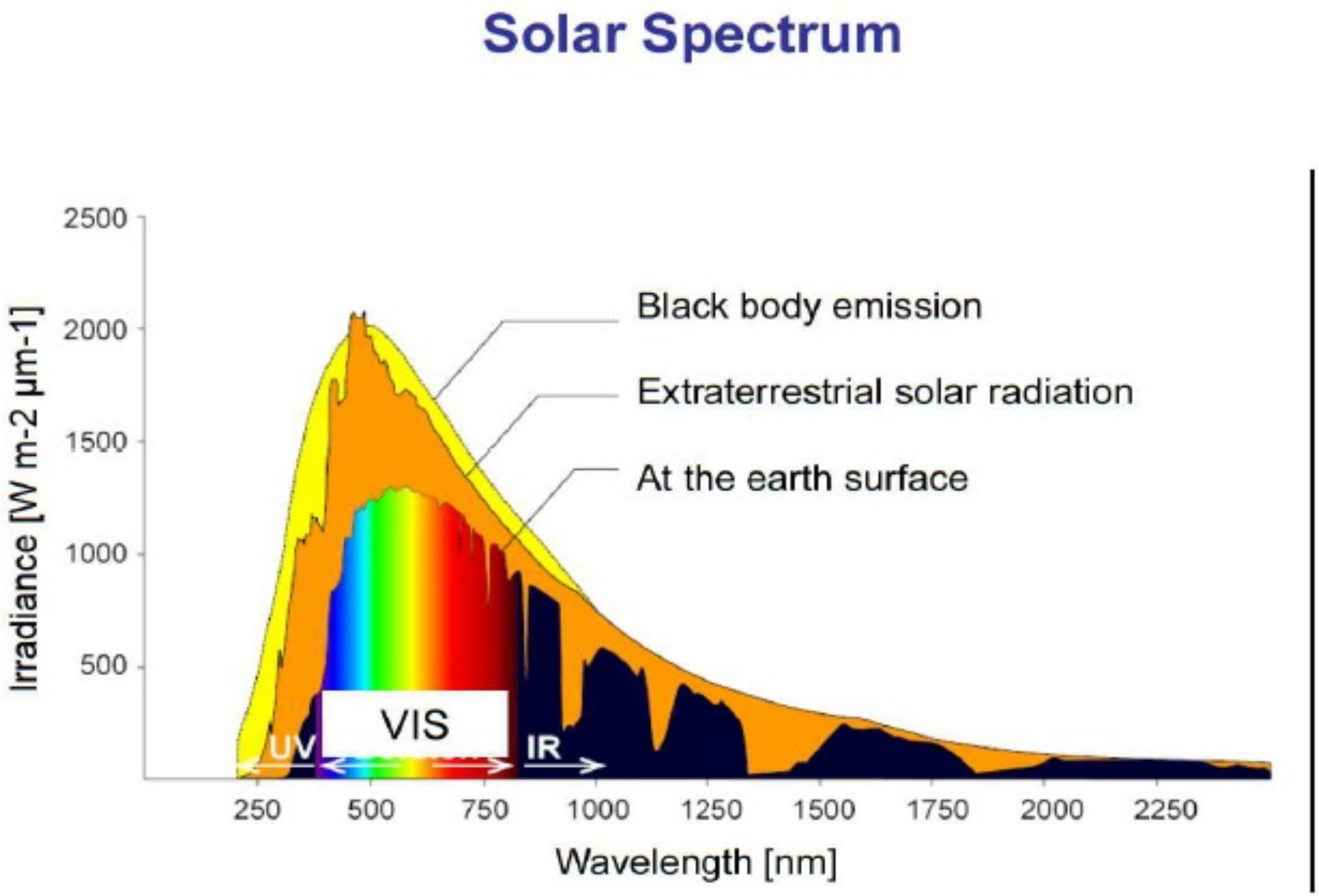
- **Inversion**:

$R_{rs} \Rightarrow$ IOPs // concentrations of water constituents

Coloured water constituants:

- *Phytoplankton (Chla)*
- *Dissolved organic material (CDOM)*
- *Non-algal particles (NAP)*

Solar spectrum



Physical measurement of the « ocean colour » =

Radiance L in W/m²/sr/nm, i.e. the light intensity coming from a specific direction

➔ $R_{rs} = L_w / E_d$, en 1/sr

Derived from ocean colour satellite data

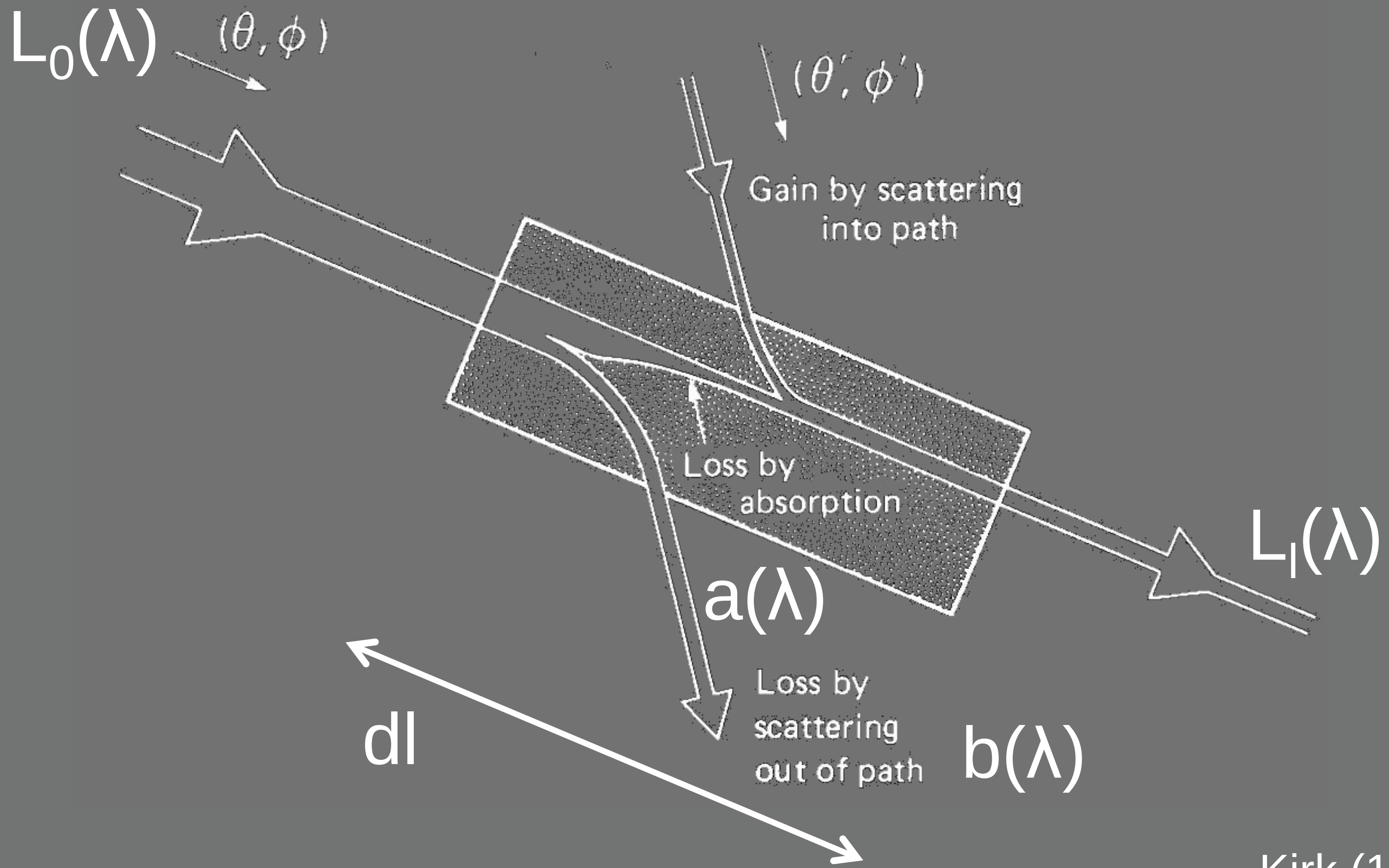
2. Radiative transfer – Modelling

Radiative transfer is the physical phenomenon of energy* transfer in the form of electromagnetic radiation. The propagation of radiation through a medium (atmosphere, natural waters and interfaces) is affected by absorption, emission, and scattering processes. The radiative transfer equation describes these interactions mathematically.

Radiative transfer numerical models compute radiance distributions and derived quantities (irradiances, reflectances, K functions, etc.) within the atmosphere and natural water bodies.

* *Here radiance (in $W.m^{-2}.sr^{-1}.nm^{-1}$), i.e. number of photons at specific wavelength and direction and per unit of solid angle.*

Radiative transfer



Kirk (1983)

Radiative transfer Modelling

Examples of codes:

HydroLight (Mobley 1994) solves the 1D time-independent radiative transfer equation to compute the radiance distribution within and leaving any plane-parallel water body. The spectral radiance distribution is computed as a function of depth, direction, and wavelength within the water.

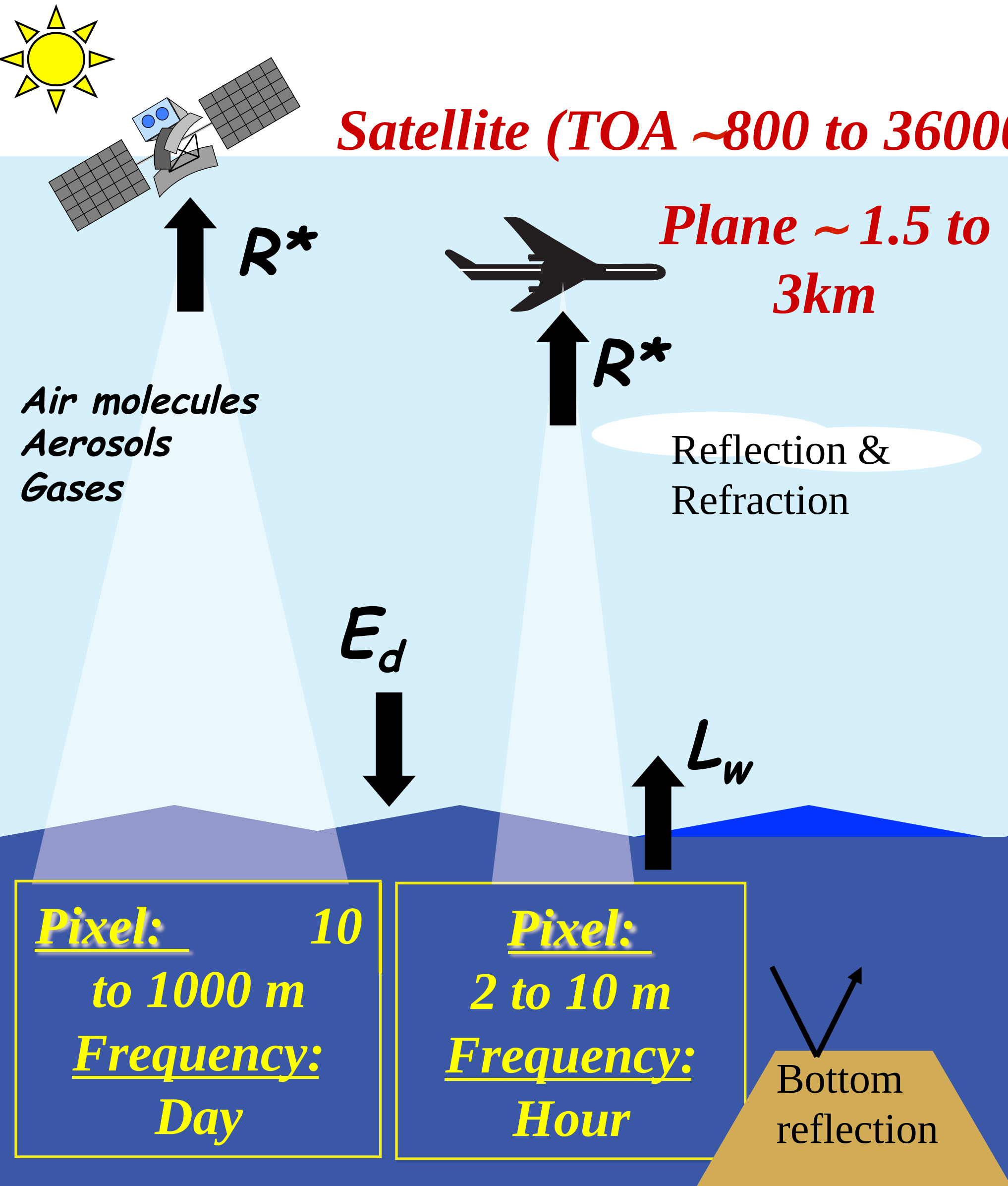
6S (Vermote et al. 1997)) and **MODTRAN** (Acharya et al. 1999) codes solve the radiative transfer equation including the effects of molecular and particulate absorption/emission and scattering, surface reflections and emission, solar/lunar illumination, and spherical refraction.

Also:

Monte Carlo simulations have been widely used to solve and understand marine optics and ocean colour remote sensing problems (e.g., Kirk 1992, 1993).

Mie theory allows computing the absorption, scattering and attenuation of light by particles of different composition, size and shape (Bohren and Huffmann 1983).

3. Satellite remote sensing



Method

- **Atmospheric correction**:
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Coloured water constituants:

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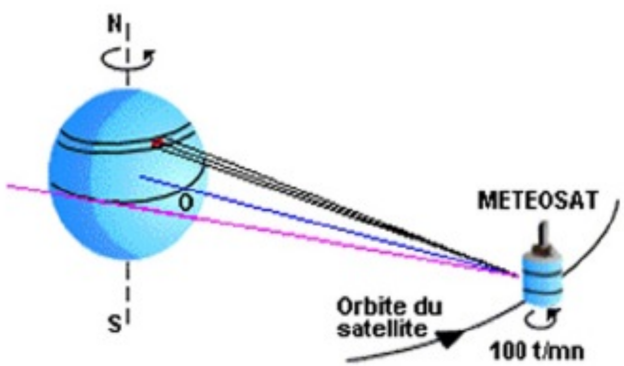
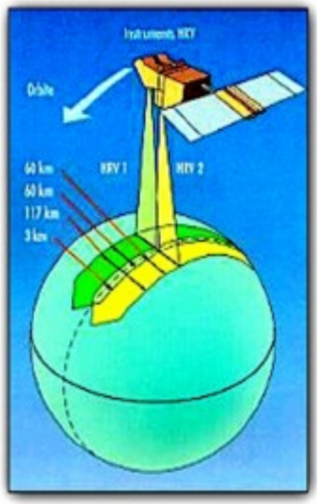
- *Non-algal particles (NAP)*

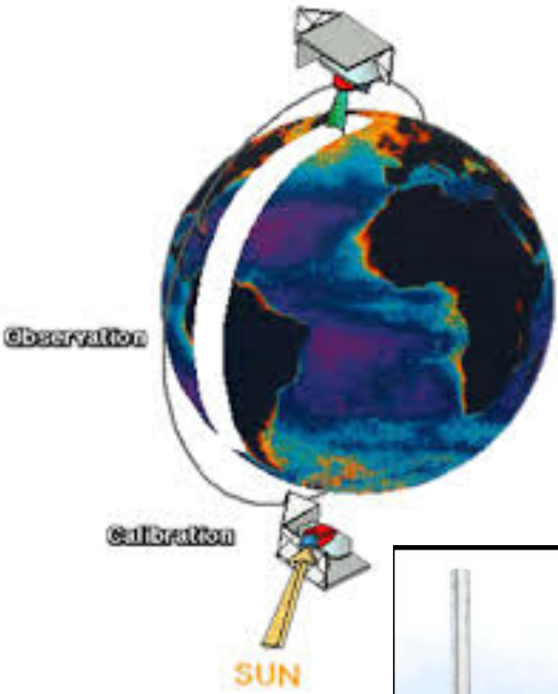
Ocean colour remote sensing

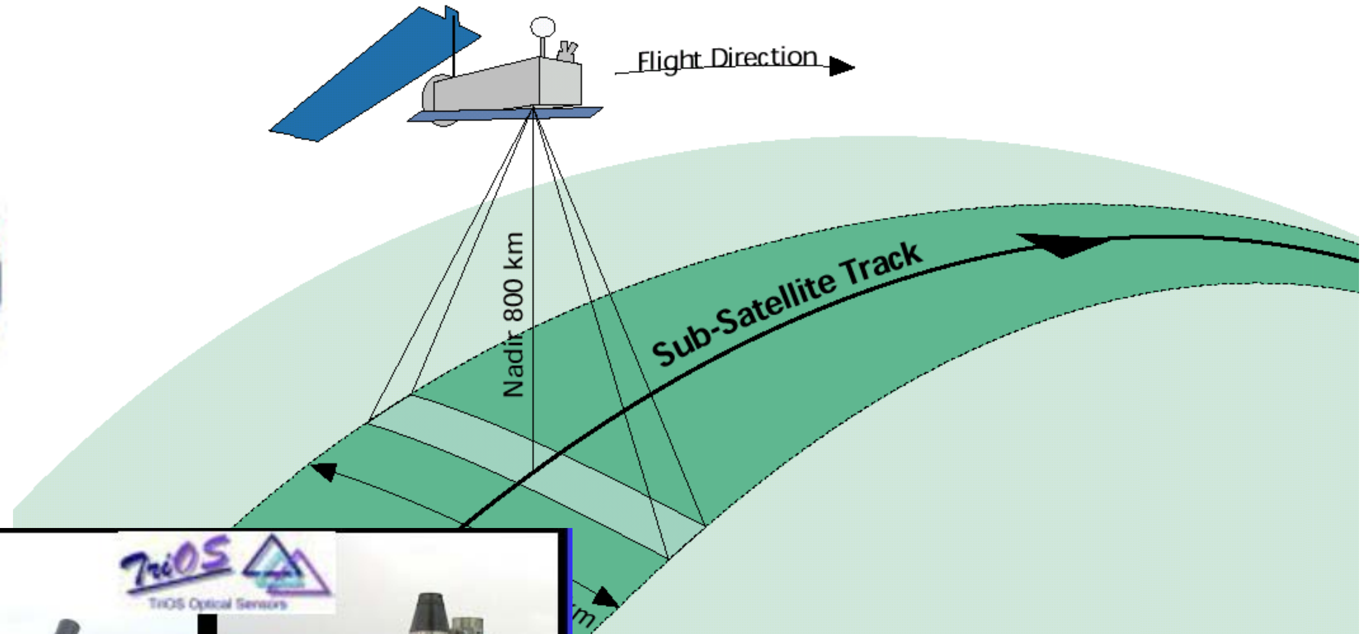
Spectrometers onboard satellite platforms following a polar (LEO), geostationary or geosynchronous (GEO) orbit.

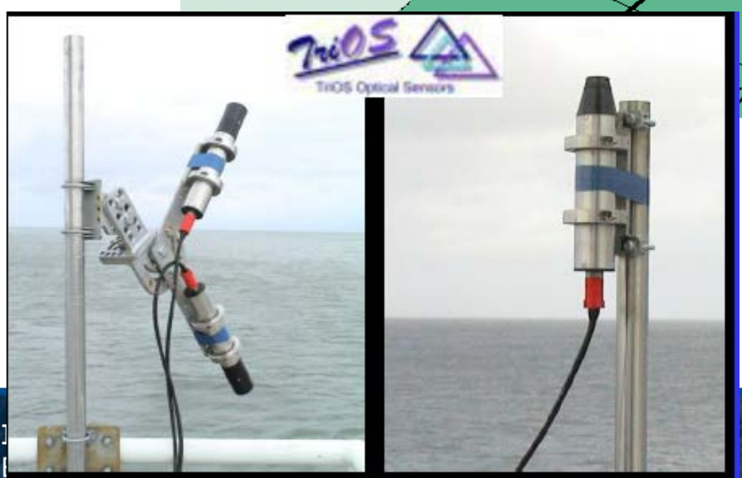




Satellite platforms







Ocean colour satellite sensors

www.ioccg.org/sensors_ioccg.html

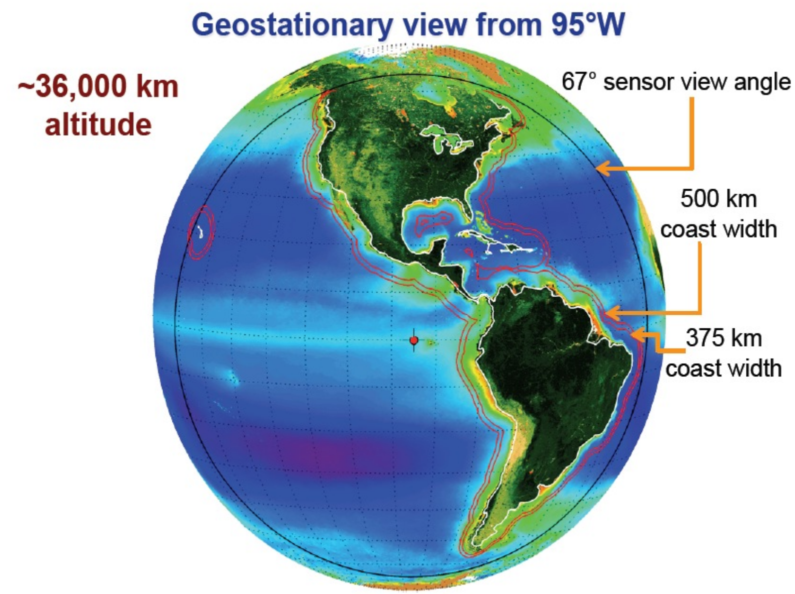
SENSOR	AGENCY	SWATH (km)	SPATIAL RESOLUTION (m)	BANDS	SPECTRAL COVERAGE (nm)	ORBIT
MERIS	ESA (Europe)	1150	300/1200	15	412-900	Polar
MODIS	NASA (USA)	2330	250/500/1000	36	405-14,385	Polar
VIIRS	NOAA / NASA (USA)	3000	370 / 740	22	402 - 11,800	Polar
HICO	ONR and DOD Space Test Programme	50 km Selected coastal scenes	100	124	380 - 1000	Polar
GOCI	KARI/KORDI (South Korea)	2500	500	8	400 - 865	Geostationary

Future ocean colour satellite sensors / projects

SENSOR (Year)	AGENCY	SWATH (km)	SPATIAL RESOLUTION (m)	BANDS	SPECTRAL COVERAGE (nm)	ORBIT
OLCI (2014)	ESA (Europe)	1270	300/1200	21	4-1020	Polar
GOCI-2 (2018)	KARI/KORDI (South Korea)	2500 / full disk	250	13	380 - 865	Geostationary
GEOCAPE (2025?)	NASA (USA)	Full disk	250	20	345-1600	Geostationary
GEOCAPI (2025?)	CNES	Full disk	250	18	380-1020	Geostationary

The future…

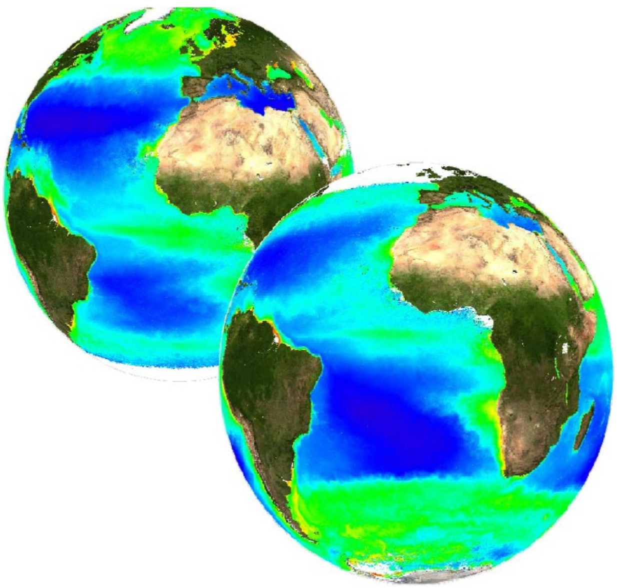
Future ocean colour geostationnary missions



• Within AMF ≤ 5, where atmospheric correction is feasible, coverage extends to nearly ~60° latitude in summer and ~50° in winter and from ~30°W to ~155° W (at equator).

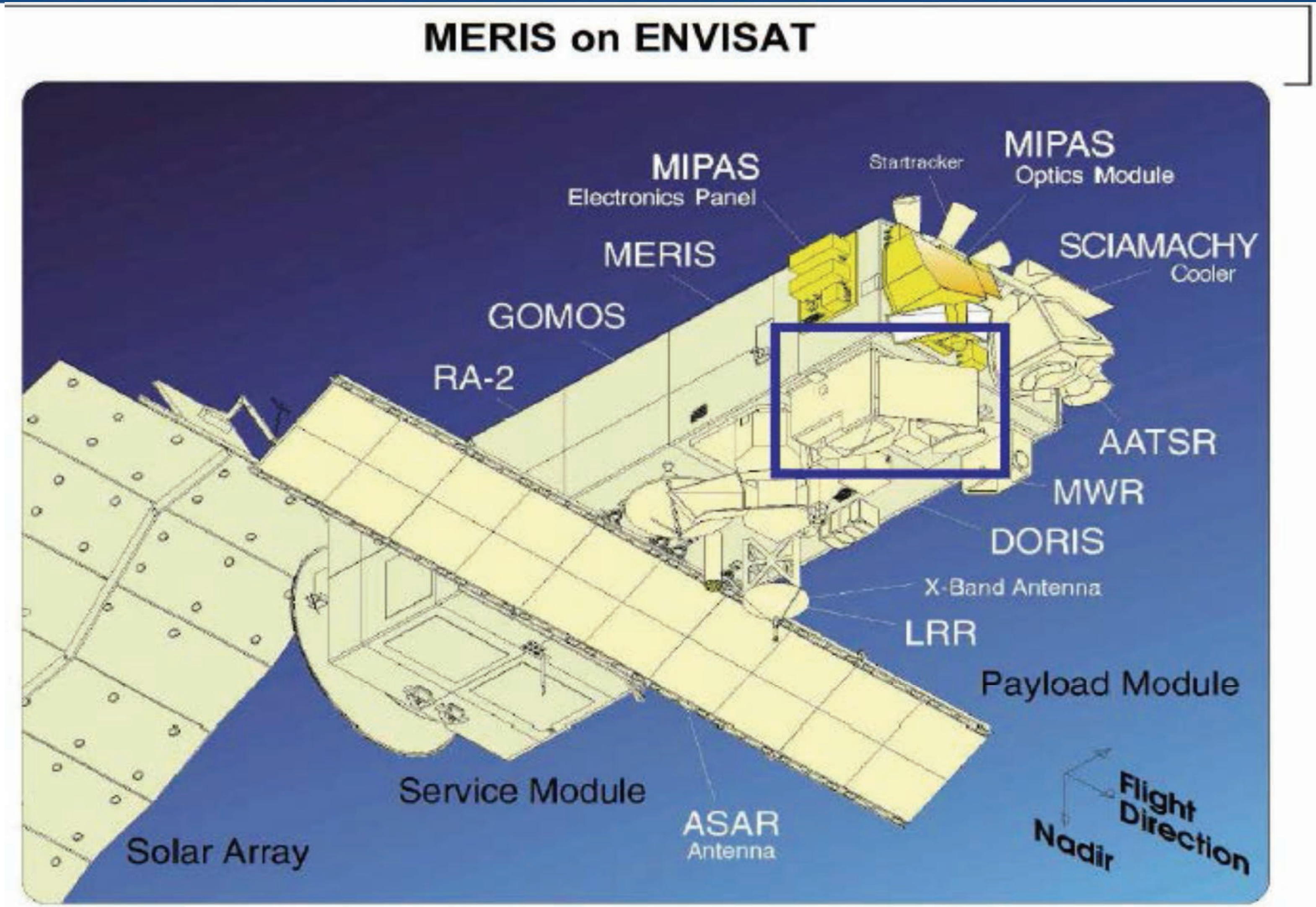
OCAPI

Ocean **C**olour **A**dvanced **P**ermanent **I**mager



Towards full Earth's coverage every hour…

MERIS (2002-2012)



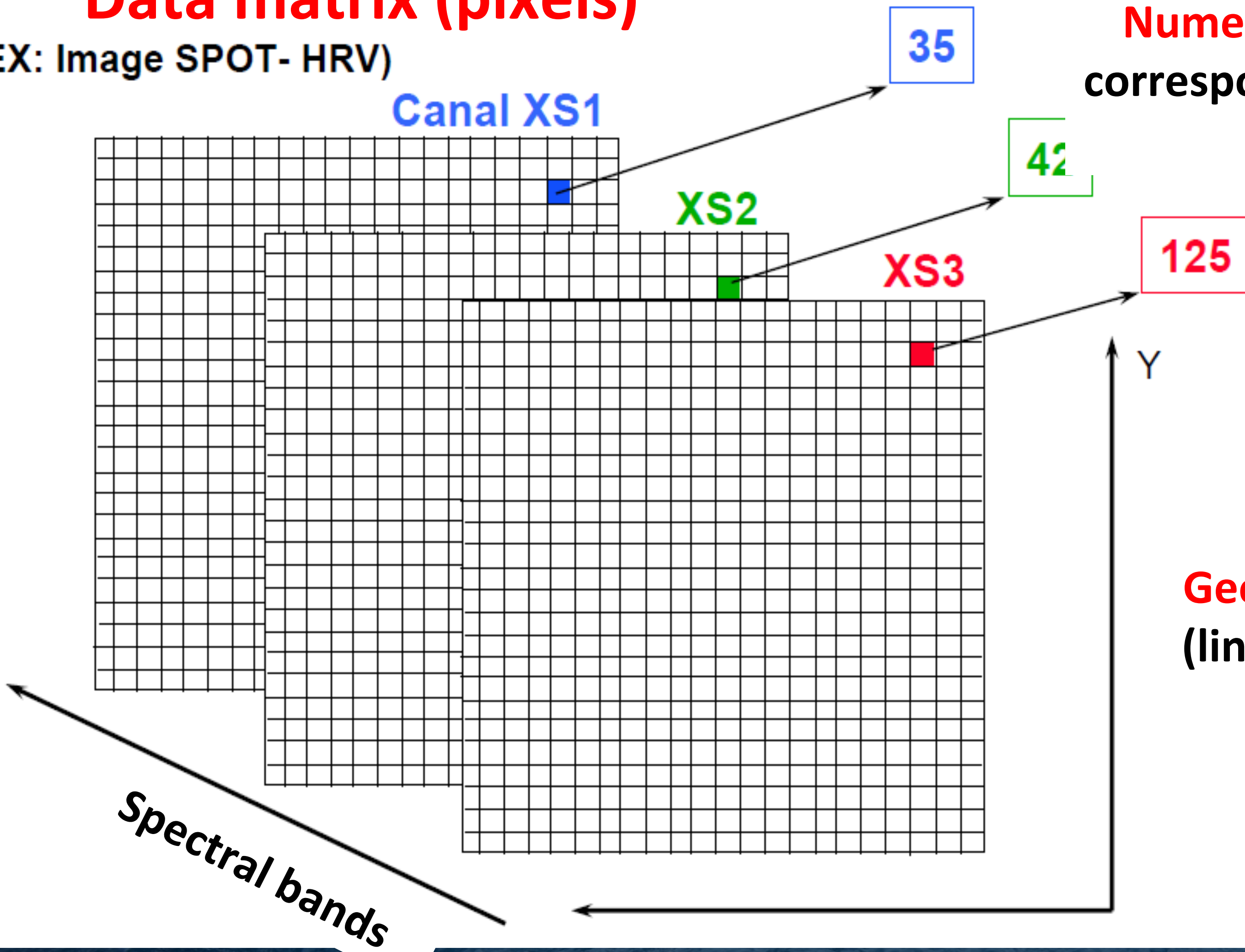
MERIS Spectral Bands

Bd Nr.	Band centre (nm)	Bandwidth (nm)	Potential Applications
1	412.5	10	Yellow substance, turbidity
2	442.5	10	Chlorophyll absorption maximum
3	490	10	Chlorophyll, other pigments
4	510	10	Turbidity, suspended sediment, red tides
5	560	10	Chlorophyll reference, suspended sediment
6	620	10	Suspended sediment
7	665	10	Chlorophyll absorption
8	681.25	7.5	Chlorophyll fluorescence
9	705	10	Atmospheric correction, red edge
10	753.75	7.5	Oxygen absorption reference
11	760	2.5	Oxygen absorption R-branch
12	775	15	Aerosols, vegetation
13	865	20	Aerosols corrections over ocean
14	890	10	Water vapour absorption reference
15	900	10	Water vapour absorption, vegetation

Satellite image

Data matrix (pixels)

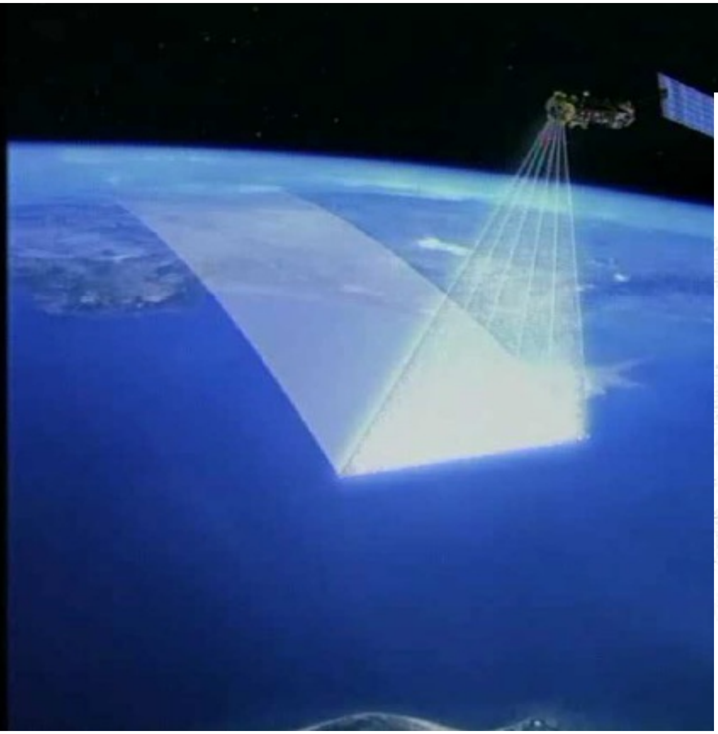
(EX: Image SPOT- HRV)

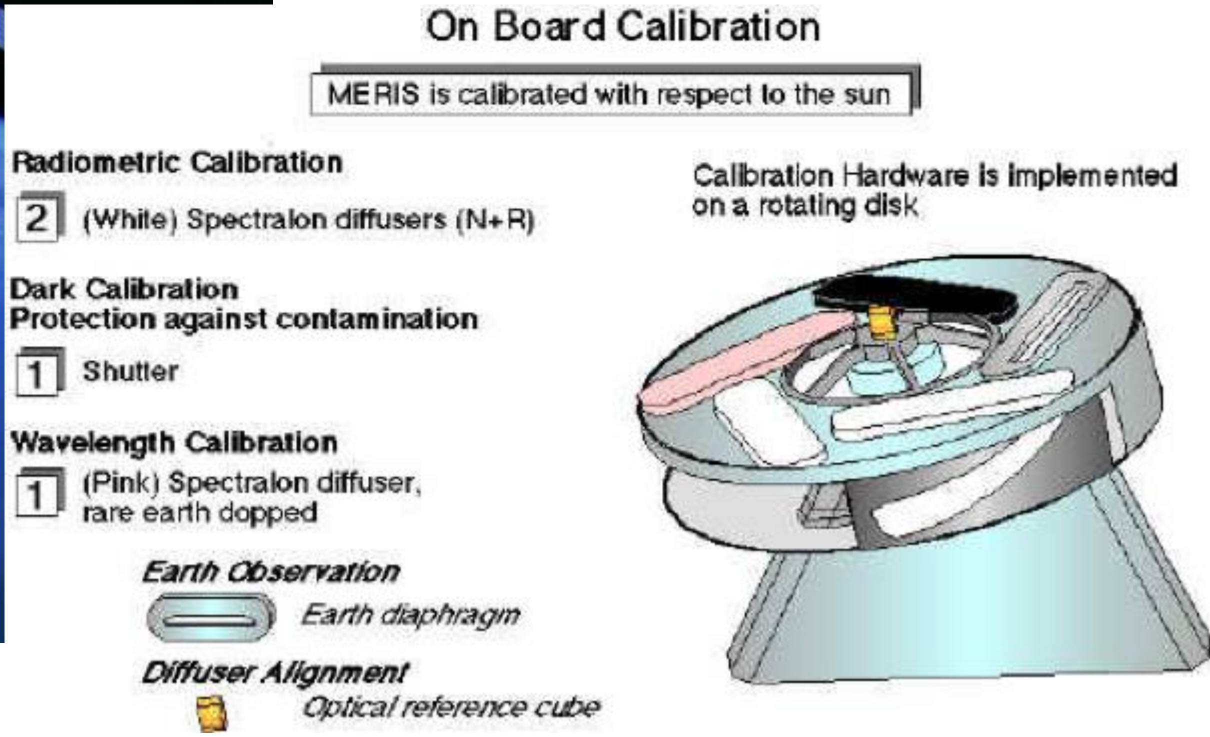


Numerical counts (CN) correspond to radiometric values

Geographical location (line/row ➔ latitude/ longitude)

1) On-board calibration



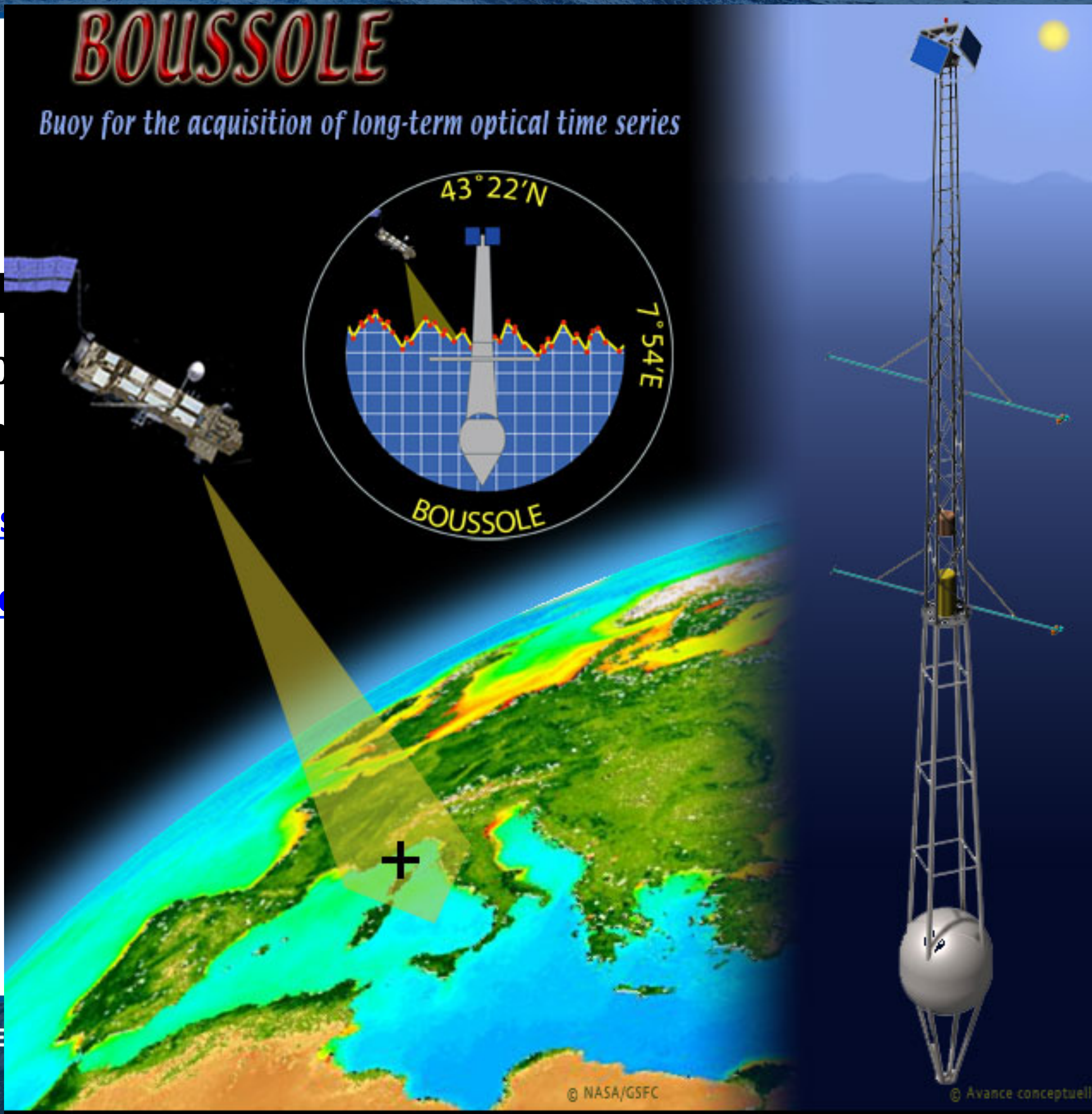


2) Vicariou

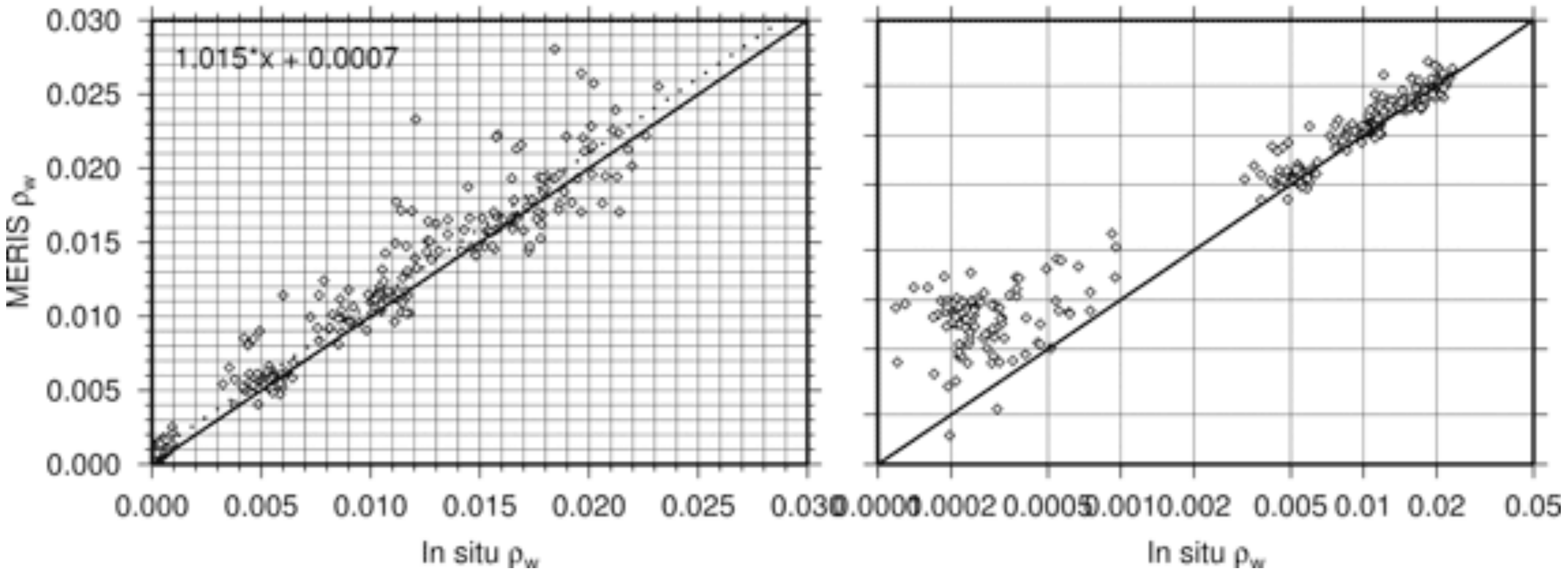
Use of continuous fiel autonmous buoys (Bo Pacific Ocean) and m

http://www.obs-vlfr.fr/Bous

http://moby.mlml.calstate.e



Vicarious calibration / Validation



MERIS matchups (in terms of rw) at the BOUSSOLE site, including the following wavelengths : 412, 443, 490, 510, 560, 670, 683 nm. The same data are plotted with a linear scale on the left and a log scale on the right, in order to highlight the low reflectance values of the red wavelengths. The solid line is the 1:1 line. The dotted line is a simple linear fit on the data. The slope and intercept of this curve are also indicated.

Classification of natural waters

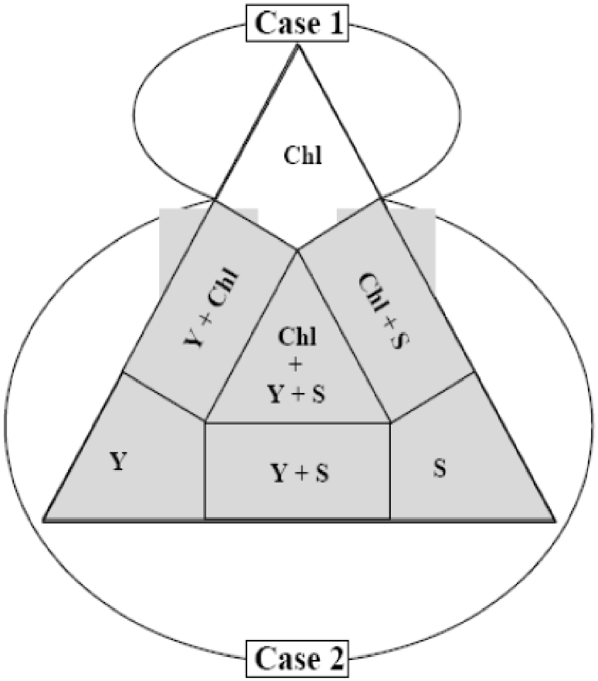


Figure 1. Partitioning of seawater into optical main optical classes.

- **Phytoplankton chlorophyll (and degraded products) is the unique coloured constituent in Case 1 waters**

- **Case 2 waters are also influenced by terrestrial substances (NAP, gelbstoff)**

Morel / Antoine MERIS Case 1 water ATBD

Apparent and inherent optical properties

Preisendorfer (1961): apparent optical properties (**AOPs**) depend on the **radiance distribution** whereas inherent optical properties (**IOPs**) such as the absorption coefficient (**a**), the scattering coefficient (**b**), and the beam attenuation coefficient (**c**) which are intrinsic properties of the aquatic medium itself not affected by the prevailing distribution of radiance.

AOPs (radiometric measurements)

R = Eu/Ed (dl); **Rrs** = Lw/Ed (1/sr) = reflectance or colour of the water

Ed(z) = Ed (0-) exp(-**Kd** × z) = Solar light penetration into water column

Apparent and inherent optical properties

Semi-analytical models relating the AOPs and IOPs (Gordon et al. 1975, Morel & Prieur 1977, Kirk 1983), e.g.:

$$K_d \cong (a + b_b) \,/\, \cos(\theta_{\mathrm{sw}}) \qquad (1/\mathrm{m})$$

$$R \cong f \times b_b \,/\, (a + b_b)$$

Total absorption and backscattering coefficients (a and b_b, in 1/m) are the sums of contributions by pure water (w), phytoplankton (Chla), non-algal particles (NAP) and gelbstoff (y):

$$a = a_{\mathrm{w}} + a_{\mathrm{Chla}} + a_{\mathrm{NAP}} + a_{\mathrm{y}}$$

$$b_b = b_{b\mathrm{w}} + b_{b\mathrm{Chla}} + b_{b\mathrm{NAP}}$$

Optical properties

IOPs measurements

Light absorption (*a*) can be measured using:

- Collimated source, reflective sample cell with diffuser in front of wide area detector (Wetlabs ac9, acs)
- Spectrophotometers (cuvette, filter-pads)

Light backscattering (β) is measured at specific angles:

$$b = 2\pi \int_{0}^{\pi} \sin(\theta)\beta(\theta)d\theta$$

total scatter

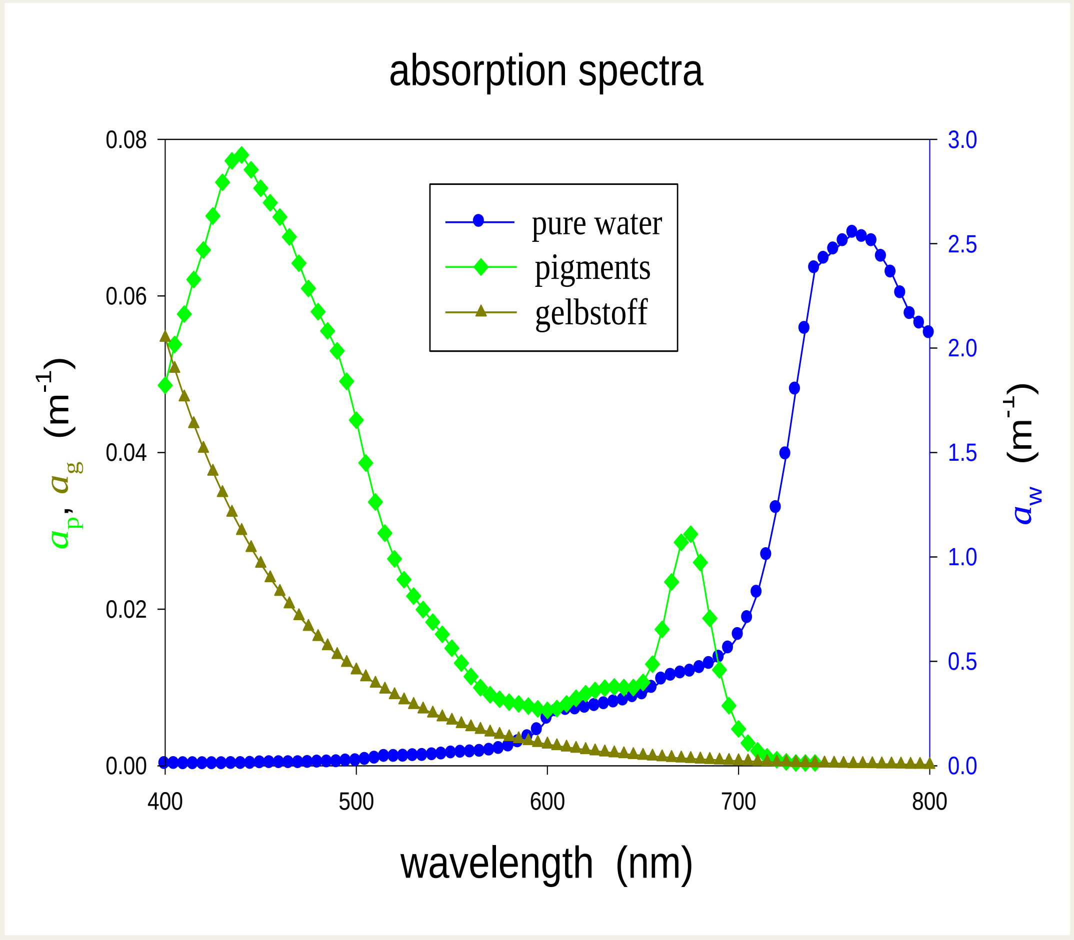
$$b_b = 2\pi \int_{\frac{\pi}{2}}^{\pi} \sin(\theta)\beta(\theta)d\theta$$

backscatter

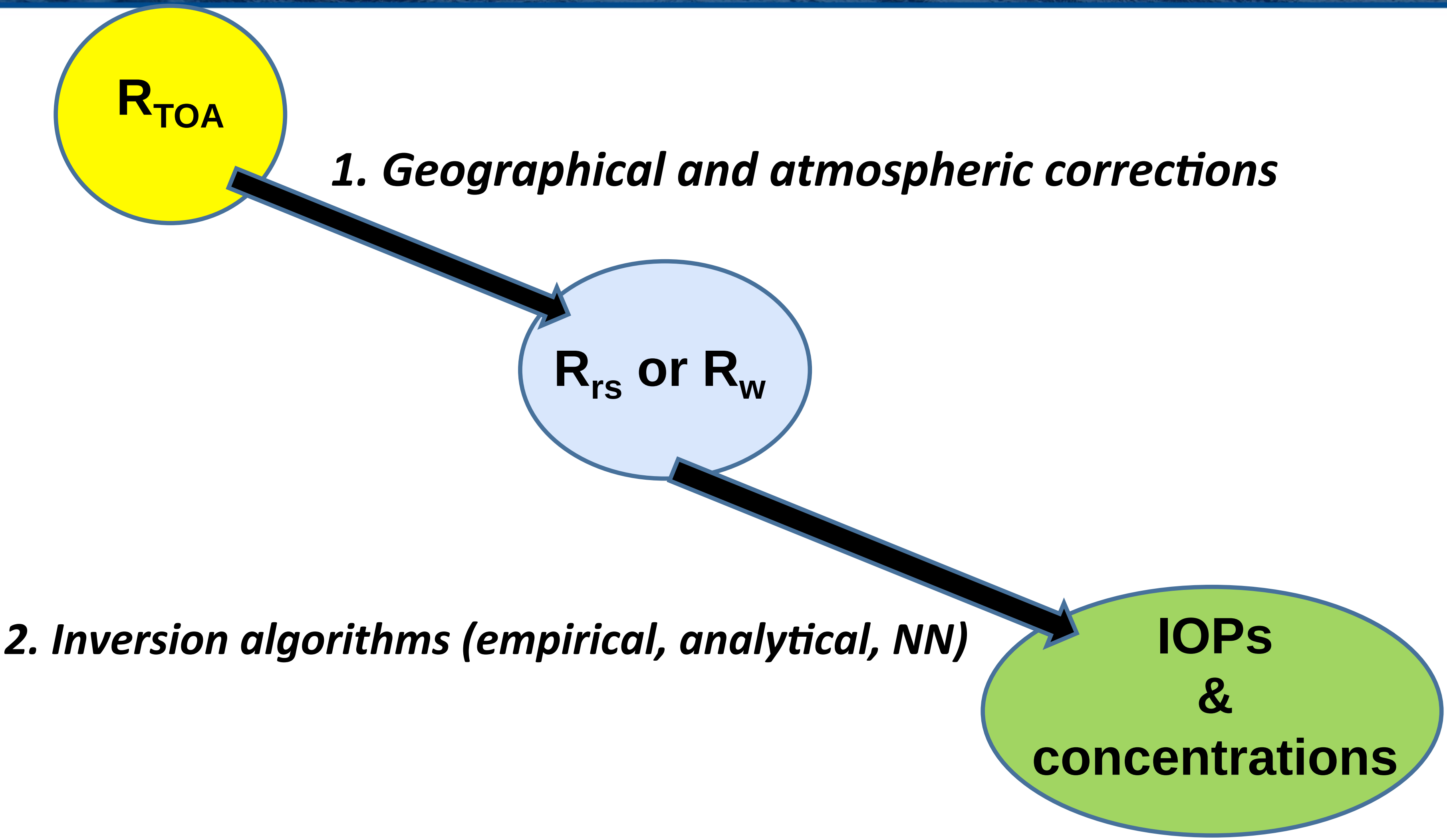
θ = angle

$\beta(\theta)$ = volume scattering function ($m^{-1}\ sr^{-1}$)

Spectral absorption coefficients.



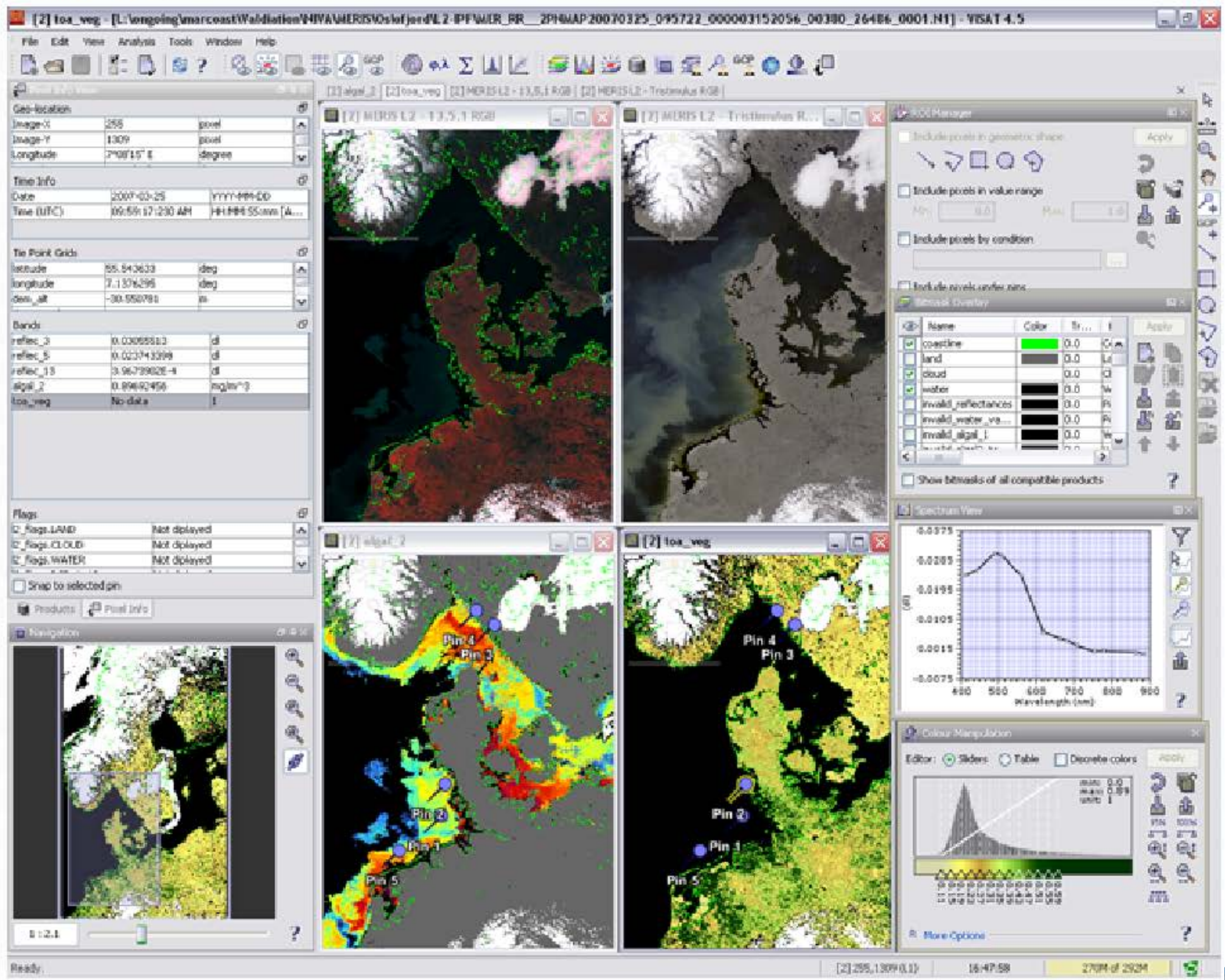
5. Ocean colour algorithms



Processing softwares

Beam-VISAT, ODESA (ESA): MERIS, OLCI

SeaDAS (NASA): (SeaWiFs, MODIS)



6. Applications

In Case-1 and Case-2waters, ocean colour remote sensing provides useful information on:

- Primary production
- Formation/degradation of particulate matter
- Organic carbon fluxes and cycles
- Food web / Ecosystems dynamics
- Fishery and (harmful) algal blooms
- Water quality
- Sediment transport and dynamics, fluxes
- etc…

Case-1 waters

Primary production of the global ocean
(Antoine et al. 1996)

Impact of Climate Change
(Martinez et al. 2009)

ANTOINE ET AL.: OCEANIC PRIMARY PRODUCTION 65

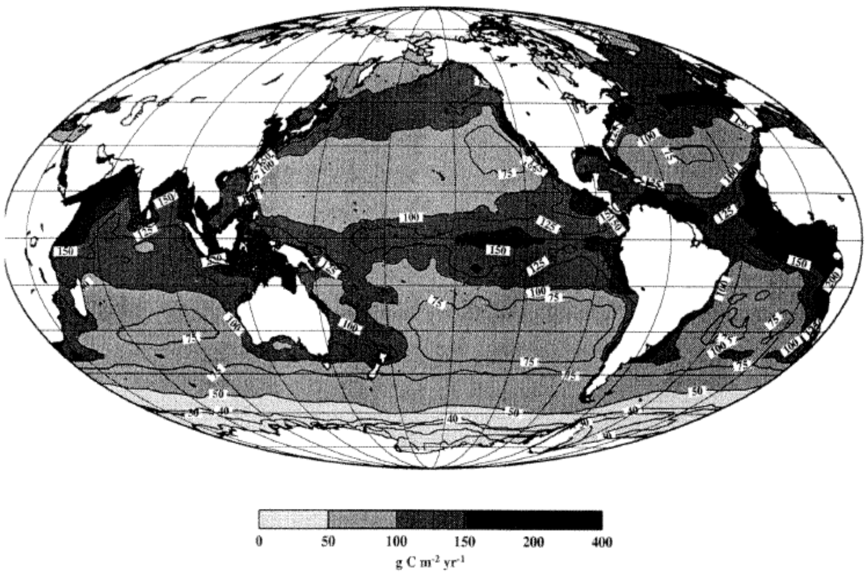
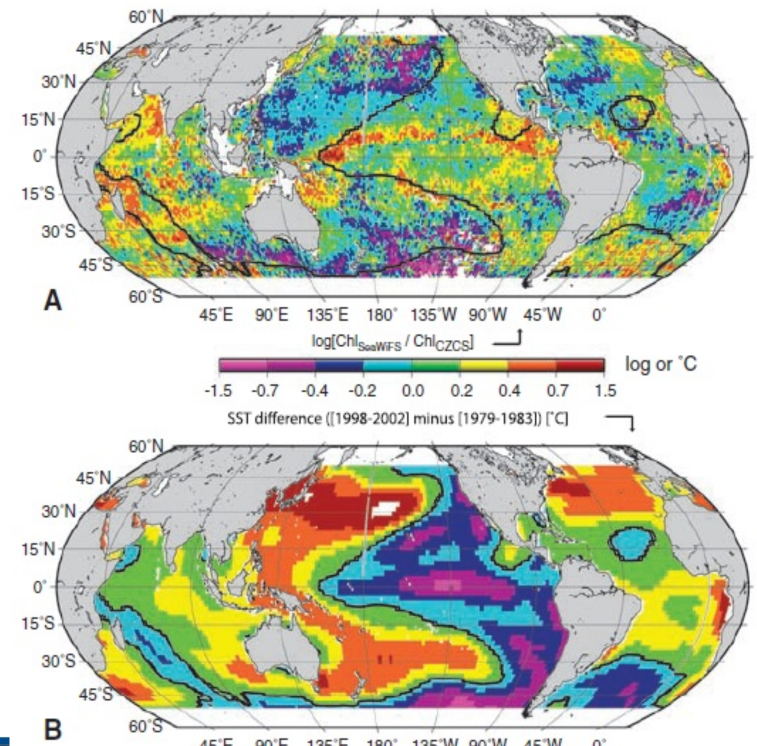
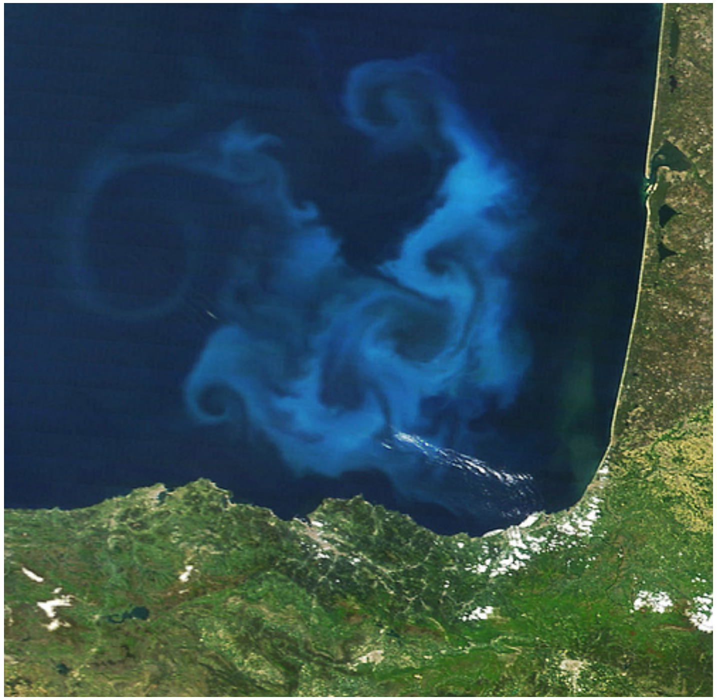


Figure 3. Annual primary production within the world ocean (equal surface "Mollweide" projection), obtained by summing the 12 monthly maps. This map shows the values obtained through the "standard" computation, which leads to a global annual carbon fixation of 36.5 Gt C yr^{-1} (Table 1, line 1). This map can be compared to the historical primary production maps, as derived from compilations of in situ carbon fixation [e.g., *Koblentz-Mishke et al.*, 1970; *Berger et al.*, 1987].

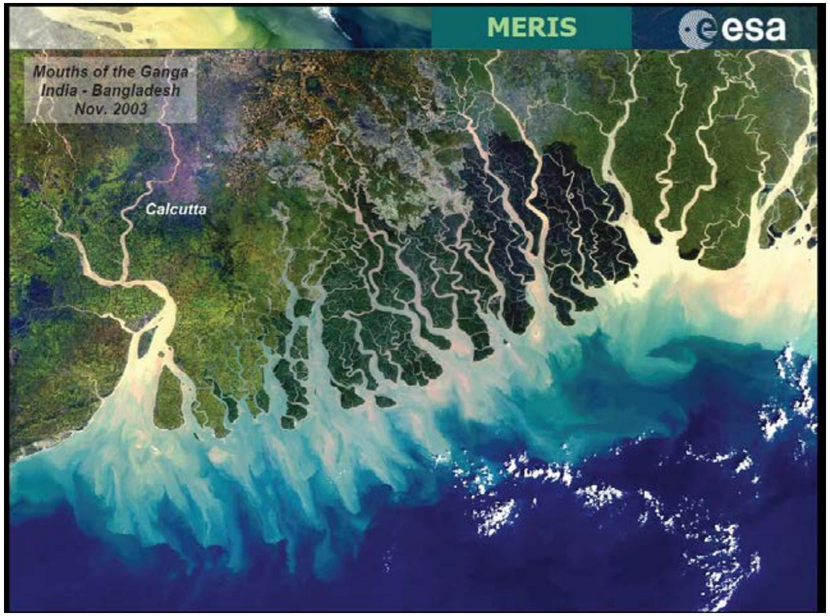


Case-2 waters

Detection of phytoplankton blooms
(Froidefond et al. 1999)



Fluxes at the land/ocean interface
(Doxaran et al. 2012)



7. References: web links

International Ocean Colour Coordinating Group
http://www.ioccg.org/

European Space Agency (ESA) MERIS Handbook
https://earth.esa.int/handbooks/meris/

ESA Beam Earth Observatiopn Toolbox and development platform
http://www.brockmann-consult.de/cms/web/beam/

NASA Ocean Color Homepage and SeaDAS software
http://oceancolor.gsfc.nasa.gov/

Thank you for attention!

LOV Remote Sensing Group publications as pdf files
http://omtab.obs-vlfr.fr/