1st INIOAS Training Course on Ocean Remote Sensing, 2023

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https://www.inio.ac.ir/ORSA

Phytoplankton Dynamics from Space

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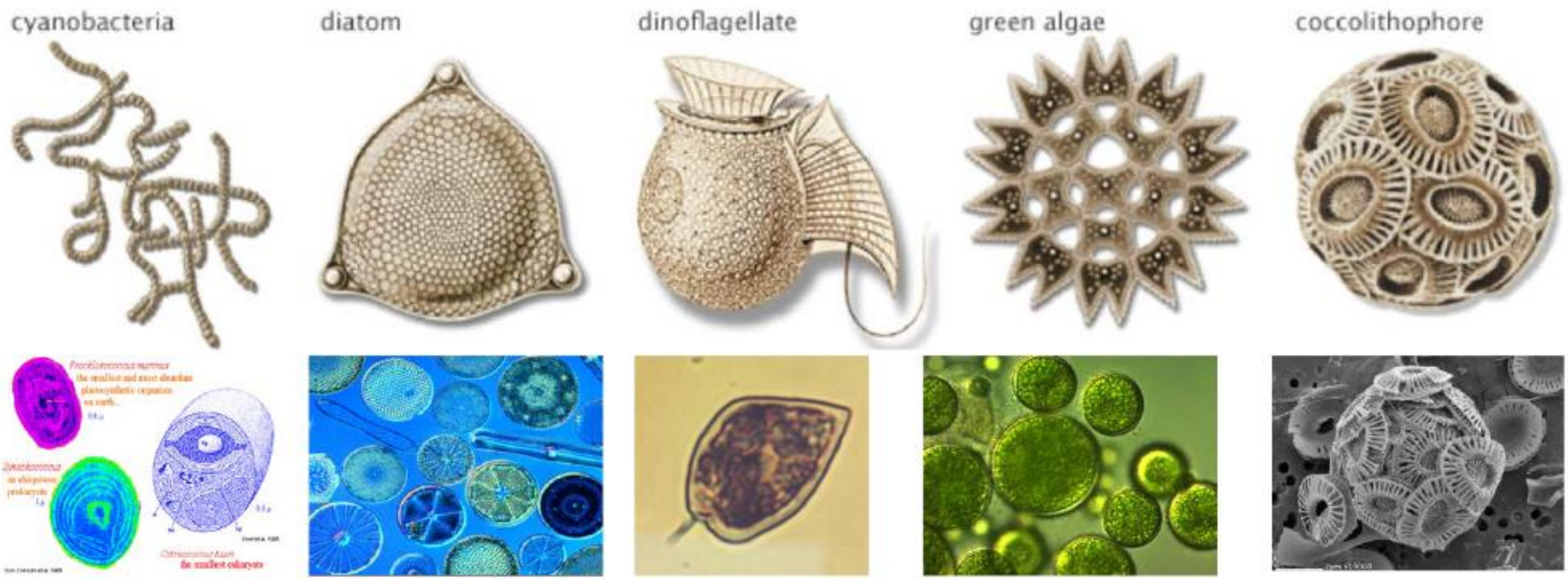
Outlines

- Introduction to phytoplankton: diversity, pigments, cell size, global distribution
- Principles of Ocean Color Remote Sensing
- Monitoring and detecting harmful algal blooms (HAB)

Phytoplankton diversity

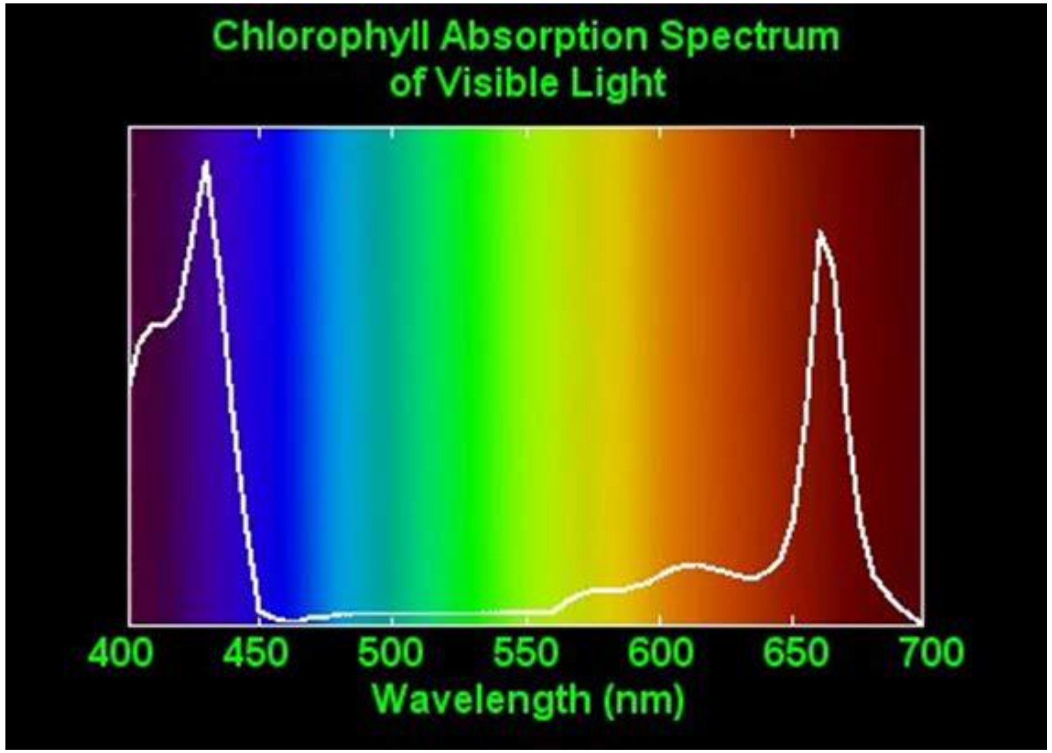


https://earthobservatory.nasa.gov/features/Phytoplankton

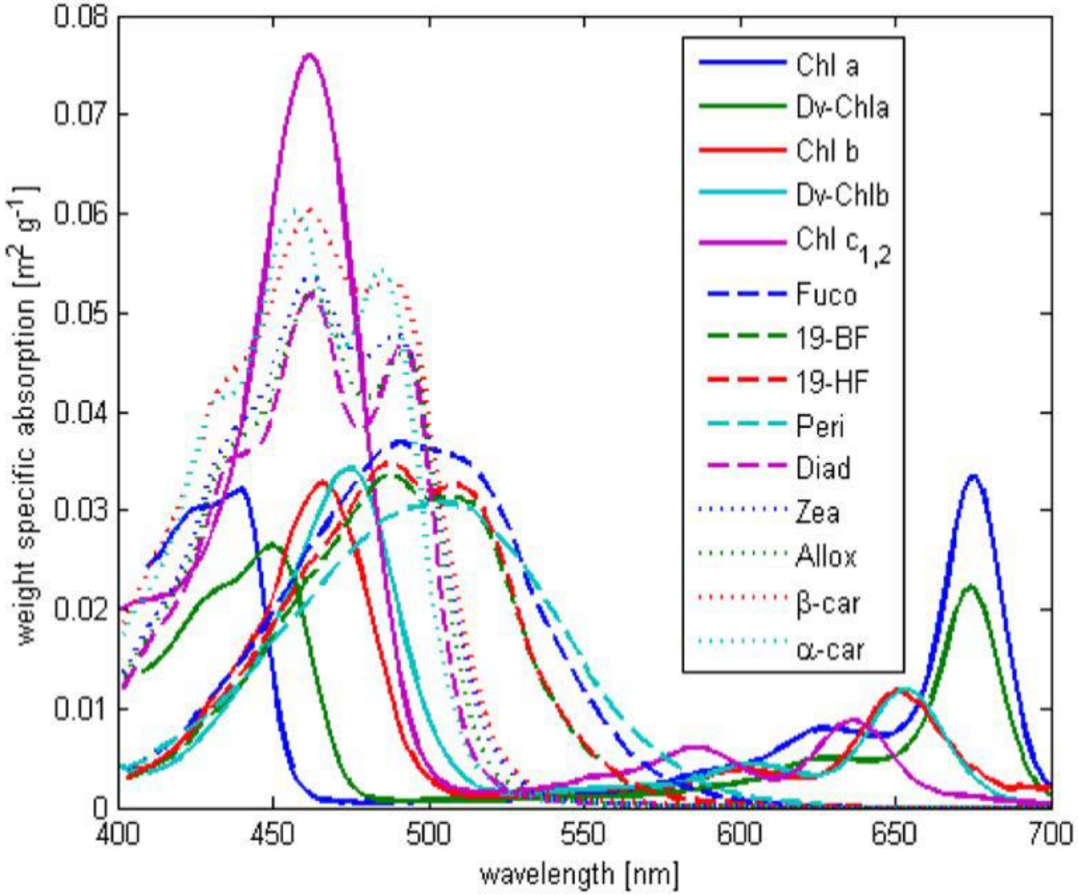
Photo by Ye.Maltsev/Shutterstock

Credit: Alex Poulton/NOC

Phytoplankton pigments

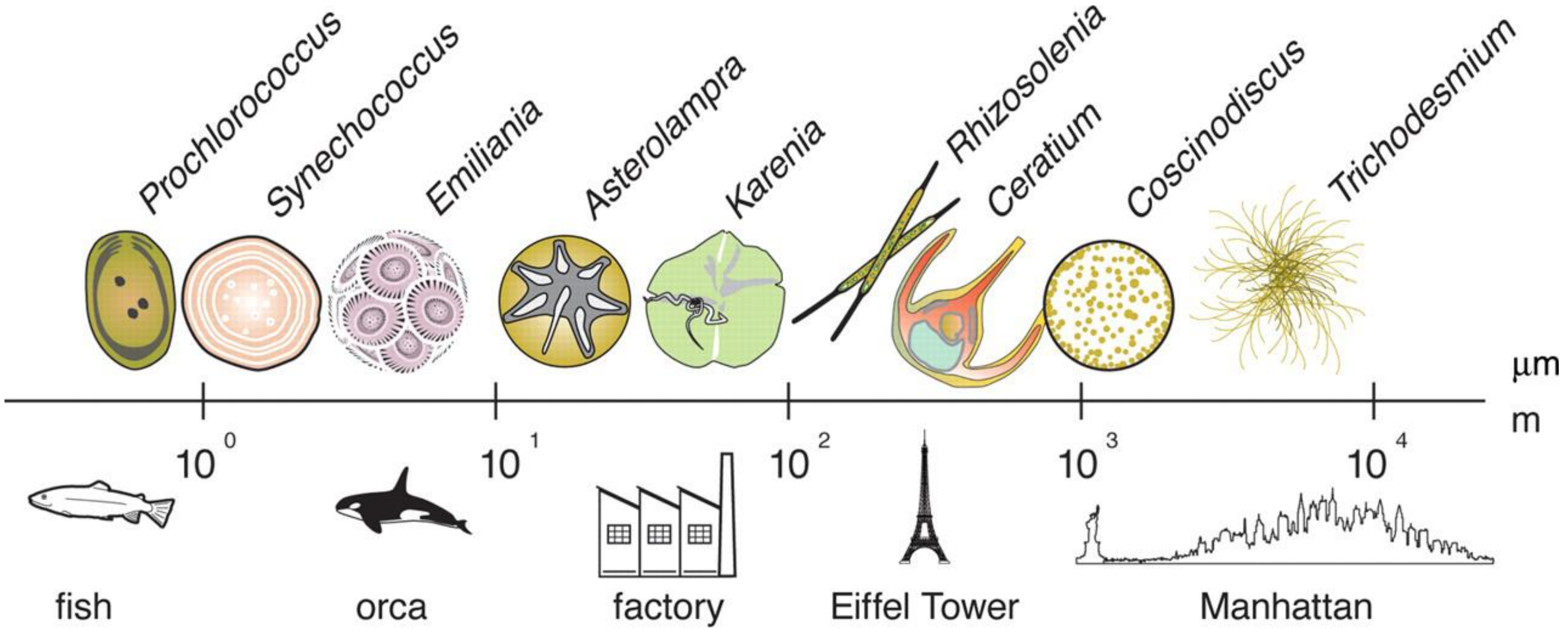


in vivo spectra



Phytoplankton cell size

Phytoplankton cell sizes
0.6 μm – 200 μm



A comparison of the size range (maximum linear dimension) of phytoplankton relative to macroscopic objects.

Phytoplankton Functional Types

Size-based classification (Sieburth et al. 1978)

- **Picophytoplankton** (< 2 μm):

  Prochlorophytes, *Prochlorococcus*, *Synechococcus*)

- **Nanophytoplankton** (2–20 μm)

  chromophytes, nanoflagellates, chryptophytes

- **Microphytoplankton** (> 20 μm)

  diatoms, dinoflagellates

Size is recognized to influence many processes:

- Optical properties
- Ecological distribution (light-nutrient regime)
- Photophysiological properties
- Carbon fluxes

Different phytoplankton species absorb light slightly different resulting in different Rrs spectral signatures (regional and seasonal natural variations)

Phytoplankton Functional Types

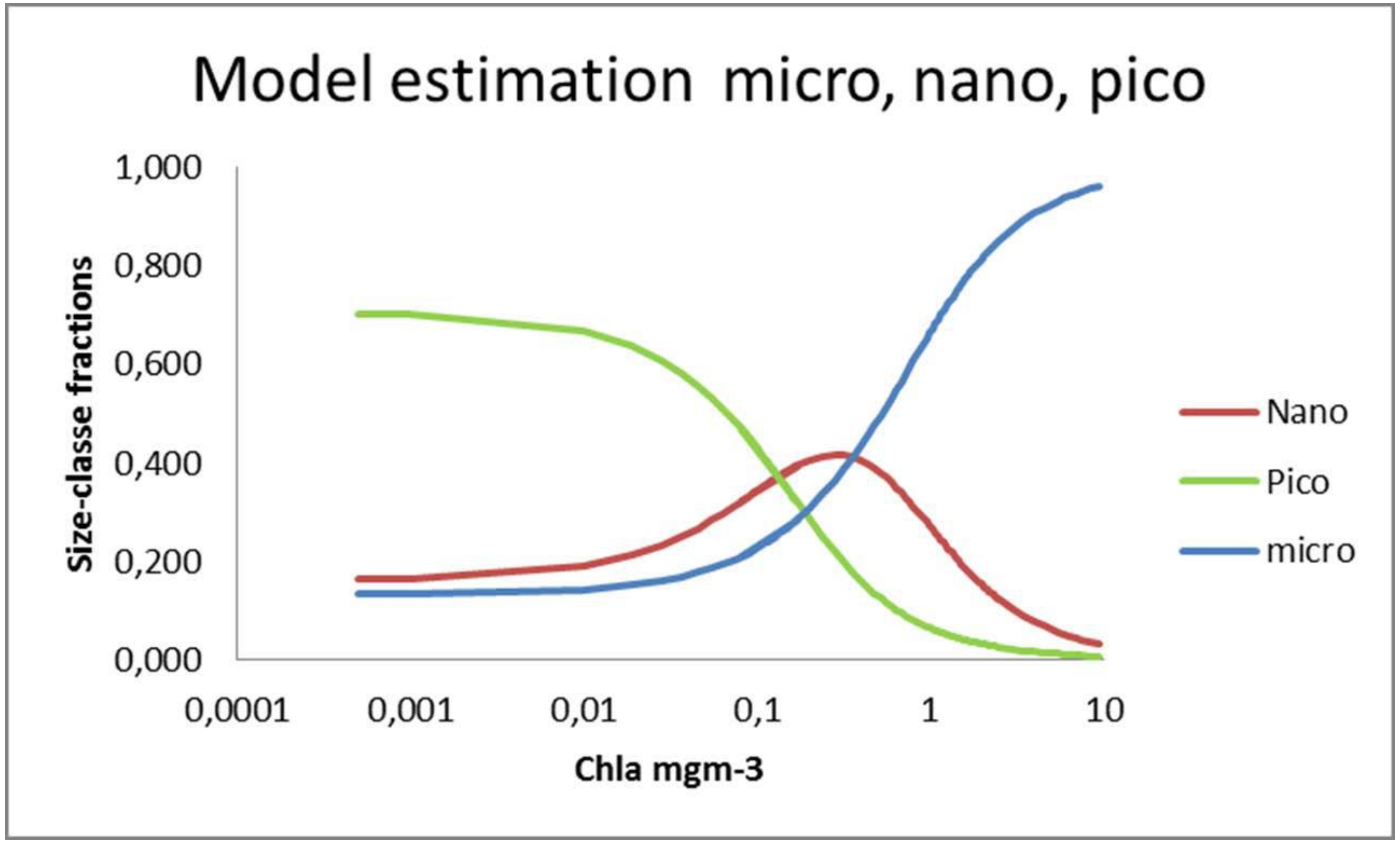
Deriving and validating size-classes from satellite data (PSC)

The rate of resource utilization is the main factor controlling phytoplankton structure and cell size in the ocean.

Microplankton > 20 μm

Nanoplankton: 2 – 20 μm

Picoplankton: 0.2 – 2 μm



Phytoplankton distribution

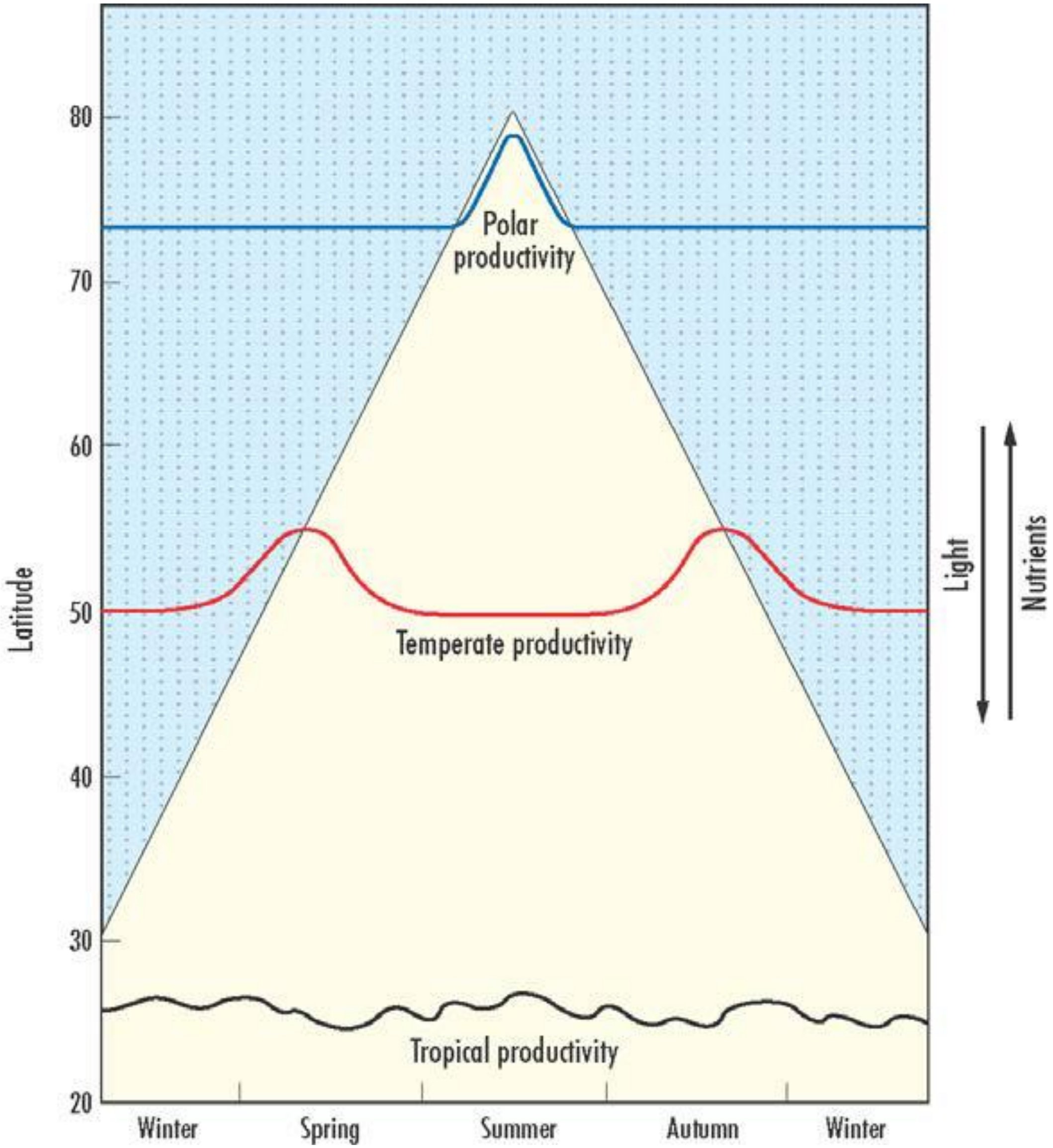
• Factors affecting growth: **light** and **nutrients**

• Seasonality as a function of latitude

• Microplankton dominate the subartic and the major upwelling zones (euthrophic). Its presence is reduced to 20% along the equator, and 10% in the subtropical gyres (oligotrophic).

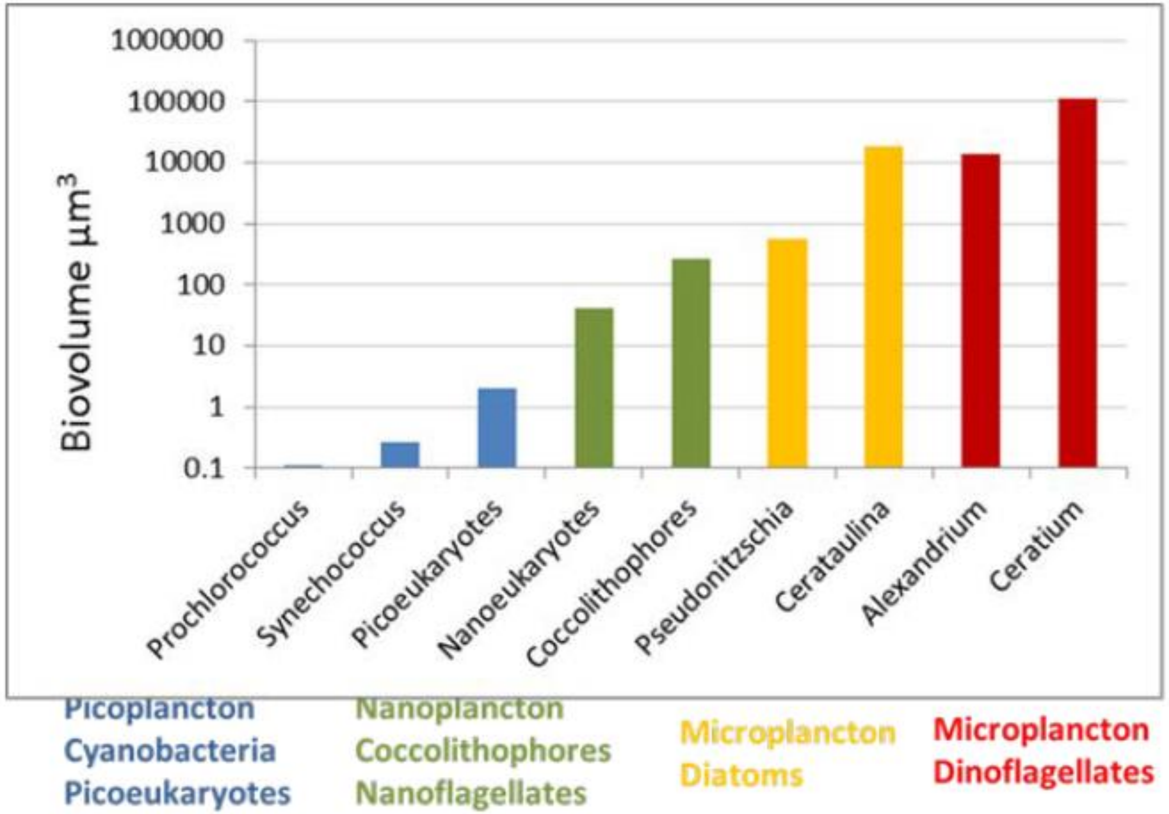
• Nanoplankton more stable: 17% in subtropical gyres; 55% in upwelling areas.

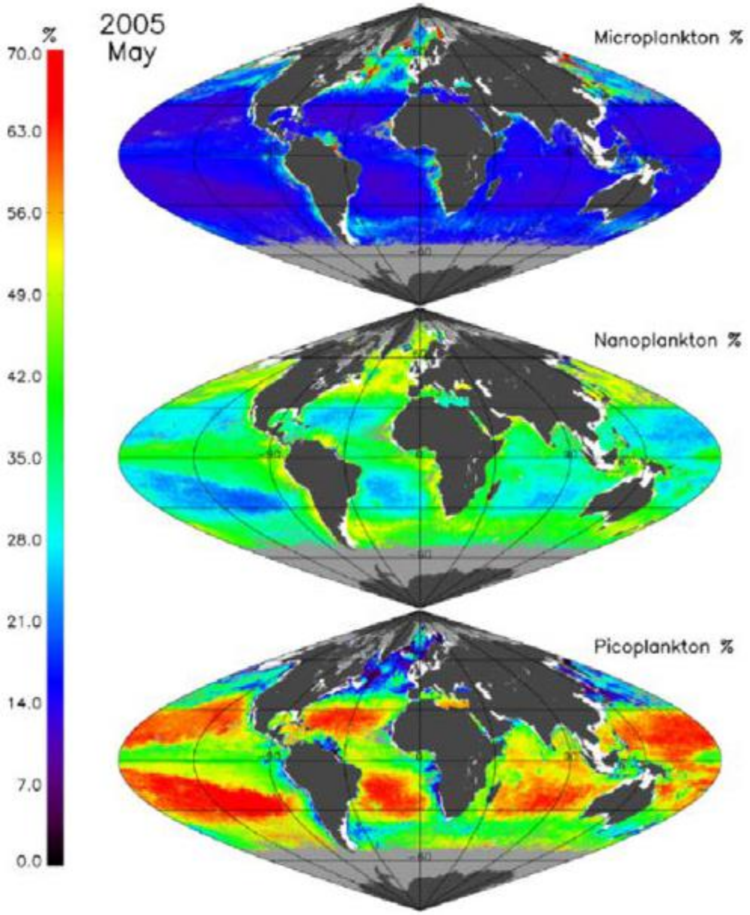
• Picoplakton dominant within the subtropical gyres (70%); 40% at equator and subantartic convergence; 1% in subarctic and upwelling zones.



Phytoplankton distribution

Eutrophic, mesotrophic and oligotrophic zones and cell-size dominance





Remote sensing of Ocean Color

Water quality describes the condition of the water, including chemical, physical, and biological characteristics, usually with respect to its suitability for a particular purpose such as ecosystem function or human health.

- Turbidity and Sediments
- Colored Dissolved Organic Matter (CDOM)
- Sea Surface Temperature (SST)
- Chlorophyll-a (phytoplankton)
- Salinity
- Total Suspended Solids (TSS)
- Fluorescence Line Height
- Euphotic Depth
- Diffuse Attenuation of Light

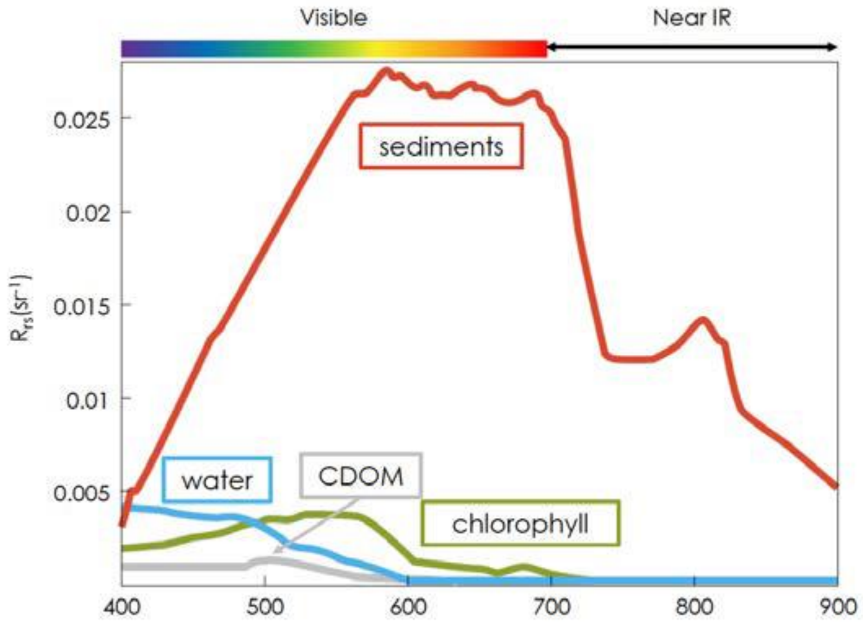
} Observed by Satellites

Water color = water reflectance

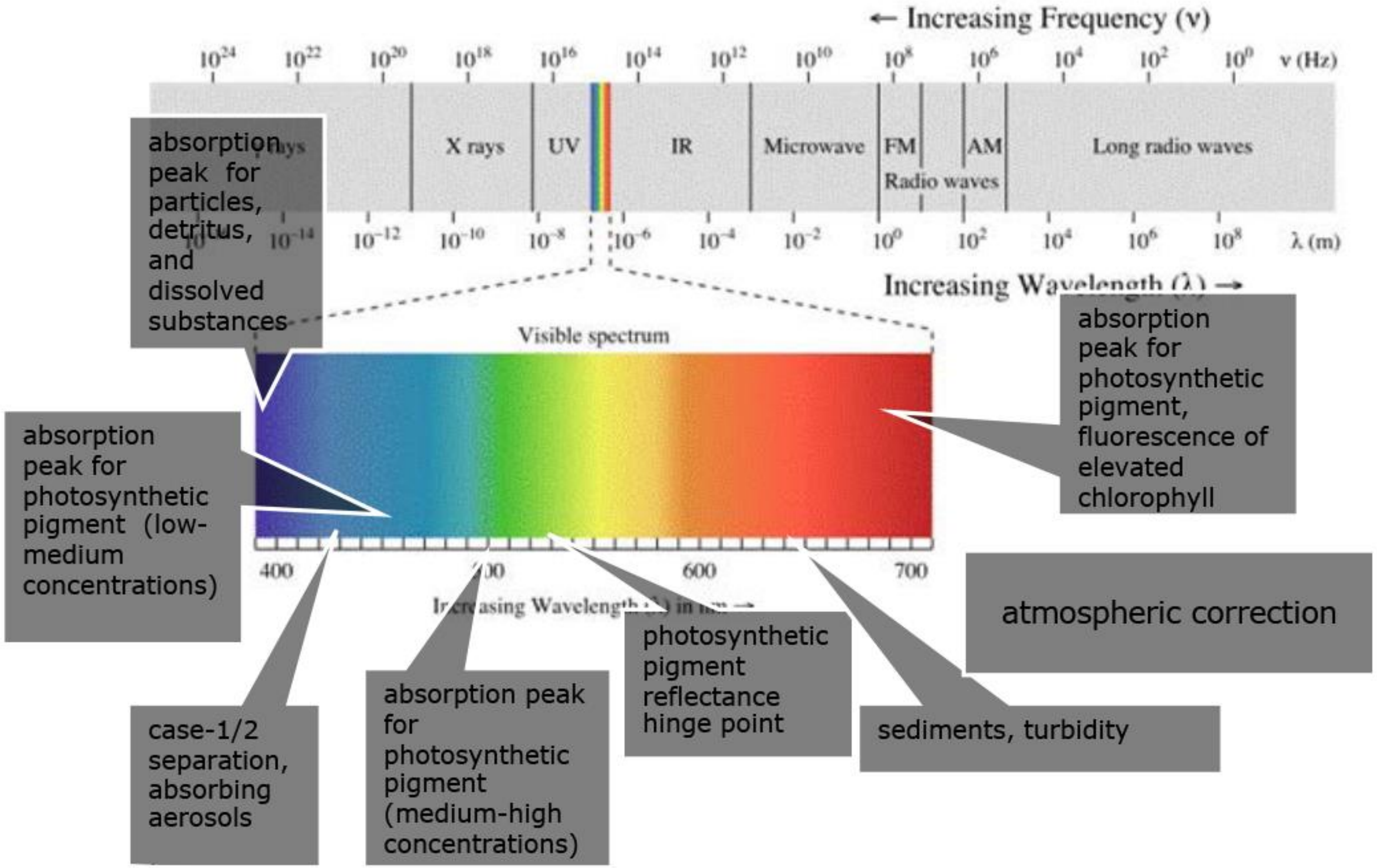
Identification / quantification of the colored water constituents

=

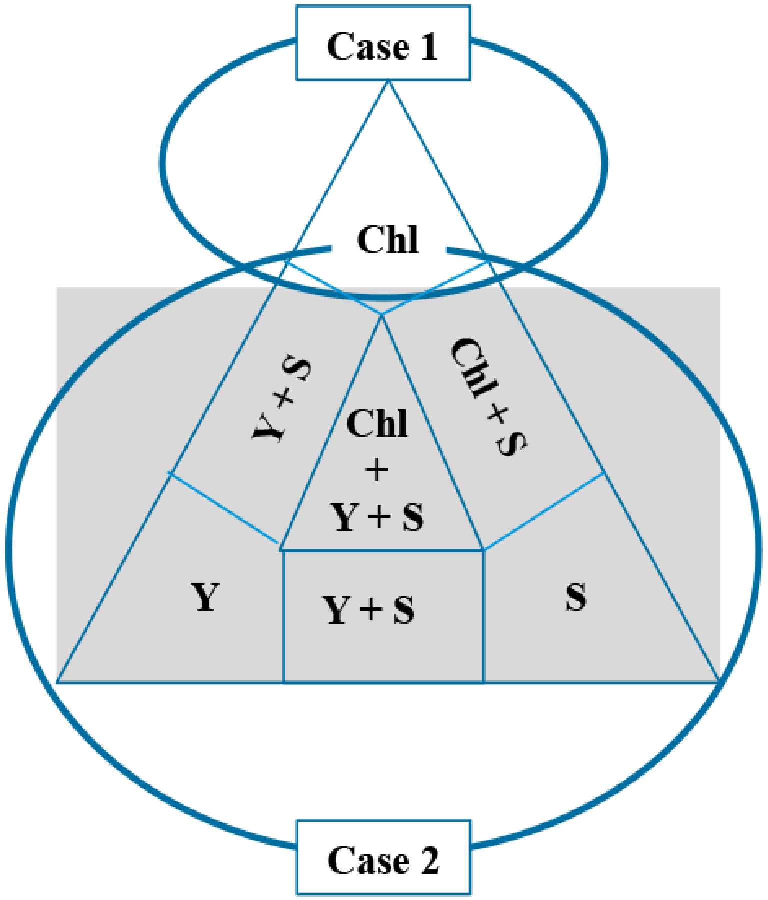
non-algal particles, CDOM, Chl-a (+ phyto-species)



Observable parameters



Classification of natural waters



Case 2

Water bodies where the optical properties are significantly influenced by other constituents, such as mineral particles, CDOM, or microbubbles, whose concentrations do not covary with the phytoplankton concentration

Remote sensing of Ocean Color

Essentials:

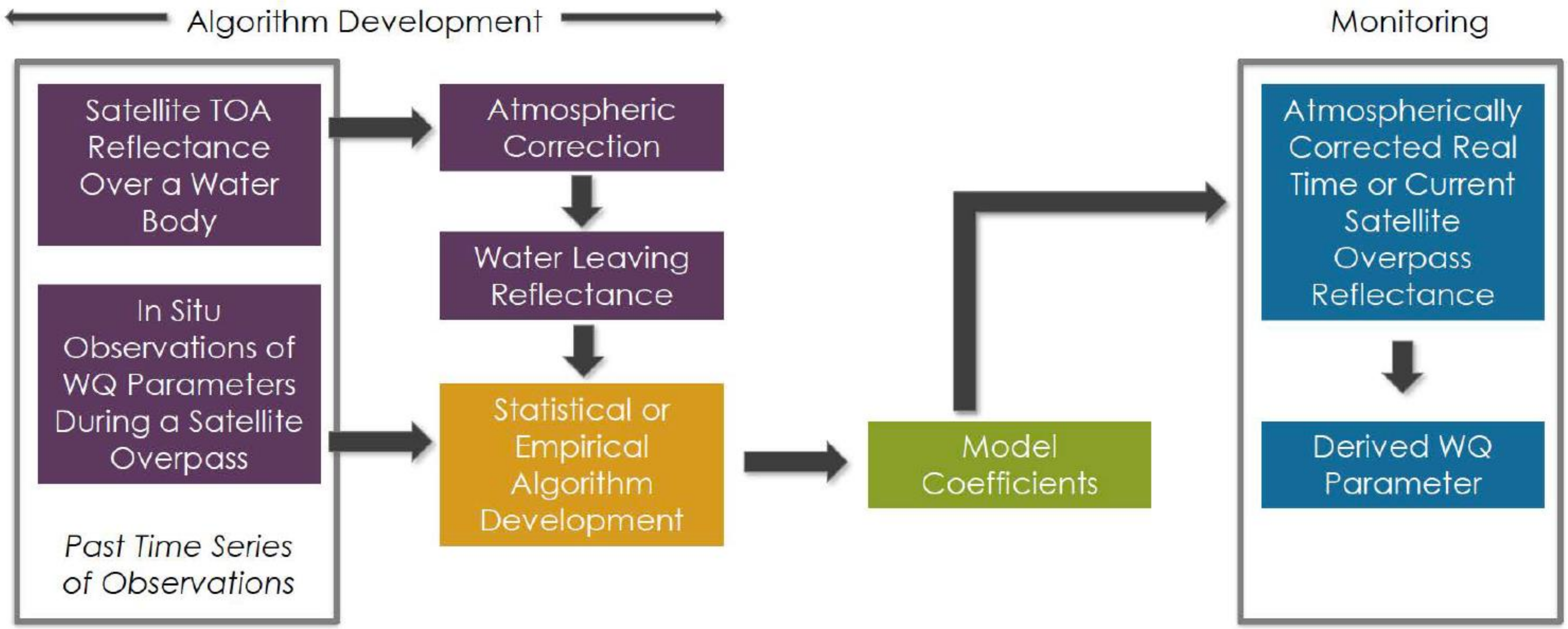
- AOPs
- IOPs
- In-Situ data
- Regional Algorithms

Radiative transfer modeling:

- **HydroLight** (Mobley 1994)
- **6S** (Vermote et al. 1997) and **MODTRAN** (Acharya et al. 1999)
- **Monte Carlo simulations** (Kirk 1992, 1993)
- **Mie theory** (Bohren and Huffmann 1983).

Remote sensing of Ocean Color

Processing chain to obtain chl-*a*



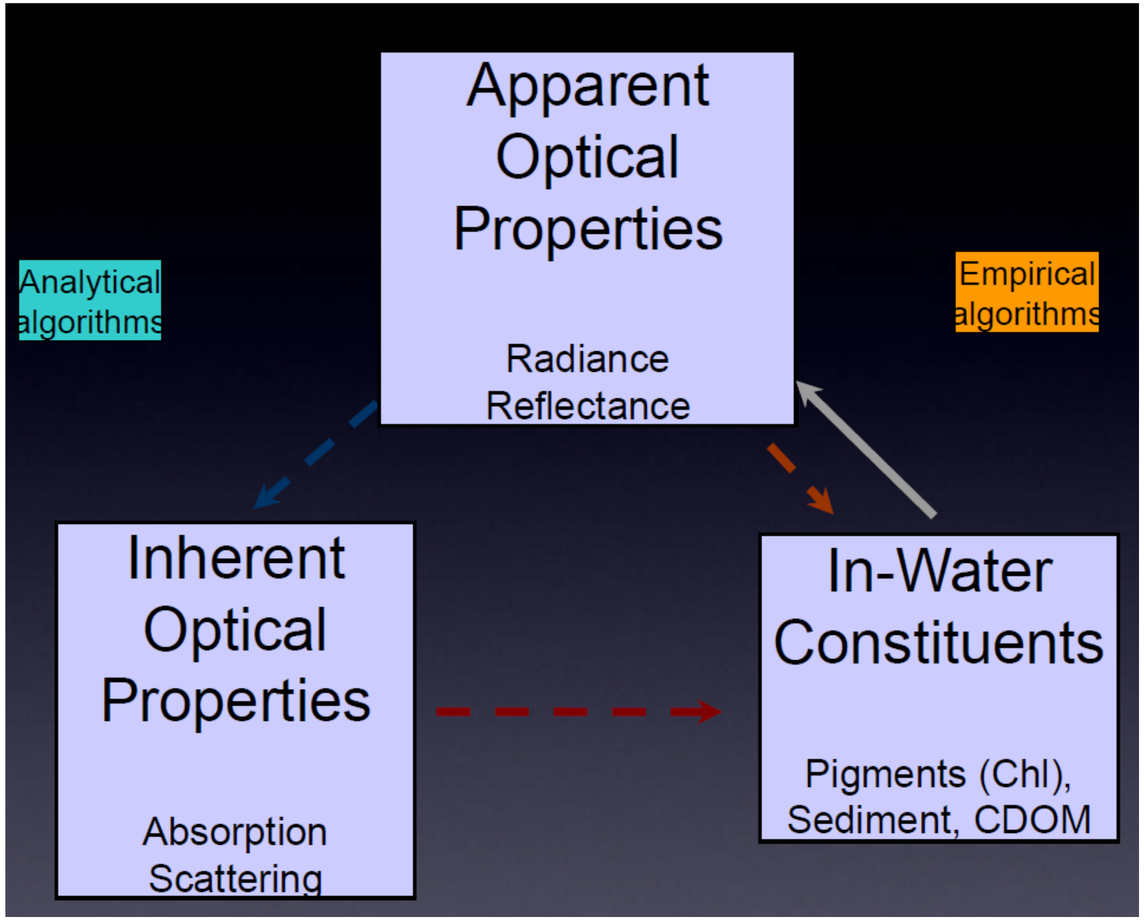
Chl-a algorithms

- Empirical
- Semi-analytical

Empirical algorithms statistically relate measurements (*in situ*) of CHL and Rrs(**λ**).

- Maximum Band Ratio (MBR) (O'Reilly et al., 1998)
- Line-height methods (Hu et al., 2012)
- Linear red-edge ratio (Moses et al., 2012
- Artificial neural network methods (Doerffer and Schiller, 2007).

semi-analytical algorithms (SAA) provide estimates of CHL using a combination of empiricism and simplification of the radiative transfer equations. Most SAAs attempt to estimate simultaneously the magnitudes of CHL, spectral backscattering and the combined absorption by non-algal particles and colored dissolved organic material.



$$\mathrm{Rrs}\left(\lambda,0^{+}\right)\cong C\,\frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)}$$

Chl-a algorithms, empirical

OCX

X = 1:4

$$log_{10}(chlor\_a) = a_0 + \sum_{i=1}^{4} a_i \left(log_{10} \left(\frac{R_{rs}(\lambda_{blue})}{R_{rs}(\lambda_{green})} \right) \right)^i$$

OC5, empirical combined with local lookup tables (Gohin et al., 2002)

OC6, newly developed (Werdell, et al., 2019)

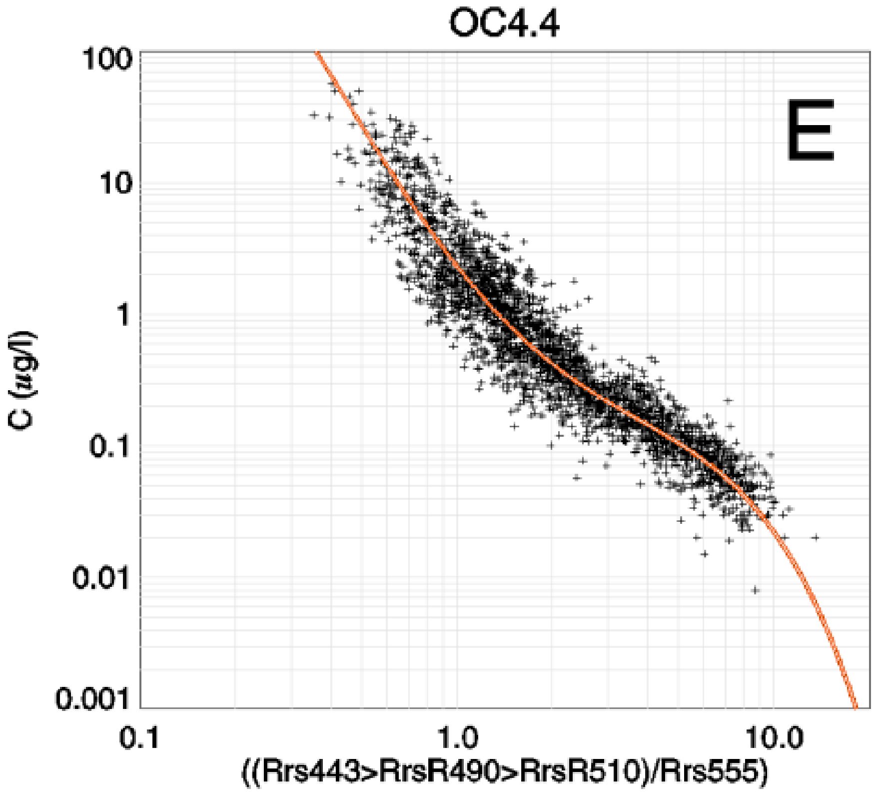
Table 1. Coefficients for the OCx algorithm series in standard processing.

sensor	Algorithm	OCx R_{rs} used (blue/green)	a(0,1,2,3,4)
SeaWiFS	OC4, CI	Rrs(443>489>510)/Rrs555	0.32814; -3.20725; 3.22969; -1.36769; -0.81739
MODIS	OC3M, CI	Rrs(443>488)/Rrs547	0.26294; -2.64669; 1.28364; 1.08209; -1.76828
VIIRS-SNPP	OC3_VIIRS_SNPP, CI	Rrs(443>486)/Rrs551	0.23548; -2.63001; 1.65498; 0.16117; -1.37247
VIIRS-NOAA20	OC3_VIIRS_NOAA20, CI	Rrs(445>489)/Rrs556	0.28153; -2.65472; 1.30882; 1.31521; -2.08622
VIIRS-NOAA21	OC3_VIIRS_NOAA21, CI	Rrs(445>488)/Rrs555	0.24765; -2.54926; 1.55323; 0.39485; -1.54632
MERIS	OC4E, CI	Rrs(443>489>510)/Rrs560	0.42487; -3.20974; 2.89721; -0.75258; -0.98259
OCTS	OC4O, CI	Rrs(443>489>516)/Rrs565	0.54655; -3.51799; 3.39128; -0.91567; -0.97112
GOCI	OC4,CI	Rrs(412>443>489)/Rrs555	0.28043; -2.49033; 1.53980; -0.09926; -0.68403
HAWKEYE	OC4, CI	Rrs(447>488>510)/Rrs556	0.32814, -3.20725,3.22969, -1.36769, -0.81739
OLCI	OC4, CI	Rrs(443>490>510)/Rrs560	0.42540; -3.21679; 2.86907; -0.62628; -1.09333
CZCS	OC3, CI	Rrs(443>520)/Rrs555	0.31841; -4.56386; 8.63979; -8.41411; 1.91532

https://oceancolor.gsfc.nasa.gov/atbd/chlor_a/

Chl-a algorithms, empirical

Example: OC4



OC4 version 4

C = 10.0^(a(0) + a(1)*R + a(2)*R^2 + a(3)*R^3 + a(4)*R^4)

R = ALOG10((Rrs443>Rrs490>Rrs510)/Rrs555)

a = [0.366,-3.067,1.930,0.649,-1.532]

Remote-sensing reflectance maximum band ratio
([443,490,510]/555)
as a function of chlorophyll-a concentration

Chl-a algorithms, empirical

$$CI = R_{rs}(\lambda_{green}) - [R_{rs}(\lambda_{blue}) + (\lambda_{green} - \lambda_{blue})/(\lambda_{red} - \lambda_{blue}) * (R_{rs}(\lambda_{red}) - R_{rs}(\lambda_{blue}))]$$

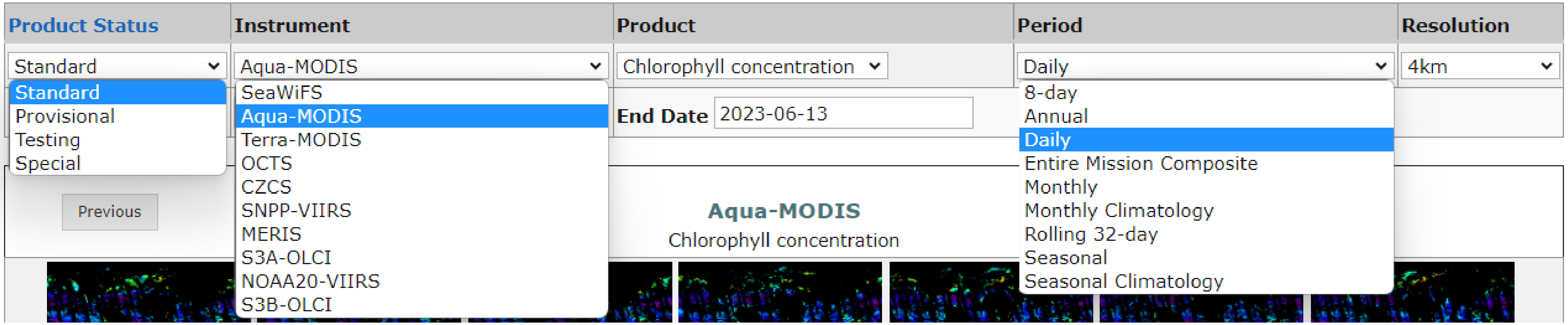
- For chlorophyll retrievals below 0.25 mg m^{-3}, the CI algorithm is used.
- For chlorophyll retrievals above 0.35 mg m^{-3}, the OCx algorithm is used.
- In between these values, the CI and OCx algorithm are blended using a weighted approach where:

$$chlor\_a = \frac{chlor\_a_{CI}(t_2 - chlor\_a_{CI})}{t_2 - t_1} + \frac{chlor\_a_{OCx}(chlor\_a_{CI} - t_1)}{t_2 - t_1}$$

with t_1 = 0.25, and t_2=0.35 (edges of the current blending region).

NASA standard Ocean Color Products: OCX & CI (chlor_a)

NASA Standard Ocean Color Products

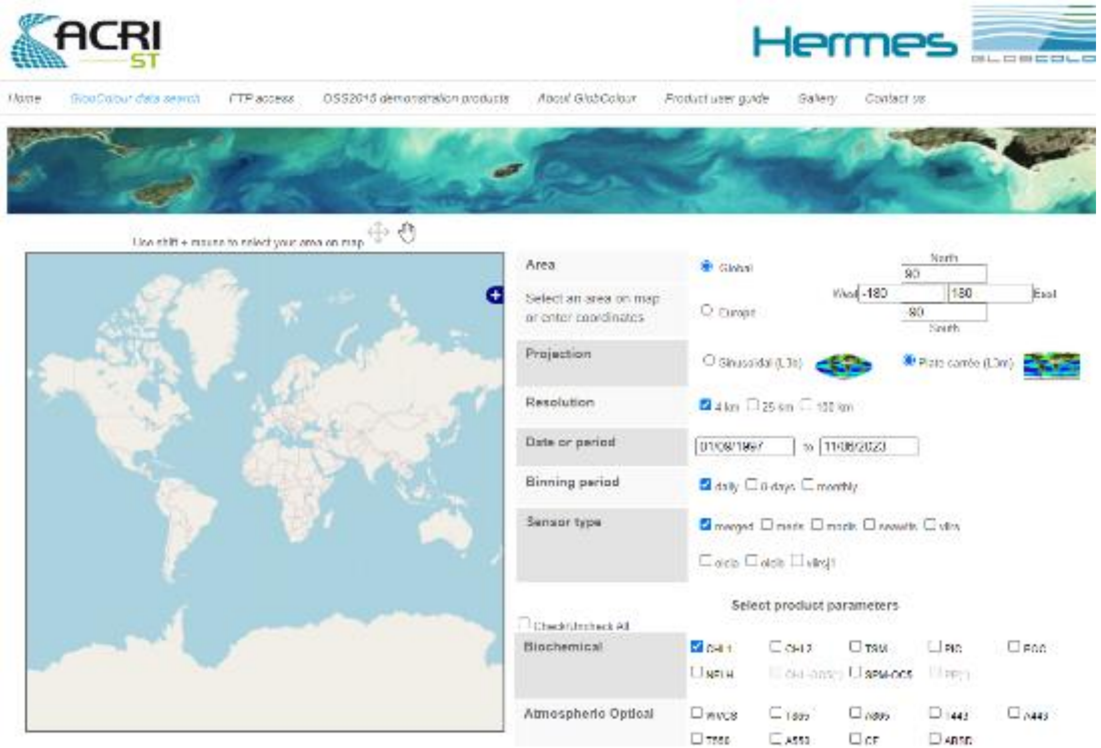


https://oceancolor.gsfc.nasa.gov/

International Ocean Color Products

HERMES GloubColour

https://hermes.acri.fr/index.php?class=archive

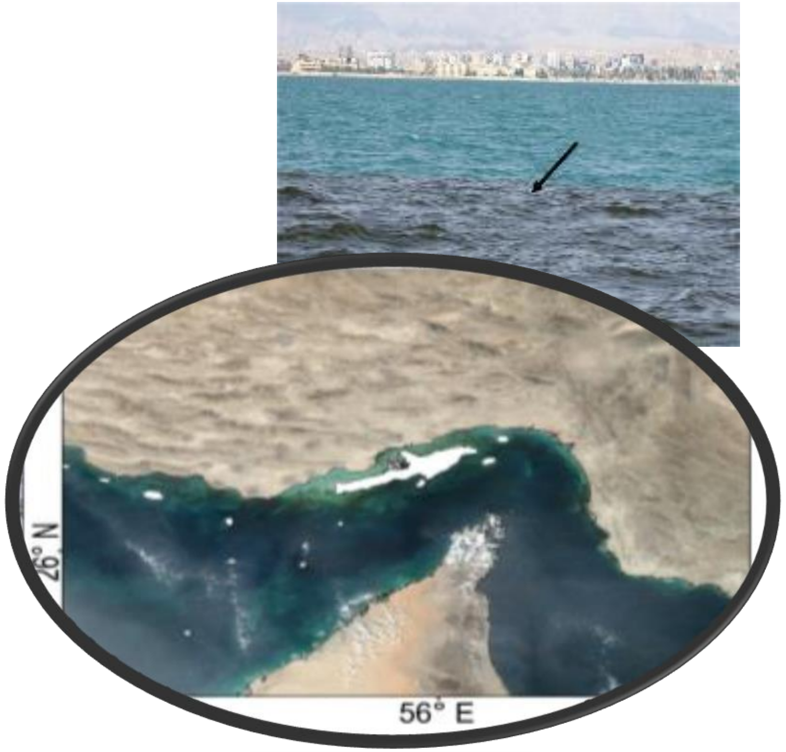


ESA Ocean Color Climate Change Initiative

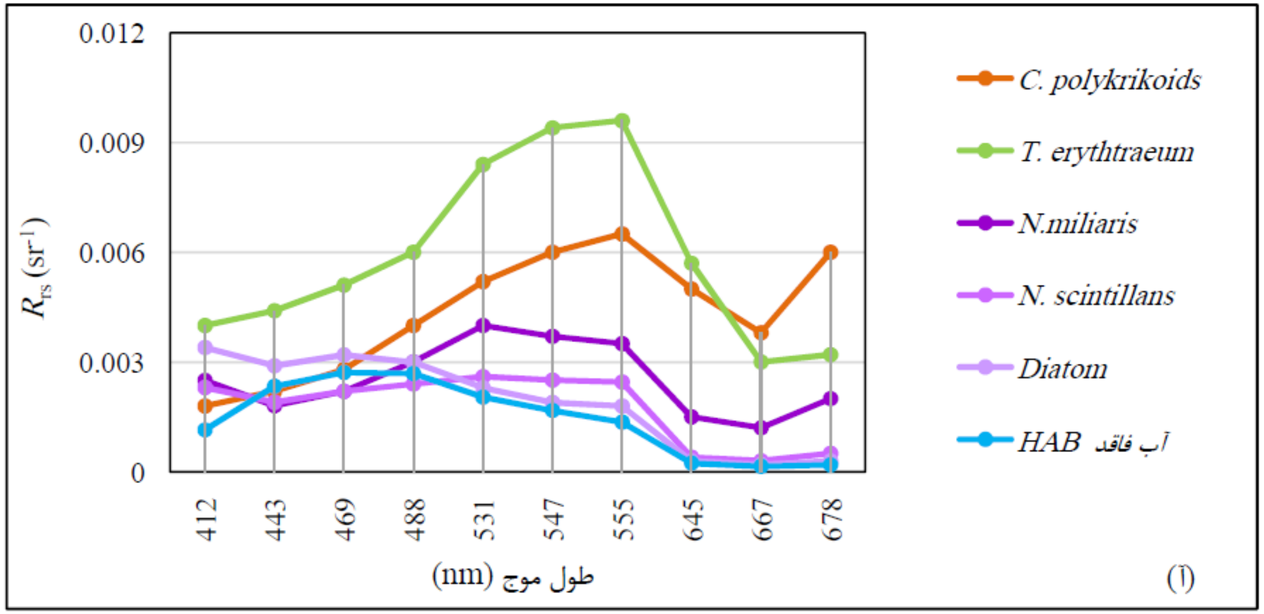
https://climate.esa.int/en/projects/ocean-colour/

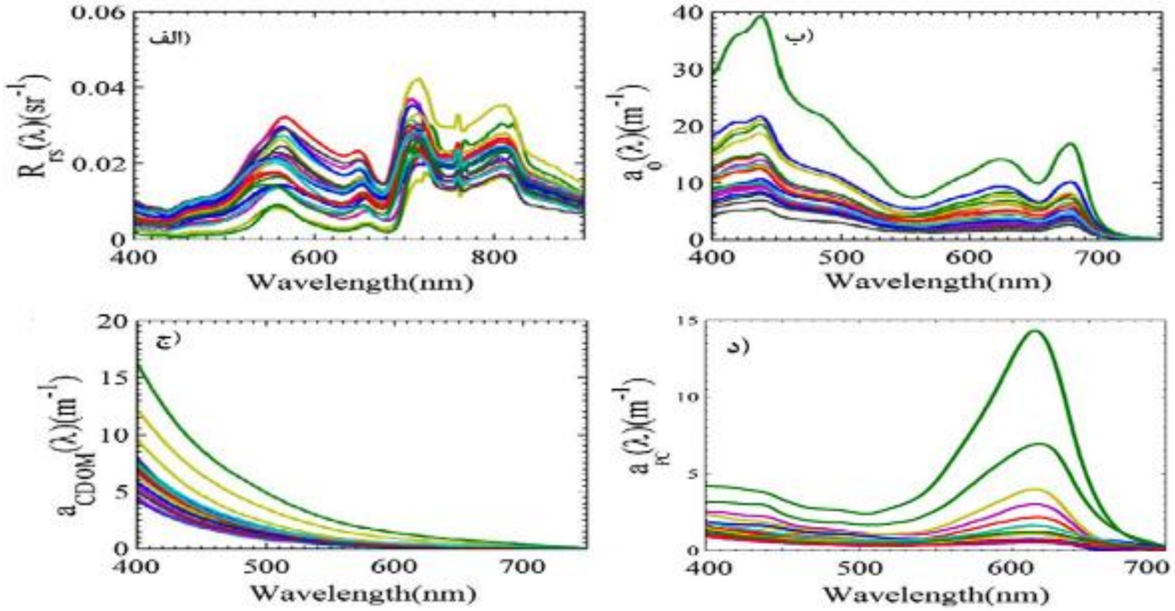
How remote sensing can help?

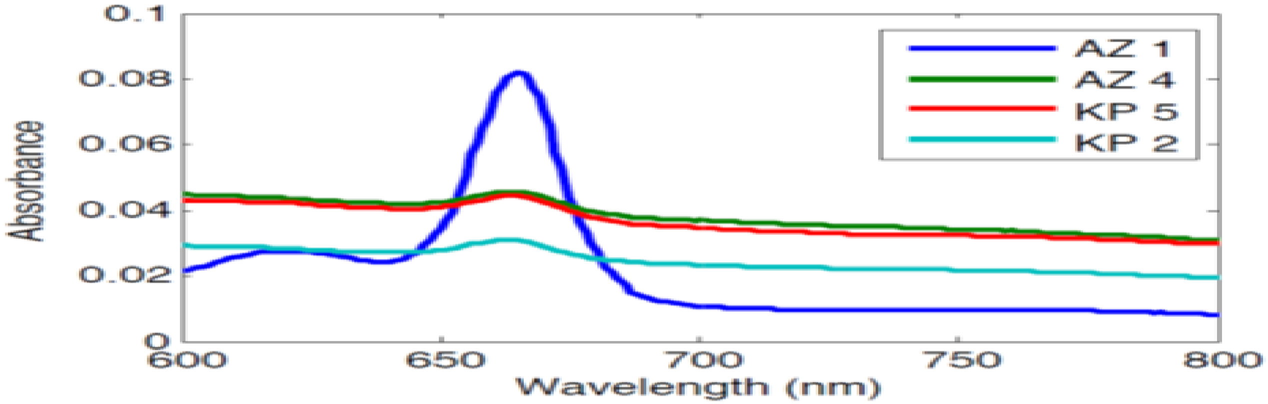
Marine Algae Blooms

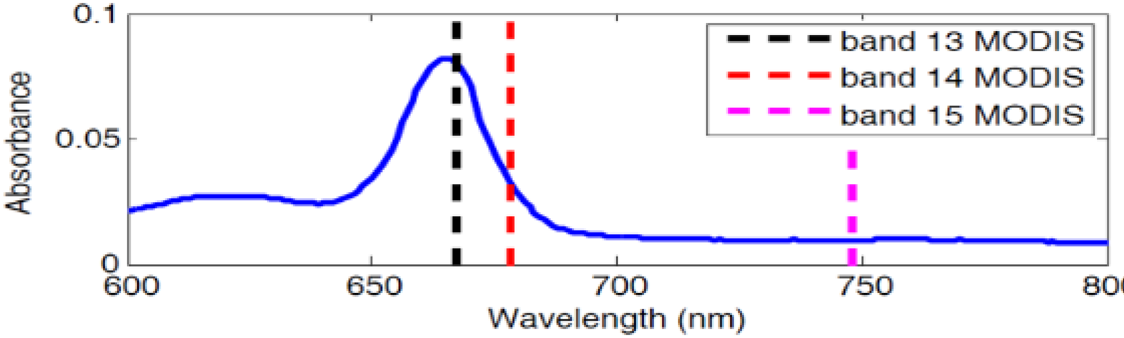


How remote sensing can help?

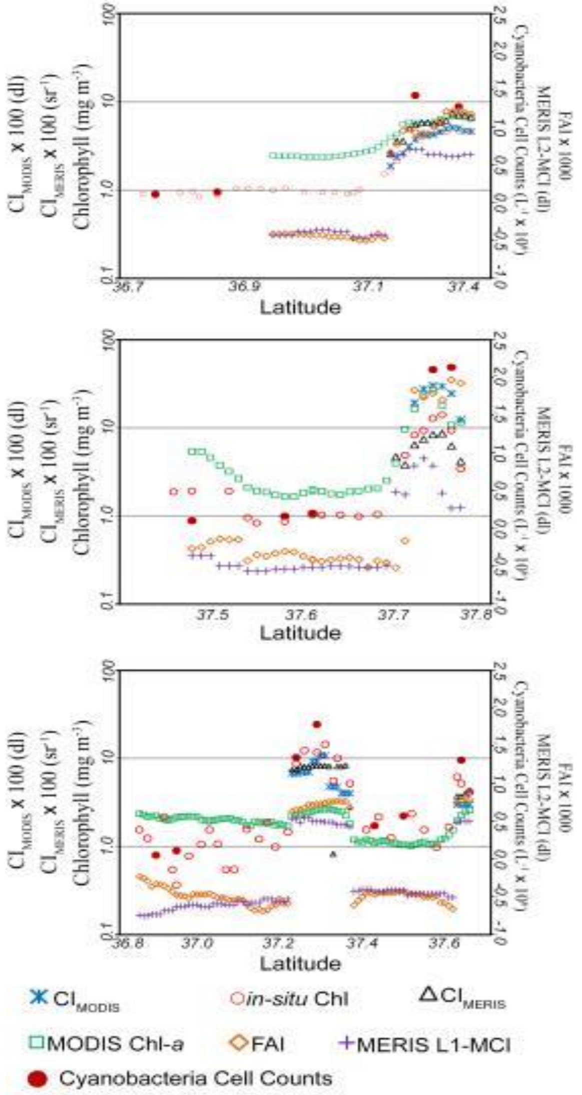


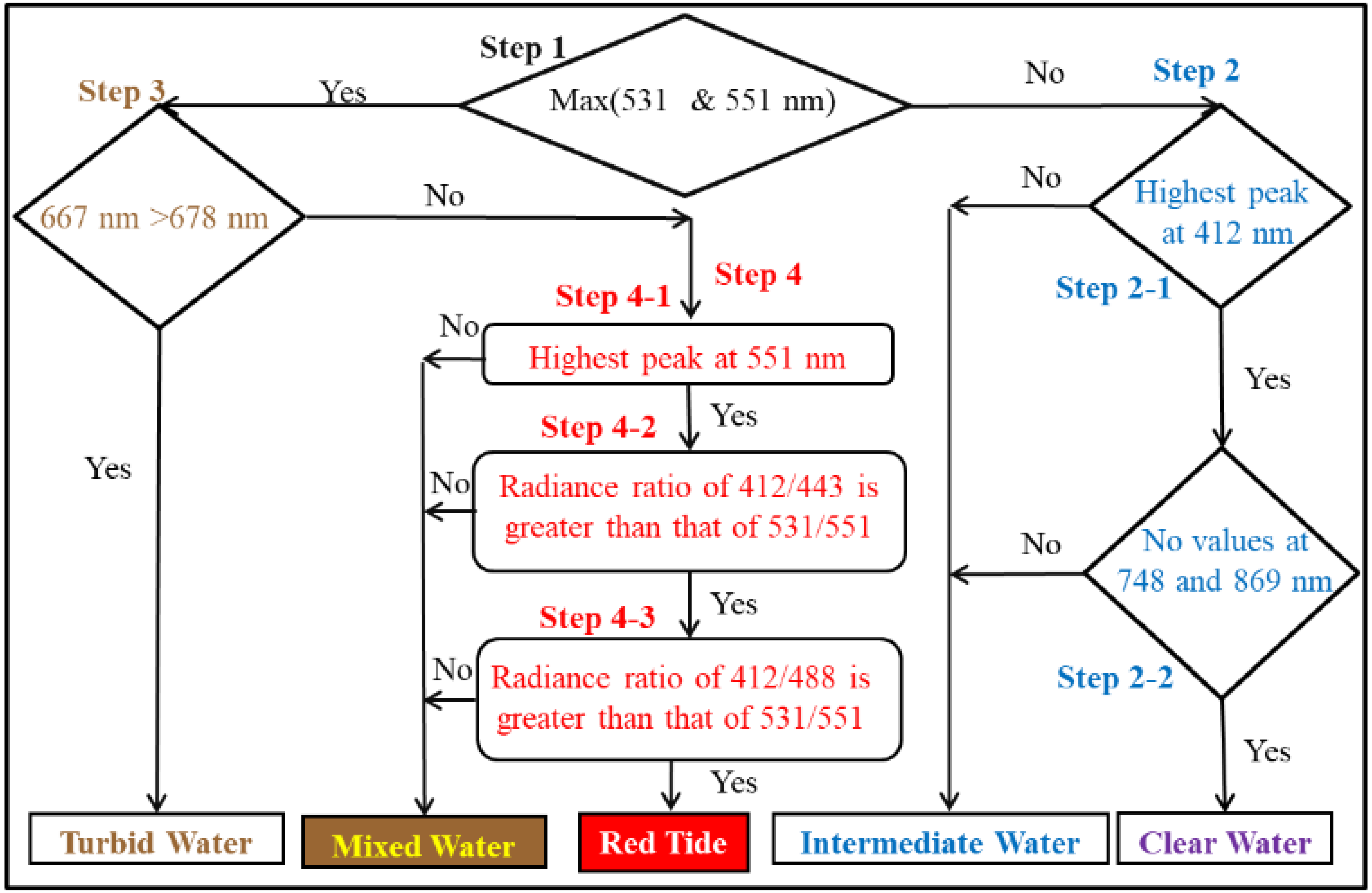




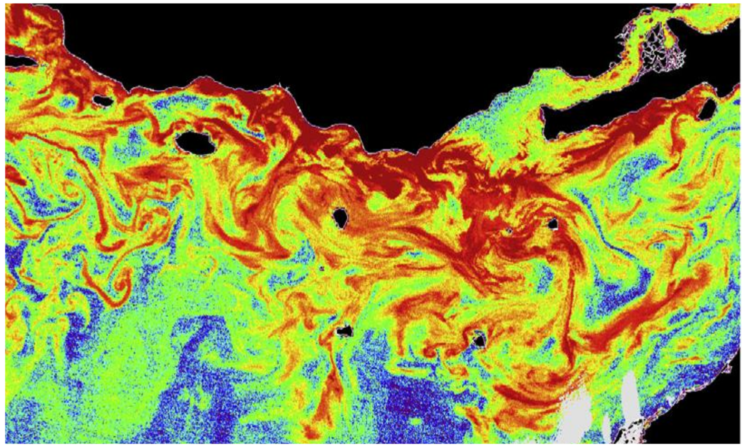


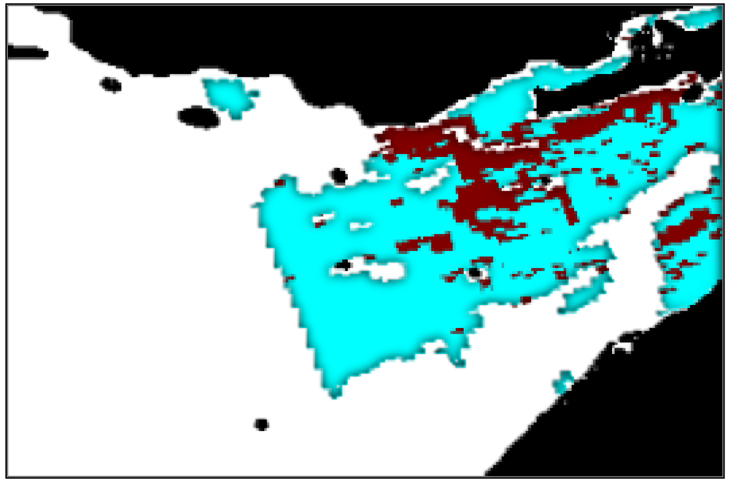
How remote sensing can help?

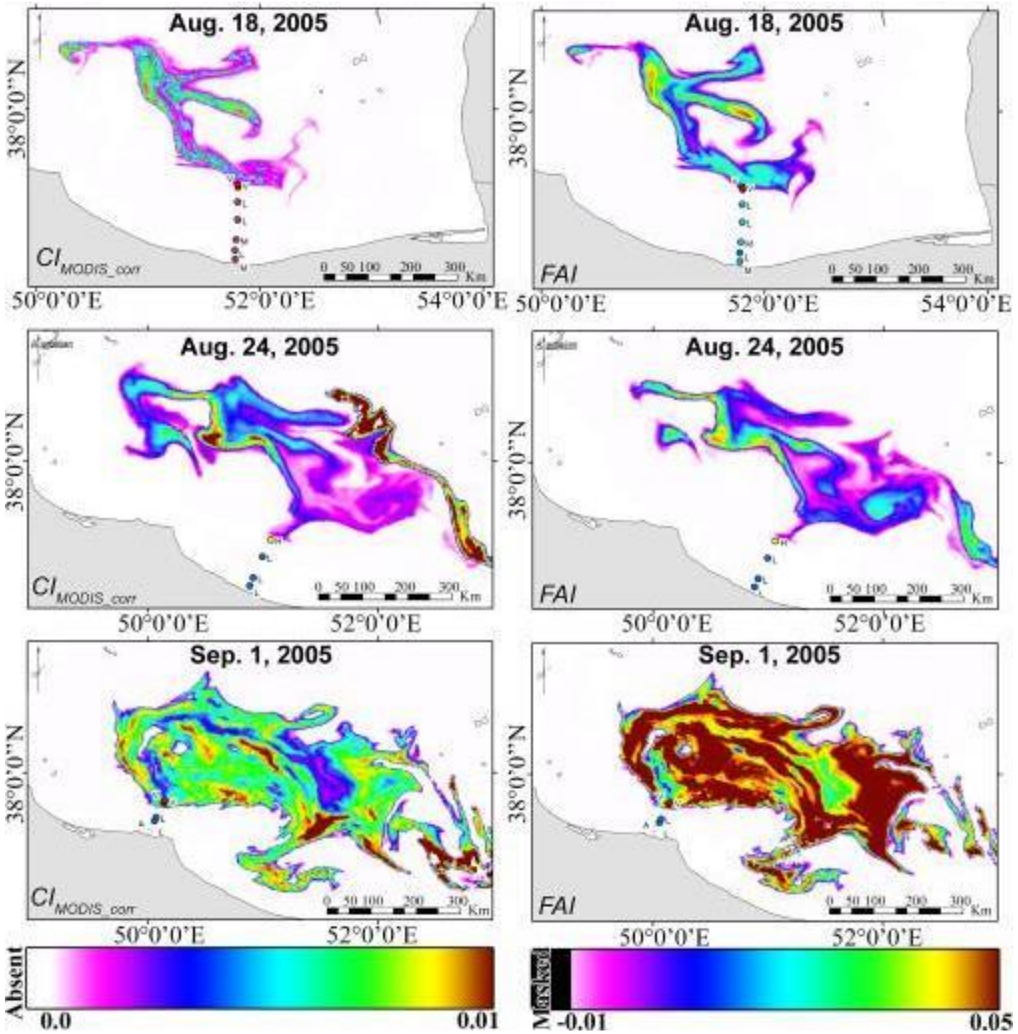




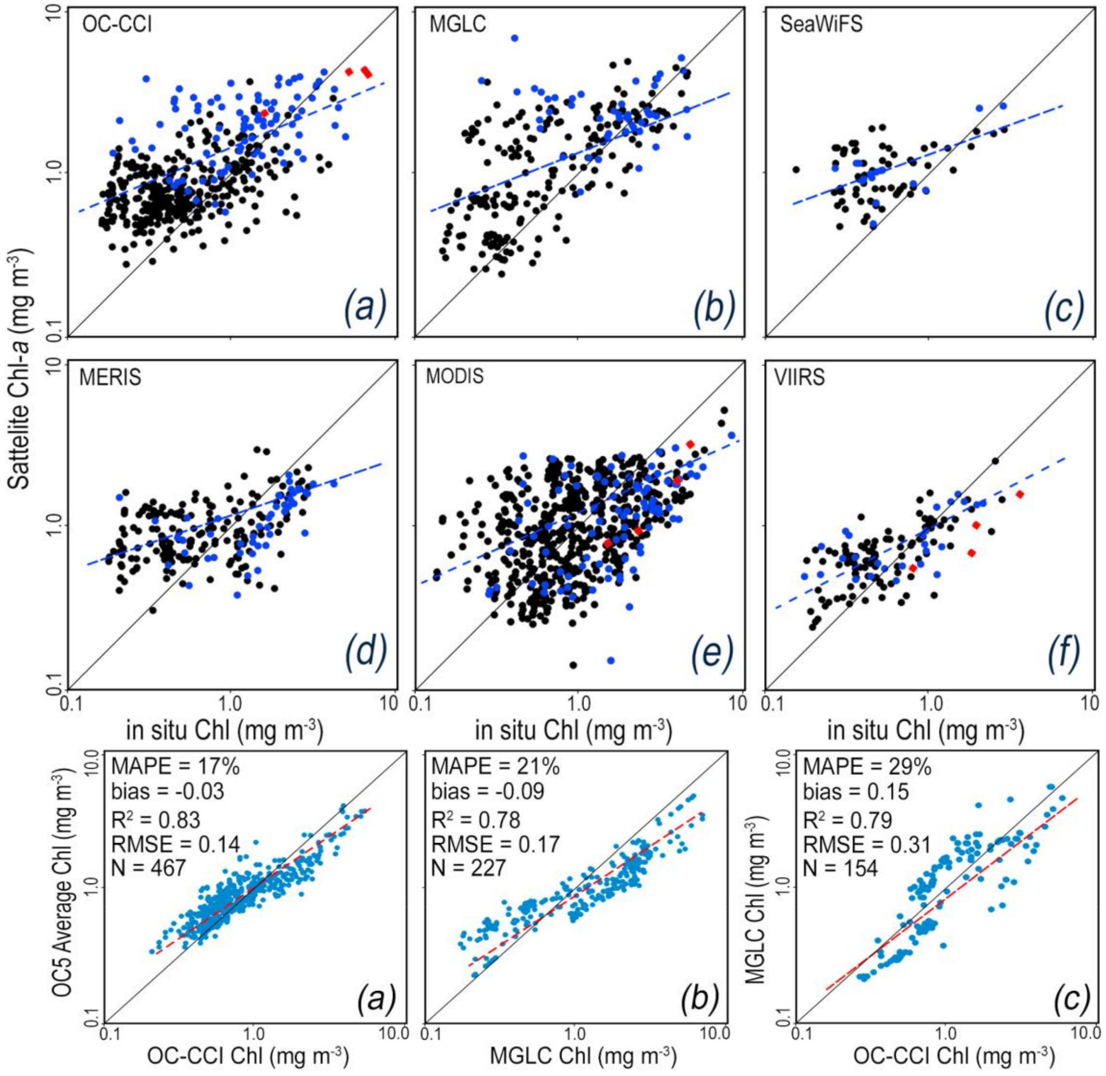
How remote sensing can help?

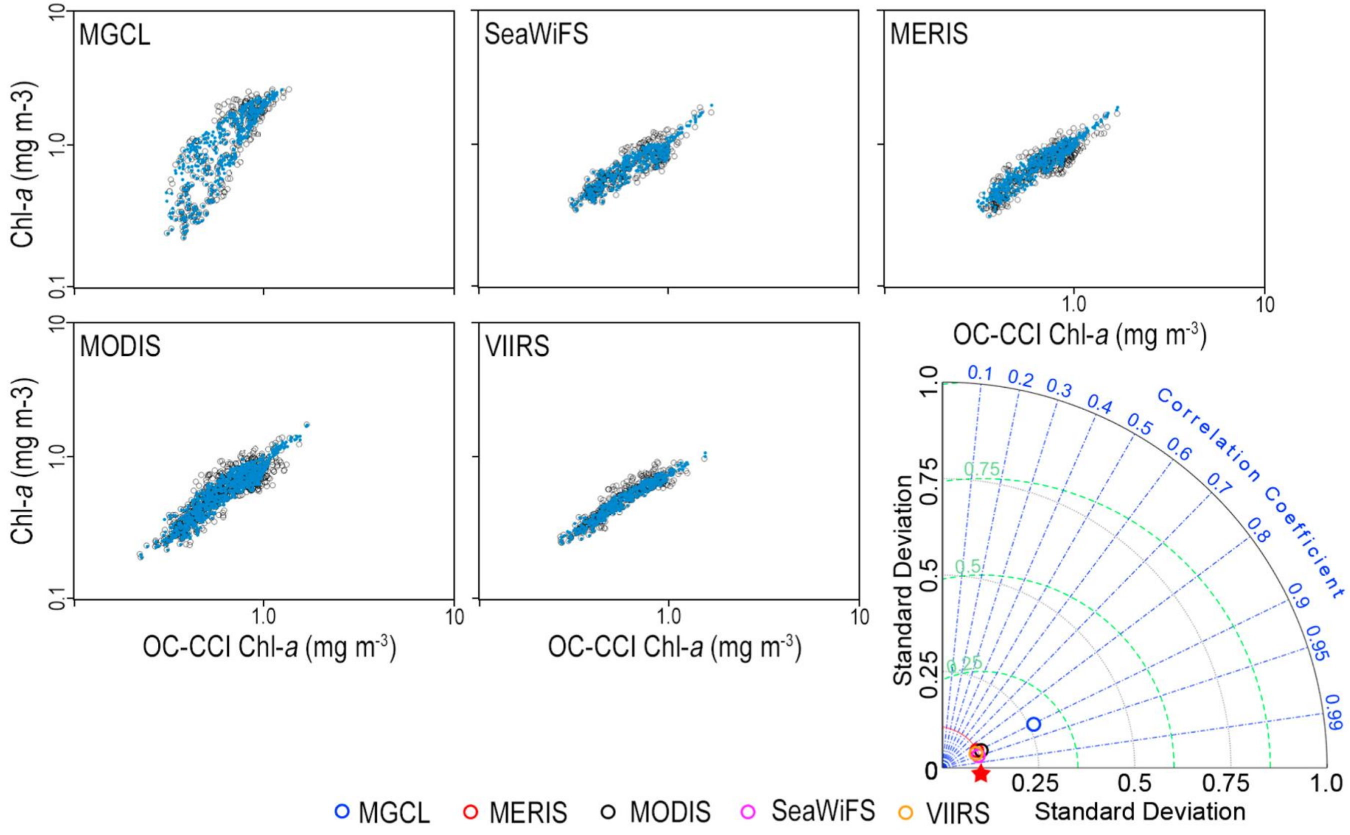




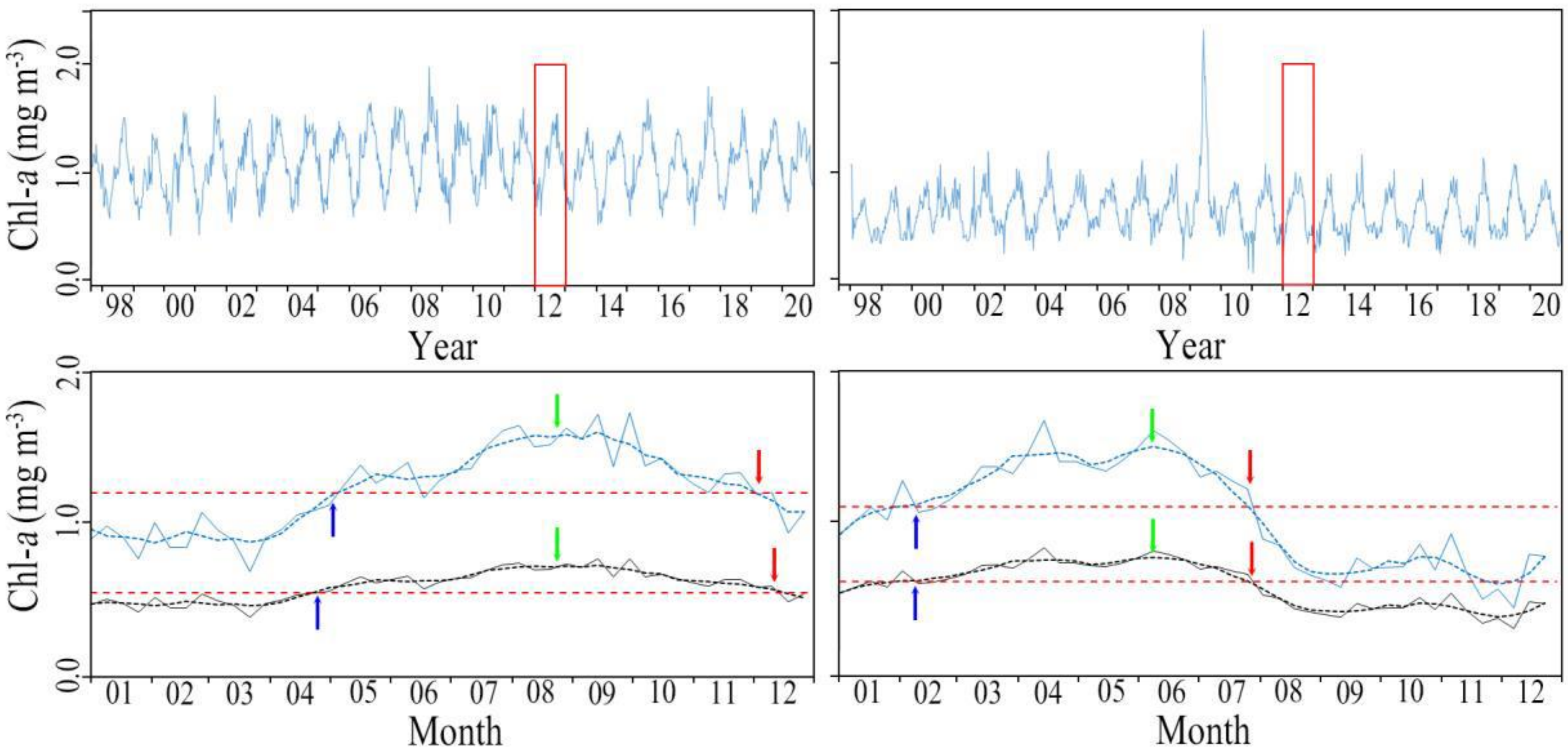


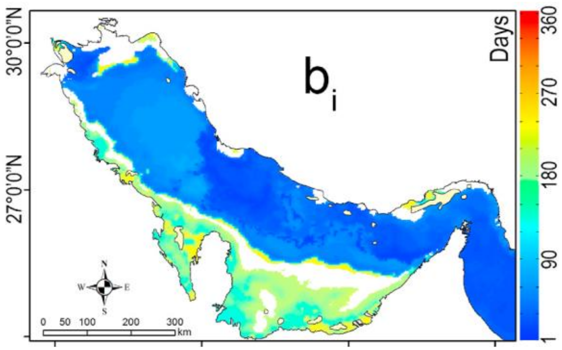
Application: Ocean Color Assessment, Persian Gulf

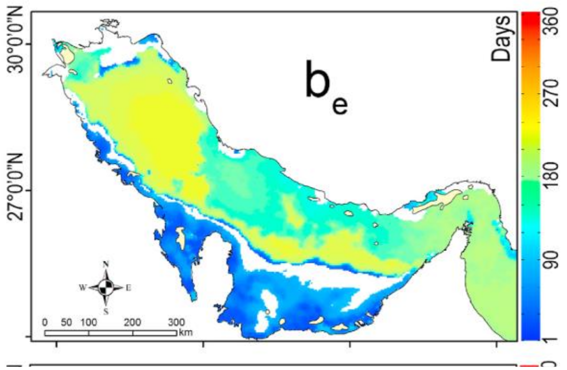




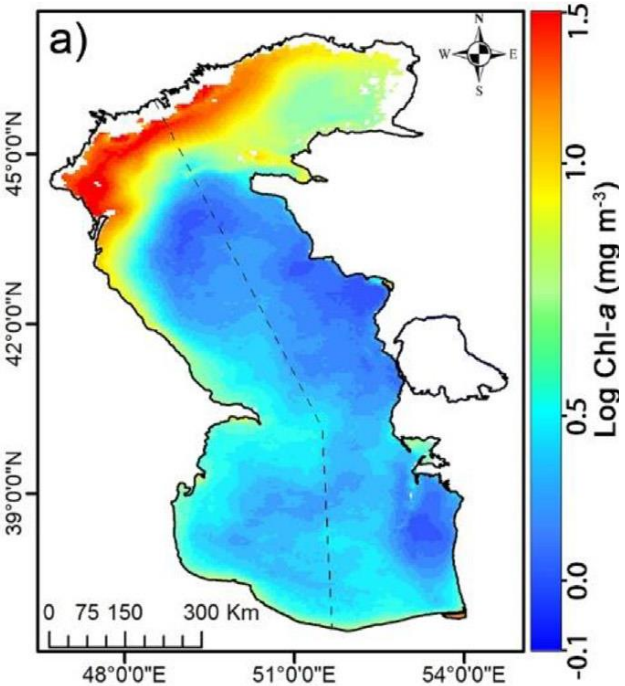
Application: Phytoplankton Phenology, Persian Gulf

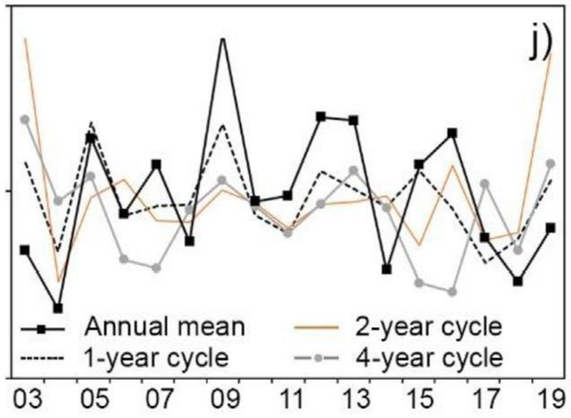


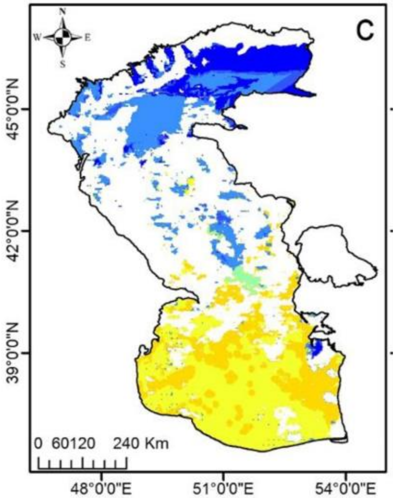




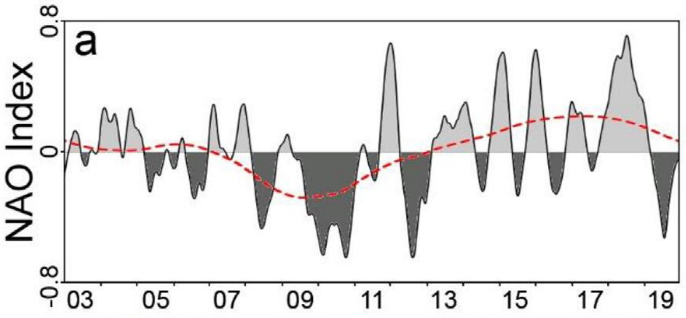
Application: Environmental factors regulating Chlorophyll distribution, Caspian Sea

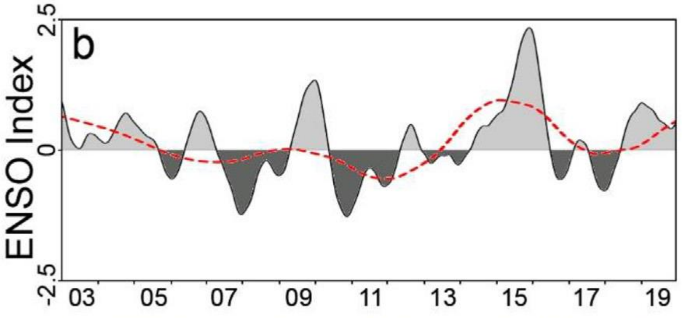


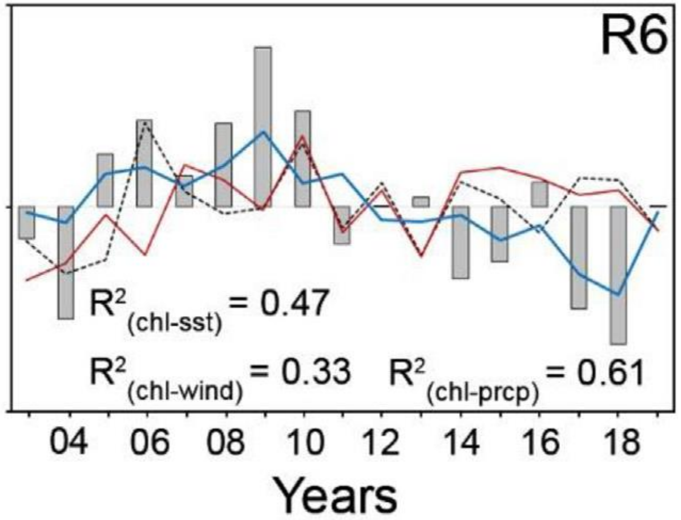




Spatial distribution of the maximum cross-correlation coefficients between the 2-year cycles in Chl-a and NAO







Seasonal mean values of Chl-a (grey bars), precipitation (blue line), SST (red line) and wind stress (black dashed line) anomalies in different SOM regions

Thank You