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FACULDADE DE CIÊNCIAS

A Ciência de hoje é mais que a Tecnologia de amanhã

Satellite Remote sensing over water surfaces

I-Passive sensing of the water surface

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Outline of the Lecture (Part I):

1) Introduction:

- Remote sensing methods: satellite passive sensors
- Satellite orbits for Remote Sensing
- Technical issues: corrections

2) Basic principles of satellite sensing of water bodies: colour

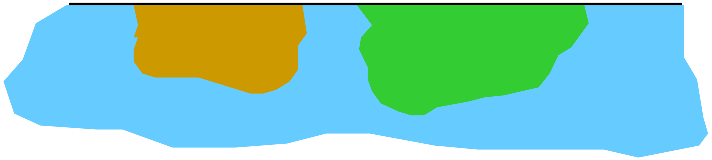
- Spectra of some water constituents
- Case study of ocean colour: the Tagus turbid river plume

3) Thermal infrared and water temperature determination

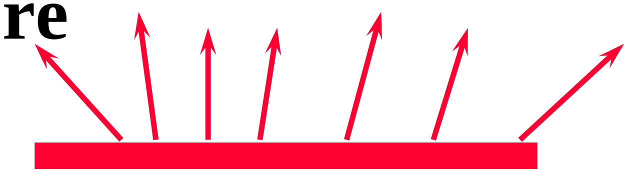
- Atmospheric correction
- An example of an application

What can be measured?

- Water colour



- Sea Surface Temperature

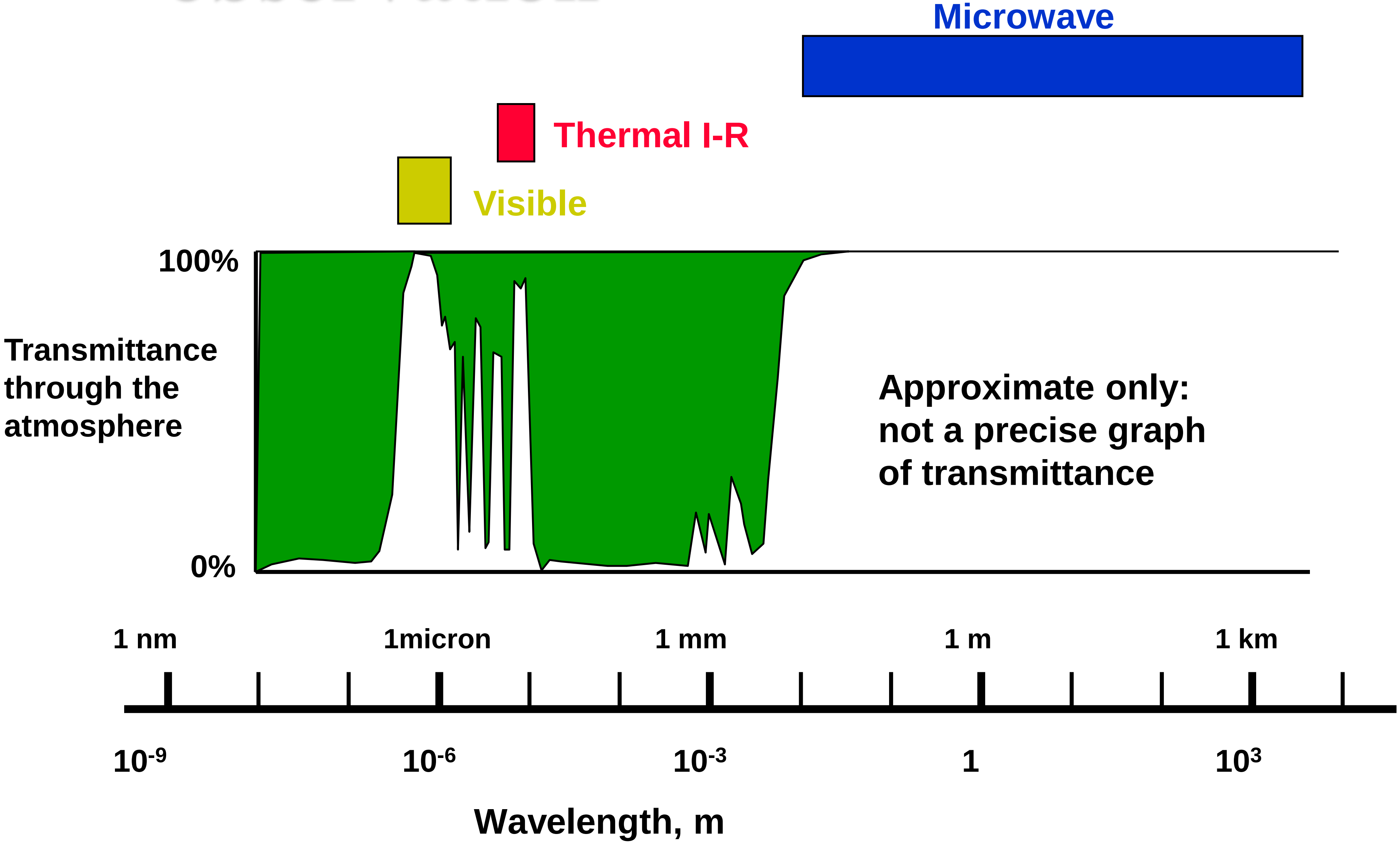


- Roughness of water surface

- Surface inclination

- Salinity of ocean surface (or humidity of land); but resolution is low

Spectral 'windows' for earth observation

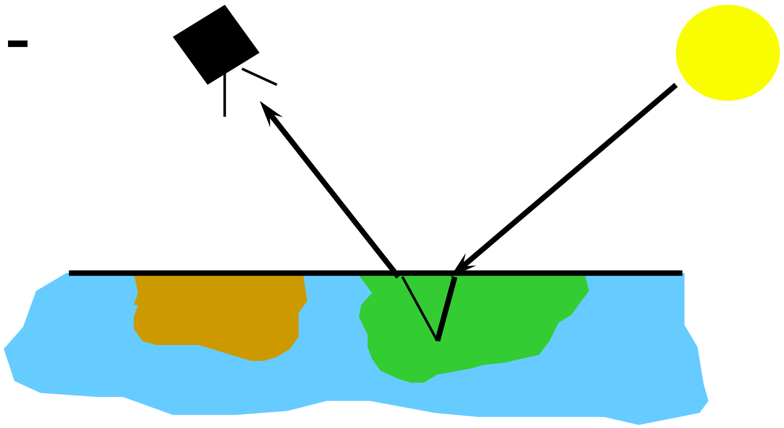


Approximate only: not a precise graph of transmittance

R-S methods- Passive Sensors

- Visible wavelength devices - Reflected sunlight

  Ocean colour

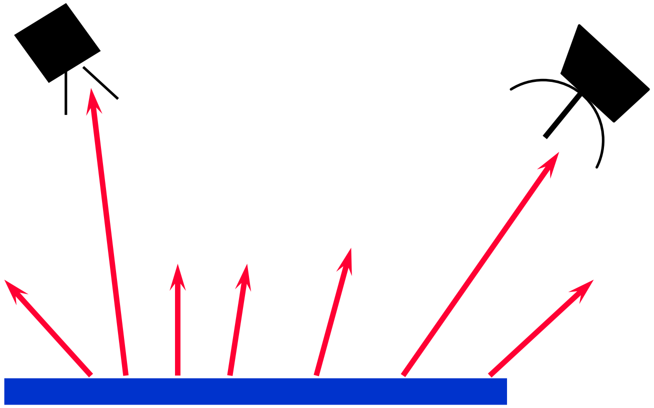


- Thermal Infra-red radiometers - emitted radiation

  Microwave radiometers - emitted radiation

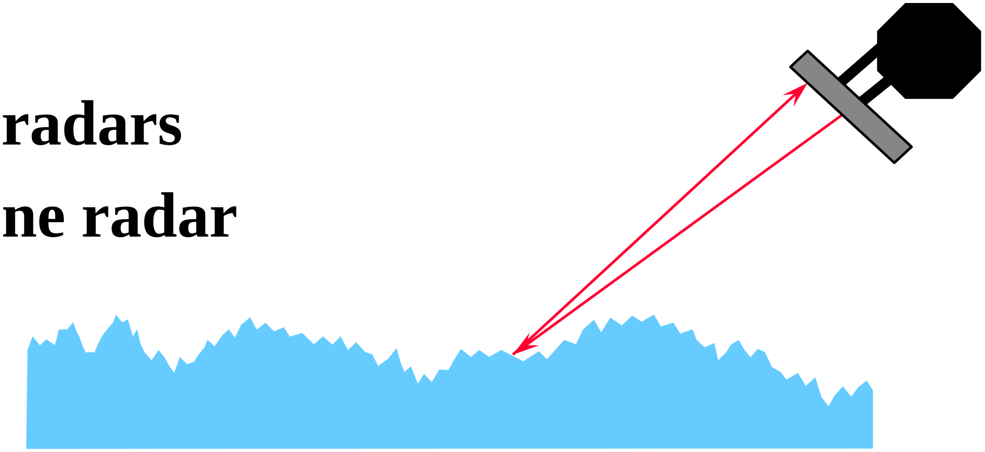
  Sea surface temperature

  Other factors affecting emissivity

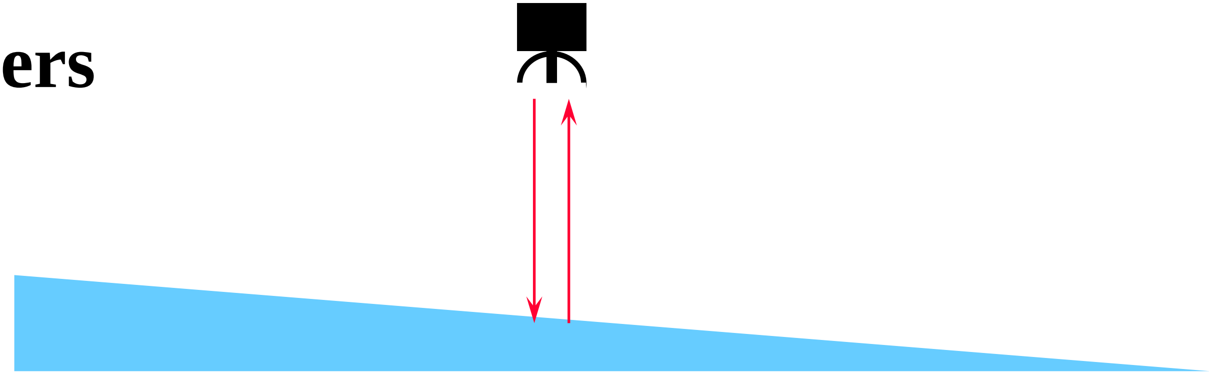


R-S methods- Active Sensors

- Radar (microwave) scatterometers
- Imaging radars
    - Synthetic aperture radars
    - Side looking airborne radar

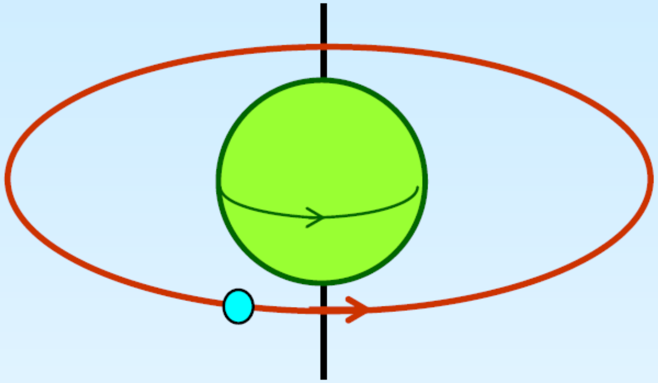


- Radar Altimeters

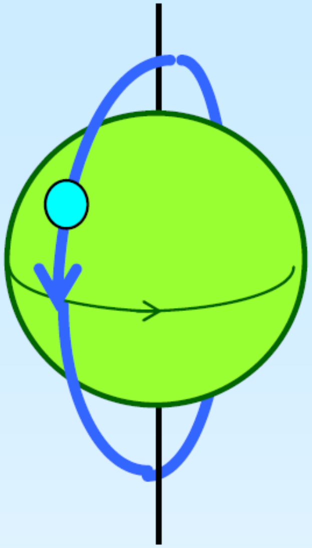


Typical orbits for earth observation

- Geostationary orbits
  - Orbital period one sidereal day (T = 23.93 hrs) so the satellite travels round with the earth.
  - This requires r = 42290 km, h = 35910 km.
  - Always remains at the same point on Equator



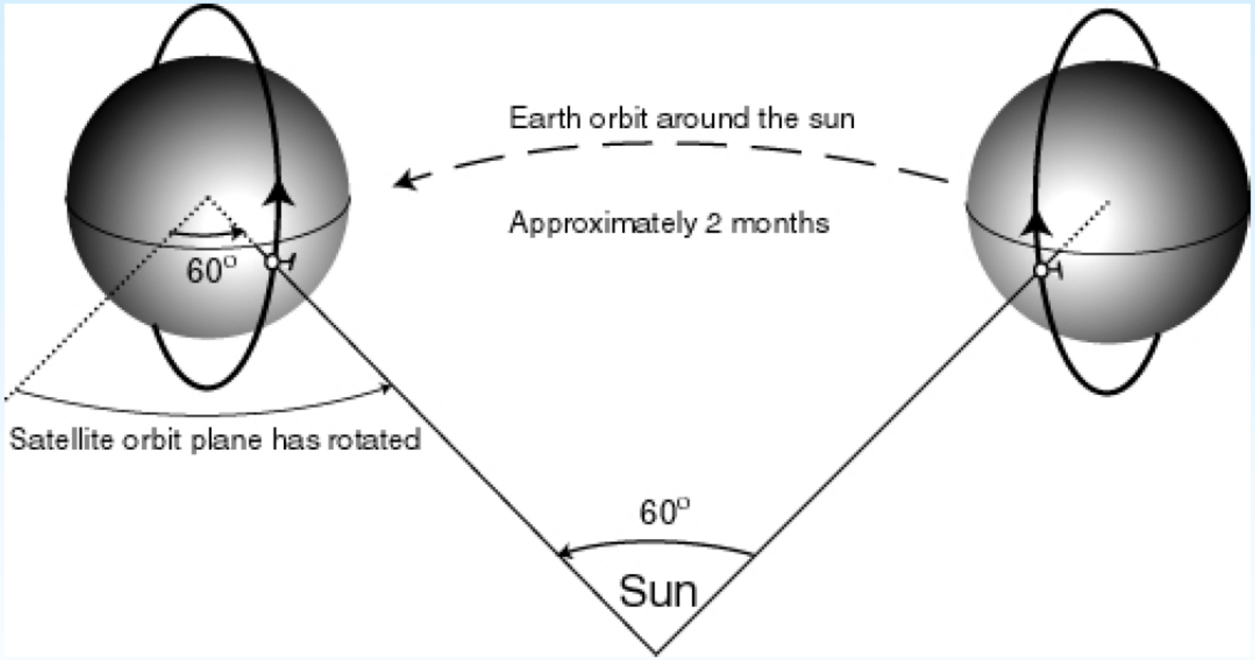
Near-polar orbits



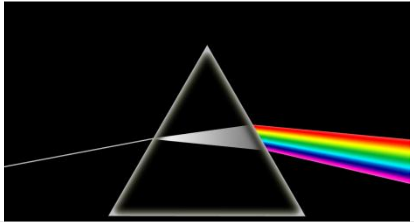
- Near-polar orbits
  - h is 700 to 1000 km.
  - T is approximately 100 min.
  - That is ~14 -15 orbits per day

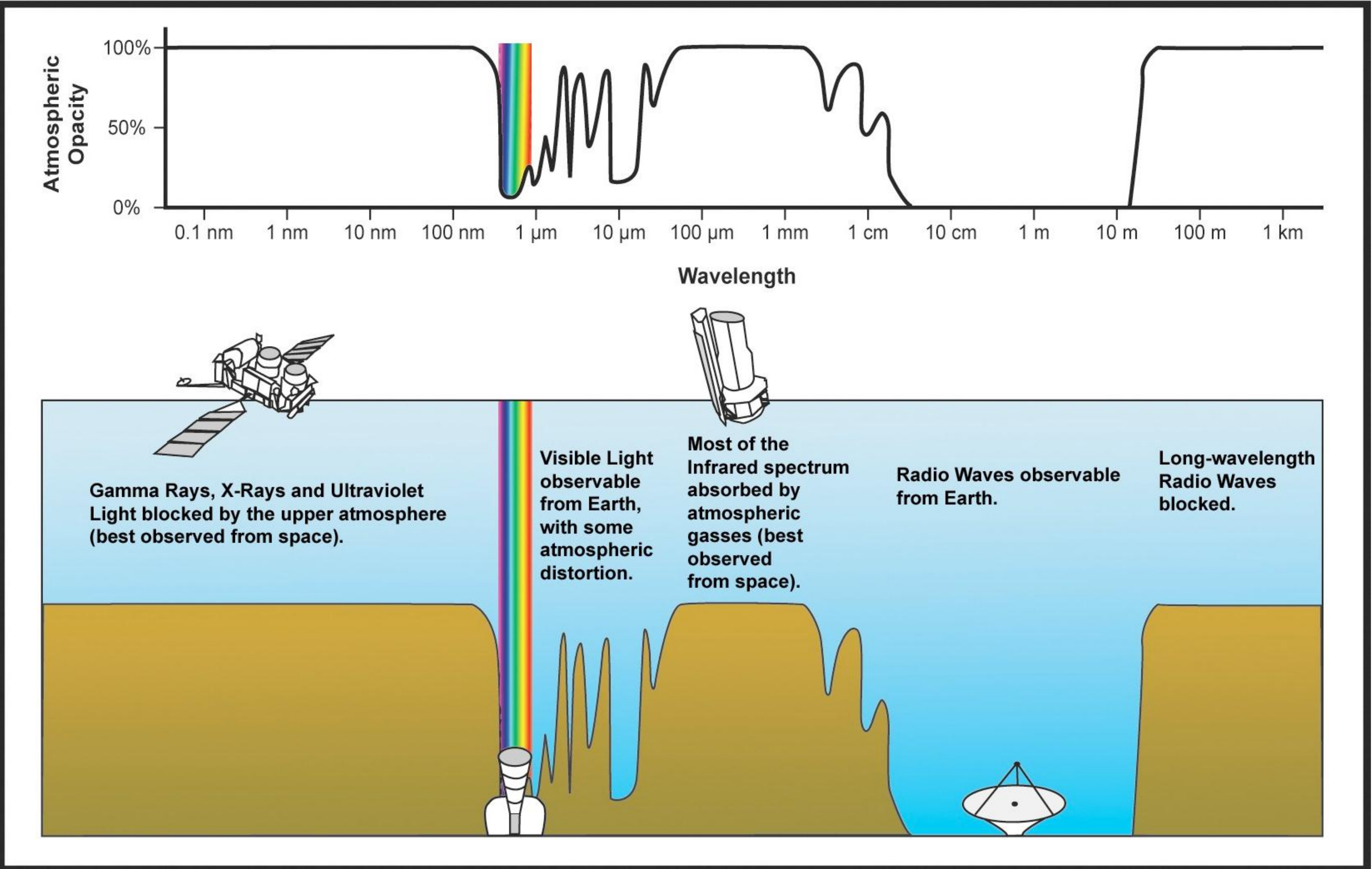
Sun-synchronous orbits

- A special class of polar orbit
- The orbit plane *precesses* in phase with the sun



- Satellite passes over a given latitude at the same local (solar) time every day.
- Provides consistent solar illumination for all overpasses
- But aliases any diurnal variations in the parameter / process being observed
  - This renders it unsuitable for accurate altimetry





Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).

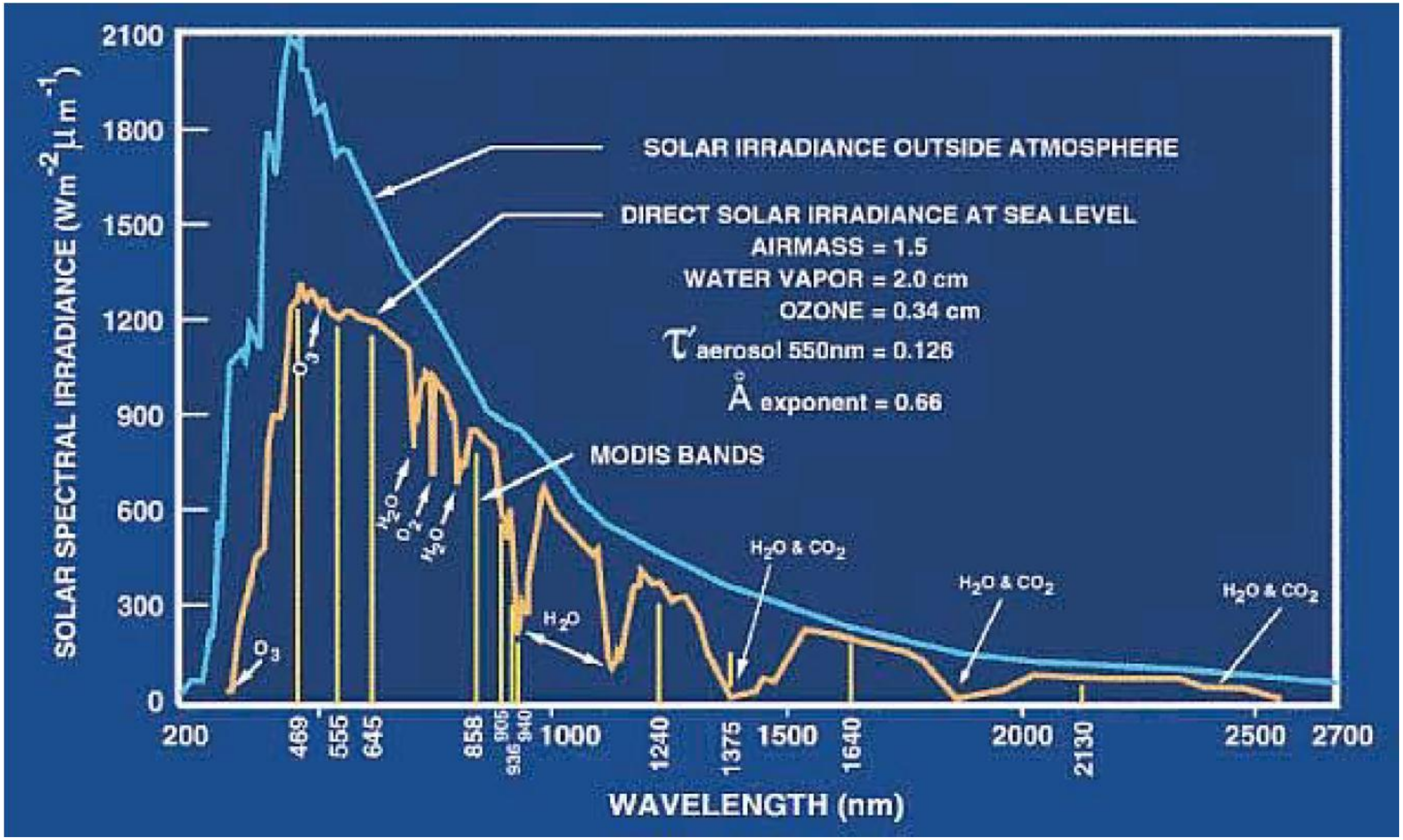
Visible Light observable from Earth, with some atmospheric distortion.

Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).

Radio Waves observable from Earth.

Long-wavelength Radio Waves blocked.

Surface vs. TOA solar radiation

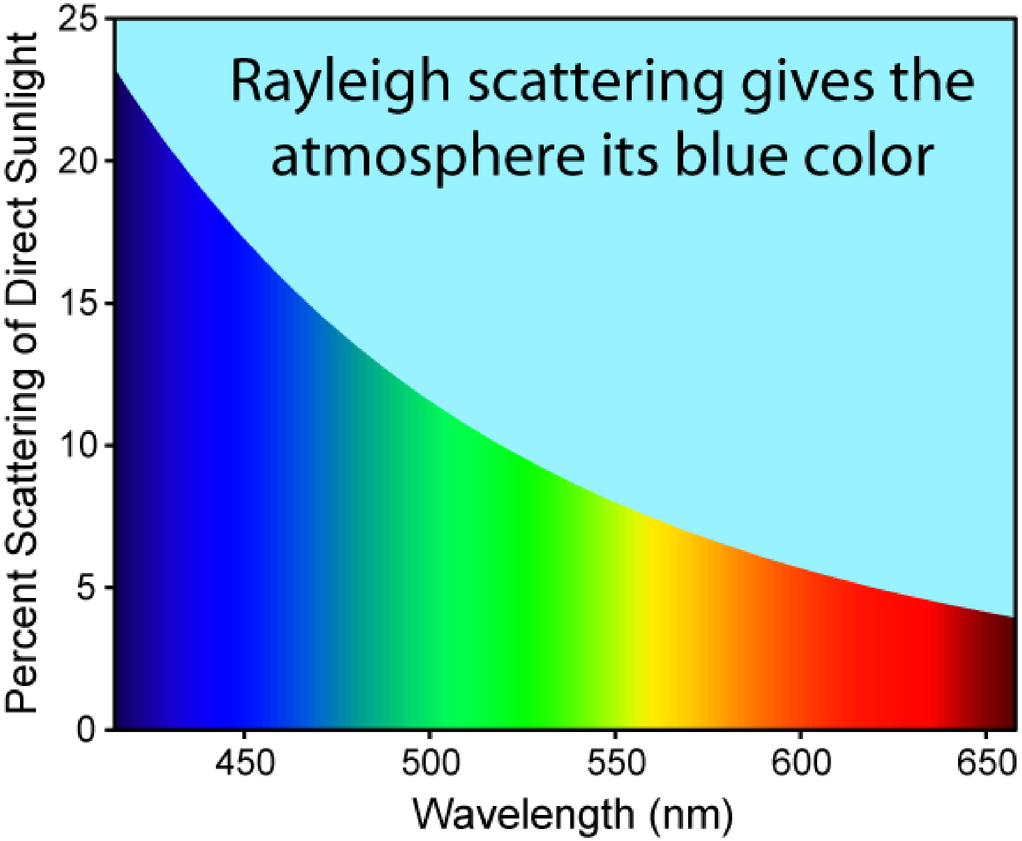


Courtesy
NASA

Scattering

- Rayleigh scattering
  - -by particles much smaller than wavelength of light -
  - wavelength dependent (inverse dependence on fourth power) -
  - blue light is scattered more than red light
- Mie scattering
  - Particles about one tenth of wavelength or larger
- Scattering by much larger bodies

Rayleigh scattering in the atmosphere



$I \sim 1/\lambda^4$

The reason why the sky is blue!

http://en.wikipedia.org/wiki/Rayleigh_scattering

Sizes of particles in atmosphere

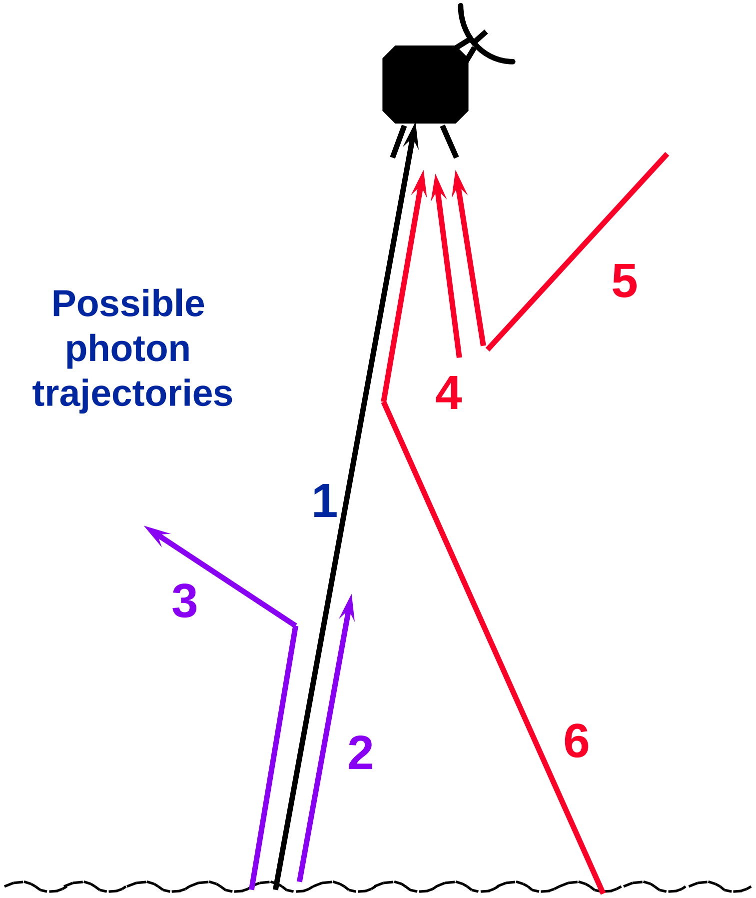
- Gases

- Aerosol

Absorption

- Molecular absorptions
  - Rotational
  - Vibrational (bending, stretching)
  - Electrons moving between energy levels (also for atoms)

Atmospheric correction



Sensor measures 1+4+5+6

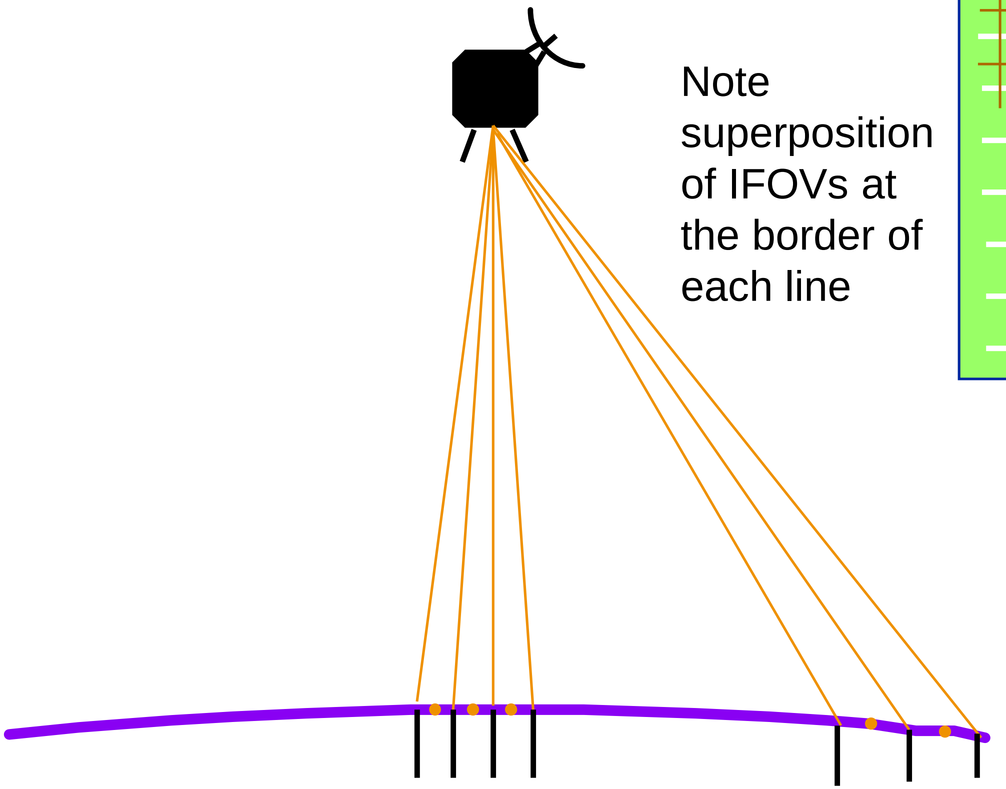
The objective of atmospheric correction is to estimate 1+2+3.

Explanation	Importance		
	Vis	I-V	MW
1 signal arriving directly to sensor			x
2 absorbed signal		x	
3 signal scattered outside of field of view (FOV)	x		
4 atmospheric emission		x	
5 solar radiation scattered in the direction of FOV	x		
6 signal from outside FOV scattered into the FOV	x		

Geometric distortion

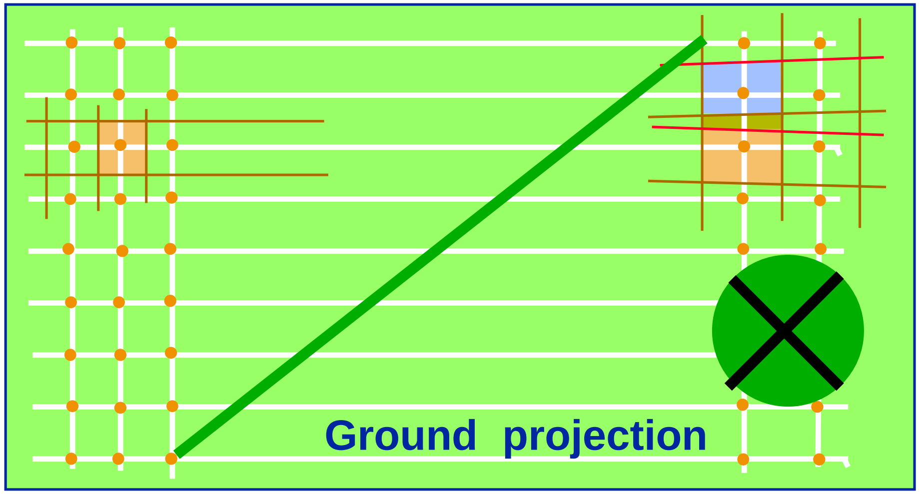
An image acquired by a type of sensor called “*mechanical scanning*” is assembled by taking measurements in uniform angular increments along a line.

Without correction an image would be assembled into a distorted map



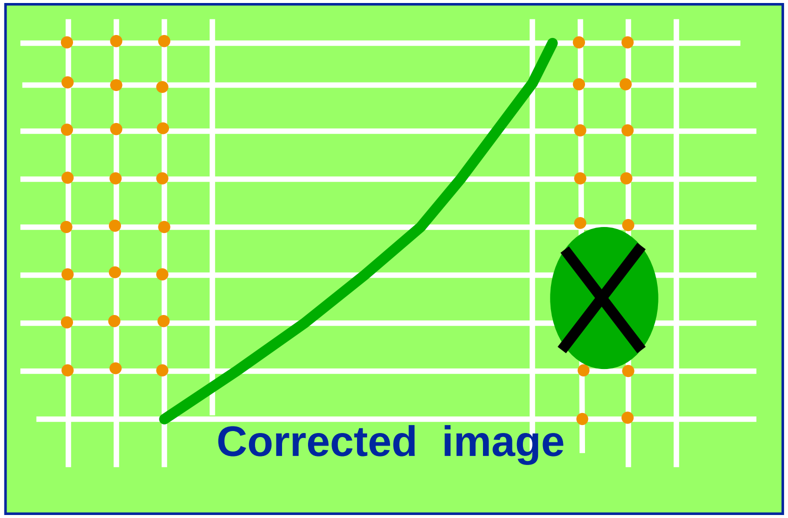
Note superposition of IFOVs at the border of each line

Distance between *pixels* increases along an image line

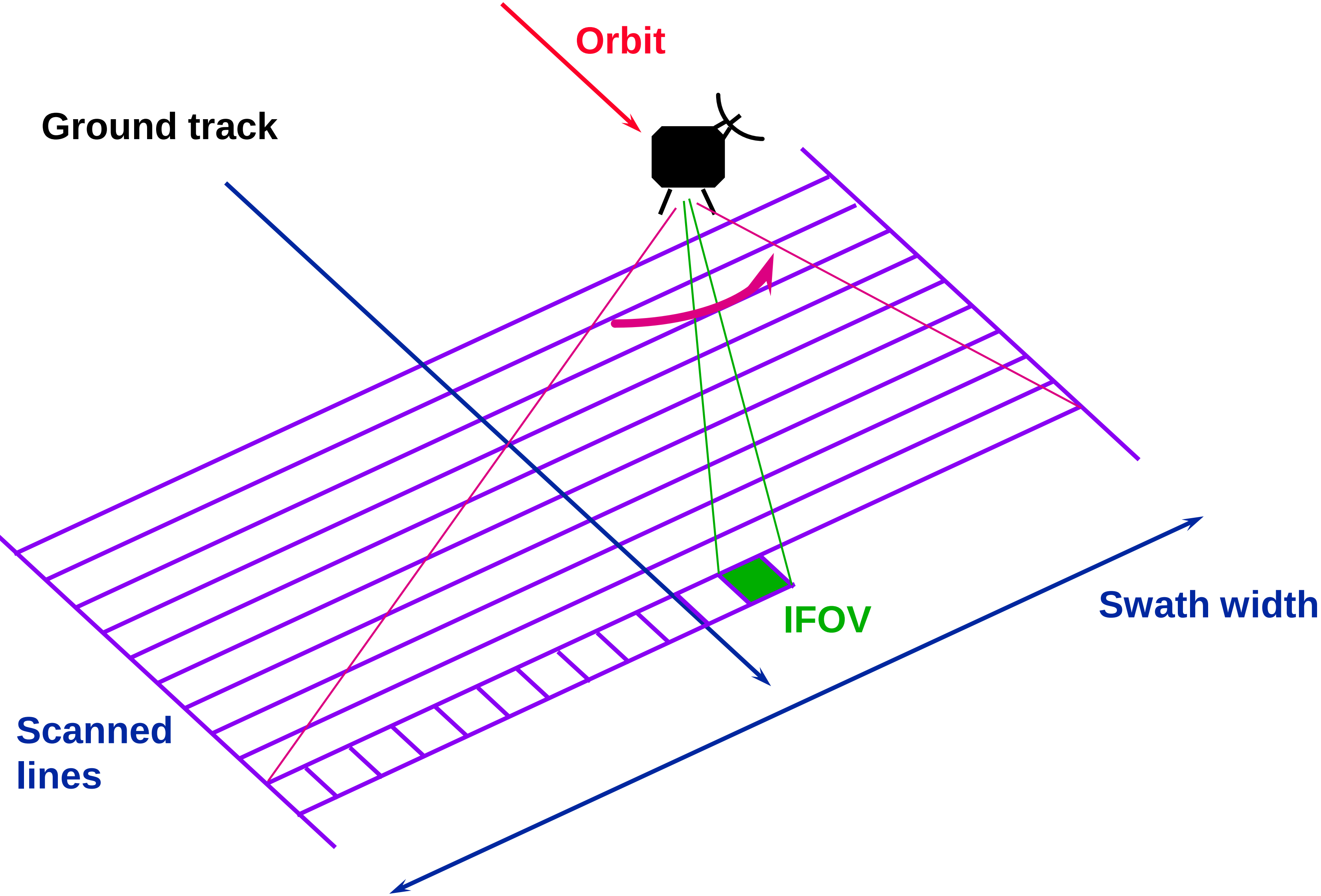


Satellite Nadir

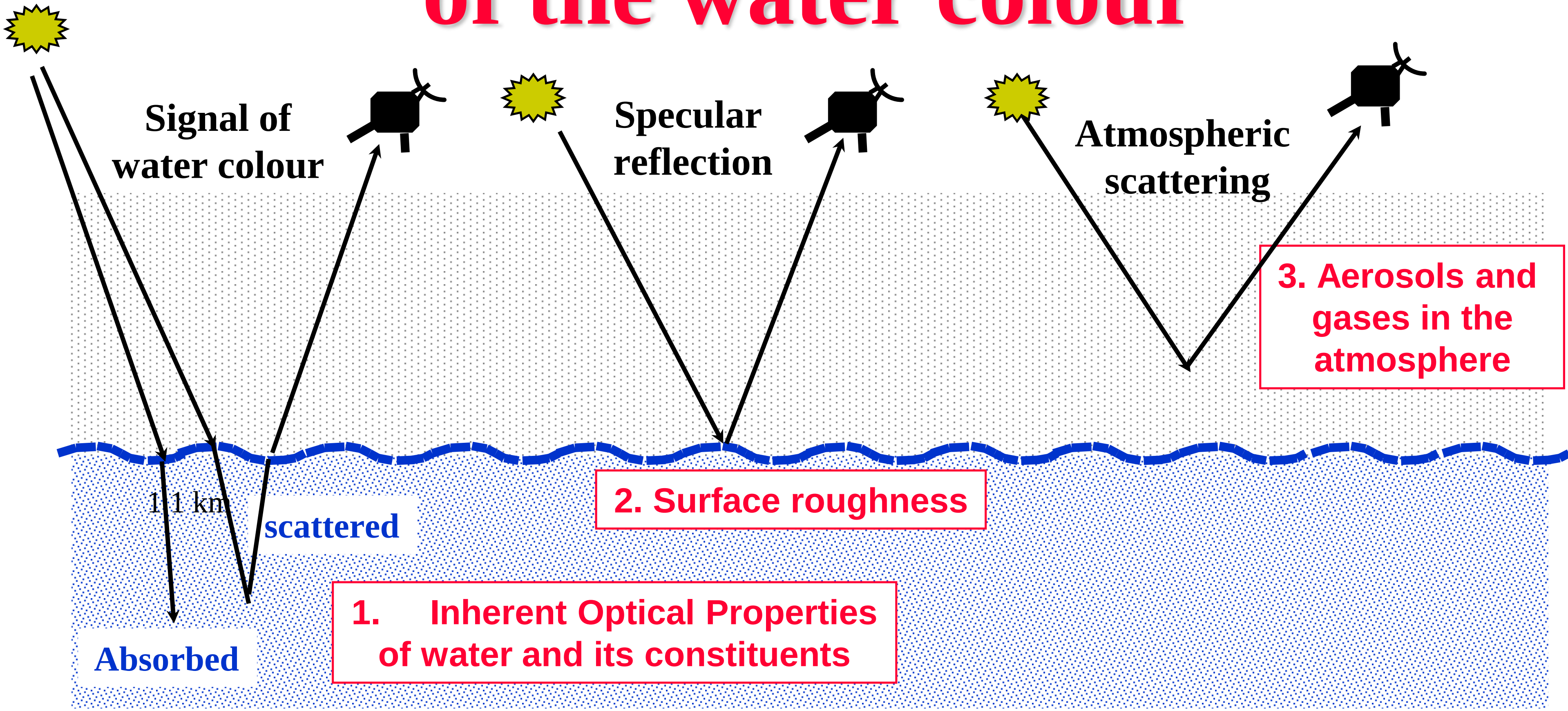
Border of scan



Mechanical *Scanning* Sensors



Basic principles of remote sensing of the water colour



Signal of water colour

Specular reflection

Atmospheric scattering

3. Aerosols and gases in the atmosphere

2. Surface roughness

1 1 km

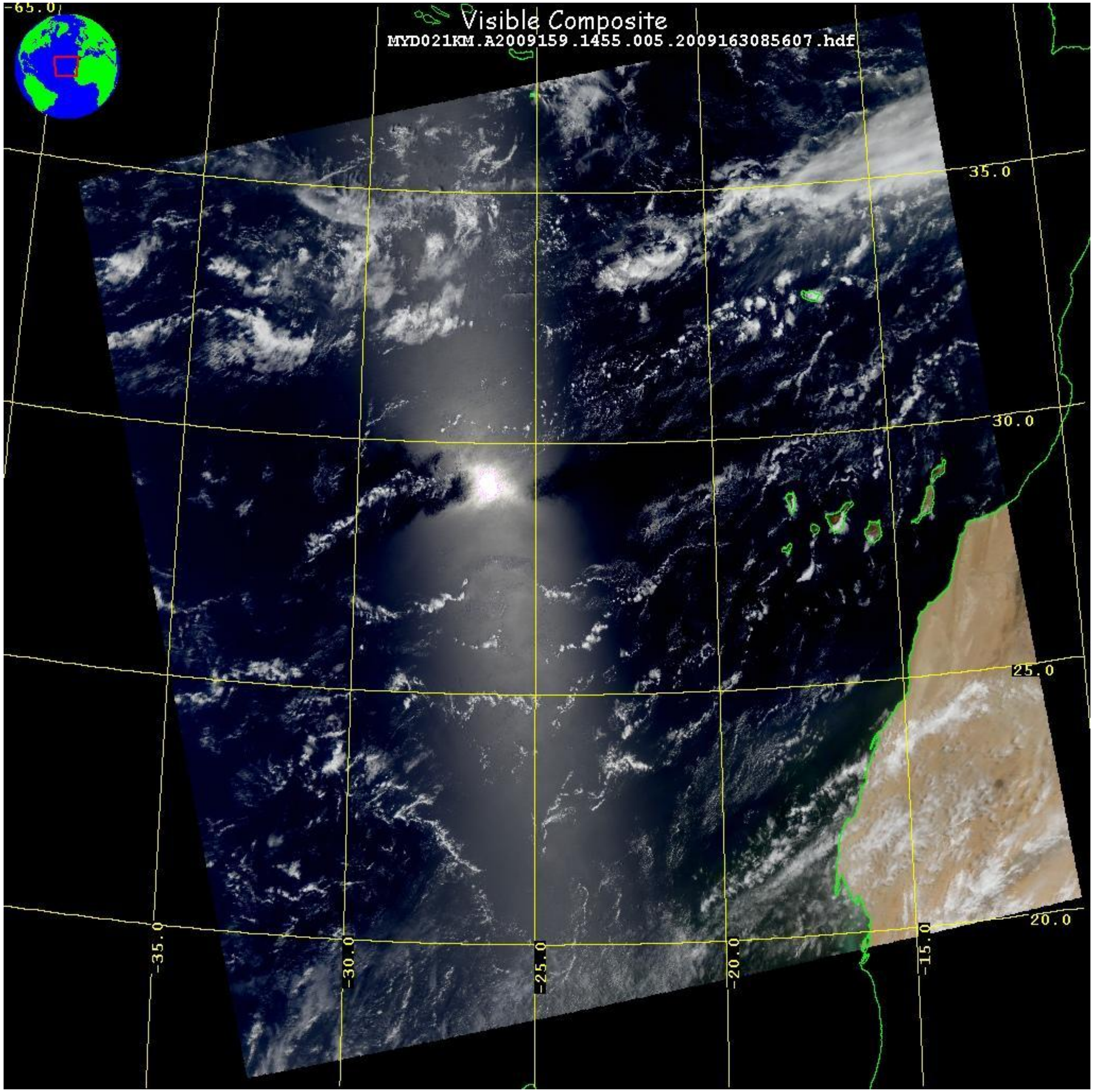
scattered

Absorbed

1. Inherent Optical Properties of water and its constituents

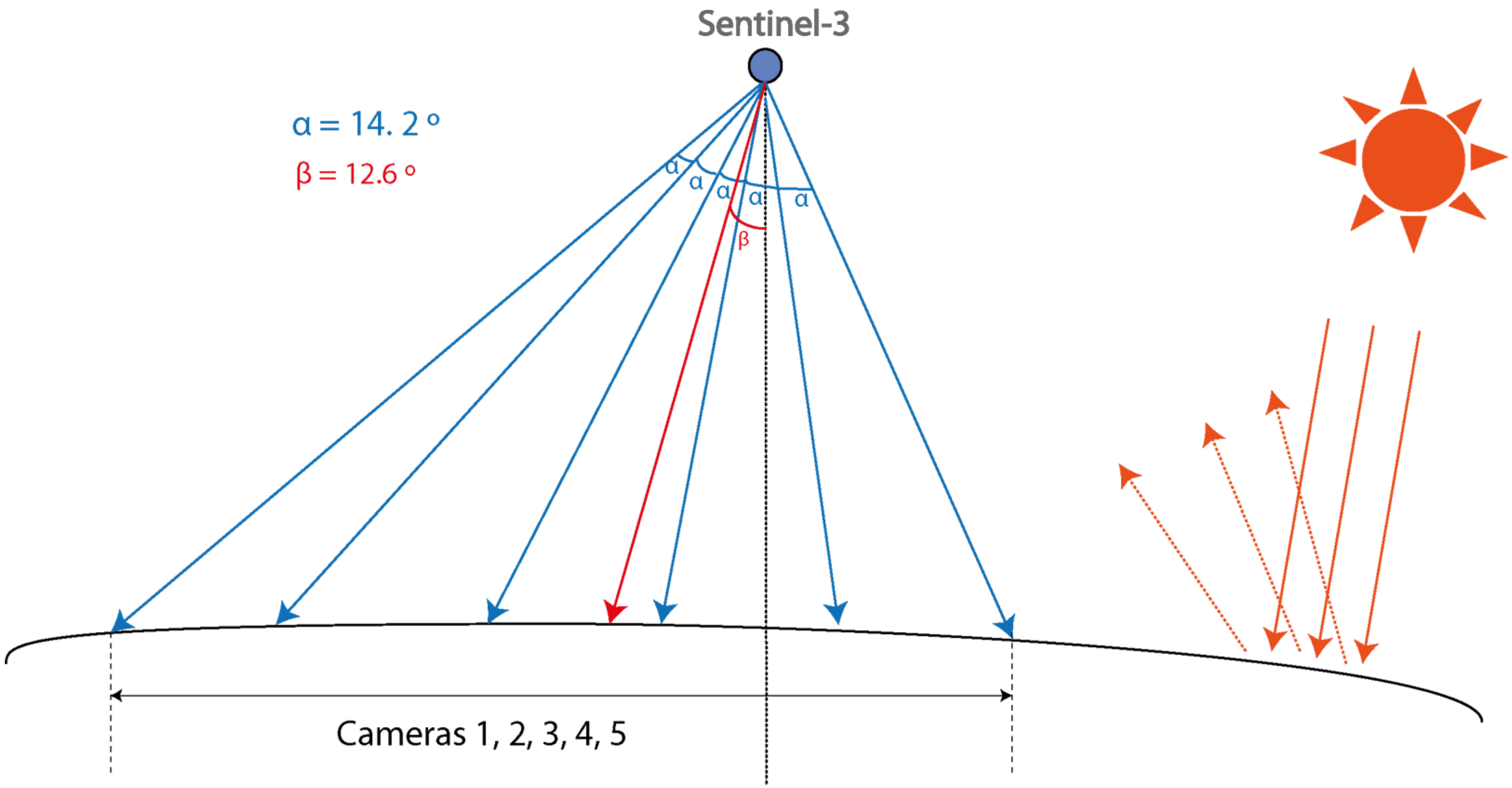
Note that processes 1, 2 and 3 all depend on wavelength.
We want to measure the signal of the water colour with enough spectral detail to distinguish between the constituents of the water and the atmosphere. Idealy, the surface roughness is known.

Example of *sunglint*



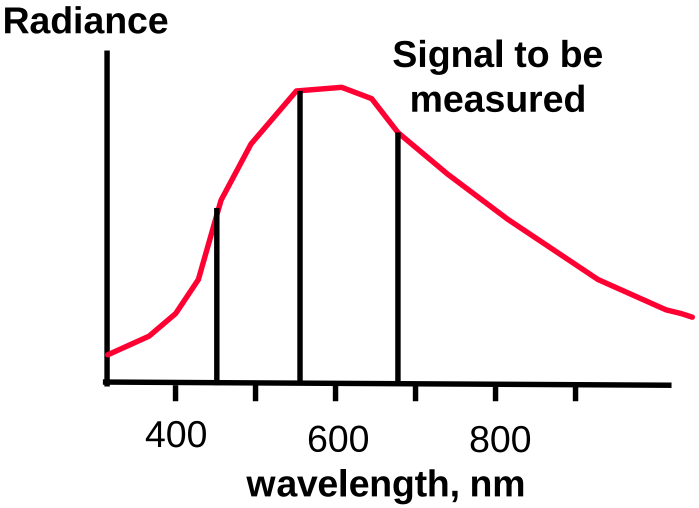
Satellite image affected by sunglint

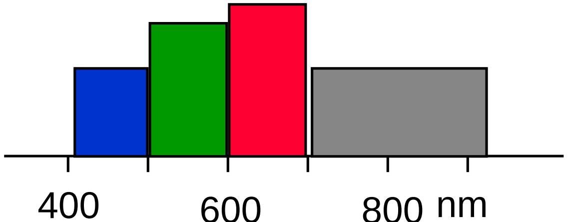
Aerial photograph with sunglint

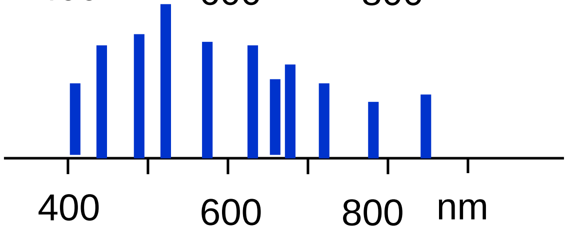

Sentinel-3
α = 14. 2 °
β = 12.6 °
α
α
α
α
α
β
Cameras 1, 2, 3, 4, 5

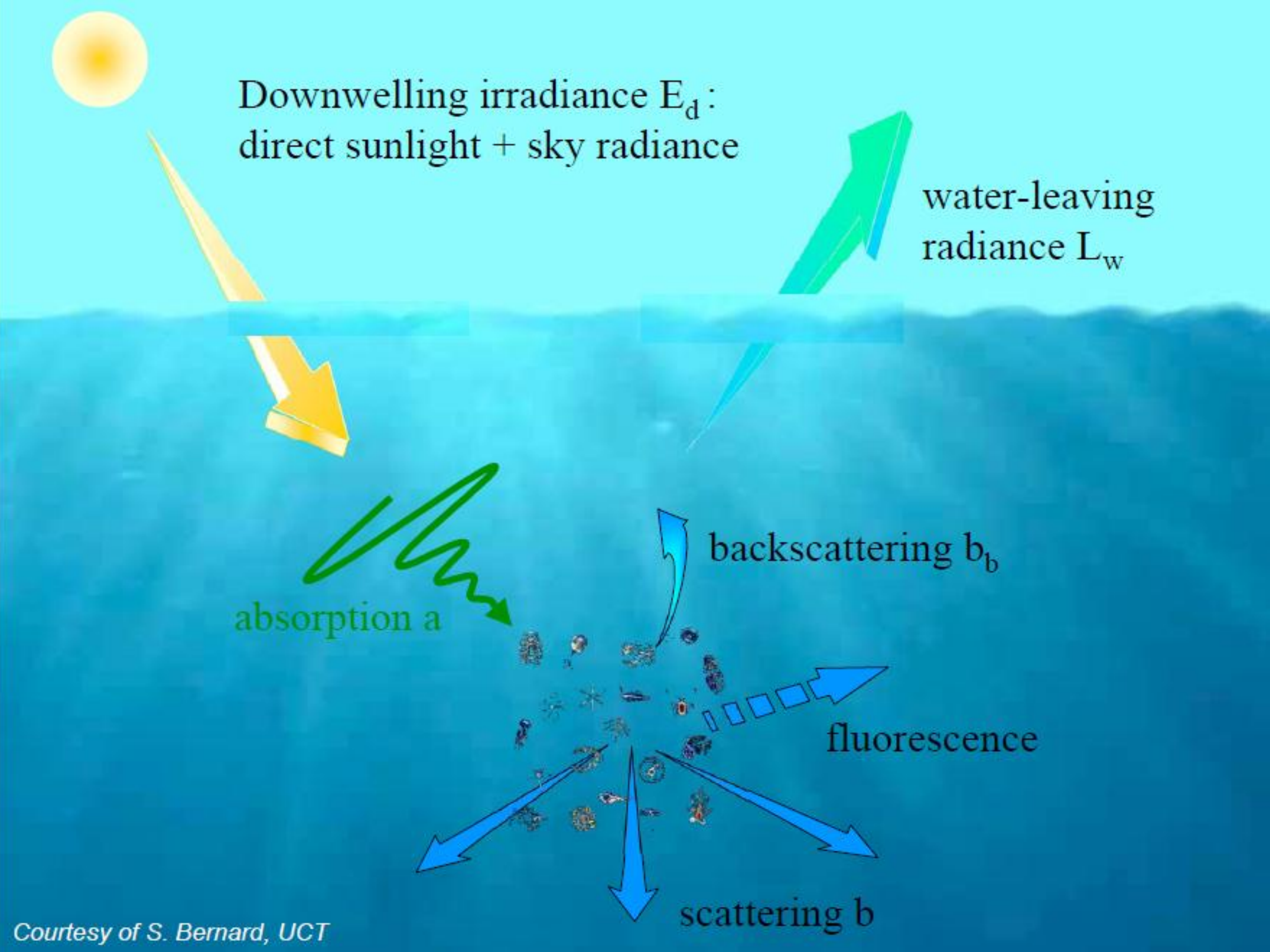
Use colour as a “vehicle” of information

- What is colour?
  - It’s the spectral distribution of visible light
  - The spectrum is tipically continuous
- How is the measurement made?
  - A sensor measures radiance in discrete e.m. bands
  - The human eye detects a response in three distinct bands defined by three spectral functions
  - The “colour” is, basically, a set of values measured in different bands, or “channels” .
  - Can be some wide bands (e.g. the human eye) or many narrow bands (spectrometers)









Downwelling irradiance E_d :
direct sunlight + sky radiance

water-leaving
radiance L_w

absorption a

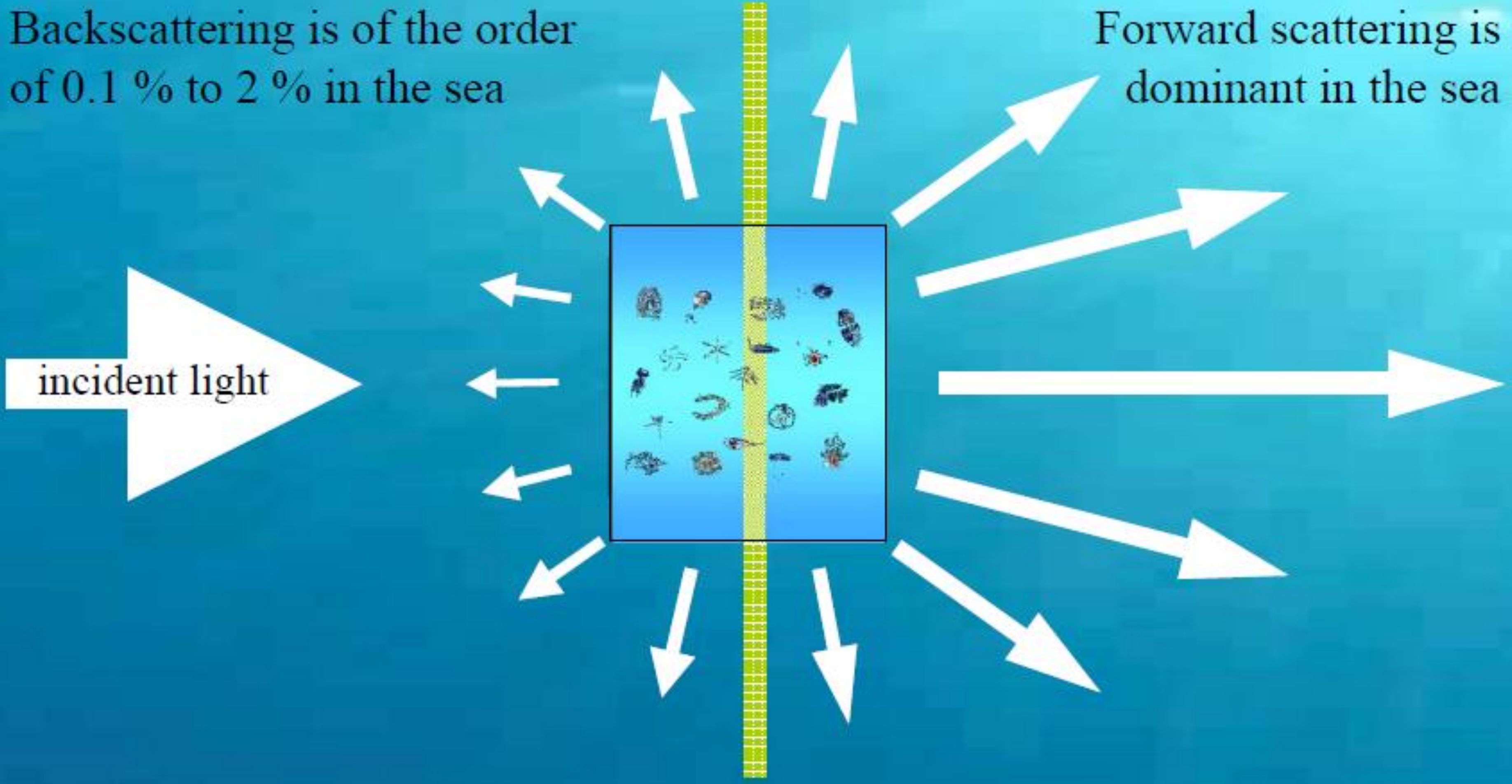
backscattering b_b

fluorescence

scattering b

Courtesy of S. Bernard, UCT

Scattering is the change of direction of a photon



Backscattering is of the order of 0.1 % to 2 % in the sea

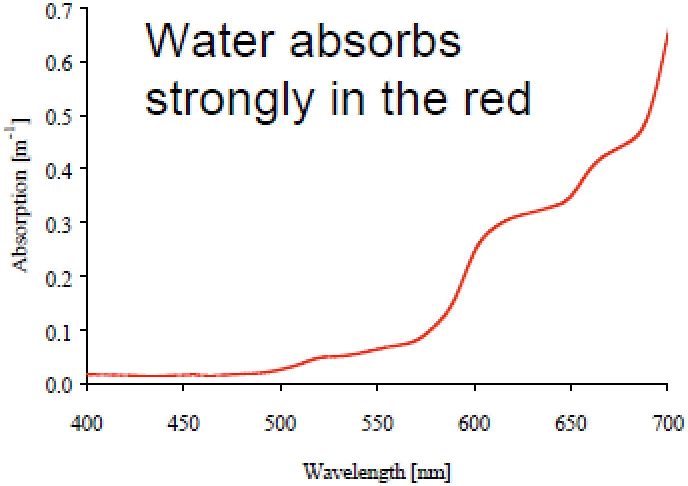
Forward scattering is dominant in the sea

incident light

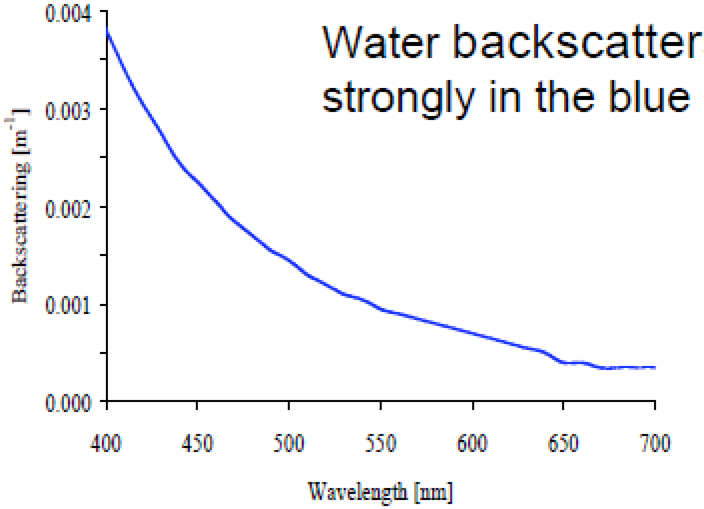
Absorption is the loss of a photon

Courtesy of S. Bernard, UCT

Absorption and scattering in “pure” water

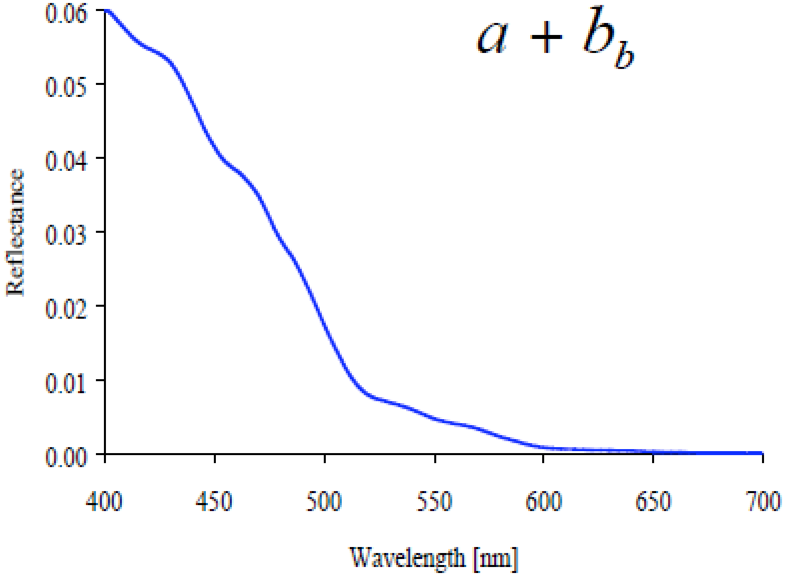


Water absorbs strongly in the red



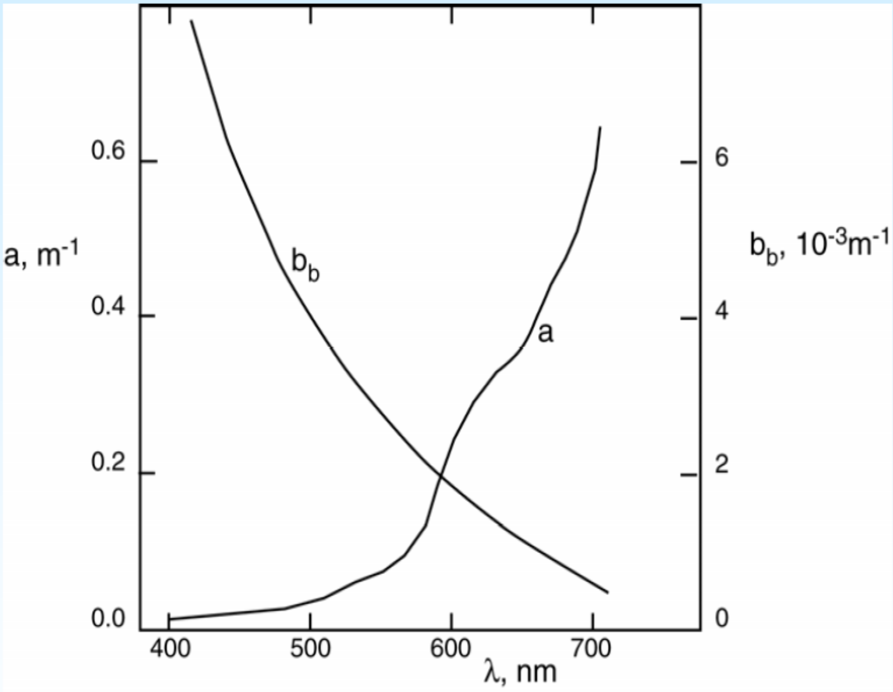
Water backscatters strongly in the blue

$$R = 0.33 \frac{b_b}{a + b_b}$$

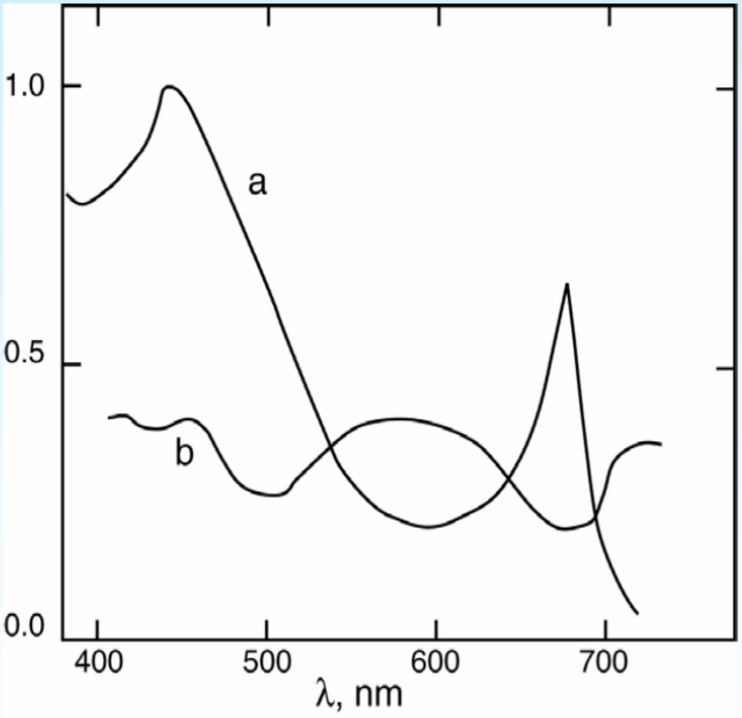


Reflectance of pure water is strongest in the blue

Spectral variation of absorption and scattering of light in the sea

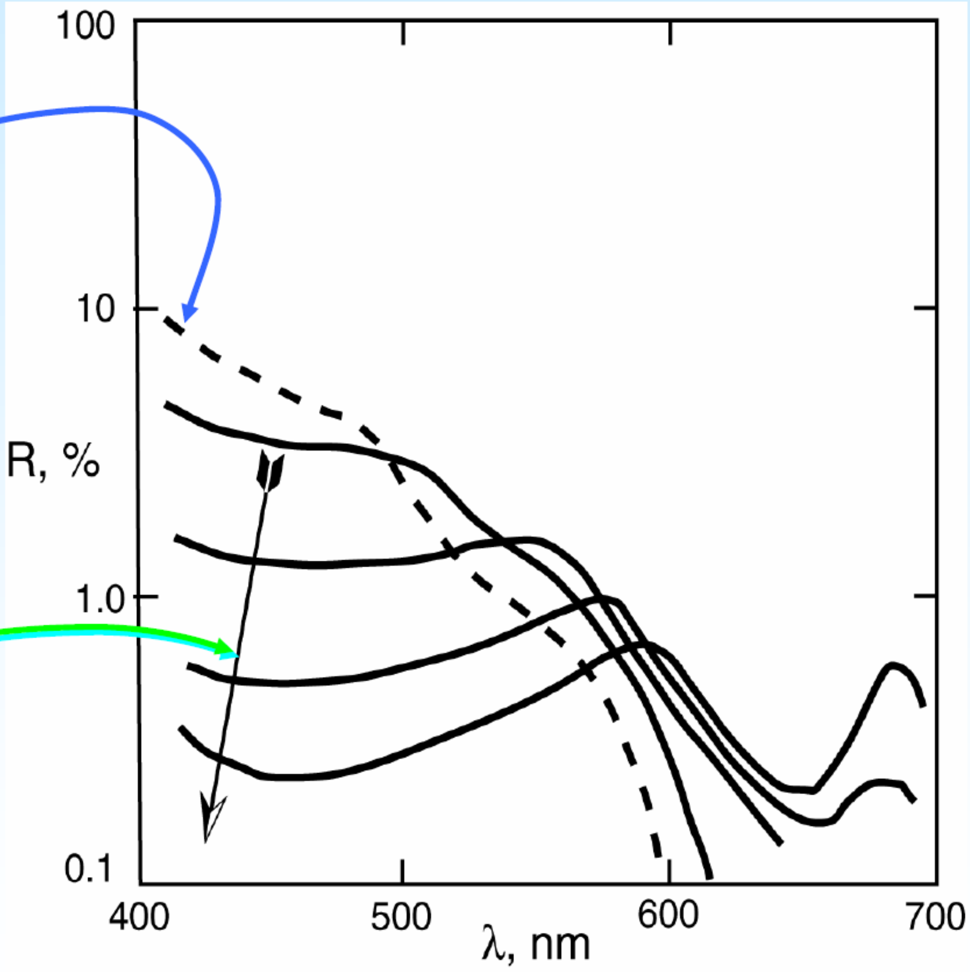


Absolute values for sea water absorption, a
and backscattering, b_b



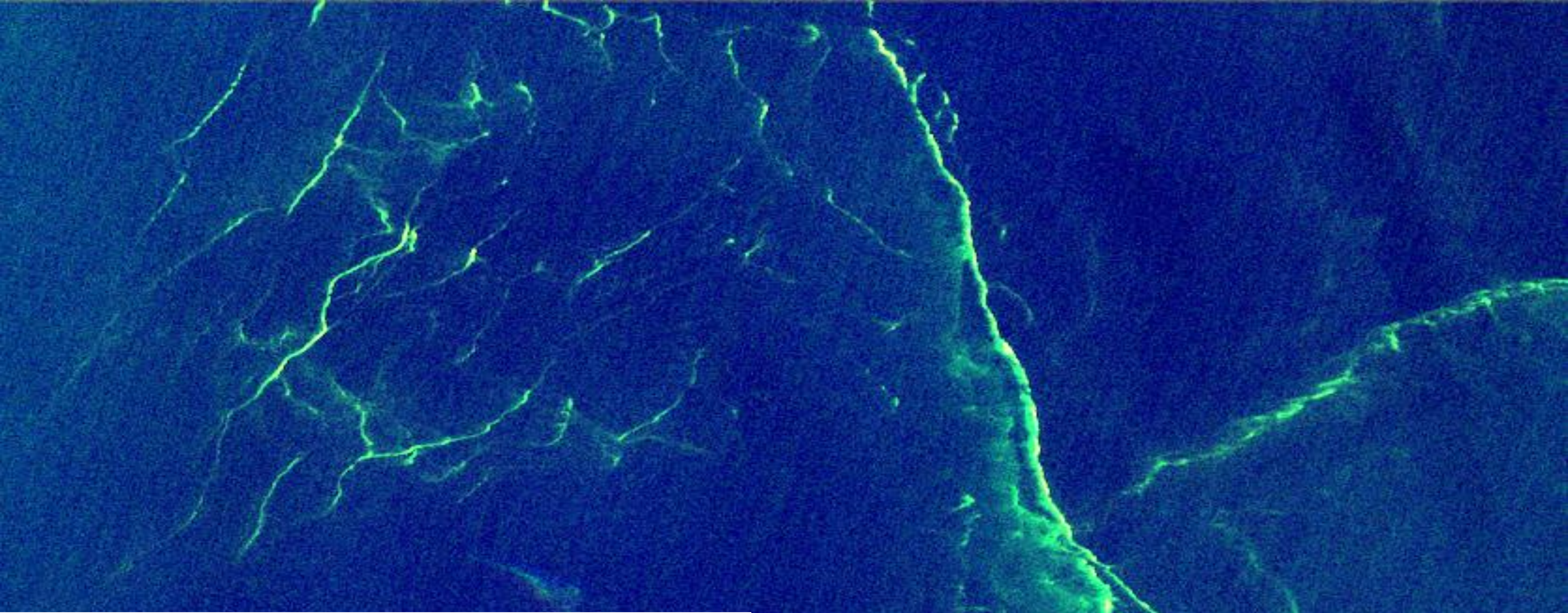
Relative values of absorption, a and backscattering, b for Chlorophyll in Phytoplankton

Reflectance spectra associated with phytoplankton



The dashed line is the reflectance associated with pure sea water

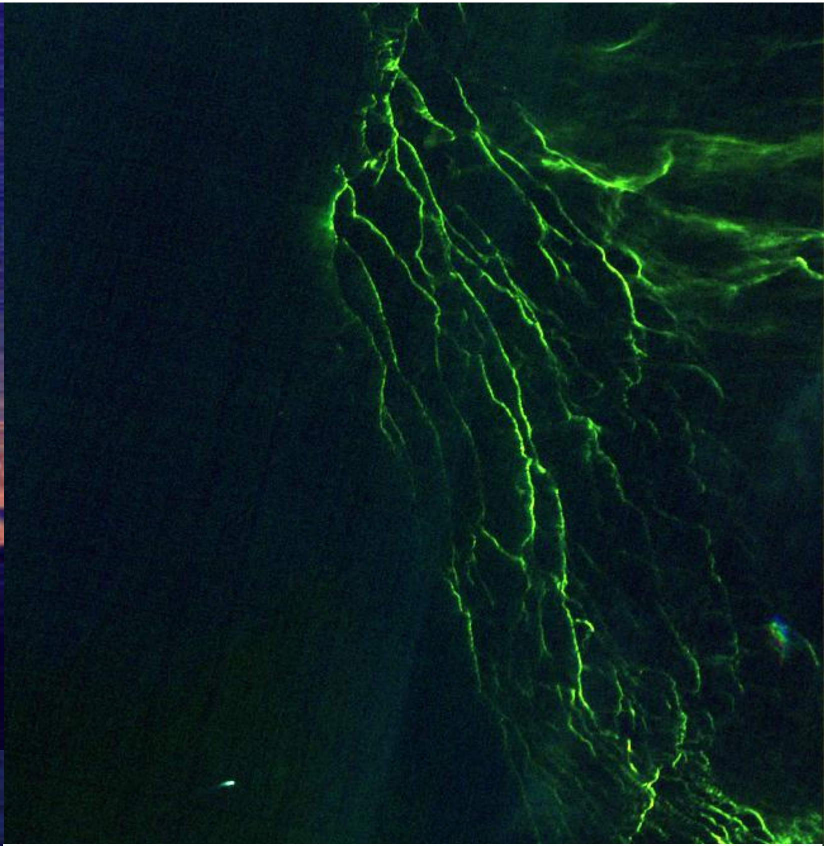
The arrow indicates the direction of increasing chlorophyll concentration for the different lines drawn.



Phytoplankton Blooms and Physical Environement

Noctiluca scintillans that has accumulated at a front formed by a nonlinear internal wave off the coast of San Diego CA, USA.

Bands of the dionflagellate *Lingulodinium polyedrum* moving onshore over the troughs of a series of internal waves

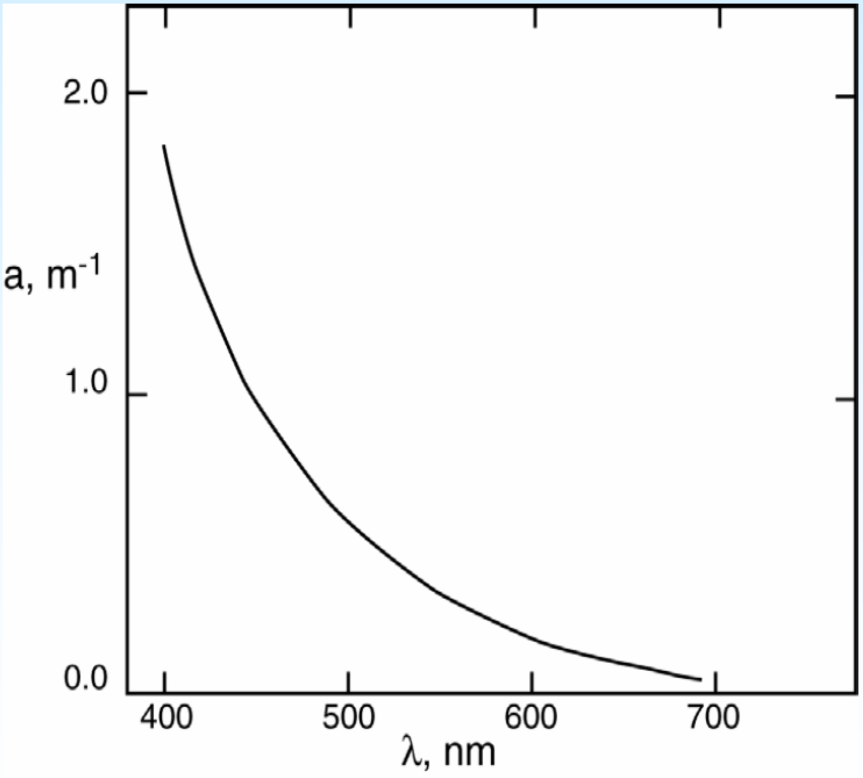


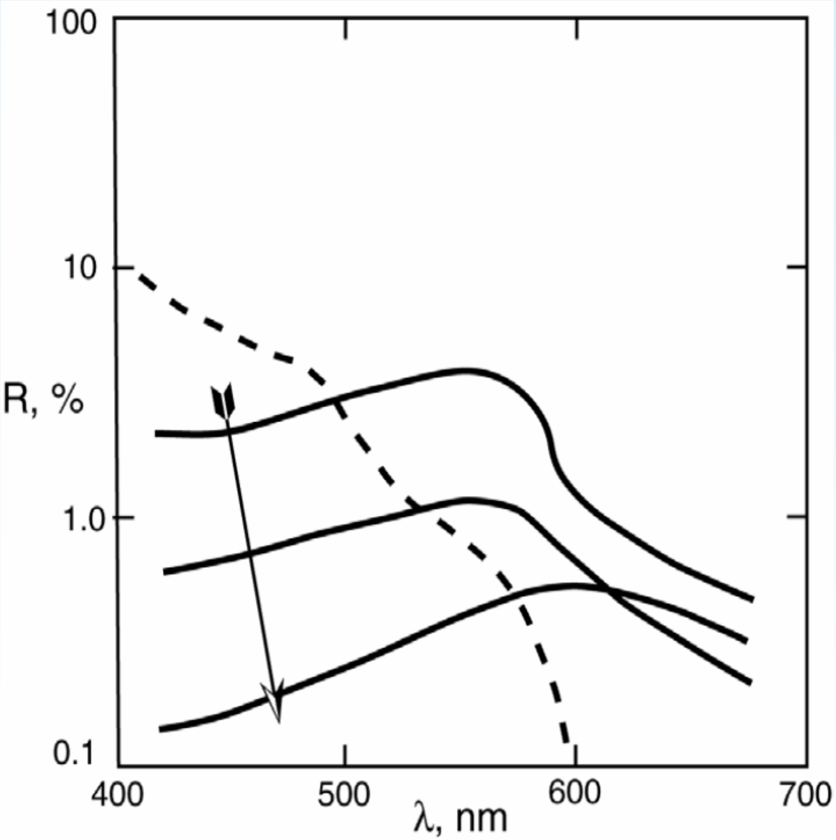
Plankton Blooms

Bands of the dionflagellate *Lingulodinium polyedrum* moving onshore over the troughs of a series of internal waves

Absorption and reflectance spectra associated with CDOM

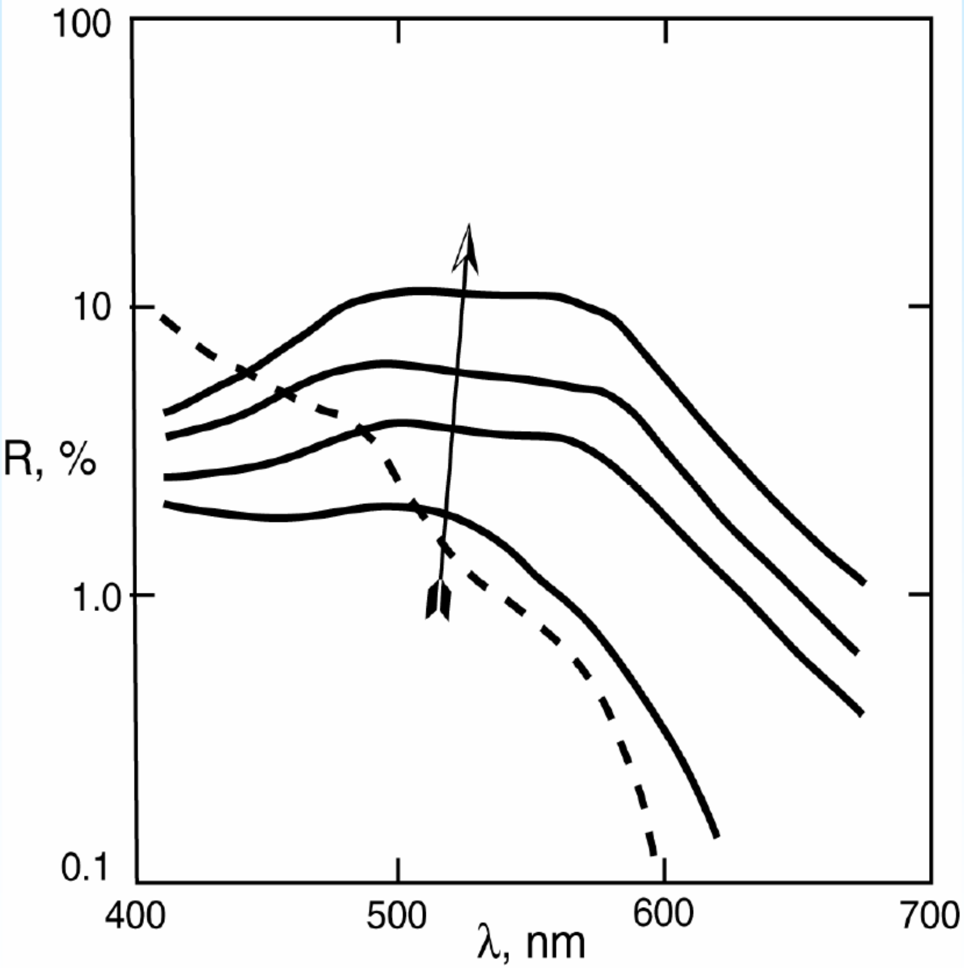
Yellow Substance



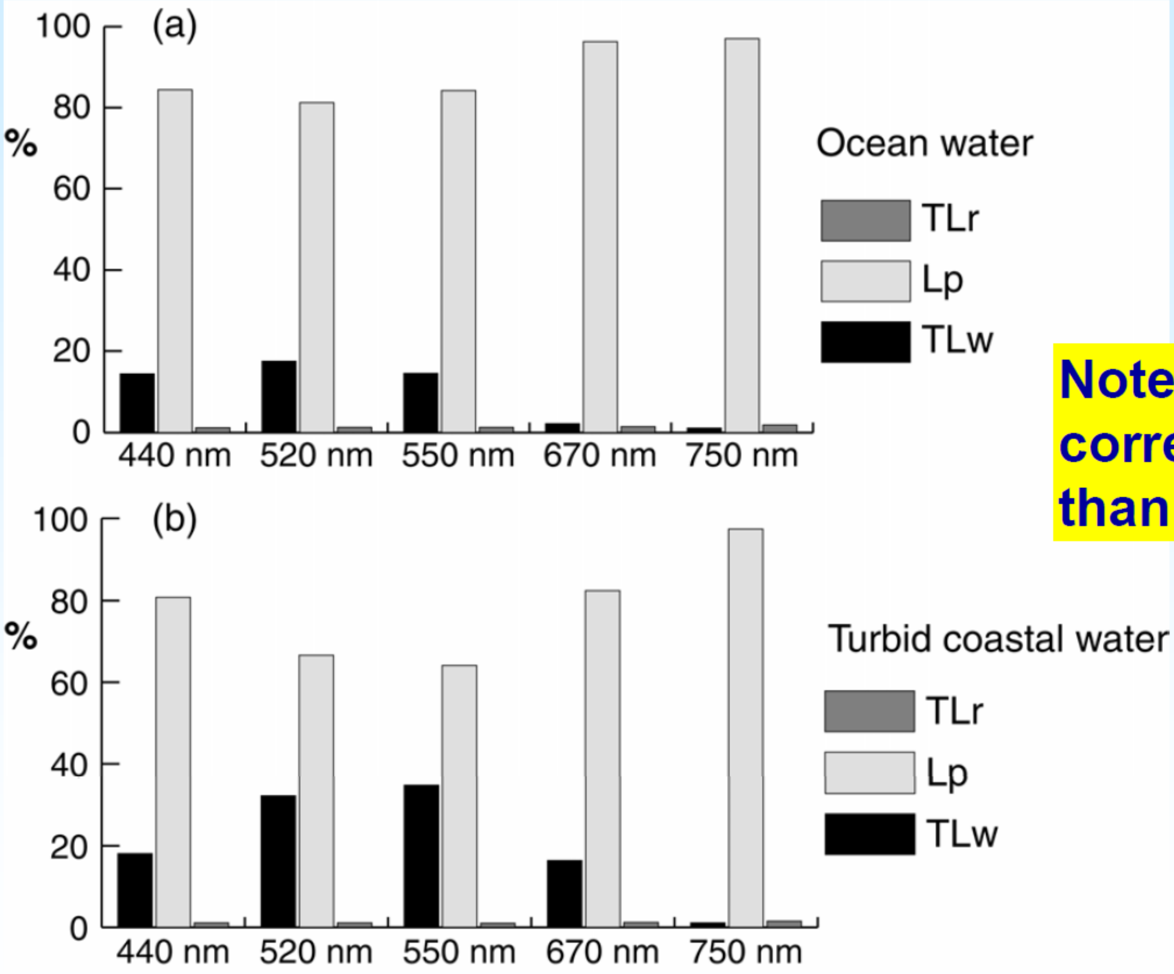


Colored dissolved organic matter (CDOM) is the optically measurable component of the dissolved organic matter in water. Also known as chromophoric dissolved organic matter, yellow substance, and gelbstoff, CDOM occurs naturally in aquatic environments primarily as a result of tannin-stained waters released from decaying detritus.

Reflectance curves associated with suspended particulates

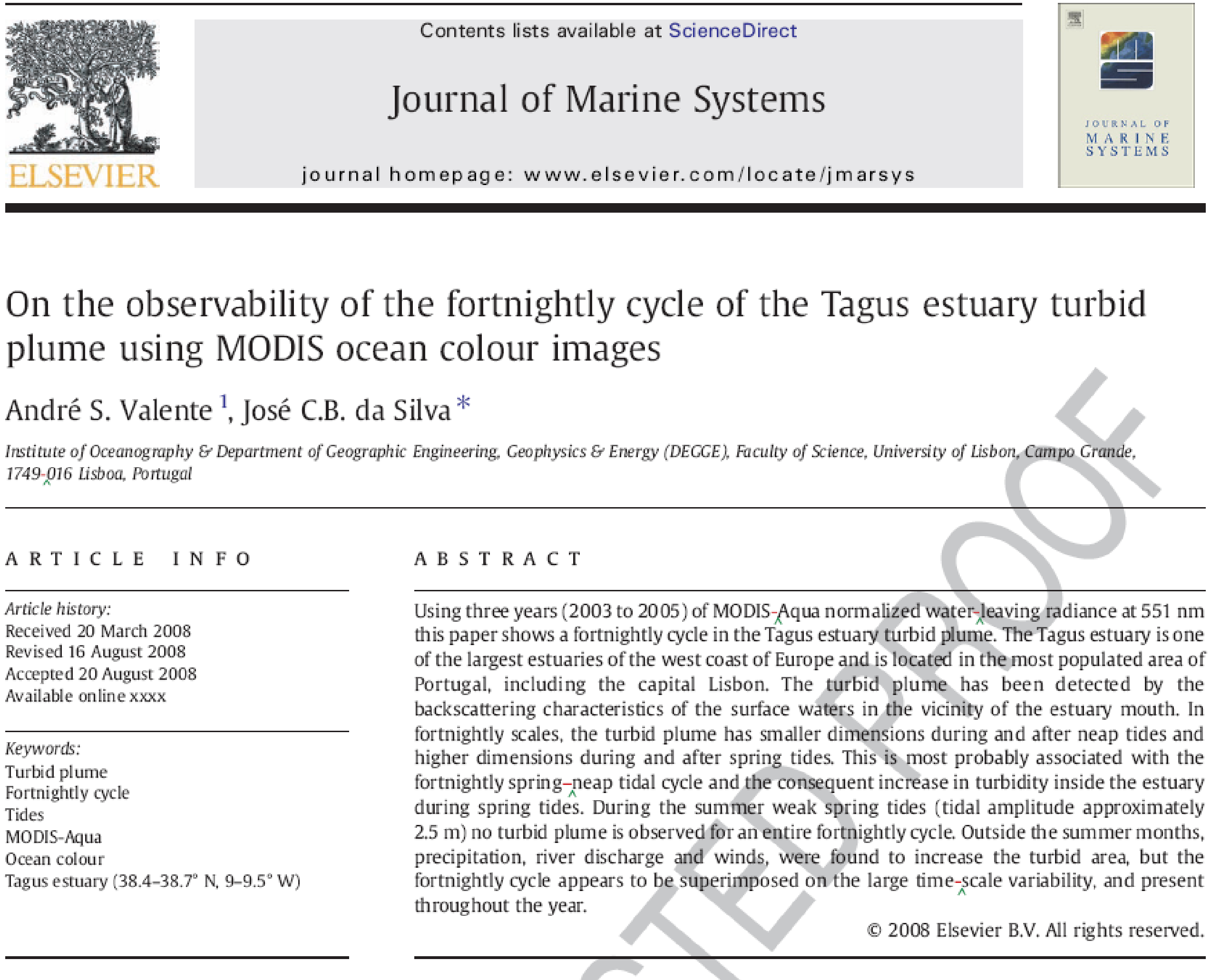


Typical proportions of water-leaving signal and atmospheric scattering



Note that the atmospheric correction Is always larger than the water-leaving signal

Example of “simple” a Case study



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On the observability of the fortnightly cycle of the Tagus estuary turbid plume using MODIS ocean colour images

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Tagus estuary (38.4–38.7° N, 9–9.5° W)

ABSTRACT

Using three years (2003 to 2005) of MODIS-Aqua normalized water-leaving radiance at 551 nm this paper shows a fortnightly cycle in the Tagus estuary turbid plume. The Tagus estuary is one of the largest estuaries of the west coast of Europe and is located in the most populated area of Portugal, including the capital Lisbon. The turbid plume has been detected by the backscattering characteristics of the surface waters in the vicinity of the estuary mouth. In fortnightly scales, the turbid plume has smaller dimensions during and after neap tides and higher dimensions during and after spring tides. This is most probably associated with the fortnightly spring-neap tidal cycle and the consequent increase in turbidity inside the estuary during spring tides. During the summer weak spring tides (tidal amplitude approximately 2.5 m) no turbid plume is observed for an entire fortnightly cycle. Outside the summer months, precipitation, river discharge and winds, were found to increase the turbid area, but the fortnightly cycle appears to be superimposed on the large time-scale variability, and present throughout the year.

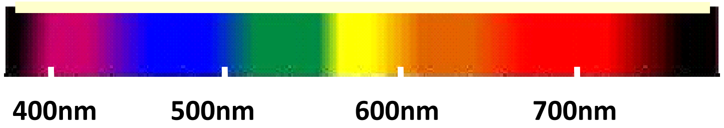
How do we measure water turbidity with satellite?

Clean water absorbs longer wavelengths.

Phytoplankton (chlorophyll *a*) absorbs most in the blue and red wavelengths.

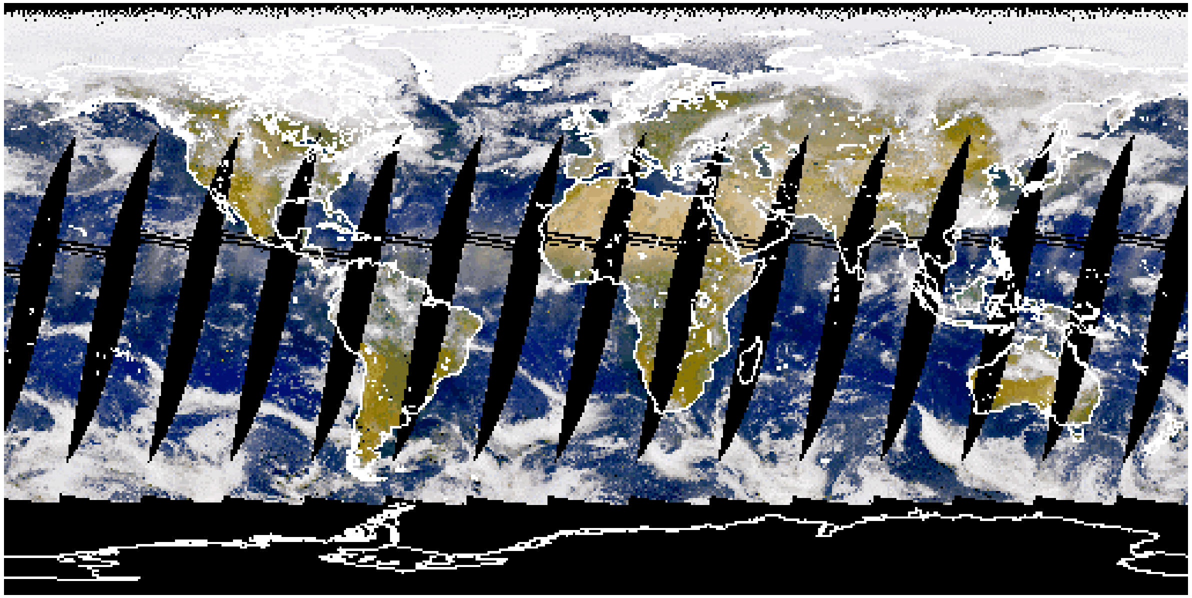
Yellow substance absorbs strongly in short wavelengths.

Inorganic matter equally scatters for all visible wavelengths.



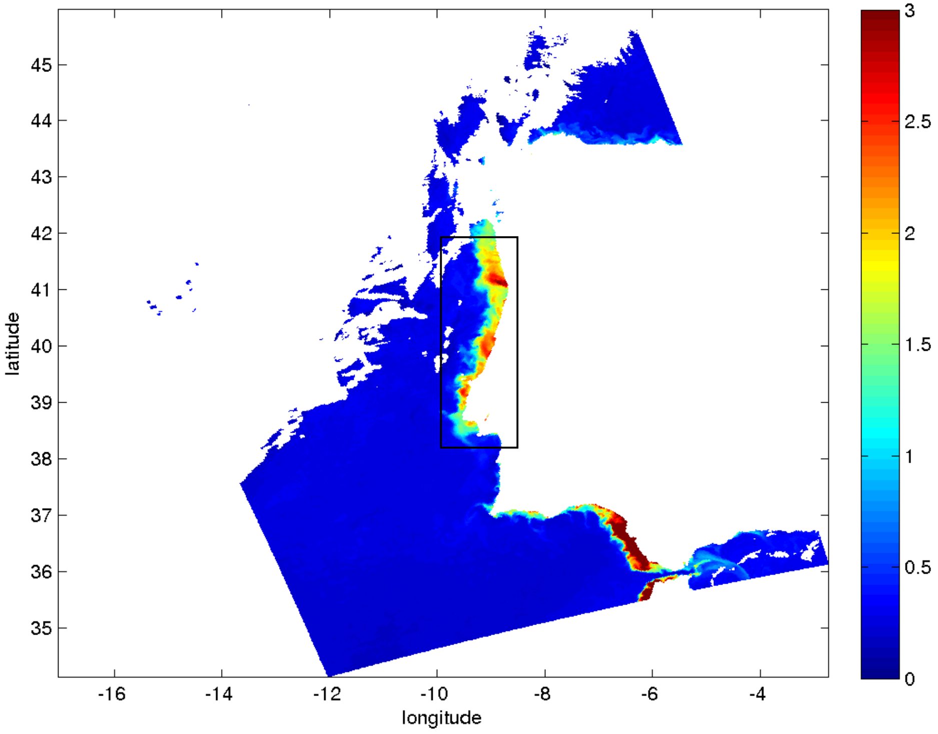
Sensor MODIS

- Altitude is 700km (sun-synchronous orbit).
- Temporal resolution is a day!
- Spatial resolution of 1km.
- Measures the ocean colour.
- All images from the Bay of Lisbon were acquired, processed and analysed between 2002 and 2005



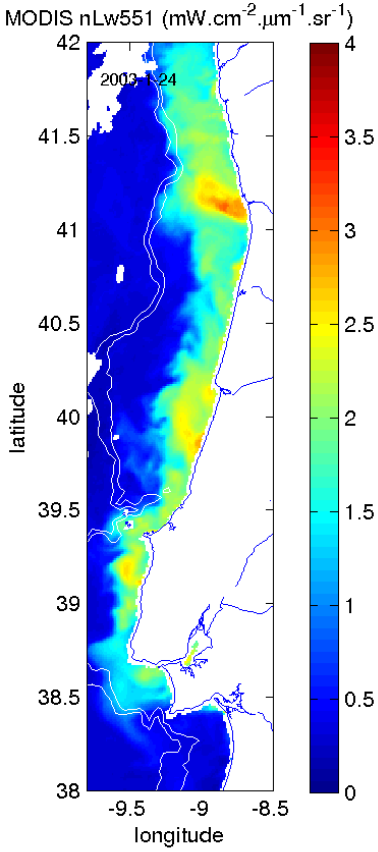
Satellite image processing

(2789 satellite images of nLw 551nm = 20.7GB).

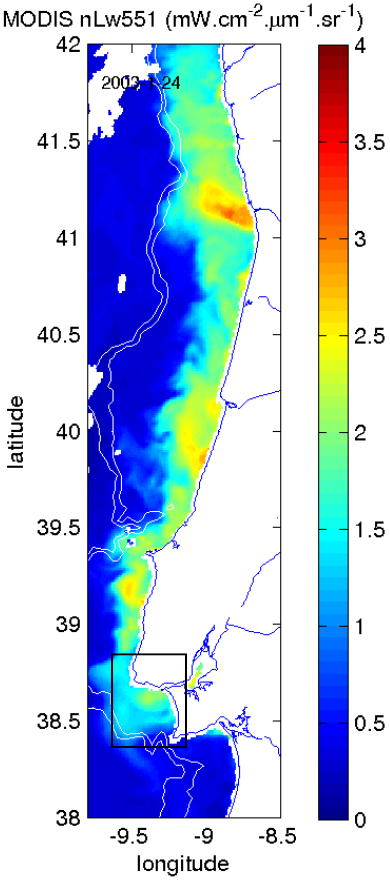


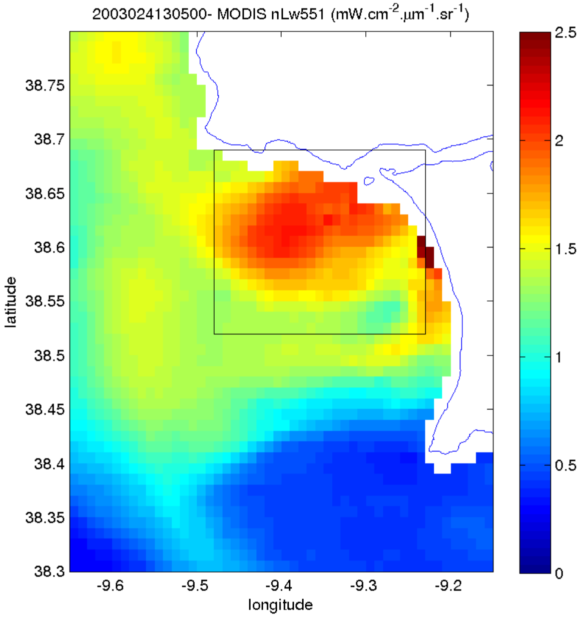
MATLAB :

Interpolation to a regular grid Lat-Lon (linear)

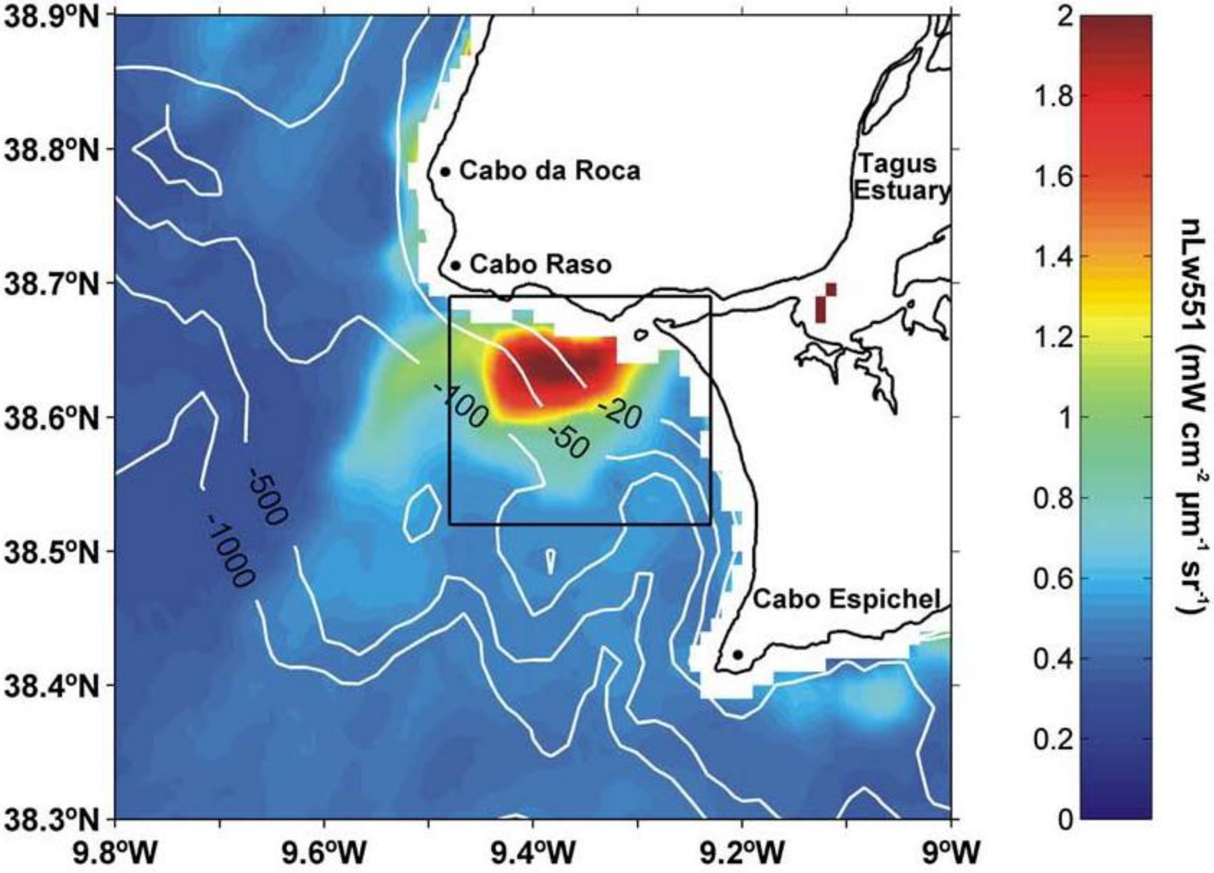


The river plume study region was defined (box)





Method to evaluate the variability of the river plume (Rio Tejo) by reflectance threshold



An image pixel is considered turbid if nLw551>1.3mW.cm^{-2}.µm^{-1}.sr^{-1}

Key question? !

What is the environmental variable that most affects the temporal and spatial variability of the river plume?

Precipitation, river outflow, wind direction and speed, tides?

Data bases for environmental data.

Daily river flow (Tejo) (2002-2005):

- Estação hidrométrica de Almourol (www.snirh.pt)

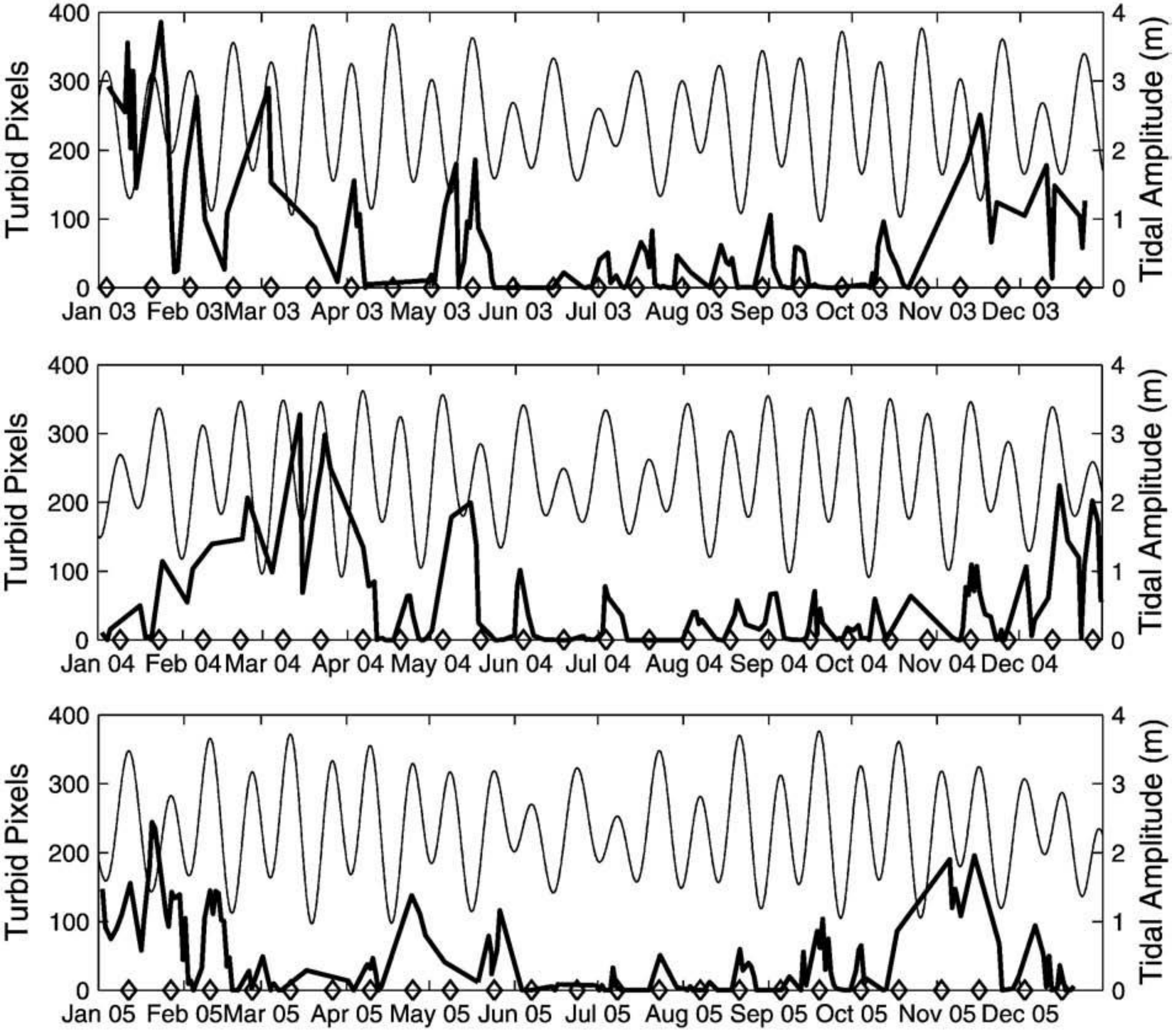
Precipitation and wind (daily basis) (2002-2005): :

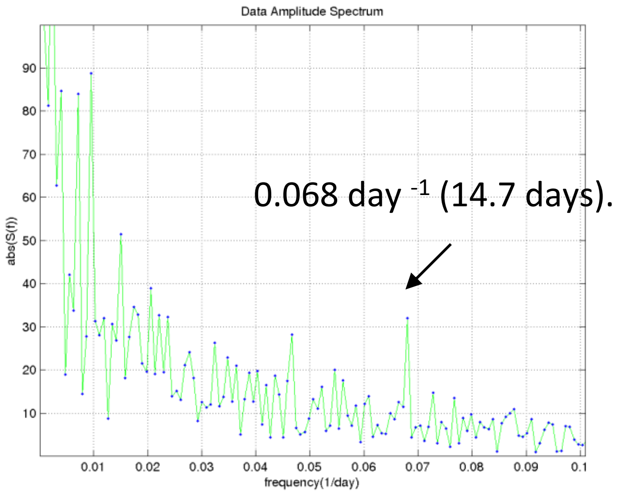
- EMA's (Geofísico) (www.meteo.pt).

Tides (2002-2005): :

- OCEANUS (www.oceanus2000.com).
- Each and every image is caracterized with tidal amplitude (spring/neap tides – forthnightly cicle) and (semi-diurnal) tidal phase (High/Low tide).

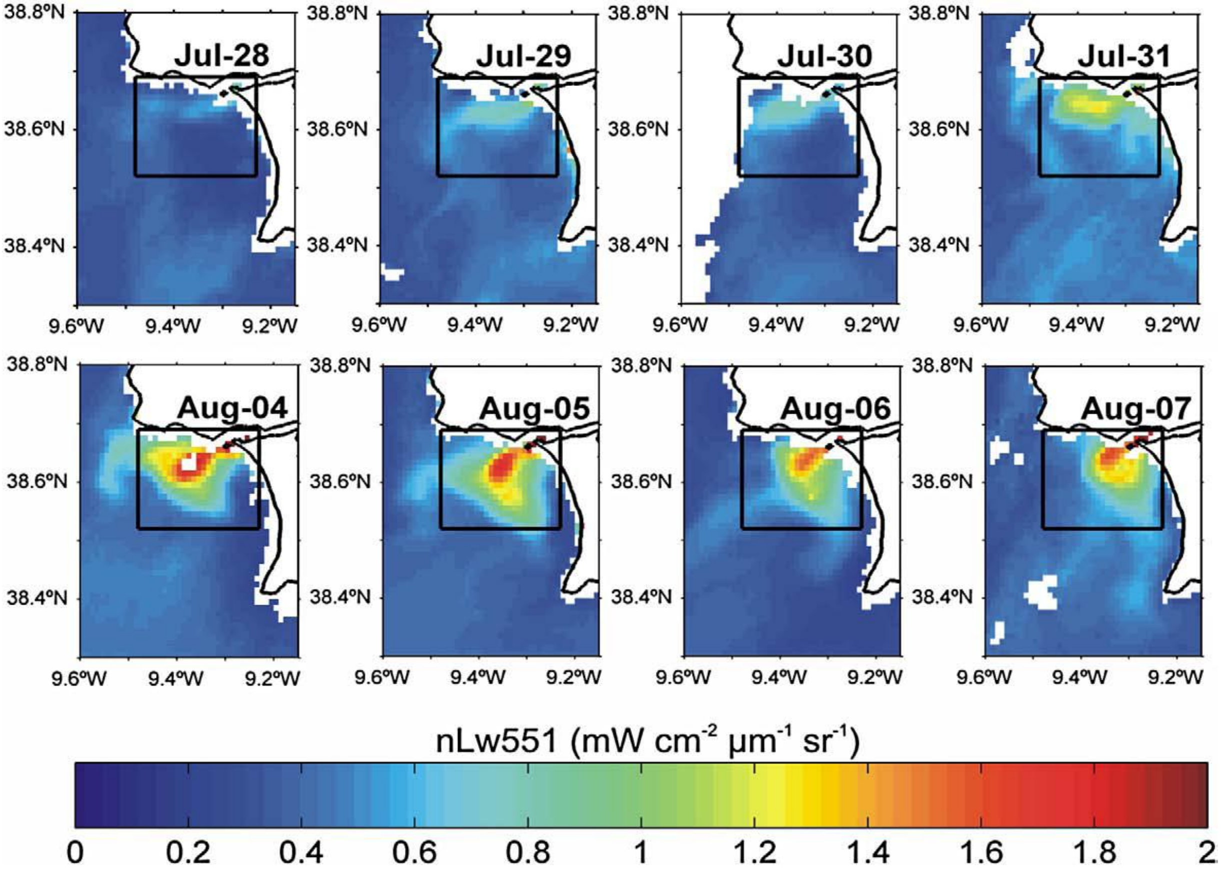
Tidal amplitudes Vs nº of turbid pixels (plume area)

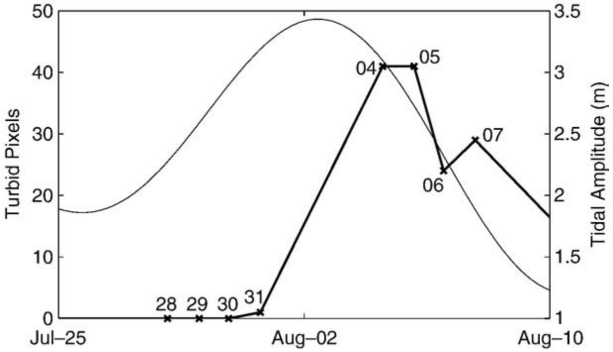




0.068 day $^{-1}$ (14.7 days).

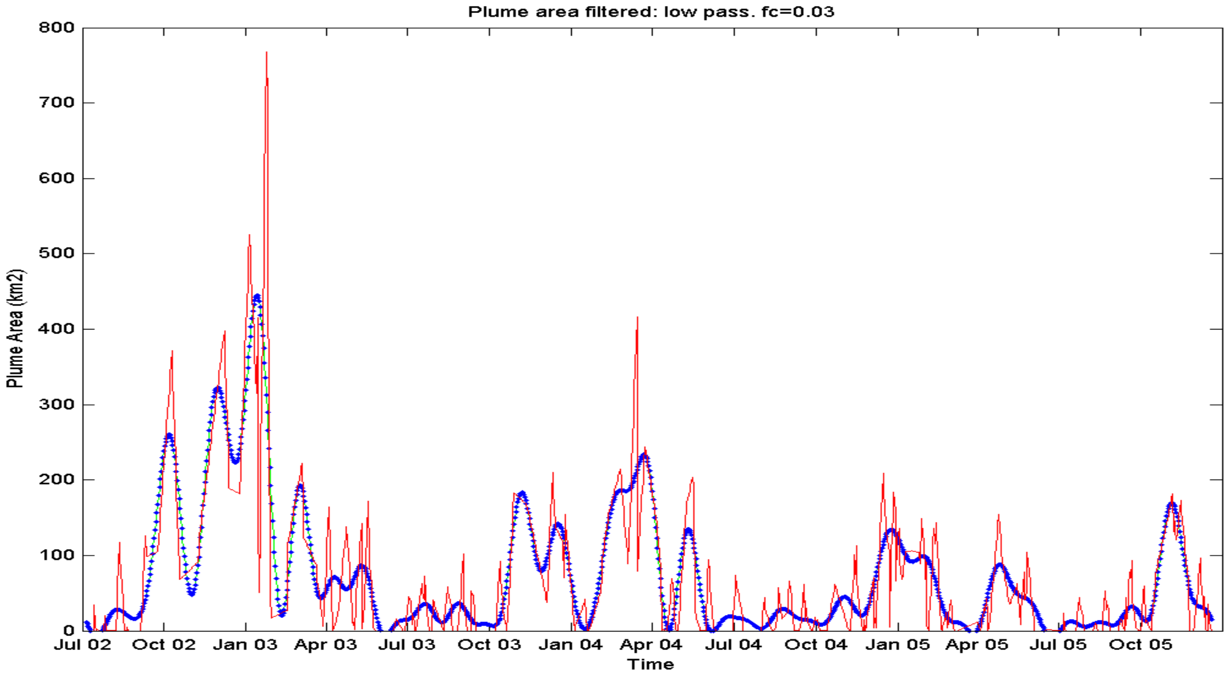
Tidal amplitudes Vs nº of turbid pixels (plume area)

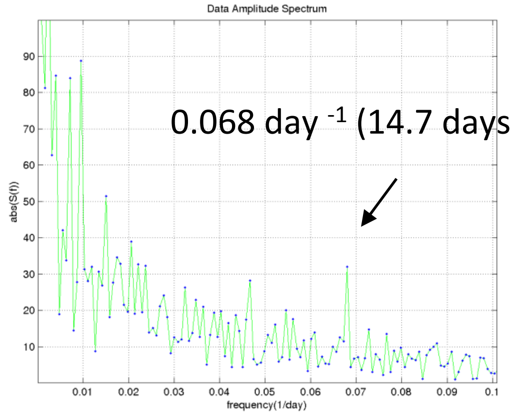




The turbid plume is largest after the spring tide (of August 2nd).

Precipitation and River Flow Vs nº of turbid pixels



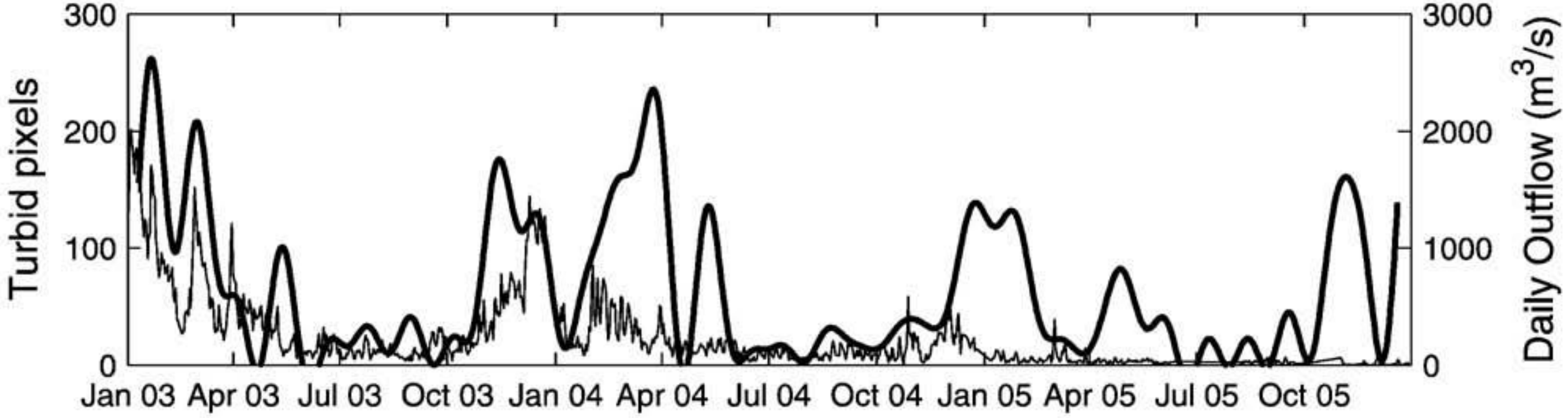


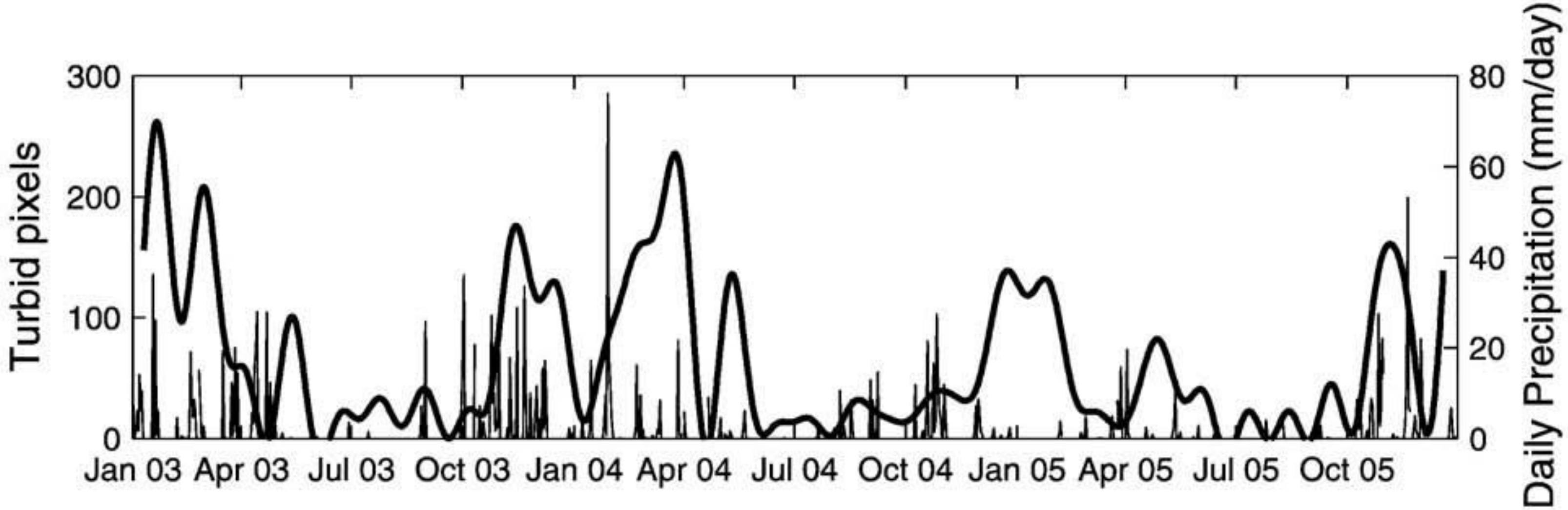
0.068 day $^{-1}$ (14.7 days).

Cut frequency :
fc = 0.06 days^{-1}.

Time series (2002-2005) of the number of turbid pixels with a low pass filter.

Precipitation and River Flow Vs number of turbid pixels





Conclusions

- It is possible to observe the Tejo River plume using satellite images at a daily temportal resolution.
- There is a fortnightly signal of the turbid plume all-year-round, which is due to the fortnightly tidal cicle (spring-neap tides).
- The precipitation and river outflow also affect the size of the buoyant plume.

Infra-red Measurements of water-surface temperature

Thermal emission from the sea surface

Black body radiation M_λ (measured in $Wm^{-2}m^{-1}$), **at wavelength** λ**, is emitted by an ideal surface according to the Plank equation:**

$$M_\lambda = \frac{C_1}{\lambda^5\left[\exp\left(\frac{C_2}{\lambda T}\right) - 1\right]}$$

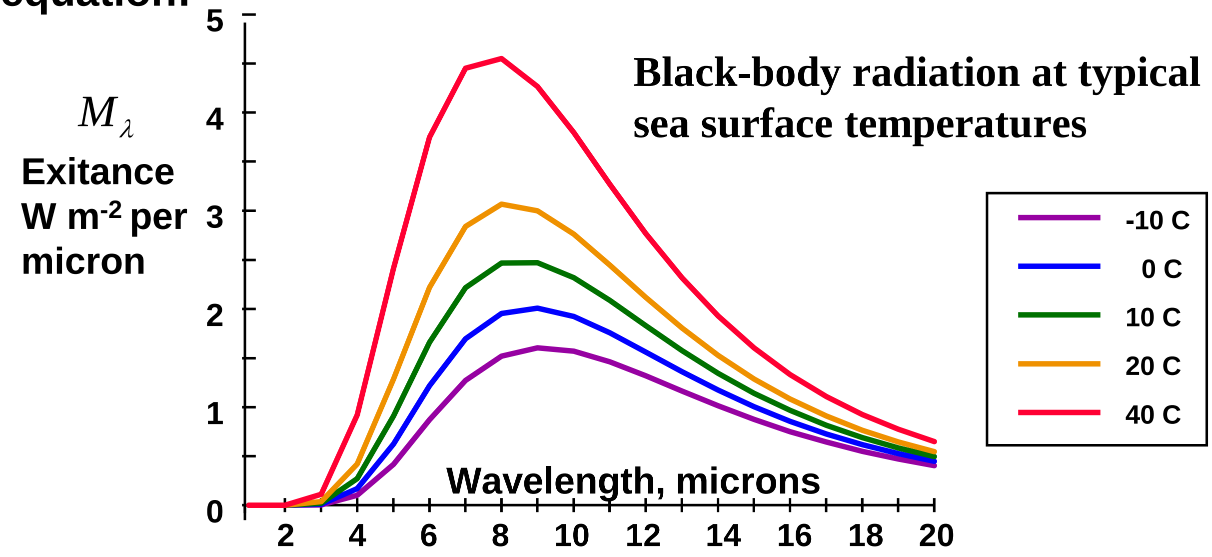
where

λ is the wavelength in m.

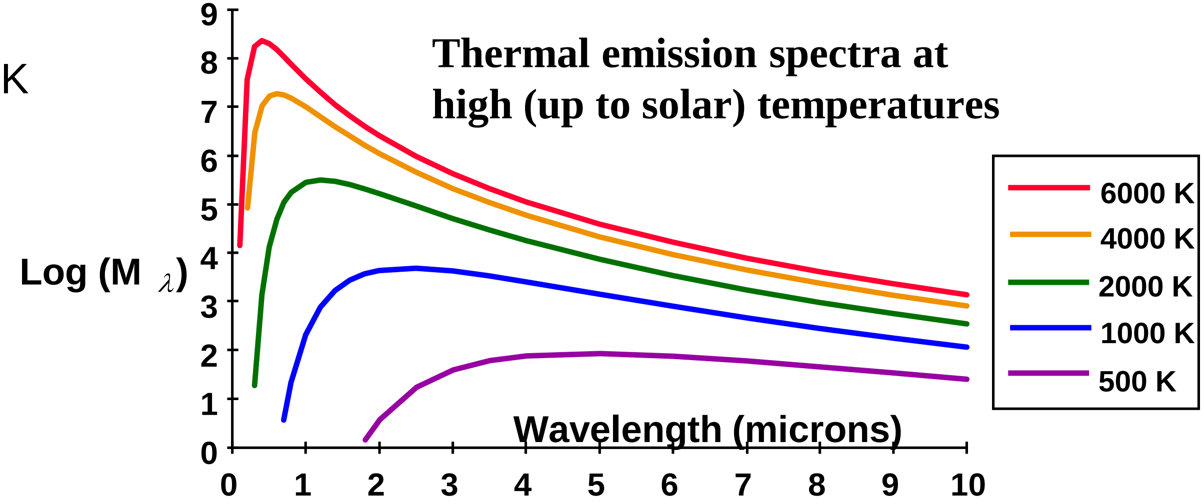
C_1 is a constant = 3.74 10 $^{-16}$ Wm^2

C_2 is a constant = 1,44 10 $^{-2}$ m deg K

T = temperature of the surface in K



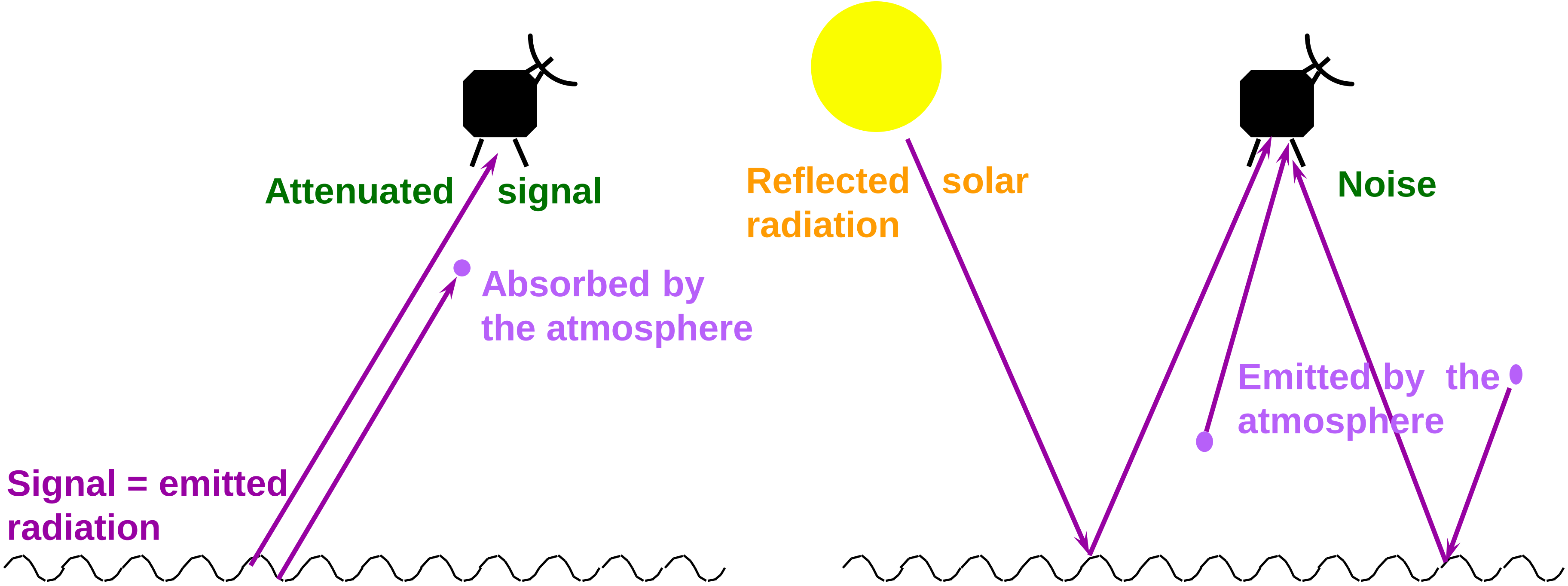
Black-body radiation at typical sea surface temperatures



Thermal emission spectra at high (up to solar) temperatures

The real surface emits less than the black-body radiation, by a factor ε called the Emissivity

Atmospheric interactions wih I-R radiation



Attenuated signal

Absorbed by the atmosphere

Signal = emitted radiation

Reflected solar radiation

Noise

Emitted by the atmosphere

ε for sea water is about 0.99 so the water-leaving signal is almost the black body radiation

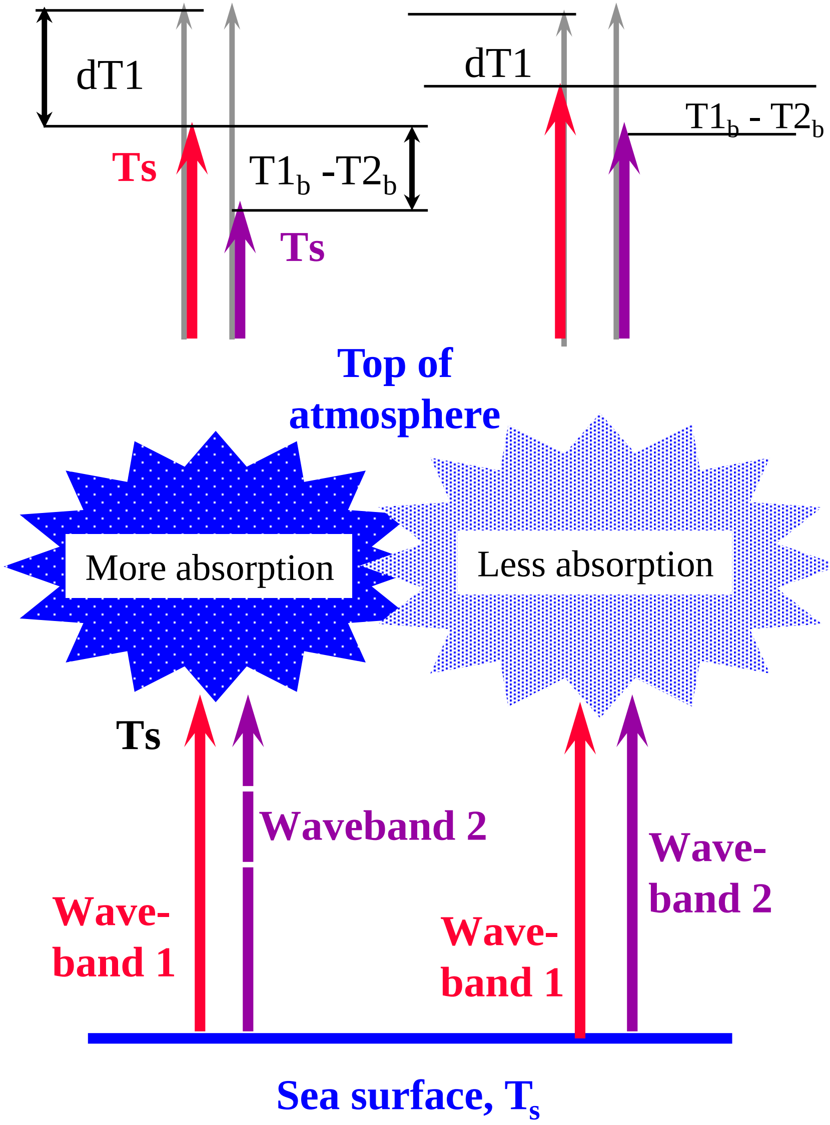
Reflectance is (1 - ε) which is very small, so solar reflection is negligible at 11 microns

Thermal emission is approximately Lambertian, i.e. it is uniform in all directions and does not depend on the surface slope, but it may be affected by surface foam and films.

Thermal emission by the atmosphere (which is generally colder than the sea) is the greates source of atmospheric noise.

Atmospheric correction of infra-red data

- **The Problem to be corrected:**
  - The measured radiance is described by its "Brightness temperature", T_b.
  - T_b is generally less than than the true sea surface temperature T_s.
  - The difference, dT, is caused by atmospheric absorption of I-R.
- **The Objective of atmospheric correction:**
  - Estimate Ts as accurately as possible
  - Allow for variable absorption (dT not uniform)
- **The approach**
  - Measure T_b in different ways, for which dT differs even for the same pixel.
  - e.g. Measure T_b in different wavebands, $T1_b$,$T2_b$, . .
  - ($T1_b$ - $T2_b$) gives a measure of the amount of atmospheric absorption at each pixel
  - dT = function of ($T1_b$ - $T2_b$)



Atmospheric correction algorithms

- Simple multichannel
  - Assume a linear relation between dT and $T1_b$ - $T2_b$
  - T_s = a T1b + b $(Ti_b\text{-}T2_b)$ + c
- Non-linear
  - T_s = a T1b + b $(Ti_b\text{-}T2_b)$ + c $(Ti_b\text{-}T2_b)^2$ + d
  - or T_s = a T1b + b $(Ti_b\text{-}T2_b)$ + c $(Ti_b\text{-}T2_b)$ (1 - cos(θ) + d
    - where θ is the viewing angle of incidence
- Multi-channel
  - Use more than two wavebands
  - Or use second viewing angle
- Coefficients
  - The values of a, b, c etc. are determined empirically
    - Either to match in situ temperature measurements
    - or to match model-simulated data

NOAA MCSST algorithms

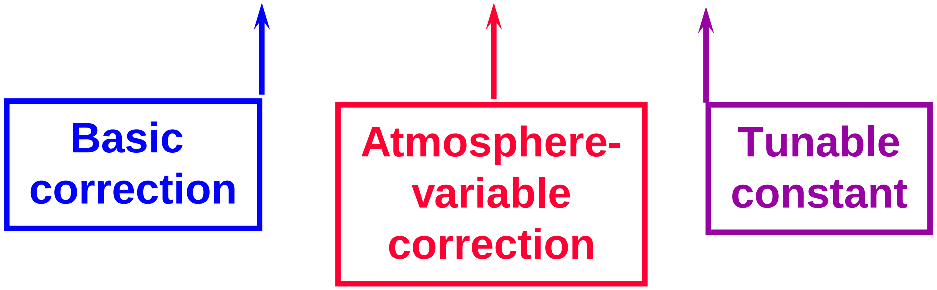
- **Multi-Channel Sea Surface Temperature algorithms**

  Incorporate data from a network of drifting buoys.

  Empirical algorithm coefficients vary with satellite.

  Different algorithms for day and night, e.g.:

			approx. accuracy
DAY:	$T_{sst} = a_1 T_{b11} + b_1 (T_{11} - T_{12}) + c_1$	*Split window*	0.6 deg C
NIGHT	$T_{sst} = a_2 T_{b11} + b_2 (T_{11} - T_{12}) + c_2$	*Split window*	0.6 deg C
	$T_{sst} = a_3 T_{b11} + b_3 (T_{3.7} - T_{12}) + c_3$	*Triple window*	0.64 deg C
	$T_{sst} = a_4 T_{b11} + b_4 (T_{3.7} - T_{11}) + c_4$	*Dual window*	0.72 deg C

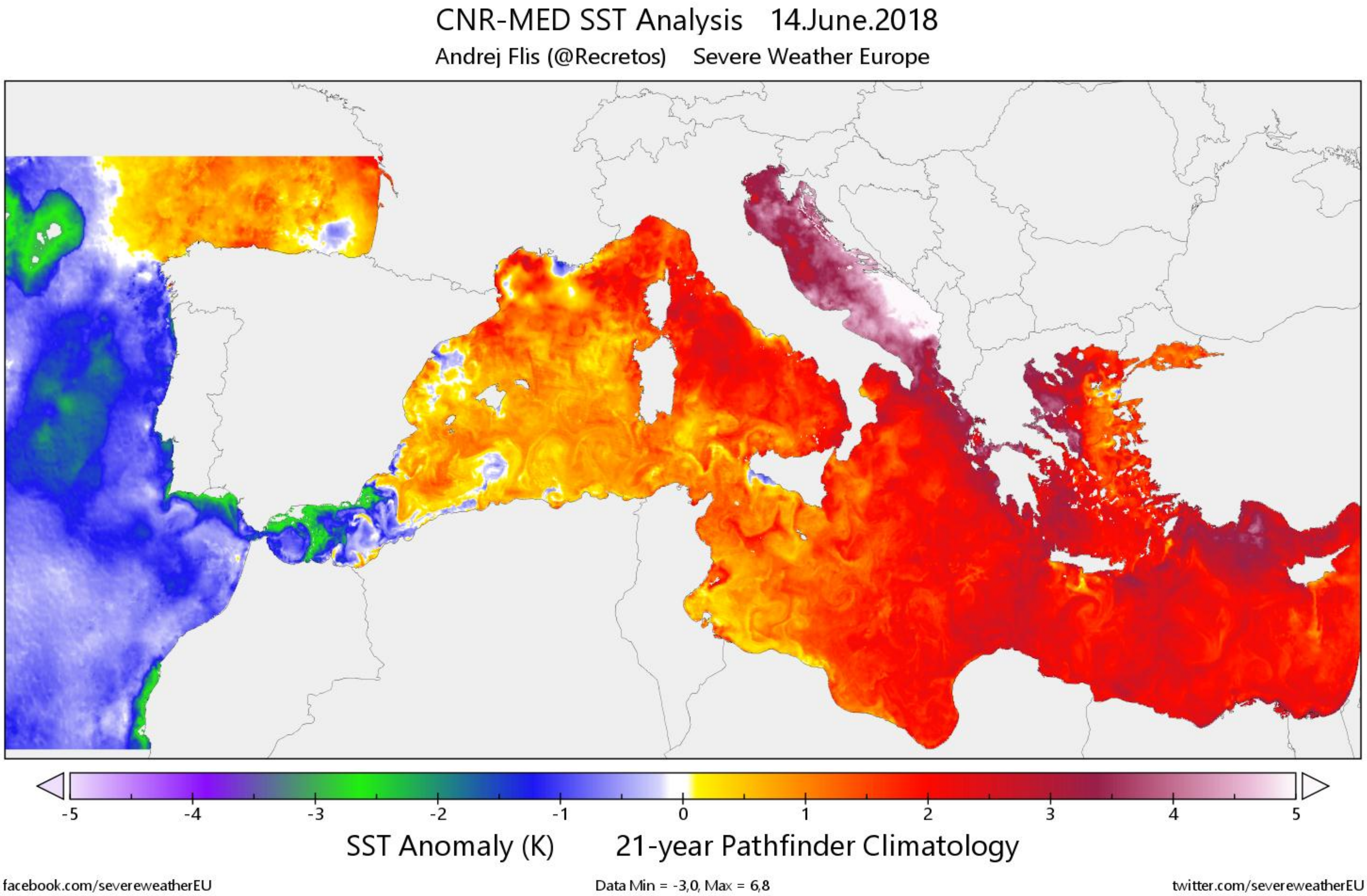


Basic correction

Atmosphere-variable correction

Tunable constant

Application: thermal anomalies / climate related



End of Part I (Passive Sensing)