Atmospheric correction and ocean colour

1. Introduction

Observing the colour of the ocean and understanding its causes provide information on the substances present in it. Regarding eutrophication, two key parameters are derived from the ocean colour: the quantity of chlorophyll and the penetration of light in the water.

When observing the ocean from above its surface, the reflection on the surface (of light coming directly from the sun and the sky) is added to the signal coming from the ocean itself. When observing the ocean from space, we need to consider the double path through the atmosphere (sun-surface-satellite). The atmospheric correction aims to remove these interferences from the signal to retrieve the intrinsic water colour.

2. Fundamental Optic

- **The solar light**

At a given point at the top of the atmosphere, the solar light is white and comes from one direction. We all know that this white light can be decomposed in colours: in the visible, it is the rainbow from the violet to the red; before the violet, the ultra-violet and above the red, the infrared

- **The atmospheric scattering**

In absence of atmosphere, during the day we would only see the very bright solar disk and the sky dome will be dark. With the atmosphere, the solar light is attenuated and interacts with the atmosphere first by scattering, the light is scattered in all the directions (for instance, in a dark cellar, when a sun beam penetrates in it, you can see it by the scattering of the dust), and second by absorption.

Molecular scattering

This scattering is intense in the blue and sharply decreases towards the red. In upper mountains, the sky is deep blue because of the purity of the atmosphere. The molecules amount, and therefore the intensity of the molecular scattering is proportional to the barometric pressure.

Aerosol scattering

The particles in the air (aerosols) scatter and their colours go from the blue (very small aerosols) to the white (big aerosols). Their nature and quantity are very variable in time and space.

Scattering by clouds and fogs

This scattering by water droplets is white and intense. We do not see the sun through the clouds and therefore, it is not possible to see the ocean from space in the presence of clouds.

- **Atmospheric absorption**

By the molecules

We all know that the ozone layer protects us from the UV radiation. Other atmospheric gases absorb the solar light in the visible and the infra-red. In the design of the satellite sensor, the selection of the colours (spectral filters) is made to avoid the atmospheric absorption (atmospheric windows)

Absorption by the aerosols

Many pictures have been taken above major cities to illustrate the atmospheric pollution through the darkness of the atmosphere above. Black sues are for example very absorbing.

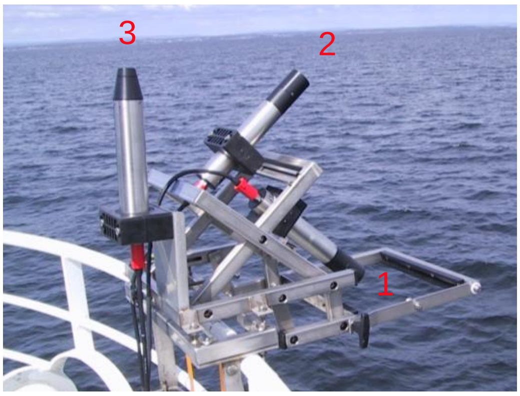
Fortunately, it is not the case over the ocean where the aerosol absorption remains usually weak.

If we knew the atmospheric composition then we can compute the atmospheric scattering and absorption. It is the domain of the radiative transfer.

3. Measure the water colour just above the surface

- **The reflection of the sun beam on the surface**
- The image of the sun by reflection over water is very intense but well localized in direction. This geometry is avoided for space observations
- **The sky dome reflection**

When we want to study the water colour from above the surface, we measure it in a given direction but we have to remove the reflection of the sky dome in this direction. The simplest experimental approach is to measure simultaneously the sky dome signal in the opposite direction. The simple law of the reflection will permit to subtract this sky dome reflection.



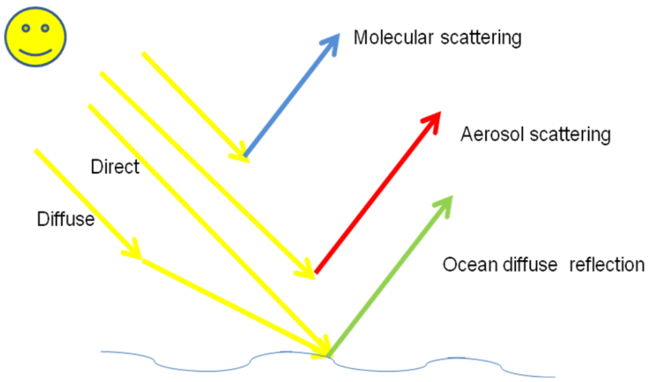
The sensor 1 measures the above water signal. The sensor 2 measures the atmospheric signal. The reflection law is applied to the measurement 2 to subtract to measurement 1 the sky dome reflection. The sensor 3 measures the total solar energy.

4. Measurement of the ocean colour from space

- **The reflection of the solar beam**

We always try to avoid as much as possible this circumstance during the mission design. If it appears, we do not use the portion of the satellite image contaminated by the sun glint.

The figure below is a schematic of the different contributions to the satellite signal.



The table below gives the relative importance of the marine signal, our useful term in this study. The ocean is black in the near infra red which offer the opportunity to characterize the atmosphere. In the visible, the contribution of the water colour is weak which implies to perform accurate atmospheric correction.

For three colours and two solar angles (45 et 75 degrees), we report in percent the relative contributions to the satellite signal of the molecular scattering, the aerosol scattering and of the ocean. The aerosols are continental and two horizontal visibilities are considered: 8 km and 23 km

		8 km			23 km		
		blue	red	Near infra red	blue	red	Near infra red
Molecules	45°	62.6	34.7	23.1	75.8	53.1	42.9
	75°	58.2	29.7	18.8	70.7	45.2	32.4
Aerosols	45°	32.3	61.2	76.9	16.4	40.6	57.1
	75°	39.8	68.8	81.3	26.0	52.3	67.6
Sea	45°	5.2	4.1	0.0	7.8	6.3	0.0
	75°	1.9	1.5	0.0	3.3	2.5	0.0

- **Aerosol remote sensing**

It is well known that the atmospheric scattering is proportional to the barometric pressure. Also known is the law of reflection of the light above water. What is missing is the roughness of the ocean surface, which we can model as a function of the wind speed (usually measured). The largest unknowns lie on the aerosols: their nature and abundance.

In the near infra red, the water is black and the satellite signal is purely atmospheric. We subtract the molecular scattering to get the aerosols. Using two spectral filters, we know the colour of the aerosol and therefore its nature (blue=small, white=big). The intensity of the signal provides their abundance.

- **The regional optical properties of the aerosols**

In order to better use the two pieces of information on the aerosols provided from space observations, we need to use a library of aerosol models. We have access to a regional network of ground based optical measurements which allows us to improve the knowledge of the aerosol optical properties.

- **The atmospheric correction scheme**

We now know all the components of the atmospheric signal:

(i) The attenuation by the atmosphere of the oceanic signal
(ii) The gaseous absorption
(iii) The molecular scattering
(iv) The aerosol scattering
(v) The surface reflection

It is easy to derive from the satellite signal the signal coming from the ocean body (the ocean colour)