Optical properties and water clarity, a comparison between *in situ* measurements and satellite derived products in the Adriatic sea.

Giuliana Pennucci, Raffaele Grasso, Pietro Zanasca
NURC-NATO Undersea Research Centre,Viale San Bartolomeo 400, 19138 La Spezia

INTRODUCTION: local measurements, carried out by autonomous vehicles, buoys, land stations and ships provide accurate ground-truth used to validate and calibrate algorithms and numerical models. Remote sensing tools (airborne and satellite based) complement these local observations by providing wide area synoptic coverage of near surface features, or water column integrated properties. In this regard, it is essential to combine local and remote sensing observations to create complete and accurate physical fields snapshots, allowing an expert extrapolation of the satellite and aircraft imagery and sound local dynamics characterization.

AIM: evaluate the performance of algorithms to estimate biophysical properties from satellite remote sensing imagery. For this purpose SeaWiFS, MODIS and MERIS derived products are compared to ocean optical measurements taken during NATO cruises in the Adriatic sea.

BACKGROUND: ocean color can be measured from space to provide global information on subsurface oceanographic parameters. The ocean color is the spectrum of radiation from sun and sky in the visible region, which emerges from below the sea surface after being scattered upward at subsurface depths. This spectrum of water leaving radiance is influenced by concentrations and optical properties of various organic and inorganic constituents of seawater.

Measurements of water leaving radiance/reflectance in the visible from multi/hyperspectral satellite passive sensors are used to retrieve sea water inherent optical properties (IOPs) as well as constituent concentrations by inverting a suitable bio-optical direct model.

As IOPs are directly linked to the constituent in the water, their values are used to determine the type of water, subsurface light intensity, solar heat flux with depth, turbidity, pigment concentration, water clarity and sediment.

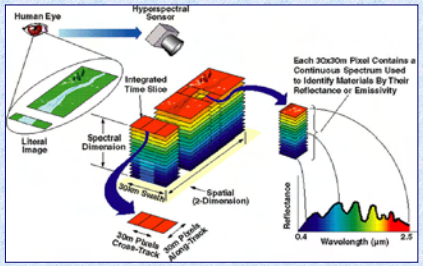


Figure 1: description of the multi/hyperspectral data (www.cs.may.ie)

The algorithm proposed in [1] was developed in order to retrieve the sea water absorption and backscattering coefficients. From these quantities the beam attenuation coefficient and the water clarity have been estimated and compared with *in situ* measurements.

REMOTE SENSING DATA (optical sensors): the data used for this research are acquired from the NURC mobile X-band antenna. NURC is able to select an area of interest from the quick look image, and to specify the processing level and the type of output products. The figure below shows an example of MODIS/AQUA acquisition.

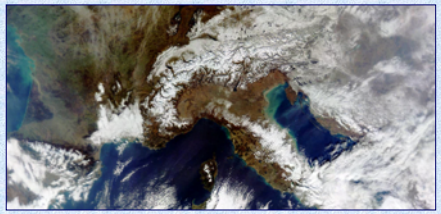


Figure 2: L1B products from AQUA satellite (MODIS sensor)

The MODIS instrument provides high radiometric sensivity in 36 spectral bands ranging in wavelengths from 400nm to 1440nm (the visible range is covered by 8 channels with 10nm of resolution).

NUMERICAL MODEL: the methodologies developed here are based on models that relate the reflectance spectra to IOPs of seawater. The remote sensing reflectance above the surface, $R_{rs}(\lambda)$, is related to the subsurface remote sensing reflectance, $r_{rs}(\lambda)$, by the following equation:

$$R_{rs}(\lambda) = \frac{[1-\rho][1-\bar{\rho}]}{n_w^2(1-rR)} r_{rs}(\lambda).$$

$\rho, \bar{\rho}$: surf. refl. for upward/downward radiance.
n_w : refractive index of seawater.
r : surf. refl. For diffuse upward irradiance.
R : surf. refl. For diffuse upward irradiance.

This relationship permits to convert the above surface remote sensing reflectance in the reflectance below the surface. The ratio:

$$u(\lambda) = \frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)},$$

b_b : backscattering coefficient.
a : absorption coefficient.

can be estimated from $r_{rs}(\lambda)$ by inverting the following relationship[3]:

$$r_{rs}(\lambda) = g_0 u(\lambda) + g_1 [u(\lambda)]^2.$$

$g_0 = 0.0895$
$g_1 = 0.1247$

Knowing $u(\lambda)$ and a (or b_b) will lead to b_b (or a).

PARAMETER ESTIMATION: the absorption coefficient is estimated for a chosen reference wavelength (λ_0) by using an empirical model relating a to the sensor reflectance[1]. Then $b_b(\lambda)$ can be calculated from $u(\lambda_0)$. $b_b(\lambda_0)$ can be extrapolated for a generic wavelength using the following relationship[1]:

$$b_b(\lambda) \propto b_b(\lambda_0)\left(\frac{\lambda_0}{\lambda}\right)^Y. \qquad \hat{Y} \in [0:2]$$

The scattering coefficient value can be estimated from the backscattering (b). The beam attenuation coefficient is then evaluated as $c(\lambda) = a(\lambda) + b(\lambda)$.

CRUISES: the *in situ* data used for this research have been taken in the Adriatic sea during two NATO cruises. The figure on the right shows the vessels involved (Leonardo in the lower part of the picture and the R/V Alliance in the upper part of the picture) and the measurements station distribution.

***IN SITU* MEASUREMENTS**: the measurements available for the comparison have been taken by using two different types of active instruments:

- ALPHAtracka II transmissometer (see figure 3);
- AC-9 spectrophotometer (WET Labs).

The first one measures, in a certain position and time, the vertical profile of the beam attenuation coefficient at 660nm; the second measures both the absorption and the beam attenuation coefficient at nine wavelengths (421, 440, 488, 520, 532, 555, 650, 676, and 715nm). These instruments are lowered into the sea from the ship with special arms.

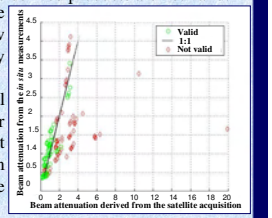
The visual water clarity has been measured using Secchi Disk, a white or black-and-white disk that is lowered into the water until the image is judged to disappear from view. The depth of disappearance is a useful index of water clarity.

Figure 3: the Secchi Disk (on the left) and the transmissometer (on the right). This latter sensor measures the beam attenuation coefficient at 660 nm.

Experimental results[2] have shown that the beam attenuation coefficient (c) can be estimated from horizontal observations of the visual range of a Secchi disk, with the simple empirical equation: Water Clarity $\cong 4.8/c(550\text{nm})$

VALIDATION STRATEGY: before presenting the results, there is a need to describe the strategies used to define the conditions for which the satellite derived products are not valid.

- Depth of the local stations: the satellite signal in very shallow water areas can be corrupted by the sea bottom irradiance;
- Sensor resolution: the spatial resolution of the satellite sensor gives indications of the correct distance that we can take from the coast, the cloud, and the noise pixels.



The figure above shows all the 38 stations available from the AC-9. The red diamond represents the stations that have been classified as not valid (these values have been considered like outliers), while the green circles are the measurements that will be used for the comparisons.

RESULTS: the comparisons covered a broad range of conditions from clear waters to very turbid coastal waters affected by river (the Po). The absorption values predicted by the remote sensing image in homogeneous waters showed good agreement with the *in situ* measurements. The algorithm performance was significantly degraded for strong stratification of the optical properties in the near-surface layer that is typical of the northern Adriatic. In these cases the beam attenuation coefficient values have been underestimated (see figure 4) and, consequently, these values overestimated the water clarity.

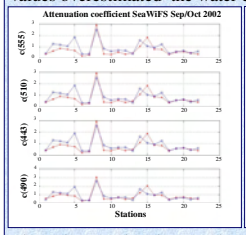


Figure 4: comparison between the values of beam attenuation coefficient in the green-blue wavelength; the AC-9 values are represented with a blue circle, while the SeaWiFS values are represented with a red asterisk.

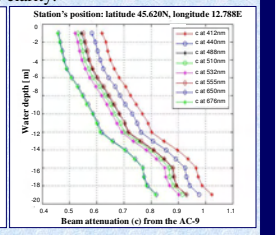
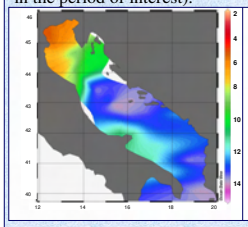
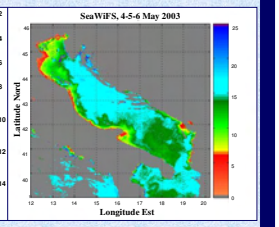


Figure 5: vertical profile obtained from the AC-9 for a critical station (high stratification).

The figures below show the visibility retrieved from the *in situ* measurements (left side), and the visibility derived from SeaWiFS sensor (result of the average of the images available in the period of interest).





As showed the satellite derived products give similar structures to that the transmissometer, but, generally, the remote sensing derived water clarity overestimate the *in situ* water clarity.

CONCLUSIONS: the comparison shows good agreement in clear water, while in most turbid water the beam attenuation coefficient values are underestimated as compared to the *in situ* measurements, and, consequently, these values overestimate the water clarity. Part of these discrepancies were most likely attributable to the lack of proper atmospheric corrections, which are beyond this study.

FURTHER INVESTIGATION: the evaluation of accuracy and procedures to determine IOPs from satellite measurements remains an important challenge. Future work will include a more in-depth analysis of the errors.

[1] ZhongPing Lee, Kendall L. Carder, and Robert A. Arnone, *Deriving inherent optical properties from water color: a multiband quasi-analytical algorithm for optically deep waters*, Applied Optics, Vol. 41, No. 27, September 2002
[2] J. Ronald V. Zaneveld, and W. Scott Pegau, *Robust underwater visibility parameter*, Optics Express 2997, Vol. 11, No. 23, 17 November 2003.
[3] H.R. Gordon, O. B. Brown, R. H. Evans, J. W. Brown, R. C. Smith, K. S. Baker, and D. K. Clark, *A semi-analytic radiance model of ocean color*, J. Geophys. Res. 93, 10909-10924, 1988.