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Remote Sensing of Environment 95 (2005) 29–46

Remote Sensing of Environment

www.elsevier.com/locate/rse

Satellite-derived parameters for biological modelling in coastal waters: Illustration over the eastern continental shelf of the Bay of Biscay

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Received 28 January 2004; received in revised form 3 November 2004; accepted 7 November 2004

Abstract

In biological modelling of the coastal phytoplankton dynamics, the light attenuation coefficient is often expressed as a function of the concentrations of chlorophyll and mineral suspended particulate matter (SPM). In order to estimate the relationship between these parameters over the continental shelf of the northern Bay of Biscay, a set of in situ data has been gathered for the period 1998–2003 when SeaWiFS imagery is available. These data comprise surface measurements of the concentrations of total SPM, chlorophyll, and irradiance profiles from which is derived the attenuation coefficient of the photosynthetically available radiation, K_{PAR}. The performance of the IFREMER look-up table used to retrieve the chlorophyll concentration from the SeaWiFS radiance is evaluated on this new set of data. The quality of the estimated chlorophyll concentration is assessed from a comparison of the variograms of the in situ and satellite-derived chlorophyll concentrations. Once the chlorophyll concentration is determined, the non living SPM, which is defined as the SPM not related to the dead or alive endogenous phytoplankton, is estimated from the radiance at 555 nm by inverting a semi-analytic model. This method provides realistic estimations of concentrations of chlorophyll and SPM over the continental shelf all over the year. Finally, a relationship, based on non living SPM and chlorophyll, is proposed to estimate K_{PAR} on the continental shelf of the Bay of Biscay. The same formula is applied to non living SPM and chlorophyll concentrations, observed in situ or derived from SeaWiFS radiance.

Keywords: Ocean color; Chlorophyll; Sediment; SeaWiFS; Bay of Biscay

1. Introduction

Despite their well-known limitations in coastal waters, the ocean colour sensors provide a unique means for observing the phytoplankton distribution over the continental shelf. However, optical techniques from space platforms are hampered by clouds and cannot be used alone for the monitoring of the phytoplankton all over the year. For that purpose, they need to be associated to biogeochemical models to be fully efficient. Satellite maps, calibrated on in situ measurements, can be used to validate and constrain the physical and biological parameters of the models or provide data for assimilation (Gregoire et al., 2003). In coastal waters, light is very often a key limiting factor for the phytoplankton growth and the light attenuation coefficient in the euphotic layer is a major parameter in ecological modelling. As we deal with biological simulations, the light is integrated over the PAR (Photosynthetically Available Radiation) domain [400, 700 nm] and its attenuation coefficient is expressed as K_{PAR}. K_{PAR} can be derived from the optically active components of water which are related to chlorophyll, suspended particulate matter (SPM), and dissolved organic matter. The chlorophyll, as an indicator of the biological particles, and the inorganic SPM govern a large part of the absorption and scattering properties of the coastal waters. Both quantities are simulated in the coastal ecological models and can also be retrieved from ocean colour data.

The chlorophyll concentration in the Bay of Biscay has been routinely retrieved from SeaWiFS data for several years now by using a look-up table described in Gohin et al. (2002). The SPM concentration can be derived from

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0034-4257/$ - see front matter
doi:10.1016/j.rse.2004.11.007

the reflectance at 555 nm, R[555], as proposed for the Bay of Biscay by Froidefond et al. (2002). Considering that the phytoplankton, whose quantity is related to chlorophyll, is also a component of SPM, the relationship proposed by Froidefond et al. has to be modified to take into account the chlorophyll-*a* concentration derived from the look-up table.

For modelling the availability of light with depth in the English Channel (Cugier, 1999; Cugier et al., 2004; Menesguen et al., 1995) and in the Bay of Biscay (Loyer, 2001), K_{PAR} is calculated from the chlorophyll and the suspended matter concentrations (Prieur & Sathyendranath, 1981; Nelson & Smith, 1991). If we could express K_{PAR} by a combination of the chlorophyll-*a* (Chl), and SPM concentrations, observed in situ or derived from satellite, we could also assimilate K_{PAR} derived from both types of data. This paper presents some statistical properties of Chl, SPM, and K_{PAR} over the continental shelf of the Bay of Biscay. The analysed properties will be the mean, the variance, and also the structure function, or variogram, which aims to expand the definition of the variance for space variables. These properties will be discussed from the observations and from the satellite-derived quantities.

After having estimated the spatial distribution of the two optically active quantities that are Chl and SPM, we have tested the application of the Ocean Color 4 band algorithm (OC4) to the coastal waters of the Bay of Biscay. OC4 is an algorithm which has been defined to retrieve the chlorophyll concentration from the remote sensing reflectance in clear waters (O'Reilly et al., 1998). Clear waters, also called Case 1 waters, contain only pure water and phytoplankton particles (with their associated detrital material) which are well correlated with Chl. Although this algorithm has not been proposed for coastal waters, also called Case 2 waters, where the SPM and the yellow substances altered significantly the optical properties of the medium, it is largely applied without geographical restrictions. In many cases, the boundary between the water types is largely unknown and its seasonal evolution, from winter to summer, contributes to make the question still more complex.

2. The optical parameters derived from ocean colour

In our coastal region, the optical properties of the water depend on three main constituents in addition to pure water itself: phytoplankton, inorganic suspended material, and yellow substances (dissolved organic matter). The contribution by phytoplankton to optical properties can also be divided into two components as coccoliths-bearing species have their own optical characteristics (Smyth et al., 2002). The ordinary phytoplankton component groups living cells and other microscopic organisms or particles whose concentration co-varies with the chlorophyll-*a* pigment which is considered as representative of the whole component. Inorganic materials are transported from the land in the river plumes (mainly Loire, Gironde, and Adour) or resuspended from the bottom. Resuspension of SPM are observed in shallow waters subjected to strong tidal stirring or, more often in the Bay of Biscay, in mixed waters following frequent and energetic autumn and winter storms. Coccoliths are produced by a coccolithophore (*Emiliana Huxleyi*) abundant over the slope of the continental shelf. Their presence is regular in spring and summer over the Celtic Sea but they have also been observed closer to the coast in winter. The calcareous plates of the coccoliths are highly reflective at any wave length and are well discriminated from the satellite reflectance spectrum. The yellow substances are coloured dissolved organic matter. They may have a local origin, from degradation of plankton cells, or be advected in estuaries and river plumes.

The spectral diffuse attenuation coefficient of light $K(\lambda)$ depends on the concentration of the optically active constituents of water. It is defined as the rate at which the natural logarithm of the descending irradiance at wavelength λ , Ed(z,λ), is attenuated with depth following the Beer–Lambert law (Defant, 1961).

$$K(z,\lambda) = -\frac{\mathrm{d}[\ln(\mathrm{Ed}(z,\lambda))]}{\mathrm{d}z} \quad \text{where } z \text{ is depth} \tag{1}$$

$K(z,\lambda)$ is used to relate Ed (expressed in W m^{-2}) at depth z to the irradiance Ed(0,λ) just below the surface. By integrating Eq. (1) from the surface to a depth z, with $K(\lambda)$ constant with z, one obtains:

$$E(z,\lambda) = \mathrm{Ed}(0,\lambda)\exp[-K(\lambda)z] \tag{2}$$

In biology, K_{PAR} is defined as the rate at which the total quanta $Q(z)$, integrated over the PAR domain, declines with depth.

$$Q(z) = \frac{1}{hc}\int_{400}^{700} \mathrm{Ed}(z,\lambda)\lambda \mathrm{d}\lambda \tag{3}$$

where h is Planck's constant, c is the velocity of light. $Q(z)$ is the flux of photons, expressed in μEinstein per square meter and per second.

The remote sensing reflectance, $R_{RS}(\lambda)$, is defined as the ratio of the upwelling radiance to the downwelling irradiance at the water surface. $R_{RS}(\lambda)$ depends on the backscattering coefficient b_b and the attenuation coefficient $a(\lambda)$ which are inherent optical properties, IOPs, of the medium.

$$R_{RS}(\lambda) = C\frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)} \tag{4}$$

where C is a function of the zenith solar angle, the observation angle, and the surface roughness (Gordon et al., 1975; Morel et al., 1995). C is often, as in Sydor and Arnone (2002), considered as a constant for the sake of simplification.