Geofísica Internacional (2014) 53-4: 385-398

Original paper

Spectral Reflectance Analysis of the Caribbean Sea

Raúl Aguirre Gómez

Received: March 03, 2013; accepted: January 21, 2013; published on line: October 01, 2014

Resumen

En este trabajo se analizaron curvas de reflectancia espectral mediante el método de derivada. Los espectros de derivada de la reflectancia revelaron picos ocultos tanto en curvas de reflectancia y absorción del agua del Mar Caribe y de elementos contenidos en ella. Las curvas de reflectancia mostraron un predominio del color azul (400-500 nm), el cual es característico de aguas oligotróficas del Caribe, los picos de absorción están influenciados por las propiedades ópticas de la clorofila *a* y el agua de mar. Las curvas de reflectancia mostraron respuesta espectral similar. En este artículo se analizaron los espectros de reflectancia del agua marina en 31 estaciones en el Mar Caribe en el verano de 2001.

Palabras clave: Propiedades ópticas, Oceanografía óptica, análisis de derivada de la reflectancia, Mar Caribe.

Abstract

Reflectance spectral curves were analysed by a derivative method. Derivative reflectance spectra revealed concealed peaks of both reflectance and absorption curves of Caribbean seawater and elements contained within it. Reflectance curves showed a predominant blue colour (400-500 nm) characteristic of Caribbean oligotrophic waters, conspicuous peaks result from the optical properties of chlorophyll *a* and seawater. Reflectance curves had a similar spectral response. This paper analyses reflectance spectra of surface seawater at 31 stations in the Caribbean Sea during the summer of 2001.

Keywords: Optical properties, optical Oceanography, derivative reflectance analysis, Caribbean Sea.

Raúl Aguirre Gómez
Laboratorio de Análisis Geoespacial
Instituto de Geografía
Universidad Nacional Autónoma de México
Circuito Exterior, Ciudad Universitaria
04510, México D.F., México
Corresponding author: raguirre@igg.unam.mx

Introduction

Sea surface reflectance R(λ) is operationally defined as the ratio between upwelling irradiance $E_u(\lambda,0)$ and the downwelling irradiance $E_d(\lambda,0)$ at wavelength λ at the surface (depth $Z=0$) and is expressed as:

$$R(\lambda,0)=\frac{E_u(\lambda,0)}{E_d(\lambda,0)} \qquad (1)$$

The parameter $E_u(\lambda,0)$ possesses information on the sea water and the dissolved and particulate matter contained within it, whilst $E_d(\lambda,0)$ stands for the total incoming irradiance. Changes of ocean colour are determined by the spectral variations of the reflectance $R(\lambda,0)$.

The operational expression of Equation (1) can be related to physical properties of water. Many models of radiative transfer are useful for establishing a relationship between $R(\lambda)$ and the absorption (a) and backscattering (b_b) coefficients (e.g. Morel and Prieur 1977, Gordon and Morel 1983). Both coefficients are influenced by the optical characteristics of pure sea water and those of the particulate and dissolved substances present in variable amounts in the sea. Thus, reflectance spectra are a consequence of absorption and backscattering processes due to water (w), phytoplankton ($phyto$), carbon dissolved organic matter or CDOM (y) and non-phytoplankton particles (x). Hence, any interpretation of the reflectance must consider the optical properties of these substances.

Morel and Prieur (1977) proposed a simple relationship for the reflectance of oceanic waters:

$$R=f\frac{b_b}{a} \qquad (2)$$

Where f is a function of solar altitude and the scattering phase function (Gordon *et al*., 1988). Thus, f can take different values depending on the angle of measurement. Historically, it had the value of 0.33 at the zenith angle of incident light (Morel and Prieur, 1977; Kirk 1984); however, other authors have estimated the f value for different angle intervals (e. g. Hirata and Højerslev, 2008). Nonetheless, this equation is only valid for waters where $b_b \ll a$, and it is assumed that the coefficients a and b_b follow the principle of superposition (Sathyendranath and Morel 1983).

Experimental data and theory indicate that, under most conditions, values of $b_b(\lambda)$ are relatively small compared to values of $a(\lambda)$ and decrease monotonically with respect to wavelength (Gordon and Morel 1983).

In order to analyze reflectance spectra a number of techniques have been employed. Thus, ratios and differences have traditionally been used in ocean colour studies, although they are restricted to a small number of spectral bands.

Nowadays, the advent of high-spectral-resolution sensors requires the use of powerful analytical methods of study such as the derivative analysis. The derivative method undertakes many of the problems of quantitative analysis more effectively than ratios and differences by considering a larger amount of data, which stands for more information potentially available (Jia *et al.*, 2008). Derivative analysis has been applied to a different kind of spectra obtained by high spectral-resolution sensors (e. g., Evangelista *et al*., 2006). These sensors are characterised by having a bandwidth less than 5 nm and/or more than 100 spectral bands. Thus, high-spectral-resolution sensors can provide information about smaller spectral variations than coarse bands do. The derivative method has been used for minimizing low-frequency background noise and for resolving overlapping spectra (Butler and Hopkins 1970). This method has successfully been applied in aquatic remote sensing for studying suspended solids in water (Chen *et al*., 1992, Goodin *et al.,* 1993; Hunter *et al.,* 2008) and detecting photosynthetic algal pigments (Aguirre-Gómez *et al.,* 2001; Han, 2005), among other topics.

In general, data provided by high-spectral-resolution sensors mounted on an aircraft, on a satellite, and on a field spectroradiometer, can be useful for testing new types of algorithms designed to analyse the reflectance of seawater. Particularly, data provided by field spectroradiometers are important in remote sensing studies because they may simulate those obtained through sensors mounted on aircraft or satellites. Additionally, these measurements are essential for determining the atmospheric effect between the airborne or spaceborne remote sensor and the ground, instead of using models for removing atmospheric influences (Philpot, 1991). Finally, under certain circumstances, it could be better to use ship-based information because of higher confidence of in situ related data.

Consequently, the in situ optical properties, as calculated by equation (2), can be related to ocean colour observations through reflectance information on the marine surface as measured by equation (1).