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Retrieving aerosol characteristics and sea-surface chlorophyll from satellite ocean color multi-spectral sensors using a neural-variational method

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ABSTRACT

We developed a two-step algorithm for retrieving and then monitoring the concentration of Saharan dusts and of the sea-surface chlorophyll from satellite ocean-color multi-spectral observations. The first step consisted in classifying the top of the atmosphere (TOA) spectra using a neuronal classifier, which provided the aerosol type and a first-guess value of the aerosol parameters that was used to initialize the variational method. The variational method was the second step, which retrieved accurate measurements of the aerosol and chlorophyll-*a* concentrations. The algorithm was conditioned to take into account the absorbing aerosols, such as the Saharan dusts. We used this algorithm to analyze 13 years of SeaWiFS images (September 1997–December 2009) over an area of the Atlantic Ocean off the coast of West Africa. Since our method allowed us to take Saharan dusts into account, the number of pixels processed for retrieving the chlorophyll-*a* concentration was an order of magnitude higher than that processed by the standard SeaWiFS algorithm. The analysis of the SeaWiFS images showed that the Saharan dust concentration was maximal in summer during the rainy season and minimal in autumn, which could be explained by the seasonal variability of dust emission triggered by mesoscale atmospheric processes (low-level jet and convection) and soil characteristics (humidity and vegetation).

1. Introduction

Aerosols are an important component of the Earth climate system. On the one hand, they reflect the downwelling solar radiation and thus contribute to cooling the atmosphere and, on the other hand, they may also absorb the infrared radiation emitted by Earth, thus contributing to warming the atmosphere, depending on their quality (Zhao et al., 2010). A good knowledge of aerosol properties is therefore necessary for understanding climate variability and modeling it. The mass concentration of aerosols is closely related to the optical thickness, τ, which is a measure of the light attenuation. Aerosols are also characterized by their type (dust, maritime, soot etc.).

A major source of aerosols of the tropical Atlantic atmosphere is the Sahara Desert, which seeds the atmosphere with Saharan dusts. These aerosols cross the Atlantic Ocean transported by the trade winds and may be detected as far away as the Caribbean and South America (Moulin et al., 1997).

During the last 15 years, several satellites carrying multi-spectral radiometers dedicated to ocean-color observation have been launched. They measure the reflectance of the atmosphere and ocean system, providing a daily global coverage of Earth at a resolution of about a kilometer. These observations contain information on both atmospheric and oceanic parameters. Ocean-color radiometric signals have been intensively used to estimate sea-surface chlorophyll concentration and to monitor aerosol parameters over the ocean (Gordon and Wang, 1994; Tanré et al., 1997), both parameters being strongly coupled in the sense that an error in the computation of the atmospheric parameters (atmospheric correction) can generate an error in the determination of the chlorophyll concentration (Nobileau and Antoine, 2005). These measurements have permitted retrieval of the most significant aerosol parameters: aerosol optical thickness and the angstrom exponent over the ocean. The SeaWiFS and MODIS signals have also been applied to retrieve aerosols over lands by using specific algorithms. The difficulty is to retrieve aerosol information over such bright surface regions as the Sahara Desert, due to a strong spectral contribution by reflection from the ground in the visible range which masks the atmospheric contribution. However, a new algorithm, the so-called "Deep Blue Algorithm" (Hsu et al., 2006) allows retrieval of the aerosol optical thickness (AOT) over desert regions by processing ocean-color sensor measurements.

For Case-1 waters, the standard aerosol products provided by the SeaWiFS data center (Husar et al., 1997; Wang and Gordon; 1994)

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were computed by extrapolating the atmospheric reflectances at visible wavelengths from the atmospheric reflectance in the near-infrared (865 nm) for which the ocean is black at first approximation; i.e., the signal recorded by the satellite sensor in these bands is due to the atmosphere alone. The algorithms used for SeaWiFS products are limited to a relatively low optical thickness (less than 0.35) and are not able to deal with absorbing aerosols such as Saharan dusts.

Algorithms able to deal with absorbing aerosols have been developed. The Nobileau and Antoine (2005) algorithm identified blue-absorbing aerosols from near-infrared and visible remote-sensing observations. The spectral matching algorithm (SMA) (Banzon et al., 2004; Chomko and Gordon, 1998; Gordon and Wang, 1994; Moulin et al., 2001a, 2001b) used all ocean-color spectral bands to simultaneously retrieve aerosol parameters and ocean biophysical properties. The SMA procedure used a set of candidate aerosol models and a water bio-optical model contained in Look Up Tables (LUT) to compute the top-of-the-atmosphere (TOA) radiance. The best set of aerosol and oceanic parameters was found by a minimization procedure between measured TOA and computed TOA over all the spectral bands.

Another absorbing-aerosol algorithm, the so-called spectral optimization algorithm (SOA), was proposed by Chomko and Gordon (2001). The SOA is used for simultaneous atmospheric correction and retrieval of water properties. In this algorithm, a simple Junge size–distribution parameter was used for the size–shape distribution of aerosols, along with a wavelength-independent complex refractive index.

This paper presents a complete methodology, which is an extension of SOA. It uses two statistical models applied sequentially to derive aerosol characteristics and chlorophyll concentration from satellite ocean-color data in an ocean region off the coasts of Senegal and Mauritania (Fig. 1). In the present paper, we mainly focus on aerosol retrieval. Section 2 describes the ocean-color data we processed. Section 3 presents the methodology we used. Section 4 is devoted to the validation of the method. Section 5 analyzes the results in the studied region. Section 6 is devoted to a critical summary and a conclusion.

2. The data

For this study we have used three distinct data sets: satellite observations, synthetic data provided by radiative transfer codes, and in situ measurements.

2.1. The satellite observations

The daily reflectances, $\rho_{toa}^{obs}(\lambda)$, were observed at the top of the atmosphere (TOA) by the SeaWiFS sensor in an ocean area off the west coast of Africa, between 8° and 24°N and 14° and 30°W (Fig. 1). These measurements cover a 13-year period (1997–2009).

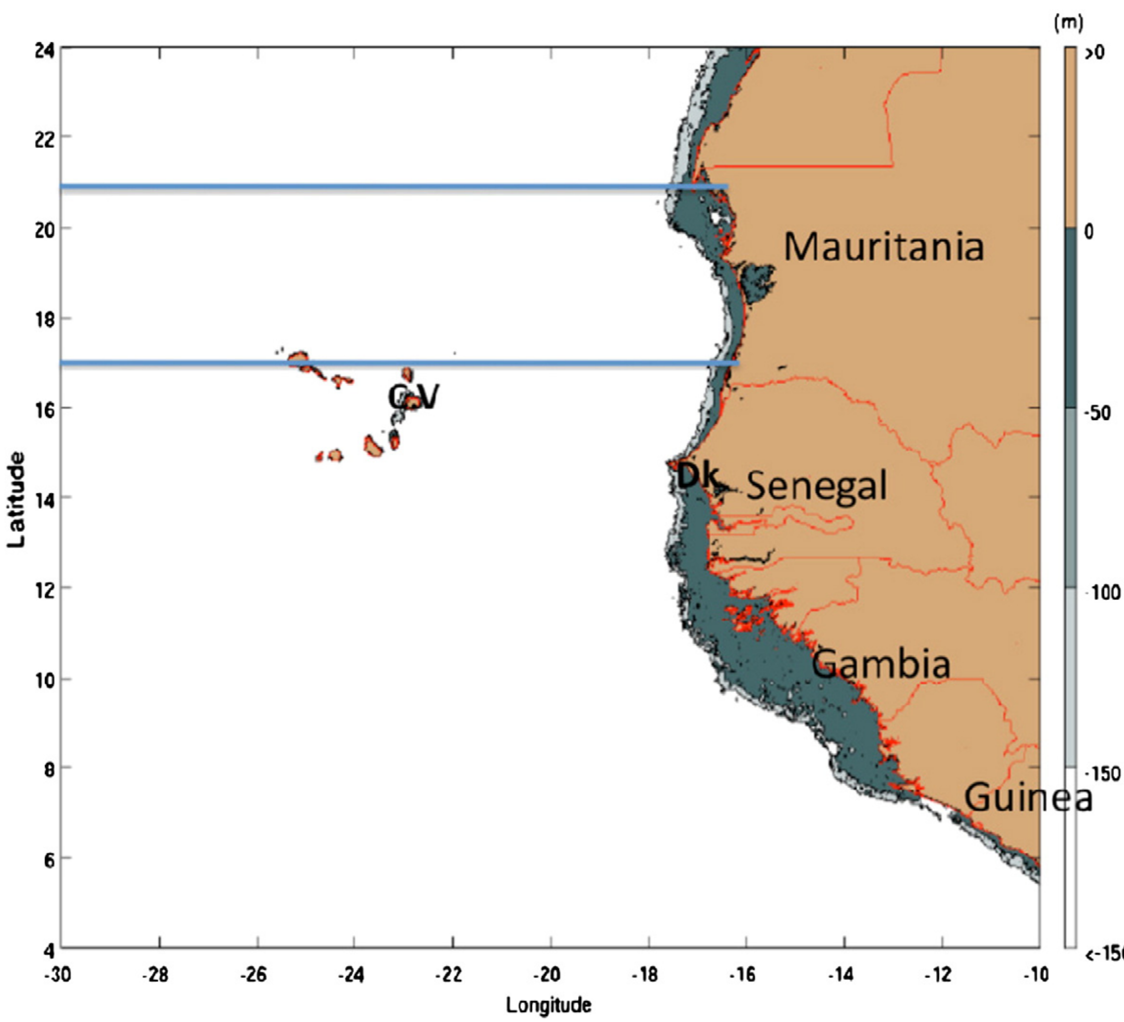

Fig. 1. The studied ocean region. The label *Dk* corresponds to the location of Dakar and *CV* to the Cape Verde islands. The two horizontal lines correspond to zonal sections presented in Fig. 11.