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Use of SeaWiFS data for light availability and parameter estimation of a phytoplankton production model of the Bay of Biscay

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Abstract

Processing SeaWiFS (Sea-viewing Wide Field-of-view Sensor) data provides useful information for the observation and modelling of the phytoplankton production of the Bay of Biscay. Empirical algorithms allow the retrieval of chlorophyll *a* and non-living Suspended Particulate Matter (SPM) concentrations. These data are used to constrain a coupled 3D physical–biogeochemical model of the Bay of Biscay continental shelf. Two issues are investigated, depending on the variable used, to constrain the winter to spring phytoplankton production for the year 2001. First, SPM data is used as forcing data to correct the corresponding state variable of our model. This allows the realistic simulation of the light limited bloom at the end of February 2001, as observed with SeaWiFS chlorophyll *a* images and from the NUTRIGAS field cruise. Second, chlorophyll *a* data is used for parameter estimation of the biogeochemical model. The ability of assimilating these data is tested to improve the simulation of strong blooms observed in late May 2001 in the Loire and Gironde plumes. A global optimization method (Evolutive Strategies) is adapted to the complete 3-D coupled model, in order to find the best set of parameters. The hydrological conditions during the bloom can be validated with data from the PEL01 field cruise. After selection of the most sensitive parameters, the method is tested with twin experiments. Then, the use of real SeaWiFS data reduces the model/data misfit by a factor of two, improving the simulation of bloom intensities and extensions. The sets of parameters retrieved in each plume are discussed.

Keywords: Physical–biogeochemical modelling; Suspended Particulate Matter; Chlorophyll; Parameter estimation; SeaWiFS; Bay of Biscay

1. Introduction

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data, since the launch of the sensor aboard Sea Star in September 1997, has been processed with empirical algorithms adapted to the Bay of Biscay. Chlorophyll *a* (Gohin et al., 2002) and non-living Suspended Particulate Matter (the particulate matter non-correlated to phytoplankton, here after referred as SPM) are thus retrieved with an acceptable reliability level (Gohin et al., 2005). This satellite database, together with the *in situ* observations collected during the numerous oceanic cruises carried out in the Bay of Biscay, have allowed a deeper understanding of the spatio-temporal distribution of phytoplankton. Hydrological features related to river plumes, and light availability, seem to be the two major factors regulating the winter to spring phytoplankton production in the Bay of Biscay (Morin et al., 1991; Labry et al., 2001; Gohin et al., 2003).

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This ecological *a priori* knowledge introduced in a modelling approach can help us extrapolating in space and time the view we have of the ecosystem. In this work, we use the MARS3D hydrodynamical model of IFREMER (Lazure and Jegou, 1998; Lazure and Dumas, submitted for publication) applied to the Bay of Biscay. With the appropriate high resolution atmospheric forcings, the main hydrological characteristics can be reproduced at the shelf scale. This model is coupled to a phytoplankton production model derived from that developed in Loyer (2001).

A critical issue of phytoplankton modelling in coastal areas is the retrieving of the amount of light in the water column, a major controlling factor of the winter primary production. For the Bay of Biscay, the model should simulate the recurrent blooms in the Loire and Gironde plumes at the end of winter. These blooms develop during sunny periods in the distal part of the plumes, where SPM concentration is low, and halostratification induces a thin mixed-layer (Labry et al., 2001; Gohin et al., 2003). The scattering and absorption of the solar irradiance depend on particulate organic and mineral matter, as well as yellow substances, the Coloured Dissolved Organic Matter (CDOM). Living organic matter and associated detritus can be deduced from the corresponding state variables of the model. Mineral suspended matter can be another state variable of the model. However, the complexity of the deposition and erosion processes and their forcings, and the variability in the quality of the constitutive particles of the sediment, are both strong sources of error in the simulation of this variable concentration.

Another complicated task is the choice of appropriate parameter values. Parameterizations often integrate several processes, for model components encompassing several families and species. In this case, associated parameters can be highly variable. In addition, many of them cannot be directly issued from measurements, like mortality rates. Uncertainties in the parameter values are thus a major source of error in an ecosystem model. Multiplying the number of state variables becomes critical for the model stability and efficiency, mainly because it multiplies dramatically the number of degrees of freedom (Denman, 2003; Arhonditsis and Brett, 2004). Thus, the biogeochemical model we use remains quite simple, with the choice of variables depending on data available over the Bay of Biscay shelf.

Data assimilation is a promising strategy for constraining models with observations. Numerous assimilation studies show the usefulness of the highly informative chlorophyll *a* satellite data. Most of these works have been done for estimating the parameter values of biological models (Fasham et al., 1995; Prunet et al., 1996; Gunson et al., 1999; Lellouche et al., 2000; Friedrichs, 2002; Garcia-Gorriz et al., 2003; Hemmings et al., 2003; Losa et al., 2004), rather than looking for a forecasting assimilation scheme updating the model state (Ishizaka, 1990; Carmillet et al., 2001; Natvik and Evensen, 2003), for which a much clearer understanding of the intricacies of marine ecosystems is required (Hofmann and Friedrichs, 2001). This statement is even truer for coastal areas, where physical mechanisms, biogeochemical processes, and their coupling are more sensitive and complex as compared with the open ocean.

The goal of this work is to investigate the potential improvement of our biogeochemical model by using SeaWiFS derived quantities. This goal can be articulated along two objectives. The first objective is to better constrain the light attenuation coefficient, which is a prerequisite for a good estimation of the winter phytoplankton production in coastal areas. For this purpose, we will use SPM derived from SeaWiFS images. The second objective is to derive a set of biological parameters consistent with the SeaWiFS chlorophyll *a* observations over the Bay of Biscay. To achieve properly this calibration step, we will use an objective cost function between model and data together with a minimization routine. Several methods have been employed in the last few years, most of them based on the adjoint model (Lawson et al., 1995; Spitz et al., 1998; Gunson et al., 1999; Lellouche et al., 2000; Spitz et al., 2001; Fennel et al., 2001; Friedrichs, 2001; Schartau et al., 2001; Friedrichs, 2002; Garcia-Gorriz et al., 2003; Faugeras et al., 2003; Kuroda and Kishi, 2004). Other authors have used global optimization methods, like simulated annealing (Matear, 1995; Hurtt and Armstrong, 1996; Vallino, 2000) or the genetic algorithms (Athias et al., 2000; Schartau and Oschlies, 2003). The latter show best results in computational time and maximum recovery efficiency. We will use here the Evolution Strategies (Schwefel, 1995), based on the same principles than genetic algorithms, but more appropriate for continuous problems (Bäck, 1996). The method is adapted to our three dimensional coupled model. It is tested in the recovery of a parameter set allowing the correct simulation of strong blooms observed on SeaWiFS chlorophyll *a* images in the river plumes of the Bay of Biscay in May 2001.

2. The coupled model and data

2.1. The hydrodynamical model

We use the MARS3D circulation model designed for shelf to small embayment scale hydrodynamics. Its principles are fully described in Lazure and Dumas (submitted