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A multi-decadal hindcast of a physical–biogeochemical model and derived oceanographic indices in the Bay of Biscay

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ABSTRACT

Multiple year oceanographic simulations (hindcast) are identified as a priority oceanography product for fisheries and environment studies since they provide a unique continuous long-term dataset allowing integrated assessment of the ocean state and evolution. We performed a 37 year (1972–2008) hindcast run with a coupled physical–biogeochemical model in the Bay of Biscay. The coupled model and the hindcast configuration are described. A model skill assessment is performed with a large set of in-situ data. Average seasonal currents show major circulation patterns over the shelf. Among tracers, temperature and salinity have the best agreement, ahead of nitrates and silicates, chlorophyll, and finally phosphates and ammonium. For chlorophyll, improved pattern statistics are found when compared to monthly composites of satellite-derived chlorophyll data. From the hindcast, we derived indices related to mesoscale activity (eddies, plumes, fronts, stratification) and production (chlorophyll and primary production). They help characterise the evolution of the environment in a functional way, on both the seasonal and multi-decadal scales. From these indices, first, a multivariate analysis reveals an increasing number of years that deviate from the mean seasonal pattern. Second, we propose interpretations of the simulated increasing trends detected in several of them (temperature, thermocline depth and primary production). We also recommend further developments to confirm these simulated evolutions, from addition of open boundary forcing with a global circulation model, to the improvement of the dynamics of nutrient regeneration and of the seasonal variability of secondary production. As a perspective, we review the different applications made from our hindcast in relation to anchovy life cycle, a species of major interest in the Bay of Biscay.

1. Introduction

There is a growing interest in continuously monitoring the ocean environment, from surface to bottom and over several decades from past to future, with the need to understand and anticipate its implication in global change. Among other needs, a reference state of the marine environment is required by the Marine Strategy Framework Directive (Anonymous, 2008), as well as the assessment of the impact of the ocean evolution on marine resources and fisheries (Cury et al., 2008).

Satellite remotely sensed data has already shown its potential in deriving ecosystem indicators (Chassot et al., 2011), however temporal coverage is historically limited to launch of earth observation satellites (end of the seventies) and spatial coverage is limited to the ocean surface layers. Coupled physical–biological models provide an extensive source of information on both the physical and biological state of the ocean in three dimensions. Limitations on the duration of model simulations decrease while computing power increases, the main remaining constraint being then external forcing conditions (atmospheric or river discharges). Also, an extensive list of oceanographic or ecosystem indices may be derived from these models (e.g. Crosnier et al., 2008; Planque et al., 2006). The indices are useful to explicit mesoscale physical structures that are implicit in the model outputs of the state variables, and relate those to primary production and higher trophic levels.

Multi-decadal hindcast using hydrodynamic model have been run recently and assessed on their ability to simulate both seasonal and interannual variability (e.g. Meyer et al., 2011; Vidal-Vijande et al., 2011). Also coupled physical–biogeochemical models have been developed and used for two decades, and are now ready for hindcast simulations: see two products available at www.wgoofe.org for the North Sea based on the ECOSMO (Schrum et al., 2006) and NORWECOM (Hjollo et al., 2009) models. In this paper, we present the hindcast of a physical–biogeochemical model (ECOMARS) run for the Bay of Biscay over a 37 year period (1972–2008). The model is a N3-P3-Z2-D3 type model, and was used to simulate the dynamics

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of pico-nanoplankton, diatoms and dinoflagellates, under the limitations of nitrogen, silicates and phosphates, and of micro- and mesozooplankton. The model is constrained by realistic meteorological forcing as well as daily river run-off and loads. As both the physical and biogeochemical models were primarily developed to study the shelf dynamics (Lazure and Dumas, 2008; Loyer, 2001), this paper also focuses on the continental shelf area.

The oceanography of the Bay of Biscay is not forced by one major driver and is best characterised by a variety of mesoscale features being active according to climatic and seasonal conditions (Puillat et al., 2004) which inevitably affects fish populations (Koutsikopoulos and Le Cann, 1996). Typically, mesoscale structures range from tens to a few hundred kilometres and last from a few weeks to months. Mesoscale structures are highly energetic and are often associated with areas of strong biological activity under the Bakun's fundamental triad (Bakun, 1996) processes (enrichment, retention and concentration). Consequently, in addition to model state variables, we derived a suite of indices describing the depth and strength of stratification, location of fronts, eddies and upwellings, and extension of river plumes. Biological production is provided through the vertically integrated primary production. As a whole, the hindcast provides half of the variables listed as useful by the ICES Working Group on Operational Oceanographic Products for Fisheries and Environment (WGOOFE) and among them, the eight most requested variables by the ICES community (Berx et al., 2011).

The present paper's objectives are (i) to present the coupled model and hindcast configuration, (ii) to provide a general skill assessment of the model results, (iii) to introduce the derived oceanographic indices, and (iv) to give an integrated view of the system at the seasonal and multi-decadal scale based on these indices. A validation step has already been assessed on physical variables (Lazure et al., 2009). Here we complete it over a longer time-series, but we emphasise the assessment of biological variables, using in-situ available data over the whole time-series and ocean-colour satellite data from 1998. The model and some of its derived indices has already shown its potential for defining a spatial typology of the hydrological structures of the bay (Planque et al, 2006) or for statistical monitoring of the environment (Woillez et al., 2010), taking into account deviance from reference spatial patterns based on EOF analysis. Here, leaving apart the spatial patterns, we focus on the temporal evolution benefiting from the long time series available. This allows the characterisation of the seasonal pattern using Multiple Factor Analysis (MFA), and the description of the major environment trends observed in the last decades. Our paper finally highlights perspective uses of such a product for fisheries oceanography studies and discusses areas of further development in order to improve such modelling exercises.

2. The coupled model and hindcast simulation

2.1. The hydrodynamic model

The hydrodynamic component of our coupled model is MARS (hydrodynamic Model for Application at Regional Scale, Lazure and Dumas, 2008). The model was set up over the Bay of Biscay area and validated for tide and hydrology (Lazure and Dumas, 2008; Lazure et al., 2009). The geographic domain of the 3D model extends from 43.2°N to 50.8°N, and from 8°W to 0.4°W, covering the whole Bay of Biscay and the entrance of the English Channel (Fig. 1). It uses an ~4 km horizontal regular grid in a polar coordinate system, with 30 sigma layers in the vertical with refinement in the surface layers. A 2D model is run over a larger area (from Portugal to Norway) to provide surface elevation to the 3D model boundaries. A total of eight tidal constituents along the open boundary of the large model were extracted from FES2004 (Lyard et al., 2006). The 3D model is run with an adaptive time-step, never exceeding 15 min.

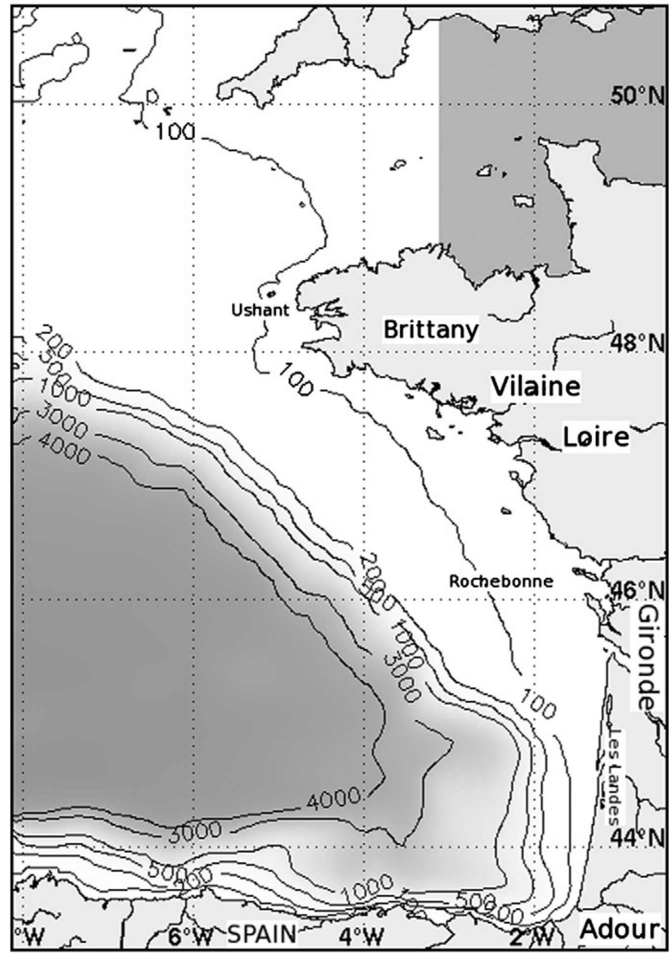

Fig. 1. Model domain with bathymetry and rivers considered for freshwater and nutrient discharges.

2.2. The biogeochemical model

The model MARS is coupled to a biogeochemical model (Fig. 2) describing the seasonal evolution of primary production by diatoms, dinoflagellates and pico-nanoplankton, with limitations by nitrates, ammonium, phosphates and silicates. Phosphates can be adsorbed to and desorped from Suspended Particulate Inorganic Matter (SPIM) and may be a limiting factor for production in some coastal locations during certain period of the year (Labry et al., 2002). All elements are present in the detritus under particulate matter form. We model two zooplankton compartments, microzooplankton and mesozooplankton, the latter being the closure term of our model. This model results from successive coupled model works over the Bay of Biscay (Huret et al., 2007; Loyer, 2001) or local areas within the region (Chapelle et al., 1994; Menesguen et al., 2006).

All biogeochemical tracers are coupled to the hydrodynamics through the advection–diffusion equation:

$$\frac{\partial X}{\partial t} = -\vec{V}\cdot\nabla X + \nabla\cdot(\kappa\nabla X) + \frac{DX}{Dt}$$

with X the tracer, V the 3D velocity field, κ the eddy diffusivity coefficient, and DX/Dt the source-minus-sink term representing the biological processes. Source-minus-sink equations are available in Annex A and model state variables and parameter values in Annex B. Light availability for primary production is limited by cloud cover, available from the meteorological forcing, and by Suspended Particulate Matter (SPM) available as a monthly climatology product based on ocean-colour data (Gohin et al., 2005).