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ScienceDirect
Journal of Marine Systems 65 (2007) 561–583
JOURNAL OF MARINE SYSTEMS
www.elsevier.com/locate/jmarsys

Application of a SEEK filter to a 1D biogeochemical model of the Ligurian Sea: Twin experiments and real in-situ data assimilation

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Received 23 September 2004; accepted 14 June 2005
Available online 20 October 2006

Abstract

The Singular Evolutive Extended Kalman (SEEK) filter has been implemented to assimilate in-situ data in a 1D coupled physical-ecosystem model of the Ligurian Sea. The biogeochemical model describes the partly decoupled nitrogen and carbon cycles of the pelagic food web. The GHER hydrodynamic model (1D version) is used to represent the physical forcings. The data assimilation scheme (SEEK filter) parameterizes the error statistics by means of a set of empirical orthogonal functions (EOFs). Twin experiments are first performed with the aim to choose the suitable experimental protocol (observation and estimation vectors, number of EOFs, frequency of the assimilation,...) and to assess the SEEK filter performances. This protocol is then applied to perform real data assimilation experiments using the DYFAMED data base. By assimilating phytoplankton observations, the method has allowed to improve not only the representation of the phytoplankton community, but also of other variables such as zooplankton and bacteria that evolve with model dynamics and that are not corrected by the data assimilation scheme. The validation of the assimilation method and the improvement of model results are studied by means of suitable error measurements.

Keywords: Data assimilation; Coupled physical-ecosystem model; Kalman filter; Error analysis; Ligurian Sea

1. Introduction

The Ligurian Sea is a semi-enclosed area located in the NW part of the Mediterranean Sea (Fig. 1). The Liguro-Provençal current is the main large-scale hydrodynamic feature of the region: two strong and variable currents, the Western and Eastern Corsican Currents (W.C.C. and E.C.C.) enter the domain of the Ligurian Sea. Both advect the Modified Atlantic Water at the surface. The E.C.C. also transports the denser Levantine Intermediate Water. These currents join and give birth to the Northern Current (N.C.) or the Ligurian Current, flowing along the French coast. The N.C. and the W.C.C. describe a cyclonic circulation along the Liguro-Provençal front.

The seasonal cycle of the biological productivity is characterized by the presence of a winter–early spring

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0924-7963/$ - see front matter
doi:10.1016/j.jmarsys.2005.06.006

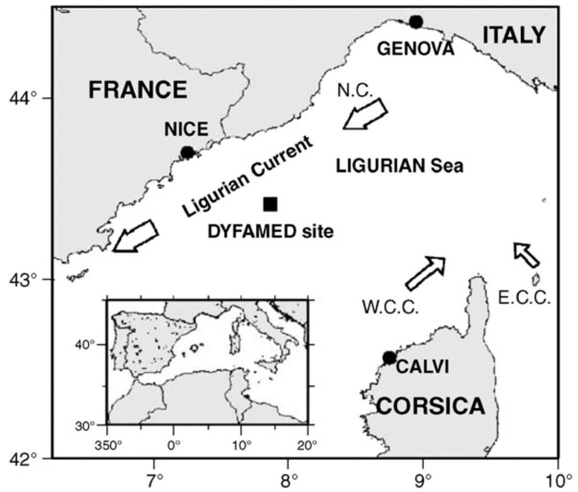

Fig. 1. Location of the Ligurian Sea, the DYFAMED station (reprinted from Marty and Chiaverini, 2002). The hydrodynamic currents are also represented.

bloom starting in February after the winter mixing, and usually followed by a secondary bloom in April–May depending on the spring vertical mixing. Oligotrophy prevails in summer due to the nutrients depletion in the water column. Another bloom occurs in autumn due to the enrichment in nutrients of the surface layers by the vertical mixing induced by strong wind events. Marty et al. (2002) report a significant interannual variability with a general increase in the phytoplankton biomass during a 9-years study (1991–1999), mainly due to the lengthening of the summer stratification period, favouring the growth of the small-size species supporting the regenerated production. They report an indicative value of 3.1 mgChl m^{-2} yr^{-1} for the 0–200 m integrated chlorophyll increase, when considering the entire chlorophyll data set. They also note that the short-term variations can introduce some bias in the determination of tendencies.

In the last few decades, the Mediterranean ecosystem has experienced changes in biodiversity due to the effect of human activity (e.g. Bethoux et al., 1998, 2002). A thorough understanding of the Mediterranean Sea ecosystem functioning and evolution requires the development of dynamic biogeochemical models coupled with the physical environment to determine the spatio-temporal evolution of the biological production and the influence of environmental factors on its intensity and distribution.

Data assimilation is a challenging task in ecosystem modelling. Ecosystem models are generally strongly non-linear and their response depends largely on the chosen biogeochemical processes parameterizations and their parameters values. Because much parameters values cannot be known with a certain degree of precision, and because of the model limitations according to which some variables and processes are too simply or not represented in the ecosystem model, errors in model results are unavoidable, even if a special care is given in the model conceptualization. By combining the numerical model and the available observations, data assimilation techniques are useful to improve the state estimation of the ocean. Two major and distinct families of data assimilation techniques are now well known (Kasibhatla et al., 2000): variational methods seek to minimize the misfit between data and model simulation (i.e. the cost function) by optimizing a well-chosen set of control parameters, while sequential methods proceed by sequential optimal corrections of the state estimate taking the accuracy of the model and observations into account. Variational data assimilation has already been applied at the DYFAMED station by Faugeras et al. (2003). Chlorophyll and nitrate profiles of year 1997 have been assimilated in a six-nitrogen compartments model embedded in a 1D physical model, developed by Mémery et al. (2002) for the DYFAMED site. They showed the feasibility of using the adjoint data assimilation method to constrain the biological part of the coupled model. They obtain an improvement of the representation of chlorophyll and nitrate, but fluxes such as primary production or export were not recovered with such a simple model by assimilating chlorophyll and nitrate data. These methods rely on the same hypothesis that a coupled model with a unique parameters set can reproduce the observations, neglecting the possibility of other sources of errors (Carmillet et al., 2001). Also, a large investment in term of coding (especially for the adjoint model) is required. The Kalman filter is a sequential data assimilation technique which estimates the state of the system recurrently, taking into account the error of the model and of the observations. It is coded in parallel to the model, which requires less initial investment when applied to different models. The Singular Evolutive Extended Kalman (SEEK) filter developed by Pham et al. (1998b) based on the concept of order reduction and for non-linear systems has been successfully applied in hydrodynamic models (e.g. Brasseur et al., 1999; Parent et al., 2003; Testut et al., 2003) and was recently applied to coupled physical-ecosystem models. Carmillet et al. (2001) have assimilated ocean colour data in a 3D physical–biochemical model of the north Atlantic ocean using a twin experiment approach. Hoteit et al. (2003) have used the SEEK filter in a 1D complex ecosystem model of the Cretan Sea assimilating oxygen and nitrate data,