OBSERVATIONAL REQUIREMENTS FOR VALIDATION OF MARINE ECOSYSTEM MODELS IN THE MEDITERRANEAN

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Abstract

To test, verify and improve marine ecosystem models, data sets of key variables are necessary. Such data sets ideally should reflect the state of the system in terms of trophic status, productivity, nutrient cycling and oxygen dynamics. The data sets available presently for (sub-regions of) the Mediterranean generally are far removed from this ideal, because they contain only information on concentrations or density/abundance, but not on rates-of-change, nor on the spatial variability of the variables. An observational strategy to acquire internally consistent data sets of key variables, comprising physical, biological as well as chemical variables is suggested, with a rationale for the choice of variables.

Key-words: models, geochemical cycles, Adriatic Sea, eutrophication, oxygen

Introduction

Simulation models of ecological processes have slowly become established tools for integrating and testing our understanding of the different components of marine ecosystems. The first models were dealing with parts of ecosystems, often seen as steady state systems [1, 2, 3] and sometimes as dynamical systems [4, 5]. From the end of the 70's on, complex dynamical models began to appear, describing complete estuarine and marine ecosystems, including pelagic and benthic processes as well as advection and dispersion processes [6 - 9]. Apart from a mathematical description of the biogeochemical processes and a physical model to describe the water transports, data are needed to run a model. This paper sketches the requirements and the availability of data sets necessary for models of the Mediterranean Sea in general and of the Adriatic Sea in particular, as well as some recommendations for observational strategies.

ERSEM

ERSEM is a comprehensive ecosystem model which dynamically simulates the cycling of organic carbon, oxygen and the macronutrients N, P and Si over the seasonal cycle. The model consists of an interlinked set of modules, describing the biological and chemical processes in the stratified or non-stratified water column and in the benthic system, as forced by light and temperature. The model domain is subdivided into smaller units, which are called boxes or grid cells, depending on their size. Physical transport between the boxes or grid cells is included by either driving the model with the aggregated output of physical circulation and dispersion models in the form of a time series of daily advective and diffusive exchange coefficients across all box boundaries or by directly forcing the biological model with a hydrodynamical model. In all the different spatial set-ups the biology in each of the boxes or grid cells is exactly the same.

The ERSEM model has been implemented in different regional seas and in different spatial set-ups, *e.g.* in the North Sea in a 15-box set-up and a 130-box set-up as well as a 1D-vertically resolved column model of a mooring site [10]. In the first two set-ups the transport model consists of daily exchange coefficients between the boxes calculated from a fine-scale hydrodynamical model [11], while the last set-up is coupled to a entrainment/detrainment model [12], forced with a meteorological high-frequency data set. In [13] and in the papers published in two special issues of the (Netherlands) *Journal of Sea Research* [9-11, 12-28] a full description of the biological modules has been given.

Data needs

Apart from the physical set-up (bathymetry) the model needs initial values for all state variables before it can be run. Then, during a run it needs time series for the forcing functions and the boundary conditions for the entire duration of the model run. Last but not least, after the model run, independent data are needed data to calibrate and/or verify the model results.

The initial values for those state variables not available from observations are obtained by running the model for a number of years repeating the same forcing and boundary conditions for each year until the model reaches a repeating cycle, so-called perpetual-year forcing. The forcing functions, as water temperature, irradiance, and the boundary conditions for all transported state variables have to be extracted from measurements. Calibration/verification data in the form of concentrations and fluxes are necessary to calibrate the model and to draw conclusions as to how well or badly the model reproduces the biogeochemistry of the modelled system.

ERSEM in the Adriatic Sea

For the Adriatic Sea ERSEM has been coupled to 1D and to 3D versions of the Princeton Ocean Model, a general circulation model described in [29]. A 1D-vertically resolved water column model has been constructed by [30]. This model has been applied to three different sites in the Adriatic Sea representing the northern, the central and the southern Adriatic Sea, with depths of 30, 150 and 1000 m, respectively.

The 3D model uses an idealised Adriatic Basin as described in [31]. It is constituted by a rectangular basin, without open boundaries, with approximately the same size and geographical position as the real Adriatic Sea. The basin has a minimum depth in the North of 50 m, sloping towards a maximum depth of 500 m in the south. The grid used in this model set-up has a horizontal resolution of ~25 km and 10 sigma layers in the vertical. As forcing functions climatological data of wind-stress, heat flux and river runoff have been used.

Data availability and use

For the Adriatic Sea the following data sets are available:

• May data, a data set of monthly climatology, compiled by May [32] and used for the atmospheric surface forcing.

• ATOS, the Adriatic Temperature, Oxygen and Salinity data set, reported by Artegiani *et al.* [33, 34], used to initialise the temperature and salinity fields.

• ABCD, the Adriatic BiogeoChemical Data set [35], used for verification of the model. The number of casts containing nutrient and chlorophyll-a data ranges from 1353 for nitrite and nitrate down to 611 for Chl-a. Even at the coarse spatial scale (~25 km) of the POM 3D/ERSEM set-up in the Adriatic, the observational coverage is such that it has not been possible to extract climatological monthly means at this spatial resolution. Instead, it has been necessary to aggregate the data into a seasonal climatology (winter, spring, summer, autumn) for much larger sub-regions of the Adriatic [31]. This necessitates aggregating the model results to a much coarser spatial resolution in order to compare them directly to the available data. The requirement here clearly is for finding more synoptic data sets. This has partly been accomplished by extracting information from the

• CZCS, the Coastal Zone Colour Scanner data set held by ISPRA [31], containing chlorophyll-a data.

Implications of model results and data

In the Adriatic, the results of the 1D model show remarkable similarities and differences between the northern, the central and the southern study sites. At all three sites the seasonal cycles show a well-mixed period during winter with relatively cold water and a stratified summer period when vertical mixing is weak, decoupling the euphotic zone from regenerated nutrients. Benthic-pelagic coupling plays a significant role in nutrient recycling, weakening with increasing depth from north to south.

Although the 3D model was primarily developed to test the coupling of the physical model with the biogeochemical modules, the results do show the North-South trophic gradient with the northern part of the basin being the most productive by river-borne nutrients inputs and by the recycled nutrients from the benthic system. The south with smaller river inputs and a more distant benthic-pelagic coupling is a less productive system. The model correctly predicts the occurrence of a winter phytoplankton maximum in the northern sub-basin, confirmed by the CZCS chlorophyll data, and it reproduces observed regional differences in nutrient distributions over the whole