Agència
de Gestió d'Ajuts
Universitaris
i de Recerca

Memòria justificativa de recerca de les convocatòries BCC, BE, BP, CTP-AIRE, DEBEQ, FI, INEFC, NANOS i PIV

La memòria justificativa consta de les dues parts que venen a continuació:
1.- Dades bàsiques i resums
2.- Memòria del treball (informe científic)

Tots els camps són obligatoris

1.- Dades bàsiques i resums

Nom de la convocatòria

BE

Llegenda per a les convocatòries:

BCC	Convocatòria de beques per a joves membres de comunitats catalanes a l'exterior
BE	Beques per a estades per a la recerca fora de Catalunya
BP	Convocatòria d'ajuts postdoctorals dins del programa Beatriu de Pinós
CTP-AIRE	Ajuts per accions de cooperació en el marc de la comunitat de treball dels Pirineus. Ajuts de mobilitat de personal investigador.
DEBEQ (Modalitat A3)	Beques de Cooperació Internacional i Desenvolupament
FI	Beques predoctorals per a la formació de personal investigador
INEFC	Beques predoctorals i de col·laboració, dins de l'àmbit de l'educació física i l'esport i les ciències aplicades a l'esport
NANOS	Beques de recerca per a la formació en el camp de les nanotecnologies
PIV	Beques de recerca per a professors i investigadors visitants a Catalunya

Títol del projecte: ha de sintetitzar la temàtica científica del vostre document.
Two Different 3D Biogeochemical Models for the NW Mediterranean Sea. Validation with Meris Data and Intercomparison.

Dades de l'investigador o beneficiari

Nom	Cognoms
Raffaele	Bernardello

Correu electrònic
raffaele@ceab.csic.es

Dades del centre d'origen

Centre d'Estudis Avançats de Blanes- Consejo Superior de Investigaciones Cientificas

Agència
de Gestió d'Ajuts
Universitaris
i de Recerca

Número d'expedient
2006 BE-2 0010

Paraules clau: cal que esmenteu cinc conceptes que defineixin el contingut de la vostra memòria.
3D biogeochemical model, NW Mediterranean Sea, MERIS remote sensing data, Quantitative validation, Models inter-comparison.

Data de presentació de la justificació
30/07/2008

Nom i cognoms i signatura
del/de la investigador/a

Visttiplau del/de la responsable de la
sol·licitud

Generalitat de Catalunya
Departament d'Innovació,
Universitats i Empresa

Resum del projecte: cal adjuntar dos resums del document, l'un en anglès i l'altre en la llengua del document, on s'esmenti la durada de l'acció

Resum en la llengua del projecte (màxim 300 paraules)
Dos diferents models biogeoquímics han estat acoblats a una configuració tridimensional del Princeton Ocean Model (POM) per a la Mar Mediterrània Nord-occidental (Ahumada i Cruzado, 2007). El primer model biogeoquímic es la versió tridimensional del model descrit per Bahamón i Cruzado (2003) i quantifica els fluxos de nitrogén a través de sis comparts emprant una descripció semi-empirica dels procéssos biogeoquímics. El segon model biogeoquímic es el model biomecànic NPZD descrit per Baird et al. (2004), que empra una combinació de descripcions fisiològiques i físiques per quantificar les intraccions planctòniques. Els processos fisics inclouen la difusió de nutrients a les cèl•lules fitoplanctòniques i la taxa d'encontre entre el fitoplàncton i el zooplàncton. La dependència entre els processos fisics i biogeoquímics en els dos models s'expressa mitjançant l'advecció-difusió dels traçadors no conservatius. Les similituds entre els dos models en la formulació matemàtica dels processos biogeoquímics s'ha aprofitat per determinar el conjunt de paràmetres per el model biomecànic que oferix la millor correspondència amb el conjunt del primer model. Han estat necessaris tres anys d'integració per a obtenir l' anomenat any perpetu per les condicións biogeoquímiques. Els resultats dels dos models han estat promediats mensualment i comparats amb les imatges del sensor MERIS per la clorofila. Per a obtenir les imatges mensuals s'ha emprat un conjunt de dades de tres anys (Juny 2002- Juny 2005) que ha estat interpolat a la resolució dels models. Per a quantificar la proximitat de les dades simulades pels dos models a les dades de MERIS, s'han emprat quatre indicadors estadistícs i s'han examinat les diferències entre les prestacions dels dos models.

Resum en anglès (màxim 300 paraules)
Two different biogeochemical models are coupled to a three dimensional configuration of the Princeton Ocean Model (POM) for the Northwestern Mediterranean Sea (Ahumada and Cruzado, 2007). The first biogeochemical model (BLANES) is the three-dimensional version of the model described by Bahamon and Cruzado (2003) and computes the nitrogen fluxes through six compartments using semi-empirical descriptions of biological processes. The second biogeochemical model (BIOMEC) is the biomechanical NPZD model described in Baird et al. (2004), which uses a combination of physiological and physical descriptions to quantify the rates of planktonic interactions. Physical descriptions include, for example, the diffusion of nutrients to phytoplankton cells and the encounter rate of predators and prey. The link between physical and biogeochemical processes in both models is expressed by the advection-diffusion of the non-conservative tracers. The similarities in the mathematical formulation of the biogeochemical processes in the two models are exploited to determine the parameter set for the biomechanical model that best fits the parameter set used in the first model. Three years of integration have been carried out for each model to reach the so called perpetual year run for biogeochemical conditions. Outputs from both models are averaged monthly and then compared to remote sensing images obtained from sensor MERIS for chlorophyll.

Resum en anglès (màxim 300 paraules) – continuació -.
A three-year data set is used (June 2002- June 2005) and the images are interpolated to the resolution of the model domain. In order to quantify the closeness of the data simulated by both models to remote sensing data, four statistical indicators are used and the differences between the performances of the two model are discussed.

2.- Memòria del treball (informe científic sense limitació de paraules). Pot incloure altres fitxers de qualsevol mena, no més grans de 10 MB cadascun d'ells.

Two Different 3D Biogeochemical Models for the NW Mediterranean Sea. Validation with Meris Data and Intercomparison.

Raffaele Bernardello

Index

1. Introduction (p. 2)
2. The models (p. 2)
The hydrodynamic model (p. 2)
The biogeochemical models (p. 3)
BLANES model (p. 3)
BIOMEC model (p. 3)
3. The coupling (p. 3)
Parameter sets (p. 4)
4. Simulation details (p. 4)
Physical details (p. 4)
Initial conditions, boundary conditions and forcings (p. 4)
Biogeochemical details (p. 5)
Initial conditions (p. 5)

Boundary conditions (p. 5)
Forcings (p.5)
5. Validation (p. 5)
Statistics (p. 5)
Cost function (p. 6)
Percentage Model Bias (p. 6)
Model Efficiency (p. 7)
Correlation Coefficient (p. 7)
MERIS data (p. 7)
6. Results and discussion (p. 7)
7. References (p. 8)
8. List of figures (p. 10)

Two Different 3D Biogeochemical Models for the NW Mediterranean Sea. Validation with Meris Data and Intercomparison.

1. Introduction

The coupling of hydrodynamic and biogeochemical models in a three-dimensional framework is a key-step in the comprehension of the ecological processes and in the management of marine resources. Ecological processes are heavily influenced by the high, vertical and horizontal, hydrodynamic heterogeneity that can be represented only by mean of high resolution 3-D models. As regarding biogeochemical properties, the Mediterranean Sea presents a marked spatial variability and a significant seasonal excursion with variances of the same order as the mean values (Crispi et al., 1998). In the Northwestern Mediterranean Sea the biogeochemical seasonal cycle is characterized by the presence of a spring bloom following the winter mixing. After the bloom, the depletion of nutrients causes the summer oligotrophy and, in autumn, the onset of vertical mixing is responsible of a second, less marked, bloom.
Besides the prominent seasonal cycle in the forcings (Crise at al., 1998) several temporal and spatial scales (basin, subbasin, and mesoscale) interact to form a highly complex and variable circulation (Fernández et al., 2005). The upward flux of nutrients is enhanced over a considerable portion of the area by the predominant cyclonic circulation with the interference of variable mesoscale structures during the year.
The models object of this study resolve both hydrodynamical and biogeochemical processes in the Northwestern Mediterranean Sea with a high spatial resolution (1/16ºx1/16º). The effort of modelling physical and biogeochemical features at sub-basin scale is justified by the necessity of describing mesoscale hydrodynamics in the belief that this will add detail to the biogeochemical prediction
Two biogeochemical models are coupled to the same physical model for the NW Mediterranean Sea (Ahumada and Cruzado, 2007), based on the Princeton Ocean Model (Blumberg and Mellor, 1987). The similarities in the mathematical formulation of the biological processes in the two models are exploited to determine the two parameter sets that best meet each other.

The physical model is climatologically forced to obtain the seasonal variation observed in the area. The model domain ranges from 38.5ºN to 44.5ºN and from 0.5ºW to 10.5ºE but only the central part of it is used in this study to avoid the noise introduced by the limitations of having a nearby open boundary. Monthly averaged outputs for chlorophyll-a are compared with MERIS remote sensing data by using four criteria based on error statistic. The aim of this study is to evaluate objectively the performance of the two models within the same physical frame.

2. The models

2.1 The hydrodynamic model

The regional model for the Northwestern Mediterranean Sea (NMS model hereafter) implemented by Ahumada and Cruzado (2007) is based on the Princeton Ocean Model (POM), (Blumberg and Mellor, 1987). The POM has a free surface and solves the non-linear primitive equations on a horizontal orthogonal curvilinear grid and a vertical sigma coordinate system using finite difference methods. Vertical mixing coefficients are computed according to the Mellor-Yamada 2.5 turbulence closure scheme (Mellor and Yamada, 1982).
The model domain is included between 38.5°N and 44.5°N of latitude and between 0.5°W and 10.5°E of longitude. The NMS model is configured with a horizontal resolution of 1/16° (6.93 km) in latitude as well as in longitude (from 5.40 km to 4.93 km) . In the vertical dimension, 27 sigma layers are employed, with reduced thickness for the upper 9 layers and for the deeper 6 layers.

2.2 The biogeochemical models

2.2.1 BLANES Model

The first biogeochemical model is the three-dimensional version of the model described by Bahamón and Cruzado (2003) and computes the nitrogen fluxes through six compartments using semi-empirical descriptions of biological processes .
It is an aggregated-type (NPZD) model which means that the whole planktonic autotrophic organisms are aggregated in a unique compartment represented by the state variable P (Phytoplankton). The same happens for the planktonic heterotrophic organisms, represented by the variable Z (Zooplankton), while nitrogen is present in the forms of dissolved nitrite (NO2-), nitrate (NO3-) and ammonium (NH4+). A state variable representing the detritus term (D) is added with respect to the original formulation and comprises all the particulate forms of decaying material. The fluxes among compartments are schematically represented in Fig.2. The uptake of nitrate, nitrite and ammonium by phytoplankton, as well as the grazing of phytoplankton by zooplankton, are based on the Michaelis-Menten formulation taking into account the inhibition of nitrate uptake in presence of ammonium. The zooplankton mortality is expressed as a quadratic function of its biomass and the remineralization of detritus follows a linear dynamic.

2.2.2 BIOMEC Model

The second biogeochemical model is the biomechanical NPZD model described in Baird et al. (2004), which uses a combination of physiological and physical description to quantify the rates of planktonic interactions. The biomechanical model contains 6 state variables: dissolved inorganic nitrogen (N), phytoplankton (P), zooplankton (Z), detritus (D), and phytoplankton reserves of nitrogen (R_N) and energy (R_I). The model includes the processes of nutrient uptake and light capture by phytoplankton, phytoplankton growth from internal reserves, zooplankton grazing on phytoplankton, and the mortality and sinking of phytoplankton, zooplankton and detritus. Where possible, biomechanical descriptions of ecological processes have been used. For example, the description of grazing rates for zooplankton on phytoplankton incorporates an encounter rate calculation, based on the encounter rates of particles in a turbulent fluid.

3. The coupling

The link between biogeochemical dynamics and physical properties of the sea is expressed by the advection-diffusion of the biogeochemical tracers. The coupling of the hydrodynamic model (NMS) to the two biogeochemical models (BLANES and BIOMEC) resolves this link following the equation:

$$\frac{\partial B}{\partial t} + \vec{v} \cdot \nabla B + (w_B)\frac{\partial B}{\partial Z} - \frac{\partial\left(k_h \frac{\partial B}{\partial Z}\right)}{\partial Z} - F_B = R_B$$

where:

$$F_B = \frac{\partial\left(A_m \frac{\partial B}{\partial X}\right)}{\partial X} + \frac{\partial\left(A_m \frac{\partial B}{\partial Y}\right)}{\partial Y}$$

where B is a generic biological tracer, R_B is the local rate of change of that tracer due to biological processes, w_B is the sinking velocity for phytoplankton and detritus, k_h is the vertical diffusivity and A_m is the horizontal kinematic viscosity . Both couplings (NMS-BLANES and NMS-BIOMEC) are on-line so the two models run at the same time and resolution. The partial differential equations describing the advection of biological tracers are integrated using 2 iterations of a positive definite advection scheme (Smolarkiewicz, 1984). The POM model calculates the free surface elevation (baroclinic mode) and the vertical structure (barotropic mode) separately, the time steps adopted are respectively 9 s and 720 s. The time stepping of biogeochemical tracers is done using explicit Euler integration with the same time step of the barotropic mode. The different integration schemes are combined by updating the state variables sequentially.

3.1 Parameter sets

The parameter set used for the BLANES model is the same defined for the Catalan Sea in the 1-D version of the model (see Bahamón and Cruzado, 2003). Where possible the parameters for the two models were set equal but the more complex formulation of the BIOMEC model makes impossible a perfect match between the two sets. Some parameters, taken as constant in the BLANES Model, are obtained from the mechanical description of the processes in which they are involved in the BIOMEC Model. The Zooplankton maximum growth rate, for example, is proportional to the encounter rate that depends on the cell radius chosen and on the vertical diffusivity.

4. Simulation details

4.1 Physical details

4.1.1 Initial conditions, boundary conditions and forcings.

The NMS model is implemented by means of nesting (in one-way off-line mode) to a general circulation model of the Mediterranean Sea – OGCM (Pinardi and Masetti, 2000; Demirov and Pinardi, 2002). Consequently, along the two open lateral boundaries, the NMS model is forced with velocity, salinity and temperature fields obtained from the 8th year of the Mediterranean Sea OGCM climatological integration (perpetual year run). These same fields corresponding to the end of the 8th year are used as initial conditions. All atmospheric forcing (wind stress, heat flux and freshwater
flux components) are obtained from climatological data.
In this work we use the outputs of the 15th year of climatological integration that corresponds to the perpetual year run of the NMS model.

4.2 Biogeochemical details

4.2.1 Initial conditions

The initial conditions for biogeochemical fields are obtained from climatological vertical profiles computed by Manca et al. (2004), using EU/MEDAR/MEDATLAS II and EU/MTPII/MATER databases. The full set of spatially averaged vertical profiles can be downloaded from the World Wide Web data server (http://doga.ogs.trieste.it/medar/climatologies/). To our purposes, annual averaged vertical profiles of nitrate and chlorophyll are used because seasonally vertical profiles are not available for all the regions included in the model's domain. The atom/weight ratio of chlorophyll to nitrogen was taken as 1

(mg/mmol) (Marra et al., 1990) in order to convert input data as well as output data. The profiles give values at discrete depths so a vertical interpolation to sigma layers depth is necessary. Climatological data for nitrite, ammonium, zooplankton and detritus are not available thus their initial values are set to 1% of the chlorophyll concentration for Zooplankton and to 1% of Nitrate concentration for the other variables. A spin-up period of two years has been necessary to achieve the biogeochemical perpetual year-run and the outputs of the third year are presented here.

4.2.2 Boundary conditions

The open lateral boundary conditions for biological fields are extrapolated from the interior solution using an upstream advection scheme, whenever the normal velocity is directed outwards from the NMS model's domain (outflow condition). Otherwise, in cases of inflow through the boundary, biological fields are prescribed from the initial conditions. The biological boundary conditions at the surface, bottom and coast are zero flux.

4.2.3 Forcings

The biogeochemical models are forced by daily and seasonal variation of the photosynthetically available radiation (PAR). The total irradiance is calculated at each time step at 41.5°N using the Brock (1981) formulation. A constant fraction of the total irradiance (0.45) is assumed to be PAR (Baker and Frouin, 1987). Exponential extinction of PAR flowing through the water column is formulated as depending on absorption and dispersion by the water and on the self-shading effect by phytoplankton.

5. Validation

5.1 Statistics

A key step in a process of validation is the choice of error statistics. In the following description of the four statistical indicators chosen *D* are the observational data, *M* are the corresponding model estimates, $\overline{D}$ and $\overline{M}$ are their respective means over the dimension considered. For example, $\overline{D}_x$ is the average of observed data in the place *x* over the time (*t*=1....*n*) while $\overline{M}_t$ is the average of the modelled data at the time *t* over a given area (*x=1...m*), being *x* the index of a spatial unit and *t* the index of a temporal interval. All the statistical indicators chosen can be calculated for a spatial unit over time (subindex *x*) or for a time interval over a set of spatial units (subindex *t*). Only results from the regional application (subindex *x*) are reported here (fig. 6 and 7).

5.1.1 Cost function

The cost function was defined as the sum of the absolute deviation of the model values from the observations, normalized by the standard deviations (*sd*) of the observations in each spatial unit (*x*) and temporal interval (*t*) (Radach and Moll, 2006).
The normalized deviation between model and observations was defined as:

$$C_{x,t} = \frac{M_{x,t} - D_{x,t}}{sd_{x,t}}$$

The regional (C_x) and temporal (C_t) cost function averaged over time and space, respectively, were calculated as:

$$C_x = \frac{\sum_{t=1}^{n} \left| C_{x,t} \right|}{n} \qquad C_t = \frac{\sum_{x=1}^{m} \left| C_{x,t} \right|}{m}$$

The cost function gives a non-dimensional value which is indicative of the "goodness of fit" between two sets of data (Moll, 2000). The closer the value is to zero the better the fit, we used a classification of results as in Radach and Moll (2006): $C_{x,t}$<1 *very good*, 1< $C_{x,t}$ <2 *good*, 2< $C_{x,t}$ <3 *reasonable*, $C_{x,t}$ >3 *poor*.

5.1.2 Percentage Model Bias

It corresponds to the sum of model error normalized by the data:

$$PMB_x = \frac{\sum_{t=1}^{n}\left(D_{x,t} - M_{x,t}\right)}{\sum_{t=1}^{n} D_{x,t}} * 100 \qquad PMB_t = \frac{\sum_{x=1}^{m}\left(D_{x,t} - M_{x,t}\right)}{\sum_{x=1}^{m} D_{x,t}} * 100$$

and gives measure of whether the model is systematically underestimating ($PMB_{x,t}$>0) or overestimating ($PMB_{x,t}$ <0) the observations (Allen et al., 2007). The classification of results was defined as follows: $\left|PMB_{x,t}\right|$<10 *very good*, 10< $\left|PMB_{x,t}\right|$<20 *good*, 20<$\left|PMB_{x,t}\right|$<40 *reasonable*, $\left|PMB_{x,t}\right|$>40 *poor*.

5.1.3 Model Efficiency

Is the proportion of the initial variance accounted for by the model (Nash and Sutcliffe, 1970):

$$ME_x = 1 - \frac{\sum_{t=1}^{n}\left(D_{x,t} - M_{x,t}\right)^2}{\sum_{t=1}^{n}\left(D_{x,t} - \overline{D_x}\right)^2} \qquad ME_t = 1 - \frac{\sum_{x=1}^{m}\left(D_{x,t} - M_{x,t}\right)^2}{\sum_{x=1}^{m}\left(D_{x,t} - \overline{D_t}\right)^2}$$

The model efficiency gives the deviation of the predicted values from the observed values in relation to the scattering of the observed values (Alewell and Manderscheid, 1998). The maximum value for this indicator is 1 which corresponds to an explained variance of 100%. The classification of results was defined as follows: $ME_{x,t}$ >0.65 *very good*, 0.65<$ME_{x,t}$>0.5 *good*, 0.5<$ME_{x,t}$>0.2 *reasonable*, $ME_{x,t}$ <0.2 *poor*.

5.1.4 Correlation Coefficient

It indicates the quality and direction of a linear relationship between two variables:

$$R_x = \frac{\sum_{t=1}^{n}\left(D_{x,t} - \overline{D_x}\right)\left(M_{x,t} - \overline{M_x}\right)}{\sqrt{\sum_{t=1}^{n}\left(D_{x,t} - \overline{D_x}\right)^2 \sum_{t=1}^{n}\left(M_{x,t} - \overline{M_x}\right)^2}} \qquad R_t = \frac{\sum_{x=1}^{m}\left(D_{x,t} - \overline{D_t}\right)\left(M_{x,t} - \overline{M_t}\right)}{\sqrt{\sum_{x=1}^{m}\left(D_{x,t} - \overline{D_t}\right)^2 \sum_{x=1}^{m}\left(M_{x,t} - \overline{M_t}\right)^2}}$$

Since we are interested only in positive correlations the classification of results was defined as follows: $R_{x,t}$>0.9 *very good*, 0.9< $R_{x,t}$ <0.8 *good*, 0.8< $R_{x,t}$ <0.7 *reasonable*, $R_{x,t}$ <0.7 *poor.*

5.2 MERIS data

Satellite chlorophyll data is very well suited for validation of spatial maps of temporally-averaged model results for chlorophyll, showing regions were the model may be performing less well (Lacroix et al., 2007). In this study, is considered the "algal 1" product which represents chlorophyll concentration for oceanic waters where only phytoplankton and its degradation products affect the optical properties of water.
A three year data set is used and the images are interpolated to the resolution of the model domain. On average 11.44 data for each pixel has been used to compose the image of each month.

6. Results and Discussion

From fig. 6 and 7 it can be observed that both models are not able to reproduce the seasonal trend in the Gulf of Lion underestimating the chlorophyll a concentration all year long. In fact all the four indexes give results classified as poor with little difference between the two models. This behaviour can be partly explained considering that rivers discharge is not yet included in the models so they are not able to reproduce the effect of the Rhone River. Better results are given in the central part of the Ligurian Sea although the geographical match is far from being perfect. Both models simulate the spring bloom as can be observed in fig. 3 and 5 but with some difference, being the BLANES Model concentrations higher than the BIOMEC model ones in March and April. Such low concentrations for the BIOMEC Model can be addressed to a high zooplankton grazing that is proportional to the vertical diffusivity. In fact during winter and in the transition from winter to spring the vertical diffusion is enhanced because of the weak stratification. In the northern part of the Ligurian Sea the BIOMEC Model produces good results as can be guessed from all four criteria in fig. 7.
There is not a substantial difference between the performances of the two models, suggesting that probably the physical model is the main source of variability in the simulations regardless of the choice of the ecosystem model.

7. References

-Ahumada, M.A., Cruzado, A., 2007. Modeling of the circulation in the Northwestern Mediterranean Sea with the Princeton Ocean Model. Ocean Science 3, 77-89.

-Alewell, C., Manderscheid, B., 1998. Use of objective criteria for the assessment of biogeochemical ecosystem models. Ecological Modelling 107 (2-3), 213-224.

-Allen, I.J., Holt, J.T., Blackford, J., Proctor, R. Error quantification of a high-resolution coupled hydrodynamic-ecosystem coastal-ocean model: Part2. Chlorophyll-a, nutrients and SPM. Journal of Marine System, 68, 381-404 (2007).

-Bahamón, N., Cruzado, A. Modelling nitrogen fluxes in oligotrophic environments: NW Mediterranean and NE Atlantic. Ecological Modelling, 163, 223-244 (2003).

-Baker, K.S., Frouin, R., 1987. Relation between photosynthetically available radiation and total insulation at the ocean surface under clear skies. Limnology and Oceanography 32, 1370–1377.

-Baird, M.E., Oke, P.R., Suthers, I.M., Middleton, J.H. A plankton population model with biomechanical descriptions of biological processes in an idealised 2D ocean basin. Journal of Marine System, 50, 199-222 (2004).

-Blumberg, A., Mellor, G. A description of a three-dimensional Coastal Ocean Circulation Model. In: Three-Dimensional Coastal Ocean Models, Coastal Estuarine Science, N.S. Heaps (Ed.). American Geophysical Union, 1-16 (1987).

-Brock, T.D., 1981. Calculating solar radiation for ecological studies. Ecological Modelling 14, 1-19.

-Crise, A., Crispi, G., Mauri, E., 1998. A seasonal three-dimensional study of the nitrogen cycle in the Mediterranean Sea: Part I. Model implementation and numerical results. Journal of Marine Systems 18 (1-3), 287-312.

-Crispi, G., Crise, A., Solidoro, C., 1998. Three-dimensional oligotrophic ecosystem models driven by physical forcing: the Mediterranean Sea case. Environmental Modelling and Software 13 (5-6), 483-490.

-Demirov, E., Pinardi, N., 2002. Simulation of the Mediterranean Sea circulation from

1979 to 1993: Part I. The interannual variability. Journal of Marine Systems 33-34, 23-50.

-Fernandez, V., Dietrich, D.E., Haney, R.L., Tintore, J., 2005. Mesoscale, seasonal and interannual variability in the Mediterranean Sea using a numerical ocean model. Progress In Oceanography 66 (2-4),321-340.

-Lacroix, G., Ruddick, K., Park, Y., Gypens, N., Lancelot, C. Validation of the 3D biogeochemical model MIRO&CO with field nutrient and phytoplankton data and MERIS-derived surface chlorophyll a images. Journal of Marine System, 64, 66-88 (2007).

-Manca, B., Burca, M., Giorgetti, A., Coatanoan, C., Garcia, M. -J., Iona, A., 2004. Physical and biochemical averaged vertical profiles in the Mediterranean regions: an important tool to trace the climatology of water masses and to validate incoming data from operational oceanography. Journal of Marine Systems 48 (1-4), 83-116.

-Marra, J., Bidigare, R.R., Dickey, T.D., 1990. Nutrients and mixing, chlorophyll and phytoplankton growth. Deep Sea Research Part A 37 (1), 127-143.

-Mellor, G., Yamada, T., 1982. Development of a turbulence closure sib-model for geophysical fluid problems. Rev. Geophys., 20, 851-872.

-Moll, A., 2000. Assessment of three-dimensional physical-biological ECOHAM1 simulations by uantified validation for the North Sea with ICES and ERSEM data. ICES Journal of Marine Science 57, 1060-1068.

-Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I -- A discussion of principles. Journal of Hydrology 10 (3), 282-290.

-Pinardi, N., Masetti, E., 2000. Variability of the large scale general circulation of the Mediterranean Sea from observations and modelling: a review. Palaeogeography, Palaeoclimatology, Palaeoecology 158 (3-4), 153-173.

-Radach, G., Moll, A., 2006. Review of three-dimensional ecological modelling related to the North Sea shelf system. Part II: model validation and data needs. Oceanography and Marine Biology: An Annual Review 44, 1–60.

-Smolarkiewicz, P.K., 1984. A fully multidimensional positive definite advection transport algorithm with small implicit diffusion. Journal of Computational Physics 54 (2), 325-362.

8. List of figures

Fig. 1. Area of study.

Fig. 2. Pathways of the simulated nitrogen flow in the BLANES model.

Fig. 3. Monthly averaged outputs for chlorophyll a from BLANES Model (1st sigma layer).

Fig. 4. Monthly averaged chlorophyll a from MERIS sensor products for the period:June 2003-June 2005.

Fig. 5. Monthly averaged outputs for chlorophyll a from BIOMEC Model (1st sigma layer).

Fig. 6. The four indexes computed only over time (regional application, subindex x) for the BLANES Model.

Fig. 7. The four indexes computed only over time (regional application, subindex x) for the BIOMEC Model.