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One-dimensional ecosystem model tests in the Po Prodelta area (Northern Adriatic Sea)

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Abstract

The application of a one-dimensional ecosystem model to a water column in front of the Po Prodelta area in the Northern Adriatic Sea is illustrated here. Validation was carried out for pelagic nutrients and phytoplankton biomasses by comparing simulations with historical data. Calibration was limited to the sediment parameters and to the suspended inorganic matter data from recent PRISMA-I (Programma di RIcerca e Sperimentazione per il Mare Adriatico) data sets. Primary production and nutrient abundance is found to be in overall agreement with climatological observations at the seasonal time scales. Model-data discrepancies are interpreted in the light of model assumptions. Main conclusions concern the importance of the inorganic suspended matter concentrations in determining the seasonal cycle of primary producers hinting to a strong light limitation in algal growth in this river dominated area. The need for further improvements in the pelagic dynamical processes of the silica cycle is also discussed.

Keywords: Ecological modelling; Adriatic Sea

1. Introduction

In recent years the Adriatic Sea has attracted many research interests since it offers the possibility of studying a river dominated ecosystem bordering an oligotrophic open ocean area. The Adriatic basin is important for the overall Mediterranean Sea dynamics, because it is a site of deep water formation processes (Artegiani et al., 1989; Artegiani et al., 1997) and because it presents (especially in its northern part) a high productivity area which has a relevant impact in the maintenance of the fish standing stocks.

In this paper we show the implementation of a numerical ecosystem model in the Northern Adriatic Sea in order to understand the complex interactions between the physical environment and the trophic chain development. Previous Adriatic Sea ecosystem modelling work has implemented different versions of the ERSEM model (European Regional Seas Ecosystem Model, Baretta et al., 1995), which is a generic ecosystem model developed in recent years. Allen et al. (1997) and Allen and Blackford (1996) have applied a one-dimensional model version in three different areas of the basin, one in the North Eastern part far from direct sources of nutrients and the others in the more oligotrophic regions of the Middle and Southern Adriatic Sea. A complete three-dimensional ecosystem model has also been developed coupling the Princeton Ocean Model (POM) and ERSEM (Zavatarelli et al., 1998a). It is implemented in an idealised Adriatic basin and it has been shown to be capable to reproduce the main climatological patterns of the entire basin, especially the north-south trophic gradient. Moreover such a complicated model has not yet a supporting data base for model validation and calibration. The available data base allows now only to explore model sensitivity and model validation in one dimension, as we will show later.

The meridional trophic gradient is an important feature of the basin, and its causes can be traced back to the Po River runoff, which attains a mean flow rate of

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1500 $m^3 s^{-1}$. The Po runoff is also responsible for the dilution characteristics of the entire Adriatic Sea basin. Its influence can also be observed in all the ecosystem components, especially because of the high land-derived input of allochtonous nutrients and the relevant transport of particulate inorganic suspended matter (mean solid discharge 14 10^6 t y^{-1}; Dal Cin, 1983).

These considerations bring to the question of understanding and simulating the realistic ecosystem dynamics under the direct and 'overbearing' influence of the Po River runoff. In this paper we show a validation of the nutrient distribution and primary production with climatological data.

Another question of interest concerns the possibility of calibrating some of the ecosystem model parameters and understand their importance in the simulation of this particular ecosystem.

To partially answer these questions we have applied a one-dimensional vertically resolved ecosystem model in a station near the Po Prodelta area. The station is the S1 station of the PRISMA-I project (Programma di RIcerca e Sperimentazione per il Mare Adriatico, a National Research Program in Italy), which is located 6 nautical miles offshore from the Po di Goro mouth (Fig. 1), and whose position is considered to be out from the Northern Adriatic Western boundary current but strongly influenced by Po River freshwater input. It is therefore representative of a water column which is always stratified by means of a surface freshwater layer coming directly from the Po river. We use a one-dimensional ecosystem model because we believe this is the first step toward calibration of complex ecosystem model parameters and because of the relevance of the coupling between water column stratification and ecosystem functioning. Furthermore the available data set allow only a climatological validation on the basis of vertical profiles of nutrients and chlorophyll. The limited historical data availability and especially the time gaps allow us only a consistent definition of the biogeochemistry in the vertical dimension together with range of variability. In addition we use a limited extent data set for model parameters validation, available only at the PRISMA-I station location. The historical data set allows a validation of the simulated cycles of primary producers and the PRISMA-I data allows us to calibrate both sediment parameters and the input of particulate inorganic suspended matter.

In the following sections we present the results of climatological simulations conducted at the S1 site, concentrating our attention on the seasonal description of the cycle of primary producers and the response of the system to different inorganic suspended matter forcing. An attempt has also been done to select those morphological (sediment parameters) and functional parameters that are considered to be essential in the calibration of the model.

2. Data set description

In order to provide a realistic climatological forcing to the model and to validate the simulations, some of the PRISMA-I data and a collection of existing data prepared by Zavatarelli et al. (1998b) has been used. The Adriatic BiogeoChemical Dataset (ABCD) contains the following parameters: temperature, salinity, phosphate, nitrate, nitrite, ammonium, silicate, oxygen, chlorophyll-a and other parameters such pH, total suspended matter (TSM) and alkalinity. Information on biochemical parameters are available from the seventies, because data before that period are thought to be biased by different sampling methodologies. The PRISMA-I data and parameters used here concern the inorganic suspended matter concentration, the type of the sediment (grain size and porosity), the nutrient and organic matter contents in the sediment and interstitial waters and parameters affecting the dissolution of phosphate from the solid phase to the liquid phase. This is a limited number of calibrating parameters as yet, but we hope in the future more will be released at the same station location, allowing a complete model calibration exercise.

The choice of an area that could be representative of the S1 station climatology is a hard problem in this region, because of the high local variability common to the river-dominated areas. We have decided to extract from the data set all the casts from the land to 12.55° E, which is the eastward extension of the Po Delta, and to divide the casts in seasons following the astronomic definition (january, february and march are winter, etc.). The cast spatial distributions for the four seasons are shown in Fig. 1a–c. The temporal distribution is very inomogeneous, showing the highest number of casts in summer (36) and the lowest in winter (17).

All the casts have been interpolated linearly with a 1 m vertical resolution, and for each season the mean profile and standard deviation have been calculated for the physical parameters, chlorophyll-a and nutrients (nitrate and nitrite have been grouped together referring to as nitrate).

3. Model description

The model used in this work is composed by three different sub-modules, interacting with each other as shown in Fig. 2.

The Physical Module consists of the one-dimensional version of the Princeton Ocean Model (Blumberg and Mellor, 1987), which is mainly based on the second-order turbulence closure scheme developed by Mellor and Yamada (1982). It calculates prognostically the vertical mean fields for velocity, temperature and salinity, together with the turbulent diffusion coefficients for momentum and tracers.

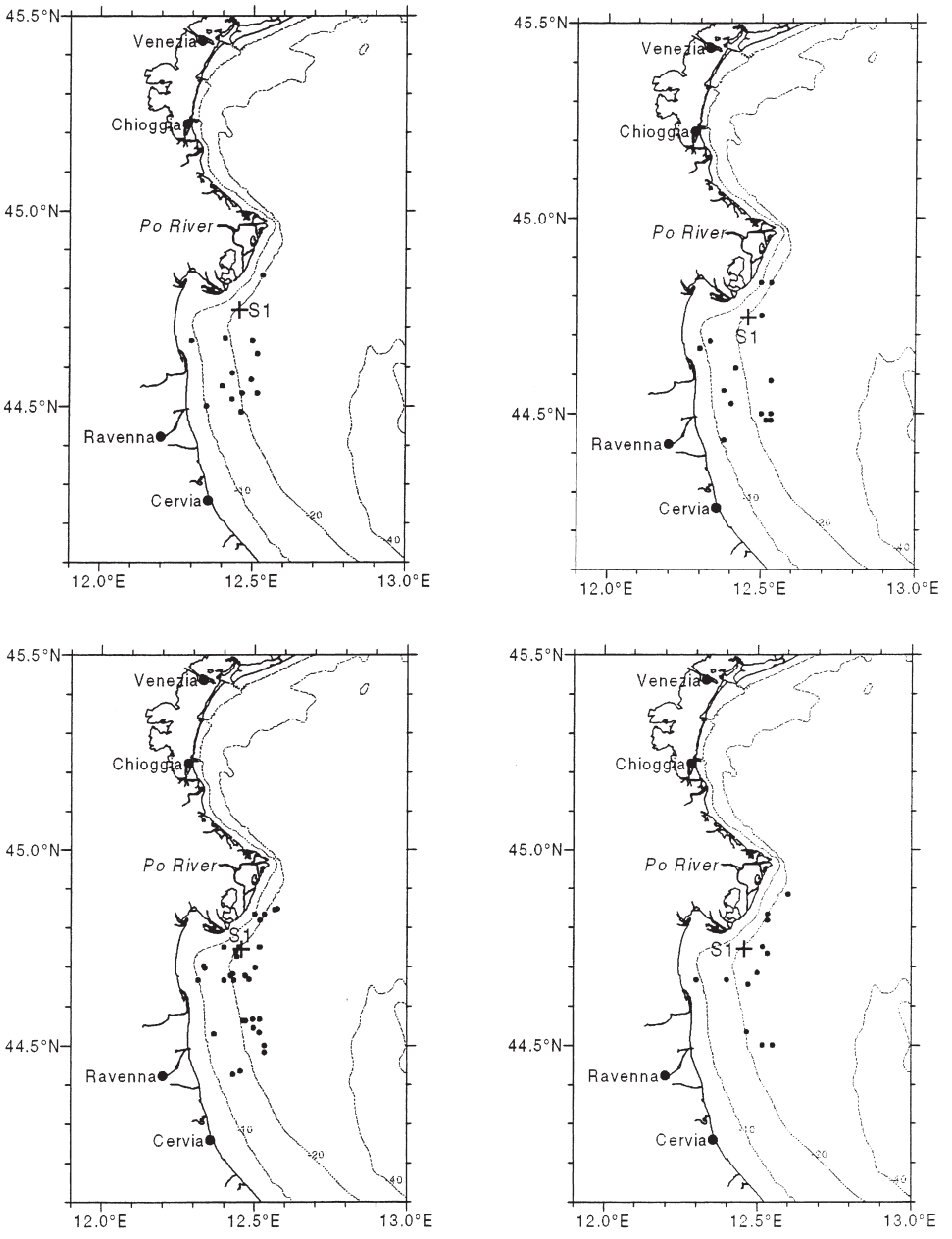

Fig. 1. Bathymetry of the Po Prodelta area (depths in metres), position of the S1 station and seasonal spatial distributions of ABCD data (Upper: Winter and Spring; Lower: Summer and Autumn).

The one-dimensional primitive equations and the equations for physical tracers, written only for the z and t independent variables, are:

$$\frac{\partial U}{\partial t} - fV = \frac{\partial}{\partial z}\left(K_M \frac{\partial U}{\partial z}\right) + F_x \tag{3.1a}$$

$$\frac{\partial V}{\partial t} + fU = \frac{\partial}{\partial z}\left(K_M \frac{\partial V}{\partial z}\right) + F_y \tag{3.1b}$$

$$\frac{\partial P}{\partial z} = -\rho g \tag{3.1c}$$

$$\frac{\partial W}{\partial z} = 0 \tag{3.1d}$$

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_H \frac{\partial T}{\partial z}\right) + m_T \tag{3.1e}$$

$$\frac{\partial S}{\partial t} = \frac{\partial}{\partial z}\left(K_H \frac{\partial S}{\partial z}\right) + m_s \tag{3.1f}$$

where U, V and W are the mean velocity components; T and S indicate the mean temperature and salinity vertical fields; f is the Coriolis parameter taken to be equal to

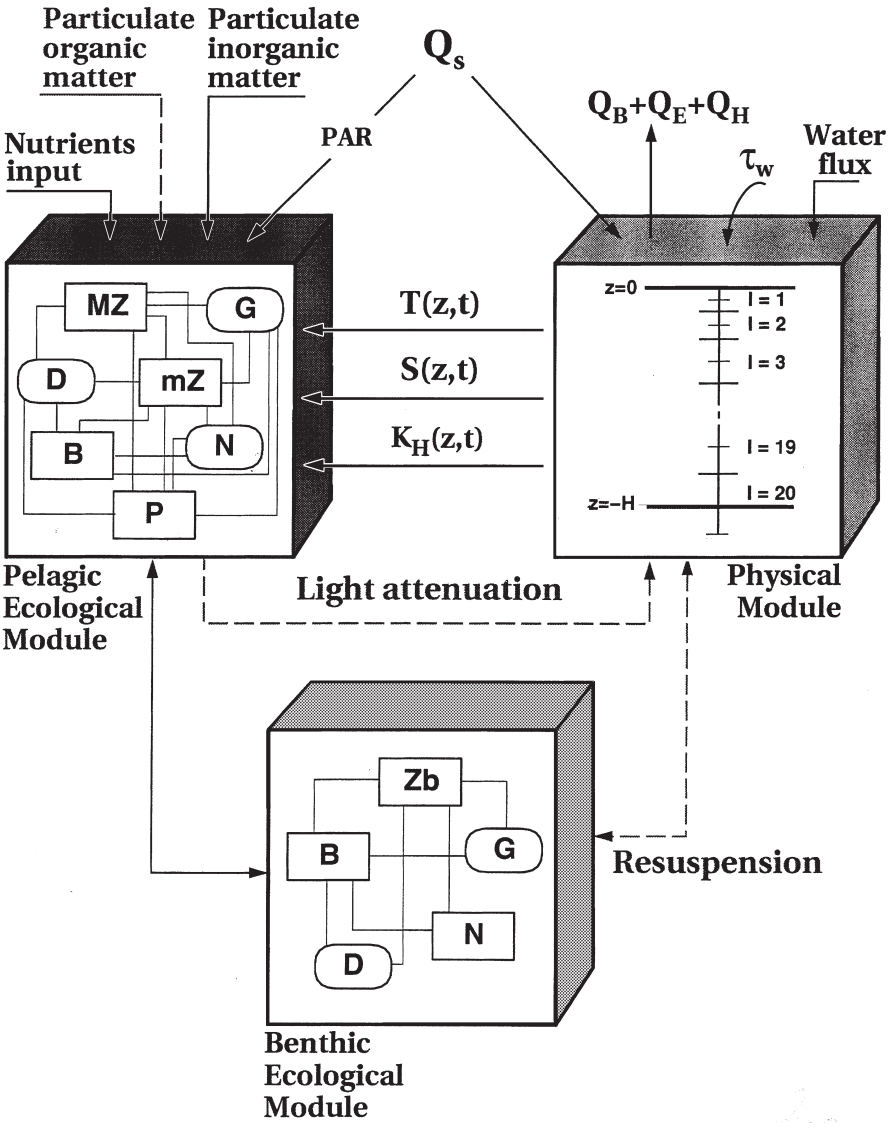

Fig. 2. Schematic description of physical and biogeochemical models, general interactions and sub-models. The dashed arrows represent forcing and interactions not yet implemented in the model. Explanation of flow diagram symbols: P = phytoplankton, MZ = mesozooplankton, mZ = microzooplankton, B = bacteria, D = organic matter (POM + DOM), G = dissolved gases, N = nutrients, Zb = Zoobenthos (after Baretta et al., 1995).

be 7.04 10^{-5} s^{-1}; P is the pressure; K_M and K_H are the turbulent diffusion coefficients for momentum and tracers respectively and F_x, F_y, m_T, m_S parameterize other processes, such as molecular diffusion, internal waves and tidal effects. The parameterization of these terms is an important issue, especially in our study site, and especially during strong stratification conditions because they are responsible for the diapycnal transport of nutrients between the different layers. Likewise the turbulent diffusion terms in Eq. (3).(1a), (3).(1b), (3).(1c), (3).(1d), (3).(1e), (3).(1f), they have been written as folllows:

$$F_x = \frac{\partial}{\partial z}\left(\chi \frac{\partial U}{\partial z}\right), \qquad F_y = \frac{\partial}{\partial z}\left(\chi \frac{\partial V}{\partial z}\right) \tag{3.2a}$$

$$m_T = \frac{\partial}{\partial z}\left(\chi \frac{\partial T}{\partial z}\right), \qquad m_S = \frac{\partial}{\partial z}\left(\chi_S \frac{\partial S}{\partial z}\right) \tag{3.2b}$$

where χ and χ_S are the background diffusion coefficient and the corresponding values are shown in Table 1.

According to the 2.5 Mellor-Yamada turbulence closure scheme, two other prognostic equations must be solved in order to determine the values of the turbulent diffusion coefficients, and they are the ones for the turbulent kinetic energy ($q^2/2$) and for the master length scale of turbulent processes (l). A complete description of these equations can be found in Mellor and Yamada (1982).

The water column implemented in the model has a

Table 1
Overview of the significant model parameters

Description	Value	Reference
Background diffusion coefficient for momentum and temperature (χ)	3 10^{-5} (m^2 s^{-1})	Calibrated
Background diffusion coefficient for salinity (χ_S)	10^{-7} (m^2 s^{-1})	Calibrated
Relaxing coefficient for the salt flux boundary condition (α)	0.5 (m d^{-1})	Calibrated
Phosphate adsorption distribution coefficient for porosity = 0.4	100 (–)	Ruardij and Van Raaphorst (1995)
Phosphate adsorption distribution coefficient for porosity = 0.7	400 (–)	Ruardij and Van Raaphorst (1995)
Suspended sediment light attenuation coefficient	0.00013 (m^2 mg^{-1})	Baker and Lavelle (1984)

total depth of 20 m and a schematic view is showed inside the Physical Module (PM) Box in Fig. 2. The vertical grid is formed by 20 levels whose depths vary following a logarithmic distribution near surface, in order to resolve more accurately the boundary layer dynamics. Velocity and scalars are referred to the centre of each cell, whereas turbulent diffusion coefficients are calculated at the cell interfaces. Level 20 corresponds to the water-sediment interface where all the benthic variables are calculated. The PM is forced at surface by the daily water (W_S), momentum (τ_w, wind stress) and total heat fluxes (Q_{tot}). At the beginning of each simulation day the Physical Module gives to the Ecological Module all the informations about the physical environment, expressed as the vertical distributions of temperature, salinity and turbulent diffusion coefficient, and these values remain unchanged during the calculation of all the biogeochemical processes.

The Pelagic and Benthic Modules are essentially represented by the ERSEM trophic web structure, which is shown in a very schematic form inside the other two boxes of Fig. 2 (for an extended flow diagram scheme see Baretta et al., 1995).

The equations for biogeochemical tracers in the water column are expressed in the following way:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[(K_H + \chi)\frac{\partial C}{\partial z}\right] + \left.\frac{\partial C}{\partial t}\right|_b \tag{3.3}$$

where C is a generic biogeochemical variable (biomass, dissolved nutrients, etc.), and the last term represent the source or sink term of biogeochemical processes that is resolved within ERSEM.

ERSEM is a generic biomass-based ecosystem model, originally developed for the North Sea, which consists of a set of differential equations like (3.3) describing the fluxes of carbon and macronutrients (nitrogen, phosphorus and silica) between different compartments of the marine ecosystem. Biological components are aggregated into functional groups. Each one of these groups represents a set of organisms belonging to different species that have been grouped together according to their trophic level and functional ecological behaviour. For this reason the functional group has also an implicit dimensional connotation, because the functional features of an organism are often correlated to its spatial dimensions. The modelization of functional groups has been done following the idea of a standard organism, in which all physiological functions are divided in a series of main processes such as feeding, assimilation, respiration, excretion and egestion. Pelagic processes are directly coupled with sedimentary dynamics by the implementation of a state variable describing the amount of biogenic detritus that reaches the bottom. The organic detritus entering in the sedimentary reactor can be remineralized and then the pore water nutrients molecularly diffuse back to the water column. For a detailed description of specific part of the model, see Varela et al. (1995), Baretta-Bekker et al. (1995), Broekhuizen et al. (1995), Ebenhöh et al. (1995), Ruardij and Van Raaphorst (1995).

The ERSEM model used in this work is version 11, which is described in Baretta-Bekker et al. (1997). In the pelagic system the model calculates prognostically the water column concentrations for primary producers, microzooplankton, mesozooplankton, bacterioplankton, nutrients, oxygen and organic matter (both dissolved and particulate). In the benthic submodel, the area concentrations for zoobenthos, aerobic and anaerobic bacteria, pore water nutrients, benthic gases and different reactive forms of organic detritus are calculated. The Pelagic Ecological Module (PEM) is externally forced by the incident solar radiation, which is scaled by a factor that gives the Photosynthetic Available Radiation, and the riverine input of dissolved nutrients and particulate inorganic suspended matter.

At present, the only feedback processes are active between the PEM and the Benthic Ecological Module (BEM) are sedimentation, grazing and predation by benthos, and molecular diffusion of pore water nutrients. The feedback between PEM and PM does not exist yet (heat extinction), and there is not an interface between the benthic system and the physical model (resuspension). Main potential feedbacks which could be very significant in coastal area, are the control that suspended material operates on the penetration depth of surface heat flux, and changes in the roughness length due to resuspension events. This last process has to be con-

sidered as a further exchange pathway between sediments and the water column, because it gives back a lot of particulate organic matter which could be a potential source of nutrients for the pelagic environment.

4. Simulations

4.1. Initialisation and forcing functions

The model has been forced by perpetual year forcing functions, that means it has been driven by monthly mean climatological parameters repeated for every year of simulation in a perpetual seasonal cycle.

Generally a water column has an annual closed cycle for temperature and salinity, which is determined by the surface input of heat, turbulent kinetic energy, water and horizontal advection processes; otherwise this interaction leads to interannual variability. In the case of a purely one-dimensional model controlled by perpetual year forcing, we have to introduce a parameterization of local horizontal advection if we want to maintain stable physical conditions of the water column.

The heat forcing at the surface and the wind stresses comes from a climatological analysis of the ECMWF meteorological re-analysis for the period 1982–93 by Maggiore et al. (1997), from which we have extracted the monthly mean time-series of fluxes for the study area. The annual heat budget obtained from data has a negative value, that is, the water column in this position looses heat at the surface being compensated by horizontal advection of heat. We have to correct for this heat loss by a heat correction function $Q_{corr}(t)$ which mantain null the yearly mean value of heat gained in the whole water column, thus in the boundary condition for temperature we use:

$$K_H \frac{\partial T}{\partial z}\bigg|_{z=0} = \frac{1}{\rho c_p}(Q_{tot} + Q_{corr}). \tag{4.1}$$

The shape of Q_{corr} and the resulting corrected heat flux forcing at the surface of the model are shown in Fig. 3a. This correction is a parameterization of lateral heat flux in the region which we now add only at the surface.

The boundary condition for salinity has been imposed using the following method. The Sea Surface Salinity (S^*) monthly mean data from ABCD has been assimilated in the model using a relaxation boundary condition for the salt flux:

$$W_S(t) = K_H \frac{\partial S}{\partial z}\bigg|_{z=0} = -\alpha(S - S^*). \tag{4.2}$$

The relaxation coefficient α is given in Table 1. A

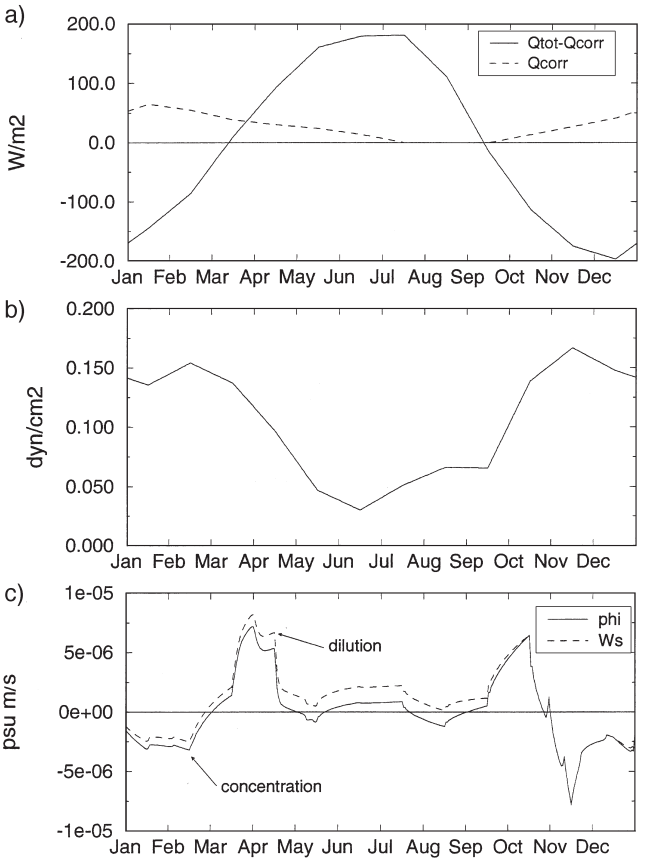

Fig. 3. (a) Total surface heat flux and heat correction function, (b) absolute value of surface wind stress and (c) uncorrected (W_S)/corrected (Φ_S) salt flux as a function of months.

daily diagnostic salt flux has been then calculated for a year of simulation and such value is now called W'_S. In order to obtain a null annual water flux budget, an empirical time-dependent correction function W'_{Scorr} has been evaluated and subtracted from as follows:

$$K_H \frac{\partial S}{\partial z}\bigg|_{z=0} = \Phi_S(t) = W'_S(t) - W'_{Scorr}(t) \tag{4.3}$$

Again the correction function is a parameterization of lateral salt flux, here assumed to be all concentrated at the surface mimiquing a Po River freshwater input seasonal cycle. The function $\Phi_S(t)$, which is shown in Fig. 3c, has then been used as the final boundary condition for the simulation.

A particular fingerprint of the shallow Northern Adriatic are the winter profiles for temperature and salinity. In order to mantain the stratification which persists also in winter because of the Po River runoff, the model has been initialized at the last month of autumn using the corresponding seasonal profiles from ABCD dataset, interpolated at the model levels. This method gives also the right storage of heat in the bottom of the water column (in autumn the bottom waters reach their maximum

temperatures) without affecting the cooling of the whole column which takes place in winter.

The Po River is the major source of nutrient for the northern basin (Degobbis and Gilmartin, 1990), and for this reason the choice of the right nutrient boundary conditions is crucial for the simulation results. In Fig. 4 are shown the seasonal surface nutrient concentrations that we have imposed as Dirichlet boundary conditions for the equation of biogeochemical tracers like (3.3). These values are derived from the ABCD data set analysed at the S1 station. Since the extracted winter value for silicate has been thought to be unrealistic respect to other literature informations probably due to scarcity of data, we have changed it to 2 mmol m^{-3}, which is in the observational range of values for the site. The initial vertical distributions of dissolved nutrients have been evaluated from ABCD; in accordance with the physical parameter initialization, the autumn vertical distributions have been calculated and interpolated to the model levels. Due to the lack of climatological data, initialization values for biological variables (phytoplankton, zooplankton and zoobenthos) have been taken from the ERSEM North Sea model, and for the same reason, there are no open boundary conditions for biology.

Initializations and parameters for the sediments come from analysis of the S1 station data from the PRISMA-I project and other available climatological data (Spagnoli and Bergamini, 1997). The seabed is classified as silty clays and a light attenuation coefficient for this type of suspended sediment has been used, whose value is shown in Table 1. The constant dissolution rate for biogenic silicate has been changed to 0.007 d^{-1} (North Sea value was 0.01 d^{-1}), following Giordani et al. (1996).

4.2. Results

Four different simulation experiments have been conducted, which are summarised in Table 2. All the experiments have been run for three years and the results are shown for the third year of simulation.

In RUN1 and RUN2 we changed the type of the sediments and calibrated the porosity. The other two experiments (RUN3, RUN4) have different inorganic sus-

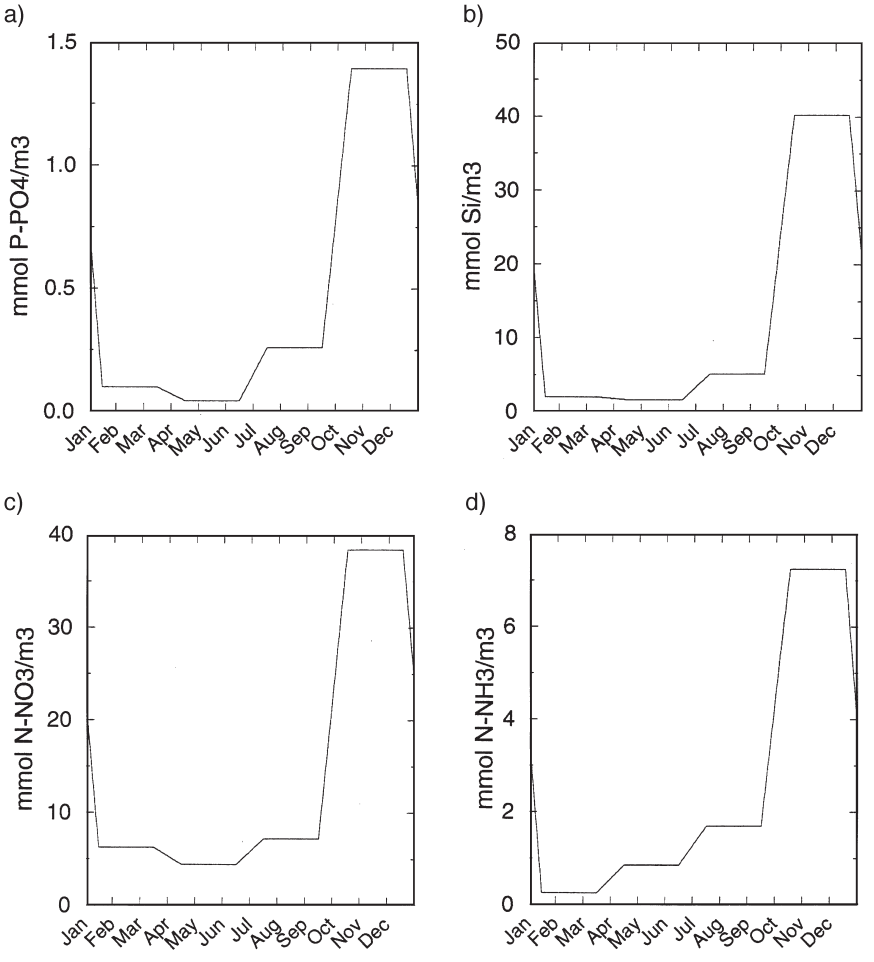

Fig. 4. Nutrient surface boundary conditions from ABCD data set.

Table 2
Table of experiments showing the different set-ups used in the experiments and the different inorganic suspended matter forcing (ISM)

Name	Porosity	ISM forcing	Length of run (d)
RUN1	0.4	constant	1080
RUN2	0.7	constant	1080
RUN3	0.7	ISM(z)	1080
RUN4 (central)	0.7	ISM(z,t)	1080

pended matter (ISM) profiles imposed as an external forcing parameter (see Fig. 2) which have been calibrated from the PRISMA-I data set.

4.2.1. Validation

The central experiment RUN4 was used to validate the model climatology. In order to do so, the seasonal mean for significant parameters has been calculated from the simulation and then compared with the observations. We call this a validation exercise. The results for winter and summer, which correspond to the two extreme dynamical situations found in the area, are shown in Fig. 5. Climatological profiles are described by the mean and the range of variability. In winter the modelled physical structure of the water column is representative of well-mixed conditions, which is in rather good agreement with the observations. All the calculated nutrient profiles show an increase with depth reaching the maximum near the bottom, with an evident homogeneous distribution in the first 10 m. The first 10 m nutrients are clearly connected to the river input, giving rise to the new production evidenced by the chlorophyll profile. The lower layer nutrient distributions are instead originated from the late summer/autumn regeneration processes, since material fluxes from the BEM to PEM become high during this period (not shown).

In summer all the nutrient modelled variables present a good agreement with data, even if the physical model is not capable to reproduce well the observed stratification, probably because of the limitations in our surface heat and salt forcing parameterizations. In our forcing parameterization of Eqs. (4).(1), (4).(3) we assumed lateral heat and salt flux to be all concentrated at the surface. If this would be relaxed, the T and S simulated profiles would agree more with observations (not shown). The nutrient profiles calculated by the model agree with data more than during winter with the exceptions of nitrate. This means that during summer the simulated profiles fit within the maximum-minimum range of values while during winter less. In particular they show a nutrient concentration minima located 5 m from the surface in correspondence to the pycnocline. This structure cannot be detected looking only to the modelled T and S profiles.

4.2.2. Calibration

The model sensitivity to the type of sediments has been tested in RUN1 and RUN2. In RUN1 we used a porosity of 0.4, which corresponds to a silty seabed, and so to a more pelagic dynamical environment. With this set-up the model had a failure after a brief period of simulation, because all the phosphate in the sediment was released to the water column. In the other runs the porosity was changed to 0.7, proper of silty clay sediments that are the one found in the area. According to Ruardij and Van Raaphorst (1995), also the adsorption coefficient of phosphate, which is a function of the sediment grain size, has to be changed. The corresponding values of the adsorption distribution coefficient used in the model for the two runs are given in Table 1.

In order to investigate the dependence of the solution on the ISM, we have performed a sensitivity analysis comparing the last three experiments in Table 2. In this region ISM is mainly due to the direct influx of the Po River suspended materials. Due to the lack of climatological time series for ISM, we used a vertical distribution, ISM^*, derived from an annual mean value of the PRISMA-I data. This profile has then been related to the Po River influence using a non-dimensional scaling factor which is a function of the observed surface salinity S^* as follows:

$$ISM(z,t) = \gamma(S^*(t)) \cdot ISM^*(z). \tag{4.4}$$

The ISM profiles are all different degrees of parameterization of ISM profiles based upon data. In Fig. 6 the three ISM profiles used are plotted together with the corresponding water column chlorophyll concentration (mg chl/m^2) which is calculated in the model as a function of phytoplankton biomasses. From Fig. 6b it is clear that the suspended sediment concentration has a large influence on the modelled light penetration and hence on the development of the phytoplankton bloom. RUN2 has an expected higher mean annual production than the others, but the spring bloom is lower because the higher winter biomass level maintains a relevant stock of zooplankton (not shown) which can exerts a predation control on the phytoplankton. In RUN3 experiment, which is the more light limited, the spring bloom can develop only in summer when the solar radiation is sufficiently high. In RUN4 the phytoplankton bloom develops in March, with two other lower peaks in summer and in October.

4.3. Conclusions

Despite the simple one-dimensional implementation, the model is capable of reproducing the qualitative behaviour of nutrient cycles and primary production at seasonal time scales. The experiments have shown that the water column structure determines the overall cycle

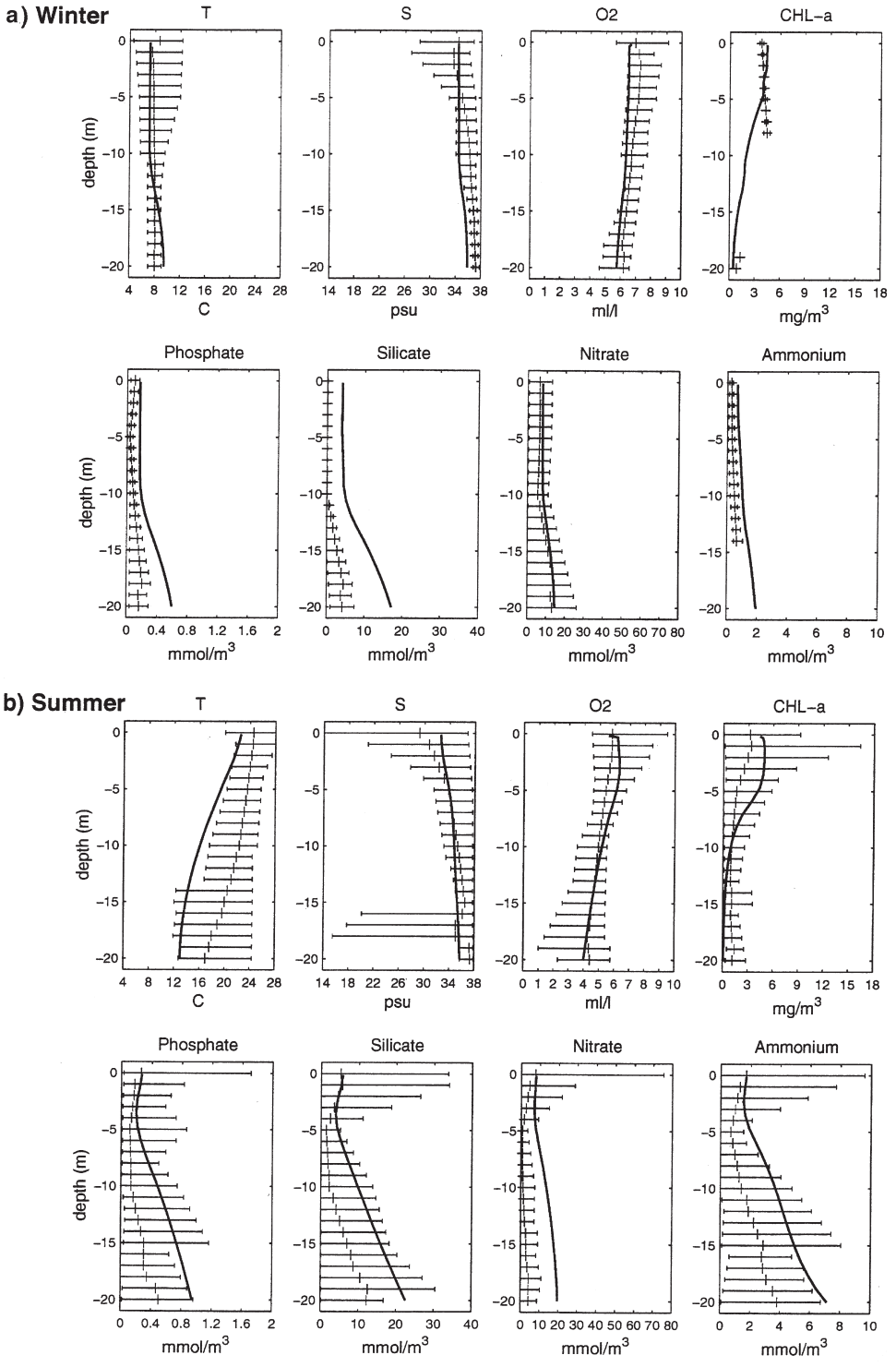

Fig. 5. Model and data comparison in winter (a) and summer (b). The continues line is the modelled seasonal mean and the climatological observational means are shown with the range of variability (interval between maximum and minimum values found in the observations).

development, but the absence of the horizontal transport is a relevant limitation to the proper quantification of biogeochemical variables.

The sensitivity and calibration analysis performed on the benthic-pelagic coupling has highlighted the importance of the right sediment structure parameterization. The resulting benthic fluxes tuned to the appropriate sediment structure determine the right abundance of nutrient cycling in the pelagic compartment.

The primary production in such a strong river-dominated area has been shown to be greatly affected by the turbidity of water, showing light limitation to be higher

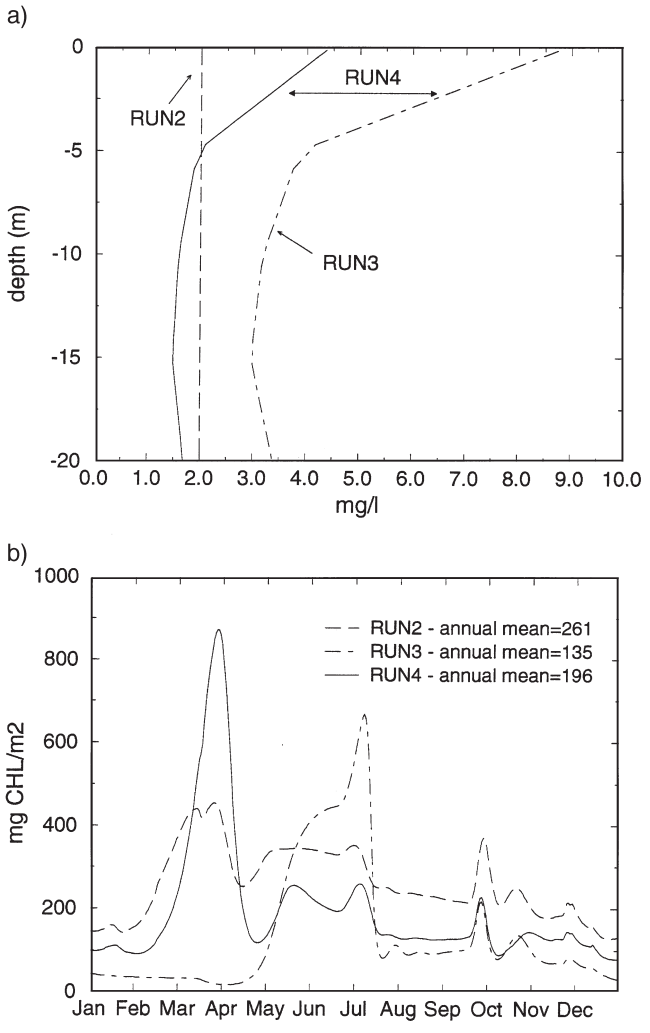

Fig. 6. Model result intercomparison for light limitations. (a) Inorganic suspended matter profiles (ISM) for the three different experiments. RUN2 has a stationary homogeneous distribution characteristic of more pelagic environments, RUN3 is an annual mean from existing data and RUN4 is the same profile of RUN3 but scaled by a factor that is a time-function of the river forcing (only the maximum and minimum resulting profiles are showed). (b) Resulting vertically integrated chlorophyll concentration for the three different experiments.

than nutrient limitation. Thus this forcing could be considered as important as the meteorological ones in order to obtain the right seasonal cycle of primary production.

This work has also highlighted some problems that have to be addressed by further investigations. The dynamics of silica seem to play an important role in the overall ecosystem, because the dominant phytoplankton species during the spring bloom are prevalently diatoms. Nevertheless silicate resulted to be one of the variables that much departed from observations (see Fig. 5). Probably the discrepancy between simulation and observations can be related to the absence in the model of chemical interactions that will dissolve particulate silica in the water column. The amount of particulate silicate concentration calculated by the model is in fact large (not shown), and this sinks directly to the bottom without any kind of chemical processes. At the contrary, observations indicate that the dissolution rate in the area is high (PRISMA-I, 1998), thus preventing particulate silica to reach the sediments and be remineralized. The parameterization of this dissolution rate in the pelagic model could be an improvement in the model results, enhancing the cycling of silicate in the upper water column and its uptake by phytoplankton. Furthermore the advection processes could have a relevant part in determining the observed vertical concentration. This feature could also be important for the other modelled macronutrients.

Another important aspect is the role played by the bacteria in the utilisation of the dissolved organic matter (DOM), and hence in the pelagic regeneration processes. This functional group has a model implementation which reflects the dynamics of higher latitudinal seas, where the model has been originally developed. Such bacterial processes at higher latitudes do not consider the refractivity of DOM to bacterial assimilation. Our experiments suggest the necessity of a reduced bacterial activity on the DOM, which will give rise to the persistence of a DOM pool throughout the year, as it has been found to exist in the Northern Adriatic.

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