MODELLING THE VERTICAL BIOGEOCHEMICAL STRUCTURE OF THE BLACK SEA

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Abstract

A vertically resolved, coupled physical-biogeochemical model is developed to describe the food web structure, nitrogen cycling and redox processes taking place near the oxic-anoxic interface zone of the Black Sea. The model thus provides a unified representation of dynamically coupled oxic-suboxic-anoxic system which allows to simulate a realistic yearly succession of diatom, dinoflagellate, *Emiliania huxleyi* blooms, as well as basic features of the suboxic zone dynamics, and the way in which it is controlled by upward and downward material fluxes from the interior of the anoxic layer and chemocline zone of the surface layer, respectively.

Key words: Black Sea, phytoplankton blooms, suboxic zone, redox reactions, modeling

The major processes controlling the food web structure, recycling of nutrients, and oxidation/reduction reactions taking place nears the anoxic interface of the Black Sea is studied by a coupled physical-biogeochemical model. It relates the annual cycle of plankton production in the form of a series of successive phytoplankton, mesozooplankton blooms to organic matter generation and to the remineralization-ammonification-nitrification-denitrification chain of the nitrogen cycle as well as to anaerobic sulfide oxidation through a series of reactions catalyzed by dissolved and particulate manganese.

The ecosystem model includes three most dominant phytoplankton taxonomic groups in the Black Sea comprising Bacillariophyta (diatoms, P_d), Dinophyta (dinoflagellate, P_f), Chrysophyta (coccolithophore *E. huxleyi*, P_e). The fourth group comprises small phytoplankton community (P_s) representing phytoflagellates and picopyhtoplankton. The zooplankton community is represented by microzooplankton (Z_s), and mesozooplankton (Z_l) groups. They consume different phytoplankton groups with different preferences, as specified in their grazing terms. All plankton biomass are expressed in nitrogen units; nitrogen is considered to be the most important limiting nutrient for the interior Black Sea ecosystem. Silicate and phosphate are abundant elements in the Black Sea with respect to total dissolved inorganic nitrogen even though their anthropogenic suppy have been reduced in 1990s after the dam constructions along the River Danube; thus, silicate and phosphorus do not limit diatom and *E. huxleyi* productions, respectively. Even though *E. huxleyi* are grown in the Black Sea under nitrogen limited conditions, the model is supported by a simplified phosphorus cycle in order to explore its competitiveness under phosphorus limitation. The simplified nitrogen and phosphorus cycles involve labile pelagic detrital nitrogen (D_n) and phosphorus (D_p), as well as dissolved inorganic nitrate (N_n), ammonium (N_a), and phosphate (N_p). In addition, the model includes attached and detached coccolith concentrations as two additional prognostic variables.

The annual phytoplankton community structure simulated by the model involves a diatom-based bloom during the late winter-early spring period. It is strongest bloom of the year and followed by a series of successive other bloom events mainly dominated by subsurface summer productions of dinoflagellates, and subsequently a weaker, mixed assemblage of diatom and dinoflagellate community development in autumn months. They are robust features of the annual phytoplankton structure, and appear as distint signals in the monthly composite chlorophyll data. The signature of the intense late winter diatom bloom is high chlorophyll concentration of more than 2 mg m^{-3} distributed uniformly over the 40-50 m thick euphotic zone. The autumn bloom is less intense and relatively shallower characterized by chlorophyll concentrations of around 1 mg m^{-3} within the surface mixed layer of 25-30 m. These two blooms are linked to the weaker summer subsurface bloom confined at deeper part of the euphotic zone below the seasonal thermocline. It is characterized by chlorophyll concentrations in the range of 0.3-to-1.0 mg m^{-3}. The simulations have further suggested *E. huxleyi* as yet another essential element of the annual phytoplankton community structure during summer months within the shallow surface mixed layer. The summer *E. huxleyi* bloom typically initiates during mid-May, attains its strongest phase throughout June, and finally terminates by mid-July.

Almost continuous particulate organic matter production associated with the year-long biological activity supports an efficient nitrogen cycling within approximately the upper 75 m of the water column, where dissolved oxygen generated photosynthetically and by air-sea interactions is depleted due to consumption during aerobic particulate matter decomposition. The layer below could not be ventilated even for the conditions of exceptionally high winter cooling due to the presence of a strong density stratification. Even with a highly simplified representation of the redox processes, the model provided a quasi-steady state suboxic-anoxic interface zone structure similar to observations. It was able to give quantitative evidence for the presence of an oxygen depleted and non-sulfidic suboxic. This model pointed out the crucial role of the downward supply of nitrate from the overlying nitracline zone and the upward transport of dissolved manganese from the anoxic pool below for maintenance of the suboxic layer. The model is also used to test the assumption of isopycnal homogeneity of the SOL properties and their independence from the circulation features, as asserted previously. It is found that the SOL properties do not possess isopycnal uniformity throughout the basin, and vary depending on the intensity of vertical diffusive and advective oxygen fluxes across the oxycline. Anticyclones, with downwelling and downward diffusion (i.e, with stronger net downward supply of oxygen), attain a thinner suboxic layer at a deeper part of the water column relative to cyclones. The position of the upper boundary of the SOL changes from $\sigma t \sim 15.6$ kg m^{-3} in cyclonic to 15.9 kg m^{-3} in anticyclonic regions, whereas its position in the peripheral Rim Current transition zone occurs at intermediate density values. Re-analysis of the existing data provides firm evidence for such differences.