Reconnaissance of the Black Sea's ecohydrodynamics by means of a 3D interdisciplinary model

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1 Introduction

The Black Sea is practically an enclosed sea with restricted exchange with the Mediterranean Sea through the Bosphorus Strait. As a result, a strong permanent pycnocline (halocline) develops and prevents deep ventilation in the basin interior. These restrictions are responsible for anoxia in 87 % of its volume. For all the Black Sea riparian countries, shoaling of the oxic/anoxic interface which might occur as a response to decrease in fresh water input due to intensive irrigation projects in the Former Soviet Union might have a catastrophic effect. Recent data reveal a remarkable stability of the oxic/anoxic interface and of the chemocline in terms of isopycnal co-ordinates on a long term scale. However, our understanding of the real reasons for such stability is poor and, furthermore, a considerable variability of the Black Sea pycnocline structure has also been revealed by recent basin wide surveys showing variations in the intensity of the pycnocline ventilation on a decadal time scale. Since the Black Sea is permanently anoxic below the pycnocline, its deep water chemistry is controlled by entirely different chemical and biological processes than the rest of the world oceans. Also, eutrophication and other types of ecosystem degradation have led to reduced biodiversity and imbalanced ecosystems in the Black Sea. In the past 25-30 years, the Black sea has been transformed from a diverse ecosystem supporting varied marine life to a eutrophic plankton culture-environmental conditions unsuitable for most organisms higher in the food chain. As species diversity is reduced, often as a result of eutrophication, opportunistic settler species, brought in the ballast water of ships, can easily find an ecological niche in which to flourish. These opportunistic species, such as Aurelia Aurita, the invader ctenophore Mnemiopsis leidyi, Noctiluca ... represent a trophic "dead end".

It feeds on other zooplankton, including fish larvae, but as yet appears to have no significant natural predator in the Black Sea.

2 Short description of the models

The GHER 3D Eco-Hydrodynamic model is used to test the sensitivity of the Black Sea's ecosystem to the physical processes.
The hydrodynamical model of the general circulation in the Black Sea has been build up, using the GHER primitive equation model. In a first experiment, a model with 15 km horizontal resolution and 20 vertical levels is used to compute the typical seasonal cycle by forcing the model with climatological monthly mean fields of temperature, salinity and wind stress at the air sea interface. Furthermore, the corresponding river discharges of the Danube, Dnestr, Dnepr and Rioni are taken into account.
In a preliminary study, a very simple ecosystem model has been implemented. The state variables of this model has been defined, according to the recommendations of the Globec Numerical Modelling Group, as those which are necessary and sufficient to assess the effects of the physical processes on the space-time distribution of the primary and secondary productions (the so-called "minimum critical set"). The ecosystem model can be defined by a nitrogen cycle which is described by five state variables, i.e. NO_3^-, NH_4^+, Phytoplankton, Zooplankton and Dissolved organic matter. The microbial loop has been short-circuited and particulate organic matter is taken into account as sedimenting fractions of both phytoplankton and zooplankton biomasses. The ecosystem model is imbedded on-line into the 3D hydrodynamical model with a superimposed cycle for the light intensity.
The model results suggest that the initiation of the bloom is essentially influenced by the water column stability. They display a highly three-dimensional aspect with important horizontal and vertical variations, obviously imparted to the system by the physical processes (horizontal and vertical advection, vertical mixing and diffusion, upwelling ...) associated with light limitation at depth and sinking of dead organisms.
However, a lot of problems remain in this simple version.
For instance :

1. Silicate and phospate are not taken into account

2. The calibration, initialisation and validation of the ecosystem model are not optimal

3. The representation of particulate organic matter and the short circuiting of the microbial loop are very likely oversimplifications

4. The model can not perceive that the bloom is in reality a succession of blooms of different species
5. The possibility of development of opportunistic species is not tackled by the model

Thus, this model must be regarded rather as a first tool for testing the coupling of hydrodynamic and ecosystem submodels while acquiring some preparatory assessment of the effect of physical processes on the ecodynamics. So, a more complex ecosystem model involving 12 state variables has been developed. This model includes the microbial loop and considers three classes of autotrophic plankton, diatoms, non-siliceous netphytoplankton and nanoflagellates, three groups of heterotrophic organisms, bacteria, ciliates and copepodes, four nutrients, nitrate, ammonium, silicate and phosphate, particulate and dissolved organic matter. The C:N:P ratio of each state variable is assumed constant.
The results show that the bloom can be perceived as the succession of 3 blooms of different species. A winter bloom, made of diatoms, occurs, in February, in the region of the eastern and western main cyclonic gyres where strong upwellings bring to the surface cold nutrient rich water, later this diatoms bloom begins in the region of the Danube's plume and extends to the north-western shelf. Following this winter bloom, the model predicts a weaker and shorter bloom of nanoflagellates in April, the formation of this bloom is caused by the ammonium , generated as a by-product at the winter bloom, and trapped in the mixed layer. Finally, the results show a bloom of microflagellates occuring in June.

3 Future work

A more complex ecosystem model taking into account the development of opportunistic species will be implemented. However, computational and intellectual limitations, the difficulty of interpreting too large sets of data, the increasing uncertainity on the values of parameters as their number increases faster than the number of state variables and the difficulty of to collect enough data to operate and initiate large models, set a limit to the size of the set of state variables