HYPOXIA IN THE BLACK SEA NORTH WESTERN SHELF : FROM EUTROPHICATION TO CLIMATIC STRESSORS

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Abstract

The dynamics of seasonal hypoxia, which affects the Black Sea north-western shelf since the mid 1970's until present days, is investigated by means of a 3D biogeochemical model. Comparison of the model results with in-situ data reveals that the phenomenon may have been underestimated after the mid 1990's due to the distribution of observations. We investigate the mechanism of hypoxia at seasonal scale, and identify the main drivers of its interannual variability. While high nutrients discharge caused severe hypoxia in the 1980's, it was sustained in the 1990's by the pool of organic matter accumulated during the previous years in the sediments layer. With an increasing intensity, climatic stressors intensifies the response of hypoxia to nutrient discharge, and affect the seasonal dynamics of hypoxia by extending its temporal scale.

Keywords: Black Sea, Oxygen, Models, Benthic-pelagic coupling, Continental shelf

As many other stratified continental shelves exposed to eutrophication (Diaz and Rrosenberg, 2008), the Black Sea North-western shelf (NWS) is affected by seasonal hypoxia : the summer stratification isolates bottom waters from the atmosphere and prevents ventilation to compensate for the large consumption of oxygen due to respiration in the bottom waters and in the sediments.

We used a 3D coupled physical biogeochemical model to investigate the dynamics of bottom hypoxia in the Black Sea NWS at seasonal and interannual scales (1981-2009). The model integrates the biological model presented in Grégoire et al.,2008, within the hydrodynamical 3D model GHER (Capet et al., 2012) and includes a dynamical representation of organic matter in the sediment layer (i.e. resuspension and benthic diagenesis) (Stanev et al., 2012 ; Soetart et al. 2000). Model skills are evaluated with 14500 in-situ oxygen measurements available in the NOAA World Ocean Database and the Black Sea Commission data. Specific validation procedures prove the model's ability to resolve the seasonal cycle and interannual variability of oxygen concentration as well as the spatial location of the oxygen depleted waters and the resolution of the specific threshold of hypoxia ($[O_2] < 62$ mmolO/m³). Spatial variability and seasonal fluctuations complicate the monitoring of hypoxia leading to contradictory conclusions when different sets of data are considered. Noteworthy, the recovery process was overestimated after 1995 due to the concentration of observations in areas and months not typically affected by hypoxia. This stresses the urging need of a dedicated monitoring effort in the NWS of the Black Sea focused on the areas and the period of the year concerned by recurrent hypoxic events.

The severity of hypoxia for a given year is quantified by an index H which combines the aspects of spatial and temporal extension of hypoxia, and is equivalent to the maximal spatial extension if the duration is equal to the average. In order to explain the interannual variability of H and to identify and disentangle its main drivers, a multilinear stepwise regression analysis ($p < 0.01$) is applied on the long time series provided by the model. This statistical model gives a general relationship (Fig. 1.) that links the intensity of hypoxia to eutrophication and climate related predictors. It is known that hypoxia is caused by an enrichment of river waters in nutrients (e.g. Diaz and Rosenberg, 2008). Here we show that the accumulation of organic matter in the sediments, during the years of high nutrient discharge, continues to cause an important benthic oxygen demand, even after the reduction of discharge (in the early 1990's for the Black Sea NWS), with a typical inertia timescale of 9.3 years.

This introduces an important aspect in the dynamics of recovery from eutrophication by riverine discharge management. The major climate-related driver of hypoxia is the sea surface temperature (SST) in March, which fixes the solubility of Oxygen in sea water, hence the pool of oxygen content in the bottom watermass, before it is locked by the summer stratification. Also, high SST in the late summer extends the duration of the stratification period, which increases the damages caused by hypoxia since the last days of the stratification is when the bottom waters bear the lowest oxygenation levels, eventually reaching anoxia and causing the release of hydrosulphide from the sediments. Higher summer temperature observed in the Black Sea for the last decade thus adds a new challenge in the management of eutrophication as it intensify the sensitivity to the nutrient discharge.

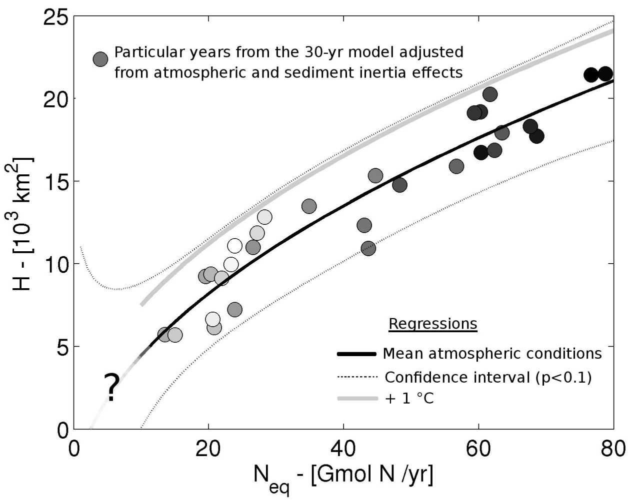

Fig. 1. The role of atmospheric drivers and sediment inertia on the intensity of hypoxia, as revealed by the stepwise regression, allows to redraw the distribution between H, the intensity of hypoxia, and N, the riverine nitrogen discharge, for mean atmospheric conditions and equilibrated sediment pool of organic matter. The effect of warming (+1°C) on the H(N) relationship is indicated by the gray line. This statistical relationship is not validated for the low level of nitrogen discharge that were not experienced during the period of the modeling experiment (1981-2009).

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