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Drivers, mechanisms and long term variability of bottom seasonal hypoxia in the Black Sea north-western Shelf. Is there any recovery after eutrophication ?

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The Black Sea North-western shelf (NWS) is a shallow eutrophic area in which seasonal stratification of the water column 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.

A 3D coupled physical biogeochemical model is used to investigate the dynamics of bottom hypoxia in the Black Sea NWS at different temporal scales from seasonal to interannual (1981-2009) and to differentiate the driving factors (climatic versus eutrophication) of hypoxic conditions in bottom waters.

Model skills are evaluated by comparison with 14500 in-situ oxygen measurements available in the NOAA World Ocean Database and the Black Sea Commission data. The choice of skill metrics and data subselections orientate the validation procedure towards specific aspects of the oxygen dynamics, and 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 specific threshold of hypoxia.

During the period 1981-2009, each year exhibits seasonal bottom hypoxia at the end of summer. This phenomenon essentially covers the northern part of the NWS, receiving large inputs of nutrients from the Danube, Dniestr and Dniepr rivers, and extends, during the years of severe hypoxia, towards the Romanian Bay of Constanta.

In order to explain the interannual variability of bottom hypoxia and to disentangle its drivers, a statistical model (multiple linear regression) is proposed using the long time series of model results as input variables. This statistical model gives a general relationships that links the intensity of hypoxia to eutrophication and climate related variables.

The use of four predictors allows to reproduce 78$\%$ of hypoxia interannual variability: the annual nitrate discharge (N), the sea surface temperature in the month preceding stratification (T), the amount of semi-labile organic matter in the sediments (C) and the duration of the stratification (D). Eutrophication (N,C) and climate (T,D) predictors explain a similar amount of variability ($\sim$ 35$\%$) when considered separately. A typical timescale of 9.3 years is found to describe the inertia of sediments in the recovering process after eutrophication.

From this analysis, we find that under standard conditions (i.e. average atmospheric conditions, sediments in equilibrium with river discharges), the intensity of hypoxia can be linked to the level of nitrate discharge through a non-linear equation (power law).

Bottom hypoxia does not affect the whole Black Sea NWS but rather exhibits an important spatial variability. This heterogeneous distribution, in addition to the seasonal fluctuations, complicates the monitoring of bottom hypoxia leading to contradictory conclusions when the interpretation is done from different sets of data. We find that it was the case after 1995 when the recovery process was overestimated due to the use of observations concentrated in areas and months not typically affected by hypoxia. This stresses out 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.