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Unraveling the linkages among hydrodynamics, primary production, benthic nutrient fluxes and bioturbation in the southern North Sea

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Benthic fluxes of dissolved nutrients and oxygen measured in the southern North Sea using ex situ incubation chambers indicate a prominent annual cycle characterized by low level from mid-autumn (Oct) to early spring (Mar) and enhanced values from mid-spring (Apr) to early autumn (Sep) with peak in late summer (late Aug/early Sep). The same cycle is also shown in the budget of total organic carbon (TOC) and macrobenthic biomass in surface sediments. The significant positive correlations between the benthic nutrient fluxes, oxygen, sedimentary TOC and macrobenthos suggest that their variation might respond to a common source, i.e. the primary production. However, the linkages between these quantities and pelagic primary production, which exhibits a dominant bloom in early spring (Mar/Apr) and a secondary bloom in early summer (Jun/Jul) in the study area, is not straightforward.

We present a numerical study to unravel the complex linkages. A 3-D coupled hydrodynamic-biogeochemical model (ECOSMO) was used to provide benthic boundary conditions for a 1-D biogeochemical model in the sediment (TOCMAIM) that mechanistically resolves the interaction between macrobenthos and organic matter through bioturbation. Simulation results based on a satisfactory hindcast from 1948 to 2015 reveal that although the spring algal bloom normally starts in late winter (Feb) and peaks in early spring (Mar/Apr), deposition of labile OC to seafloor is limited in this period due to energetic hydrodynamic conditions. Sedimentation and accumulation of labile OC (originated from fresh planktonic detritus) in seafloor surface sediments are facilitated in summer when wind-waves become weak enough. This drives the blooming of macrobenthos, with peak of biomass in late summer (Aug). Bioturbation intensity, which is dependent upon macrobenthic biomass, community structure as well as local food resource, peaks also in later summer. Enhanced bioturbation and benthic metabolism result in an increased oxygen flux into sediments, promoting remineralization of OC and release of nutrients. The following period (late Sep/Oct) is characterized by low level of pelagic primary production in combination with enhanced wind-waves, which not only reduce the input of labile OC into sediments substantially but also remobilize surface material (sediments and OC) on a major part of the shallow coastal seafloor. Depletion of labile OC in the uppermost centimeters of sediments by a combined effect of erosion, macrobenthic uptake and downward mixing (through bioturbation) accounts for the rapid decline of benthic nutrient fluxes in Oct, which remain low through the stormy winter until the next spring.