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Causes of variability in diatom and *Phaeocystis* blooms in Belgian coastal waters between 1989 and 2003: A model study

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Abstract

Massive blooms of *Phaeocystis* colonies usually occur in the Belgian coastal zone (BCZ) between spring and summer diatom blooms but their relative magnitude varies between years. In order to understand this interannual variability, we used the biogeochemical MIRO model to explore the link between diatom and *Phaeocystis* blooms and changing nutrient loads and meteorological conditions over the last decade. For this application, MIRO was implemented in a simplified 3-box representation of the domain between the Baie de Seine and the BCZ. MIRO was run over the 1989–2003 period using actual photosynthetic active radiation (PAR), seawater temperature and riverine nutrient loads as forcing. The water mass residence time was calculated for each box based on a monthly water budget estimated from 1993–2003 water flow simulations of the three-dimensional hydrodynamical model COHSNS-3D. Overall MIRO simulations compare fairly well with nutrient and phytoplankton data collected in the central BCZ but indicate the importance of the hydrodynamical resolution frame for correctly describing the extremely high nutrient concentrations and biomass observed in the BCZ. Analysis of model results suggests that while interannual variability in diatom biomass depends on both meteorological conditions (light and temperature) and nutrient loads, *Phaeocystis* blooms are mainly controlled by nutrients. Further sensitivity tests with varying N and P loads suggest that only N reduction will result in significantly decreased *Phaeocystis* blooms without negative affects on diatoms, while P reduction will negatively affect diatoms. Moreover, Atlantic nutrient loads play such a great role in BCZ enrichment that reduction of Scheldt nutrient loads only is not sufficient to significantly decrease phytoplankton blooms in the BCZ. It is concluded that future nutrient reduction policies aimed to decrease *Phaeocystis* blooms in the BCZ without impacting diatoms should target the decrease of N loads in both the Seine and the Scheldt rivers.

Keywords: North Sea; Eutrophication; *Phaeocystis*; Diatoms; Ecological modelling; Interannual variability

1. Introduction

Due to their impact on the marine ecosystem, *Phaeocystis* colony blooms are generally reported as undesirable (e.g. Smayda, 1990; Granéli et al., 1999). *Phaeocystis* colonies have formed recurrent spring blooms in the nutrient-enriched continental coastal waters of the Southern Bight of the North Sea at least since the early 1970s (Lancelot et al., 1987). In this area *Phaeocystis* colonies bloom every spring between mid-April and May–June (Rousseau, 2000; Cadée and Hegeman, 2002; Rousseau et al., 2002) after an early-spring diatom bloom but their magnitude varies from

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year to year. This variability has been attributed to either climatic changes (Owens et al., 1989) or changing nutrient inputs due to human activity (Billen et al., 1991, 1999; Cadée and Hegeman, 2002). Interaction between these driving forces has recently been suggested for the Belgian coastal waters, based on a statistical analysis of contemporary nutrient and phytoplankton time series (Breton et al., 2006).

Biogeochemical models which are based on chemical and biological principles and describe ecosystem carbon and nutrient cycles as a function of environmental forcing are ideal tools to investigate the link between phytoplankton blooms and changing environmental conditions. Such a model — the MIRO model (Lancelot et al., 2005) — has been developed to describe diatom and *Phaeocystis* blooms in the eastern Channel and Southern Bight of the North Sea. In the present paper we use the MIRO model to describe and understand the last decade's variability in diatom and *Phaeocystis* colony blooms in the Belgian coastal zone (BCZ) in response to changing meteorological conditions and river loads. The BCZ, located in the Southern Bight of the North Sea, is appropriate to explore the dual role of natural and human factors in *Phaeocystis* bloom magnitude. The BCZ is a highly dynamic system with water masses resulting from mixing between inflowing southwest Atlantic waters through the Strait of Dover and Scheldt freshwater and nutrient inputs (Fig. 1). Atmospheric deposition and local benthic remineralisation also contribute to BCZ enrichment. An annual budget of inorganic nitrogen (DIN), phosphate (PO_4) and dissolved silicate (DSi) has been established on the scale of the BCZ, using riverine, atmospheric and transboundary loads estimated for the year 1992 (Rousseau et al., 2004). This budget evidences the major contribution of transboundary loads to the nutrient enrichment of the BCZ under average hydro-

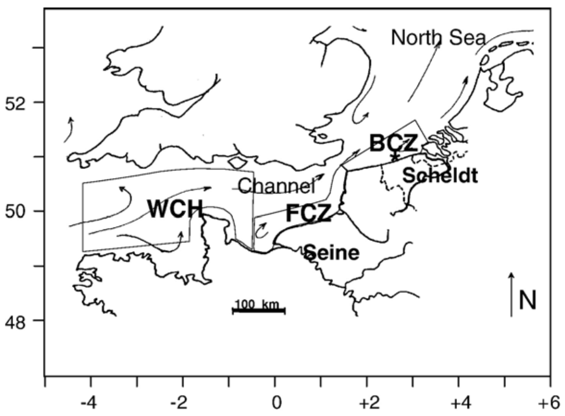

Fig. 1. Map of the area studied with position of the monitored station 330 (*) and the MIRO multi-box frame.

dynamical conditions. Supporting this, De Jonge et al. (1996) conclude that eutrophication of coastal waters in the whole of the southern North Sea is not only related to the nutrient loads of the local rivers but also to the nutrient levels in the sea governed by the nutrient loads from the Strait of Dover. This nutrient enrichment fluctuates on an annual and a decadal scale, depending on changes in human activity in the drainage basin (Billen et al., 2005; Soetaert et al., 2006) and meteorological conditions (rainfall and wind direction and force). The latter also influences English Channel water inflows to the BCZ, modifying the water mass budget in the coastal zone (Reid et al., 2003; Breton et al., 2006). Human pressure and rainfall conditions determine river discharges and nutrient loads. The geographical extent of the Scheldt plume in the BCZ is mainly driven by wind force and direction (Yang, 1998; Lacroix et al., 2004; Breton et al., 2006).

Between 1989 and 2003, monitoring of nutrients and phytoplankton was performed in the central BCZ (Station 330 51°26.05 N; 02°48.50 E, Fig. 1). The usual diatom-*Phaeocystis* succession was clearly observed every year but the magnitude of their bloom showed marked interannual fluctuations (Breton et al., 2006). Over this period, riverine PO_4 loads to the North Sea were reduced by 50% compared to the late 1980s (OSPAR, 2003) but no direct responding trend in diatom and *Phaeocystis* blooms could be identified from the phytoplankton time-series at station 330 (Breton et al., 2006). This lack of visible trends was recently related with the variable influence of Scheldt nutrient loads at station 330, modulated by meteorological conditions and nutrient discharges (Breton et al., 2006).

In the present paper we describe simulations over the 1989–2003 period of the seasonal cycles of nutrients (N, P, Si) and phytoplankton (diatom and *Phaeocystis*) in the BCZ as obtained with the multi-box MIRO model constrained with Global Solar Radiation (GSR), sea-water temperature and actual riverine nutrient loads. The MIRO simulations are compared with monthly-averaged nutrient and phytoplankton observations recorded at station 330 between 1989 and 2003 with focus on diatom and *Phaeocystis* blooms which represent more than 90% of phytoplankton in the investigated area (V. Rousseau, pers. comm., 2006). Model results are further analysed to understand the link between the variability of diatom and *Phaeocystis* blooms and the changing riverine nutrient loads and meteorological conditions. Finally, as a first step towards *Phaeocystis* mitigation, N or P reduction scenarios are run to better understand how nutrient loads control the magnitude of diatom and *Phaeocystis* blooms.