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# Model assessment of present-day *Phaeocystis* colony blooms in the Southern Bight of the North Sea (SBNS) by comparison with a reconstructed pristine situation

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ABSTRACT

We performed simulations with the existing MIRO&CO-3D ecological model to assess the present-day magnitude and geographical extent of undesirable *Phaeocystis* colony blooms in the Southern Bight of the North Sea (SBNS) receiving anthropogenic nutrient inputs from large European rivers that mix with the inflowing Atlantic waters. The criterion of $4{\cdot}10^6$ *Phaeocystis* colonial cells $L^{-1}$ of Lancelot et al. (2009) is used to scale the presence of undesirable bloom. These simulations are compared with a reconstructed pristine SBNS ecosystem making use of nutrient inputs calculated with the Seneque/Riverstrahler model of the river system when all human activities on the watershed have been erased. Interannual variability is considered by performing model runs for two contrasted meteorological years: wet (2001) and dry (2005). Results show a large excess of nitrogen (N) and phosphorus (P) delivery to the SBNS, i.e., 12 and 5 times the pristine situation respectively. In contrast, the total silicon (Si) input is decreased with respect to natural conditions due to freshwater diatom growth in some eutrophied rivers. Qualitatively, rivers deliver nutrients in large Si excess for pristine condition but N excess for both 2001 and 2005, when scaled to the N, P and Si requirement of coastal diatoms.

Responding to the river nutrient inputs, either natural or of anthropogenic origin, phytoplankton blooms are simulated in the vicinity of the river mouths, especially in the eastern SBNS receiving 78–98% of the direct river inputs. In this area nutrients cumulate along a SW-NE gradient and the bloom is forming a wide ribbon parallel to the coast. A short time-delay is simulated between the western and eastern SBNS due to light limitation imposed by the amount of suspended particles carried by the Thames River. A spring diatom-*Phaeocystis* succession is simulated for both present-day and pristine condition. Diatoms dominate the bulk of the pristine phytoplankton community; *Phaeocystis* colonies develop in the whole domain, especially in the Thames and Scheldt river plume though their biomass remains low and never exceed the threshold of $4{\cdot}10^6$ cells $L^{-1}$. In contrast, present-day *Phaeocystis* colonies start growing when diatoms attain their maximum in April, co-occur with and supplement them in May and June, reaching colonial cells densities $>4{\cdot}10^6$ cells $L^{-1}$ in many locations of the SBNS. Overall, *Phaeocystis* colonies are favored by wet meteorological conditions that enhance river N delivery. The geographical extent of undesirable *Phaeocystis* blooms thus varies between dry and wet years and affects 72% of the modeled SBNS domain distributed in three areas: the eastern band (90%), the Thames plume (6%) and a small offshore area (4%) possibly connected to the eastern band.



## 1. Introduction

Eutrophication in the Southern Bight of the North Sea (SBNS) results from the input of transboundary (SW – Atlantic waters enriched by mainly the Seine and the Somme rivers) and local (Ijzer, Scheldt, Rhine/Meuse, Thames) sources (Fig. 1) of land-based nutrients (nitrogen N, phosphorus P, silicon Si). The magnitude and extent of each source depend on the geomorphology, the development of human activity in the watershed and large-scale climatic phenomena such as the North Atlantic Oscillation (NAO; Hurrell, 1995). The latter determines the weather conditions over northwestern Europe and hence the discharge and spreading of river loads in the SBNS (e.g., Lacroix et al., 2004; Breton et al., 2006).

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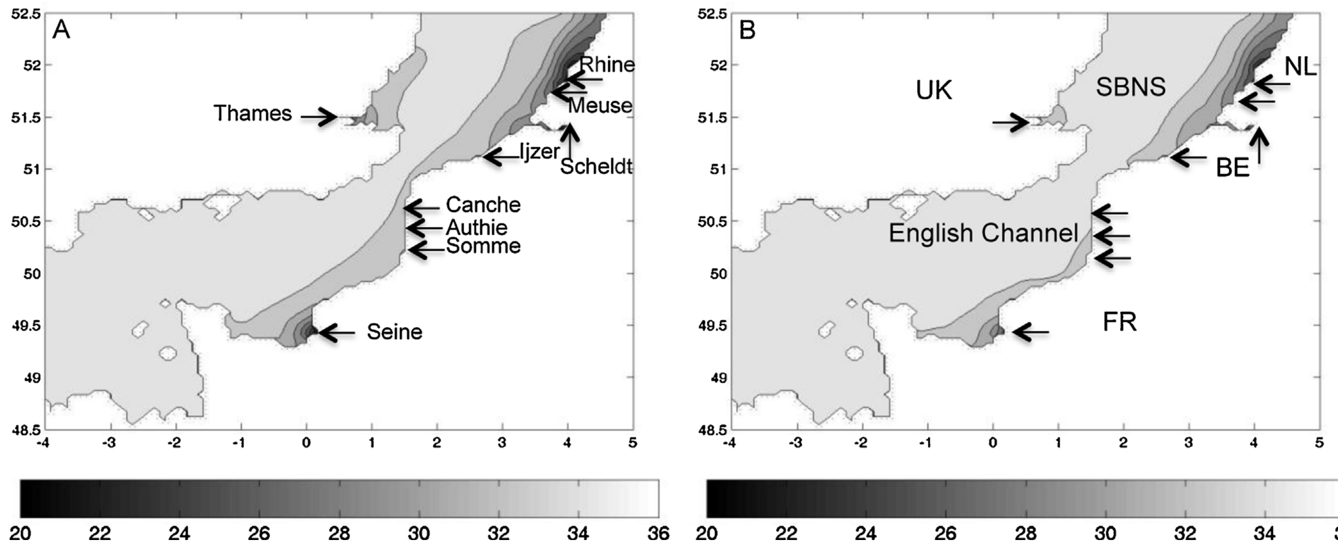


**Fig. 1.** Winter-simulated salinity distribution in the MIRO&CO-3D domain in the wet year 2001 (A) and in the dry year 2005 (B). Arrows show river inputs in the English Channel and SBNS. Freshwater discharges are detailed in Table 1. BE: Belgium; FR: France; NL: The Netherlands; UK: United Kingdom.

The eutrophication symptom in the SBNS is visible as massive algal blooms and foam deposits in spring-summer especially along the eastern coast that receives most of nutrients discharging in the SBNS (Table 1). In this area spring bloom events are regular (e.g., Batje and Michaelis, 1986; Baretta-Bekker et al., 2009; Cadée and Hegeman, 2002; Lancelot et al., 1987). Algal blooms are more transient in the western part of the SBNS and are generally located in areas under the influence of the Thames River (Mills et al., 1994; Weston et al., 2008). All these blooms are composed of ungrazable colony forms of the *haptophycea Phaeocystis globosa* (hereafter referred to as *Phaeocystis*) that supplement early spring diatoms (e.g., Rousseau et al., 2002; Weston et al., 2008) and dominate in spring-summer a mixed community of diatoms and flagellates. Previous observational work suggests that the success of *Phaeocystis* remains in its ability to benefit from nitrate excess (Lancelot et al., 1998) and form large gelatinous colonies reaching sizes that mismatch with the filtering capacity of indigenous copepods (*Temora longicornis* in the SBNS; Antajan, 2004). Indeed, reported diameter of colonies for the coastal SBNS ranges from 20 $\mu$m to >1 mm (Cadée and Hegeman, 2002; Van Rijssel et al., 1997; Rousseau et al., 1990) while the average particle size above which filtering by neretic copepods is prevented is 400 $\mu$m (Weisse et al., 1994). In a former paper we combined field microscopic observations and 0D model simulations to determine an ecological quality criterion for scaling healthy *Phaeocystis* ecosystem i.e., an ecosystem where the built *Phaeocystis* colony biomass is efficiently transferred to copepods and higher trophic levels. This criterion was set at $4{\cdot}10^6$ colonial cells $L^{-1}$ (Lancelot et al., 2009) and corresponds to the maximum *Phaeocystis* cells contained in the aggregate grazable colonies (<400 $\mu$m). In the absence of top-down control, colonies with cell density above $4{\cdot}10^6$ cells $L^{-1}$ grow fast, accumulate in the water column and are prone to foaming under windy conditions (e.g., Lancelot et al., 1987). These blooms are reported as undesirable hereafter. Undesirable is preferred to harmful as no harm other than food chain disruption and foam deposits has been attributed to *Phaeocystis* in the SBNS (Lancelot et al., 2011).

*Phaeocystis* colony blooms with cell density largely higher than $4{\cdot}10^6$ cells $L^{-1}$ have been regularly reported as one single event lasting about one month in the Belgian (Breton et al., 2006) and English (Weston et al., 2008) coastal waters of the SBNS. In the Dutch coastal waters, *Phaeocystis* blooms of such magnitude last up to mid-summer and alternate or co-occur with diatoms (Baretta-Bekker et al., 2009; Cadée and Hegeman, 1991, 2002). In contrast, little is known about the status of *Phaeocystis* colony blooms in offshore SBNS waters. Yet the presence in spring-summer of *Phaeocystis* colonies has been regularly reported in the entire SBNS already since 1948 by the Continuous Plankton Record (CPR) survey, supporting the hypothesis that these blooms are governed by large-scale meteorological phenomena rather than anthropogenic interference (Owens et al., 1989; Gieskes et al., 2007). However, the actual magnitude of these blooms in the open SBNS is not known as monitoring stations are obviously located in the near shore waters while offshore waters are sporadically sampled during field cruises. Moreover ocean color algorithms for *Phaeocystis* detection (e.g., Astoreca et al., 2009) are not operational yet in the turbid SBNS.

In this paper we use the previously validated tridimensional MIRO&CO-3D model describing diatom/*Phaeocystis* blooms and nutrient cycles in the SBNS (Lacroix et al., 2007) to assess the present-day dynamics (timing, magnitude, geographical extent) of diatom and *Phaeocystis* blooms in the whole SBNS. The criterion of $4{\cdot}10^6$ *Phaeocystis* cells $L^{-1}$ is used as a colonial cell abundance limit beyond which a healthy *Phaeocystis* ecosystem shifts toward an undesirable state. The possible effect of hydro-climatic fluctuations is explored by running simulations for two extreme years, however chosen sufficiently close to avoid changes in anthropogenic nutrient emissions due to nutrient reduction policy: the wet 2001 and dry 2005 years (Passy et al., 2013). These results are scaled to a pristine-like SBNS ecosystem (hereafter referred as pristine) i.e., obtained when human activities and hydraulic managements in the watershed do not affect nutrient loads while meteorological conditions are contemporary (2001 and 2005). The pristine river loads are extracted from Seneque/Riverstrahler model simulations at the river mouths obtained when erasing all human activity on the SBNS watershed (Thieu et al., 2009) and are coupled to the MIRO&CO-3D model describing diatom and *Phaeocystis* blooms in the SBNS marine domain. From these simulations unresolved questions such as (i) the occurrence of and conditions for a healthy *Phaeocystis* ecosystem in the SBNS, (ii) the geographical extent and the maxima reached by *Phaeocystis* colonies under pristine and present-day conditions as compared to the $4{\cdot}10^6$ colonial cells $L^{-1}$ criterion as well as (iii) the competitive ability of diatoms and *Phaeocystis* for nutrients and their response to anthropogenic nutrients, will be addressed.