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The exceptional surface turbidity of the North-West European shelf seas during the stormy 2013–2014 winter: Consequences for the initiation of the phytoplankton blooms?

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ABSTRACT

A succession of storms during the winter 2013–2014 enhanced the resuspension of sediments in the surface waters of the North-West European shelf seas. The effects of waves on satellite-derived non-algal SPM (Suspended Particulate Matters) are discussed for the January 2008–March 2014 period. A simple statistical model relating locally SPM to tidal intensity and waves helps us analyse the main characteristics of the winter 2013–2014. The exceptional run of storms observed in this stormy and rainy winter has resulted in the highest SPM concentration in the Celtic Sea and the Bay of Biscay ever observed by remote-sensing during the 1998–2014 period. Despite the lower clarity of the surface waters over a large part of the continental shelf during the first days of March 2014, blooms occurred early off the coast of Southern Brittany (Bay of Biscay) and later in April, as usual, in the Celtic Sea. Off the coast of southern Brittany, a region of freshwater influence, the lower clarity of the waters was counterbalanced by stronger haline stratification, due to high river discharges, enabling the initiation of blooms in late winter when the solar irradiance is sufficient; which was the case in March 2014 with 7 sunny days in a row just after the last storm. As a consequence, we can postulate that a possible increase in the intensity of waves occurring from December to early March, along with a possible scenario of global change, would not restrict the productive period in the Bay of Biscay. However an extension of the period of storms later in March would delay the timing of the blooms as observed in March 2008 in most of the investigated area.

1. Introduction

The impacts of climate change on phytoplankton are expected to be diverse (Winder and Sommer, 2012). Amongst the consequences of an increase in sea surface temperature, we may observe a change in phytoplankton populations and their phenology through a temporal shift in the establishment of stratification, with the onset of the first blooms occurring earlier in the year (Sharples et al., 2013). The overall impact of an increase in temperature is nevertheless difficult to model, as the growth of the phytoplankton biomass results from an equilibrium between cell multiplication and grazing by herbivores (Behrenfeld and Boss, 2014). How grazers and prey will evolve in the future is therefore an open question. The first significant blooms of the year are mainly due to a temporal imbalance between increased growth within nutrient-rich waters and growing populations of grazers at the time at which both the mixed layer depth decreases and sun light increases. These blooms are generally well observed by satellite sensors as they occur on sunny days and in surface waters, light being limiting. The initiation time, the duration and the amplitude of the blooms are major ecological indicators of the marine environment, which can be derived at regional scale from remote-sensing data (Platt and Sathyendranath, 2008). The light available for phytoplankton development is the solar irradiance at the sea surface, which is attenuated during its path through the water column. At the end of winter, light attenuation within the water column is governed by the concentration of mineral suspended particulate matter (SPM). Therefore a variation in the SPM concentration, owing to the action of storms (Fettweiss et al., 2012; Rivier et al., 2012), has a direct effect on the phytoplankton growth.

Although it is not yet proven that the recent storminess observed in the North-Eastern Atlantic is directly induced by the global climate change, Wang et al. (2012) observed an increase in the frequency and lifespan of storms in Northern Europe since 1871. Amongst more dramatic aspects such as coastal damage and persistent flooding, the winter storms also affect the water clarity in coastal waters. It is this aspect that will be developed in this study. We will investigate the consequences of the exceptional run of storms observed in Western Europe from late December 2013 to early March 2014 (Sligo et al., 2014) on the

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timing of the phytoplankton blooms in late winter and at the beginning of spring. When investigating the hydro-climatic conditions in the North-East Atlantic in winter, it is very usual to refer to the North-Atlantic-Oscillation (NAO) index. Positive anomalies of NAO at this season are associated with strong westerly winds and wetter/milder weather over Western Europe. With a mean index of 2.3 for the months of December 2013 to March 2014, the station-based NAO (Hurrell, James and National Center for Atmospheric Research Staff, 2014) was the highest observed in the period 1998–2014, during which ocean colour sensors have been available on an operational basis. We will take advantage of the opportunity brought to us by this windy winter to investigate the effects of exceptional levels of turbidity in winter on the phytoplankton blooms.

The area under study concerns the continental shelf of the Celtic Sea, the English Channel and the Bay of Biscay (Fig. 1). Garcia-Soto and Pingree (2009) describe the regional characteristics of the seasonal cycle of chlorophyll and its yearly variability along a ferry-line, including satellite observations, in the Bay of Biscay and the Western English Channel. In this study we focus on the timing of the spring blooms in relation to the water clarity, whose indicator will be the satellite-derived SPM content. The spring bloom is a critical event in the marine food chain, representing the first significant supply of phytoplankton following the winter. The timing of the bloom is therefore critical for the growth and survival of the diverse components of the marine ecosystem. The onset of the bloom is closely dependent on the stability of the surface layer and on the attenuation of the diffuse descending light, K_{PAR}. For this reason, Capuzzo et al. (2013) partition the North-Sea in distinct ecohydrodynamical regions based upon their ability to stratify or not and also their clarity, through the attenuation coefficient of light, K_{PAR}. Here, we will consider four stations related to different hydrodynamical and biological conditions considered as representative of the main situations encountered in the studied area, without being exhaustive.

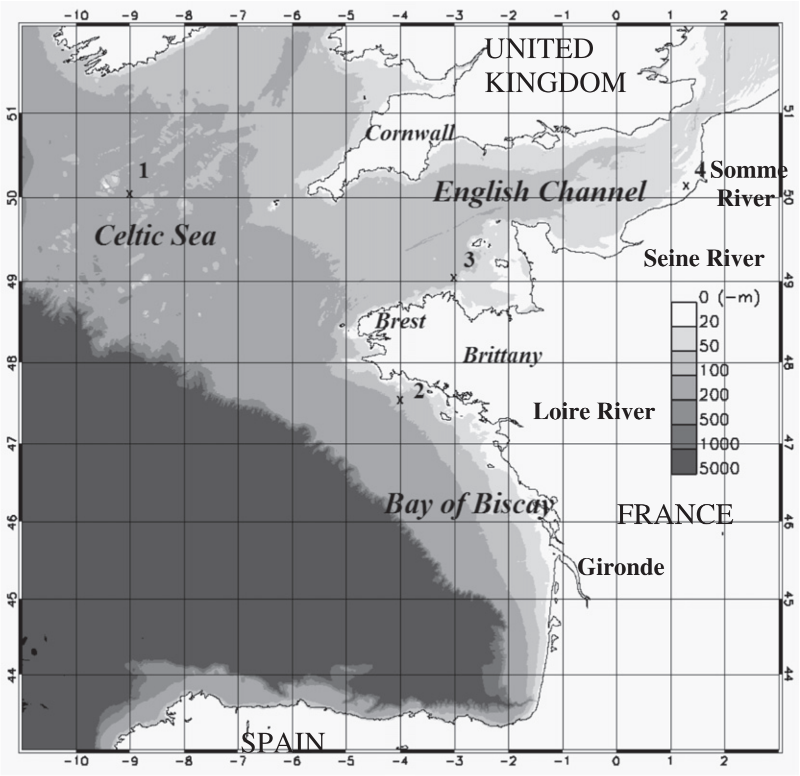
We will analyse the effect of the winter storms on the resuspension of particulate matter using the model developed by Rivier et al (2012). This very simple statistical model, based on satellite-derived SPM, gives a quantitative assessment of the relation between tide, waves and resuspension over the English Channel. In this model, the "wave" variable groups together their effect on the resuspension of sediment, through bottom shear stress, wind-generated turbulence and the settling of particles.

Despite the high variability in the hydrodynamical characteristics of our area we will only consider four sites in detail. From the west, moving eastward, these points are noted 1 to 4 on Fig. 1. Station 1 (9°W, 50°N) is located in the Celtic Sea, where the exposure to the westerly waves is high and where the first bloom occurs relatively late each year, often in April (Pingree, 1980; Rees et al., 1999). At this location we may consider that the first bloom occurs in relation to near surface stabilisation after transition to a positive net heat flux in spring, similarly to station L4 situated off Plymouth in the Western English Channel (Smyth et al., 2014). The second site (4°W, 47.5°N) is located off the southern coast of Brittany. At this location, haline stratification may occur early due to the fresh water discharge of the Loire River, as in March 2000 when a late winter bloom was captured by SeaWiFS imagery. Hydrological conditions prior to this bloom were described in detail by Gohin et al. (2003). The third site is located in the middle of the Channel, where the tidal current is the major driver of resuspension (Bréhat Point 3 at 3°W, 49°N). The last site (1.3°E, 50.1°N) is located in the eastern part of the English Channel, near the French coast, where a shallow bathymetry permits an early initiation of the phytoplankton growth, as soon as the end of February. An overview of the chlorophyll-a cycle over the region, derived from satellite reflectance or observed in-situ by the Ifremer REPHY network of phytoplankton monitoring, is described in Gohin (2011). Table 1 gives the main characteristics of the environment surrounding the four sites.

2. Data and methods

2.1. Satellite data

Two sets of images will be considered in this study. The first one, which is our main data set providing non-algal SPM and chlorophyll-a,



Station 1 (9°W, 50°N)
Celtic Sea
Seasonally stratified area with a spring bloom

Station 2 (4°W, 47.5°N)
Southern Brittany
Bloom events possible in late winter

Station 3 (3°W, 49°N)
Northern Brittany
Tidally mixed waters

Station 4 (1.3°E, 50.1°N)
Eastern Channel
Long winter blooms in shallow waters

Fig. 1. The studied area and the locations of the four stations analysed.