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Biogeochemistry and carbon mass balance of a coccolithophore bloom in the northern Bay of Biscay (June 2006)

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ABSTRACT

Primary production (PP), calcification (CAL), bacterial production (BP) and dark community respiration (DCR) were measured along with a set of various biogeochemical variables, in early June 2006, at several stations at the shelf break of the northern Bay of Biscay. The cruise was carried out after the main spring diatom bloom that, based on the analysis of a time-series of remotely sensed chlorophyll-a (Chl-a), peaked in mid-April. Remotely sensed sea surface temperature (SST) indicated the occurrence of enhanced vertical mixing (due to internal tides) at the continental slope, while adjacent waters on the continental shelf were stratified, as confirmed by vertical profiles of temperature acquired during the cruise. The surface layer of the stratified water masses (on the continental shelf) was depleted of inorganic nutrients. Dissolved silicate (DSi) levels probably did not allow significant diatom development. We hypothesize that mixing at the continental slope allowed the injection of inorganic nutrients that triggered the blooming of mixed phytoplanktonic communities dominated by coccolithophores (*Emiliania huxleyi*) that were favoured with regards to diatoms due to the low DSi levels. Based on this conceptual frame, we used an indicator of vertical stratification to classify the different sampled stations, and to reconstruct the possible evolution of the bloom from the onset at the continental slope (triggered by vertical mixing) through its development as the water mass was advected on-shelf and stratified. We also established a carbon mass balance at each station by integrating in the photic layer PP, CAL and DCR. This allowed computation at each station of the contribution of PP, CAL and DCR to CO_2 fluxes in the photic layer, and how they changed from one station to another along the sequence of bloom development (as traced by the stratification indicator). This also showed a shift from net autotrophy to net heterotrophy as the water mass aged (stratified), and suggested the importance of extracellular production of carbon to sustain the bacterial demand in the photic and aphotic layers.

1. Introduction

During coccolithophore blooms, carbon (C, all abbreviations are defined in Table 1) cycling in the photic zone is driven by the production and degradation of organic matter (primary production (PP) and community respiration), and the production and dissolution of biogenic calcite ($CaCO_3$). Both processes transfer C to depth and impact on the speciation of dissolved inorganic C (DIC) and CO_2 flux across the air–sea interface (Purdie and Finch, 1994; Buitenhuis et al., 1996, 2001; Crawford and Purdie, 1997; Frankignoulle and Borges, 2001; Suykens et al., 2010a). Changes of C fluxes of pelagic calcifiers under ocean acidification (e.g., Orr et al., 2005), namely a decrease in calcification rates, could provide a negative feedback in response to increasing atmospheric CO_2 as suggested by controlled experiments either in cultures (e.g., Riebesell et al., 2000; Sciandra et al., 2003; De Bodt et al., 2008, 2010) or mesocosms (e.g., Delille et al., 2005; Riebesell et al., 2007). Further, due to their relatively large contribution to the phytoplanktonic community, and their complex life cycle which alternates between naked and calcified forms, the effect of coccolithophores on CO_2 fluxes is variable during bloom development, altering the ratio of calcification (CAL) to PP (Billard and Inouye, 2004). Understanding and quantifying the C cycling associated with coccolithophore blooms under natural conditions is needed to correctly parameterize and validate biogeochemical

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Table 1
List and definition of abbreviations used in text.

Abbreviation	Definition
$\%O_2$	Oxygen saturation
AVHRR	Advanced very high resolution radiometer
BOD	Biological oxygen demand
BP	Bacterial production
C	Carbon
$CaCO_3$	Calcium carbonate
CAL	Calcification
Chl-a	Chlorophyll-a
CO_2	Carbon dioxide
CTD	Conductivity-temperature-depth
DCR	Dark community respiration
DIC	Dissolved inorganic carbon
DSi	Dissolved silicate concentration
GPP	Gross primary production
HPLC	High performance liquid chromatography
HR	High reflectance
K_d	Diffuse attenuation coefficient
$L_{wn}(555)$	Normalized water-leaving radiance at 555 nm
MLD	Mixed layer depth
MODIS	Moderate-resolution imaging spectrometer
NMCF	Net metabolic carbon flux
NCP	Net community production
O_2	Oxygen
PAR	Photosynthetically active radiation
pCO_2	Partial pressure of carbon dioxide
PIC	Particulate inorganic carbon
PO_4	Phosphate concentration
POC	Particulate organic carbon
PP	Primary production
PP_d	Dissolved primary production
PP_{tot}	Total primary production
SeaWIFs	Sea-viewing Wide Field-of-view Sensor
SST	Sea surface temperature
TCA	Trichloroacetic acid
TEP	Transparent exopolymer particles
TEP-C	Transparent exopolymer particles carbon concentration
TPC	Total particulate carbon
UML	Upper mixed layer

models that aim at predicting feedbacks related to ocean acidification and incorporate knowledge obtained from perturbation laboratory experiments.

Coccolithophore blooms have an identifiable spectral signature (reflectance) on the 555 nm band from remote sensing (Balch et al., 2005, 2007; Balch and Utgoff, 2009) and have frequently been observed in the English Channel (GREPMA, 1988; Garcia-Soto et al., 1995), the Celtic Sea and the Bay of Biscay (Holligan et al., 1983; Garcia-Soto and Pingree, 2009; Harlay et al., 2010; Suykens et al., 2010a) from high reflectance (HR) patches on satellite images. These HR patches have been attributed to blooms of the coccolithophore *Emiliania huxleyi*, which can reach concentrations above 10^8 liths L^{-1} (Holligan et al., 1993).

We carried out a survey at the continental margin of the northern Bay of Biscay in early June 2006 when a HR patch associated with a coccolithophore bloom was observed. We report physico-chemical and biogeochemical parameters (temperature, nutrients, chlorophyll-a (Chl-a), and oxygen saturation ($\%O_2$)), elemental composition of suspended particulate matter as well as community metabolic rates like the daily rates of CAL, PP, bacterial production (BP), and dark community respiration (DCR). Remotely sensed images and the output of a physical model were used to analyse the seasonal phytoplankton dynamics. Finally, based on community metabolic rate measurements, we compute and discuss a C mass balance for the photic zone.

2. Materials and methods

2.1. Study site

The study area is at the shelf break of the Celtic Sea in the northern Bay of Biscay, located in the eastern North Atlantic Ocean (Fig. 1). The topography of the shelf-edge of the northern Bay of Biscay defines the particular physical conditions at the La Chapelle Bank and the Meriadzek Terrace: combined to strong tidal currents,

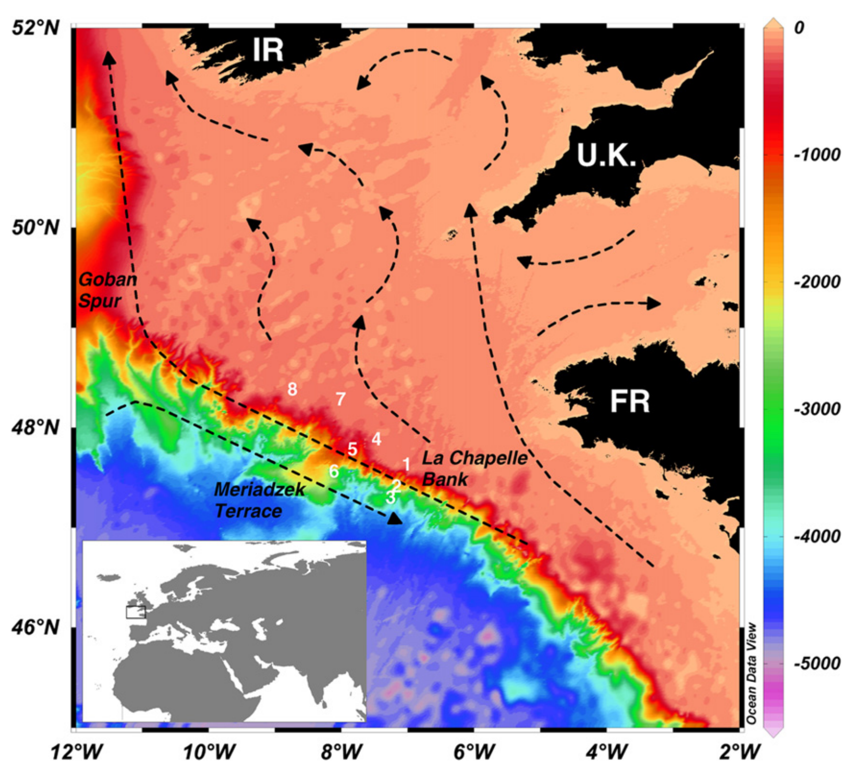

Fig. 1. Map of the northern Bay of Biscay showing bathymetry (Smith and Sandwell, 1997), the location of the stations and surface currents (Pingree and Le Cann, 1989; Pingree, 1993; Pingree et al., 1999 and Huthnance et al., 2001). The stations 1 and 4 were revisited after 9 and 6 days, respectively, and referred to as 1bis and 4bis in the text.