Towards a comprehensive C-budgeting approach of a coccolithophorid bloom in the Northern Bay of Biscay (June 2006)

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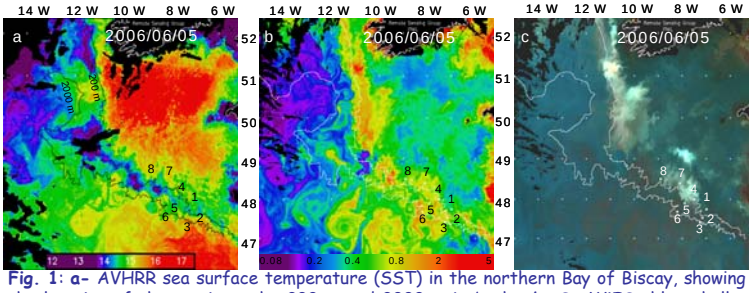

Fig. 1: **a-** AVHRR sea surface temperature (SST) in the northern Bay of Biscay, showing the location of the stations, the 200 m and 2000 m isobaths, **b-** SeaWiFS chlorophyll-a (Chl-a) and **c-** SeaWiFS reflectance satellite images.

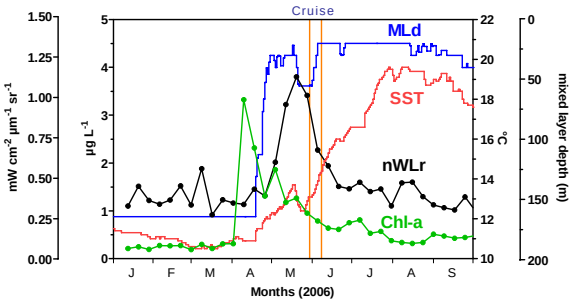

Fig. 2: Time series of remote sensed weekly Chl-a concentrations and normalized water-leaving radiance @555 nm (nWLr), modelled daily mixed layer depth (MLd) and SST in the studied area from January to September 2006. Chl-a and nWLr are Level-3 SeaWiFS data (http://reason.gsfc.nasa.gov/Giovanni/) and MLd and SST were simulated with Met Office National Centre for Ocean Forecasting for the North-East Atlantic 1/8° model (http://www.nerc-essc.ac.uk/godiva/).

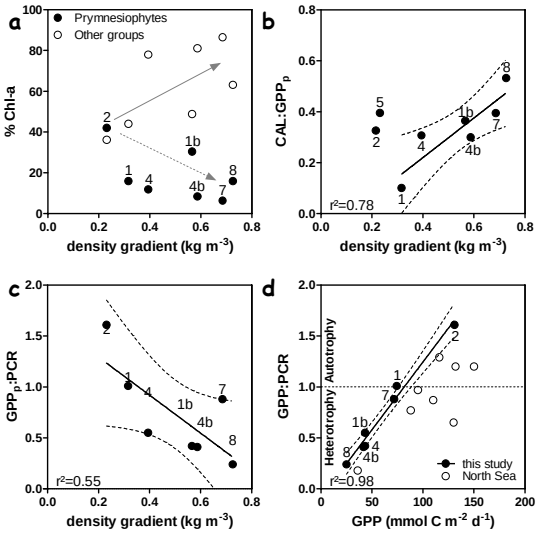

Fig. 3: **a-** Depth averaged HPLC relative percentage of Prymnesiophytes (filled circles) and other phytoplankton groups (open circles) in the 30 m top layer, **b-** calcification to gross particulate primary production ($CAL:GPP_p$) ratio and **c-** GPP_p to pelagic respiration (GPP_p:PCR) ratio *versus* the degree stratification computed as the difference of density at 3 m depth and at 100 m depth. The linear regression and the 95% confidence interval (dashed curves) are represented together with the determination coefficient (r^2). **d-** GPP:PCR ratio *versus* GPP in June 2006 in the Bay of Biscay (filled circles) and in June 1999 (open circles) for the North Sea (Robinson *et al.*, 2002).

INTRODUCTION

During coccolithophorid blooms, carbon (C) cycling in the photic zone is driven by the production and the degradation of organic matter (primary production and community respiration), and the production and the dissolution of biogenic calcite ($CaCO_3$). Organic and inorganic metabolisms lead to a transfer of carbon to depth and both impact the flows of carbon dioxide (CO_2) into the water column and CO_2 flux across the air-sea interface. Further, due to complex dynamics of coccolithophores, the impact of metabolic C fluxes on CO_2 fluxes is variable in time, depending on the bloom development phase, and mainly dependant on the ratio of calcification to primary production (CAL:GPP ratio). Understanding and quantifying C cycling of coccolithophorid blooms in natural conditions is a prerequisite to correctly validate biogeochemical models that aim at predicting feedbacks related to ocean acidification incorporating knowledge obtained from perturbation laboratory experiments.

We carried out a trans-disciplinary cruise on board the R/V *Belgica* at the continental margin of the Bay of Biscay in June 2006 (Fig. 1), in a coccolithophorid bloom, during which ^{14}C primary production (GPP_p), ^{14}C calcification (CAL) and O_2-based pelagic respiration rates (PCR) were determined in the water column.

Table 1: Carbon fluxes [mmol C m^{-2} d^{-1}] based on a mass balance where the ^{14}C incubations are assumed to correspond to gross primary production (GPP_p), where pelagic community respiration (PCR) is the sum of autotrophic and heterotrophic respiration based on oxygen incubations converted to C units using a respiratory quotient of 1, and where CAL is the rate of calcification based on ^{14}C incubations.

			Rate measurements			CO_2 Fluxes					C fluxes	
Station	Date	pCO_2	GPP_p	CAL	PCR	GPP_p	CAL	PCR	Net CO_2 flux based on metabolic rates	Net CO_2 flux based on measured pCO_2	Export	Aphotic C demand
5	2 June	320	74.2	24.2	-	-74.2	14.5	-	-	-9.1	-	-
2	1 June	306	130.8	51.7	81.3	-130.8	31.0	81.3	-18.5	-11.4	49.5	89.0
1	31- May	265	74.2	7.5	73.7	-74.2	4.5	73.7	4.0	-17.8	0.5	98.2
4 (HR)	2 June	293	43.3	13.3	78.9	-43.3	8.0	78.9	43.6	-13.4	-35.6	66.9
1b	9 June	273	43.3	15.8	103.5	-43.3	9.5	103.5	69.7	-16.1	-60.2	159.0
4b (HR)	8 June	307	41.7	12.5	101.2	-41.7	7.5	101.2	67.0	-10.7	-59.5	168.5
7 (HR)	7 June	309	71.7	28.3	81.4	-71.7	17.0	81.4	26.7	-10.2	-9.7	35.1
8 (HR)	6 June	325	25.0	13.3	104.3	-25.0	8.0	104.3	87.3	-8.5	-79.3	72.3

RESULTS

The time series of remotely sensed parameters reveals a rise of SST accompanied by a shoaling of the thermocline to 25 m depth during the period of the cruise (Fig. 2). This situation is favourable for coccolithophorid development, as indicated by elevated nWLr, moderate (~1 µg L^{-1}) Chl-a concentration (Fig. 2) and nutrient exhaustion (not shown).

In agreement with Margalef's Mandala, the degree of stratification was hypothesized to control biological processes and allowed reconstructing the bloom succession phases of the coccolithophore-dominated bloom (Fig. 3). Bloom aging was characterized by a decrease of Prymnesiophyte biomass relative to other phytoplankton groups (Fig. 3a). With increasing stratification from early coccolithophorid bloom stations (1-2-5) to the later stages (station 8), GPP_p decreased as CAL increased over the shelf, leading to a significant $CAL:GPP_p$ ratio for later stages of the bloom (Fig. 3b). The aging of the bloom lead to a lower GPP:PCR ratio (Fig. 3c) and an evolution from net phytoplanktonic community autotrophy to net heterotrophy (Fig. 3d). Consistency of this ratio was checked against Robinson *et al.* (2002) in the North Sea (Fig. 3d).

A C-budget was computed along a gradient from the productive (station 2) to the high reflectance zone (station 8). Surface waters remained as a net sink for atmospheric CO_2 (Table 1), although TA data (not shown) indicated that calcification had a large impact on surface carbonate chemistry. However, net autotrophy was only found for the early phase of the bloom (station 2) where the potential export was of the same magnitude as the aphotic C demand. In other cases, the C export was neutral or negative and insufficient to sustain aphotic demand.

CONCLUSIONS

Our classical C-budgeting approach suffers from several caveats. Firstly, steady state is assumed but C production and degradation are decoupled in time and space, as well as biomineralization and dissolution. Secondly, the importance of dissolved production (GPP_d) is not considered, here. The importance of GPP_d and its potential fate into transparent exopolymer particles (TEP) is likely a significant C flux (12% of the POC, Harlay *et al.*, 2009) to sustain the heterotrophic C demand in the twilight zone, as suggested by Koeve (2005).

The estimate of GPP_d from the particulate nitrogen to carbon ratio in surface waters, based on parameterization by Joassin *et al.* (2008) and the computation of C budget based on GPP_{tot} (GPP_{tot} = GPP_d + GPP_p) contributes to better balanced C fluxes to the twilight zone by providing a net export of the same magnitude than aphotic demand (Harlay *et al. in prep*).

References:

Harlay *et al.* (2009) Abundance and size distribution of transparent exopolymer particles (TEP) in a coccolithophorid bloom in the northern Bay of Biscay. *Deep Sea Research part I. accepted*

Joassin *et al.* (2008) A mathematical modeling of an *Emiliania huxleyi* coccolithophores bloom occuring in a mesocosm experiment. *Biogeoscience discussions.*

Koeve (2005) Magnitude of excess carbon sequestration into the deep ocean and the possible role of TEP. *Marine Ecology Progress series.* 291: 53-64

Robinson *et al.* (2002) Plankton community respiration during a coccolithophore bloom. *Deep Sea Research Part II.* 49(15): 2929-2950

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