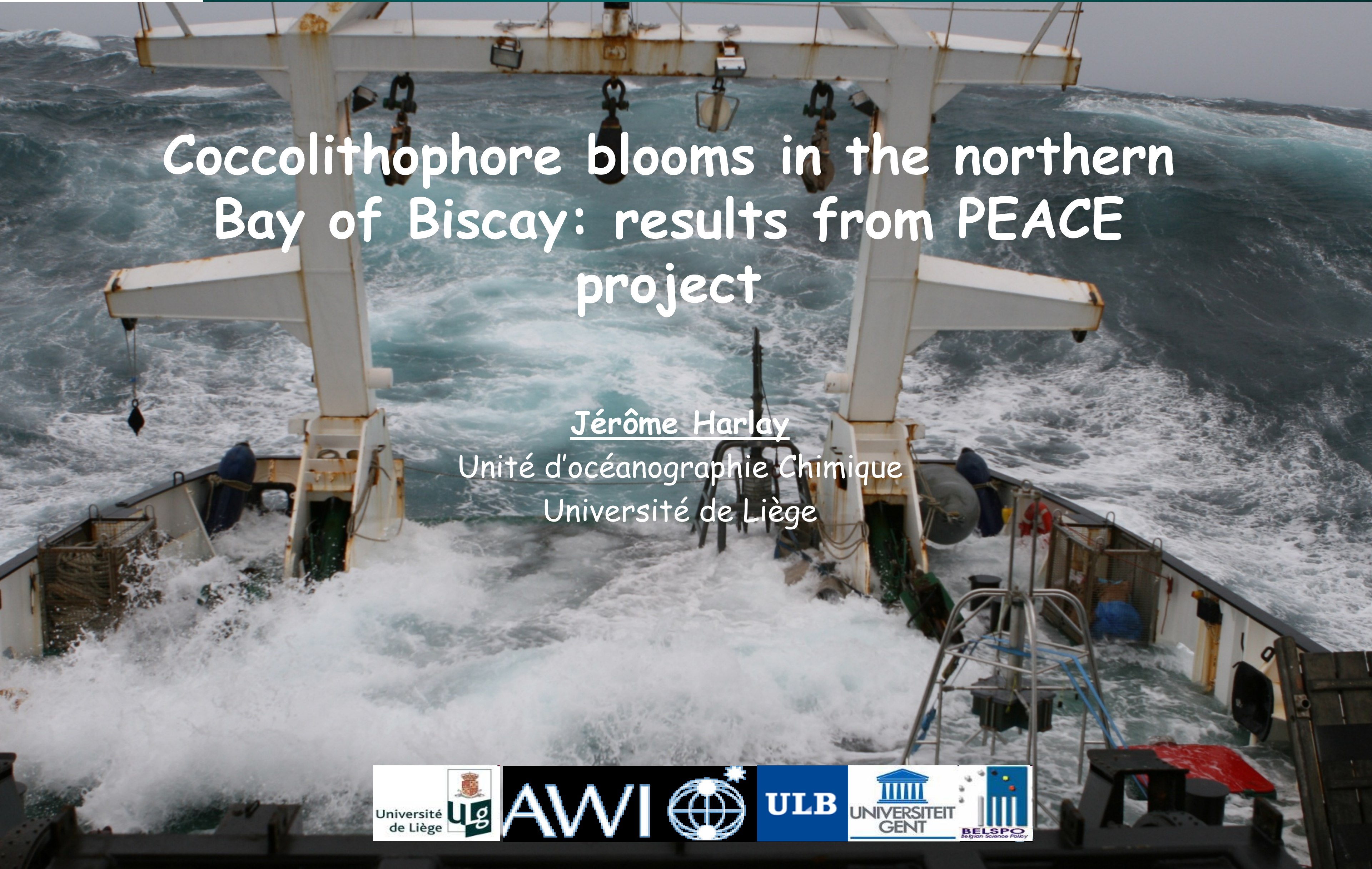

Coccolithophore blooms in the northern Bay of Biscay: results from PEACE project

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Co-authorship

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- Koen Sabbe, Nicolas Van Oostende (UGent, Belgium)
- Anja Engel, Judith Piontek, Corinna Borchard (AWI, Germany)

ROLE OF **PE**LAGIC CALCIFICATION **A**ND
EXPORT OF **C**ARBONAT**E** PRODUCTION
IN CLIMATE CHANGE
(2005-2009)
Belgian Federal Science Policy Office

Outline

- **Introduction**
  - Pelagic Calcification
  - Coccolithophores
  - Problematic
  - Objectives
- **Material and Methods**
  - Study site
  - Pelagic processes
  - Benthic processes
- **Results**
- **Synthesis**
- **Conclusions**

Pelagic Calcification

Estimates of global calcification rates

Coccolithophores (Balch *et al.*, 2007)

~1600 10^{12} g C yr^{-1}

Foraminifera (Langer *et al.*, 1997)

~162 10^{12} g C yr^{-1}

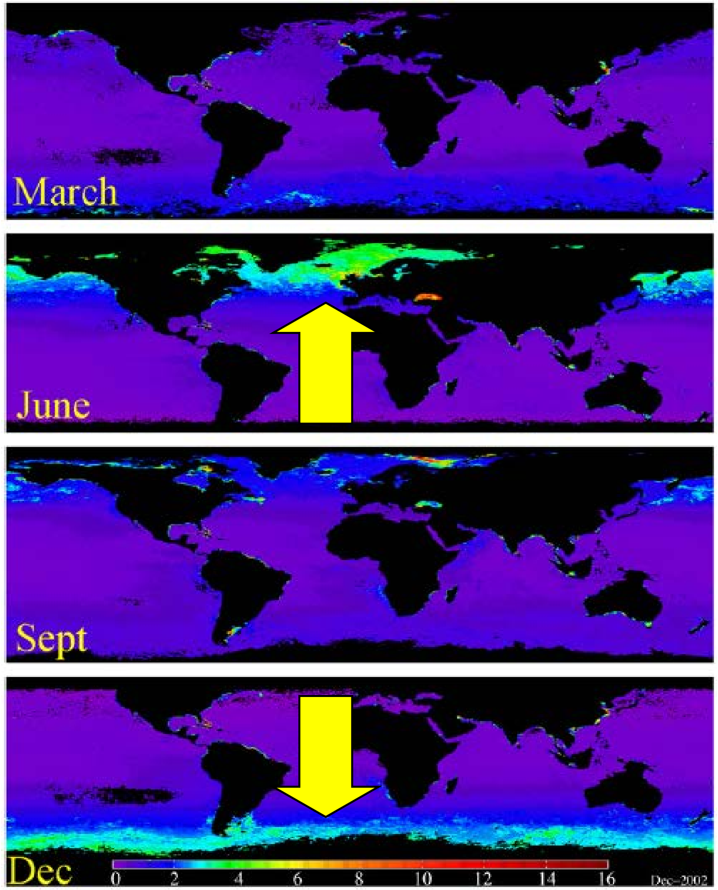
Pteropods (Honjo, 1981)

~160 10^{12} g C yr^{-1}

Coral Reefs (Vescei, 2004) **~90 10^{12} g C yr^{-1}**

Benthic Molluscs, Echinoderms… ?

They are the main contributors to contemporary biogenic $CaCO_3$ precipitation



Balch *et al.*, 2007 – DSR II

Coccolithophores

Coccolithophores play a key role in the biogeochemical cycle of the world Ocean:

- Primary producers:

$$106CO_2 + 16NO_3^- + H_2PO_4^- + 17H^+ + 122H_2O \leftrightarrow (CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2$$

- Key role in total alkalinity (TA) distribution:

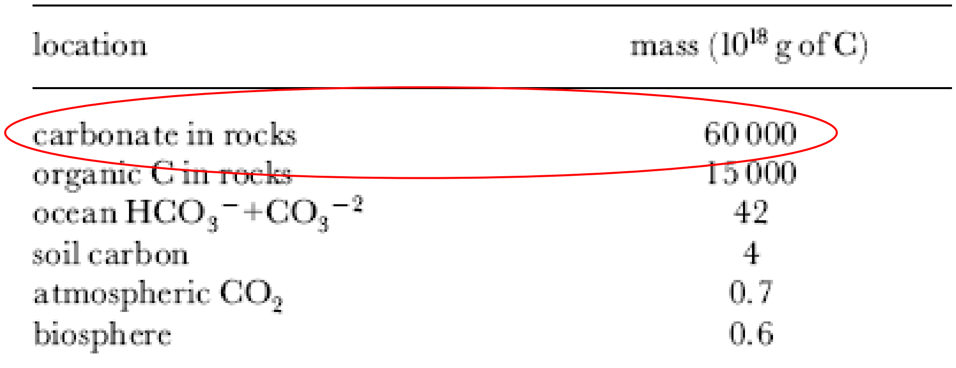
$$2HCO_3^- + Ca^{2+} \leftrightarrow CaCO_3 + CO_2 + H_2O$$

- $CaCO_3$ ballasts particulate organic carbon (POC) and participates to the biological pump that removes CO_2 from the surface ocean to the ocean interior.

Problematic

How important are pelagic calcifiers in the biogeochemical C cycle?

- "Carbonate rocks" is the most important reservoir of C on Earth



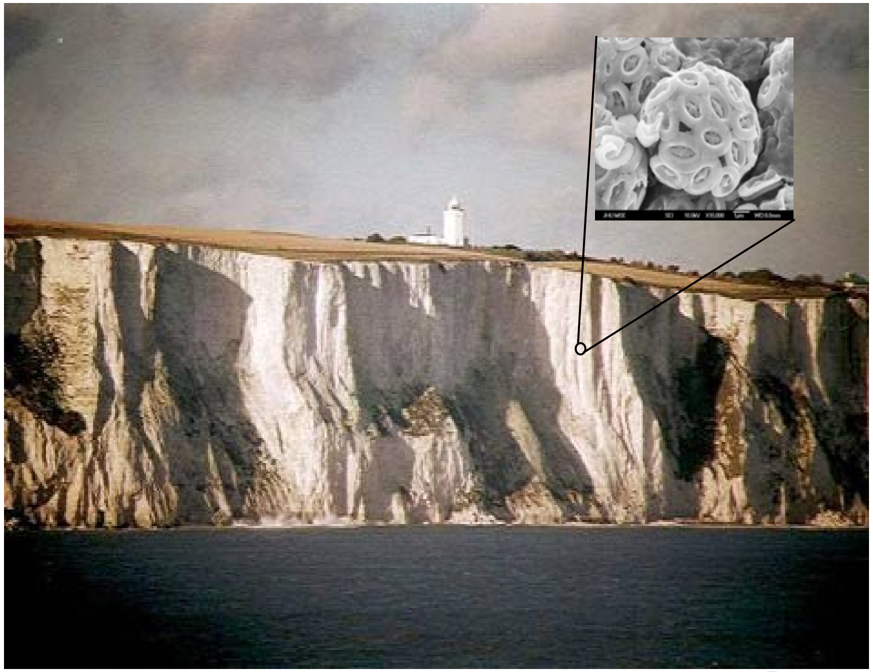
location	mass (10^{18} g of C)
carbonate in rocks	60 000
organic C in rocks	15 000
ocean $HCO_3^- + CO_3^{-2}$	42
soil carbon	4
atmospheric CO_2	0.7
biosphere	0.6

Berner, 1998

- $CaCO_3$ production is a biotic process

- Ocean acidification and Global Warming will affect the distribution and the abundance of the pelagic calcifiers.

(The Royal Society Report, 2005, IPCC, 2007)



Objectives

Objectives: ecosystem dynamics and bentho-pelagic coupling during coccolithophore blooms

- PEACE project: 3 cruises in the Bay of Biscay (May-June 2006; 2007 and 2008) :

ROLE OF **PE**LAGIC CALCIFICATION **A**ND
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Understanding the functioning and characteristics of coccolithophore blooms is of crucial importance to describe the efficiency of the biological pumps.

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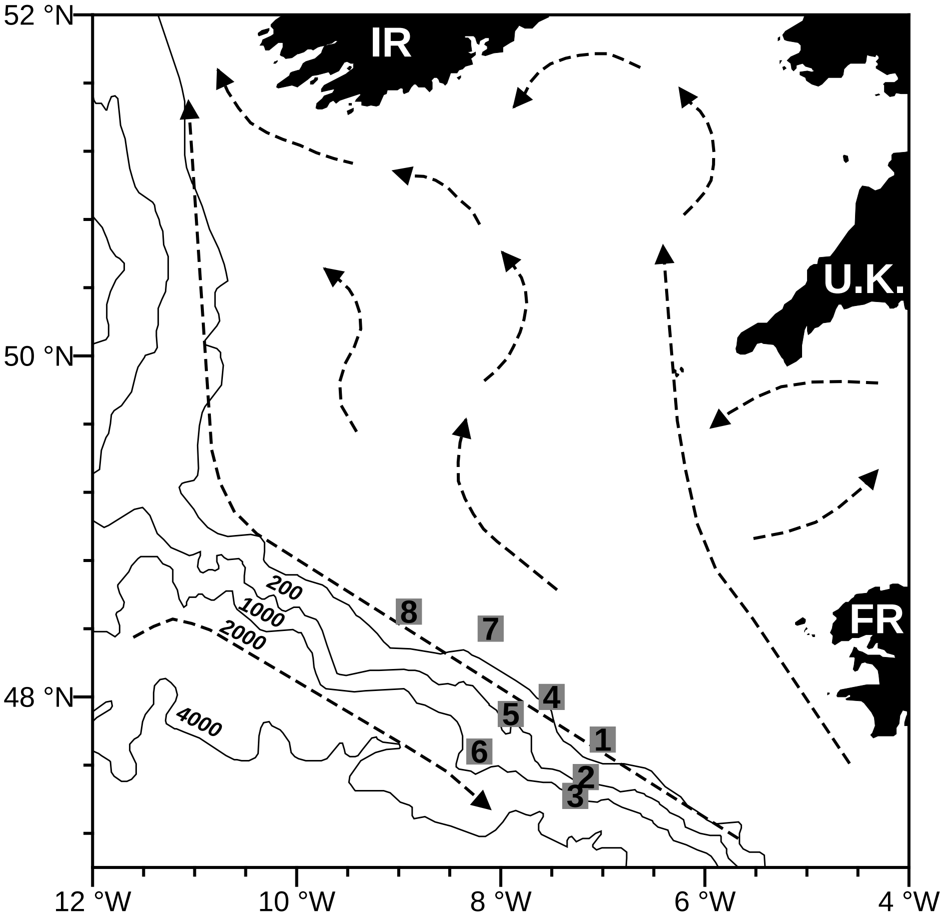
Material and Methods

Study site: Northern Bay of Biscay
NE Altantic Ocean

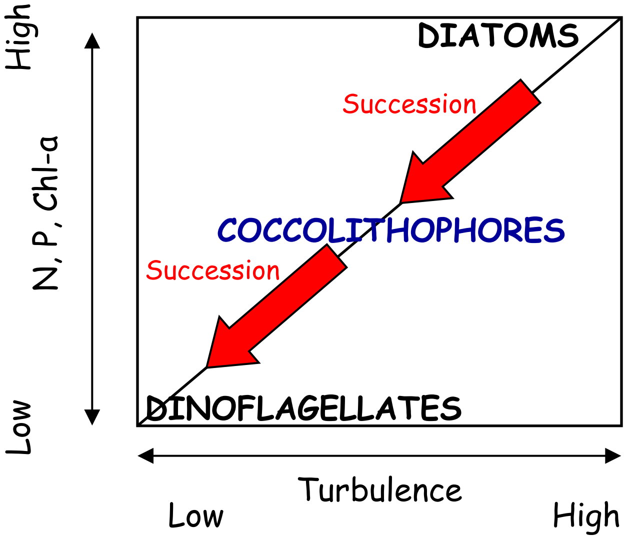


Pelagic Processes

We applied an original approach based on the Margalef's Mandala.

→ *"A shift towards oligotrophy is accompanied by a change in the relative dominance of phytoplankton species."*

Margalef's Mandala (1997)

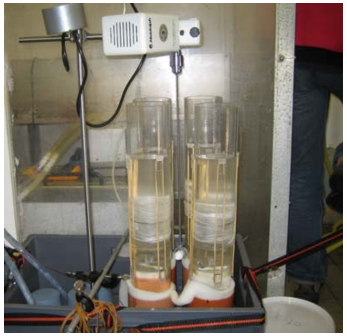


Pelagic Measurements (2006):

- ^{14}C-Primary production
- ^{14}C-Calcification
- O_2-based **D**ark **C**ommunity **R**espiration
- DSi, PO_4
- HPLC pigments (Chemtax re-analysis)
- POC, PIC
- Total Alkalinity, pCO_2
- ^{3}[H]-Thy Bacterial Production

Working hypothesis: the thermal stratification favours the blooming of Coccolithophores at the continental margin.

Benthic Processes



Incubations of sediment cores with overlying waters

- biogeochemical water-sediment fluxes (O_2, TA, NO_3^-)
  - FO_2 : Benthic respiration rate
  - FTA*: $FTA^* = FTA + FTA_{AR} - FTA_{denitr}$ corrected for:
    - nitrification/denitrification : $FTA_{denitr} = \frac{16|FO_2|}{138} - FNO_3^-$
    - aerobic OM remineralisation: $FTA_{AR} = \frac{17|FO_2|}{138}$
- sediment characteristics (grain size, chlorophyll-a (Chl-a), POC and PIC content)

Water sampled above the bottom at depths between 208 and 4460 m)

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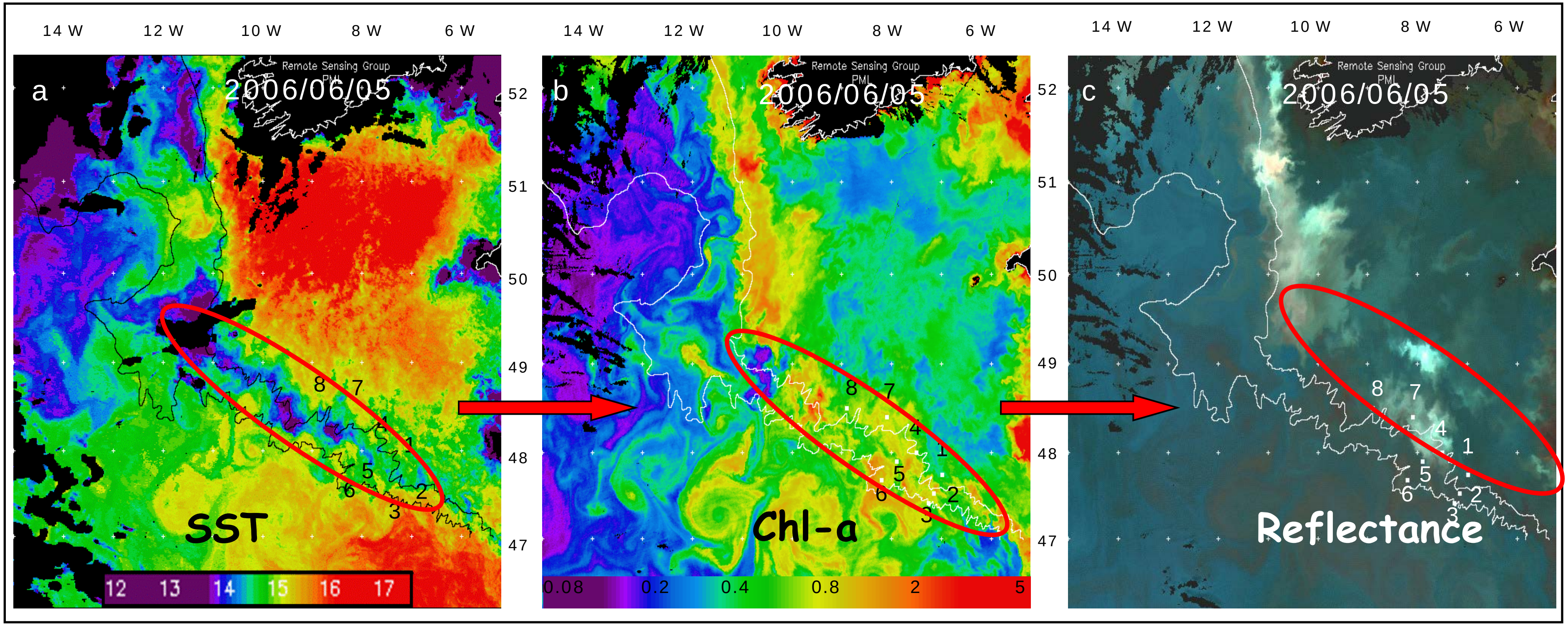
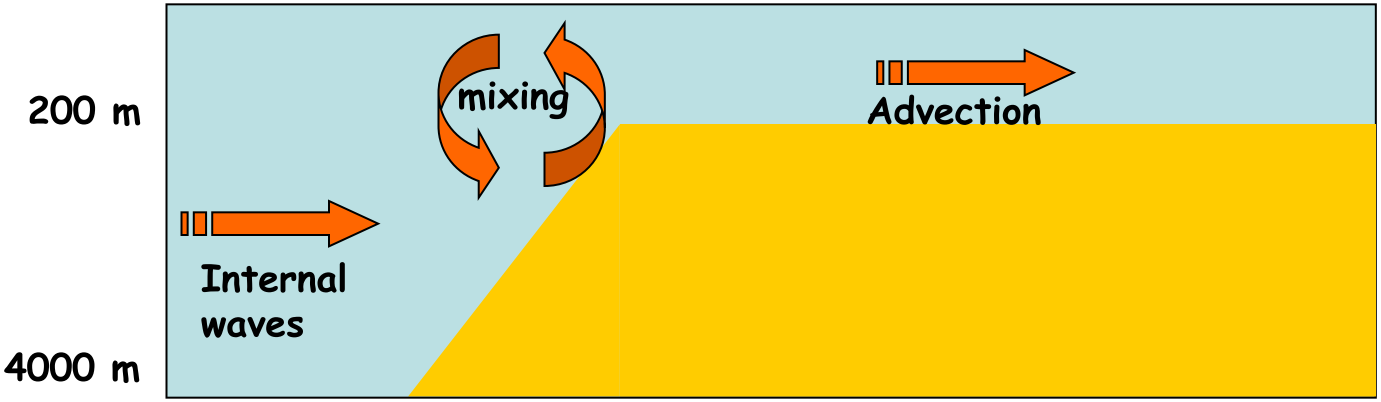
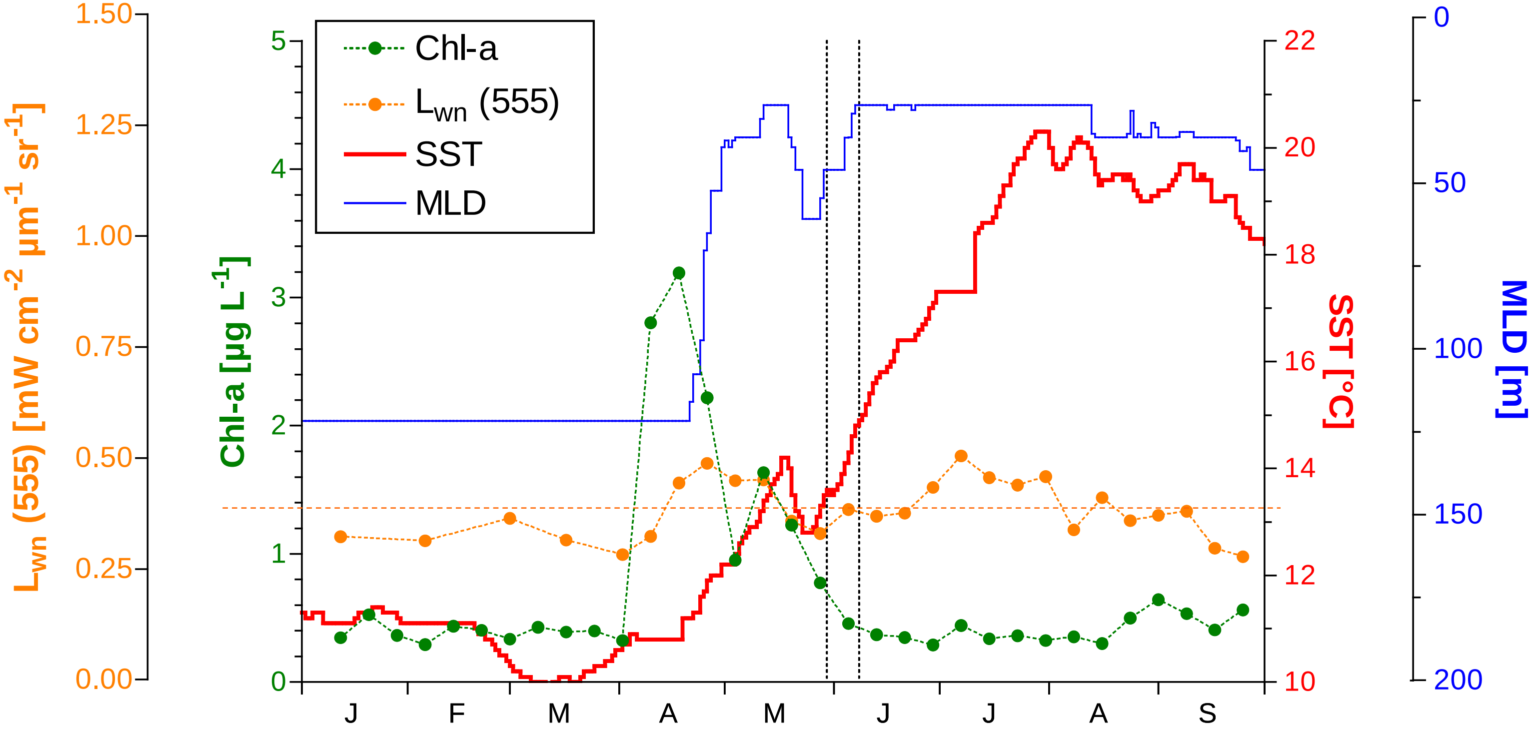
Satellite images





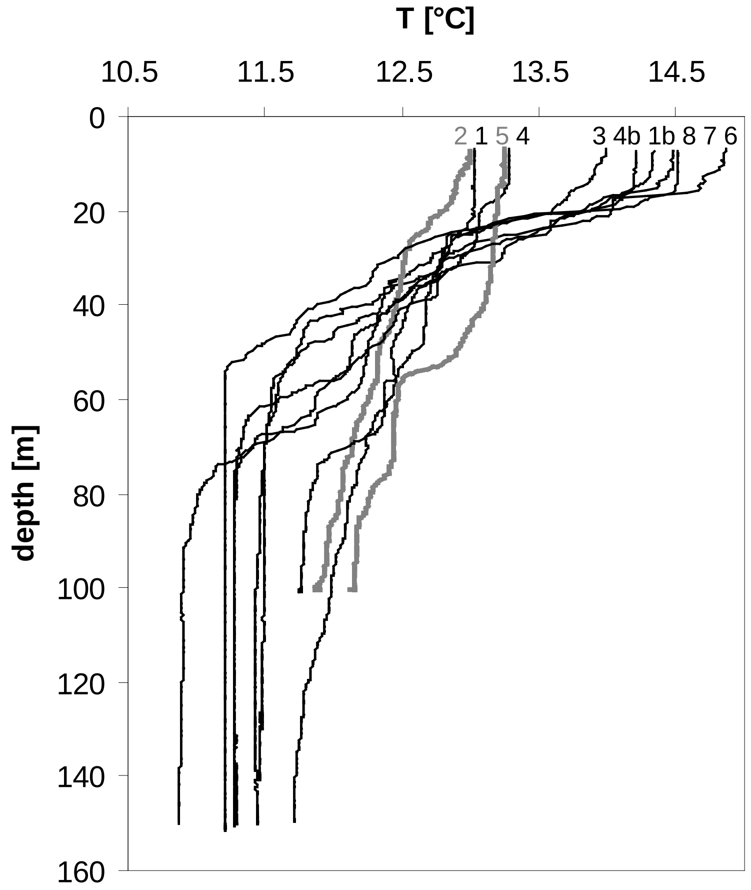
Time series



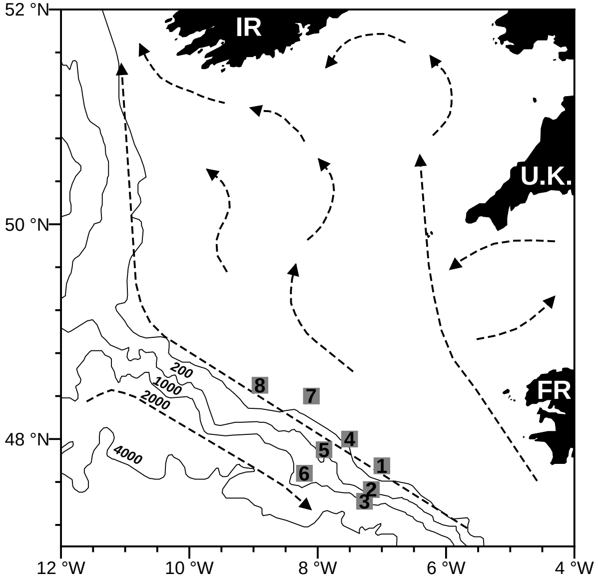
The onset of the coccolithophore bloom (L_{wn}(555)) coincides with a **warming** (SST) and a **shoaling of the mixed layer depth** after the first peak of Chl-a in early April

Data from:
GIOVANNI (Lwn (555), Chl-a)
GODIVA (Grid for Ocean Diagnostics, Interactive Visualisation and Analysis) (MLD)
Reynolds *et al.* (2002) (SST)

Environmental Settings

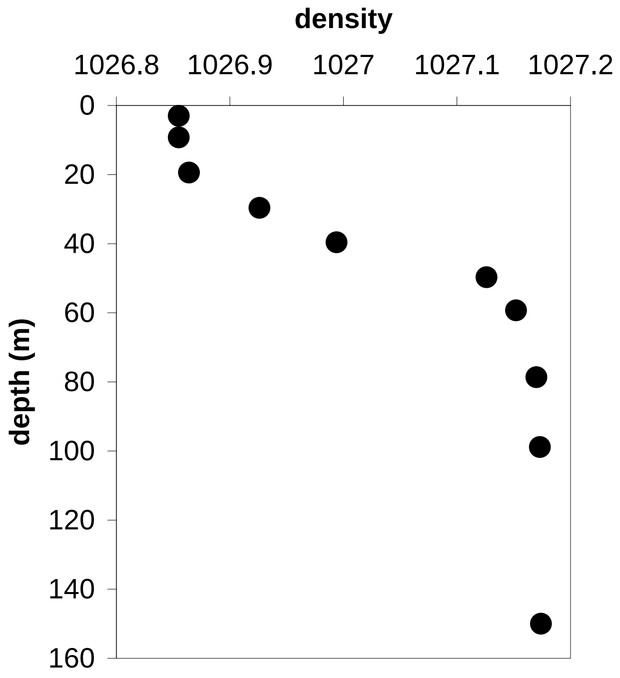


The vertical profiles of temperature exhibit a warming over the shelf, compared to the station located on the shelf-break (in grey).



Pelagic: Results

We used the **density gradient** to build a **stratification index** as an indicator for the preferential niche of coccolithophores to characterize the status of the different stations regarding the **bloom development**.



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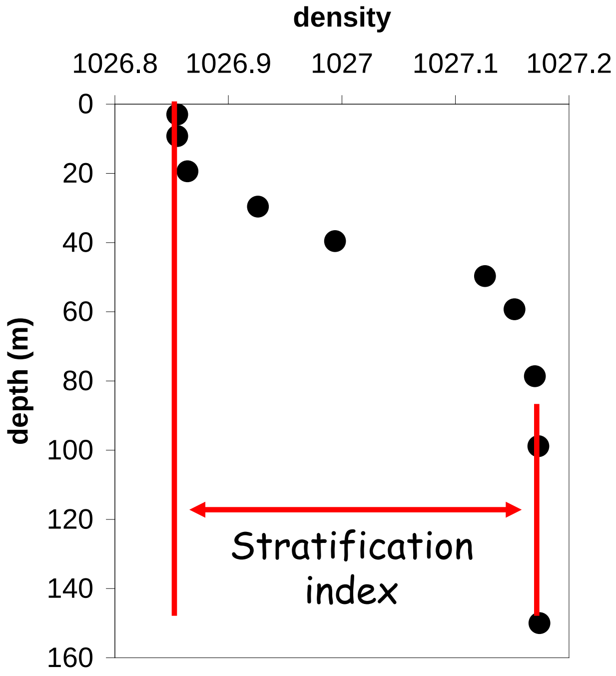

Higher index corresponds to more stratified conditions

Pelagic: Results

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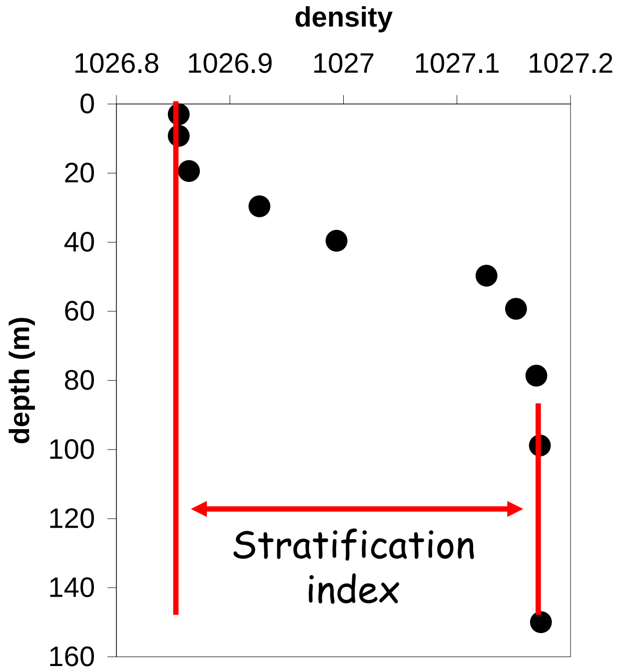
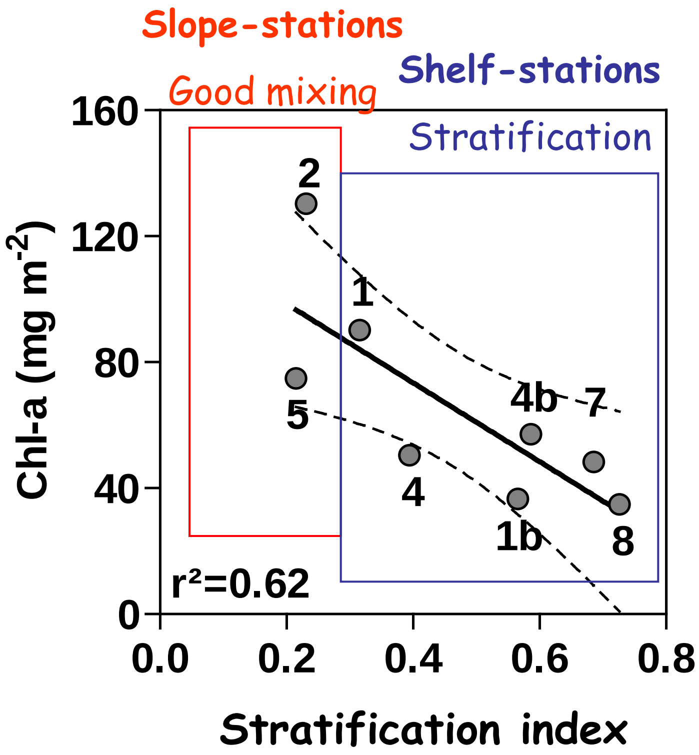
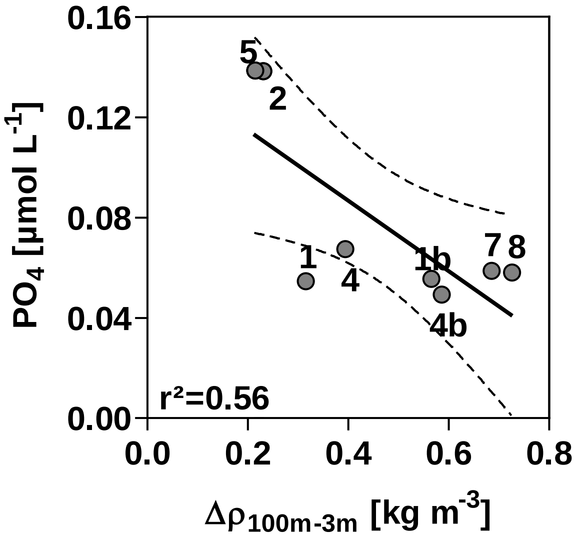


Higher index corresponds to more stratified conditions

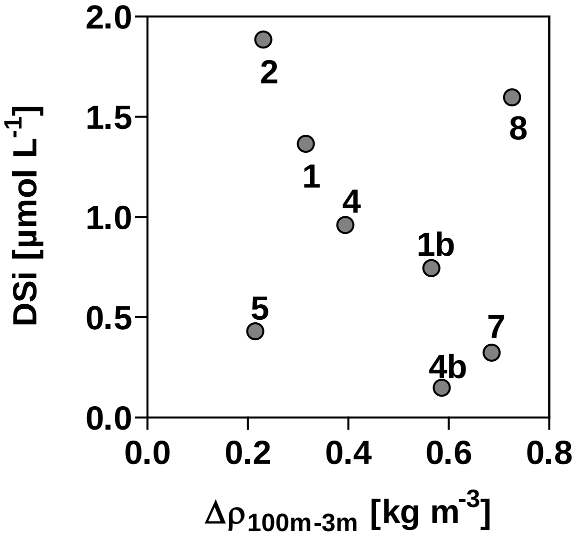
Example: Integrated Chl-a concentration



Pelagic: Results



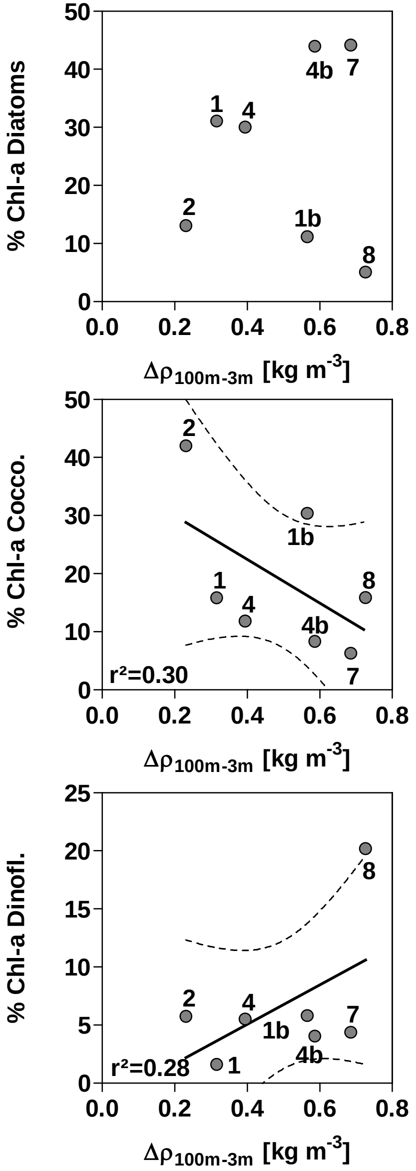
The availability of PO$_4$ decreased with increasing stratification.



DSi remained at limiting concentration for diatom's growth (< 2.0 µmol L^{-1})

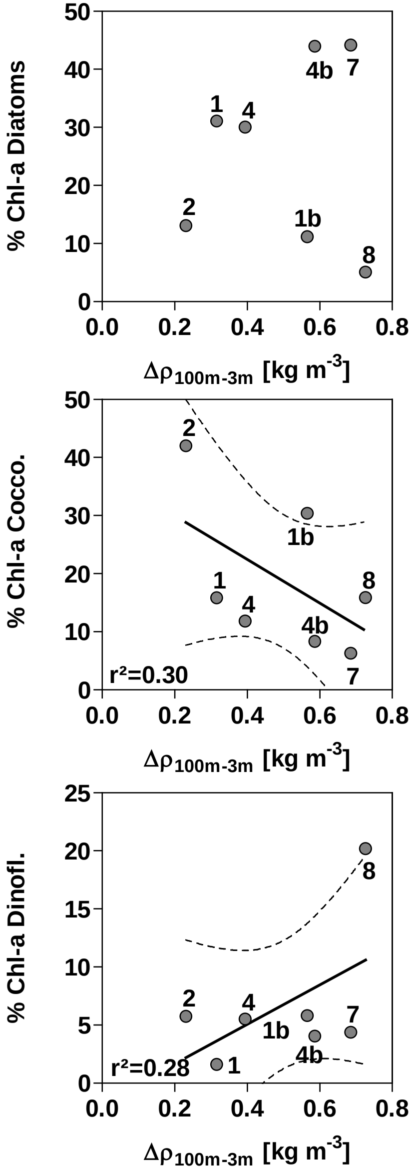
(Egge & Aksnes, 1992)

Pelagic: Results



The relative proportion of diatoms was unrelated to stratification

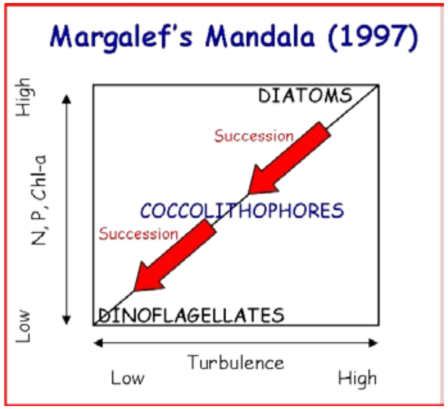
Pelagic: Results



The relative proportion of diatoms was unrelated to stratification

The relative proportion of coccolithophores decreased while dinoflagellates increased with stratification

Agreement with the Mandala



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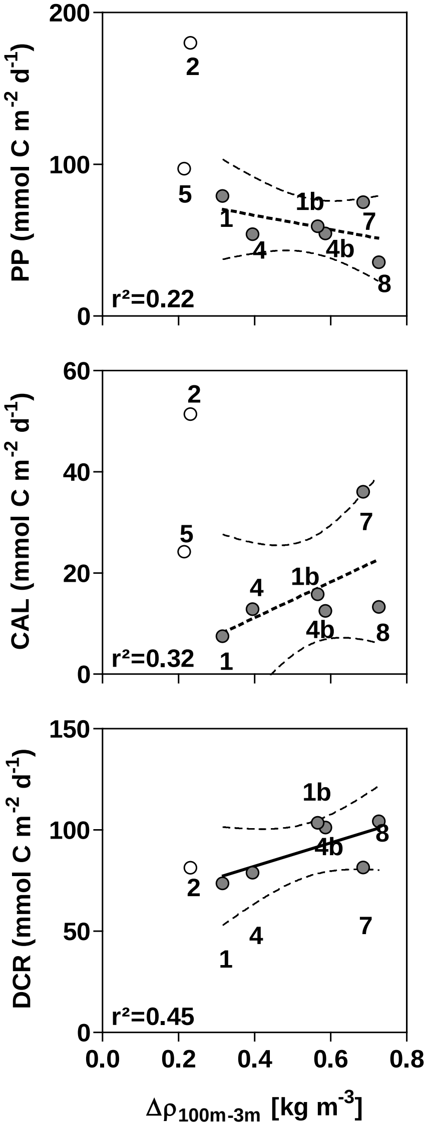

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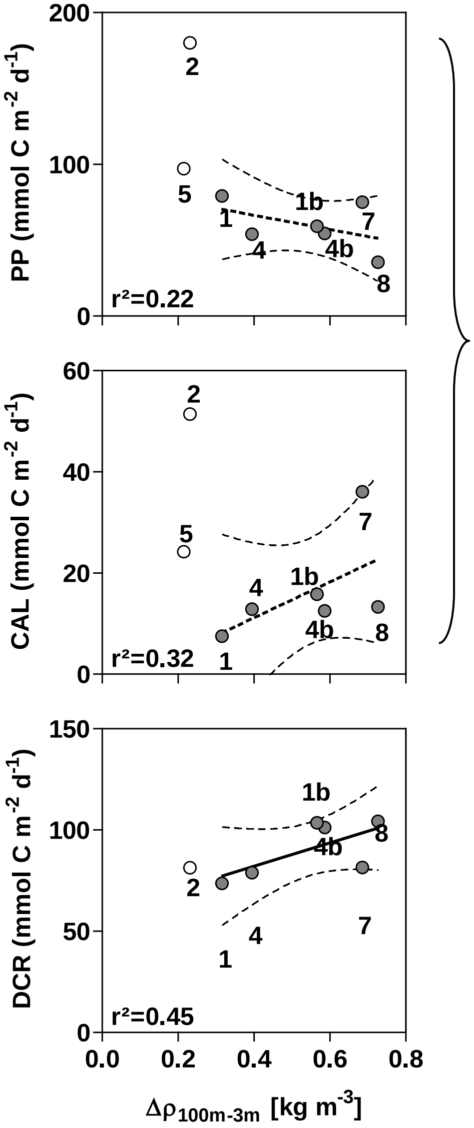
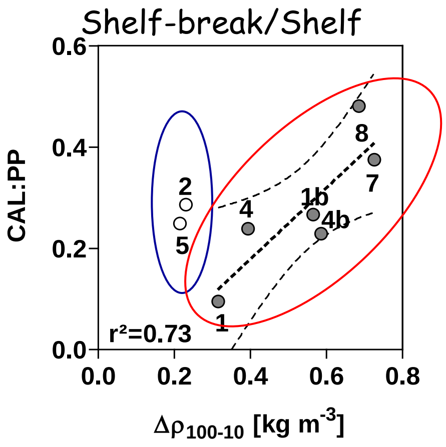
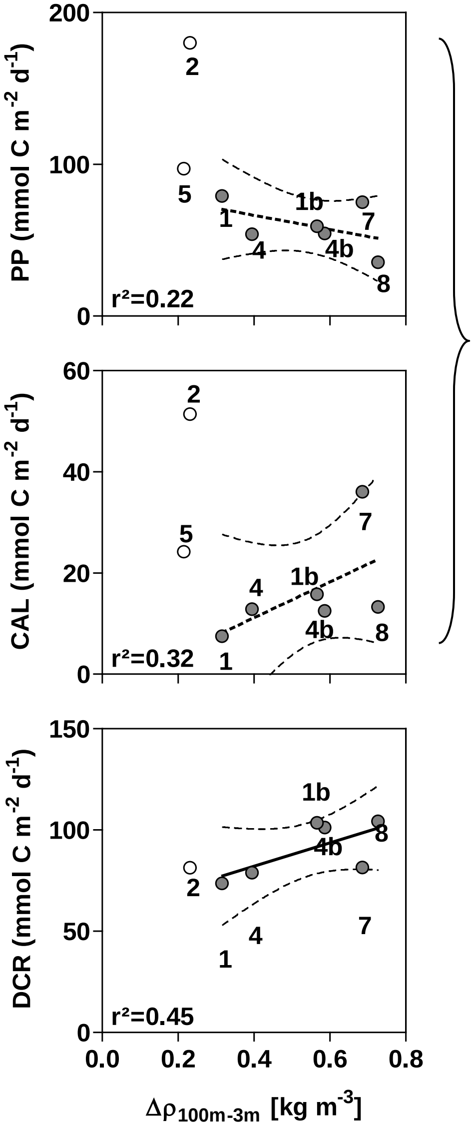
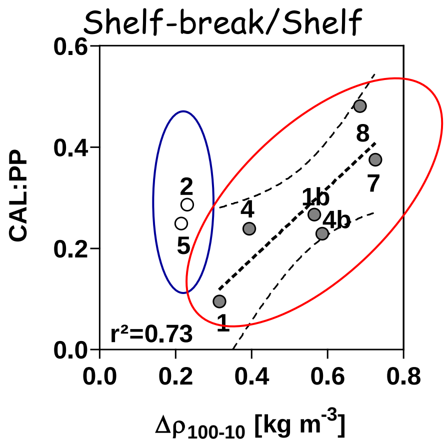


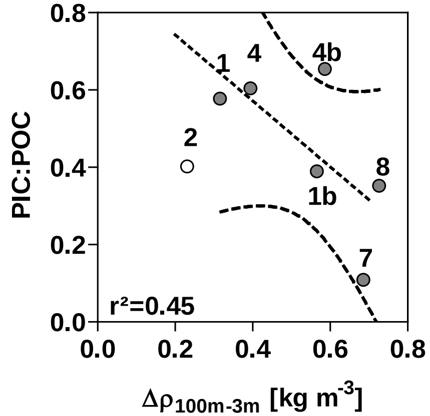


The CAL:PP ratio increases with increasing stratification over the shelf if one excludes the stations located on the slope

Pelagic: Results





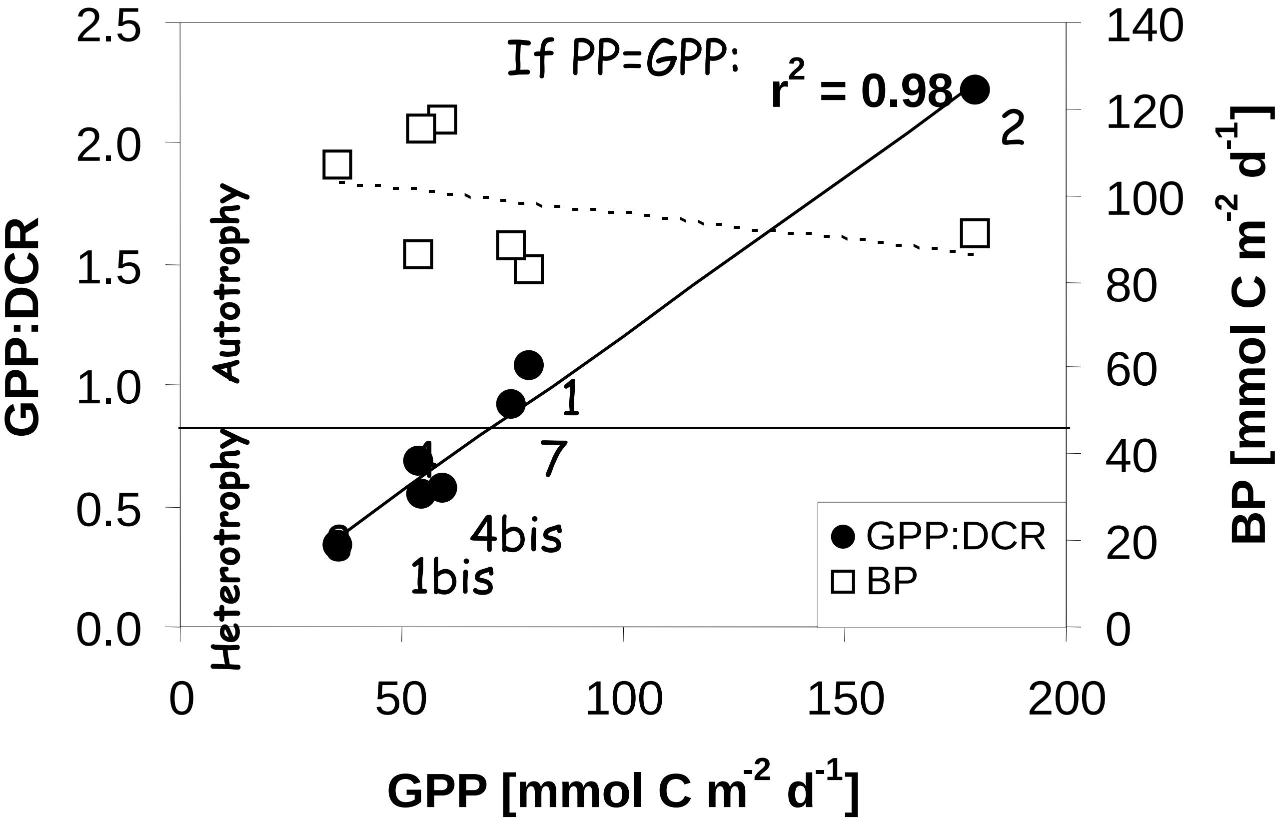


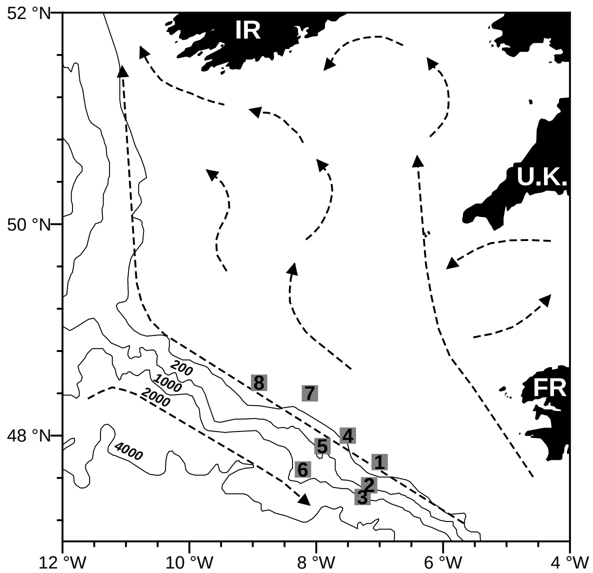
The CAL:PP ratio increases with increasing stratification over the shelf if one excludes the stations located on the shelf-break

An increase of the process ratio associated to a decrease of the standing-stock ratio would indicate the **export**

Pelagic: Results

Trophic status of the bloom (2006)





Pelagic: Synthesis

Stations	Rate measurements (mmol C m^{-2} d^{-1})			CO_2 fluxes (mmol CO_2 m^{-2} d^{-1})					C fluxes (mmol C m^{-2} d^{-1})	
	^{14}C prim. Prod. (PP)	^{14}C calcif. (CAL)	Resp. (DCR)	f_{PP}	f_{CAL}	f_{DCR}	Net CO_2 flux based on metabolic rates	Net CO_2 flux based on measured pCO_2	NCP	*Aphotic C demand*
2	180.0	51.4	81.3	-180.0	30.9	81.3	-67.9	-11.4	98.7	*89.0*
1	79.3	7.5	73.7	-79.3	4.5	73.7	-1.0	-17.8	5.5	*98.2*
7(HR)	75.1	36.1	81.4	-75.1	21.7	81.4	28.0	-10.2	-6.4	*35.1*
4(HR)	54.0	12.9	78.9	-54.0	7.8	78.9	32.6	-13.4	-24.9	*66.9*
1bis	59.2	15.8	103.5	-59.2	9.5	103.5	53.8	-16.1	-44.4	*159.0*
4bis(HR)	54.6	12.5	101.2	-54.6	7.5	101.2	54.1	-10.7	-46.6	*168.5*
8(HR)	35.5	13.3	104.3	-35.5	8.0	104.3	76.8	-8.5	-68.8	*72.3*

$$\psi = \frac{CO_2}{CaCO_3} = 0.7$$ **(Frankignoulle *et al.*, 1994)**

Net CO_2 flux = $f_{PP}+f_{CAL}+f_{DCR}$

O_2:C for Resp. = 1:1

NCP (net community production) = PP-DCR

Aphotic C demand = Respiration in the aphotic zone

<u>Our approach has some caveats</u>:

- Steady state is assumed

- No dissolved C production nor C-overconsumption products are included

Pelagic: Synthesis

					CO_2 fluxes						C fluxes	
	Station	date	Pelagic Calcification	PIC export	GPP rates	0.7*CAL CO^2 Flux	PCR	GPP:PCR	NC flux based on	Air-sea metabolic	NCP	Aphotic
Cruise 1 2006	2	1/06/2006	51	35	-180	36	93	1.9	-51	-12	87	118
	1	31/05/2006	8	15	-79	5	81	1.0	7	-13	-2	73
	7	7/06/2006	36	14	-75	25	89	0.8	40	-8	-14	41
	4	2/06/2006	13	10	-54	9	89	0.6	44	-10	-35	74
	1bis	9/06/2006	16	11	-59	11	121	0.5	73	-13	-62	177
	4bis	8/06/2006	13	10	-55	9	117	0.5	71	-9	-63	155
	8	6/06/2006	13	7	-36	9	116	0.3	90	-7	-80	42
	5	2/06/2006	24	19	-97	17				-7	-24	97
	Average	2006	22	15	-79	15	101	0.8	39	-10		
Cruise 2 2007	11	16/05/2007	65	-38	-198	45	78	2.5	-74	-15	120	136
	9	14/05/2007	44	26	-134	31	55	2.4	-48	-11	79	132
	2bis	24/05/2007	24	18	-96	17	62	1.5	-17	-6	34	122
	8	13/05/2007	82	23	-118	57	117	1.0	57	-12	0.2	102
	10	15/05/2007	118	11	-56	82	65	0.9	91	-14	-9	46
	4	23/05/2007	47	14	-72	33	85	0.8	46	-10	-13	107
	8bis	21/05/2007	59	11	-58	41	96	0.6	79	-14	-38	
	2	10/05/2007	140	10	-54	98	90	0.6	134	-6	-36	87
	5bis	22/05/2007	42	8	-42	30	88	0.5	76	-14	-46	90
	5	12/05/2007	10	6	-30	7	90	0.3	67	-14	-60	88
	7	23/05/2007	36	8	-41	25				-15	152	
	Average	2007	61	9	-82	42	83	1.1	41	-12	3	106
Cruise 3 2008	1	7/05/2008	26	30	-154	18	54	2.9	-82	-6	100	118
	9bis	21/05/2008	67	14	-75	47	68	1.1	39	-8	8	77
	12	18/05/2008	15	8	-43	10	46	0.9	13	-8	-3	81
	6	9/05/2008	14	7	-36	10	39	0.9	13	-3	-3	84
	8	11/05/2008	21	11	-55	15	62	0.9	22	-8	-7	51
	5bis	22/05/2008	17	14	-72	12	86	0.8	27	-7	-15	73
	11	14/05/2008	5	7	-38	4	51	0.7	17	-9	-13	52
	13	20/05/2008	24	11	-57	17	87	0.7	46	-9	-30	142
	10	13/05/2008	10	9	-45	7	85	0.5	47	-9	-40	63
	5	10/05/2008	6	5	-26	4	76	0.3	54	-8	-50	61
	9	12/05/2008	31	8	-41	22	174	0.2	155	-10	-134	60
	2	8/05/2008	2	3	-16	1	122	0.1	107	-8	-106	158
	4	23/05/2008	10	9	-48	7				-6		
	Average	2008	19	10	-54	13	79	0.8	38	-8	-24	85
	3 year	average	34 ± 32	11 ± 11	-70 ± 44	24 ± 22	86 ± 28	0.9 ± 0.7	39 ± 56	-10 ± 3	-15 ± 57	95 ± 39

Average values (2006-2008)

- GPP = 70 ± 44 mmolC/m²/d
- Cal = 34 ± 32 mmol/m²/d
- Pelagic respiration = 95 ± 39 mmolC/m²/d

Benthic results

Core incubations:

Characteristic of bottom waters:

- Low temperature (10.5-11°C)
- O_2% ~85% -> oxygenated waters
- Ω_{CAL} 3.5
- NO_3^-: 3.9-11 µmol/L
- DSi: 1.4-4.7 µmol/L
- Chl-a: 0.03-0.58 µg/L
- SPM: 0.2-1.5 mg/L
- POC: 14-97 µgC/L
- PIC: 5-72 µgC/L

Characteristics of surface sediments:

- Visual aspect: recent phytoplankton deposition
- Fine to coarse sandy sediments (median grain size: 190-285 µm)
- Chl-a content: 0.01-0.95 µgChl-a/g
- Low %OM: 1.4-4.0%
- %PIC: 1.5-9.5% (mainly bivalve debris)

Benthic: Results

Core incubations:

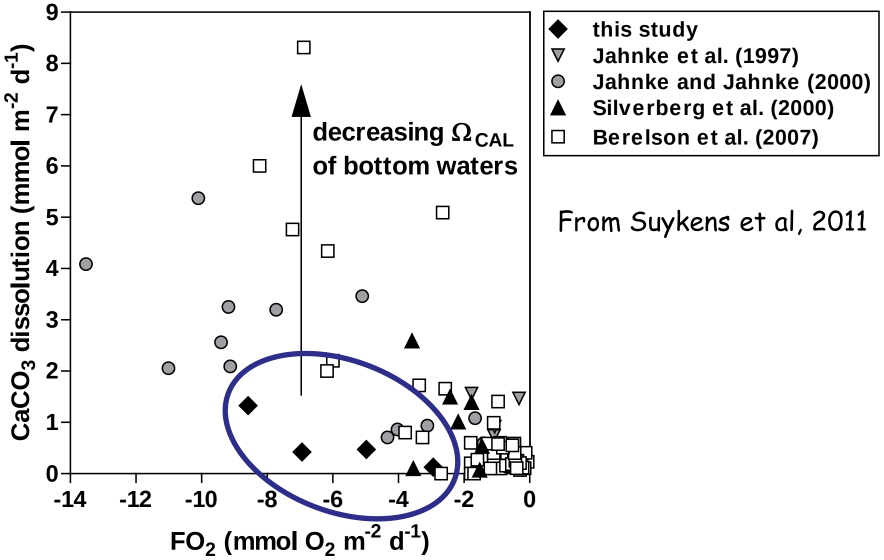
FO_2: -2.4 to -8.4 mmol/m²/d

FTA*: -1.1 to +3.7 mmol/m²/d
negative values = noise

Average Dissolution rates:

- FTA*/2= 0.33 mmol $CaCO_3$/m²/d)

Low $CaCO_3$ dissolution rates compared to other studies (e.g.) due to high saturation state Ω_{CAL} 3.5 in the Bay of Biscay

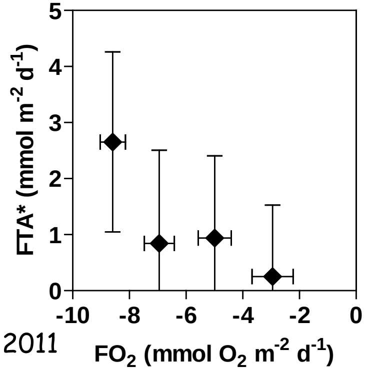


From Suykens et al, 2011

Average $CaCO_3$ dissolution to OC oxidation ratio:

- -FTA*/(2xFO_2)= 0.06 ± 0.09

metabolic driven dissolution of $CaCO_3$ in sediments underlying bottom waters highly over-saturated with respect to $CaCO_3$ (Jahnke and Jahnke, 2004)



From Suykens et al, 2011

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Synthesis

Average $CaCO_3$ Dissolution rate = 0.33 ± 0.47 mmol/m^2/d

~1% of the Pelagic Calcification (34 ± 32 mmol/m^2/d)

Average Benthic respiration: -5.5 ± 1.5 mmol O_2 /m^2/ d

~8% of the Pelagic Primary production (70 ± 44 mmolC/m^2/d)

~6% of the Pelagic respiration in the aphotic zone (95 ± 39 mmolC/m^2/d)

Correlation between FTA and FO_2 => metabolic driven $CaCO_3$ dissolution in the sediments

Conclusions

Bentho-pelagic coupling:

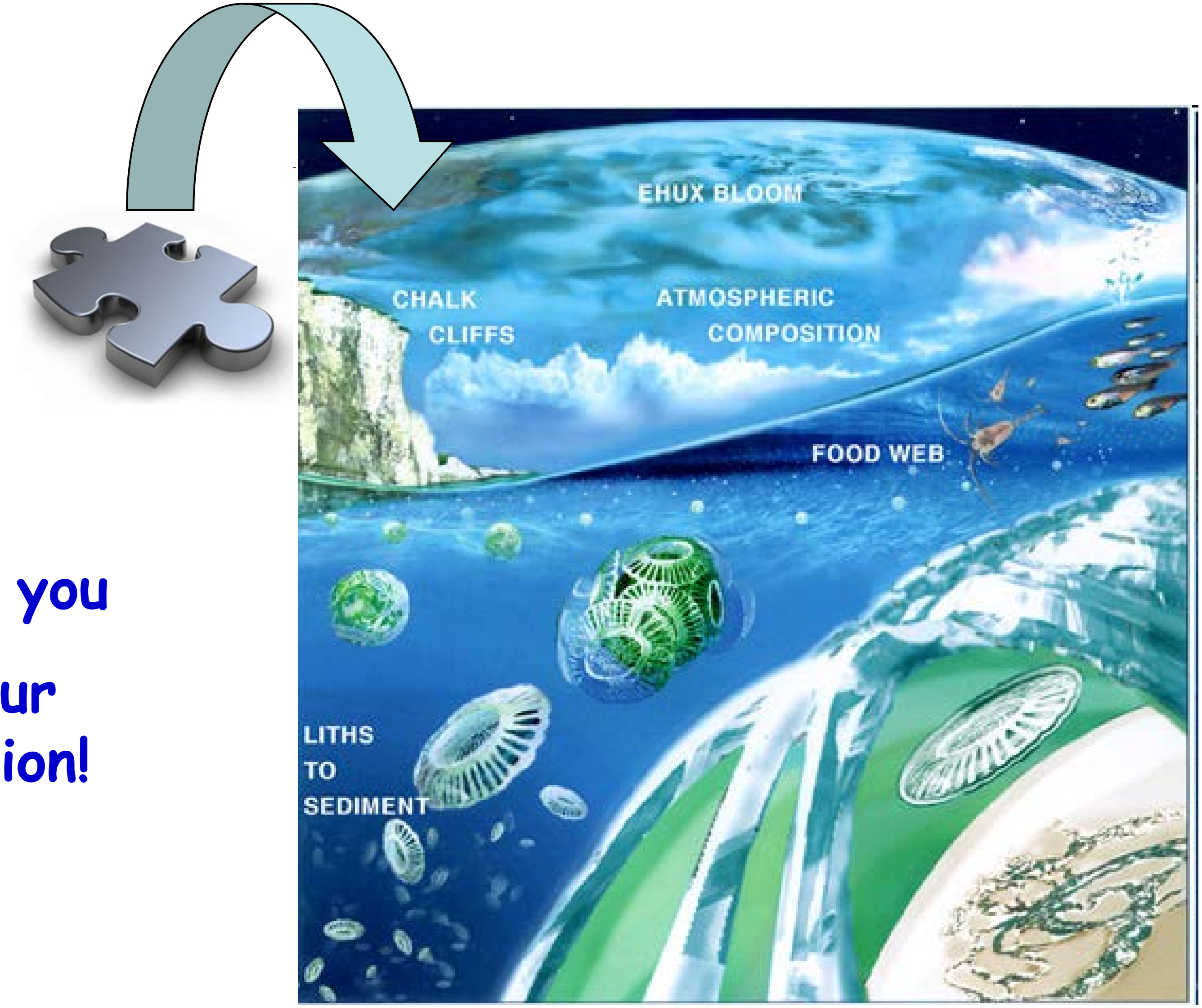
- $CaCO_3$ dissolution:
  - is a **metabolic process** that occurs in waters over-saturated with respect to calcite and
  - is driven by OM respiration in the sediment

  (in contrast to biogenic silica dissolution that is a thermodynamic process)

- $CaCO_3$ dissolution and benthic respiration are low compared to surface productions

Evidence of a decoupling of calcification by coccolithophores and the dissolution of $CaCO_3$ in the sediments.
PIC produced by coccolithophores is either:

- stored in the sediments or
- exported out of the system (advection)
- but does not seem to be significantly dissolved in the sediments.



Jess & Glynn Gorick

Thank you

for your attention!