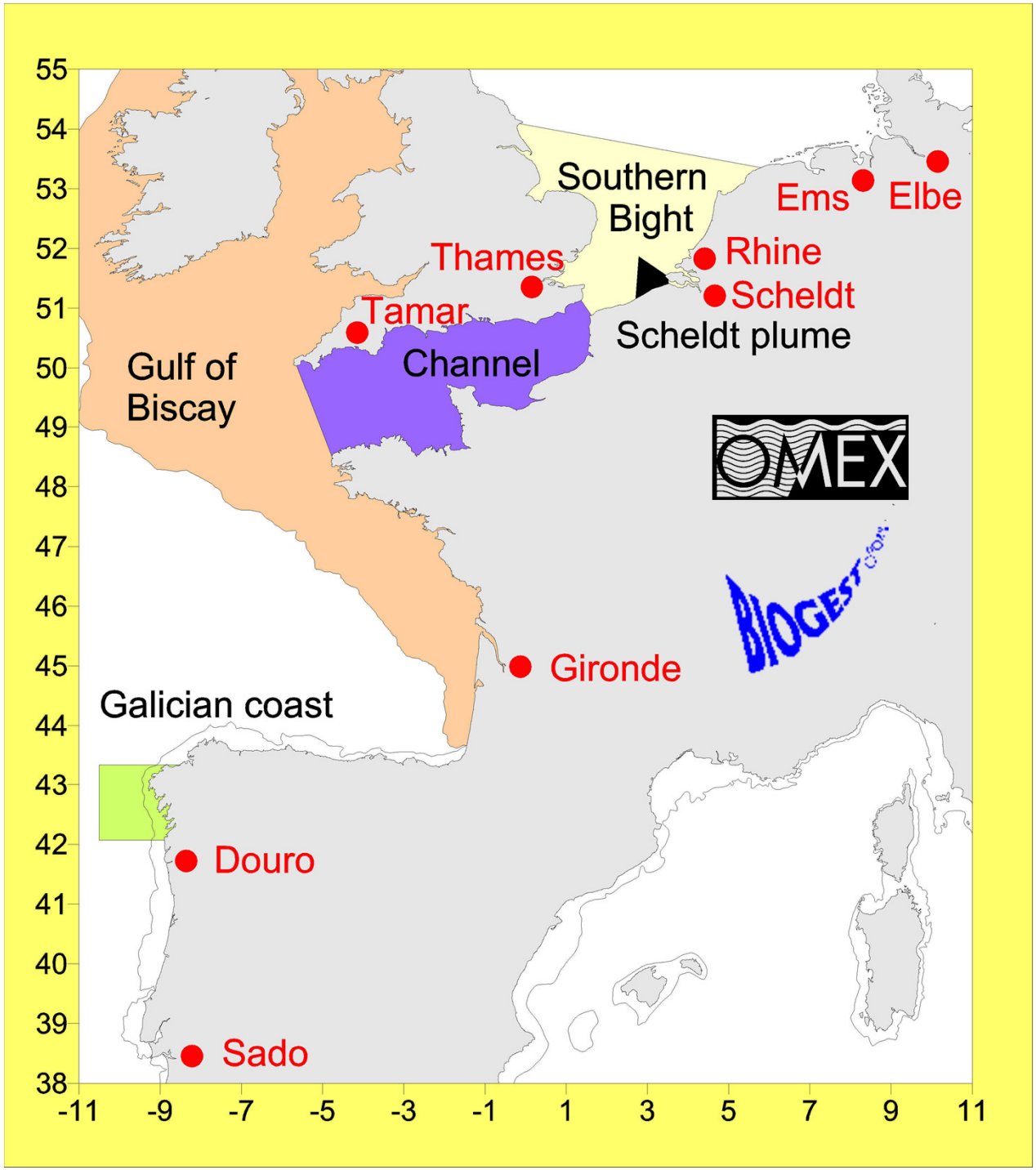
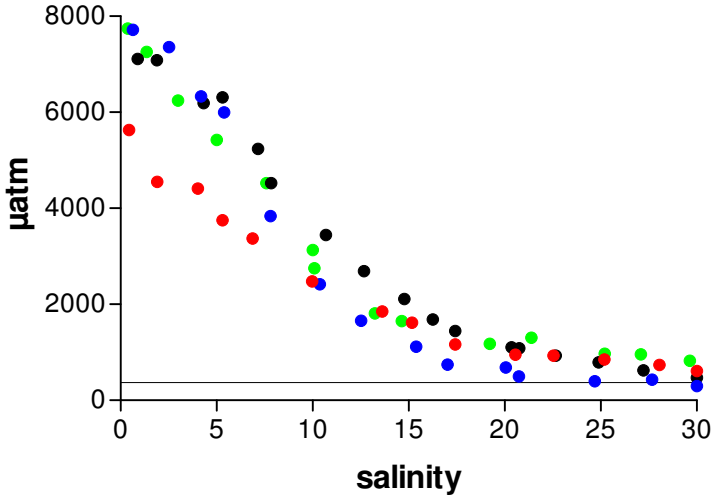
Atmospheric CO_2 exchanges over the European Continental Shelf

Alberto Borges & Michel Frankignoulle

University of Liège
Chemical Oceanography Unit
http://www.ulg.ac.be/oceanbio/co2

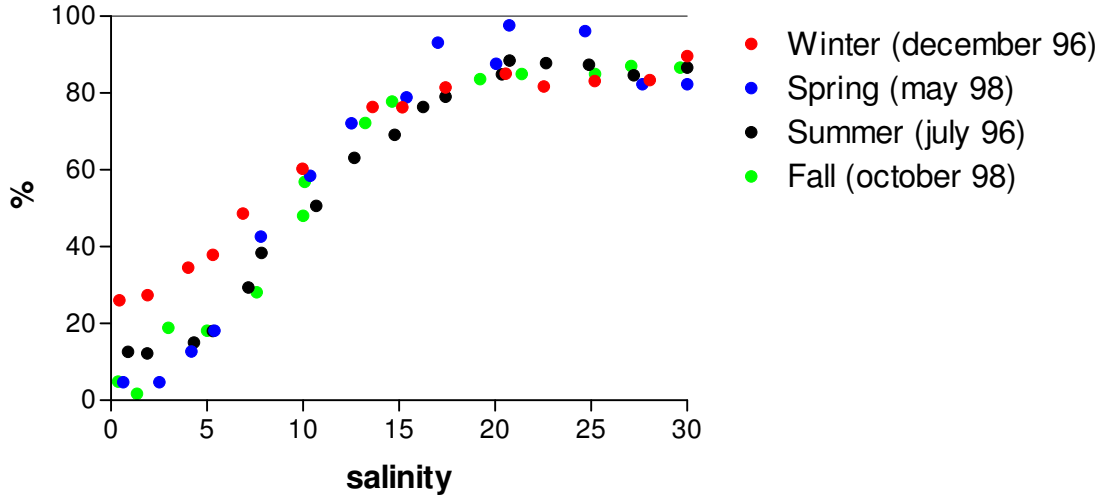

55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
39
38
-11
-9
-7
-5
-3
-1
1
3
5
7
9
11
Southern Bight
Ems
Elbe
Rhine
Thames
Scheldt
Tamar
Scheldt plume
Channel
Gulf of Biscay
OMEX
BIOGEST
Gironde
Galician coast
Douro
Sado

pCO_2 in the Scheldt estuary Biogest cruises

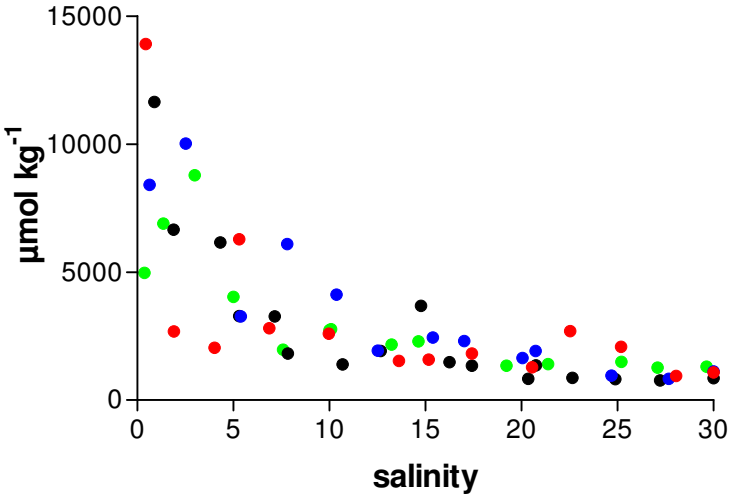


- Winter (december 96)
- Spring (may 98)
- Summer (july 96)
- Fall (october 98)

O_2 saturation level in the Scheldt estuary Biogest cruises

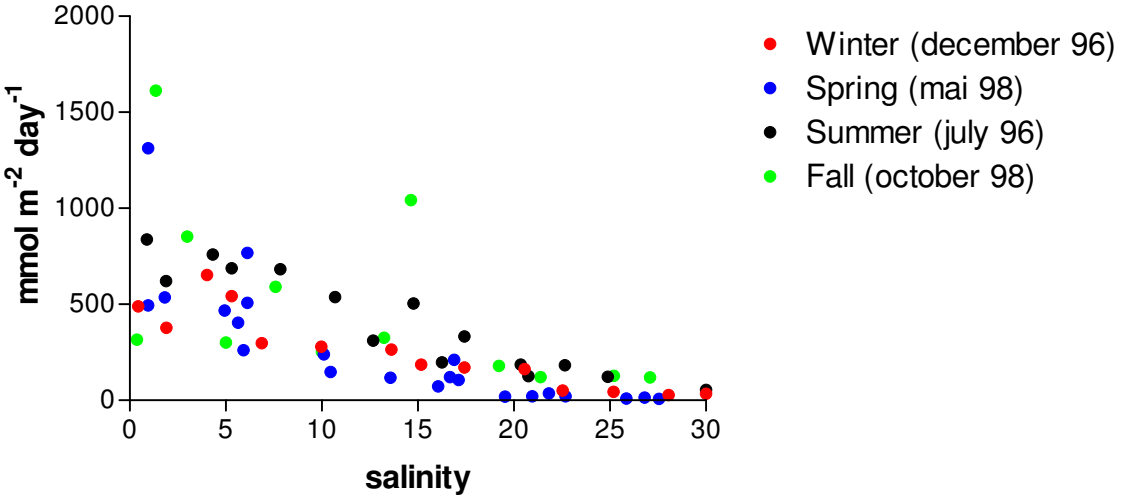


Total organic carbon in the Scheldt estuary Biogest cruises

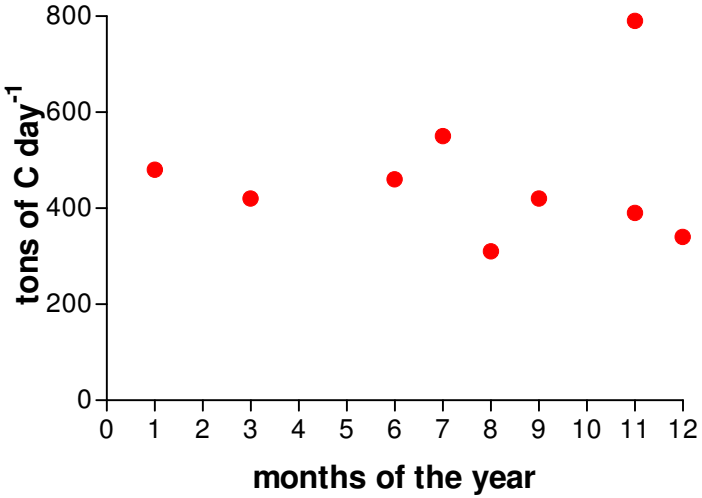


- Winter (december 96)
- Spring (may 98)
- Summer (july 96)
- Fall (october 98)

CO_2 atmospheric fluxes in the Scheldt estuary Biogest cruises

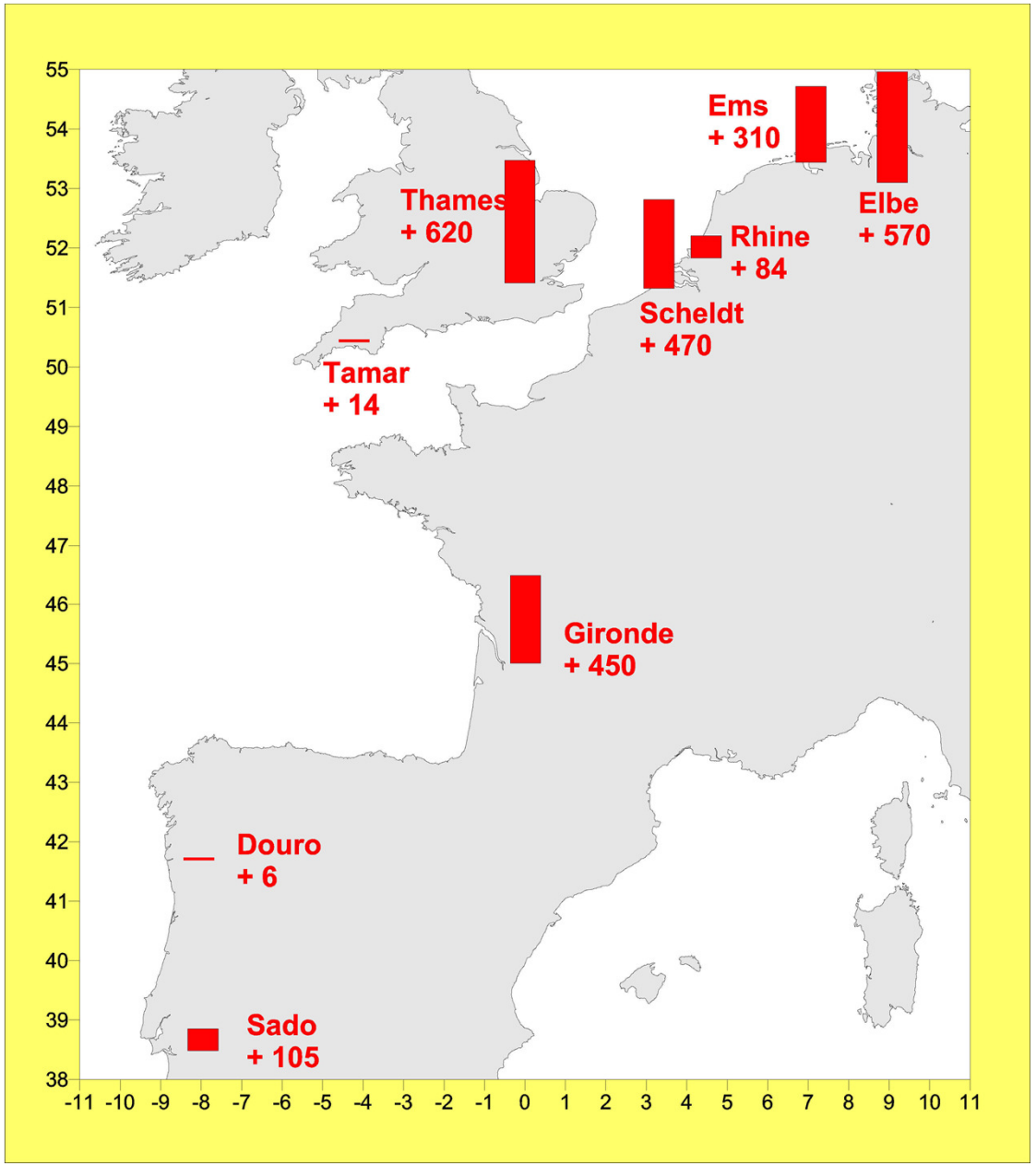


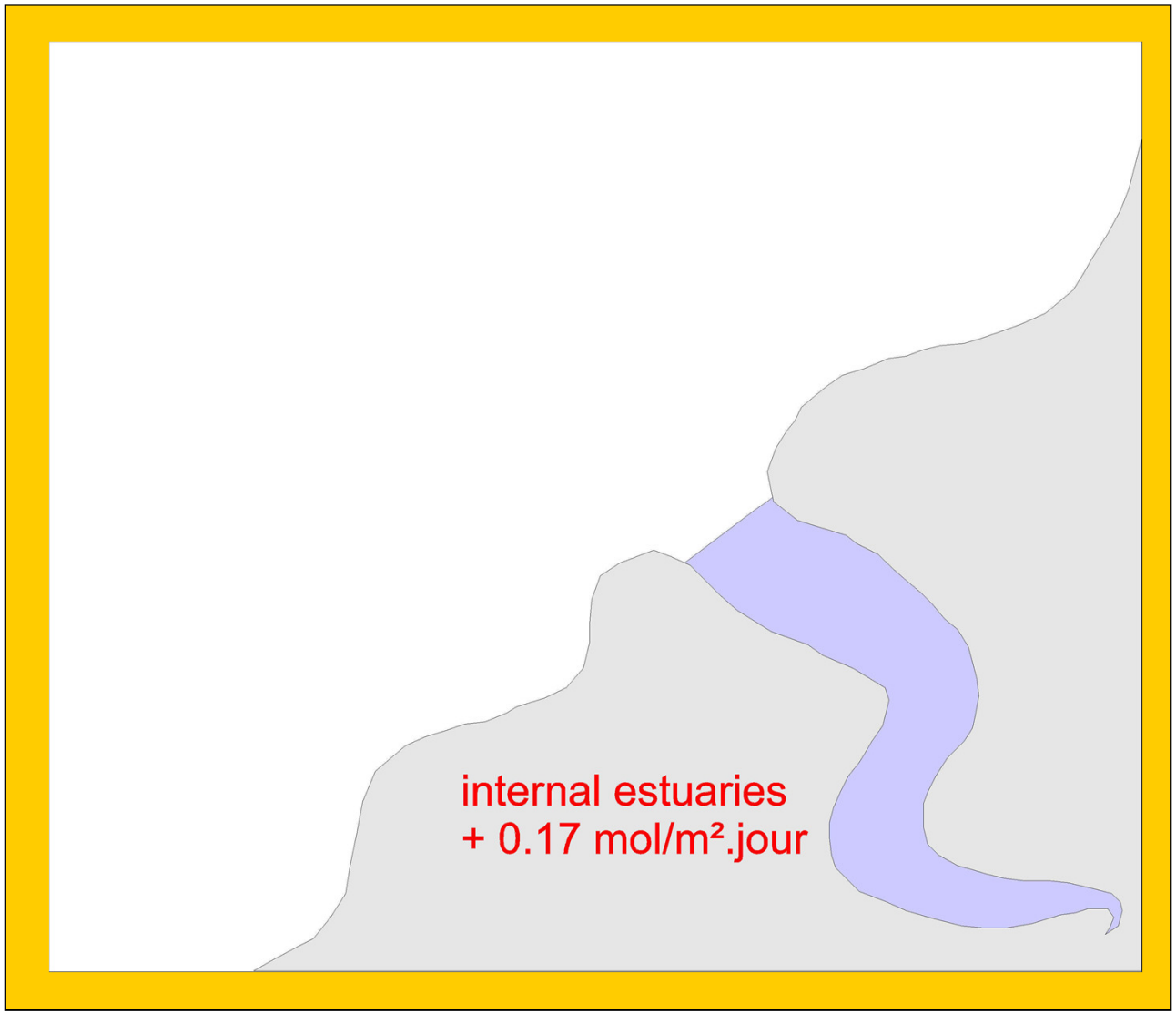
net emission of CO_2
from the Scheldt estuary
historical data-set

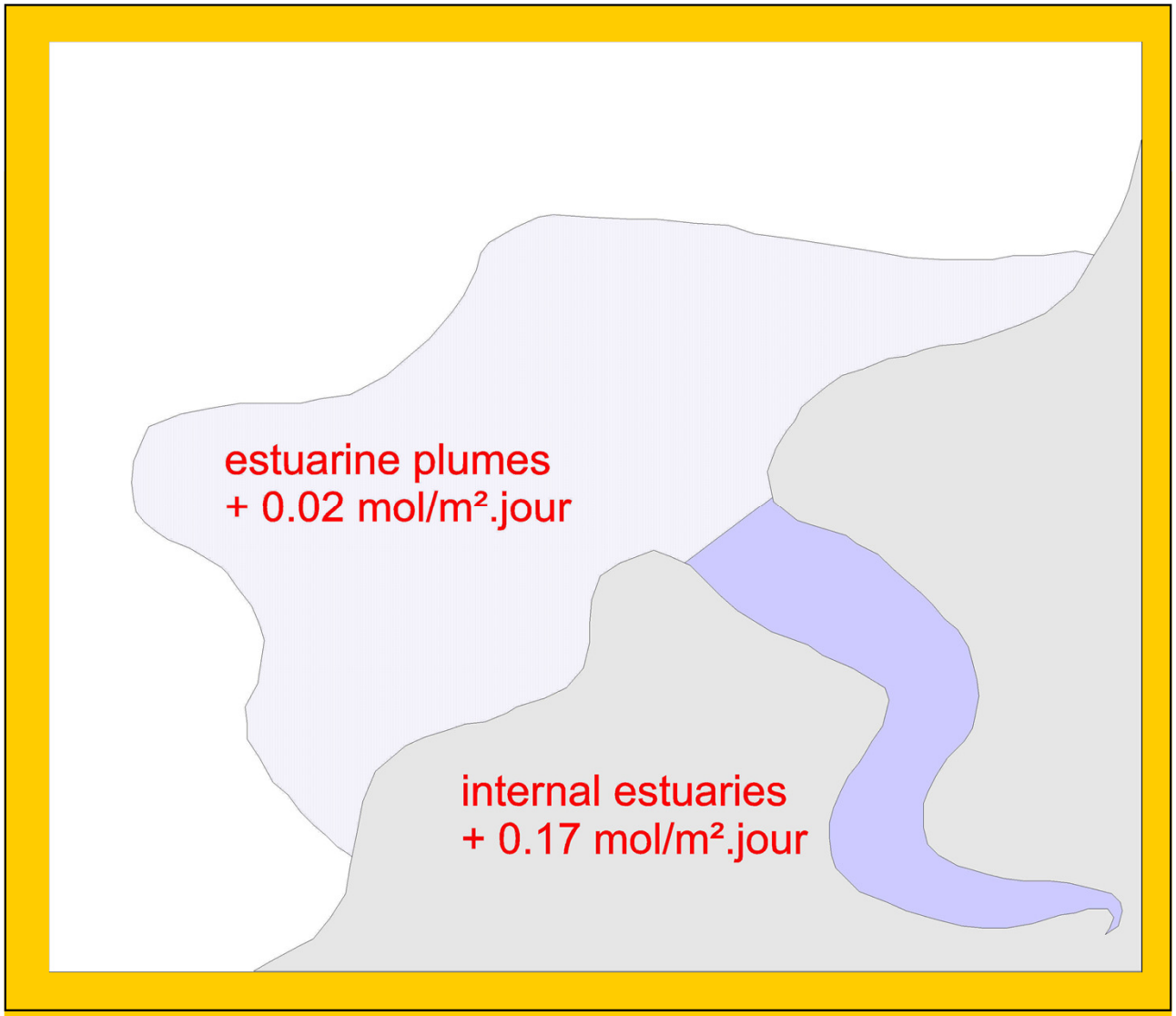


470 tons of C per day

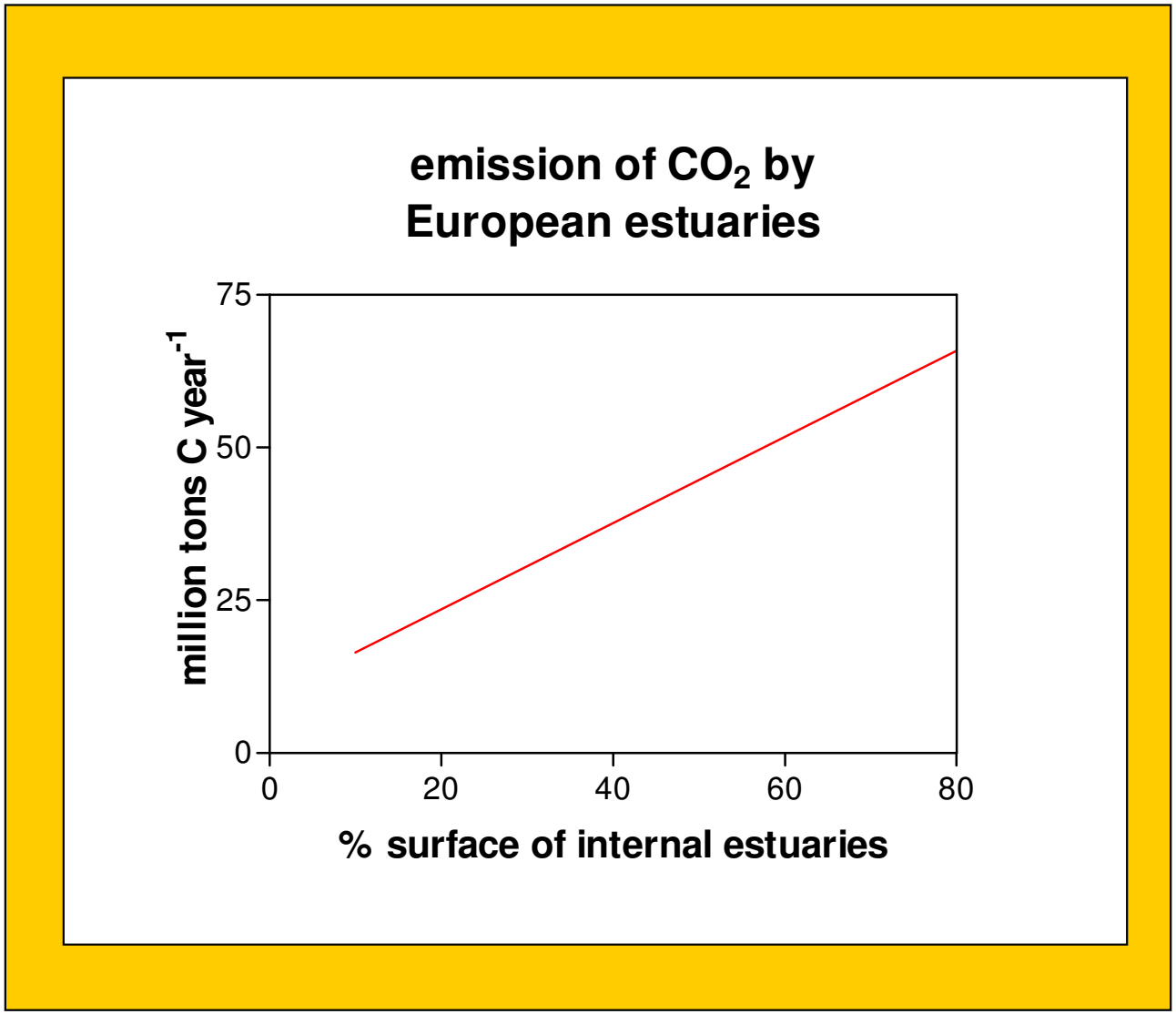
CO_2 emission by the Biogest estuaries
tons of C per day

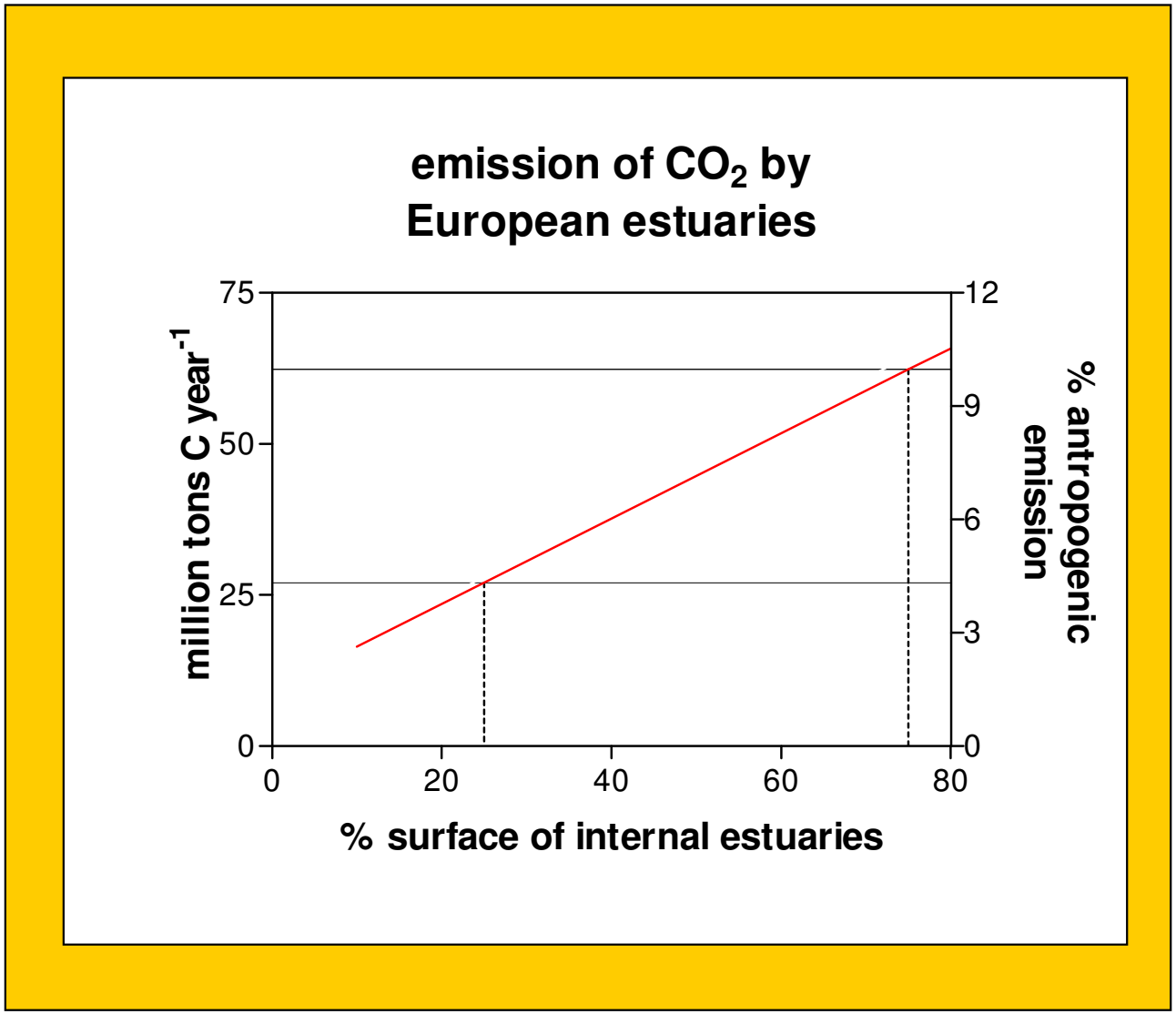


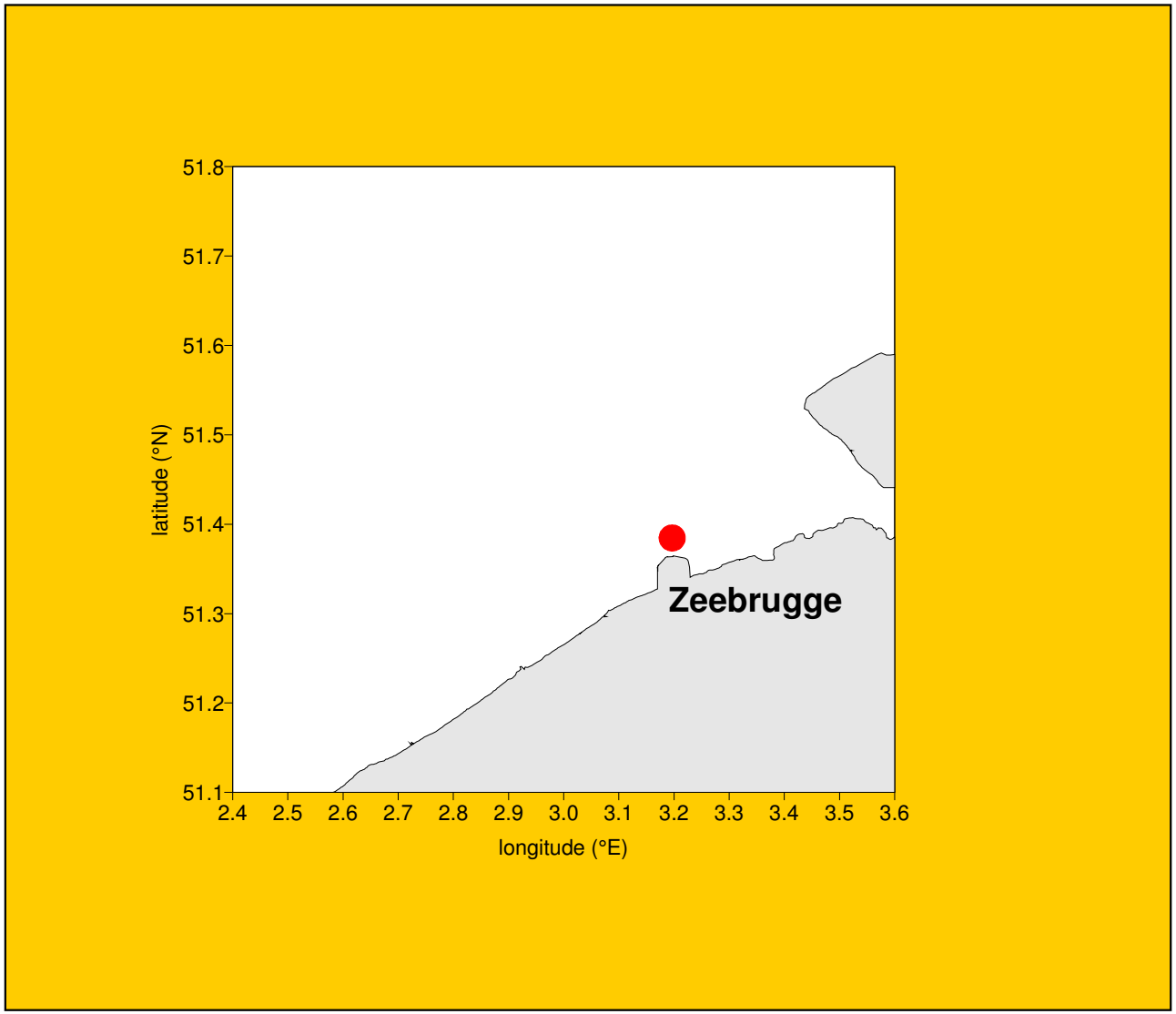

internal estuaries
+ 0.17 mol/m².jour

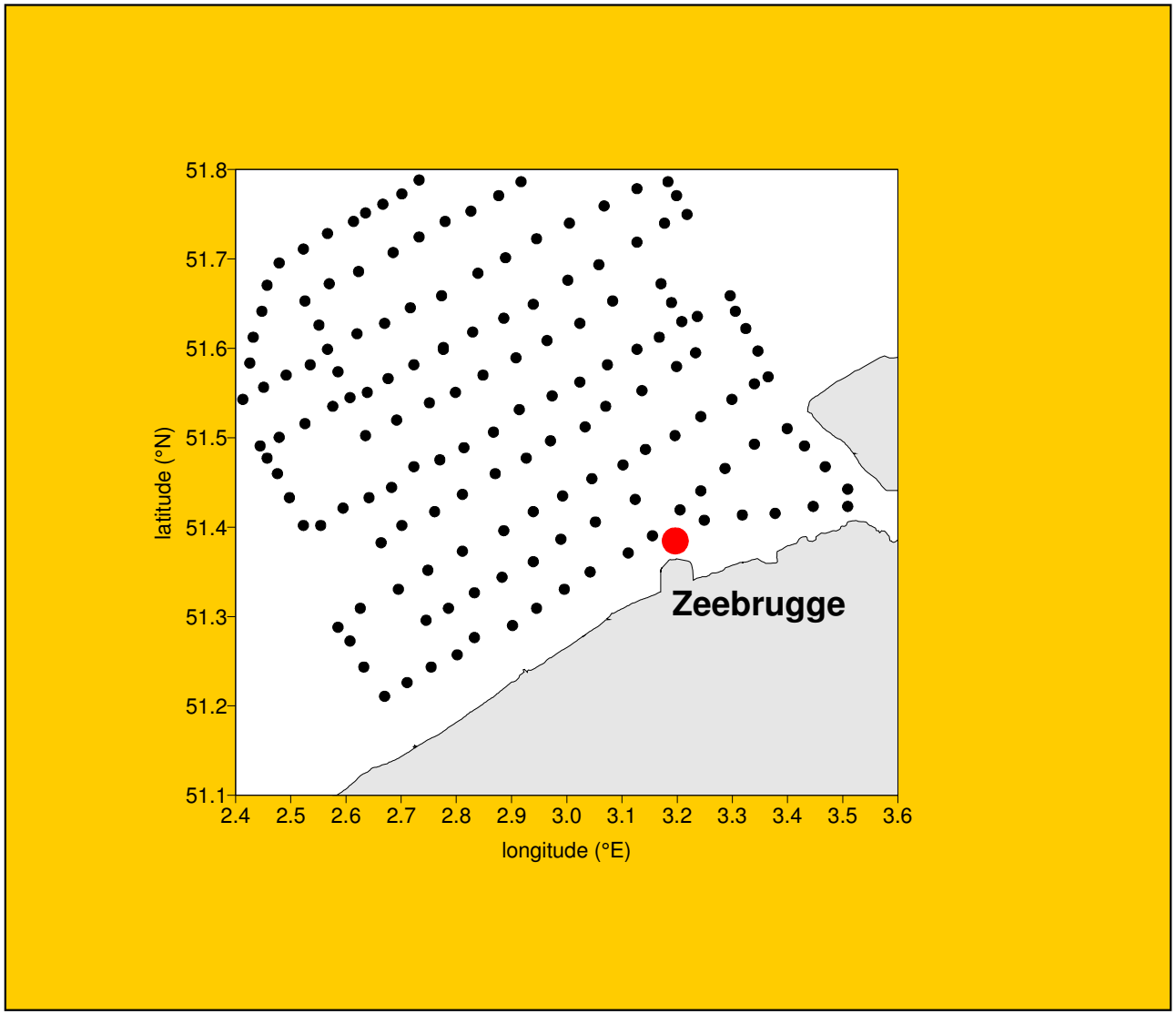


Surface area in Europe of salinity < 34
111 200 km²

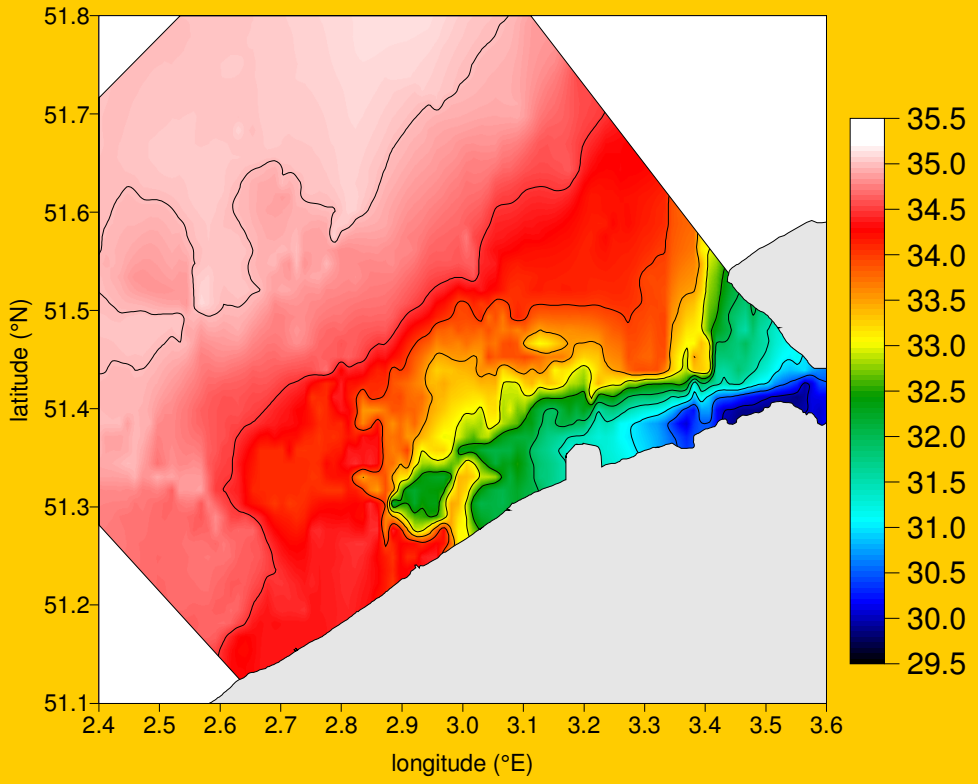

emission of CO_2 by
European estuaries
million tons C year^{-1}
75
50
25
0
0
20
40
60
80
% surface of internal estuaries


emission of CO_2 by
European estuaries
75
50
25
0
million tons C year^{-1}
12
9
6
3
0
% antropogenic
emission
0
20
40
60
80
% surface of internal estuaries

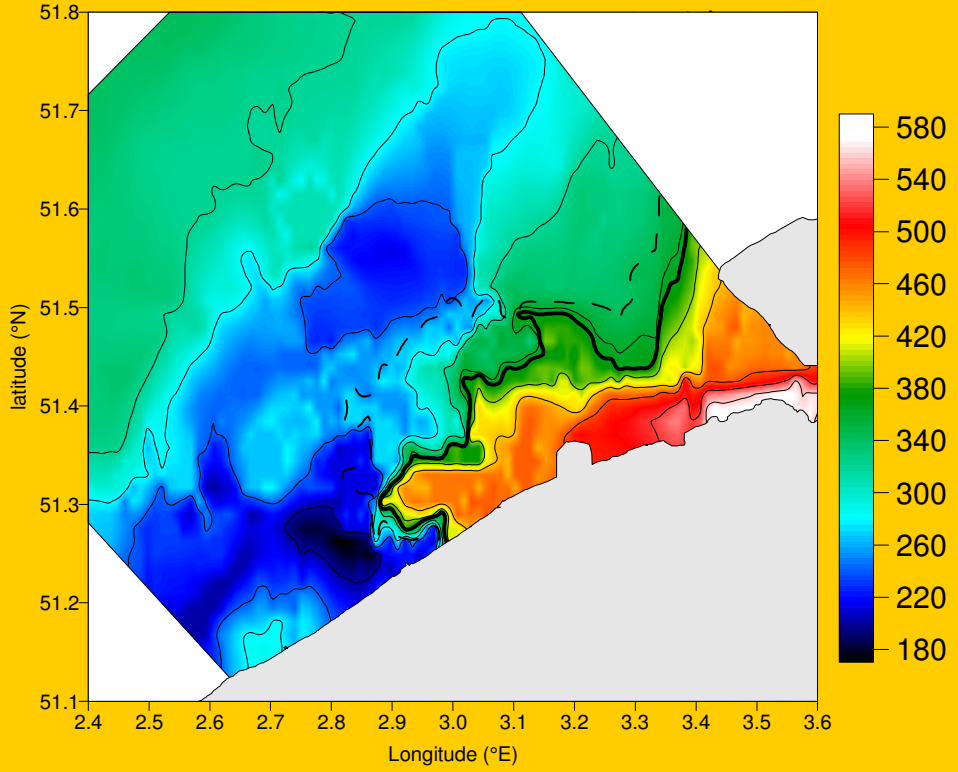

51.8
51.7
51.6
51.5
51.4
51.3
51.2
51.1
latitude (°N)
2.4
2.5
2.6
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
longitude (°E)
Zeebrugge

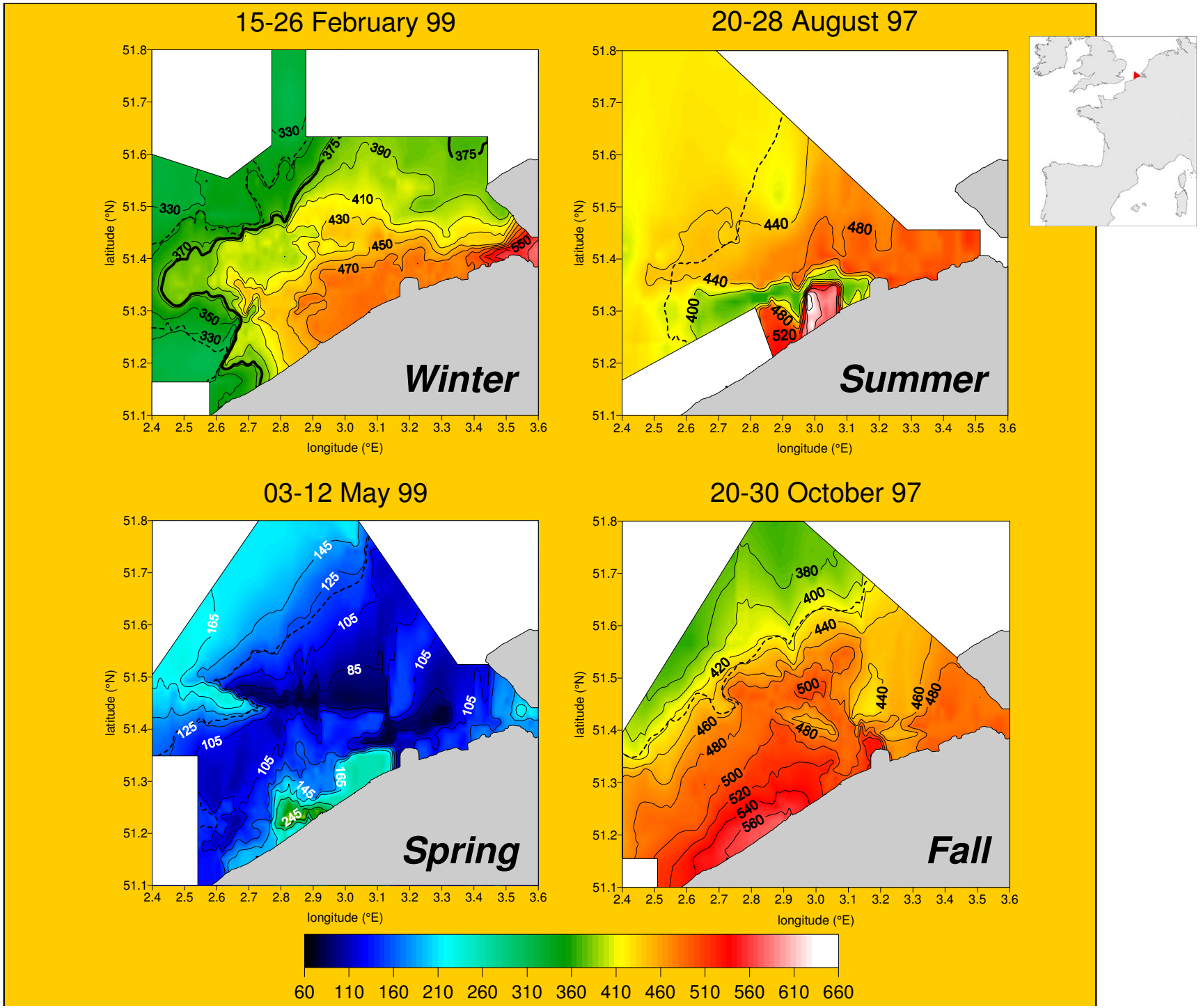

51.8
51.7
51.6
51.5
51.4
51.3
51.2
51.1
latitude (°N)
2.4
2.5
2.6
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
longitude (°E)
Zeebrugge

Salinity 10-21 march 97

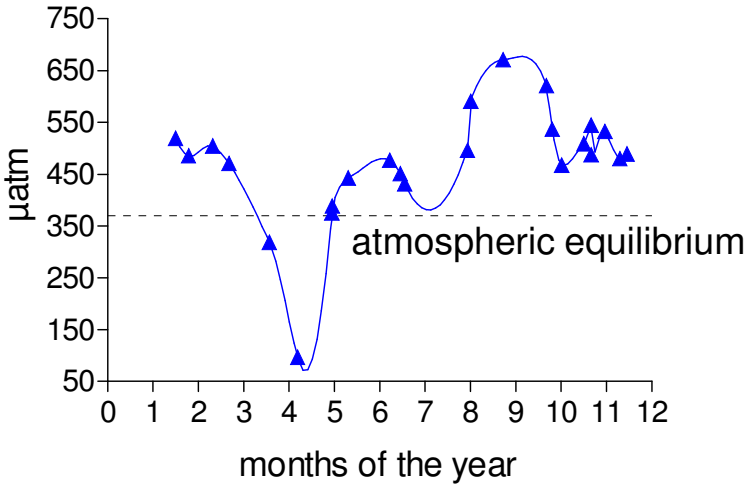


Partial pressure of CO_2 (pCO_2)
10-21 march 97

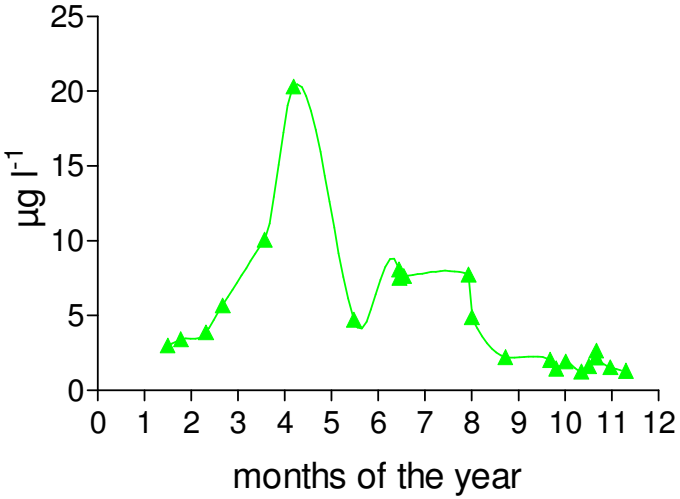



15-26 February 99
20-28 August 97
03-12 May 99
20-30 October 97
Winter
Summer
Spring
Fall
latitude (°N)
longitude (°E)
51.8
51.7
51.6
51.5
51.4
51.3
51.2
51.1
2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5 3.6
330 375 390 375 410 430 450 470 550 330 370 350 330
440 480 440 400 480 520
145 125 105 165 105 85 105 105 125 105 105 165 145 245
380 400 440 420 500 440 460 480 460 480 500 520 540 560
60 110 160 210 260 310 360 410 460 510 560 610 660

pCO_2
Zeebrugge Station



chlorophyll a



Annually integrated flux: + 4.5 mmol m^{-2} day^{-1} **(exchange coeff. Wanninkhof 1992)**

Annually integrated flux:	+ 4.5 mmol m^{-2} day^{-1} **(exchange coeff. Wanninkhof 1992)**
Surface of the Scheldt plume:	2100 km^2
Annual emission of CO_2:	112 tC day^{-1}

Annually integrated flux: + 4.5 mmol m^{-2} day^{-1} **(exchange coeff. Wanninkhof 1992)**

Surface of the Scheldt plume: 2100 km^2

Annual emission of CO_2: 112 tC day^{-1} = **26%**

Of the inner Scheldt estuary characterised by:

Flux = + 173 mmol m^{-2} day^{-1} = 456 tC day^{-1}
Surface = 220 km^2

<u>Provisional</u> C budget for the Scheldt plume (tC day^{-1})

Inputs

CO_2 from the Scheldt	34[a]
Organic C from the Scheldt	16[b] - 52[c]
Organic C from the coast	47[c]

Outputs

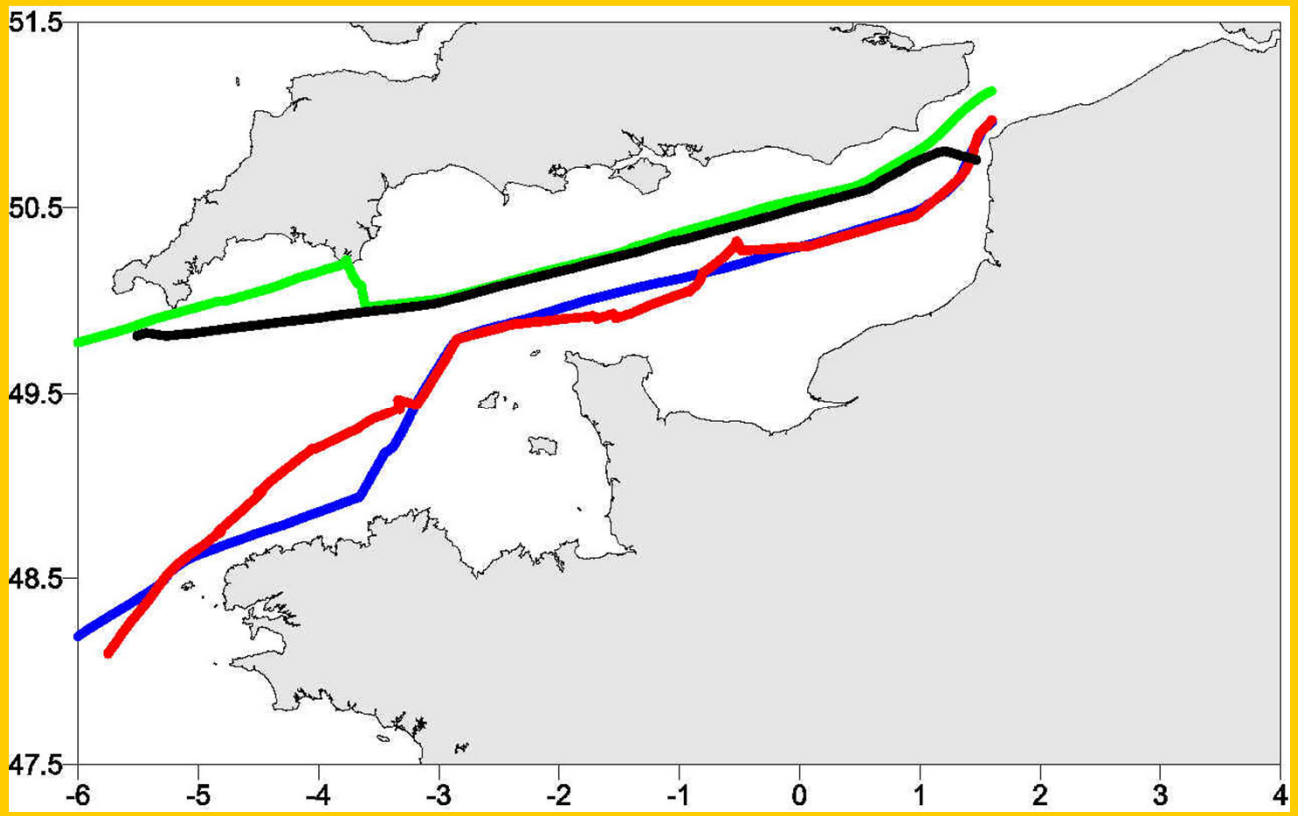
Organic carbon preservation in sediments	62[c]
CO_2 emission	112[a]

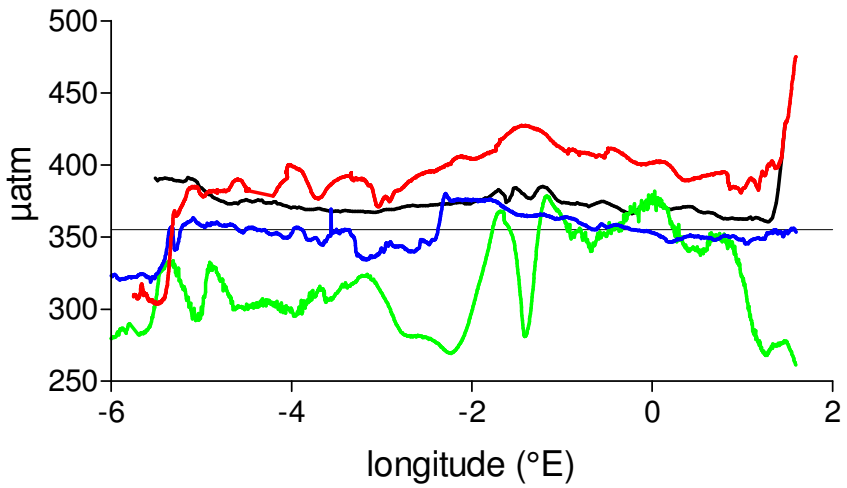
Sum

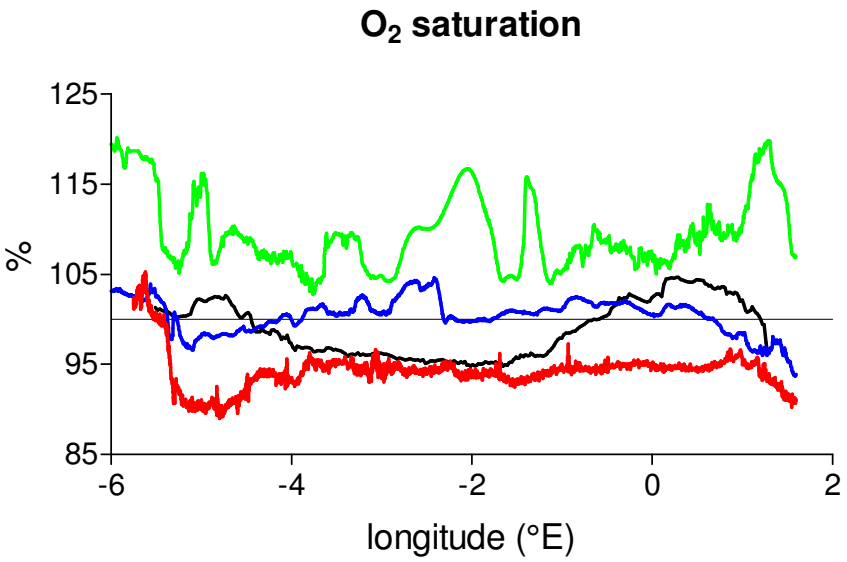
97 - 133	175

[a] Borges & Frankignoulle (2002)
[b] Soetaert & Herman (1995)
[c] Wollast (1976; 1983)

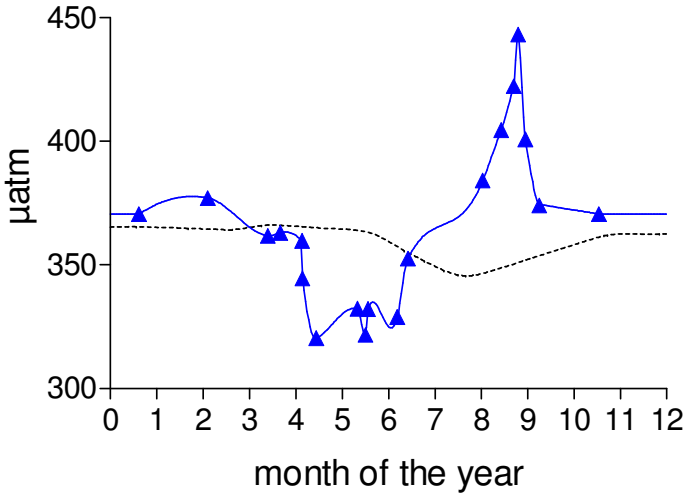
English Channel



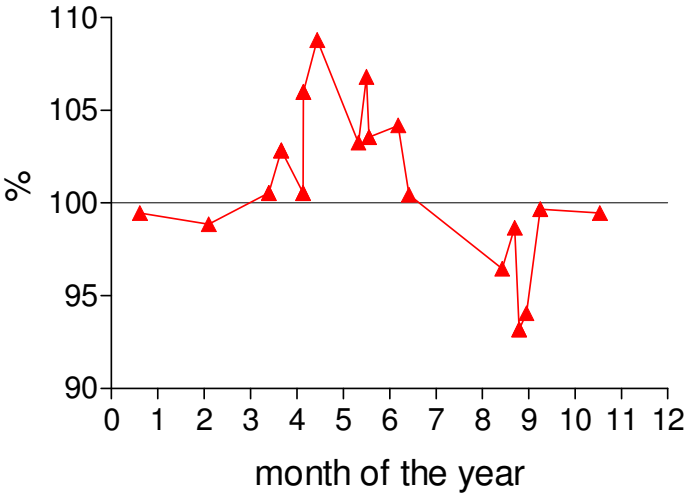

pCO2
English Channel
500
450
400
350
300
250
µatm
-6
-4
-2
0
2
longitude (°E)
Winter (March 95)
Summer (July 98)
Spring (May 97)
Fall (September 95)


O2 saturation
125
115
105
95
85
%
-6
-4
-2
0
2
longitude (°E)

pCO_2
English Channel (1993-1999)



O_2 saturation



Annually integrated $\int pCO_2 \approx 0$

Annually integrated $\Delta pCO_2 \approx 0$

Annually integrated CO_2 air-sea flux ≈ 0

Annually integrated ◑pCO_2 ≈ 0

Annually integrated CO_2 air-sea flux ≈ 0

Why?

Annually integrated $\Delta pCO_2 \approx 0$

Annually integrated CO_2 air-sea flux ≈ 0

Why?

New primary production = 1.0 mmolC m^{-2} day^{-1}
(^{15}N incubations from L'Helguen et al. (1996))

Annually integrated $\Delta pCO_2 \approx 0$

Annually integrated CO_2 air-sea flux ≈ 0

Why?

New primary production = 1.0 mmolC m^{-2} day^{-1}
(^{15}N incubations from L'Helguen et al. (1996))

9 mmolC m^{-2} day^{-1}	**Continental shelf average**
5 mmolC m^{-2} day^{-1}	**Southern Bight of the North Sea**
7 mmolC m^{-2} day^{-1}	**Gulf of Biscay**

Annually integrated $\Delta pCO_2 \approx 0$

Annually integrated CO_2 air-sea flux ≈ 0

Why?

New primary production = 1.0 mmolC m^{-2} day^{-1}
(^{15}N incubations from L'Helguen et al. (1996))

9 mmolC m^{-2} day^{-1}	**Continental shelf average**
5 mmolC m^{-2} day^{-1}	**Southern Bight of the North Sea**
7 mmolC m^{-2} day^{-1}	**Gulf of Biscay**

Benthic calcification in Eastern Channel = 19 mmol$CaCO_3$ m^{-2} day^{-1}
(Migné et al. 1998)

Annually integrated $\Delta pCO_2 \approx 0$

Annually integrated CO_2 air-sea flux ≈ 0

Why?

New primary production = 1.0 mmolC m^{-2} day^{-1}
(^{15}N incubations from L'Helguen et al. (1996))

9 mmolC m^{-2} day^{-1}	**Continental shelf average**
5 mmolC m^{-2} day^{-1}	**Southern Bight of the North Sea**
7 mmolC m^{-2} day^{-1}	**Gulf of Biscay**

Benthic calcification in Eastern Channel = 19 mmol$CaCO_3$ m^{-2} day^{-1}
(Migné et al. 1998)

Release of CO_2 = +13 mmolC m^{-2} day^{-1}

Area 5400 km^2

Annually integrated $\Delta pCO_2 \approx 0$

Annually integrated CO_2 air-sea flux ≈ 0

Why?

New primary production = 1.0 mmolC m^{-2} day^{-1}
(^{15}N incubations from L'Helguen et al. (1996))

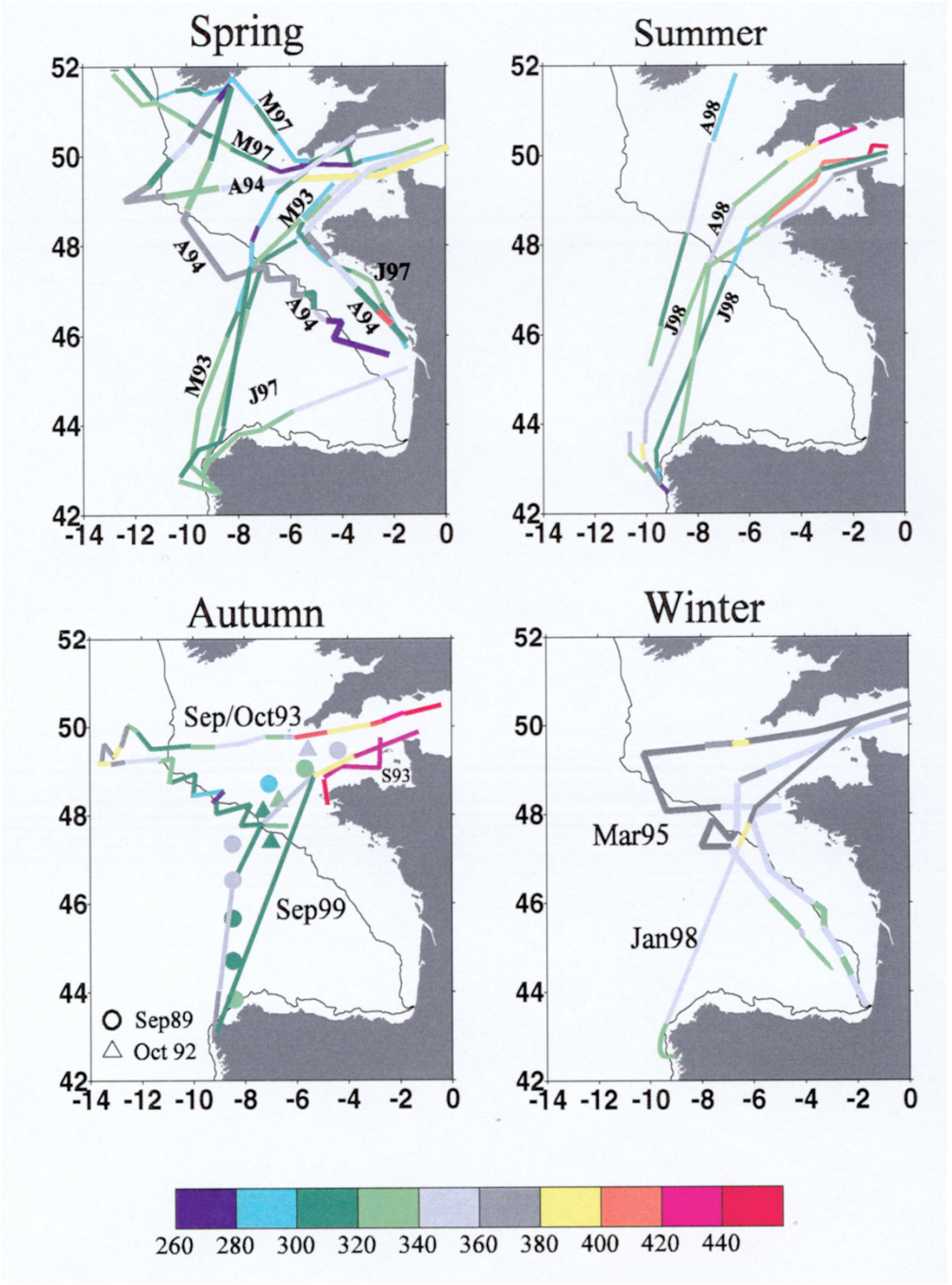
9 mmolC m^{-2} day^{-1}	**Continental shelf average**
5 mmolC m^{-2} day^{-1}	**Southern Bight of the North Sea**
7 mmolC m^{-2} day^{-1}	**Gulf of Biscay**

Benthic calcification in Eastern Channel = 19 mmol$CaCO_3$ m^{-2} day^{-1}
(Migné et al. 1998)

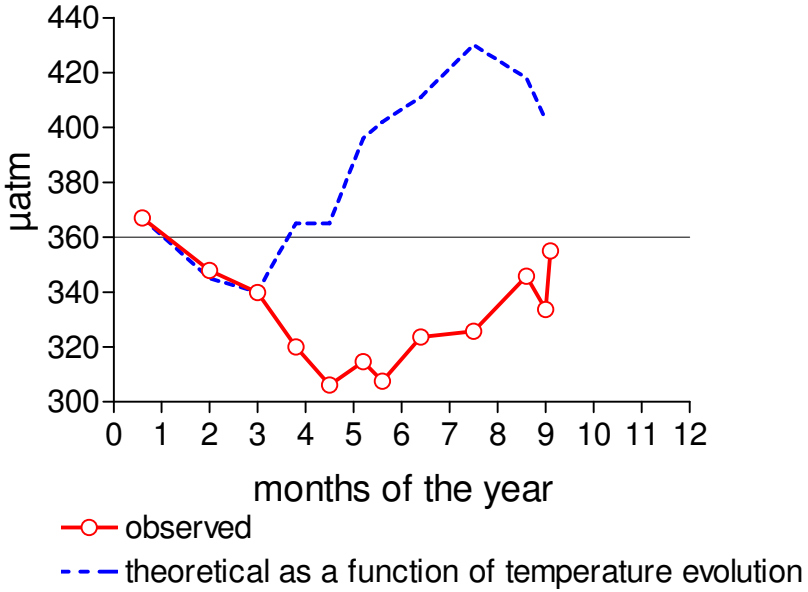
Release of CO_2 = +13 mmolC m^{-2} day^{-1}

Area 5400 km^2

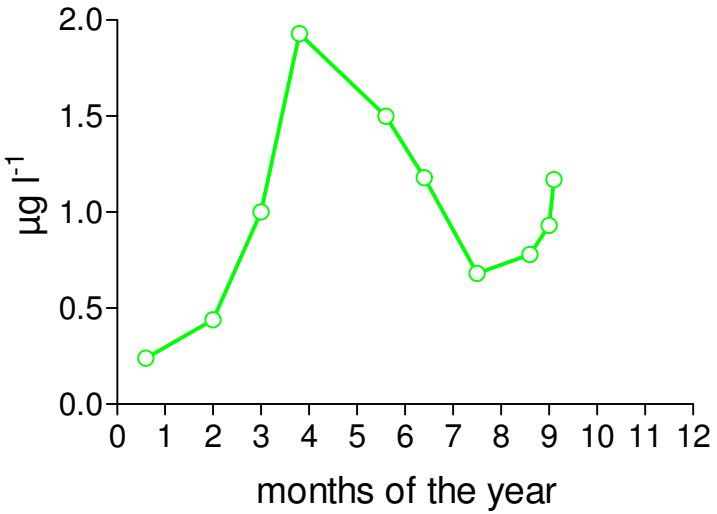
Whole of Channel
Release of CO_2 = +0.9 mmolC m^{-2} day^{-1}


Spring
Summer
Autumn
Winter
M97
M97
A94
M93
A94
J97
A94
A94
M93
J97
A98
A98
J98
J98
Sep/Oct93
S93
Sep99
Sep89
Oct 92
Mar95
Jan98
52
50
48
46
44
42
-14 -12 -10 -8 -6 -4 -2 0
260 280 300 320 340 360 380 400 420 440

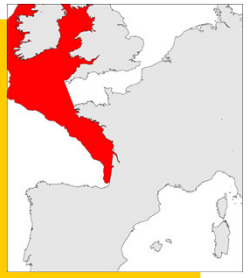
pCO_2
Gulf of Biscay



Chlorophyll a

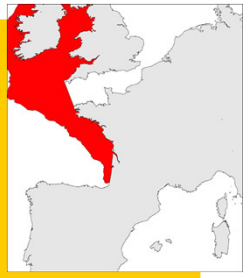


Air-sea exchange of CO_2 integrated annually in the Gulf of Biscay:



Wanninkhof (1992) **- 7.9 mmol m^{-2} day^{-1}**

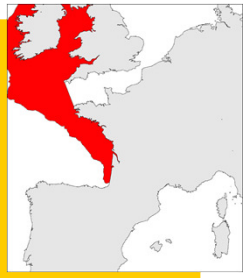
Air-sea exchange of CO_2 integrated annually in the Gulf of Biscay:



Wanninkhof (1992) **- 7.9 mmol m^{-2} day^{-1}** **=** **0.17 GtC $year^{-1}$**

Extrapolation to the overall European continental shelf (5 million km^2)

Air-sea exchange of CO_2 integrated annually in the Gulf of Biscay:



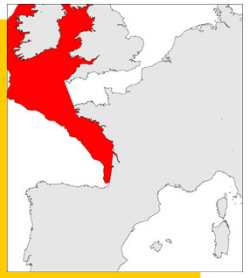
Wanninkhof (1992) **- 7.9 mmol m^{-2} day^{-1}** **=** **0.17 GtC $year^{-1}$**

Extrapolation to the overall European continental shelf (5 million km^2)

North Atlantic Ocean (42° to 78°N):

Wanninkhof (1992) **=** **0.34 GtC $year^{-1}$** **(Sarmiento *et al.* 1995)**

Air-sea exchange of CO_2 integrated annually in the Gulf of Biscay:



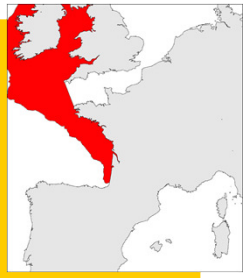
Wanninkhof (1992) **- 7.9 mmol m^{-2} day^{-1}** **=** **0.17 GtC $year^{-1}$**

Extrapolation to the overall European continental shelf (5 million km^2)

North Atlantic Ocean (42° to 78°N):

Wanninkhof (1992) **=** **0.34 GtC $year^{-1}$** **(Sarmiento *et al.* 1995)**

European Continental shelf is an additional CO_2 sink of 50%



Air-sea exchange of CO_2 integrated annually in the Gulf of Biscay:

Wanninkhof (1992) **- 7.9 mmol m^{-2} day^{-1}** **=** **0.17 GtC $year^{-1}$**

Extrapolation to the overall European continental shelf (5 million km^2)

North Atlantic Ocean (42° to 78°N):

Wanninkhof (1992) **=** **0.34 GtC $year^{-1}$** **(Sarmiento *et al.* 1995)**

European Continental shelf is an additional CO_2 sink of 50%

East China Sea (Wang *et al.* 2000):

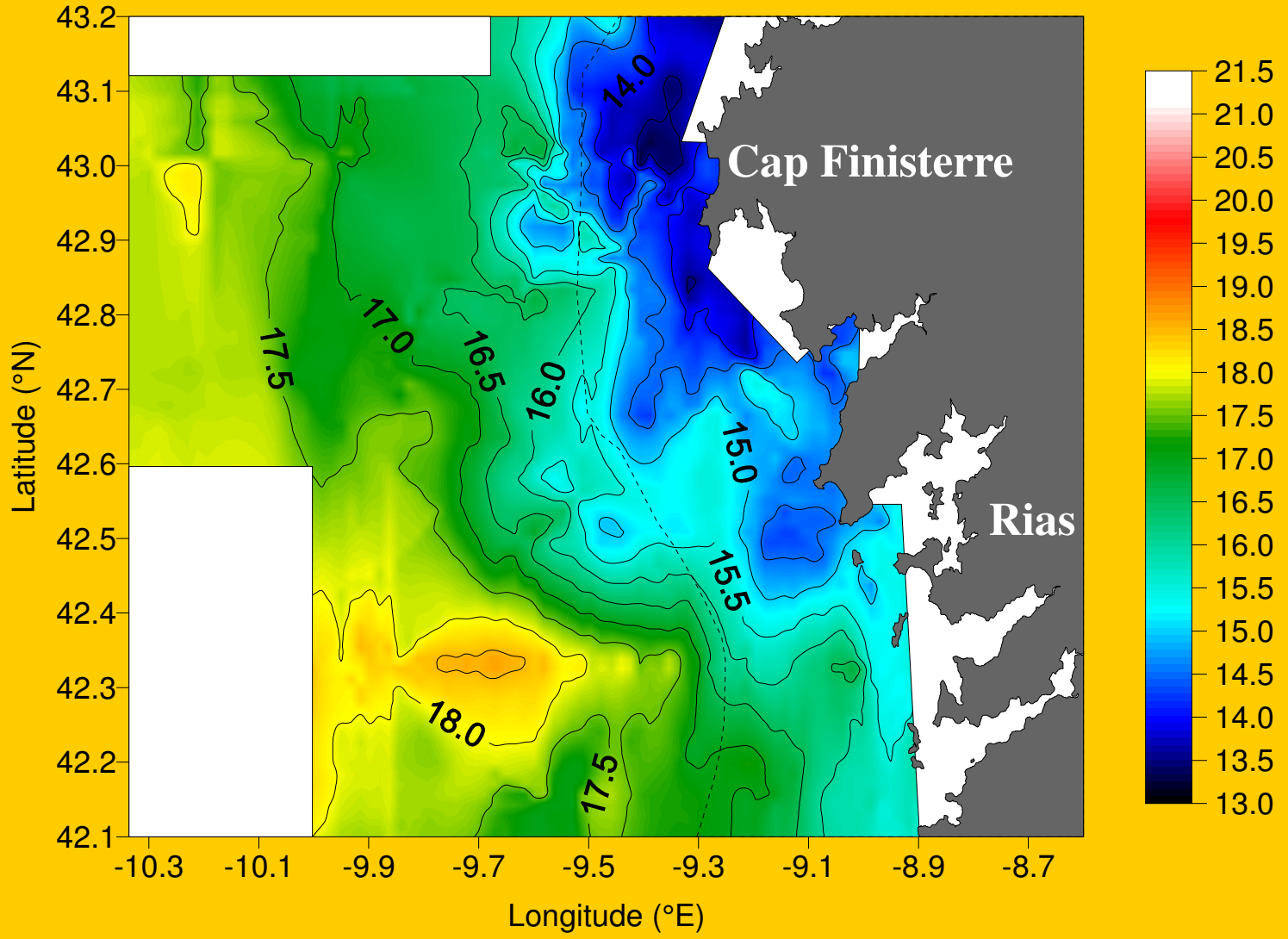
Liss & Merlivat (1986) **- 3.3 mmol m^{-2} day^{-1}**

Tans *et al.* (1990) **- 7.7 mmol m^{-2} day^{-1}**

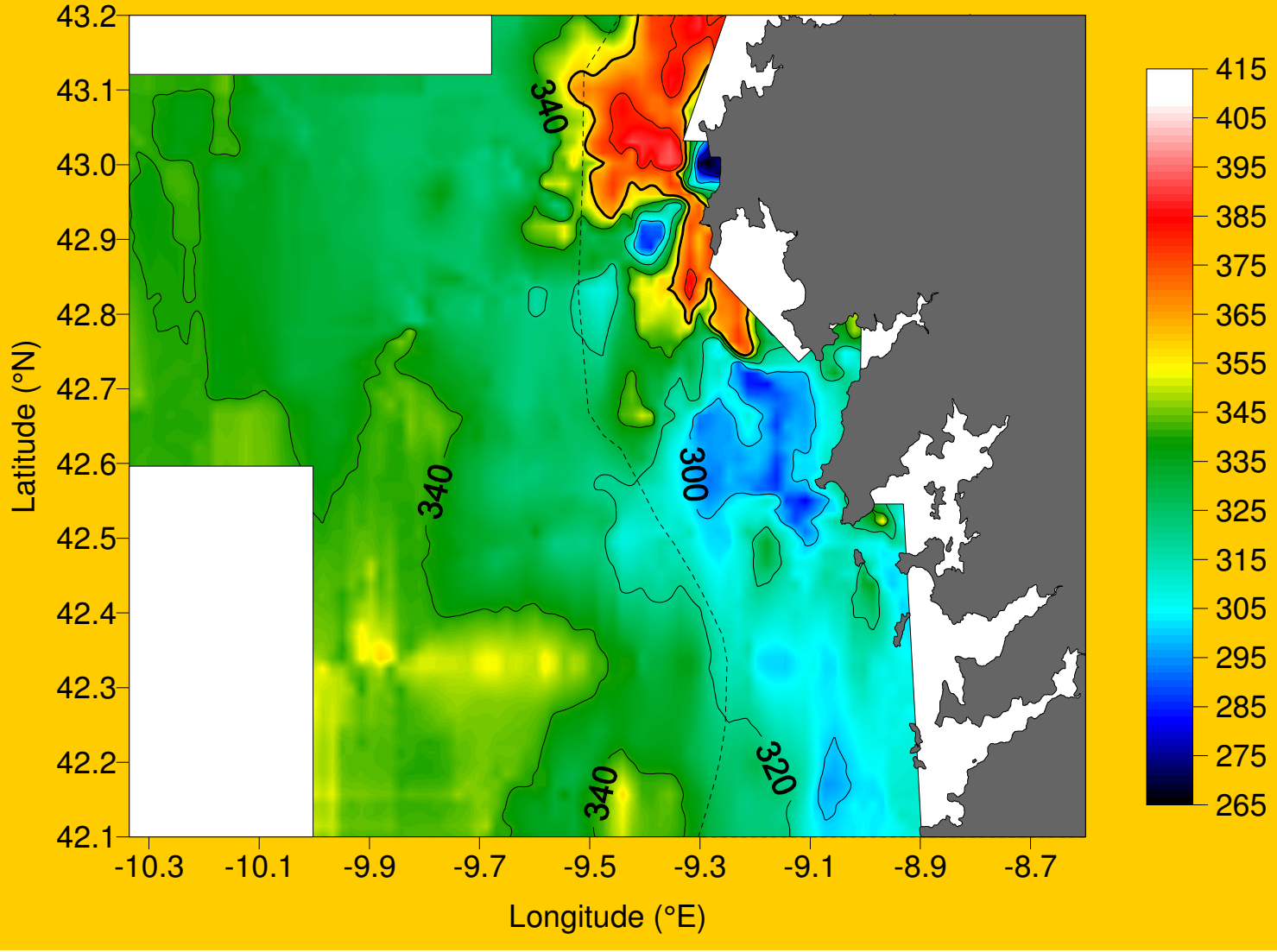
Confirms the « continental shelf pump hypothesis » of Tsunogai *et al.* (1999):

Globally continental shelf is a sink of 0.5 to 1.0 GtC $year^{-1}$

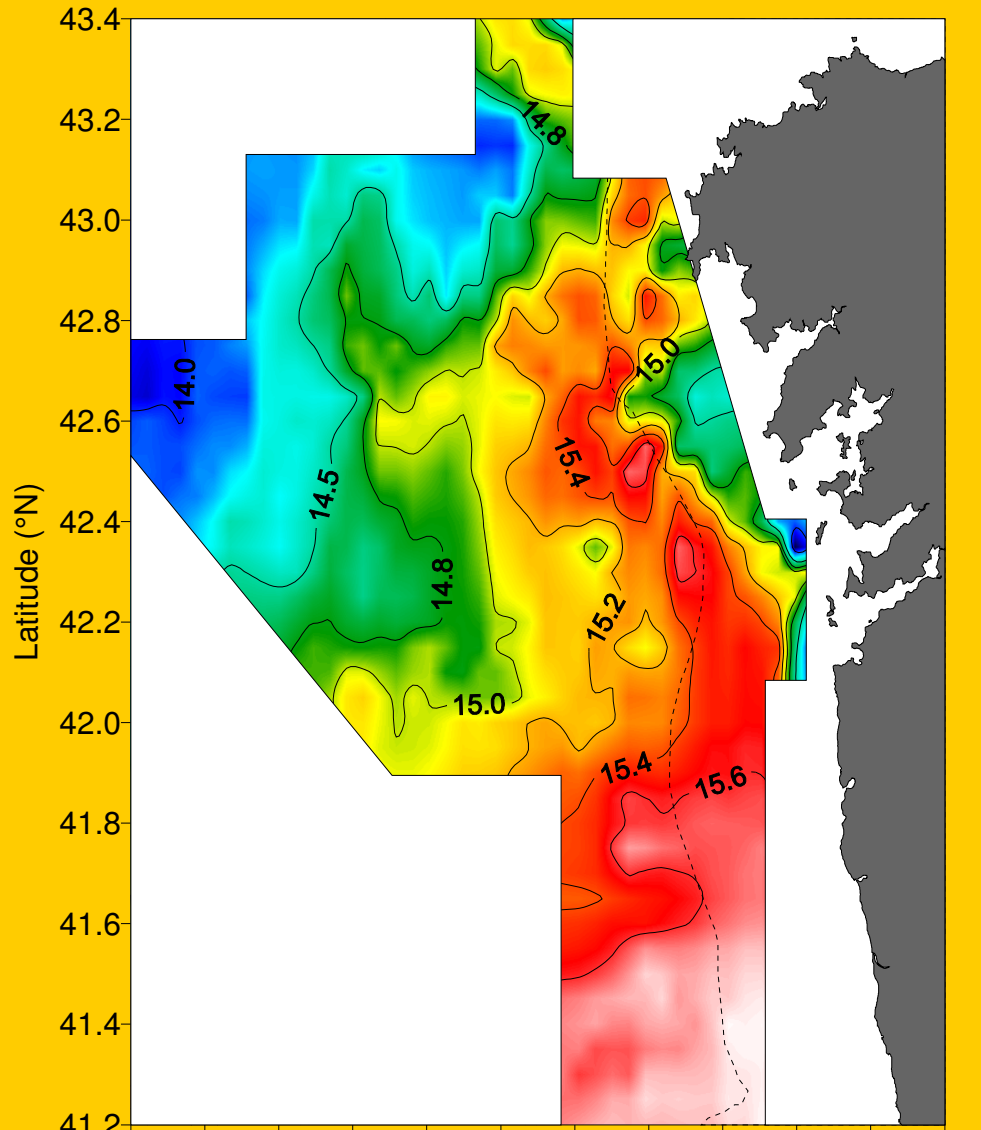
Galician coast
temperature (°C) 27 June - 7 July 98

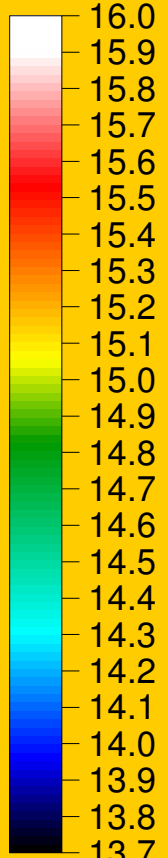


pCO_2 (µatm) 27 June - 7 July 98

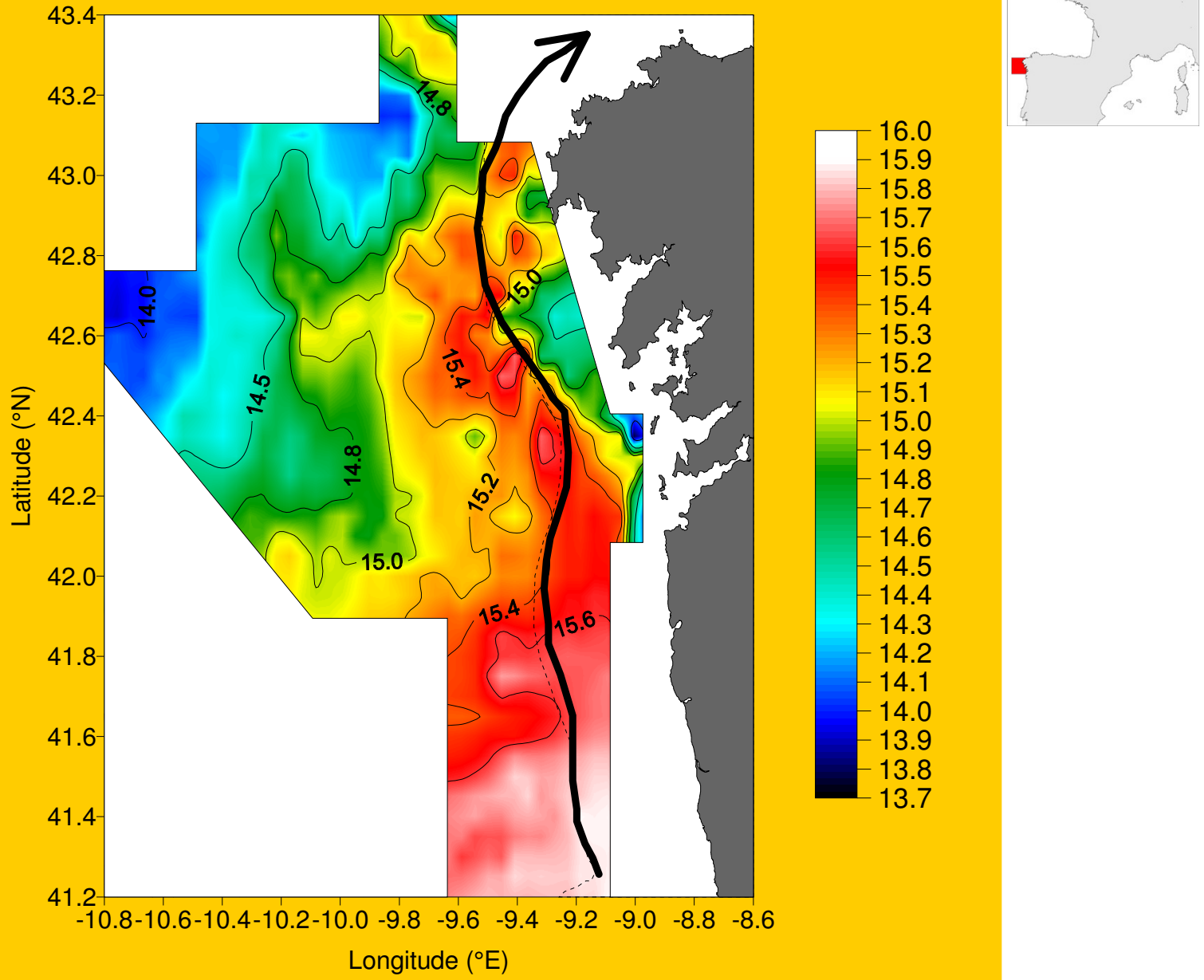


temperature (°C) 6 - 16 January 98

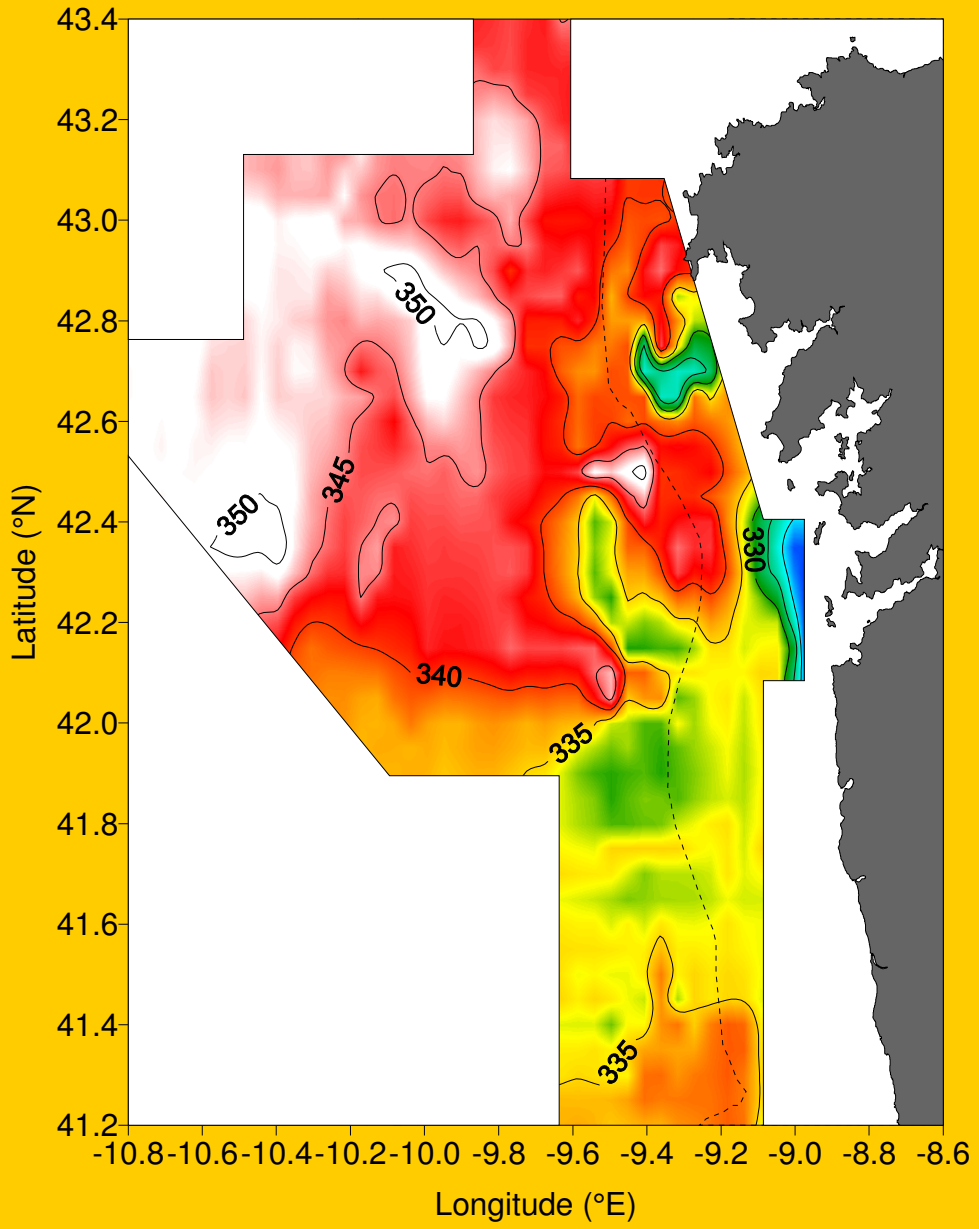




temperature (°C) 6 - 16 January 98



pCO_2 (µatm) 6 - 16 January 98



Annual integration of the air-sea CO_2 fluxes:

June/July 97
june/july 98 upwelling season
August 98
September 99

Annual integration of the air-sea CO_2 fluxes:

June/July 97
june/july 98 upwelling season
August 98
September 99
January 98 downwelling season

Annual integration of the air-sea CO_2 fluxes:

June/July 97
june/july 98 upwelling season
August 98
September 99
January 98 downwelling season

Upwelling season = March to October = 6 months

Continental shelf:

- 6.1 mmol m^{-2} day^{-1} (exchange coeff. Wanninkhof 1992)

Annual integration of the air-sea CO_2 fluxes:

June/July 97
june/july 98 upwelling season
August 98
September 99
January 98 downwelling season

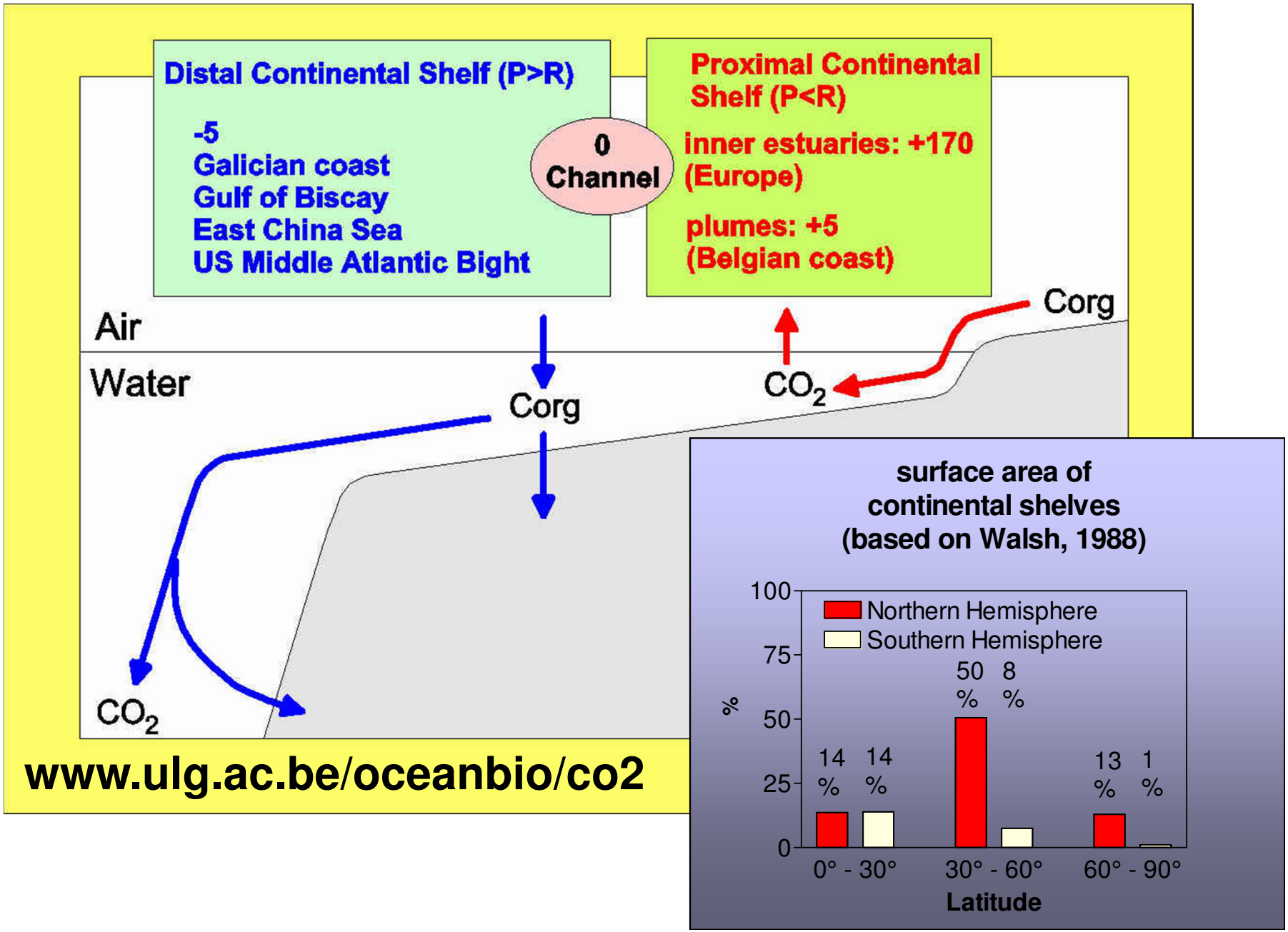
Upwelling season = March to October = 6 months

Continental shelf:

- 6.1 mmol m^{-2} day^{-1} (exchange coeff. Wanninkhof 1992)

Off-shore region:

- 4.4 mmol m^{-2} day^{-1}


Distal Continental Shelf (P>R)
-5
Galician coast
Gulf of Biscay
East China Sea
US Middle Atlantic Bight
0
Channel
Proximal Continental Shelf (P<R)
inner estuaries: +170
(Europe)
plumes: +5
(Belgian coast)
Air
Water
Corg
Corg
CO_2
CO_2
www.ulg.ac.be/oceanbio/co2
surface area of
continental shelves
(based on Walsh, 1988)
100
75
50
25
0
%
Northern Hemisphere
Southern Hemisphere
14 %
14 %
50 %
8 %
13 %
1 %
0° - 30°
30° - 60°
60° - 90°
Latitude