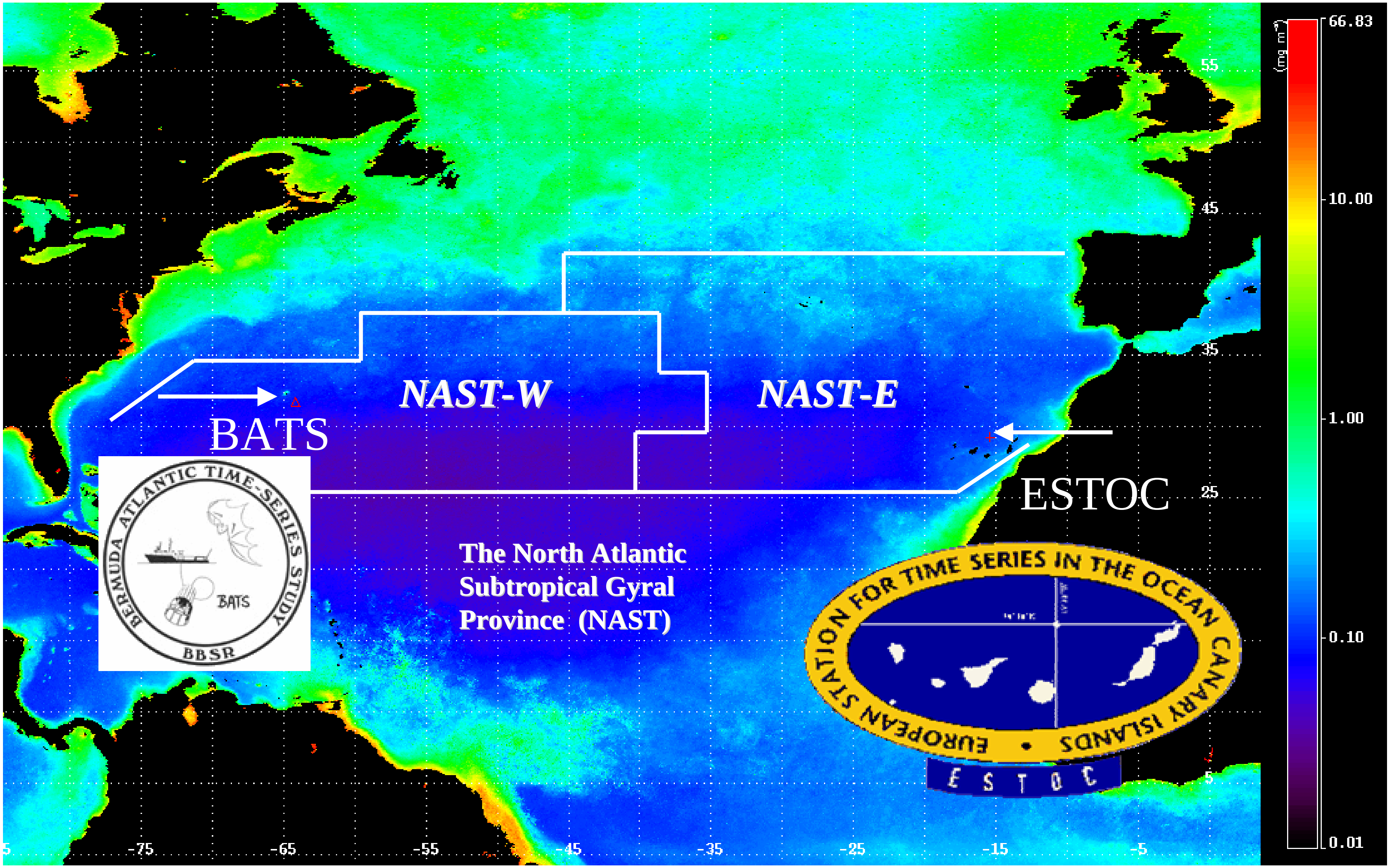
European Time-series Station ESTOC in the Eastern Subtropical North Atlantic Gyre

Susanne Neuer

Arizona State University


NAST-W
NAST-E
BATS
ESTOC
The North Atlantic
Subtropical Gyral
Province (NAST)
BERMUDA ATLANTIC TIME-SERIES STUDY
BBSR
EUROPEAN STATION FOR TIME SERIES IN THE OCEAN CANARY ISLANDS
E S T O C
(mg m⁻³)
66.83
10.00
1.00
0.10
0.01
55
45
35
25
5
-75
-65
-55
-45
-35
-25
-15
-5

ICCM, Telde, Gran Canaria

ICCM, Telde :

Group of Octavio Llinas

Maria-Jose Rueda
Andres Cianca
Francisco Luzardo
Juana Godoy
Marimar Villagarcia
Javier Marrero
Lleire Moroto
Rosa Montana

Univ. Las Palmas:

Group of
Melchor Gonzalez-Davila

Magdalena Casiano
Lluis Laglera

Group of
Joaquin Hernandez-Brito

Buque oceanografico
‘TALIARTE’

IfM Kiel:
Group of Gerold Siedler

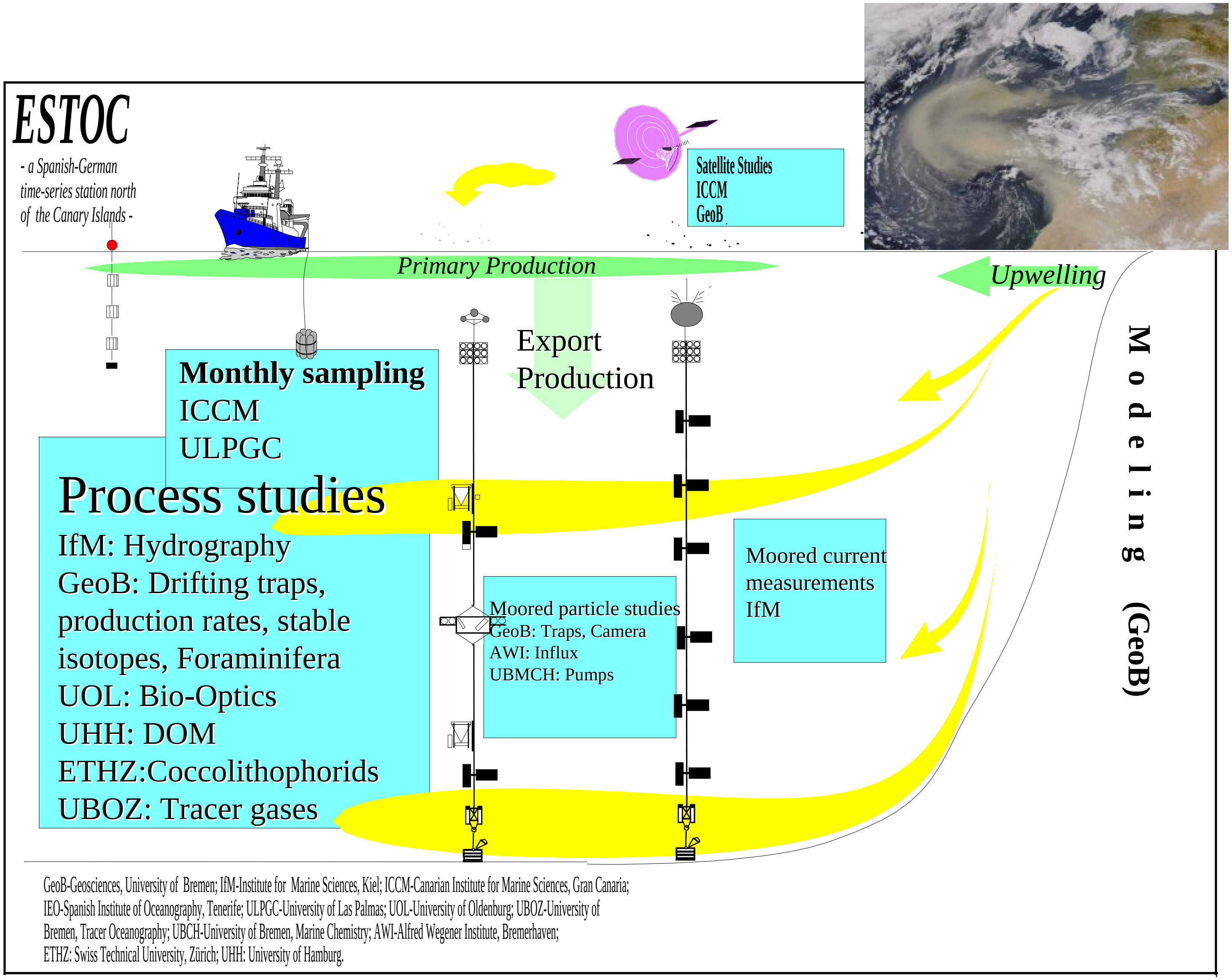
Thomas Müller
Michaela Knoll
Uwe Koy
Markus Busse
Jörg Reppin
Christian Haag

Univ. Bremen:
Group of Gerold Wefer
Peer Helmke
Tim Freudenthal
Helge Meggers
Christina Hayn
Jens Langer
Götz Ruhland
Volker Ratmeyer

Support:

❖German ministry for Research and Education [BMBF]
❖EU (CANIGO, ANIMATE, MERSEA)
❖Gobierno de Canarias
❖RCOM (DFG), Germany

❖NASA (EOS) Co-PIs, R. Najjar, D. McGillicuddy



ESTOC
- a Spanish-German time-series station north of the Canary Islands -
Satellite Studies
ICCM
GeoB
Primary Production
Upwelling
Export Production
Monthly sampling
ICCM
ULPGC
Process studies
IfM: Hydrography
GeoB: Drifting traps, production rates, stable isotopes, Foraminifera
UOL: Bio-Optics
UHH: DOM
ETHZ:Coccolithophorids
UBOZ: Tracer gases
Moored particle studies
GeoB: Traps, Camera
AWI: Influx
UBMCH: Pumps
Moored current measurements
IfM
Modeling (GeoB)
GeoB-Geosciences, University of Bremen; IfM-Institute for Marine Sciences, Kiel; ICCM-Canarian Institute for Marine Sciences, Gran Canaria; IEO-Spanish Institute of Oceanography, Tenerife; ULPGC-University of Las Palmas; UOL-University of Oldenburg; UBOZ-University of Bremen, Tracer Oceanography; UBCH-University of Bremen, Marine Chemistry; AWI-Alfred Wegener Institute, Bremerhaven; ETHZ: Swiss Technical University, Zürich; UHH: University of Hamburg.

‘Exploring-in-space’....has been the traditional way of ocean exploration since the first oceanographic expeditions.

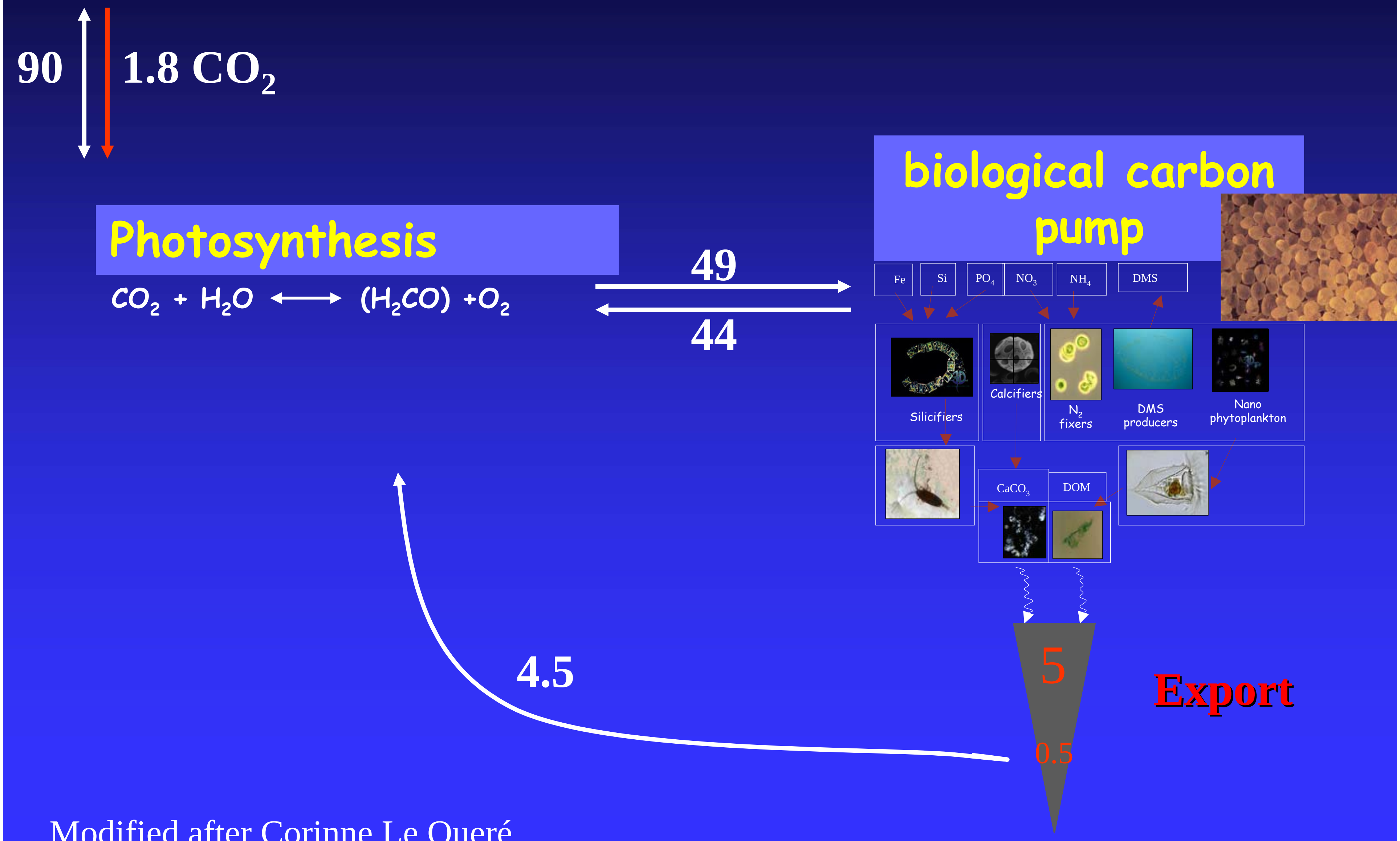
But...

Few characteristics of the ocean and the seafloor are in steady state, therefore the need is paramount for sustained time-series investigations

‘Exploration-in-time’

Ideally in the combination of hypothesis-testing and development of measurement strategies and new observational tools...in the time domain, not space domain.....

oceanic carbon cycle PgC/y



Modified after Corinne Le Queré

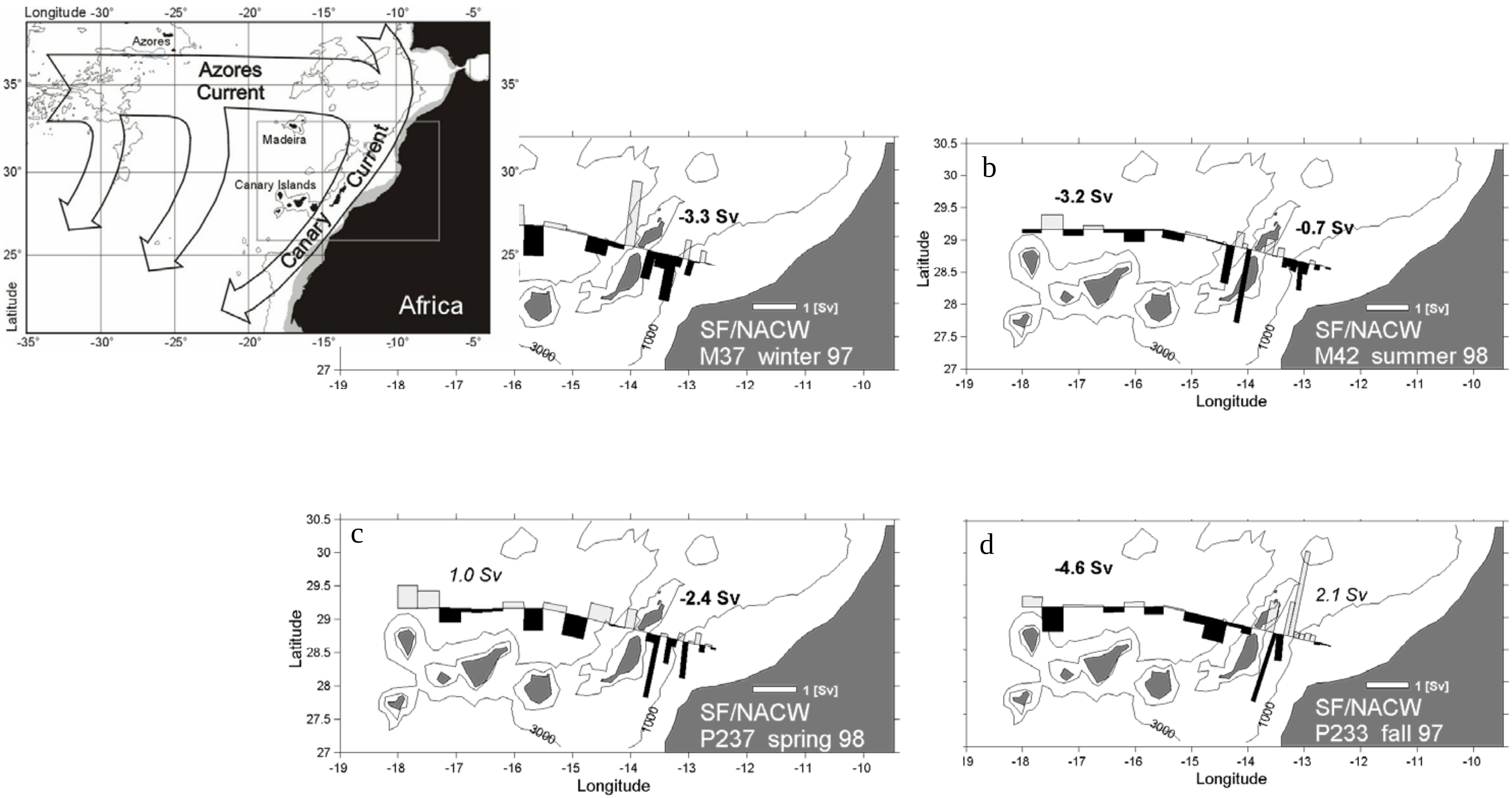
ESTOC

- Hypothesis 1: Dust input influences primary and export production
- Hypothesis 2: Export ratio scales with input of ‘new’ nutrients

ESTOC

- The physical context and biogeochemistry

ESTOC is located in the eastern boundary current region of the subtropical NA Gyre



Seasonal geostrophic transports for upper few hundreds meters along 29°
Michaela Knoll in John et al., 2004

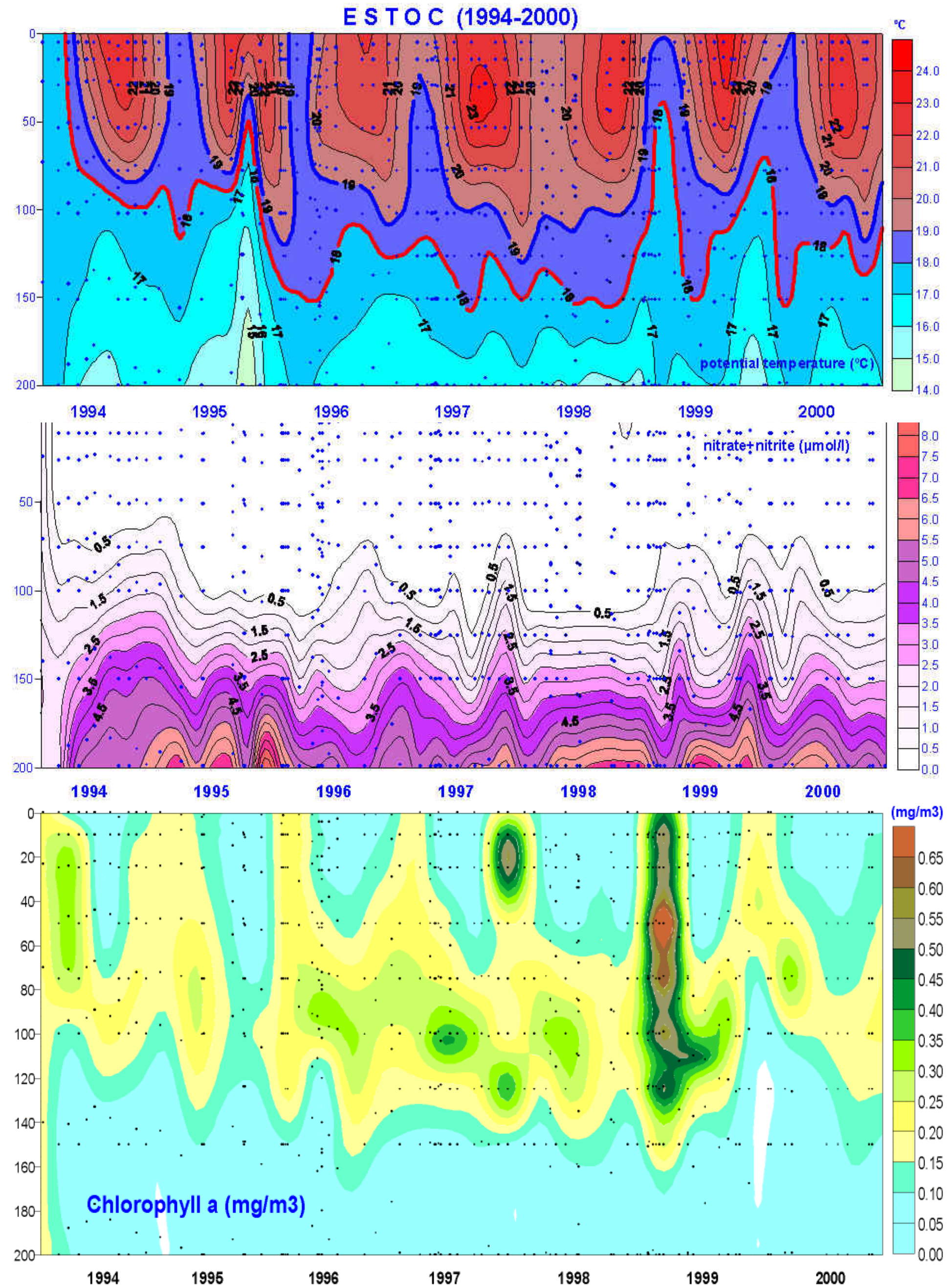
Seasonal cycle at ESTOC

- Typical of a subtropical gyre station
- Winter mixed layer from around 20 m in summer to up to 150 m in winter
- Nitrate not measurable in upper mixed layer with standard methods
- Phytoplankton biomass maximum in winter follows the break-up of the seasonal thermocline in late fall
- Chlorophyll levels in winter are usually around 0.4 mg l^{-1}, and in summer around 0.05 mg l^{-1} in the surface

T

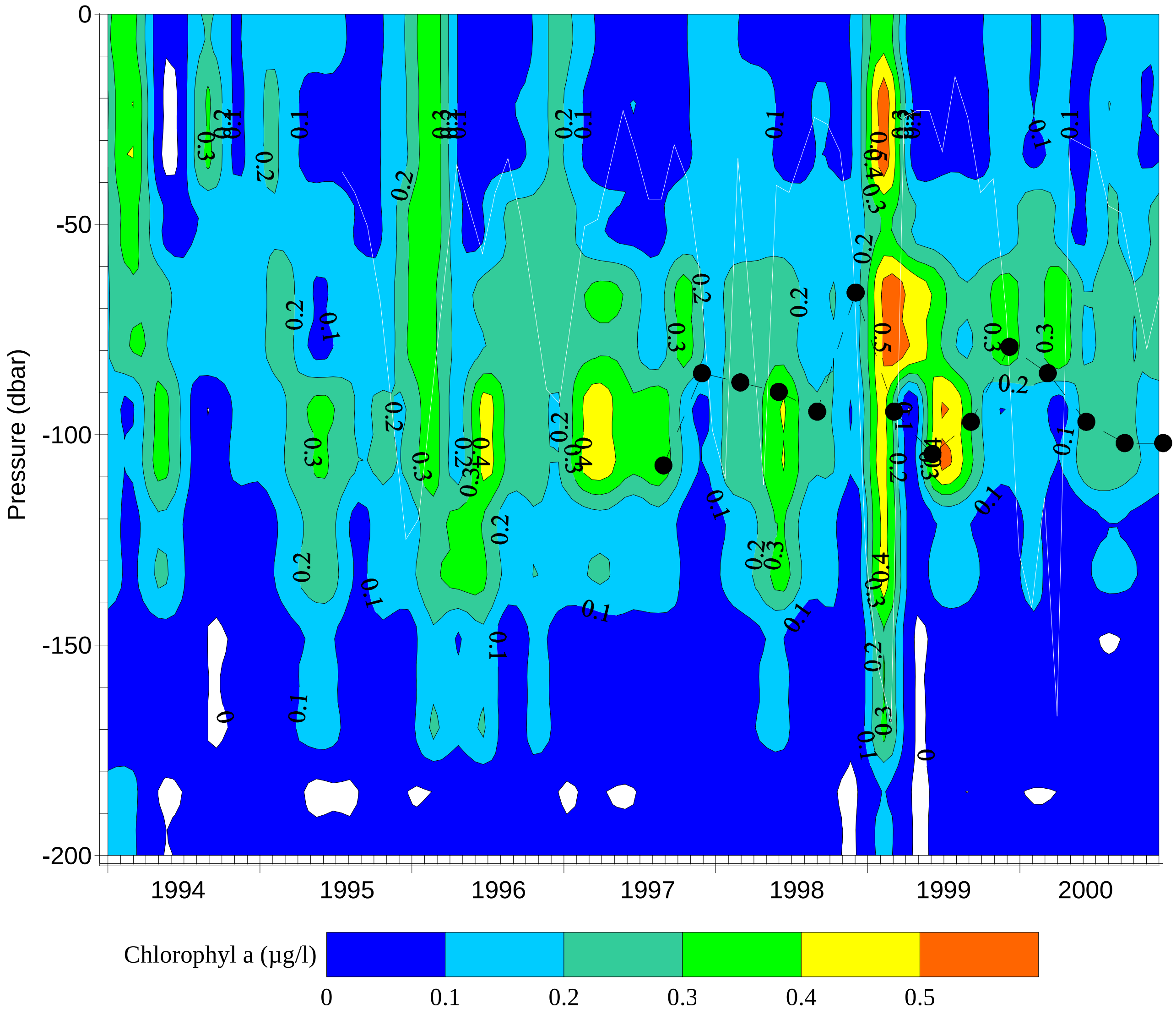
NO_3

Chl



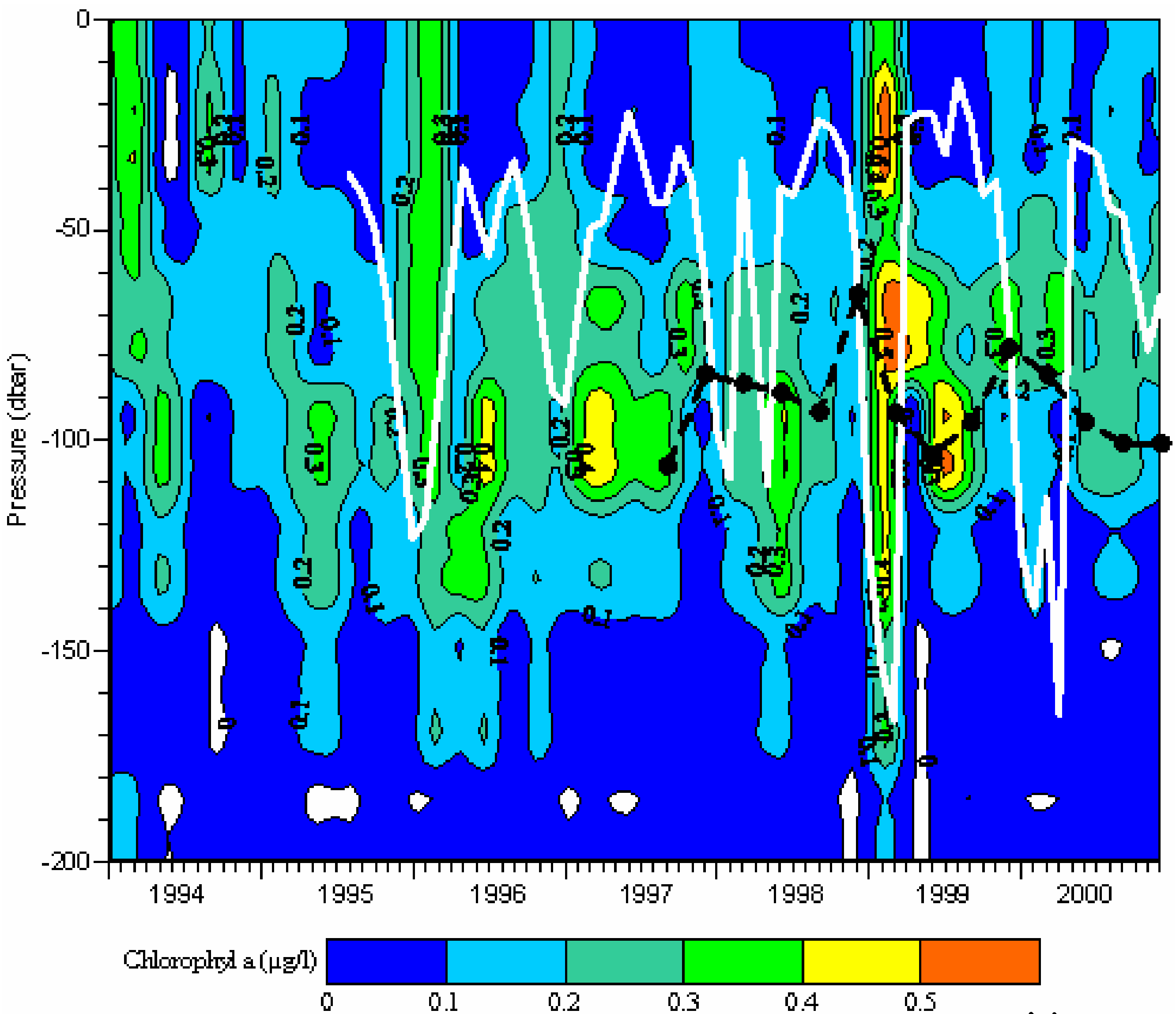
Neuer et al, in prep.

Chlorophyll peaks during time of deepest mixing in winter.



Neuer et al, in prep.

Chlorophyll peaks during time of deepest mixing in winter.



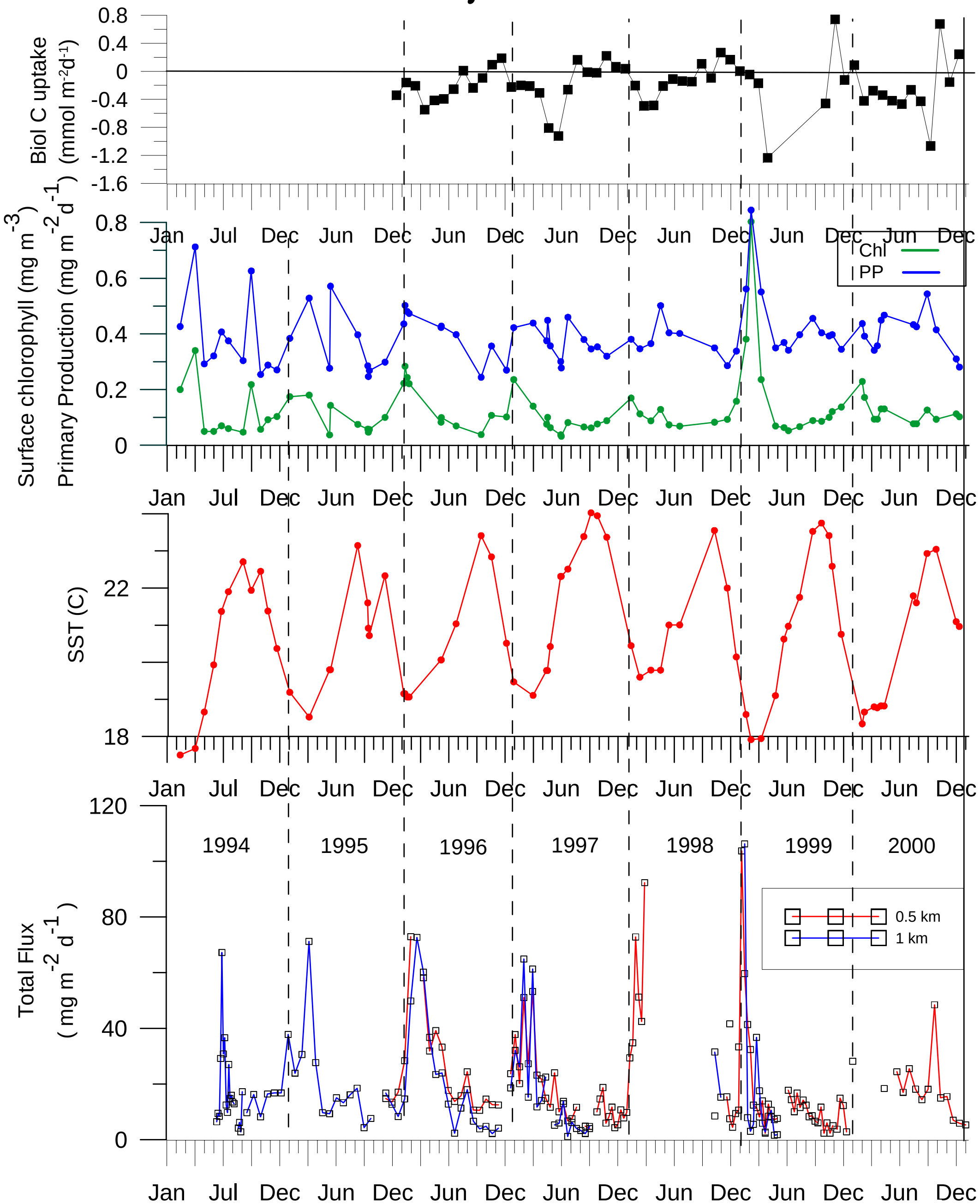
Neuer et al, in prep.

Particle flux and its relationship to surface water processes

- Particle flux maxima in late winter following the maxima of chlorophyll and primary productivity

- Strong interannual variability concomitant with the variability in mixing depth

- Yearly integrated primary production at ESTOC = 12 mol C m^{-2} yr^{-1} and integrated particulate C-export = 0.2 mol C m^{-2} yr^{-1}



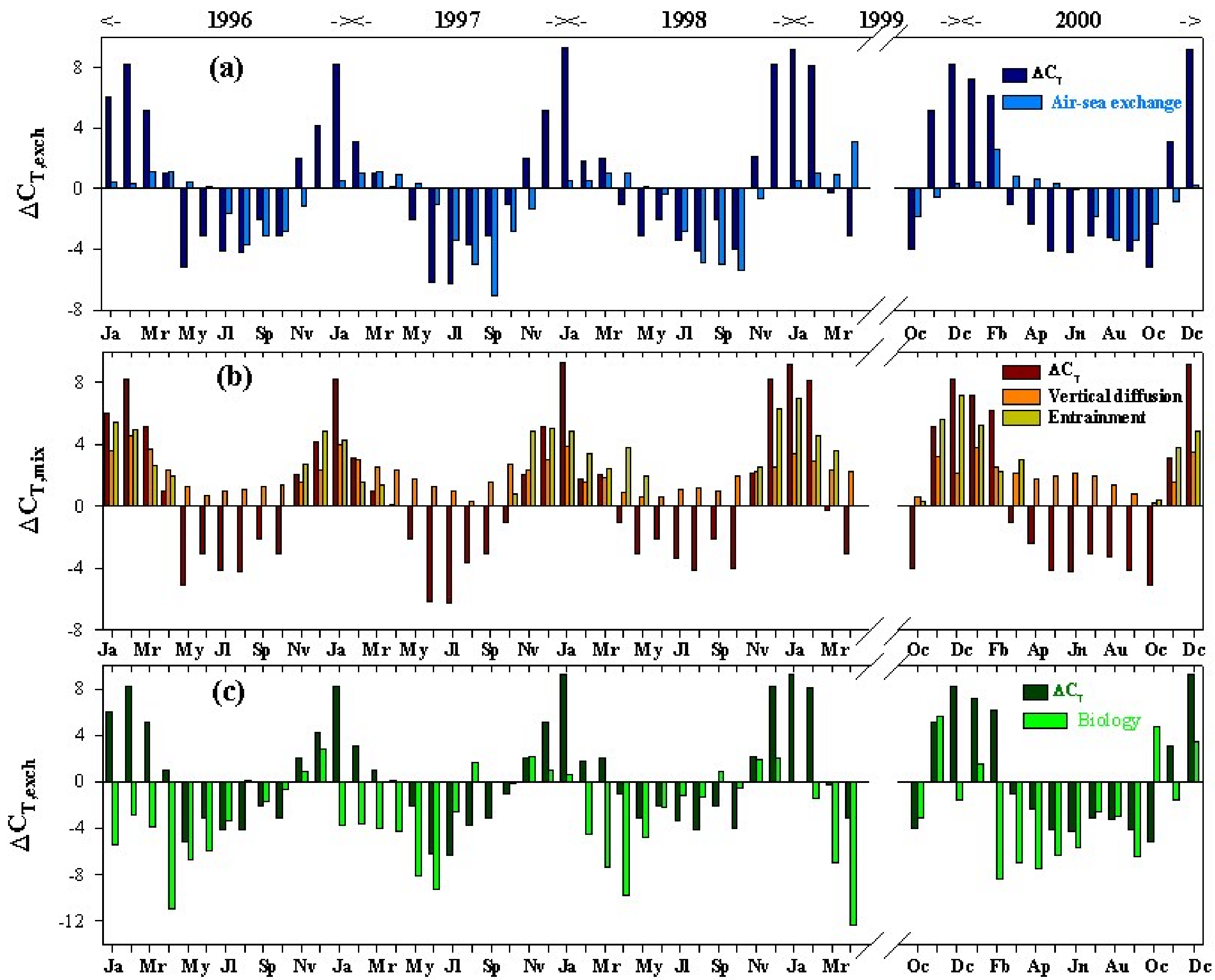
Neuer et al., in prep.

Seasonal and interannual variability in the carbon dioxide species

C_T biol. calculated as difference between total NCt change and contribution from air sea exchange and mixing.

1. Jan-March
Increase of C_T due to winter convection
2. March-October:
C_T decrease due to biol. productivity + outgassing

C_T(biol) ranges between 2-4 mol/m2/yr



Gonzalez-Davila et al. , GBC, 2003

Seasonal and interannual variability in the carbon dioxide species

Net CO_2 fluxes at ESTOC are positive with an average value of 0.05 mol CO_2 m^{-2} yr^{-1}

p CO2 increases at a rate of 1.2 ± 0.3 μatm/yr

pH decreases 0.001 units/yr

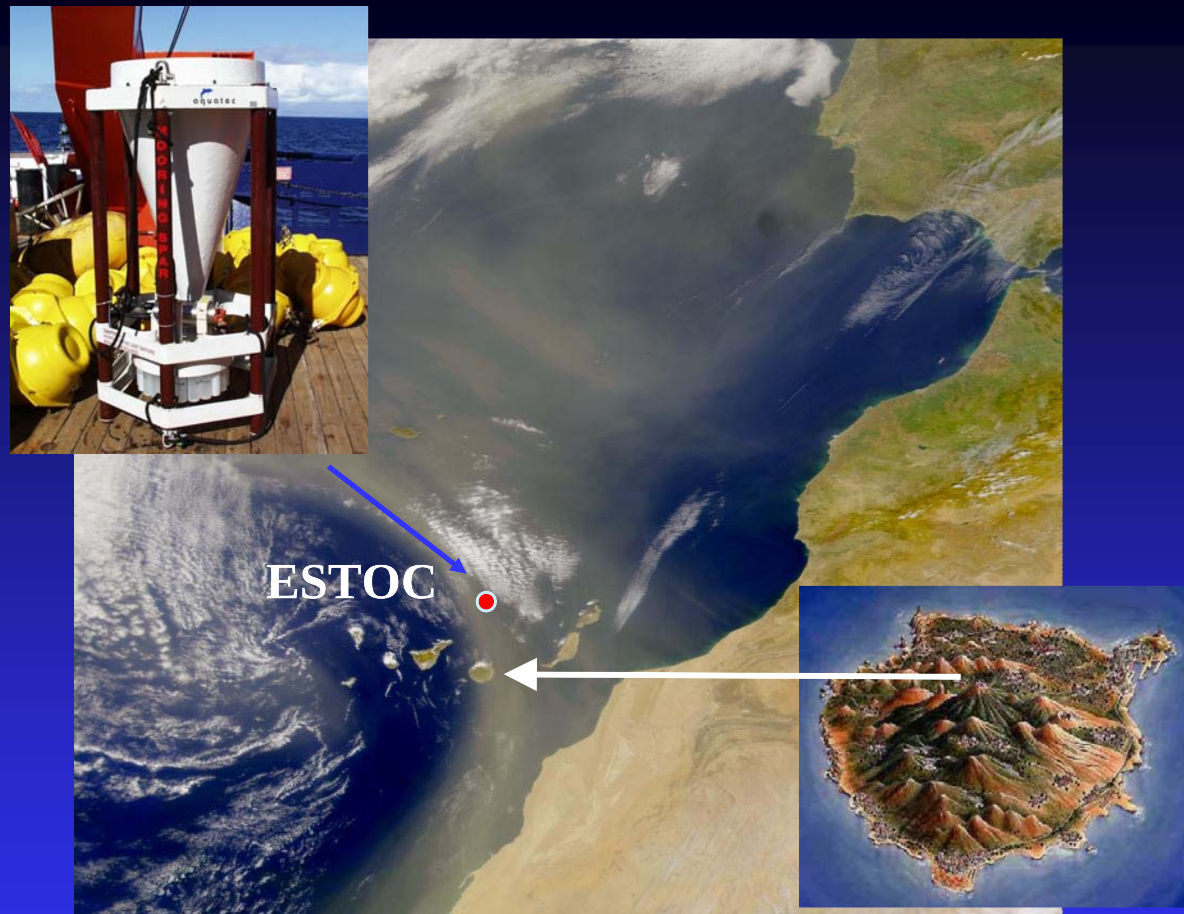
C_T increases at 0.9 ±0.2 μmol/kg/yr

Gonzalez-Davila et al. , GBC, 2003
Neuer et al. in prep.

ESTOC

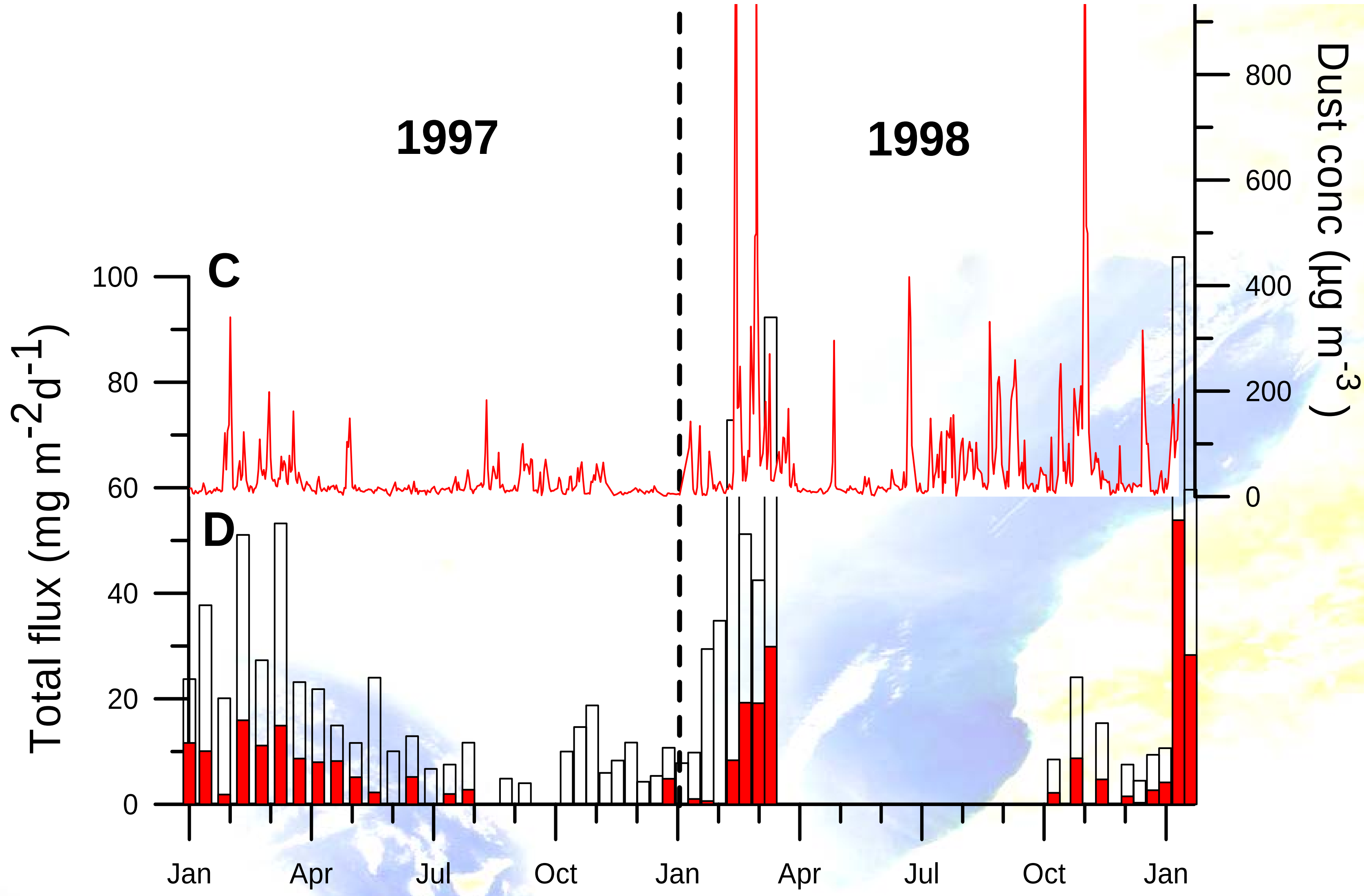
- Hypothesis 1: Dust input influences export production

ESTOC



- Hypothesis 1:

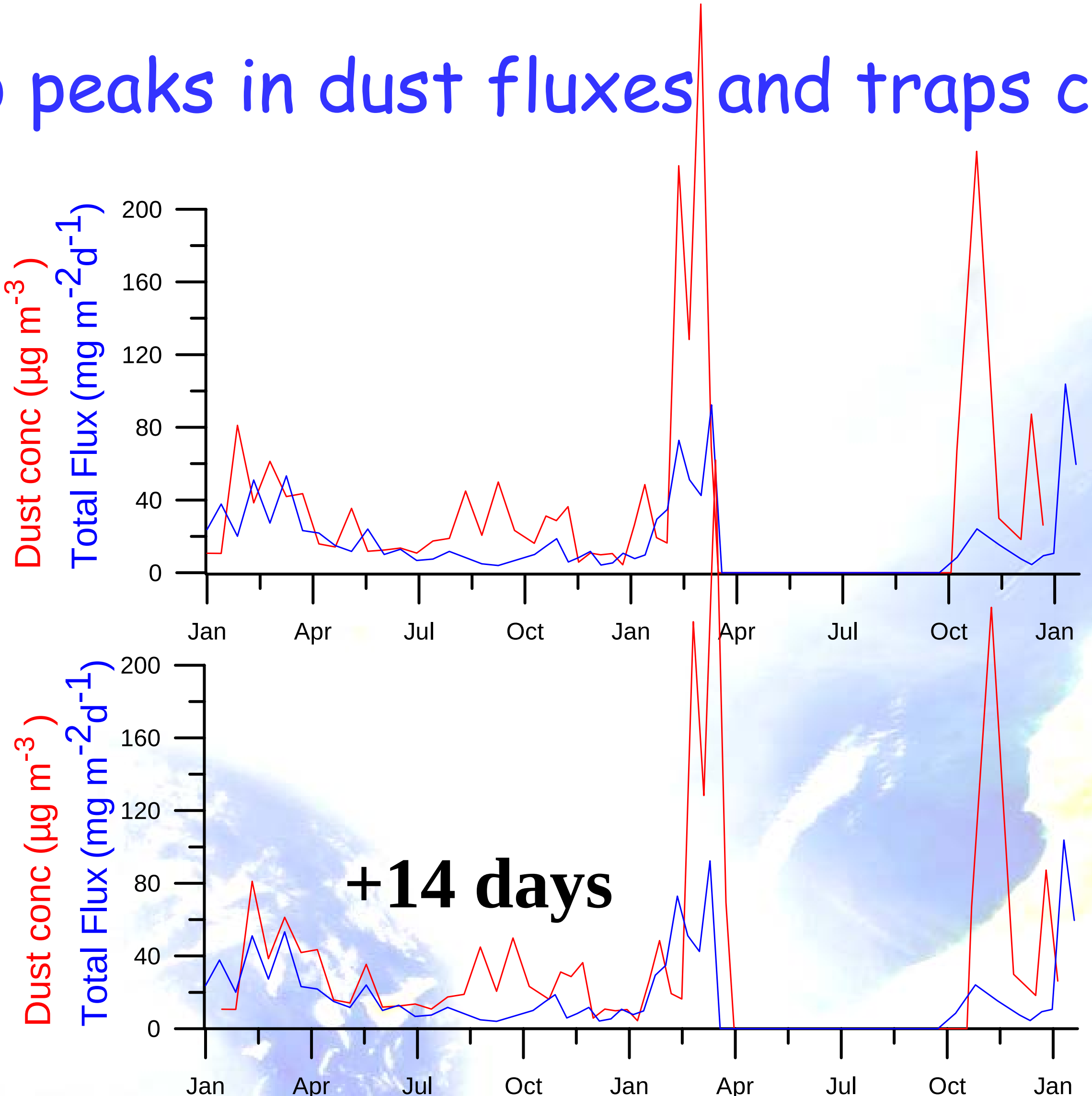
Dust input influences export production



Particle fluxes at ESTOC and dust deposition determined at Gran Canaria

Neuer et al., GBC, 2004

Do peaks in dust fluxes and traps coincide?



- At ESTOC winter particle fluxes coincide with (or follow with a short lag) dust deposition

Neuer et al., GBC, 2004

OK, there is a coupling, but does that imply a causal relationship?

Rates ($g\ m^{-2}$, Jan-March)	1997	1998
Aeolian deposition[1...]	3.3	8.1
Primary production[2]	38	33
Export production[3] (C org, 150 m)	0.73	0.76

[1]assuming mean deposition rate of 1 cm s^{-1} (Torres-Padrón et al. 2002);

[2] Neuer et al., 2002; [3]normalized to 150m (Martin et al., 1987, open ocean composite).

Dust derived N deposition (wet and dry) amounts to 4-6% of new nitrogen need at ESTOC (on an annual basis).

So, what about iron?

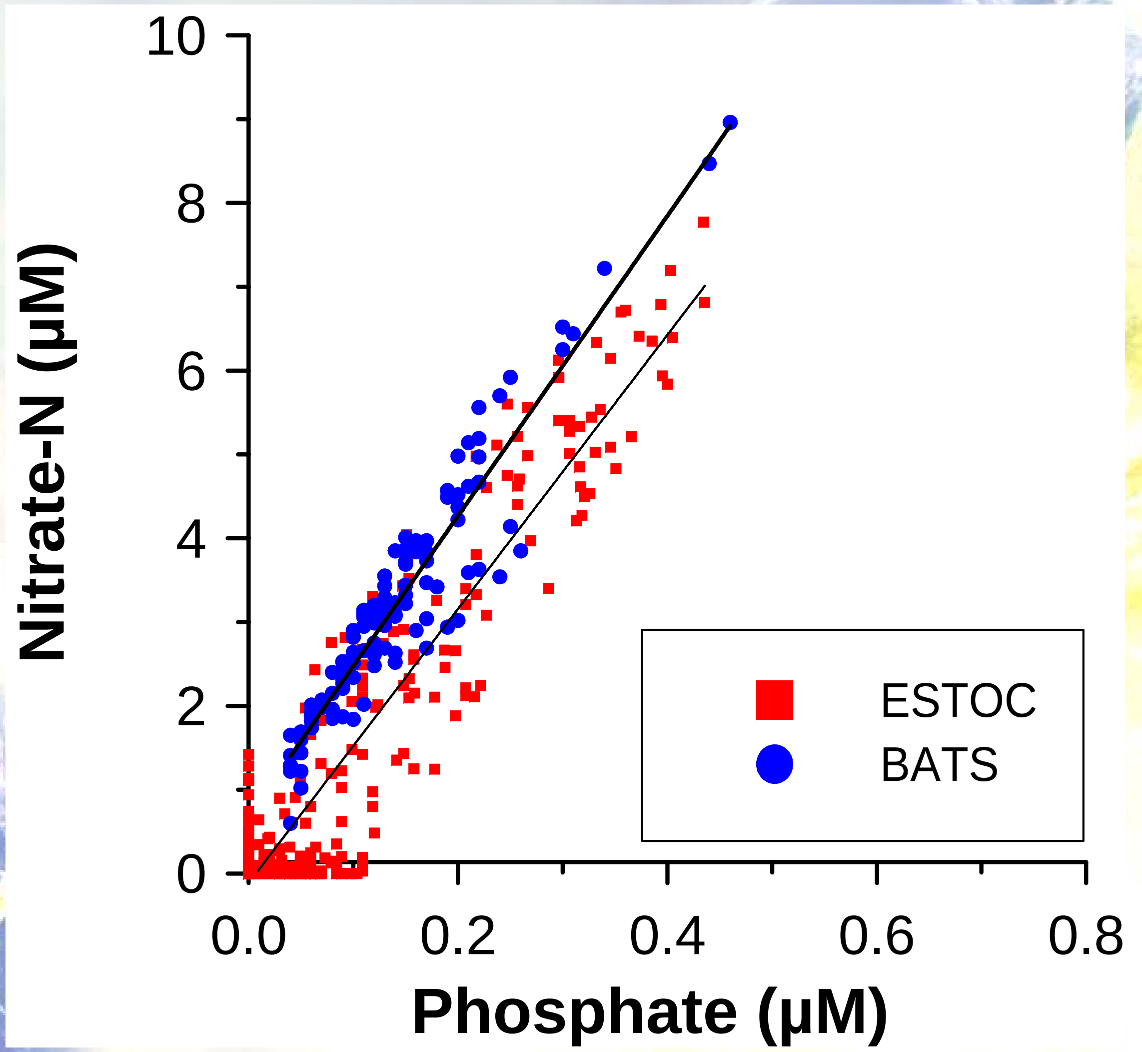
Fluxes	1997	1998
Dust deposition [1] ($g\ m^{-2}\ yr^{-1}$)	11	29
Total Fe-deposition[2] ($g\ m^{-2}\ yr^{-1}$)	0.38	1.03
Soluble Fe-deposition[3] ($mmol\ m^{-2}\ yr^{-1}$)	0.07-0.7	0.18-1.8
Total Fe-assimilation[4] ($\mu mol\ m^{-2}\ yr^{-1}$)	113	116
Supplied/Assimilated	0.6	1.6

[1]Torres-Padrón et al. 2002, [2] assuming Fe-content of 3.5% WT (Duce 1986); [3]assuming a solubility index range of 1-10% (Fung et al. 2000); [4]primary production of 12 mol C $m^{-2}\ yr^{-1}$(Neuer et al. 2002) and Fe:C ratio of 10 µmol/mol (Sunda and Huntsman 1995, 1997)

- **Iron:**

  Highly episodic nature of dust deposition might impose feast-famine situation on the phytoplankton and eolic iron deposition may relief iron stress in winter when phytoplankton biomass is high (which might explain some of the observed temporal coupling in winter).

But: What about N_2-fixation?

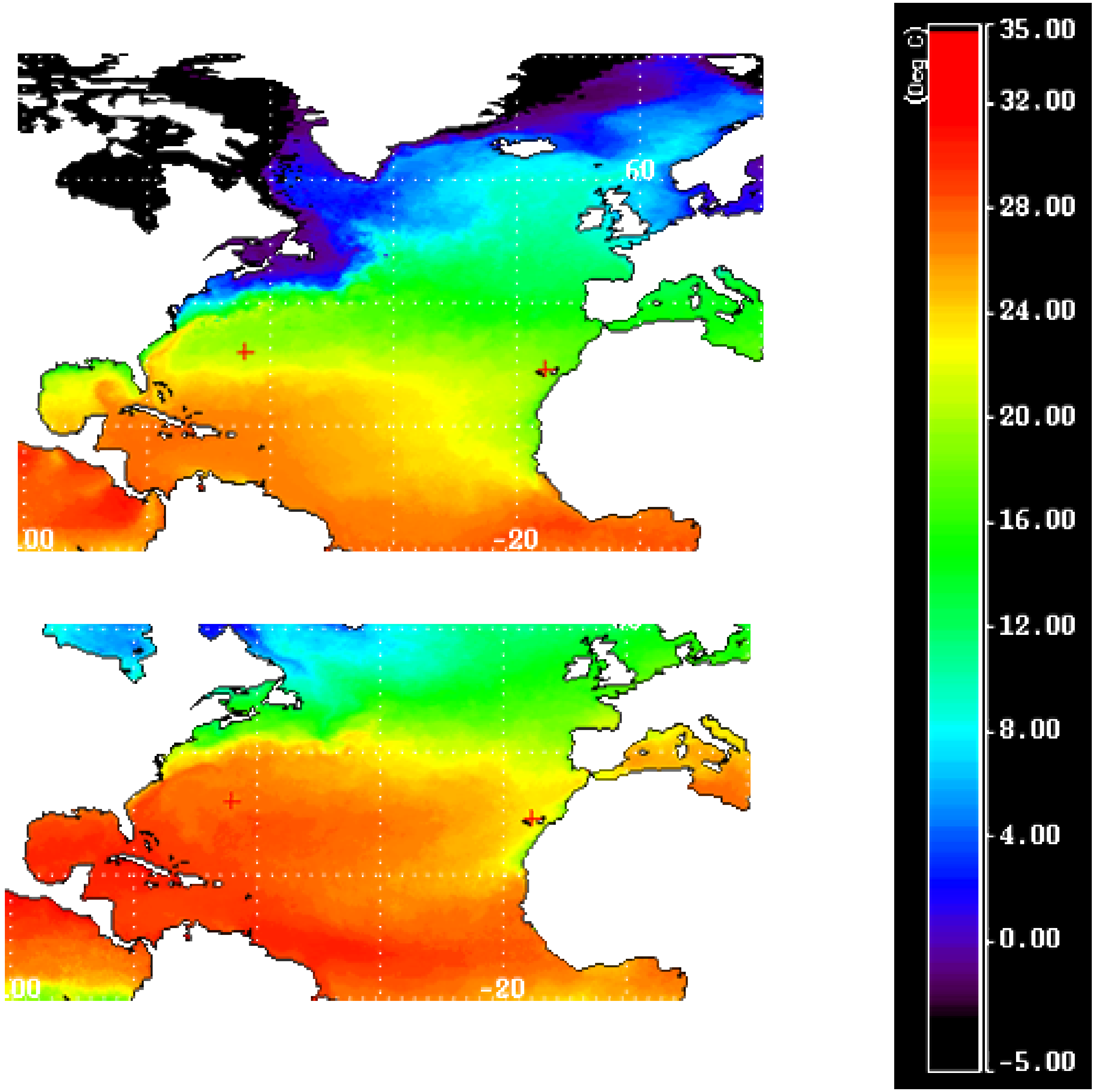


DIN/DIP is at Redfield ratio at ESTOC, but elevated at BATS. There is no indication of significant N_2 fixation at ESTOC, i.e., stimulation by iron not relevant.

Neuer et al., GRL, 2002

Winter

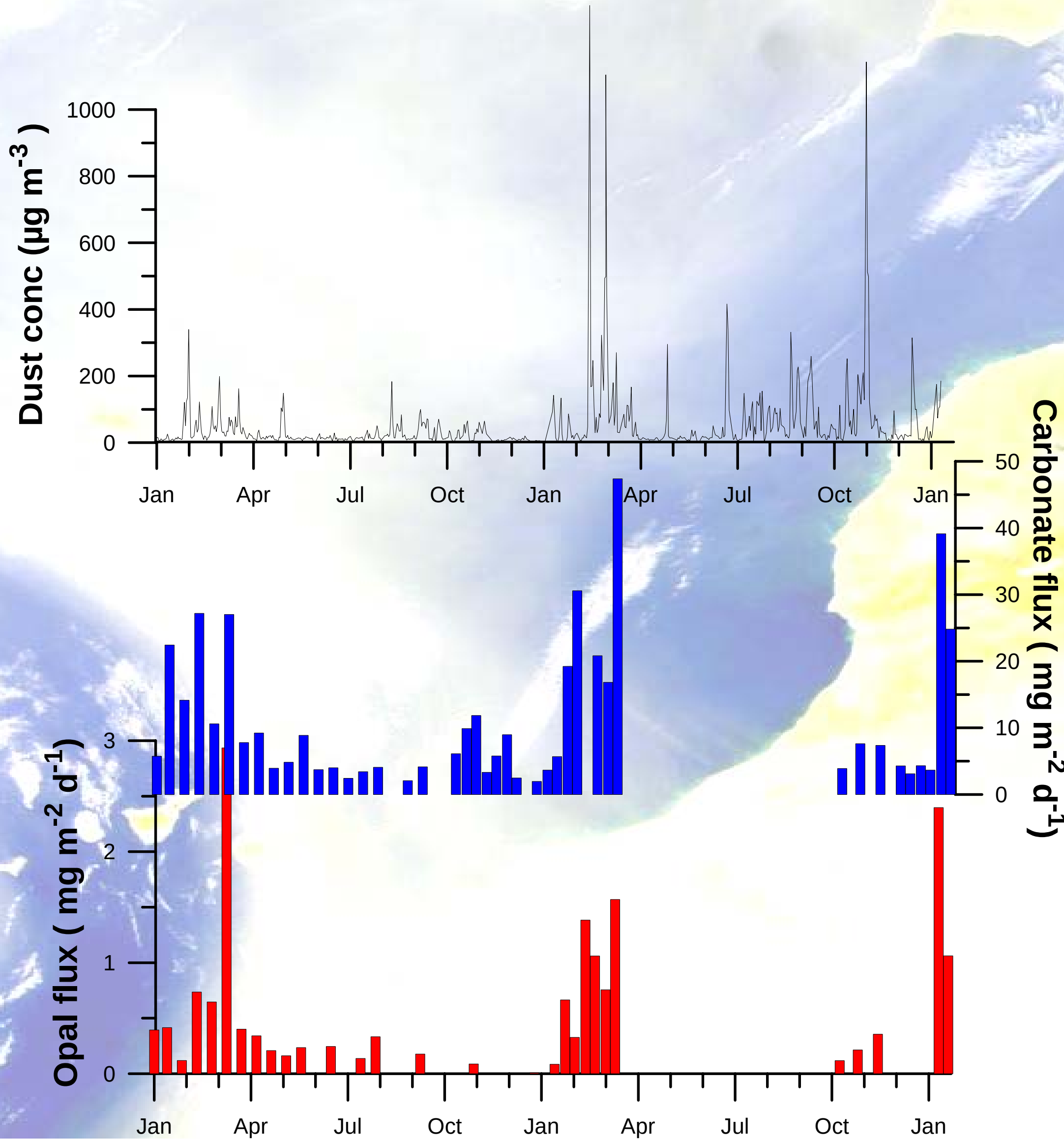
Summer



OK, no (major) enhancement of (new) production, what about a response on the organisms level?

Carbonate

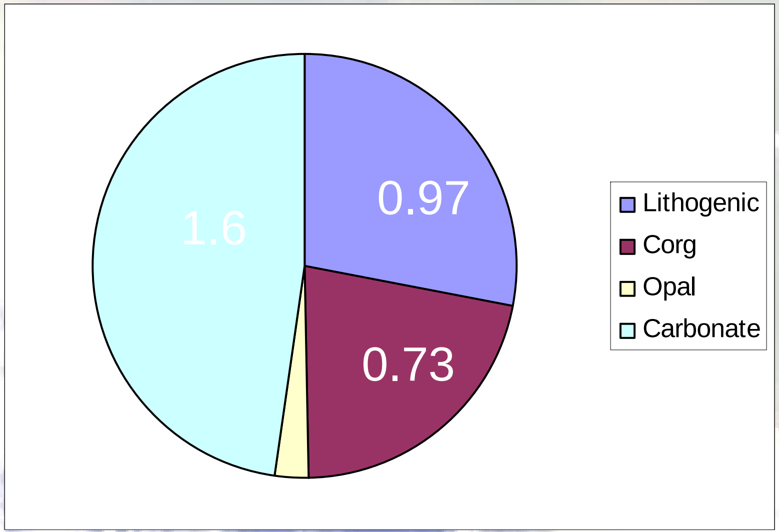
Opal

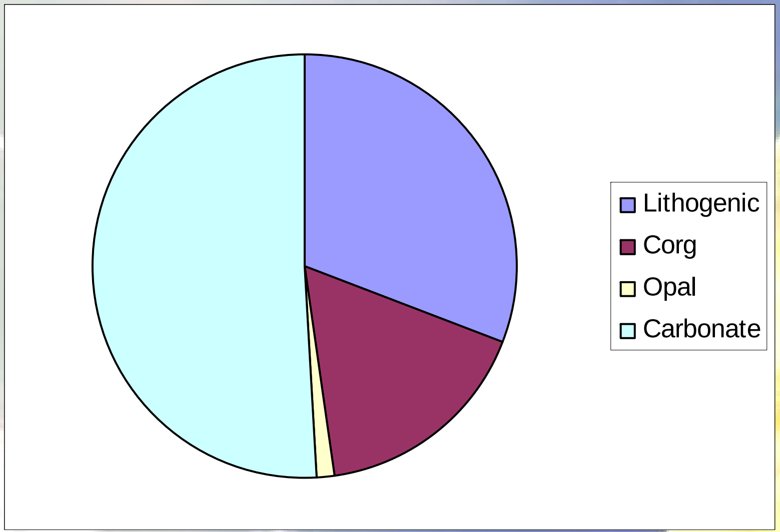


Carbonate sedimentation is higher by a factor of 1.4, similar to the enhancement of lithogenic matter, in winter 1998

Rates (g m^{-2}, Jan-March)	1997	1998
Aeolian deposition [1]…	3.3	8.1
Primary production[2]	38	33

Trap fluxes[3]

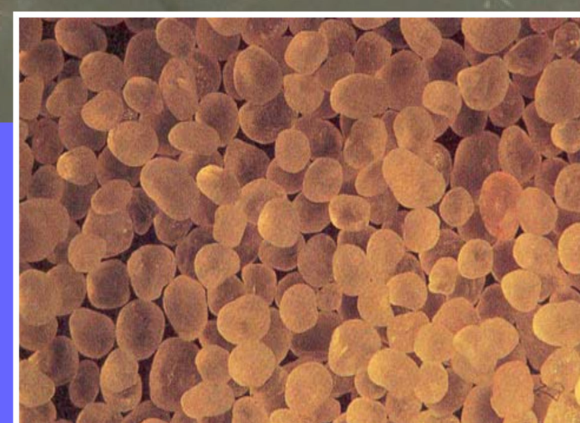




[1] assuming mean deposition rate of 1 ms^{-1} (Torres-Padrón et al. 2002);

[2] Neuer et al., 2002; [3] Corg: normalized to 150m (Martin et al., 1987, open ocean composite).

- **Ballast: Despite the high lithogenic matter loading of sinking particles, carbonate is the main ballasting agent**



Density? 2.71 g cm^{-3} 2.65 g cm^{-3}

ESTOC

- Hypothesis 1: Dust input influences primary and export production (nutrients, ballasting).

Little influence on primary and export production

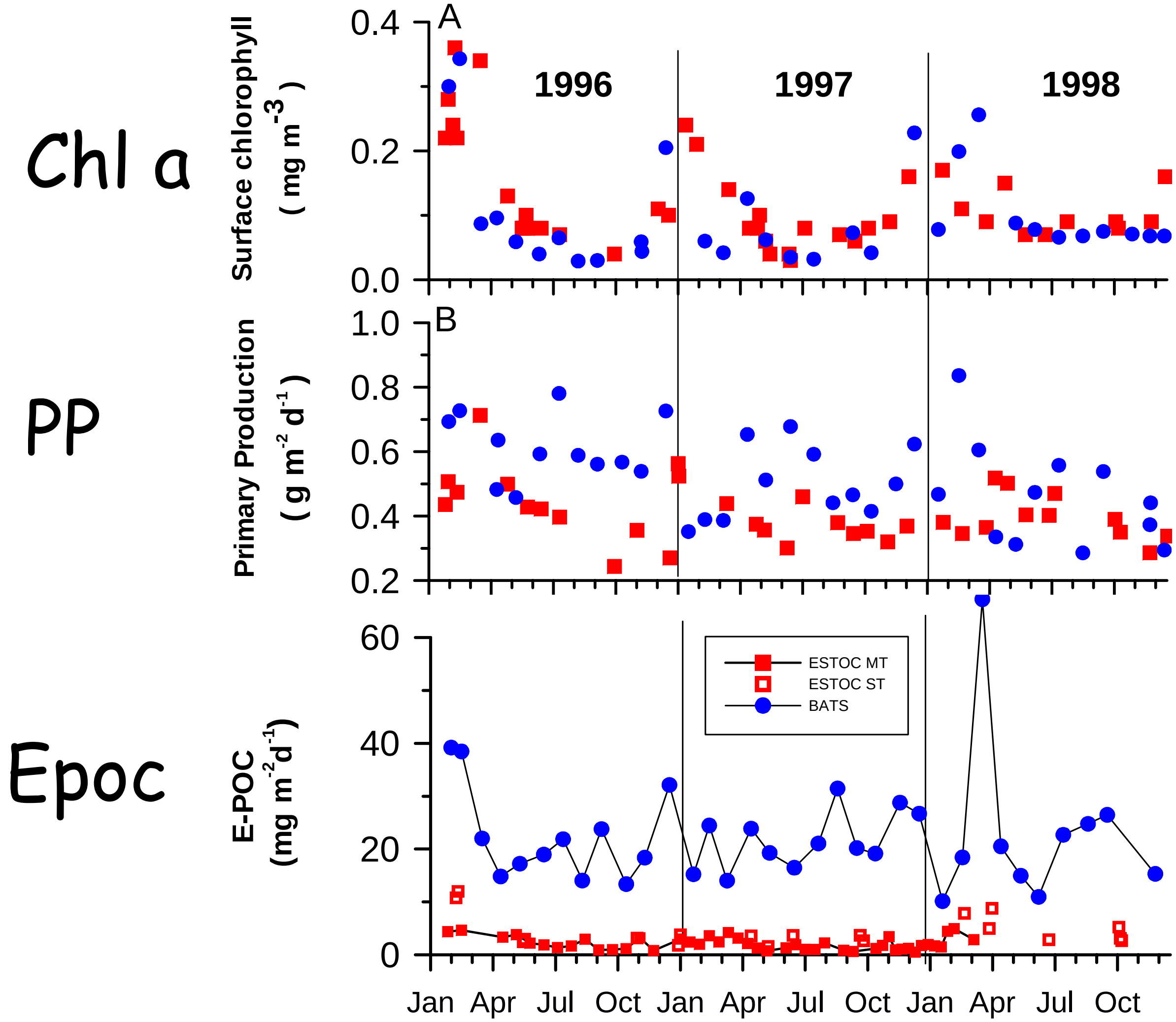
Feast/famine situation imposed by highly episodic iron

Ballasting effect: rather small

ESTOC

- Hypothesis 2: Export ratio scales with input of 'new' nutrients

Seasonality of surface chlorophyll, integrated primary production and export production at ESTOC and BATS



Neuer et al., GRL, 2002

Yearly integrated PP, E_{POC} and ER (E_{Poc} /PP) for ESTOC and BATS

	PP mol C m^{-2} yr^{-1}		E_{POC} mol C m^{-2} yr^{-1}		ER	
	BATS	ESTOC	BATS	ESTOC[a]	BATS	ESTOC[b]
1996	16.3	11.9	1.4	0.24 / 0.16	0.086	0.017
1997	13.3	12.0	1.3	0.16 / 0.16	0.098	0.013
1998	13.9	11.7	0.7	-- / 0.20	0.050	0.017
AVG	14.5	11.9	1.1	0.2	0.08	0.016

[a]Shallow moored/surface tethered trap. Surface tethered trap value of 1996 and 1997 composite of both years [b] Mean of moored and surface tethered traps.

Neuer et al., GRL, 2002

What we would expect…

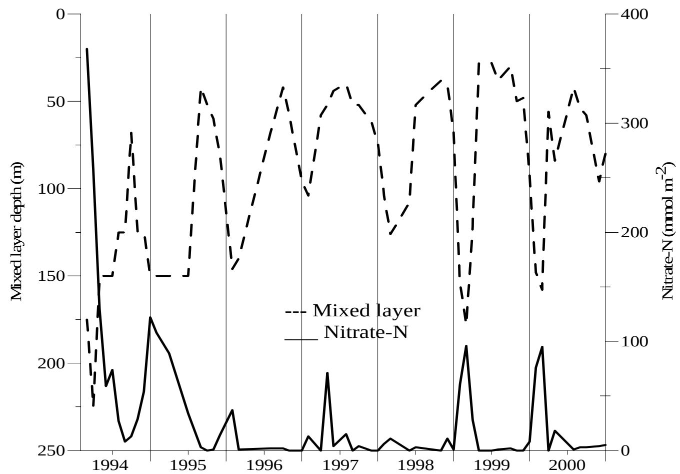
- When averaged over appropriate spatial and temporal scales, new production is equal to export production.
- Thus, under steady-state conditions, one would expect the ratio of new to total production (*f*-ratio) to be equivalent to the export ratio (ER)

What does that mean…

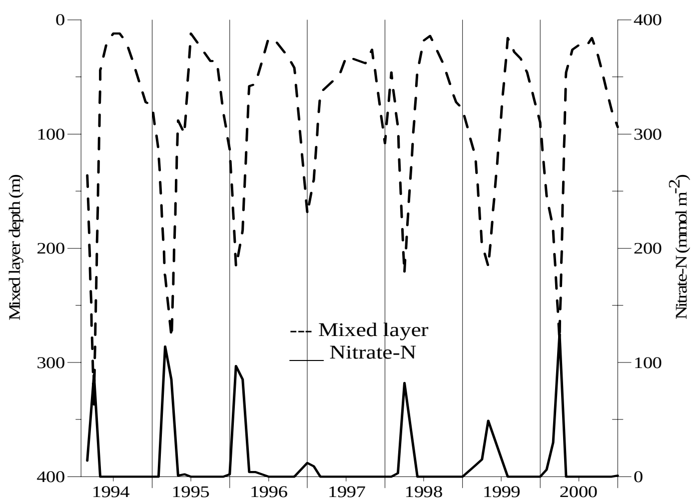
- Does a lower ER at ESTOC also imply lower input of new nutrients into the mixed layer compared to BATS?
- Three main sources of new nutrients:
  - Wintertime convective mixing
  - Mesoscale eddies
  - Nitrogen fixation

Mixed layer depth and Nitrate-N input at ESTOC and BATS

ESTOC



BATS



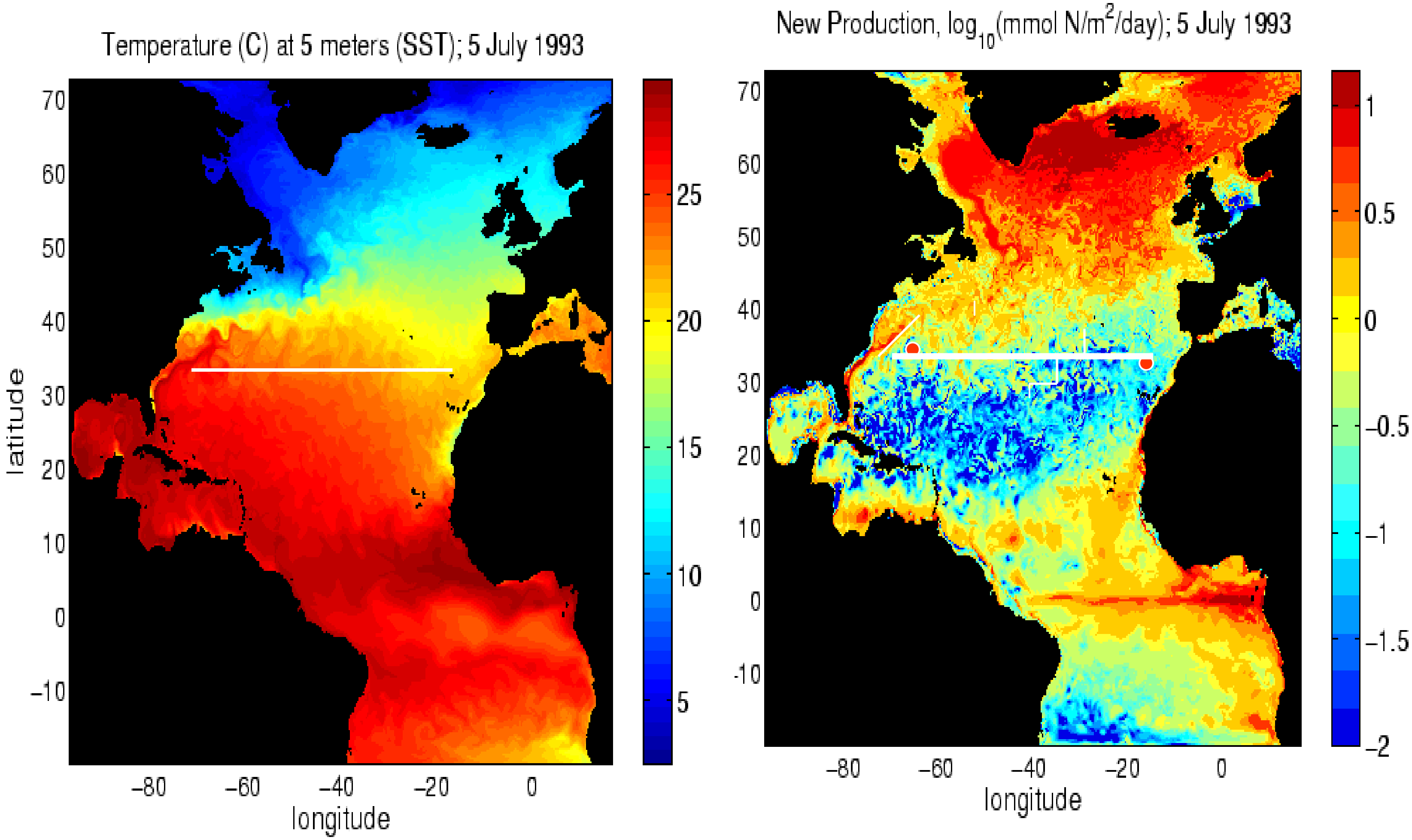
Cianca et al., in prep.

New Production based on nitrate draw down and mesoscale eddy Activity at ESTOC and BATS

	Nitrate draw down (mol N/m2/yr)	Eddy-induced nitrate input[a] (mol N/m2/yr)
ESTOC	**0.03 - 0.2**	0.02
BATS	**0.07- 0.2**	0.12

What does that mean…

- Does a lower ER at ESTOC also imply lower input of new nutrients into the mixed layer compared to BATS?
- Three main sources of new nutrients:
  - Wintertime convective mixing
  - Mesoscale eddies
  - Nitrogen fixation



Snapshots of temperature and new production in a 0.1 degree resolution simulation of the North Atlantic

(McGillicuddy et al., GBC, 2004)

New Production based on nitrate draw down and mesoscale eddy Activity at ESTOC and BATS

	Nitrate draw down (mol N/m2/yr)	Eddy-induced nitrate input[a] (mol N/m2/yr)
ESTOC	0.03 - 0.2	**0.02**
BATS	0.07- 0.2	**0.12**

ESTOC

- Hypothesis 2: Export ratio scales with input of 'new' nutrients

Yes, low export production at ESTOC is accompanied by a lower input of new nutrients compared to BATS
(by mesoscale eddy activity and nitrogen fixation)

AND: Lower input of new nutrients does not necessarily result in lower PP (or biomass) but influences the removal efficiency (export ratio) of biologically produced carbon into the ocean's interior.

Conclusions

Time-series station ESTOC enables a view into "the other side" of the subtropical NAtlantic gyre (which is different)

Especially by inter site comparisons can we learn and test hypotheses on biogeochemical processes on a global scale and on multi-year time scales.

Andrés Cianca:

BATS and ESTOC: A comparison between Western and Eastern parts of the Subtropical Atlantic Ocean

Peer Helmke:

Vanished without a trace: sedimentation pulses in the deep sea, can we determine their origin?

NASA-EOS