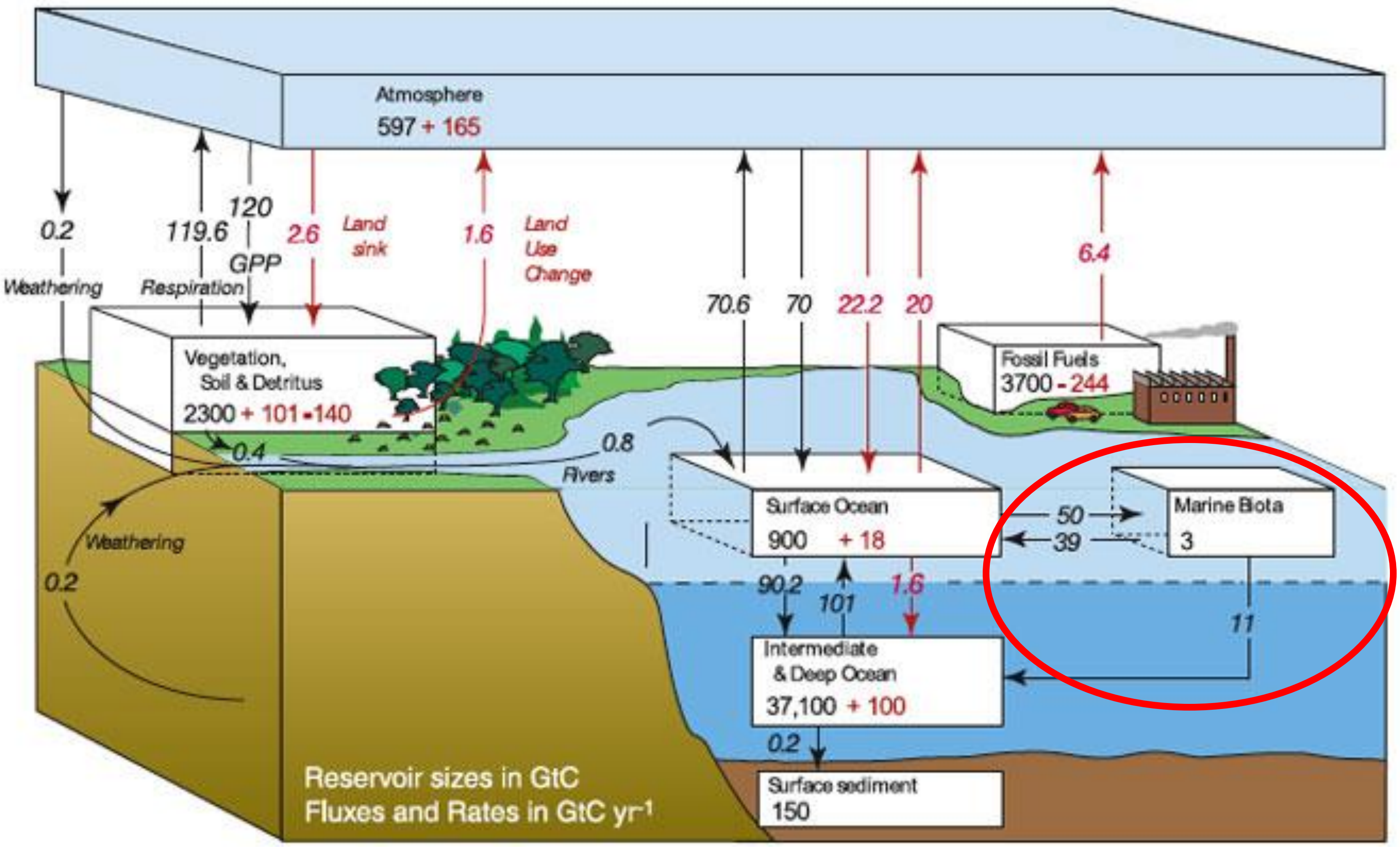
# Biological contributions to the ocean carbon cycle

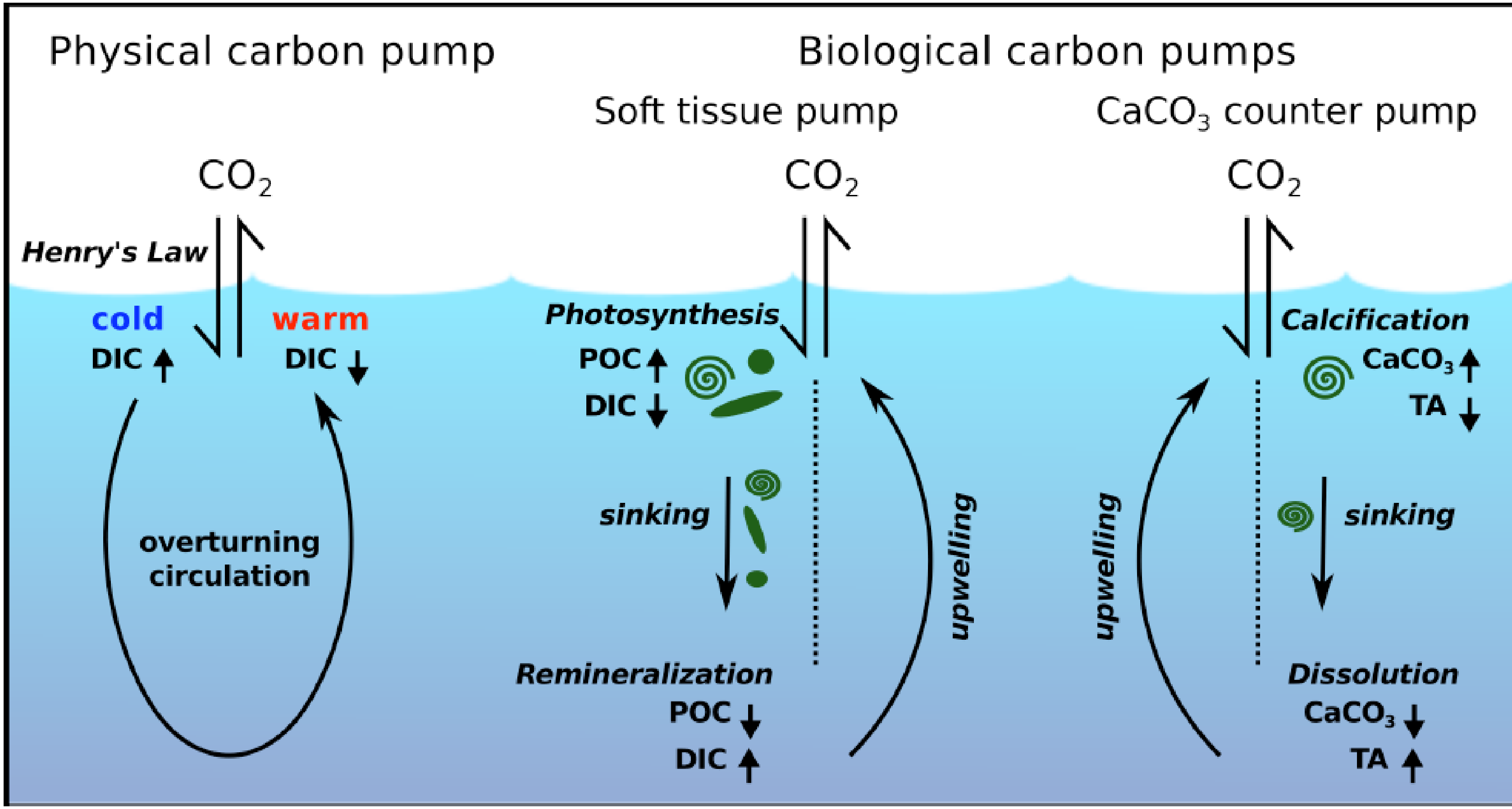
Stephanie Henson

s.henson@noc.ac.uk

# Global carbon cycle

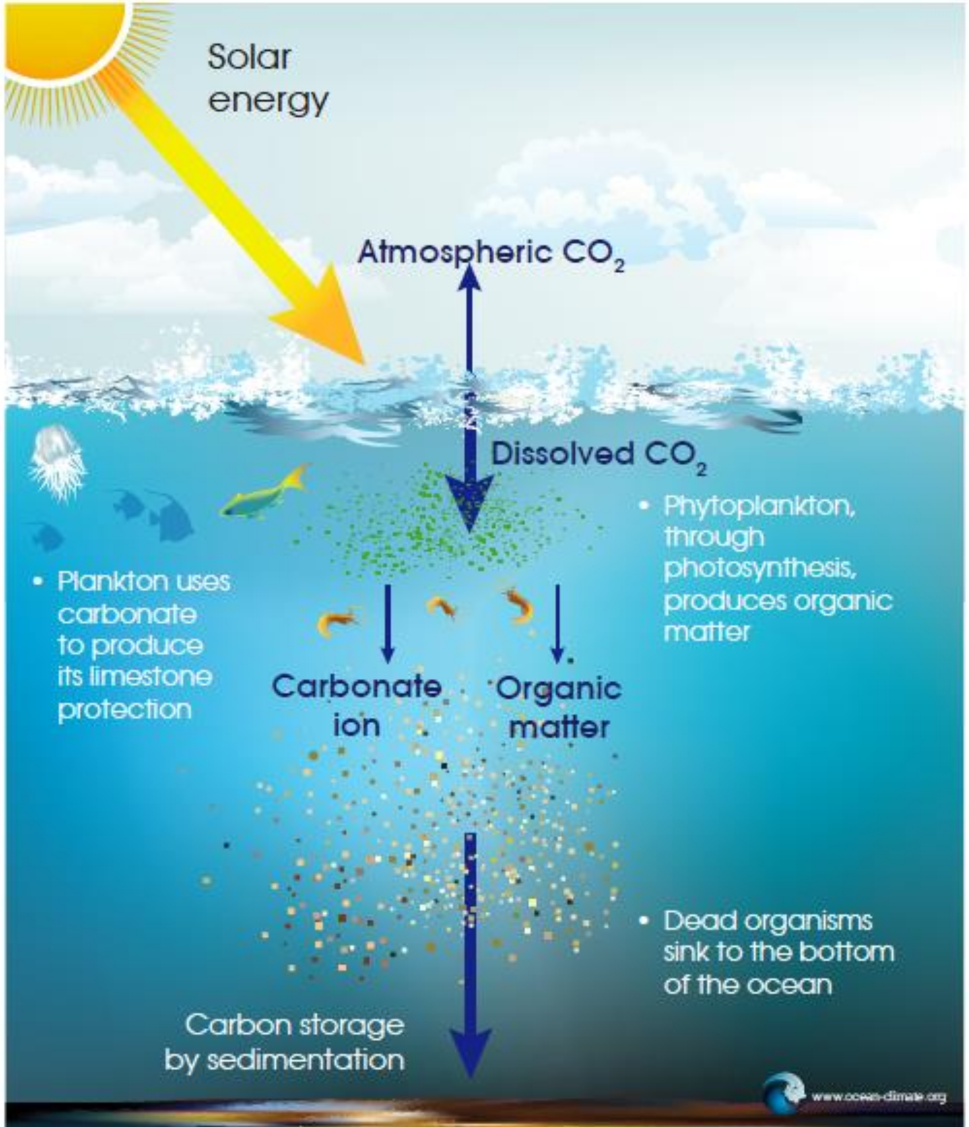


# 3 ocean carbon pumps



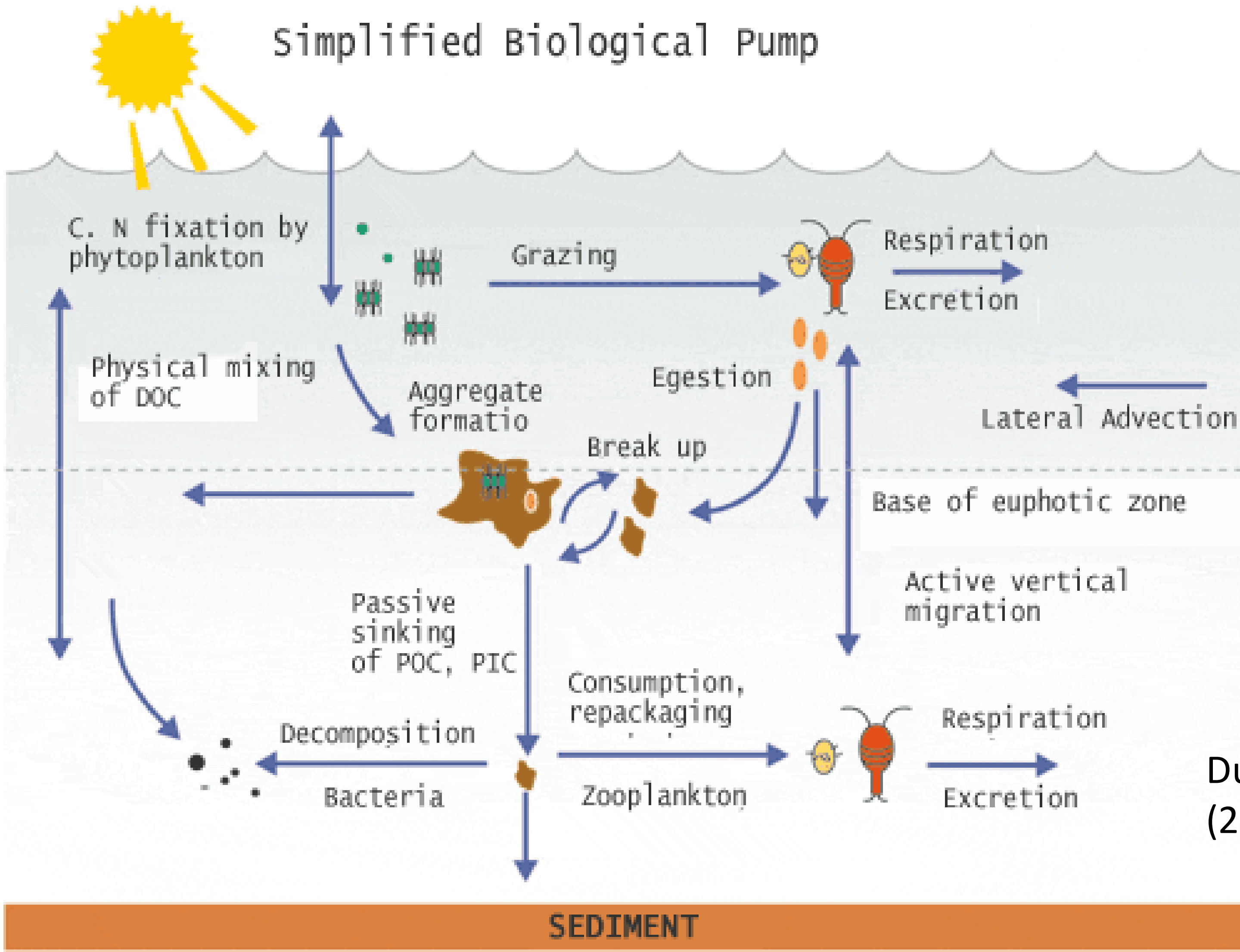

Heinze et al. (1991)

# The simple version



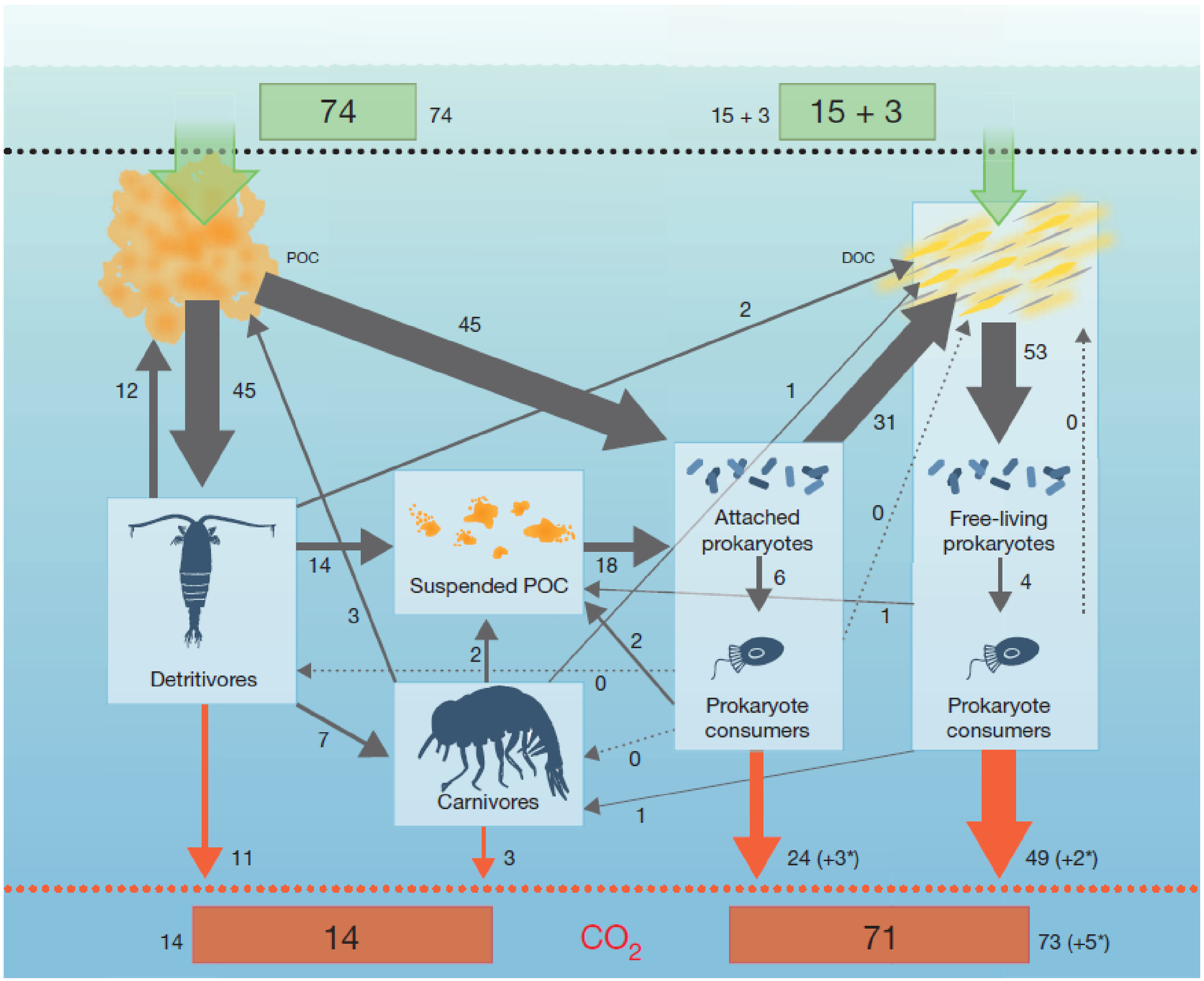

- Biological activity takes up CO2 and turns into organic matter
- Some of that carbon makes it into the deep ocean

# The slightly more complicated version



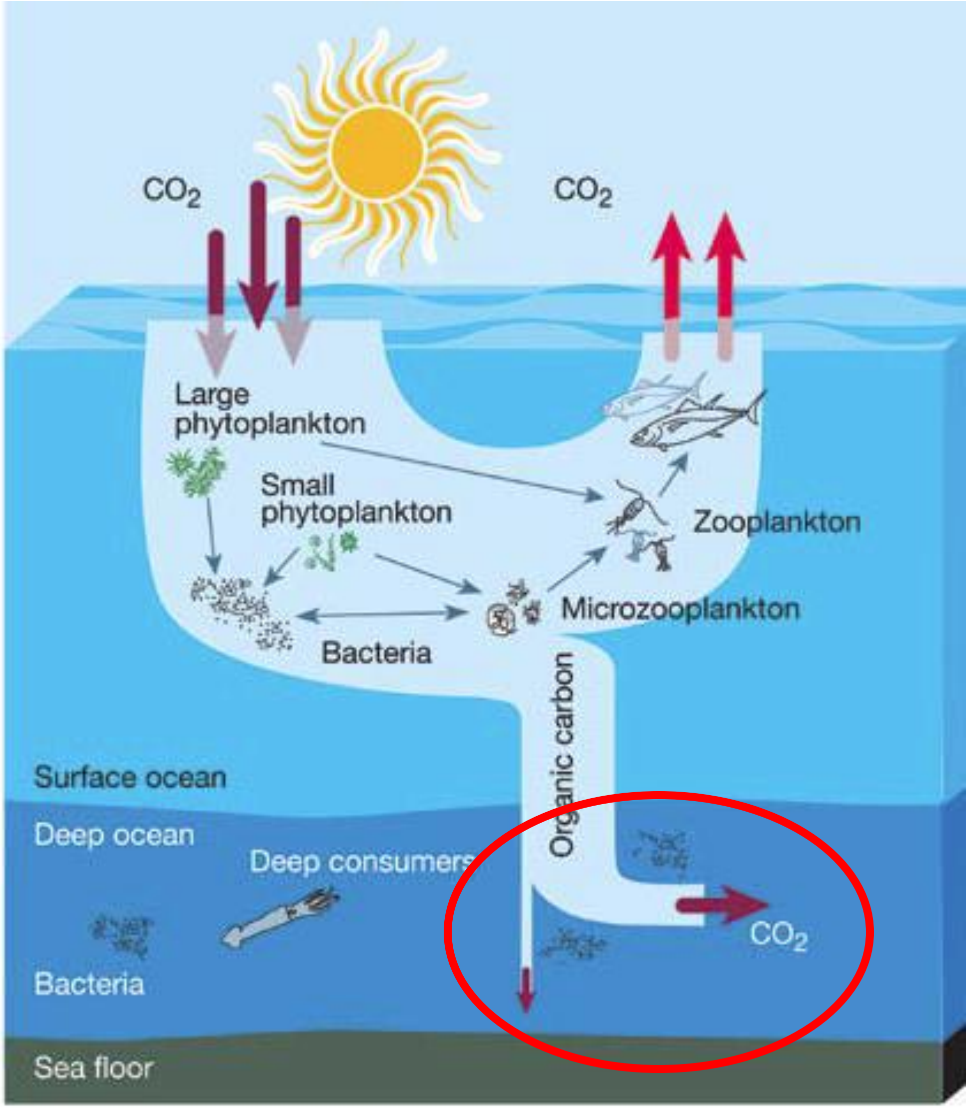

Ducklow et al. (2001)

# And more complicated….



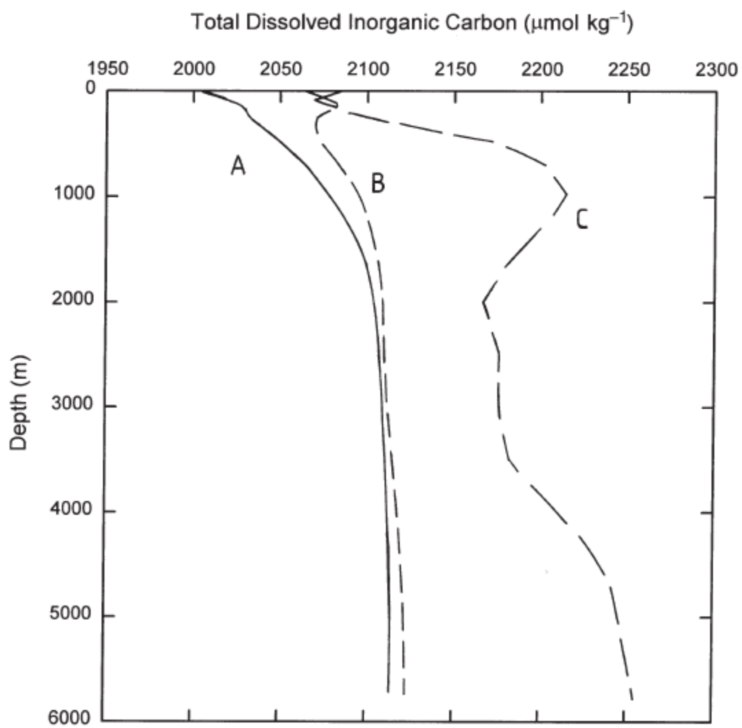

Giering et al. (2014), Nature

# The biological carbon pump




- Contributes to the long-term storage of carbon in the deep ocean
- Is driven by primary production by phytoplankton
- And modulated by the upper ocean food web
- Mesopelagic remineralisation is the key to the efficiency of this pump

# Why are we interested in the BCP?




Raven and Falkowski, 1999

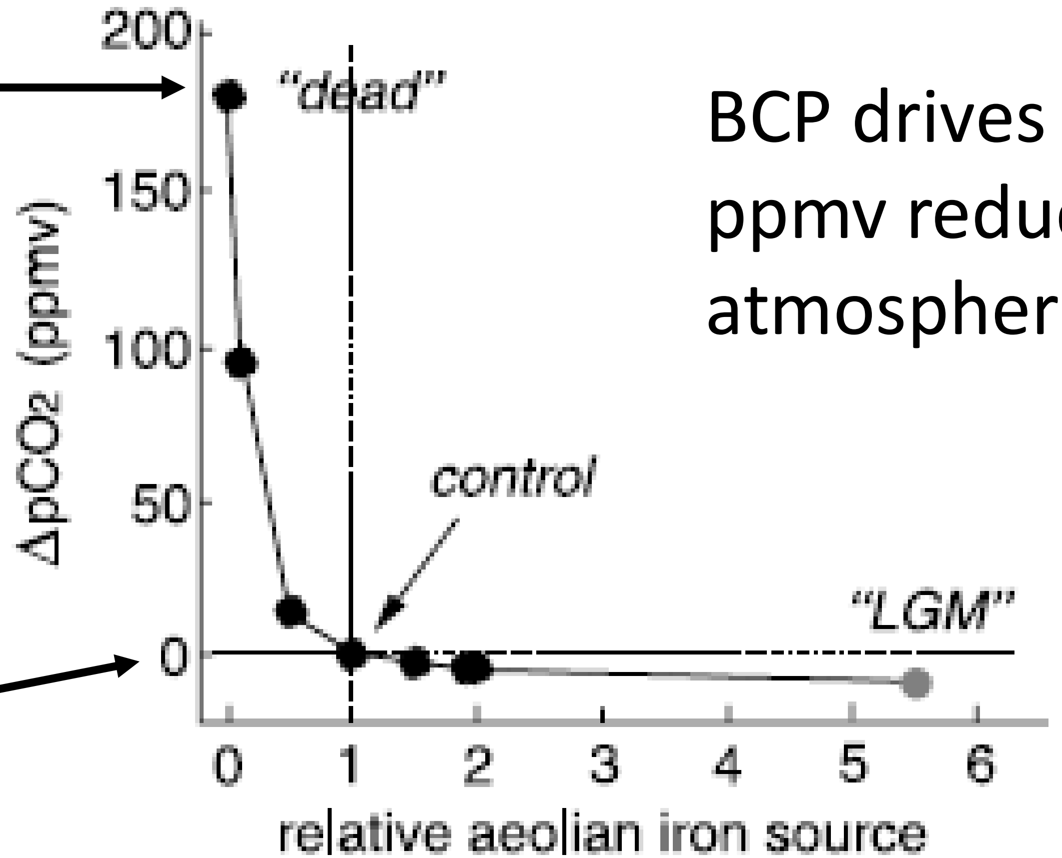
Approximately two-thirds of the vertical gradient in dissolved inorganic carbon in the ocean is attributed to the biological pump

A: DIC profile prior to Industrial Revolution (solubility only)
B: DIC profile in 1995, calculated on the basis of solubility only
C: Actual profile of DIC in 1995
The difference between B and C is the BCP contribution to the uptake of CO2

# Why are we interested in the BCP?

No BCP

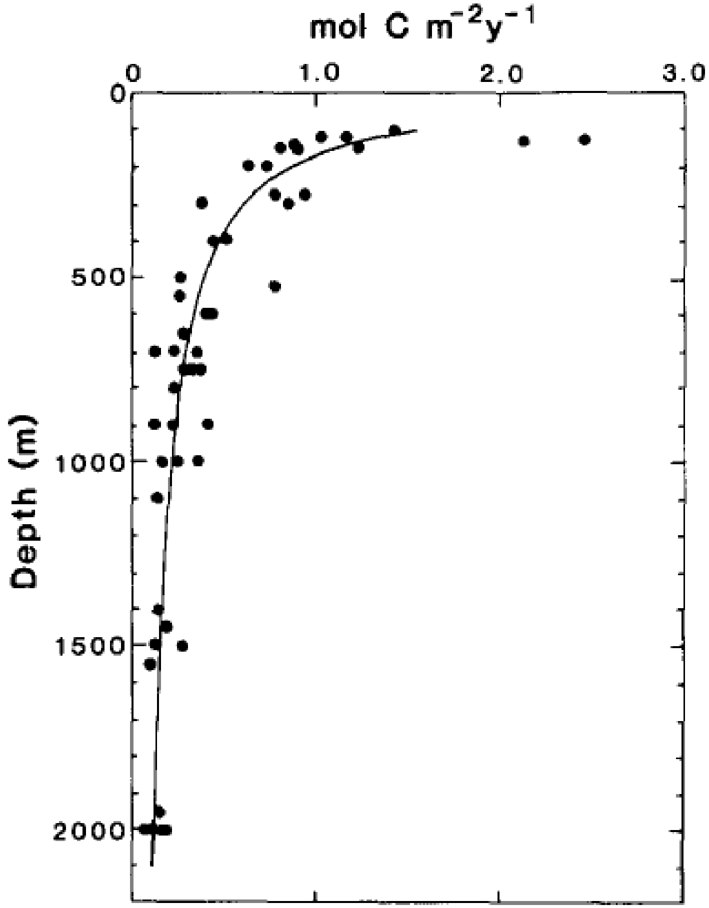
Modern BCP




BCP drives 200 ppmv reduction in atmospheric $pCO_2$

*Parekh et al., 2006, GRL*

# Attenuation of POC with depth fits the 'Martin curve'



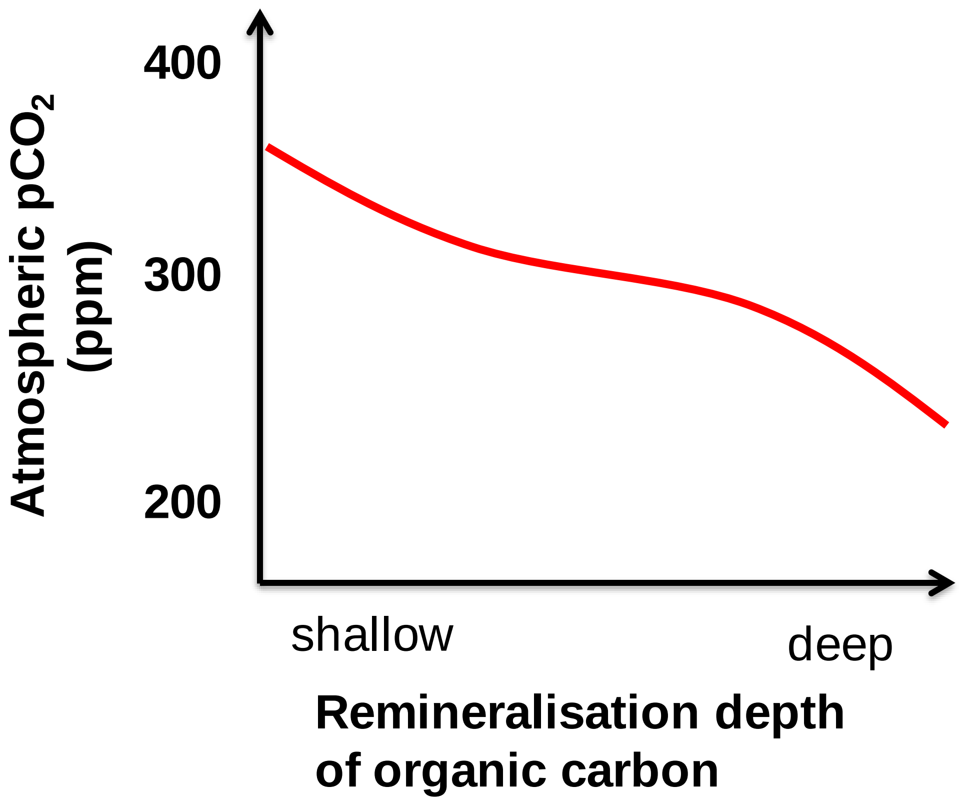

Martin et al. 1987, DSRA

$$f_z = f_{z_0}(z/z_0)^{-b}$$

"Martin's b" describes how rapidly flux decreases with depth

Remineralisation occurs through biological activity (zooplankton and bacteria)

# Importance to global C cycle




Atmospheric $CO_2$ concentration reduced if organic C is remineralised deeper

i.e. the biological carbon pump is *more efficient*

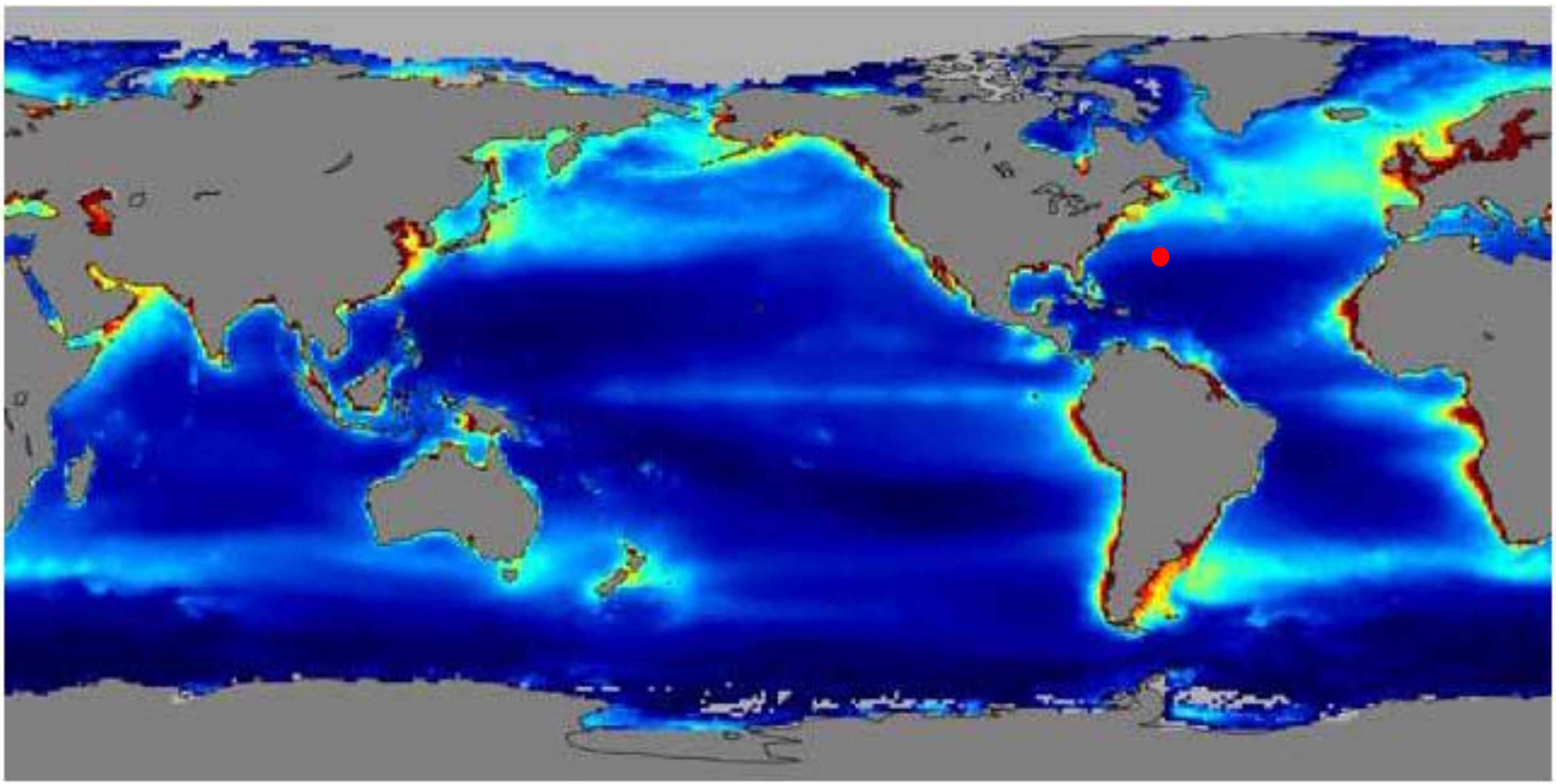
After Kwon et al. (2009), Nature Geo

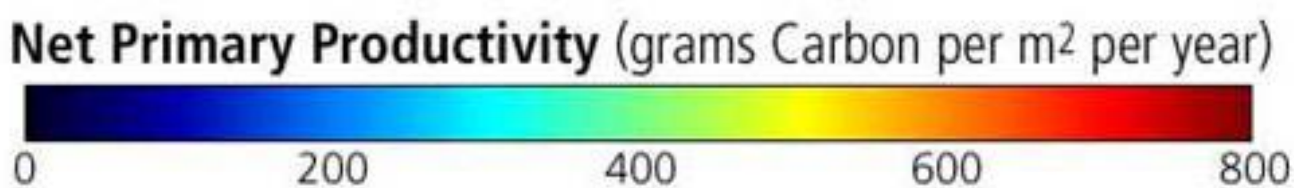
# Overview

1. How much carbon does biological activity in the surface ocean fix?
2. When/where does biological activity dominate $CO_2$ uptake?
3. How much organic carbon gets down to the deep ocean?
4. Why is there currently no net anthropogenic $CO_2$ uptake via the biological carbon pump?
5. Could that change in the future?

1. How much carbon does biological activity in the surface ocean fix?

# Ocean primary production

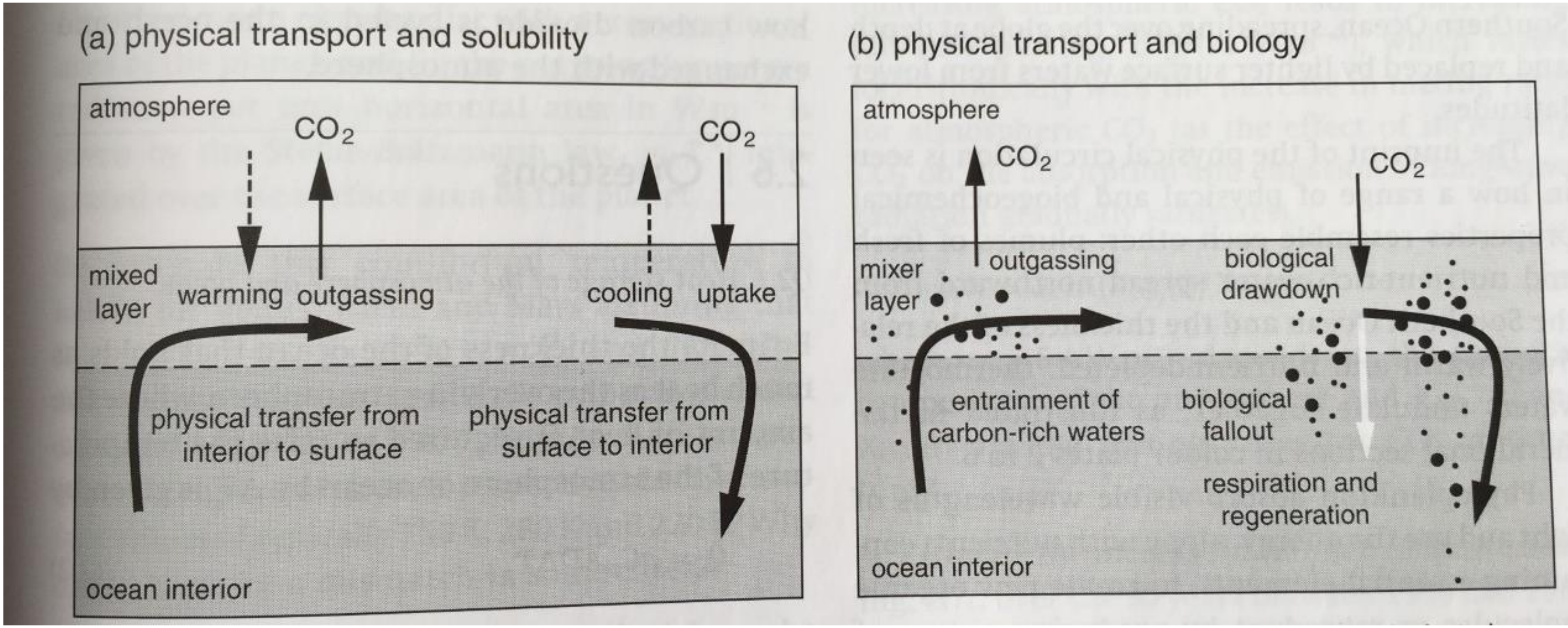





Total of
50-60 Gt C

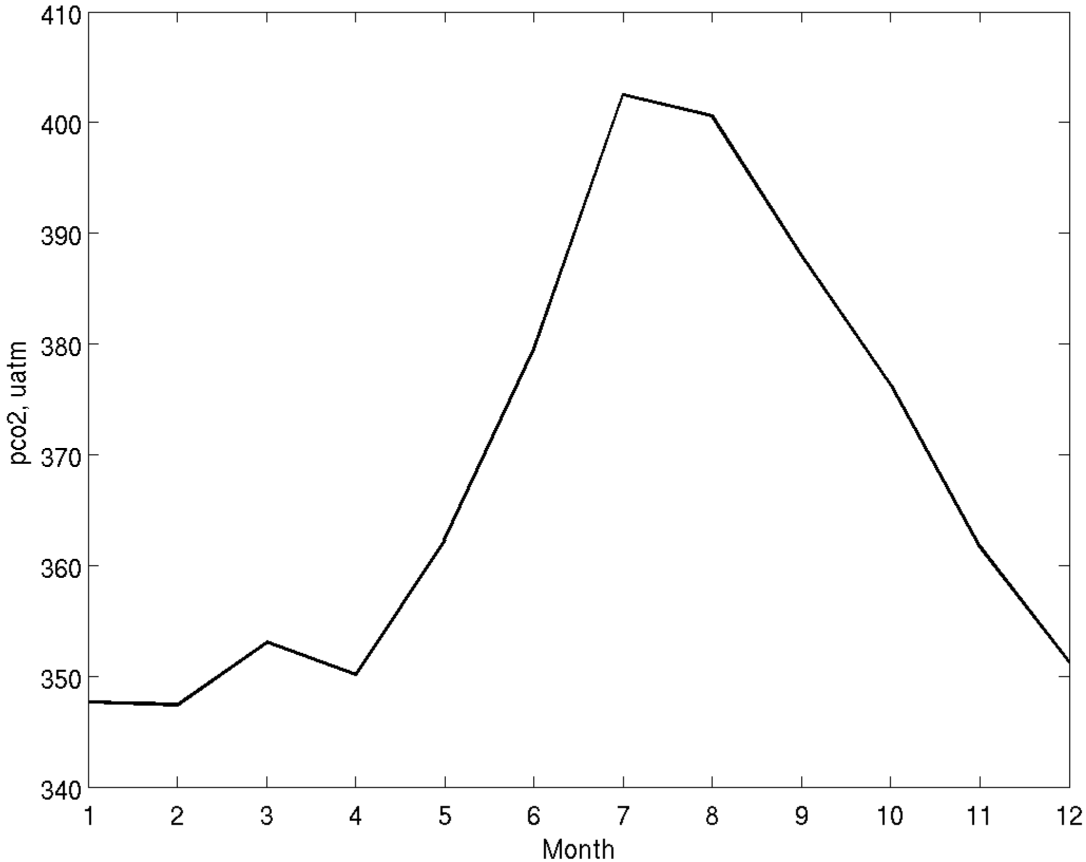
# 2. When/where does biological activity dominate $CO_2$ uptake?

# What controls pCO2?




Williams and Follows, 2011, ‘Ocean dynamics and the carbon cycle’

# Seasonal cycle of pCO2 in subtropical North Atlantic



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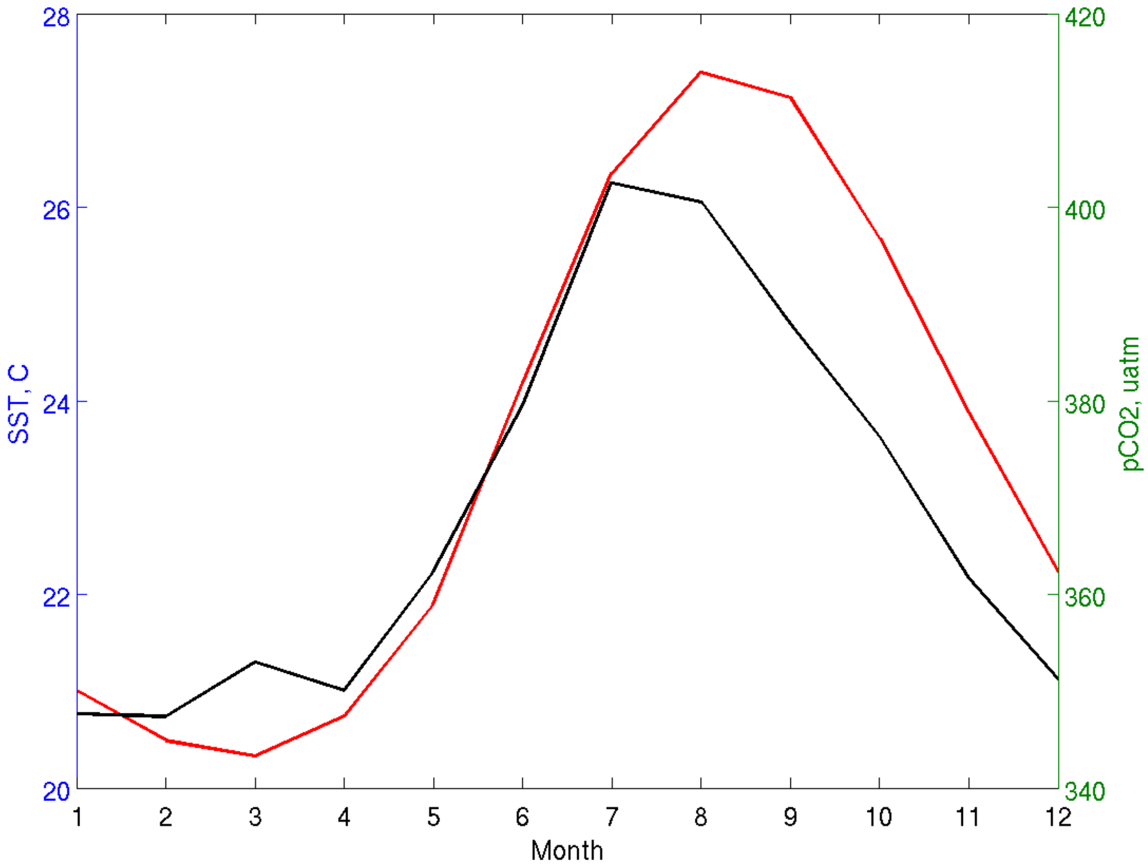
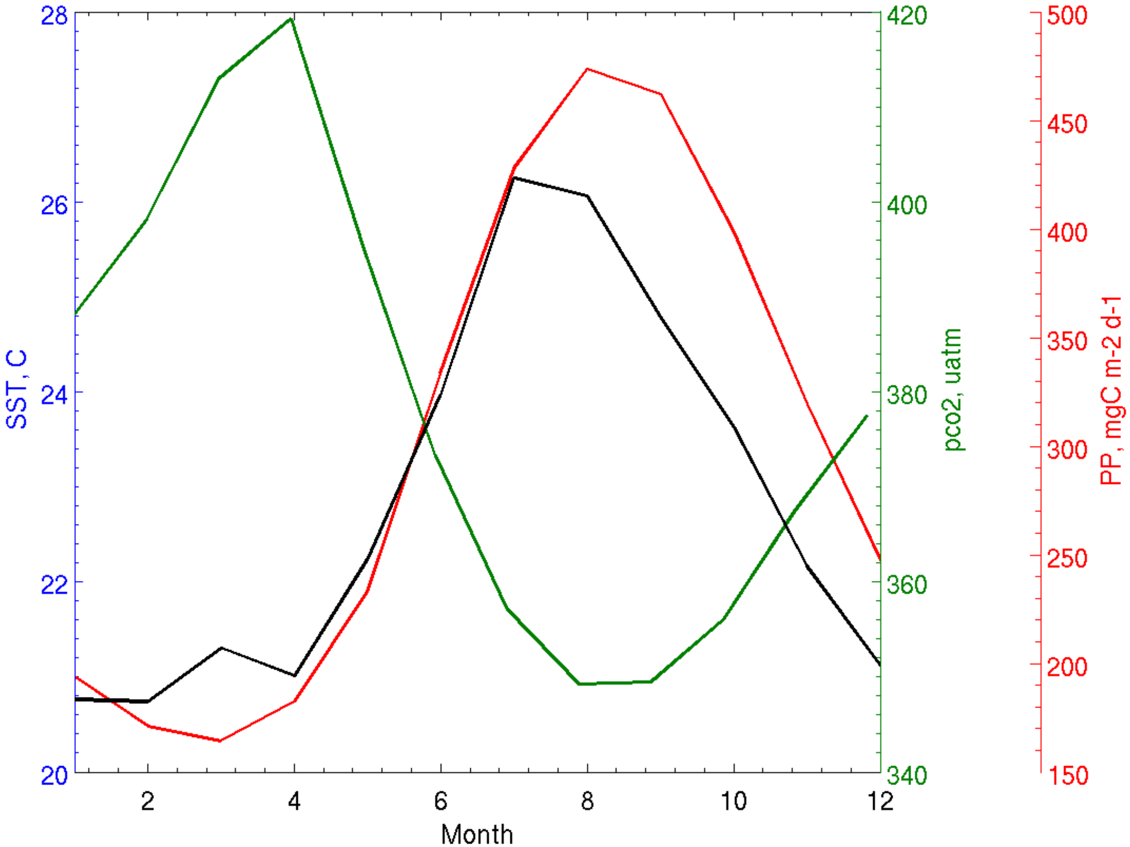


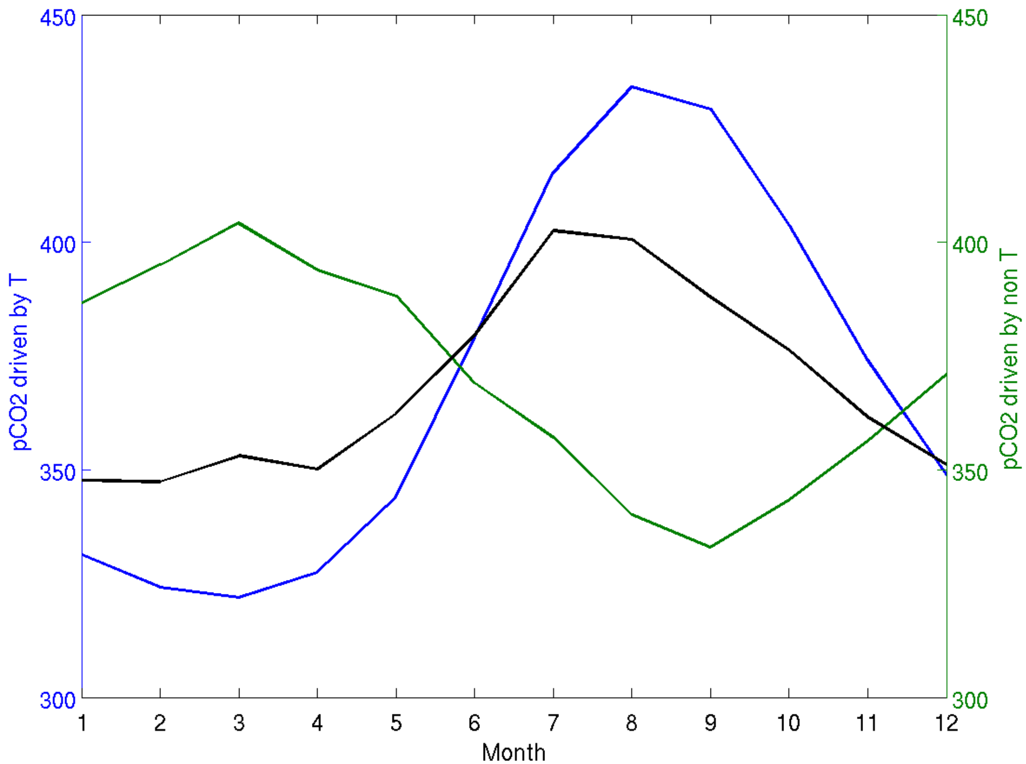

Black – pCO2
Red - SST

# Seasonal cycle of pCO2 in subtropical North Atlantic




Black – pCO2
Red – SST
Green - PP

# Seasonal cycle of pCO2 in subtropical North Atlantic

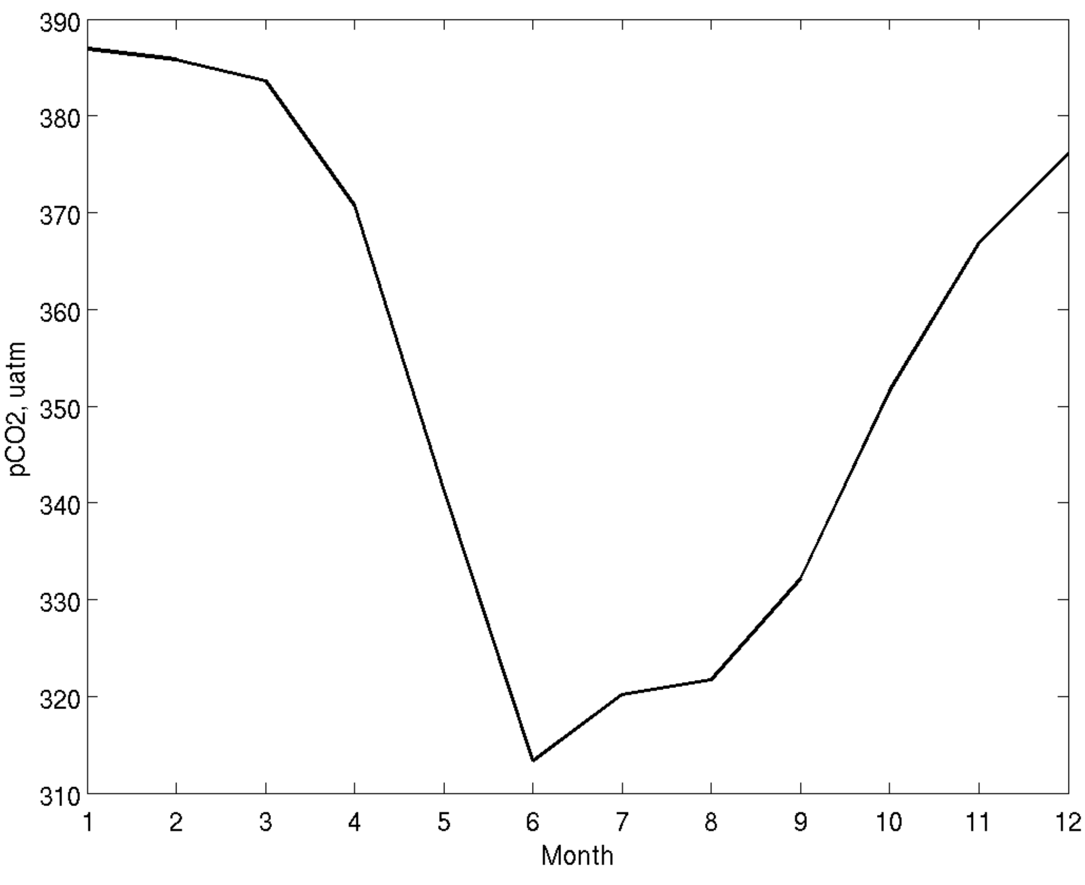



Black = pCO2

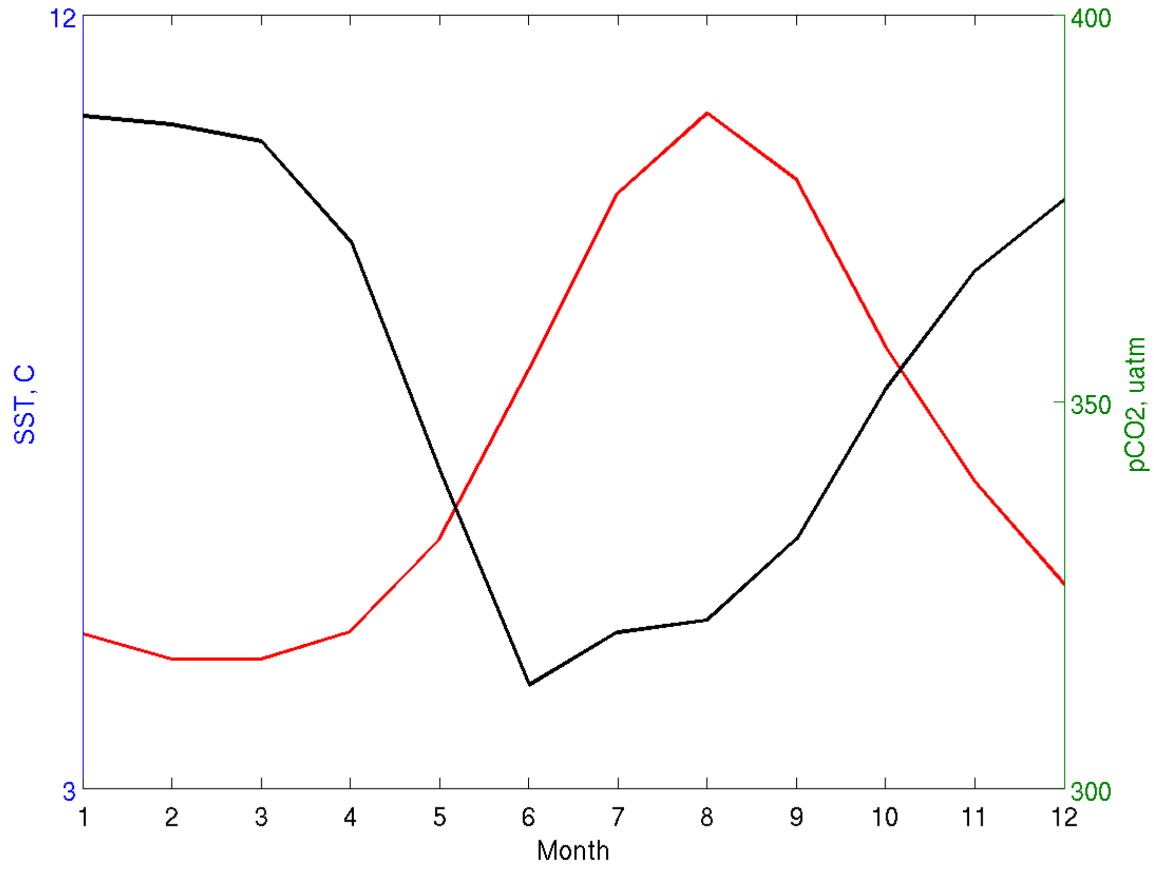
Takahashi et al. (2002), DSR II

- Include seasonal cycle in SST and calculate pCO2 (blue) – gets the seasonal change right
- Keep SST constant and calculate pCO2 (green) – can't capture the seasonal changes

# Seasonal cycle of pCO2 in subpolar North Atlantic



# Seasonal cycle of pCO2 in subpolar North Atlantic

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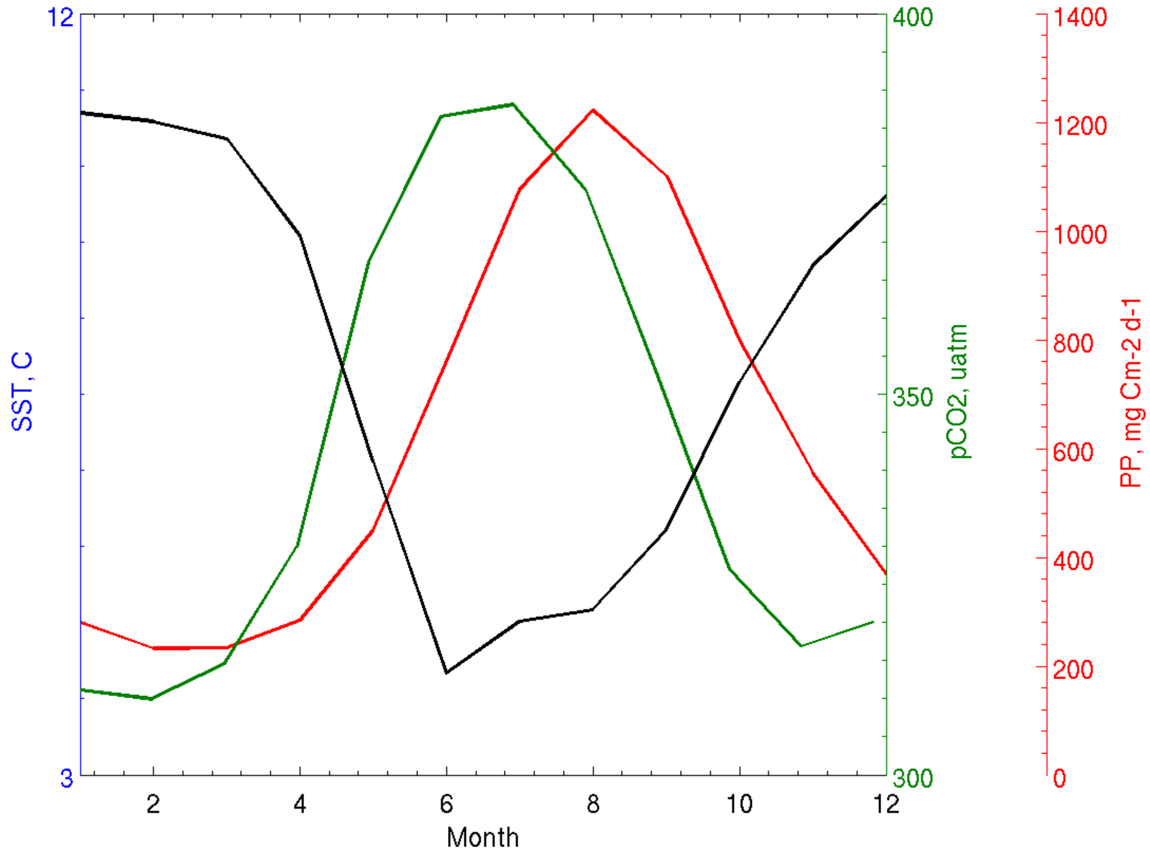


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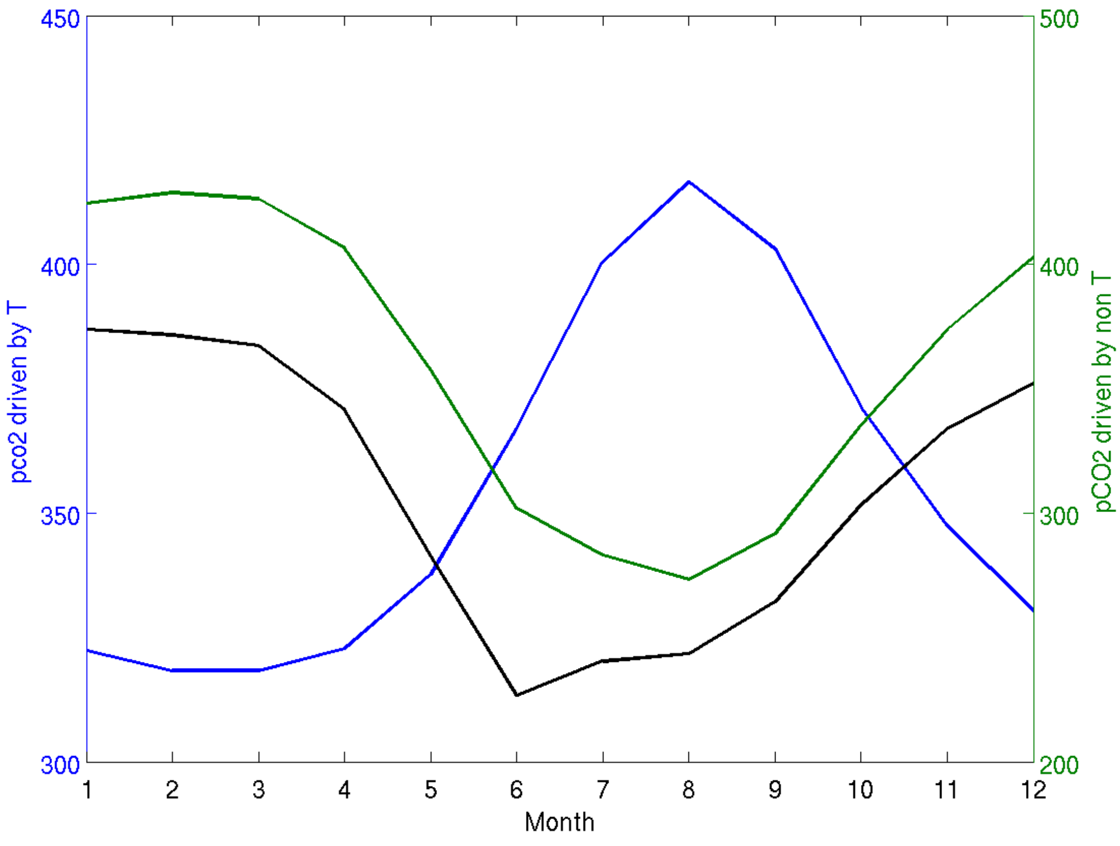
# Seasonal cycle of pCO2 in subpolar North Atlantic

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Takahashi et al. (2002), DSR II

- Include seasonal cycle in SST and calculate pCO2 (blue) – doesn't get seasonal change right
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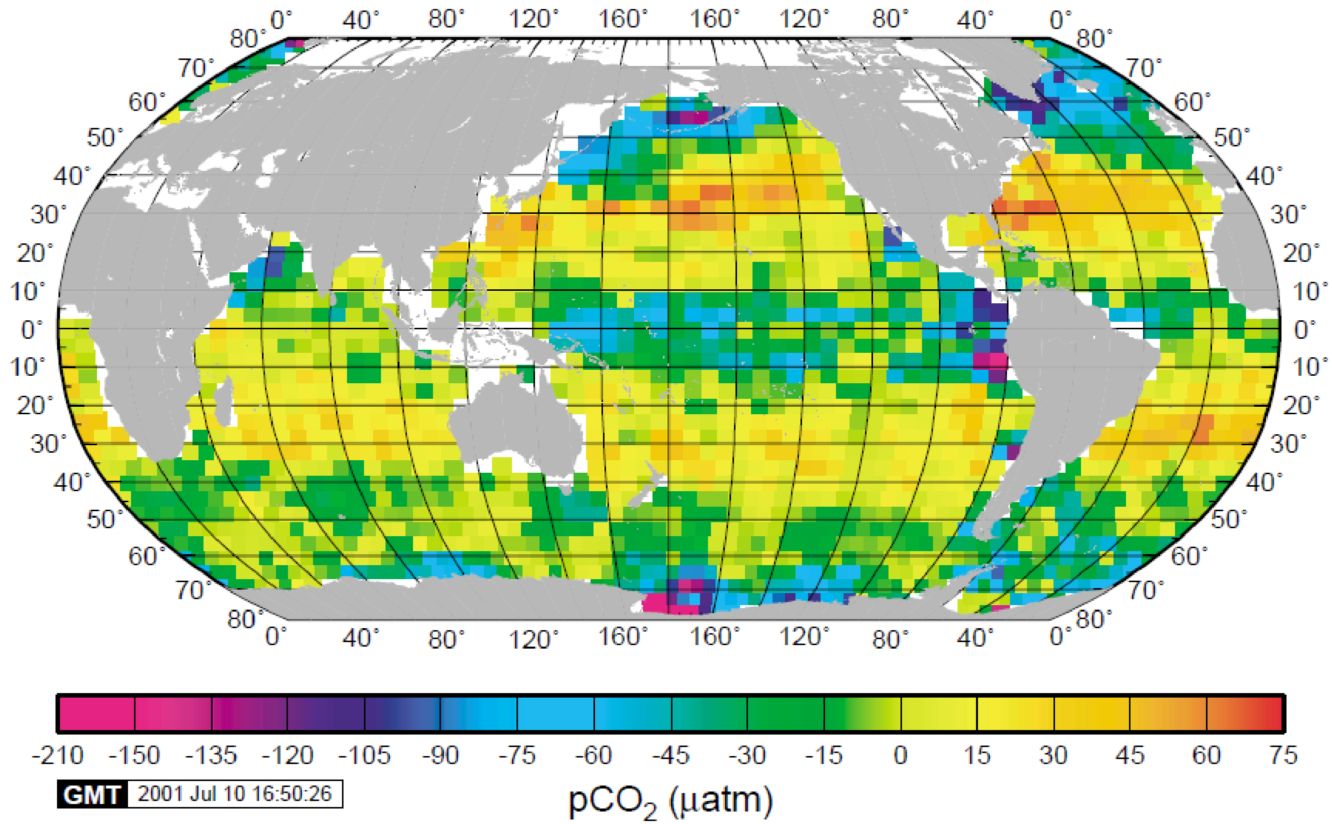
# SST vs biology



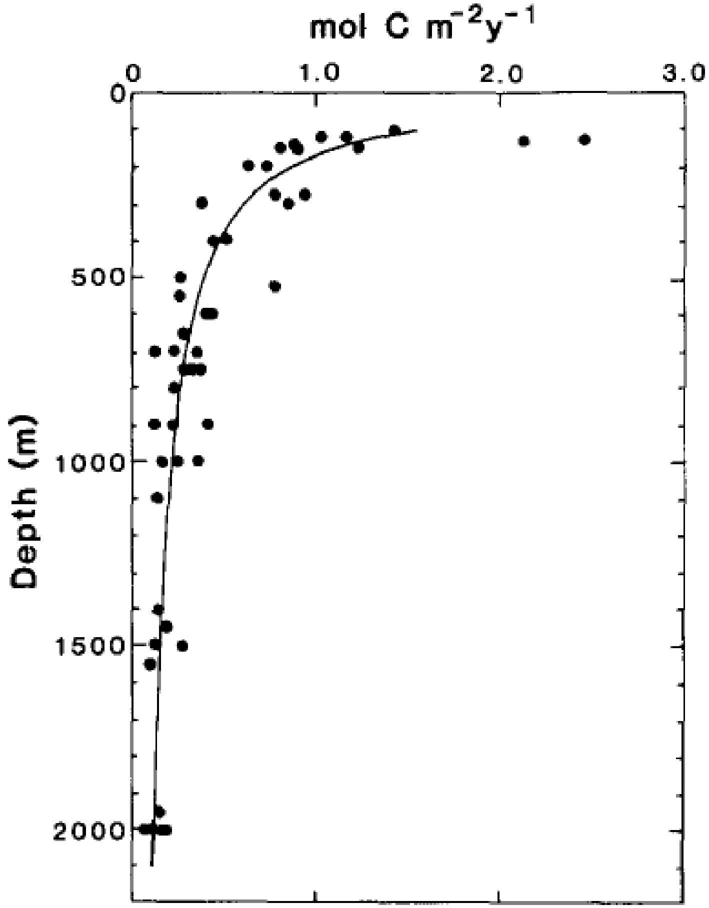

Difference between effects on pCO2 of seasonal change in SST and biology.

Positive: temperature > biology; Negative: biology > temperature

Takahashi et al. (2002), DSR II

# 3. How much organic carbon gets down to the deep ocean?

# Attenuation of POC with depth fits the 'Martin curve'




The depth that organic carbon is remineralised determines ~ timescales of storage.  Shallower depth = $CO_2$ re-exchanged with atmosphere sooner.

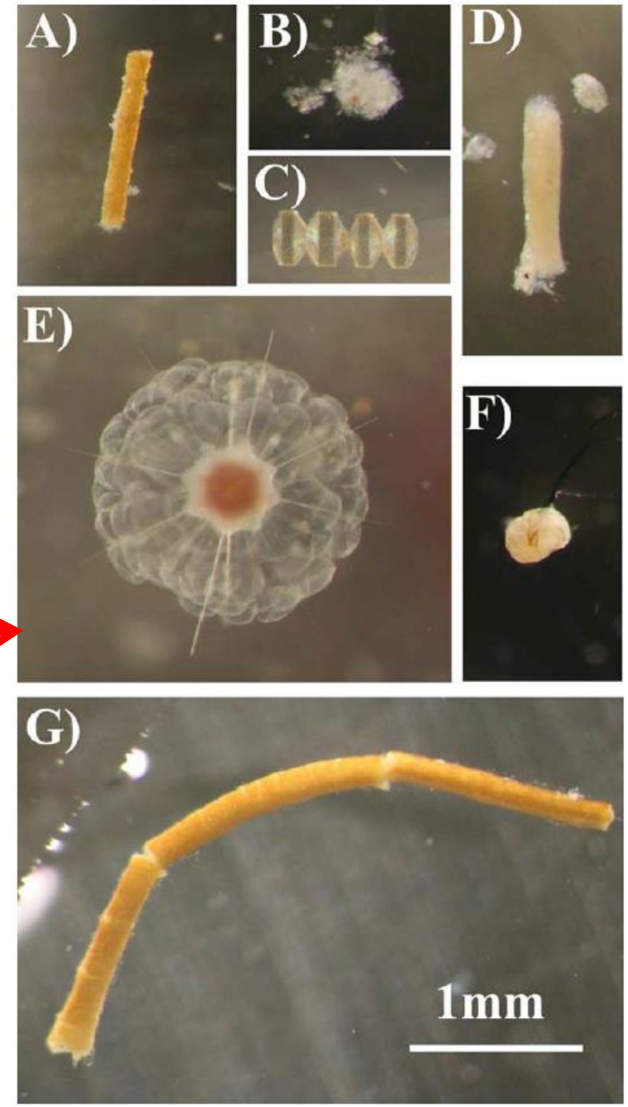
Want to know how much carbon is lost through respiration and at what depth

Martin et al. 1987, DSRA

# How do we measure the sinking organic carbon?

# More than meets the eye….

Sinking material sample from NE Atlantic ~ 600 m depth

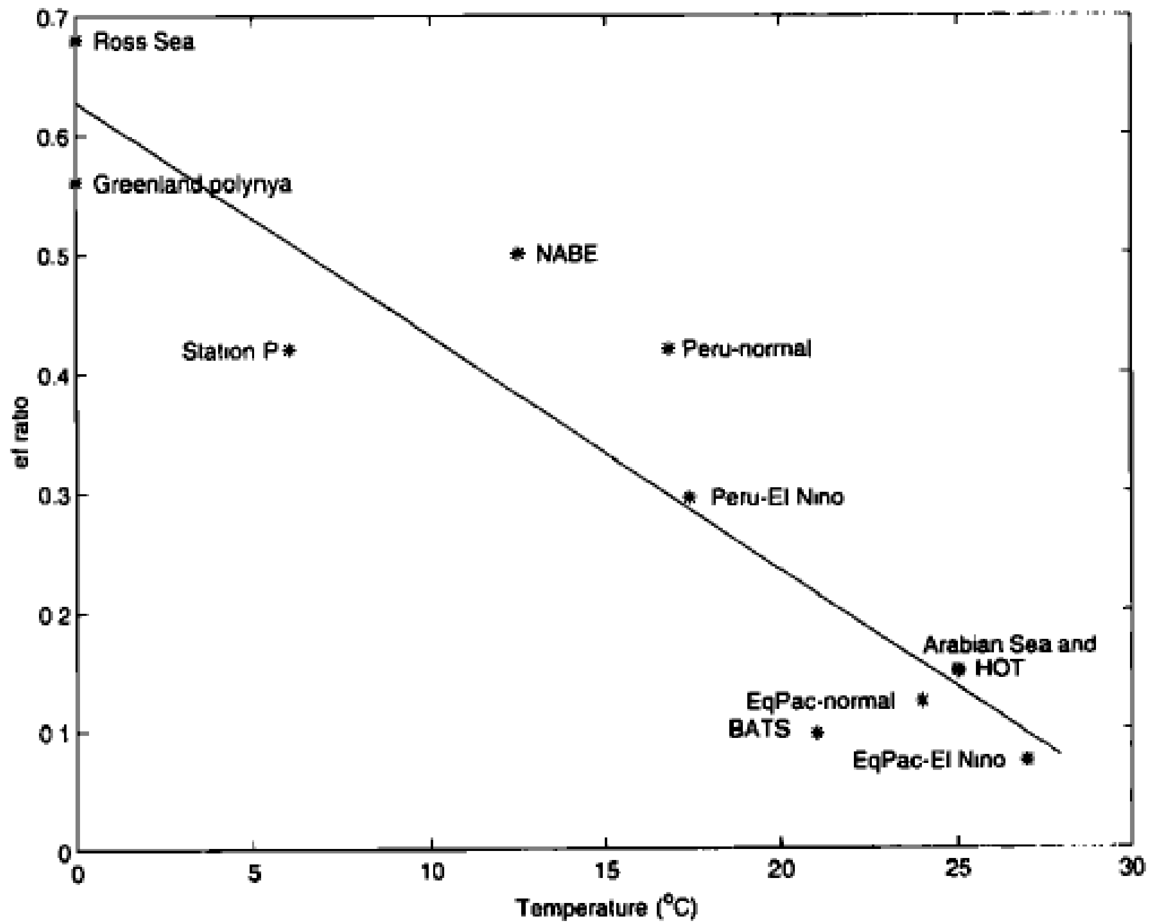



Belcher et al. (2016), L&O

# How do we measure the sinking organic carbon?

- Snapshots of flux
- The ocean is BIG and undersampled
- Need to extrapolate in situ observations to global scale to assess magnitude of the pump
- Look for proxies which can be measured on global scale – typically satellite data

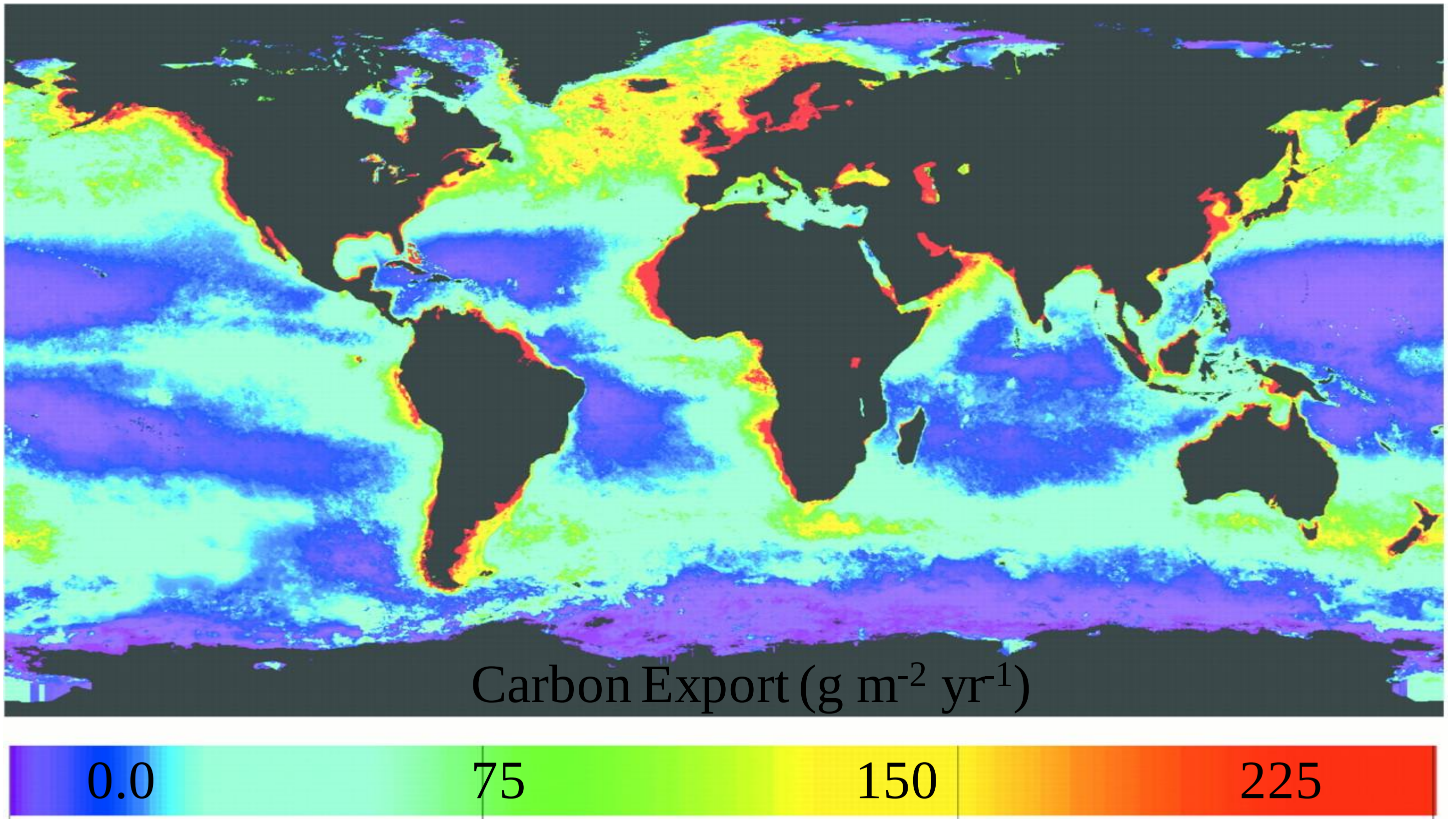
# Scaling up – proxies




Laws et al. (2000), GBC

- Database of measurements…
- Use satellite data to estimate global export

# Biological C export




Derived from satellite data using algorithms based on 11 sites

Integral = ~ 12 GT C $yr^{-1}$

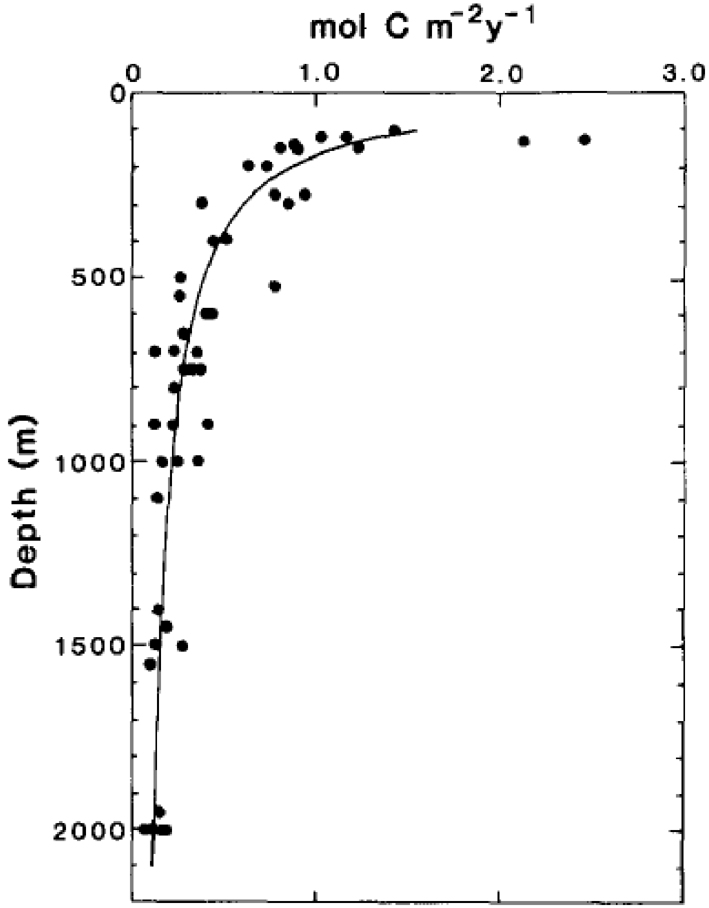
Laws et al., 2000, GBC

# Comparison to other estimates

| **Method** | **Value (GT C $yr^{-1}$)** | **Reference** |
|---|---|---|
| Sediment trap extrapolation | 10 | *Lampitt and Antia, 1997* |
| f-ratio | 20 | *Eppley and Peterson, 1979* |
| Data analysis | 10 | *Dunne et al., 2007* |
| f-ratio & SST | 12 | *Falkowski et al., 1998*<br>*Laws et al., 2000* |
| Inversion of nutrient data | 10 | *Schlitzer, 2004* |
| ThE-SST | 5 | *Henson et al., 2011* |

Magnitude of massive C flux in earth system still uncertain

# How efficient is the biological C pump?

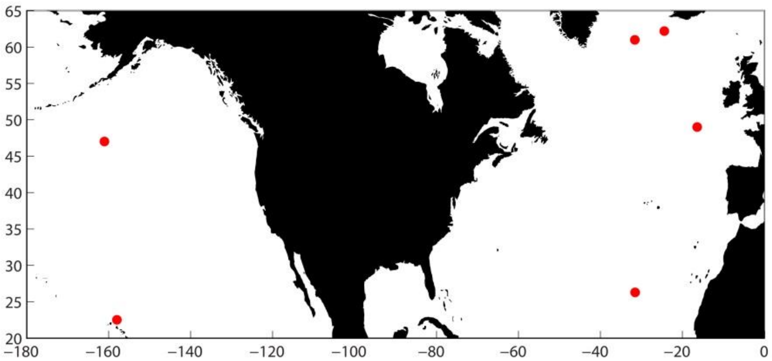


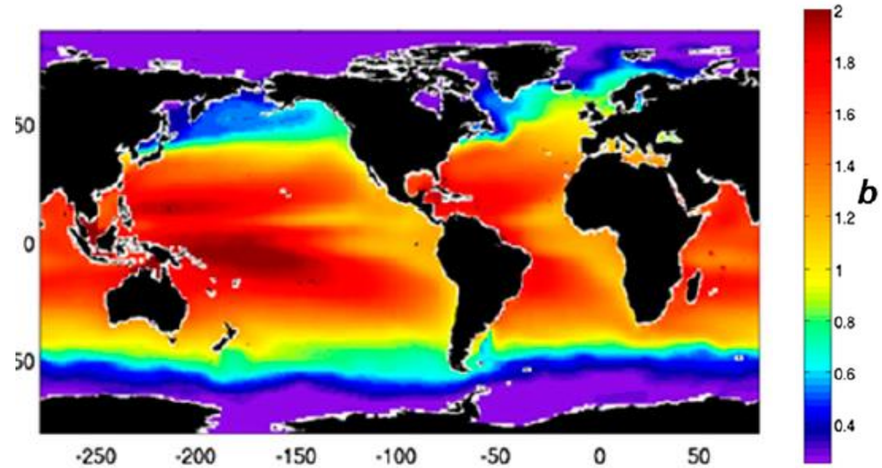

$$f_z = f_{z_0}(z/z_0)^{-b}$$

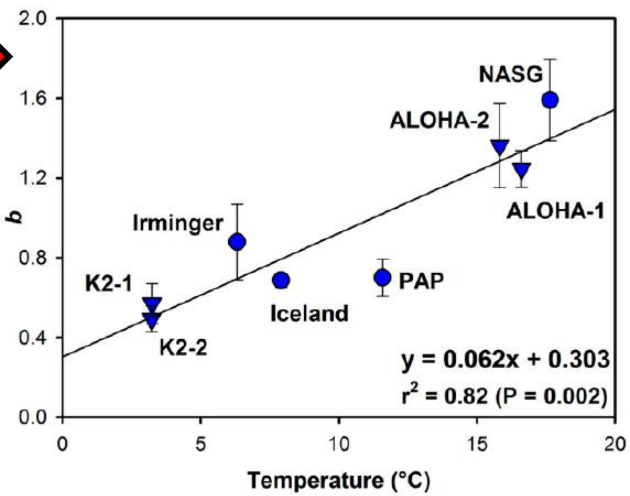
One measure is "b"

"Martin's b" describes how rapidly flux decreases with depth

# The global database of direct measurements of b




Empirical algorithms for BCP efficiency derived from limited in situ data.

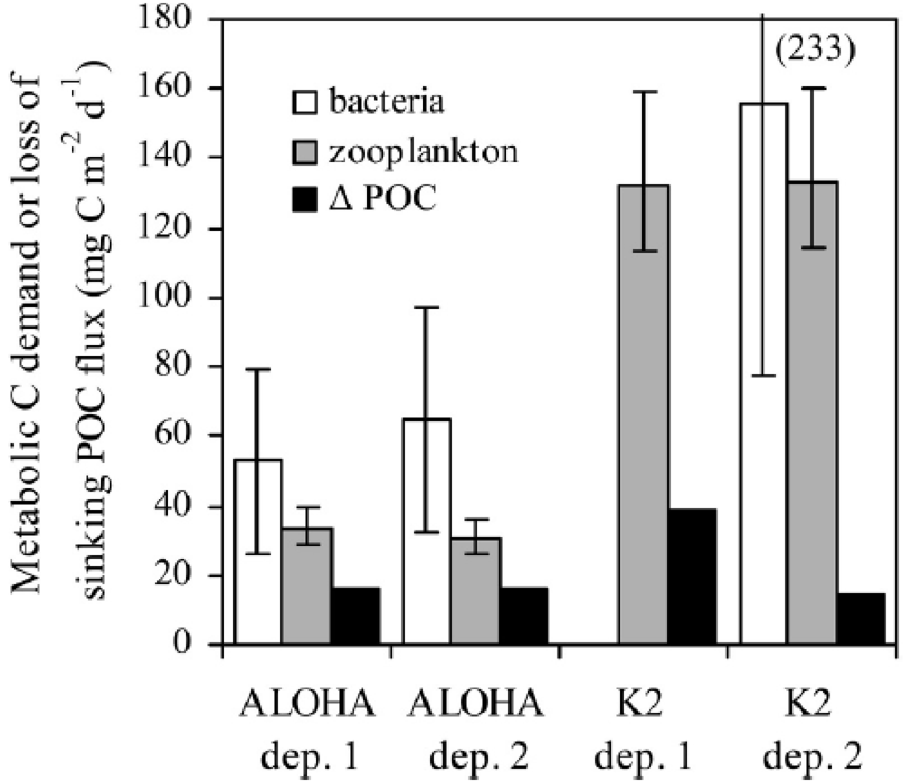
Marsay et al. (2015), PNAS

# How efficient is the biological C pump?

- One measure is to compare how much C enters the mesopelagic to how much leaves it
- Similar issue with undersampling and need for extrapolation
- Estimates of global deep organic C flux also have a big range: 0.2-1.6 PgC/year (Henson et al. 2012, GBC)

→ efficiency could be anywhere from 1-35% (global average)

# If we understood all the processes going on, this wouldn't happen……



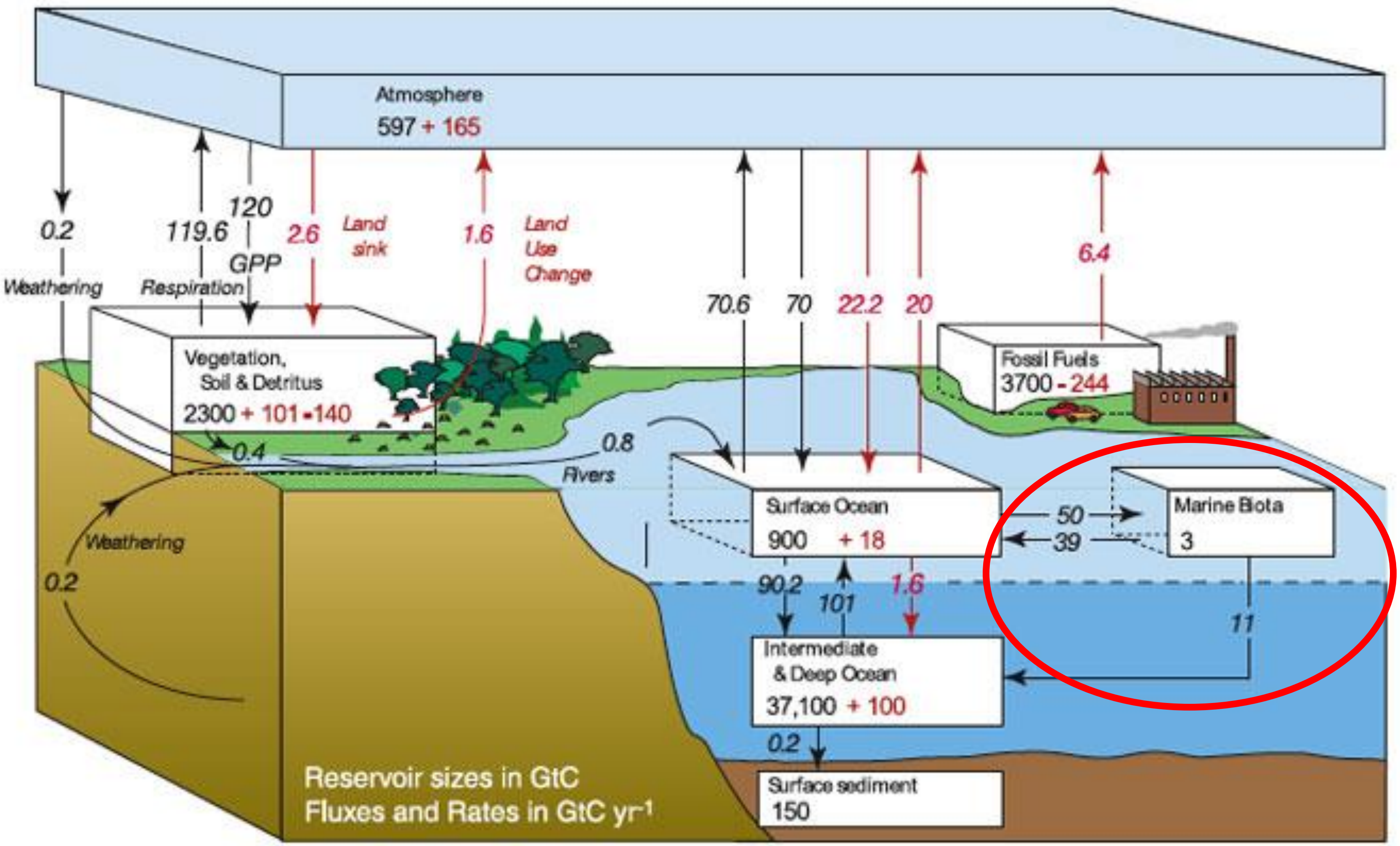

Carbon supply should equal carbon demand

But it doesn't…..

Steinberg et al. (2008), L&O

4. Why is there currently no net anthropogenic $CO_2$ uptake via the biological carbon pump?

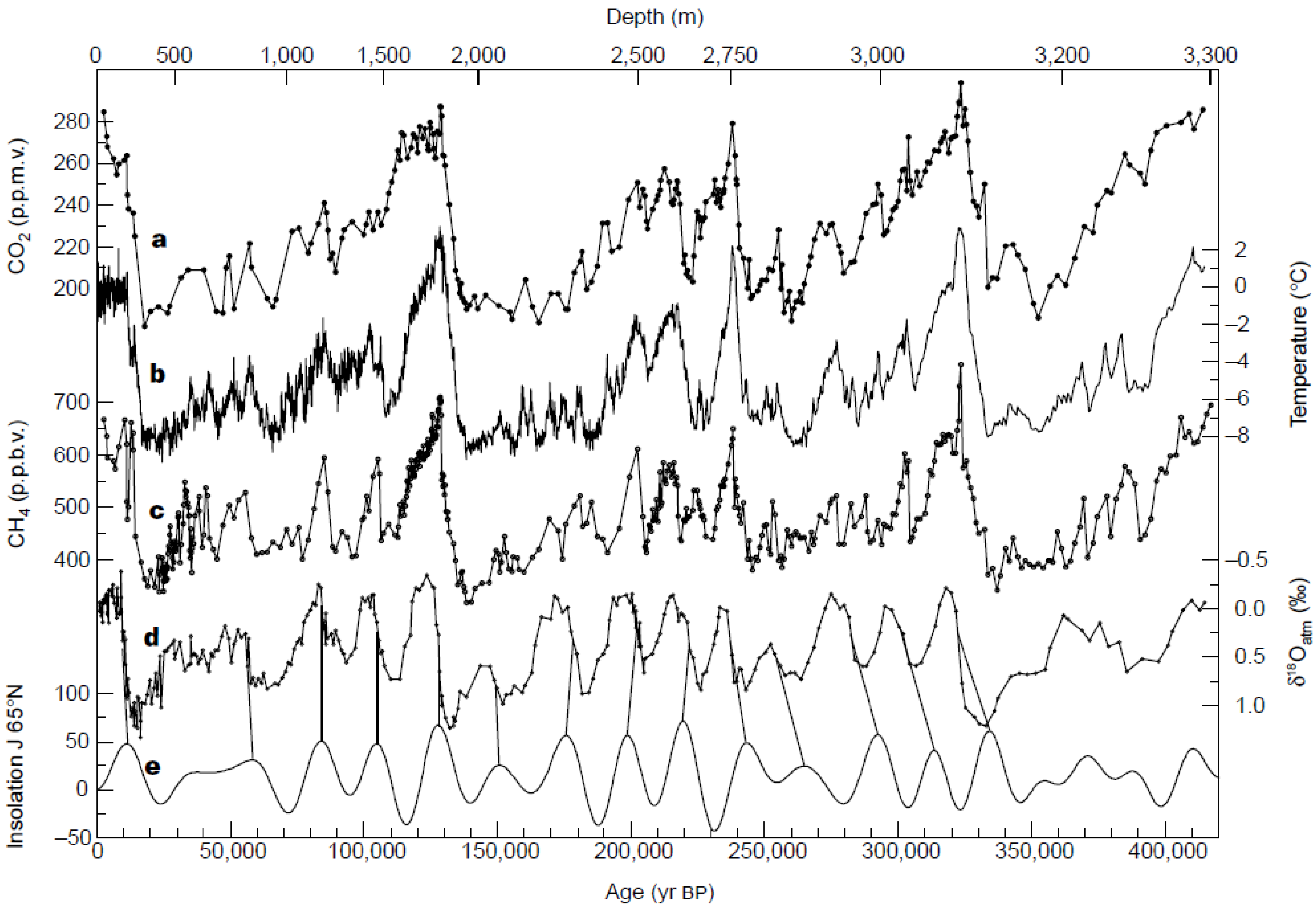
# Global carbon cycle



# What goes down, must come up

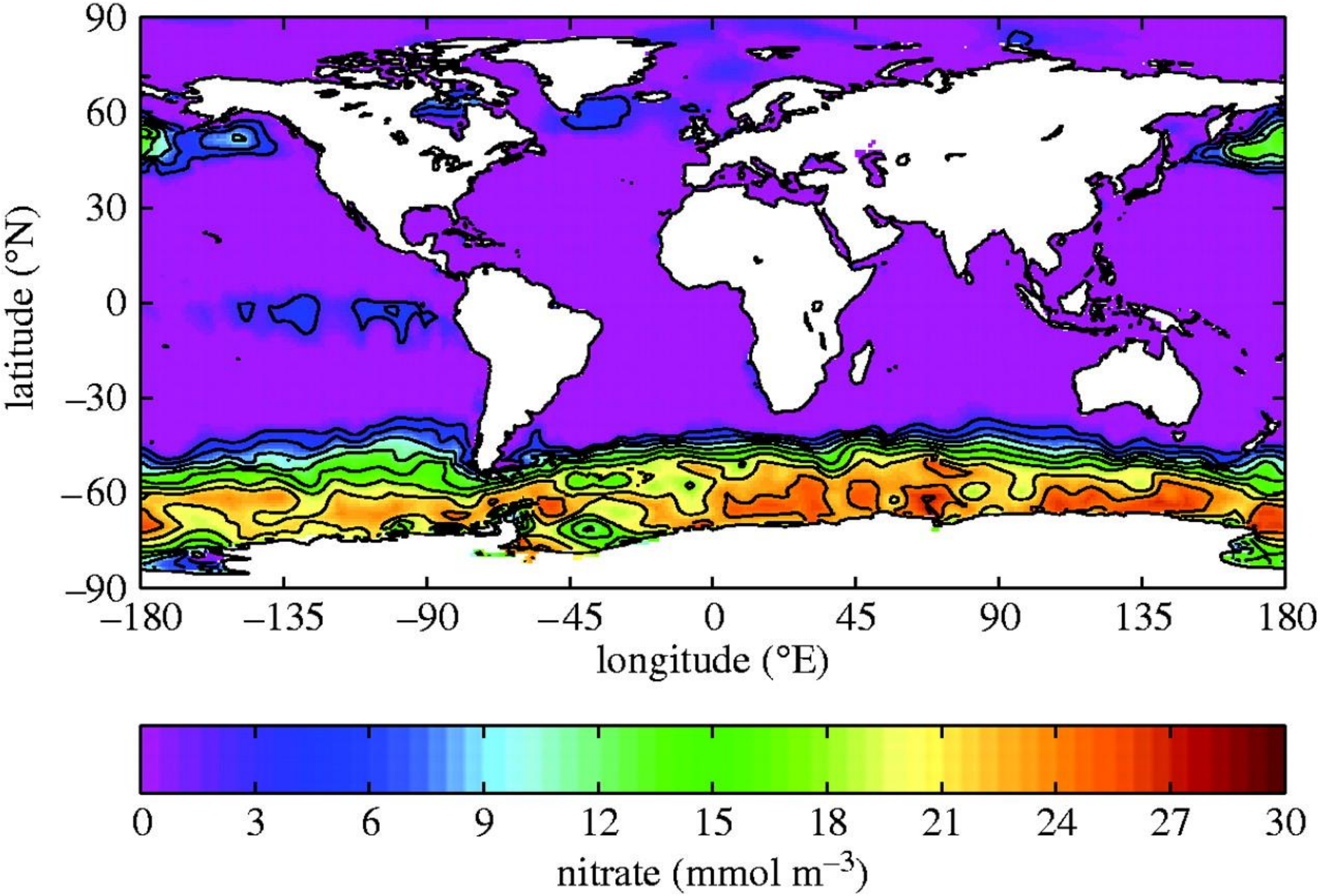
- BCP is responsible for ~2/3 of the surface to deep gradient in DIC – so why doesn't it result in net transport of anthro $CO_2$ into deep ocean?
- This part of the C cycle seems to be in steady state….downward transport of DIC balanced by equally large upward transport

# Glacial-interglacial cycles

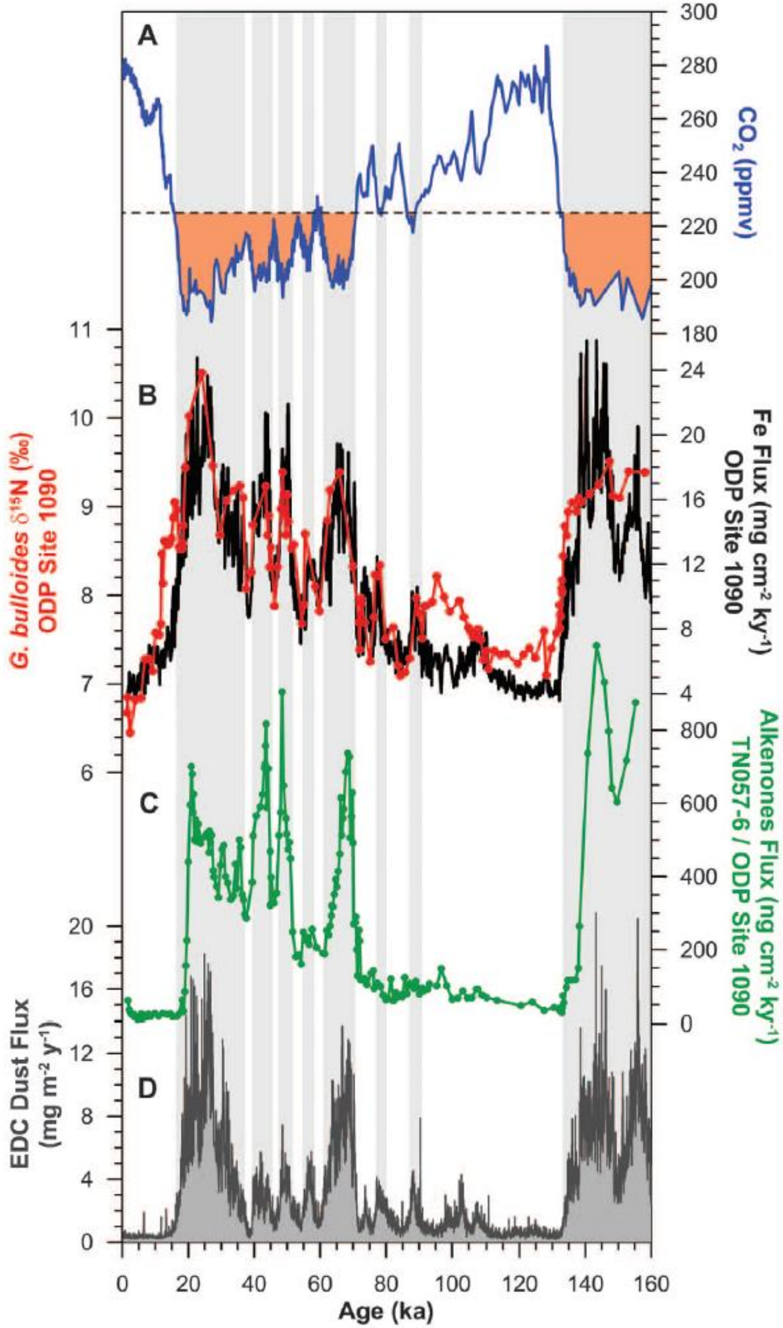



Petit et al. (1999), Nature

# Role of BCP



90
60
30
0
–30
–60
–90
latitude (°N)
–180
–135
–90
–45
0
45
90
135
180
longitude (°E)
0
3
6
9
12
15
18
21
24
27
30
nitrate (mmol m^−3)




# Role of BCP

Increased dust associated with decreased CO2 suggests ocean PP was 'fertilised' and could take up extra ~ 40 ppm (Watson et al. 2000)

Martinez-Garcia et al. (2011), Nature

# 5. Could the biological uptake of $CO_2$ change in the future?

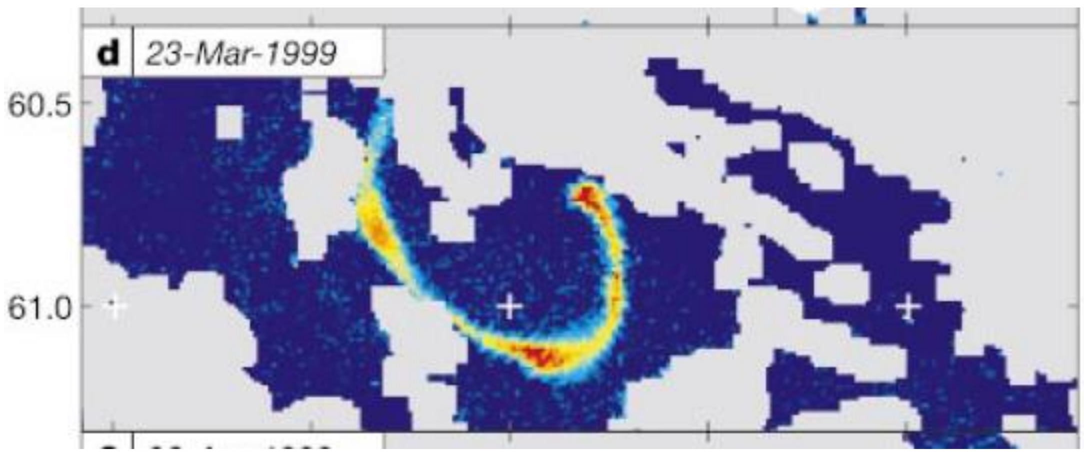
# The short answer is yes…

| | New production | | Carbon export flux | | Carbon sequestration flux |
|---|---|---|---|---|---|
| ↑ | Increased $N_2$-fixation | ? | Depends on new production | ? | Depends on sinking velocity & packaging of POM |
| ↑ | More efficient nutrient utilization[a] | ↓ | Decrease in diatoms, shift towards smaller phytoplankton | ? | Shifts in food web structure: e.g. salps replace euphausids[d] |
| ↓ | Increased stratification[b] | ↓ | Fewer large blooms due to elevated respiration and grazing | ? | Spatial or temporal decoupling between grazers & flux events |
| ↑ | Increased nutrient input: iron in HNCL areas | ↑ | Decreased bioavailability of carbon-rich DOM | ↓ | Lack of ballasting by coccoliths and diatom frustules |
| ↓ | Prolonged periods of recycled production | ? | Changes in TEP formation and stickiness[c] | ? | Mesopelagic microbial activity |
| | | ↓ | Glucosidase activity increased at lower pH | ↑ | Preferential remineralization of nutrients |
| | | ? | Formation rate of marine snow | | |

Although it's difficult to pin down the exact mechanisms (or sometimes even direction of potential change)

Passow and Carlson (2012), MEPS

# Even the iron story isn’t straightforward…..

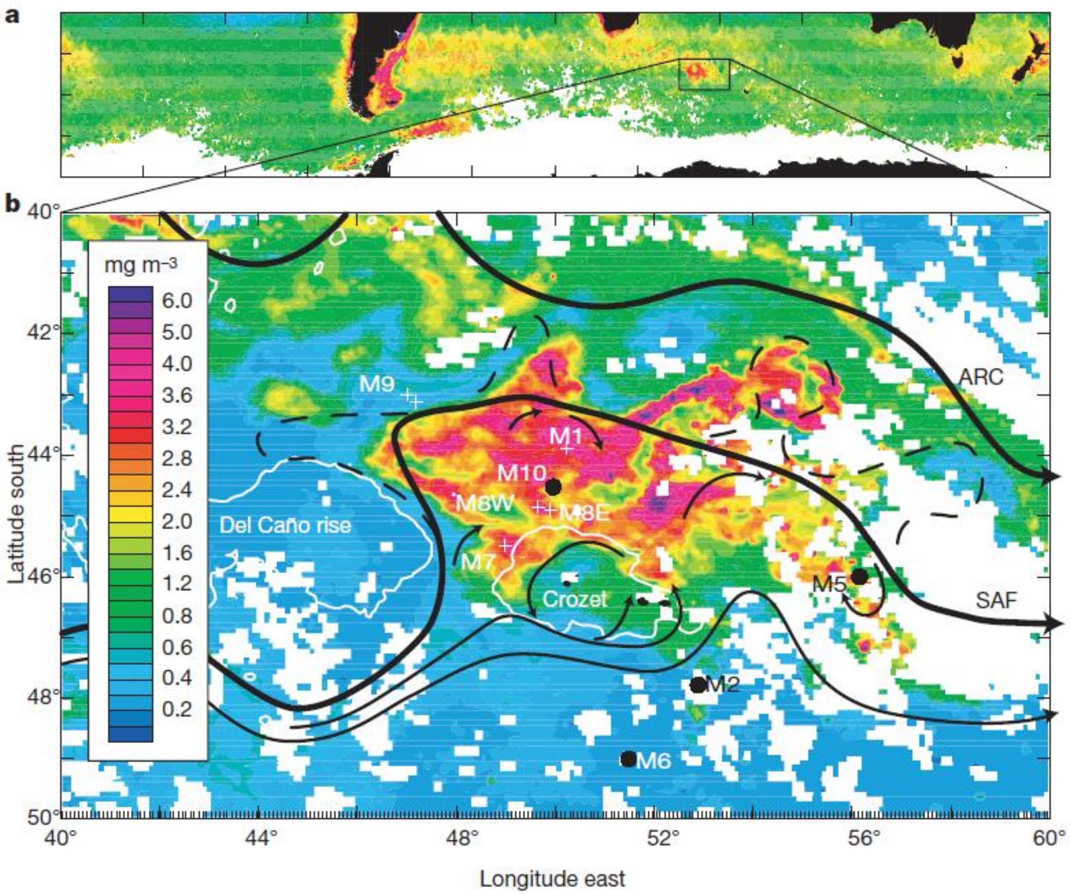



Abraham et al. (2000), Nature
Boyd et al. (1999), Nature

Artificial iron fertilisation experiment in Southern Ocean

Increase in surface productivity, but no increase in carbon export!

# Natural iron fertilisation

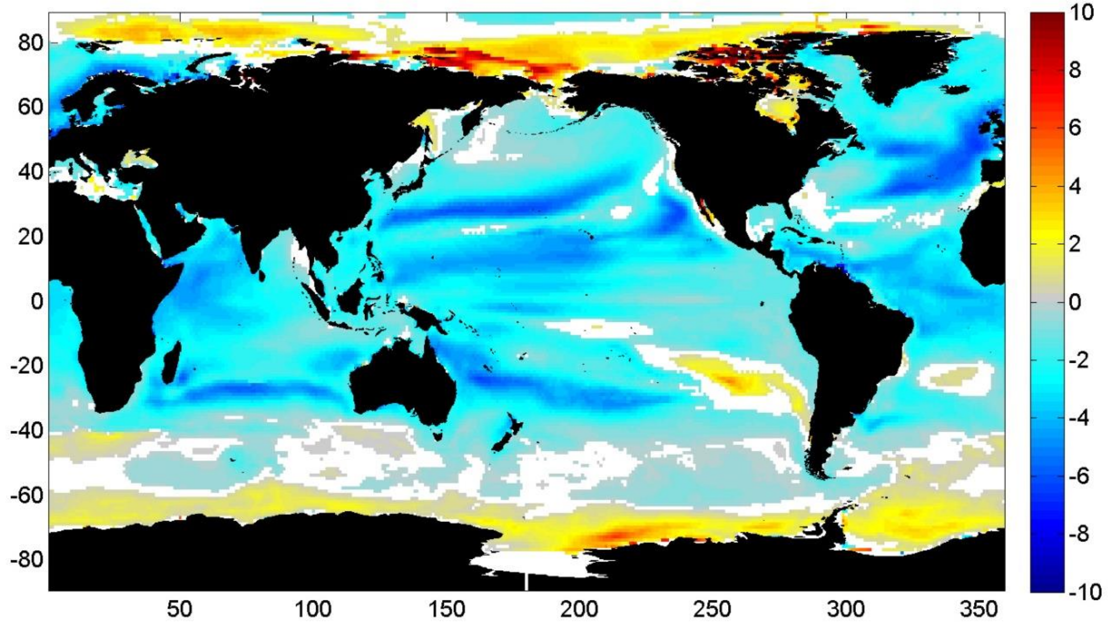



Islands in the Southern Ocean are a source of lithogenic iron

Increased productivity downstream AND increased C flux

Pollard et al. (2009), Nature

# Future changes in the BCP




% change per decade (2006-2100) in organic C flux at 100m depth w.r.t. present day
IPCC CMIP5 model average
Henson et al., 2016, GCB

Decreased biological C flux into deep ocean predicted in future

Could represent a positive feedback to atmospheric $CO_2$ (but unclear how mesopelagic remineralisation will change in future)

# Summary

**1. How much carbon does biological activity in the surface ocean fix?**

- About half of global productivity takes place in ocean.

**2. When/where does biological activity dominate CO2 uptake?**

- At high latitudes, in spring, places with a substantial phytoplankton bloom.

**3. How much organic carbon gets down to the deep ocean?**

- Still under debate, but probably a few percent of C export. Mechanisms controlling remineralisation not well understood.

**4. Why is there currently no net anthropogenic CO2 uptake via the biological carbon pump?**

- BCP seems to be in steady state during recent past.

**5. Could that change in the future?**

- Yes, although the mechanisms are currently unclear.