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COURSE ON CLIMATE VARIABILITY STUDIES IN THE OCEAN
"Tracing & Modelling the Ocean Variability"
16 - 27 June 2003

301/1507-11

How is N supplied to phytoplankton over the Atlantic?

Ric G. Williams
University of Liverpool
United Kingdom

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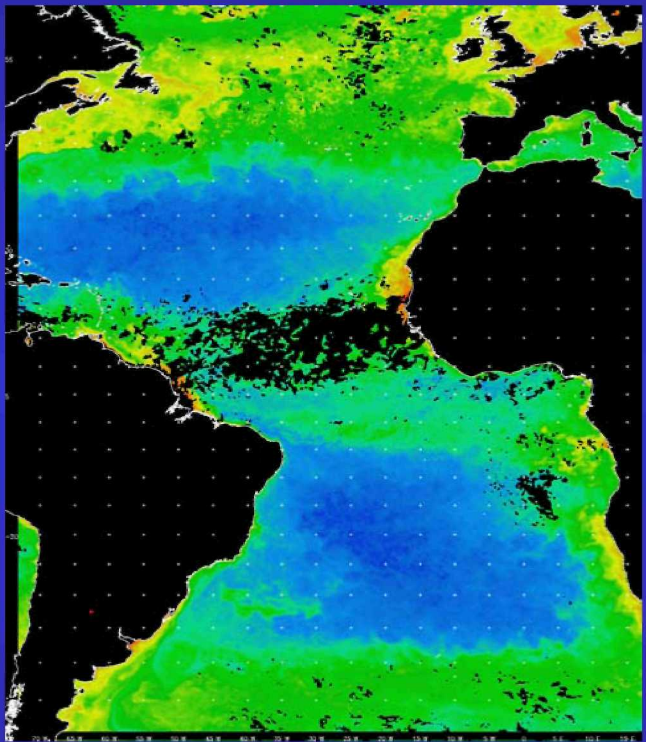


Refr: Mahaffey, Williams, Wolff, Mahowald, Anderson, Woodward (2003) Biogeochemical signatures of nitrogen fixation in the eastern North Atlantic. GRL, 30, 6, 1300.

Mahaffey, Williams and Wolff (2003) Physical supply of nutirents to phytoplankton. In preparation.

Claire Mahaffey,
Ric Williams, George Wolff
University of Liverpool

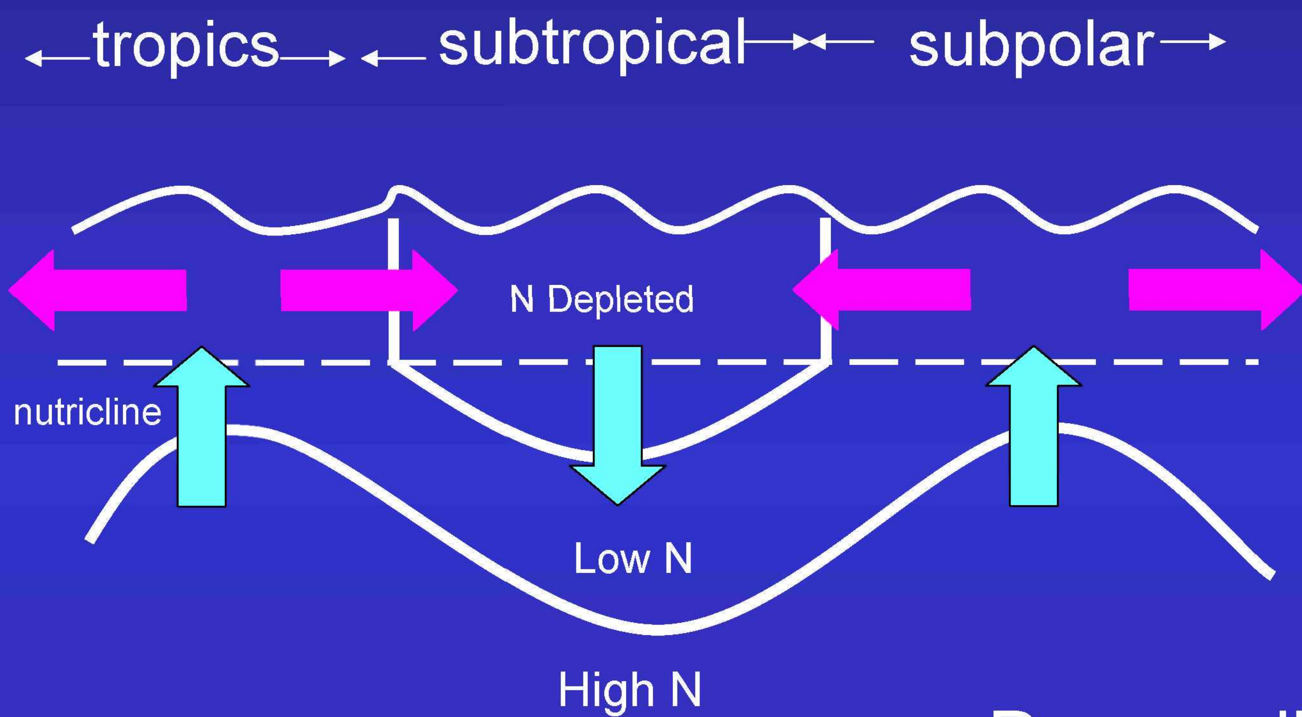
- Review nutrient problem
- Isotopic analysis

  nitrogen fixation

  transient upwelling
- Role of organic nutrients

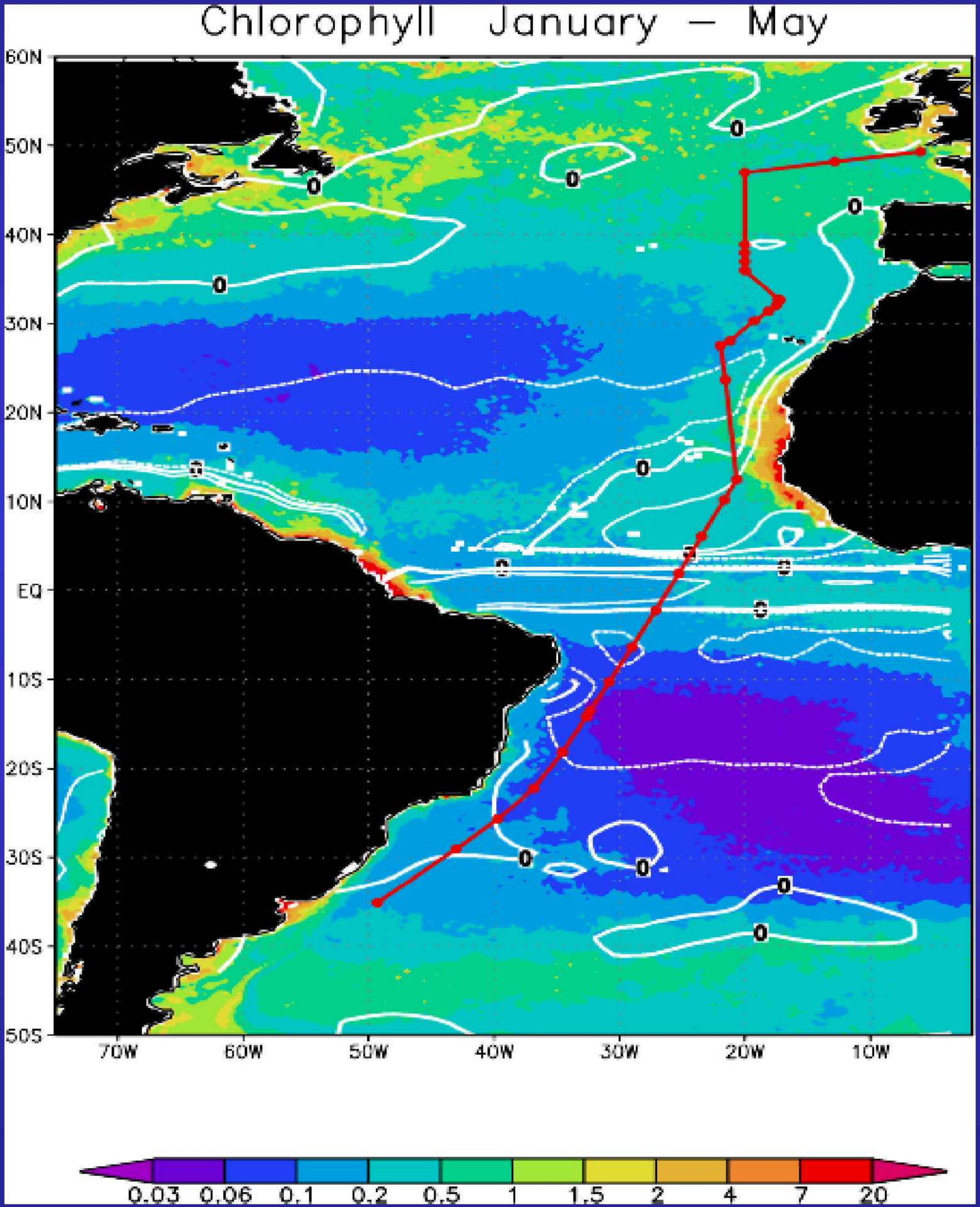
Part of the Atlantic Meridional Transect programme

Large-scale context



- Downwelling over subtropical gyres
- Lateral transfer at gyre boundaries

Atlantic Meridional Transect (AMT10)



Colours: Surface chlorophyll

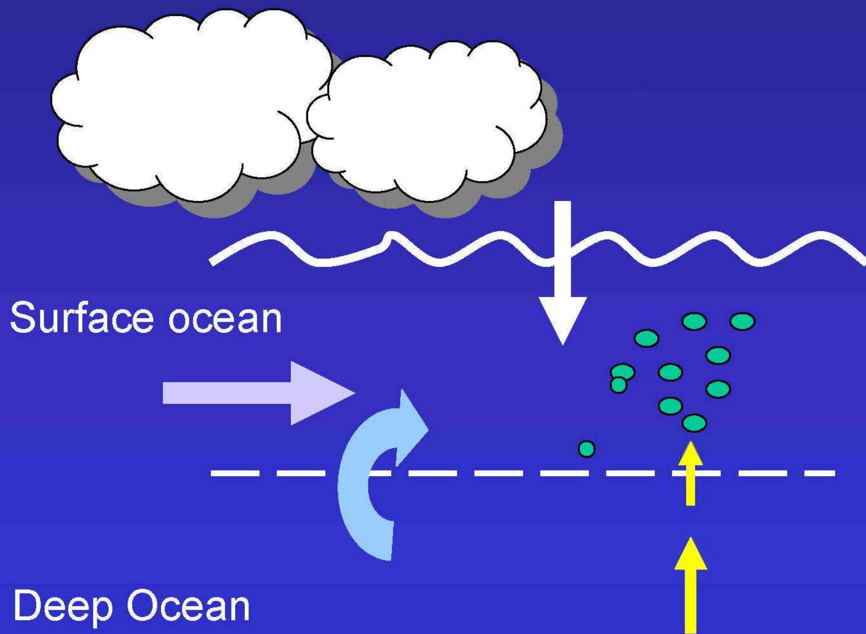
Contours: wind-induced upwelling (m/y)

- Extensive downwelling

- How is production sustained here?

Might account for half the global export of organic C (Emerson et al., 1997)

Traditional view of N supply



- Atmospheric deposition
- Vertical diffusion
- Entrainment
- Lateral Ekman

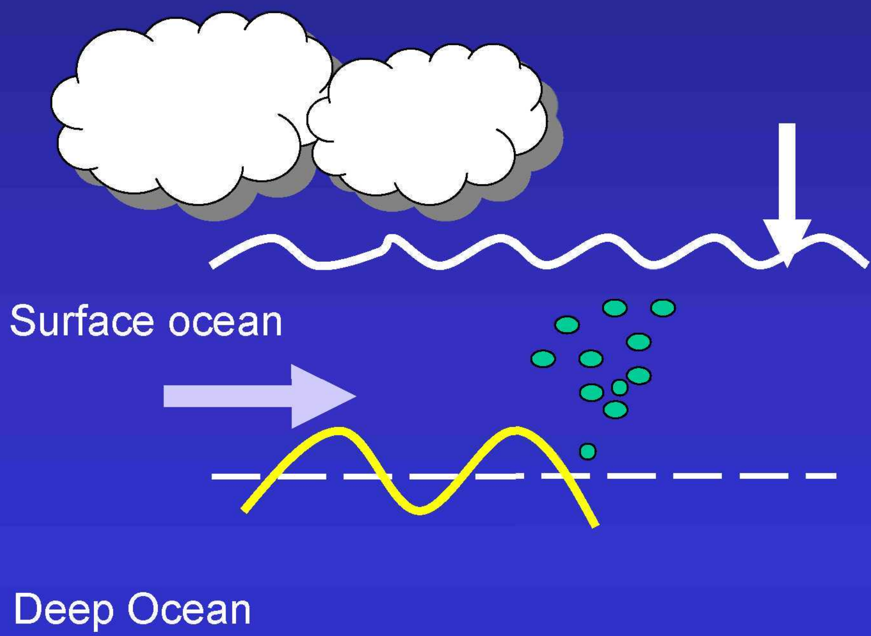
Supply of N = 0.24 ± 0.08 mol N m^{-2} yr^{-1}

Export of N = 0.42 to 0.56 mol N m^{-2} yr^{-1}

(Jenkins 1985, 88, 89; McGillicuddy et al., 1998)

Mismatch

New hypotheses for N supply



- Nitrogen fixation

  ~ 0.07 mol N m^{-2} yr^{-1}

- Lateral transfer of organics

- "Eddy upwelling" of nitrate

  0.19 to 0.24 mol N m^{-2} yr^{-1}

  (McGillicuddy & Robinson, 1997; Siegel et al., 1999)

Do phytoplankton respond to a transient supply of N ?

Stable nitrogen isotopes

$$\delta^{15}N = \frac{R_{sample} - R_{standard}}{R_{standard}}$$

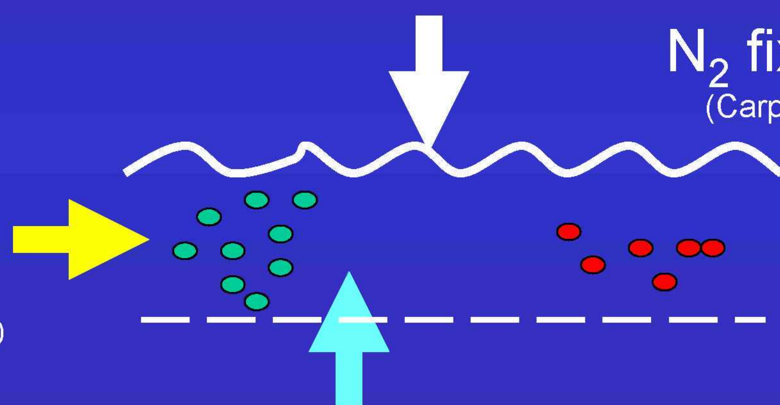
$R = {}^{15}N/{}^{14}N$ relative to N_2

Stable nitrogen isotopic composition of phytoplankton ($\delta^{15}N$ PON) :

1. $\delta^{15}N$ of the N source

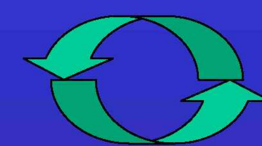
Horizontally advected DON

-2 ‰ (Altabet et al 1988, Checkley and Miller, Abell 2000



N_2 fixation 0 ‰

(Carpenter et al 1997)



Regenerated N –1.5 to –2.1 $^{o}/_{oo}$ (Altabet 1988)

Deep Ocean NO_3^- 5 to 6 ‰

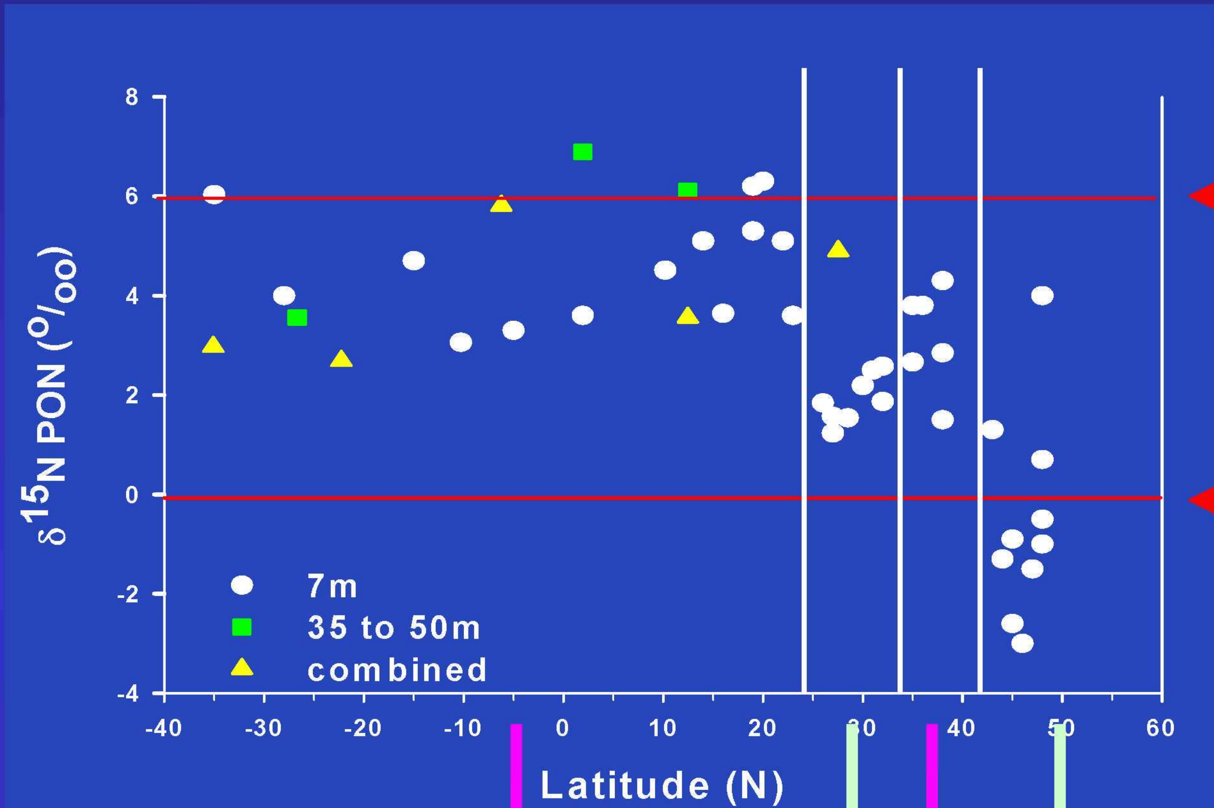
(Liu et al 1987, Sigman et al 1997)

2. Biological fractionation – biology preferentially use ^{14}N

N "excess" - $\delta^{15}N$ PON << $\delta^{15}N$ N source

N "deplete" - $\delta^{15}N$ PON ≈ $\delta^{15}N$ N source

Latitudinal variation in $\delta^{15}N$ PON



Range: -3‰ to +7‰

Heavy N source

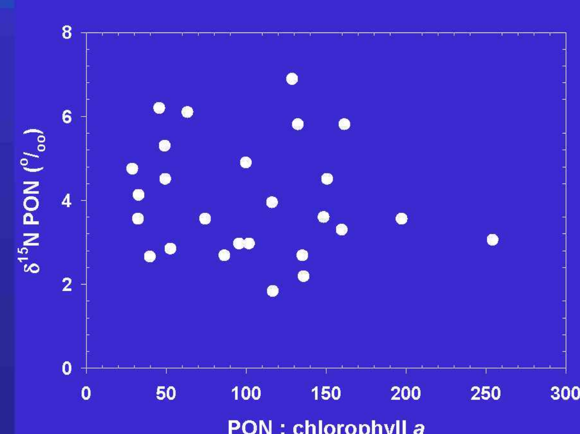
~ 6 $^{o}/_{oo}$

Light N source

~ 0 $^{o}/_{oo}$

Isotopically heavy

Isotopically light



- **Higher trophic influence negligible**

Stable nitrogen isotopes

$$\delta^{15}N = \frac{R_{sample} - R_{standard}}{R_{standard}}$$

$R = {}^{15}N/{}^{14}N$ relative to N_2

Stable nitrogen isotopic composition of phytoplankton ($\delta^{15}N$ PON) :

1. $\delta^{15}N$ of the N source

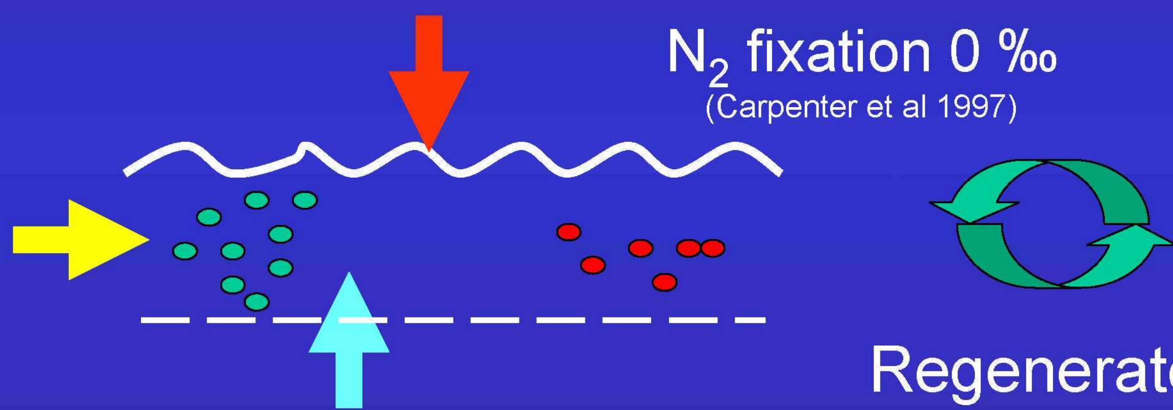
Horizontally advected DON

-2 ‰ to 4.5 ‰

(Abell 2000)

N_2 fixation 0 ‰

(Carpenter et al 1997)



Regenerated N

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N "excess" - $\delta^{15}N$ PON << $\delta^{15}N$ N source

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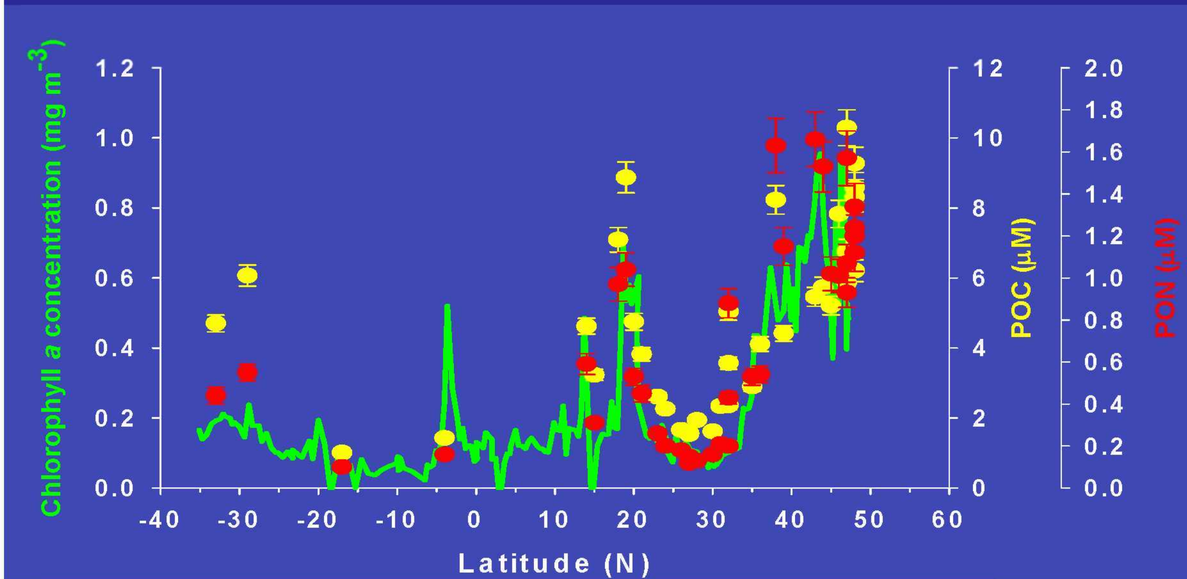
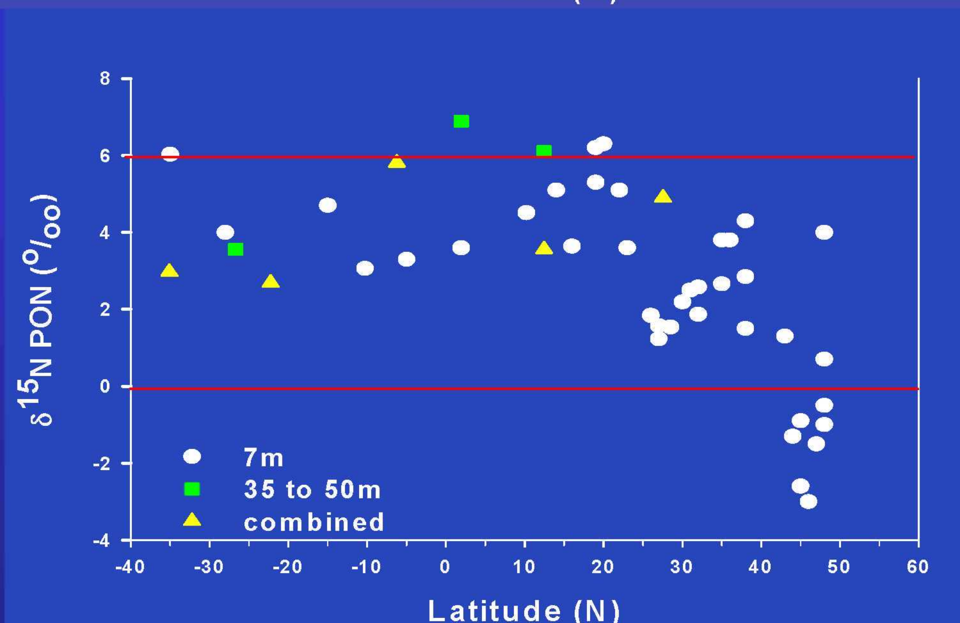
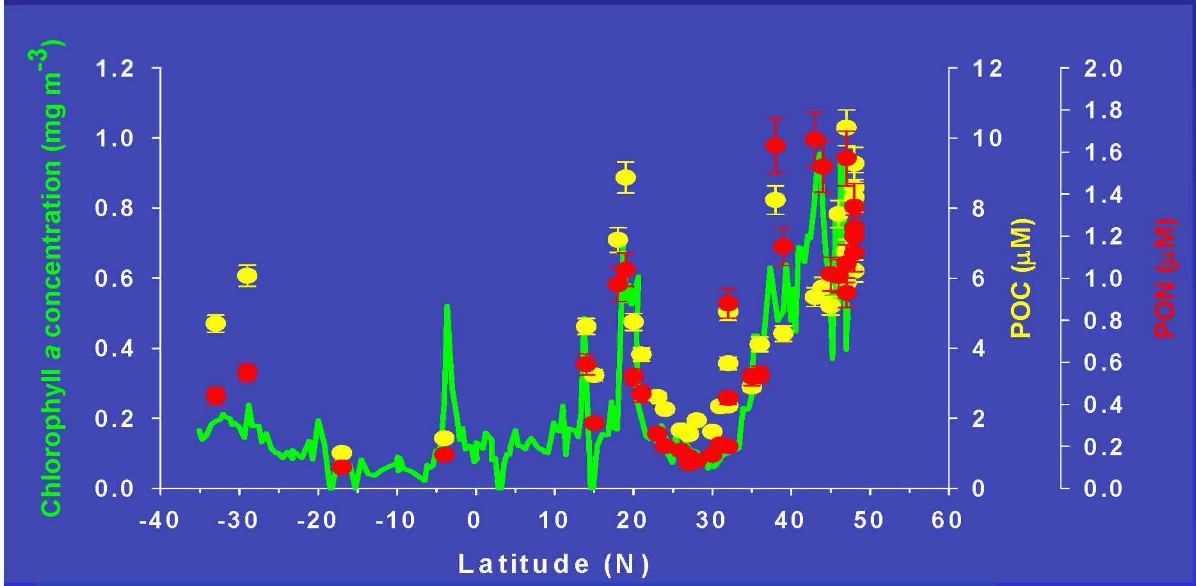
Spring Bloom



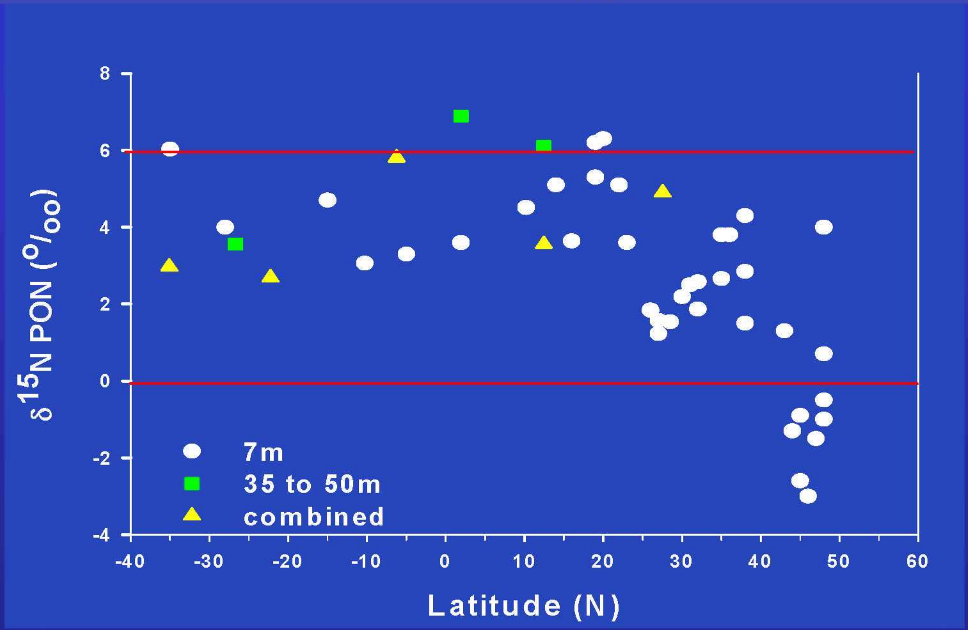


- Isotopically light δ^{15} N PON (1 to -3 ‰)
- High NO_3^- results in biological fractionation (Altabet *et al* 1991).

Oligotrophic light signal

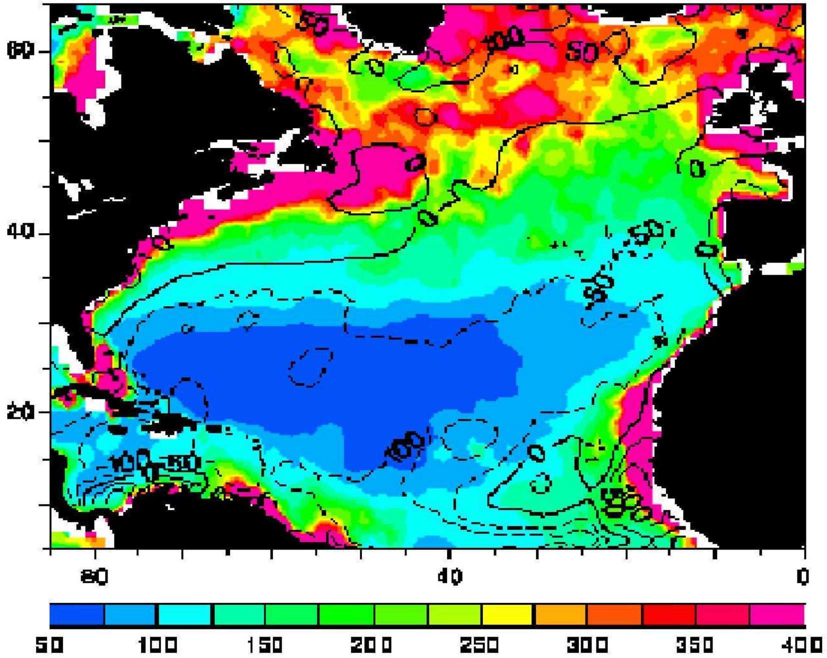


- $\delta^{15}N$ PON << 2 $^{o}/_{oo}$
- Implies isotopically light source of N
- Regenerated N or N_2 fixation ?



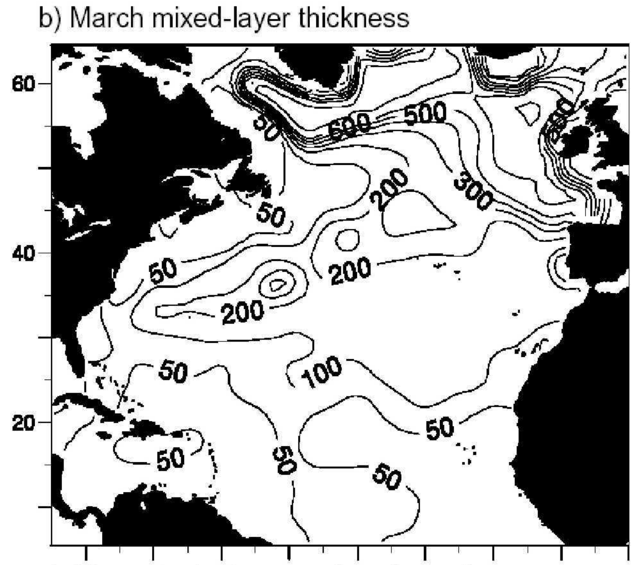
Probably N_2 fixation
- high N:P ratios
- pigment variations

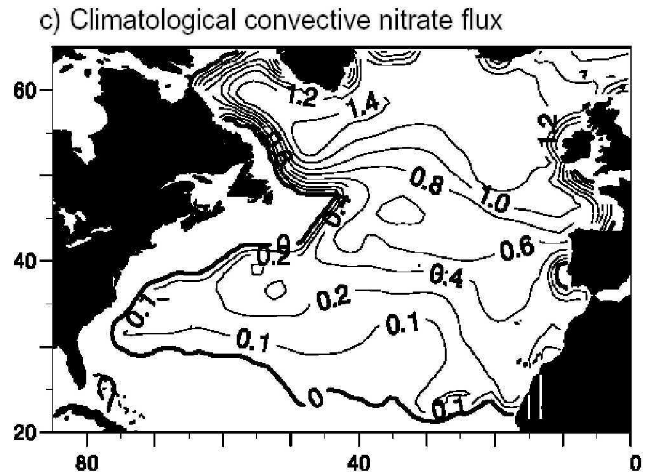
3. Convection



Satellite estimate of primary production (gC m^{-2} y^{-1})

Sathyendranathan et al. (1995)

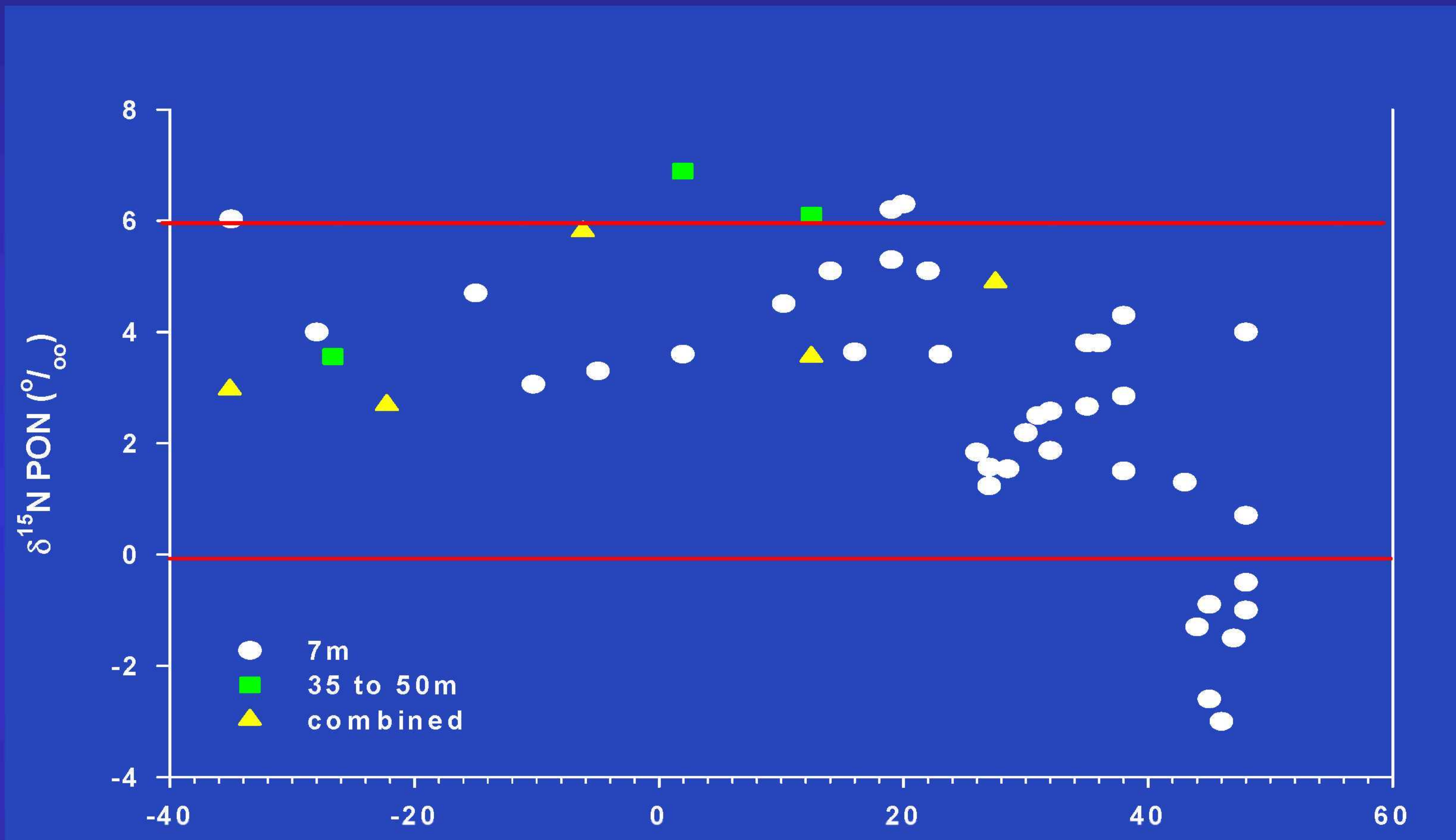




Williams & Follows (2003)

Is convection alone sufficient?

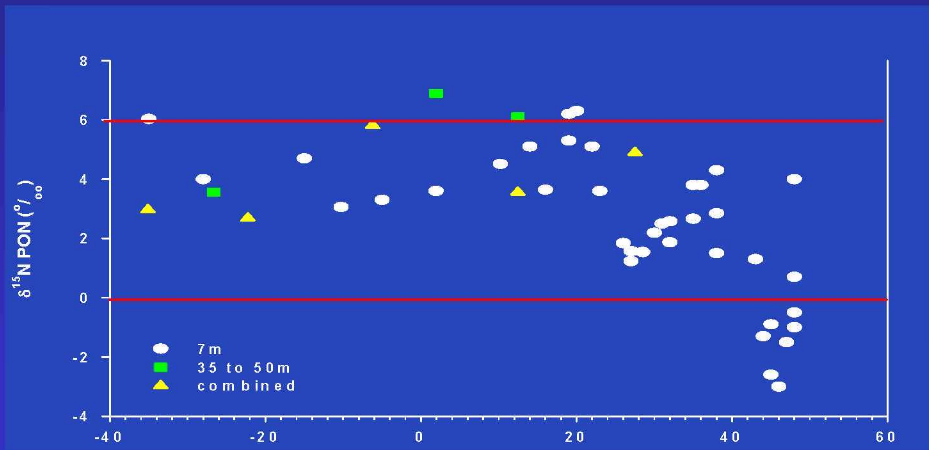
Oligotrophic heavy signals



Generally, isotopically heavy

δ^{15}N PON from 2.7 to 6.9 $^{o}/_{oo}$

How important is deep nitrate supply?



Assume 2 sources:

- deep N ~ 5.5 to 6 $^o/_{oo}$

(Sigman et al 1997)

- light N ~ 0 $^o/_{oo}$

	Mean $\delta^{15}N$	***% nitrate supply***
• Southern gyre	4.1 ± 0.5	***68 – 75 %***
• Tropics	4.8 ± 0.3	***79 – 87 %***
• Northern gyre		
24^o - 32^oN	2.3 ± 0.4	***37 – 41 %***
33^o - 38^oN	3.2 ± 0.4	***53 – 58 %***

Time-varying circulations

Uplift of nutricline

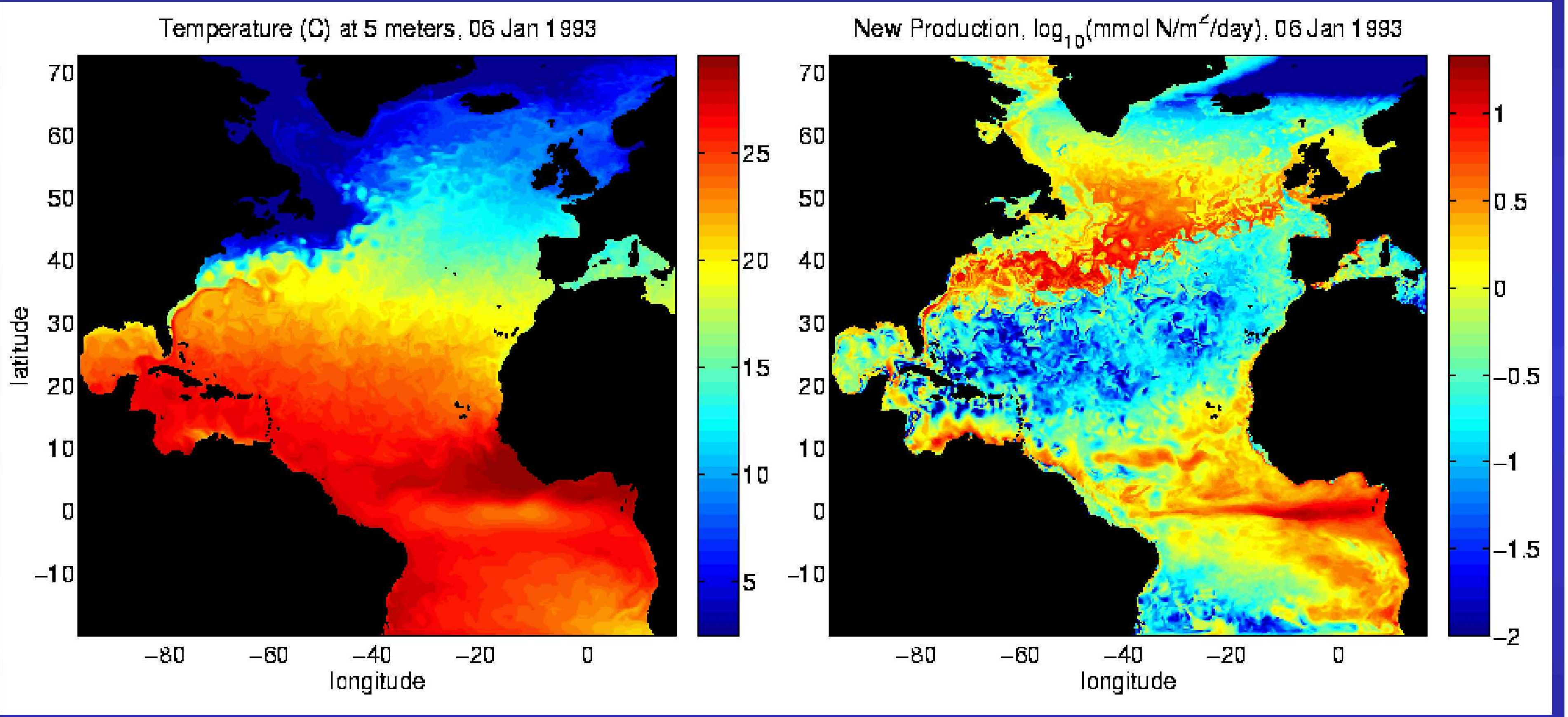
Ecosystem response

Depression of nutricline

No Ecosystem response

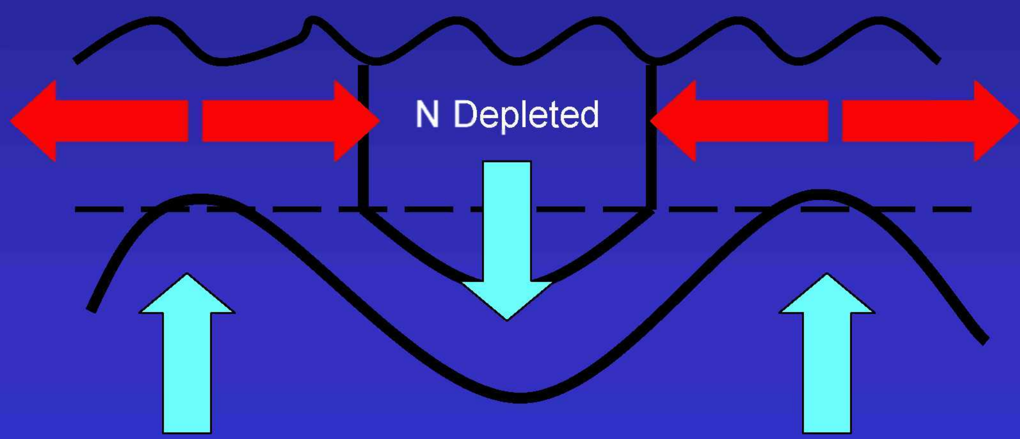
- Mesoscale eddies (Falkowski *et al*., 1991, McGillicuddy and Robinson 1997)
- Fine scale frontal circulations (Mahadavan and Archer 2000, Levy *et al.* 2001)
- Planetary Waves (Uz *et al* 2001, Cipollini *et al* 2001)

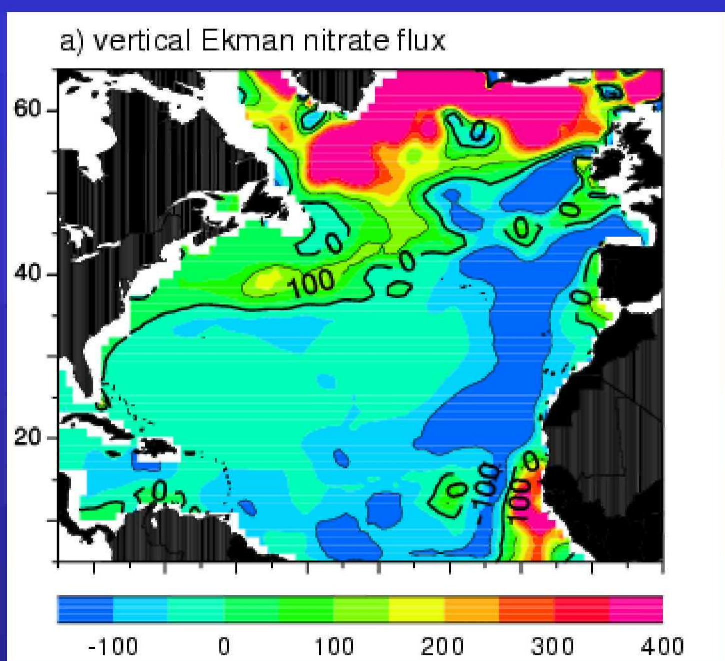
High resolution GCM integrations

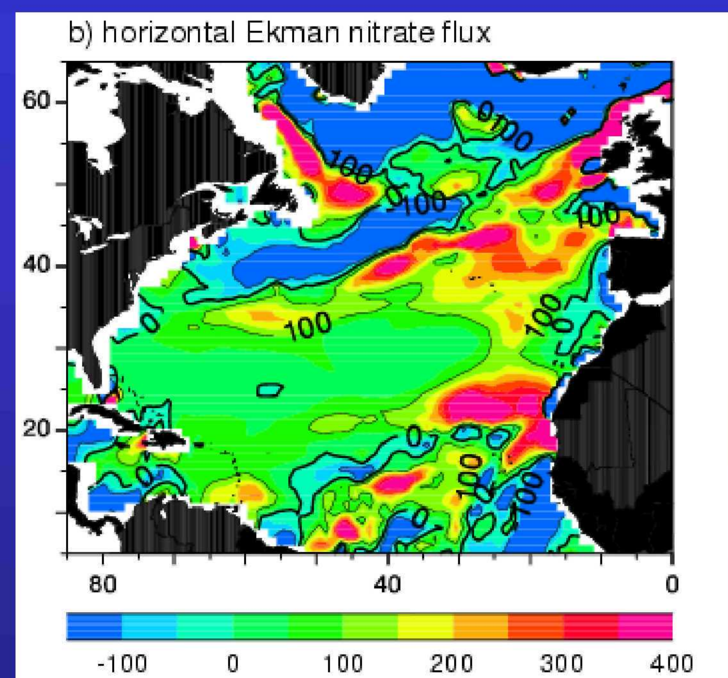


Fine resolution integrations by Dennis McGillicuddy

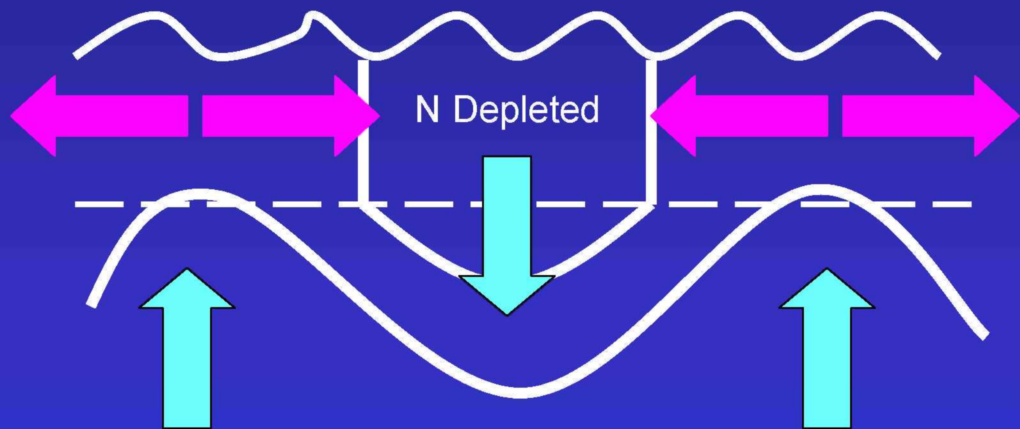
Lateral transfer of nitrate



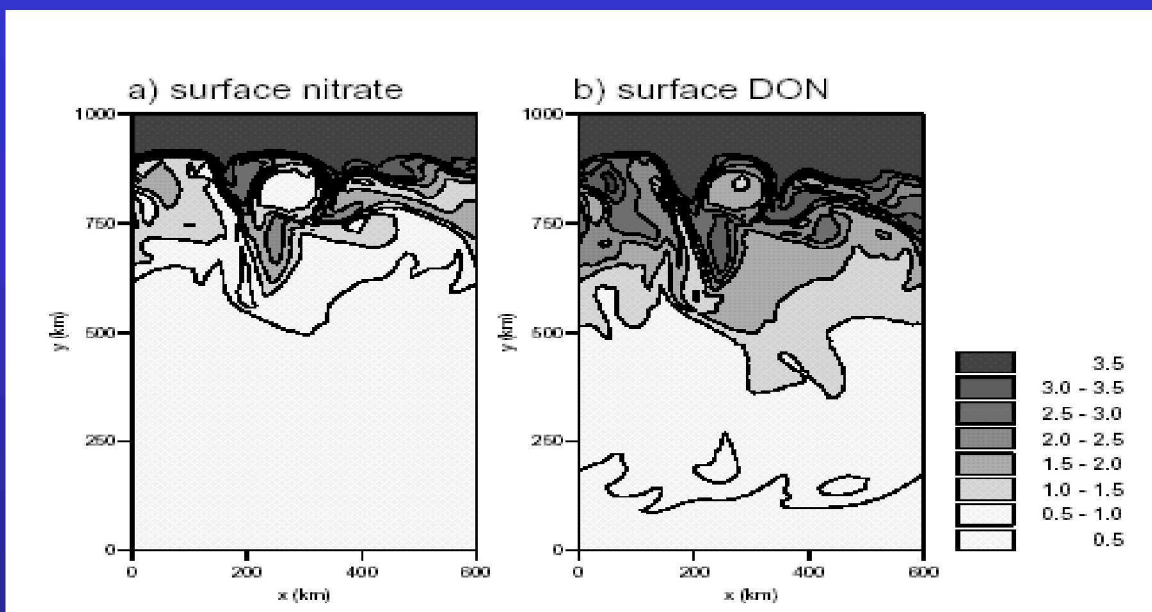




Lateral transfer of organic N

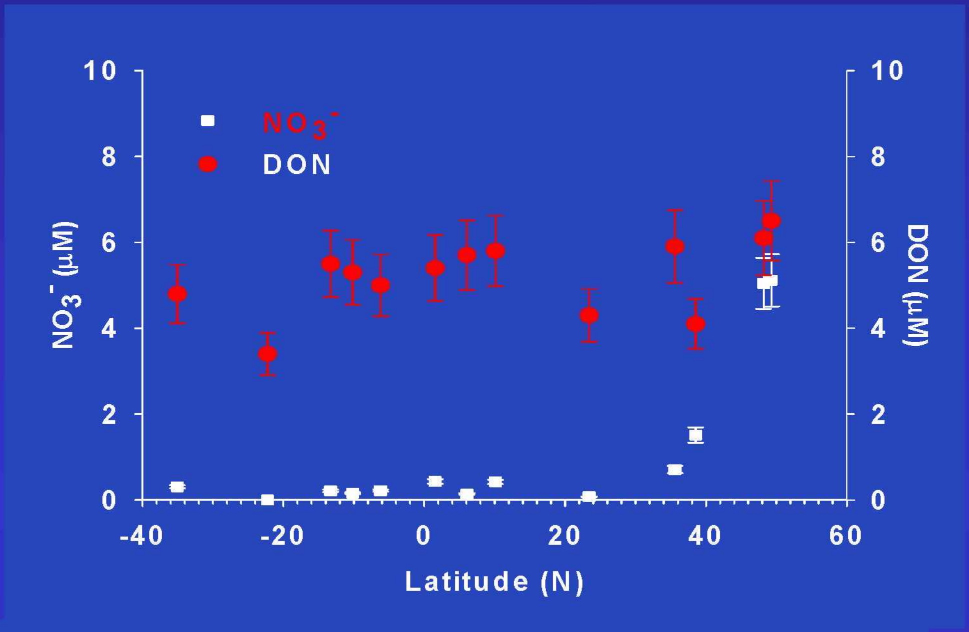


• expect DON production at the flanks & consumption in the gyre

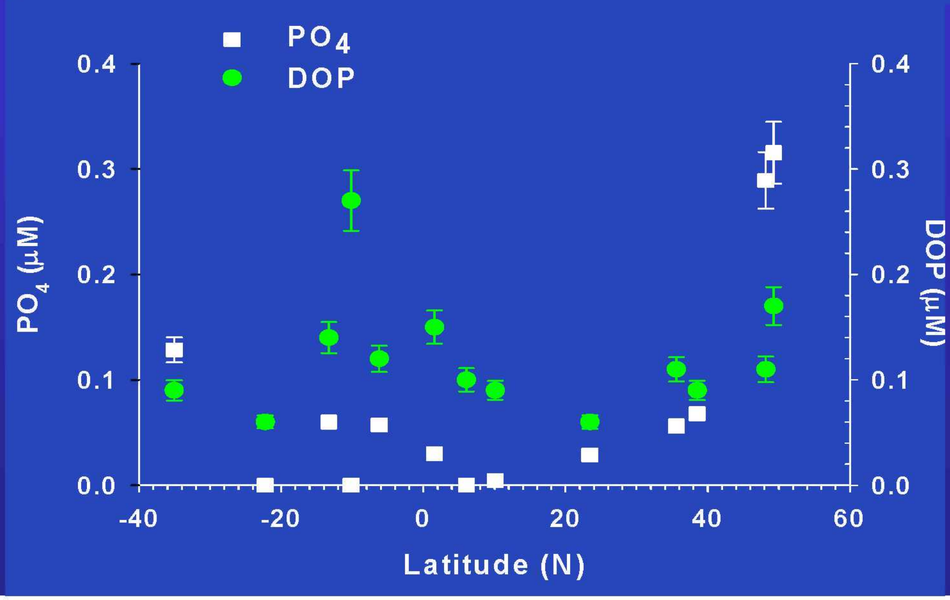


• expect lateral influx of DON to penetrate further than nitrate (Lee and Williams, 2000)

Latitudinal variation in organic nutrients DON and DOP



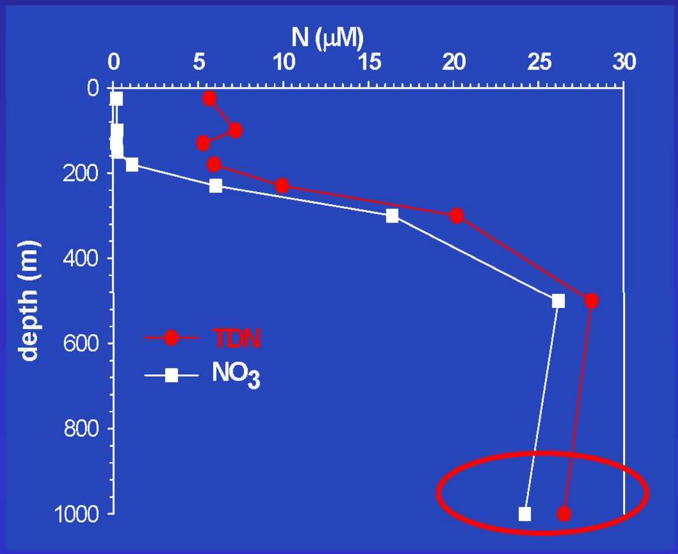
- *Relatively uniform DON*



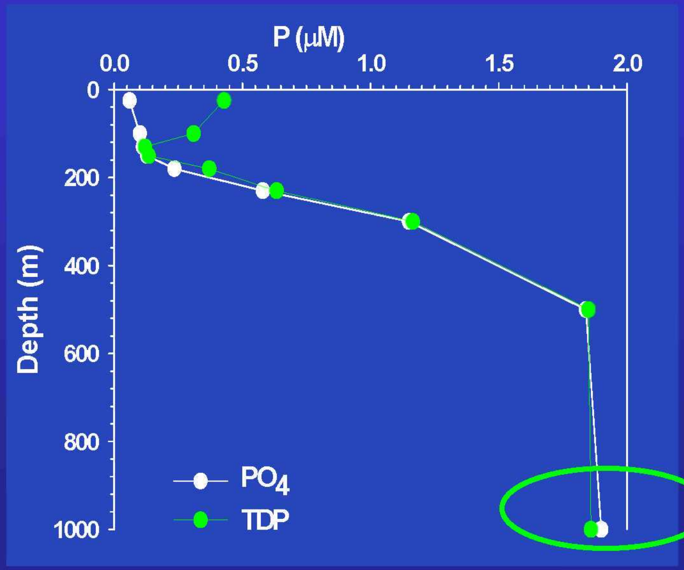
- *Reduced DOP in centre of gyre*

Depth variation in organic nutrients DON and DOP

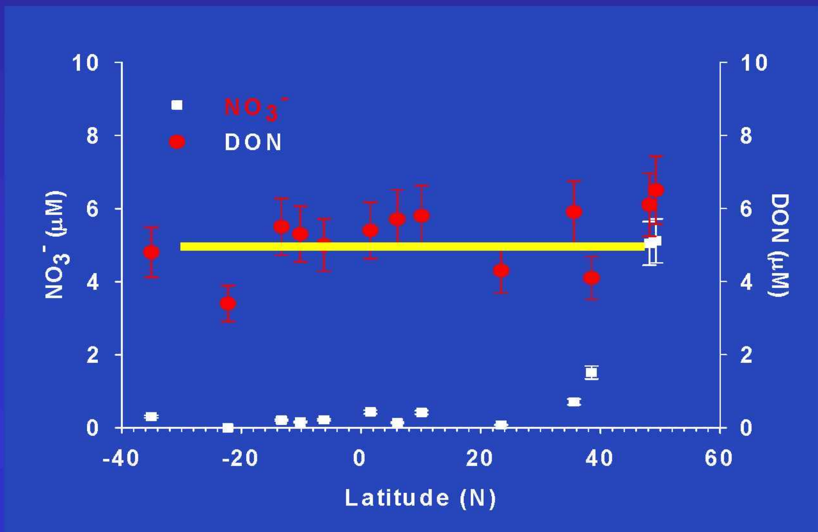
Refractory DON 2.14uM

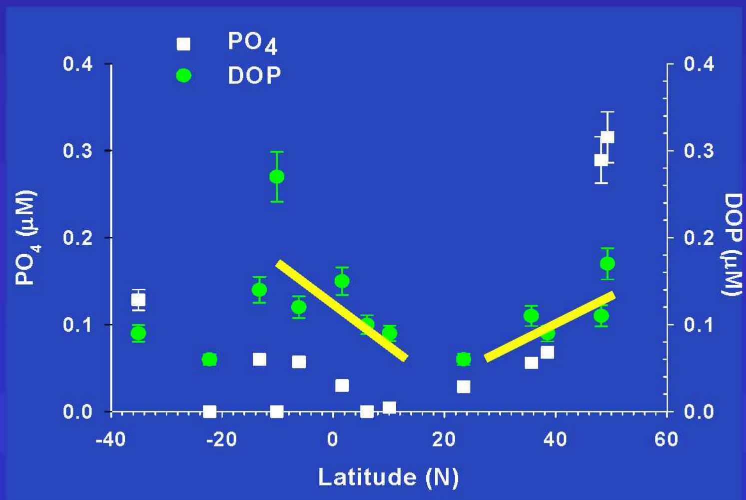


Refractory DOP negligible



Biological or Physical control?





- Biological: input of DON from N_2 fixation
- Physical: eddy upwelling of deep refractory DON

Conclusions

- Localised region of nitrogen fixation

- reflecting episodic atmospheric dust inputs

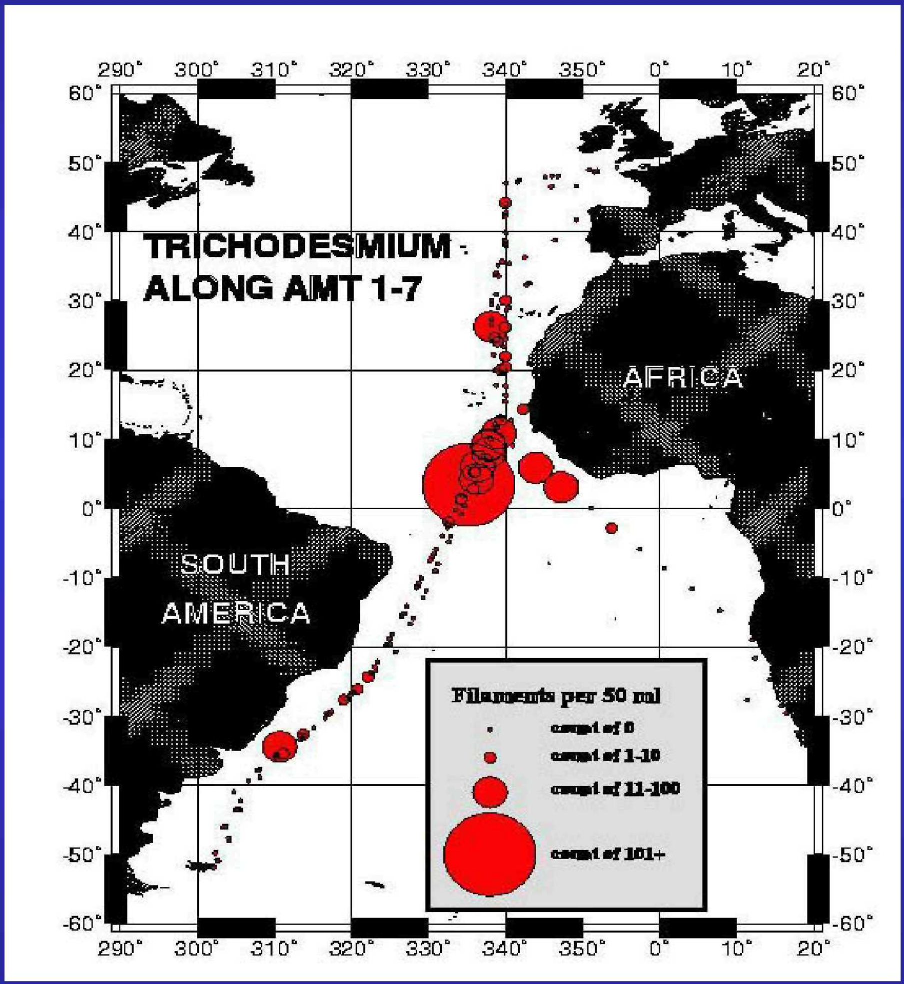
- Deep nitrate supplied to phytoplankton

- source is 53% to 75% in North & South gyres
- unclear as to precise mechanism

- Lateral influx of DOP might be significant in sustaining production

- N & P cycling appears to differ

Mismatch with Trichodesmium?



- Mismatch between *Trichodesmium* abundance and light isotopic signals:

  - over the tropics

    - **Other processes masking isotopic signals for N_2 fixation?**
    - **Presence but low activity?**

  - over the northern subtropics

    - **sampling issue?**
    - **Other N_2 fixing species? Zubkov *et al* 2000**

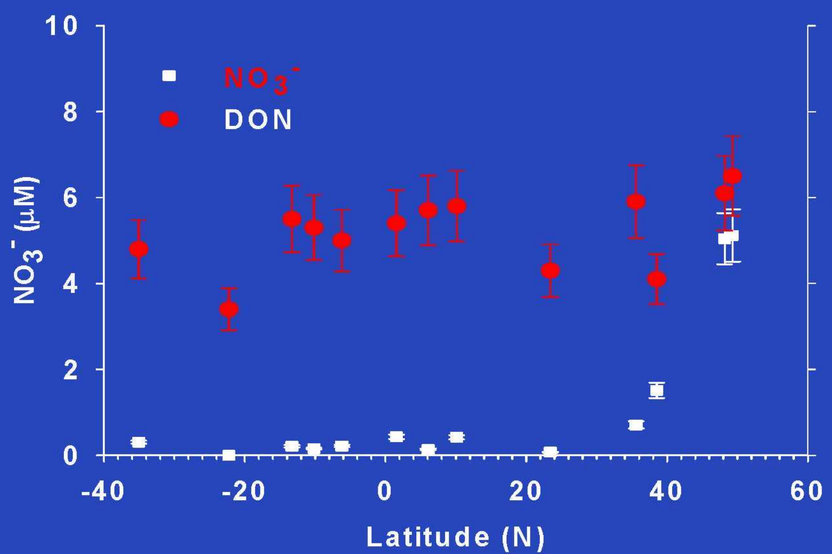
Tyrrell et al 2002 submitted

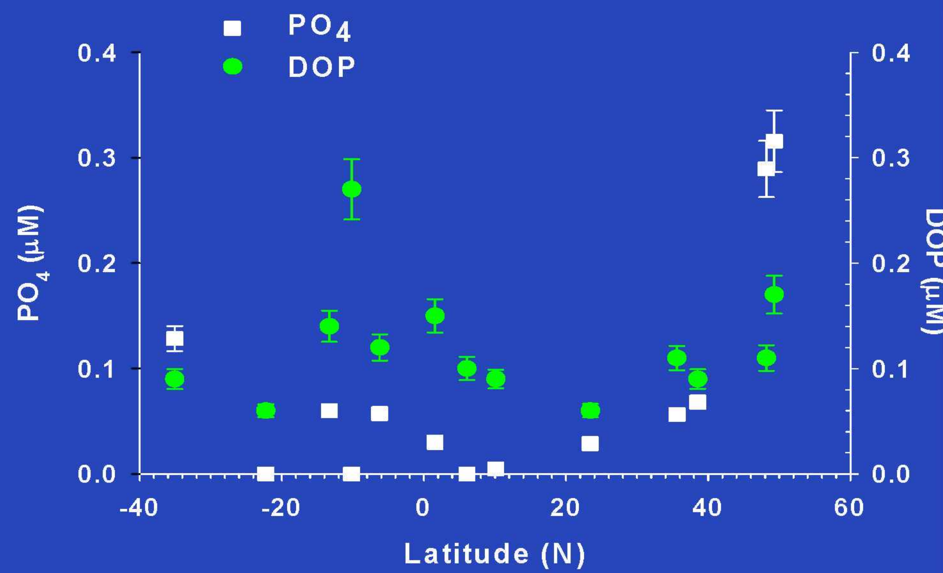
How important is deep nitrate supply?

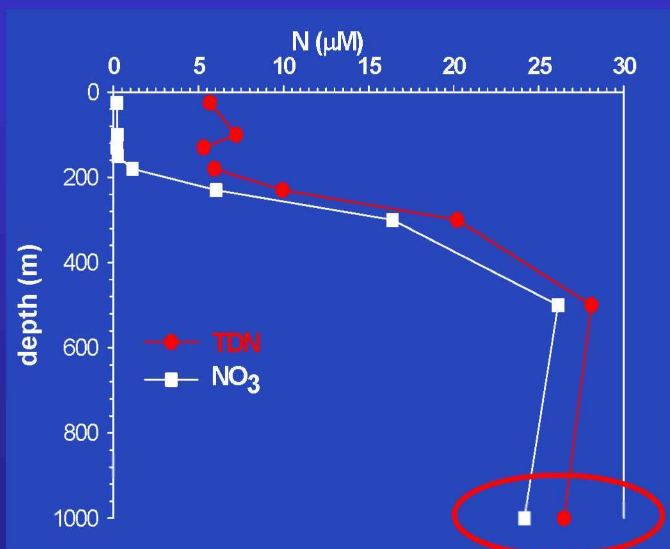
- 2-end member model
  - Heavy N source ~ 6 $^o/_{oo}$
  - Light N source ~ 0 $^o/_{oo}$
- only applicable were N limiting

Region	Mean $\delta^{15}N$	SE	n	% new N	
• S. Atlantic subtropical Gyre, 36°S to 6°S	4.09	0.46	8	68 %	
• Equatorial and coastal Upwelling, 5°S to 23°N	4.75	0.29	16	79 %	
• N. Atlantic subtropical Gyre, 24°N to 32°N	2.25	0.36	9	37 %	N_2 fixation 63%?
33°N to 38°N	3.16	0.41	6	53 %	
39°N to 48°N	-0.72	0.52	13	n a	

Latitudinal variation in organic nutrients DON and DOP







Refractory DON 2.14uM

Refractory DOP negligible