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

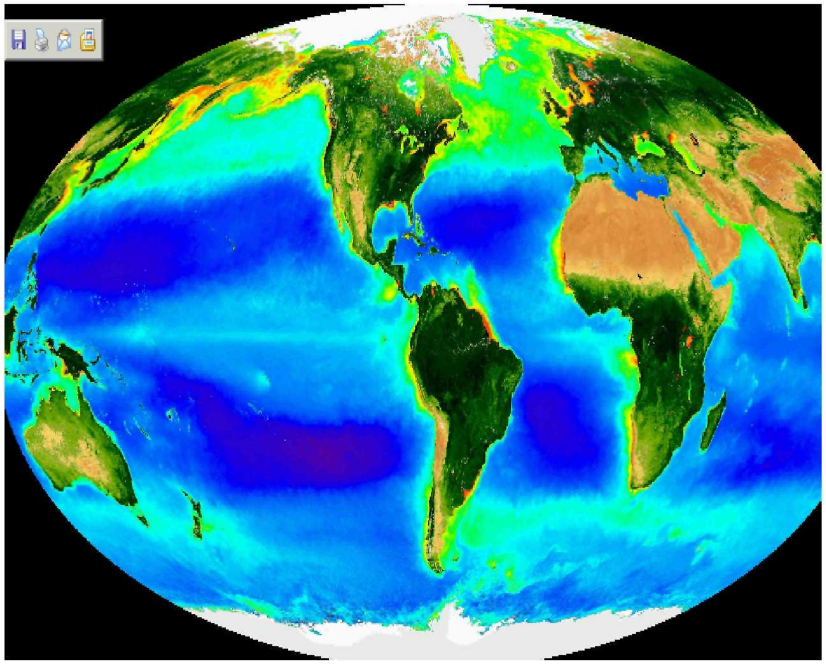
301/1507-10

Impact of physical processes on nutrients and biological production

Ric G. Williams
University of Liverpool
United Kingdom

Impact of physical processes on nutrients and biological production

- How is biological production sustained?
- How are nutrient distributions controlled?



Seawifs average chlorophyll

Mar 21 to June 20 for 1998 to 2001
http://seawifs.gsfc.nasa.gov/

Williams & Follows (2003) Physical transport of nutrients and the maintenance of biological production. 19-51. In `Ocean Biogeochemistry: The role of the ocean carbon cycle in global change'. Edited by Mike Fasham.

Impact of physical processes on nutrients and biological production

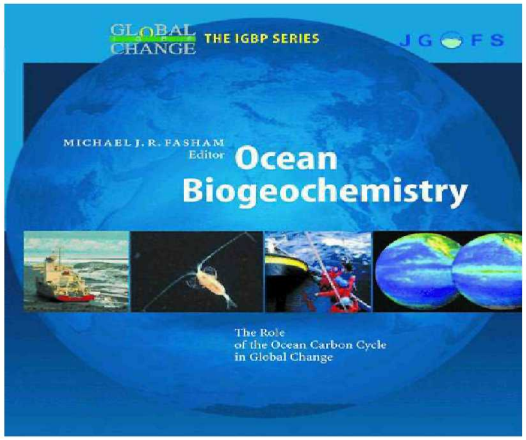
A. Mechanistic Review

1. Basin-scale distributions
2. Overturning
3. Convection
4. Gyre circulations
5. Eddies & Fronts
6. Interannual variability

B. How is biological production sustained in the Atlantic

Atlantic Meridional Transect Programme

Collaboration with Mick Follows (MIT)



Williams & Follows (2003) In `Ocean Biogeochemistry: The role of the ocean carbon cycle in global change'. Edited by Mike Fasham.

Collaboration with Claire Mahaffey & George Wolff (Liverpool) + AMT partners

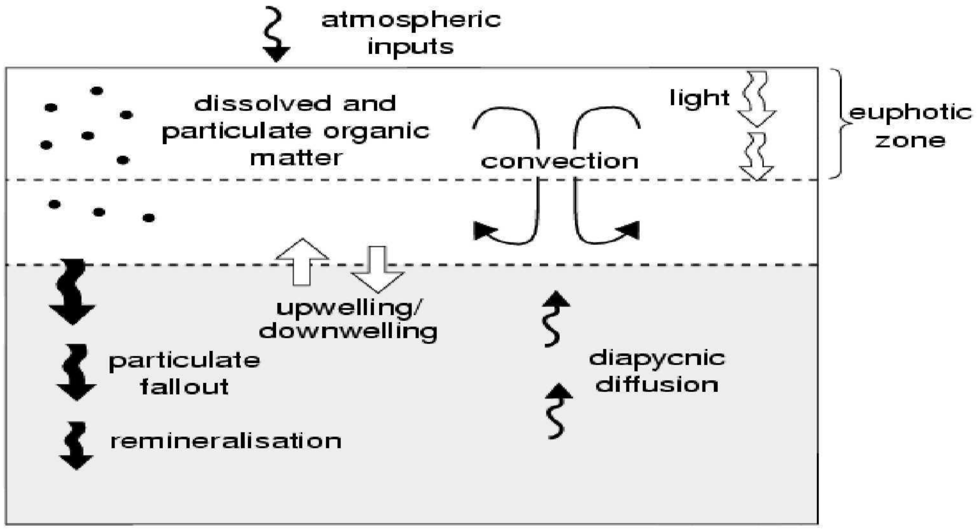
1.Basics

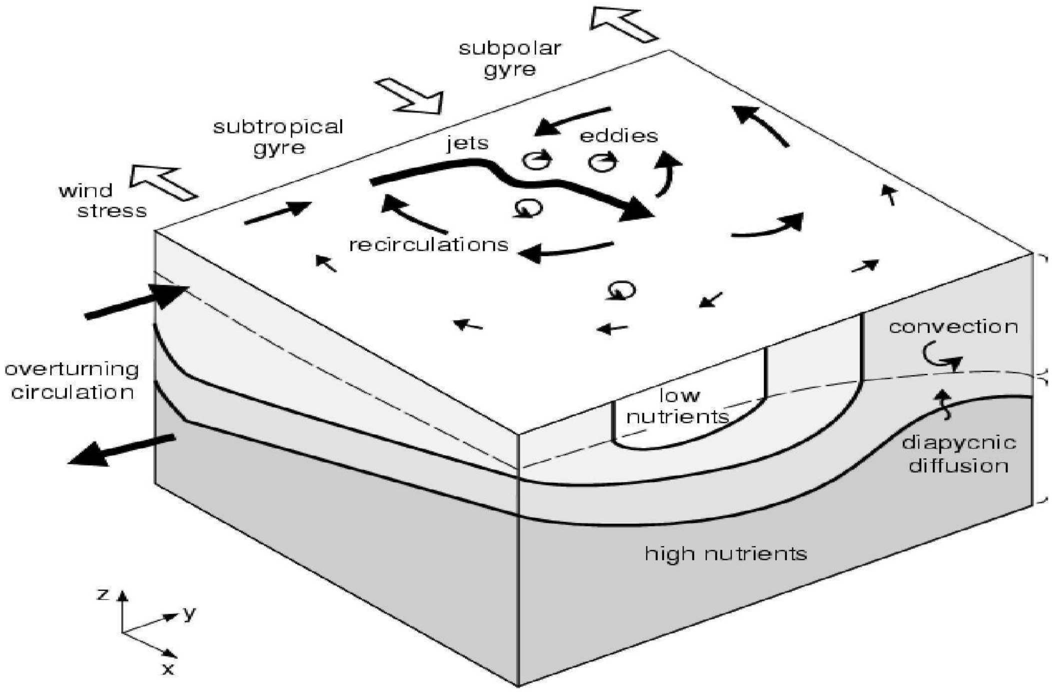
- Biological growth is in sunlit, surface ocean

- Organic matter formed with C : N : P ratio

112 : 16 : 1

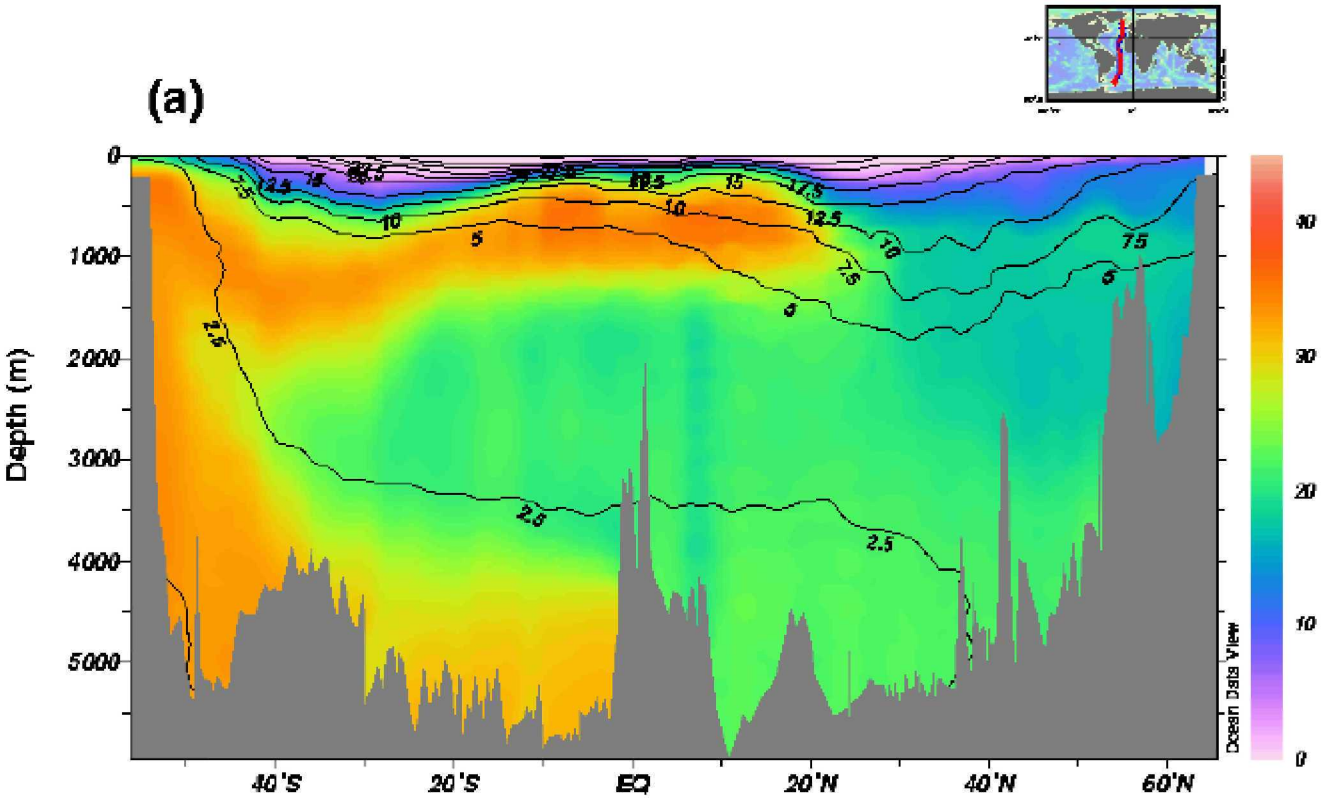
- Gravitational fallout requires nutrients to be supplied to surface





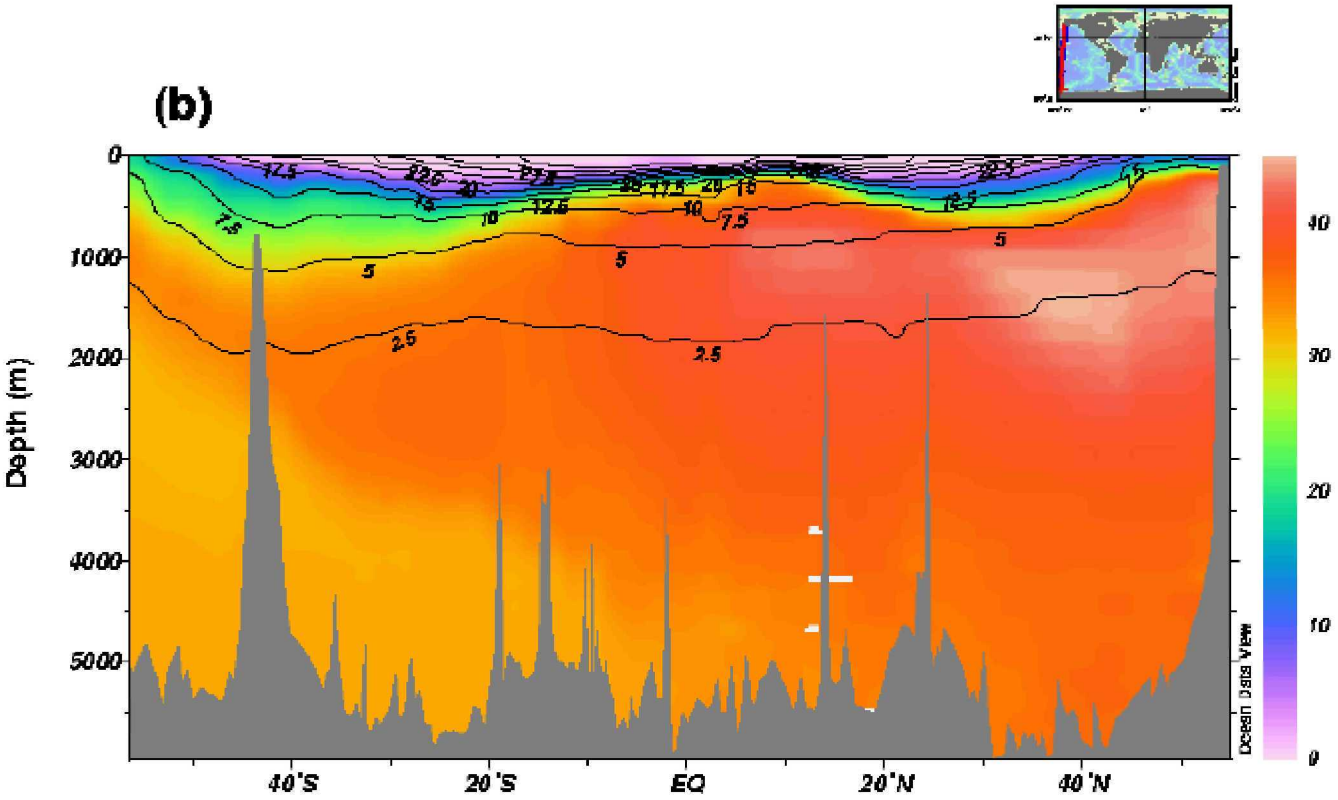
Atlantic

NO_3 (μmol kg^{-1})



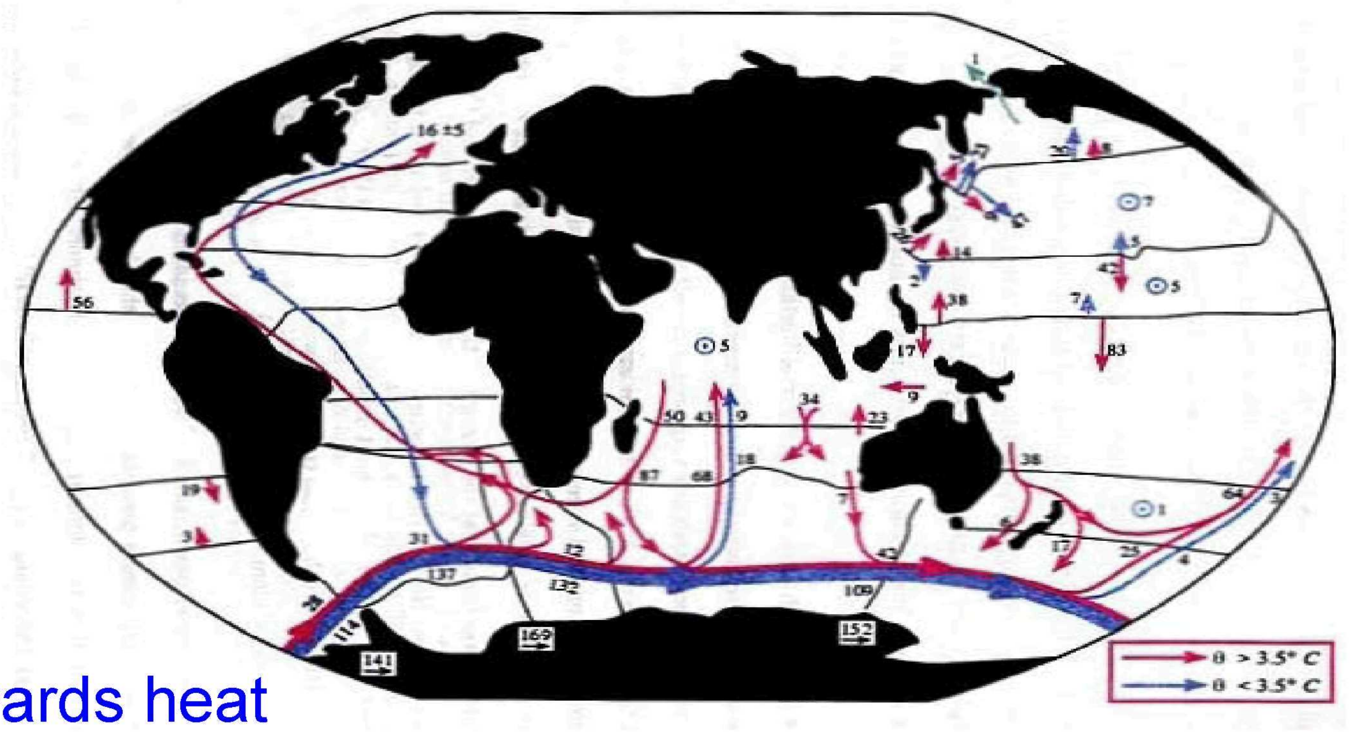
WOCE A16

Pacific



WOCE P15

2. Global circulation



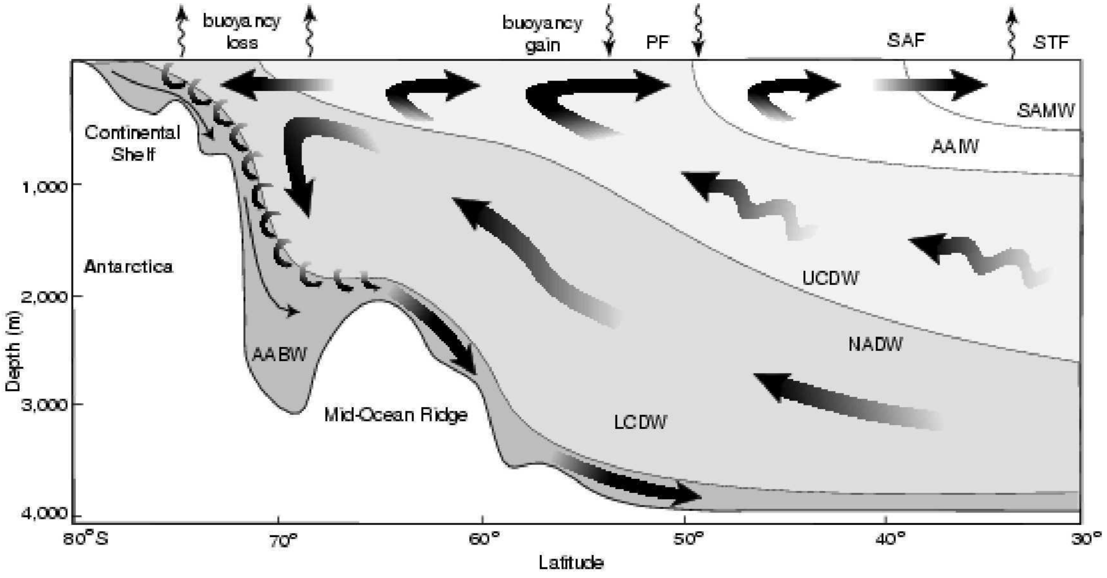
- Atlantic northwards heat flux
- S. Ocean connects basins
- Recirculations

Macdonald and Wunsch (1996) inversion

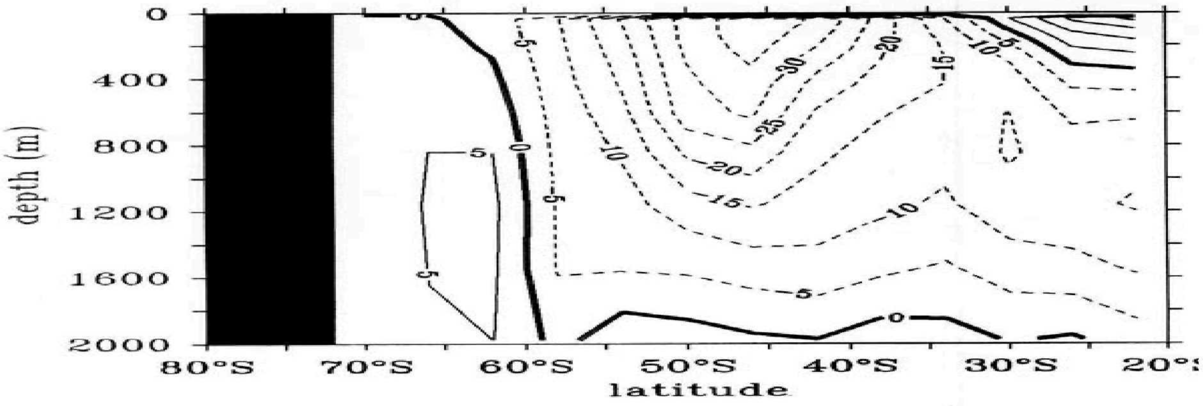
Volume flux of warm & cold water

Southern Ocean

- northwards Ekman flux
- northwards bottom flux
- eddy-driven southwards flux at mid-depths



Speer et al. (2000)

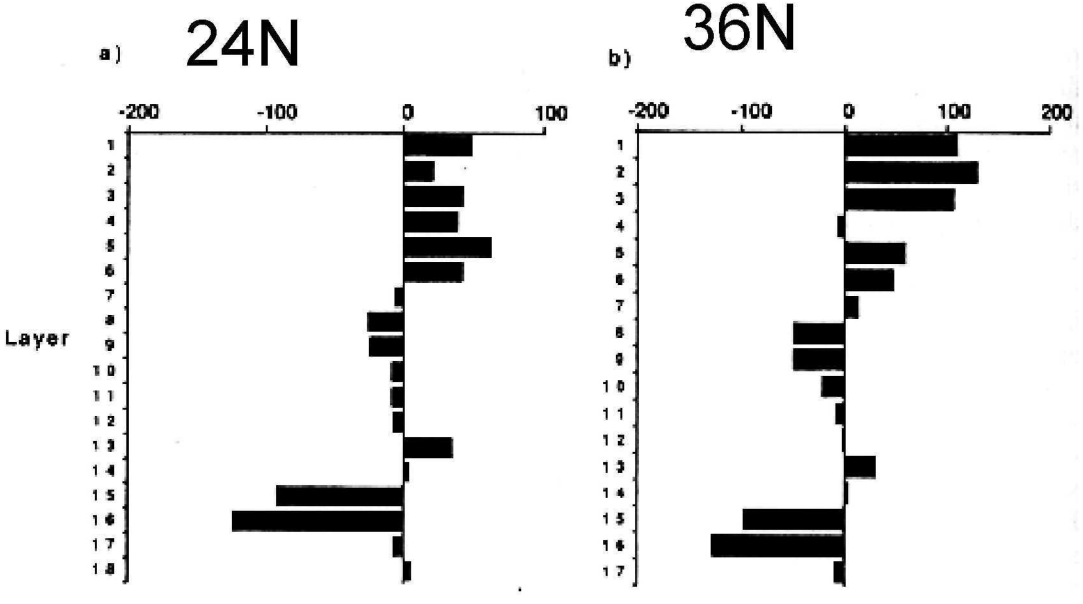


Typical time-mean overturning streamfunction ***if*** *eddy effects not included*

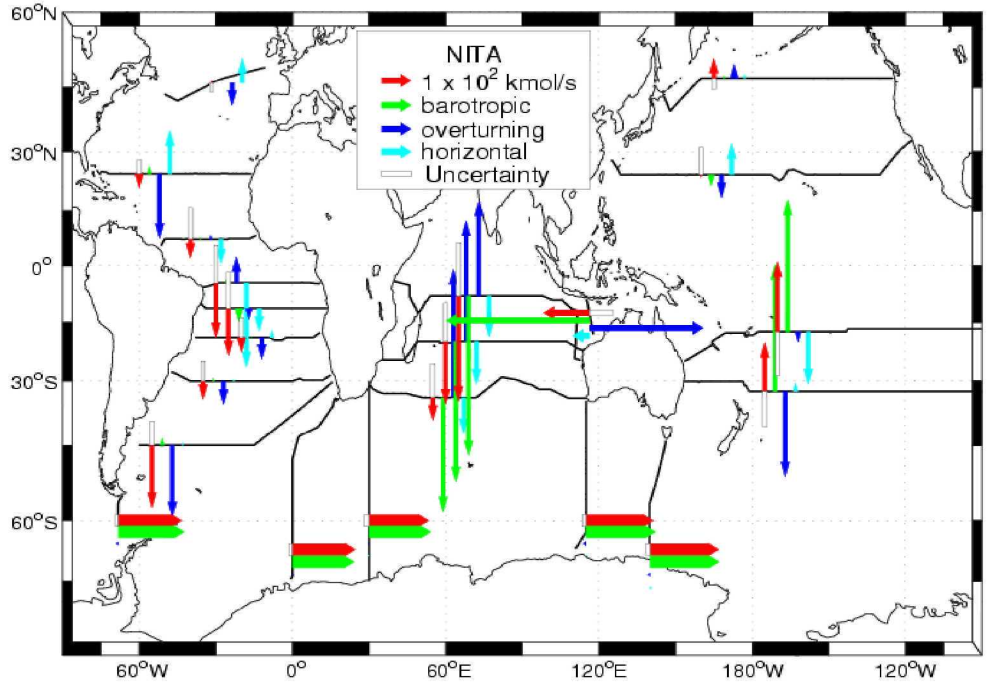
Nitrate transport

Rintoul & Wunsch (1991) for N. Atlantic

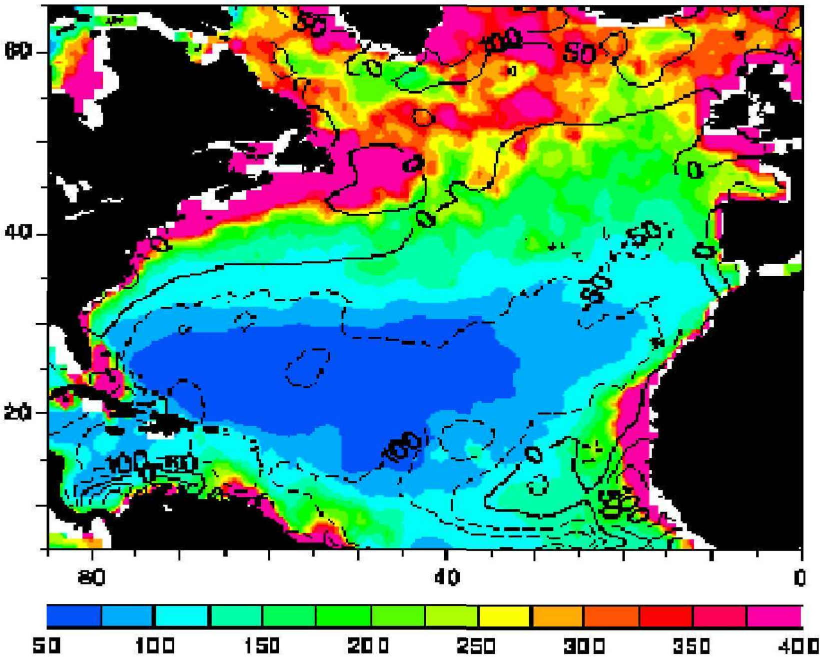
- predicts northwards NO_3 flux at 36N
- loss of NO_3 between 24N and 36N



Ganachaud & Wunsch (2002) global inversion



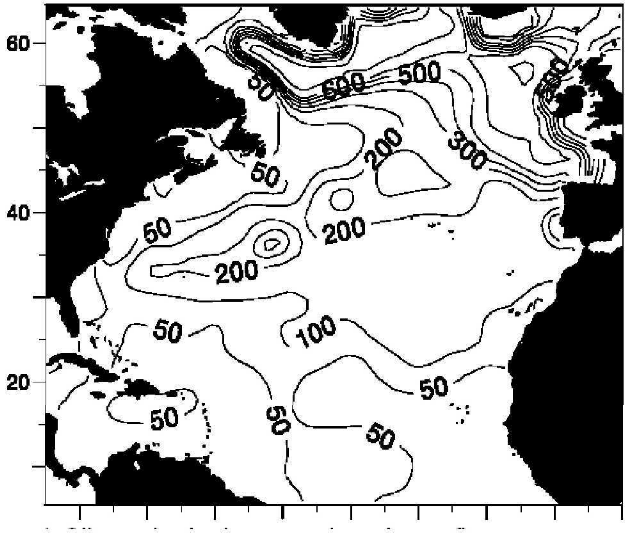
3. Convection



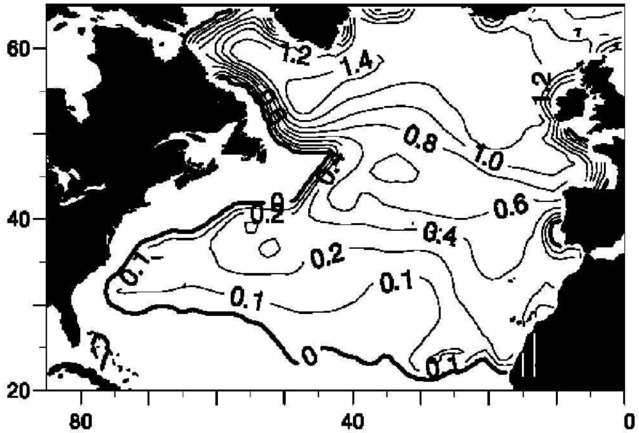
Satellite estimate of export production (gC m^{-2} y^{-1})

Sathyendranathan et al. (1995)

b) March mixed-layer thickness



c) Climatological convective nitrate flux

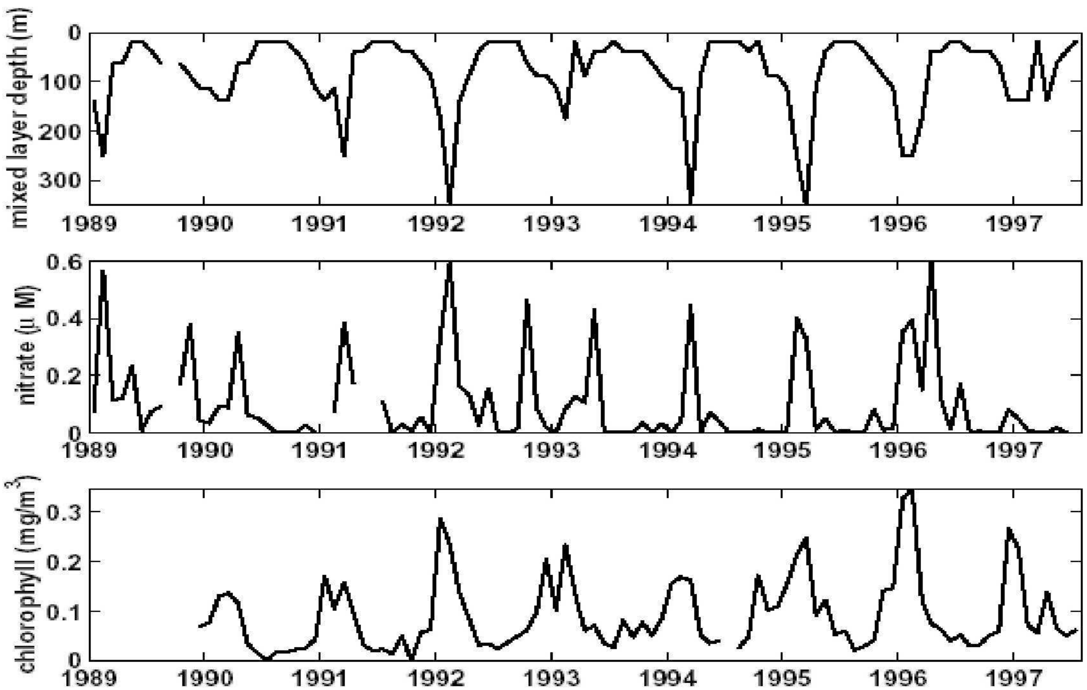


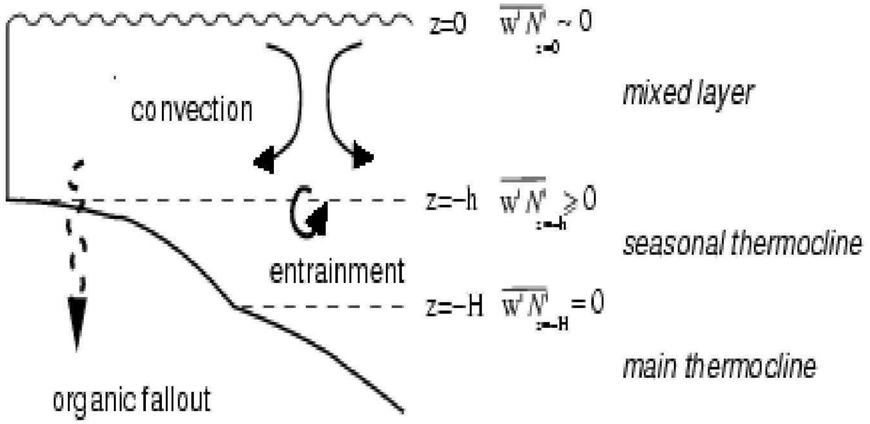
Williams & Follows (2003)

Is convection alone sufficient?

Convective variability

Variability at Bermuda



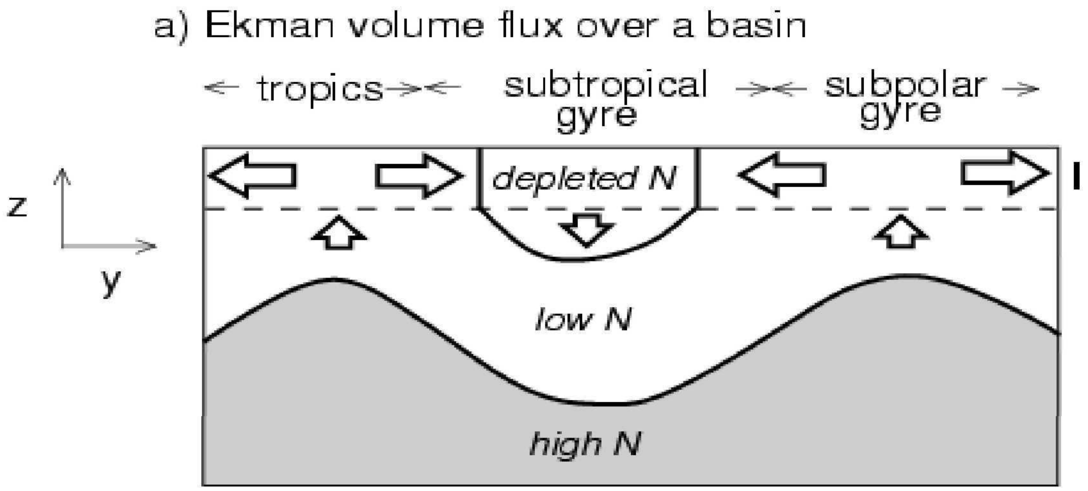


Eventually need a N source above main thermocline

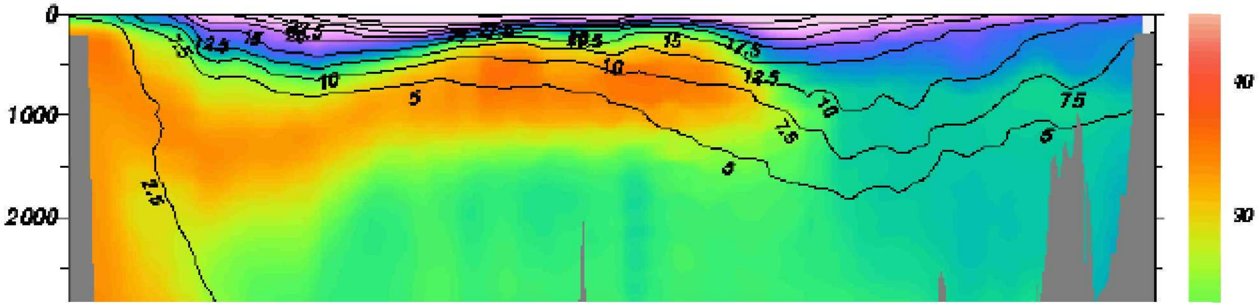
— otherwise N diminish

4. Gyres

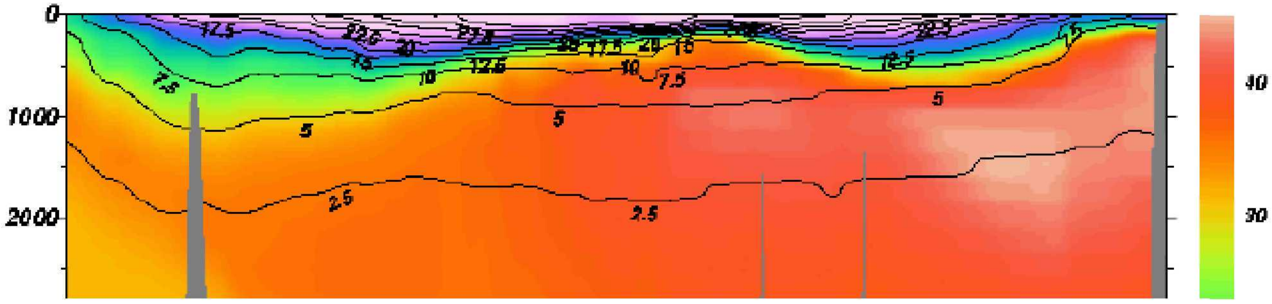
Characteristic thermocline undulations


a) Ekman volume flux over a basin

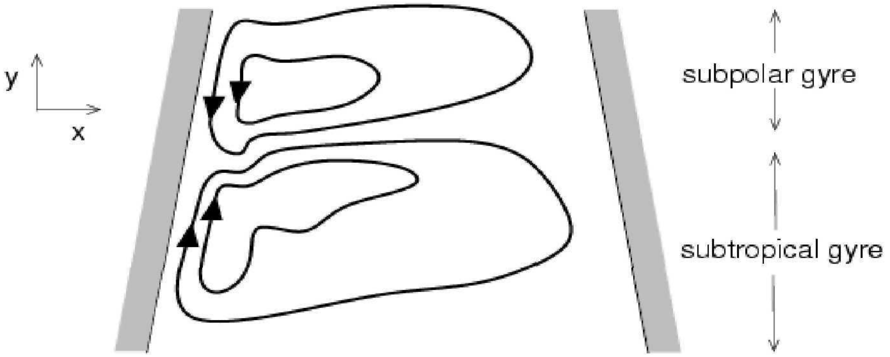
Atlantic NO_3 section

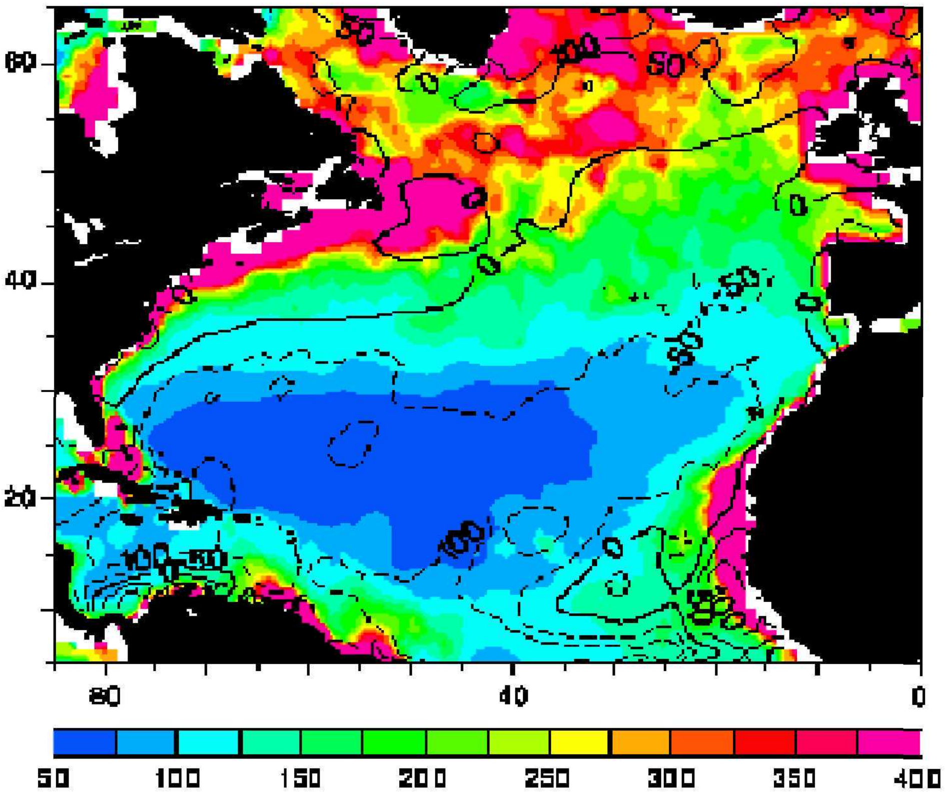


Pacific NO_3 section



Gyres

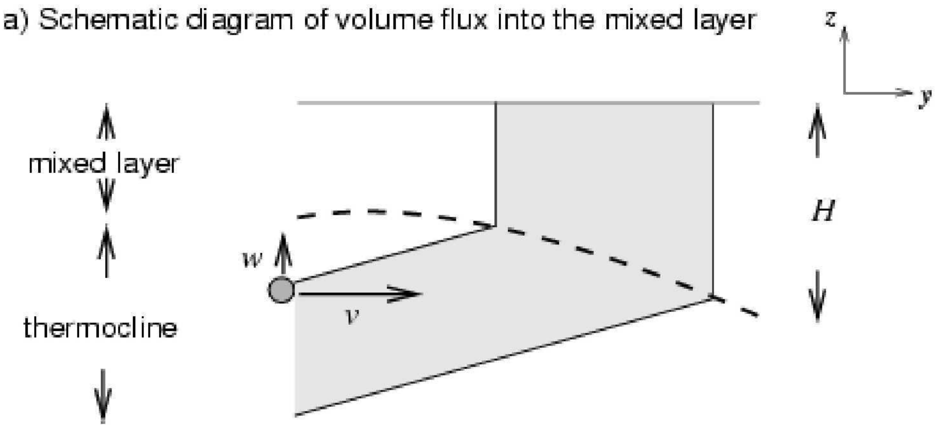


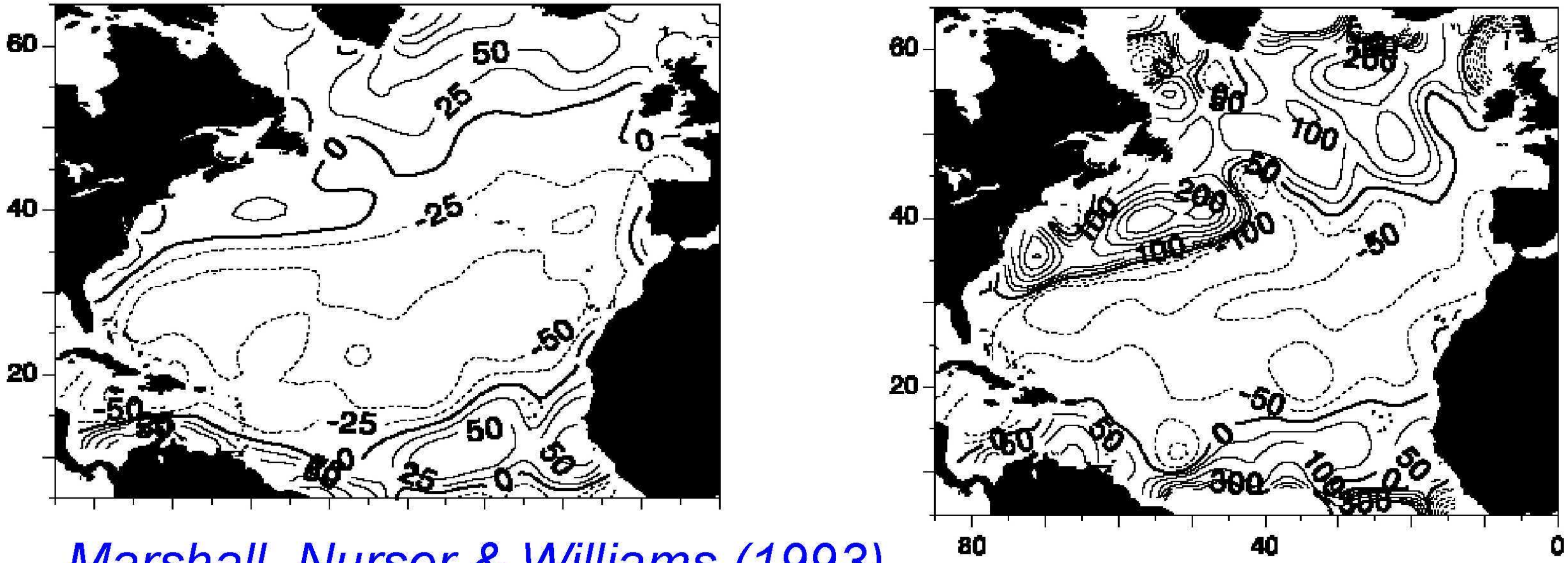


w (m y^{-1}) (contours)
Export production
(gC m^{-2} y^{-1}) (colour)

Does the vertical velocity control production?

Subduction


a) Schematic diagram of volume flux into the mixed layer

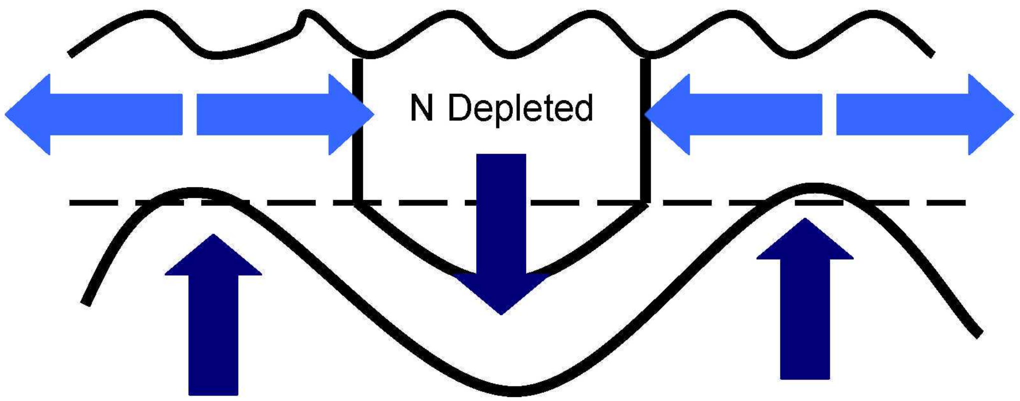

b) Ekman upwelling velocity

c) Volume flux into seasonal-boundary layer

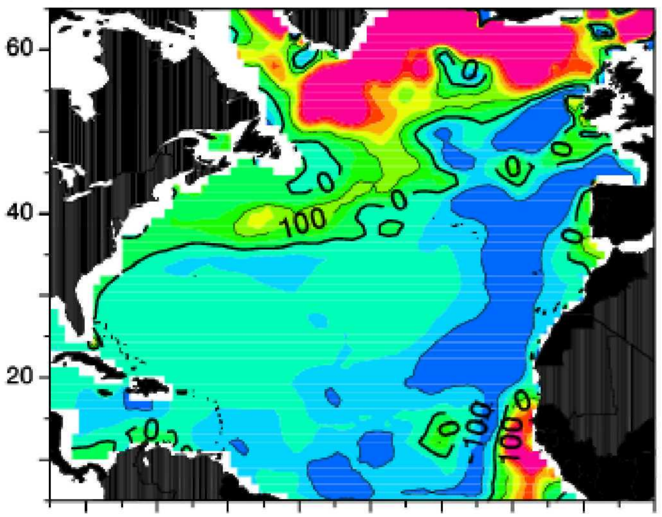
Marshall, Nurser & Williams (1993)

Lateral influx into mixed layer in subpolar gyre
— expect high influx of NO_3

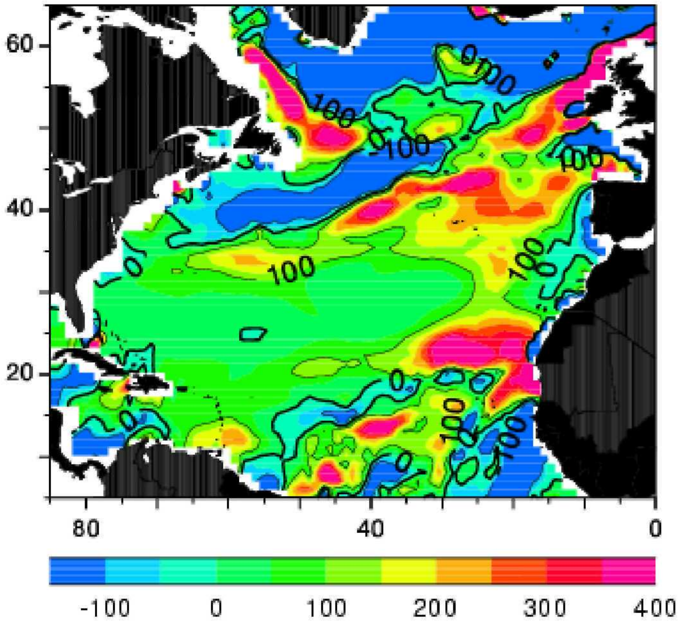
Lateral transfer of nitrate



a) vertical Ekman nitrate flux



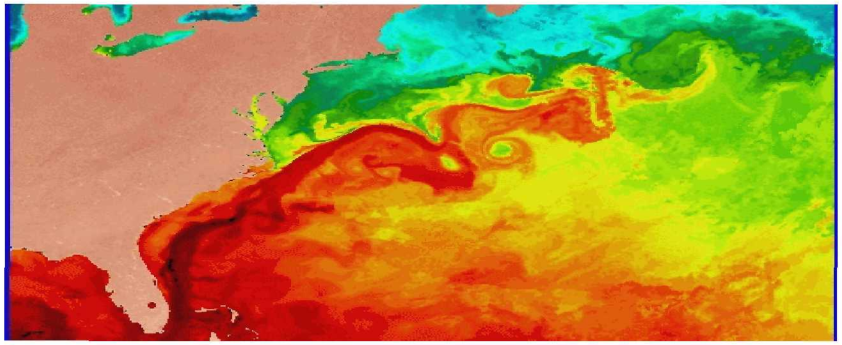
b) horizontal Ekman nitrate flux



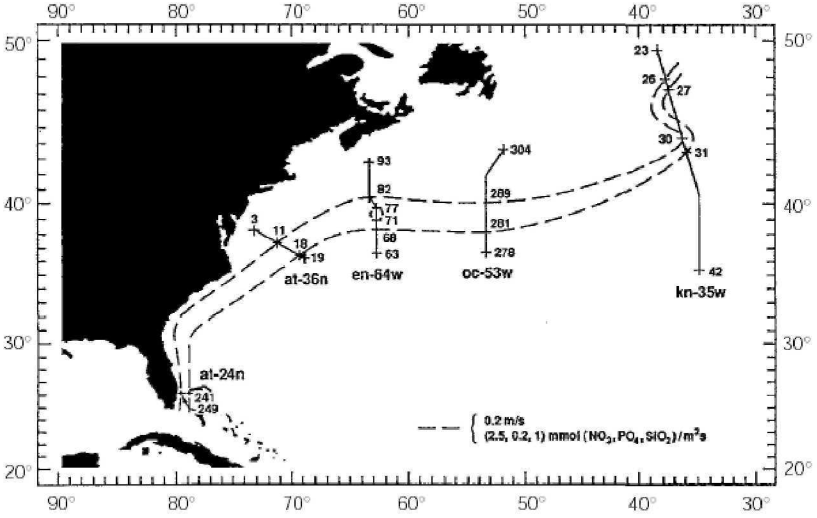
How does NO_3 get back to the surface?

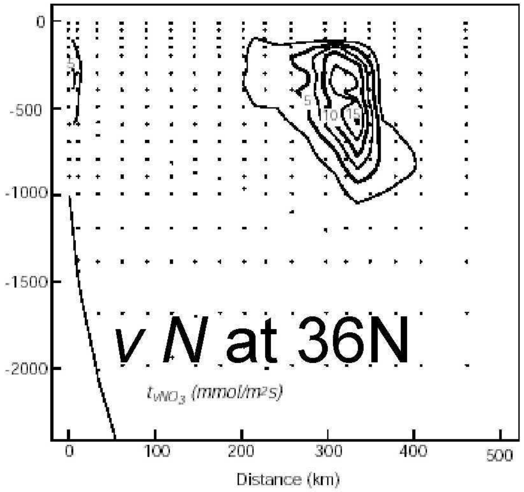
Williams & Follows(1998)

Nutrient streams

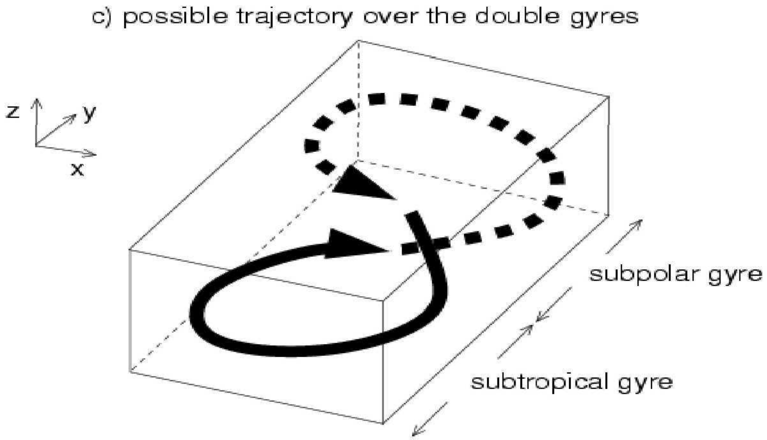


Pelegri & Csanady (1991)

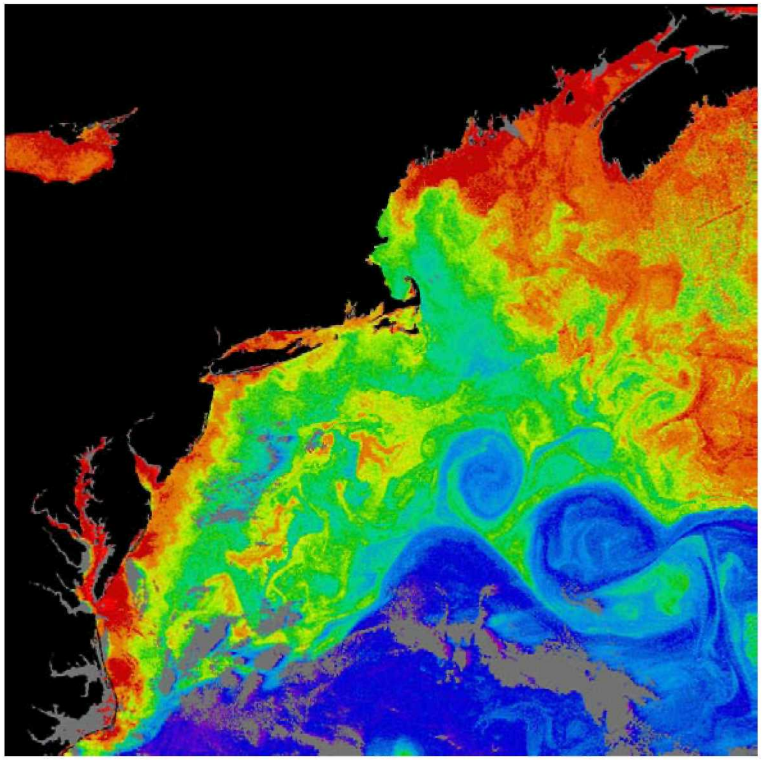

'Nutrient Stream' in the North Atlantic

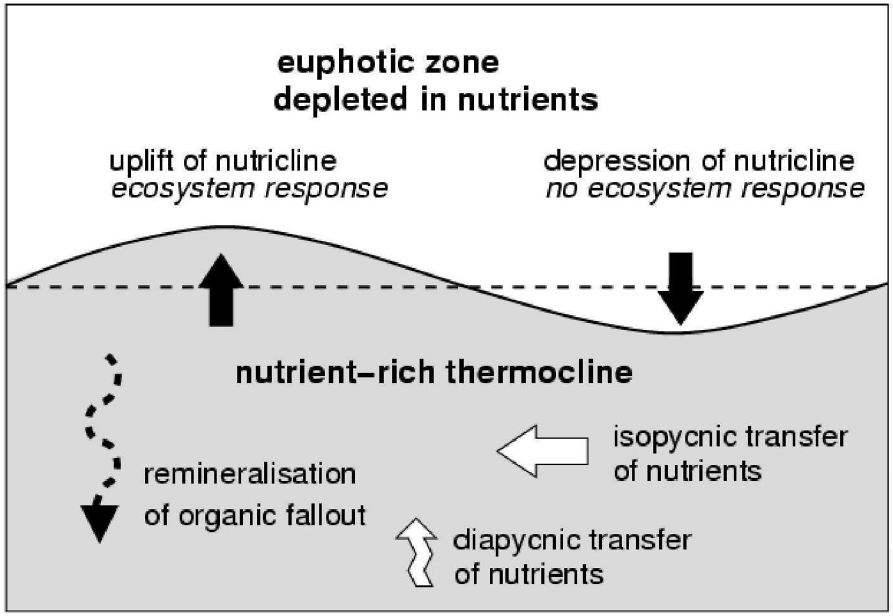


N pathway involves a figure of 8 :


c) possible trajectory over the double gyres

5. Eddy/Fronts



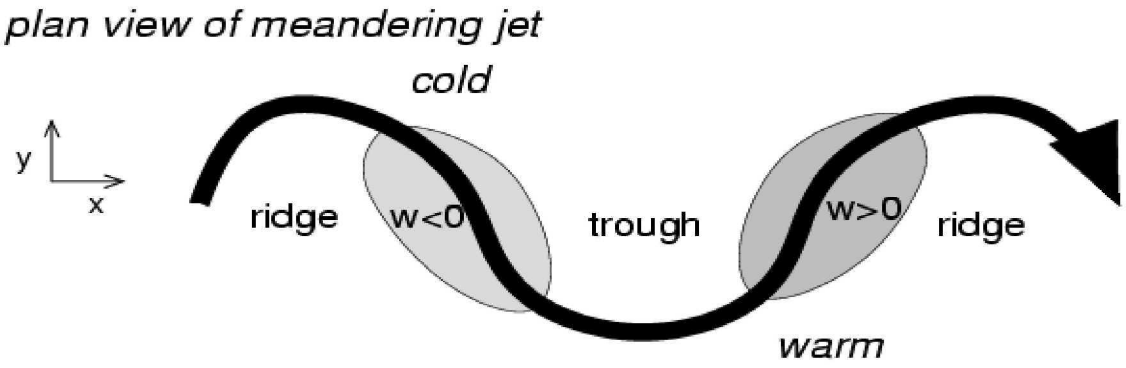


Eddy Rectification

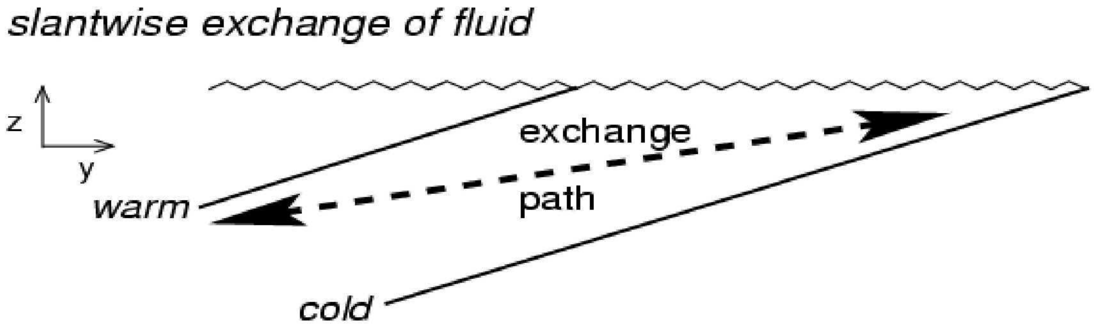
McGillicuddy & Robinson (1997)

How does the process work?

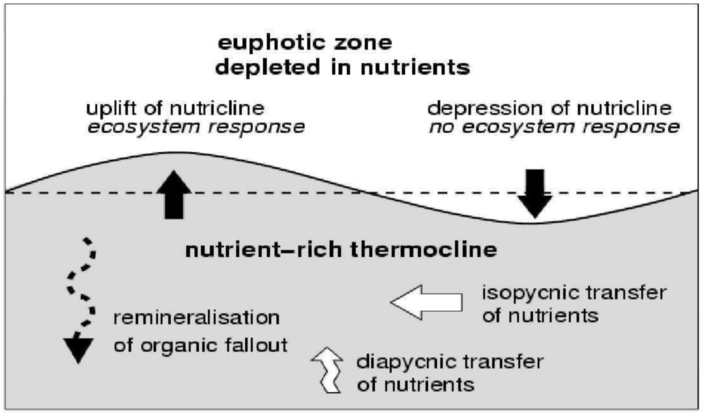
Instability process



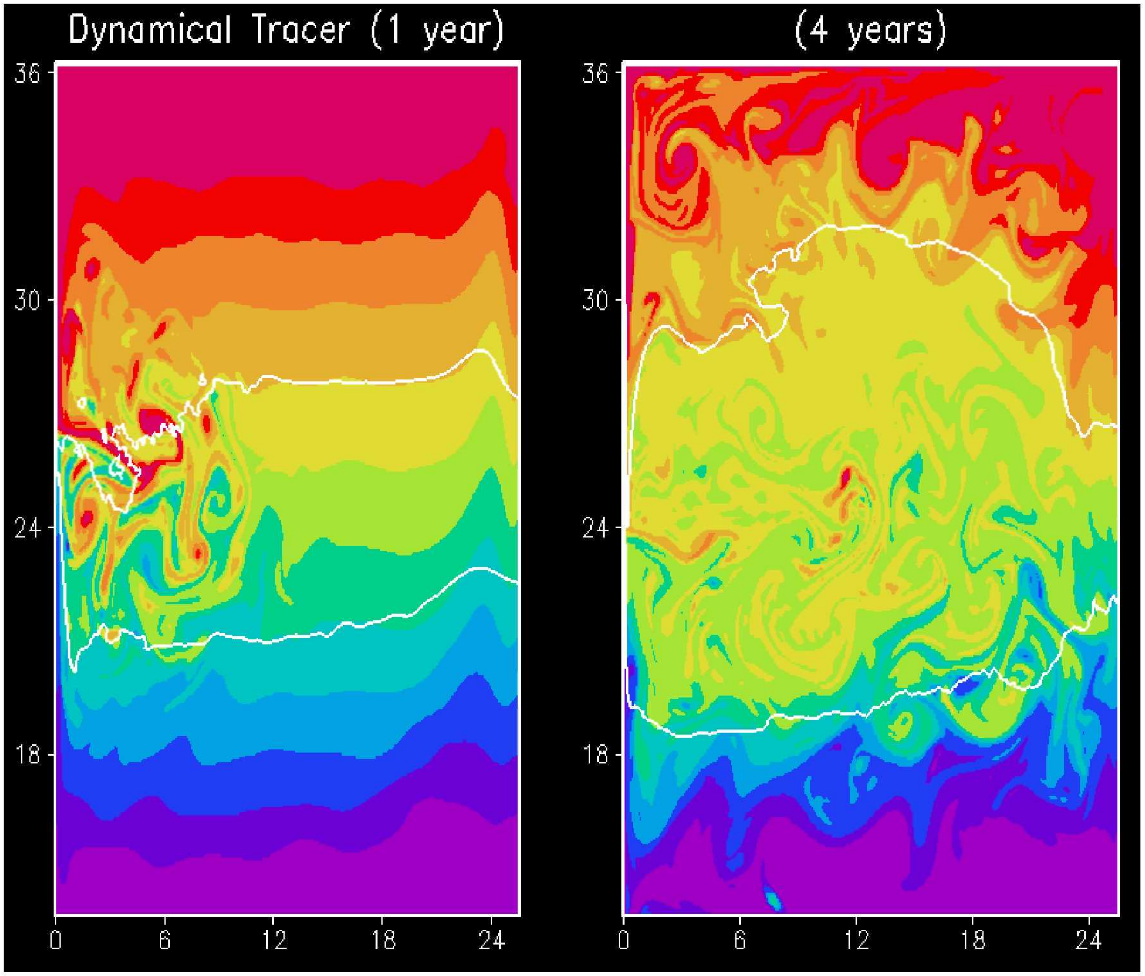
Warm waters *rise*
Cold waters *sink*



High N in surface waters of cold eddy is from lateral exchange, <u>not</u> local upwelling



Idealised eddy example



Wilson and Williams (2003)

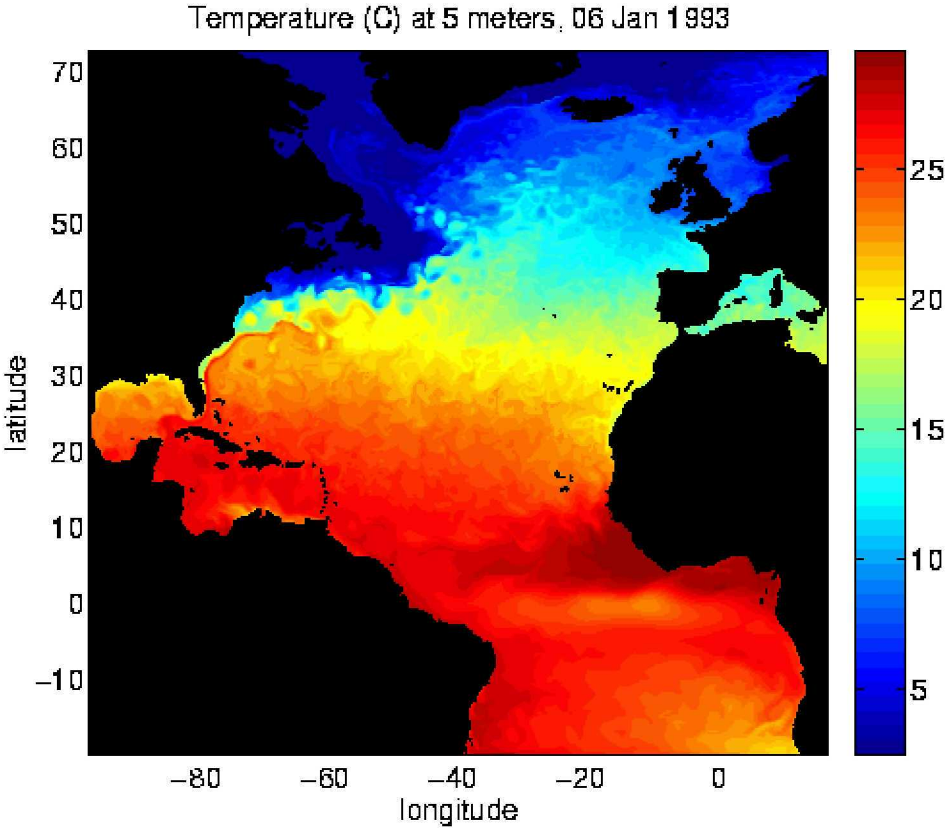
Double wind-driven gyre

- 1/16 deg.

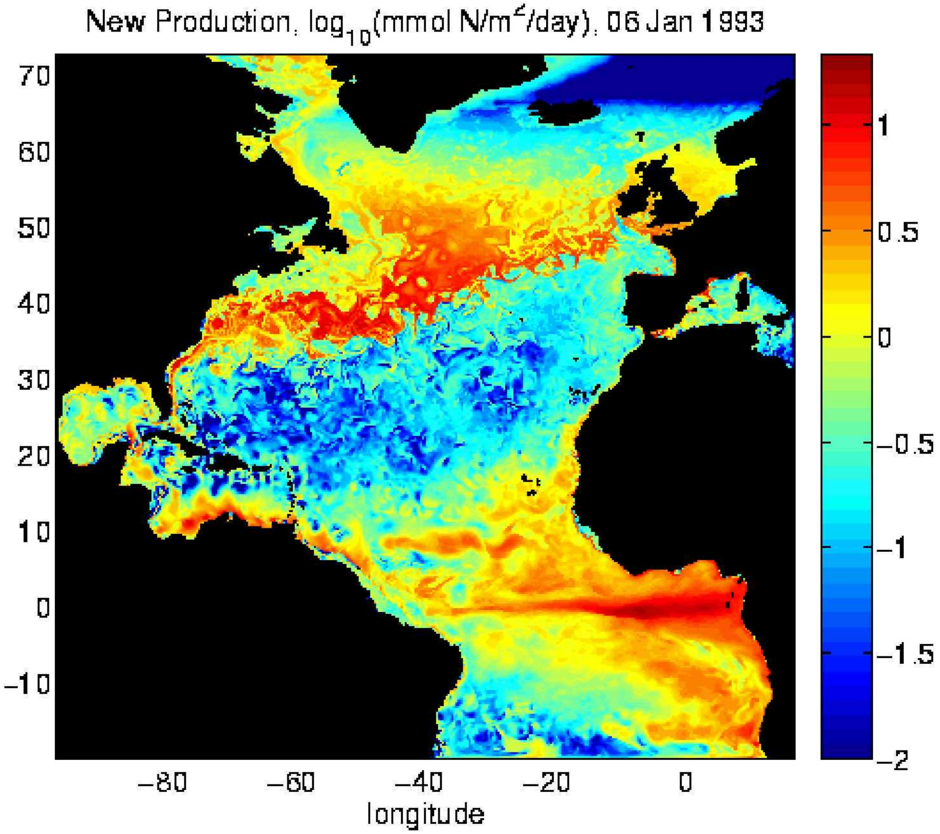
see dynamic tracer plotted on isopycnal

Realistic GCM example

Surface T


Temperature (C) at 5 meters, 06 Jan 1993

New Production


New Production, $\log_{10}$(mmol N/m^2/day), 06 Jan 1993

McGillicuddy et al. (2003)

1/10°, Los Alamos, 40 levels. 6 hr ECMWF winds 1985-1991, 11 year integration. N relaxed to climatology on 30 day timescale.

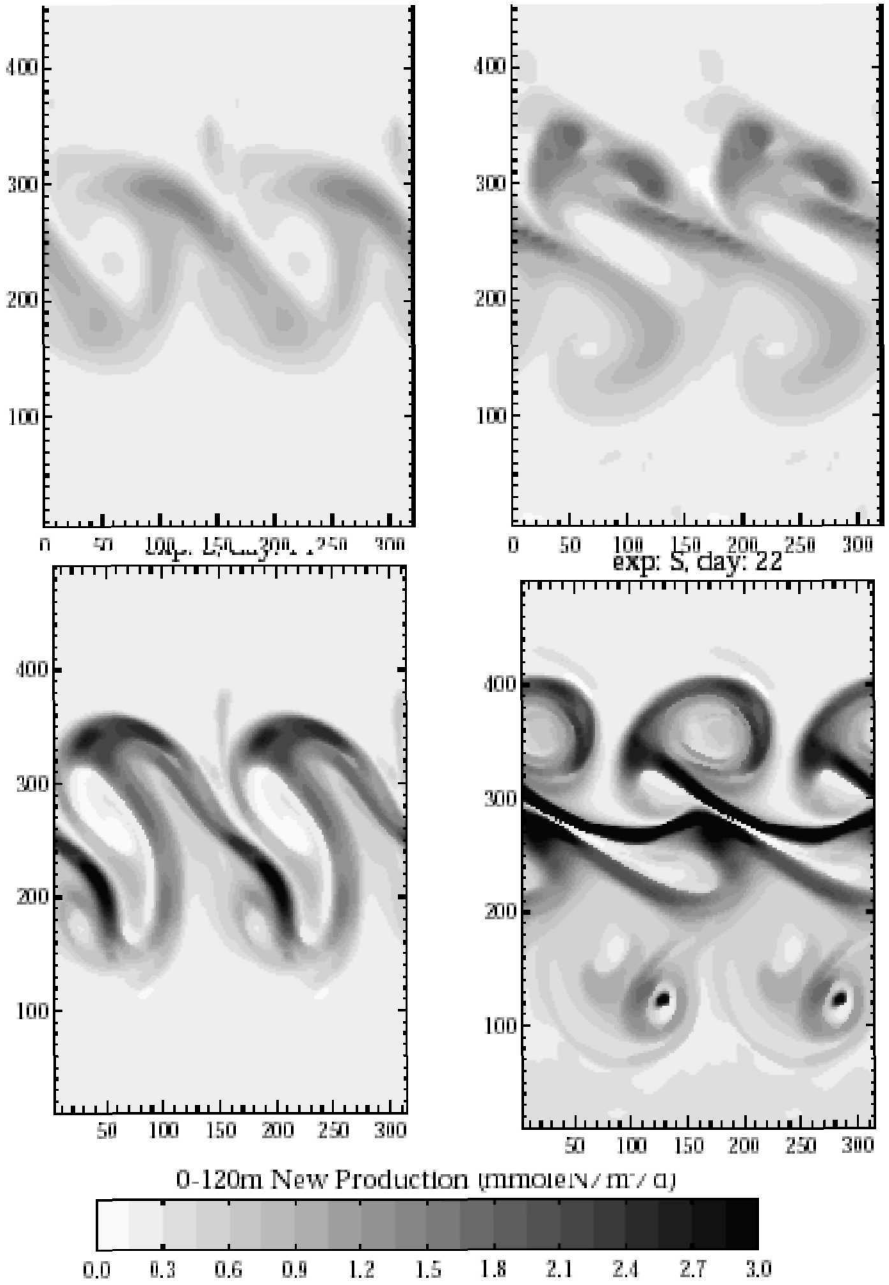
Fronts

day 14

day 24

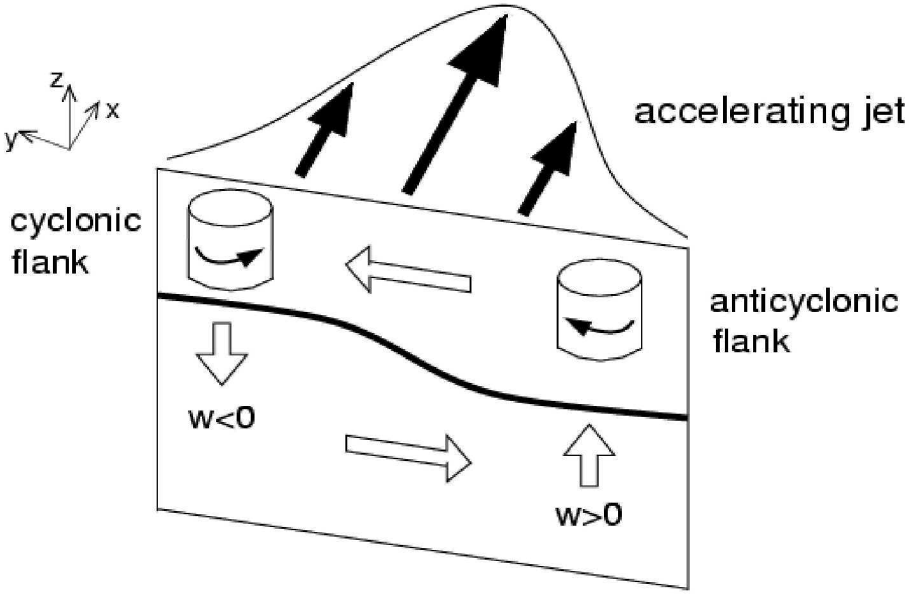
$1/3^o$

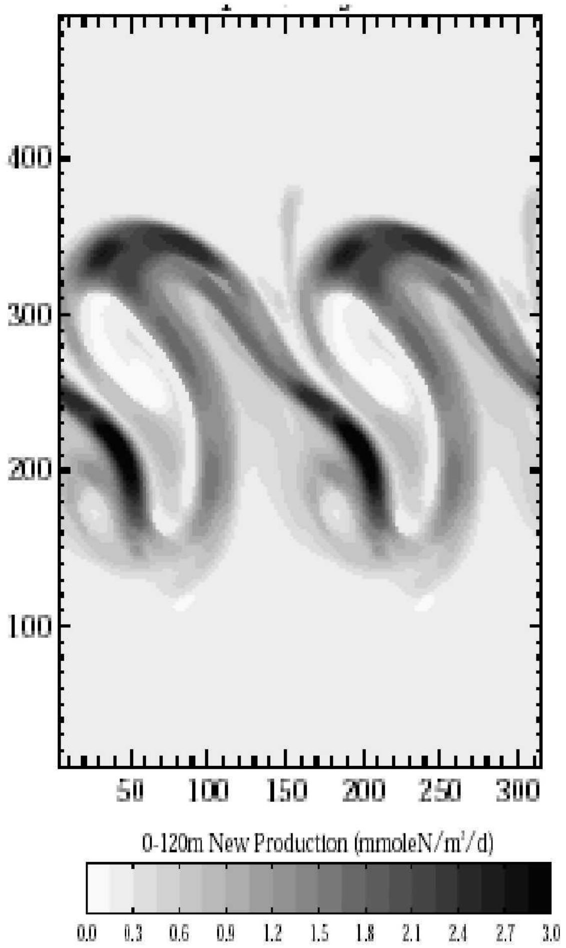
$1/12^o$



Levy et al. (2001)

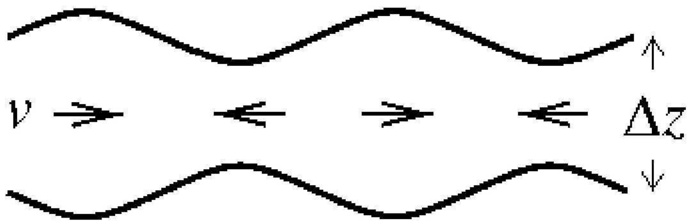
Frontal circulation


embedded frontal–scale circulation

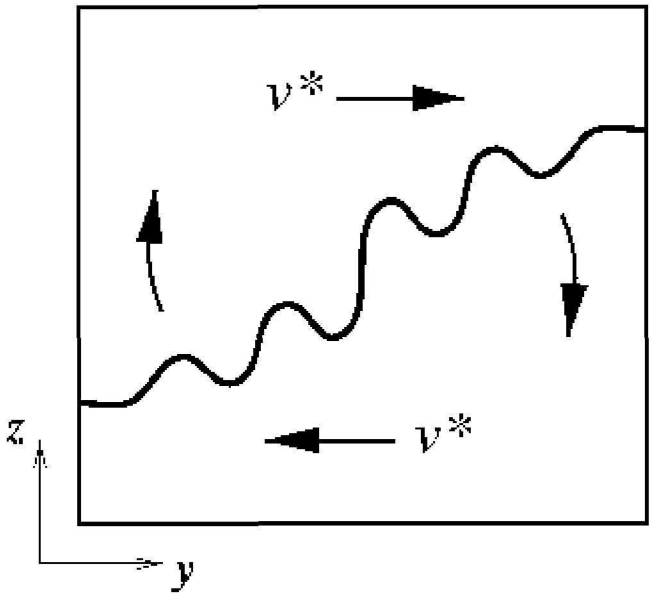


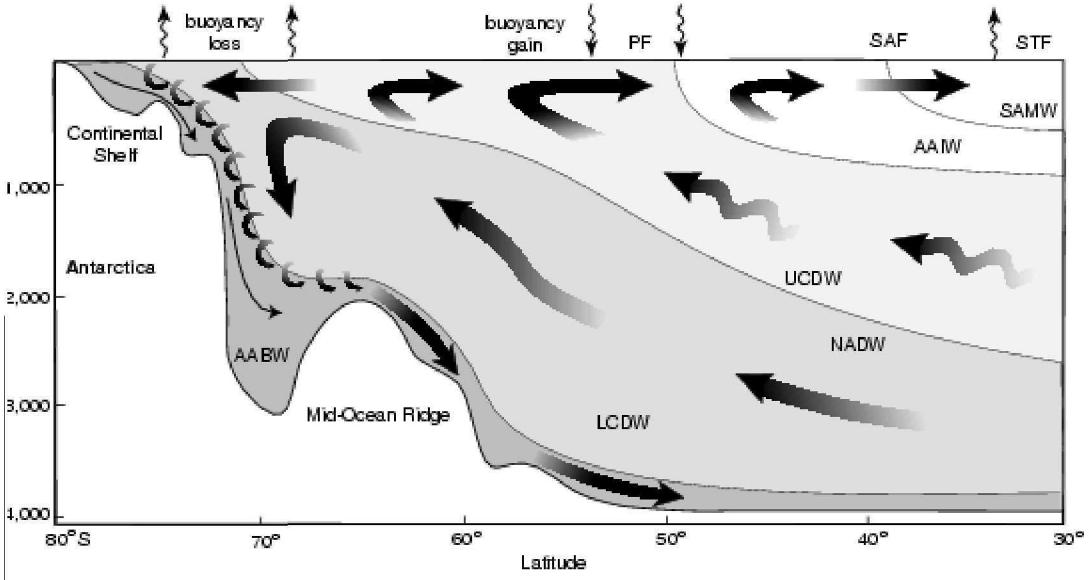
Eddy lateral transfer

a) eddy transport from velocity and thickness oscillations



b) eddy transport arising from slumping of isopycnals



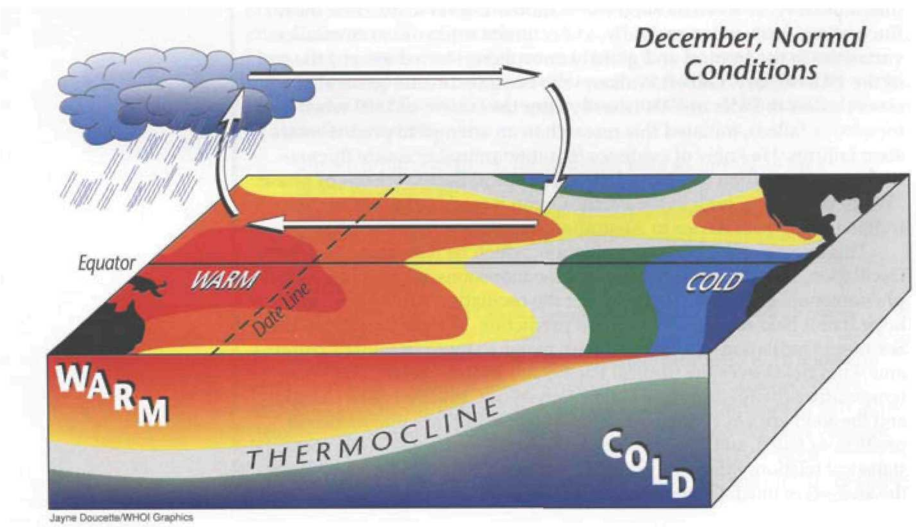


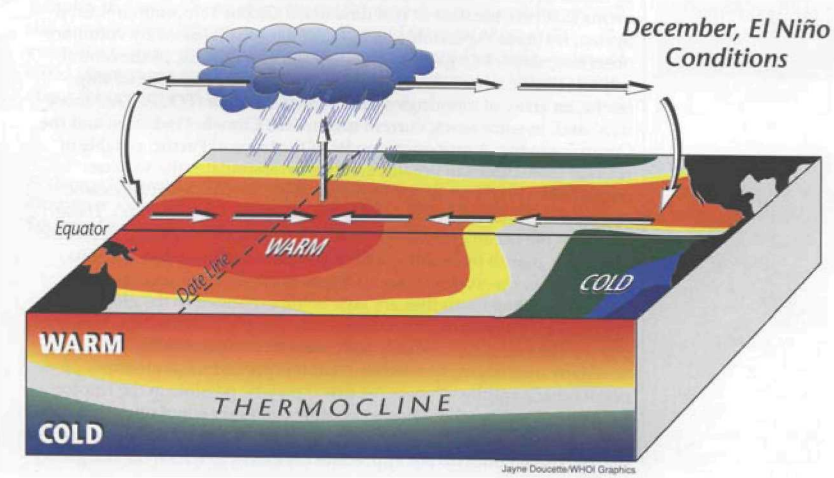
Eddy transport probably crucial for southwards spreading in S. Ocean

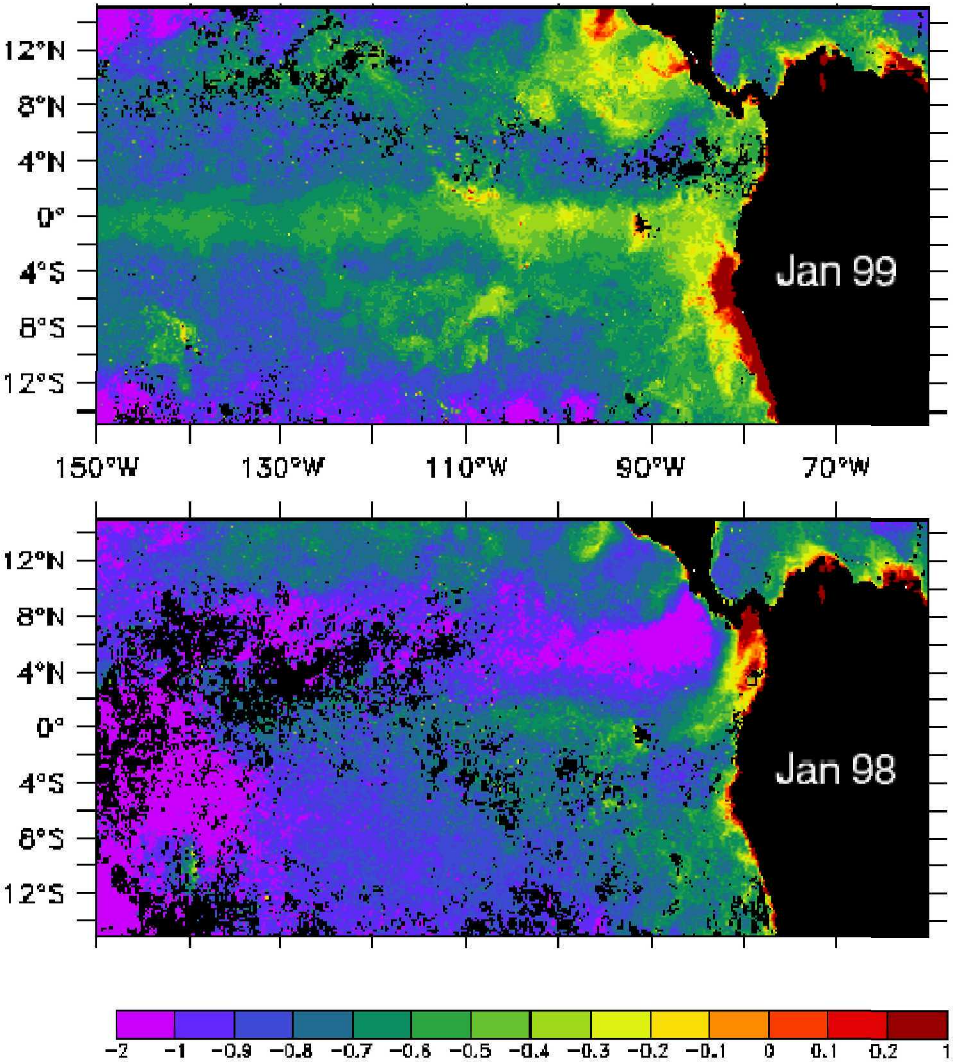
6. Temporal variability

Steady state view omits significant variability:	*examples:*
• Coupled atmosphere-ocean	*El Nino*
• Atmosphere forced changes	
convection	*NAO*
overturning	*Mediterranean*

El Nino







Chlorophyll a (mg/m^3)

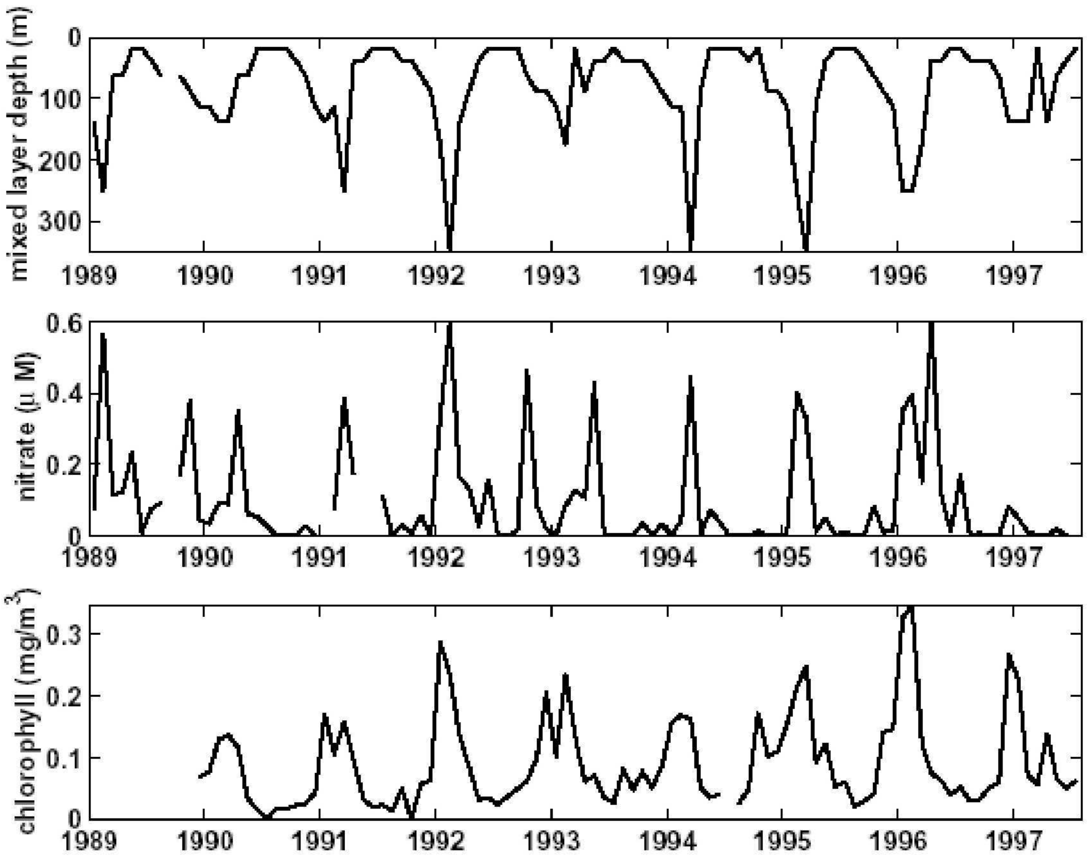
Philander (1990)

Bermuda Atlantic Time Series

Mixed layer thickness

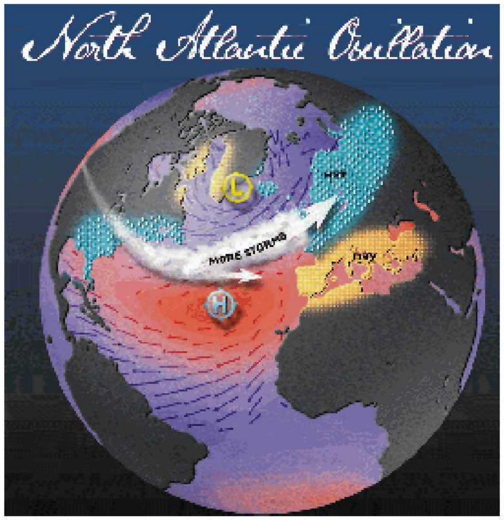
Nitrate

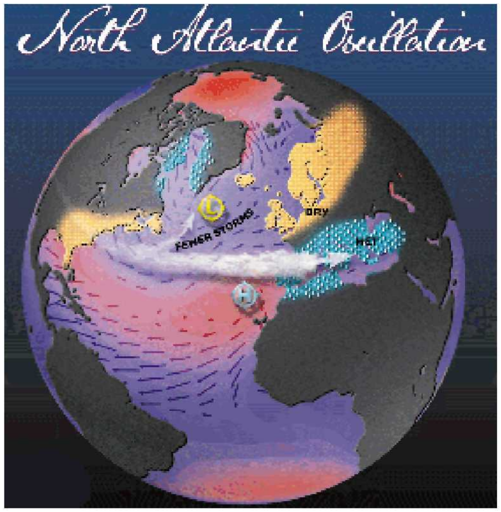
Chlorophyll

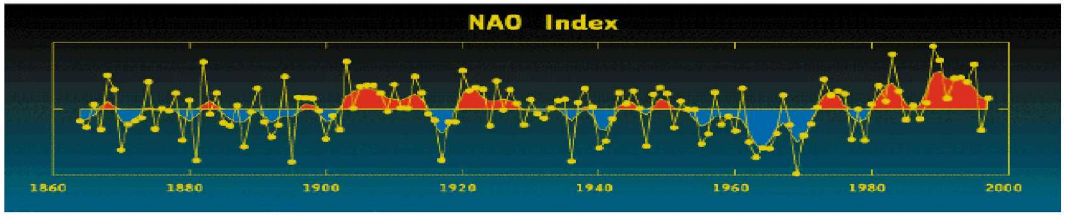


NAO

Dominant N. Atlantic atmospheric mode captures 30% of variability





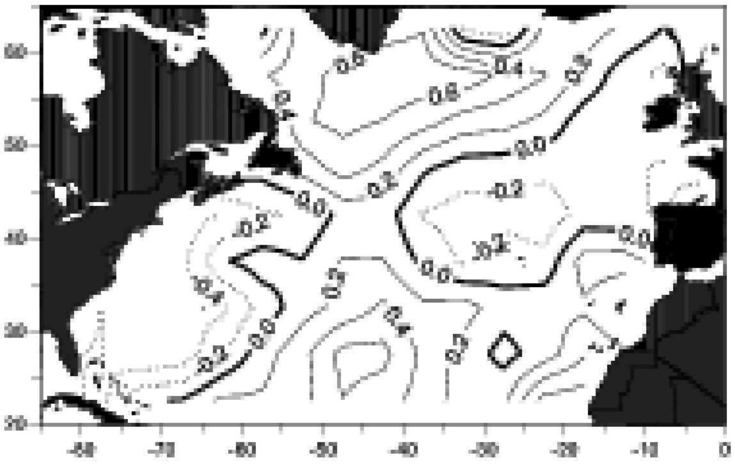


http://www.ldeo.columbia.edu/NAO/

For nutrient supply, simple model predicts strong correlation over W. Atlantic, but not E. Atlantic

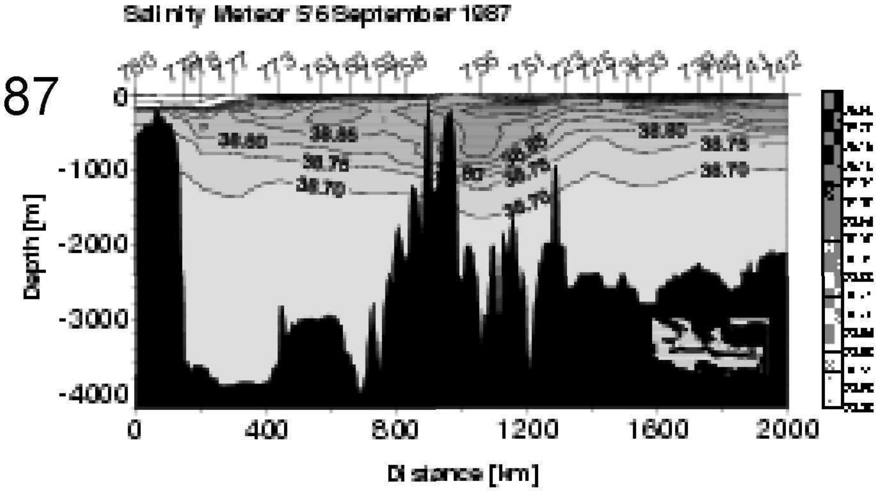
Williams et al. (2000)

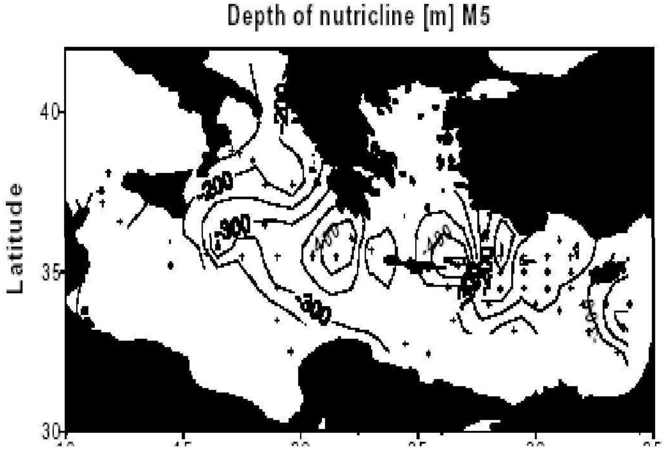
d) Correlation: NAO and Convective nitrate supply



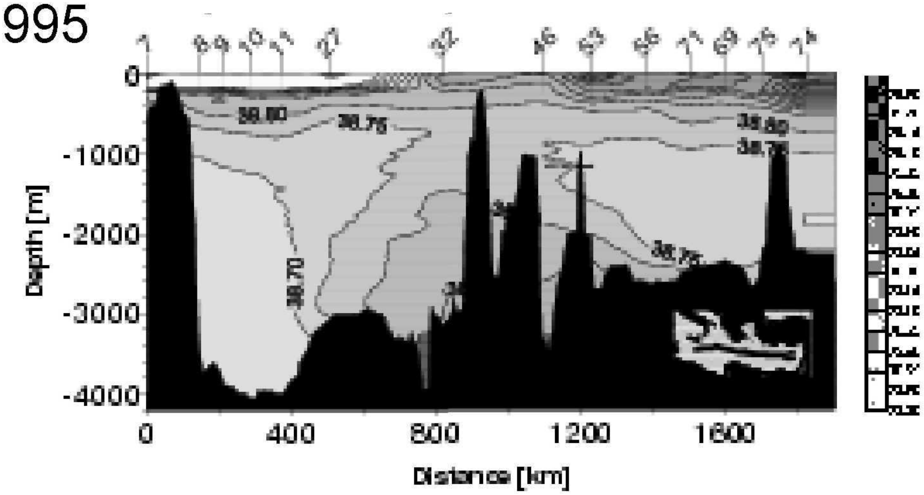
Mediterranean: abrupt change

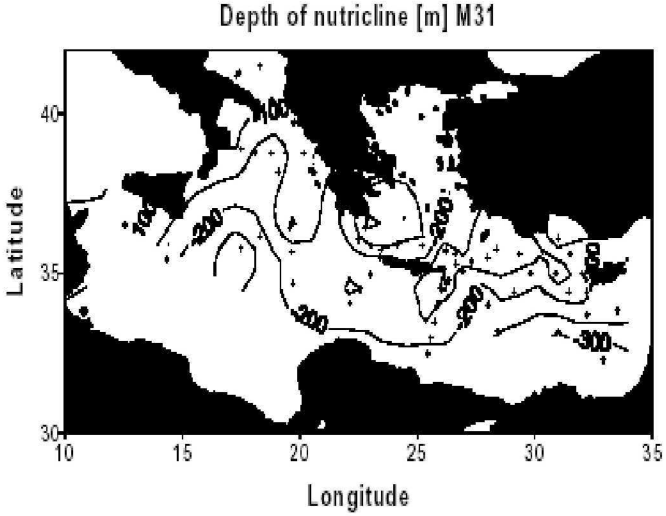
1987





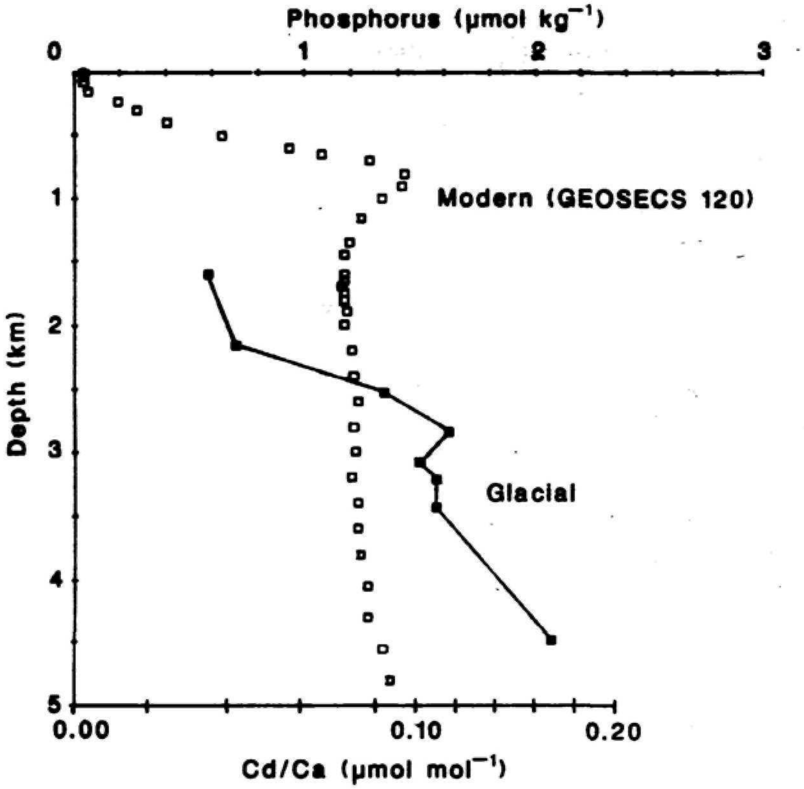
1995





Roether et al. (1996); Klein et al. (1999)

Glacial/ Interglacial in Atlantic



Glacial reconstruction based on Cd/Ca ratios

Boyle & Keigwin (1987)

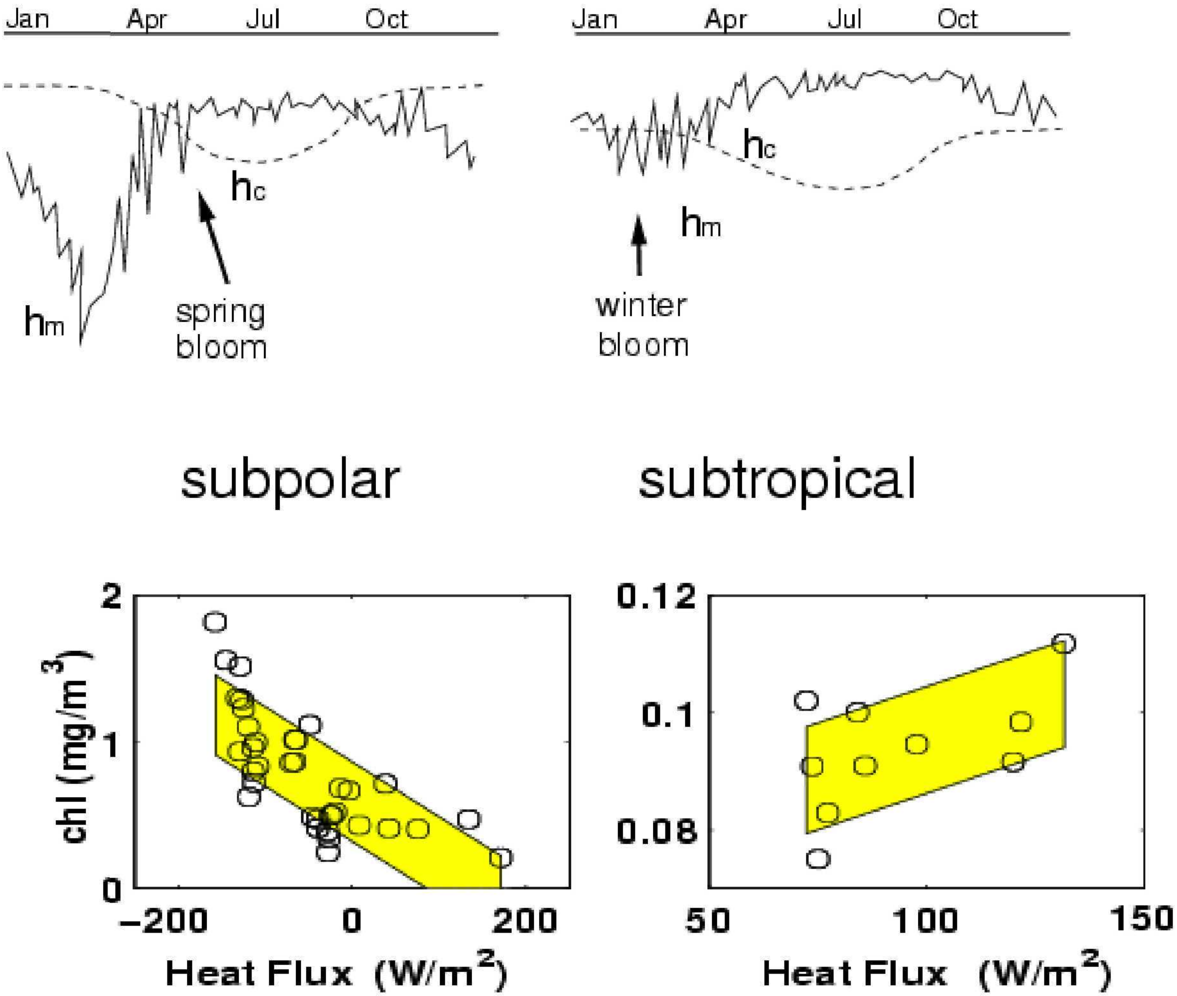
Conclusions

- Basin contrasts in N controlled by overturning circulation. Productive high latitudes due to convection & upwelling
- Separate gyres connected by Ekman flows and boundary currents
- Eddy & frontal productivity due to vertical & *lateral* transfers
- Significant interannual variability, usually linked to atmospheric forcing

Challenges:

- acquire a more quantitative assessment
- separate perturbation effects & long term changes
- understand mechanistic links with the atmospheric

Convective variability



Follows & Dutkiewicz (2002)