The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

SMR/1837-11

2007 ICTP Oceanography Advanced School

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Ocean biological productivity and climate change - part II

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Ocean biological productivity and climate change

Ric Williams, Earth & Ocean Sciences, Liverpool University

Lecture 1: basin scale view

- Background state
- High latitude productivity

Lecture 2: subtropical gyres

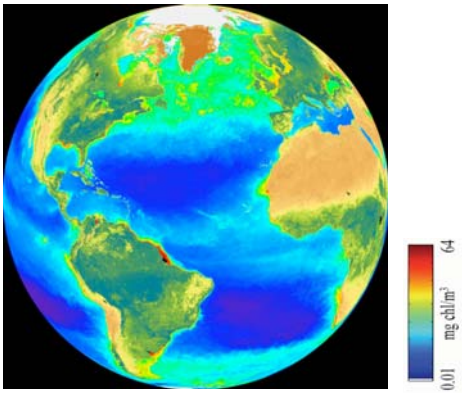
- Mid latitude productivity
- Eddy transfers

Lecture 3: boundary currents

- Stirring/strain
- Barriers/blenders

Lecture 4: Climate change

- Heat content changes in the N. Atlantic
- Ocean overturning



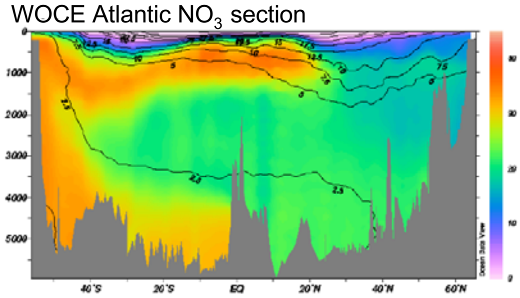
False colour picture of chlorophyll concentration

September 97 - August 98, SeaWIFS, NASA

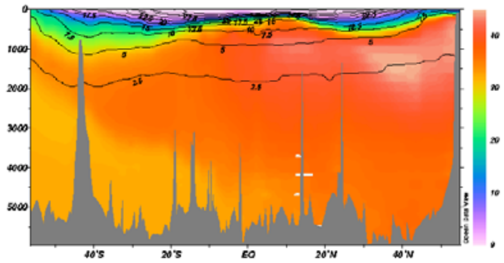
FROM LECTURE 1

How is the background state determined?

WOCE Atlantic NO_3 section

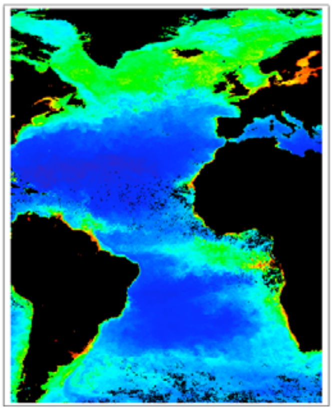


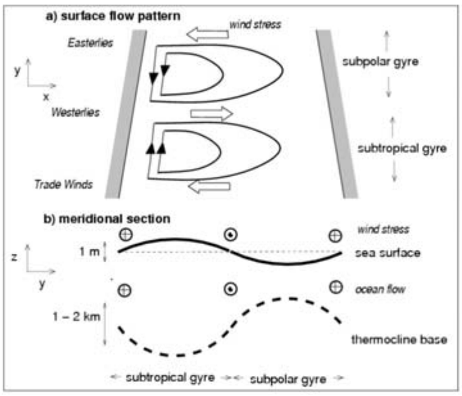
WOCE Pacific NO_3 section



FROM LECTURE 1

Signatures of ocean gyres



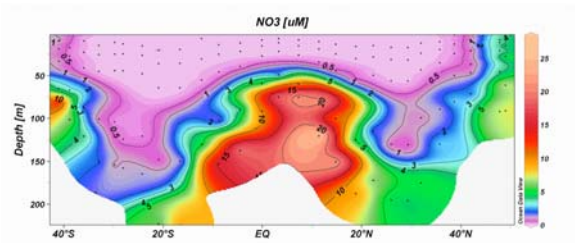


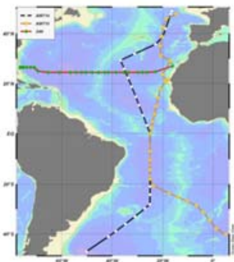
Extensive regions of low productivity over subtropical gyres

FROM LECTURE 1

Extensive regions of low producitivity

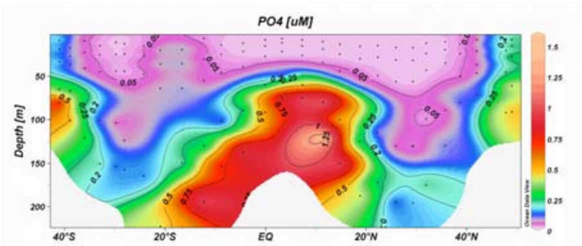
NO_3





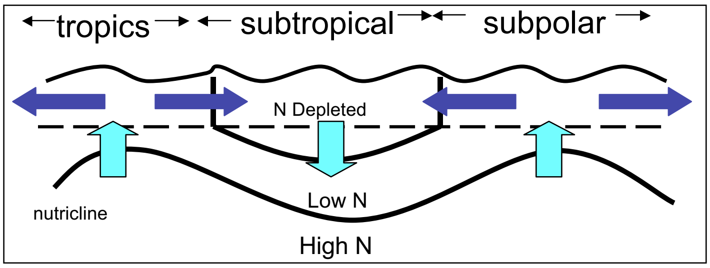
AMT14 April-June 2004

PO_4

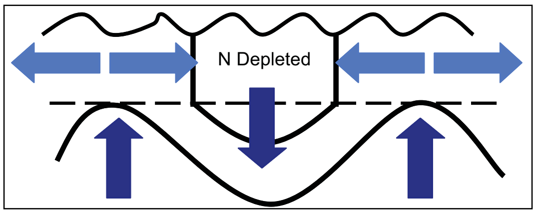


Surface inorganic nutrients are depleted over surface waters in mid latitudes

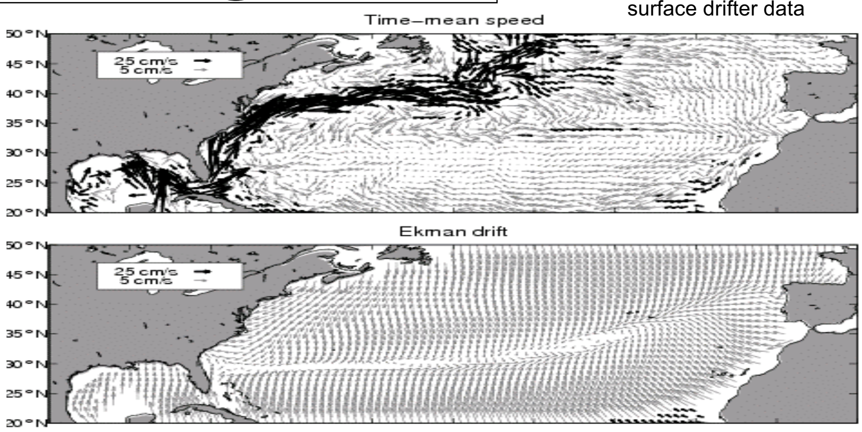
1. How is productivity at mid latitudes sustained?



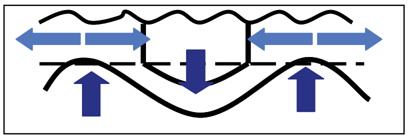
1.1 Ekman transfer

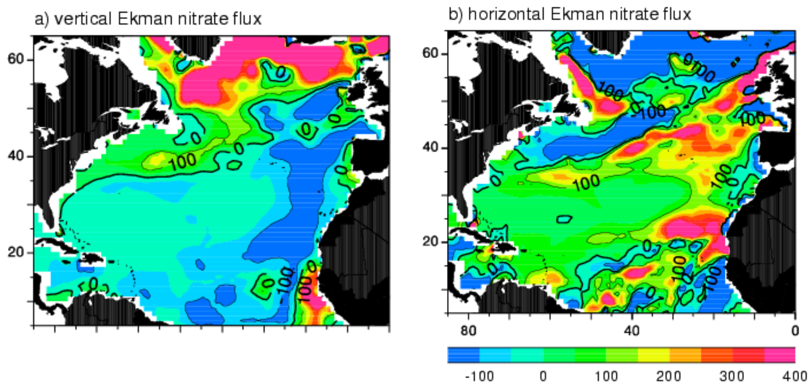


From Rick Lumpkin, surface drifter data



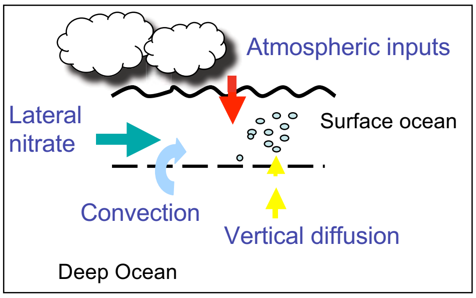
Ekman lateral transfer of nitrate

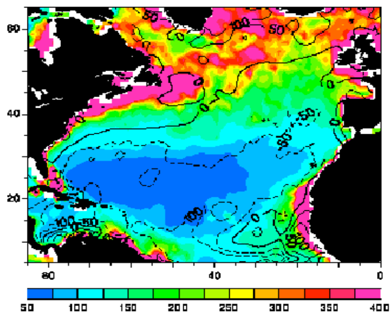




Williams & Follows (1998)

1.2 Estimates of P supply and export





Satellite estimate of primary production (gC m^{-2} y^{-1})
Sathyendranath et al. (1995)

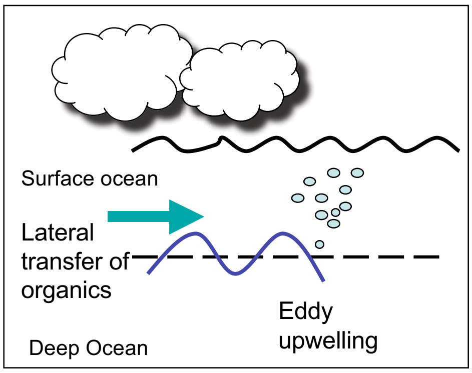
In Sargasso Sea,

P supply = 15 ± 5 mmol P $m^{-2}y^{-1}$

Export = 26 to 35 mmol P $m^{-2}y^{-1}$
(Jenkins 1985, 1988, 1989)

need extra P supply
(10 to 20 mmol P $m^{-2}y^{-1}$)

How might additional P be supplied?



- lateral transfer of organics

  3 - 12 mmol P m^{-2} y^{-1} ??

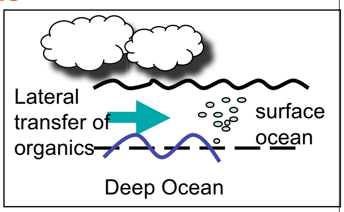
  Roussenov et al (2006)

- eddy upwelling

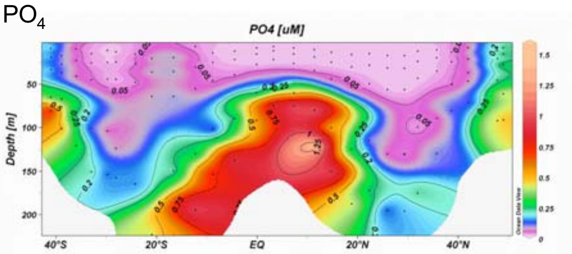
  12 mmol P m^{-2} y^{-1} ? ??

  McGillicuddy & Robinson (1997)

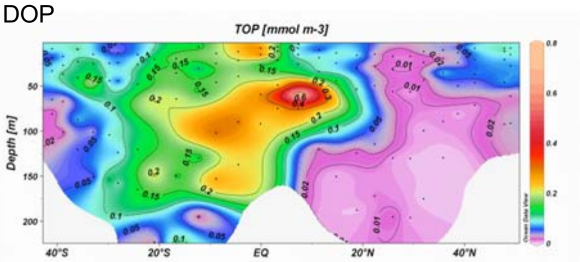
1.3 Role of dissolved organic nutrients

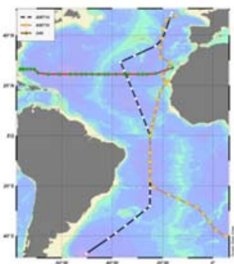


PO_4

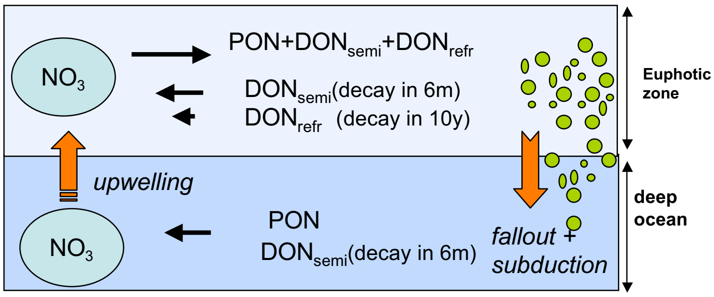


DOP

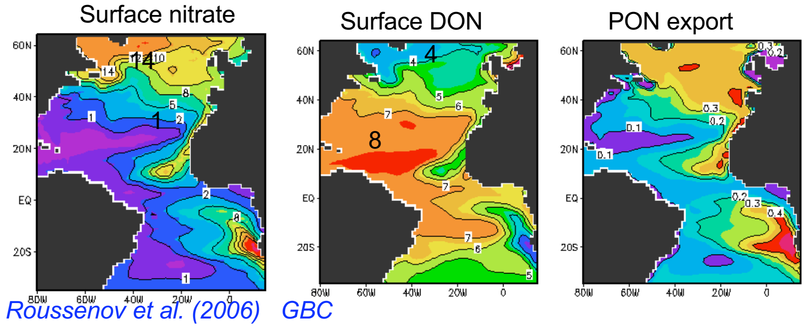




[DOP] ~ 0.02 to 0.2 μM in surface waters

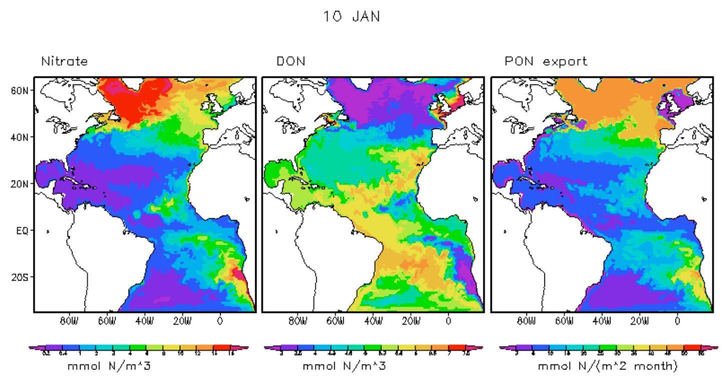


Coupled isopycnic model output after 100 y



Roussenov et al. (2006) GBC

Model simulation

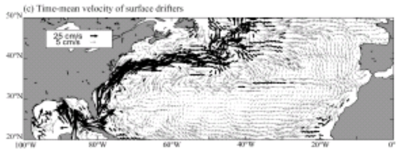


1.4 Nitrogen fixation

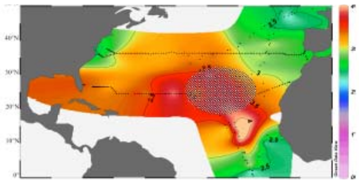
- For N, cyanobacteria can fix N_2 rather than use nitrate.
- Signals of elevated nitrate to phosphate in upper ocean
- Signal of depleted N isotope (indicative of atmospheric source)

Still require a phosphorus and iron source

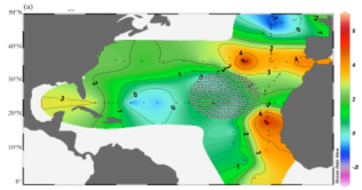
Reynolds et al. (2007) GBC submitted



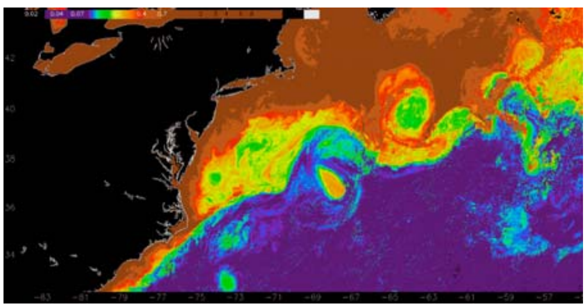
$$N^* = (N - 16P + 2.90\ \mu\text{mol kg}^{-1})\ 0.87$$



$$\delta^{15}N = \left[\frac{(^{14}N/^{15}N)_{\text{sample}}}{(^{14}N/^{15}N)_{\text{standard}}} - 1 \right] \times 100\% ,$$

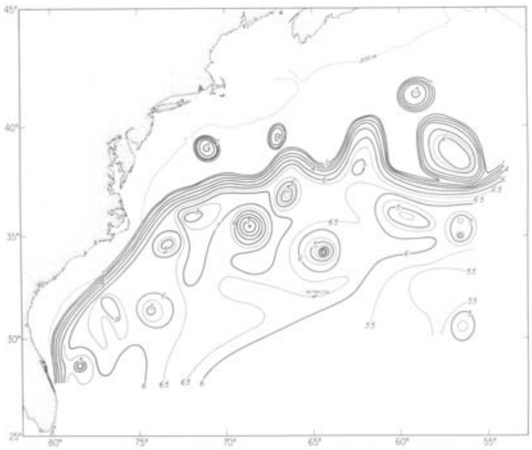


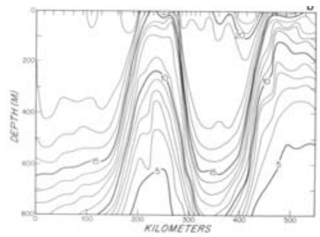
2. Time-varying eddy and frontal circulation



MODIS Chlorophyll
16-20 June 2006

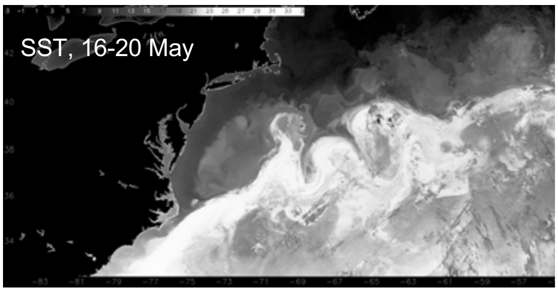
2.1 Examples of time-varying circulation

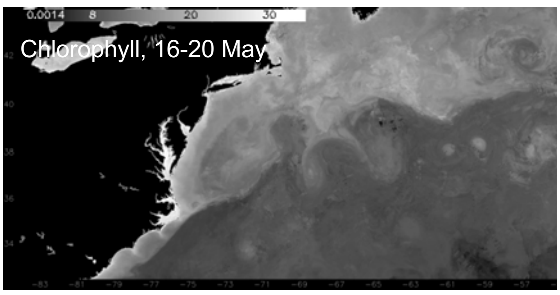




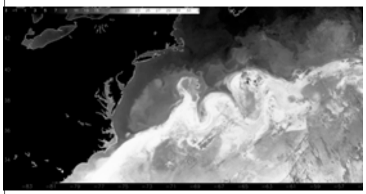
From Phil Richardson, WHOI

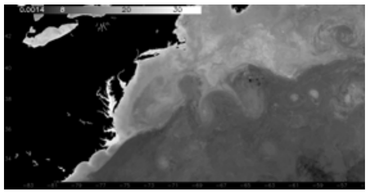
Remotely-sensed SST & Chlorophyll from MODIS, 2006



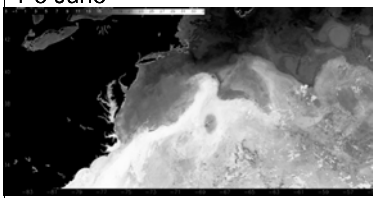


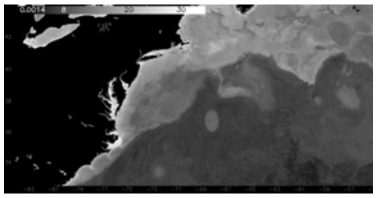
16-20 May 2006 NASA MODIS Sea-surface temperature and Chlorophyll



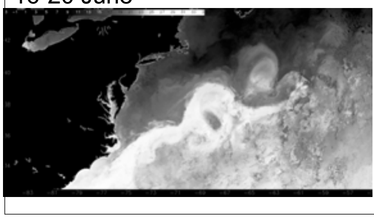


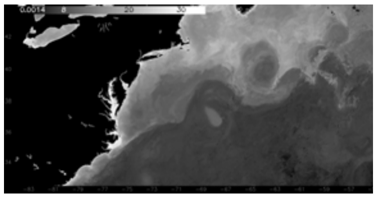
1-5 June

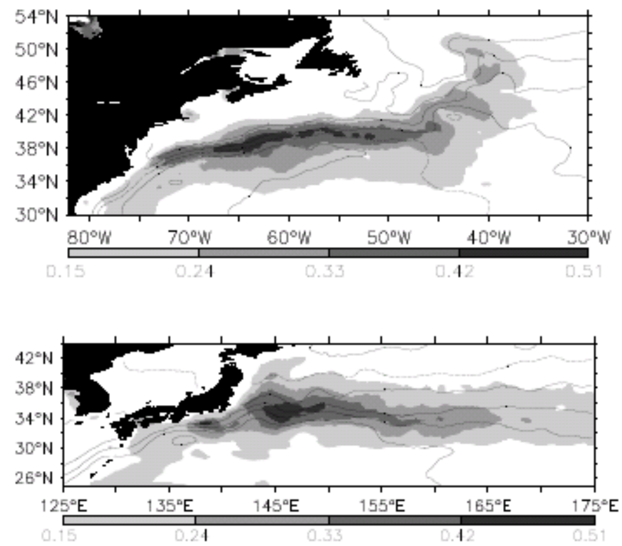




16-20 June

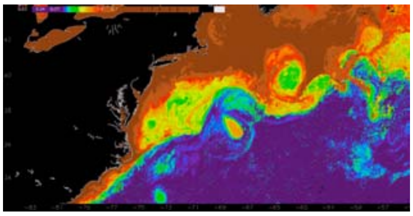




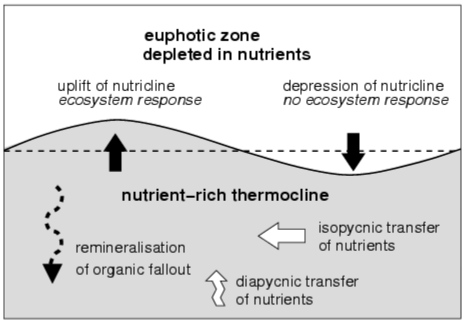


Diagnostics of the square root of eddy kinetic energy (m s^{-1}) from altimetry for (a) the North Atlantic and (b) North Pacific. The mean dynamic topography from Niiler is given by thin contours (solid=0.2 m; dashed=0.4 m).

2.2 Role of time-varying upwelling



MODIS Chlorophyll
16-20 June 2006



Upwell nutrients into sunlit zone, phytoplankton growth

Downwell nutrients, no phytoplankton response

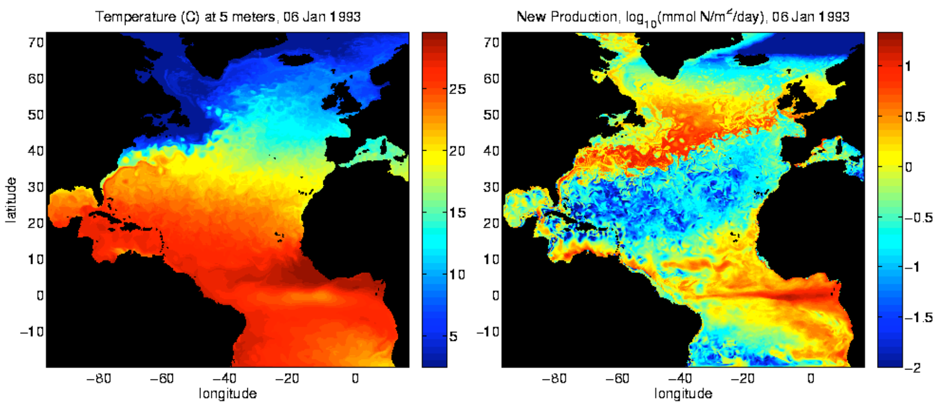
— rectified response to time-varying circulation

McGillicuddy & Robinson (1997)

Falkowski et al. (1991)

Model simulation

Surface T — New Production

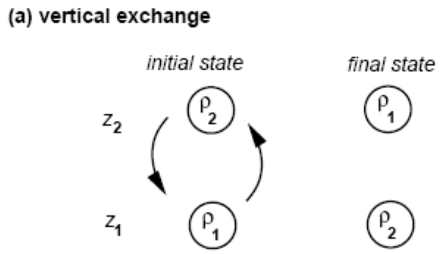


McGillicuddy et al. (2003)

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

Questions though about long-term average affect?

2.3 Energetics of particle exchange



change in PE

$$\Delta PE = g(m_1 z_1 + m_2 z_2) - g(m_1 z_2 + m_2 z_1) = g(m_1 - m_2)(z_1 - z_2).$$

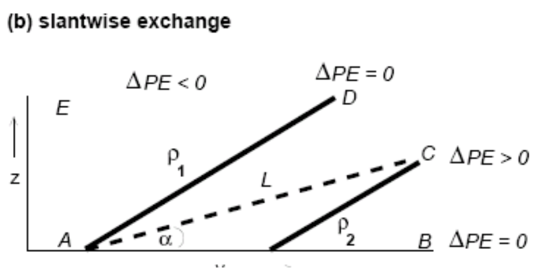
change in KE

$$\frac{1}{2}(m_1 + m_2)\Delta v^2,$$

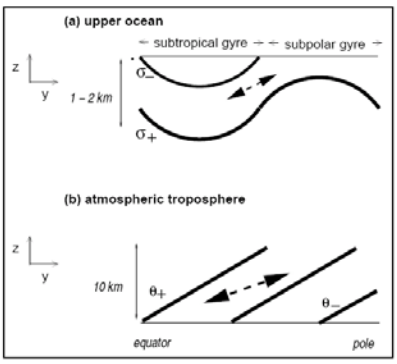
Change in KE = change in PE

$$\Delta v^2 = 2g\frac{(m_1 - m_2)}{(m_1 + m_2)}(z_1 - z_2),$$

$$\Delta v^2 = 2g\frac{(\rho_1 - \rho_2)}{(\rho_1 + \rho_2)}(z_1 - z_2).$$

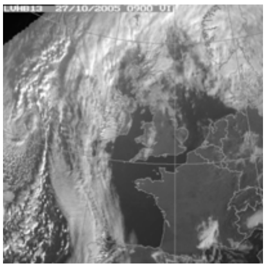


$$\Delta v^2 = 2g\frac{(\rho_1 - \rho_2)}{(\rho_1 + \rho_2)}(z_1 - z_2).$$

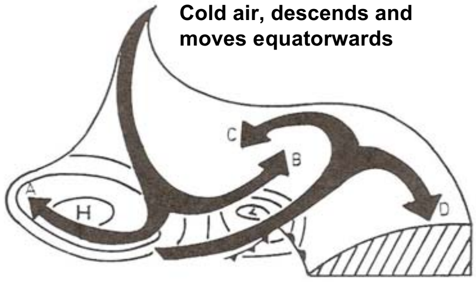


2.4 Baroclinic Instability process

Atmospheric case

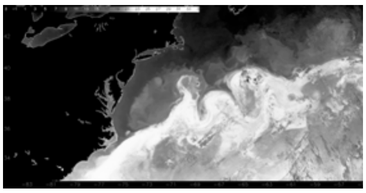


Cold air, descends and moves equatorwards

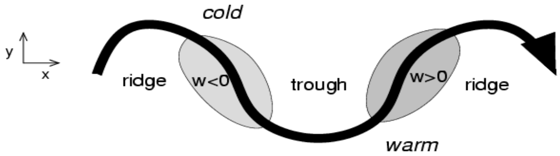


Warm air, ascends and moves polewards

Oceanic case

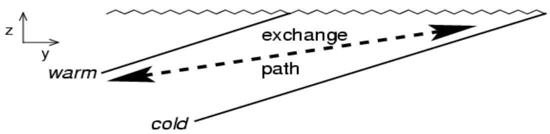


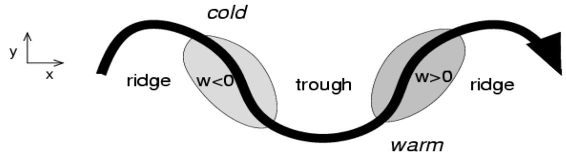
plan view of meandering jet

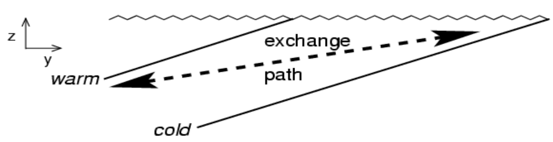


Warm waters *rise*
Cold waters *sink*

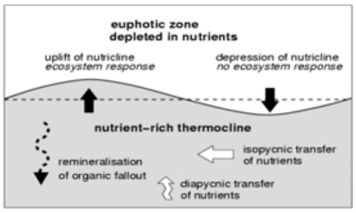
slantwise exchange of fluid





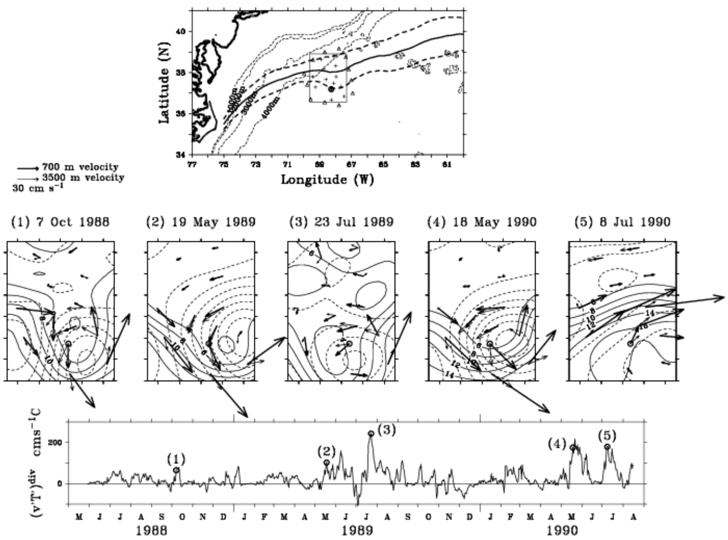


Warm waters *rise*
Cold waters *sink*



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

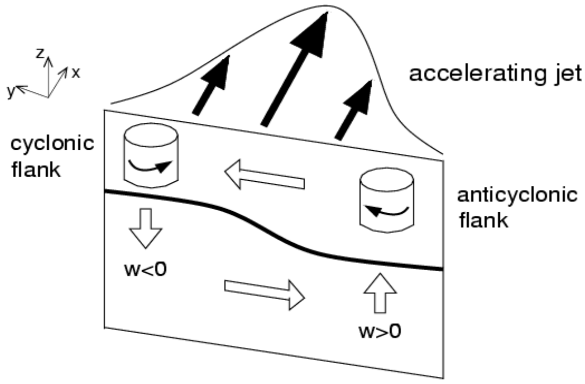
Eddy heat fluxes in the Gulf Stream



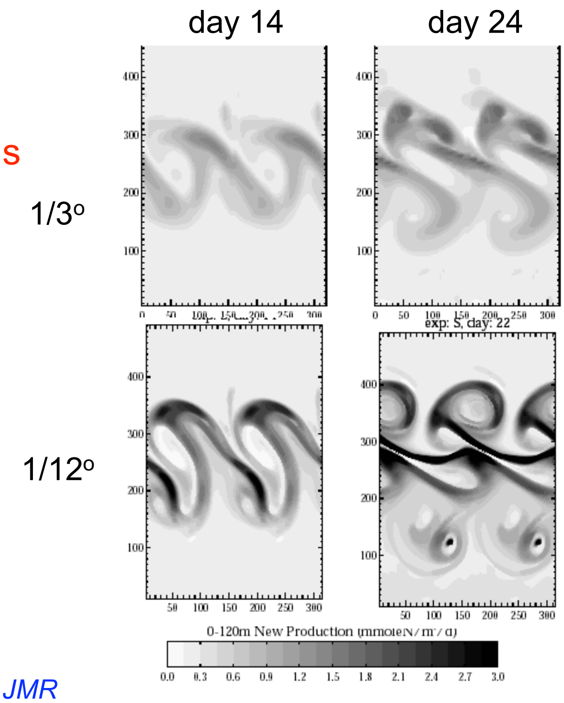
Signals of eddy heat flux. From M. Cronin.

2.5 Frontal circulation

embedded frontal–scale circulation

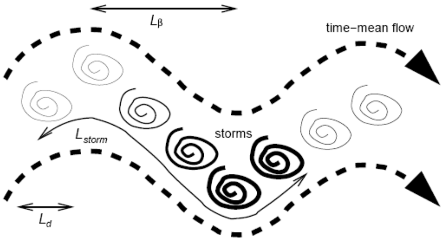


Frontal simulations



Levy et al. (2001) JMR

2.6 Eddy lifecycles



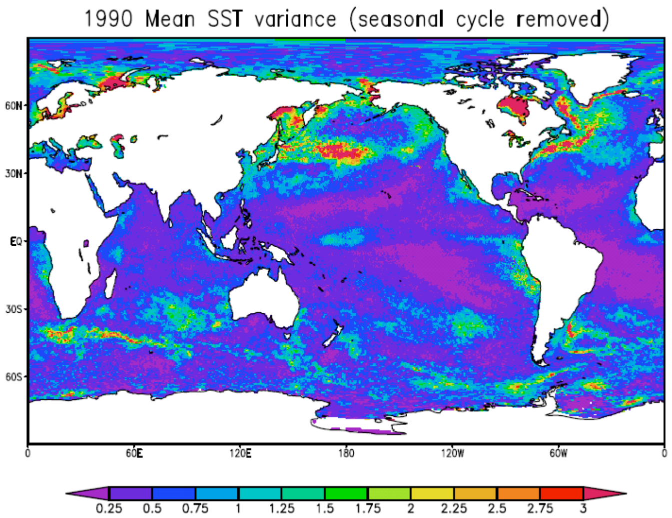
Ocean eddies form in unstable jets, amplify, then decay.

— eddy fluxes change during this life cycle

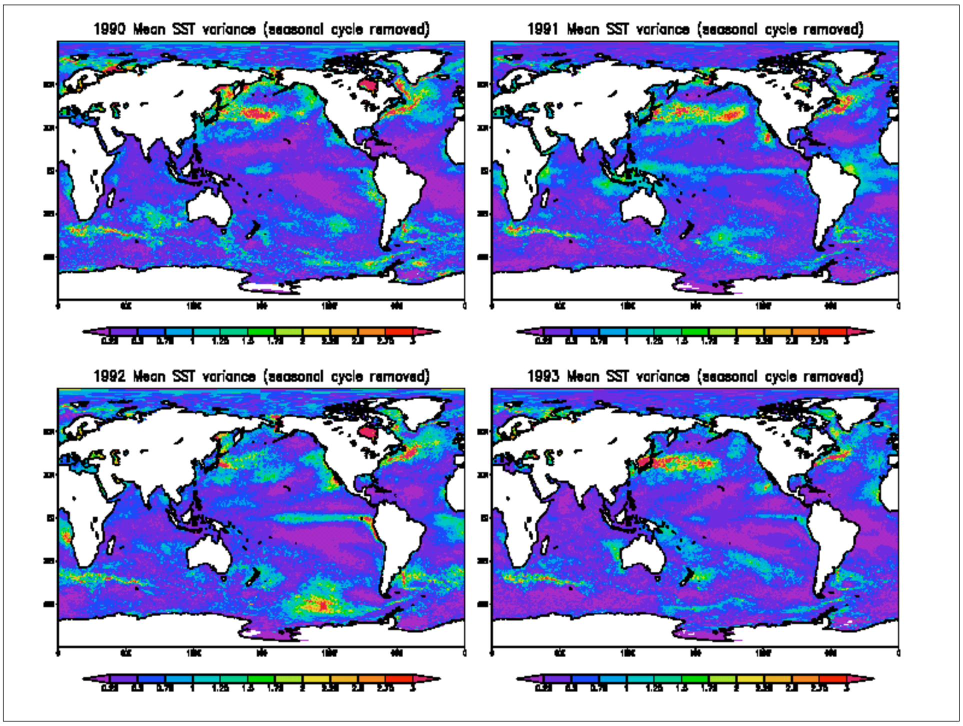
Analogous to atmospheric storm tracks

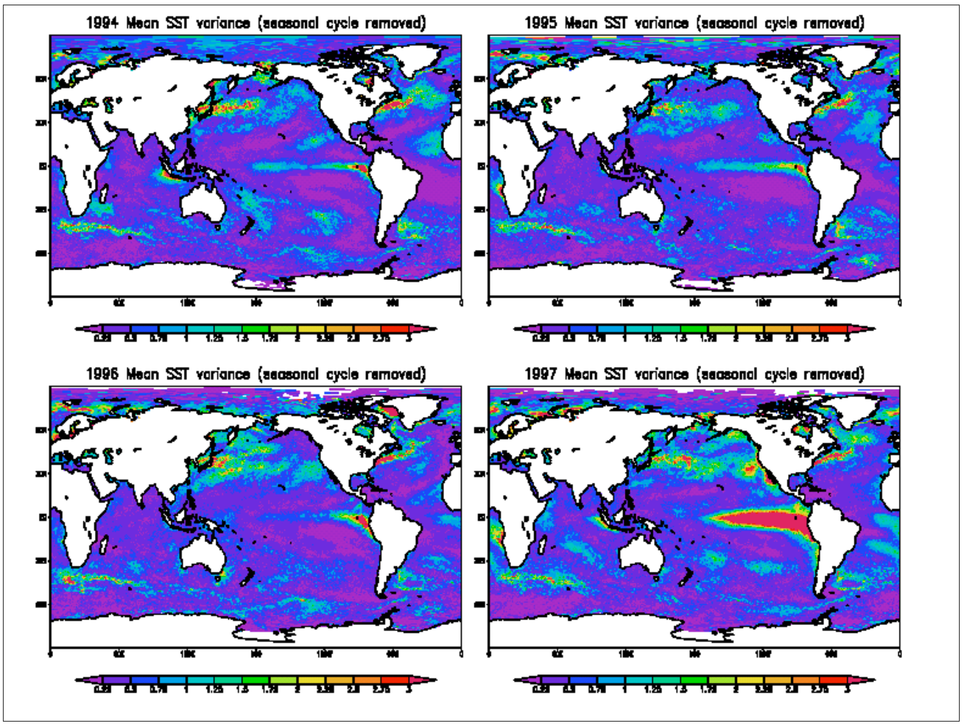
Variance in AVHRR SST data

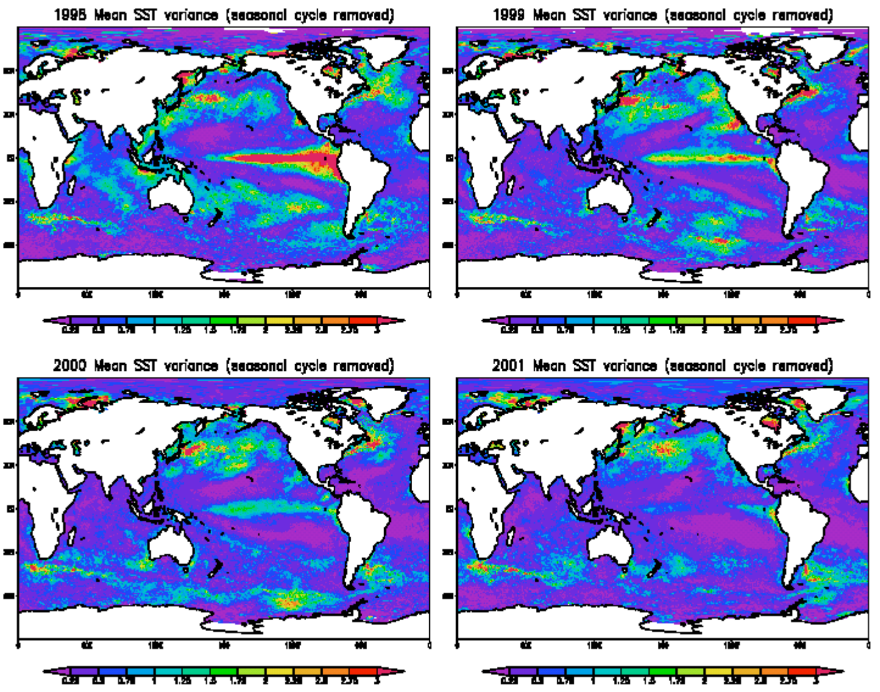
0.5° resolution, 5d repeat



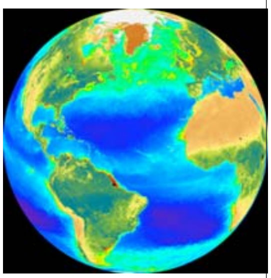
(Removed 5-daily mean seasonal cycle for 1990-2002)


1990 Mean SST variance (seasonal cycle removed)
1991 Mean SST variance (seasonal cycle removed)
1992 Mean SST variance (seasonal cycle removed)
1993 Mean SST variance (seasonal cycle removed)


1994 Mean SST variance (seasonal cycle removed)
1995 Mean SST variance (seasonal cycle removed)
1996 Mean SST variance (seasonal cycle removed)
1997 Mean SST variance (seasonal cycle removed)



Conclusions



Background state

- Wind-forced undulations of thermocline/nutricline

Mid-latitudes

- Transfer of organic nutrients
- Rectified effect of time-varying circulation
- Eddy and frontal circulations

Next lecture: discuss stirring, boundary currents (barriers/blenders), and eddy transfers further

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