The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

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2007 ICTP Oceanography Advanced School

30 April - 11 May, 2007

Ocean biological productivity and climate change - part IV

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University of Liverpool UK

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

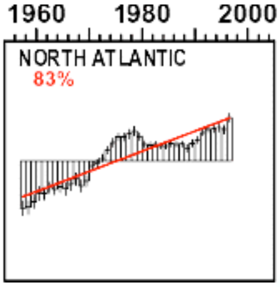
- Mid latitude productivity
- Eddy transfers

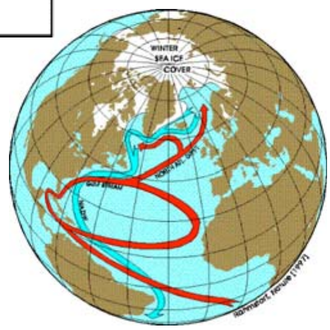
Lecture 3: boundary currents

- Barriers/blenders
- Eddy lifecycles

Lecture 4: Climate change

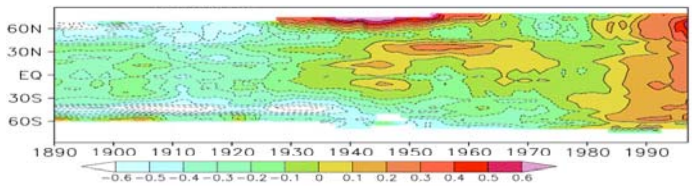
- Heat content changes in the N. Atlantic
- Ocean overturning





Heat content changes in the North Atlantic

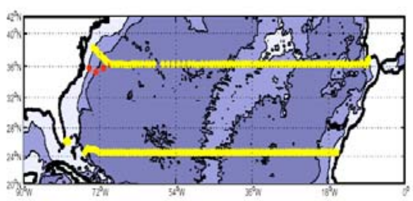
Observed change in *global* air temperature(*Delworth)*



1. How is the ocean warming?
2. How spatially coherent are changes in overturning?

A. Historical data study & linked modelling

B. Repeat hydrography along 36N



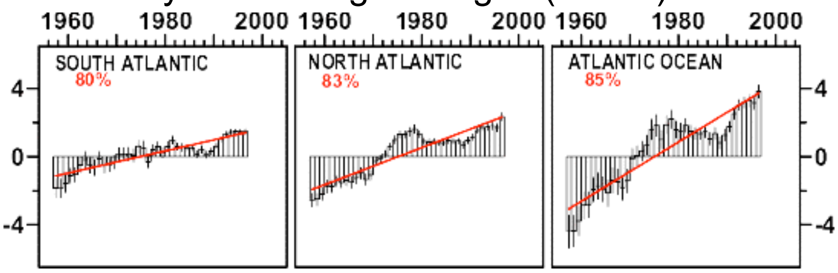
C. Modelling of overturning signals

Susan Lozier (Duke), Ric Williams, Susan Leadbetter, Vassil Roussenov (Liv) Rory Bingham & Chris Hughes (POL)

Intro

Heat Content Change (1955-2003)

- Levitus – rise in heat content of upper 3000m from 5 year running averages (10^{22} J)



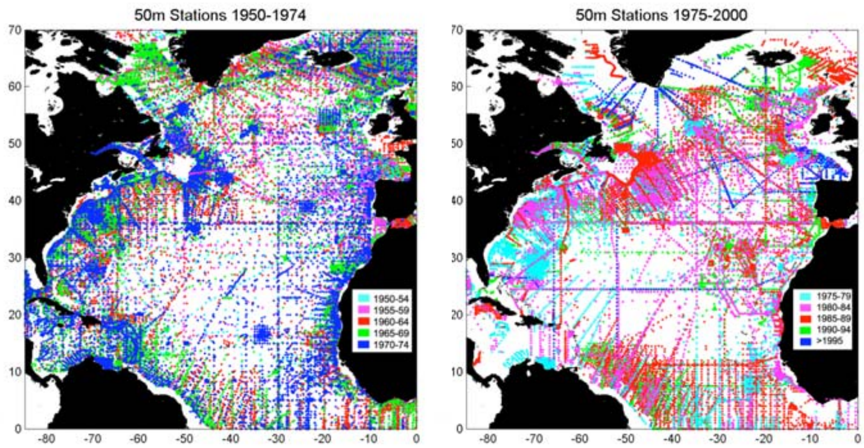
For N. Atlantic, consistent with warming of ~2 W m^{-2} over 40 y

- **What is the spatial pattern of warming?**
- **How is the warming controlled**?

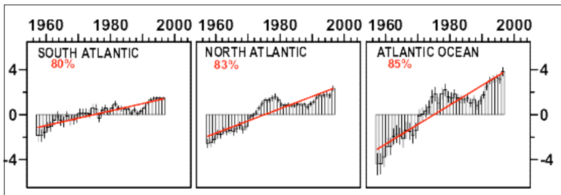
Data

Ocean Heat Content

1950-1974 | 1975-2000

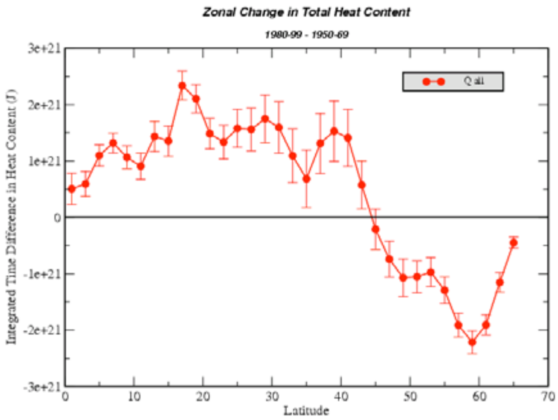


Lozier and Moore - data from NODC World Ocean Atlas (2001) and WOCE programme



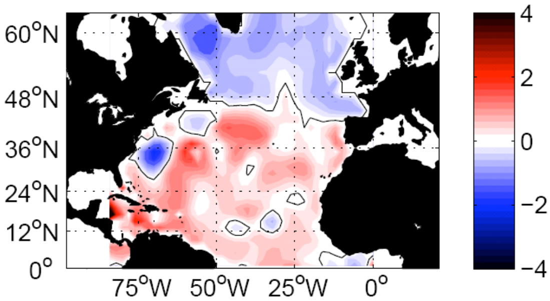
10^{22}J for whole domain

$3x10^{22}J/33= 10^{21}J$



Data

Patterns of Heat Content Change



15Wm^{-2}

-15Wm^{-2}

- Subpolar cooling
- Subtropical warming
- Tropical warming

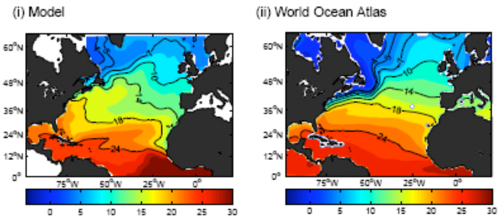
Observed depth-integrated heat content change (1980-2000 minus 1950-1970) (J for 2° squares)

MICOM

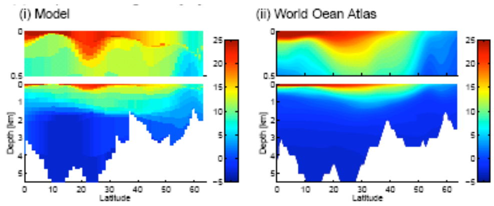
Ocean model study

- MICOM
- Isopycnic model
- 1.4° by 1.4° cosθ
- 15 isopycnal layers + mixed-layer
- 60-year spinup
- ERA-40 or NCEP forcing
- 1 year relaxation to SST

Sea Surface Temperature



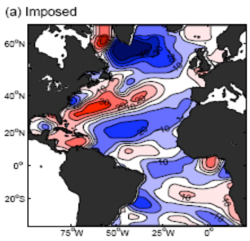
Temperature along 30W



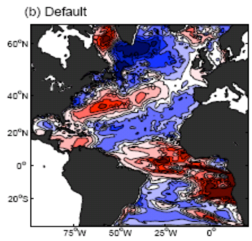
Change in fluxes between two periods (1980-2000 and 1950-1970)
(positive is ocean input)

- ECMWF – Tripole pattern of heating and cooling

ECMWF

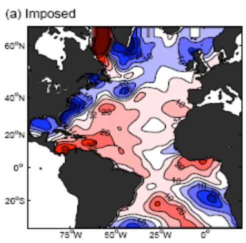


ECMWF+SST relaxation

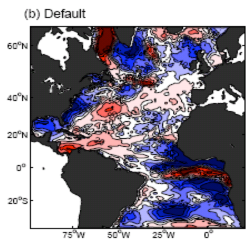


- NCEP – Dipole pattern of heating and cooling

NCEP

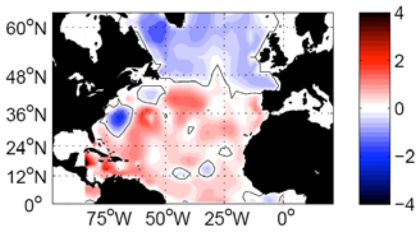


NCEP+SST relaxation



MICOM

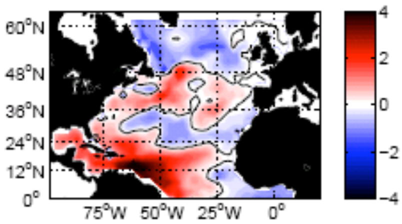
Default Model Results



Observations

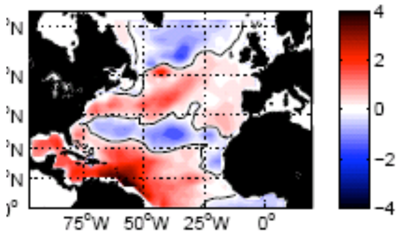
- Comparison of two 20-year runs (1980-2000 – 1950-1970)
- 1.4° resolution
- Heat content difference (10^{20}J on 2° grid)

(a)(ii) ECMWF forced 1.4° Model



Model - ECMWF

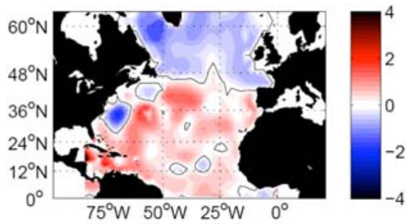
a)(i) NCEP forced 1.4° Model



Model - NCEP

MICOM

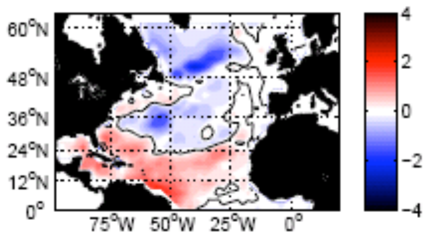
Variable Buoyancy or wind forcing



Observations

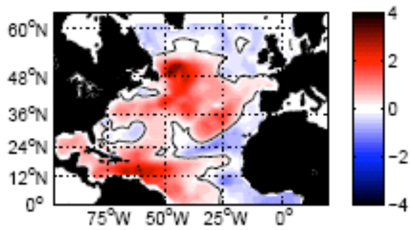
- Comparison of two 20-year runs (1980-2000 – 1950-1970)
- 1.4° resolution
- ECMWF

(a) Climatological Winds and Variable Buoyancy



Variable buoyancy

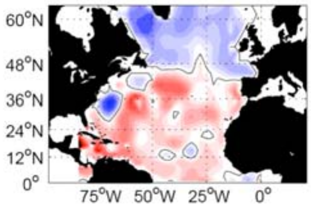
(b) Climatological Buoyancy and Variable Winds



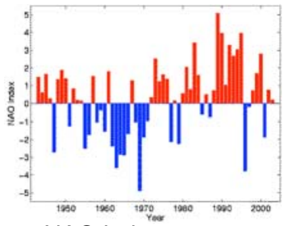
Variable winds

MICOM

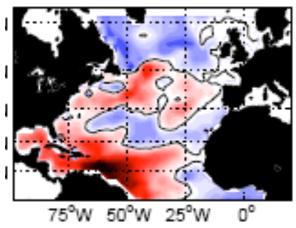
North Atlantic Oscillation (NAO)



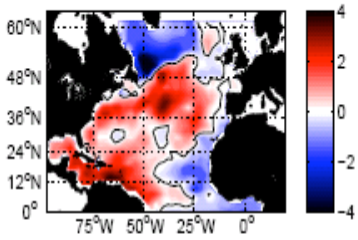
Observations



NAO Index



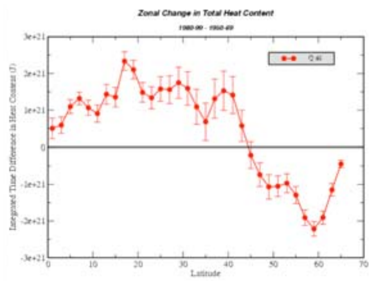
Model - Default



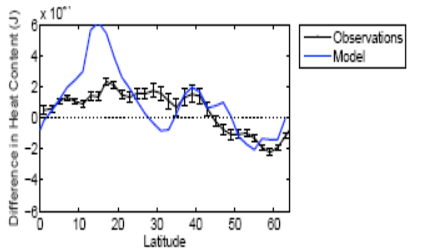
Model – NAO+/-

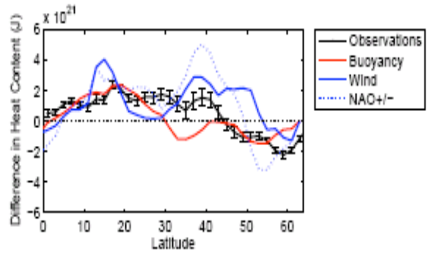
- Recent decadal variation of NAO forcing
- Compared NAO+ and NAO- runs
- Heat content difference (J)

Warming in tropics and subtropics

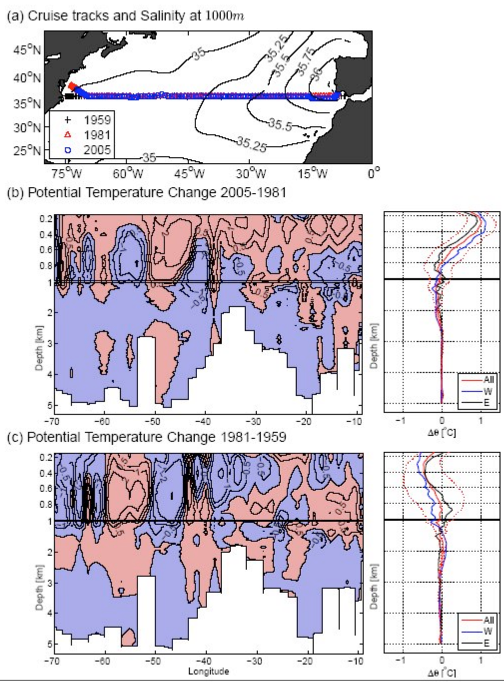


- Gain in heat in tropics from surface flux and wind redistribution
- Gain in subtropics from wind redistribution
- Loss in heat in subpolar gyre from air-sea fluxes

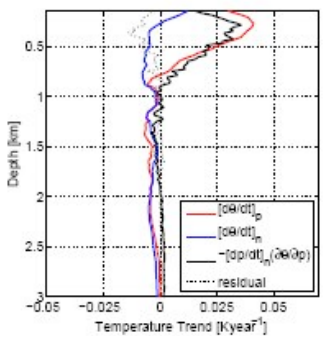




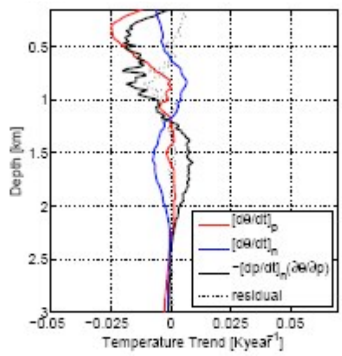
What is seen in single sections?



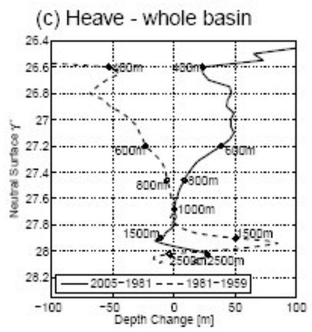
2005-1981



1981-1959

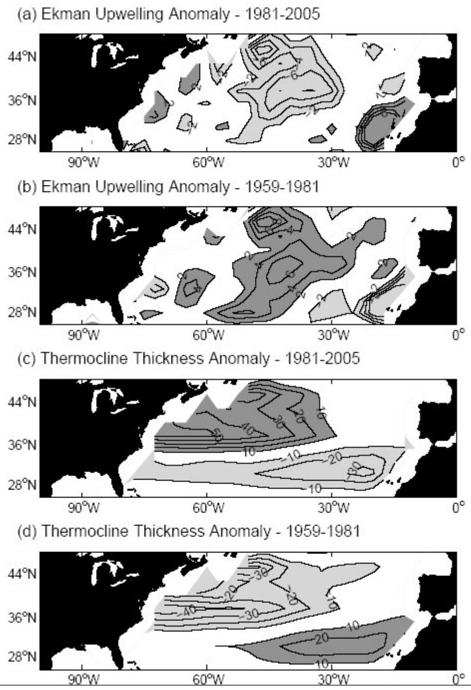


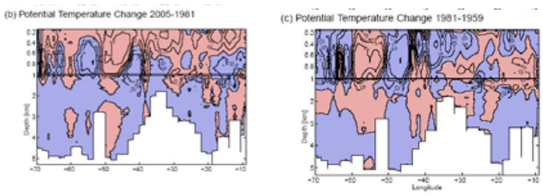
$$\frac{\partial\theta}{\partial t}_{depth} = \frac{\partial\theta}{\partial t}_{neutral} - \frac{dz}{dt}_{neutral}\frac{\partial\theta}{\partial z}$$



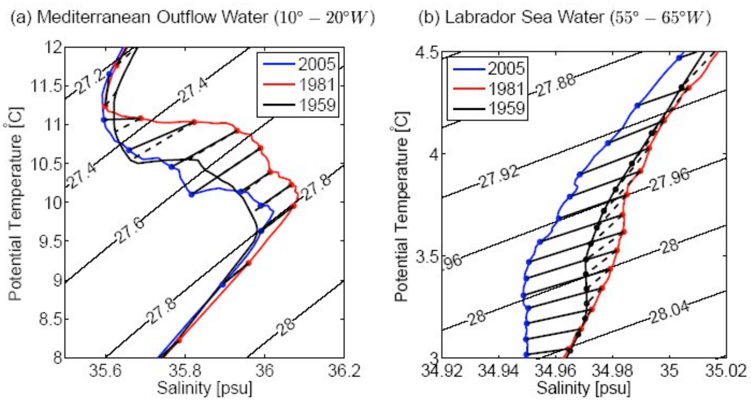
Reversing pumping/heave signals in upper 800m

$$h^2(x,y) = h_e^2 - \frac{2f^2}{\beta g'}\int_x^{x_e} w_e(x,y)dx$$



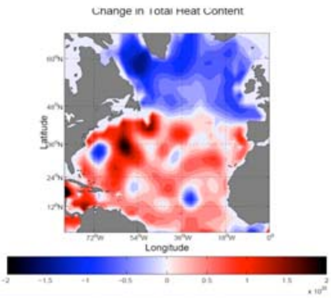


Reversing T/S changes seen below 1 km



Conclusions for heat content change

- Clear signal of tropical and subtropical warming and subpolar cooling --- larger than area-integrated change
- Model suggests
  - In subtropics this is linked to wind-induced redistribution of heat
  - In subpolar and tropical regions, linked to surface heat fluxes
- Data suggests reversing pattern
  - Wind-induced heave in upper 800m
  - Water-mass changes in deeper waters

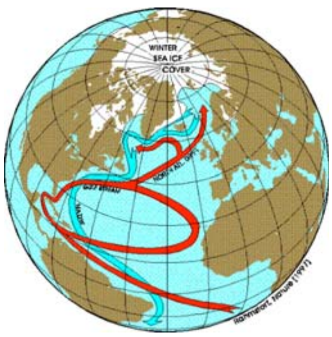


2. Overturning in the North Atlantic

How are overturning changes communicated?

How spatially coherent is the overturning?

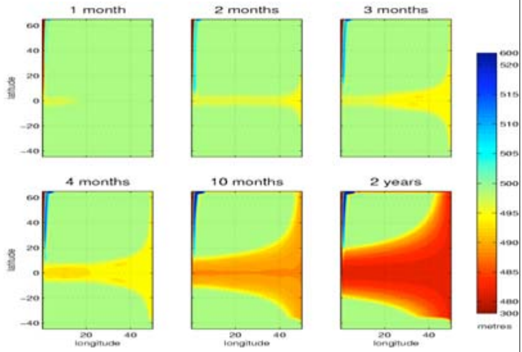
What is the link between bottom pressure and the overturning?



Based on modelling studies with Chris Hughes and Rory Bingham (POL), and Vassil Roussenov (Liverpool)

Background

Kawase (1987) showed deep water spreading is accompanied by fast Kelvin waves, producing tropical sea surface temperature anomalies.



Using an idealised model, Johnson & Marshall (2002) demonstrate how overturning changes are communicated through the propagation of fast Kelvin and slower Rossby waves.

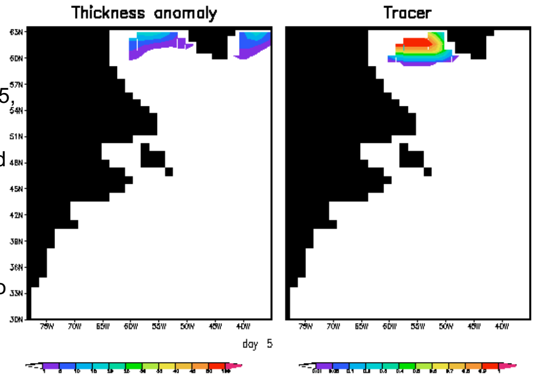
Boundary Wave response

Kelvin waves — vertical sidewall with stratification
Topographic Rossby waves — sloping sidewalls and no stratification
Boundary waves are a hybrid of these two types (Huthanance, 1978), resembling Kelvin waves as the stratifcation increases.
Speed ~ 1 m/s at equator, 2-3 m/s at higher latitudes
-

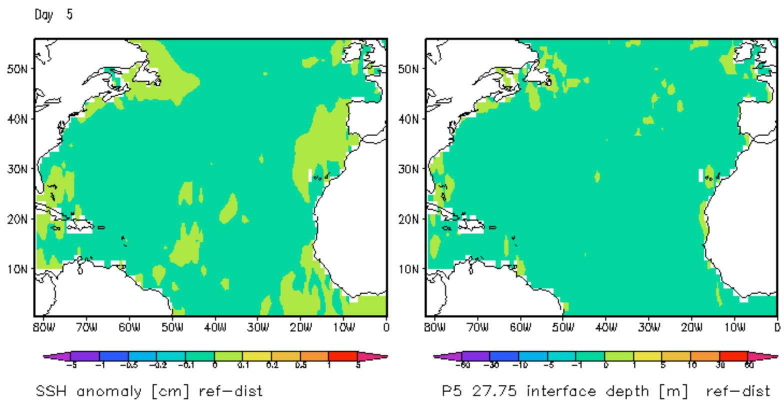
Coarse-resolution 1.4° model integration

Isopycnal MICOM model

- 1.4 deg., 6 sigma layers (26.0, 27.0, 27.5, 27.7, 27.8, 27.9).
- forced by annual mean winds, integrated for 110 y
- initial conditions from Levitus.
- Isopycnal interfaces are relaxed to Levitus in northern buffer zone. In order to preserve the mean vertical stratification implicit diapycnal mixing is introduced, which compensates for the dense water inflow from the northern boundary.
- tracer released during the last 10 years.
- twin experiment is run during the last 10 years, which is forced to produce extra deep water by gradual uplift of upper interfaces of layer 4 and 5 - 120m/10 days over the north relaxation region.



Fine-resolution 0.28º model integration



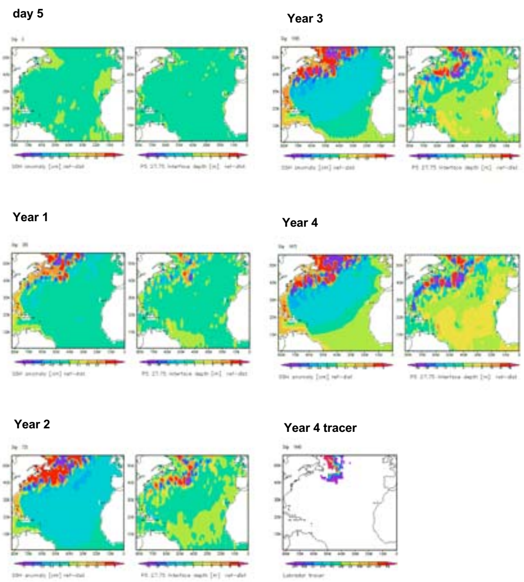
•The model set-up same as the coarse model

• horizontal resolution is increased to 0.28º

• Integrated for 44 years with deep northern tracer released during the last 4 years

• Twin experiment is run during the last 4 years,

Snapshots

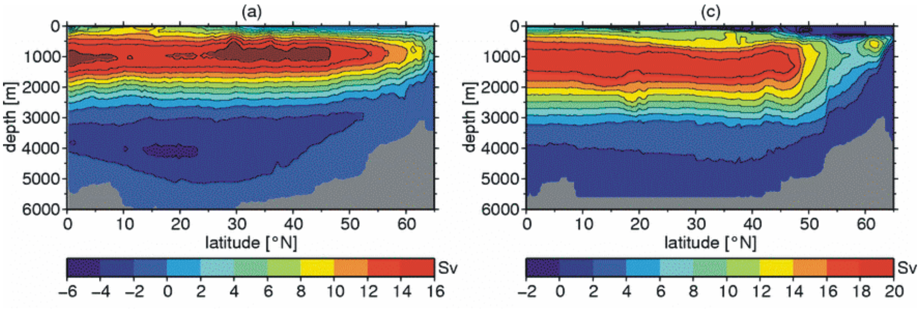


Model snapshots of the sea surface height anomaly and the depth/pressure of a dense isopycnal

- there is a rapid spreading along the western boundary
- a slower spreading along the eastern boundary
- the SSH and isopycnal height anomalies appear related, but with SSH signals on a slightly broader scale.

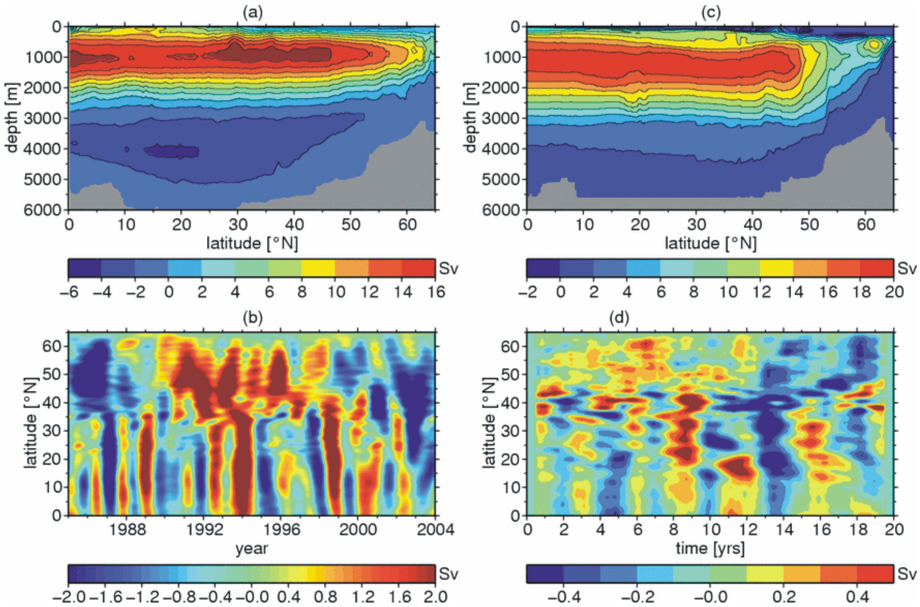
- slow advective response, marked by the Labrador tracer

OCCAM (0-19y) MICOM (150-170y)



- Consider overturning in 2 models:
- OCCAM, cartesian, 19y after 4y spin-up 0.25 degree, 66 levels, 6hr ECMWF forcing
- MICOM, 20y after 150y spin up
- 0.23 degree, 16 layers, climatological forcing

OCCAM (0-19y) MICOM (150-170y)



Low-pass (>400 days) filtered northwards transport anomaly between 100m and 1000m

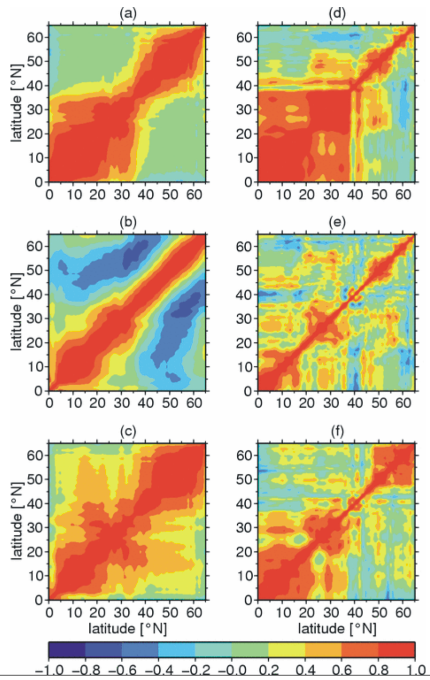
OCCAM MICOM

Low frequency cross-correlation

0-1000m

Ekman, 0-100m

100-1000m



Layers 1-8

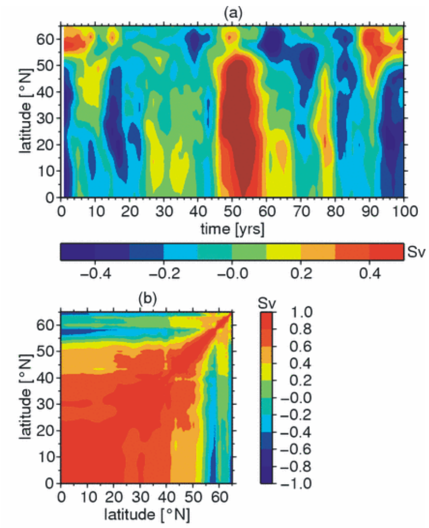
Layer 1

Layer 2-8

MICOM diagnostics over 100 years

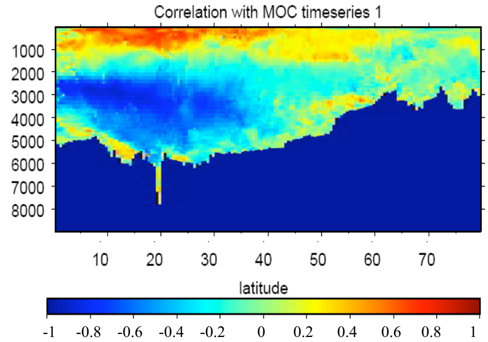
Low-pass (>400 days) filtered northwards transport anomaly between 100m and 1000m

Low frequency cross-correlation

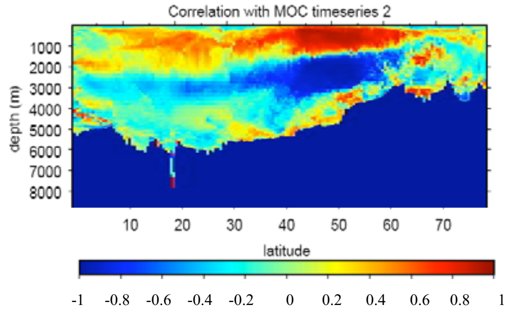


Correlations of northwards transport for OCCAM, 20y:

MOC time series 1 (0-30degrees)



MOC time series 2 (40-60degrees)



Overturning and bottom pressure contrasts

Geostrophic balance

$$\rho f v_g = \frac{\partial P}{\partial x}$$

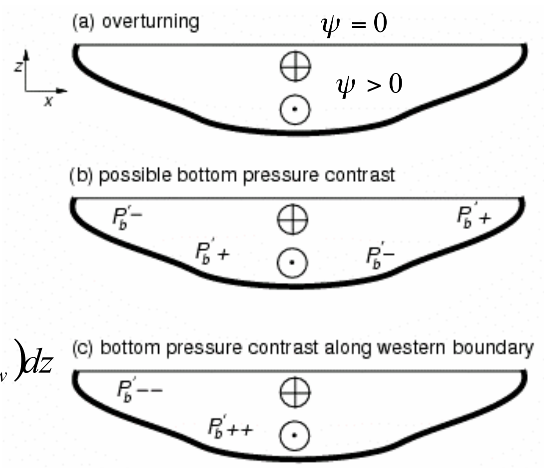
Zonal integral

$$\rho f \int_{x_w}^{x_e} v_g dx = P_e - P_w$$

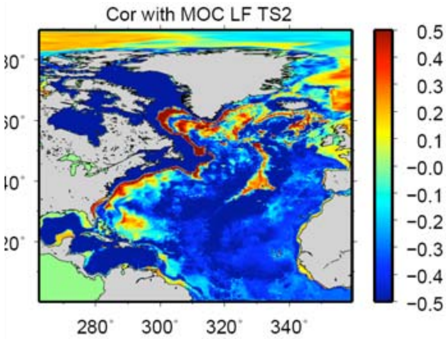
Depth integral

$$\rho f \int_z^0 \int_{x_w}^{x_e} v_g dxdz = \int_z^0 (P_e - P_w) dz$$

$$\rho f \frac{\partial \psi}{\partial z} = \int_z^0 (P_e - P_w) dz$$

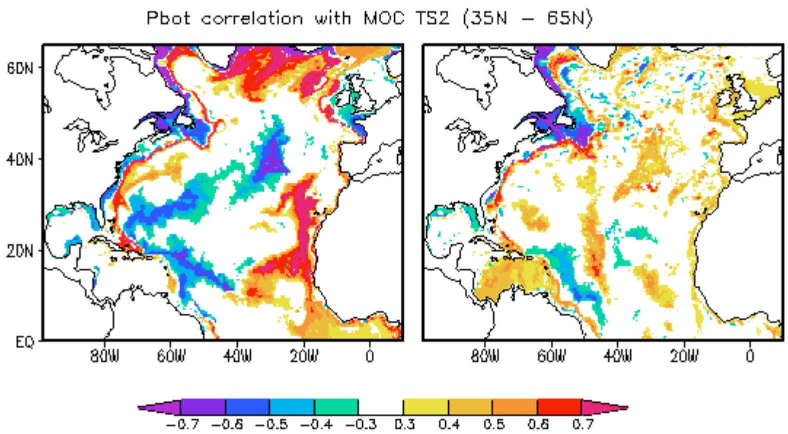


Bottom Pressure correlations with overturning from OCCAM

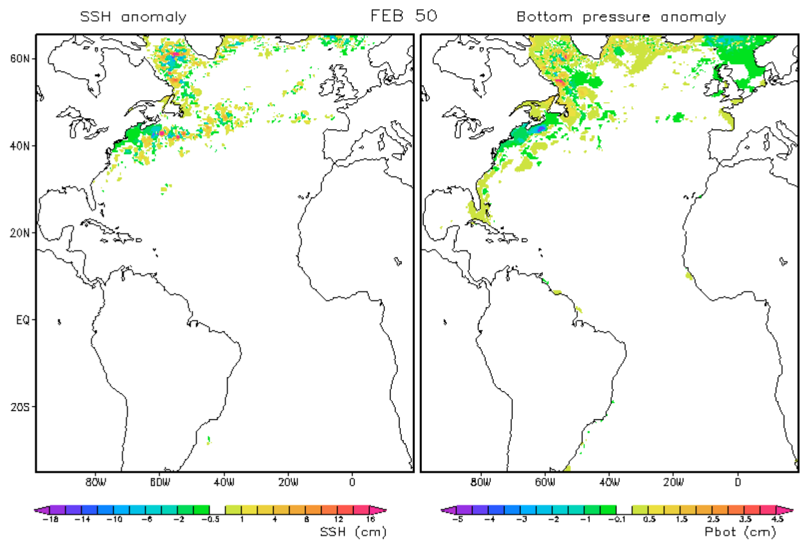


Correlation of time series of overturning streamfunction over upper 1 km at 40-60^{o}N with bottom pressure

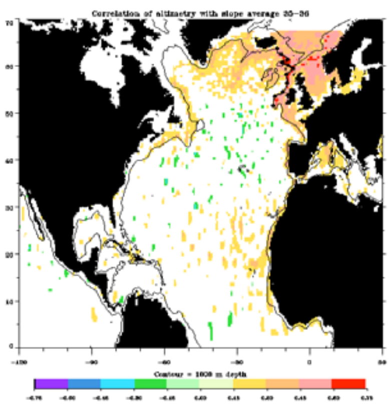
Bottom Pressure correlations with overturning from MICOM



left panel is high-pass, right panel is low-pass (>360 days)



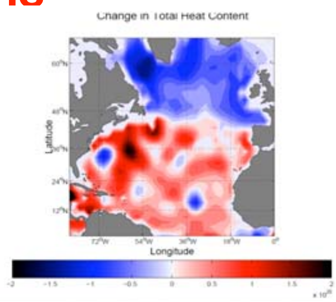
Altimetry signals of variability

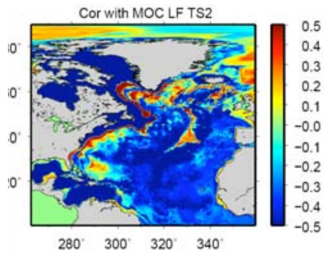


Correlation of high pass filtered altimetry everywhere with that averaged in the northern NE Atlantic (100 grid point section 35-36 marked in black dots). Places where correlation is not significant at the 95% level are left white (Hughes & Meredith),

Conclusions

- Changes on decadal timescales
  - Tropical & subtropical warming and subpolar cooling in the N. Atlantic
  - Wind-induced heave in upper 800m
  - Water-mass changes in deeper waters
- Overturning signals are only spatially coherent over the whole basin after several decades
  - Separate subtropical & subpolar signals
  - Bottom pressure contrasts provide integrated measure





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