Ocean circulation & heat content in millennial climate simulations

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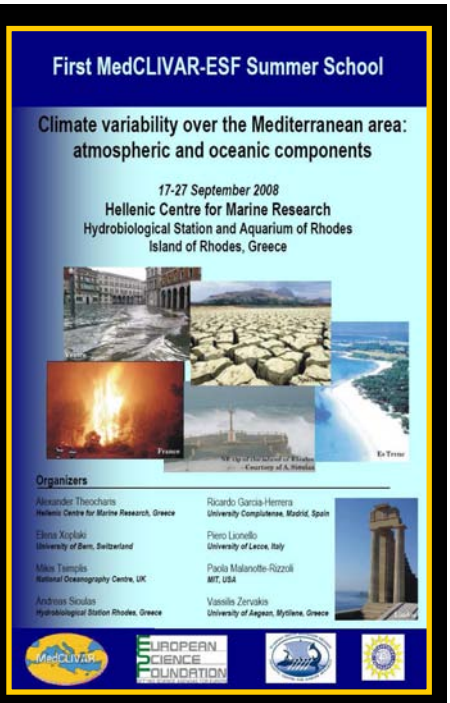

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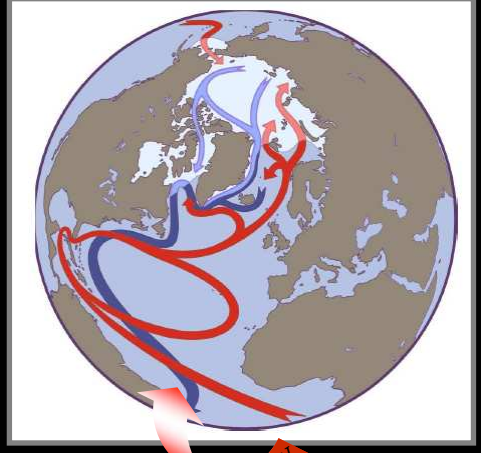
1. Background
2. MOC
3. Heat storage

Oceans are W E T !

R A N S P O R T

MOC

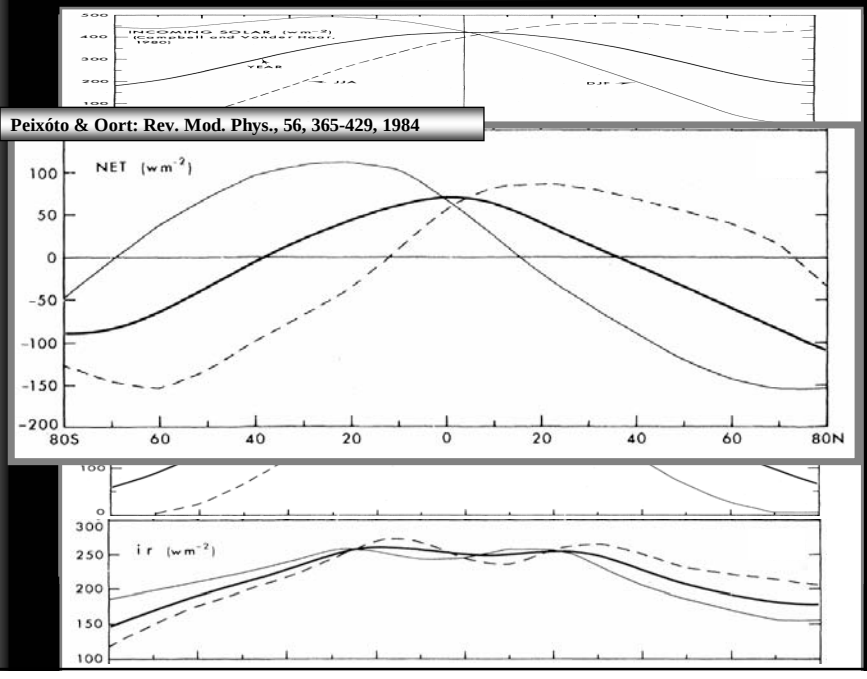


1 PW

A few words about energy

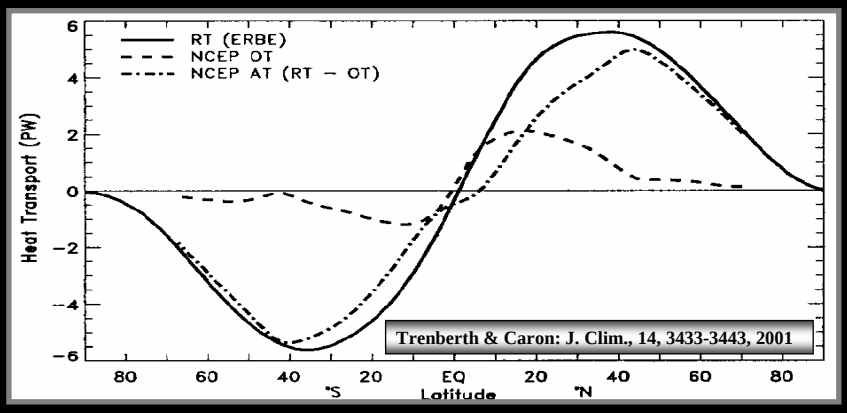
Radiation balance

Peixóto & Oort: Rev. Mod. Phys., 56, 365-429, 1984



A few words about energy

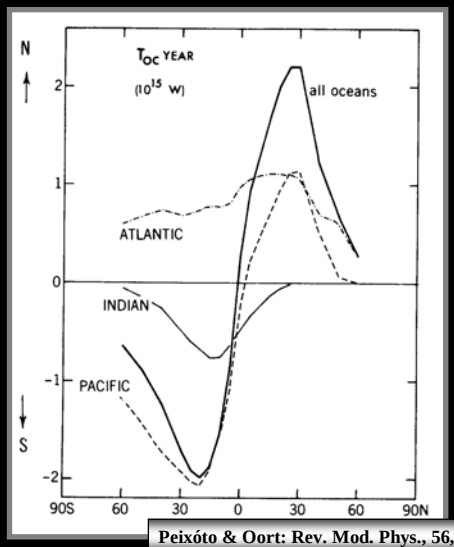
Transport



Trenberth & Caron: J. Clim., 14, 3433-3443, 2001

A few words about energy

Transport

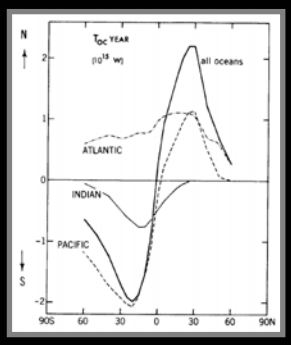


Peixóto & Oort: Rev. Mod. Phys., 56, 365-429, 1984

A few words about energy

Transport

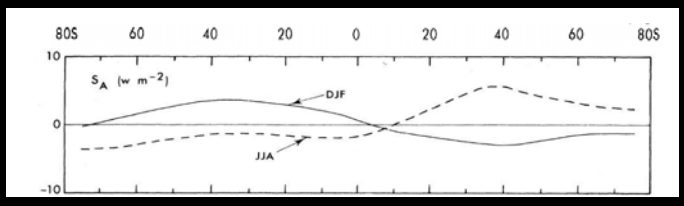
$$\Delta T = \frac{Q}{\rho c_p \dot{V}}$$



= 12 K

A few words about energy

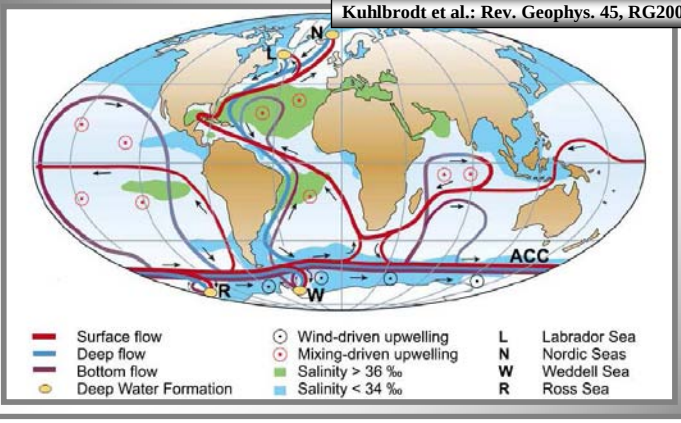
Storage



AMOC

Atlantic Meridional Overturning Circulation

Kuhlbrodt et al.: Rev. Geophys. 45, RG2001, 2007

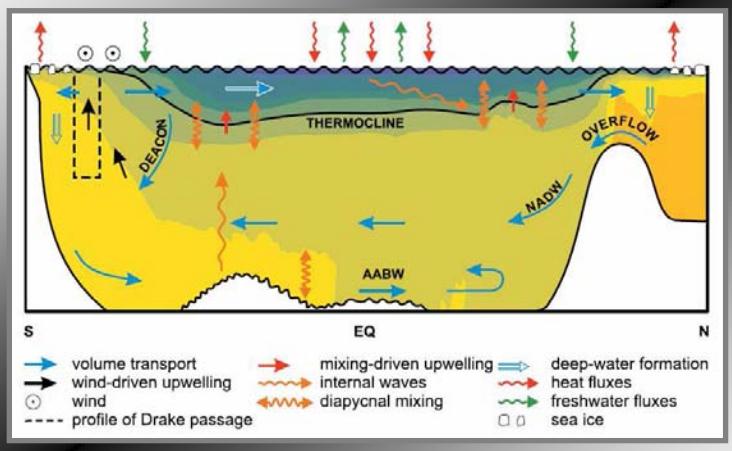


"It appears to be extremely difficult, if not quite impossible, to account for this degree of cold at the bottom of the sea in the torrid zone, on any other supposition than that of cold currents from the poles; and the utility of these currents in tempering the excessive heats of these climates is too evident to require any illustration"

Sir Benjamin Thompson, 1797

AMOC

Atlantic Meridional Overturning Circulation

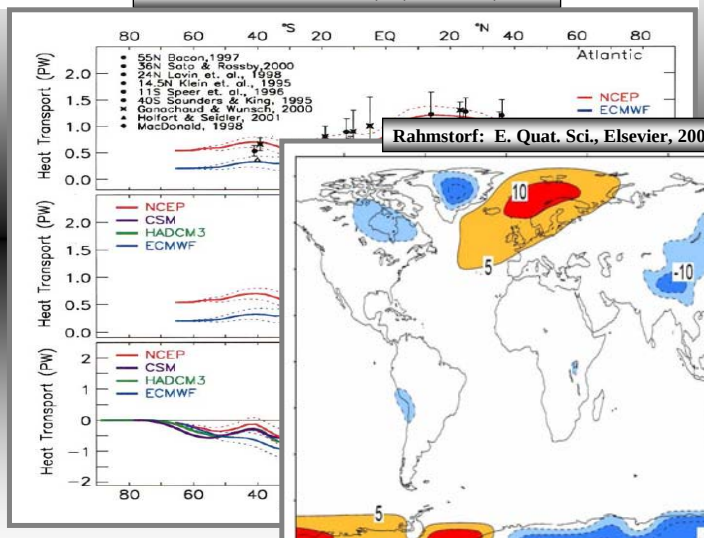


Kuhlbrodt et al.: Rev. Geophys. 45, RG2001, 2007

AMOC

Estimates of Meridional Atmosphere and Ocean Heat Transports

Trenberth & Caron: J. Clim., 14, 3433-3443, 2001

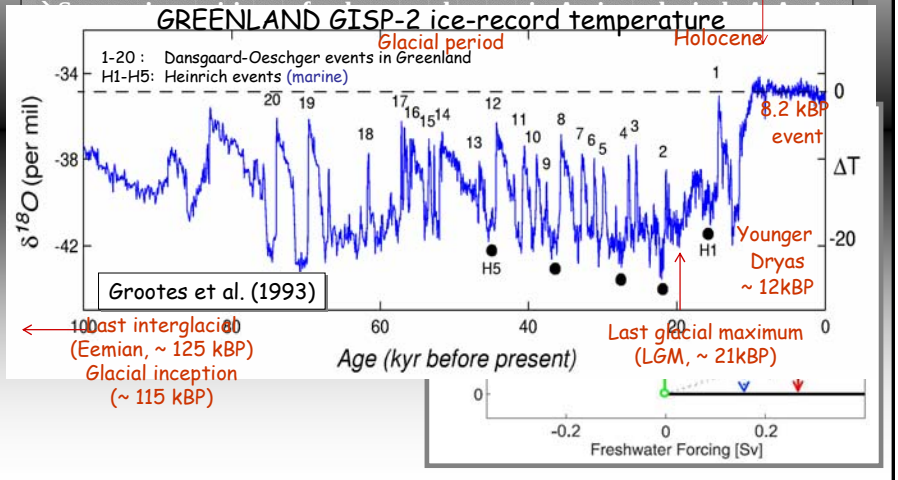


Rahmstorf: E. Quat. Sci., Elsevier, 2006

AMOC

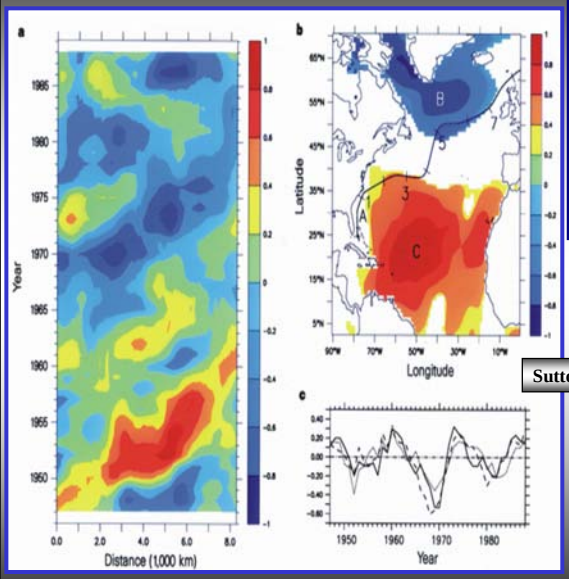
Thermohaline circulation hysteresis

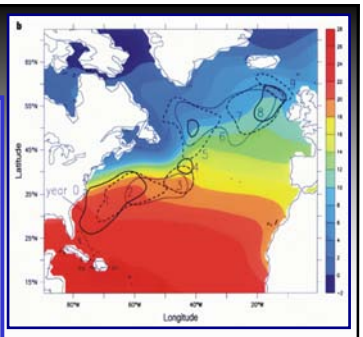
→MOC major contribution to heat budjet in the North Atlantic region



AMOC

Atmosphere ocean interaction





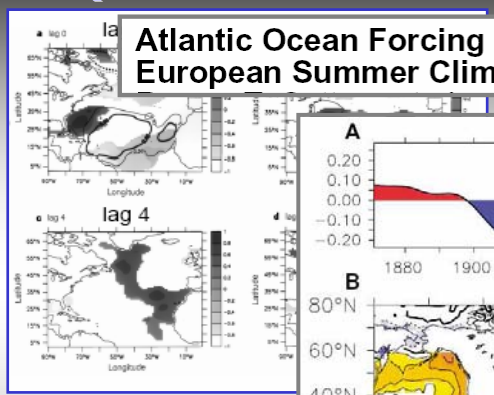
Sutton & Allen, Nature, 368, 563-7, 1997

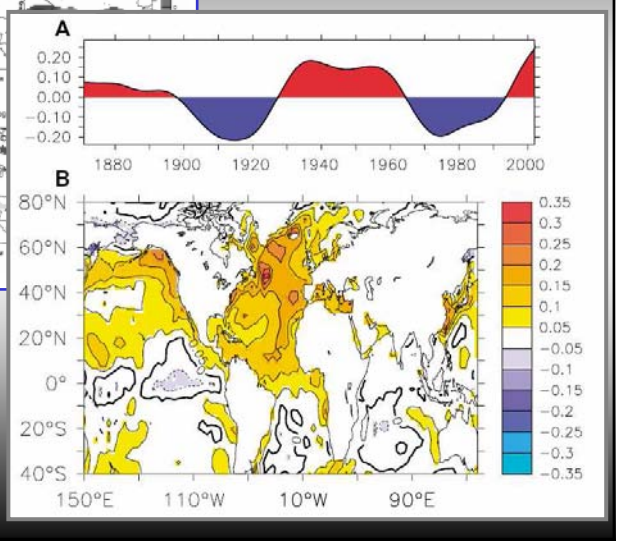
AMOC

Atmosphere ocean interaction

Atlantic Ocean Forcing of North American and European Summer Climate

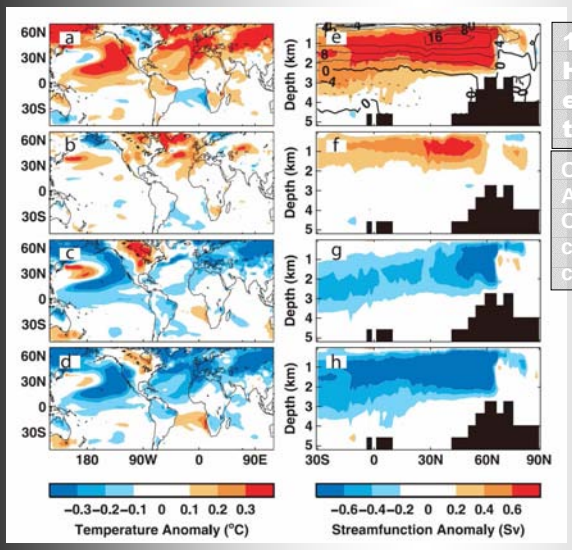
Sutton & Allen, Nature, 368, 563-7, 1997





AMOC

A signature of persistent natural thermohaline circulation cycles in observed climate



1400 yr control HadCM simulation to explore AMOC long-term variability

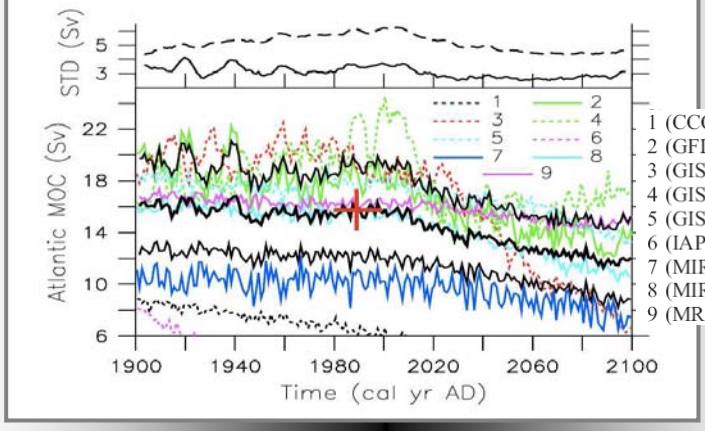
Oscillatory mode where the Atlantic Multidecadal Oscillation is driven by changes in the overturning circulation

Knight et al.: GRL, 32, L20708, 2005

AMOC

Model projections of the North Atlantic thermohaline circulation for the 21st century

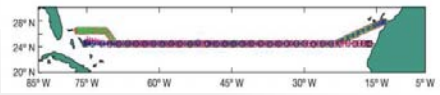
Schmittner et al.: GRL, 32, L23710, 2007

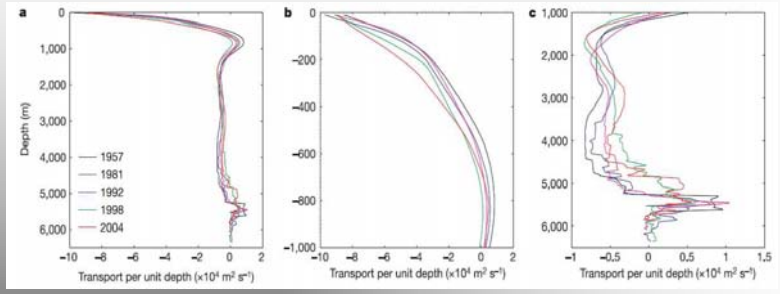


1 (CCCMA) 5,5[b]
2 (GFDL-2.0) 2,1[b]
3 (GISS-AOM) 2,2[b]
4 (GISS-EH) 5,3[b]
5 (GISS-ER) 4,5[b]
6 (IAP) 3,3[b]
7 (MIROC-HI) 1,1[b]
8 (MIROC-MED) 3,3[b]
9 (MRI) 5,5[b]

AMOC

Slowing of the Atlantic meridional overturning circulation at 25° N





Bryden et al.: Nature, 438,655-657, 2007

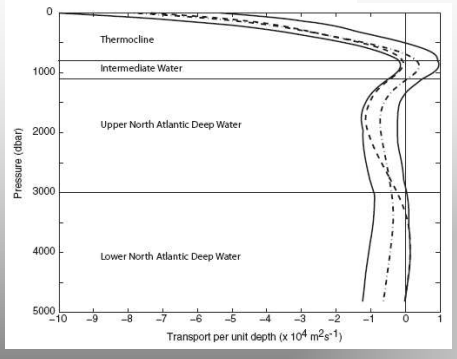
Table 1 | Meridional transport in depth classes across 25° N

	1957	1981	1992	1998	2004
Shallower than 1,000 m depth					
Gulf Stream and Ekman	+35.6	+35.6	+35.6	+37.6	+37.6
Mid-ocean geostrophic	−12.7	−16.9	−16.2	−21.5	−22.8
Total shallower than 1,000 m	+22.9	+18.7	+19.4	+16.1	+14.8
1,000–3,000 m	−10.5	−9.0	−10.2	−12.2	−10.4
3,000–5,000 m	−14.8	−11.8	−10.4	−6.1	−6.9
Deeper than 5,000 m	+2.4	+2.1	+1.2	+2.2	+2.5

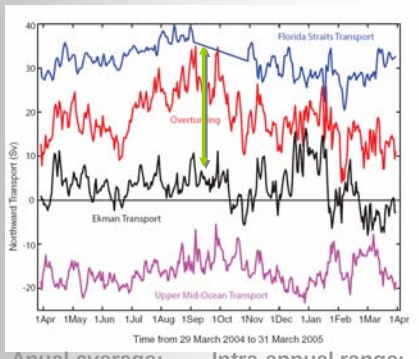
Values of meridional transport are given in Sverdrups. Positive transports are northward.

AMOC

Temporal Variability of the Atlantic Meridional Overturning Circulation at 26.5°N



Cunningham et al.: Science, 317, 935-938, 2007

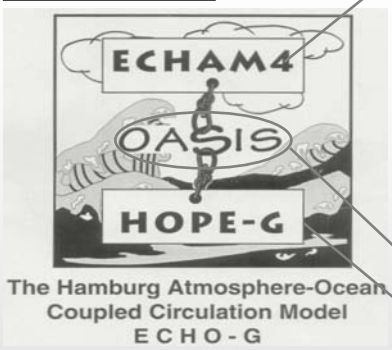


Anual average: 18.7±5.6 Sv

Intra-annual range: 4.0 to 34.9 Sv

GCM: ECHO-g

Model description



Atmospheric component
(MPI Rep. 218, 1996)

- ECMWF➔MPI
- ~ECHAM3
  - + fresh water on glaciers
  - + river runnoff + partial ice cover
- T30 ~ 3.75 x 3.75 ºlat x ºlon
- 19 vertical levels:
  - Highest: 10 hPa~ 30 km
  - Lowest:~ 30 m

Ocean component
(DKRZ Rep. 13, 1997)

- Prim. Eq. & Thermodyn.
  - + sea ice model with snow cover
- Gauss. T42 ~ 2.8 x 2.8 ºlat x ºlon
  - ➔0.5 ºlat x ºlon Equator
- 20 levels

Coupler
(CERFACS Rep. CMGC/98-05, 1998)

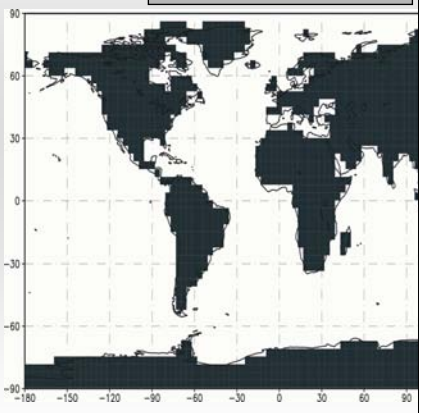
- Coupling: 1 day
- Atm ➔ Oce: Heat, fresh watter, momentum fluxes
- Oce ➔ Atm: Surface conditions
- Grid interpolation

GCM: ECHO-g

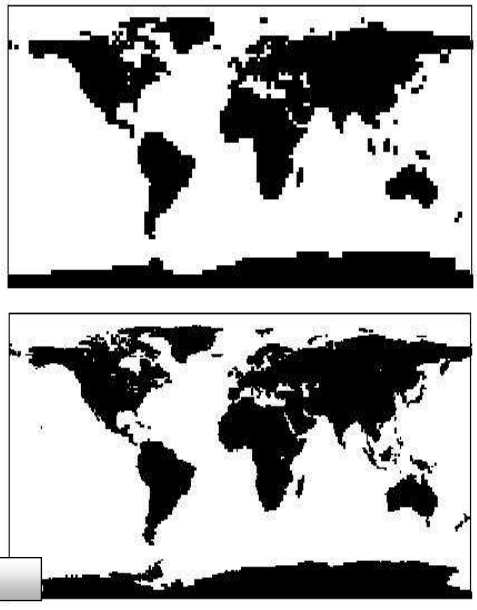
Model description

Model resolution

T30 Land-Sea Mask



T42 Land-Sea Mask



T106 Land-Sea Mask

Experiments

External forcing

1 Control experiment

Present-day values

S=1365 $W\ m^{-2}$ $[CO_2]$=353 *ppm*

$[CH_4]$=1720 *ppb* $[N2O]$=310.0 *ppb*

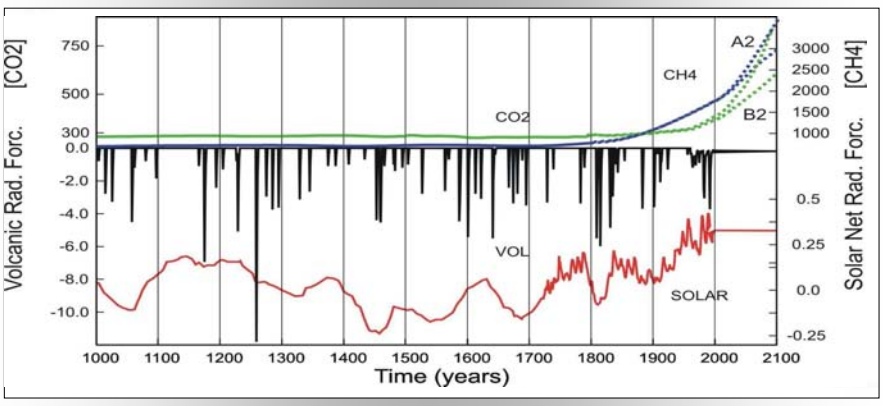
Forced simulations

1000 to 1990 A. D.

(Crowley, Science, 289 270-277, 2000)

After 1990 A. D.

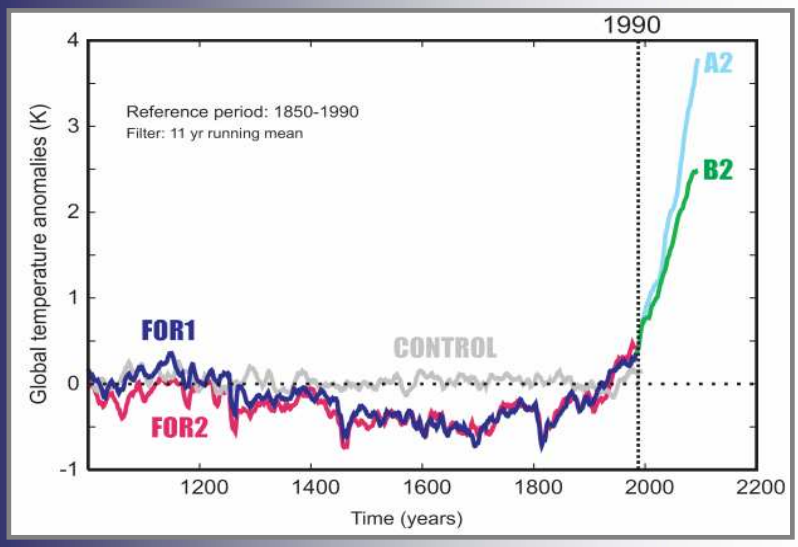
(IPCC SRES, 2001)



ECHO-G: climate since 1000 AD

T response

González-Rouco et al., GRL, 33, L01703, 2006

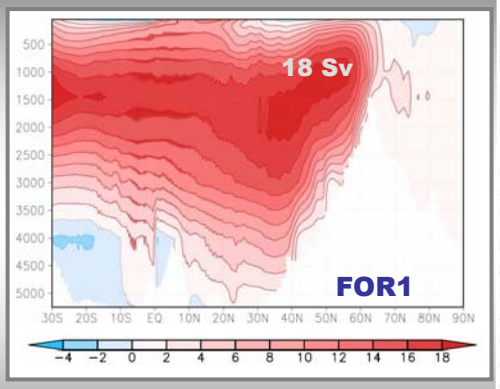


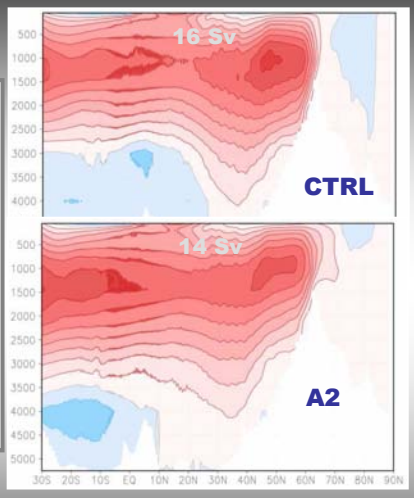
AMOC

CLIMATOLOGY

Long-term mean AMOC streamfunction

MEAN STATE





Circulation: realistic & close to estimates by Ganachaud & Wunsch (2000); 15±2 Sv

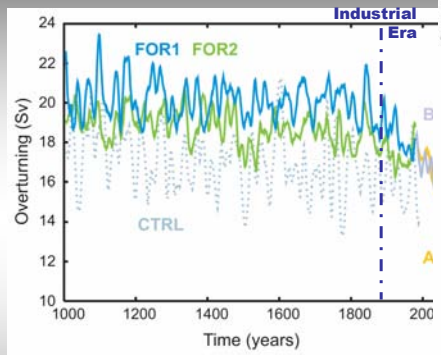
1Sv = $10^6 m^3/s$

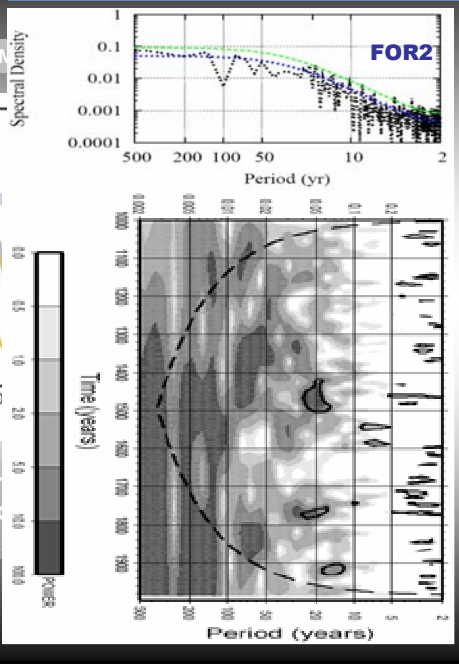
AMOC

TEMPORAL EVOLUTION

Fourier and Wavelet spectrums

The meridional overturning index (M



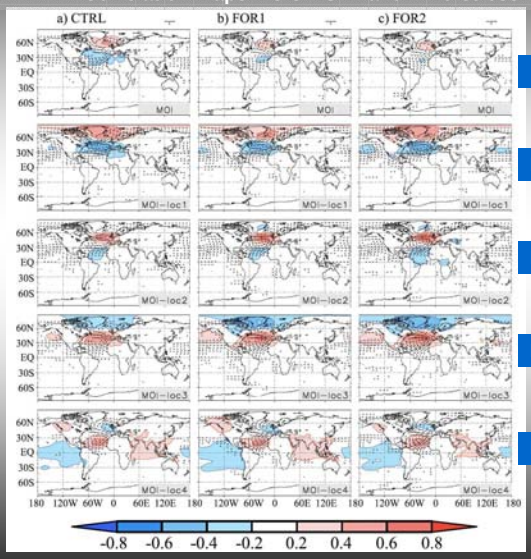


Weakes beginning of the industr era & deepens along the future change scenarios

MODES IN HIGH-FREQUENCY

The patterns are common to the three millennial simulations

Correlation maps MOIs – SLP and wind stress



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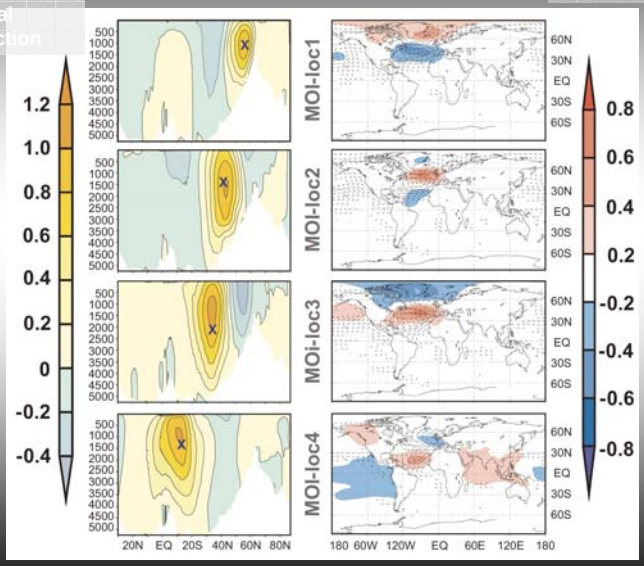
MODES IN HIGH-FREQUENCY

Regression patterns
MOI-local
Streamfunction

Correlation maps
MOI-local
SLP and
wind stress



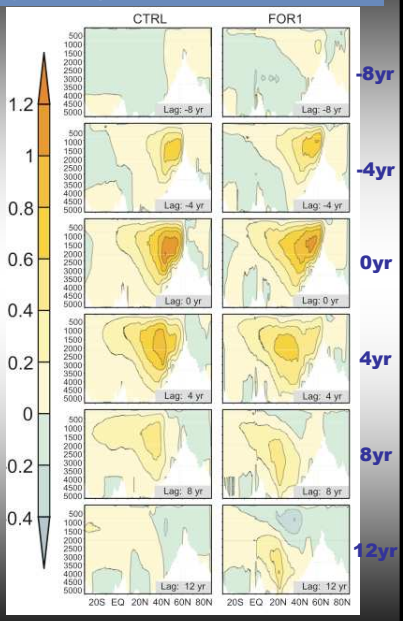
AMOC

AMOC

MODES IN LOW-FREQUENCY

- In the low frequency it is identified a propagating mode that differs in some extent from CTRL to the forced runs.
- Positive overturning anomalies appear in the sinking regions of the North Atlantic several years before a MOI maximum (7-8 yr).
- When the lag is 0 the overturning reaches its maximum anomalies and extension.
- About 8 years after the maximum the overturning in the sinking region becomes negative.
- The positive anomalies move southwards in latitude in CTRL, while in the forced runs they are confined to the deep ocean.

Regression patterns MOI-Streamfunction



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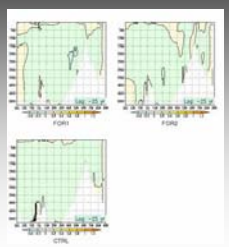
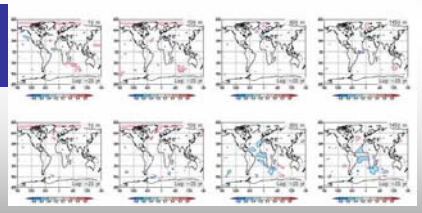
MODES IN LOW-FREQUENCY



CTRL

FOR1

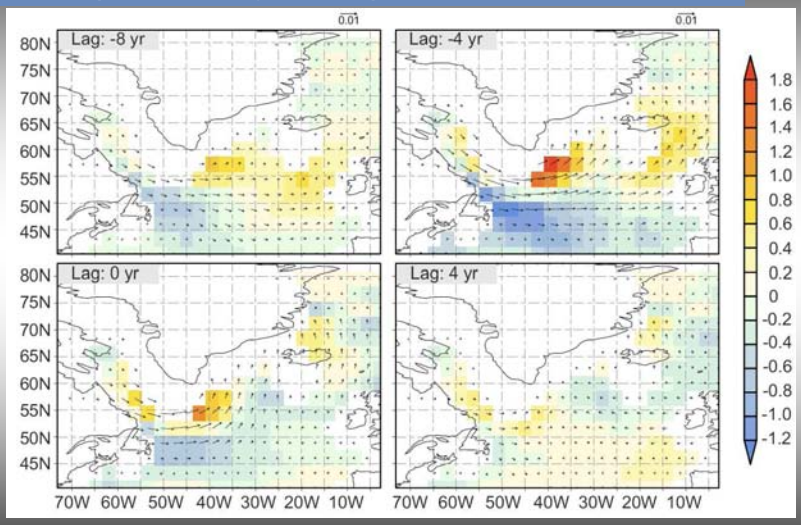


AMOC

MODES IN LOW-FREQUENCY

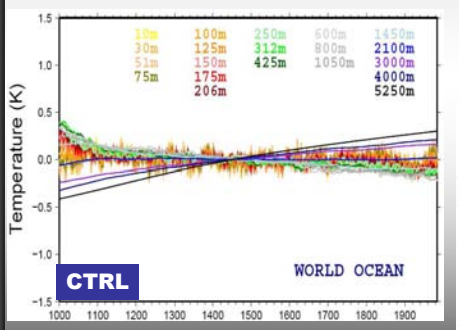
Piuckart et al.: Nature, 424, 152-156, 2003

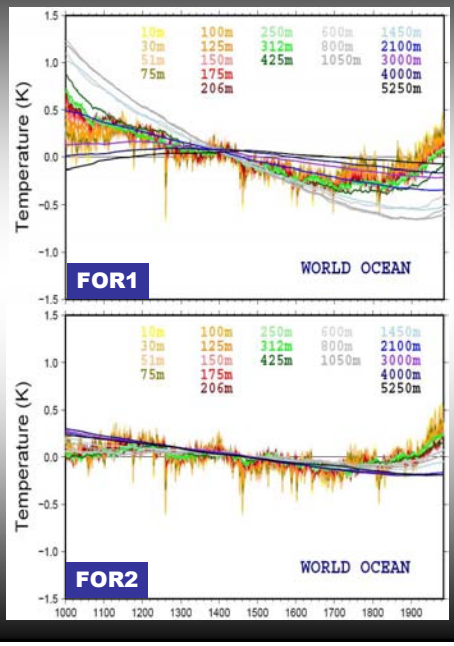
Greenland Tip Jet Events: Regression maps MOI – Wind Stress and Wind Curl



OHC

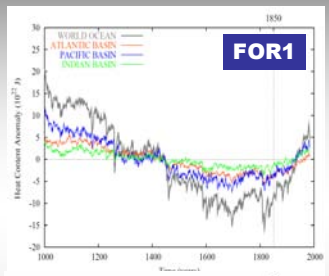
Temperature profiles

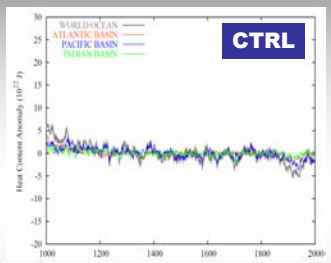


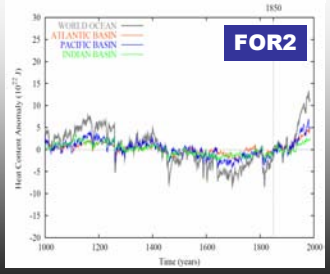


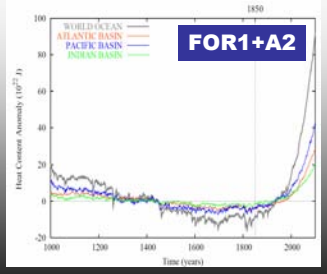
OHC

OHC in the upper 275m



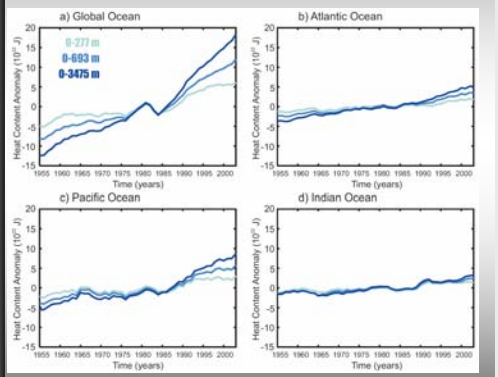




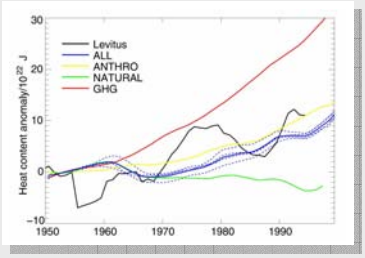


OHC

The OHC in the last 50 years



From Gregory et al. (2004)



ALL: anthropogenic and natural forcing

NATURAL: solar and volcanic forcing

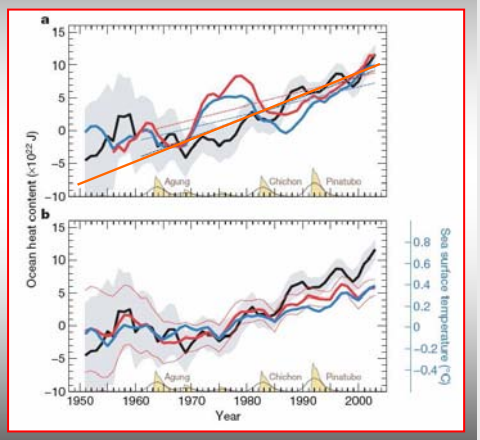
GHG: greenhouse gas

ANTHRO: GHG and sulphate aerosols

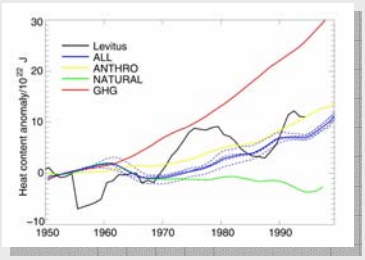
Five-year running means of world ocean heat content from Levitus and the HadCM3 ensembles. Solid lines show the mean of four ensemble members and the blue dashed lines show the values for individual members of the ALL ensemble.

OHC

Improved estimates of upper-ocean warming and multi-decadal sea-level rise



From Gregory et al. (2004)



ALL: anthropogenic and natural forcing

NATURAL: solar and volcanic forcing

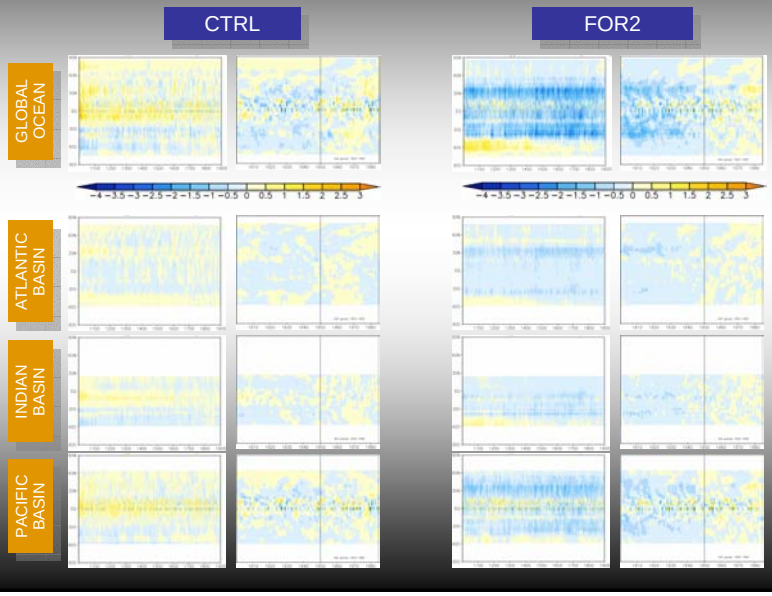
GHG: greenhouse gas

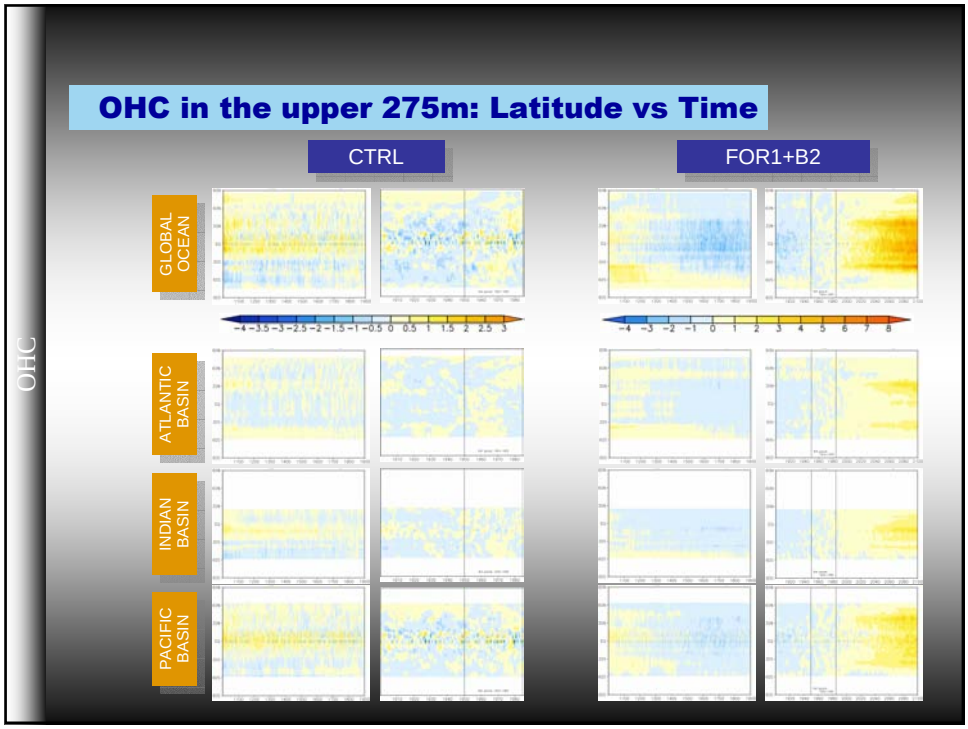
ANTHRO: GHG and sulphate aerosols

Five-year running means of world ocean heat content from Levitus and the HadCM3 ensembles. Solid lines show the mean of four ensemble members and the blue dashed lines show the values for individual members of the ALL ensemble.

OHC

OHC in the upper 275m: Latitude vs Time





In brief ...

I. **All simulations show a realistic AMOC, with maximum values close to estimates.**

II. During the industrial era the forced runs exhibit a weakening in the AMOC that is intensified in the future scenario simulations.

III. **The high-frequency modes are common to the three simulations and forced by various wind regimes.**

IV. In the low-frequency two propagating modes are identified, one in the forced runs and the other in CTRL. Both are related to the irruption of density anomalies in the North Atlantic sinking region several years before the MOI maximum.

V. **Heat storage compares well with present estimates, accounting for the forcings considered ...**

Gracias