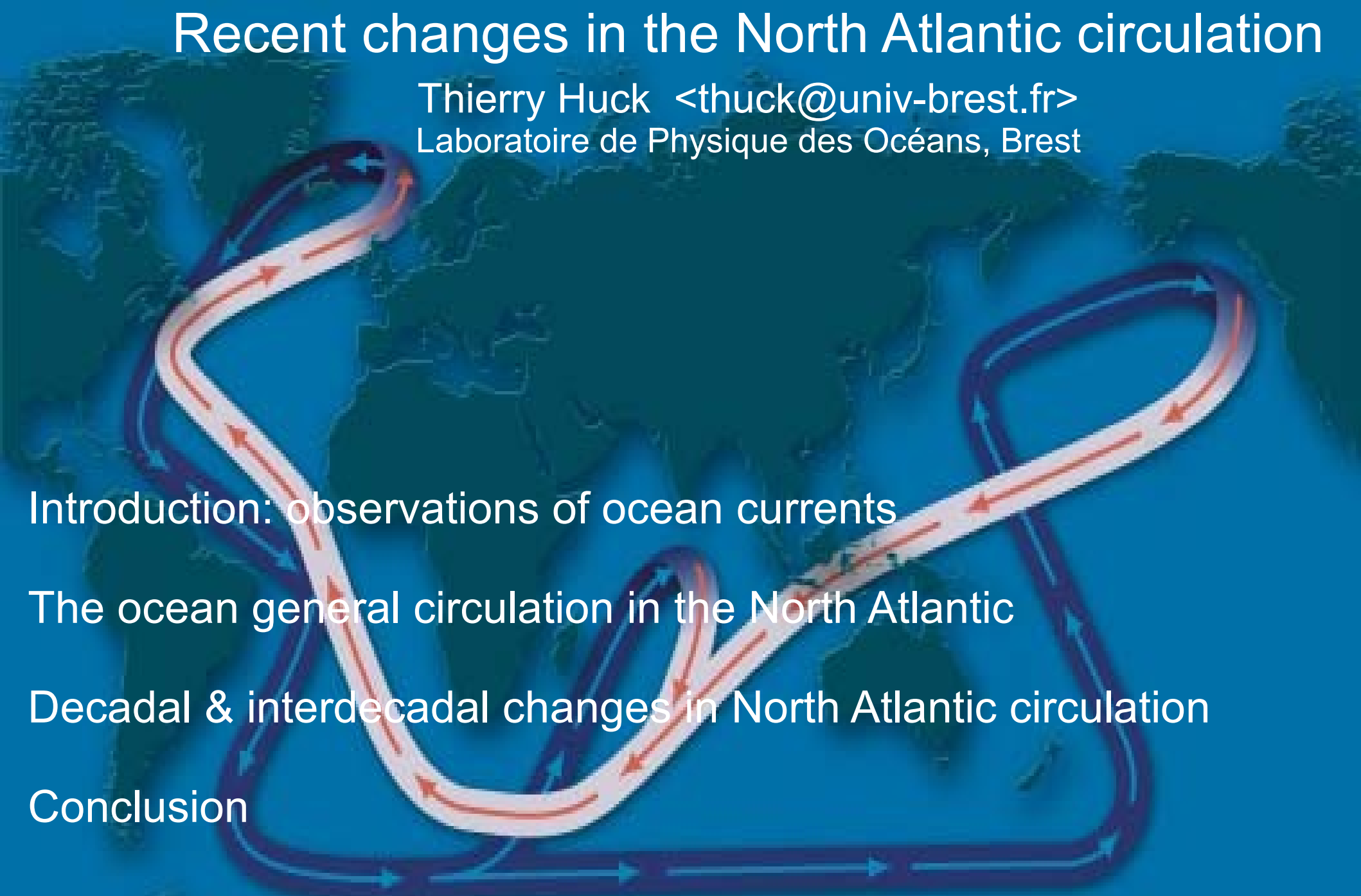
Recent changes in the North Atlantic circulation

Thierry Huck <thuck@univ-brest.fr>
Laboratoire de Physique des Océans, Brest



Introduction: observations of ocean currents

The ocean general circulation in the North Atlantic

Decadal & interdecadal changes in North Atlantic circulation

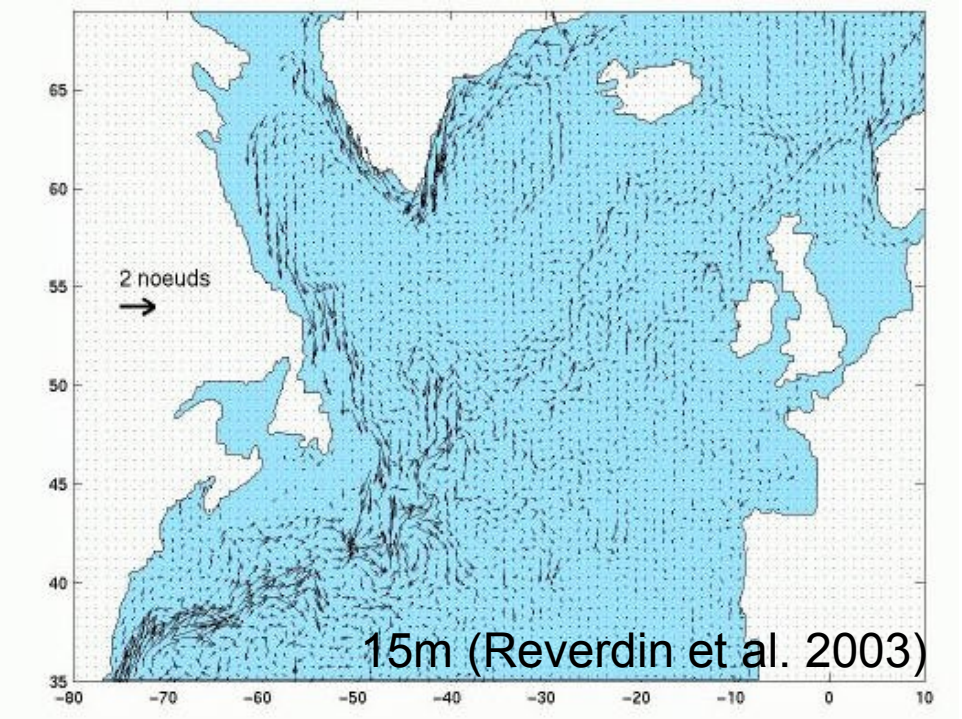
Conclusion

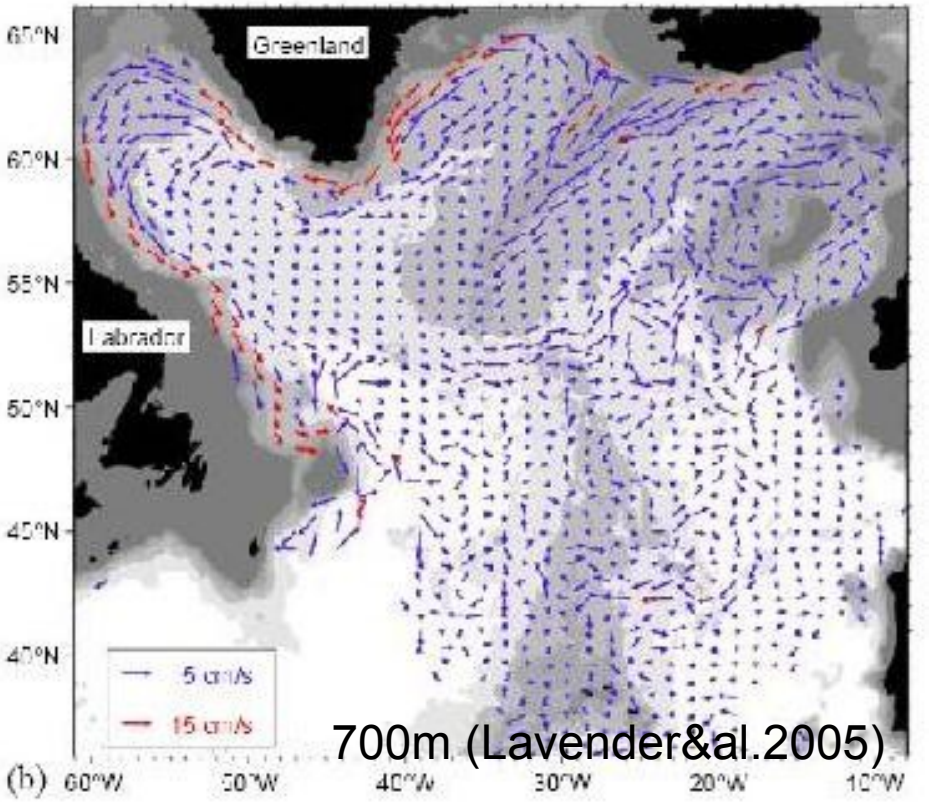
The global ocean circulation system, often called the Ocean Conveyor, transports heat worldwide. White sections represent warm surface currents. Purple sections represent cold deep currents. (after Gagosian 2003)

Observations of ocean currents

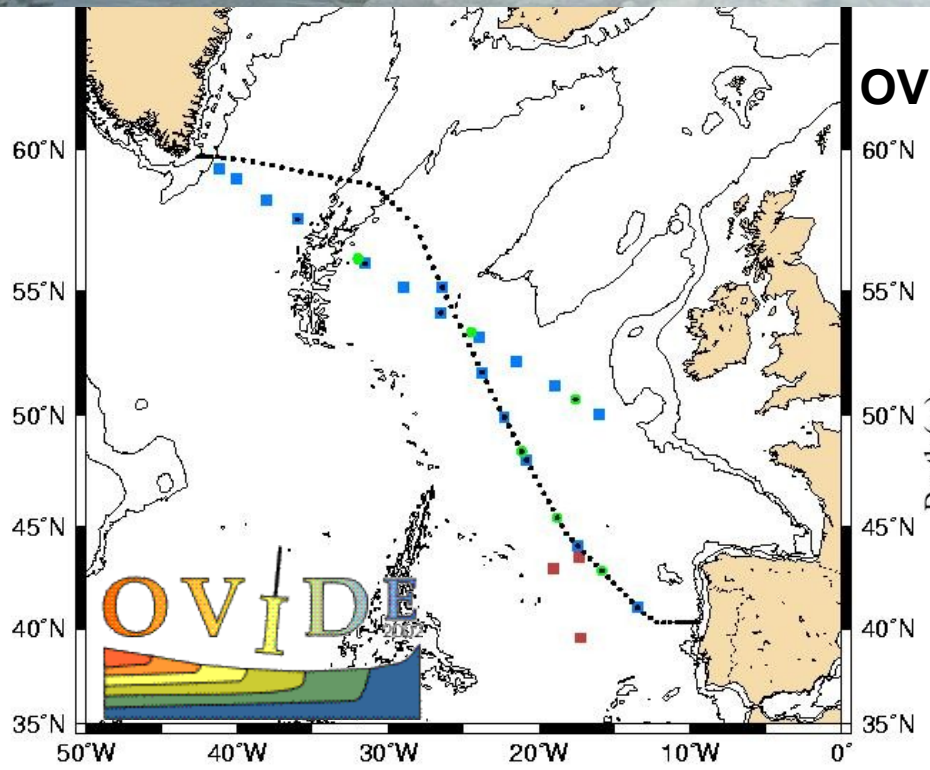
Direct:
- **surface drifters**
- **subsurface floats trajectories**
- current meters + ADCP

Indirect:
- CTD + theory
  (thermal wind + reference level)
- satellite altimetry:
  surface geostrophic currents

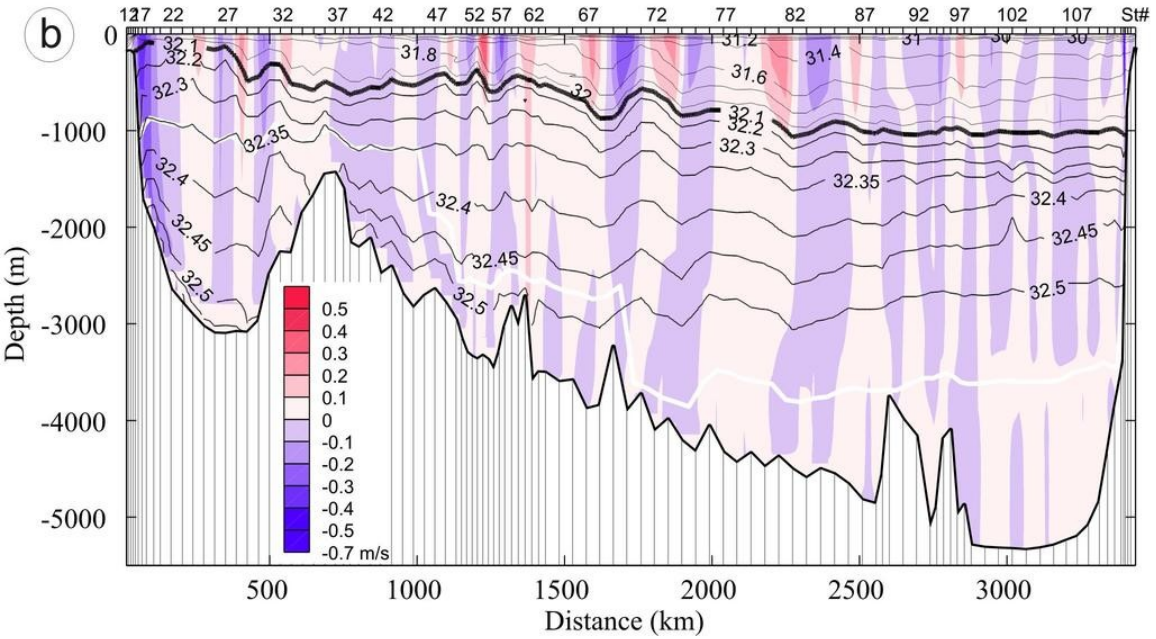




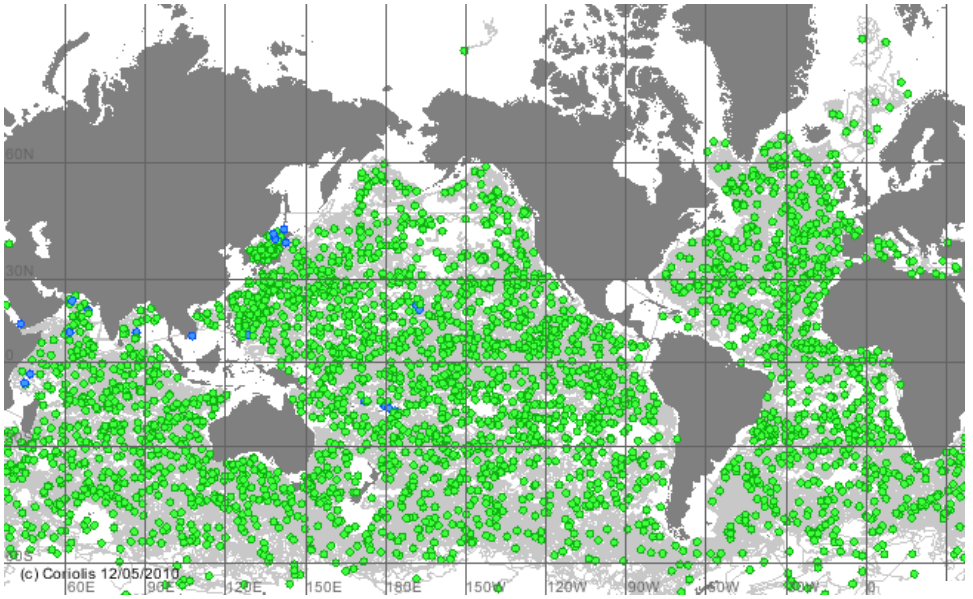
Ocean currents inferred from CTD measurements

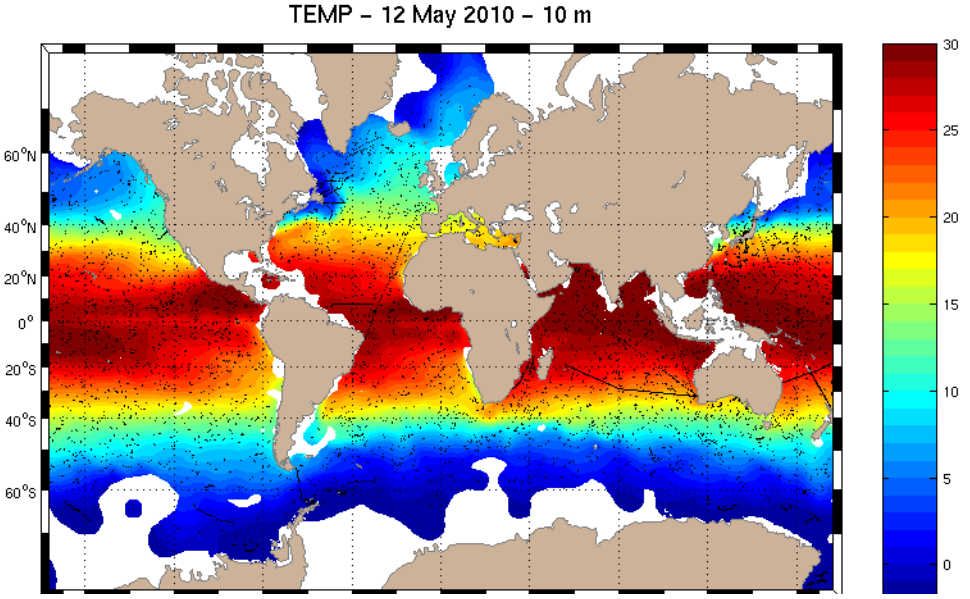


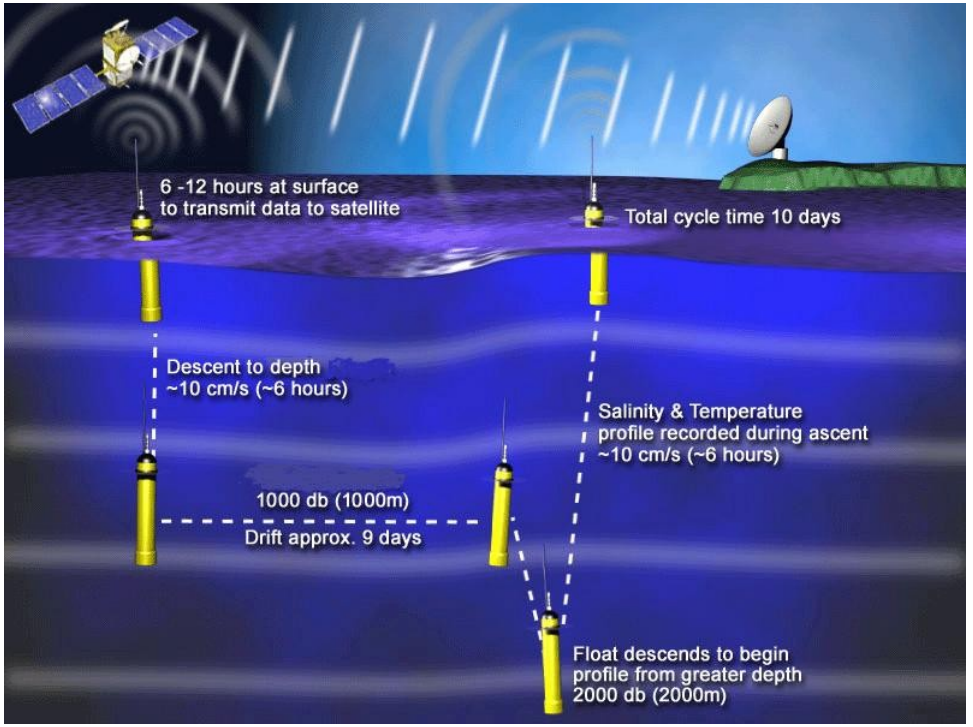
OVIDE 2002 VELOCITY SECTION AFTER INVERSION

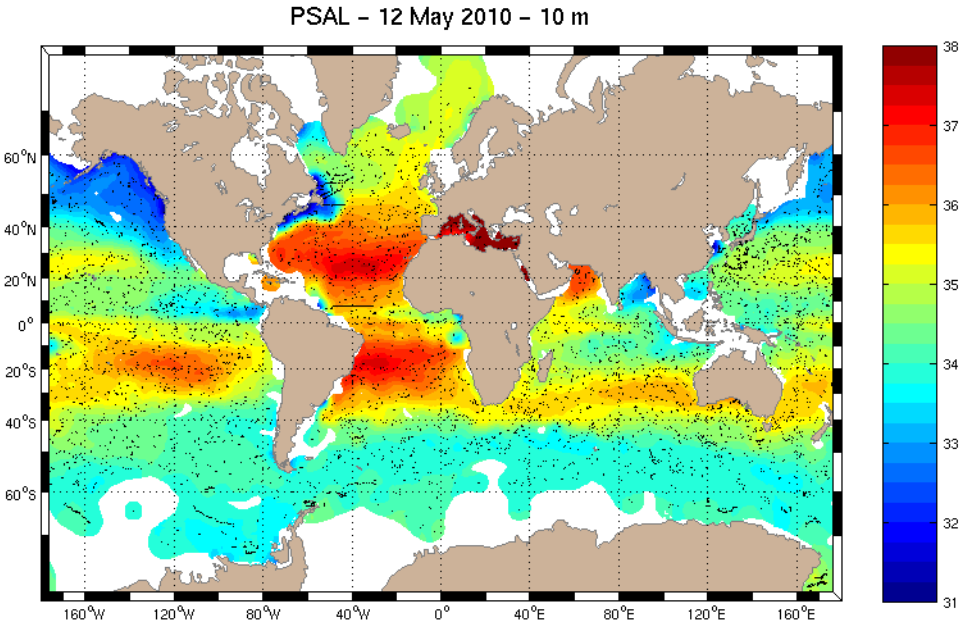


3000 Argo profiling floats worldwide... since nov.2007





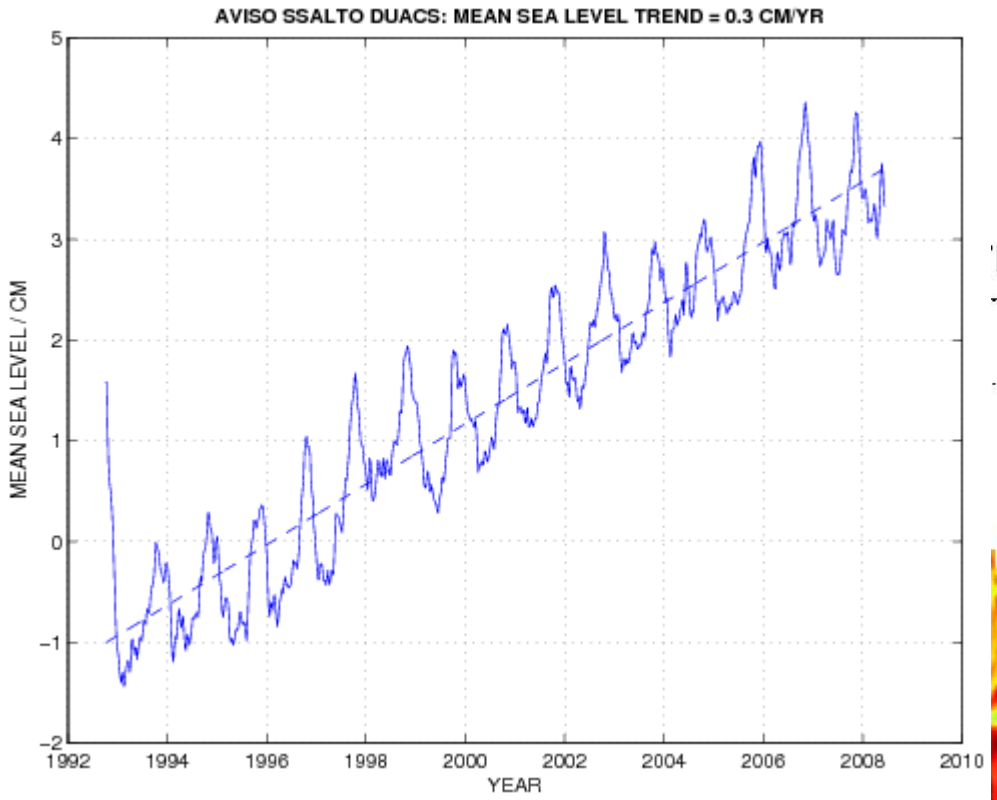


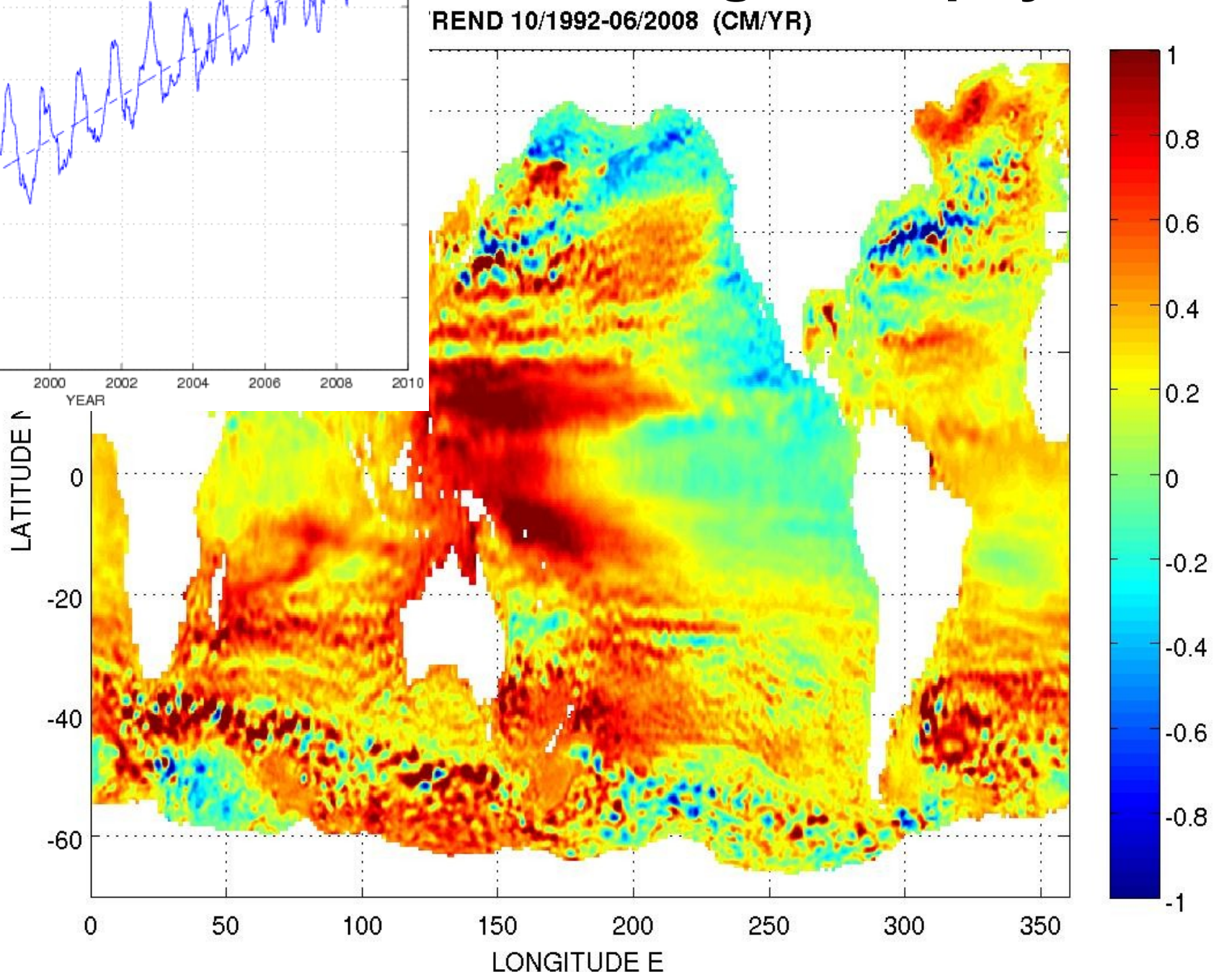


Coriolis

min = 5.00 max = 40.50 count = 6837 last update : 12/05/2010

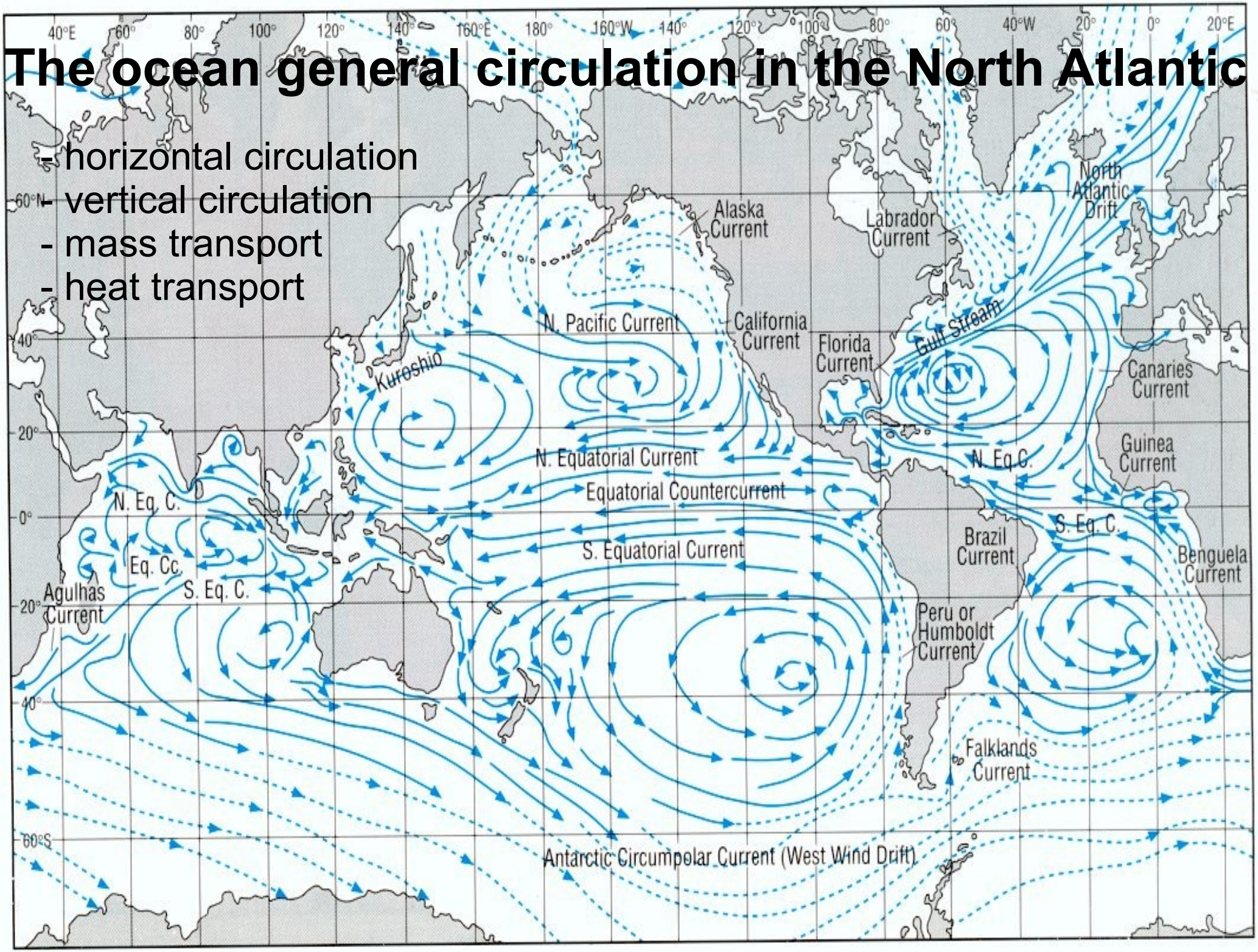
Satellite altimetry and geostrophy





The ocean general circulation in the North Atlantic

- horizontal circulation
- vertical circulation
- mass transport
- heat transport



Schematic circulation of the subpolar North Atlantic

Topographic features:
- CGFZ Charlie Gibbs Fracture Zone
- MAR Mid-Atlantic Ridge

Different current branches:
- DWBC Deep Western Boundary Current
- NAC North Atlantic Current
- DSOW Denmark-Strait Overflow Water
- ISOW Iceland-Scotland Overflow Water
- LSW Labrador Sea Water

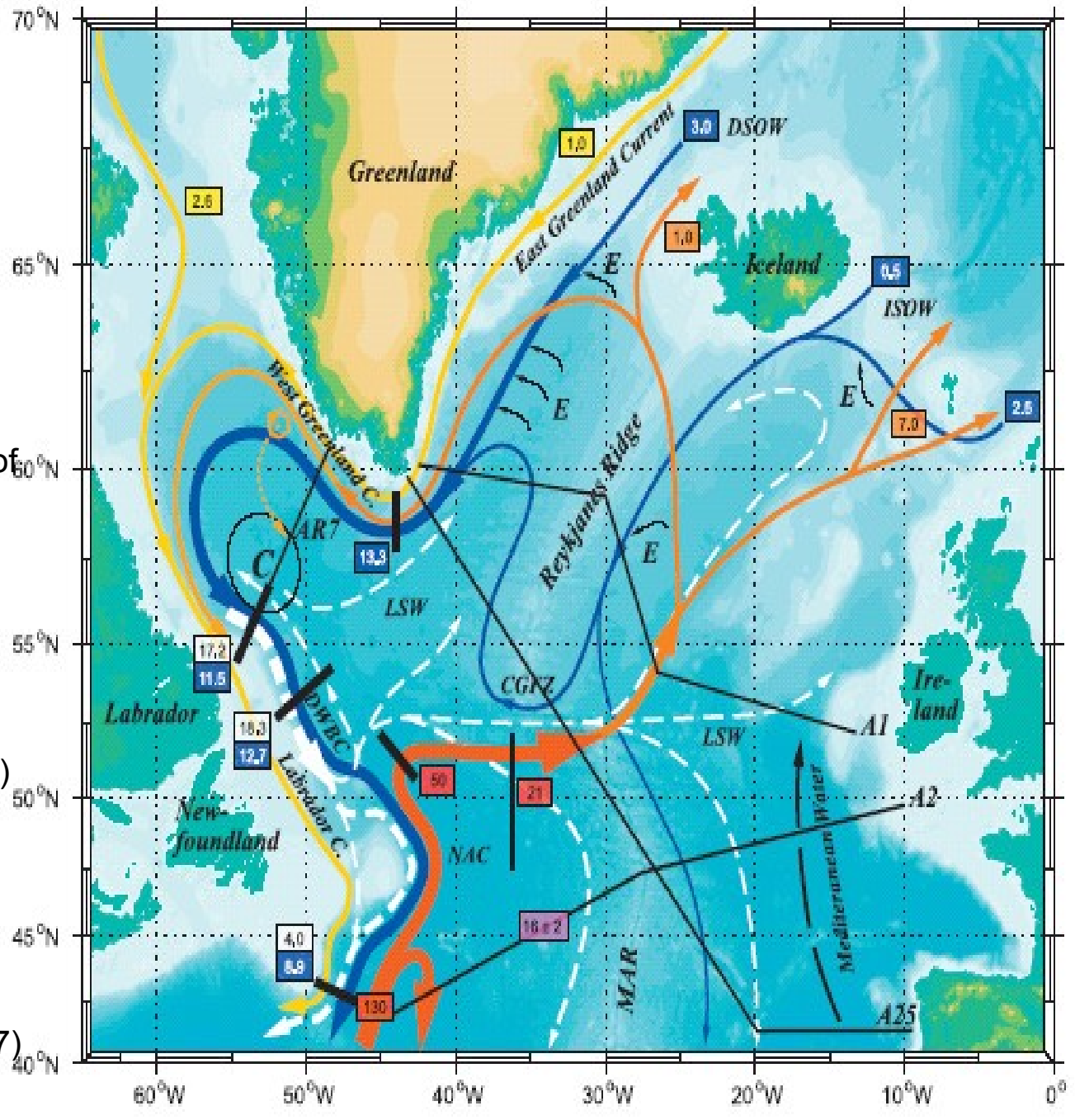
C Convection
E Entrainment

Locations of moored current-meter arrays of quoted transports in Sv = 10^6 m^3/s (heavy black bars)
WOCE Hydrographic Program lines A1, A2 and A25 (Ovide) across the Atlantic and AR7 across the Labrador Sea (thin black).

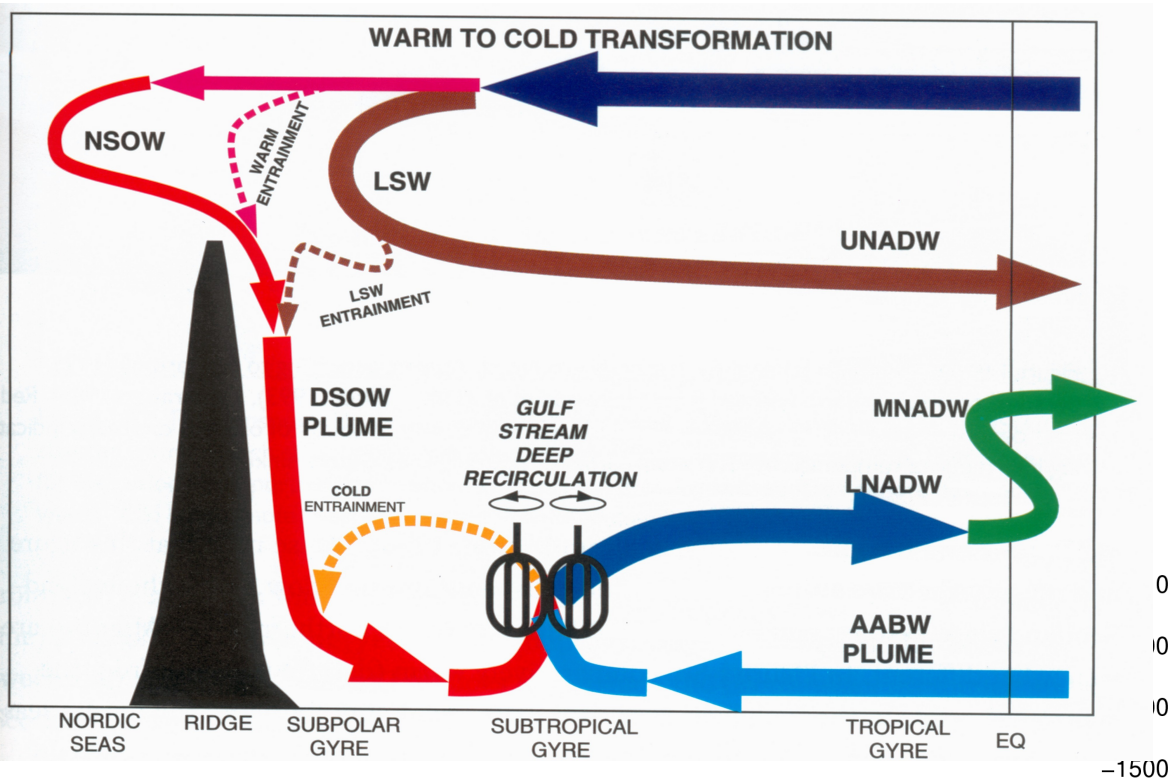
Transports for mean DWBC (LSW layer in white box, deeper layers in blue box), for NAC (red box) and extensions (orange box) as well as for the shallow Arctic inflow (yellow box)

MOC Meridional Overturning Circulation across A2 (magenta box) as obtained from inverse models

(after Schott & Brandt 2007)

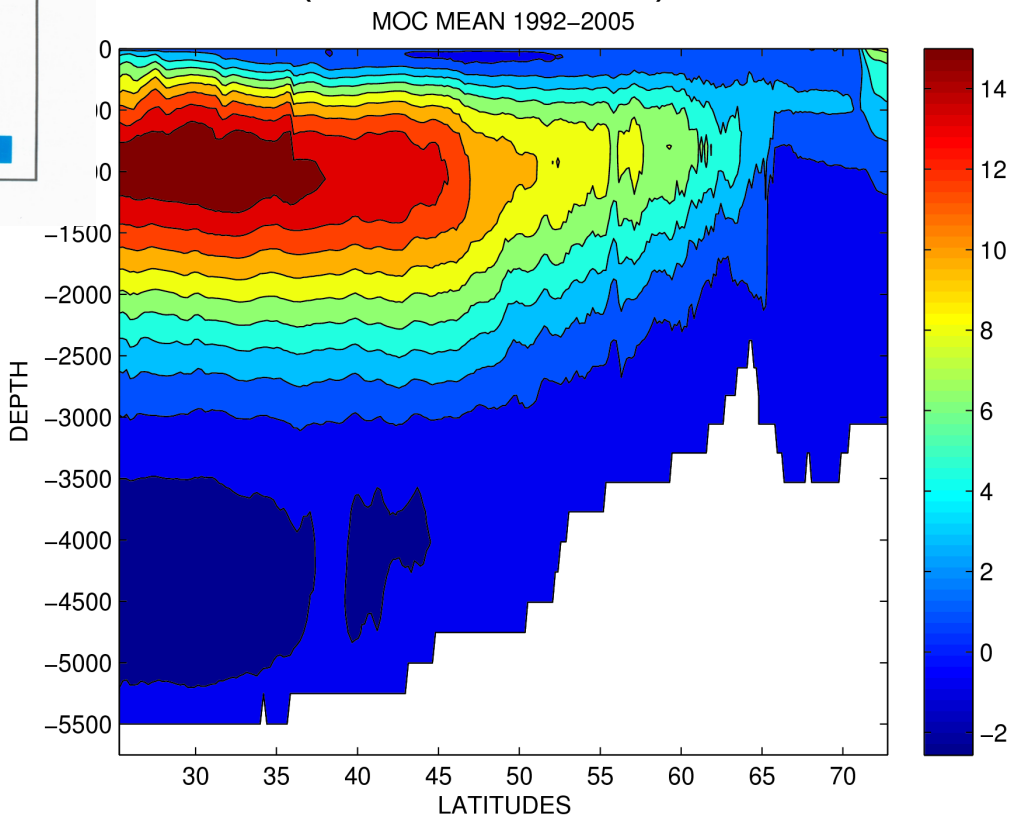


ThermoHaline Circulation: a latitude-depth view



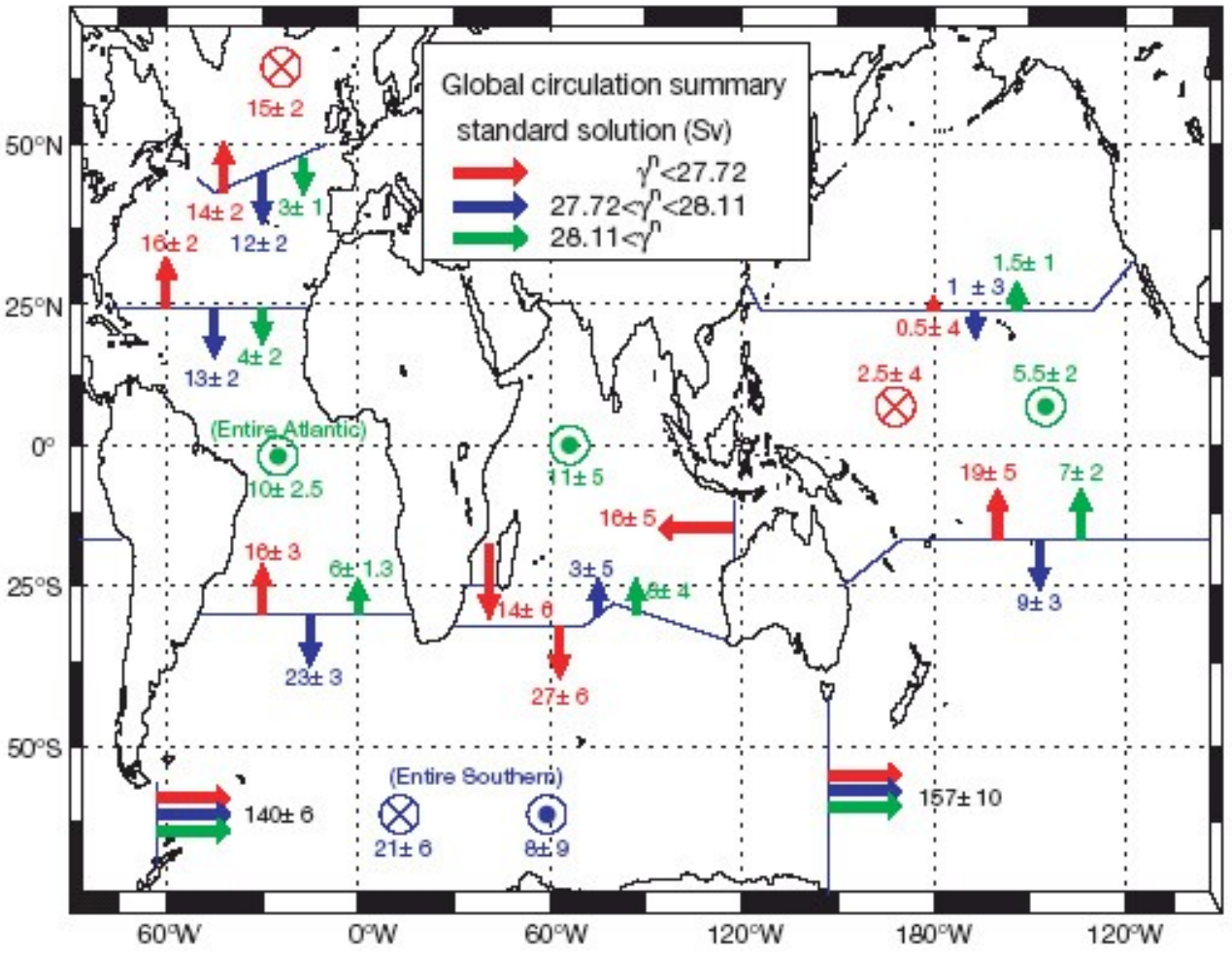
Schematic
(after Schmitz 1996)

Meridional Overturning Circulation
from numerical ocean models
(in Sv = 10^6 m^3/s)



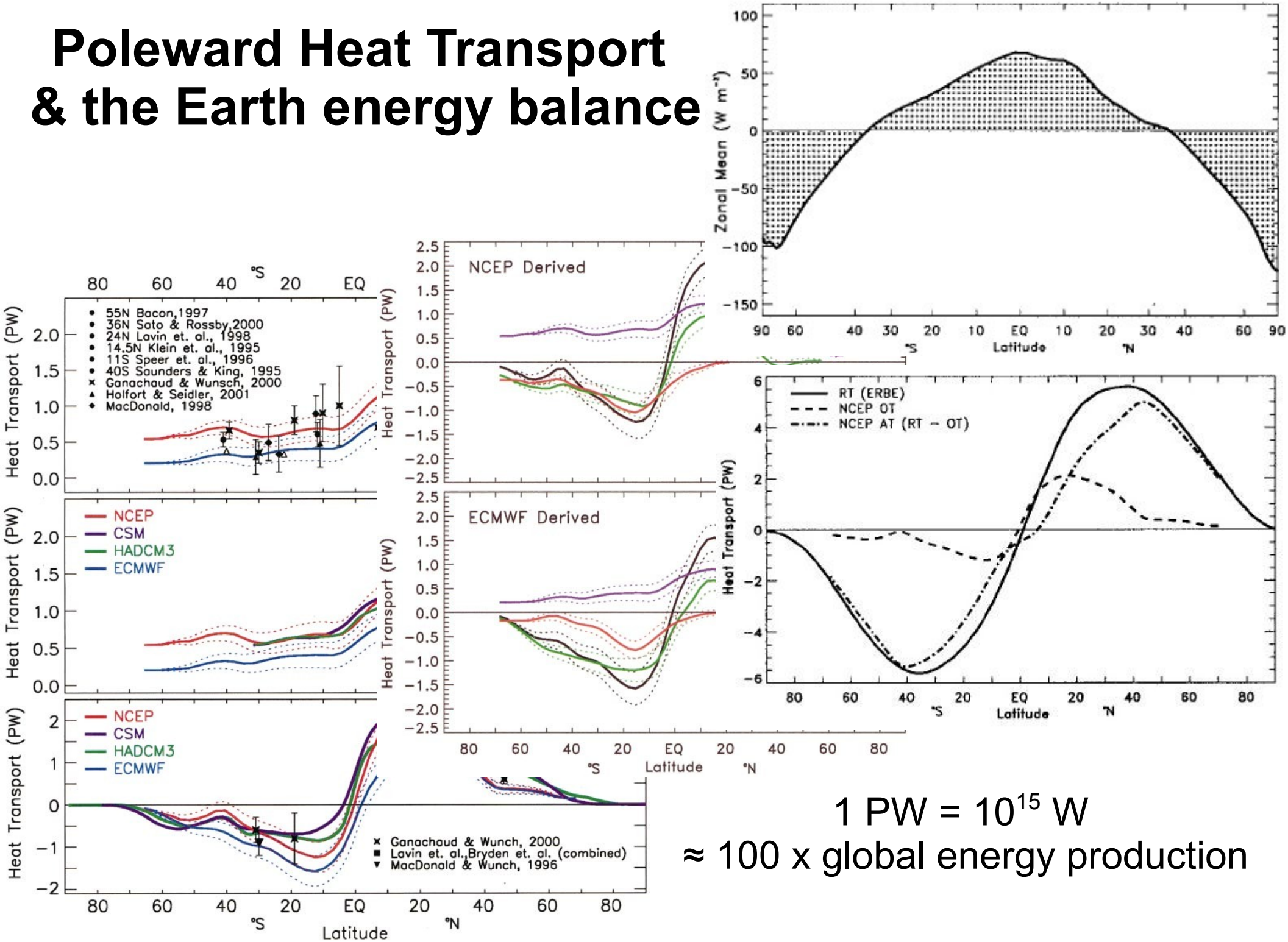
Quantitative estimate of THC ?

- hydrographic sections "synoptic"
- synthesis of hydrographic sections through inverse models



Ganachaud & Wunsch 2000

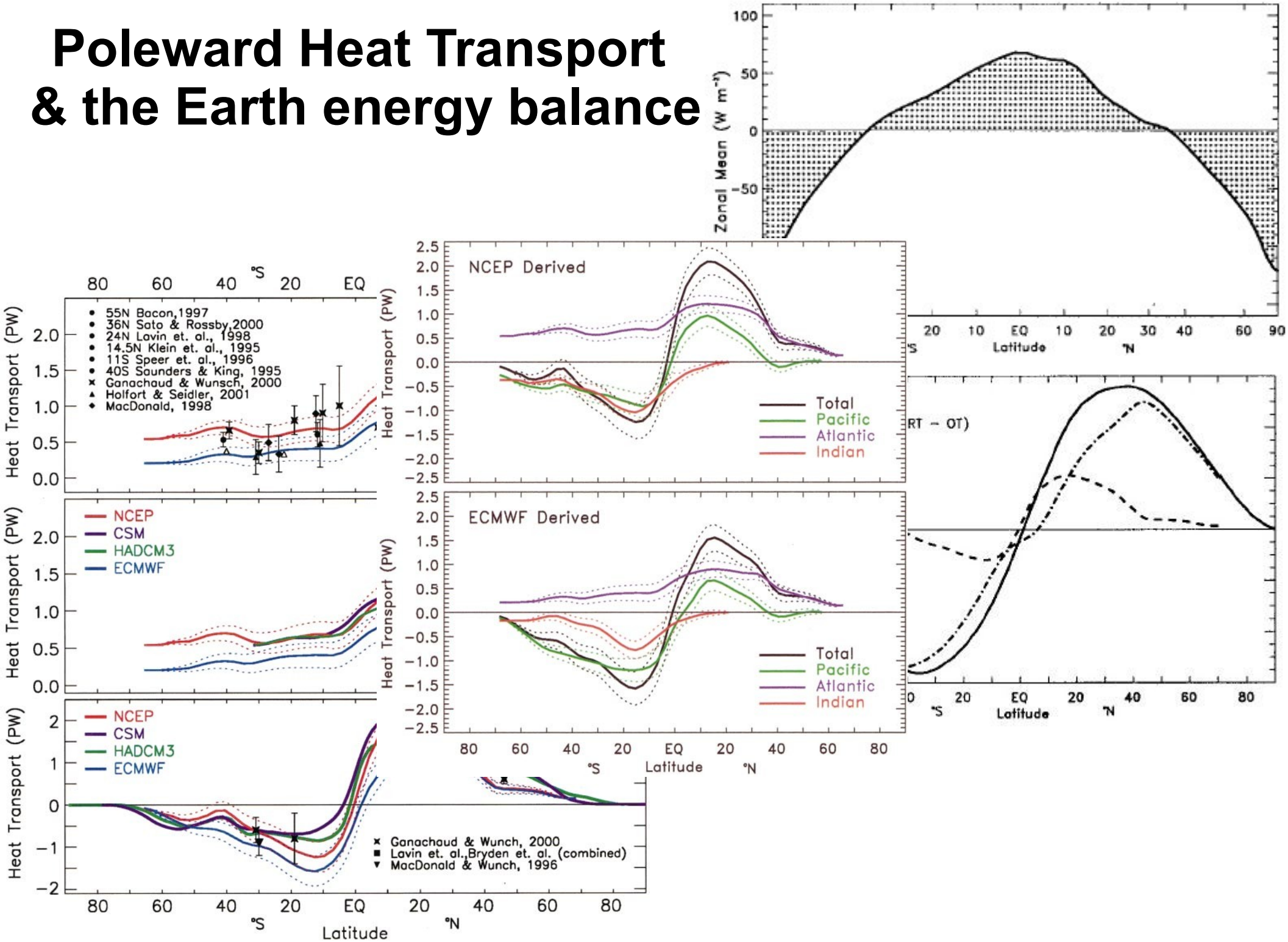
Poleward Heat Transport & the Earth energy balance



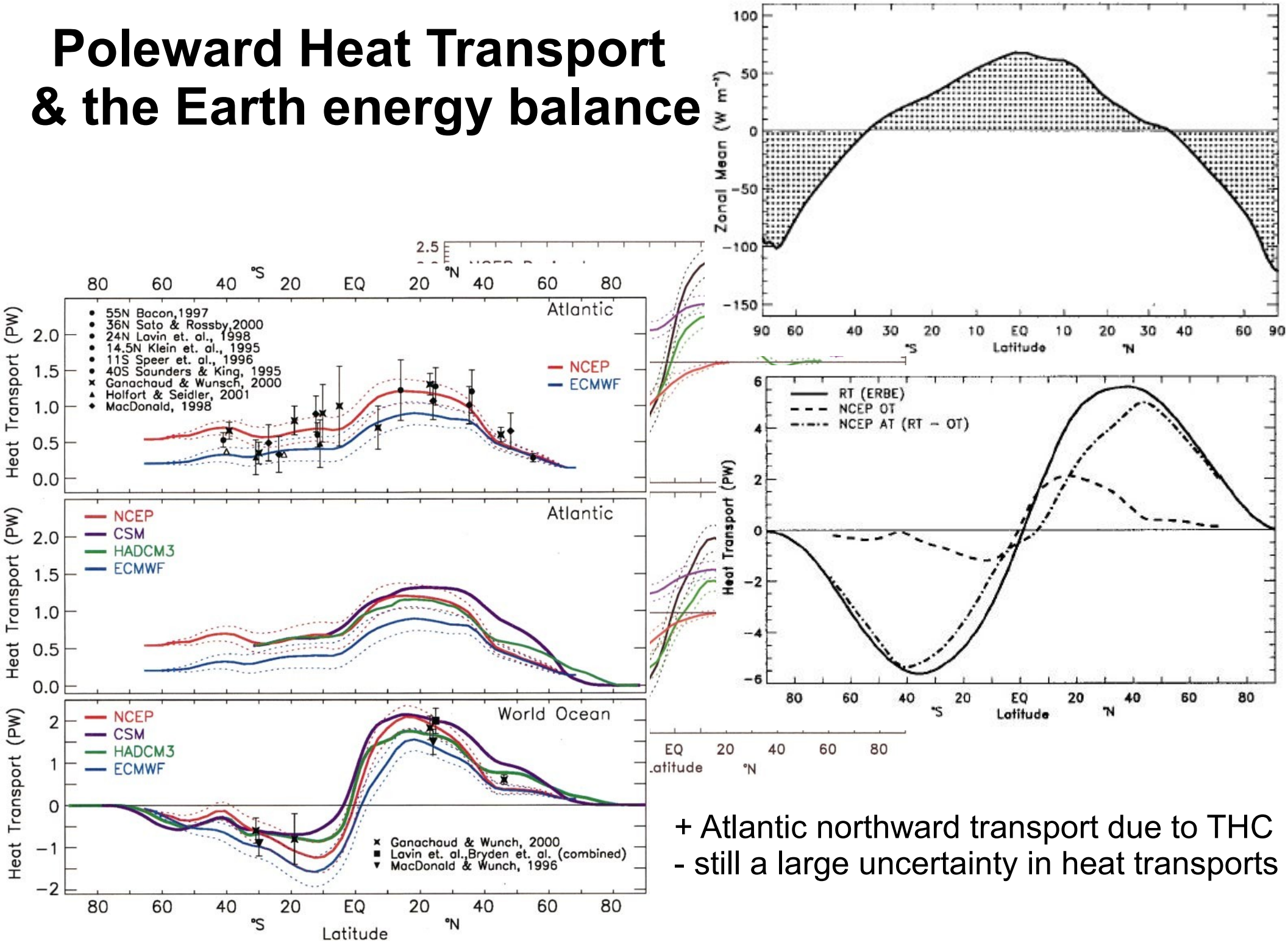
1 PW = 10^{15} W

≈ 100 x global energy production

Poleward Heat Transport & the Earth energy balance



Poleward Heat Transport & the Earth energy balance



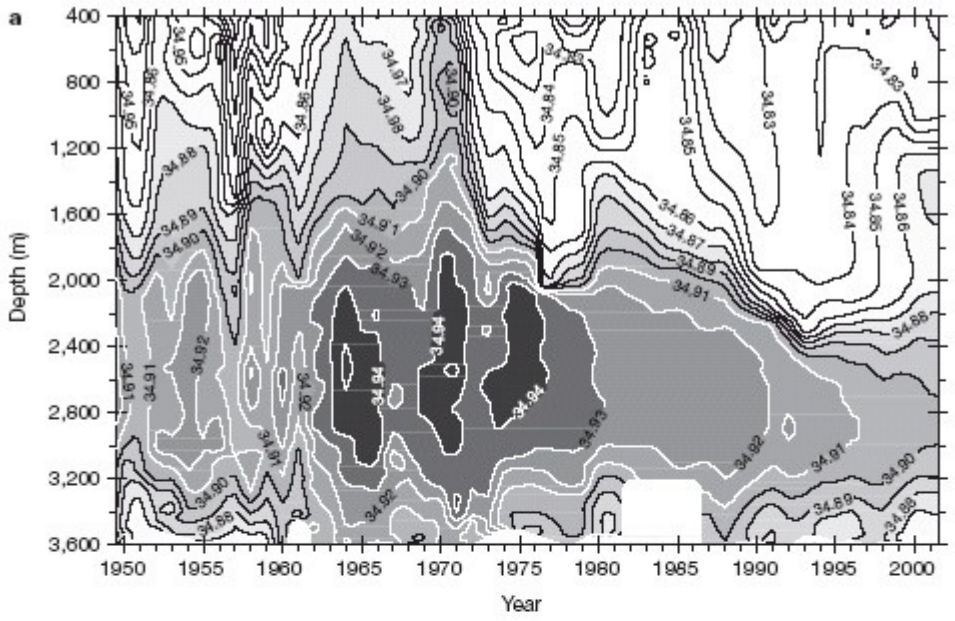
+ Atlantic northward transport due to THC
- still a large uncertainty in heat transports

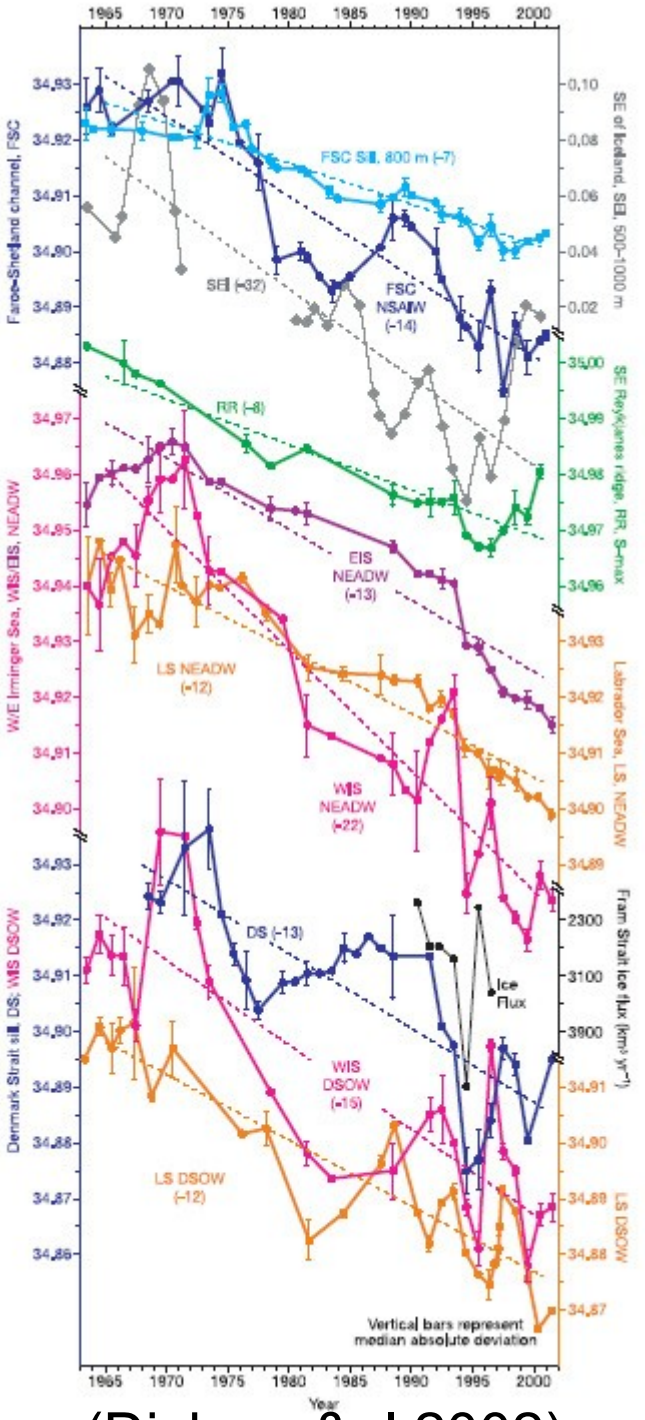
Decadal and interdecadal changes of the North Atlantic circulation

Statistical analyses:
- hydrographic data series available in specific locations: 50 yr max
- SST: 100 yr record
- SLA: 17 yr record
- use of proxys for extending time series: tree-rings, corals, ...

Associated circulation changes?
- hints from numerical ocean general circulation models
- mechanisms?

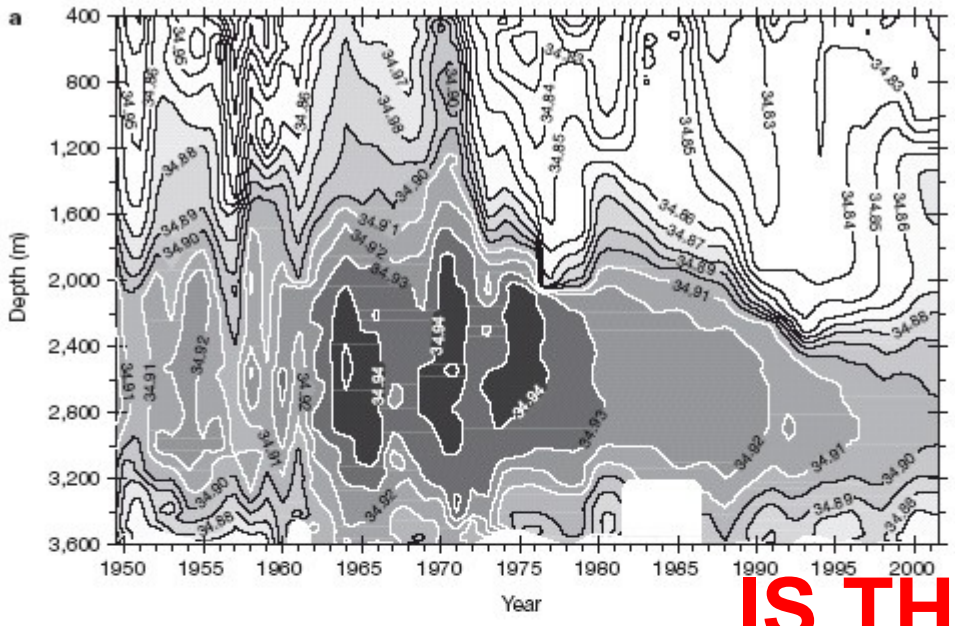
Rapid freshening of the deep North Atlantic Ocean over the past 4 decades

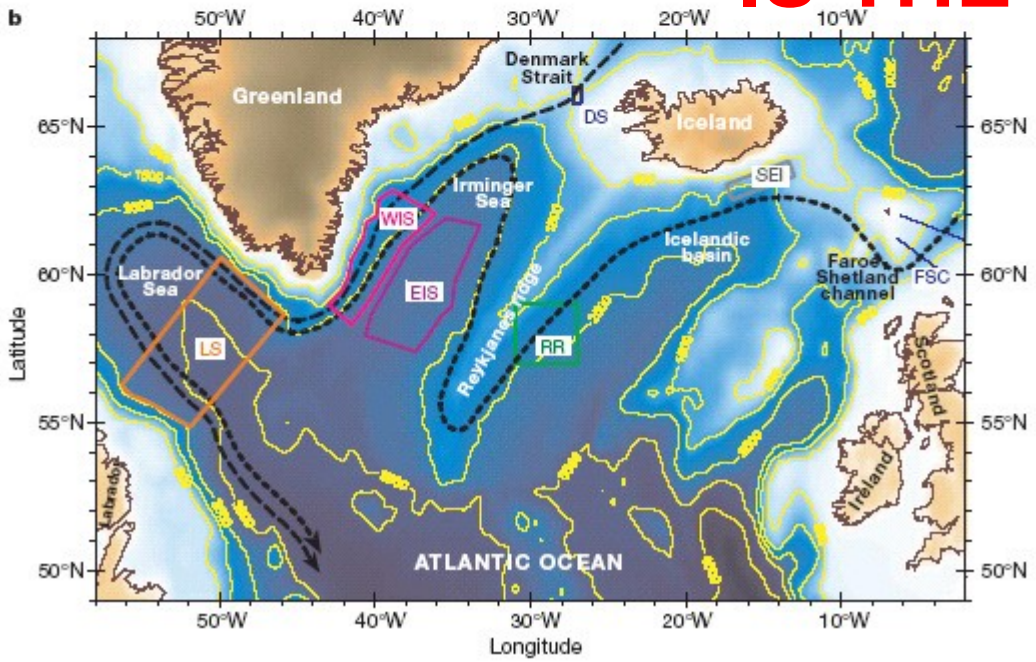




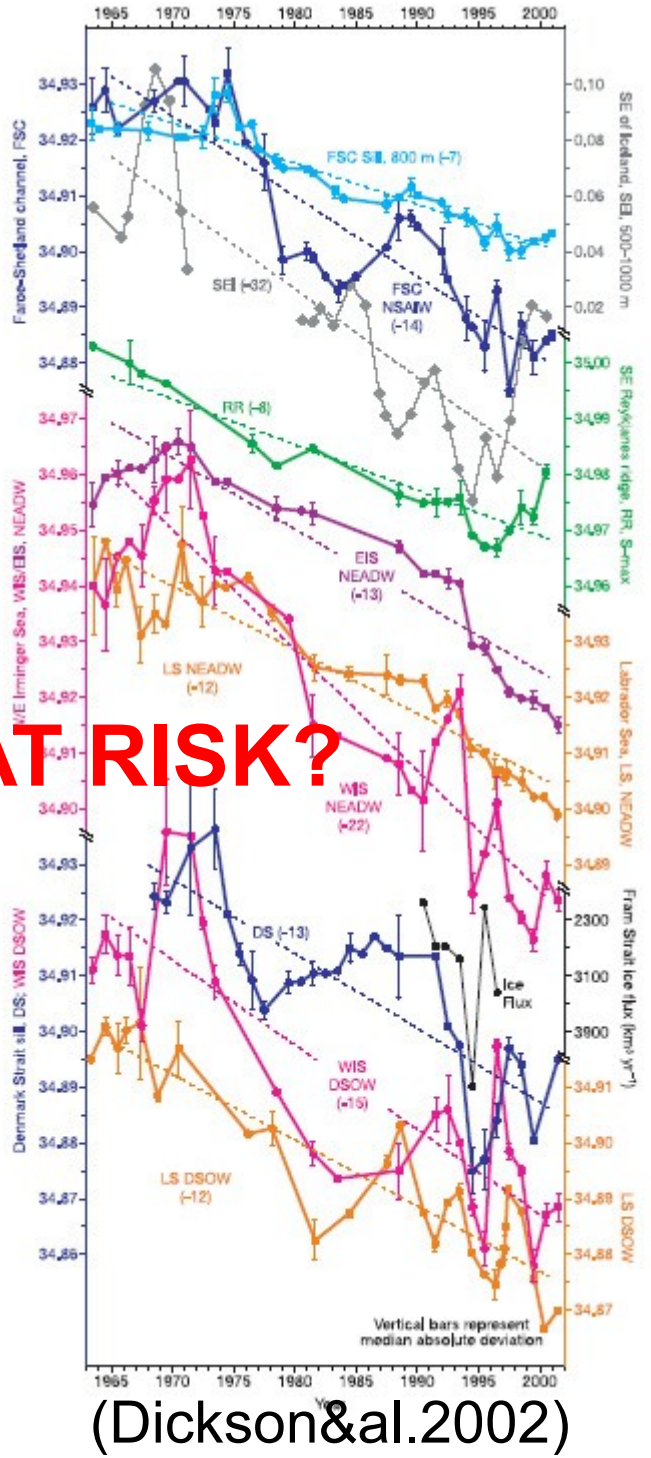
(Dickson&al.2002)

Rapid freshening of the deep North Atlantic Ocean over the past 4 decades





IS THE MOC AT RISK?



(Dickson&al.2002)

The Atlantic Multidecadal Oscillation - AMO

3rd EOF of global SST and Night Marine Air Temperature (Parker&al.2007)

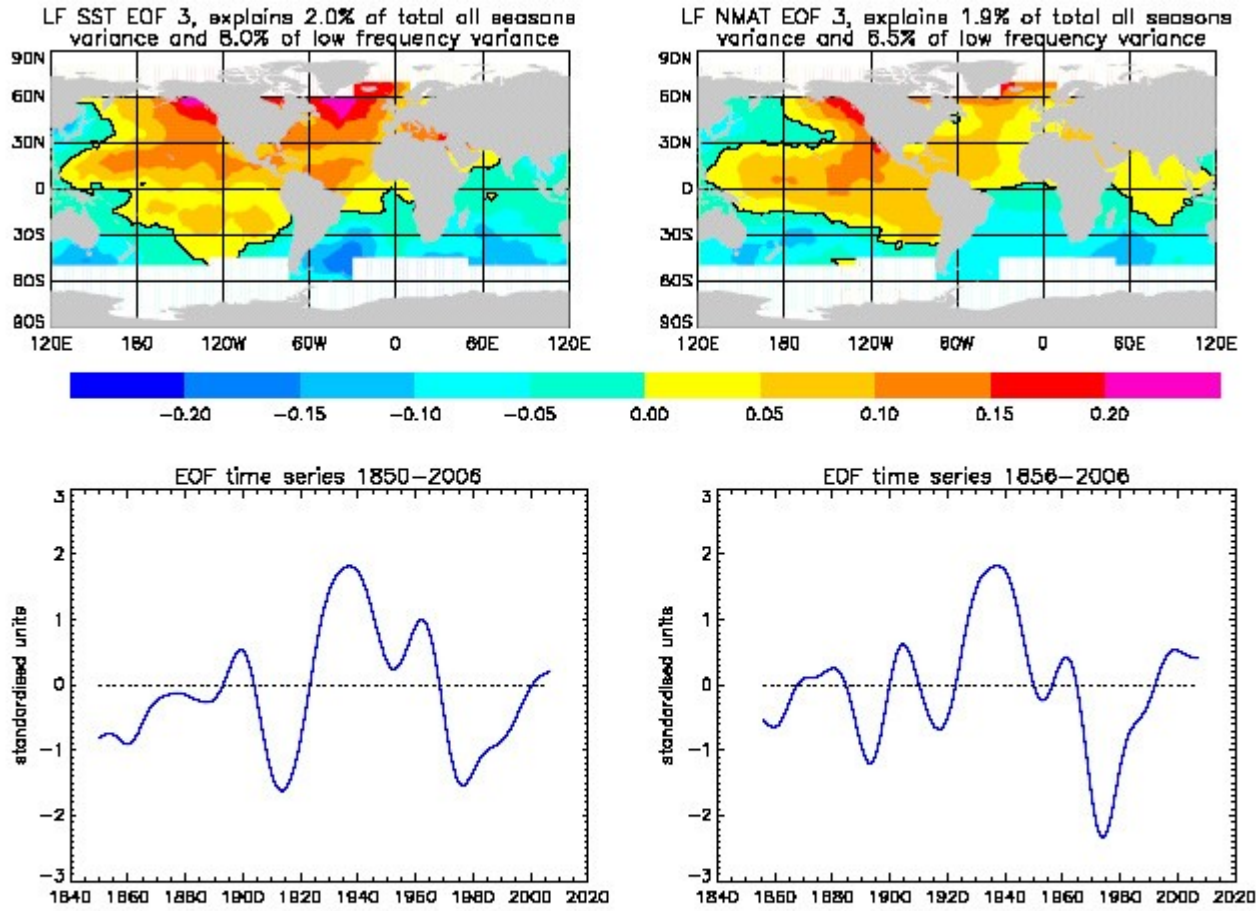
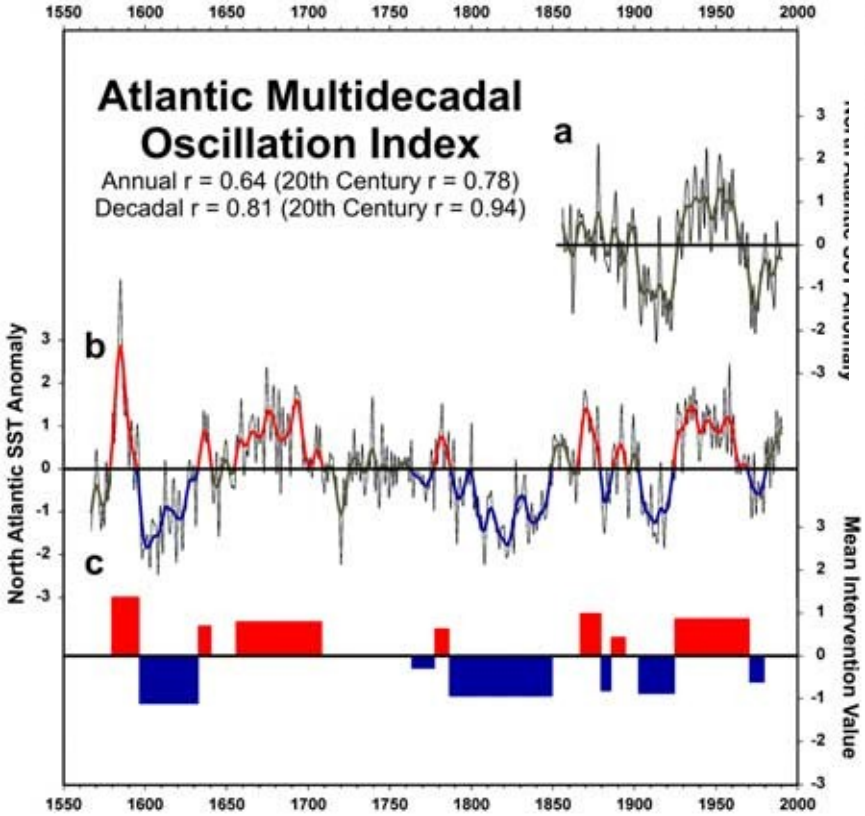


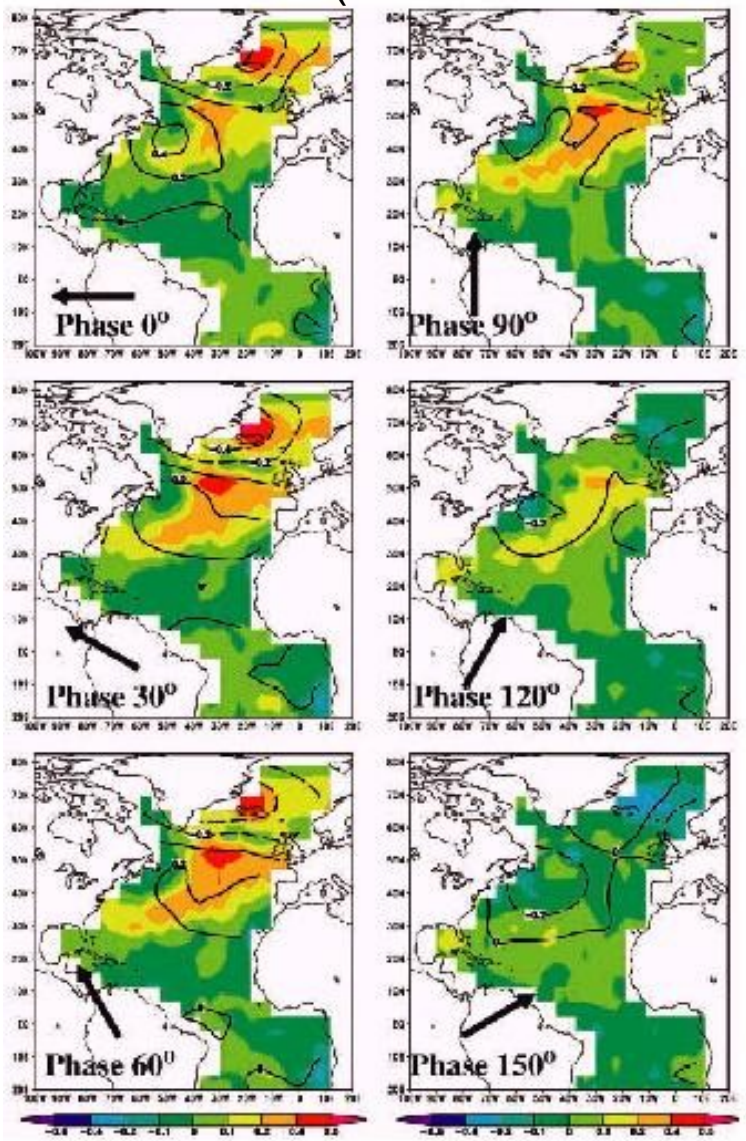
Figure 6. Spatial patterns and temporal behavior of temperature at the ocean surface associated with the Atlantic Multidecadal Oscillation. (top) Third covariance EOFs of low-pass-filtered (see text) (left) SST and (right) NMAT for 1891–2005 and the variance explained for that period. (bottom) Temporal variations of the projections of these patterns onto global fields of low-pass-filtered SST for 1850–2006 and NMAT for 1856–2006. The horizontal line is the mean of the time series for 1891–2005.



extended time series using tree-ring proxy (Gray&al.2004)

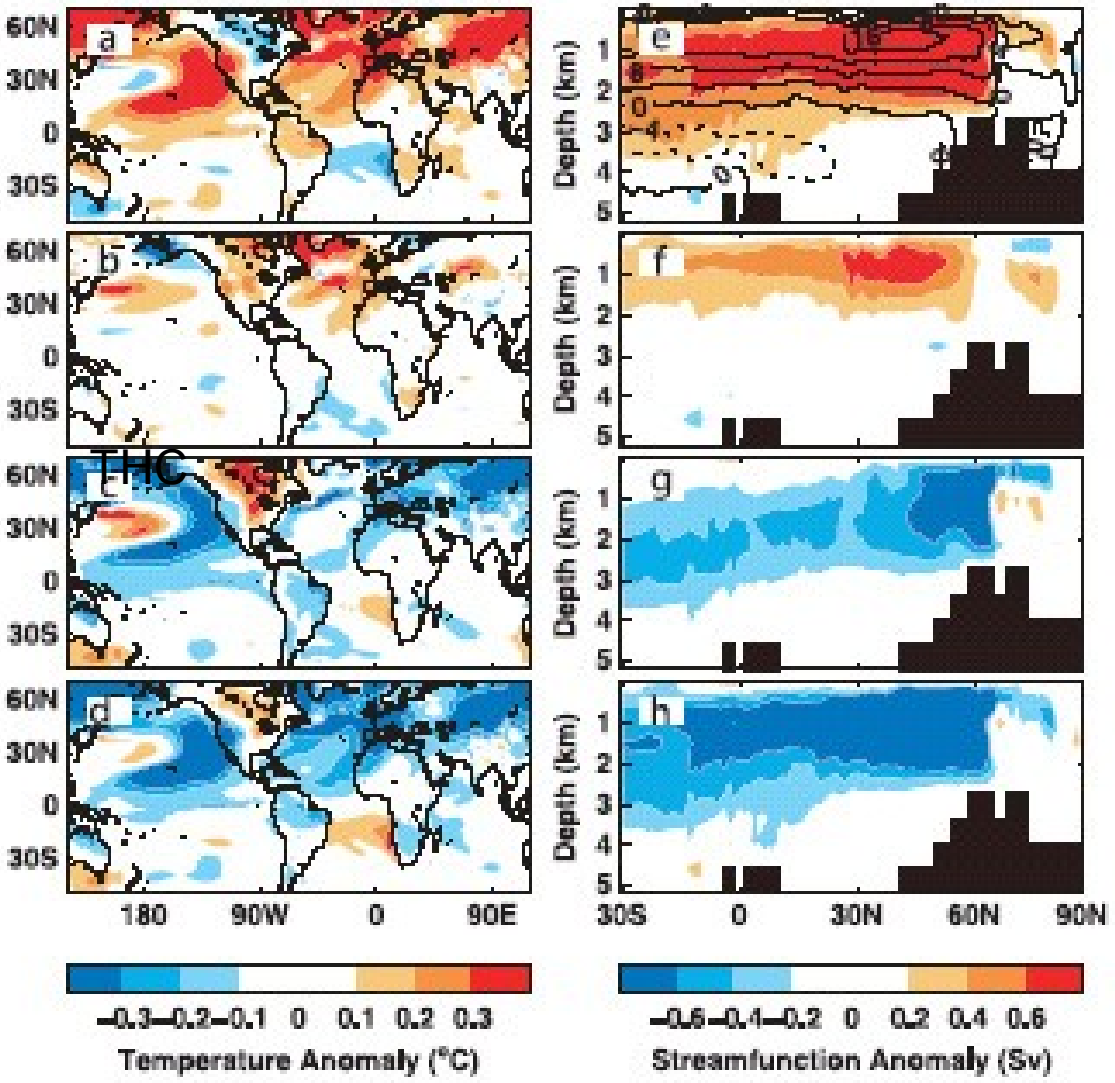
THC changes associated with the AMO?
in phase in coupled models

SST ANOMALY (ARROW FOR MOC)



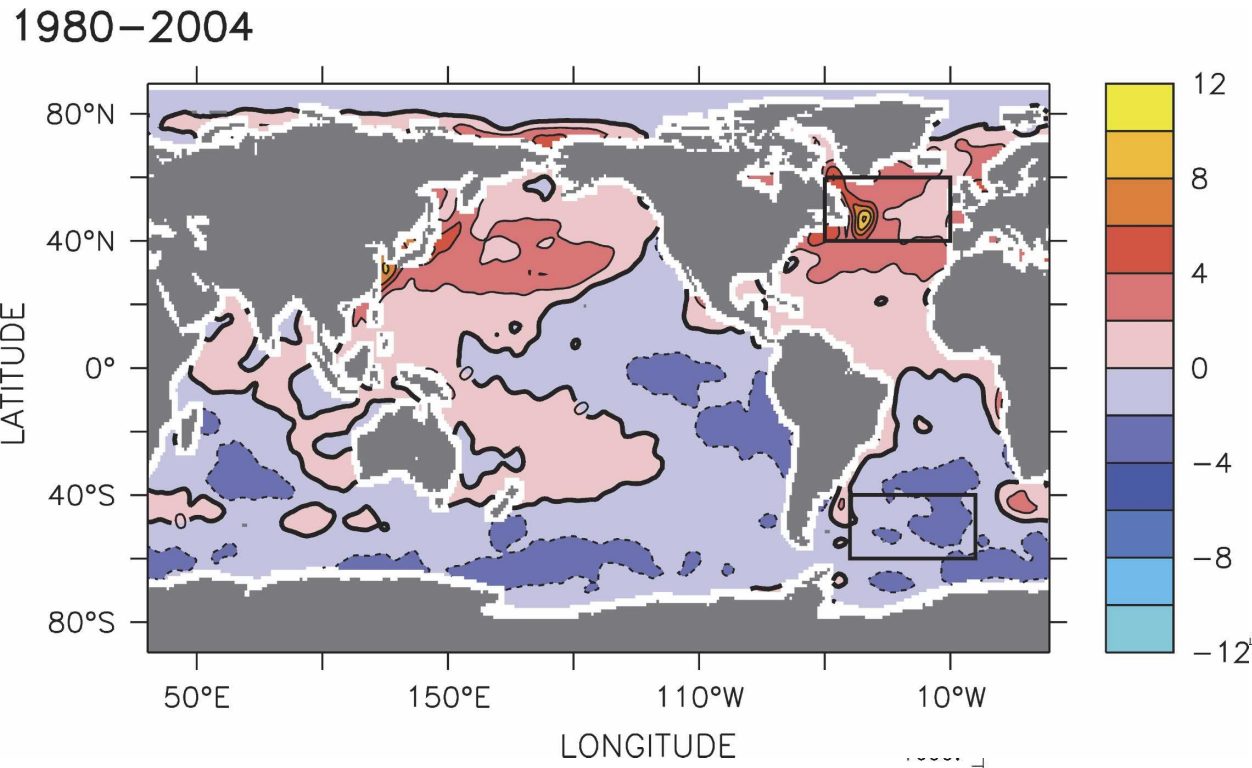
GFDL coupled model with internal ocillations ~50yr period (Delworth&Mann2000)

SST ANOMALY MOC ANOMALY

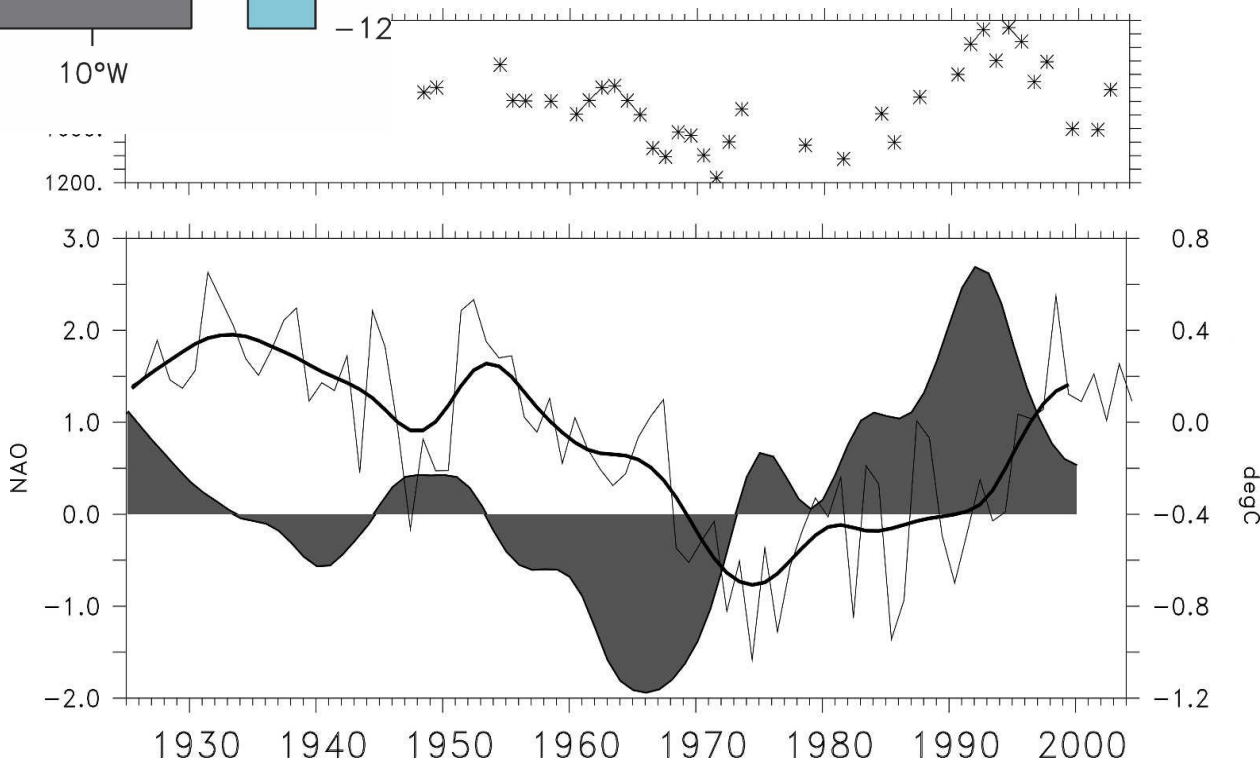


Hadley center coupled climate model control simulation with internal variability ~100yr period (Knight&al.2005)

on the other hand...



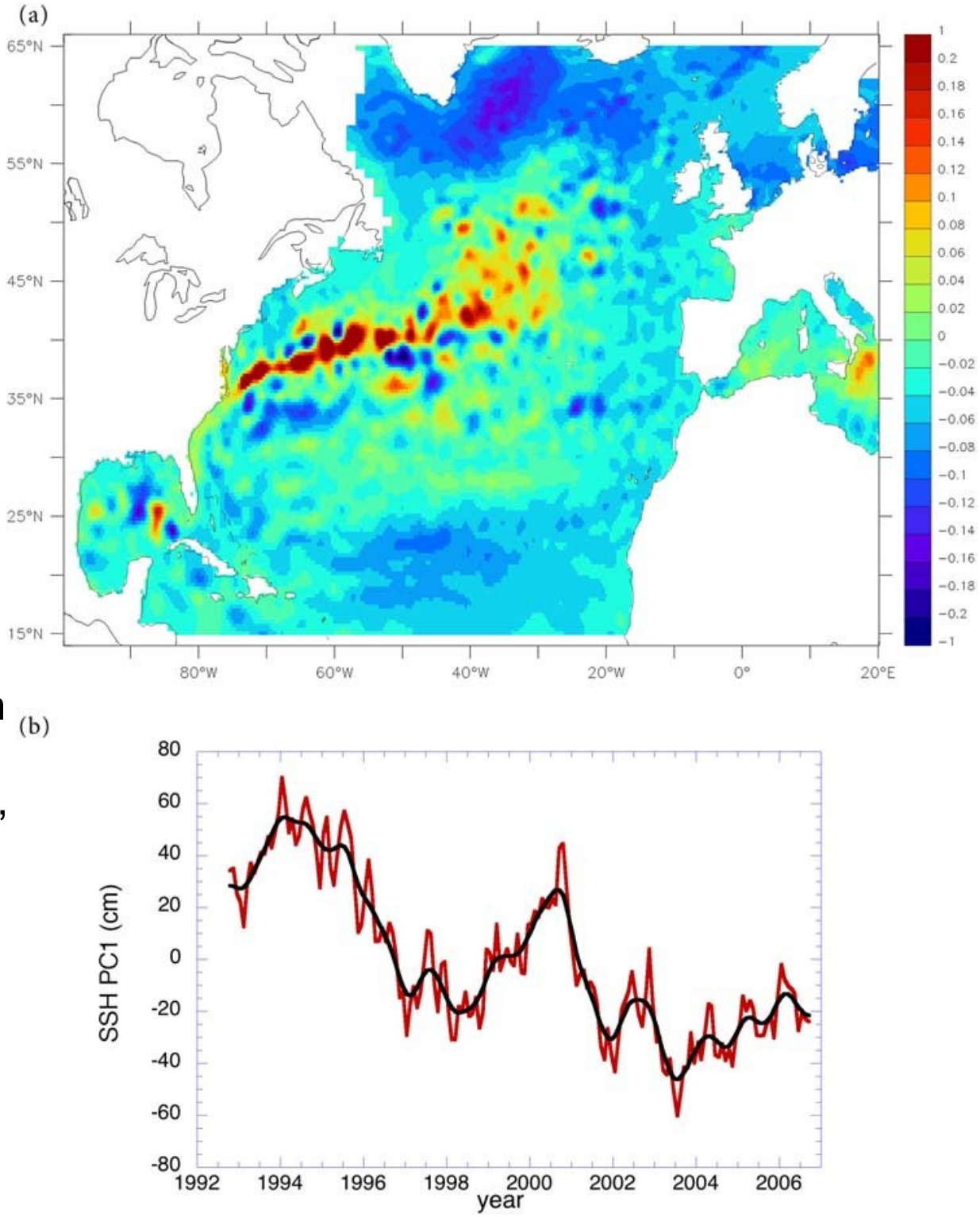
using the difference of temperature between the North and South Atlantic as a proxy for the MOC



Latif&al.2006 predict a weakening of the MOC following the low NAO values of the 2000's...
(i.e. a period with positive AMO!)

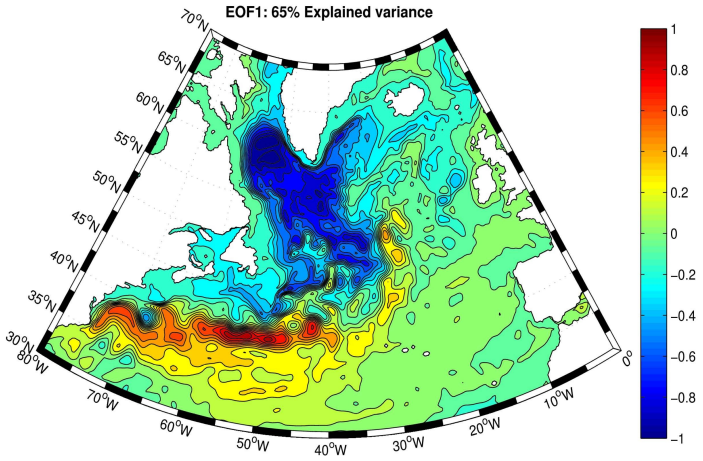
Decline of the subpolar gyre circulation since 1994

Spatial pattern of the first empirical orthogonal function and associated time series for the sea surface heigh from AVISO altimeter data.
The spatial pattern is dimensionless, the time series have units of centimeters
(after Häkkinen and Rhines 2009)

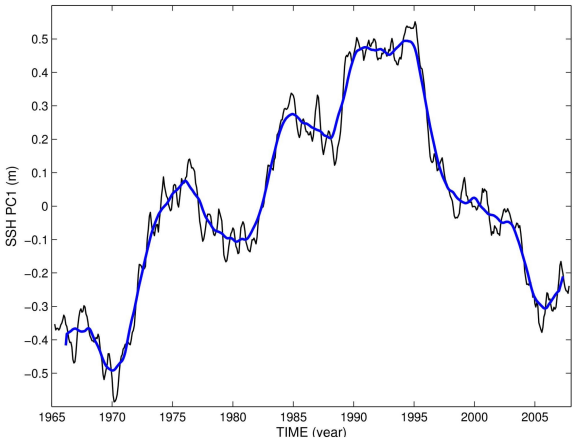


Relation between horizontal and vertical circulation

SSH

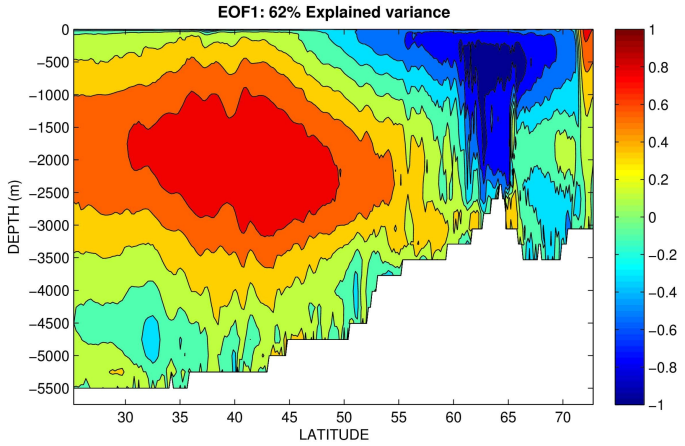


(A)

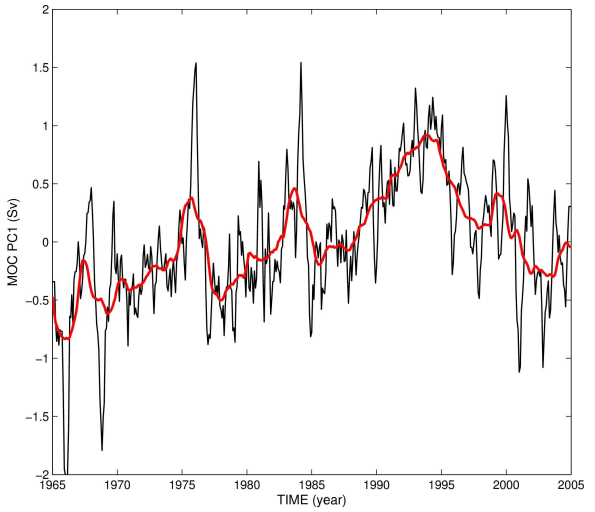


(B)

MOC



(C)

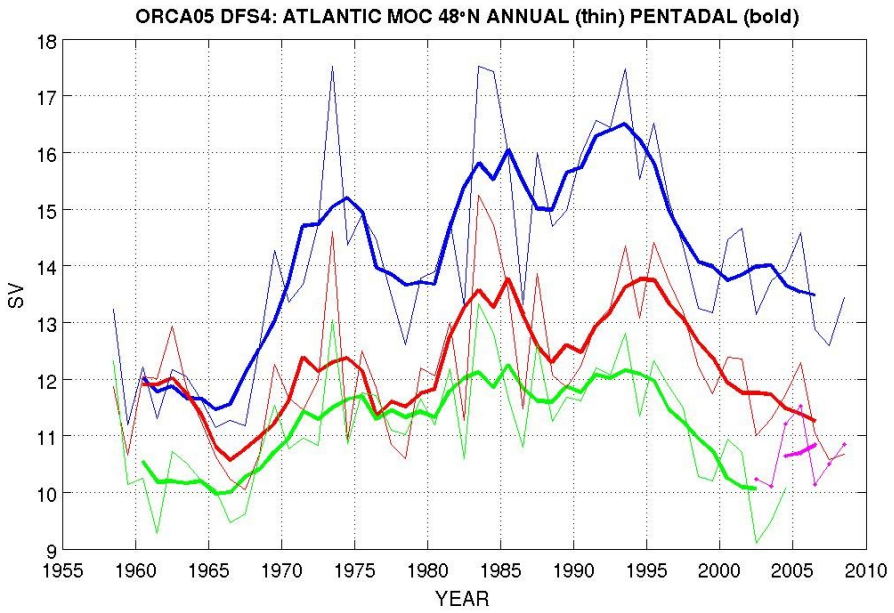


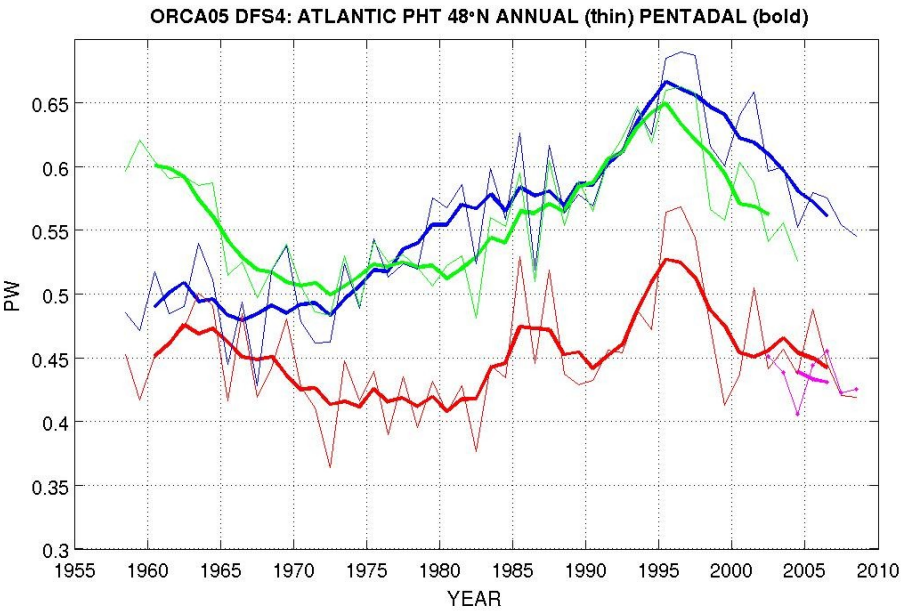
(D)

First EOF of (A) sea surface height and (C) meridional overturning cell in the north Atlantic calculated from the ORCA025-G70 simulation (time periods extending from 1965 to 2008 and from 1965 to 2005 respectively). EOFs are non-dimensional. Figures (B) and (D) show the associated principal components (units are meters and Sverdrups respectively).

Drakkar ORCA025-G70 global ¼° ocean model forced by atmospheric reanalysis 1958-2008
(courtesy of Damien Desbruyères, LPO)

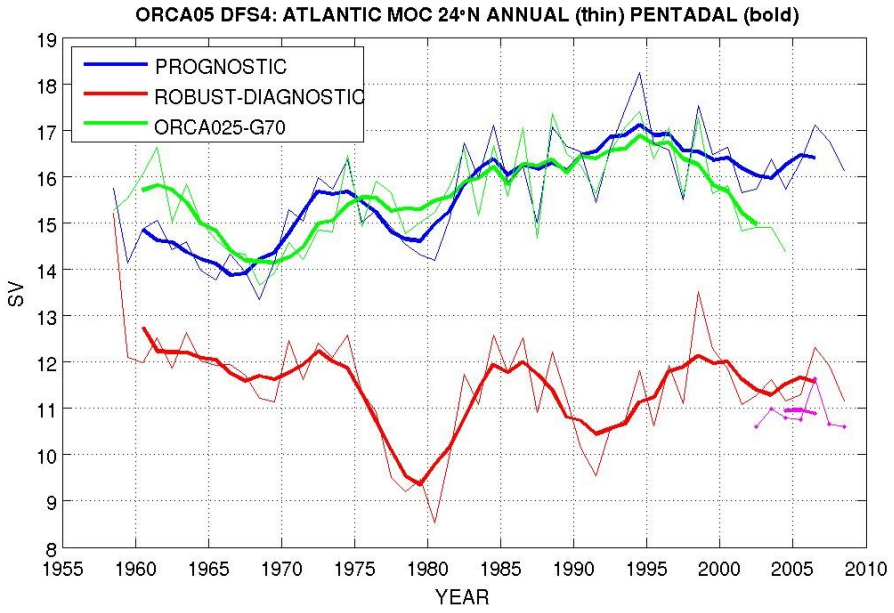
Models constrained by observations "robust diagnostic"

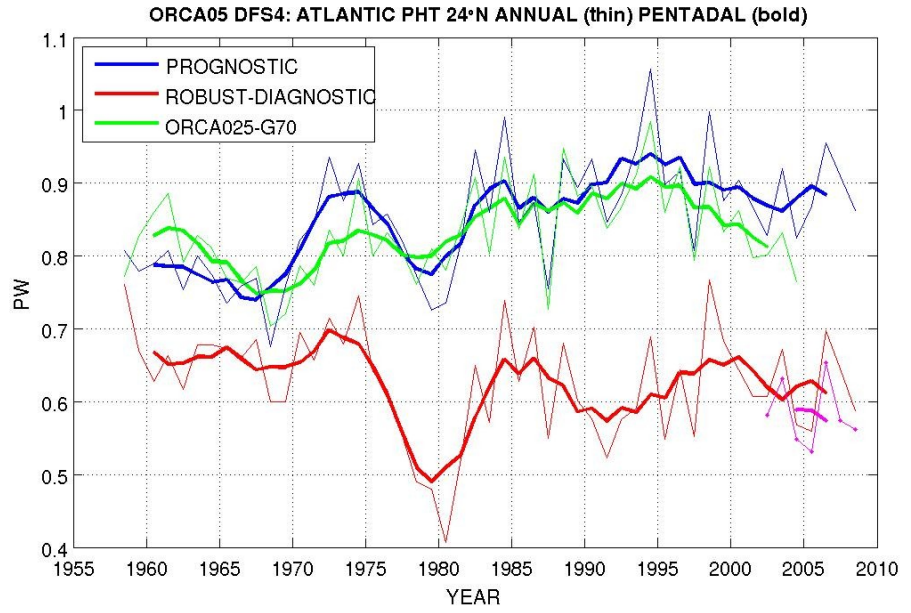




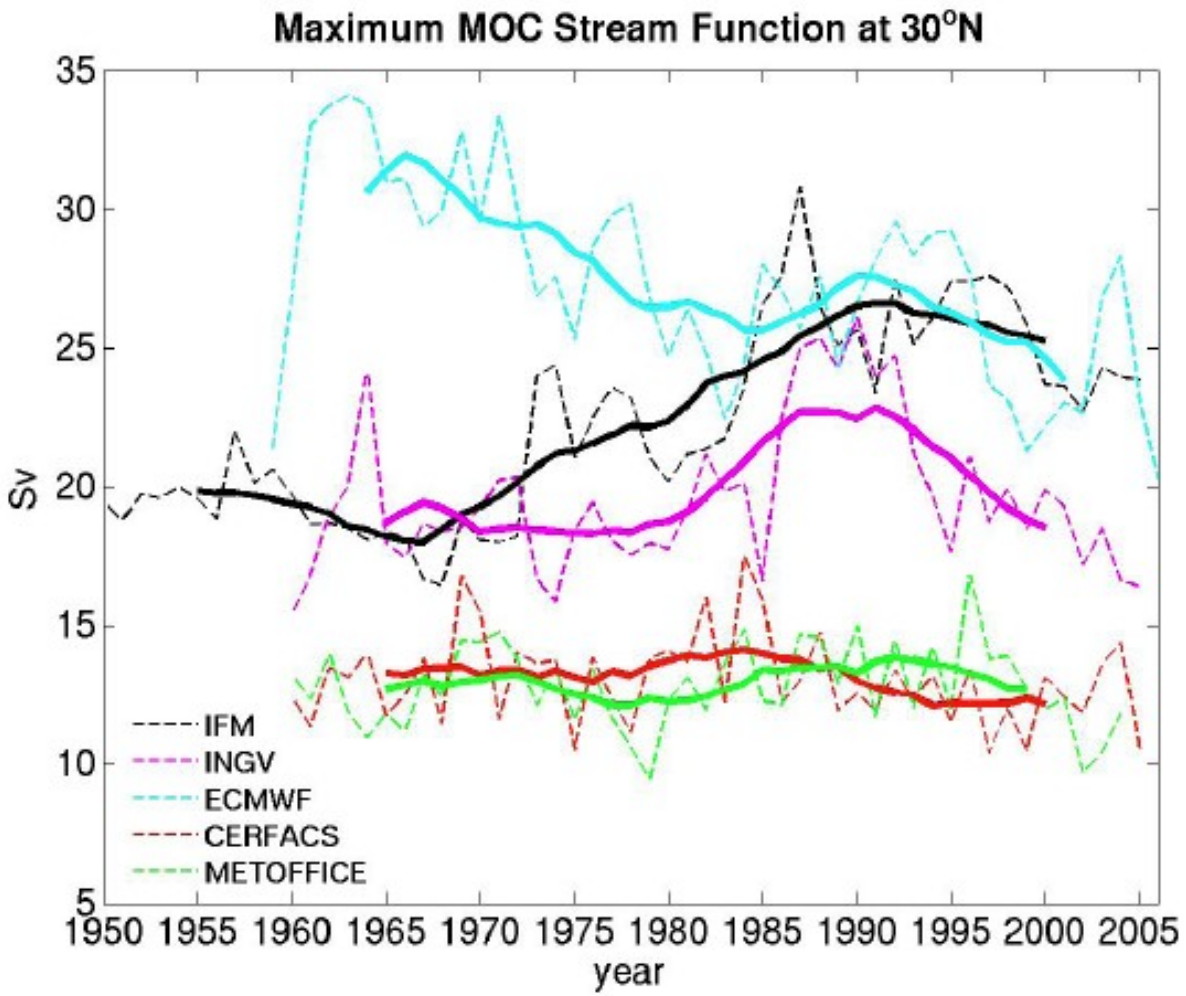
MOC

PHT





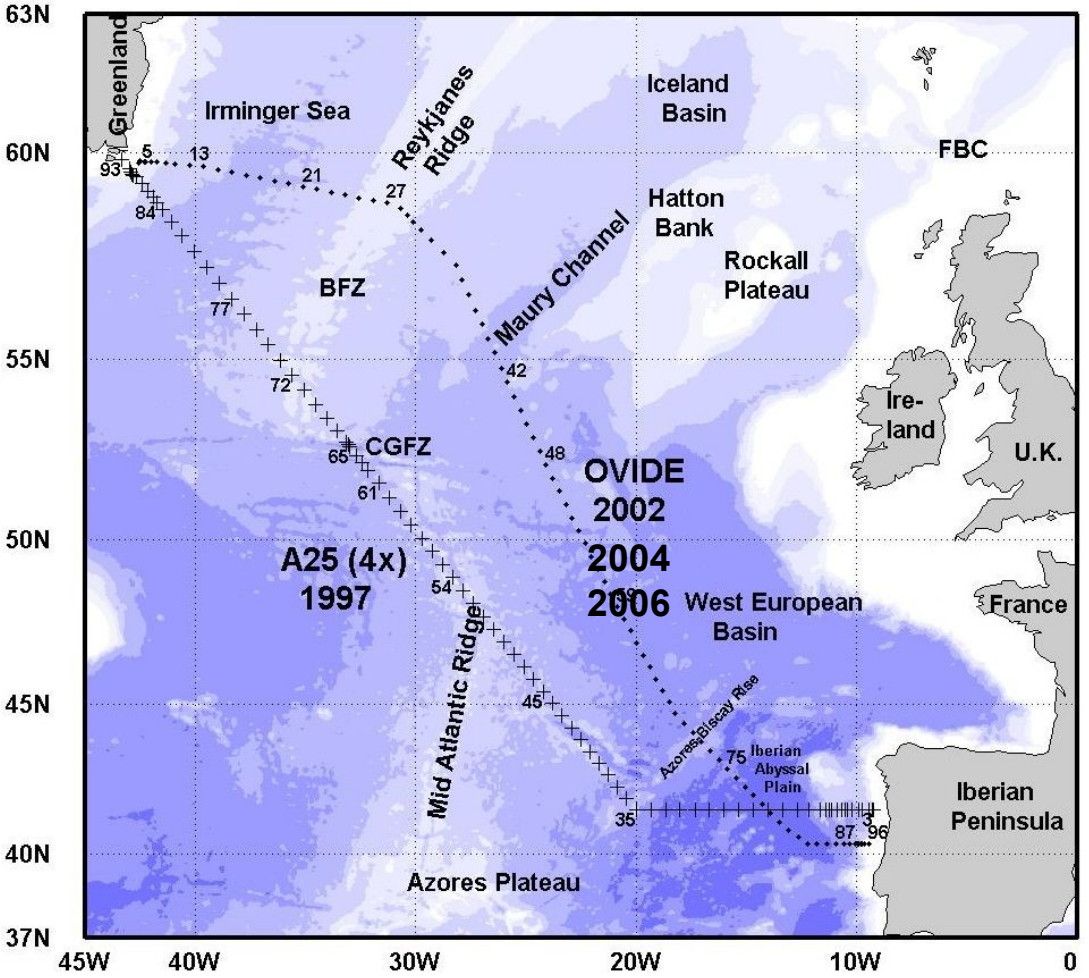
MOC since 1950 in different analyses



There still is a large uncertainty…
but most analyses show
a declining trend since 1994?

(courtesy of Jin Ba, IFM-GEOMAR)

Repeated hydrographic sections: A25 Ovide



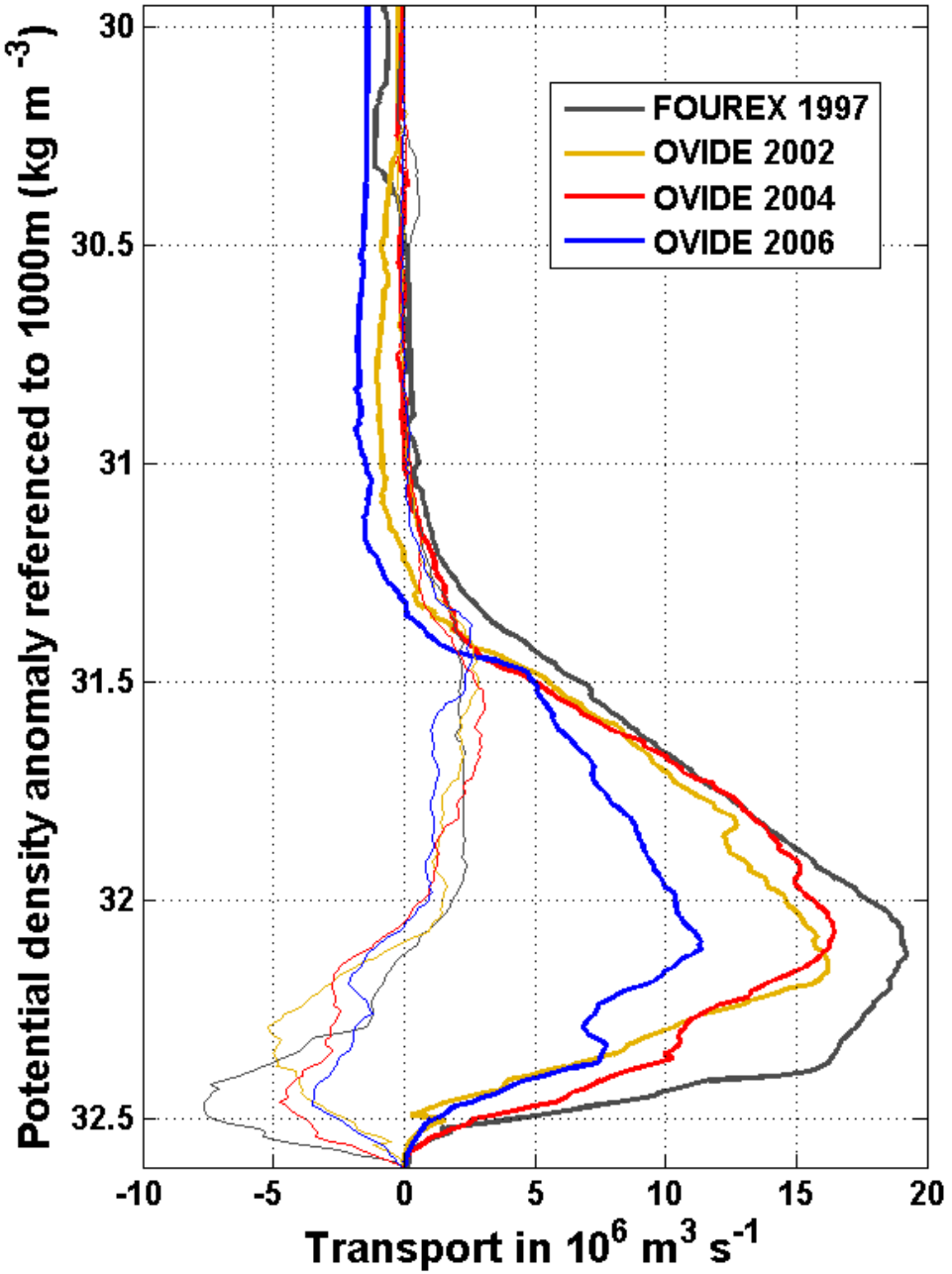
	MOCσ	HF	NAC*
4x97	18.5	0.69	20.1
ov02	16.2	0.44	17.1
ov04	16.4	0.50	16.4
ov06	11.2	0.29	11.4

MOC in Sv; error ~ 2 Sv
HF in PW; error ~ 0.05 PW
*East of the SAF, above σ_1=32.1

The absolute transports perpendicular to the sections are estimated *for the month of the cruise* using a geostrophic inverse model that combines hydrography and ship-mounted ADCP measurements under an overall mass balance constraint (Lherminier&al.2007)

(courtesy of H. Mercier OS2010)

MOC_σ and heat transport variability



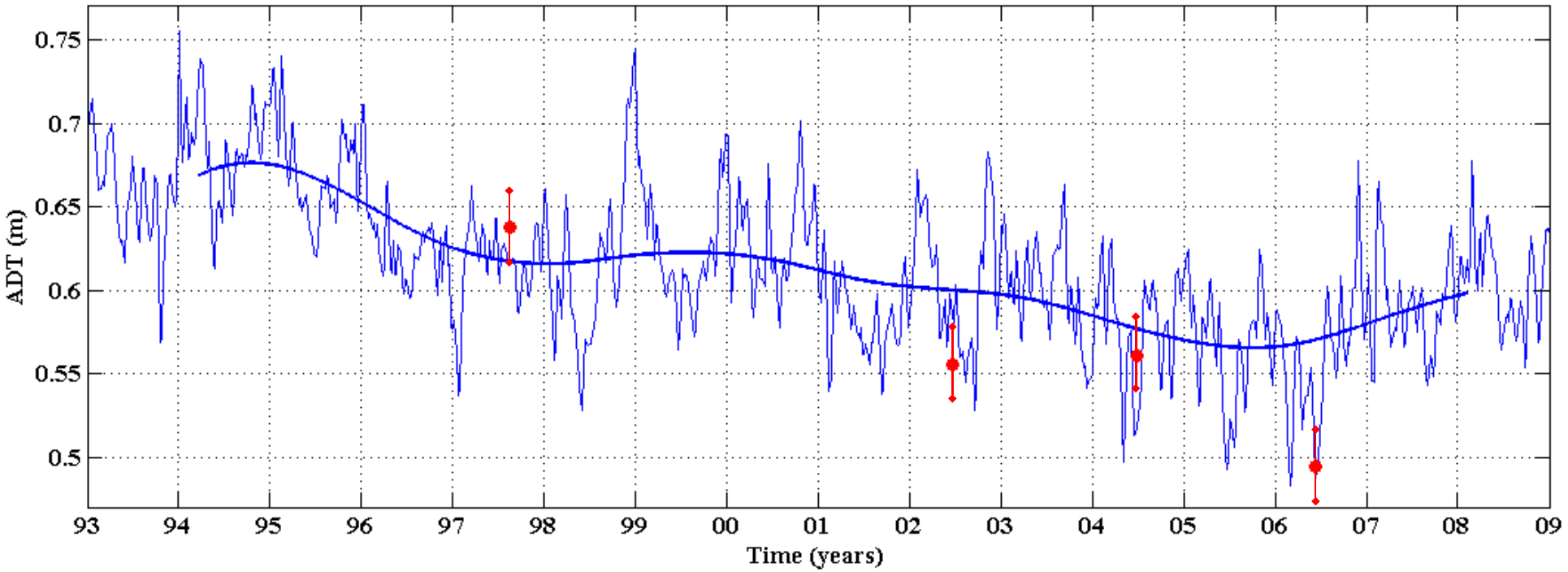
	MOCσ	HF_{iso}	HF_{MOC}
4x97	18.5	0.05	0.60
ov02	16.2	0.03	0.41
ov04	16.4	0.08	0.42
ov06	11.2	-0.07	0.33

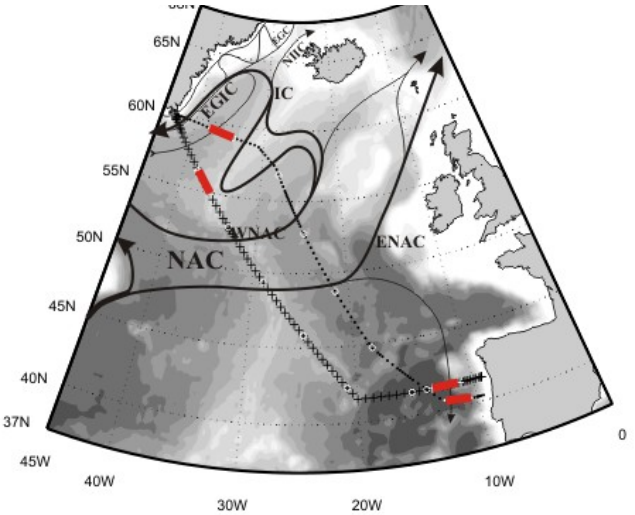
MOC in Sv; error ~ 2 Sv

HF in PW; error ~ 0.05 PW

(courtesy of H. Mercier OS2010)

An index of the surface “warm water” transport across A25-Ovide from altimetry





- A25-Ovide

(courtesy of H. Mercier OS2010)