The coherence of Atlantic meridional heat transport in climate models

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Outline

- Background
- Objectives
- Data and models
- Results
- Conclusion
- Future work

Background: MHT in the Atlantic

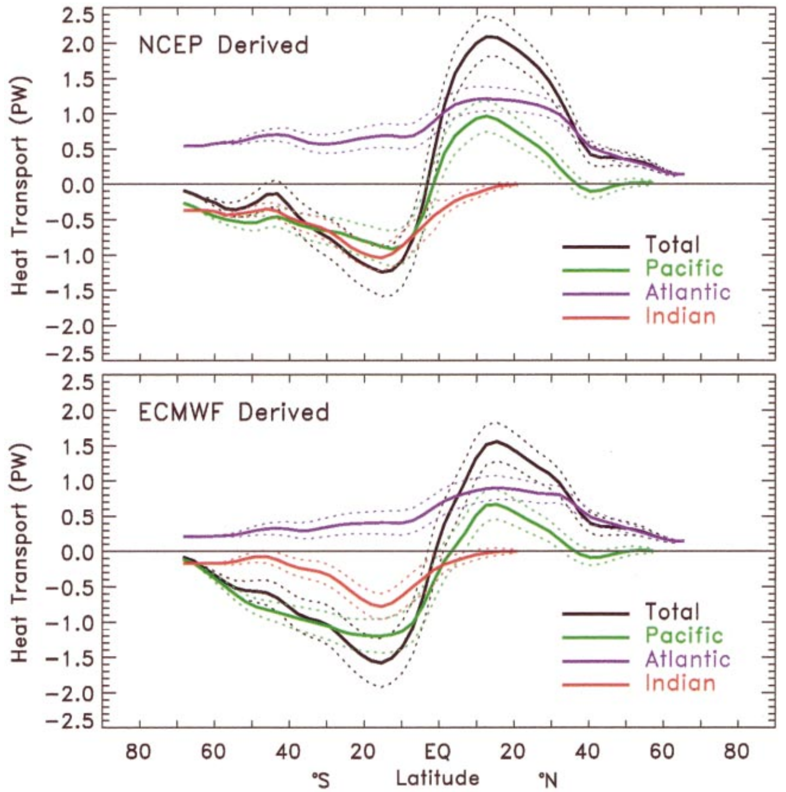


FIG. 5. Implied zonal annual mean ocean heat transports based upon the surface fluxes for Feb 1985–Apr 1989 for the total, Atlantic, Indian, and Pacific basins for NCEP and ECMWF atmospheric fields (PW). The 1 std err bars are indicated by the dashed curves.

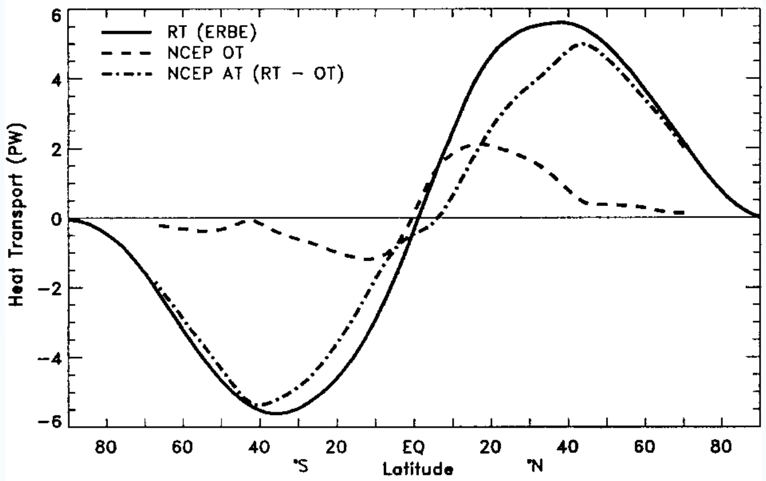


FIG. 7. The required total heat transport from the TOA radiation RT is compared with the derived estimate of the adjusted ocean heat transport OT (dashed) and implied atmospheric transport AT from NCEP reanalyses (PW).

From *Trenberth and Caron* (2001)

IMPORTANT !

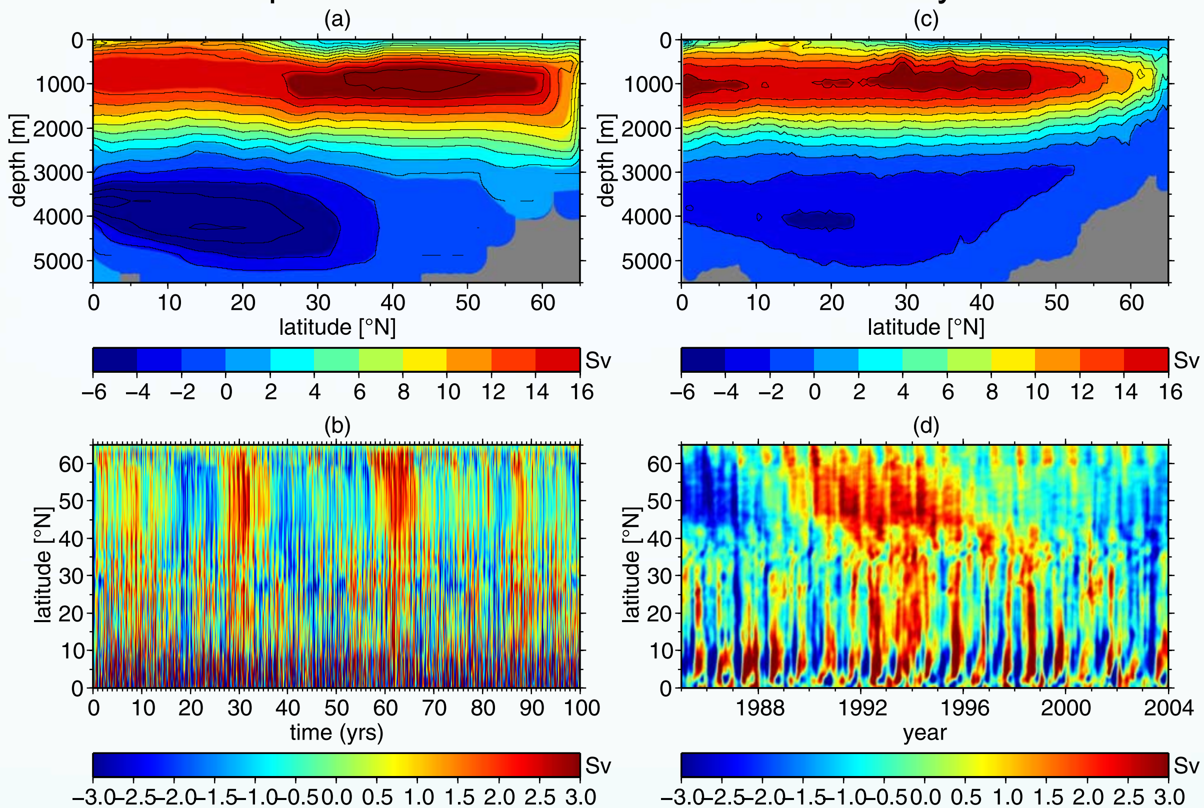
- Ocean releases heat to atmosphere in mid-latitude
- Northward meridional heat transport (MHT) in the Atlantic Ocean
- Relative small changes in MHT in the oceans could have significant climatic impacts (Rind and Chandler 1991; Cohen-Solal and Le Treut 1997).

Background: coherence of AMOC anomaly

coupled model

ocean-only model

100 years



19 years

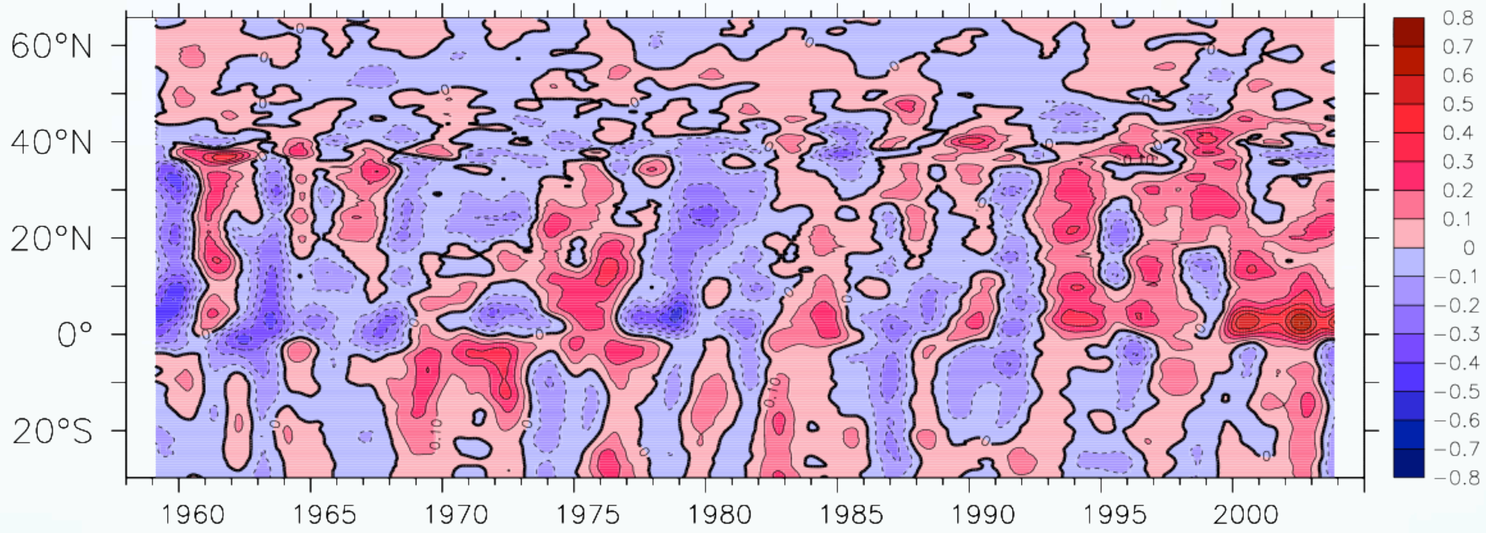
Figure 1. (a) The (a) HadCM3 and (c) OCCAM time-averaged overturning stream function. The (b) HadCM3 and (d) OCCAM northward transport anomaly between 100 m and 1000 m depth.

From *Bingham et al*. (2007)

- Anomalies in AMOC are different south and north of 40°N
- Strong decadal signals to the north and higher frequency signals to the south (Zhang 2010; Zheng and Giese 2009)

Background: coherence of Atlantic MHT anomaly

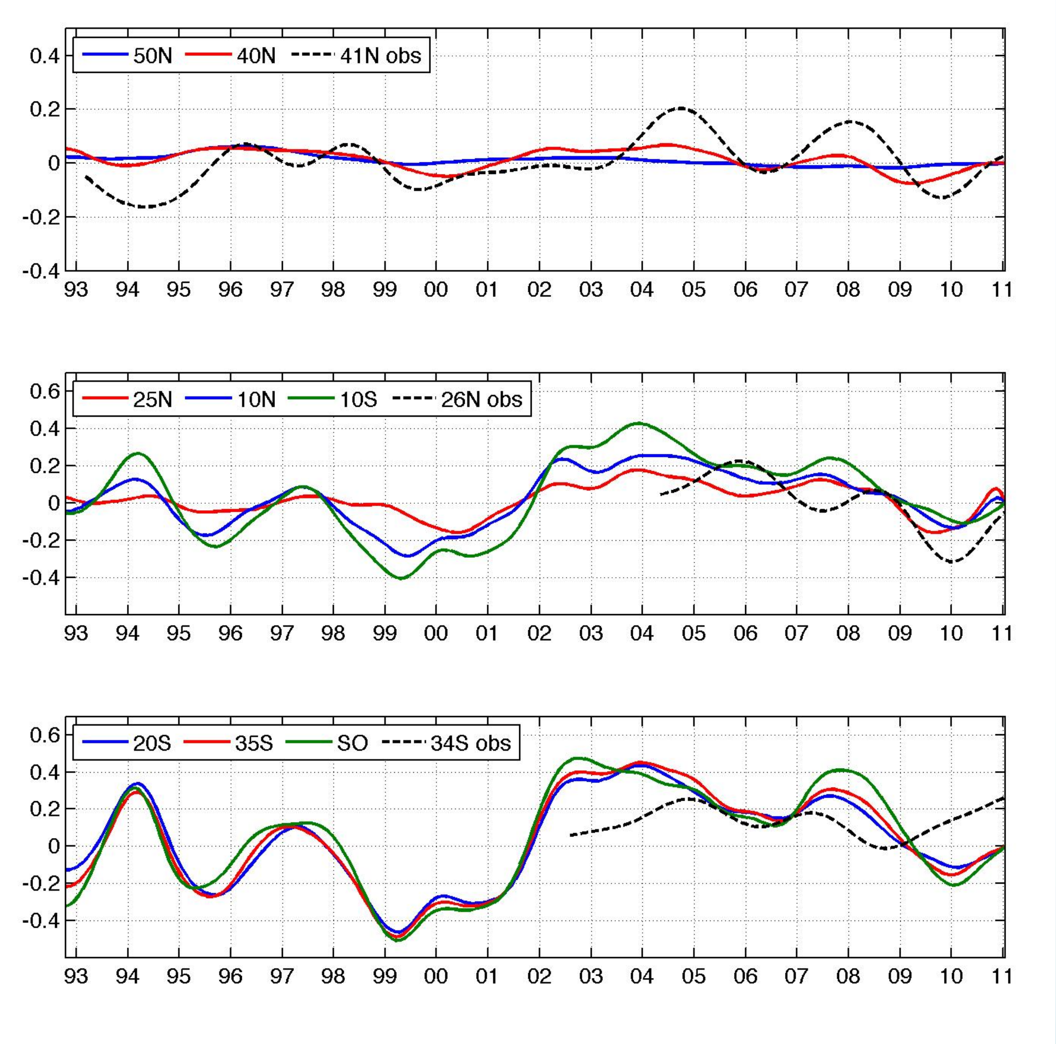
Latitude-time evolution of MHT anomalies
in Atlantic Ocean during 1958 – 2004
(from Simple Ocean Data Assimilation (SODA))



From *Zheng and Giese* (2009)

- At low latitudes, interannual variability dominates
- At middle and high latitudes, decadal and multidecadal variability is more pronounced.

Background: coherence of Atlantic MHT anomaly



From *Kelly et al.* (submitted to *J.Climate*)

$$\frac{\partial \eta_H}{\partial t} = \frac{\alpha Q_{net}}{\rho c_p} + HTC$$

Heat transport convergence

Heat flux term

Rate of change in SSH associated with changes in heat content

- MHT anomalies are coherent from the SO to south of 40° N

Objectives

I Characteristics of MHT anomalies

- What are the spatial structures of the EOF modes of MHT?
- What is the importance of the EOF modes at different latitudes?
- Is there an obvious meridional propagation of MHT?

II Speculations on mechanisms of MHT anomalies

Direct estimates of MHT:

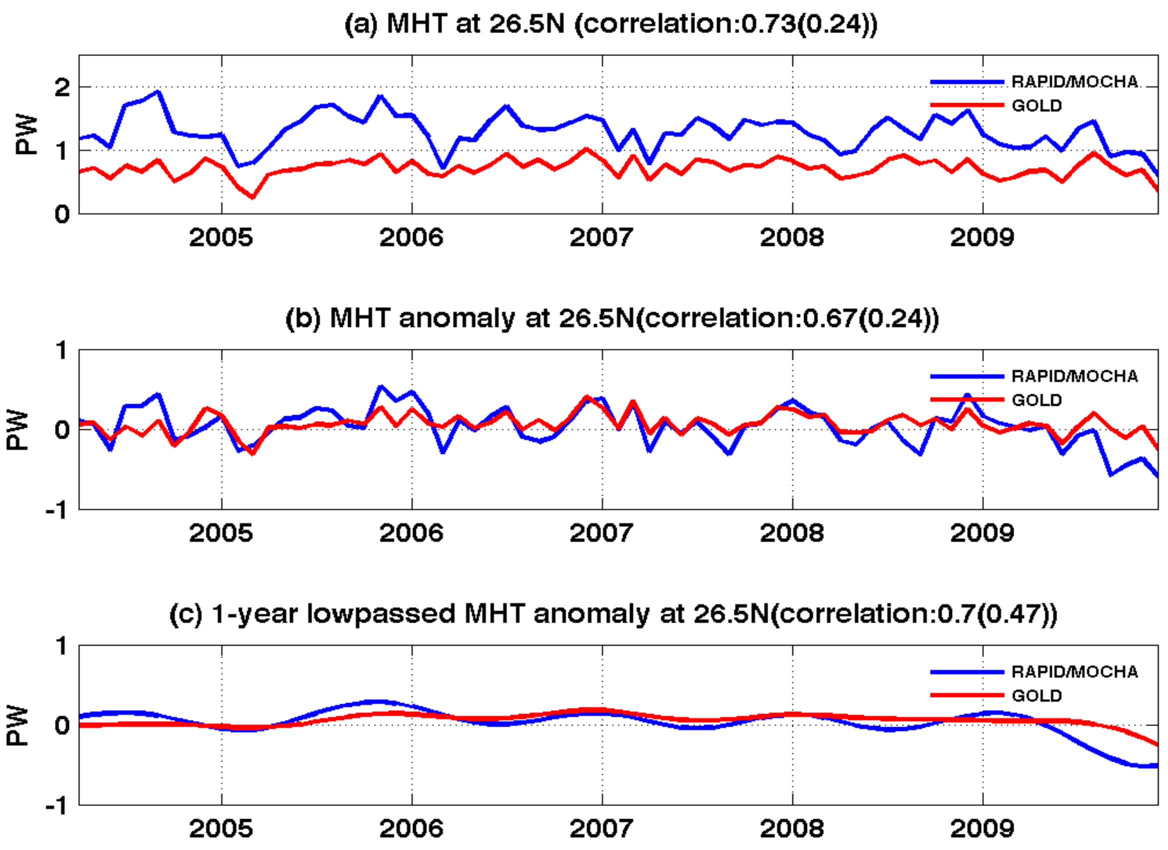
$$H = \iint \rho \, c_p \theta v dA$$

ρ - density
Cp - specific heat of seawater
θ - potential temperature
v - meridional velocity
$dA=dxdz$ represents integration over a vertical east-west section

Model: Generalized Ocean Layer Dynamics (GOLD)

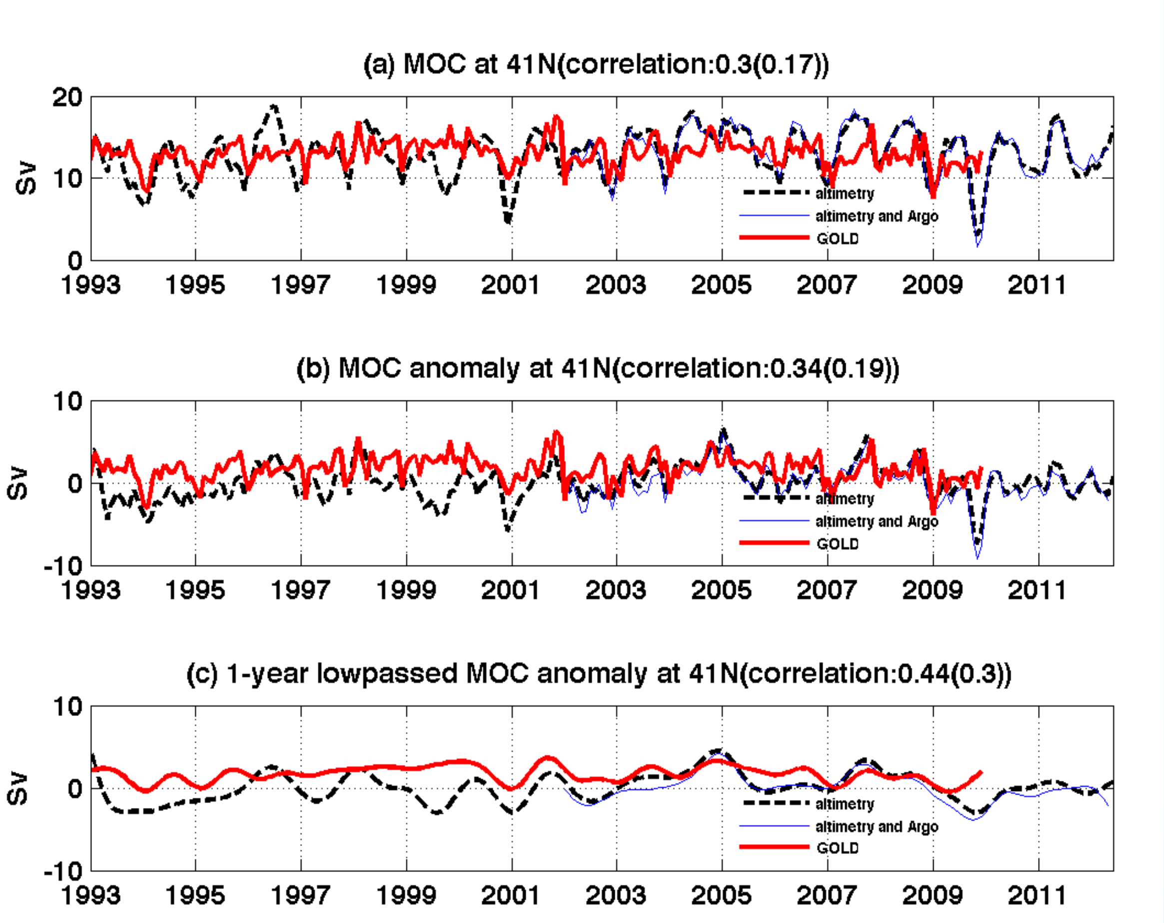
- A global ocean mass conserving isopycnal model
- 2 mixed layers, 2 buffer layers and 59 isopycnal layers with constant potential densities referenced to 2000m – total 63 layers
- 1° × 1° resolution but with 0.5° for the latitudes at tropics
- Density intervals are chosen to provide the highest resolution of thermocline
- Surface winds and buoyancy fluxes for the hindcast run are from CORE-II during 1948-2009 (Large and Yeager 2009)
- One hindcast run from 1948 to 2009

Model Validation for GOLD



- Compared with the MHT from RAPID-MOCHA mooring array at 26.5°N during 2004-2009 (Johns et al. 2011)

Model Validation for GOLD



- Compared with the MOC derived from SSH and Argo data at 41°N from 1993 to 2009 (Willis 2010) .

GOLD is valid and useful!

Models: Coupled Model Intercomparison Project Phase 5 (CMIP5)

MRI-CGCM3

- Meteorological Research Institute - Coupled Global Climate Model 3
- MRI-AGCM3 - atmospheric model
  - ~120km with 48 layers
- MRI.COM3 - ocean-ice model
  - 1° × 0.5° with 50 vertical levels plus a bottom boundary

GFDL-ESM2M

- Geophysical Fluid Dynamics Laboratory - Earth System Models 2.1 with Modular Ocean Model version 4.1
- AM2 - atmospheric model
  - 2° latitude × 2° longitude with 24 vertical levels
- MOM4p1 - ocean model
  - 1° × 1° but with up to 1/3° for the latitudes at tropics
  - 50 vertical levels

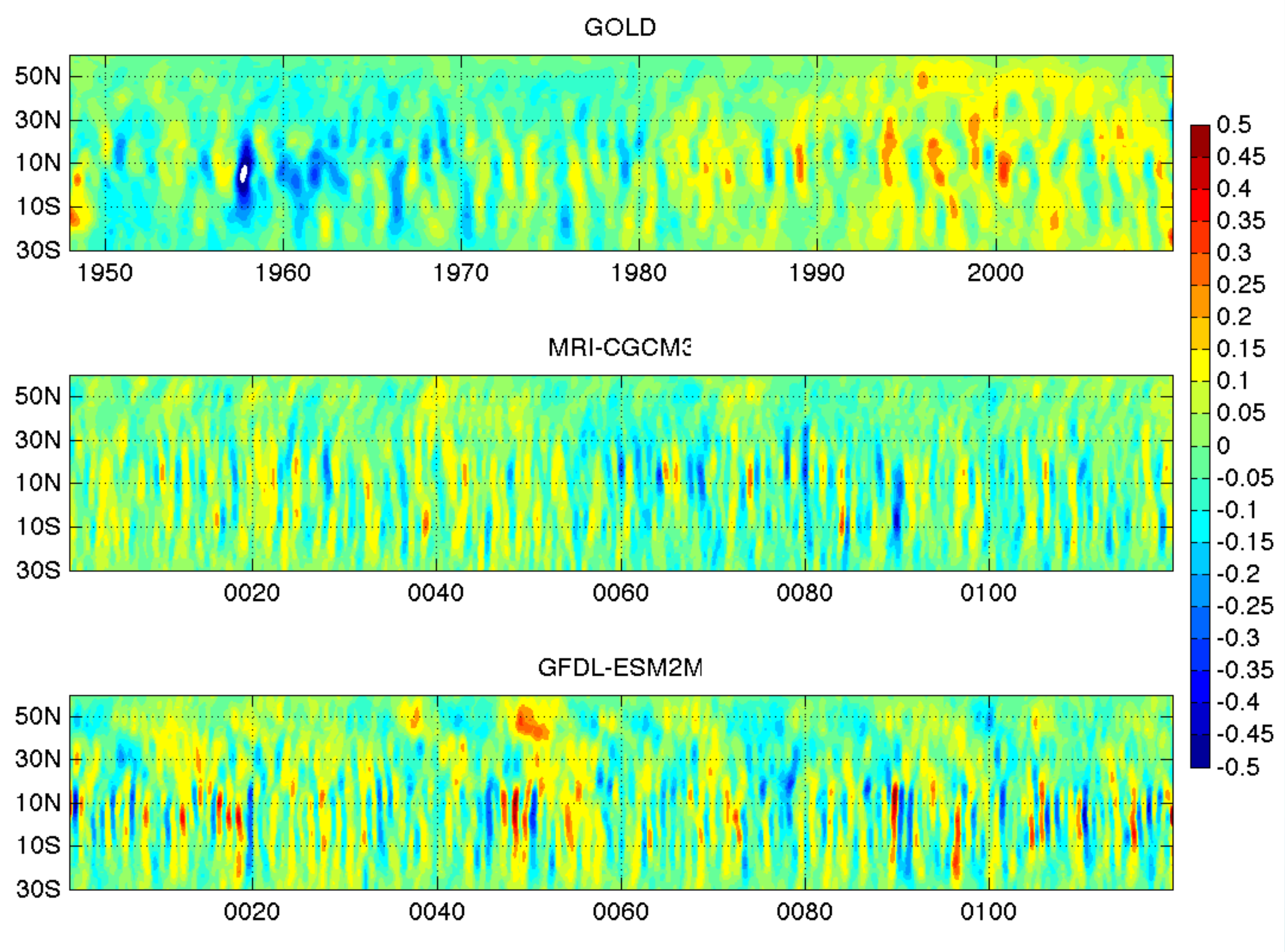
- Ocean monthly northward heat transport in pre-industrial control run

Result: 1yr low-pass MHT anomaly in different models

ocean-only model hindcast run

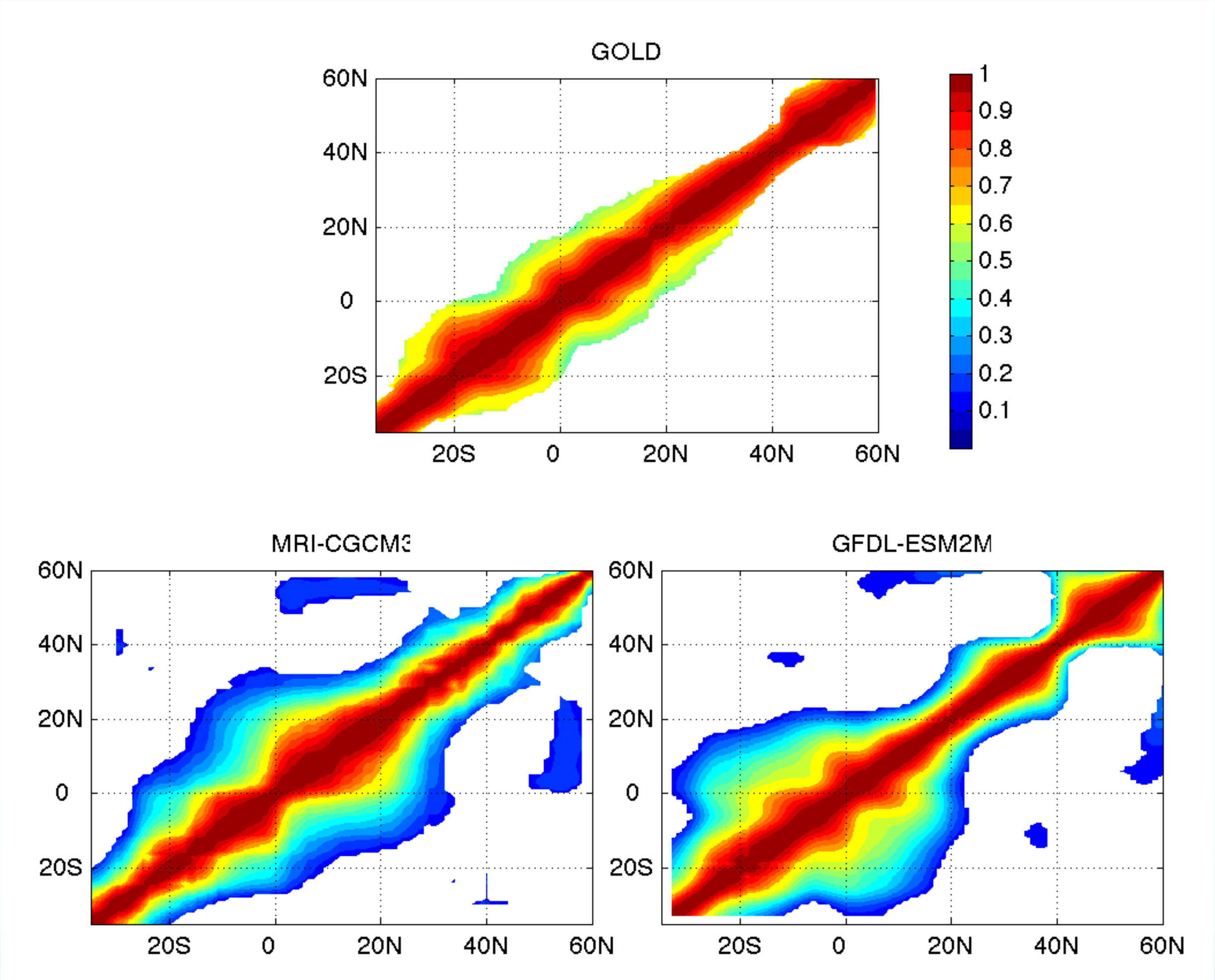
coupled model pre-industrial control run

coupled model pre-industrial control run



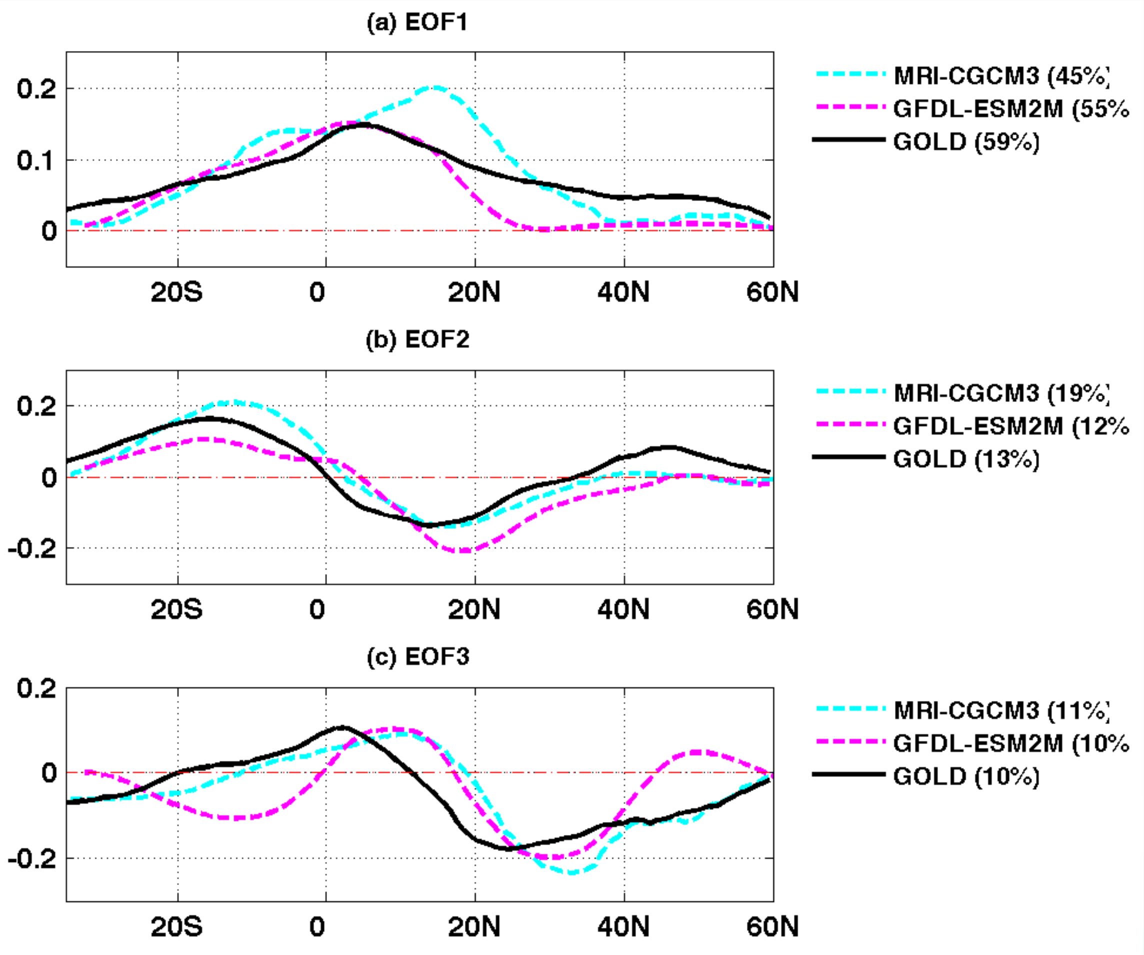
- Interannual variability of MHT anomaly from 30°S to 40°N
- Decadal MHT anomaly in the North Atlantic North of 40°N.

Result: Cross correlation of 1yr low-pass MHT anomaly at latitudes



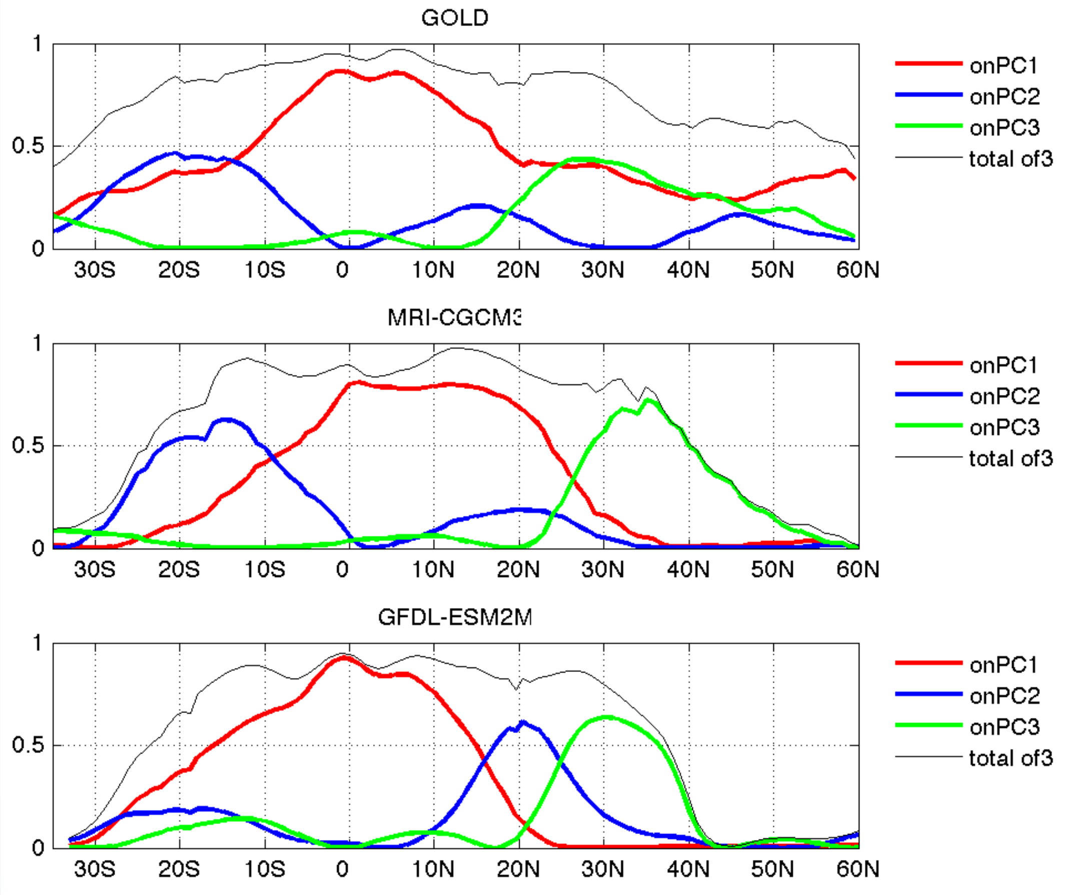
- The regions between 25°S – 40°N have correlated latitudinal width ranging from 25 degrees to 45 degrees
- The narrowing at 40°N is seen in models.

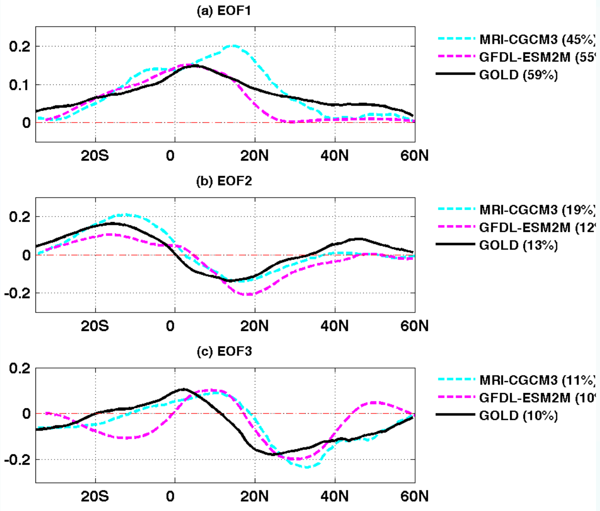
Result: EOFs of the 1yr low-pass MHT anomaly



- Generally consistent between models
- EOF mode 1 - the dominant coherence mode from 35°S to 40°N, with its maximum in the tropics.
- EOF mode 2 - opposite sign in the northern and southern subtropical areas
- EOF mode 3 - opposite sign between tropics and subtropics, but GFDL-ESM2M in southern hemisphere is different.

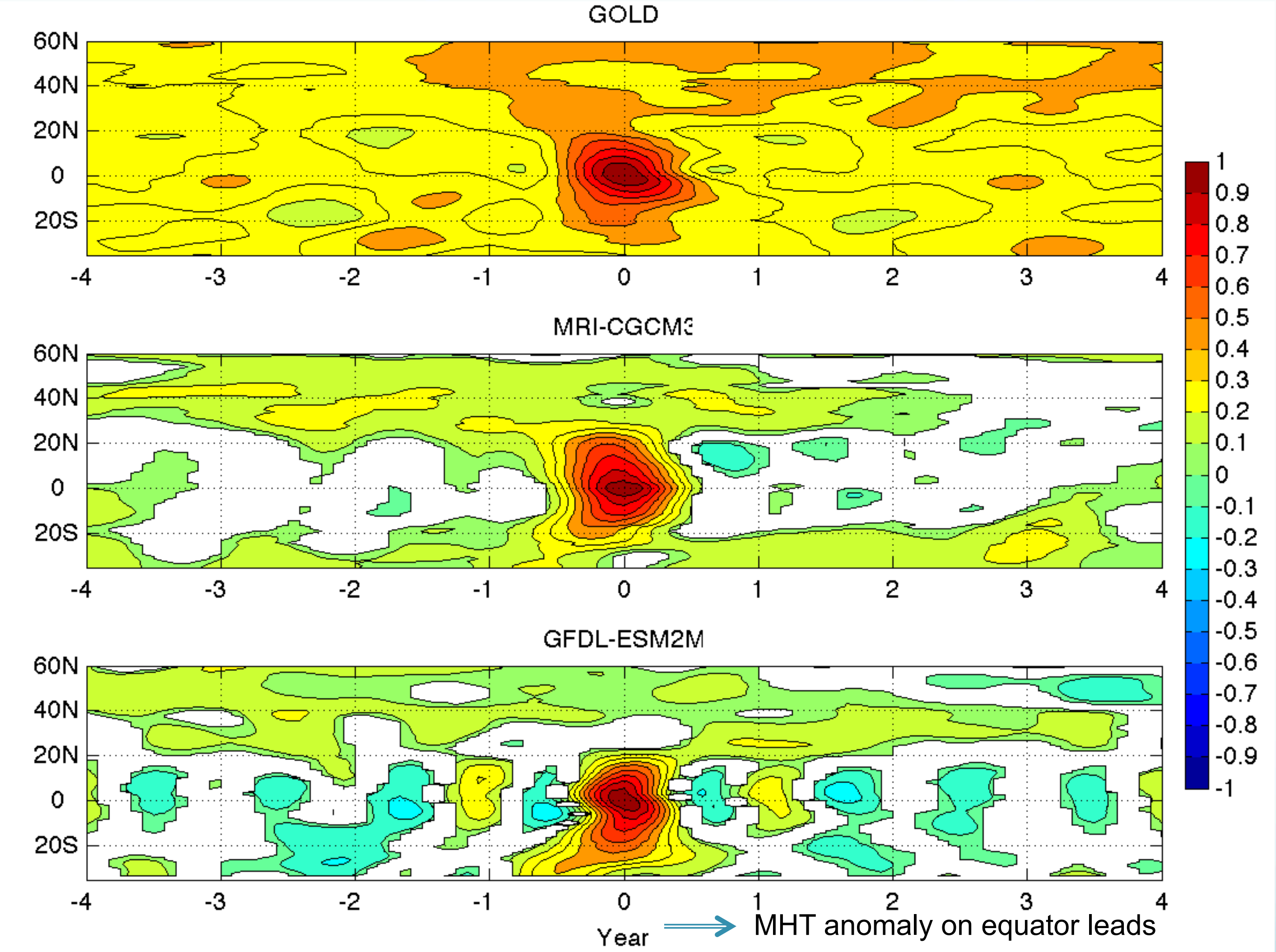
Result: Fraction of variance of 1yr low-pass MHT anomaly explained by PCs





- Mode 1 - dominating in the tropics and part of subtropical areas
- Mode 2 - dominating in the south Atlantic, except for GFDL-ESM2M
- Mode 3 – dominating in the northern subtropical areas
- The latitudinal width of the coherence mode 1 in different models differs.

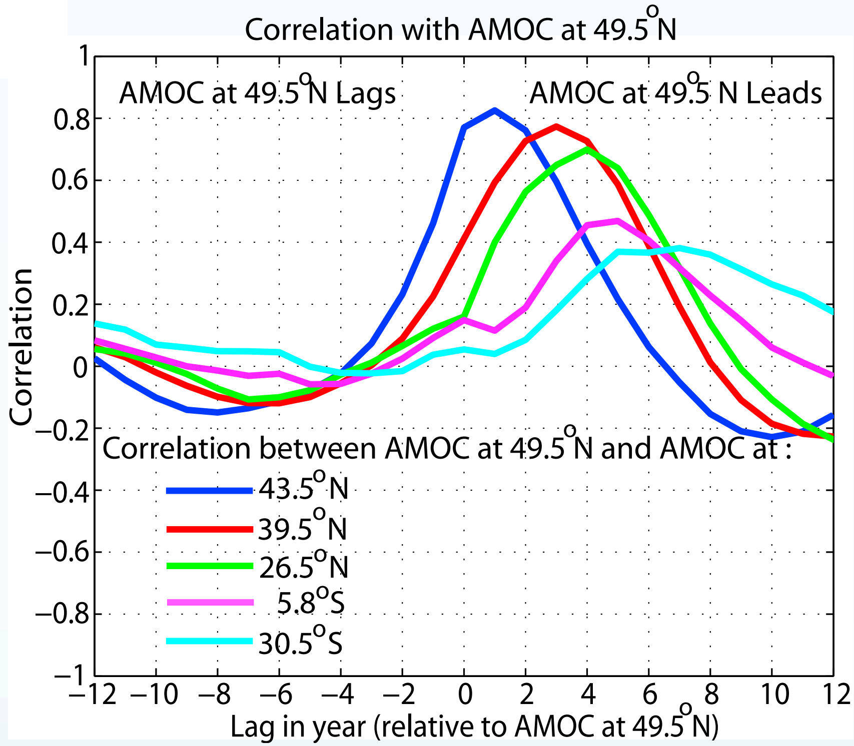
Result: lagged correlation relative to the MHT anomaly on equator



- Southward propagation
-
- Northward propagation
-

Possible explanation: Southward propagation

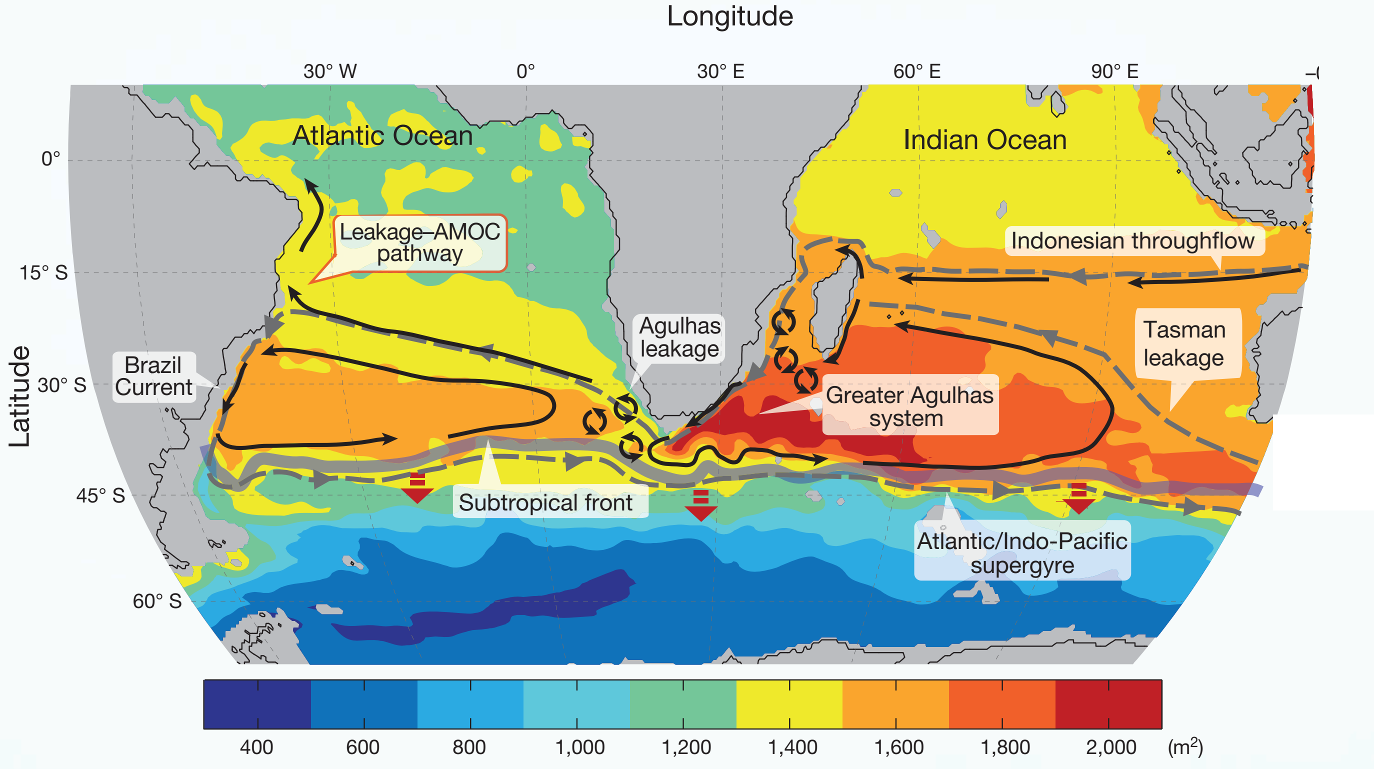
Correlation between AMOC anomaly and AMOC at 49.5°N
(GFDL CM2.1 1000 year control run)



From *Zhang* (2010)

- Signals might propagate from northern subtropics to tropics via rapid Kelvin wave (Johnson and Marshall 2002; Zhang 2010).

Possible explanation: Northward propagation

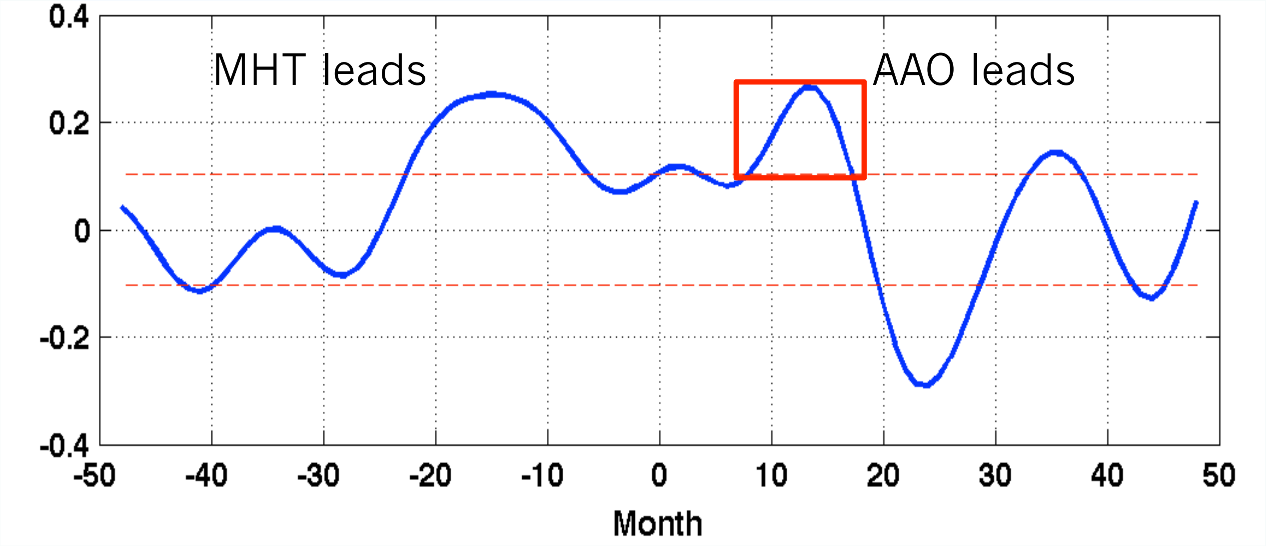


From *Beal et al* (2011)

- Leakage-AMOC pathway might contribute to the coherence mode of the MHT anomaly.

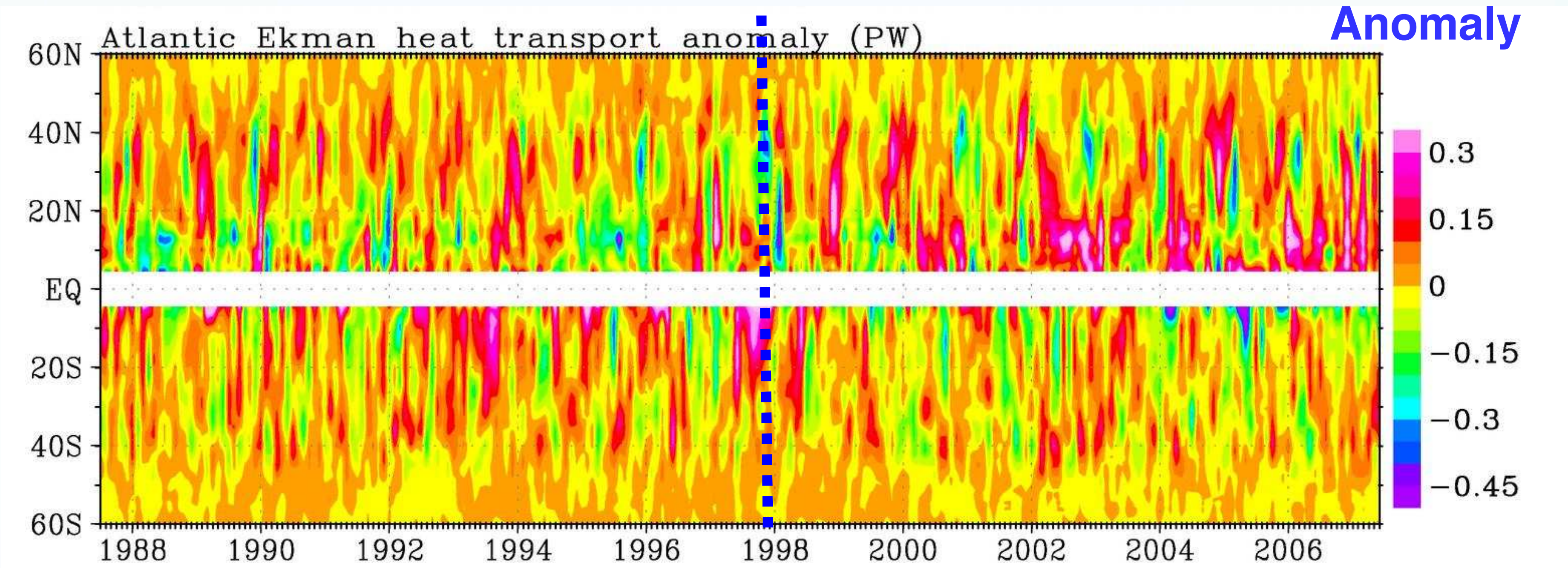
Possible explanation: AAO and MHT

Lagged correlation between AAO and EOF PC1 of MHT in GOLD



- It indicates that there might be a northward propagation of the MHT signals responding to the winds in the Southern Ocean within 1-1.5 years.
- Stronger and poleward westerly in the Southern Ocean -> southward subtropical front -> increased Agulhas leakage

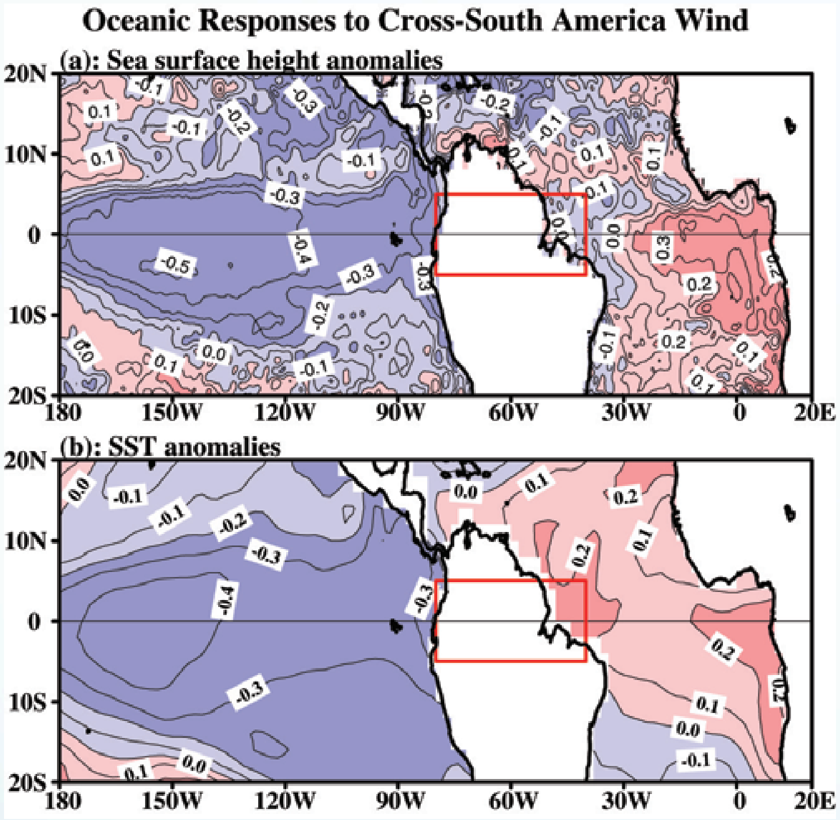
Possible explanation: Ekman heat transport



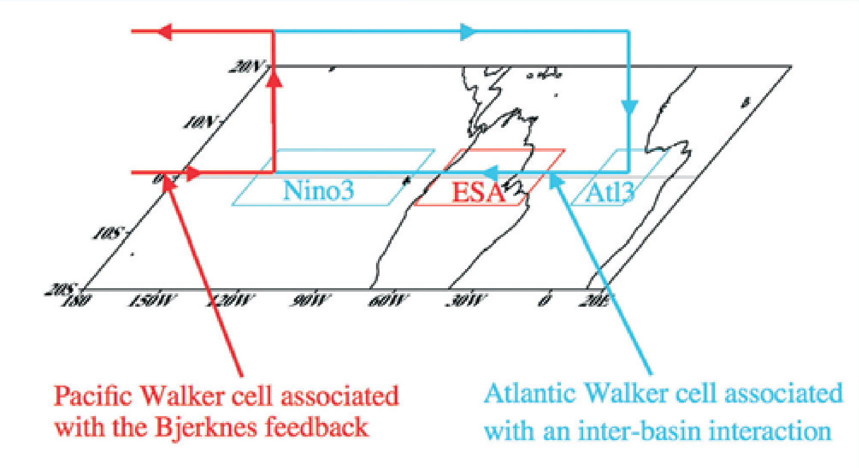
From *Liu and Xie's* preliminary results

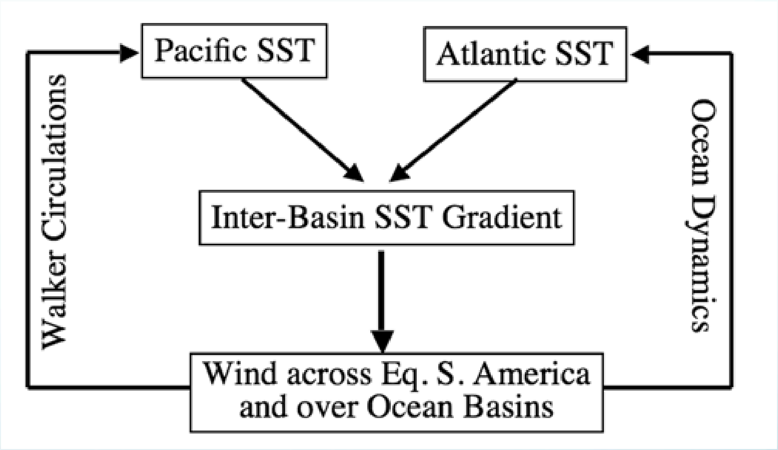
- Atlantic Ekman heat transport anomaly also shows coherence pattern.

Possible explanation: teleconnection between Pacific and Atlantic



From *Wang* et al (2009)





- Teleconnection between tropical Pacific and Atlantic might cause coherence response of MHT anomaly in tropical areas.

Conclusions

- Strong interannual variability of MHT anomaly are from 30°S to 40°N, decadal signals are in the North Atlantic North of 40°N.
- The interannual to decadal MHT anomaly has a dominant coherence mode from the southern subtropics to 30- 40°N, with its maximum and dominance in the tropics, consistent in all of the models.
- EOF mode 2 has opposite sign in the northern and southern subtropical areas, dominating in the south Atlantic, except for GFDL-ESM2M
- EOF mode 3 has opposite sign between tropics and subtropics, but GFDL-ESM2M in southern hemisphere is different; its dominance is in the northern subtropical gyre.
- Southward signal propagation from subpolar region, northward propapgation of Agulhas leakage eddies, Ekman heat transport and teleconnection between Pacific and Atlantic are the possible explanations for the coherence mode of the MHT anomaly.

Future work

- Is the MHT anomaly in the south Atlantic associated with Agulhas leakage or transport through the Drake Passage?
- How do the teleconnection between Pacific and Atlantic contribute to the coherence mode of the MHT anomaly in the Atlantic Ocean?
- What are the mechanisms that winds can influence the MHT on interannual and decadal time scales, Ekman transport or Sverdrup transport?
- What is the structure of the meridional velocity and temperature associated with the MHT in the models?