Atlantic meridional overturning circulation (AMOC) in forced versus coupled simulations

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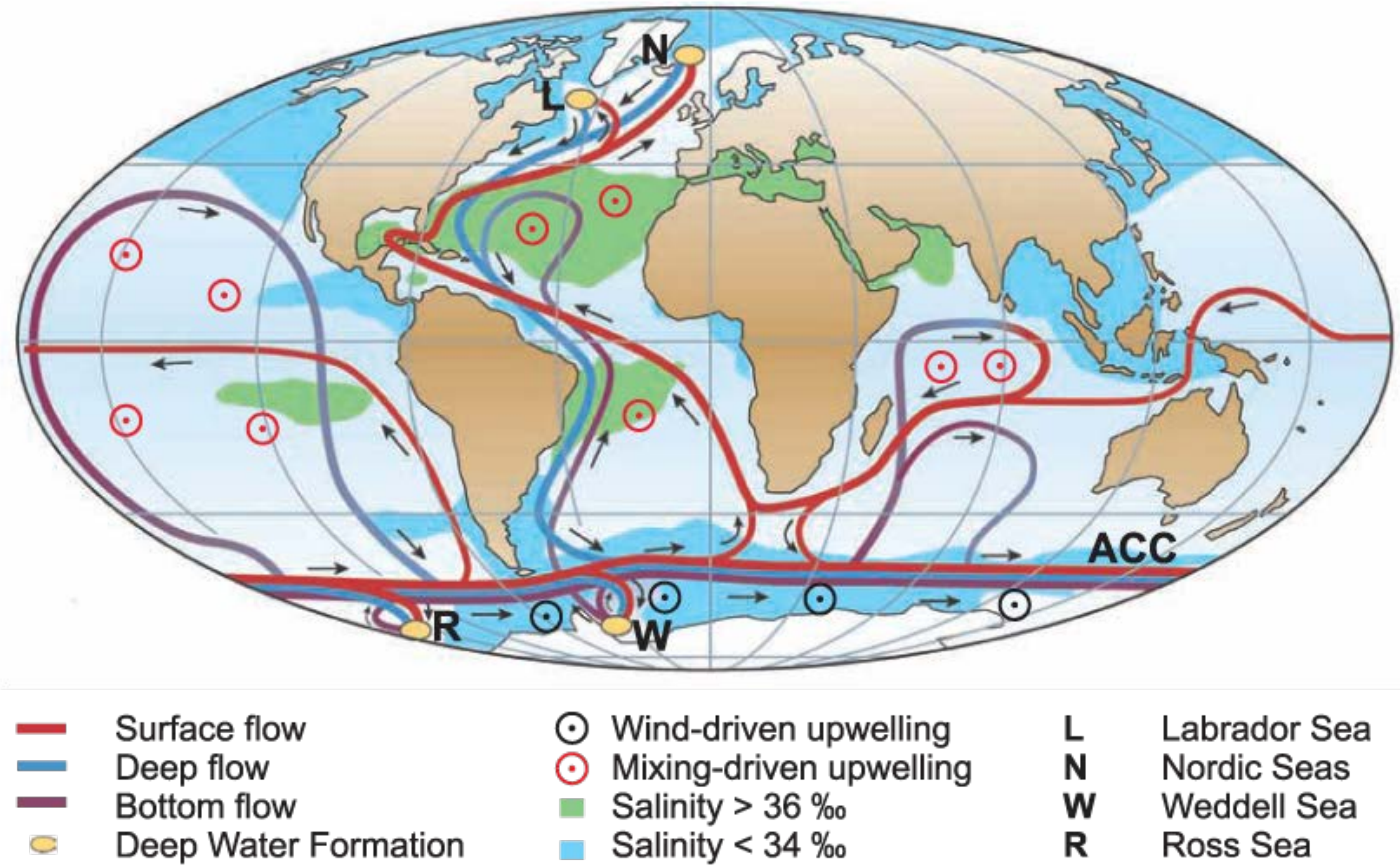
Lessons from numerical modelling of the ocean and climate for the AMOC dynamics

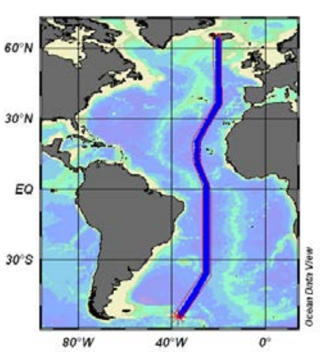
1. ***AMOC in eddy-resolving HYCOM simulations and observations***
2. ***AMOC in coarse-resolution forced versus coupled simulation***

References: Xu et al. (2012, 2014, 2016, 2017)

Atlantic MOC in global ocean

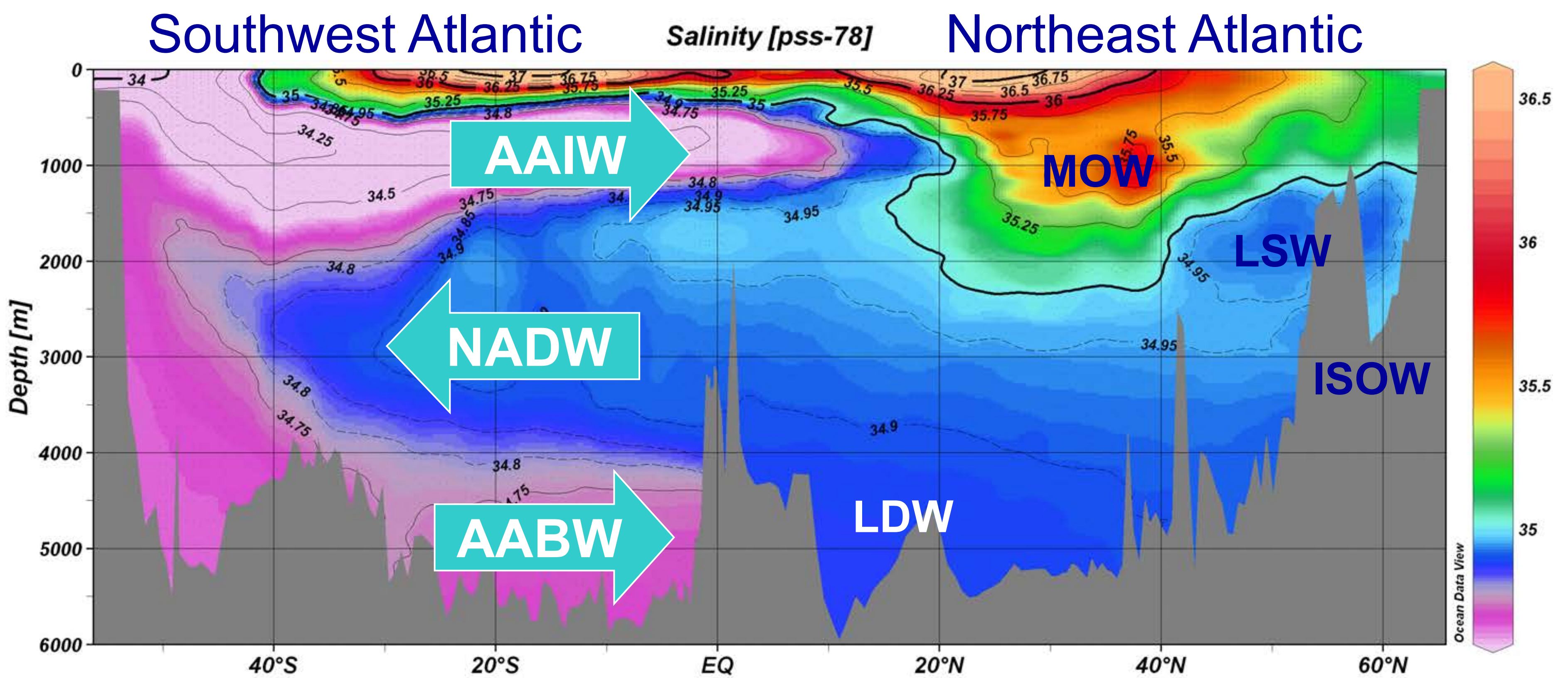


Schematic of the global overturning circulation (*Kuhlbrodt et al., 2007)*



Hydrographic section

Tsuchiya et al. (1992)



South Georgia Island

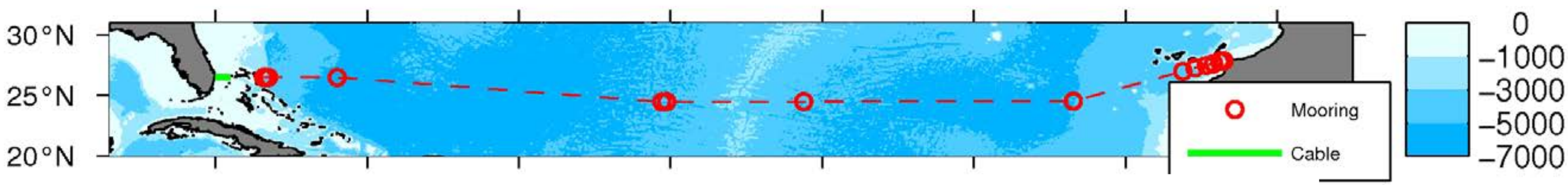
Iceland

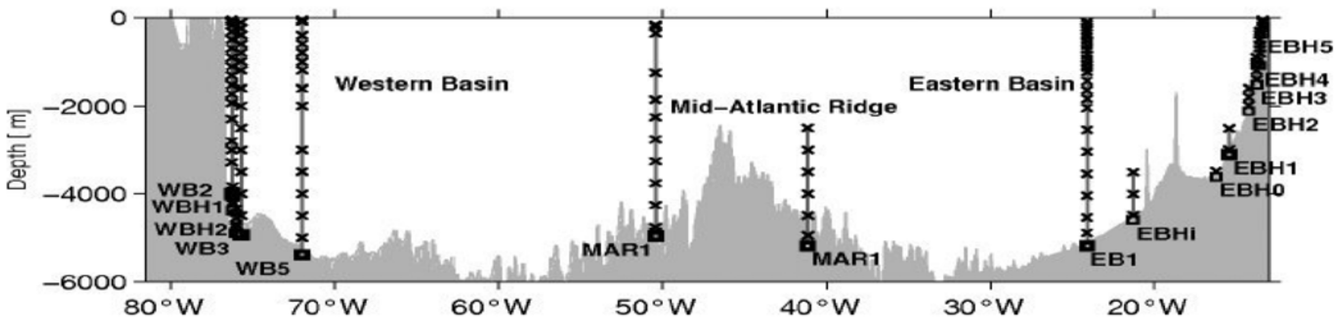
Part I: AMOC, heat and freshwater transports at 26.5ºN in HYCOM eddy-resolving simulations

Eddy-resolving HYCOM simulations

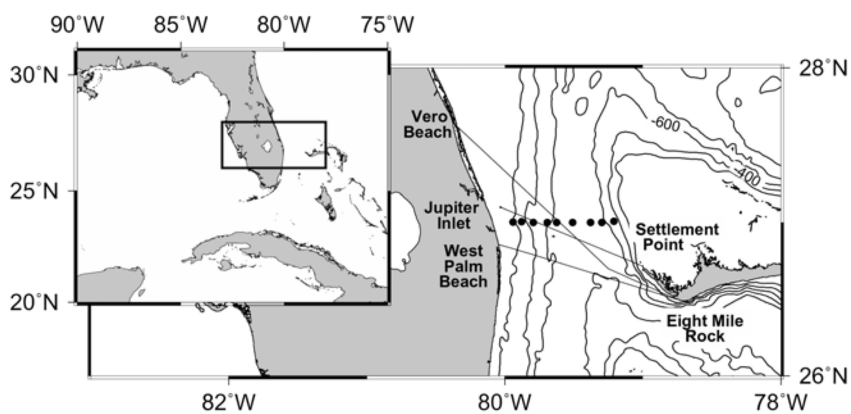
- HYbrid Coordinate Ocean Model (Bleck 2002; Chassignet et al., 2003)
- 1/12º global and basin-scale simulations
- Atlantic model domain is a subset of the global and covers the North and Equatorial Atlantic (28ºS to 80ºN)
- 32 layers (typically) in σ_2
- Initialization using T/S GDEM3, surface forcing: ECMWF reanalysis ERA40 for climatological simulations, NOGAPS for interannual simulations.

RAPID/MOCHA at 26.5ºN

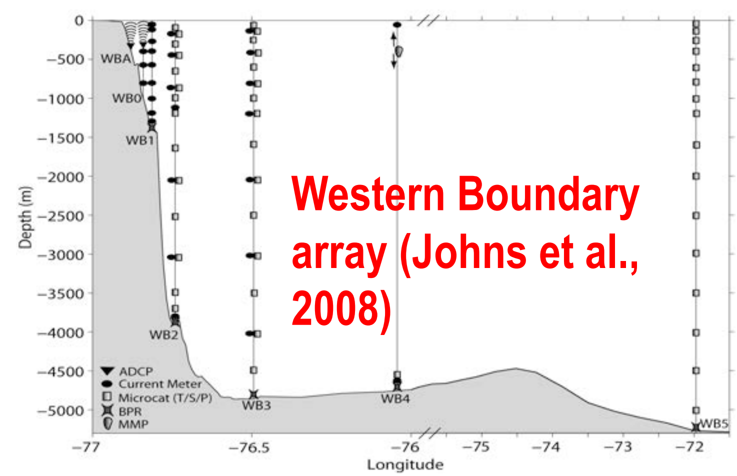




Mid-ocean Array (Cunningham et al., 2007; Kanzow et al., 2007)



Florida Current (Meinen et al., 2010)



Western Boundary array (Johns et al., 2008)

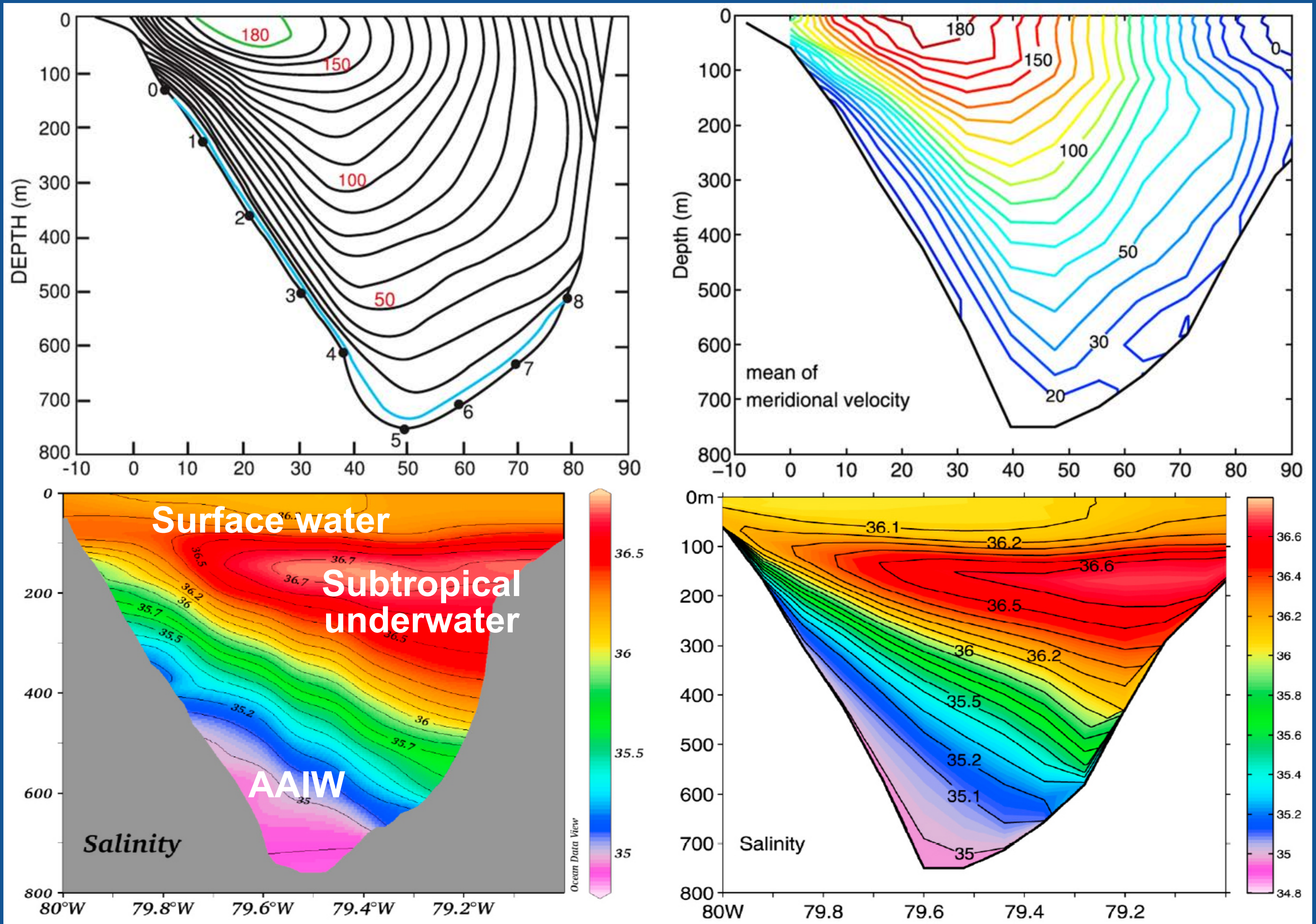
AMOC = FC + Ekman + Interior

17.5 Sv = 31.5 Sv + 3.5 Sv - 17.5 Sv

The Florida Current

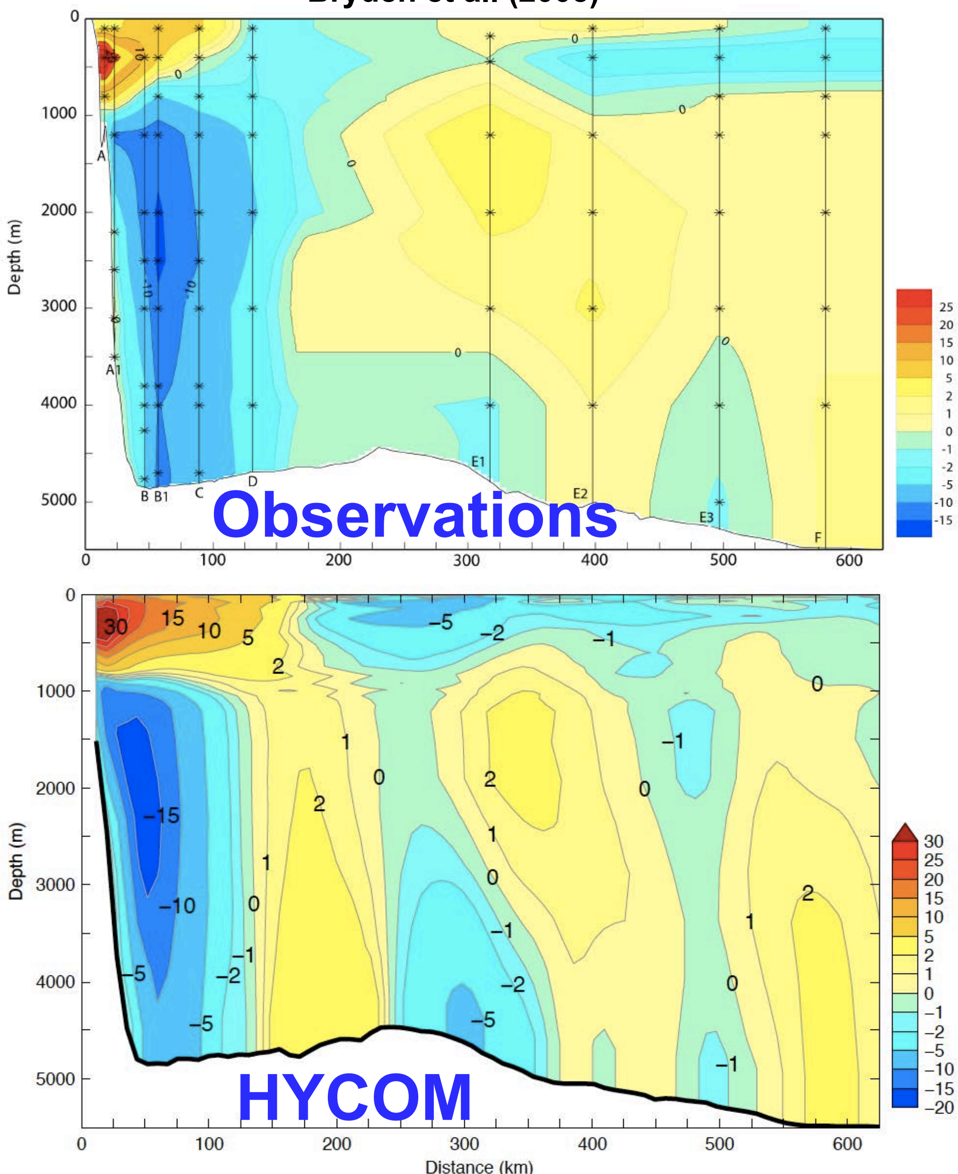
Observations (Leaman et al. (1987) and word ocean database)

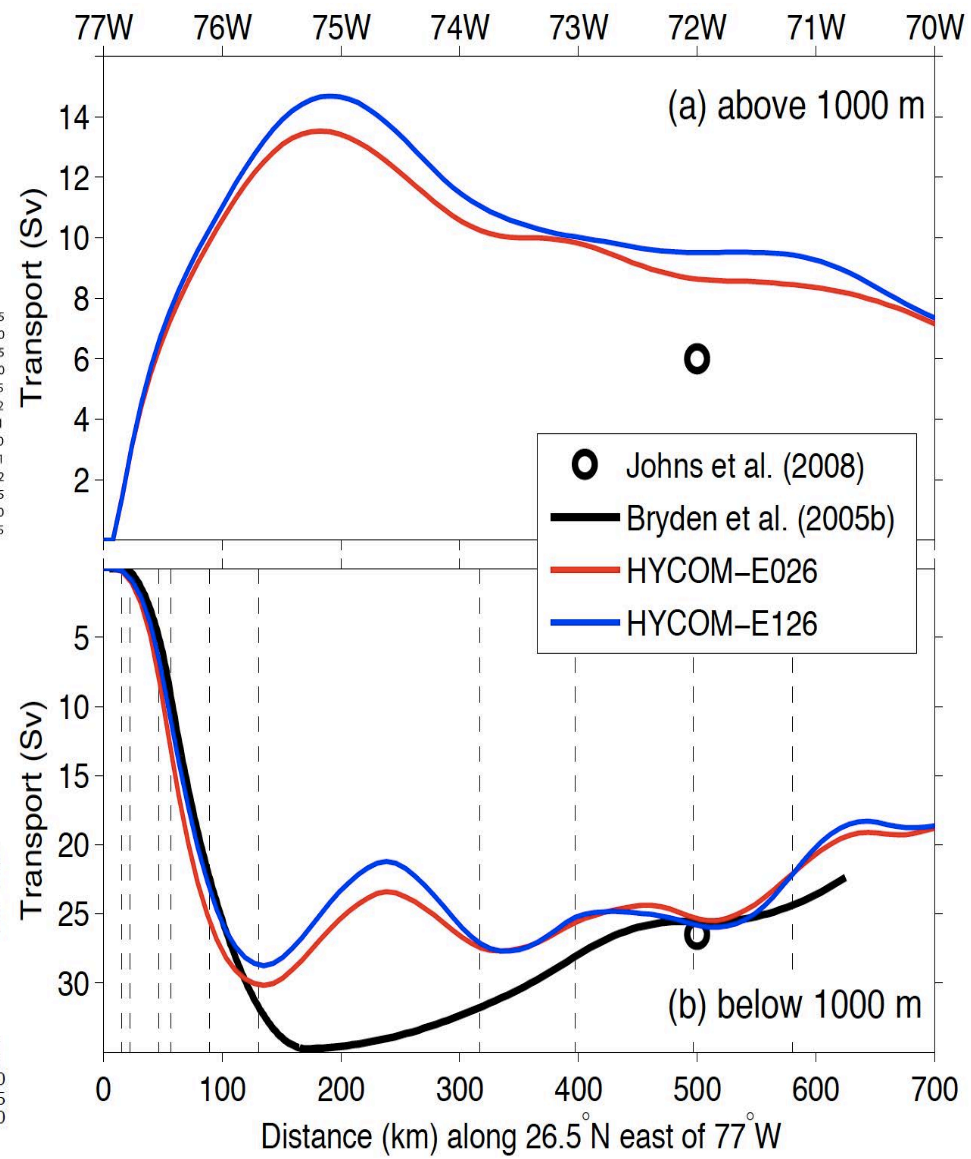
HYCOM



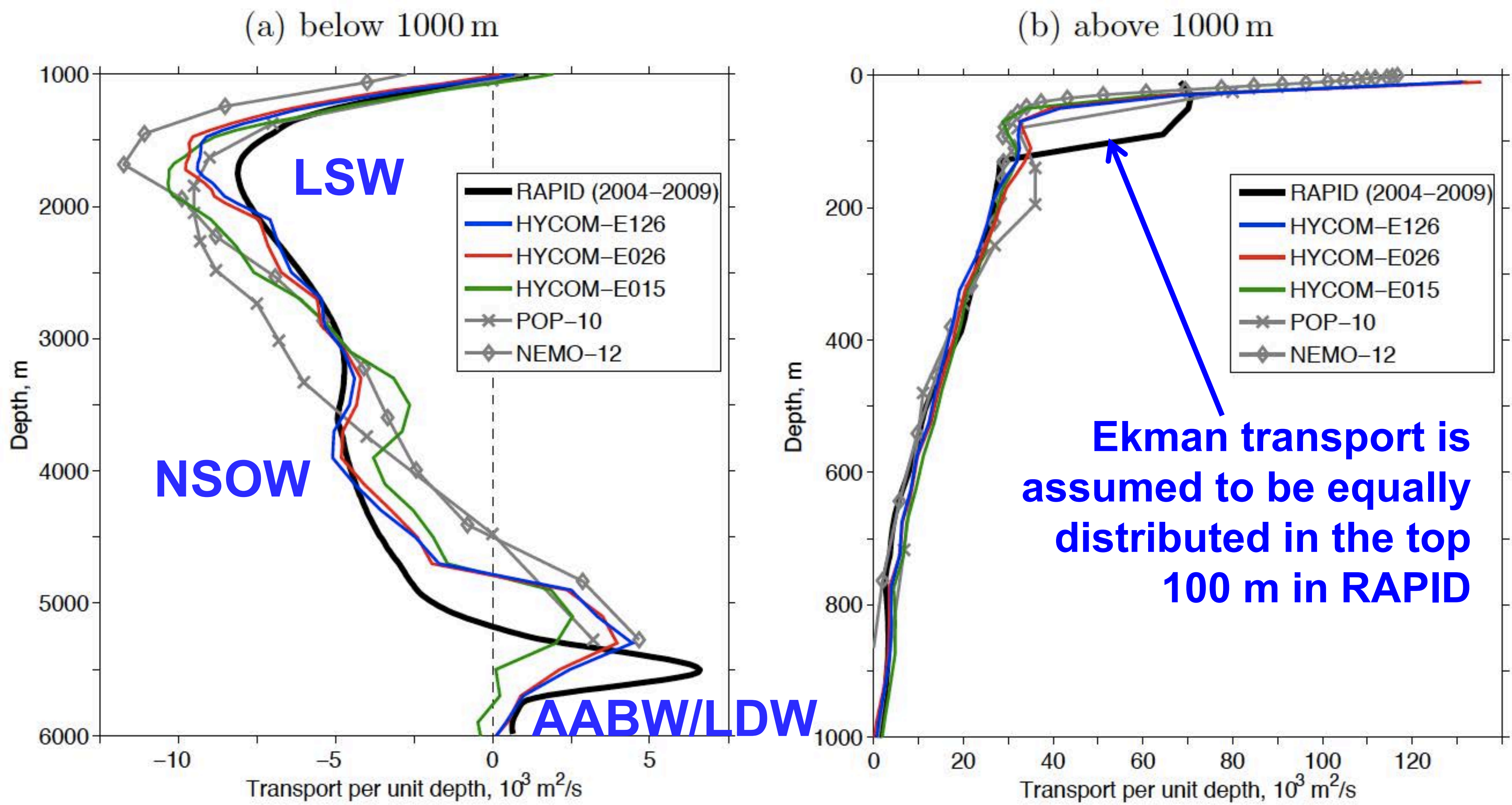
WBC east of Abaco

Bryden et al. (2005)



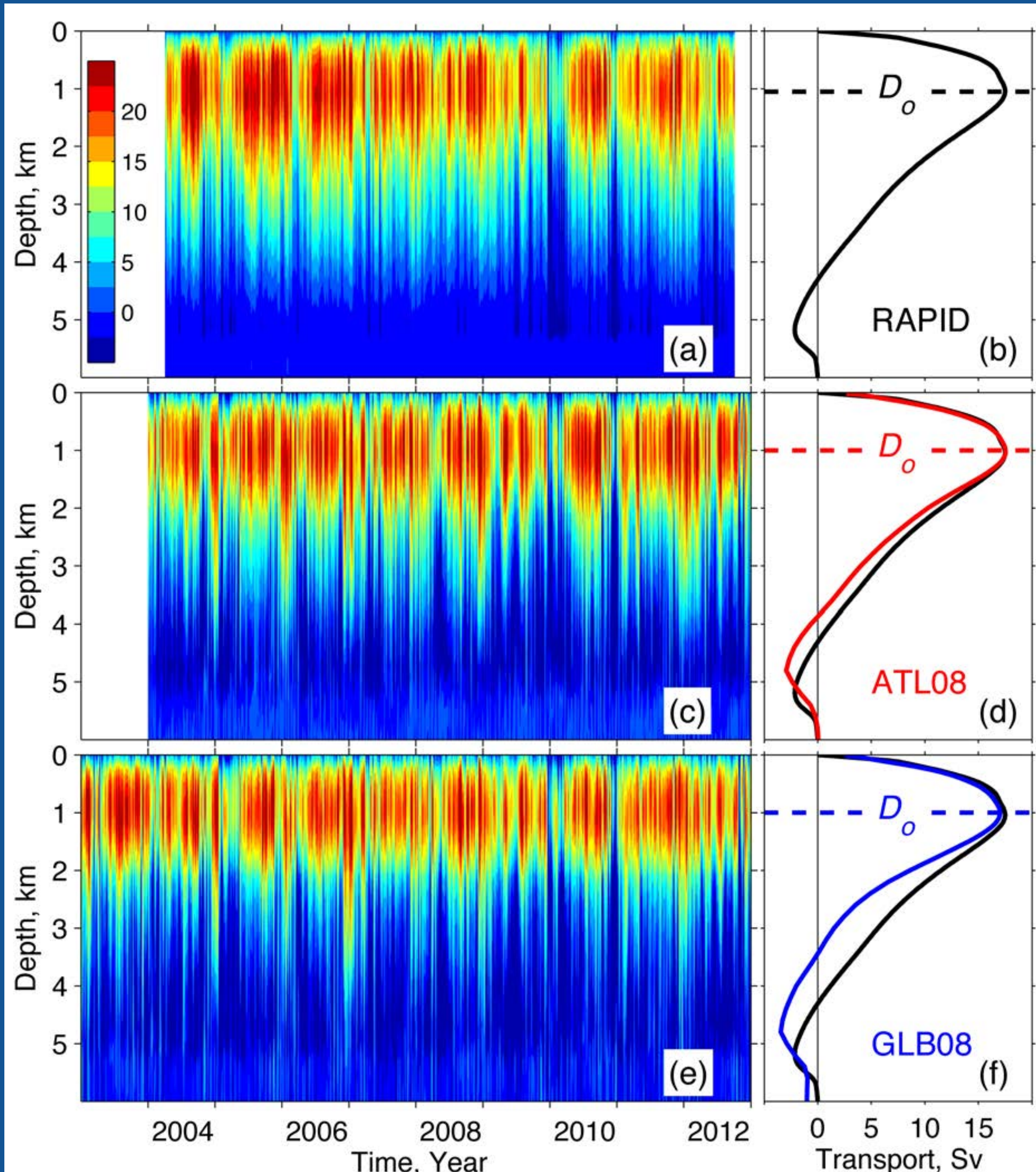


Time mean vertical structure



Improved vertical structure in HYCOM for southward transport of the NADW (below 1km); similar model structure in the upper 1km; see Xu et al. (2012)

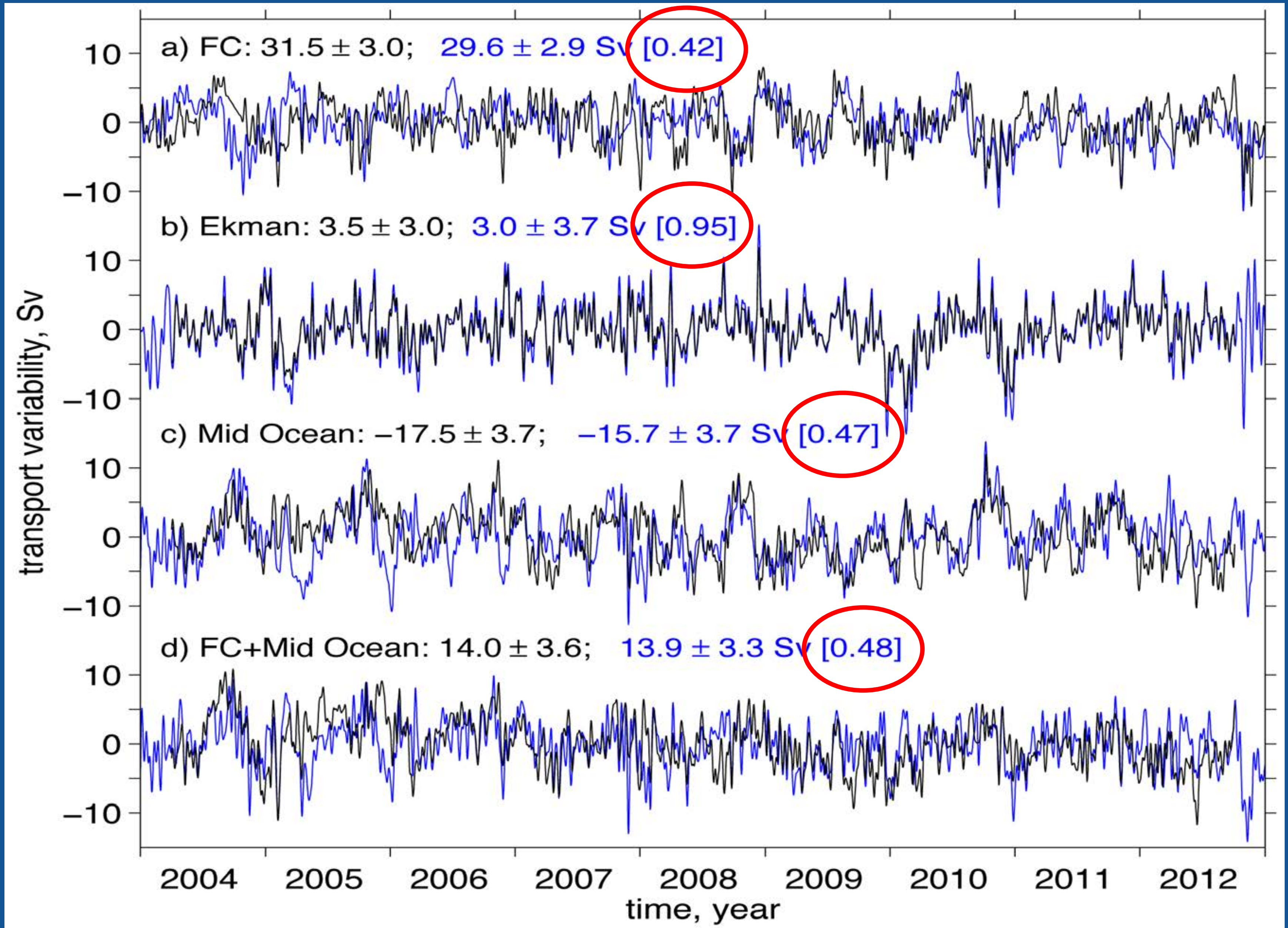
26.5ºN



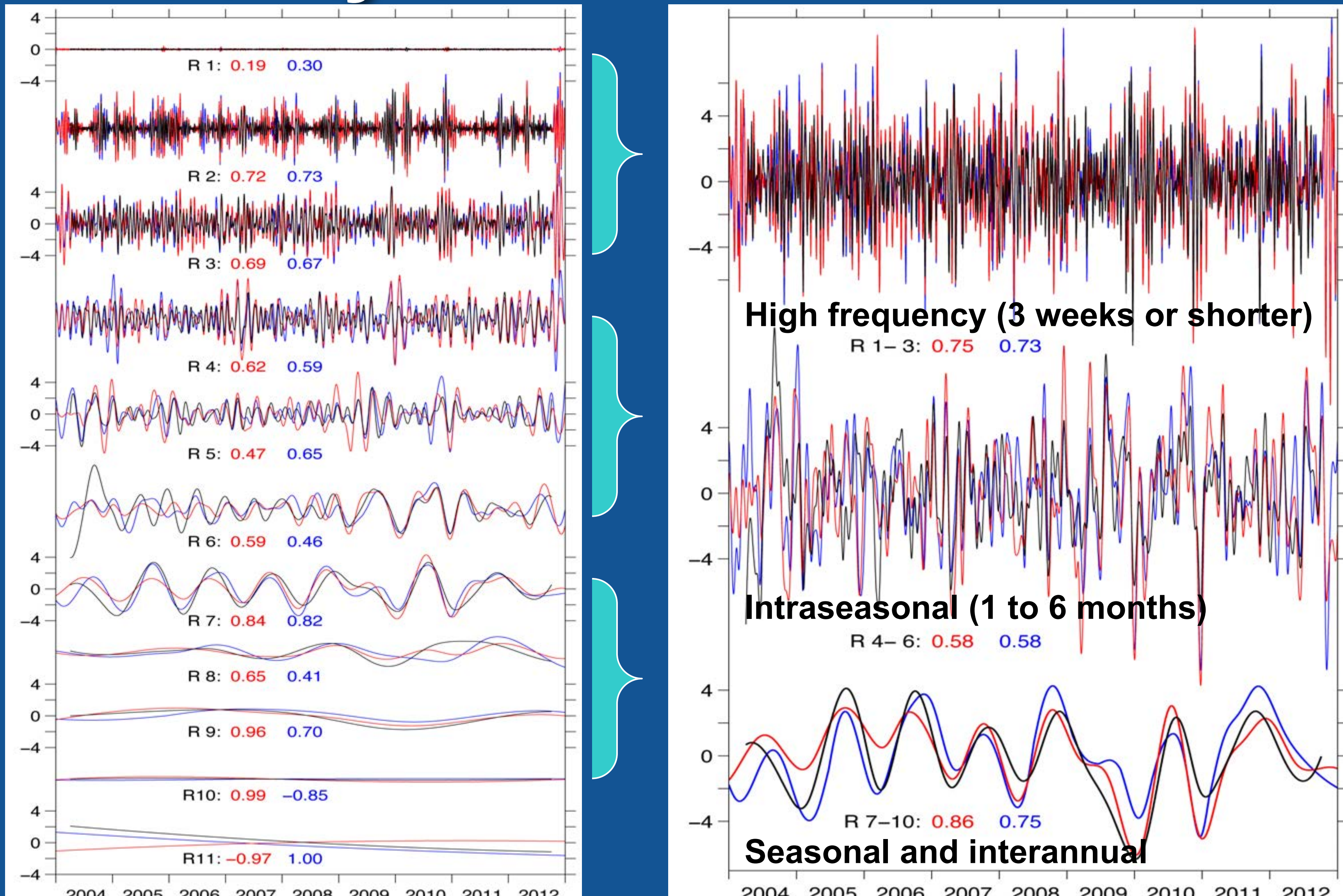
The AMOC stream function from the observations and in Atlantic and global 1/12º HYCOM simulations

(0.7 correlation)

26.5ºN AMOC components (Global)

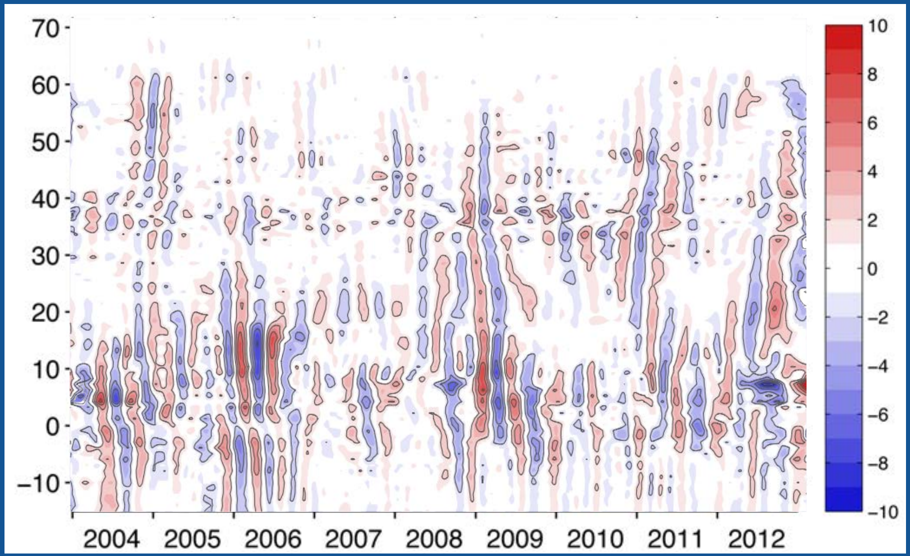


Variability on different time scales

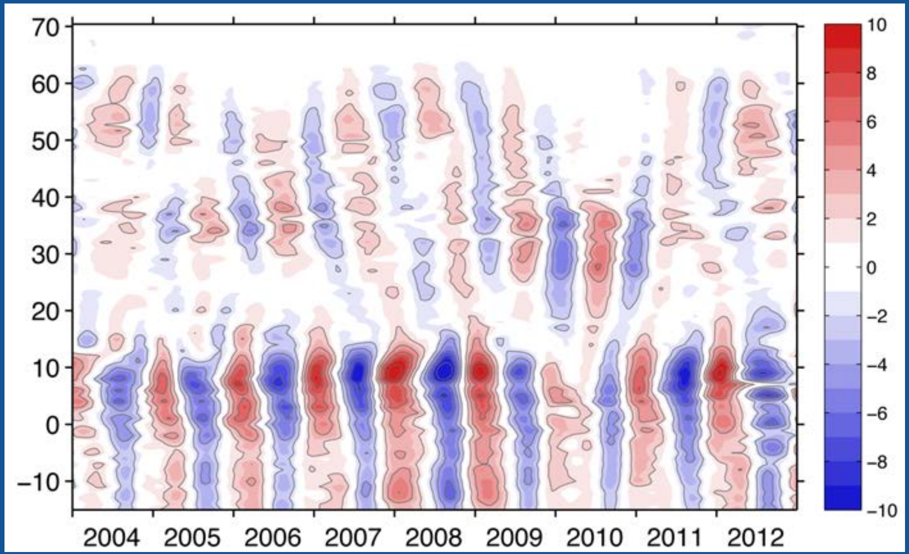


AMOC time series decomposed using the Ensemble Empirical Mode Decomposition (EEMD) (*Huang and Wu, 2008; Wu and Huang, 2009*)

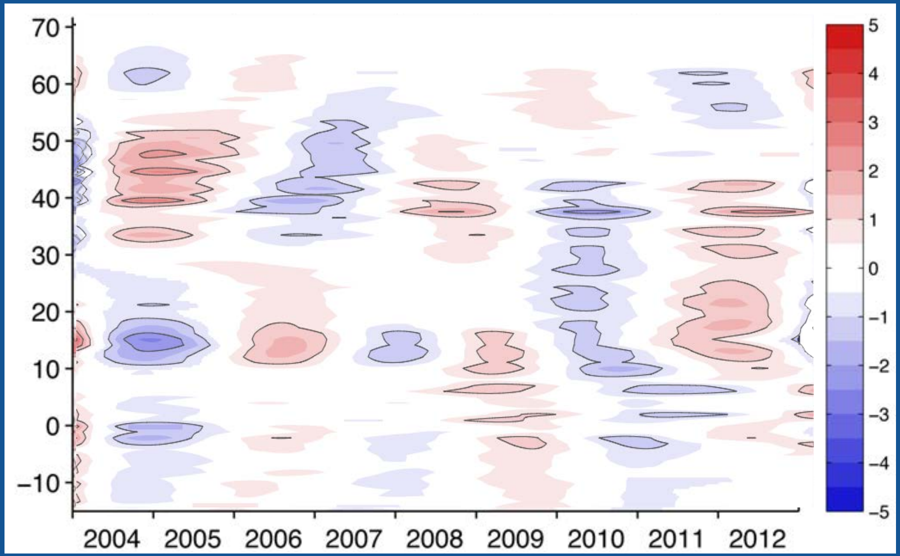
Intraseasonal



Interannual



Interannual



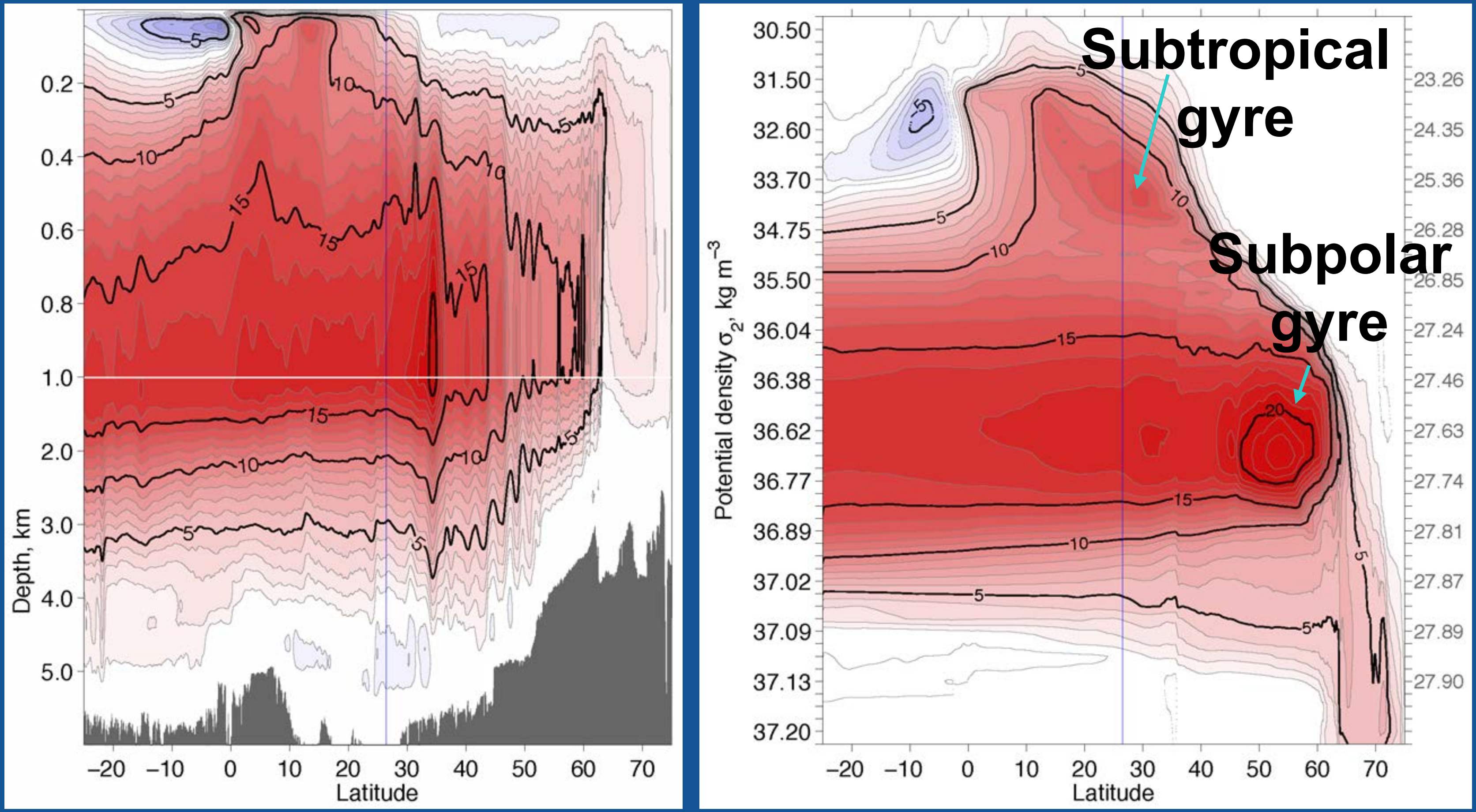
Xu, Chassignet, et al. (2014)

Partitioning of the meridional heat and freshwater transports:

What are the relative contribution of the AMOC and wind-driven gyres?

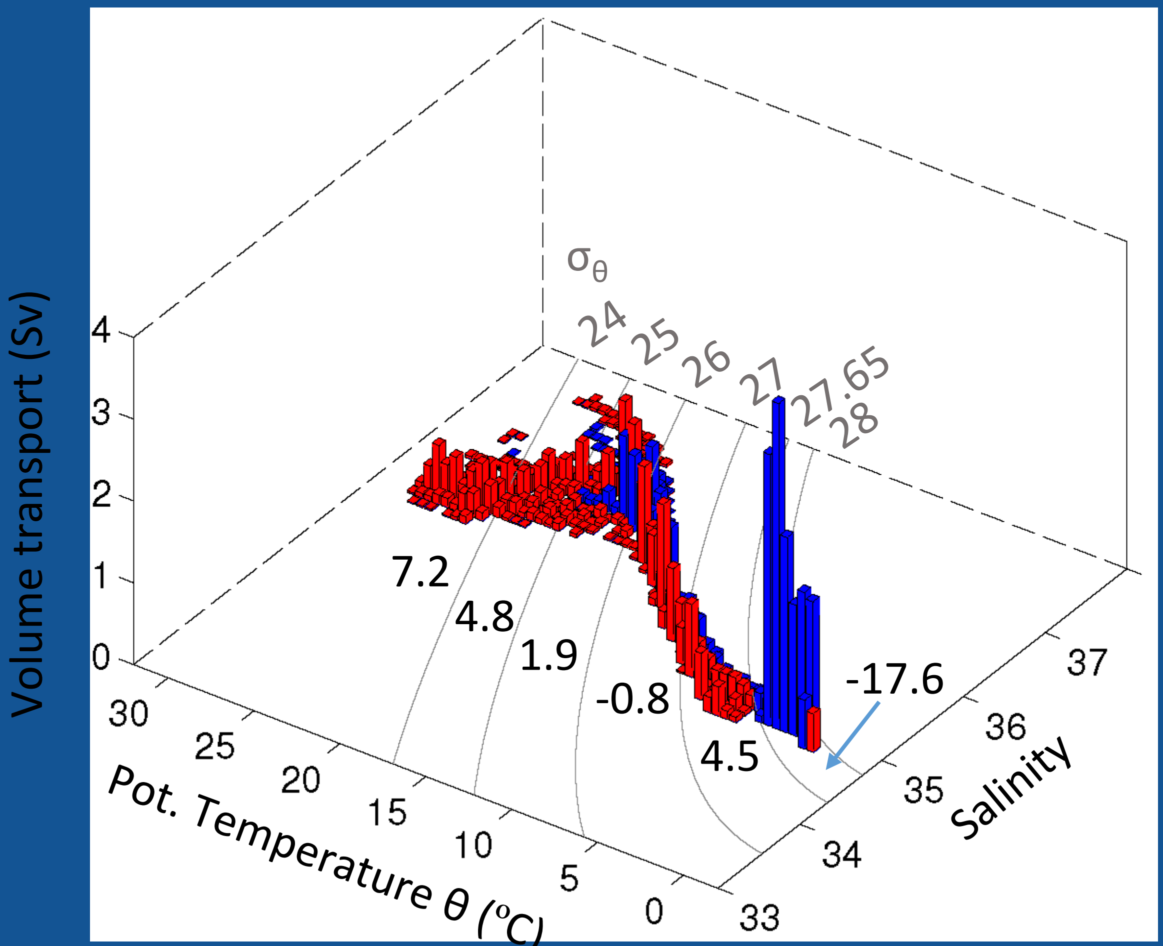
- Meridional heat transport (MHT): At 25°N, the classical vertical-horizontal decomposition suggests that 90% of the meridional heat transport (MHT) is due to the AMOC and the remaining 10% is due to the subtropical gyre (e.g., Bryden and Imawaki , 2001; Johns et al., 2011; McCarthy et al., 2015) -- To be contrasted to 30% subtropical gyre contribution (Talley, 2003) or 40% (Ferrari and Ferreira, 2011)
- Meridional freshwater transport (MFWT): Vertical-horizontal decomposition of the RAPID data based transports suggests that -0.78 Sv MFWT is due to the AMOC, 0.35 Sv due to the subtropical gyre (McDonagh et al., 2015)

In the basin-scale perspective



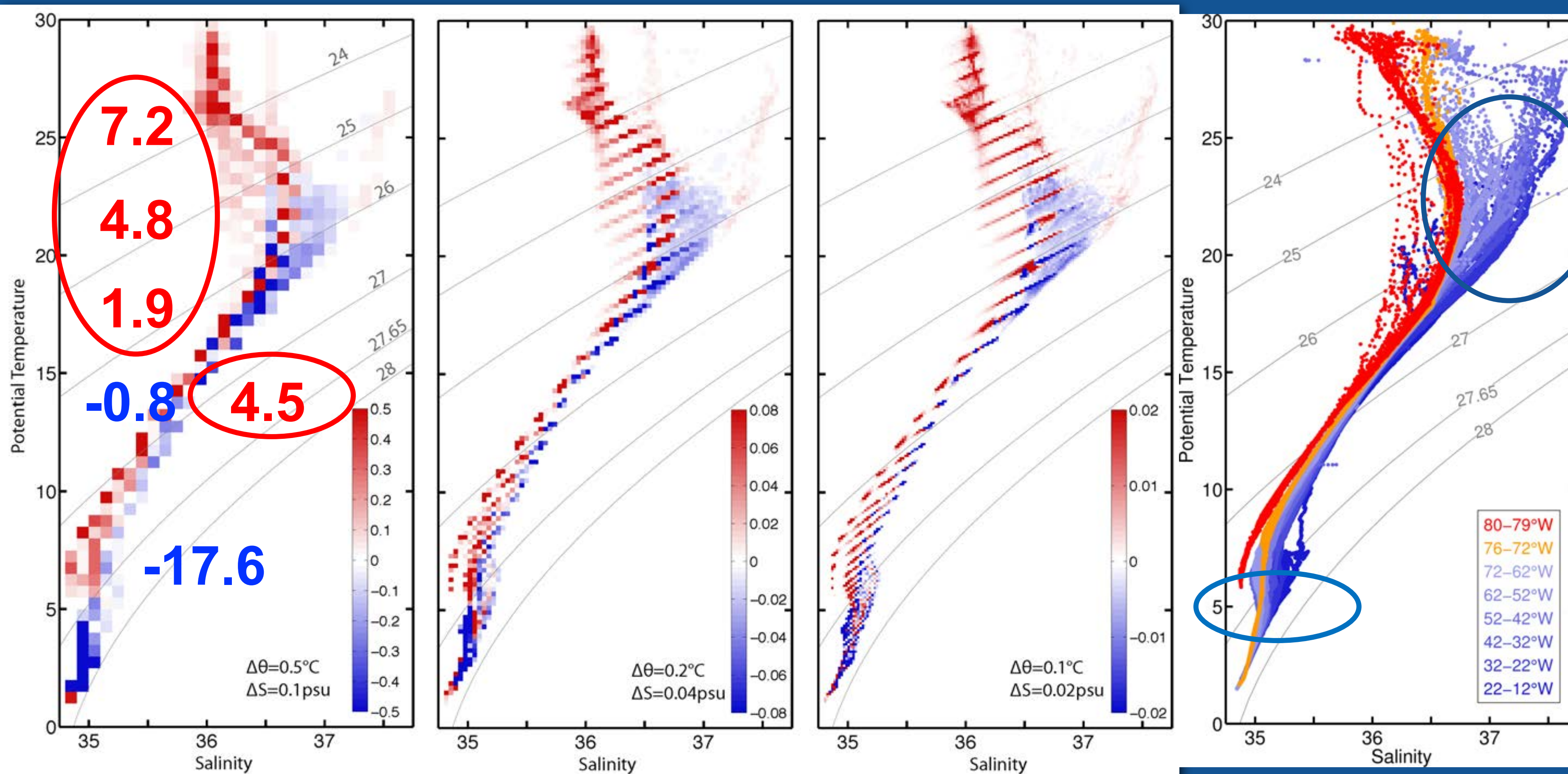
Meridional overturning circulation projected on depth and density spaces: the latter shows sub-basin scale diapycnal overturning cells (in both the subtropical and subpolar NA), which are not part of the basin-scale AMOC. How does this difference impact the MHT/MFWT?

A natural approach to summarize the nature of the meridional flows (of different water masses) across a zonal section is to project the meridional transports on a θ-s plane. For example, the **northward** and **southward** transports across 26ºN

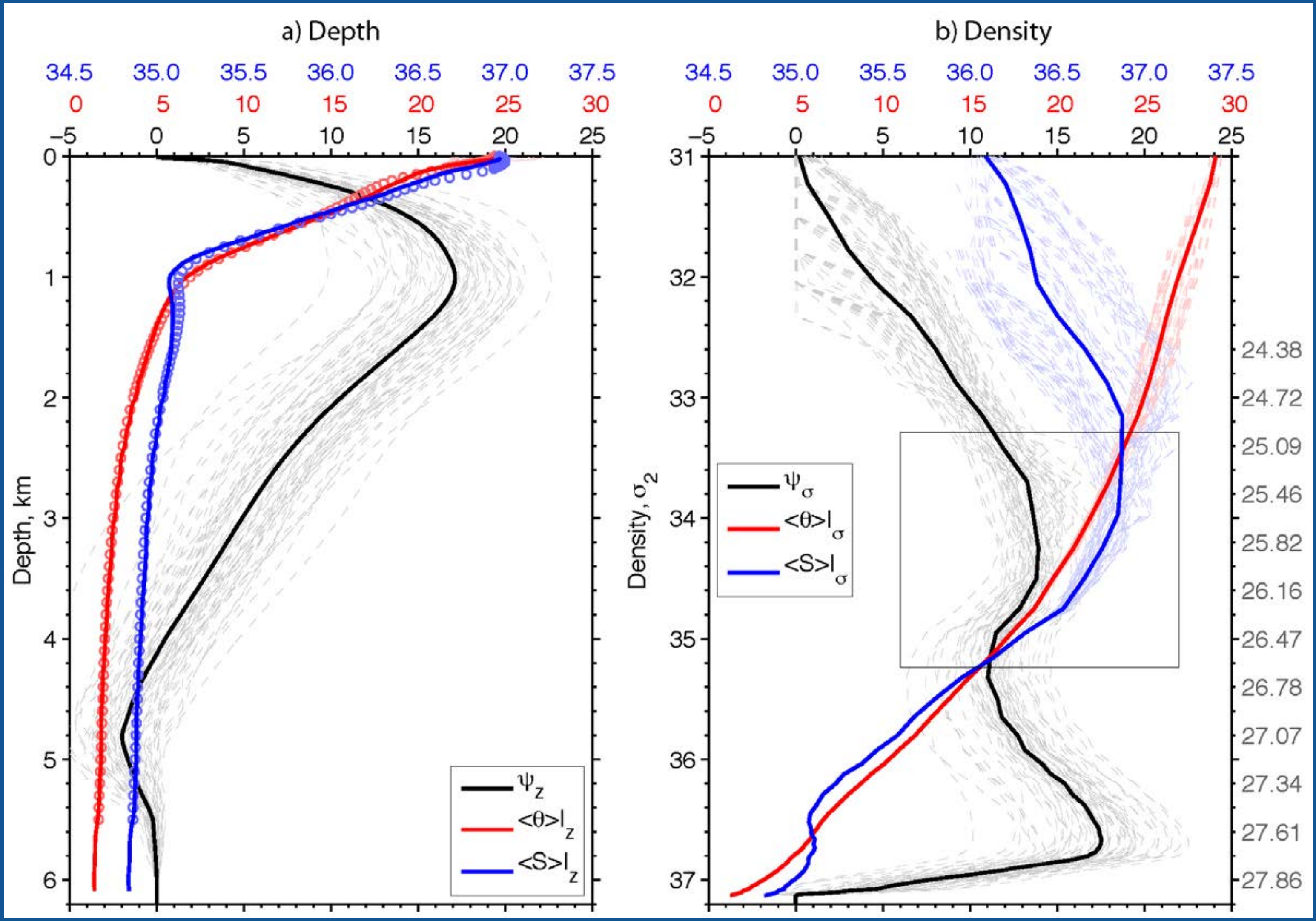


From a different angle …

Model meridional transport on θ-S plane for three ΔθxΔS **Observed θ-S**

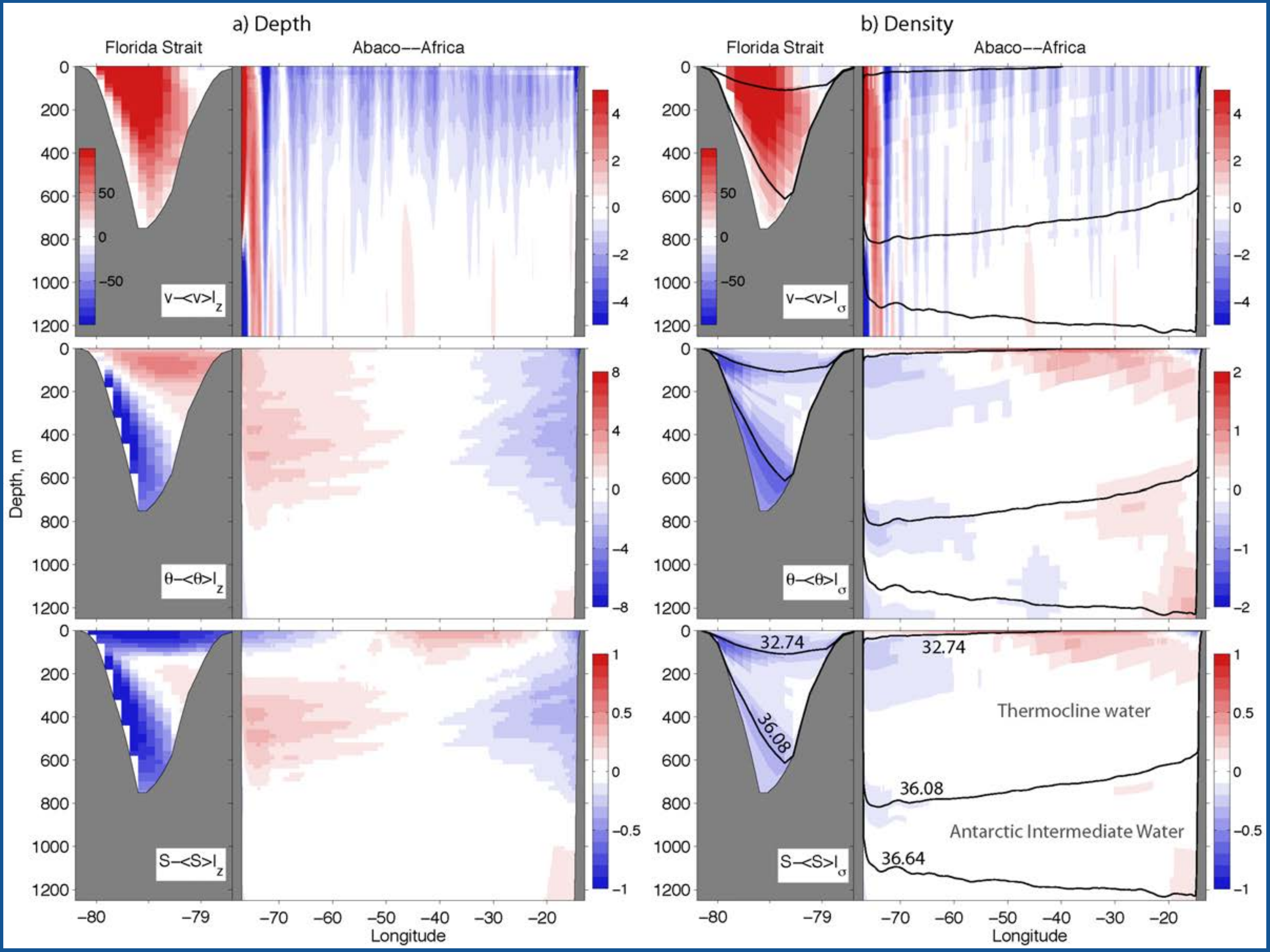


Vertical vs. diapycnal transport



MHT:	**1.10 PW**	**[total 1.24 PW]**	**1.29 PW**
MFWT:	**-0.71 Sv**	**[total -0.37 Sv]**	**-0.53 Sv**

Horizontal vs. isopycnal transport

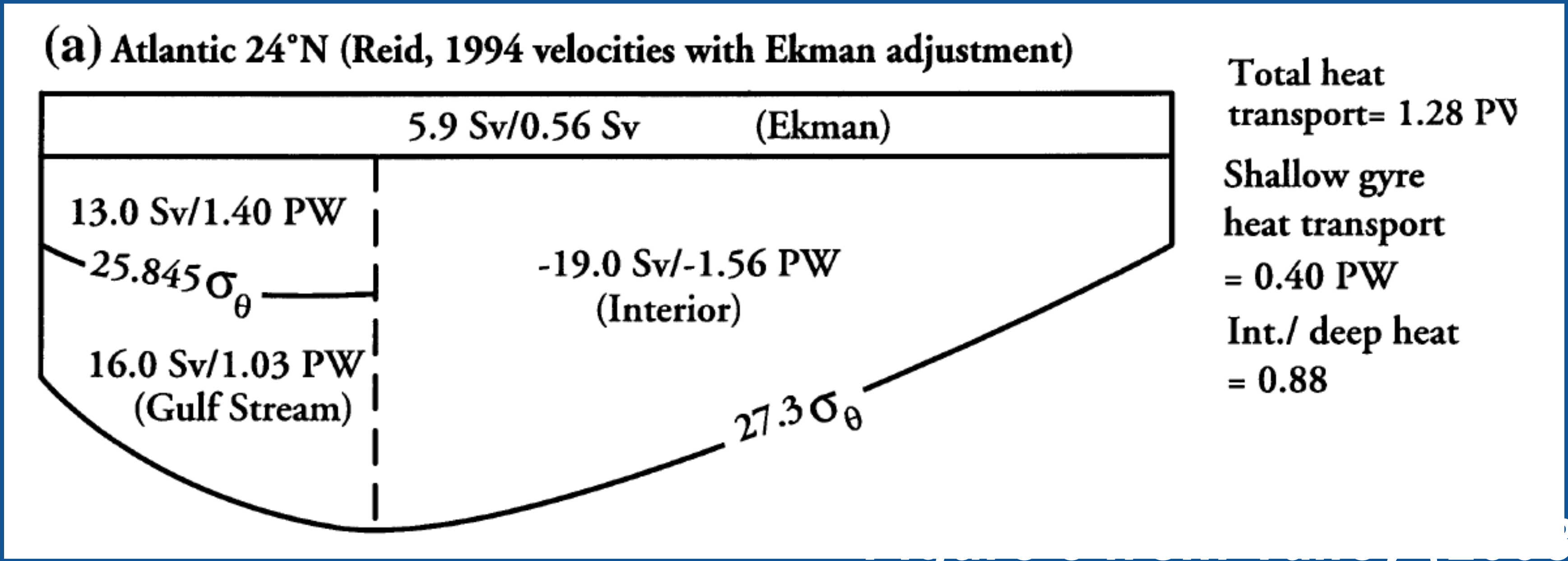


0.14 PW **[total 1.24 PW]** **-0.05 PW**

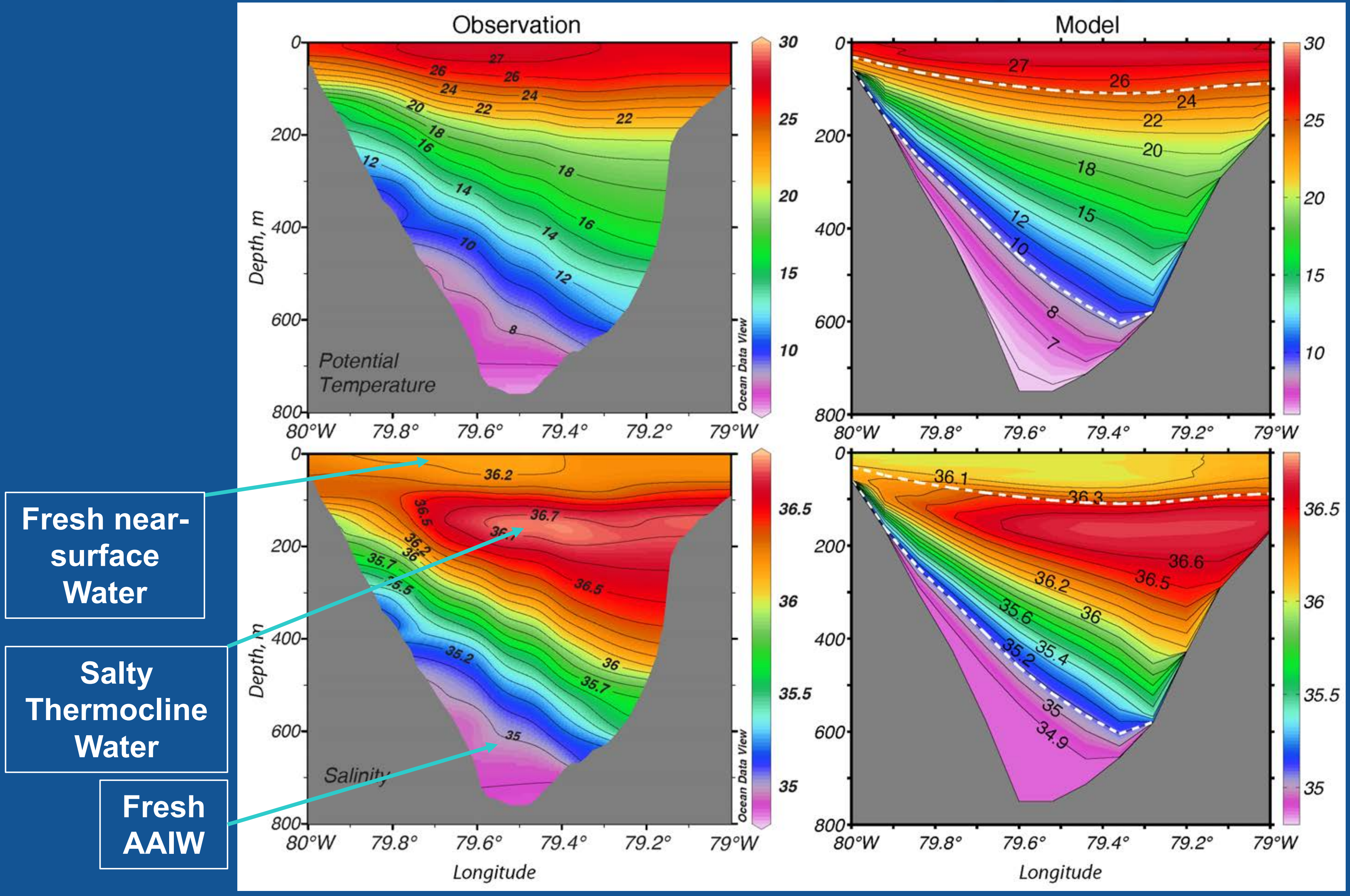
0.34 Sv **[total -0.37 Sv]** **0.16 Sv**

Why not a higher gyre MHT contribution?

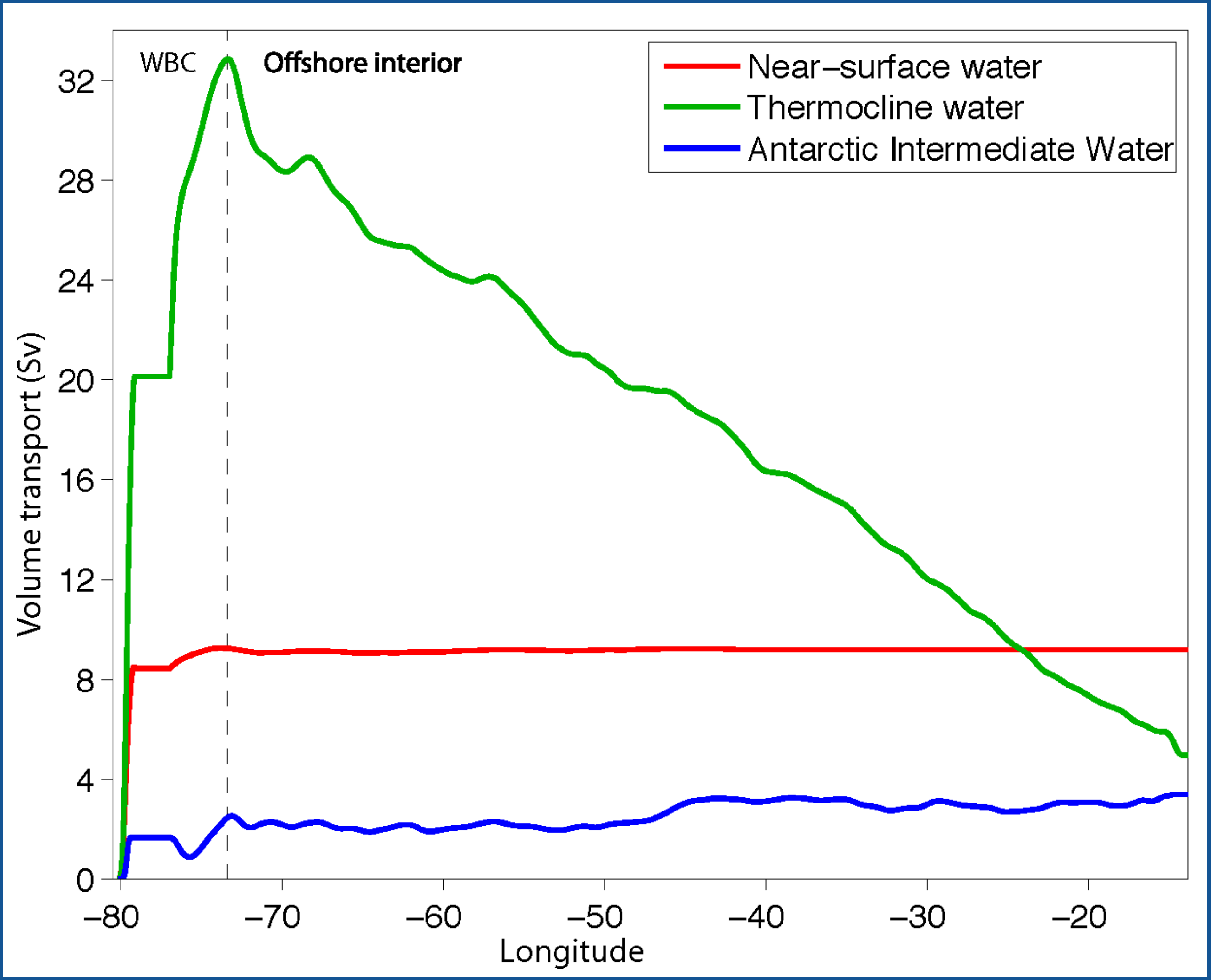
- 0.4 PW gyre contribution in Talley (2003) comes from using the upper part of the Florida Current (and Ekman) transports to balance the returning component of the subtropical gyre



However, T/S in the WBC (FC)



It is thermocline water that constitutes the subtropical gyre, and the near-surface water and AAIW contribute to the basin-scale AMOC. If we refine the Talley (2003) calculation (using the thermocline water only), we obtain ~0 PW MHT and 0.13 Sv MFWT, consistent with the results of diapycnal-isopycnical decomposition.



Gyre vs. AMOC in the MHT/MFWT

- The subtropical gyre (including a large isopycnic circulation and a small diapycnal overturning) contributes near zero PW MHT and about 0.13 Sv MFWT northward; The basin-scale AMOC is responsible for virtually all the MHT across the subtropical North Atlantic at 26ºN;
- The zero gyre MHT is even lower than the 10% contribution based on the classical vertical-horizontal decomposition, let alone the higher gyre contributions in by Talley (2003) and Ferrari and Ferreria (2011);
- The northward gyre MFWT, also lower than the contribution based on vertical-horizontal decomposition, is opposite of that by the diapycnal AMOC: one corresponds to the positive E-P within the subtropical gyre, the other to the overall negative E-P in the northern North Atlantic that forms the NADW.

Part II: Variability of the Atlantic meridional overturning circulation in forced versus coupled simulations

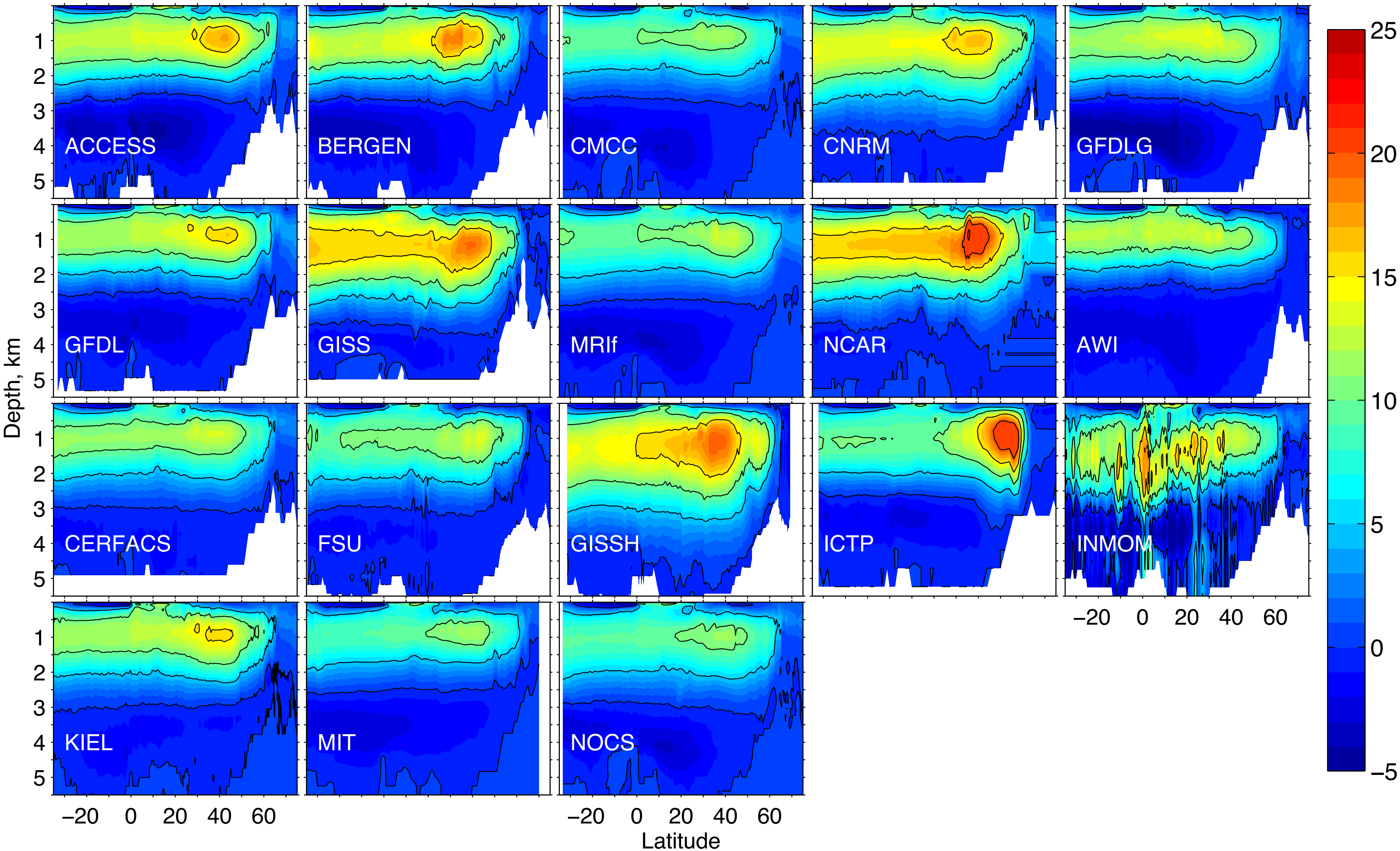
Questions:

- How comparable is the AMOC variability in forced global ocean-sea ice (COREII) and coupled climate (CMIP5) simulations?
- Is the variability forced or intrinsic?

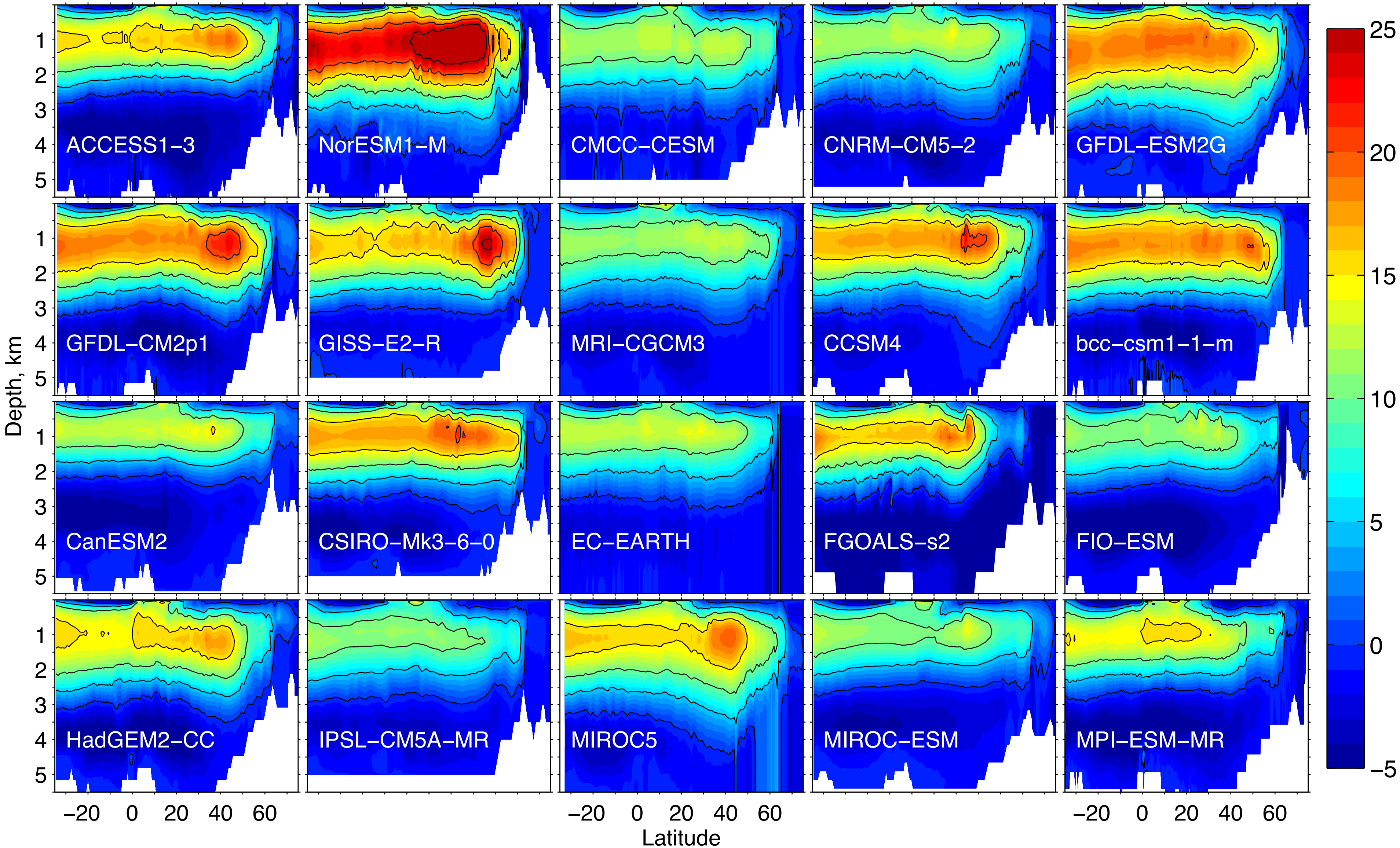
Approach

- 18 global simulations forced with CORE II 60-year atmospheric forcing. Focus is on the last cycle of 5 (Danabasoglu et al., 2014, 2016). Grid spacing is on the order of 1 degree – same models used in CMIP
- 20 global ocean simulations from CMIP5 historical runs (current atmospheric composition)
- Period of analysis is 1948-2006 for the COREII forced runs and 1947-2005 for the CMIP5 runs

Mean AMOC-COREII



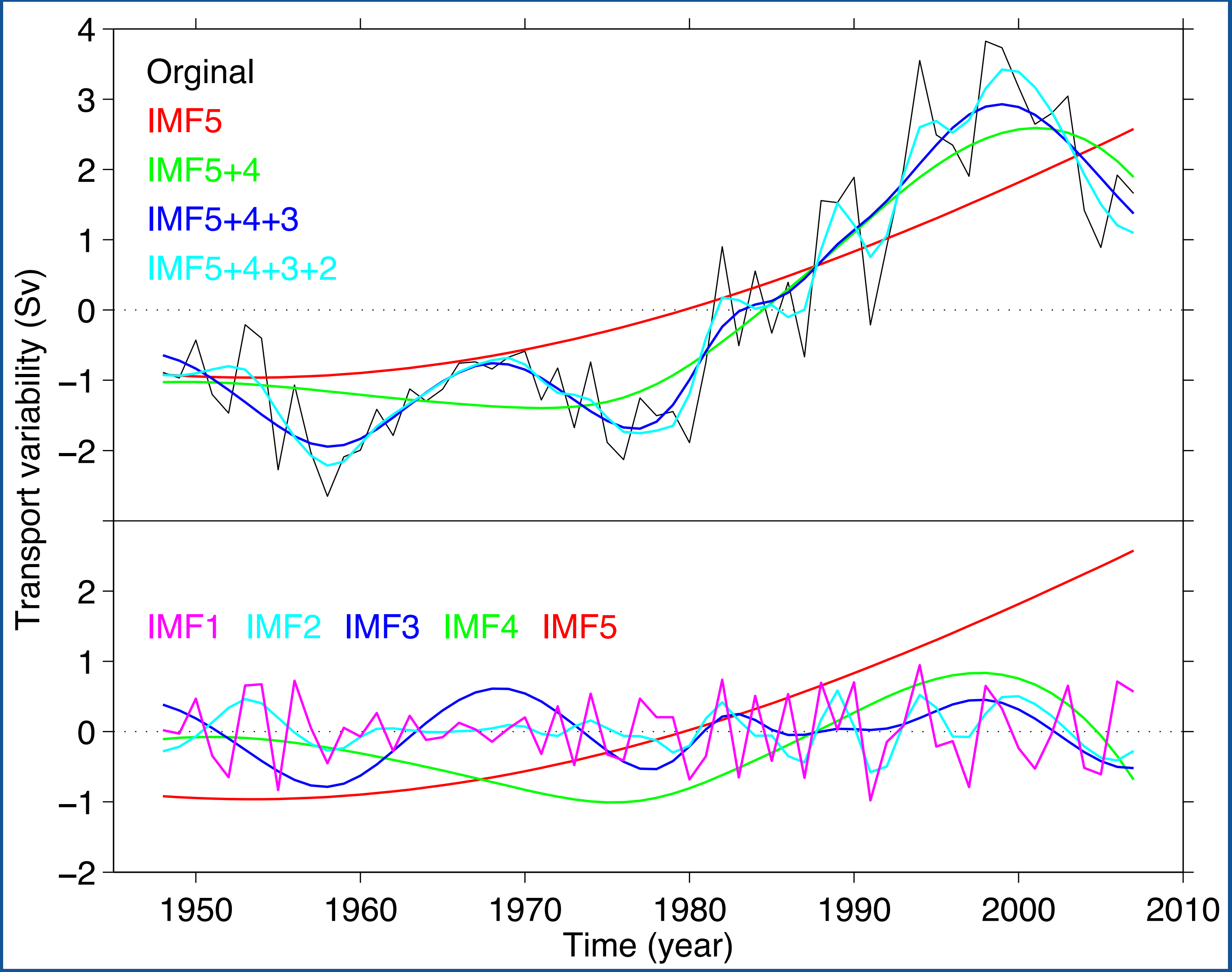
Mean AMOC-CMIP5



Time mean AMOC

- Both COREII and CMIP5 simulations exhibit a similar extent of the meridional overturning circulation, with a maximum at depth near 1 km.
- The range of the AMOC transport varies greatly at 26° N:
  - 10.5-18 Sv in COREII (mean is 13.9 Sv)
  - 11-31 Sv in CMIP5 (mean is 16.4 Sv)
  - 17 Sv (RAPID data)

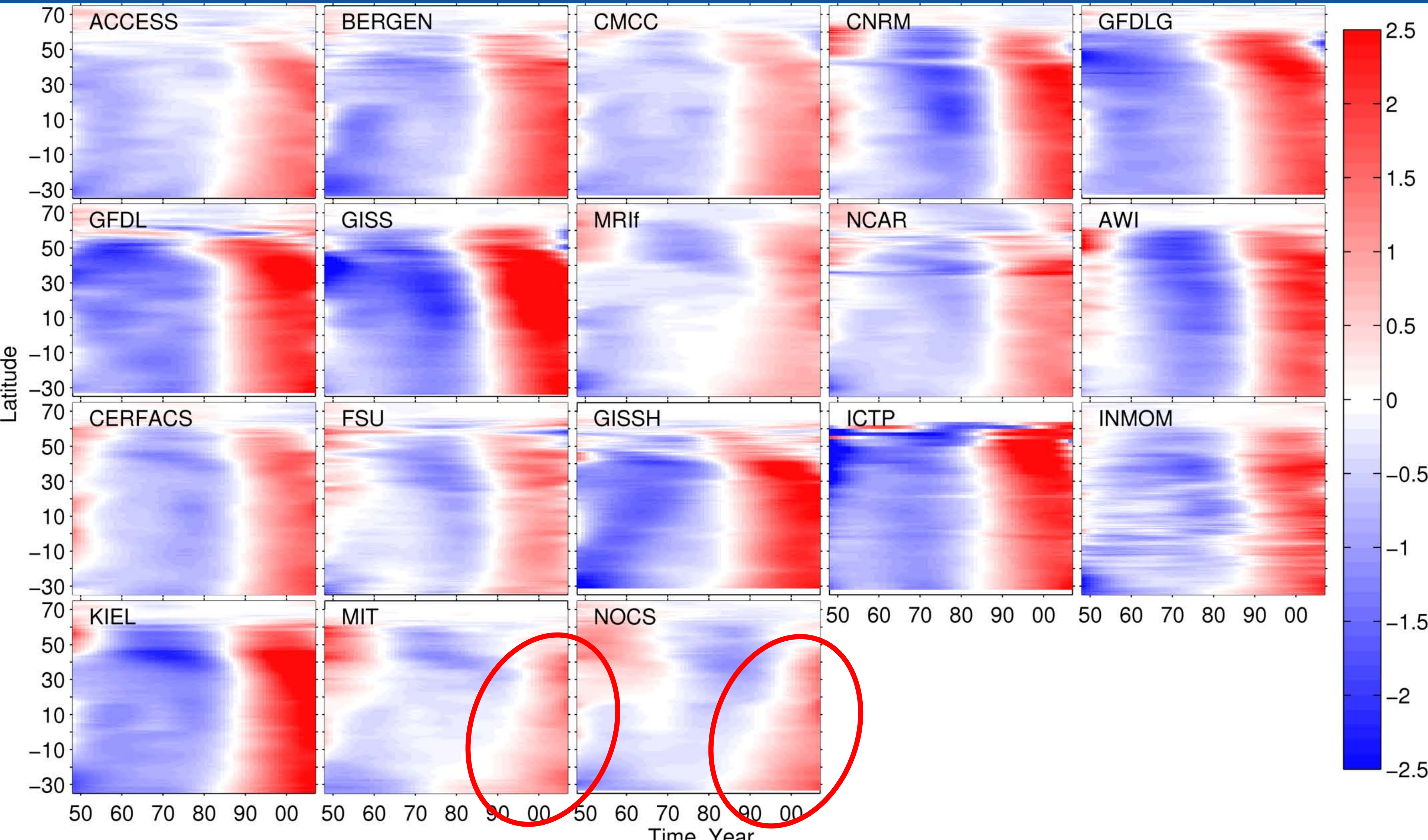
AMOC variability on different time scales



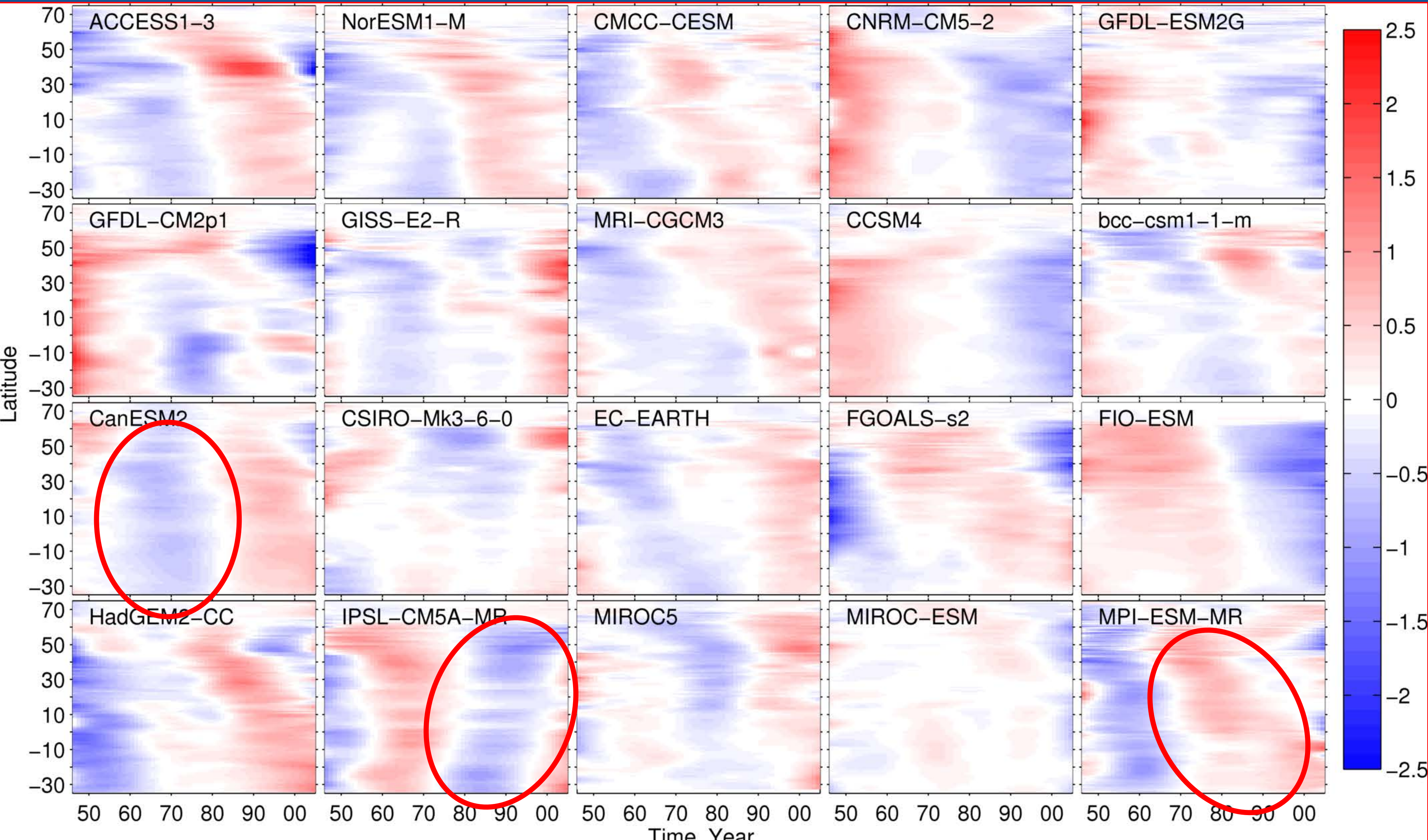
GFDL
COREII
at
26° N

AMOC transport variability decomposed using the Ensemble Empirical Mode Decomposition (EEMD) into intrinsic mode functions (IMFs)
IMF5+4 (multidecadal), IMF3 (decadal), IMF2+1 (interannual)

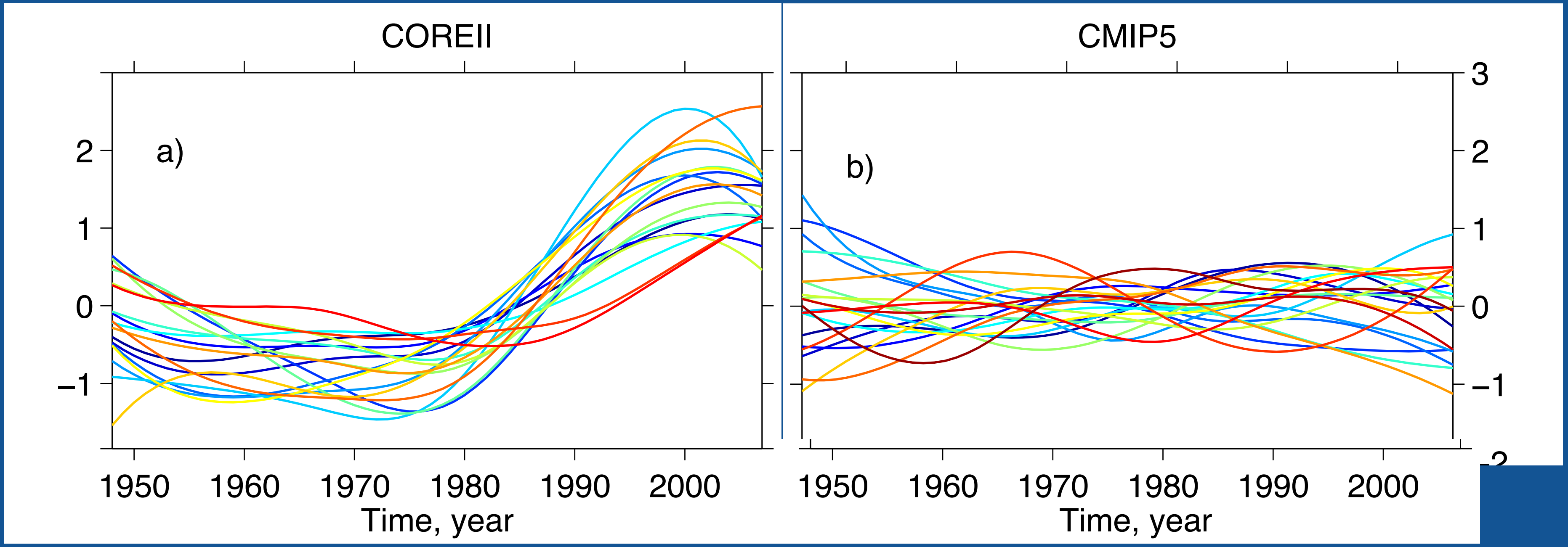
Multidecadal variability-COREII



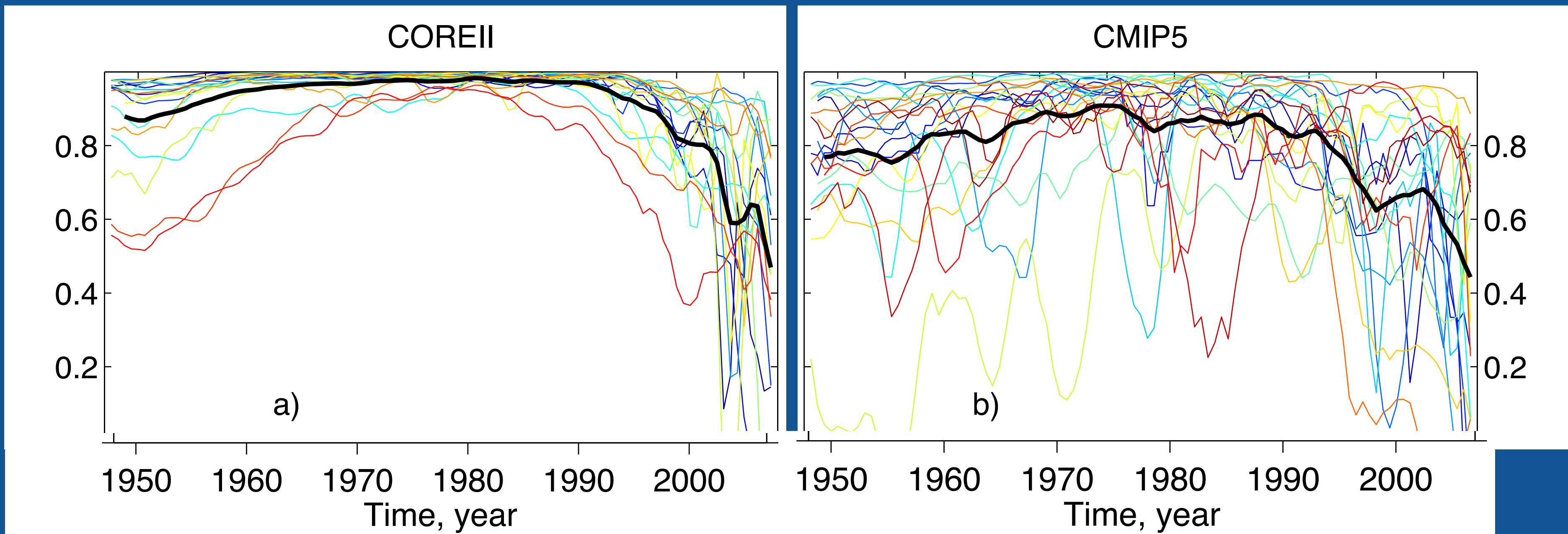
Multidecadal variability-CMIP5



Multidecadal AMOC variability for the whole Atlantic averaged over 30ºS-60ºN

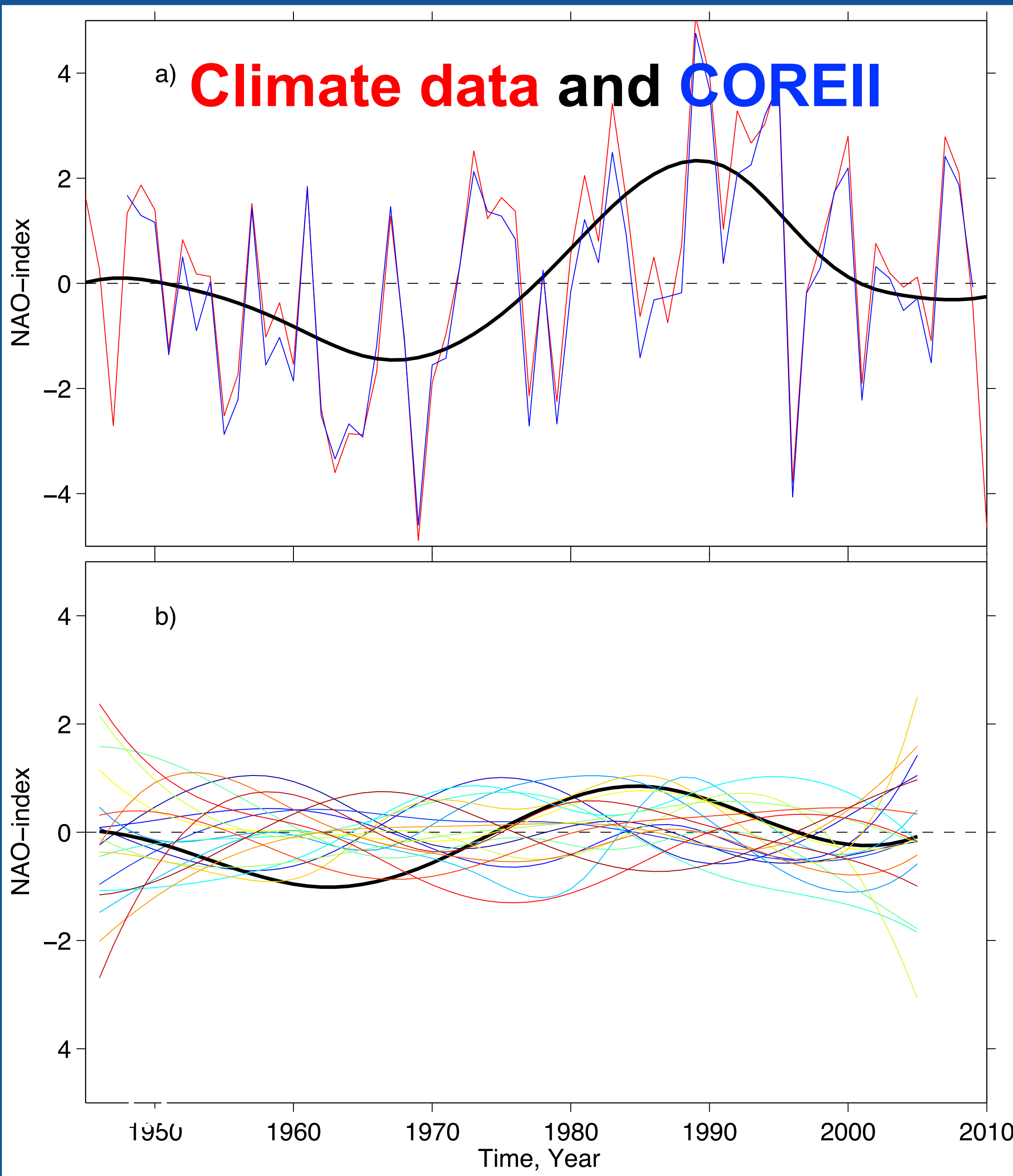


Multidecadal meridional coherence

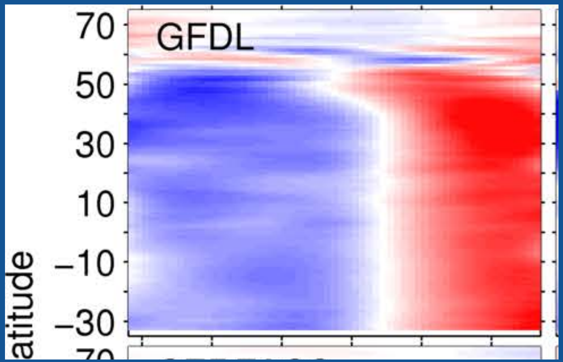


Correlation of AMOC variability at a specific latitude and averaged over 30ºS-60ºN

Why the long-term variability difference?

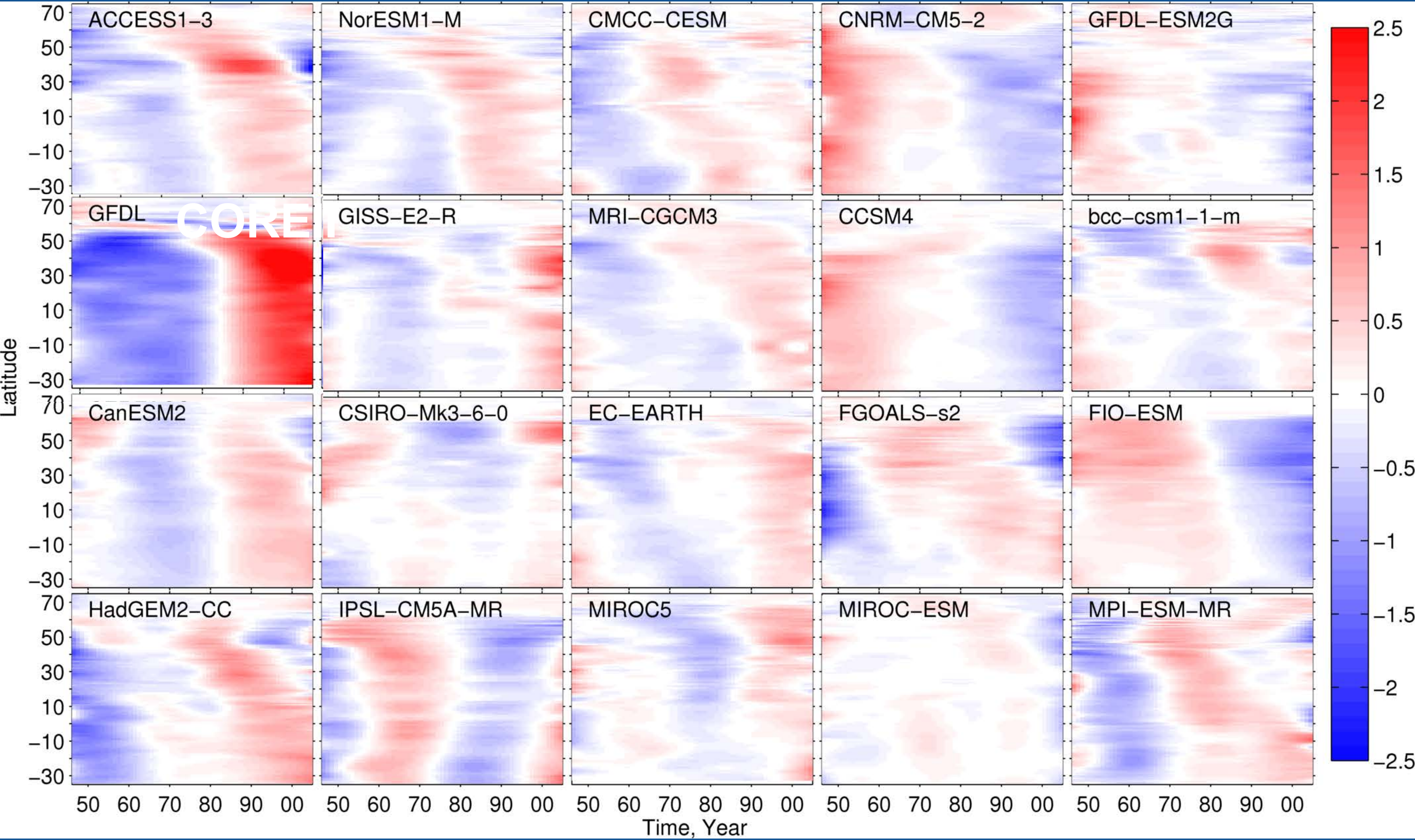


Is the long-term AMOC variability in COREII simulations associated with the NAO?

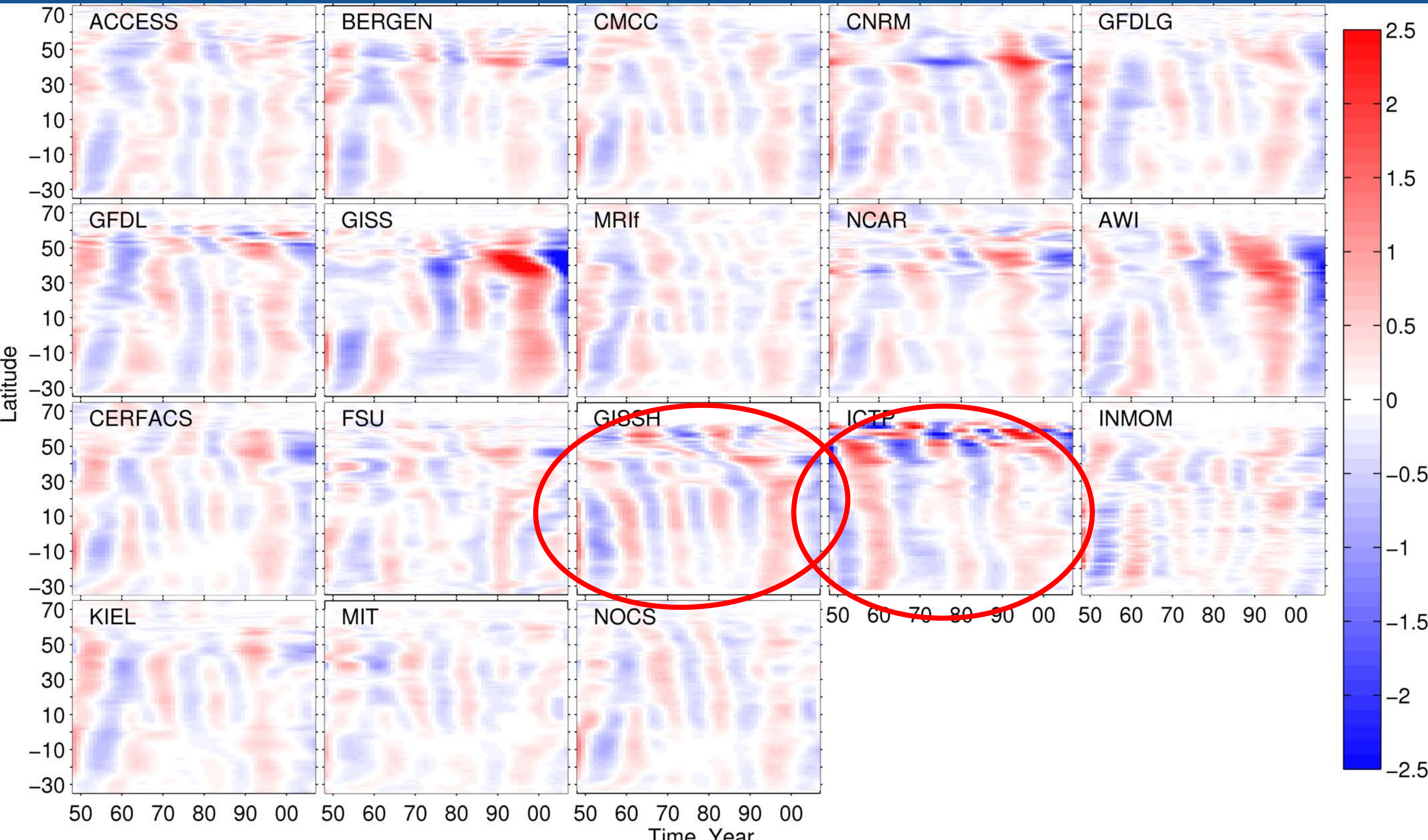


The NAO representation in the CMIP5 simulations differs significantly between the COREII simulations and observations

Multidecadal variability-CMIP5

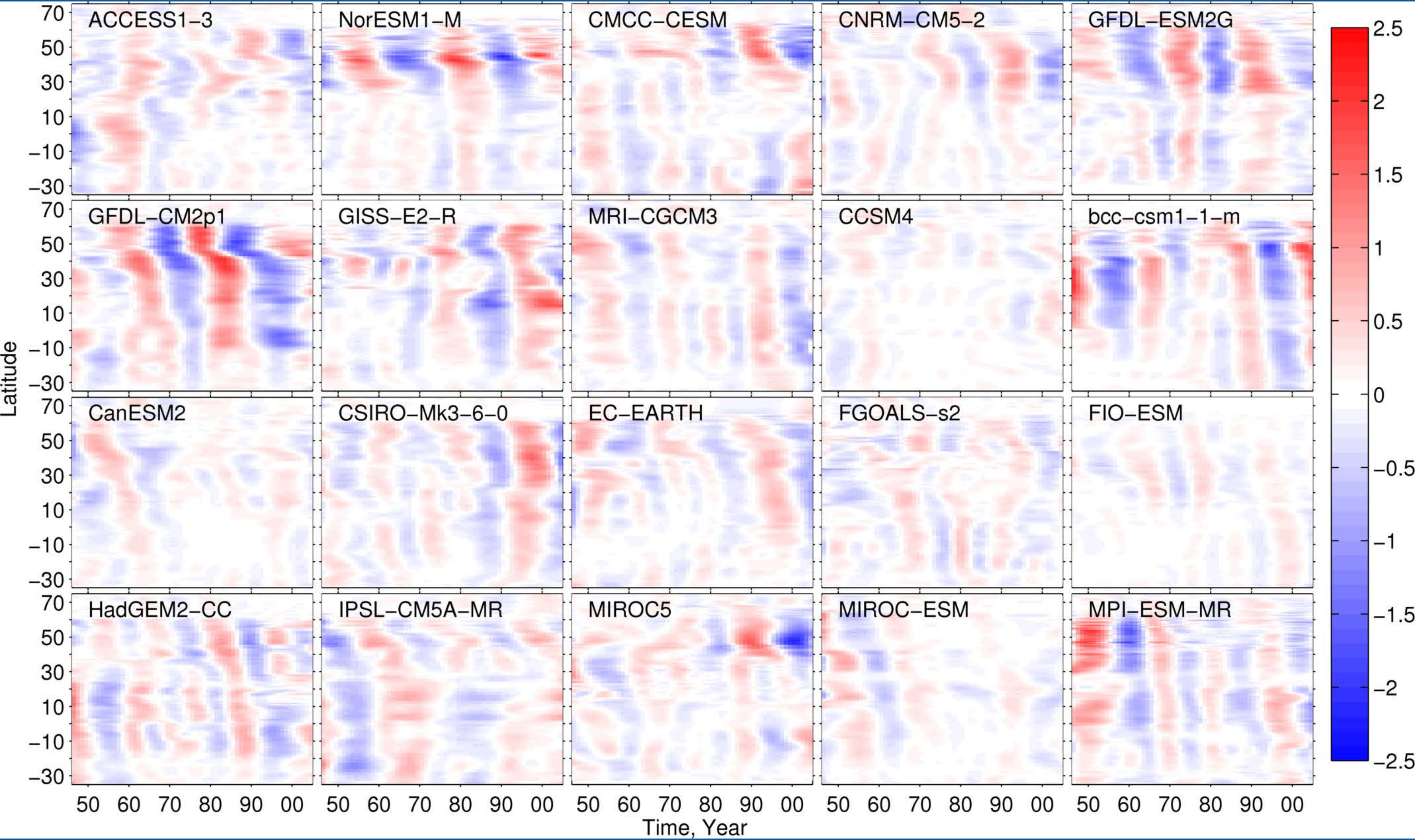


Decadal variability-COREII

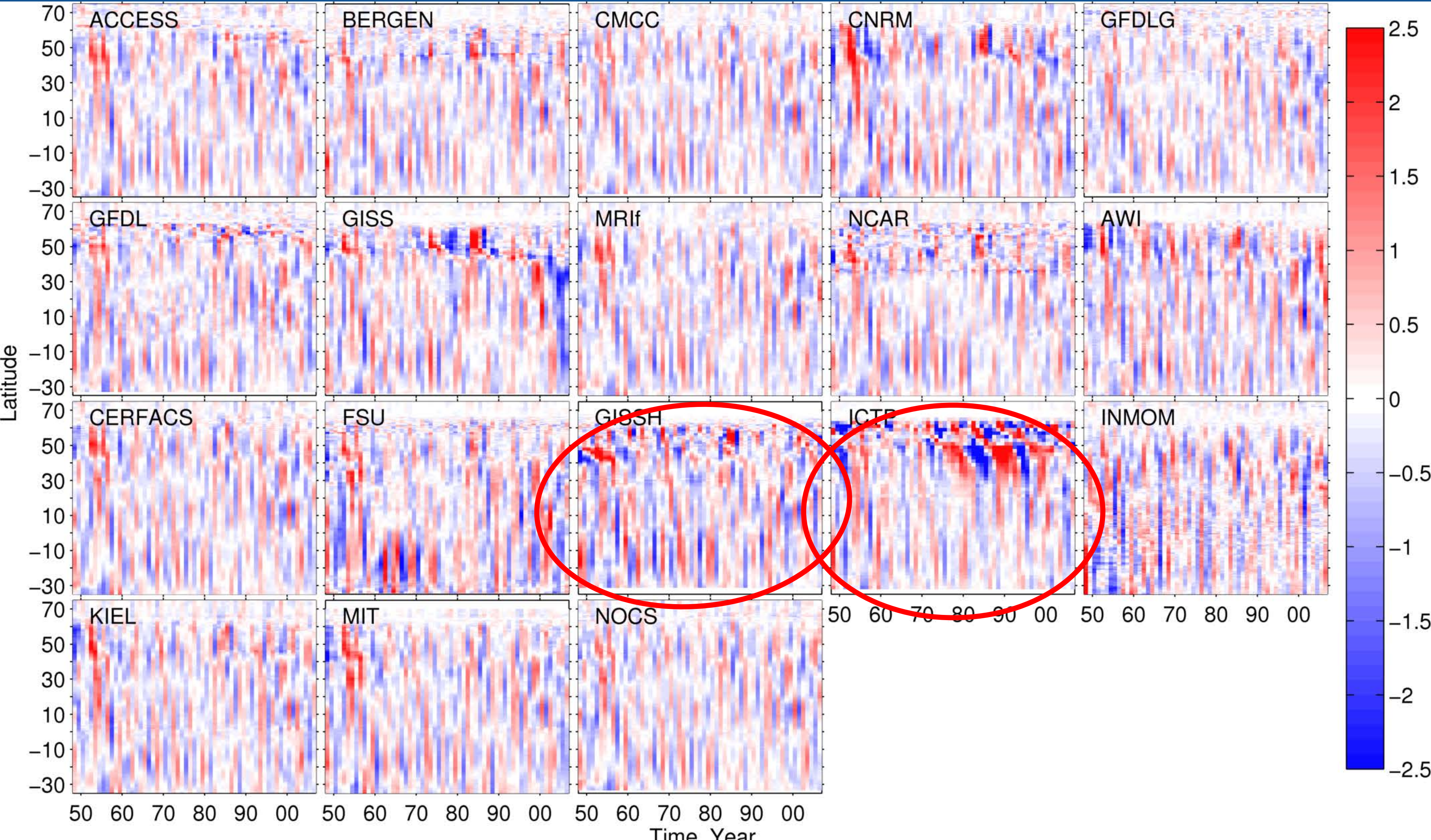


intrinsic variability?

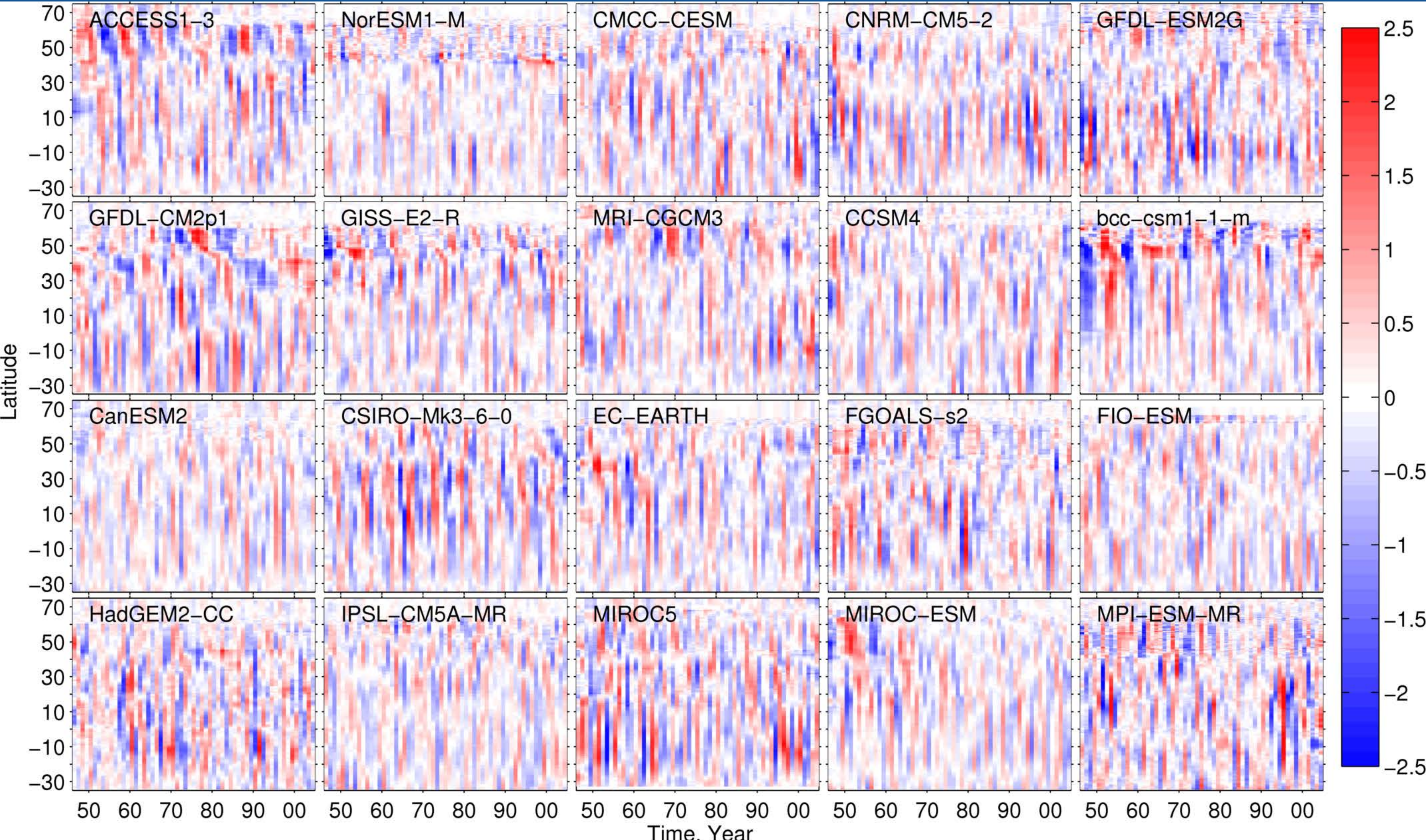
Decadal variability-CMIP5



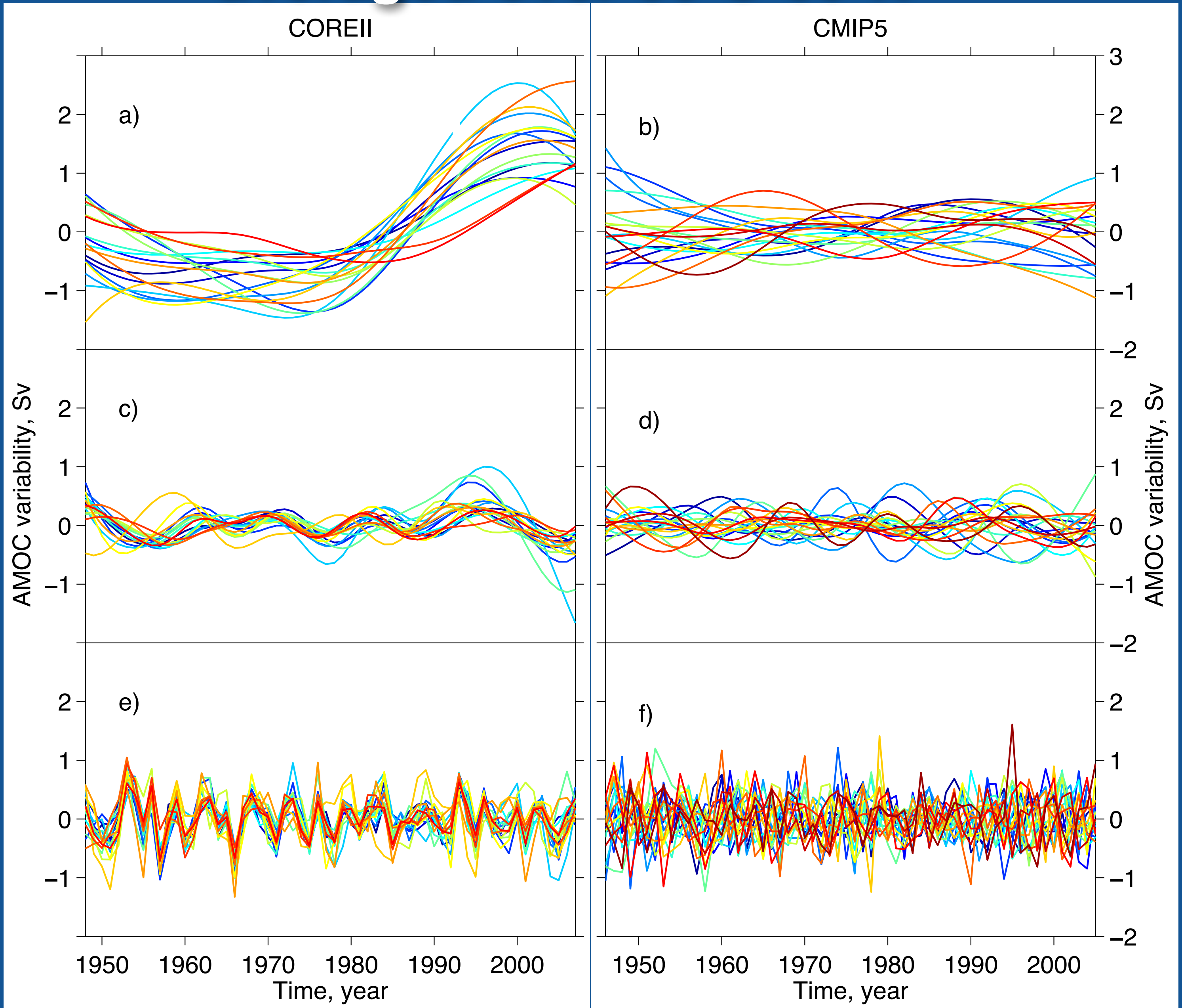
Interannual variability-COREII



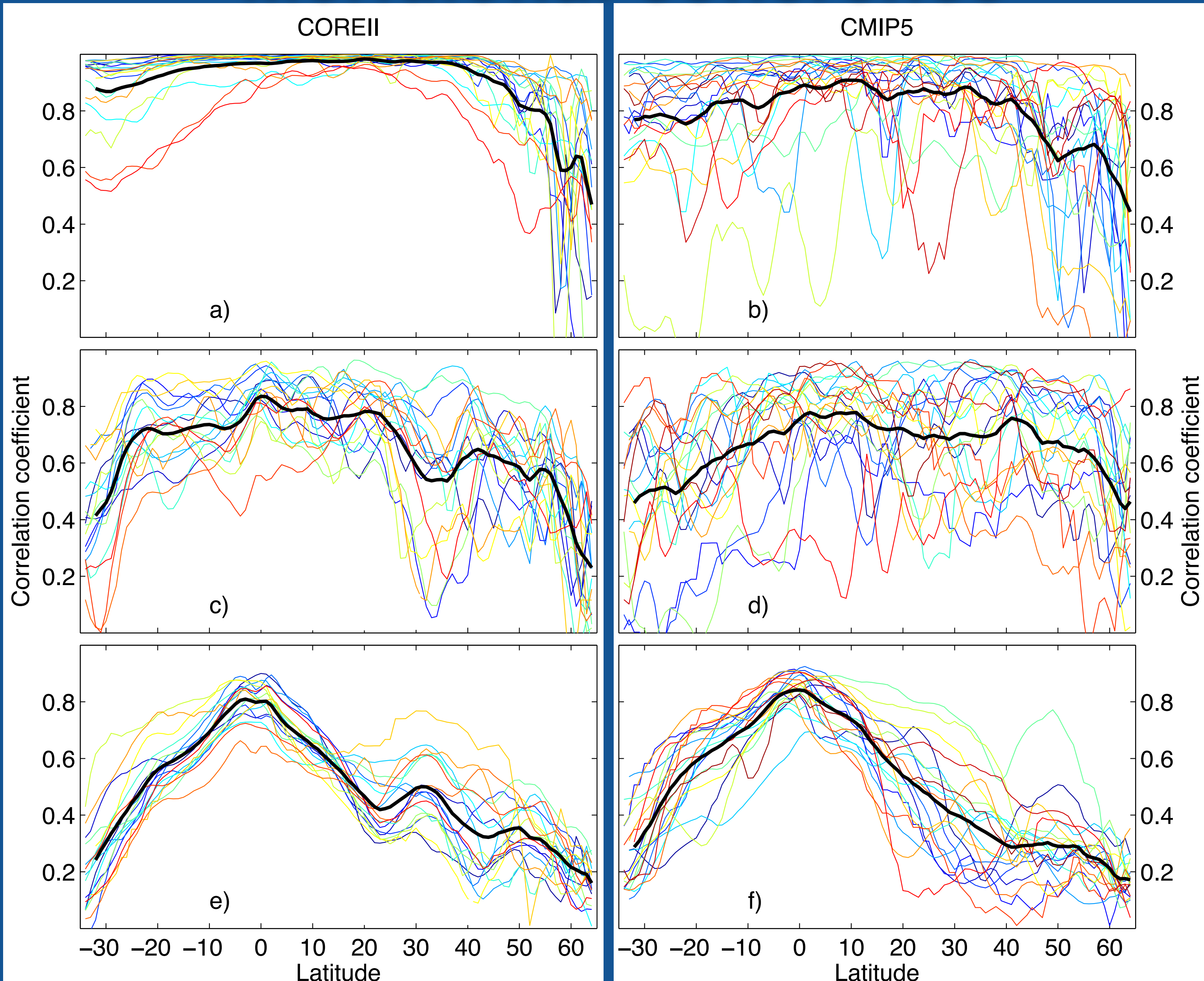
Intrannual variability-CMIP5



AMOC variability for whole Atlantic averaged over 30ºS-60ºN



Meridional coherence



Correlation of AMOC variability at a specific latitude and averaged over 30°S-60°N

Summary

- AMOC variability is consistent among the forced COREII simulations, not in the coupled CMIP5 simulations.
- On multi-decadal time, magnitude of the variability is smaller in the CMIP5 simulations than in the COREII simulations. There are significant differences in meridional coherence in the CMIP5 simulations. The NAO connection is unclear.
- On decadal and interannual time scales, the magnitude and meridional coherence of the AMOC variability in CMIP5 simulations are statistically similar to those COREII simulations, although the phase of the variability differs.

References

- Xu, X., E.P. Chassignet, and F. Wang, 2017. Variability of the Atlantic meridional overturning circulation in forced versus coupled simulations. In preparation.
- Xu, X., P.B. Rhines, and E.P. Chassignet, 2016. Temperature-salinity structure of the North Atlantic circulation and associated heat and freshwater transports. *J. Climate*, 29, 7723-7741, doi:10.1175/JCLI-D-15-0798.1.
- Xu, X., E.P. Chassignet, W.E. Johns, W.J. Schmitz Jr., and E.J. Metzger, 2014. Intraseasonal to interannual variability of the Atlantic meridional overturning circulation from eddy-resolving simulations and observations. *J. Geophys. Res.*, **119**, doi:10.1002/2014JC009994.
- Xu, X., W.J. Schmitz Jr., H.E. Hurlburt, and P.J. Hogan, 2012: Mean Atlantic meridional overturning circulation across 26.58N from eddy-resolving simulations compared to observations. *J. Geophys. Res.*, 117, C03042, doi:10.1029/2011JC007586.