Signatures of the AMOC at the ocean's surface and below

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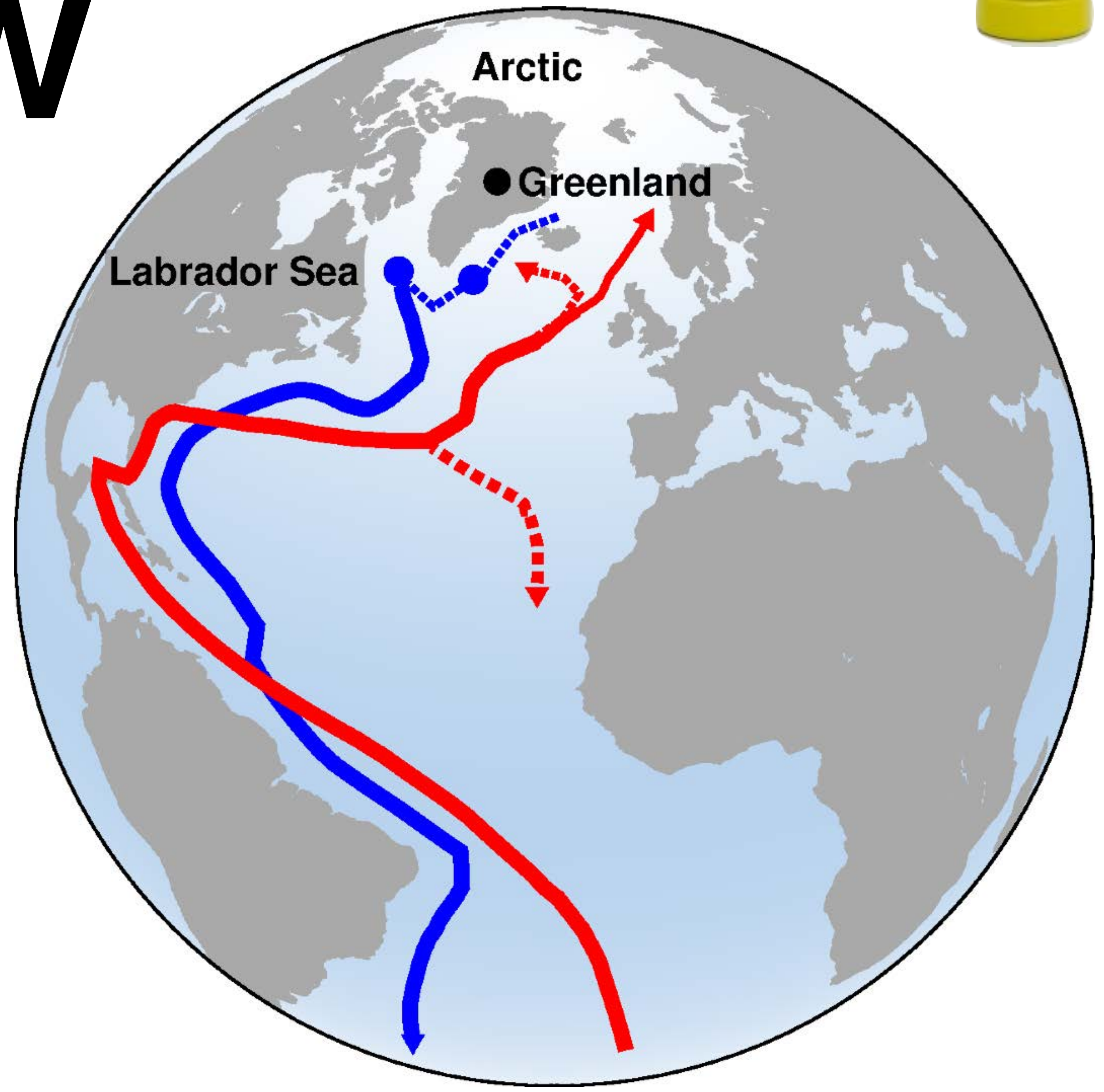

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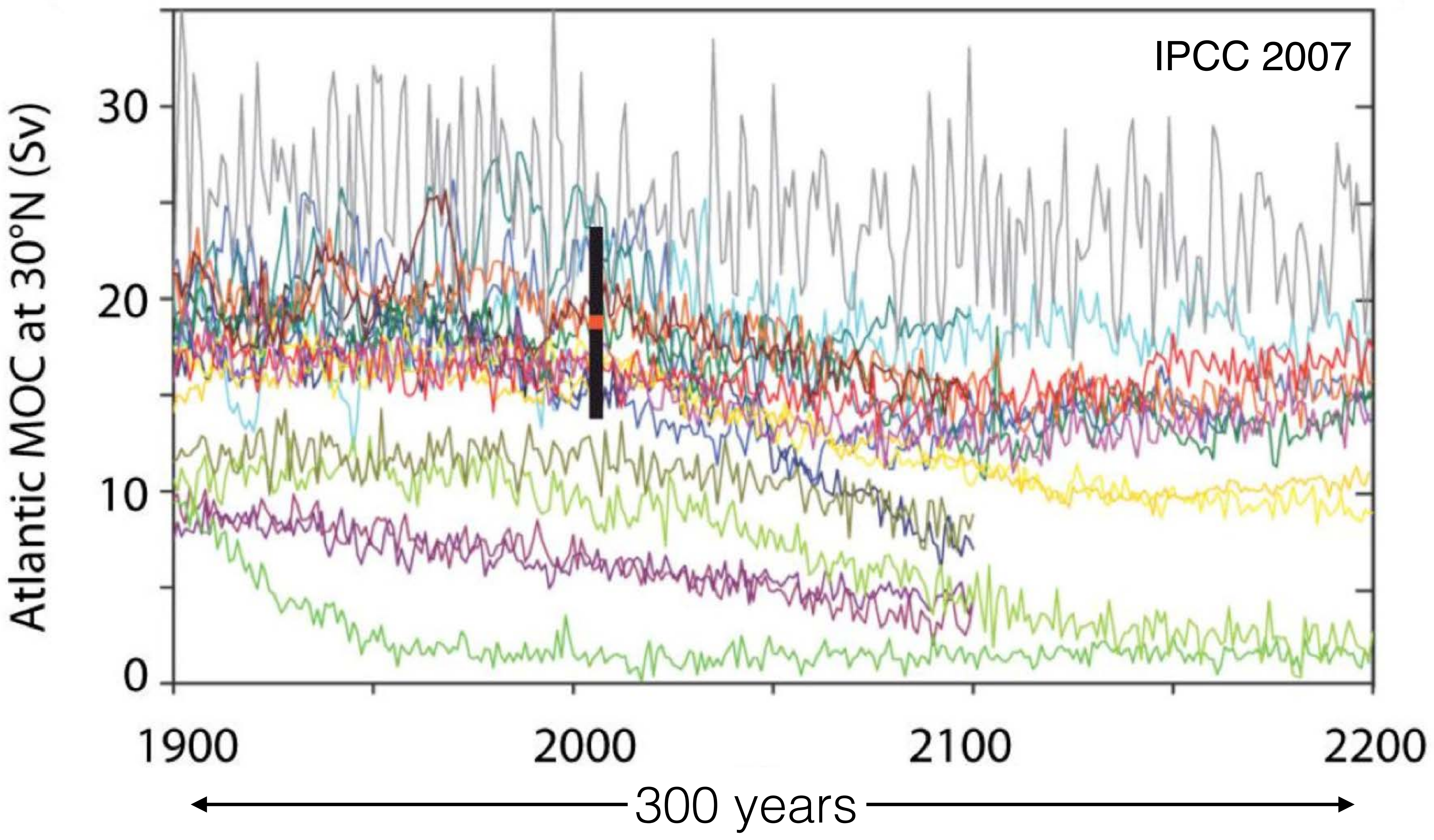
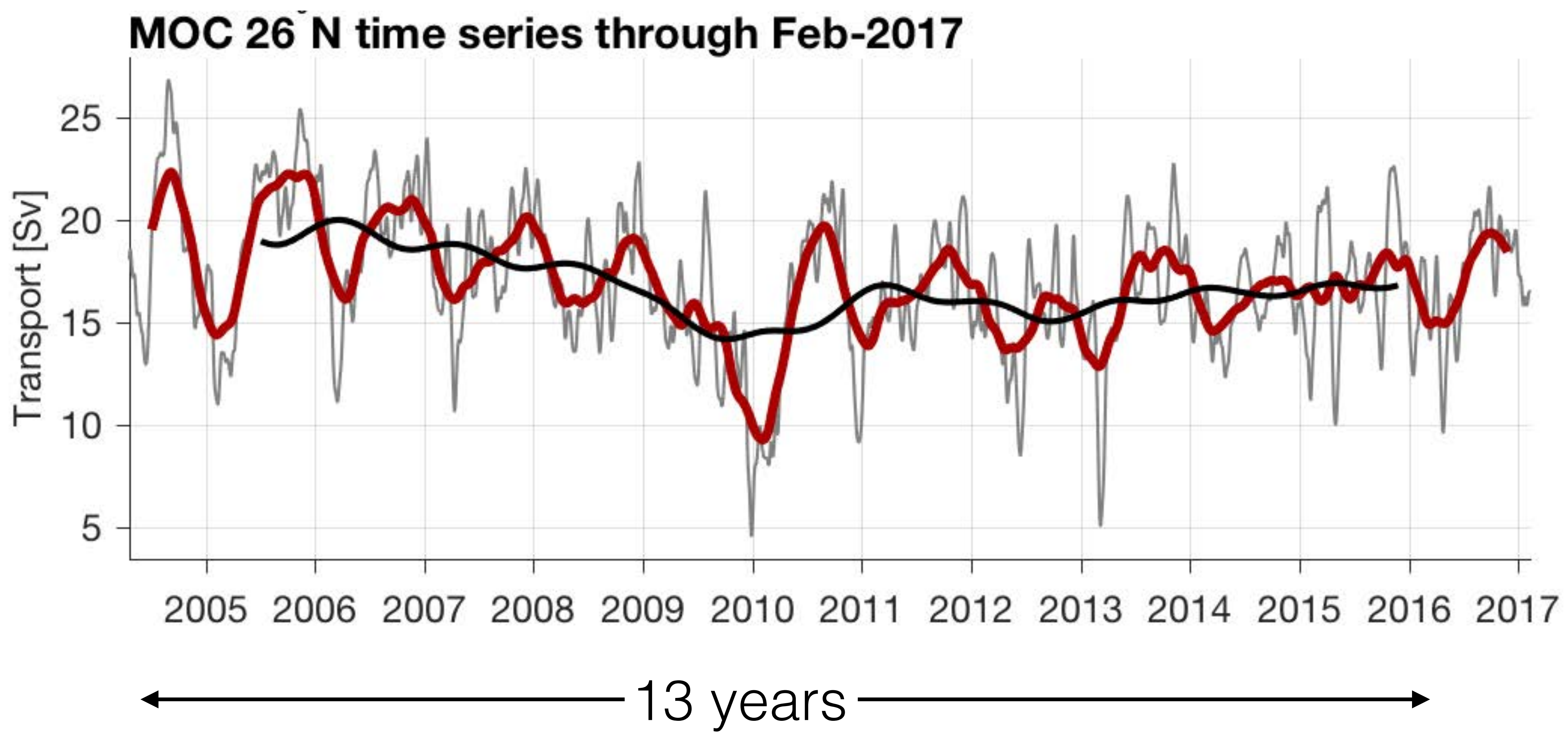
AMOC meeting, Miami 2018

AMOC slowdown?



Climate models predict that the MOC will slow down in the next century



Short observational record of the **directly observed AMOC strength** limits investigations into long term behaviour.

If we look at the **signatures of AMOC changes at the surface and subsurface** of the Atlantic, we may be able to better understand the long term behaviour and associated impacts of AMOC changes…

Fingerprints of the AMOC

What are fingerprints?

"coherent patterns of response to the ocean circulation are generally known as fingerprints"

- Alexander-Turner et al. (2018)

Importantly: Fingerprints may appear in **variables with longer records** than those of AMOC transport

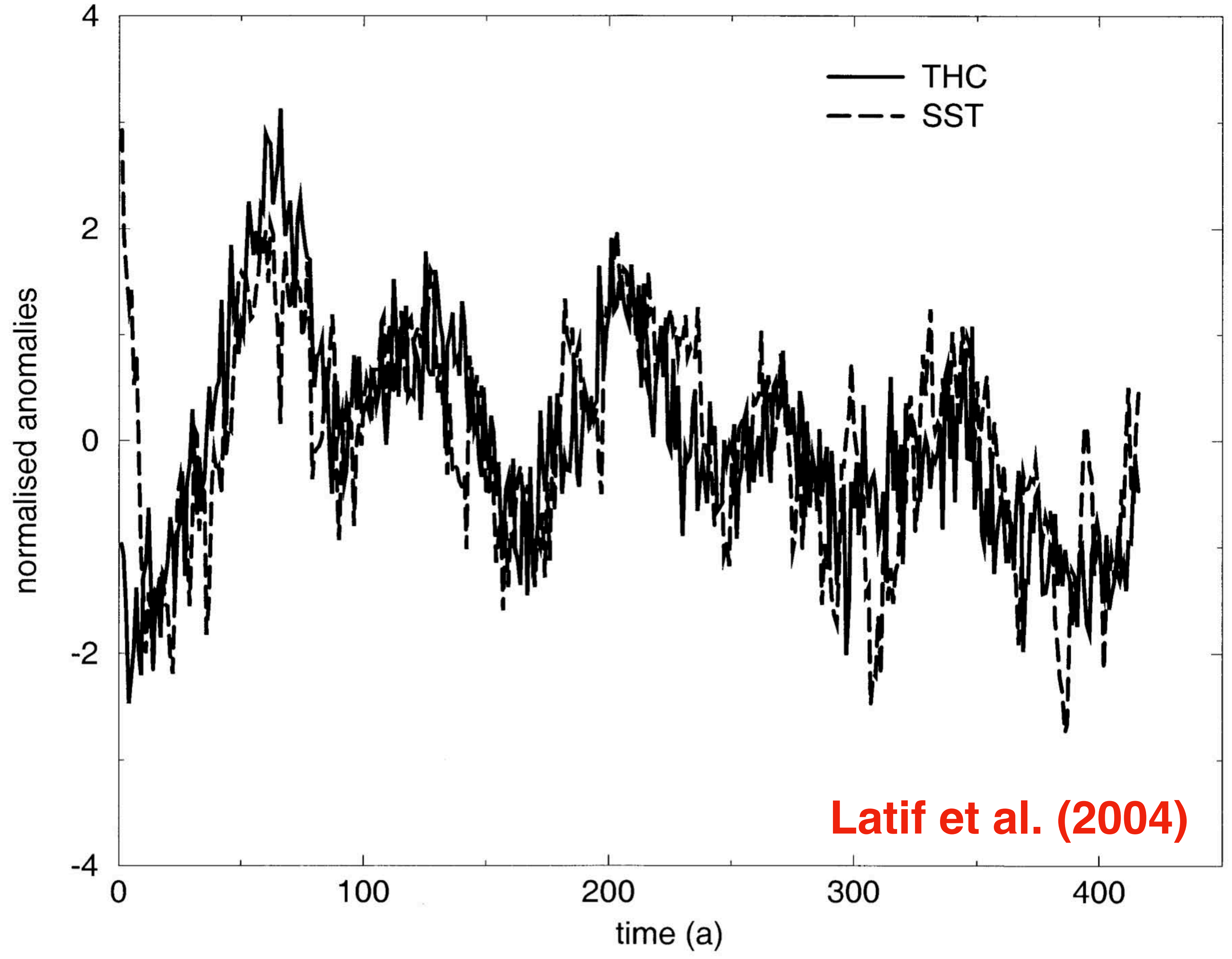


FIG. 3. Time series of simulated annual mean North Atlantic SST anomalies (40°–60°N and 50°–10°W, dashed line) and annual mean anomalies of the maximum overturning at 30°N (full line), a measure of the strength of the model's thermohaline circulation.

What are fingerprints?

“coherent patterns of response to the ocean circulation are generally known as fingerprints”

- Alexander-Turner et al. (2018)

Importantly: Fingerprints may appear in **variables with longer records** than those of AMOC transport

- Examples of a few fingerprints
- Assumptions of fingerprints
- Uses of fingerprints

This talk: Modern record

What fingerprints might we look for?

Variables often used: Sea surface height (SSH), sea surface temperature (SST), subsurface temperature and upper ocean heat content (OHC)

OHC changes due to fluxes:

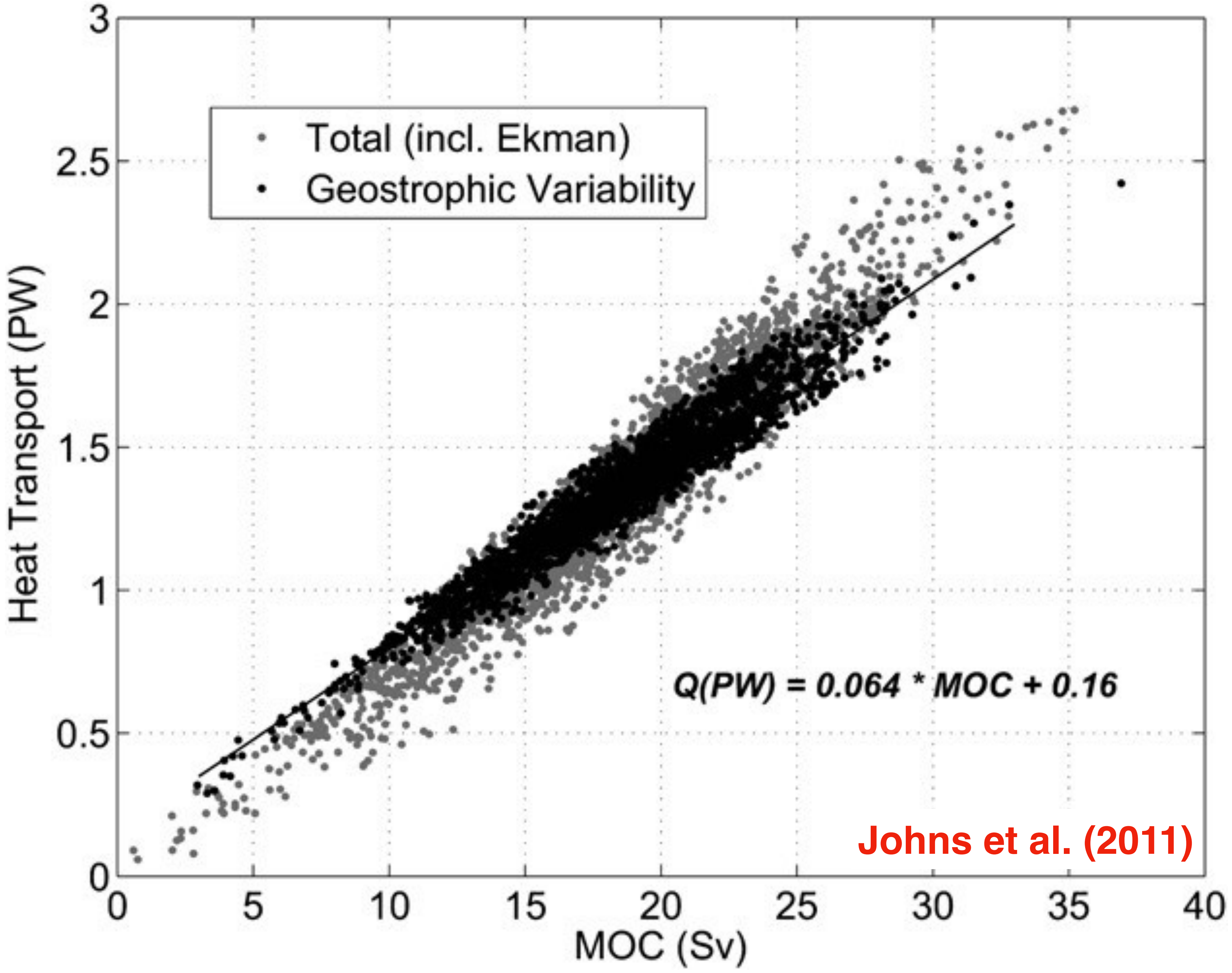
$$\mathrm{OHC}(t) - \mathrm{OHC}(t_0) = \int_{t_0}^{t} F' + S' - N' \mathrm{d}t,$$

Where F' is air-sea flux, S' (N') are heat transport through a southern (northern) boundary

$$\frac{dOHC}{dt} \propto HT$$

(SSH may track OHC due to steric changes)

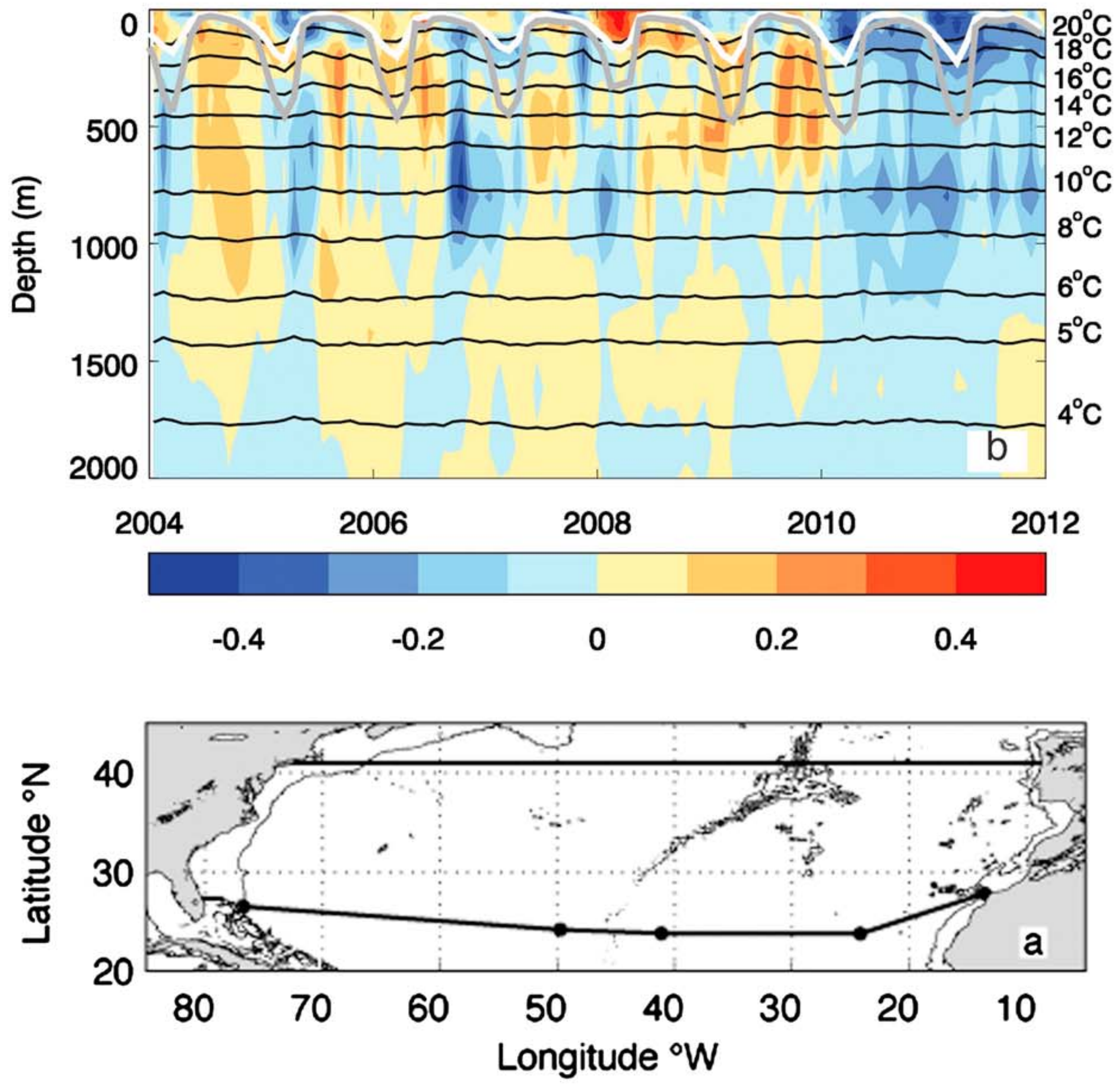
AMOC vs Meridional Heat Transport at 26N



What fingerprints might we look for?

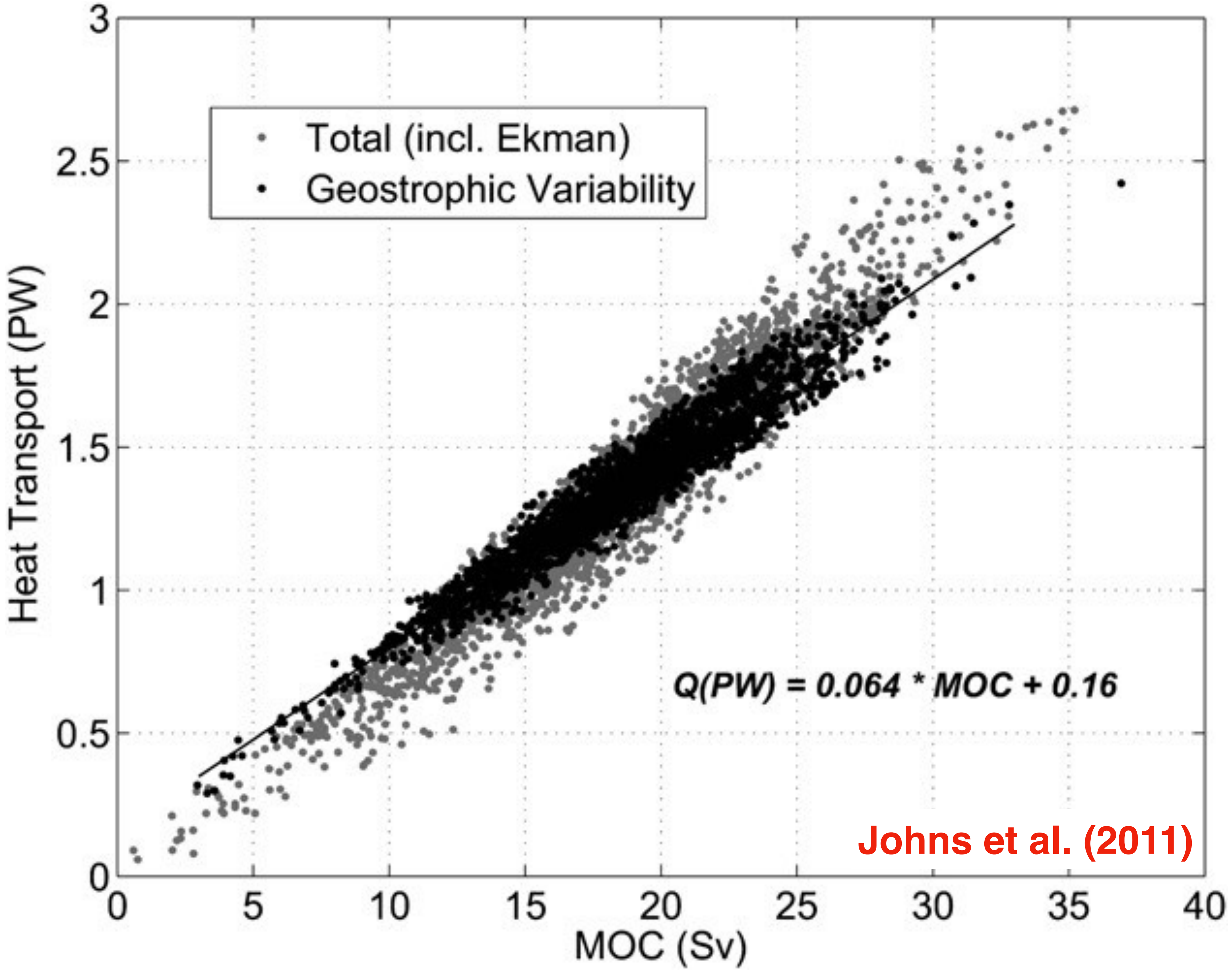
A change in the AMOC may drive a change in heat content in part of the ocean volume.

Subtropical cooling following AMOC dip in 2009/10



Cunningham et al. (2013)
Also Bryden et al. (2013)

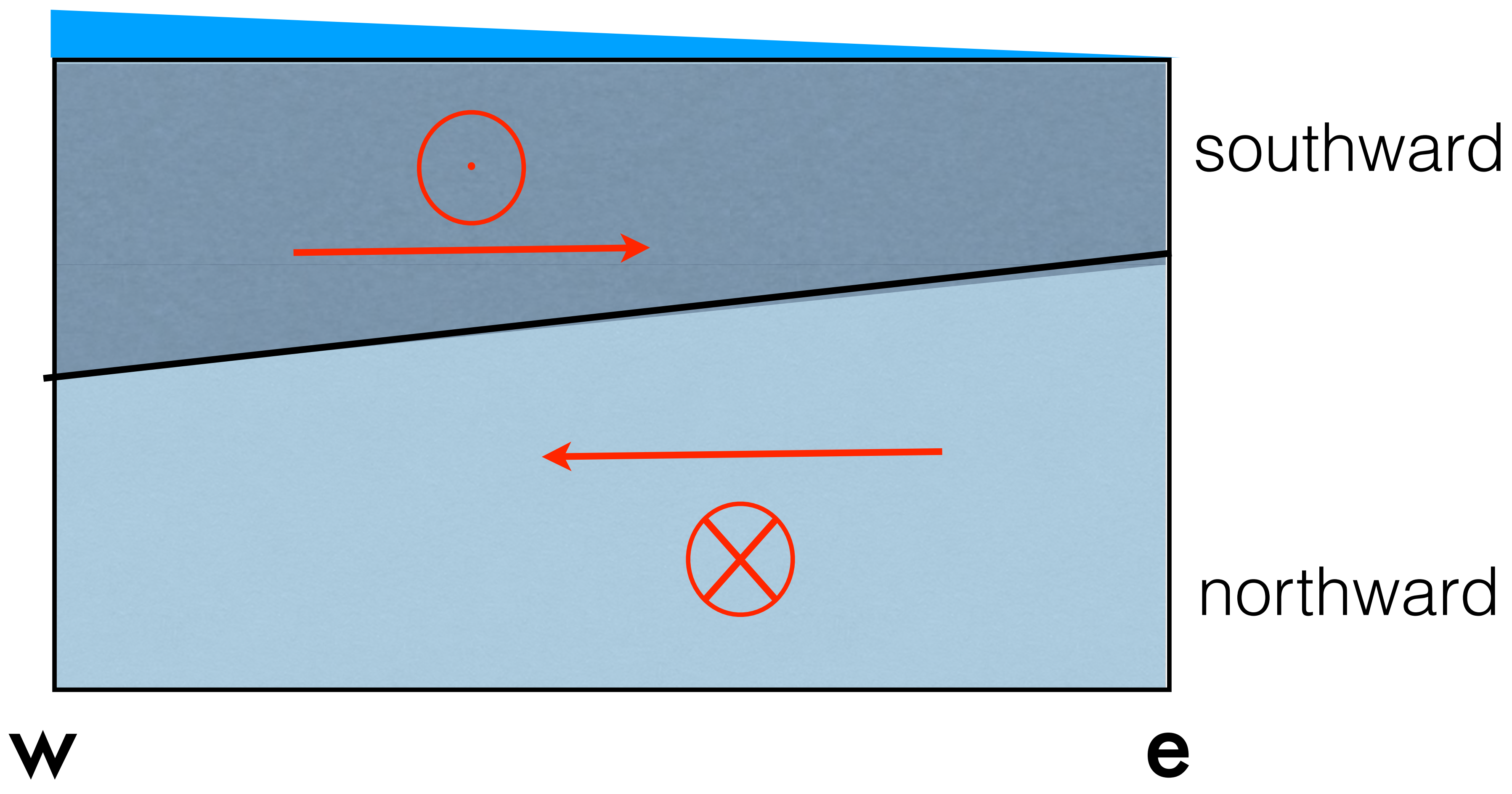
AMOC vs Meridional Heat Transport at 26N



Johns et al. (2011)

What fingerprints might we look for?

Variables often used: Sea surface height (SSH), sea surface temperature (SST), subsurface temperature and upper ocean heat content (OHC)



SSH gradients directly related to meridional velocities:

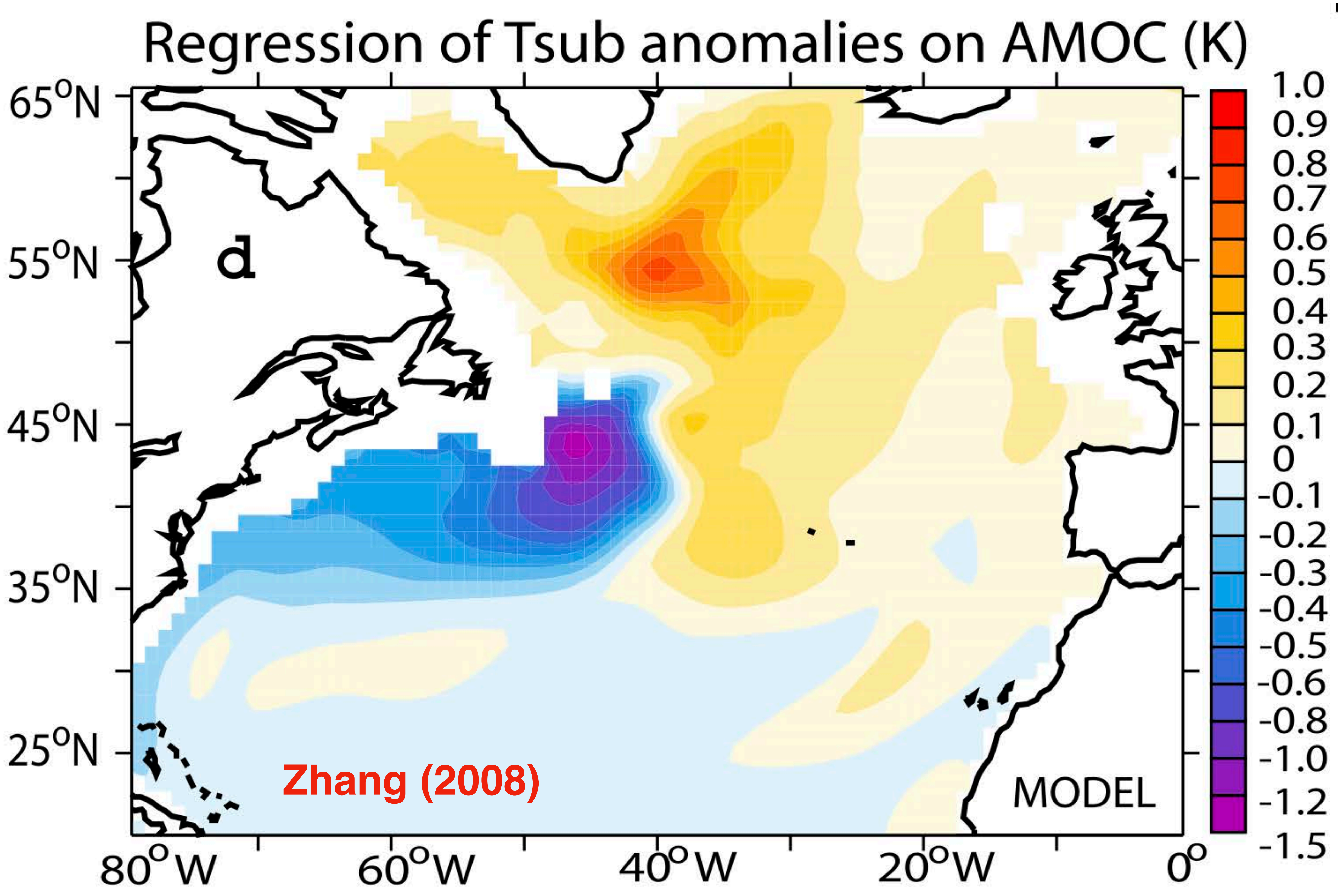
$$-fv_1 = -g\frac{\partial \eta}{\partial x}$$

inversely related to thermocline displacement, which is associated with shear

$$-f_0\frac{\partial v}{\partial z} = \frac{g}{\rho_0}\frac{\partial \rho}{\partial x}$$

Fingerprints of the AMOC

Often determined as a **correlation between the AMOC and a proxy** (e.g., SST or subsurface temperature)



Fingerprint: Regression between modelled AMOC at 40N and subsurface temperature at 400m

Model: GFDL CM2.1, 1000-year integration

Proxy: Tsub, SLA

Filtering/timescale: Detrended, annual means

Zhang (2008)

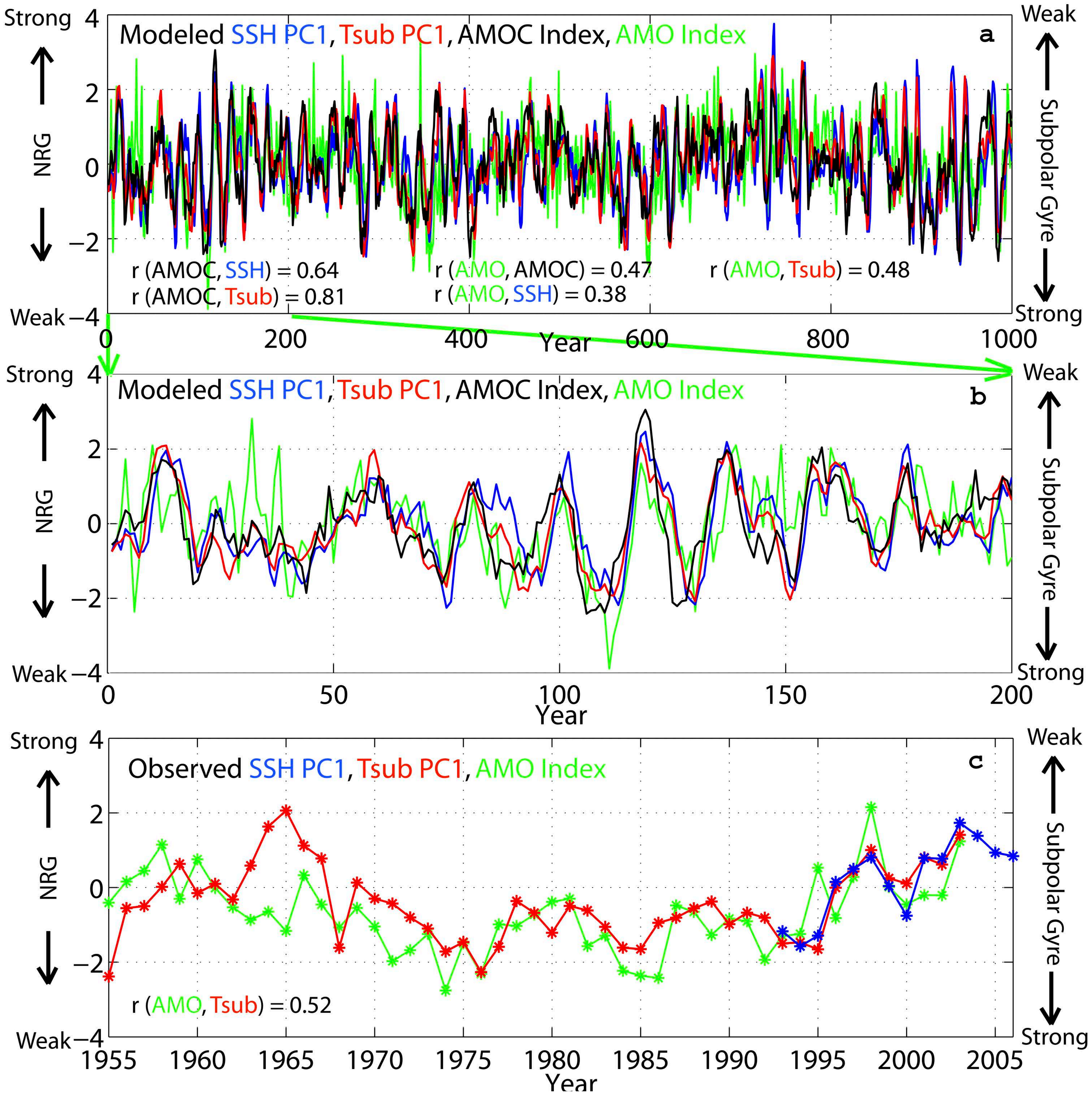
AMOC & AMO

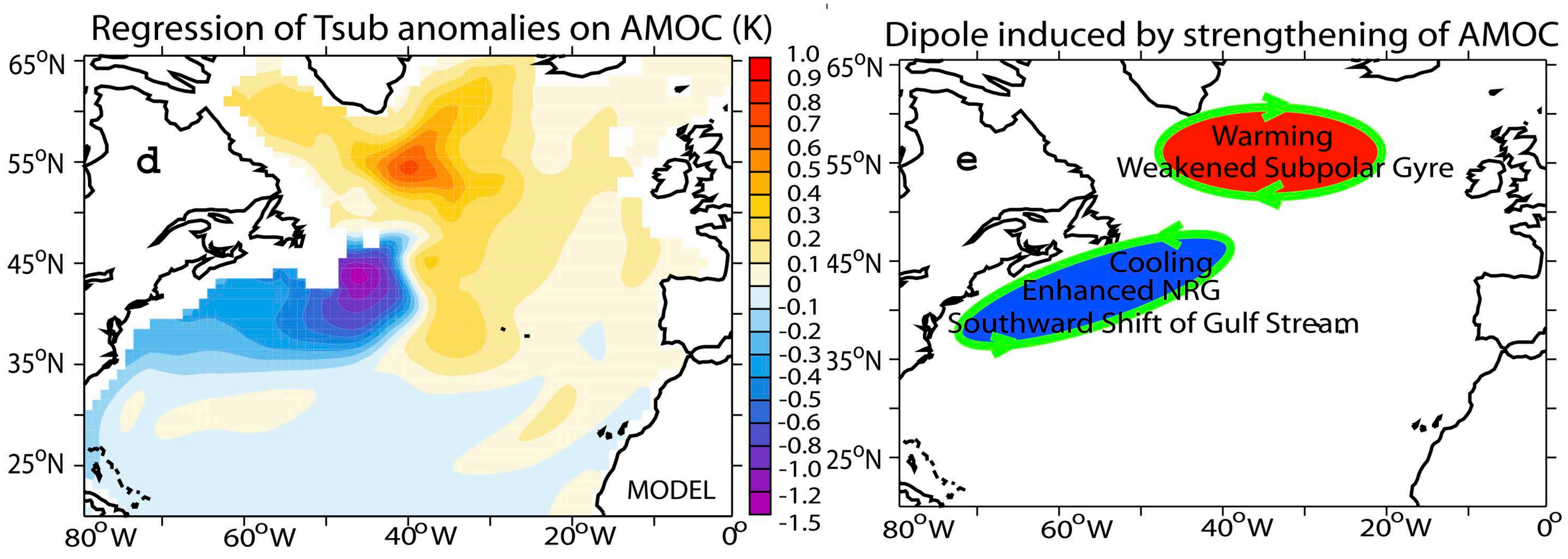
Data: Subsurface (400m) temperature, SSH 1993-2006

Model: GFDL CM2.1, 1000-year integration

Against: Modelled AMOC at 40N

Filtering/timescale: Annual means, detrended





Fingerprints with lags

Typically determined as a correlation between the AMOC and the proxy (e.g., SST or subsurface temperature)

Fingerprint: Lagged regression

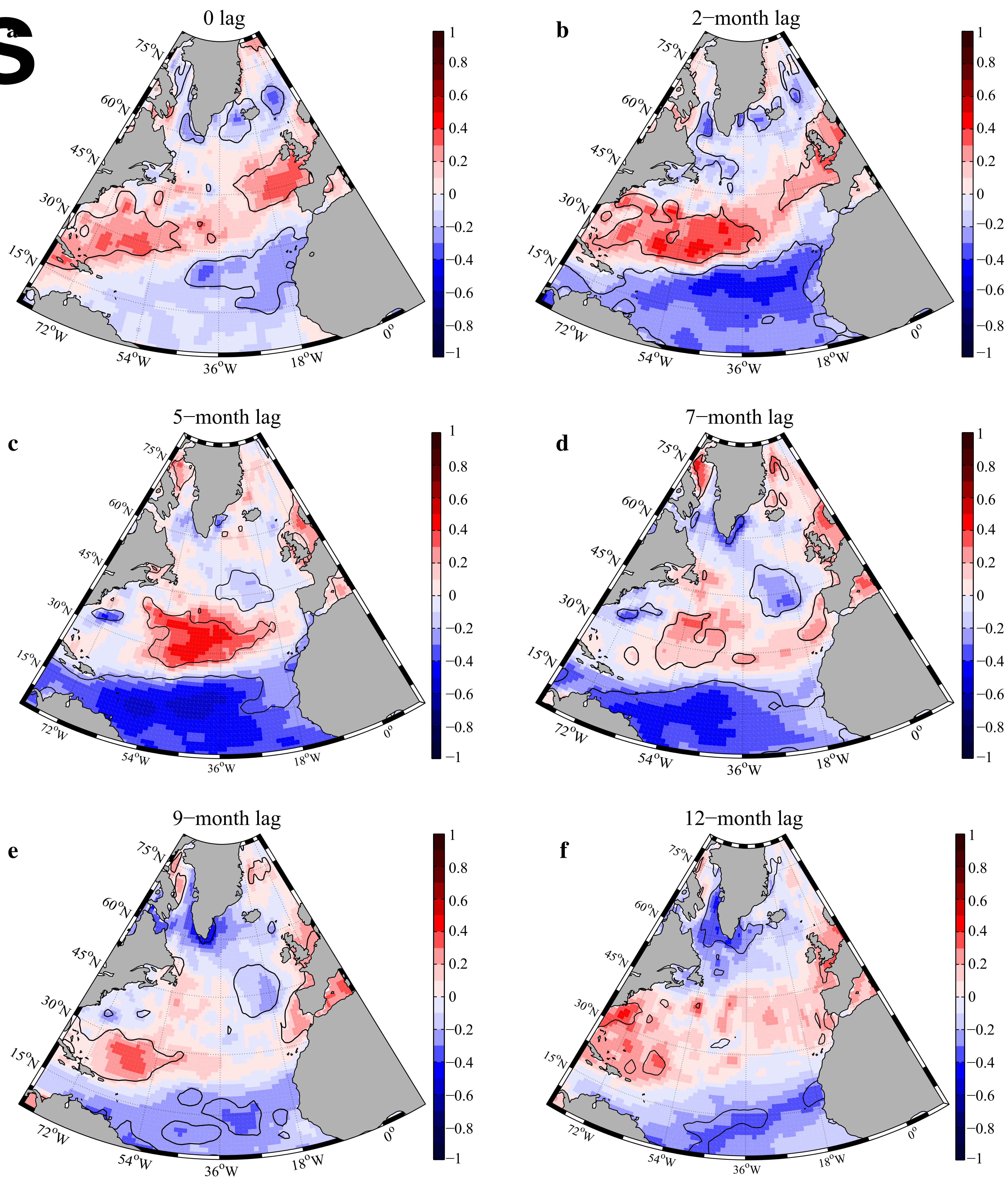
Proxy: SST - NOAA Reynolds OI

Against: RAPID AMOC 2004-2014

Filtering/timescale: Monthly data, 2-month running mean

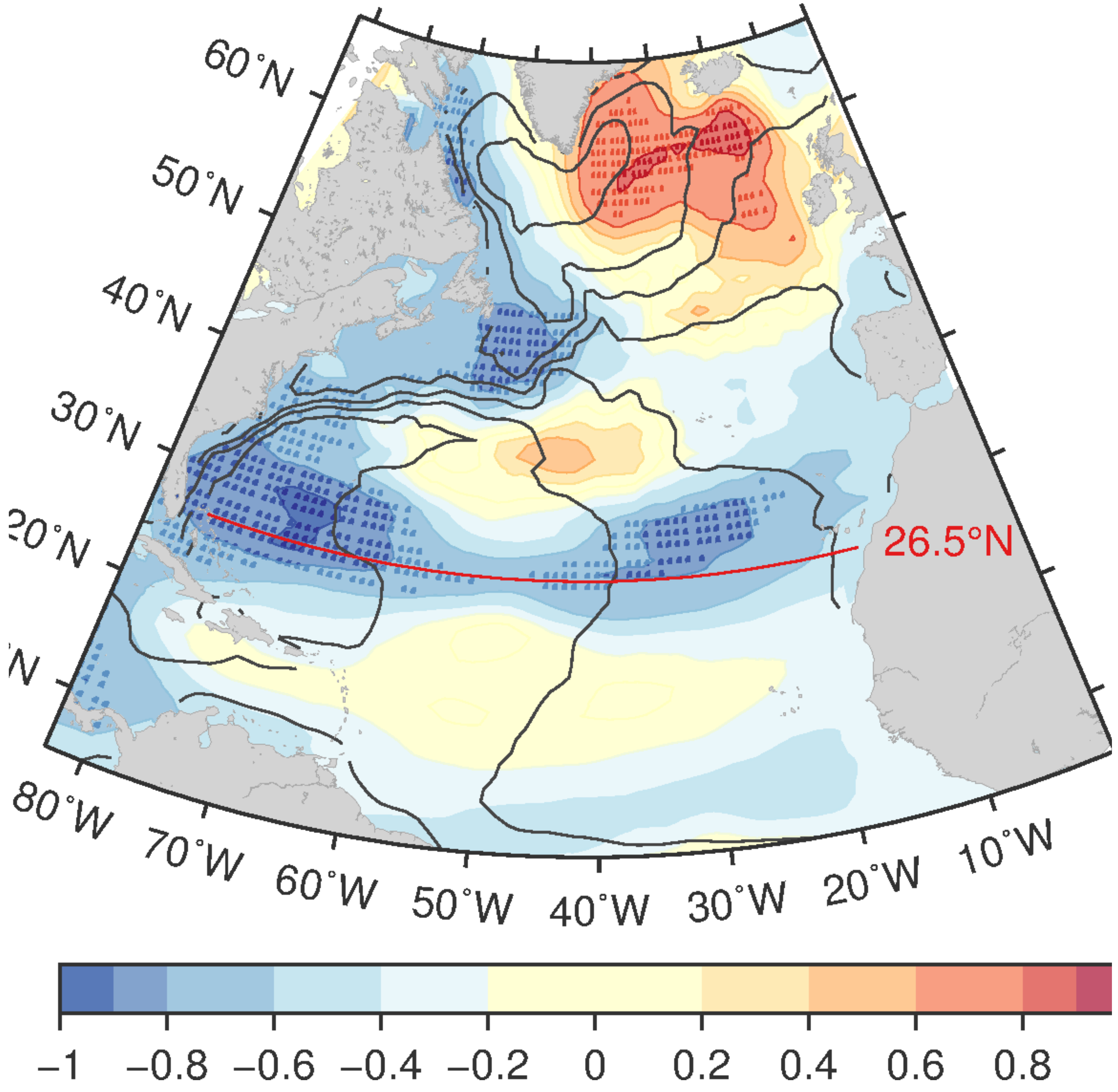
Lag: 5 months

AMOC−SST lagged correlations (AMOC leads) **Duchez et al. (2016a)**



Frajka-Williams (2015)

SSH proxy for ocean circulation

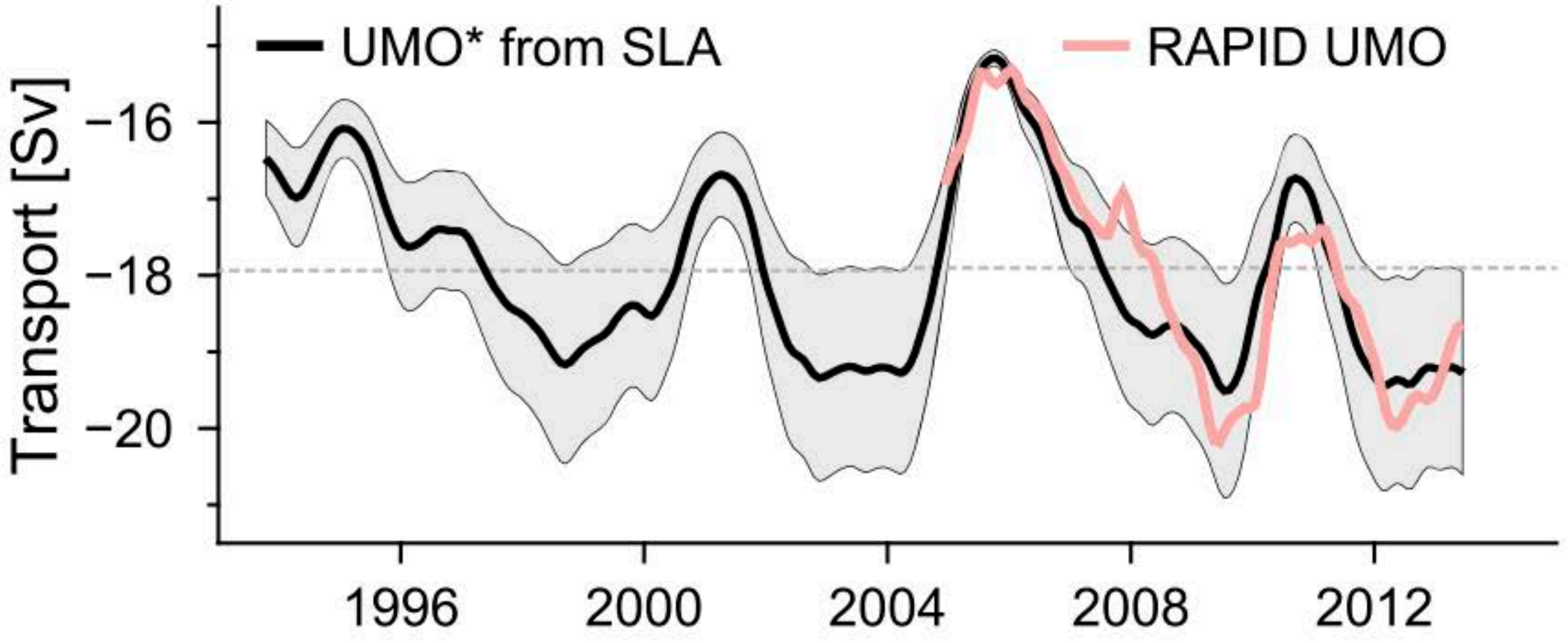


Fingerprint: AVISO SSH at west (30N,70W)

Built AMOC proxy: SSH for UMO (1993-2012), then added Florida Current and Ekman

Comparison: RAPID AMOC at 26N

Filtering/timescale: Deseasonalised, 1.5-year Turkey filter, spatial filter on AVISO of 5x10 deg.



Frajka-Williams (2015)

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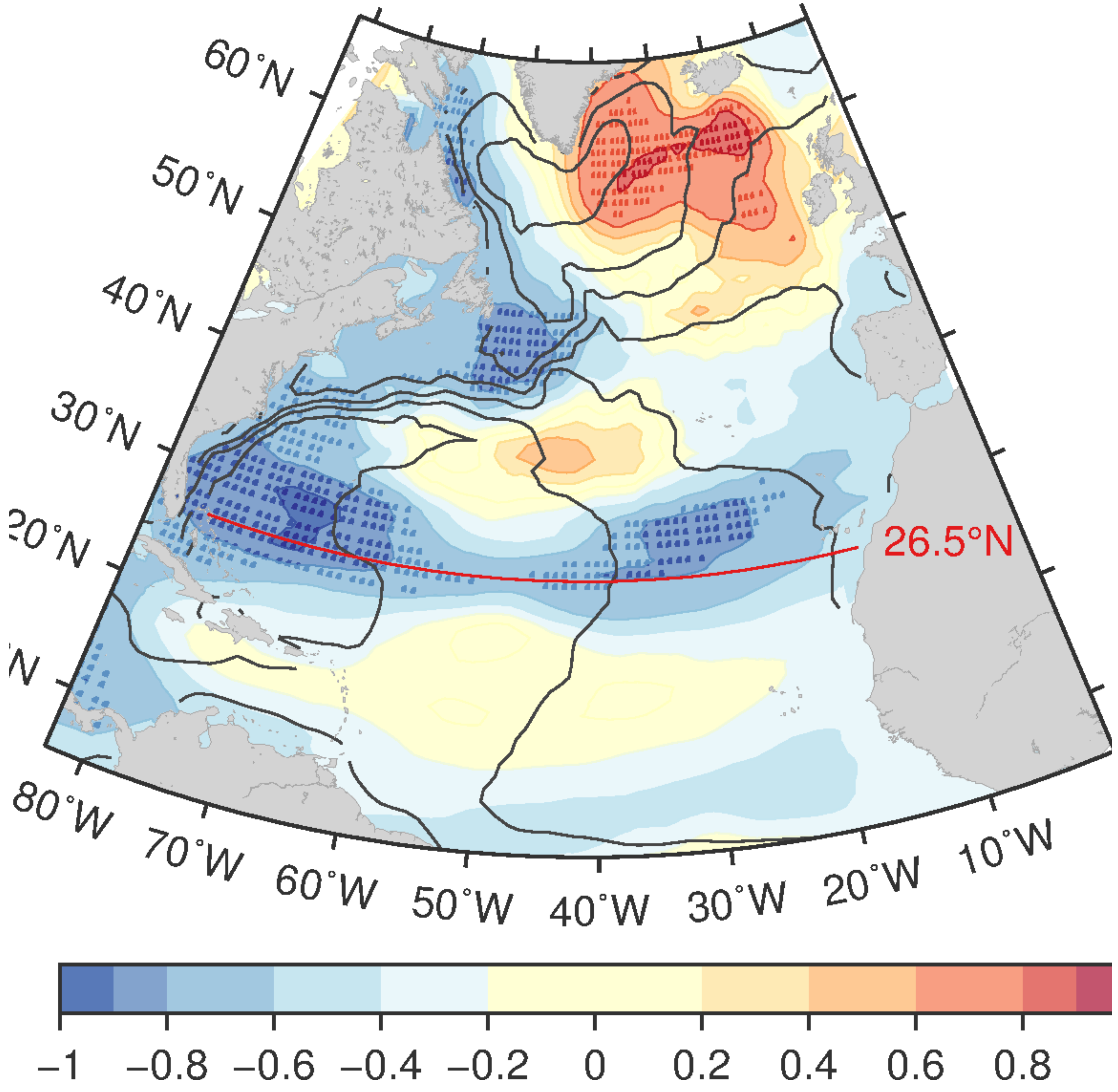

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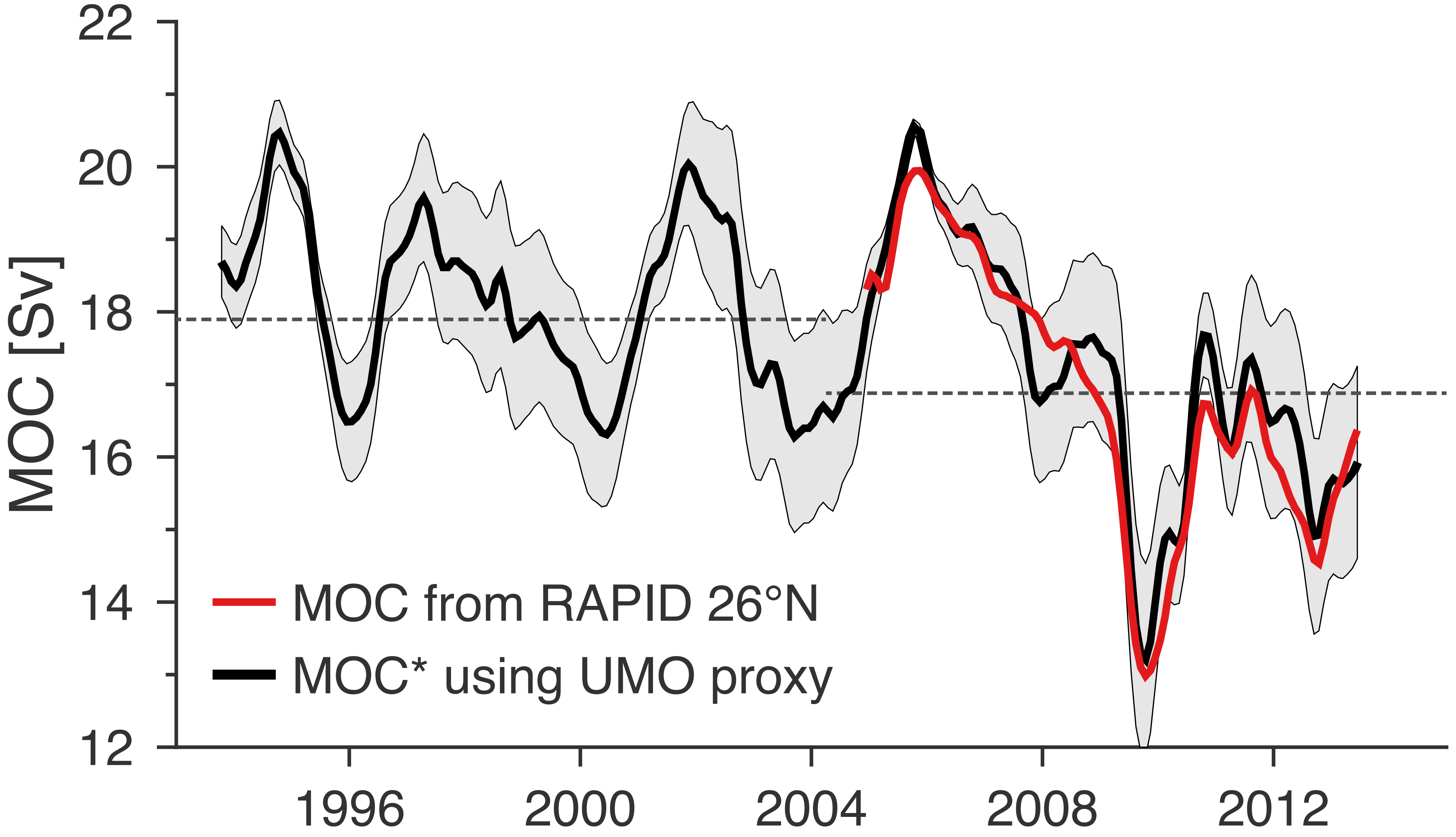
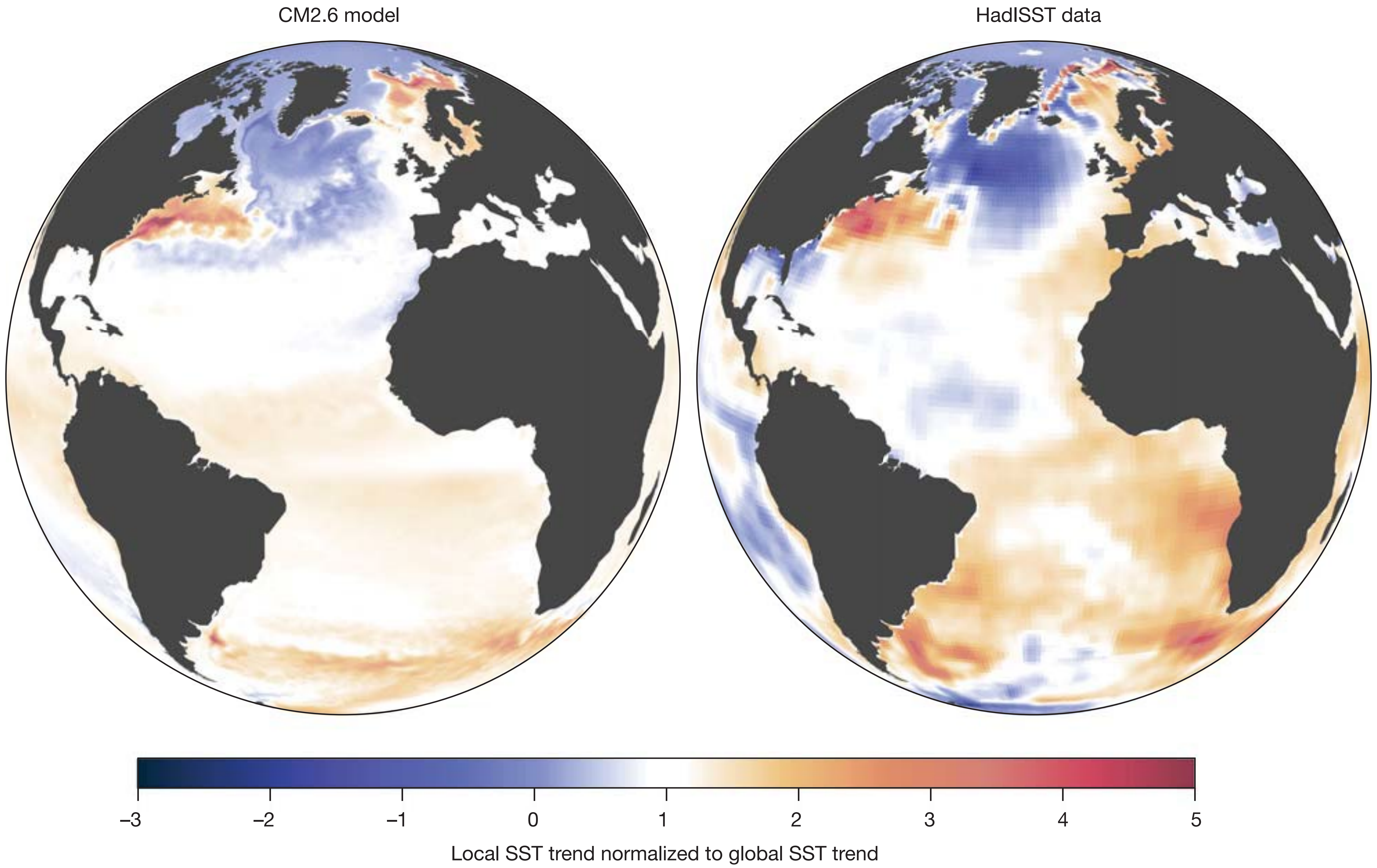


Caesar et al. (2018)

Long time reconstruction



Fingerprint of AMOC: SST in the subpolar gyre

Model: GFDL CM2.6 CO_2 doubling, 80-year integration

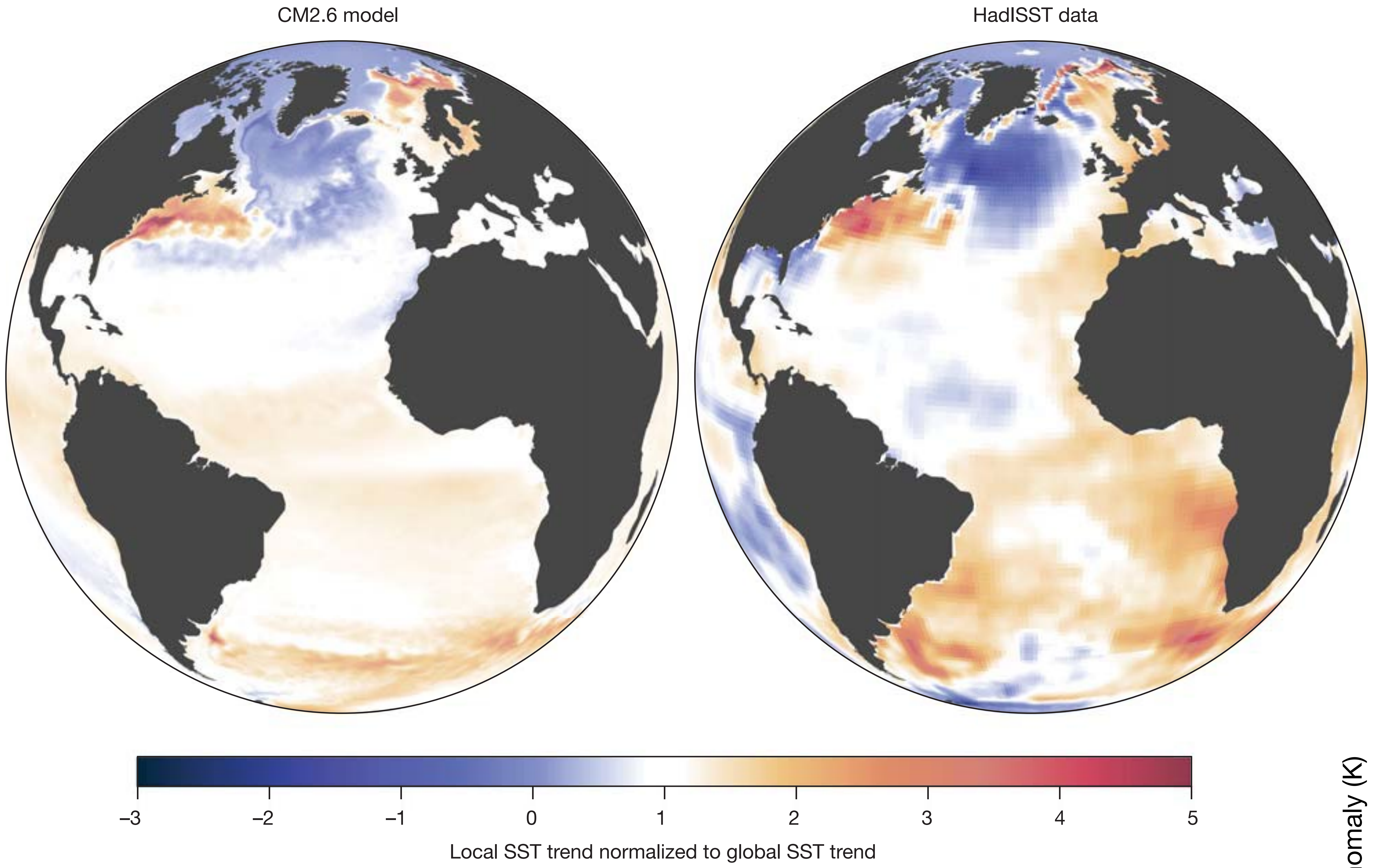
Built AMOC proxy: SST anomalies in the subpolar gyre from HadiSST 1870-2016

Comparison: AMOC at 26N

Filtering/timescale: Nov-May averages of SST

Caesar et al. (2018)

Long time reconstruction



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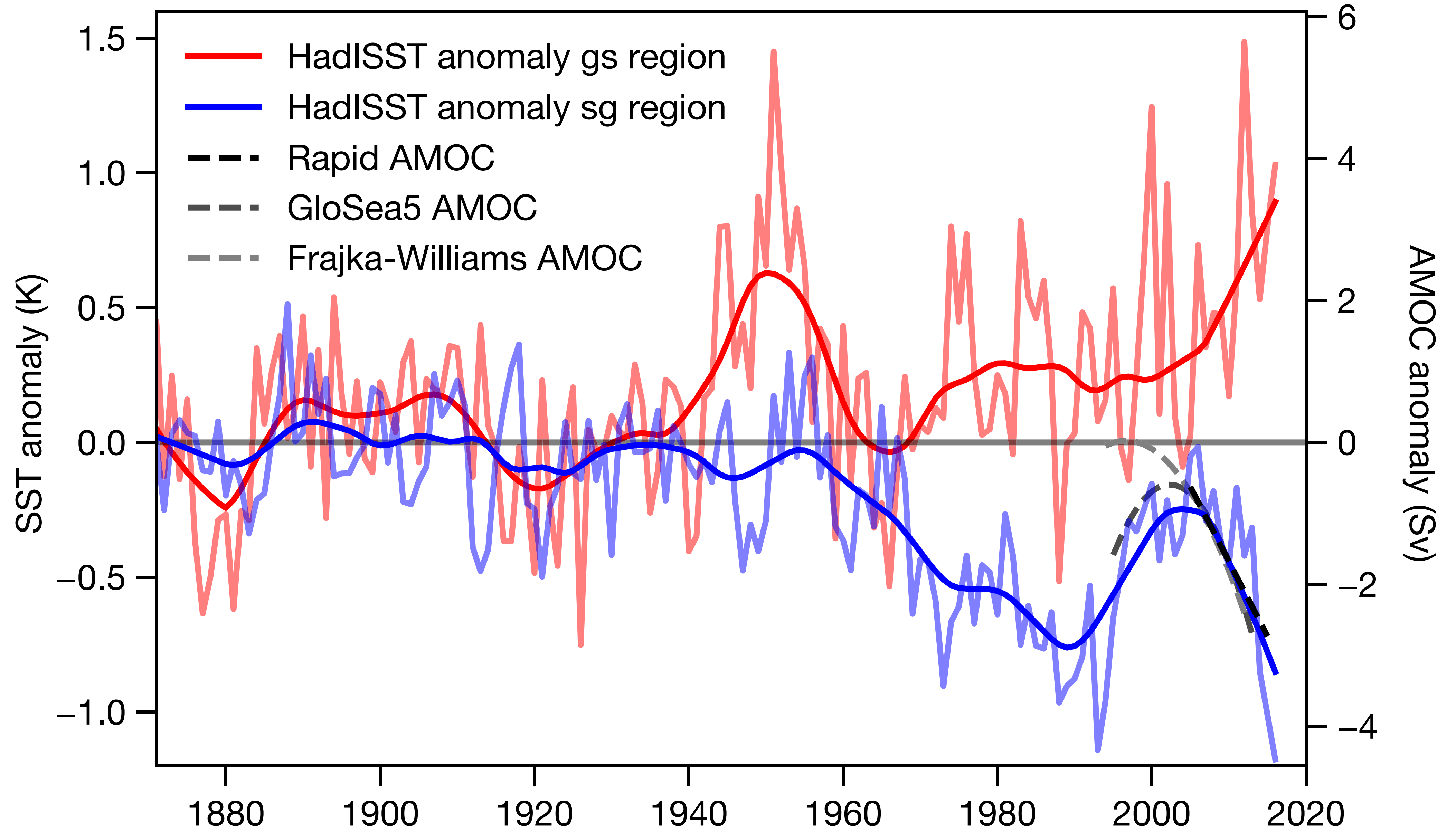
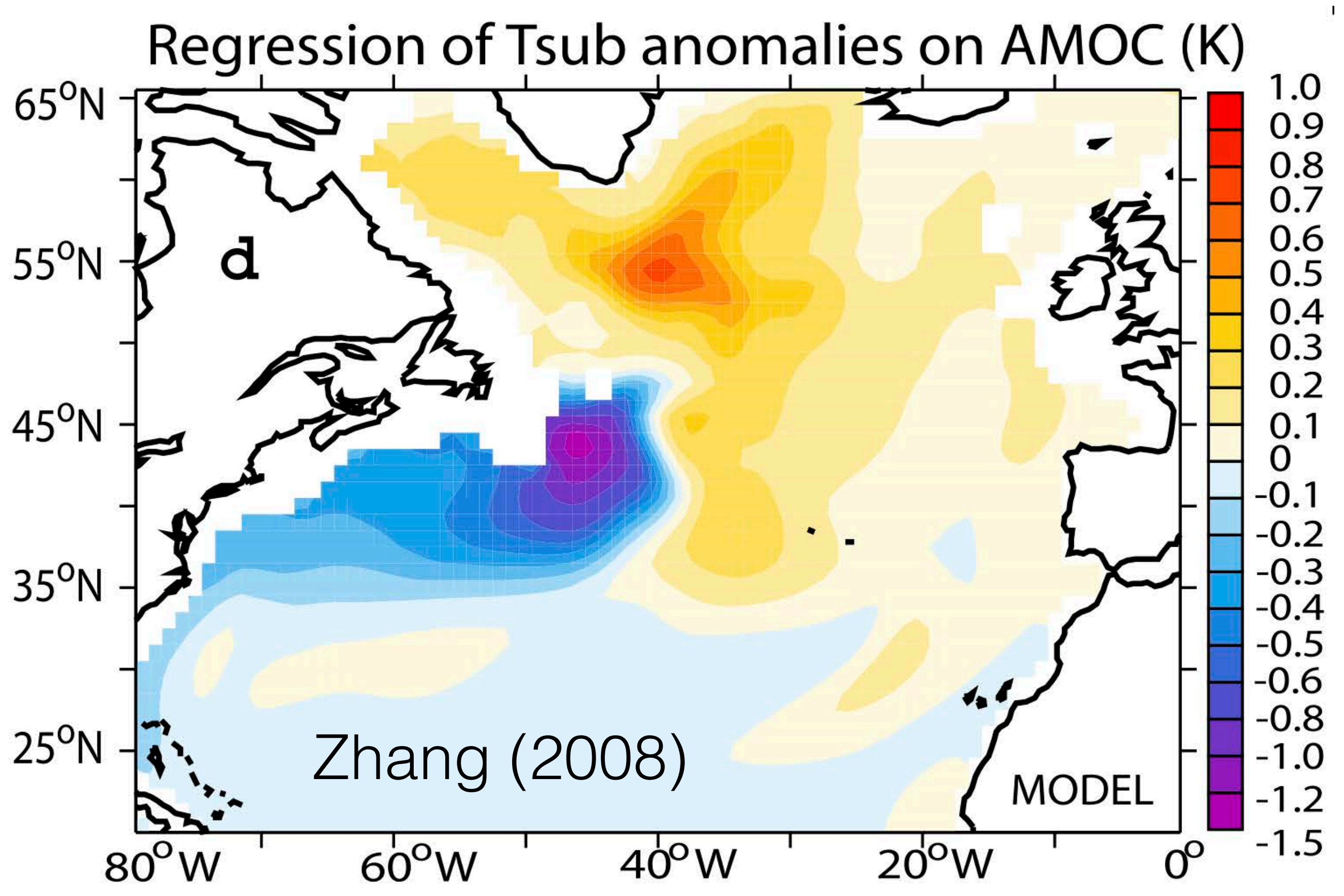


Assumptions of fingerprints

- **Linear** relationship between AMOC and proxy
- Implicit **timescales** based on data filtering
- Assumption of **stationarity**

- Potential for **misattribution**

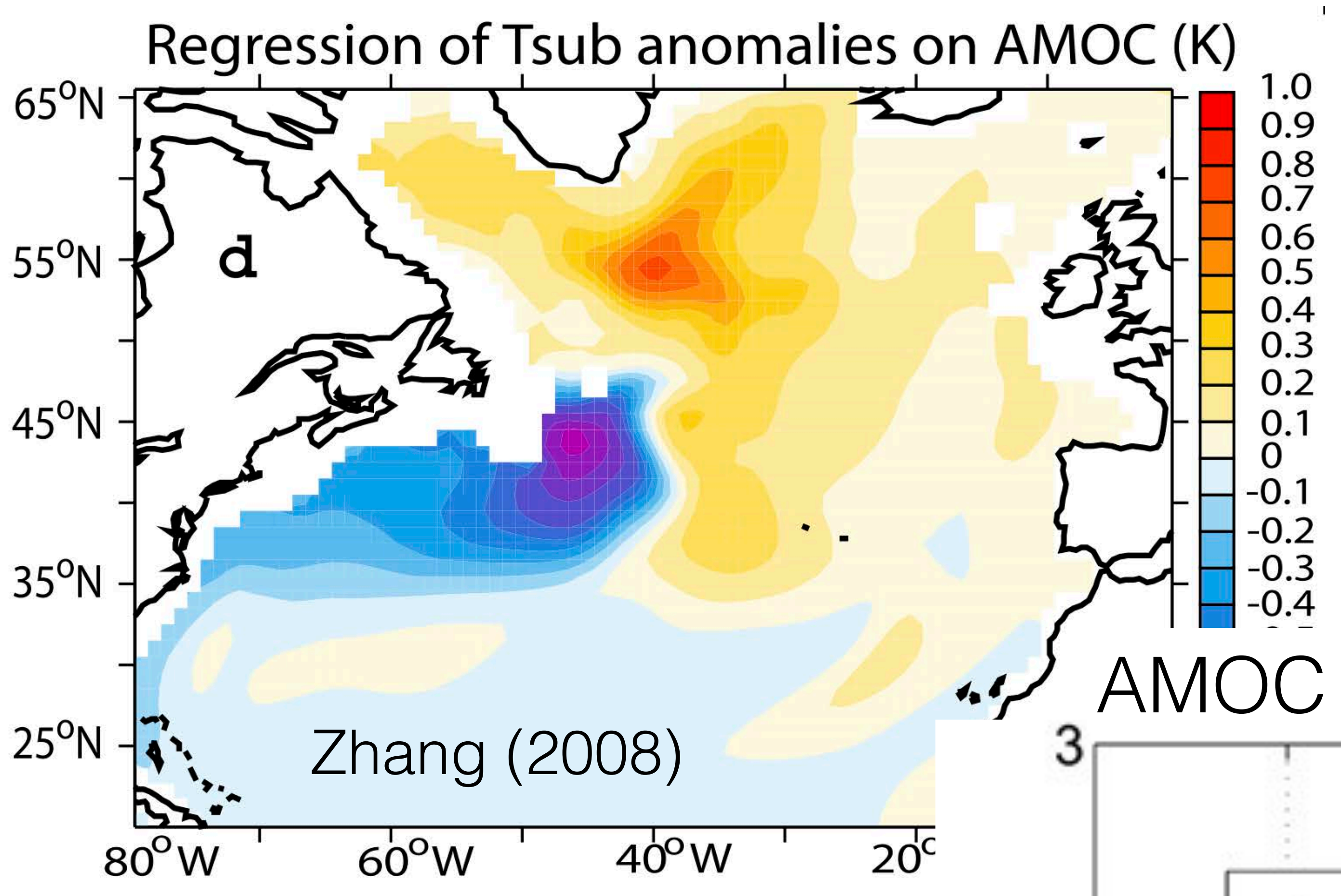
Fingerprints: Linear assumption



A **linear regression** between the AMOC and the proxy:

- Assume (or determine) that temperature varies linearly with AMOC

Fingerprints: Linear assumption



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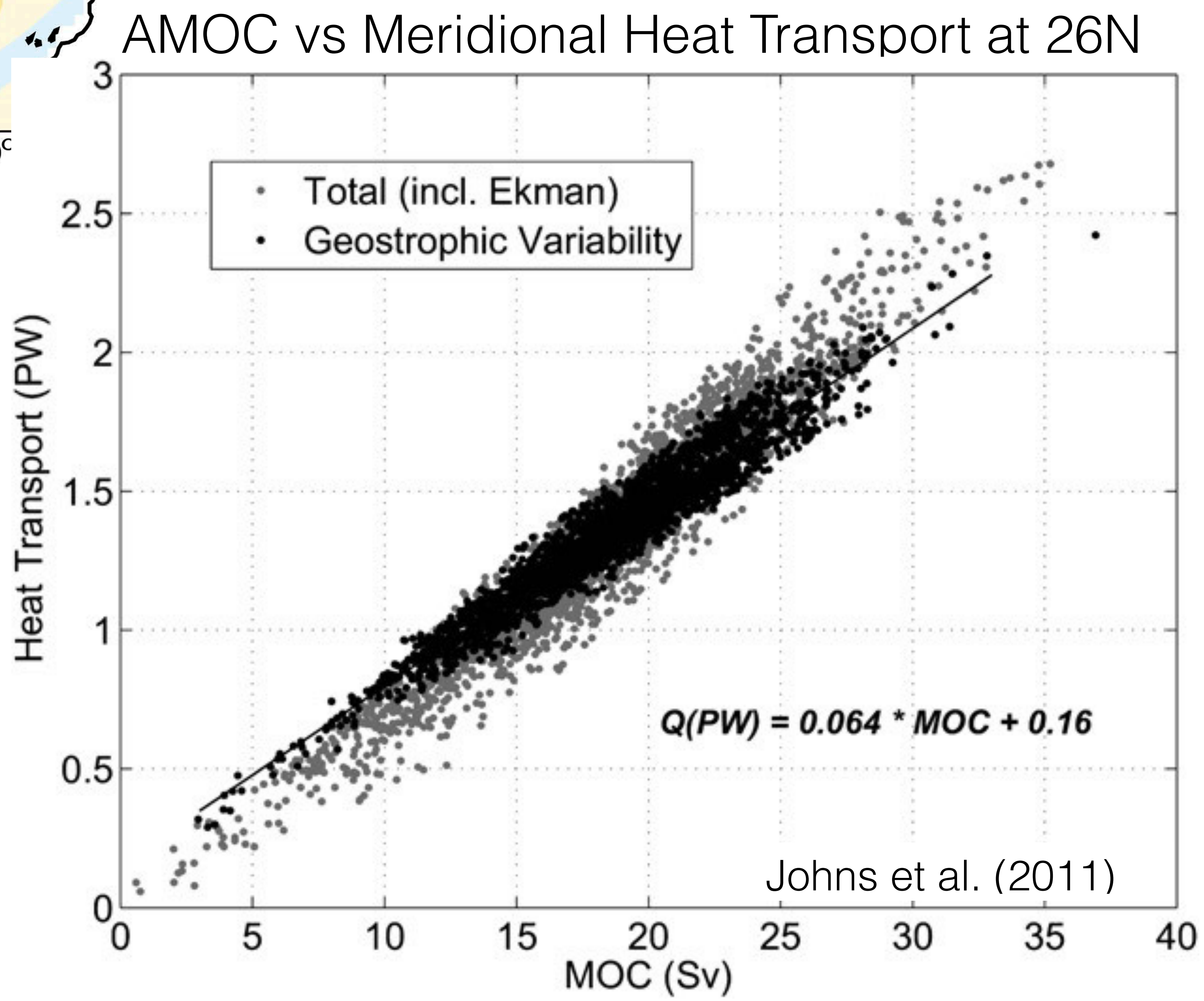
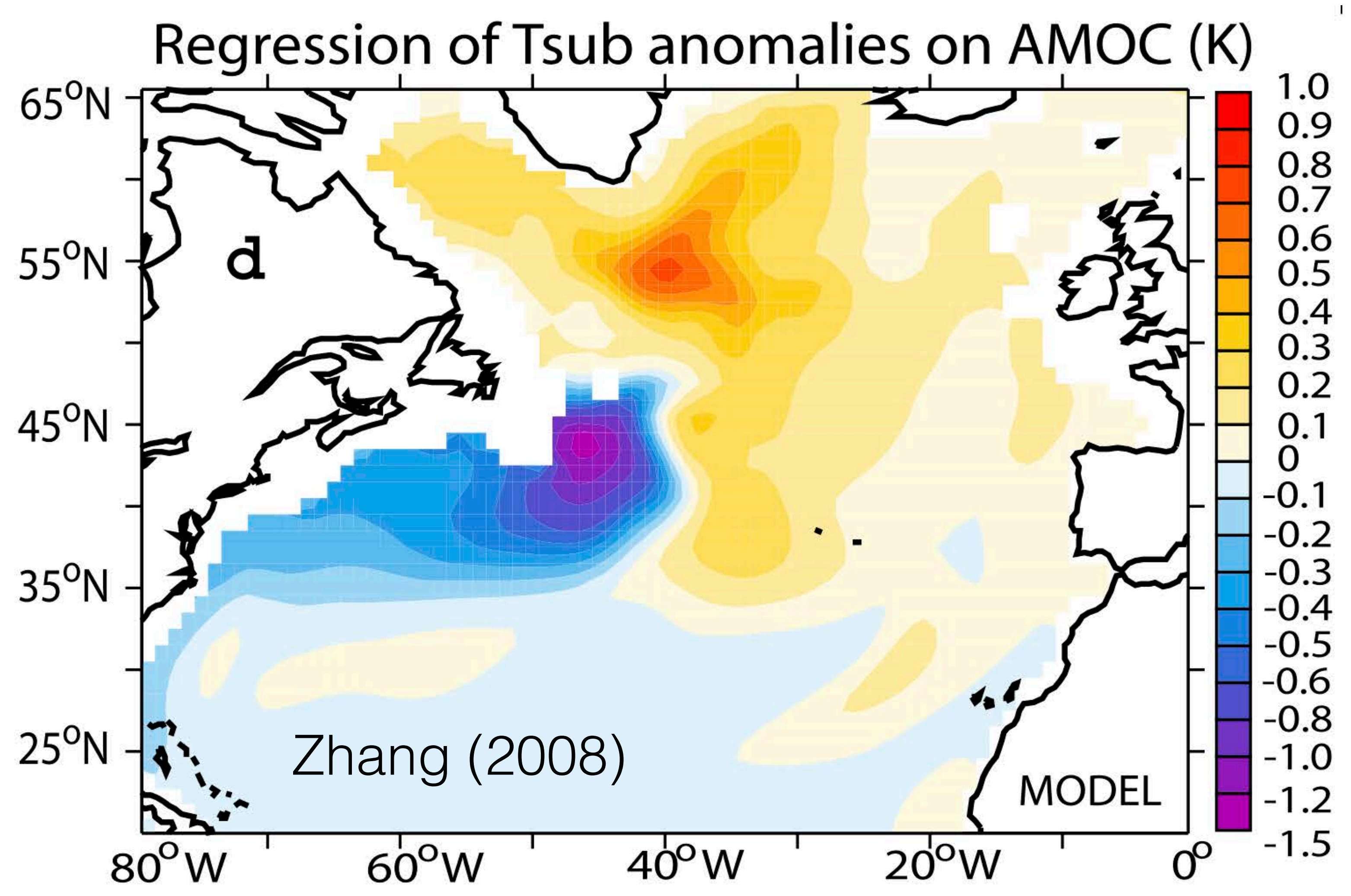


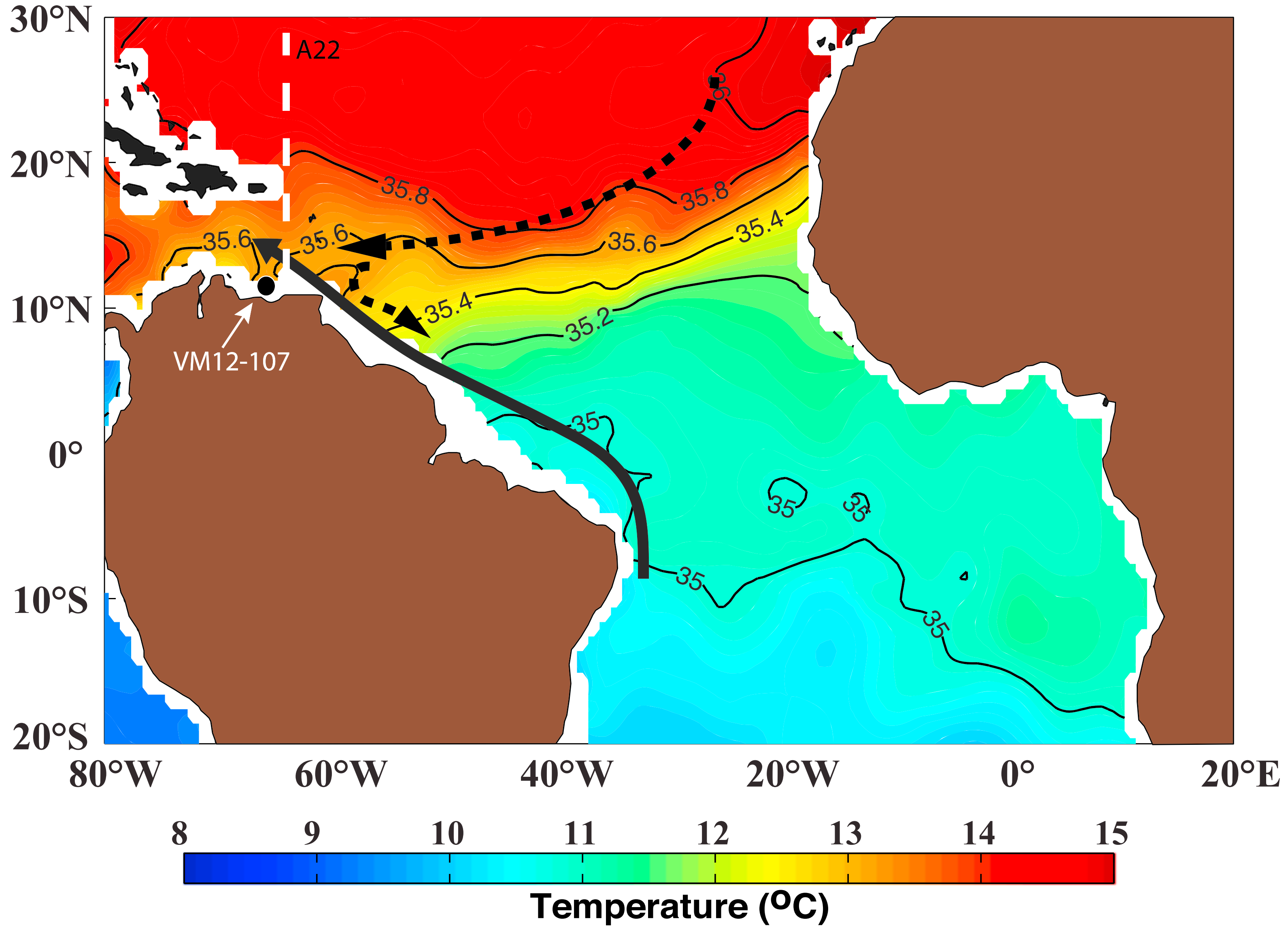
Seems OK: AMOC and MHT are linearly related

But

$$\frac{dOHC}{dt} \propto HT$$

Fingerprints vs Circulation pathway change

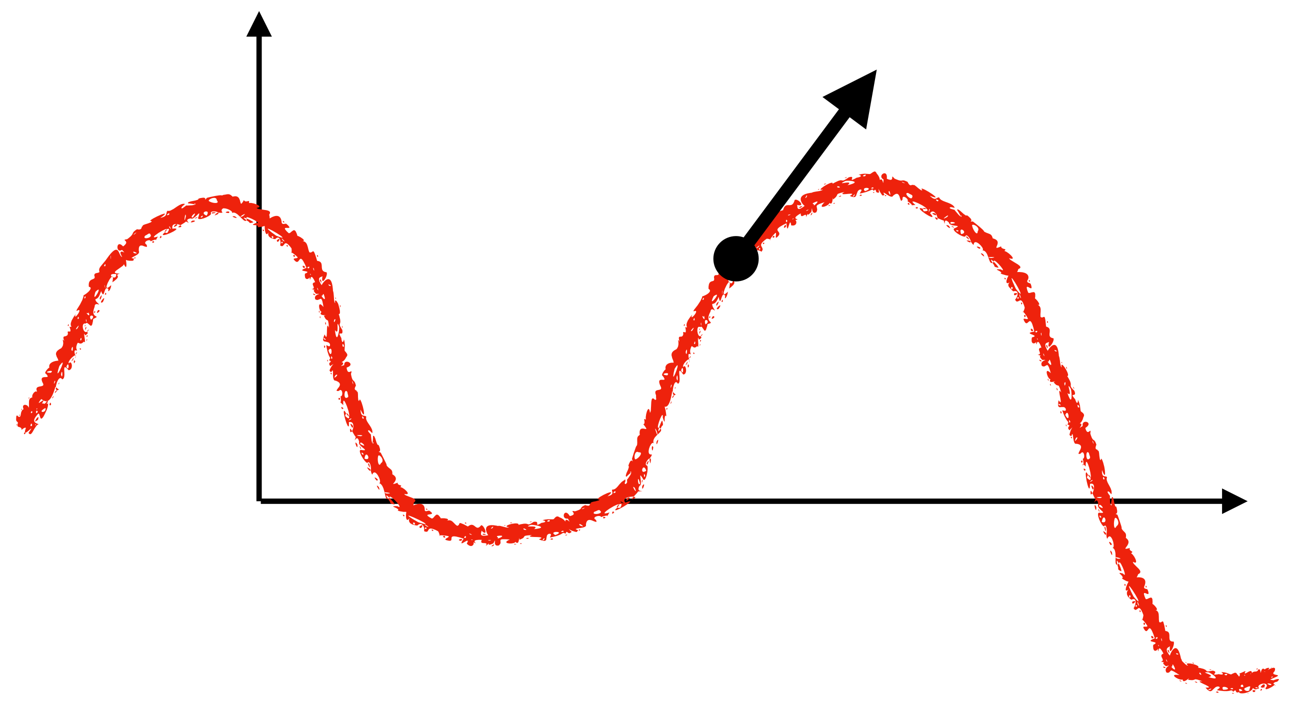




Parker et al. (2015)
Also Zhang (2007)

Linear assumption is like making small perturbations around a mean:

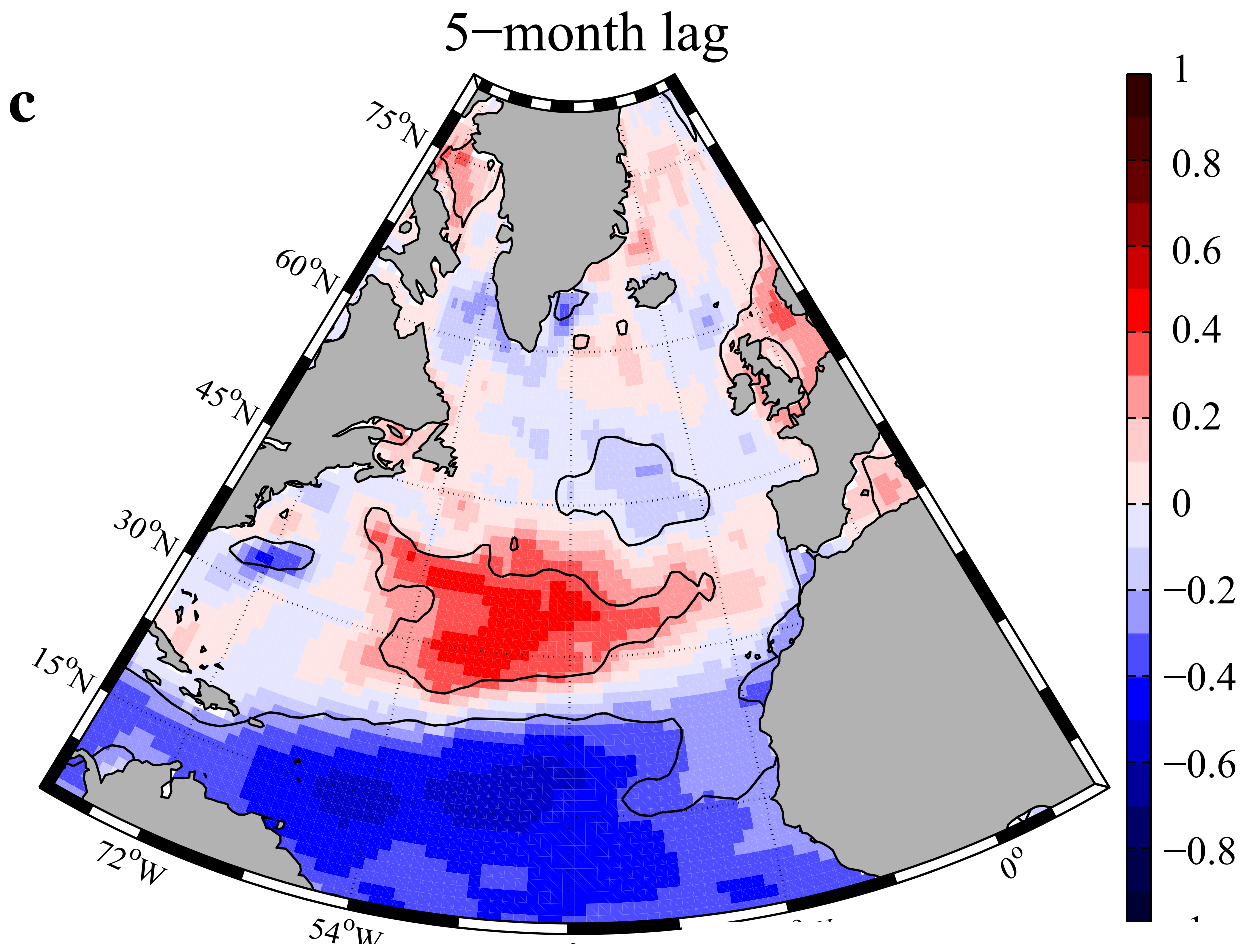
Marginally stronger heat transport *strength* -> marginally warmer ocean north of the line



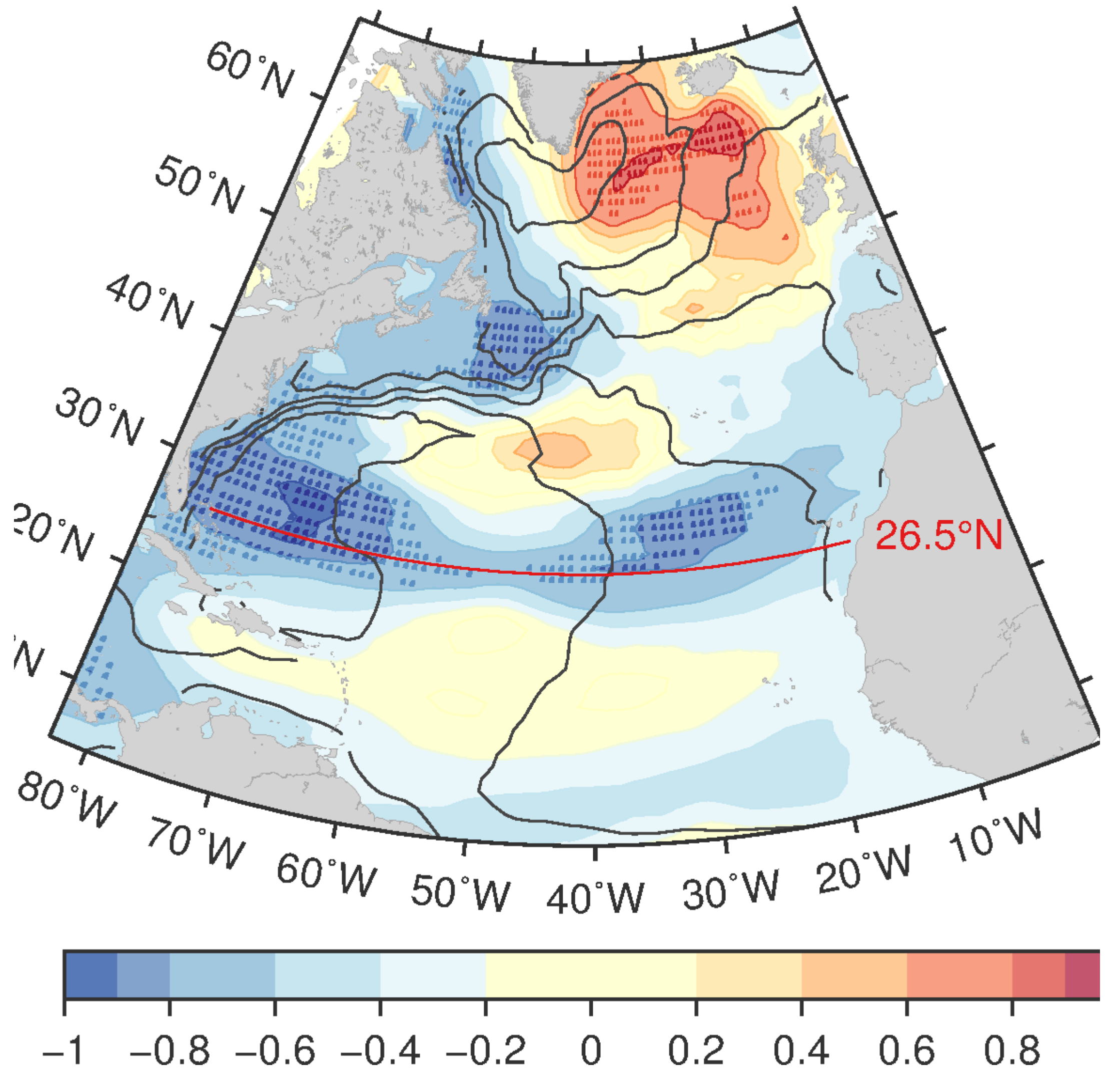
Vs Circulation *pathway* change

When the AMOC weakened, a new pathway opened up to bring warm, saline subtropical Atlantic water towards the equator

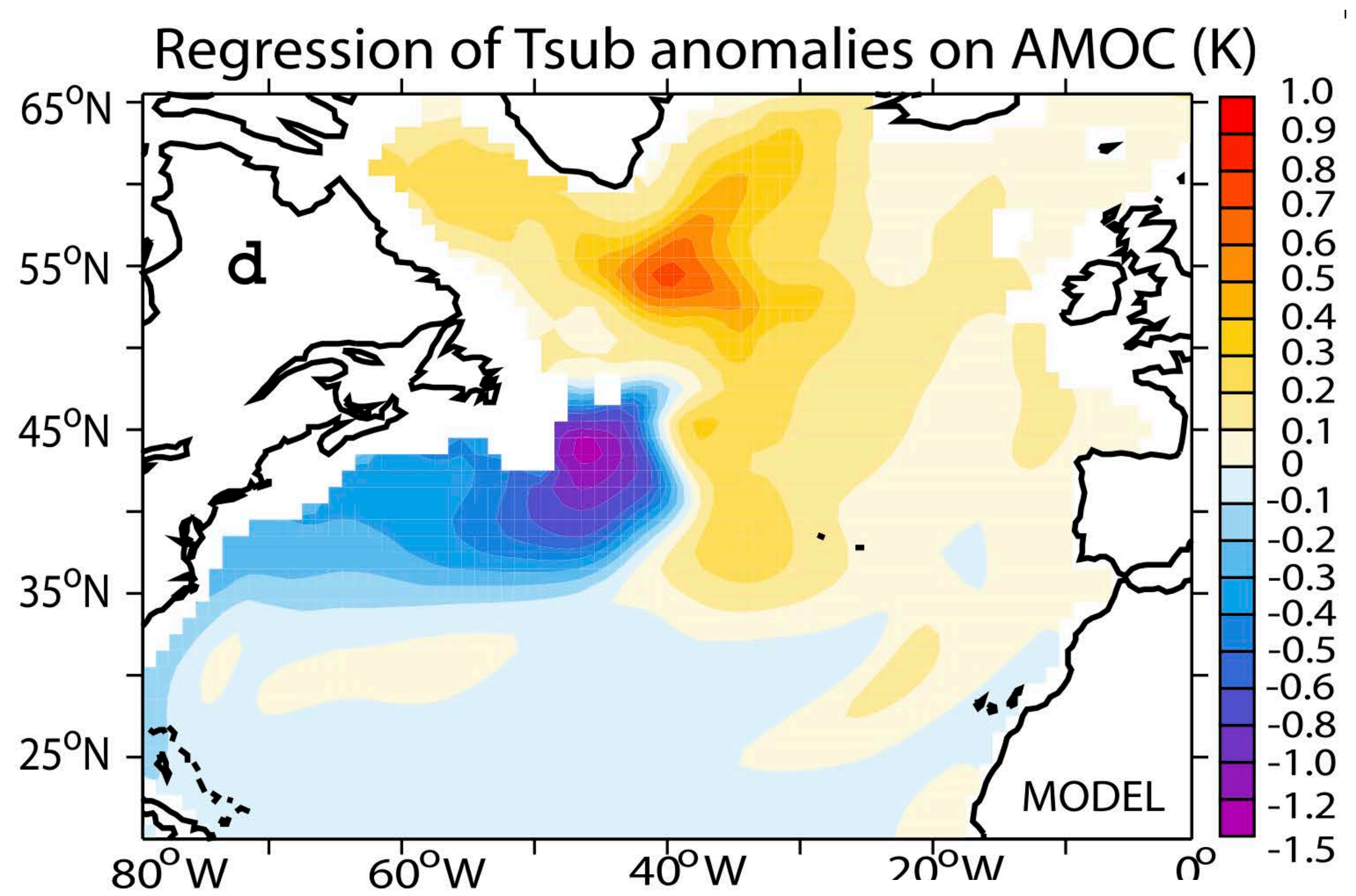
Fingerprints: Implicit Timescales



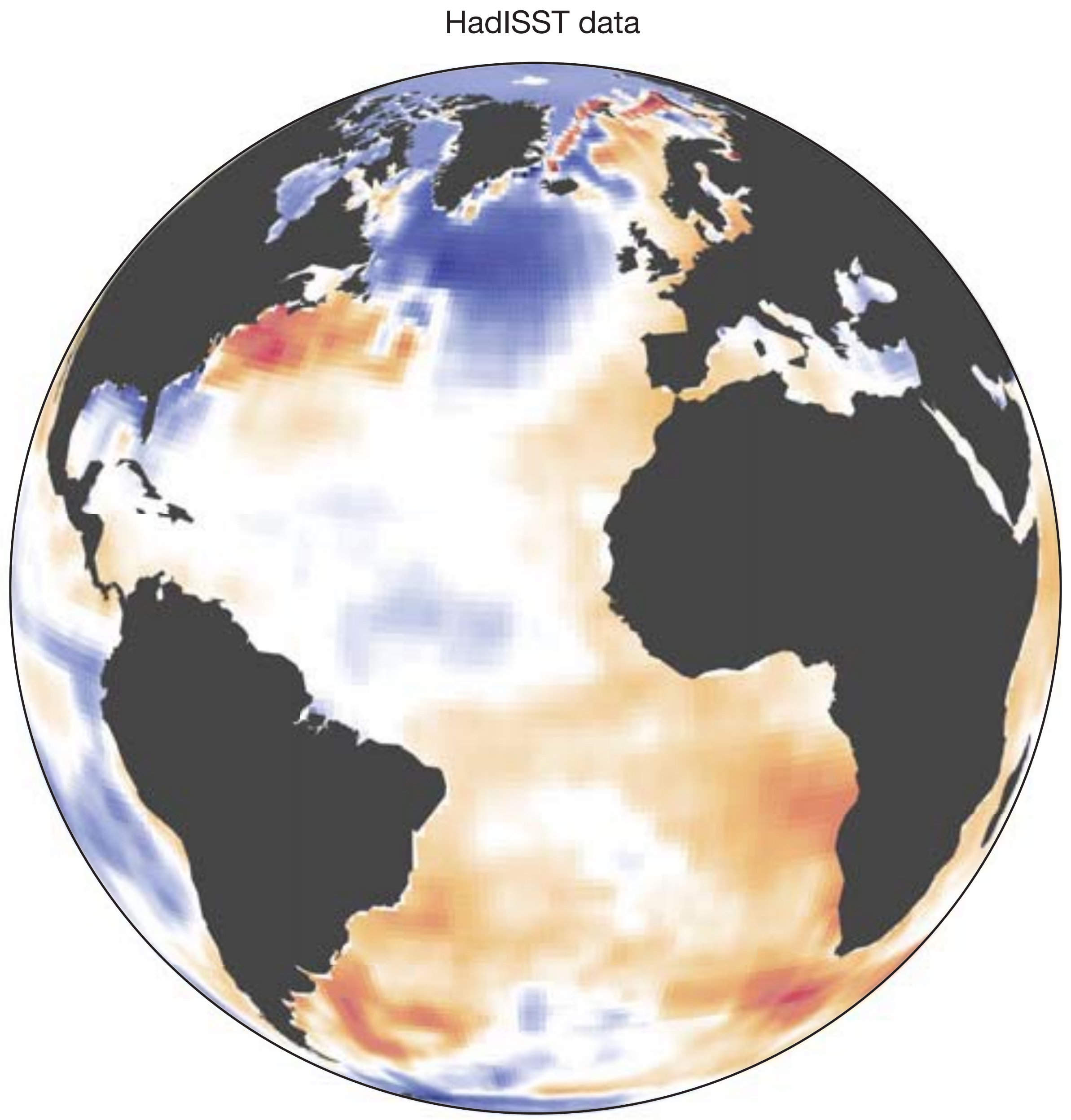
Duchez et al (2016a)



Frajka-Williams (2015)



Zhang et al. (2008)



Caesar et al. (2018)

AMOC variability

Deriving fingerprints has an implicit expectation about timescale.

- The observed AMOC at 26N shows variability on a range of timescales

Timescales relate to processes

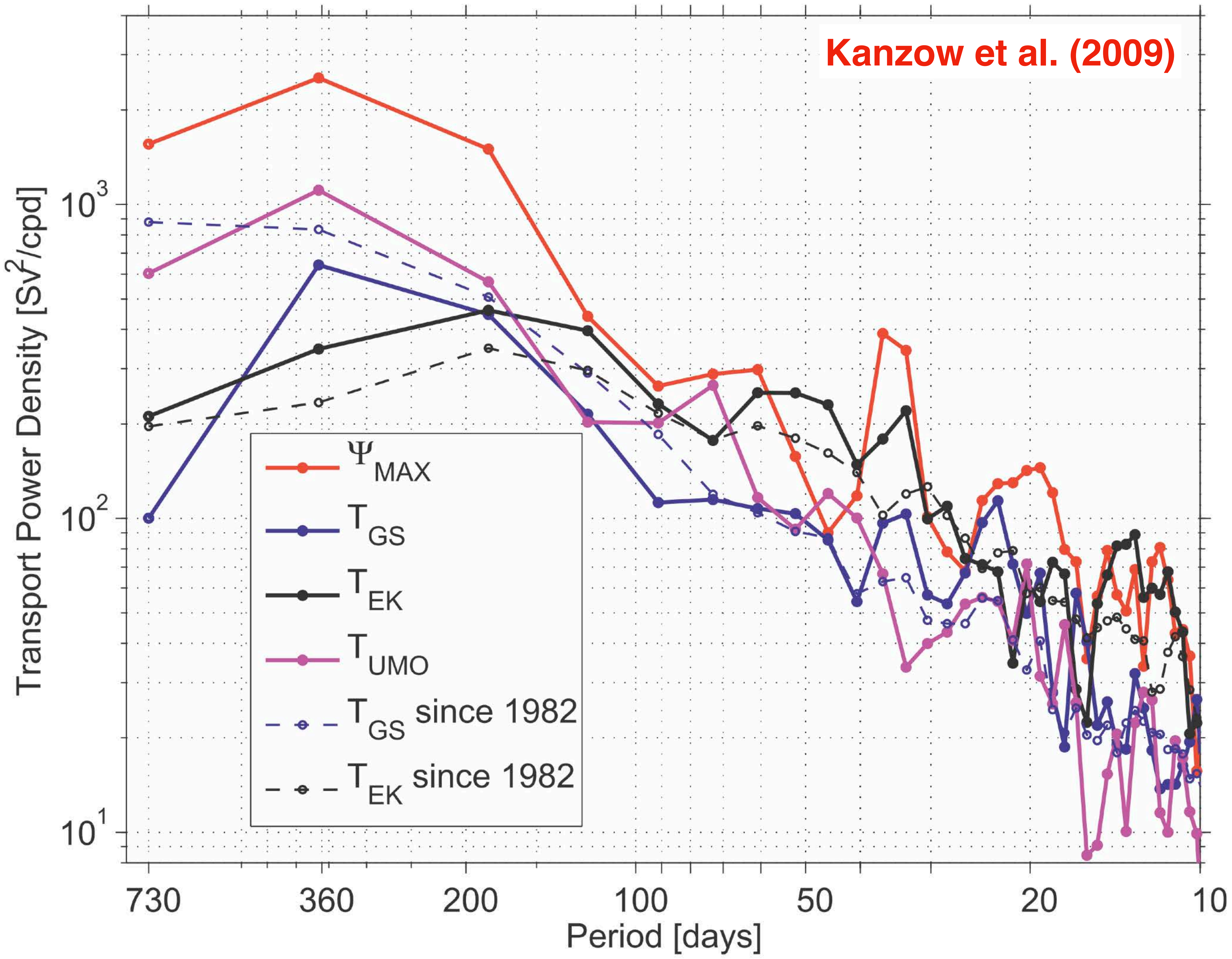
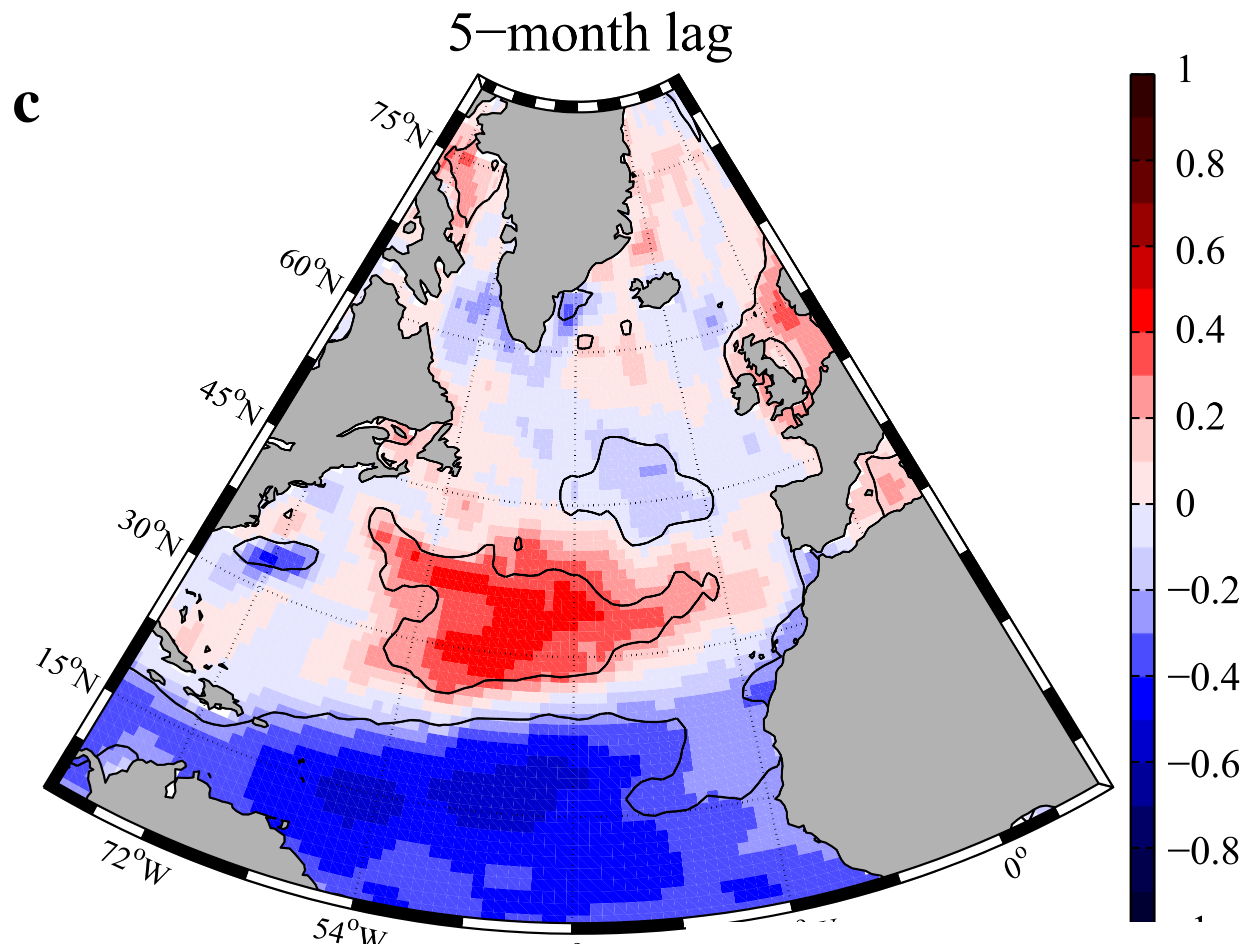


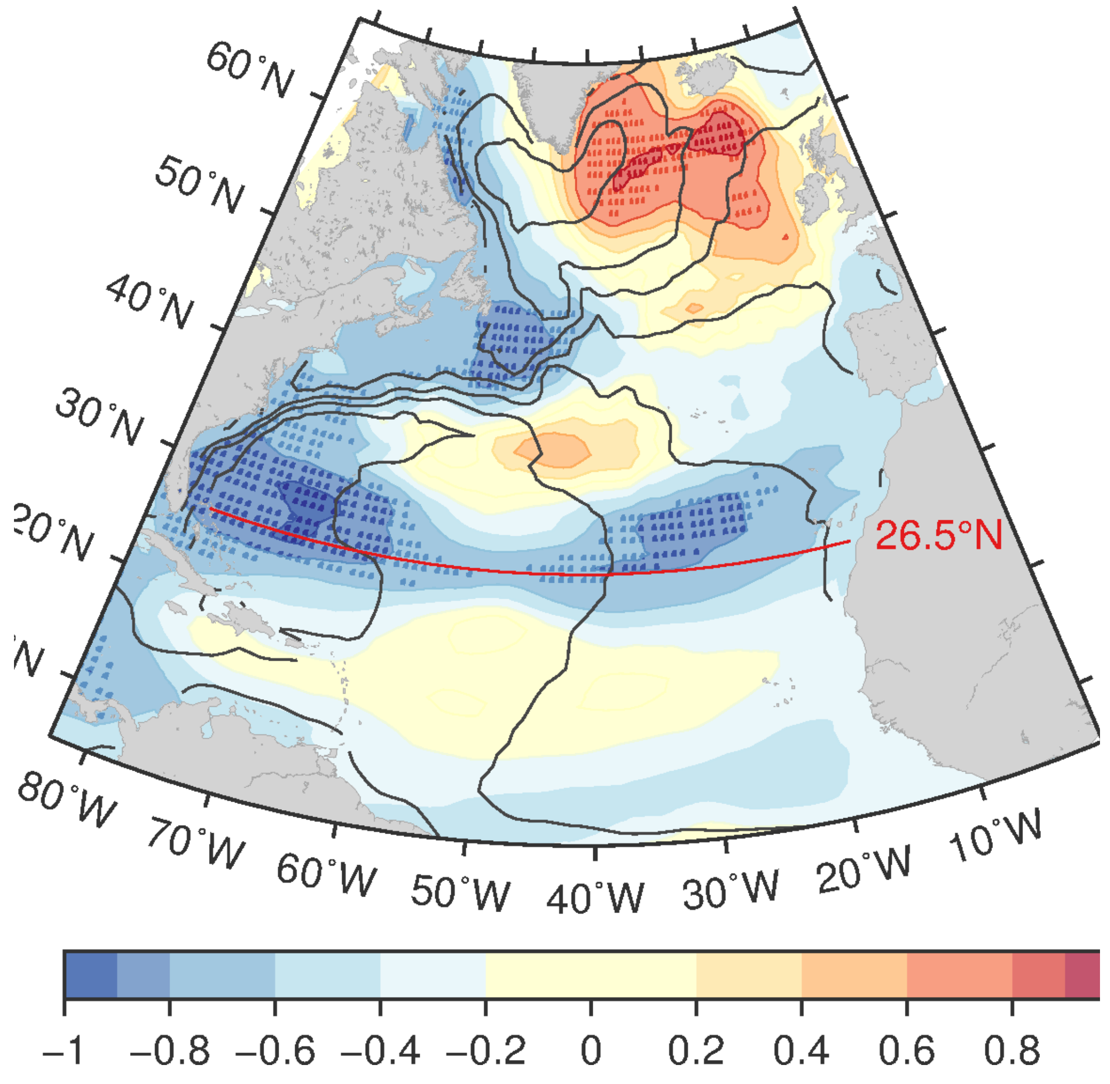
FIG. 8. Solid lines denote power spectra of Ψ^{MAX} (red), T_{GS} (blue), T_{EK} (black), and T_{UMO} (magenta) for the period from April 2004 to April 2008 (as shown in Fig. 7). Also shown for reference purposes as dashed lines are the transport spectra of T_{GS} (blue) and T_{EK} (black) based on time series between March 1982 and January 2008. The long T_{EK} time series is based on NCEP–NCAR reanalysis data (Kalnay et al. 1996). The spectra are based on Welch's periodogram method using a 365 (730)-days-wide Hamming window and 182 (365) days' overlap between consecutive data segments for periods $\leq$ ($>$) 365 days.

Fingerprints: Implicit Timescales



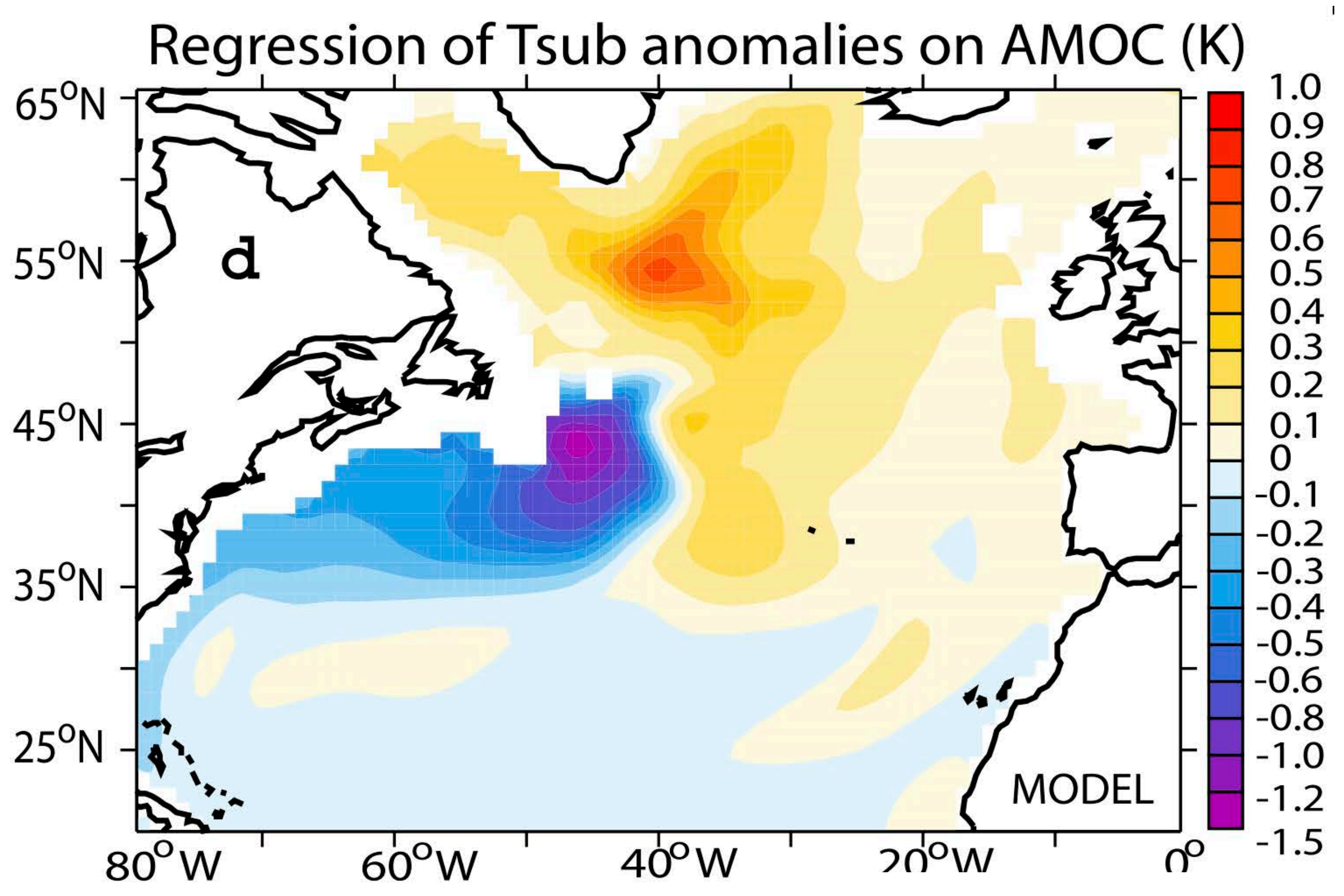
Duchez et al. (2016a)

Monthly



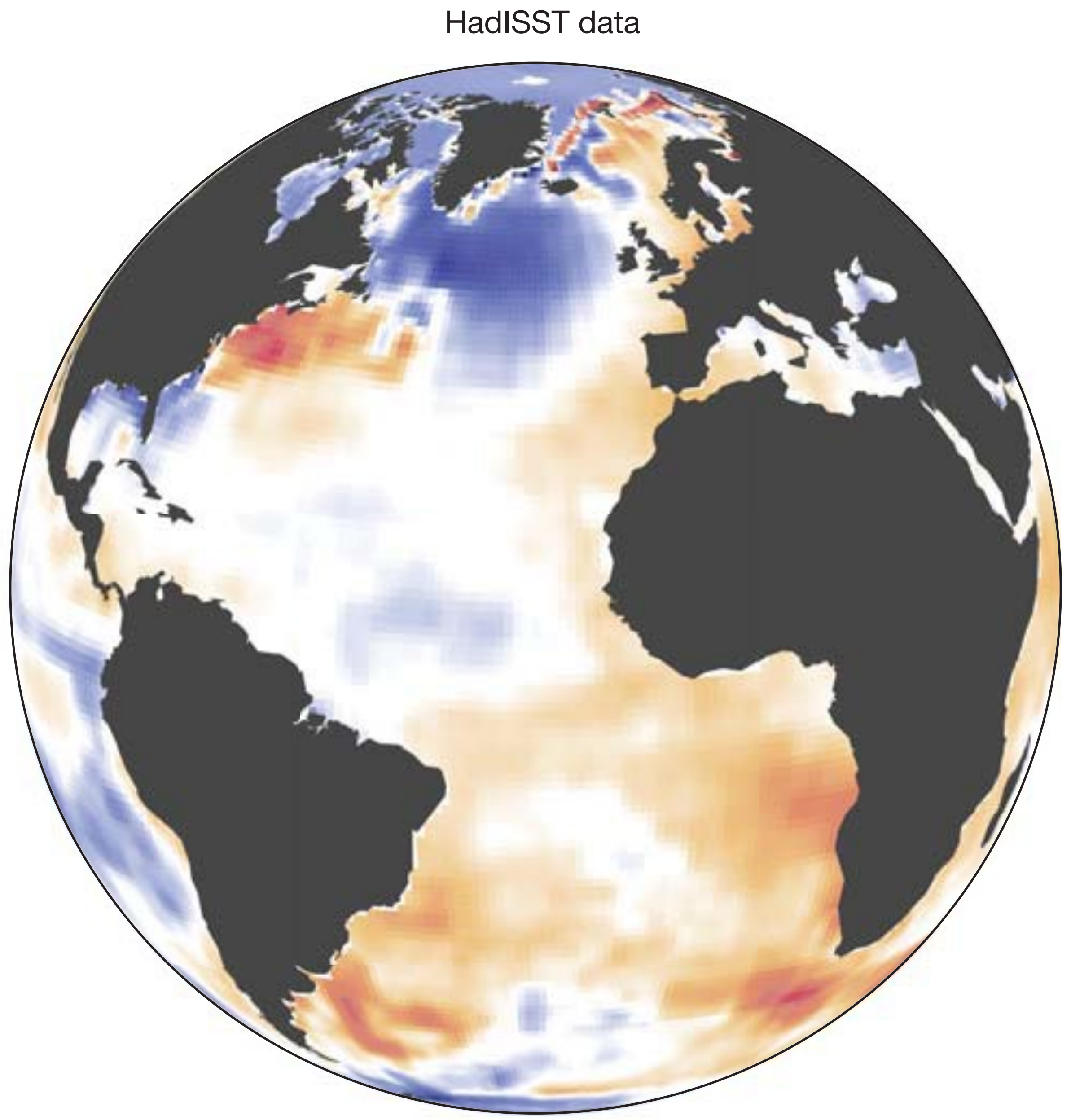
Frajka-Williams (2015)

Interannual



Zhang et al. (2008)

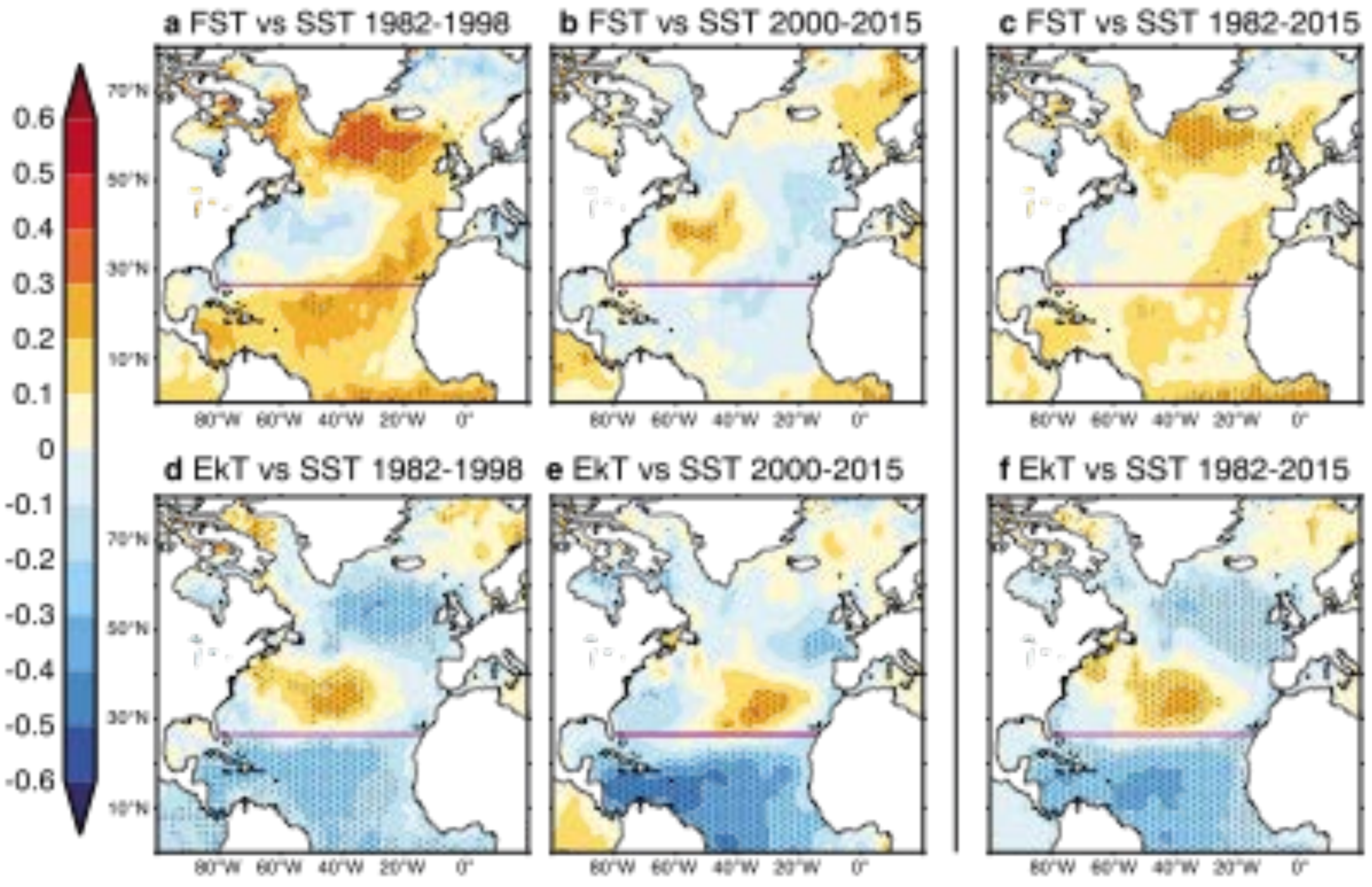
Multidecadal



Caesar et al. (2018)

Multidecadal - Centennial

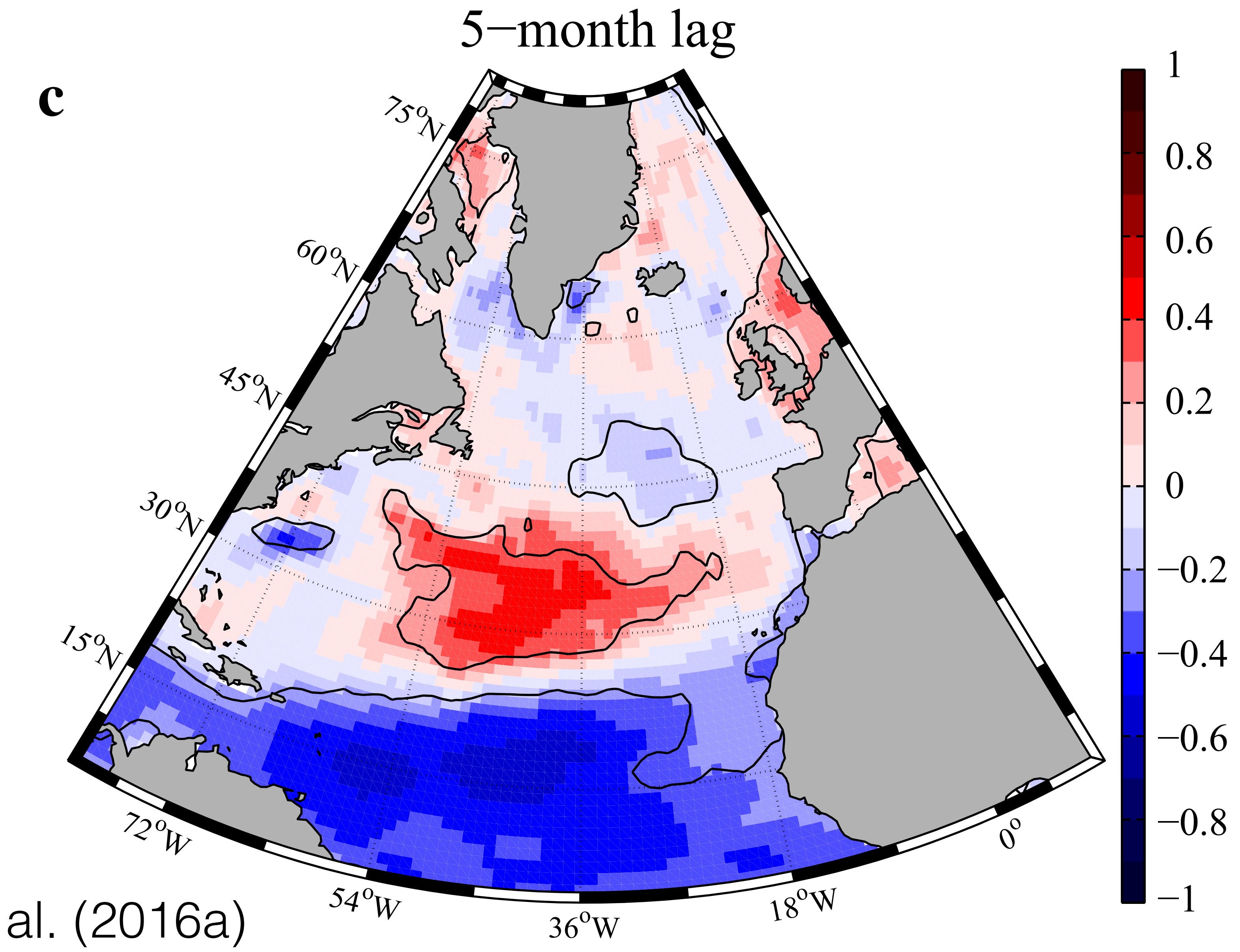
Fingerprints: Assumption of Stationarity



Alexander-Turner et al. (2018)

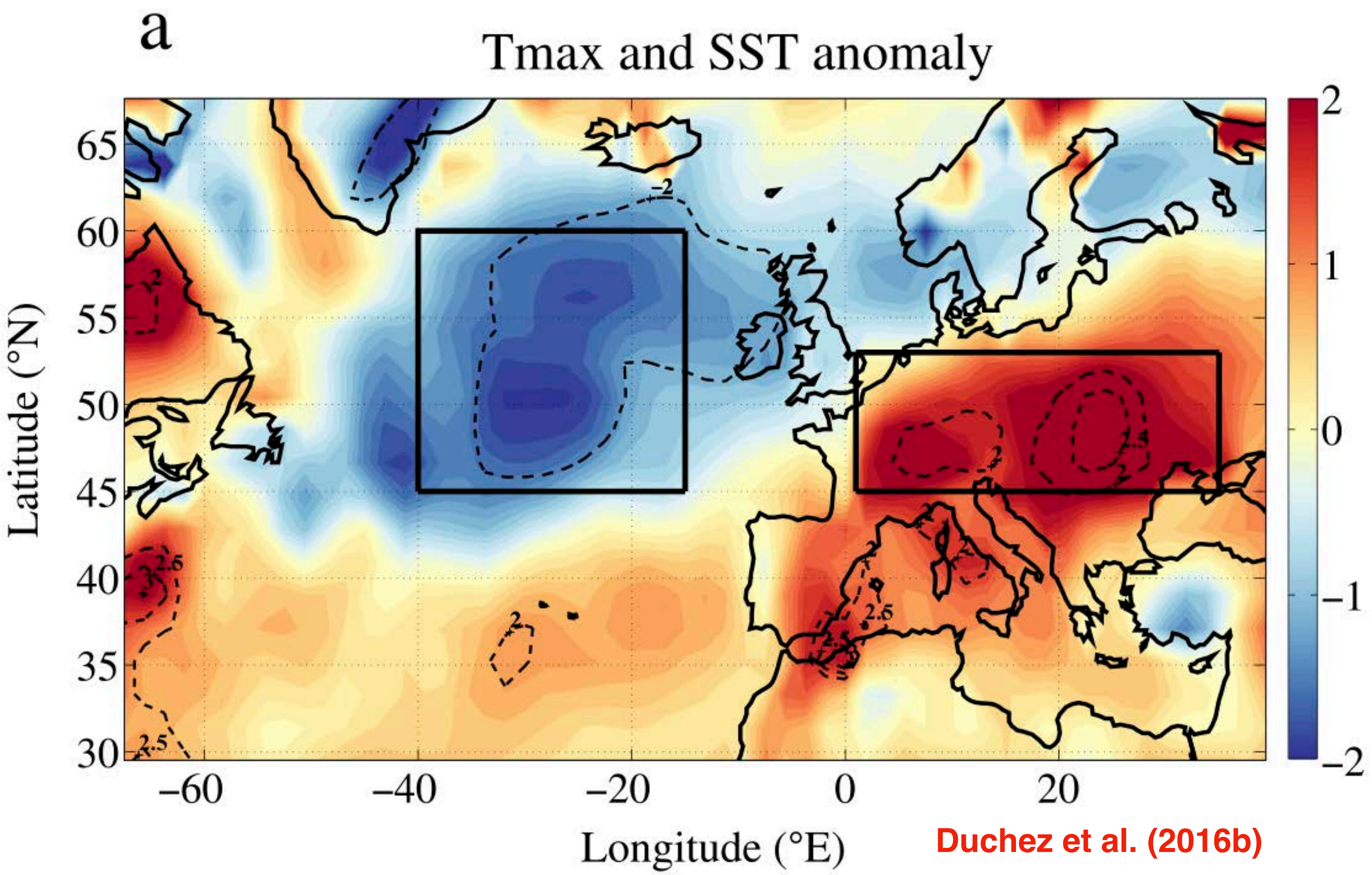
Typically assumes that the process that controls the proxy to AMOC relationship is the *dominant process* controlling that variable/proxy.

However, the relationship can change with time (non-stationary).



Duchez et al. (2016a)

Fingerprints: Potential for Mis-attribution



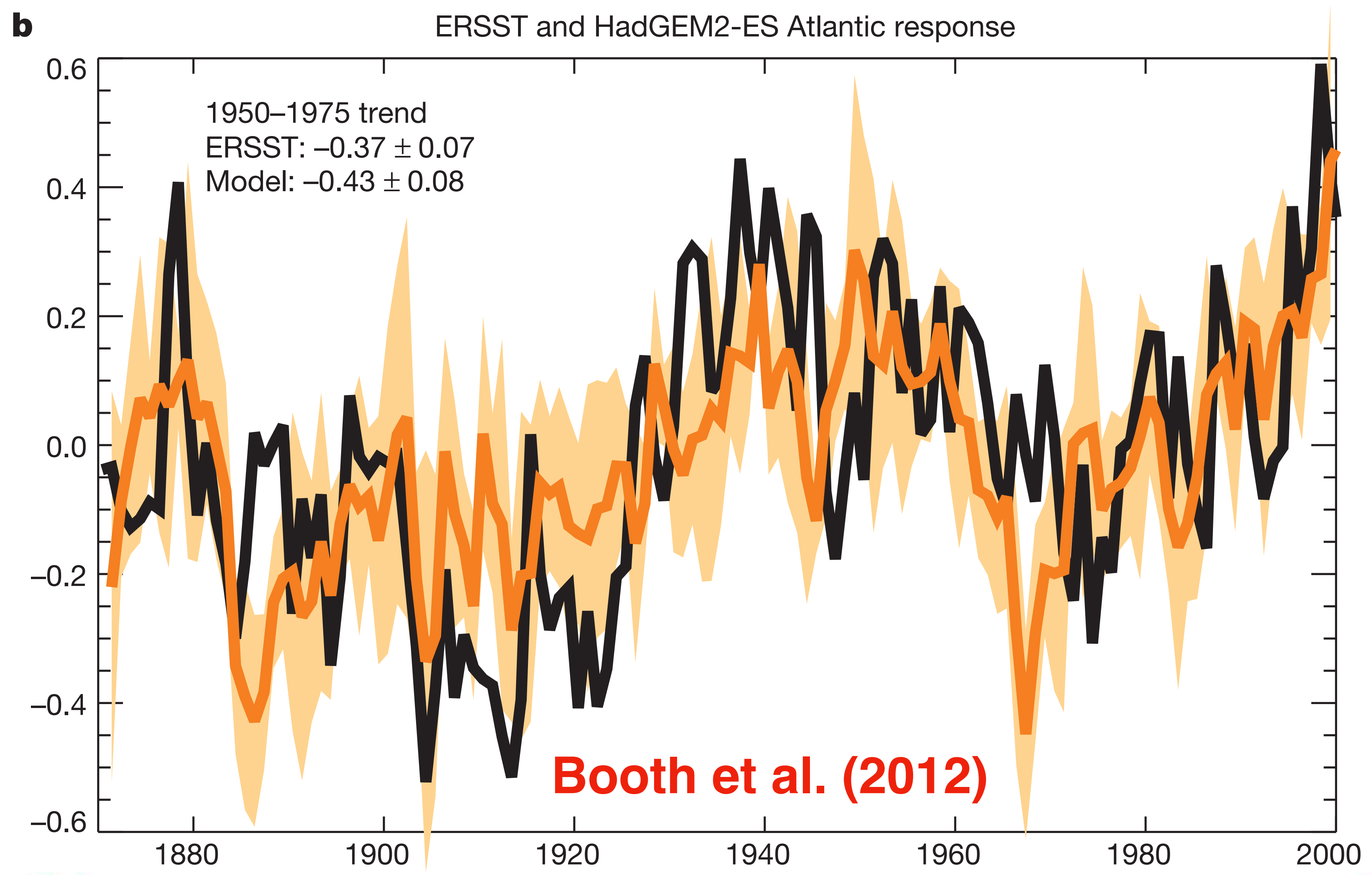
Duchez et al. (2016b)

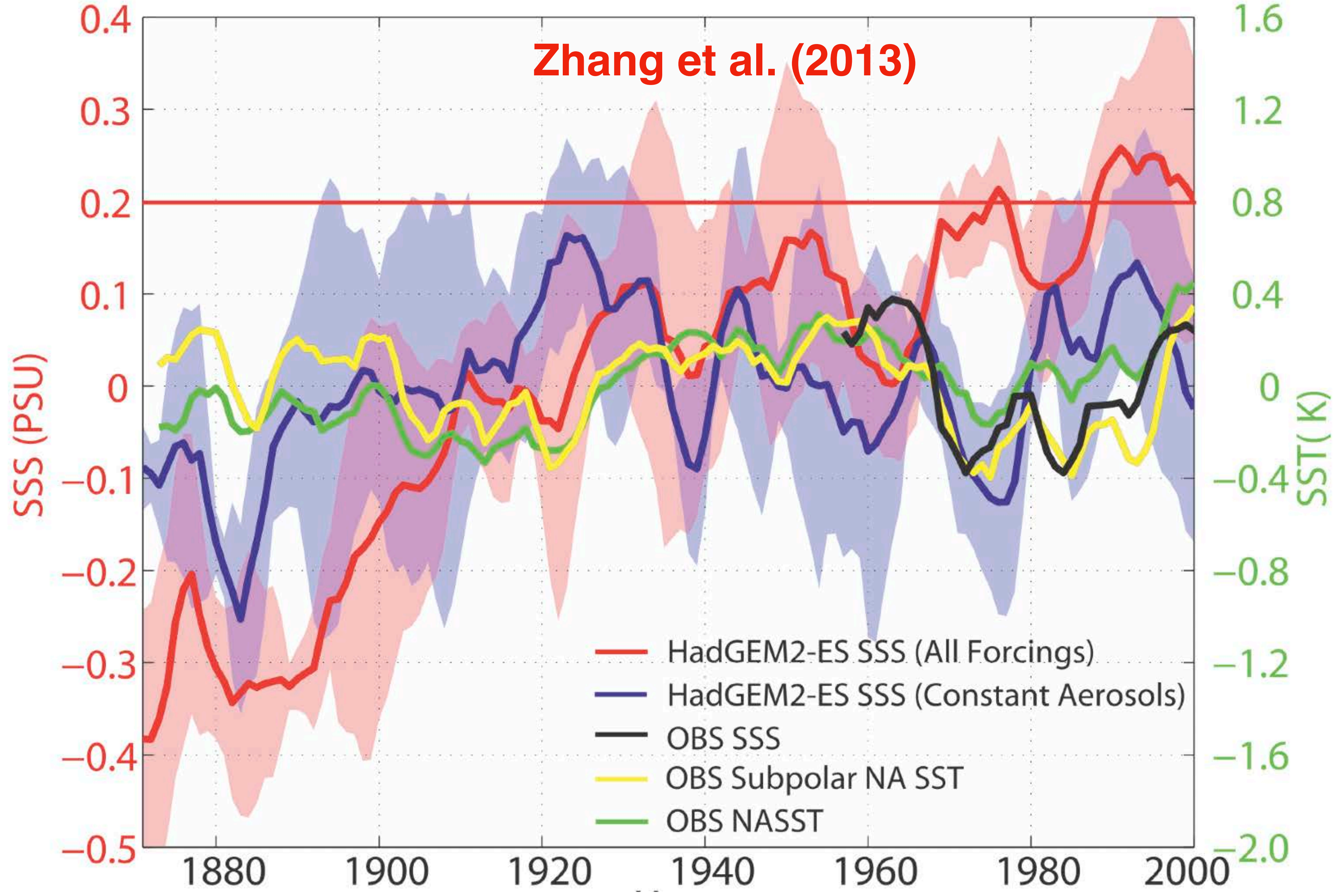
Typically assumes that the AMOC is the dominant process controlling the variable/proxy.

But, both may be driven by other changes in forcing.

E.g. SST warming hole on long timescales is a signature of a *slowing AMOC*. On interannual timescales, may be driven largely by *atmospheric forcing*.

Fingerprints: Potential for Mis-attribution





Origins of the AMO/AMV variability (a large-scale SST pattern in the Atlantic) is debated:

- **AMOC forcing** (e.g., Mann & Emmanual, 2006 + Zhang et al., 2008)
- **Aerosol forcing** (Booth et al., 2012 + rebuttal Zhang et al., 2013)
- **Atmospheric forcing** (Clement et al., 2015 + comment Zhang et al., 2016)

Model behaviour and type (slab-ocean vs coupled, strongly active aerosols) can influence the results.

What we’ve learned from fingerprints

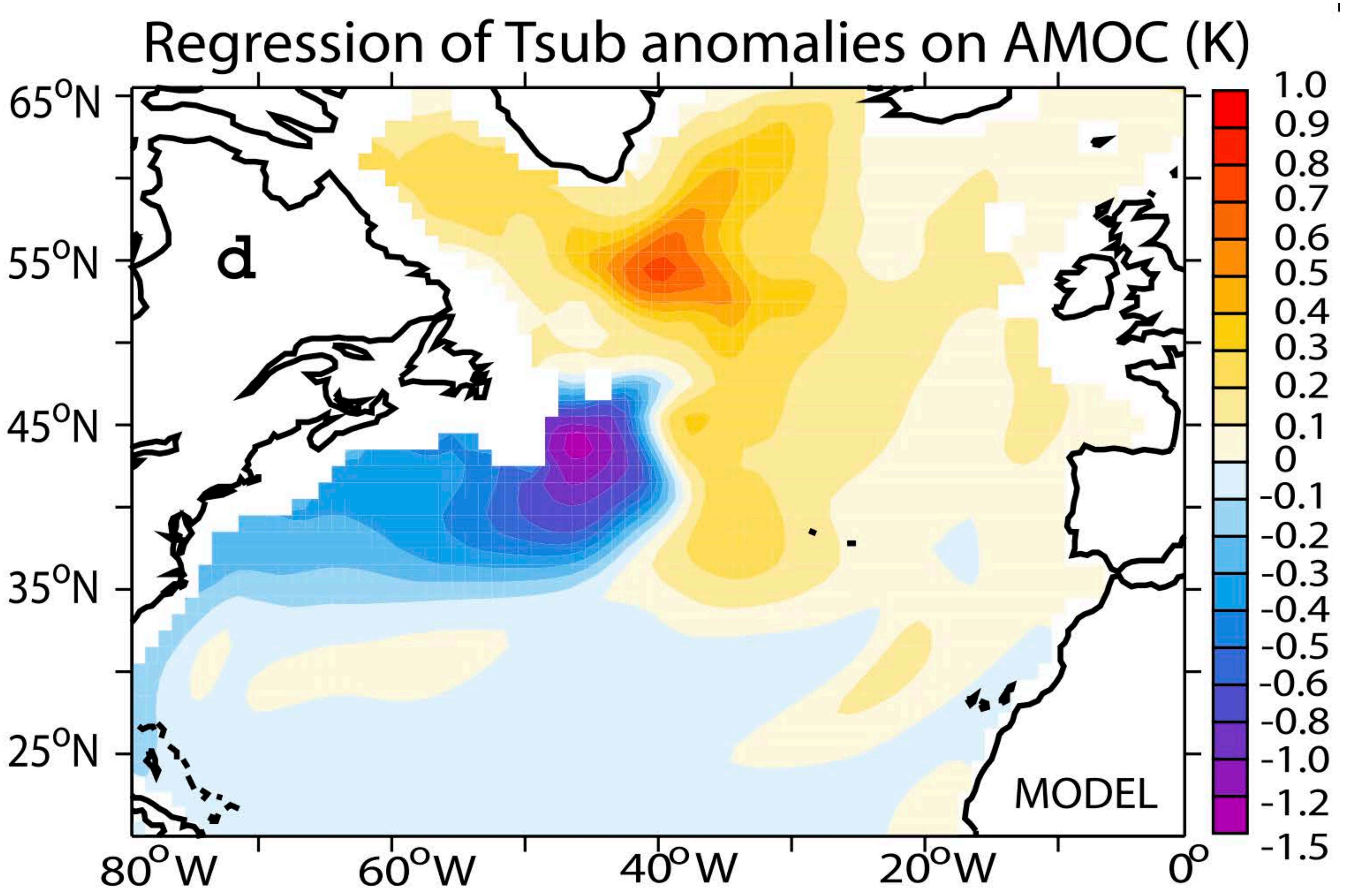
Fingerprints help us to

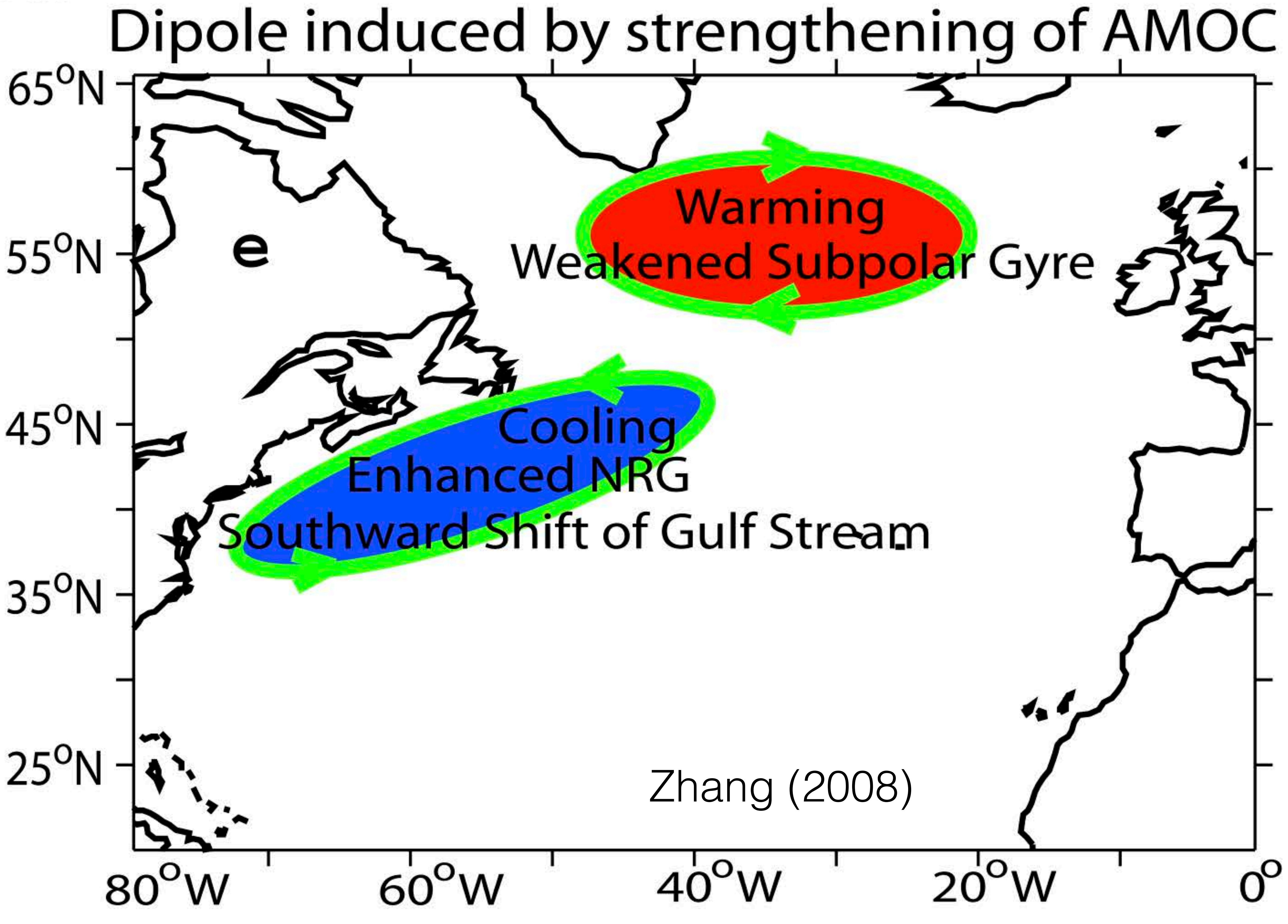
- Reconstruct past changes in the AMOC when observations didn’t exist
- Place current variability of AMOC in context of longer term variations
- Take advantage of fingerprint-variable predictability to predict AMOC changes
- Evaluate impacts of AMOC changes

A few examples…

Processes vs fingerprints

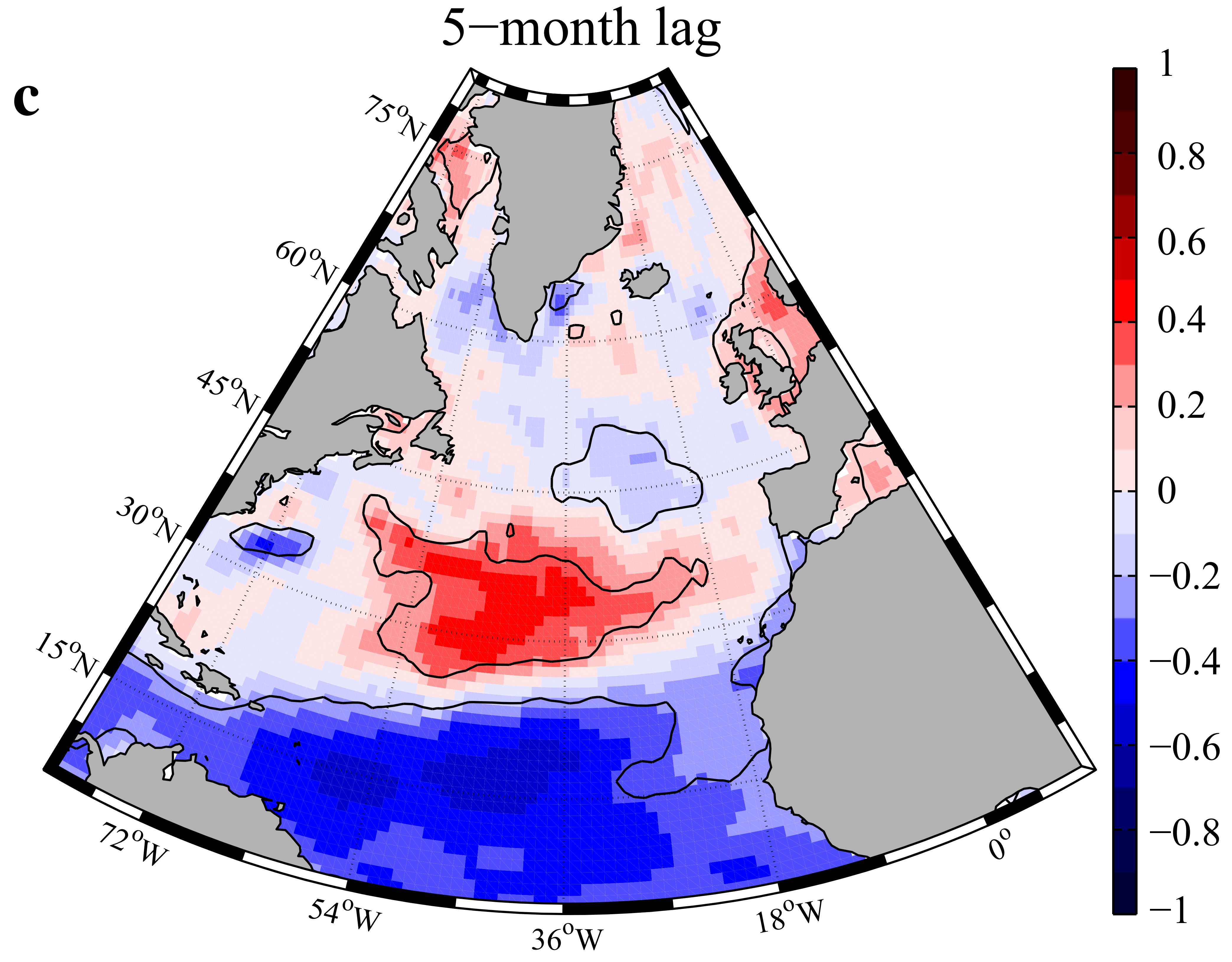
Can *potentially* be used to understand critical driving processes. A change in the AMOC may correspond to a change in the strength of particular subsets of the circulation.





Patterns as well as magnitudes of fingerprints matter (Zhang et al. 2013)

Seasonal prediction of SST



Duchez et al. (2016a)

If SST is driven (in part and sometimes) by AMOC changes, there may be the potential for predicting SST in the North Atlantic from AMOC changes

Calafat et al. (2018)
Alternative: Hirschi poster

Variability of coastal sea level

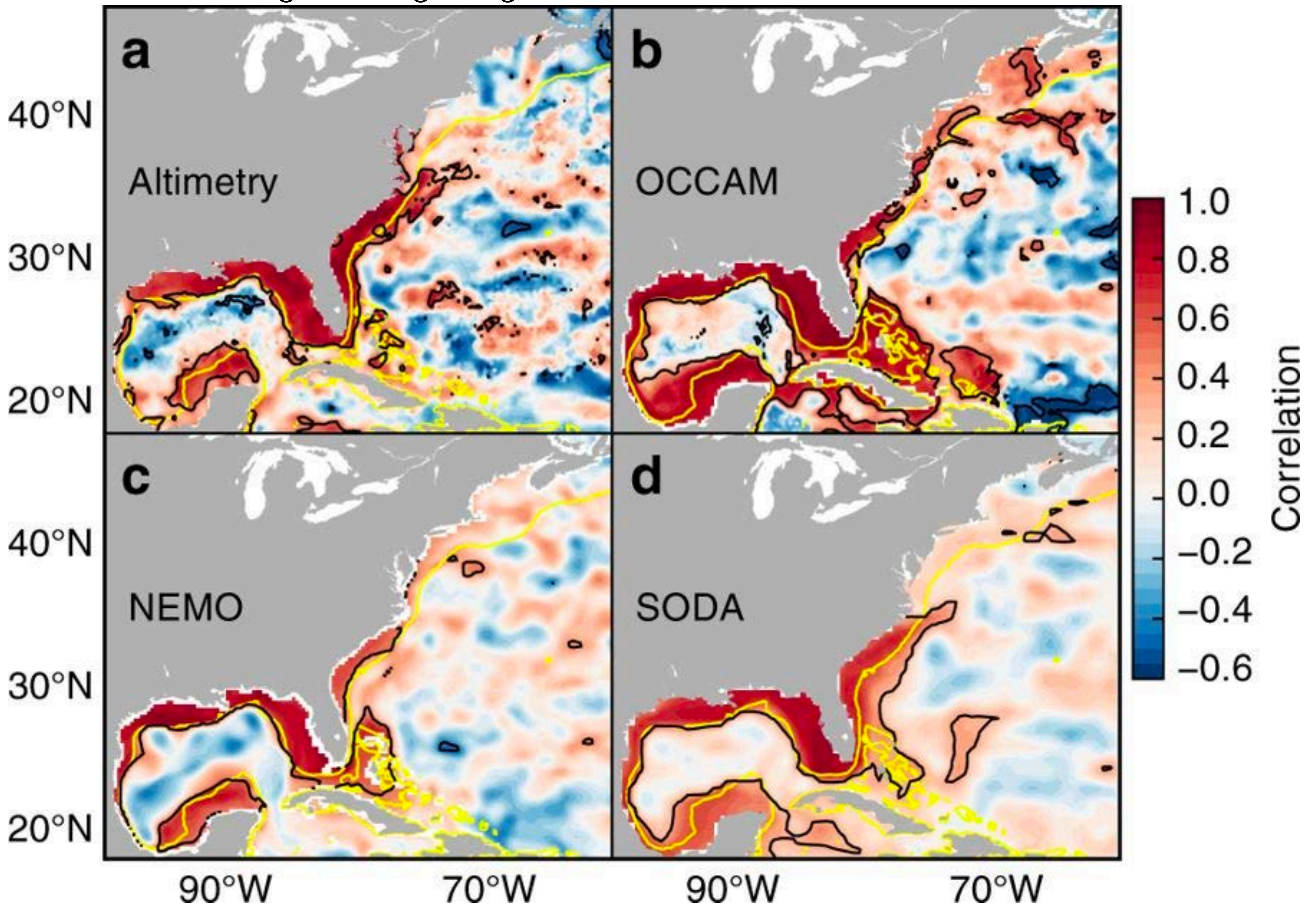
Timescales:

- Interannual

Data sources:

- Transport observations
- Property observations (temperature, sea level)
- Numerical simulations

Pointwise correlation between sea level annual cycle at each grid point
And averaged along the gulf + southeast coasts



Decadal prediction of SST/OHC

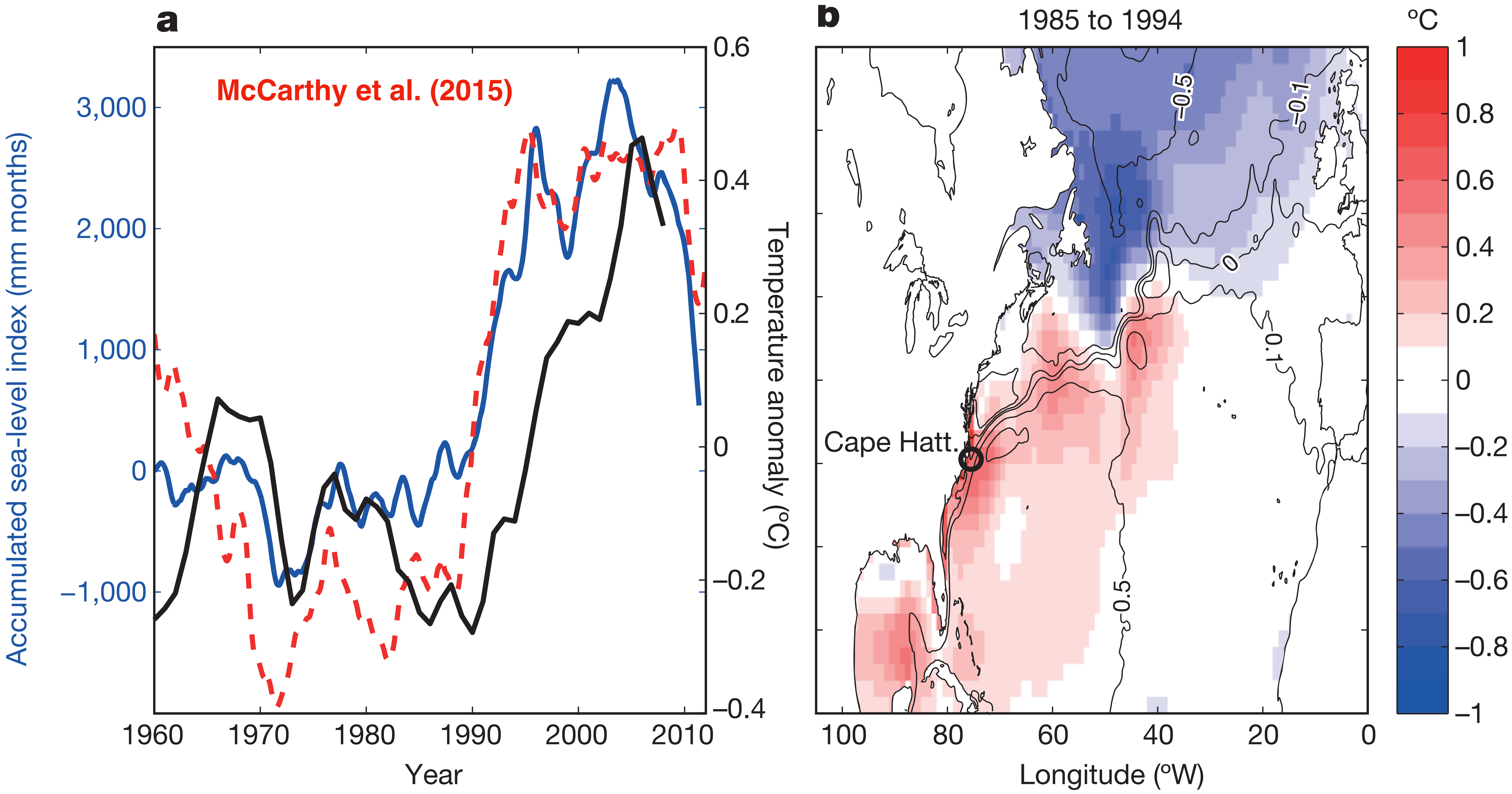
AMO/AMV

Timescales:

- Interannual to multi-decadal

Data sources:

- Transport observations
- Property observations (temperature, sea level)



Other fingerprints?

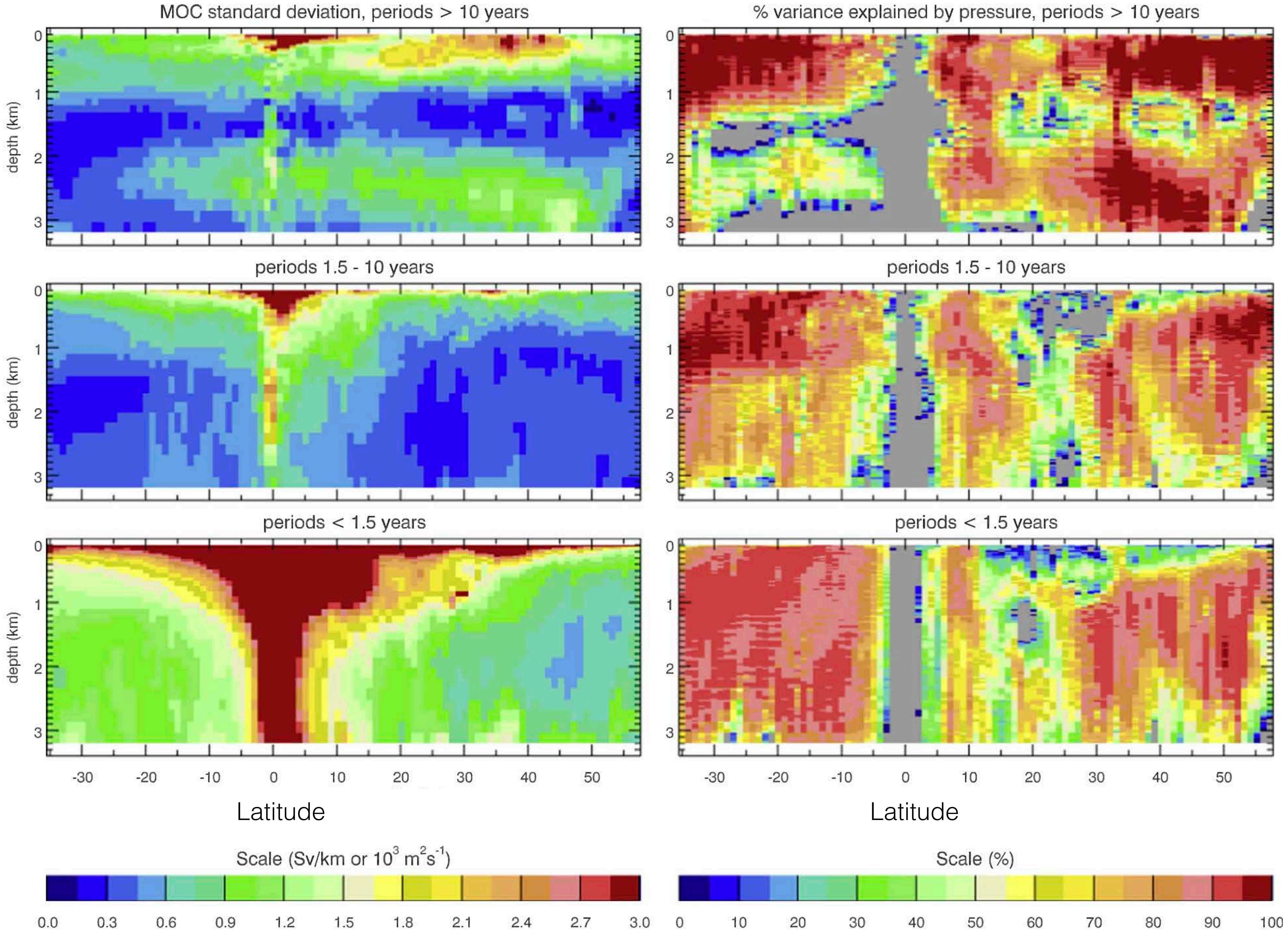
Variables often used: Sea surface height (SSH), sea surface temperature (SST), subsurface temperature and upper ocean heat content (OHC)

Can we find other fingerprint variables to use?

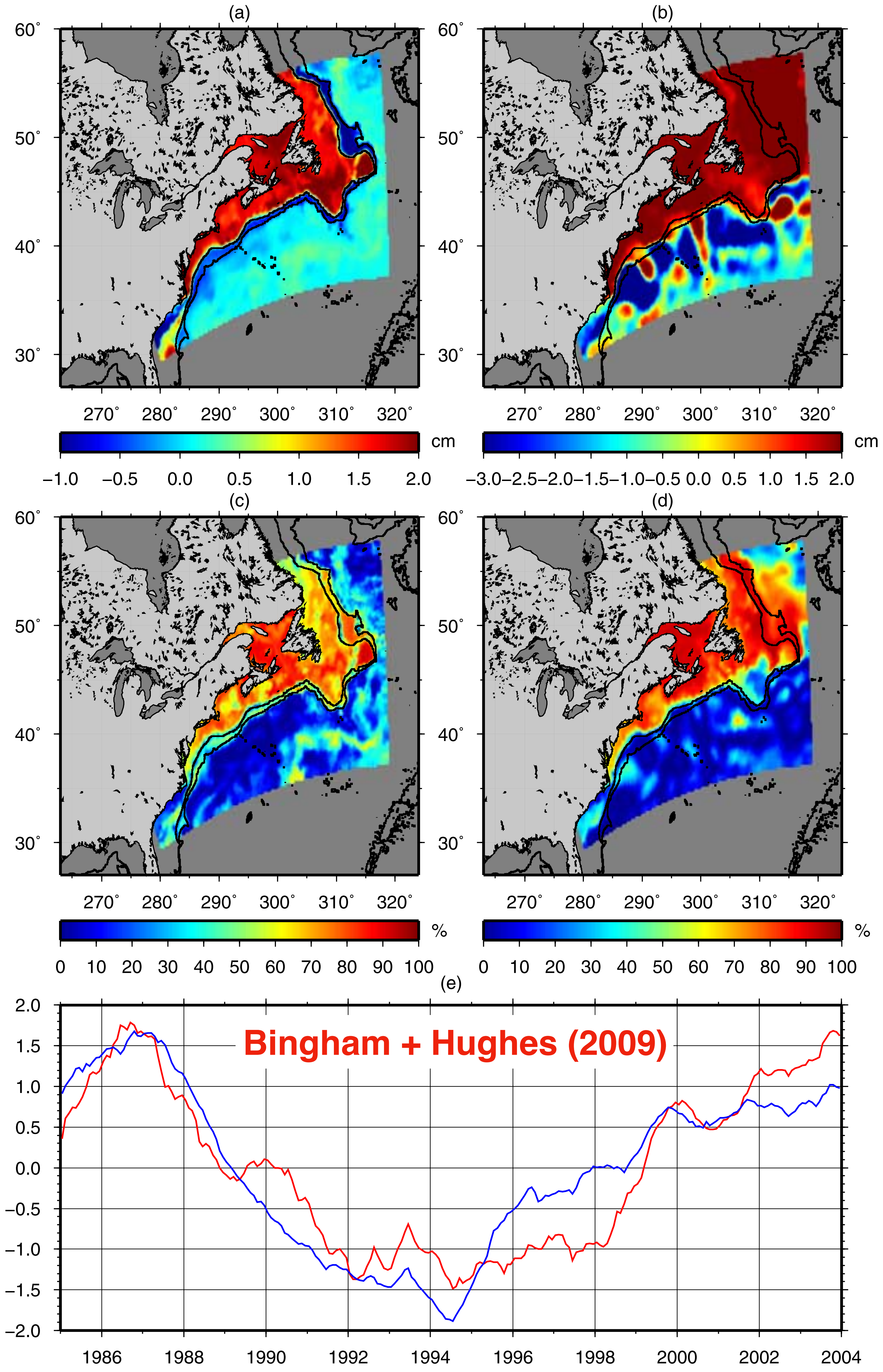
Other fingerprints?

Ocean bottom pressure?

MOC variance explained by pressure along the continental slope



Hughes et al. (2018)

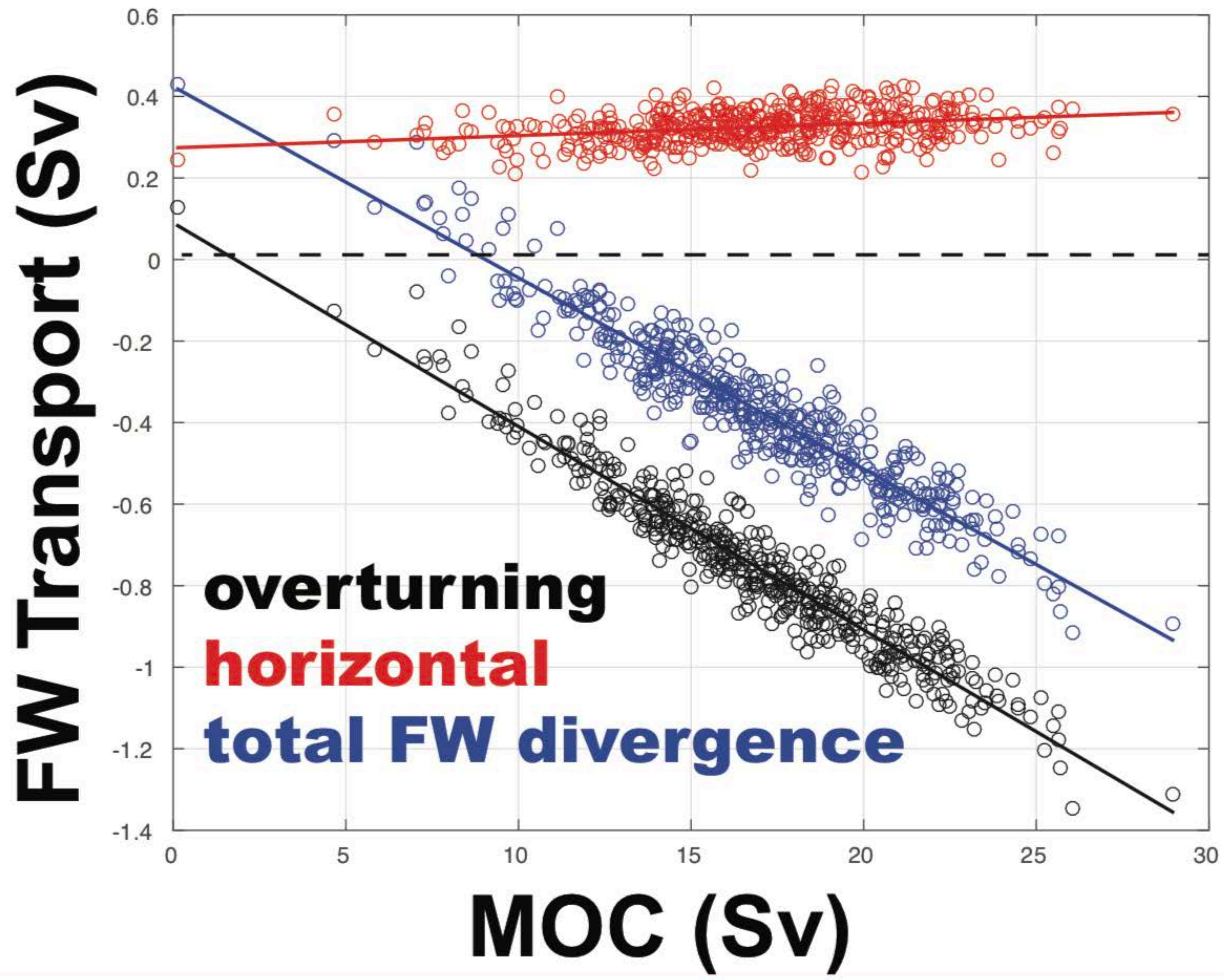


Bingham + Hughes (2009)

Other fingerprints?

Salinity?

- Meridional heat transport is driven by the AMOC at 26N, and temperature is a signature of AMOC changes.
- Meridional freshwater transport at 26N is also driven by the AMOC.
- Perhaps salinity is a potential fingerprint?
  Though records are not as long as temperature…



McDonagh et al. (2015)
Moat et al. Poster

Summary

Data sources:

- Transport observations
- Property observations and reanalyses (temperature, sea level)
- Numerical simulations

Timescales:

- <= Annual
- Interannual
- Decadal
- Centennial

Objectives:

- Seasonal prediction
- Decadal prediction
- Sea level variability
- Context for present day

+ more

+ Paleo proxies

+ Millenial and longer

+ Paleo reconstruction

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- **Timescales** may be assumed but relate to *processes*
- **Linearity** limits utility if circulation pathway shifts
- Dominance of a single driver is a necessary assumption? But assumes **stationarity**
- **Patterns** of the fingerprint may be related to *processes*
- **Potential for other fingerprints/multivariate fingerprints.** SST, subsurface T, OHC, (SSH) are linked

Thank you!

References

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