AMOC Variability at High CO_2

Is it consistent with a shift towards bifurcation?

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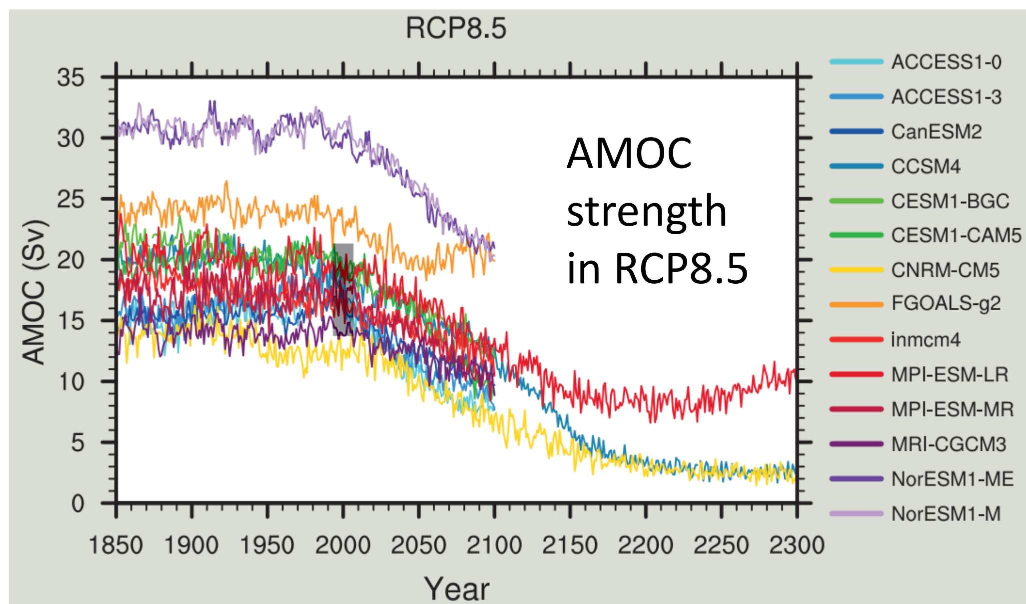
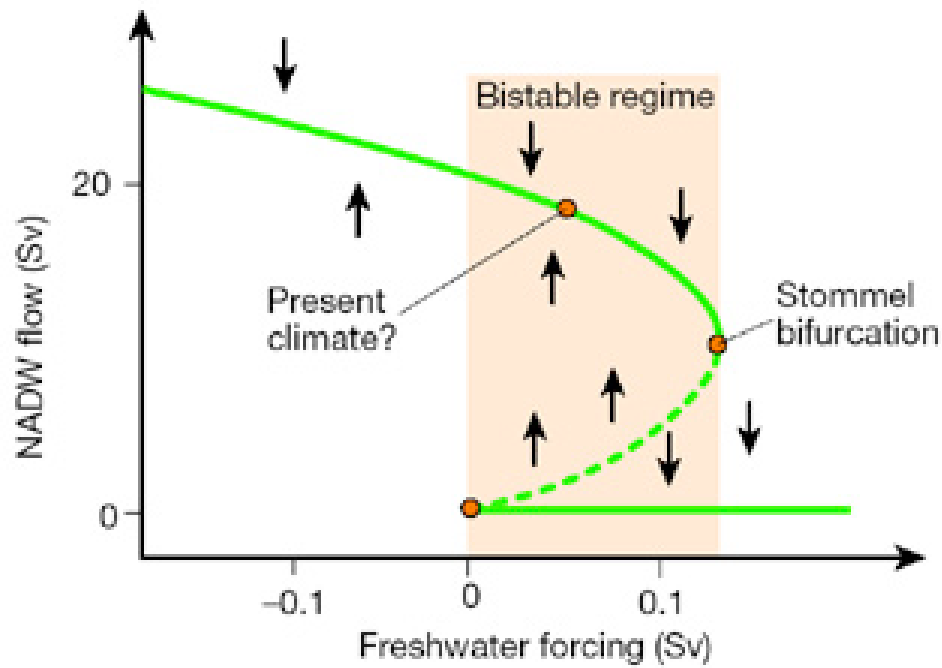
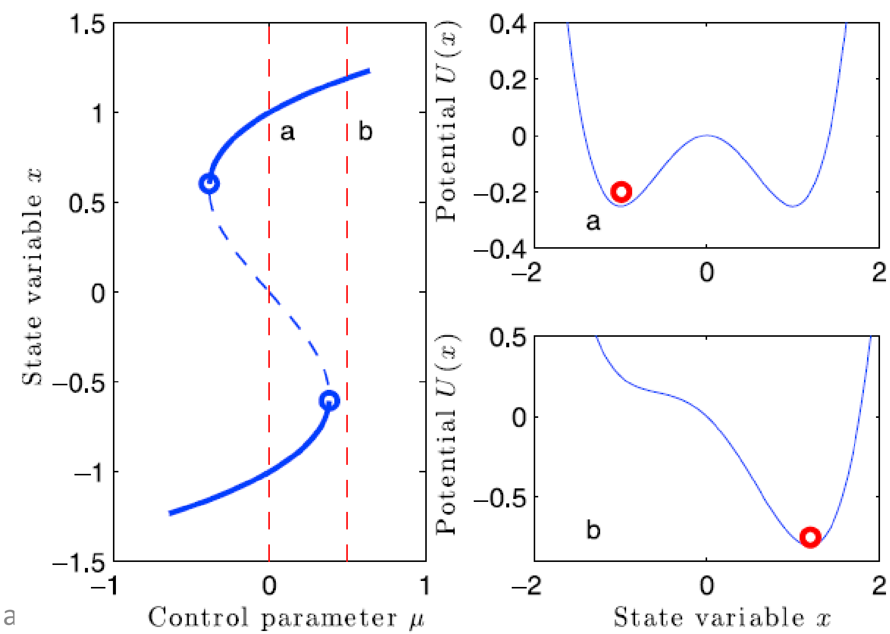
MacMartin, D.G., L. Zanna, and E. Tziperman, “Suppression of AMOC variability at increased CO_2” *J. Climate*, **29**(11), 4155-4164, 2016.
doi: [10.1175/JCLI-D-15-0533.1](https://doi.org/10.1175/JCLI-D-15-0533.1)



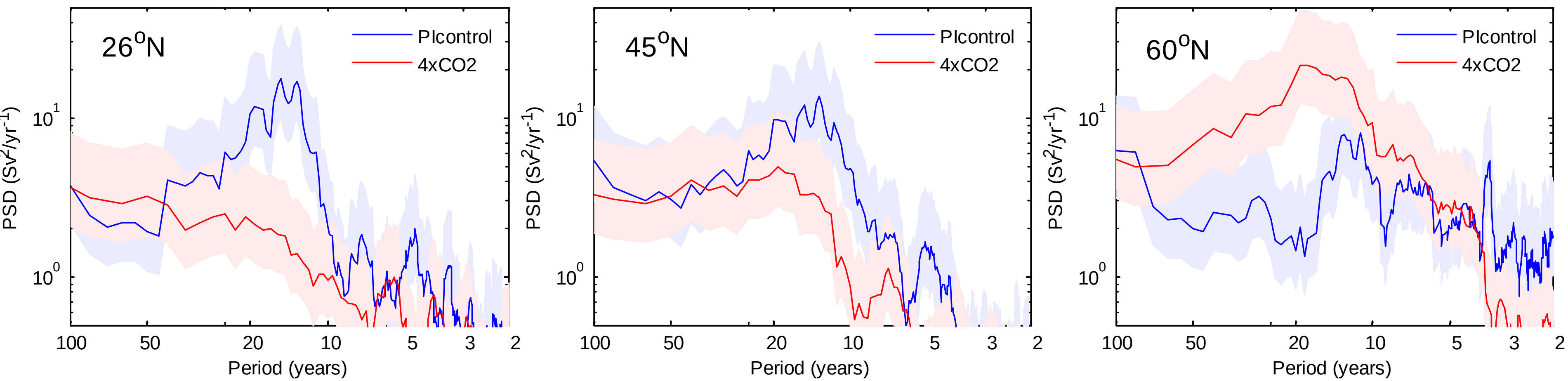
AMOC bifurcation / tipping points

- Stommel bifurcation, 1961: MOC vs. freshwater forcing:
  - MOC weakens approaching bifurcation
- At bifurcation, eigenvalues of linearization have zero real part
- As bifurcation is approached,
  - Increased variance
  - (Complex eigenvalues) Higher spectral peak
  - (Real eigenvalues) Slower response
- So what happens when we increase CO_2 in a GCM?
  - Only look at GFDL ESM2M
  - AMOC mean strength decreases, as expected

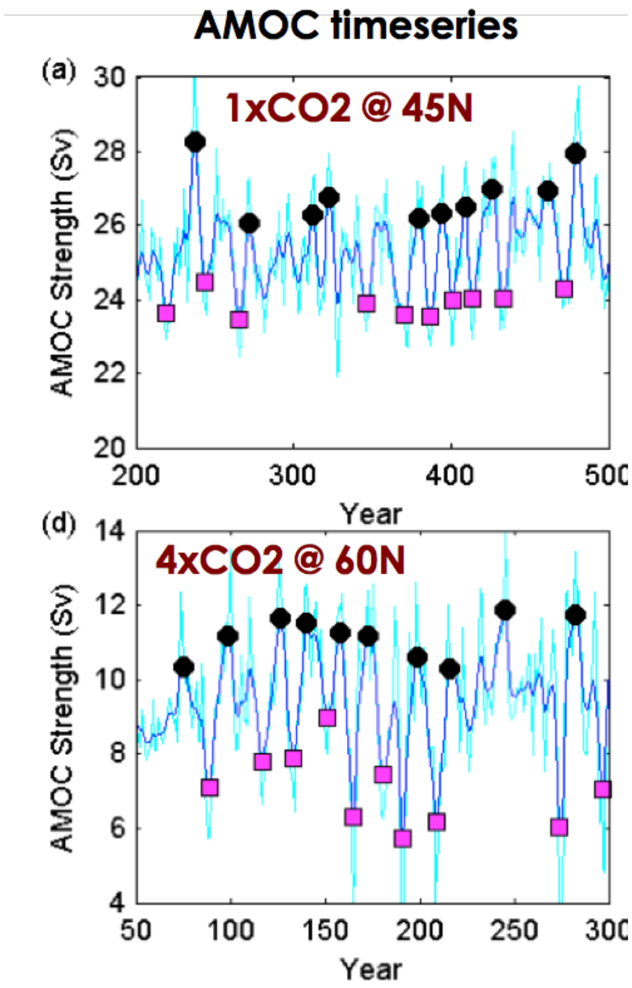




AMOC in GFDL ESM2M



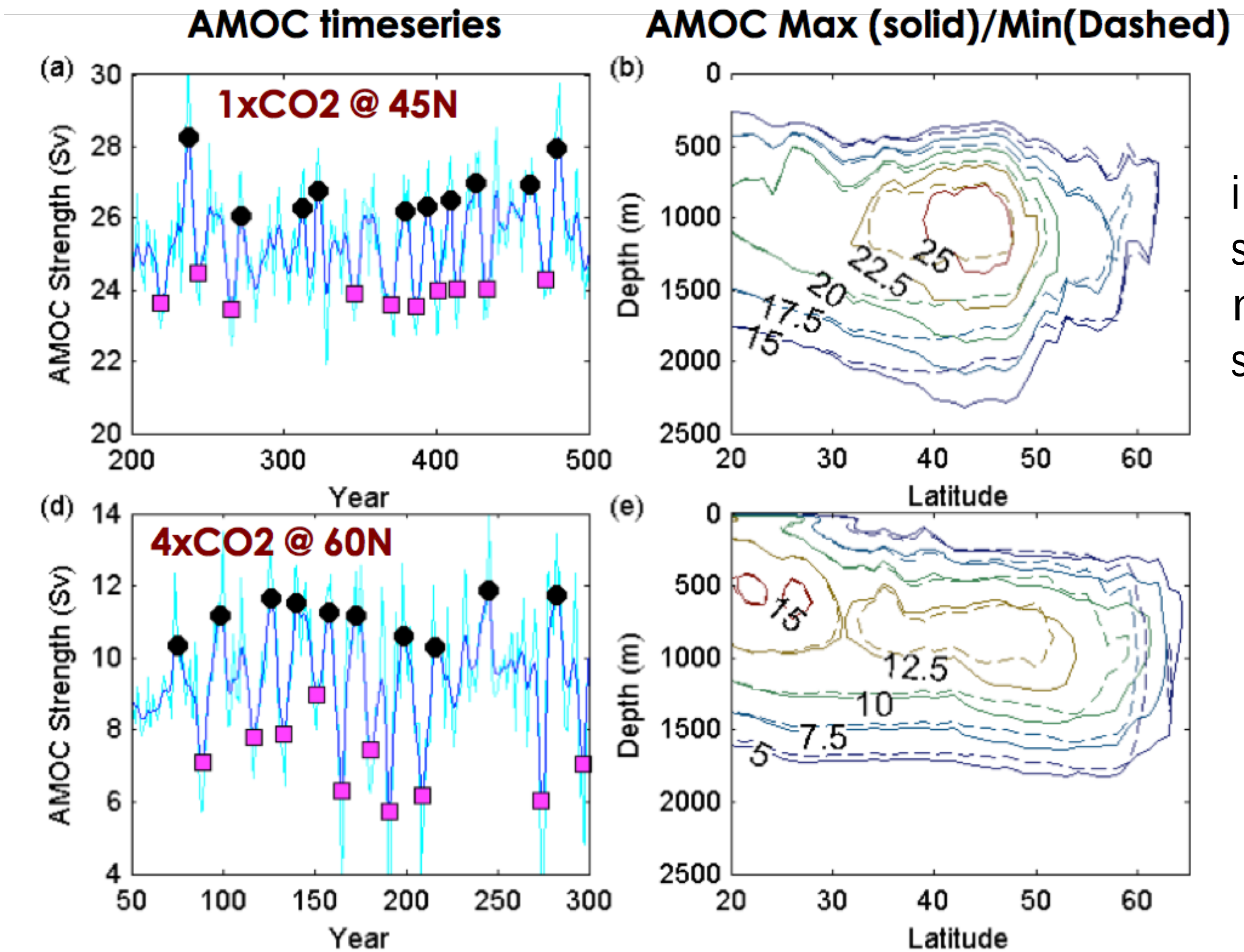
Patterns associated with the variability



Preindustrial (1xCO2) simulation: AMOC at 45N

4xCO2 simulation: AMOC at 60N

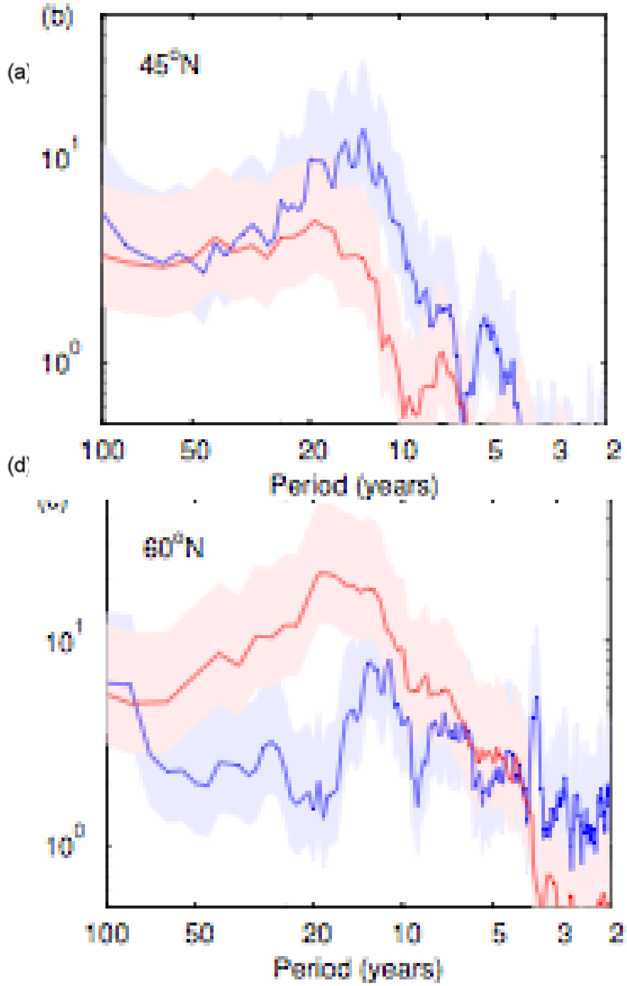
Patterns associated with the variability

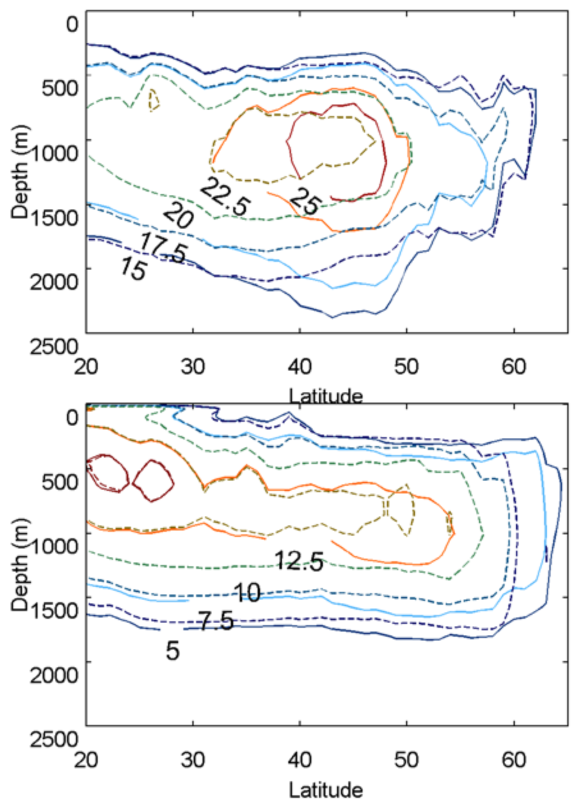


Preindustrial = changes in max overturning strength & depth + slight northwards shift of the streamfunction ~50N

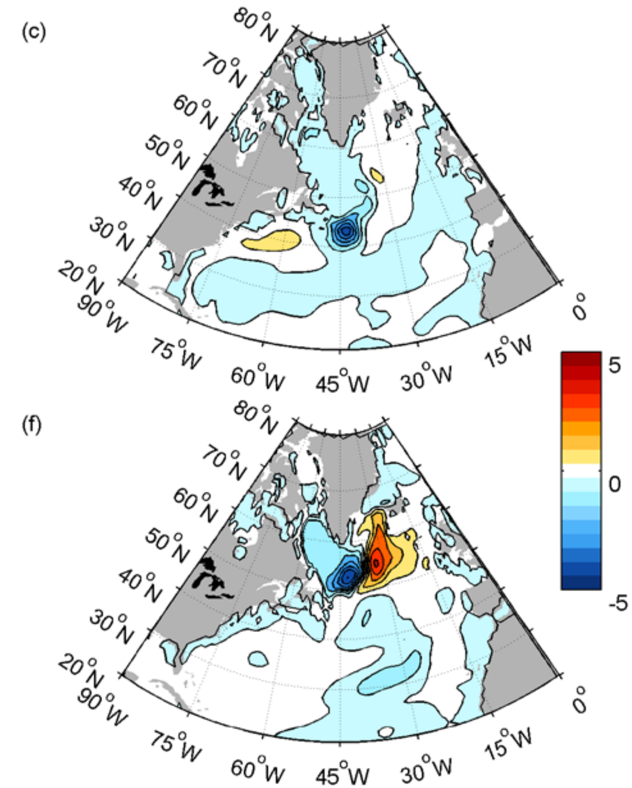
4xCO2 = northward extension of the overturning, well north of the latitude of max overturning. Patterns of upper ocean heat content anomalies are also shifted northwards.

Patterns associated with the variability





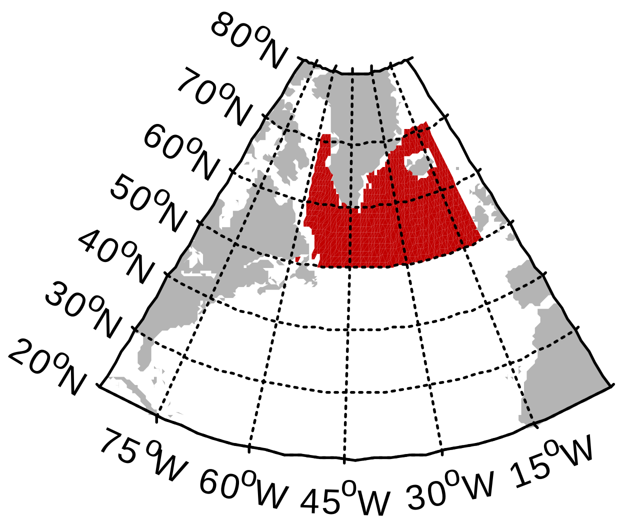
Upper 1km Ocean heat content Max-Min

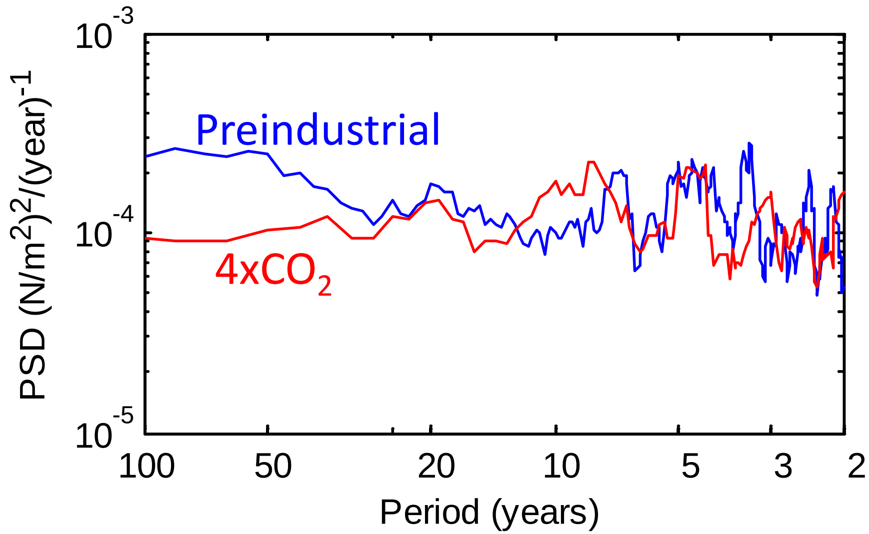


Are the differences due to the atmospheric forcing or the ocean state?

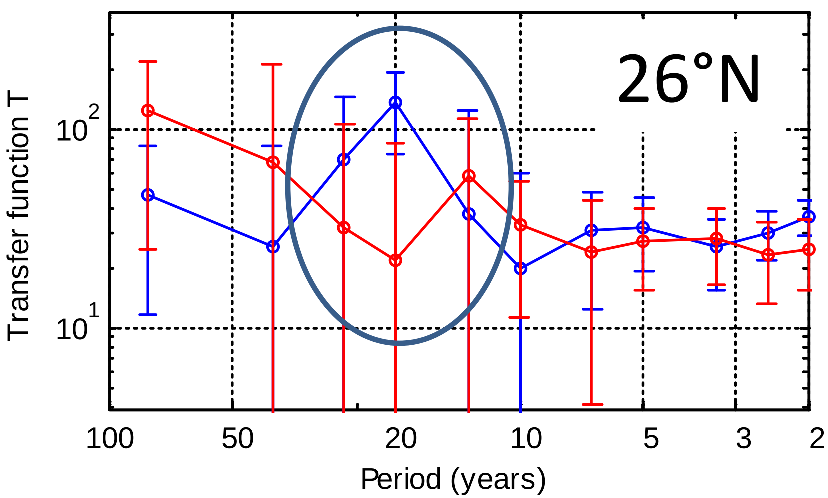
Atmospheric forcing

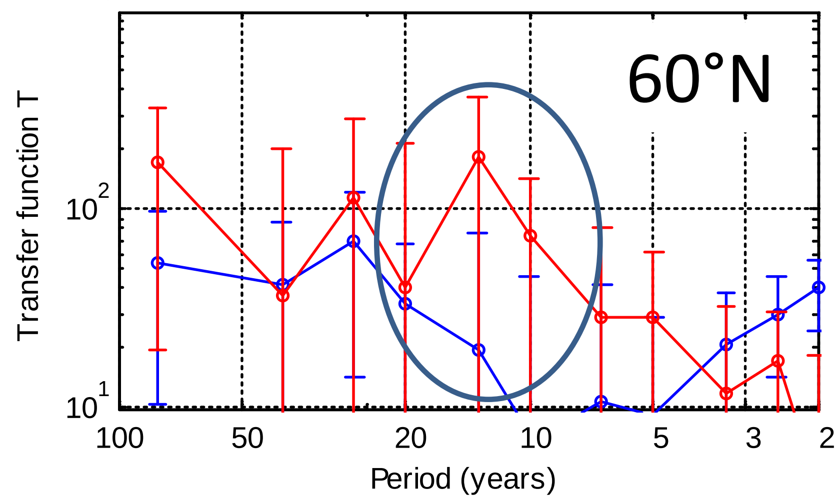
The atmospheric forcing spectrum is relatively unchanged at 4xCO2





But the dynamics have… can evaluate using transfer functions



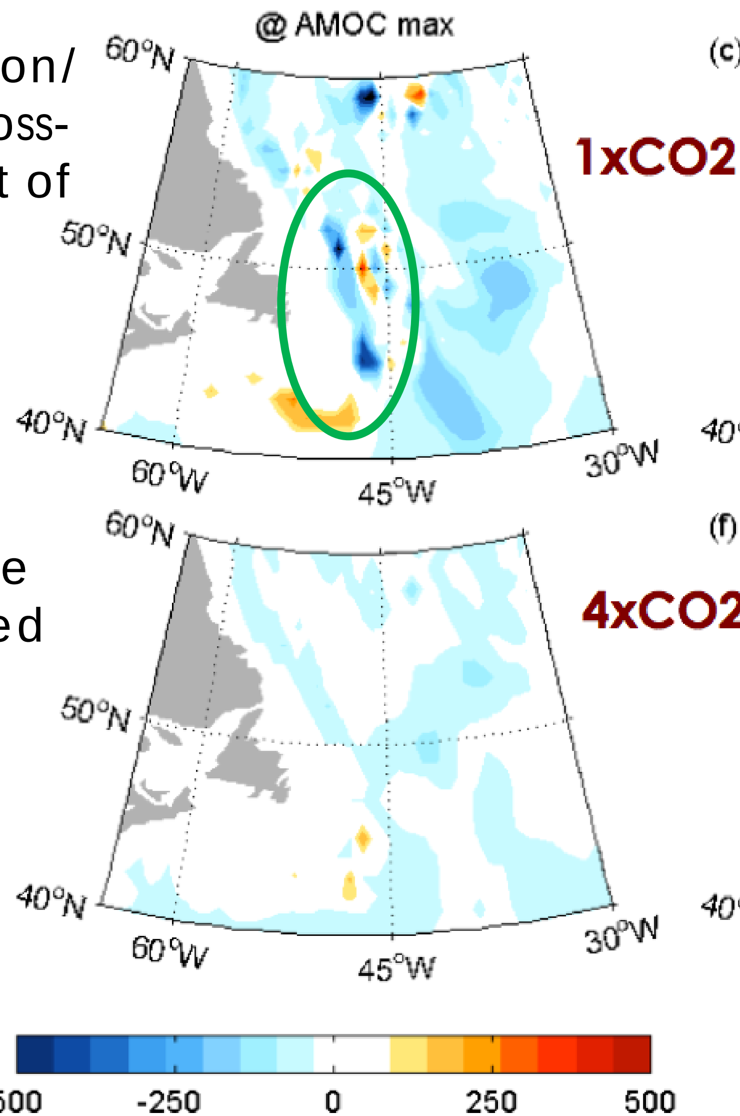


Vertical velocity & stratification

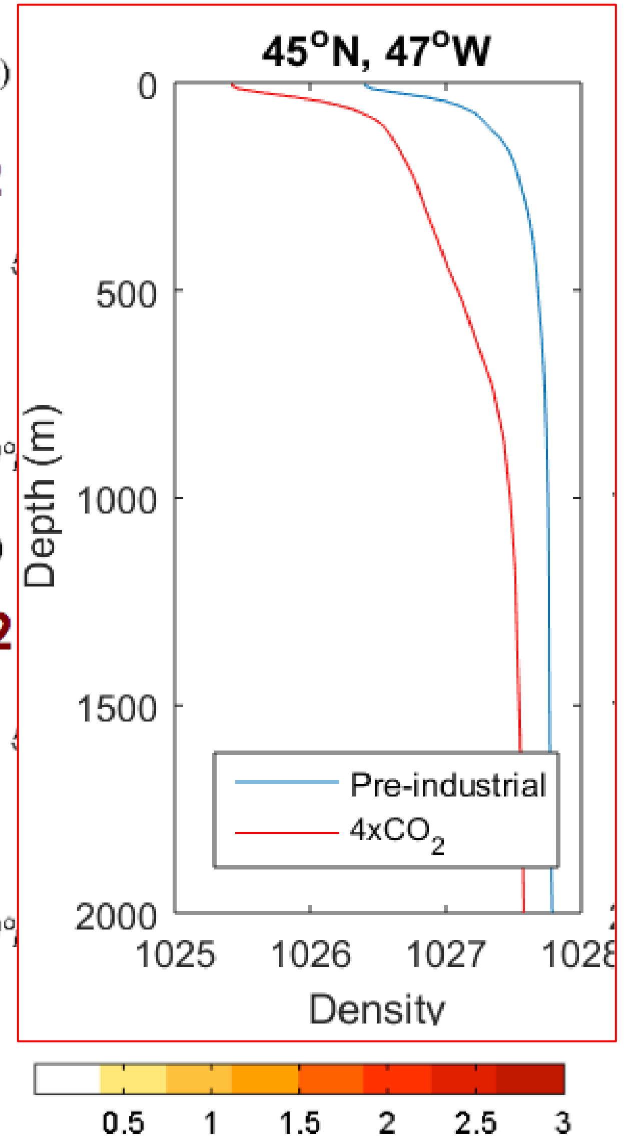
Preindustrial = Oscillation/ variability in vertical cross-isopycnal velocity, east of the Grand Banks

4xCO2 = Warming in the upper ocean + increased stratification in areas; reduces sinking + mid-latitude variability

Vertical Velocity



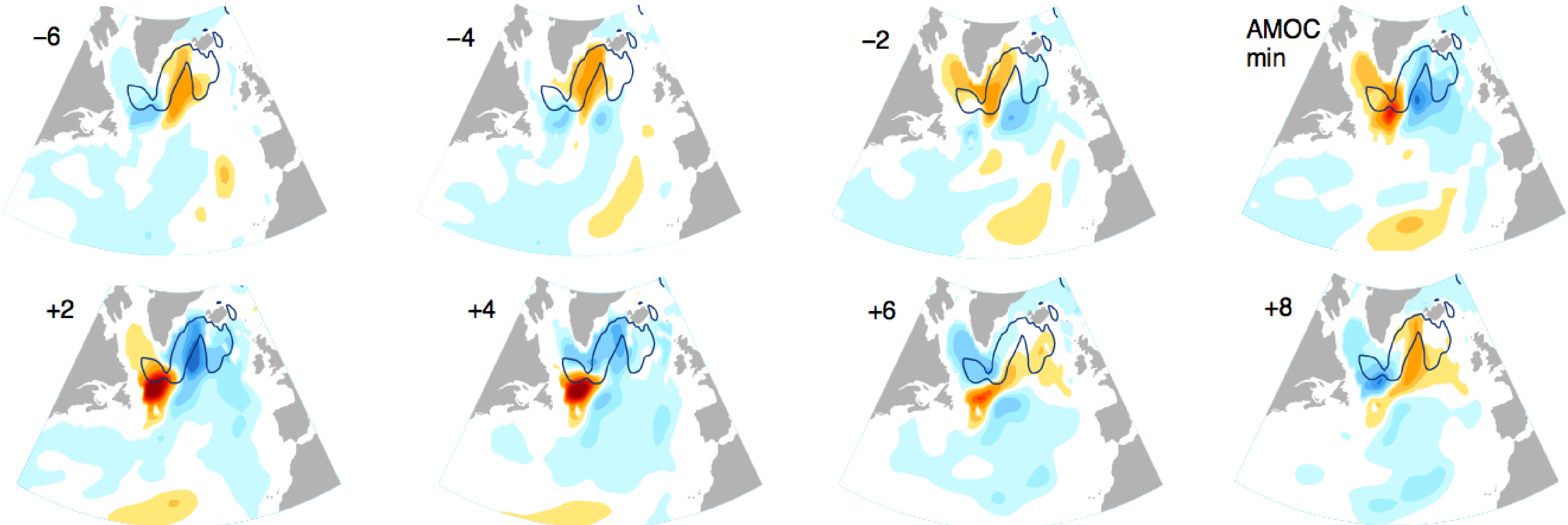
Stratification



4xCO2 = Low and mid-latitude reduced variability due to increased stratification

Composite of Min/Max Upper ocean heat content

Composite maps upper ocean temperature @ 4xCO2 before & after AMOC minimum



- Subpolar gyre is weaker at 4xCO2
- Upper ocean heat content anomalies are advected by the subpolar gyre on a timescale of the AMOC variability at 60N ~12-15 years
- Advection of anomalies in the subpolar gyre is strongly coupled with (possibly even causing) the AMOC variability at 60N in the 4xCO2 (via thermal wind), but decoupled from the weaker AMOC variability south of 50N

Summary & Implications

- Changes in AMOC variability predominantly due to a shift in the internal ocean dynamics rather than a change in stochastic atmospheric forcing
- Reduction in variance south of 45N is due to an increased stratification east of Newfoundland
  - Resulting from the shallower & weaker mean overturning
- The reduced AMOC variance that accompanies the reduced mean value of the AMOC at $4xCO_2$ is in contrast to the predictions of simple box models that predict a weaker circulation to be closer to a stability bifurcation point
- The high-latitude variability in the $4xCO_2$ simulation is due to the advection of anomalies by the subpolar gyre, distinct from the variability mechanism in the control run at lower latitudes – is it only in the GFDL model?
- The $4xCO_2$ variability has only a small effect on meridional heat transport, but does significantly affect sea ice in the northern North Atlantic
- Decadal subpolar gyre variability is often linked to changes in European weather - see O'Reilly et al, 2016 - impact under climate change?

MacMartin, Zanna, Tziperman J. of Climate, 2016