Frequency-domain analysis of AMOC Processes

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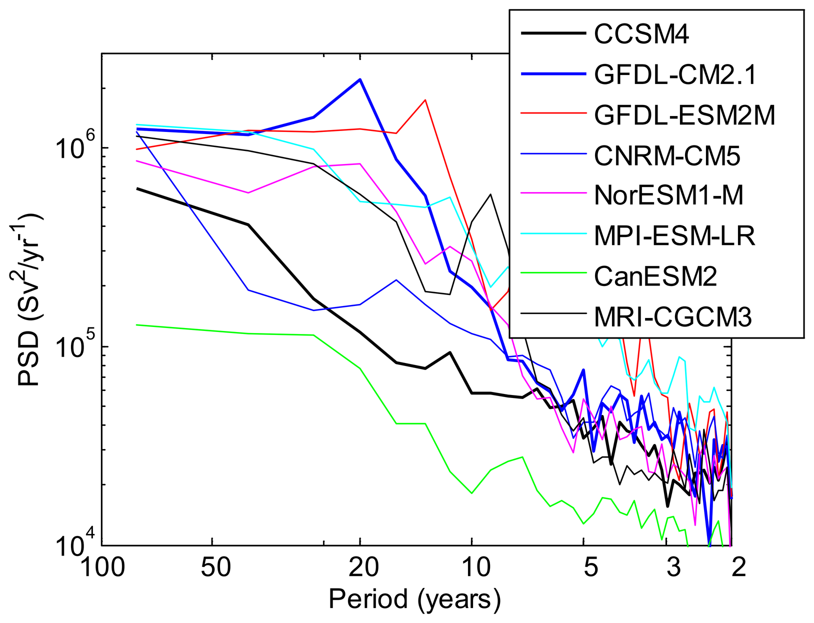
Goals

- Interannual AMOC variability differs across CMIP5 models
  - Several models have peaks in power spectrum



- Since differences depend on frequency, **Compare processes in *frequency domain***
  - What processes are robust across models
  - Help understand why models differ
- Key tool introduced here is the *transfer function* between input and output variables

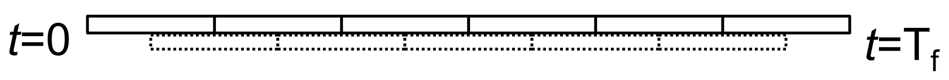
Transfer Function

- The transfer function describes the linear, causal, input/output dynamics of a process *in the frequency domain*

- From differential equation, e.g. $\dot{y} = \alpha x - \epsilon y$ take Fourier transform, with frequency *f*, $s = 2\pi i f$

$$T_{xy}(s) \equiv \frac{\hat{y}(s)}{\hat{x}(s)} = \frac{\hat{x}(s)\hat{y}^*(s)}{\hat{x}(s)\hat{x}^*(s)} = \alpha \frac{1}{s+\epsilon}$$

- From data:
  - Divide time series for *x* and *y* into *n* segments



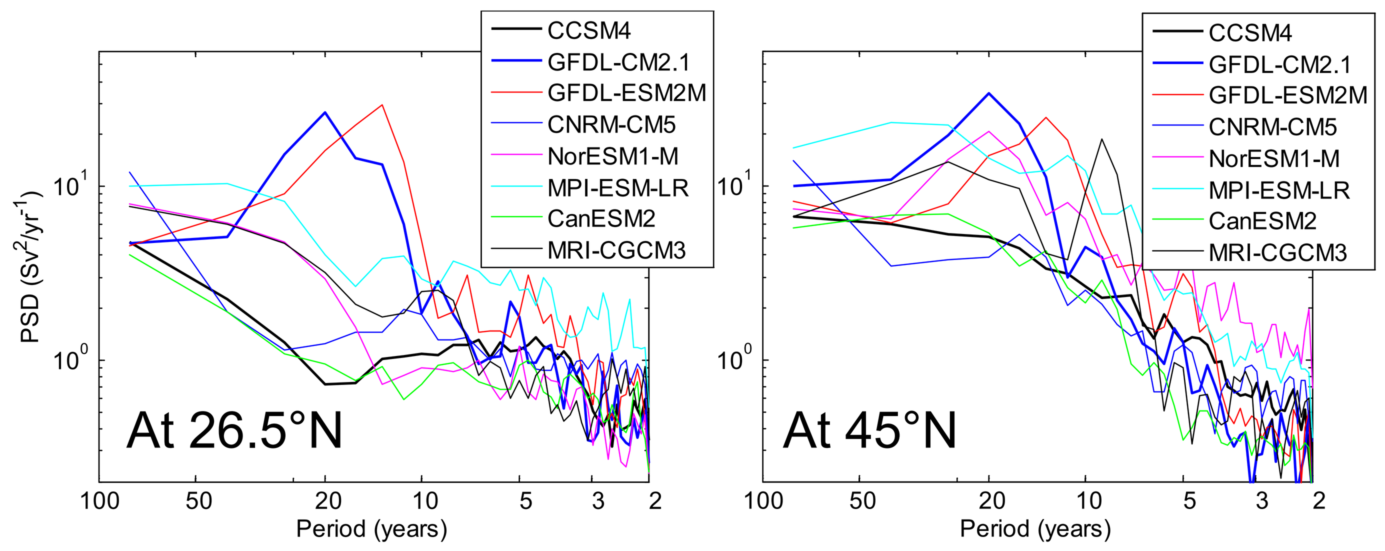
  - Compute Fourier transform of each segment
  - Average over segments to estimate cross- and auto-correlation: Tne ratio is the transfer function
    - Averaging reduces the effect of contributions to "output" time series *y* that are not due to "input" time series *x*
  - The estimation error can also be computed
- Both magnitude and phase are useful
  - Phase provides insight into causality

- For further details, see

  - MacMartin, Tziperman and Zanna, "Frequency-domain multi-model analysis of the response of Atlantic meridional overturning circulation to ocean surface forcing", *in prep.*
  - MacMynowski & Tziperman, "Using transfer functions to quantify ENSO dynamics in data and models", *submitted, Phil. Trans. Royal Society A*
  - MacMynowski & Tziperman, "Testing and improving ENSO models by process using transfer functions", *Geophys. Res. Lett.*, 37, 2010.

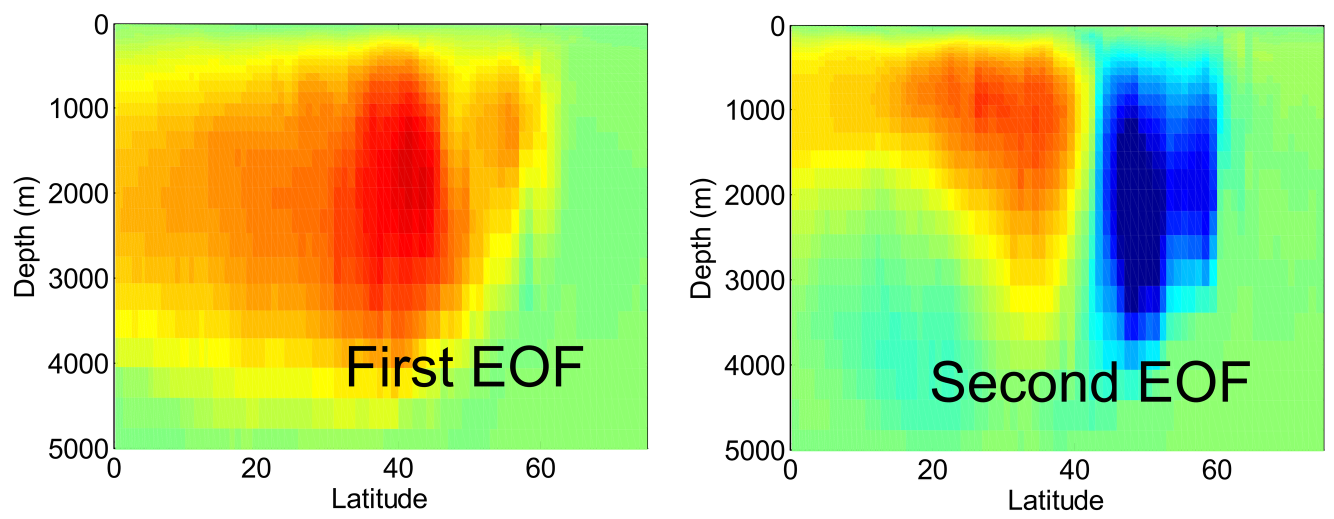
Characterizing AMOC Variability

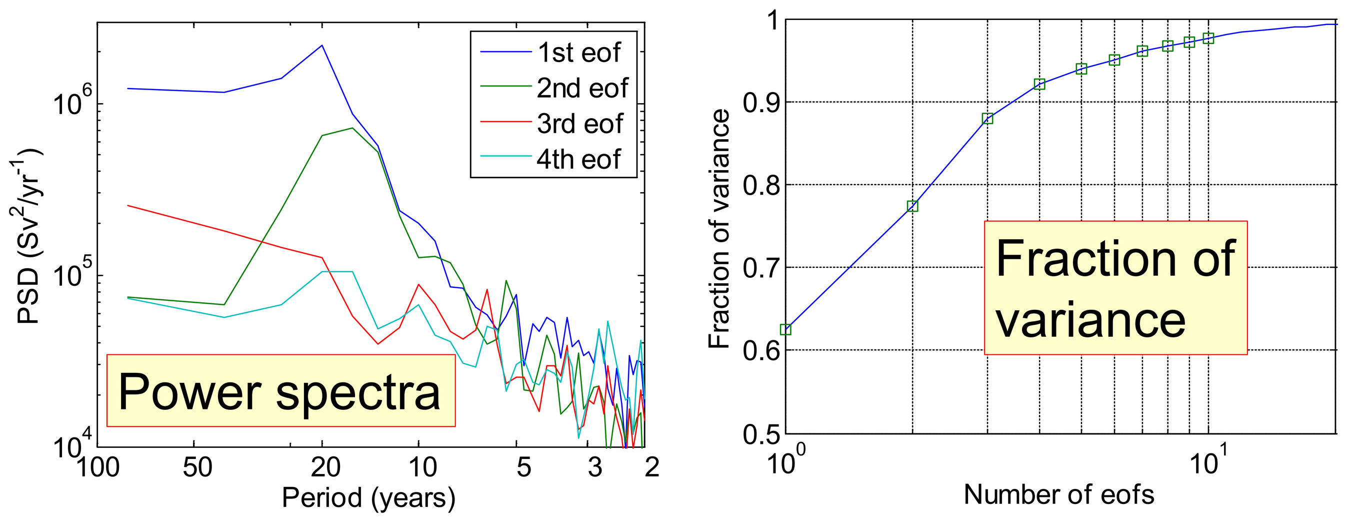
- Significant differences between models at interannual time-scales
- Significant difference in variability with latitude



- Empirical orthogonal functions (eofs) of overturning streamfunction:
  - First eof captures overall overturning strength
  - Second eof (typically) captures north-south variability in overturning
  - Third eof (typically) captures variability in depth
  - Peak in power spectra for GFDL models is mostly associated with 2nd eof (N-S variation)
  - We use amplitude of projection onto 1st eof as measure of AMOC variability.

GFDL CM2.1

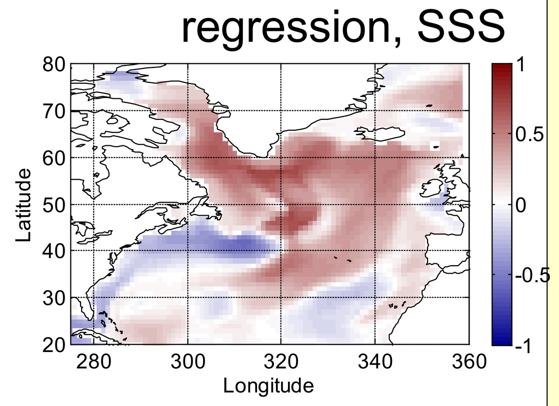




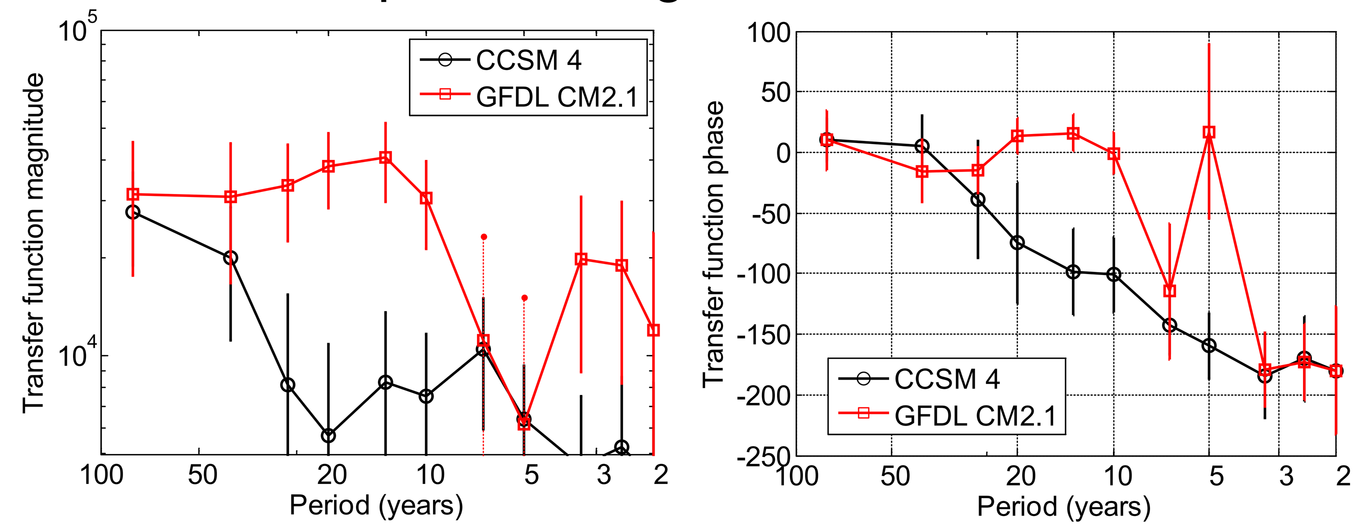
Transfer function analysis

- Model differences evident in process dynamics
  - E.g. AMOC response to
    - Sea surface temperature (SST)
    - Sea surface salinity (SSS)
    - Wind stress (TAU)
  - Compute regression patterns:
    - Largest correlation >50°N
    - For consistency, use average 50-70N for all models and all fields

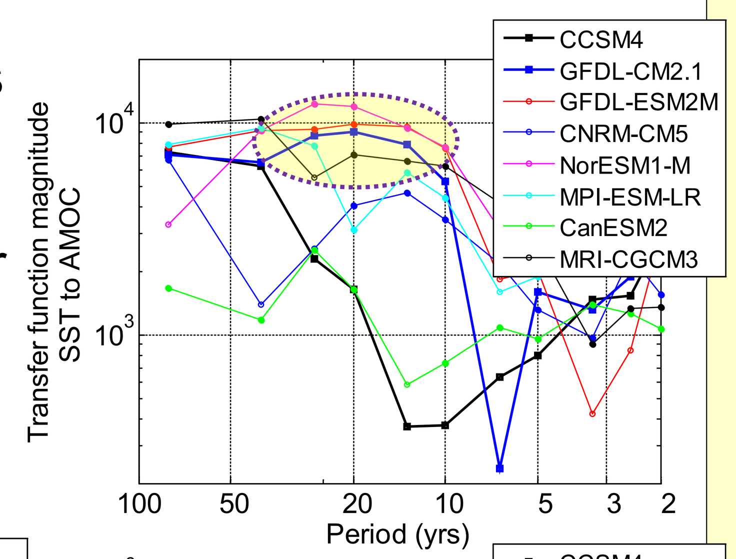
GFDL CM2.1 regression, SSS

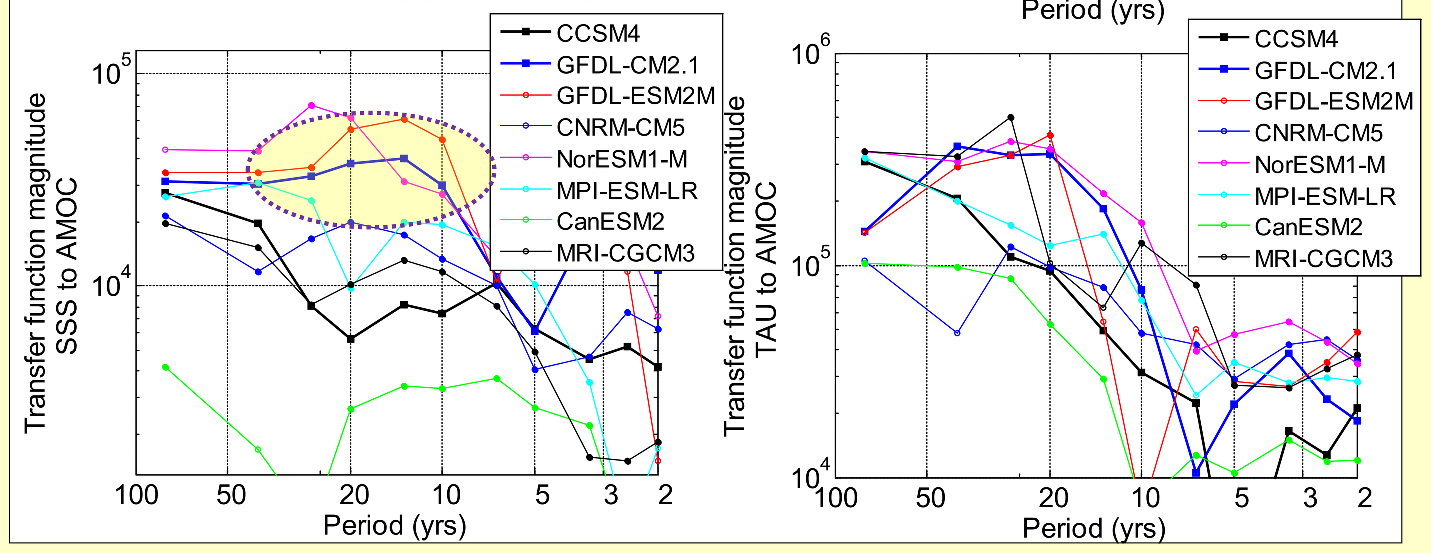


- Transfer function for CCSM4 and GFDL CM2.1, AMOC response to high-latitude SSS:



  - Error bars based on coherence
  - Transfer function emphasizes process differences between models
- Results are robust across multiple models
  - 10-30 year variability in SST, SSS, or wind stress all lead to higher excitation of AMOC in models with spectral peak (GFDL, NCC) than in those without





Summary

- Analysis of Atlantic Meridional Overturning Circulation (AMOC) suggests important dynamical differences between models
- Frequency domain estimation of process dynamics (using transfer functions) provides useful information
  - **Models with significant peaks in power spectrum of AMOC variability are those where MOC responds more strongly to surface forcing, in the frequency range corresponding to that of higher MOC variability**

Future

- Consider additional relevant processes for AMOC
  - 3D fields
- Compare changes in dynamics between pre-industrial and climate-change scenarios