MULTI-DECADAL VARIABILITY OF THE ATLANTIC MERIDIONAL OVERTURNING CIRCULATION (AMOC) IN CCSM3

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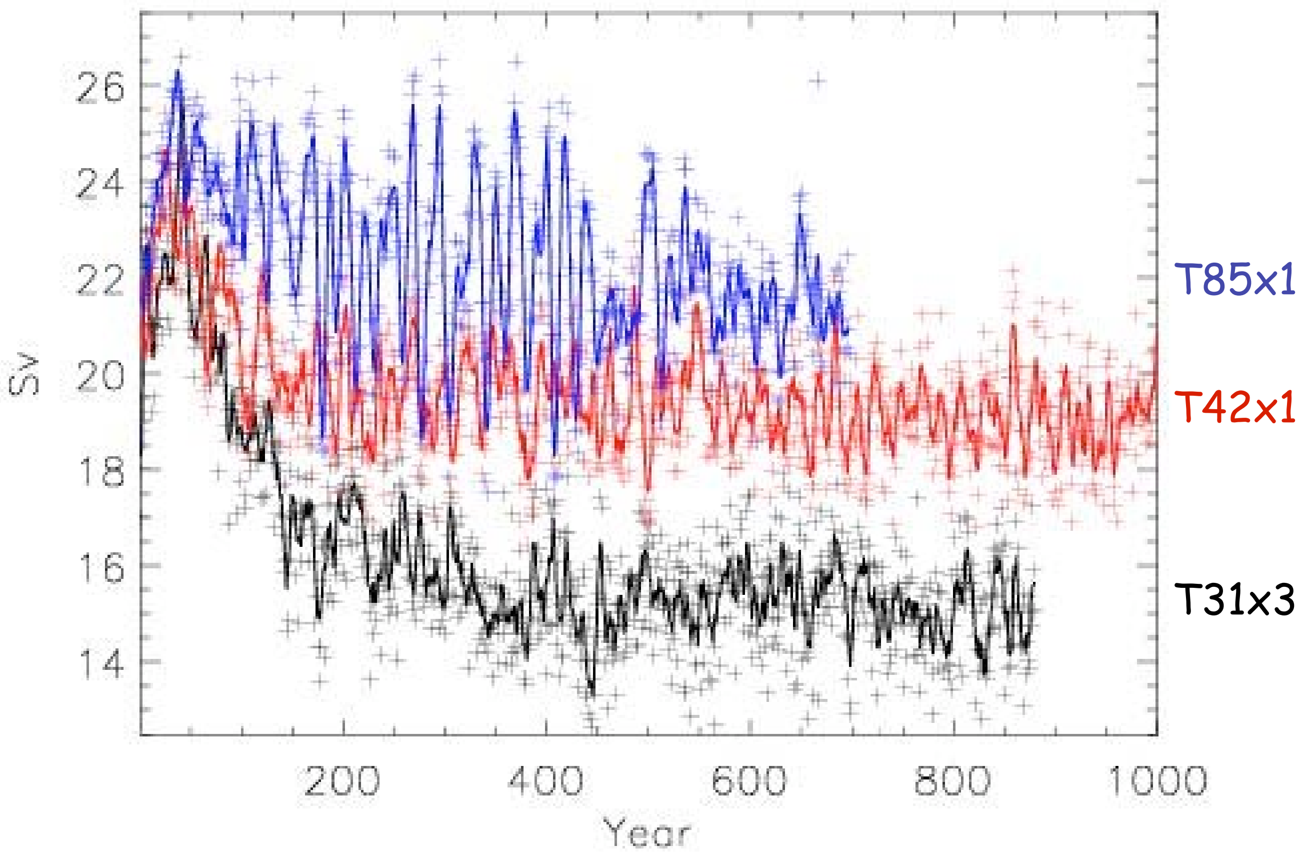
OUTLINE

- Examples and description of AMOC variability,
- Examples of its potential predictability,
- Brief discussion of AMOC features in a CCSM3 present-day control simulation,
- Questions / Summary.

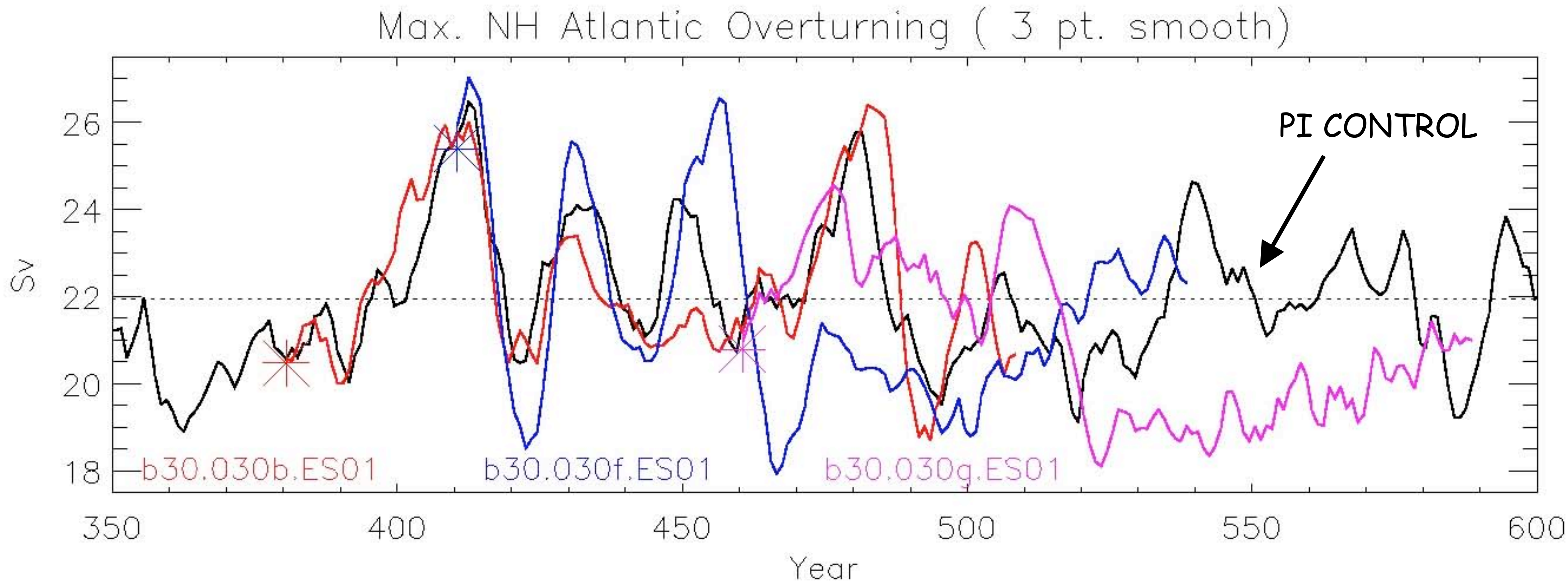
Many coupled general circulation models (CGCMs) exhibit multi-decadal or longer time scale (20 - 100+ years) variability in their AMOCs.

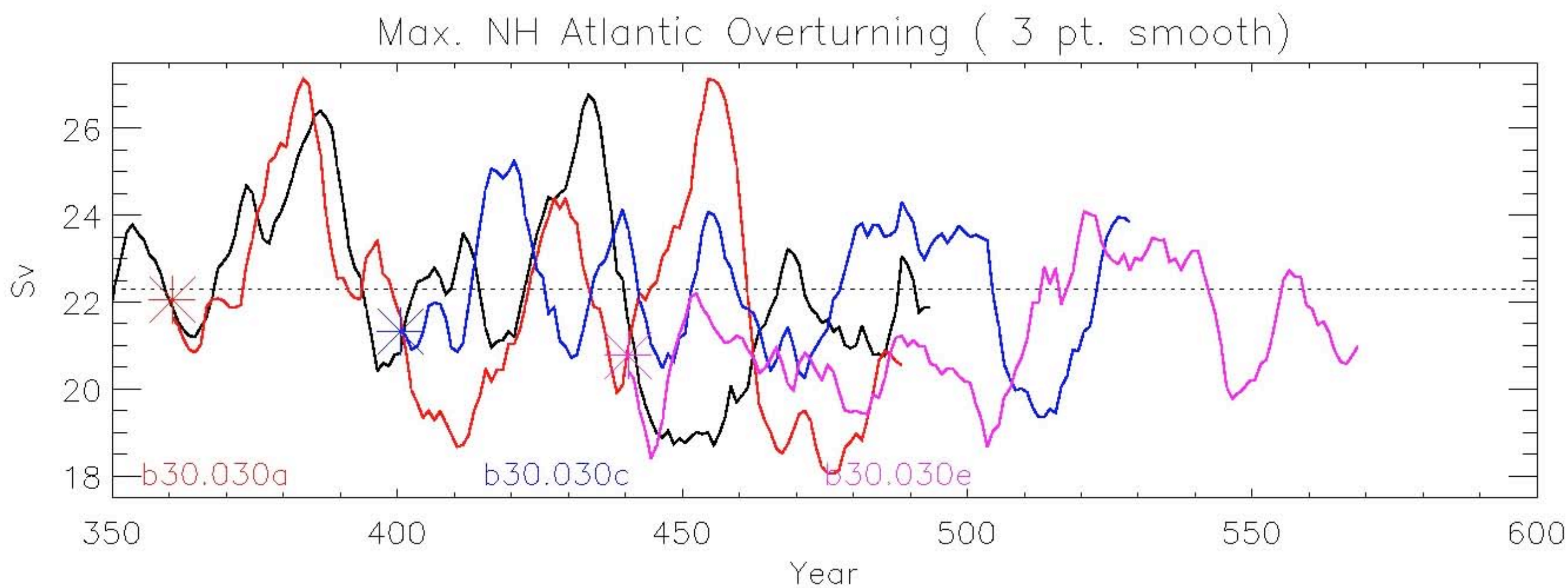
Time series of the AMOC maximum from CCSM3 present-day control simulations



Bryan et al. (2006, J. Climate)

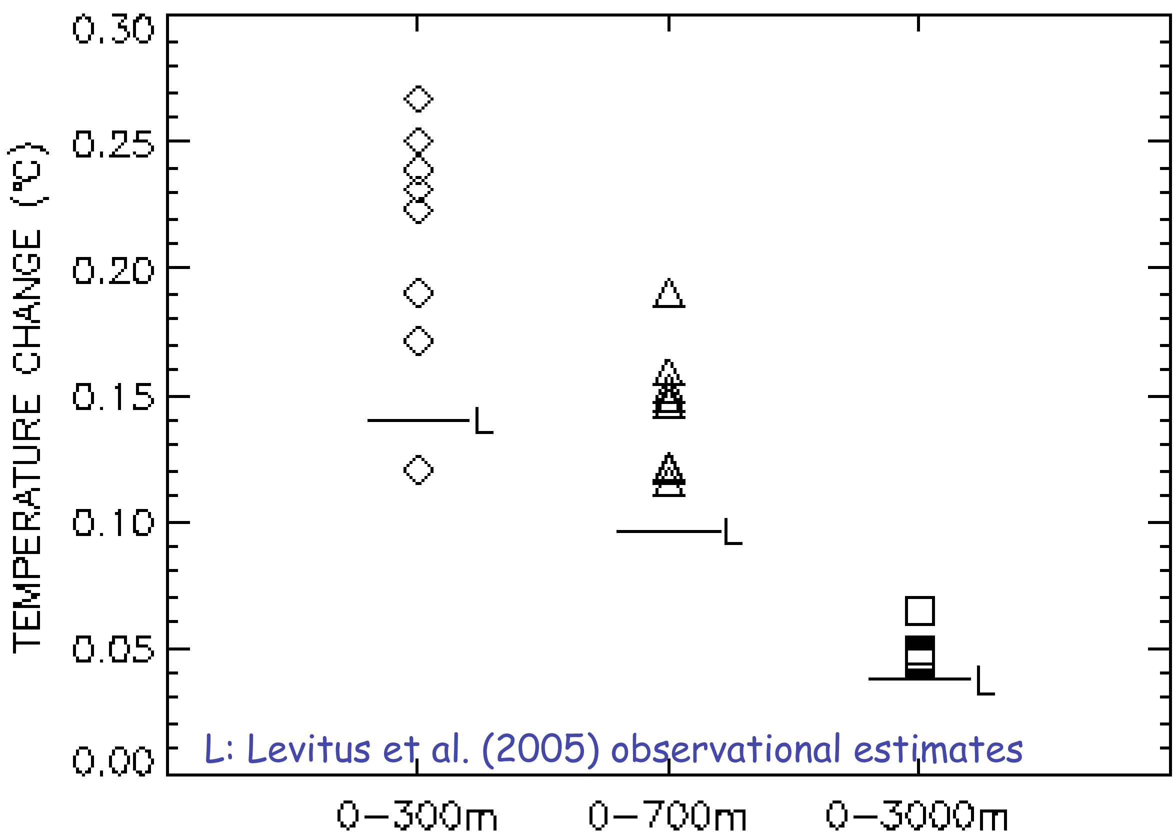
MOC IN THE 20th CENTURY ENSEMBLE INTEGRATIONS





HEAT CONTENT CHANGES between mid-1990s and mid-1950s

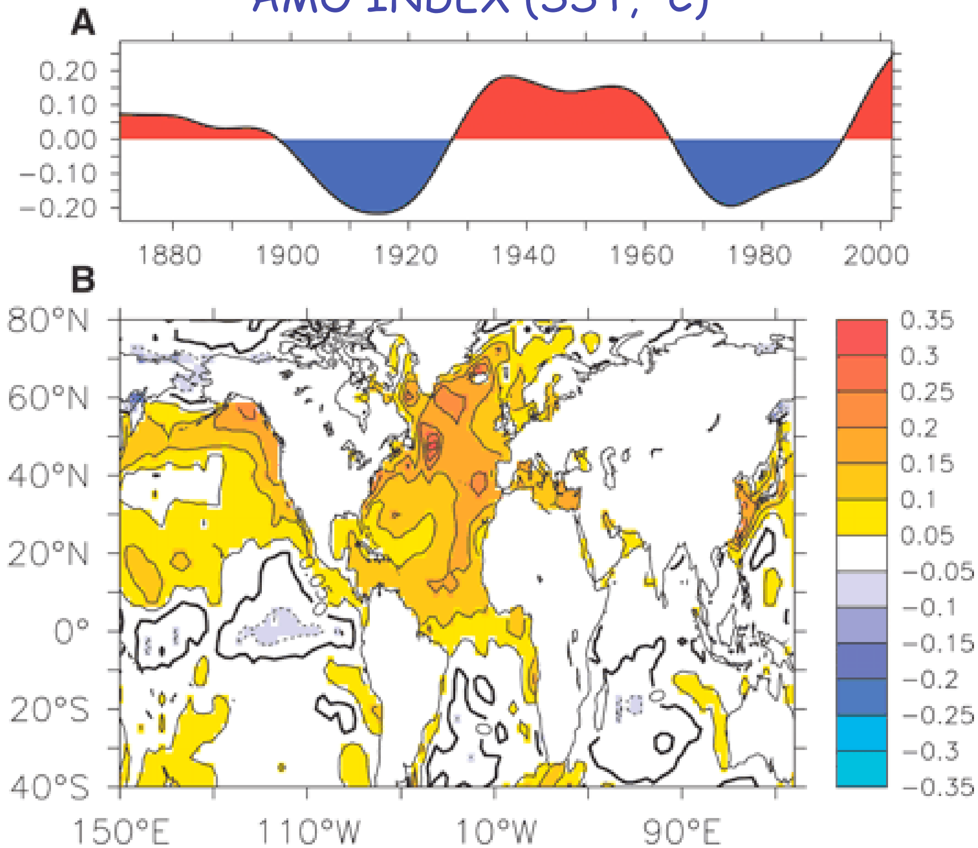
(CCSM3 20th Century simulations – 1870 control integration)



Gent et al. (2006, J. Climate)

ATLANTIC MULTI-DECADAL OSCILLATION (AMO)

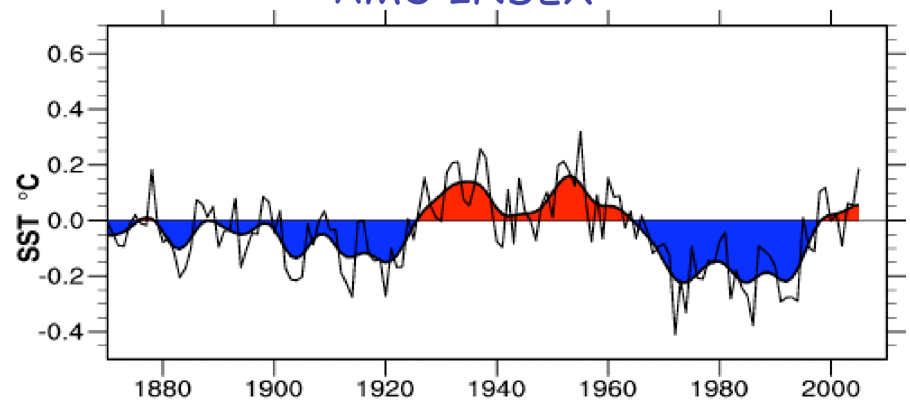
AMO INDEX (SST, °C)



SST vs AMO INDEX REGRESSION (°C/SD)

Sutton & Hodson (2005)

AMO INDEX



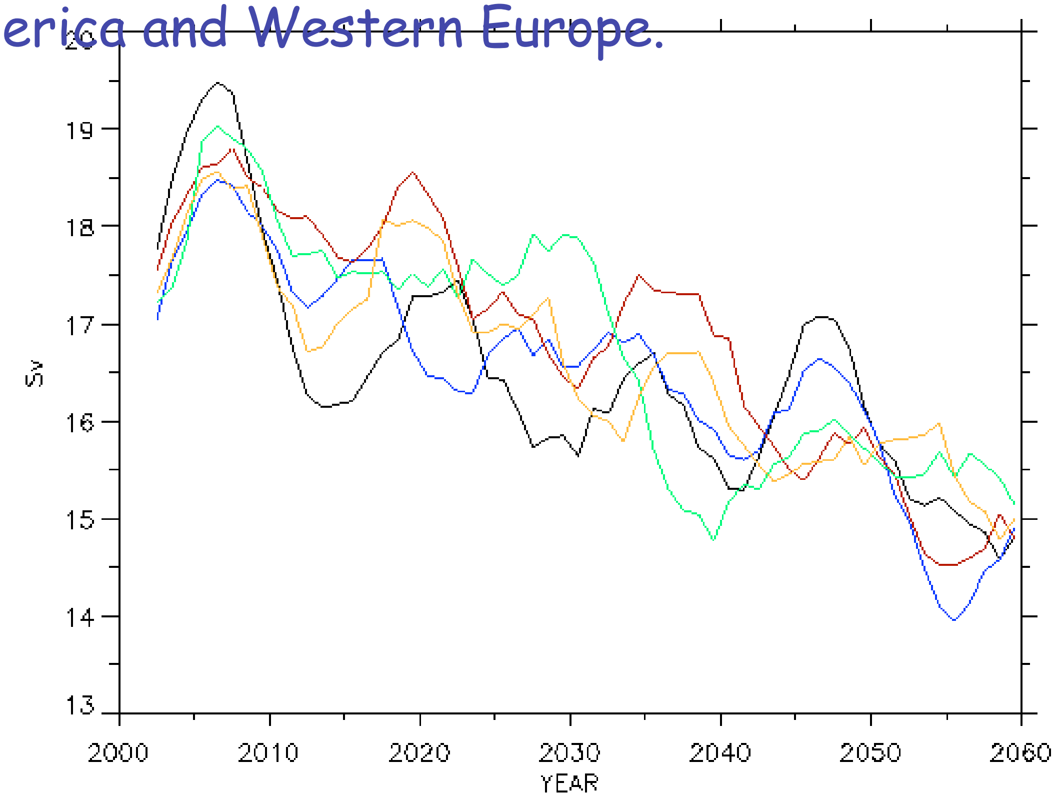
Trenberth & Shea (2006)

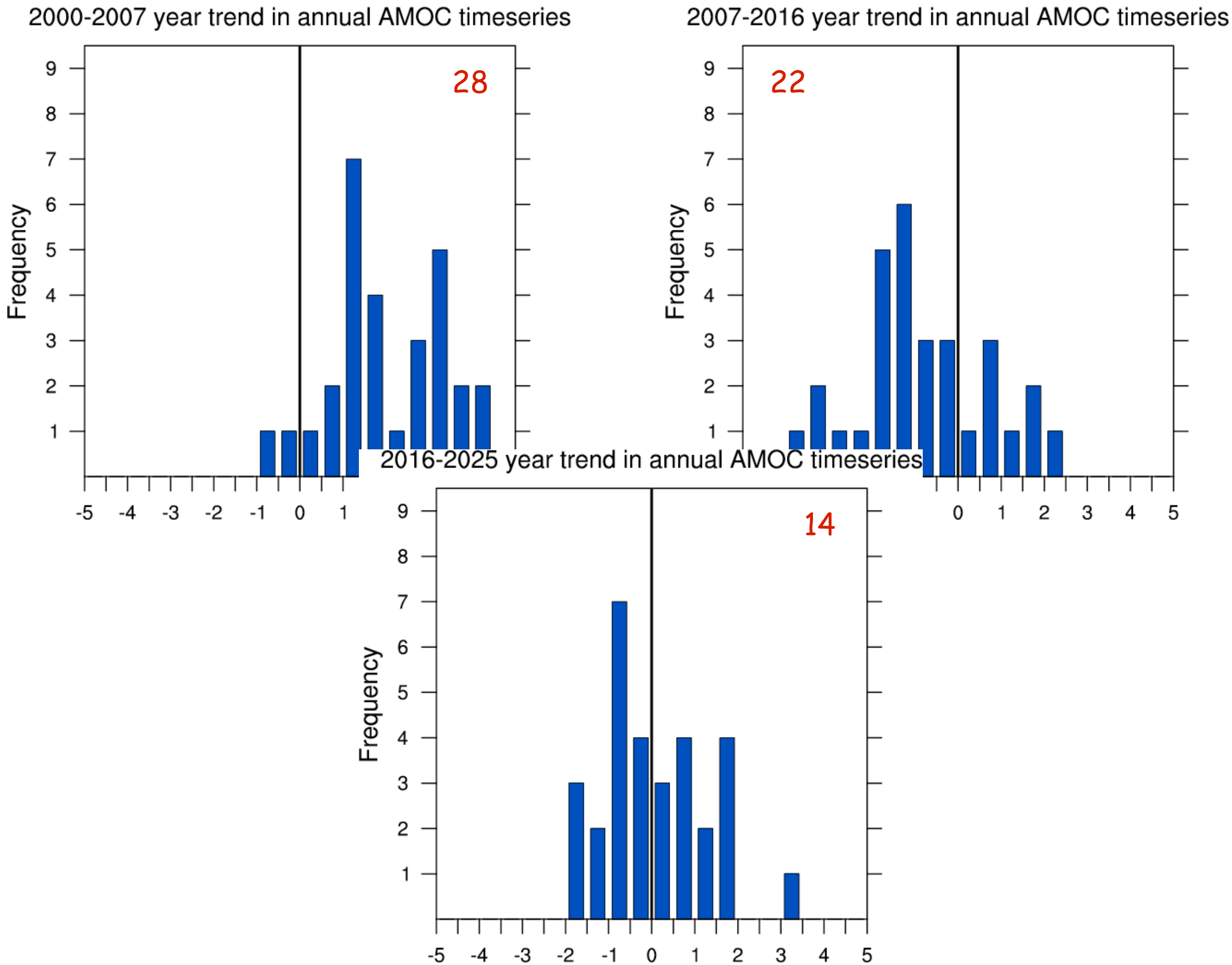
Some recent observational and CGCM studies have:

- shown significant climate impacts of these AMO and AMOC variabilities, respectively, over a broad region that stretches to the Indian Ocean,

- suggested that the AMOC variability may be predictable on decadal time scales, implying potential predictability of the associated climate changes in North America and Western Europe.

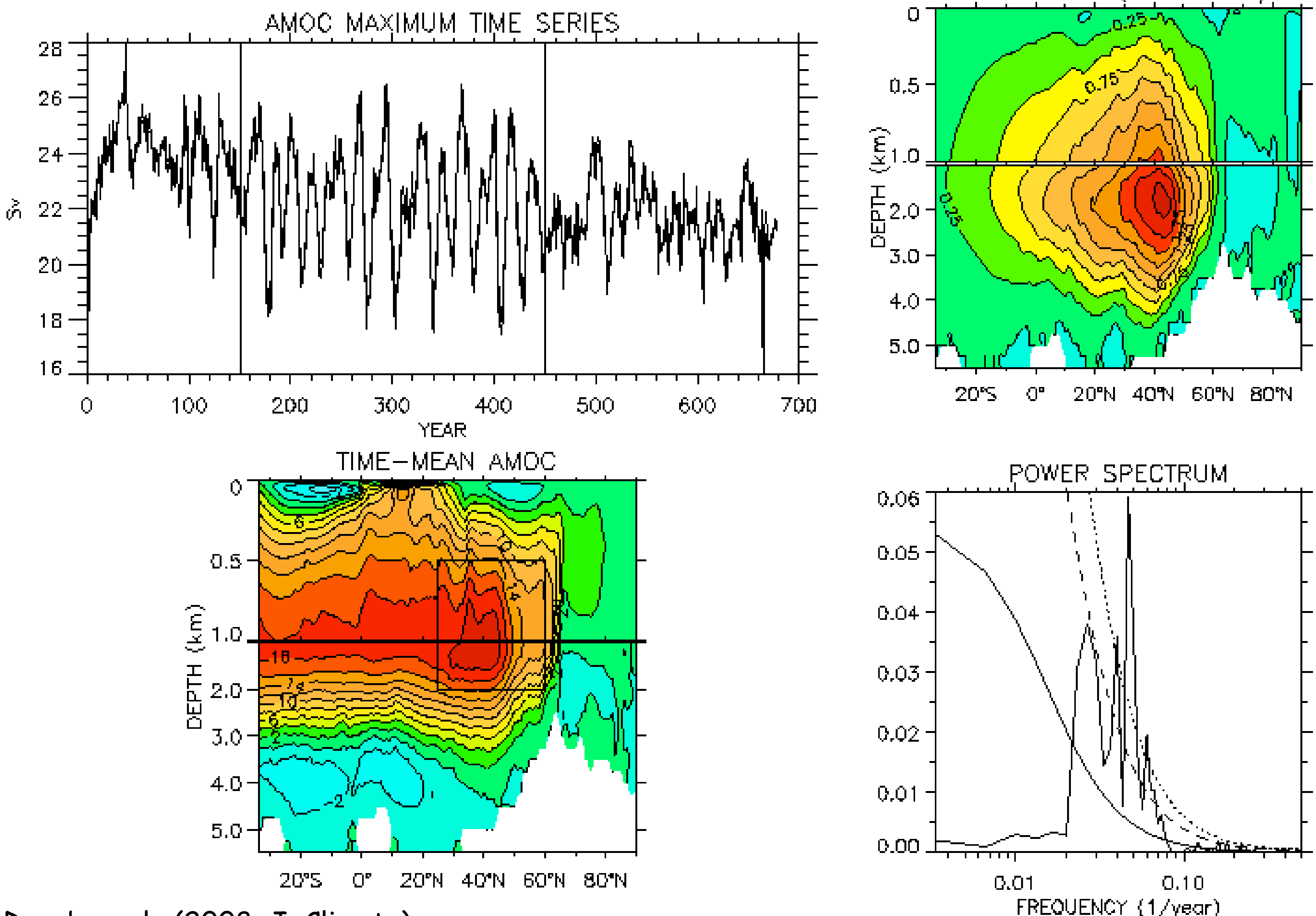
Time series of AMOC maximum from 5 members of a 30-member ensemble of CCSM3 (T42x1) A1B scenario simulations




2000-2007 year trend in annual AMOC timeseries
28
Frequency
2007-2016 year trend in annual AMOC timeseries
22
Frequency
2016-2025 year trend in annual AMOC timeseries
14
Frequency

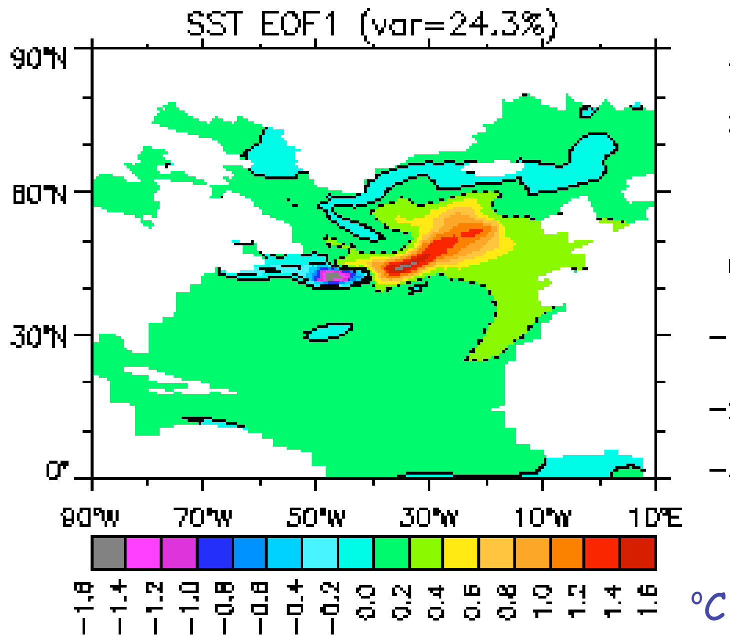
ATLANTIC MERIDIONAL OVERTURNING CIRCULATION (AMOC)

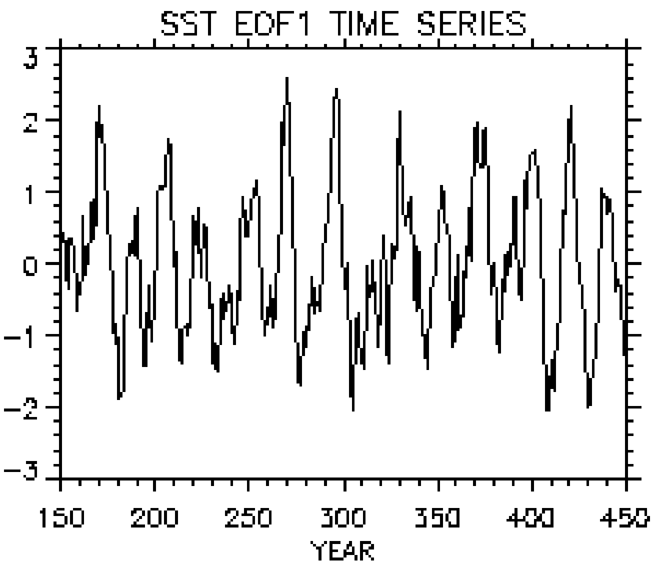
T85x1 resolution, present-day control

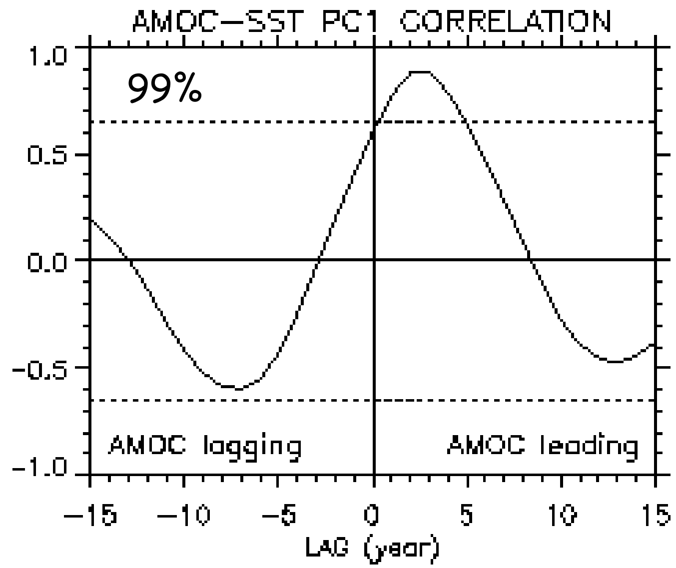


Danabasoglu (2008, J. Climate)

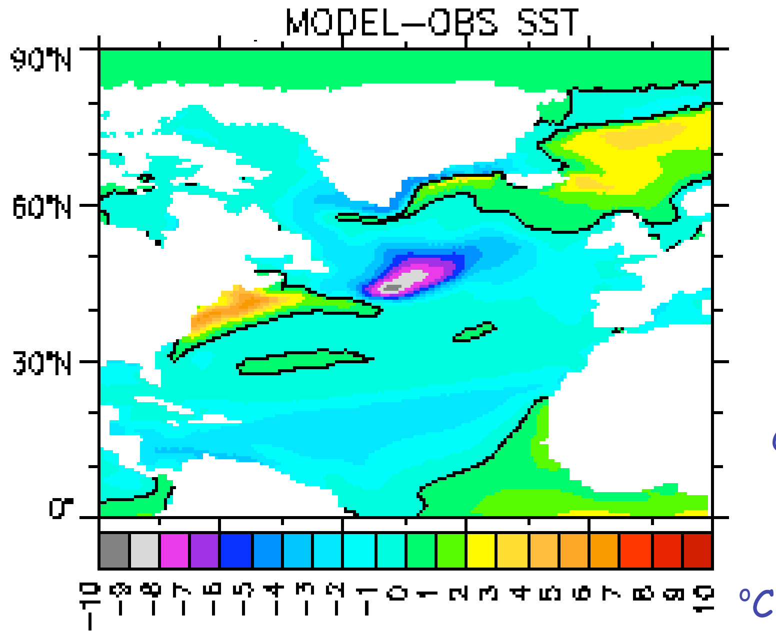
SEA SURFACE TEMPERATURE (SST)





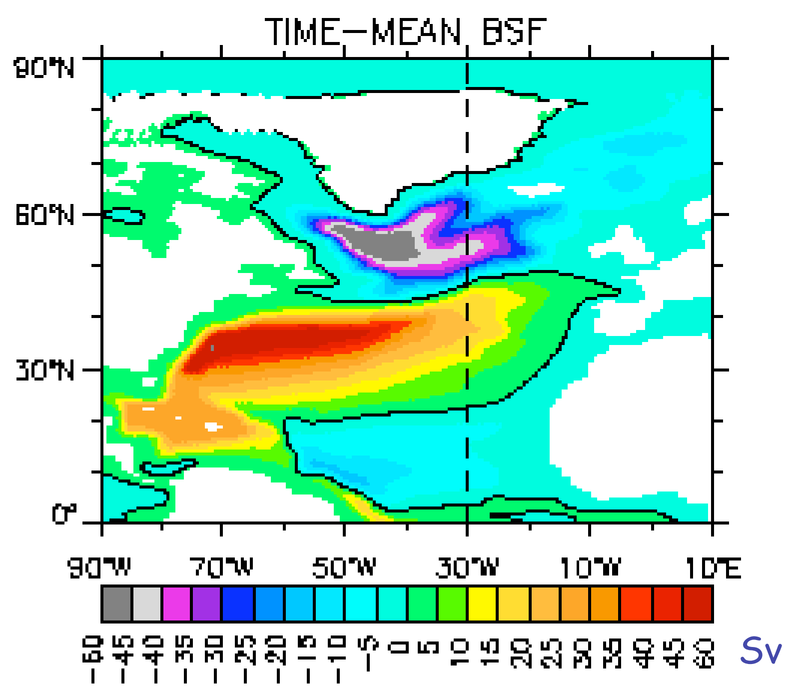


MEAN SST BIAS

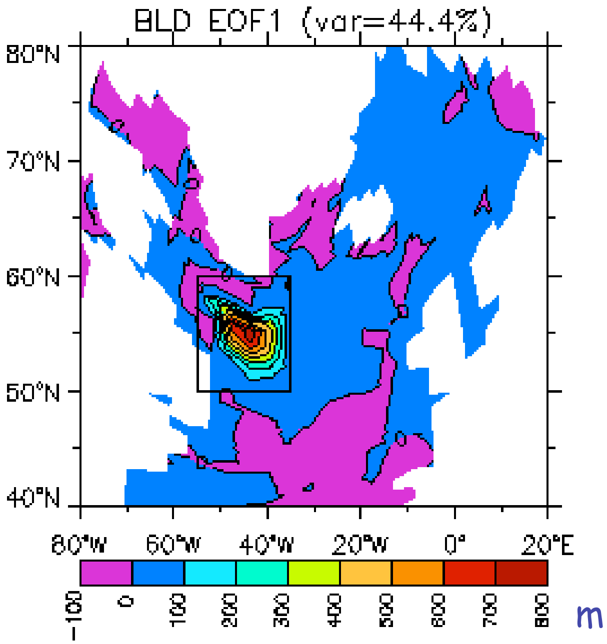


OBS: Levitus et al. (1998) & Steele et al. (2001)

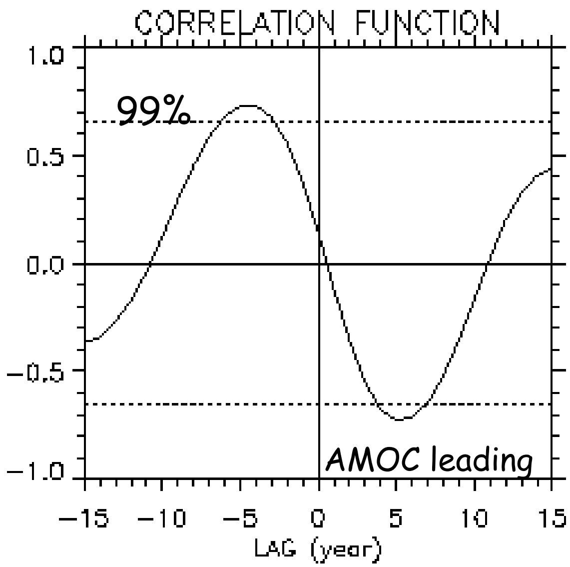
BAROTROPIC STREAMFUNCTION



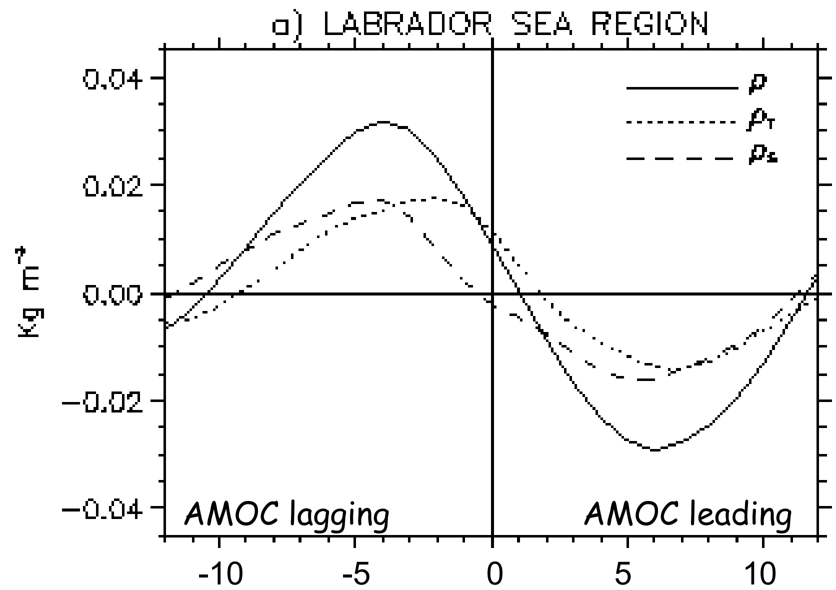
MARCH-MEAN BOUNDARY LAYER DEPTH (BLD)



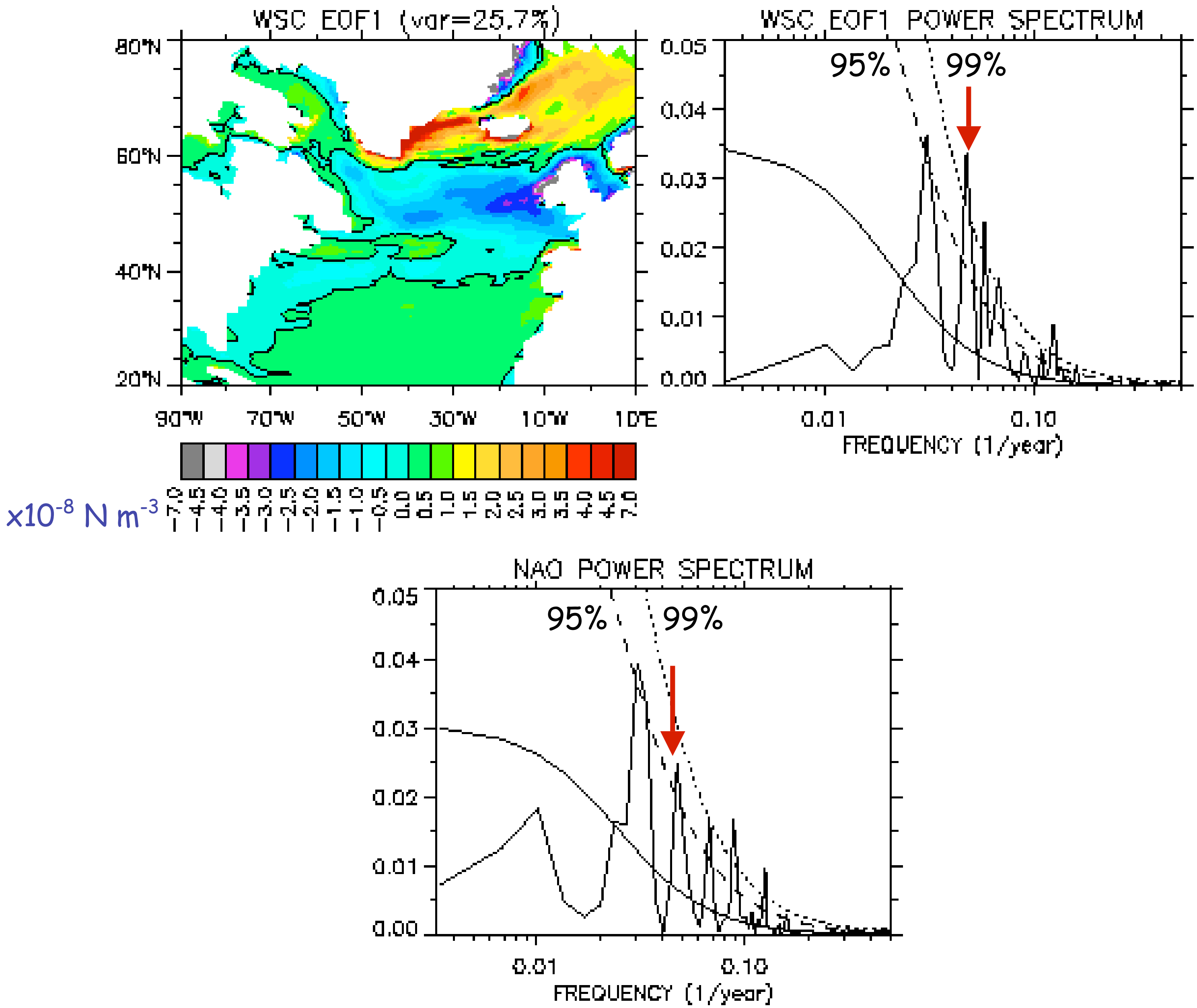
BLD and AMOC PC1 time series



DENSITY REGRESSIONS WITH AMOC PC1 TIME SERIES



WIND STRESS CURL



QUESTIONS / SUMMARY

Since Delworth et al. (1993) study, there is a broad consensus that the density anomalies in the "sinking region" of the AMOC drives this variability.

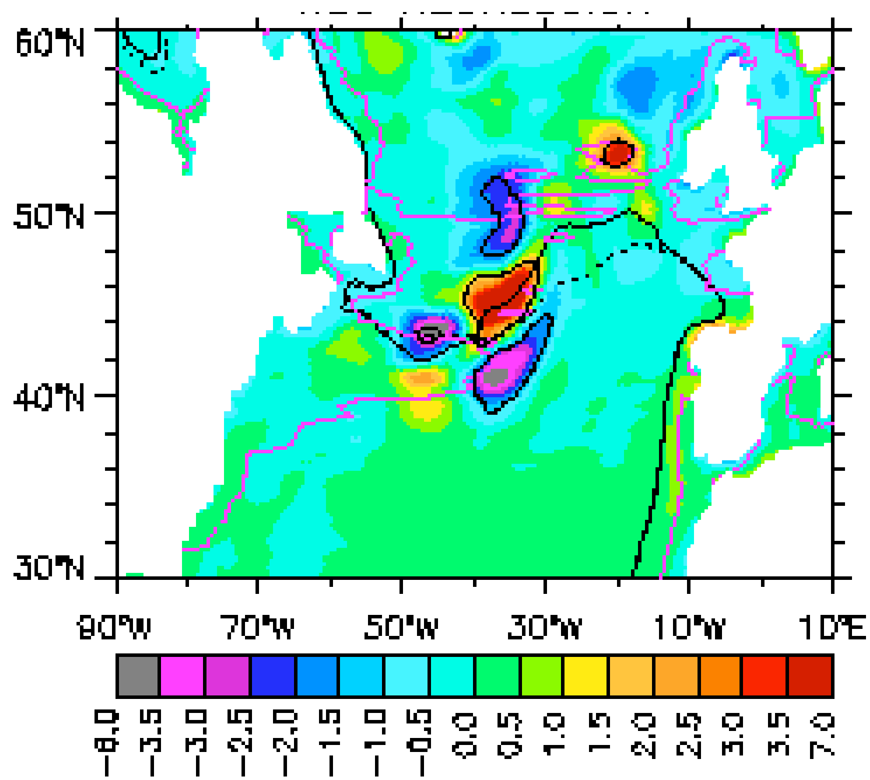
However, many fundamental questions still remain largely unanswered:

- mechanism [nature of this mode, role of the North Atlantic Oscillation (NAO)],
- robustness of mechanism,
- time-scale,
- implications for initialization and predictability,
- implications for our assessments of 20th century, future scenario, etc. climates,

SUMMARY and CONCLUSIONS

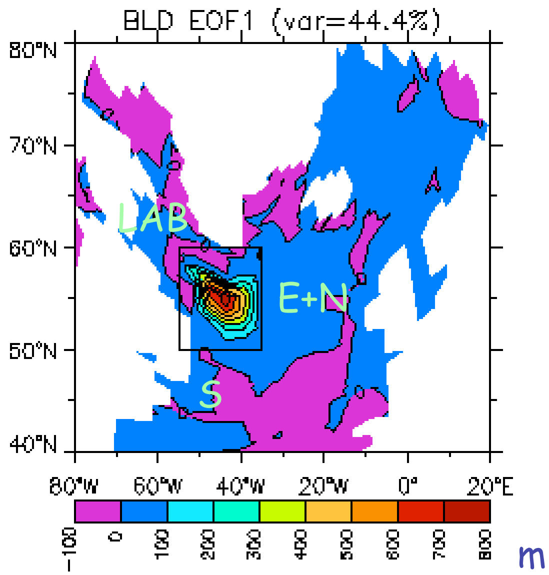
- This multi-decadal variability shows rather large amplitudes in both AMOC and SST. Comparisons of the latter with observations indicate that neither the pattern nor the magnitude of the SST anomalies is realistic. However, the role of the mean-state biases remains unclear.
- These SST anomalies are created by the fluctuations of the subtropical -subpolar gyre boundary driven by small scale WSC anomalies.
- The present results do not support an ocean mode that relies on a phase lagged relationship between temperature and salinity in their contributions to the total density in the model's associated deep water formation region.
- Atmospheric variability associated with the model's NAO appears to play a prominent role in maintaining this variability.
- A hypothesis is that regimes involving "strong" oscillatory behavior indicate an ocean-atmosphere coupled mode in contrast with an ocean-only mode that can be excited by stochastic atmospheric forcing during "weak" / "irregular" regimes.

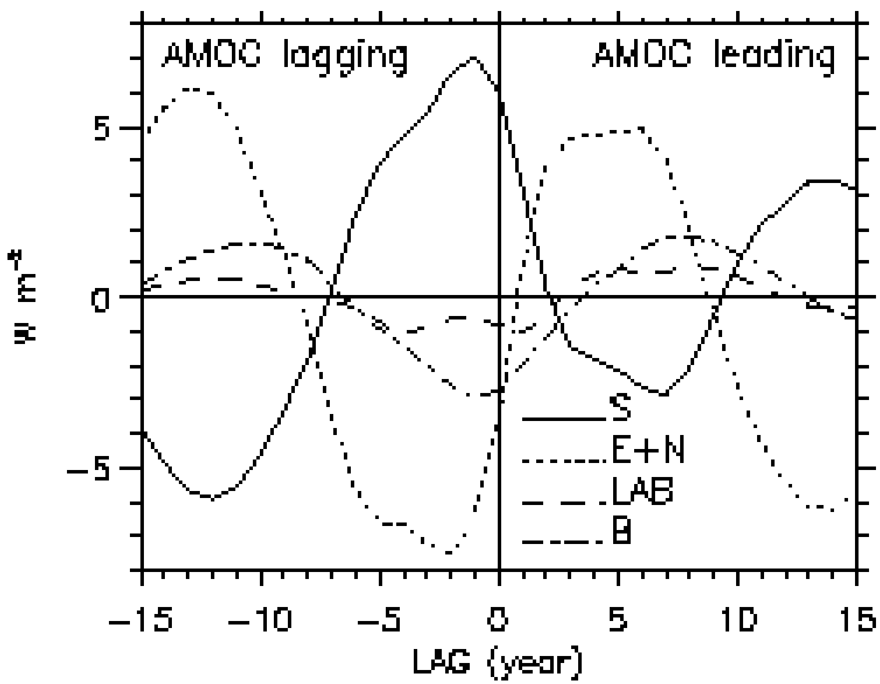
NORTH-SOUTH GYRE BOUNDARY FLUCTUATION and WIND STRESS CURL SIMULTANEOUS REGRESSION



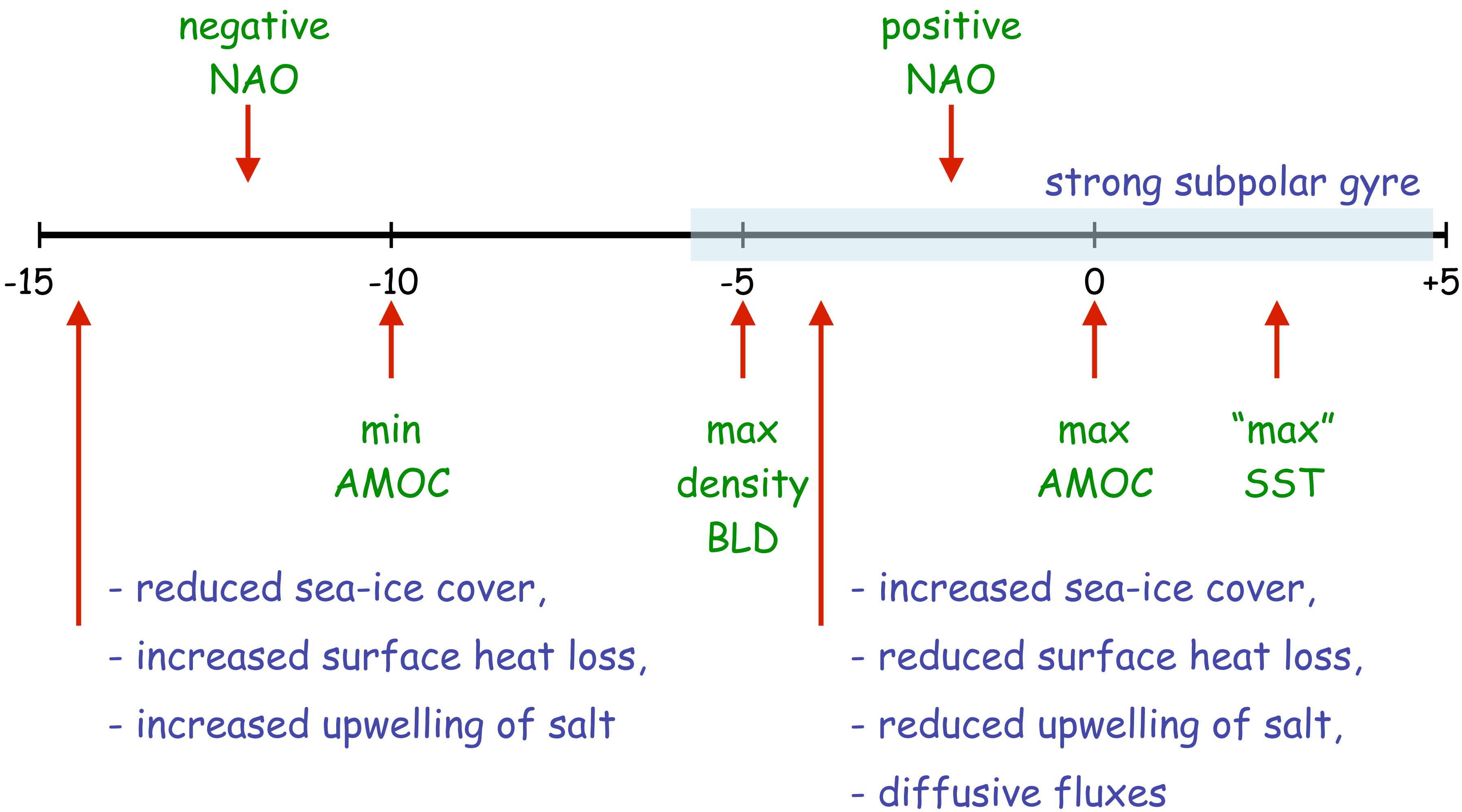
$\times 10^{-8}$ N m^{-3} / ° lat

LABRADOR SEA ADVECTIVE HEAT FLUX REGRESSIONS WITH AMOC PC1 TIME SERIES





SIMPLIFIED DIAGRAM OF PHASE RELATIONSHIPS



Unfortunately, observational data are not long and good enough to say whether such decadal or longer time scale AMOC variability exists in nature.

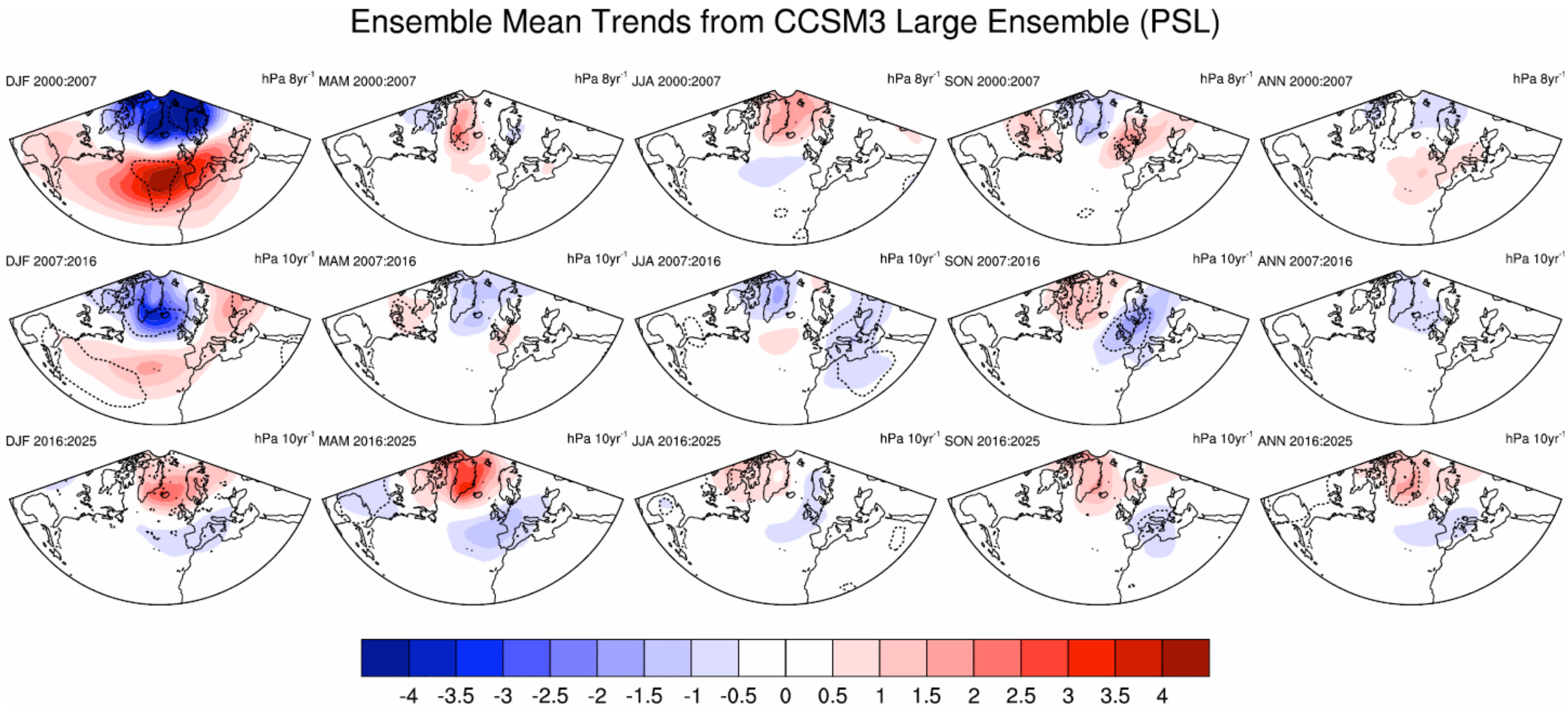
Recent observational studies based on instrumental and proxy data show distinct multi-decadal variability in SSTs with periods of about 50-80 years, particularly dominant in the North Atlantic. Its spatial pattern is largely hemispheric, indicating broad warming / cooling with a maximum local amplitude of 0.5°C. This variability is usually referred to as the Atlantic Multi-decadal Oscillation (AMO) and its has been associated with multi-decadal variations of the North American and Western European climates.

A broad resemblance between the CGCM simulated and observed SST variability patterns in the North Atlantic. This variability is usually associated with the AMOC variability in CGCM studies despite significant differences in the associated SST patterns, amplitudes, and periods.

To summarize …… because of

- its association with variations in the meridional oceanic heat transport, North Atlantic SSTs and climatic variables such as air temperature, precipitation, hurricanes, etc.,
- its potential predictability,
- its possible role in abrupt climate change, particularly in response to anthropogenic forcing,

there is an intense interest in the AMOC variability to answer the above issues and to develop nowcasting and projection systems for AMOC.


Ensemble Mean Trends from CCSM3 Large Ensemble (PSL)
DJF 2000:2007
hPa 8yr⁻¹
MAM 2000:2007
hPa 8yr⁻¹
JJA 2000:2007
hPa 8yr⁻¹
SON 2000:2007
hPa 8yr⁻¹
ANN 2000:2007
hPa 8yr⁻¹
DJF 2007:2016
hPa 10yr⁻¹
MAM 2007:2016
hPa 10yr⁻¹
JJA 2007:2016
hPa 10yr⁻¹
SON 2007:2016
hPa 10yr⁻¹
ANN 2007:2016
hPa 10yr⁻¹
DJF 2016:2025
hPa 10yr⁻¹
MAM 2016:2025
hPa 10yr⁻¹
JJA 2016:2025
hPa 10yr⁻¹
SON 2016:2025
hPa 10yr⁻¹
ANN 2016:2025
hPa 10yr⁻¹
-4 -3.5 -3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4

Ensemble Mean Trends from CCSM3 Large Ensemble (TS)