Review of some proposed mechanisms for decadal to multidecadal AMOC and Atlantic variability

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1. Motivation

2. Observational basis

3. Model based mechanisms of AMOC variability

- Internal variability (grouping by timescale/physics)
- Forced variations (SH winds, radiative forcing changes)

4. How can we advance our understanding?

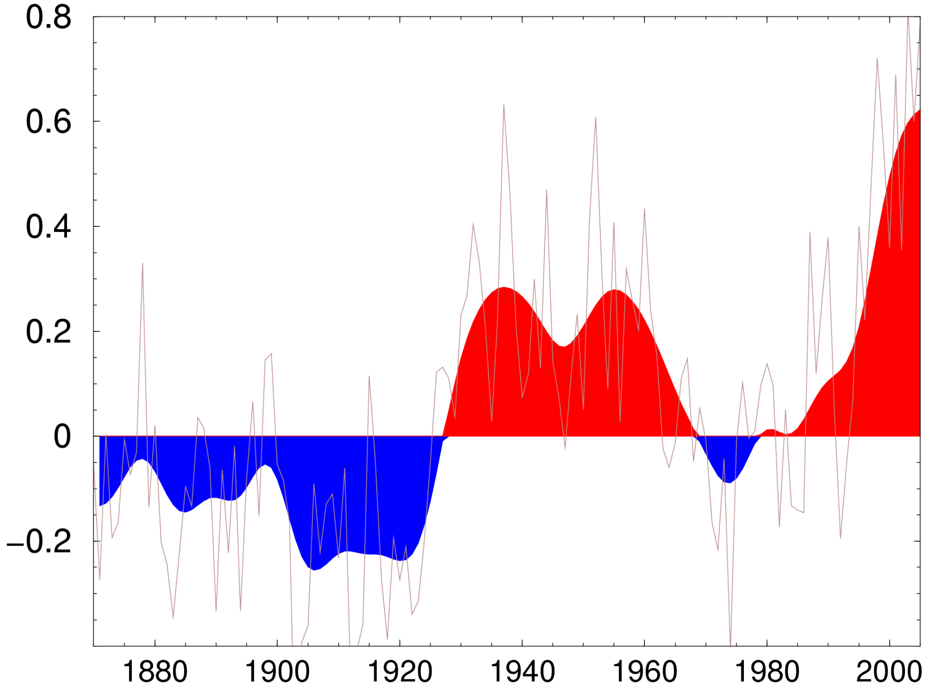
AMOC PI meeting August 16, 2012 Boulder, CO

Key motivating goals:

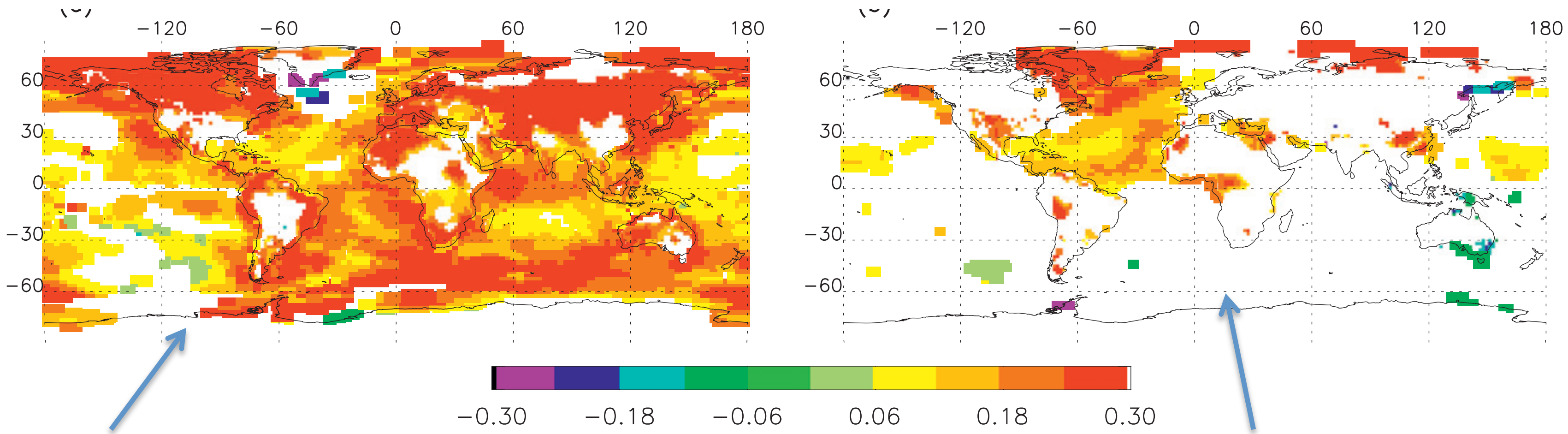
Need to:

(a) understand the mechanisms responsible for observed Atlantic variability over the last century

(b) “improve” predictions of the evolution of the Atlantic over the coming decades to century



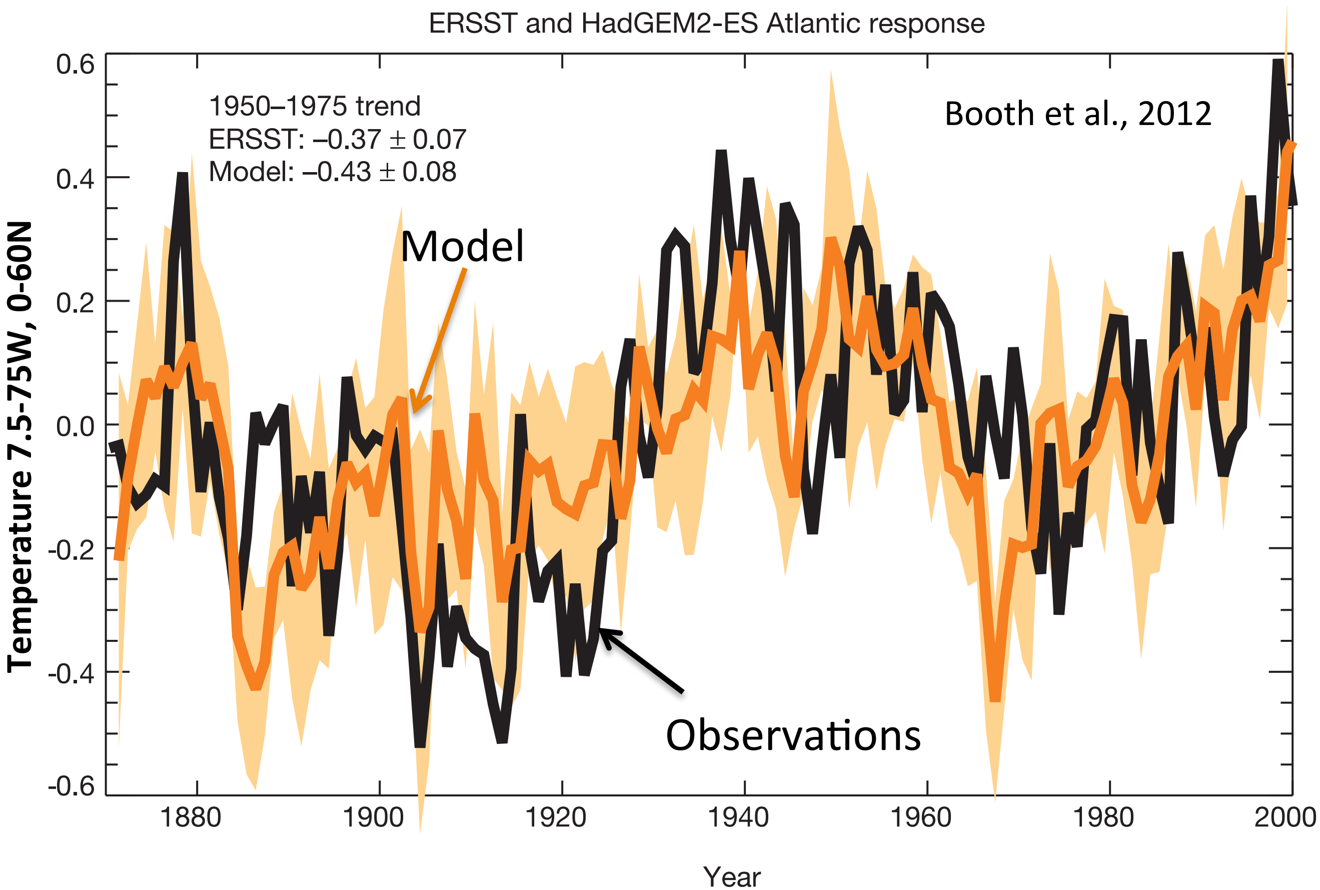
- Radiative forcing changes associated with changing greenhouse gases, aerosols
- Internal variability of the coupled ocean-atmosphere-land system



Regression of local temperature on "forced" NA SST signal.

Regression of local temperature on "internal variability" component of NA SST signal.

Results from Ting et al (2009) suggest a strong role for internal variablity in generating the multidecadal NA SST variations.

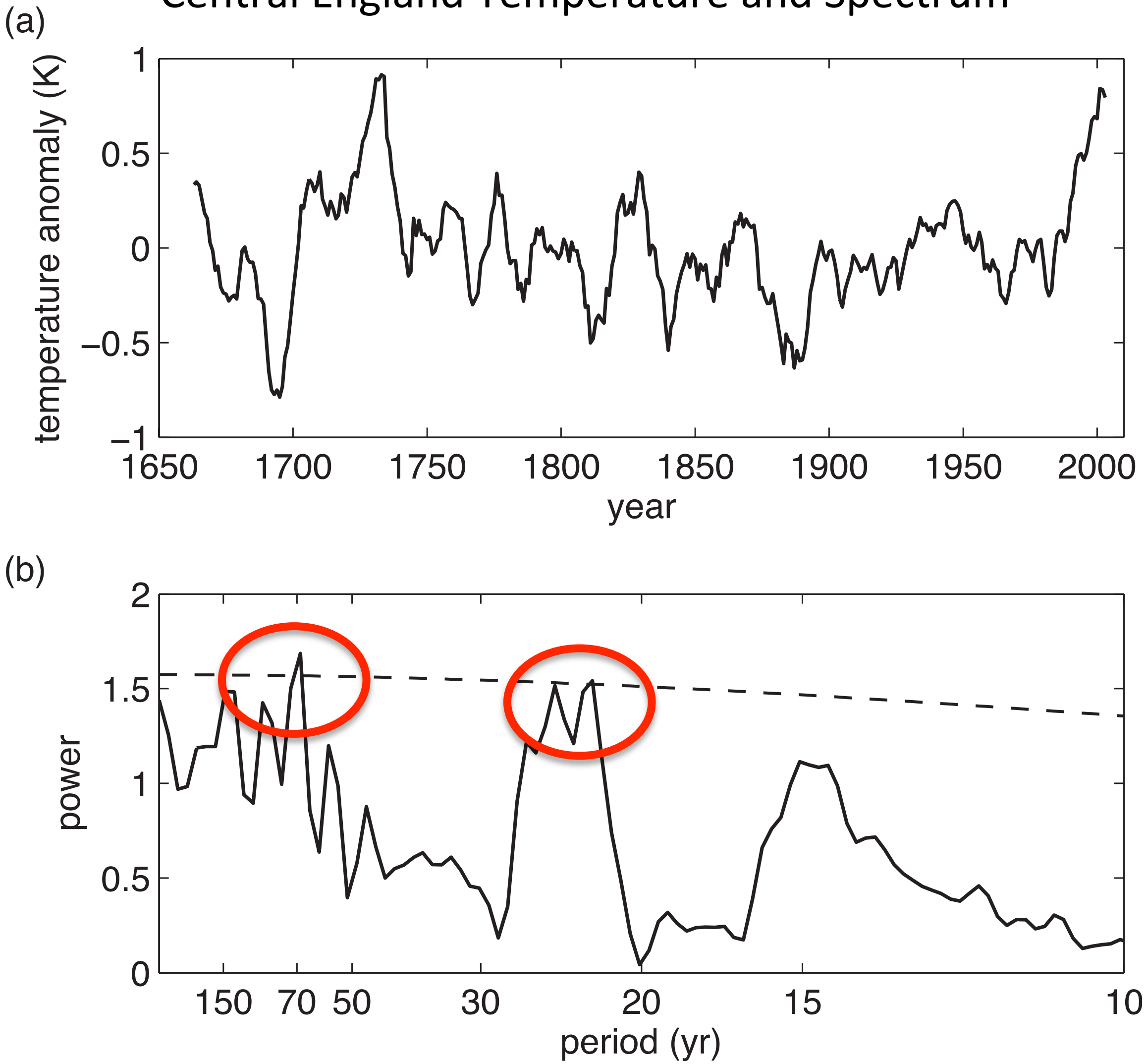


In this paradigm, late 20th century North Atlantic SST changes are driven almost exclusively by aerosol indirect effects.

Critical question:

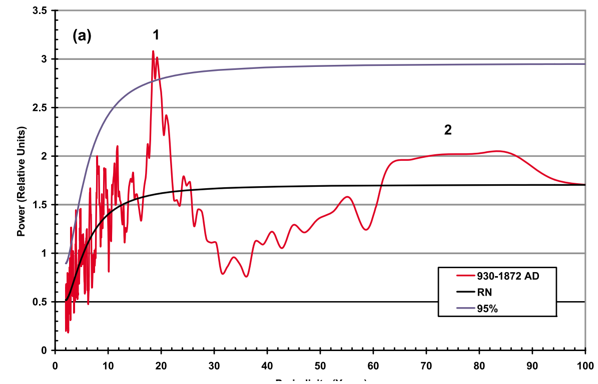
What are the roles of AMOC variability and external radiative forcing in generating the observed multidecadal SST variability in the instrumental record?

Central England Temperature and Spectrum

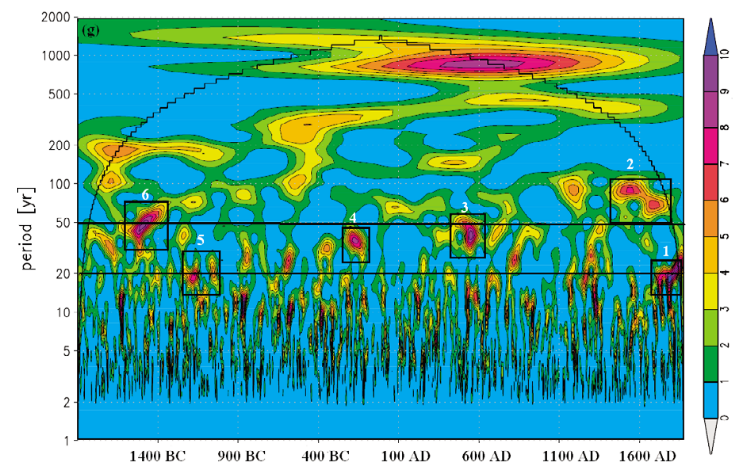


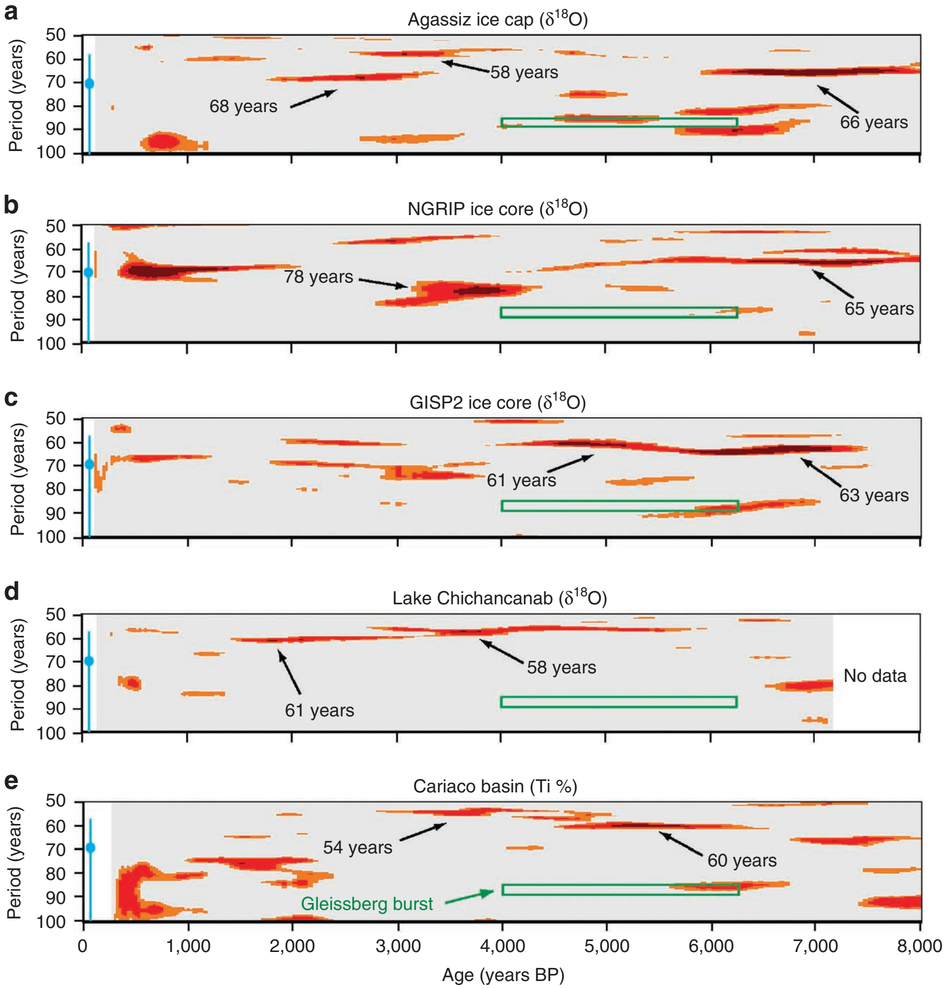
Frankcombe and Dijkstra, 2010

Records from ice cores support the existence of 20-30 year variability



Chylek et al., 2012





Greenland ice cores

Yucatan

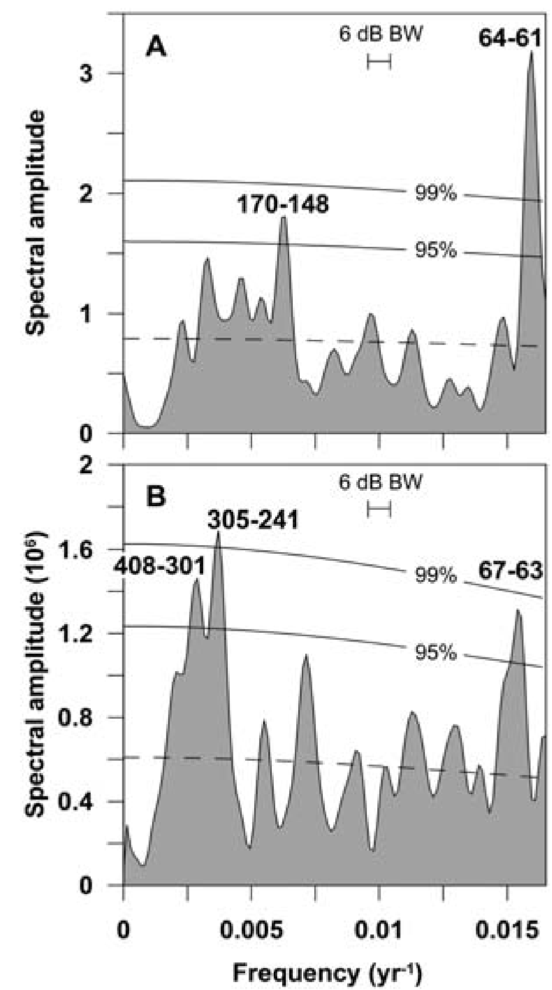
Cariaco Basin

Knudsen et al (2011)

"We therefore conjecture that a quasi-persistent ~55- to 70-year AMO, linked to internal ocean-atmosphere variability, existed during large parts of the Holocene. Our analyses further suggest that the coupling from the AMO to regional climate conditions was modulated by orbitally induced shifts in large-scale ocean-atmosphere circulation."

Chiessi et al 2009

(South American Summer Monsoon)



20-30 year timescale

One postulated mechanism for interdecadal AMOC variability:

Mode of variability characterized by westward propagating thermal anomalies at mid-latitudes.

- The overall timescale is set by the time it takes for a wave to cross the basin.
- The mode can exist without forcing in a highly idealized setting, but often requires stochastic atmospheric driving in a more realistic setting.

A subset of papers discussing this general topic include:

De Verdiere and Huck (1999)
Te Raa and Dijkstra (2002)
Dijkstra et al (2006)
Frankcombe and Dijkstra (2008,2009,2010,2011)
Buckley et al. (2012)
Sevellec and Fedorov (2012)

Some other possible mechanisms:
Dong and Sutton (2005)
Msadek and Frankignoul (2009)
Escodier and Mignot (2011)

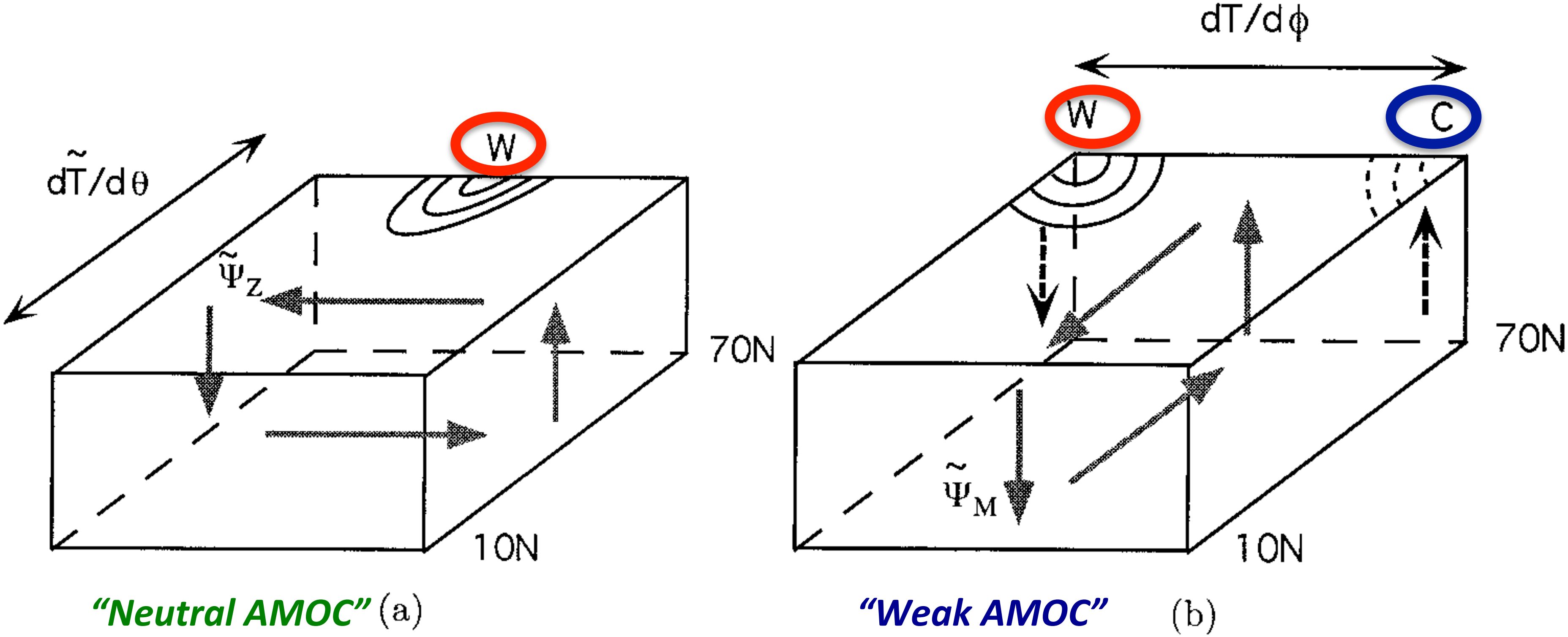
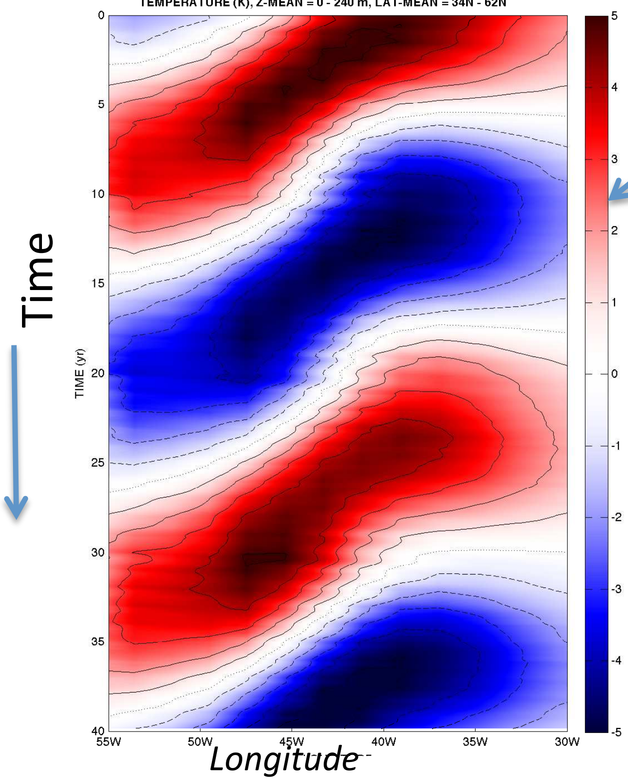


FIG. 18. Schematic diagram of the oscillation mechanism: a warm anomaly in the north-central part of the basin causes a positive meridional perturbation temperature gradient, which induces a negative zonal overturning perturbation (a). The anomalous upwelling and downwelling associated with this zonal overturning are consistent with westward propagation of the warm anomaly, while a cold anomaly appears in the east (b). Due to the westward propagation of the warm anomaly, the east–west temperature difference decreases and becomes negative, inducing a negative meridional overturning perturbation. The resulting upwelling and downwelling perturbations along the northern and southern boundary reduce the north–south perturbation temperature difference, causing the zonal overturning perturbation to change sign and the second half of the oscillation starts.

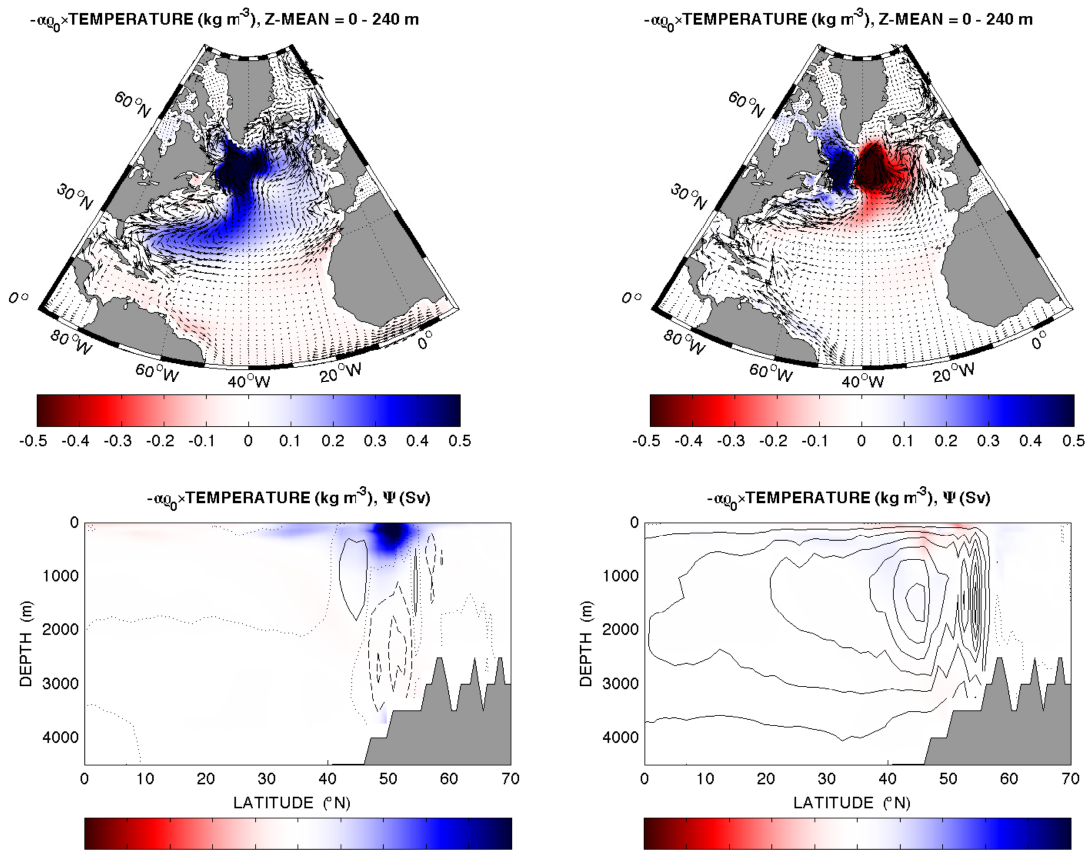
Te Raa and Dijkstra, 2002



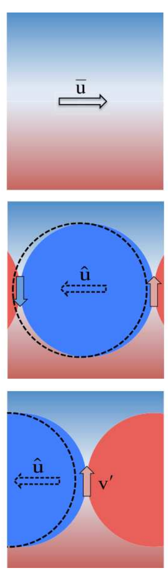
Westward propagation

Sevellec and Fedorov, 2012

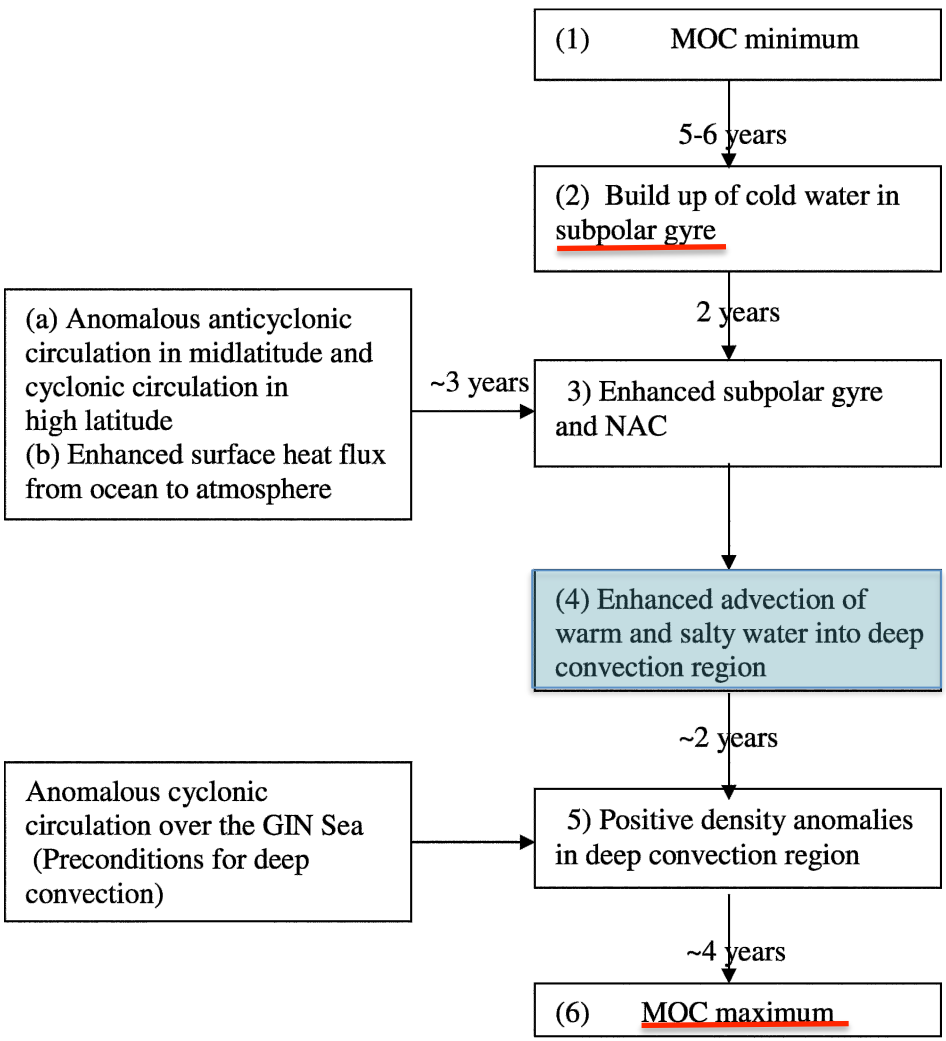
Spatial pattern of mode



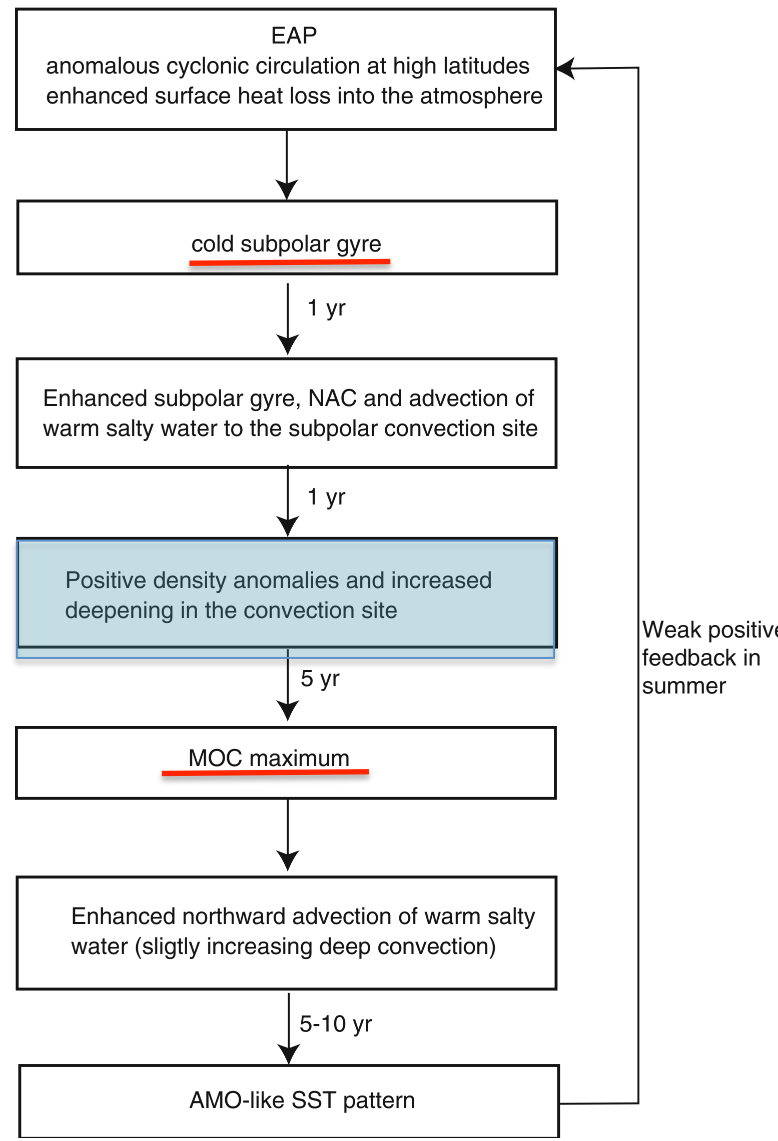
Schematic of propagation



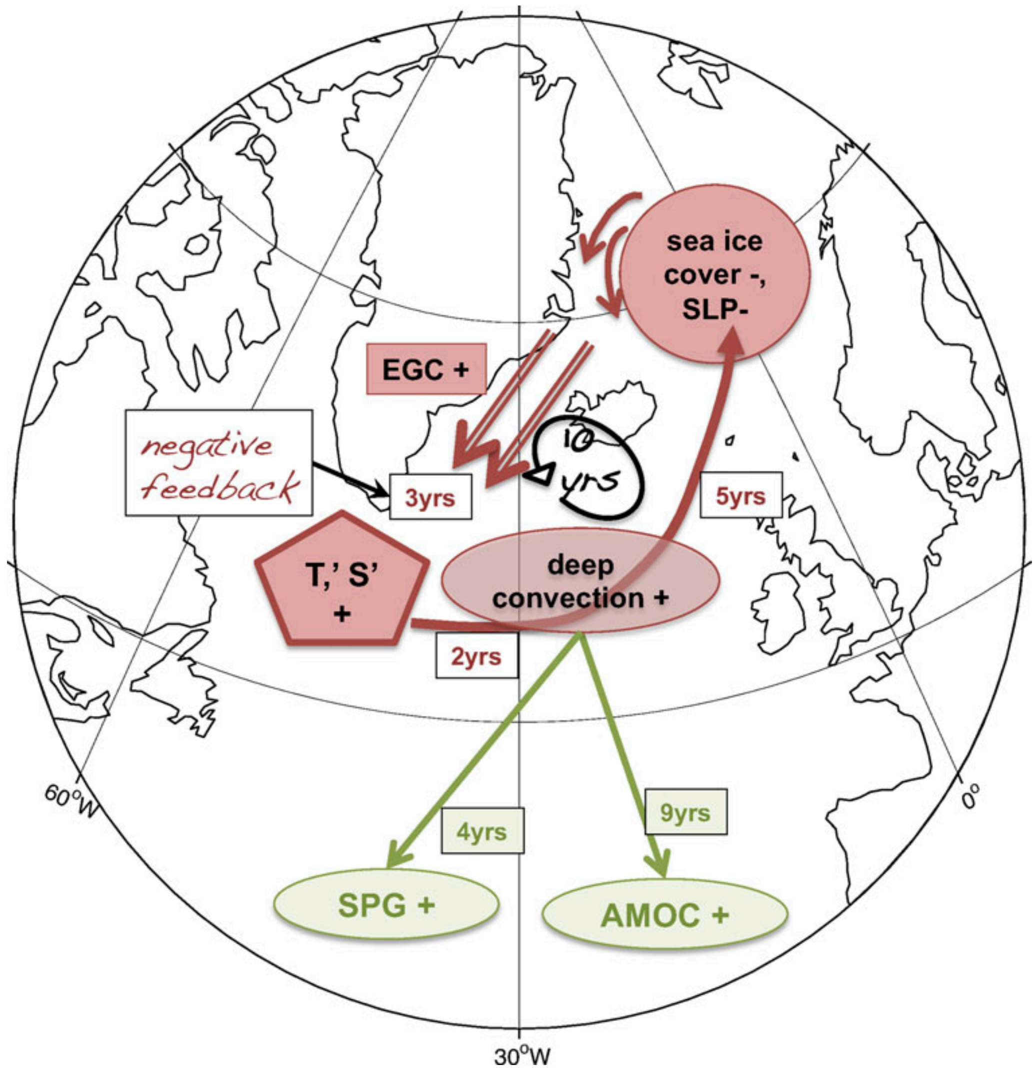
From coupled GCMs, mechanisms are postulated that involve advection or propagation of density anomalies that alter Lab Sea convection, the zonal density gradient and the AMOC.



Dong and Sutton, 2005



Msadek and Frankignoul, 2009



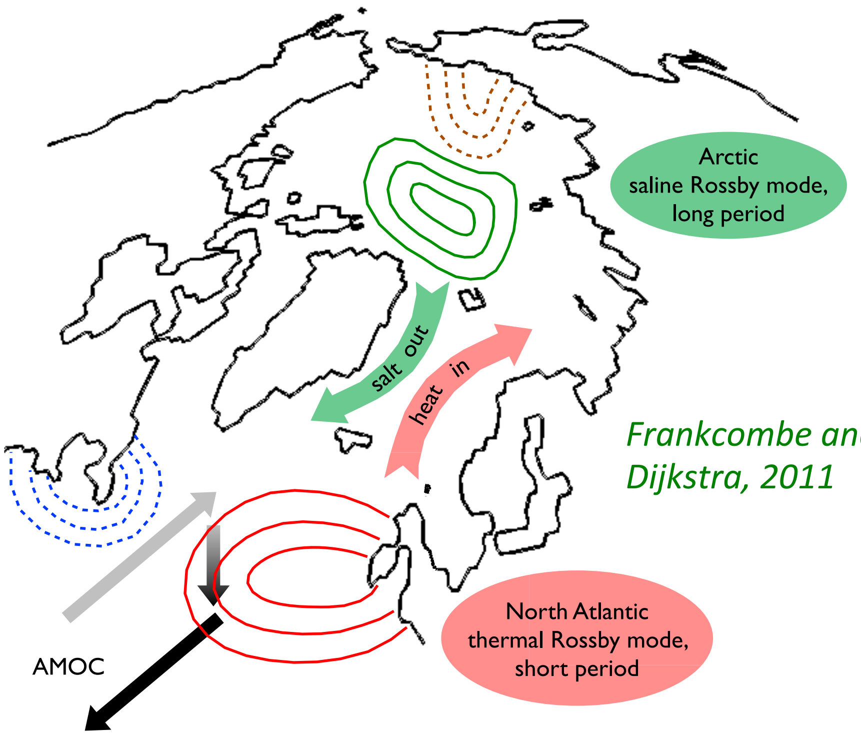
Escodier and Mignot suggest that active atmosphere-ocean feedbacks are critical to the variability seen in the IPSL model; SLP response that modulates EGC is important.

See also Timmermann et al., 1998 for coupled mode.

Escodier et al, 2012
IPSL CM5A-LR

Interactions between the North Atlantic and Arctic have also been cited as an important component of AMOC multidecadal variability.

Examples include Delworth et al, 1997; Jungclaus et al., 2005; Frankcombe and Dijkstra, 2011



Frankcombe and Dijkstra, 2011

Figure 4. Illustration of the interaction of the two internal modes. The shorter period mode in the North Atlantic appears as a strengthening/weakening of the AMOC associated with the westward propagation of temperature anomalies near the surface. The longer period mode in the Arctic involves salinity anomalies propagating across the pole.

"The strength of the overturning circulation is related to the convective activity in the deep-water formation regions, most notably the Labrador Sea, and the time-varying control on the freshwater export from the Arctic to the convection sites modulates the overturning circulation. The variability is sustained by an interplay between the storage and release of freshwater from the central Arctic and circulation changes in the Nordic Seas that are caused by variations in the Atlantic heat and salt transport."

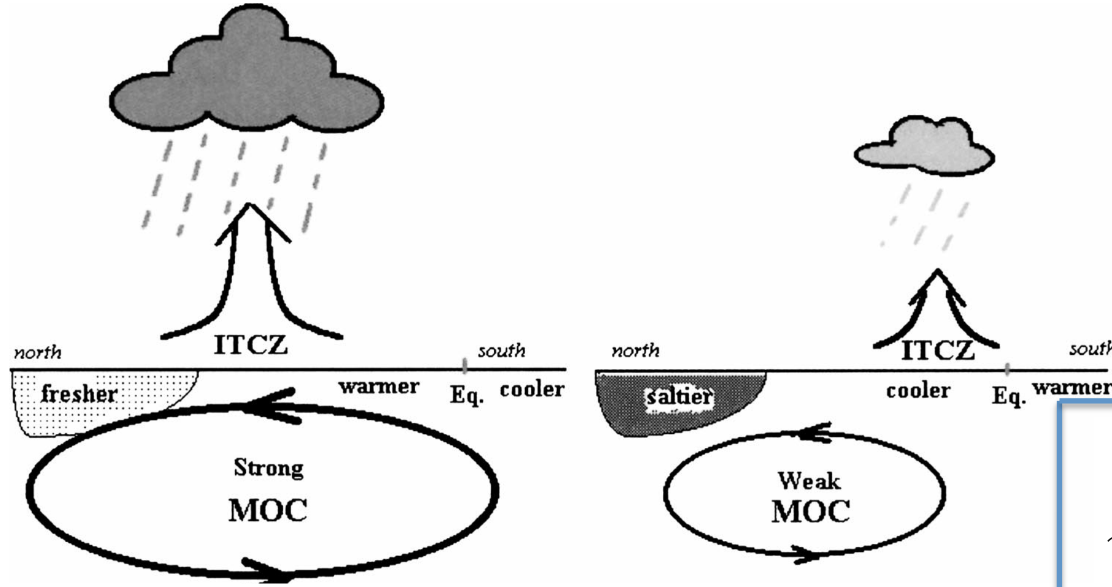
"We conclude that the MOI variability arises from a *damped mode of the ocean* that is continuously excited by the atmosphere."

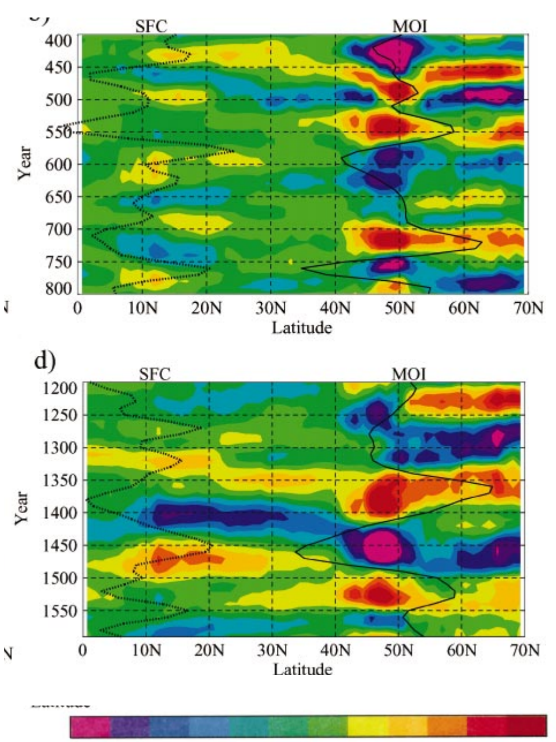
Jungclaus et al., 2005

Vellinga and Wu, 2004

AMOC oscillation in HADCM3 driven by interaction between AMOC strength and latitudinal position and strength of ITCZ

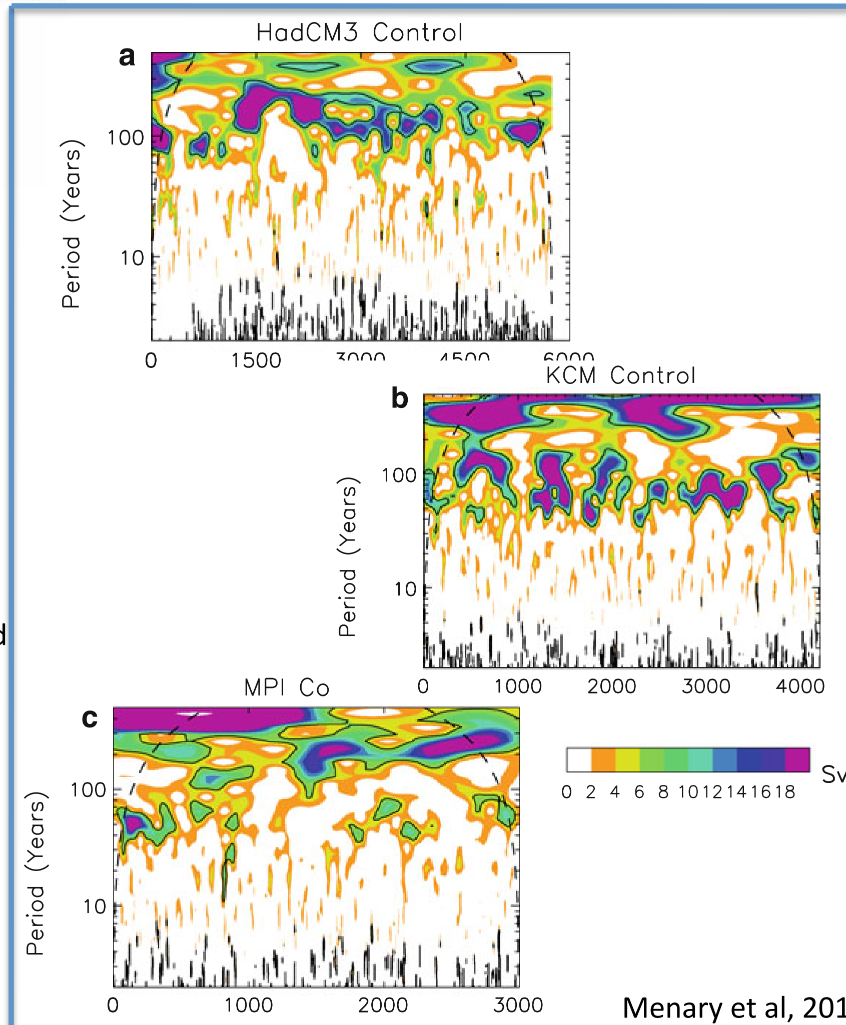
Menary et al., 2011 suggest this mechanism also operating in Kiel and MPI models





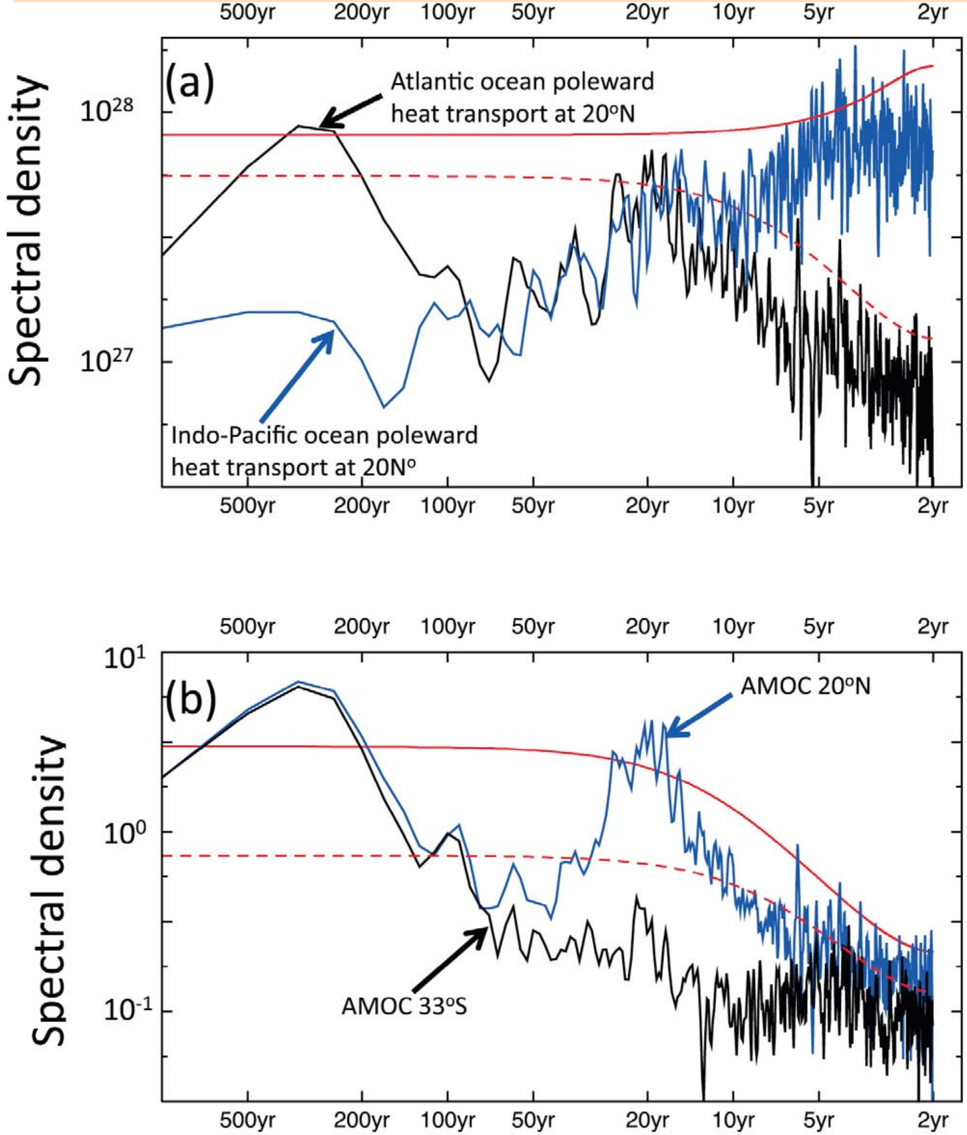
Analyses from 1600 year control simulation of HADCM3: Color shading shows zonally averaged Atlantic salinity anomalies averaged over the top 800 m expressed as as potential density anomalies

Vellinga and Wu, 2004



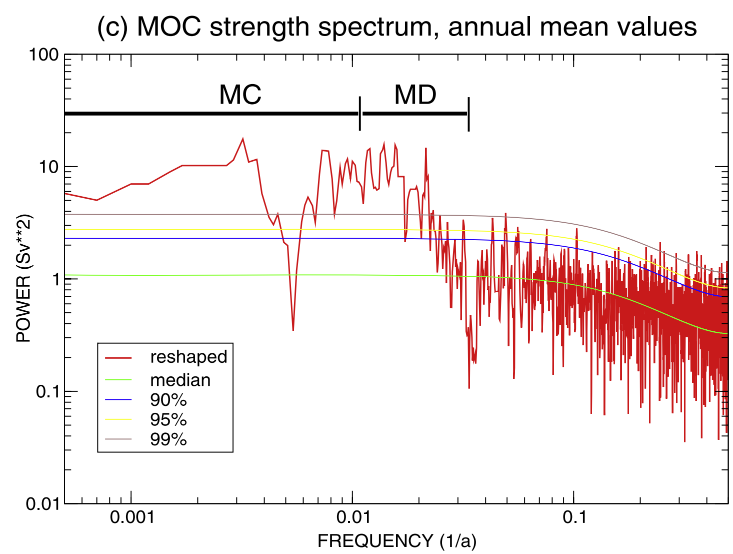
Menary et al, 2011

For GFDL CM2.1 model, AMOC in North Atlantic has two distinct timescales of variability, but only one timescale in South Atlantic

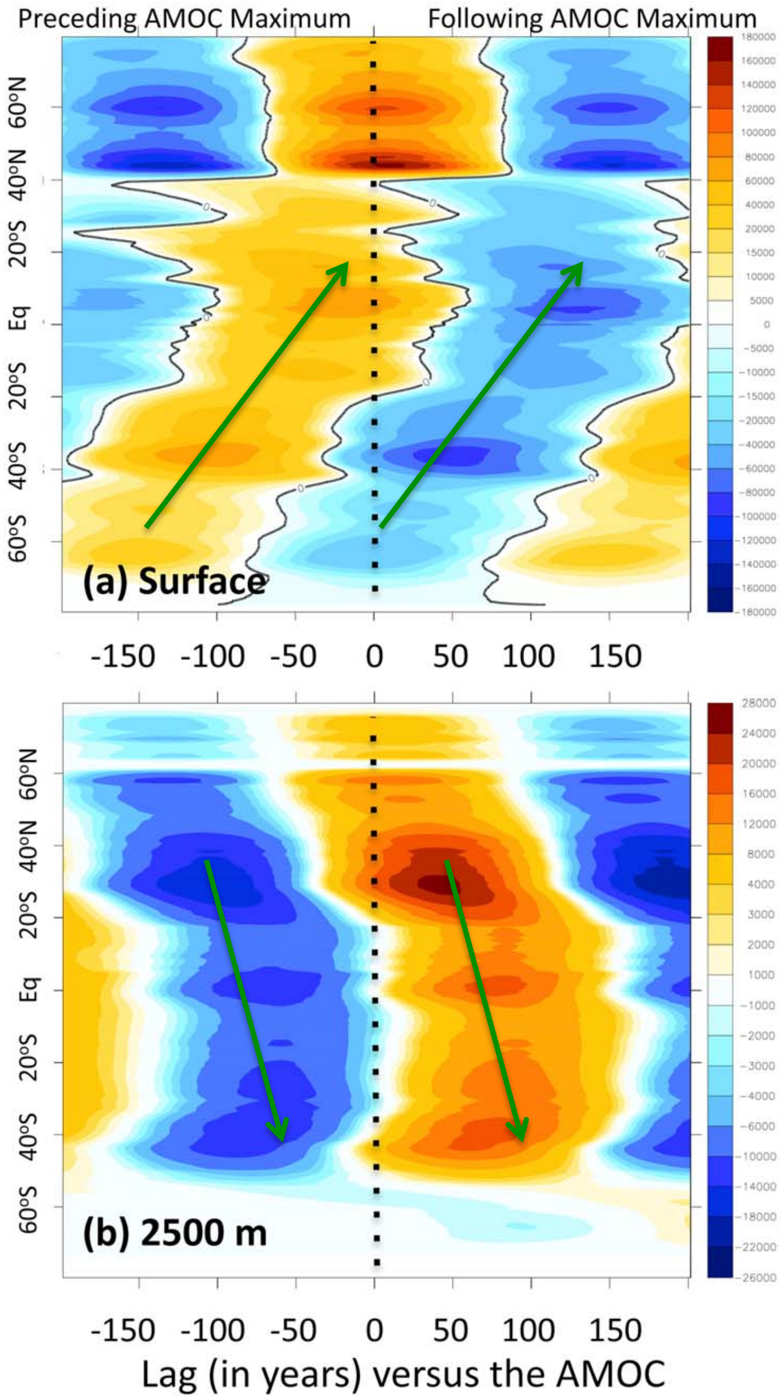


Delworth and Zeng, 2012

In Kiel Climate Model, separate peaks at multidecadal and multi-centennial timescales



Park and Latif, 2008



Mechanism of multi-centennial AMOC variability in GFDL CM2.1 is associated with propagation of salinity signal between high latitudes of the North Atlantic and the Southern Ocean

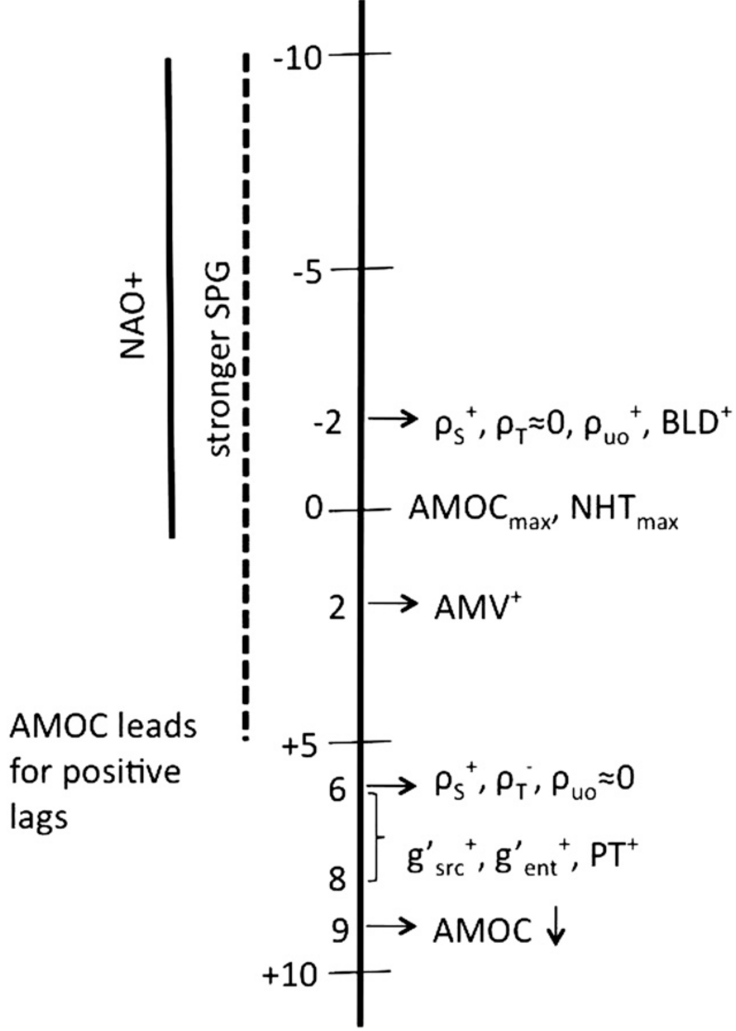


FIG. 13. Schematic of the sequence of some anomalies with respect to an AMOC maximum event at lag 0. The superscripts + and − refer to approximate peaks of positive and negative anomalies, respectively. AMOC leads for positive lags.

AMOC variability in CCSM3 and CCSM4

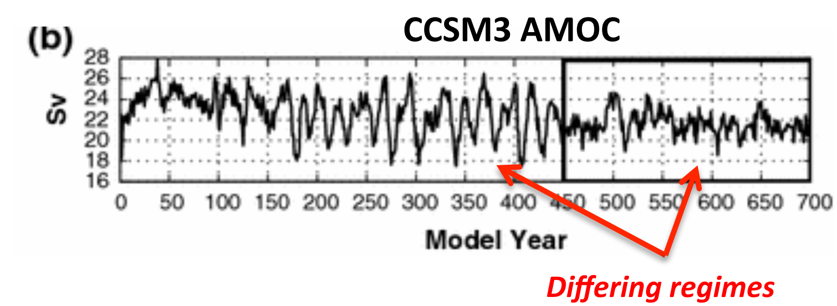
(Danabasoglu et al, 2012; Kwon and Frankignoul, 2012)

Similarities:

- *Spatial pattern*
- *Relationship to Lab Sea density*

Differences

- *Timescales (20 years; 50-200 years; red noise)*
- *Role of overflow parameterization*
- *Amplitude of AMOC variability*



"Such dependence of AMOC variability on these parameterizations has important implications for both AMOC variability characteristics and search for a robust mechanism as they may depend on parameter choices and implementation details of these schemes in various ocean general circulation models."

Danabasoglu et al., 2012

Perspectives …

(1) "Jungclaus et al (2006) analyze a 500-yr control integration with the ECHAM5-Max Planck Institute Ocean Model (MPI-OM) and find pronounced multidecadal fluctuations in the Atlantic MOC and associated heat transport with a period of 70-80 yr. From a *different simulation with the same model* (Sterl et al. 2008) it appears that the dominant variability in the AMO Index is in the 20-40 yr band. Variability on the longer time scale (50-80 yr) also exists but is not significant at the 95% level (van Oldenborgh et al 2009)."

- ***State dependence of variability, and presumably of mechanisms***; see also Kwon and Frankignoul, 2012.

(2) Look to analogy with ENSO …

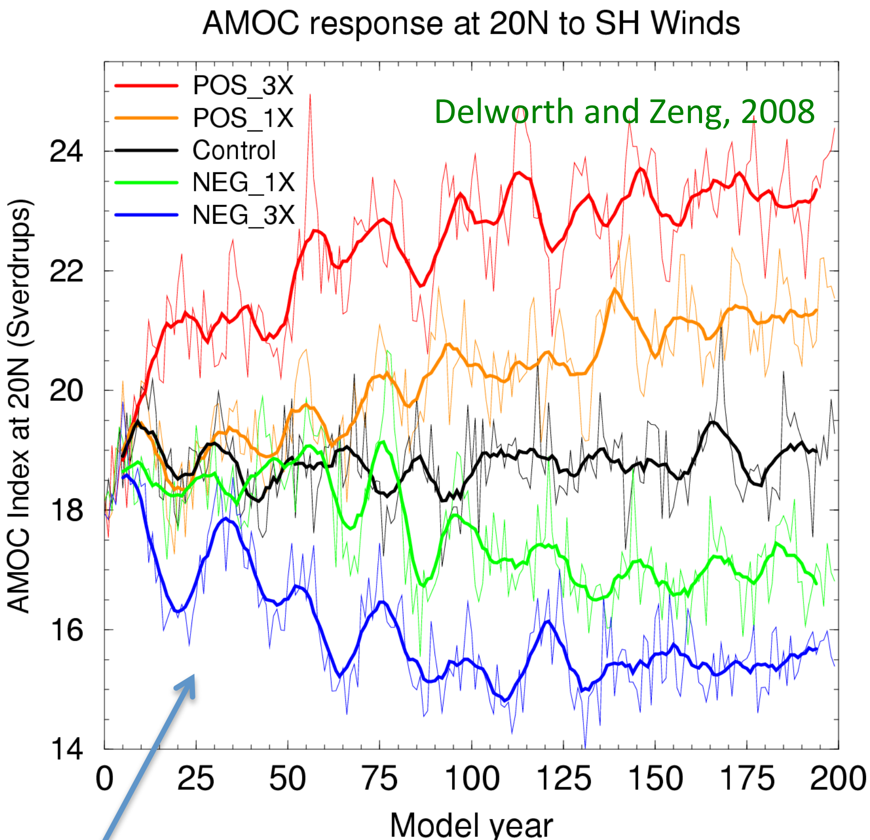
- far better observed phenomenon
- 30+ years of work on theory and modeling

… and yet while state of the art GCMs generally have some sort of ENSO, they vary greatly in time scale, spatial structure and details of mechanisms.

… further, there can be substantial centennial-scale modulation of simulated ENSO, similar to what we see with AMOC variability (Wittenberg, 2009)

→ ***With AMOC variability the observational basis is much smaller, and the challenges are formidable.***

External factors: Response of AMOC to Southern Hemisphere Wind Changes

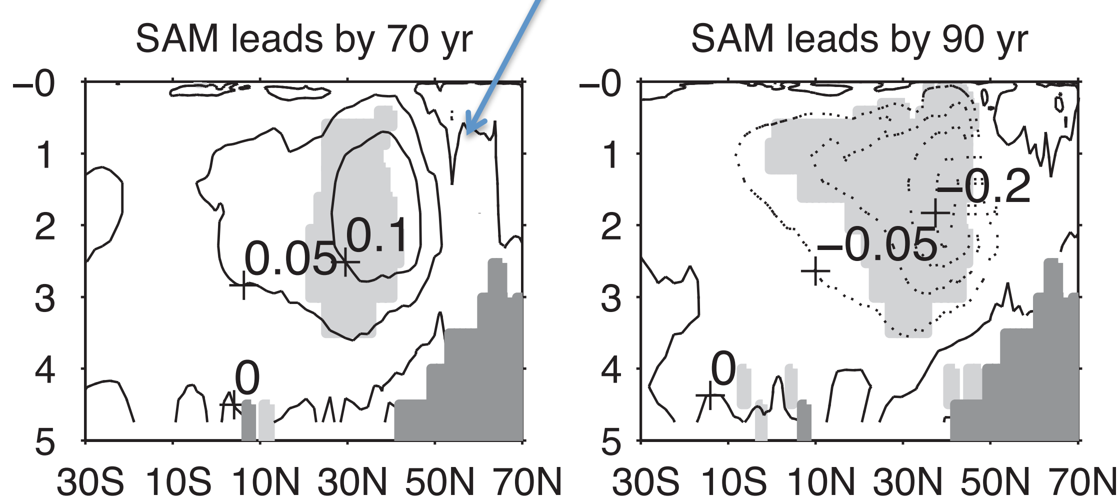


Enhanced Southern Hemisphere winds can lead to strengthened AMOC – but there may be a dependence of this effect on eddy representation in models

AMOC changes at 20N in response to artificially strengthening or weakening SH westerly winds

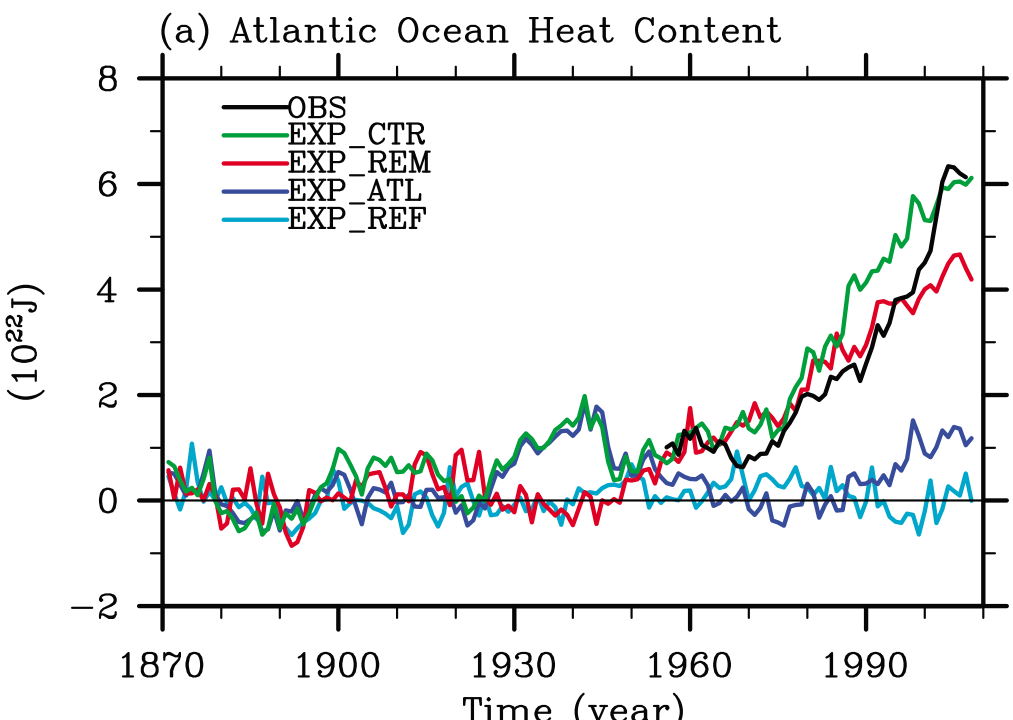
Strengthened AMOC 70 years after strengthened Southern Annular Mode (SAM)

Marini et al, 2011

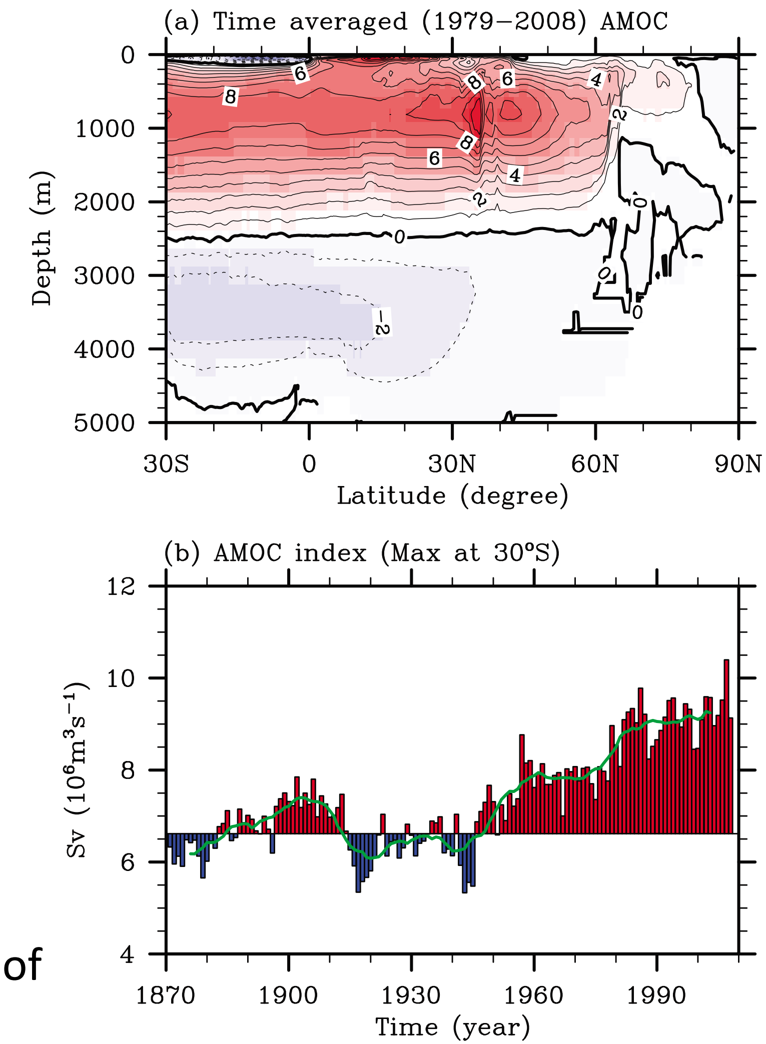


External factors: Response of AMOC to Southern Hemisphere Wind Changes

Altered Southern Hemisphere winds can influence salt and heat transport into the South Atlantic via Aghulas



Lee et al., 2011

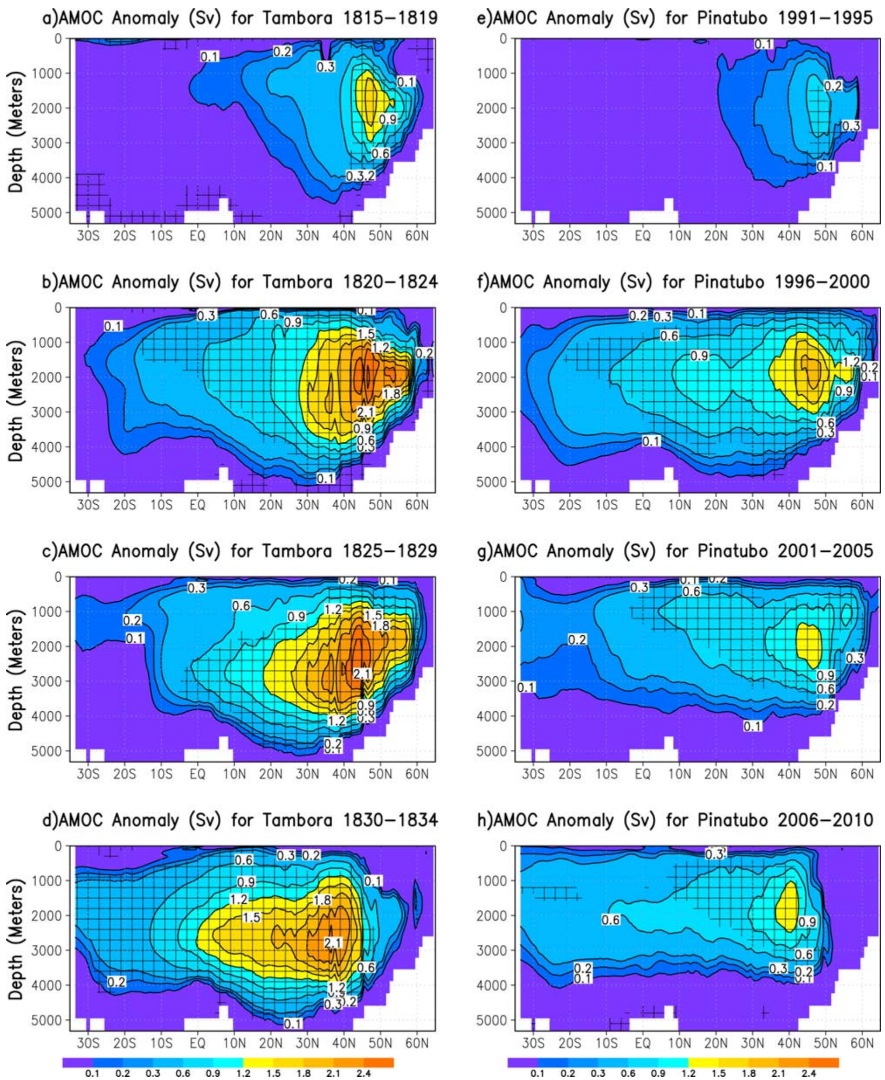


… but presentation from Yeager showed little impact of SAM forcing

External factors: Response of AMOC to changing aerosols

Increased volcanic activity “spins up” the AMOC

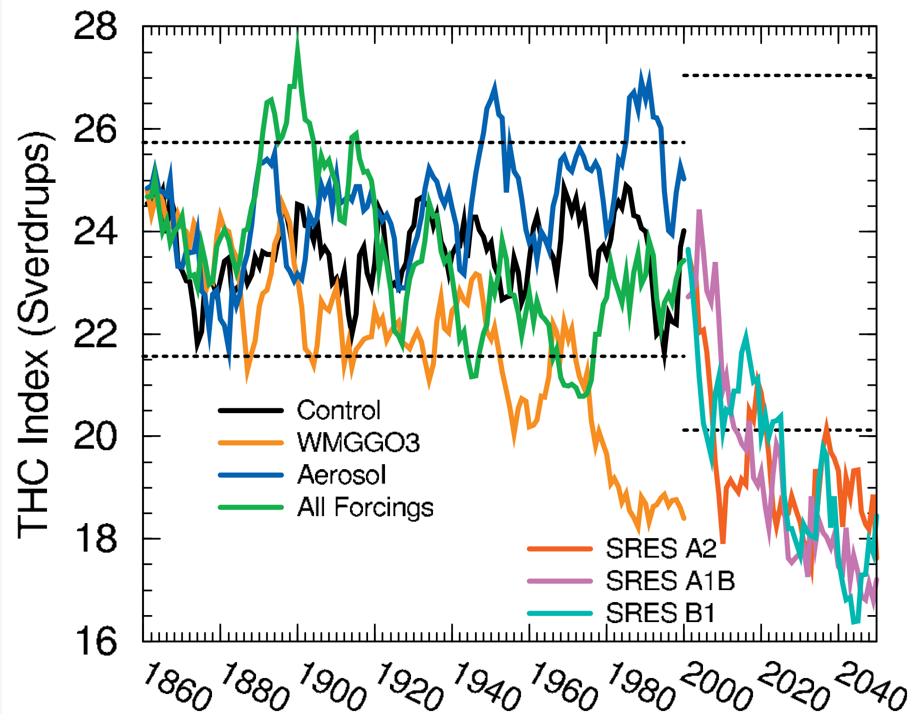
Response to Tambora *Response to Pinatubo*



Stenchikov et al., 2008

For both cases, aerosols weaken upper ocean stratification at high latitudes (colder, saltier in upper ocean) through impacts on surface heat and water fluxes; this leads to stronger AMOC.

Anthropogenic aerosols have similar impact



Delworth and Dixon, 2006

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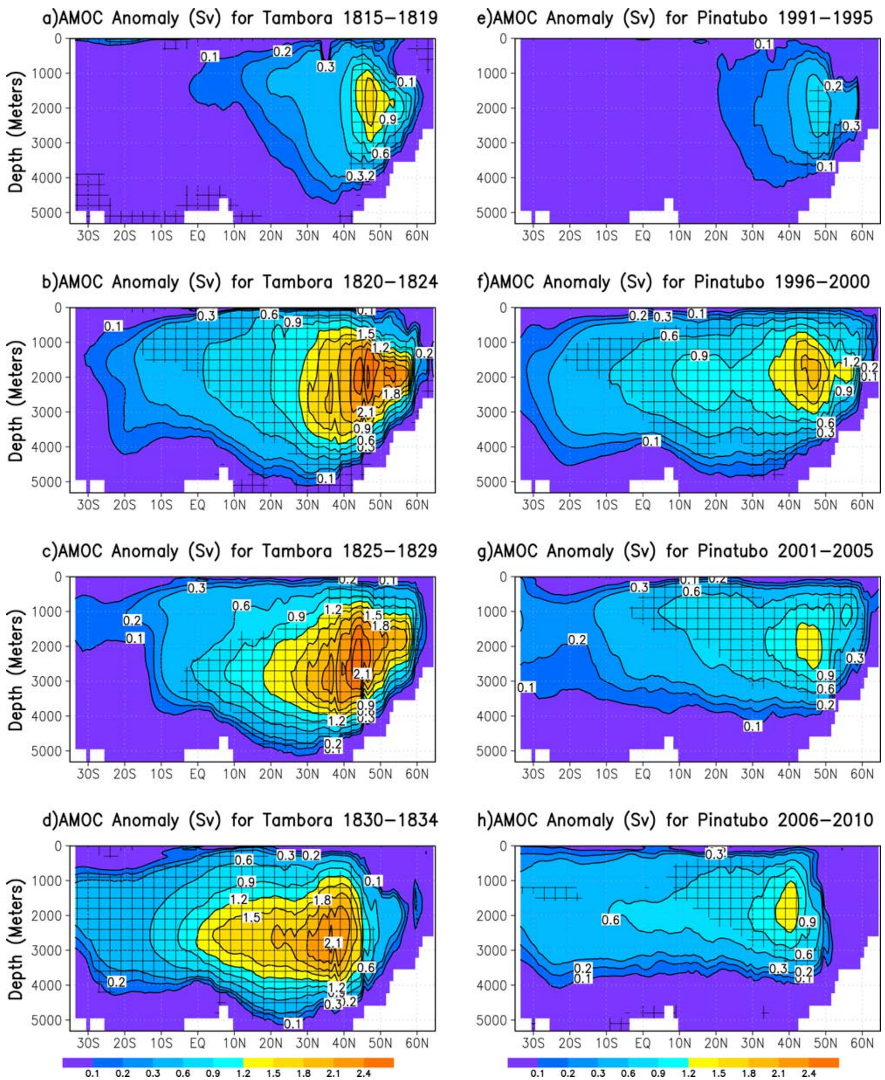


Stenchikov et al., 2008

Mignot et al, 2011, further explore these issues with a simulation of the last millenium.

"This study thus stresses the diversity of AMOC responses to volcanic eruptions in climate models and tentatively points to an important role of the seasonality of the eruptions."

See also Zhong et al., 2010.

Aerosols can also come from natural sources – potential interaction of Saharan dust and Atlantic temperatures on multidecadal scales

Evan et al., 2008; 2011; Wang et al., 2012;

SOLAR

AMOC variability can also be induced by solar variations (Park and Latif, 2011).

Summary

1. Evidence for multiple time scales in the Atlantic, possibly related to AMOC
(20-30 yr, 50-100 yr, multicentennial)

2. Key goal is to assess what role AMOC plays in generating the observed SST variations

3. Evidence that different timescales may be associated with different sets of physical processes

A. No distinct timescale (eg, last 250 years of CCSM3)

B. Distinctive timescale

a. internal damped ocean mode within North Atlantic (20-30 yrs, sometimes much longer); different types of propagating or advecting signals
b. coupled air-sea mode within North Atlantic (20-30 yrs, or much longer)
c. interaction with Arctic (40-80 yrs)
d. coupled air-sea mode with connections to Tropics (~100 yrs)
f. Driven from Southern Hemisphere/Aghulas (multidecadal)
e. Pan-Atlantic mode with connections to Southern Ocean (multicentennial)

4. External radiative driving may also play a role (aerosols, solar, ozone through SH winds)

How can we make progress?

We have different proposed mechanisms – which (if any) occur in Nature?

Some possible pathways to improve understanding:

1. Continued hierarchy of models is crucial.

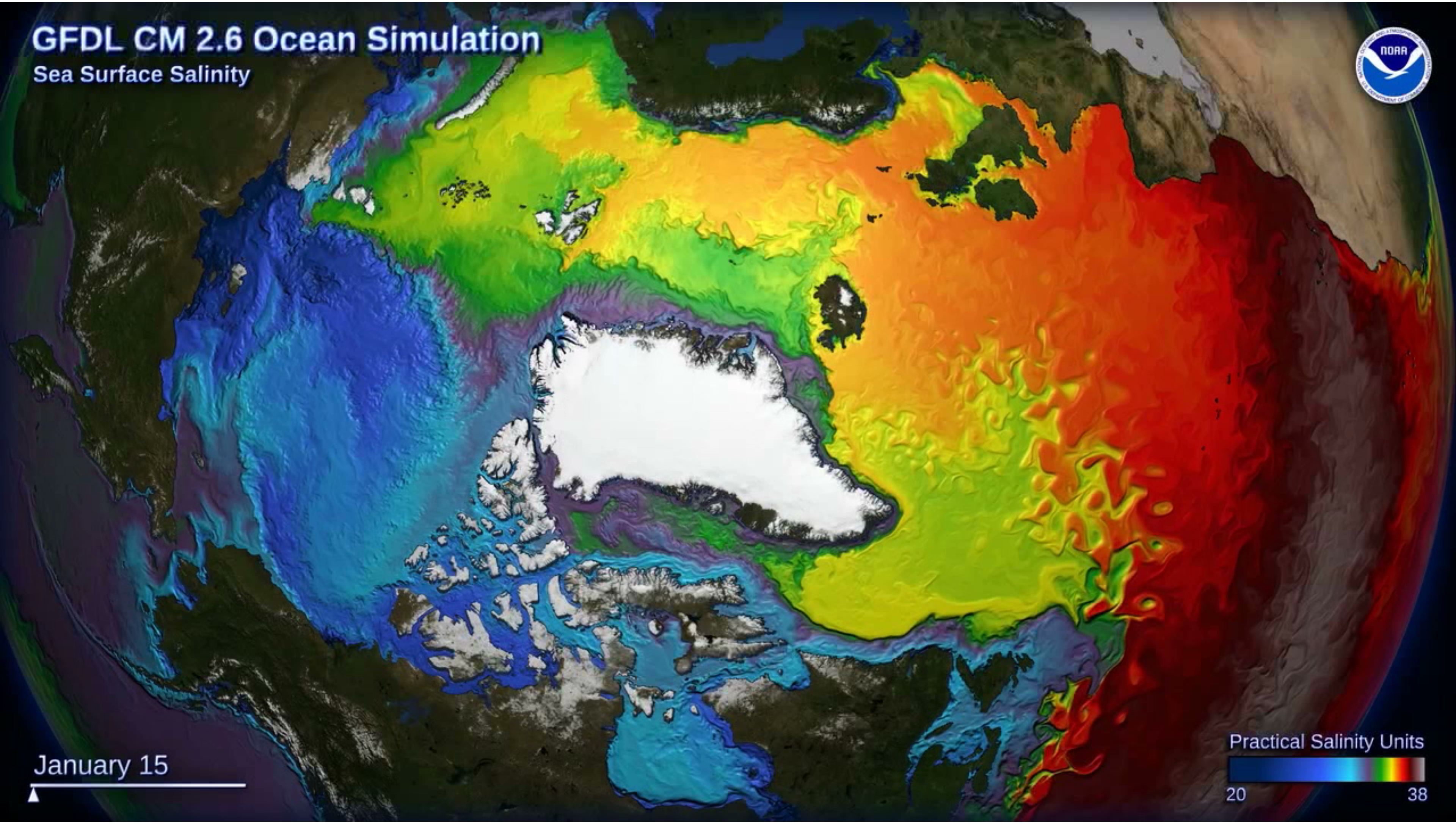
2. Confronting models with available observations is paramount (both instrumental and paleo data).

3. Improve models so that dependence on uncertain parameterizations is reduced. High resolution is one key component in a hierarchy of models - ocean eddy resolving coupled models are now at hand. Nature of air-sea coupling may be different at very high resolution. Will there be some convergence of mechanisms as models improve?

4. Similar mechanisms in multiple models might imply robustness – but care must be taken due to underlying similarities in model formulations.

5. Can we use the proposed mechanism(s) to predict some previously unknown relationship that can be examined in other models, as well as in instrumental or paleo observations?

6. Analyses can form hypotheses, and then suggest additional model experimentation to test hypotheses. Multi-model testing of such hypotheses is preferable.


GFDL CM 2.6 Ocean Simulation
Sea Surface Salinity
NOAA
January 15
Practical Salinity Units
20
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