

# Nonlinear Mechanisms of Interdecadal Climate Modes: Atmospheric and Oceanic Observations, and Coupled Models

Michael Ghil

Ecole Normale Supérieure, Paris, and  
University of California, Los Angeles

***Collaborators:***

S. Kravtsov, UW-Milwaukee; W. K. Dewar, FSU; P. Berloff, WHOI;  
J.C. McWilliams, UCLA; A. W. Robertson, IRI;  
J. Willis, S. L. Marcus, and J. O. Dickey, JPL

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## North Atlantic Ocean–Atmosphere Co-Variability: A Nonlinear Problem

- Persistent atmospheric patterns, which are most likely to be affected by O–A coupling, arise from complex eddy–mean flow **interactions**.
- The region of strongest potential coupling is also characterized by vigorous oceanic **intrinsic variability**.
- Linear atmospheric response to weak SST anomalies (SSTAs) is small. Hence, active coupling requires **nonlinear** atmospheric sensitivity to SSTA.

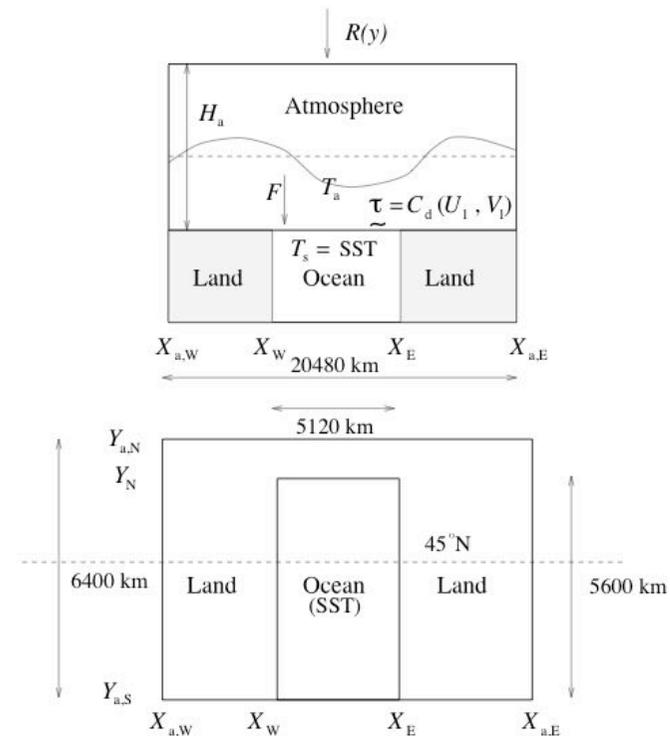
# Observational Analyses

- NCEP/NCAR Reanalysis (Kalnay *et al.*, 1996)  
zonally averaged **zonal wind data** set:  
58 Northern Hemisphere winters  
[10°N–70°N] and (Dec.–March)
- **Sea-surface temperature (SST)**  
observations (annual means, same period)
- Upper **ocean heat content (OHC) data** (detrended,  
1965–2006) (Levitus *et al.*, 2005; Lyman *et al.*, 2006)

# Two Coupled Models

(1) **Quasi-geostrophic (QG)** atmospheric and ocean components, both characterized by vigorous intrinsic variability.

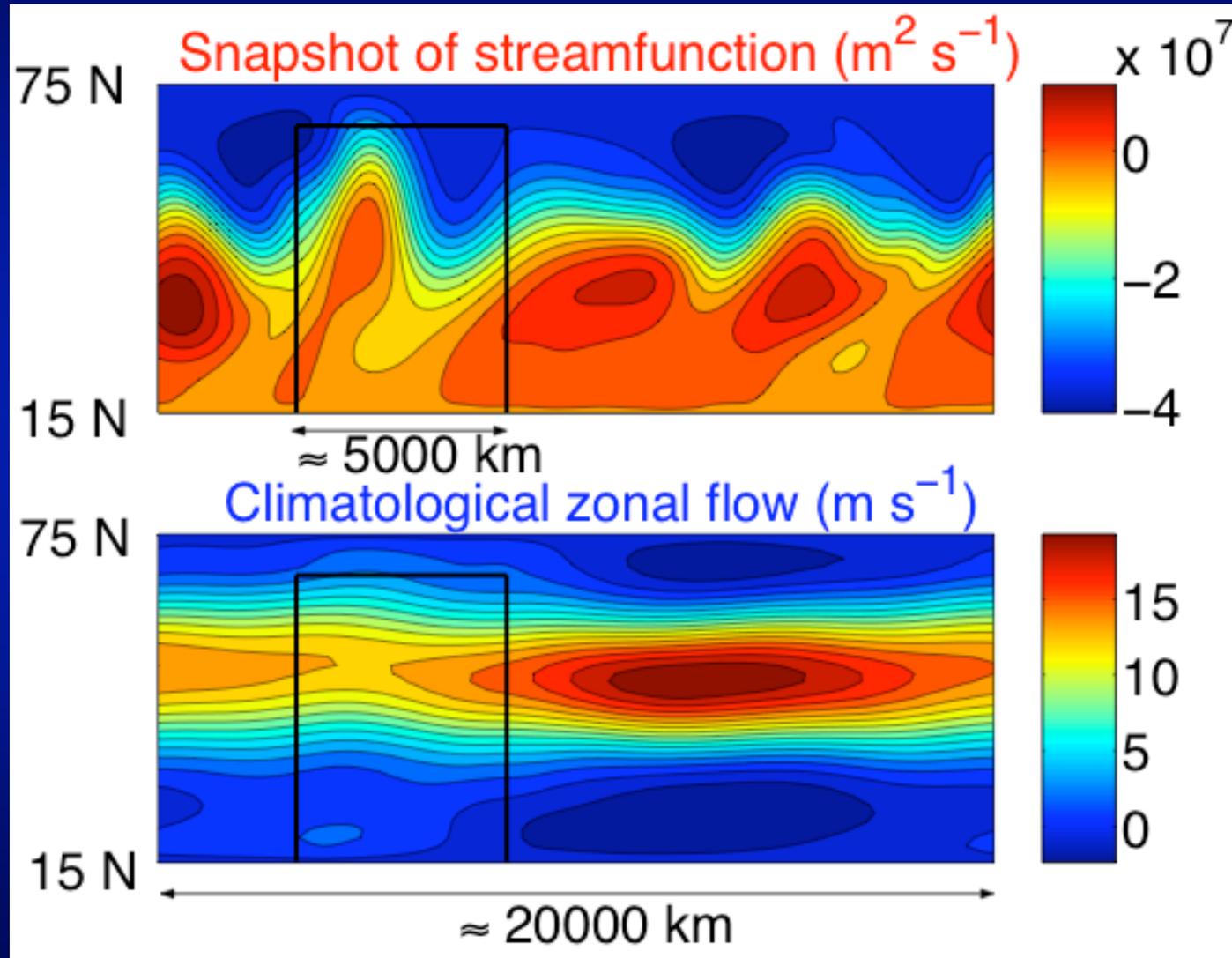
(2) The same atmospheric QG model coupled to a coarse-resolution, **primitive-equation (PE) ocean** (called **OPE**).



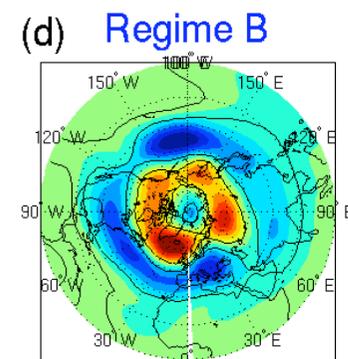
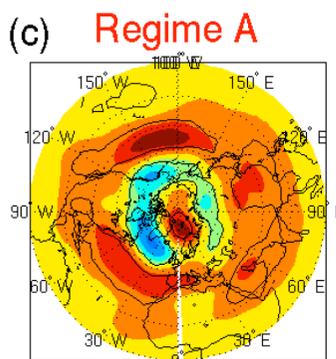
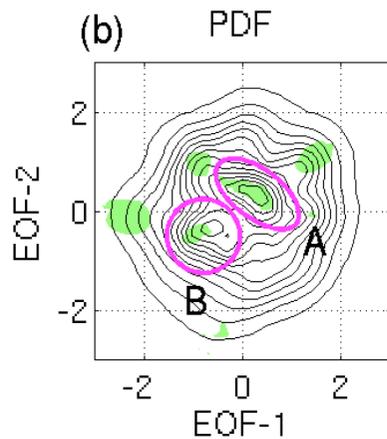
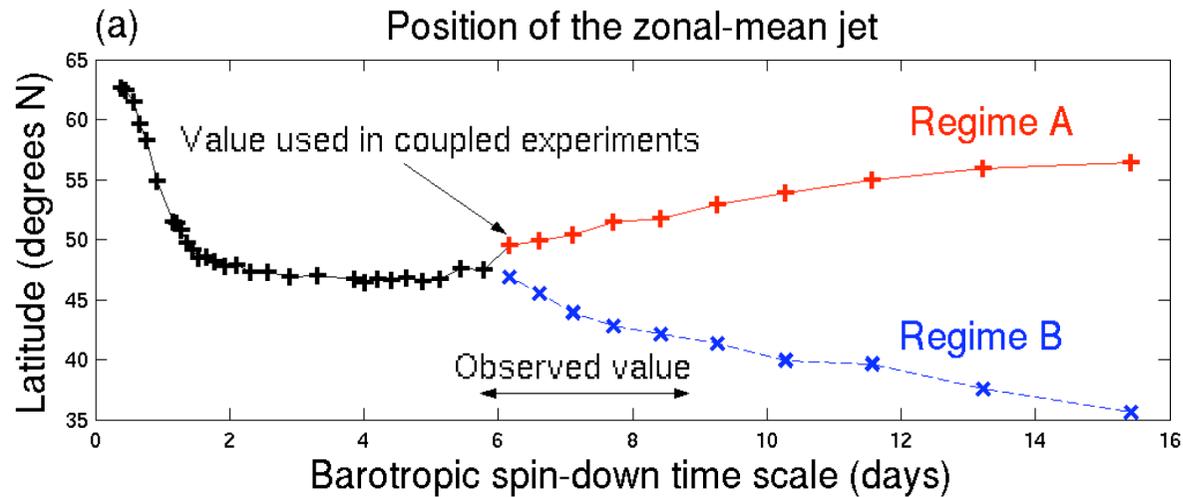
# Methodology

- Study **nonlinear** aspects of intrinsic atmospheric variability by identifying **anomalously persistent** patterns (time scales longer than about a week).
- Identify long-term (decadal and longer) changes in the **frequency of occurrence** of such states.
- Connect the latter changes with the changes in boundary forcing (e.g., SST anomalies), as well as with the **upper-ocean's (inter-)decadal variability**.

# Atmospheric circulation in the QG model



# Atmospheric bimodality in models and observations

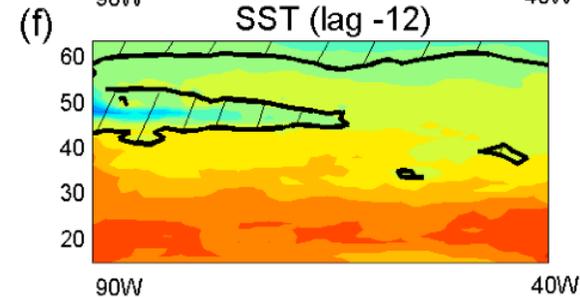
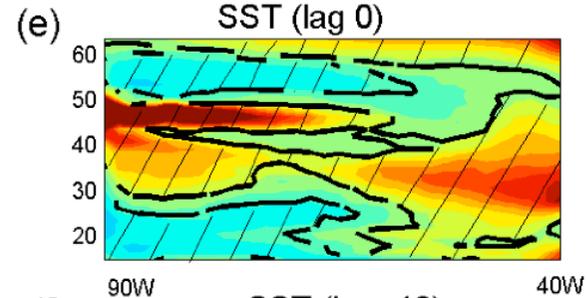
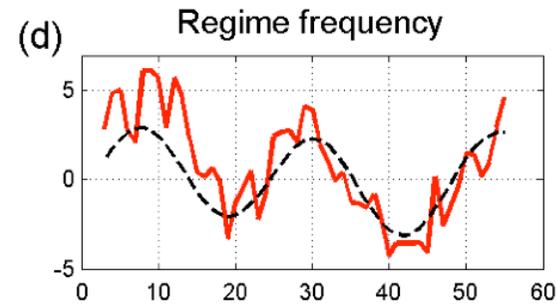
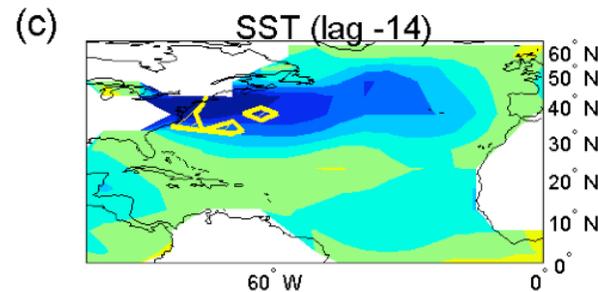
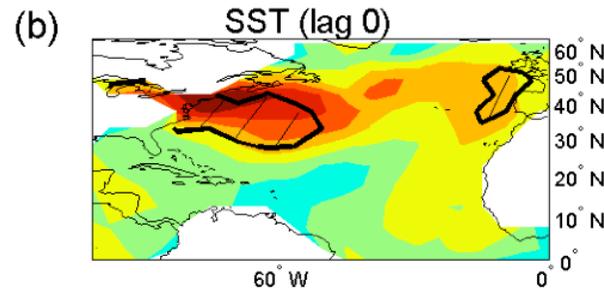
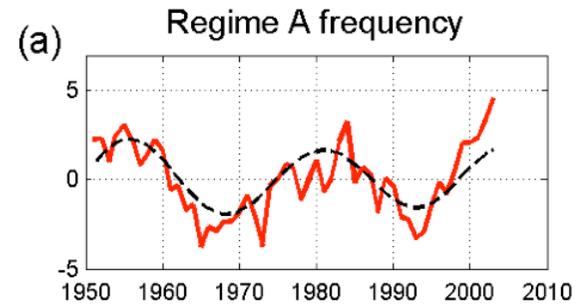


MODEL  
OBSERVATIONS

# 20–25-yr Coupled Mode

OBSERVATIONS

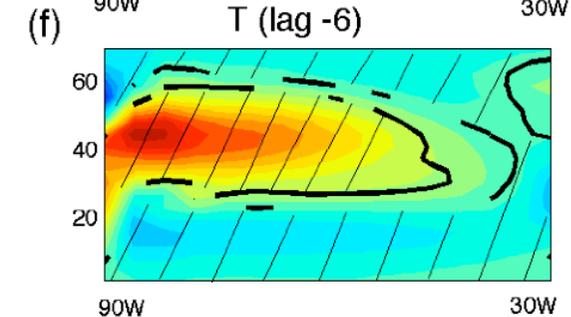
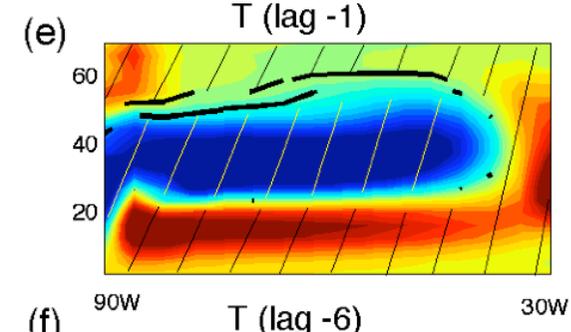
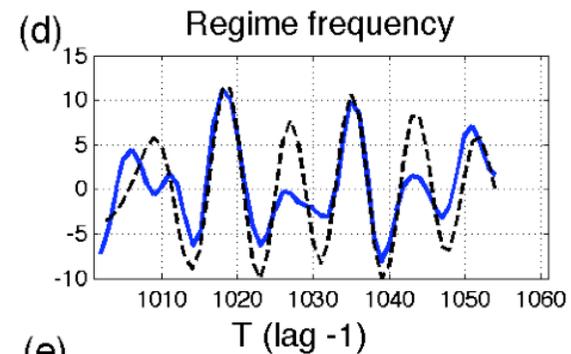
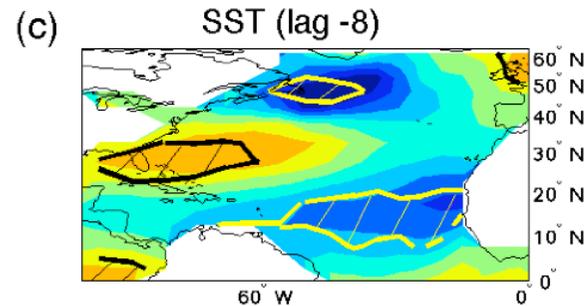
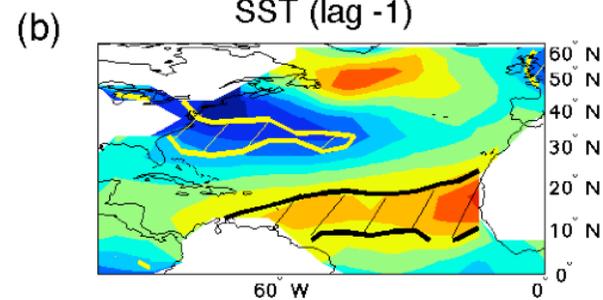
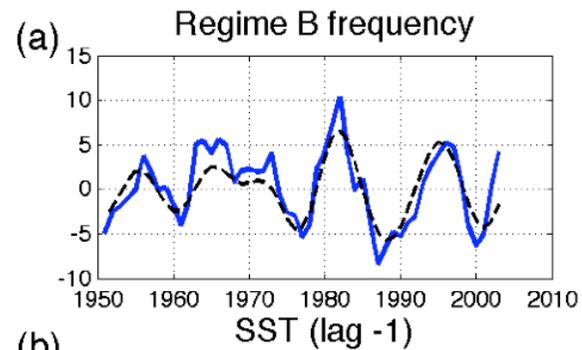
COUPLED QG MODEL



# 10–15-yr Mode

OBSERVATIONS

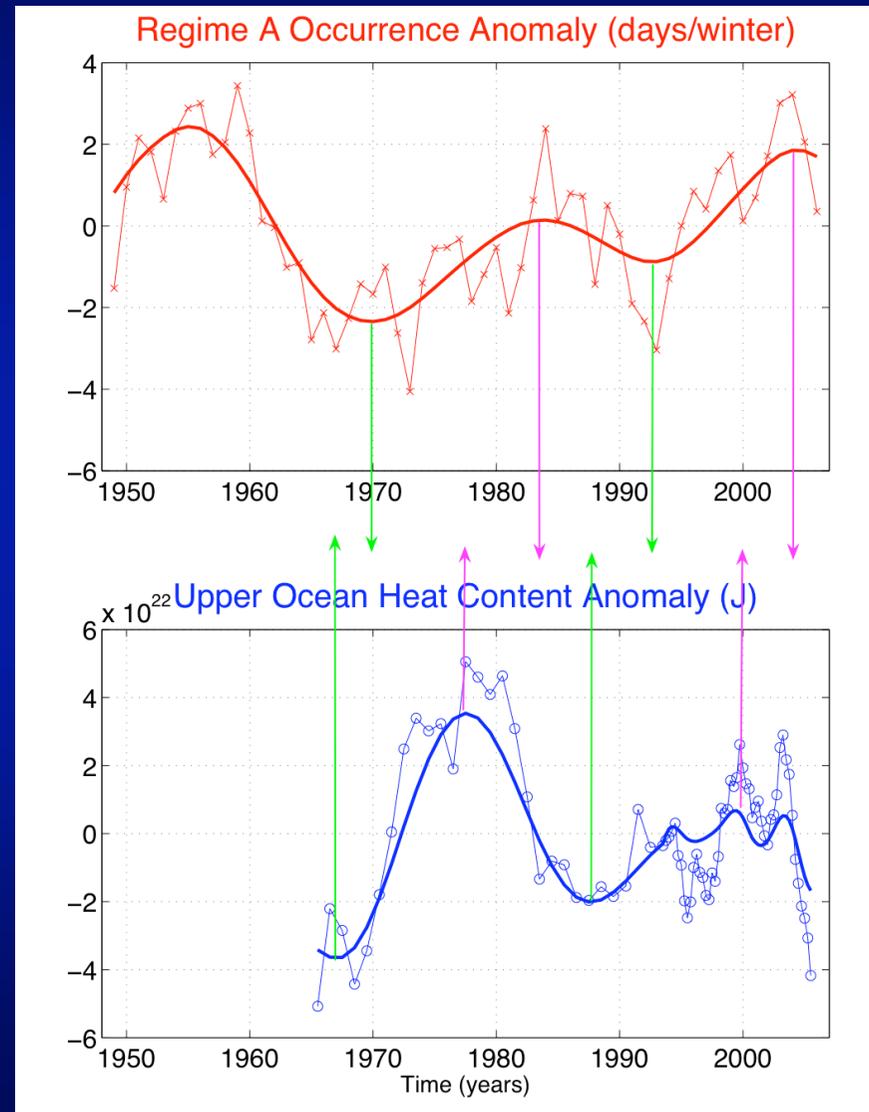
COUPLED OPE MODEL



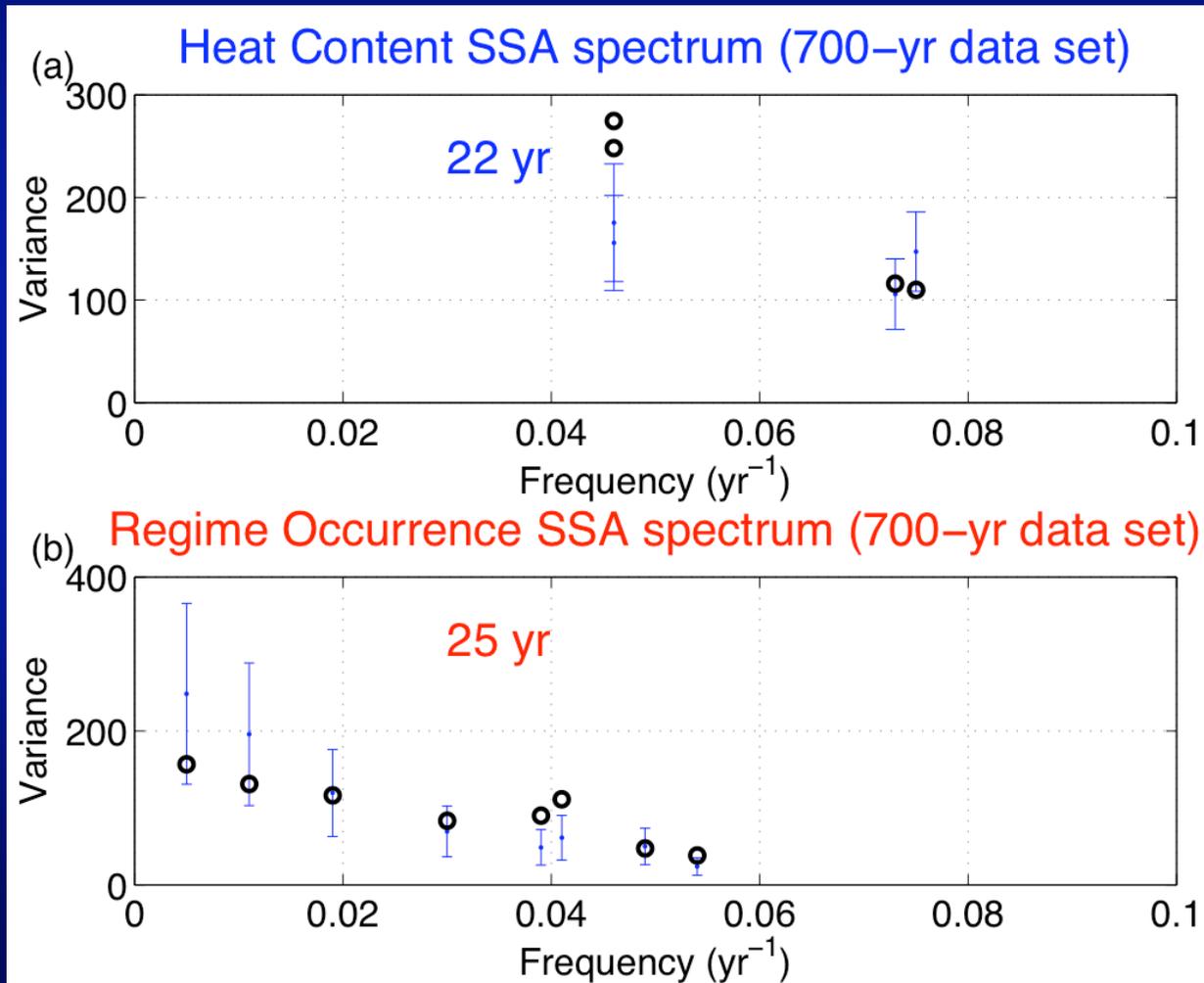
# Observations of OHC variability

The observational record is relatively short, **but**

- Both Regime A occurrences and the OHC time series exhibit **bidecadal variability**; and
- OHC **leads** changes in regime occurrences by a few years.



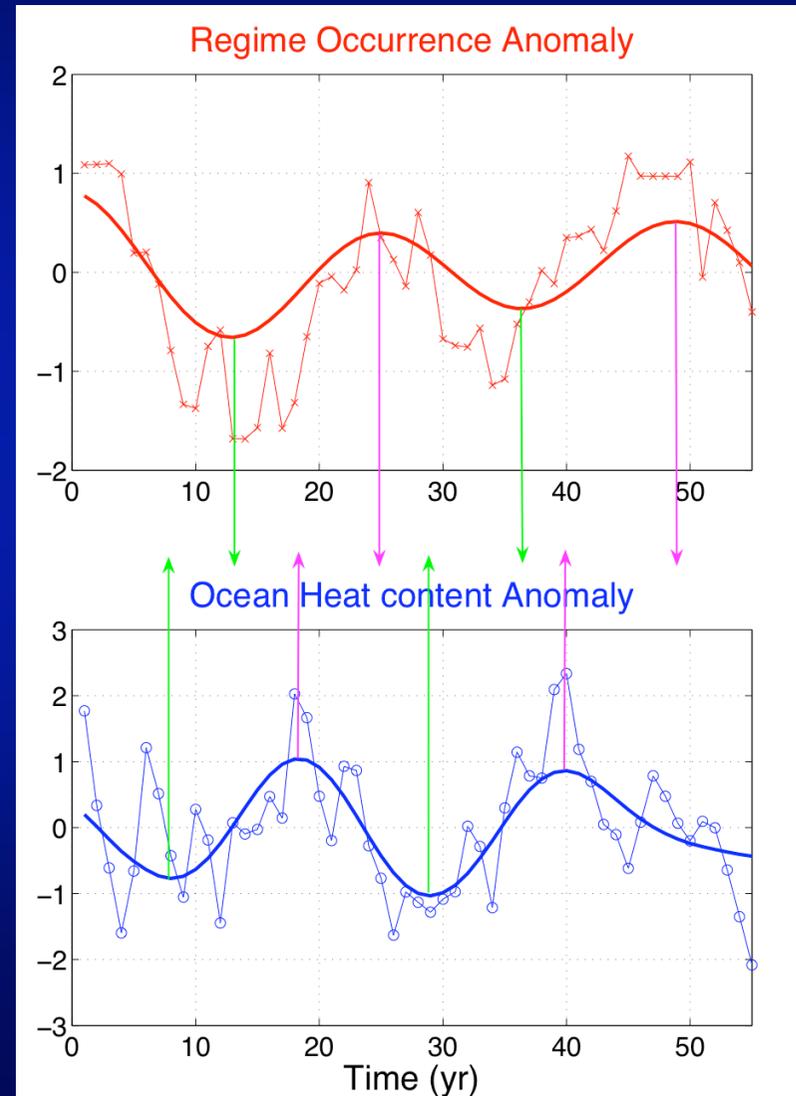
# OHC variability in a coupled QG model-I



# OHC variability in a coupled QG model-II

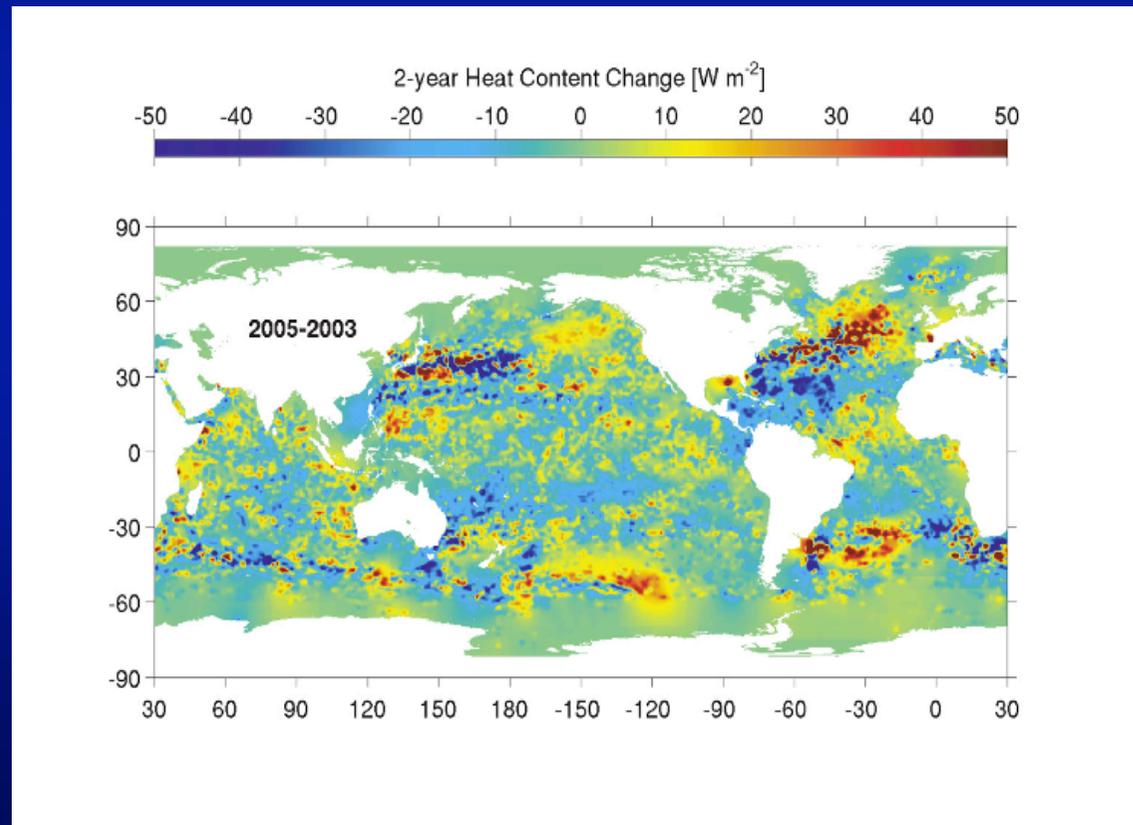
The observational result applies to the coupled QG model's variability as well:

In the model's bidecadal, coupled oscillation, **OHC leads regime occurrence frequency** by a few years!



# Spatial pattern of OHC change

- In the North Atlantic region, there is a substantial spatial correlation between **the OHC drop from 2003 to 2005** and the SST pattern of our 20–25-yr mode.
- Similar correlations exist in the Pacific (not shown).



# Summary

- Evidence is mounting for decadal and **bidecadal coupled climate signals**, whose centers of action lie in the North Atlantic Ocean.
- Signatures of these signals are found in the NH **zonal wind and SST data**, as well as in global upper-**ocean heat content (OHC)** data.
- Intermediate **coupled models exhibit oscillations** that correctly reproduce the observed time scales and phase relations between key climate variables.
- The **bimodal character of atmospheric LFV** is the amplifier of atmospheric sensitivity to SSTAs.

## Selected references

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