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

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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.

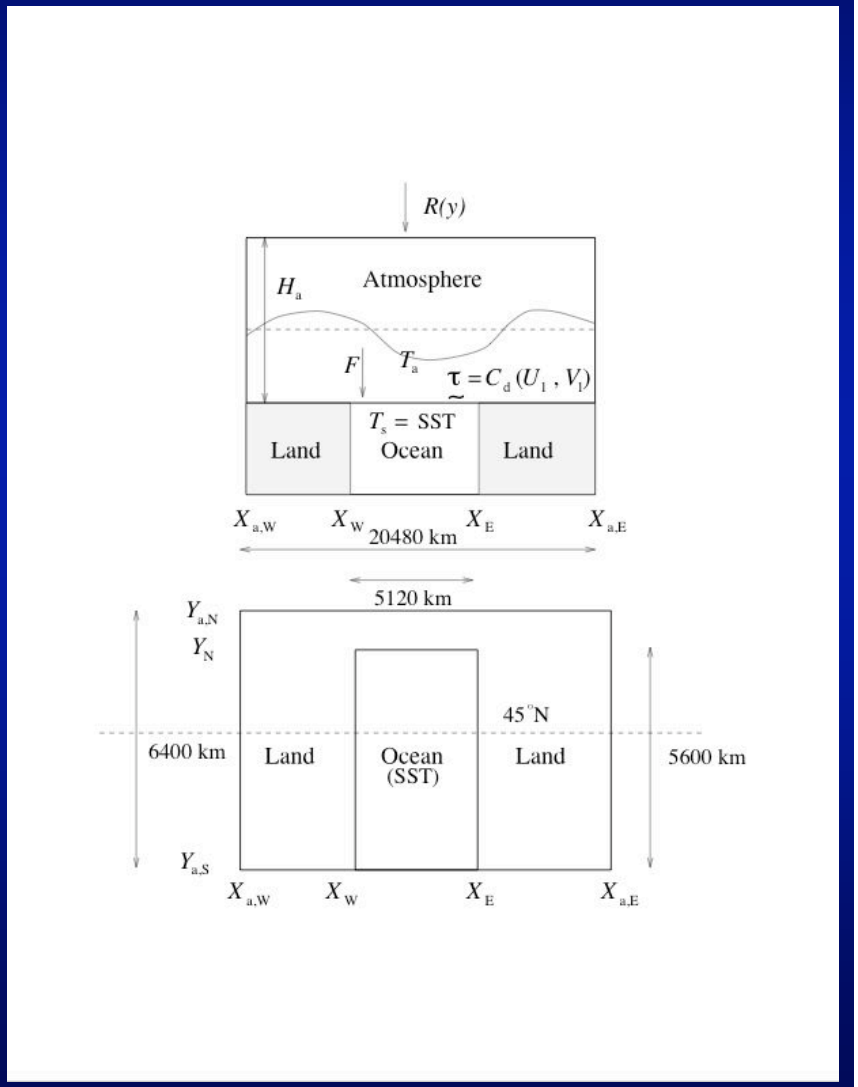
Observational Analyses

- NCEP/NCAR Reanalysis (Kalnay *et al*., 1996) zonally averaged zonal wind data set: 58 Northern Hemisphere winters [10^0N–70^0N] 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.

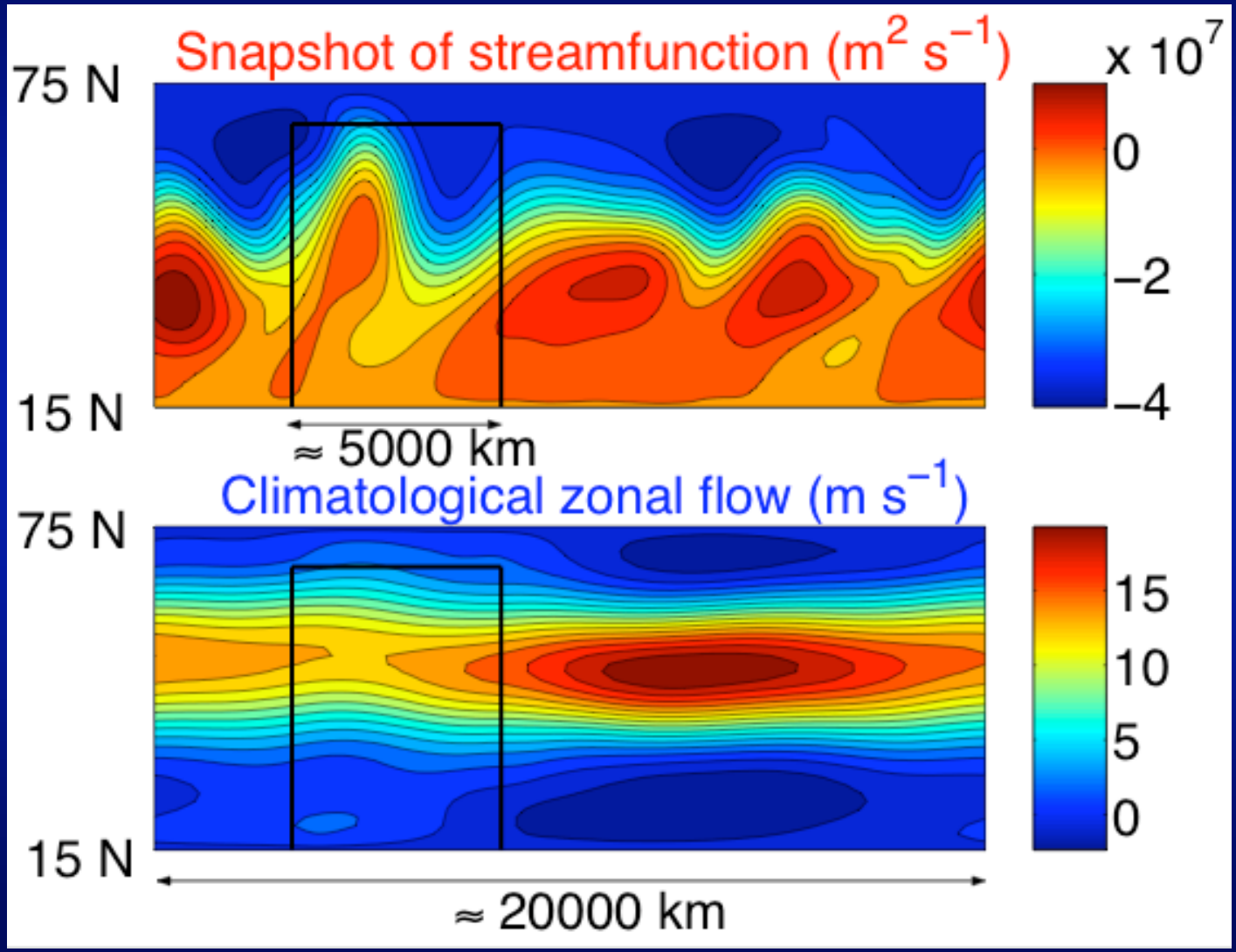
(2) The same atmospheric QG model coupled to a coarse-resolution, primitive-equation (PE) ocean (called OPE).



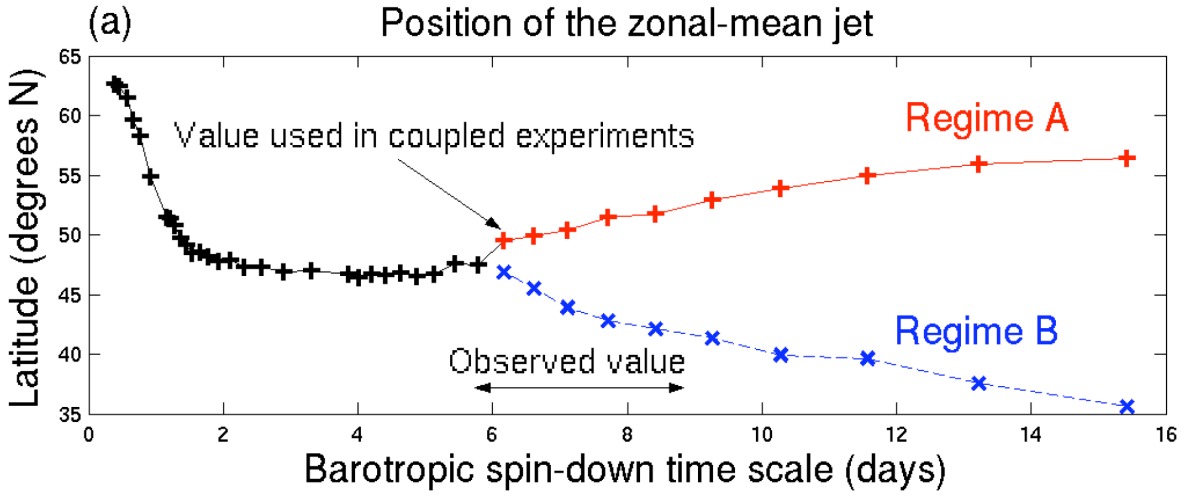
Methodology

- 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



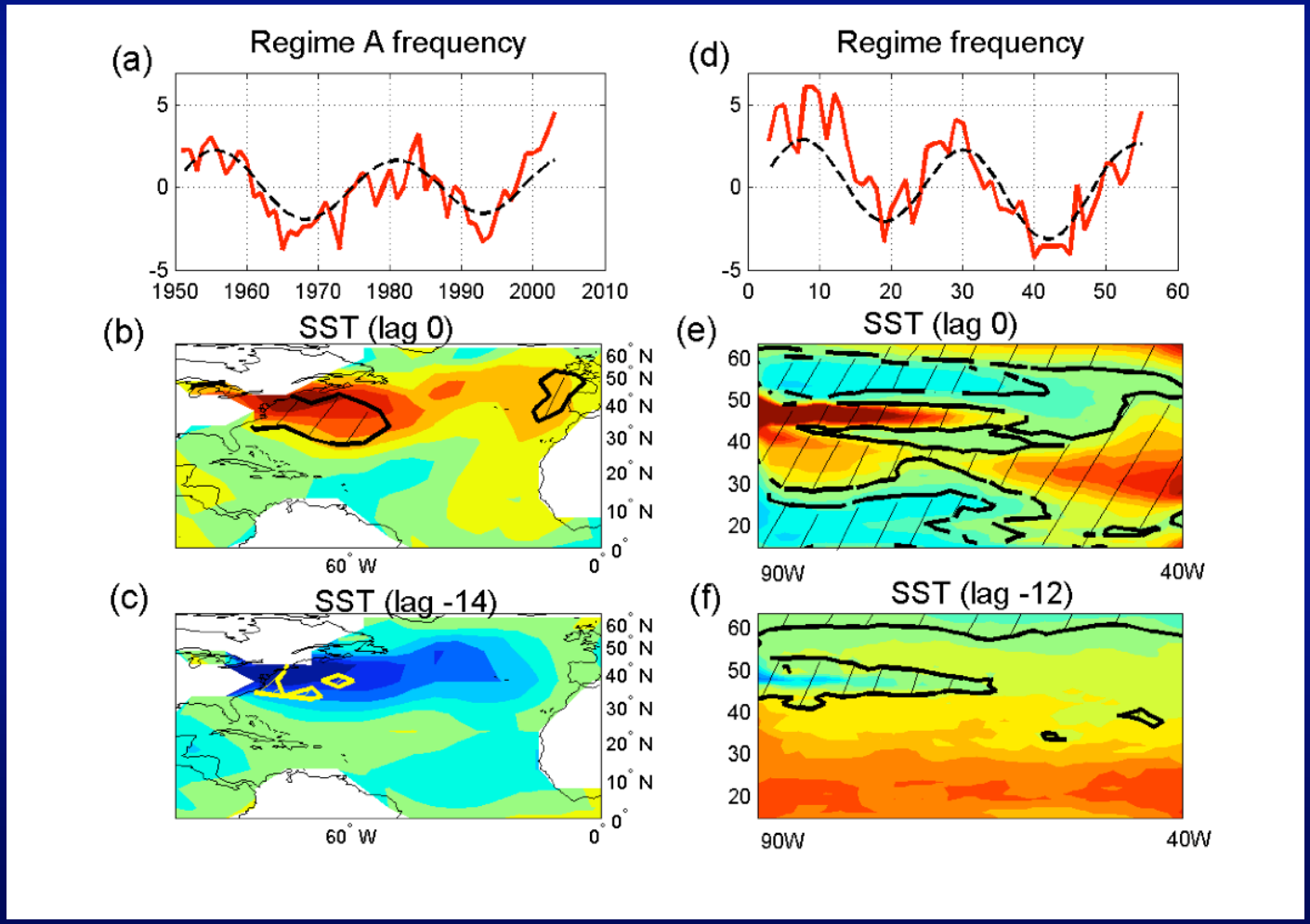
Atmospheric bimodality in models and observations



MODEL OBSERVATIONS

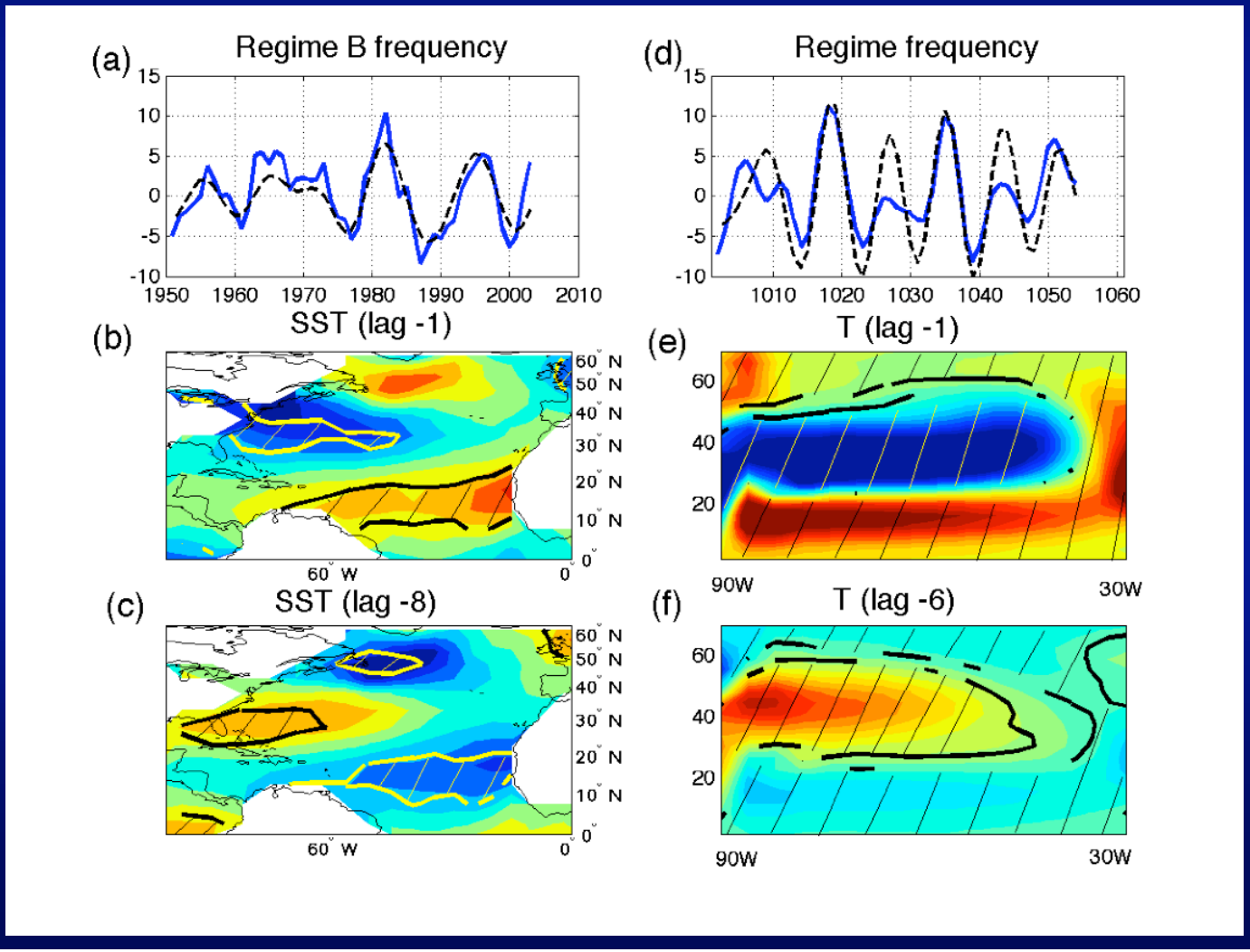
20–25-yr Coupled Mode

OBSERVATIONS COUPLED QG MODEL



10–15-yr Mode

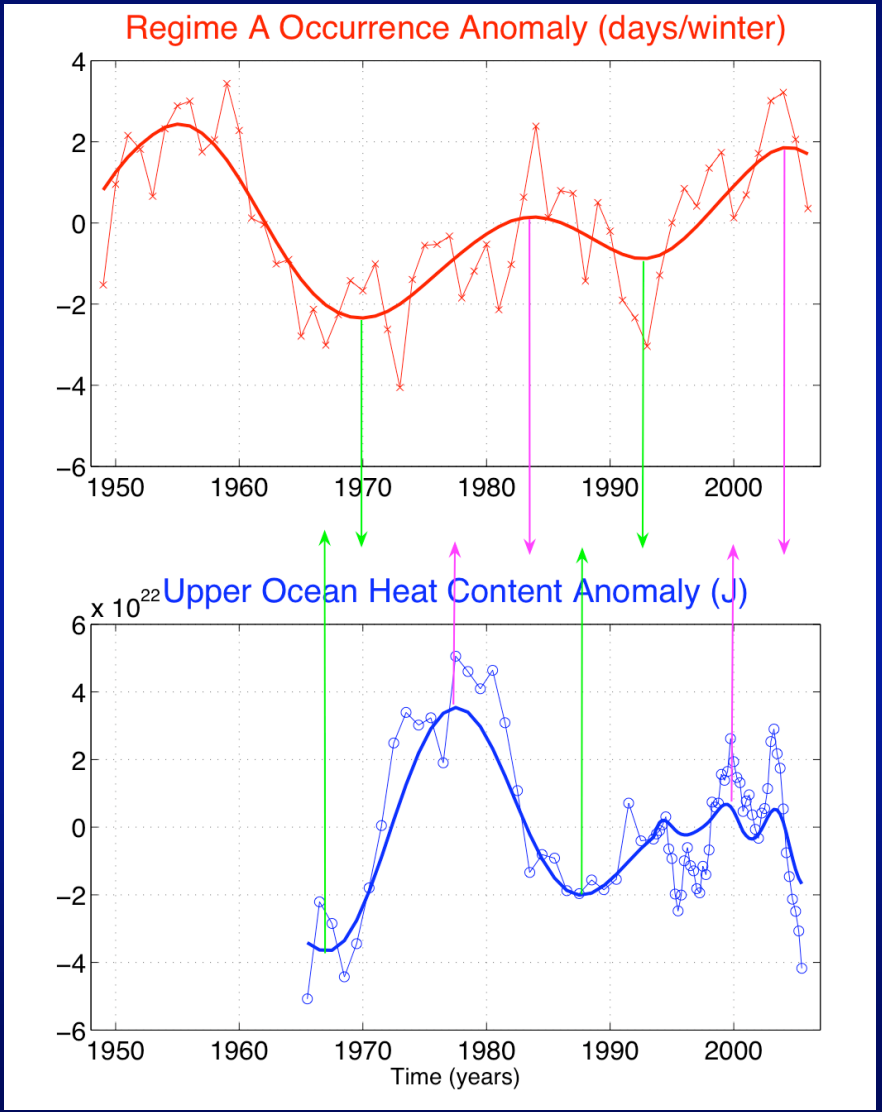
OBSERVATIONS COUPLED OPE MODEL



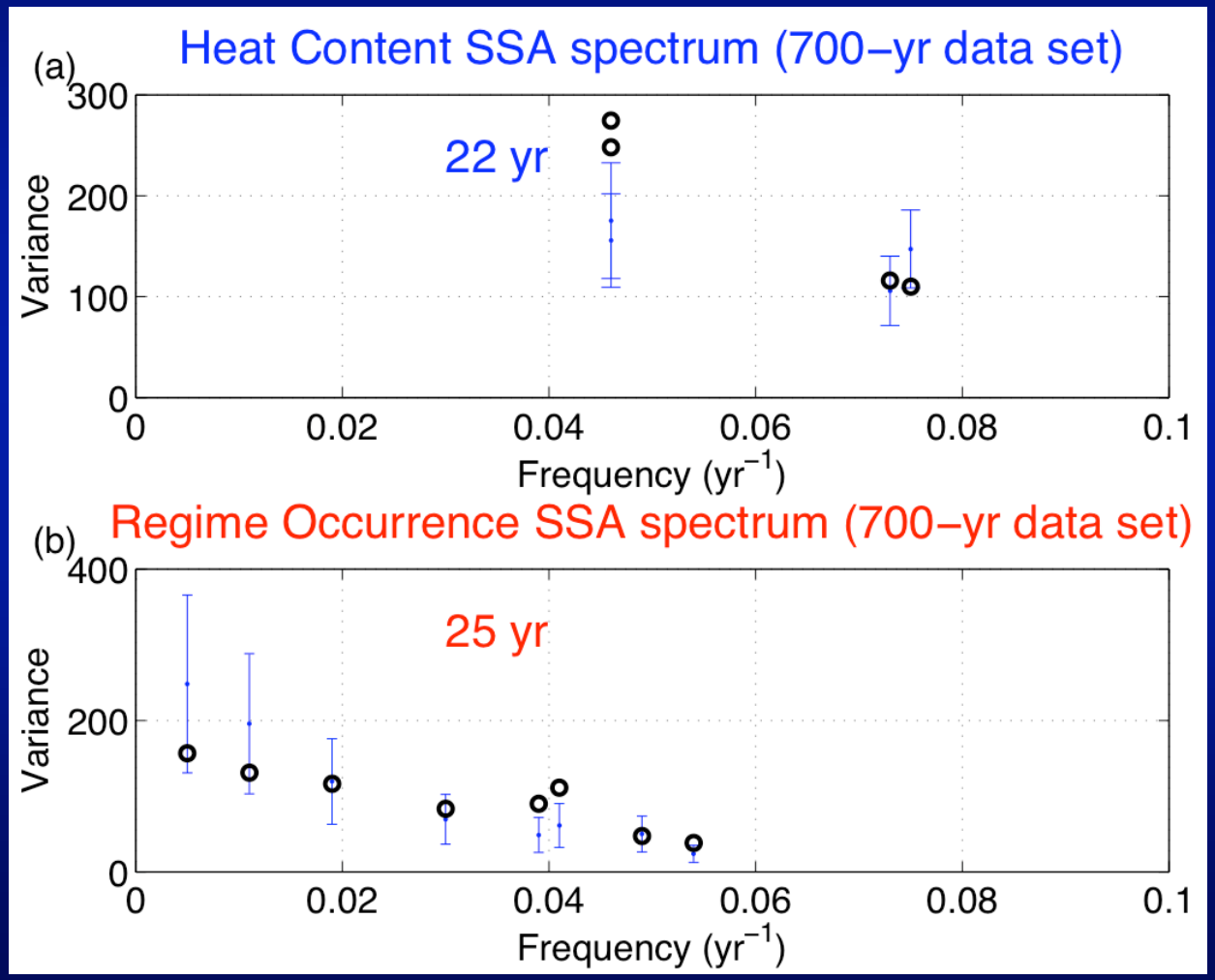
Observations of OHC variability

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.



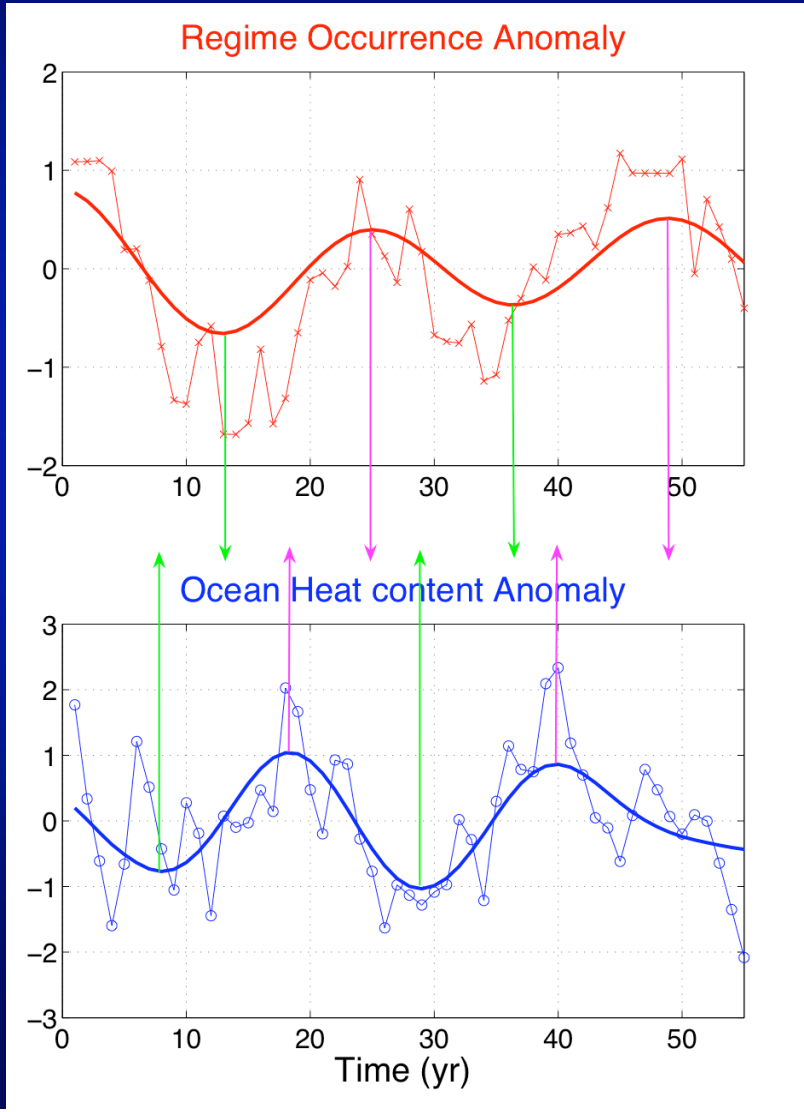
OHC variability in a coupled QG model–I



OHC variability in a coupled QG model–II

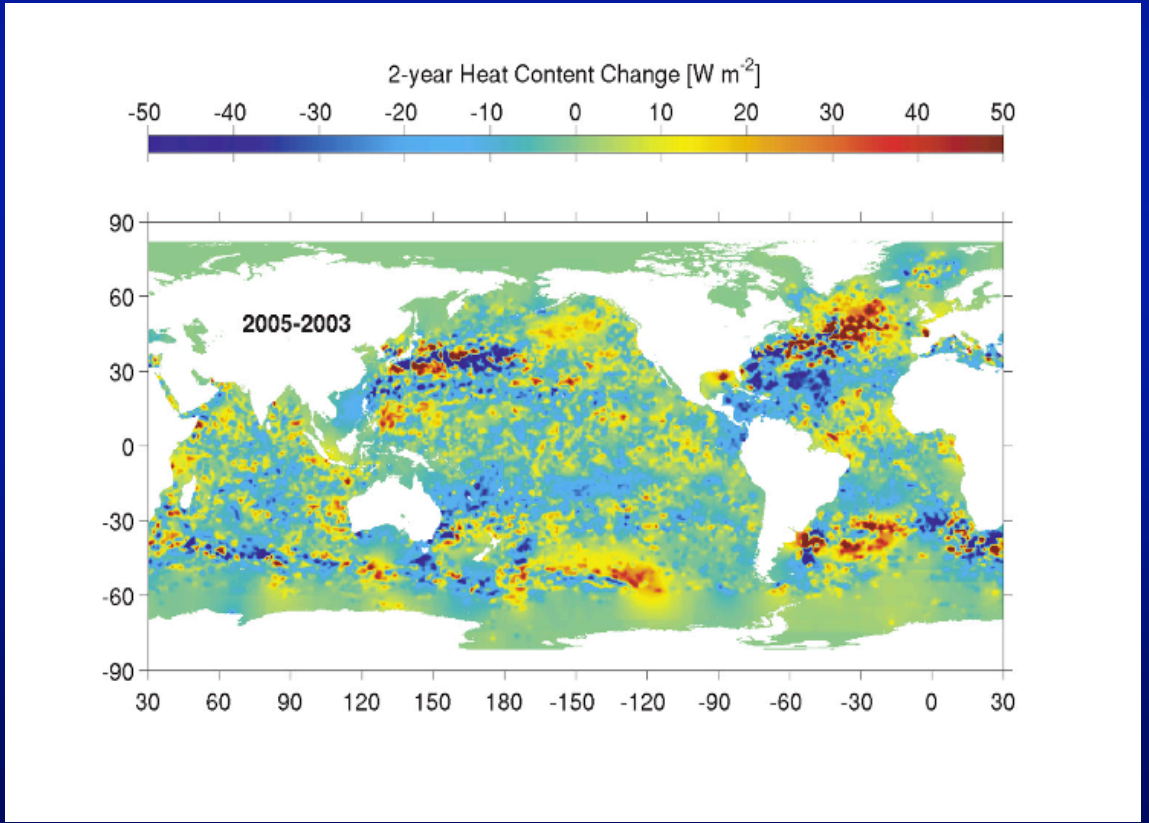
The observational result applies to the coupled QG model's variability as well:

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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