Understanding Observed Climate Variability …[1]

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[1]by Unifying CGCM Dynamics, Idealized Stochastic Models, and Observed Data Using the Interactive Ensemble CGCM

Pre-Motivation

- The chaotic nature of the climate system and complex climate models makes it really difficult to understand what is going on.

Physical Problem

- Understand the mechanisms of decadal/multidecadal variability in the observed climate system.
  - Externally forced
  - Forced by atmospheric internal variability.
  - Forced by ocean internal variability
  - Intrinsic to coupled atmosphere-ocean feedbacks.

Interactive Ensemble (courtesy of Ben Kirtman)

- Atmospheric model has no intrinsic internal variability (noise) and is coupled to an ocean.

- Illustrate using conceptual models.

Stochastic Forcing of SST Variability

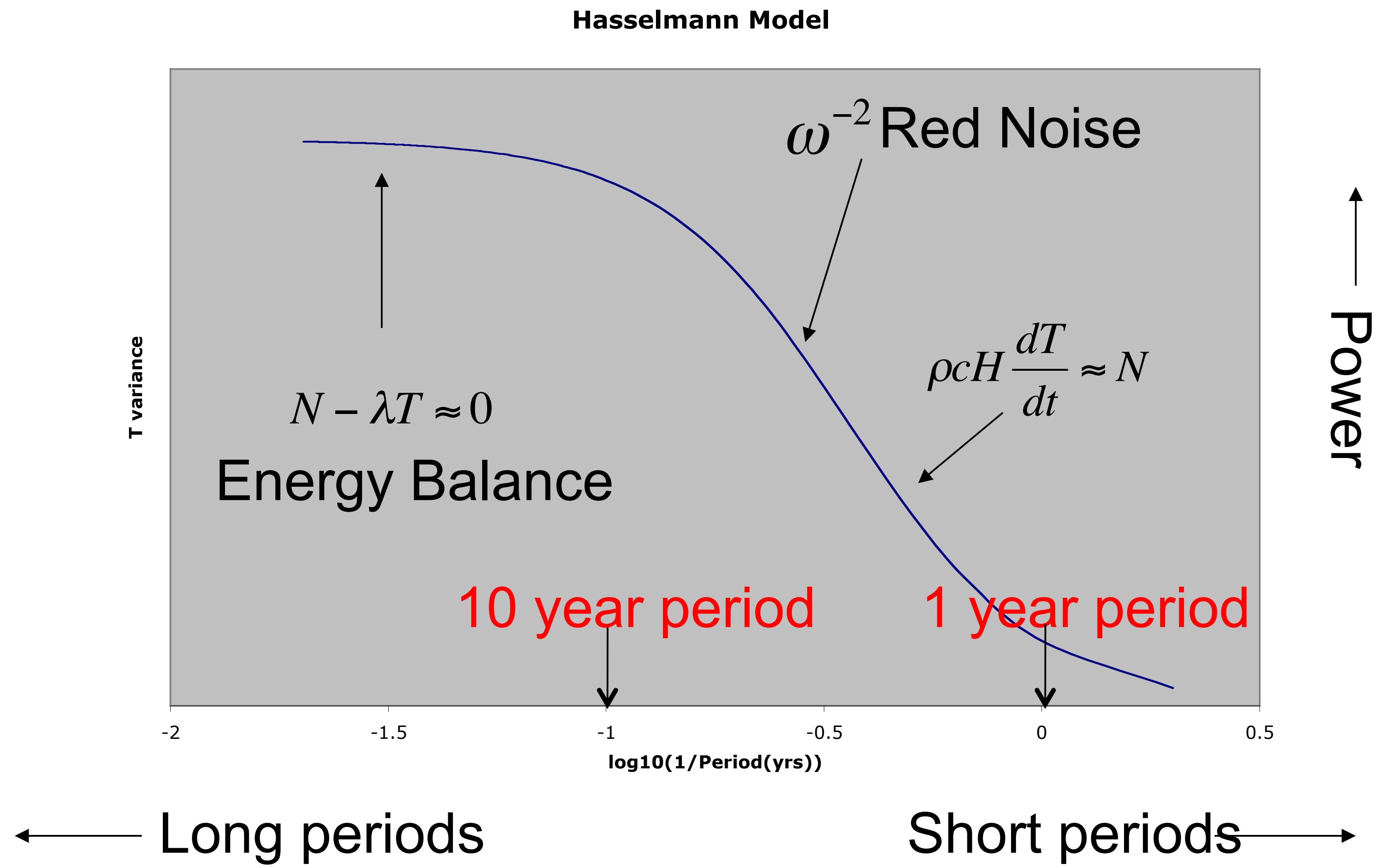
- Hasselmann model (1976)
  - Slab mixed layer ocean forced by noise
  - Damped random walk

$$\rho c H \frac{dT}{dt} = N - \lambda T$$

T represents ocean temperature

N represents atmospheric noise

Response to white noise forcing for 50m slab mixed layer, damping 15 W m^{-2} K^{-1}



Coupled Stochastic Model
Barsugli and Battisti (1998)

- Atmosphere and ocean coupled heat budgets. Atmosphere (T_A):

$$\frac{dT_A}{dt} = -aT_A + bT_O + N$$

- Ocean (T_O):

$$\beta\frac{dT_O}{dt} = cT_A - dT_O$$

- N is internal atmospheric noise
- Reduces to Hasselmann model for slave atmosphere ($dT_A/dt \cong 0$).

Important Result from Barsugli and Battisti Model

- The coupled model atmosphere and the (uncoupled) SST forced atmosphere have different statistics, even if the SST is the same in both.
- Corollary: If you want to develop a CGCM with as close to observed climate statistics as possible, it is a really bad strategy to tune the uncoupled AGCM (forced by observed SST) to produce observed climate statistics.

- Next
  - Develop AMIP ensemble and Interactive Ensemble versions of the Barsugli and Battisti model.

AMIP Ensemble

$$\frac{dT_{A_1}}{dt} = -aT_{A_1} + bT_O + N_1$$

$$\frac{dT_{A_2}}{dt} = -aT_{A_2} + bT_O + N_2 \qquad V(N_1) = V(N_2) = \ldots = V(N_m) = V$$

...

$$\frac{dT_{A_m}}{dt} = -aT_{A_m} + bT_O + N_m$$

Ensemble mean

$$\frac{d\overline{T}_A}{dt} = -a\overline{T}_A + bT_O + \overline{N} \qquad V(\overline{N}) = V/m \longrightarrow 0$$

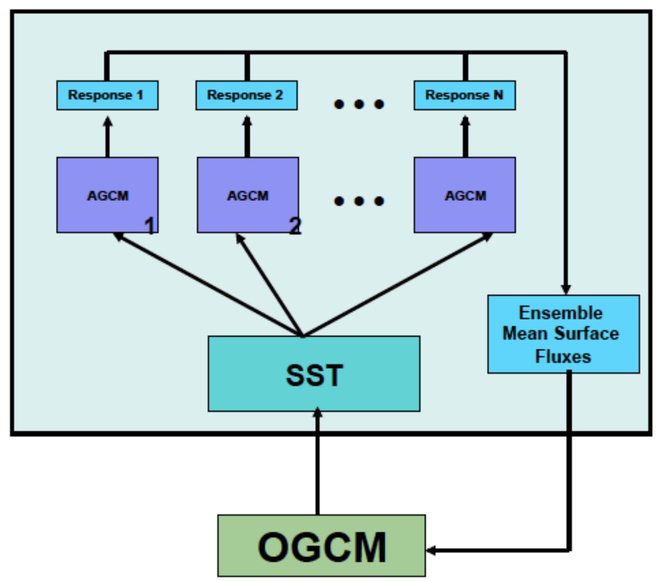
Interactive Ensemble (IE) Couples AMIP Ensemble to the Ocean

$$\frac{d\bar{T}_A}{dt} = -a\bar{T}_A + bT_O + \bar{N}$$

$$\beta\frac{dT_O}{dt} = c\bar{T}_A - dT_O$$

Note: for application in a CGCM setting, the atmospheric forcing of the ocean is through the mean surface fluxes of the AMIP ensemble. The ocean forcing of the atmosphere is by SST.

Interactive Ensemble CGCM



IE-CGCM

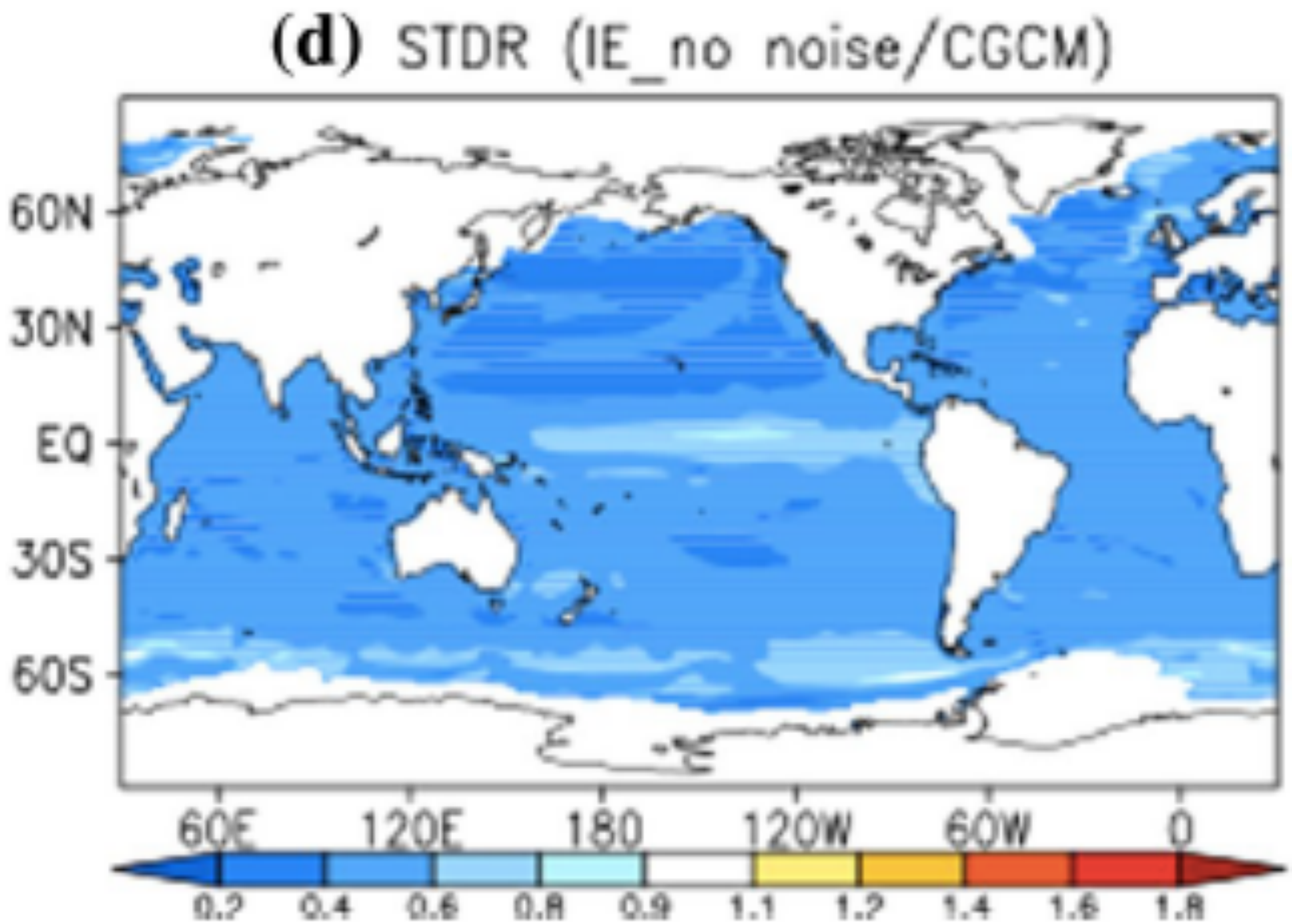
- SST variability forced by atmospheric internal variability is filtered out.
- Possibility of coupled atmosphere-ocean SST variability (ENSO?), among other things.

- More expensive than a CGCM

- How much SST variability in a CGCM is the response to atmospheric noise?
  - Compare long CGCM and IE-CGCM simulations with the same external forcing
  - IE-CGCM based on CCSM3 has 6 atmospheres, so ratio of variance of the atmospheric noise standard deviation IE:Control is 0.4=sqrt(1/6).

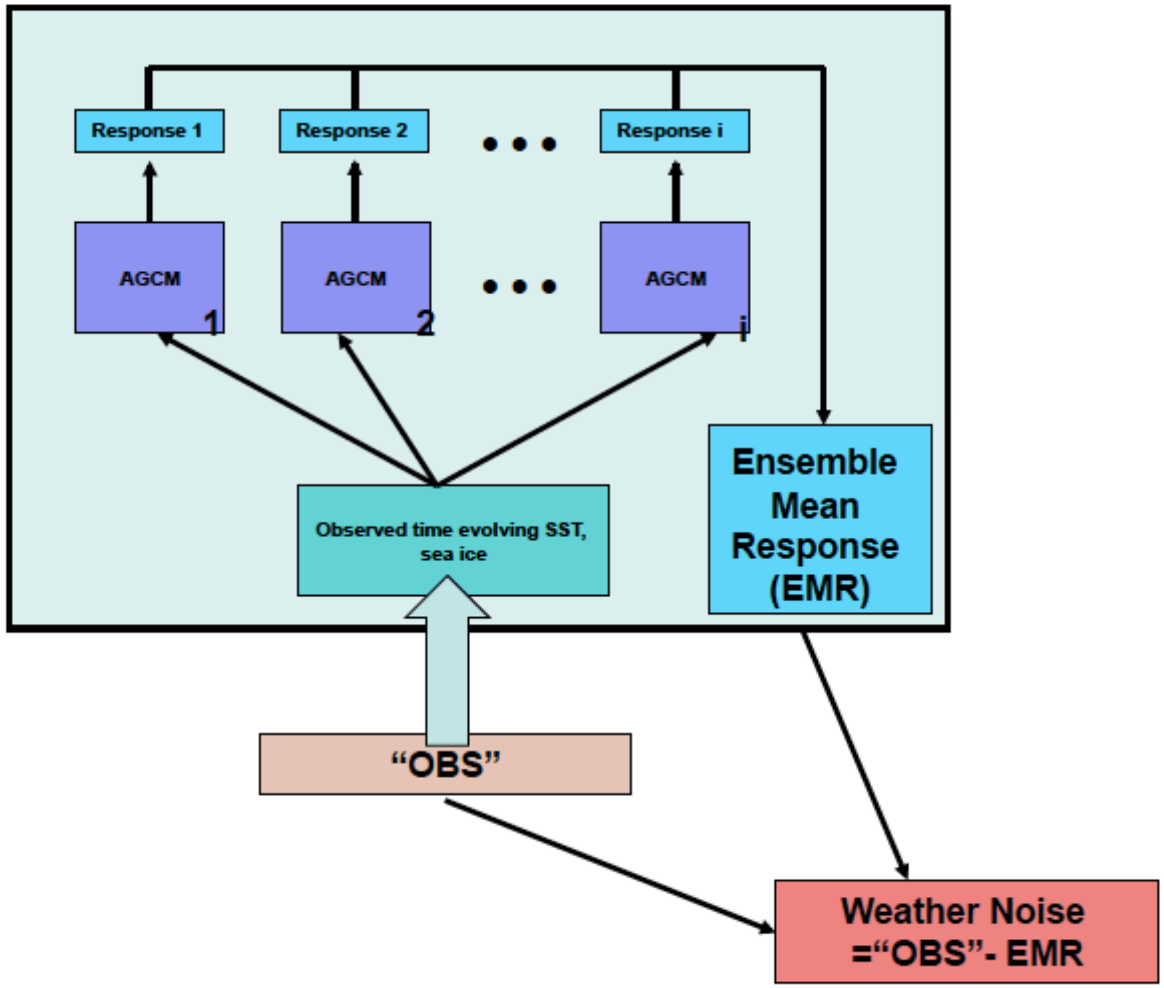
Coupled and Ocean Variability

Ratio IE:Control of Standard Deviation of SSTA



- How does the atmospheric noise forcing of SST variability work?
  - Determine the noise surface fluxes in a CGCM simulation (after the fact).
  - Force the IE (ocean model) with this realization of the atmospheric noise surface fluxes.
  - This works because the IE has atmospheric noise removed, and the response to specified forcing is quasi-deterministic.

Determination of the Weather Noise



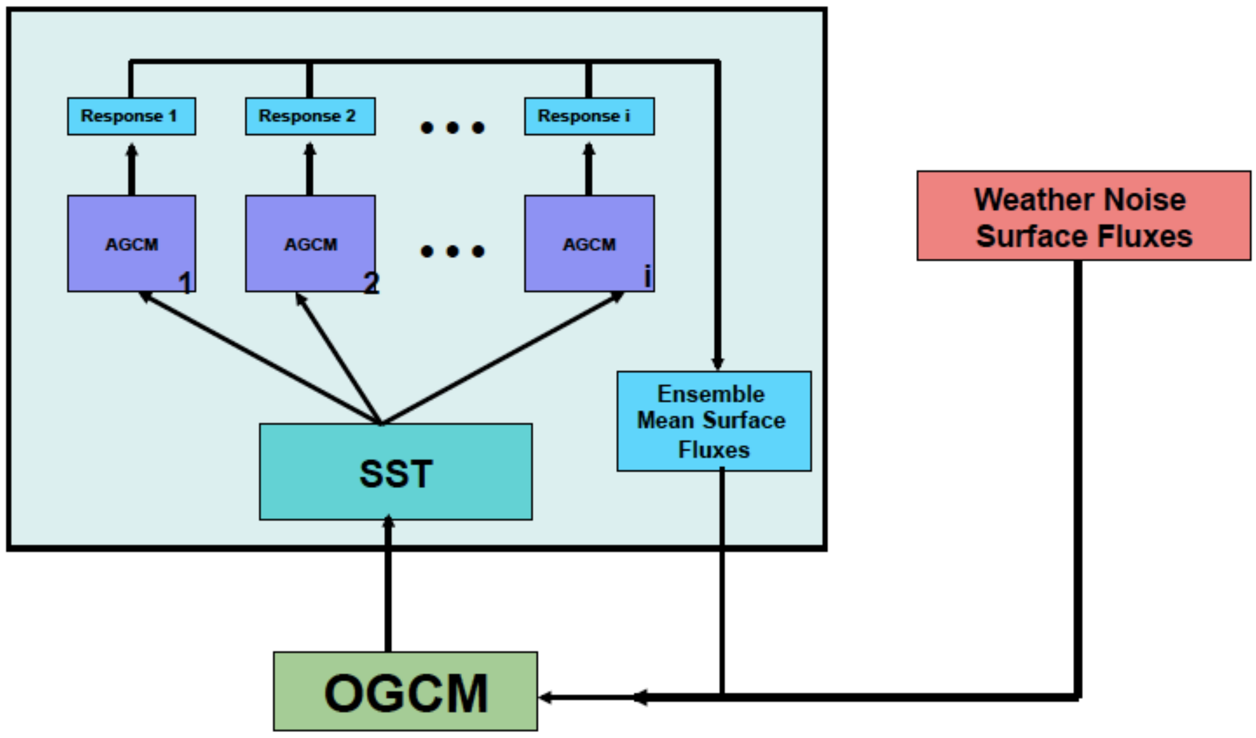
Noise Forced Interactive Ensemble

$$\frac{d\overline{T}_A}{dt} = -a\overline{T}_A + bT_O + \overline{N}$$

Noise surface flux

$$\beta\frac{dT_O}{dt} = c\overline{T}_A - dT_O + H(t)$$

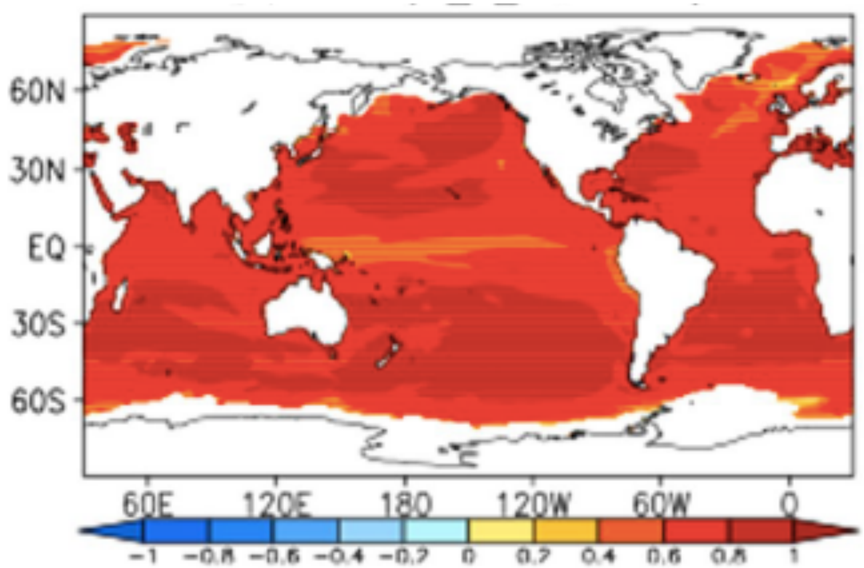
Mean surface flux



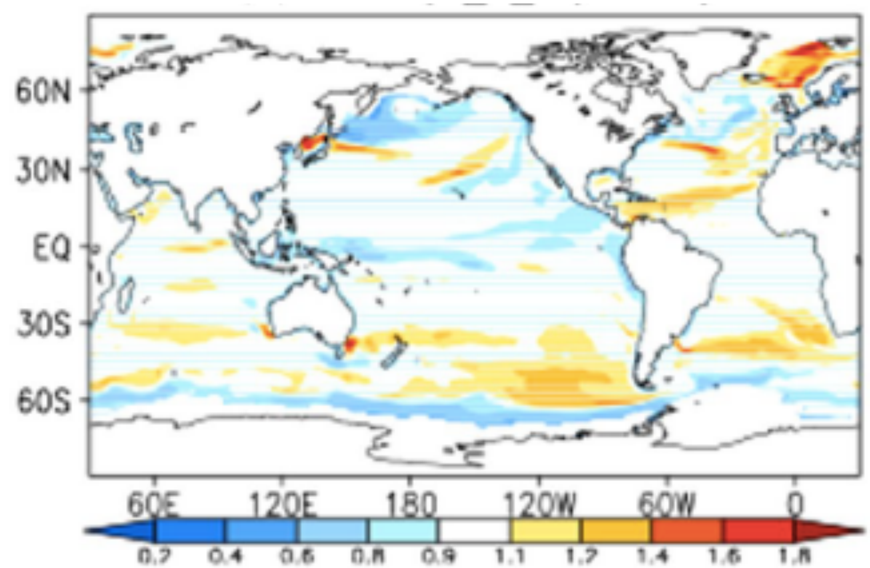
Comparison of 100-year Simulated SSTA

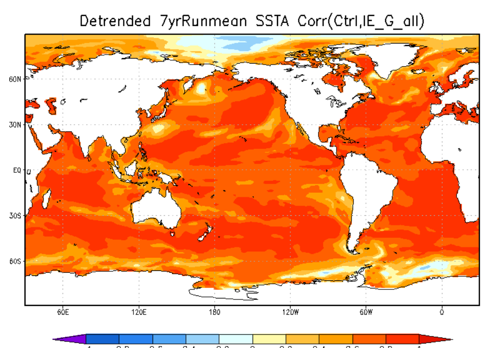
Between Noise Forced IE-CGCM and Control

Correlation monthly means



Standard Deviation Ratio





Correlation 7-year running means

- What are the roles of atmospheric noise components in forcing multidecadal AMV?
    - Heat flux
    - Wind stress
    - Fresh water flux

Decomposition of Simulated Multidecadal AMV by noise forcing process

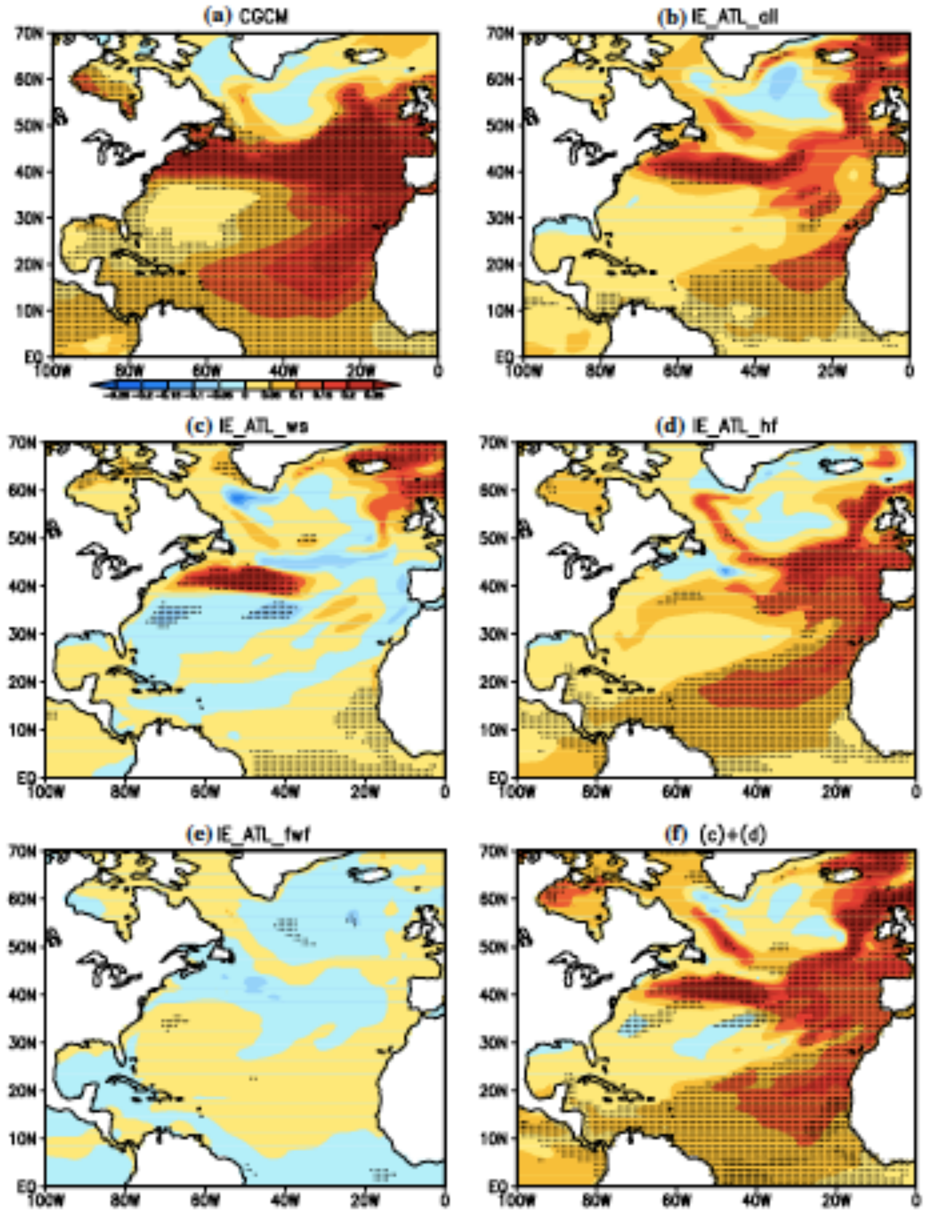
CGCM

IE (all noise)

Wind stress noise

Heat flux noise

Fresh water flux noise



Other/Possible Uses

- Force IE with noise from reanalyses
- Other possible IE configurations
  - Multimodel atmosphere
  - Simplified components (such as slab mixed layer ocean)
- Use IE for seasonal and longer lead climate prediction (can including unpredictable noise make things better)?

Some IE-Related References

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