The Interactive Ensemble Coupling Strategy for Quantifying ENSO Predictability

Ben Kirtman

University of Miami - RSMAS

Center for Ocean-Land-Atmosphere Studies (COLA)

Why Do We Use Ensembles?

- Quantify Uncertainty Due to Uncertainty in Initial Condition
  – Perturbed Initial States
- Quantify Uncertainty Due to Uncertainty in Model Formulation
  – Perturbed Model Formulation (Multi-Model)

- Understanding How Weather and Climate Interact
  – Why Climate Modelers Should Worry About the Weather

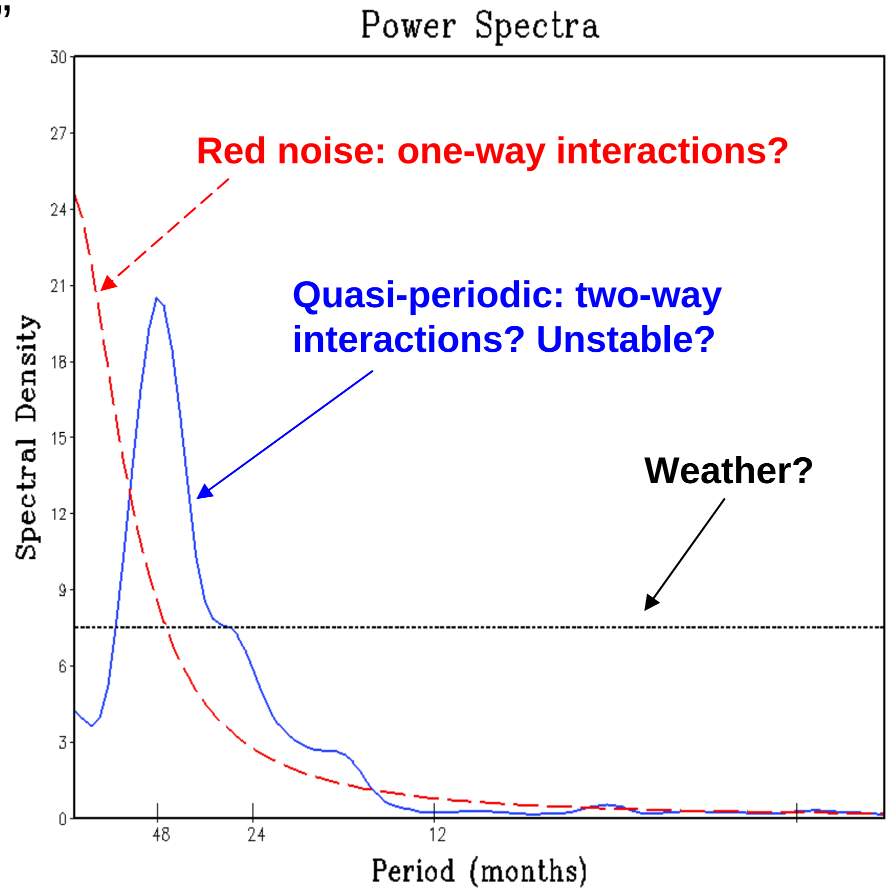
What if Your Coupled Model Has Incorrect Weather Statistics?

- ENSO Prediction Problem
- Western Pacific Problem

- Introduce the Interactive Ensemble Coupling Strategy

Weather - Climate Interactions

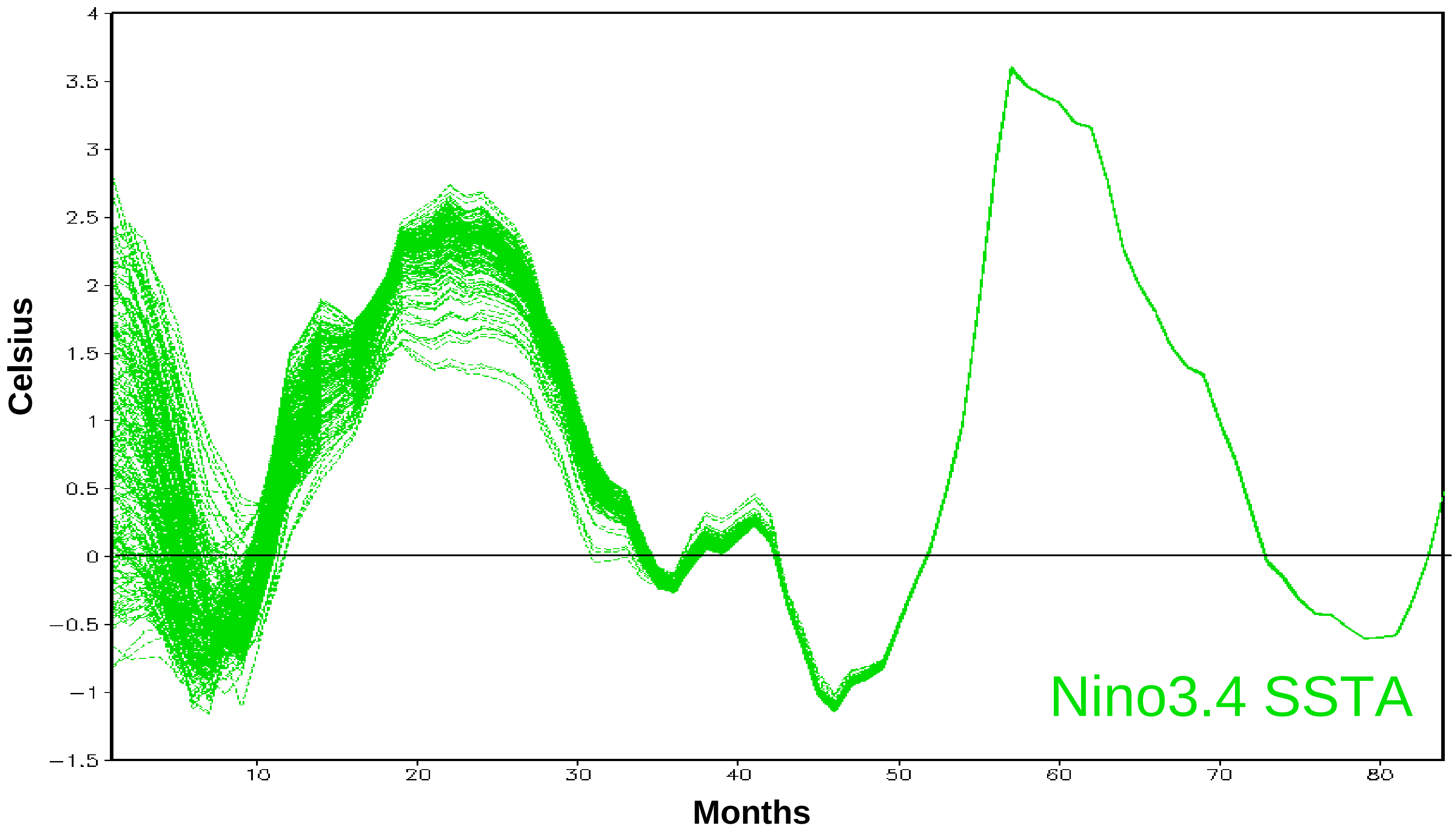
- One-way air-sea interactions (stochastic atmosphere, aka weather noise, forces ocean)
  - Ocean = thermodynamic “red filter” -- Hasselmann (1976)
  - Ocean-dynamics: preferred low frequency time scale(s)



- One-way air-sea interactions (stochastic ocean forces atmos.)
  - Tropical instability waves
  - Kuroshio current extension

- Two-way air-sea interactions
  - (Stable) coupled feedbacks + weather noise (MJO, WWB)
  - **(Stable) coupled feedbacks + weather noise + dynamics**
  - **Unstable coupled feedbacks + weather noise + dynamics**

Weather Noise as a Pacemaker for Climate: ENSO Example

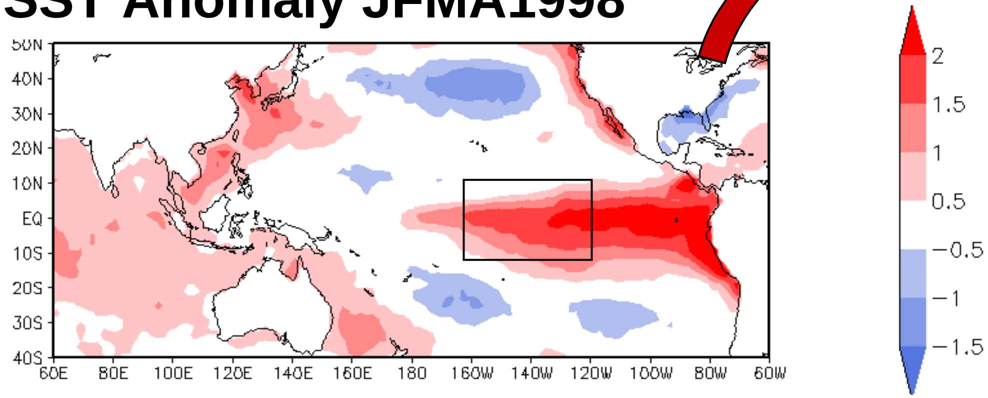


1. Simplified “noiseless” coupled model (a la Z-C)
2. Random initial states
3. Identical prescribed idealized weather noise

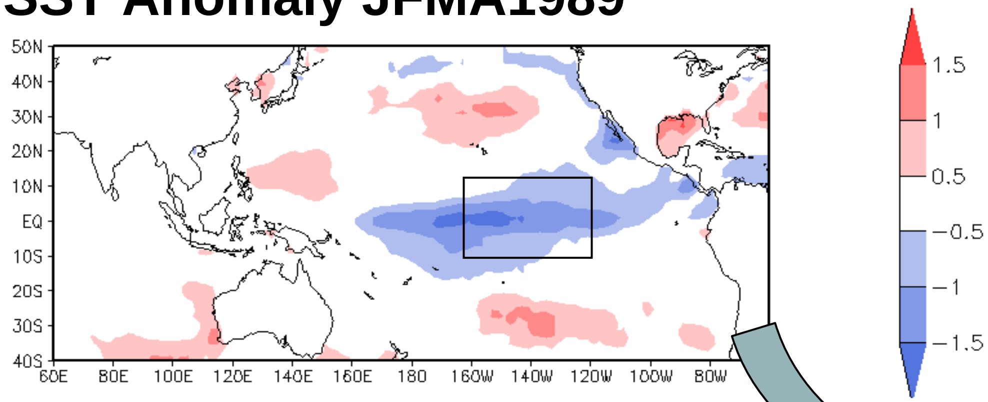
How Should Weather Noise be Defined?

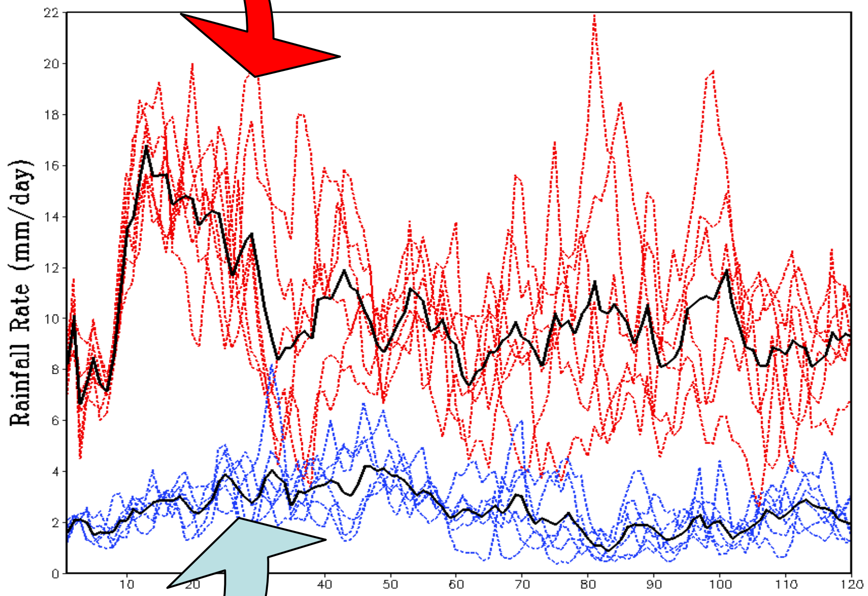
- Use ensemble realizations
  - Ensemble mean defines “climate signal”
  - Deviation about ensemble mean defines weather noise
  - Climate signal & weather noise are not necessarily independent
  - Examples:
    - <u>Atmospheric model simulations with prescribed SST</u>
    - Climate change simulations

SST Anomaly JFMA1998



SST Anomaly JFMA1989





Tropical Pacific Rainfall (in box)

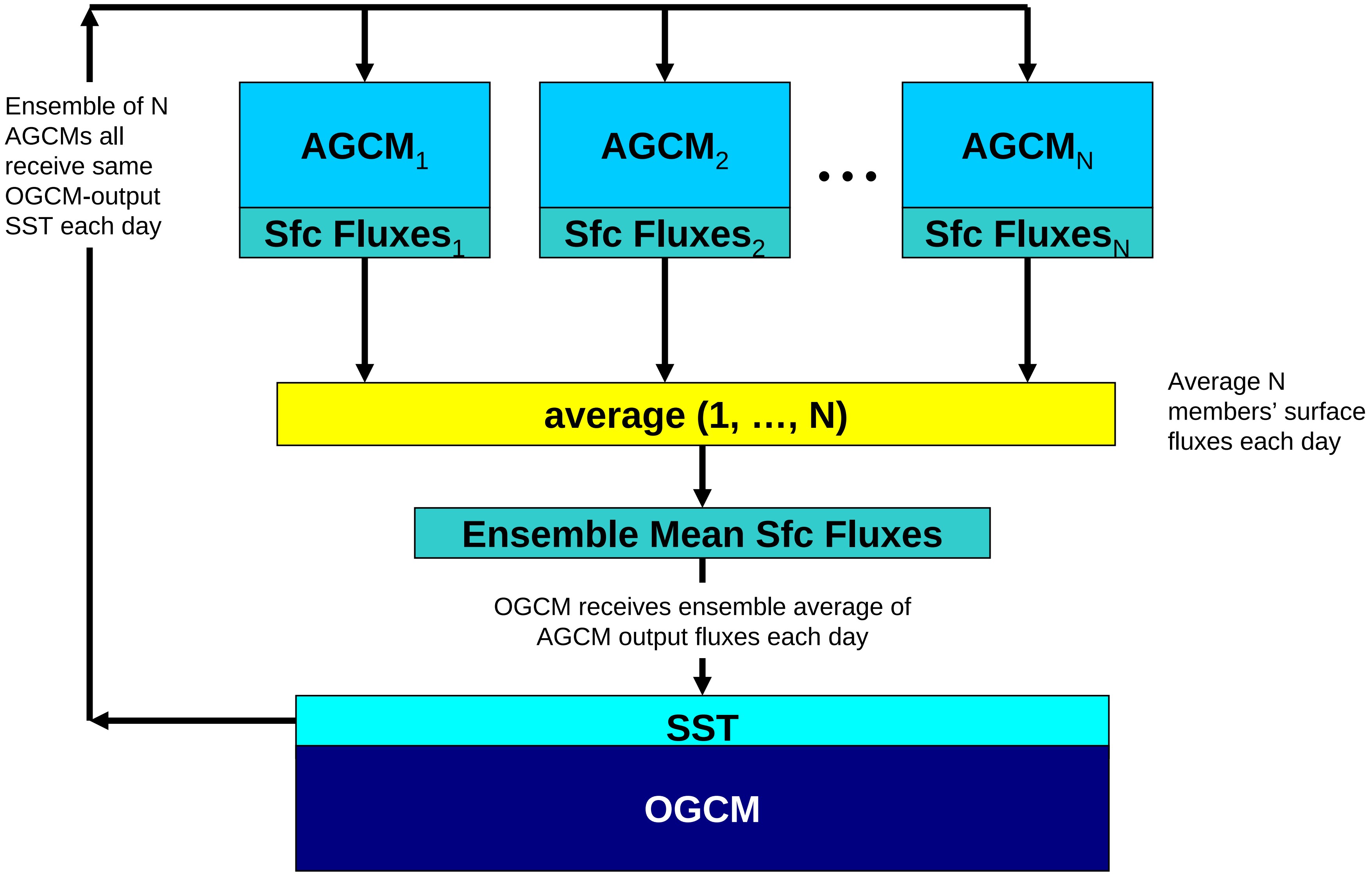
Different SST →

Different tropical atmospheric mean response
Different characteristics of atmos. noise

Modeling Weather & Climate Interactions

- Previously, this required ad-hoc assumptions about the weather noise and simplified theoretically motivated models
- We adopt a coupled GCM approach
  - Weather is internally generated
    - Signal-noise dependence
  - State-of-the-art physical and dynamical processes

$\Rightarrow$ Interactive Ensemble



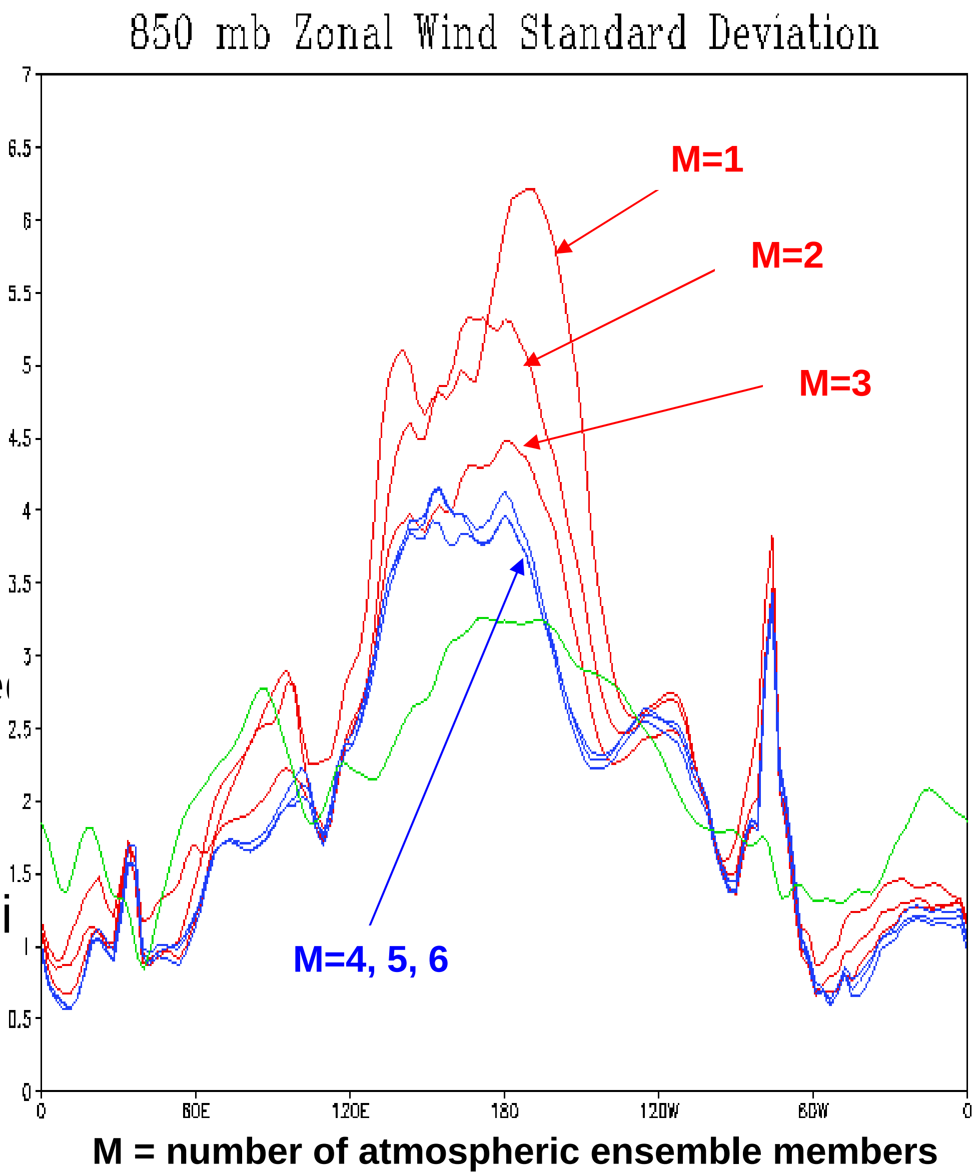
Interactive Ensemble Approach

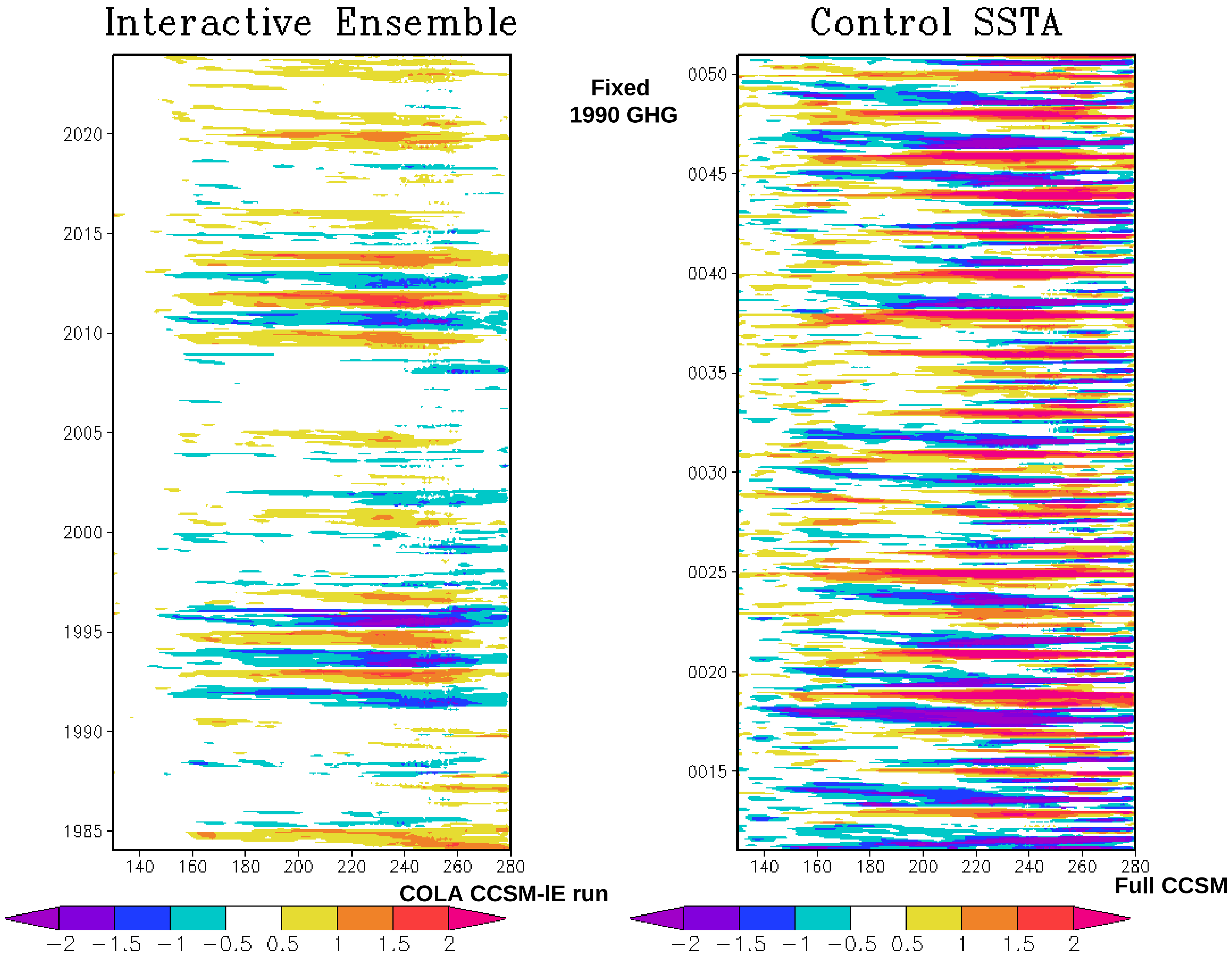
Interactive Ensemble

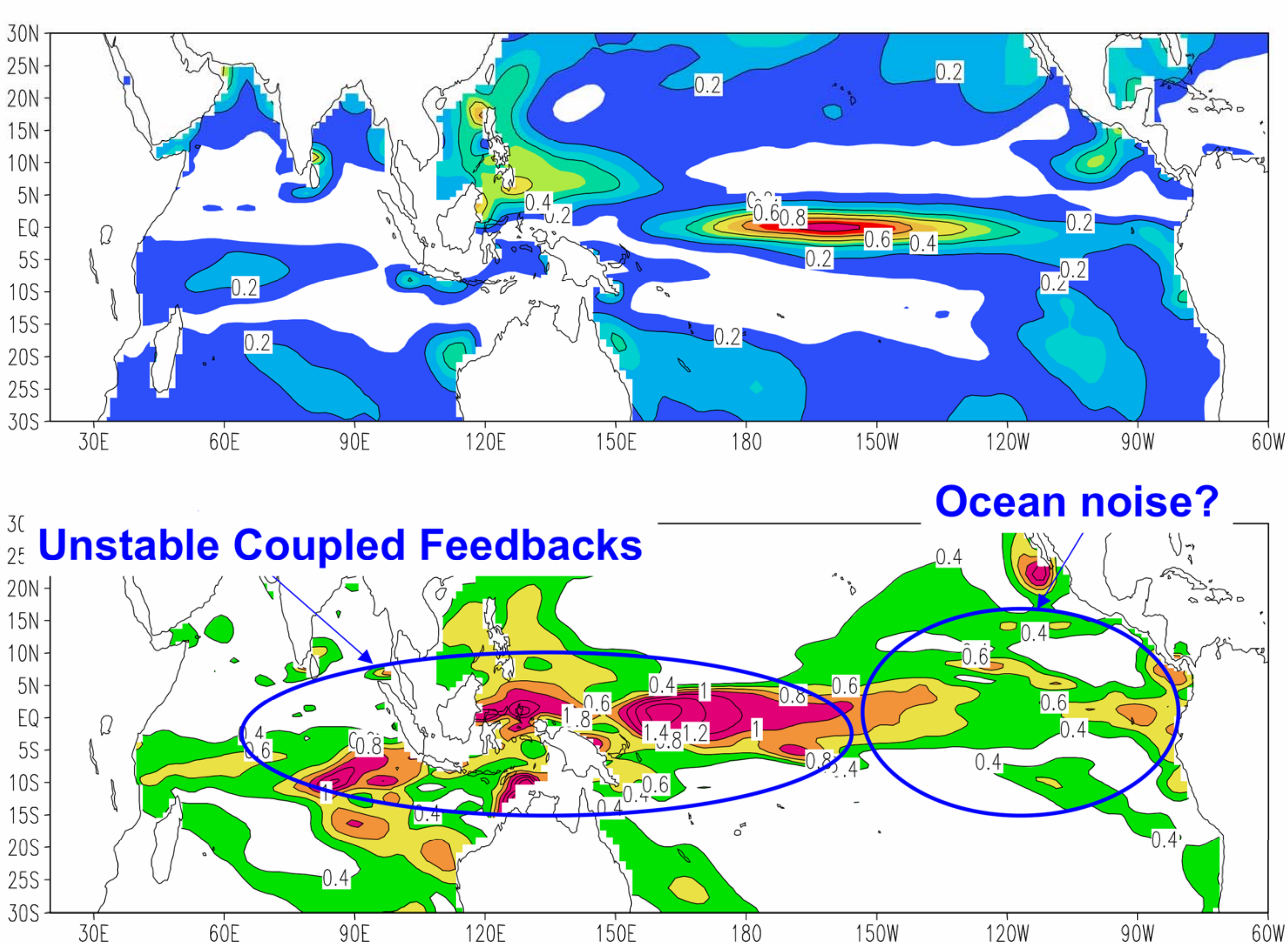
- Ensemble realizations of atmospheric component to isolate "climate signal"

  Ensemble mean = Signal + ε

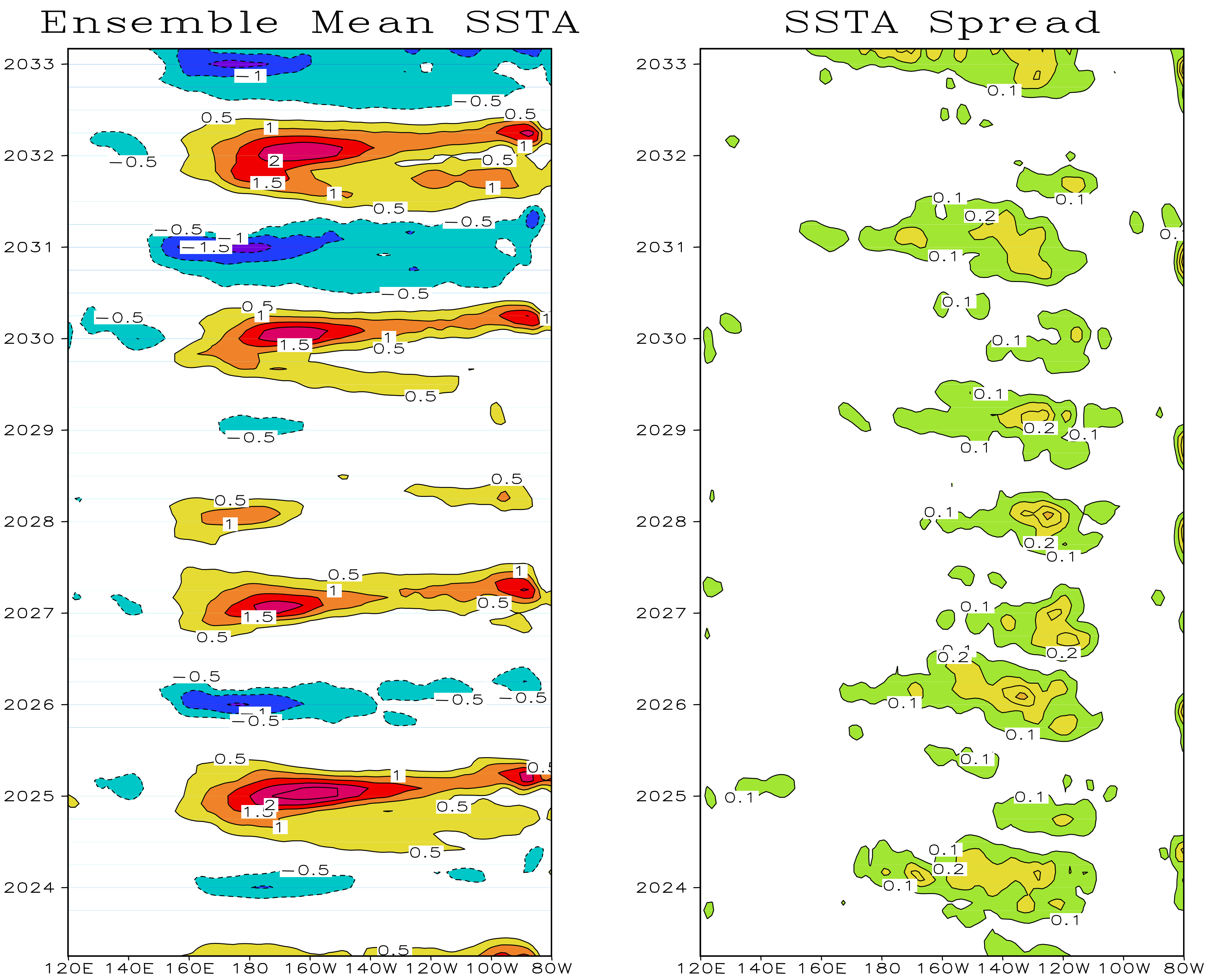
- Ensemble mean surface fluxes coupled to ocean component
  - Ensemble average only applie at air-sea interface
  - Ocean "feels" an atmospheric state with reduced weather noi

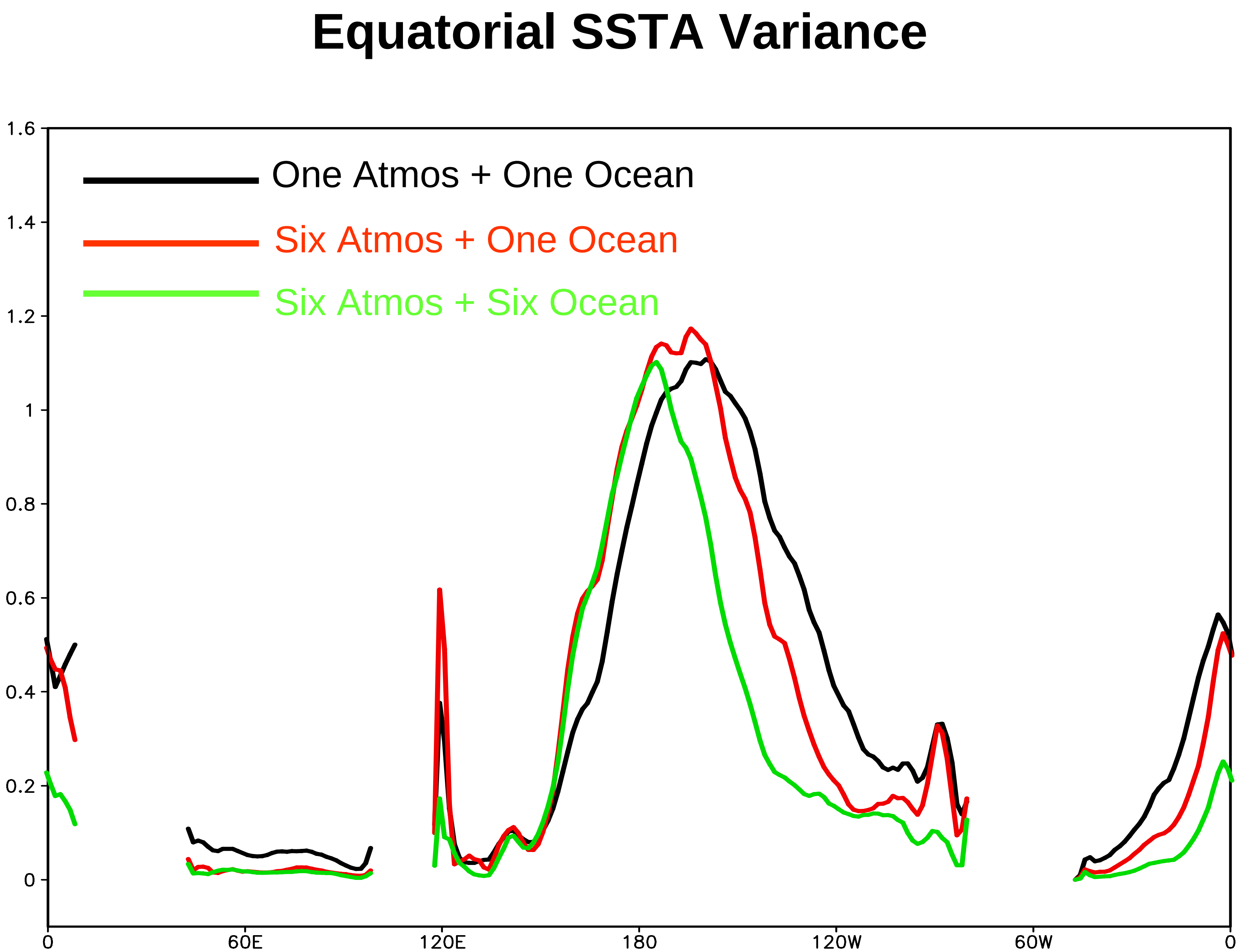



Interactive Ensemble
Control SSTA
Fixed
1990 GHG
2020
2015
2010
2005
2000
1995
1990
1985
0050
0045
0040
0035
0030
0025
0020
0015
140 160 180 200 220 240 260 280
140 160 180 200 220 240 260 280
COLA CCSM-IE run
Full CCSM
−2 −1.5 −1 −0.5 0.5 1 1.5 2
−2 −1.5 −1 −0.5 0.5 1 1.5 2



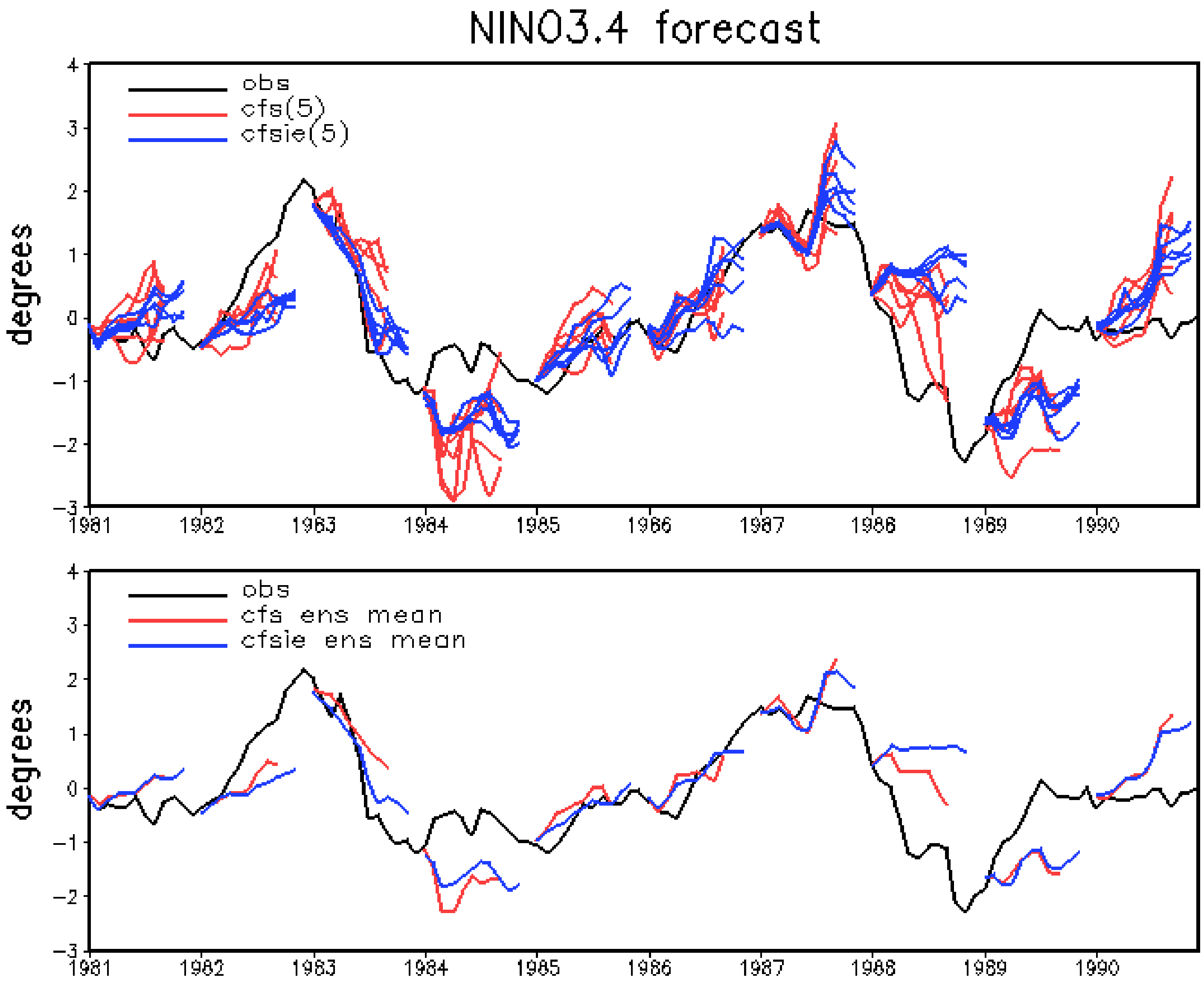
Ocean noise?
Unstable Coupled Feedbacks
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
25S
30S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
0.2
0.4
0.6
0.8
1
1.2
1.4
1.8


Ensemble Mean SSTA
SSTA Spread
2033
2032
2031
2030
2029
2028
2027
2026
2025
2024
120E 140E 160E 180 160W 140W 120W 100W 80W

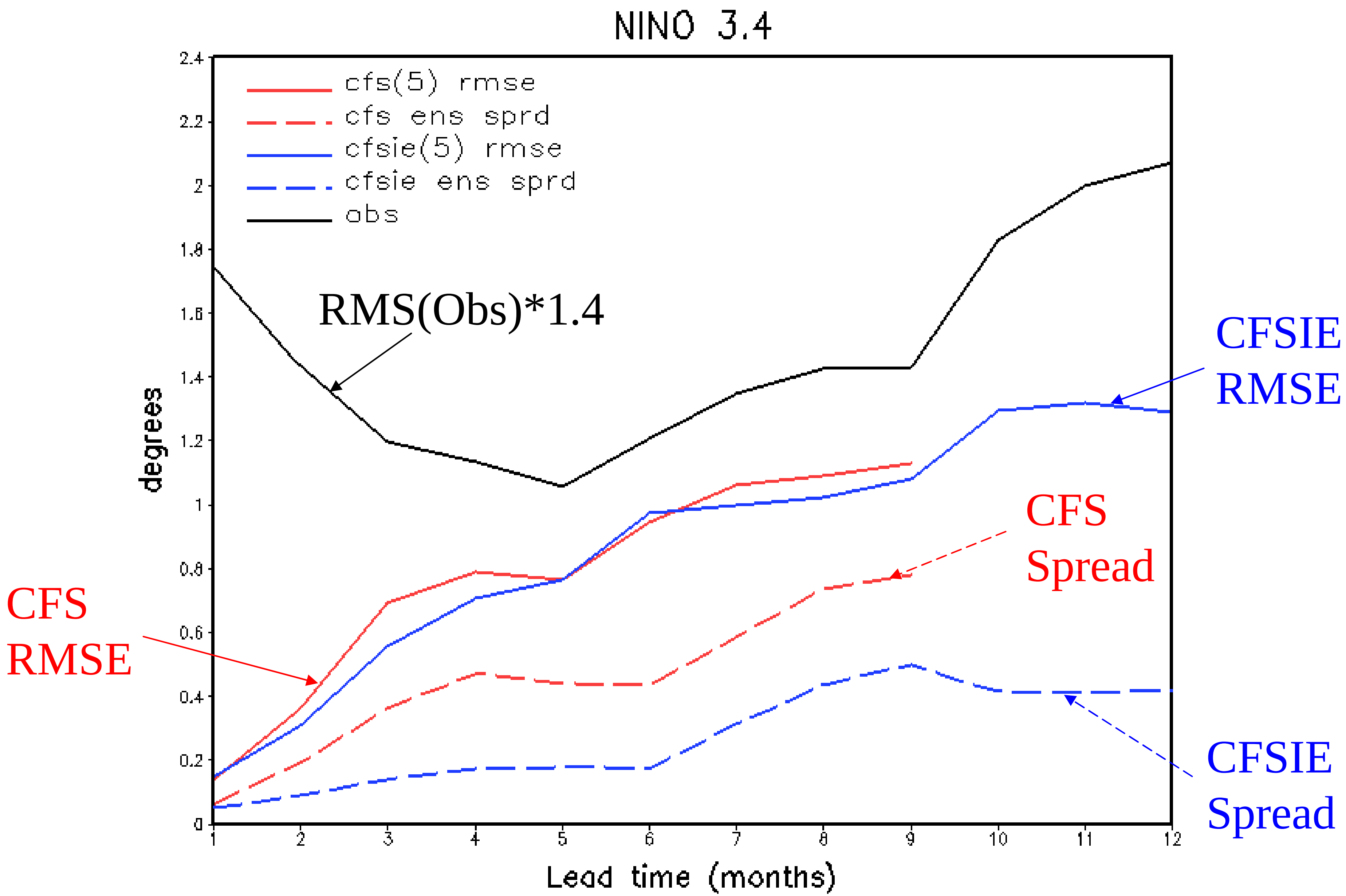

Equatorial SSTA Variance
One Atmos + One Ocean
Six Atmos + One Ocean
Six Atmos + Six Ocean
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
60E
120E
180
120W
60W
0

Understanding Forecast Skill

- What is the Overall Limit of Predictability?
- What Limits Predictability?
  - Uncertainty in Initial Conditions: Chaos within Non-Linear Dynamics of the Coupled System
  - Uncertainty as the System Evolves: External Stochastic Effects
- Model Dependence?
  - Model Error



CFSIE - Reduce Noise Version (interactive ensemble) of CFS



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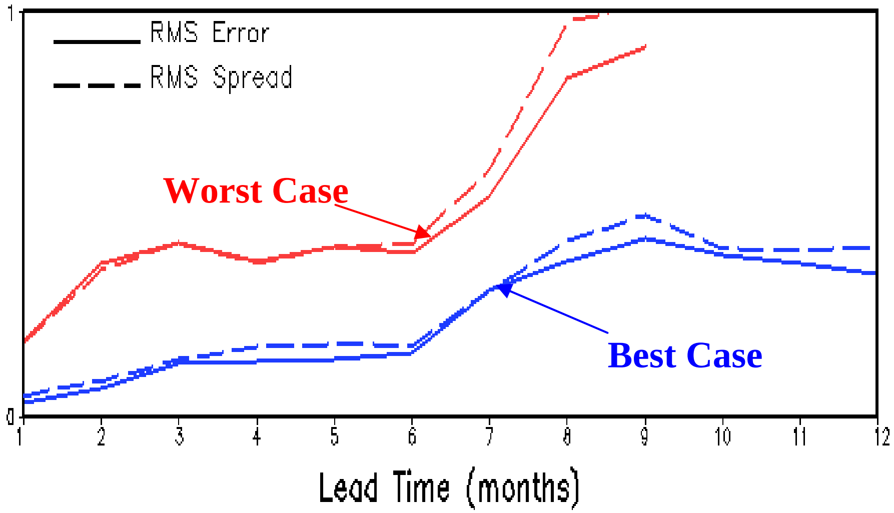
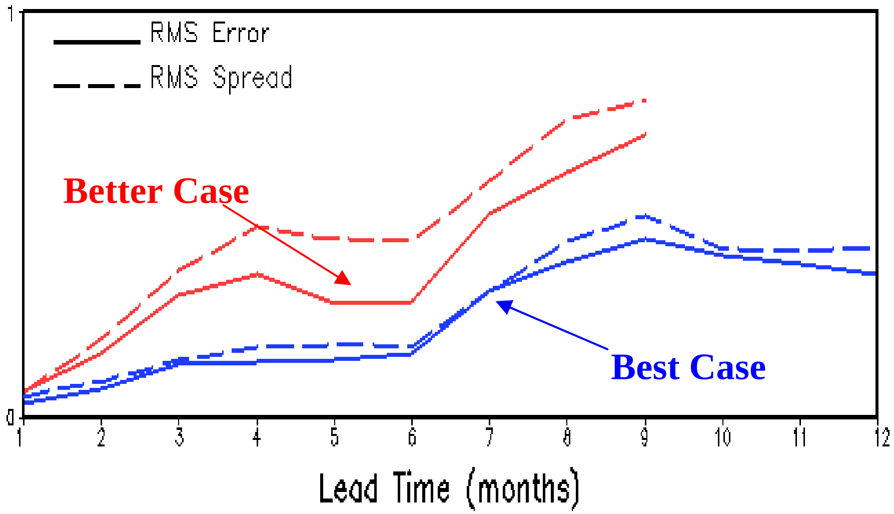


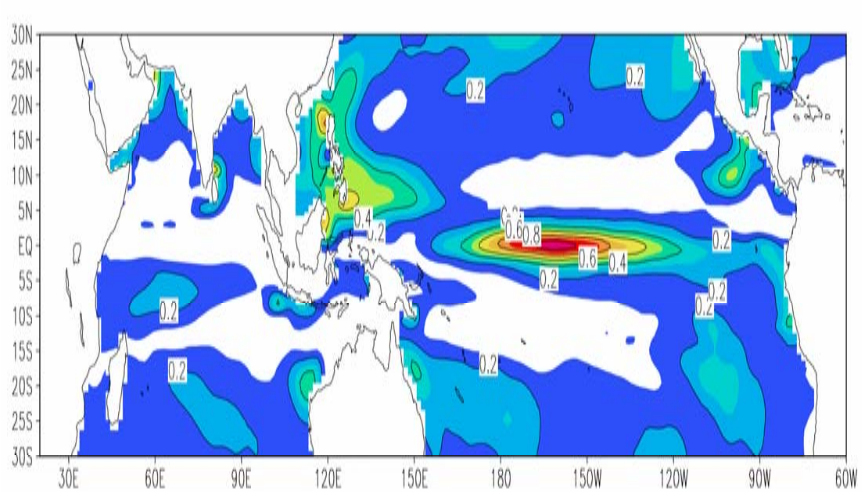
Worst Case: Initial Condition Error (A+O) + Model Error (WX)

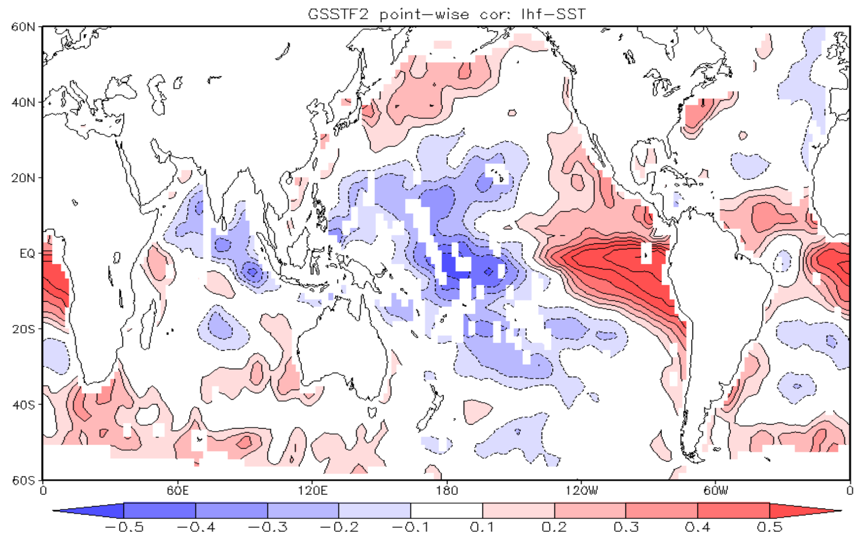
Best Case: Initial Condition Error (A) + No Model Error (WX)

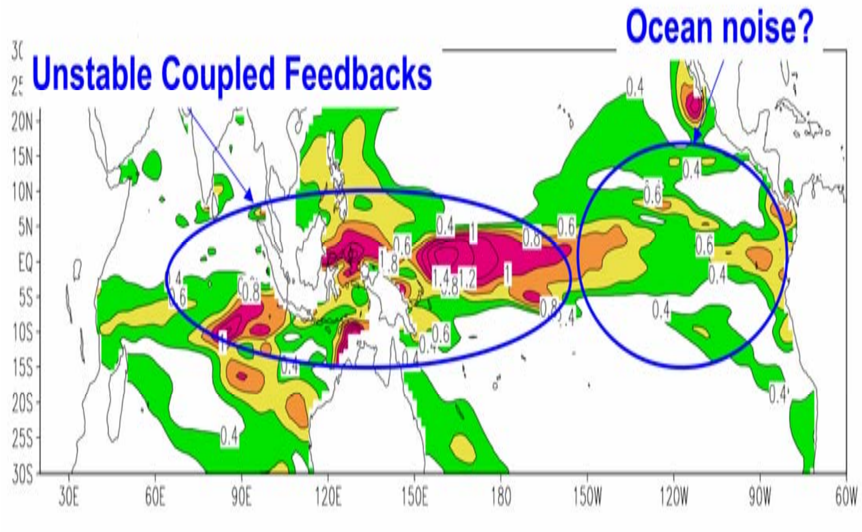


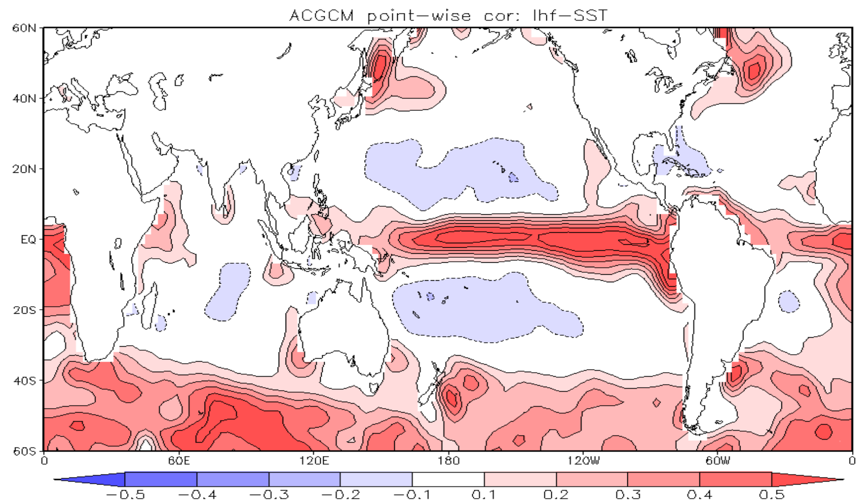
Better Case: Initial Condition Error (A) + Model Error (WX)

1. Eastern Pacific - Ocean Weather Noise - Tropical Instability Waves?
2. Enhanced Variance in Western Pacific - Not Enough Weather?









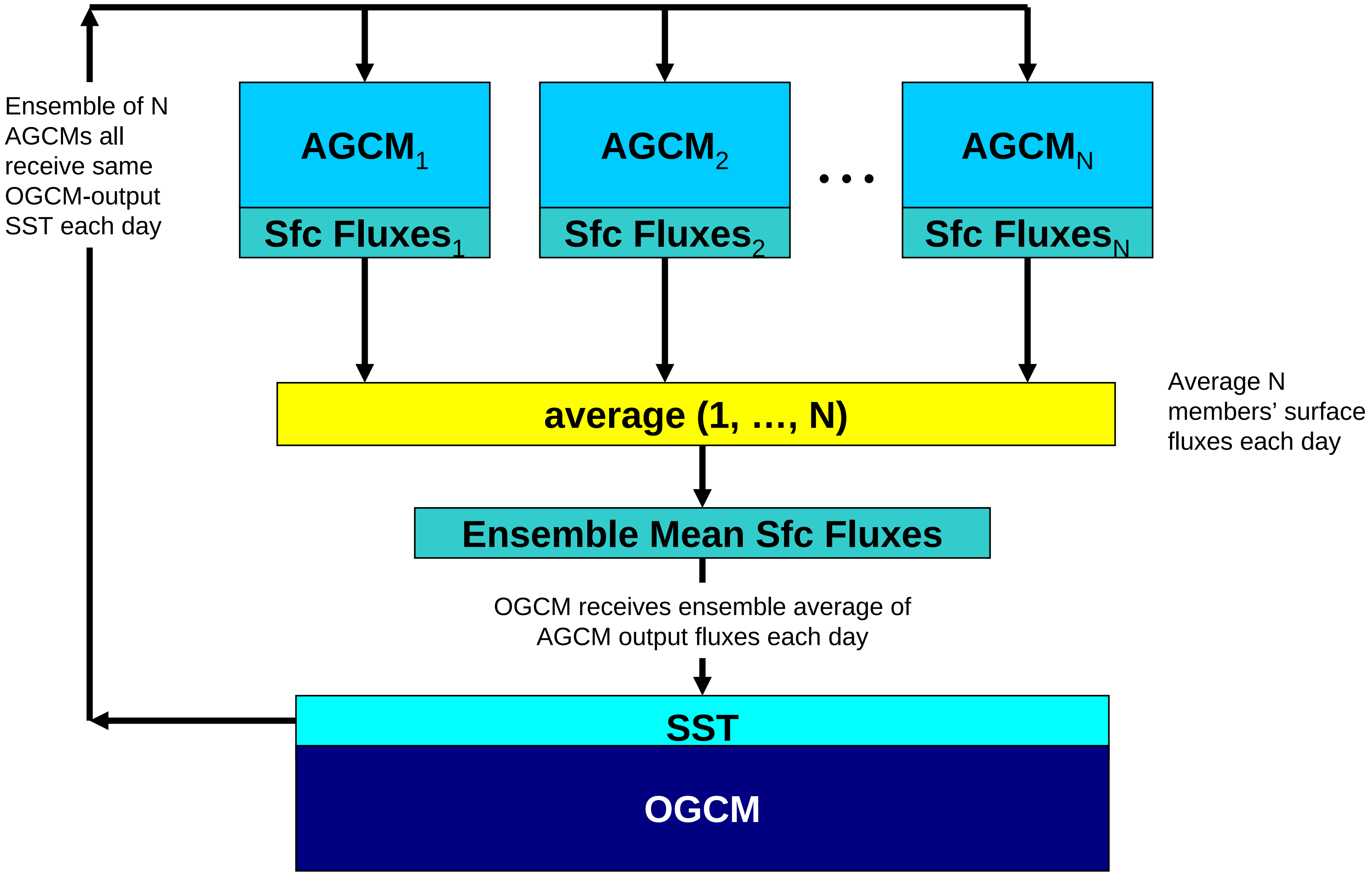
Western Pacific Problem

- **Hypothesis:** Atmospheric Internal Dynamics (Stochastic Forcing) is Occurring on Space and Time Scales that are Too Coherent

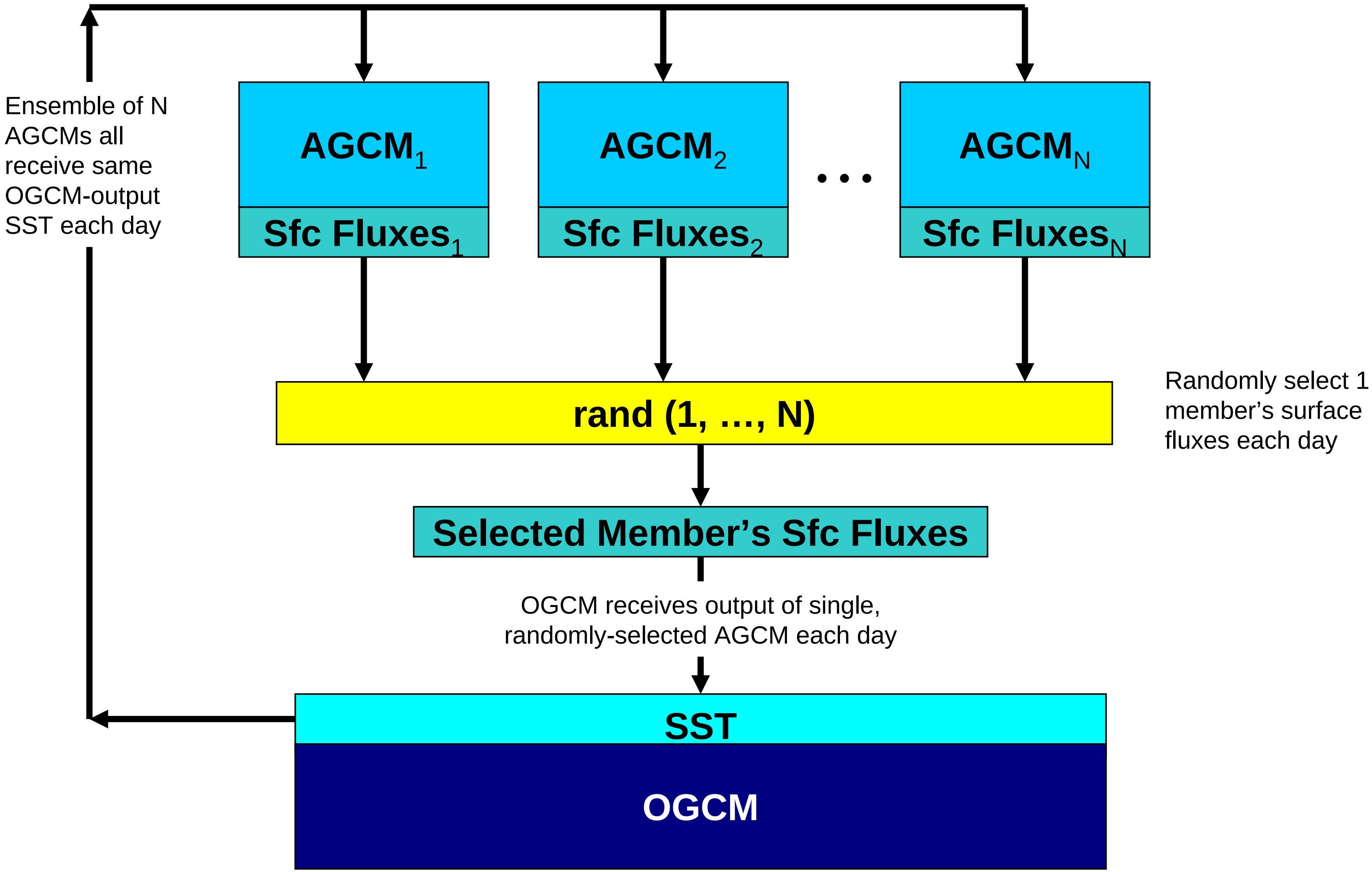
$\Rightarrow$ Too Coherent Oceanic Response

$\Rightarrow$ Excessive Ocean Forcing Atmosphere

$\Rightarrow$ **Test:** **Random Interactive Ensemble**

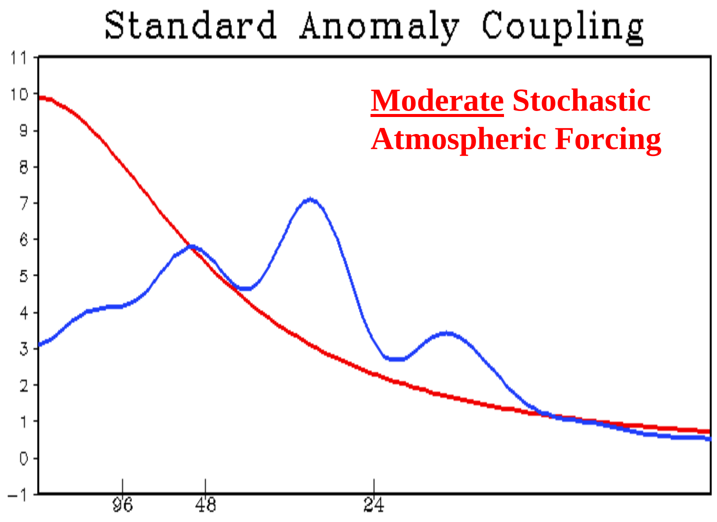


Interactive Ensemble Approach

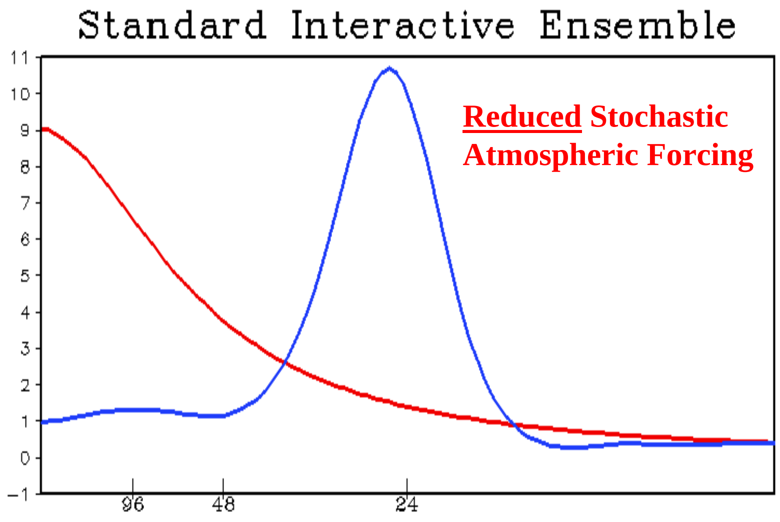


Random Interactive Ensemble Approach

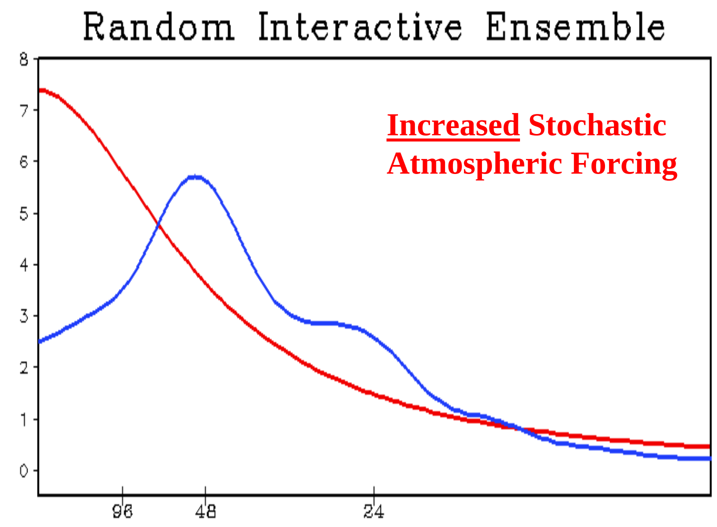
Nino3.4 Power Spectra



Period (months)

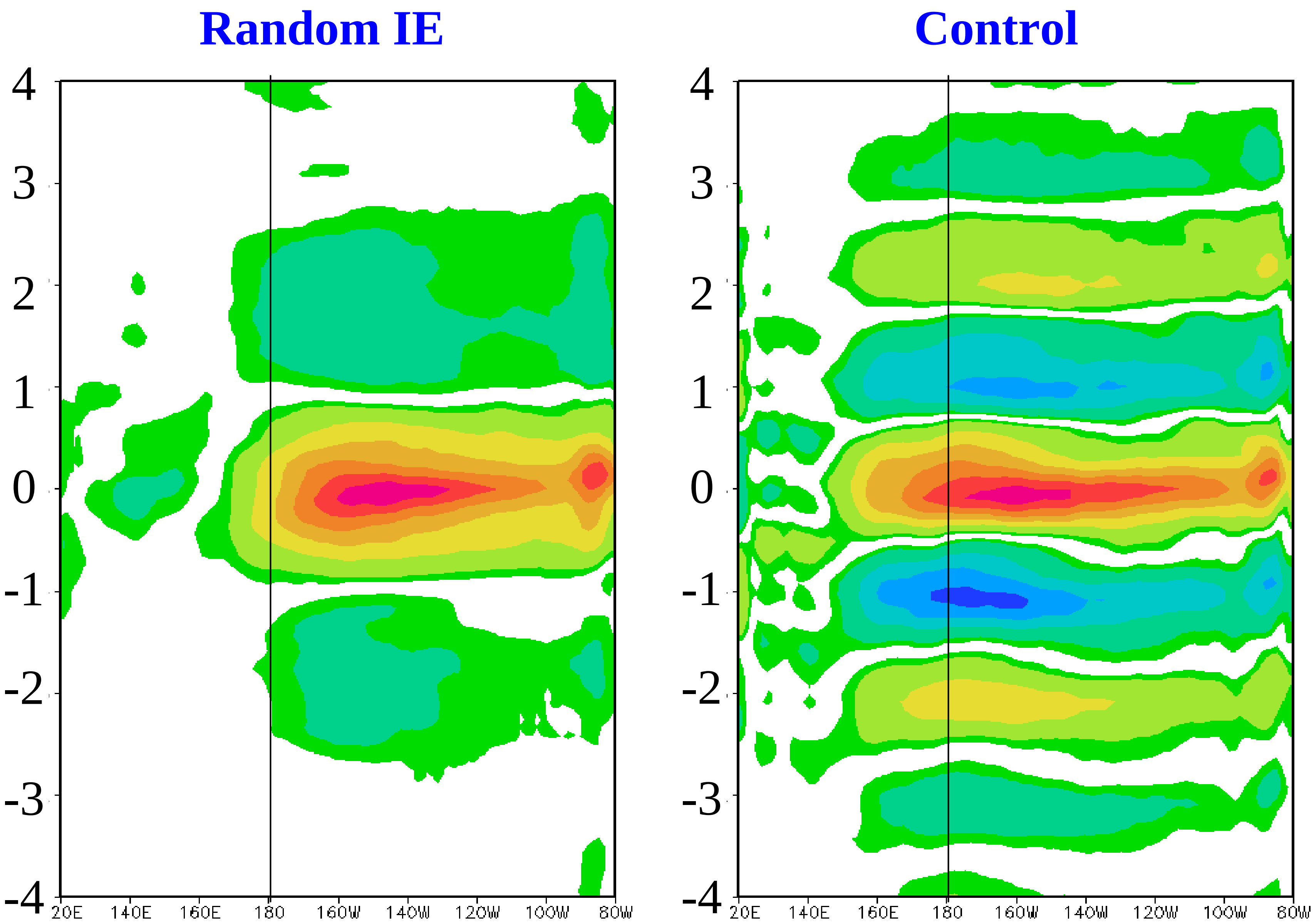


Period (months)



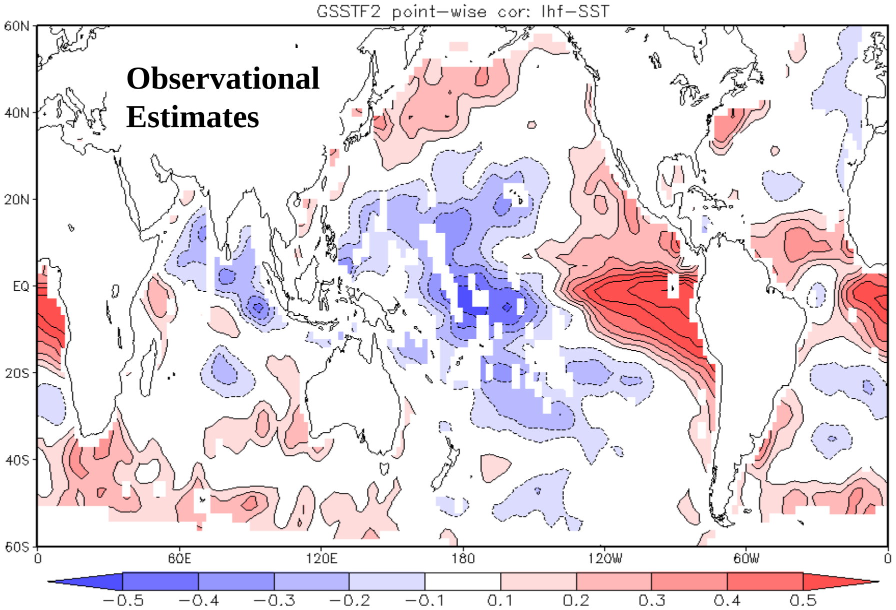
Period (months)

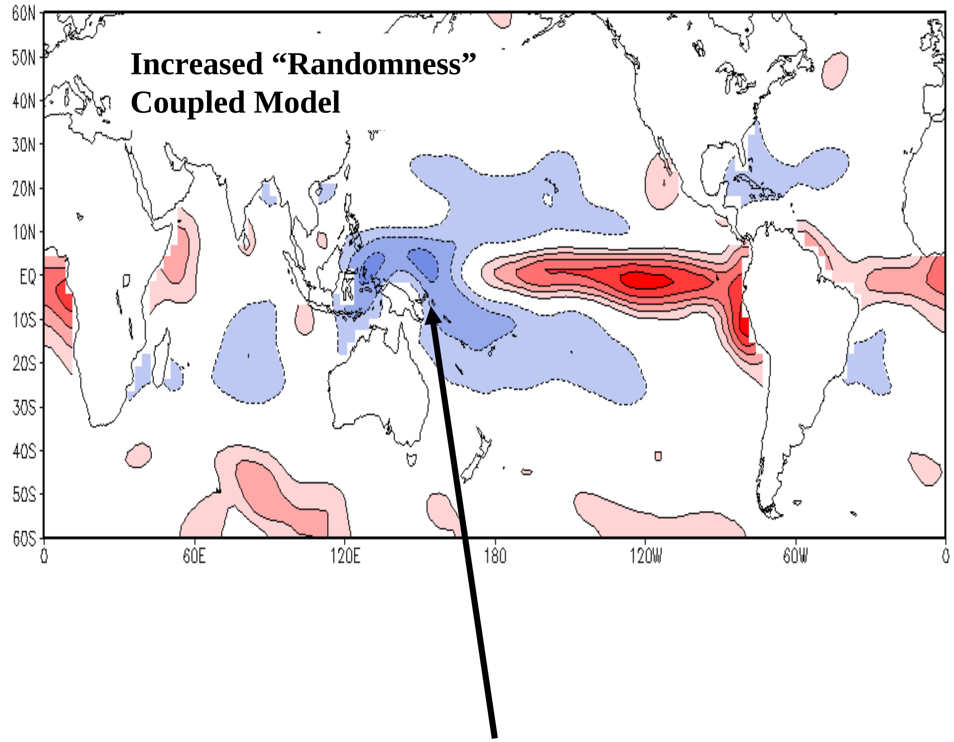
Increasing Stochastic Atmospheric Forcing Increase the ENSO Period

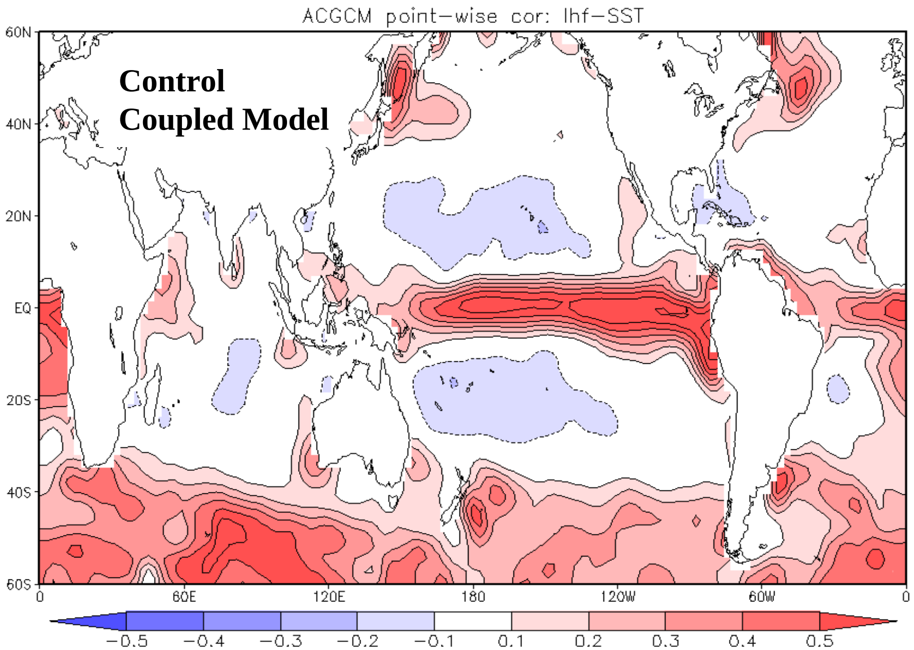


Nino34 Regression on Equatorial Pacific SSTA

Contemporaneous Latent Heat Flux - SST Correlation







Random Interactive Ensemble:
Increased the Whiteness of the
Atmosphere forcing the Ocean

Random (Stochastic) Thoughts

- Interactive Ensemble Strategy for Quantifying Role of Stochastic Processes in Climate Variability
- Initial Condition Uncertainty is “Largest” Contributor to Loss of Predictability
  - Stochastic Processes also Important
- **To Get the Climate Right Must Get the Weather (Statistics) Right**
  - **Seamless Prediction**