Detection and Attribution of Climate Change Using the CCSM Interactive Ensemble

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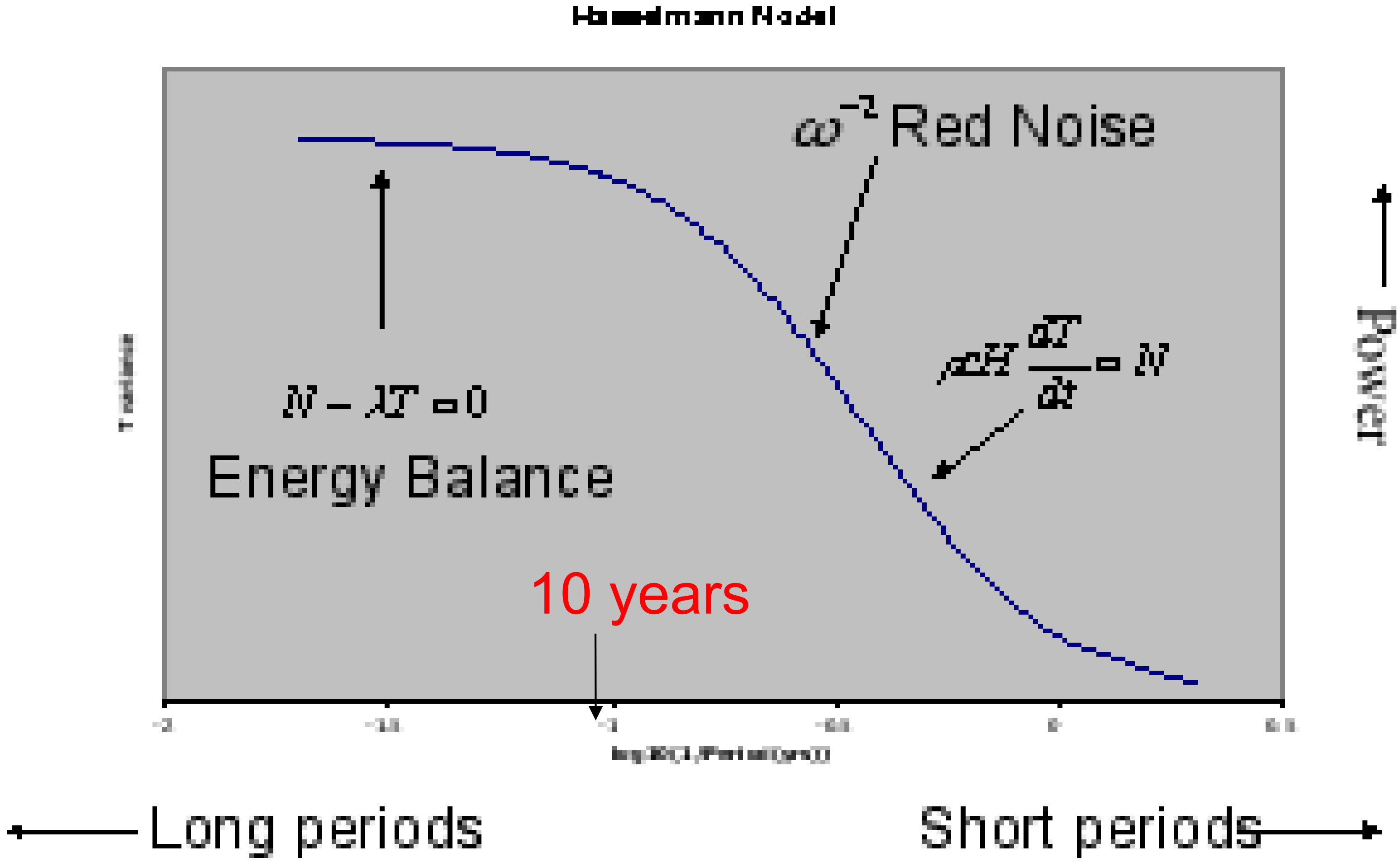
Objective

- Distinguish causes of observed climate variability (e.g. for surface temperature)
  - External forcing
  - Internal ("natural") variability
    - Atmospheric internal variability (weather noise; Hasselmann mechanism)
    - Ocean internal variability (oceanic weather noise)
    - Unstable coupled atmosphere-ocean variability

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



Motivation

- Force a “CGCM” with reanalysis surface fluxes (minus the feedbacks from the observed evolution of the surface boundary conditions, e.g. SST).
- The observed evolution of the surface (e.g. SST) will be recovered if
  - The primary forcing is atmospheric weather noise
  - Model errors are small
  - The reanalysis surface fluxes are accurate.
- Roles of different mechanisms in the various observed climate modes or events can then be diagnosed.

First Try

- Used COLA CGCM
  - Not a climate model (no polar ocean, sea ice, external forcing), large systematic biases
- Forced with NCEP reanalysis
  - Serious (fatal) flaws in surface fluxes become obvious in tropics (1976 jump)
- Results
  - North Atlantic tripole and monopole SST modes 1950-99, were forced by weather noise surface heat fluxes

Current Effort

- CCSM3: climate model, includes global ocean, sea ice, external forcing
- ERA-40 reanalysis surface fluxes: apparently substantially better than NCEP, include GHG evolution
- In progress

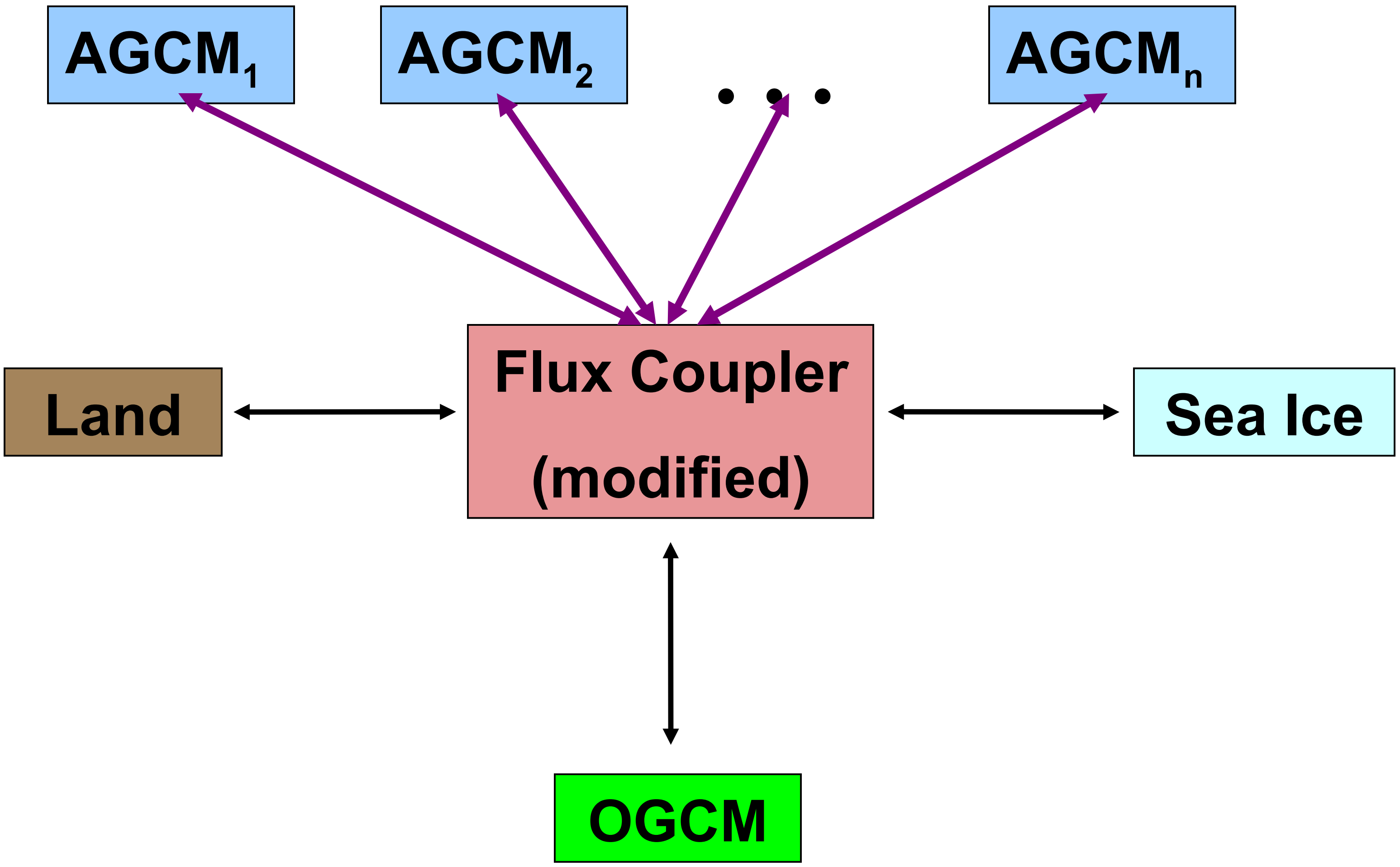
Our Approach

Simulate and diagnose externally forced and natural climate variability with a new tool, the Interactive Ensemble (IE) CGCM version of CCSM3

- Surface fluxes from ensemble mean of AGCMs (different ic's) forces the other components: OGCM, LSM, SIM*.
- Each AGCM sees the same surface conditions (e.g. SST).
- **Filters out the stochastic part of the weather noise surface fluxes.**
- Can be thought of as turning CCSM3 into an intermediate coupled model with parameterized atmospheric eddy fluxes (which are functions of the external and boundary forcing evolution).

* current implementation for OGCM only

Interactive Ensemble CCSM3



Project Outline

1) **Model world**
   - Develop and test tools (perfect data and perfect model)
   - Determine CCSM3 internal variability in the absence of weather noise forcing
   - Examine IE response to external forcing and compare to CCSM3 20C3M ensemble mean
   - Diagnose weather noise surface fluxes in one of the CCSM3 20C3m ensemble members
   - Force IE-CCSM3 with diagnosed weather noise to attribute causes event by event
2) **Apply to real world** detection and attribution

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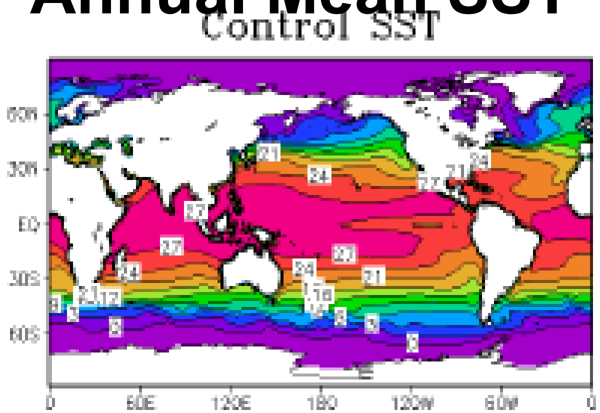
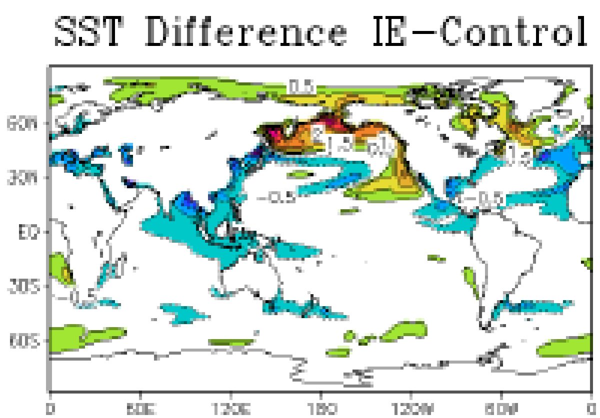
IE-CCSM3

- 6 copies of T85 CAM3 coupled to other components through flux coupler
- OGCM receives mean surface fluxes from the AGCM ensemble
- Due to technical issues that are being resolved, land and sea ice are forced by mean state of the AGCM ensemble, not mean fluxes.

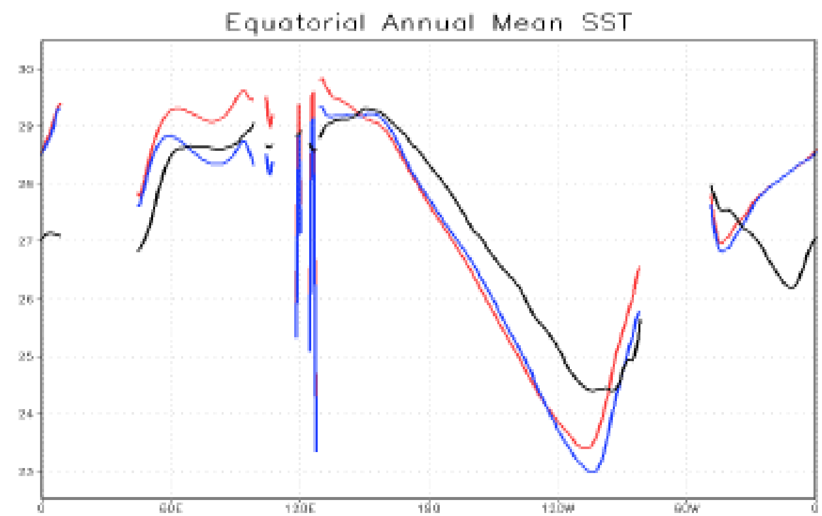
1990 IE-CCSM3 Control Simulation

Annual Mean SST





Equator



Black: obs
Control: red
IE: blue

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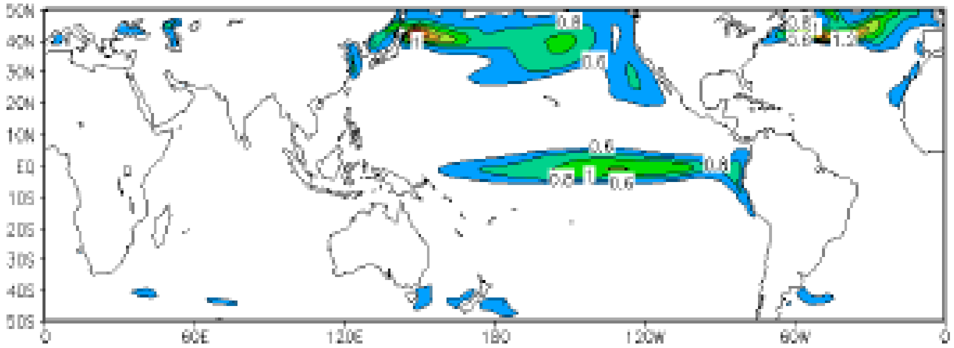
Variability IE-CCSM3 1990 Control

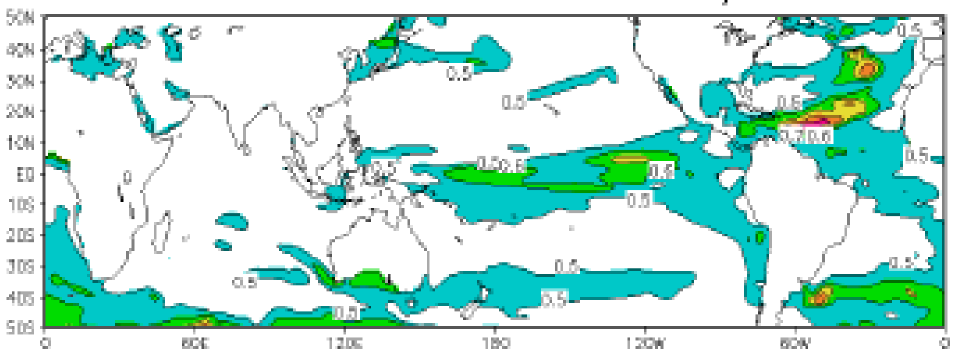
If all SST
variability forced
by random atmospheric
weather noise,
the ratio IE/CGCM
will be $(1/6)^{1/2}$=.41

Shaded area has ratio
>0.5, larger than can
Be explained by local
weather noise forcing.

Control SST Standard Deviation



SST Standard Deviation Ratio IE/Control



Sources of CCSM3 Internal Variability (preliminary)

- **ENSO**: coupled instability + atmospheric weather noise
- **MOC**: atmospheric weather noise (Ping Chang's analysis of IE-CCSM3 shows much reduced MOC variability)
- **North Atlantic and North Pacific SST modes:** ENSO remote effects, atmospheric and oceanic weather noise
- **Southern ocean SST**: atmospheric and oceanic weather noise

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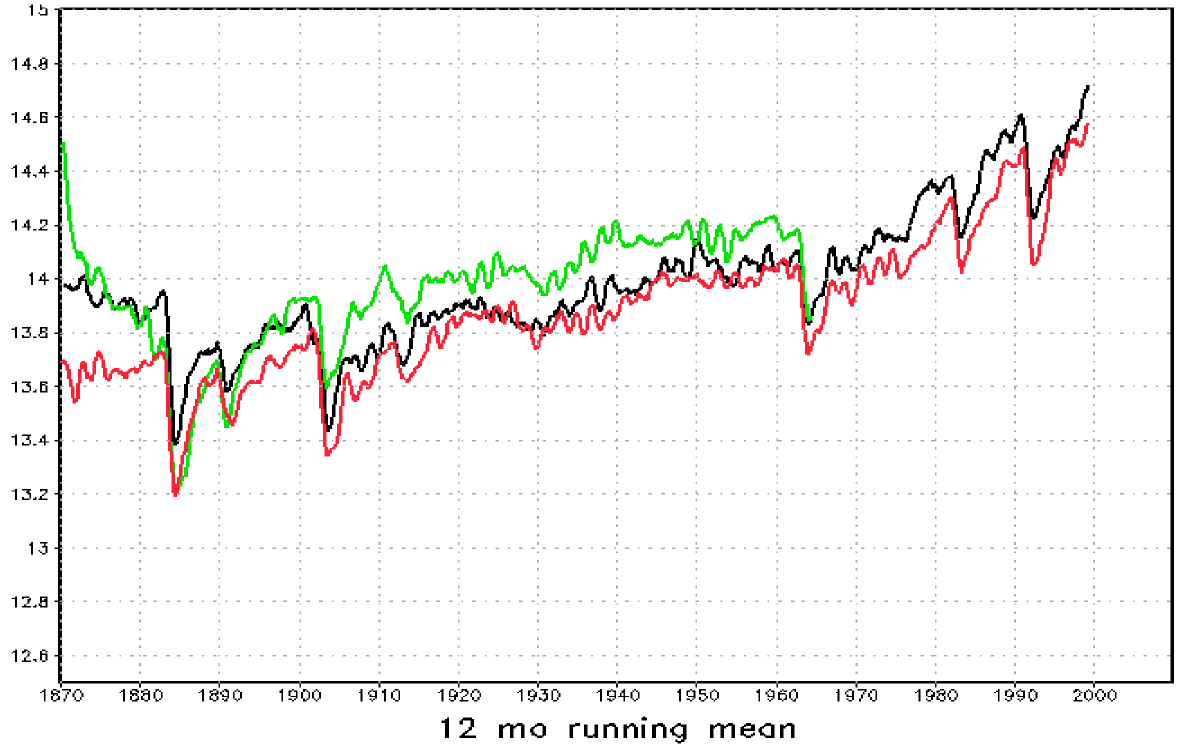
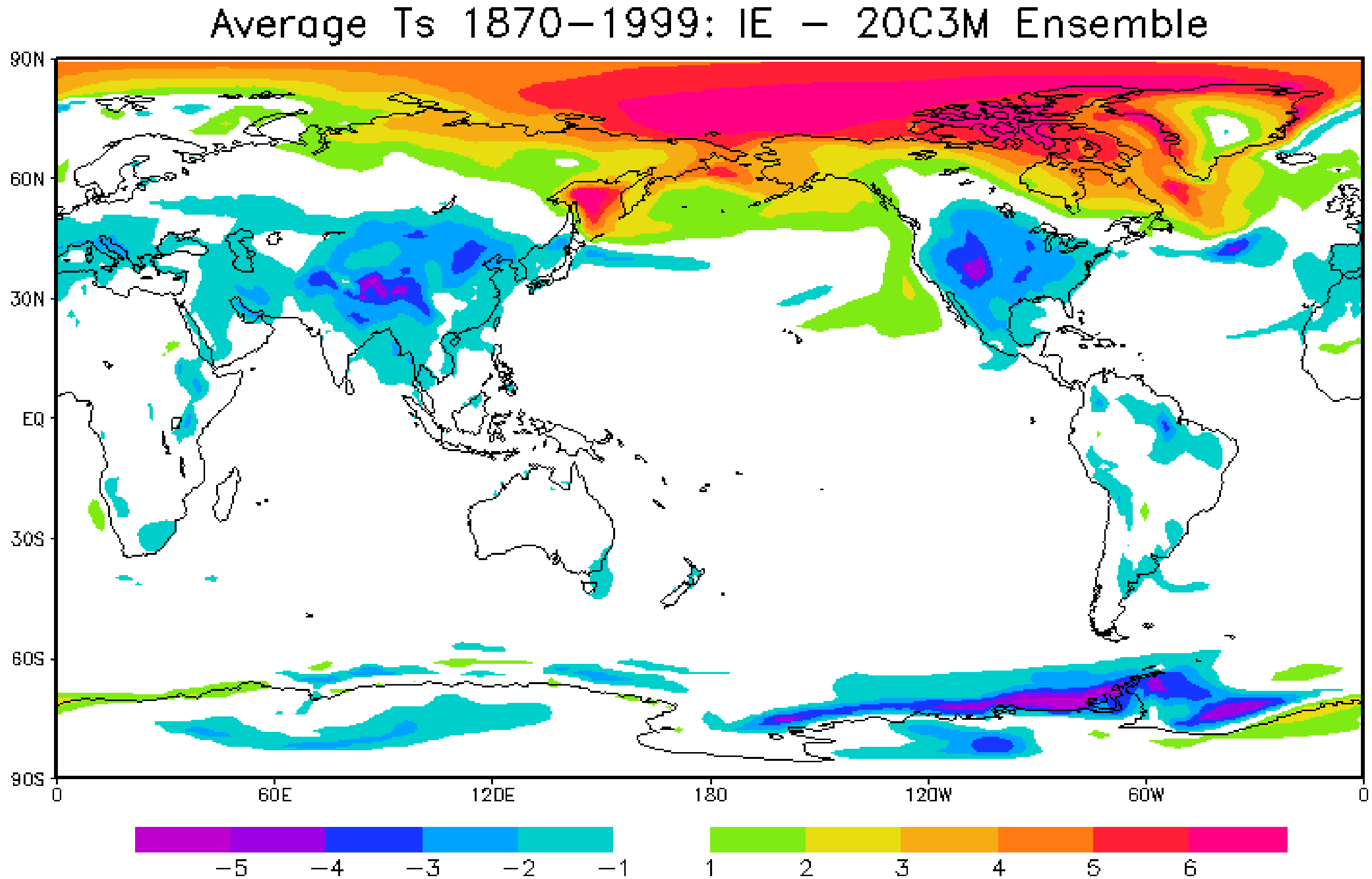
IE-CCSM3 with 20C3M Forcing

Global mean surface air temperature
Black: CCSM3 20C3M ensemble
Red: IE-CCSM3 with 20C3M forcing
Green: as red but 1990 ocean ic



IE-CCSM3 Coupling: A Work in Progress

IE-CCSM3 has a systematic bias (~time independent) relative to CCSM3 ensemble (global mean ~-0.1°C). This will hopefully be Corrected in IE-CCSM4, where land and sea ice should feel AGCM surface fluxes instead of mean AGCM state.



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No time to discuss these, but also no results to describe yet for CCSM3

References

Fan, M., 2008: **Low Frequency North Atlantic SST Variability: Weather Noise Forcing And Coupled Response.** PhD thesis, George Mason University.

Kirtman, B. P., and J. Shukla, 2002: **Interactive coupled ensemble: A new coupling strategy for GCMs**. *Geophys. Res. Lett*., 29, 1029-1032.

Kirtman, B. P., D. M. Straus, D. Min, E. K. Schneider, and L. Siqueira, 2009: **Understanding the link between weather and climate in CCSM3**. *Geophys. Res. Lett*., accepted.

Schneider, E.K., and M. Fan, 2007: **Weather Noise Forcing of Surface Climate Variability**. *J. Atmos. Sci.*, 64, 3265–3280.

Wu, Z., E. K. Schneider and B. P. Kirtman, 2004: **Causes of low frequency North Atlantic SST variability in a coupled GCM**. *Geophys. Res. Lett*. 31, L09210, doi:10.1029/2004GL019548.