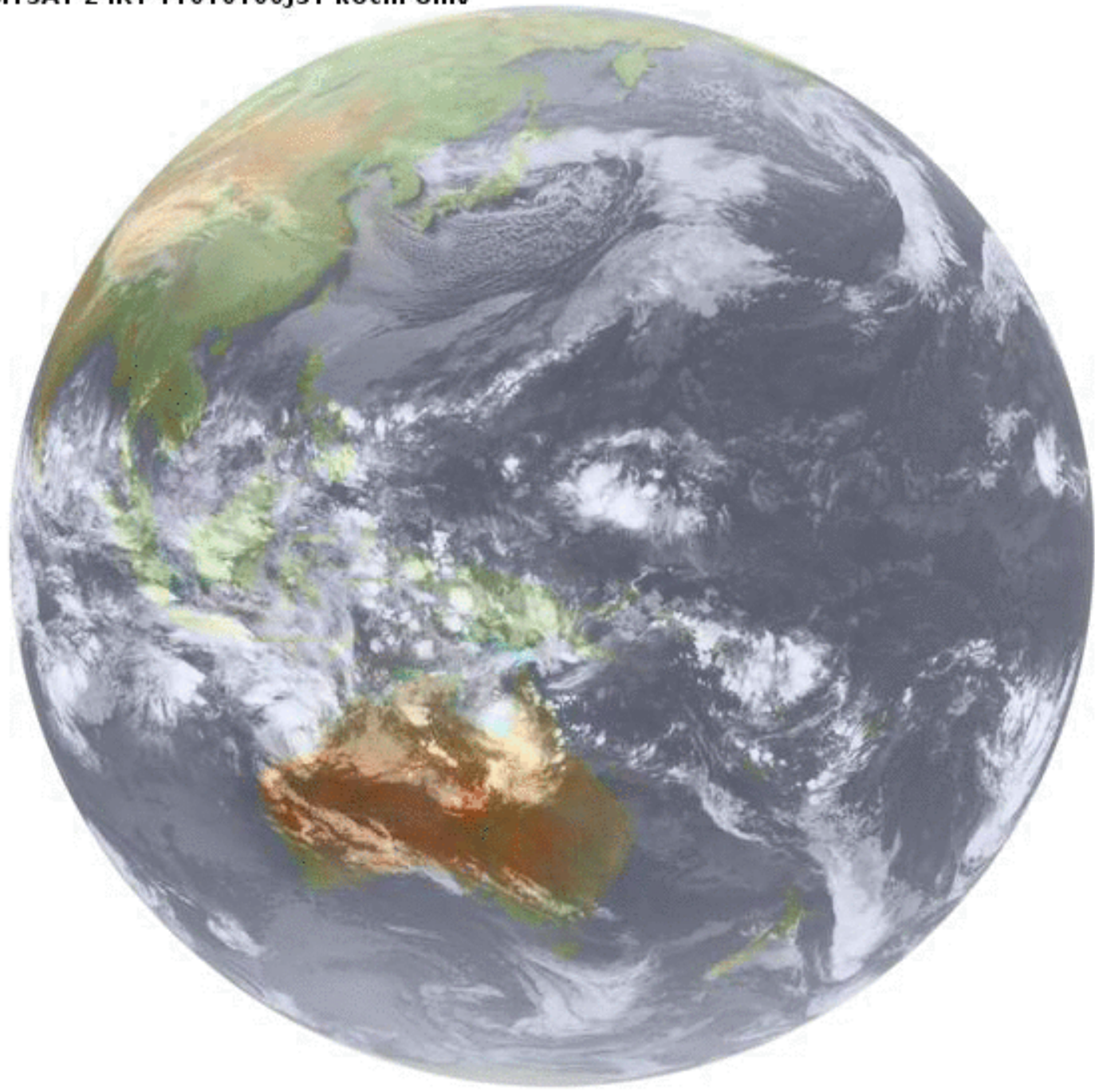


**Ultra-low frequency variability in CCSM4:  
insights from millennial-scale forced and unforced simulations**

**Toby Ault<sup>1</sup>, Clara Deser<sup>1</sup>, Matt Newman<sup>2,3</sup> and Julien Emile-Geay<sup>4</sup>**

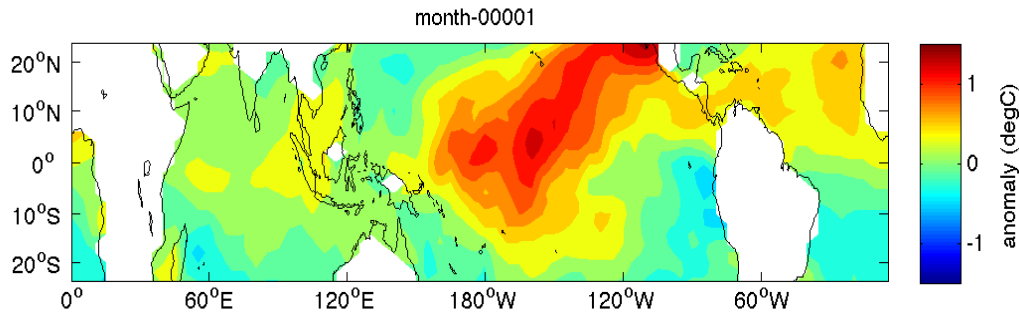
1. NCAR, 2. NOAA/ESRL/PSD, 3. CIRES/CDC, 4. USC



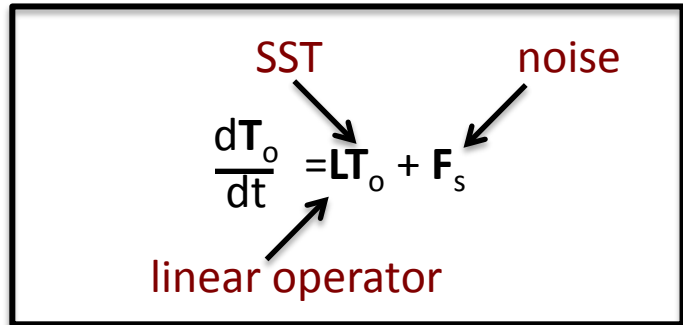
# Understanding the last millennium: proxies, obs, and GCMs



# Linear Inverse Model (LIM)\*



Null hypothesis:



Empirical model of dynamics

Based on (late) 20<sup>th</sup> century obs

One hundred 1000 year simulations

\*Newman et al., 2011 (Clim. Dyn)

# Linear Inverse Model (LIM)\*



Null hypothesis:

$$\frac{dT_o}{dt} = LT_o + F_s$$

SST →  $LT_o$   
noise →  $F_s$   
linear operator →  $L$

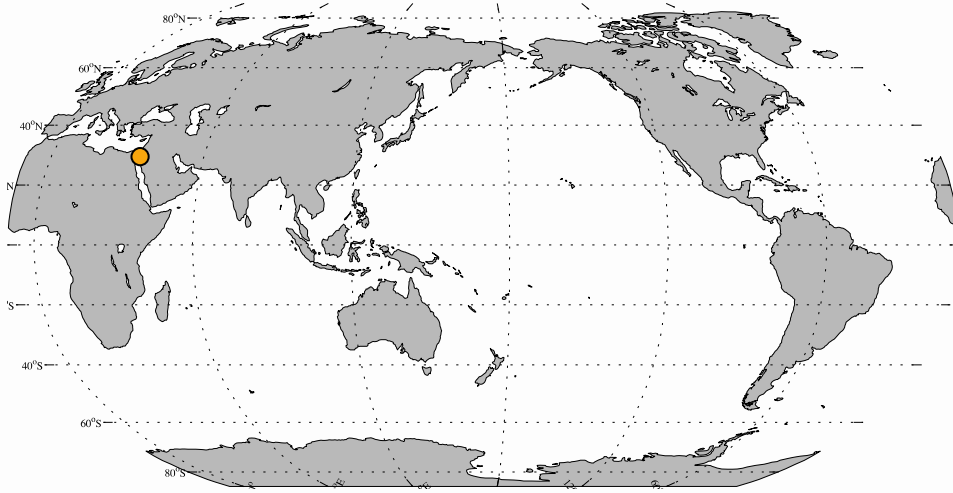
Empirical model of dynamics

Based on (late) 20<sup>th</sup> century obs

One hundred 1000 year simulations

**Benchmark for low-frequency  
variability**

# Paleoclimate reconstructions\*

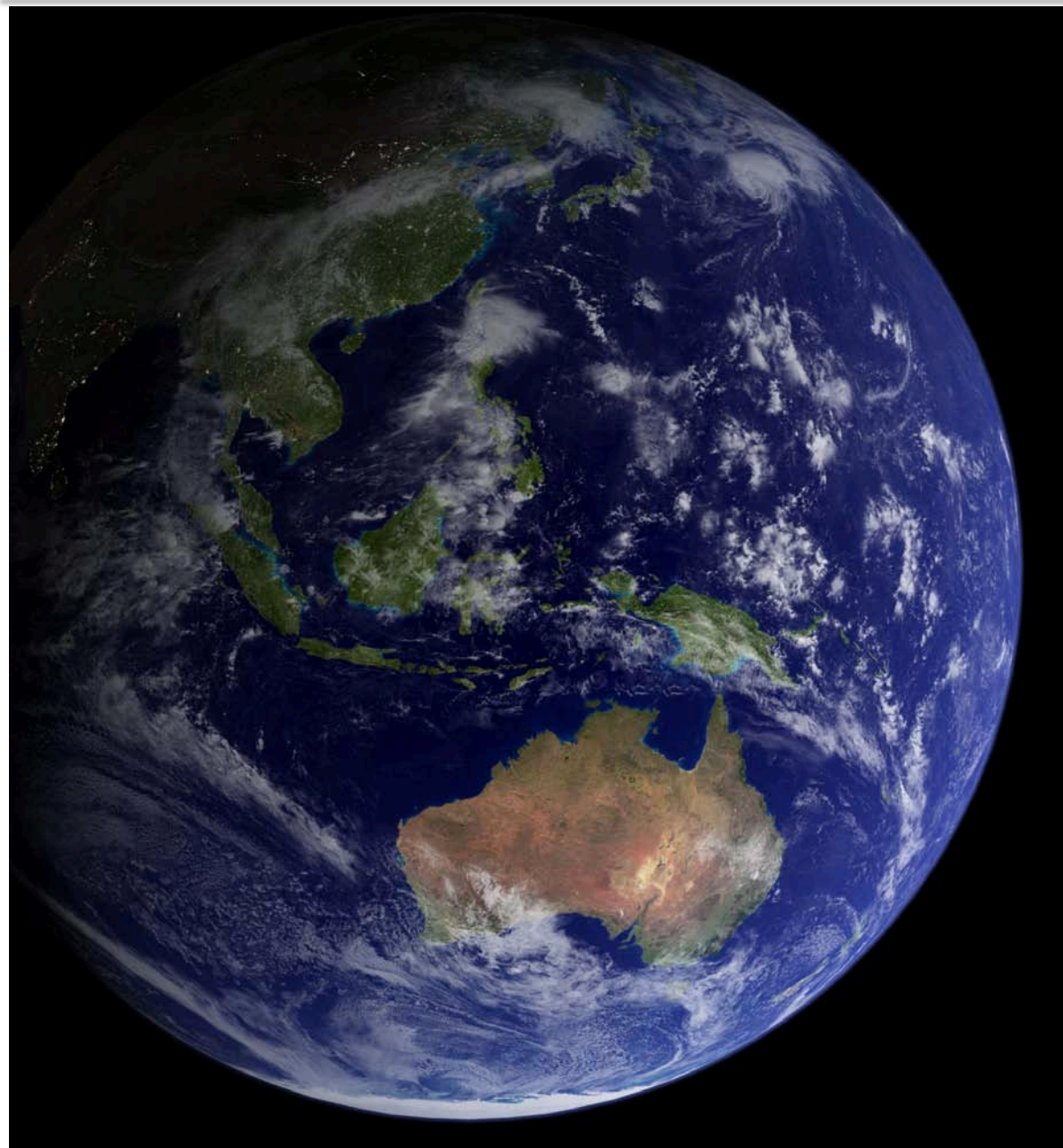


**Multiple reconstruction methods**  
(CPS, RegEM, TTLS)

**Multiple proxy types**  
(corals, ice cores, trees, sediment  
cores, caves)

**Multiple targets**  
(Kaplan, HadISST, ERSSTv3)

# CCSM4 Simulations



**CMIP5/PMIP3 simulations**  
(~ 1x1 atm, ocn)

**20<sup>th</sup> century**  
(6 runs, 155 years from 1850-2005)

**Pre-industrial control<sup>1</sup>**  
(1 run, 1300 years, used last 1000)

**Last millennium (forced)<sup>2</sup>**  
(1 run, 1155 years)

1. Deser et al., 2011

2. Landrum et al., (submitted)

# Last millennium forcings



**Volcanic aerosols\***  
(reconstructed from ice and  
sediment cores)

Sarychev (Russia), June 12, 2009 (NASA Photo)

[http://eoimages.gsfc.nasa.gov/images/imagerecords/38000/38985/ISS020-E-09048\\_lrg.jpg](http://eoimages.gsfc.nasa.gov/images/imagerecords/38000/38985/ISS020-E-09048_lrg.jpg)

\*Gao, C., A. Robock, and C. Ammann, 2008.



# Last millennium forcings

---



## **Volcanic aerosols**

(reconstructed from ice and sediment cores)

## **Solar variability\***

(reconstructed from sunspot observations and  $^{14}\text{C}$ ,  $^{10}\text{Be}$  and  $^{36}\text{Cl}$  archives)

\*Vieira and Solanki, 2010; Schmidt et al., 2011.

# Last millennium forcings



## **Volcanic aerosols**

(reconstructed from ice and sediment cores)

## **Solar variability**

(reconstructed from sunspot observations and  $^{14}\text{C}$ ,  $^{10}\text{Be}$  and  $^{36}\text{Cl}$  archives)

## **Milankovitch forcing**

(timing of NH/SH summer)

**Volcanic aerosols**

(reconstructed from ice and sediment cores)

**Solar variability**

(reconstructed from sunspot observations and  $^{14}\text{C}$ ,  $^{10}\text{Be}$  and  $^{36}\text{Cl}$  archives)

**Milankovitch forcing**

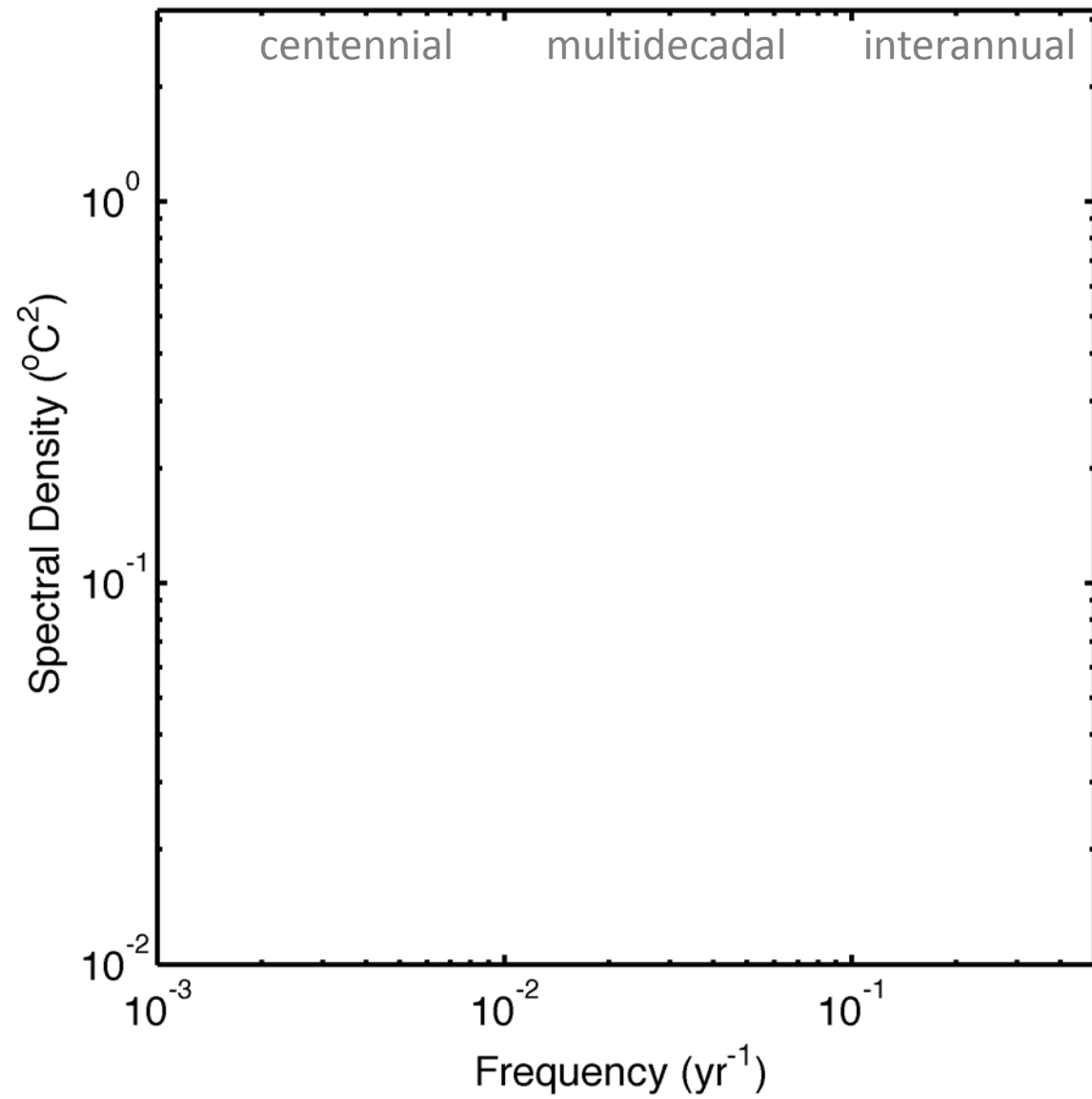
(timing of NH/SH summer)

**Greenhouse gasses**

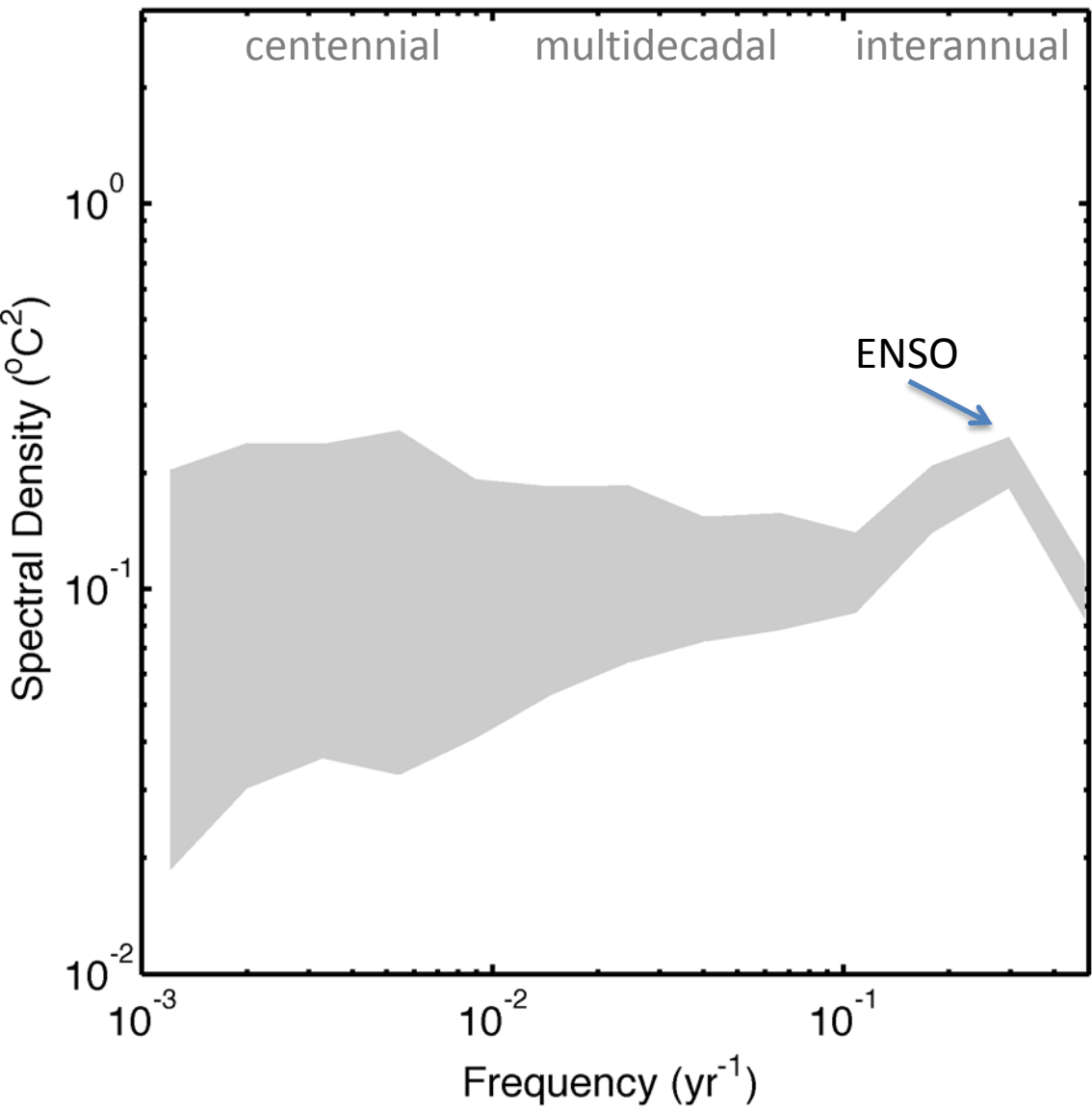
( $\text{CO}_2$ ,  $\text{N}_2\text{O}$ ,  $\text{CH}_4$ )

**Land surface changes**

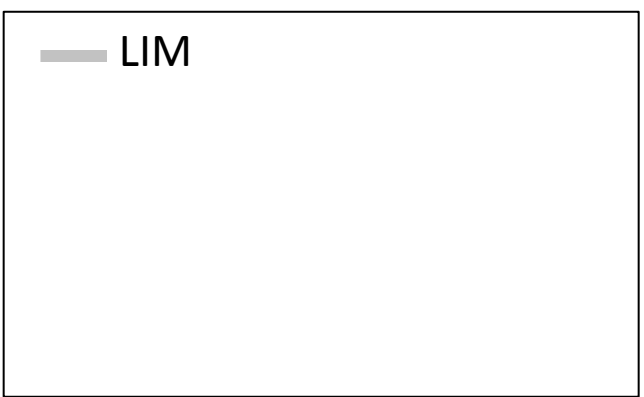
# The power spectrum



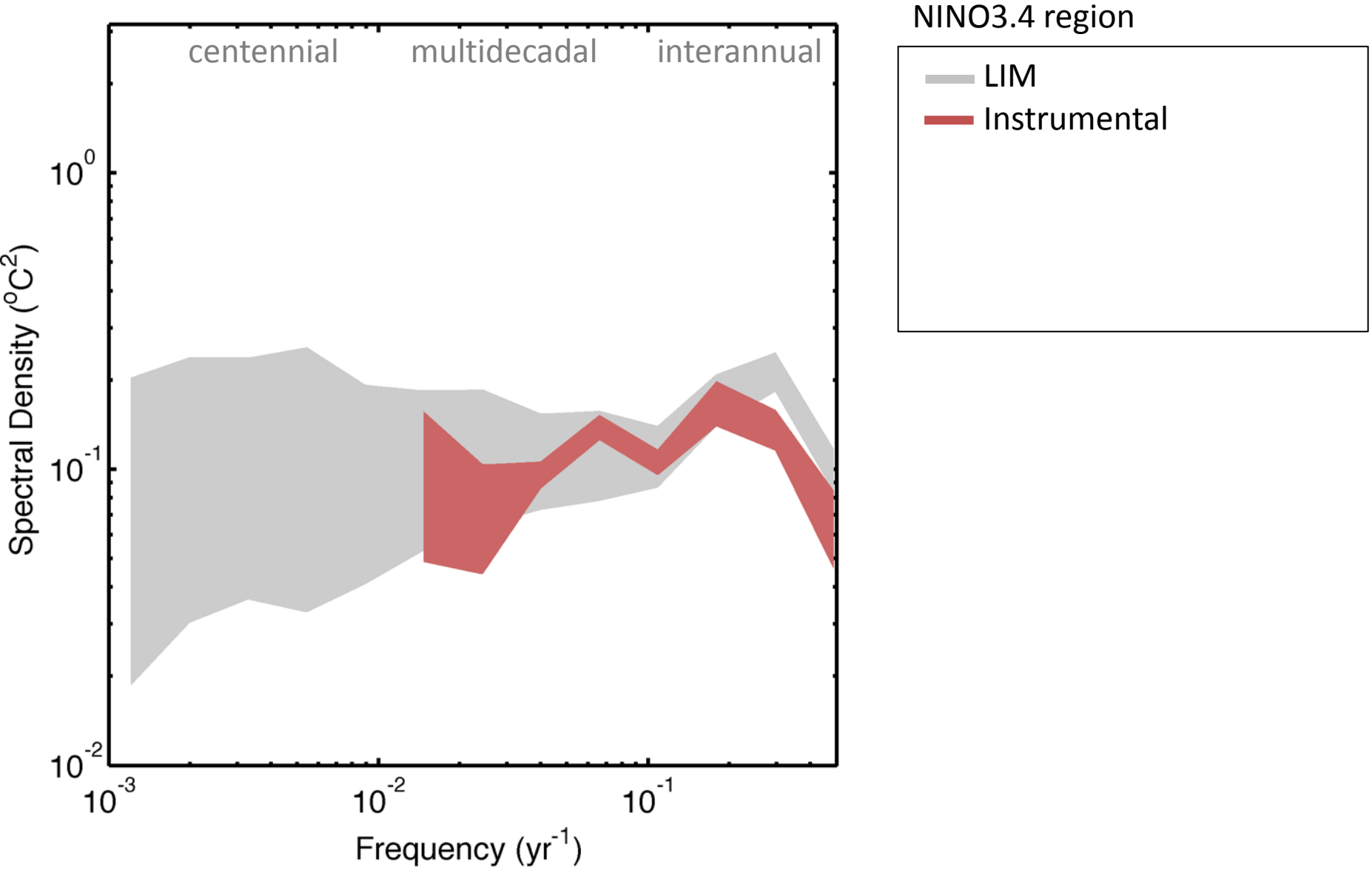
# NINO3.4 spectra



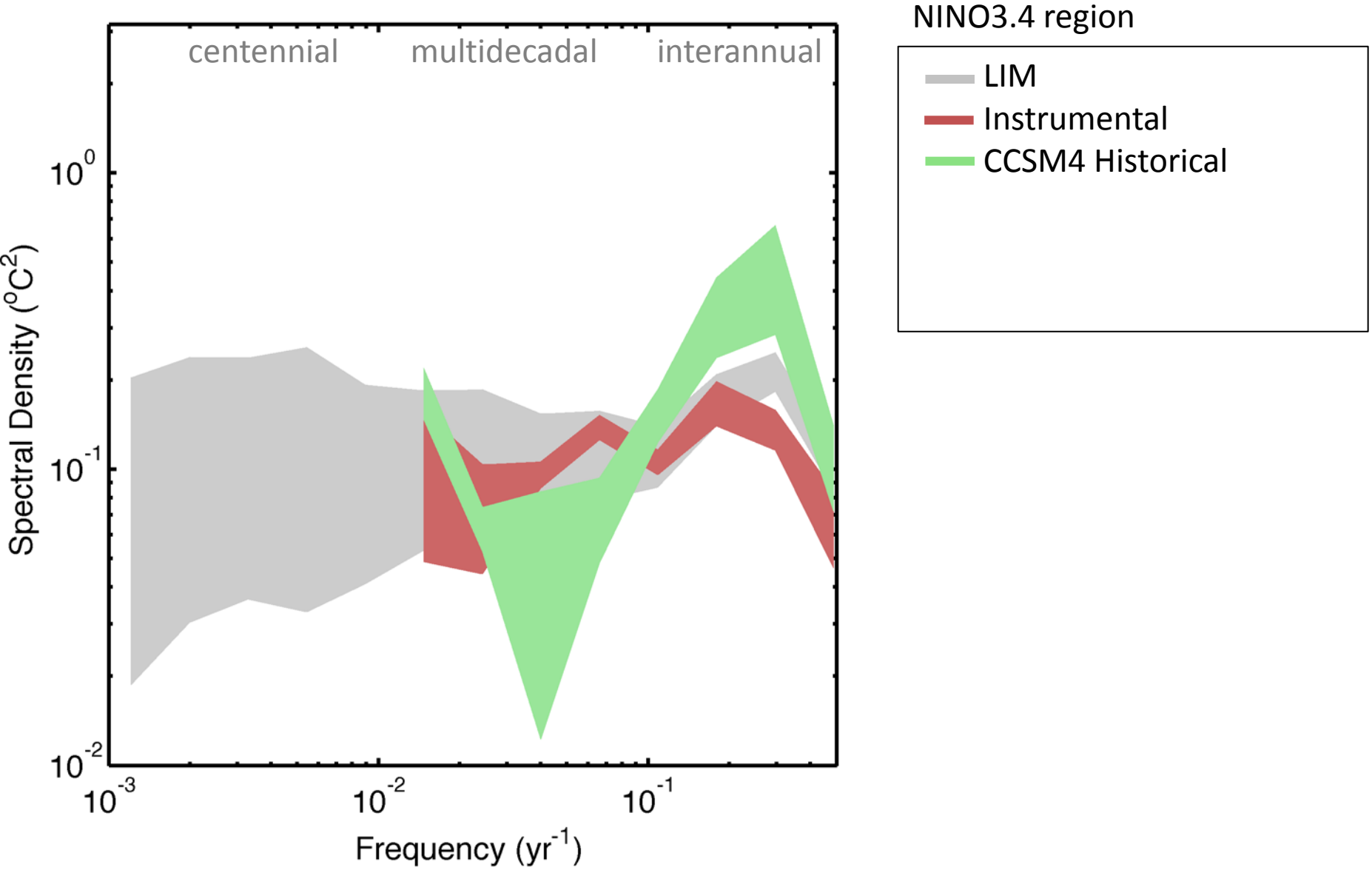
NINO3.4 region



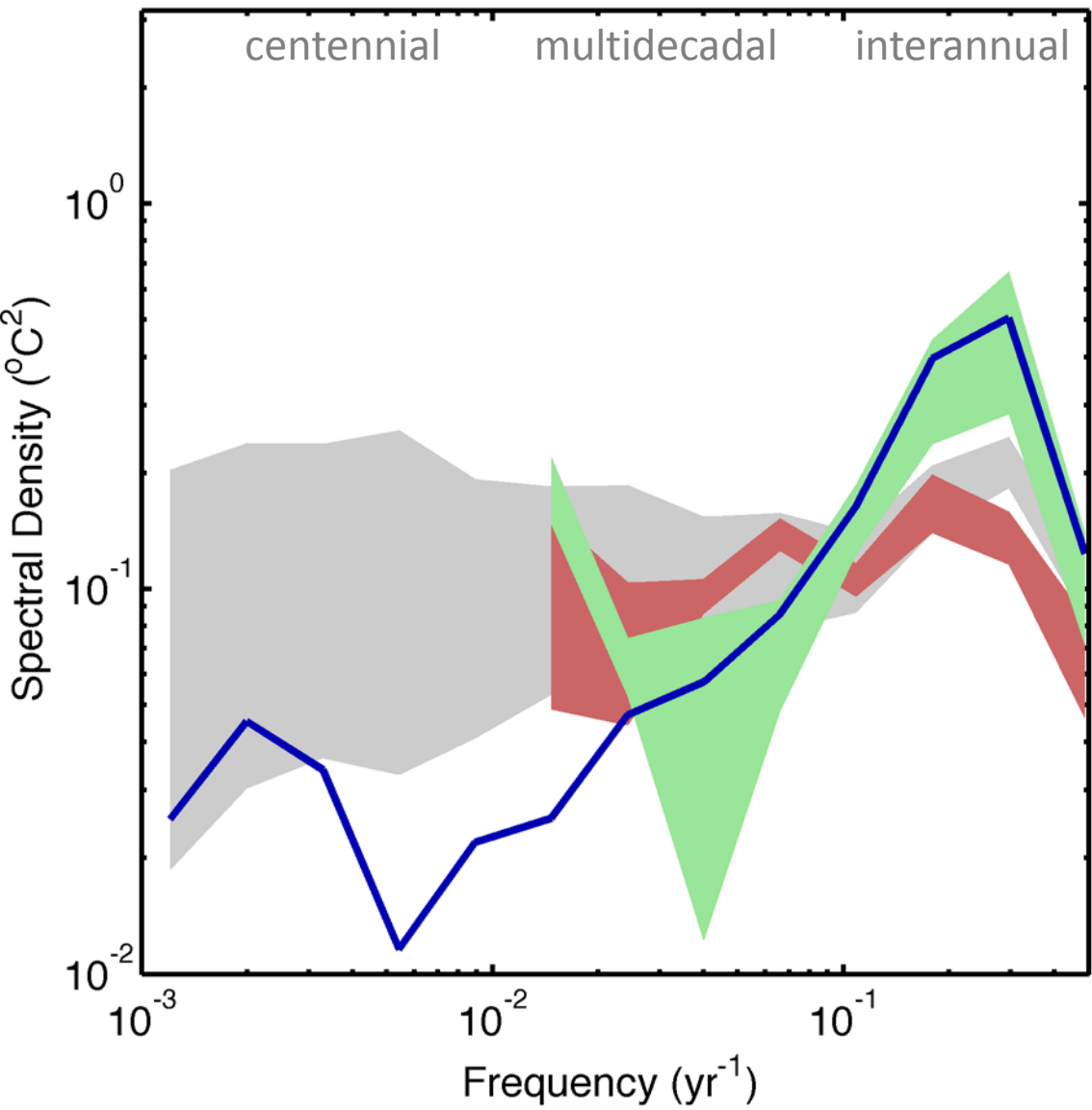
# NINO3.4 spectra



# NINO3.4 spectra



# NINO3.4 spectra

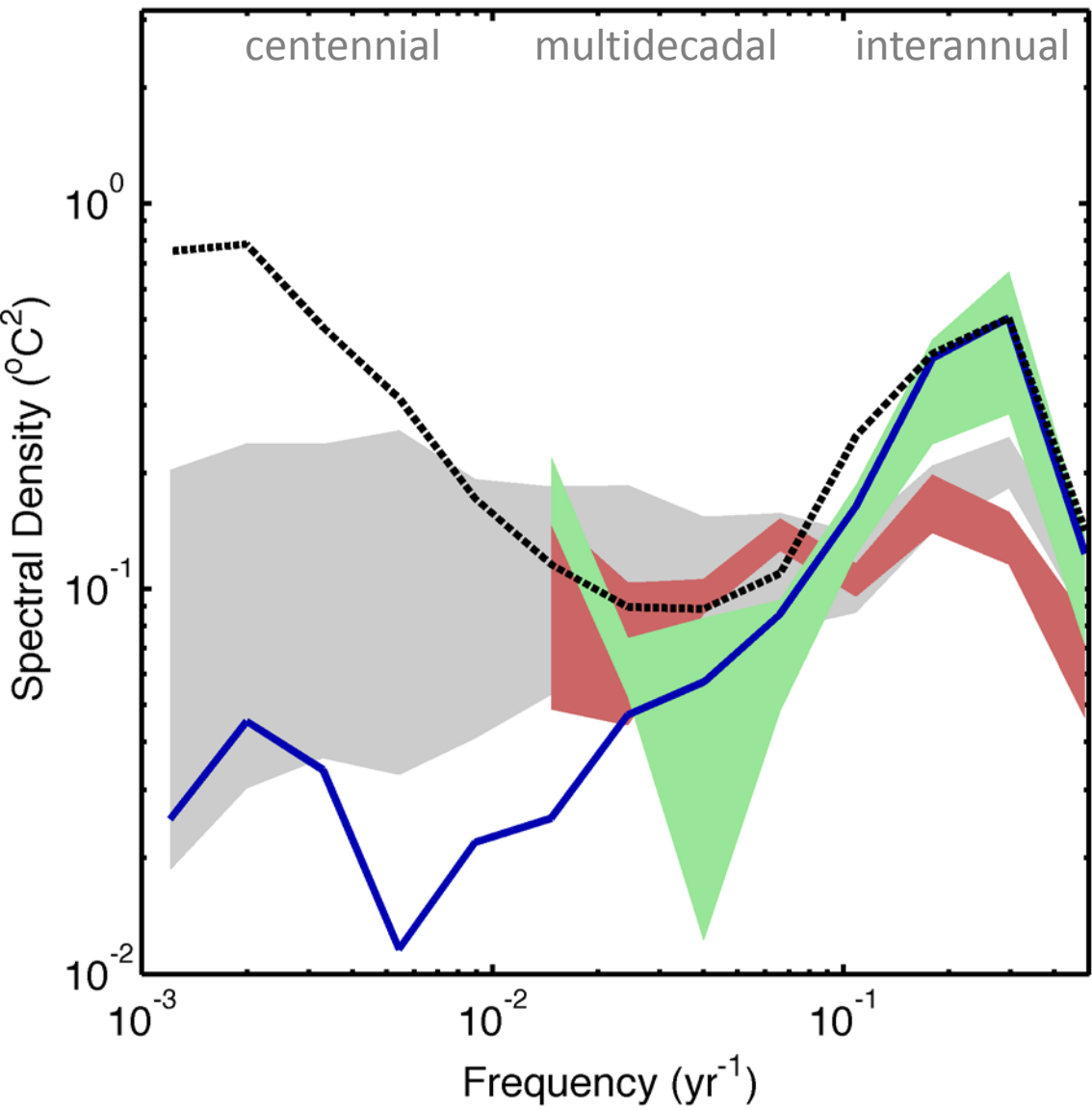


NINO3.4 region

- LIM
- Instrumental
- CCSM4 Historical
- CCSM4 Control



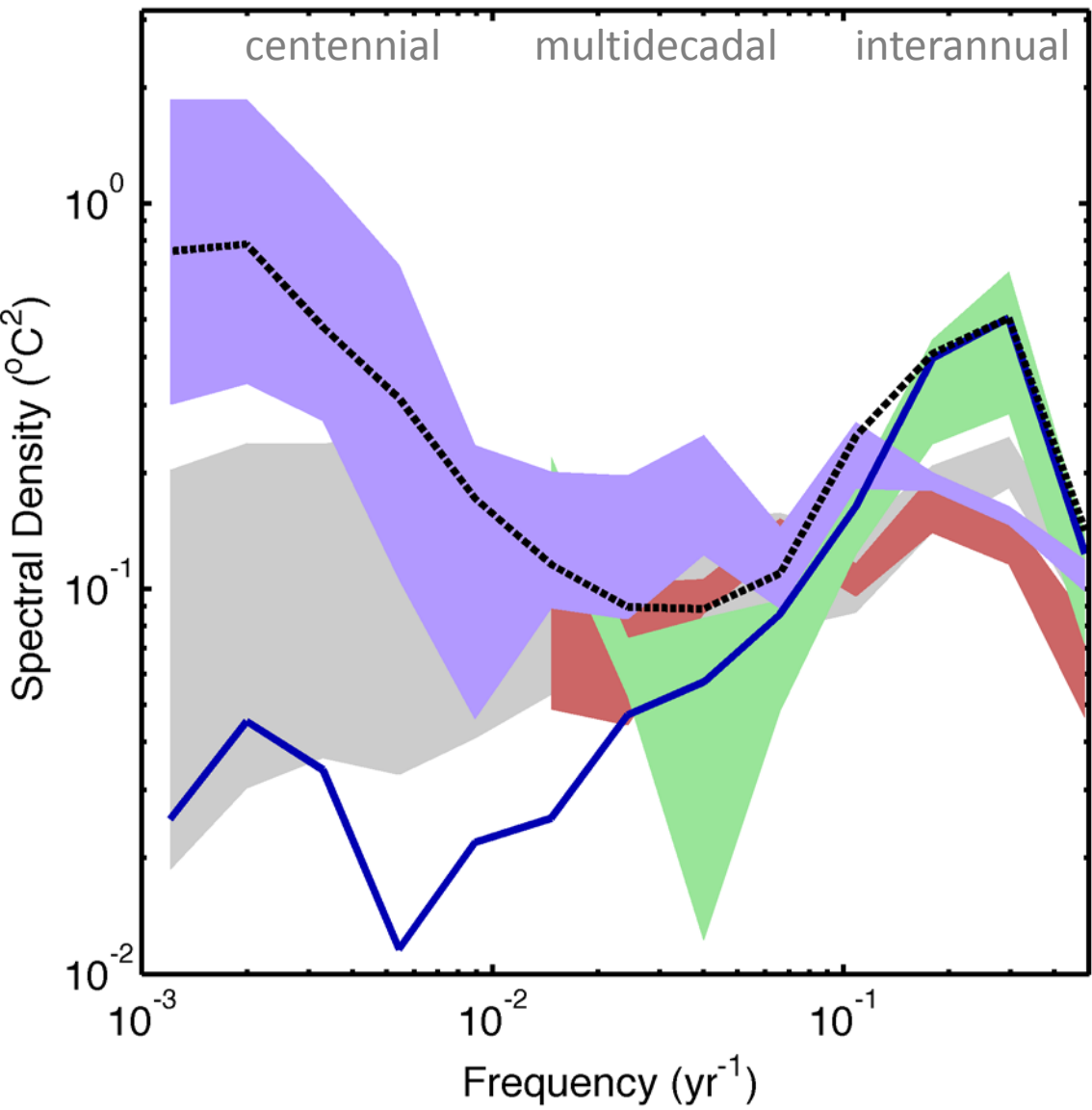
# NINO3.4 spectra



## NINO3.4 region

- LIM
- Instrumental
- CCSM4 Historical
- CCSM4 Control
- CCSM4 Last Millennium

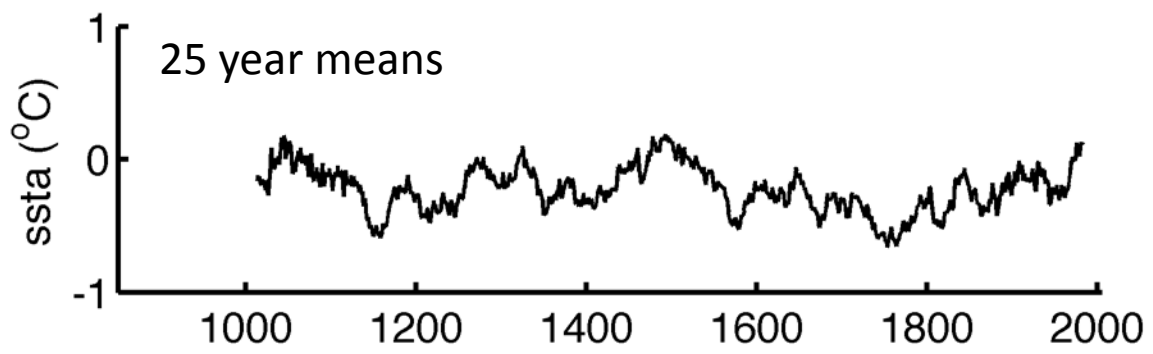
# NINO3.4 spectra



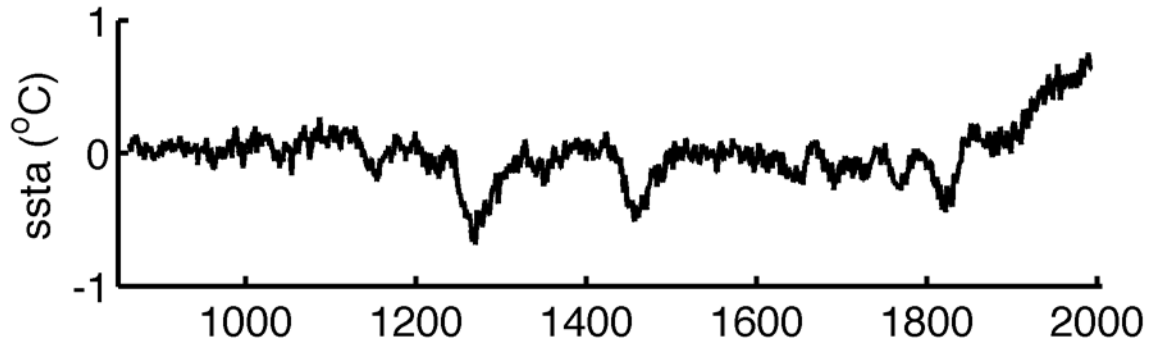
## NINO3.4 region

- LIM
- Instrumental
- CCSM4 Historical
- CCSM4 Control
- CCSM4 Last Millennium
- Paleo Reconstruction

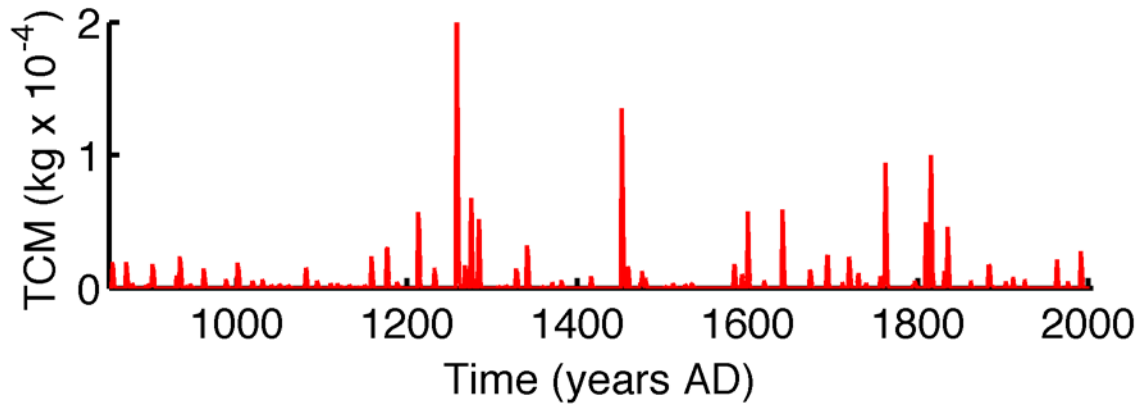
# Role of forcings



Paleo reconstruction  
(ensemble mean)

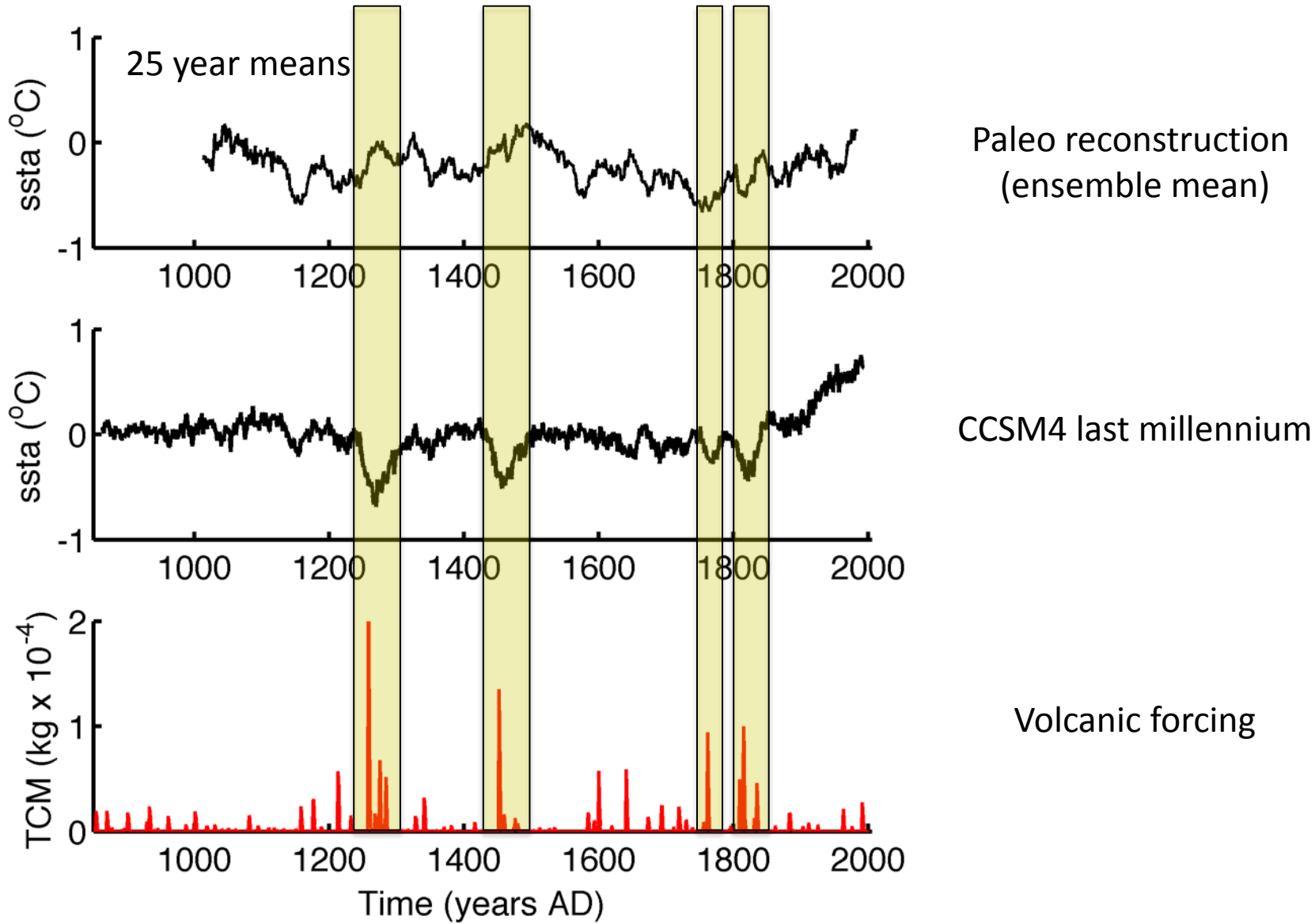


CCSM4 last millennium

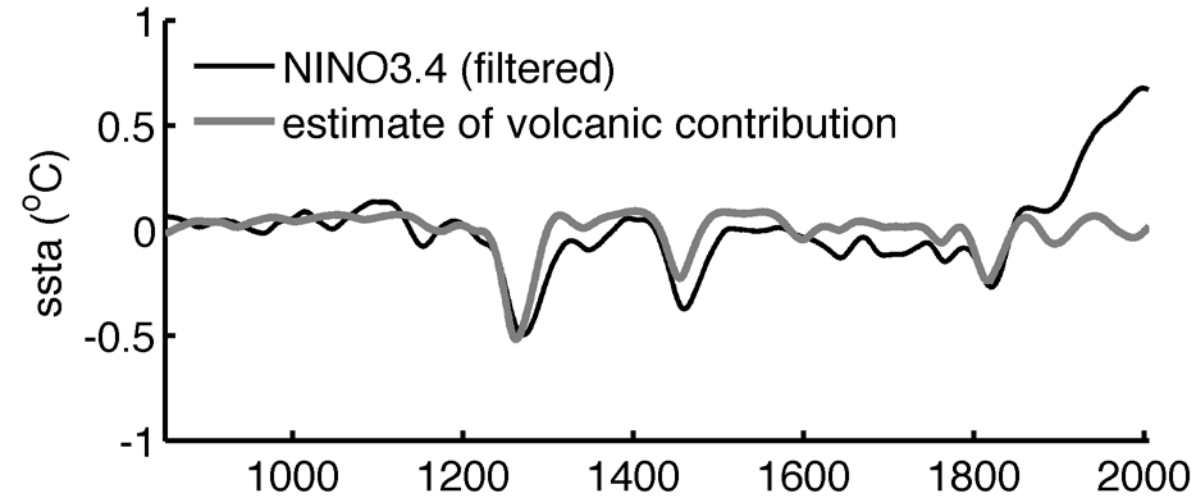


Volcanic forcing

# Role of forcings

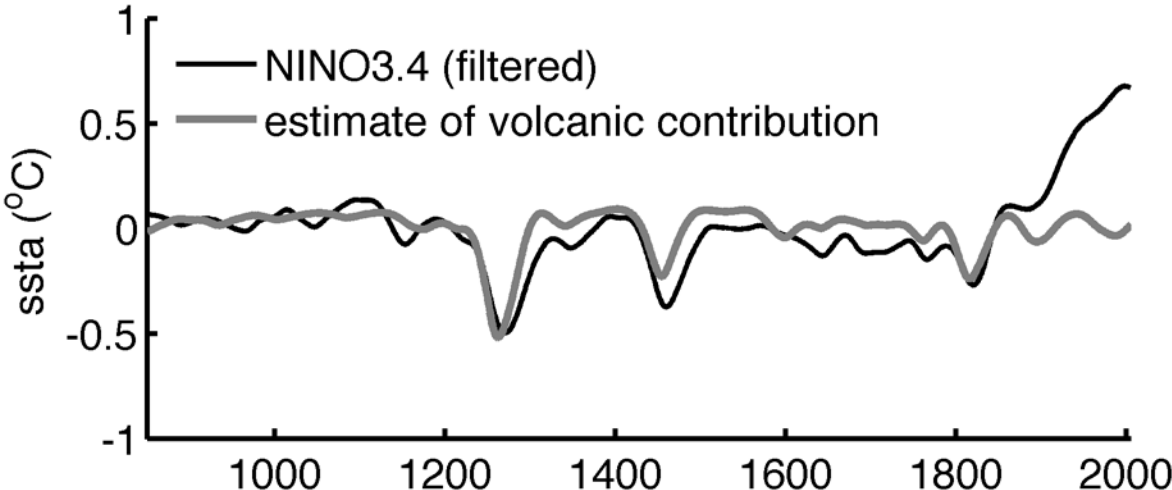


# Role of forcings

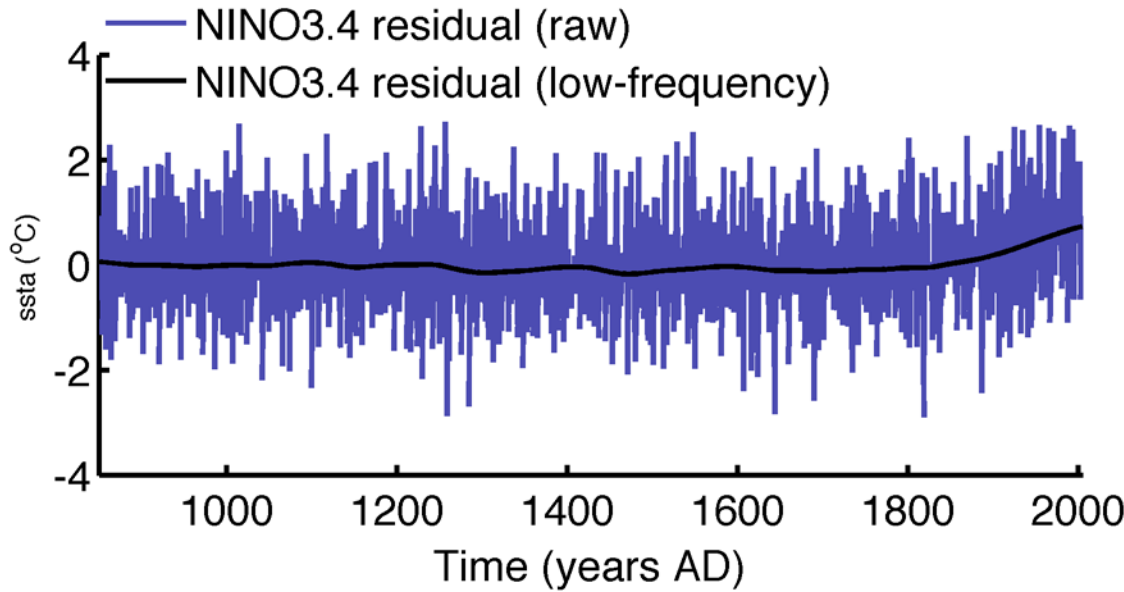


Regression-based removal  
of volcanic forcing

# Role of forcings

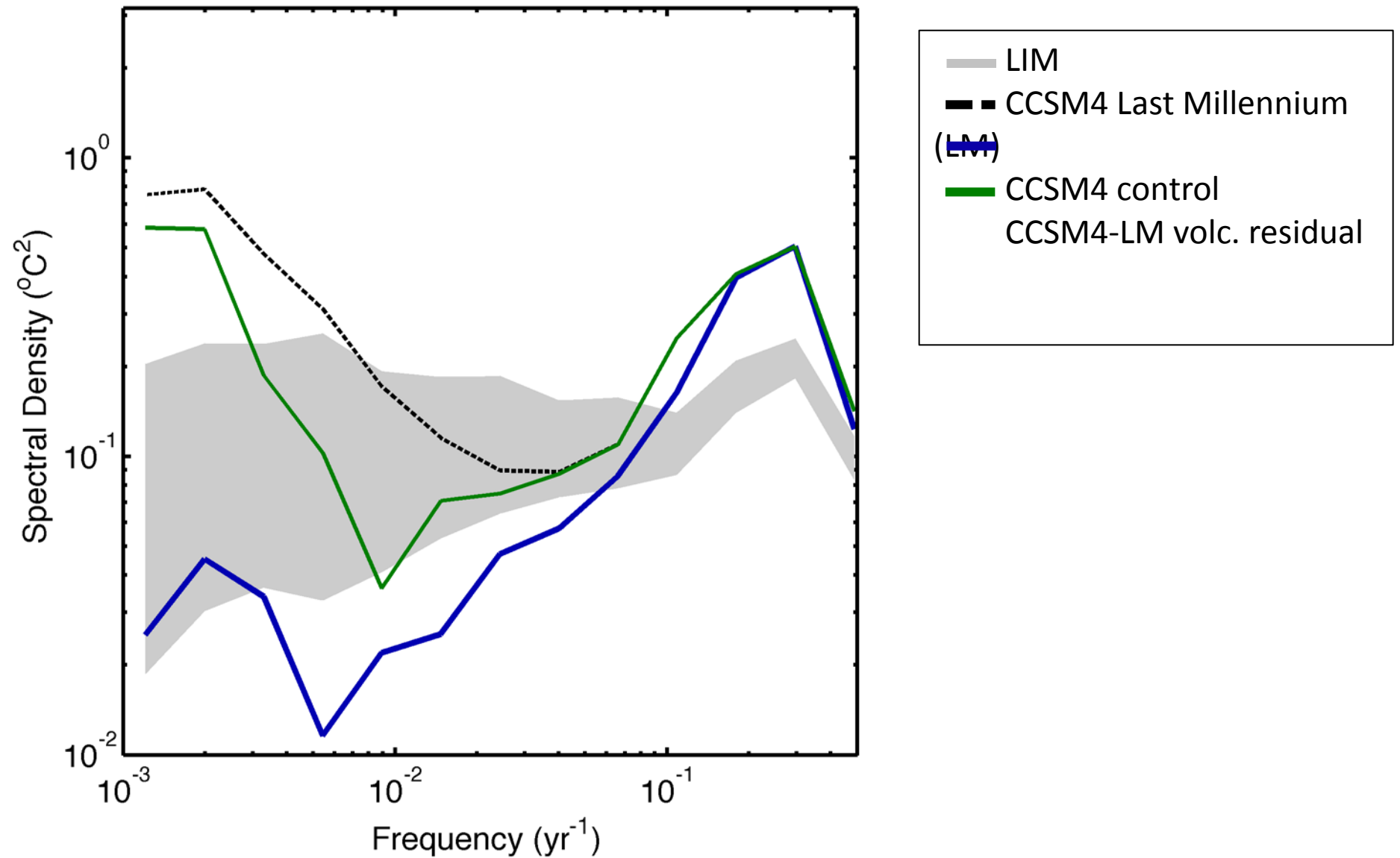


Regression-based removal of volcanic forcing

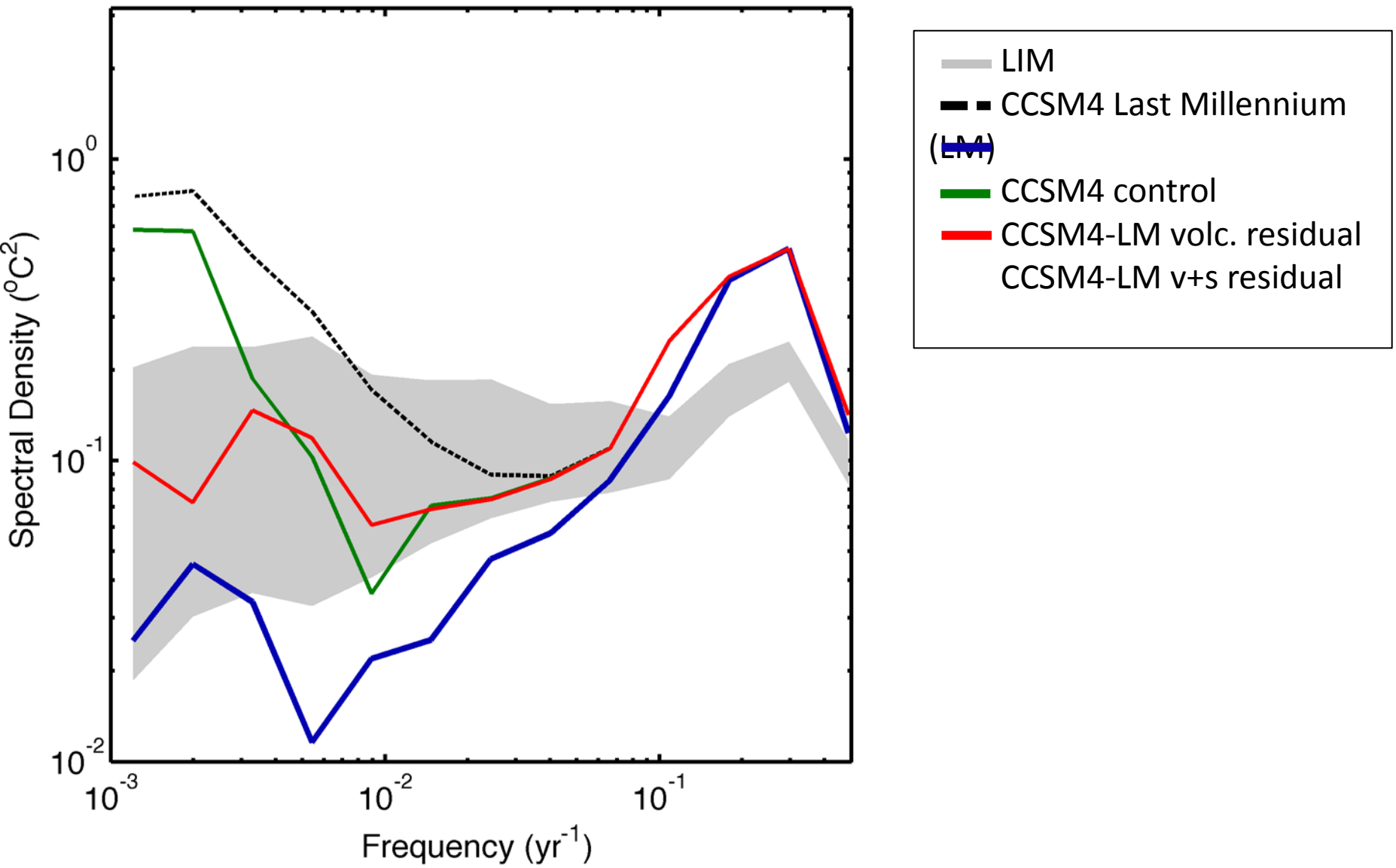


Residual after removing volcanic signal

# Role of forcings

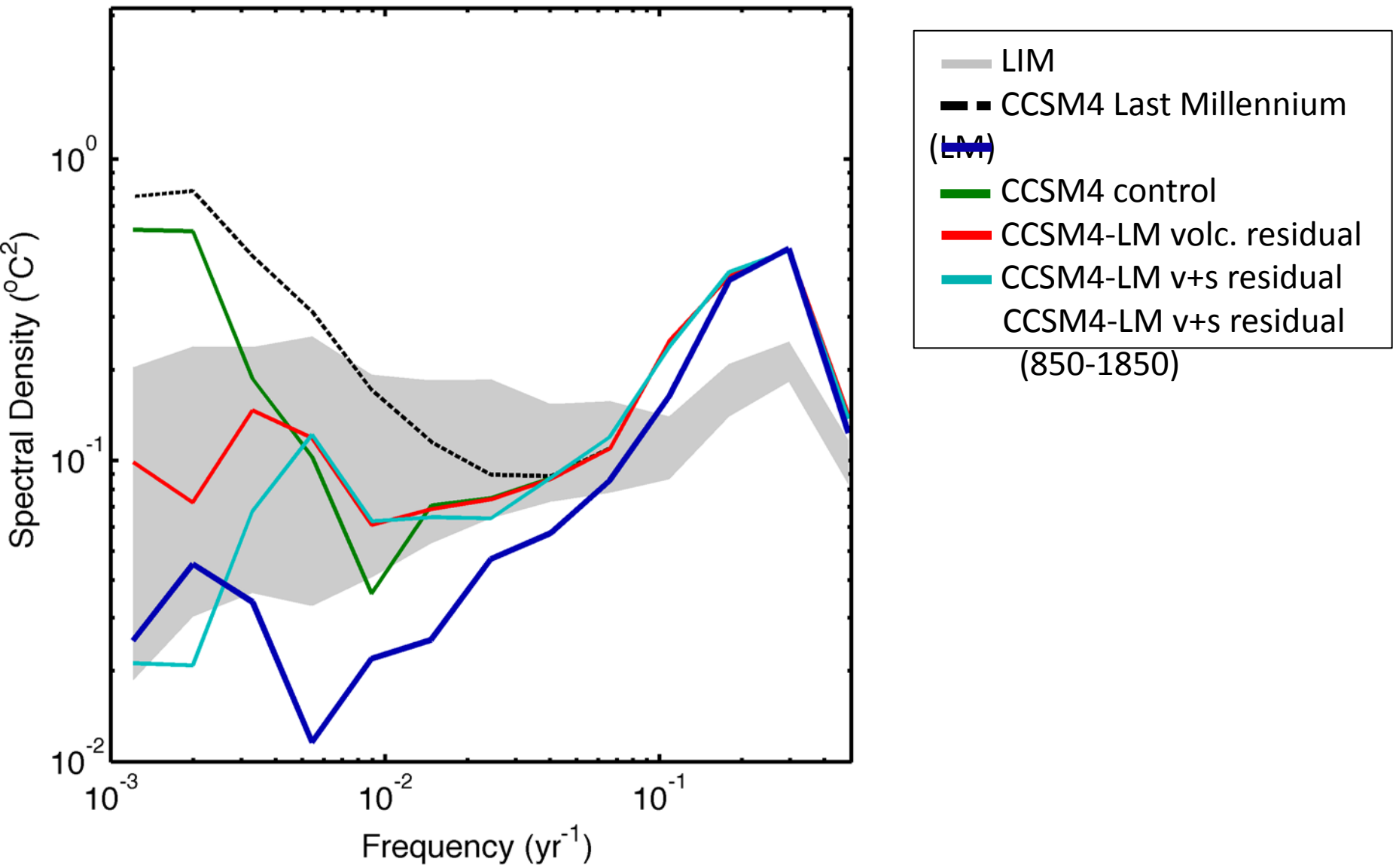


# Role of forcings

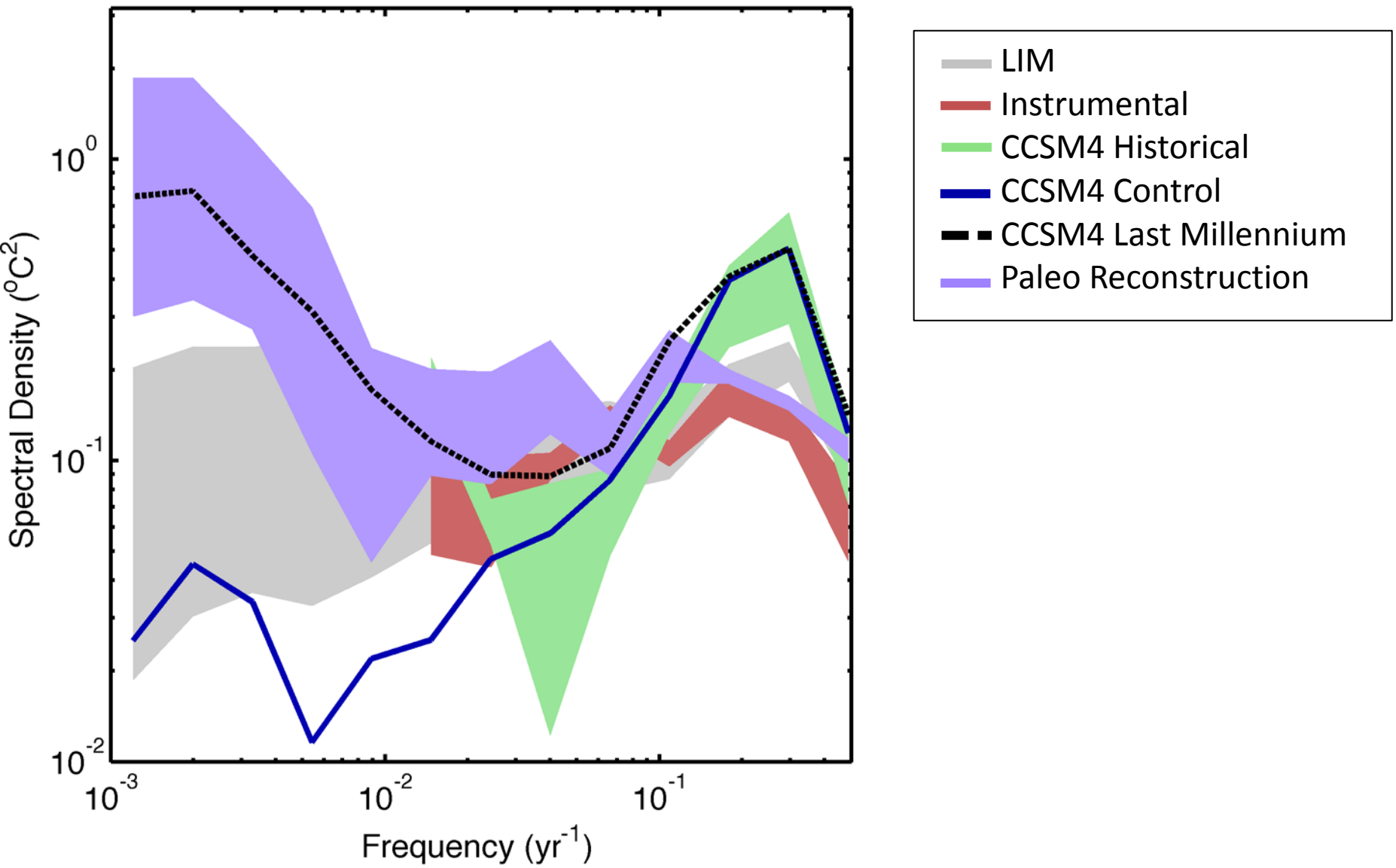




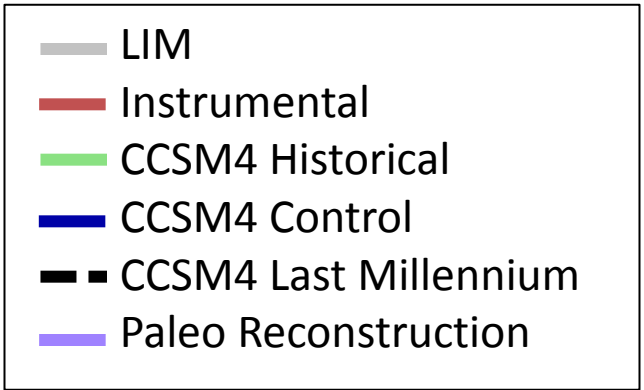
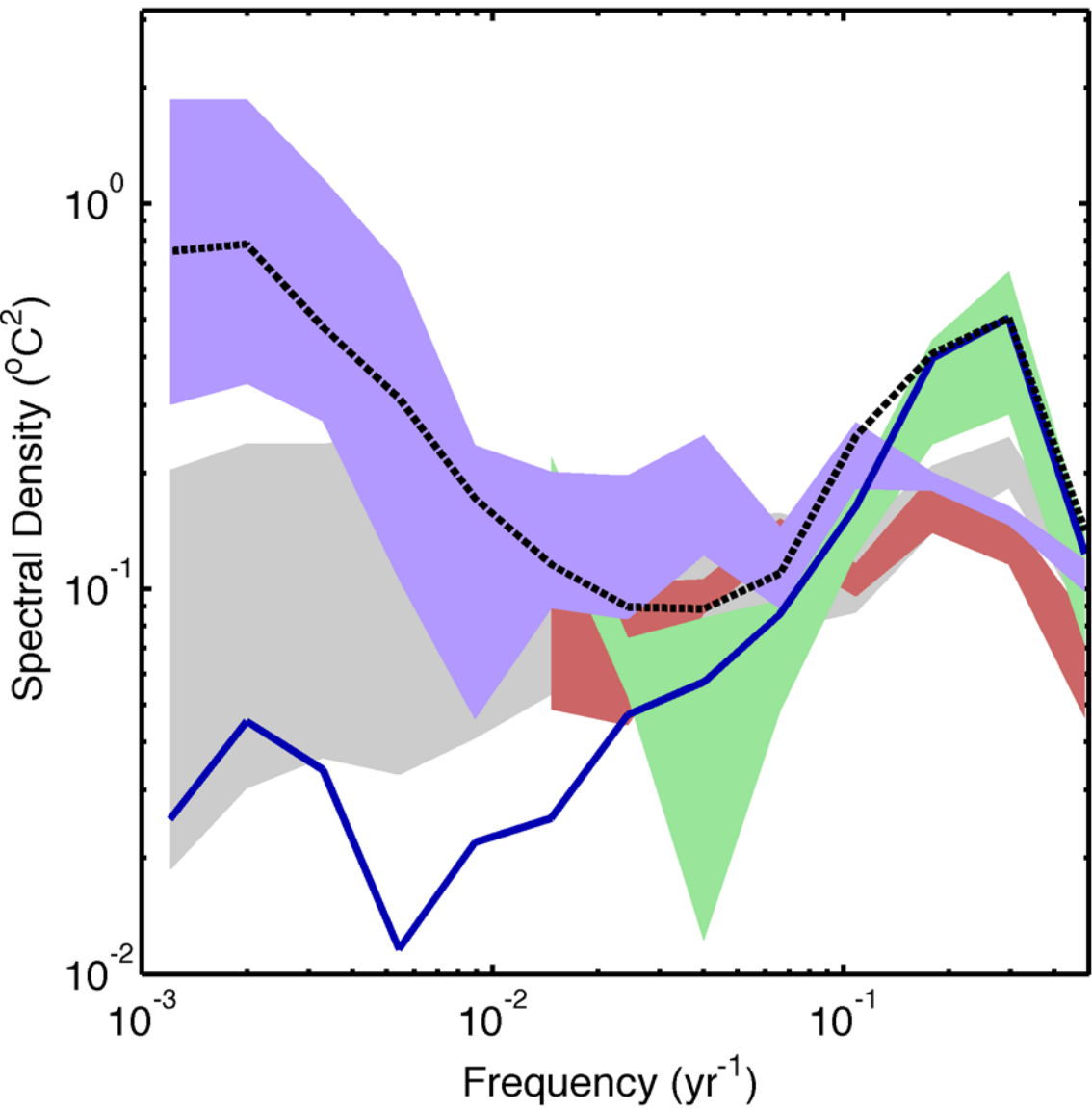
# Role of forcings



# Role of forcings



# Role of forcings

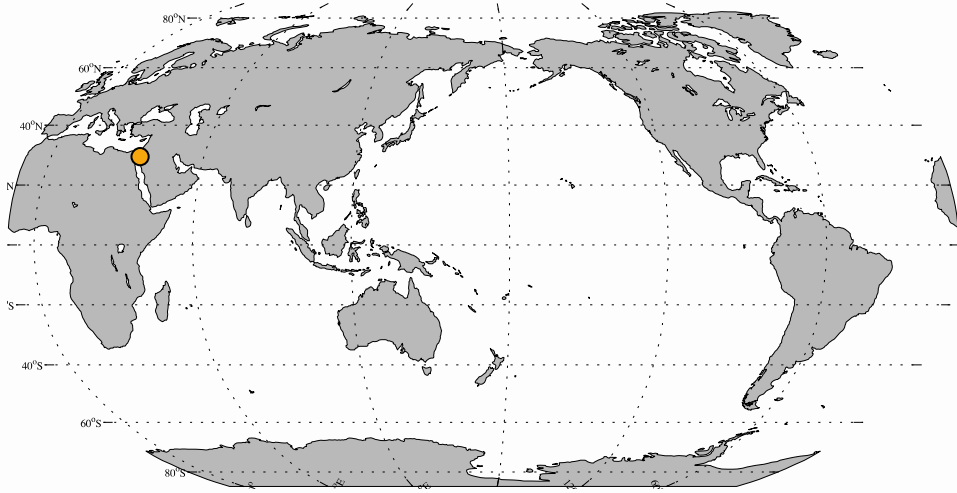


Cannot reject **null hypothesis** for decadal to multidecadal variability

Agreement between paleo and model might be **fortuitous**

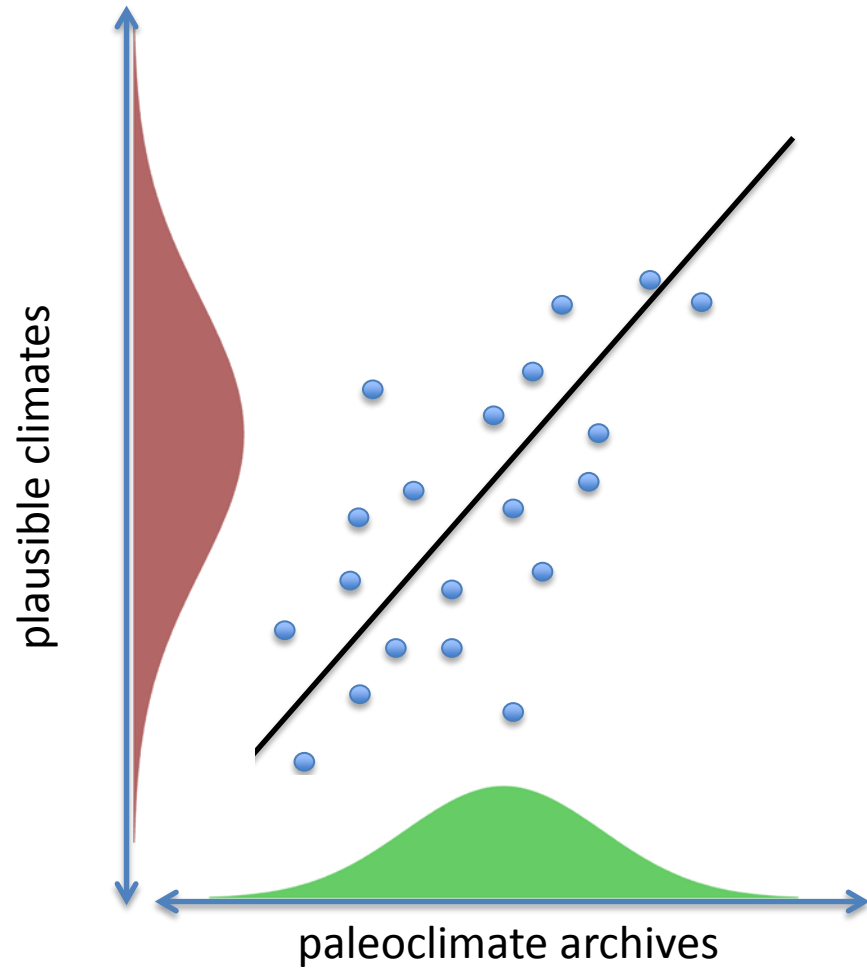
Origin of ultra-low frequency variability:  
**CCSM4 - mostly forced**  
**Paleo - mostly natural, or ...**

# Role of forcings



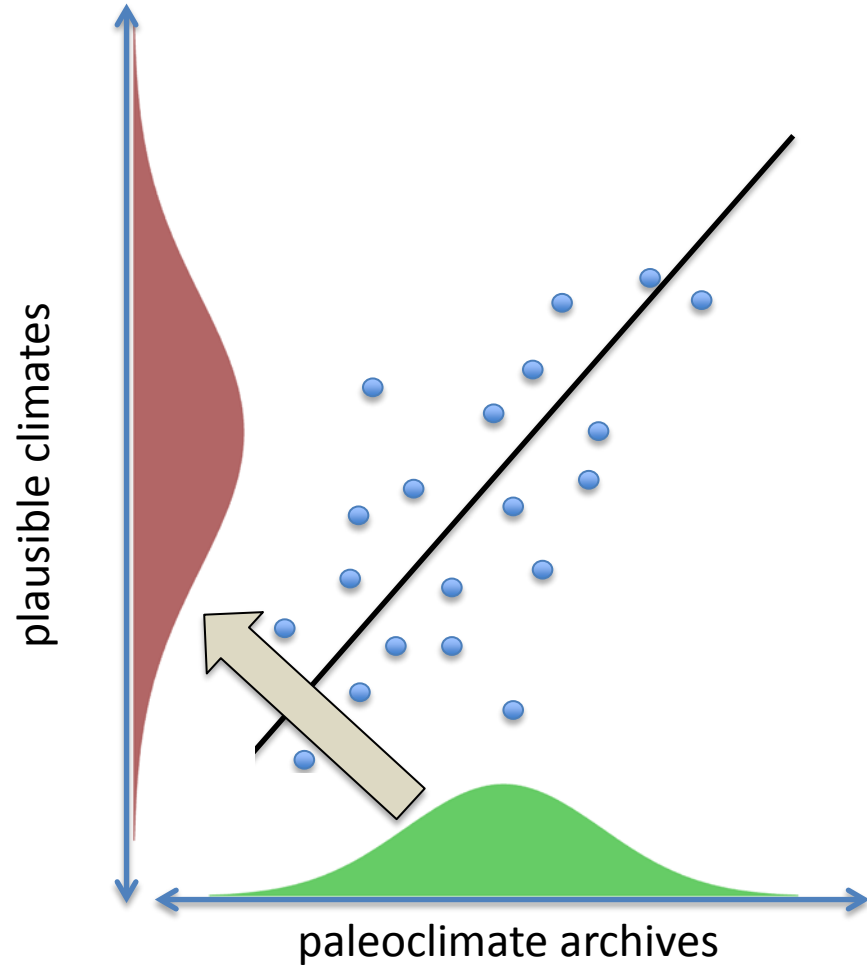
Network biases?

# Future work



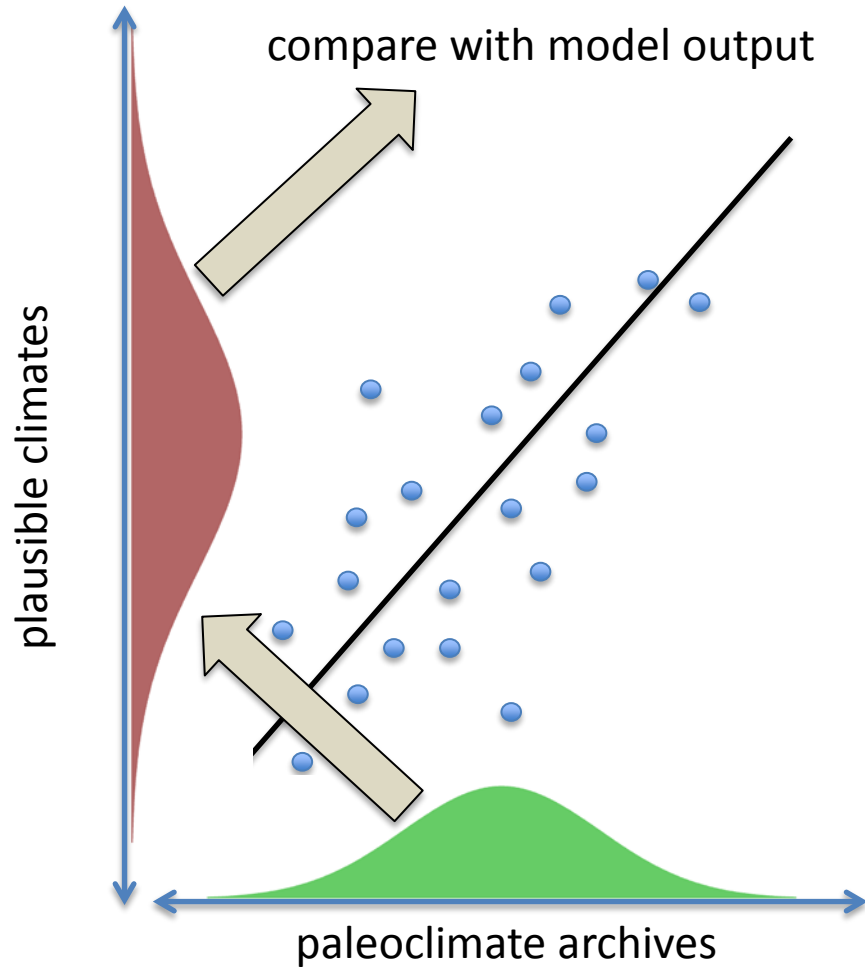
(current approach)

# Future work



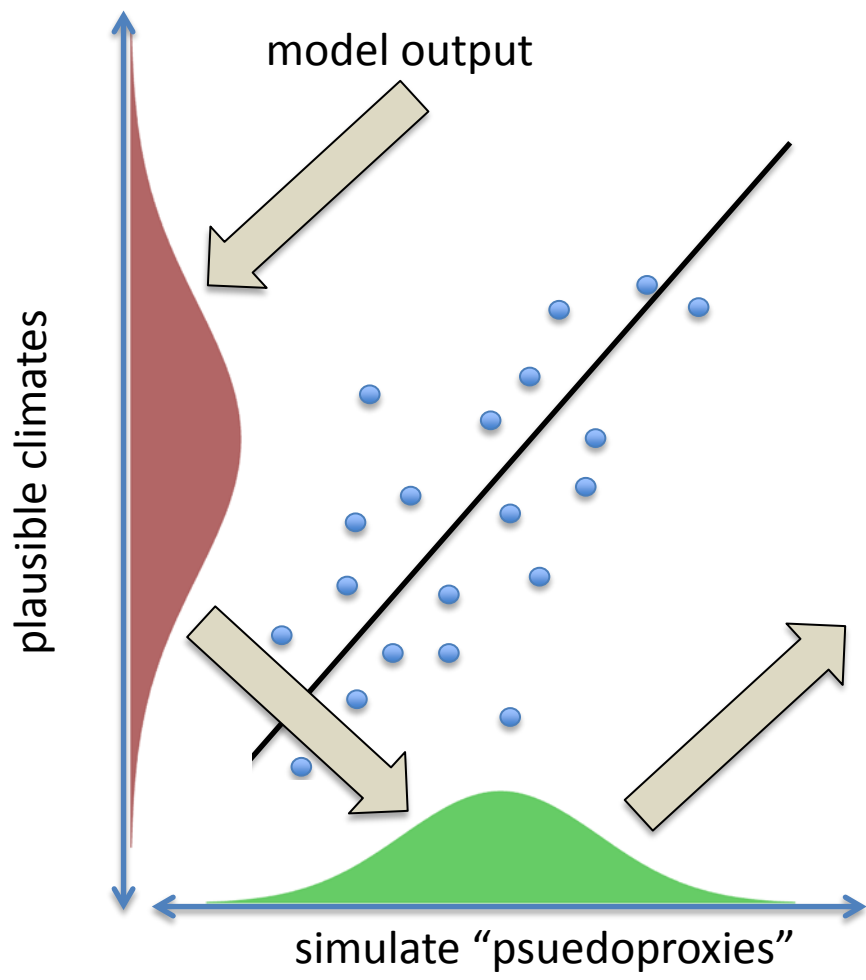
(current approach)

# Future work



(current approach)

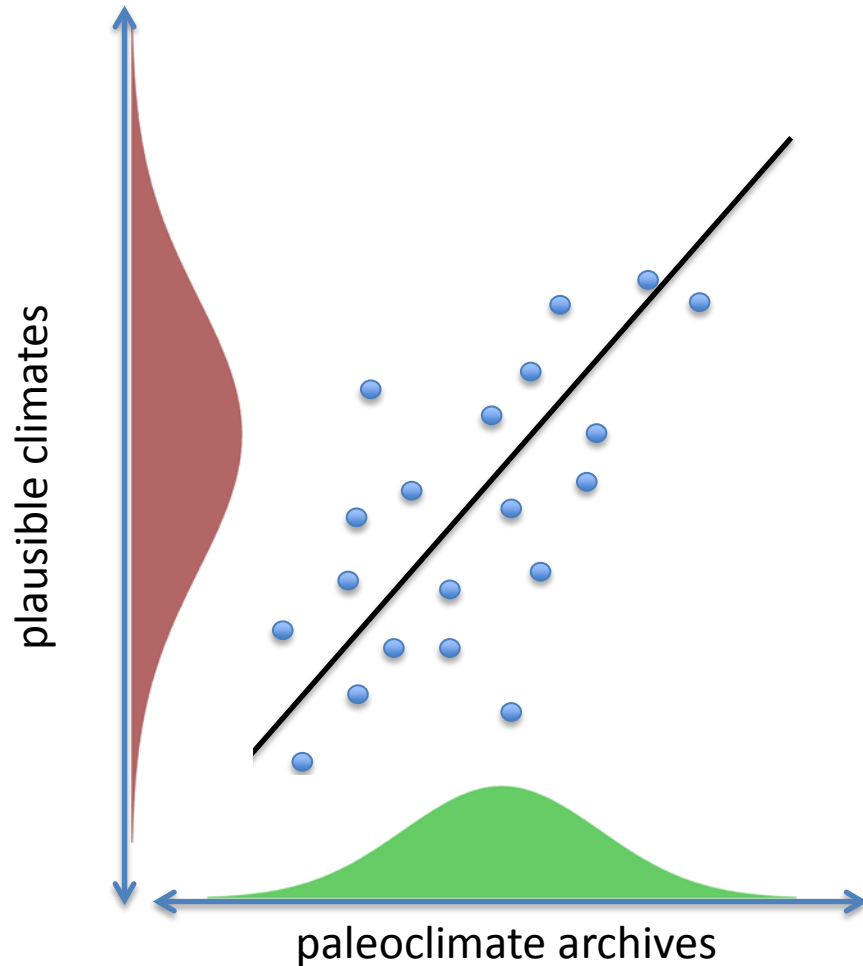
# Future work



(coming soon...)



# Future work



**Single-forcing experiments**  
(proposed)

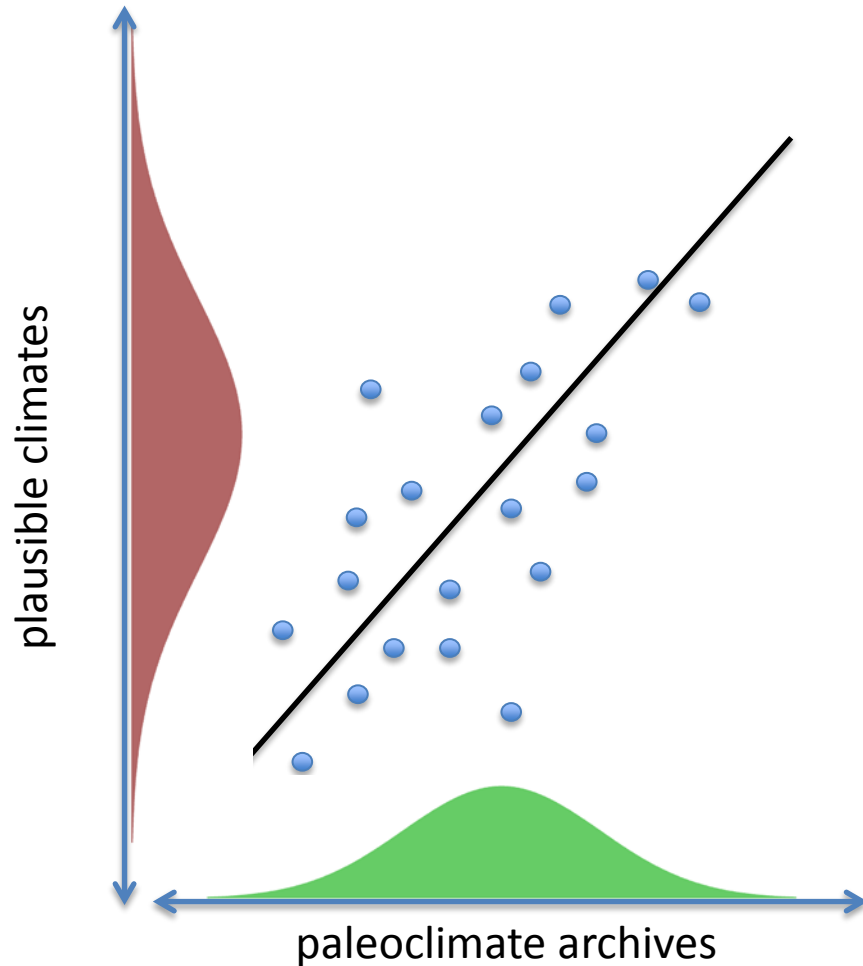
**Comparison with other models**  
(CMIP5/PMIP3)

**Model Hierarchy**  
(e.g., last 1ka forcings with CAM5)

**Forward or “process” models**  
(model the proxy from GCM output)

**Dynamically-constrained reconstructions**

# Future work



**Single-forcing experiments**  
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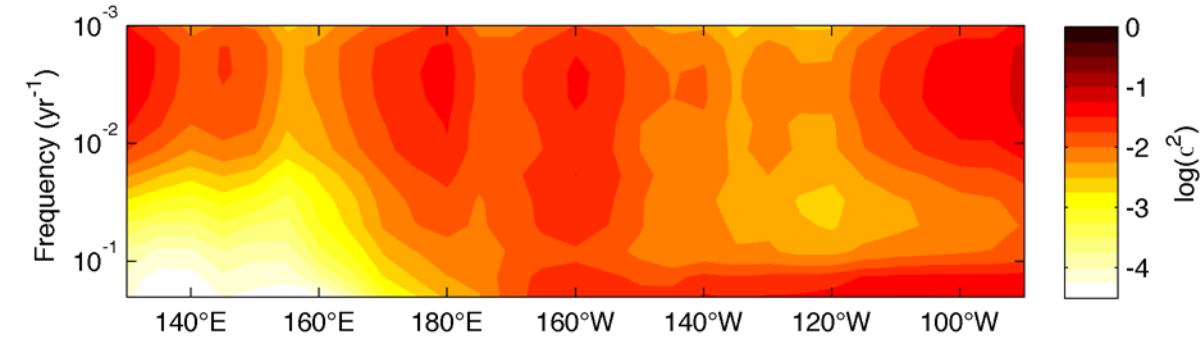
Thanks!

[extra slides]

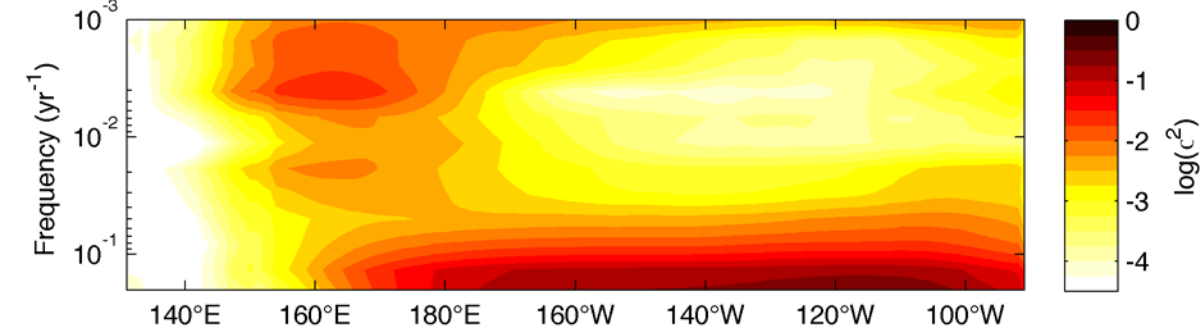
# Spatial information

## Model spectra

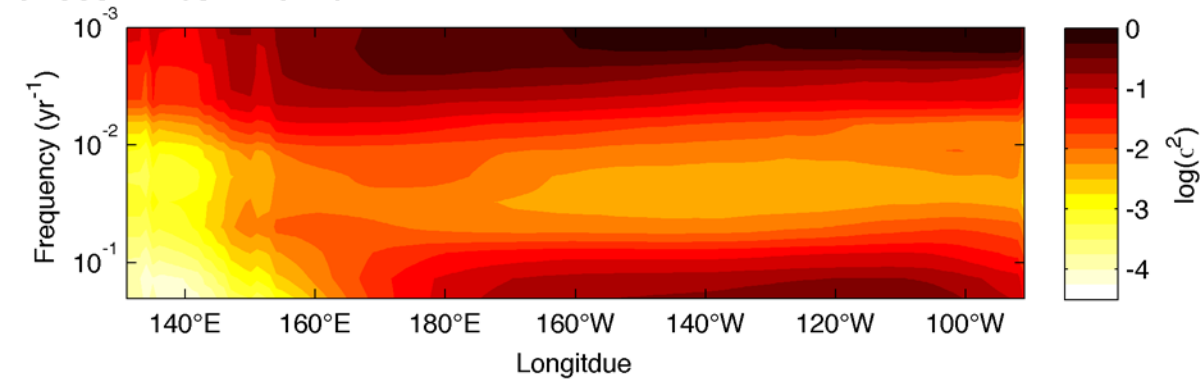
a. LIM - ensemble mean



b. CCSM4 - control

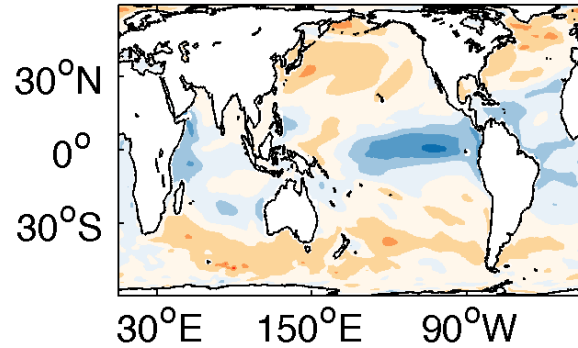


c. CCSM4 - last millennium

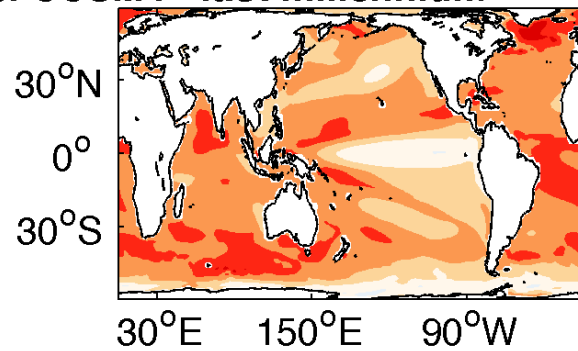


# Spatial information

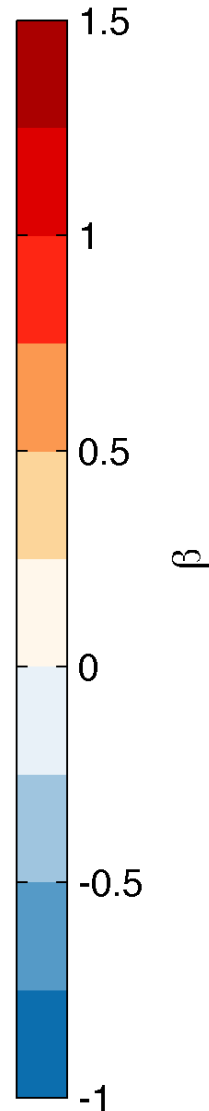
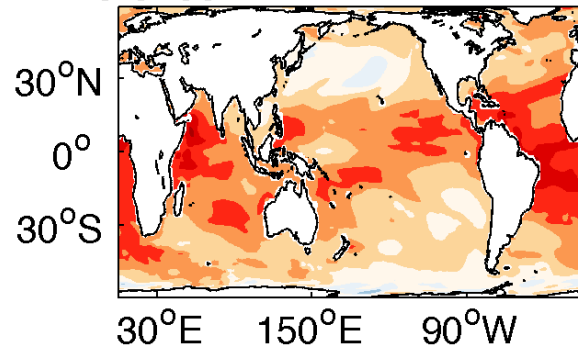
a. CCSM4 - control

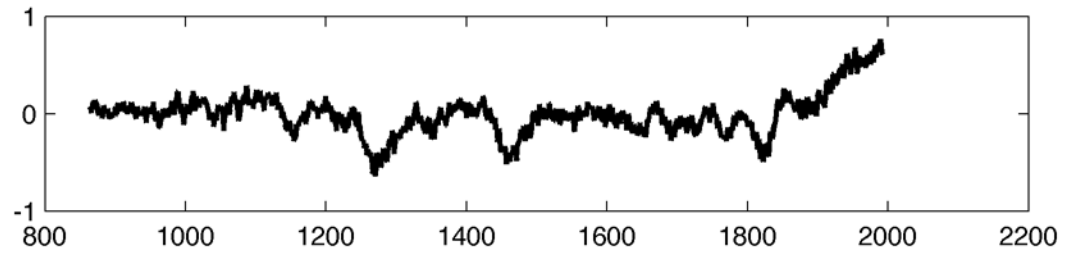
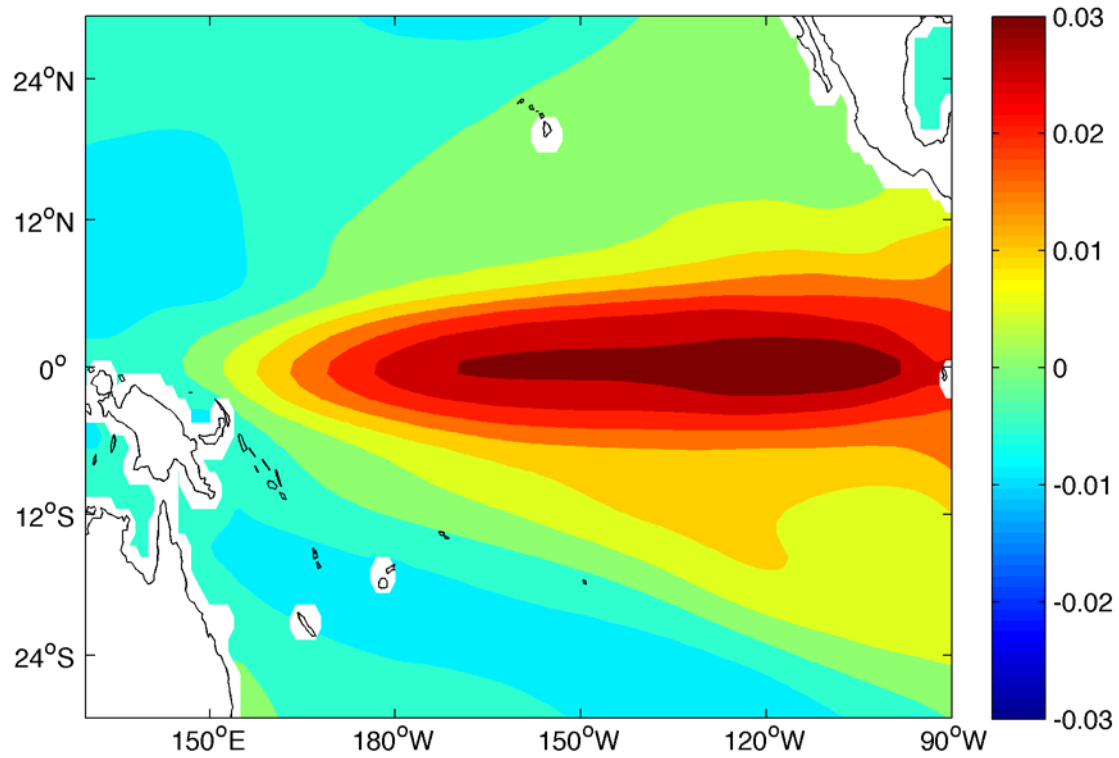


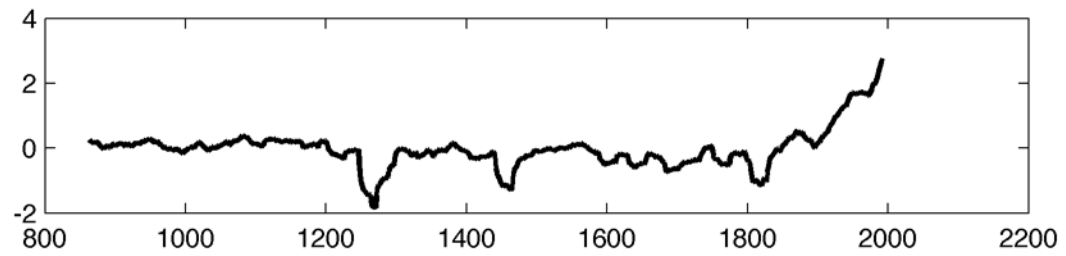
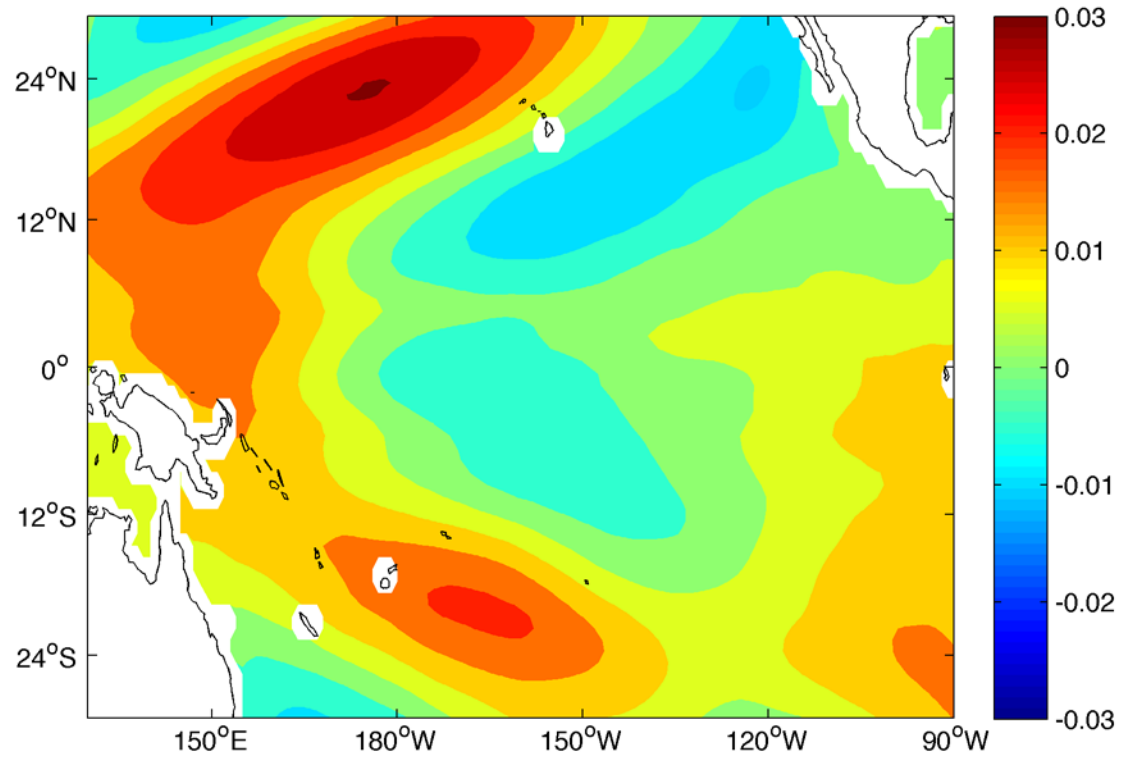
b. CCSM4 - last millennium



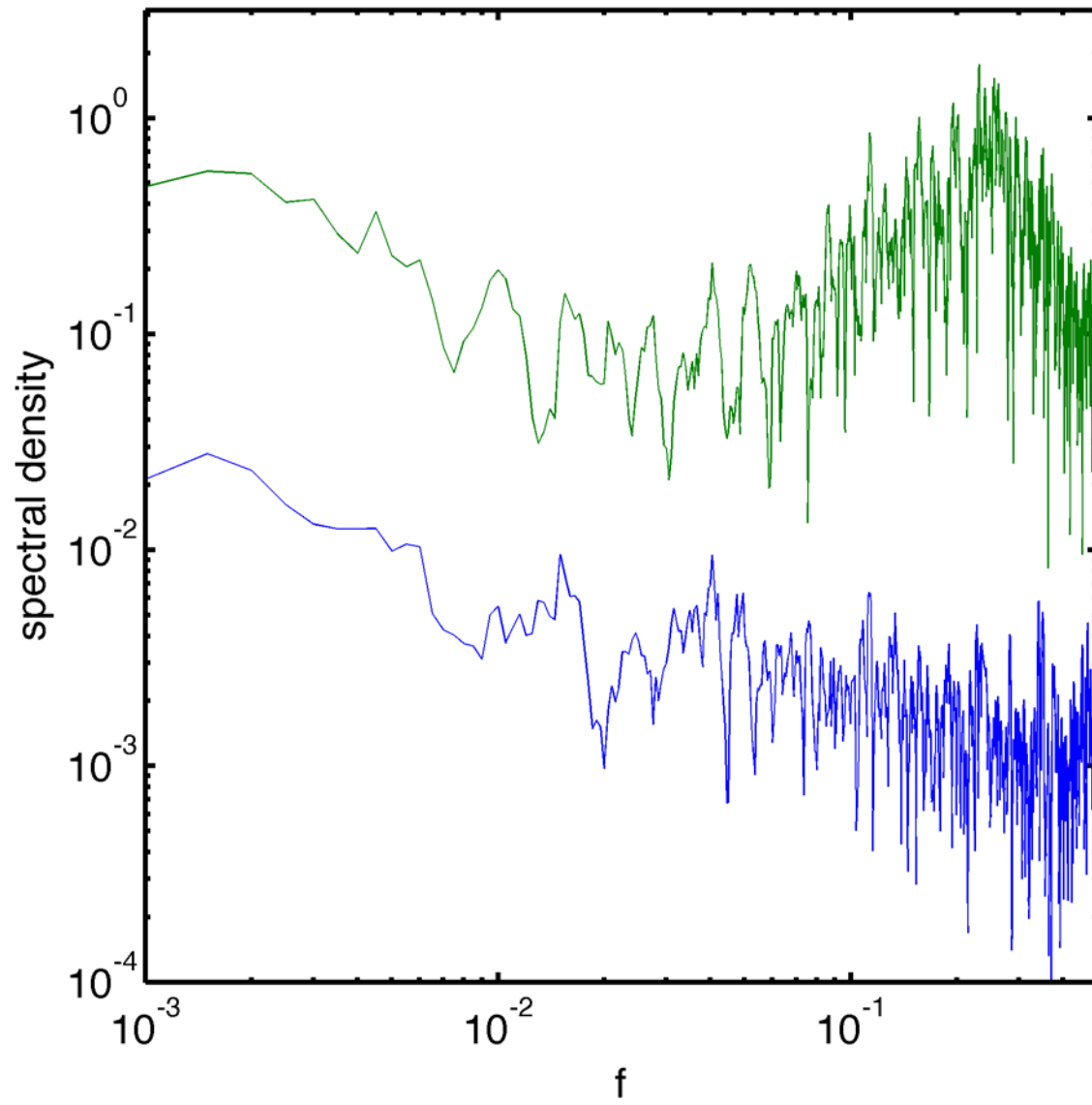
c. Difference

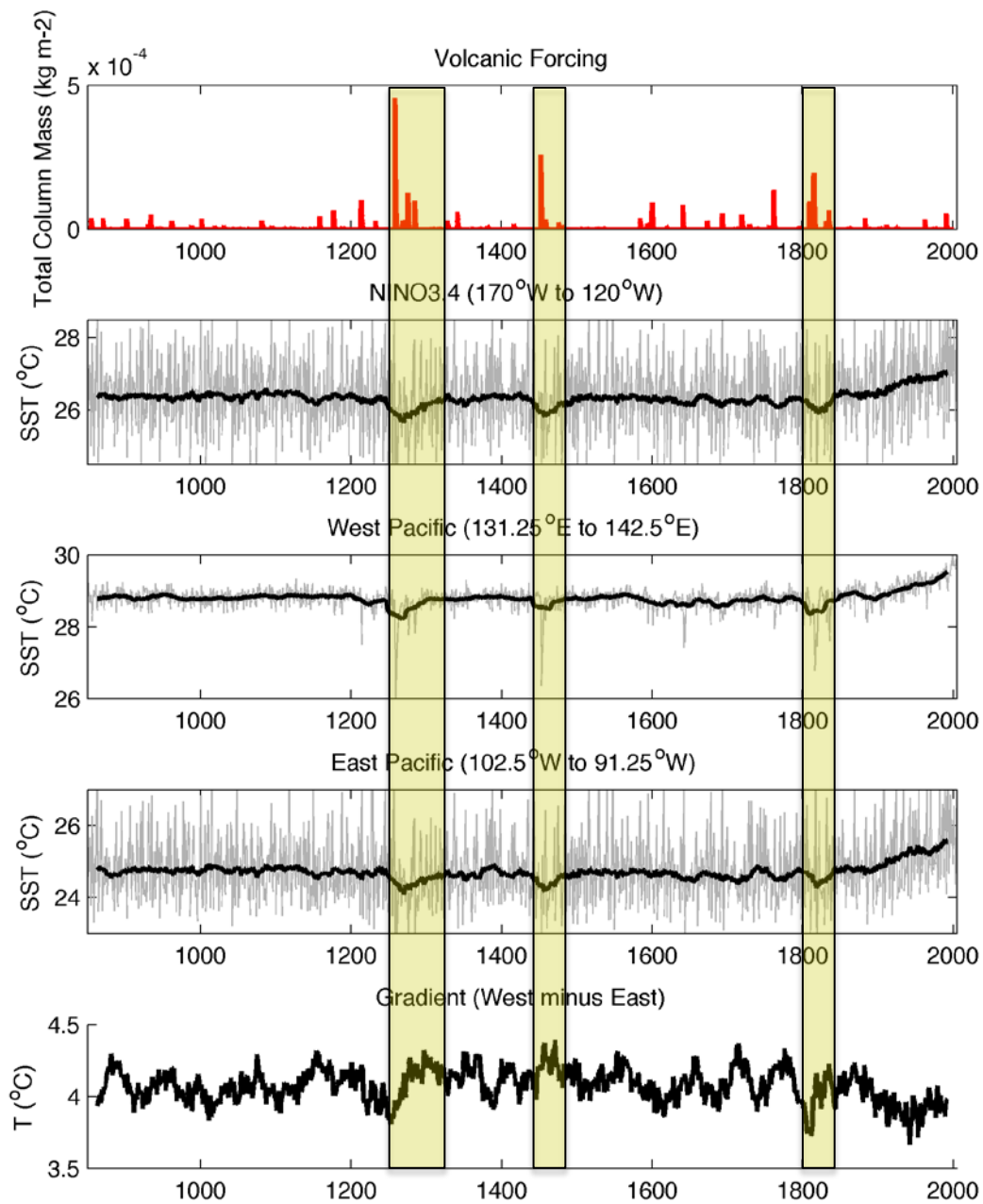






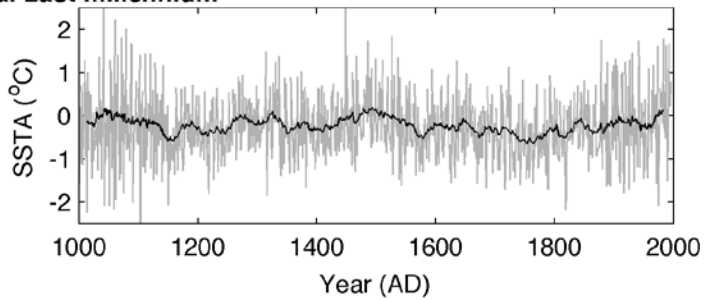




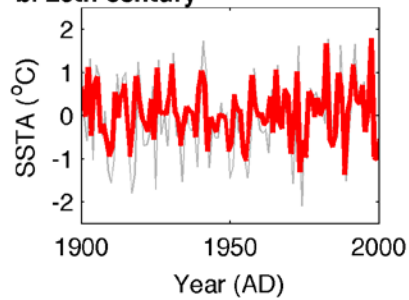


# NINO3.4 time series

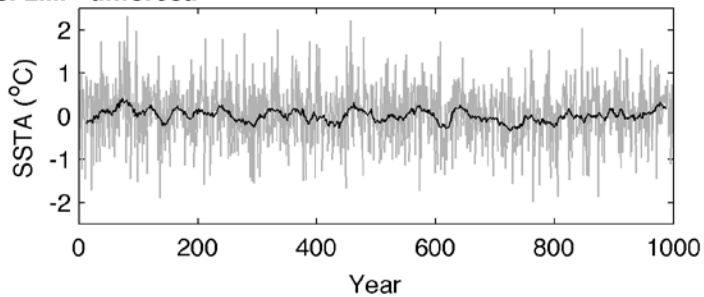
**a. Last millennium**



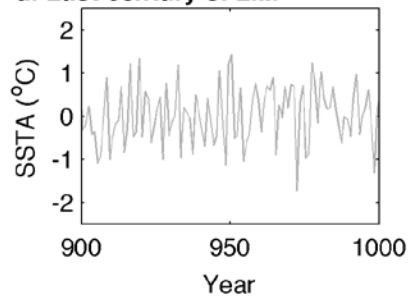
**b. 20th century**



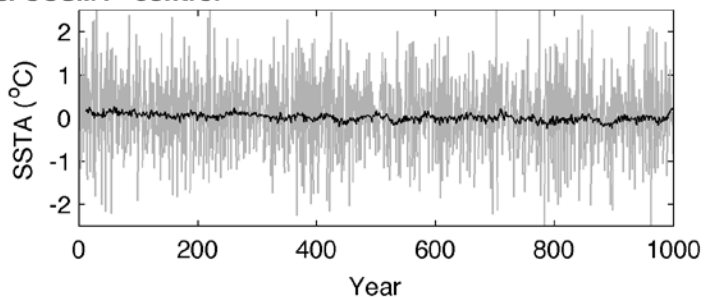
**c. LIM - unforced**



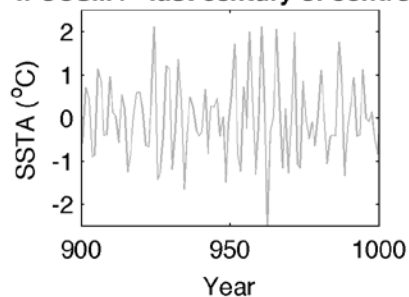
**d. Last century of LIM**



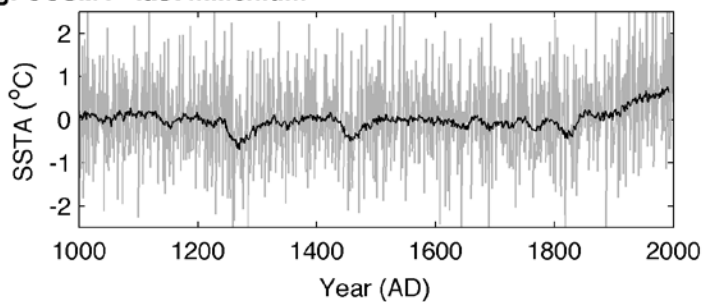
**e. CCSM4 - control**



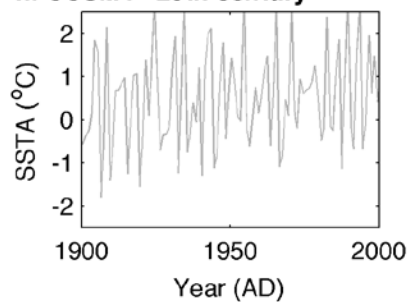
**f. CCSM4 - last century of control**



**g. CCSM4 - last millenium**



**h. CCSM4 - 20th century**



# Global Annual Tom Fluxes [Nov 22 2

