Proxies and processors: Integrating palaeoclimate archives with climate system models

Steven J. Phipps

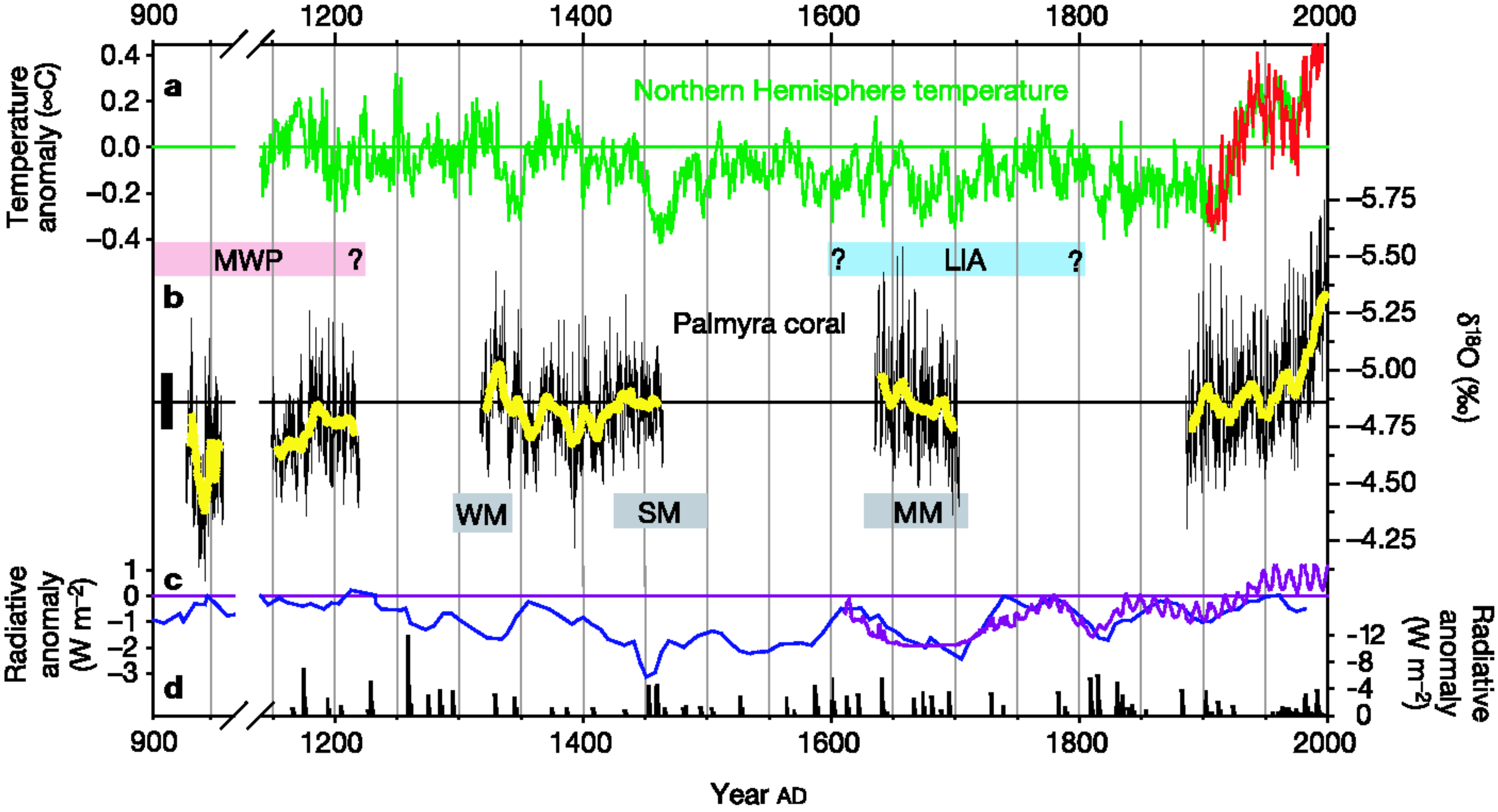
Climate Change Research Centre
University of New South Wales

Overview

- Data-model integration
- Example 1: El Niño over the past 8,000 years
- Example 2: Climate of the past 2,000 years
- Example 3: Regime classification
- Conclusions

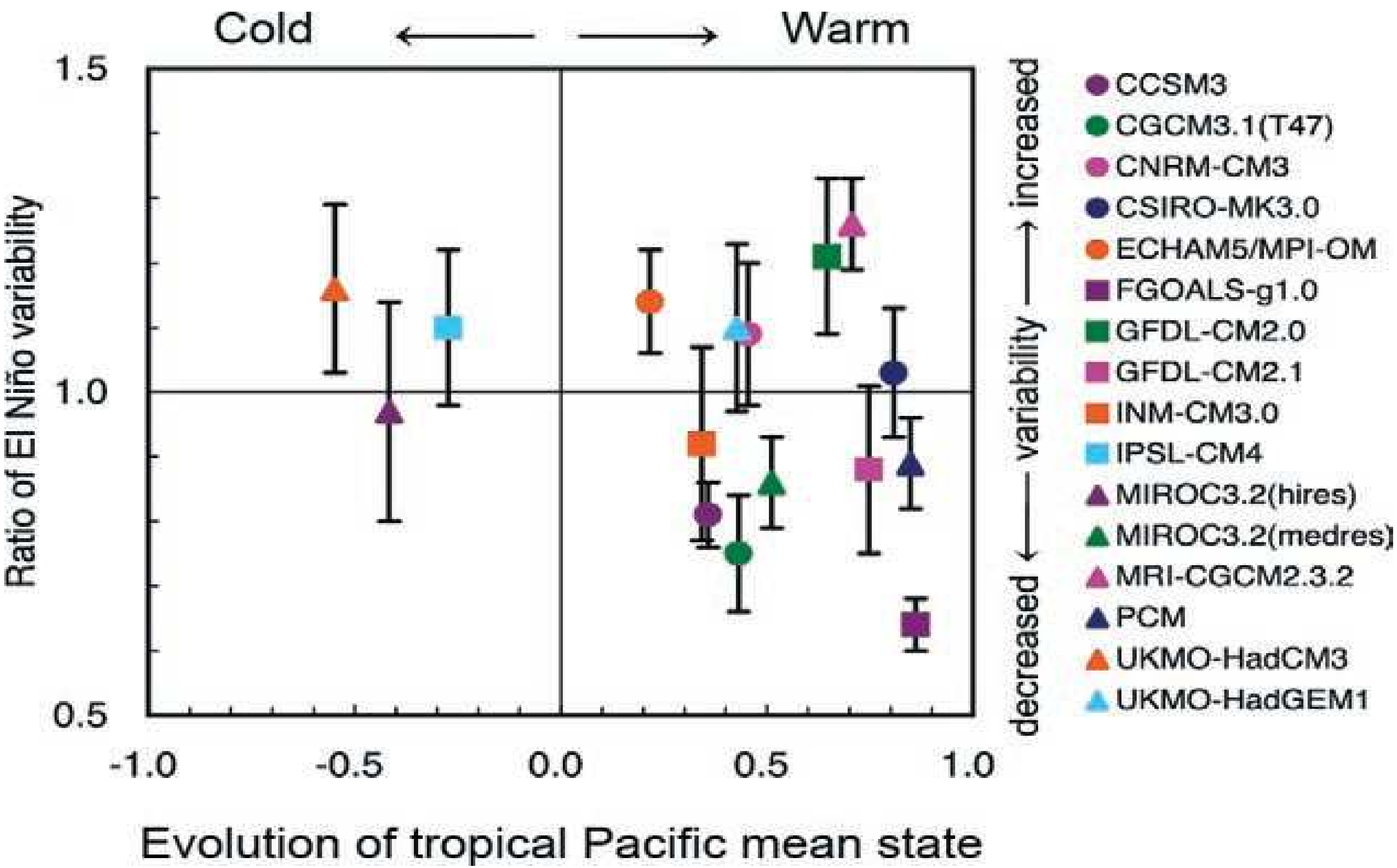
Data-model integration

Palmyra Island: El Niño over the past millennium



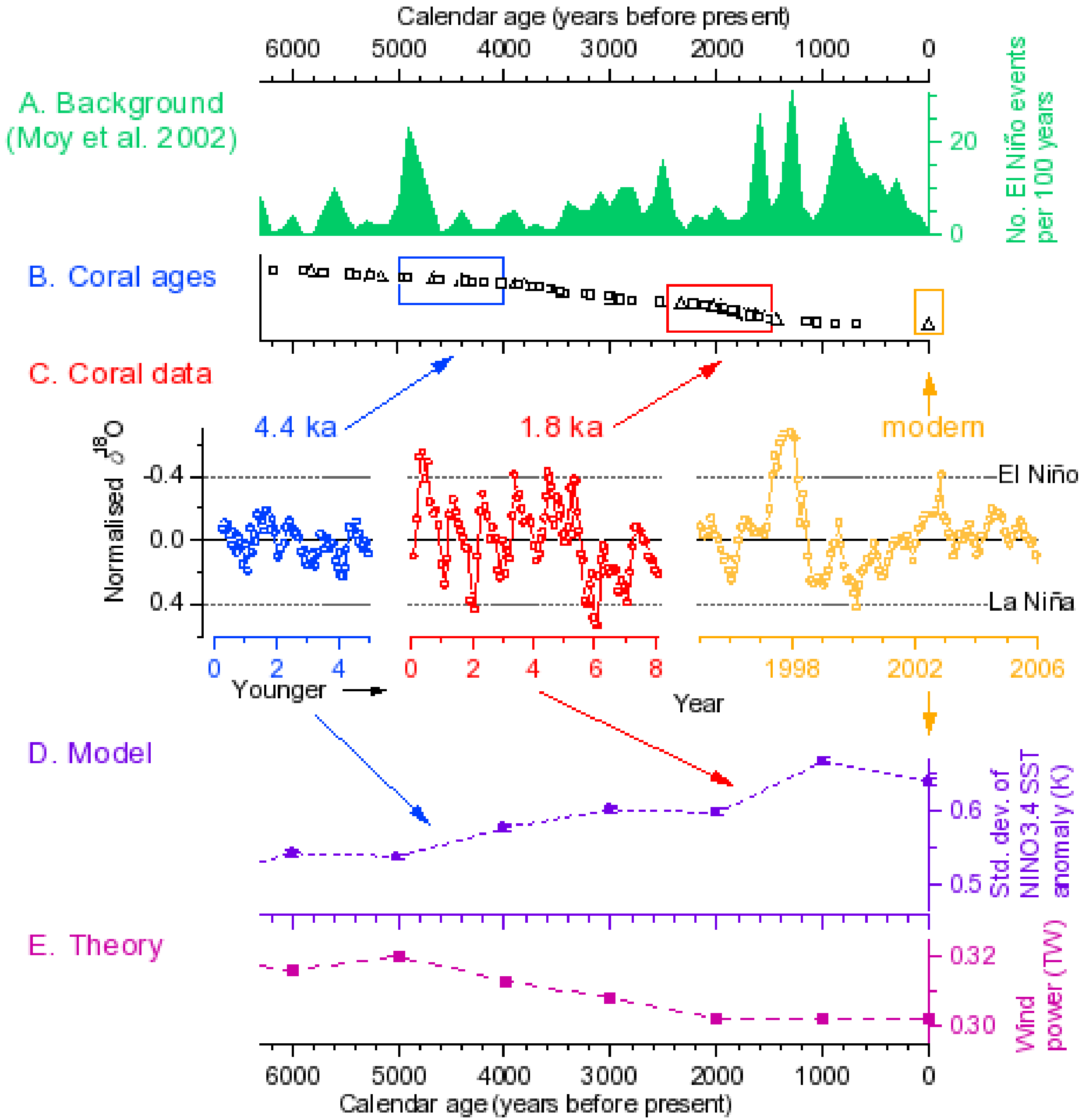
Cobb et al. (2003), *Nature*

But what about the future?



Guilyardi et al. (2009), *BAMS*

Integrating the data and the models

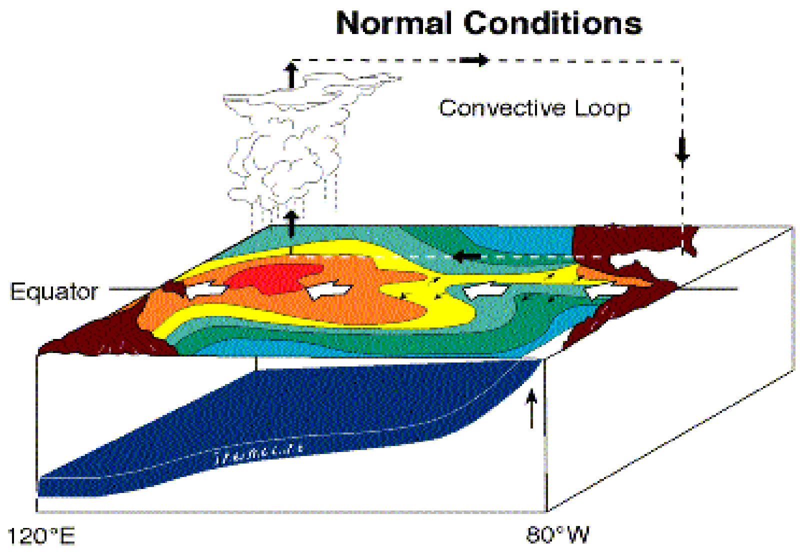


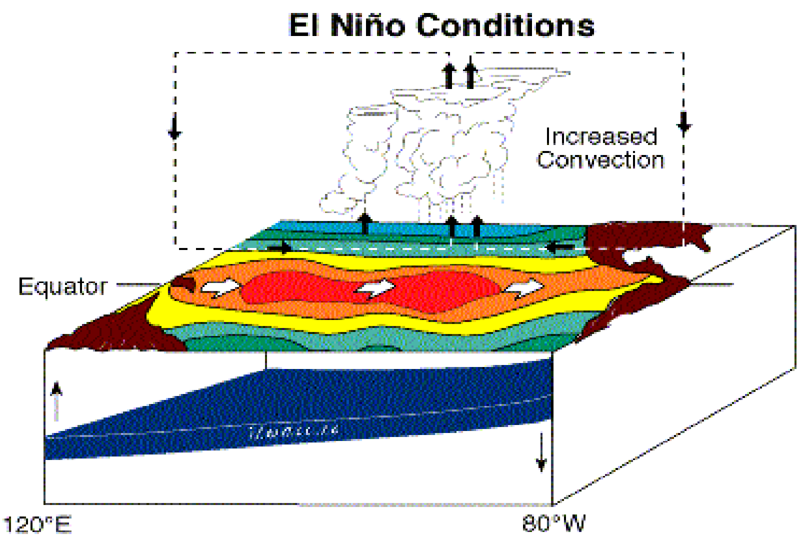
- Data-model integration is a two-way process
- The data constrains the model simulations
- The models provide the dynamical interpretation of the data

Example 1:

El Niño over the past 8,000 years

What is El Niño?

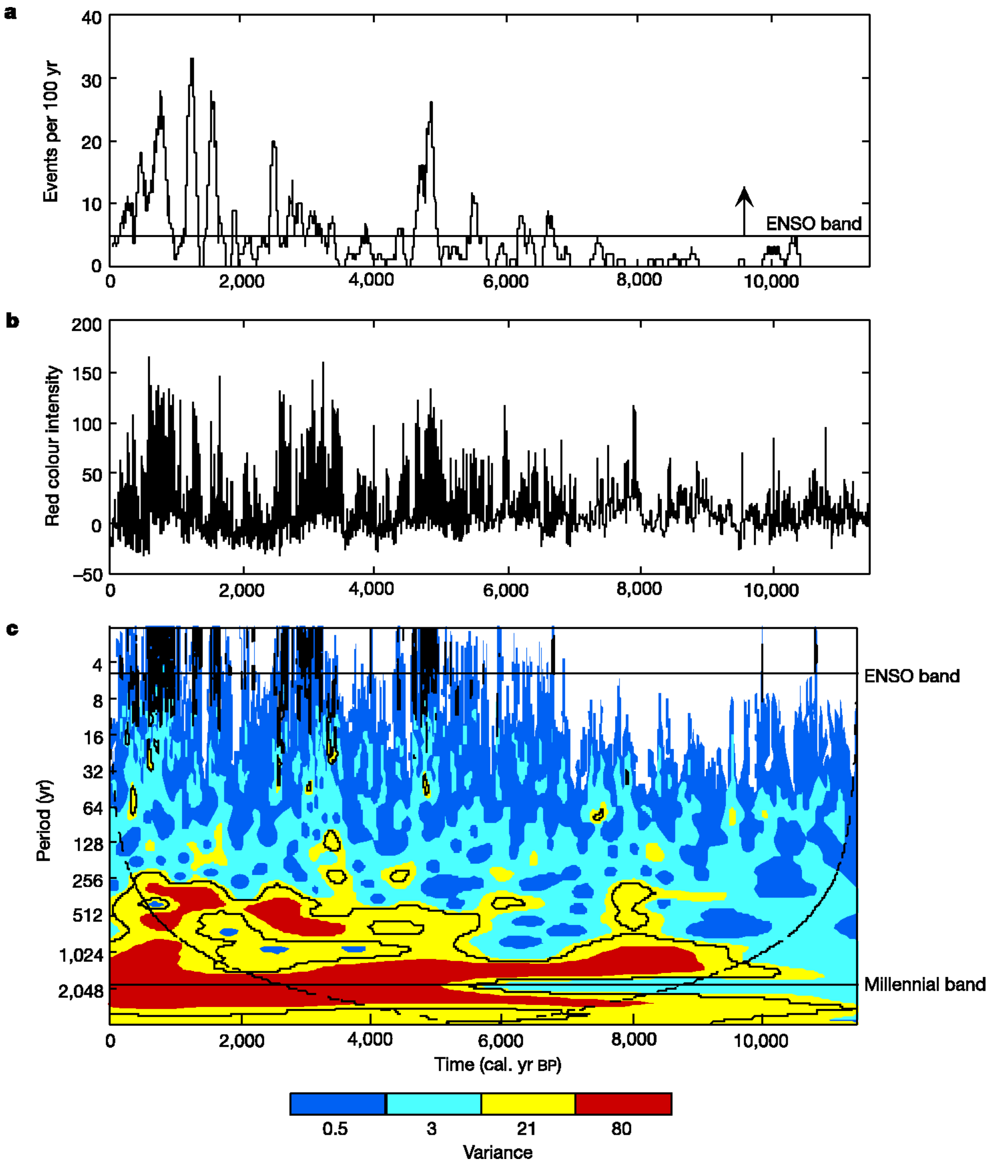




NOAA/PMEL/TAO

- El Niño–Southern Oscillation (ENSO) is the dominant mode of internal variability within the coupled atmosphere-ocean system
- Irregular period of ∼2–7 years
- Average state of the system involves strong easterly trade winds pushing warm water to the east
- In an El Niño event, these winds slacken and the warm water flows eastwards
- Increased rainfall in the eastern Pacific, reduced rainfall in the west

El Niño has changed over the Holocene ...



Moy et al. (2002), *Nature*

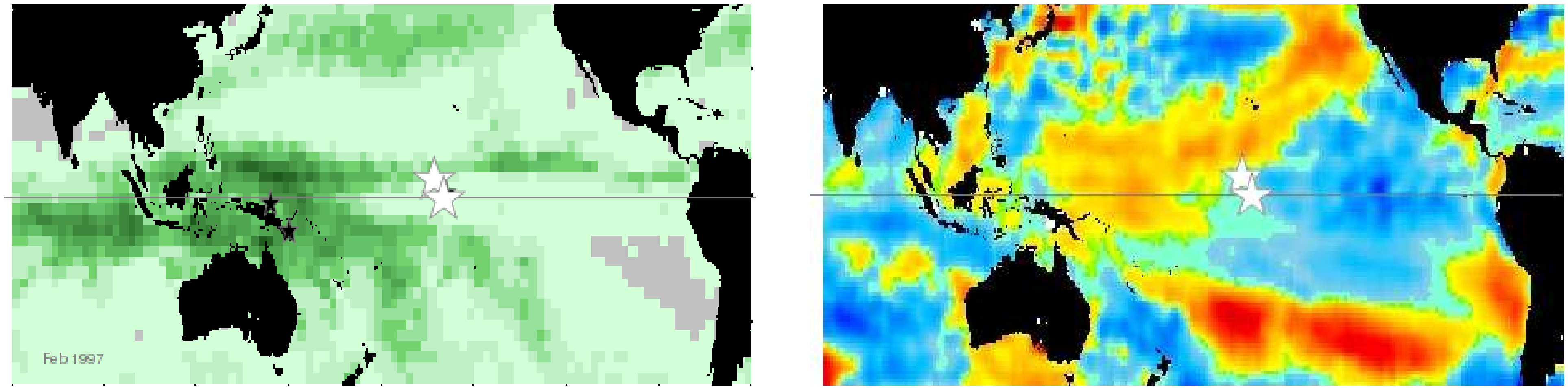
- ENSO variability has increased over the past 8,000 years
- El Niño events have increased in frequency and magnitude
- Evidence of a peak in ENSO variability at 2–1 ka BP
- Strong variability on centennial and millennial timescales
- These changes provide an opportunity to learn more about ENSO dynamics

Data: the coral record

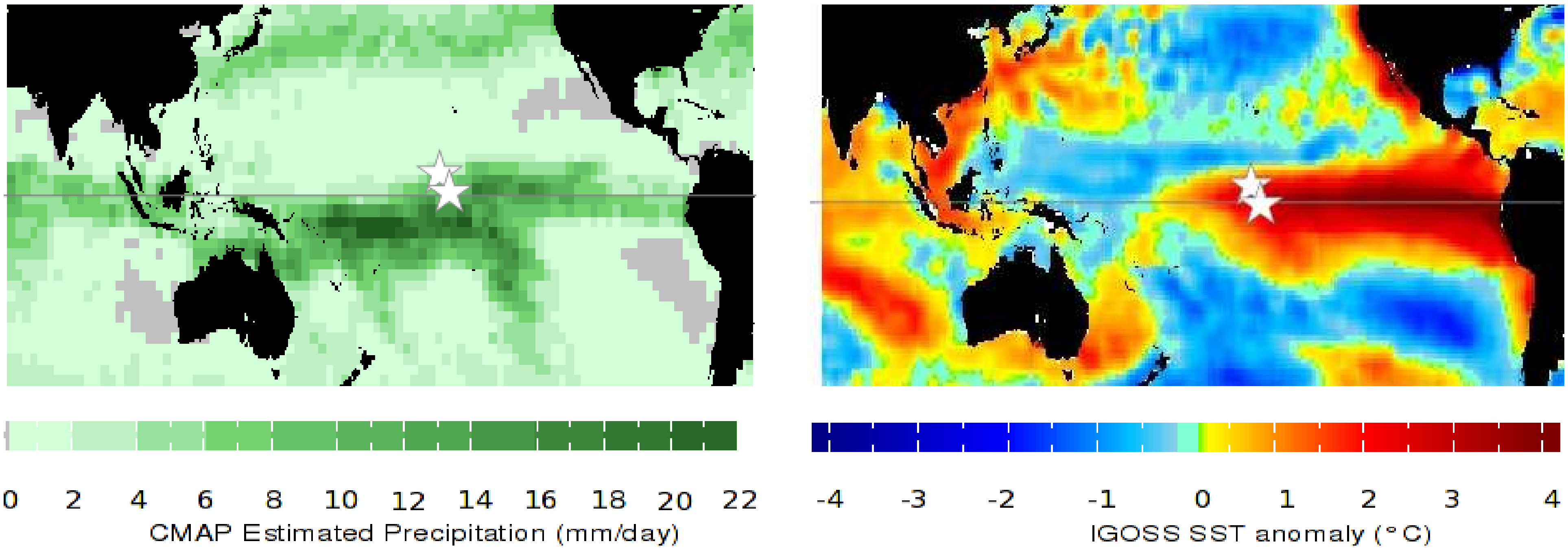
 

El Niño centres of action

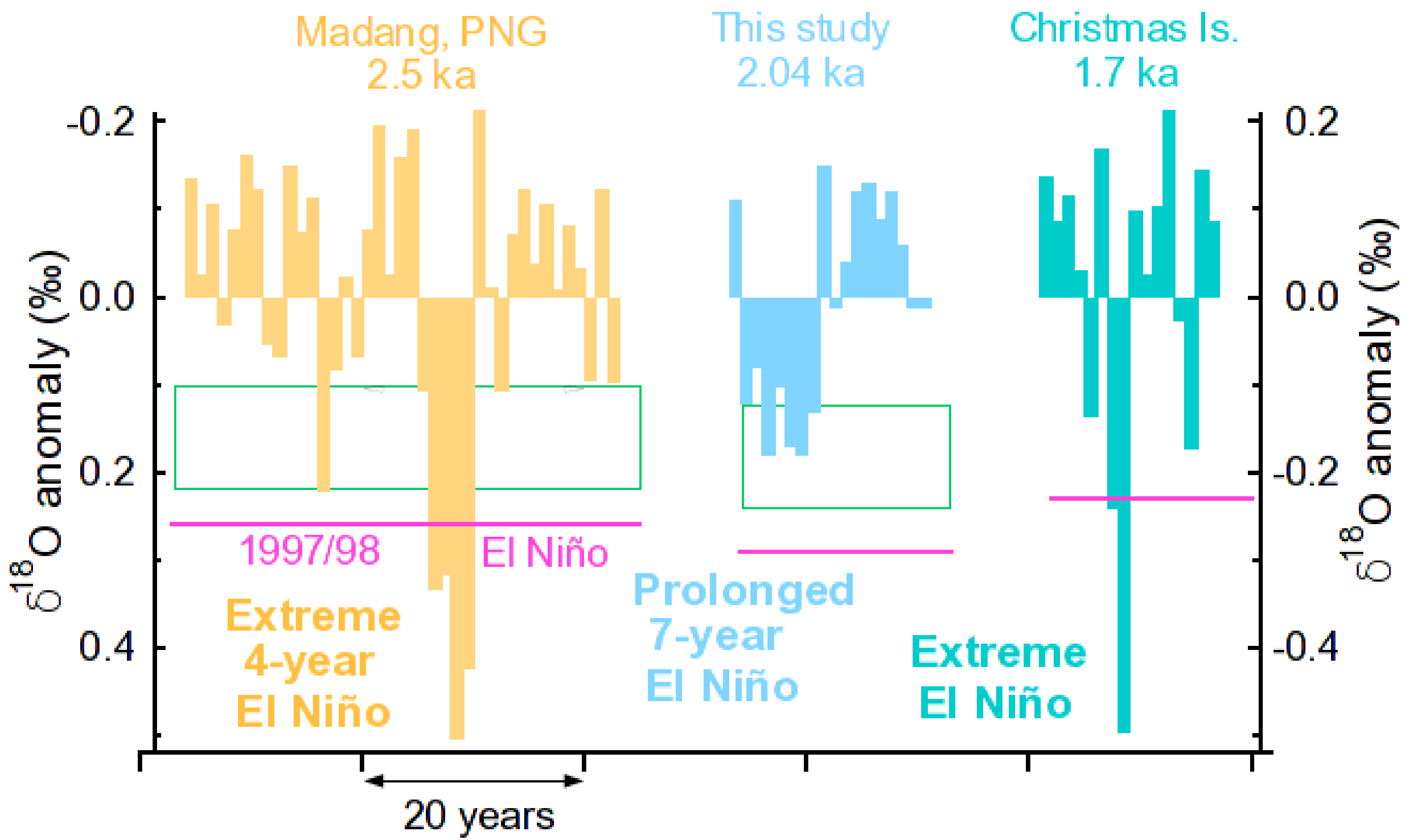
Normal years



El Niño years



Severe El Niño events at ∼2 ka?

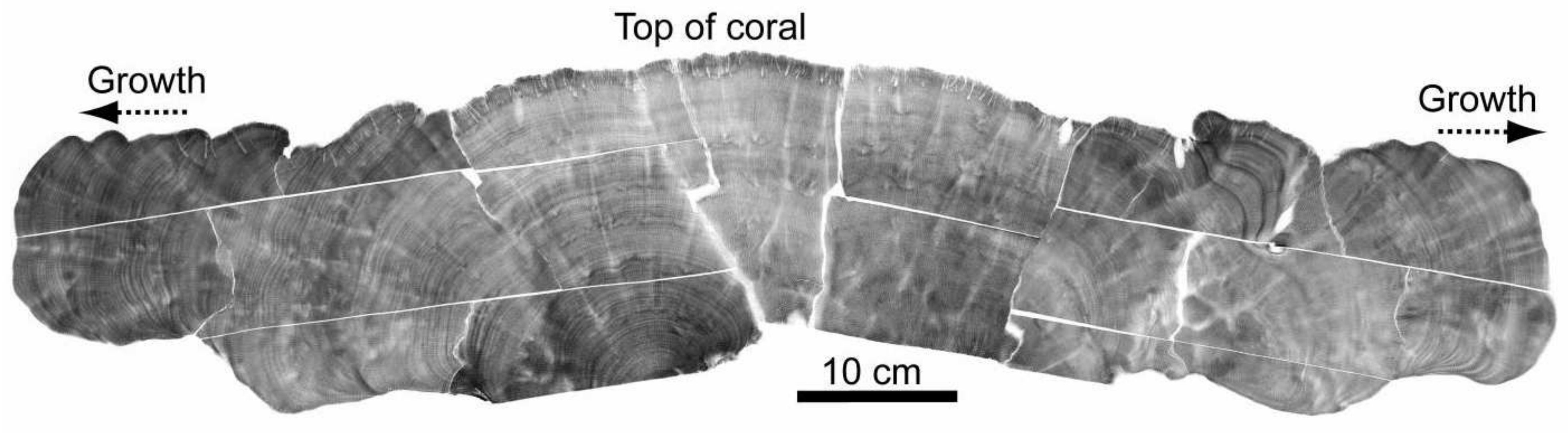


McGregor and Gagan (2004), *GRL*

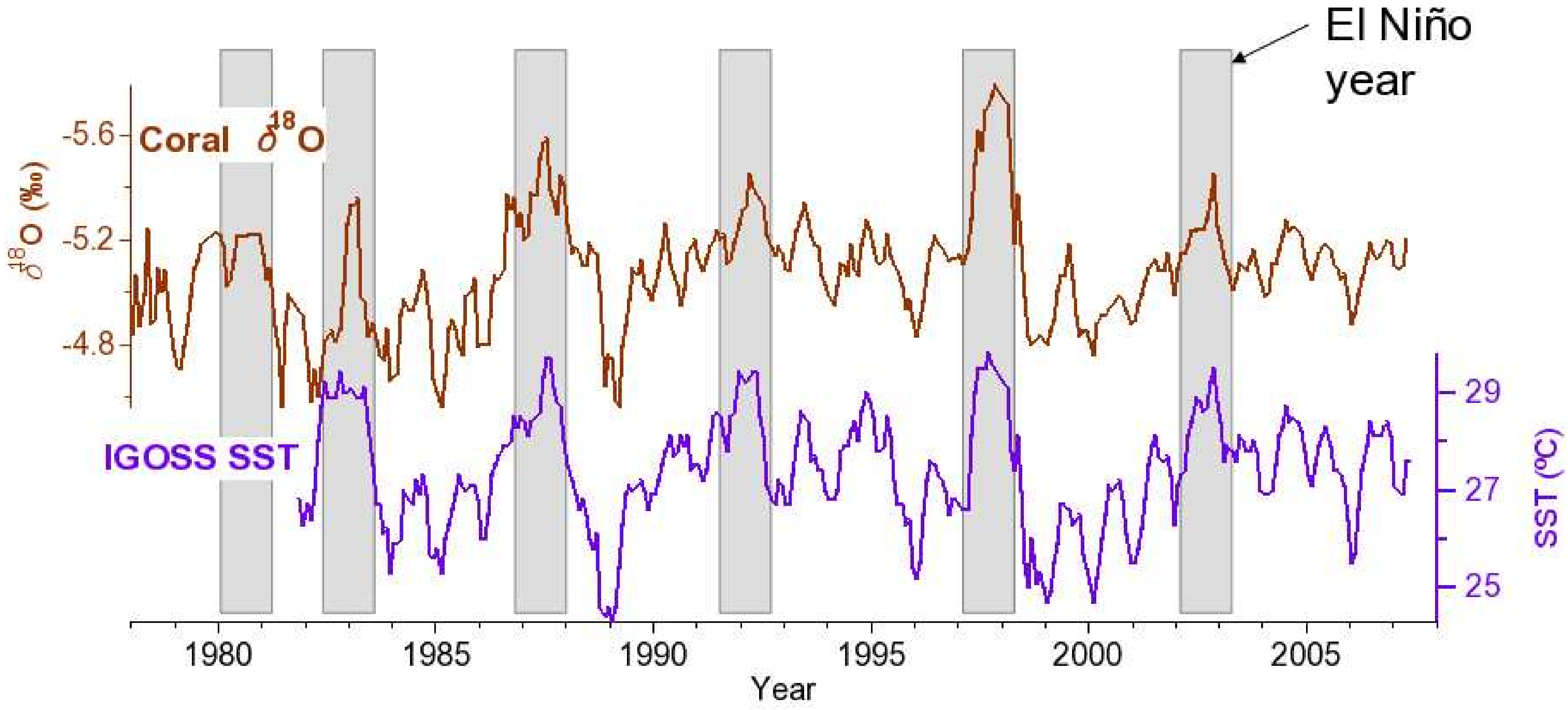
Extending the record: Microatolls from Kiritimati

Porites **head coral**

Porites **microatoll**

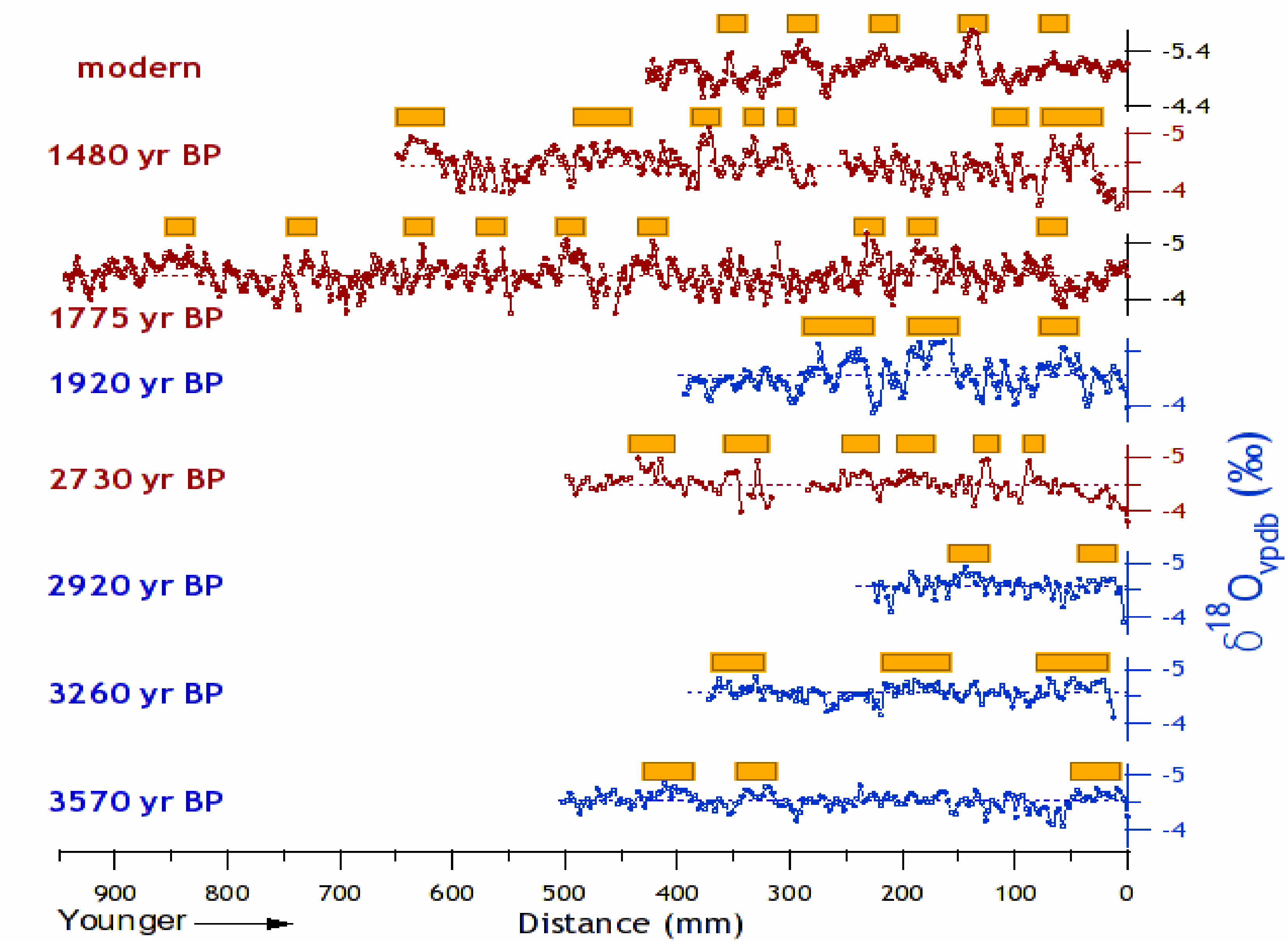


Modern coral $\delta^{18}O$ from Kiritimati calibrated against satellite sea surface temperature



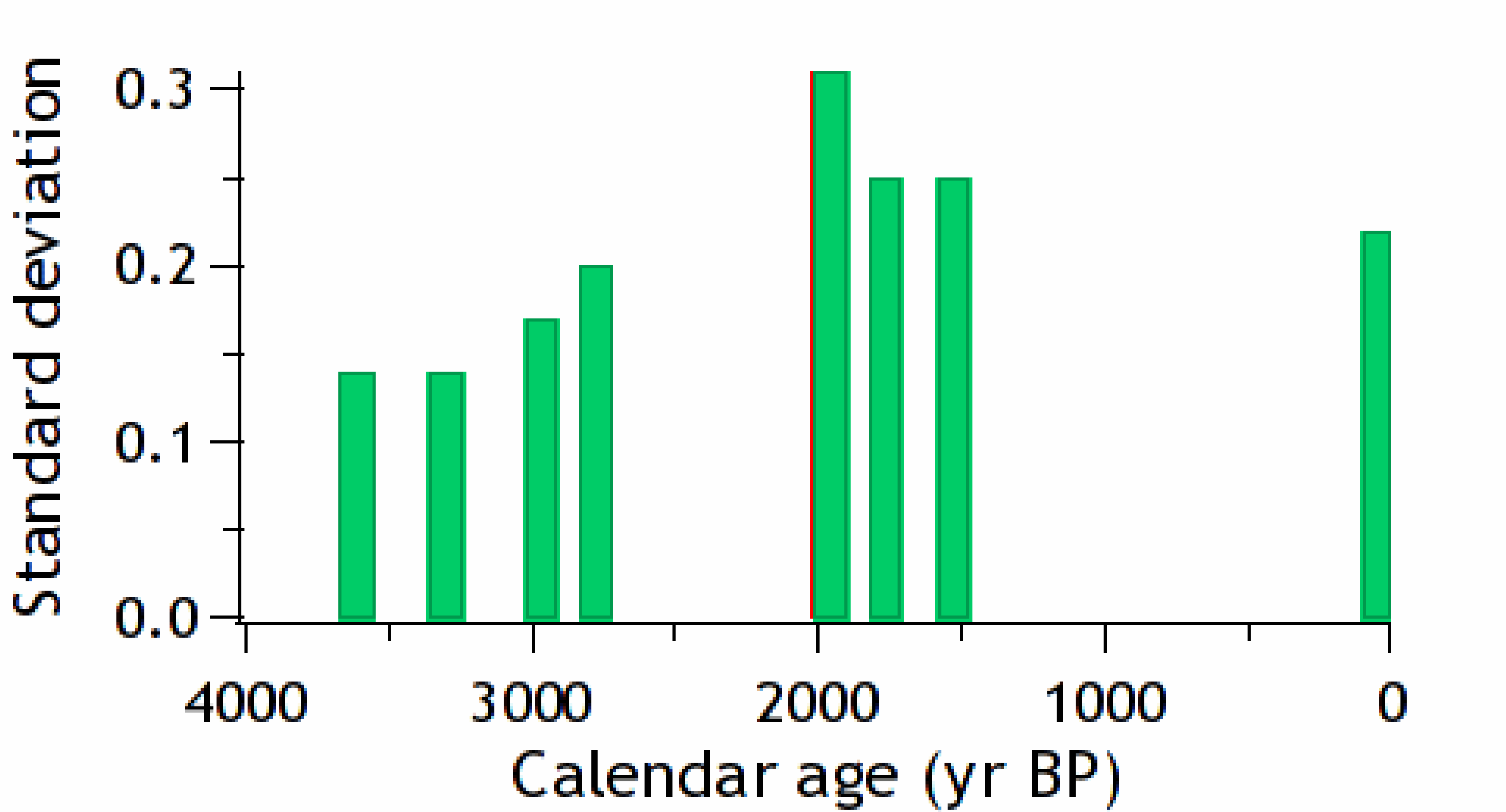
McGregor et al. (in prep.), *Geochimica et Cosmochimica Acta*

The Holocene $\delta^{18}O$ record from Kiritimati



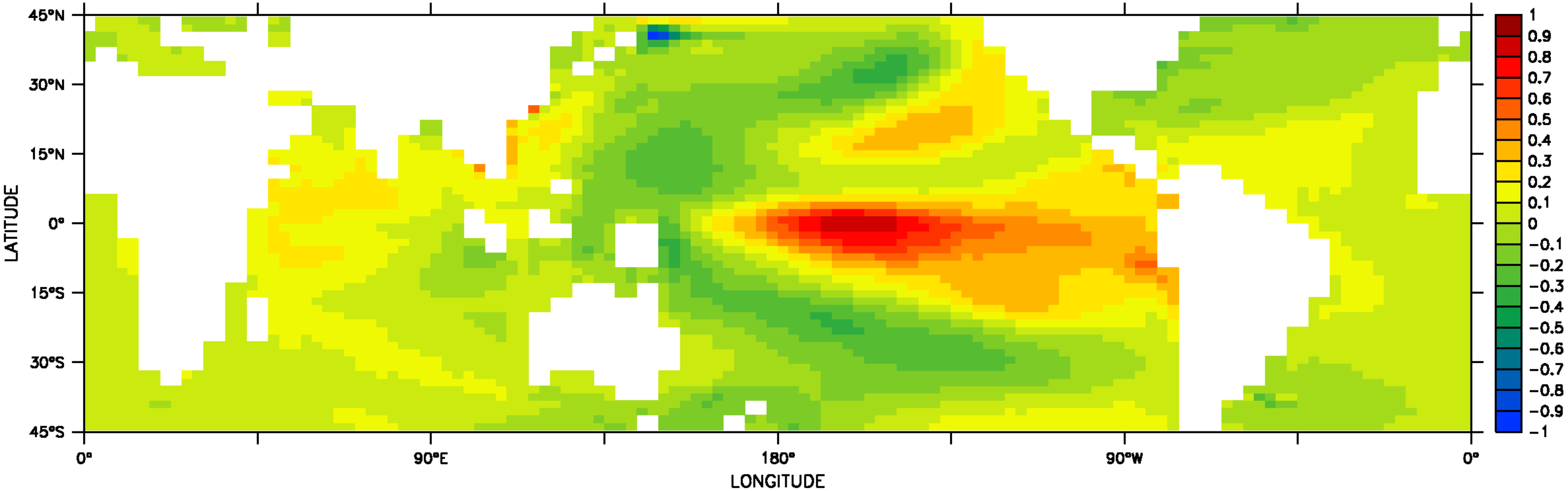
Woodroffe et al. (2003), *GRL*

Standard deviation of Kiritimati δ^{18}O: a measure of El Niño variability



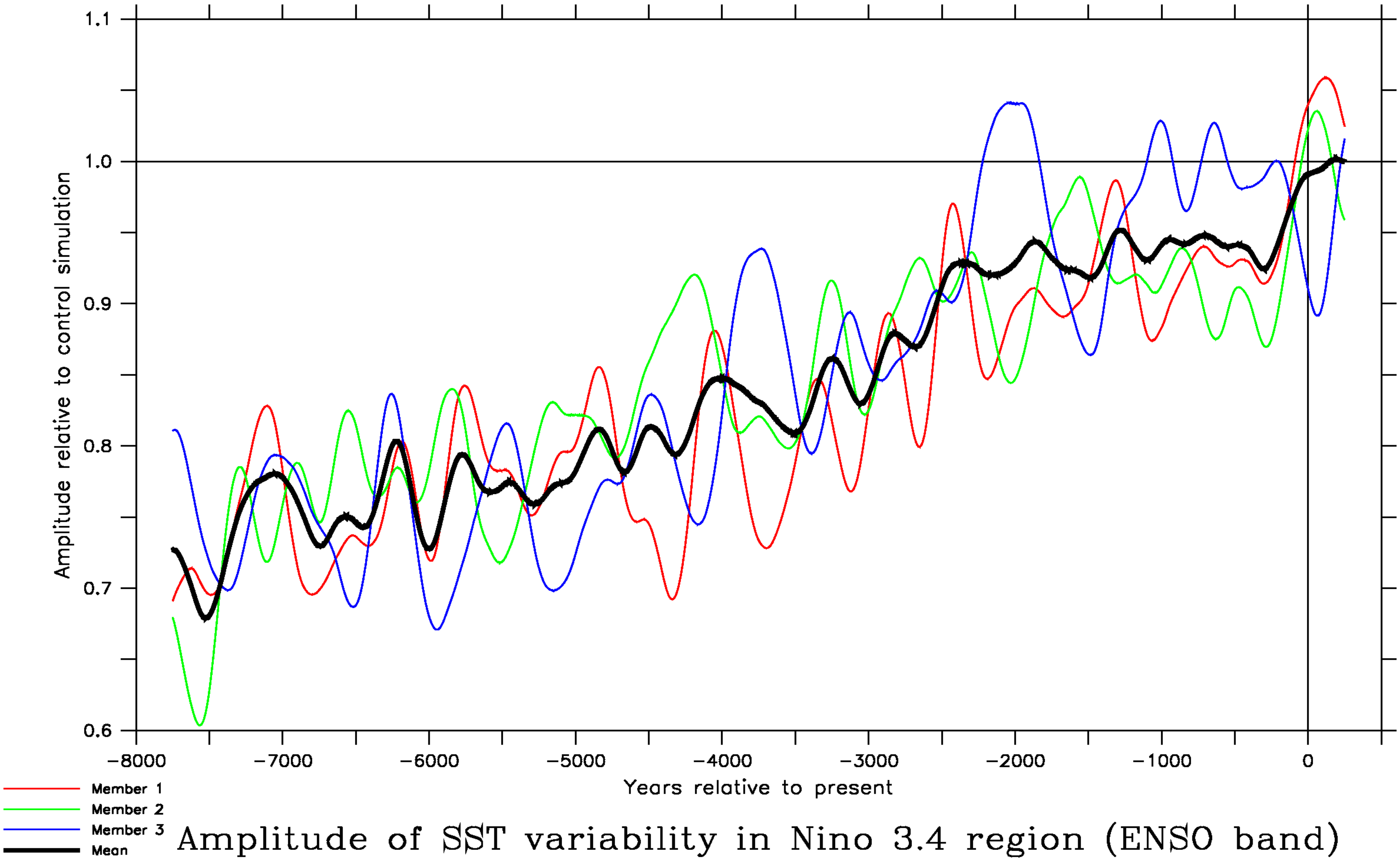
Model: CSIRO Mk3L

- Low-resolution coupled general circulation model:
  - Atmosphere: $5.6^\circ \times 3.2^\circ$, 18 vertical levels
  - Ocean: $2.8^\circ \times 1.6^\circ$, 21 vertical levels
  - Sea ice: Dynamic-thermodynamic
  - Land surface: Static vegetation
- Three transient simulations of the past 8,000 years
- Orbital forcing only



Pre−industrial control simulation: PC1 of monthly SST anomalies

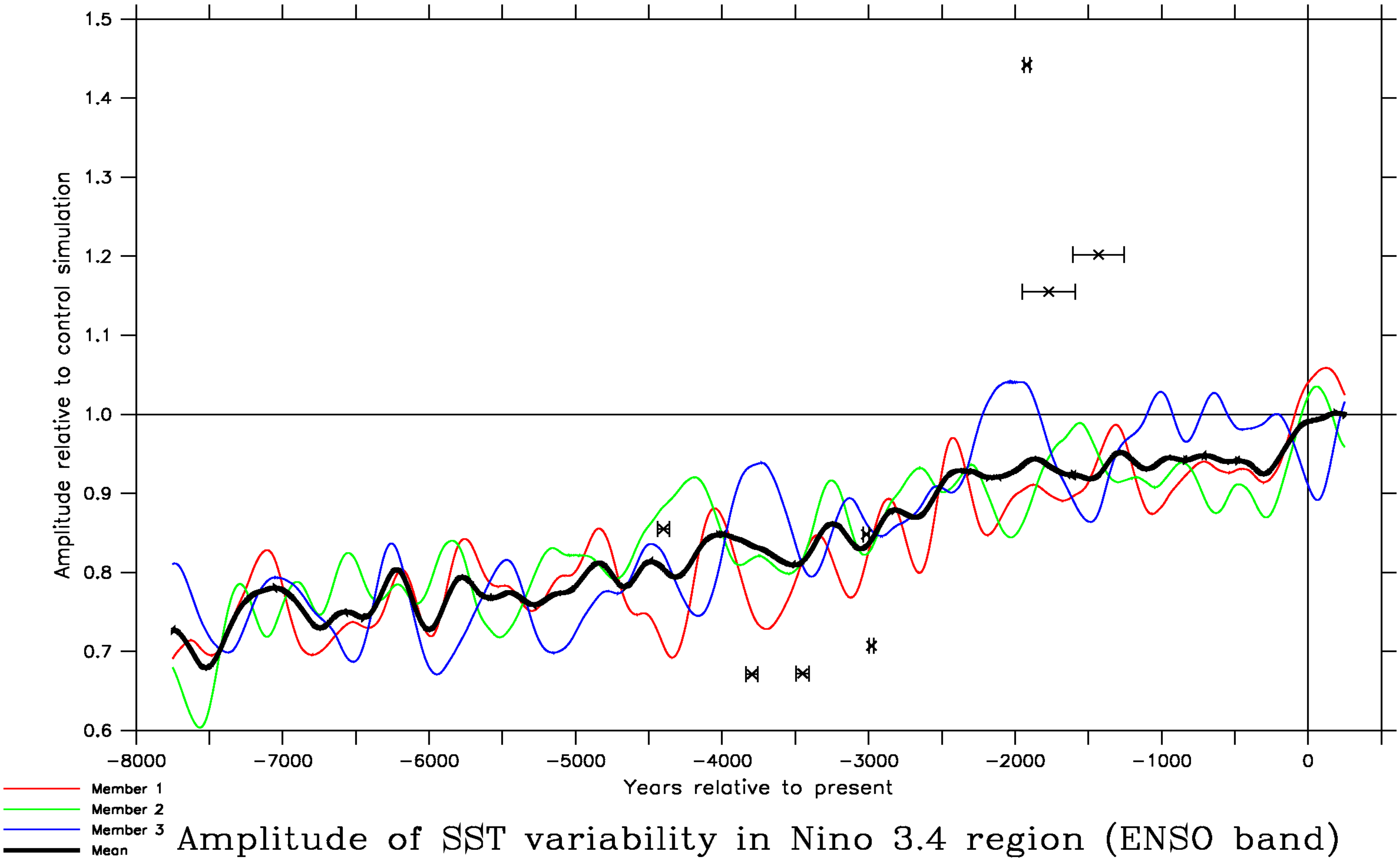
Simulated changes in El Niño variability



Amplitude of SST variability in Nino 3.4 region (ENSO band)

Phipps and McGregor (in prep.), *GRL*

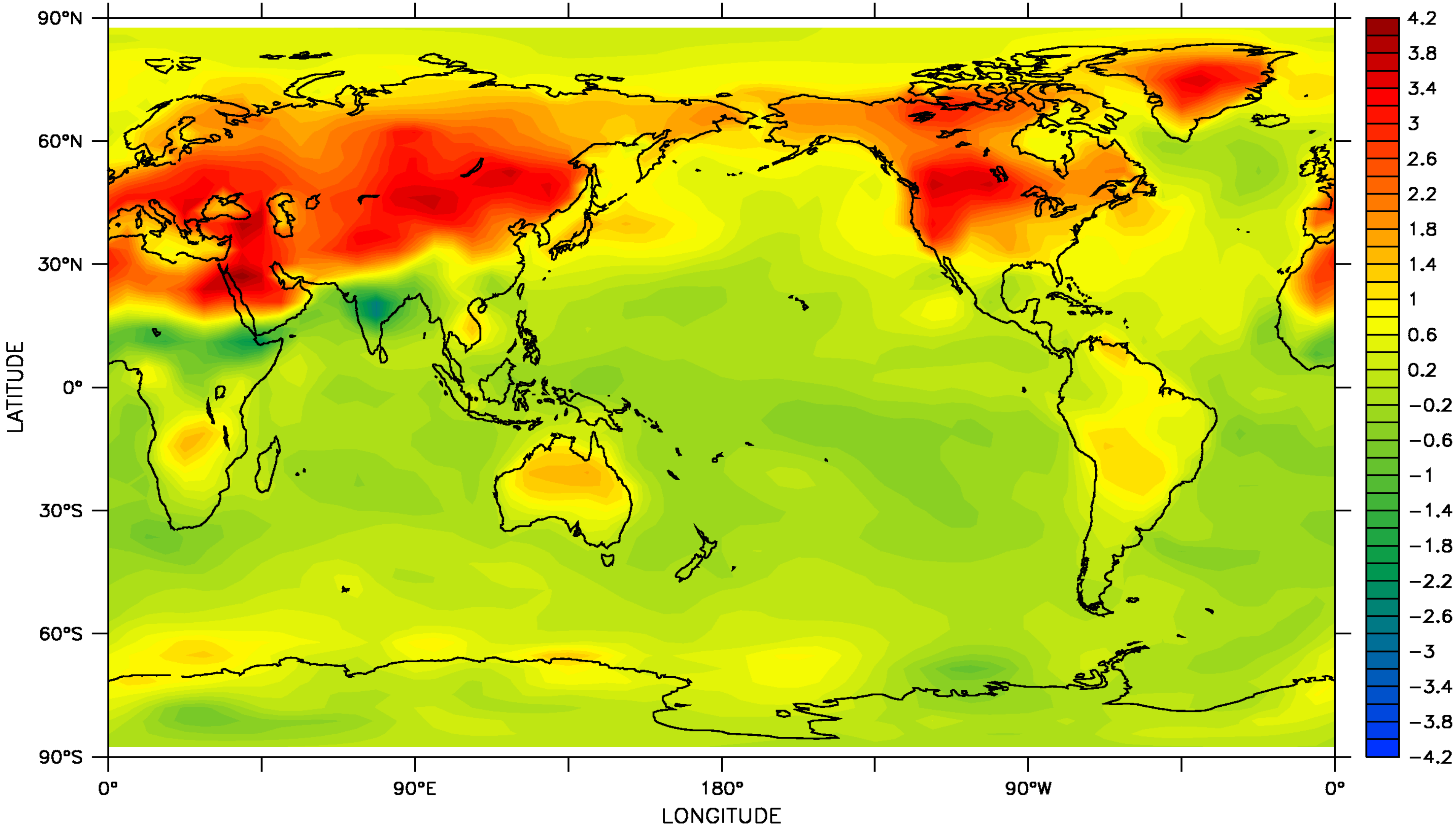
El Niño variability: data-model comparison



Amplitude of SST variability in Nino 3.4 region (ENSO band)

Phipps and McGregor (in prep.), *GRL*

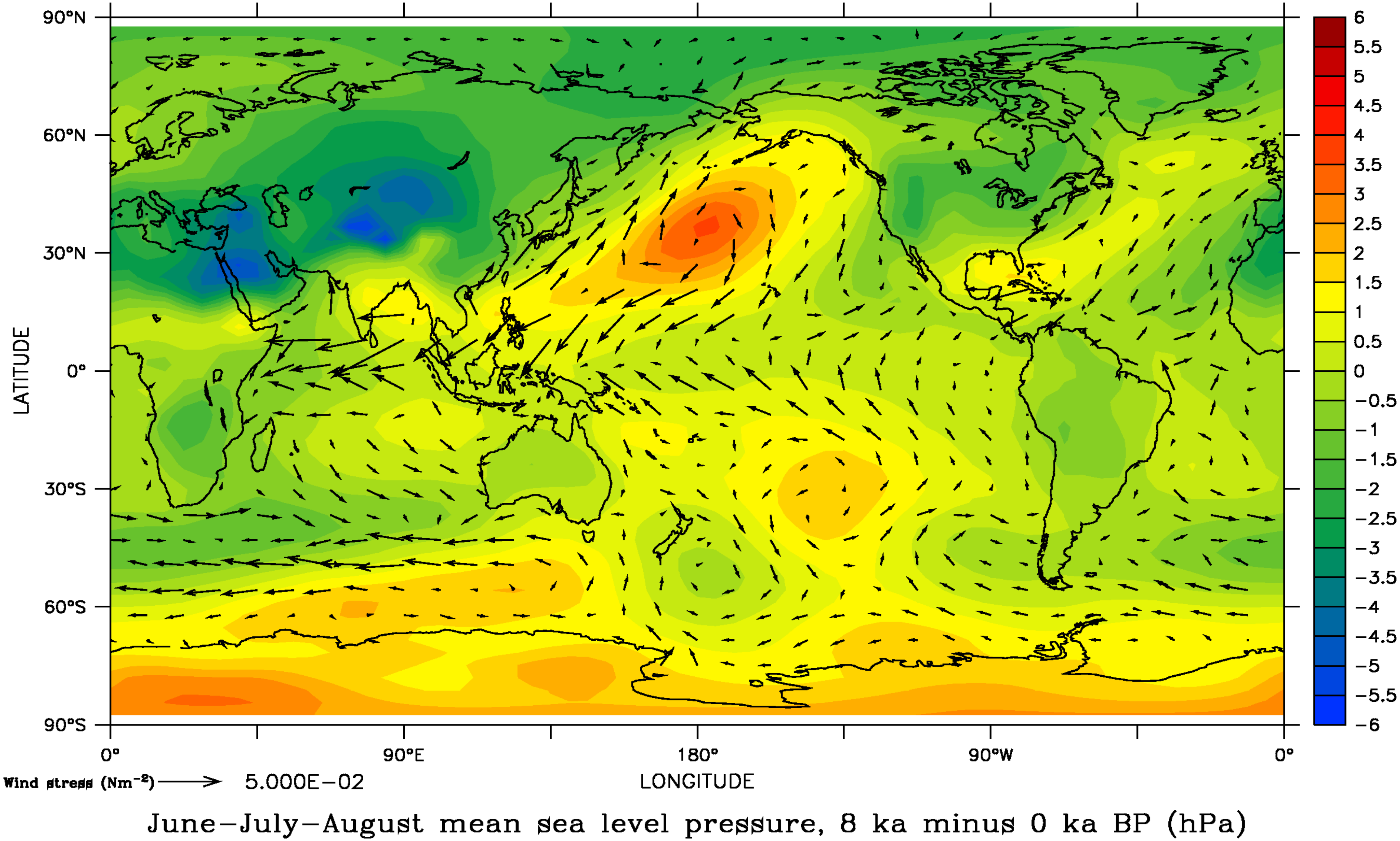
NH summers were warmer at 8 ka ...



June–July–August surface air temperature, 8 ka minus 0 ka BP (K)

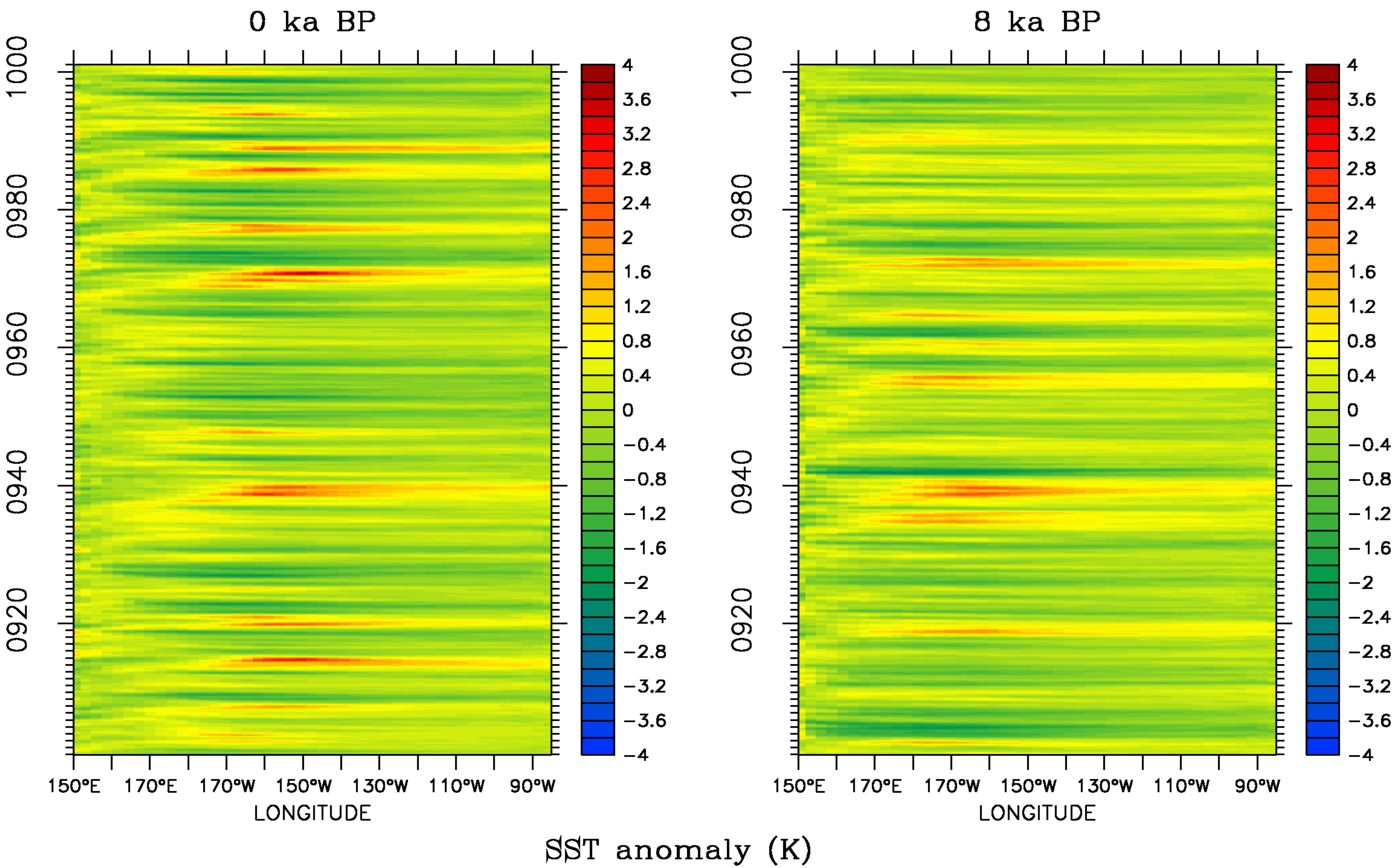
Phipps and Brown (2010), *IOP Conf. Series: Earth and Env. Sci.*

… which enhanced the Asian summer monsoon …



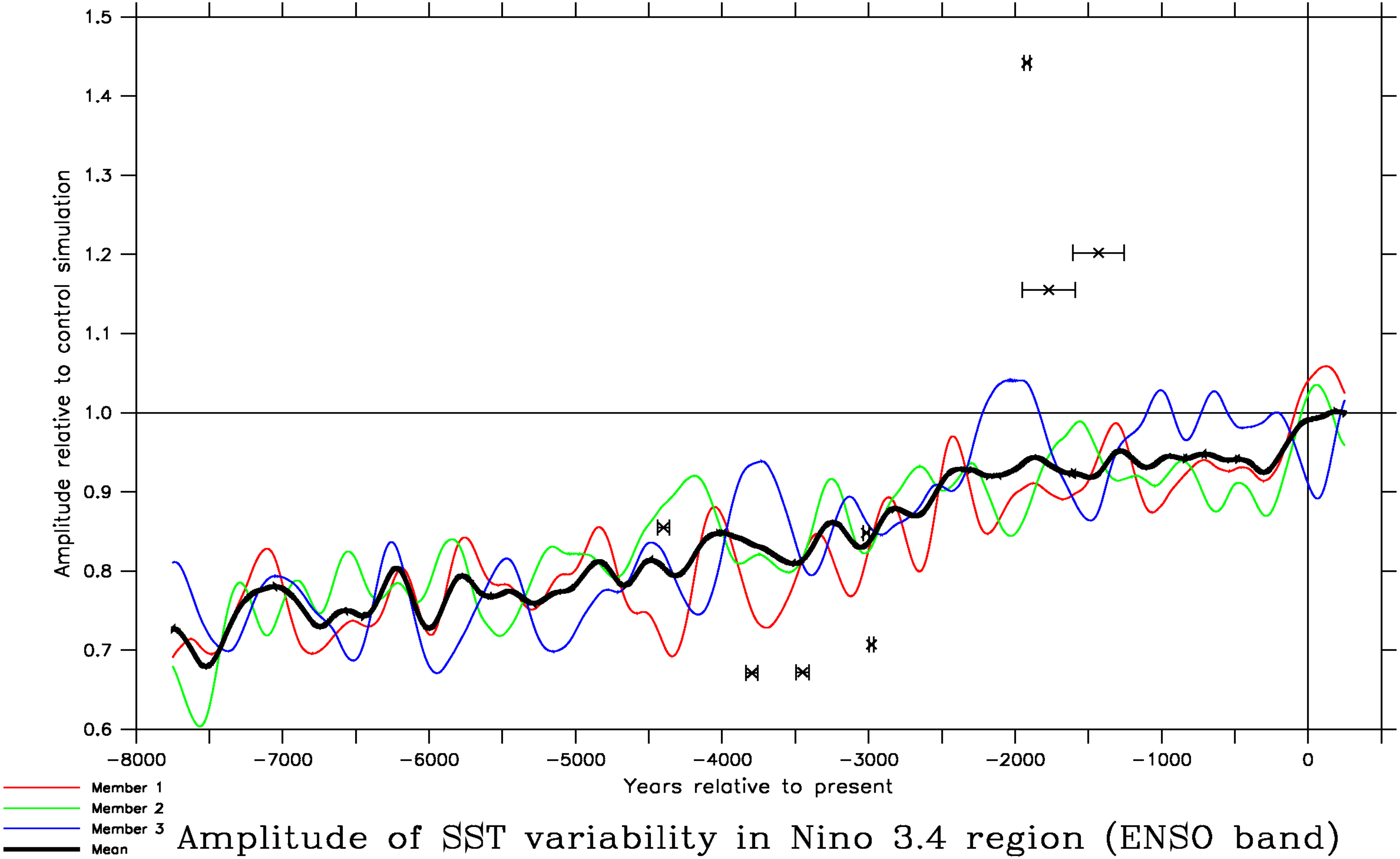
Phipps and Brown (2010), *IOP Conf. Series: Earth and Env. Sci.*

… and made it harder for El Niño events to develop



Phipps and Brown (2010), *IOP Conf. Series: Earth and Env. Sci.*

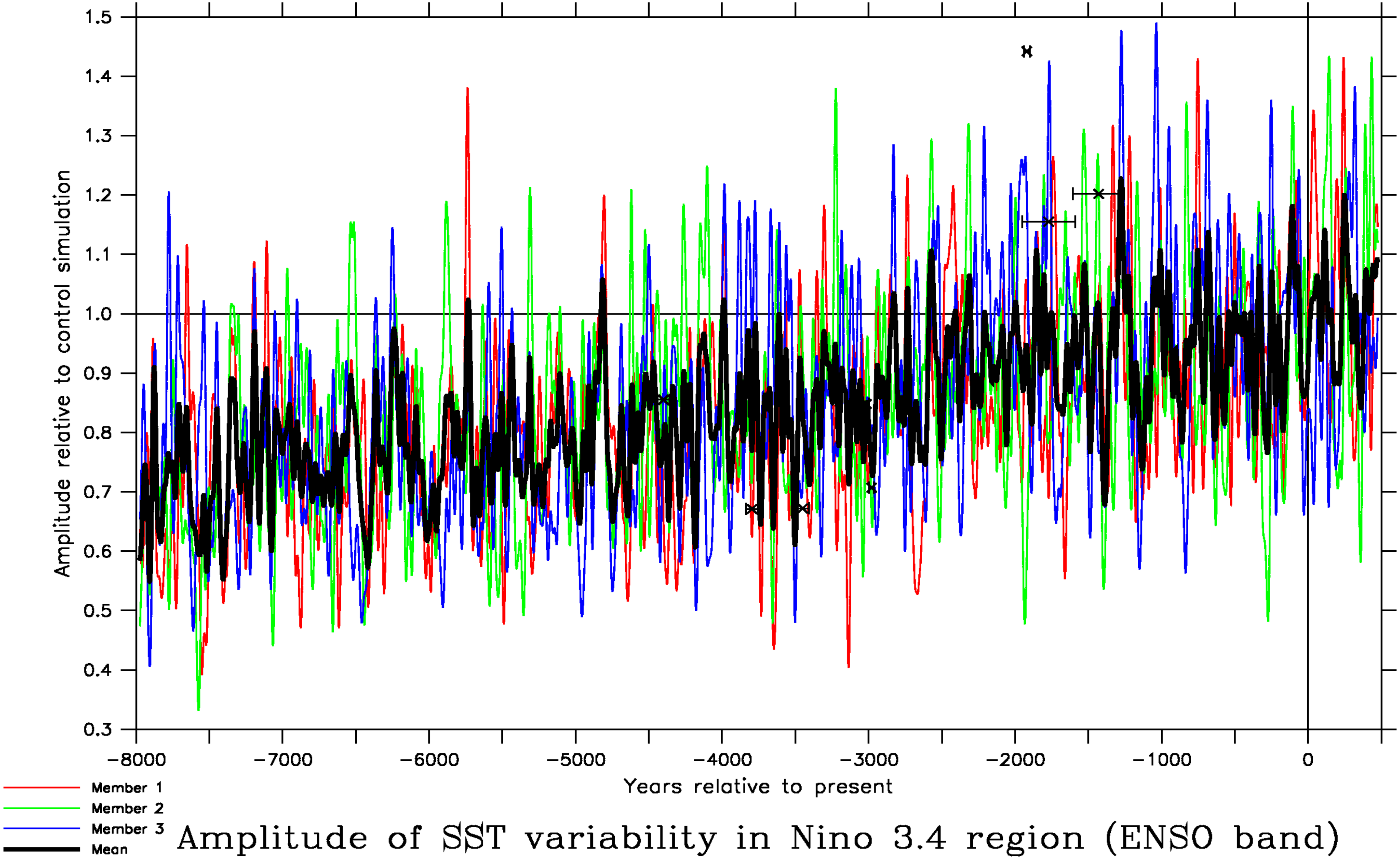
El Niño variability: data-model comparison



Amplitude of SST variability in Nino 3.4 region (ENSO band)

Phipps and McGregor (in prep.), *GRL*

Challenge: Low-frequency variability

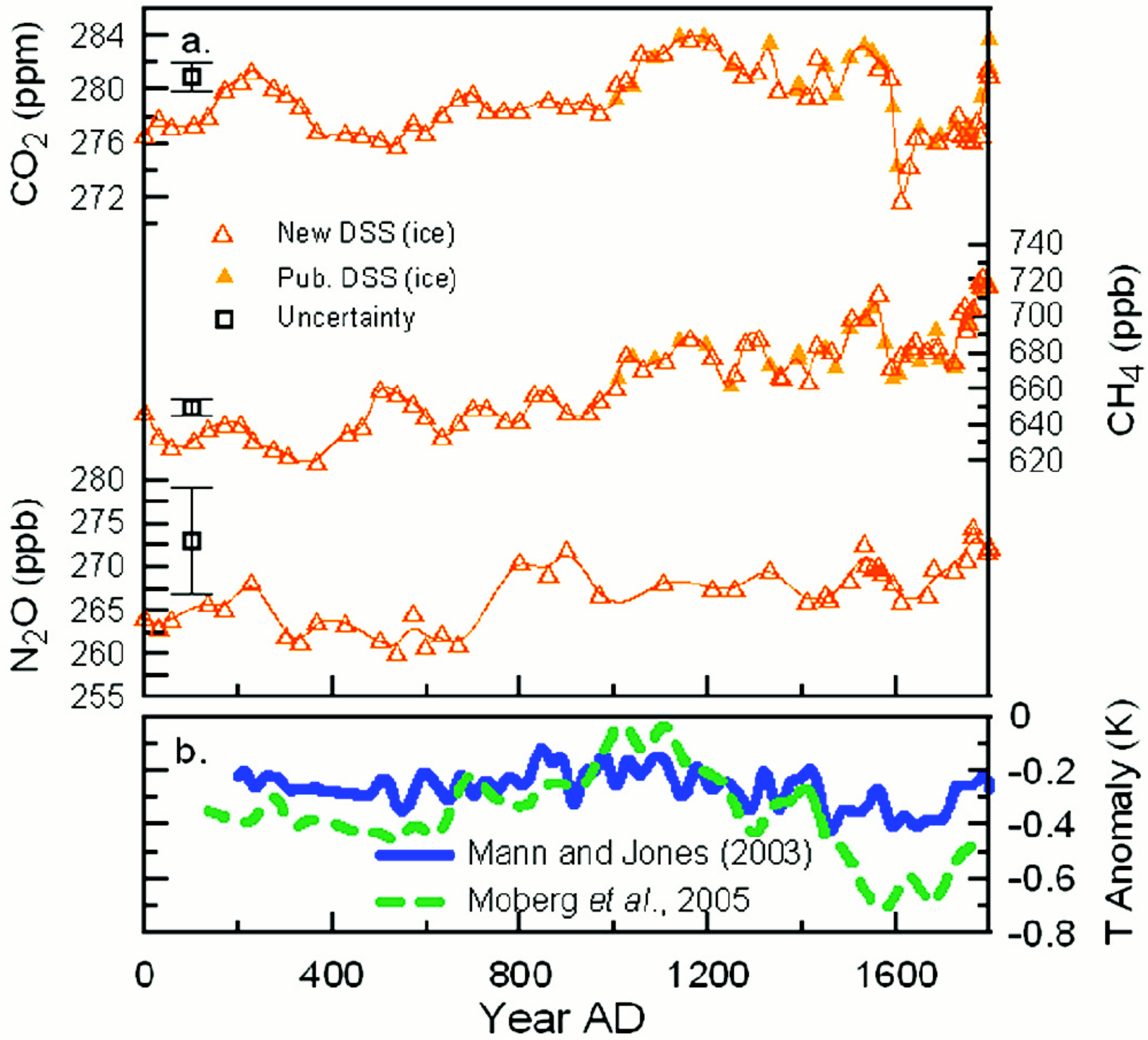


Amplitude of SST variability in Nino 3.4 region (ENSO band)

Phipps and McGregor (in prep.), *GRL*

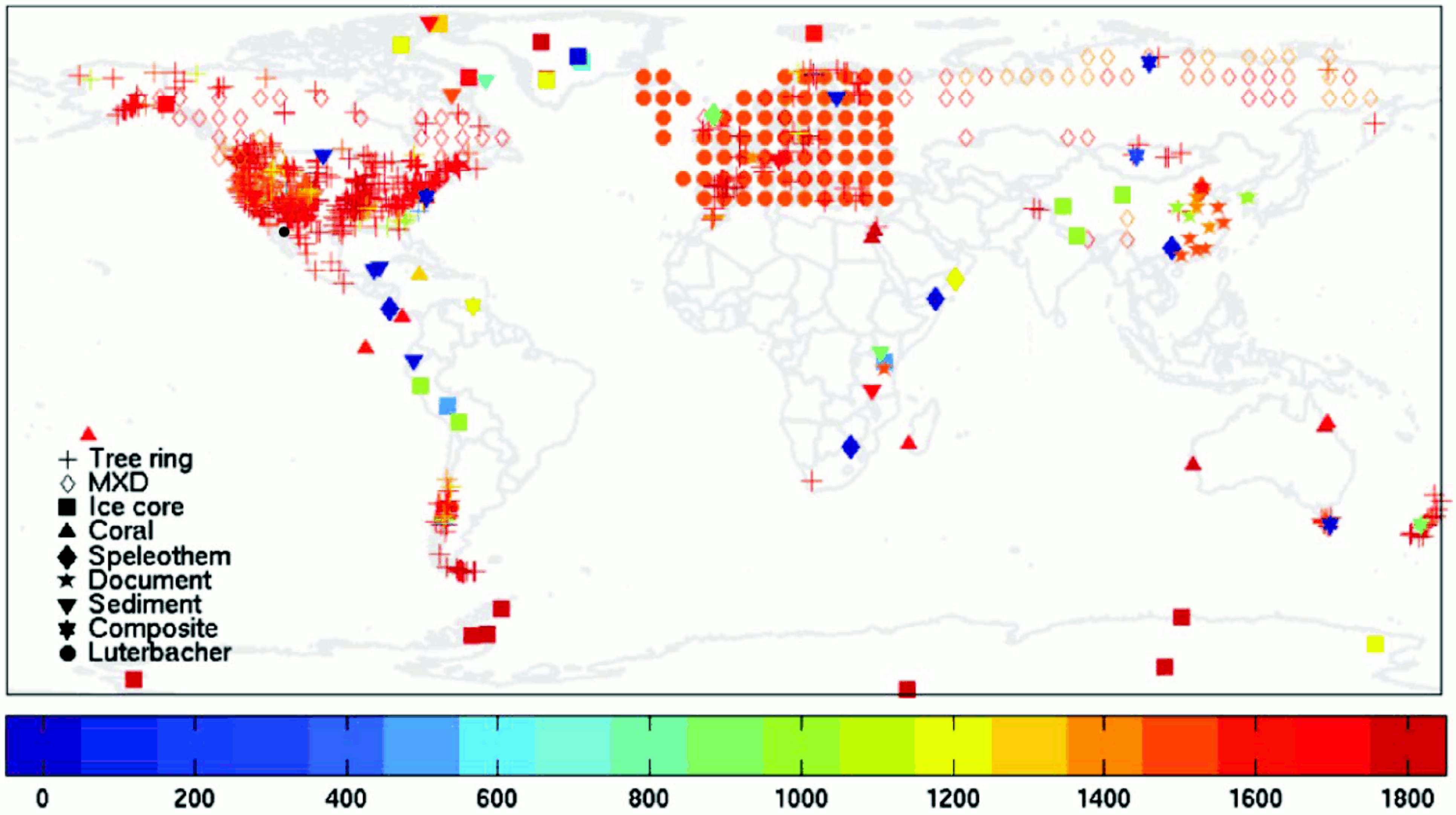
Example 2:
Climate of the past 2,000 years

Last 2,000 years: Boundary conditions well known



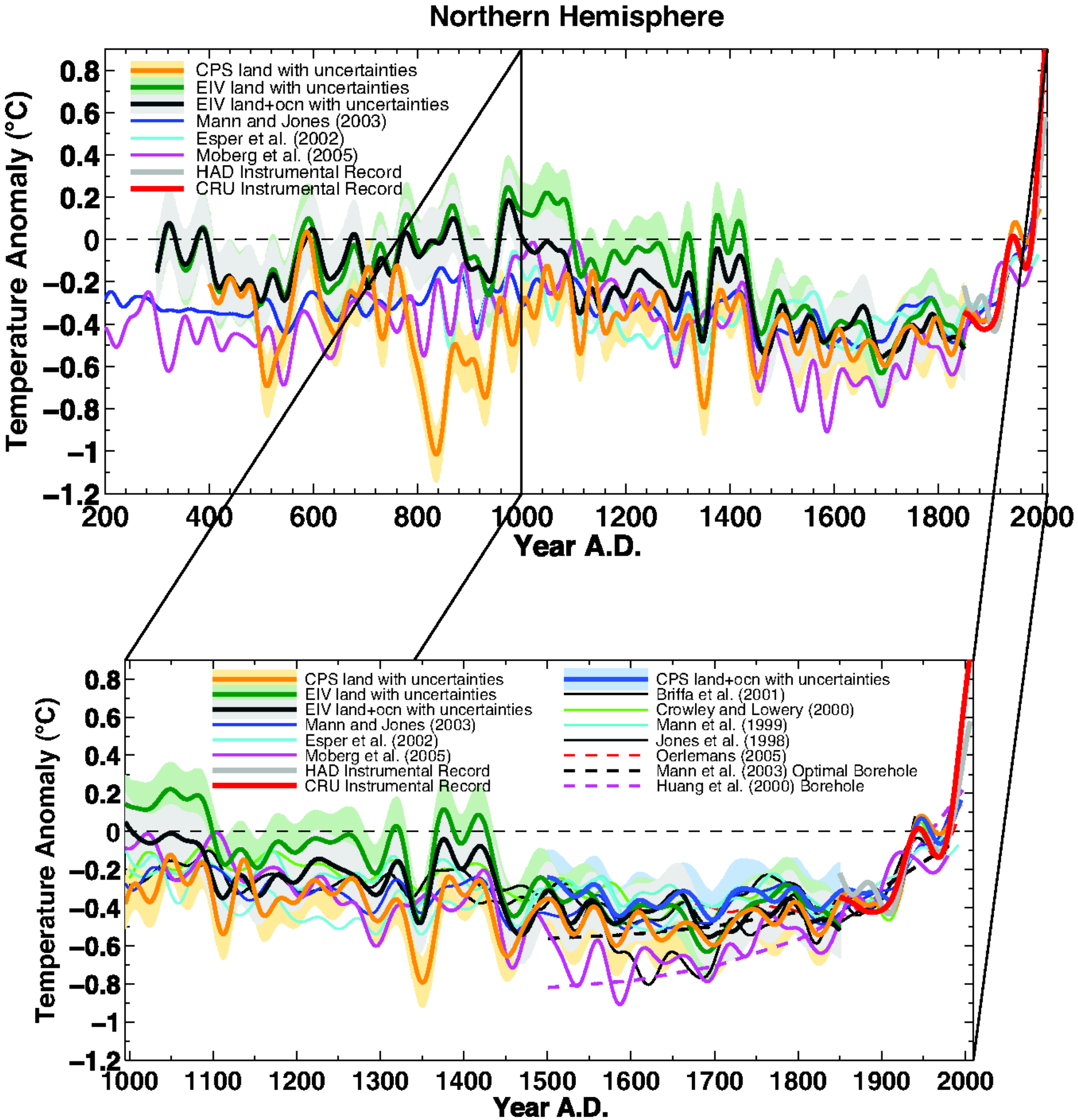
MacFarling Meure et al. (2006), *GRL*

Last 2,000 years: Abundance of proxy data



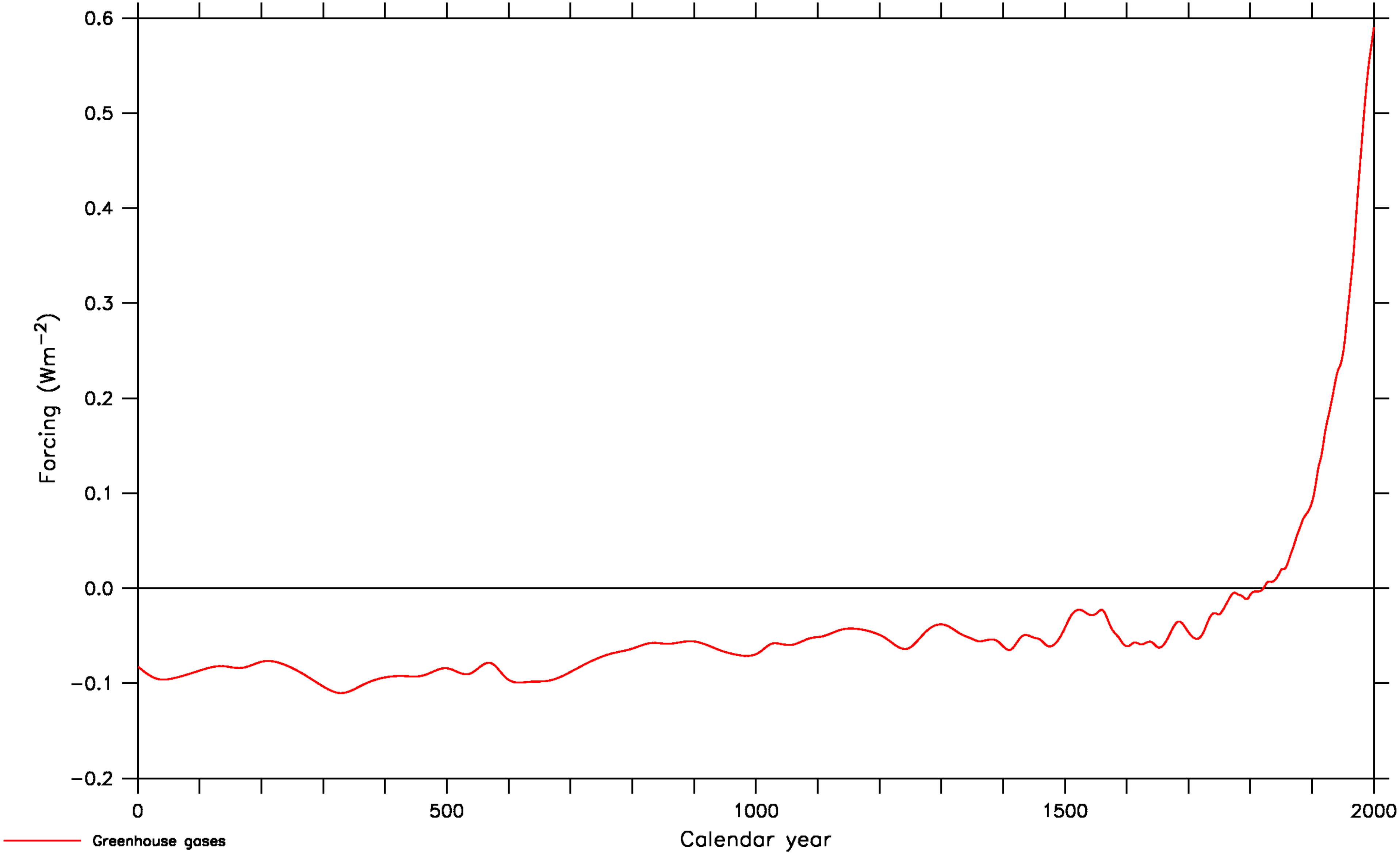
Mann et al. (2008), *PNAS*

NH surface air temperature



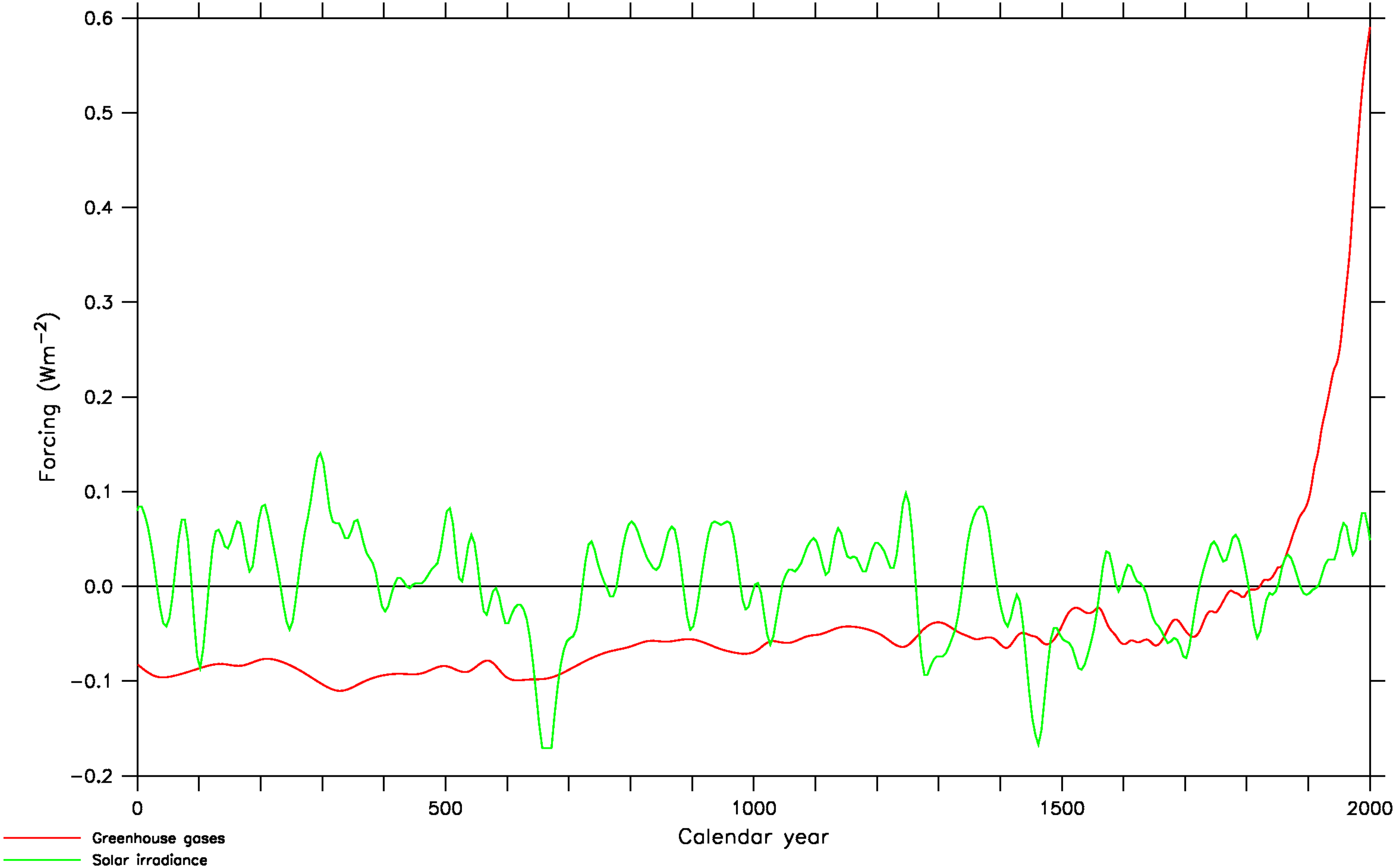
Mann et al. (2008), *PNAS*

Radiative forcing: GHGs



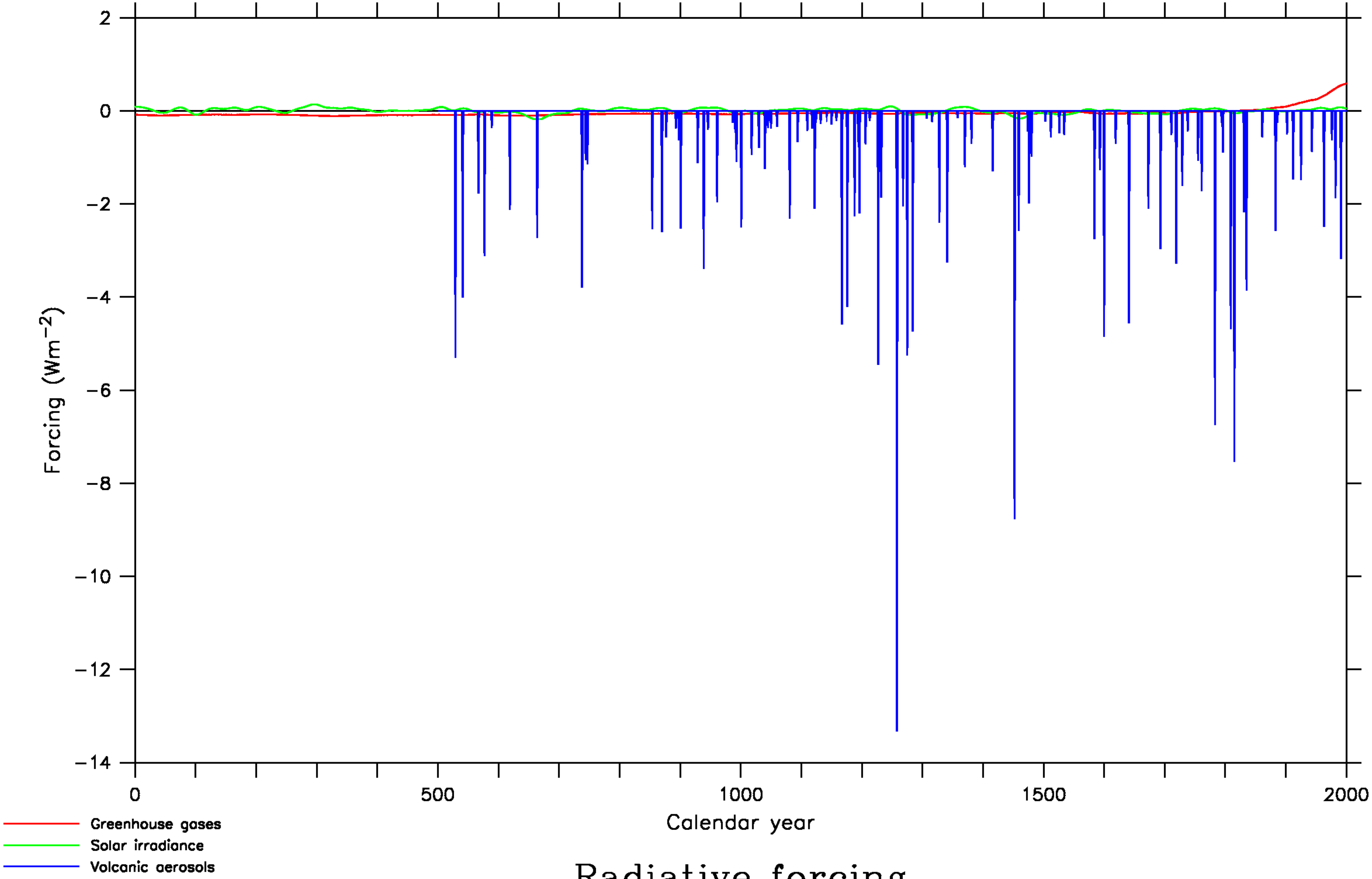
Radiative forcing

Radiative forcing: GHGs+solar



Radiative forcing

Radiative forcing: GHGs+solar+volcanic

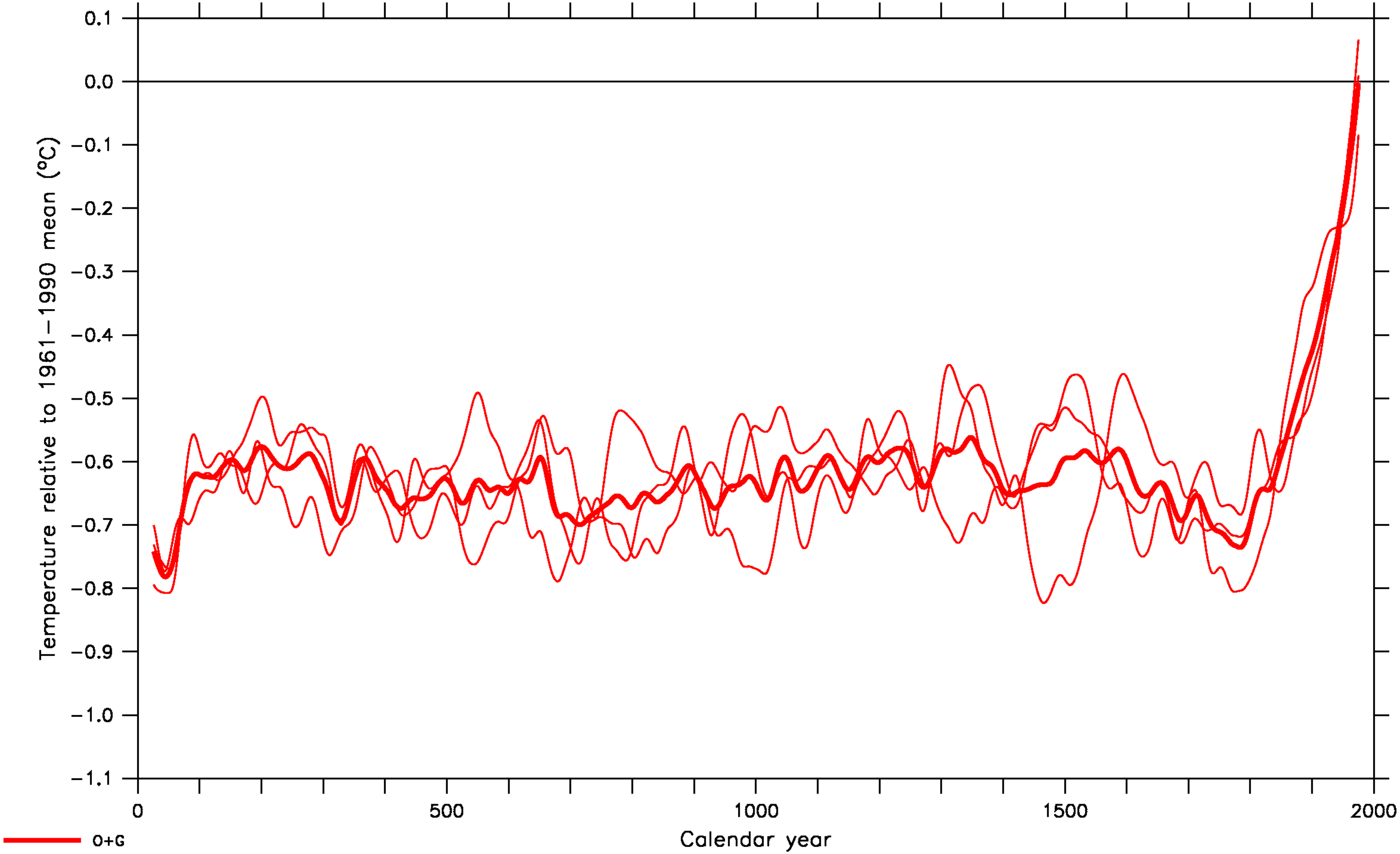


Radiative forcing

Transient simulations of the past 2,000 years

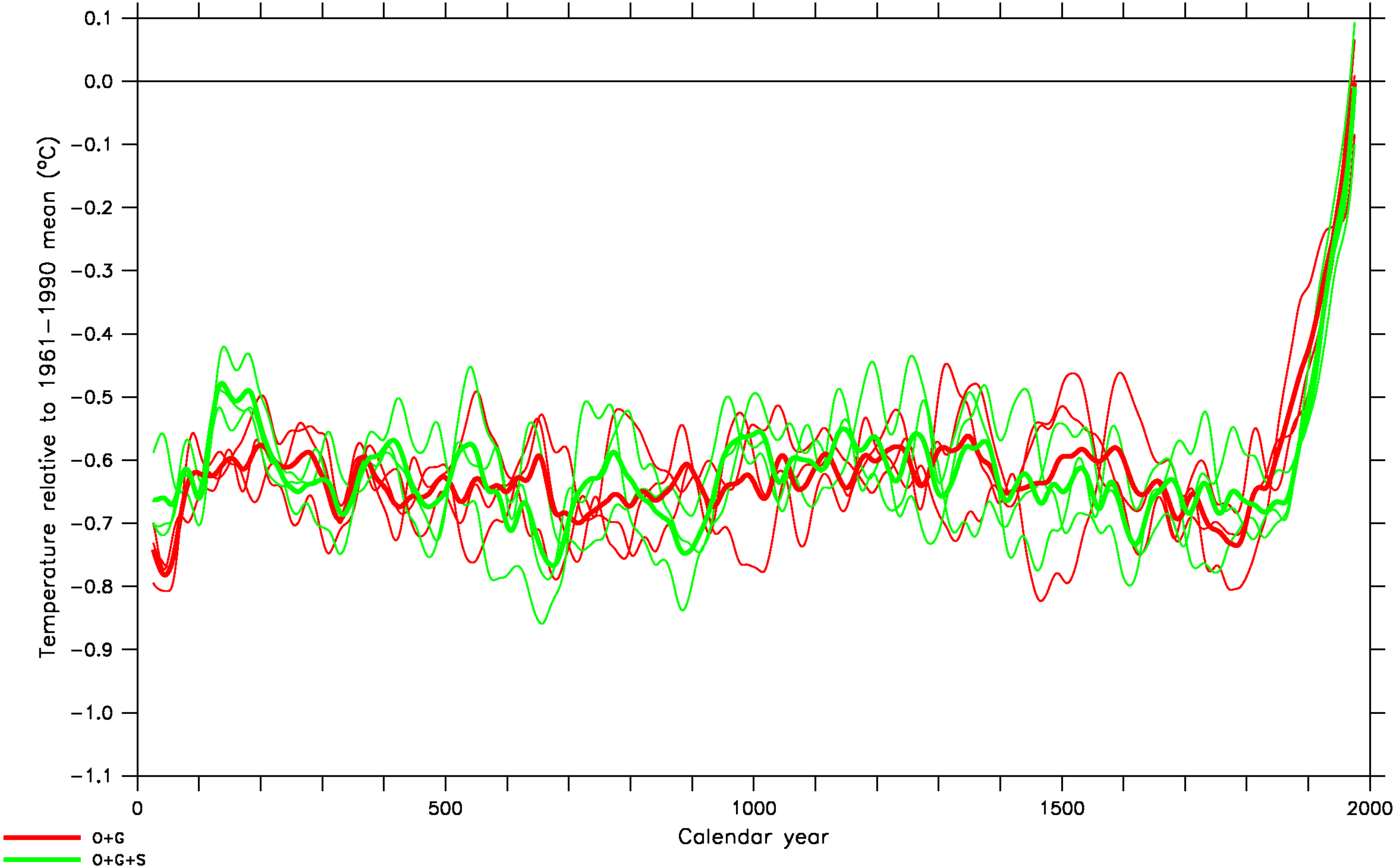
- CSIRO Mk3L climate system model v1.2
- Forcings:
  - Changes in the Earth's orbital geometry
  - Changes in atmospheric CO_2, CH_4 and N_2O concentrations (MacFarling Meure et al., 2006)
  - Changes in solar irradiance (Steinhilber et al., 2009)
  - Volcanic aerosols (Gao et al., 2008)
- 3×3 transient simulations of the past 2,000 years:
  - Orbital + greenhouse gases
  - Orbital + greenhouse gases + solar
  - Orbital + greenhouse gases + solar + volcanic

NH surface air temperature: GHGs



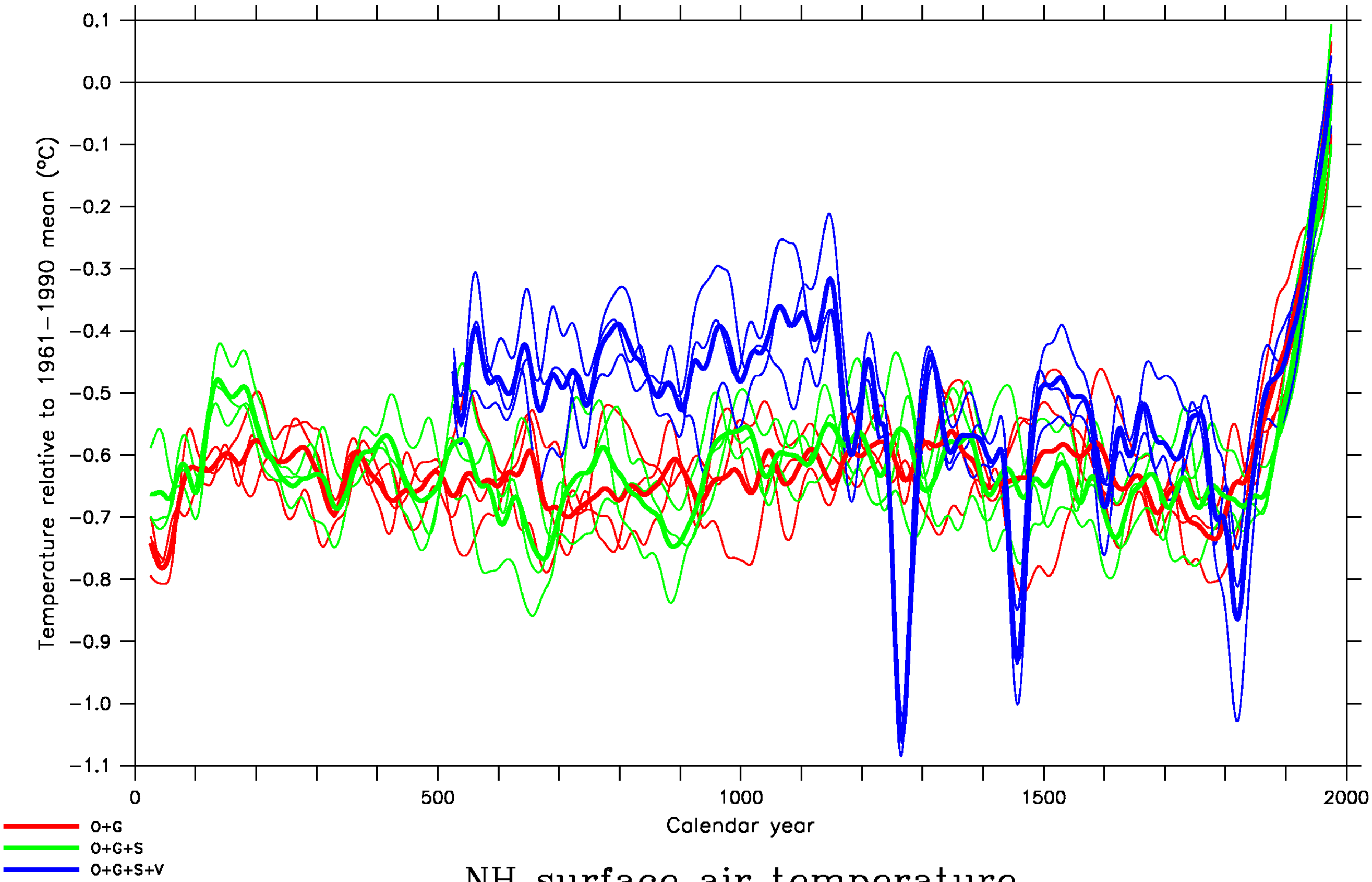
NH surface air temperature

NH surface air temperature: GHGs+solar



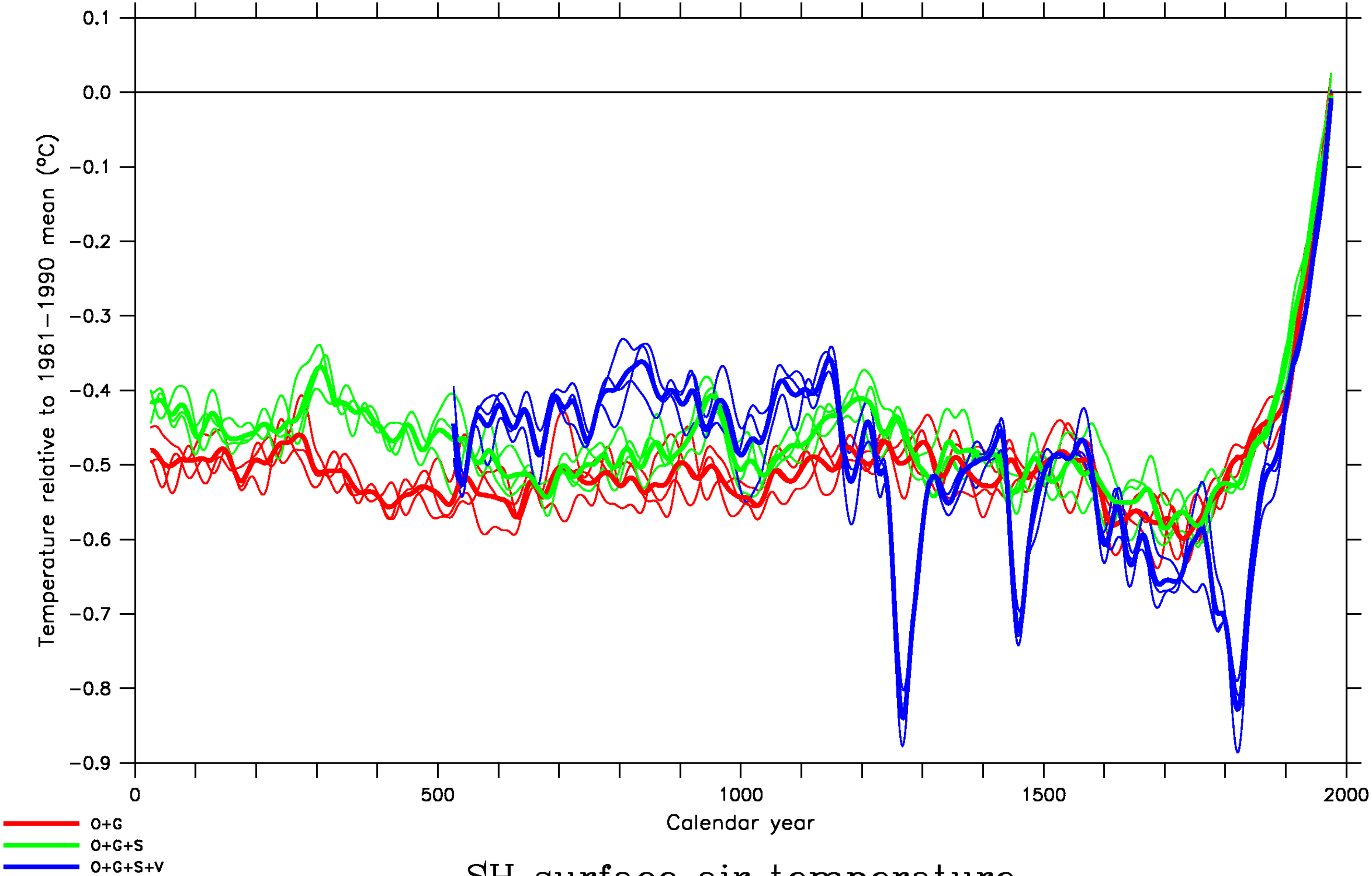
NH surface air temperature

NH surface air temperature: all forcings



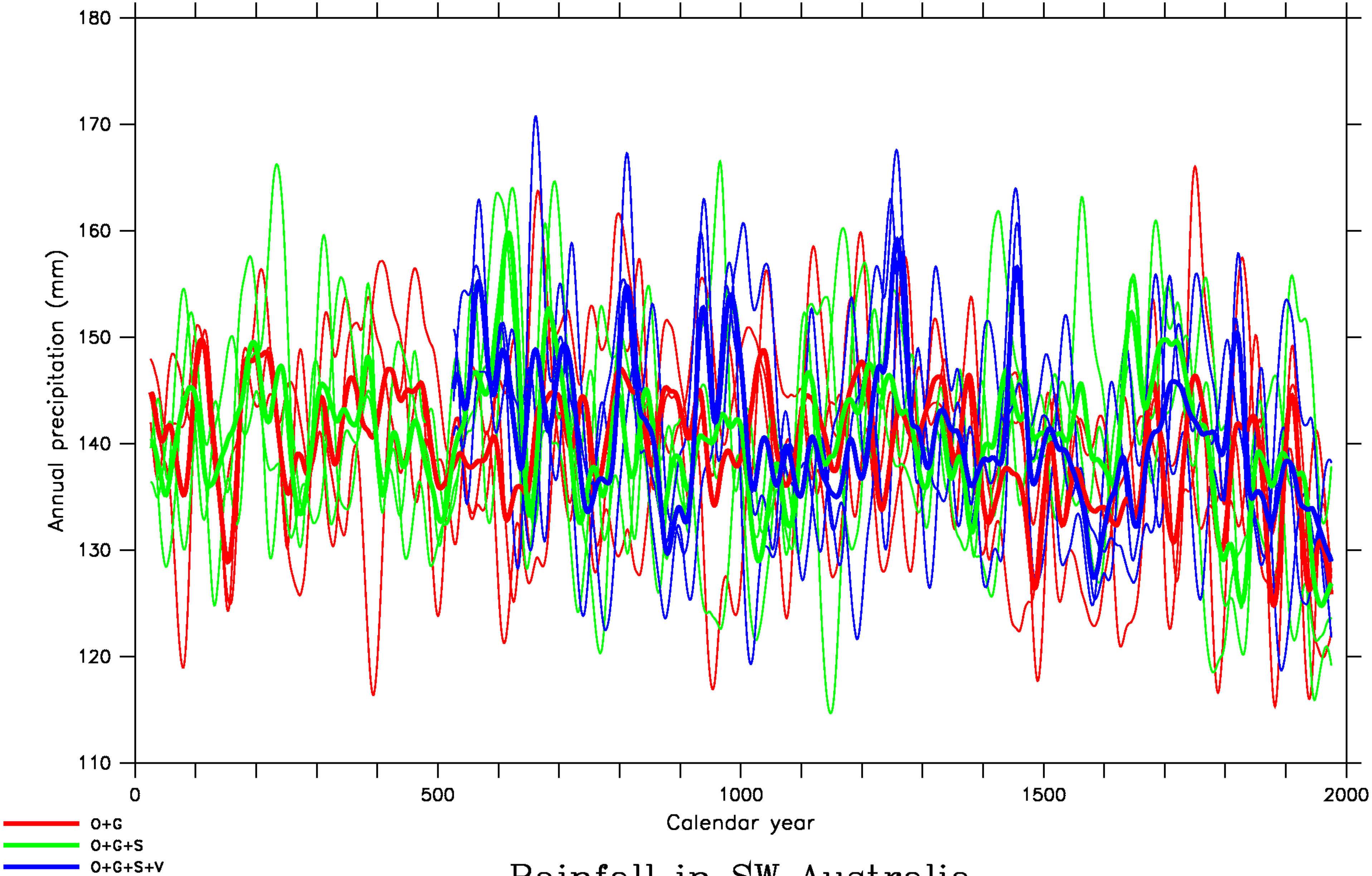
NH surface air temperature

SH surface air temperature: all forcings



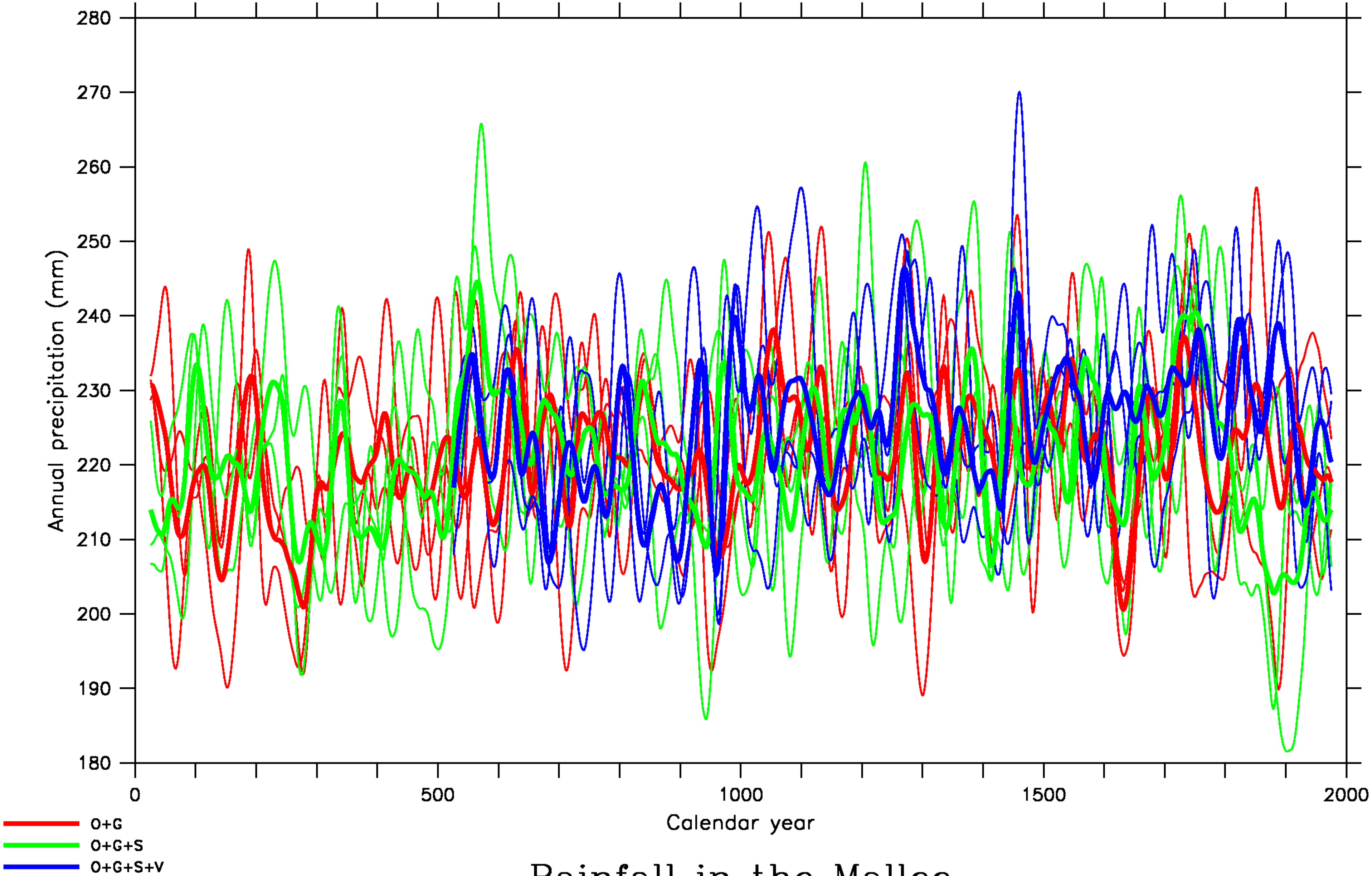
SH surface air temperature

Rainfall in SW Australia: all forcings



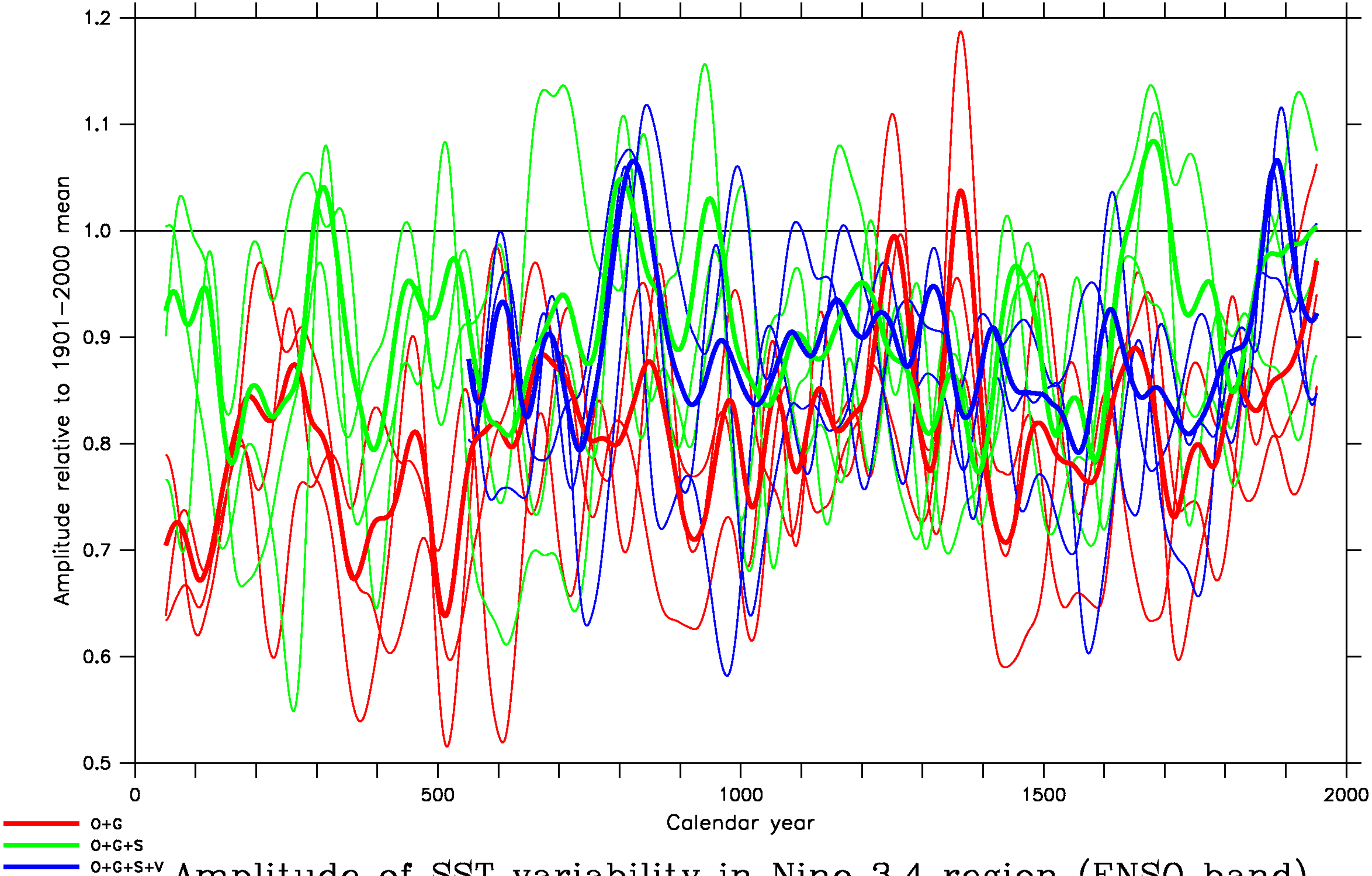
Rainfall in SW Australia

Rainfall in the Mallee: all forcings



Rainfall in the Mallee

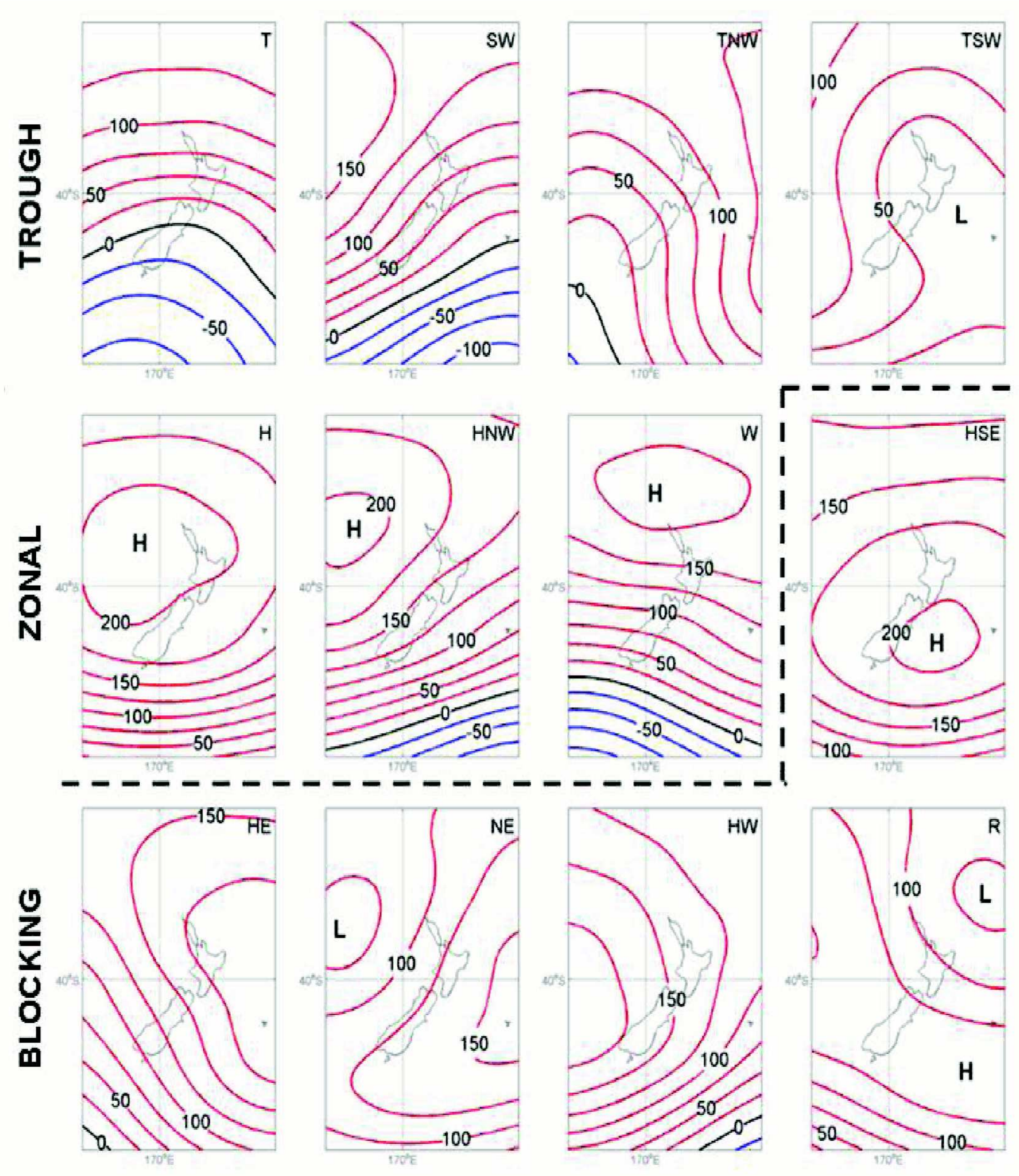
El Niño: all forcings



Amplitude of SST variability in Nino 3.4 region (ENSO band)

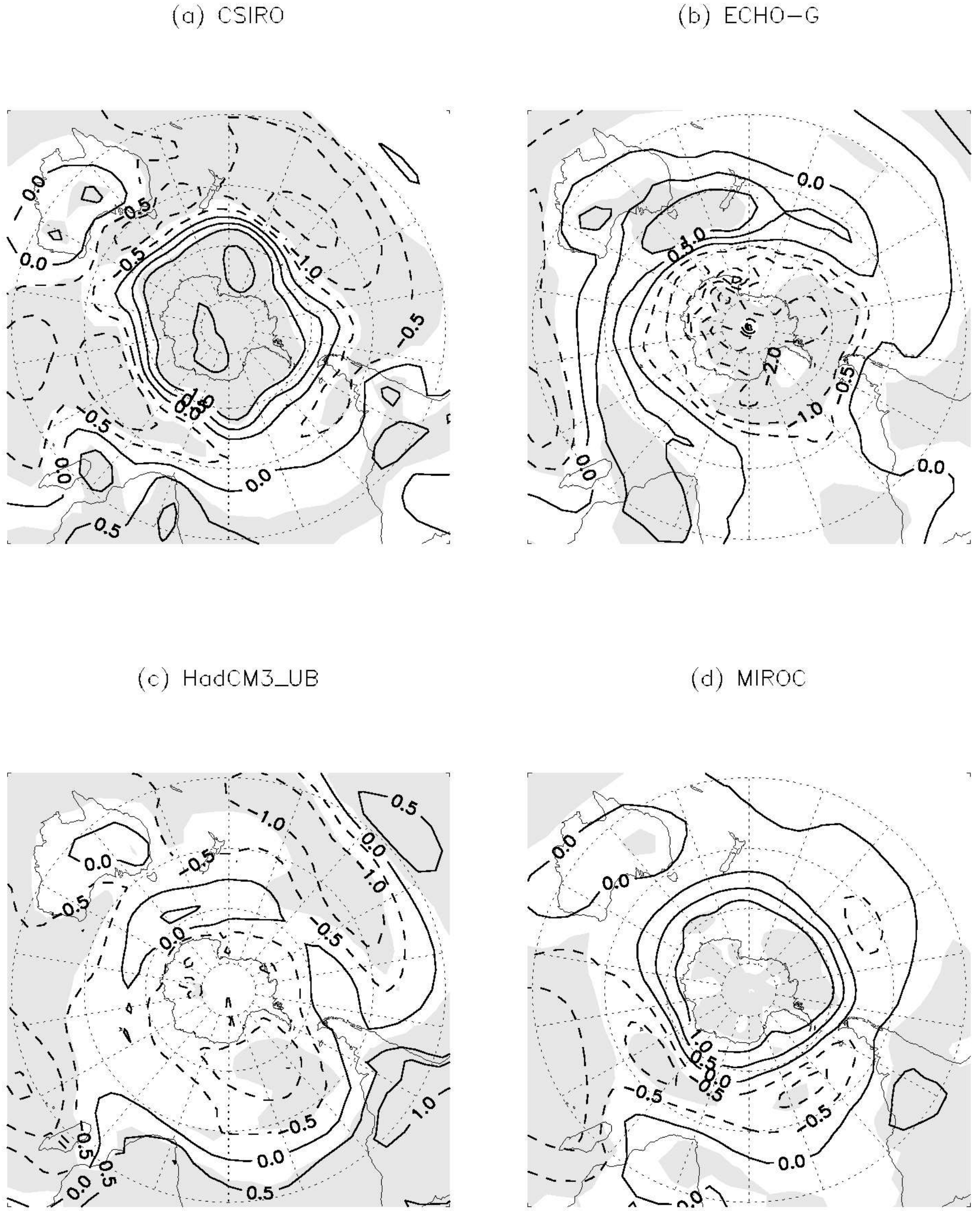
Example 3:
Regime classification

Kidson weather types



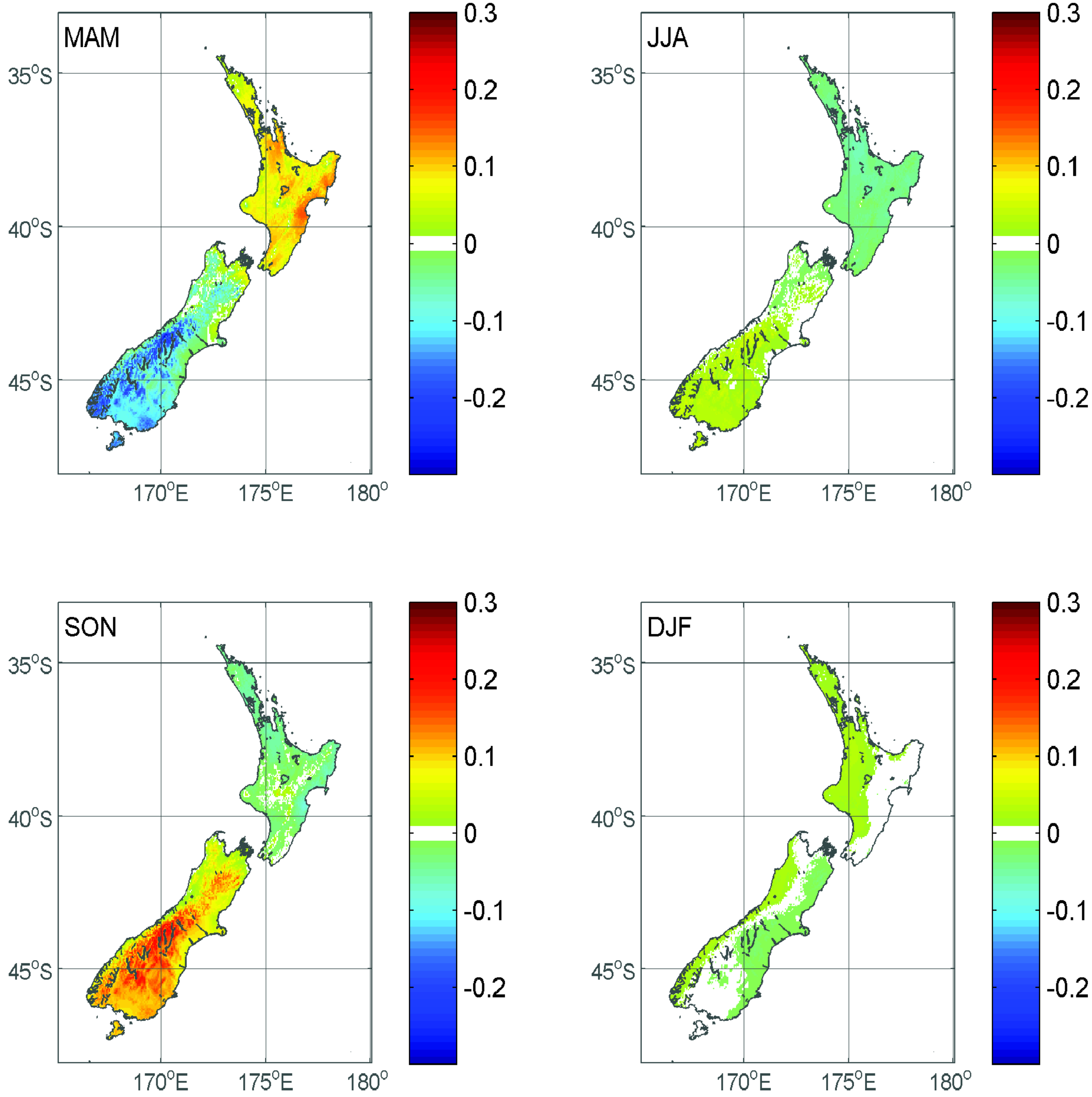
Ackerley et al. (in prep.), *Clim. Past*

DJF MSLP anomalies (6ka minus 0ka, hPa)



Ackerley et al. (in prep.), *Clim. Past*

Mean SAT anomaly (6ka minus 0ka, °C)



Ackerley et al. (in prep.), *Clim. Past*

Conclusions

- The integration of palaeoclimate archives with climate models can provide new insights into the nature of the climate system.
- Proxy data can be used to constrain and evaluate the models, while the models provide a dynamical framework within which to understand past changes.
- However, data-model integration presents challenges e.g. metrics, baselines, low-frequency variability.
- Regime classification is a promising tool for data-model integration, and should be applied to the Australian region.