A climate system model for studying past, present and future climate

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Final PhD seminar

ACE CRC Earth Systems Modelling Travel Fellowship seminar

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- Nathan Bindoff
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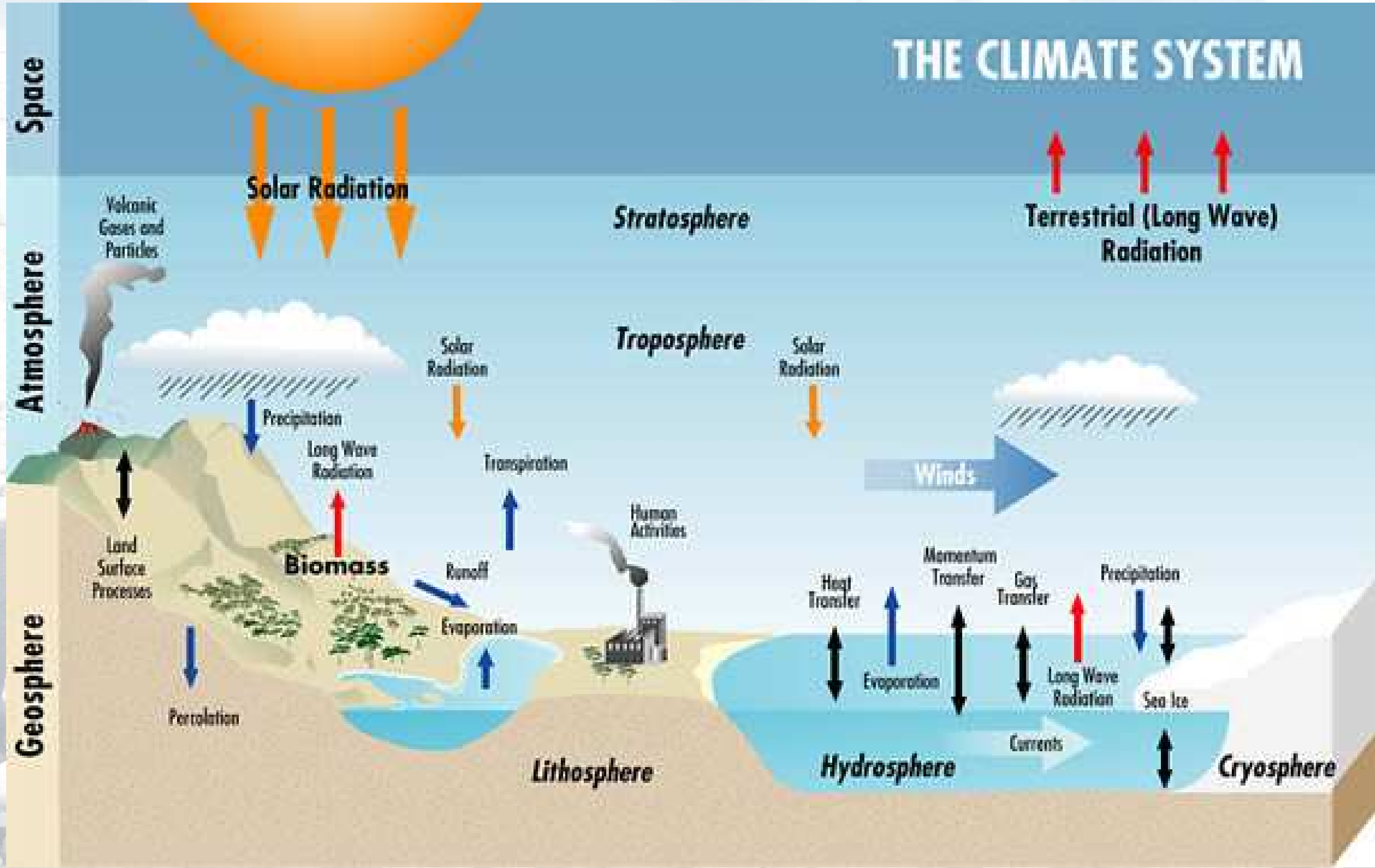
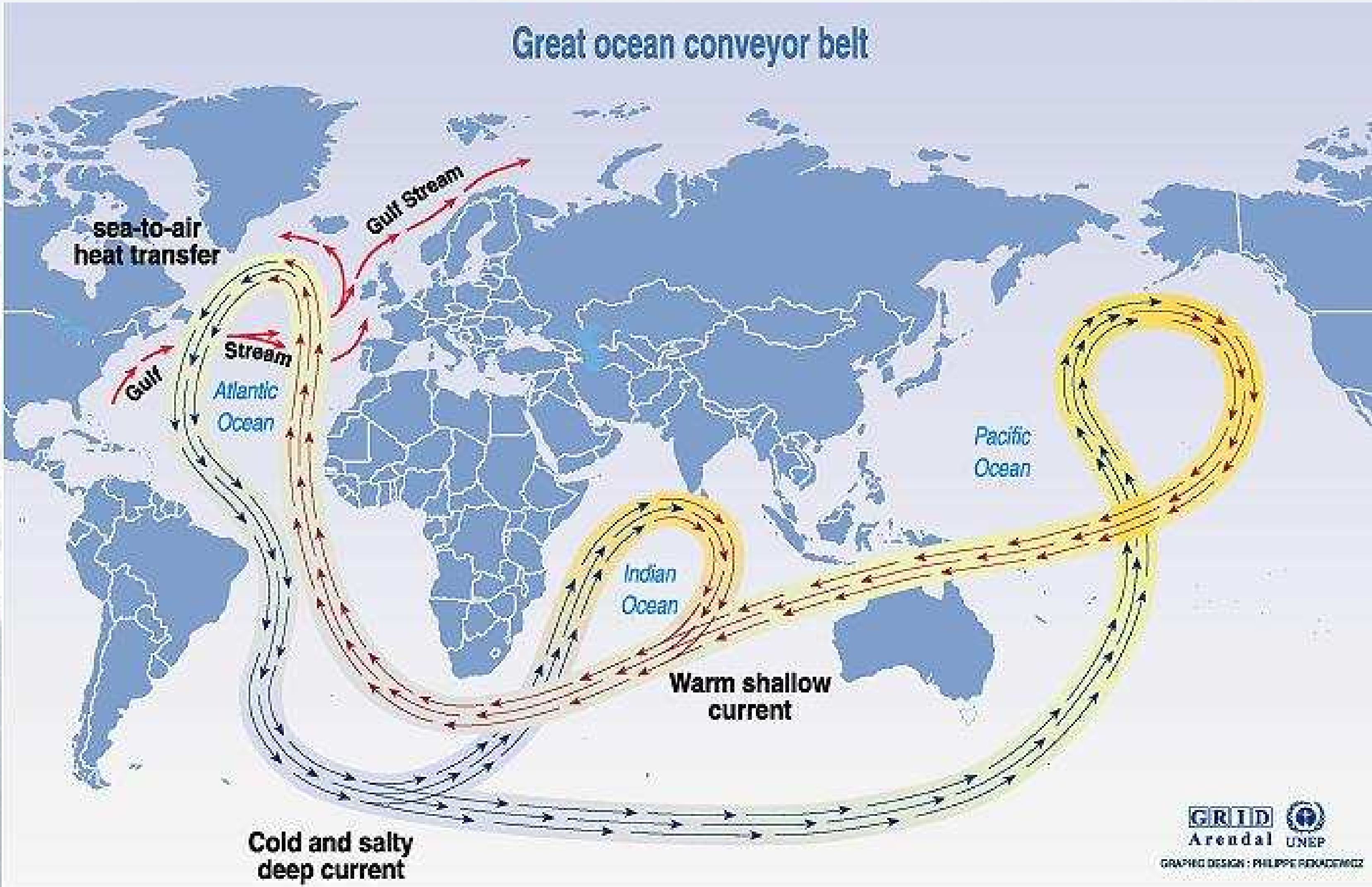
Overview

1. Introduction
2. The CSIRO Mk3L climate system model
3. The climate of the mid-Holocene
4. The climate of the late Holocene
5. Future climate

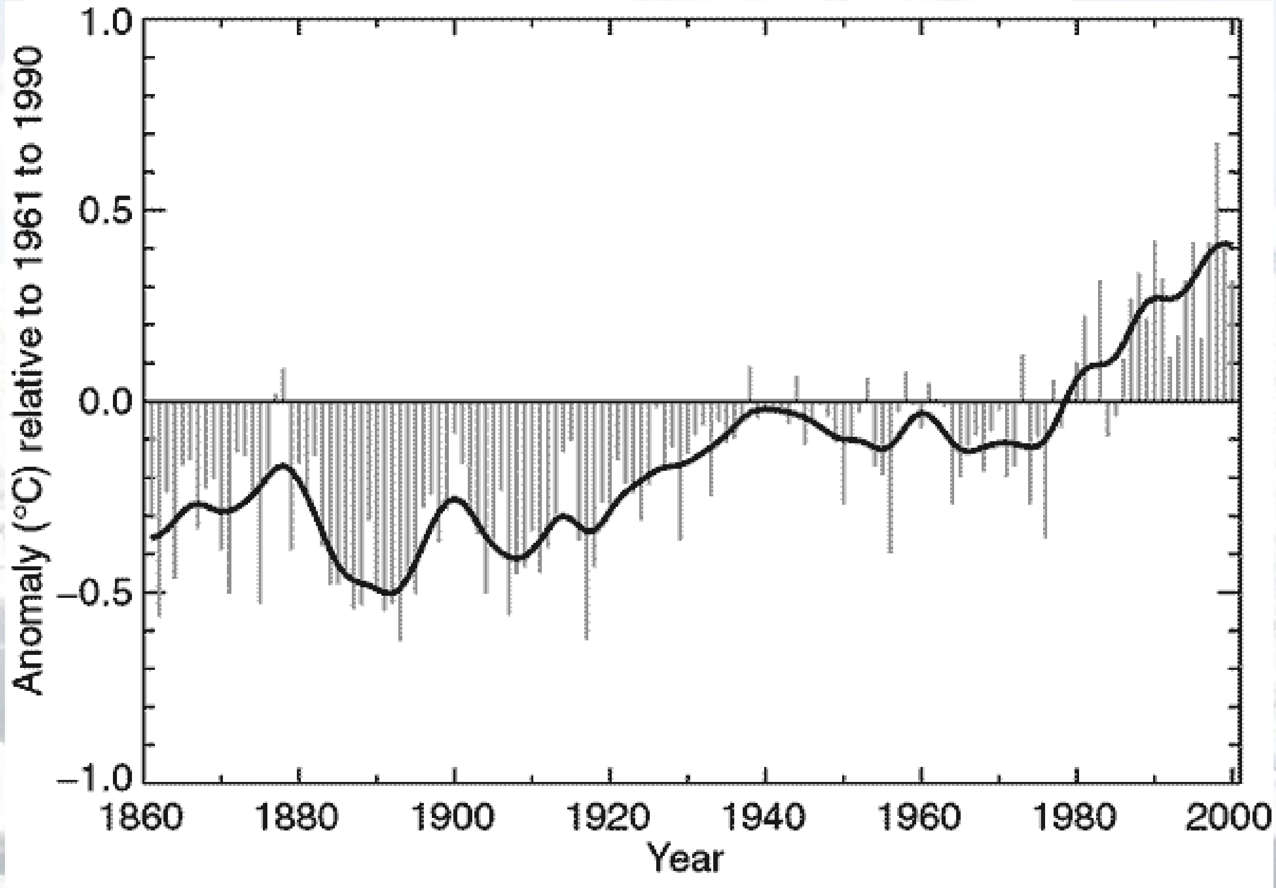
1. Introduction





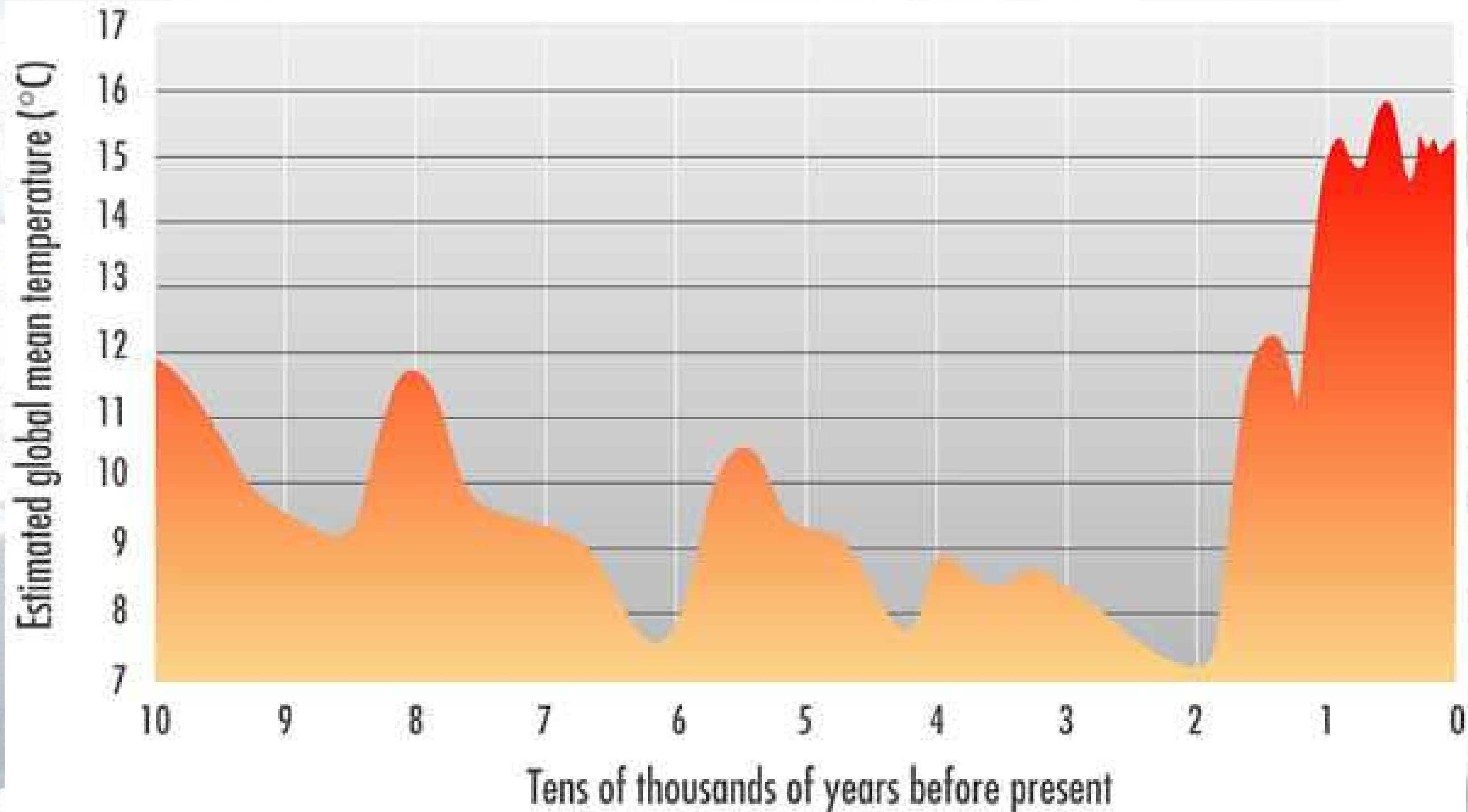
Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

The Earth's climate exhibits variability on all timescales...



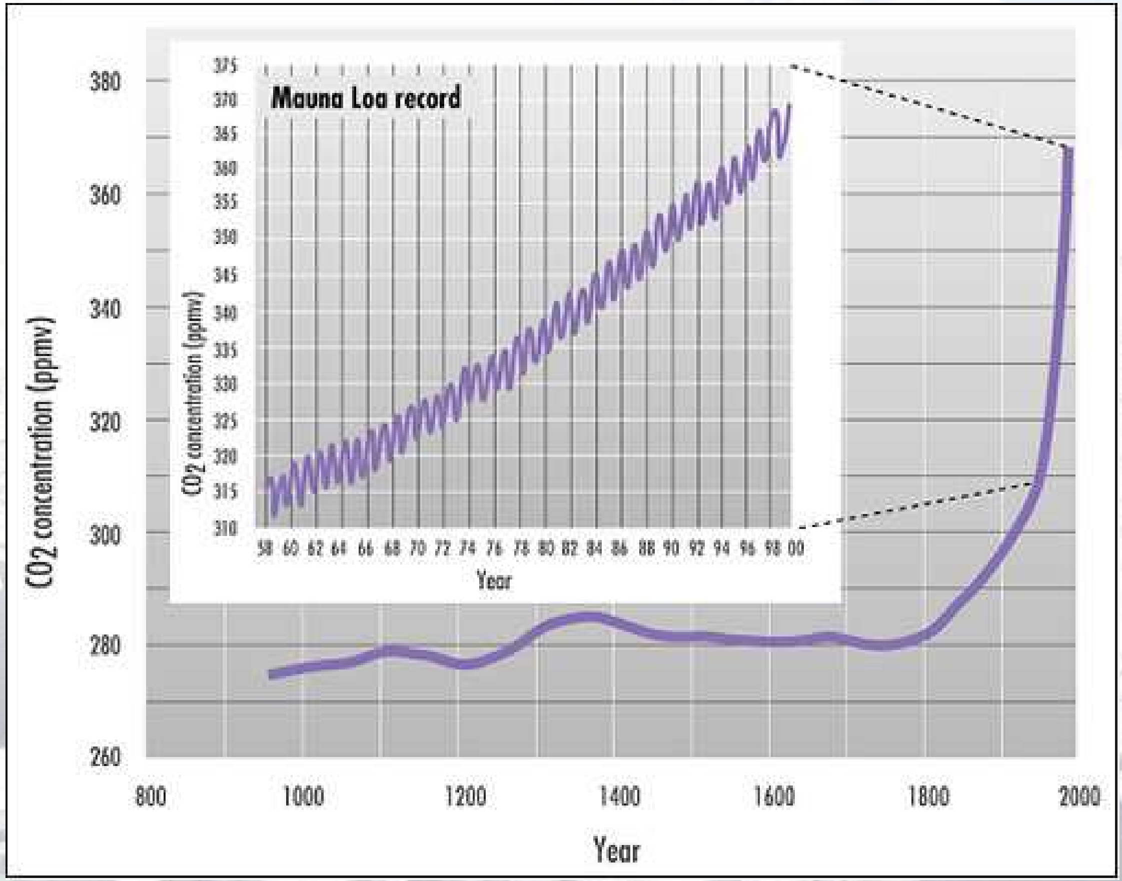
Global land-surface air temperature 1861–2000

The Earth's climate exhibits variability on all timescales...



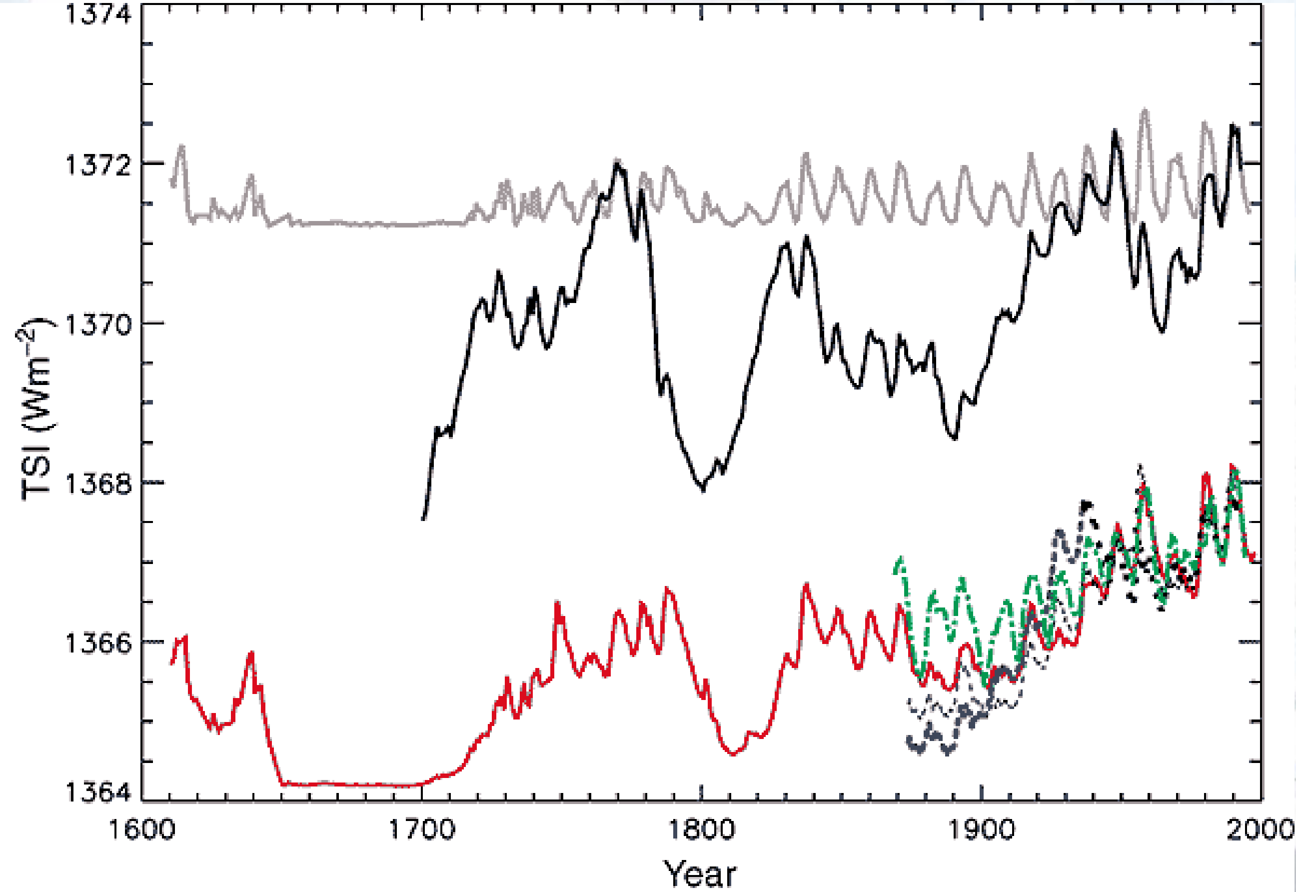
Global-mean surface air temperature over the past 100,000 years

External influences include human activity ...



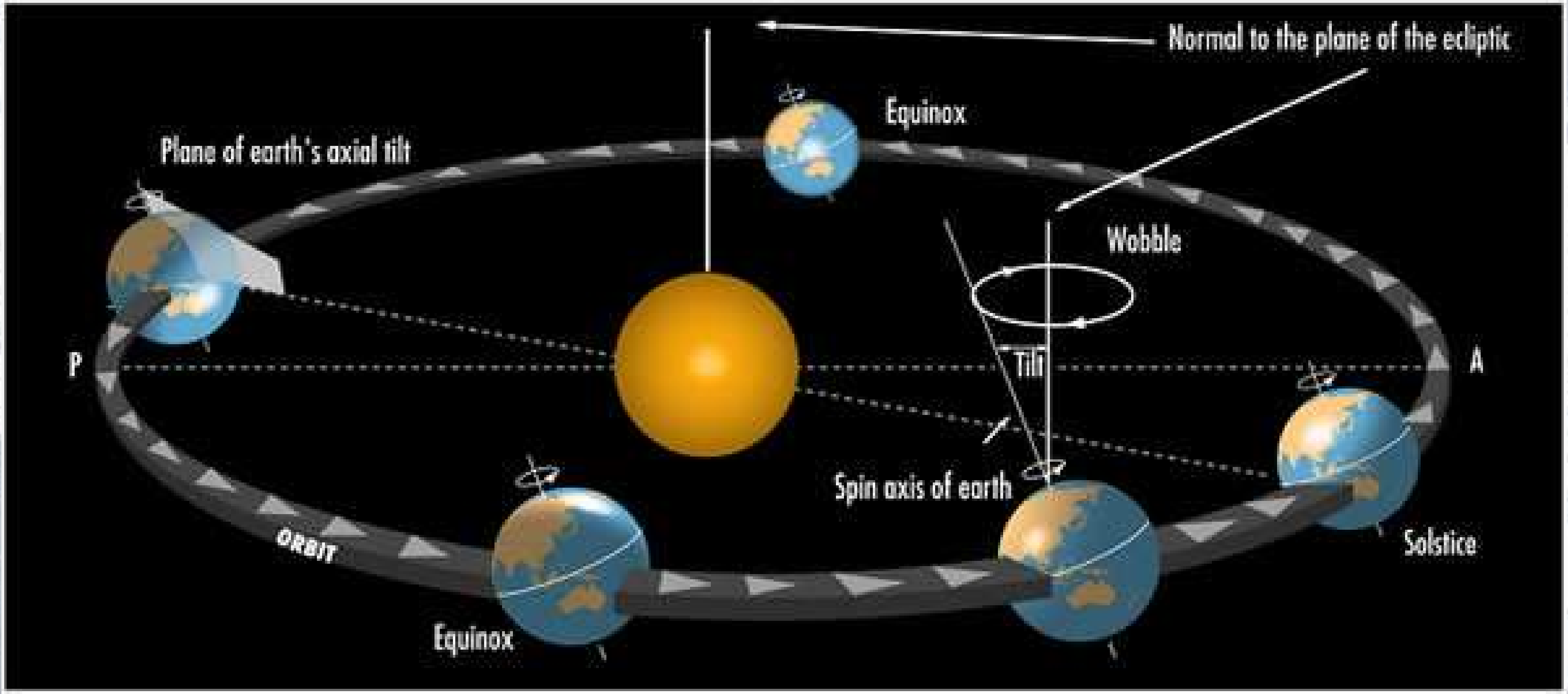
Atmospheric CO_2 concentration over the past 1000 years

... the sun ...



Total solar heat output 1600-2000

… and the Earth's orbital geometry



Understanding climate variability and change

(i) Data

- Direct measures
  - observations
- Indirect measures
  - ice cores
  - marine/lake sediments
  - tree rings
  - coral

Grape ripening as a past climate indicator

Summer temperature variations are reconstructed from harvest dates since 1370.

French records of grape-harvest dates in Burgundy were used to reconstruct spring–summer temperatures from 1370 to 2003 using a process-based phenology model developed for the Pinot Noir grape. Our results reveal that temperatures as high as those reached in the 1990s have occurred several times in Burgundy since 1370. However, the summer of 2003 appears to have been extraordinary, with temperatures that were probably higher than in any other year since 1370.

Biological and documentary proxy records have been widely used to reconstruct temperature variations to assess the exceptional character of recent climate fluctuations[1–3]. Grape-harvest dates, which are tightly related to temperature, have been recorded locally for centuries in many European countries. These dates may therefore provide one of the longest uninterrupted series of regional temperature anomalies (highs and lows) without chronological uncertainties[1].

In Burgundy, these officially decreed dates have been carefully registered in parish and municipal archives since at least the early thirteenth century. We used a corrected and updated harvest-date series[4] from Burgundy, covering the years from 1370 to 2003, to reconstruct spring–summer temperature anomalies that had occurred in eastern France. To convert historical observations into temperature anomalies, we used a process-based phenology model for Pinot Noir, the main variety of grape that has been continuously grown in Burgundy since at least the fourteenth century[5] (for details, see supplementary information).

Our yearly reconstruction is significantly correlated (Table 1) with summer temperatures deduced from tree rings in central

A fifteenth-century depiction of the grape harvest from *Les Très Riches Heures du Duc de Berry*, a medieval book of hours.

VEA MUSEUM/WWW.BRIDGEMAN.CO.UK

France[6] (correlation coefficient, $r = 0.53$), the Burgundy part of a spatial multi-proxy recon-

Understanding climate variability and change

(ii) Models

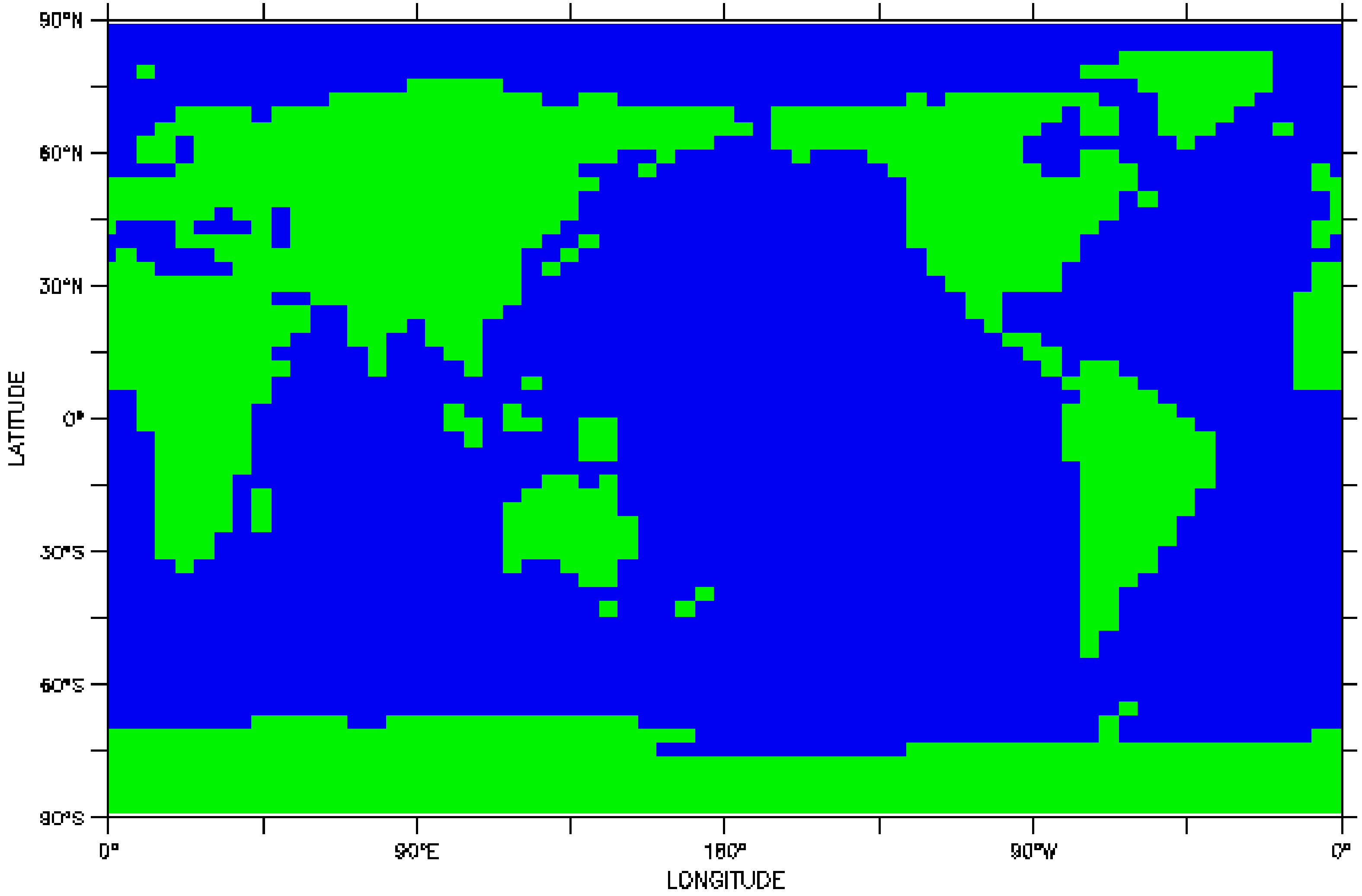
- based upon the physical laws which describe the processes within the climate system
- enable direct simulation of past, present and future climate states
- limited by:
  - the understanding of the underlying processes
  - the comprehensiveness of the model
  - computational resources

Can we trust the models?

- models require *evaluation*
- compare simulated climate with observational or historical data
- the *maximum* extent to which we can have confidence in a model is the extent to which it can reliably simulate a range of climate states
- desirable to validate the model over as wide a range of climate states as possible
- the only feasible way of doing this is to simulate past climates

2. The CSIRO Mk3L climate system model

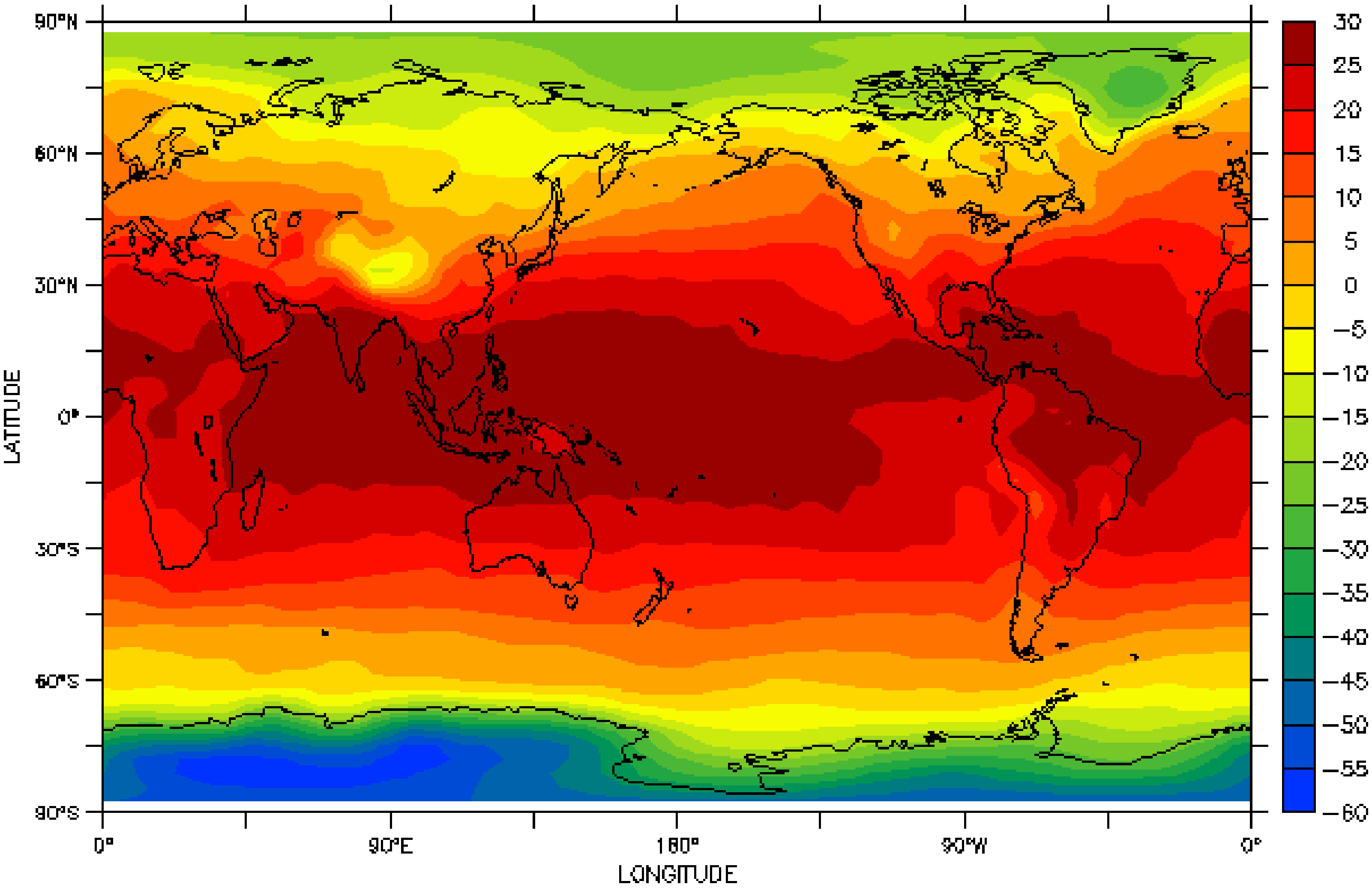
- Low-resolution version of the CSIRO Mk3 climate system model
- Includes:
  - Three-dimensional model of the atmosphere
  - Three-dimensional model of the ocean
  - Sea ice model
  - Land surface model (static vegetation)
- 64×56 horizontal grid
- 18 vertical levels in the atmosphere
- 21 vertical levels in the ocean



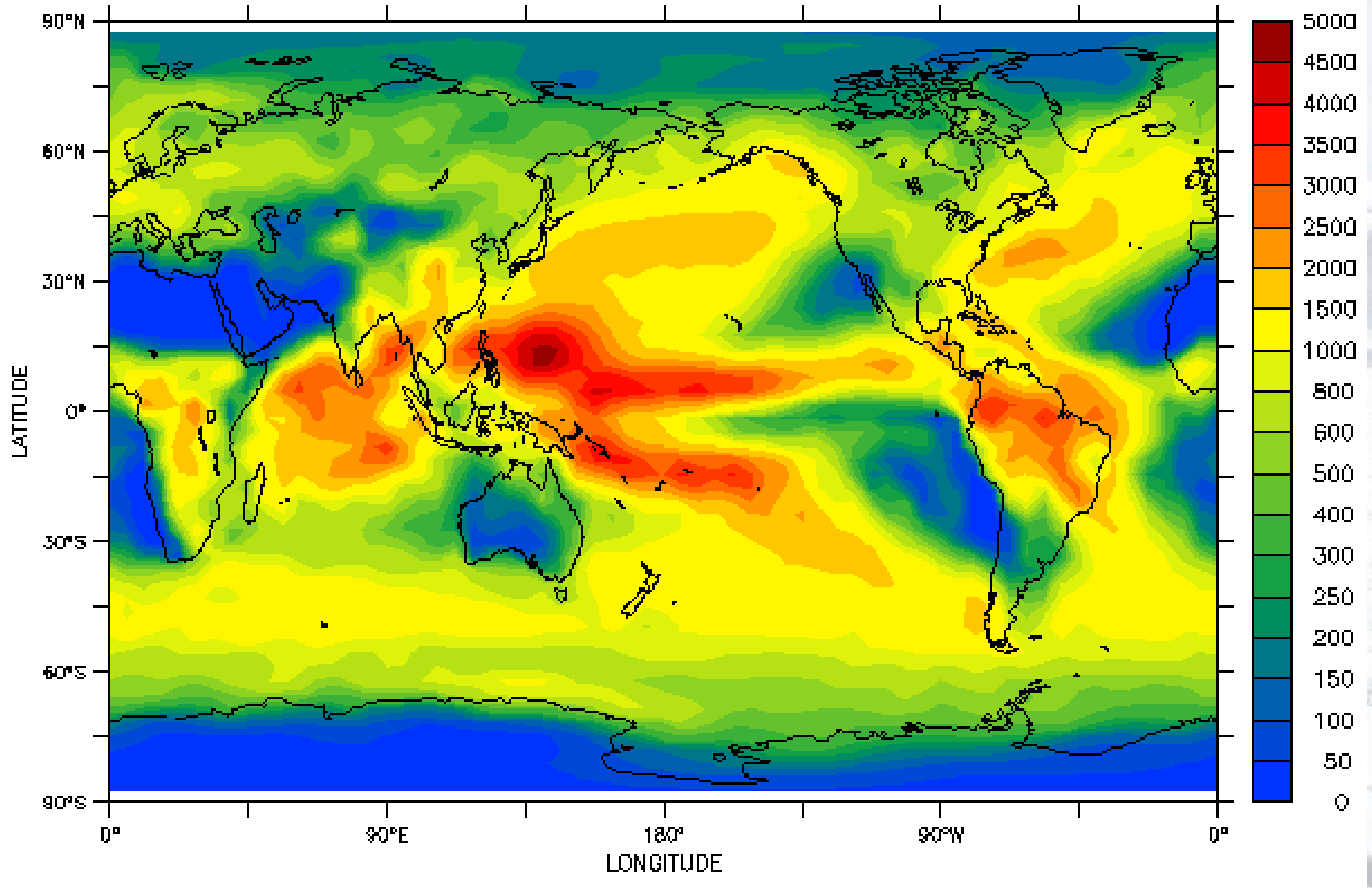
The CSIRO Mk3L model grid

The simulated "present day" climate

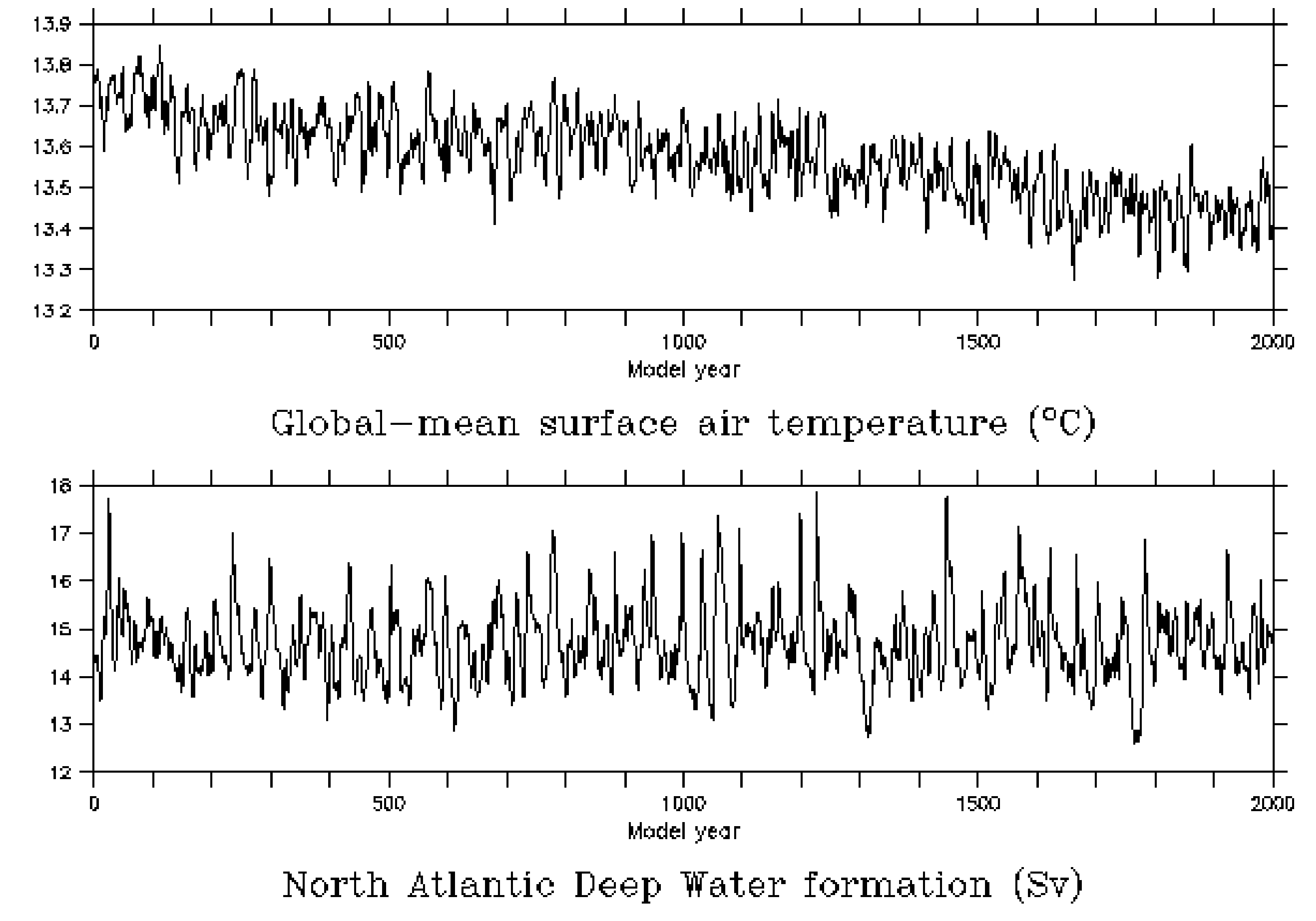
- Control simulation conducted for pre-industrial conditions
- Constant boundary conditions:
  - Atmospheric CO_2 concentration = 280ppm
  - Solar constant = 1365 Wm^{-2}
  - "Present day" orbital parameters (AD 1950)
- Integrated for 2000+ years

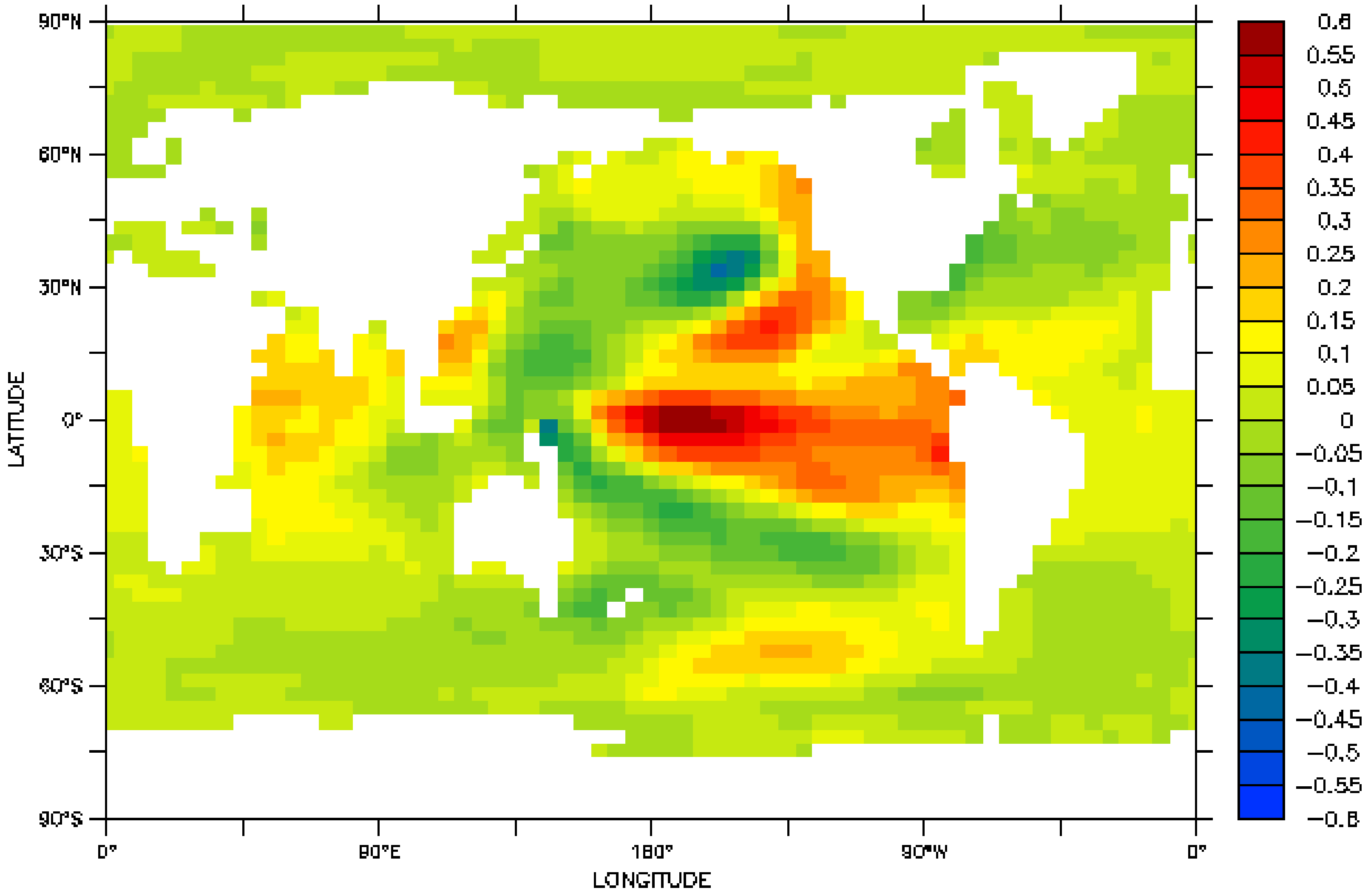


Annual−mean surface air temperature (°C)

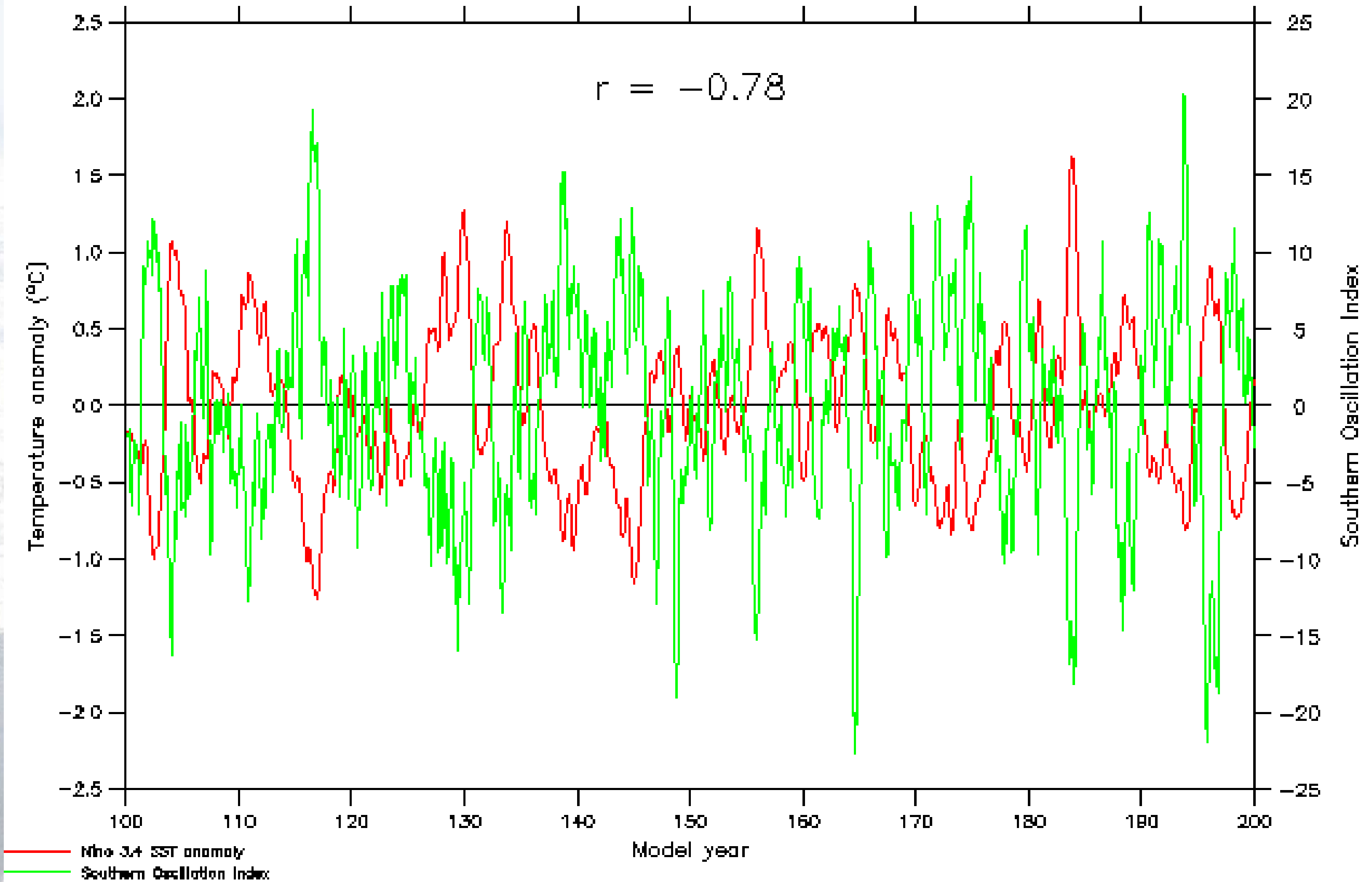


Annual precipitation (mm)


13.9
13.8
13.7
13.6
13.5
13.4
13.3
13.2
0
500
1000
1500
2000
Model year
Global−mean surface air temperature (°C)
18
17
16
15
14
13
12
0
500
1000
1500
2000
Model year
North Atlantic Deep Water formation (Sv)



EOF1 of annual−mean sea surface temperature (°C) − 22.3%



Nino 3.4 SST anomaly and Southern Oscillation Index

El Niño: model versus observed

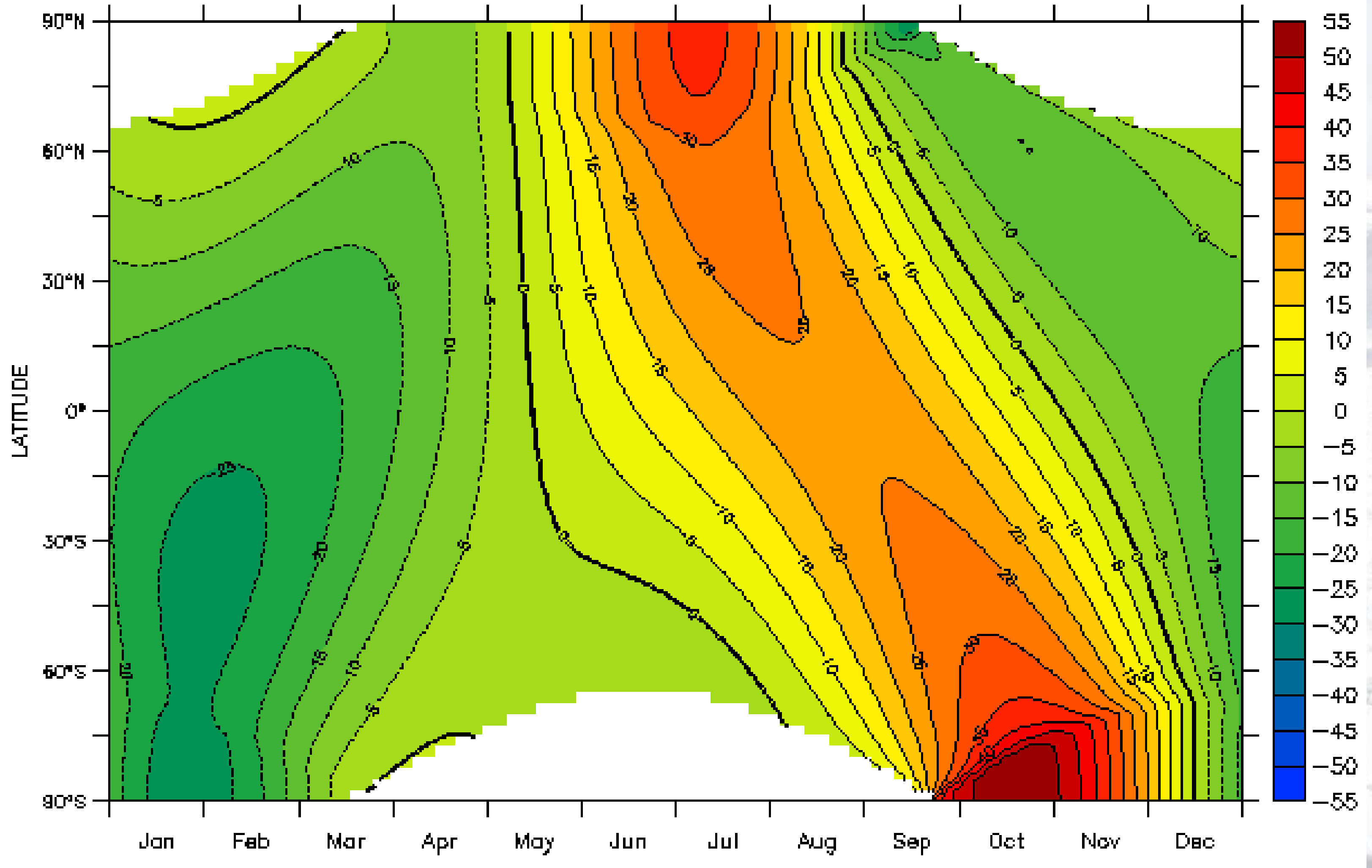
	Mk3L	Observed*
Standard deviation of Niño 3.4 SST anomaly (°C)	0.48	0.71
Average period (years)	7.8 ± 0.5	~3–6
Average duration (months)	17.2 ± 0.6	~12

*K. E. Trenberth. The definition of El Niño. *The Bulletin of the American Meteorological Society*, 78(12):2771–2777, 1997.

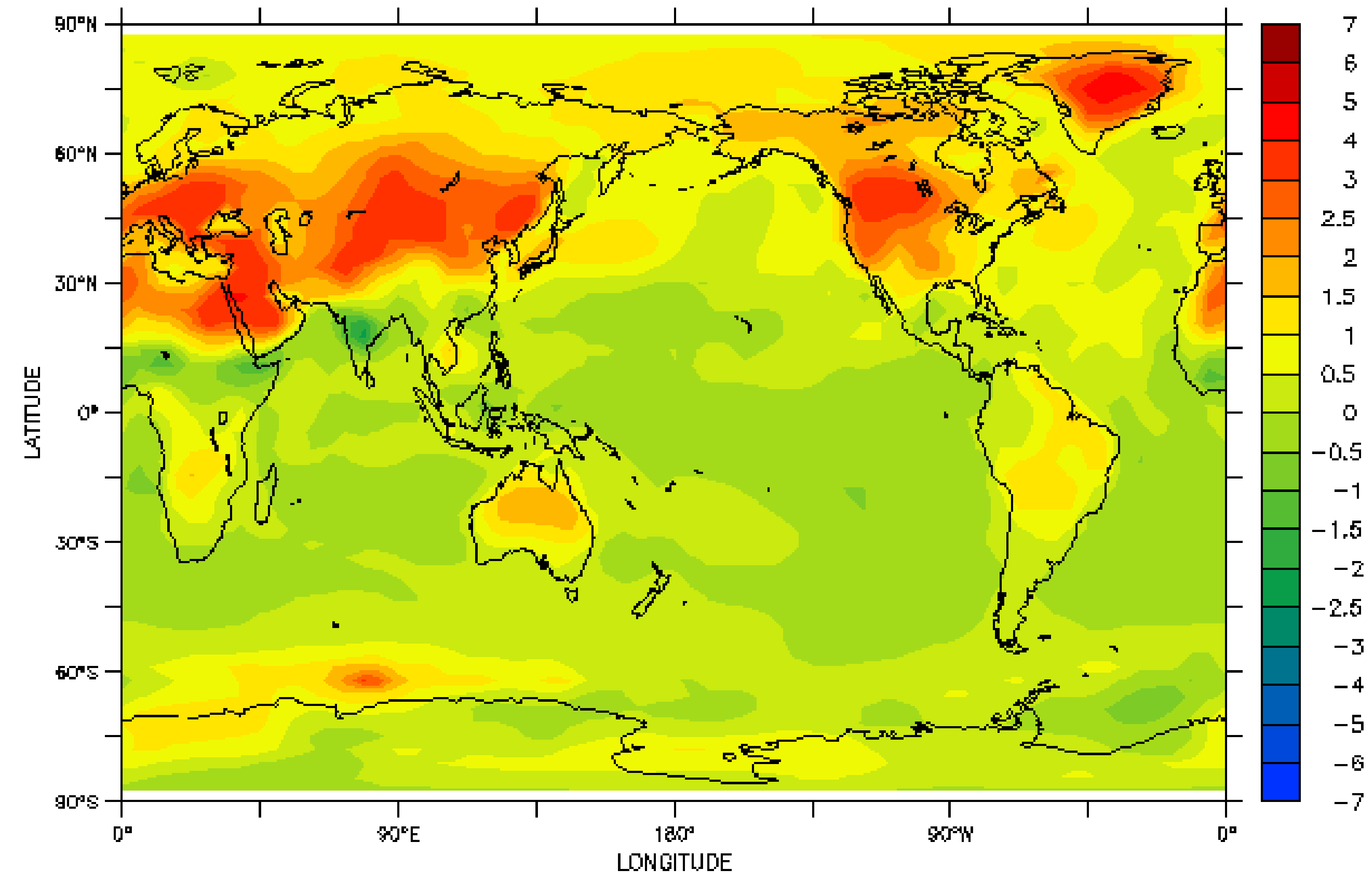
3. The climate of the mid-Holocene

- Equilibrium simulation conducted for 6,000 years BP
- Indentical to control simulation, except:
  - Orbital parameters for 6,000 years BP
- Integrated for 1200+ years
- PMIP2 experiment

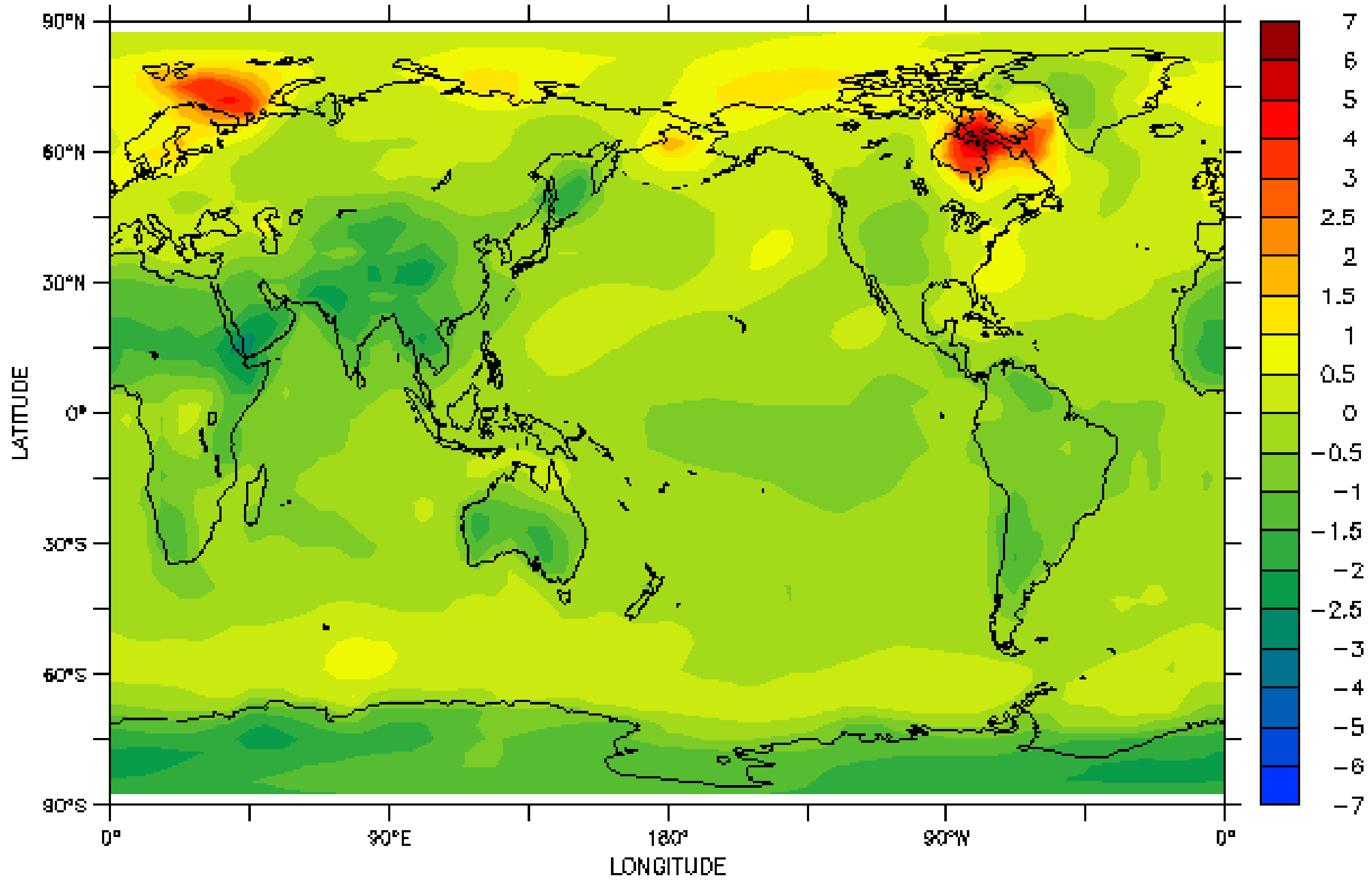
Paleoclimate Modelling
PMIP
Intercomparison Project
Phase II



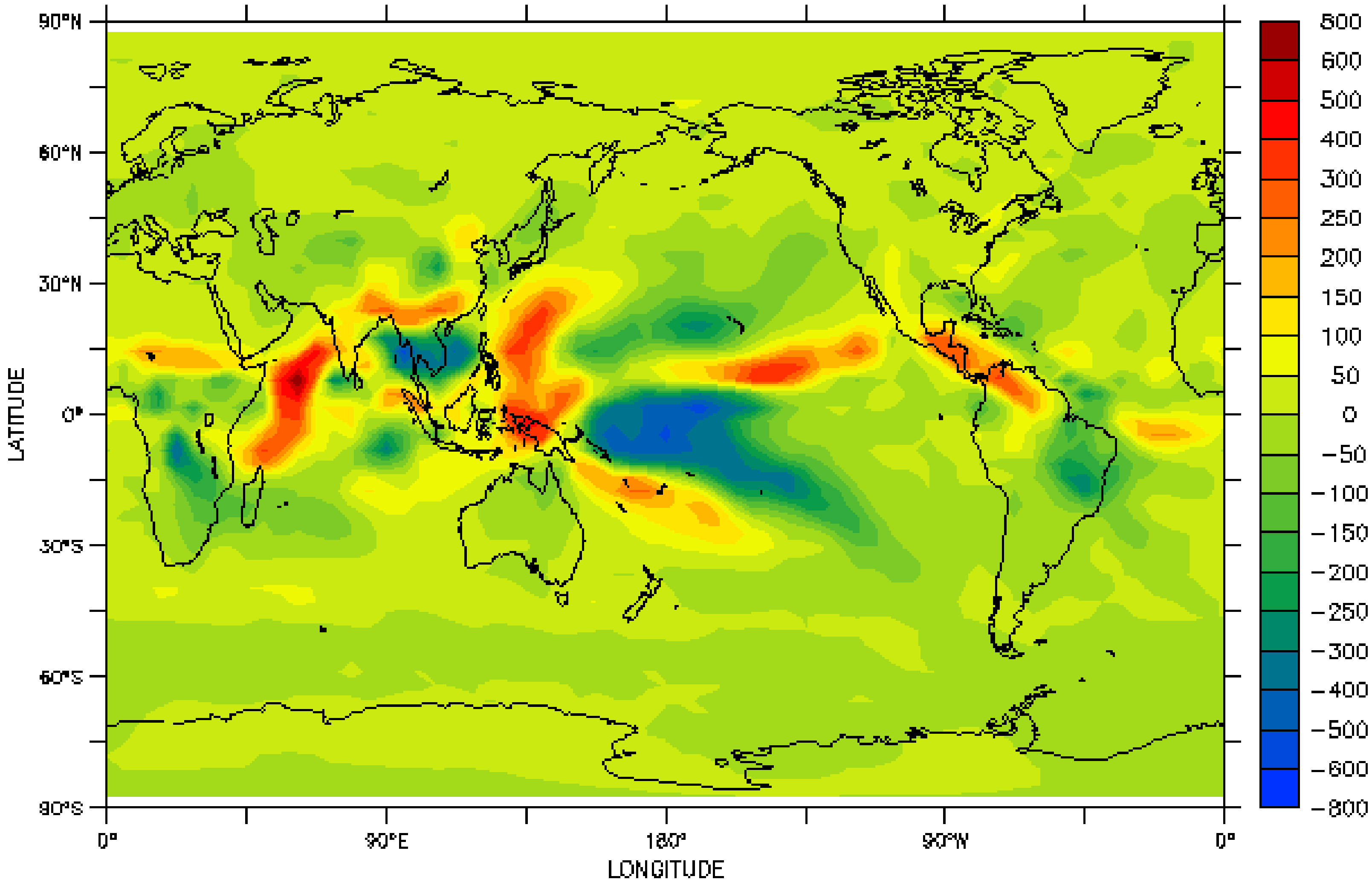
Change in insolation (Wm^{-2})



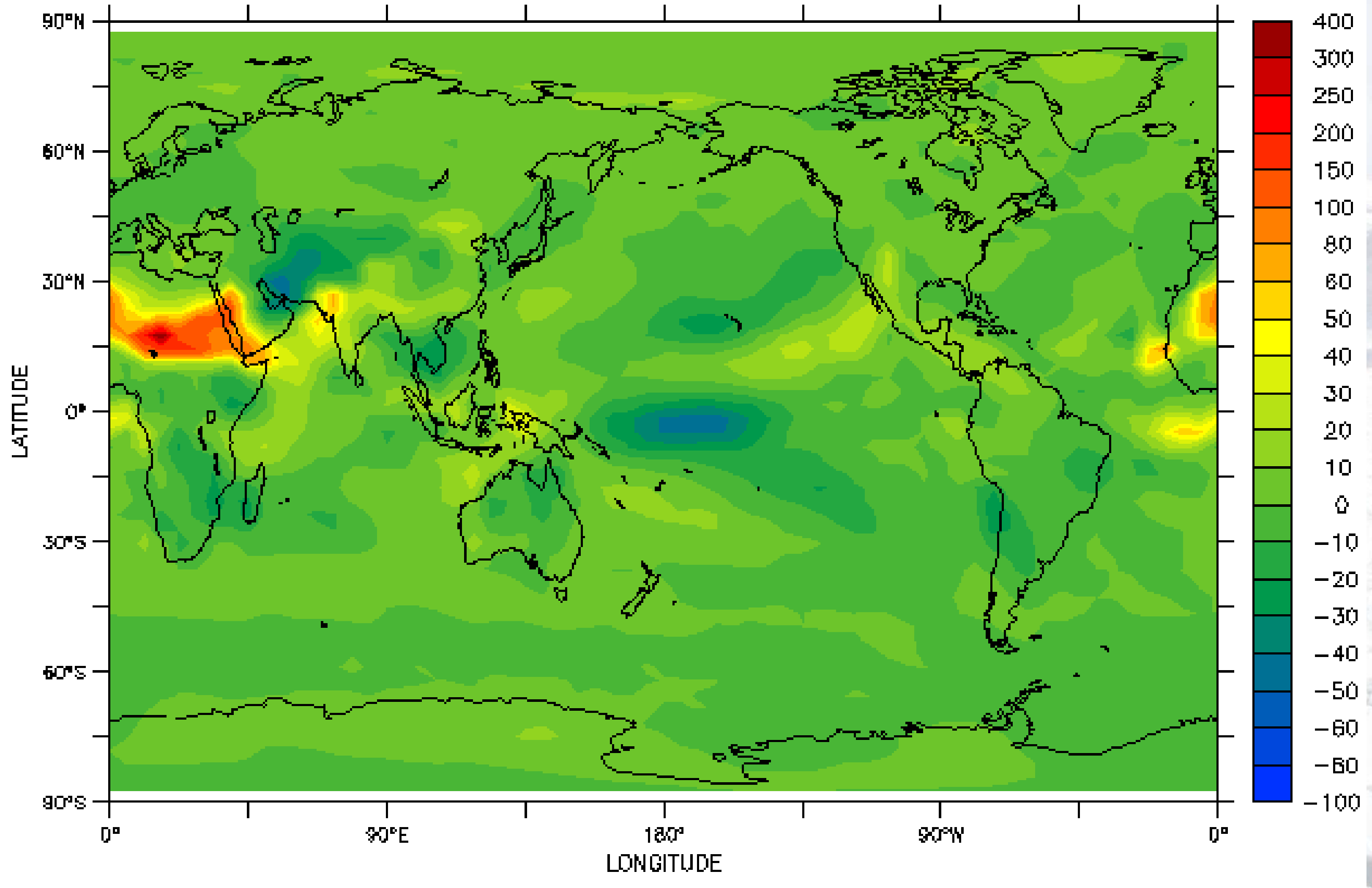
Difference in August surface air temperature (°C)



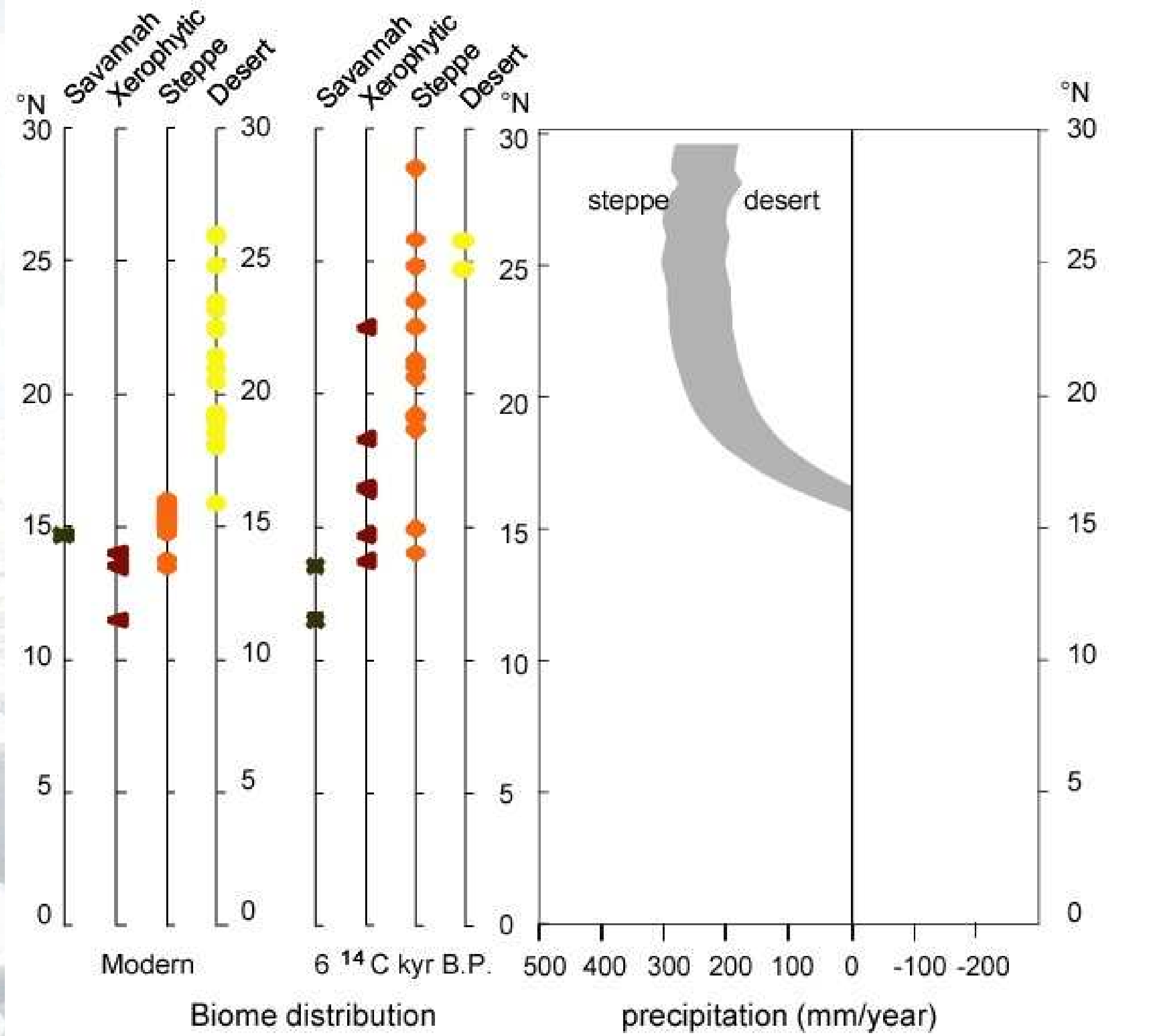
Difference in February surface air temperature (°C)



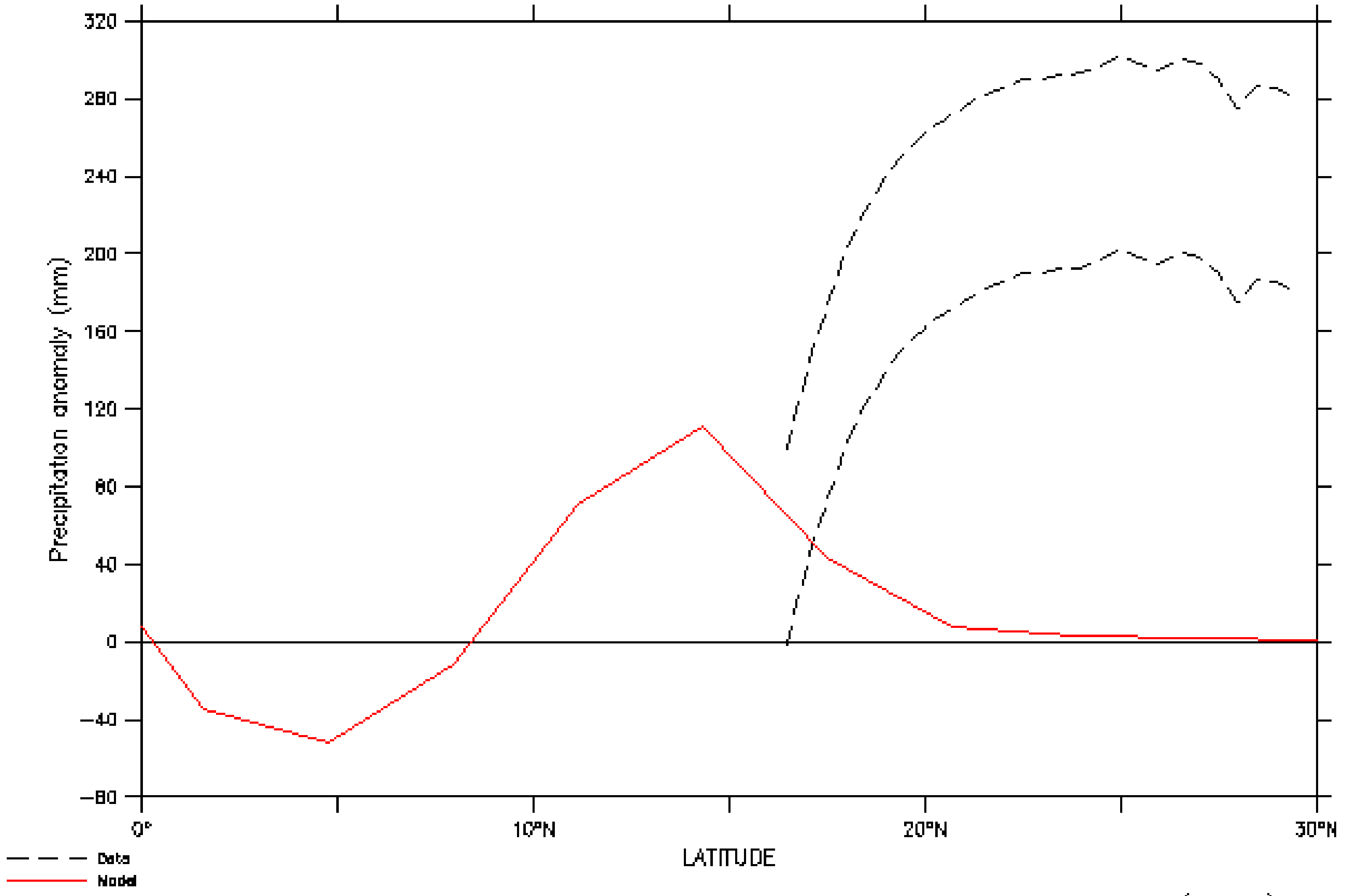
Difference in annual precipitation (mm)



Difference in annual precipitation (%)



Reconstructed precipitation anomaly over Northern Africa



Annual precipitation anomaly over Northern Africa (mm)

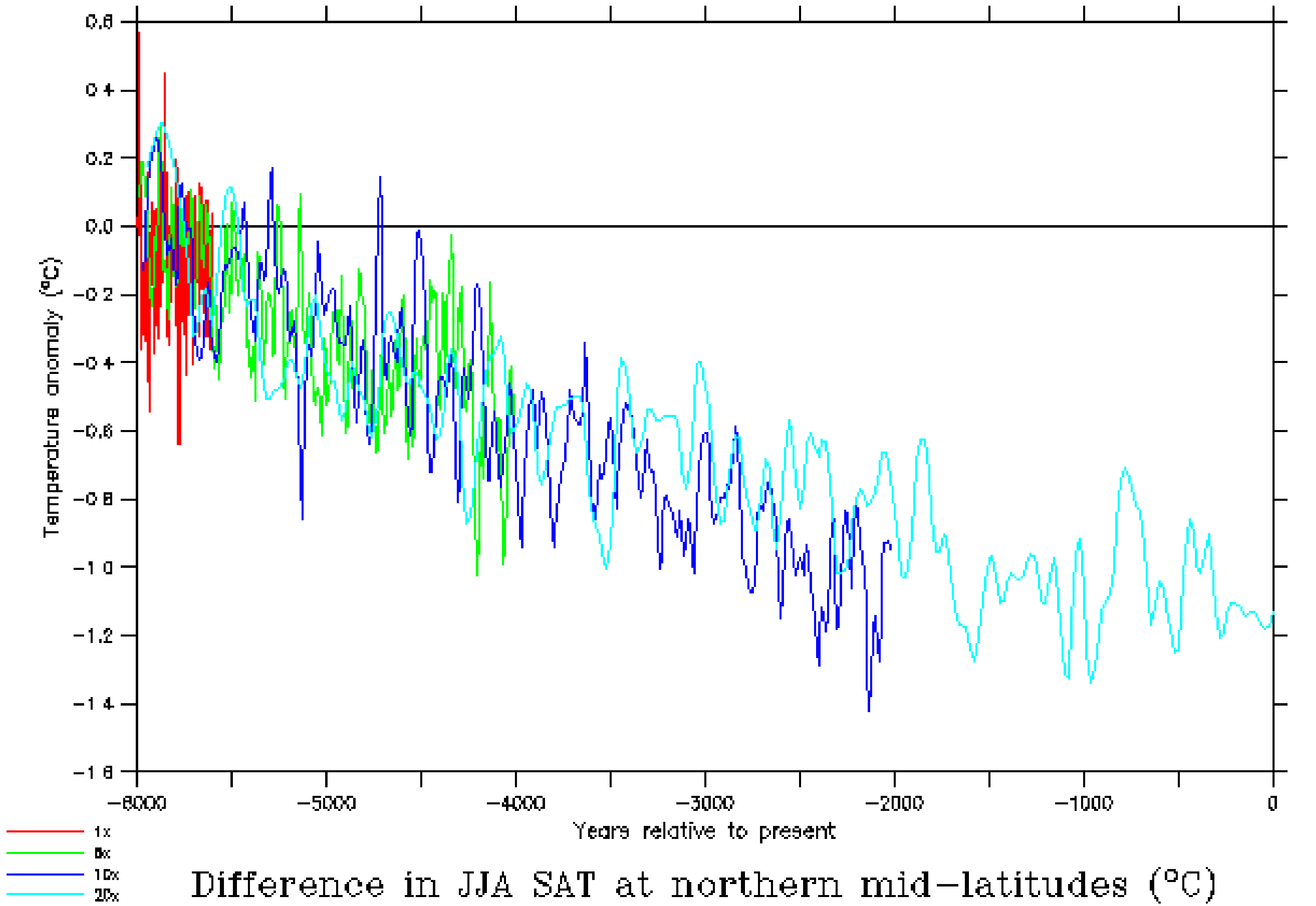
El Niño: control versus 6ka BP

	Control	6ka BP
Standard deviation of Niño 3.4 SST anomaly (°C)	0.48	0.42
Period (years)	7.8 ± 0.5	8.8 ± 0.9
Duration (months)	17.2 ± 0.6	16.6 ± 1.0

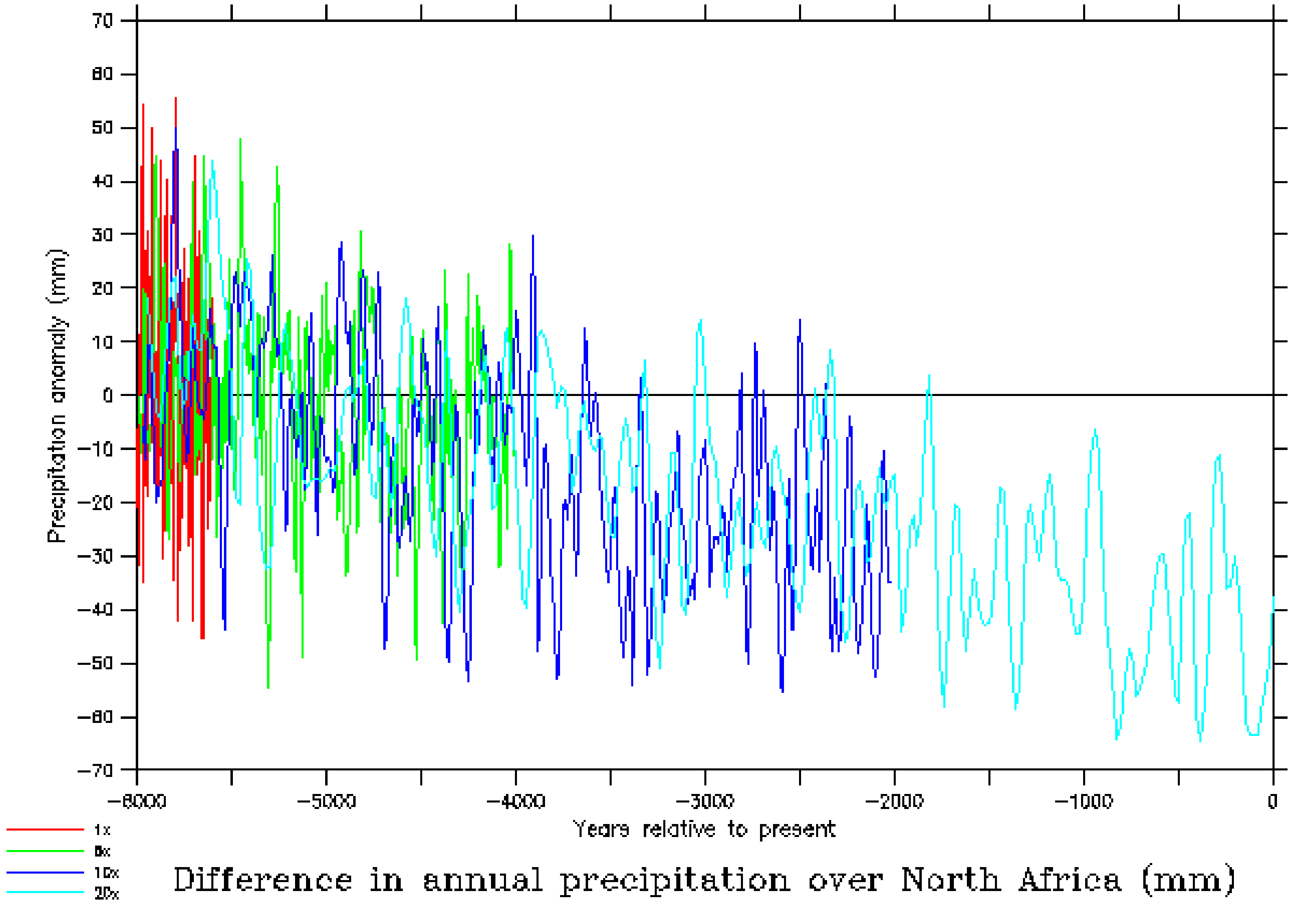
4. The climate of the late Holocene

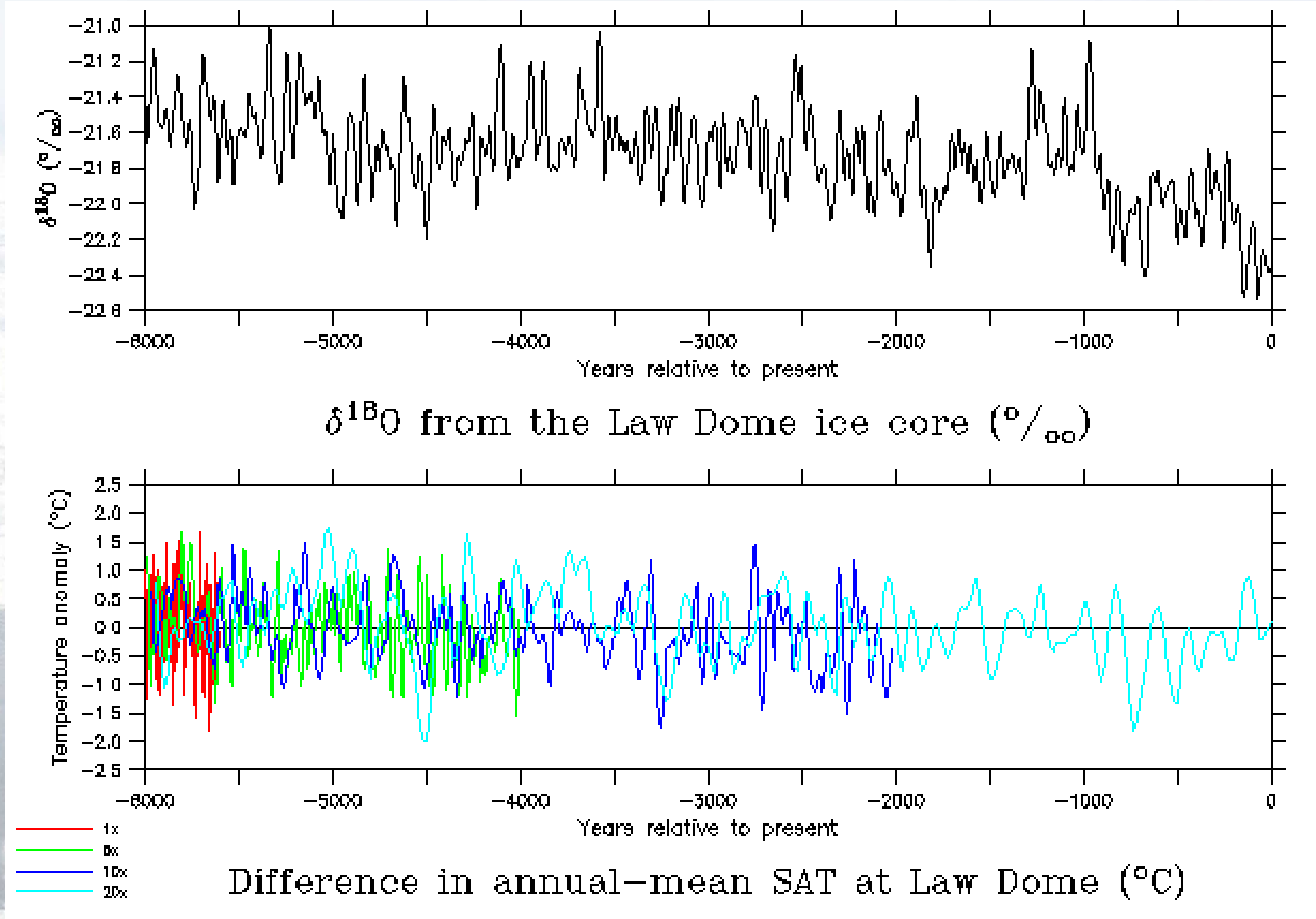
- Transient simulations from 6,000 years BP to the present day
- Identical to control simulation, except:
  - Orbital parameters varied
- The acceleration technique of Lorenz and Lohmann (2004)* is used
- Acceleration factors of 1, 5, 10 and 20

*S. J. Lorenz and G. Lohmann. Acceleration technique for Milankovitch type forcing in a coupled atmosphere-ocean circulation model: method and application for the Holocene. *Climate Dynamics*, 23:727–743, 2004.

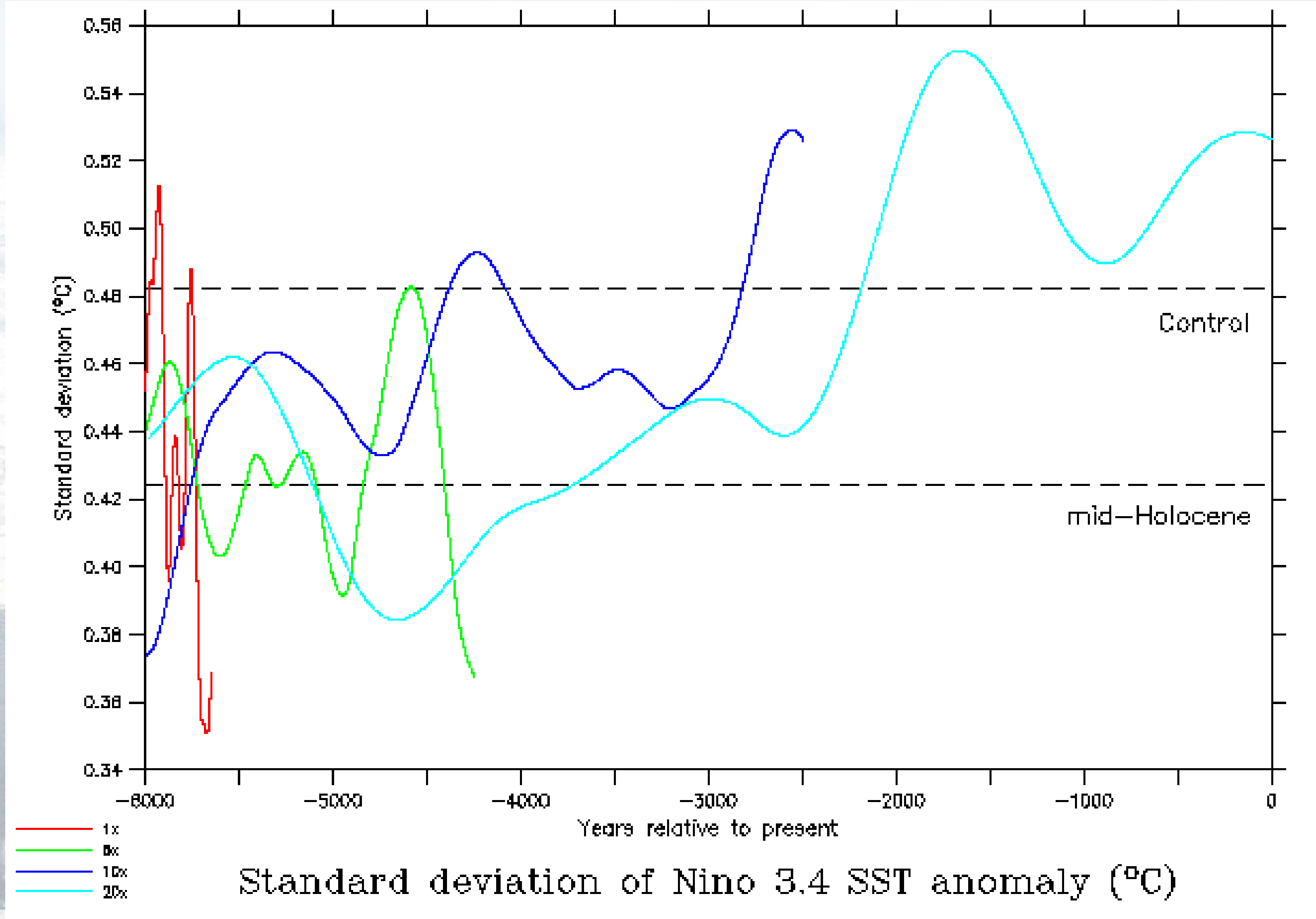


Difference in JJA SAT at northern mid–latitudes (°C)


Precipitation anomaly (mm)
Years relative to present
−6000
−5000
−4000
−3000
−2000
−1000
0
1x
10x
20x
Difference in annual precipitation over North Africa (mm)

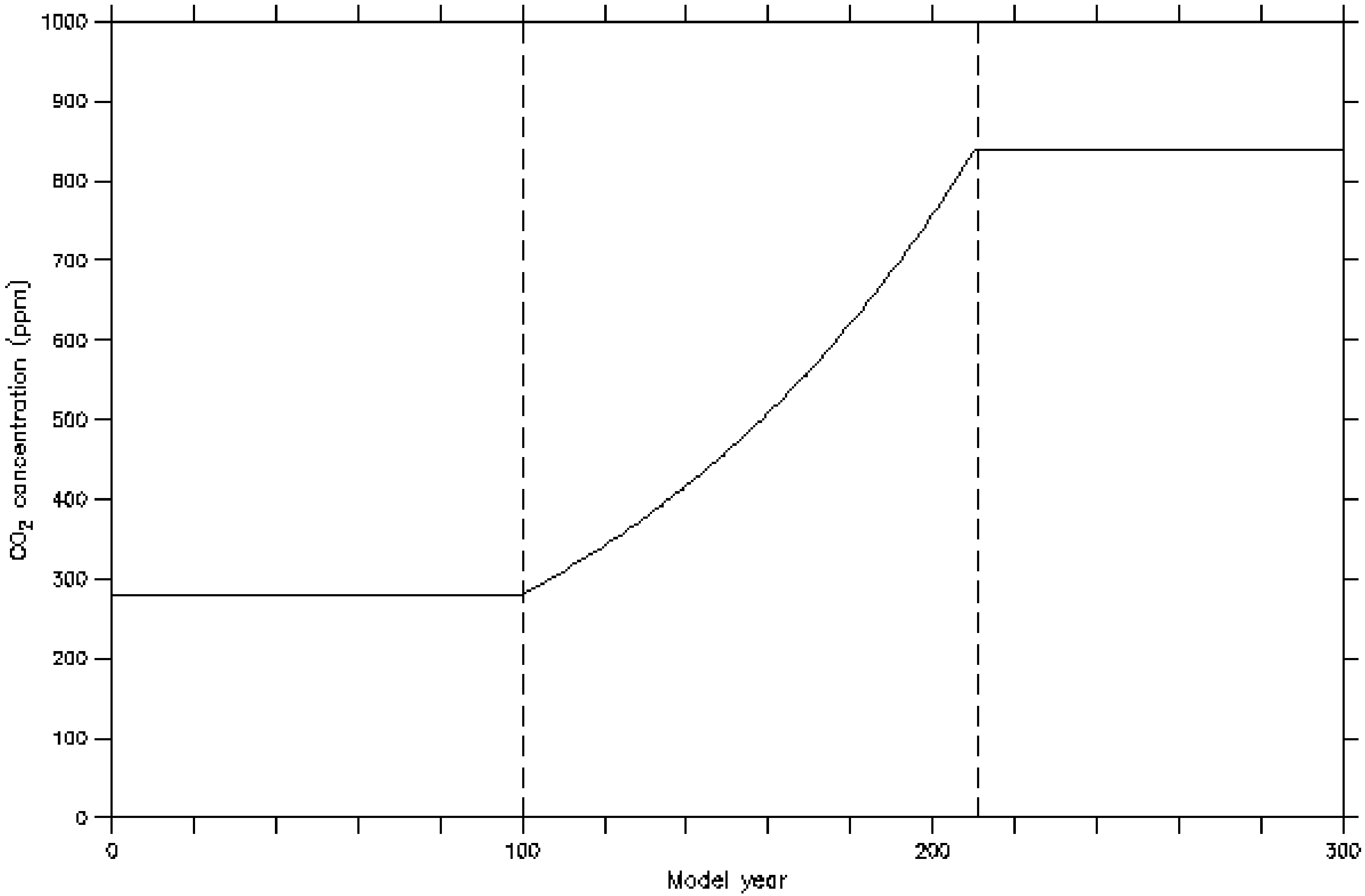


$\delta^{18}O$ (°/oo)
Years relative to present
$\delta^{18}O$ from the Law Dome ice core (°/oo)
Temperature anomaly (°C)
Years relative to present
1x
10x
20x
Difference in annual-mean SAT at Law Dome (°C)

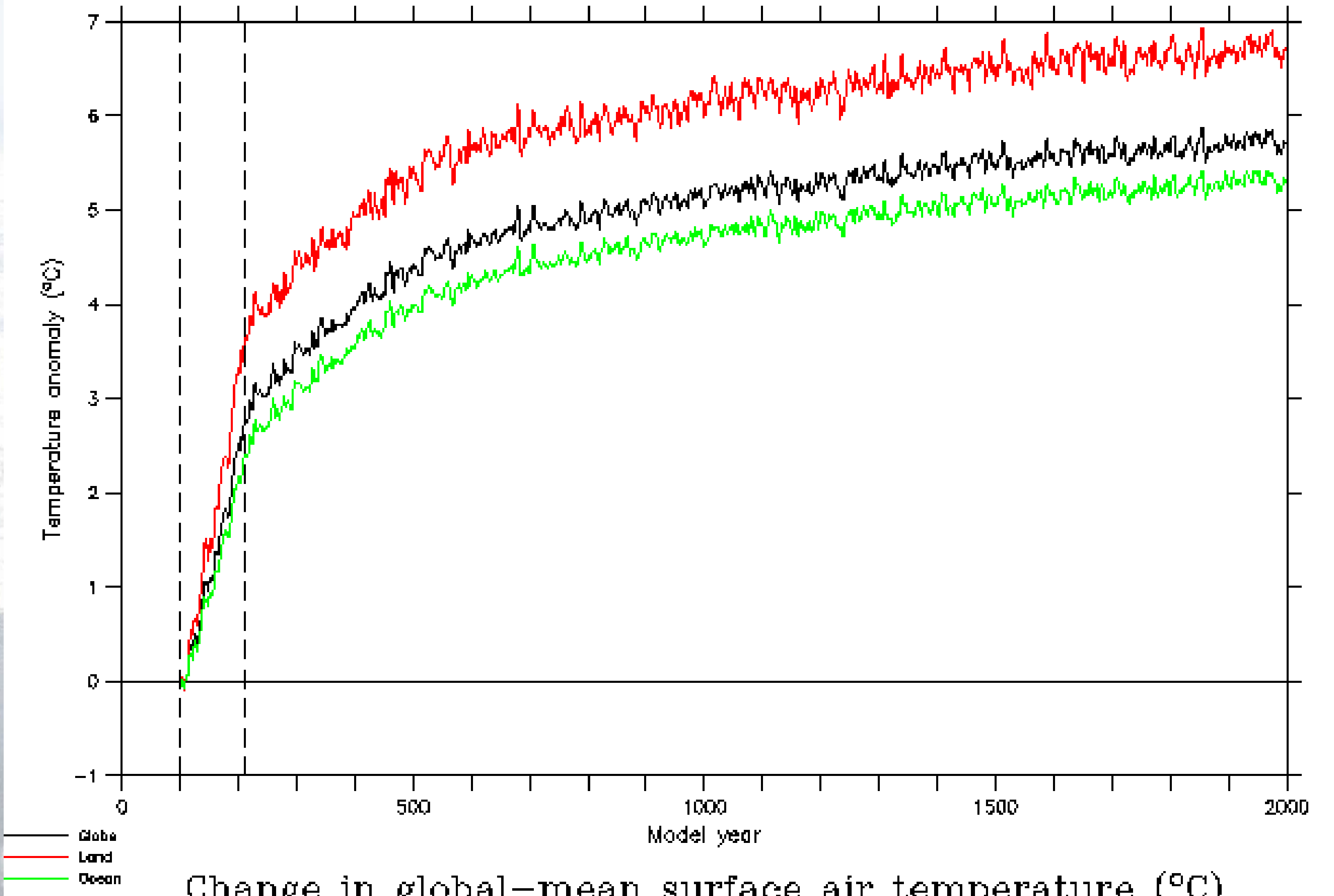

0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
Standard deviation (°C)
Control
mid–Holocene
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
10x
20x
Standard deviation of Nino 3.4 SST anomaly (°C)

5. Future climate

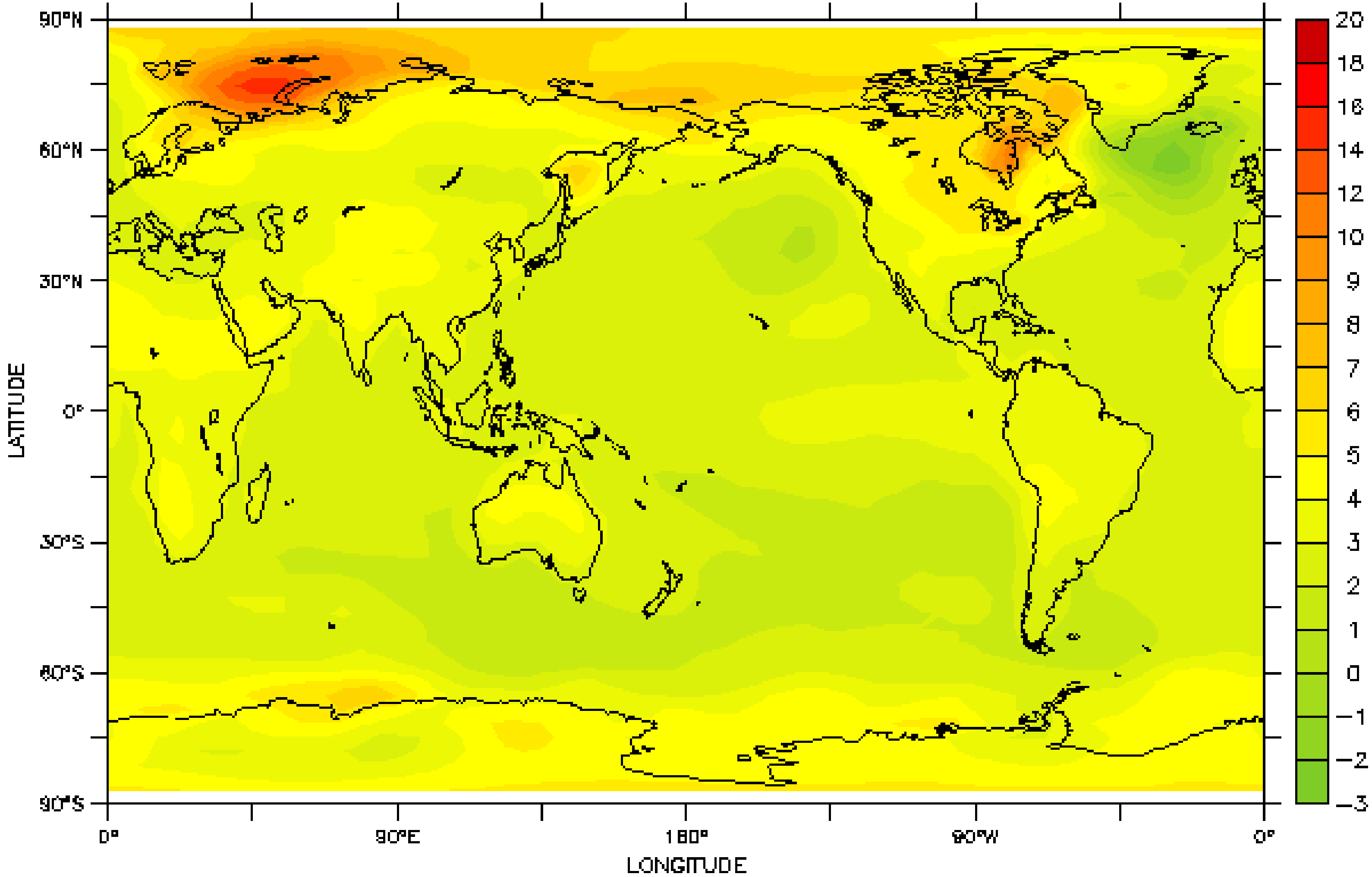
- Transient simulation in which the CO_2 concentration is stabilised at three times the pre-industrial value
- Identical to control simulation, except:
  - Increase the CO_2 concentration at 1% per year
  - Once it reaches 840ppm, hold it constant thereafter
- Integrated for 2000+ years



Atmospheric CO_2 concentration (ppm)

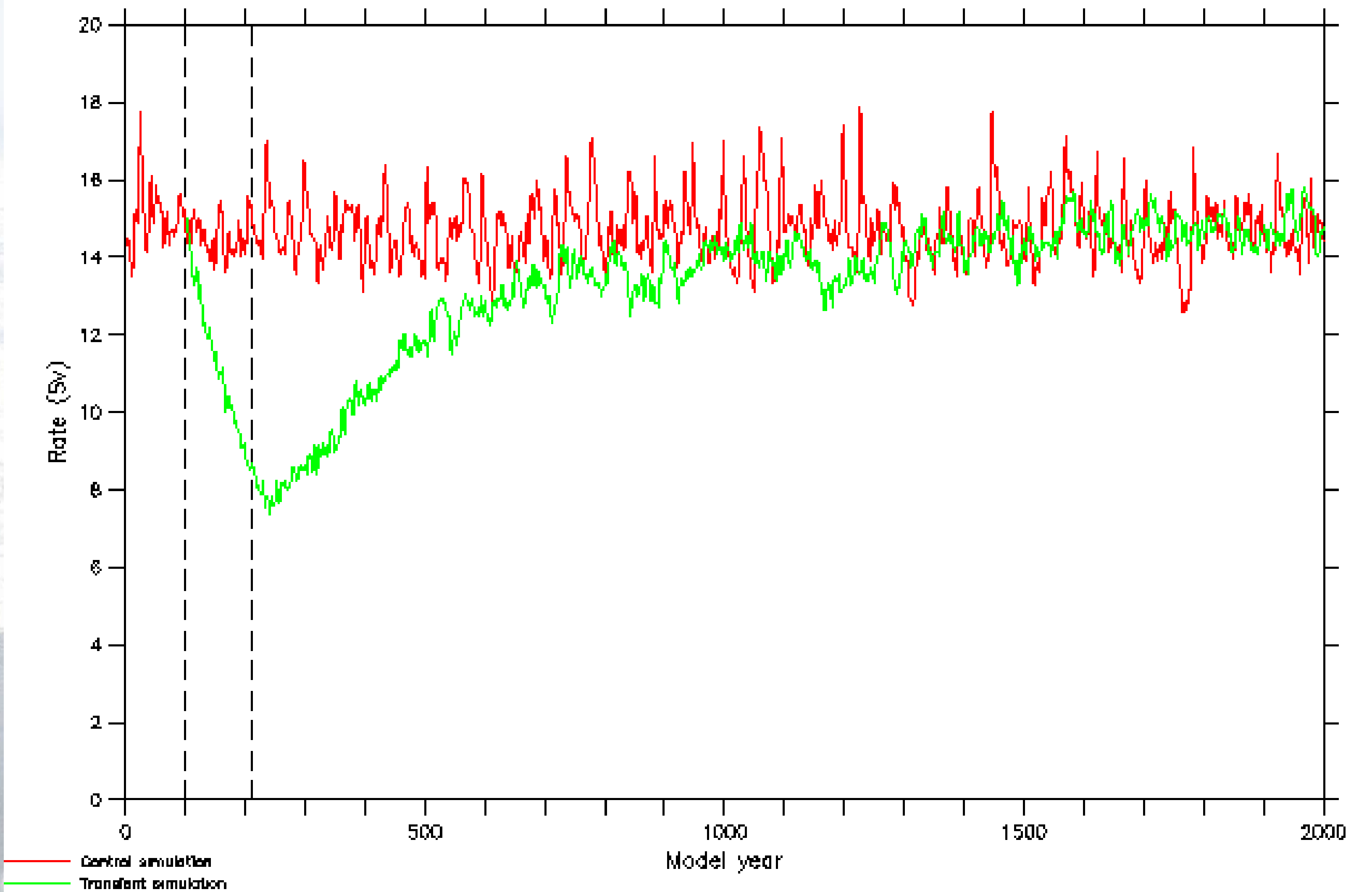


Change in global-mean surface air temperature (°C)

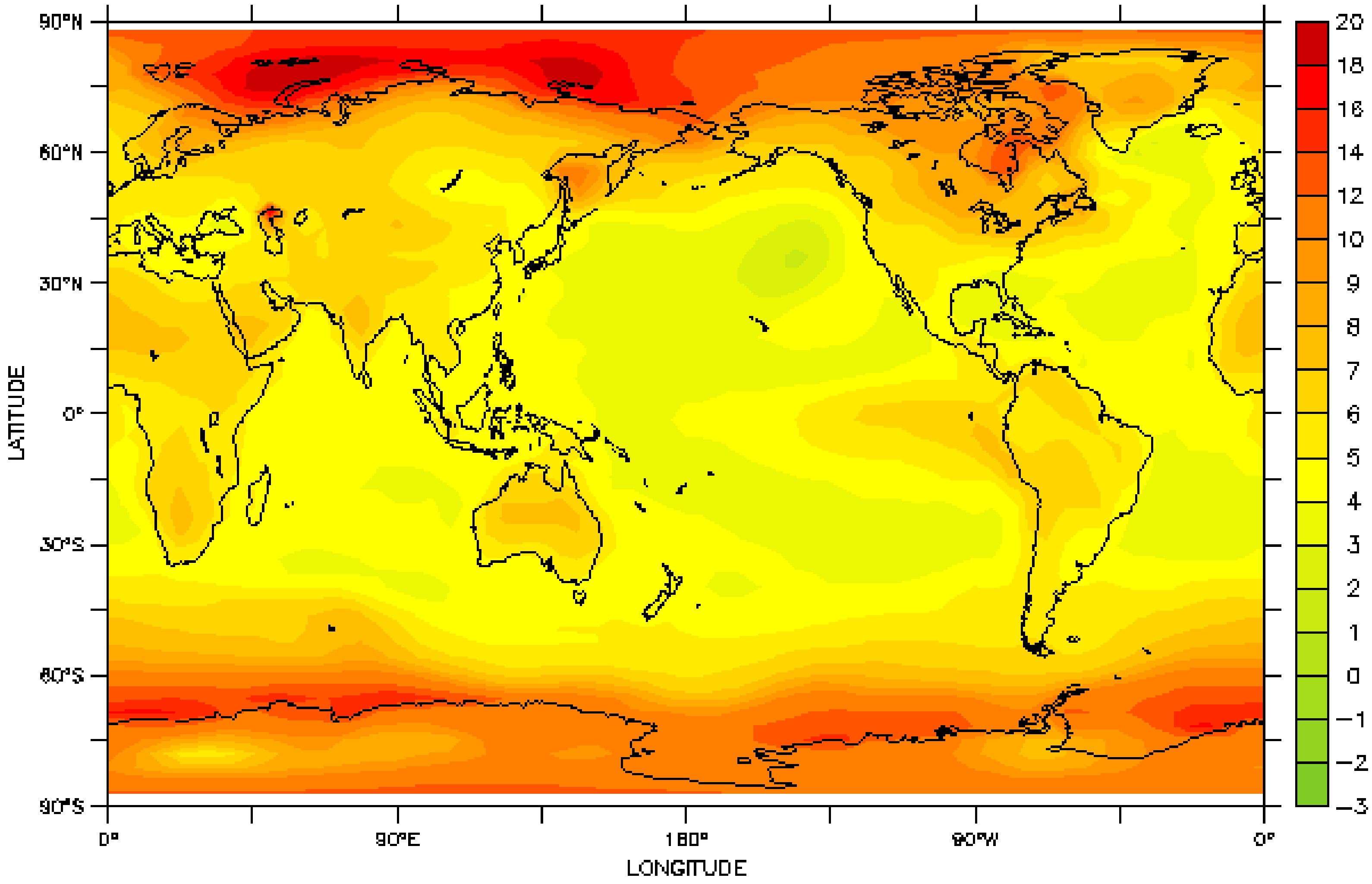


Change in annual−mean SAT by years 211−260 (°C)

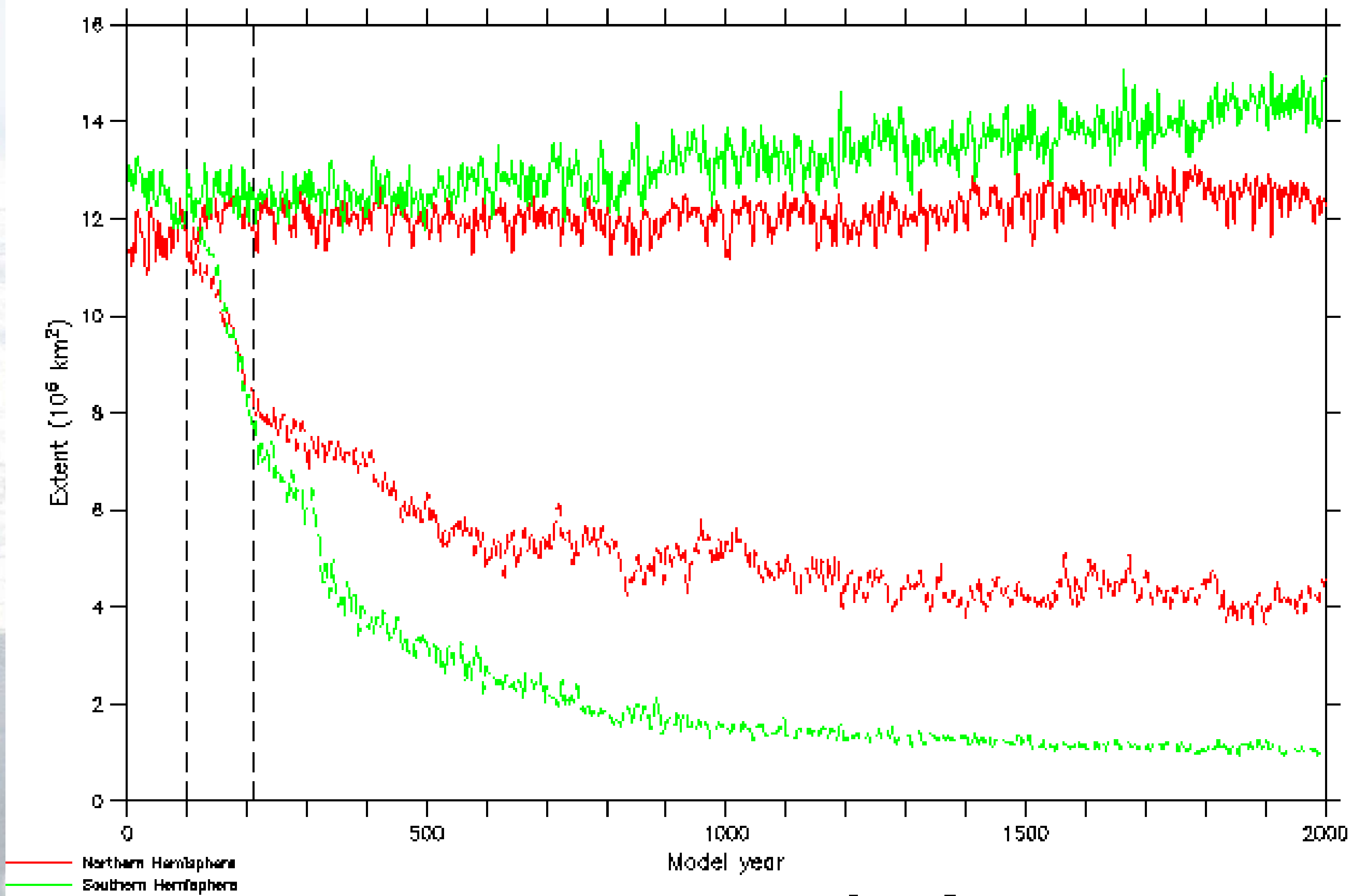

WHERE WILL YOU BE?
FROM THE DIRECTOR OF INDEPENDENCE DAY
THE DAY AFTER TOMORROW
MAY 28 ONLY IN THEATERS



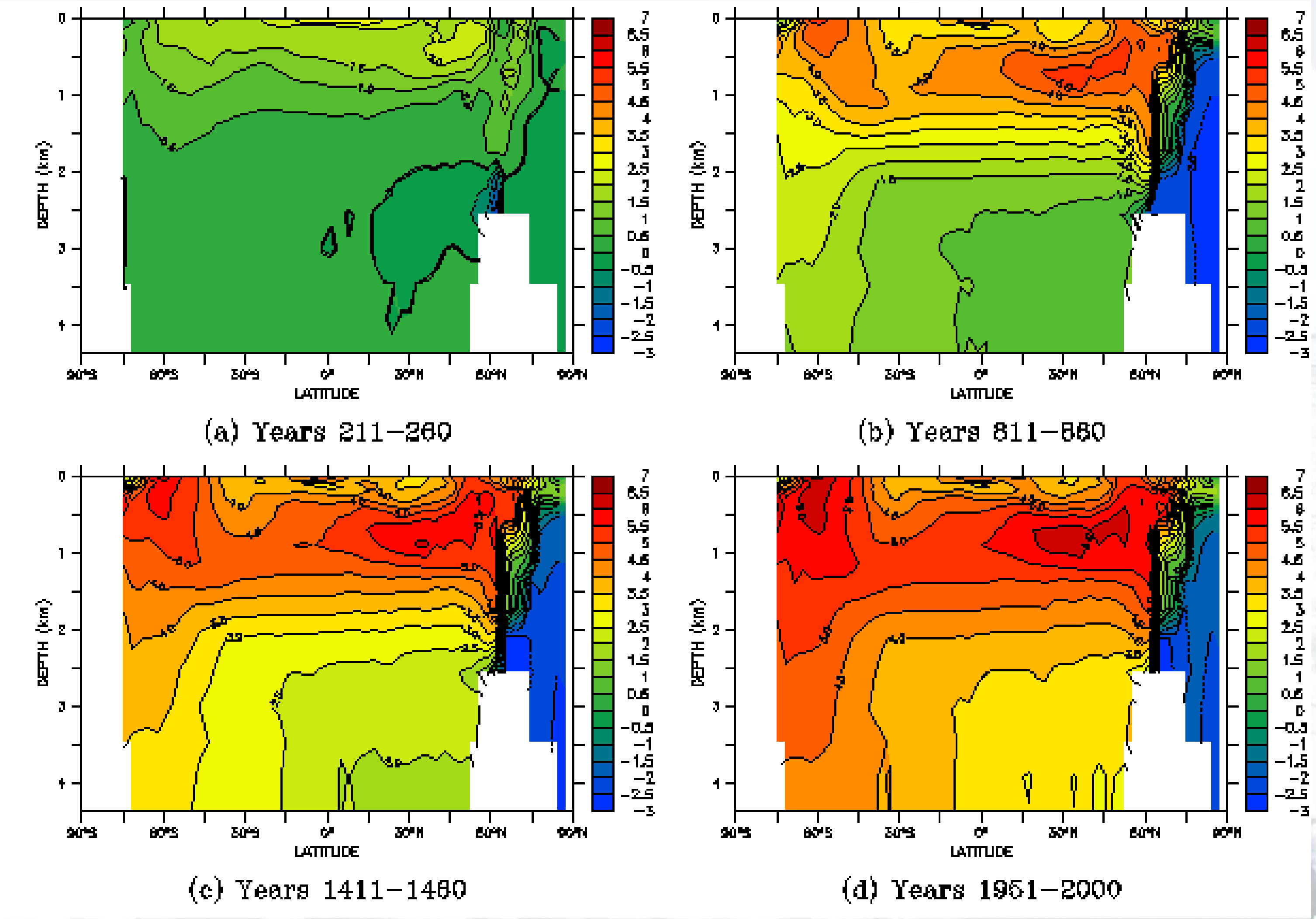
North Atlantic Deep Water formation (Sv)



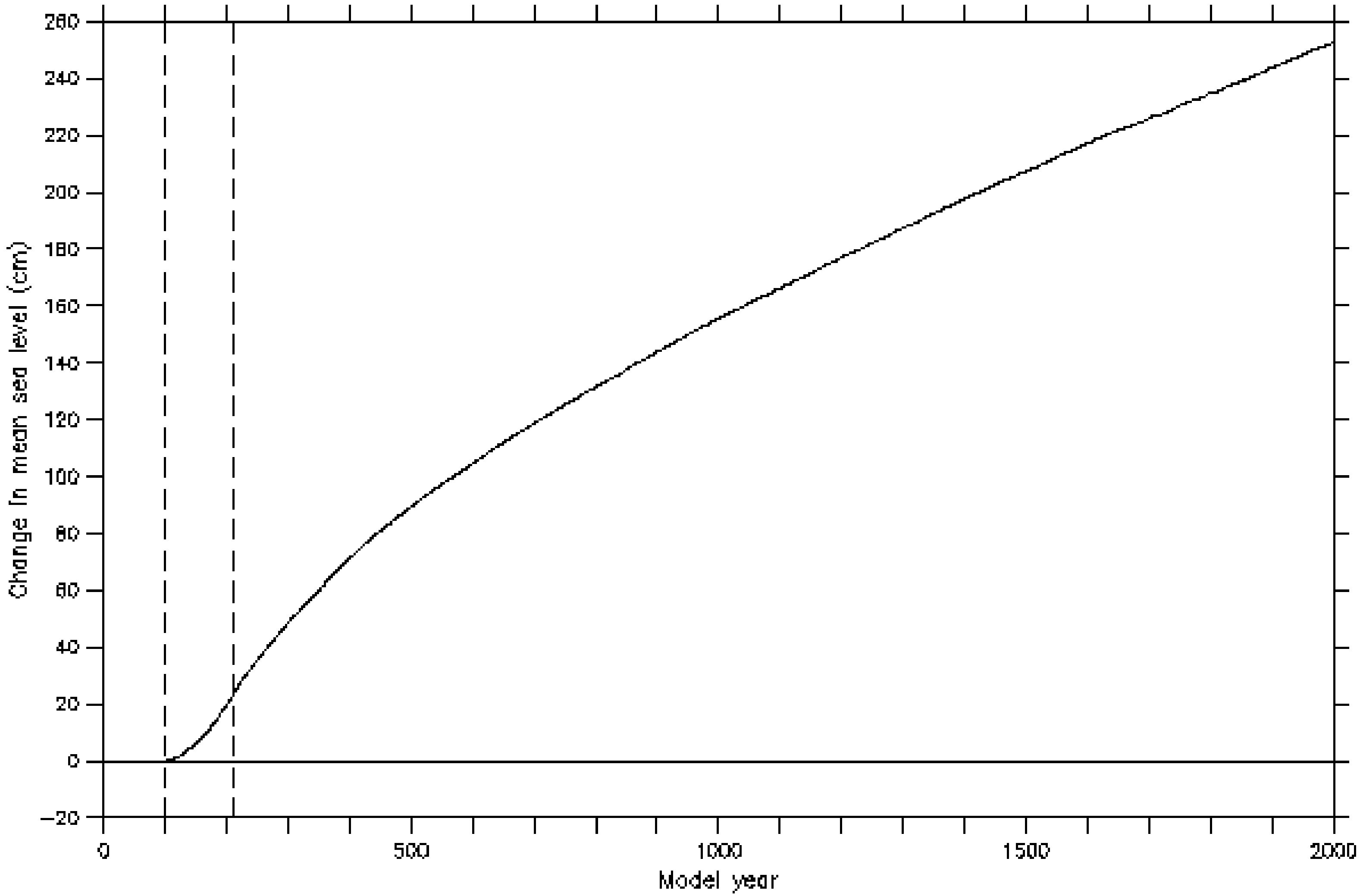
Change in annual−mean SAT by years 1951−2000 (°C)



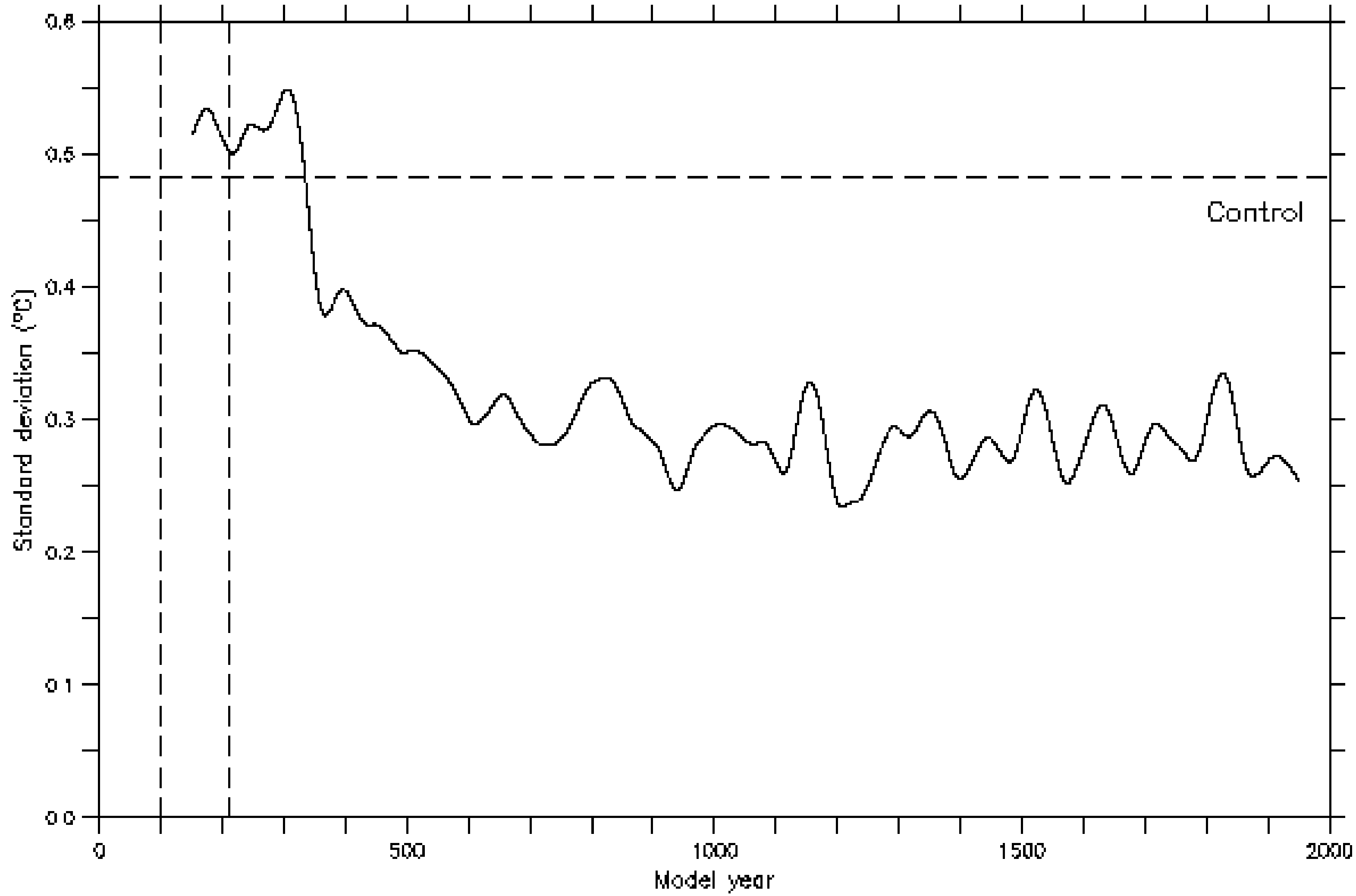
Sea ice extent (10^6 km^2)



Change in zonal-mean ocean temperature (°C)



Change in mean sea level (cm)



Standard deviation of Nino 3.4 SST anomaly (°C)

Conclusions

- The CSIRO Mk3L climate system model is a useful tool for studying past, present and future climate variability and change
- Simulations of past climate show good agreement with the data, but also reveal some limitations in the model
- The simulated response to an increase in atmospheric CO_2 indicates ongoing warming and sea level rise
- ENSO strengthens slightly at first, but weakens once the CO_2 concentration is stabilised