The CSIRO Mk3L climate system model

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Overview

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

1. The CSIRO Mk3L climate system model

- Low-resolution version of the CSIRO climate system model
- Coupled atmosphere-sea ice-ocean general circulation model
- Designed to enable millennial-scale simulations of climate variability and change
  - palaeoclimate reconstructions
  - projections of future climate
  - detection/attribution
- Is it an EMIC?

Atmosphere model

- Based on the CSIRO Mk3 atmosphere model
- Spectral general circulation model
- Reduced horizontal resolution of R21 ($\Delta\lambda \approx 5.6^\circ, \Delta\phi \approx 3.2^\circ$)
- 18 vertical levels
- Orbital parameter code
- Dynamic-thermodynamic sea ice model
- Land surface model (static vegetation)

Ocean model

- Based on the CSIRO Mk2 ocean model
- z-coordinate general circulation model
- Same horizontal grid as atmosphere model
- 21 vertical levels
- Gent-McWilliams eddy diffusion

Coupled model

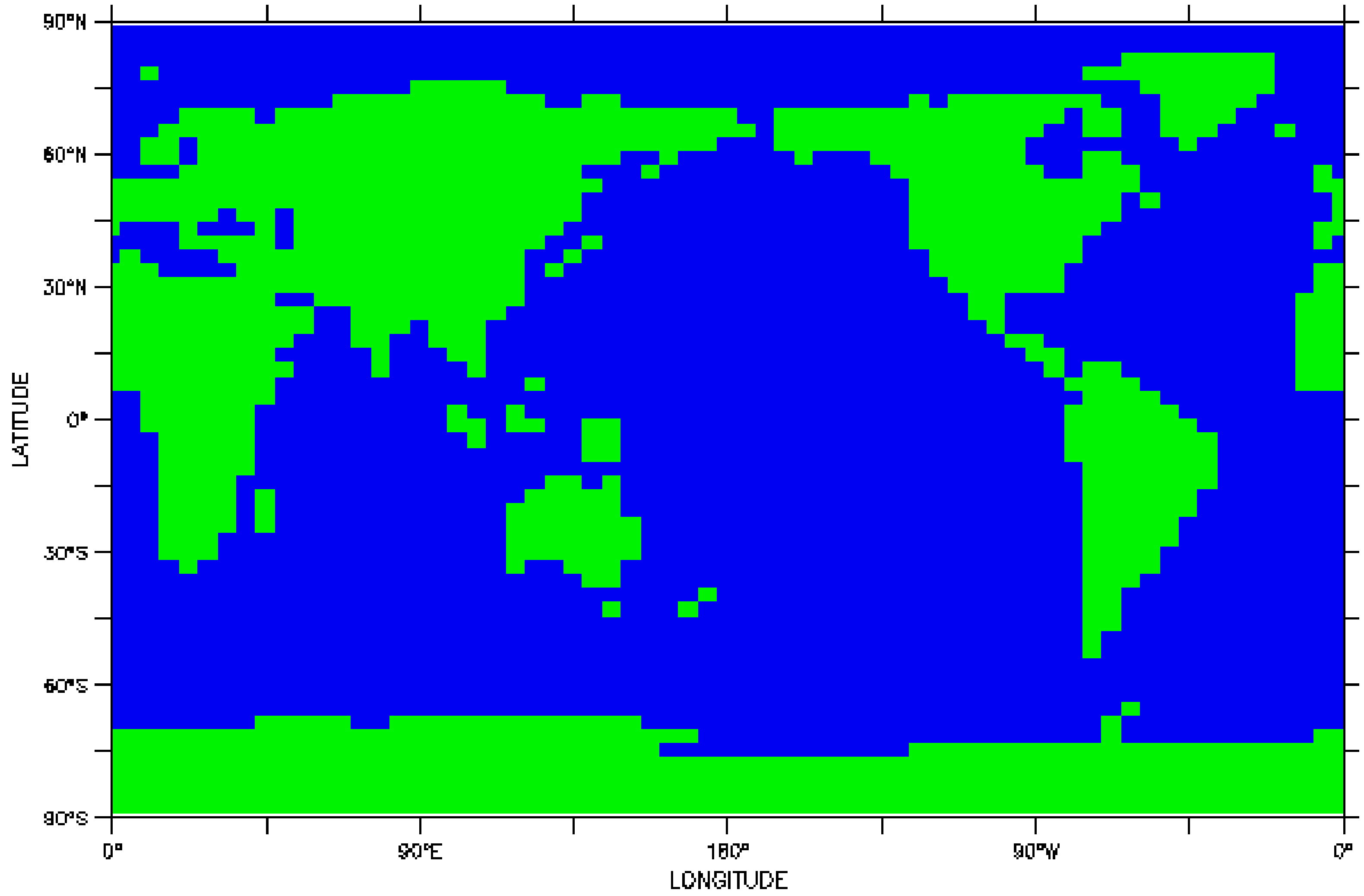
- Surface fields exchanged every one hour (3 atmosphere model timesteps for each ocean model timestep)
- Coupling rigorously conserves heat and freshwater
- Flux adjustments applied

Source code

- Designed for maximum portability across computer architectures
- Should compile on any UNIX/Linux platform
- Shared-memory parallelism achieved using OpenMP
- Dependence on external libraries restricted to netCDF and FFTW
- Loop structure optimised for serial architectures

Benchmarks on APAC Facilities

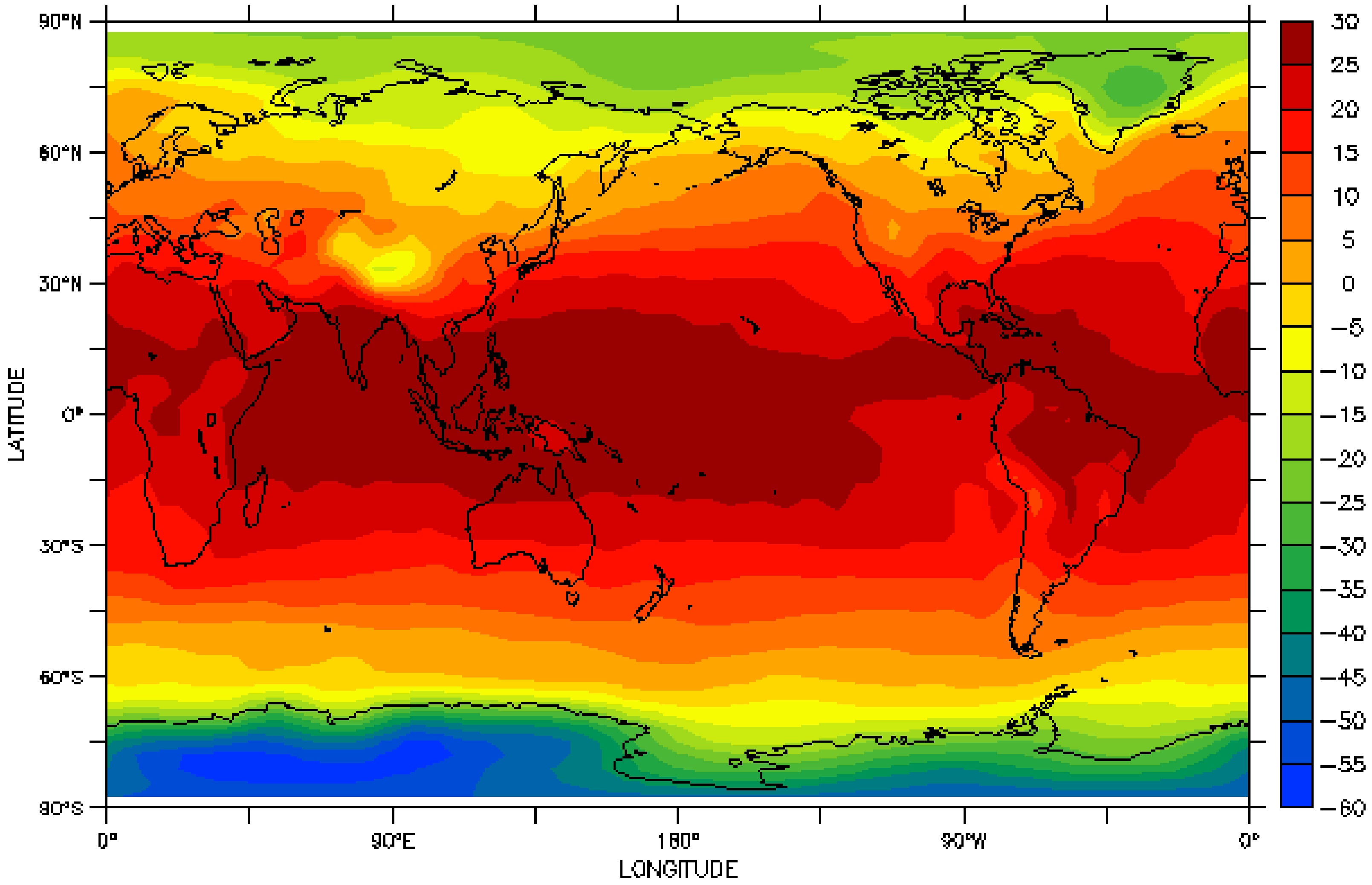
Facility	Processor type	Number of processors	Speed (years/day)
AlphaServer SC	1GHz EV68	1	4.0
		2	7.2
		4	11.7
Linux Cluster	2.66GHz Pentium 4	1	4.6



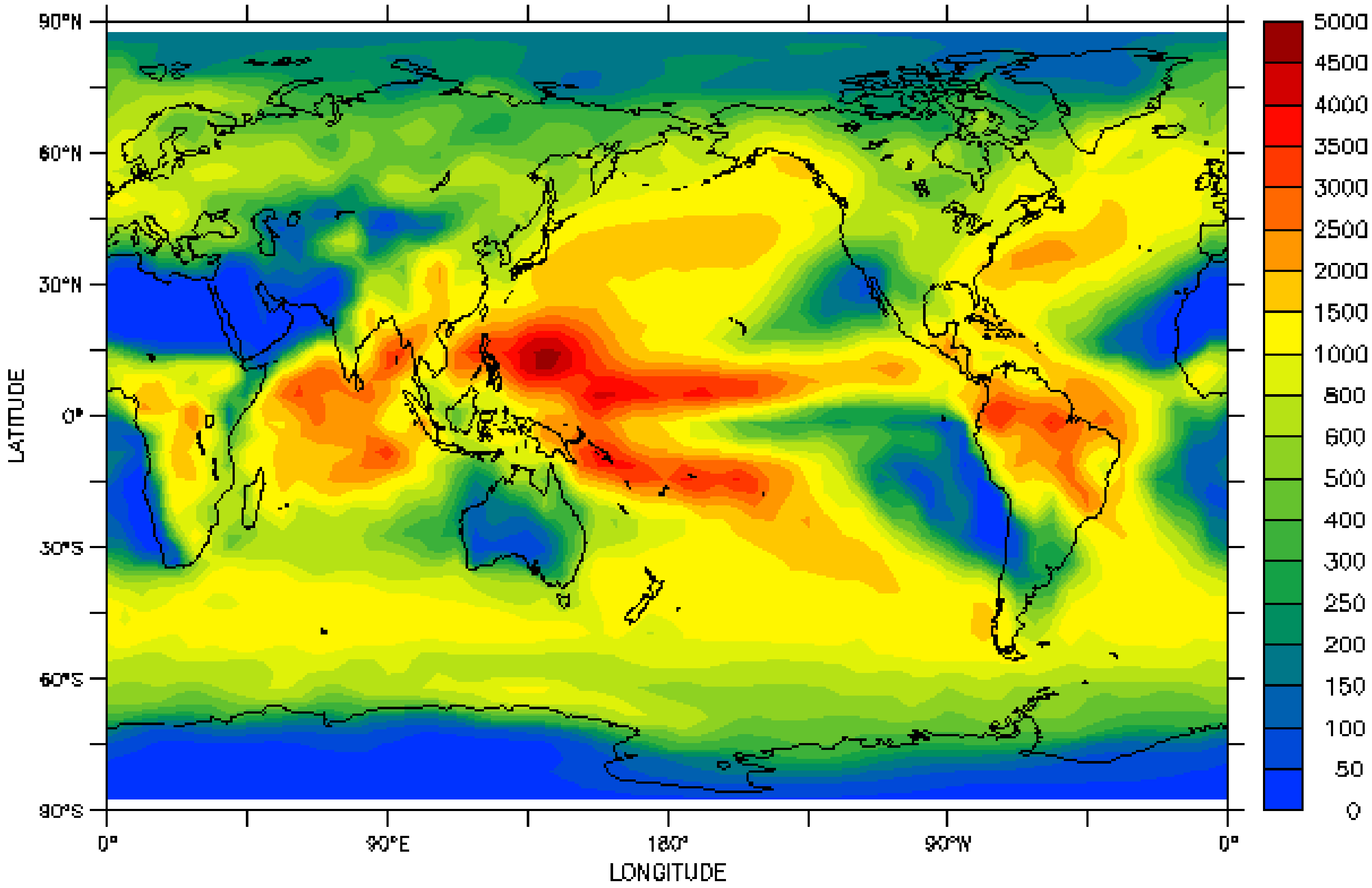
The CSIRO Mk3L model grid

2. The simulated "present-day" climate

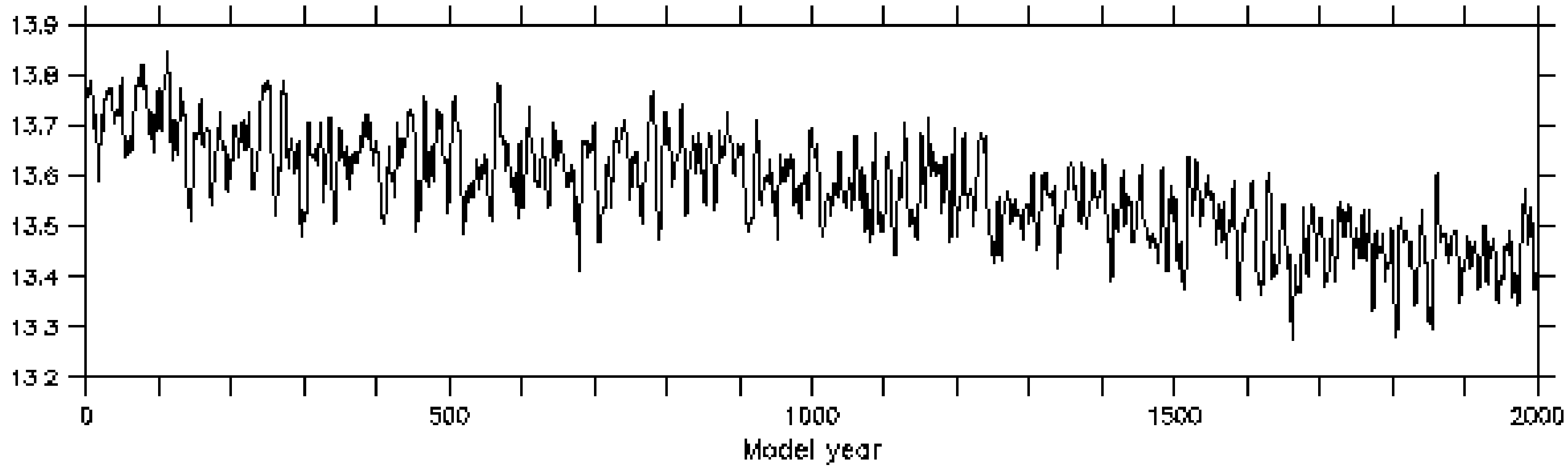
- Control simulation follows PMIP2 experimental design:
  - CO_2 concentration = 280ppm
  - Solar constant = 1365 Wm^{-2}
  - "Modern" orbital parameters (AD 1950)
- Ocean model initialised using Levitus 1998
- Atmosphere and ocean models spun up independently
- Coupled model initialised from final states of spin-up runs
- Integrated for 2000+ years



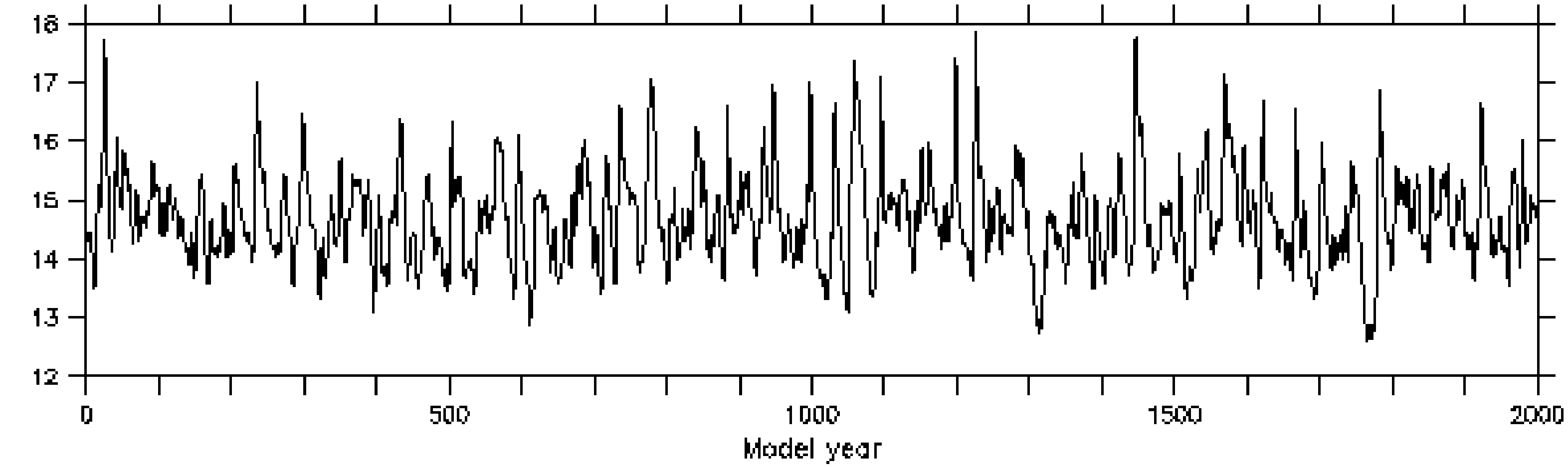
Annual−mean surface air temperature (°C)



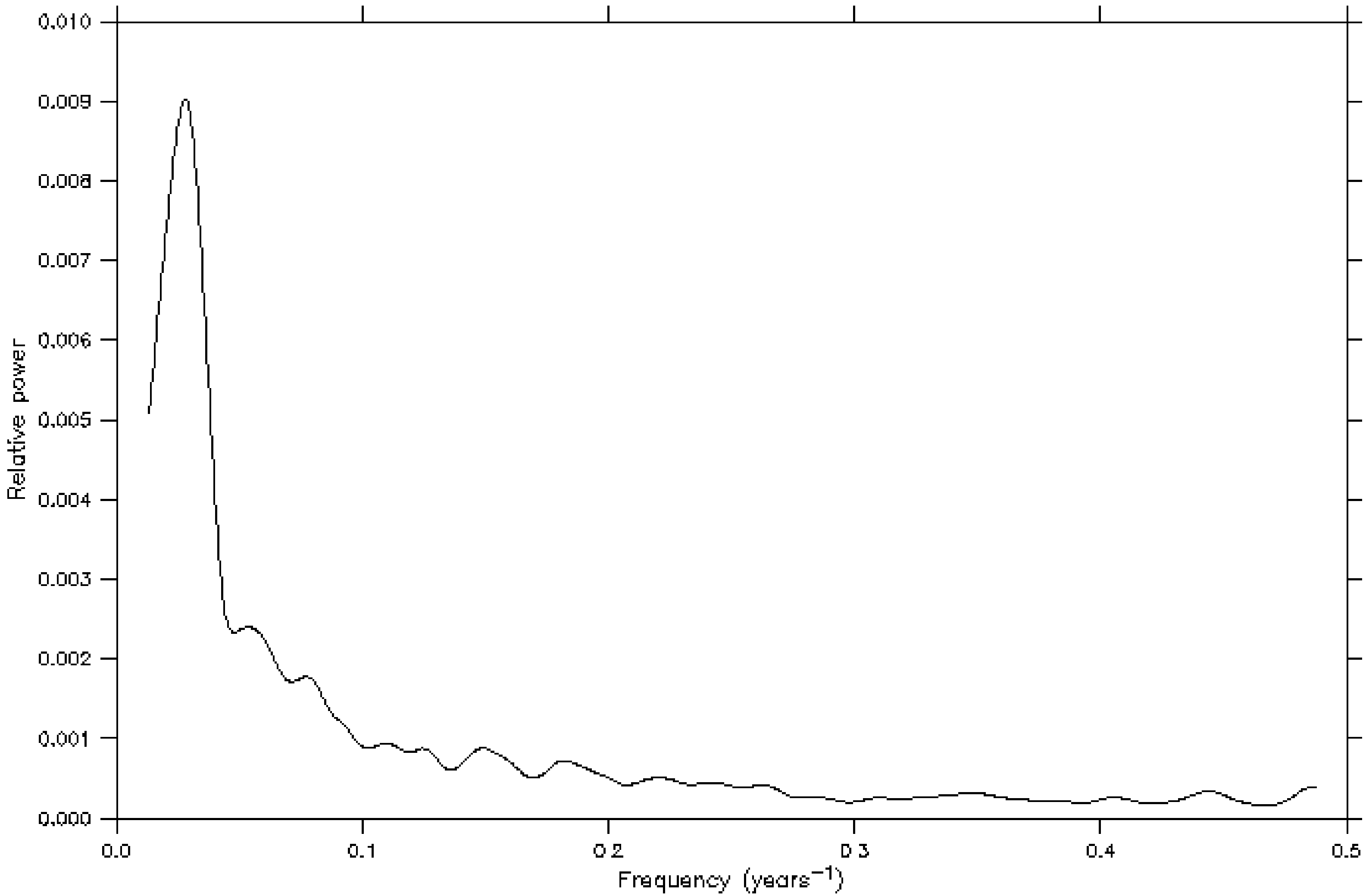
Annual precipitation (mm)



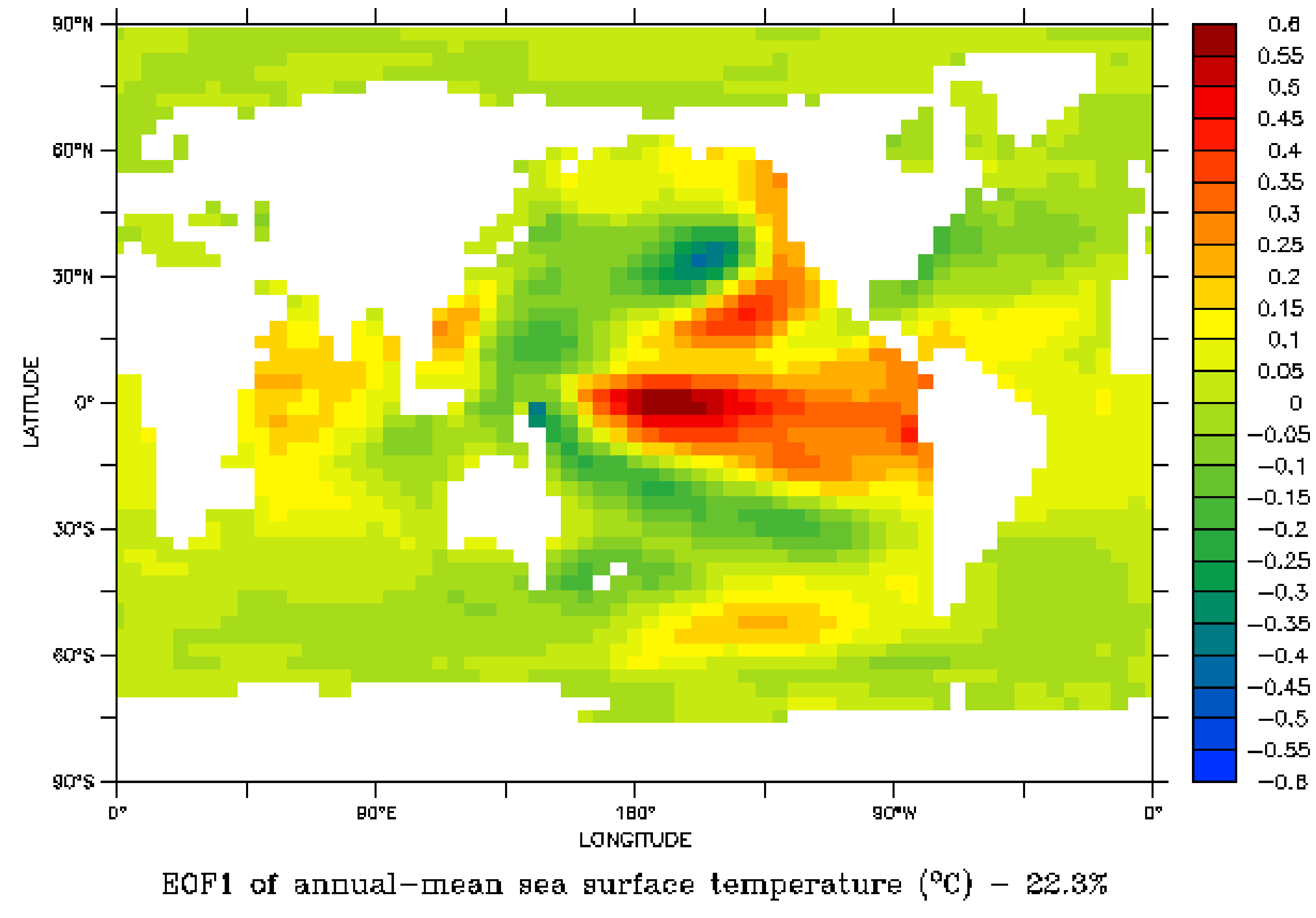
Global-mean surface air temperature (°C)

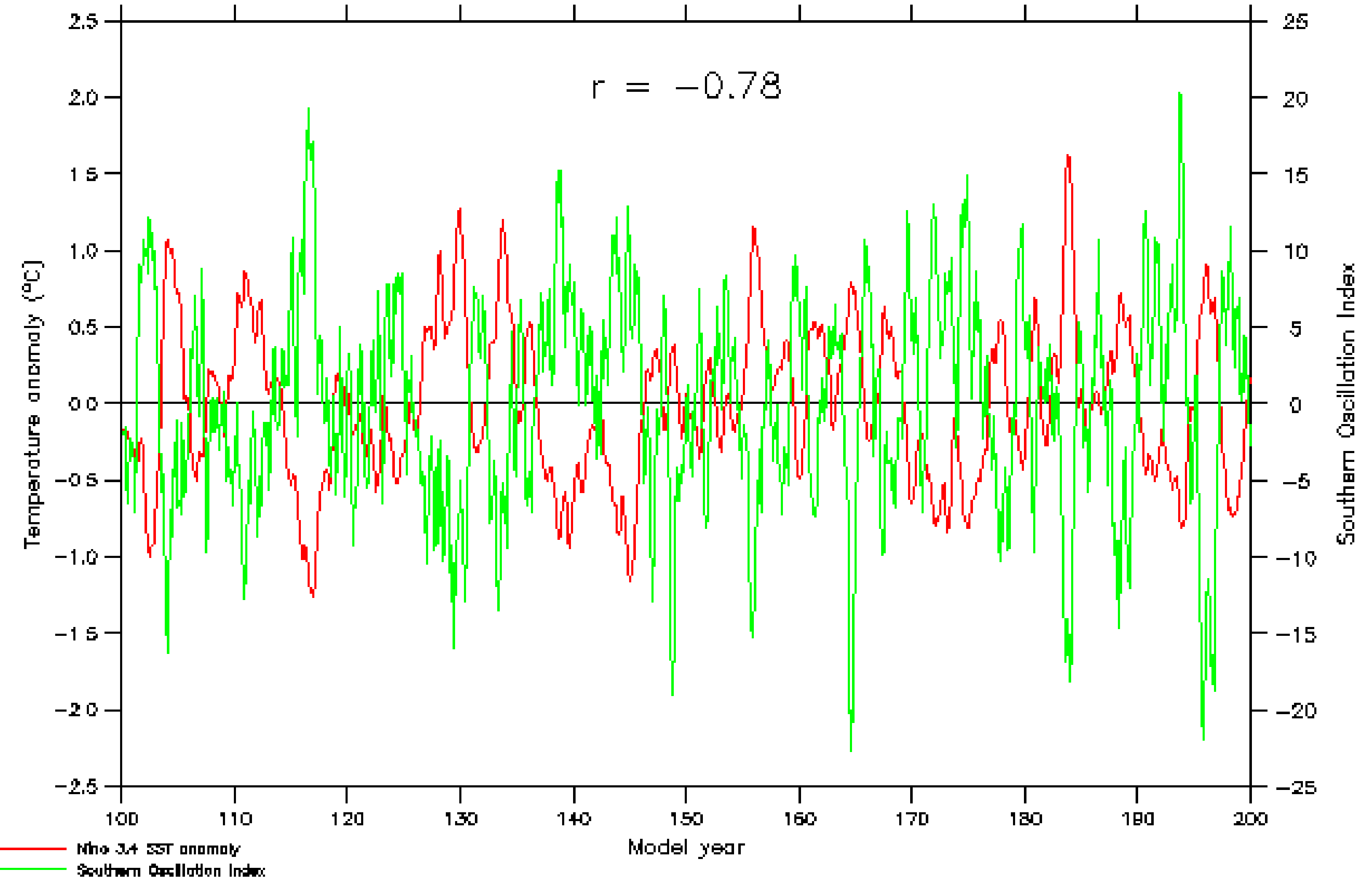


North Atlantic Deep Water formation (Sv)



NADW formation: power spectrum


90°N
60°N
30°N
0°
30°S
60°S
90°S
LATITUDE
0°
90°E
180°
90°W
0°
LONGITUDE
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25
−0.3
−0.35
−0.4
−0.45
−0.5
−0.55
−0.6
EOF1 of annual-mean sea surface temperature (°C) − 22.3%



Nino 3.4 SST anomaly and Southern Oscillation Index

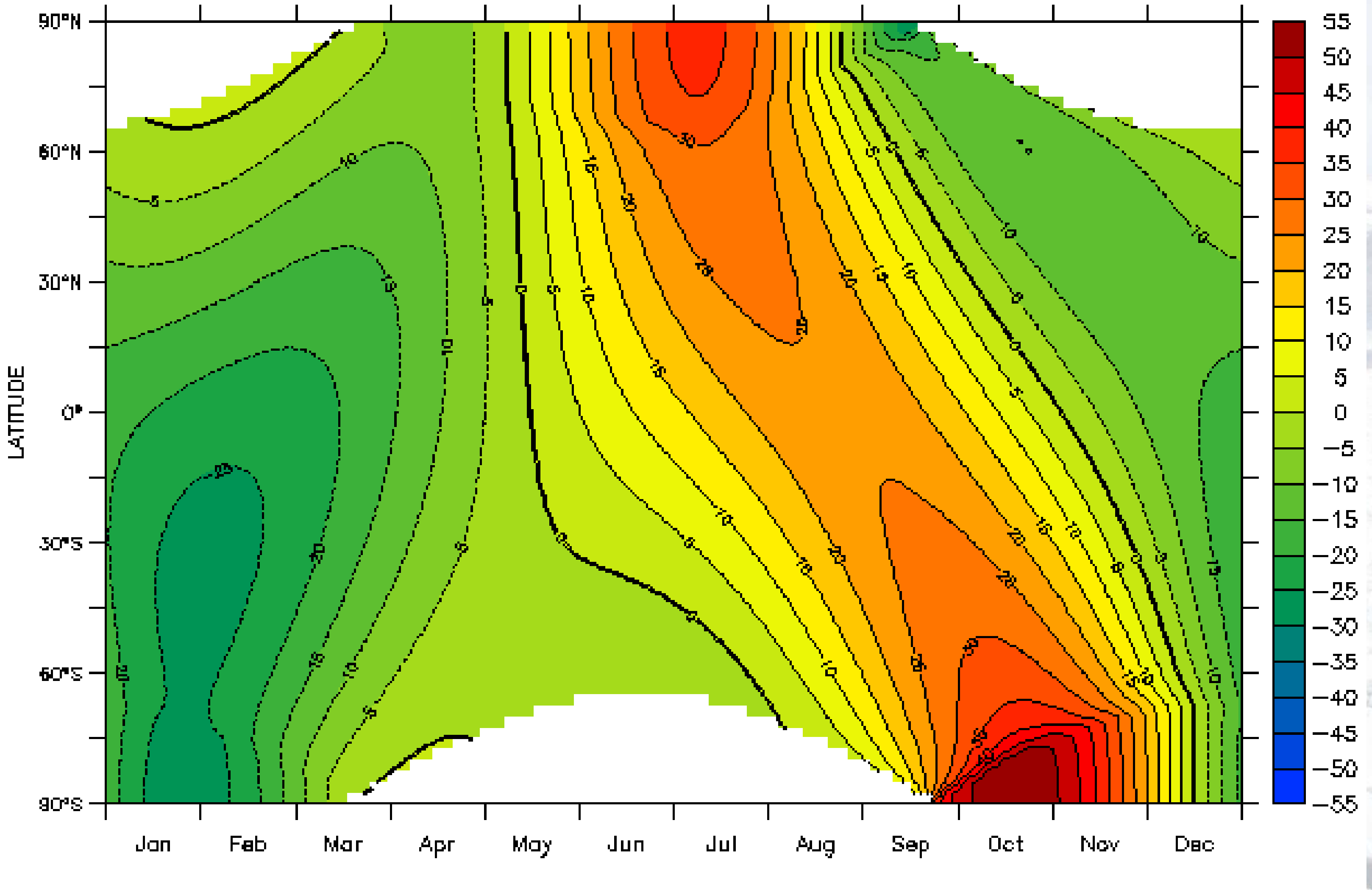
El Niño: model versus observed

	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

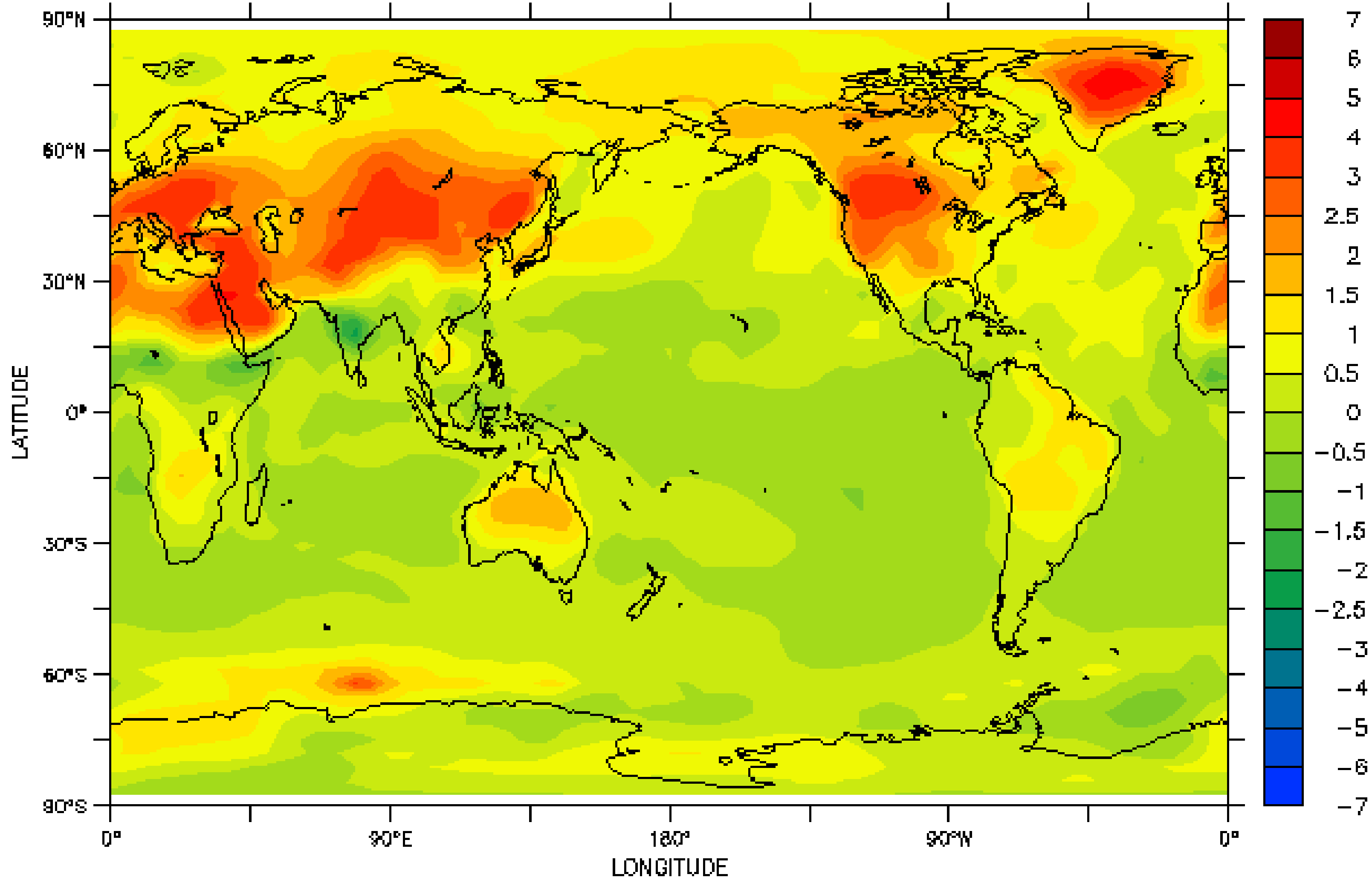
*K. E. Trenberth. The definition of El Niño. *The Bulletin of the American Meteorological Society*, 78(12):2771–2777, 1997.

3. The climate of the mid-Holocene

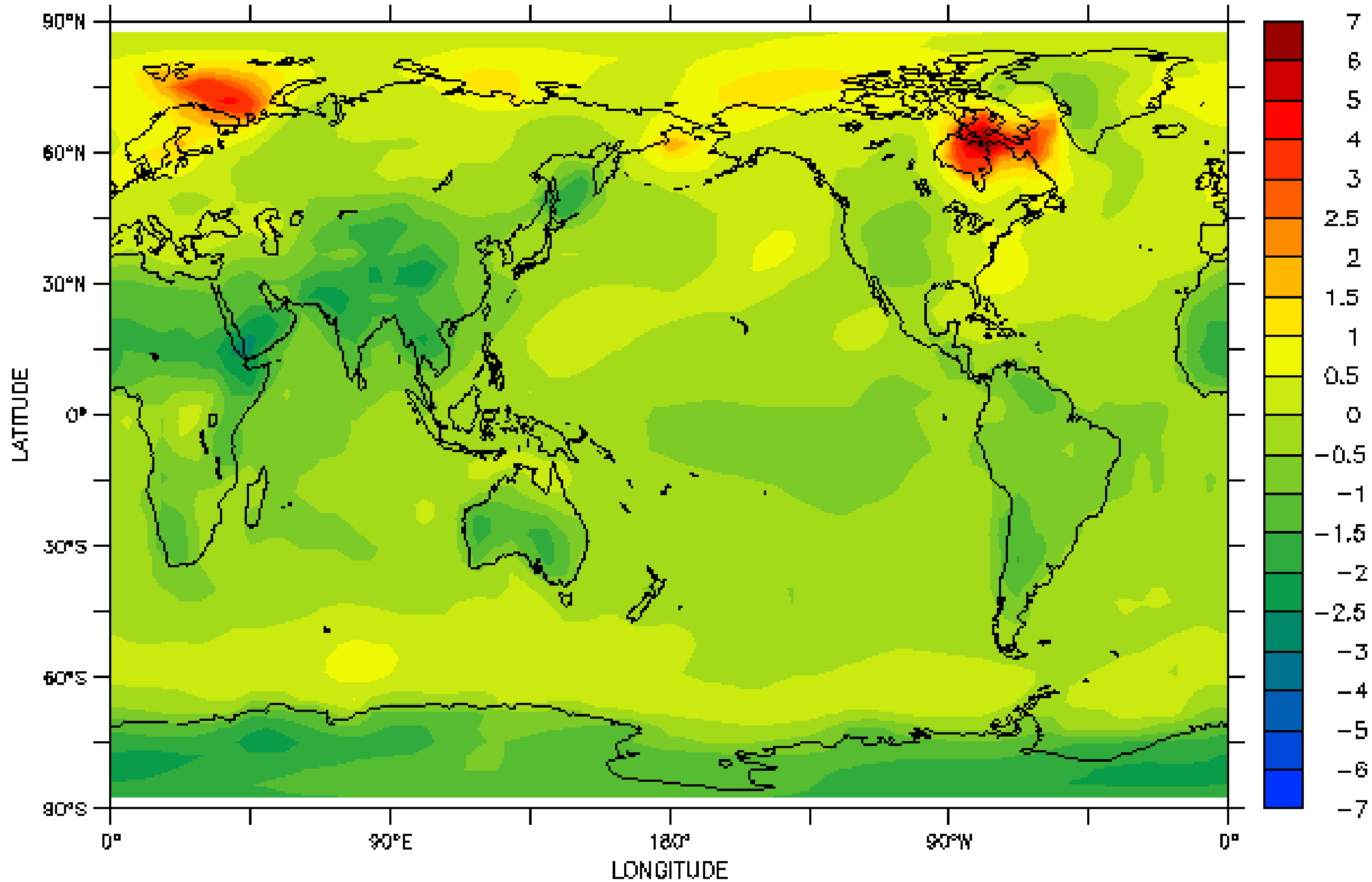
- Equilibrium simulation conducted for the mid-Holocene (6ka BP)
- PMIP2 experiment
- Orbital parameters for 6ka BP
- Atmospheric CO_2 concentration reduced from 280ppm to 277ppm
  - equivalent to a reduction in the atmospheric CH_4 concentration from 760ppb to 650ppb
- Initialised from year 100 of control simulation
- Integrated for 1200+ years



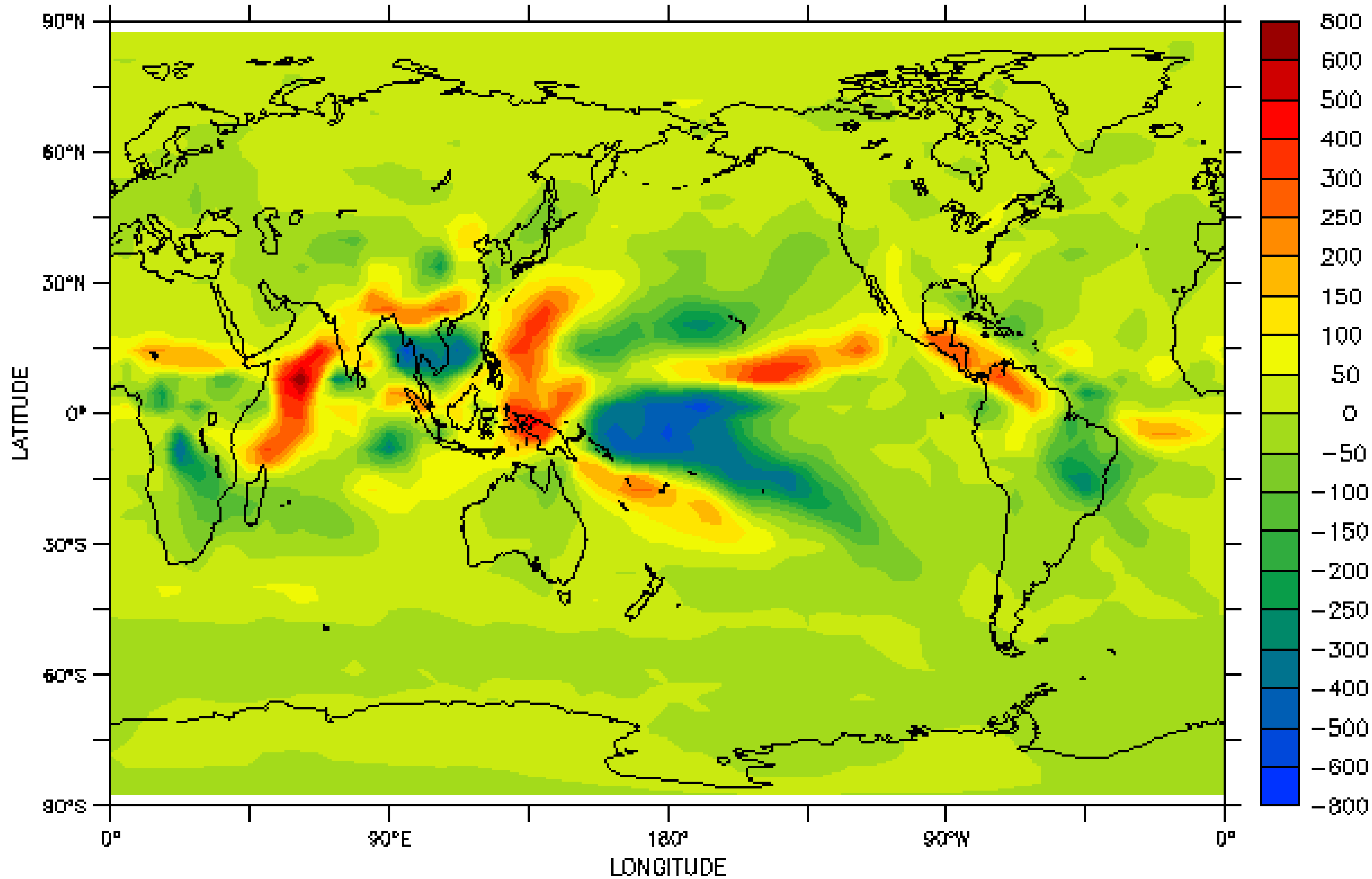
Change in insolation (Wm^{-2})



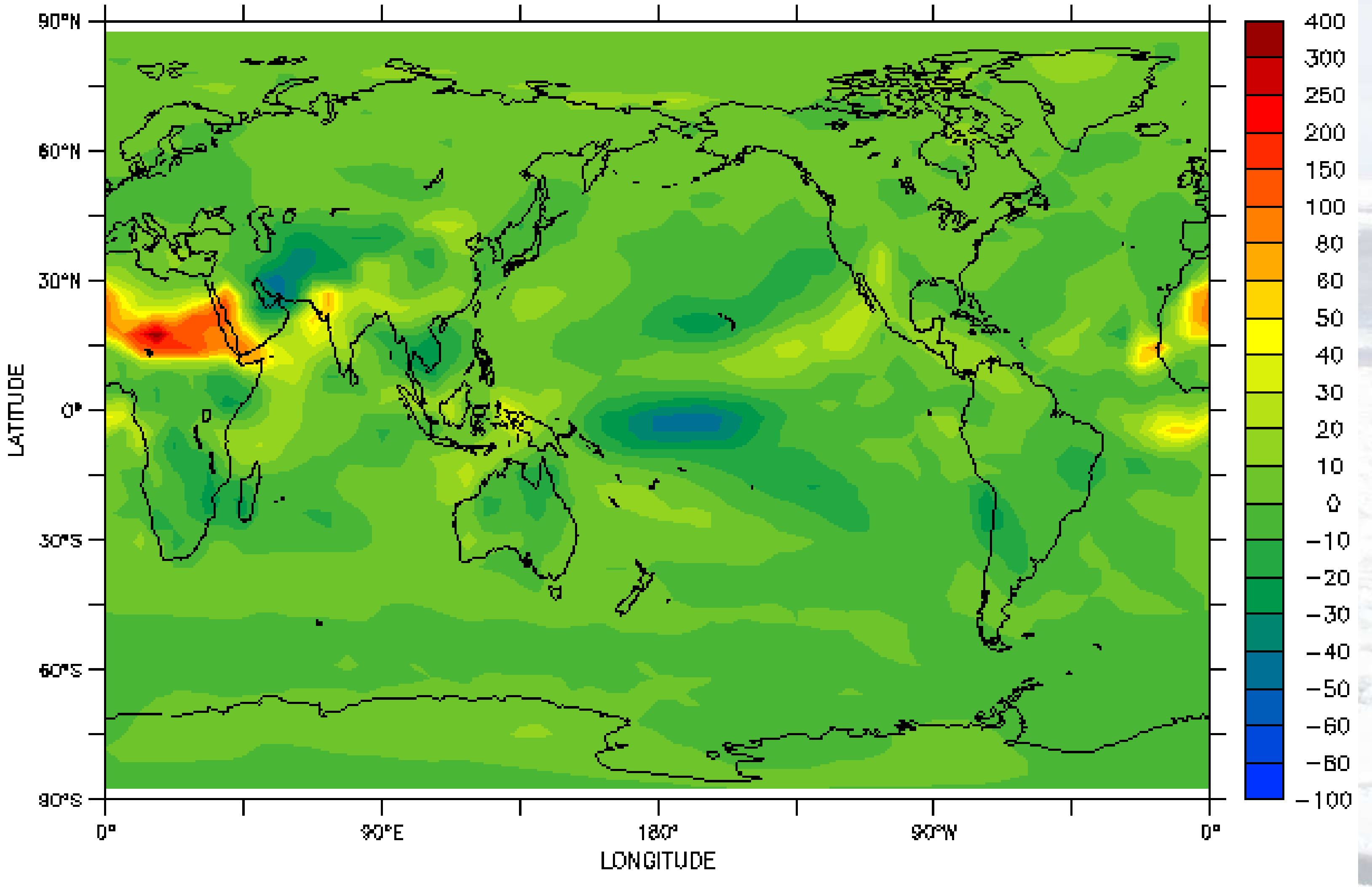
Difference in August surface air temperature (°C)



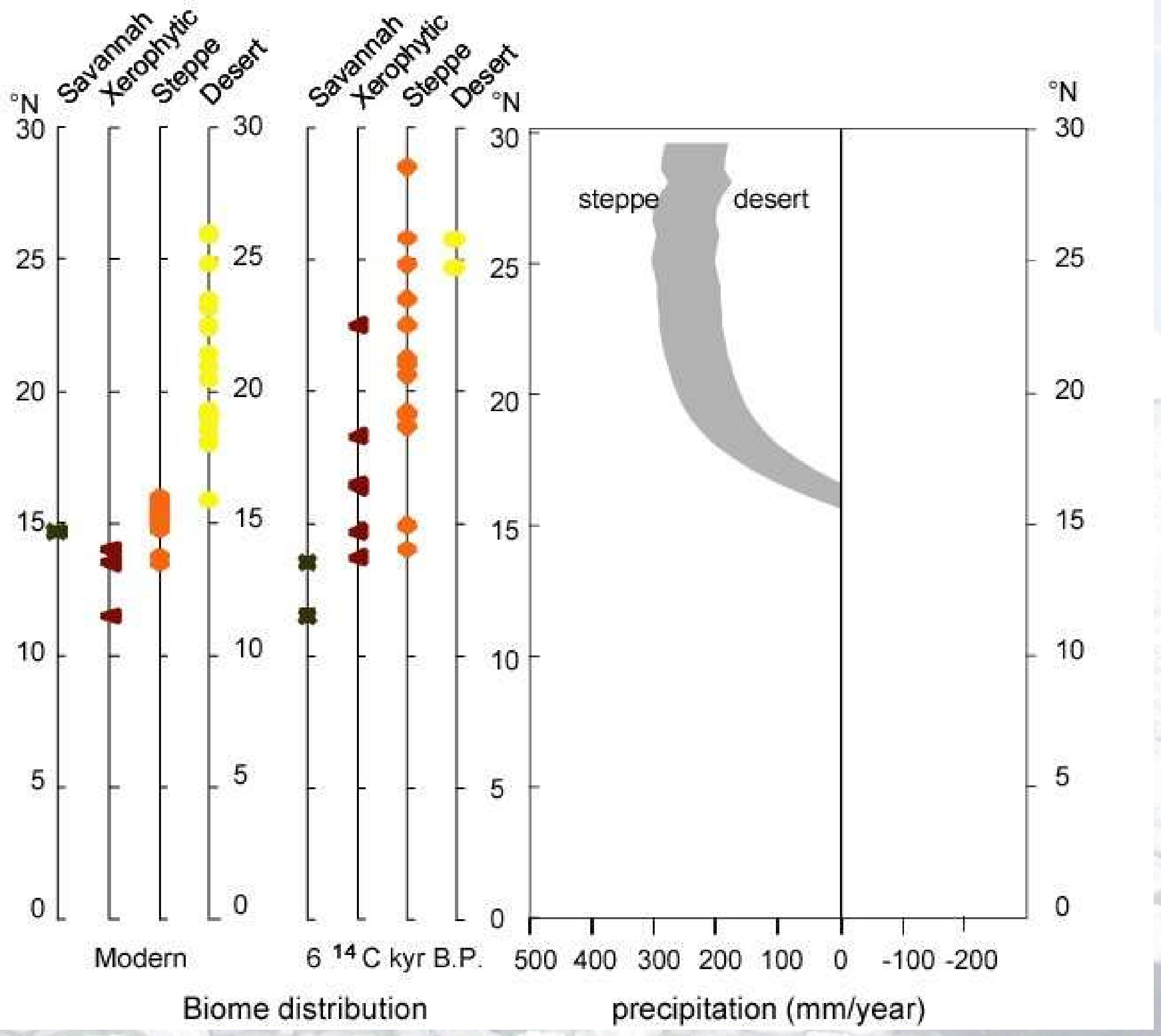
Difference in February surface air temperature (°C)



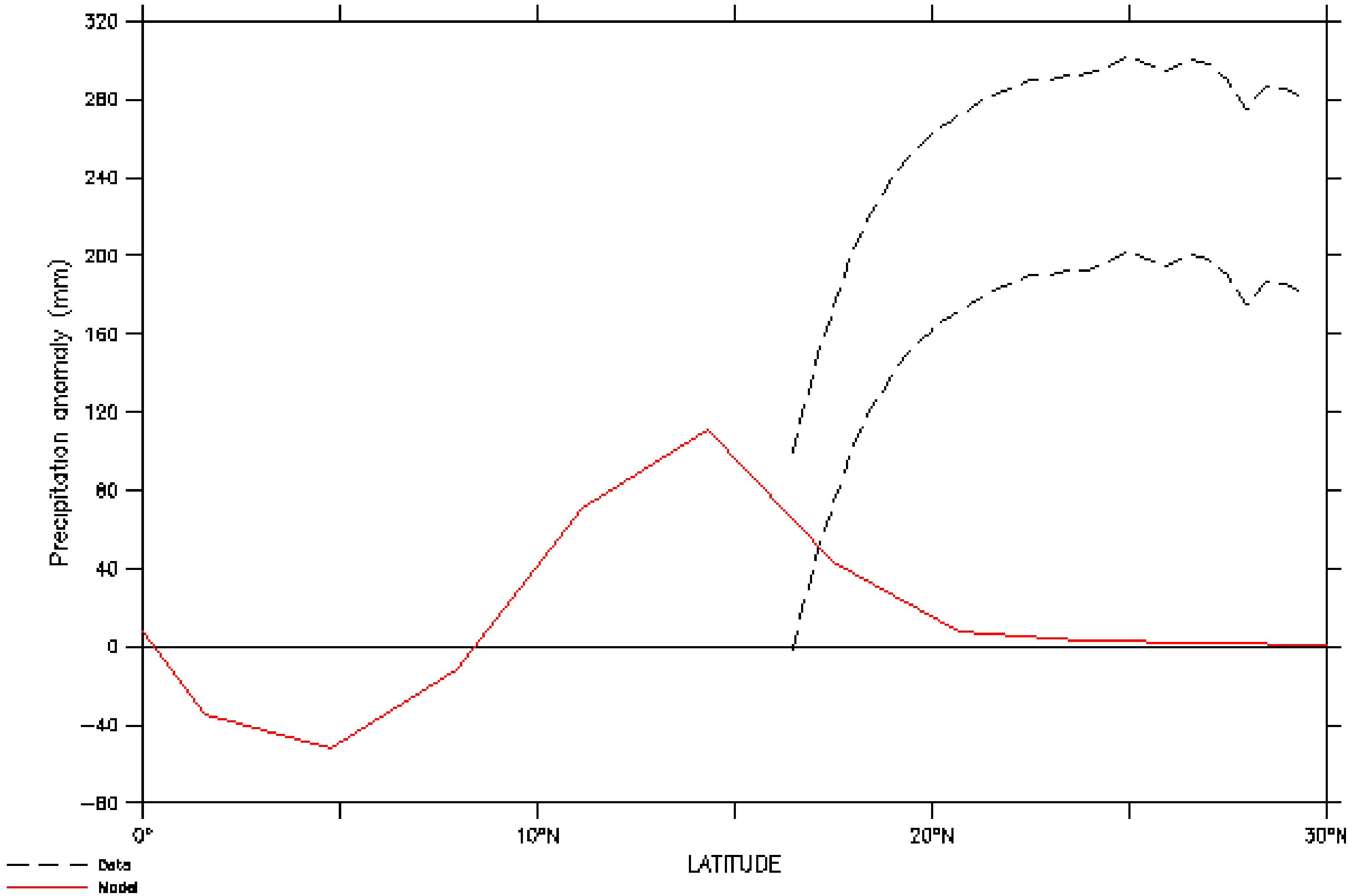
Difference in annual precipitation (mm)



Difference in annual precipitation (%)



Reconstructed precipitation anomaly over Northern Africa



Annual precipitation anomaly over Northern Africa (mm)

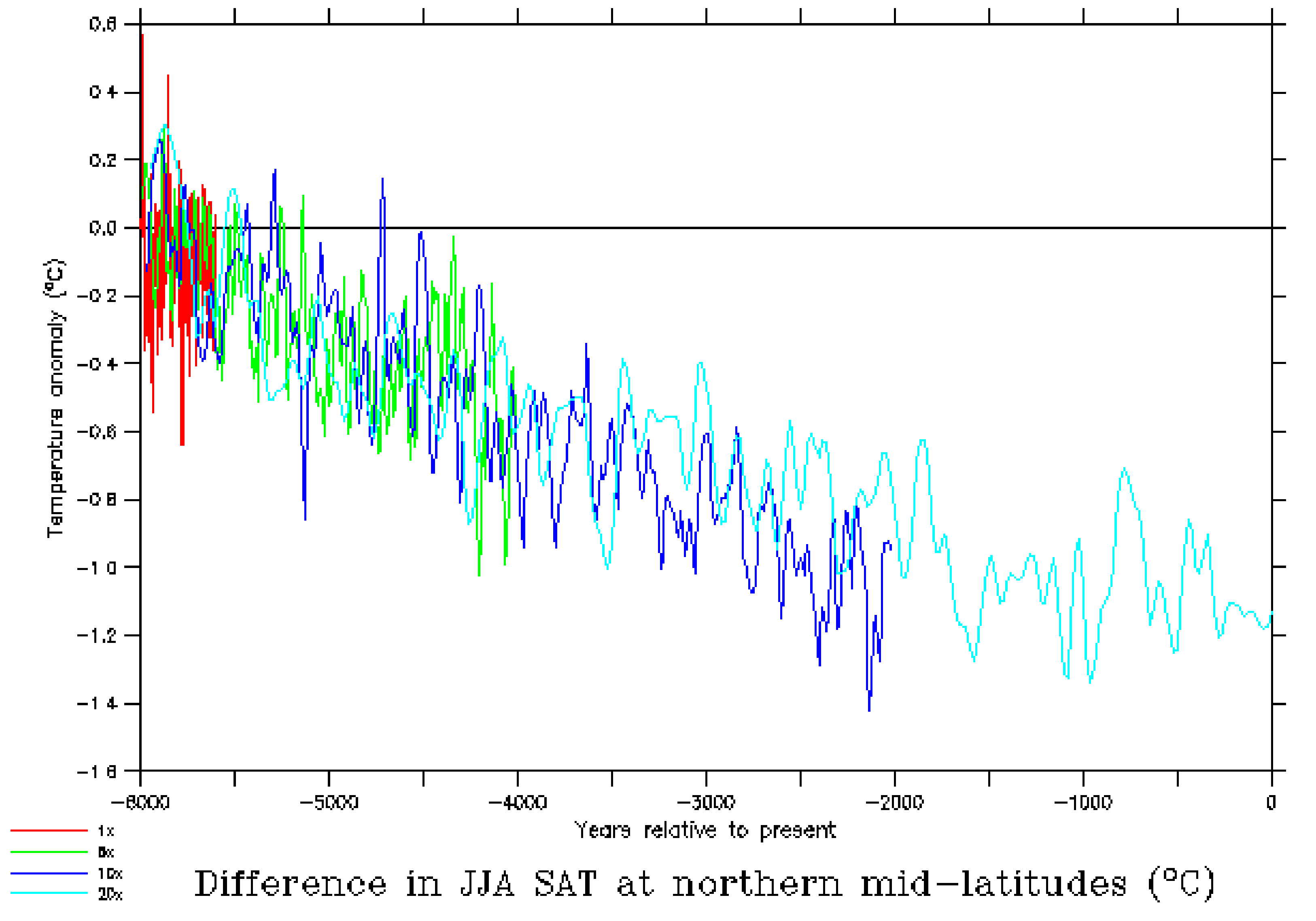
El Niño: control versus 6ka BP

	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

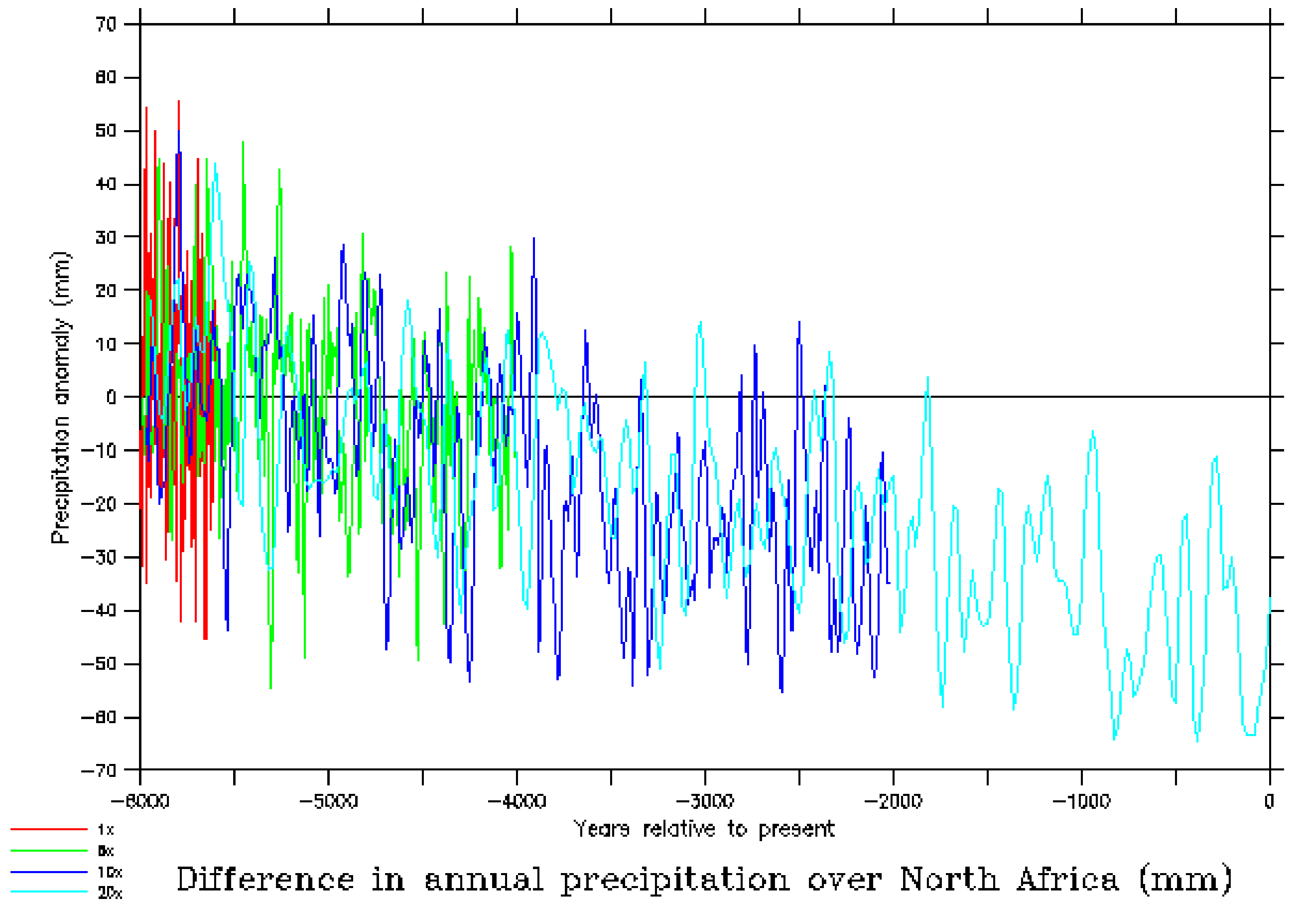
4. The climate of the late Holocene

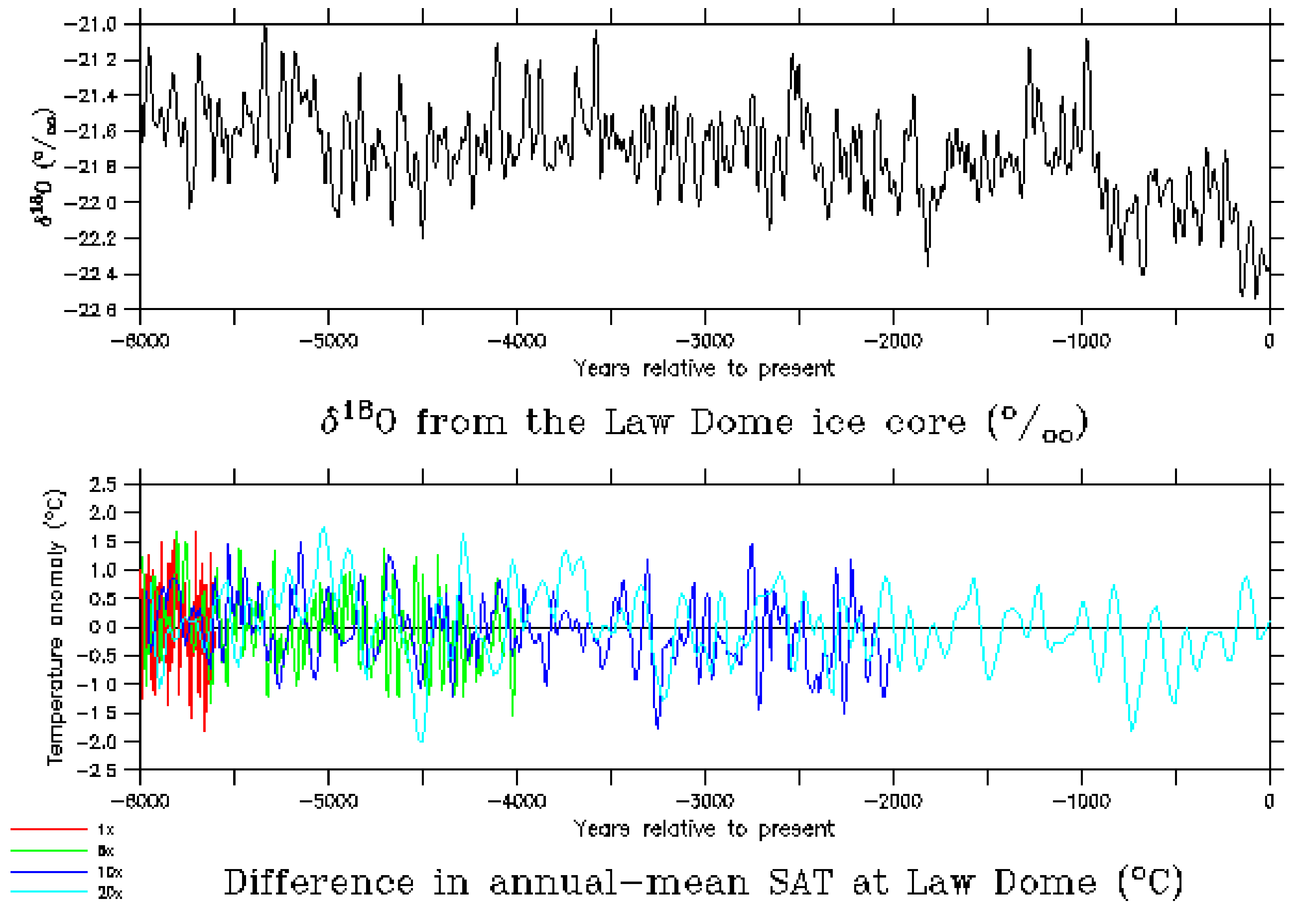
- Transient simulations from 6,000 years BP to the present day
- Initialised from year 1000 of the mid-Holocene simulation
- Orbital parameters varied, using the acceleration technique of Lorenz and Lohmann (2004)*
- Acceleration factors of 1, 5, 10 and 20
- Other boundary conditions unchanged

*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.

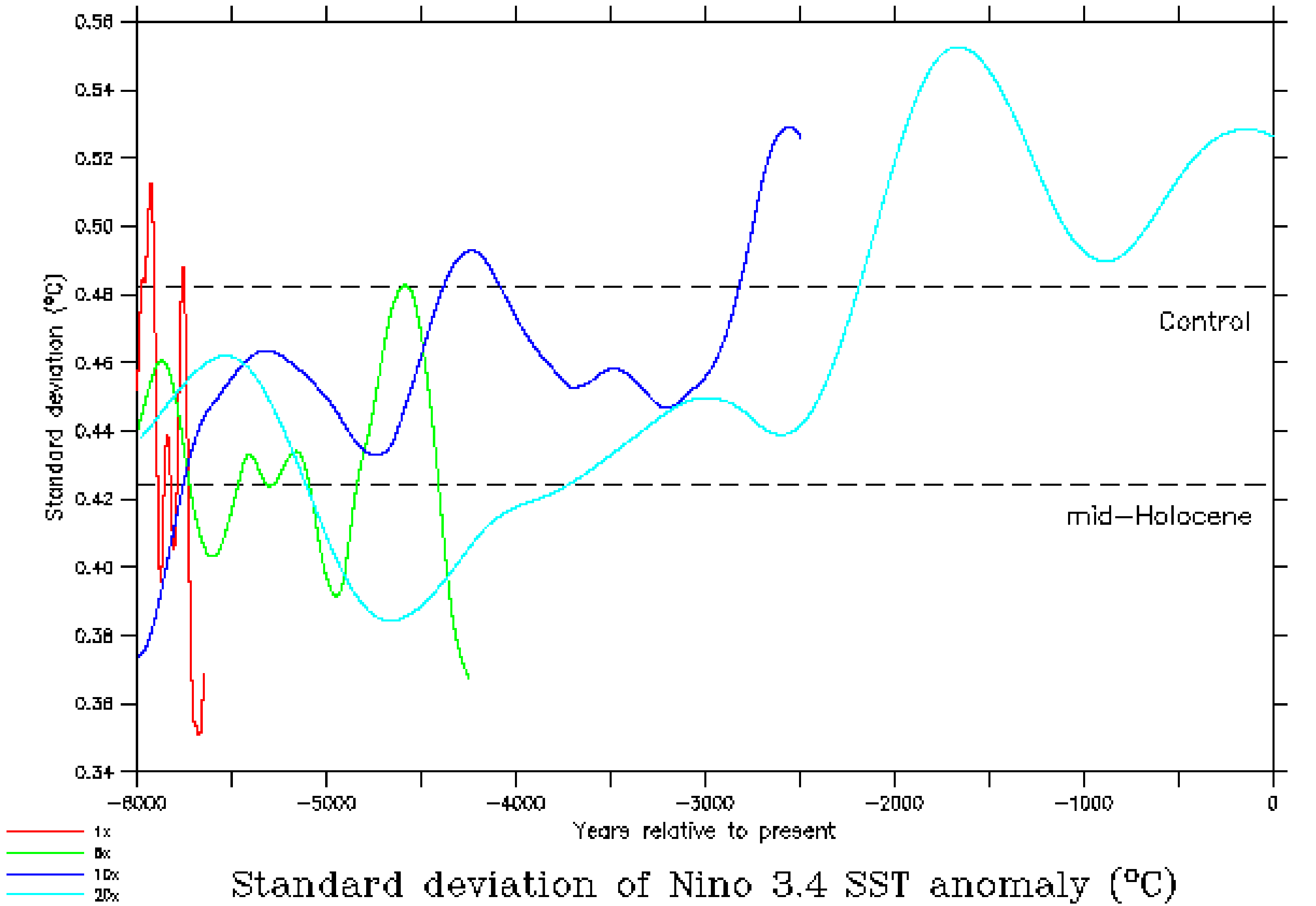


Difference in JJA SAT at northern mid-latitudes (°C)


Precipitation anomaly (mm)
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
Difference in annual precipitation over North Africa (mm)



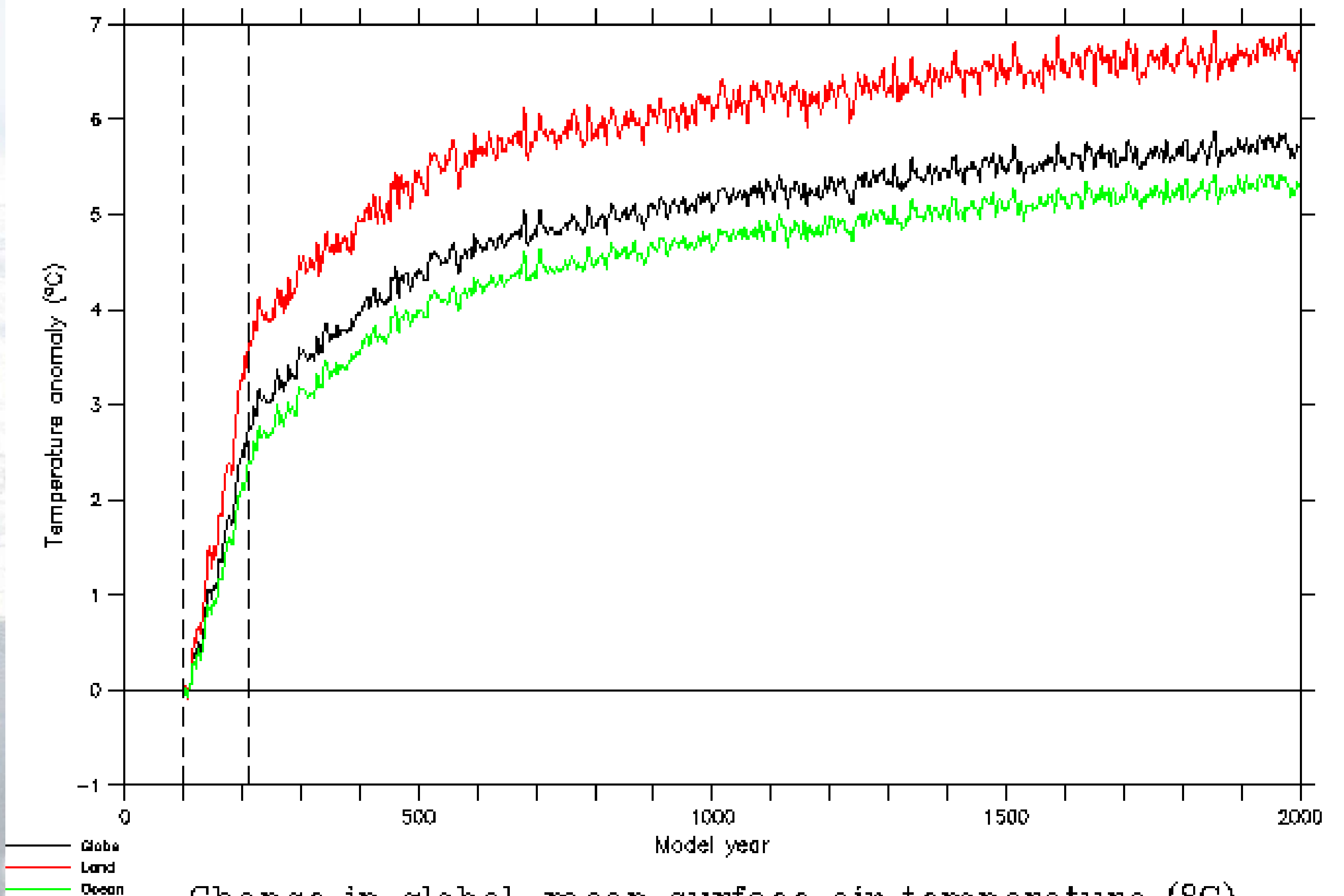
$\delta^{18}O$ (°/oo)
-21.0
-21.2
-21.4
-21.6
-21.8
-22.0
-22.2
-22.4
-22.6
-6000
-5000
-4000
-3000
-2000
-1000
0
Years relative to present
$\delta^{18}O$ from the Law Dome ice core (°/oo)
Temperature anomaly (°C)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-6000
-5000
-4000
-3000
-2000
-1000
0
Years relative to present
1x
5x
10x
20x
Difference in annual-mean SAT at Law Dome (°C)



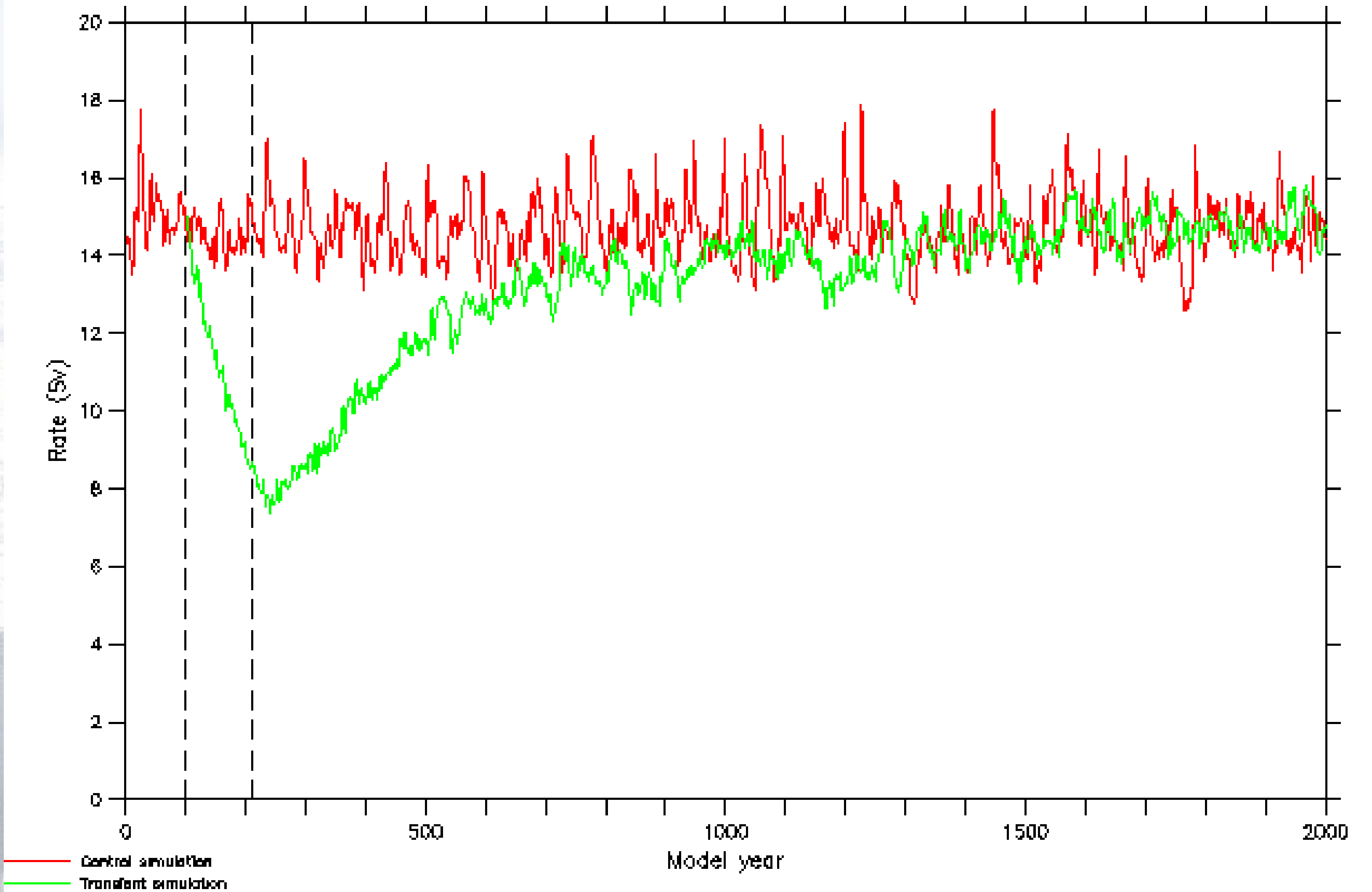
Standard deviation of Nino 3.4 SST anomaly (°C)

5. Future climate

- Transient simulation in which the CO_2 concentration is stabilised at three times the pre-industrial value
- Initialised from year 100 of control run
- Atmospheric CO_2 concentration increased at 1% p.a.
- Reaches 840ppm in year 211, and held constant thereafter
- Other boundary conditions unchanged
- Integrated for 2000+ years



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



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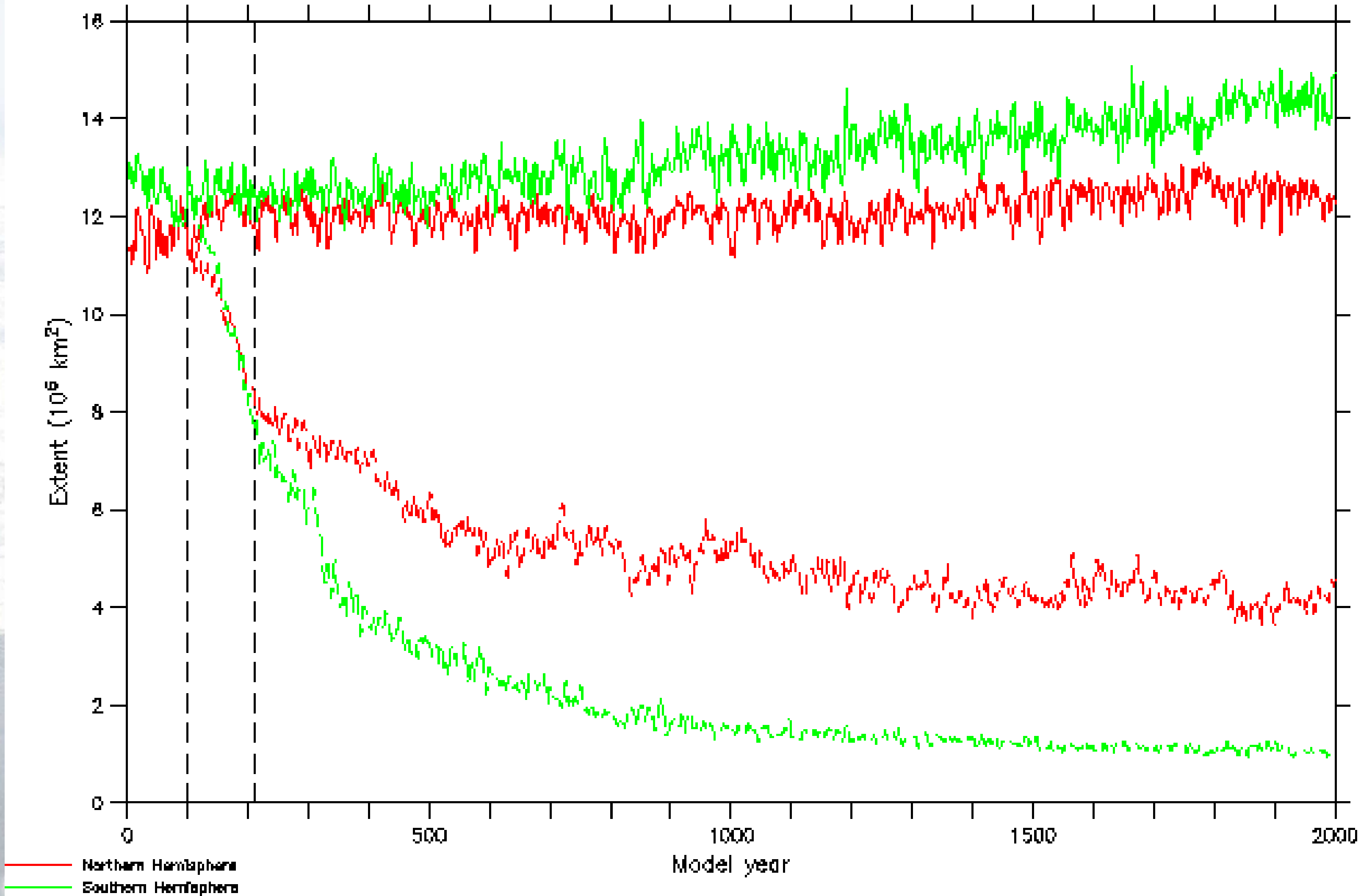
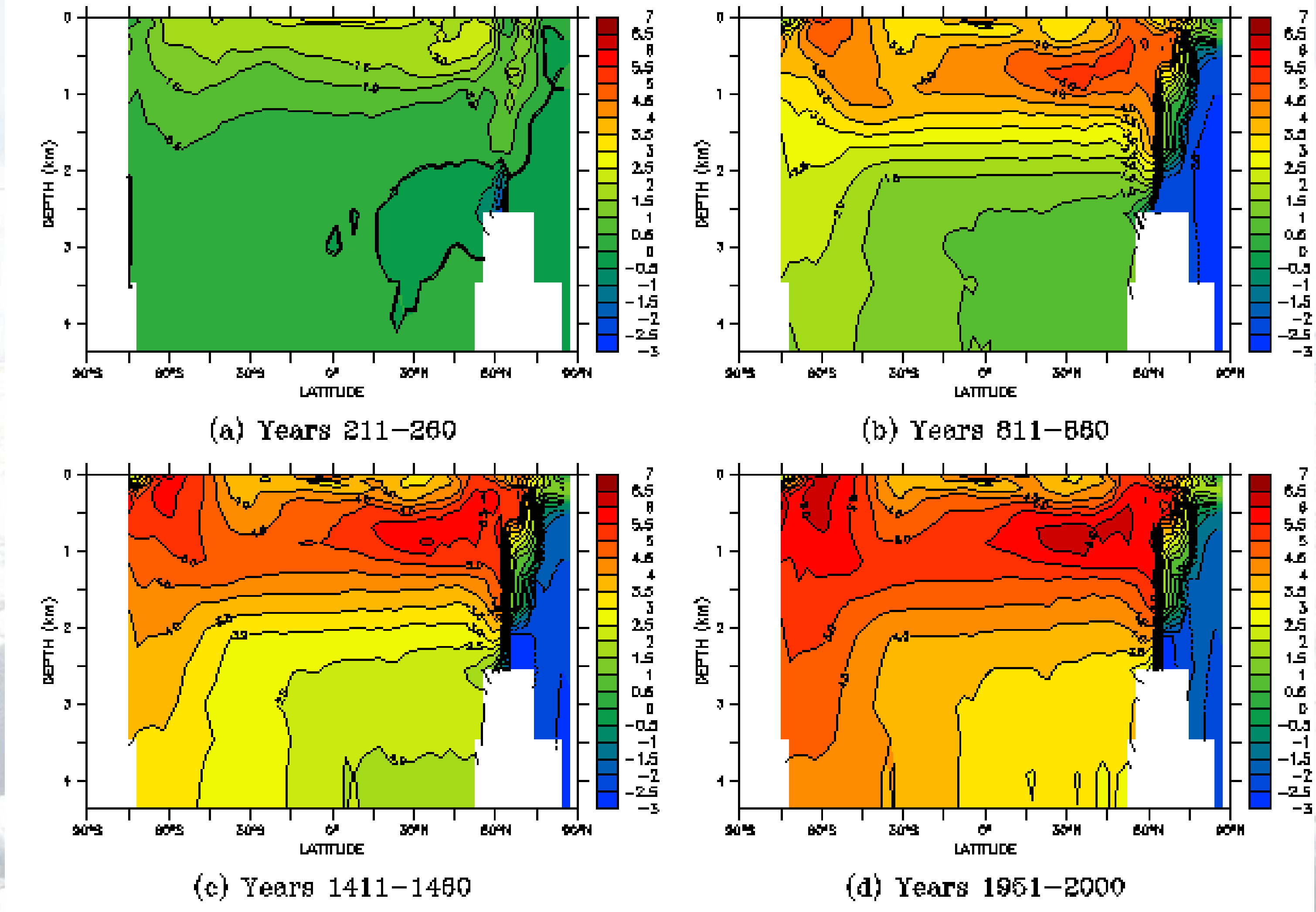
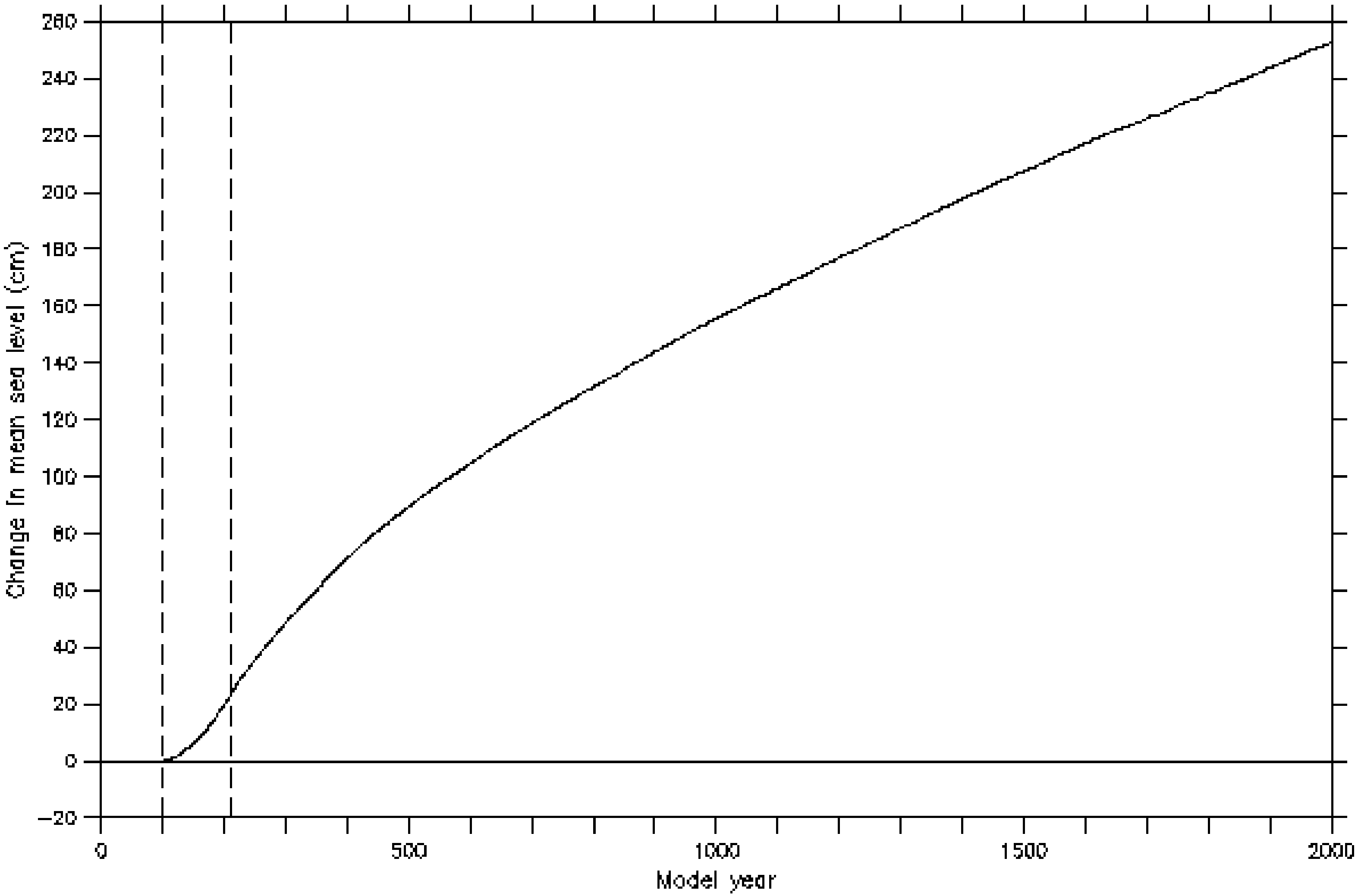


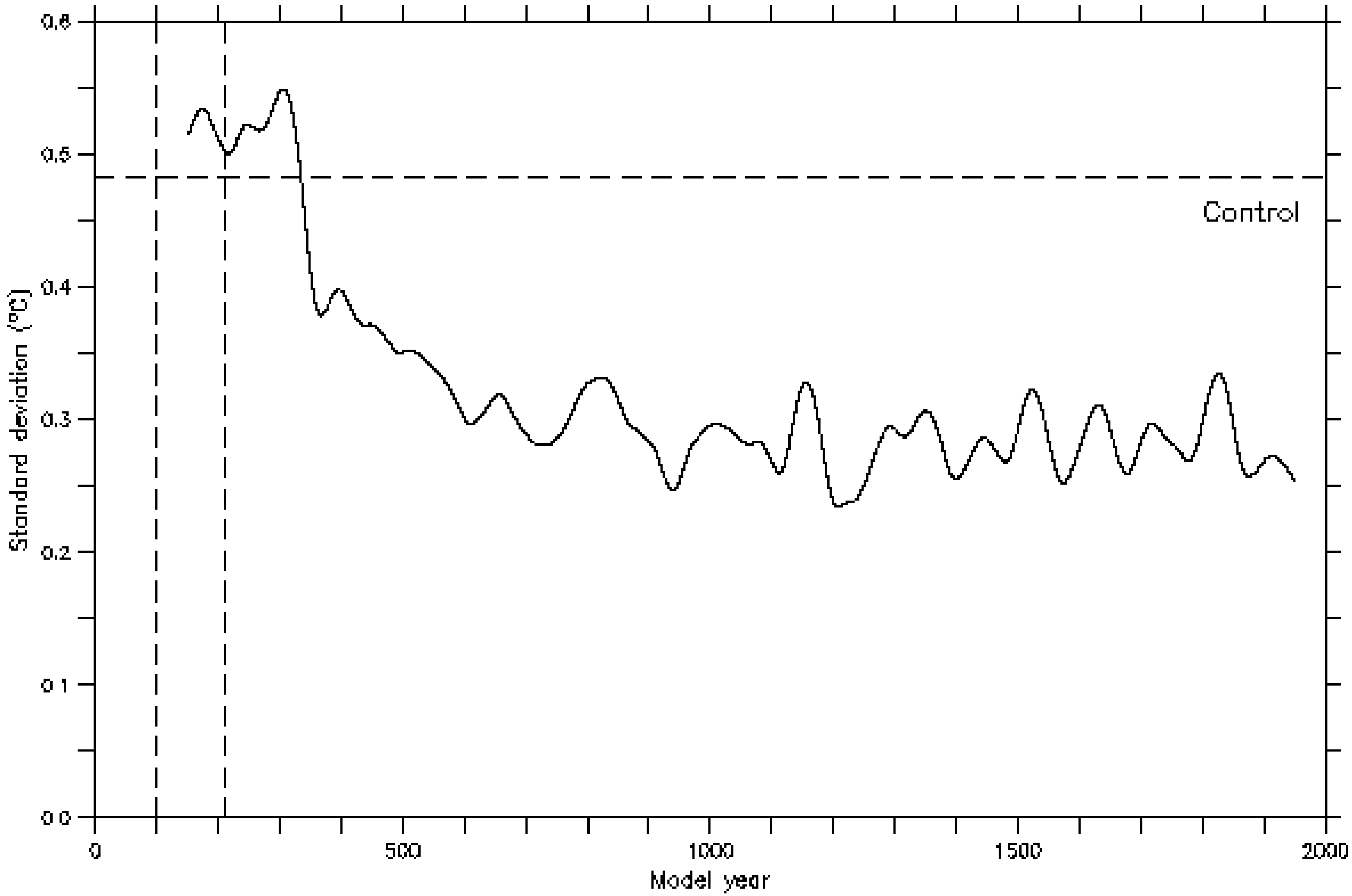
Sea ice extent (10^6 km^2)



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
- Lorenz-Lohmann acceleration enables orbital effects on very long timescales to be studied
- Simulations suggest a gradual strengthening of ENSO during the late Holocene
- The simulated ENSO strengthens slightly in response to an increase in atmospheric CO_2, but weakens once the CO_2 concentration is stabilised