Multi-millennial simulations of the climate of the late Holocene

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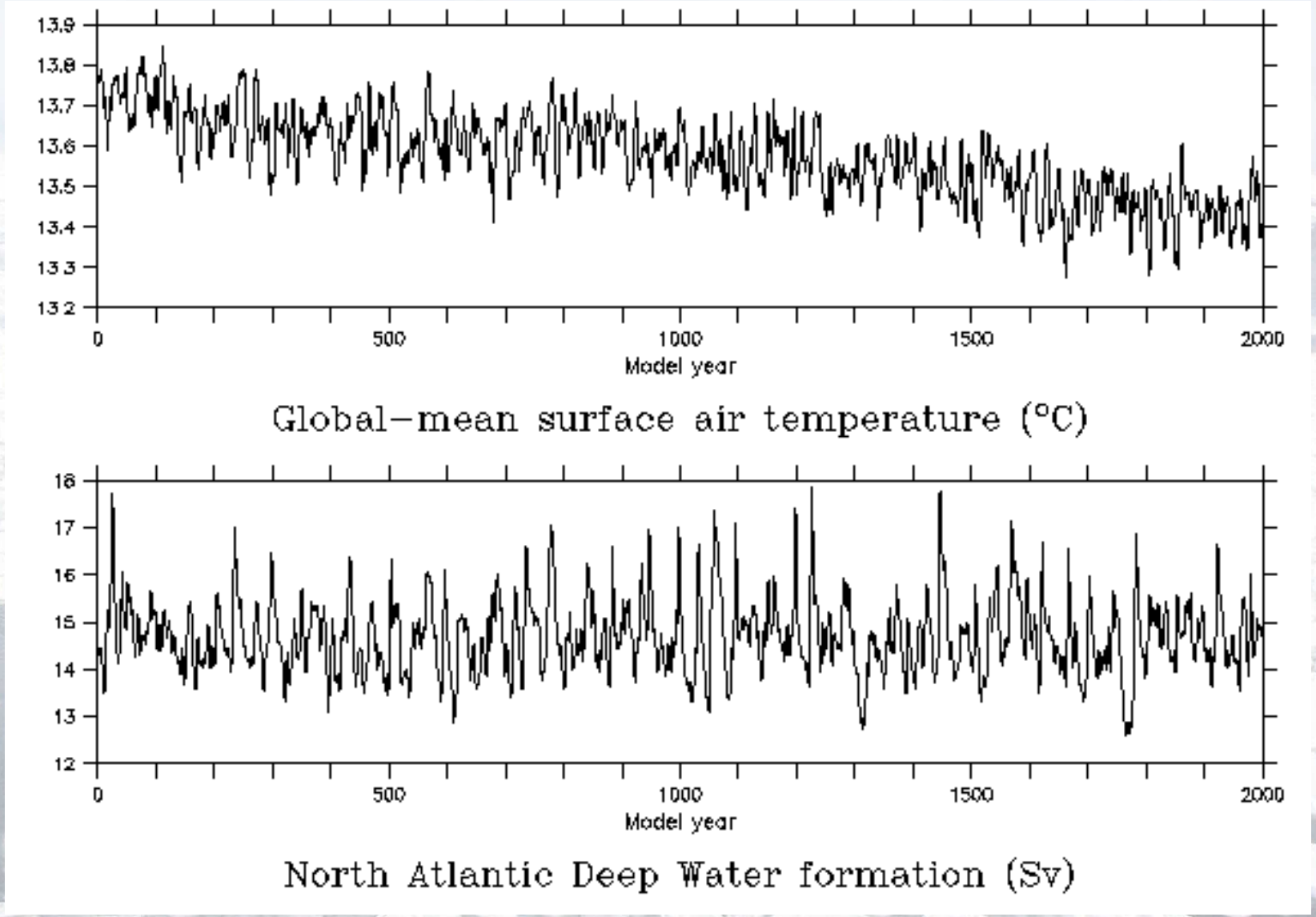
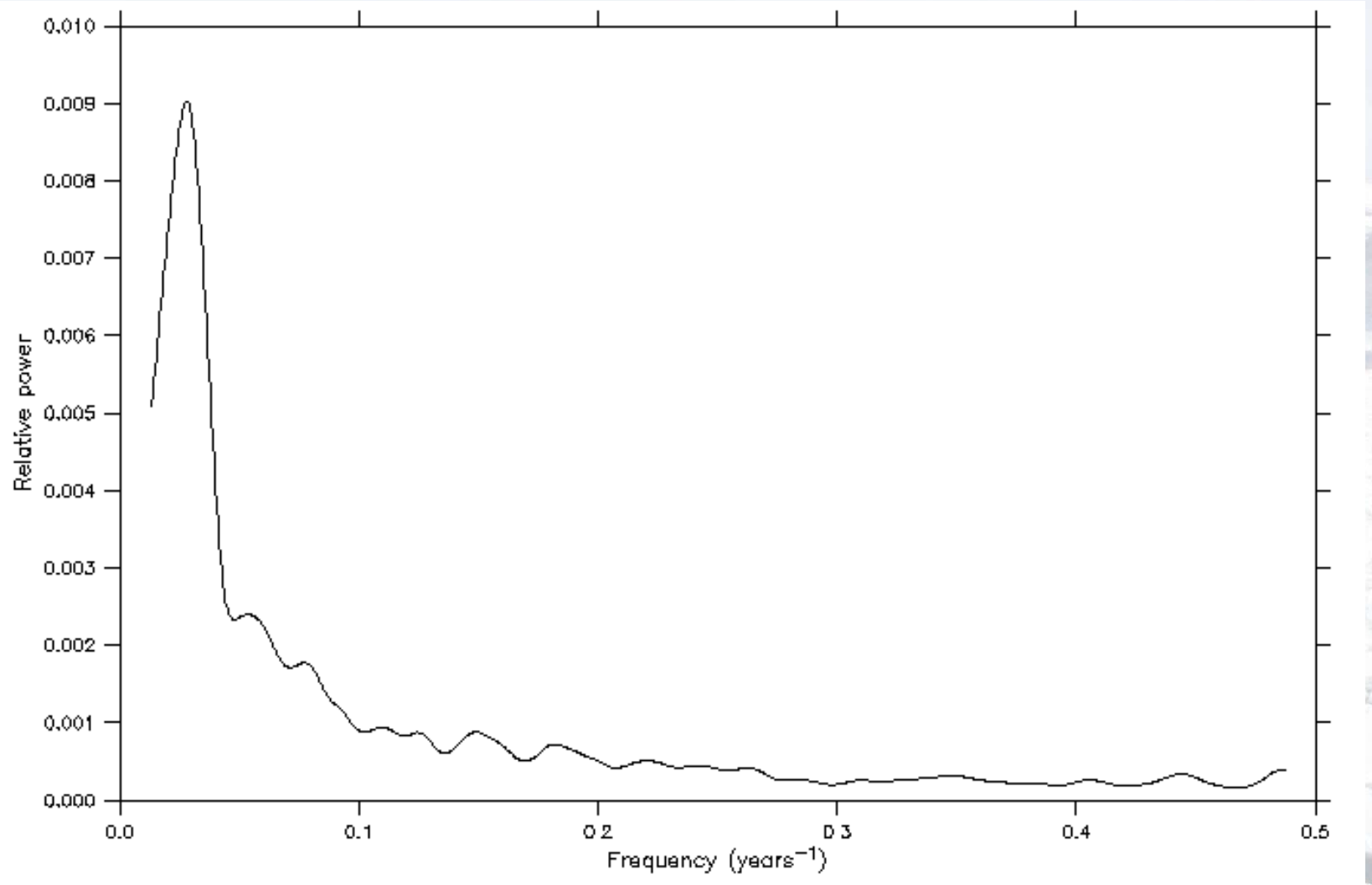
The CSIRO Mk3L climate system model

- Low-resolution version of the CSIRO Mk3 climate system model
- Atmosphere:
  - Spectral general circulation model
  - Resolution is R21 18L ($\Delta\lambda \approx 5.6^\circ, \Delta\phi \approx 3.2^\circ$)
  - Dynamic-thermodynamic sea ice model
  - Land surface model (static vegetation)
- Ocean:
  - z-coordinate general circulation model
  - Resolution is R21 21L (same horizontal grid as atmosphere model)
  - Gent-McWilliams eddy diffusion
- Flux adjustments applied
- $\sim$5 model years/day (3GHz Pentium 4)

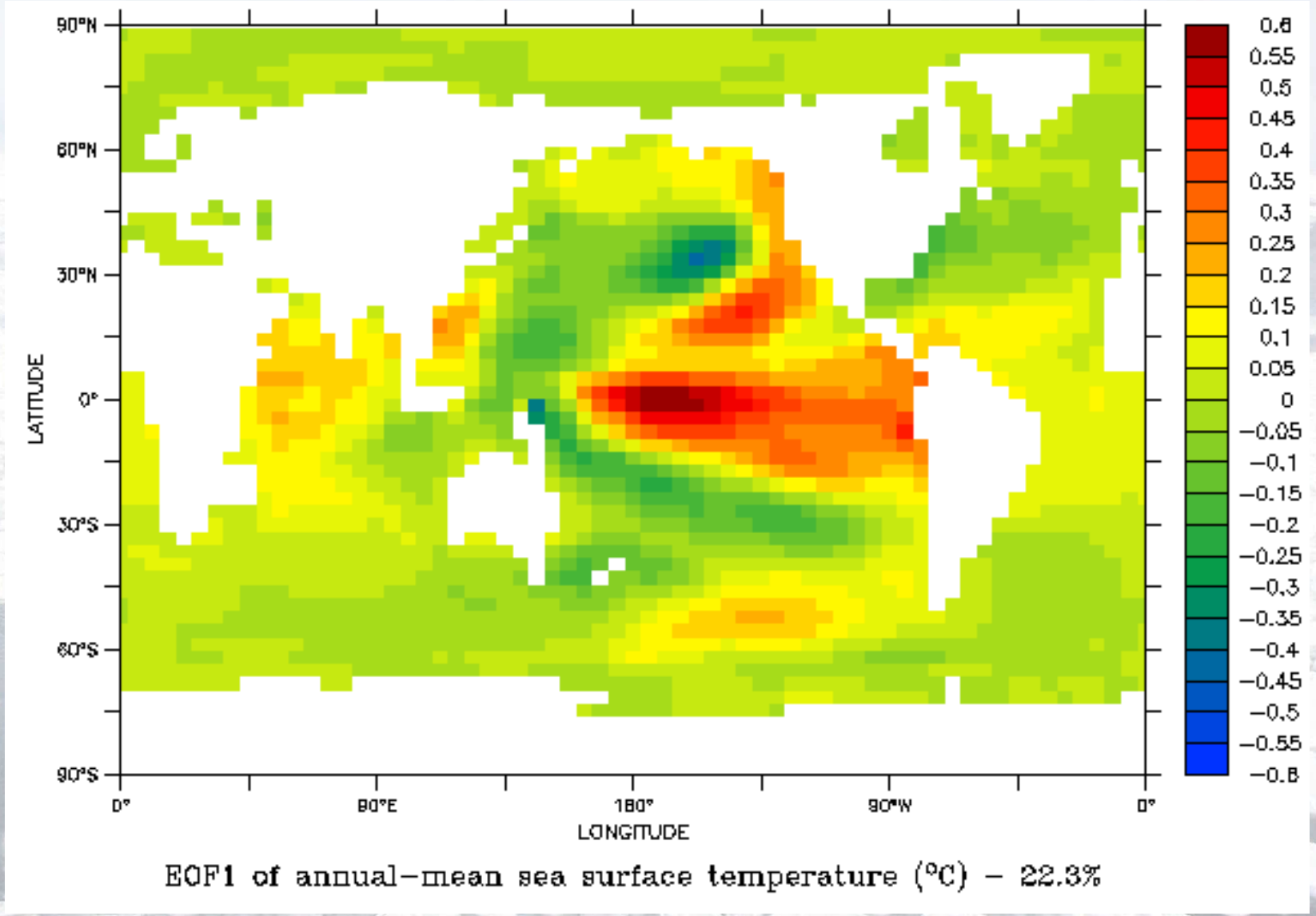
The pre-industrial climate

- Control simulation follows PMIP2 experimental design:
  - CO_2 concentration = 280ppm
  - Solar constant = 1365 Wm^{-2}
  - "Modern" orbital parameters (AD 1950)
- Integrated for 2000+ years


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)



NADW formation: power spectrum



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

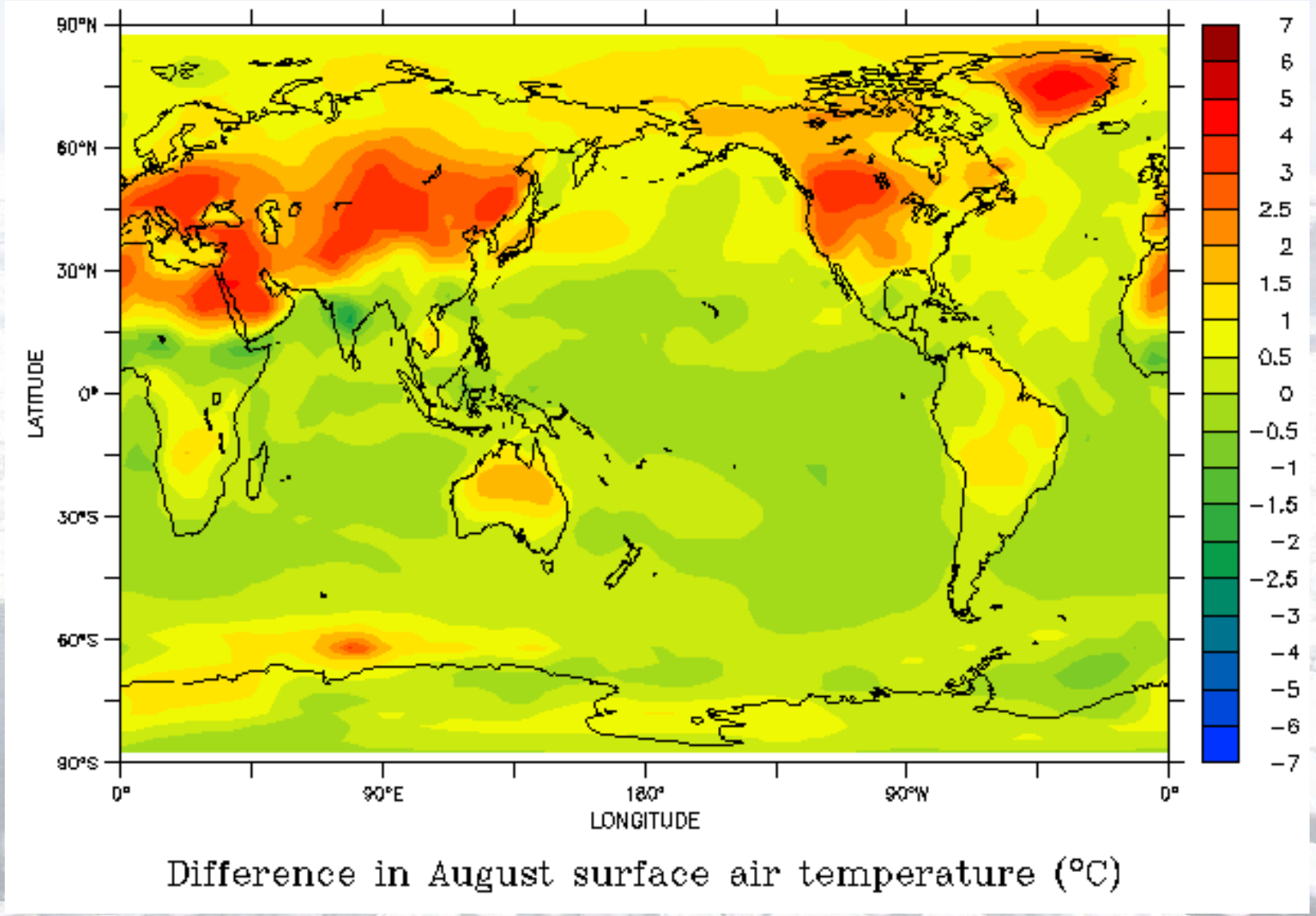
El Niño: model versus observed

	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

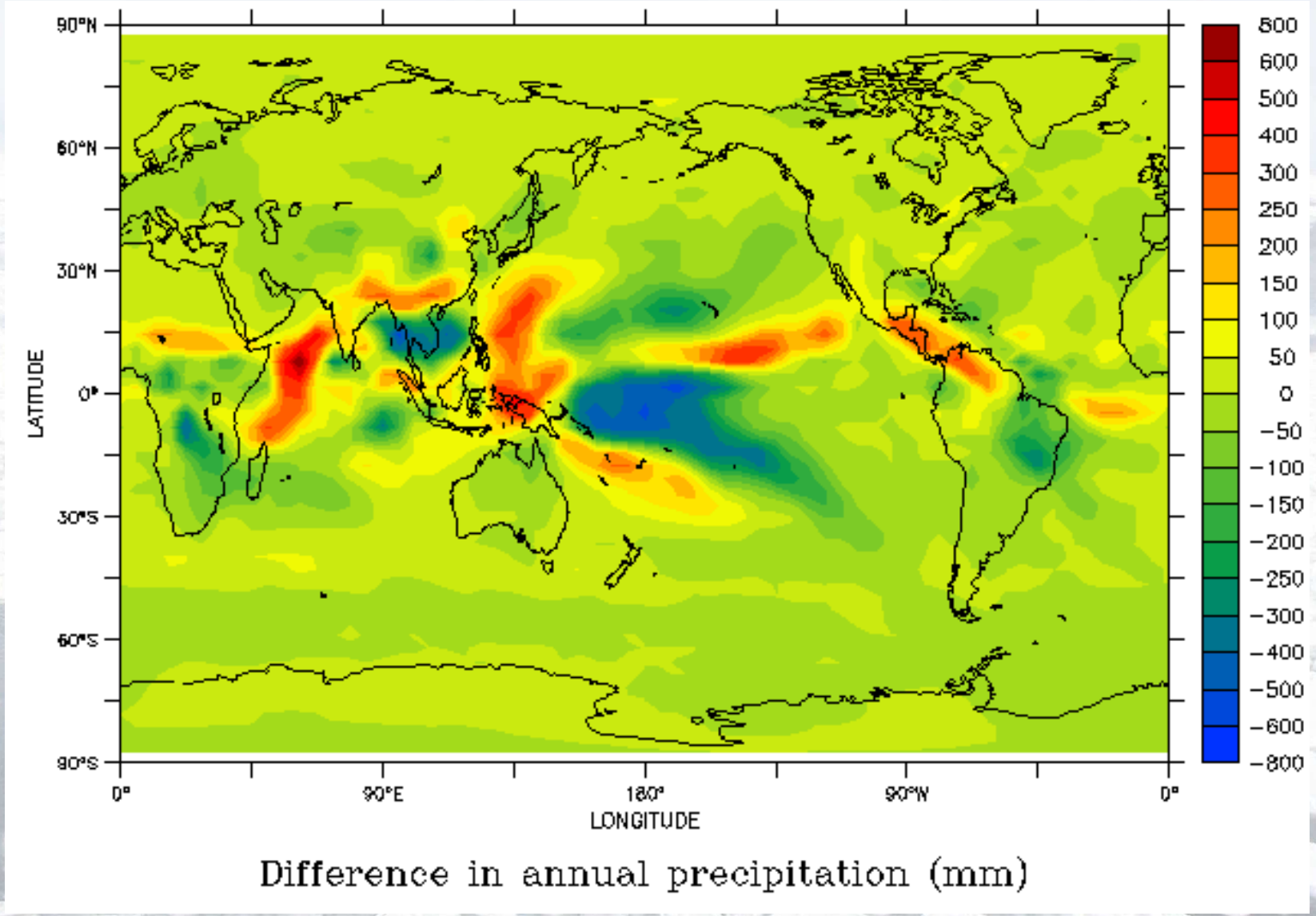
*K. E. Trenberth. The definition of El Niño. *The Bulletin of the American Meteorological Society*, 78(12):2771–2777, 1997.

The climate of the mid-Holocene

- Equilibrium simulation conducted for 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



Difference in August surface air temperature (°C)



Difference in annual precipitation (mm)

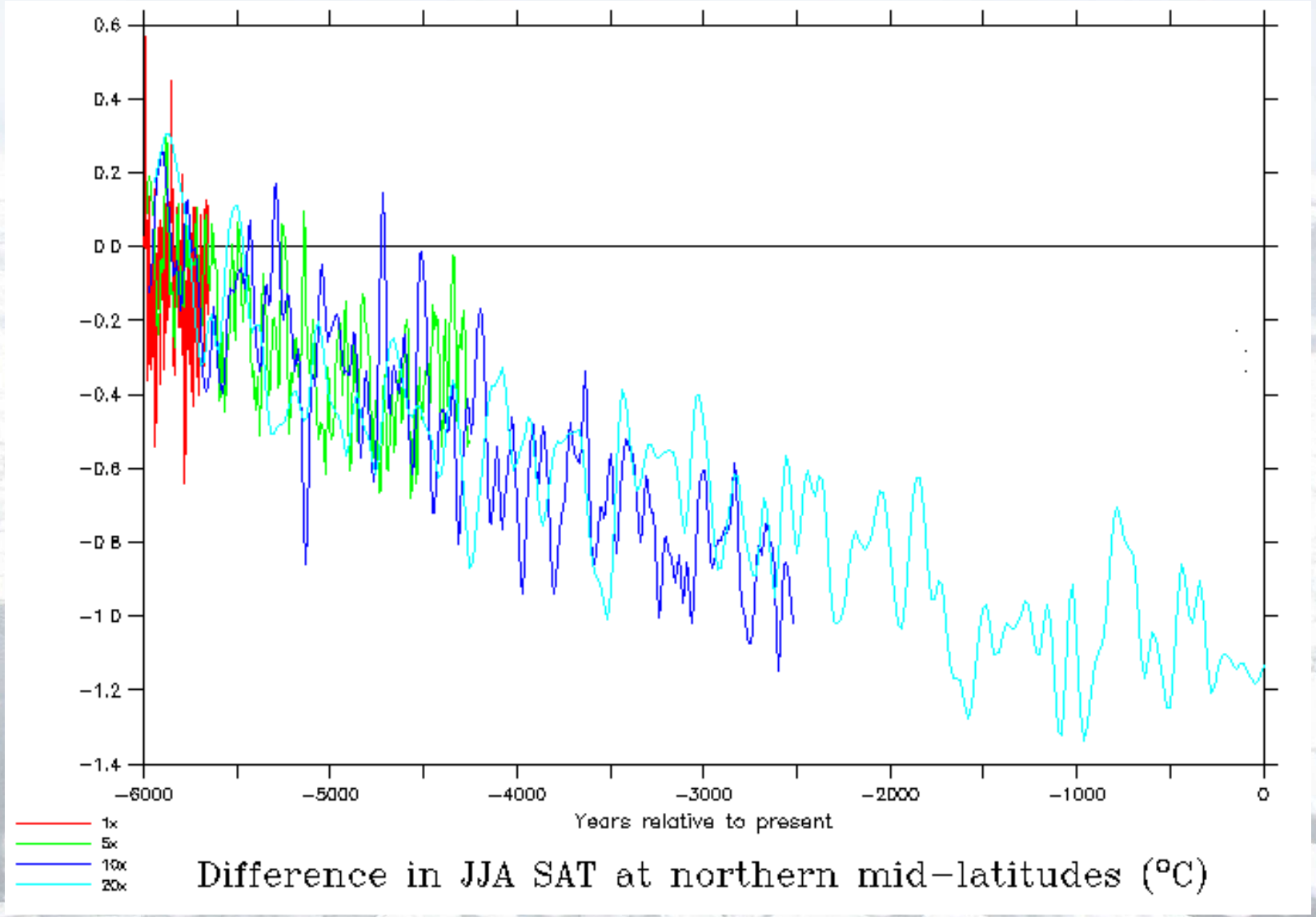
El Niño: control versus 6ka BP

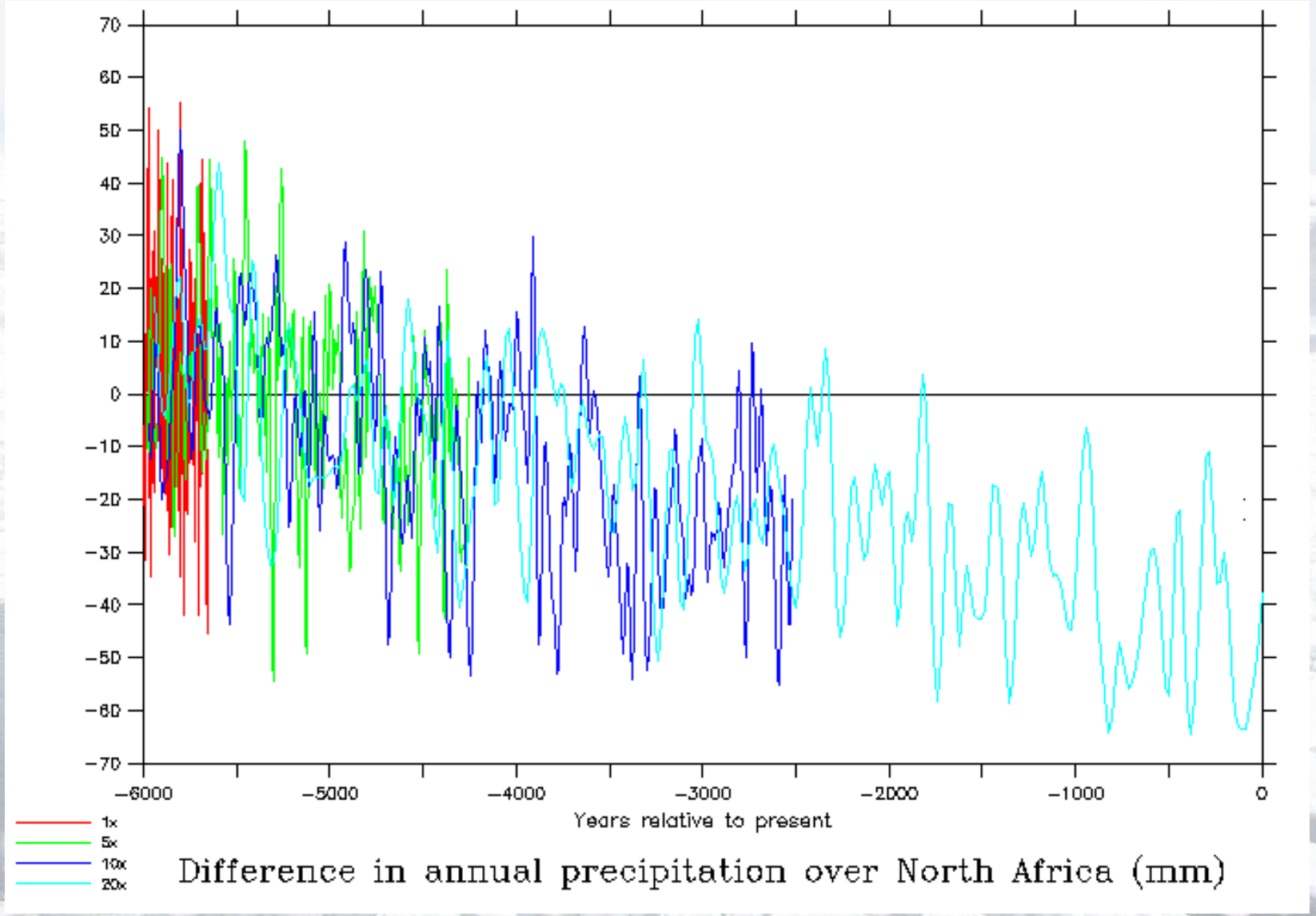
	Control	**6ka BP**
Standard deviation of Niño 3.4 SST anomaly (°C)	0.48	0.42
Period (years)	7.8 ± 0.5	8.8 ± 0.9
Duration (months)	17.2 ± 0.6	16.6 ± 1.0

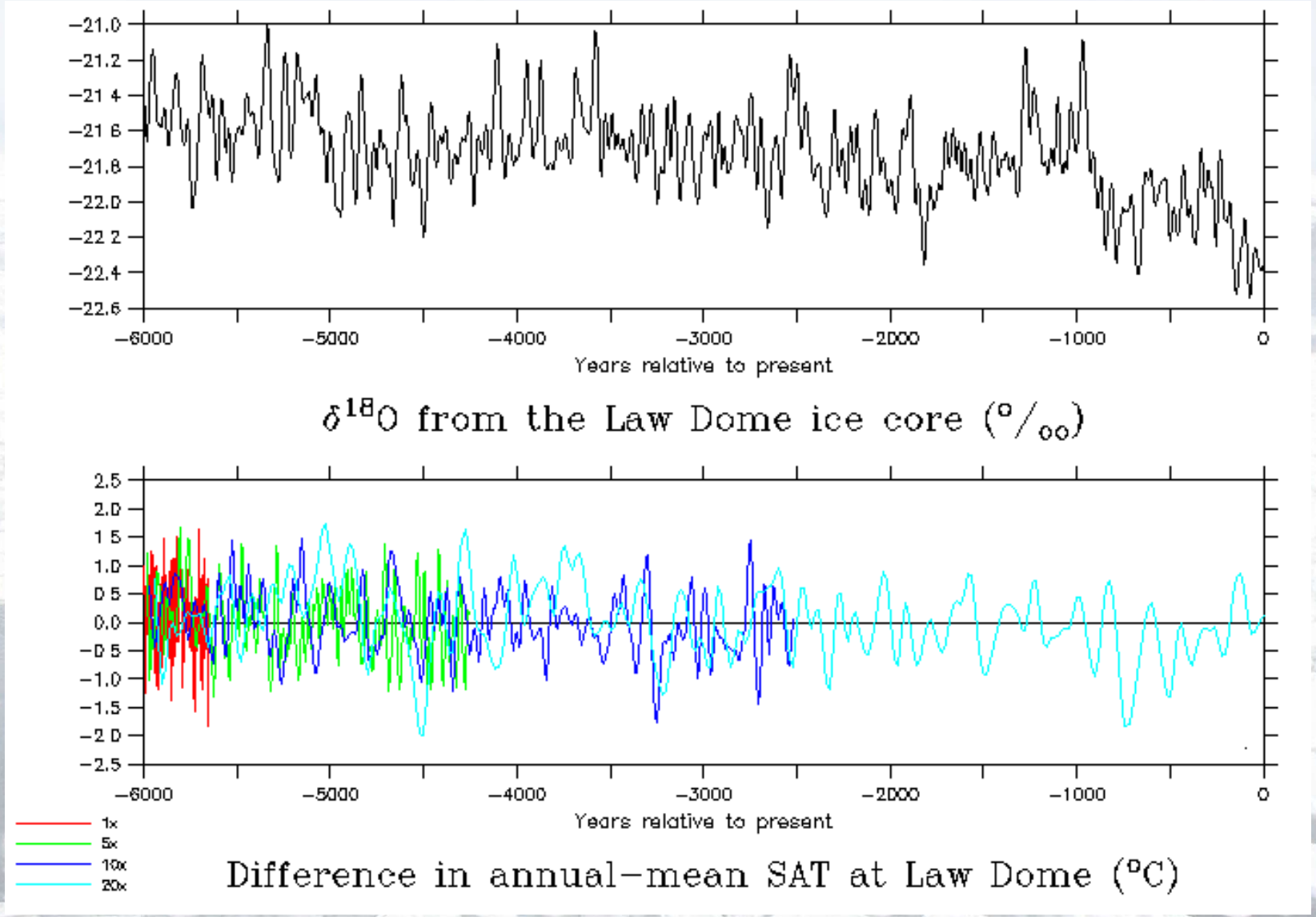
The climate of the late Holocene

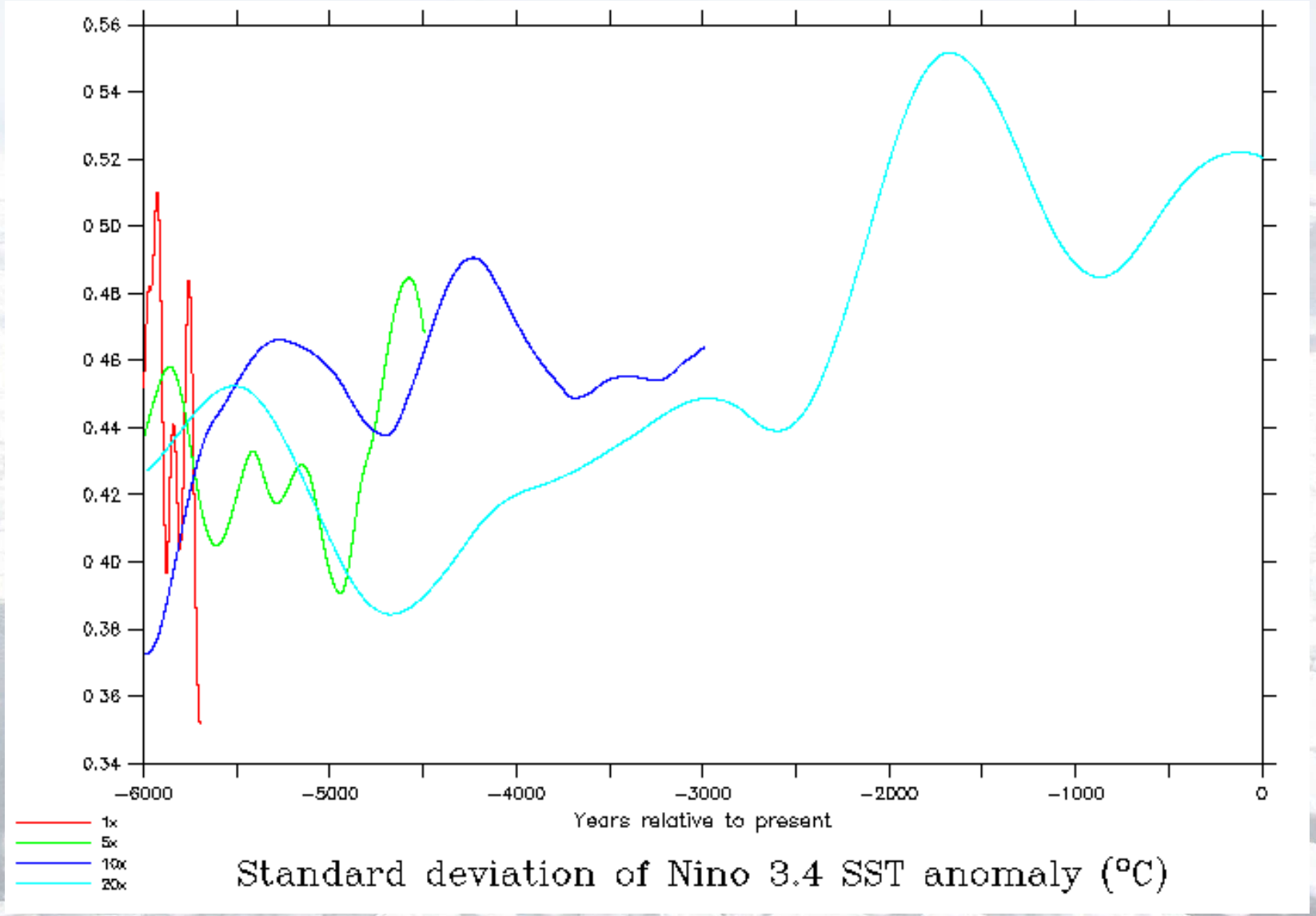
- Transient simulations from 6ka BP to the present day
- Initialised from year 1000 of the mid-Holocene simulation
- Orbital parameters varied, using the acceleration technique of Lorenz and Lohmann (2004)*
- Acceleration factors of 1, 5, 10 and 20
- Other boundary conditions unchanged

*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.


0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
Difference in JJA SAT at northern mid−latitudes (°C)


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)


−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
δ18O from the Law Dome ice core (°/oo)
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)


0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
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
- Lorenz-Lohmann acceleration enables orbital effects on very long timescales to be studied
- Simulations suggest a gradual strengthening of ENSO during the late Holocene