Multi-millennial simulations of the climate of the late Holocene

Steven J. Phipps

ARC Network for Earth System Sciences
Tasmanian Partnership for Advanced Computing

TPAC

Overview

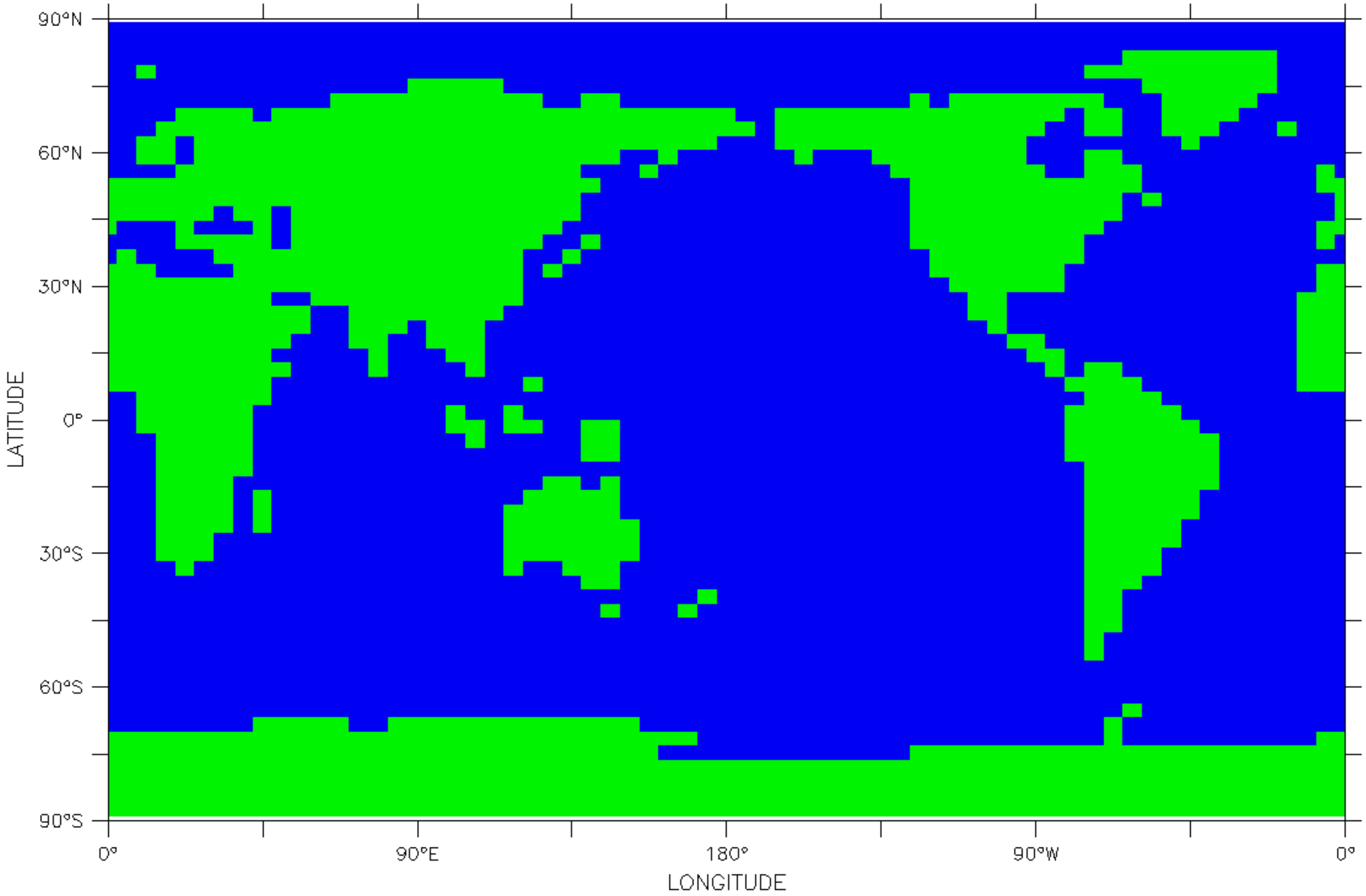
- The CSIRO Mk3L climate system model
- The climate of the present day
- The climate of the mid-Holocene
- The climate of the late Holocene

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
  - sensitivity experiments

Atmosphere model

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



The CSIRO Mk3L model grid

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

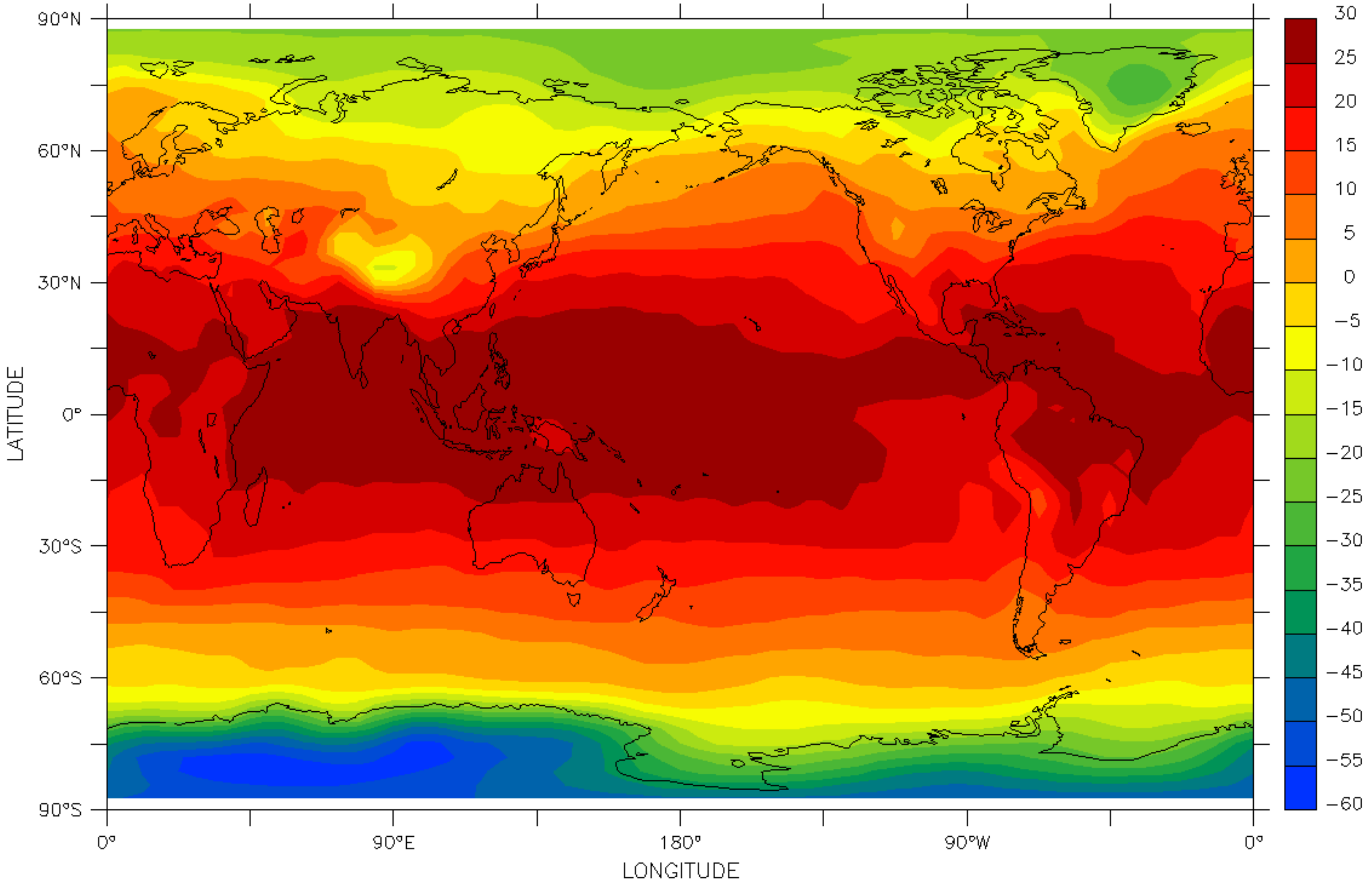
Facility	Processor type	Number of processors	Speed (years/day)
SGI Altix AC	1.6GHz Itanium 2	1	6.2
		2	10.9
		4	16.0
Linux Cluster	2.66GHz Pentium 4	1	4.6

Coming soon...

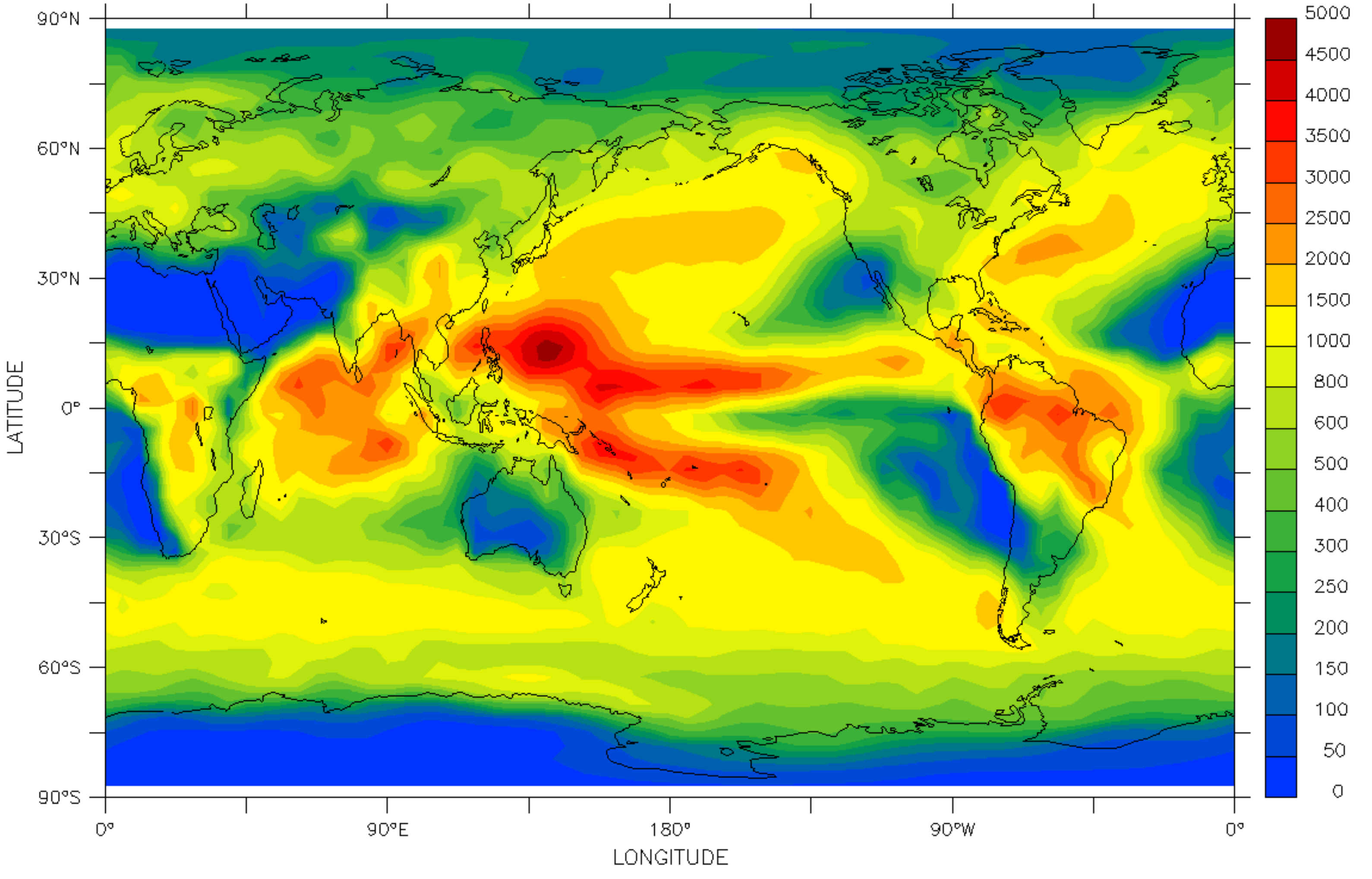
- Double the horizontal resolution of the ocean model (giving $\Delta\lambda \approx 2.8^\circ, \Delta\phi \approx 1.6^\circ$)
- Incorporate new schemes (e.g. CABLE)
- Synchronise the model physics with Mk3
- Faster, easier to use
- What do *you* want?

2. The simulated "present-day" climate

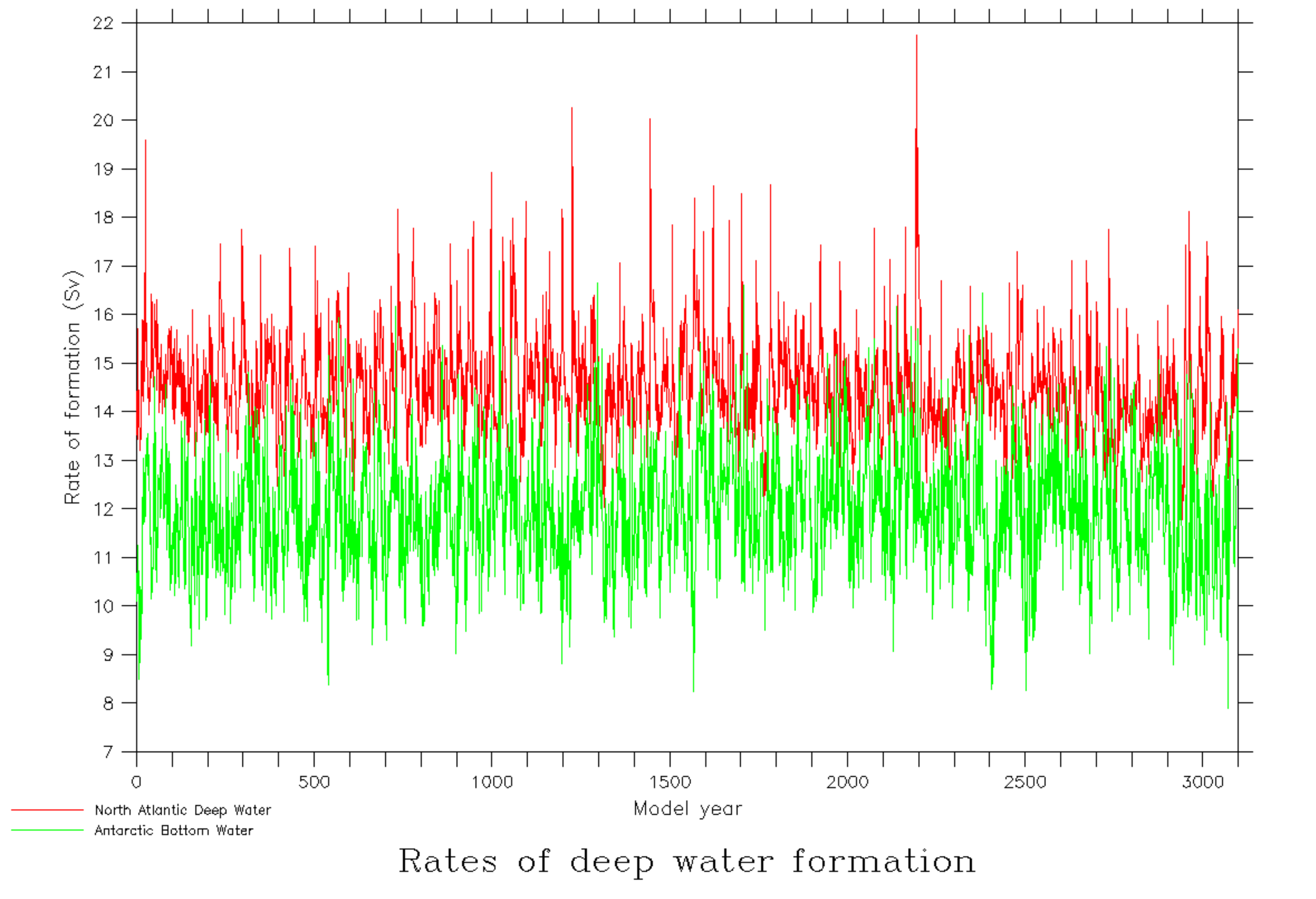
- Control simulation follows PMIP2 experimental design:
  - CO_2 concentration = 280ppm
  - Solar constant = 1365 Wm^{-2}
  - "Modern" orbital parameters (AD 1950)
- Ocean model initialised using Levitus 1998
- Atmosphere and ocean models spun up independently
- Coupled model initialised from final states of spin-up runs
- Integrated for 3100+ years

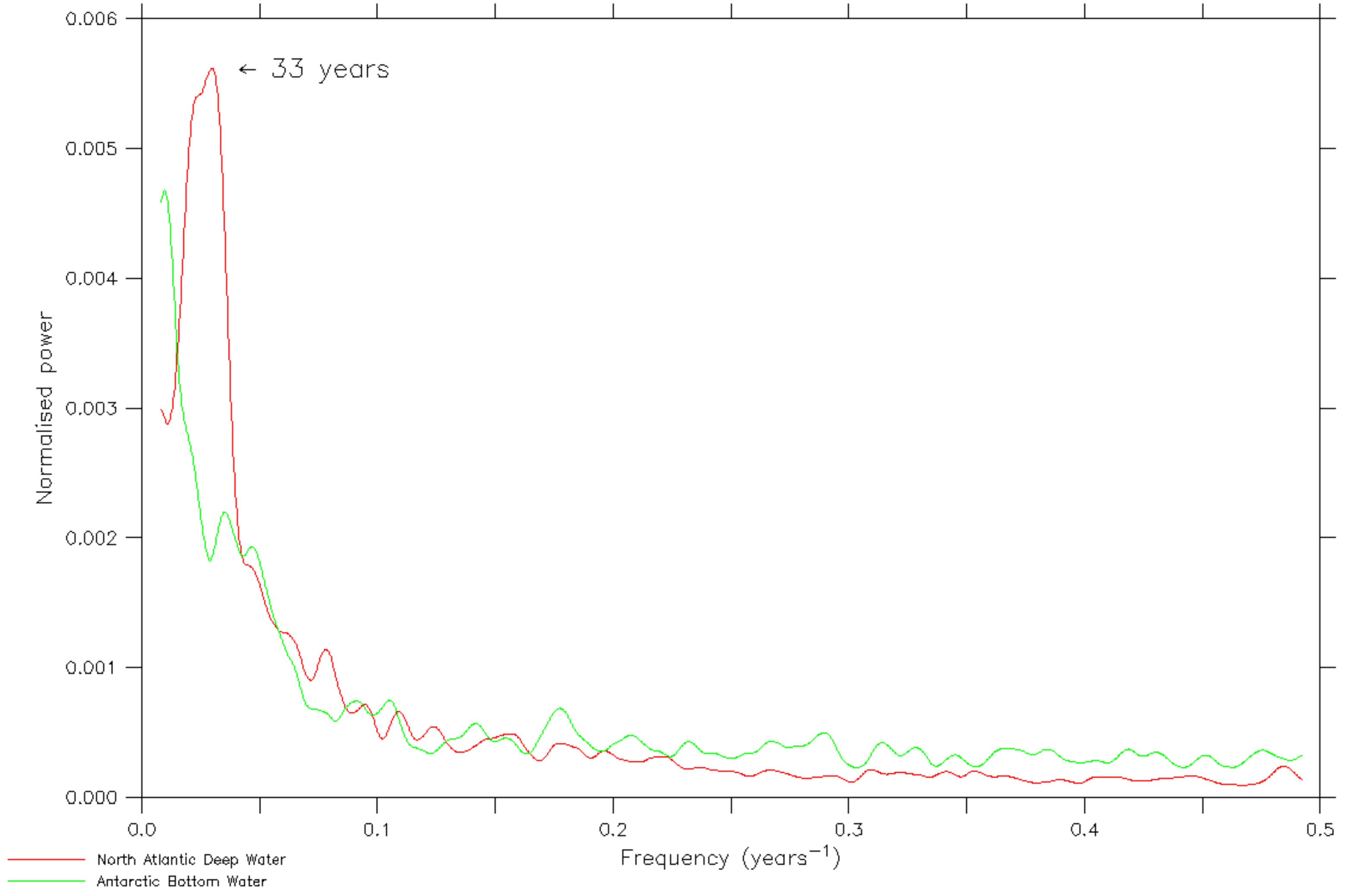


Annual−mean surface air temperature (°C)

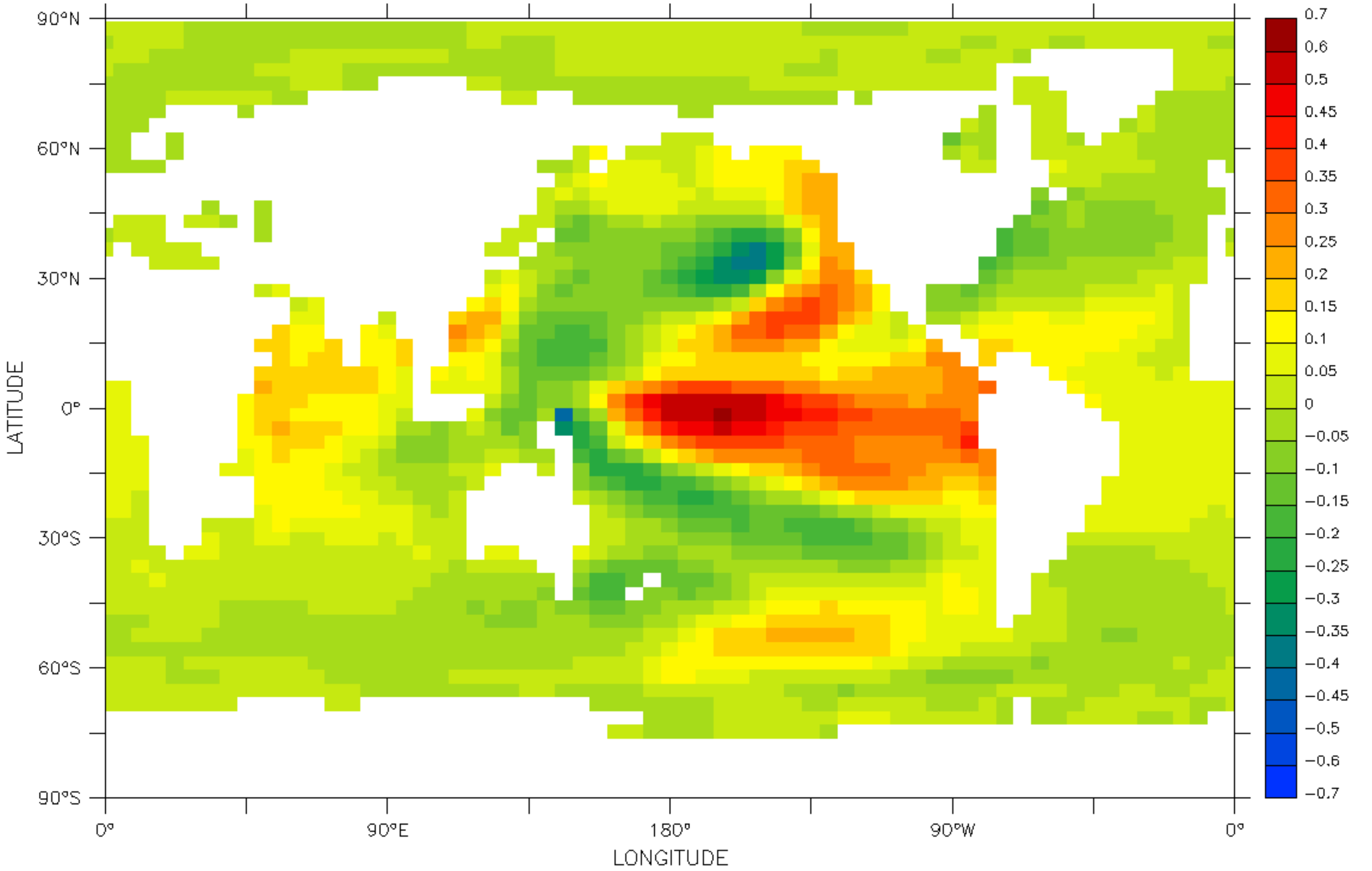


Annual precipitation (mm)

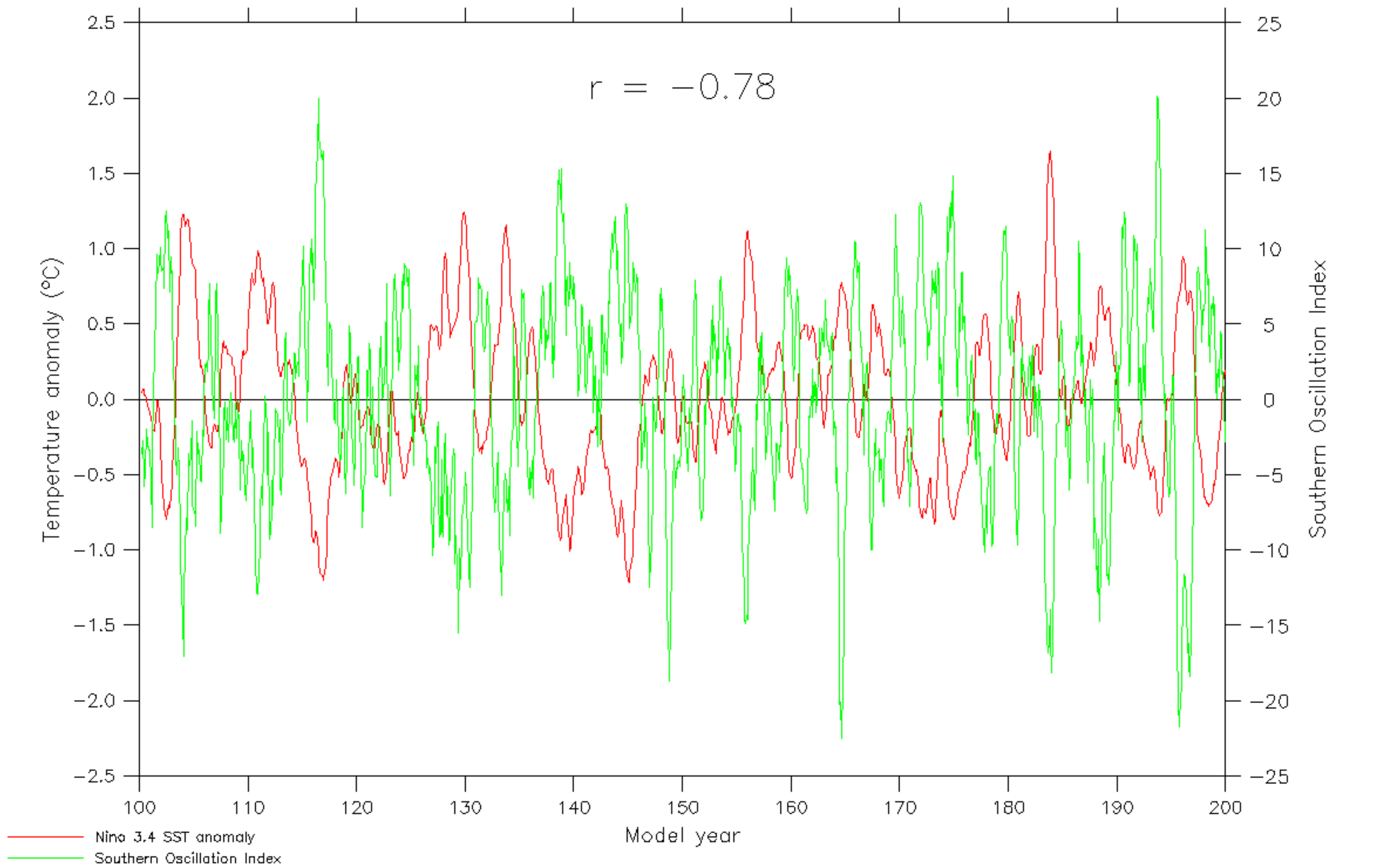

22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
Rate of formation (Sv)
0
500
1000
1500
2000
2500
3000
Model year
North Atlantic Deep Water
Antarctic Bottom Water
Rates of deep water formation



Rates of deep water formation: power spectra



EOF1 of annual−mean sea surface temperature (°C) − 22.4%



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)	7.6 ± 0.3	$\sim$3.2
Average duration (months)	17.0 ± 0.5	$\sim$12

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

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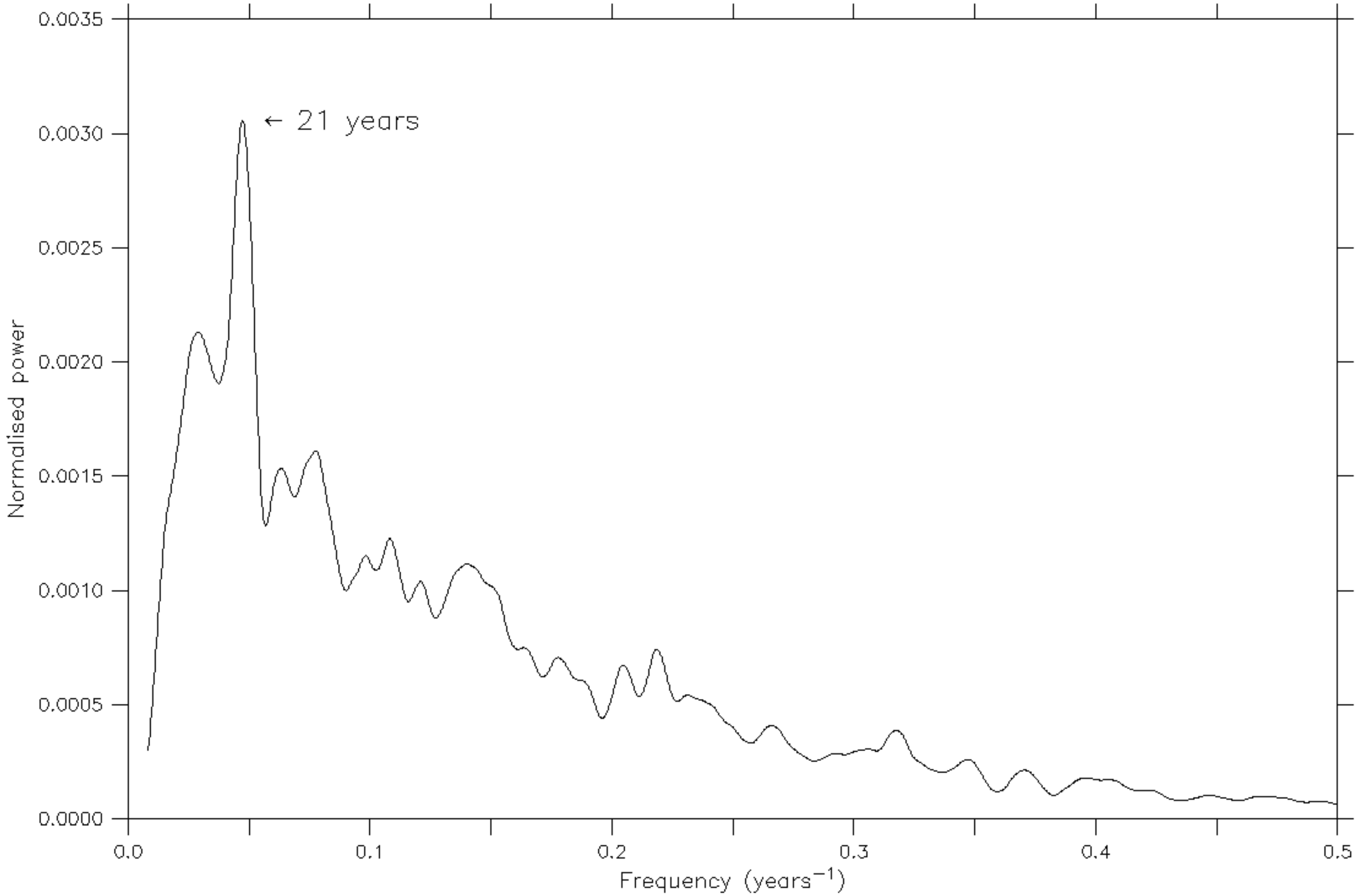
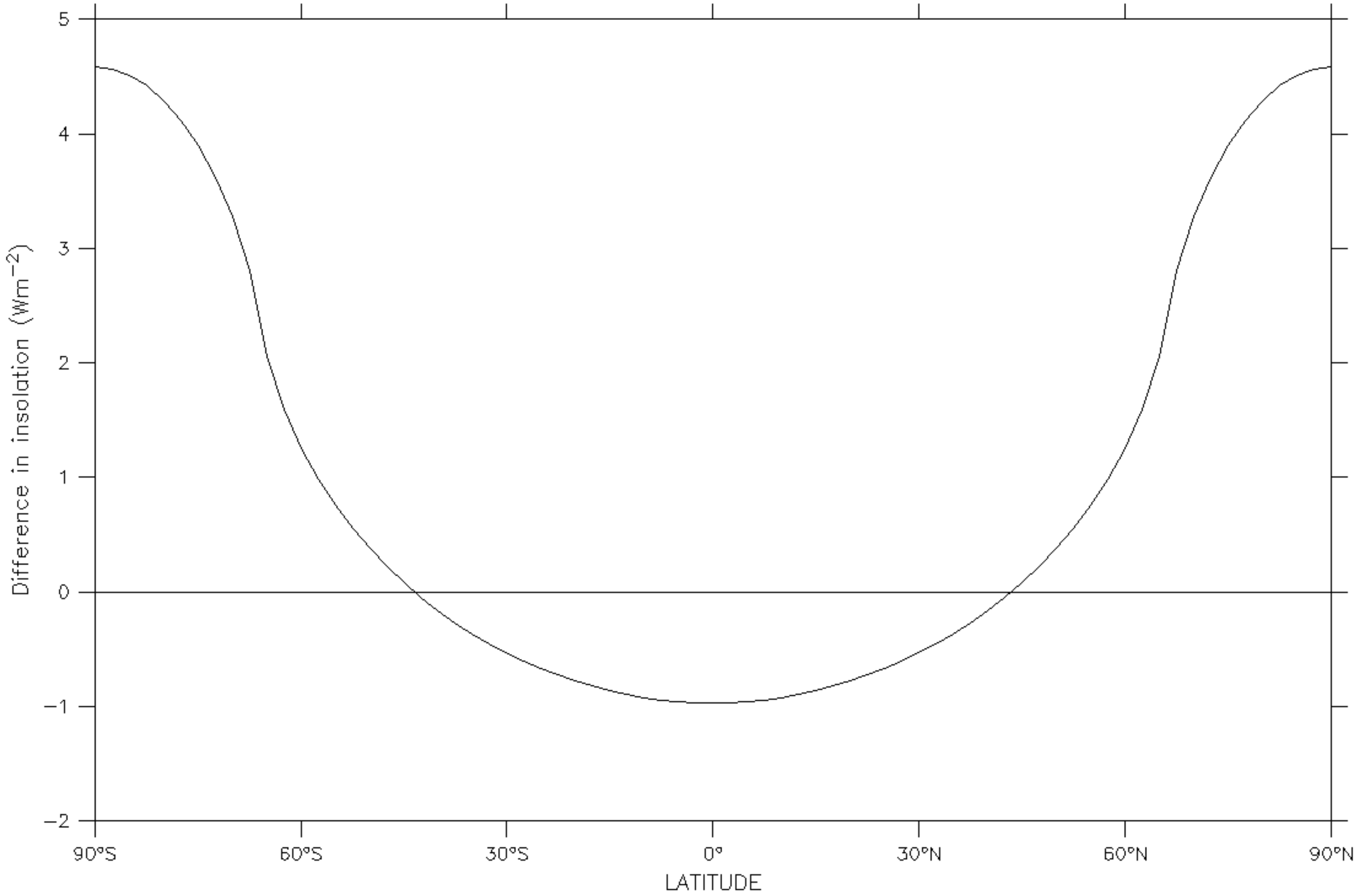


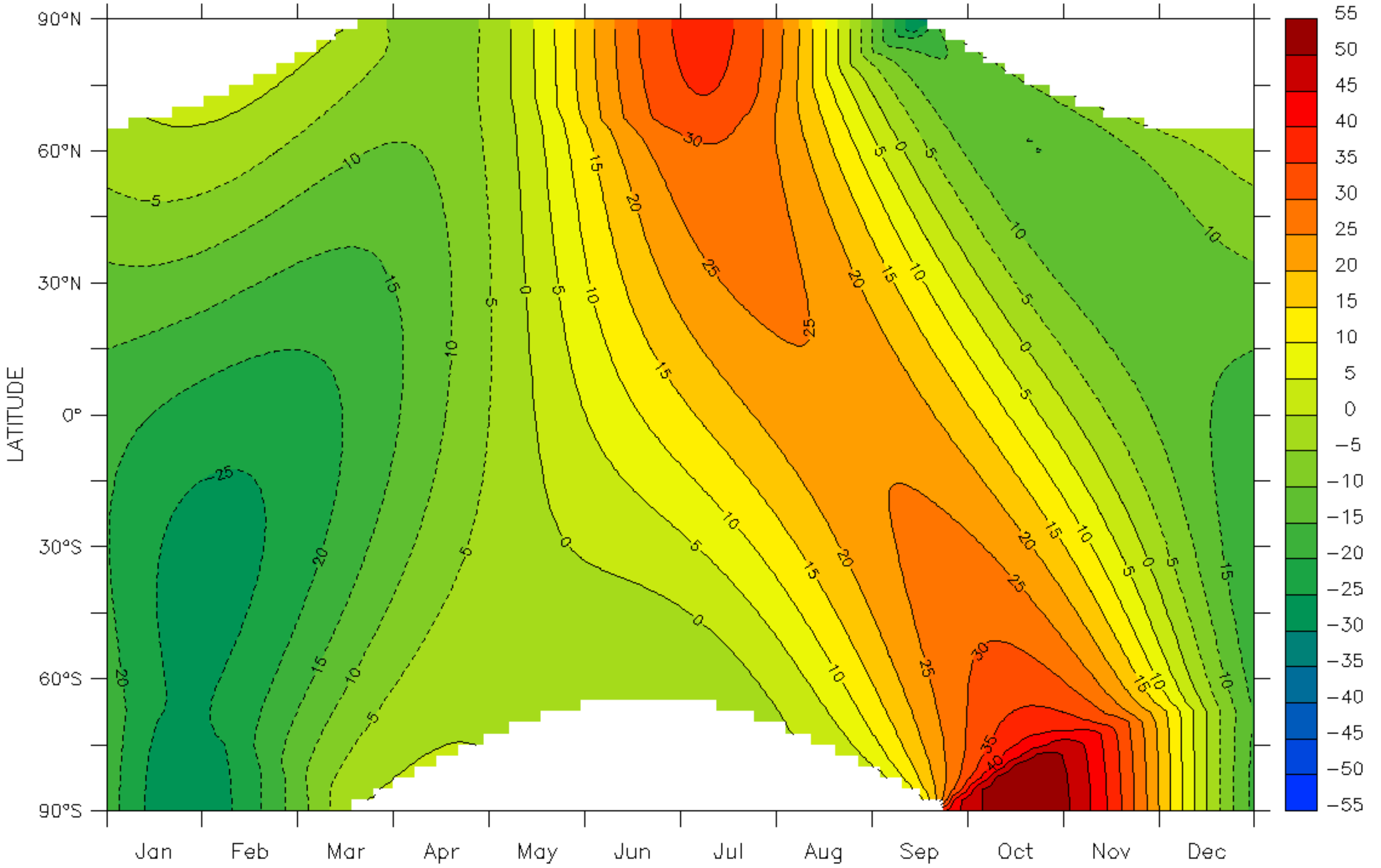
Nino 3.4 SST anomaly: power spectrum

3. The climate of the mid-Holocene

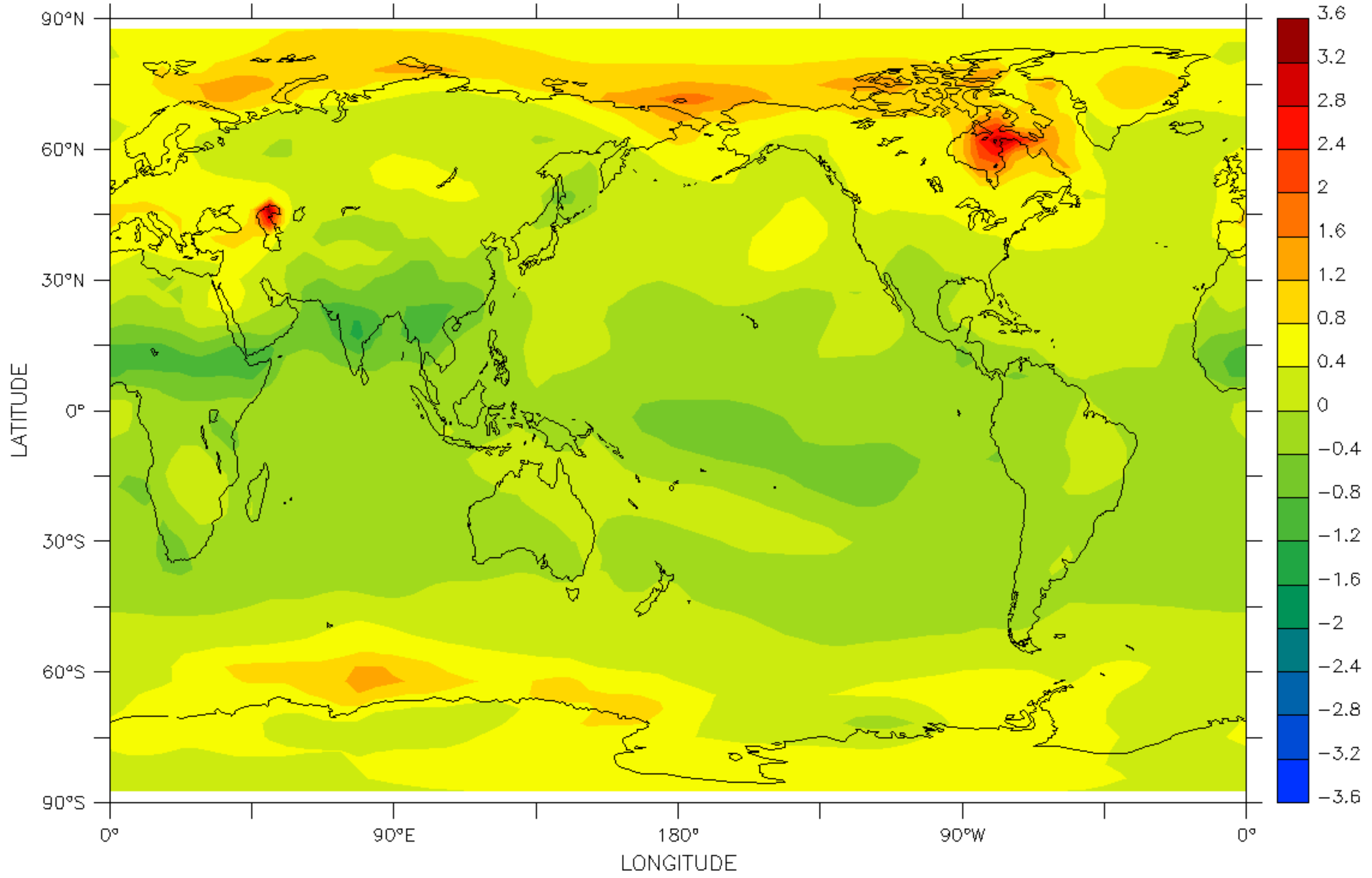
- Equilibrium simulation conducted for the mid-Holocene (6ka BP)
- PMIP2 experiment
- Orbital parameters for 6ka BP
- Atmospheric CO_2 concentration reduced from 280ppm to 277ppm
  - equivalent to a reduction in the atmospheric CH_4 concentration from 760ppb to 650ppb
- Initialised from year 100 of control simulation
- Integrated for 1700+ years



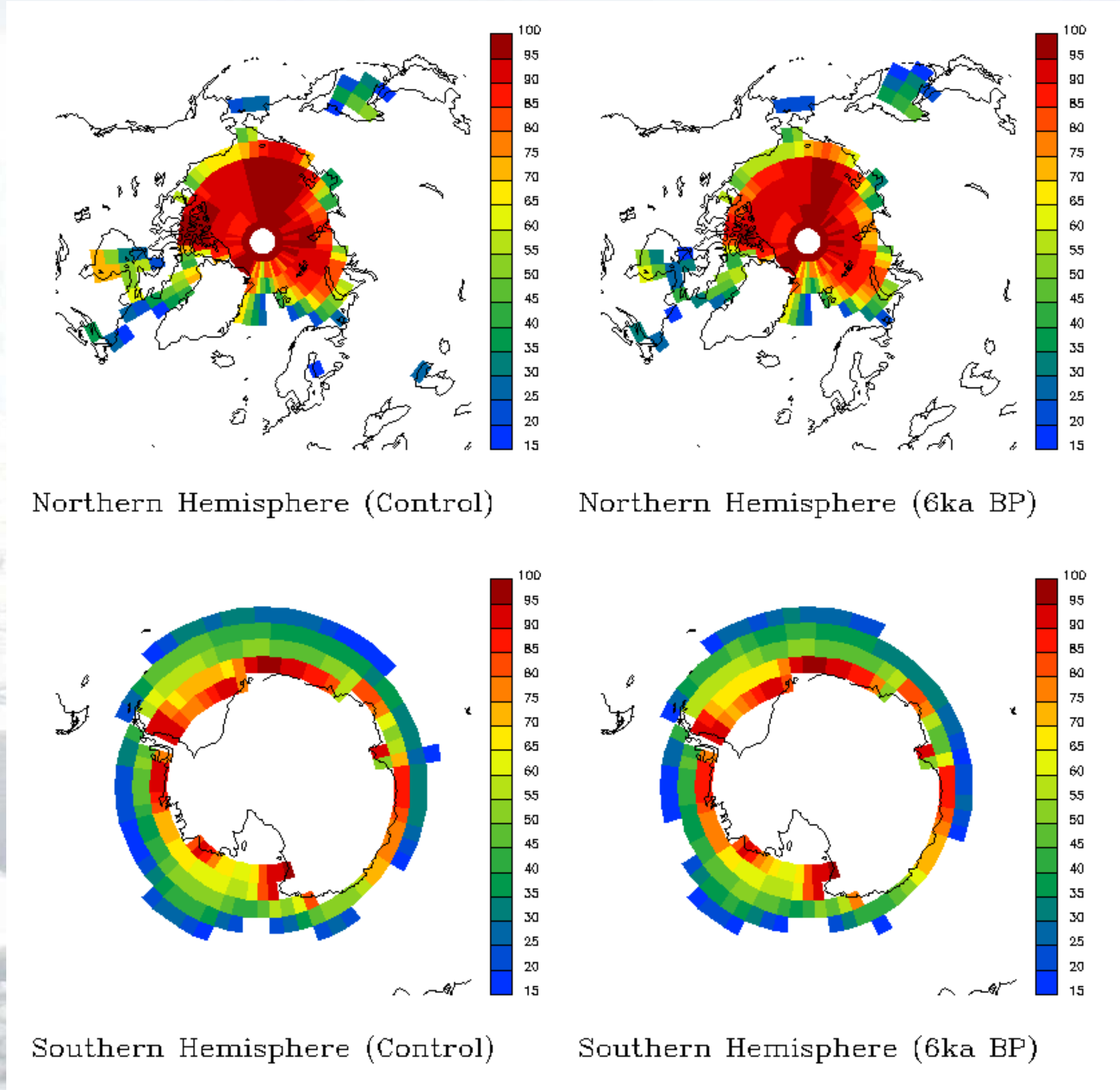
Annual−mean insolation: 6ka BP minus present day

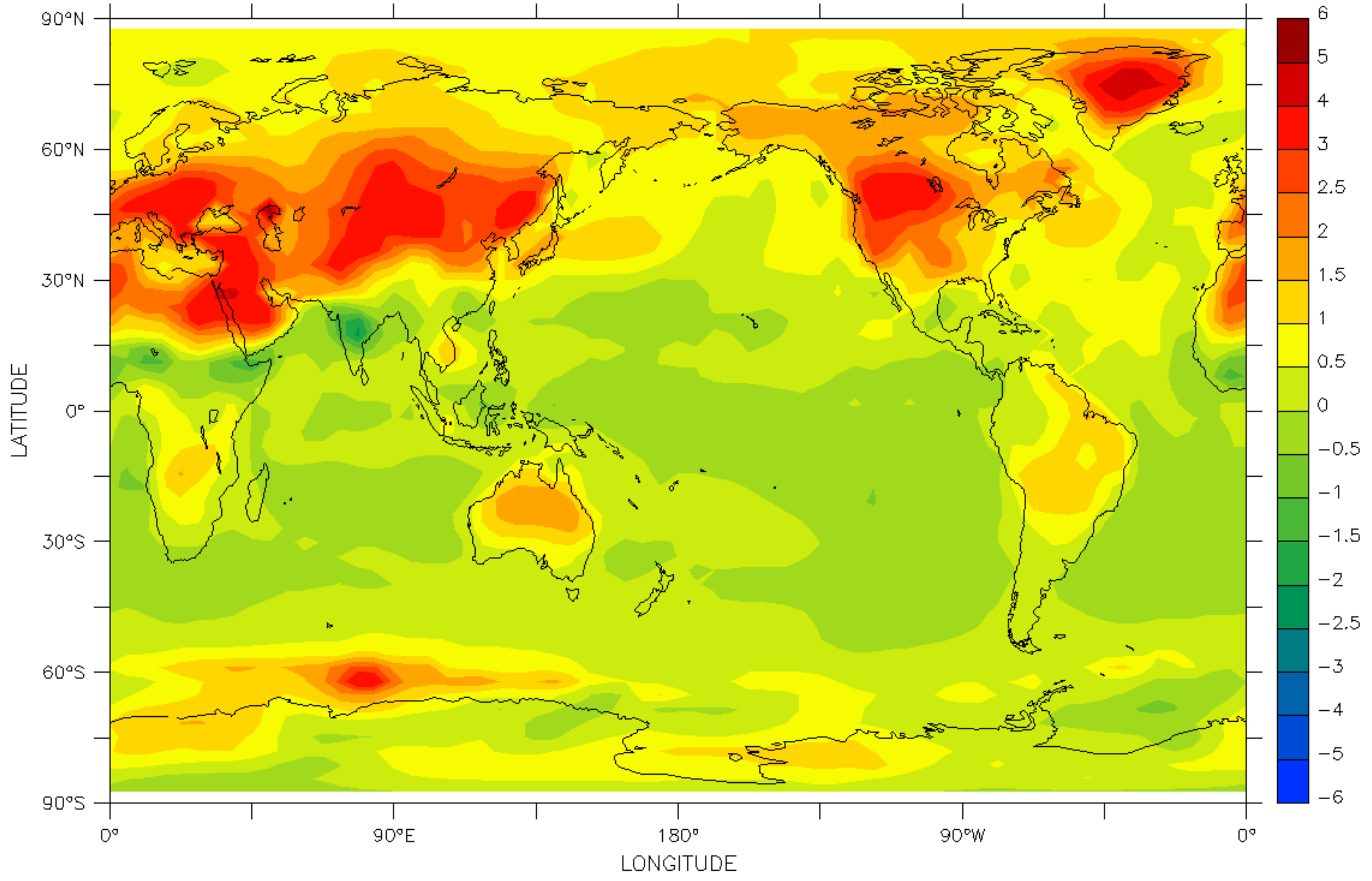


Insolation: 6ka BP minus present day (Wm^{-2})

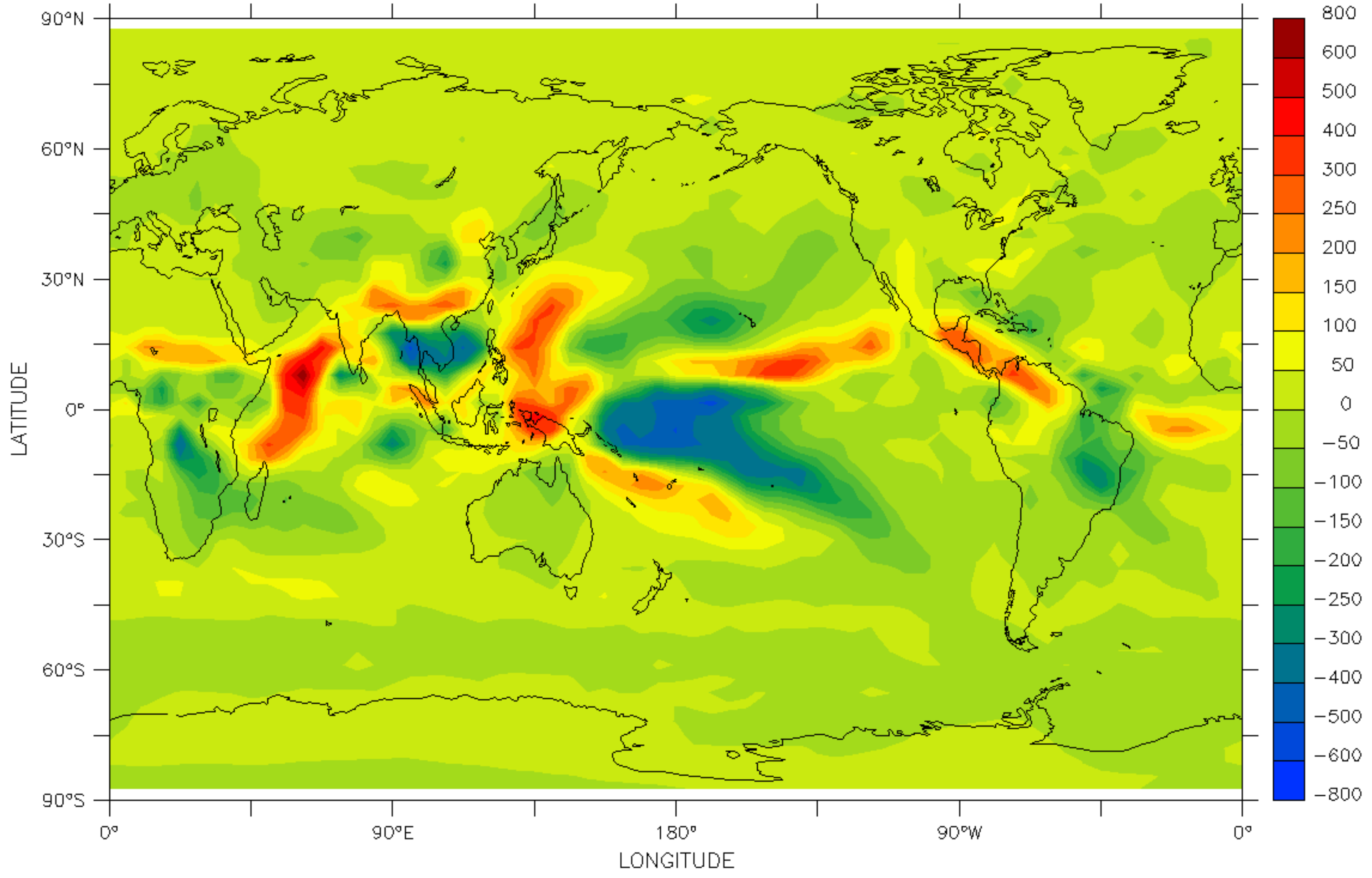


Difference in annual−mean surface air temperature (°C)

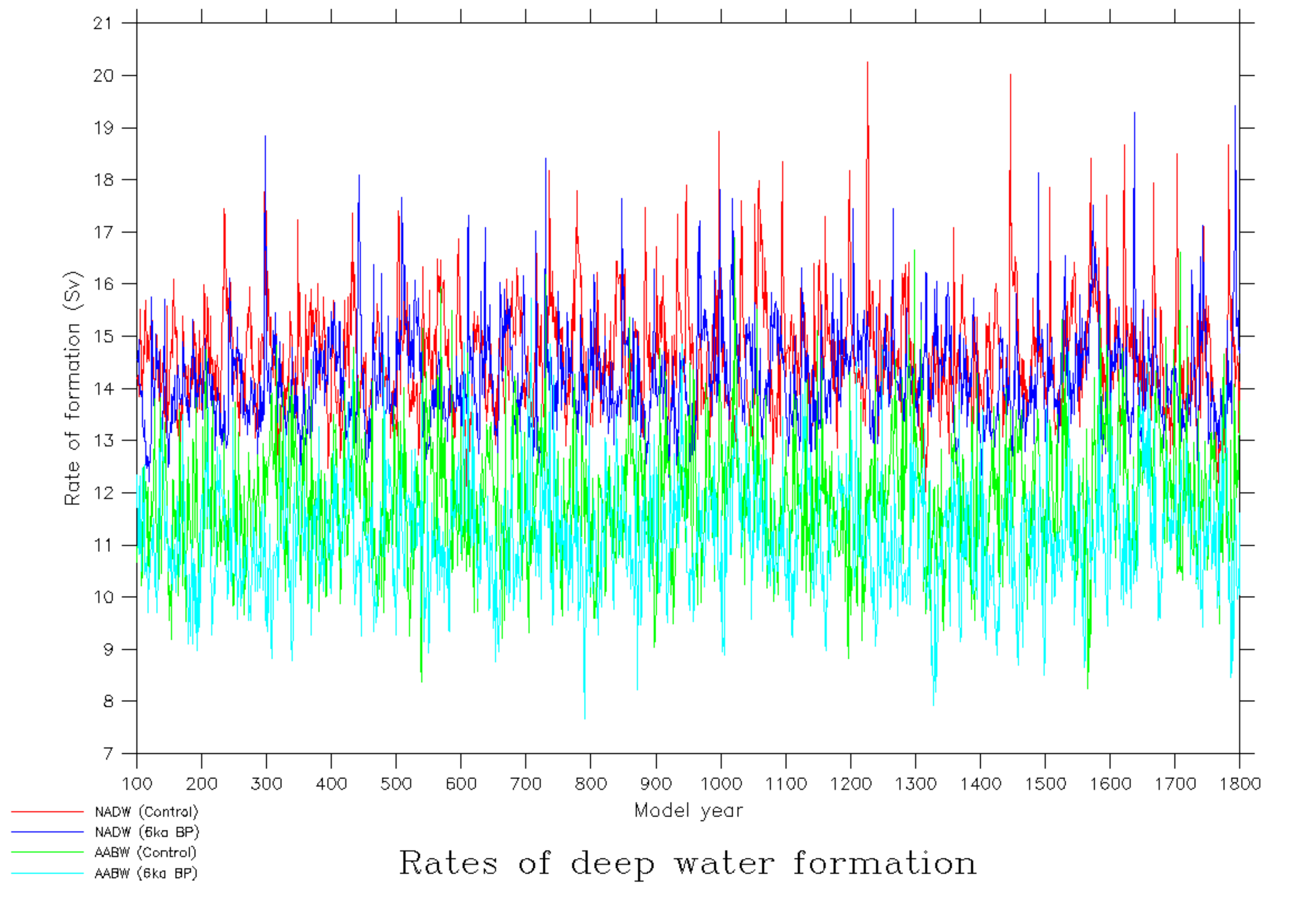

100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
Northern Hemisphere (Control)
Northern Hemisphere (6ka BP)
Southern Hemisphere (Control)
Southern Hemisphere (6ka BP)



Difference in August surface air temperature (°C)



Difference in annual precipitation (mm)



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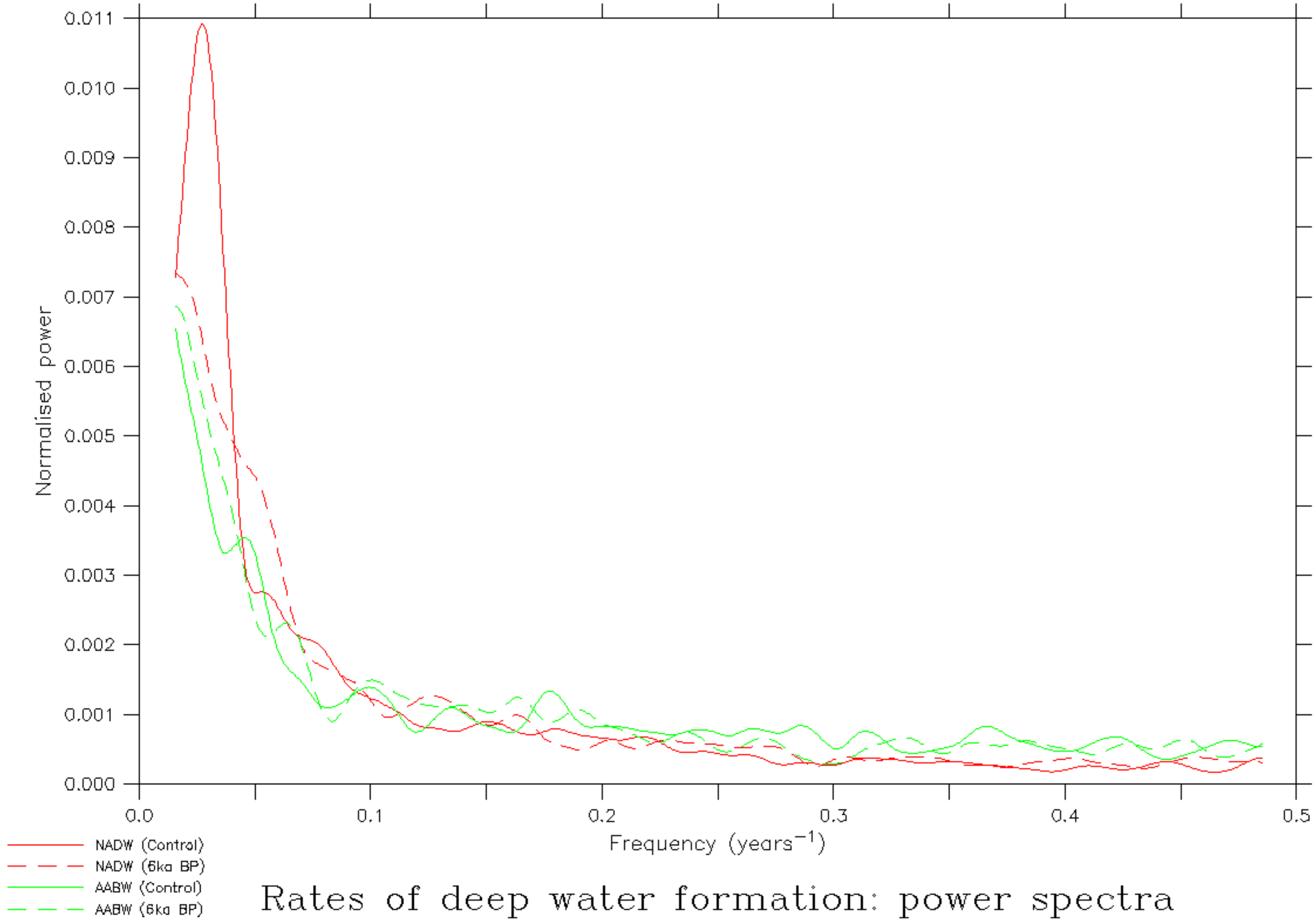
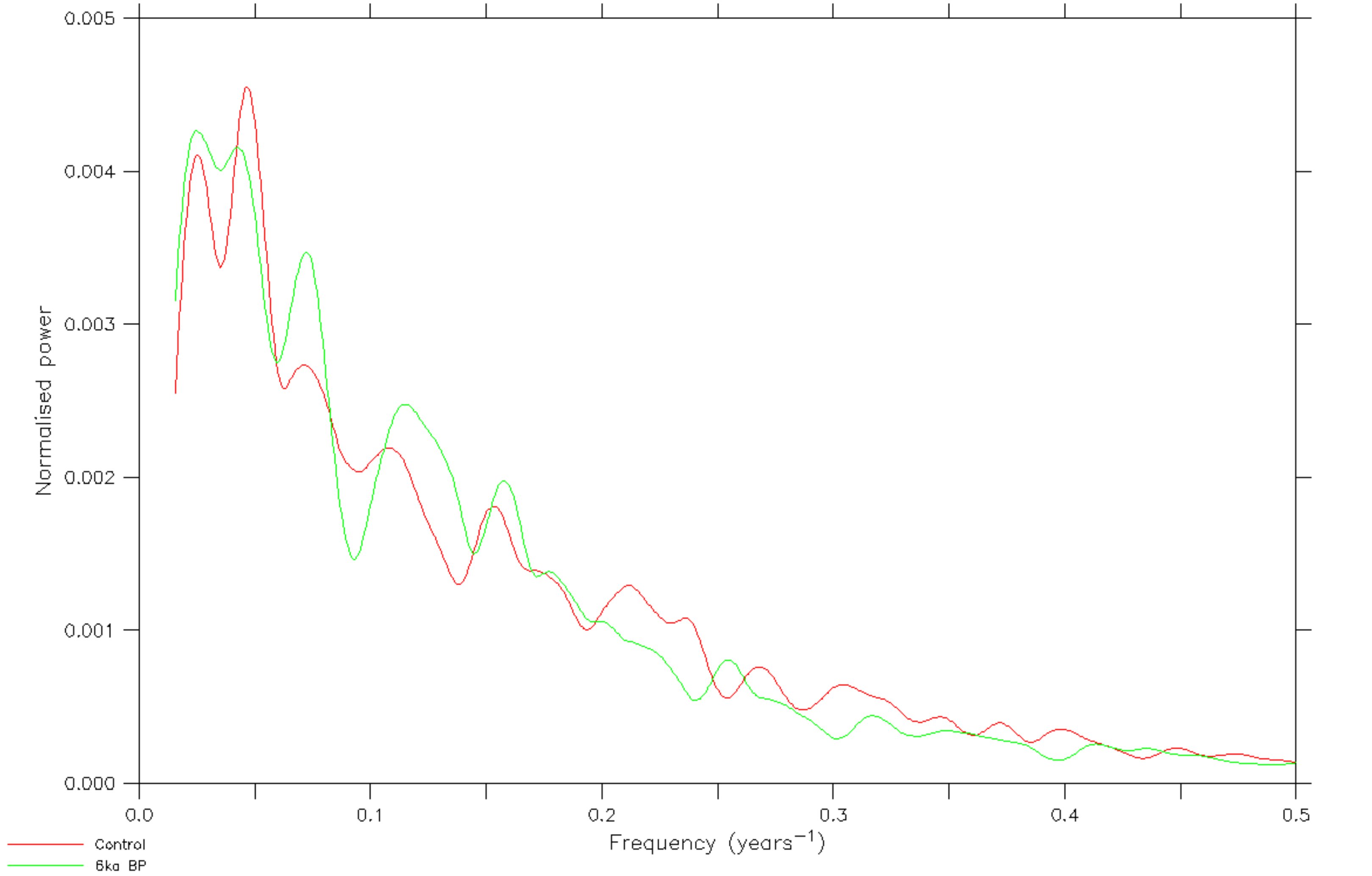
8
7
Rate of formation (Sv)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Model year
NADW (Control)
NADW (6ka BP)
AABW (Control)
AABW (6ka BP)
Rates of deep water formation



Rates of deep water formation: power spectra

El Niño: control versus 6ka BP

	Control	6ka BP
Standard deviation of Niño 3.4 SST anomaly (°C)	0.48	0.42
Period (years)	7.6 ± 0.3	9.4 ± 0.6
Duration (months)	17.0 ± 0.5	16.7 ± 0.8

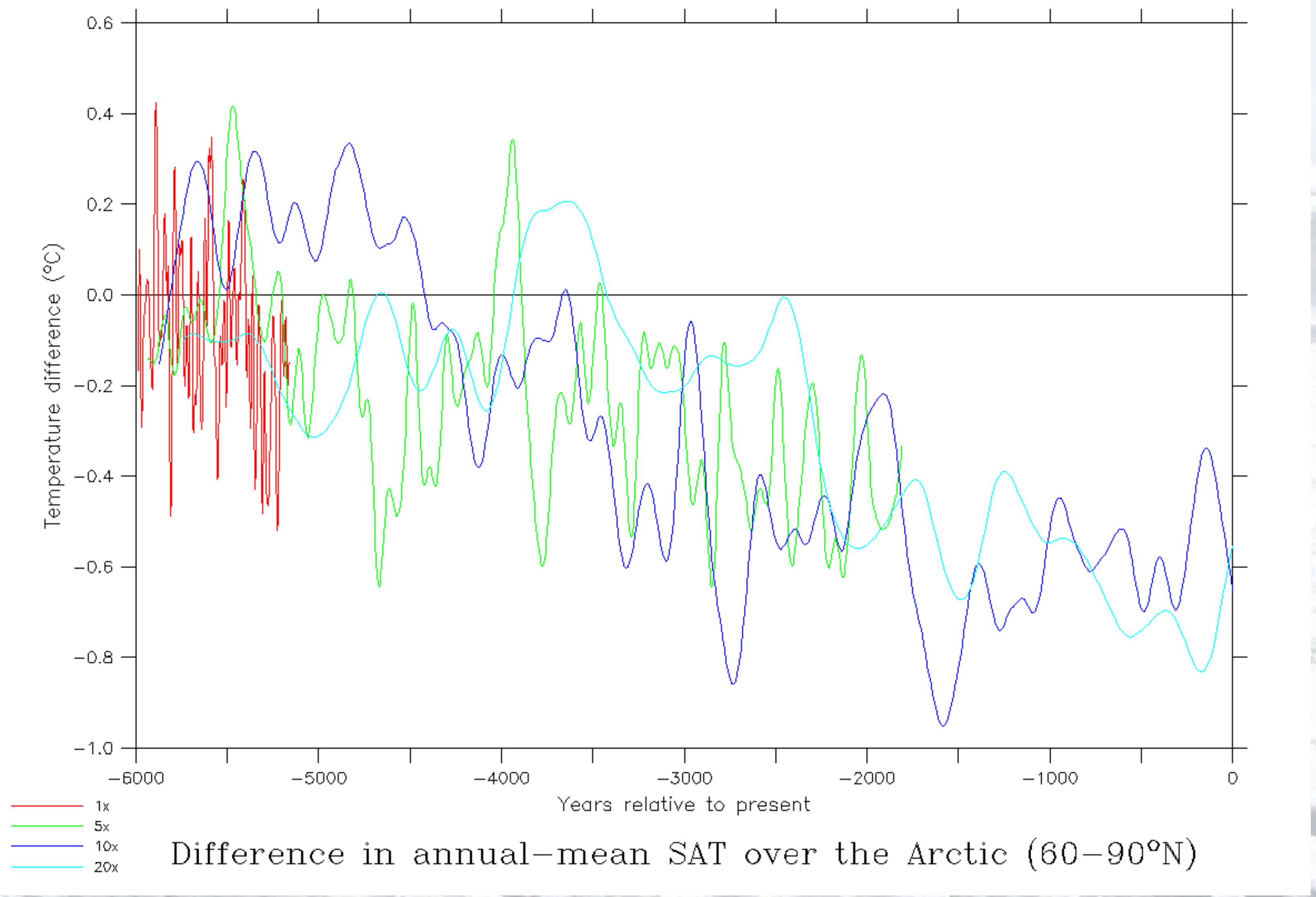


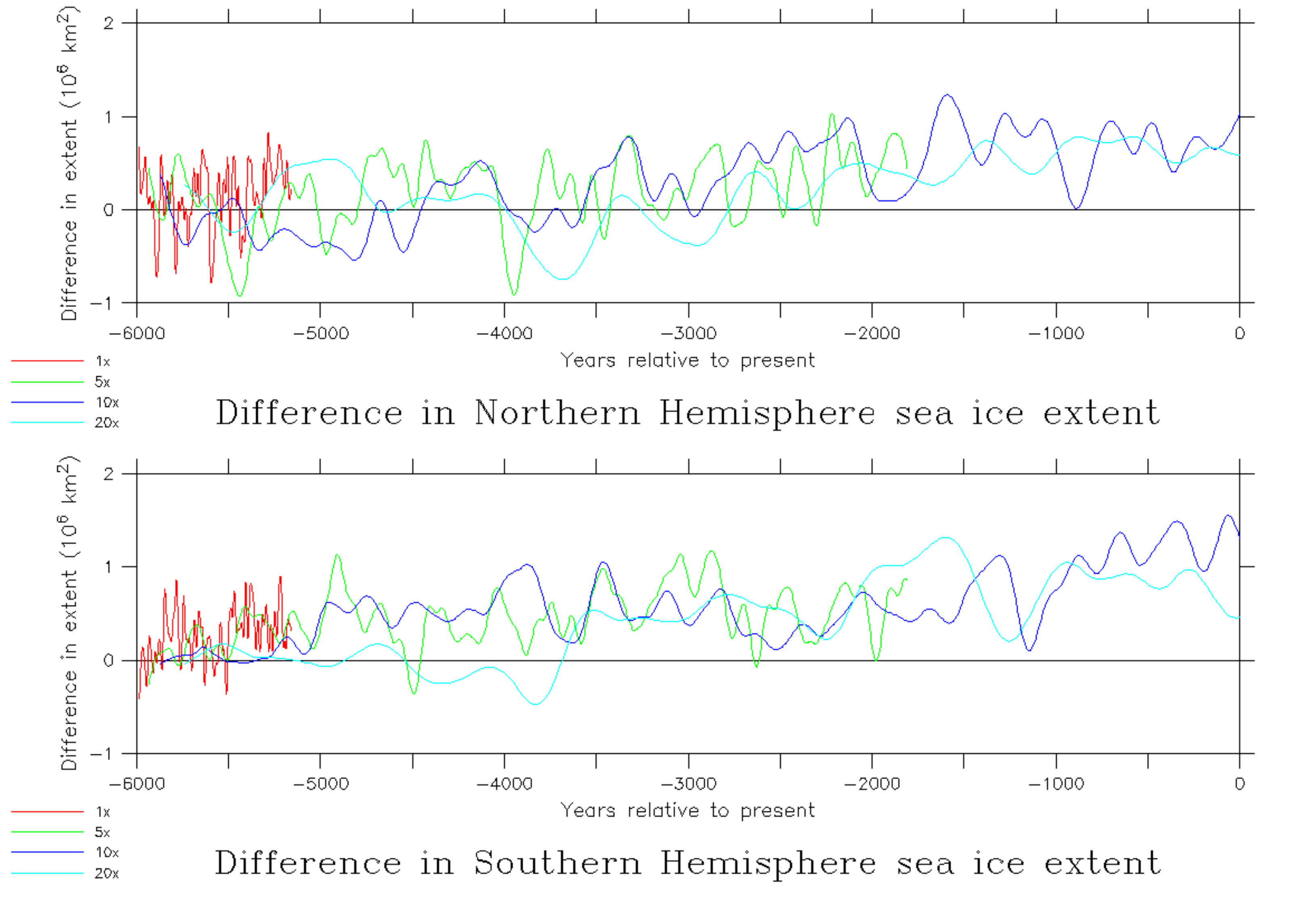
Nino 3.4 SST anomaly: power spectra

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.


0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
Temperature difference (°C)
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
Difference in annual−mean SAT over the Arctic (60−90°N)



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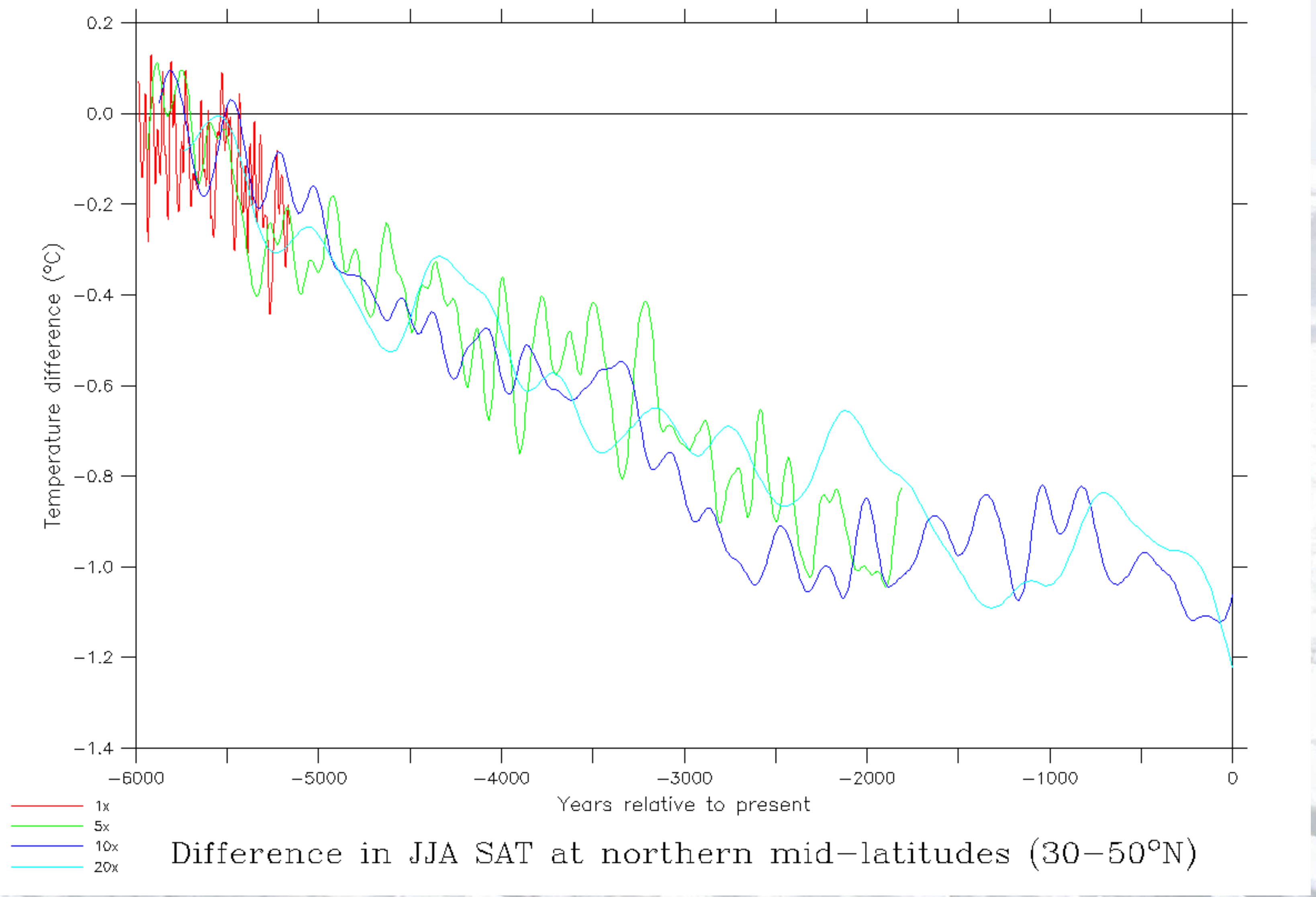
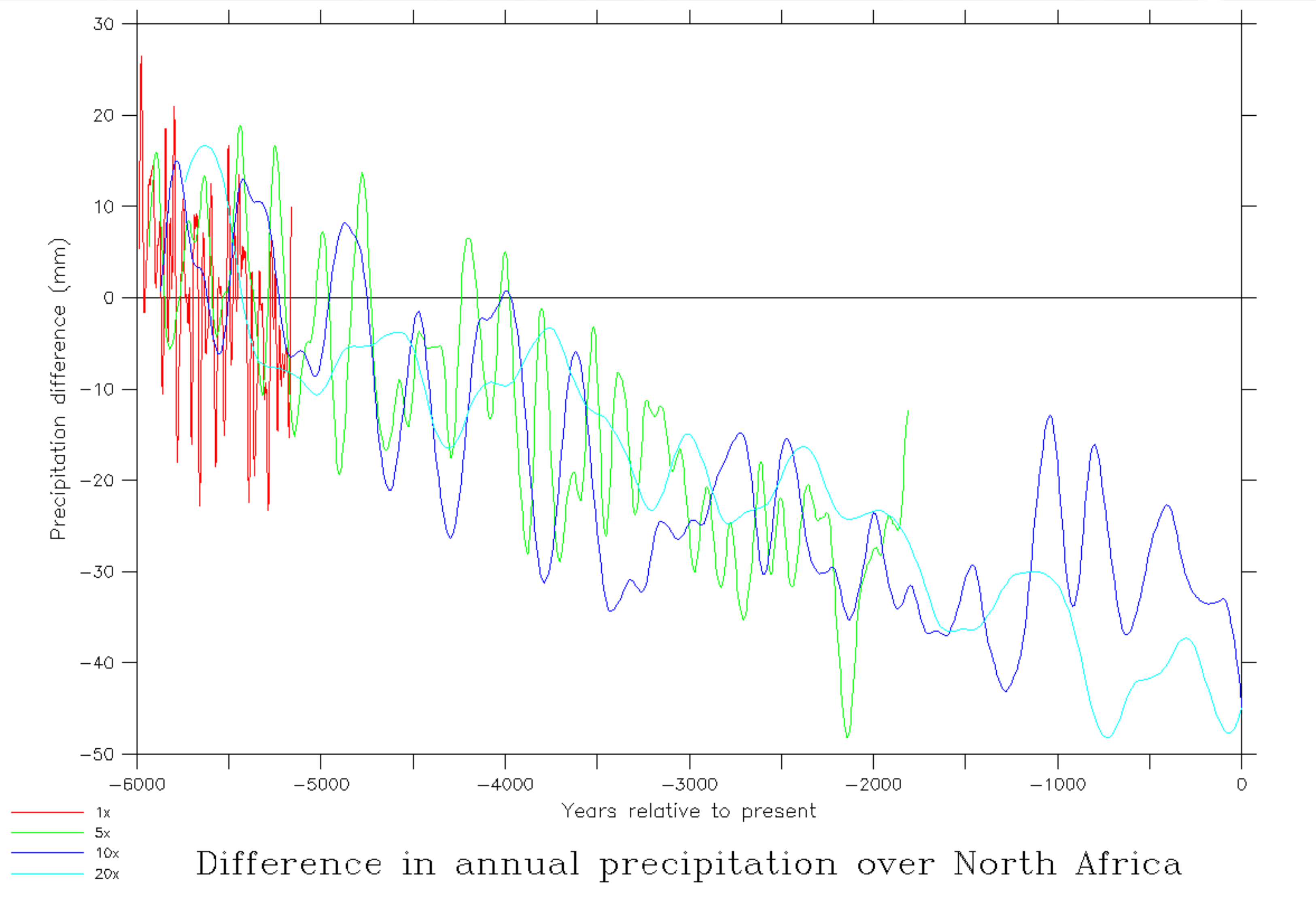
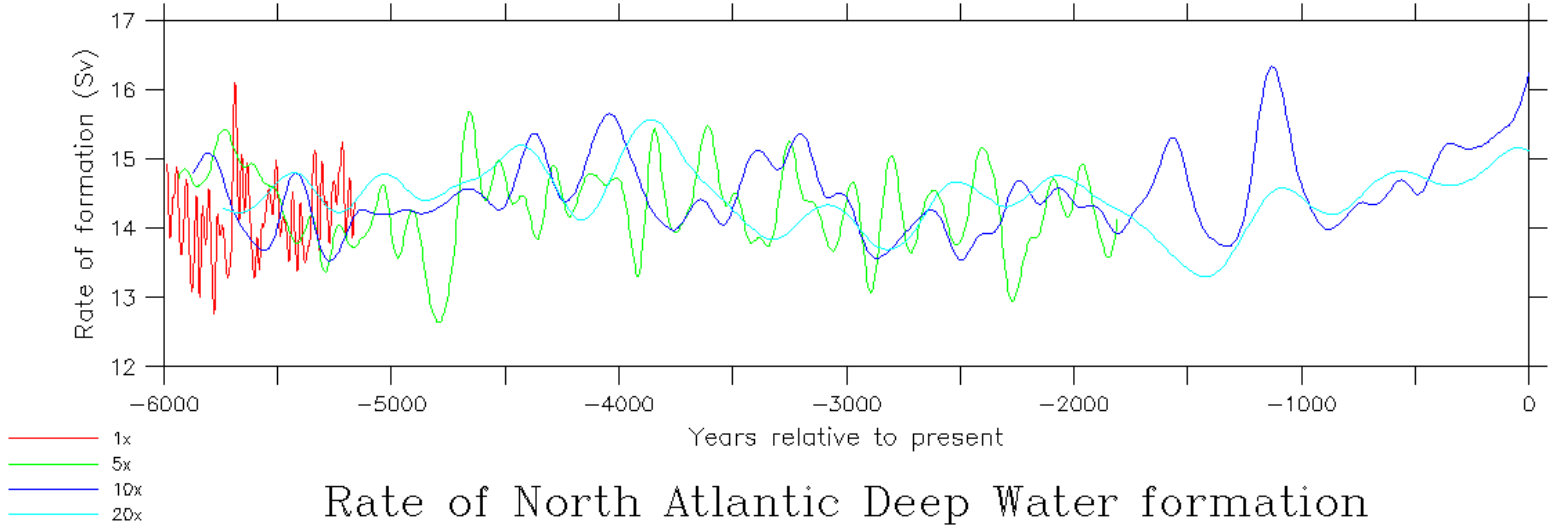
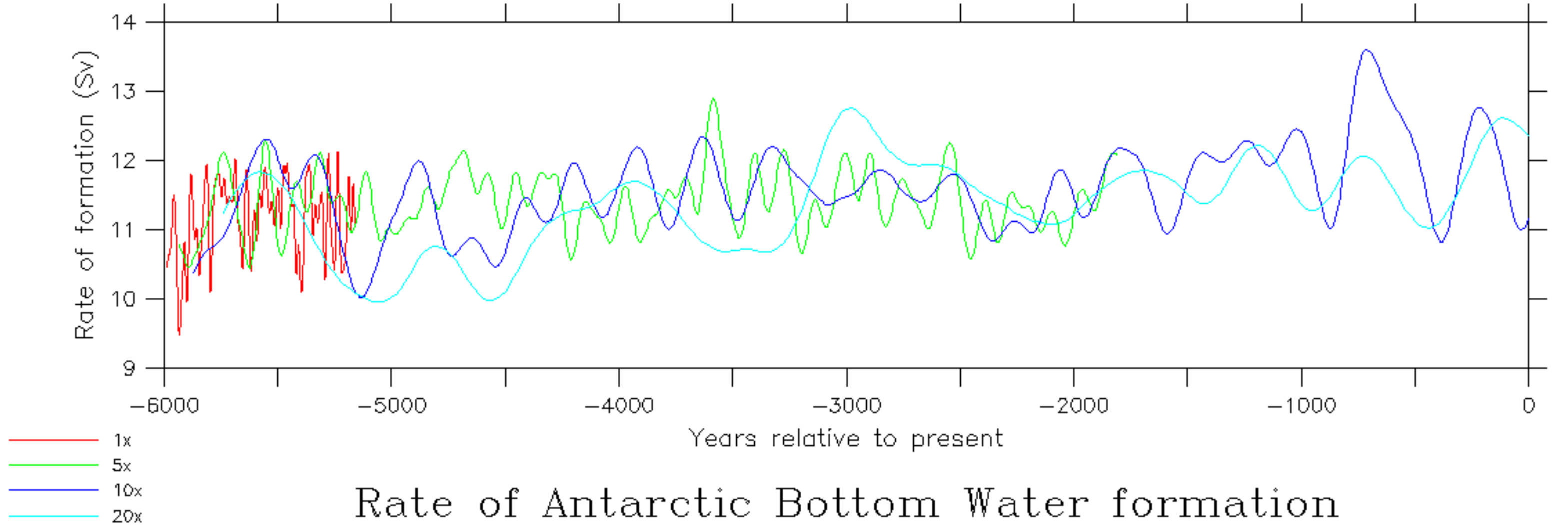
UNSW Ocean and Climate Research Retreat, 14–16 August 2006


0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
Temperature difference (°C)
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
Difference in JJA SAT at northern mid−latitudes (30−50°N)

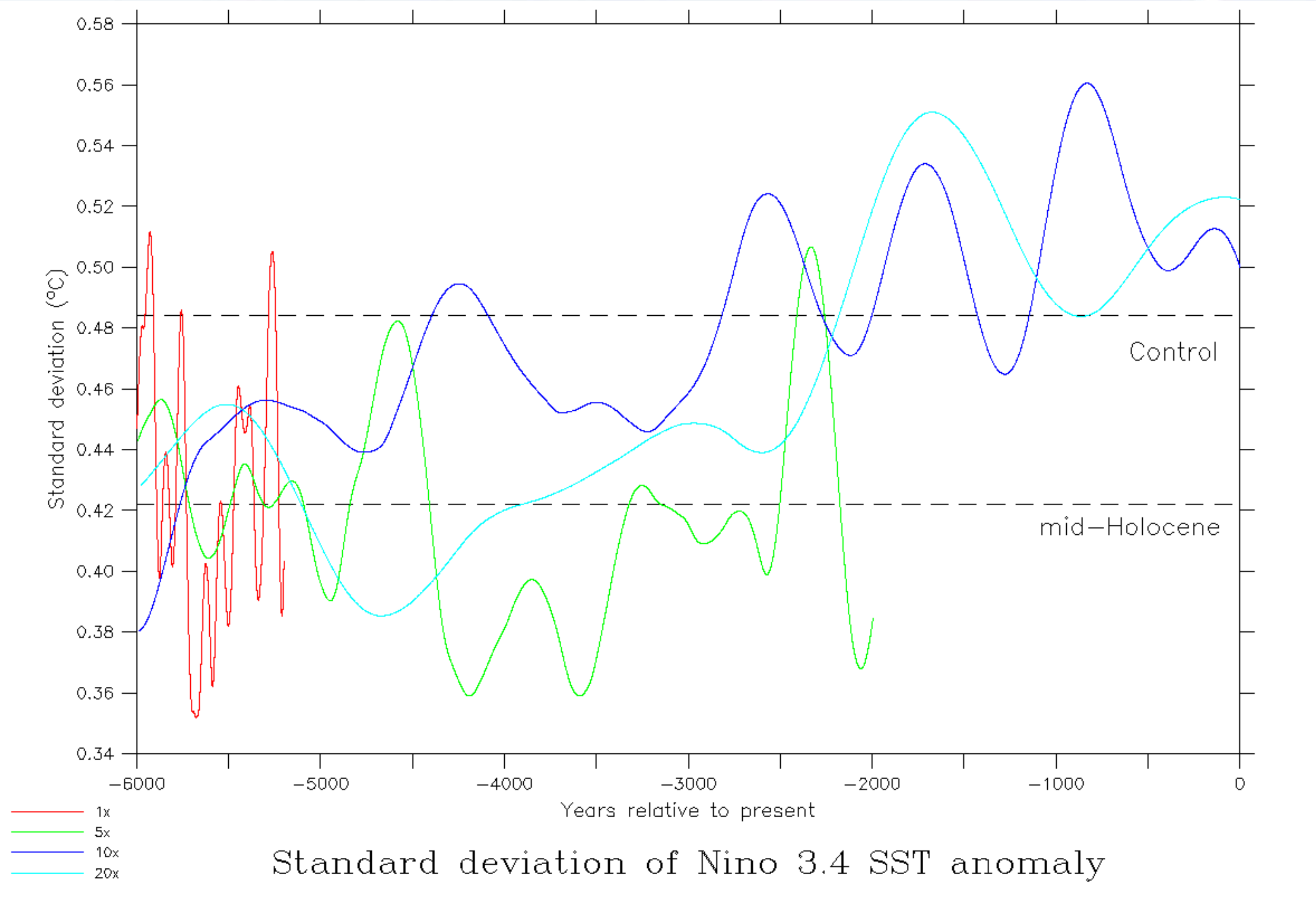

30
20
10
0
−10
−20
−30
−40
−50
Precipitation difference (mm)
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
Difference in annual precipitation over North Africa



Rate of North Atlantic Deep Water formation



Rate of Antarctic Bottom Water formation


0.58
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 (ºC)
Control
mid−Holocene
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
Standard deviation of Nino 3.4 SST anomaly

Conclusions

- Mk3L enables climate variability and change to be studied on millennial timescales
- The simulated present-day climate features an Atlantic Multidecadal Oscillation, but that of the mid-Holocene does not
- The simulated ENSO strengthens during the late Holocene
- Need to investigate the underlying mechanisms
- Lots of potential for future work!