Introduction to the CSIRO Mk3L climate system model

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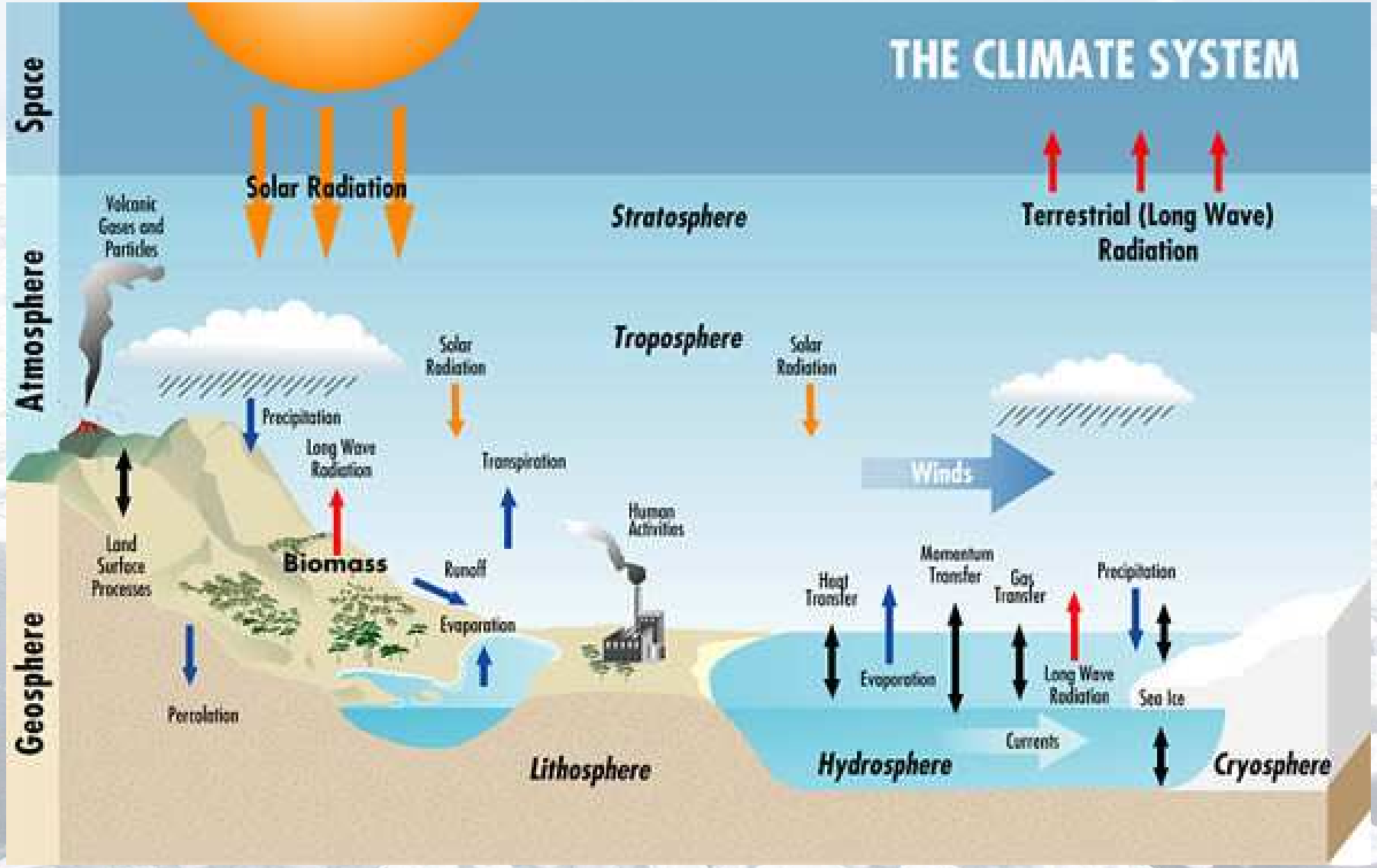
- Jason Roberts
- Tas van Ommen

Overview of workshop

- What is it?
- What can it do?
- Wow, how can I do that?

What is it?

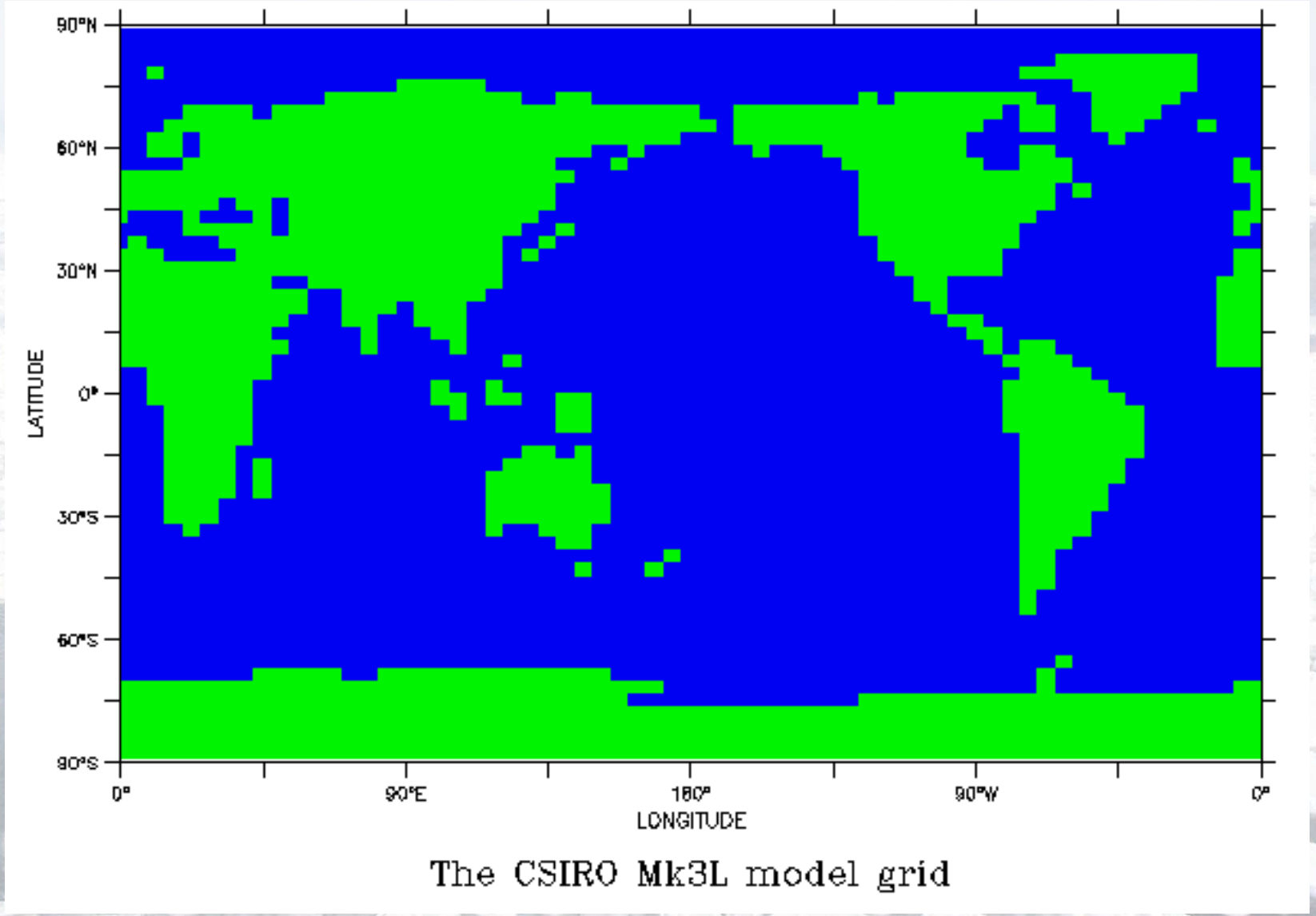

THE CLIMATE SYSTEM
Space
Atmosphere
Geosphere
Solar Radiation
Volcanic Gases and Particles
Stratosphere
Troposphere
Terrestrial (Long Wave) Radiation
Solar Radiation
Solar Radiation
Precipitation
Long Wave Radiation
Transpiration
Winds
Human Activities
Land Surface Processes
Biomass
Runoff
Evaporation
Percolation
Heat Transfer
Momentum Transfer
Gas Transfer
Precipitation
Evaporation
Long Wave Radiation
Sea Ice
Currents
Lithosphere
Hydrosphere
Cryosphere

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

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

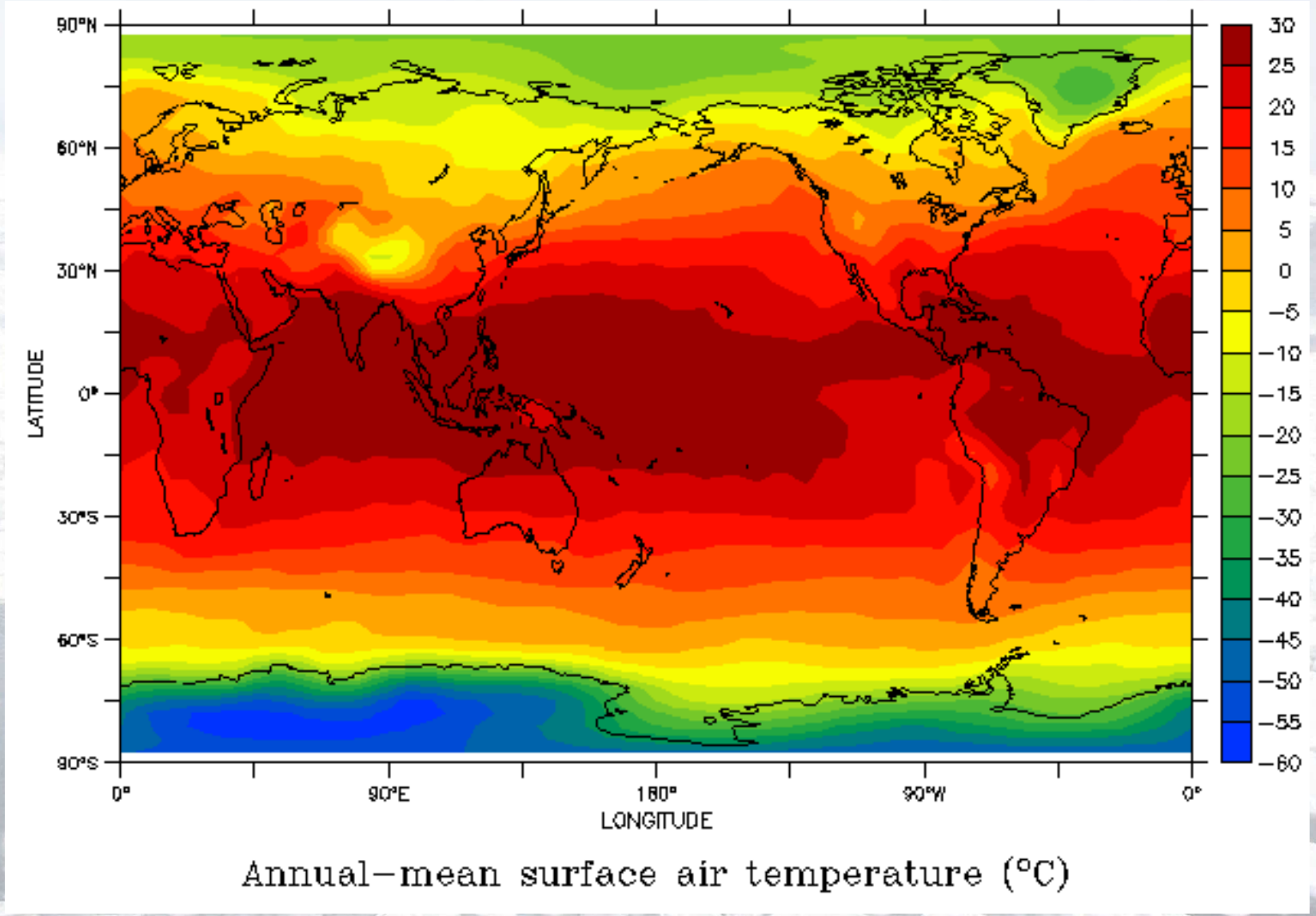
Benchmarks on APAC Facilities

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

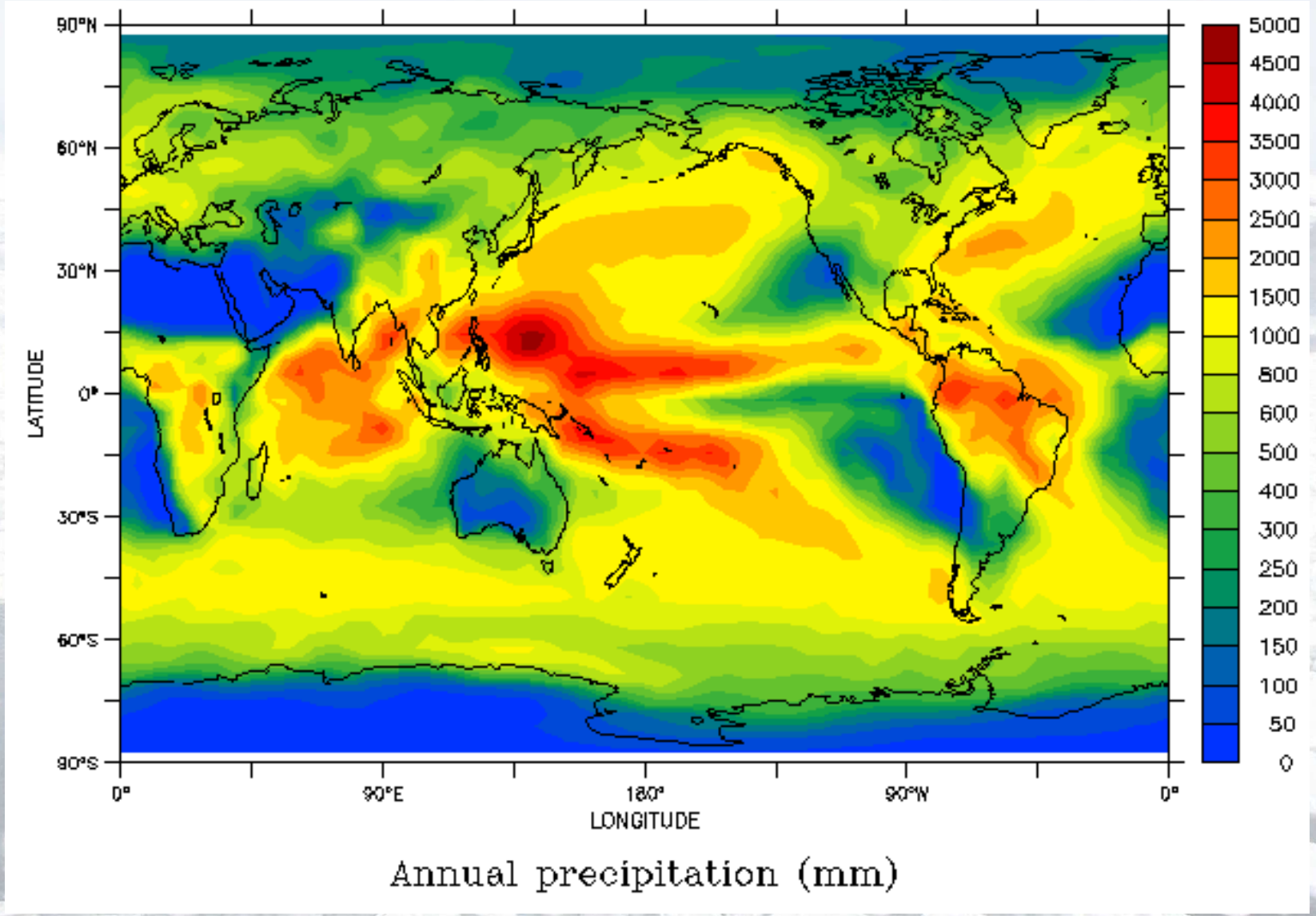
What can it do?

The simulated "present-day" climate

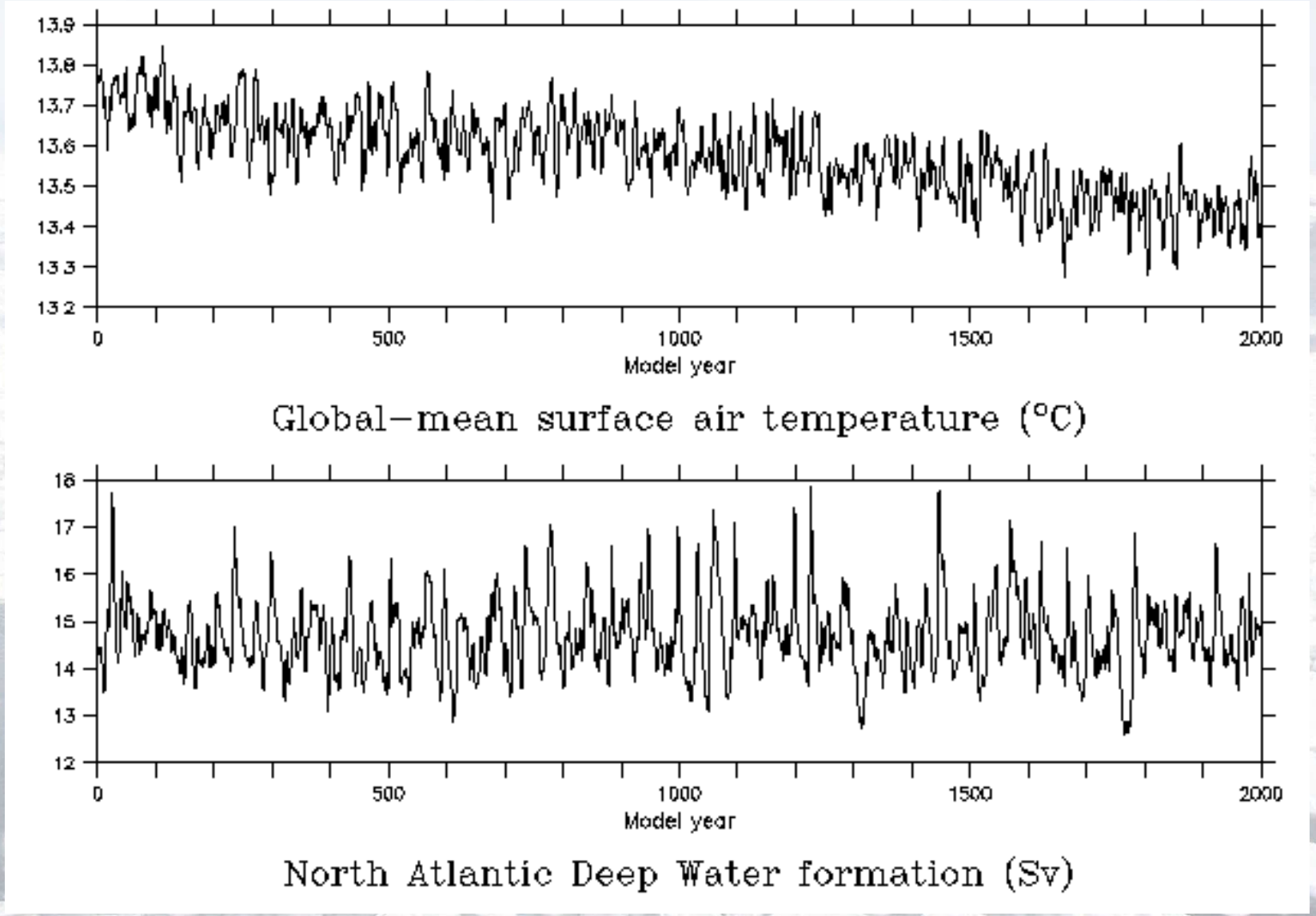
- Control simulation follows PMIP2 experimental design:
  - CO_2 concentration = 280ppm
  - Solar constant = 1365 Wm^{-2}
  - "Modern" orbital parameters (AD 1950)
- Ocean model initialised using Levitus 1998
- Atmosphere and ocean models spun up independently
- Coupled model initialised from final states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

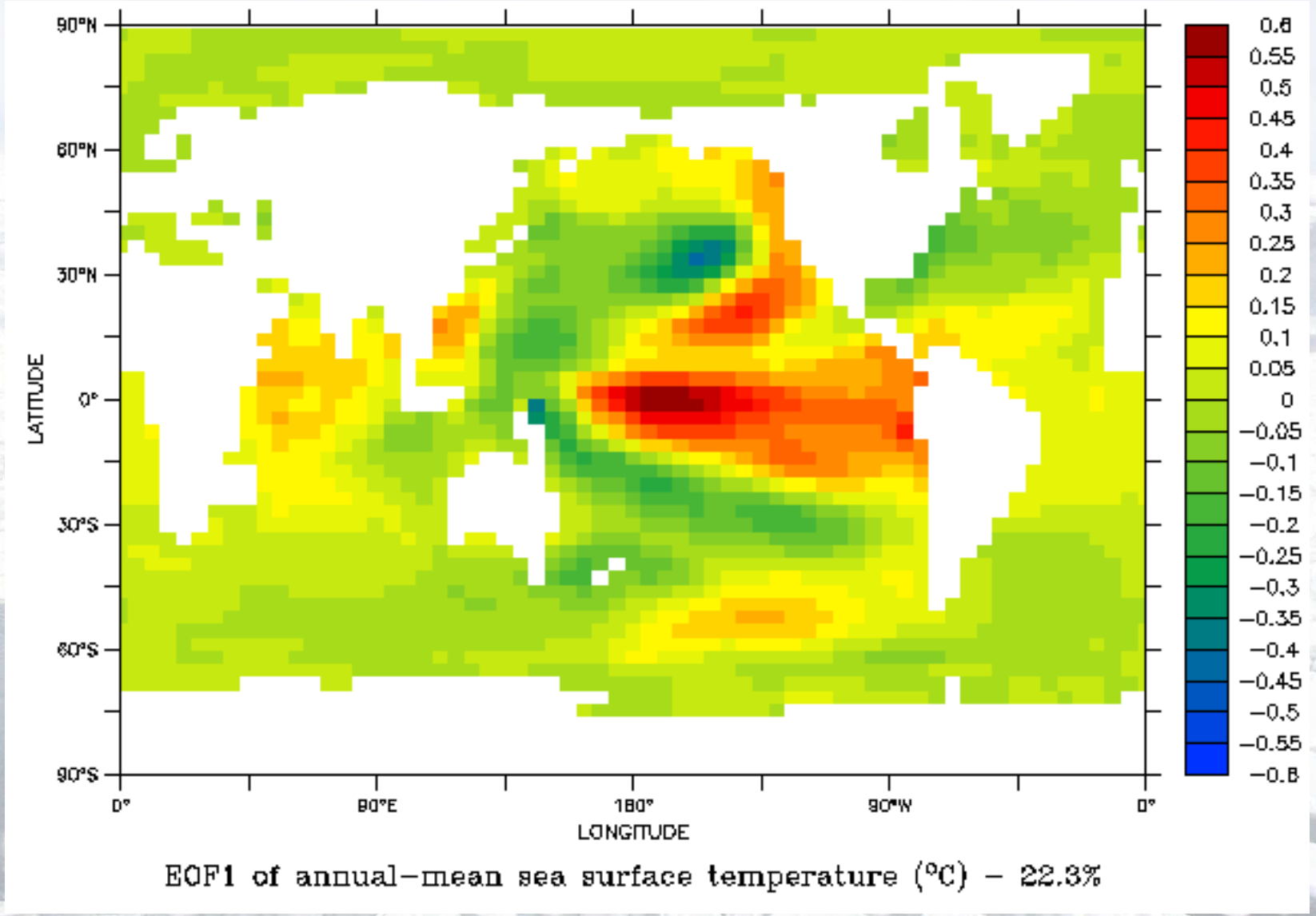


Annual–mean surface air temperature (°C)

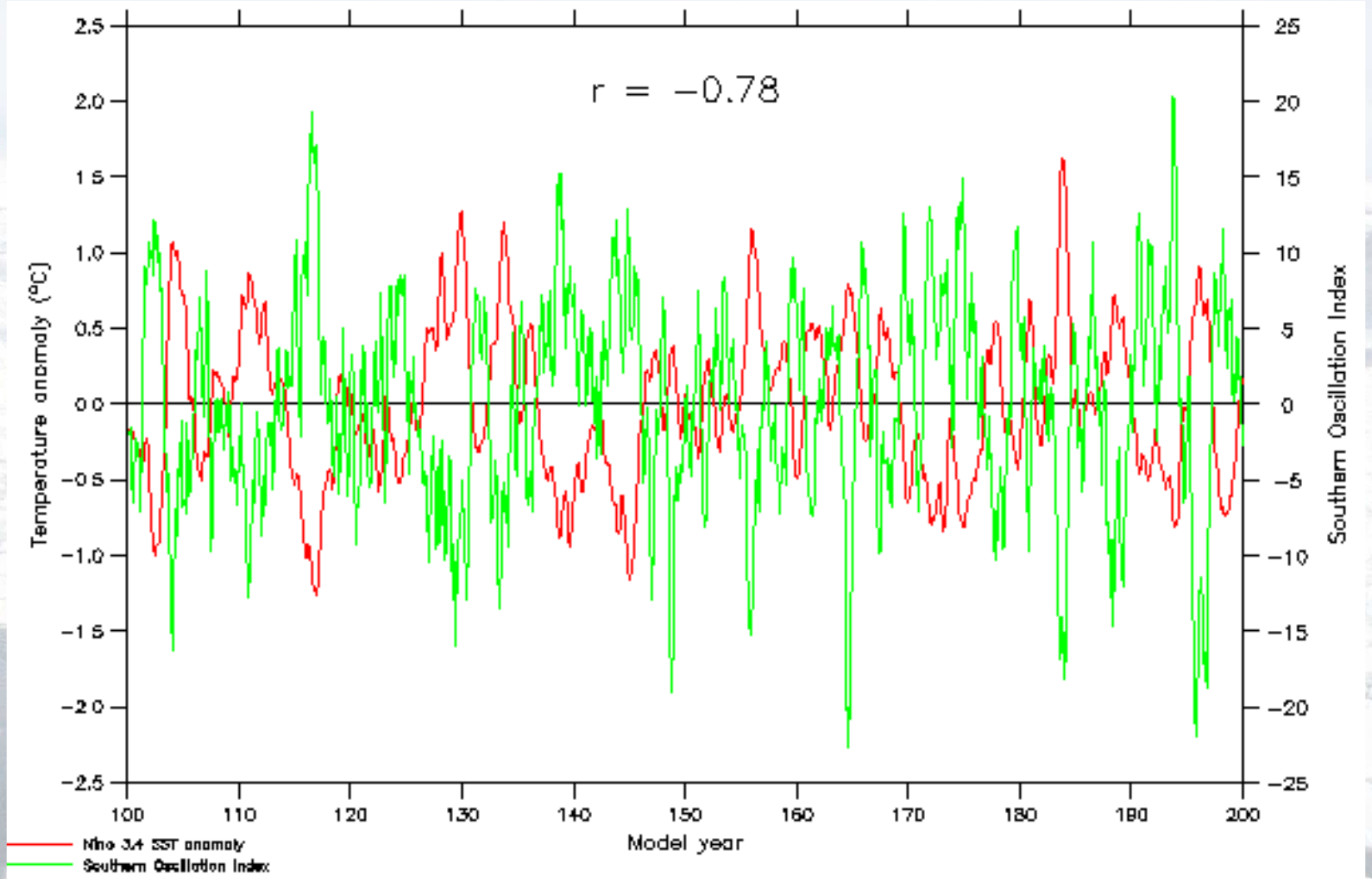


Annual precipitation (mm)


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

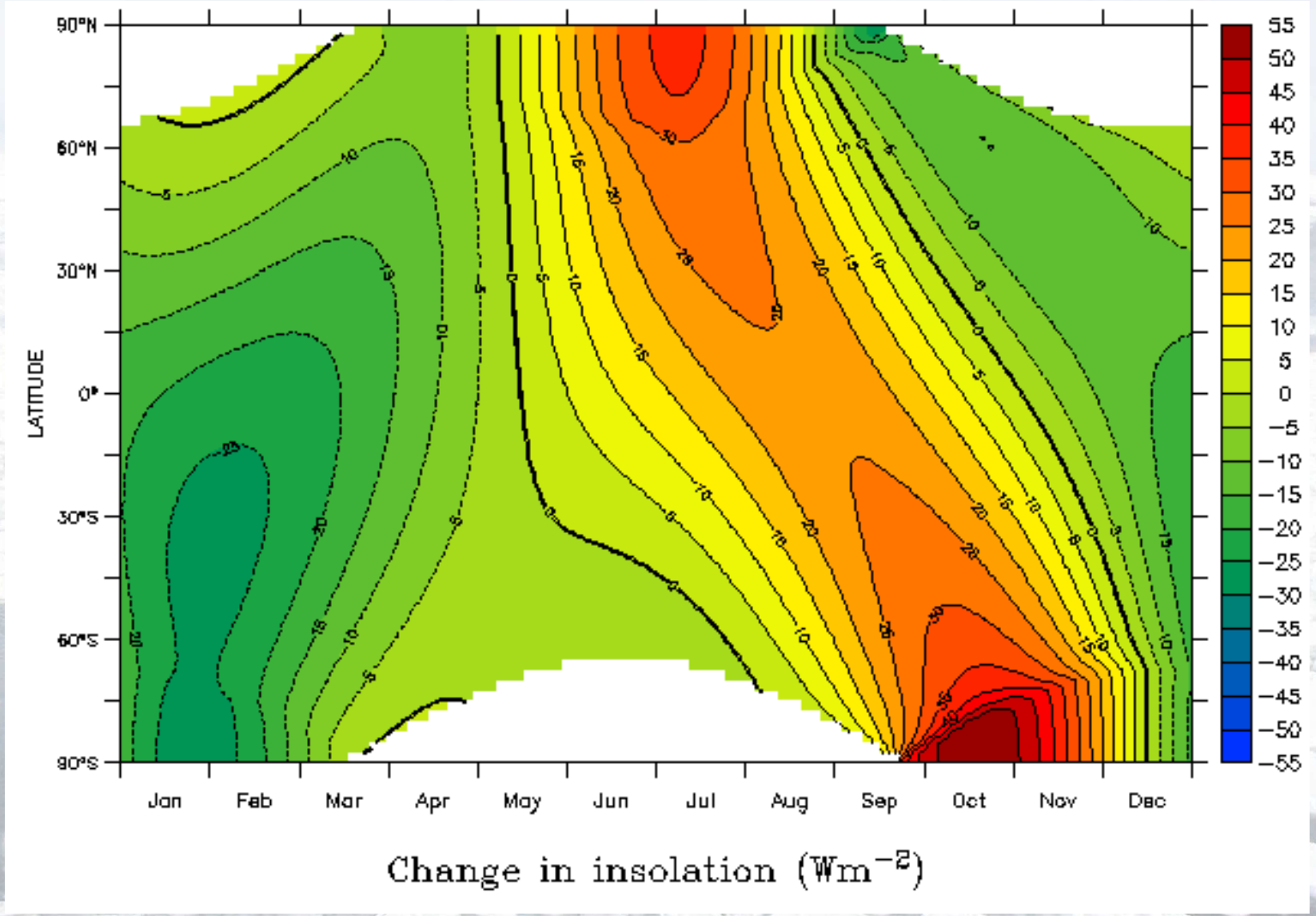
El Niño: model versus observed

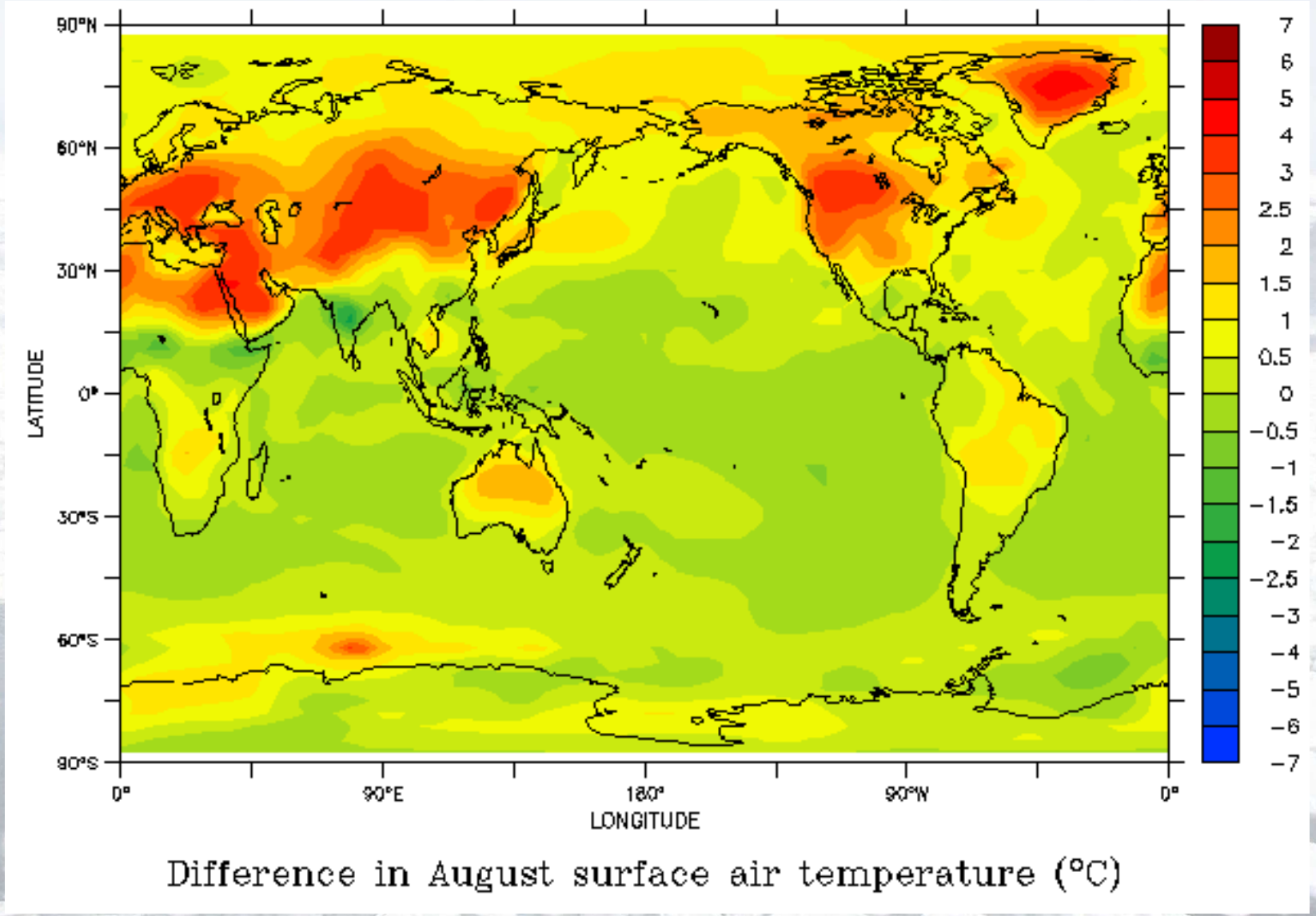
	Mk3L	Observed*
Standard deviation of Niño 3.4 SST anomaly (°C)	0.48	0.71
Average period (years)	7.8 ± 0.5	∼3–6
Average duration (months)	17.2 ± 0.6	∼12

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

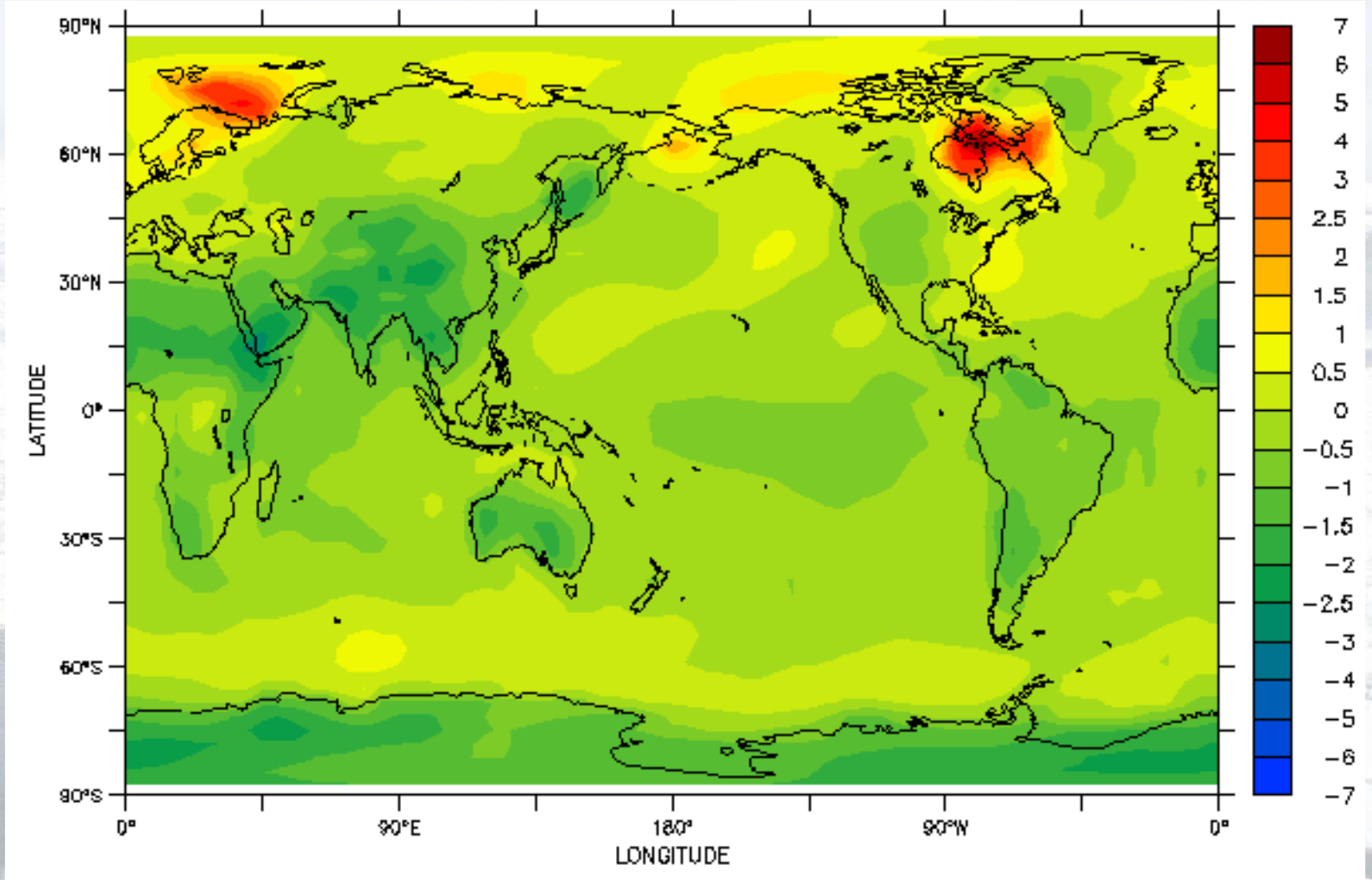
The climate of the mid-Holocene

- 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

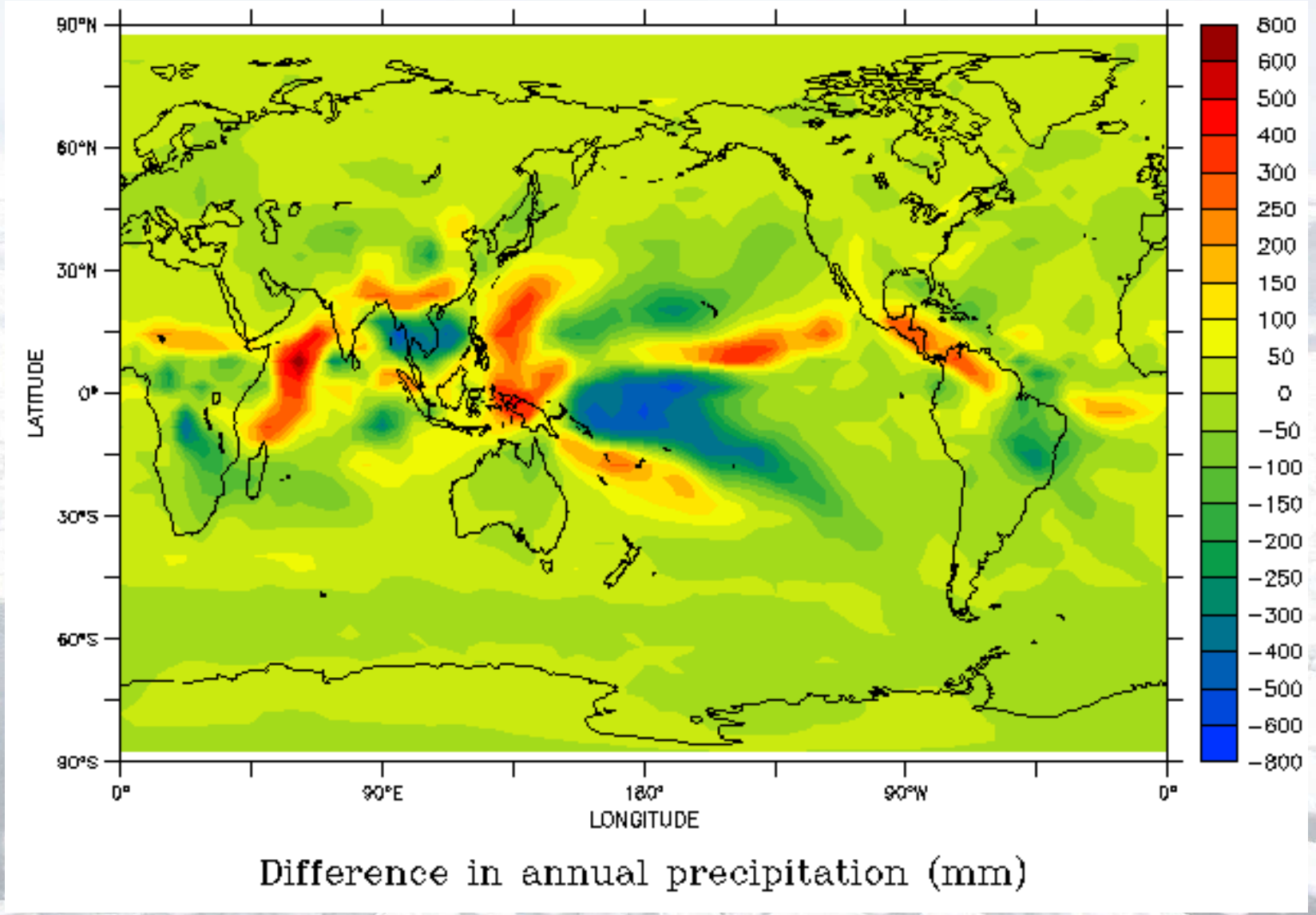

90°N
60°N
30°N
0°
30°S
60°S
90°S
LATITUDE
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
55
50
45
40
35
30
25
20
15
10
5
0
−5
−10
−15
−20
−25
−30
−35
−40
−45
−50
−55
Change in insolation (Wm^{-2})



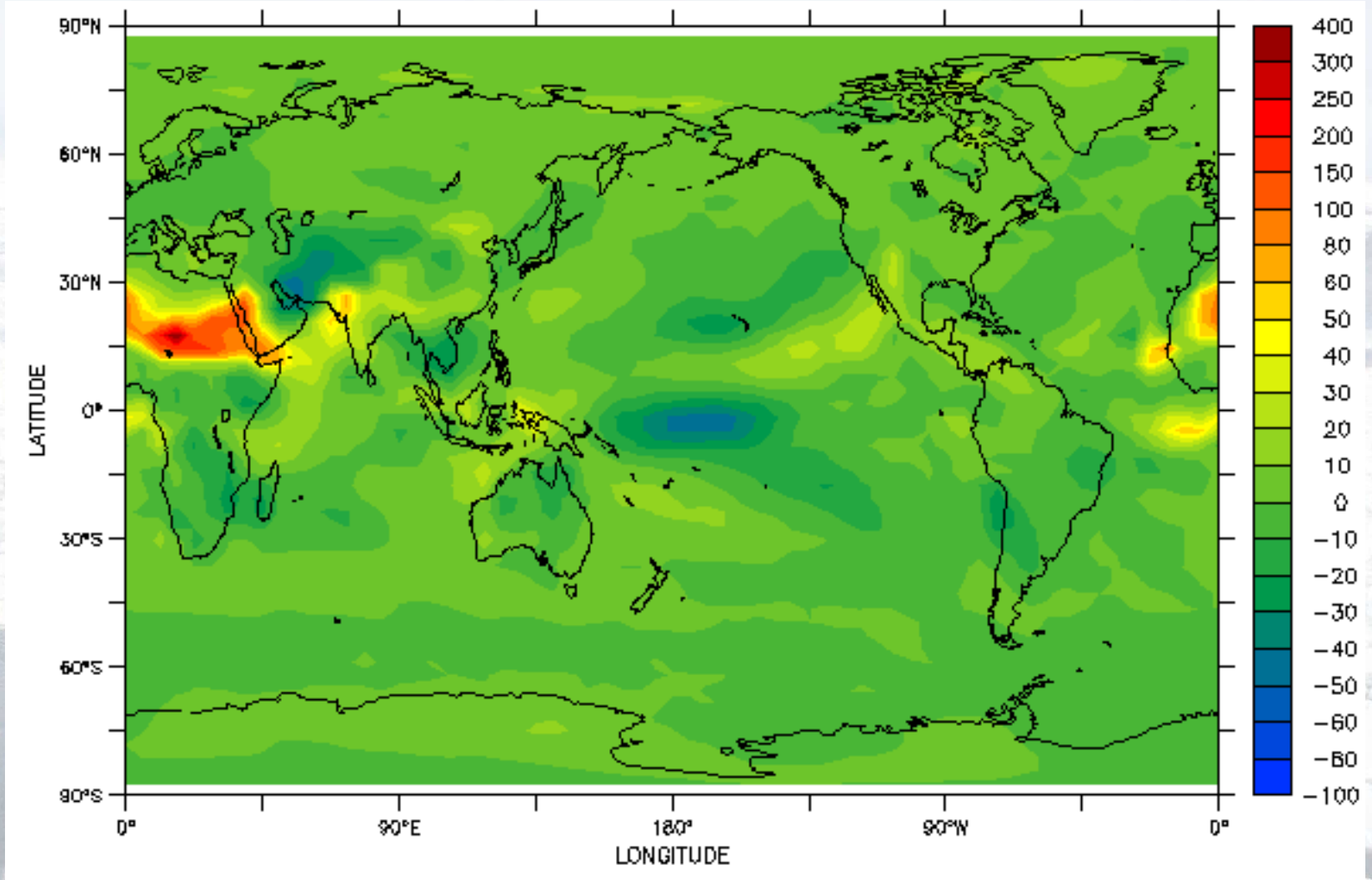
Difference in August surface air temperature (°C)



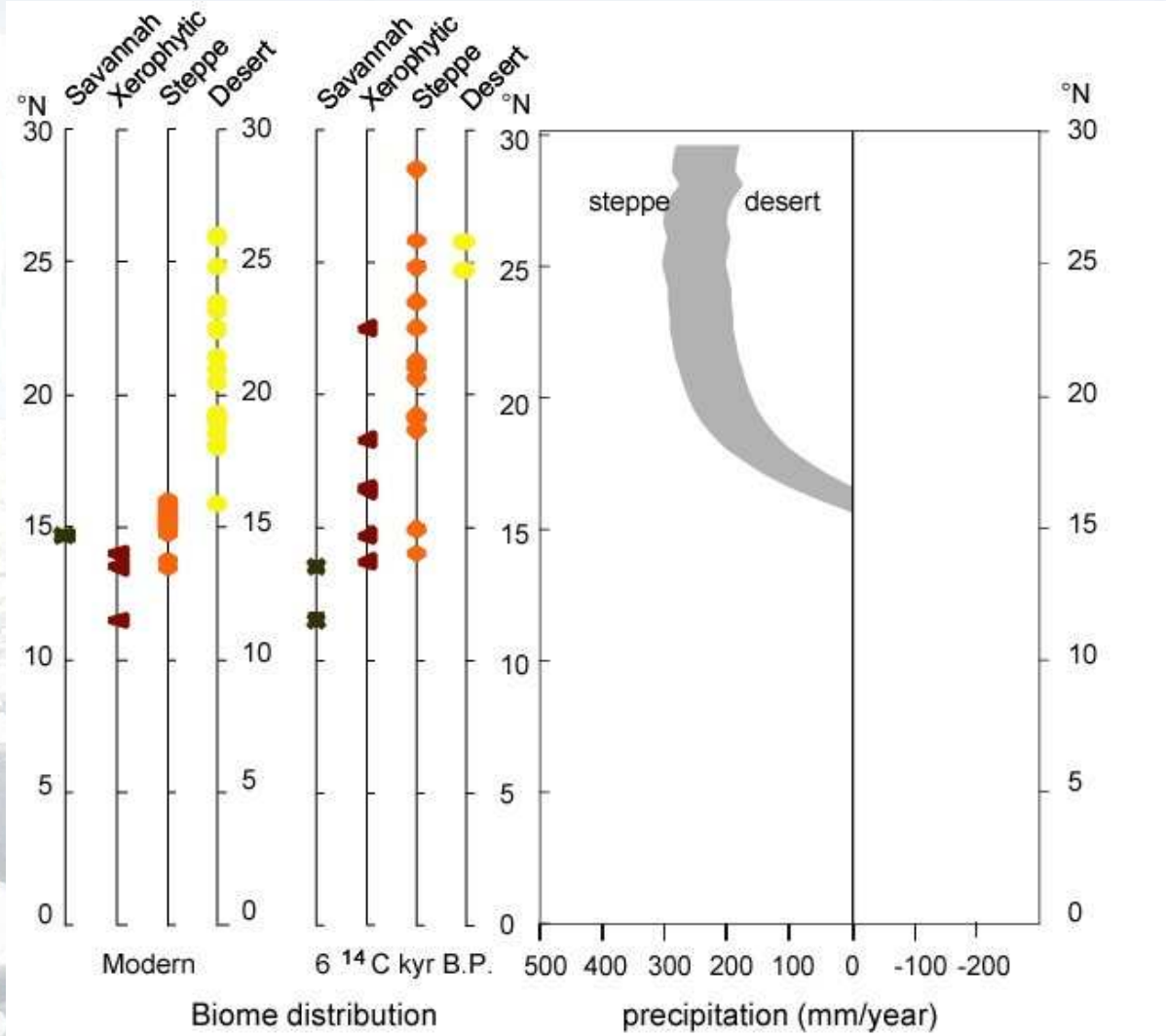
Difference in February surface air temperature (°C)



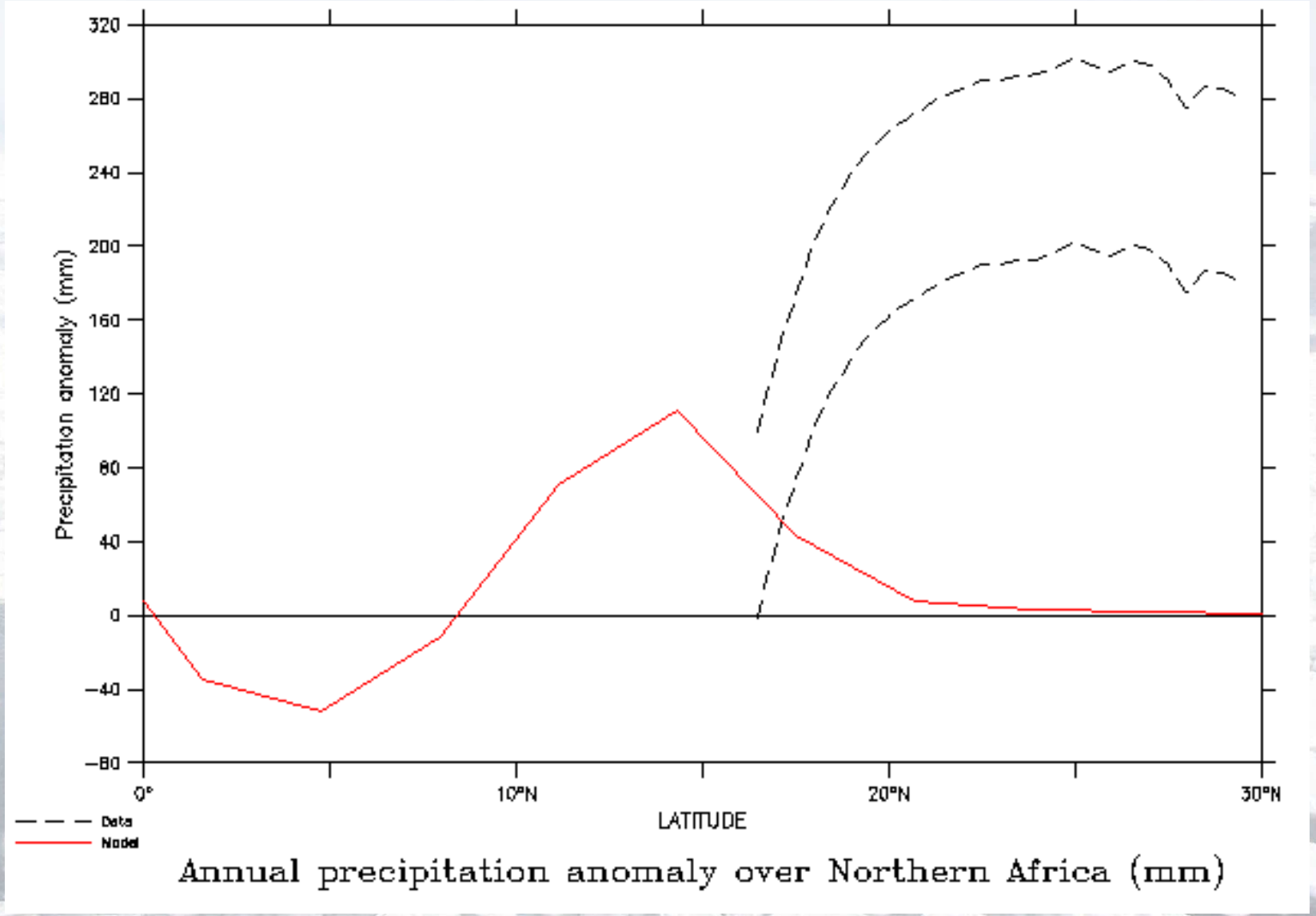
Difference in annual precipitation (mm)



Difference in annual precipitation (%)



Reconstructed precipitation anomaly over Northern Africa



Annual precipitation anomaly over Northern Africa (mm)

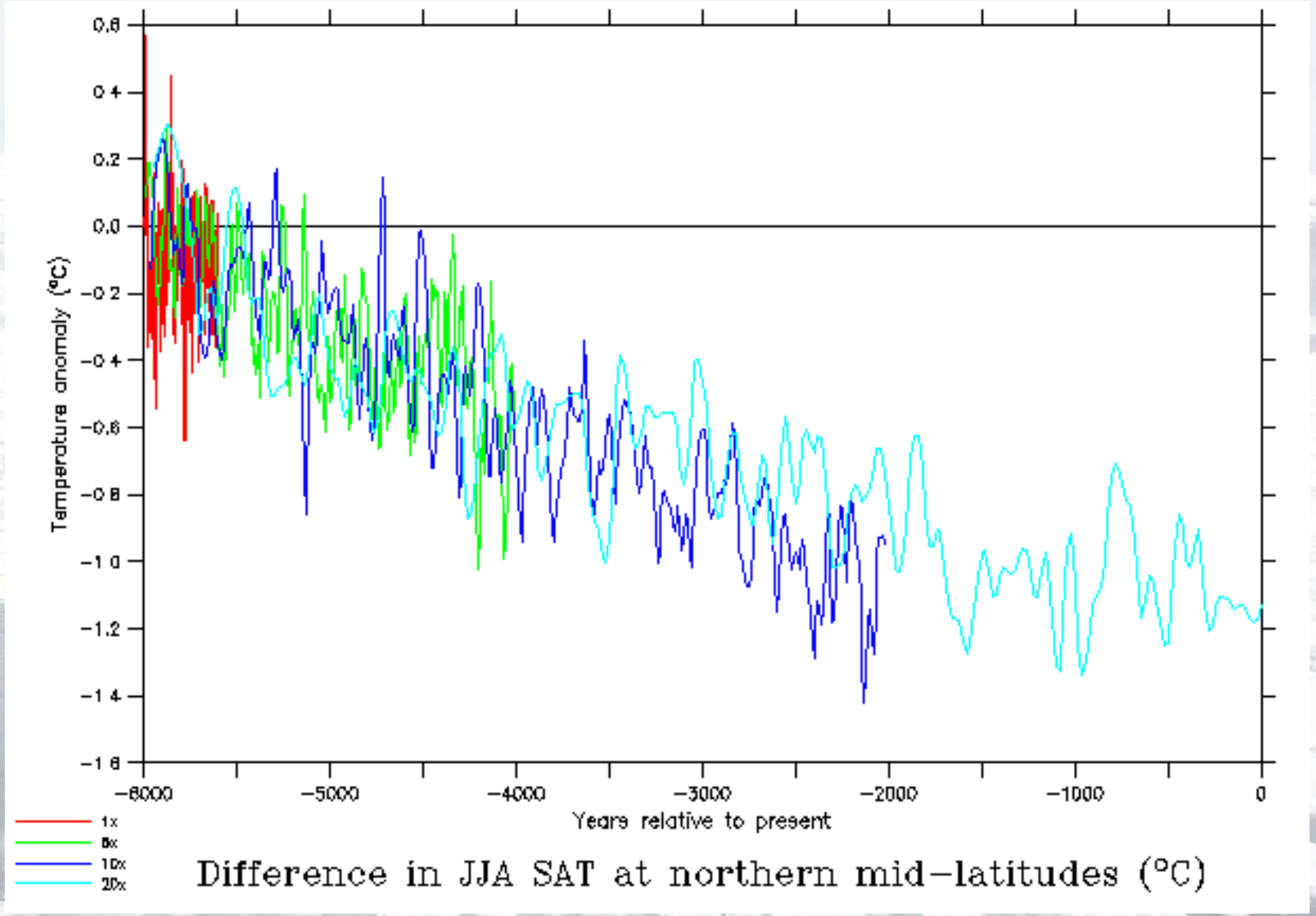
El Niño: control versus 6ka BP

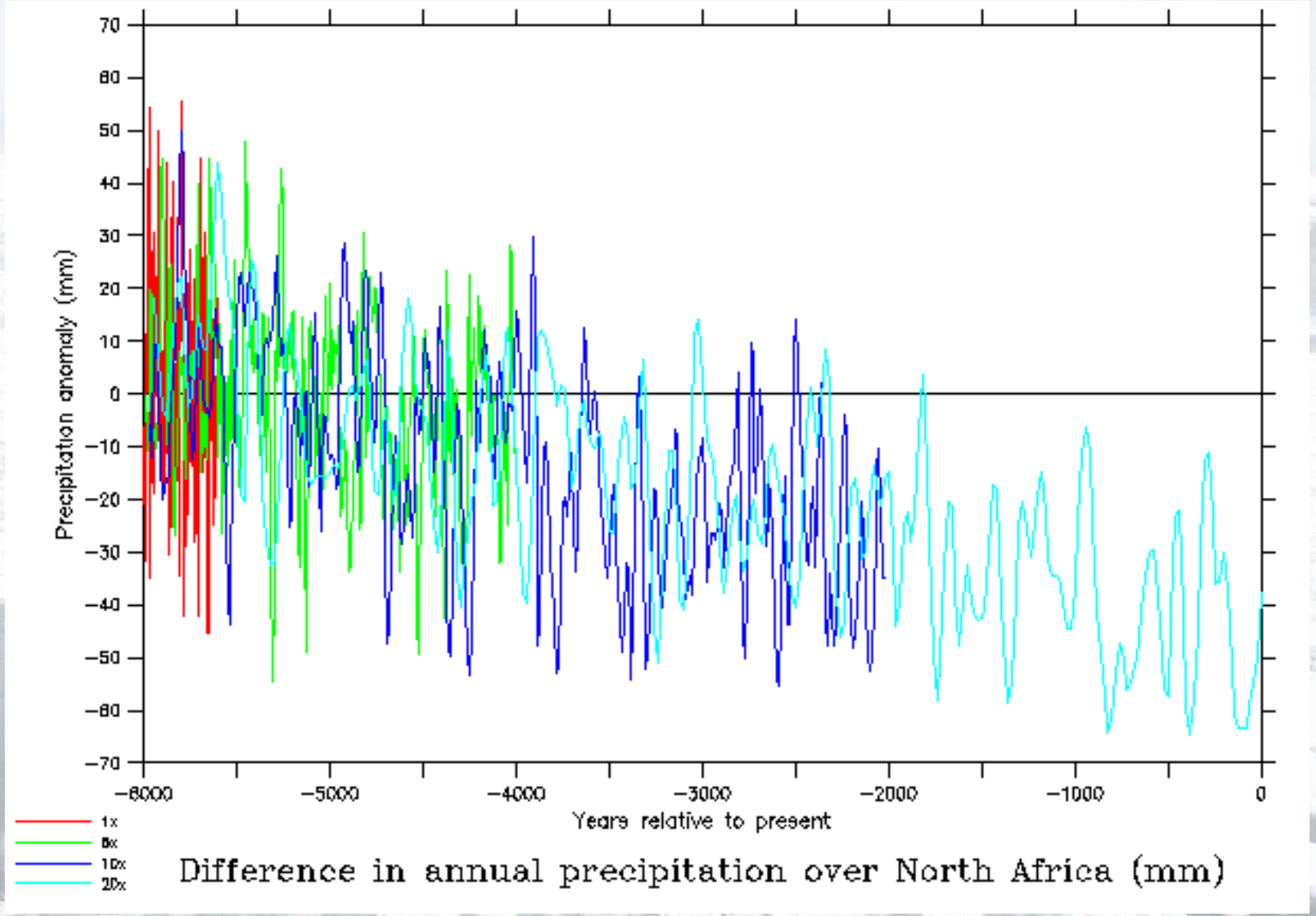
	Control	**6ka BP**
Standard deviation of Niño 3.4 SST anomaly (°C)	0.48	0.42
Period (years)	7.8 ± 0.5	8.8 ± 0.9
Duration (months)	17.2 ± 0.6	16.6 ± 1.0

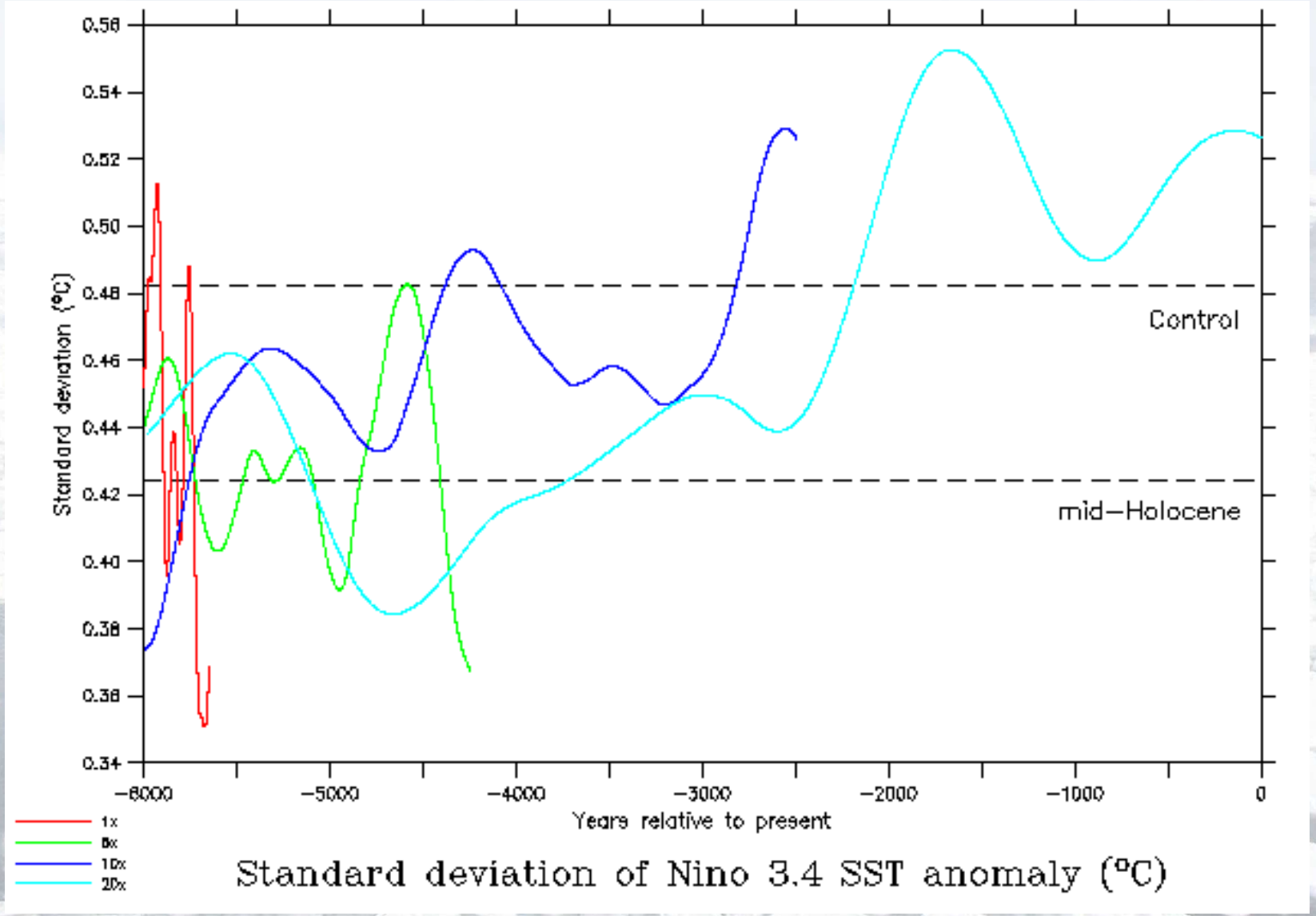
The climate of the late Holocene

- 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.

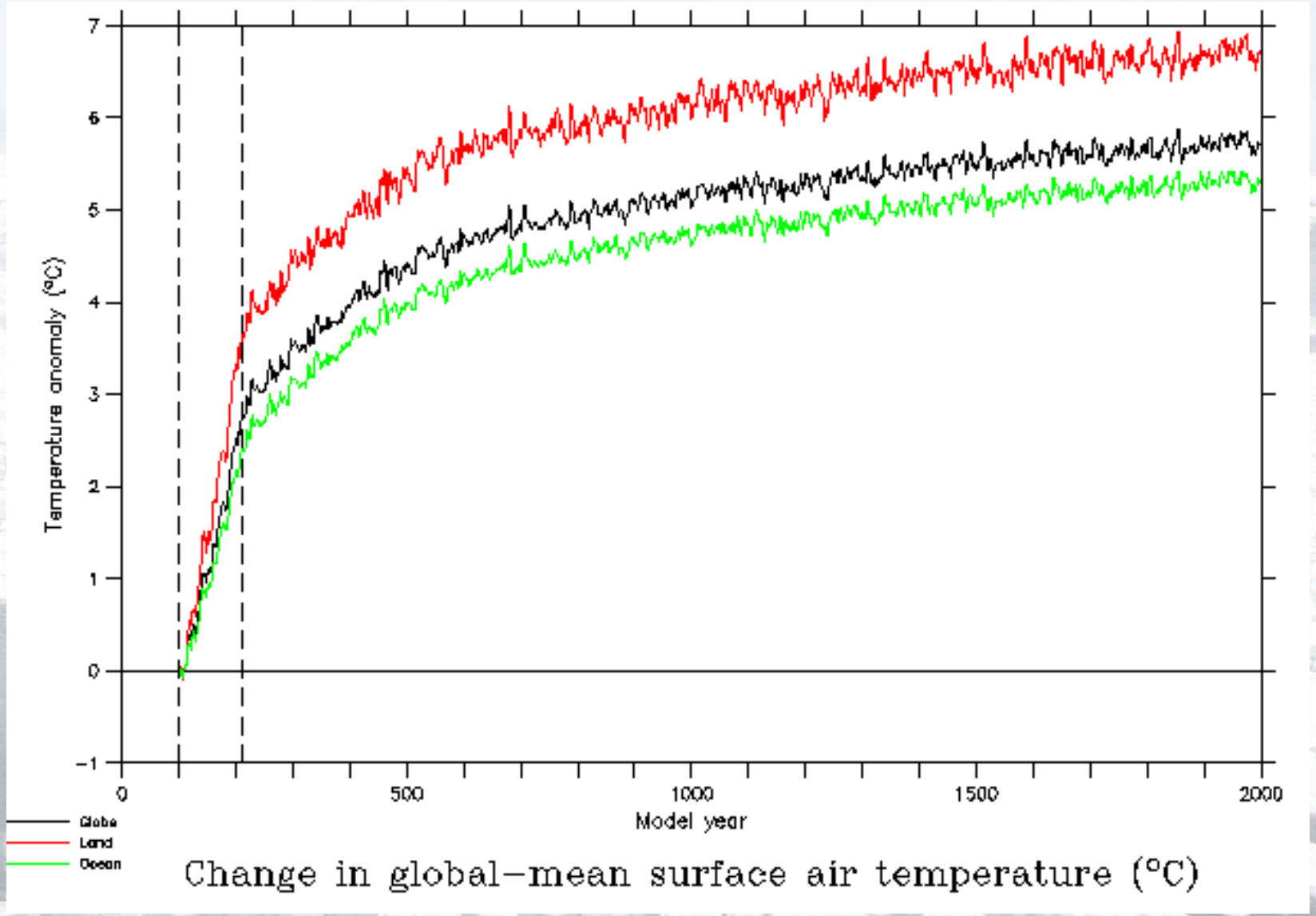

0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
Temperature anomaly (°C)
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
2x
10x
20x
Difference in JJA SAT at northern mid−latitudes (°C)


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
6x
10x
20x
Difference in annual precipitation over North Africa (mm)

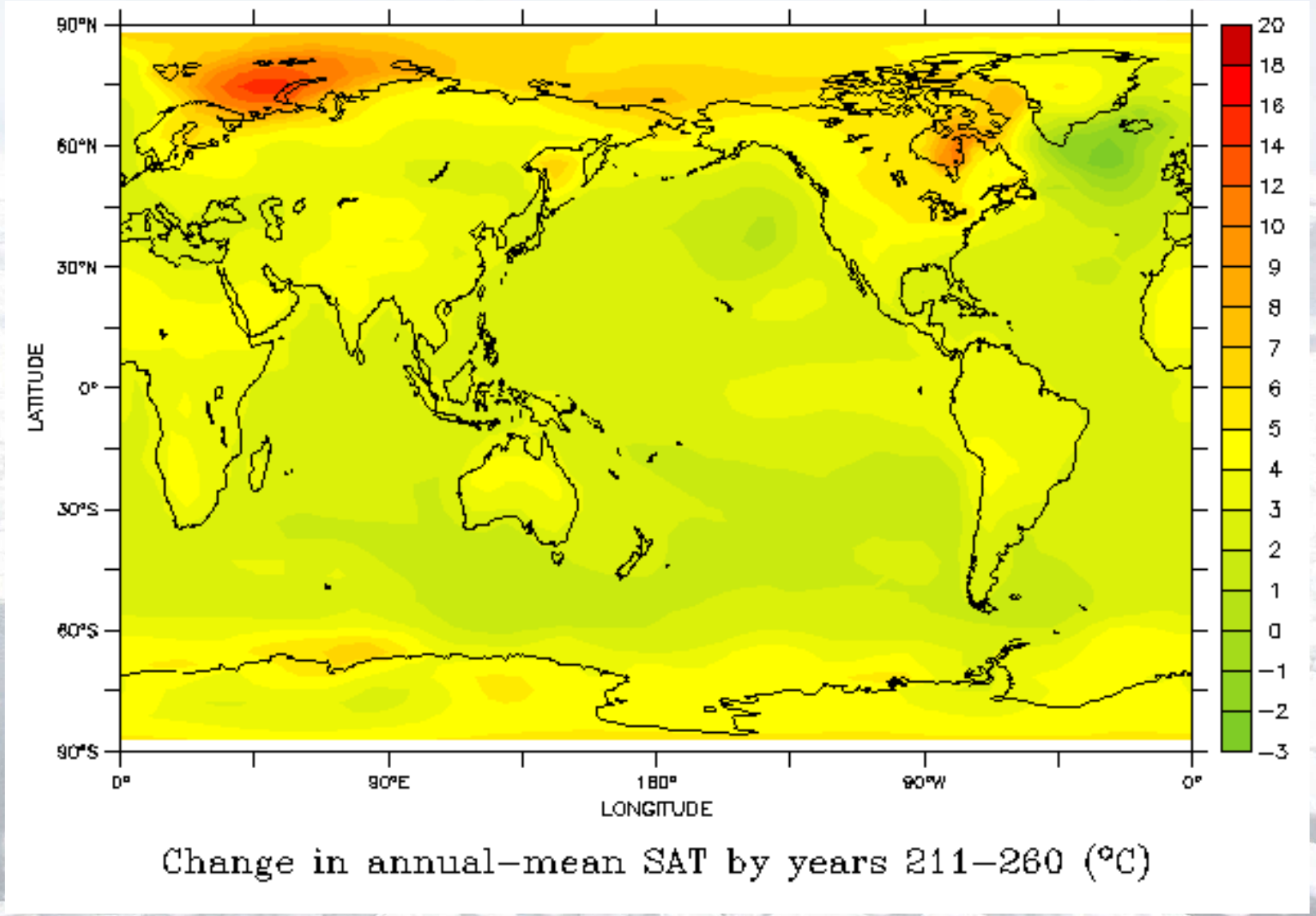

0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
Standard deviation (°C)
Control
mid−Holocene
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
2x
10x
20x
Standard deviation of Nino 3.4 SST anomaly (°C)

Future climate

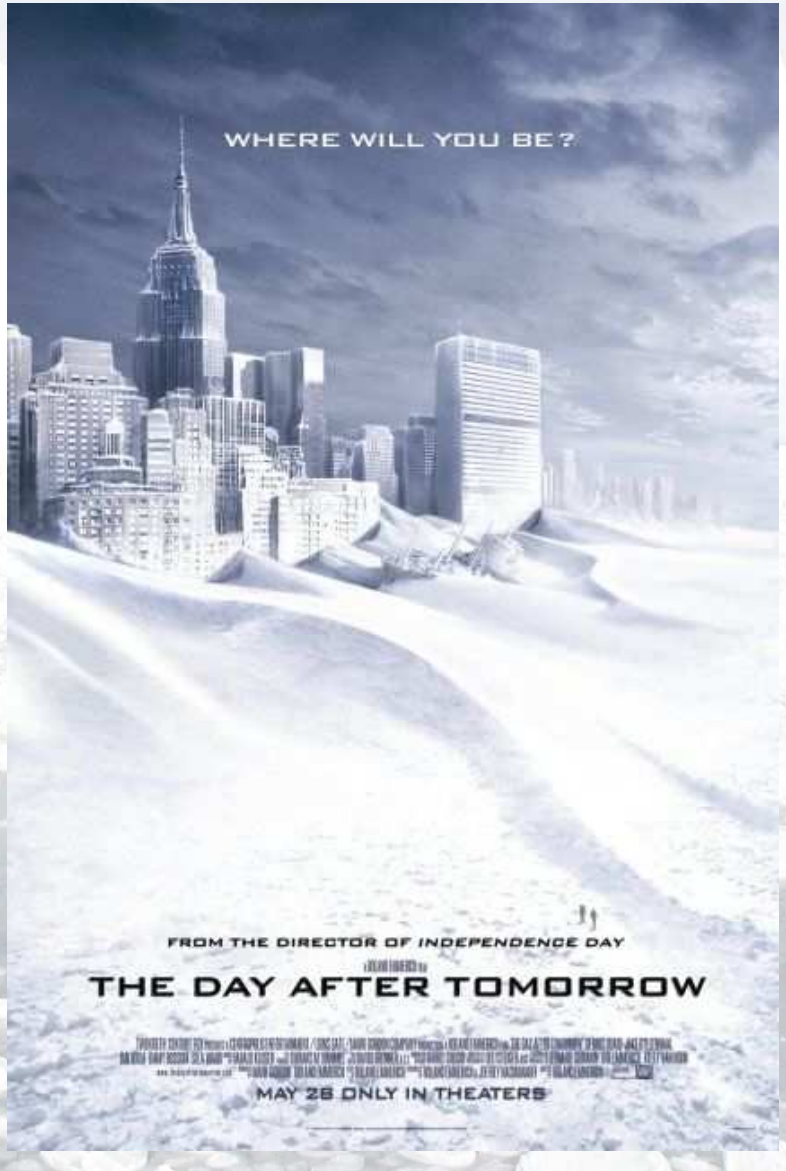
- Transient simulation in which the CO_2 concentration is stabilised at three times the pre-industrial value
- Initialised from year 100 of control run
- Atmospheric CO_2 concentration increased at 1% p.a.
- Reaches 840ppm in year 211, and held constant thereafter
- Other boundary conditions unchanged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

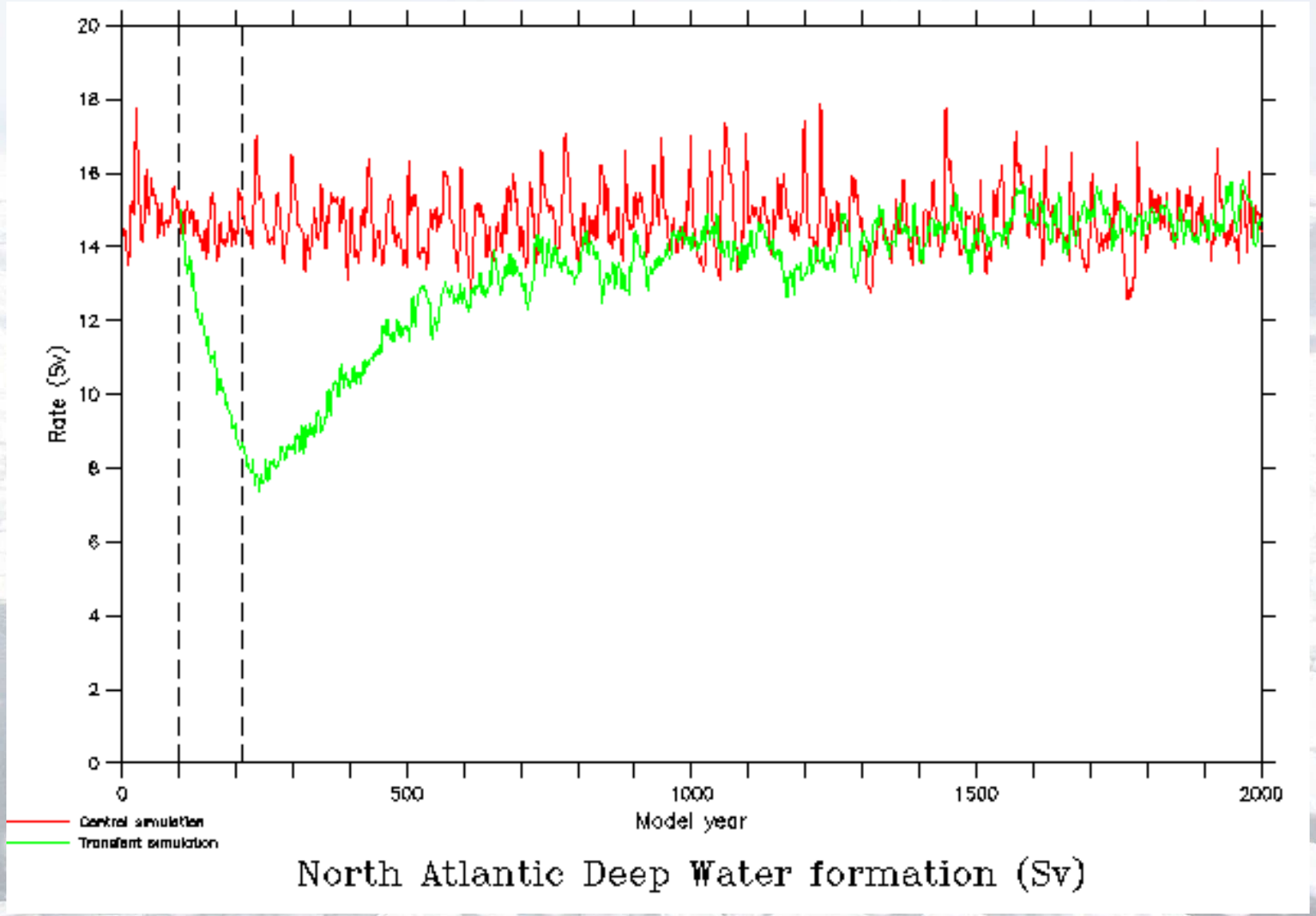


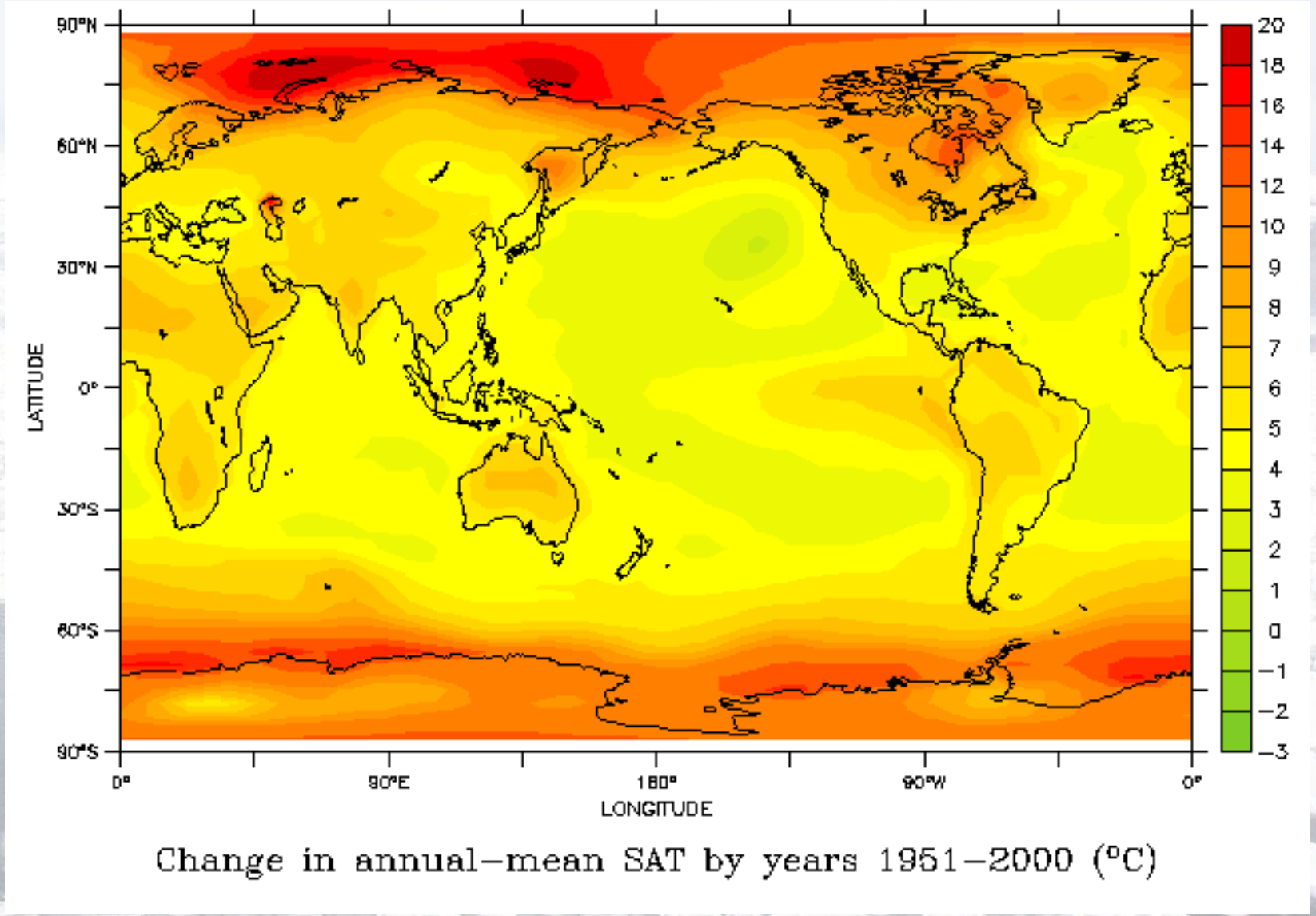
Change in global–mean surface air temperature (°C)



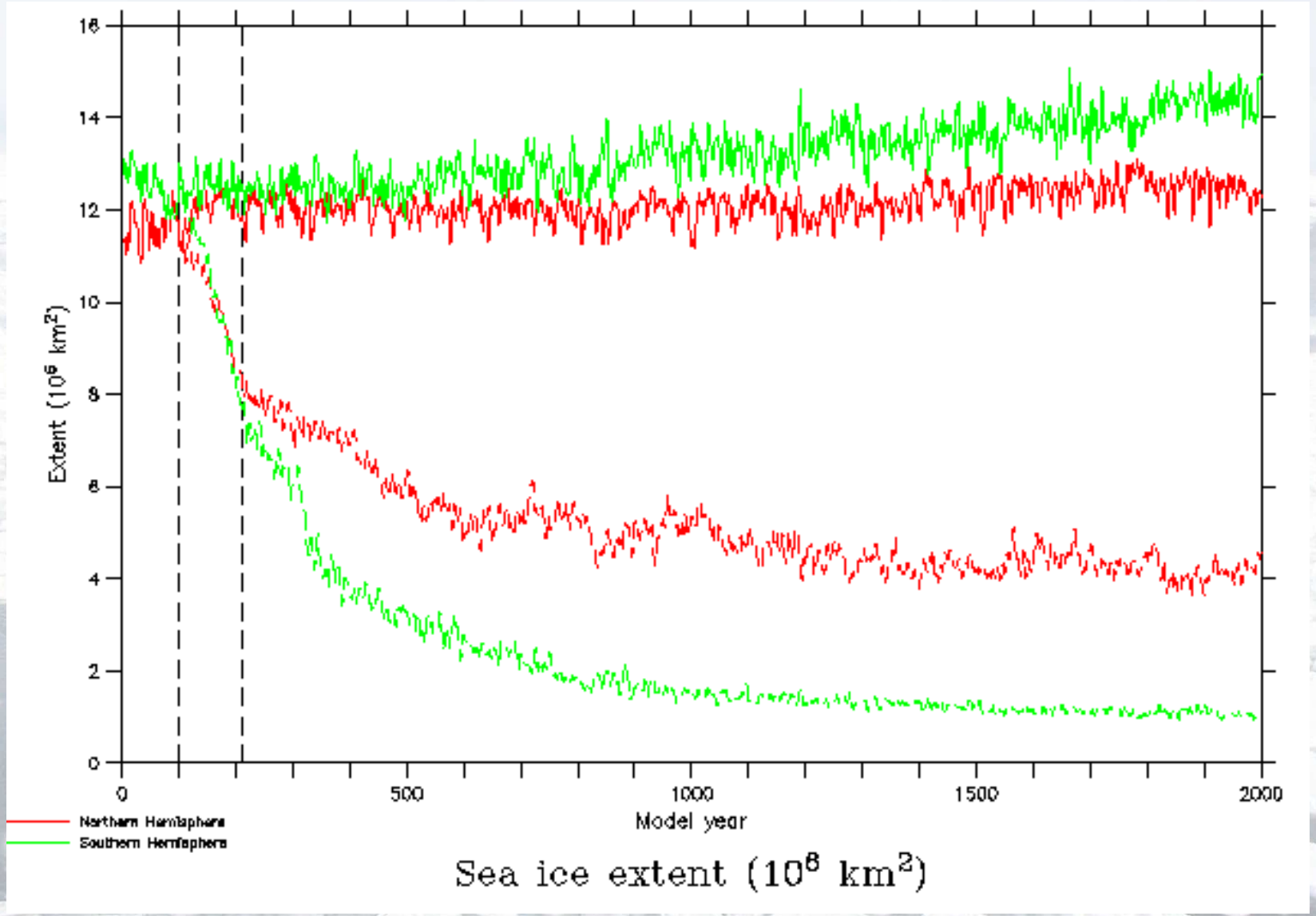
Change in annual–mean SAT by years 211–260 (°C)

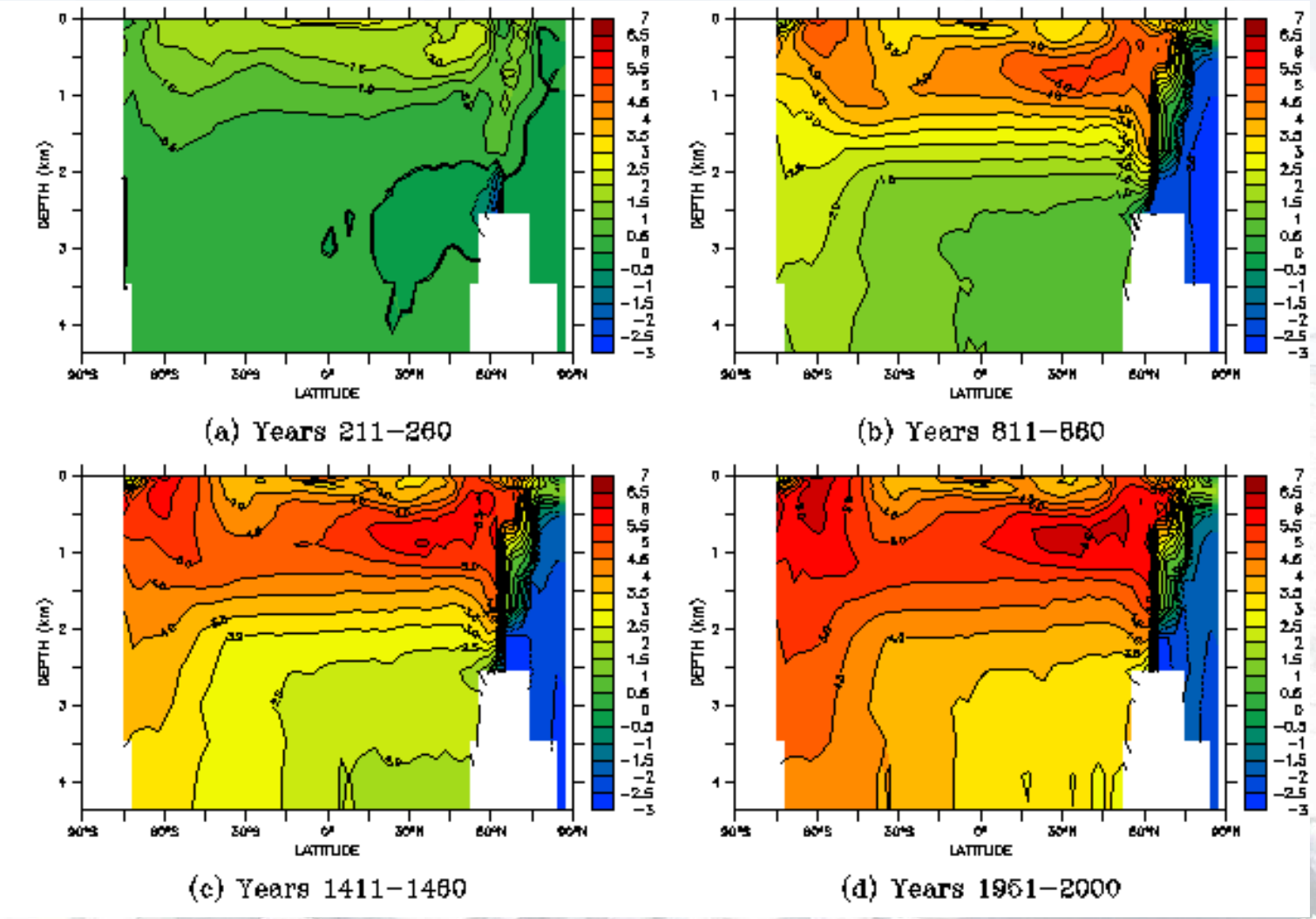

WHERE WILL YOU BE?
FROM THE DIRECTOR OF INDEPENDENCE DAY
THE DAY AFTER TOMORROW
MAY 28 ONLY IN THEATERS


20
18
16
14
12
10
8
6
4
2
0
Rate (Sv)
0
500
1000
1500
2000
Model year
Control simulation
Transient simulation
North Atlantic Deep Water formation (Sv)

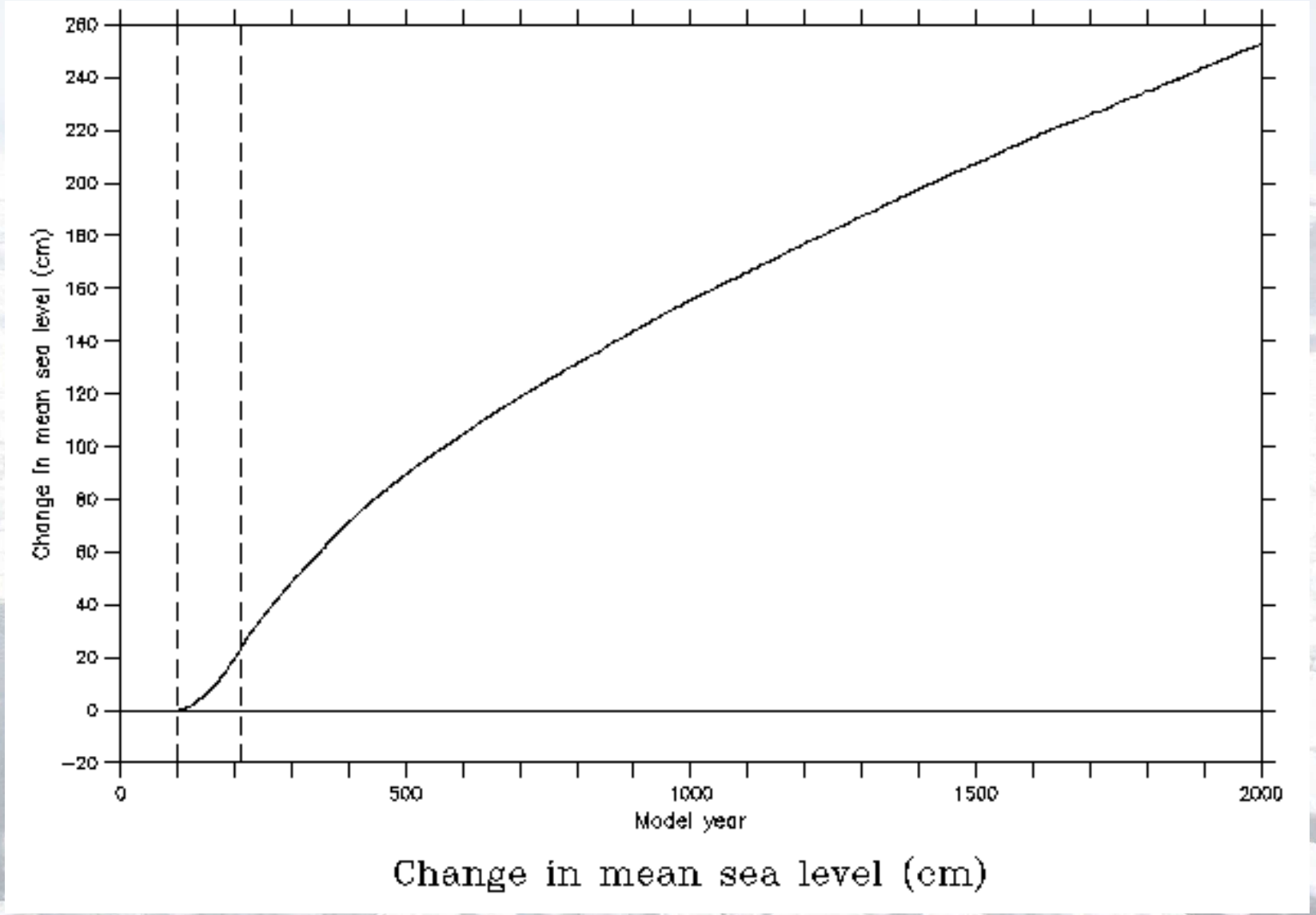


Change in annual−mean SAT by years 1951−2000 (°C)

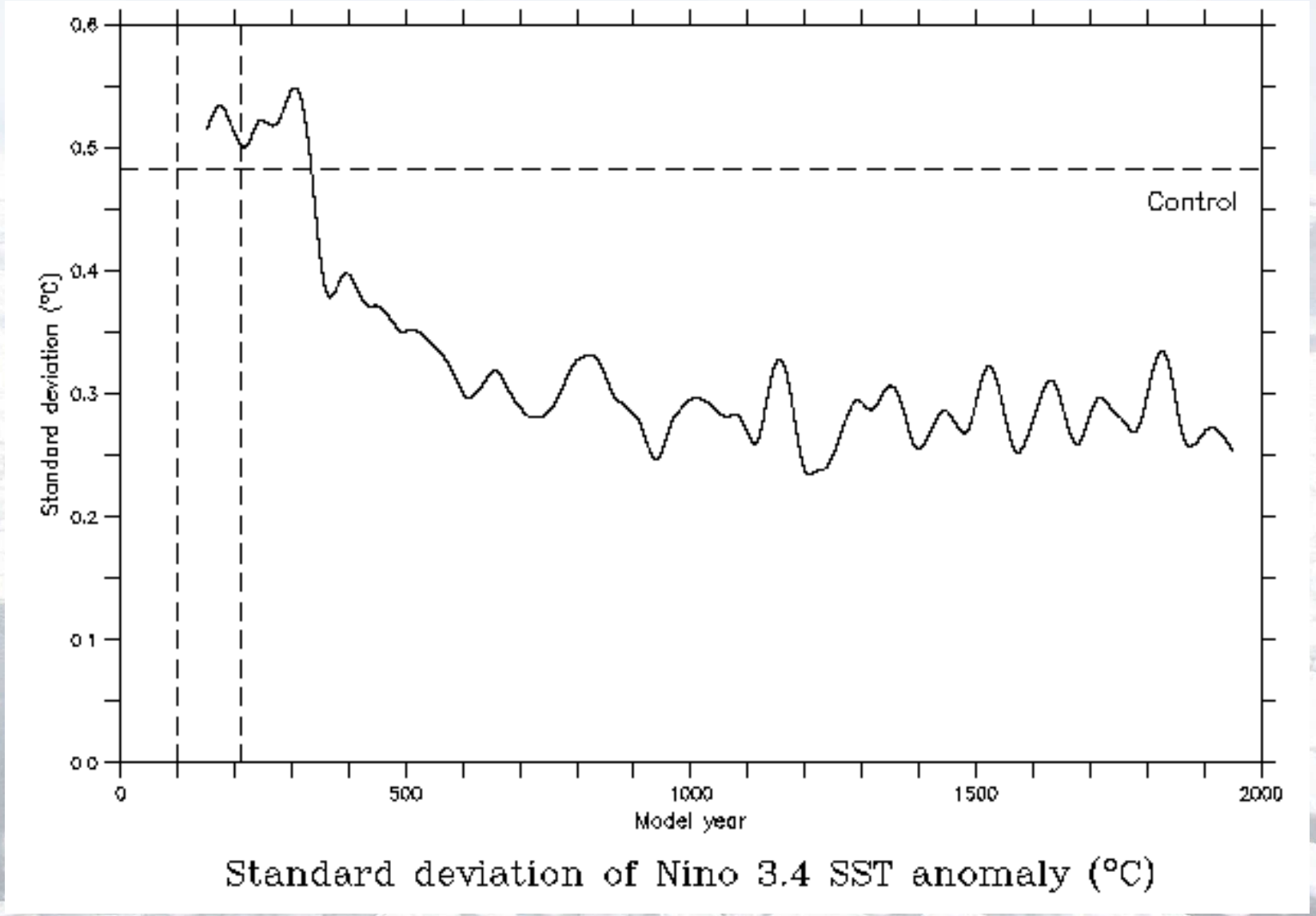

Extent (10^6 km^2)
Model year
Northern Hemisphere
Southern Hemisphere
Sea ice extent (10^6 km^2)



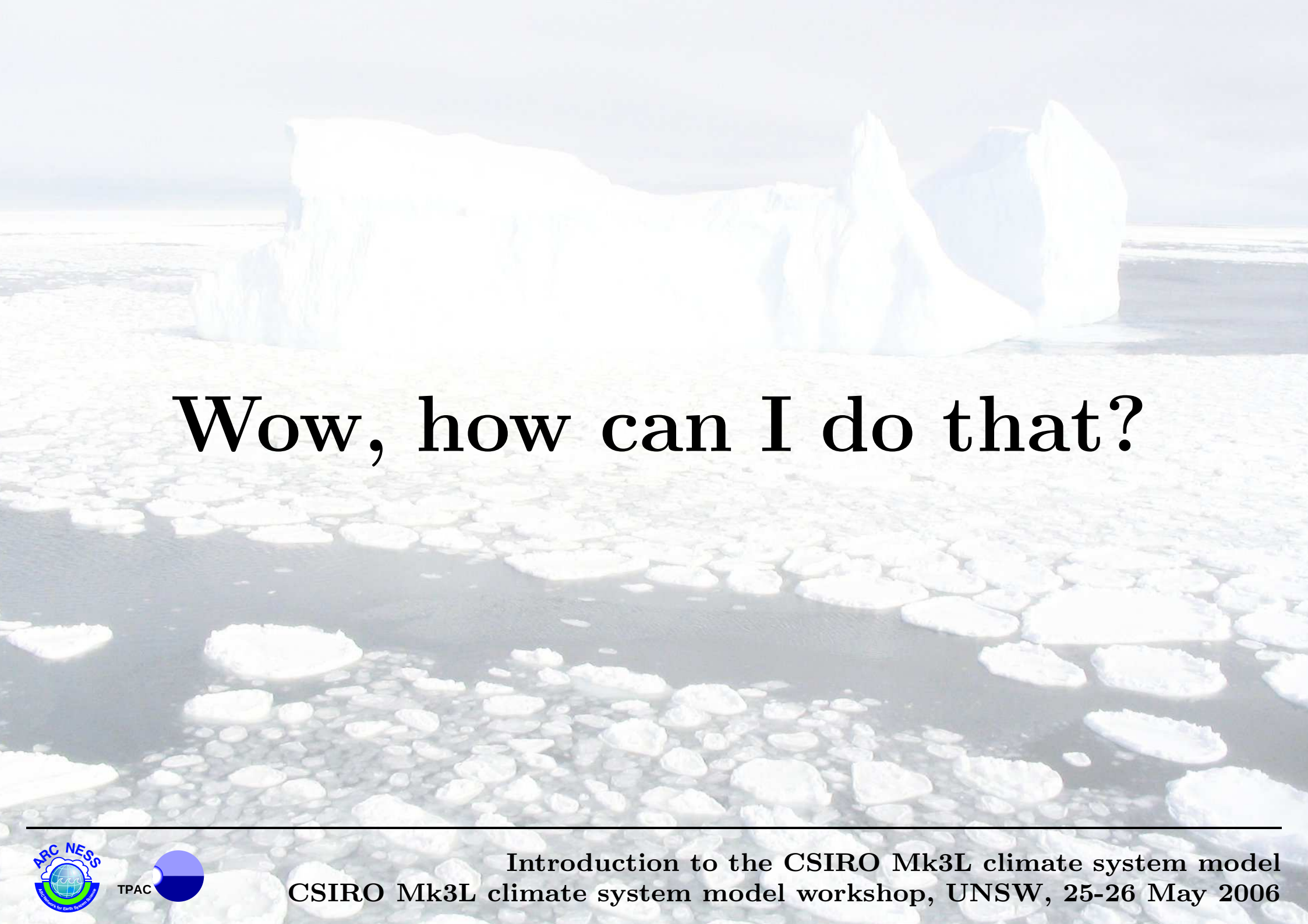
Change in zonal-mean ocean temperature (°C)



Change in mean sea level (cm)



Standard deviation of Nino 3.4 SST anomaly (°C)



Wow, how can I do that?