Multi-millennial simulations of the climate of the late Holocene

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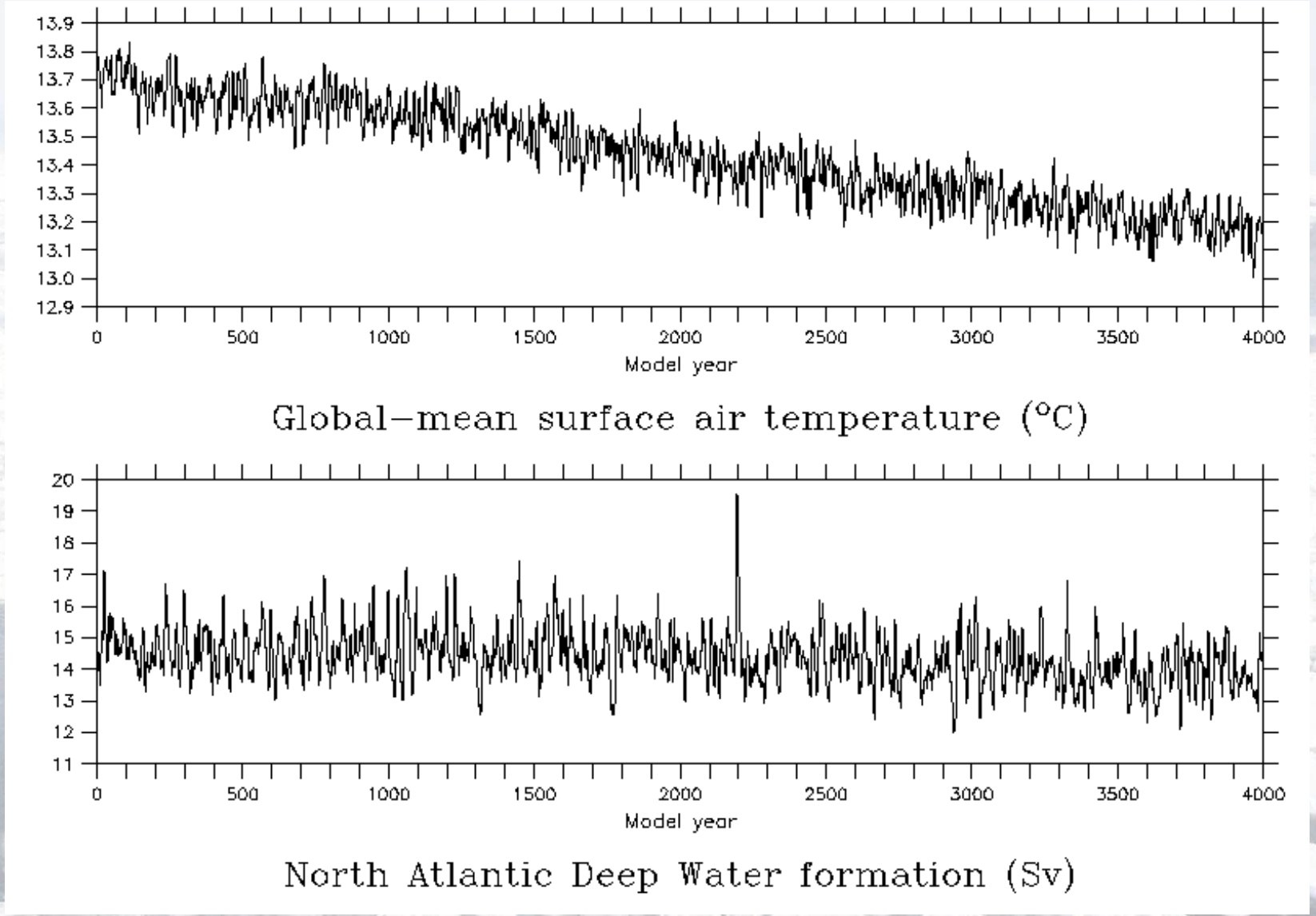
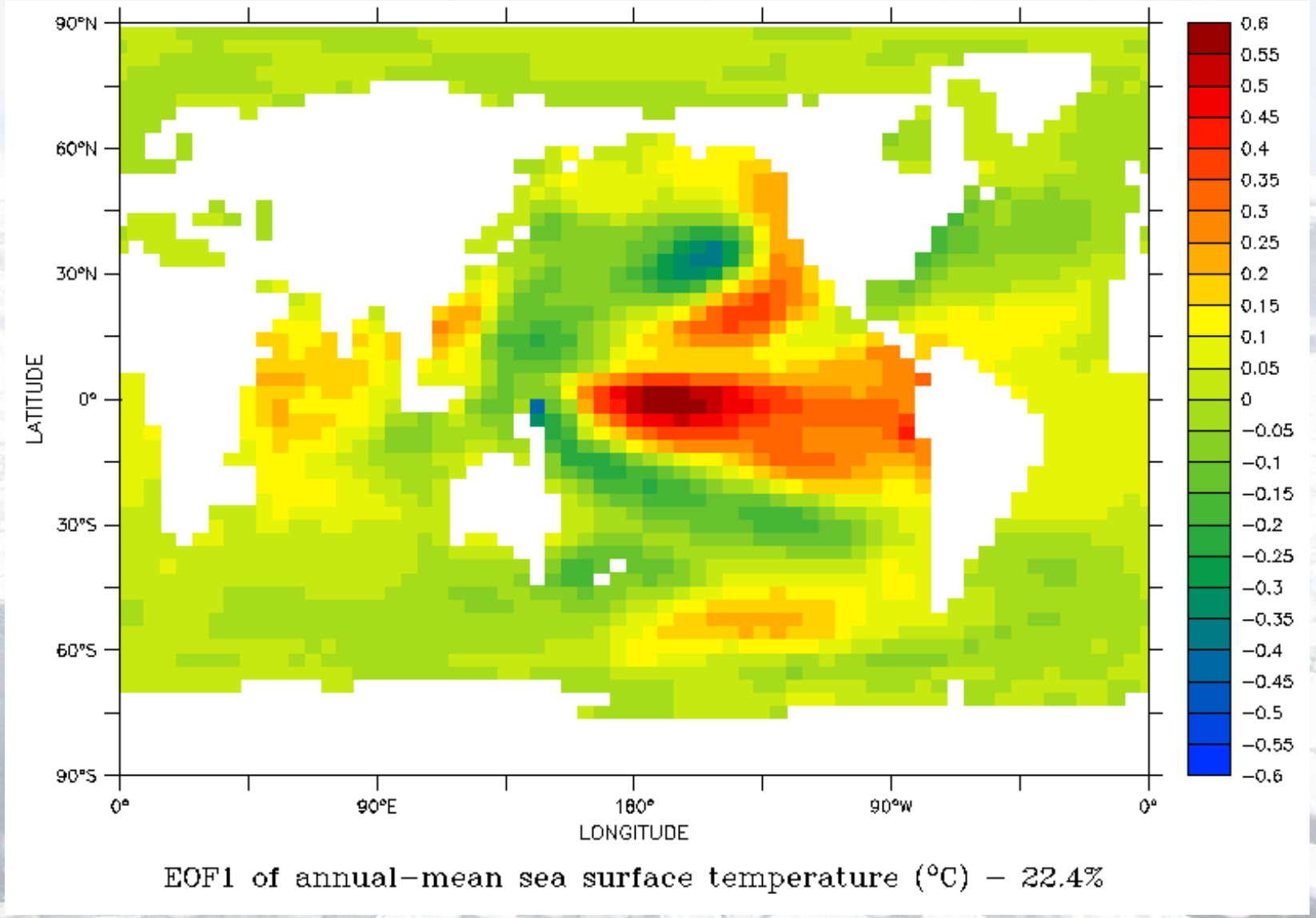
The CSIRO Mk3L climate system model

- 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$16 model years/day (4 $\times$ 1.6Ghz Itanium 2 processors)

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 4000 years


13.9
13.8
13.7
13.6
13.5
13.4
13.3
13.2
13.1
13.0
12.9
0
500
1000
1500
2000
2500
3000
3500
4000
Model year
Global−mean surface air temperature (°C)
20
19
18
17
16
15
14
13
12
11
0
500
1000
1500
2000
2500
3000
3500
4000
Model year
North Atlantic Deep Water formation (Sv)


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) − 22.4%

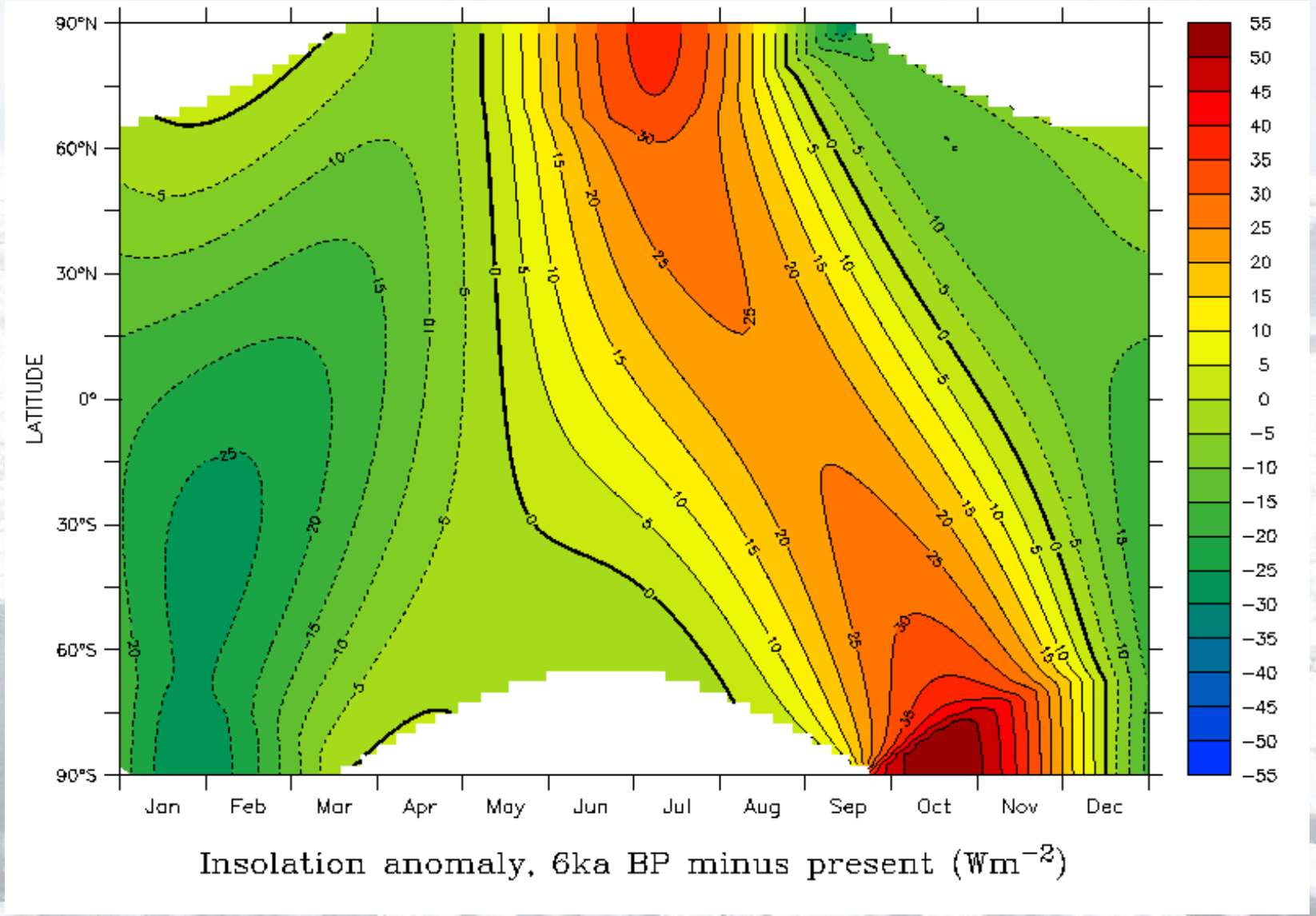
El Niño: model versus observed

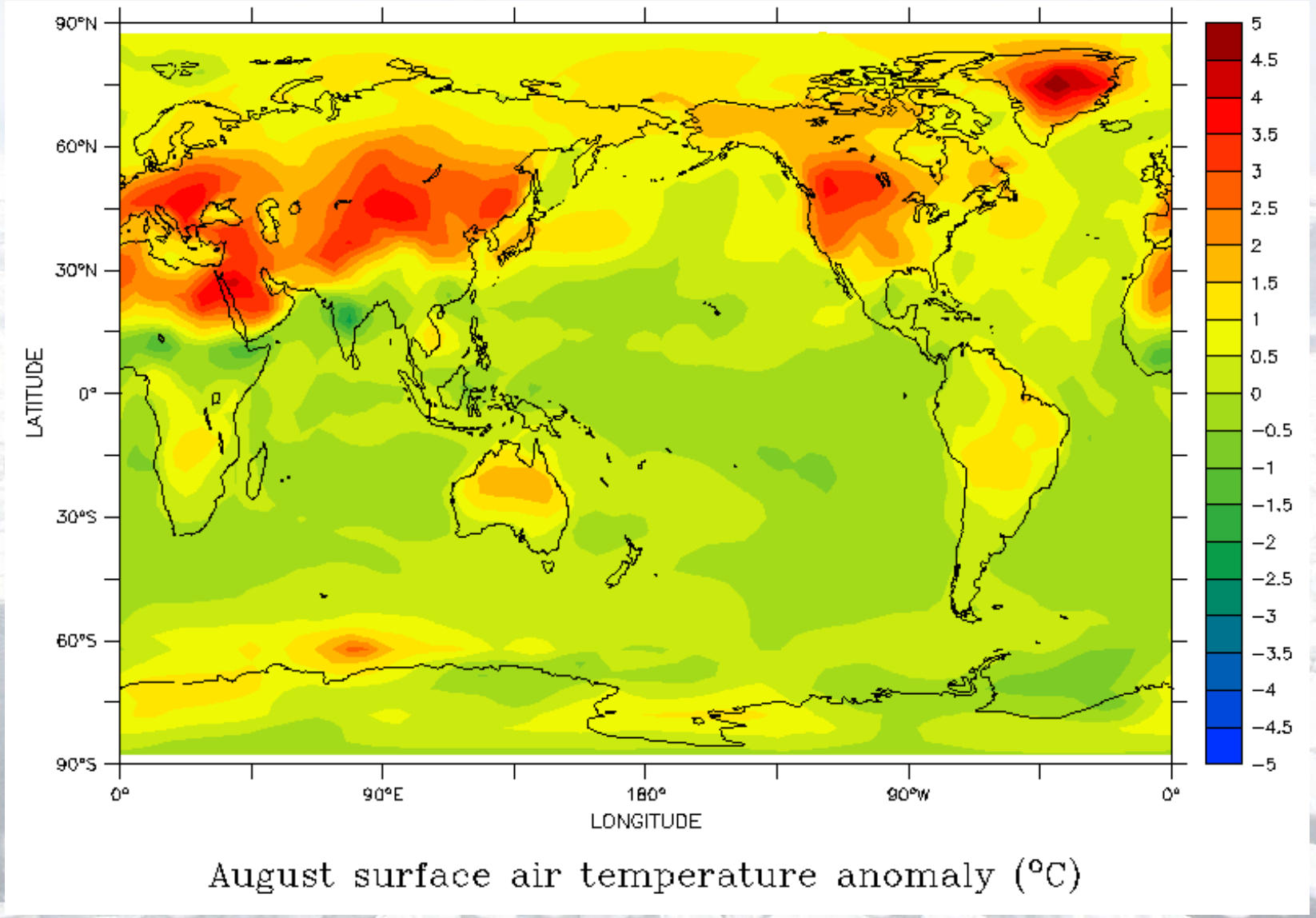
	Mk3L	**Observed***
Standard deviation of Niño 3.4 SST anomaly (°C)	0.48	0.71
Average period (years)	7.6 ± 0.3	∼3–6
Average duration (months)	16.9 ± 0.5	∼12

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

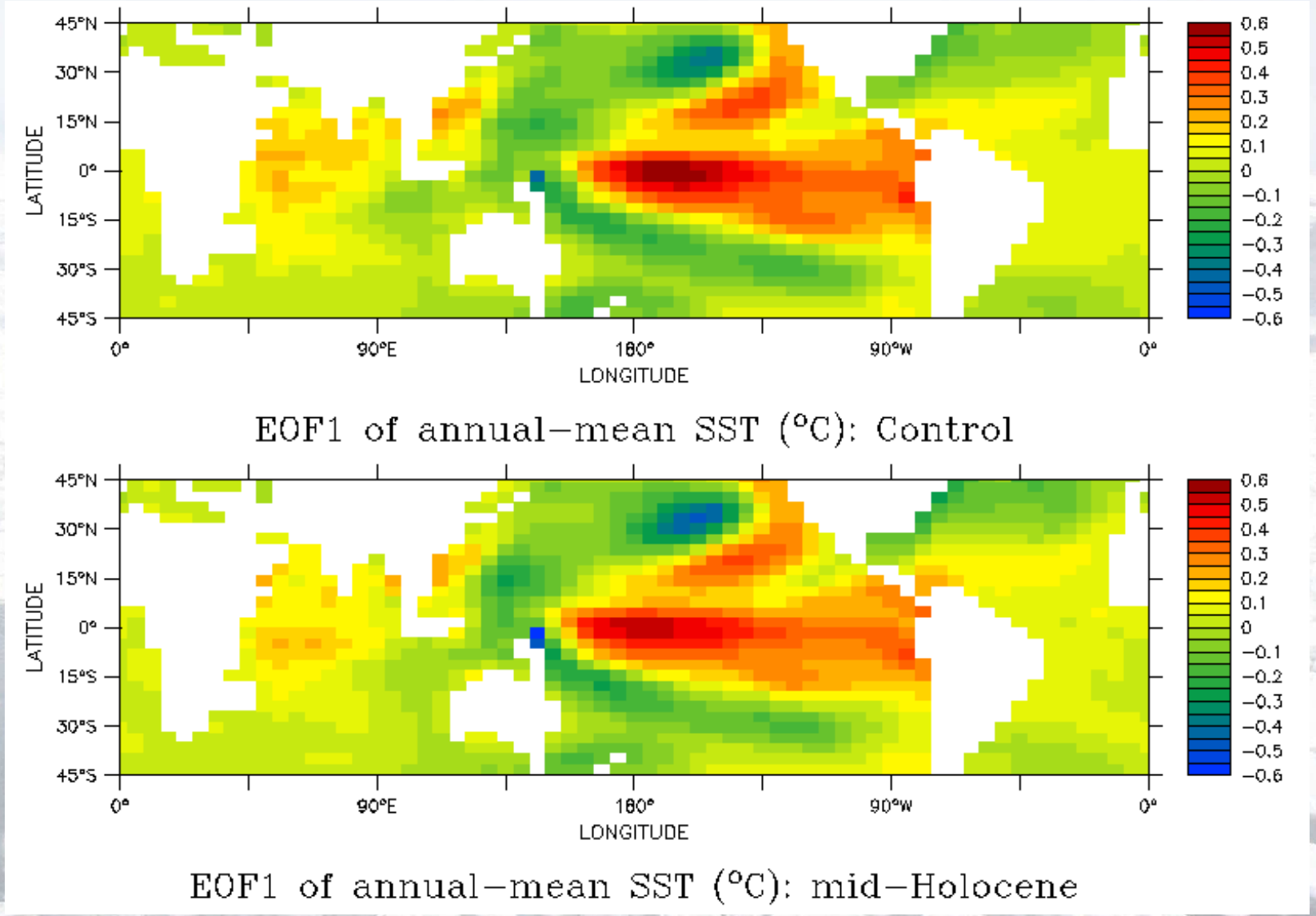
The climate of the mid-Holocene

- 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 3200+ 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
Insolation anomaly, 6ka BP minus present (Wm^{-2})



August surface air temperature anomaly (°C)


45°N
30°N
15°N
0°
15°S
30°S
45°S
LATITUDE
0°
90°E
180°
90°W
0°
LONGITUDE
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
EOF1 of annual−mean SST (°C): Control
EOF1 of annual−mean SST (°C): mid−Holocene

El Niño: control versus 6ka BP

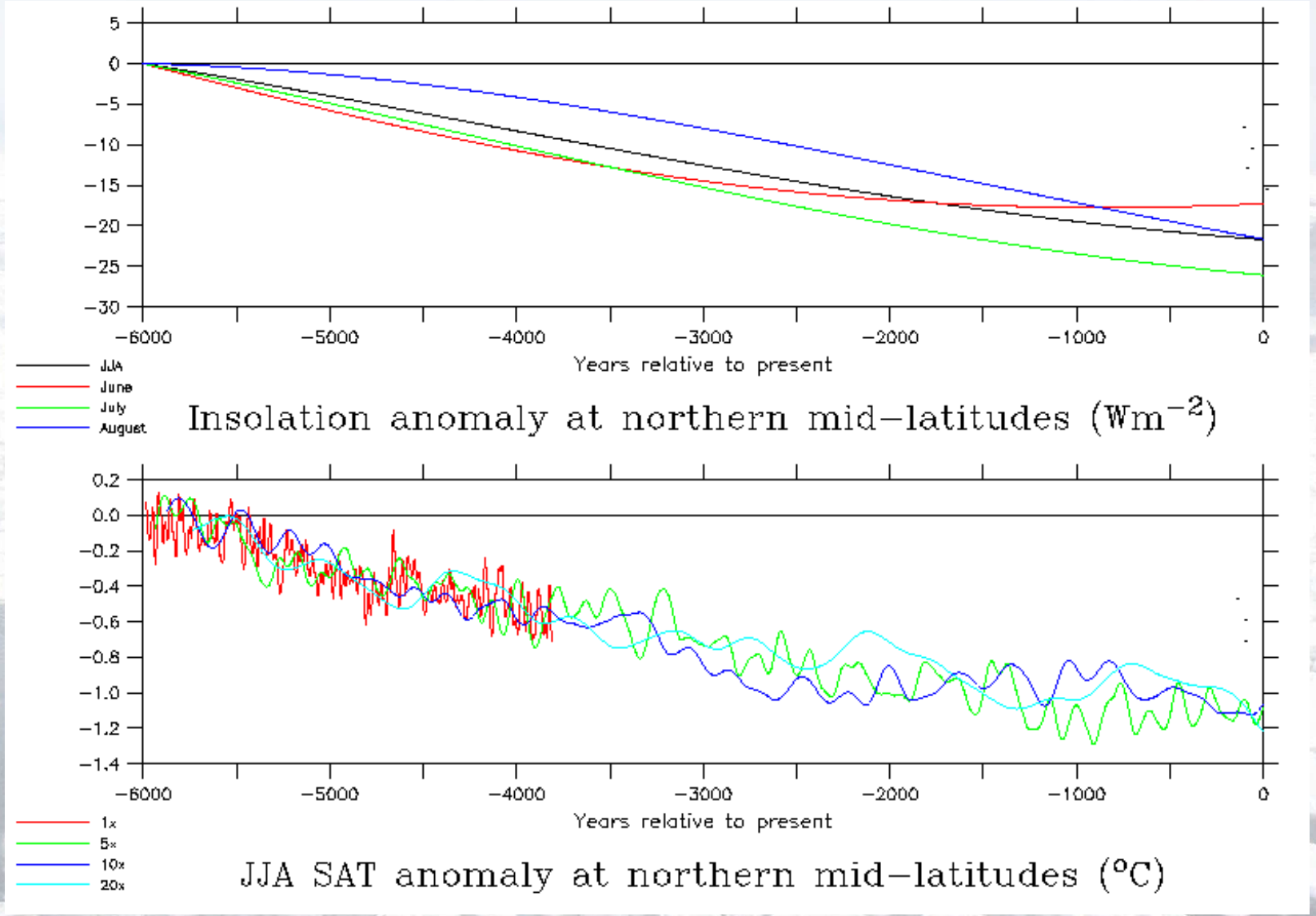
	Control	6ka BP	% change
Standard deviation of Niño 3.4 SST anomaly (°C)	0.48	0.42	-12
Period (years)	7.6 ± 0.3	9.5 ± 0.5	+25

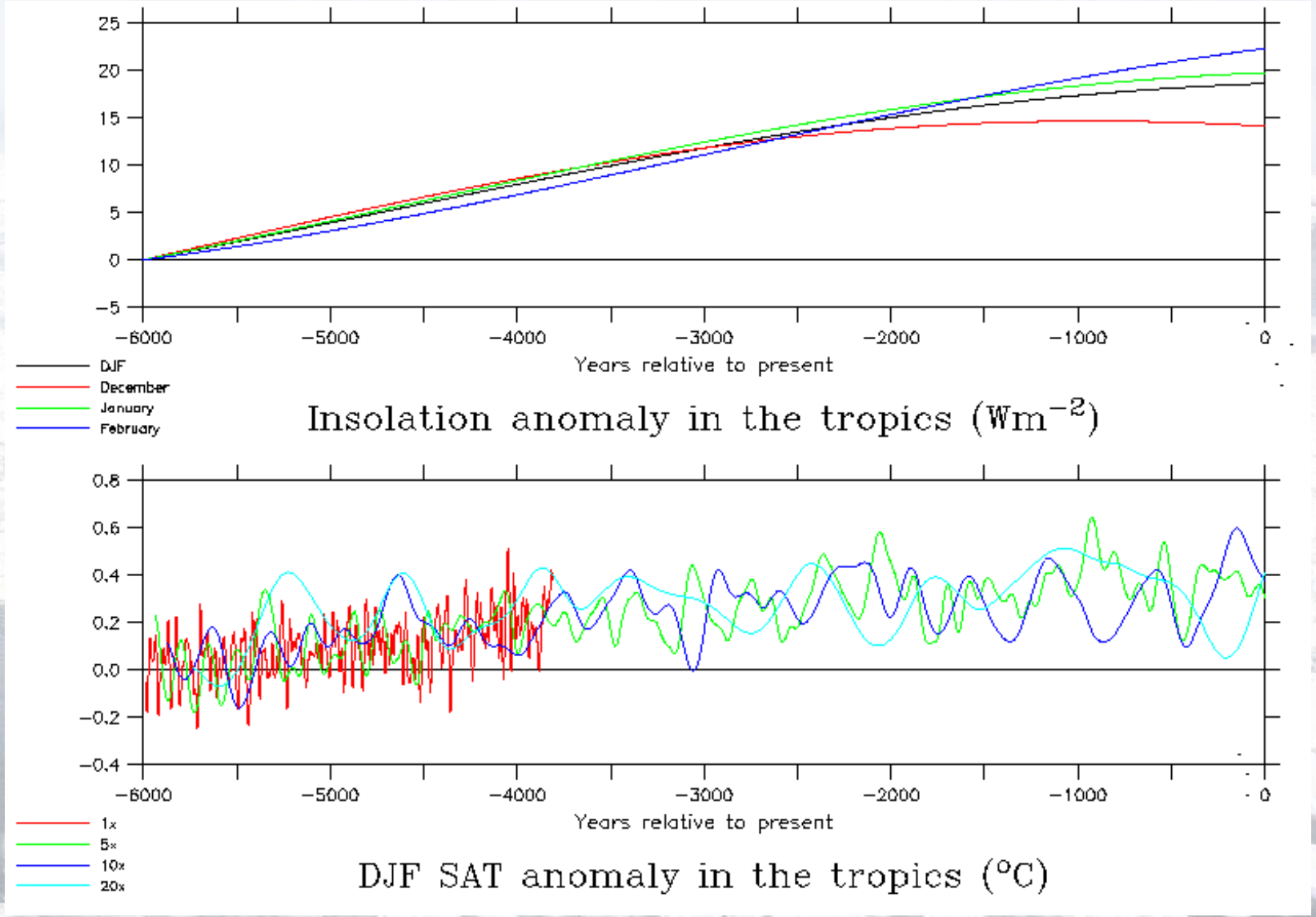
- Consistent with other models, which show decreases in the strength of El Niño ranging from ∼0% (NCAR CSM) to ∼20% (FOAM, CCSM3). PMIP2 ?
- Proxy evidence shows that El Niño was weaker, and that events were less frequent, during the mid-Holocene.

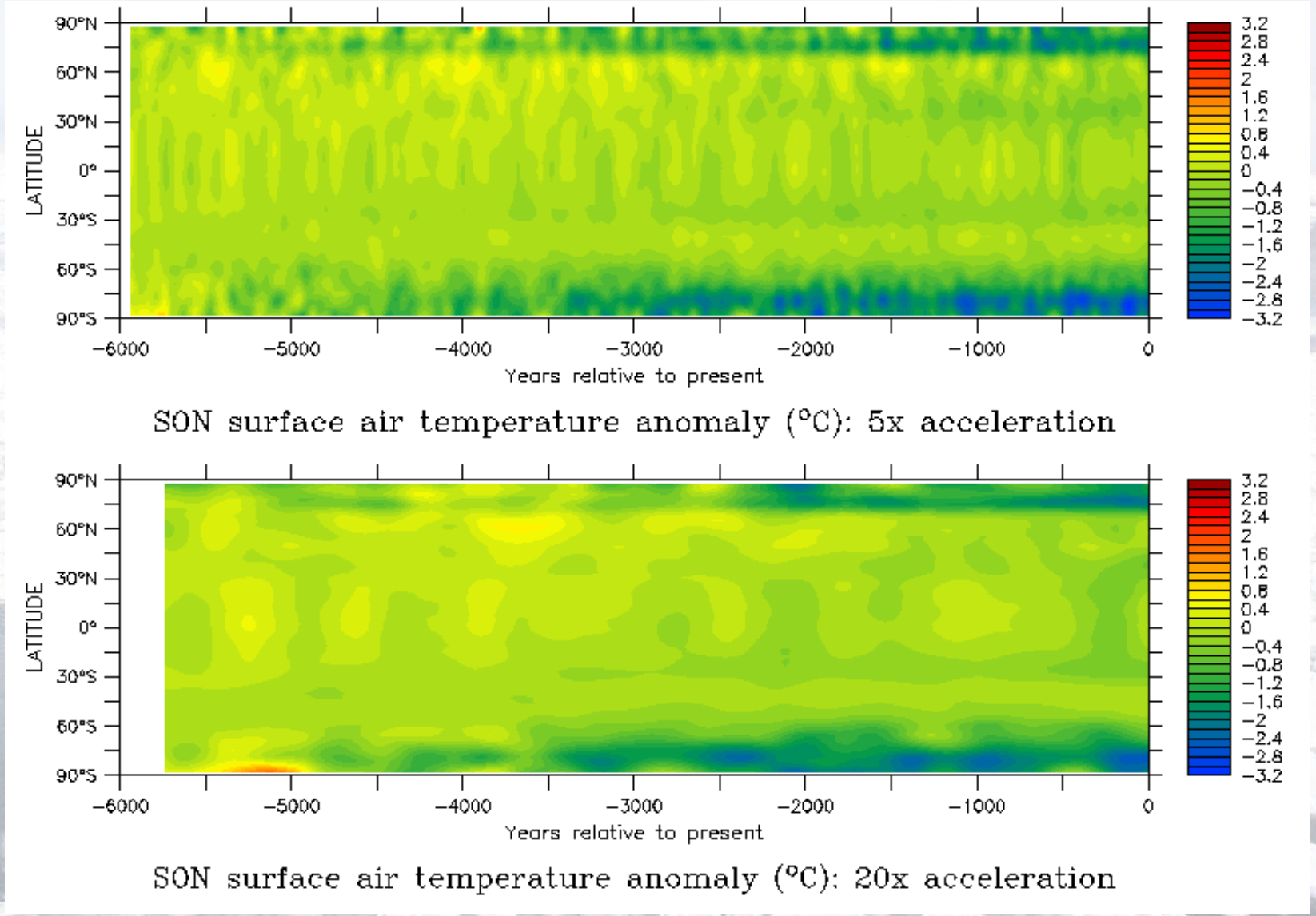
The climate of the late Holocene

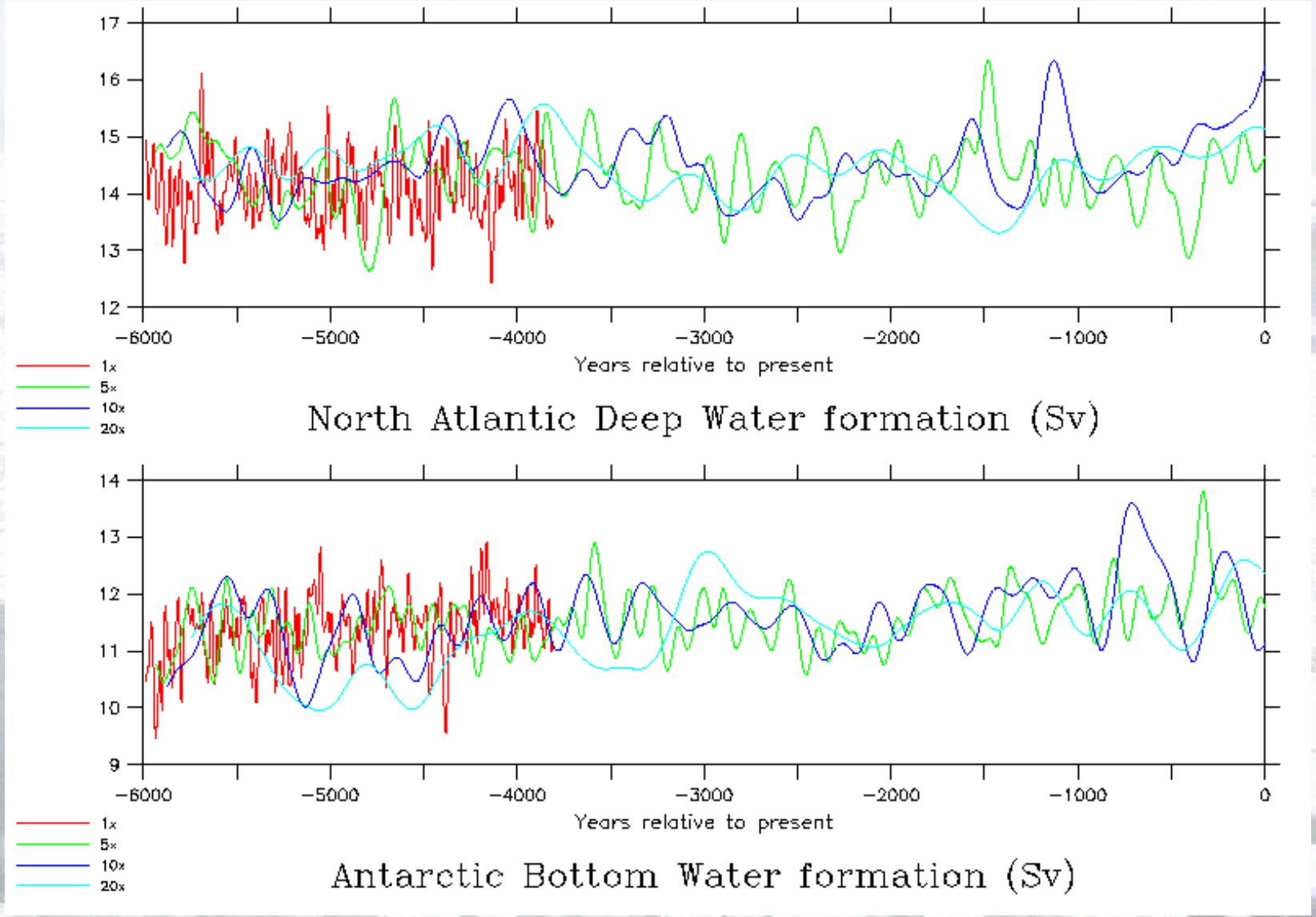
- Transient simulations from 6ka BP to the present day
- Initialised from year 1000 of the mid-Holocene simulation
- Orbital parameters varied, using the acceleration technique of Lorenz and Lohmann (2004)*
- Acceleration factors of 1, 5, 10 and 20
- Other boundary conditions unchanged
- Integrated for 2200+ years

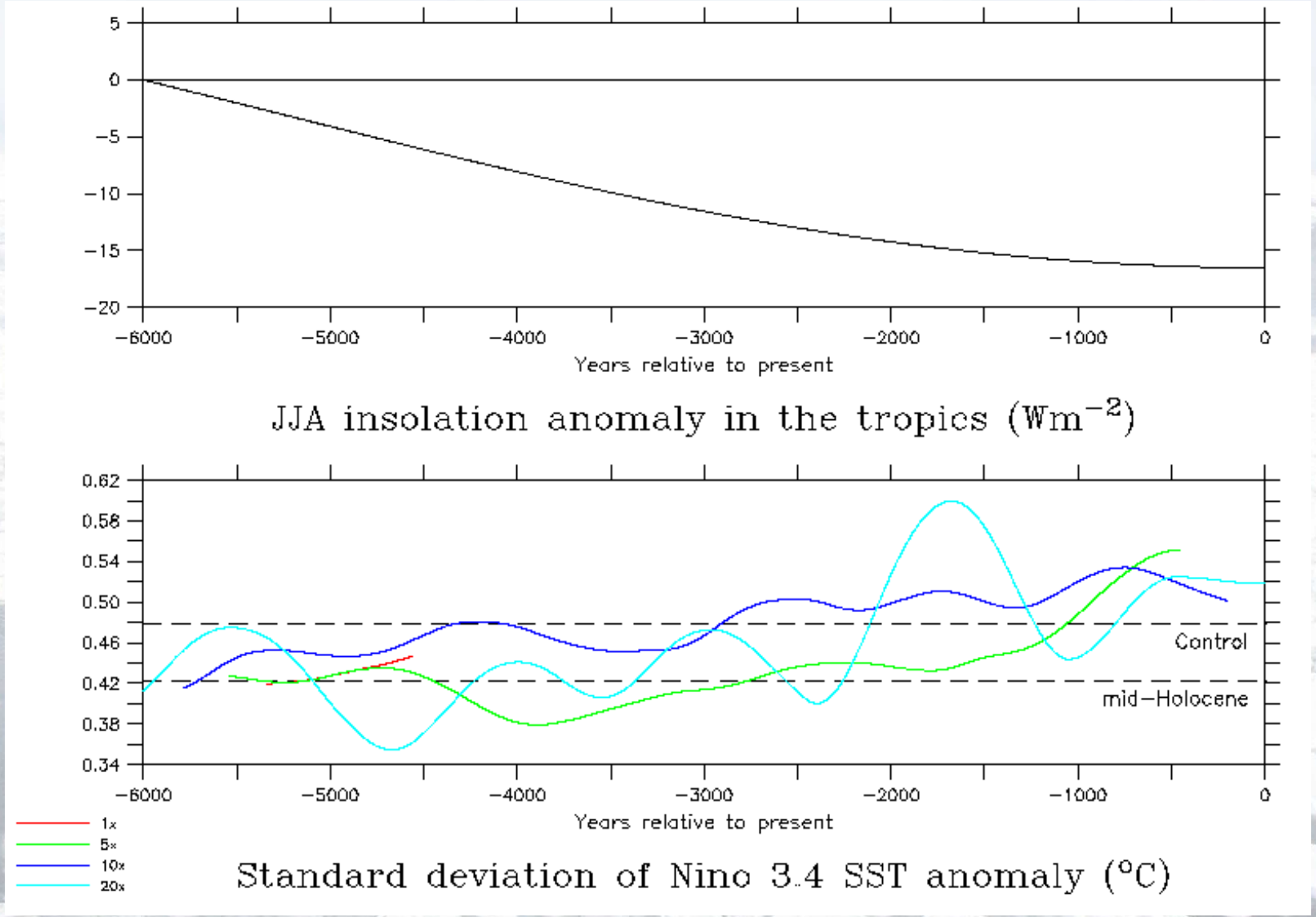
*S. J. Lorenz and G. Lohmann. Acceleration technique for Milankovitch type forcing in a coupled atmosphere-ocean circulation model: method and application for the Holocene. *Climate Dynamics*, 23:727–743, 2004.


5
0
−5
−10
−15
−20
−25
−30
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
JJA
June
July
August
Insolation anomaly at northern mid−latitudes (Wm^{-2})
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
1×
5×
10×
20×
JJA SAT anomaly at northern mid−latitudes (°C)


25
20
15
10
5
0
−5
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
DJF
December
January
February
Insolation anomaly in the tropics (Wm^{-2})
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1×
5×
10×
20×
DJF SAT anomaly in the tropics (°C)


90°N
60°N
30°N
0°
30°S
60°S
90°S
LATITUDE
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
−0.4
−0.8
−1.2
−1.6
−2
−2.4
−2.8
−3.2
SON surface air temperature anomaly (°C): 5x acceleration
SON surface air temperature anomaly (°C): 20x acceleration


17
16
15
14
13
12
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
North Atlantic Deep Water formation (Sv)
14
13
12
11
10
9
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1x
5x
10x
20x
Antarctic Bottom Water formation (Sv)


5
0
−5
−10
−15
−20
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
JJA insolation anomaly in the tropics (Wm^{-2})
0.62
0.58
0.54
0.50
0.46
0.42
0.38
0.34
Control
mid−Holocene
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
1×
5×
10×
20×
Standard deviation of Nino 3.4 SST anomaly (°C)

Conclusions

- The Lorenz-Lohmann acceleration technique has been shown to be applicable to the late Holocene, because the thermohaline circulation is essentially invariant over this period
- However, the technique can hinder the study of internal variability
- An ensemble of simulations shows a strengthening of ENSO during the late Holocene
- The simulations also suggest subtle changes in the nature of ENSO over this period

Future work

- Double the resolution of the ocean model (to $\sim 2.8° \times \sim 1.6°$)
- CABLE land surface model (+ dynamic vegetation?)
- Three-member ensemble for the late Holocene, with no acceleration
- Work with the palaeoclimate community to design further experiments
- The CSIRO Mk3L climate system model is being made freely available to the research community:

`http://www.tpac.org.au/main/csiromk3l`