Simulating the evolution of ENSO over the late Holocene

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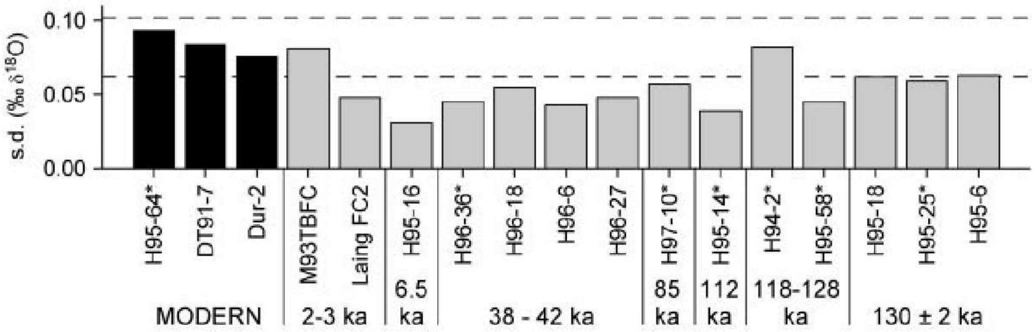
El Niño has changed...

- Proxy reconstructions from across the Pacific Basin show that:
  - "Modern" El Niño began 7-5 ka BP, with only weak decadal events beforehand
  - El Niño was 15-60% weaker at 6 ka BP than at present
  - Gradual strengthening of El Niño thereafter
  - Evidence of a peak in strength at 2-1 ka, possibly earlier in the western Pacific than in the east



Tudhope et al. (2001), *Science*

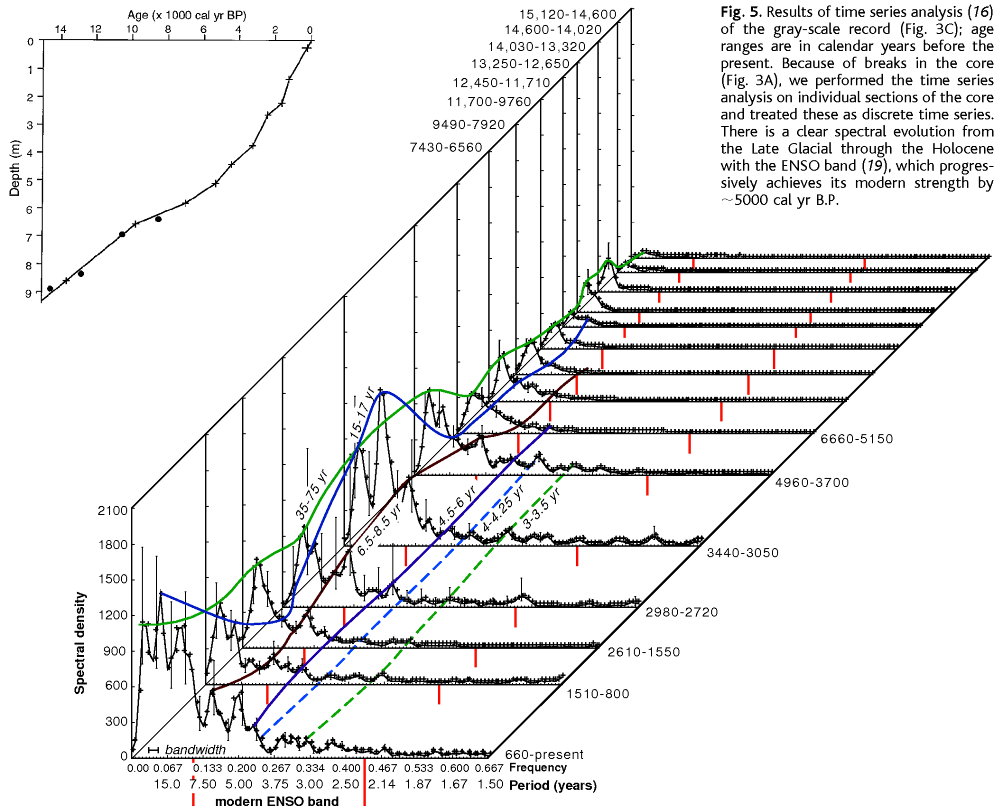
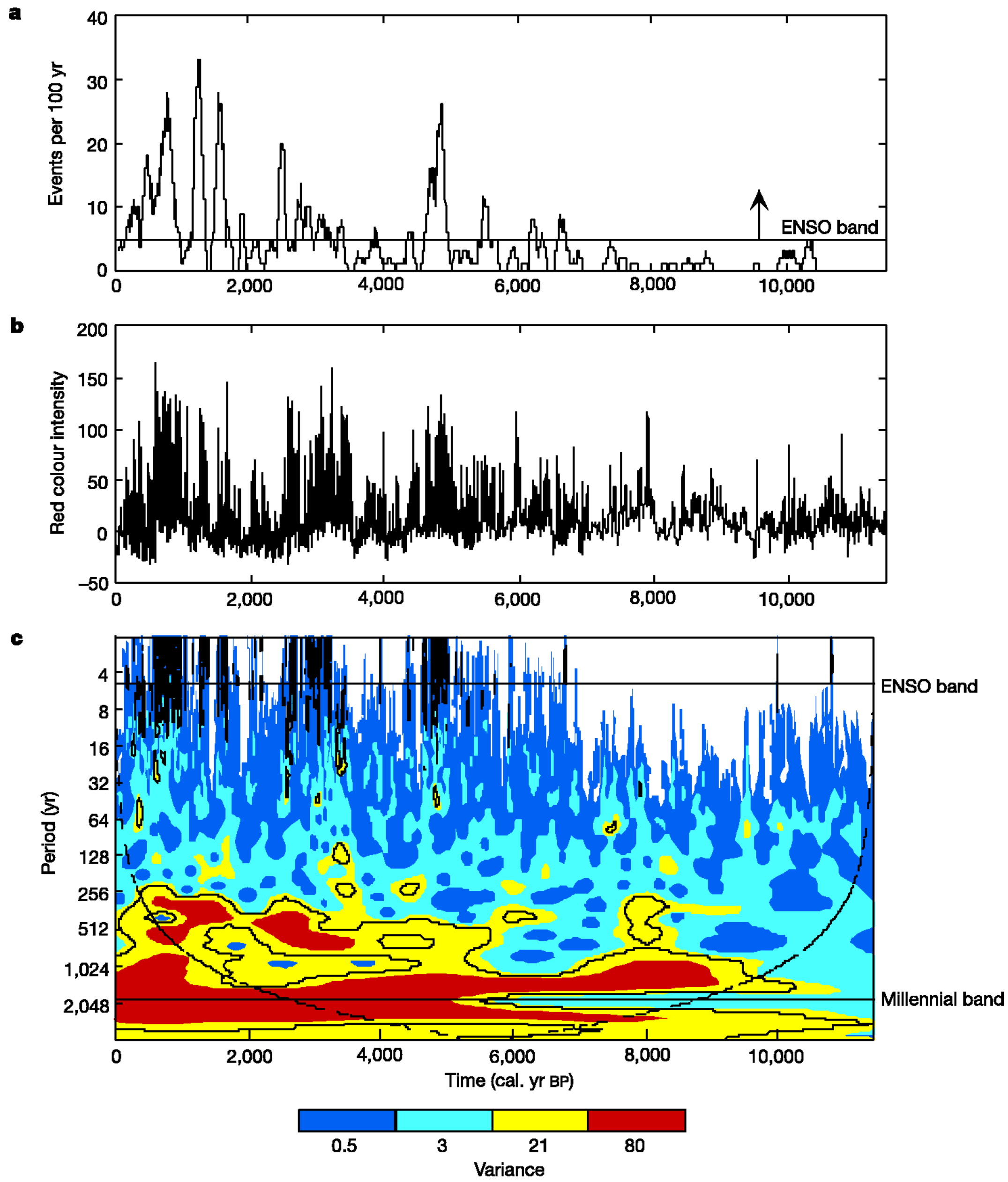


Fig. 5. Results of time series analysis (*16*) of the gray-scale record (Fig. 3C); age ranges are in calendar years before the present. Because of breaks in the core (Fig. 3A), we performed the time series analysis on individual sections of the core and treated these as discrete time series. There is a clear spectral evolution from the Late Glacial through the Holocene with the ENSO band (*19*), which progressively achieves its modern strength by ~5000 cal yr B.P.

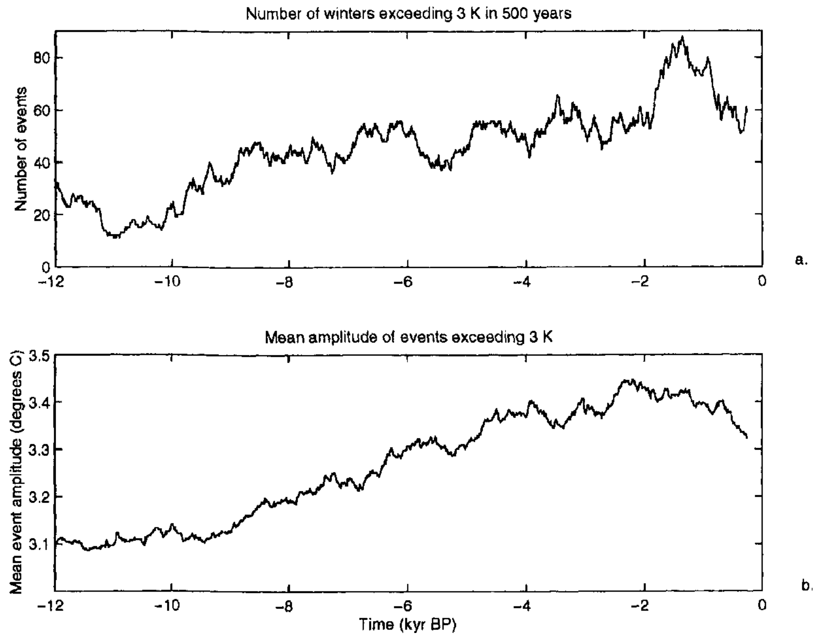
Rodbell et al. (1999), *Science*



Moy et al. (2002), *Nature*

Early modelling work

- Clement et al. (2000):
  - Used the Zebiak-Cane model to simulate the past 12 ka
  - Simple atmosphere-ocean model; restricted to the tropical Pacific
  - Established that orbitally-driven changes in the seasonal cycle of insolation in the tropics can alter ENSO behaviour



Coupled modelling studies: 6 ka versus 0 ka BP

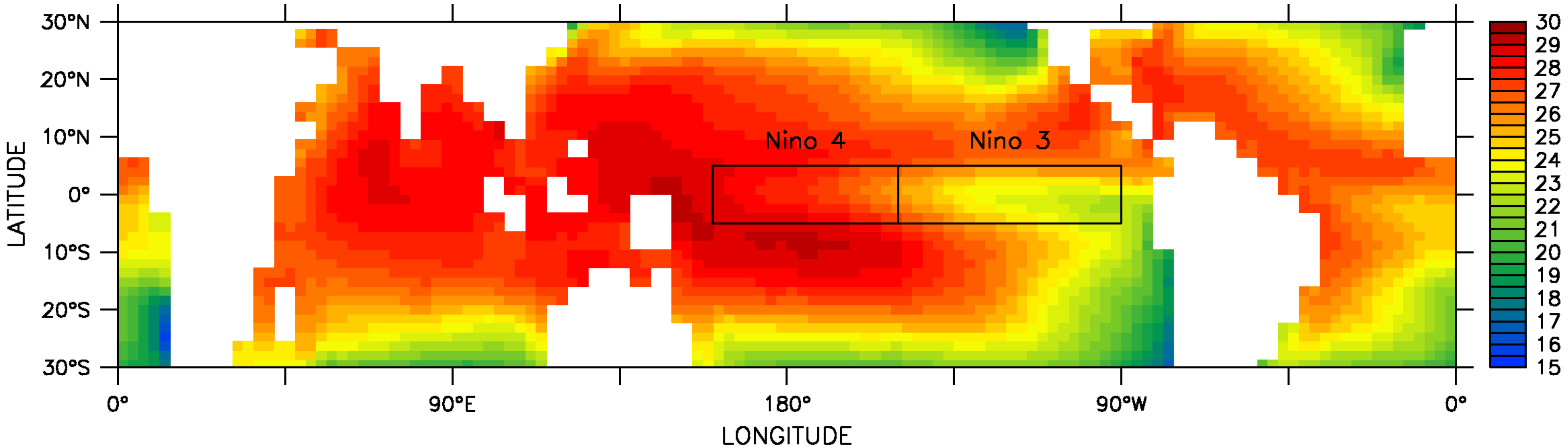
	Model	**Diagnostic**	**% change**
Otto-Bliesner (1999)	CSM	Niño 3	$\sim$0
Liu et al. (2000)	FOAM	Niño 3.4	-20
Phipps (2006)	Mk3L-1.0	Niño 3.4	-13
Brown at al. (2006)	HadCM3	Niño 3	-12
Zheng et al. (2008) (PMIP2)	CCSM3	Niño 3	-18.6
	FGOALS-1.0g		-14.6
	FOAM		-11.6
	IPSL-CM4		-2.9
	MIROC3.2		-22.5
	MRI-CGCM2.3.4fa		+3.3
	MRI-CGCM2.3.4nfa		-12.9

A picture begins to emerge?

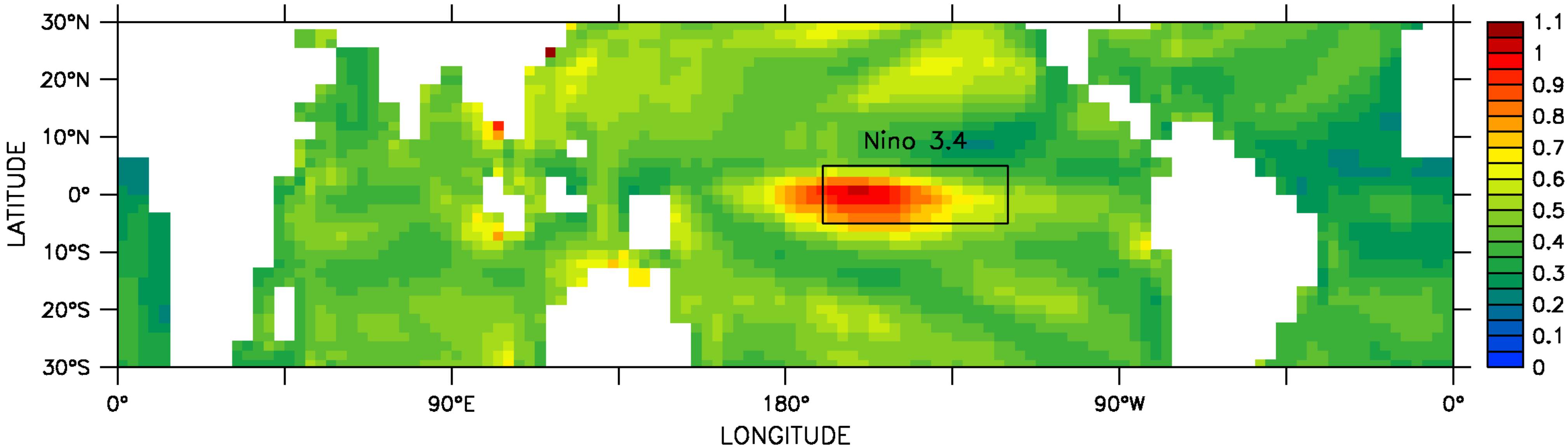
- Increased insolation over tropics in NH summer
- Increased land/sea temperature contrast
- Enhanced Asian monsoon
- Enhanced Walker circulation
- Stronger easterlies over tropical Pacific
- Steeper thermocline/increased upwelling in eastern Pacific
- Makes it harder for El Niño events to arise

Simulations of the late Holocene climate

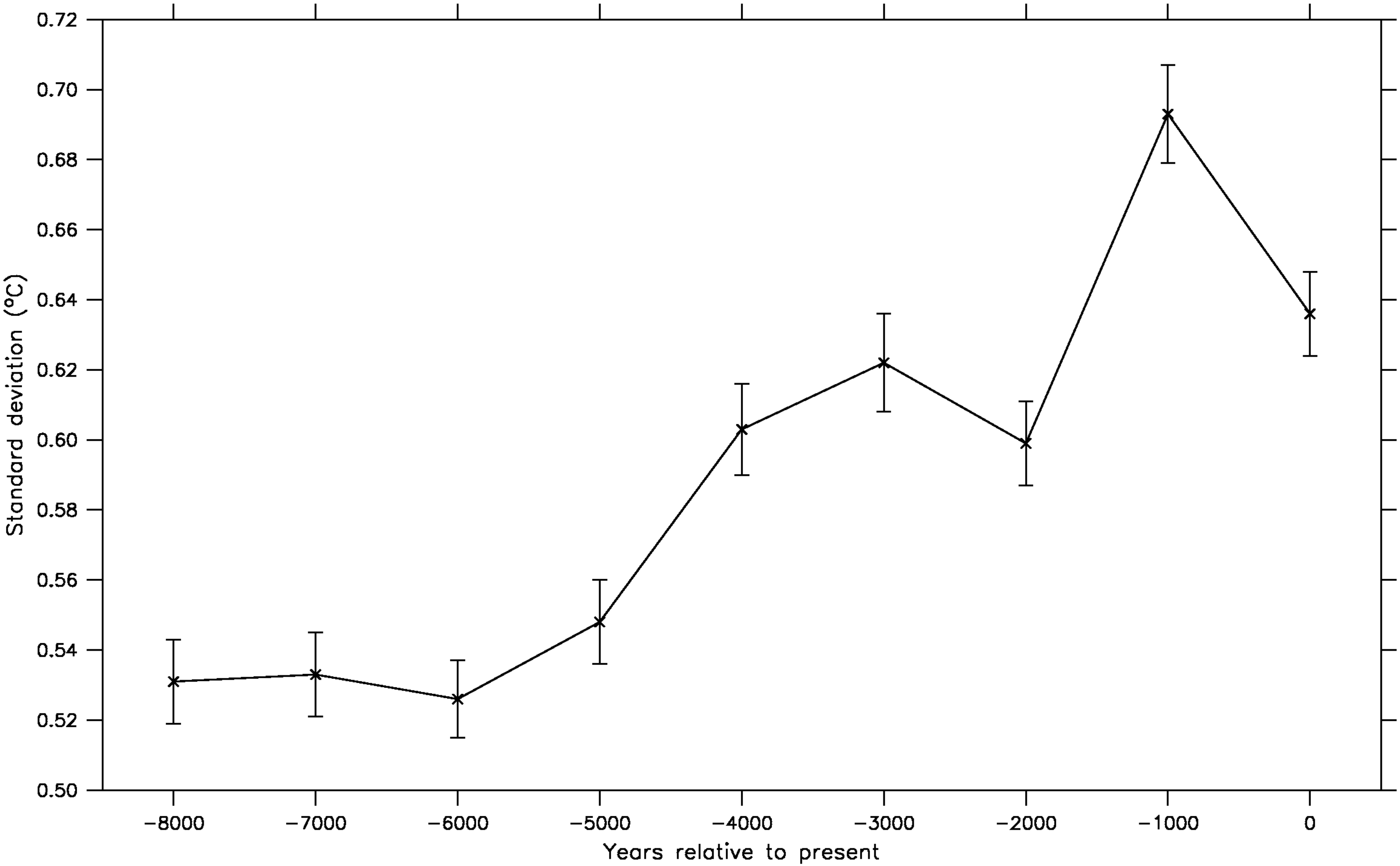
- CSIRO Mk3L climate system model v1.1:
  - Atmosphere: R21 ($5.6^\circ \times 3.2^\circ$), 18 vertical levels
  - Ocean: $2.8^\circ \times 1.6^\circ$, 21 vertical levels
  - Sea ice: Dynamic-thermodynamic
  - Land surface: Static vegetation
  - Flux adjustments applied
- Snapshot simulations for 8, 7, 6, 5, 4, 3, 2, 1 and 0 ka BP:
  - Only the Earth's orbital parameters are varied
  - Atmospheric CO_2 concentration = 280ppm
  - Solar constant = 1365 Wm^{-2}
  - Integrated for 1000 years
  - Simulations for 6 and 0 ka BP submitted to PMIP2



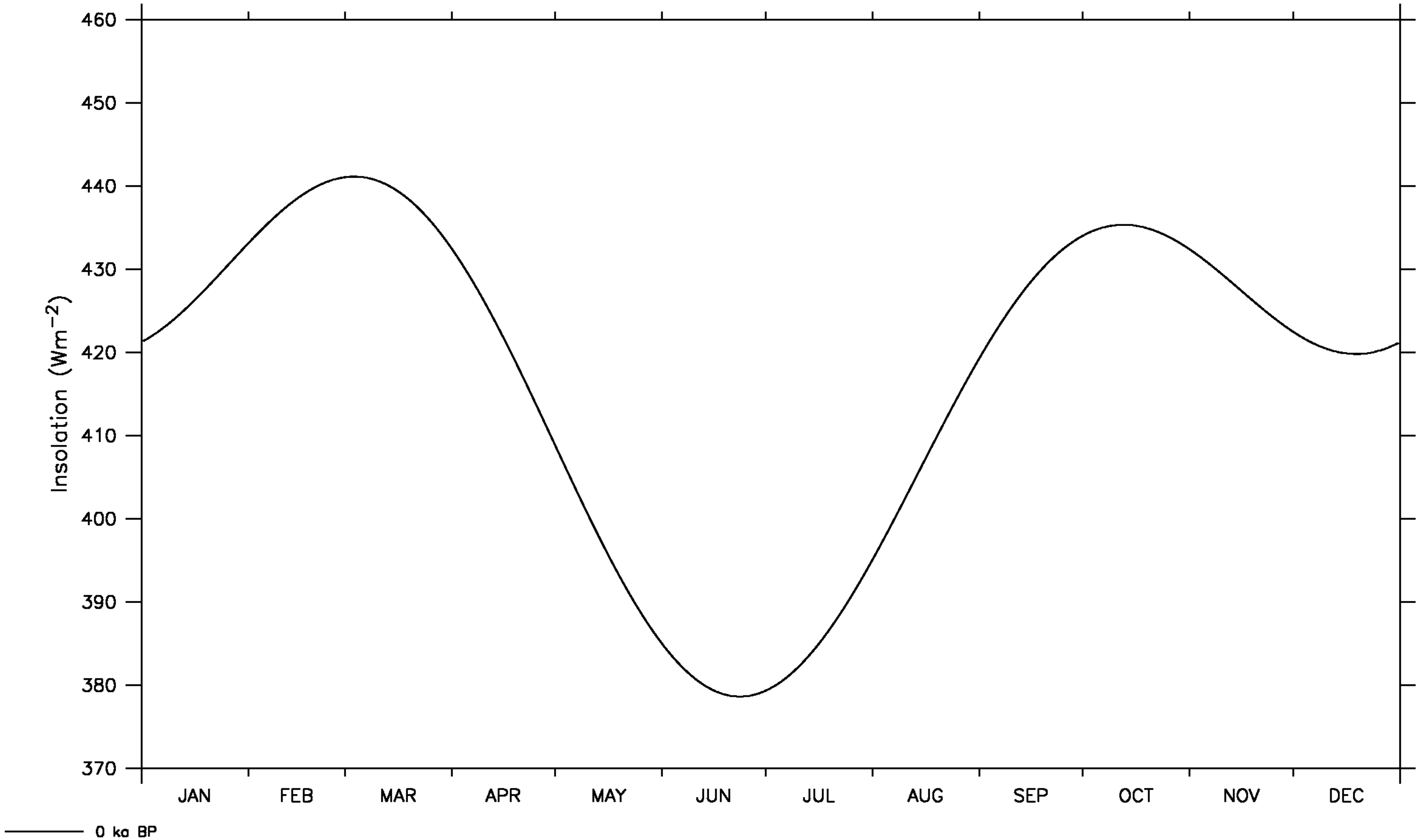
Annual−mean SST (°C)



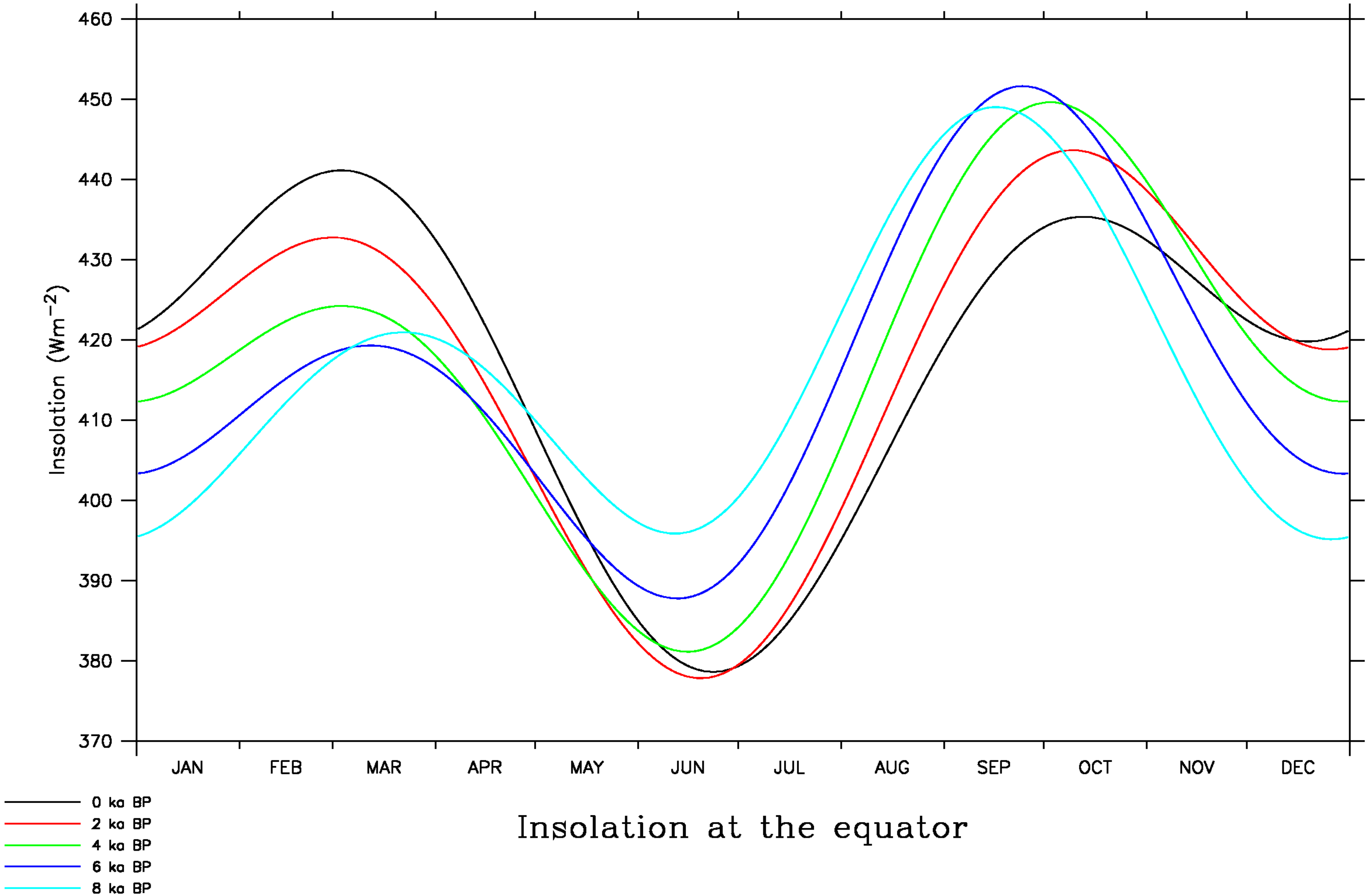
Standard deviation of monthly−mean SST (°C)



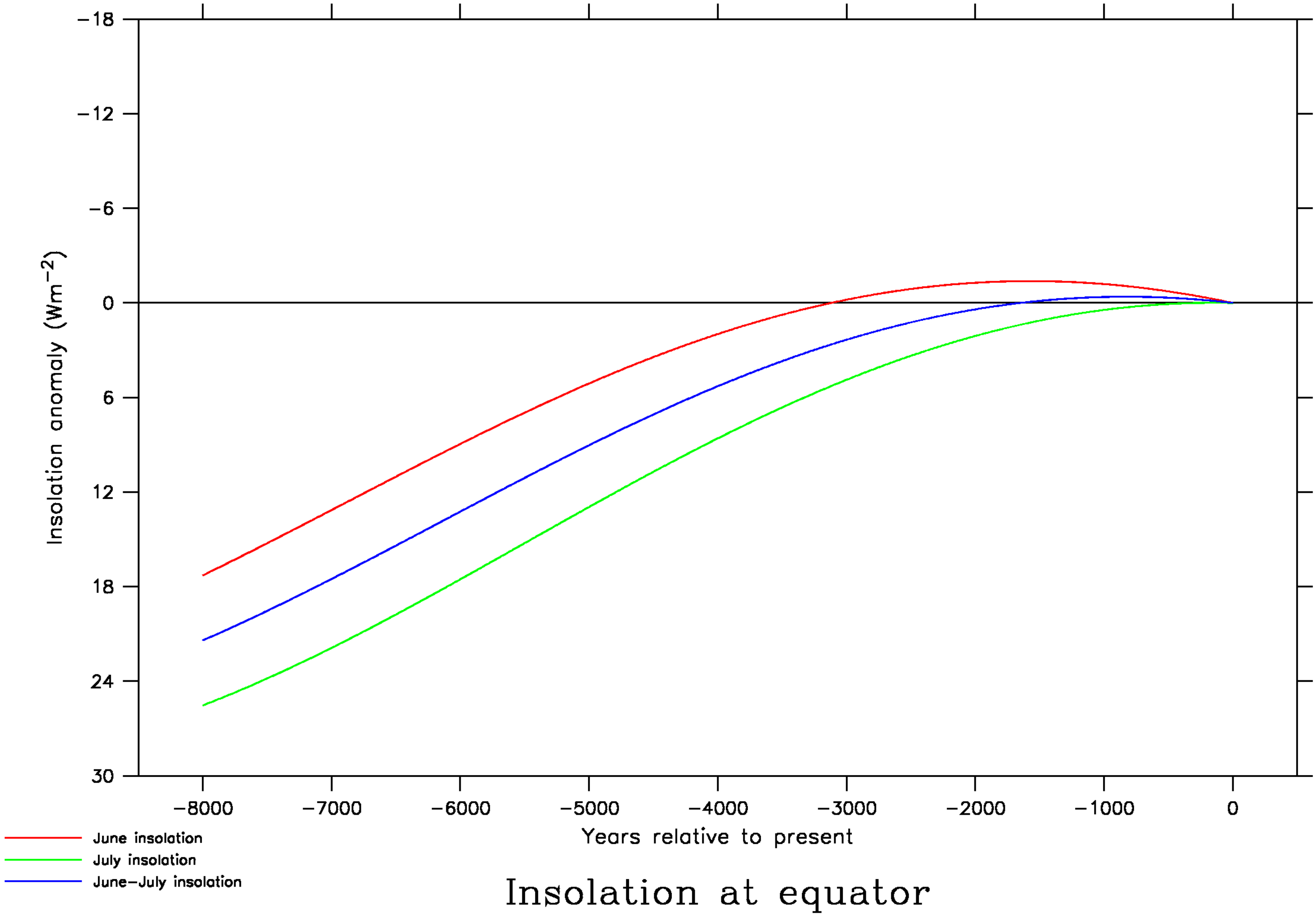
Standard deviation of Nino 3.4 SST anomaly

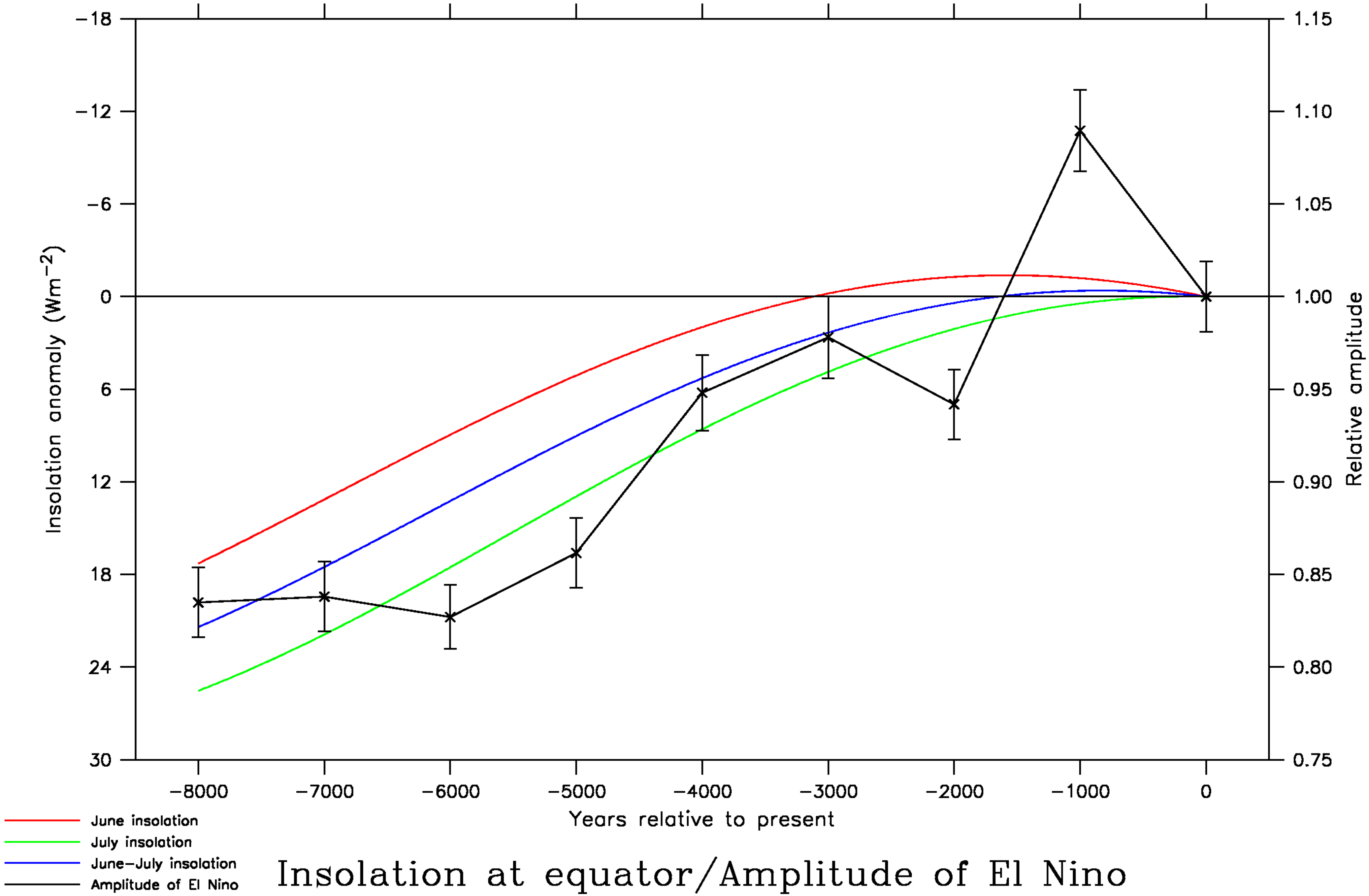


Insolation at the equator

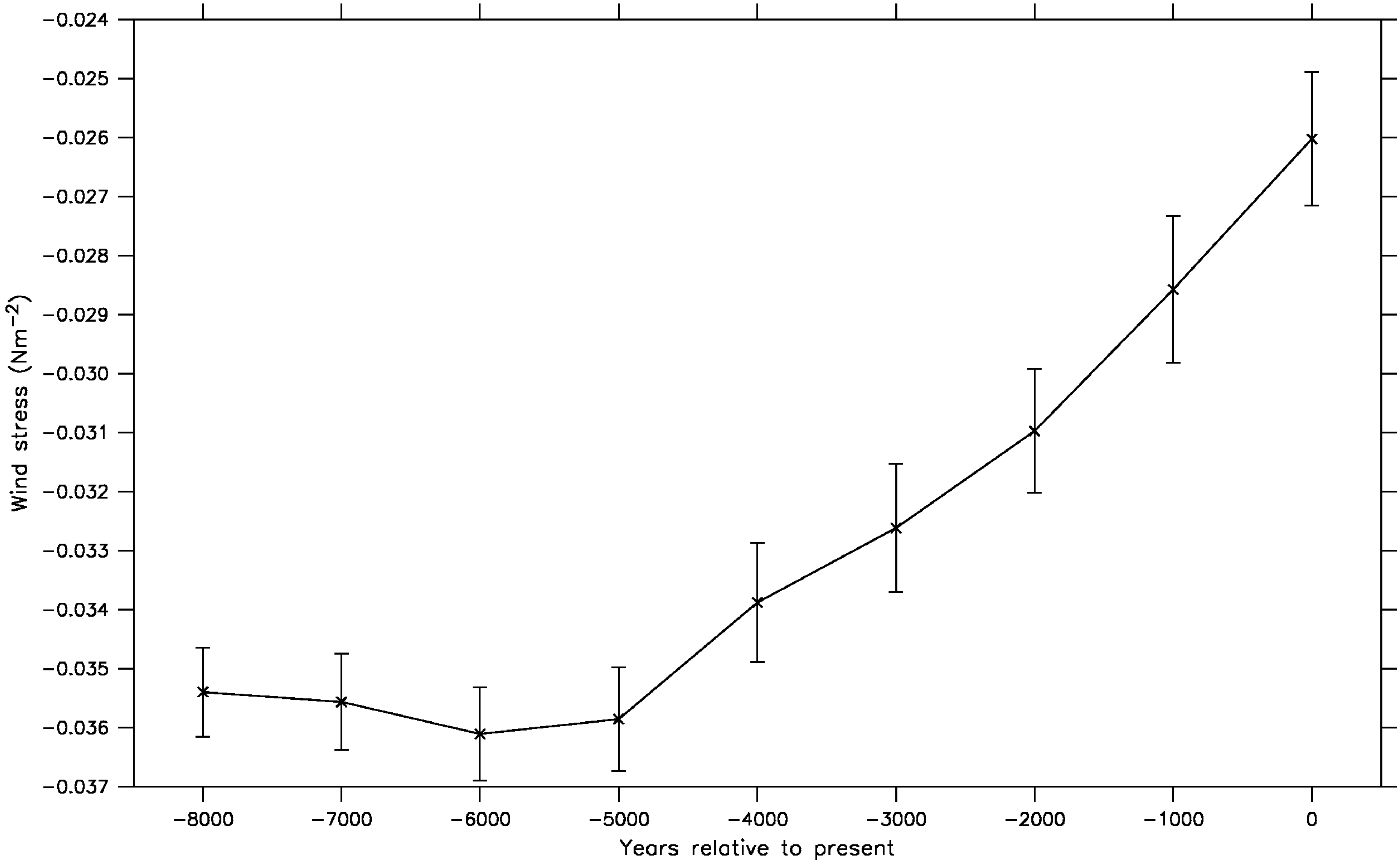


Insolation at the equator

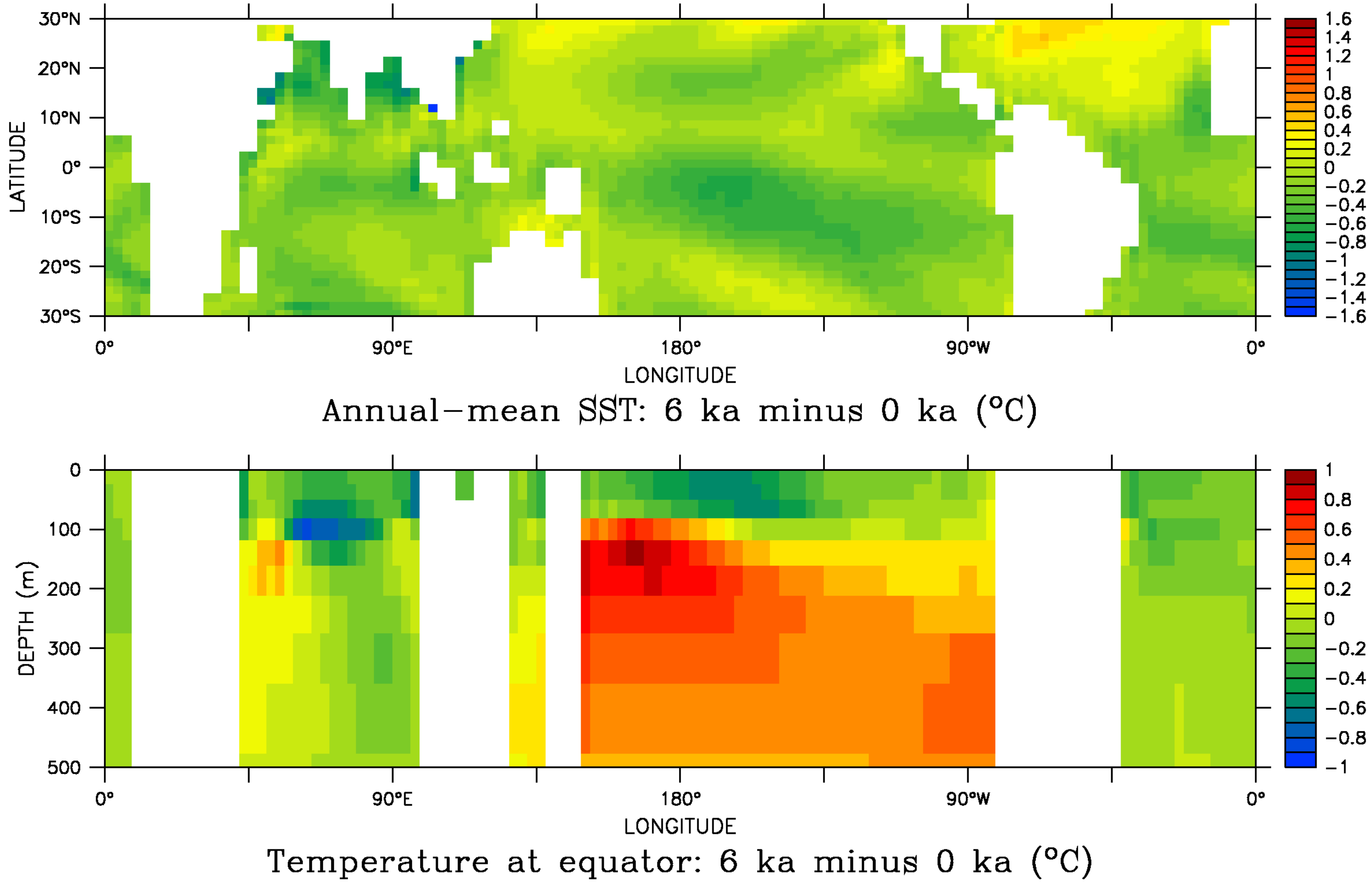

−18
−12
−6
0
6
12
18
24
30
Insolation anomaly (Wm^{-2})
−8000
−7000
−6000
−5000
−4000
−3000
−2000
−1000
0
Years relative to present
June insolation
July insolation
June−July insolation
Insolation at equator



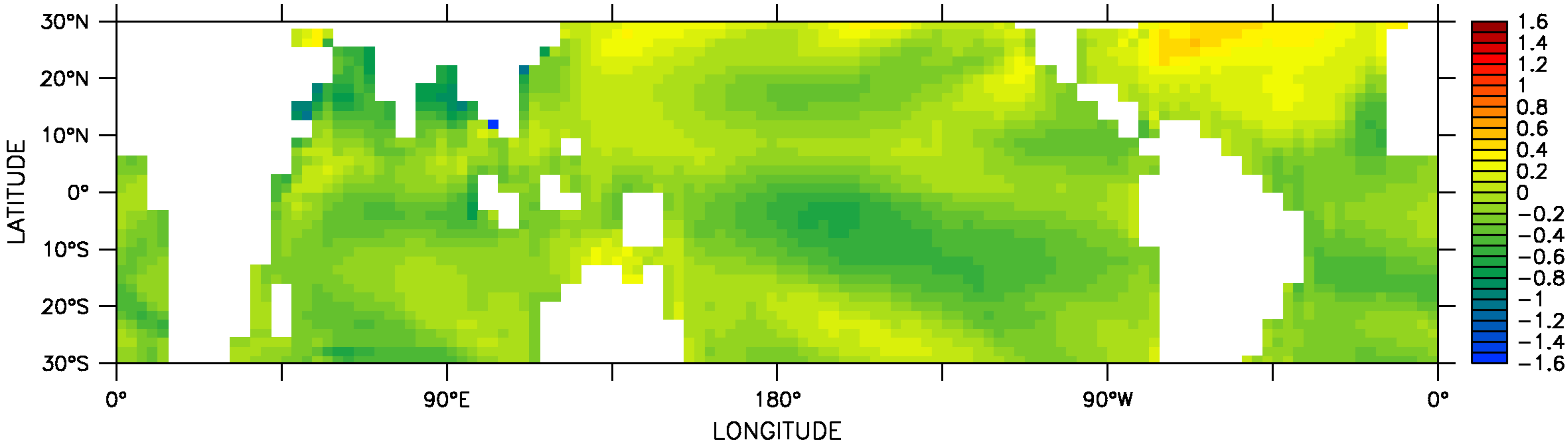
Insolation at equator/Amplitude of El Nino



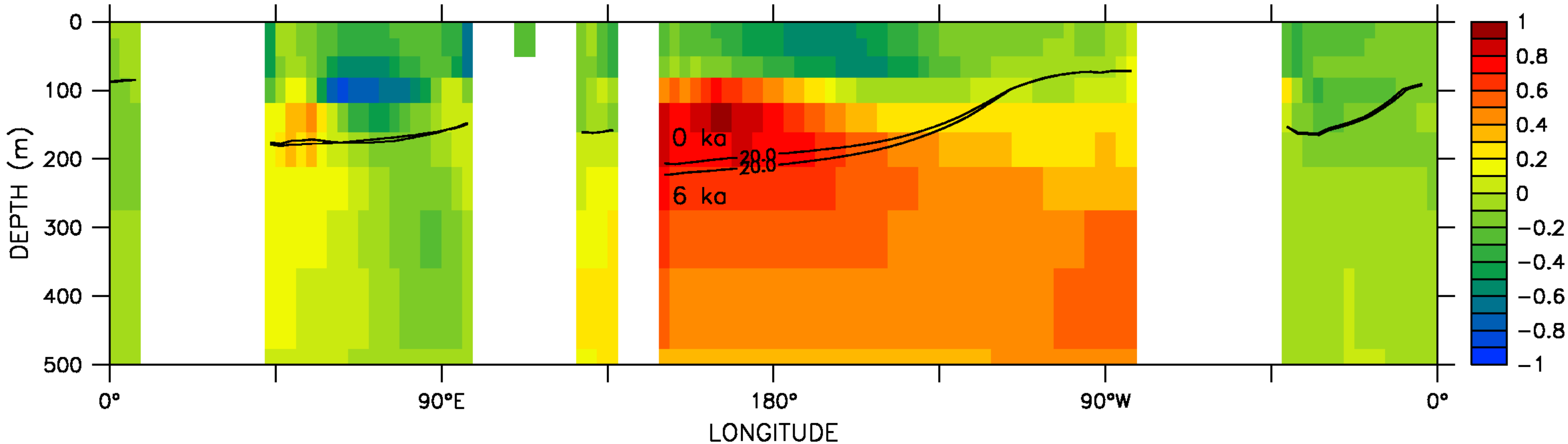
SON zonal wind stress over the Nino 4 region



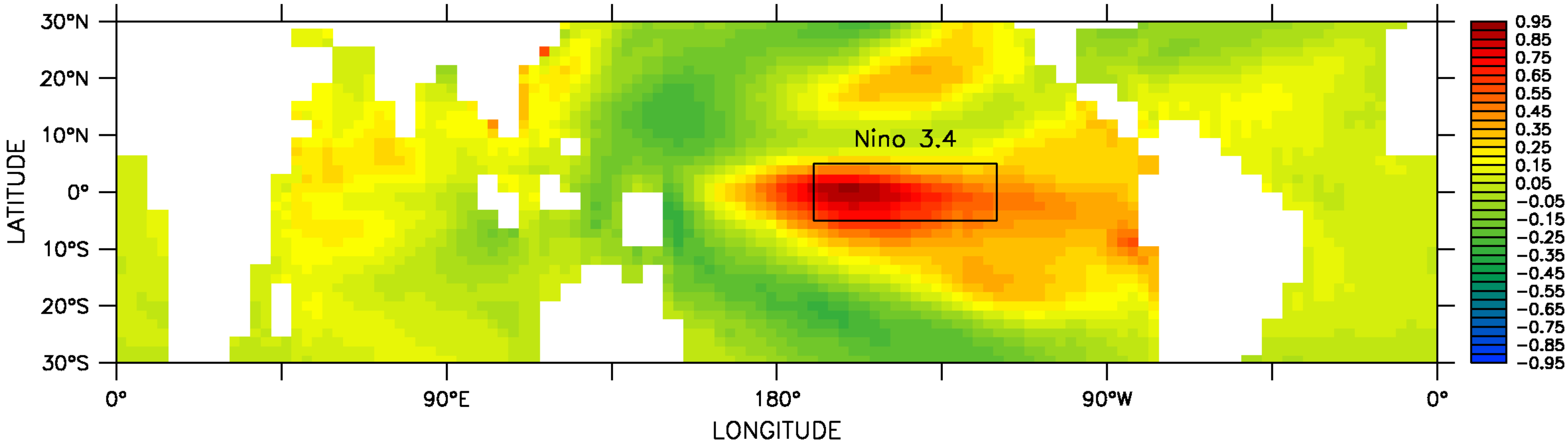
30°N
20°N
10°N
0°
10°S
20°S
30°S
LATITUDE
0°
90°E
180°
90°W
0°
LONGITUDE
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
−1.6
Annual−mean SST: 6 ka minus 0 ka (°C)
0
100
200
300
400
500
DEPTH (m)
0°
90°E
180°
90°W
0°
LONGITUDE
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
Temperature at equator: 6 ka minus 0 ka (°C)



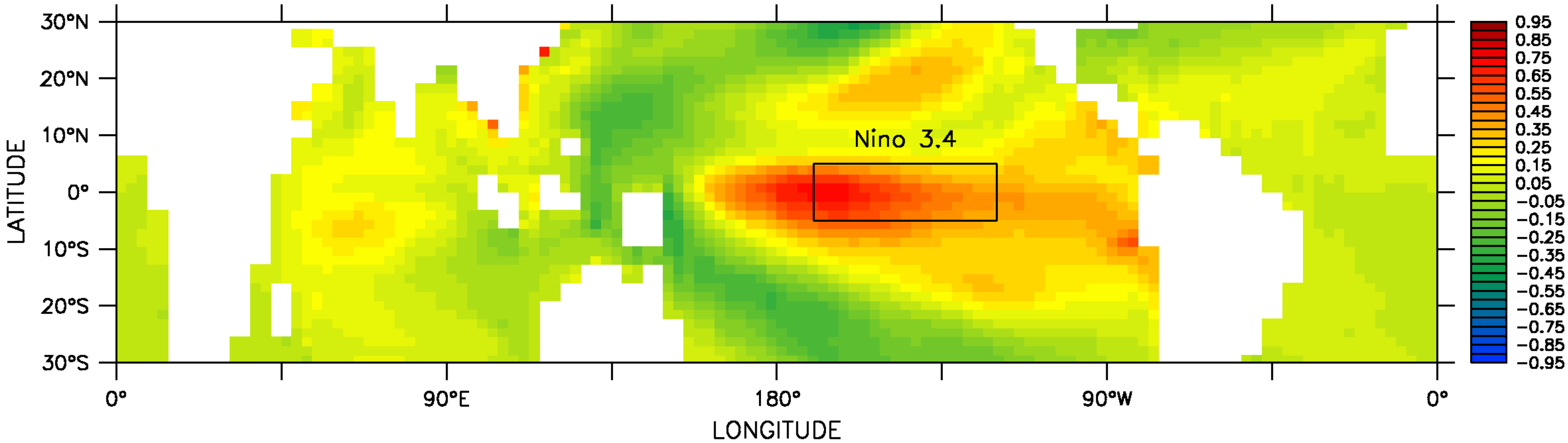
Annual−mean SST: 6 ka minus 0 ka (°C)



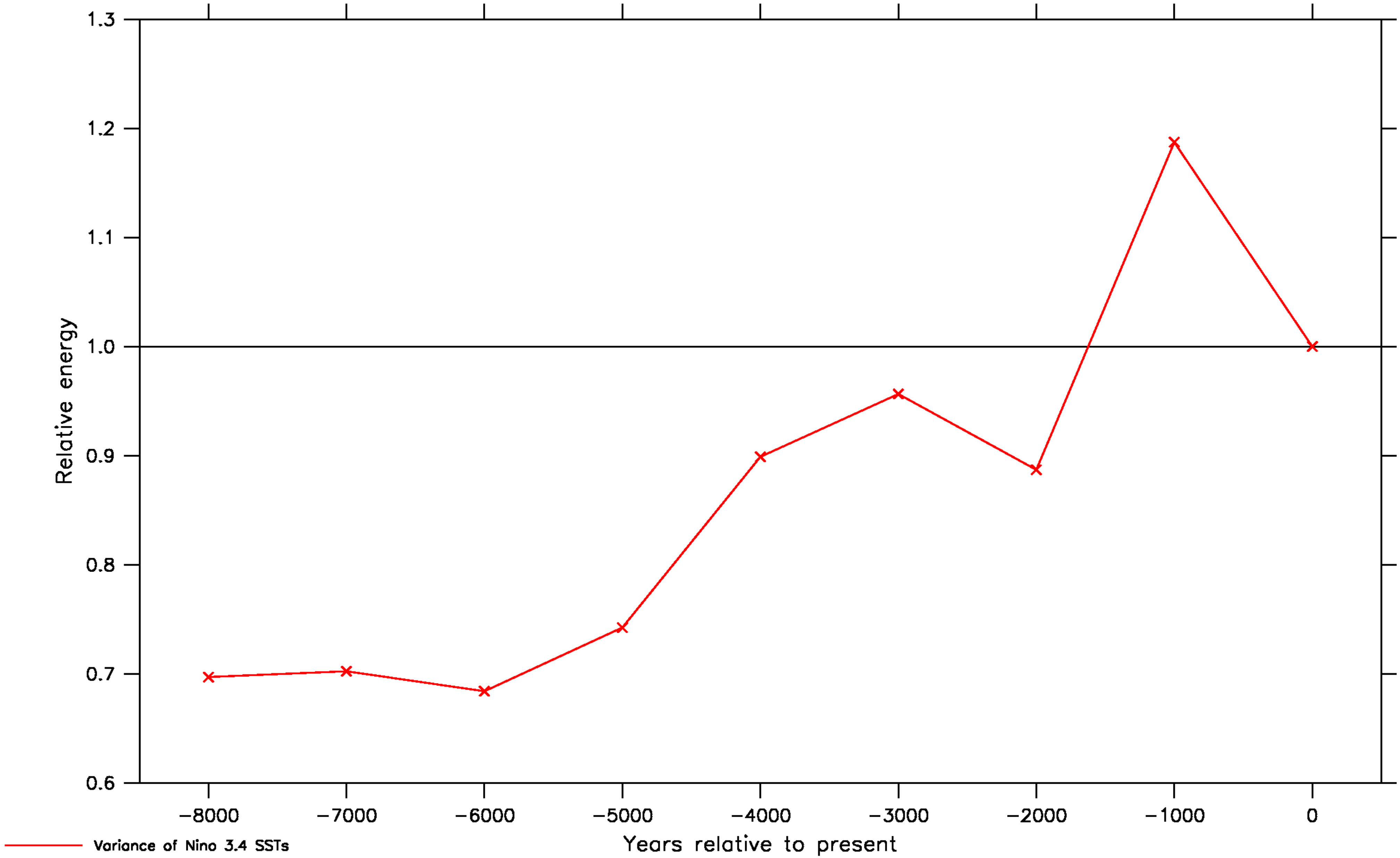
Temperature at equator: 6 ka minus 0 ka (°C)



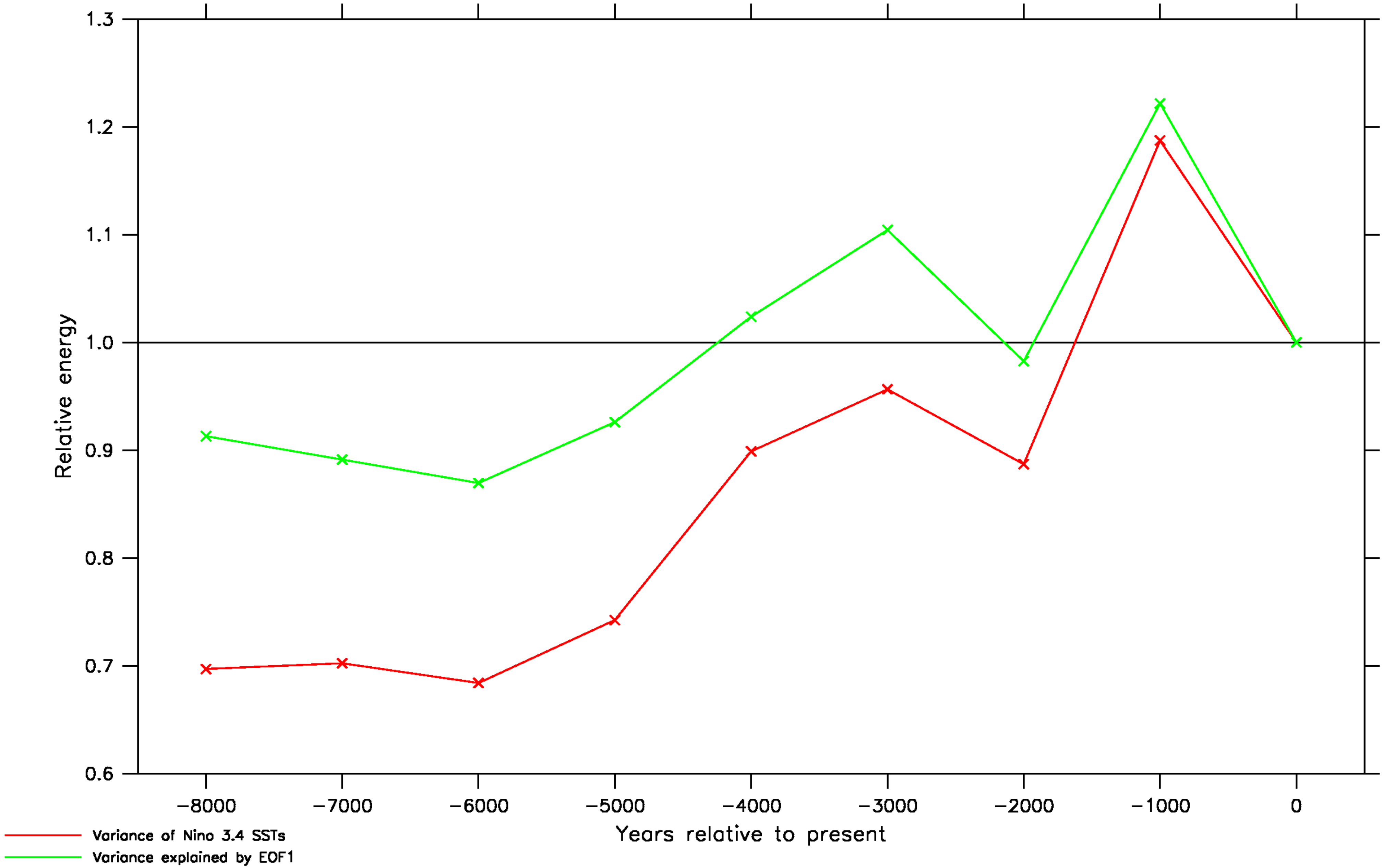
EOF1 of monthly−mean SST: 0 ka (°C)



EOF1 of monthly−mean SST: 6 ka (°C)



Energy associated with El Nino mode



Energy associated with El Nino mode

Conclusions

- Modelling studies suggest orbitally-driven insolation changes account for the changes in ENSO behaviour over the Holocene
- Models and proxy reconstructions disagree on the magnitude of the changes
- We appear to understand the link between insolation and El Niño in the mid-Holocene, but this mechanism breaks down over the past ~2,000 years
- There appear to be more processes at work
- We need to define better diagnostics, which can be applied to both models and the palaeoclimate record
- Lots more work to do!