# Understanding ENSO dynamics through the exploration of past climates

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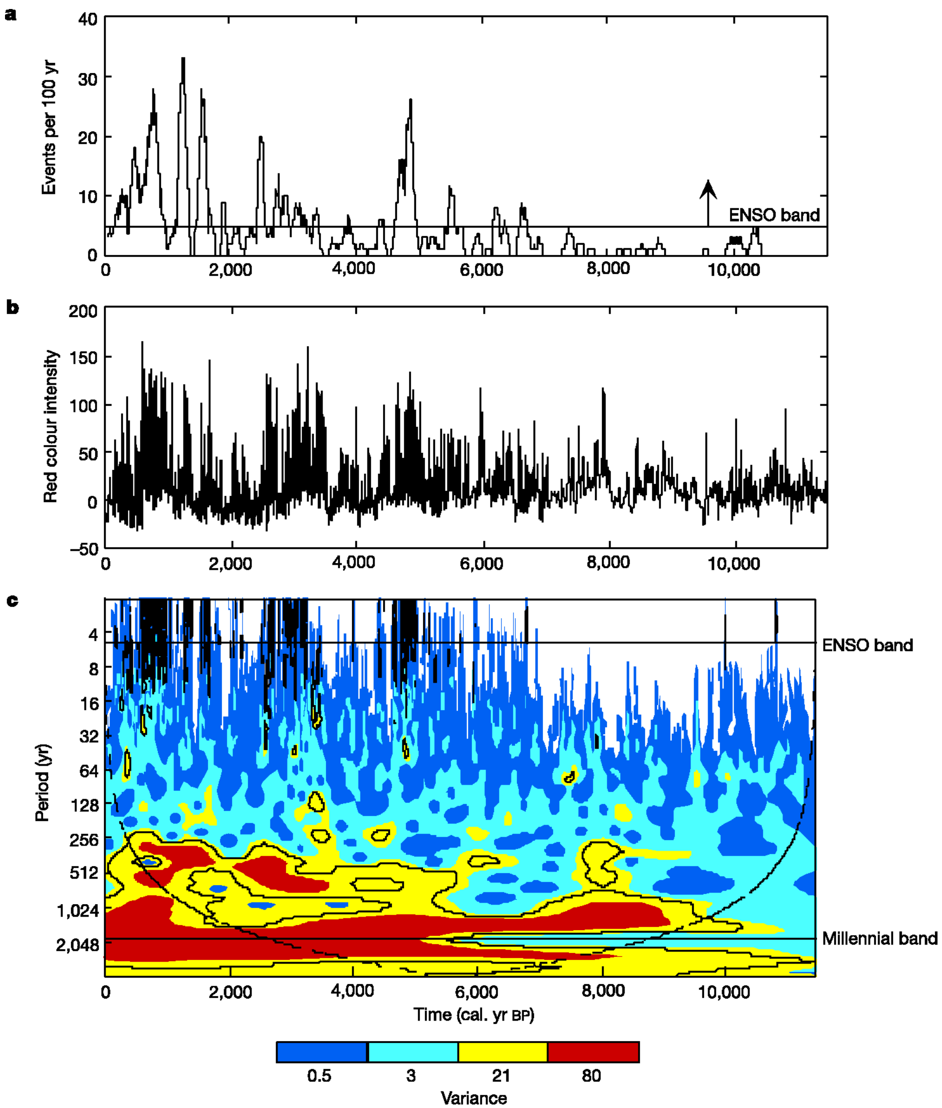
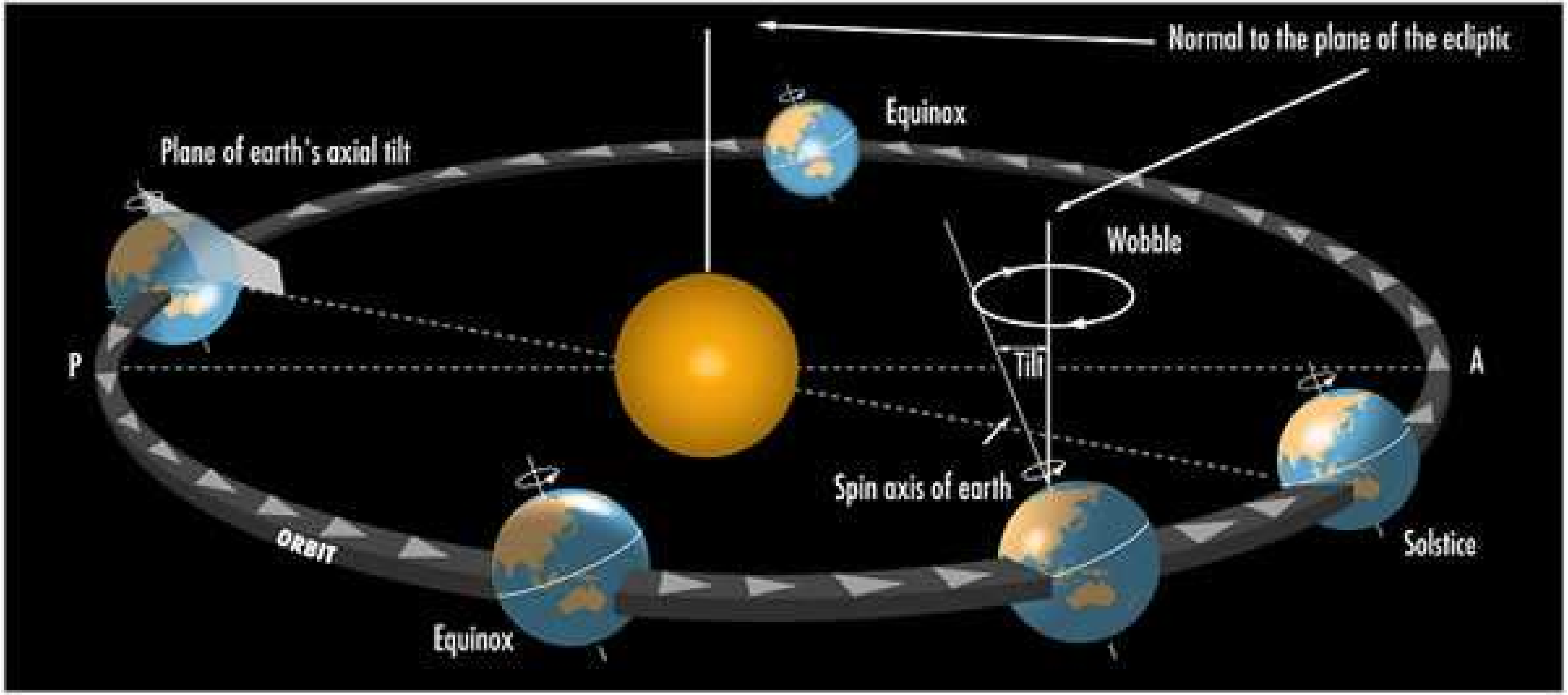
# El Niño has changed...



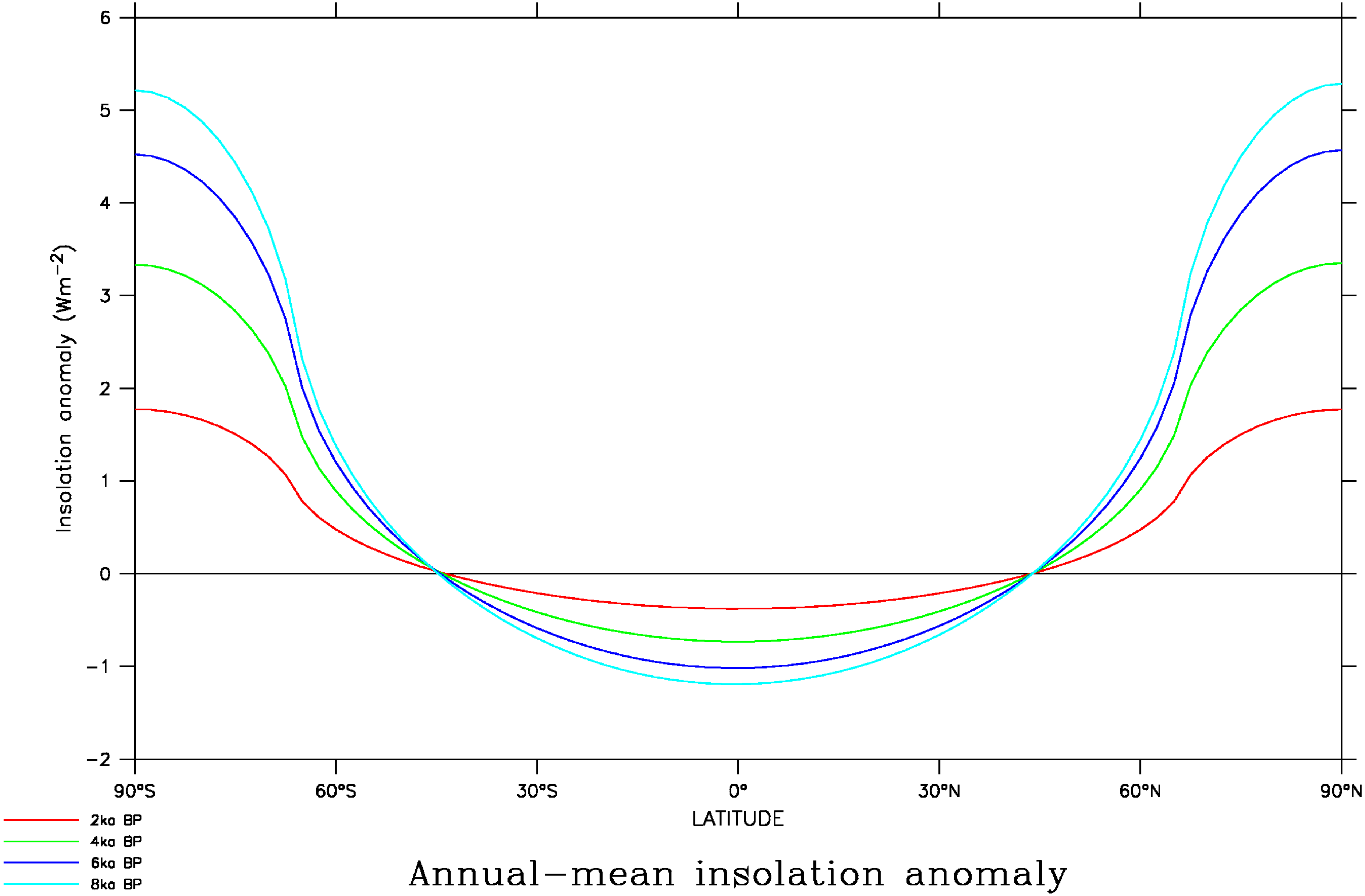

Moy et al. (2002), *Nature*

- "Modern" El Niño began 7-5 ka BP, with only weak decadal-scale 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

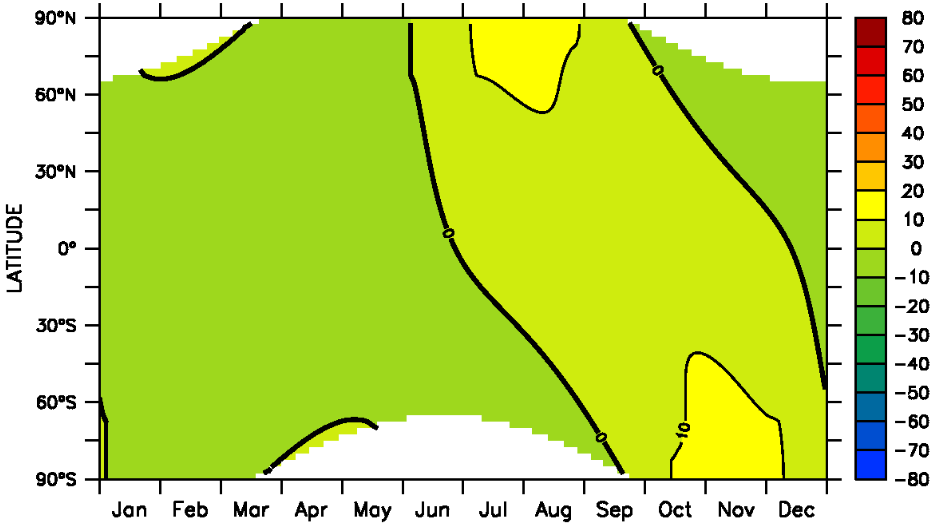
# ... driven by changes in the Earth's orbital geometry



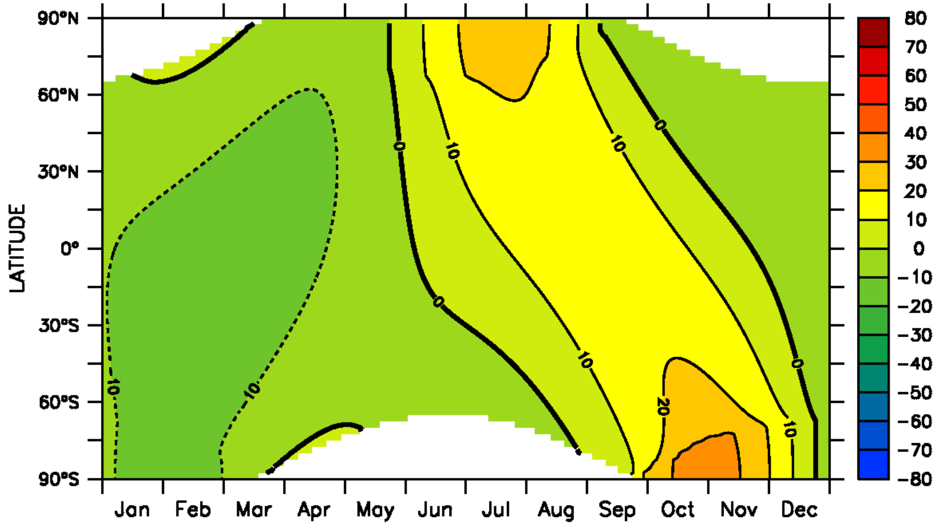
# The changes in annual-mean insolation are small...



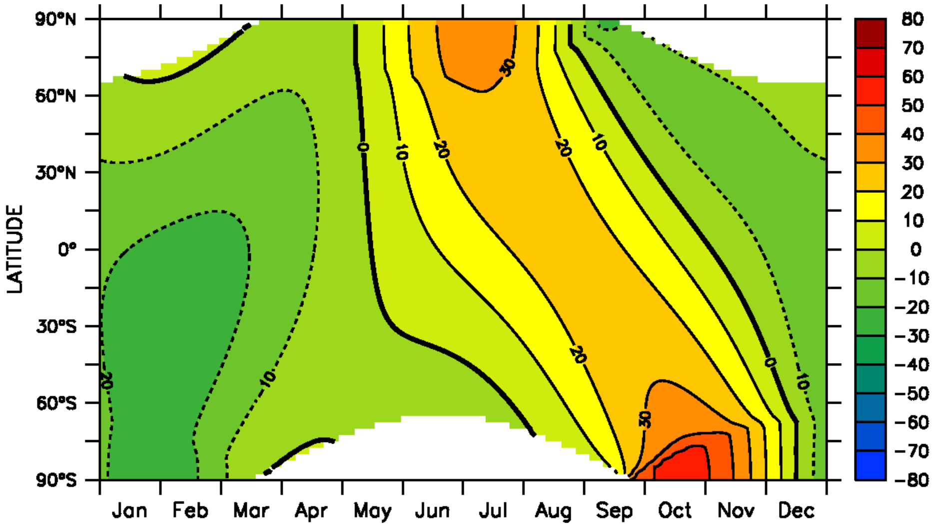
# … but the seasonal changes are large



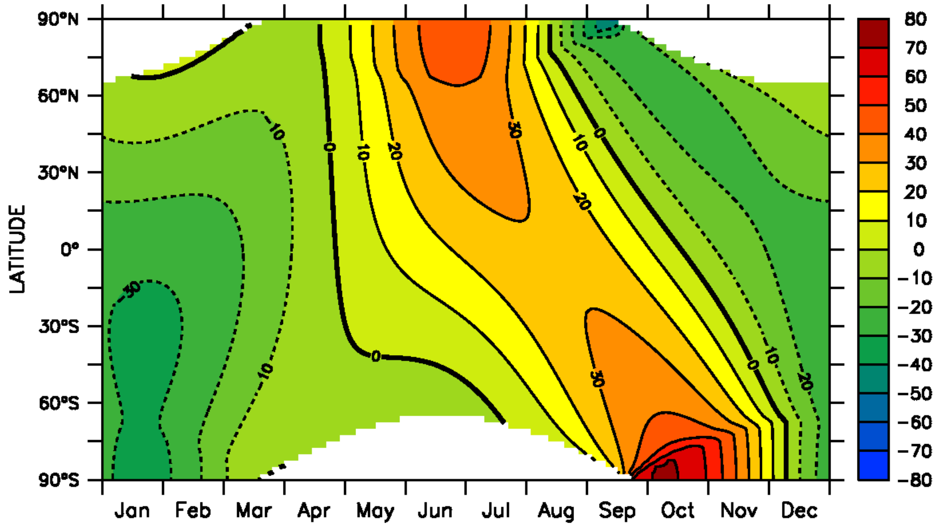

Insolation anomaly ($Wm^{-2}$): 2ka BP




Insolation anomaly ($Wm^{-2}$): 4ka BP




Insolation anomaly ($Wm^{-2}$): 6ka BP




Insolation anomaly ($Wm^{-2}$): 8ka BP

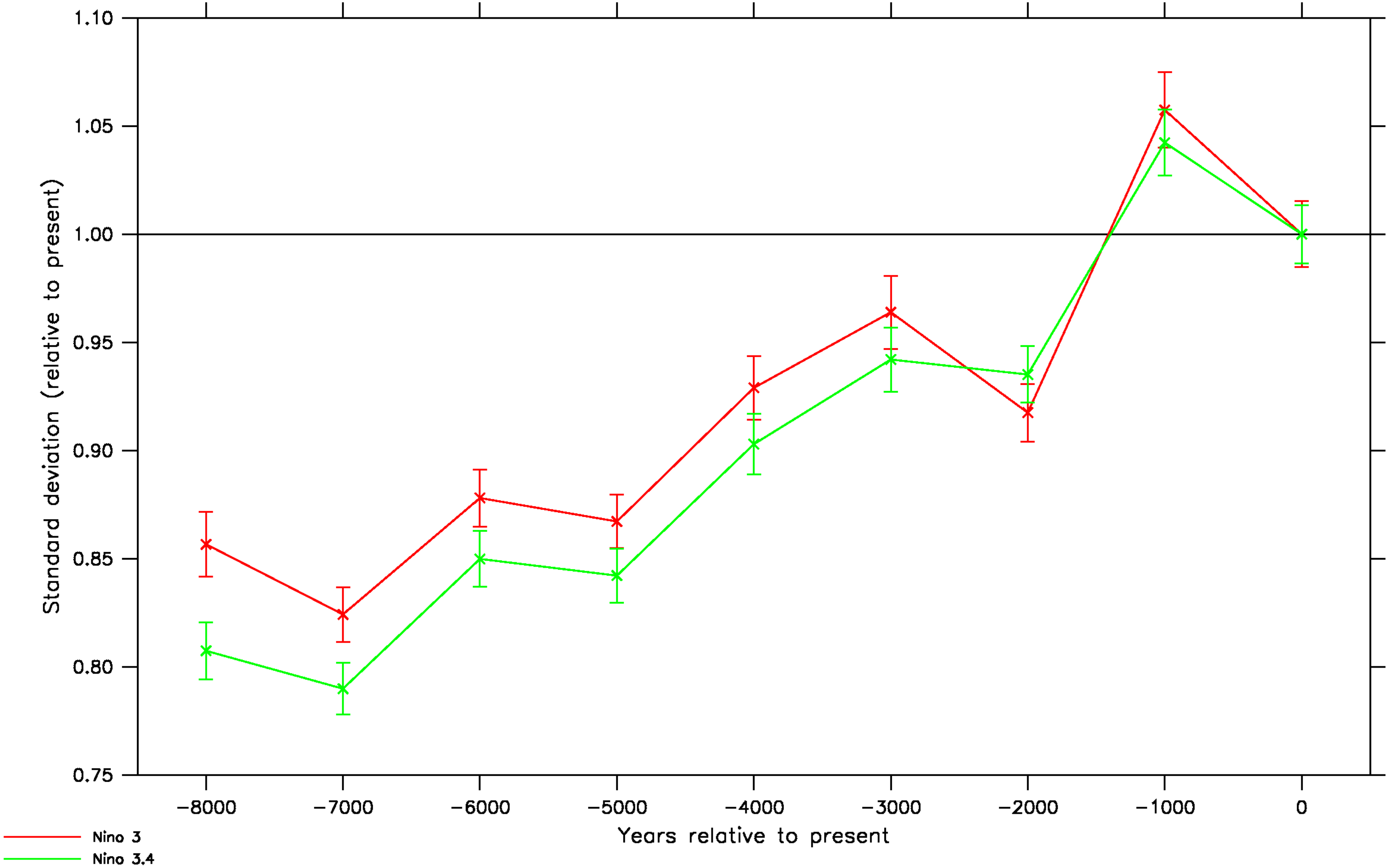
# Current understanding

- Previous modelling work has shown that orbitally-driven changes in insolation can alter ENSO behaviour
- Broadly consistent mechanism found to explain weaker mid-Holocene ENSO:
  - Insolation changes result in enhanced seasonal cycle in NH
  - Intensification of summer monsoon system
  - Enhanced Walker circulation
  - Stronger easterly trade winds in central and western Pacific
  - Steeper thermocline/increased upwelling in central and eastern Pacific
  - Suppresses development of El Niño events
- However, this proposed mechanism is qualitative in nature and has yet to be rigorously tested

# Simulations of the late Holocene climate

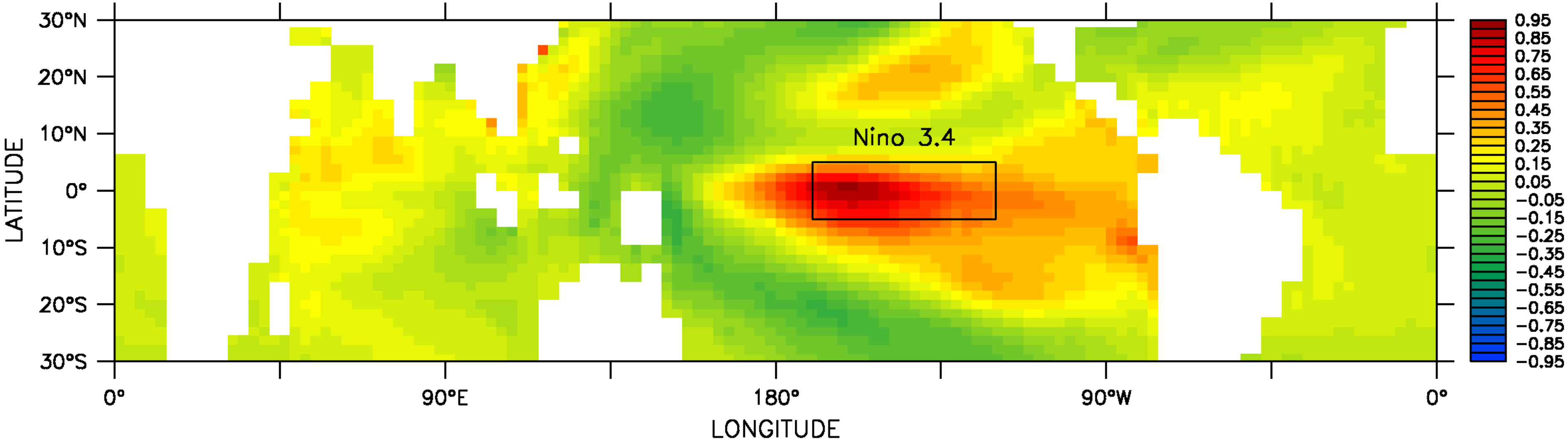
- CSIRO Mk3L climate system model v1.1:
  - Atmosphere: R21 ($5.6^\circ \times 3.2^\circ$), 18 vertical levels
  - Ocean: $2.8^\circ \times 1.6^\circ$, 21 vertical levels
  - Sea ice: Dynamic-thermodynamic
  - Land surface: Static vegetation
  - Flux adjustments applied
- Snapshot simulations for 8, 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

# Simulated changes in ENSO variability

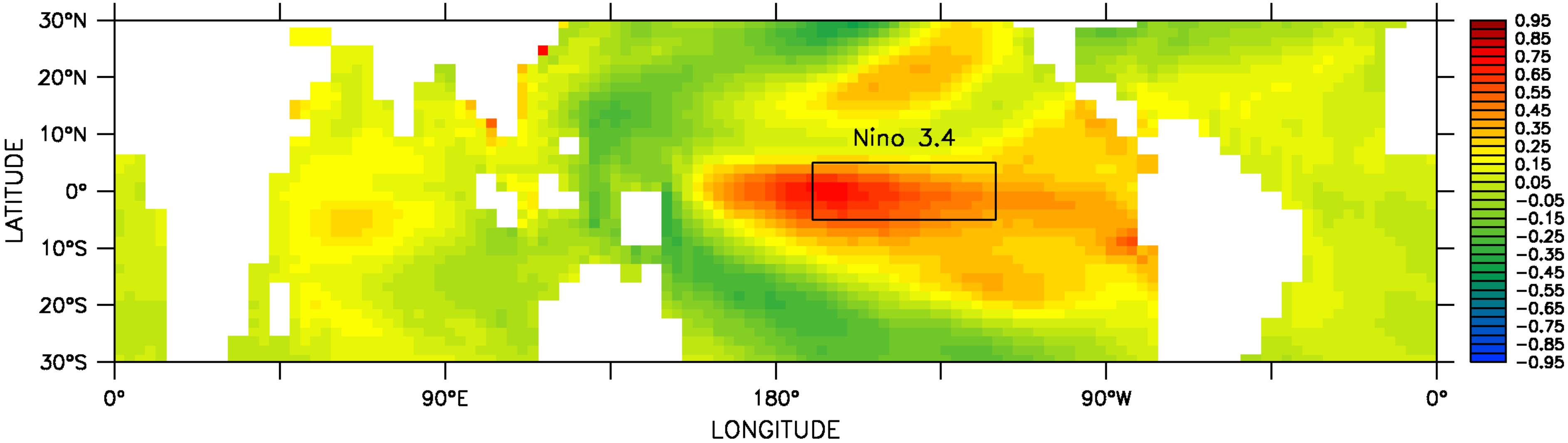



Standard deviation of Nino SST anomaly

# ENSO strengthens and shifts eastwards

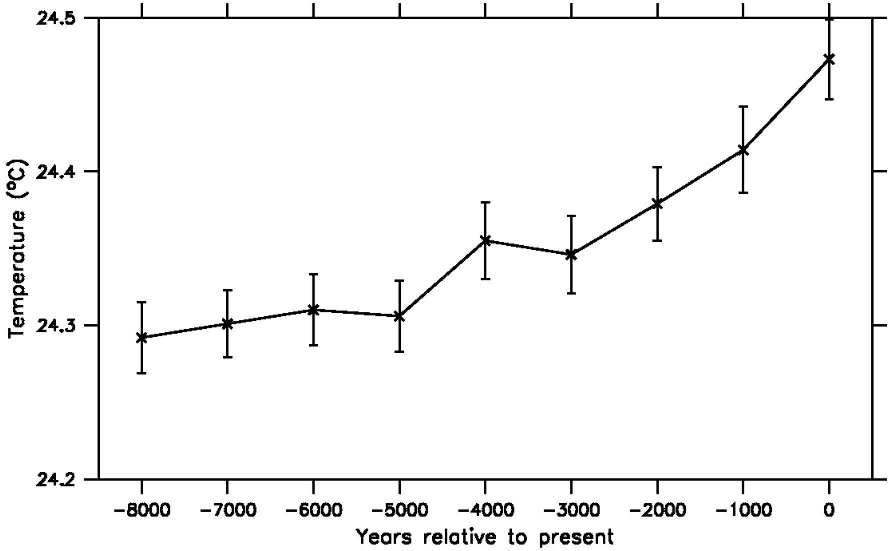



EOF1 of monthly SST anomalies (°C): 0ka BP

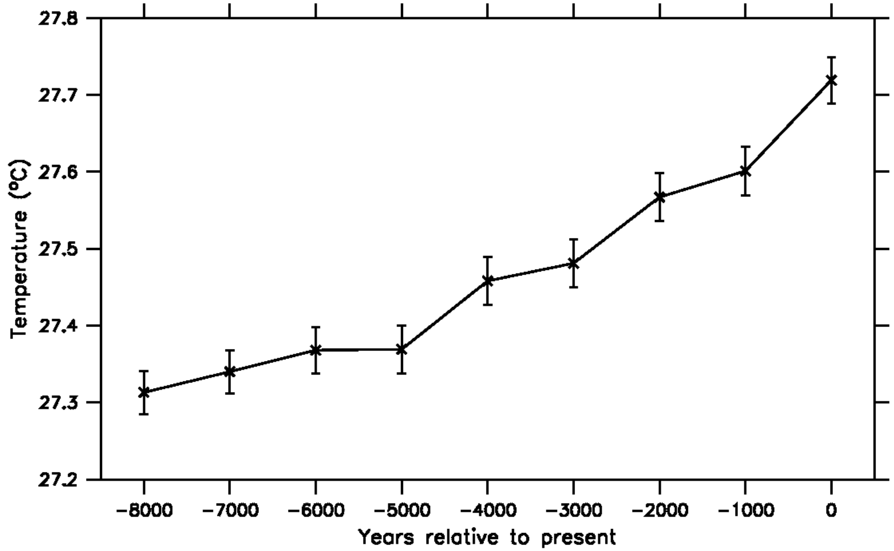



EOF1 of monthly SST anomalies (°C): 8ka BP

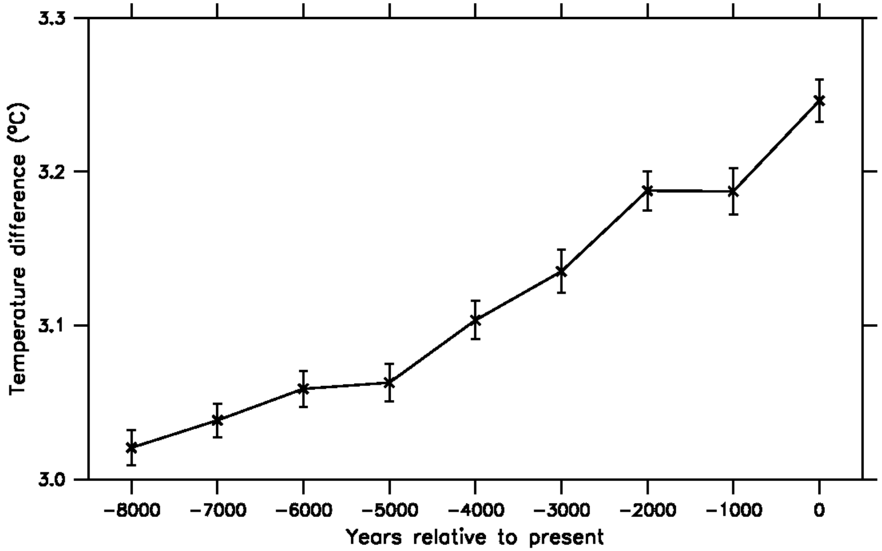
# The changes in the mean state are small...



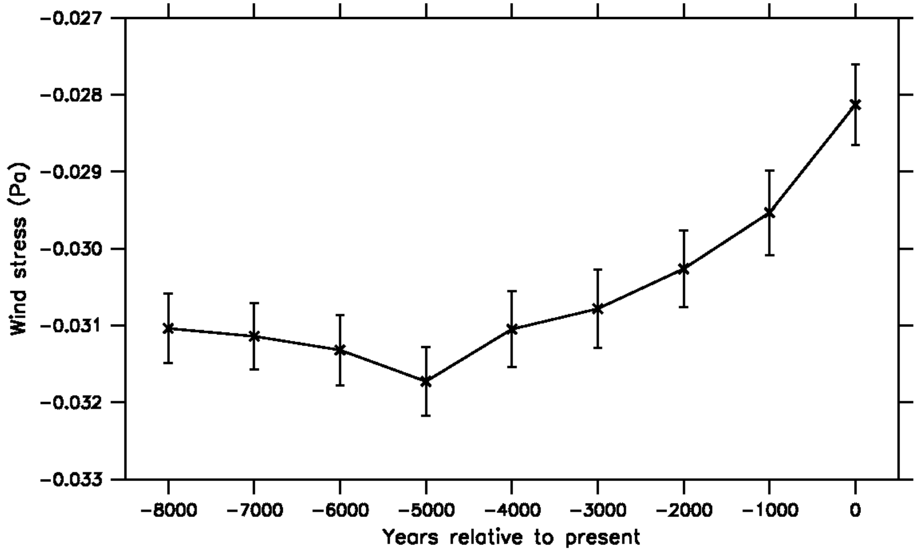

(a) Annual−mean Nino 3 SST




(b) Annual−mean Nino 4 SST

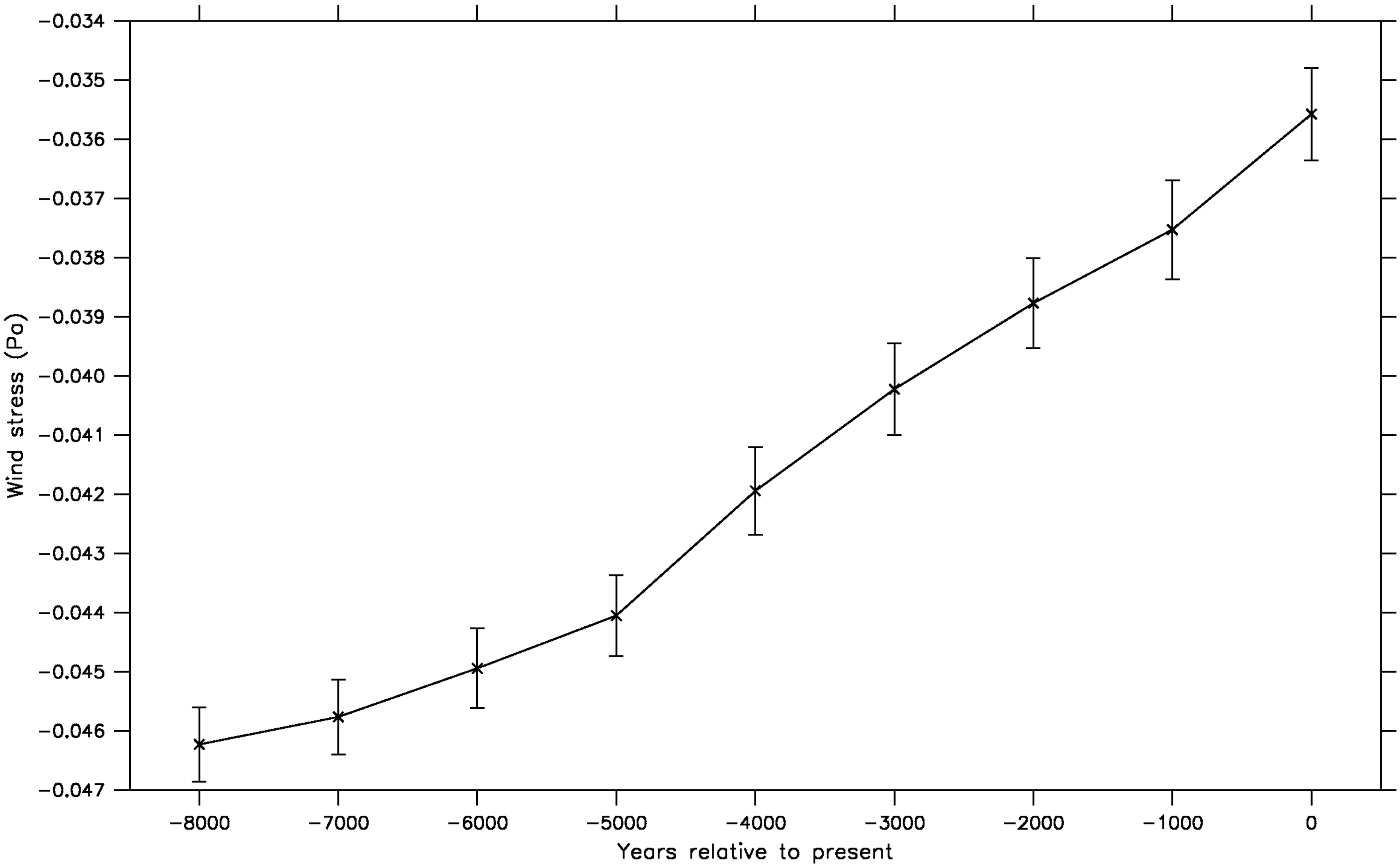



(c) Nino 4 SST minus Nino 3 SST



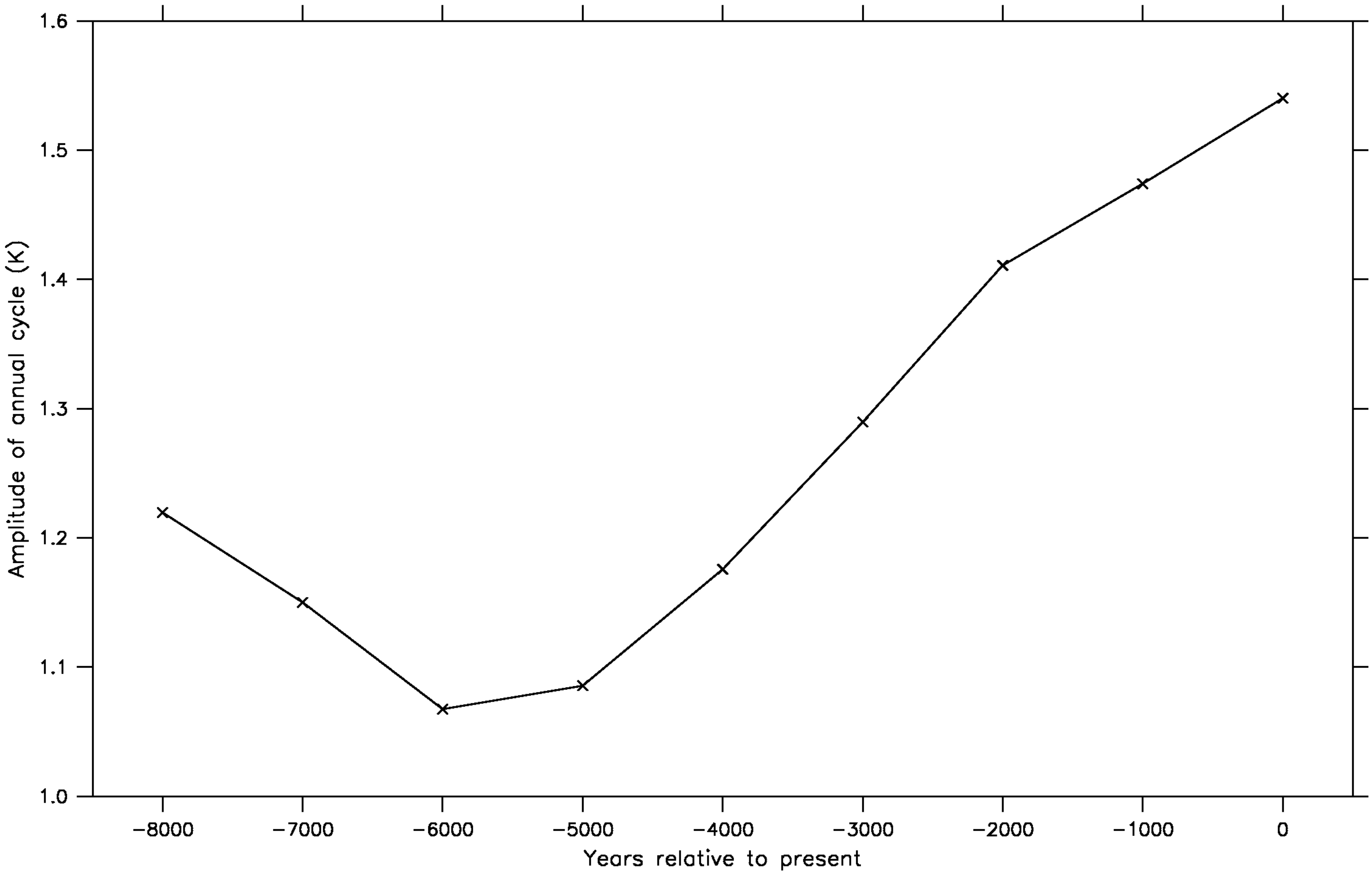

(d) Annual−mean Nino 4 zonal wind stress

# … but the seasonal changes are larger



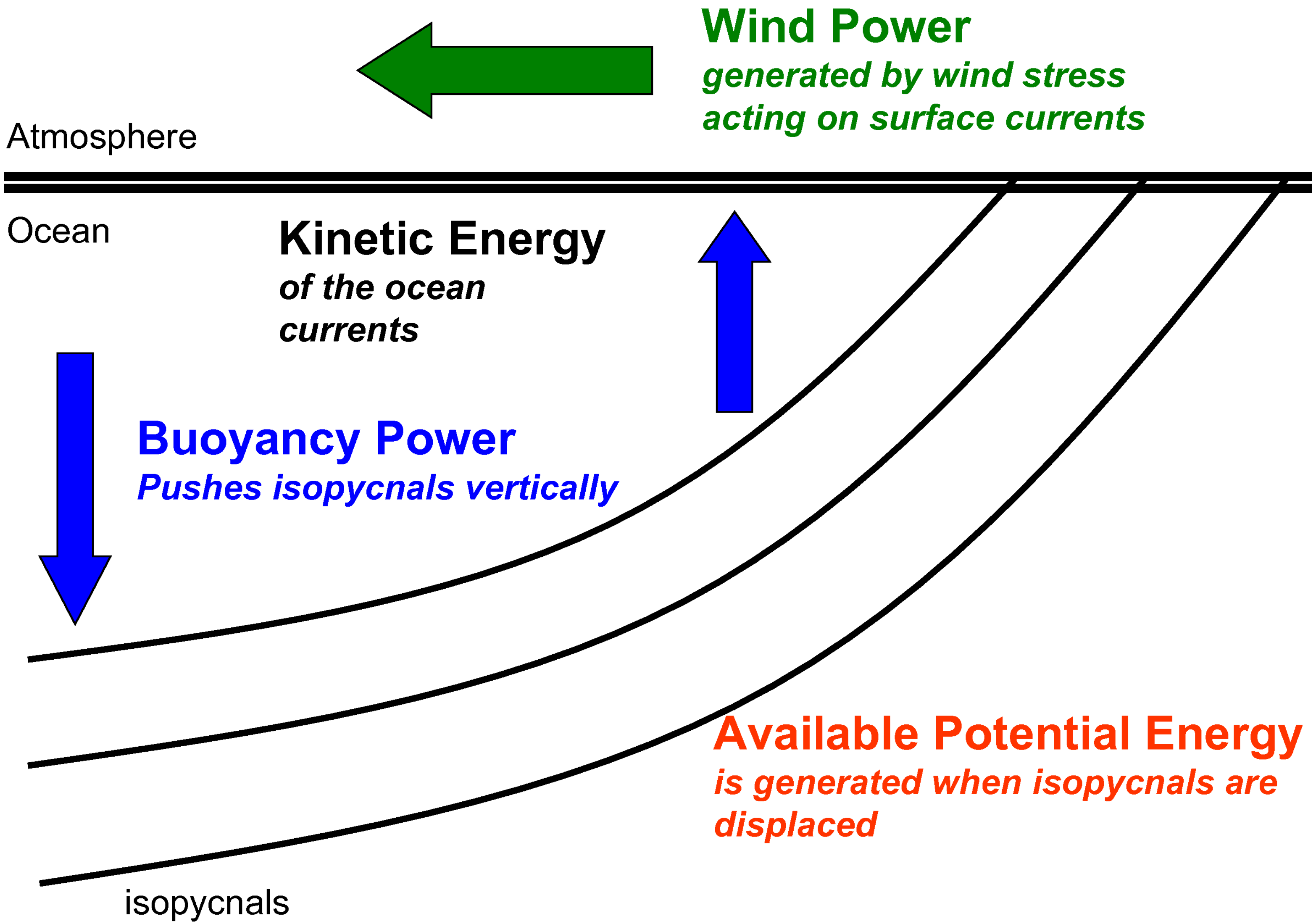

JASO zonal wind stress in Nino 4 region

# No apparent correlation with the annual cycle

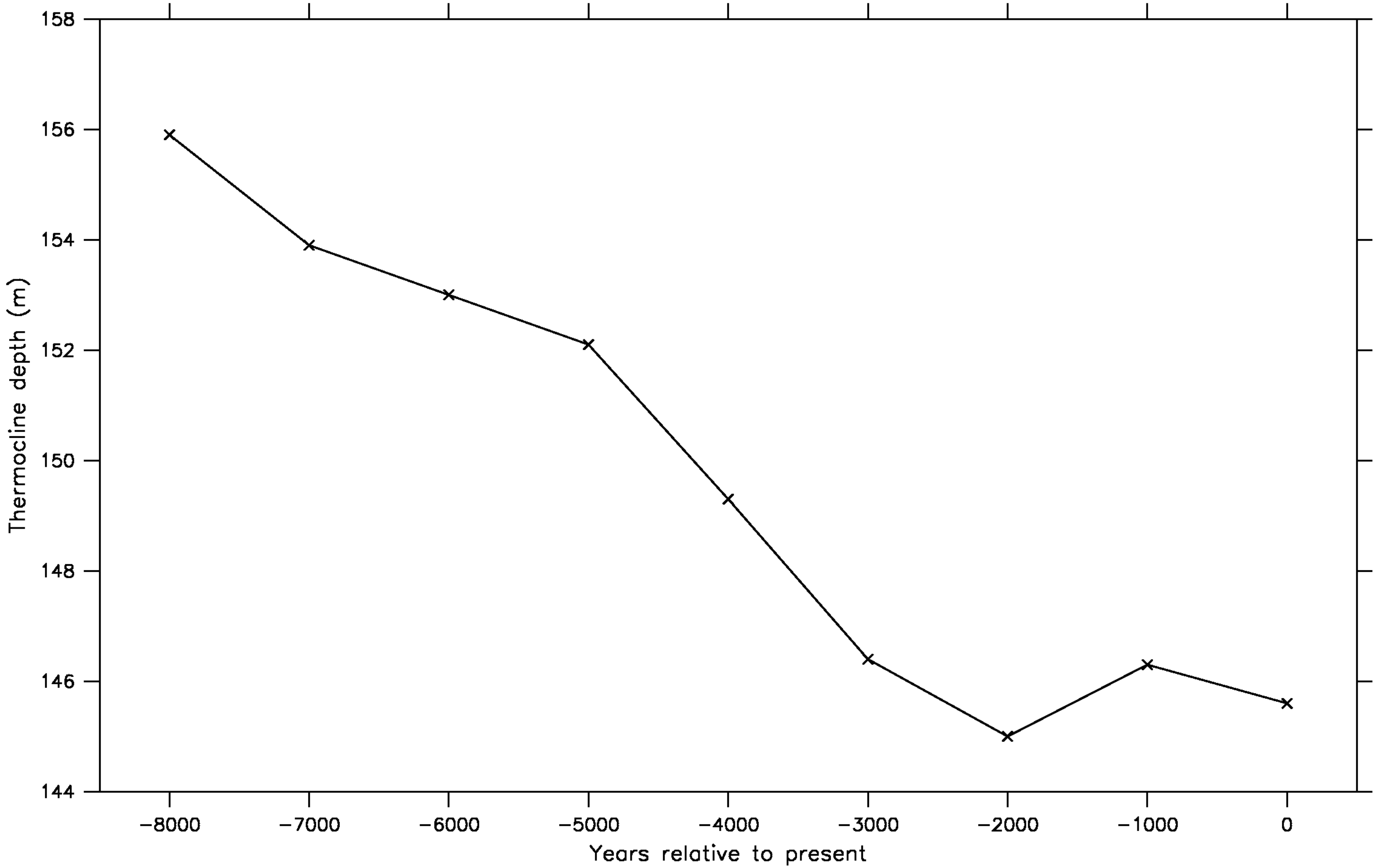



Amplitude of annual cycle in Nino 3 SST

# Ocean energetics



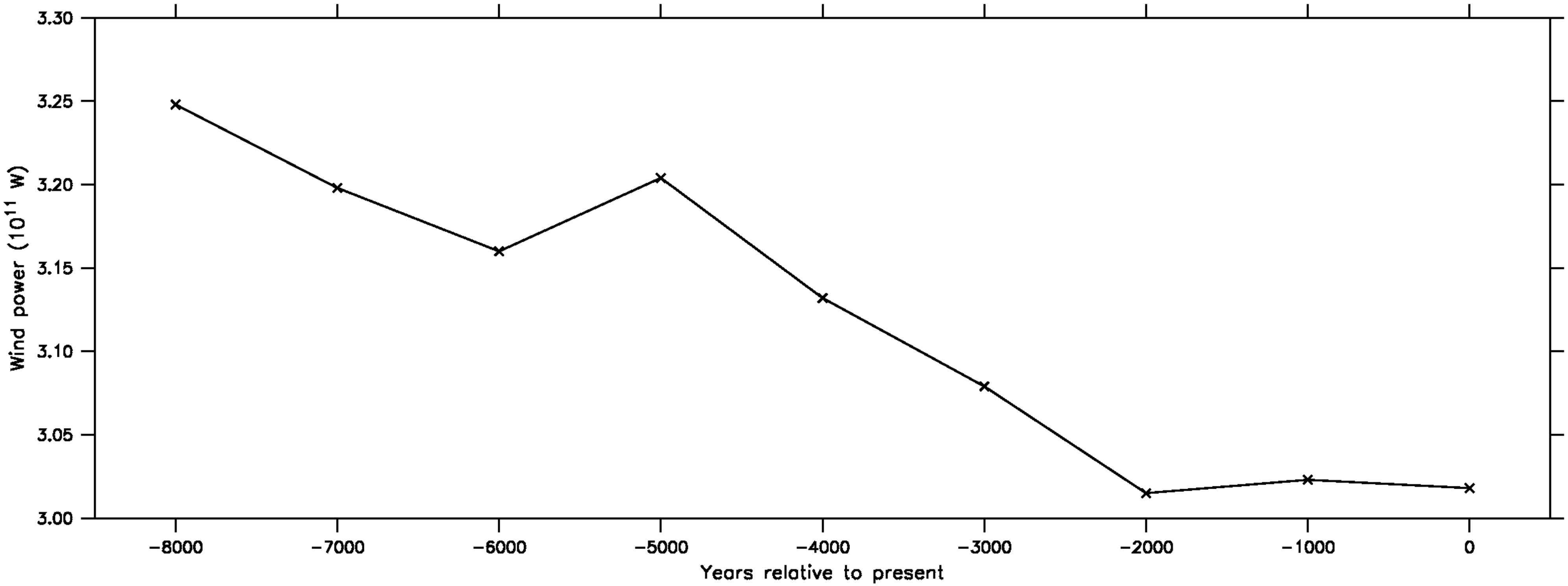
# The thermocline becomes shallower




Mean thermocline depth in equatorial Pacific

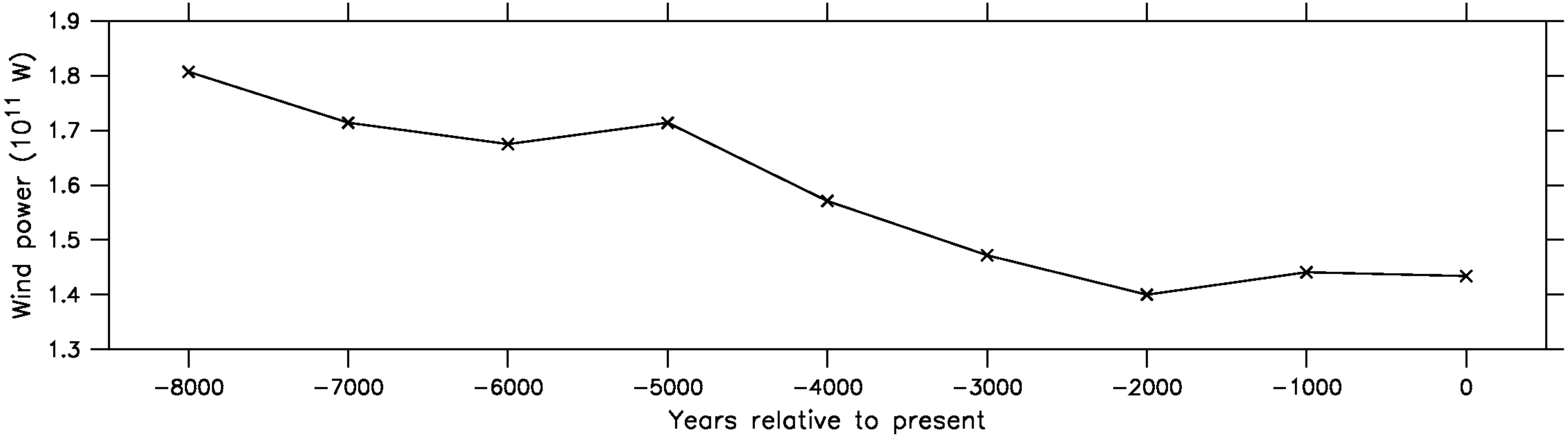
# The changes in annual-mean wind power are small...

$$W = \iint_{z=0} \underline{u}.\underline{\tau}\, dxdy$$

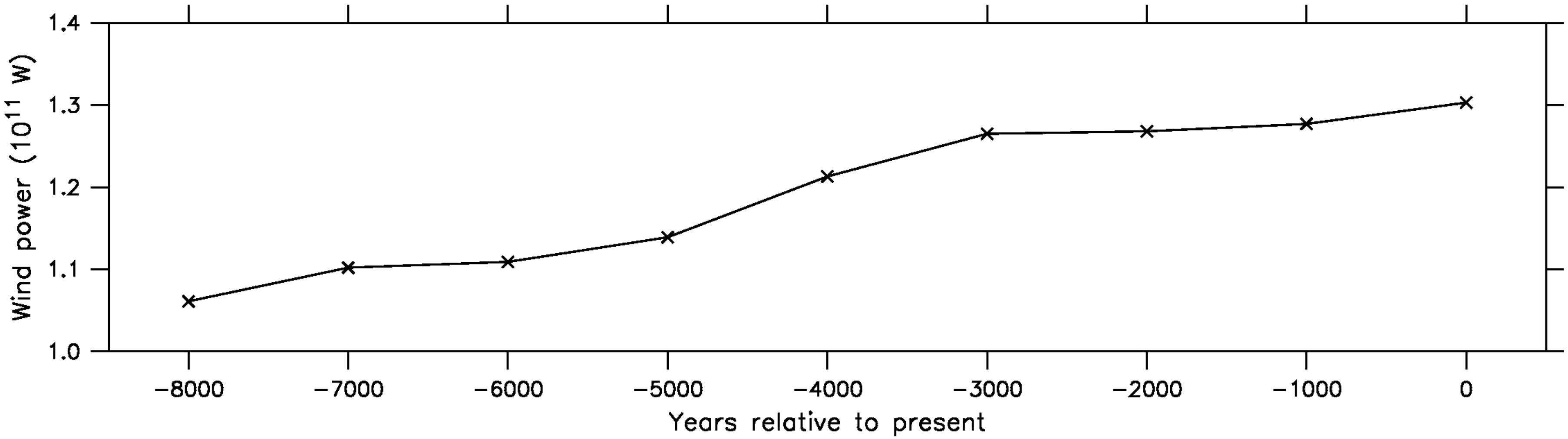



Annual−mean wind power

# ... but the seasonal changes are larger

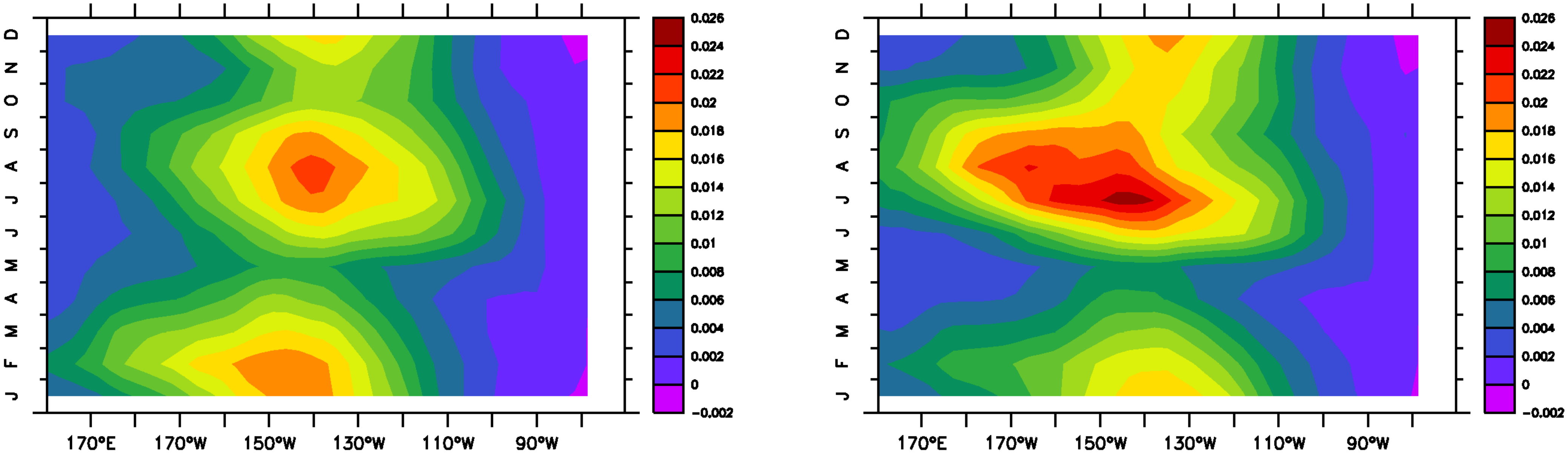



June−July−August−September wind power




January−February−March−April wind power

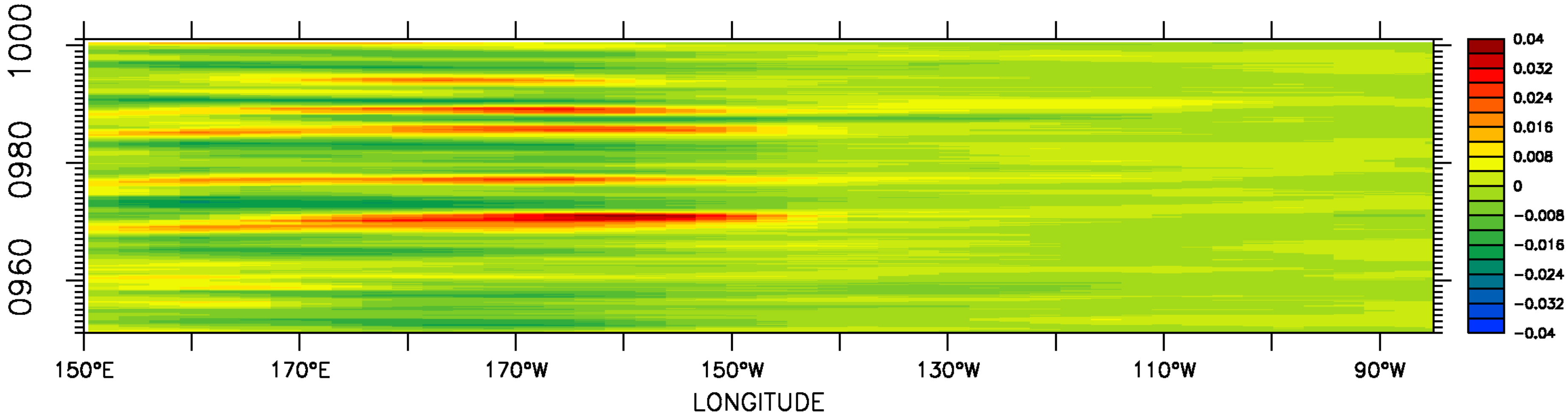
# Annual cycle in wind power on the equator



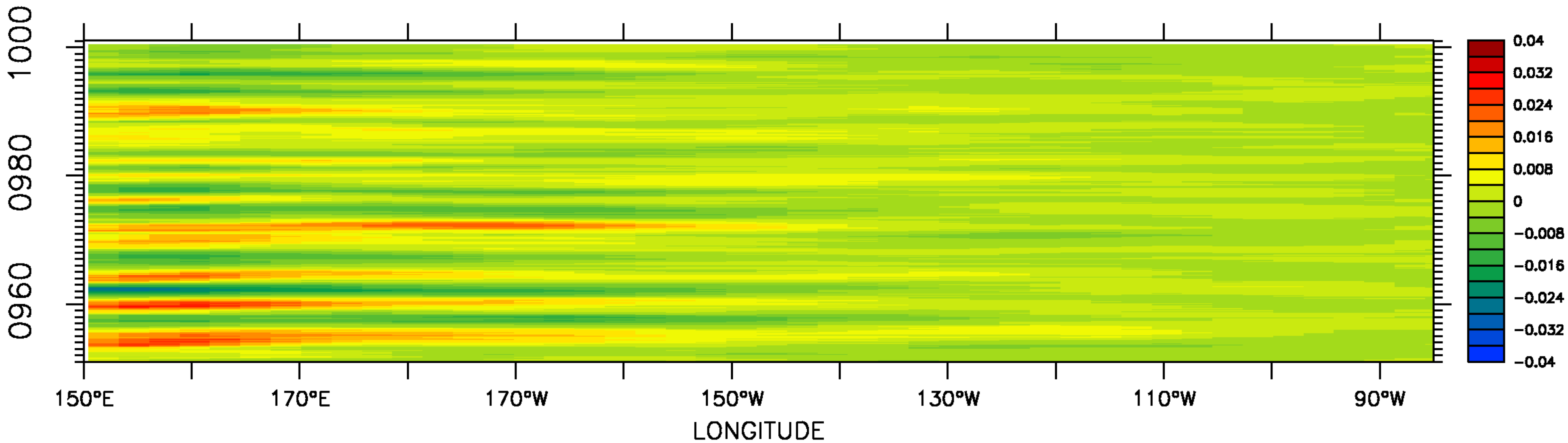

**0 ka** **8 ka**

Wind power ($Wm^{-2}$)

# Propagation of Westerly Wind Bursts




Zonal wind stress anomaly at equator (Pa): 0ka BP




Zonal wind stress anomaly at equator (Pa): 8ka BP

# Conclusions

- The study of palaeo-ENSO allows us to explore the links between ENSO and the global climate system.
- By forcing a model with orbitally-driven insolation changes only, we are able to broadly reproduce the changes in ENSO behaviour over the Holocene.
- Physical links between ENSO, the Walker Circulation and the Asian monsoon appear to explain the upward trend in variability.
- However, it does not explain the peak at 1 ka. Other mechanisms therefore appear to be at work.
- A full understanding of the processes that drive changes in ENSO variability may be within grasp. However, this will require an approach that integrates the theory, data and modelling communities.