Quantifying changes in ENSO dynamics over the Holocene

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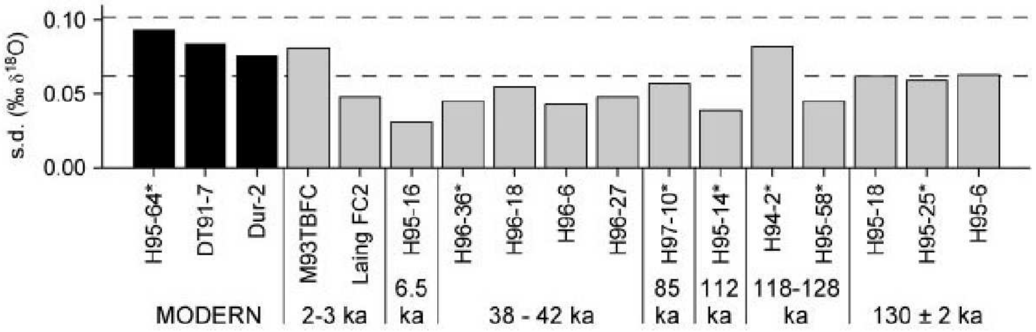
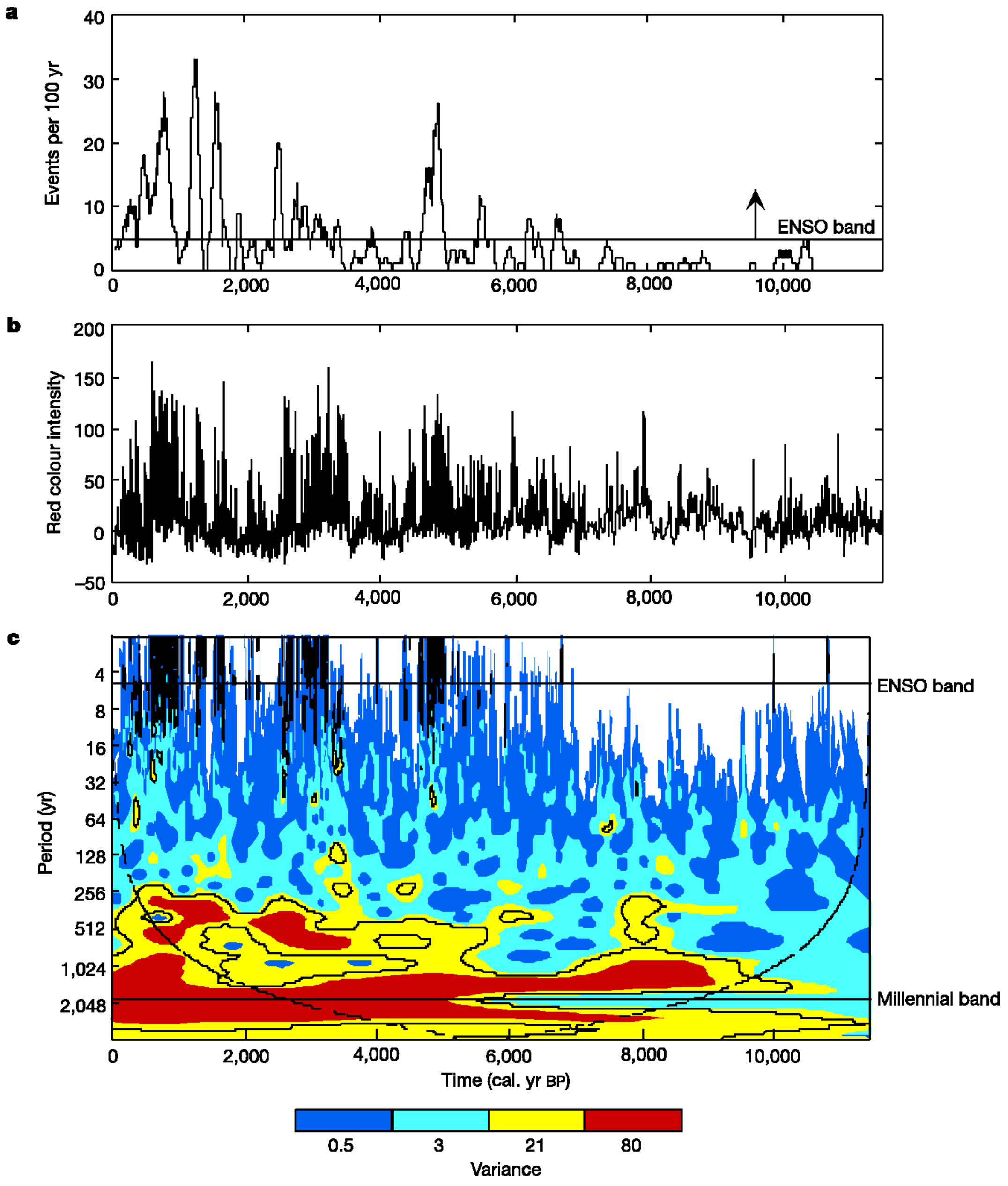
El Niño has changed...

- Proxy reconstructions from across the Pacific Basin show that:
  - "Modern" El Niño began 7-5 ka BP, with only weak decadal-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



Tudhope et al. (2001), *Science*



Moy et al. (2002), *Nature*

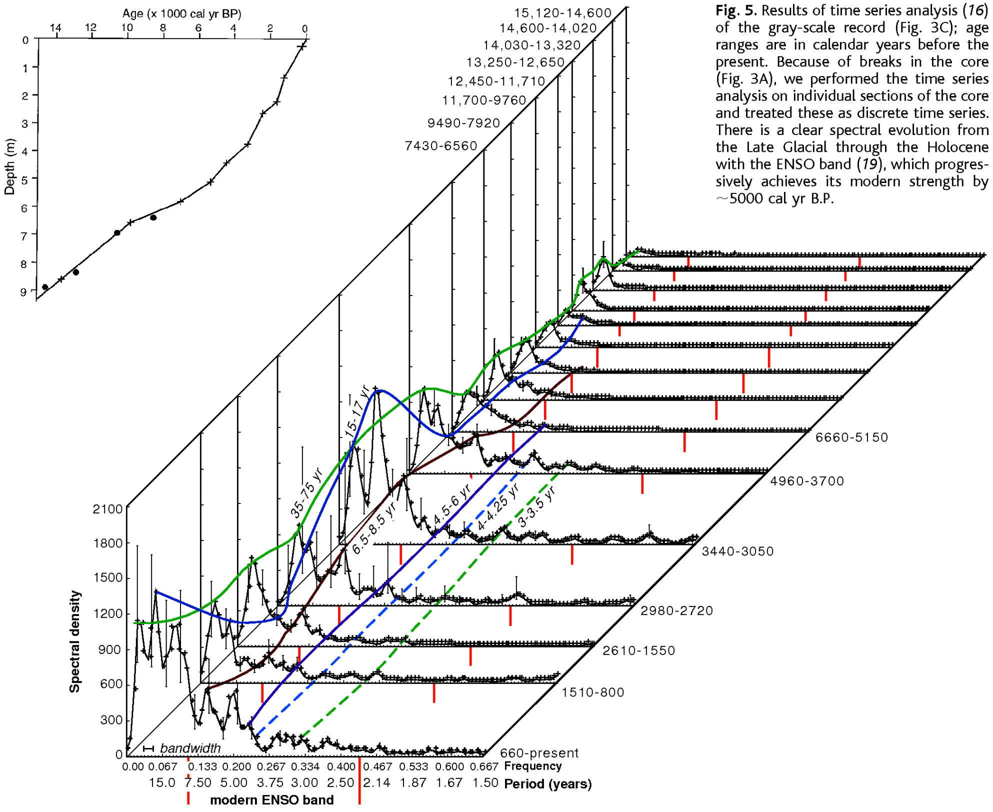
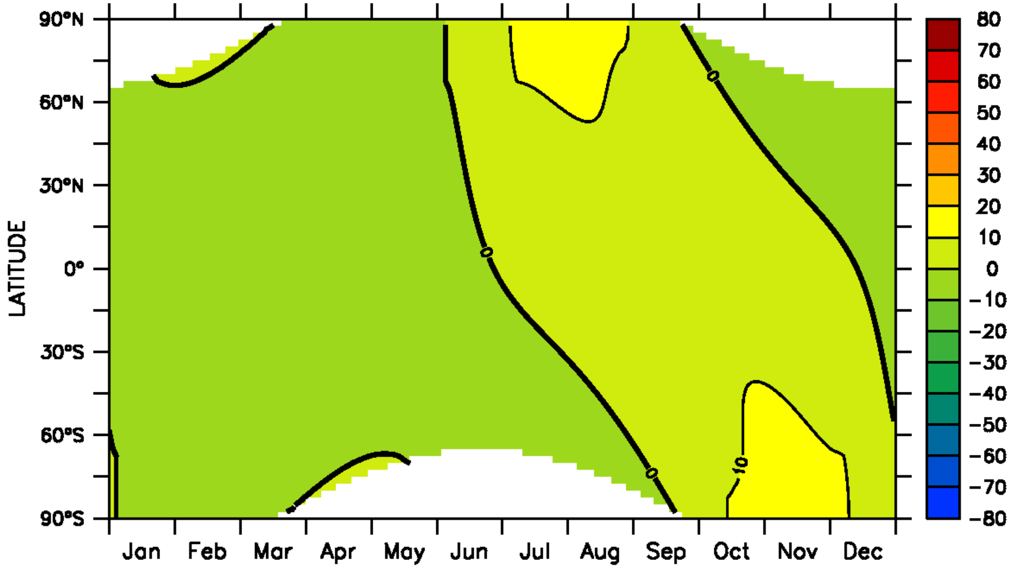
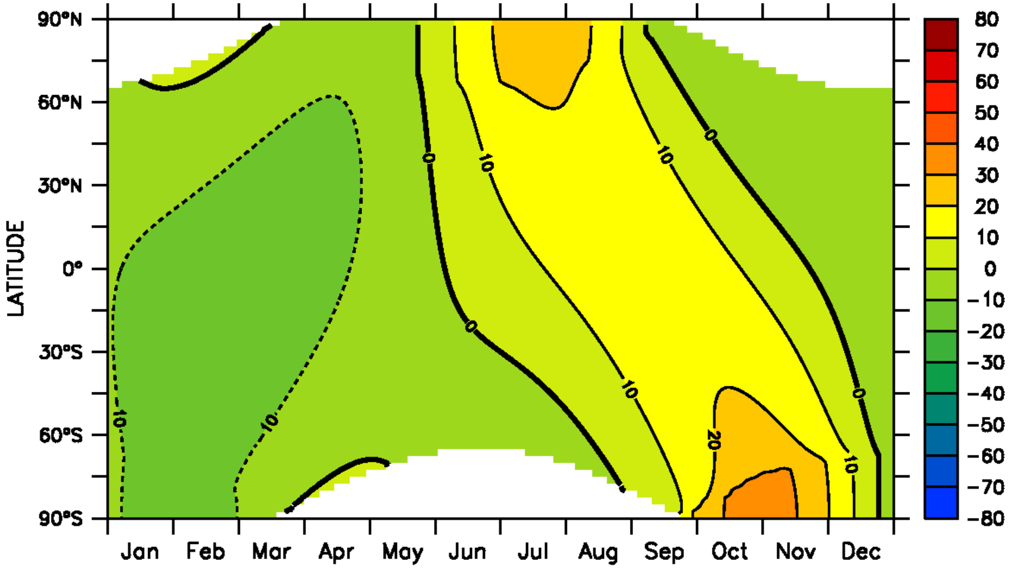


Fig. 5. Results of time series analysis (*16*) of the gray-scale record (Fig. 3C); age ranges are in calendar years before the present. Because of breaks in the core (Fig. 3A), we performed the time series analysis on individual sections of the core and treated these as discrete time series. There is 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.

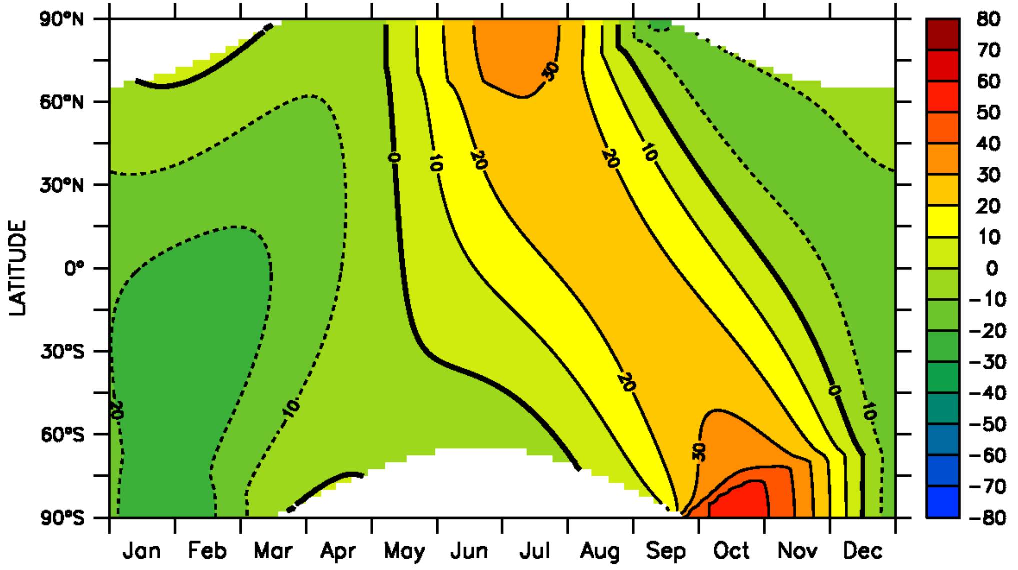
Rodbell et al. (1999), *Science*



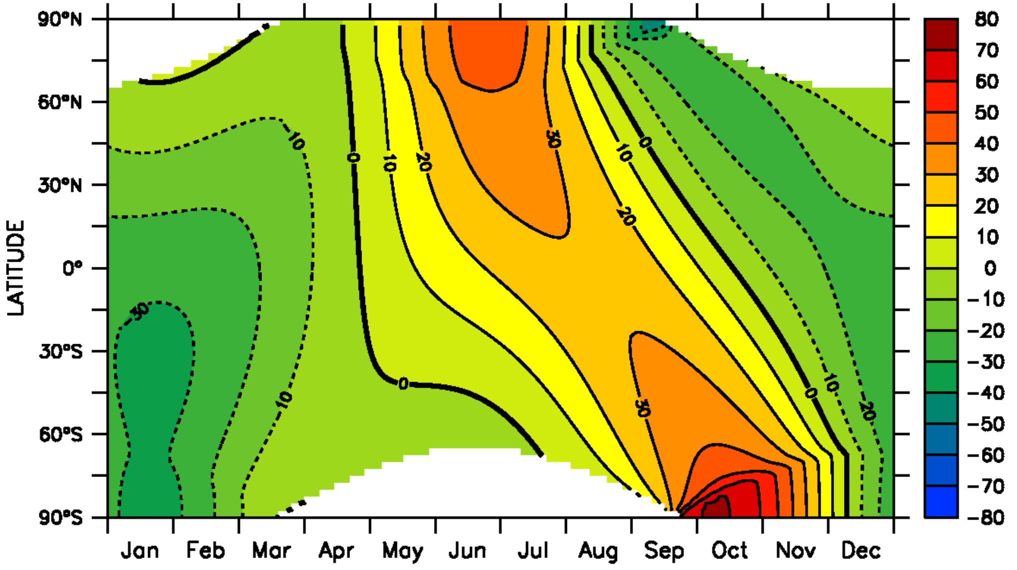
Insolation anomaly (Wm^{-2}): 2ka BP



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



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



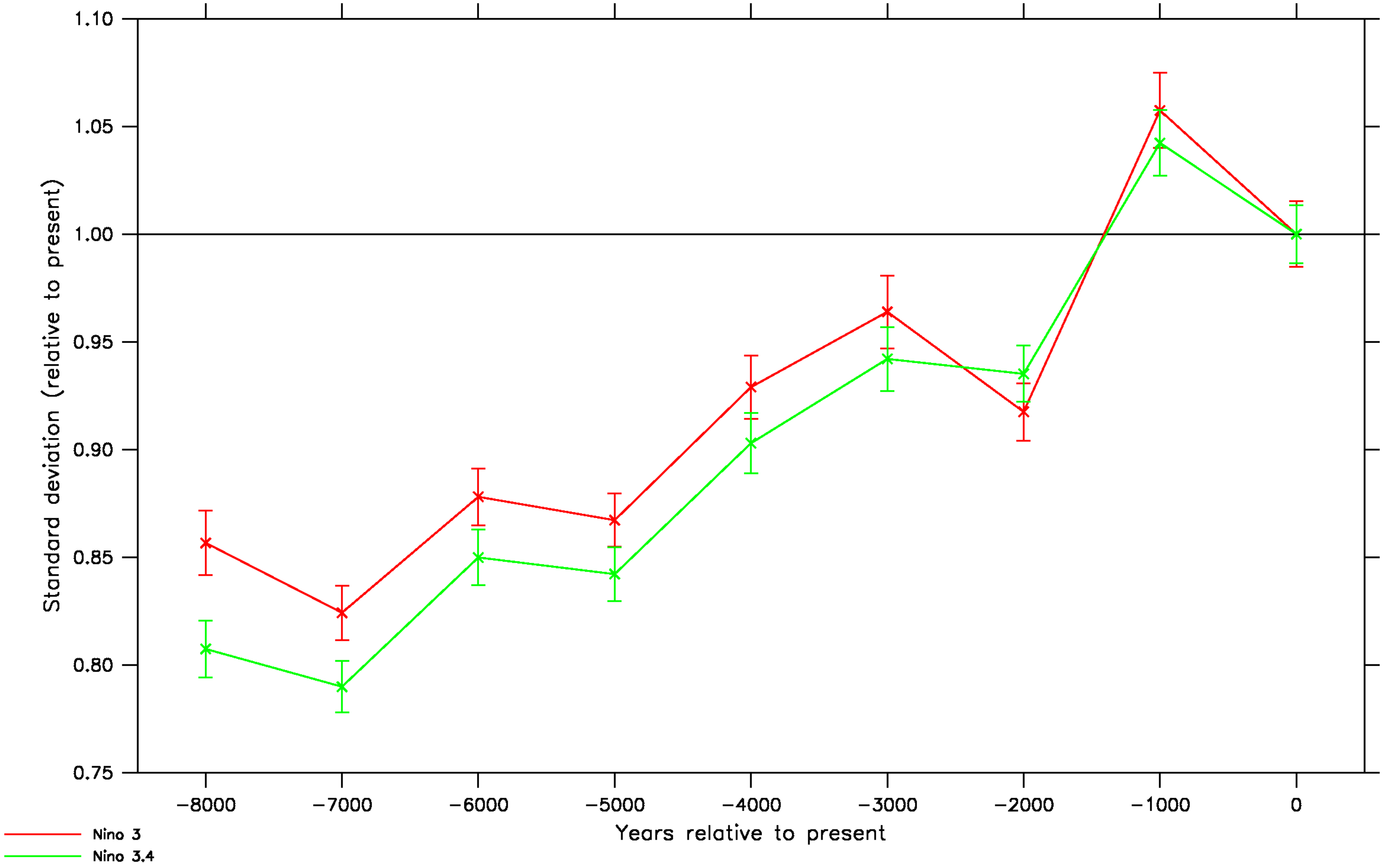
Insolation anomaly (Wm^{-2}): 8ka BP

Current understanding

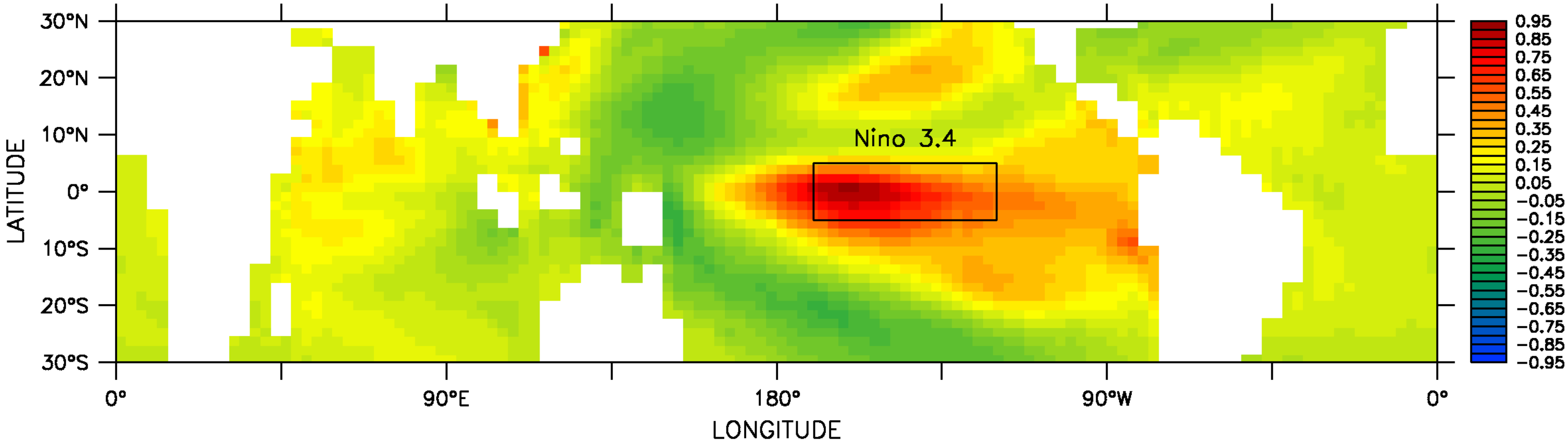
- Previous modelling work has shown that orbitally-driven changes in insolation can alter ENSO behaviour
- Broadly consistent mechanism found to explain weaker mid-Holocene ENSO:
  - Insolation changes result in enhanced seasonal cycle in NH
  - Intensification of summer monsoon system
  - Enhanced Walker 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

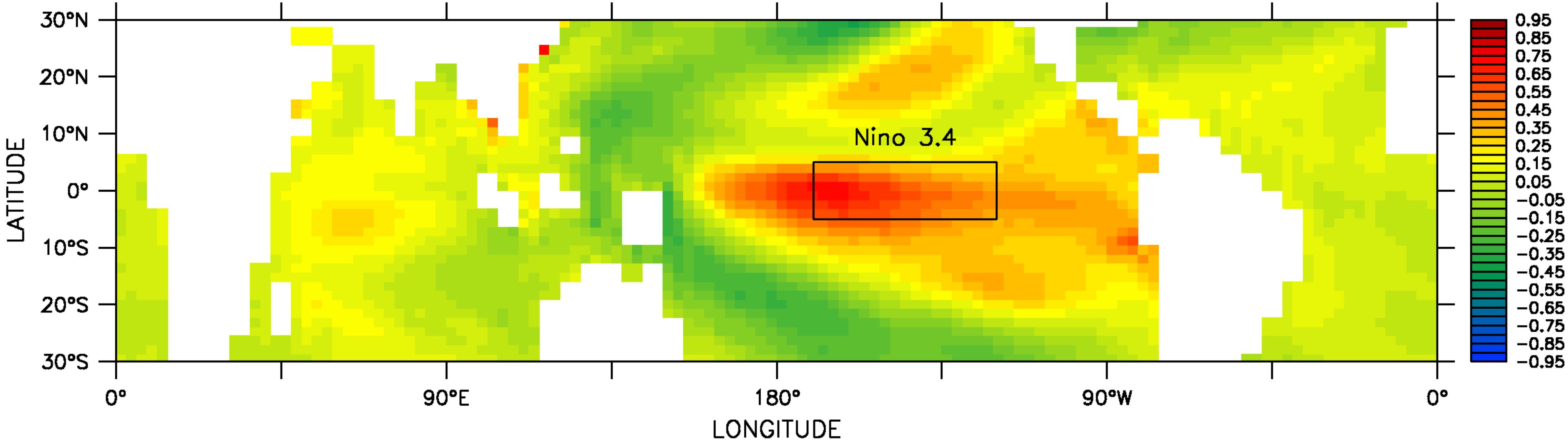
- CSIRO Mk3L climate system model v1.1:
  - Atmosphere: R21 ($5.6^\circ \times 3.2^\circ$), 18 vertical levels
  - Ocean: $2.8^\circ \times 1.6^\circ$, 21 vertical levels
  - Sea ice: Dynamic-thermodynamic
  - Land surface: Static vegetation
  - Flux adjustments applied
- Snapshot simulations for 8,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



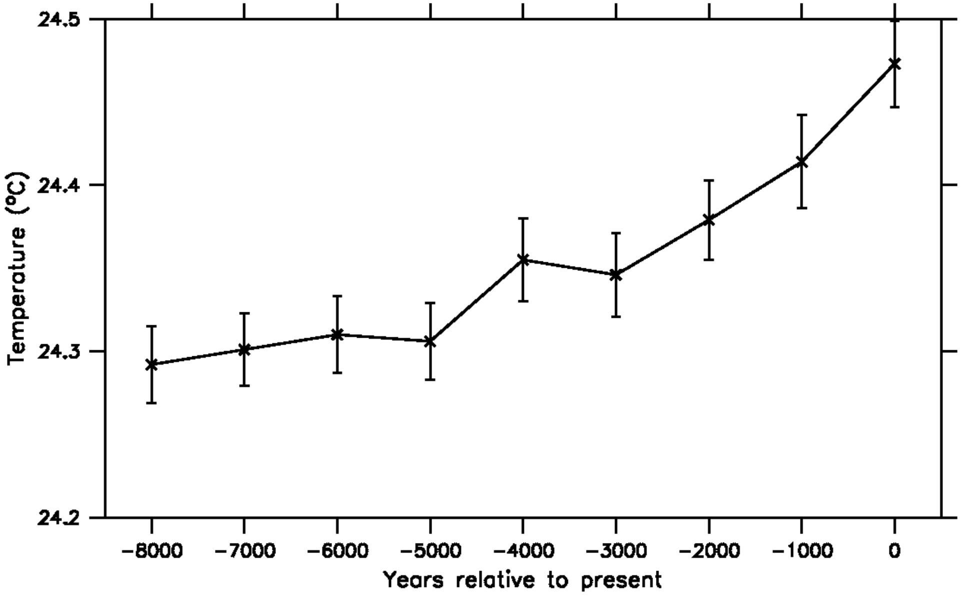
Standard deviation of Nino SST anomaly



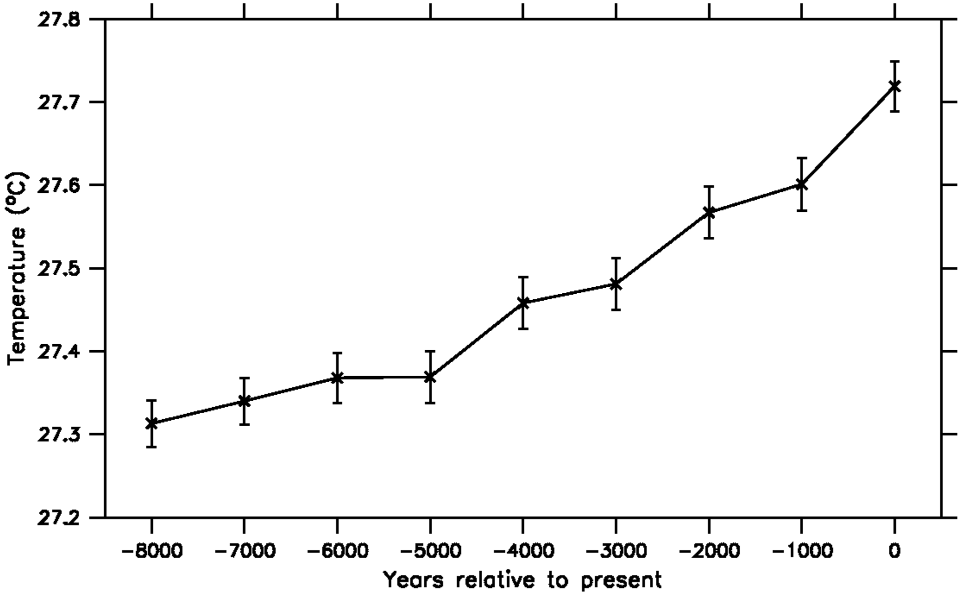
EOF1 of monthly SST anomalies (°C): 0ka BP



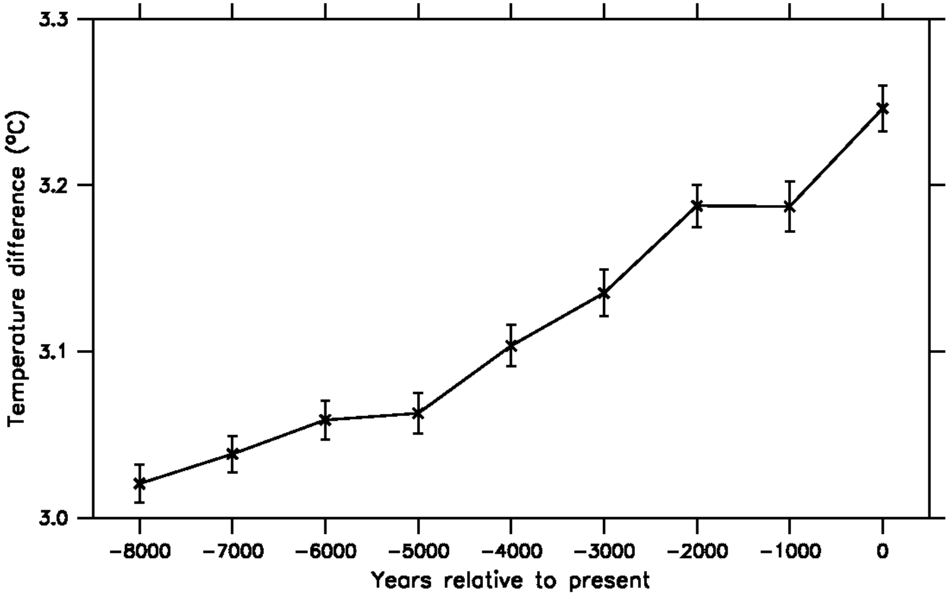
EOF1 of monthly SST anomalies (°C): 8ka BP



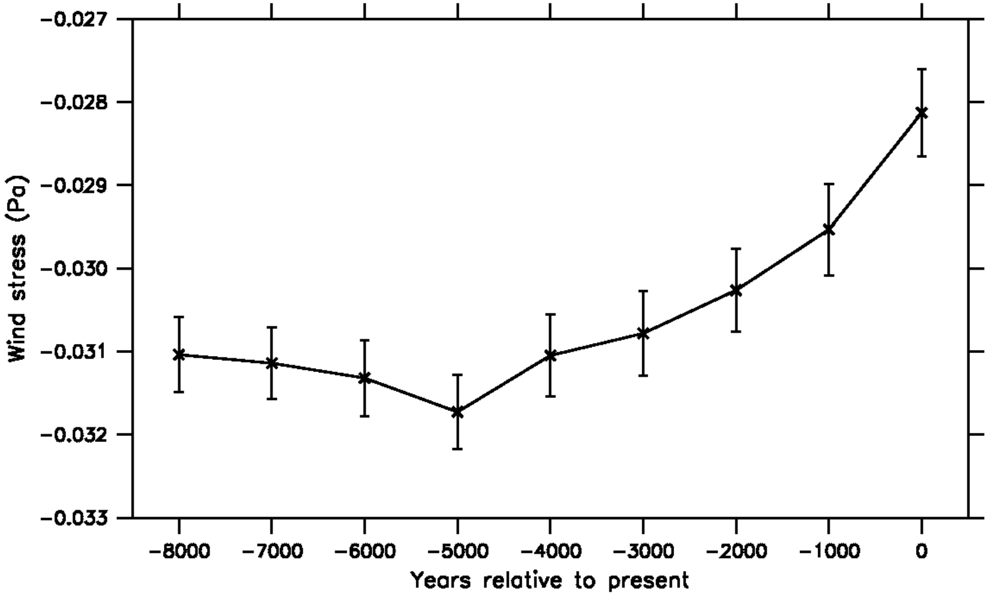
(a) Annual−mean Nino 3 SST



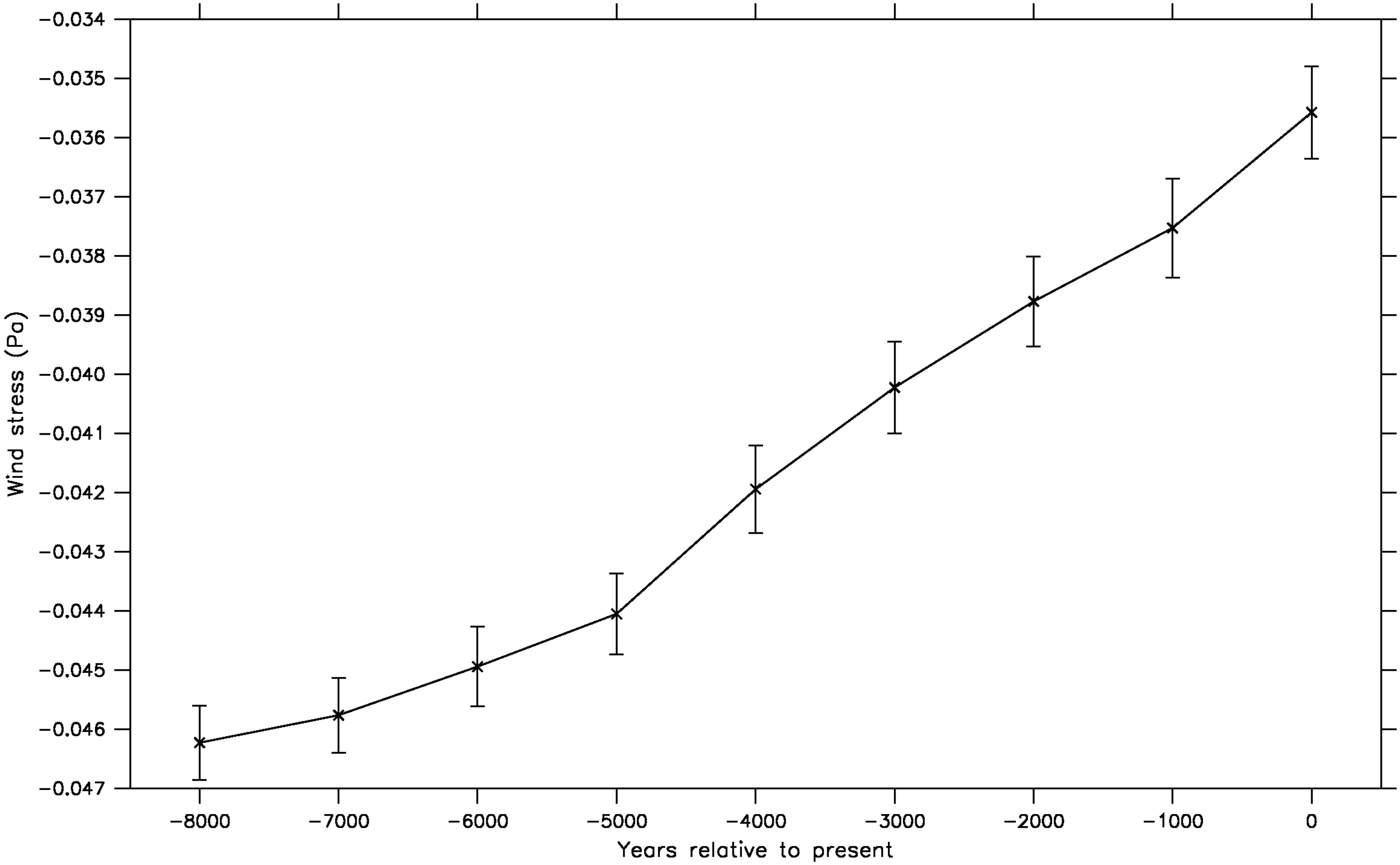
(b) Annual−mean Nino 4 SST



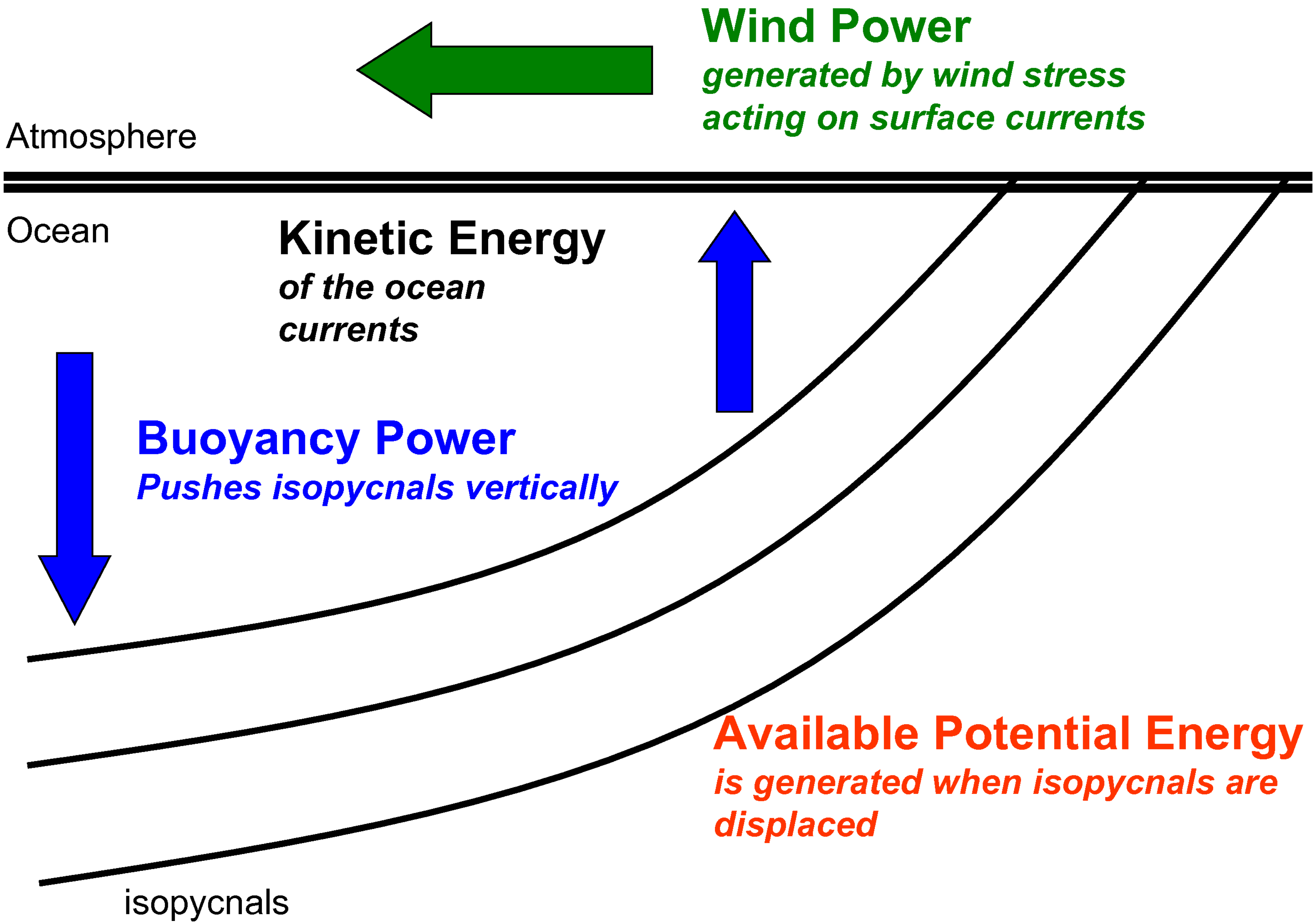
(c) Nino 4 SST minus Nino 3 SST



(d) Annual−mean Nino 4 zonal wind stress



JASO zonal wind stress in Nino 4 region



Wind Power

generated by wind stress acting on surface currents

Atmosphere

Ocean

Kinetic Energy

of the ocean currents

Buoyancy Power

Pushes isopycnals vertically

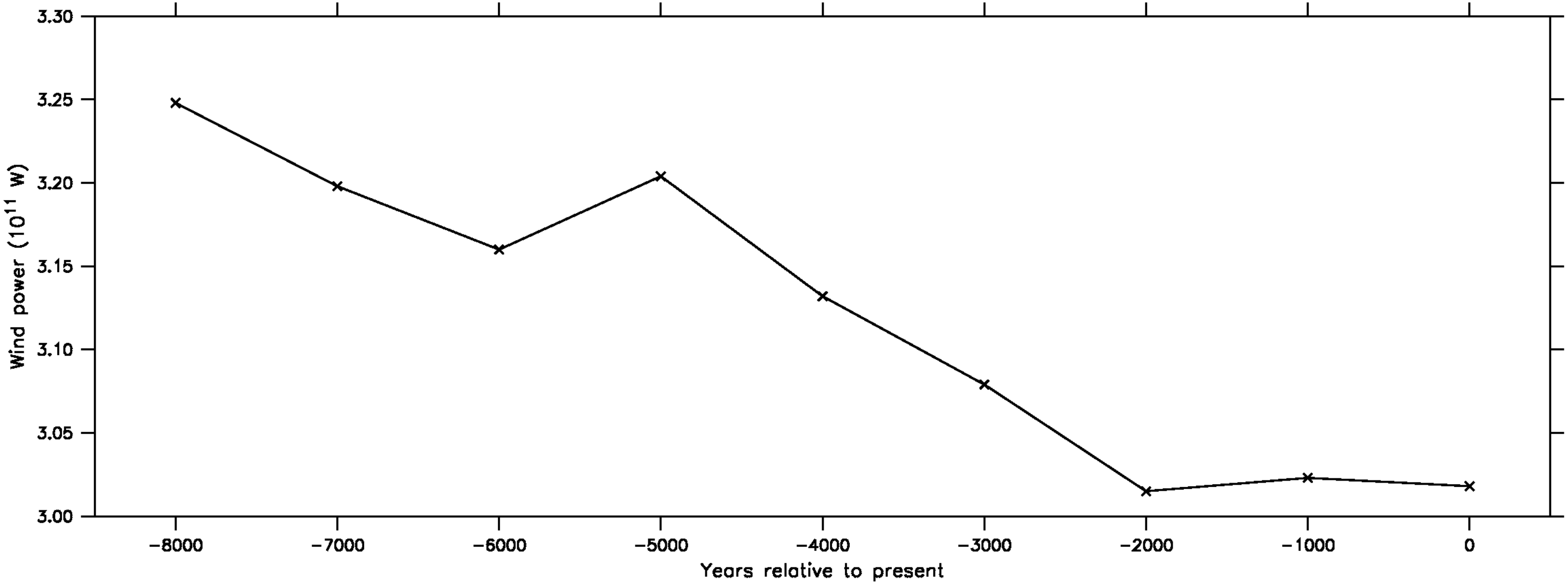
Available Potential Energy

is generated when isopycnals are displaced

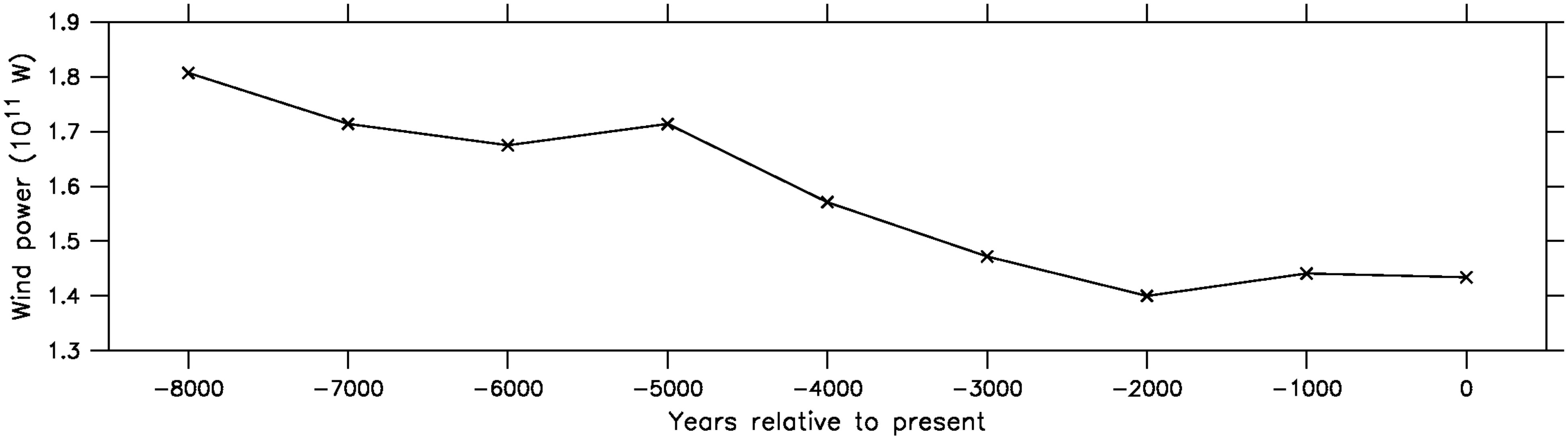
isopycnals

Wind power

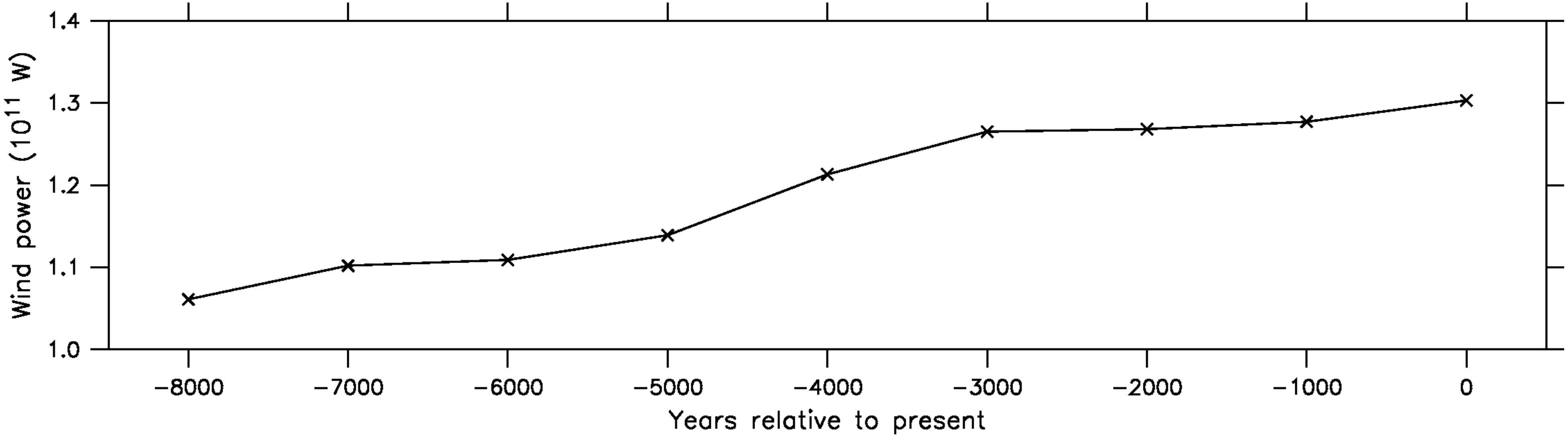
$$W = \iint_{z=0} \underline{u}.\underline{\tau}\, dxdy$$



Annual−mean wind power

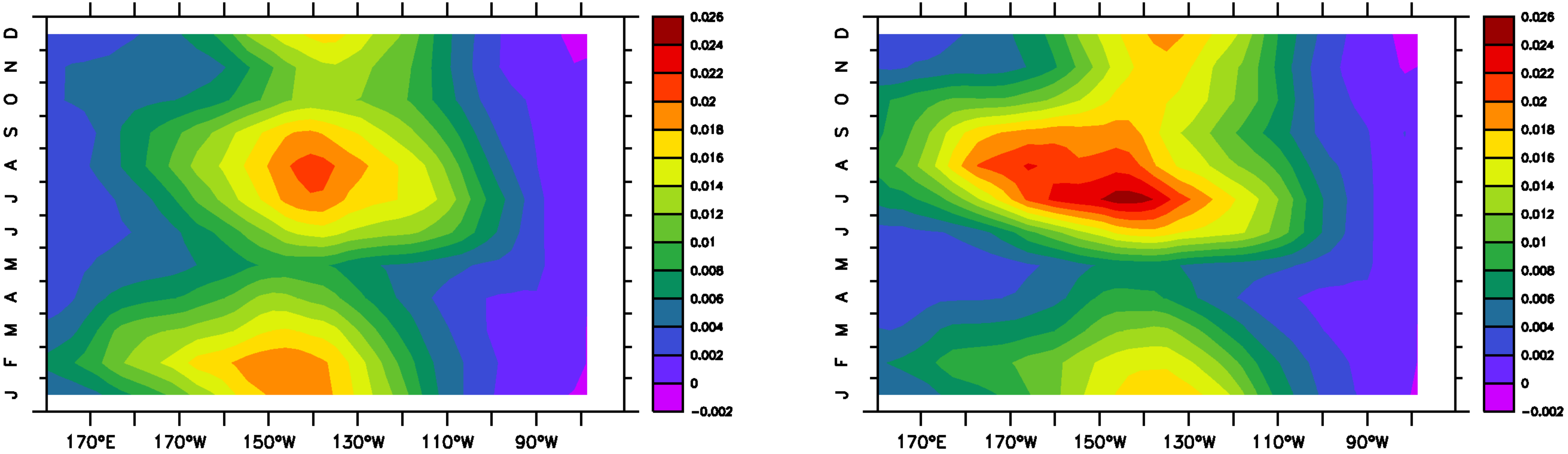


June–July–August–September wind power



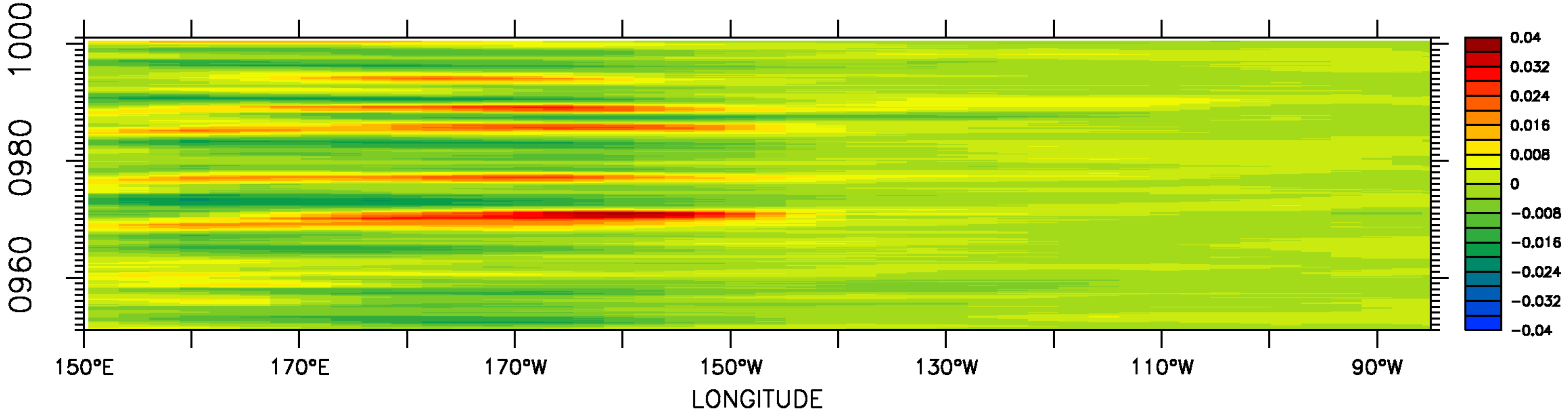
January–February–March–April wind power

Annual cycle

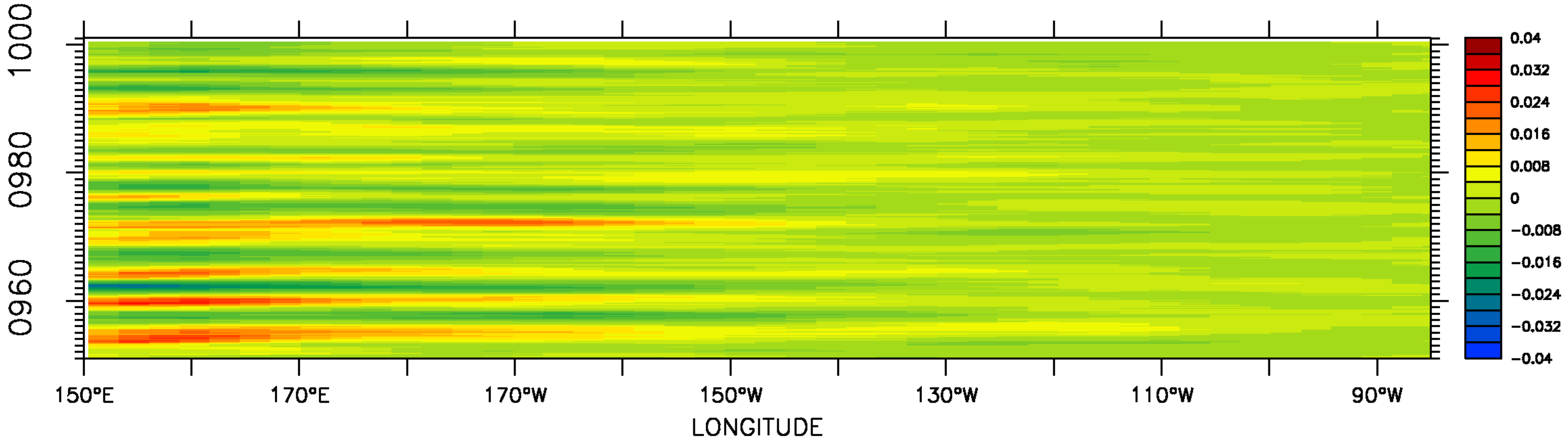


0 ka **8 ka**

Wind power (Wm^{-2})



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



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

Conclusions

- 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.
- The key to understanding and *quantifying* past changes in ENSO behaviour may be to define better diagnostics.
- 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.