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
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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° × 3.2°), 18 vertical levels
  - Ocean: 2.8° × 1.6°, 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 CO₂ concentration = 280ppm
  - Solar constant = 1365 Wm⁻²
  - Integrated for 1000 years
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Standard deviation of Nino SST anomaly
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JASO zonal wind stress in Nino 4 region
Wind power

\[ W = \iint_{z=0} u \cdot \tau \, dx \, dy \]
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June–July–August–September wind power

January–February–March–April wind power
Annual cycle

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

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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.