From Milankovitch to El Niño: Using proxies and models to understand the dynamics of the climate system

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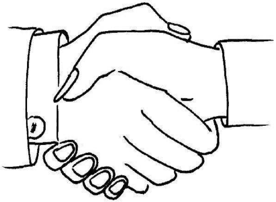
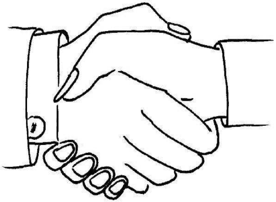
Introduction

The “handshake” question



How do we integrate proxy data and climate models in a way that extracts the maximum possible information about the dynamics of the climate system?

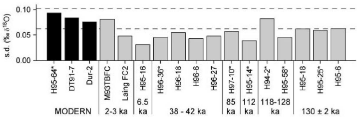
The "handshake" question



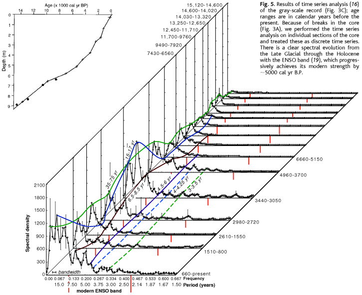
- Data-model integration is a two-way process
- Proxy data can be used to constrain climate model simulations
- Climate models can provide dynamical interpretation of proxy data
- Everyone wins: we learn more about the dynamics of the climate system than when we employ the two approaches separately

ENSO over the past 8 ka

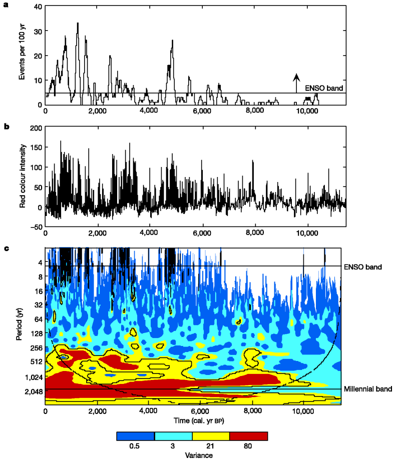
We know that ENSO has changed over the Holocene



Tudhope et al. (2001), *Science*

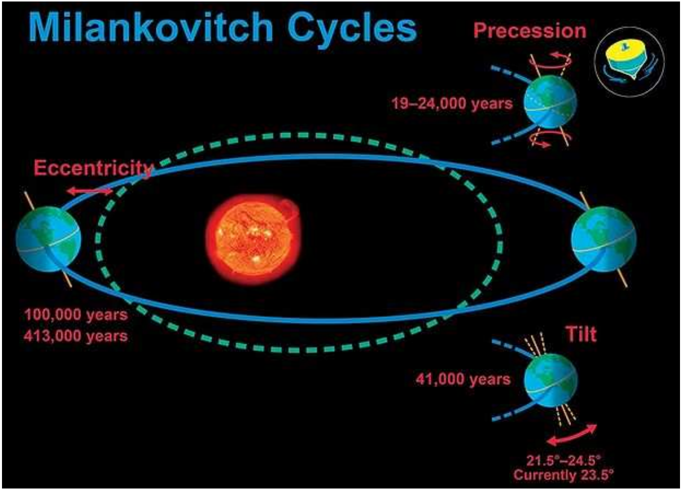


Rodbell et al. (1999), *Science*

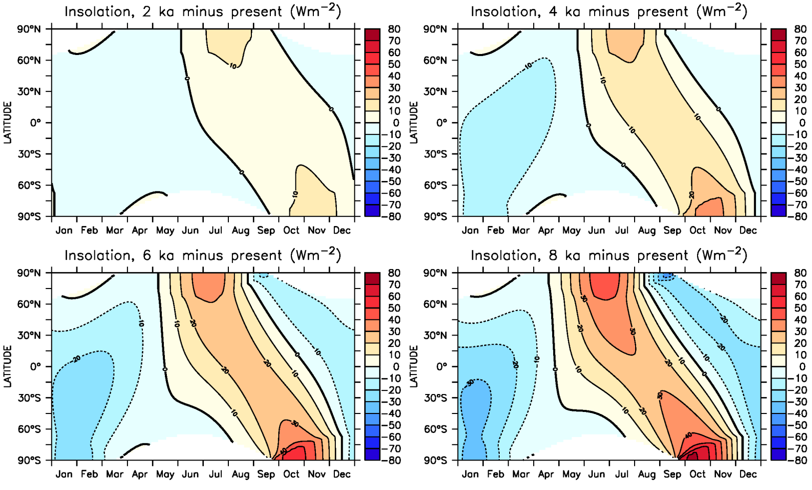


Moy et al. (2002), *Nature*

Orbital changes have been the dominant external signal ...



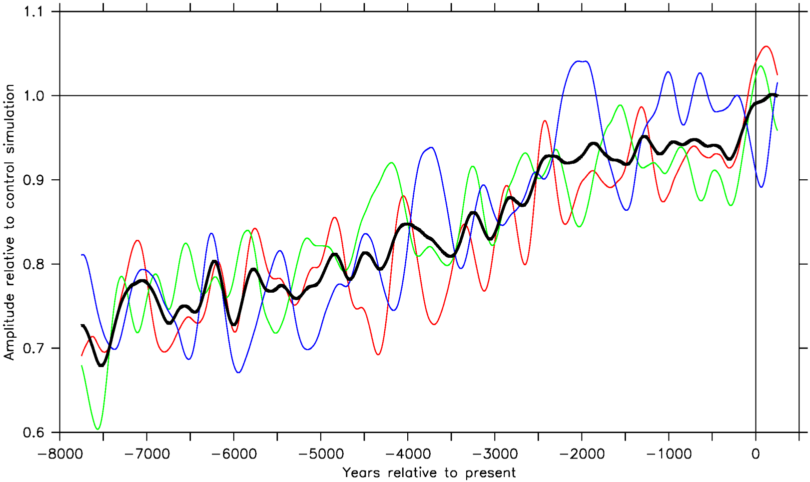
… causing large seasonal changes in insolation



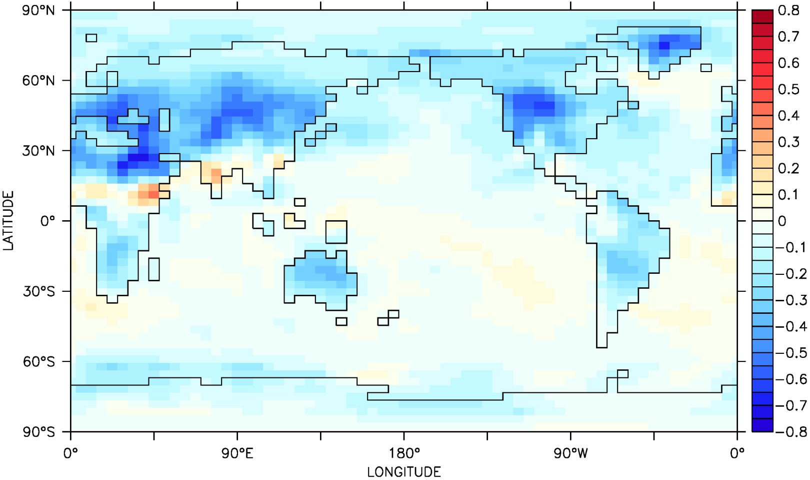
Climate model simulations

- The CSIRO Mk3L climate system model (Phipps et al., 2011, 2012)
  - Atmospheric general circulation model ($5.6^\circ \times 3.2^\circ$, 18 levels)
  - Ocean general circulation model ($2.8^\circ \times 1.6^\circ$, 21 levels)
  - Dynamic-thermodynamic sea ice model
  - Land surface scheme
- 10,000-year pre-industrial control simulation
- Three transient simulations of the past 8 ka:
  - Only the Earth's orbital geometry is varied (Berger et al., 1978)
  - Atmospheric CO_2 concentration = 280 ppm
  - Solar constant = 1365 Wm^{-2}
  - Each ensemble member is initialised from different years of the control simulation (i.e. a perturbed initial conditions ensemble)

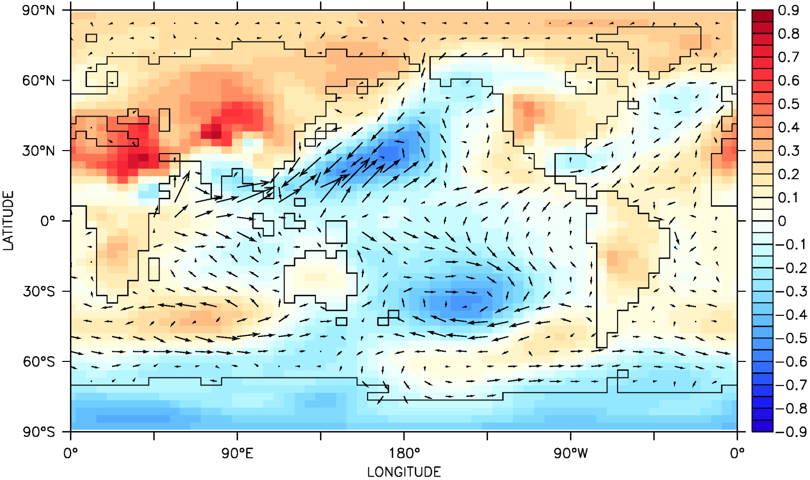
Simulated amplitude of ENSO variability (500-year mean)



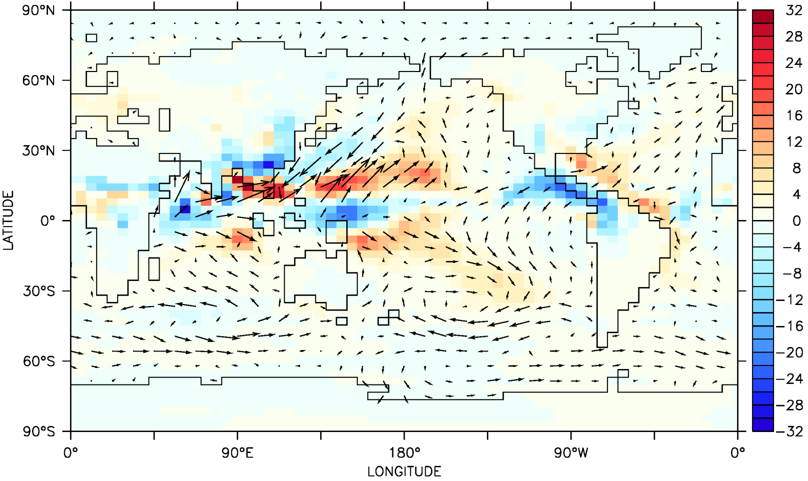
Trend in August surface air temperature (K ka^{-1})



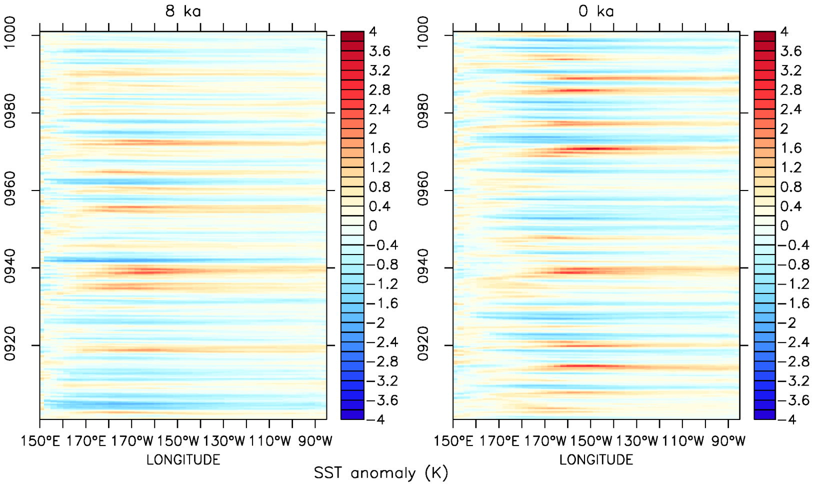
Trend in August MSLP (hPa ka^{-1}) and surface wind stress



Trend in August precip (mm ka^{-1}) and surface wind stress

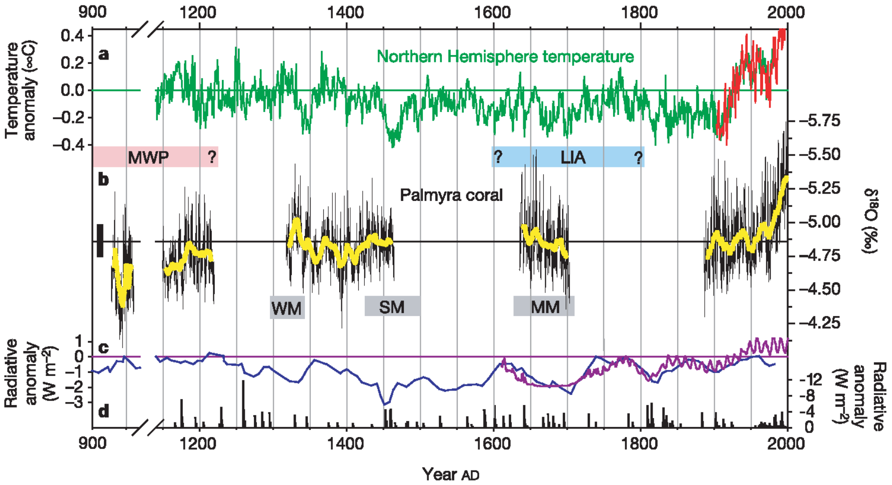


With weaker trades, El Niño events develop more easily



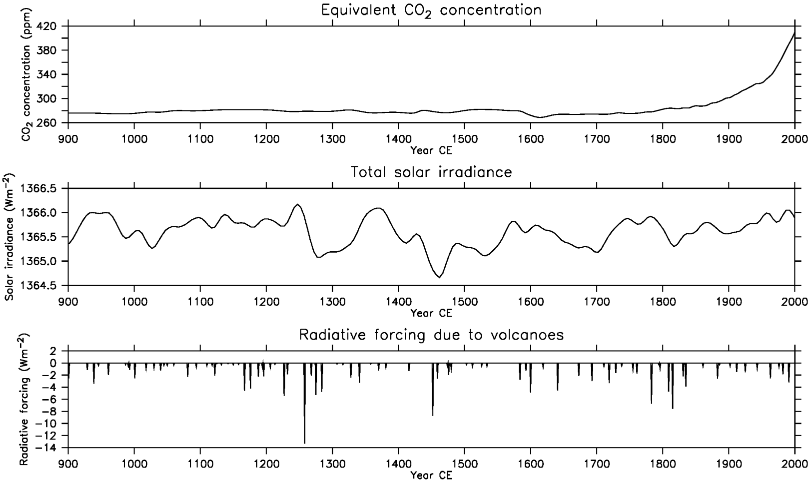
ENSO over the past 1100 years

ENSO also changes on shorter timescales



Cobb et al. (2003), *Nature*

Natural/anthropogenic forcings over the past 1100 years



Climate model simulations

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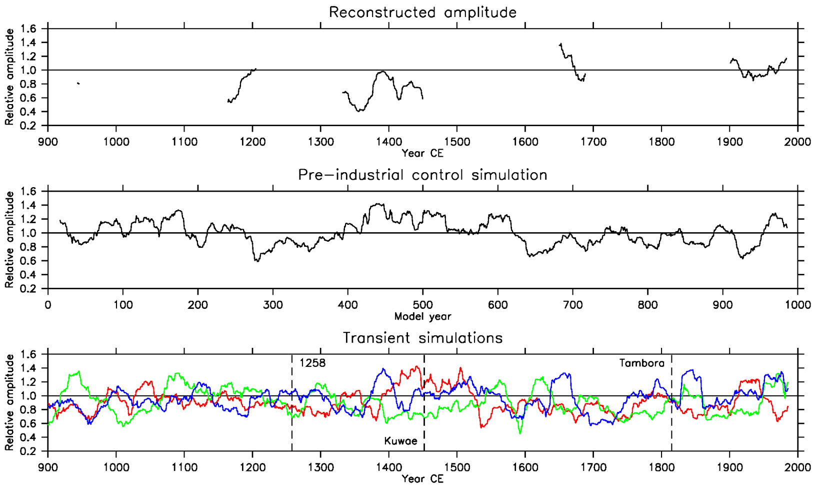
  - Dynamic-thermodynamic sea ice model
  - Land surface scheme
- 10,000-year pre-industrial control simulation
- Three transient simulations of the past 1500 years:
  - Orbital changes (Berger, 1978)
  - Anthropogenic greenhouse gases (MacFarling Meure et al., 2006)
  - Solar irradiance (Steinhilber et al., 2009)
  - Explosive volcanism (Gao et al., 2008)
  - Each ensemble member is initialised from different years of the control simulation (i.e. a perturbed initial conditions ensemble)

Reconstructed/simulated ENSO amplitude (30-year mean)



ENSO amplitude versus individual forcings

Ensemble member	Greenhouse gases	Solar irradiance	Volcanic eruptions
1	+0.02	-0.24	0.00
2	+0.14	+0.27	+0.10
3	**+0.32**	-0.09	+0.03
Mean	+0.30	-0.04	+0.09

Conclusions

Conclusions

- By integrating proxy data with climate modelling, we can use past climatic changes to study the dynamics of the climate system.
- Orbital changes can explain the long-term upward trend in ENSO variability over the past 8 ka. Decreasing summer insolation results in a weakening of the Asian monsoon, reducing the stability of the tropical Pacific and making it easier for El Niño events to develop.
- On shorter timescales, there is no evidence that natural or anthropogenic forcings influence the amplitude of ENSO variability. This supports the notion that ENSO is a system where variability arises from internal dynamics, independent of external forcing.

References

- Phipps and Brown (2010), Understanding ENSO dynamics through the exploration of past climates, *IOP Conference Series: Earth and Environmental Science*, 9, 012010, doi:10.1088/1755-1315/9/1/012010.
- Phipps, McGregor, Gergis, Gallant, Neukom, Stevenson, Ackerley, Brown, Fischer and van Ommen (2013), Paleoclimate data–model comparison and the role of climate forcings over the past 1500 years, *Journal of Climate*, doi:10.1175/JCLI-D-12-00108.1, in press.