Palaeoclimate data-model comparison and the role of climate forcings over the past 1500 years

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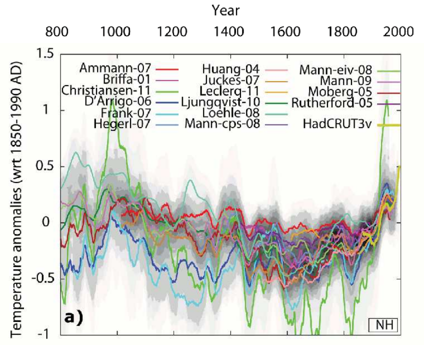
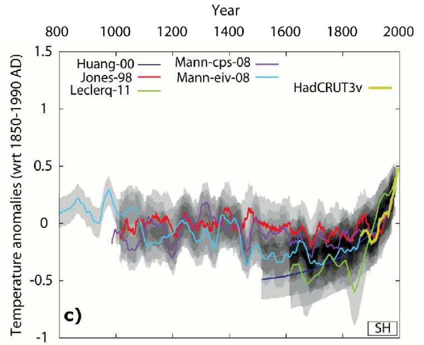
Introduction

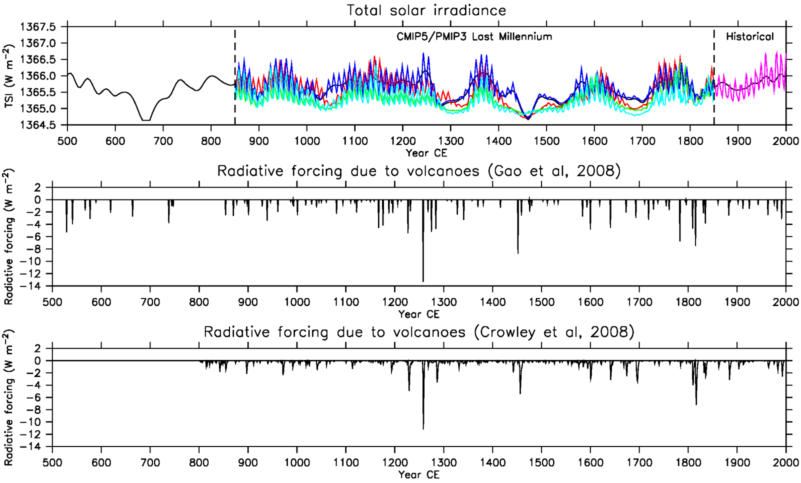
The climate of the past 1500 years





Fernández-Donado et al. (2013), *Climate of the Past*

Solar and volcanic forcing over the past 1500 years

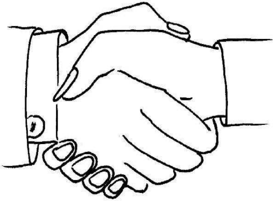


Sources of information on past climates

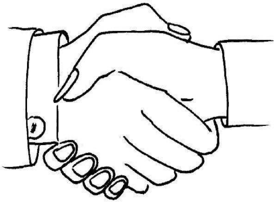
$\delta^{18}O$
Sr/Ca

Temperature
Precipitation

The "handshake" question

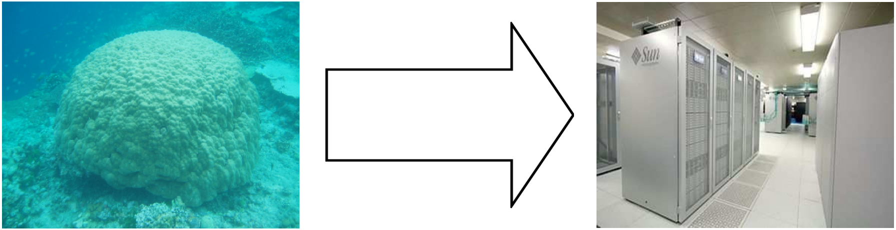


The “handshake” question



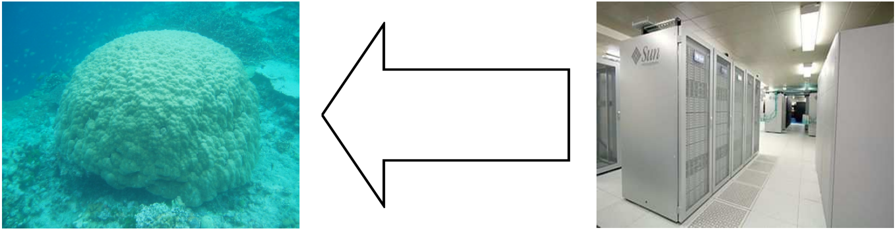
How do we integrate proxy data and climate models in a way that extracts the maximum possible information about the dynamics of the climate system?

The inverse approach



- Translate proxy variables into physical climate variables.
- Achieved by calibrating proxy variables against local or remote climatic variables, typically using observational data.
- Involves the necessary but usually implicit assumption of stationarity.
- Proxies can integrate multiple environmental variables, so information is lost when only reconstructing a single variable.

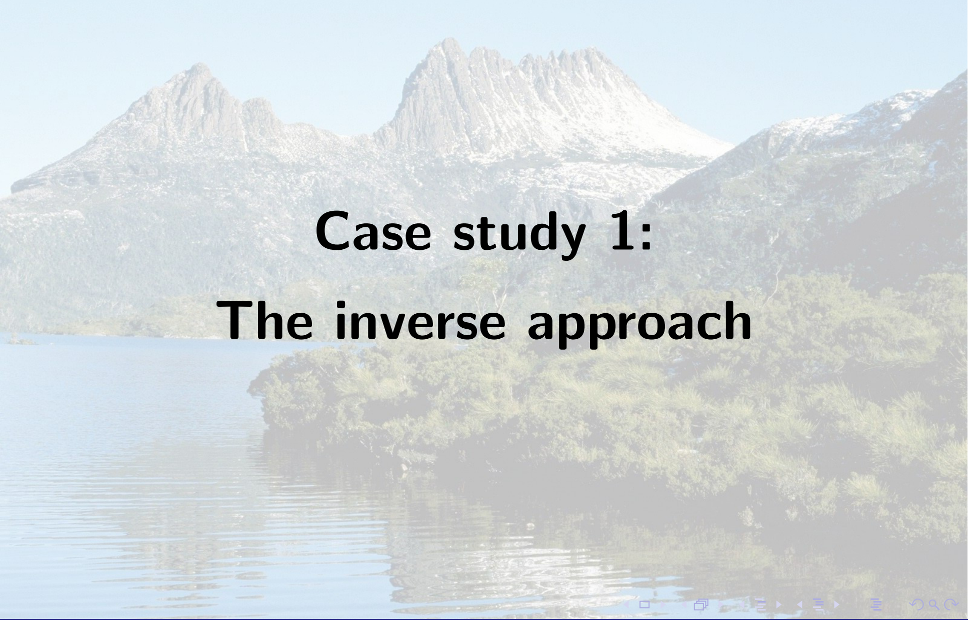
The forward approach



- Translate model variables into proxy variables.
- Achieved by using physical and biological principles to simulate the evolution of proxy variables within a modelling framework.
- Capable of avoiding the assumption of stationarity.
- Can account for the fact that proxies integrate multiple variables.
- Require a complete description of all the relevant processes.

Aims of this study

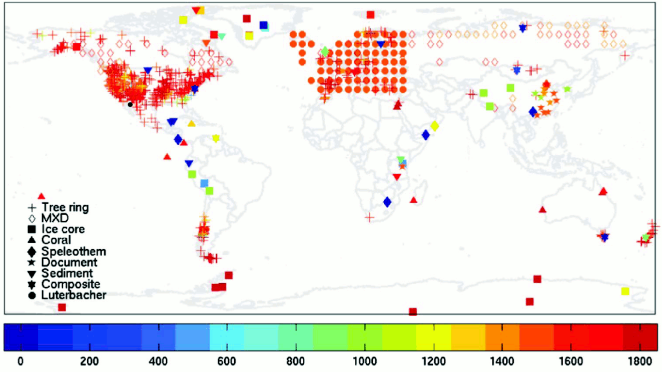
- To use palaeoclimate data-model comparison to study the role of natural and anthropogenic forcings in driving the global climate over the past 1500 years.
- To use the forward and inverse approaches to compare a suite of climate model simulations with palaeoclimate datasets.
- To identify sources of uncertainty.



Case study 1:
The inverse approach

Temperature reconstructions

- Hemispheric-mean temperature reconstructions (Mann et al., 2008)
- Global network of 1209 annually- and decadally-resolved proxies
- Decadal temperature for 300–2006 CE (NH) and 400–2006 CE (SH)

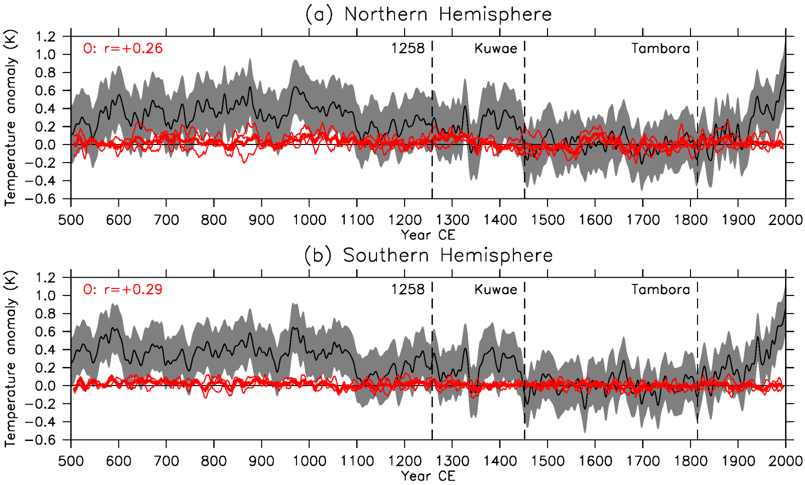


Climate model simulations

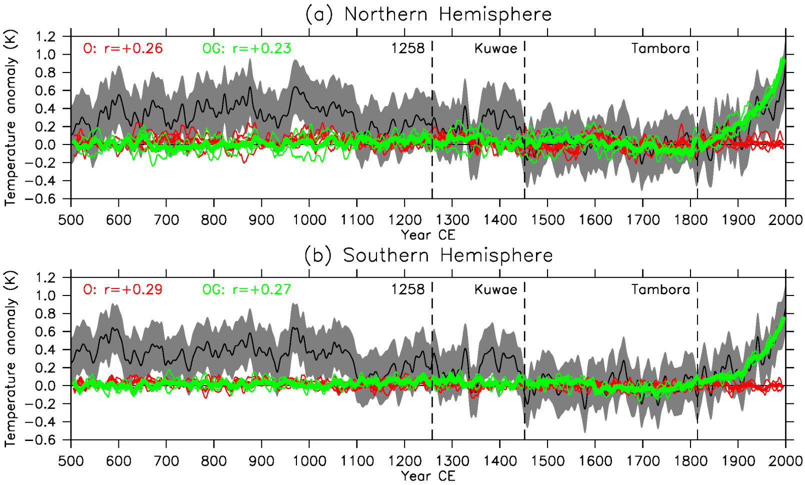
- The CSIRO Mk3L climate system model (Phipps et al., 2011, 2012)
  - Atmospheric general circulation model (5.6° × 3.2°, 18 levels)
  - Ocean general circulation model (2.8° × 1.6°, 21 levels)
  - Dynamic-thermodynamic sea ice model
  - Land surface scheme
- 10,000-year pre-industrial control simulation
- Multiple transient simulations using three-member ensembles:

Ensemble	Years (CE)	Forcing(s)
O	1–2000	Orbital (Berger, 1978)
OG	1–2000	O + GHGs (MacFarling Meure et al., 2006)
OGS	1–2000	OG + solar irradiance (Steinhilber et al., 2009)
OGSV	501–2000	OGS + volcanic aerosols (Gao et al., 2008)

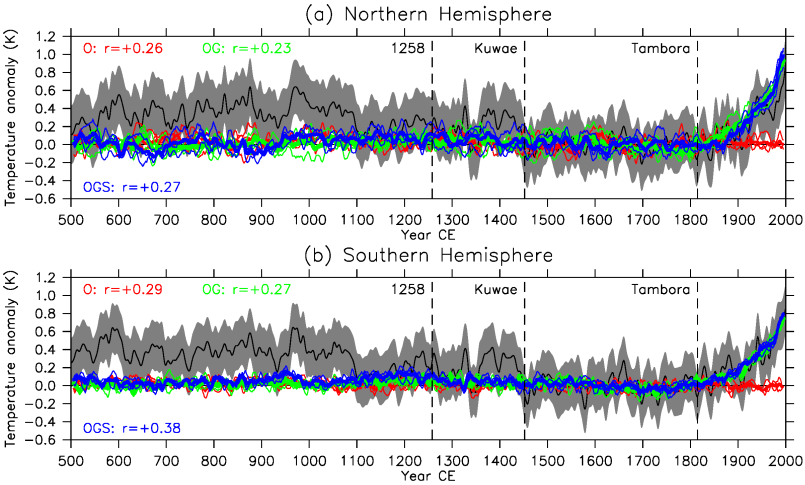
Simulated annual-mean temperature



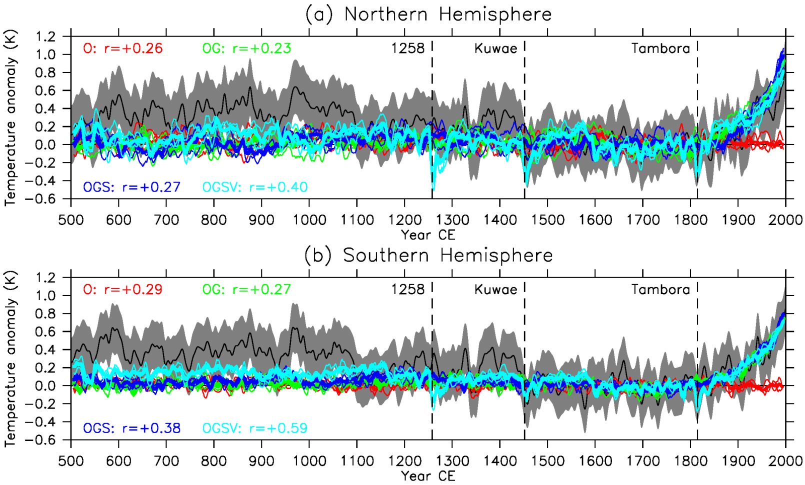
Simulated annual-mean temperature



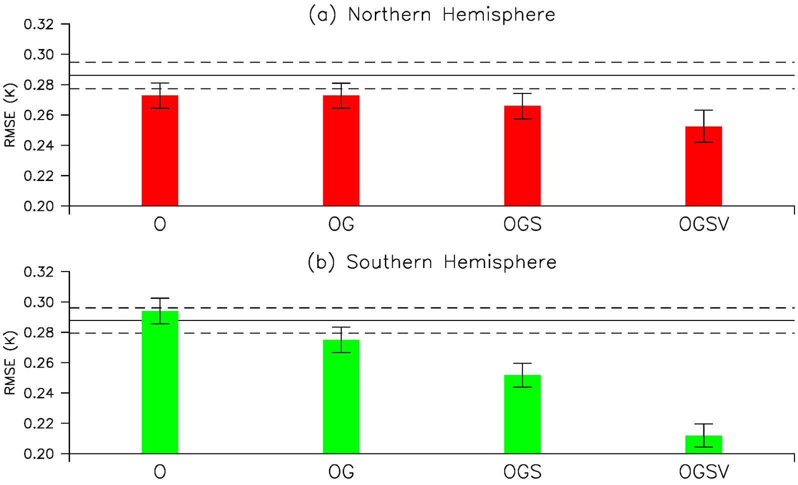
Simulated annual-mean temperature



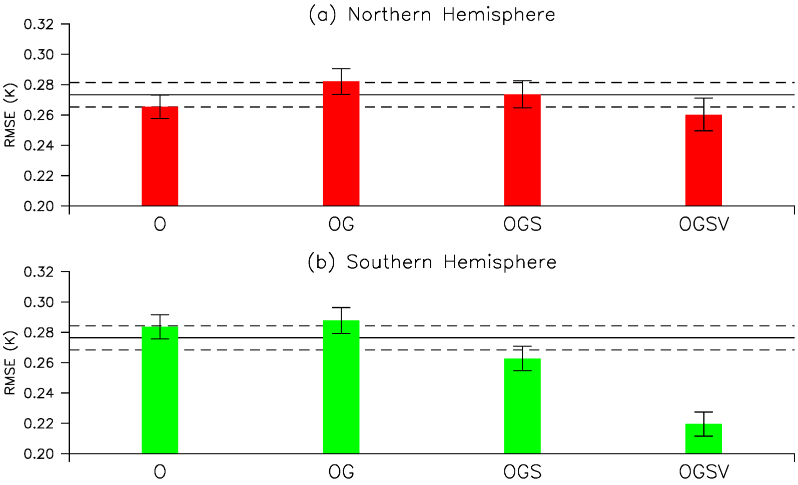
Simulated annual-mean temperature



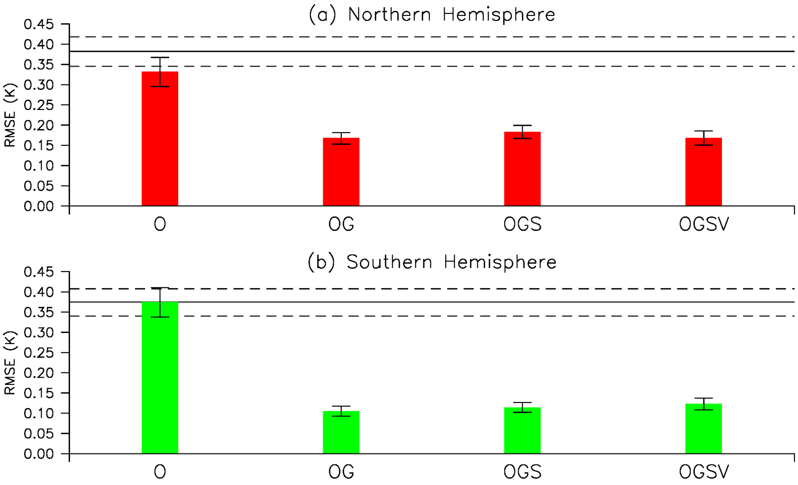
RMS errors in model simulations (501–2000 CE)



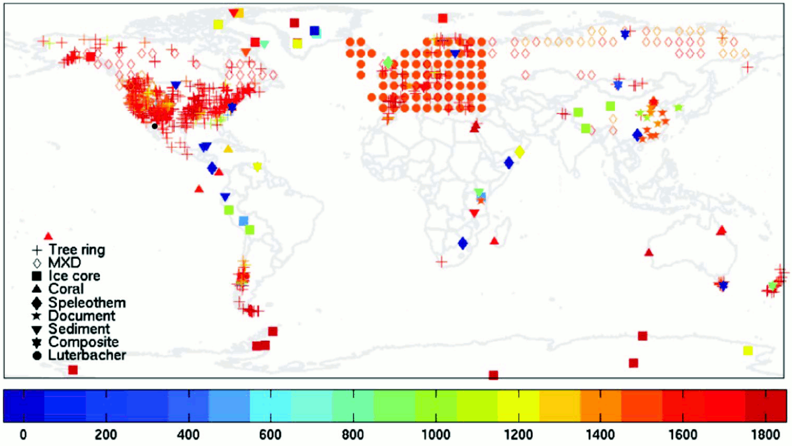
RMS errors in model simulations (501–1850 CE)



RMS errors in model simulations (1851–2000 CE)

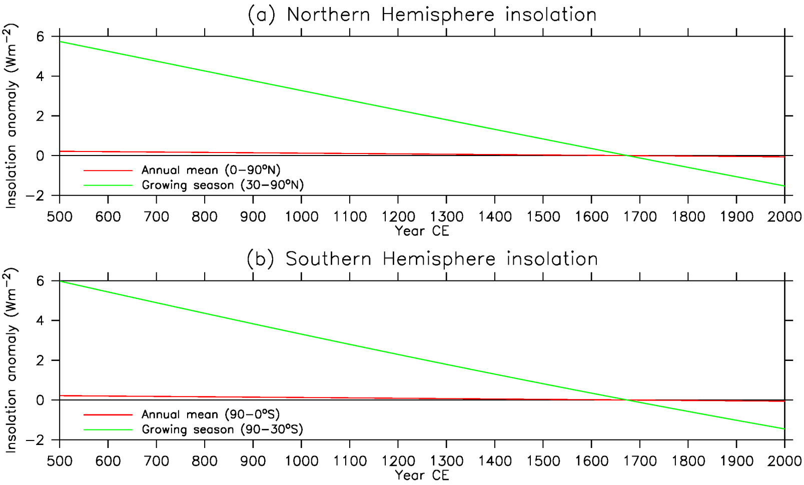


Distribution and composition of the proxy network

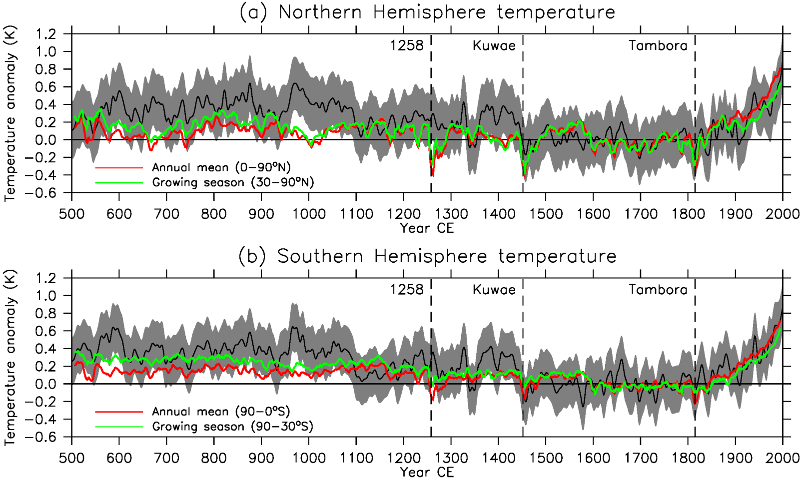


Mann et al. (2008), *PNAS*

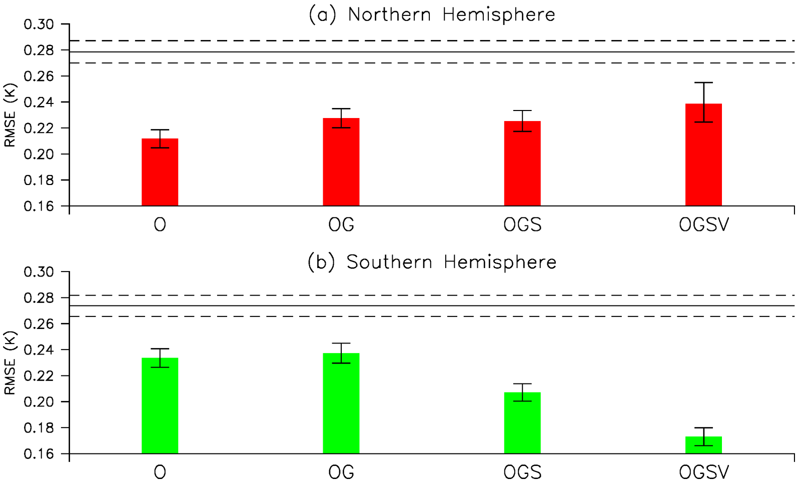
Orbitally-driven changes in insolation



Differences in simulated temperature: ensemble OGSV

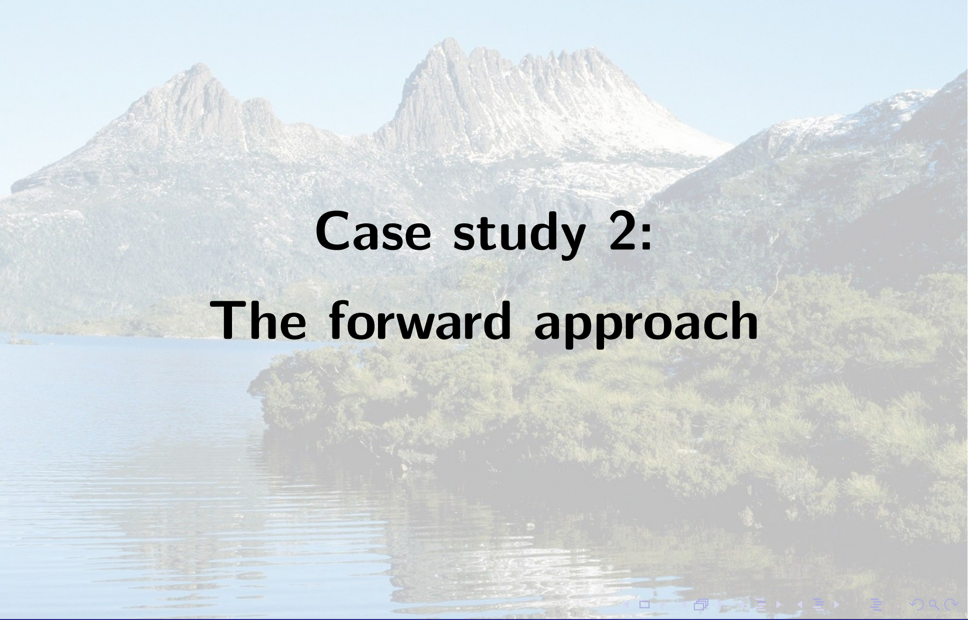


RMS errors in simulations: growing season/extratropics



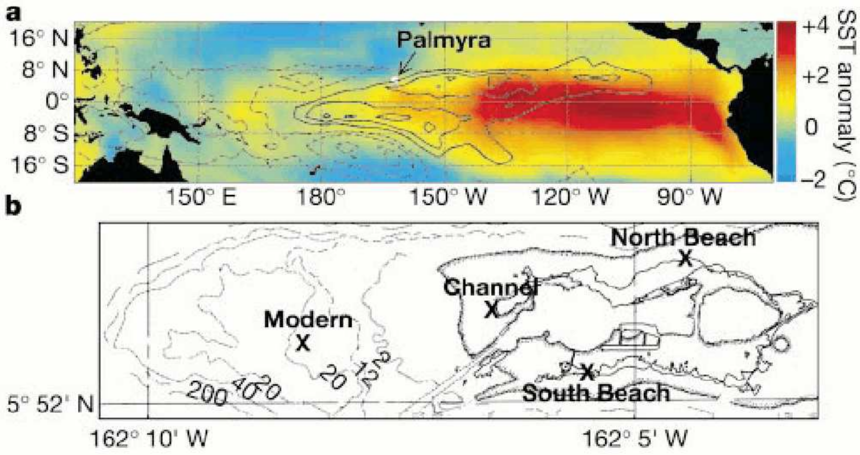
Case study 1: Conclusions

- We find evidence of solar and volcanic influences on the SH climate over the past 1500 years.
- This conclusion is robust with respect to potential seasonal and geographical biases in the response of a multi-proxy network.
- The results for the NH are more ambiguous, but suggest that orbital forcing is the dominant driver of growing season temperatures.
- During the post-1850 period, increasing greenhouse gases dominate over natural forcings in both hemispheres.
- Data-model disagreement highlights possible sources of uncertainty:
    - deficiencies in the model physics
    - errors in the forcing datasets used to drive the model
    - internal climate variability
    - techniques for multi-proxy reconstruction



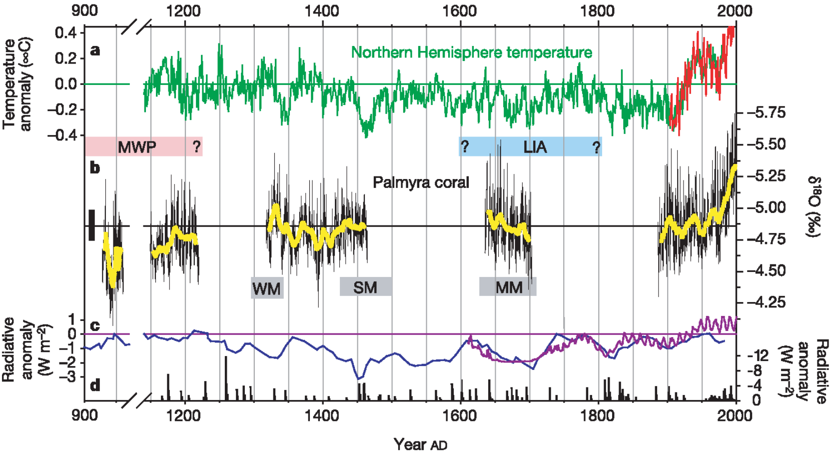
Case study 2:
The forward approach

Coral from Palmyra Island



Cobb et al. (2003), *Nature*

Coral from Palmyra Island



Cobb et al. (2003), *Nature*

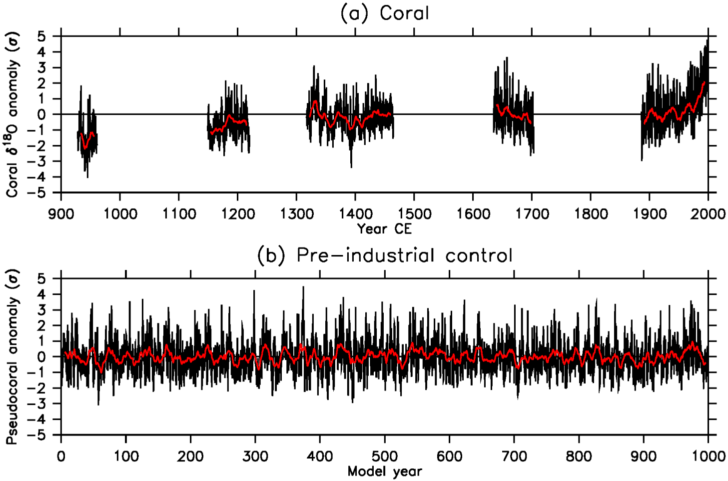
Deriving a pseudocoral

- Corals provide a single chemical variable: δ^{18}O.
- The climate model simulates physical variables: SST, SSS, P, E...
- These variables are not directly comparable.
- The solution is to construct a "pseudocoral" (Brown et al., 2008).
- Using the pre-industrial control simulation, we regress a set of potential predictors (SST, SSS, P, E) onto the simulated Niño 3.4 SST anomaly.
- We obtain the following pseudocoral:

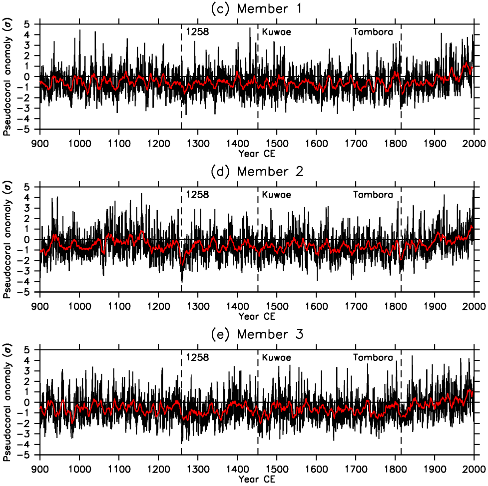
$$C = \underset{(\pm 0.015)}{0.692}\ \Delta SST - \underset{(\pm 0.056)}{0.708}\ \Delta SSS + \underset{(\pm 0.002)}{0.023}\ \Delta P + \underset{(\pm 0.013)}{0.248}\ \Delta E$$

- This indicator describes 70% of the simulated ENSO variance.

Reconstructed and simulated mean state



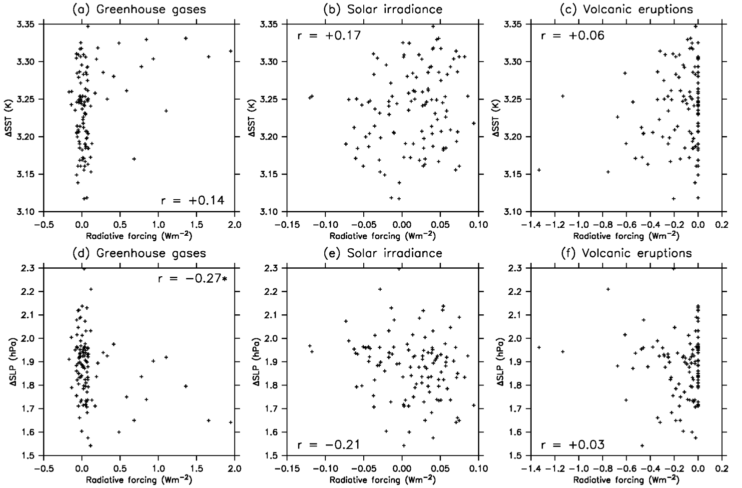
Reconstructed and simulated mean state



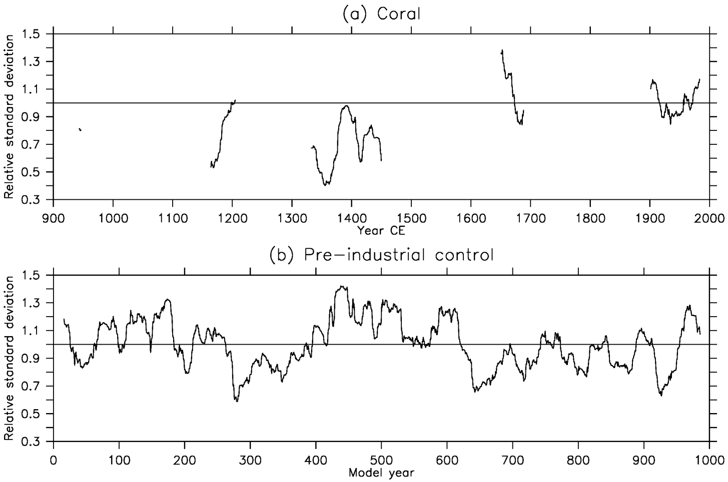
Mean state versus individual forcings

Ensemble member	Greenhouse gases	Solar irradiance	Volcanic eruptions
	(a) Annual mean		
1	**+0.31**	+0.11	0.00
2	**+0.28**	**+0.17**	+0.04
3	**+0.31**	**+0.19**	+0.05
Mean	**+0.47**	**+0.25**	+0.04
	(b) Decadal mean		
1	**+0.59**	+0.22	+0.12
2	**+0.50**	**+0.29**	**+0.33**
3	**+0.59**	**+0.35**	**+0.23**
Mean	**+0.71**	**+0.37**	**+0.29**

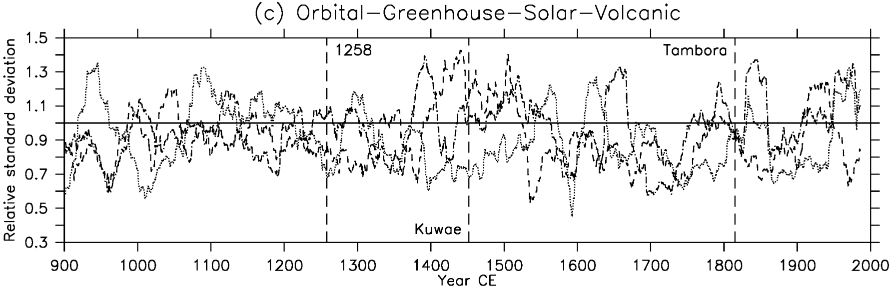
Mean state versus individual forcings



Reconstructed and simulated ENSO amplitude



Reconstructed and simulated ENSO amplitude



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

Case study 2: Conclusions

- We find evidence of solar, volcanic and anthropogenic influences on the mean state of the central Pacific over the past 1100 years.
- The dynamical response of the model is characterised by a "Weaker Walker" response to changing anthropogenic greenhouse gases.
- We find no evidence of any influence of natural or anthropogenic forcings on the amplitude of the simulated ENSO variability.
- This supports the notion that ENSO is a system where variability arises from internal dynamics, independent of external forcing.
- Data-model disagreement highlights possible sources of uncertainty:
  - deficiencies in the model physics
  - errors in the forcing datasets used to drive the model
  - internal climate variability
  - simple nature of the forward model

Conclusions

Conclusions

- By comparing a suite of climate model simulations with multiple proxy records, we have been able to study the drivers of the global climate over the past 1500 years.
- By applying both the inverse and forward approaches, we have been able to identify possible sources of uncertainty:
  - deficiencies in the model physics
  - errors in the forcing datasets used to drive the model
  - internal climate variability
- We suggest two future research priorities:
  - the ongoing development of alternative approaches, particularly forward modelling and data assimilation
  - the development of better reconstructions of past climatic forcings

Reference: Phipps, McGregor, Gergis, Gallant, Neukom, Stevenson, Ackerley, Brown, Fischer and van Ommen, 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.