Climate field reconstructions and climate modelling: Towards integrated approaches

Steven J. Phipps
ARC Centre of Excellence for Climate System Science
Climate Change Research Centre
University of New South Wales, Sydney, Australia

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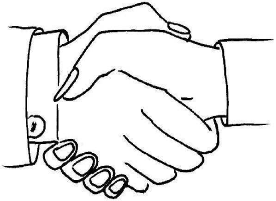
Conclusion #1

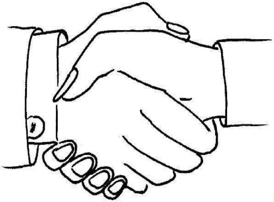
- Climate modelling has the potential to play a much more fundamental role than just post-hoc comparison with proxy data or reconstructions.

The “handshake” question



How do we integrate data from natural archives with climate models in a way that extracts the maximum possible information about the dynamics of the climate system?

The "handshake" question



- If we really want to learn everything that we can from the climate of the last 2000 years, then we need to embrace integrated approaches.
- The models and the proxies should be employed in a unified fashion to reconstruct and understand past changes in the climate.
- Climate modelling needs to be seen as part of the process of palaeoclimate reconstruction itself.

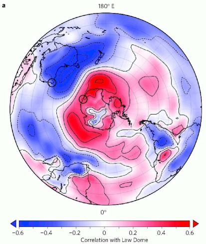
Climate model simulations

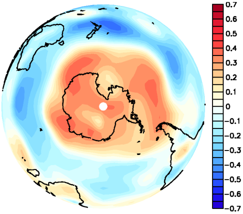
- The CSIRO Mk3L climate system model (Phipps et al., 2011, 2012)
  - Atmospheric general circulation model (5.6° $\times$ 3.2°, 18 levels)
  - Ocean general circulation model (2.8° $\times$ 1.6°, 21 levels)
  - Dynamic-thermodynamic sea ice model
  - Land surface scheme
- Three transient simulations 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)

1a. Testing assumptions: stability of teleconnections

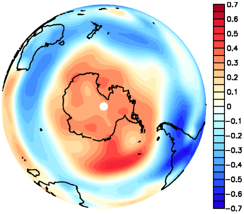
Correlation of MSLP with Law Dome precipitation (1979–2004)

van Ommen and Morgan (2010)

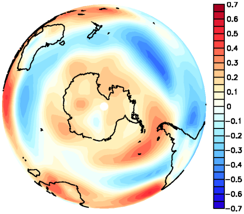




Member 1 (1975–2000)

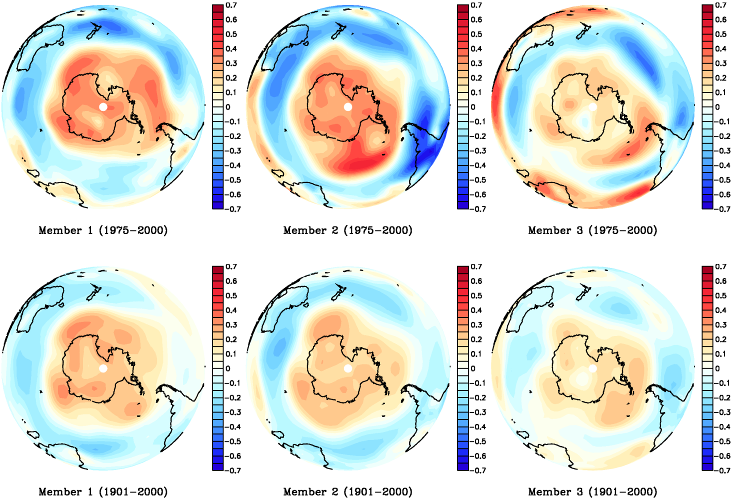


Member 2 (1975–2000)

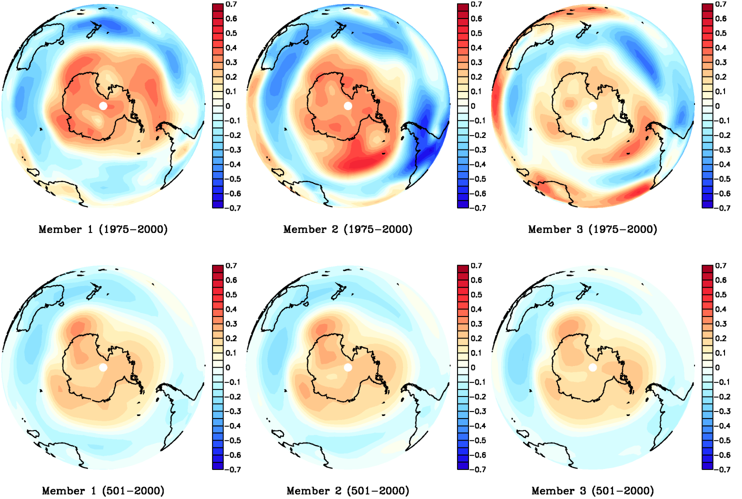


Member 3 (1975–2000)

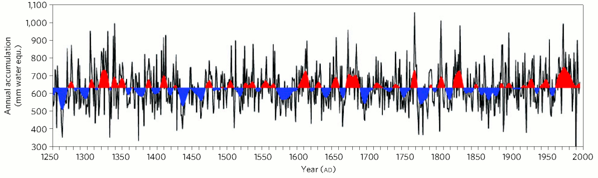
Relationship is consistent over the 20th century ...

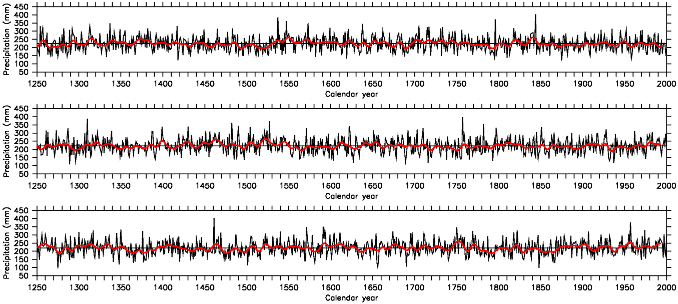


… and the full 1500 years

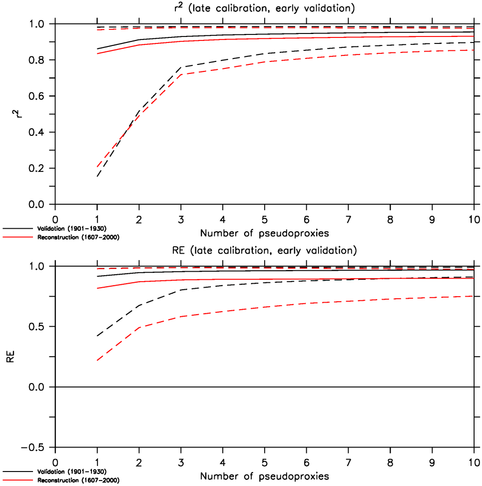


Annual precipitation at Law Dome is stable





1b. How many proxies do we need?



2. Data assimilation: an opportunity

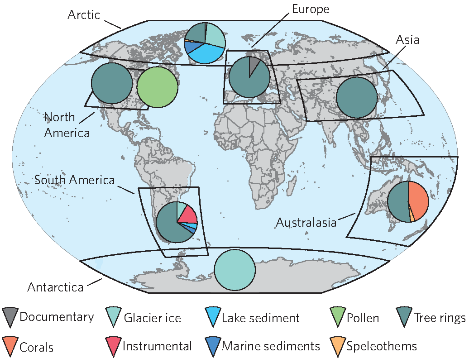
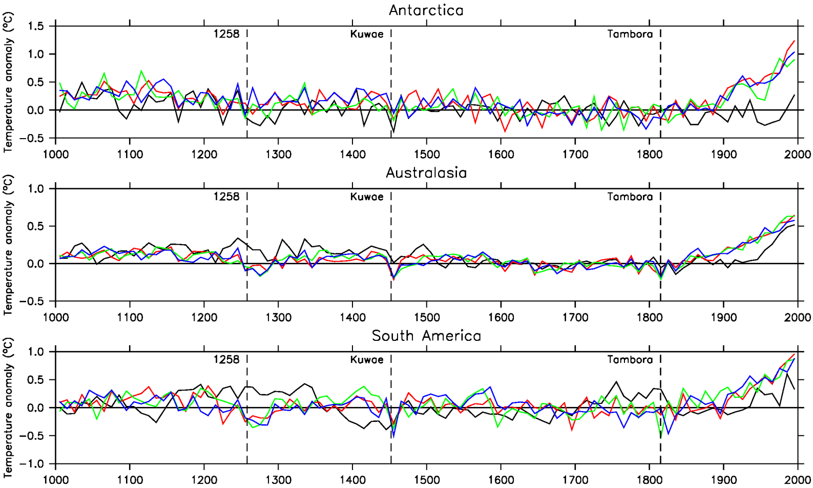


Figure 1 | The PAGES 2k Network. Boxes show the continental-scale regions used in this study. The pie charts represent the fraction of proxy data types used for each regional reconstruction. Supplementary Database S1 includes information about each study site and the proxy data for all time series used in the regional reconstructions.

PAGES 2k Consortium (2013)

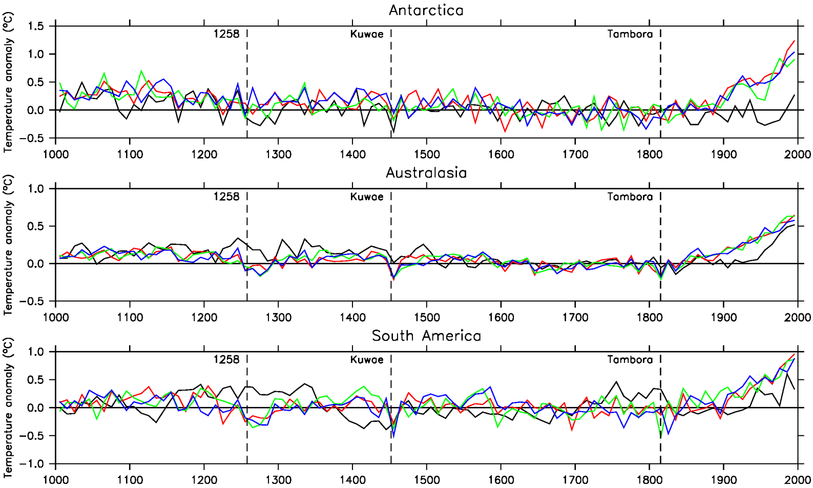
Simulated and reconstructed decadal-mean temperature



Correlations between model and reconstructions

Region	Member 1	Member 2	Member 3
Antarctica	+0.11	+0.13	+0.15
Australasia	+0.51	+0.53	+0.49
South America	+0.15	+0.06	-0.01

Simulated and reconstructed decadal-mean temperature

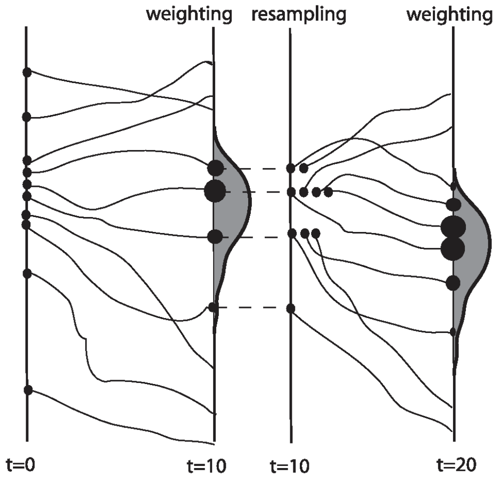


An infinite number of monkeys ...

... or data assimilation?

- In data assimilation, we constrain a climate model to follow the evolution of proxies or reconstructions.
- We cannot perform data assimilation in the same manner as dynamical meteorology, because of the limited spatial extent and temporal resolution of the proxy data (Widmann et al., 2010).
- Palaeoclimate data assimilation can be performed offline:
  - Run a large ensemble and simply choose the simulation that performs best ("infinite monkeys").
  - Run a large ensemble and generate a weighted ensemble mean, based on some assessment of skill.
- Optimally, however, we perform interactive data assimilation, using a technique such as particle filtering (van Leeuwen, 2009).

Particle filter with resampling



van Leeuwen (2009)

Proof of concept: offline data assimilation

- Let's try assimilating the three Southern Hemisphere PAGES 2k reconstructions into the ensemble of Mk3L model simulations.
- For each decade during the period 1001–2000 CE, calculate a cost function following e.g. Crespin et al. (2009):

$$C(t) = \sqrt{\sum_{\text{recon}} \left(T_{\text{recon}}(t) - T_{\text{model}}(t)\right)^2}$$

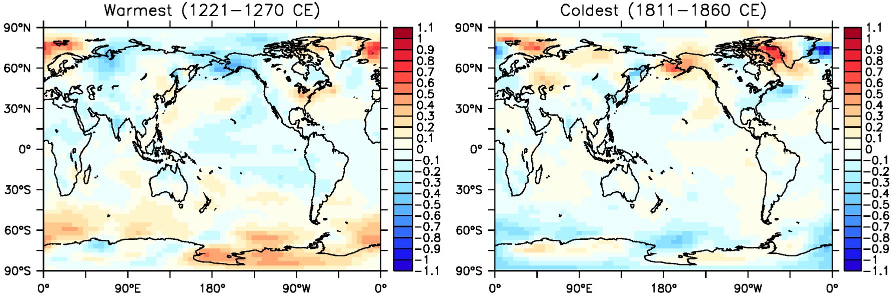
- For each decade, select the ensemble member with the smallest value of the cost function.
- Essentially we are just calculating a weighted ensemble mean, where the best member for each decade has a weight of 1 and the others have a weight of 0.

Correlations between model and reconstructions

Region	Member 1	Member 2	Member 3	Assimilation
Antarctica	+0.11	+0.13	+0.15	+0.33
Australasia	+0.51	+0.53	+0.49	+0.64
South America	+0.15	+0.06	-0.01	+0.30

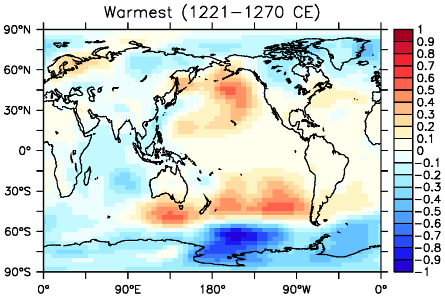
Reconstructed temperature anomalies (°C)

- Use the outcome of the data assimilation to reconstruct spatial fields for the warmest and coldest 50-year periods in Australasia during the pre-industrial period (pre-20th century).
- Anomalies are shown relative to 1501–1850 CE.



Reconstructed mean sea level pressure anomalies (hPa)

- Use the outcome of the data assimilation to reconstruct spatial fields for the warmest and coldest 50-year periods in Australasia during the pre-industrial period (pre-20th century).
- Anomalies are shown relative to 1501–1850 CE.



Data assimilation: pros

- Internal climate variability becomes the *solution*, not the *problem*.
- Avoids any assumption of stationarity.
- The cost function can be multi-variate and can seamlessly handle records with different temporal resolution: we can simultaneously assimilate low-resolution and high-resolution proxies for different climatic variables (temperature, precipitation, sea ice...).
- No lower limit on the number of records required (N.B. skill).
- Requires no modifications to existing models.
- For offline data assimilation, you don't even need to run a model.

Data assimilation: cons

- Still requires proxy variables to be converted to physical climate variables, so still requires local calibration.
- Relies on internal climate variability to sample climate states: we cannot generate the "true" state if this lies outside the range of simulated natural climate variability.
- Computationally expensive (e.g. 96 ensemble members).

Conclusions

- As part of the second phase of the PAGES 2k Network, climate modelling has the potential to play a much more fundamental role than just post-hoc comparison with reconstructions.
- Two particularly promising areas are:
  - testing and evaluating techniques for climate field reconstruction.
  - directly assimilating proxies into a climate modelling framework
- Data assimilation has the potential to generate spatial reconstructions, but careful consideration needs to be given to the nature of the assimilation (frequency, spatial degrees of freedom).
- Has the potential to act as an independent check on other methods.
- Possible activity for the Aus2k Working Group:
  - Generate a large ensemble (~25?) of model simulations.
  - Use this ensemble to test different ways of assimilating SH proxies.
  - Perform a fully interactive assimilation using particle filtering.

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