Assimilation of Southern Hemisphere proxy records into a climate modelling framework

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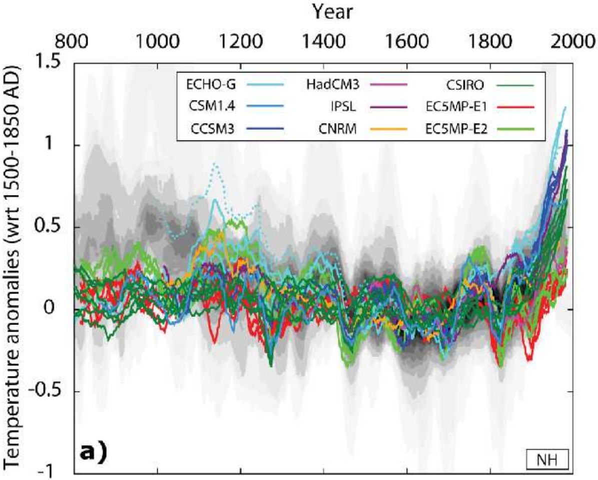
Forced versus internal variability

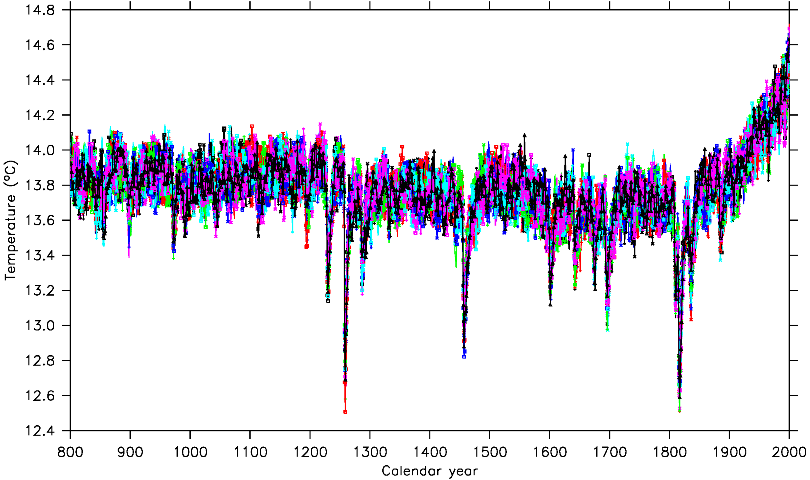


Fernández-Donado et al. (2013)

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
- External boundary conditions:
  - Orbital changes (Berger, 1978)
  - Anthropogenic greenhouse gases (MacFarling Meure et al., 2006)
  - Solar irradiance (Steinhilber et al., 2009)
  - Explosive volcanism (Crowley and Unterman, 2013)
- Ensemble OGS25: 25 simulations 1–2000 CE (O, G, S)
  - Each member initialised from different year of control simulation
- Ensemble OGSV25: 25 simulations 801–2000 CE (O, G, S, V)
  - Each member branched off equivalent member of ensemble OGS25

Simulated global-, annual-mean surface air temperature



Data assimilation: an opportunity

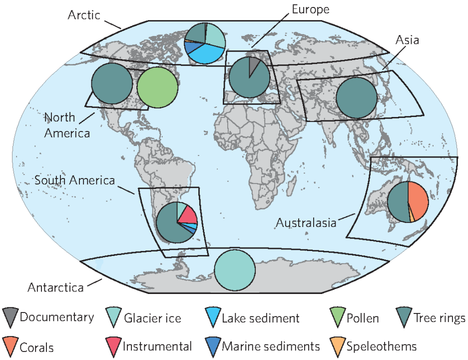


Figure 1 | The PAGES 2k Network. Boxes show the continental-scale regions used in this study. The pie charts represent the fraction of proxy data types used for each regional reconstruction. Supplementary Database S1 includes information about each study site and the proxy data for all time series used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

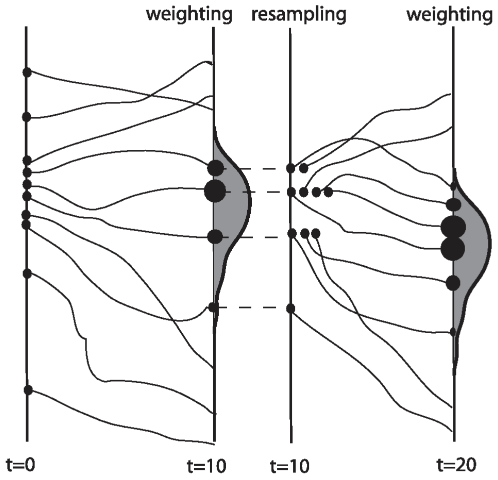
PAGES 2k Consortium (2013)

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)

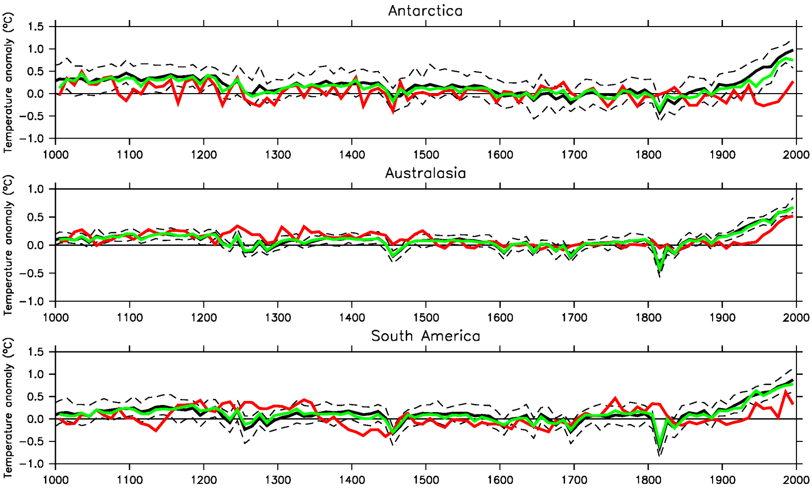
Proof of concept: offline data assimilation

- Let's try assimilating the three Southern Hemisphere PAGES 2k reconstructions into the OGSV25 ensemble.
- For each decade during the period 1001–2000 CE, calculate a cost function following e.g. Crespin et al. (2009):

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

- Use these values to calculate a *weighted* ensemble mean.
- Here, each ensemble member is weighted by e^{-10C}.

Simulated and reconstructed decadal-mean temperature

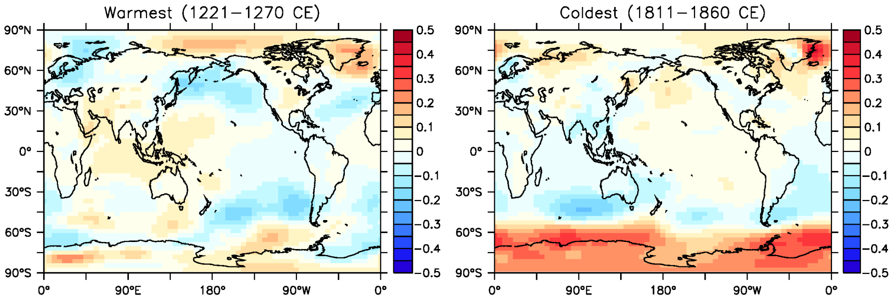


Correlations between model and reconstructions

Region	Ensemble mean	Individual members: Minimum	Individual members: Maximum	Assimilation
Antarctica	+0.20	+0.06	+0.27	+0.48
Australasia	+0.52	+0.44	+0.55	+0.56
South America	+0.15	+0.07	+0.25	+0.38

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 (although this could be resolved by combining data assimilation with forward modelling).
- 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

- Climate modelling can 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.
- Future work:
  - Generate an even larger ensemble of model simulations.
  - Use this ensemble to test different ways of assimilating SH proxies.
  - Perform a fully interactive assimilation using particle filtering.