Assimilation of Southern Hemisphere proxy records into a climate modelling framework

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1. Introduction

- The reconstruction of past climatic fields, such as temperature or mean sea level pressure, is a critical challenge within palaeoclimatology.
- Data assimilation is a particularly promising approach, as it combines the dynamical information encoded within climate models with the real-world information recorded by natural archives.
- Here, we demonstrate the potential of data assimilation by assimilating Southern Hemisphere proxy records into a climate model.

2. Palaeoclimate data assimilation

- In palaeoclimate data assimilation, we constrain a climate model to follow the evolution of proxies or reconstructions.
- We cannot use the same methods as dynamical meteorology, because of the limited spatial extent and temporal resolution of proxy data.
- Instead, we can employ offline approaches:
  - Run a large ensemble of simulations and simply choose the one that performs best ("infinite monkeys").
  - Run a large ensemble of simulations and generate a weighted ensemble mean, based on some assessment of skill.

Figure 1. "Ford, there's an infinite number of monkeys outside who want to talk to us about this script for Hamlet they've worked out." (The Hitchhiker's Guide to the Galaxy)

- In essence, we rely on using internal variability within the model to sample the full range of possible climate states.

3. Data and methods

- To generate a model ensemble, we use the CSIRO Mk3L climate system model to complete 25 simulations of the period from 801 to 2000 CE.
- Each simulation is driven by best estimates of changes in the Earth's orbit, greenhouse gases, solar irradiance and volcanic eruptions.
- We assimilate the Southern Hemisphere temperature reconstructions generated by the PAGES 2k Consortium (Figure 2).

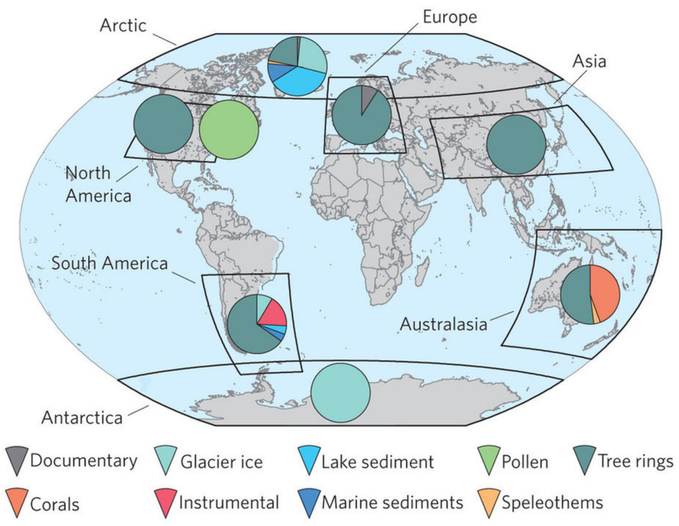

Figure 2. The continental-scale reconstructions generated by PAGES 2k Consortium (2013).

- A cost function is used to quantify the error in each model simulation:

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

- The values are then used to calculate a *weighted* ensemble mean, with each ensemble member being weighted by $e^{-\frac{1}{2}C^2}$. The resulting assimilation spans the period from 1001 to 1995 CE.

4. Outcome of data assimilation

- Examining the simulated and reconstructed temperatures for the Australasian region, we see that the reconstruction generally lies within the range of states simulated by the model ensemble (Figure 3). This is a necessary condition for the data assimilation to be successful.

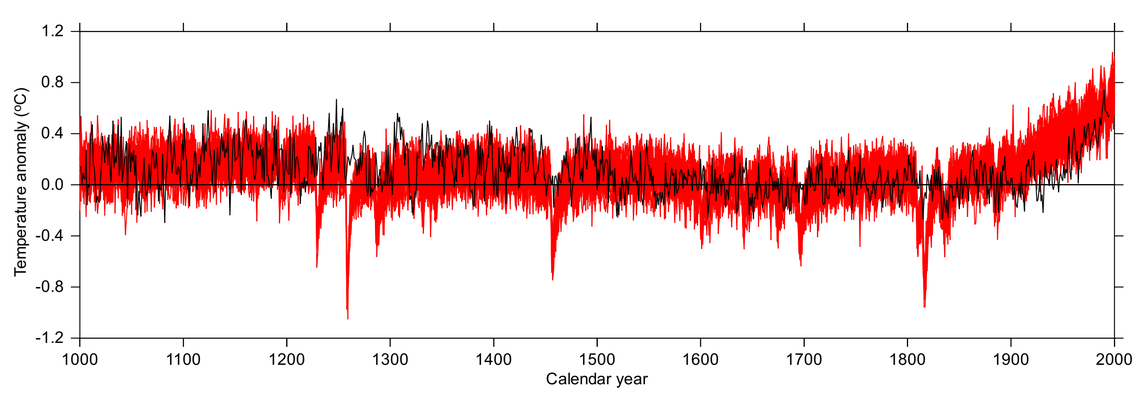

Figure 3. Surface air temperature anomaly for the Australasian region, relative to the 1501–1850 CE mean: reconstructed (black), and simulated by each of the 25 members of the model ensemble (red).

- The weighted ensemble mean reproduces the variability in the reconstructions with much greater fidelity than the unweighted ensemble mean, demonstrating the success of the data assimilation (Figure 4).

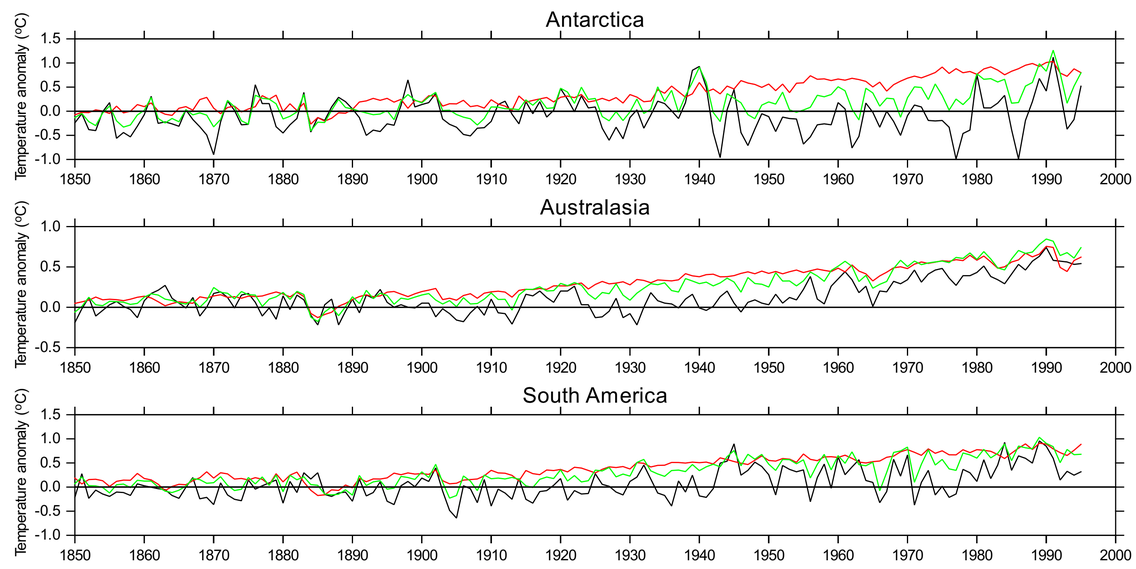

Figure 4. Surface air temperature anomaly for each region, relative to the 1501–1850 CE mean: reconstructed (black), unweighted ensemble mean (red) and weighted ensemble mean (green).

5. Field reconstructions

- We can now use the outcome of the data assimilation to reconstruct past climatic fields. Figures 5 and 6 show the reconstructed anomalies in surface air temperature and mean sea level pressure for the warmest and coldest 50-year periods in Australasia over the last millennium.

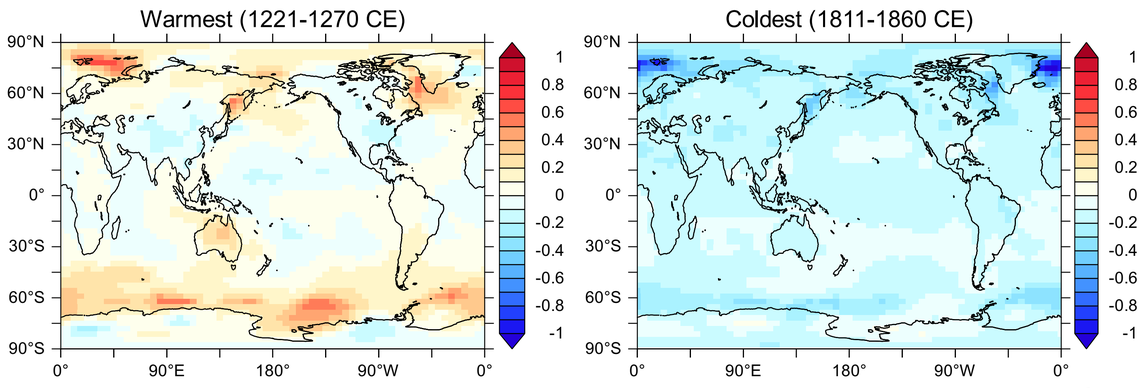

Figure 5. Reconstructed surface air temperature anomaly, relative to the 1501–1850 CE mean (°C).

- The warmest period (1221–1270 CE) is characterised by a zonal wavenumber 3 pattern, with a blocking high over New Zealand. In contrast, the coldest period (1811–1860 CE) exhibits high pressure over Antarctica and a negative phase of the Southern Annular Mode.

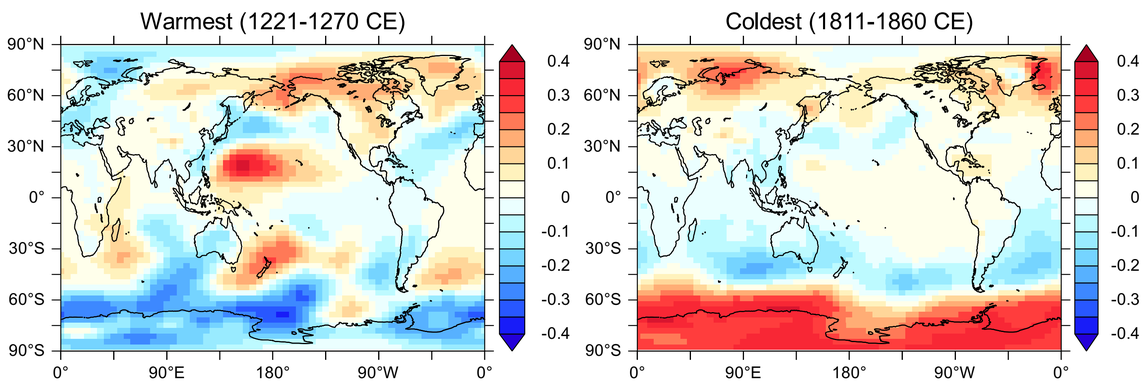

Figure 6. Reconstructed mean sea level pressure anomaly, relative to the 1501–1850 CE mean (hPa).

References

- PAGES 2k Consortium (2013), doi:10.1038/ngeo1797.