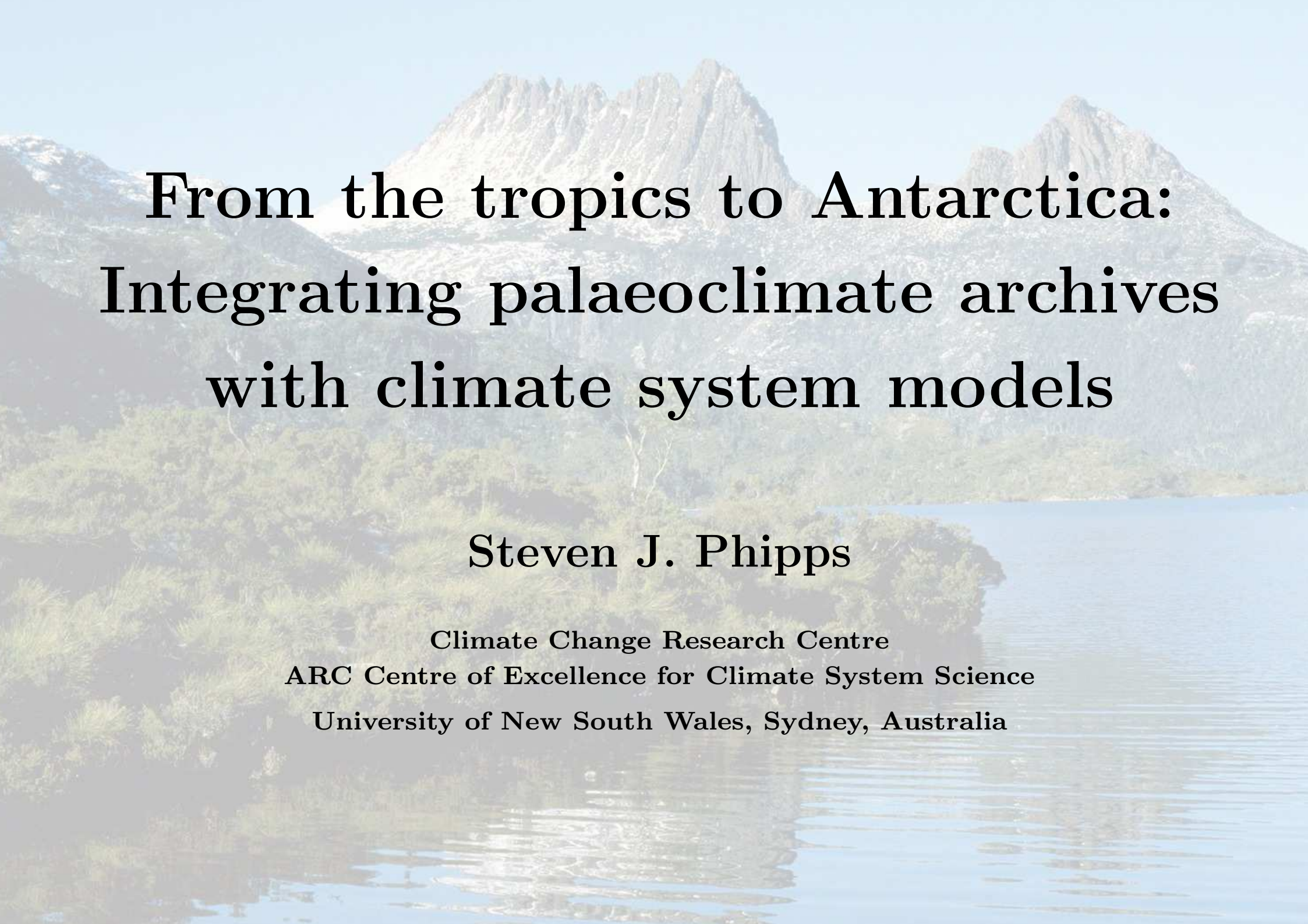

From the tropics to Antarctica: Integrating palaeoclimate archives with climate system models

Steven J. Phipps

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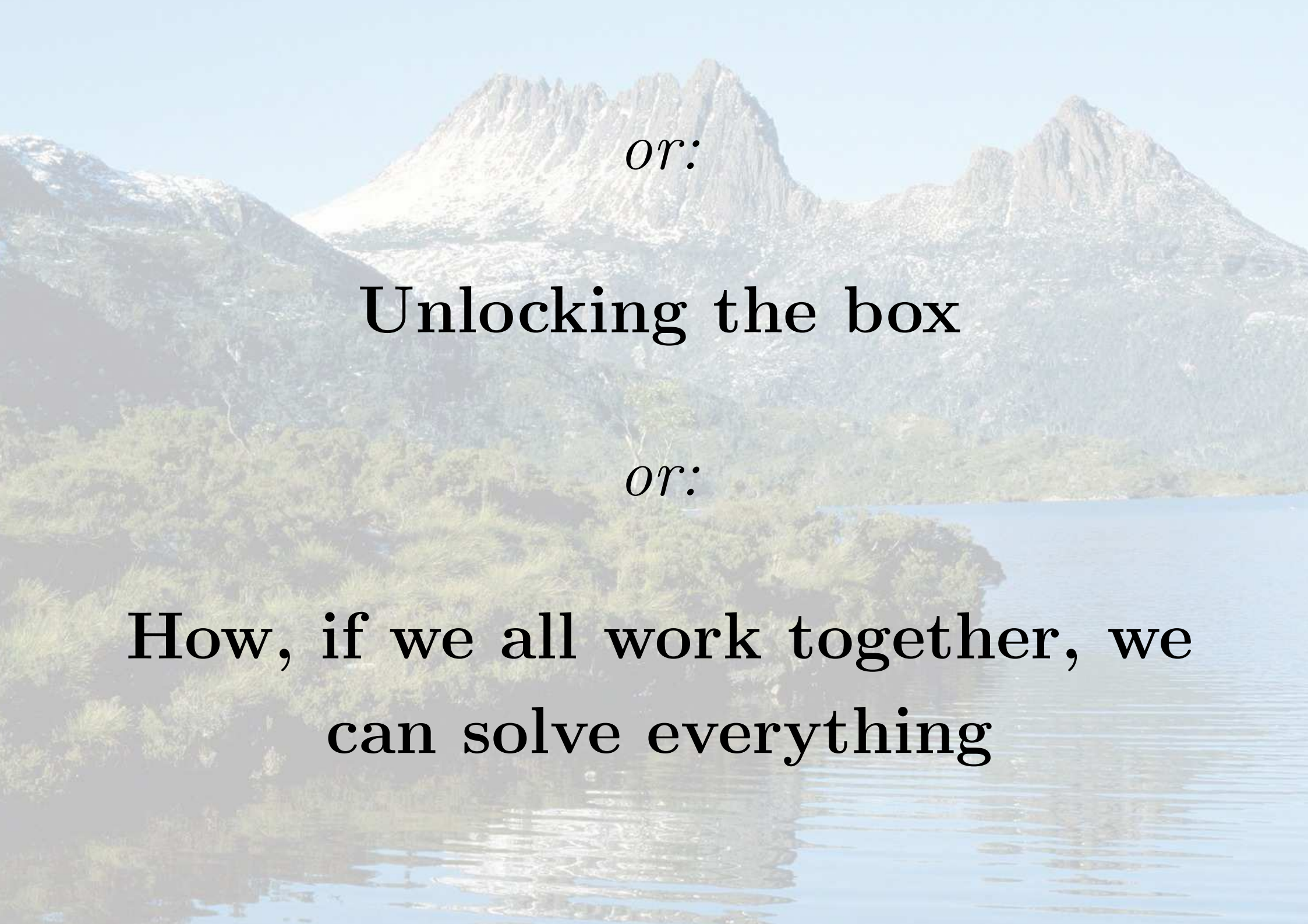


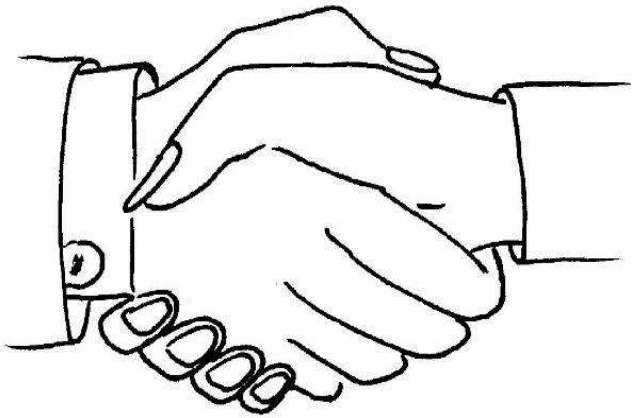
or:

Unlocking the box

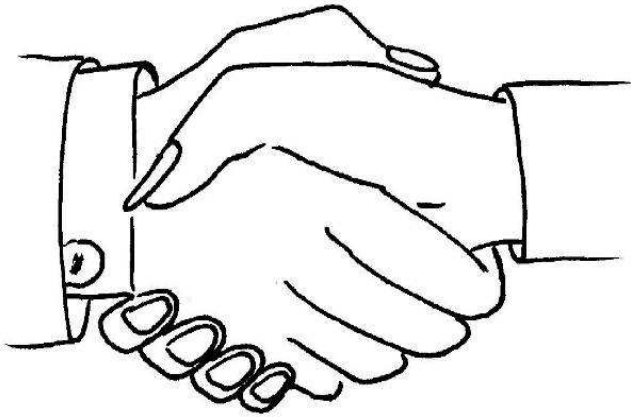
or:

How, if we all work together, we can solve everything

The “handshake” question

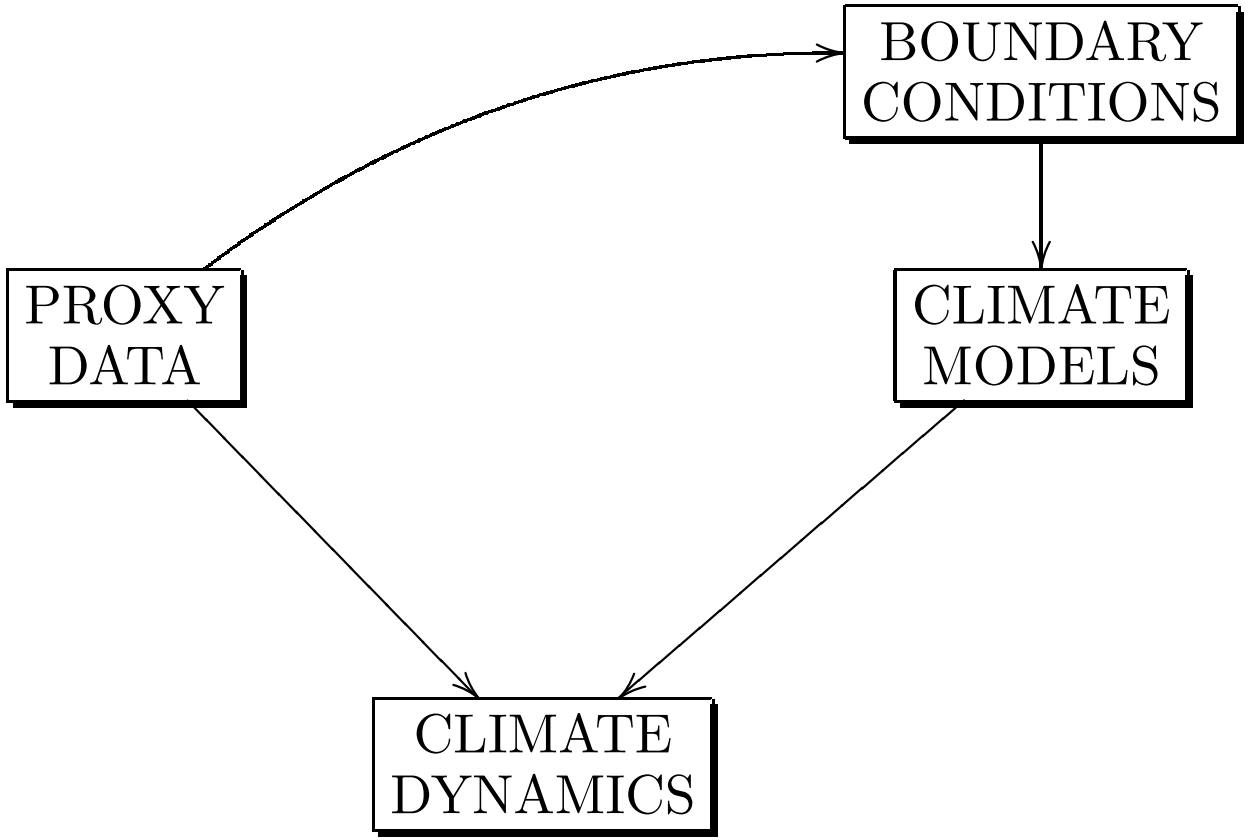


The "handshake" question



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

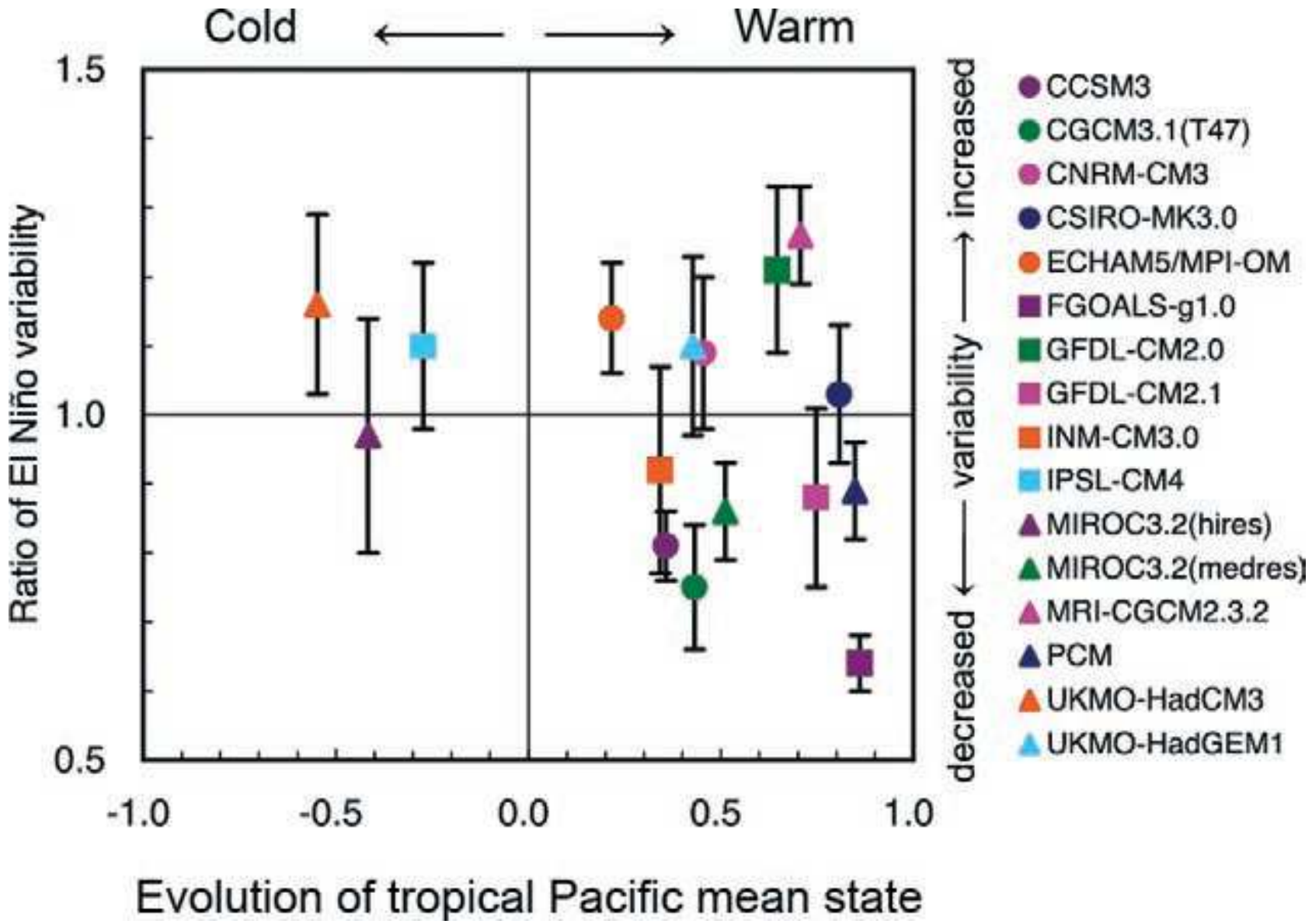
Unlocking the box...



What are the barriers to data-model integration?

1. The models are imperfect
2. Our knowledge of the boundary conditions on the climate system is limited
3. Proxies have limited spatial and temporal coverage
4. Transfer functions assume that teleconnections are stationary
5. We need to apply our understanding of climate dynamics

1. The models are imperfect

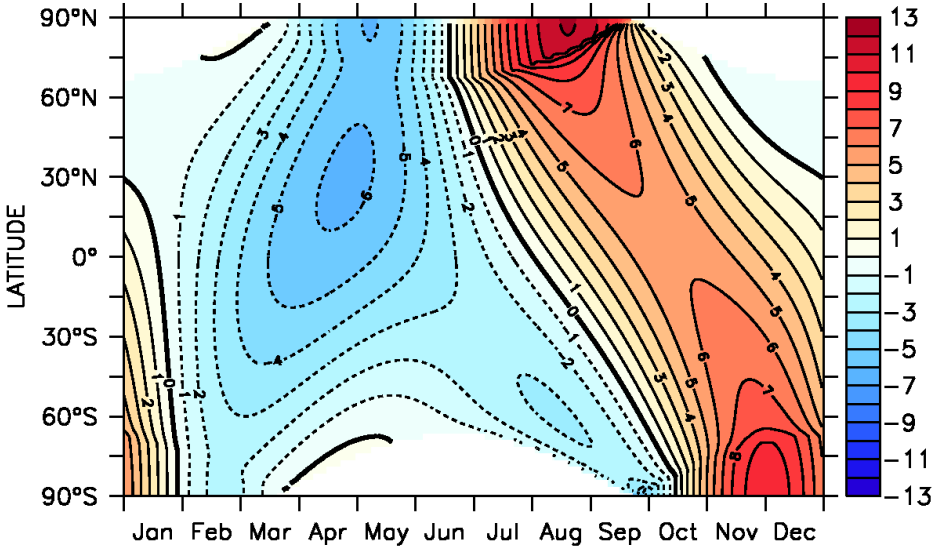


Guilyardi et al. (2009), *Bull. Am. Meteorol. Soc.*

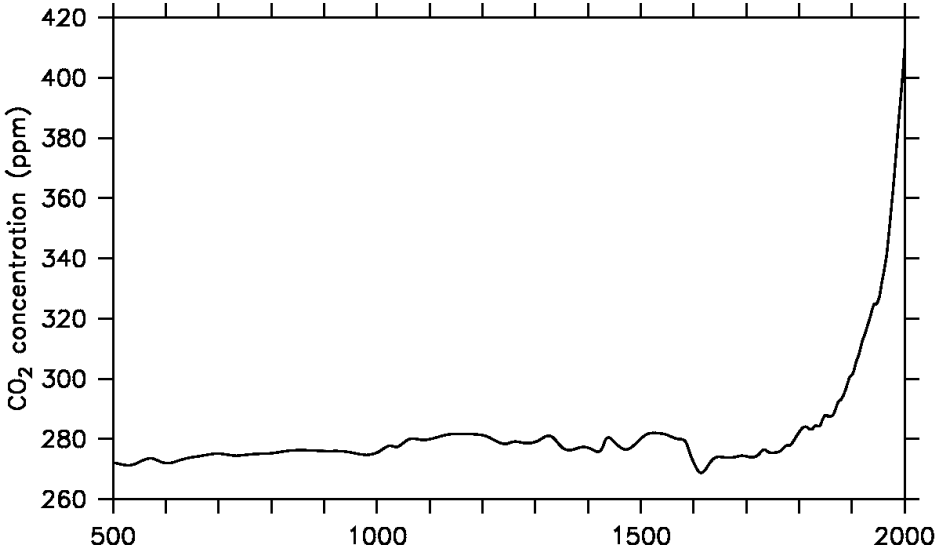
2. Limited knowledge of boundary conditions

- Even a perfect model can only simulate the climate correctly when it is supplied with the correct boundary conditions
- Boundary conditions on the climate system include:
  - Earth's orbital geometry
  - Solar irradiance
  - Volcanic aerosols
  - Anthropogenic greenhouse gases
  - Anthropogenic aerosols
  - Ozone
  - Ice sheets
  - Sea level
  - Vegetation/land use
- In general, these must be prescribed
- Knowledge of past changes can be very limited

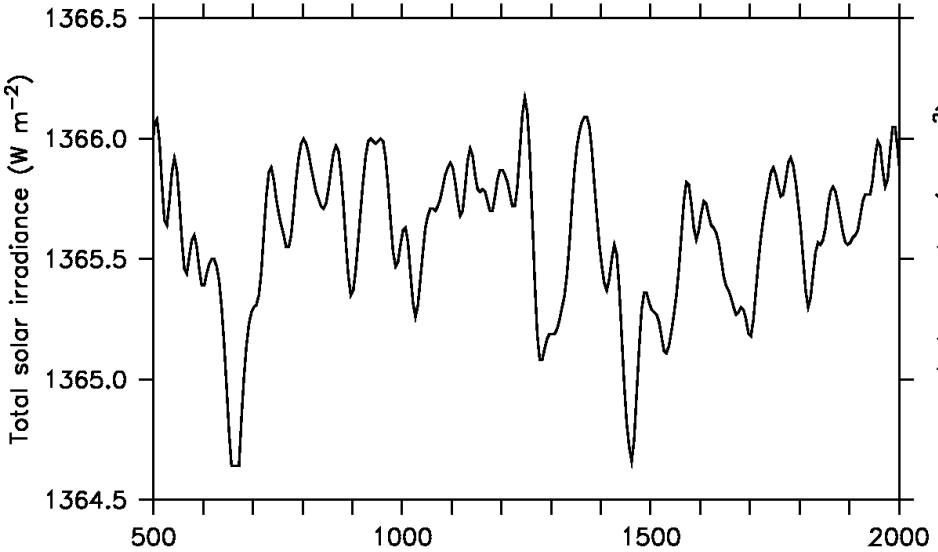
Boundary conditions over the past 1500 years



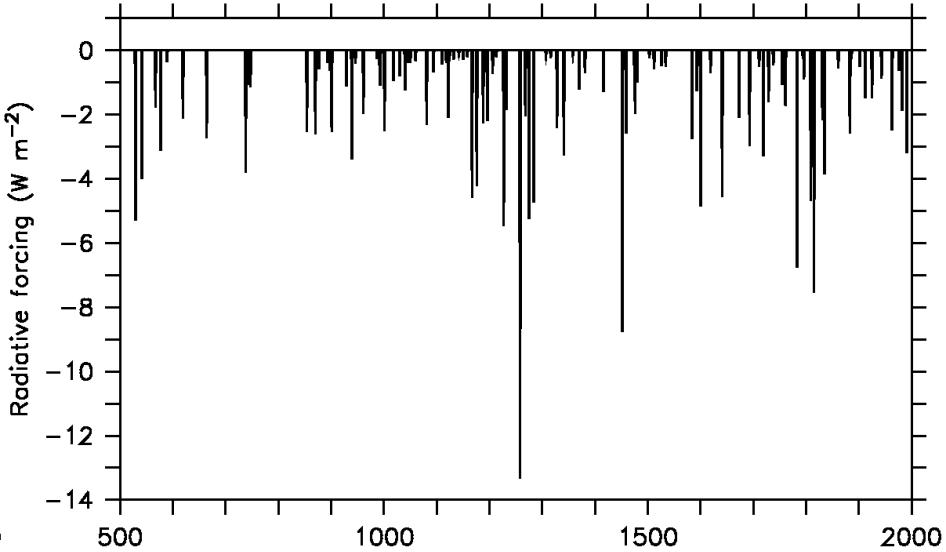
(a) Insolation (2000 CE minus 500 CE)



(b) Effective CO_2 concentration

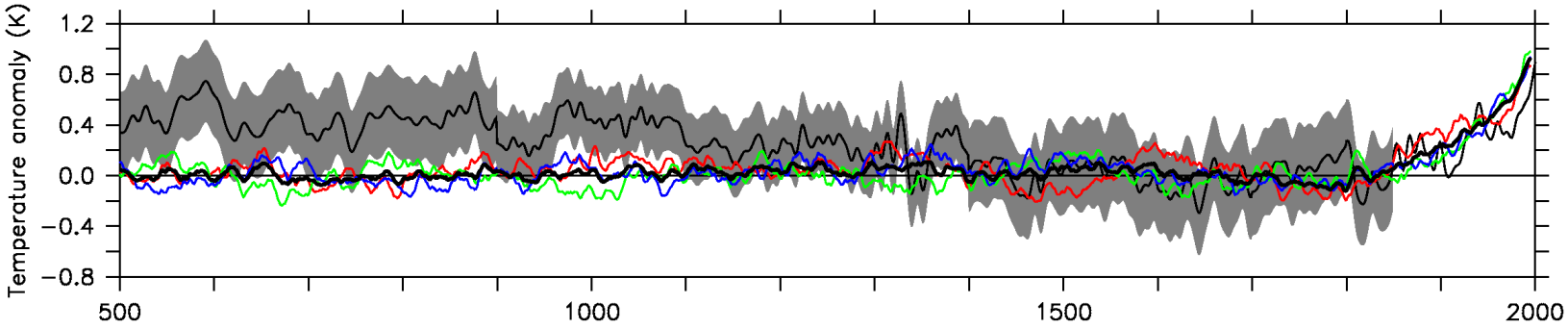


(c) Total solar irradiance

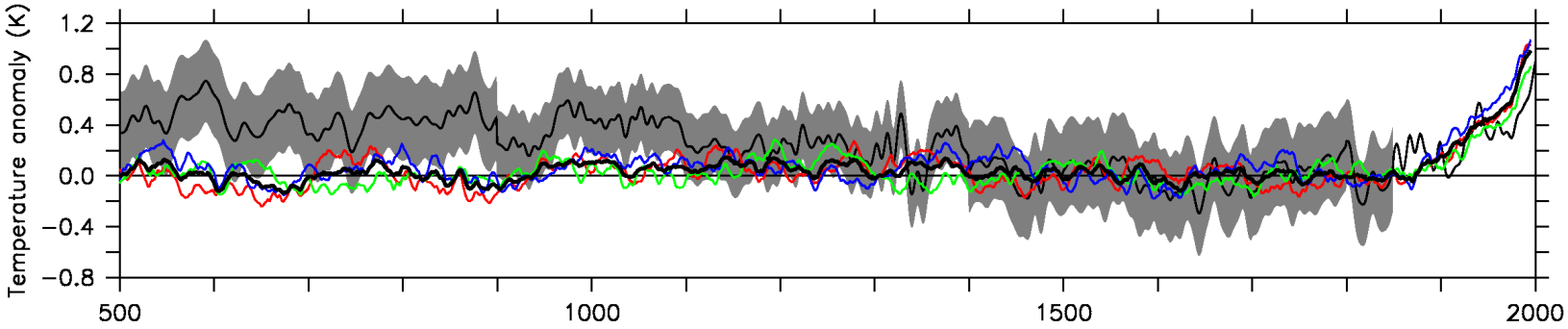


(d) Radiative forcing from volcanoes

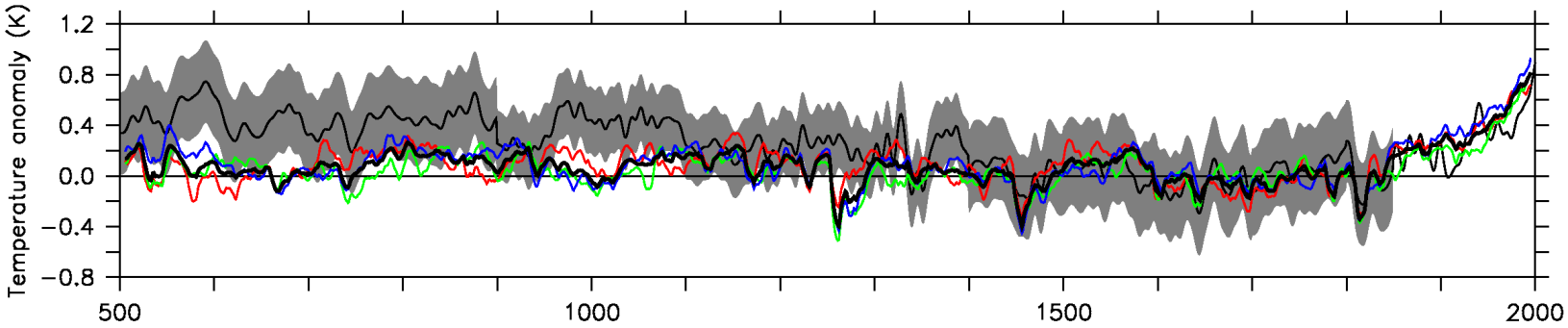
The simulated Northern Hemisphere climate



(a) Orbital + greenhouse gases



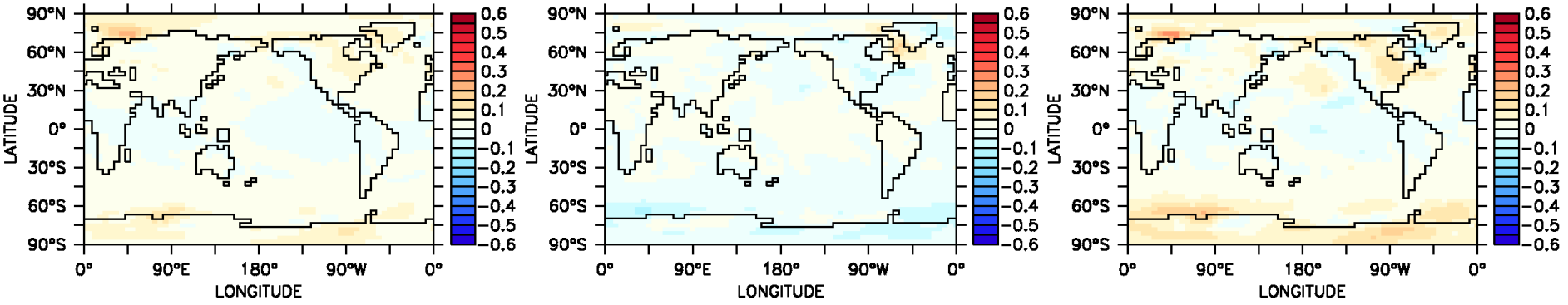
(b) Orbital + greenhouse gases + solar



(c) Orbital + greenhouse gases + solar + volcanic

Reconstruction from Mann et al. (2009), Science

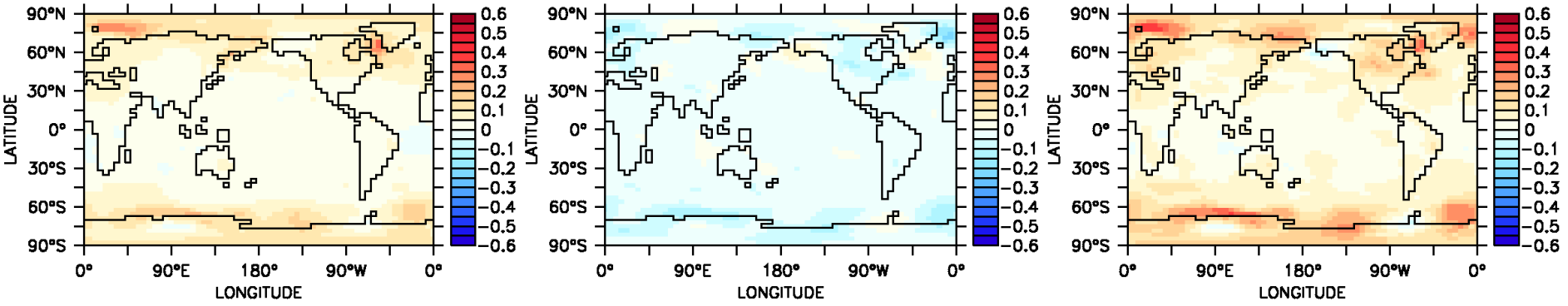
Mediaeval Climate Anomaly and Little Ice Age



(a) Mediaeval Climate Anom (O+G)

(d) Little Ice Age (O+G)

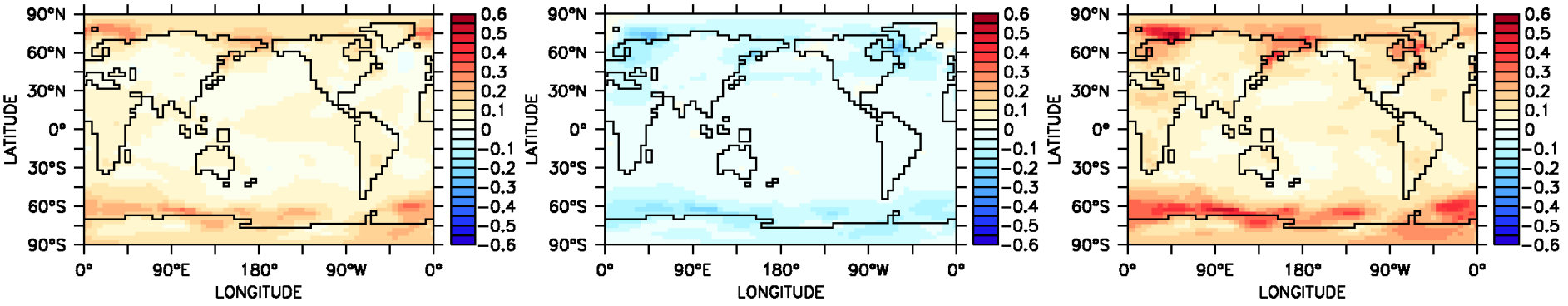
(g) MCA minus LIA (O+G)



(b) Mediaeval Climate Anom (O+G+S)

(e) Little Ice Age (O+G+S)

(h) MCA minus LIA (O+G+S)

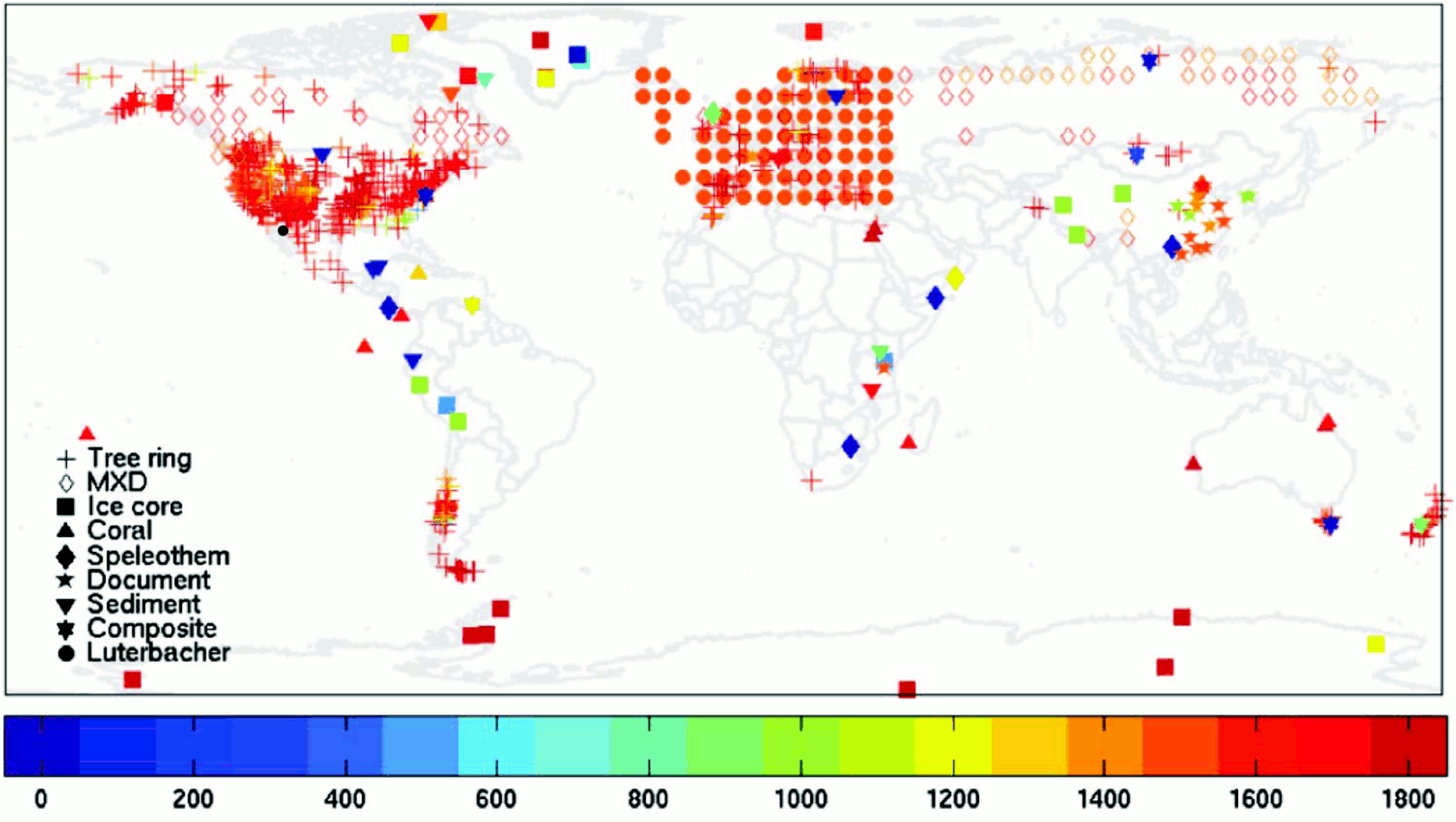


(c) Mediaeval Climate Anom (O+G+S+V)

(f) Little Ice Age (O+G+S+V)

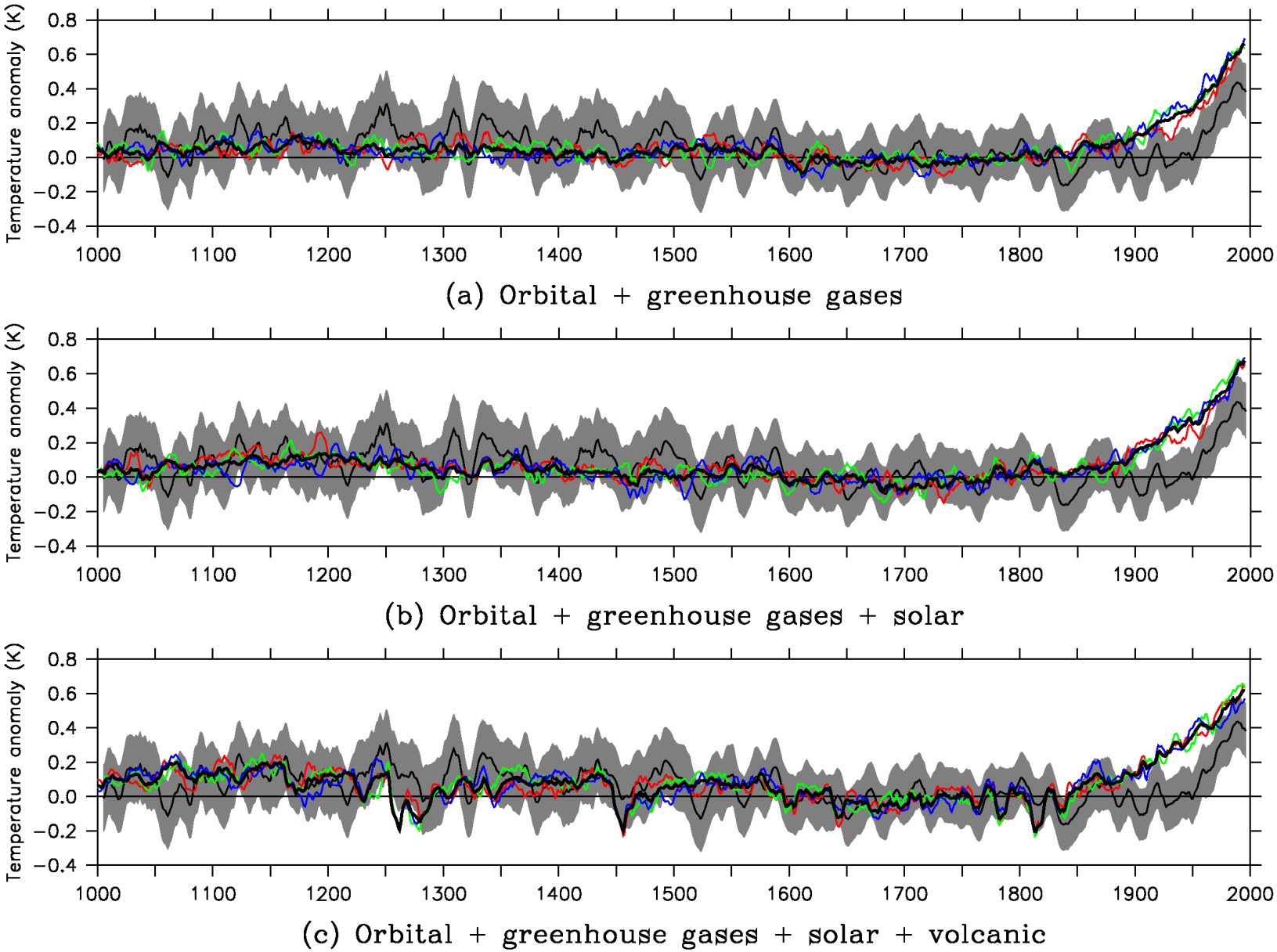
(i) MCA minus LIA (O+G+S+V)

3. Limited spatial and temporal coverage of proxies



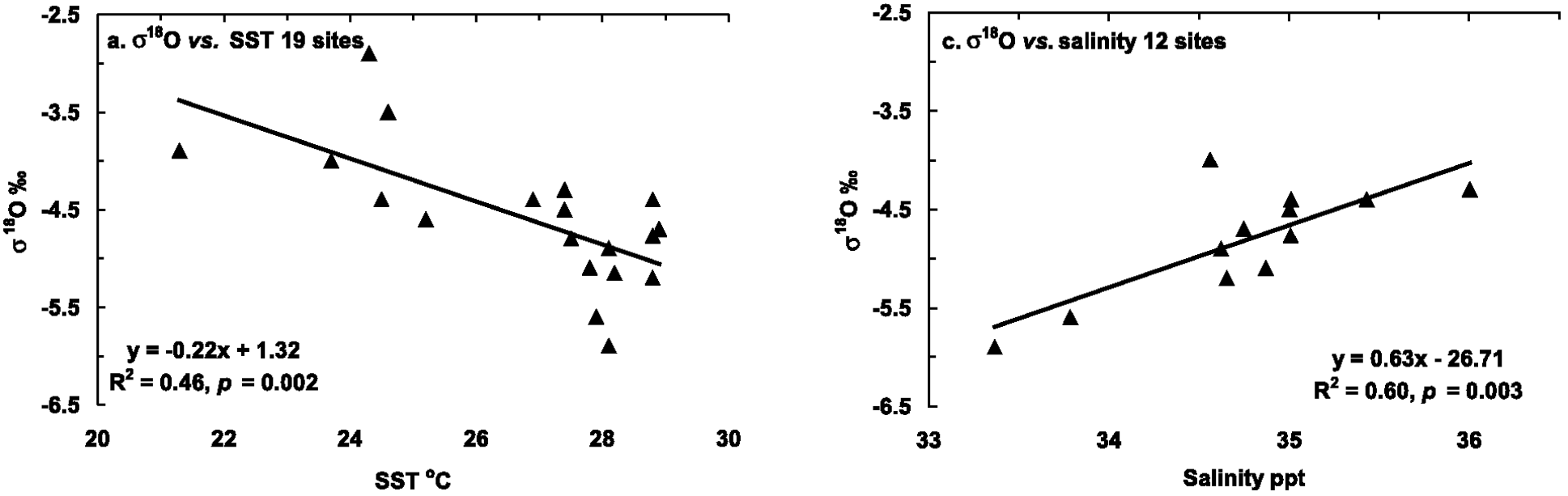
Mann et al. (2008), *PNAS*

The simulated Australasian climate



Reconstruction from Gergis, Neukom and PAGES Aus2k working group members

4. Transfer functions and stationarity

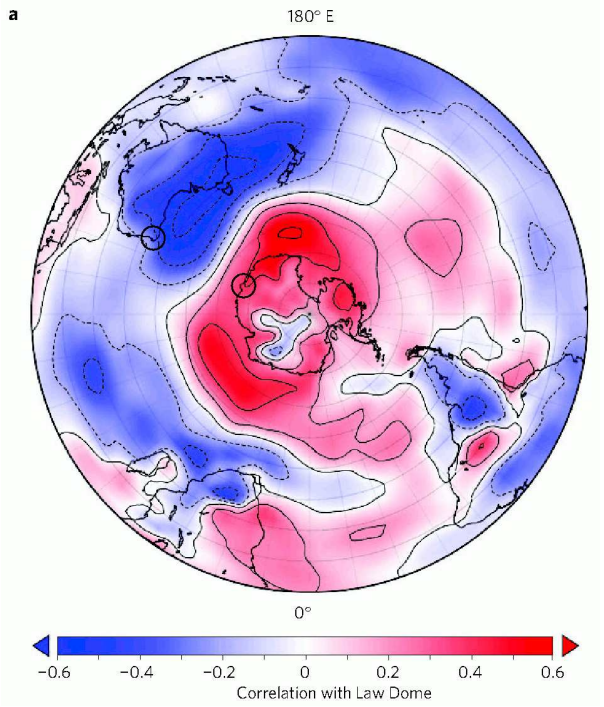


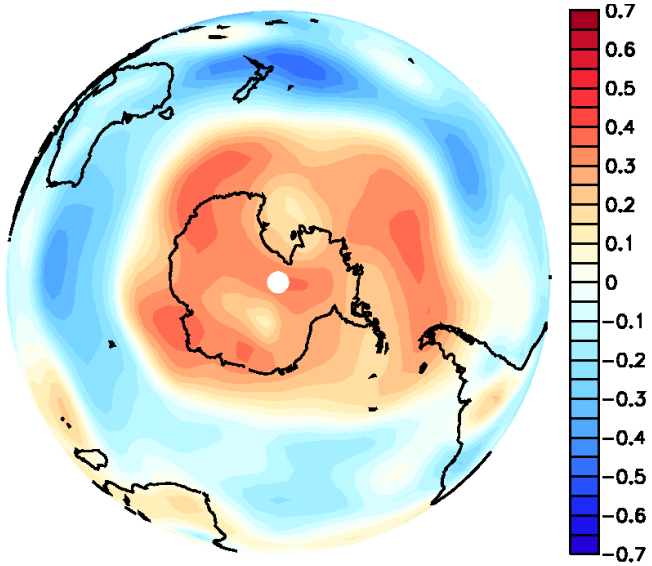
Lough (2004), *Palaeogeogr. Palaeocl.*

- Transfer functions are the only means that we have to directly convert proxy data into information about the state of the climate system
- Not all proxies give quantitative data
- Proxies generally do not respond to single environmental variables
- Transfer functions involve the assumption of stationarity
- Models can be used to test this assumption

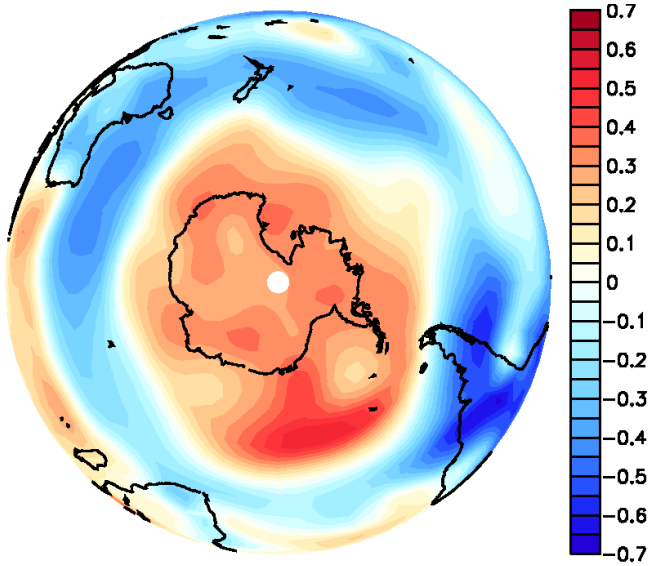
Correlation of MSLP with Law Dome precipitation (1979–2004)

van Ommen and Morgan (2010), *Nat. Geosci.*

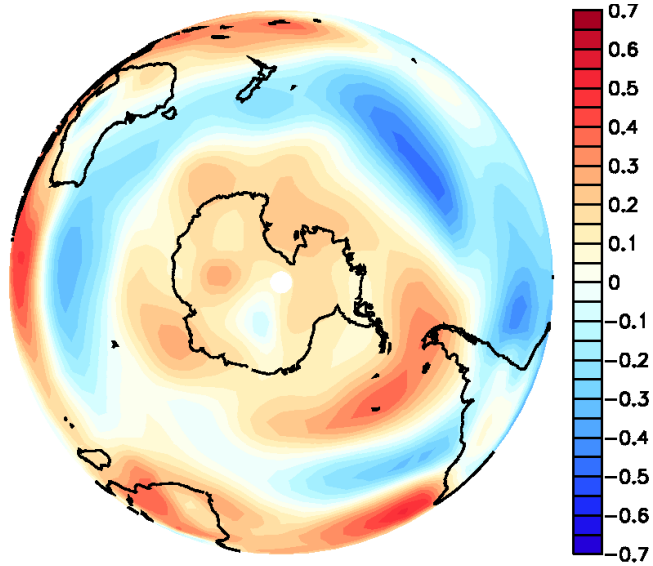




Member 1 (1975–2000)

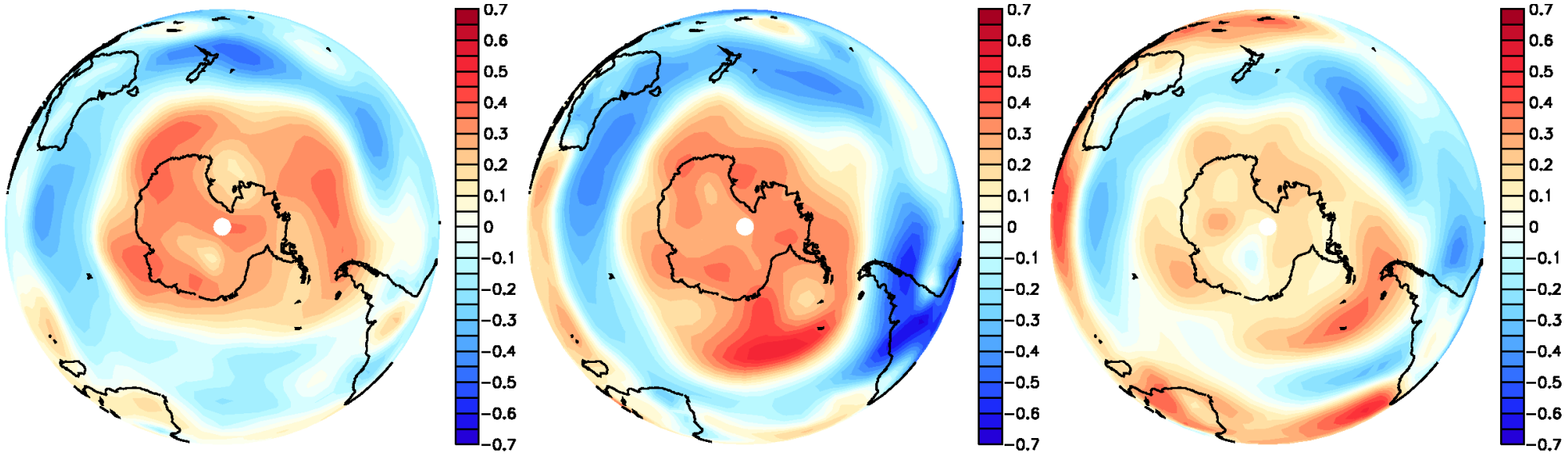


Member 2 (1975–2000)

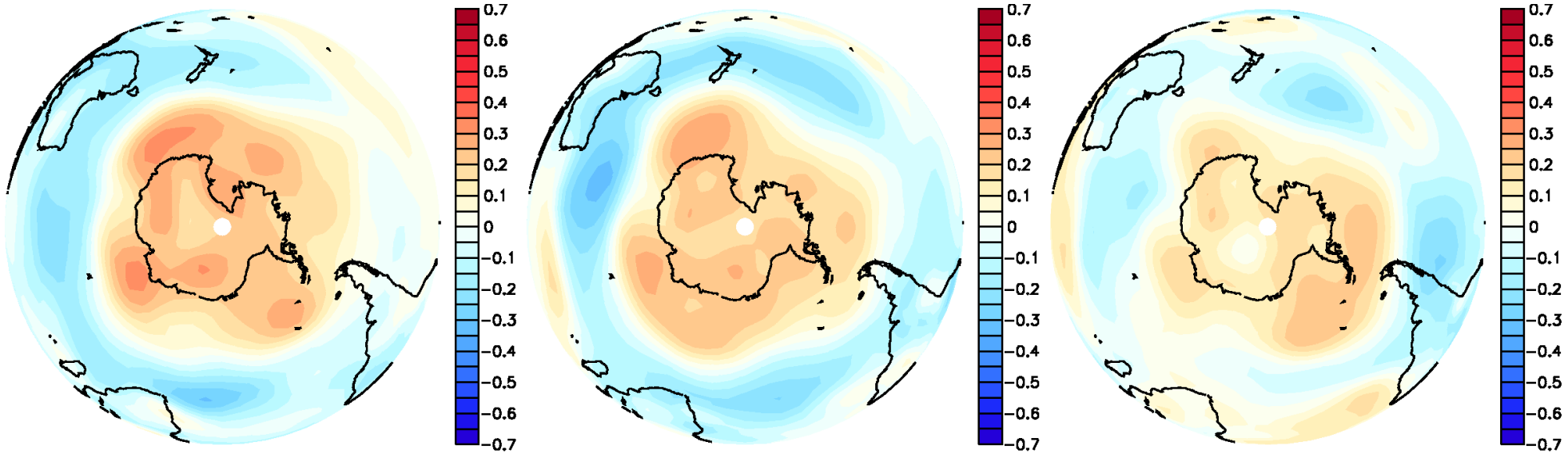


Member 3 (1975–2000)

Relationship is consistent over the 20th century ...

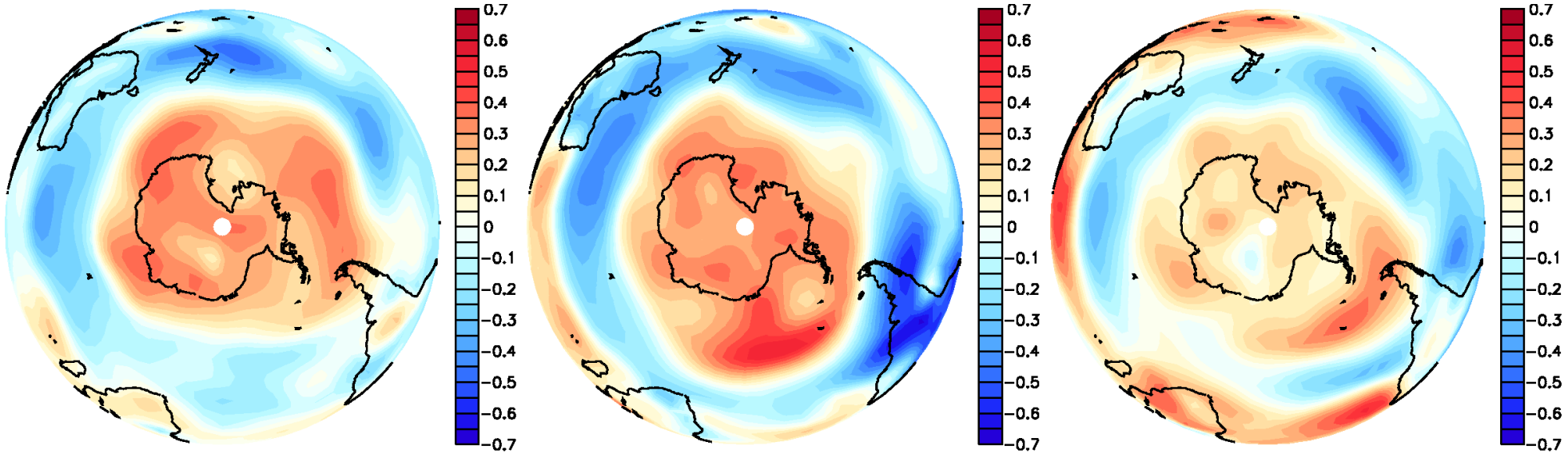


Member 1 (1975–2000) Member 2 (1975–2000) Member 3 (1975–2000)

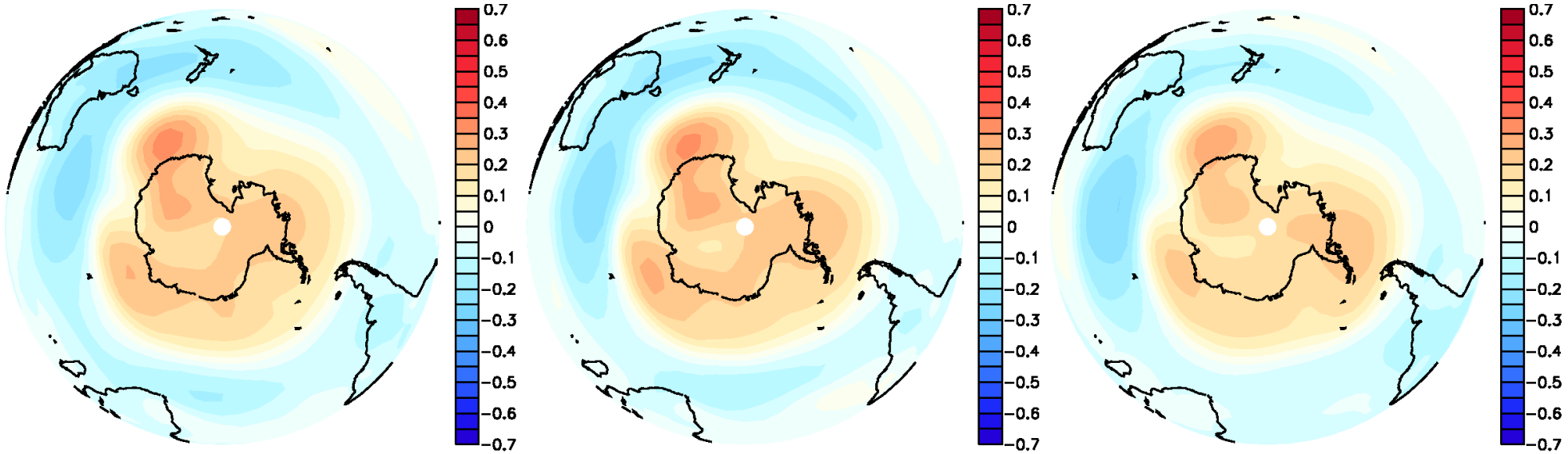


Member 1 (1901–2000) Member 2 (1901–2000) Member 3 (1901–2000)

... and the full 1500 years



Member 1 (1975–2000) Member 2 (1975–2000) Member 3 (1975–2000)

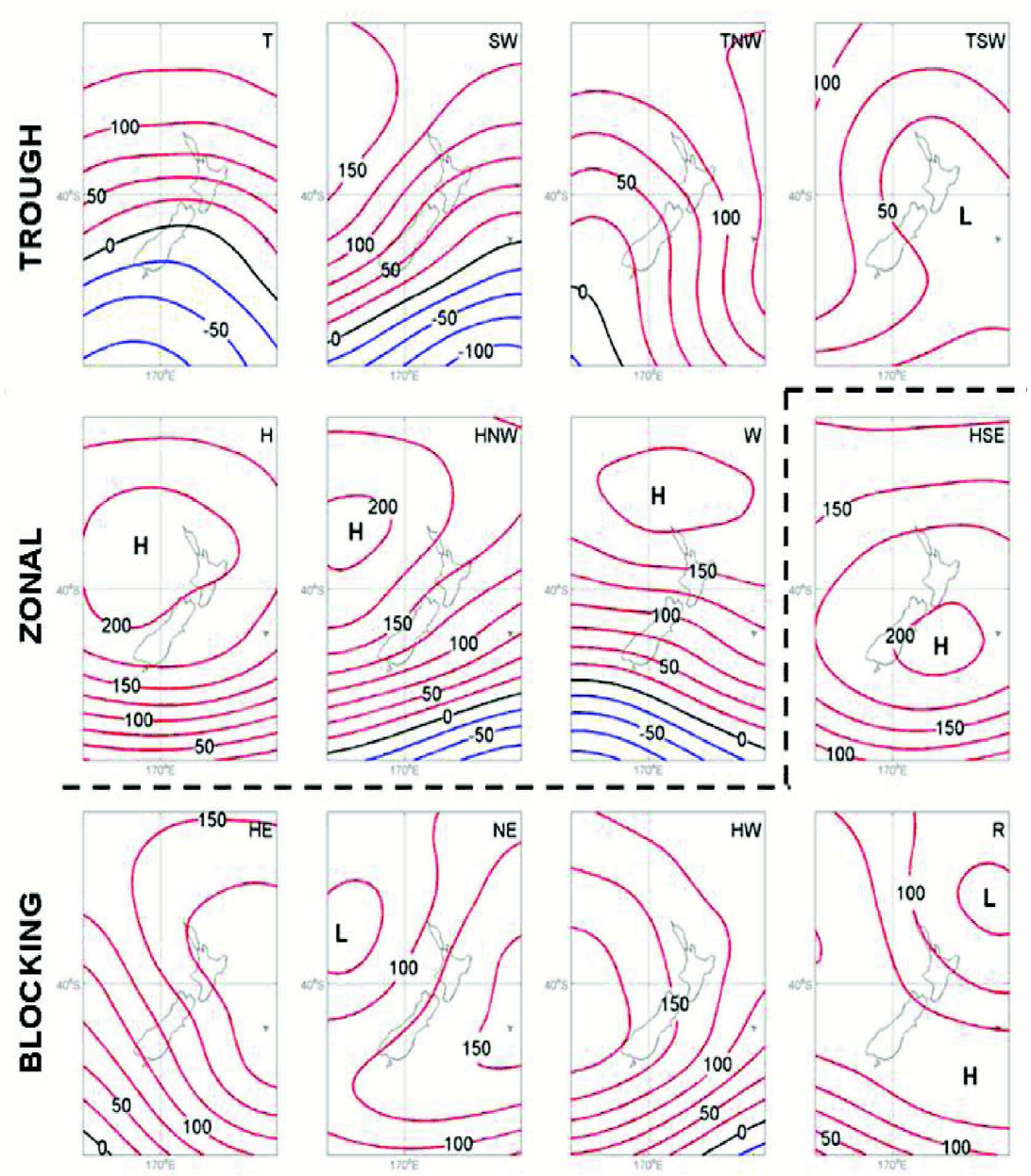


Member 1 (501–2000) Member 2 (501–2000) Member 3 (501–2000)

5. Data-model integration and climate dynamics

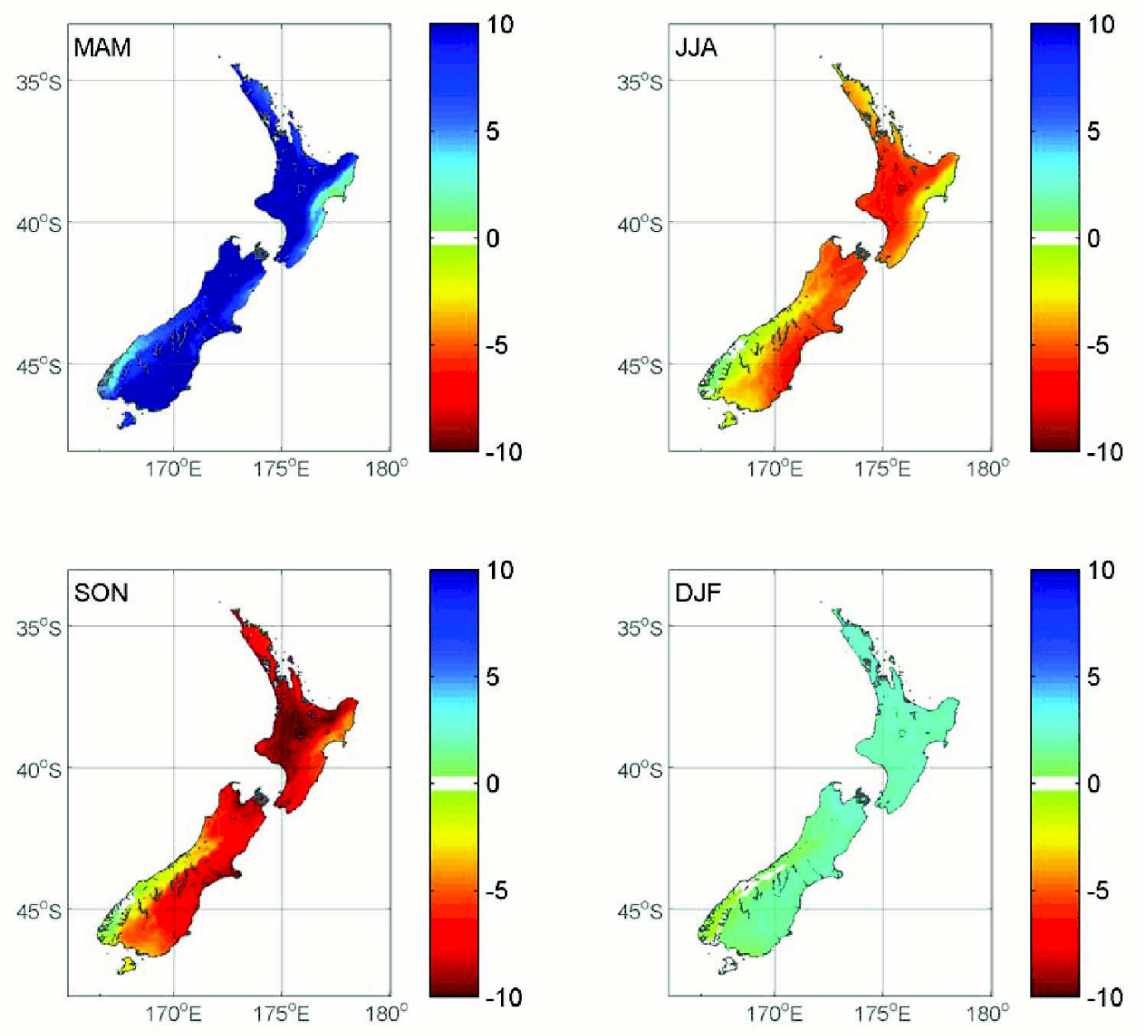
- Transfer functions have considerable limitations
- Proxies generally respond to multiple environmental variables, and we can lose dynamical information if we try to map them onto single variables
- Instead, we can extract more information if we map the proxies onto indices that describe the state of the climate system
- This defines a "common language" onto which both the proxies and the models can be mapped
- We need to involve climate dynamicists here

Example: Kidson weather types



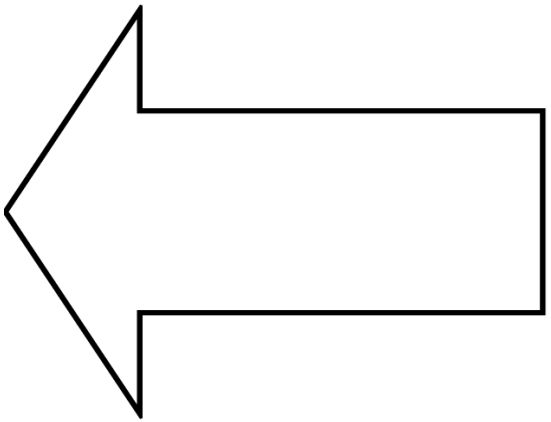
Ackerley et al. (2011), *Clim. Past Discuss.*

Mean precipitation anomaly (6 ka minus 0 ka, %)



Ackerley et al. (2011), *Clim. Past Discuss.*

Forward modelling



- Involves replication of proxy timeseries within a climate model
- Requires direct modelling of relevant physical and biological processes
- Arguably the only approach that allows true data-model integration
- Avoids the assumption of stationarity
- *Has* to be the future of palaeoclimate research, but a forward modelling capacity that covers all proxies is a long way off...
- Forward models still require boundary conditions!

Conclusions

- We can and should integrate proxy data with climate system models in a way that extracts the maximum possible information about the dynamics of the climate system
- To fully undertand the dynamics of past climates will require:
  - Better climate and earth system models (palaeoclimate has a vital role to play here)
  - Accurate reconstructions of past boundary conditions
  - Proxy data with enhanced spatial and temporal coverage
  - A better understanding of how teleconnections (transfer functions) evolve over time
  - The involvement of climate dynamicists to determine the optimal "language" for data-model integration
- In the long-term, we need to develop a comprehensive forward modelling capability