Paleoclimate insights in teleconnection dynamics

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Key time periods for developing insight into teleconnections:

**Common Era**
- Capability to extend the observational period with high temporal and spatial resolution of precip, temp
- Key to constraining decadal-centennial climate variability

**Abrupt climate change events**
- No modern analogue but may hold relevance for the future
Paleoclimate reconstructions limited by:

- Paucity of long, continuous, high-resolution proxy records from dynamically-important regions
- Limited process-level understanding of many proxy systems
- Challenges in comparing proxy data with climate model output
Recent promising developments:

- Development and application of proxy system models
- Paleoclimate data assimilation and advanced climate field reconstruction techniques
- Increased number of isotope-enabled GCM simulations,

=> Enabling improved data/model comparisons

But still need more long, high-resolution proxy records from under-sampled and dynamically-important regions (e.g. tropical Pacific, Southern Hemisphere)!
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A millennial history of central Pacific SST variability

Emile-Geay et al., 2013
A millennial history of central Pacific SST variability

- Best estimates of Nino 3.4 SSTs suggest greater tropical Pacific decadal-to-multidecadal variability in the reconstructions, as compared to CGCM simulations.
- Centennial-scale variability poorly constrained due to uncertainties in tropical Pacific SSTs since A.D. 1850 and the paucity of long, high-resolution paleoclimate records from the central/eastern Pacific.
Investigating the causes of megadroughts in the Southwest US

• Comparison between CMIP5/PMIP3 last millennium simulations & tree-ring derived North Atlantic drought atlas
  – Indicates pronounced differences in underlying teleconnection dynamics between paleoclimatic reconstructions and models

Coats et al., 2015

PDSI time series for Southwest region in models and proxy reconstructions
The Last Millennium Climate Reanalysis Project

Hakim et al., 2016
Paleoclimate Data Assimilation

(Hakim et al., 2016; Steiger and Hakim, 2015)

Paleoclimate data assimilation (PDA) uses model-simulated climate states to measure the novel information in proxy data and to distribute that information to all climate variables subject to the dynamical constraints of the climate model.

Advantages:
1. Infers multiple climate fields simultaneously
2. Generally does not assume stationary teleconnections (unlike most purely statistical approaches)
3. Uses dynamical models to infer spatial relationships within and between climate fields. The fields are thus dynamically consistent.
4. Can include proxies with dependence on multiple state parameters (e.g., temperature and moisture controls on tree-ring width) and different timescales (e.g., annual and decadal resolution)
Proxy System Models

Figure source: Kevin Anchukaitis
Proxy System Models

1. Design optimal sampling networks for paleoclimate reconstruction

2. Apply proxy system models to climate system models to improve data/model comparisons
   • Identify deficiencies in (1) process-level understanding of the proxy sensors, (2) paleo-observing network, and/or (3) climate model simulations

3. Apply proxy system models to observations to test consistency of proxy interpretations

4. Model the total uncertainty in the response of proxy systems to environmental forcing and its expression in paleoclimatic reconstructions
Proxy System Models

Application: Model/data comparison

$$\delta^{18}O_{\text{coral}} = f(T, S)$$

Application: Optimal sampling network

$$\delta^{18}O_{\text{cellulose}} = f(T, \delta^{18}O_{\text{rain}}, \delta^{18}O_{\text{vapor}}, \%RH)$$

Thompson et al., 2011

Evans et al., 2016
The Iso2k database v.0 as of 12/2015
(v.1 expected ~end of summer 2016)

~600 records

Figure source: Bronwen Konecky & Judd Partin
Best practices for proxy-model comparisons of hydroclimate during the Common Era

Comparing proxy and model estimates of hydroclimate variability and change over the Common Era

Hydro2k Consortium: Jason E. Smerdon¹, Jürg Luterbacher²,³, Steven J. Phipps⁴, Kevin J. Anchukaitis⁵, Toby Ault⁶, Sloan Coats⁷,⁸, Kim M. Cobb⁹, Benjamin I. Cook¹⁰, Chris Colose¹⁰, Thomas Felis¹¹, Ailie Gallant¹², Johann H. Jungclaus¹³, Bronwen Koneky⁸, Allegra LeGrande¹⁰, Sophie Lewis¹⁴, Alex S. Lopatka¹⁵, Wenmin Man¹⁶, Justin S. Mankin¹,¹⁰, Justin T. Maxwell¹⁷, Bette L. Otto-Bliesner⁷, Judson W. Partin¹⁸, Deepti Singh¹, Nathan J. Steiger¹, Samantha Stevenson⁷, Jessica E. Tierney¹⁹, Davide Zanchettin²⁰, Huan Zhang², Alyssa R. Atwood⁹,²¹, Laia Andreu-Hayles¹, Seung H. Baek¹, Brendan Buckley¹, Edward R. Cook¹, Rosanne D’Arrigo¹, Sylvia G. Dee²², Michael Griffiths²³, Charuta Kulkarni²⁴, Yochanan Kushnir¹, Flavio Lehner⁷, Caroline Leland¹, Hans W. Linderholm²⁵, Atsushi Okazaki²⁶, Jonathan Palmer²⁷, Eduardo Piovano²⁸, Christoph C. Raible²⁹, Mukund P. Rao¹, Jacob Scheff¹, Gavin A. Schmidt¹⁰, Richard Seager¹, Martin Widmann³¹, A. Park Williams¹, Elena Xoplaki²
Best practices for proxy-model comparisons of hydroclimate during the Common Era

Hydro2k Consortium, *Clim. Past Disc*, 2017
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High latitude teleconnections to tropical climate

Early dynamics & modeling studies of high latitude teleconnections were motivated by paleoclimate data (e.g. Chiang and Bitz, 2005)

Chiang et al., 2005
Global atm teleconnections during D/O events

SH mid-latitude storm tracks shifted in tandem with meridional migrations of the ITCZ

Markle et al., Nat. Geo., 2016
ITCZ shifts and South Pacific Split Jet during abrupt climate changes of the last glacial period

Chiang et al., 2014
Proxy reconstructions of the 8200 BP event

Temp records

More high-resolution proxy records needed from the tropical Pacific to better understand the global response to this event

Morrill et al., Clim. Past, 2013

Hydroclimate records

Atwood et al., Nat. Geo, in rev.
Conclusions

• Key periods for which proxies can provide novel insight into climate teleconnection patterns include the Common Era and abrupt climate changes of the last glacial
  – More long, high-resolution proxy records are needed from under-sampled regions to better constrain teleconnection patterns during these periods

• Emerging methods for improved proxy development and data/model comparisons may offer a wealth of new information on climate teleconnections:
  – **Proxy System Models & CGCMs with water isotopes** are enabling improved understanding of proxy records + direct comparison between proxy data, obs, models
  – **Paleoclimate data assimilation** can account for novel information in proxy data subject to the dynamical constraints of climate models

• Such approaches have led to improved understanding of hydroclimate variability during the CE and improved constraints on tropical Pacific climate variability during the last millennium