System Sensitivity to External Forcing and Internal Variability:
Understanding the South American Monsoon through isotopic proxies and model simulations

Rebecca Orrison[1], Mathias Vuille[1]

[1]University at Albany, SUNY

UNIVERSITY AT ALBANY
State University of New York

Background

The South American Monsoon is a result of interactions between land-ocean-atmosphere dynamics. The majority of the annual rainfall occurs during the monsoon season in the austral summer (NDJFM). This resource is vital for agriculture, hydroelectric power, and drinking water.

This research explores drivers of spatiotemporal variability of the South American Monsoon over the Last Millennium (850 – 1850 CE). The signal coherency of a network of stable isotopic proxies is analyzed (Table 1, Figure 2), as well as model simulations of the monsoon forced by isolated external forcing data sets (Figure 1). This represents a divergence from the traditional approach, which has focused on the interpretation of individual proxy records. We also expand on the proxy coherency analysis of Campos et al. (2019) by including a new record (#10, Table 1) and comparing proxy variability to model representation of the monsoon response to external forcings.

Record	ID	Lat (°S)	Lon (°W)	Reference
PAL03 + PAL04	1	5.92	77.35	Apaestegui et al., Clim. Past, 2014
HUA1 + HUA2	2	11.27	75.79	Kanner et al., Quat. Sci. Rev., 2013
PAR01 + PAR03	3	4.00	55.27	Wang et al., Nature, 2017
DV2	4	12.36	41.57	Novello et al., Geophys. Res. Lett., 2012
SBE3 + SMT5	5	13.81	46.35	Novello et al., Geophys. Res. Lett., 2018
TMO	6	16.00	47.00	Wortham et al., Earth Planet. Sci. Lett., 2017
CRT1	7	24.58	48.58	Vuille et al., Clim. Past, 2012
JAR1 + JAR4	8	21.08	55.58	Novello et al., Geophys. Res. Lett., 2018
ALH6 + CUR4	9	15.20	56.80	Novello et al., Glob. Planet. Change, 2016
BOTO	10	18.12	65.77	Apaestegui et al., Earth Planet. Sci. Lett., 2018
QUELC	11	13.93	70.83	Thompson et al., Science, 2013
PUM12	12	10.07	76.06	Bird et al., Proc. Natl. Acad. Sci., 2011

Table 1. Proxy records. The location of the records are illustrated in Figure 1.

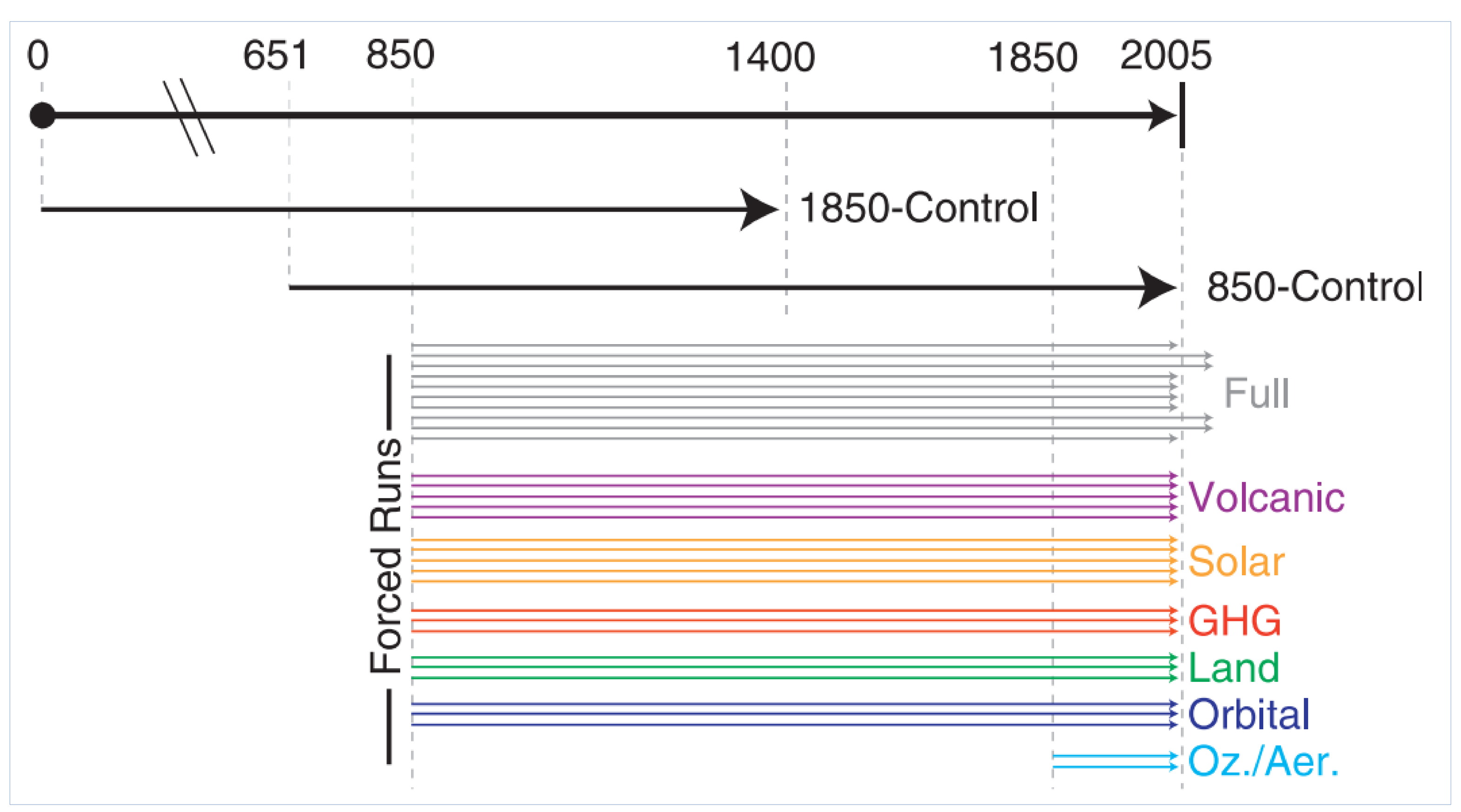


Figure 1. CESM-LME members (from Otto-Bliesner et al., 2016)

Motivating Questions

- What is the spatiotemporal pattern of $\delta^{18}O$ variability across the monsoon domain during the Last Millennium (850 – 1850 CE)?
- How does the variability of the South American Monsoon System (SAMS) respond to external forcings?
- What are the mechanisms through which the SAMS responds to external forcings and changes in internal variability?

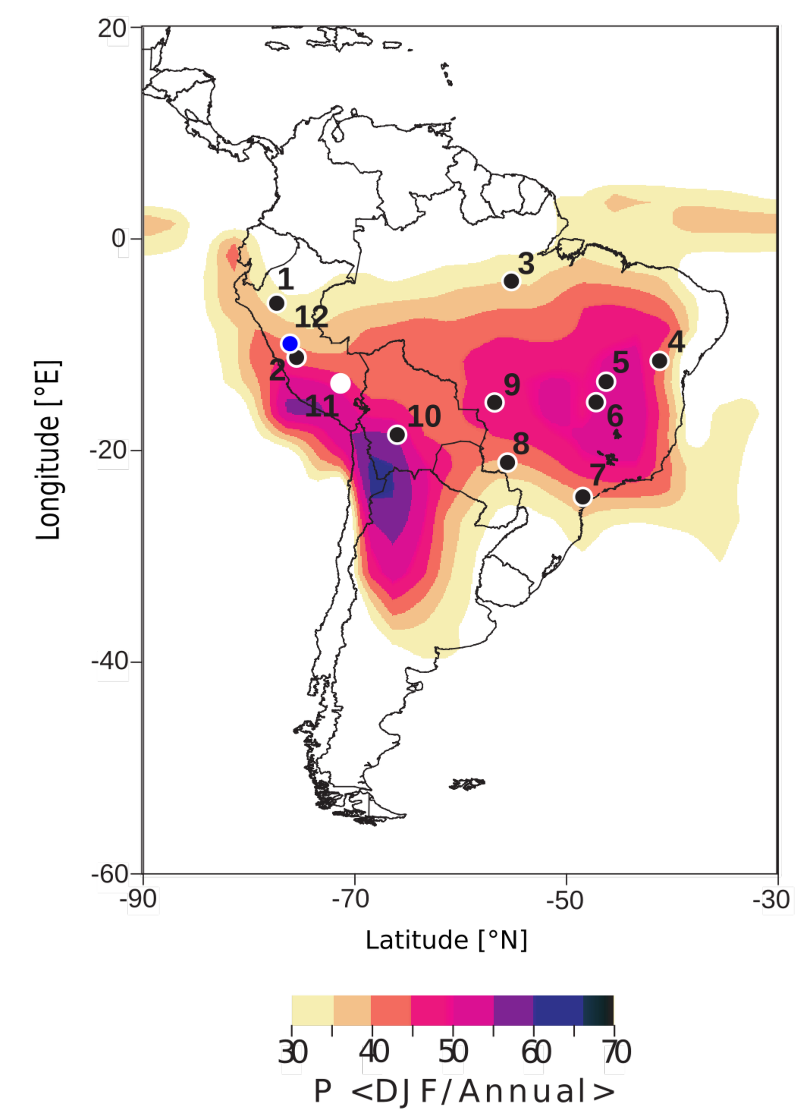


Figure 2. Shading shows percentage of annual precipitation falling during the mature phase of the South American summer monsoon (DJF), based on CMAP data (1979 – 2004). Filled circles indicate proxy record network for this study. Colors indicate type: black for speleothem, white for ice core, blue for lake sediment. Record Sites: 1) Palestina Cave; 2) Huagapo Cave; 3) Paraiso Cave; 4) Diva Cave; 5) São Bernardo and São Matheus Cave; 6) Tamboril Cave; 7) Cristal Cave; 8) Jaraguá Cave; 9) Pau d'Alho Cave and Curupira Cave; 10) Umajalanta Cave and Chiflonkhakha Cave; 11) Quelccaya Ice Cap; 12) Pumacocha Lake. Exact location and source indicated in Table 1. (Figure adapted from Vuille et al., 2012)

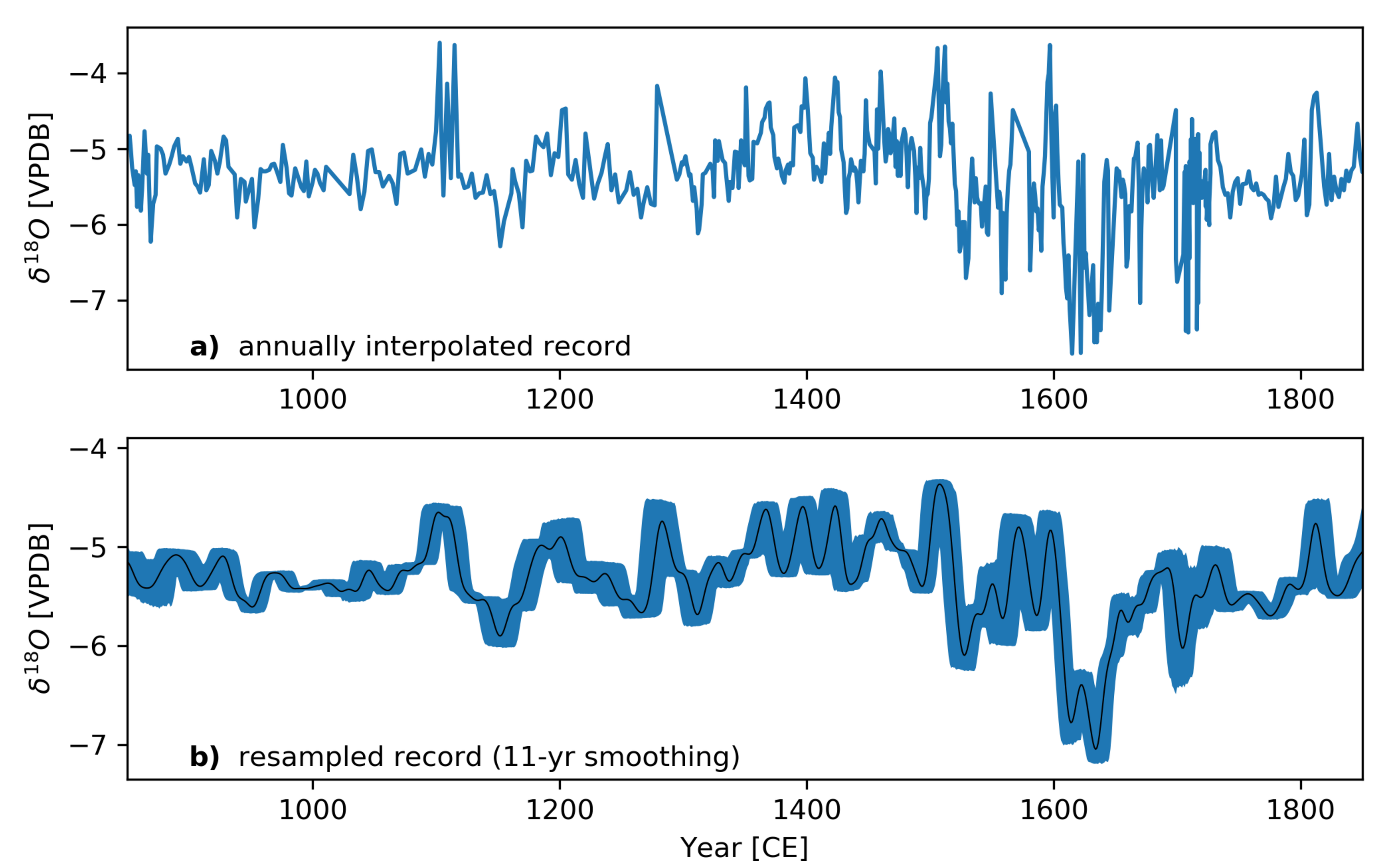


Figure 3. Isotopic time series of $\delta^{18}O$ derived from a speleothem record in Cristal Cave for **(a)** annually interpolated data and (b) Monte Carlo resampled data smoothed with an eleven year running average. Upper and lower bounds are shown in blue, the mean is shown as a black line.

Methods

A Monte Carlo resampling of age tie uncertainty was used to establish a 1,000 member ensemble of the proxy age models. For every proxy, an isotopic time series was interpolated to annual resolution for each age model in the ensemble. (Figure 3). Using the smoothed time series, a data matrix was constructed from one member taken from each proxy record ensemble. Using empirical orthogonal function (EOF) analysis, each matrix was decomposed into the leading modes of explained variance. The resulting bootstrapped loadings show the spatiotemporal variance of the isotopic signal within the bounds of the time uncertainty inherent to each record. This method follows from Anchukaitis & Tierney (2013) and Campos et al. (2019).

These modes are compared with the two sets of EOF maps derived from the CESM-LME simulations (Figure 1). The first is a set of pseudoproxy time series with added white noise whose locations were selected based on proxy locations. The second is an EOF analysis of data from the full monsoon domain (Figure 4).

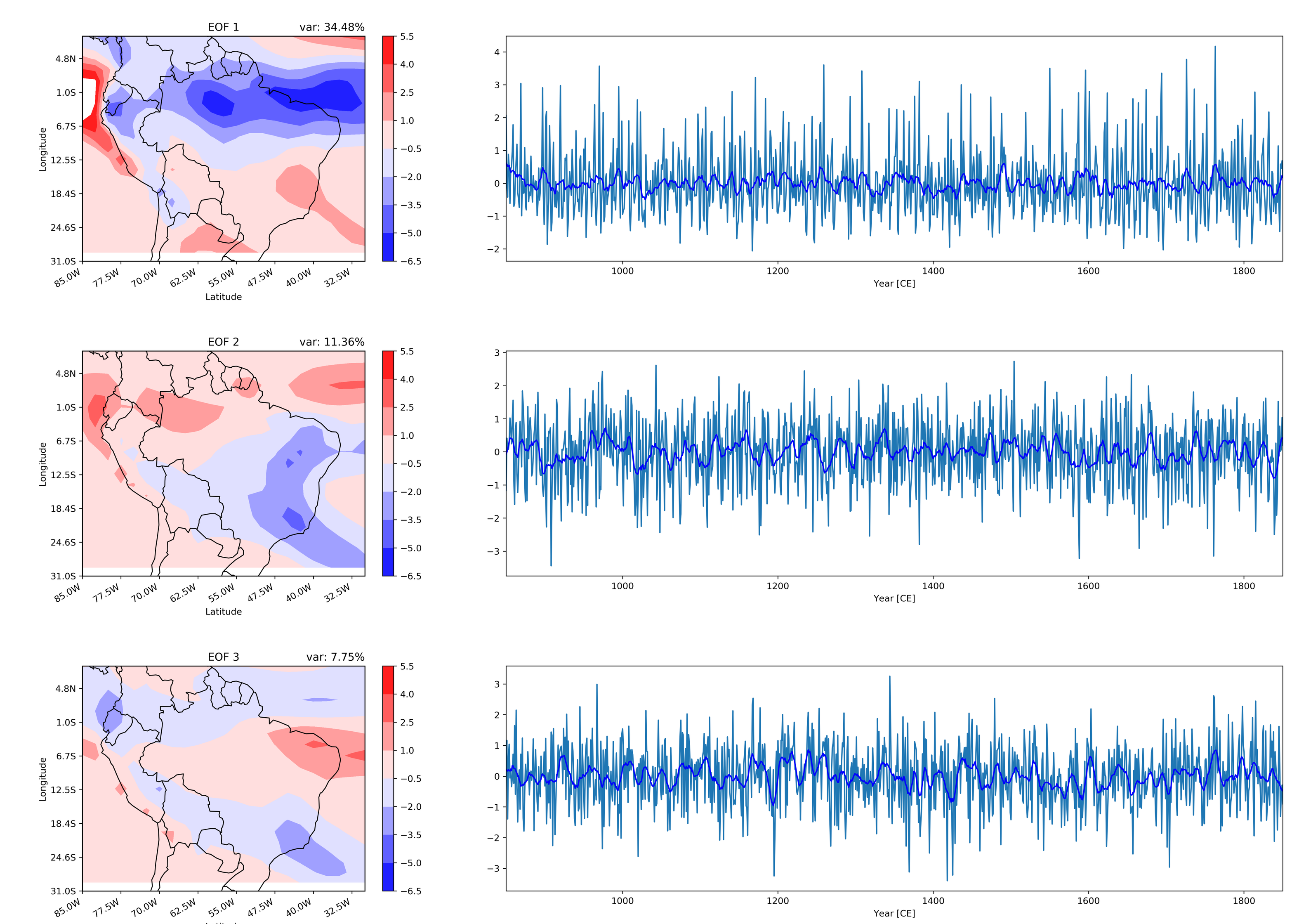
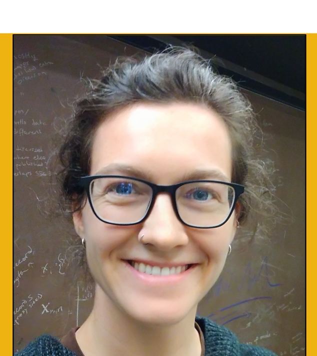


Figure 4. Leading covariance maps and principal components of EOF analysis using one ensemble member from CESM-LME data generated using full forcing input. The EOFs represent the leading modes of the SAMS (in descending order of explained variance): the Intertropical Convergence Zone (ITCZ), the central monsoon footprint, and the South Atlantic Convergence Zone (SACZ).

Future Work

- Complete the MC-EOF analysis of the proxy network.
- Perform EOF analysis of pseudopoxy records with added white noise.
- Compare EOF analysis of proxy network, pseudoproxy matrix, and full domain analysis.
- Repeat proxy-model comparison with isotope enabled simulation data.



Contact:
RORRISON@ALBANY.EDU

Acknowledgements
Thanks to José Leadro Campos for assistance with implementation of the MCEOF procedure and helpful discussion.
Funding for this research is provided by NSF OISE - 1743738 (PIRE-CREATE).

References
1.Vuille et al., Clim. Past, 8, 1309–1321, 2012.
2. Campos et al., Geophys. Res. Lett., 46, 8261-8270, 2019.
3. Anchukaitis and Tierney, Clim. Dyn., 41, 1291-1306, 2013.
4. Otto-Bliesner et al., Bull. Amer. Meteor. Soc., 97, 735-754, 2016.
5. Smerdon, Wiley Interdiscip. Rev. Clim. Change, 3, 63 -77, 2012.