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Intercomparison of Proxy Data and Model Simulations as Key to Understanding Internal Variability of the South American Monsoon System

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Motivating Questions

- What are the spatiotemporal patterns of δ18O variability across the monsoon domain during the Last Millennium (850 - 1850 CE)?
- How does 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?

Background

The South American Monsoon System (SAMS) is the dominant mode of annual hydrologic variability in South America, maturing during the austral summer (DJF). Precipitation from the SAMS is vital for agricultural production, hydroelectric power, and drinking water. This research explores the variability of the SAMS over the last millennium (850 - 1850 CE). The signal coherency of a network of stable isotopic proxies is analyzed (Fig 1, Table 1), as well as model simulations of the monsoon forced by isolated external forcing data sets (Fig 5). This is a divergence from traditional methods of analyzing individual proxy records. We expand on the proxy coherency analysis of Campos et al. (2019) by including a new record (#10, Table 1) and comparing this proxy record analysis to modeled SAMS variability.

Methods

A Monte Carlo resampling of age tie uncertainty generated a 1,000 member ensemble for each proxy age model. Each age model was linearly interpolated to generate an isotopic time series, which was then interpolated to annual resolution. For each set of proxy records, empirical orthogonal function (EOF) analysis decomposed data into leading modes of explained variance. This method follows from Anchukaitis & Tierney (2013) and Campos et al. (2019).

Results

MCEOF components (Fig 3) correspond to the leading modes of South American Monsoon System variability. Each loading point represents the contribution of a particular record to that mode.

Isotope-enabled Model Analysis

Using the isotope-enabled NCAR Community Earth System Model Last Millennium Ensemble (CESM-LME), we explore how the monsoon dynamics may have varied in the past during the Medieval Climate Anomaly (MCA) and Little Ice Age (LIA). Anomalies of δ18O relative to the last millennium reflect a weaker monsoon during the MCA (Fig 4a) and a more intense monsoon during the LIA (Fig 4b), and an opposite signal during these periods in northeastern Brazil. Anomalies in the MCA appear to be more widespread relative to LIA anomalies. Further exploration of this data will allow us to explore the atmospheric dynamics consistent with these anomaly patterns during these two intervals of time.

ICESM-LME

Isotope-enabled ensembles available for runs forced by:
- Fuel (3)
- Volcanic (2)
- Solar (1)
- GHG (1)
- Orbital (1)

Future Work

- Perform EOF analysis of precipitation weighted δ18O, with model output of the full monsoon domain and spatially discrete time series pulled from proxy locations with added white noise for each ensemble of forced runs.
- Examine SAMS dynamics using ensemble averaged data from fully forced runs by combining all members of the LME Project (isotope-enabled and non-isotope-enabled). Particular interest is given to monsoon dynamics during the MCA and LIA.
- Analyze the sensitivity of SAMS dynamics to different external forcings over the last millennium using the single forcing runs from the LME Project and comparing model results to the proxy network analysis.

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

<table>
<thead>
<tr>
<th>Record</th>
<th>ID</th>
<th>Res. (cm)</th>
<th>Lat(Lon) (°)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA02 + PA04</td>
<td>1</td>
<td>5</td>
<td>5.92, 77.35</td>
<td>Anchukaitis et al., Clim. Past, 2013</td>
</tr>
<tr>
<td>HU51 + HU52</td>
<td>2</td>
<td>5</td>
<td>11.27, 75.79</td>
<td>Kanner et al., Quat. Sci. Rev., 2013</td>
</tr>
<tr>
<td>RBM0 + RBM3</td>
<td>3</td>
<td>7</td>
<td>4.00, 55.27</td>
<td>Wang et al., Nature, 2017</td>
</tr>
<tr>
<td>SBE3 + SMT5</td>
<td>5</td>
<td>12</td>
<td>13.85, 46.35</td>
<td>Novello et al., Geophys. Res. Lett., 2018</td>
</tr>
<tr>
<td>TMD</td>
<td>6</td>
<td>3</td>
<td>16.00, 47.00</td>
<td>Worthington et al., Earth Planet. Sci. Lett., 2017</td>
</tr>
<tr>
<td>CTR1</td>
<td>7</td>
<td>2.7</td>
<td>24.58, 48.58</td>
<td>Vuille et al., Clim. Past, 2012</td>
</tr>
<tr>
<td>JAR1 + JAR2</td>
<td>8</td>
<td>3</td>
<td>21.08, 55.58</td>
<td>Novello et al., Geophys. Res. Lett., 2018</td>
</tr>
<tr>
<td>AL50 + CRU4</td>
<td>9</td>
<td>1</td>
<td>15.26, 58.50</td>
<td>Novello et al., Geophys. Res. Lett., 2018</td>
</tr>
<tr>
<td>BO2O</td>
<td>10</td>
<td>2</td>
<td>18.12, 65.77</td>
<td>Anchukaitis et al., Earth Planet. Sci. Lett., 2018</td>
</tr>
<tr>
<td>QMRCL</td>
<td>11</td>
<td>1</td>
<td>15.93, 70.83</td>
<td>Thompson et al., Science, 2013</td>
</tr>
<tr>
<td>PUM12</td>
<td>12</td>
<td>1</td>
<td>10.07, 76.06</td>
<td>Bird et al., Proc. Natl. Acad. Sci., 2011</td>
</tr>
</tbody>
</table>

Figure 1. Shading shows percentage of annual precipitation falling during the mature phase of the South American summer monsoon (DJF), based on CMAP data (1979 - 2004). The approximate locations of the Intertropical Convergence Zone (ITCZ) and South Atlantic Convergence Zone (SACZ) are indicated. Filled circles indicate proxy record network for this study. Colors indicate type: black for speleothem, white for ice core, blue for lake sediment.

Figure 2. MCEOF procedure for generating resampled isotopic time series, demonstrated with records from Jaragua Cave. a) 1,000 age models from MC procedure, with inset distribution of resampled age tie values. b) (top) Irregularly sampled raw δ18O records from Jaragua Cave; (bottom) 1,000 isotopic time series annually interpolated, with mean (black line) and envelop of maximum/minimum values (blue).

Figure 3. Leading modes of δ18O variability from proxy records recording South American Monsoon intensity. Plotted components are the average of the Monte Carlo resampling of time uncertainty inherent to each record.

Figure 4. Anomalies of δ18O from CESM-LME full forcing ensemble relative to the last millennium (850 - 1850 CE) during the a) Medieval Climate Anomaly (950 - 1250 CE) and b) Little Ice Age (1450 - 1850 CE).

Figure 5. CESM-LME members from Otto-Bliesner et al., 2016

Acknowledgments

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References