Inferring paleo-precipitation from speleothems in South America: A GCM study

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Abstract

Low latitude paleoclimate records from speleothem δ18O measurements are generally considered to reflect variations in δ18O in precipitation (δ18Oδ), and therefore, precipitation amounts. Here we test this interpretation with a water isotope enabled atmospheric general circulation model, comparing modern and Last Glacial Maximum (LGM) controls on the δ18Oδ in Brazil. The δ18Oδ is determined by the contributions from local evapotranspiration (high δ18Oδ in low latitude regions) versus transported vapor to the region (low δ18Oδ). If the isotopic composition of both local evapotranspiration and transported vapor remains the same, the changes in δ18Oδ could reflect the differences in the contribution. Since evaporation is less variable than precipitation, lower δ18Oδ implies more transported vapor, and hence, more precipitation. In northeastern Brazil, the isotopic composition of transported vapor (δ18Oδ) to the region is relatively constant for the present-day and the LGM whereas the ratio of low δ18Oδ transported vapor to high δ18Oδ local evaporation increases. In this case, δ18Oδ changes can be explained by the changes in precipitation amount, most of the difference comes from the changing partitioning of vapor source between transported vapor and local evaporation. If there is a significant change in δ18Oδ to the region, δ18Oδ cannot be explained as the changes in precipitation amount, which is controlled by the amount of transported vapor. This is the case for southeastern Brazil, where the decrease in δ18Oδ explained by the decreased δ18Oδ transported from the Amazon basin. Our analysis indicates that the amount effect, commonly used to infer precipitation amount from δ18Oδ in low latitude regions, works only where the isotopic composition of incoming vapor from the ocean stays relatively constant such as in coastal regions of the subtropics. Our analysis confirms the increase of precipitation over NE Brazil region during the LGM.

Introduction

Observation: Amount effect

As precipitation amount becomes higher, δ18O decreases. Observed in tropics, monsoon areas (Rozanski et al., 1993), even in a single storm (Miyake et al., 1968).

Problem

Can present-day spatial relationship between annual mean δ18Oδ and precipitation be used to infer past precipitation change?

Re-examine the relationship between precipitation and δ18Oδ in low-latitude region using a water isotope-enabled atmospheric general circulation model, for both the climatic conditions of present-day and Last Glacial Maximum (LGM; 21,000).

GCM Calculations

- National Center for Atmospheric Research Community Atmospheric Model (NCAR CAM3)
- Resolution (2.8x2.8°, 26 vertical layers)
- 2 runs: Present-day (PRS), Last Glacial Maximum (LGM)

Results

δ18Oδ decreases as P-E increases

Figure 2. The relationship between (a) P-E (mm/day) and δ18Oδ and (b) temperature (°C) and δ18Oδ for both the model (dots) and the GNIIP δ18Oδ and NCEP precipitation and evaporation (red cross) over 45°S to 45°N ocean. From Lee et al., 2007.

The difference in the LGM and present-day climate

Figure 3. The LGM-present day differences in (a) precipitation, (b) evaporation, (c) surface temperature (Ts) is SST for the ocean and ground temperature for the land in degrees Celsius. Locations of LGM SST estimated from paleoproxy data are marked in (c). Square and cross are for the northwest and northeast sites in Lea et al. (2000), triangle is for the site near Galapagos Islands (Koutavas et al., 2002), and x is for the Carliano Basin (Peterson et al., 2000). From Lee et al., 2009.

What δ18Oδ can tell us about the hydrological cycle during the LGM?

Figure 4. The LGM-present day differences in (a) precipitation and (b) δ18Oδ. The triangle and square denote the location of the NE Brazil speleothem record (Wang et al., 2004) and the SE Brazil record (Cruz et al., 2006) respectively. The boxes show the NE and SE Brazil regions. From Lee et al., 2009.

Conclusions

Over SE Brazil where most vapor comes from the northwestern land regions, interpreting the modeled LGM changes in δ18Oδ, by the amount effect would have yielded a precipitation rate difference of 1.3–1.8 mm/day, contrary to the model simulation difference of 0.3 mm/day.

Table 1. Precipitation (P) and evaporation (E) in Northeastern Brazil (17°S–6°S, 46°–35°S, red box in Figure 2) and southeastern Brazil (31°–20°S, 55°W–44°W, black box in Figure 2), together with the isotopic composition of P, E, and vapor Fluxes into (Fi) and out of (Fo) the region. The regions are denoted by black and red rectangles in Figure 2. Mean isotopic composition of each component is represented as δ18O. Isotopic composition of incoming and outgoing vapor was computed using vertically integrated moisture transport of H218O and H216O. From Lee et al., 2009.

References:


