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


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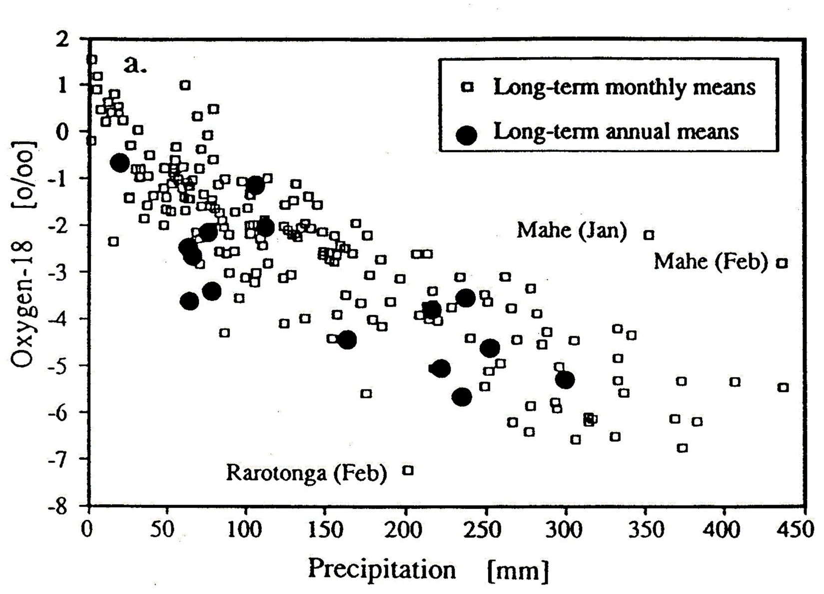
## Abstract

Low latitude paleoclimate records from speleothem $\delta^{18}O$ measurements are generally considered to reflect variations in $\delta^{18}O$ in precipitation ($\delta^{18}O_p$), 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 $\delta^{18}O_p$ in Brazil. The $\delta^{18}O_p$ is determined by the contributions from local evapotranspiration (high $\delta^{18}O$ in low latitude regions) versus transported vapor to the region (low $\delta^{18}O$). If the isotopic composition of both local evapotranspiration and transported vapor remains the same, the changes in $\delta^{18}O_p$ could reflect the differences in the contribution. Since evaporation is less variable than precipitation, lower $\delta^{18}O_p$ implies more transported vapor, and hence, more precipitation. In northeastern Brazil, the isotopic composition of transported vapor ($\delta^{18}O_v$) to the region is relatively constant for the present-day and the LGM whereas the ratio of low $\delta^{18}O$ transported vapor to high $\delta^{18}O$ local evaporation increases. In this case, $\delta^{18}O_p$ 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 $\delta^{18}O_v$ to the region, $\delta^{18}O_p$ 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 $\delta^{18}O_p$ explained by the decreased $\delta^{18}O_v$ transported from the Amazon basin. Our analysis indicates that the amount effect, commonly used to infer precipitation amount from $\delta^{18}O_p$ 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, d18O in precipitation decreases.

Observed in tropics, monsoon area (Rozanski *et al.*, 1993), even in a single storm (Miyake *et al.*, 1968).

Figure 1. Long-term monthly and annual mean $^{18}O$ values for tropical island stations of the IAEA/WMO global network (20°S to 20°N), plotted as a function of monthly precipitation. From Rozanski *et al*., 1993

## Problem

**Can present-day spatial relationship between annual mean $\delta^{18}O_p$ and precipitation be used to infer past precipitation change?**

Re-examine the relationship between precipitation and $\delta^{18}O_p$ 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 CAM2)

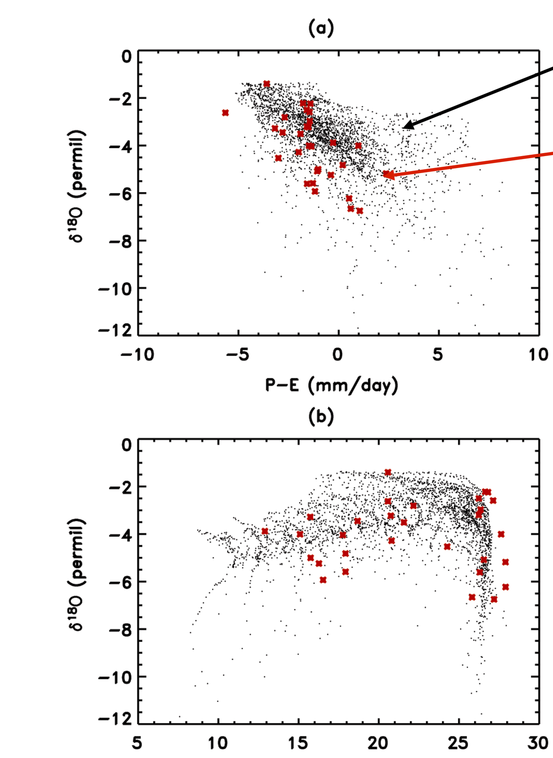
– Resolution (2.8x2.8°, 26 vertical layers)

2 runs: Present-day (PRS), Last Glacial Maximum (LGM)

- Orbital forcing
- $CO_2$ - LGM: 180ppm
  - PRS: 355ppm
- Prescribed glacial extent
- SST - PRS: observed (Had SST)
  - LGM: calculated by Coupled GCM

(NCAR Community Climate System Model, Otto-Bliesner et al., 2006)

## Results



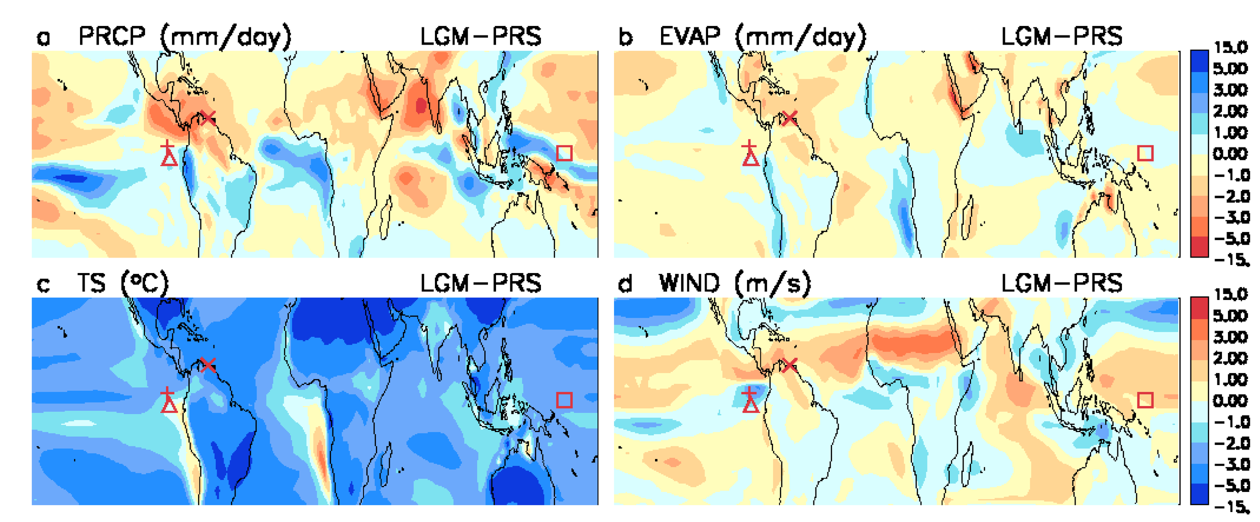

$\delta^{18}O_p$ decreases as P-E increases

Over the ocean, $\delta^{18}O_p$ (and $\delta^{18}O_v$) is related to evaporative recharge and precipitation amount.

**$\delta^{18}O_p$ varies very little over subtropical oceanic regions.**

Figure 2. The relationship between (a) *P-E* (mm/day) and $^{18}O$, and (b) temperature (C) and $_{ppt}$ (‰) for both the model (dots) and the GNIP $^{18}O$ and NCEP precipitation and evaporation (red cross) over 45°S to 45°N ocean. From Lee et al., 2007.

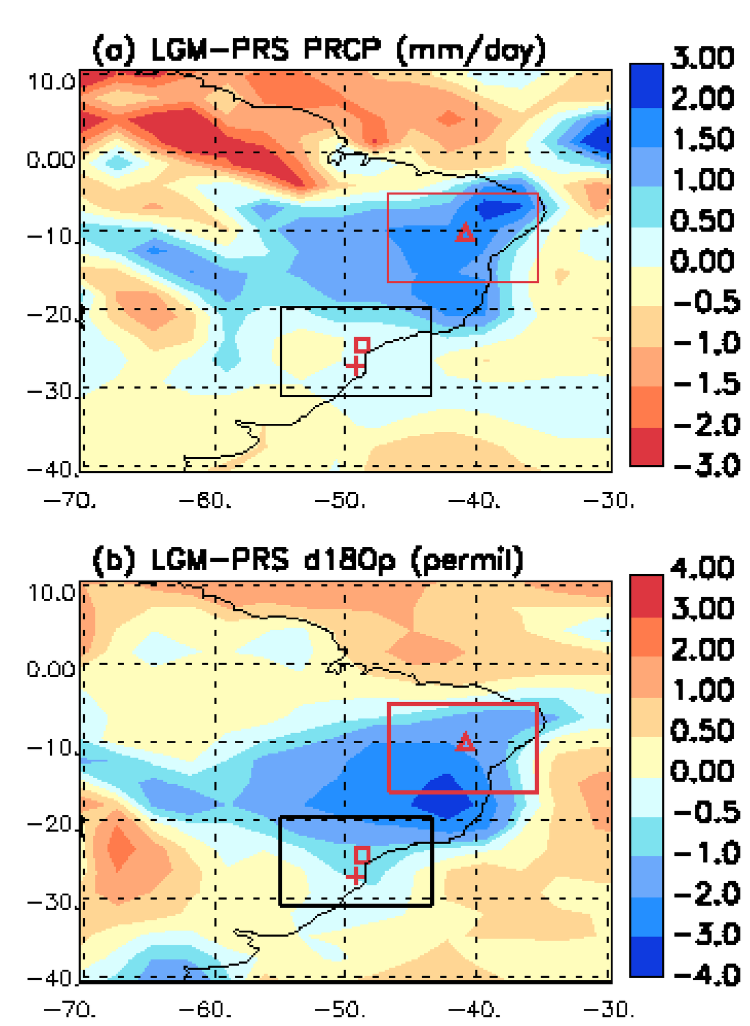
## The difference in the LGM and prsent-day climate




**More precipitation in SH tropics during the LGM**

Figure 3. The LGM-present day differences in (a) precipitation, (b) evaporation, (c) surface temperature, and (d) wind speed in the lowest atmospheric layer of the GCM. 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 Cariaco Basin (Peterson et al., 2000). From Lee et al., 2009.

## What $\delta^{18}O_p$ can tell us about the hydrological cycle during the LGM?

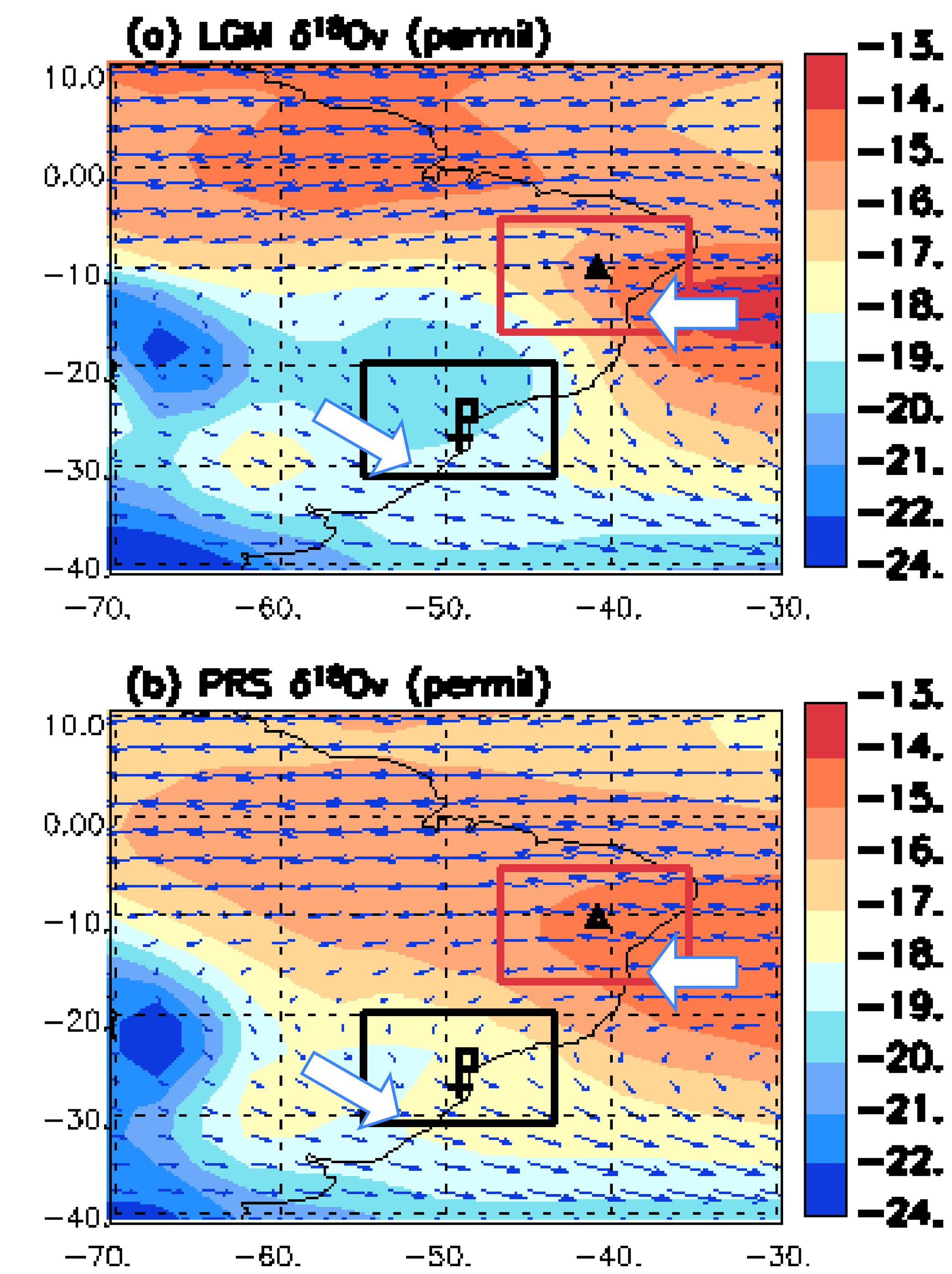



NE Brazil : yes

SE Brazil: no

Figure 4. The LGM-present differences in (a) precipitation and (b) $\delta^{18}O_p$. 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.

## Amount effect works where water vapor comes from subtropical oceanic regions




vector: column integrated water vapor transport

Water vapor comes from
- the ocean (NE Brazil)
- Amazon (SE Brazil)

Figure 5. Isotopic composition of the annual mean column vapor for (a) LGM and (b) PRS. Arrows are annual mean total column water vapor transport. From Lee et al., 2009.

NE Brazil: incoming vapor has similar $\delta^{18}O_v$ at both times

SE Brazil: incoming vapor has lower $\delta^{18}O_v$ during the LGM

Table. 1. Precipitation (P) and evaporation (E) in Northeastern Brazil (17°S-6°S, 46°S-35°S red box in Figure 2) and southeastern Brazil (31°S-20S, 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 *i* is represented as $\delta^{18}O_i$. Isotopic composition of incoming and out going vapor was computed using vertically integrated moisture transport of $H_2{}^{16}O$ and $H_2{}^{18}O$. From Lee et al., 2009.

| | NE Brazil | | SE Brazil | |
|---|---|---|---|---|
| | PRS | LGM | PRS | LGM |
| P (mm/day) | 2.35 | 3.30 | 3.18 | 3.51 |
| E (mm/day | 2.52 | 2.39 | 2.85 | 2.68 |
| $\delta^{18}O_p$ (‰) | -3.15 | -4.57 | -4.25 | -5.11 |
| $\delta^{18}O_e$ (‰) | -4.96 | -4.92 | -5.17 | -5.43 |
| $\delta^{18}O_{Fi}$ (‰) | -13.0 | -12.5 | -20.9 | -23.2 |
| $\delta^{18}O_{Fo}$ (‰) | -13.4 | -13.4 | -22.1 | -25.2 |

## Conclusions

Over SE Brazil where most vapor comes from the northwestern land regions, interpreting the modeled LGM changes in $\delta^{18}O_p$ 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. Low $\delta^{18}O_p$ in SE Brazil does not result from greater contribution of transported vapor, but low $\delta^{18}O$ of transported vapor. NE Brazil region $\delta^{18}O_p$, however, can be better explained as the changes in precipitation amount because most of the vapor transported into this region comes directly from the Atlantic Ocean where large evaporation from the ocean and the short trajectory inhibits distillation. Our analysis confirms the increase of precipitation over NE Brazil region.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