Influence of large scale climate variations on the isotopic composition of tropical precipitation

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Introduction

Water stable isotopes (HDO, $H_2^{18}O$) constitute a promising tool to reconstruct past climate variations. In the tropics, however, the interpretation of isotopic composition changes in terms of climate variations is debated. By analyzing simulations of a single-column model run in radiative-convective equilibrium and of a general circulation model (LMDZ GCM) equipped with water stable isotopes, we investigate the relative contributions of regional dynamical changes and of coherent tropical temperature changes on the isotopic composition of the tropical precipitation, at the interannual time scale and in climate change.

Notation: $\delta^{18}O$ and δD measures the enrichment in heavier isotopes. Deuterium excess $d = \delta D - 8 \cdot \delta^{18}O$ measures the enrichment in HDO relatively to $H_2^{18}O$.

1. Water stable isotopes in LMDZ

1.1 Evaluation for the present day

LMDZ simulates reasonably well the annually averaged isotopic composition of the precipitation (fig 1). The amount effect, i.e. the anti-correlation observed at the monthly scale in the Tropics between the heavy isotopes in precipitation and precipitation rate ([2]), is well reproduced (fig 2). Compared to single column model (SCM) simulations, the **horizontal advections act to damp the amount effect** in LMDZ.

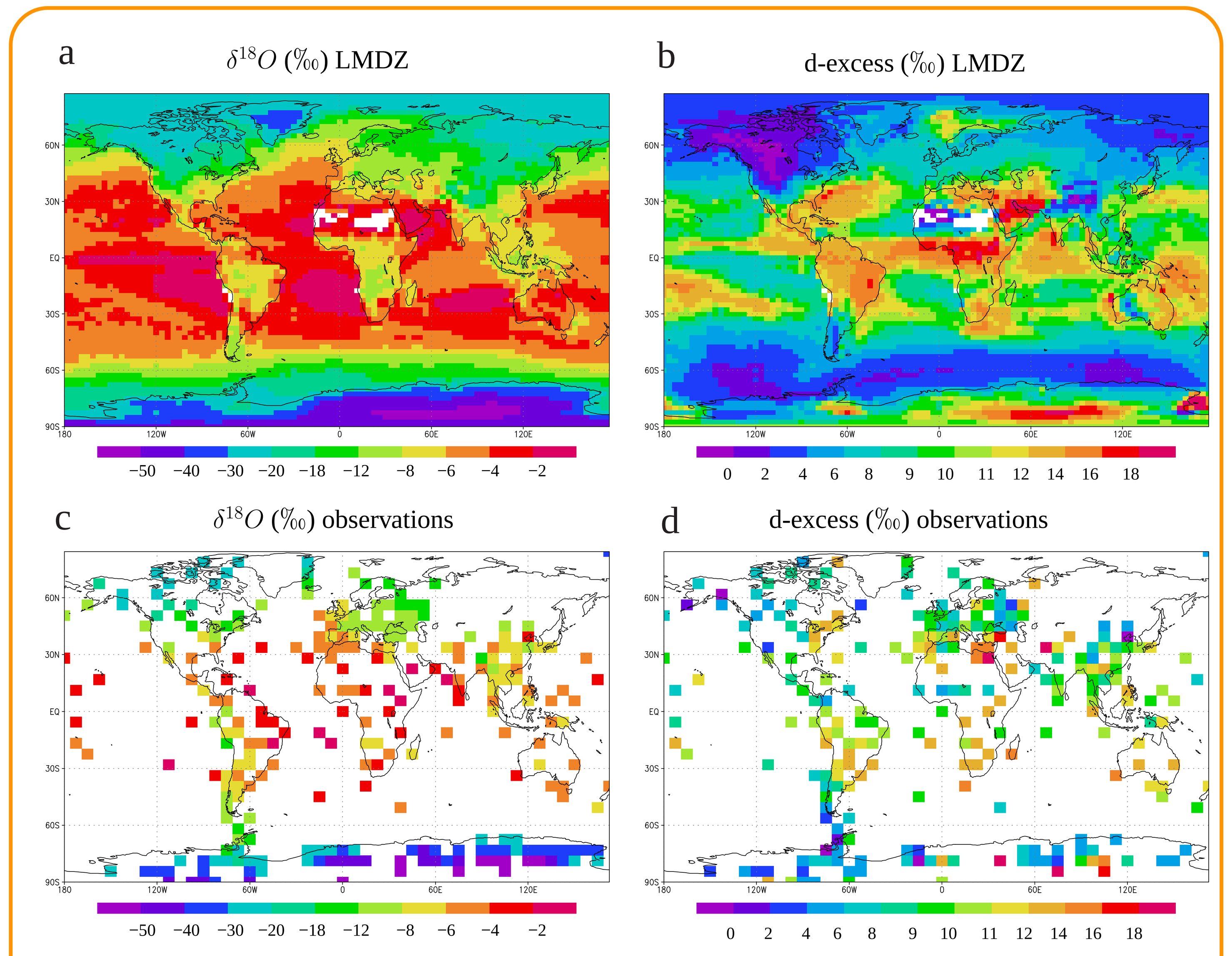

Fig 1: Annually weighted averaged δD and d-excess simulated by LMDZ (above) and from observations (below: GNIP network ([3]) and Antarctic data ([7])

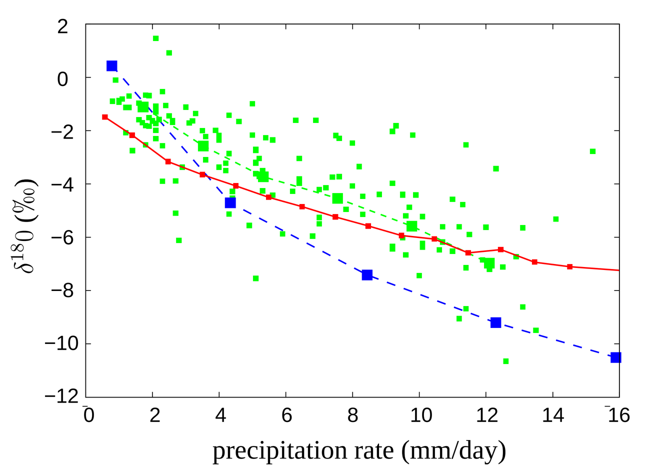

Fig 2: Averaged amount effect simulated by LMDZ and a SCM ([1]) over tropical oceans, compared with monthly data from tropical stations of the GNIP network ([3])

1.2 LGM simulation

We conducted a Last Glacial Maximum (LGM) simulation simulation forced by CLIMAP SST. The model simulates reasonably well the more depleted precipitation during the LGM at high latitudes, but underestimates the depletion observed ponctually in tropical ice cores, as most other isotopic GCM ([4, 6, 5]).

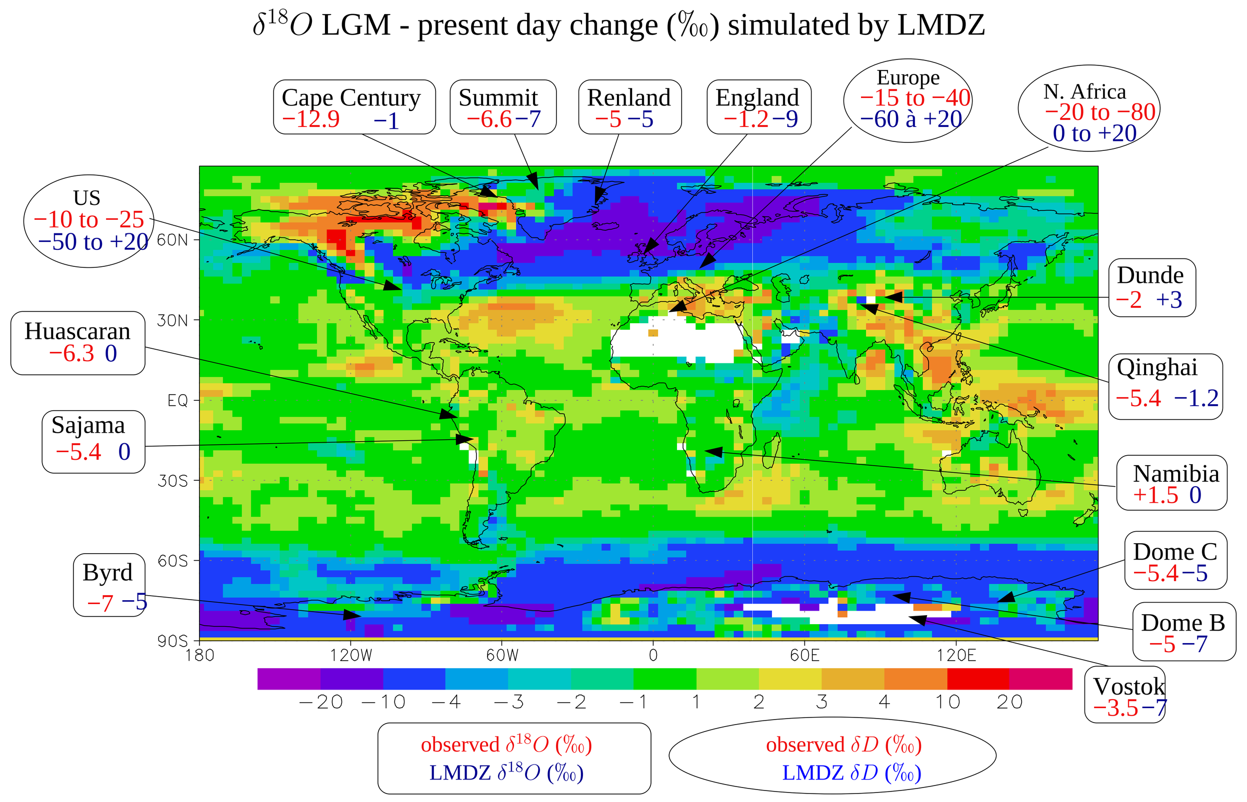

Fig 3: LGM - present day change in $\delta^{18}O$ in precipitation simulated by LMDZ, compared to some available observations from ice cores, speleothems or groundwaters (cited in [4, 6, 5]).

2. Are isotopes in tropical precipitation a good proxy for precipitation rate?

The amount effect is a major control of precipitation composition in the Tropics ([2]). To what extent can past precipitation rates (P) be reconstructed from $\delta^{18}O$ records?

In a "perfect model" experiment, we calculate in every location the slope $\frac{d\delta^{18}O}{dP}$ at the inter-annual scale for the present day (PD) simulation, using a forced SST 1979-2005 simulation (fig 4a). These slopes are then used to reconstruct, from the LGM-PD $\delta^{18}O$ change simulated by LMDZ (fig 3), the LGM-PD change in P (fig 4b). This reconstructed P change (fig 4 b) compares well with P changes directly simulated by LMDZ (fig 4c):

- the amount effect is robust and similar at the inter-annual and climatic scales,
- at first order and at the regional scale, $\delta^{18}O$ records precipitation changes.

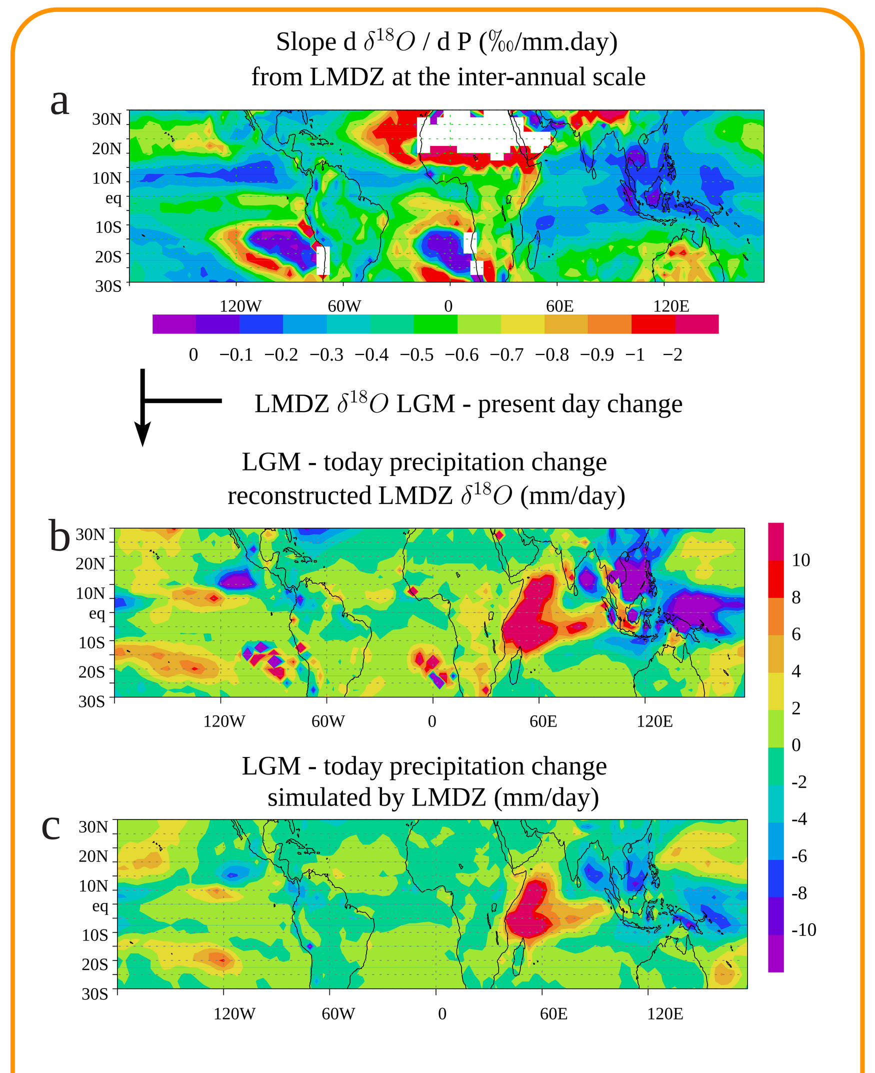

Fig 4: a) $\frac{d\delta^{18}O}{dP}$ calculated at the inter-annual scale in a 1979-2005 simulation with forced SST. b) LGM - present day change in P predicted by the slope in a and the precipitation $\delta^{18}O$ change simulated by LMDZ in fig 3. c) LGM - present day change in P simulated directly by LMDZ.

3. Relative contribution of dynamical changes in precipitation and global temperature changes

At the regional scale, the amount effect dominates the precipitation $\delta^{18}O$ signal at seasonal, inter-annual and climatic scales. But is there a larger-scale isotopic signature of climate change, as suggested by the enhanced depletion in most tropical data available at the LGM?

Fig 5 compares the relative impact on $\delta^{18}O$ of changes in tropical mean SST ($\bar{T}$) and in regional precipitation rate P, for both SCM ([1]) and LMDZ simulations.

- **The amount effect is observed only if the precipitation changes are related to dynamical changes** (related to changes in large-scale vertical velocity ωor in SST anomaly $T_s - \bar{T}$). Changes in precipitation related to changes in SST lead to a reversed amount effect (fig 5a).
- For a given P, **$\delta^{18}O$ increases as the mean tropical SST increases**, by about 0.1 to $0.2‰/K$ (fig 5a,b,c). This is robust in both SCM and LMDZ simulations, both in climate change experiments and at the inter-annual scale. As SST increases, surface evaporation, which enriches the low-level vapor, is increased (fig 6).

Consequently, **dynamical changes of precipitation dominate the $\delta^{18}O$ signal of precipitation at the regional scale. However, tropical mean changes is SST slightly shift the precipitation $\delta^{18}O$ over the whole tropics**.

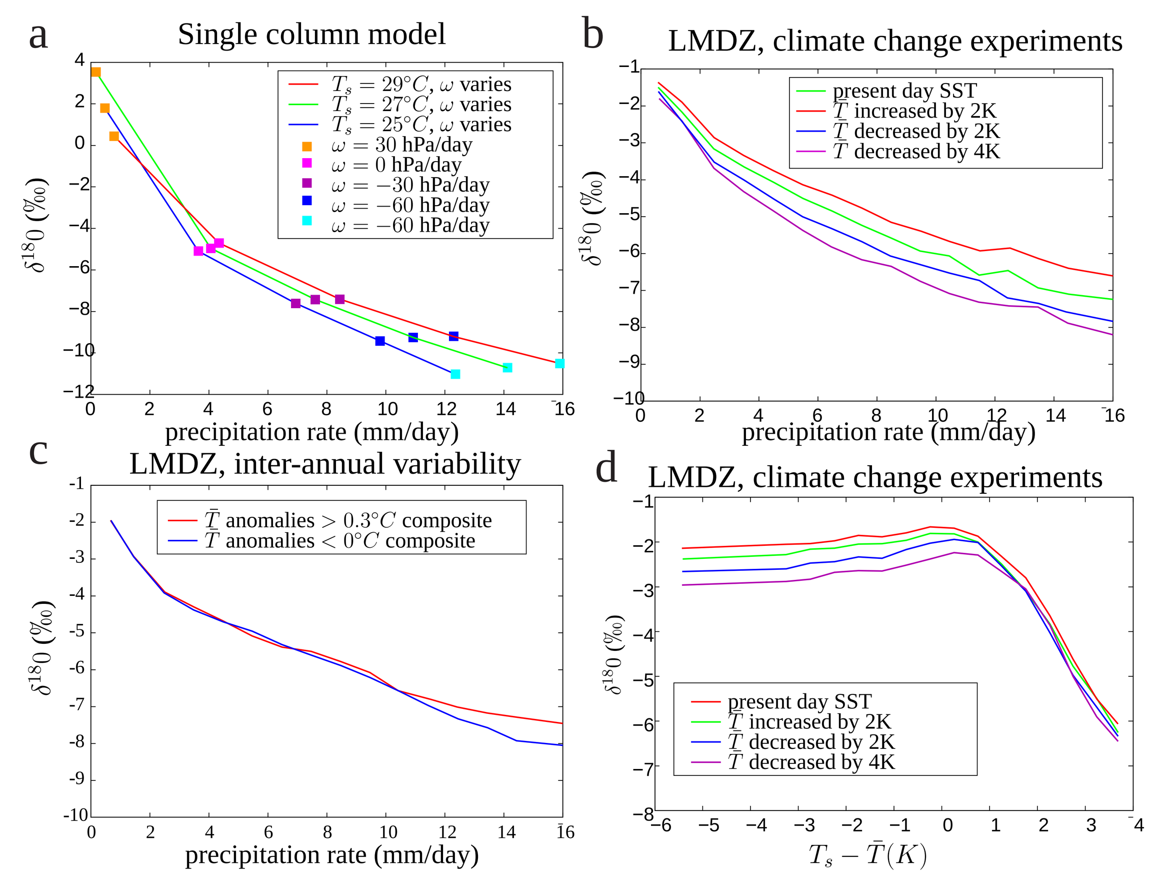

Fig 5: a) $\delta^{18}O$ as a function of precipitation rate P for different SST and ω in SCM radiative-convective equilibrium experiments. b) $\delta^{18}O$ as a function of P in LMDZ for different idealized simulation in which global SST are shifted. c) $\delta^{18}O$ as a function of P in a LMDZ 1979-2005 simulation. Monthly values are composited according to tropical mean SST. d) Same as b but as a function of $T_s - \bar{T}$ instead of P.

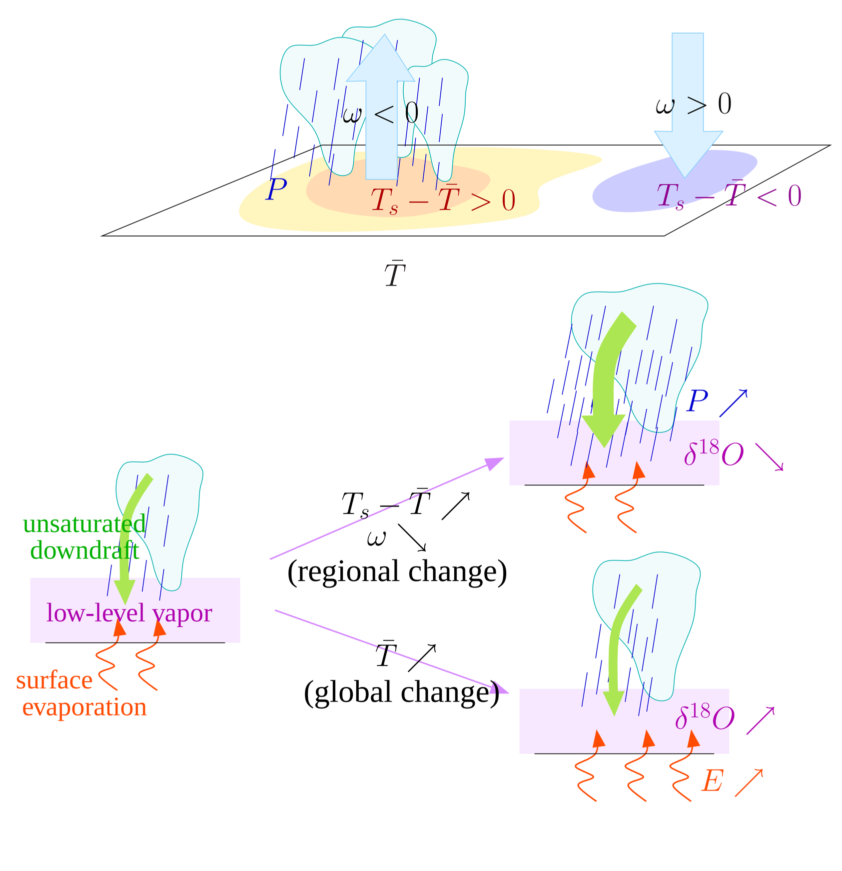

Fig 6: Conceptual scheme representing the different variables at play and comparing the impact of dynamical change at the regional scale and of global temperature changes on precipitation $\delta^{18}O$.

Perspectives

- Coud water stable isotopes in tropical precipitation be used to constrain both global temperature changes and regional changes in precipitation?
- Most archives isotopic are terrestrial. We plan to study the impact of land-atmosphere interactions using coupled land-atmosphere simulations with the LMDZ-ORCHIDEE model including water isotopes.

References

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