How are variations in convective activity recorded in the isotopic composition of tropical precipitation?

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Introduction

The stable isotopic composition of tropical precipitation (HDO, $H_2^{18}O$) is a promising tool to reconstruct past climate and better understand the present water cycle. The goal here is to better understand what information is recorded in the isotopic composition of tropical precipitation, and in particular how convection impacts this composition, using two complementary approaches:

1. **Modelisation with a single column model**, in which we implemented the water isotopes ([1])
2. **Event-scale samples collected in the Niamey area** (Niger) all along the monsoon season 2006, as part of the AMMA campaign.

1. Impact of convection on the isotopic composition of the rain in a single column model

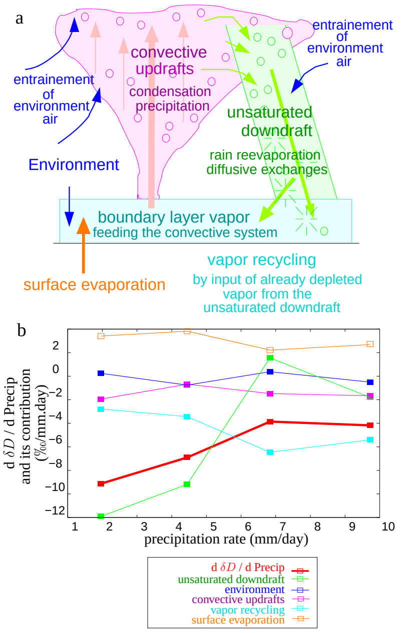


Fig 1: a) Illustration of the meanings of the different contributions. b) $\frac{d\,\delta D}{d\,Precip}$ as a function of precipitation rate ($Precip$) and its decomposition as the sum of contributions from different processes.

1.a. What causes the amount effect?

The amount effect is the anti-correlation observed at the monthly scale in the Tropics between the fraction of heavier isotopes in the precipitation ($\delta^{18}O$) and precipitation rate ([2]).

To investigate the processes explaining this effect, we used radiative-convective equilibrium simulations over ocean with a sinle column model including the Emanuel convective parametrization ([3]).

We decompose the sensitivity of the isotopic composition of precipitation to precipitation rain ($\frac{d\,\delta D}{d\,Precip}$, red curve on fig 1b) into a sum of contributions as illustrated in fig 1a. Quantitatively and the main contibutions are (fig 1b, [5]):

- **rain reevaporation**: the more intense the convection, the smaller the reevaporation and the smaller the evaporative enrichment aff the rain as it falls.
- **the recycling of the boundary layer by convective fluxes**: the more intense the convection, the more intense the convective downdrafts that bring depleted vapor into the boundary layer.

This highlight the **importance of microphysical processes such as rain reevaporation** on the control of the isotopic composition of the rain.

1.b. What are the time scales of the amount effect?

To investigate the time scales involved in the amount effect, we perform a simulation of the TOGA COARE campaign (western Pacific), on which the single column model had been optimized and which features a strong intraseasonnal variability.

The amount effect is **optimally observable at time scales longer than a few days** (red line on fig 2a), in agreement with previous observations of the amount effect at the monthly scale but not at the event scale.

Daily δD best correlates to convective activity when convective activity is averaged over the 4-5 previous days (red line on figure 2). This **integrative property of the isotopic composition** is predicted by a simple relaxation equation of the form (green line):

$$\frac{d\delta D}{dt} = S \cdot P - \frac{\delta D}{T}$$

where T is the **residence time of the water in some reservoirs**: here: a combination of boundary layer and free troposphere. Over continents, it could also be the soil moisture. How δD responds to daily precipitation could thus **yield some information about the water recycling in these reservoirs**.

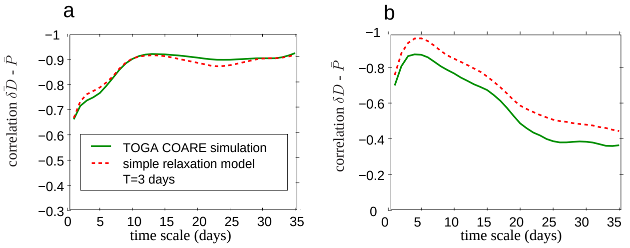


Fig 2: a) Correlation between averaged δD and averaged precipion, as a function of the time scale of averaging. b) Correlation between daily δD and averaged precipitation.

2. Control of the isotopic composition of the rain in Niger

2.a. At the seasonnal scale: regional convective activity

Precipitation samples were collected from June to september 2006 in the Niamey area (fig 3). The $\delta^{18}O$ suddenly drops and d-excess increases on the 15th of July, corresponding to the **monsoon onset** (sudden northward shift of the ITCZ resulting more convection over the Sahel). This shift may be explained by the regional increase in convective activity: the 1D model reproduces this shift (pink line on fig 2).

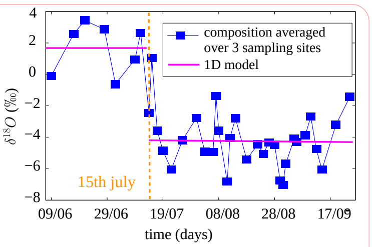


Fig 3: Blue: isotopic composition of the rain along the monsoon season. Pink: composition predicted by a 1D model forced to simulate the same precipitation amount in average as in the observations.

2.b. Before the onset: intensity of individual events

Before the onset (fig 4), there is a strong influence at the event-scale of:

- the **degree of organization** of convective systems, with organized systems (orange in fig 3) the most depleted
- the **intensity** of the indivdual event.

The very weak regional convection at this time may explain why an amount effect can be observable at the event-scale.

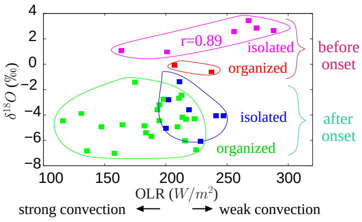


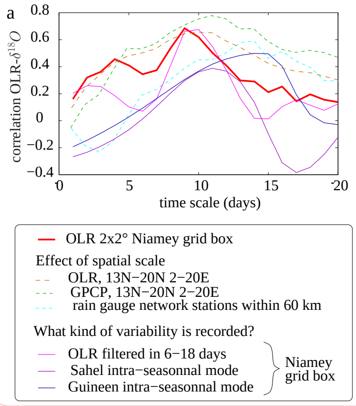
Fig 4: Relationship between OLR and $\delta^{18}O$ at the event scale for different system types.

2.c. After the onset: intra-seasonnal variability

After the onset, when convection is strong, no amount effect is seen at the event-scale (fig 4). The correlation with OLR is maximum when the OLR is integrated over the 9 previous days (figure 5a), in agreement with the 1D analysis (1.b.). The correlation is better as we average convection over larger spatial scales (fig 5a, dashed lines) and is high over the whole Sahel (fig 5b). Thus precipitation $\delta^{18}O$ after the monsoon onset records a regional, low frequency (intra-seasonnal) signal.

More particulary, $\delta^{18}O$ records intra-seasonnal variability between 6 and 18 jours corresponding to modes of variability evidenced by [4] (fig 5a). Due to its property to spatially and temporally integrate convection, $\delta^{18}O$ is thus a **good recorder of the intra-seasonnal variability**.

How $\delta^{18}O$ temporally integrates convection is more complex as in the TOGA COARE simulation (the relatiation equation do not work). In addition to atmospheric vapor, soil moisture or pond waters could be reservoirs that explain this integrative property of precipitation.



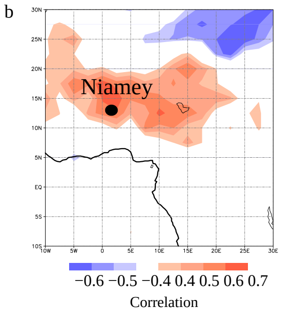


Fig 5: a) Correlation between $\delta^{18}O$ and OLR averaged over previous days (similar to fig 2b). b) Correlation between $\delta^{18}O$ and the OLR map averaged over the 9 previous days.

Perspectives

- The idealized framework of the single column framework did not allow to study processes such as **large scale processes** (3D advections, origin of air masses) or **surface processes**. In the real world as in Niger, what mechanisms explain the correlation between the isotopic composition and convection in Niger? Isotopic simulations with the **LMDZ GCM** (in which we just introduced water isotopes) **zoomed on the AMMA region** could help us better disentangle the relative importance of convective and large scale processes. Coupling LMDZ with the **land surface model ORCHIDEE** (in which we are also introducing water isotopes) could allow an investigation of the influence of surface processes.
- To better understand the effect of convective processes at small scales, we also sampled precipitation along squall lines (poster 27).

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