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

Camille Risi[1]*, Sandrine Bony[1], Françoise Vimeux[2]

[1]*LMD/IPSL, Paris (France)*, [2]*LSCE/IPSL, Paris (France)*, *contact: crlmd@lmd.jussieu.fr

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 single column simulations (section 1) and isotopic data collected during the AMMA campaign in the Sahel (sections 2 and 3)

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. Single column model simulations

To study the impact of convection on the isotopic composition of precipitation, we use a single column model of radiative convective equilibrium over ocean ([1]). We present here different equilibrium simulations forced with different vertical velocity profiles, controlling the convective activity. The model reproduces 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], fig 1).

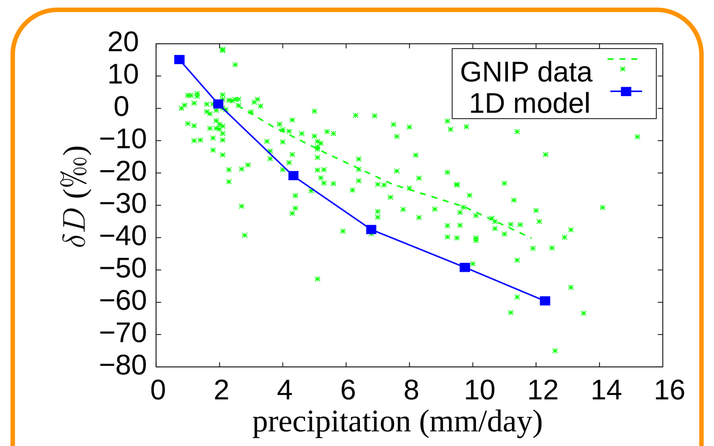
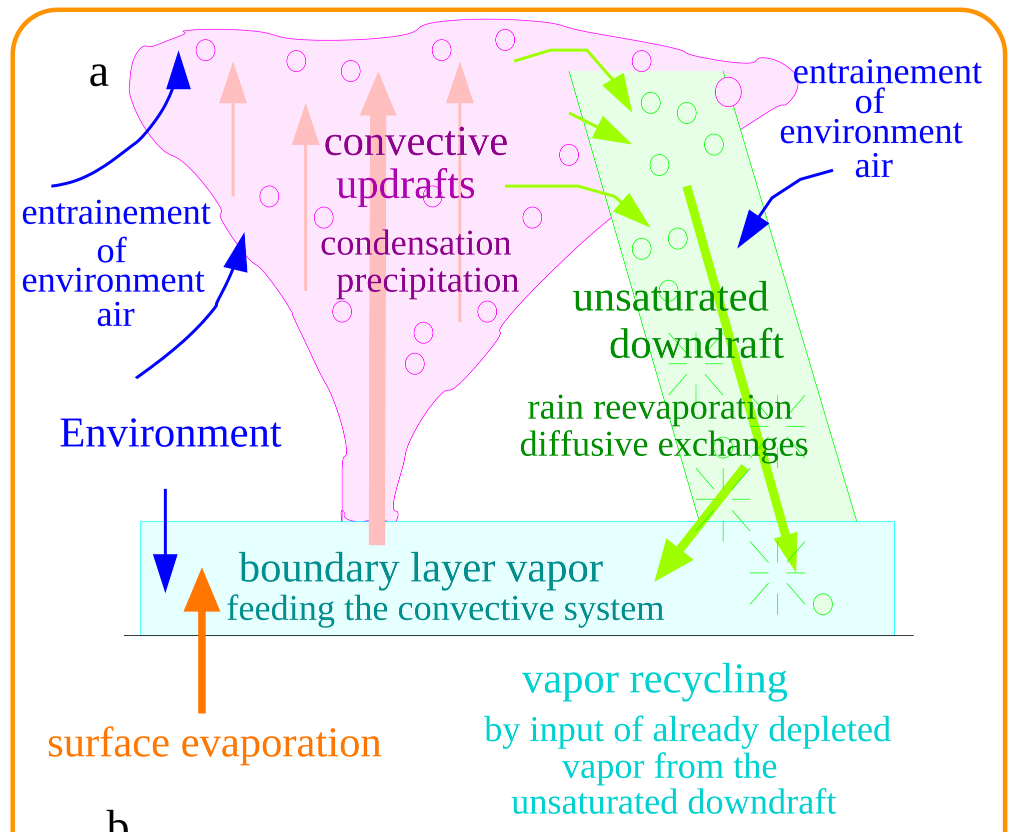
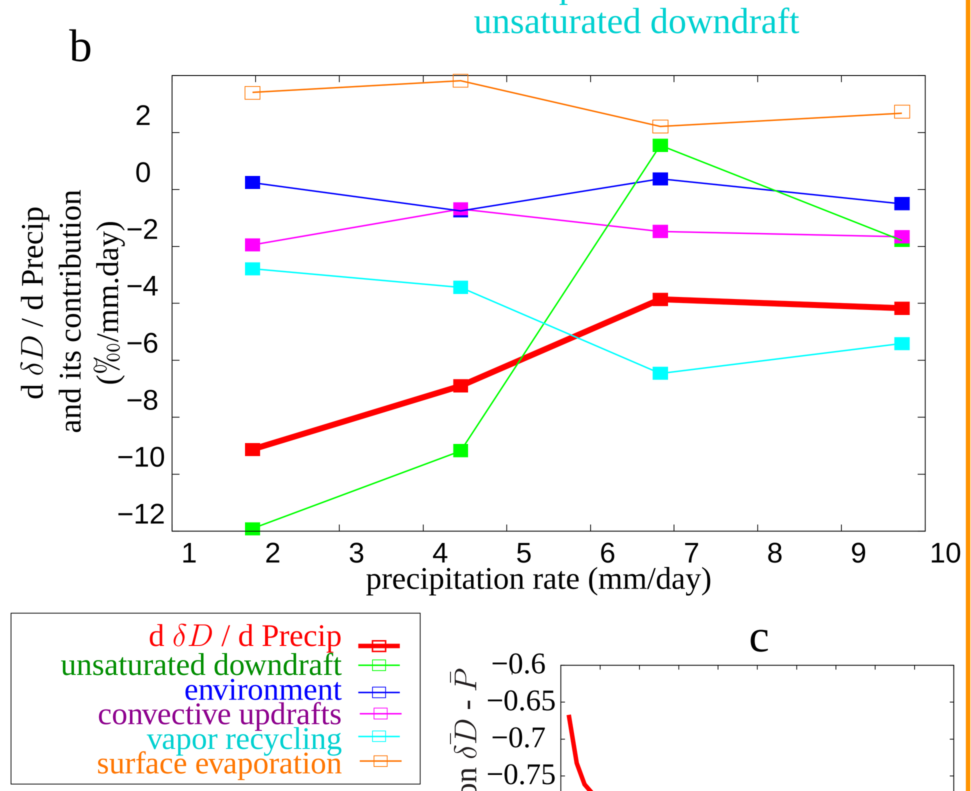
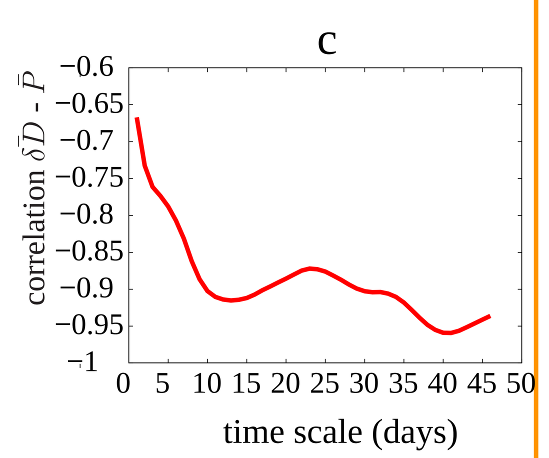


Fig 1: The amount effect simulated by the model and observed in tropical island monthly rain (GNIP, [3].







To understand the processes underlying the amount effect, we decompose the sensitivity of the precipitation δD to precipitation rate ($\frac{d\delta D}{d\,Precip}$, red curve on fig 4b) into a sum of contributions as illustrated in fig 2a ([5]). The main contibutions are (fig 4b, [5]):

- **rain reevaporation**: the more intense the convection, the smaller the reevaporation and the smaller the evaporative enrichment off 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 bringing depleted vapor into the boundary layer.

Microphysical processes such as rain reevaporation are thus key in controlling the isotopic composition of the rain.

Using a simulation of the TOGA COARE campaign (Western Pacific), we show that the amount effect is **optimally observable at time scales longer than a few days** (fig 2c), in agreement with the amount effect being observed at the monthly scale but not at the event scale.

Fig 2: 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.

c) Correlation between averaged δD and averaged precipitation, as a function of the time scale of averaging.

2. Precipitation samples along Sahelian squall lines

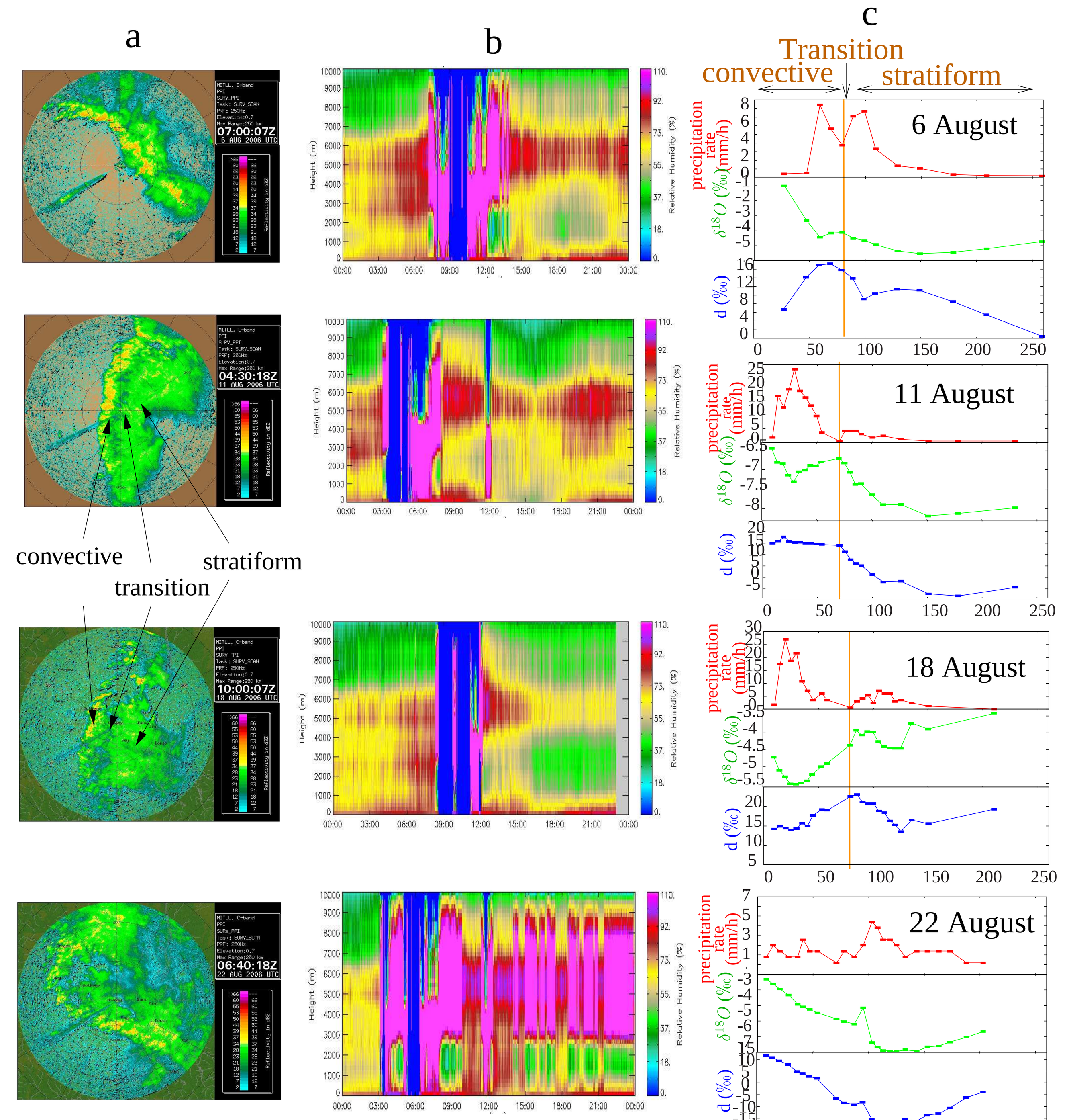


Fig 3: a) C-band horizontal reflectivity maps from the MIT radar. (b) relative humdity profiles from the ARM data. (c) precipitation rates and isotopic composition along the squall lines sampled

To further investigate the effect of convective processes, we collected rain samples at high frequency (5 mins) along squall lines in Niamey ([6]). A strong isotopîc evolution along the squall lines is noticed (fig 3). Despite some variability between the different events, some robust features emerge (fig 3):

- decrease of rain $\delta^{18}O$ and d-excess with time, especially in the stratiform zone.
- increase of $\delta^{18}O$ and decrease of d-excess when the reevaporation of the rain is high: at the start of the rain, transition zone and at the rear of the stratiform zone.

To investigate the processes explaining this evolution, we used a **2D model of transport and microphysics**, including water stable isotopes, and forced by the retrieved 3D wind field for the 11th August. Despite the strong sensitivity to the squall line dynamics, the model reproduces the robust observed features (not shown). In this 2D model:

- the $\delta^{18}O$ of the rain is similar to that of the vapor, suggesting a good isotopic equilibration. Main processes affecting the $\delta^{18}O$ of the vapor are (fig 4):
  - the **subsidence of depleted vapor in the meso-scale downdraft**: this is supported by the data showing $\delta^{18}O$ all the lower under the meso-scale downdraft as the air at the rear of the squall line is dry (fig 3).
  - the **evaporation of rain drops**, enriching the low-level vapor all the more as reevaporation is strong.
- **d-excess is affected mainly by relative humidity**: as rain reevaporates, d-excess in the rain drops decreases all the fastest as the air is dry.

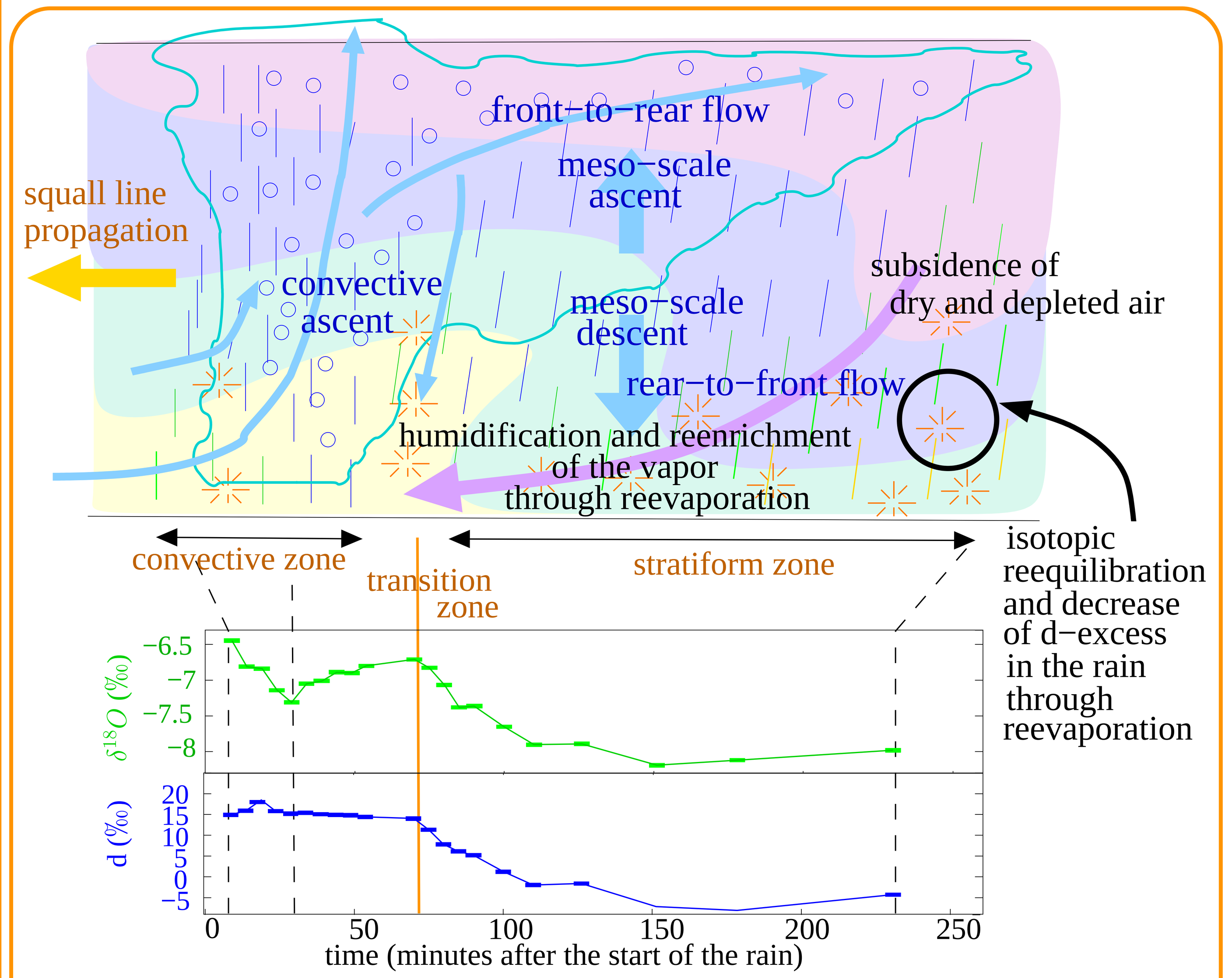


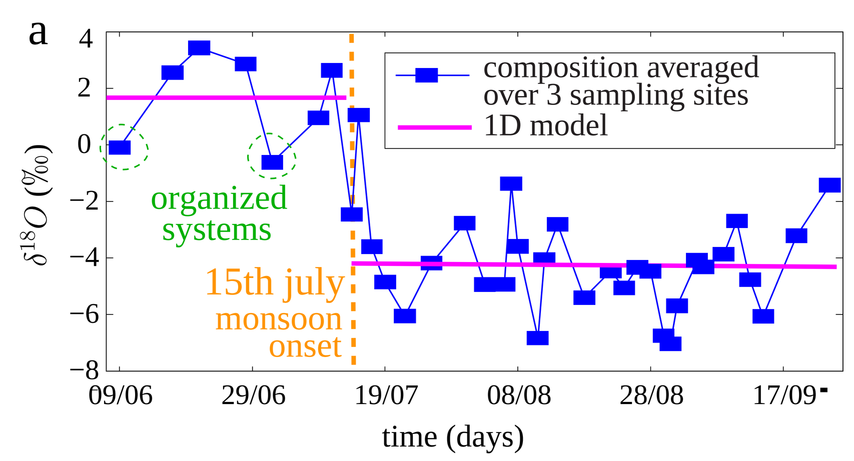
Fig 4: Processes affecting the isotopic composition along squall lines accordind to the 2D model, with the example of the 11 August data.

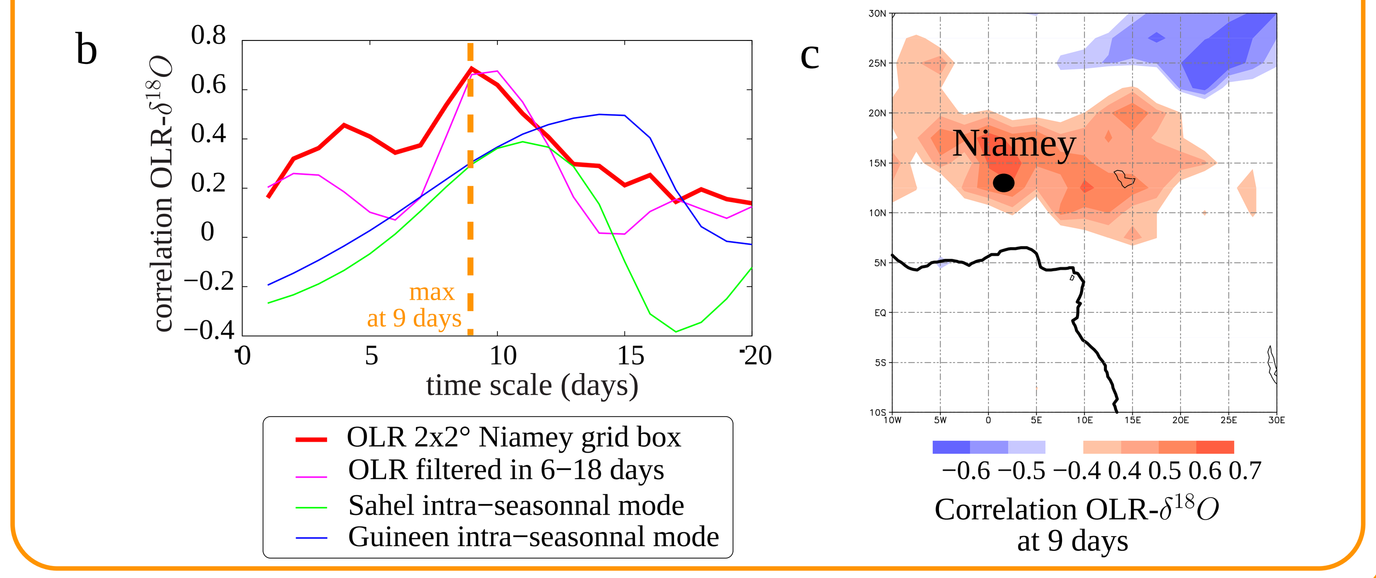
3. Sahelian event-based precipitation

To study what controls the isotopic composition of precipitation at the seasonal and intra-seasonal time scales, we collected event-scale rain samples in Niamey during the monsoon season 2006 ([7]).

- $\delta^{18}O$ decreases abruptly after the monsoon onset (northward shift of the ITCZ leading to a strong increase of convection of Niamey) (fig 3a), in agreement with the amount effect.
- Before the onset, $\delta^{18}O$ is correlated with both the **intensity** and **degree of organization** of individual convective systems (fig 5a) .
- After the onset on the contrary, no amount effect is seen at the event-scale. The correlation of $\delta^{18}O$ with OLR is maximum when the OLR is integrated over the 9 previous days (fig 5a) and is high over a large Sahel region (fig 5c). Thus precipitation $\delta^{18}O$ after the monsoon onset integrates temporally and spatially the convection, which makes $\delta^{18}O$ a **good recorder of the large-scale intra-seasonal variability**. In particular, modes of variability in the Sahel operating at 15-20 days ([4]) are well recorded (fig 5b).

Fig 5: a) Blue: isotopic composition of the rain collected in Niger along the monsoon season. Pink: composition predicted by a 1D model forced to simulate the same precipitation amount in average as in the observations. b) Correlation between $\delta^{18}O$ and OLR averaged over previous days (similar to fig 2b). c) Correlation between $\delta^{18}O$ and the OLR map averaged over the 9 previous days.





Perspectives

- isotopic measurements in the low-level vapor, in addition to rain samples, would be very useful.
- To disentangle the effects of convective, large-scale atmospheric and surface processes, we will use coupled land-atmosphere simulations with the LMDZ-ORCHIDEE GCM including water isotopes.

References

[1] S. Bony, C. Risi, and F. Vimeux. Influence of convective processes on the isotopic composition (O18 and D) of precipitation and water vapor in the tropics. part 1: Model description, vertical profiles and isotopic composition of precipitation. *J. Geophys. Res.*, 113:D19305,, 2008.

[2] Dansgaard. stable isotope in precipitation. *Tellus*, 16:436–468, 1964.

[3] IAEA. Statistical treatment of data on environmental isotopes in precipitation. Technical report, Int. At. Energ. Agency, 1992.

[4] F. Mounier and S. Janicot. Evidence of two independent modes of convection at intraseasonal timescale in the west african summer monsoon. *Geophys. Res. Lett.*, 31, 2004.

[5] C. Risi, S. Bony, and F. Vimeux. Influence of convective processes on the isotopic composition (O18 and D) of precipitation and atmospheric water in the Tropics: Part 2: Physical interpretation of the amount effect. *J. Geophys. Res.*, 113:D19306, 2008.

[6] C. Risi, S. Bony, F. Vimeux, M. Chong, and L. Descroix. Evolution of the isotopic composition (H2O18, HDO) of the rain sampled along Sahelian squall lines. *Quart. J. Roy. Meteor. Soc.*, in preparation, 2008.

[7] C. Risi, S. Bony, F. Vimeux, L. Descroix, I. Boubacar, I. Mamadou, E. Lebreton, and B. Sultan. What controls the isotopic composition of the African monsoon precipitation? Insights from event-based precipitation collected during the 2006 AMMA campaign. *Geophys. Res. Lett.*, submitted, 2008.

We thank M. Chong for providing the 3D wind field retrievals from the MIT radar and for discussions; L. Descroix without whom the collection of water samples in Niger during AMMA would not have been possible; I. Mamadou, B. Ibrahim and E. Le Breton for collecting rain samples in the Niamey area; B. Sultan for providing intra-seasonal modes of variability over the Sahel; J-P. Lafore and J-Y. Grandpeix for useful discussions.