May water stable isotopes in the precipitation constrain the water budget of squall lines?

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Introduction

Water stable isotopes ($H_2^{18}O$ and HDO) fractionate at each phase change, and thus constitute a promising tool to study the water cycle. To better understand how convective processes impact the isotopic composition of precipitation ([1]), during the **AMMA campaign** we sampled precipitation from squall lines propagating over the Sahel (Niamey, Niger) in August 2006.

The strong spatial organization of squall lines, and the **high frequency sampling (5 to 10 minutes)** of the rain sequentially from the front to the rear of the lines, allows us to investigate the effect of the different convective processes.

Notation: $\delta^{18}O$ and δD measures the enrichment in heavier isotopes ($-10‰$ means 1% less heavy isotopes than in the ocean water). Deuterium excess $d = \delta D - 8 \cdot \delta^{18}O$ measures the enrichment in HDO relatively to $H_2^{18}O$.

1) Isotopic evolution along different squall lines

The evolution of the isotopic composition along squall lines exhibits robust and consistent features (fig 1):

- decrease of $\delta^{18}O$ of the rain along the lines, especially in the stratiform zone (6, 11 and 22 august),
- increase of $\delta^{18}O$ and decrease of d-excess when the reevaporation of the rain is high: at the start of the rain, in the transition zone and at the rear of the stratiform zone.

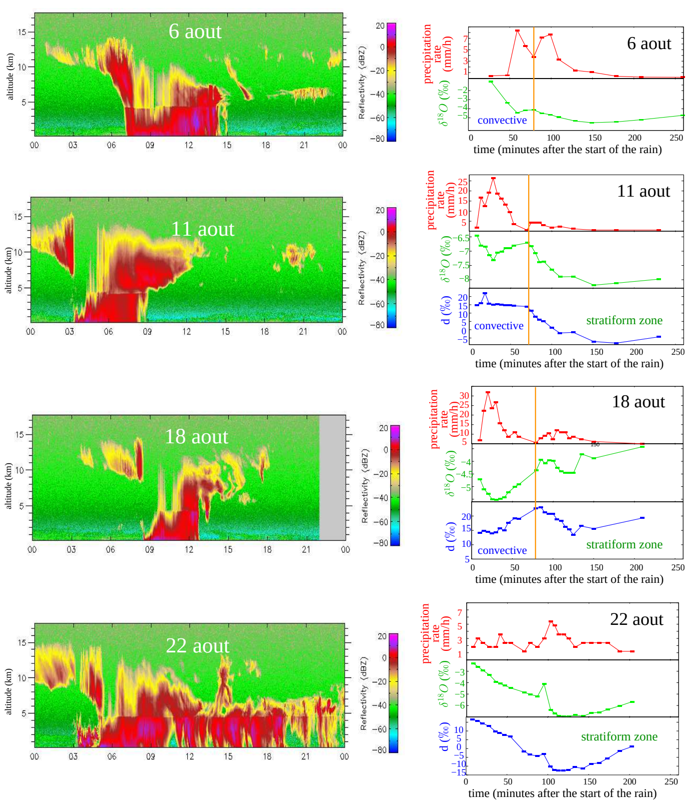
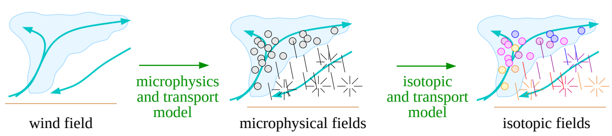


Fig 1: Left: vertical cross sections of the squall lines as observed by the ARM cloud radar. Right: evolution of the precipitation and isotopic composition along the corresponding squall lines. The orange line highlights the transition zone between the convective and stratiform zones.

Perspectives

To understand **more quantitatively** how convective processes are recorded in the isotopic composition, and to discuss the extent to which **water stable isotopes can help constraining the rain evaporation**, we develop a stationary **two-dimensional isotopic model of squall line** (fig 4). We plan to apply it to the 11^{th} of August squall line for which 3D winds have been retrieved from the MIT radar.



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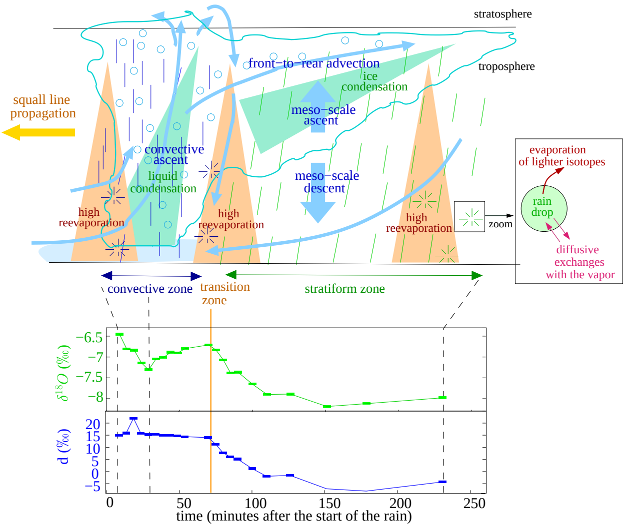
References

[1] 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.*, in revision.

2) Qualitative interpretation

Two factors predominently explain the isotopic evolution (fig 2):

- **condensation** removes preferentially heavier isotopes from the vapor. As vapor undergoes more condensation (higher in altitude), the vapor and resulting cloud particles are more depleted. This explains the progressive decrease of $\delta^{18}O$ along the line, in particular in the stratiform zone where condensation occurs at higher altitude.
- **partial reevaporation** of rain drops remove preferentially lighter isotopes from the rain. Thus the stronger the reevaporation, the higher the $\delta^{18}O$ of the precipitation. Besides, d-excess is reduced during reevaporation.



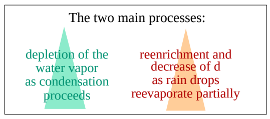


Fig 2: Main processes influencing the isotopic composition along squall lines, with the example of the 11^{th} of August squall line.

3) Constraints on the water budget?

Condensation and evaporation processes affect slightly differently $H_2^{18}O$ and HDO. These two isotopes could thus be used to help constraining the condensation temperature and the rate of reevaporation of the rain.

Fig 3 shows an example: using a simple model, assuming that the whole squall line is fed by a single source vapor (e.g. the boundary layer before the squall line) and making rough assumptions about the relative humidity and isotopic composition of the vapor in which droplets reevaporate, we estimate (fig 3a):

- the effect of a decrease of the condensation temperature T_{cond},
- the effect of an increase in the reevaporated fraction of the droplets f_{revap}.

We can thus deduce the evolution of both T_{cond} and f_{revap} (fig 3b).

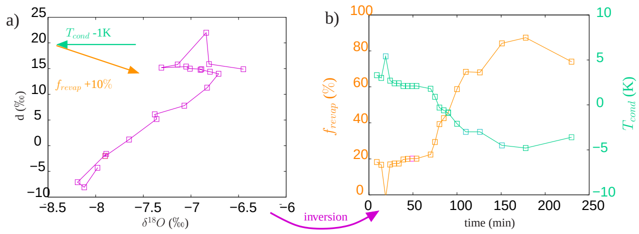


Fig 3: Example showing how condensation temperature T_{cond} and the reevaporated fraction of the rain f_{revap} could be deduced from isotopic measurments during the 11^{th} of August squall line.

The condensation temperature decreases along the squall line, in agreement with condensation higher in altitude in the stratiform zone. The decrease of the condensation temperature is smooth, which suggests an important **role of the front-to-rear advection of cloud particles and precipitation**.

However, this estimation bears **large uncertainties** due to:

- varying relative humidity and isotopic composition of the low-level vapor in which rain drops reevaporate.
- varying sources of vapor feeding the squall line (e.g. entrainment of air of various altitude or origin)

Grid (1 , 1)