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Influence of Convective Processes on the Isotopic Composition of Tropical Precipitation ($H_2^{18}O$ and HDO): a Single Column Model Analysis

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Introduction

Isotopic records (HDO and $H_2^{18}O$) in ice cores or speleothems are a valuable tool to reconstruct past climate. However, the climatic interpretation of tropical isotopic records is hampered by the lack of knowledge about the influence of convective processes on the isotopic composition of tropical precipitation.
To explore what controls the isotopic composition of tropical precipitation and to analyze the physical processes underlying the amount effect (the observed link between precipitation amount and precipitation δD or $\delta^{18}O$, [3]), stable water isotopes have been introduced into the Emanuel convective parametrization ([4]) and into a single column model of radiative convective equilibrium including this parametrization ([1]). The detailed representation of processes such as rain reevaporation in the Emanuel parametrization allows an investigation of the influence of convective processes on the isotopic composition of precipitation ([2, 6]).

1) What controls the isotopic composition of precipitation over tropical oceans?

Radiative-convective equilibrium simulations are performed over ocean for different surface temperatures (SST) and large-scale circulation (a vertical profile of large scale vertical velocity is imposed) representative of tropical oceans (figure 1).
The precipitation amount is the major control on precipitation composition. $\delta^{18}O$ decreases with precipitation by -0.5 to -1‰/mm.day, in agreement with the so called “amount effect”. d-excess increases with precipitation amount by 0.5‰$/(mm/day)$. The sensitivity of $\delta^{18}O$ and d-excess to temperature or surface wind speed are smaller.
In nature, SST and precipitation amount often vary in concert (black points on figure 1), so that their relative effect are difficult to disentangle. Figure 2 shows that changes in the large-scale circulation explain most of the amount effect, and that precipitation changes associated with temperature variations produce an "anti" amount effect. **The amount effect holds only if precipitation variations are related to changes in large-scale circulation**.

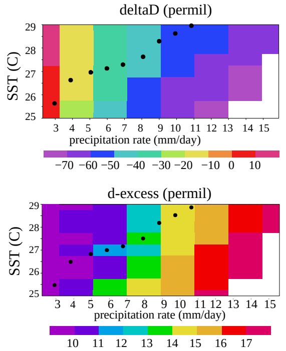


Figure 1: δD and d-excess simulated by the model as a function of SST and precipitation rate. Black points represent a mean statistical relationship observed in the Tropics between SST and precipitation rate.

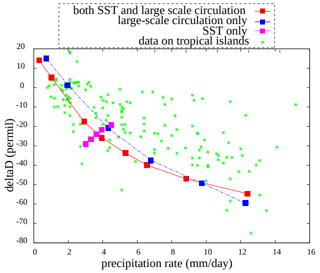
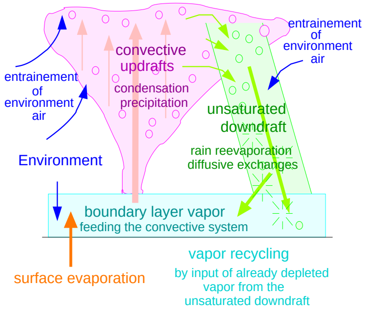


Figure 2: δD as a function of precipitation rate when both SST and large-scale circulation vary in concert (red), or when only SST (magenta) or large-scale circulation vary (blue). GNIP data for some tropical island station are also shown.

2) What processes explain the amount effect?

To identify the convective processes underlying the amount effect and to quantify their relative contributions, we decompose the amount effect ($\frac{d\,\delta D}{d\,Precip}$) into a sum of contributions from different processes (figure 3):

- composition of the vapor evaporated from the ocean surface.
- processes in convective updrafts (condensation, precipitation)
- processes in unsaturated downdrafts (downdrafts driven by the reevaporation of the falling precipitation: precipitation reevaporation and diffusive exchanges modify the composition of
  - the falling rain
  - the vapor in the unsaturated downdraft.
- recycling of the boundary layer vapor by the unsaturated downdraft. The composition of the boundary layer depends on the relative fraction of the vapor coming from unsaturated downdrafts or from surface evaporation.
- composition of the environment entrained into the convective system.



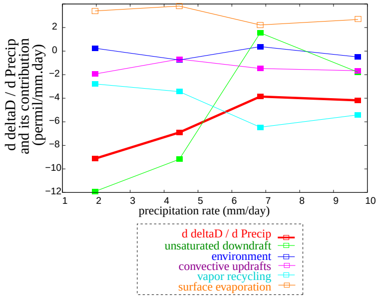


Figure 3: $\frac{d\,\delta D}{d\,Precip}$ as a function of precipitation rate ($Precip$) and its decomposition as the sum of contributions from different processes.

The main contributions to the amount effect are (figure 3):

- Processes in the unsaturated downdrafts (up to 80% of the amount effect for light precipitations): lighter precipitations are associated with drier air and thus with enhanced reevaporation. This enriches both the falling rain and the vapor in the unsaturated downdraft. Moreover, diffusive exchange that deplete the vapor of the unsaturated downdraft are les efficient for drier air.
- The recycling of the boundary layer vapor (70% of the amount effect for strong precipitations): the more intense the convection, the stronger the mass flux of the unsaturated downdrafts, and the greater the input of depleted vapor from the unsaturated downdraft into the boundary layer.

The condensation processes in convective updrafts have a smaller effect.
Therefore, **the amount effect is not a simple effect, but rather a combination of different physical processes, in particular the recycling of the boundary layer and processes in unsaturated downdrafts**.
This also suggests that explicitely representing such processes might be important to accurately simulate the isotopic composition of precipitation.

3) 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 ([5]). During this campaign, convective activity (measured here by precipitation rate) showed a large intra-seasonnal variability, with a maximum at about τ_{conv}=10-15 days (figure 4).

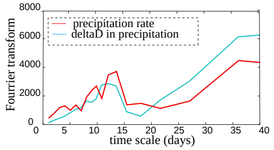


Figure 4: Variability spectrum for precipitation rate (red) and δD (blue) during the TOGA COARE simulation.

Precipitation δD responds to the convective forcing at the same periodicities but with some delay proportional to τ_{conv}. Thus the correlation between averaged precipitation and averaged δD (blue line on figure 5) only gets good at time scales longer than a few days (here 10 days). This explains why the amount effect is observable at seasonnal or interannual time scales ([7]), but not at the event scale.
Event-scale δD is best correlated to convective activity when convective activity is averaged over a fraction of τ_{conv} (here 4-5 previous days, orange line on figure 5). This is predicted if δD responds to the convective intra-seasonnal variability. This record of intra-seasonnal variability was also verified for isotopic measurements in Niger along the monsoon season (poster PP11B-0516).

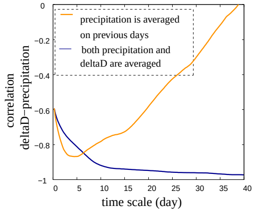


Figure 5: Correlation between precipitation δD and precipitation rate during the TOGA COARE campaign. In blue, both δD and precipitation rates are averaged over the period in x-axis. In orange, precipitation rate only is averaged over the previous days.

Perspectives

Our idealized model of radiative-convective equilibrium has some limitations, such as neglecting horizontal isotopic gradients when advecting air by the large-scale circulation, or restricting to oceanic conditions. To better evaluate our model with data and to better understand what controls the isotopic composition on tropical ice cores, we are currently implementing water stable isotopes in LMDZ, the GCM developped at LMD/IPSL.

References

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