Influence of atmospheric convection on the isotopic composition of water in the Tropics

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Introduction

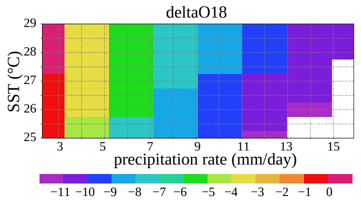
The climatic interpretation of water stable isotopic records ($H_2^{18}O$, HDO) in tropical ice cores, such as andean ice cores, is still debated. This is partly because most of the tropical precipitation is related to convective processes, whose influence on the isotopic composition of precipitation is still not well known.
Water isotopes are also used for studying troposphere-stratosphere exchanges, but the interpretation of the data collected around the tropopause requires a better understanding of the influence of convection on isotopic profiles.
In this context, **our goal is to better understand the influence of convection on the isotopic composition of precipitation and atmospheric water** ([10]).

Approach

Stable water isotopes have been introduced into the Emanuel convective parametrization ([3]) (chosen because it is close to microphysical processes and was carefully optimized against tropical data ([4])) and into a single column model of radiative convective equilibrium including this parametrization ([1]). 1D simulations are performed over ocean.

1) What controls precipitation δ^{18}O over tropical oceans?

We study the sensitivity of precipitation $\delta^{18}O$ to sea surface temperature (SST) and precipitation amount. Radiative-convective equilibrium simulations are performed for different SST and large-scale circulation conditions (a vertical profile of large scale vertical velocity is imposed). The resulting precipitation $\delta^{18}O$ for each simulation is shown below as a function of SST and precipitation rate:

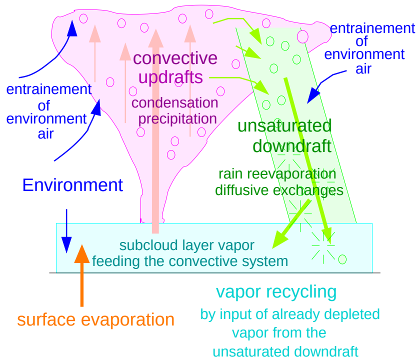


Main results:

- **The precipitation amount is the major control on precipitation δ^{18}O.** $\delta^{18}O$ decreases with precipitation by -0.5 to -1‰/mm.day, in agreement with the so called "amount effect", which is the observed anti-corelation between $\delta^{18}O$ and precipitation amount in tropical islands data ([2]). The sensitivity of $\delta^{18}O$ to temperature is only 0.3‰/°, and cannot explain much of the observed $\delta^{18}O$ variability within the Tropics.
- The weak impact of SST on $\delta^{18}O$ shows that **the amount effect holds only if precipitation variations are related to changes in large-scale circulation.**

2) What processes explain the amount effect?

The amount effect is the major control on precipitation δD in the Tropics and tropical ice cores have recently been interpretated in those terms ([6, 9]). Yet, the physical processes underlying this effect are poorly understood and quantified; it is often simply interpreted in terms of depletion of an air mass through condensation and precipitation.
To identify the convective processes underlying the amount effect and to quantify their relative contributions, we decompose the amount effect into a sum of contributions from different processes as illustrated below:



- composition of the vapor evaporated from the ocean surface. This composition influences that of the subcloud layer vapor feeding the convective system, and hence influences the whole system.
- processes in convective updrafts (condensation, precipitation)
- processes in unsaturated donwdrafts (downdrafts driven by the reevaporation of the falling precipitation). This include precipitation reevaporation and diffusive exchanges that modify the composition of the falling rain and of the vapor in the unsaturated downdraft.
- recycling of the subcloud layer vapor by the unsaturated downdraft. Depending what proportion of subcloud layer vapor comes from the unsaturated downdraft or from the surface evaporation, the composition of this layer feeding the system will vary.
- composition of the environment entrained into the convective system.

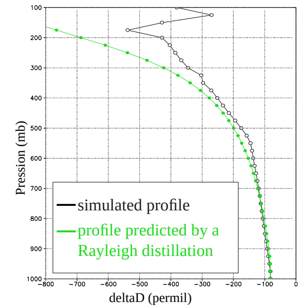
The main contributions to the amount effect are:

- Processes in the unsaturated downdrafts (up to 80% of the amount effect for light precipitations, less for stronger ones): 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. These processes were already suggested by [2] as possibly explaining the amount effect.
- The recycling of the subcloud layer vapor (70% of the amount effect for strong precipitations, slightly less for light ones): 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 subcloud layer. [7] had similarly justified depleted rains in organized convective sytems.

The condensation processes in convective updrafts have little effect.
Therefore, **the amount effect is not a simple effect, but rather a combination of different physical processes, in particular the recycling of the subcoud 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 is the convective signature on isotopic profiles around the tropopause?

Isotopes in the Tropics are often used to assess the contribution of convective transport of water to troposphere-stratosphere exchanges. Below is shown the simulated δD profile in the absence of large-scale circulation.



δD decreases with height but at all altitudes remains more enriched than predicted by the Rayleigh distillation (in which all condensate is precipitated), in agreement with observations ([8, 11, 5]). This enrichment is because the condensate (which is enriched) is kept in the convective updrafts and lofted at higher altitudes. In nature, this is possible only if updrafts are strong enough. Such a profile thus features the signature of convective transport. **This confirms that isotopes measurements are a valuable tool to track convective transport of water.**

4) Is the isotopic tool valuable for constraining cloud processes?

Sensitivity tests to model parameters showed that the δD profiles around the tropopause are very sensitive to the representation of the precipitation efficiency. The precipitation composition is on the contrary very sensitive to processes in unsaturated downdrafts.
This suggests the potential use of istopic measurements to better understand cloud processes and constrain their representation in models.

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, modelisation through a general circulation model (GCM) would be useful. For this purpose, we are currently implementing water stable isotopes in LMDZ, the GCM developped at LMD/IPSL.

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