What controls the isotopic composition of tropical tropospheric water vapor? Results from general circulation models and large-eddy simulations, and thoughts on the usefulness of the isotopic tool

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Abstract

The isotopic composition of water vapor (e.g. its Deuterium content) evolves along the water cycle as phase changes are associated with isotopic fractionation. In the tropics, it is especially sensitive to convective processes. Consequently the isotopic composition of precipitation recorded in paleoclimate archives has significantly contributed to the reconstruction of past hydrological changes. It has also been suggested that observed isotopic composition of water vapor could help better understand convective processes and evaluate their representation in climate models. Yet, water isotopes remain rarely used beyond the isotopic community to answer today's pressing climate questions. A prerequisite to better assess the strengths and weaknesses of the isotopic tool is to better understand what controls spatio-temporal variations in water vapor isotopic composition through the tropical atmosphere. A first step towards this better understanding is to understand what controls the isotopic composition of the sub-cloud layer water vapor over the ocean. Isotopic measurements show that the water vapor is the most enriched in trade-wind regions, and becomes more depleted as precipitation increases. To understand this pattern, we use global simulations with the isotope-enabled general circulation model LMDZ, large-eddy simulation in radiative-convective equilibrium and with large-scale ascent or descent, with the isotope-enabled model SAM and simple analytical models. We show that increased precipitation rate is associated with increased isotopic depletion if it is associated with stronger large-scale ascent, but with decreased isotopic depletion if it is associated with warmer surface temperature. As large-scale ascent increases, the isotopic vertical gradient in the lower troposphere is steeper, which makes downdrafts and updrafts more efficient in depleting the sub-cloud layer water vapor. The steeper gradient is caused mainly by the larger quantity of snow falling down to the melting level, forming rain whose evaporation depletes the water vapor.

What do we learn from water isotopes on clouds and convection?

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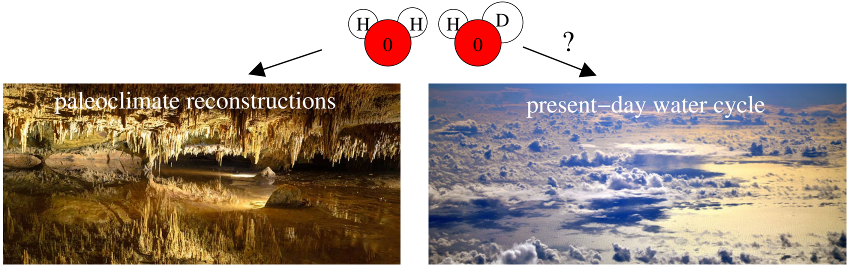
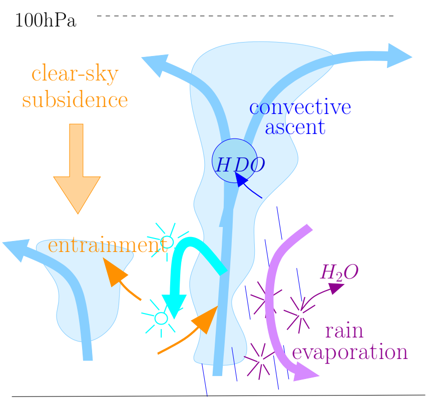
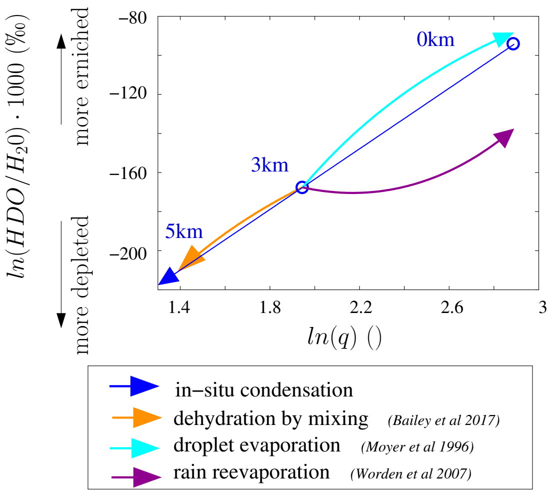


Water isotopes inform us about moistening processes





- In reality, more commplex...

Why do we want isotopes to be useful?

water isotopes

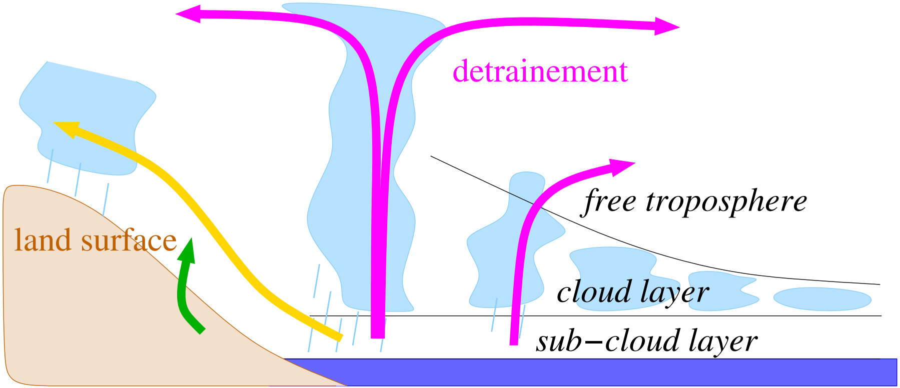
what are isotopes useful for?

what is the most efficient tool?

science question

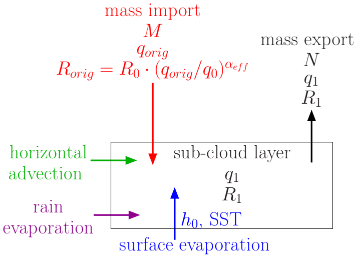
$\Longrightarrow$ Before using isotopes, we need to better understand what controls its variations

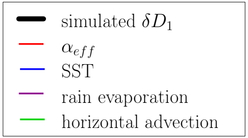
Understanding isotopic variations in the sub-cloud layer of tropical oceans is a first step

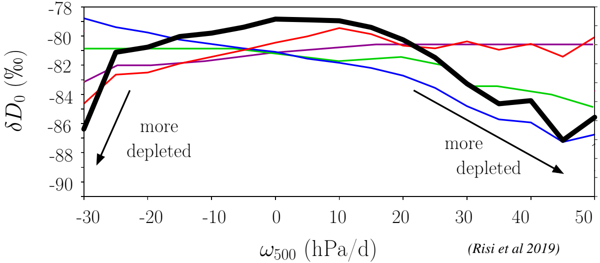


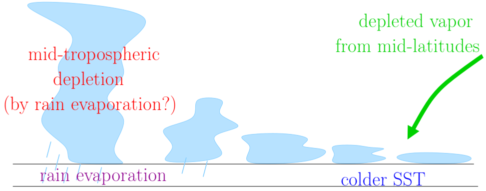
Spatial and seasonal isotopic variations in the tropics

- LMDZ general circulation model (GCM) + simple box model *(Risi et al 2019)*





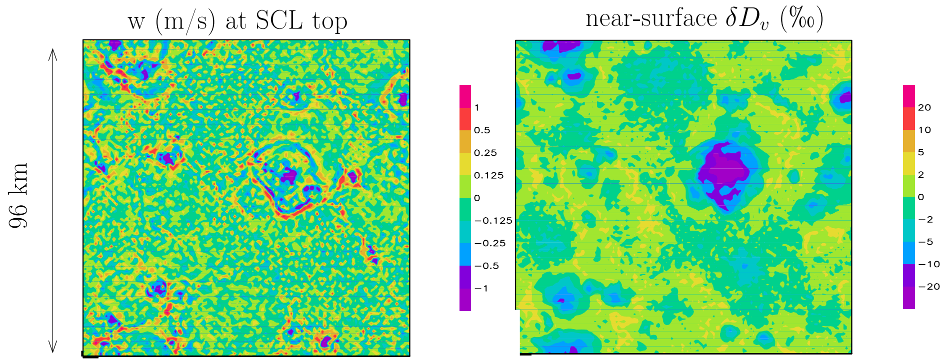




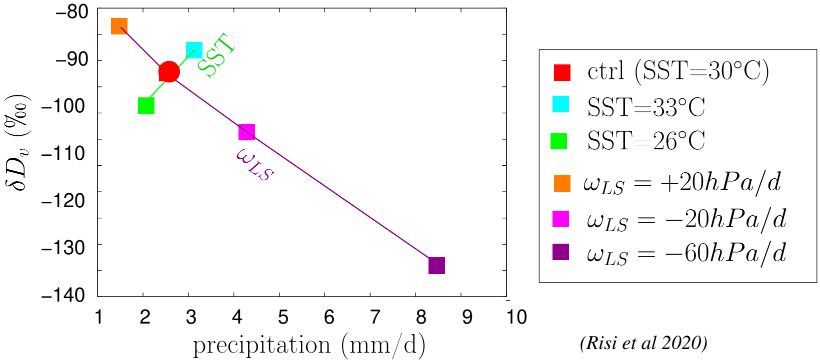
- But limitations associated with parameterizations

Using large-eddy simulations

- SAM *(Khairoutdinov and Randall 2003)* with isotopes *(Blossey et al 2010)*
- RCE, fixed SST, 750 m resolution, doubly periodic,



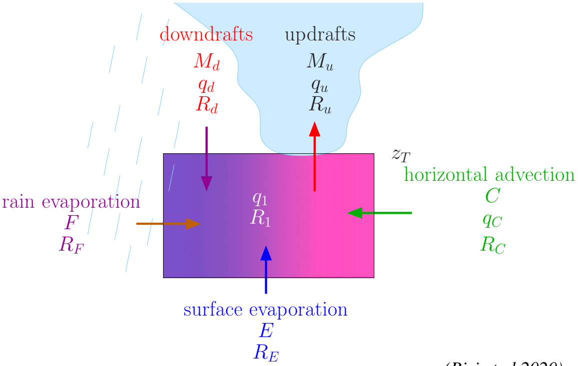
The response of water isotopes to precipitation depends on its thermodynamical or dynamical origin



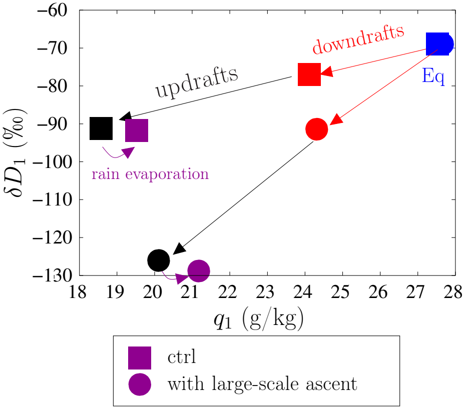
(Risi et al 2020)

- Could isotopic observations/records inform thermodynamical or dynamical origin of current/past precipitation changes? *(Bailey et al 2016, Dee et al 2017)*
  $\Rightarrow$ Preliminary results in a GCM are disappointing

What controls the sub-cloud layer δD_v?



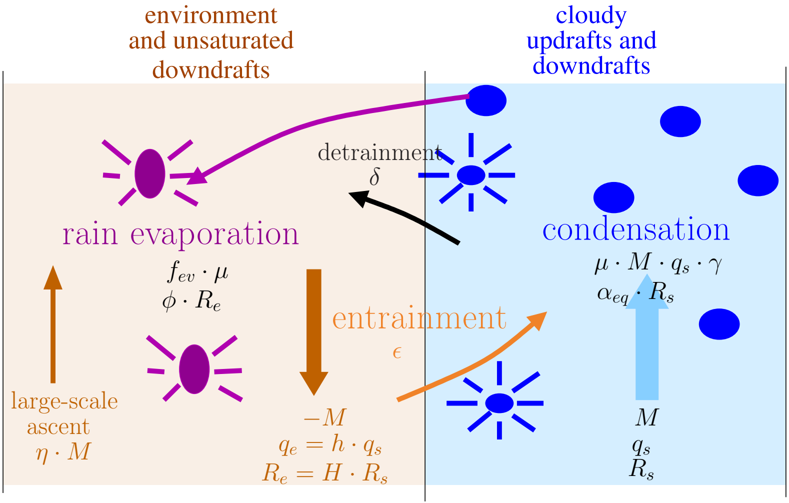
(Risi et al 2020)



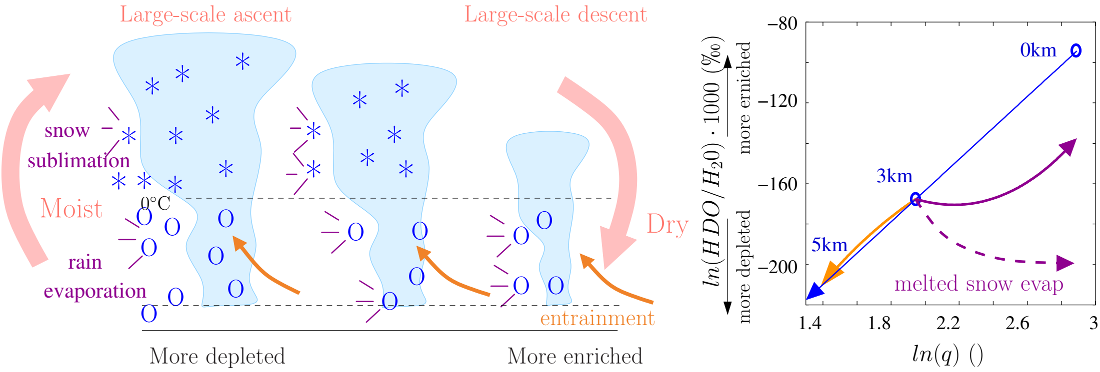
- Updrafts have the largest effect on drying and depleting the sub-cloud layer $\Rightarrow$ a missing component in climate models?
- Enhanced depletion with large-scale ascent due to steeper $q - \delta D$ vertical gradient

What controls δD_v vertical profiles?

- Simple 2-column model *(Risi et al submitted*, inspired by *Romps 2014)*



What controls δD_v vertical profiles?

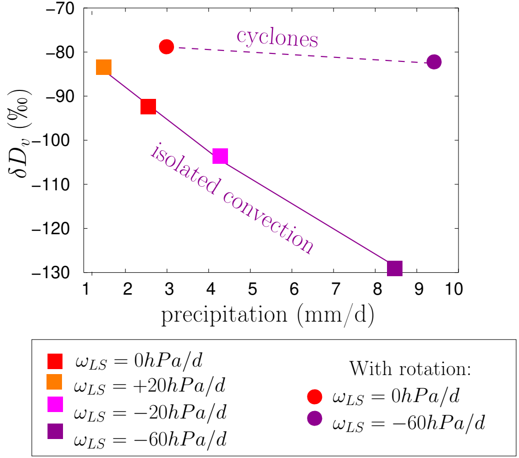


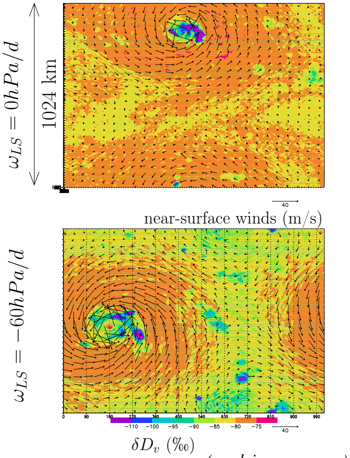
(Risi et al submitted)

- Large-scale ascent: less rain evaporation and snow sublimation
- Large-scale descent: entrainment of drier air

What role for convective organization?

- more depleted vapor in more organized convection? *(Lawrence et al 2004)*

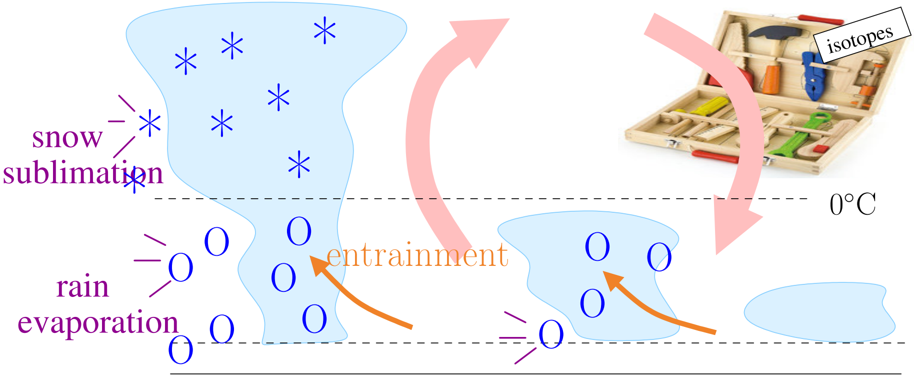




(work in progress...)

- Large-eddy simulation results at odds with expectations...

Conclusion



(Risi et al submitted)

- isotopes relevant to test hypotheses involving rain evaporation, snow sublimation, entrainment?
- processes controlling water isotopes still need to be better understood.

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