# The water stable isotopic composition of tropical water and its potential to study the water cycle

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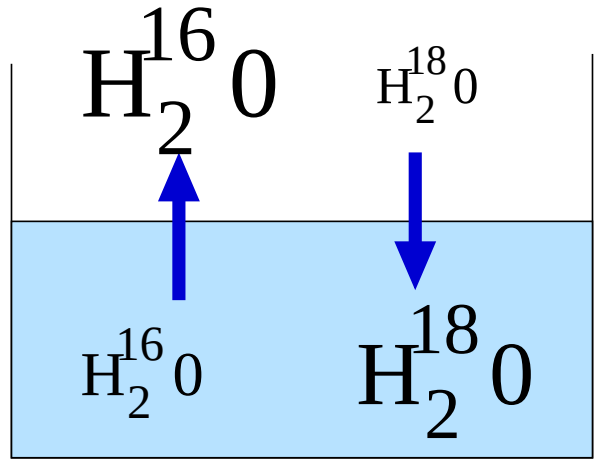
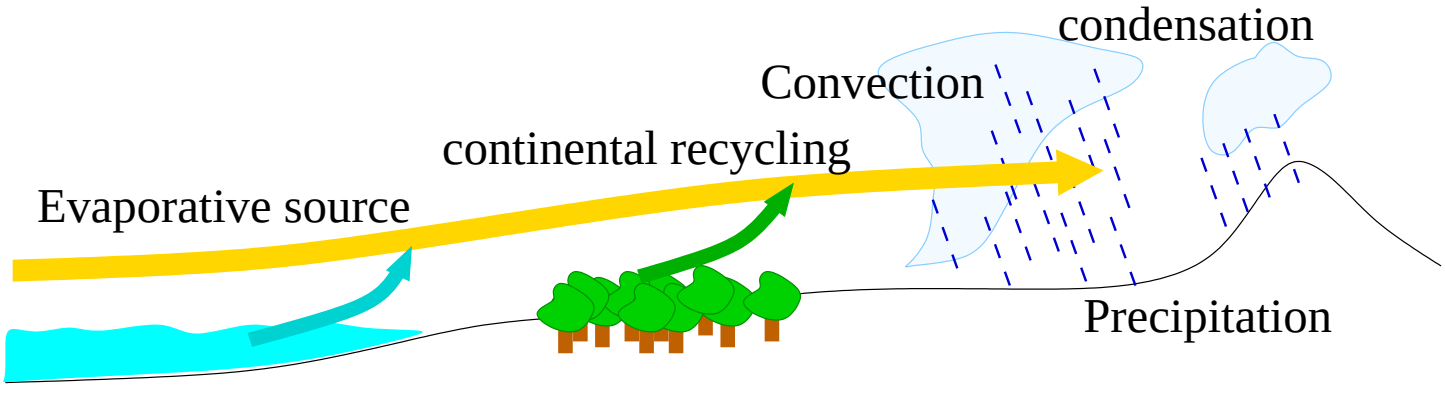
# Water stable isotopes

- water=light molecules ($H_2^{16}O$) + heavy ($H_2^{18}O$, $HDO$)
- isotopic fractionation
- use as paleothermometer in high latitudes



# Goals

- **What controls the isotopic composition** of precipitation in the Tropics? Role of atmospheric convection?
- **What information on the water cycle**, including cloud processes, surface-atmosphere interactions?
- Potential to better constrain **parametrizations** in models?
- Potential to better constrain the **variations** in the water cycle? Past climates?

# Tools

- **observations**
  - existing international networks (GNIP)
  - rain collected during AMMA, along the monsoon season and along squall lines
- **isotope-enabled models**
  - Single Column Model (SCM) of radiative-convective equilibrium
  - Squall line model
  - General Circulation Model (LMDZ)
  - Land Surface Model (ORCHIDEE)

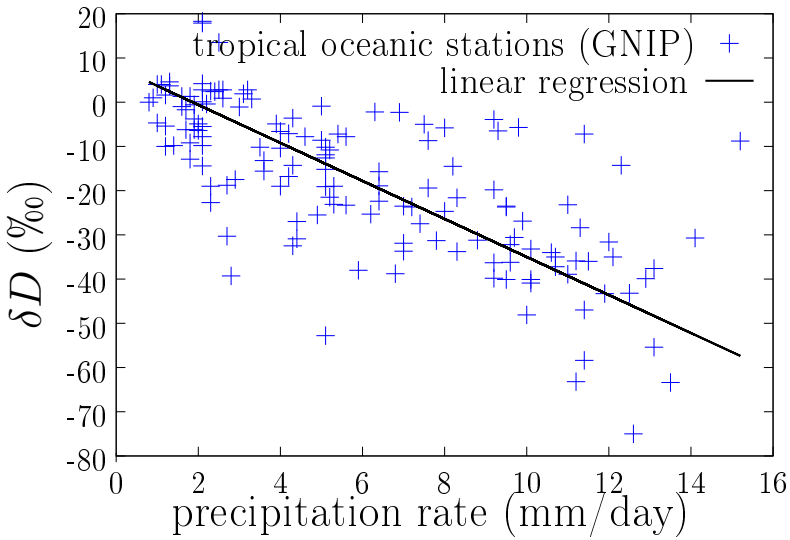
# Outline

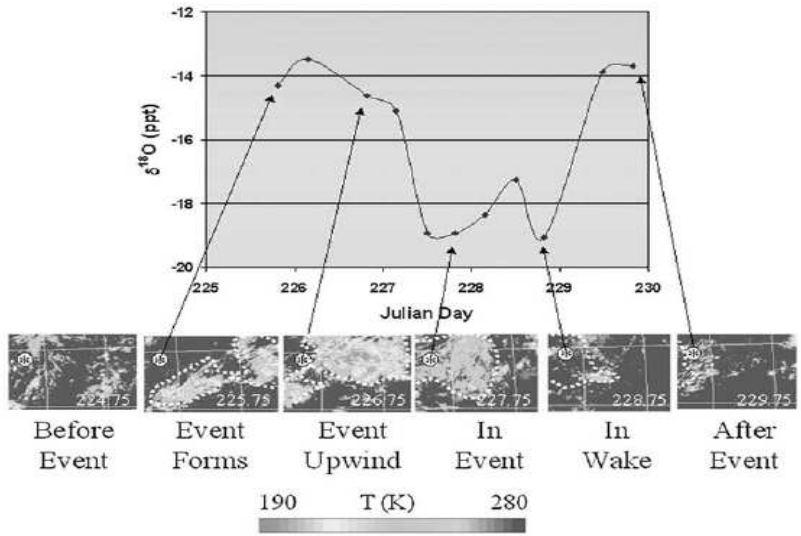
1. Isotopes and atmospheric convection
2. Isotopes and land surface processes
3. Isotopes and tropical climate variations

definitions:
$\delta^{18}O$=enrichment in $H_2^{18}O$ relatively to a standard in ‰
$\delta D$=enrichment in $HDO$ relatively to a standard in ‰
d-excess $= \delta D - 8 \cdot \delta^{18}O$

# 1. Isotopes and atmospheric convection

- **Existing observations**
  - Amount effect
  - Effect of convection at the synoptic scale



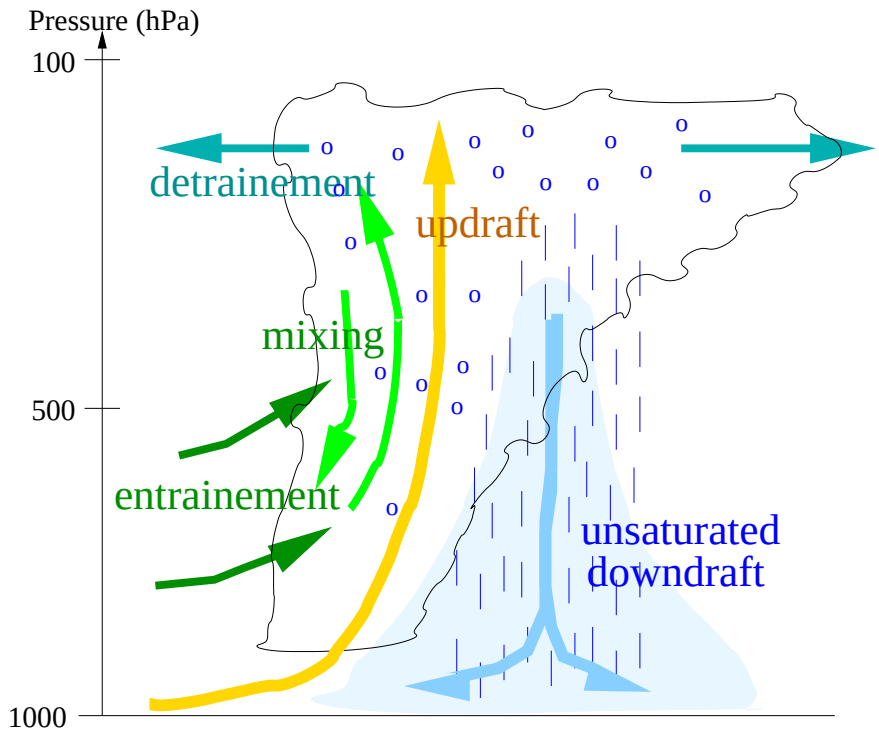

*Lawrence et al 2004*

- **Questions**: How does convection impacts the isotopic composition? By which processes? At which time scale?

# Single Column Model

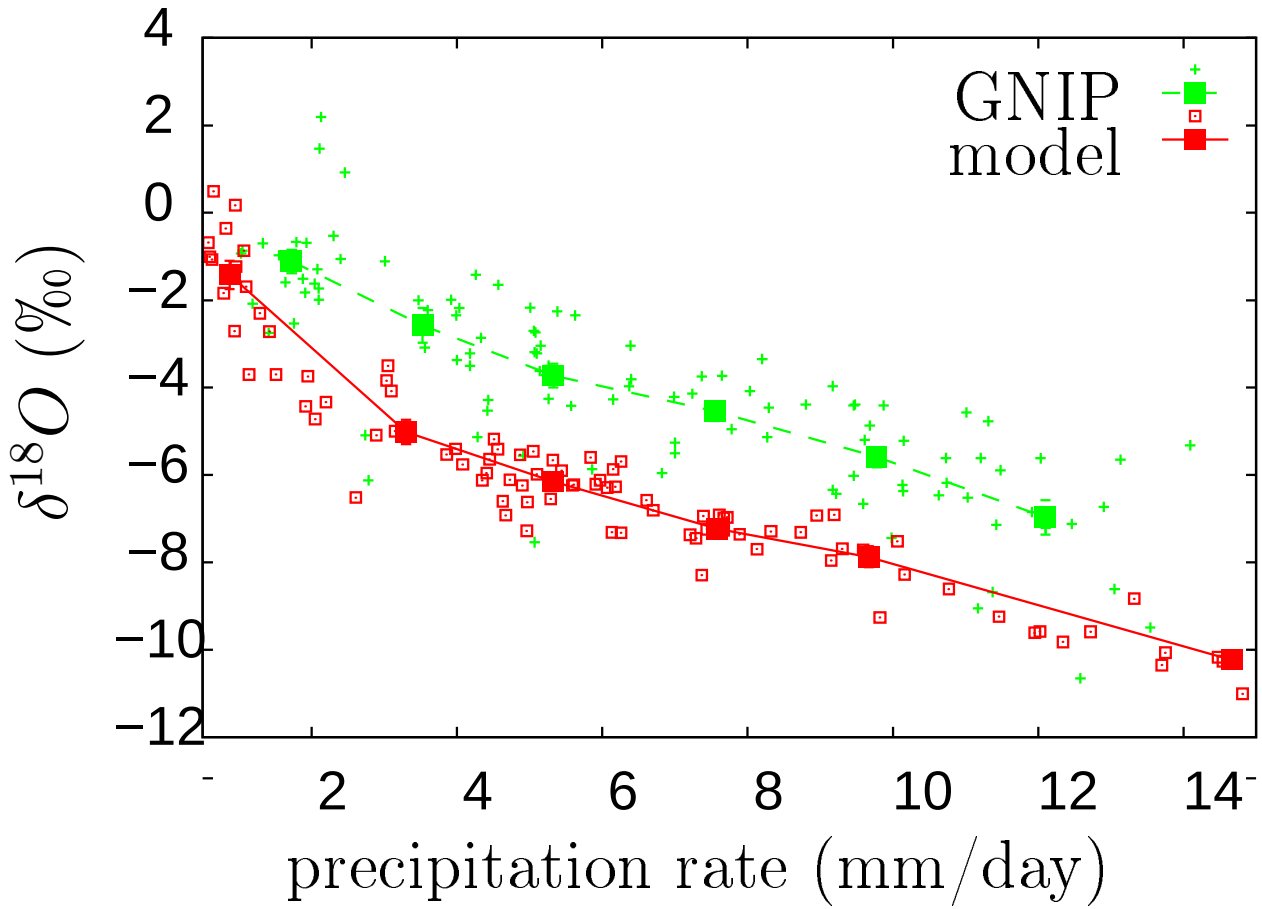
- Radiative convective equilibrium model over ocean

- Boundary conditions: sea surface temperature and wind, vertical profile of vertical velocity
- Emanuel convective parametrization $\Rightarrow$ detailled representation of rain evaporation
- neglect horizontal gradients in moisture and isotopes




Convective system in the Emanuel parametrization

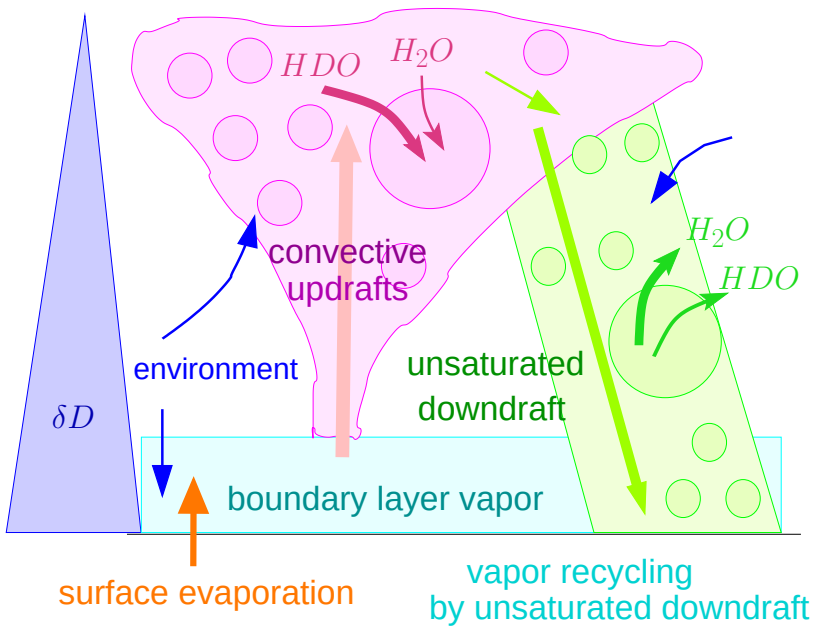
# Evaluation of the Single Column Model

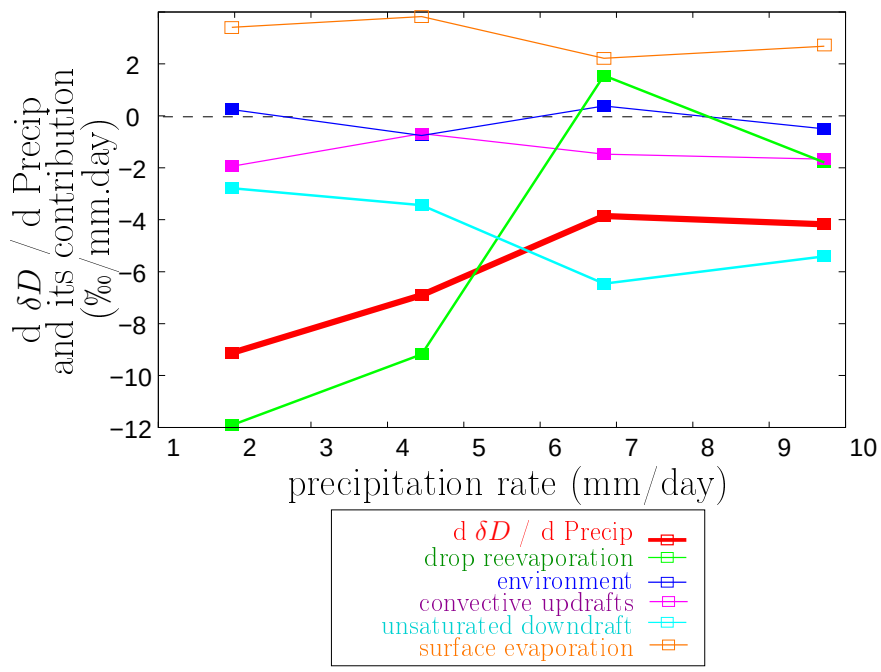



- correct simulation of the amount effect

# What explains the amount effect?

$$\text{Amount effect} = \frac{d\delta D_p}{dP} \simeq \frac{d\delta D_{evap}}{dP} + c_{cond} + c_{revap} + c_{downdraft}$$

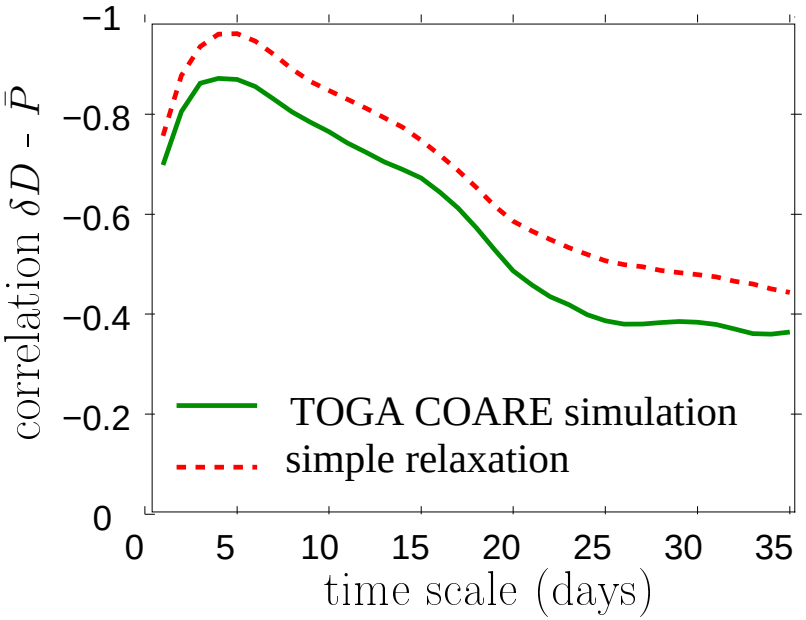



- rain reevaporation and convective downdrafts main processes
- consistent with strong sensitivity to reevaporation and downdraft parameters

# What are the time scales of the amount effect?

- TOGA COARE simulation



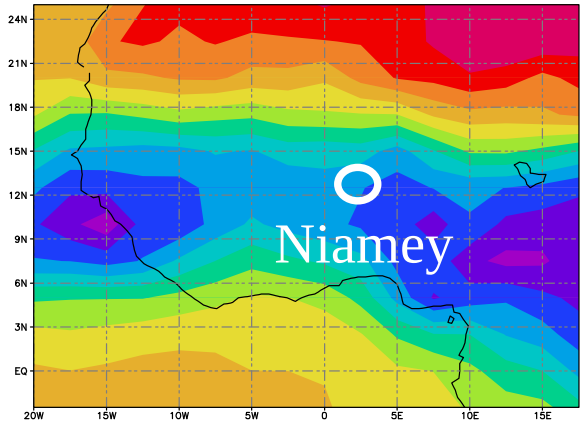

- simple relaxation model:

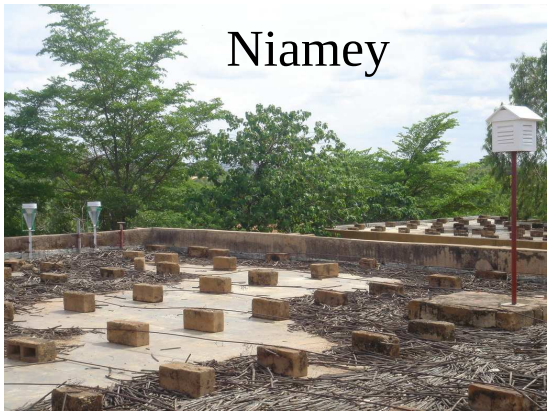
$$\frac{d\delta D}{dt} = S \cdot P - \frac{\delta D}{\tau}$$

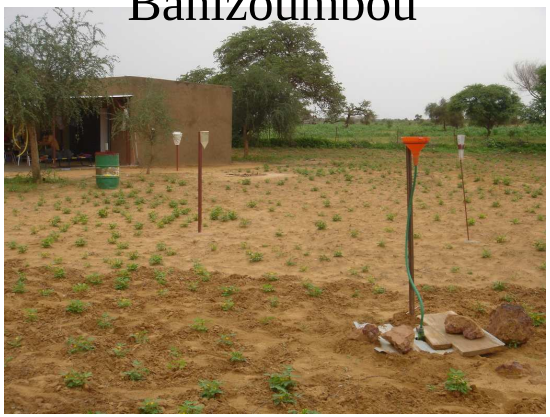
- The isotopic composition integrates convection over the previous days

# Collection of rain samples during the AMMA campaign

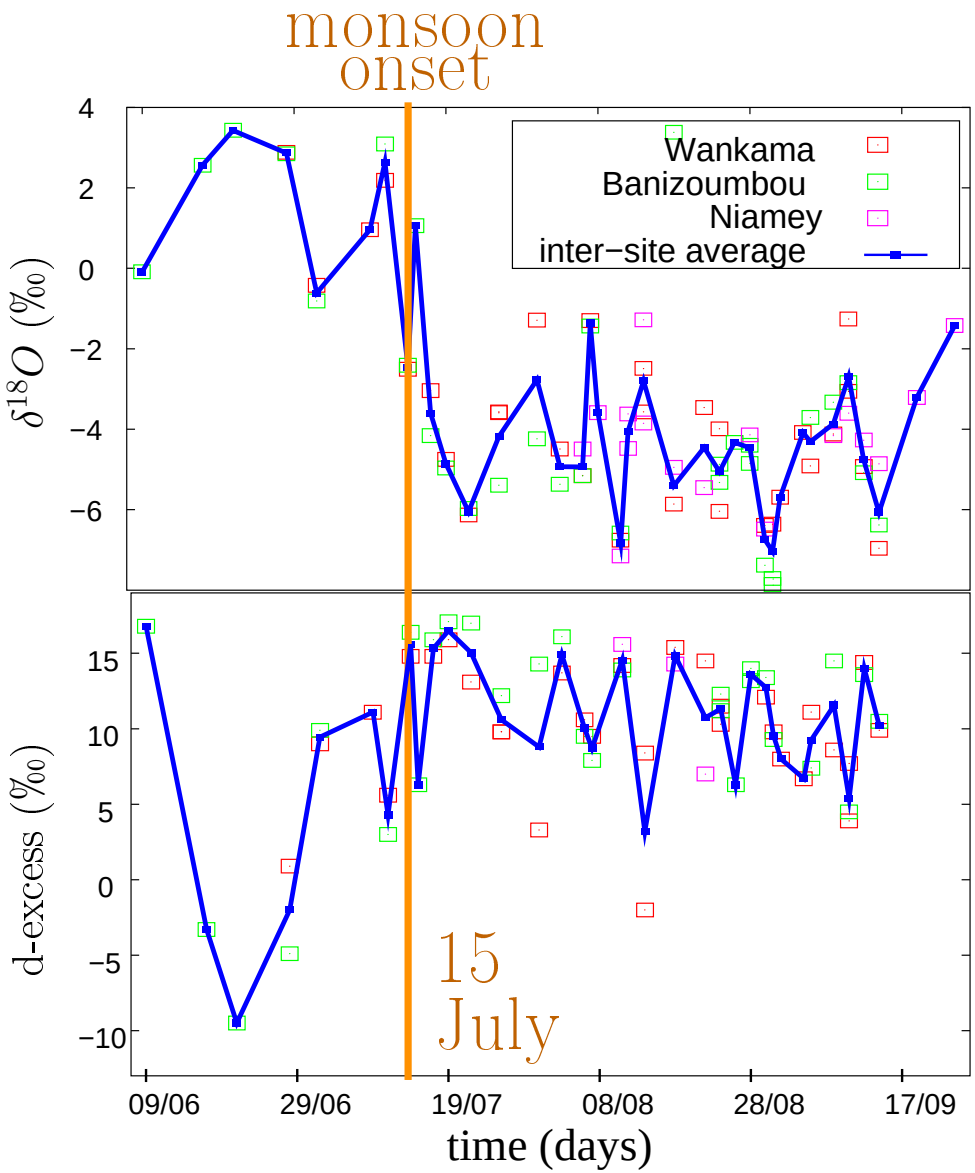
- collection at the end of each event, during the entire 2006 monsoon season, on 3 sites around Niamey

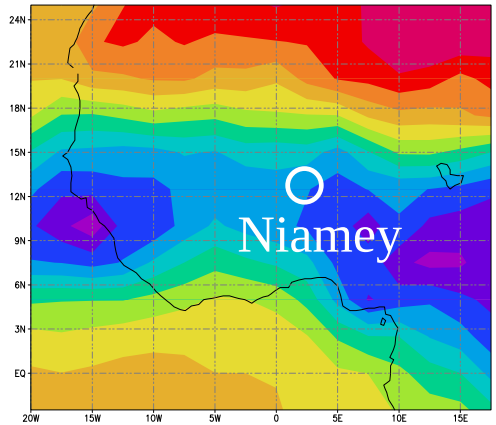


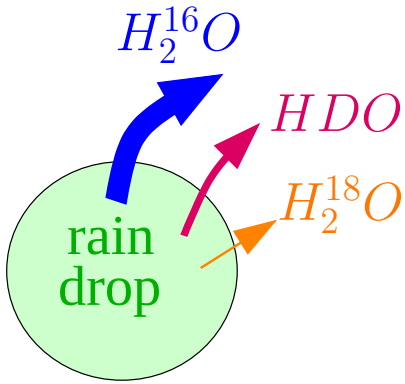




# Isotopic evolution during the season

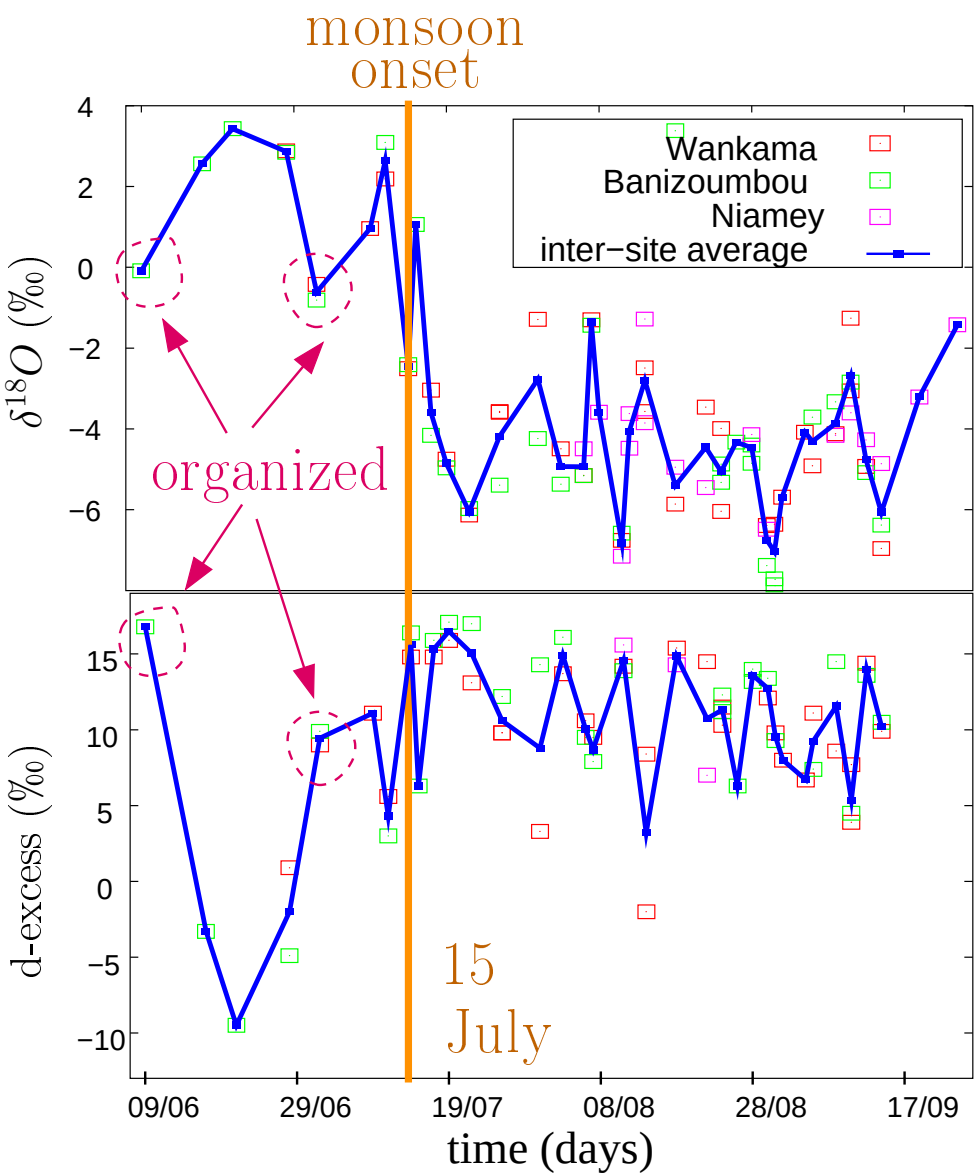


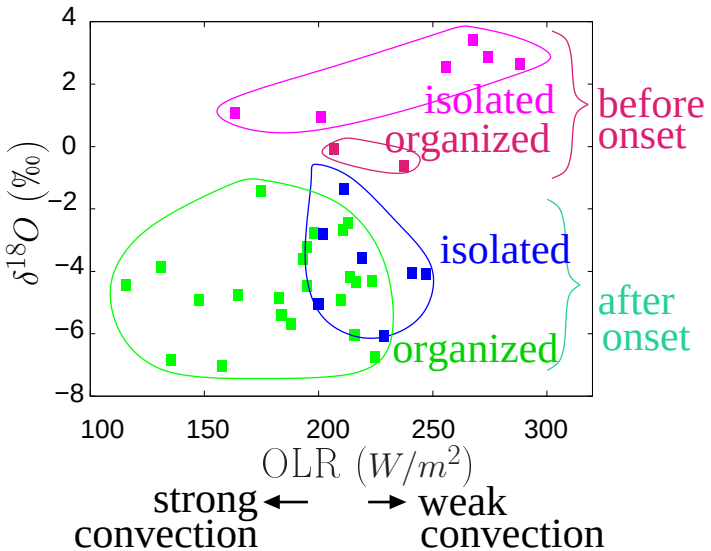




- record of the monsoon onset



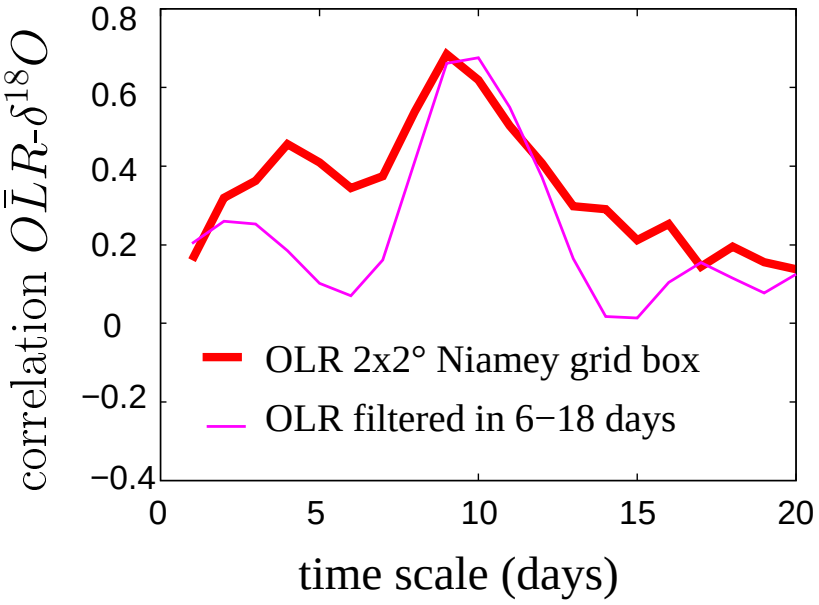
# Isotopic evolution before the onset

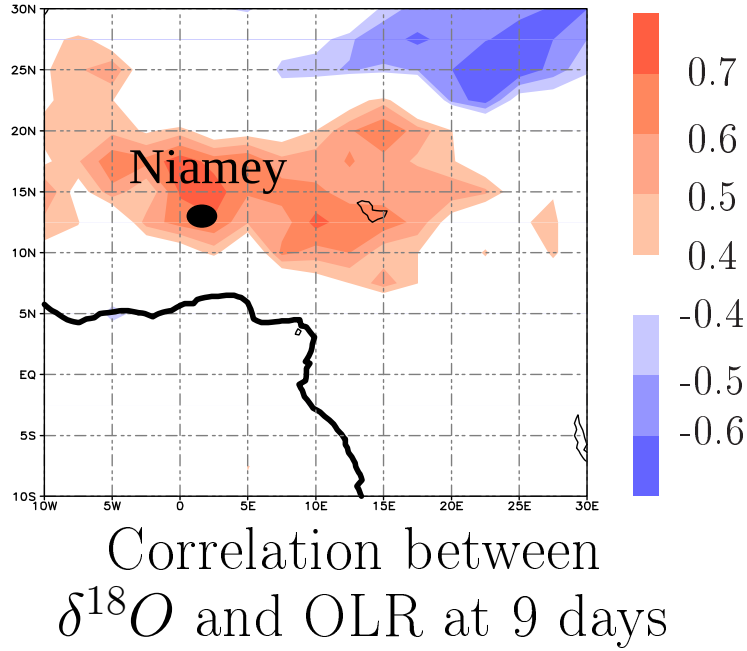



- intensity and organization of individual systems dominate

# Isotopic evolution after the onset



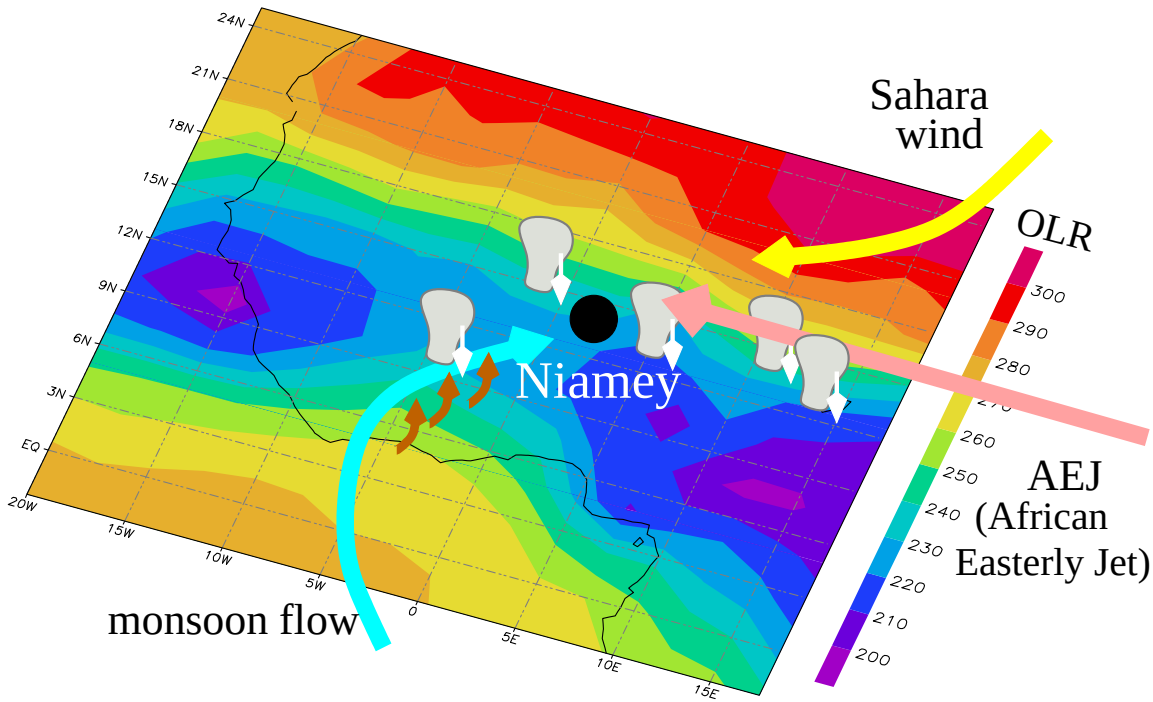




Correlation between $\delta^{18}O$ and OLR at 9 days

- temporal integration of convection
- record of the intra-seasonal variability (*Sultan et al 2003*)

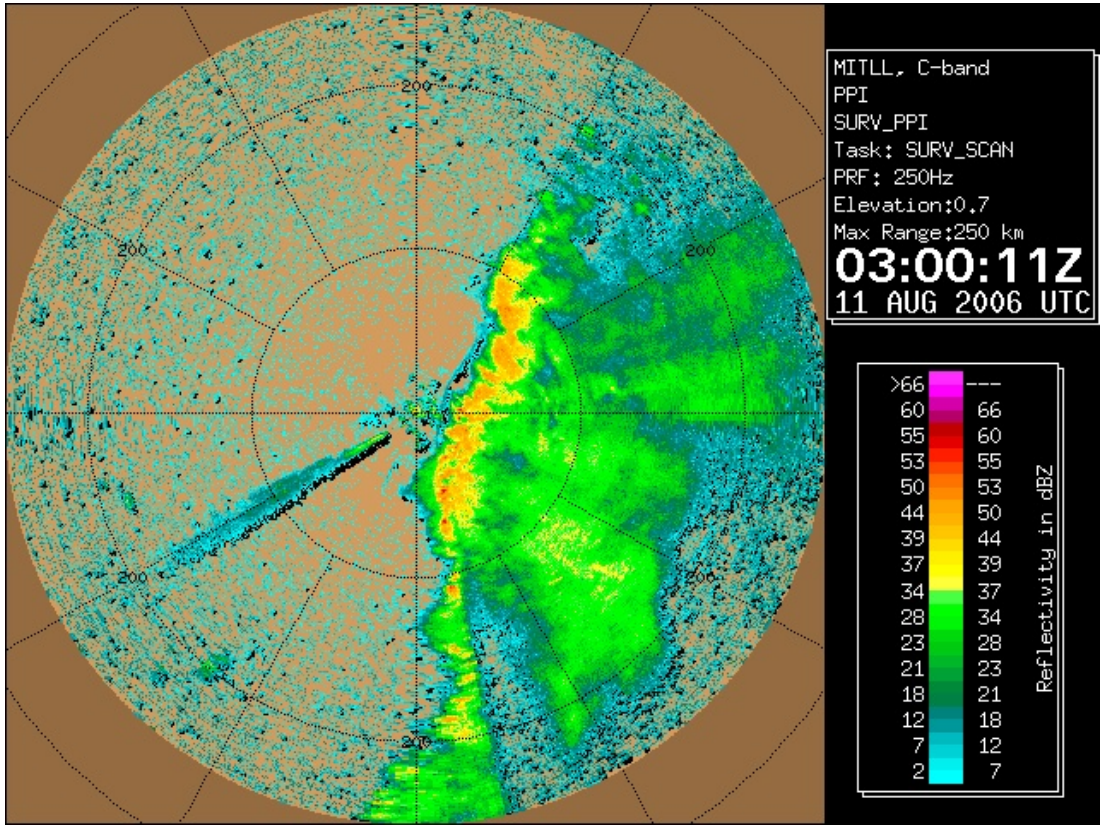
# Remaining questions

- process of temporal integration? Atmospheric vapor? Soil moisture?
- d-excess data?
- processes of convection impact? Local or regional?



# Intra-event sampling

11 August 2006 squall line



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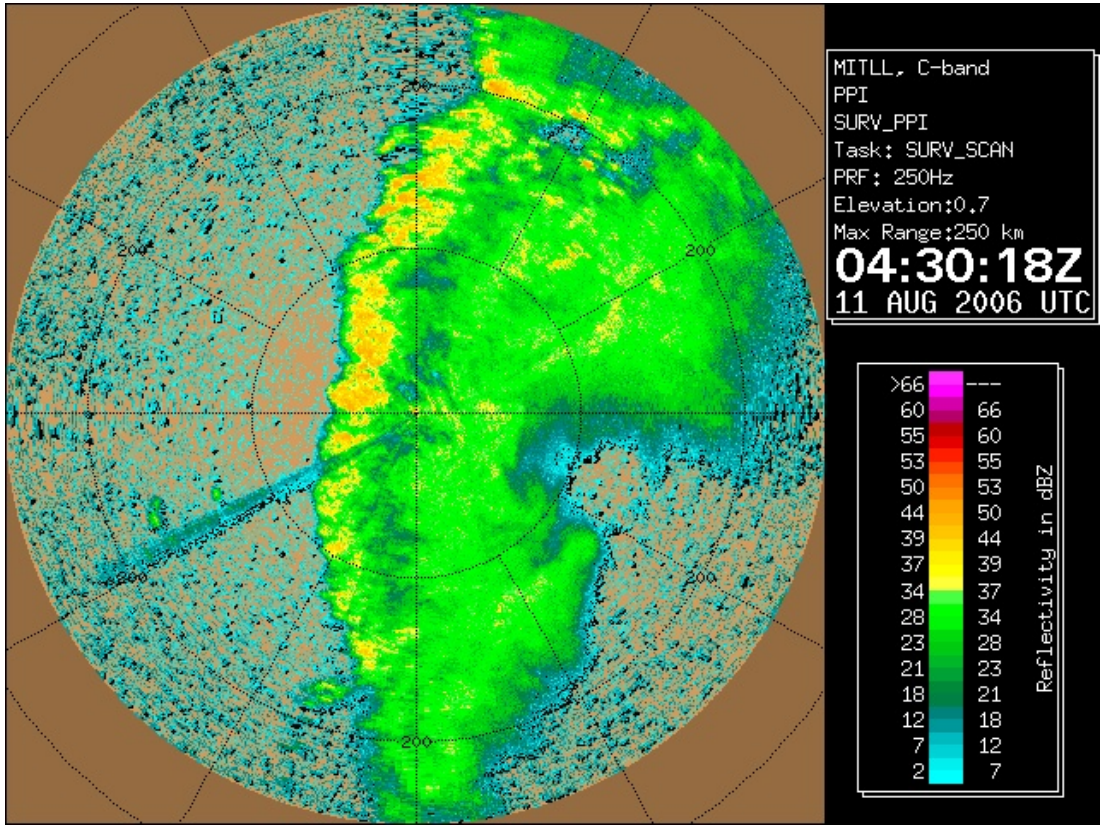

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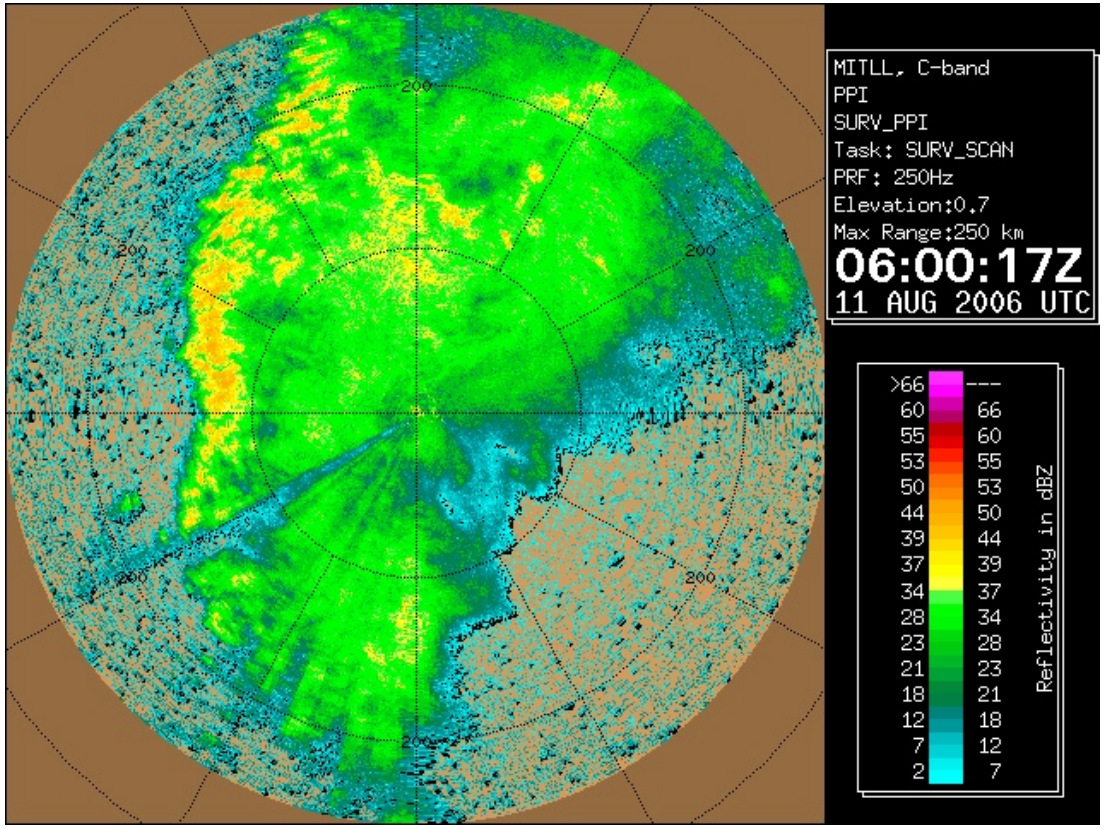
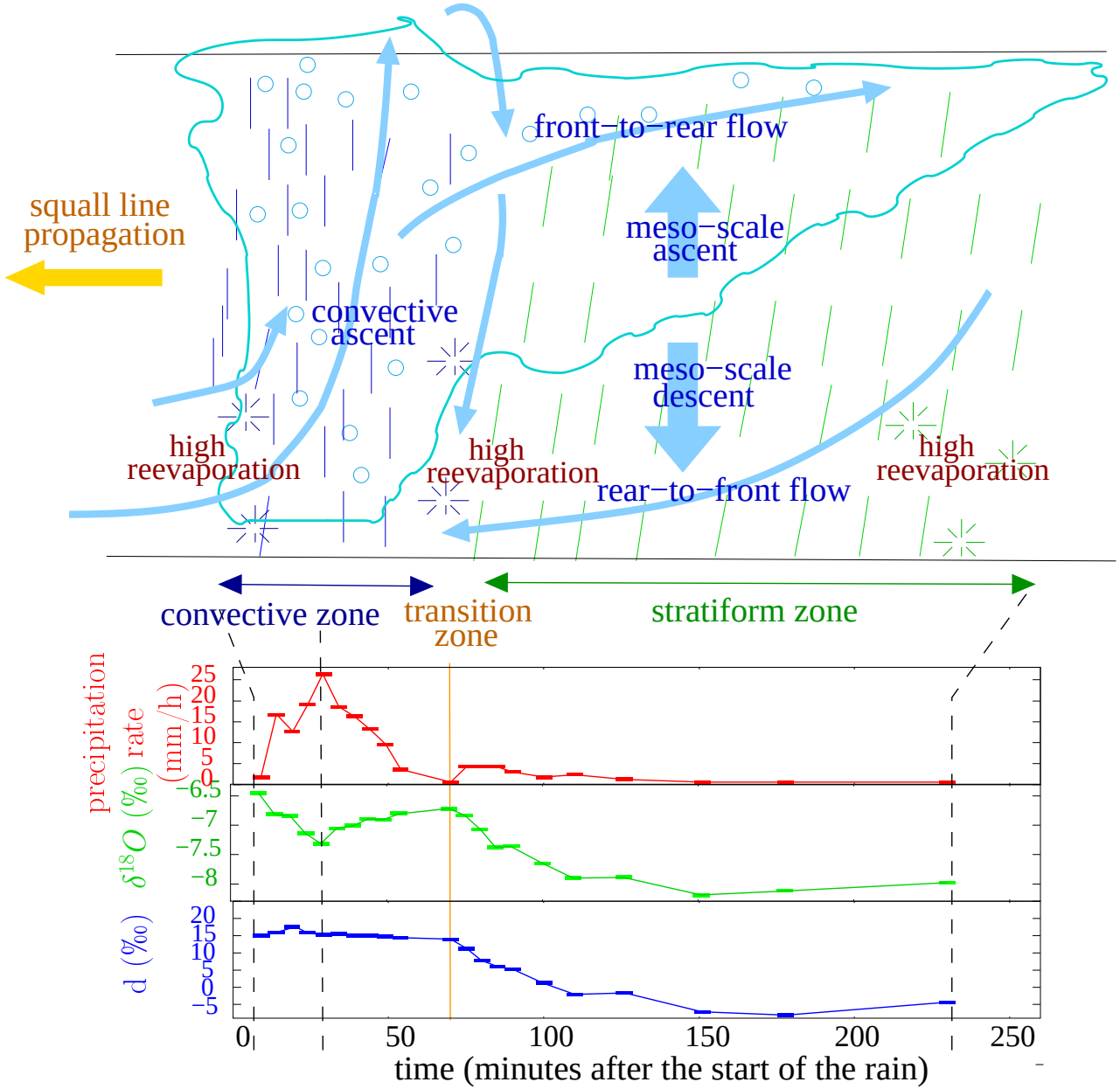
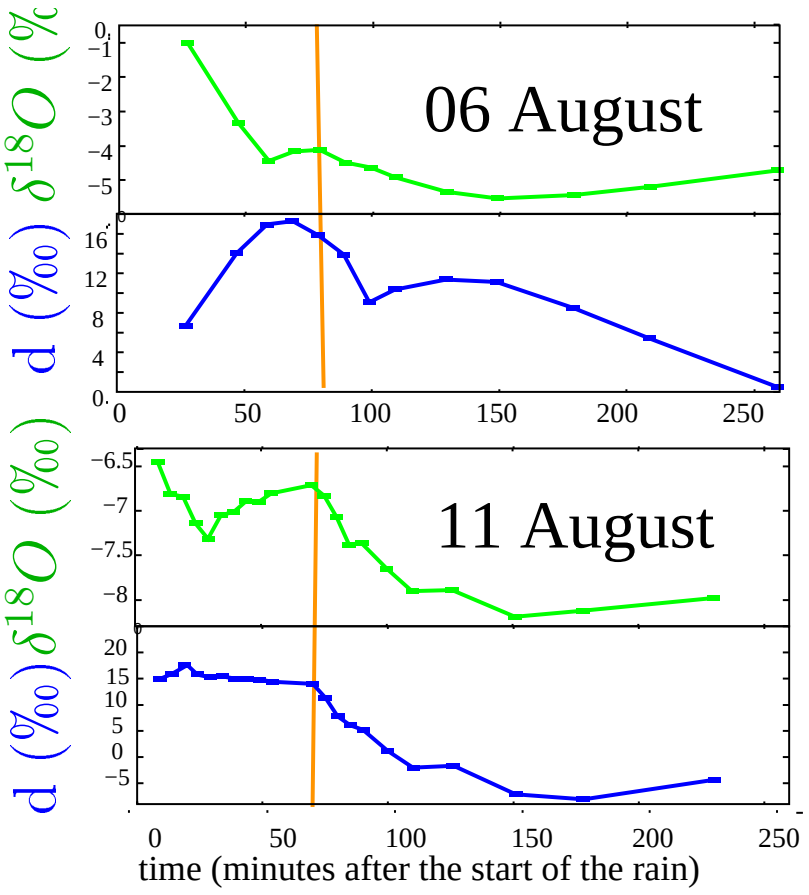
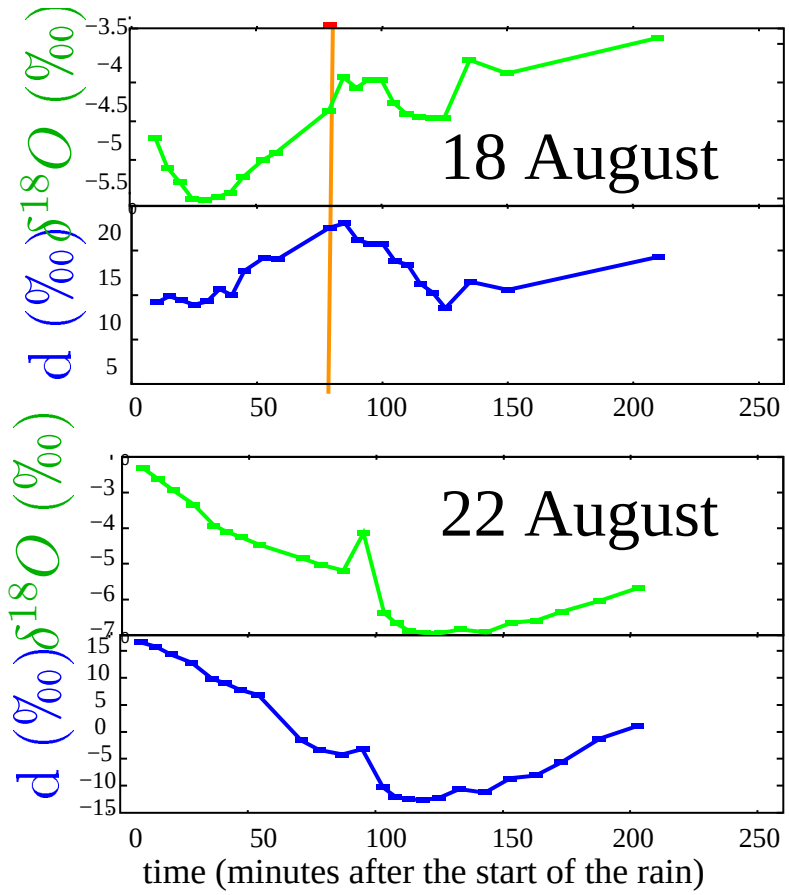


# 11 August 2006 squall line



# Robust properties among squall lines

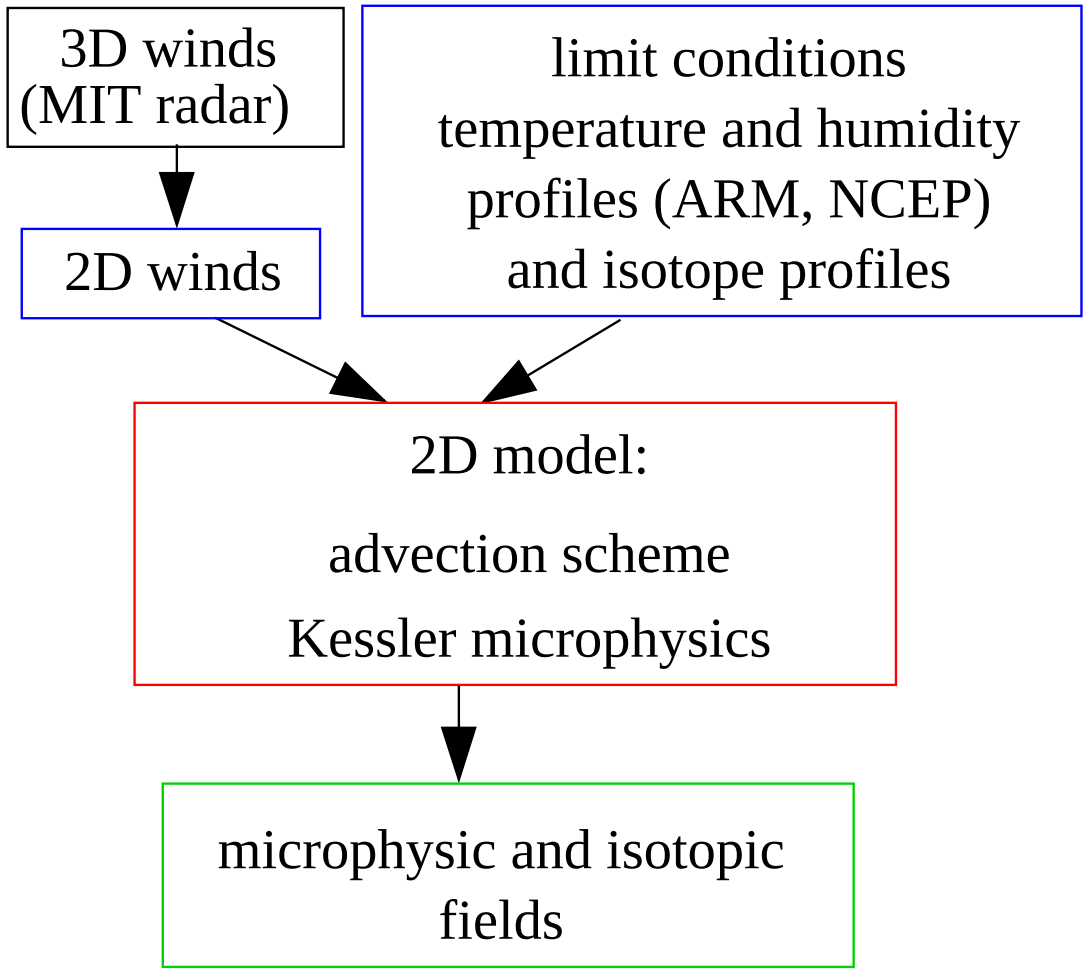


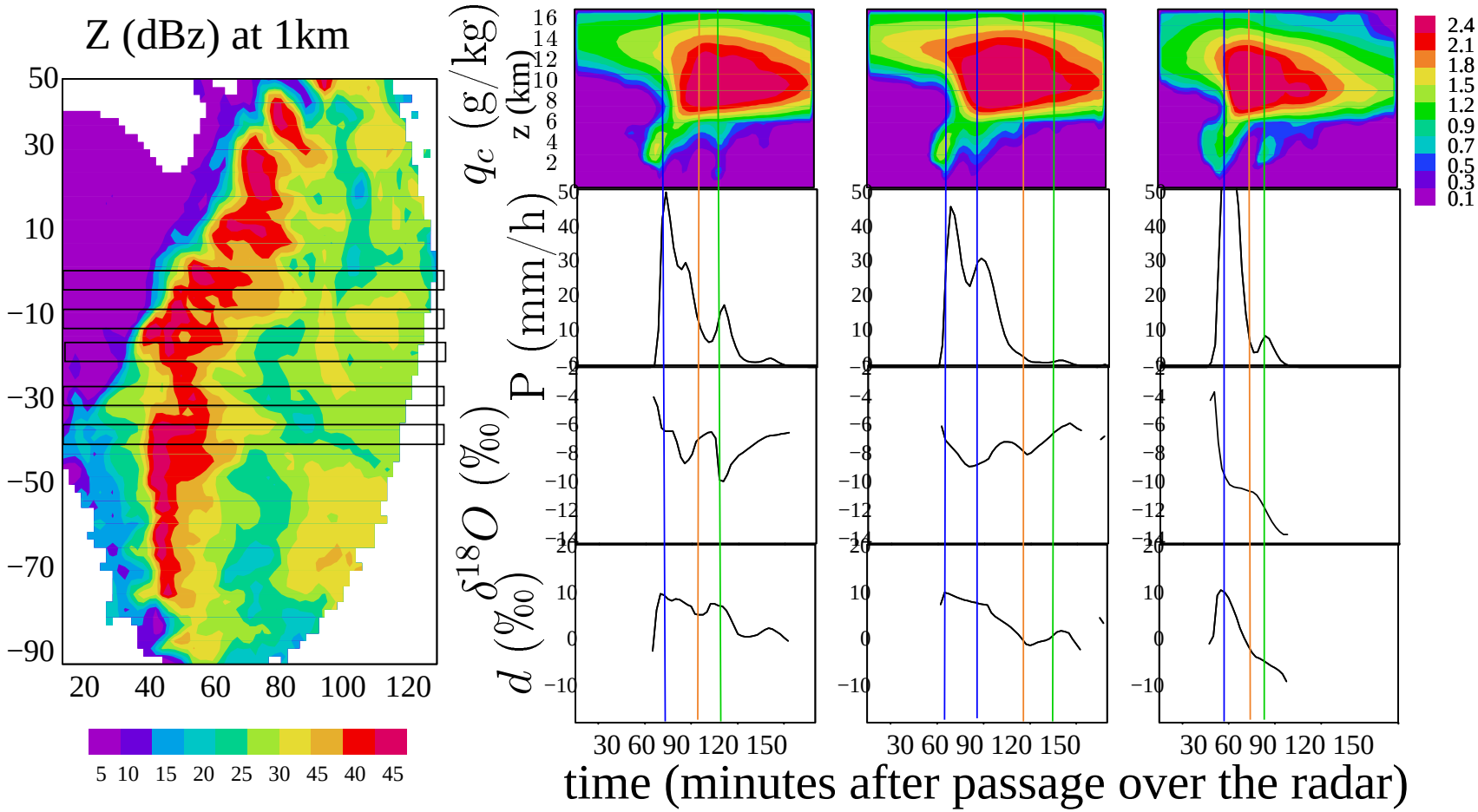

- strong variations between lines
- W shape
- d-excess decreases at the beginning of the startiform zone

# Simple 2D model of transport and microphysics

- **Assumptions**
  - 2D
  - stationarity
  - no along line winds
  - temperature and pressure horizontally constant

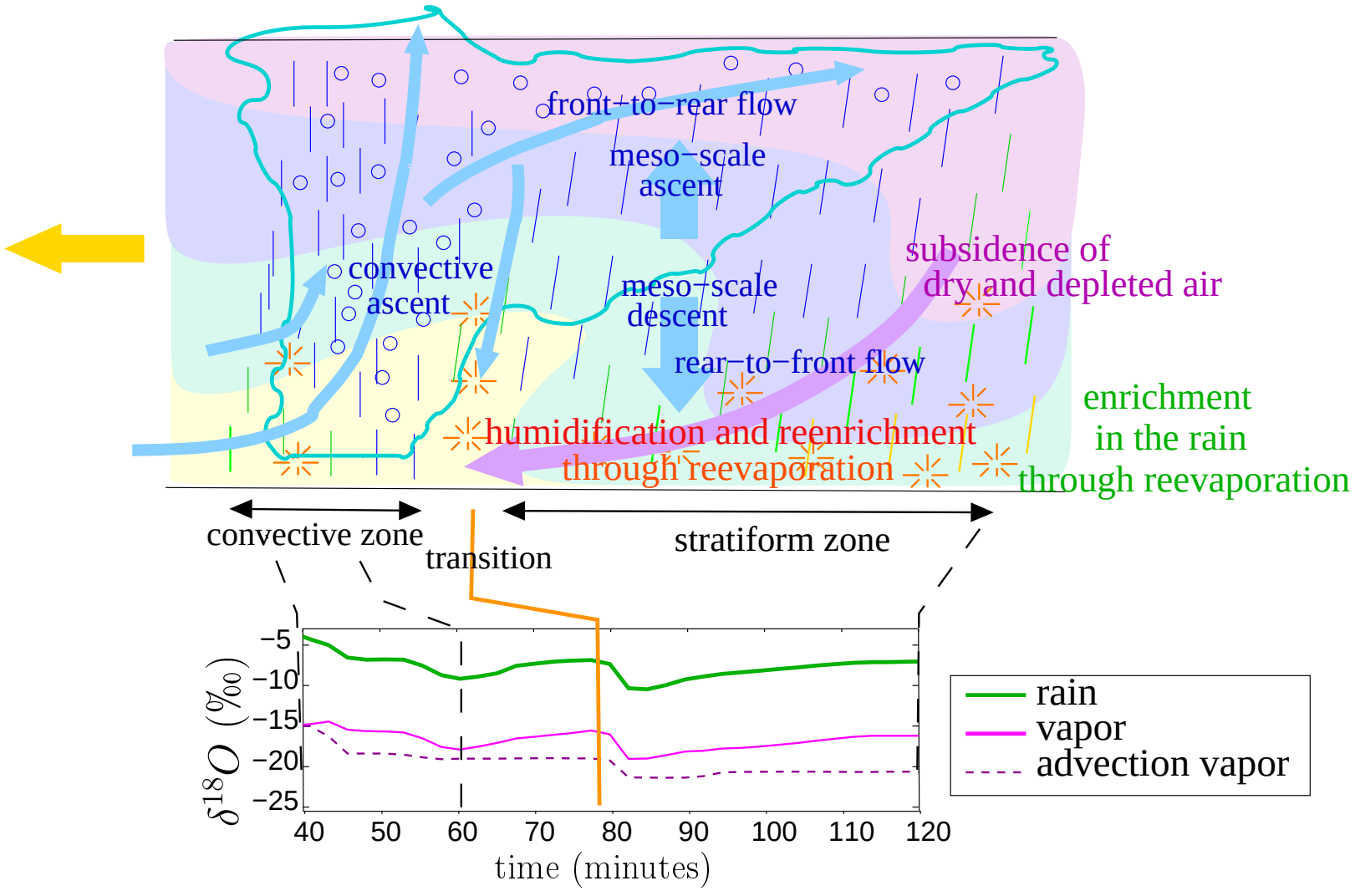


# Model results



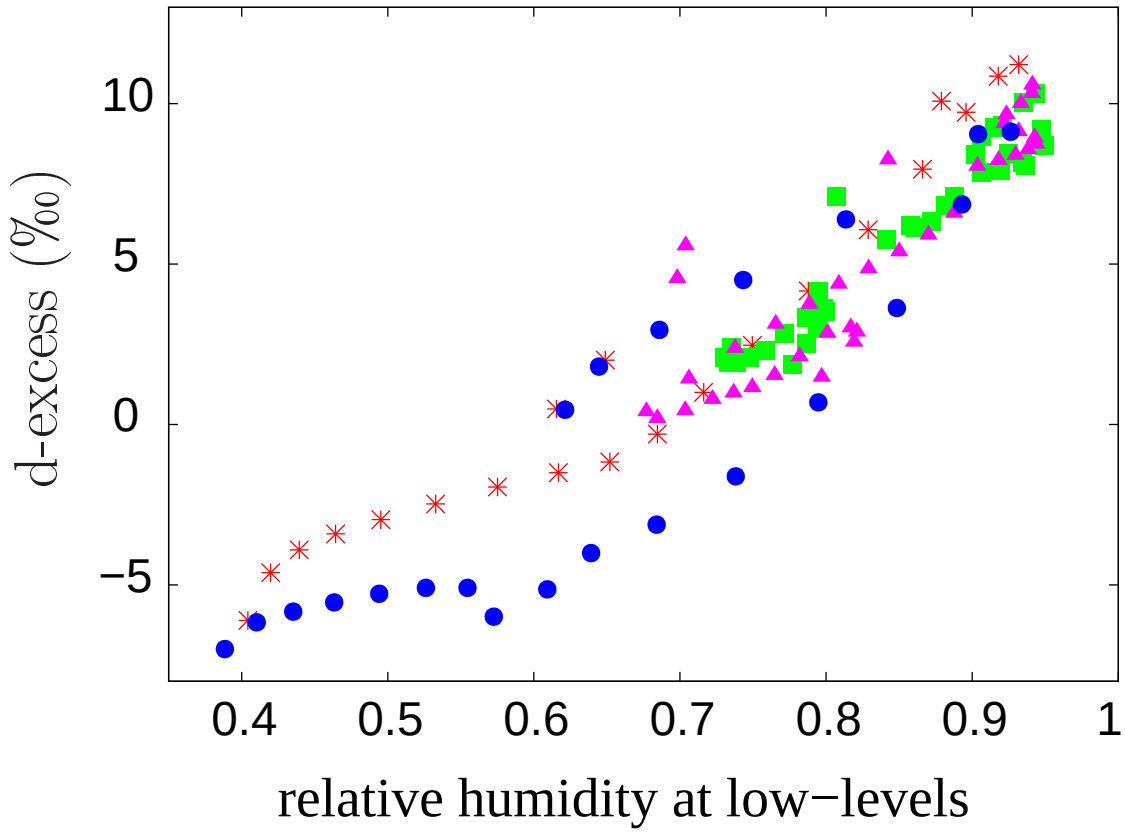

- robust properties simulated
- strong sensitivity to the dynamics

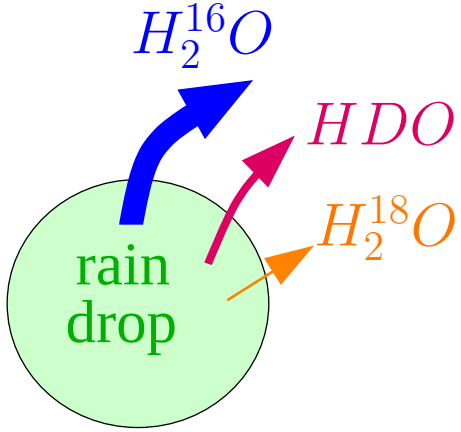
# What processes control $\delta^{18}O$?




- strong impact of downdrafts and rain evaporation

# What processes control d-excess?



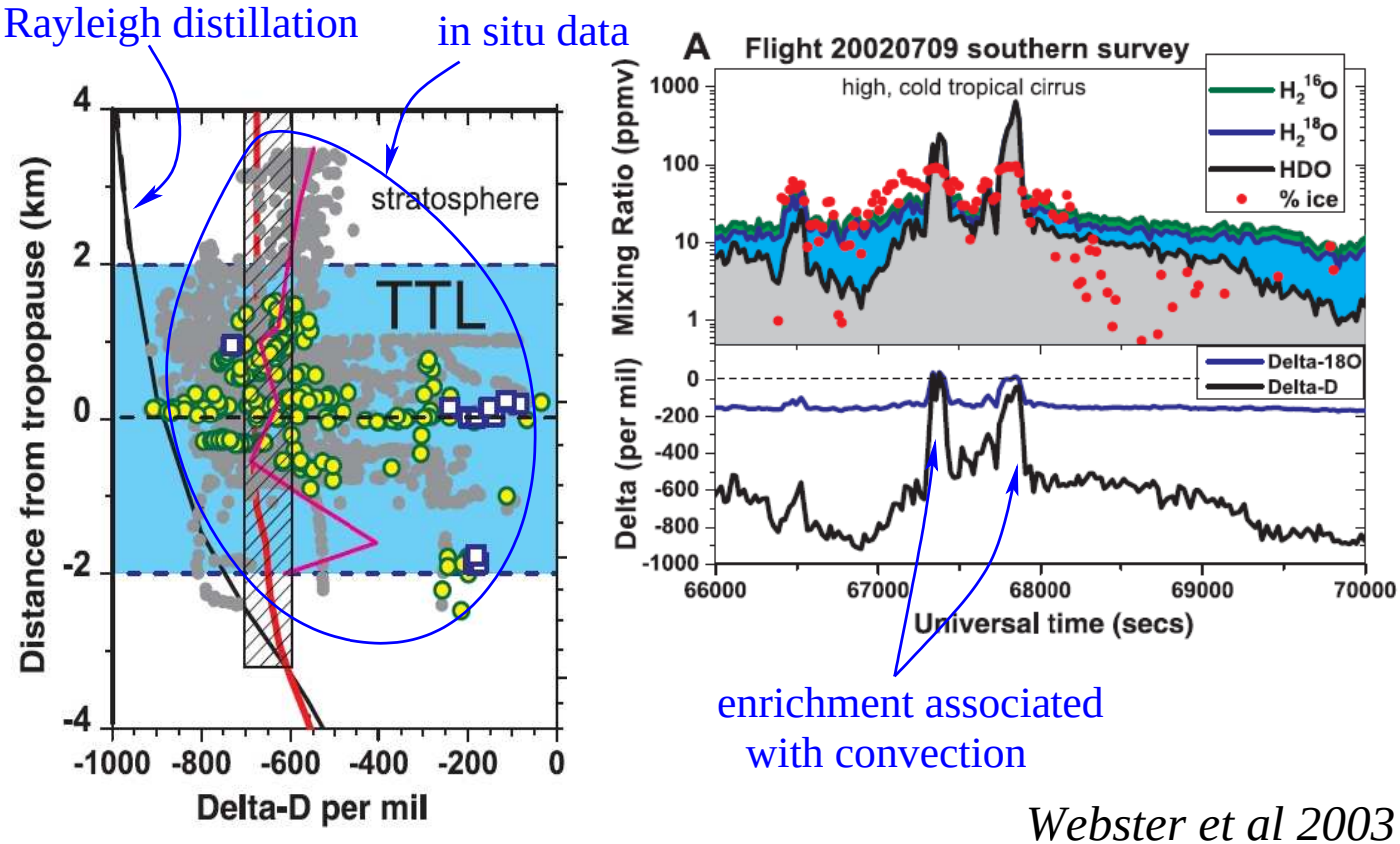

- d-excess controlled mainly by relative humidity during reevaporation

# Conclusion on the effect of convective processes on precipitation isotopes

- Both SCM and intra-event data show strong impact of
  - Convective and meso-scale downdrafts
  - Rain reevaporation
- Potential of water isotopes to better constrain water budgets in squall line and representation of convection in models?
- Link between event and intra-seasonal/seasonal scales?

# Water isotopes and water transport through the tropopause

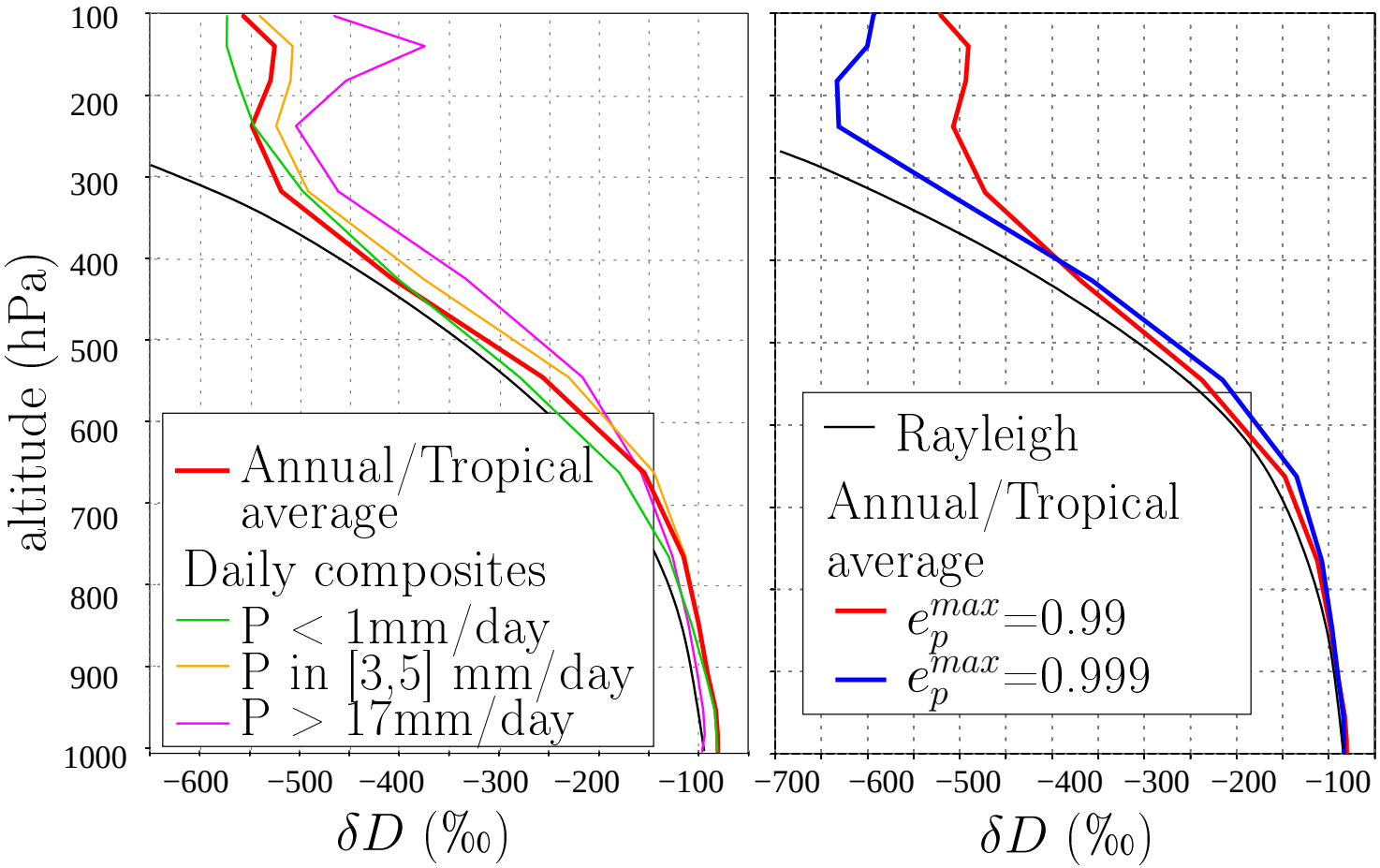
- Existing observations
  - Less depleted than expected
  - Large variablity associated with clouds




*Webster et al 2003*

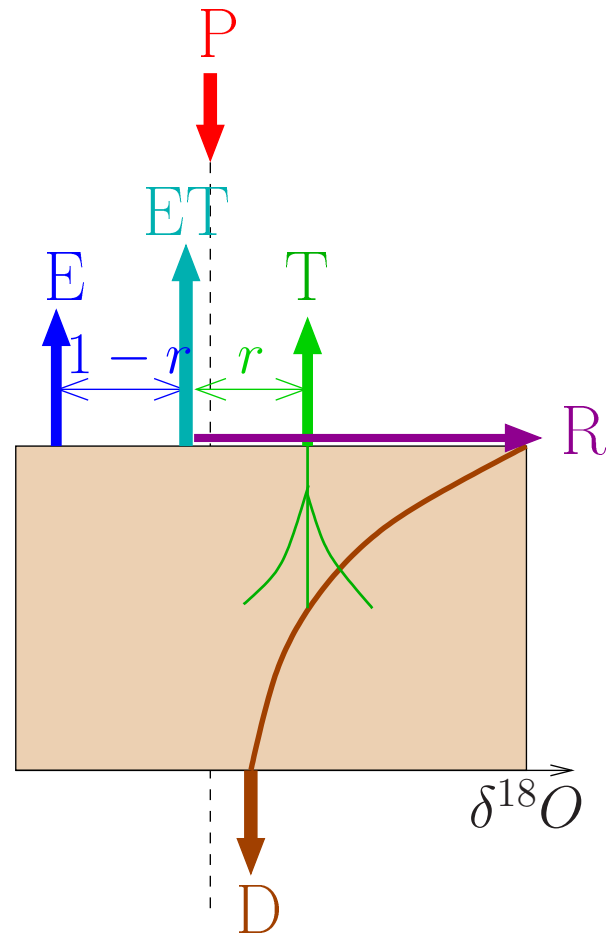
# Modelling results

- GCM with same convective parametrization
  - impact of convective activity at the daily scale
  - enrichment depending on condensate detrainment



# 2. Water isotopes and the land surface

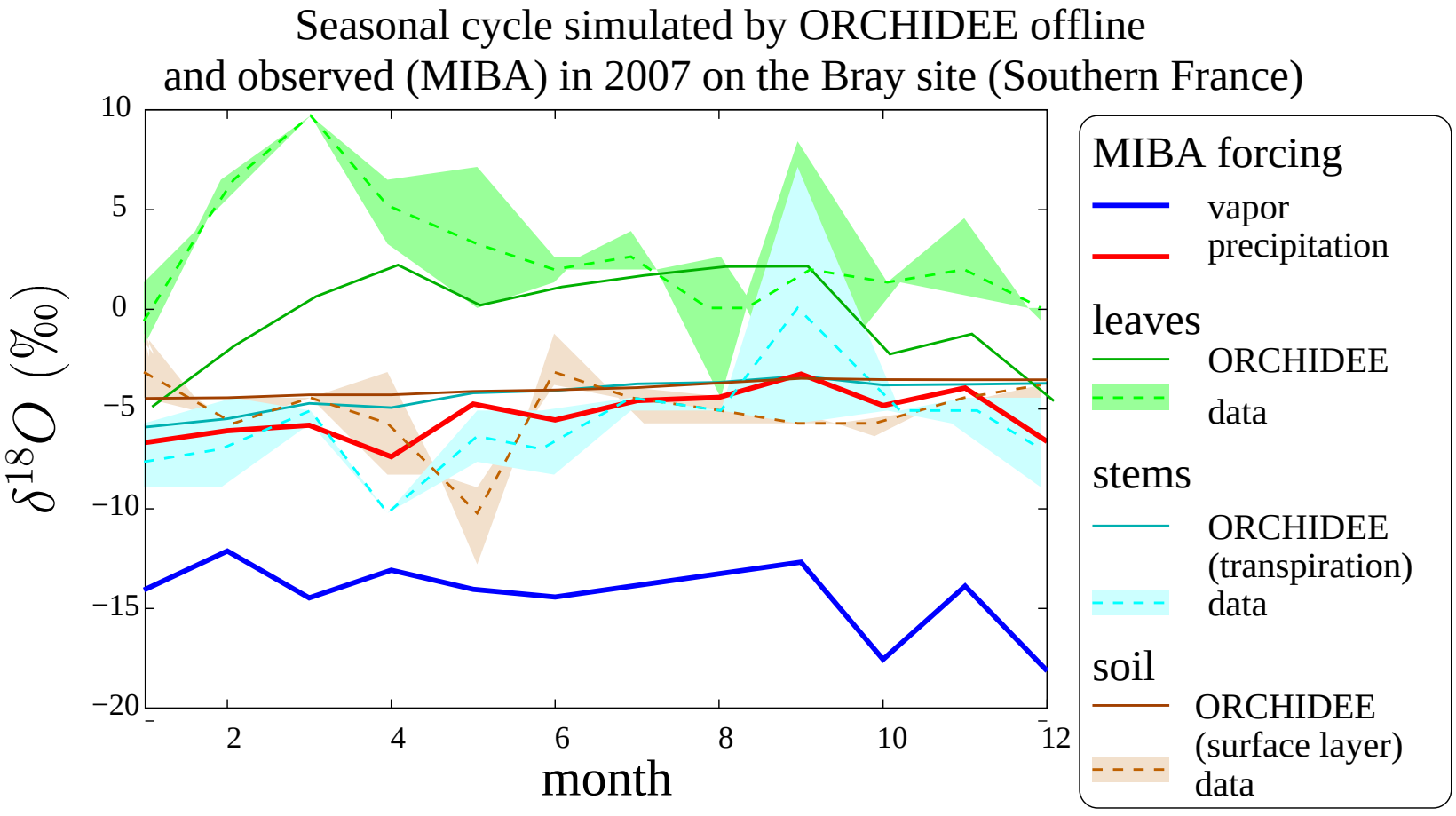
- **Motivations**
  - interpretation of AMMA data (soil memory, d-excess)
  - what is the impact of land surface processes on the isotopic distribution?
  - what information can be learned from isotopes in the land surface?




- **Tool: ORCHIDEE land surface model**
  - double bucket hydrology
  - offline or coupled mode with LMDZ GCM

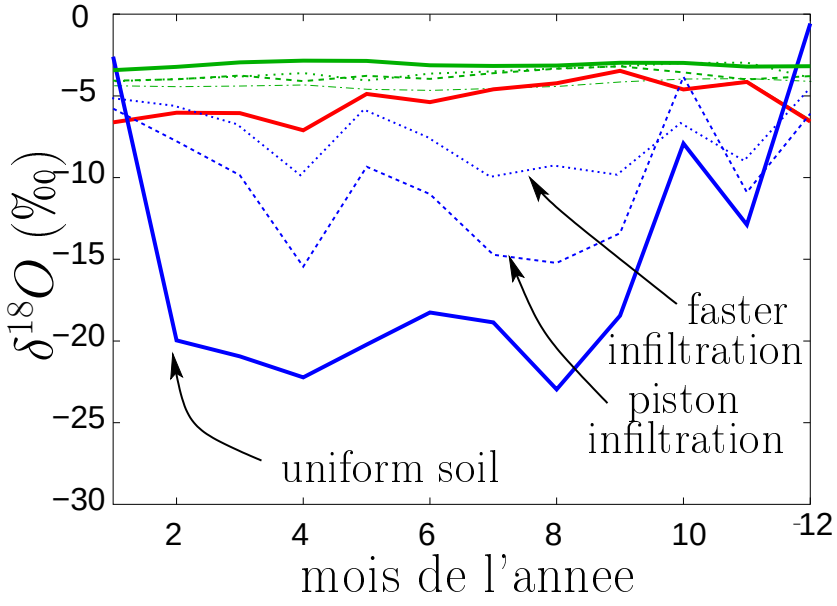
# Offline evaluation over the Bray Site

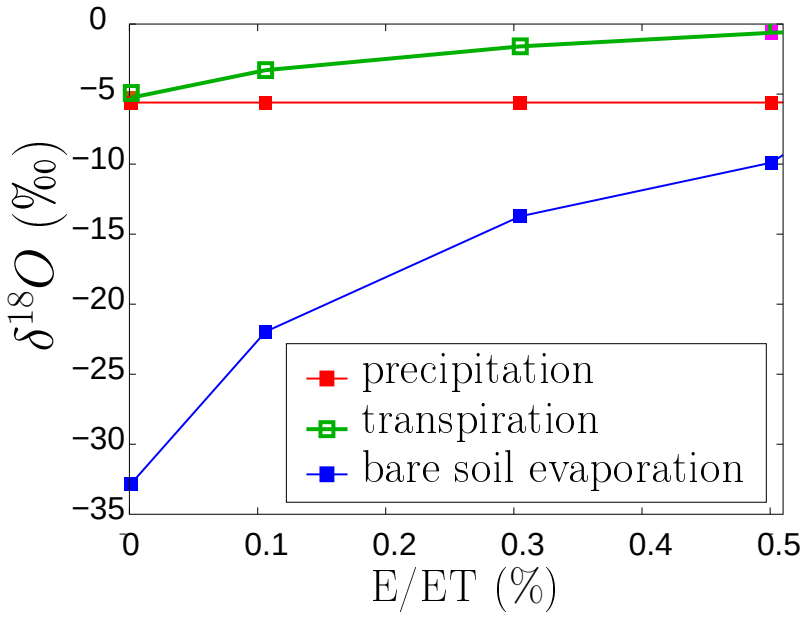
- MIBA data of precipitation, vapor, plants and soils




- Evaluation perspectives: other MIBA sites (US), use of the GNIR data base (rivers)

# Sensitivity tests

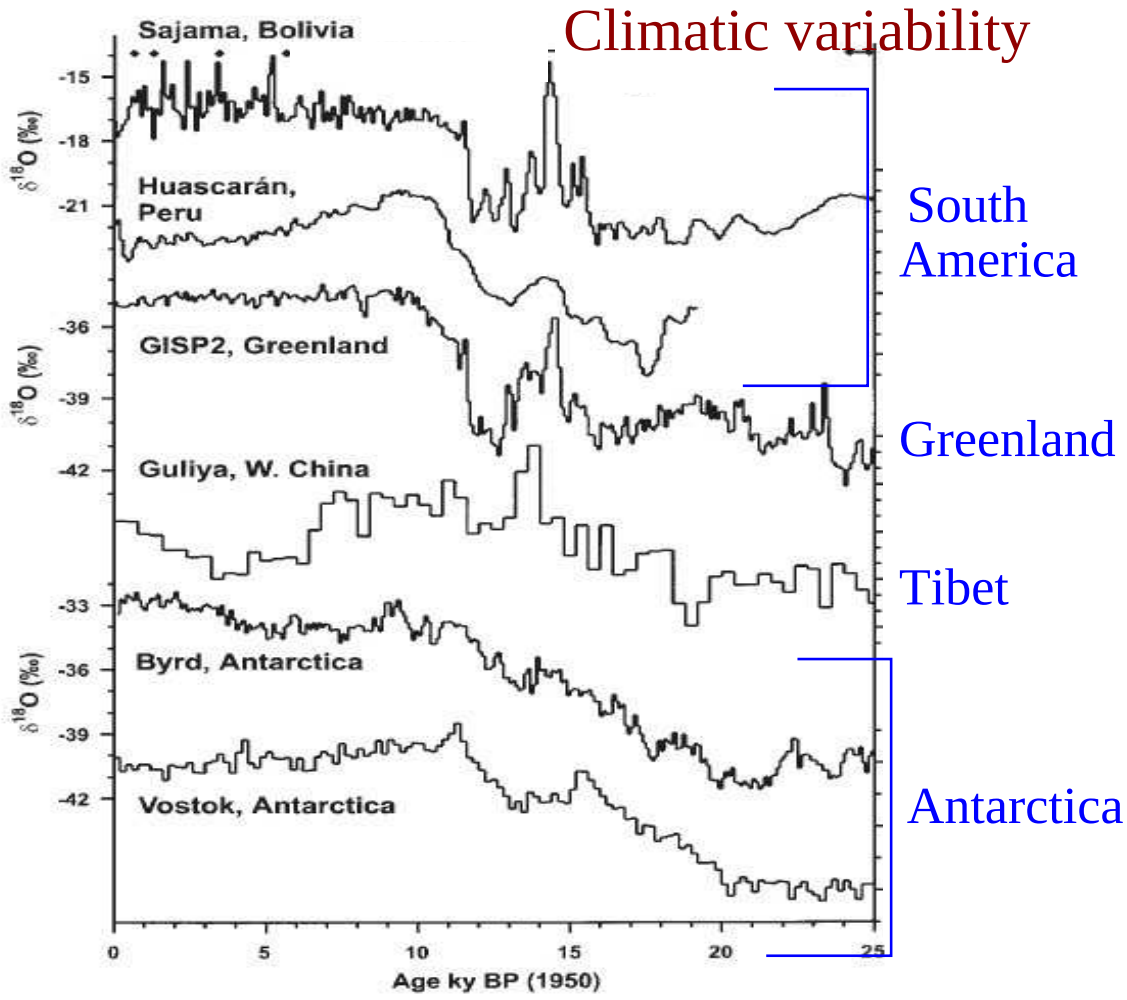



- Compositions sensitive to:
  - isotopic profiles in the soil, vertical diffusivity
  - rain inflitration
  - evaporation/transpiration partitioning
  - runoff and runoff/drainage partitioning
- Potential of water isotopes to better constrain processes in the land surface and their representation in models?

# 3. Water isotopes and climate variability

- What do isotopic archives record in the Tropics?
  - Effect of temperature or precipitation variations?



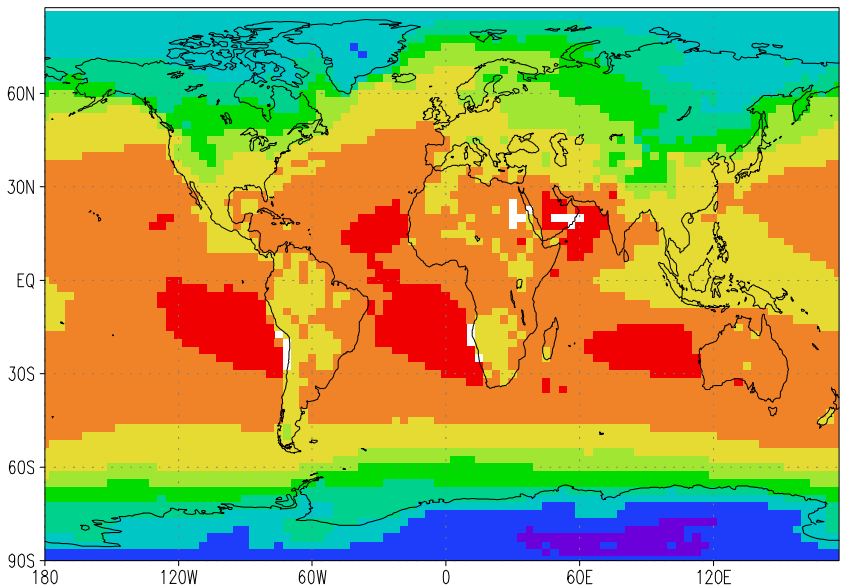

*Thompson et al 2000*

- **Tool**: water enabled LMDZ GCM

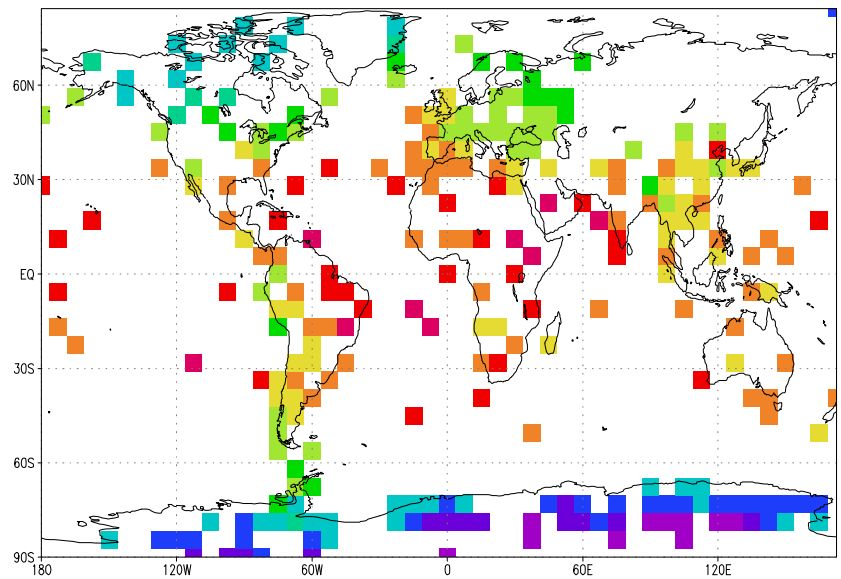
# Evaluation of LMDZ $\delta^{18}O$ in precipitation

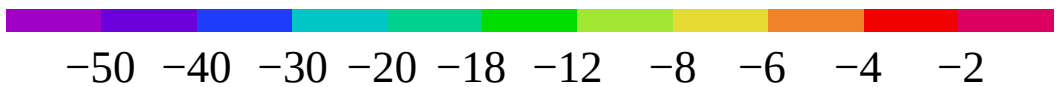
- Simulation 1979-2007 forced by observed SST and nudged by reanalyses

$\delta^{18}O$ (‰) LMDZ



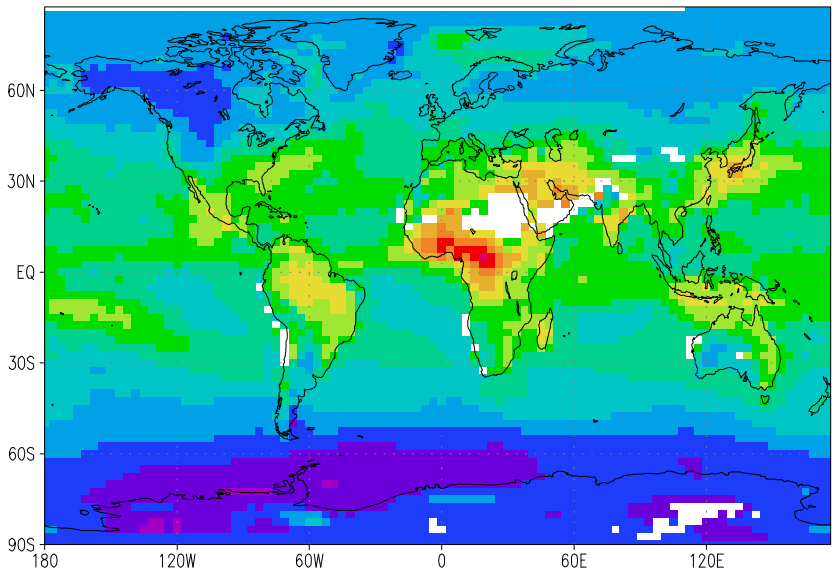

$\delta^{18}O$ (‰) observations



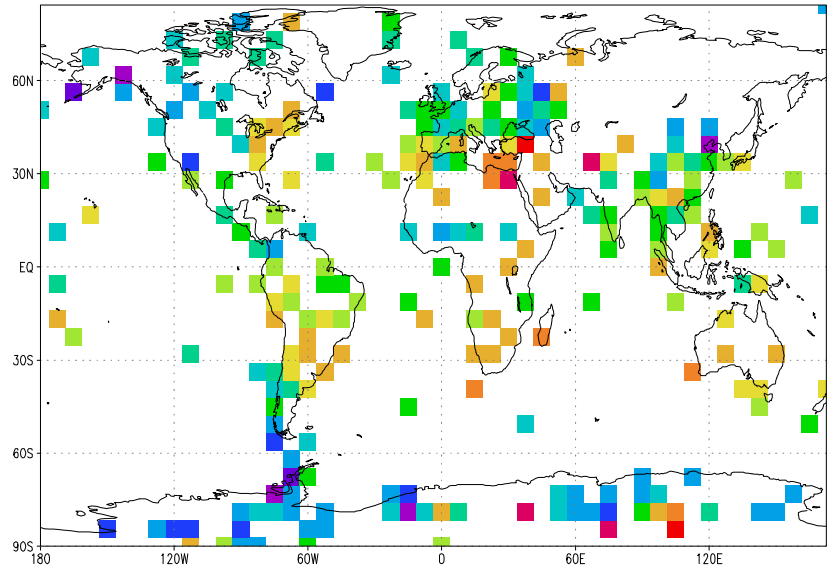



# Evaluation of LMDZ d-excess in precipitation

d-excess (‰) LMDZ



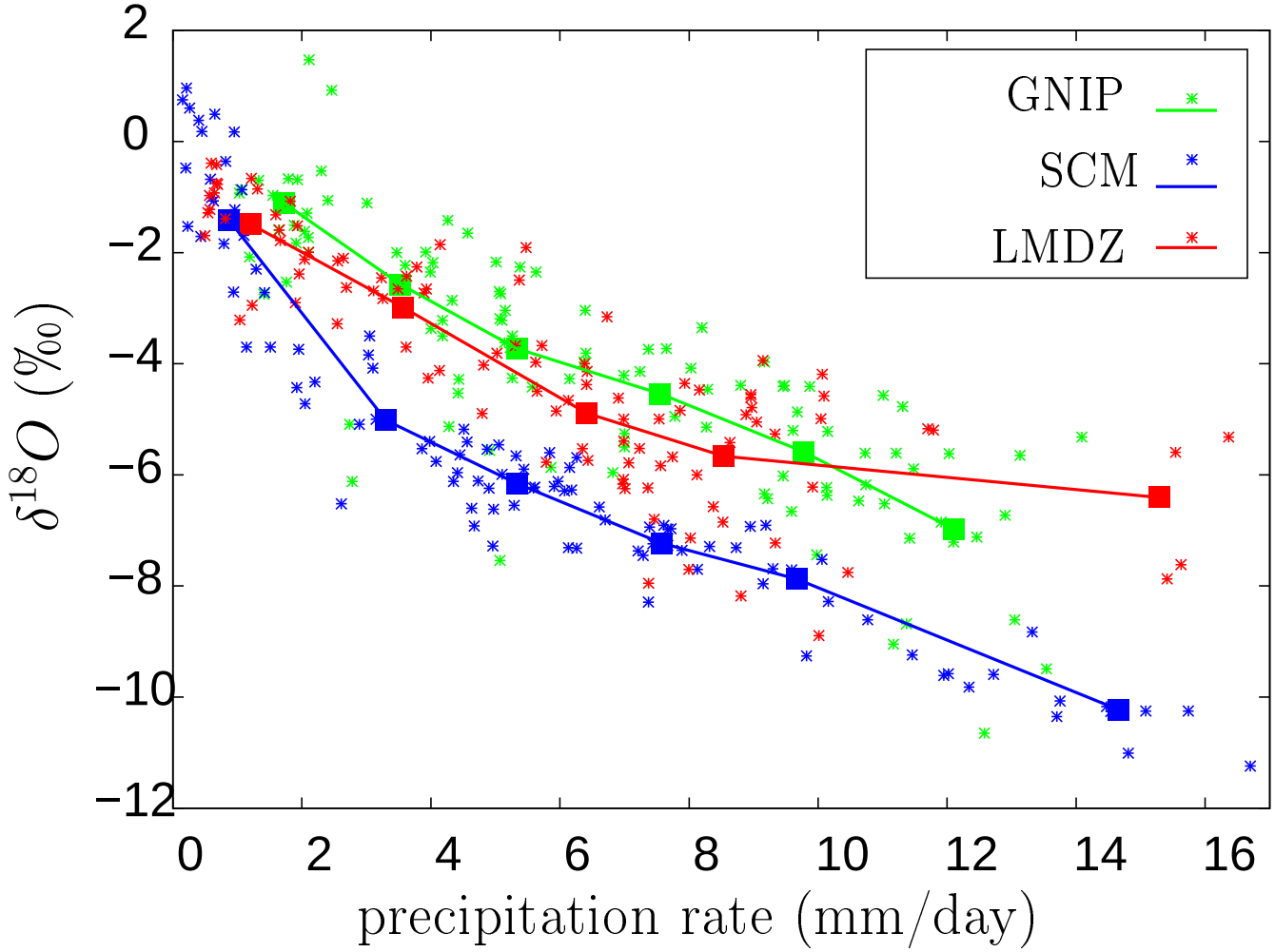

d-excess (‰) observations




0 2 4 6 8 9 10 11 12 14 16 18

- effect of neglecting bare soil evaporation on d-excess over continents?

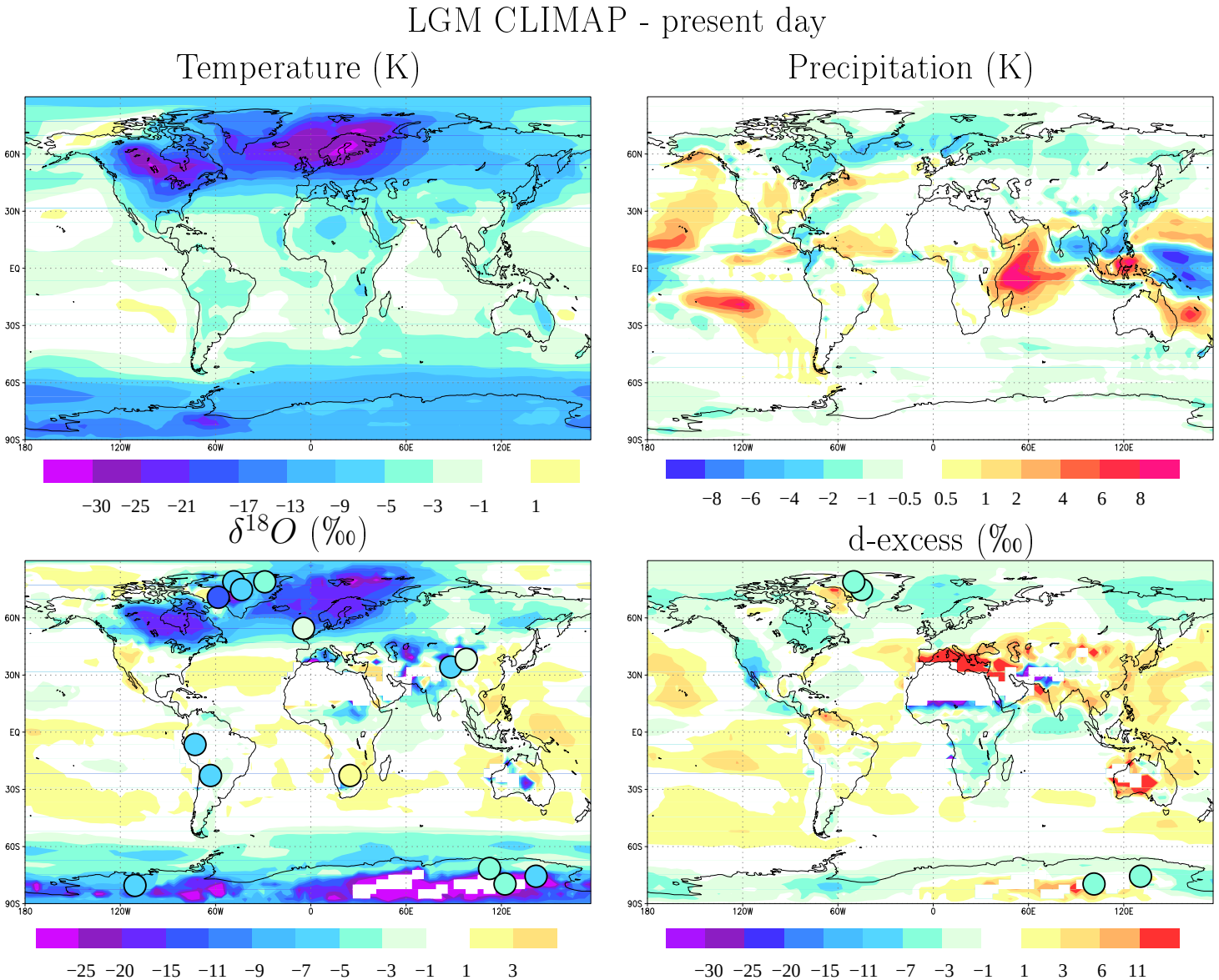
# Evaluation of the amount effect



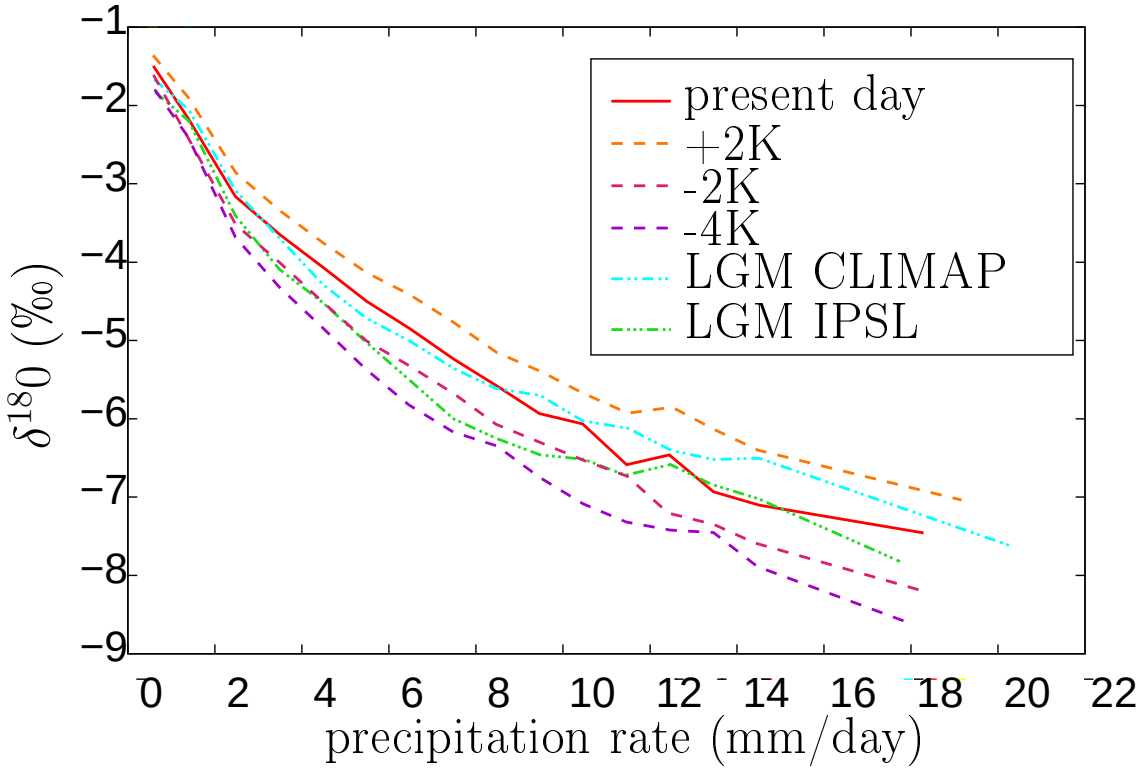

- horizontal advections dampen the amount effect

# Past climates: LGM

## CLIMAP SSTs



# What controls isotopic variations in the Tropics?



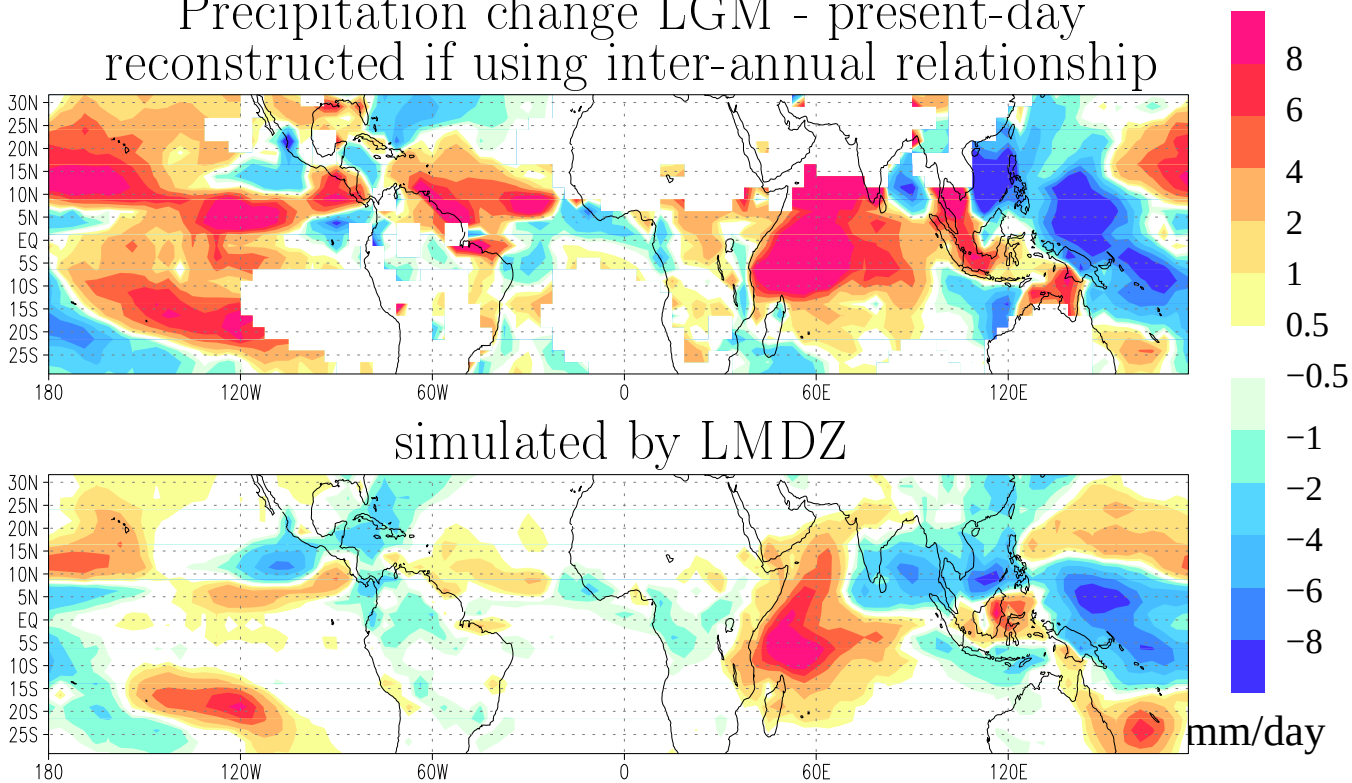

- At first order, amount effect dominant
- At second order, colder average tropical temperatures shifts the $\delta^{18}O$ distribution to more depleted values by 0.1‰/K

# Are isotopic archives a good record of precipitation variations?

- "perfect model" experiment

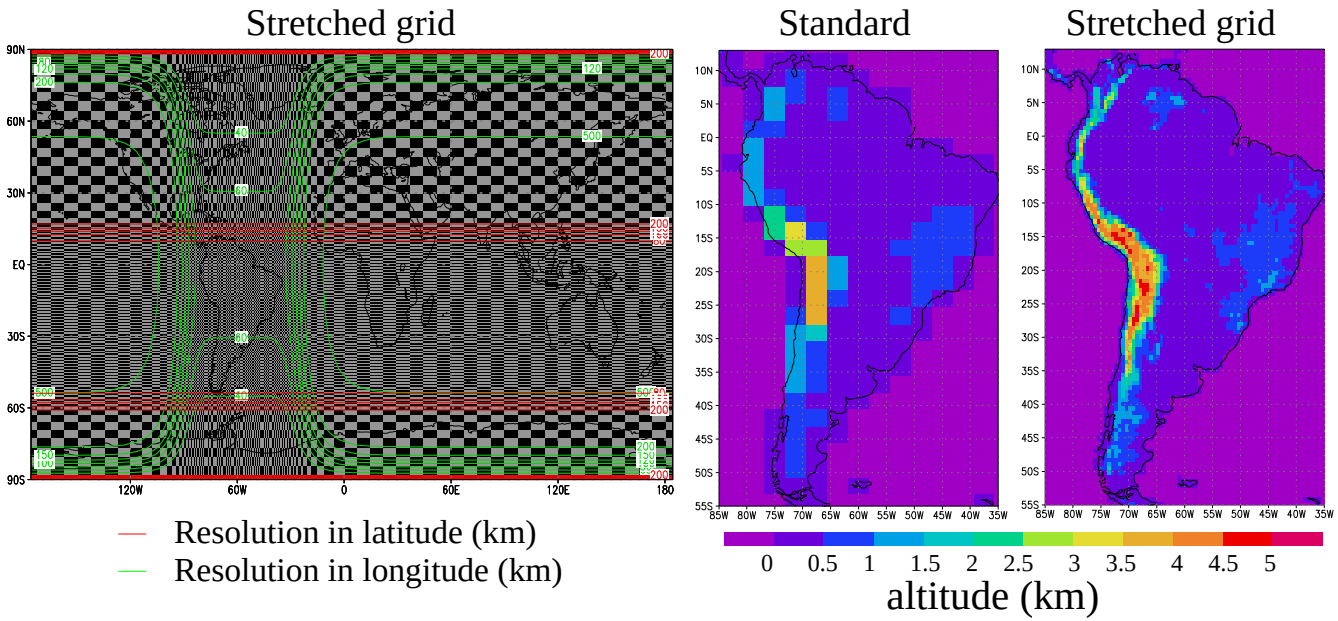
simulated LGM change in $\delta^{18}O_p$

present-day P-$\delta^{18}O_p$ at the inter-annual scale simulated during 1979-2007



# Perspectives on climate variability

- **Regional modelling** over montain regions (zoom)
  - South America
  - Tibet




- Inter-annual and decdal variability, trends
  - simulation forced by observed SST and **nudged by reanalysis**
    $\Rightarrow$ good inter-annual variability

# General conclusion and perspectives

- **Conclusion**
  - different isotopic composition of fluxes in atmosphere and land surface $\Rightarrow$ additional information from isotopes
  - combination of processes, isotopic composition changes with climate $\Rightarrow$ paleoclimatic implications
- **Perspectives**
  - Potential of isotopes to constrain continental recycling? How much and by which processes (evaporation/transpiration)
  - controls of atmospheric humidity? impact of precipitation evaporation? Large-scale motion?
- **Tools**
  - LMDZ-ORCHIDEE **coupled** simulations
  - **water tagging** $\Rightarrow$ tagging of different evaporative source (ocean/continent/precipitation, vapor maximum altitude...)
  - **regional simulations**: e.g. South America, West Africa (AMMA)