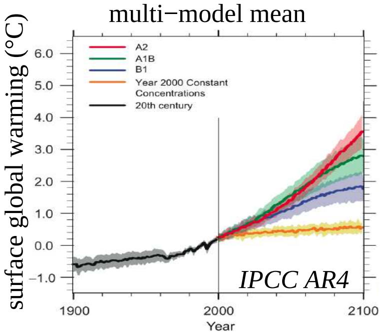
The added value of tropospheric water vapor isotopic measurements for evaluation cloud and precipitation processes in climate models

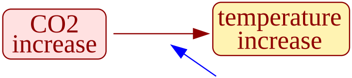
Camille Risi

LMD/IPSL/CNRS

Seminar at ITP-CAS, April 2013

Inter-model spread in climate projections



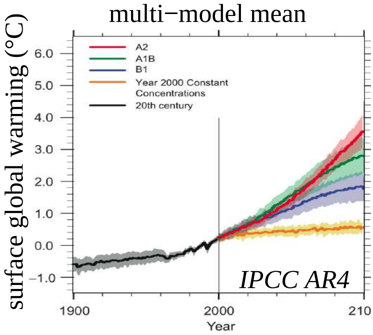


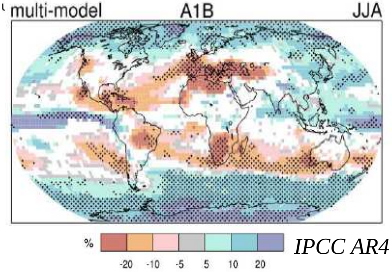
Sources of model spread:

atmospheric feedbacks especially clouds

- atmospheric convection
- boundary layer
- relative humidity

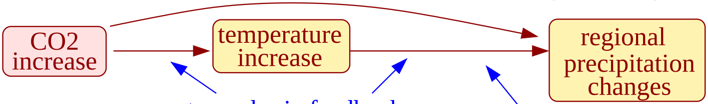
Inter-model spread in climate projections





precipitation change by 2100 (%)

☐ <2/3 agree on sign



Sources of model spread:

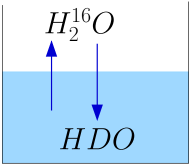
atmospheric feedbacks especially clouds

- atmospheric convection
- boundary layer
- relative humidity

land−surface feedbacks

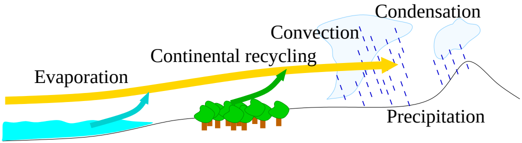
Water isotopic composition

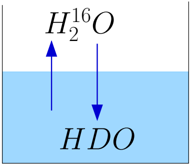
- $H_2^{16}O$, HDO, $H_2^{18}O$, $H_2^{17}O$, fractionation



Water isotopic composition

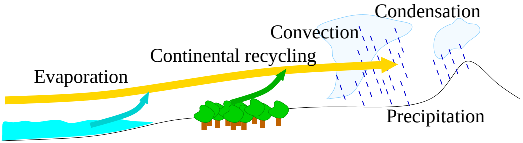
- $H_2^{16}O$, HDO, $H_2^{18}O$, $H_2^{17}O$, fractionation
- records phase changes

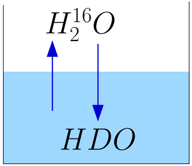


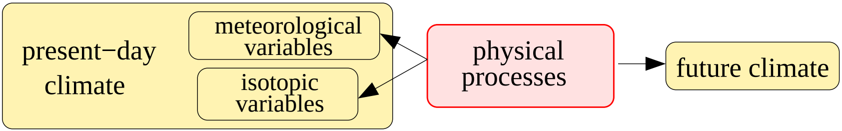


Water isotopic composition

- $H_2^{16}O$, HDO, $H_2^{18}O$, $H_2^{17}O$, fractionation
- records phase changes

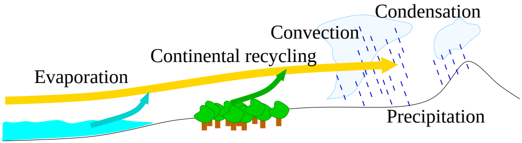


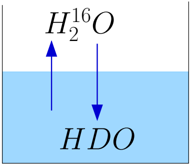


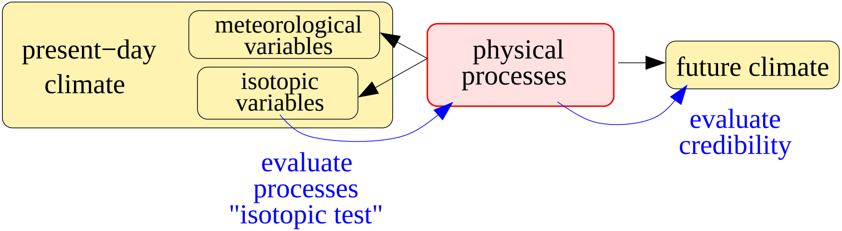


Water isotopic composition

- $H_2^{16}O$, HDO, $H_2^{18}O$, $H_2^{17}O$, fractionation
- records phase changes

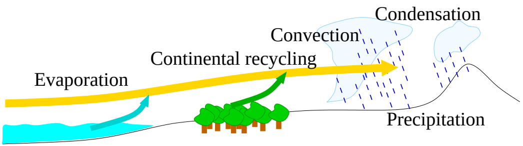


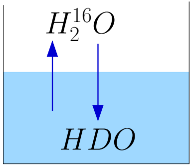


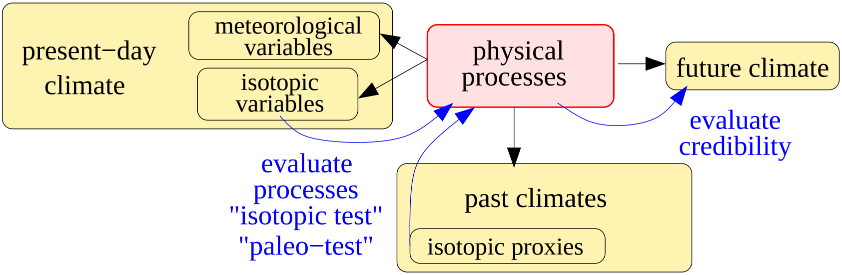


Water isotopic composition

- $H_2^{16}O$, HDO, $H_2^{18}O$, $H_2^{17}O$, fractionation
- records phase changes







Overview of my activities

1. evaluation of atmospheric processes
   - processes controlling humidity
   - atmospheric deep convection

Overview of my activities

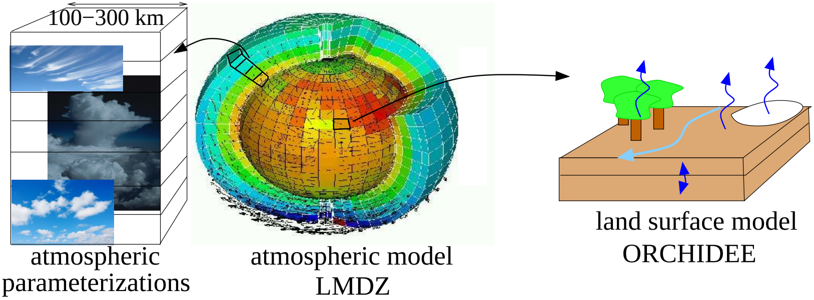
1. evaluation of atmospheric processes
   - processes controlling humidity
   - atmospheric deep convection
2. evaluation of land surface processes
   - partitionning of water fluxes at land surface
   - land-atmosphere feedbacks, continental recycling

Overview of my activities

1. evaluation of atmospheric processes
   - processes controlling humidity
   - atmospheric deep convection
2. evaluation of land surface processes
   - partitionning of water fluxes at land surface
   - land-atmosphere feedbacks, continental recycling
3. evaluation of tropical precipitation changes
   - what do tropical water isotopic proxies record
   - link between past and future behavior (CMIP5)

LMDZ and ORCHIDEE models

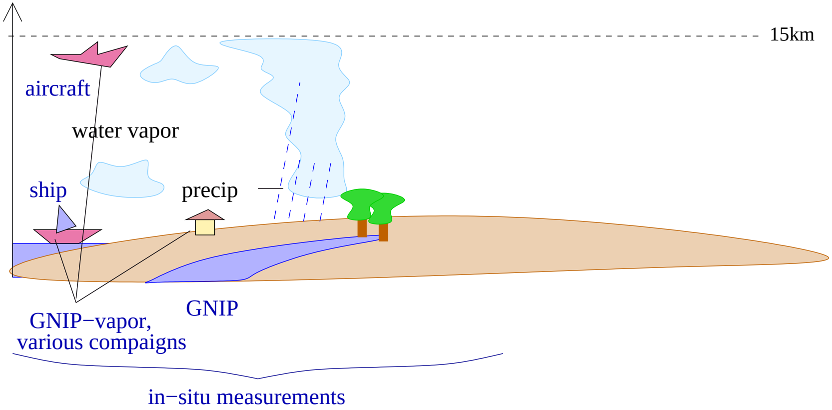
- components of IPSL climate model



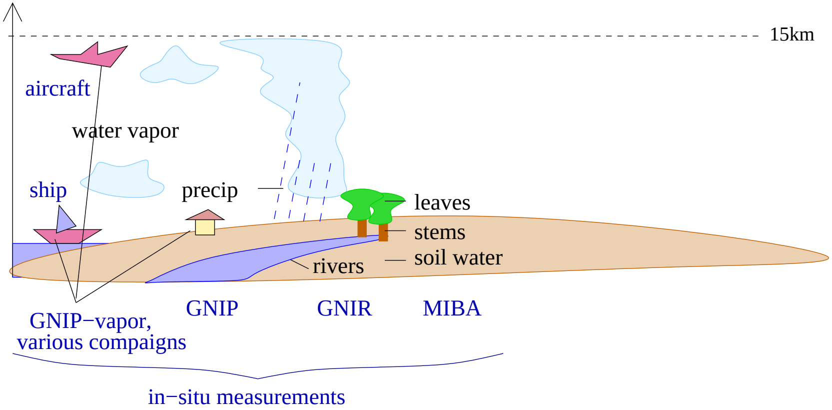
- isotope-enabled (*Risi et al 2010a*) + water tagging
- nudging capability $\Longrightarrow$ realistic dynamical context
- zoom capability down to 30km

- isotope-enabled + water tagging

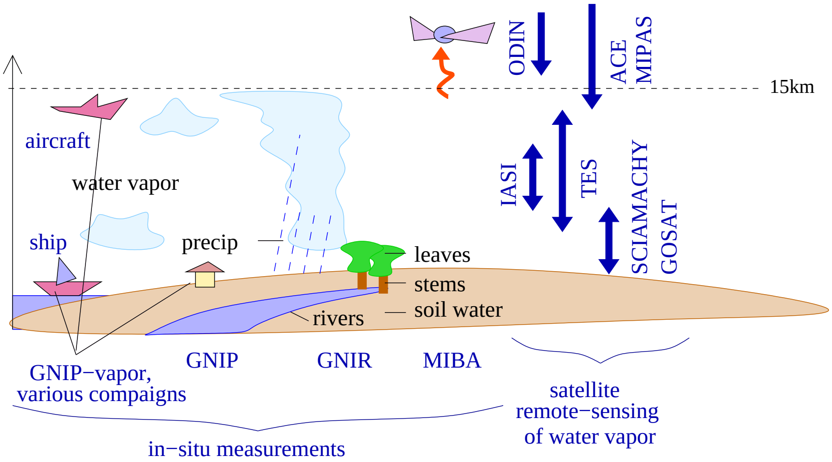
Available measurements



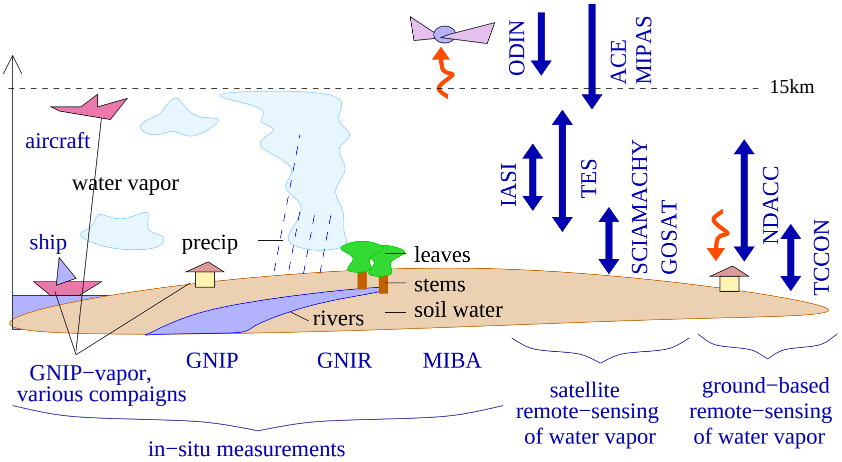
Available measurements



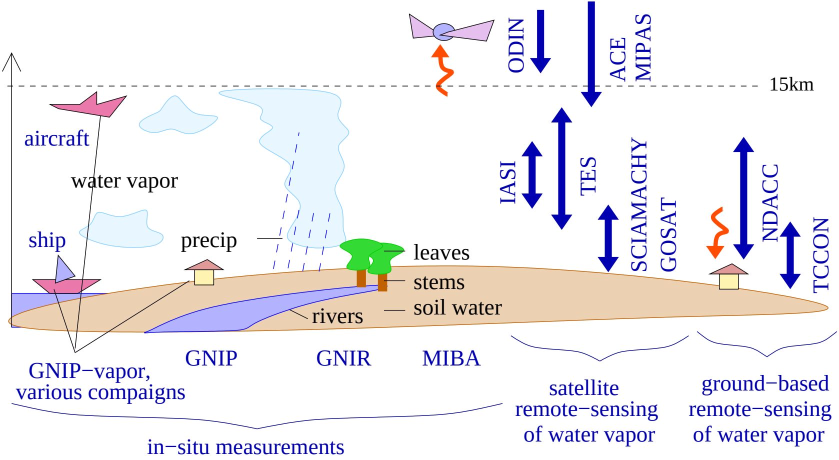
Available measurements



Available measurements

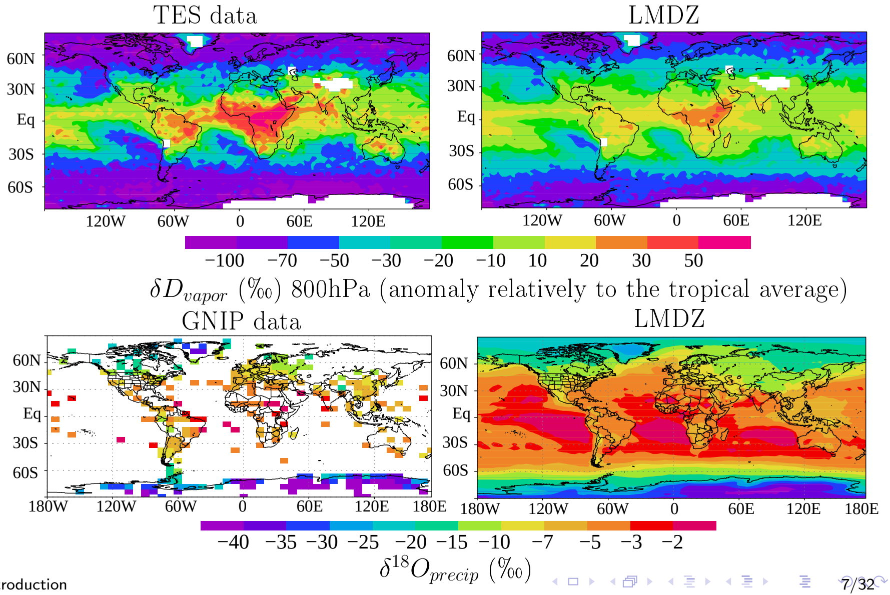


Available measurements

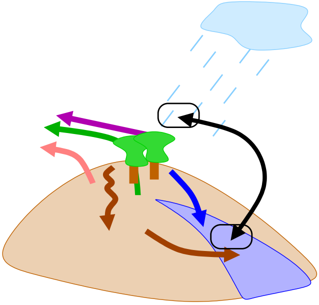


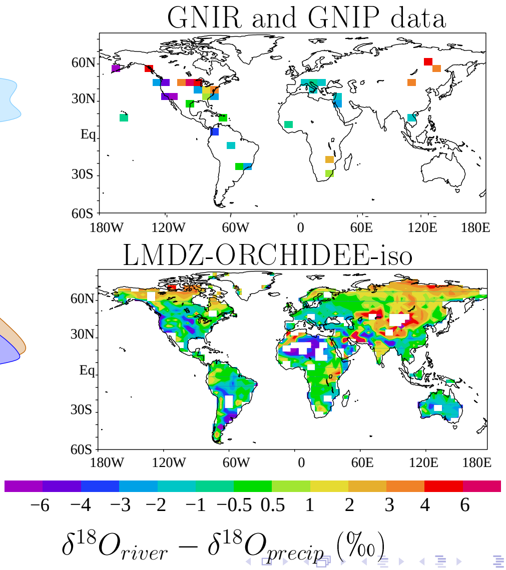
- for remote-sensing : focus on spatio-temporal variations
- account for sampling and instrument sensitivity

Evaluation of LMDZ water vapor and precip



Evaluation of LMDZ-ORCHIDEE precipitation and rivers



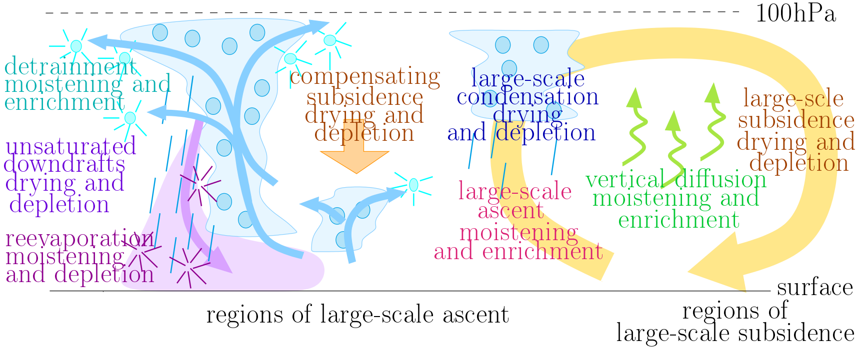


I) Using water vapor measurements to evaluate atmospheric processes

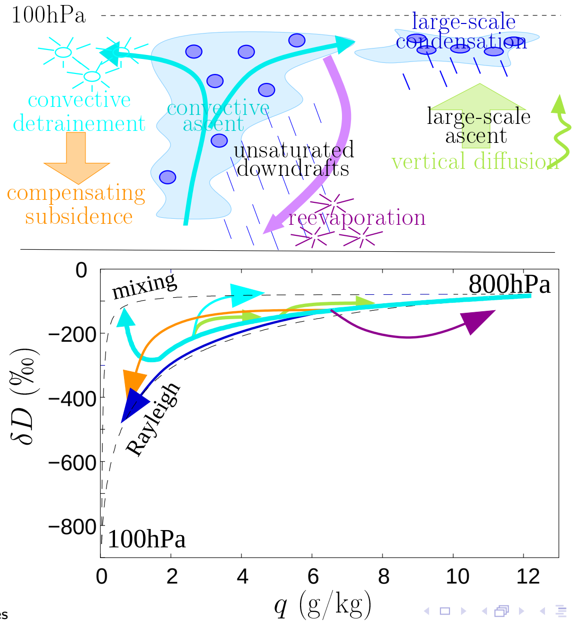
- what controls the water vapor composition
- 2 examples

Processes controlling isotopic composition

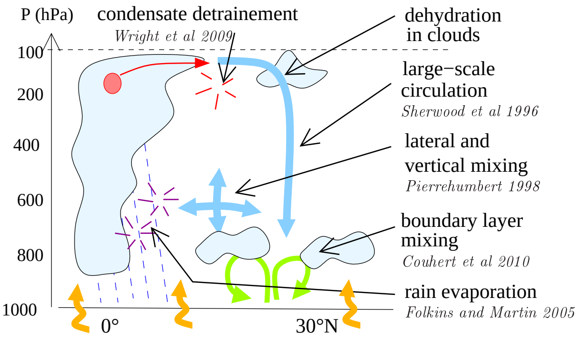
- observational studies (Risi et al 2008b), in particular at intra-event time scales (Risi et al 2010c, Tremoy et al 2012)
- modeling studies (Risi et al 2008, 2010b, 2012b)



q-δD complementarity



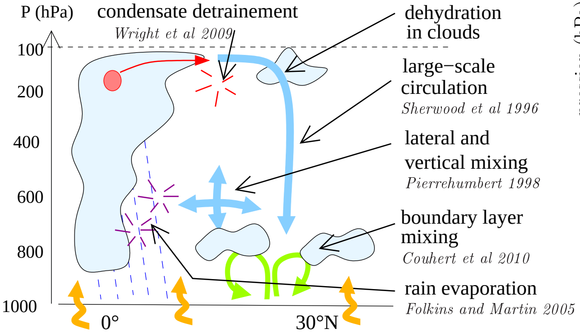
1) Processes controlling humidity

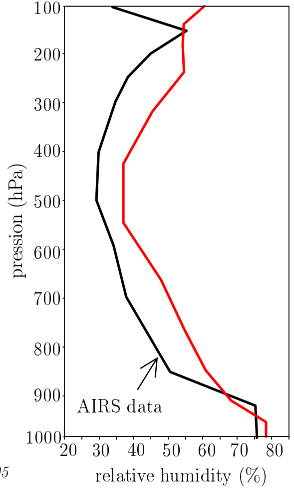


1) Processes controlling humidity

LMDZ−iso (Risi et al 2010a):

— control: AR4 version (19 levels)



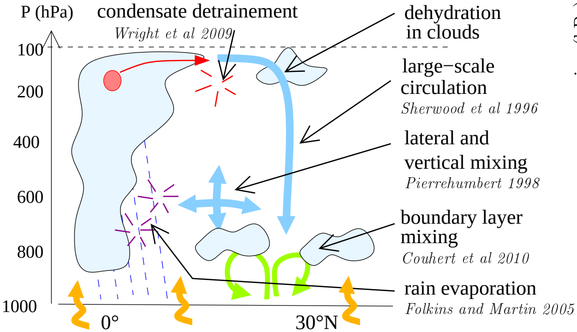


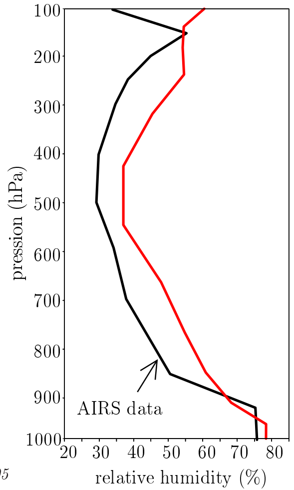
1) Processes controlling humidity

LMDZ−iso (Risi et al 2010a):

control: AR4 version (19 levels)

3 reasons for a moist bias





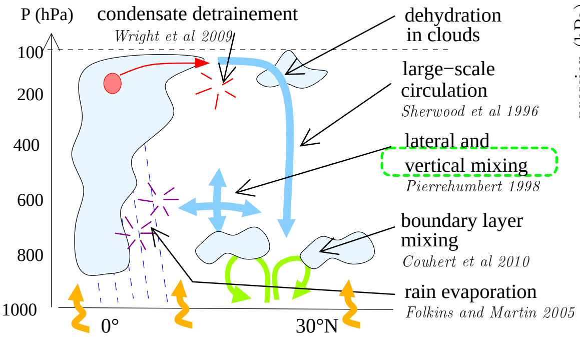
1) Processes controlling humidity

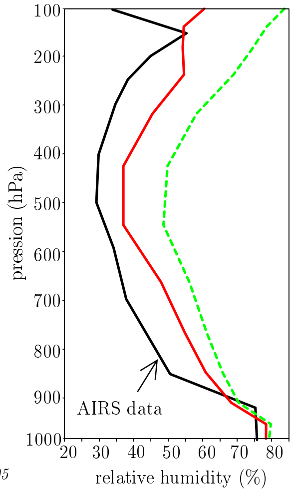
LMDZ−iso (Risi et al 2010a):

control: AR4 version (19 levels)

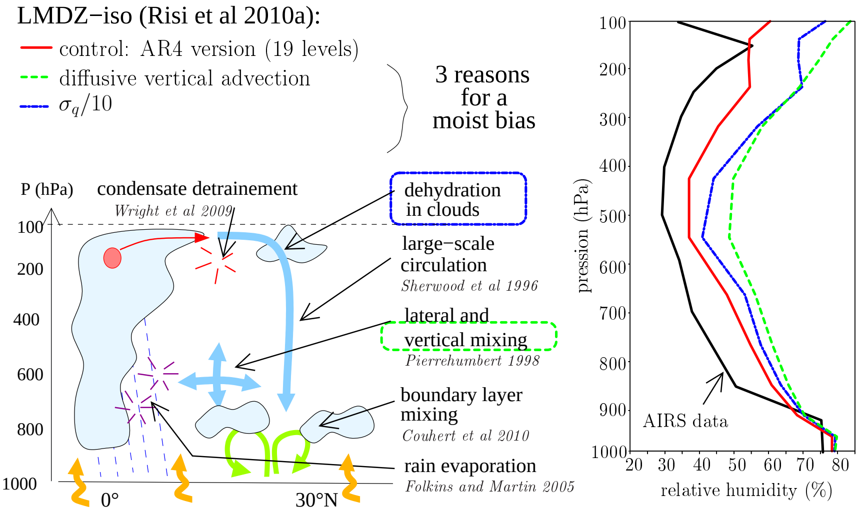
diffusive vertical advection

3 reasons for a moist bias

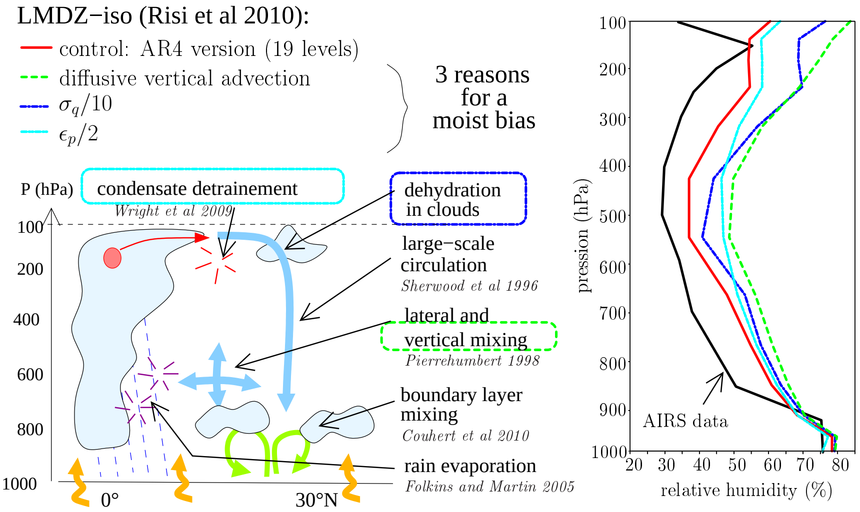




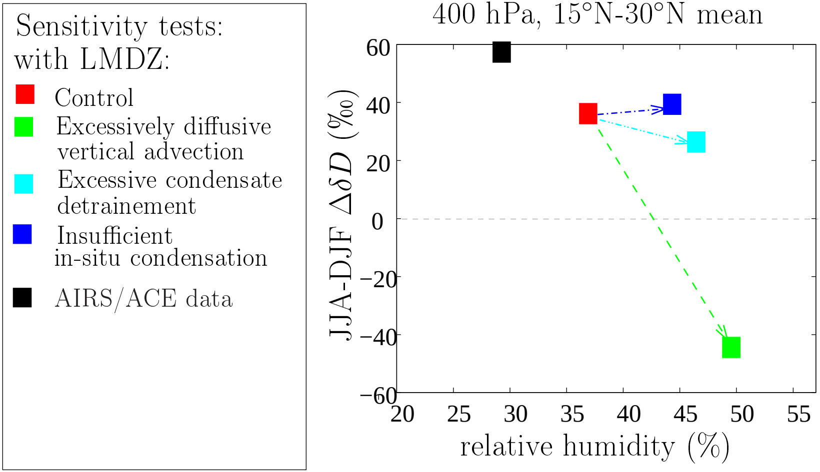
1) Processes controlling humidity



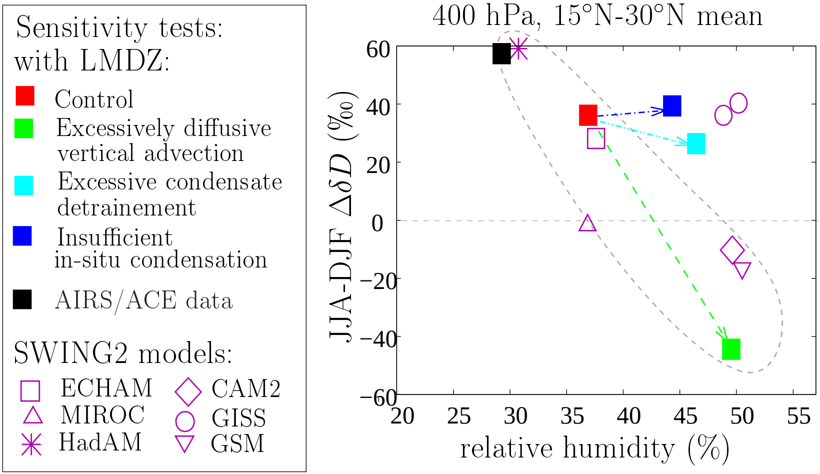
1) Processes controlling humidity



What causes the moist biases in GCMs ?

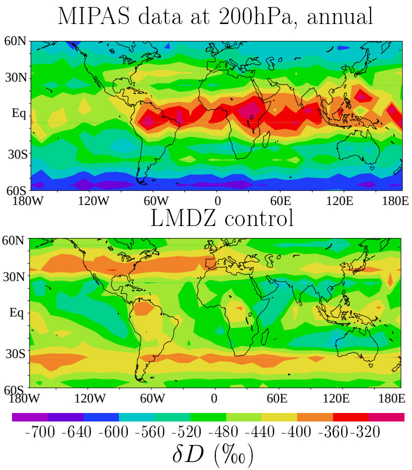


What causes the moist biases in GCMs ?

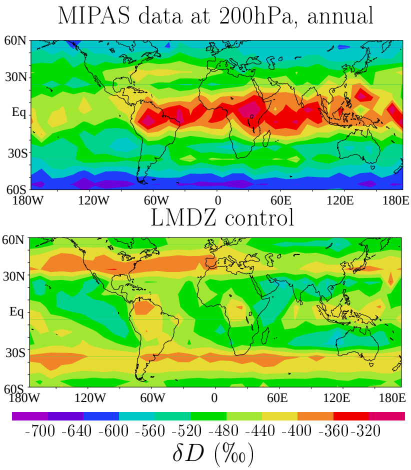


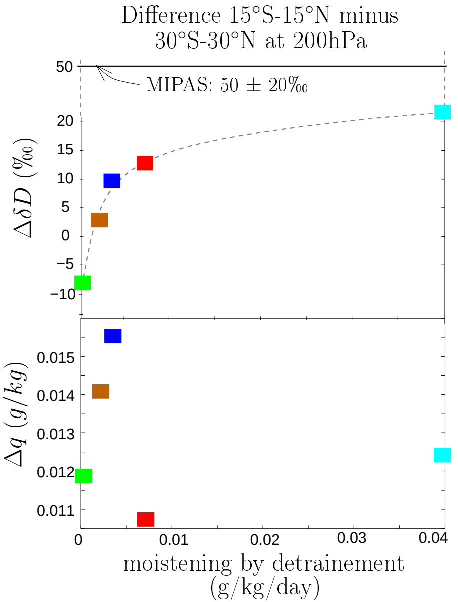
- frequent reason for moist bias=excessively diffusive advection

2) Upper tropospheric convective moistening



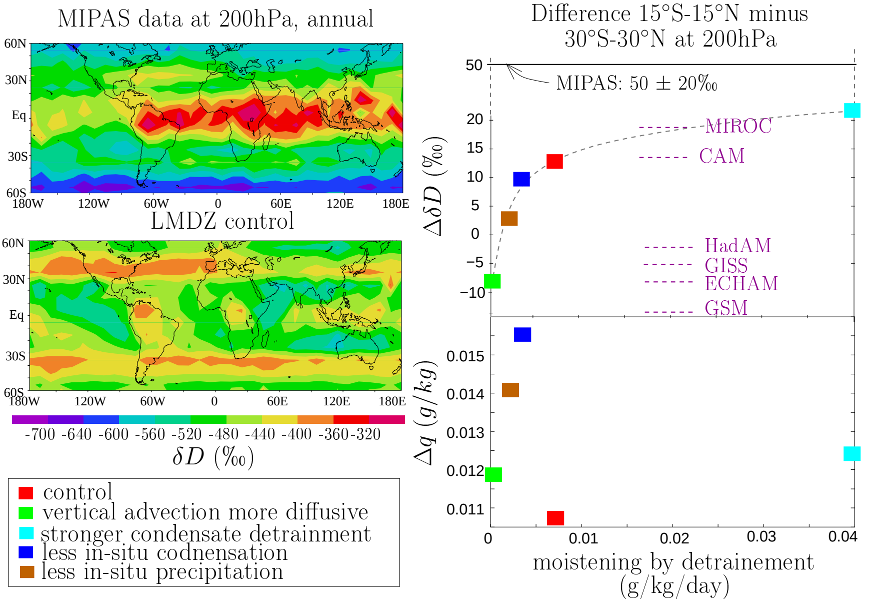
2) Upper tropospheric convective moistening





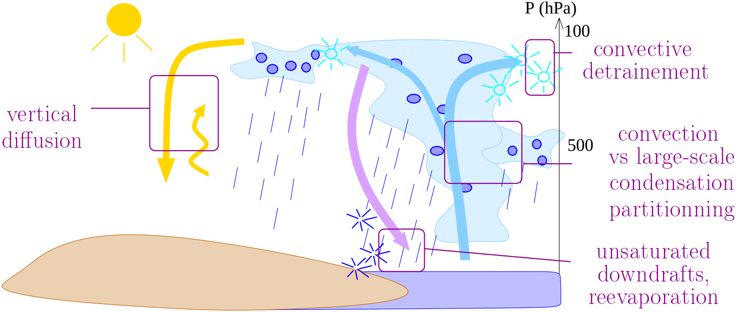
- control
- vertical advection more diffusive
- stronger condensate detrainment
- less in-situ codnensation
- less in-situ precipitation

2) Upper tropospheric convective moistening



Conclusion on atmospheric processes

- Potential of isotopic measurements to evaluate a broad range of processes in atmospheric models



Perspectives on atmospheric processes

- Combine q, δD + cloud $\Rightarrow$ better constrain large-scale precip

Perspectives on atmospheric processes

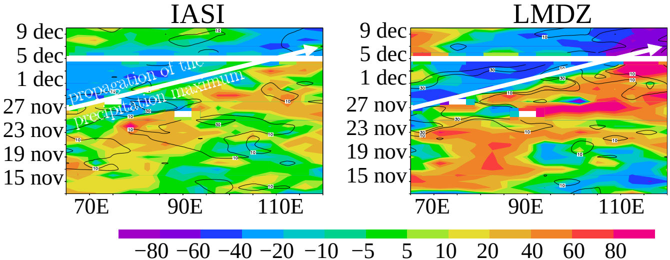
- Combine q, δD + cloud $\Rightarrow$ better constrain large-scale precip
- Combine q, δD + chemical tracers : CO, O_3, ^{10}Be $\Rightarrow$ better characterize fluxes

Perspectives on atmospheric processes

- Combine q, δD + cloud $\Rightarrow$ better constrain large-scale precip
- Combine q, δD + chemical tracers : CO, O_3, ^{10}Be $\Rightarrow$ better characterize fluxes
- MJO project : cause of models' difficulties ? $\Rightarrow$ Relate MJO biases to specific problems in parameterizations, isotopes as additional diagnostic.

Perspectives on atmospheric processes

- Combine q, δD + cloud $\Rightarrow$ better constrain large-scale precip
- Combine q, δD + chemical tracers : CO, O_3, ^{10}Be $\Rightarrow$ better characterize fluxes
- MJO project : cause of models' difficulties ? $\Rightarrow$ Relate MJO biases to specific problems in parameterizations, isotopes as additional diagnostic.
- IASI data : daily global coverage $\Rightarrow$convective organization, life cycle

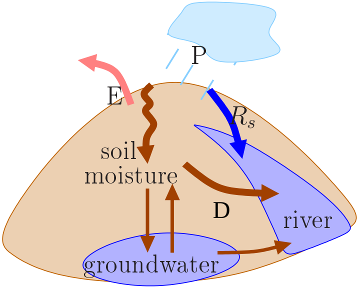


colors: δD anomaly (‰)
contours: q anomalies (%)

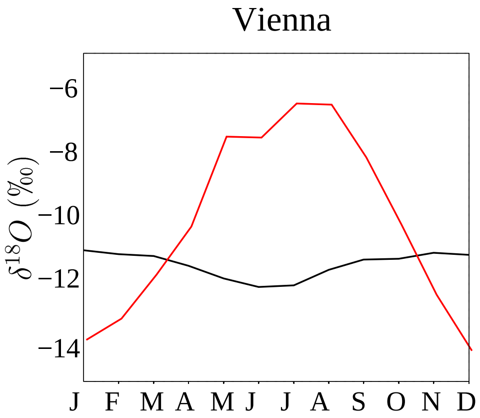
II) Using river water and water vapor measurements to evaluate land surface processes

- 2 examples

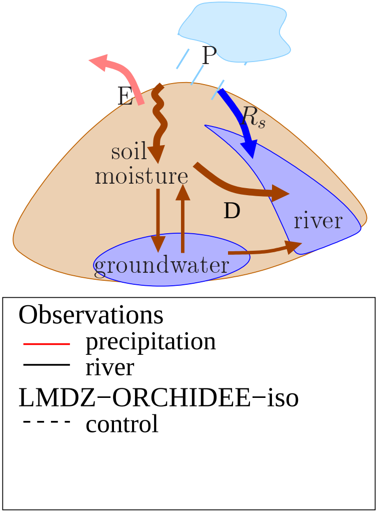
1) Pathways from precipitation to rivers

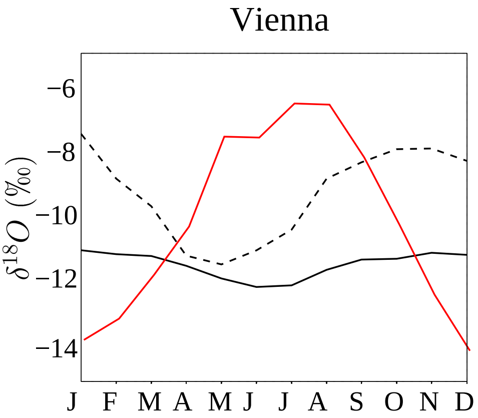


Observations
precipitation
river

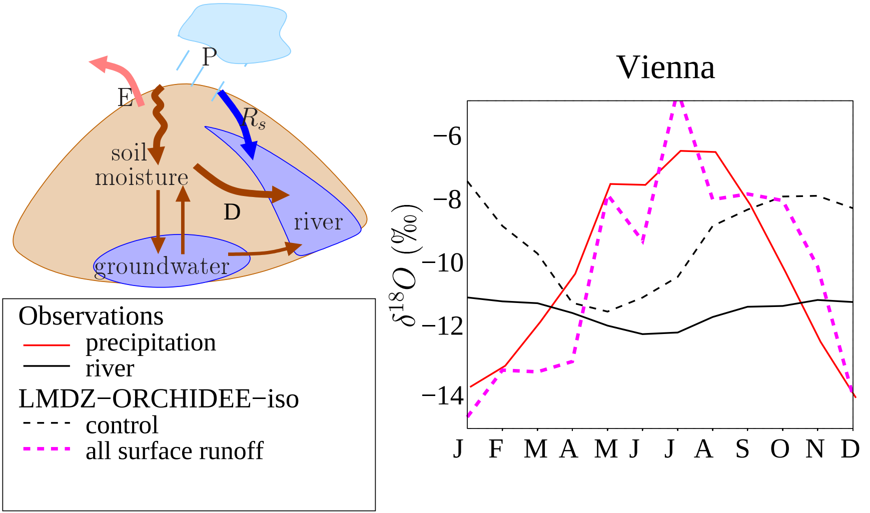


1) Pathways from precipitation to rivers

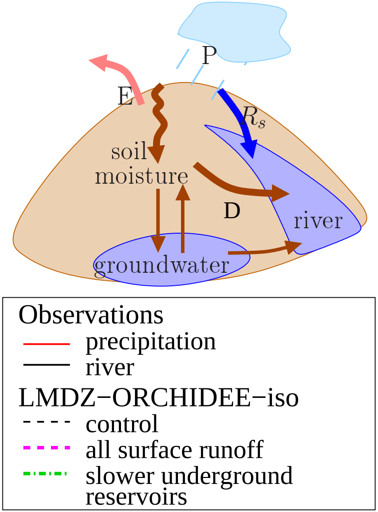


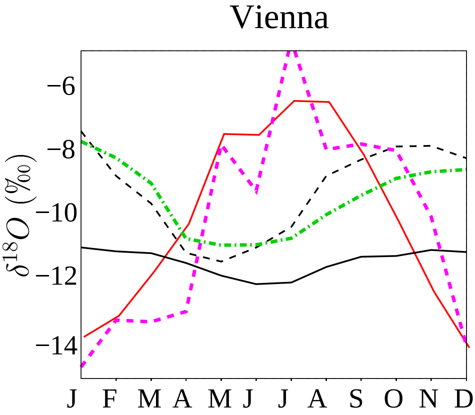


1) Pathways from precipitation to rivers



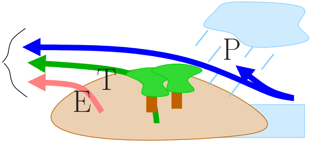
1) Pathways from precipitation to rivers





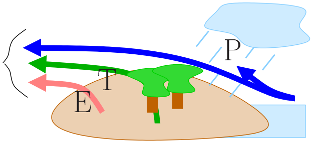
2) Continental recycling

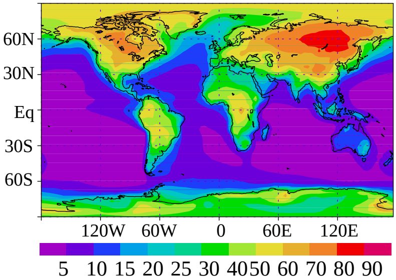
Water tagging:



2) Continental recycling

Water tagging:

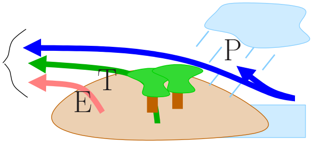


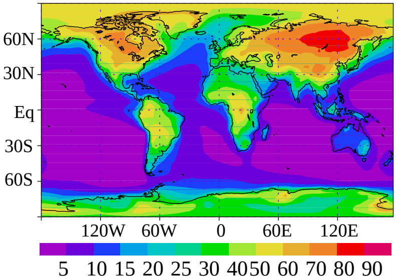


% vapor from continental evapo-transpiration (r_{con})

2) Continental recycling

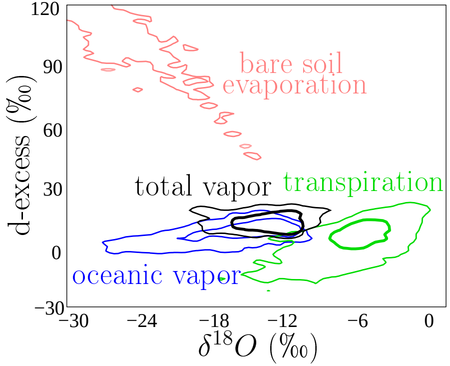
Water tagging:



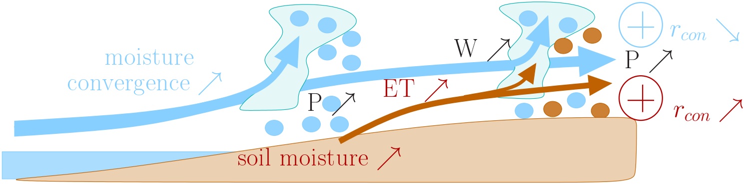


% vapor from continental evapo-transpiration (r_{con})

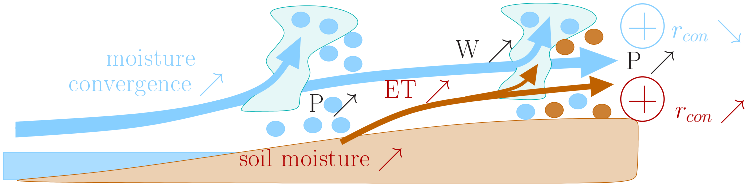
PDF of vapor composition monthly, all tropical land points

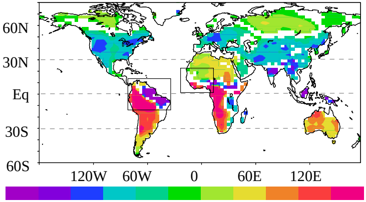


Continental recycling feedbacks



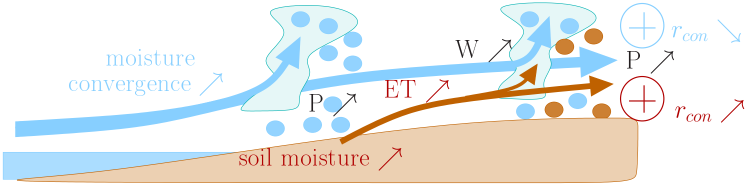
Continental recycling feedbacks

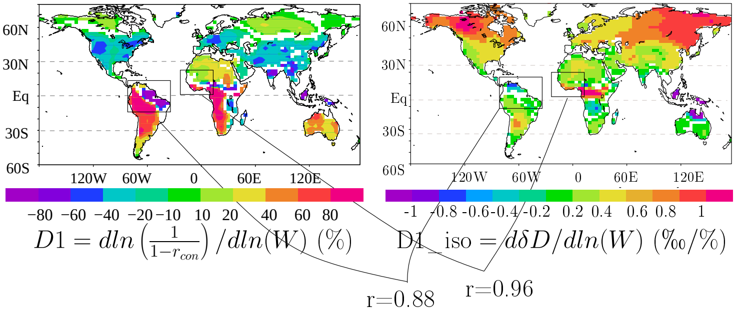




$$D1 = dln\left(\frac{1}{1-r_{con}}\right)/dln(W)\ (\%)$$

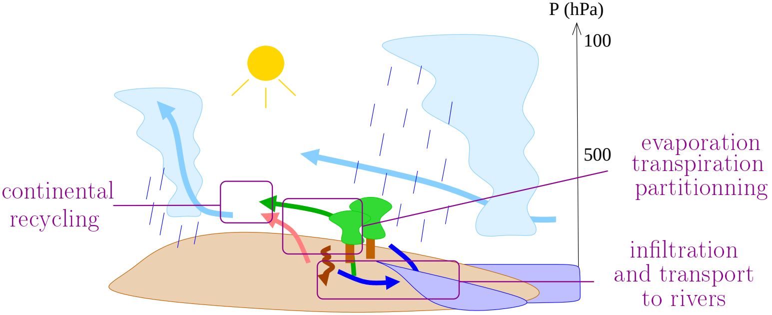
Continental recycling feedbacks





- use D1_iso to evaluate role of cont recycling

Conclusion on land surface processes

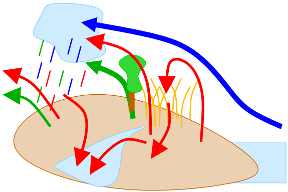


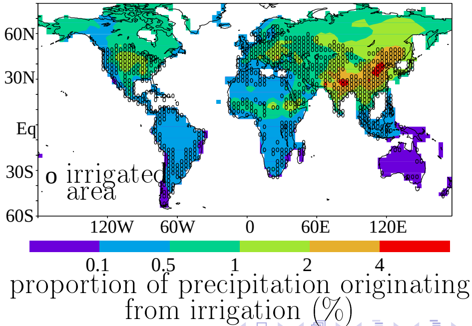
Perspectives on land surface

- isotopes in 11-layer hydrology of ORCHIDEE $\Rightarrow$ better simulation of soil profiles, more physical runoff-drainage partitioning
- use d-excess signal in the vapor to constrain evaporation/transpiration partitioning ?
- link between present-day representation of the water cycle and simulated hydrological response to climate changes

Perspectives on land surface

- isotopes in 11-layer hydrology of ORCHIDEE ⇒ better simulation of soil profiles, more physical runoff-drainage partitioning
- use d-excess signal in the vapor to constrain evaporation/transpiration partitioning ?
- link between present-day representation of the water cycle and simulated hydrological response to climate changes
- irrigation changes using water tagging



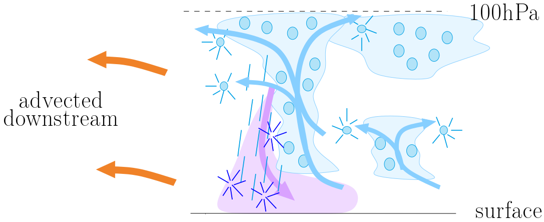


III) What does tropical $\delta^{18}O_p$ record?

- Based on new understanding, revisit interpretation of $\delta^{18}O$ records? And can we use these records to evaluate models' capacity to simulate climate changes?

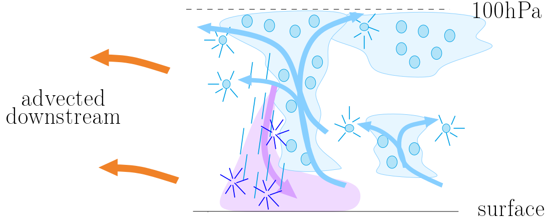
III) What does tropical $\delta^{18}O_p$ record ?

- Based on new understanding, revisit interpretation of $\delta^{18}O$ records ? And can we use these records to evaluate models' capacity to simulate climate changes ?
- Interpretations in the litterature :
  - Thompson et al 2000 $\rightarrow$ proxy for temperature
  - Vuille et al 2005, Pausata et al 2011 $\rightarrow$ proxy for monsoon intensity, upstream precipitation



III) What does tropical $\delta^{18}O_p$ record ?

- Based on new understanding, revisit interpretation of $\delta^{18}O$ records ? And can we use these records to evaluate models' capacity to simulate climate changes ?
- Interpretations in the litterature :
  - Thompson et al 2000 $\rightarrow$ proxy for temperature
  - Vuille et al 2005, Pausata et al 2011 $\rightarrow$ proxy for monsoon intensity, upstream precipitation



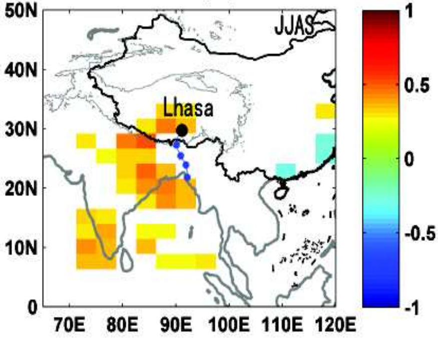
$\Longrightarrow$ process studies at the daily time scale (*Gao et al 2011, submitted*) using precip data

But missing link : vapor ?

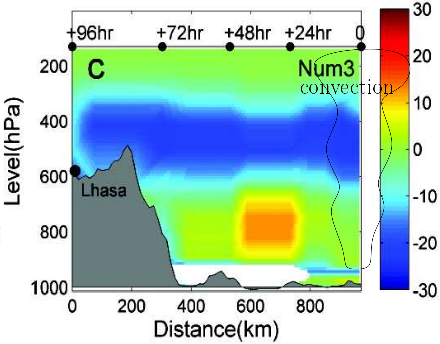
Process study using satellite observations

- He You's PhD thesis : use of TES data

daily correlation between δD at 400hPa at Lhassa and OLR around in JJAS



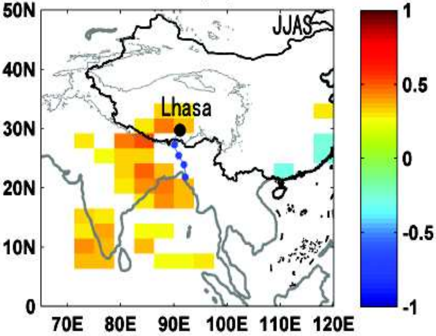
δD composite anomalies (‰) along trajectories to Lhassa when OLR is low 4 days before



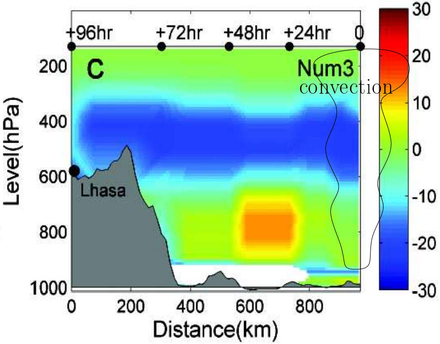
Process study using satellite observations

- He You's PhD thesis : use of TES data

daily correlation between δD at 400hPa at Lhassa and OLR around in JJAS



δD composite anomalies (‰) along trajectories to Lhassa when OLR is low 4 days before



- convection in India depletes mid-tropospheric vapor
- depleted anomaly is transported downstream to Lhassa

Does this apply to paleo scales ?

Can we use present-day observations to better understand processes controlling paleo $\delta^{18}O$ and evaluate them in models ?
$\Longrightarrow$ modelling study

Does this apply to paleo scales ?

Can we use present-day observations to better understand processes controlling paleo $\delta^{18}O$ and evaluate them in models ?
$\Longrightarrow$modelling study

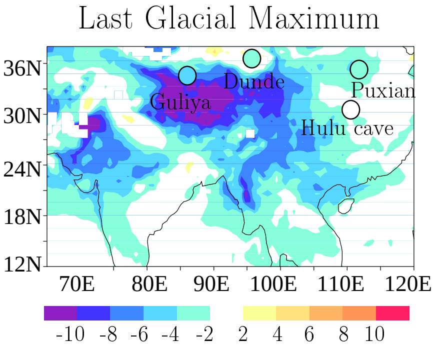
- simulations of 11 different climates : LGM with different SSTs, MH , 2x and 4x CO2 with different SSTs, last interglacial
  - paleo relationships between $\delta^{18}O$ and climate ?

Does this apply to paleo scales ?

Can we use present-day observations to better understand processes controlling paleo $\delta^{18}O$ and evaluate them in models ?
$\Longrightarrow$modelling study

- simulations of 11 different climates : LGM with different SSTs, MH , 2x and 4x CO2 with different SSTs, last interglacial
  - paleo relationships between $\delta^{18}O$ and climate ?
- sensitivity tests to model physics and resolution (including 50km zoom)
  - robustness of simulated relationships ?

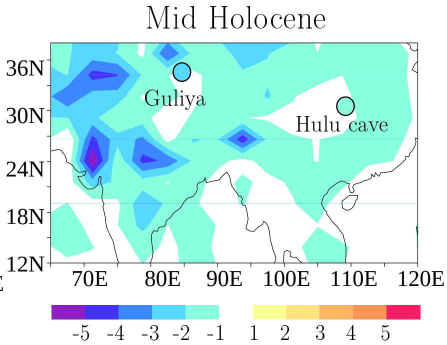
Evaluation for LGM and MH



$\Delta\delta^{18}O$ (‰)

(sea water corrected)

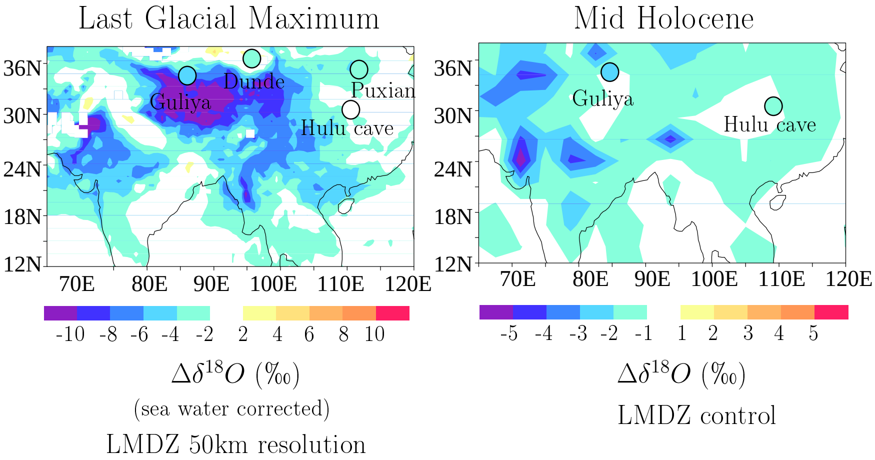
LMDZ 50km resolution



$\Delta\delta^{18}O$ (‰)

LMDZ control

Evaluation for LGM and MH

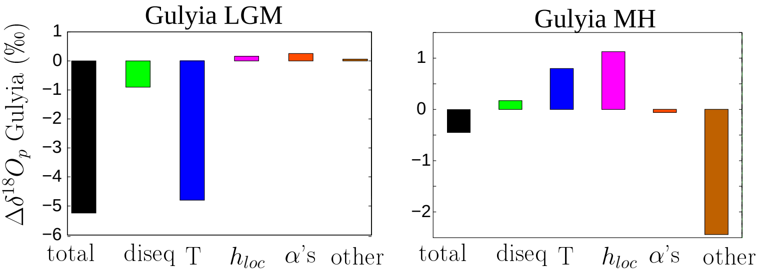


- LMDZ captures LGM and MH observed depletion

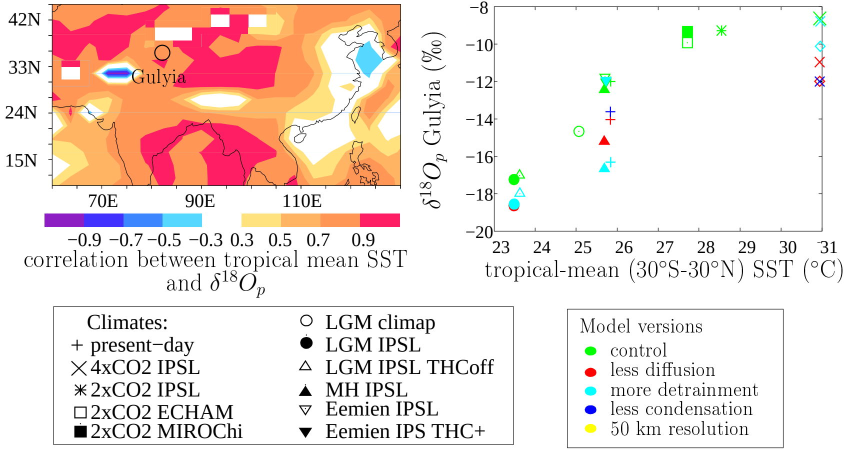
Causes of $\delta^{18}O$ changes ?

$$R_p = R_v + \underbrace{(R_p - \alpha_{loc} \cdot R_v)}_{\text{vap-cond diseq}} + (\alpha_{loc} \cdot R_v - R_v)$$

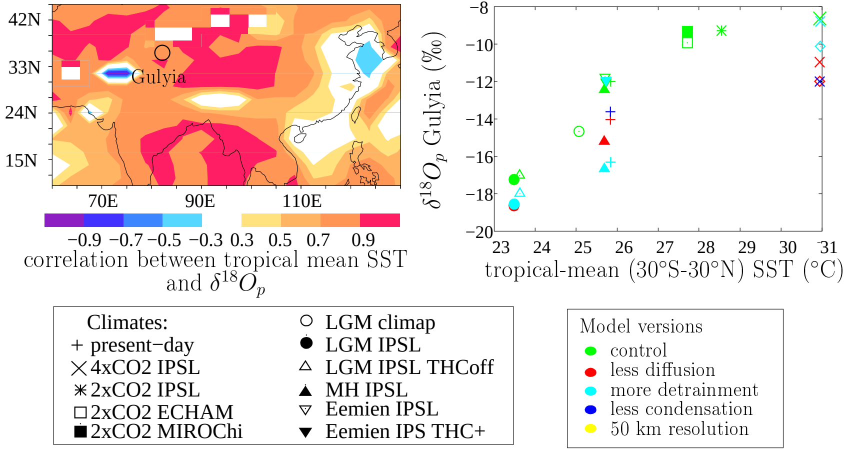
$$R_v = \underbrace{\frac{R_{oce}/\alpha_i}{\alpha_K \cdot (1-h_i)+h_i}}_{\text{initial vapor}} \cdot \underbrace{\left(\frac{h_{loc} \cdot q_s(T_{loc})}{q_s(T_i)}\right)^{\alpha_{loc}-1}}_{\text{distillation}} + \underbrace{\text{residual}}_{\text{e.g. upstream convection}}$$



Is $\delta^{18}O$ a proxy for temperature?

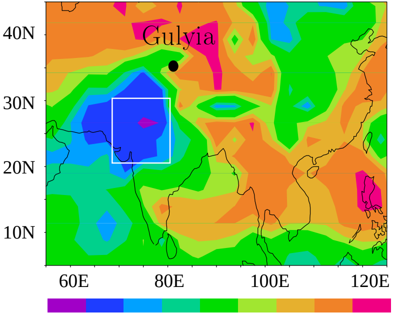


Is $\delta^{18}O$ a proxy for temperature?

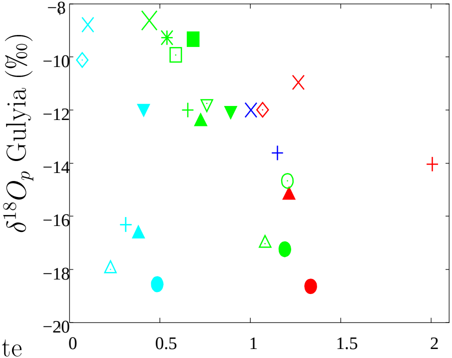


- temperature = significant control at paleo time scales
- robust to model physics

Is $\delta^{18}O$ a proxy for precipitation ?

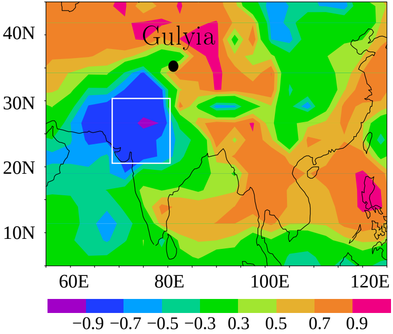


correlation between $\delta^{18}O_p$ at site and precipitation around

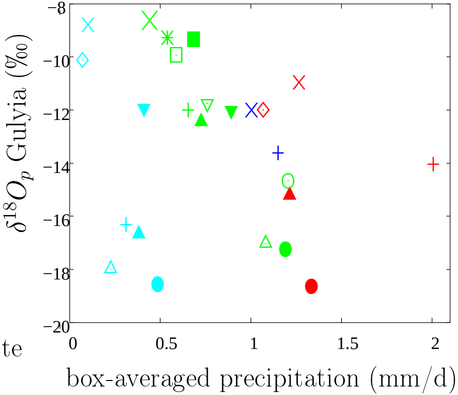


box-averaged precipitation (mm/d)

Is $\delta^{18}O$ a proxy for precipitation ?



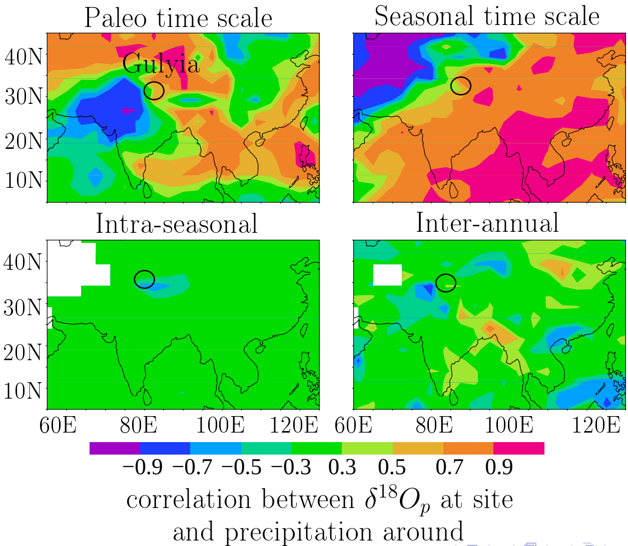
correlation between $\delta^{18}O_p$ at site and precipitation around



- Upstream precipitation plays a role at paleo time scales
- Sensitive to the model physics

$\delta^{18}O$ controls accross time scales

- Is understanding daily controls enough to understand paleo controls ?



Conclusion on paleo

- LMDZ can reproduce several aspects of past $\delta^{18}O$ changes
- At paleo time-scales and especially during LGM, temperature is a major control
- At paleo time-scales and especially during MH, relationship with upstream precip but sensitive to the model physics
- Surface and satellite data can help understand processes controlling $\delta^{18}O$ at daily time scale $\Rightarrow$ role of convection
- But relationship between precip and $\delta^{18}O$ depends on time scale

Perspectives on paleo

- Better evaluate climate-$\delta^{18}O$ relationships :
  - more data synthesis needed for paleo $\delta^{18}O$ to evaluate models
  - are some sensitivity tests more realistic at daily time scales ?
  - do we expect them to be more realistic for paleo time scales ?
  - compare with other models

Perspectives on paleo

- Better evaluate climate-$\delta^{18}O$ relationships :
  - more data synthesis needed for paleo $\delta^{18}O$ to evaluate models
  - are some sensitivity tests more realistic at daily time scales ?
  - do we expect them to be more realistic for paleo time scales ?
  - compare with other models
- use $\delta^{18}O$ records to better constrain future precip changes ?
  - common behavior in past/ future ? common mechanisms

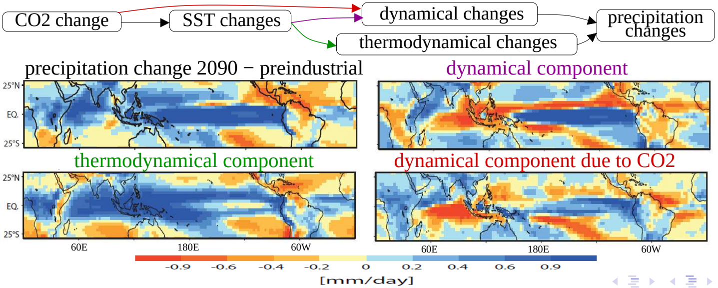
$\Rightarrow$investigation using past and future simulations in CMIP5.

Perspectives on paleo

- Better evaluate climate-$\delta^{18}O$ relationships :
  - more data synthesis needed for paleo $\delta^{18}O$ to evaluate models
  - are some sensitivity tests more realistic at daily time scales ?
  - do we expect them to be more realistic for paleo time scales ?
  - compare with other models
- use $\delta^{18}O$ records to better constrain future precip changes ?
  - common behavior in past/ future ? common mechanisms

⇒investigation using past and future simulations in CMIP5.

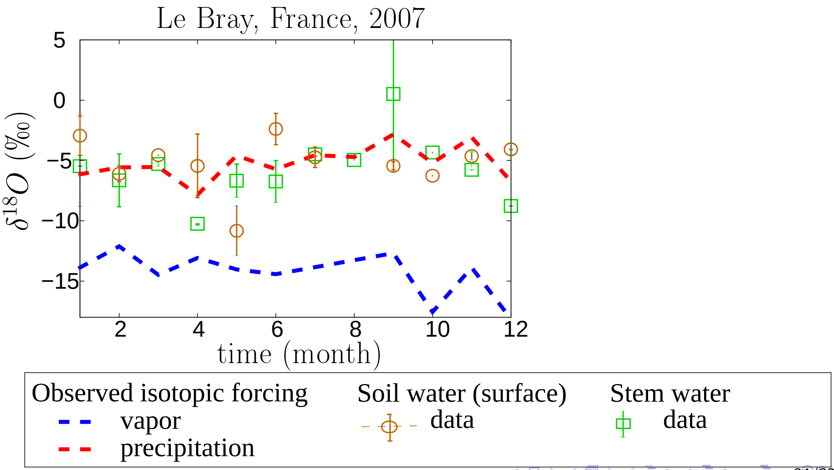
Bony et al 2013 : decomposition of future precip changes :



Appendix

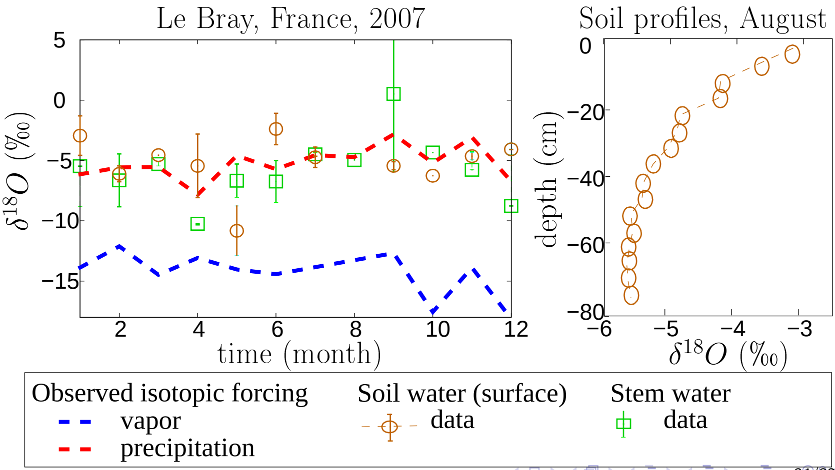
Evaluation of ORCHIDEE land surface isotopes

- Le Bray (France, *Wingate et al 2009*)



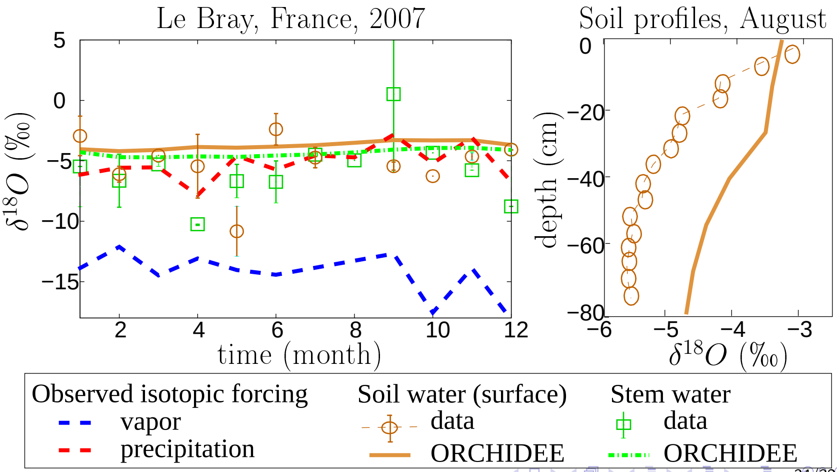
Evaluation of ORCHIDEE land surface isotopes

- Le Bray (France, *Wingate et al 2009*)

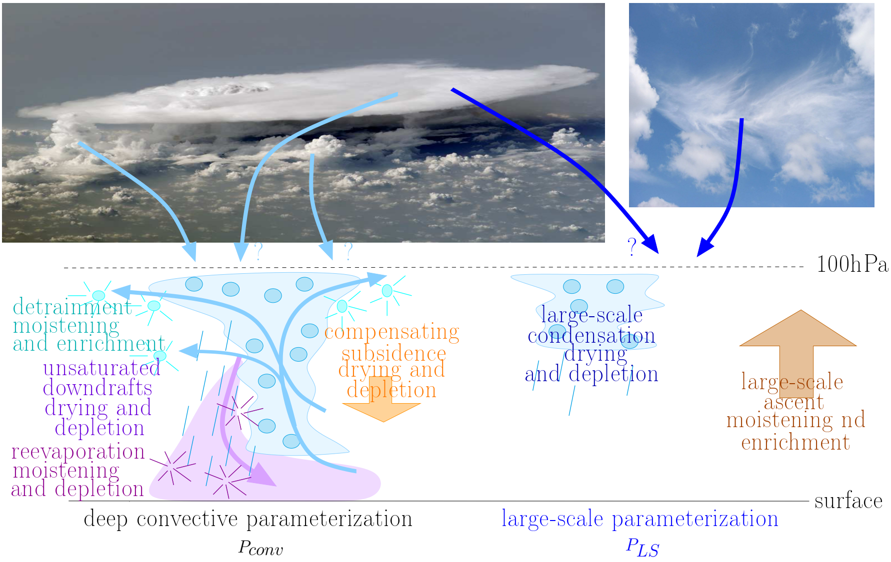


Evaluation of ORCHIDEE land surface isotopes

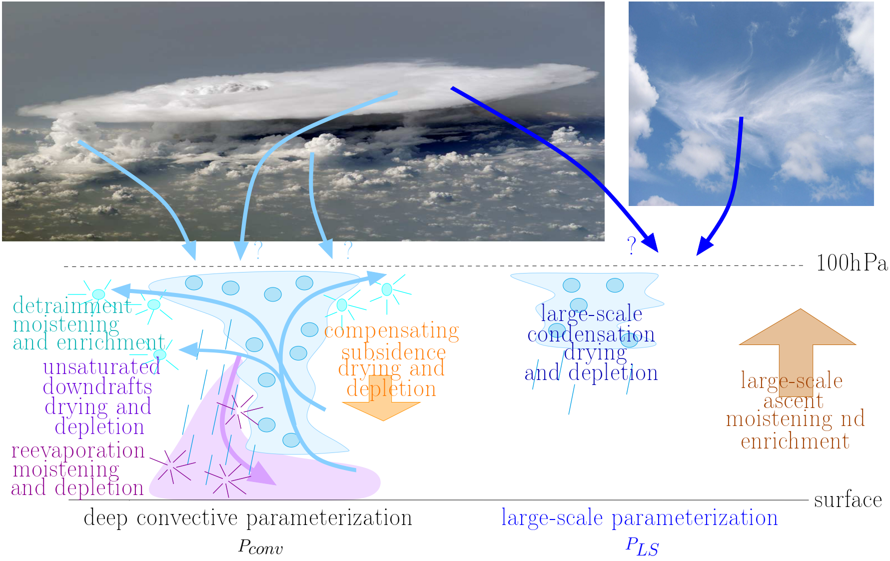
- Le Bray (France, *Wingate et al 2009*)



Interplay convection - large-scale schemes

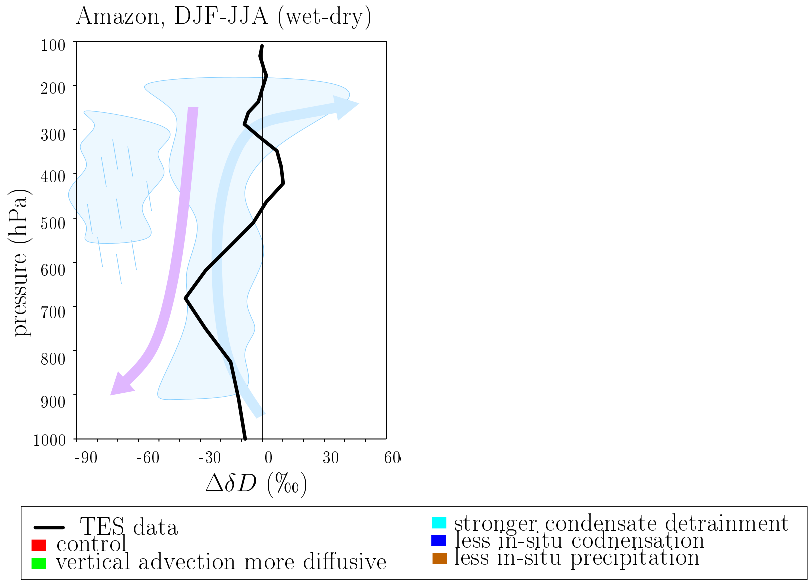


Interplay convection - large-scale schemes

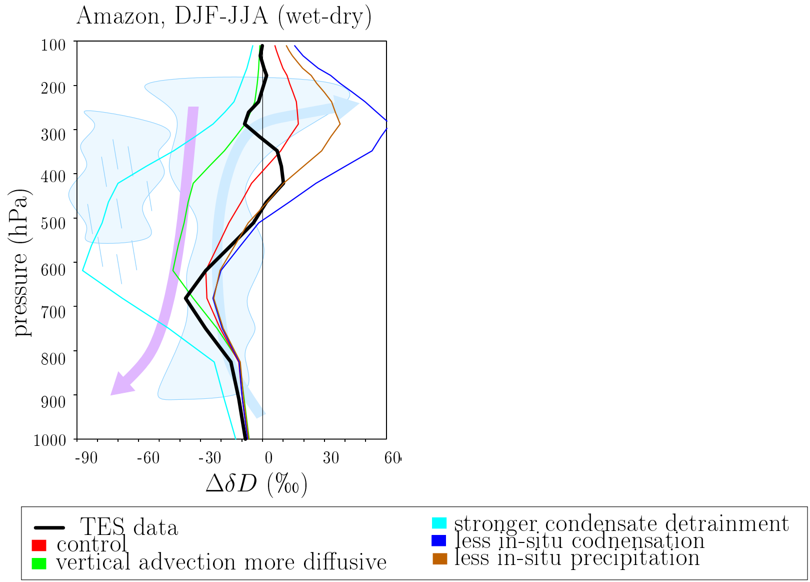


- P_{LS}/P_{tot} arbitrary, but influences cloudiness, intra-seas. variability, chemical tracor transport

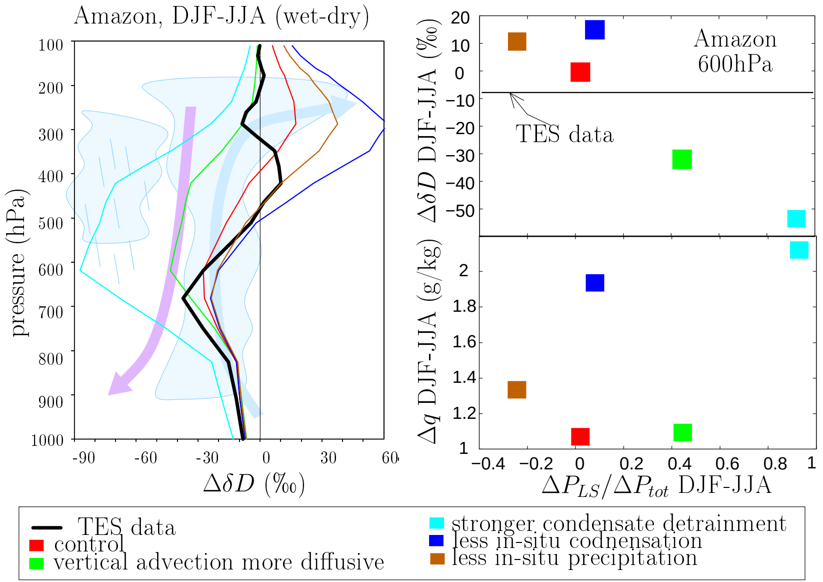
Convection vs large-scale precip



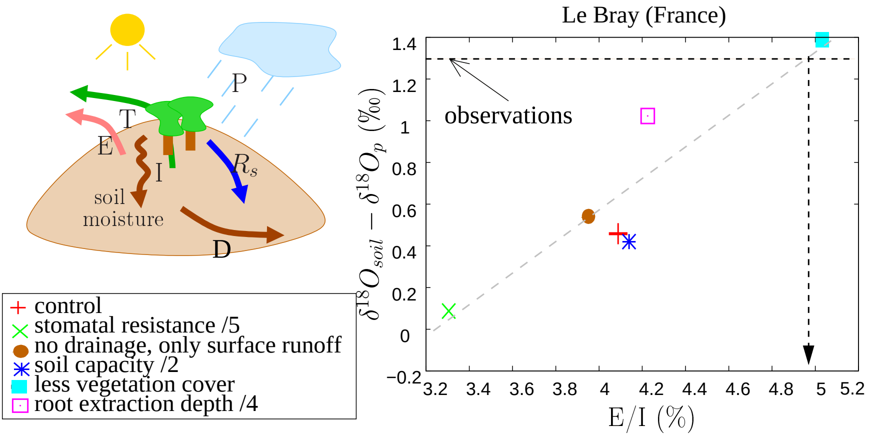
Convection vs large-scale precip



Convection vs large-scale precip

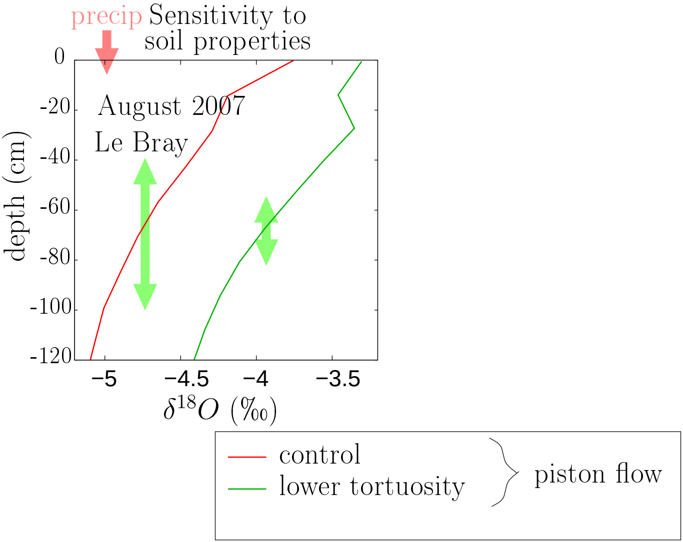


Surface water budget

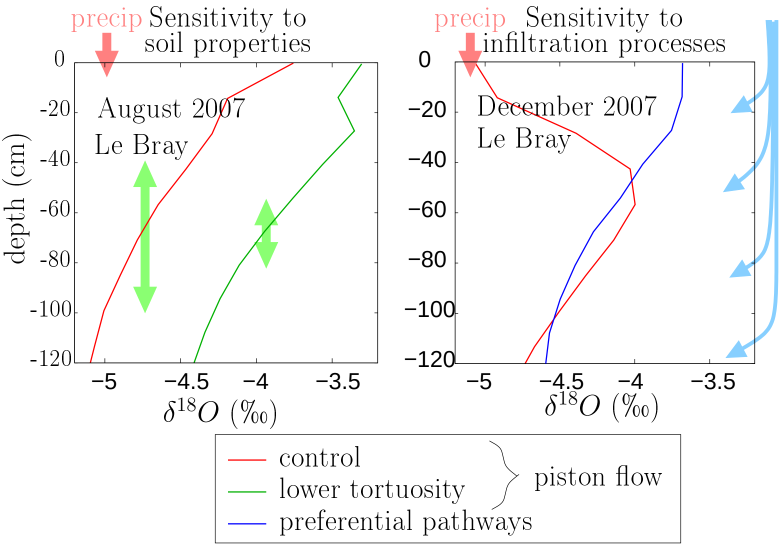


- soil water isotopic measurements -> bare soil evaporation ratio

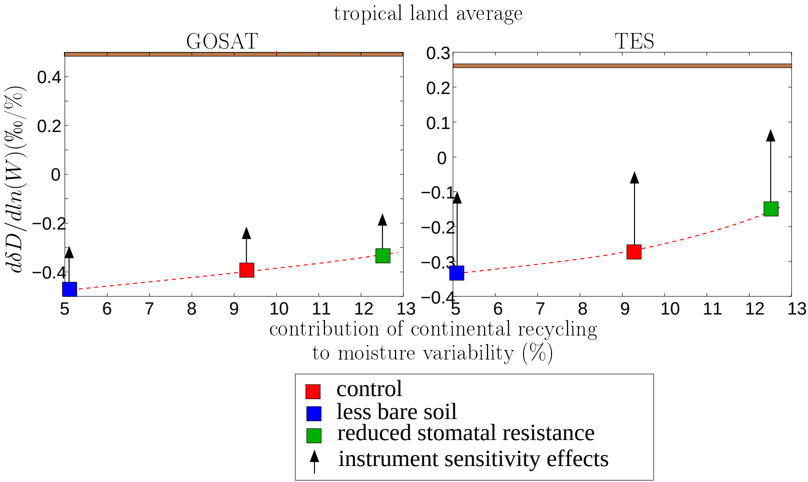
Diffusion/infiltration in soils



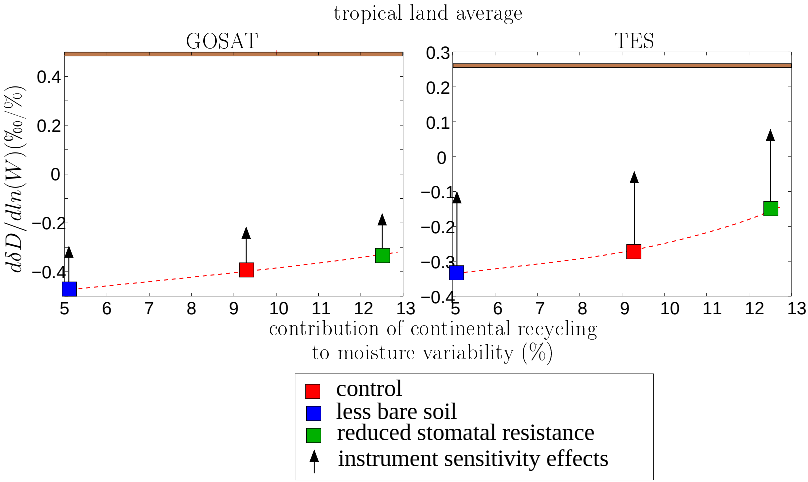
Diffusion/infiltration in soils



Evaluating continental recycling feedbacks



Evaluating continental recycling feedbacks



- Does LMDZ underestimate the role of continental recycling ?
- Or atmospheric problems ?