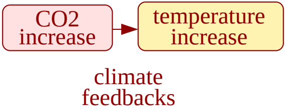
The added value of water isotopic measurements for process-oriented evaluation of atmospheric and land surface hydrological processes in climate models

Camille Risi

LMD/IPSL/CNRS

Seminar at Tsinghua University, April 24, 2013

Inter-model spread in hydrological projections



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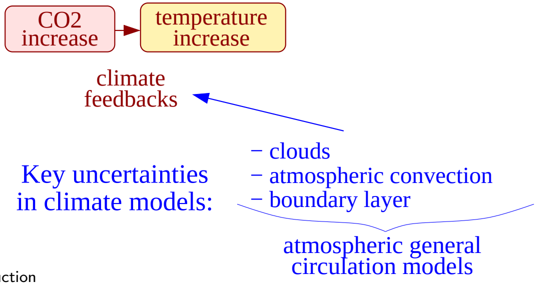

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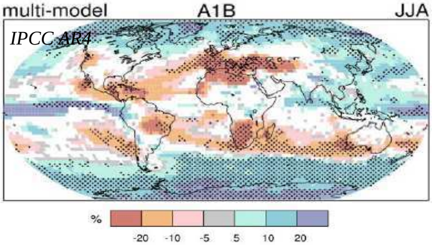

precipitation change by 2100 (%)

<2/3 agree on sign

CO2 increase → temperature increase → regional precipitation changes

climate feedbacks

Key uncertainties in climate models:

- clouds
- atmospheric convection
- boundary layer

atmospheric general circulation models

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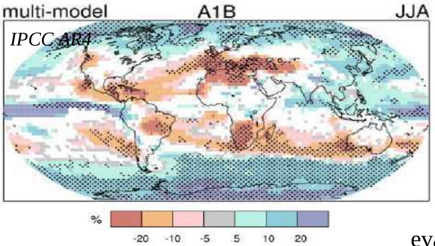

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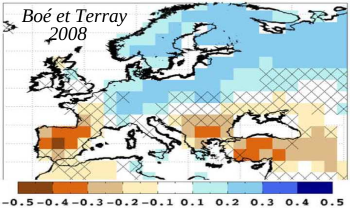
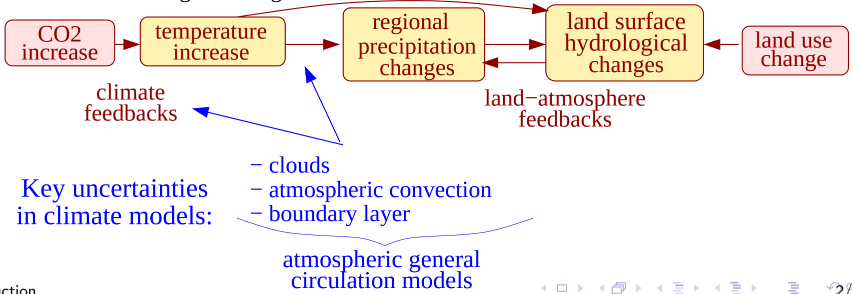


evapo−transpiration change by 2100 (mm/d)

× <70% agree on sign



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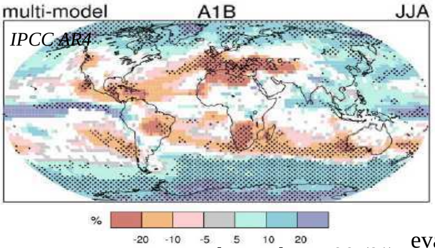

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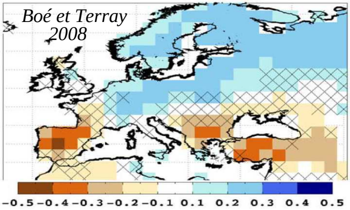

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CO2 increase → temperature increase → regional precipitation changes ⇄ land surface hydrological changes ← land use change

climate feedbacks

land−atmosphere feedbacks

Key uncertainties in climate models:

− clouds
− atmospheric convection
− boundary layer

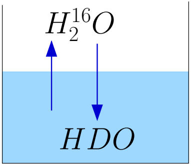
atmospheric general circulation models

− sensitivity of surface fluxes to soil moisture
− soil/groundwater storage
− spatial heterogeneities

land surface models

Water isotopic composition

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



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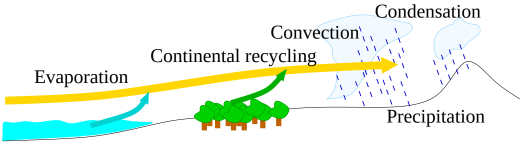
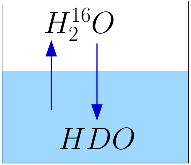
- records phase changes





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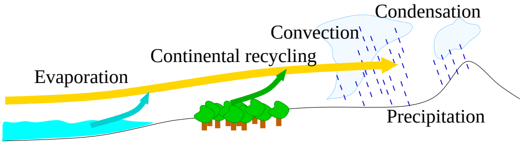

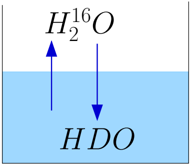

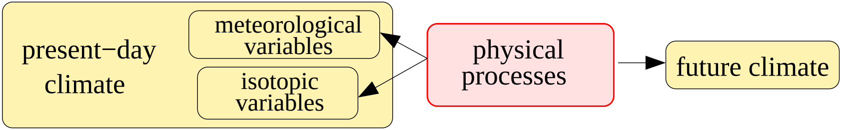

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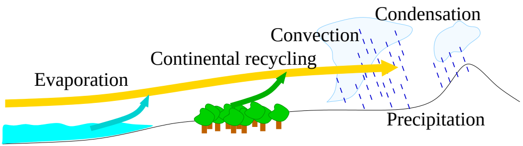

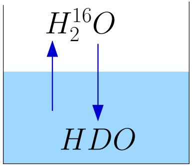

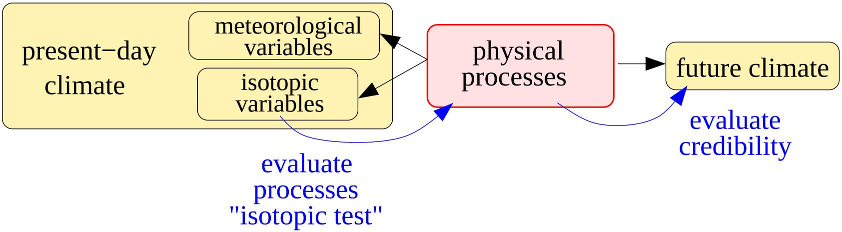

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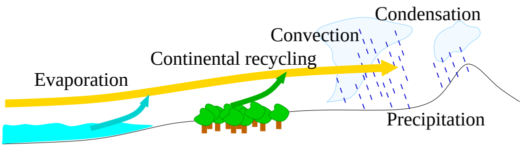

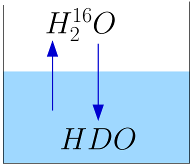

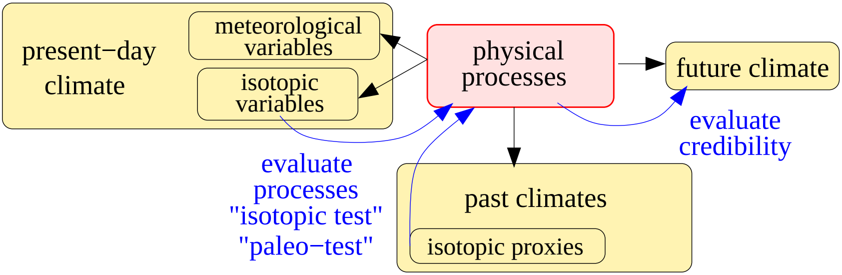

Overview of my activities

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

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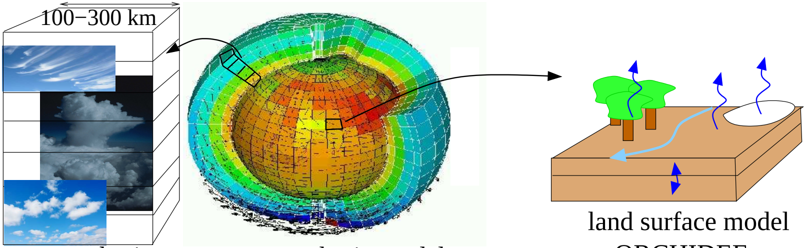
   - partitionning of water fluxes at land surface
   - land-atmosphere feedbacks, continental recycling
3. evaluation of tropical precipitation changes
   - what do tropical water isotopic proxies record
   - link between past and future behavior (CMIP5)

LMDZ and ORCHIDEE models

- components of IPSL climate model



atmospheric parameterizations

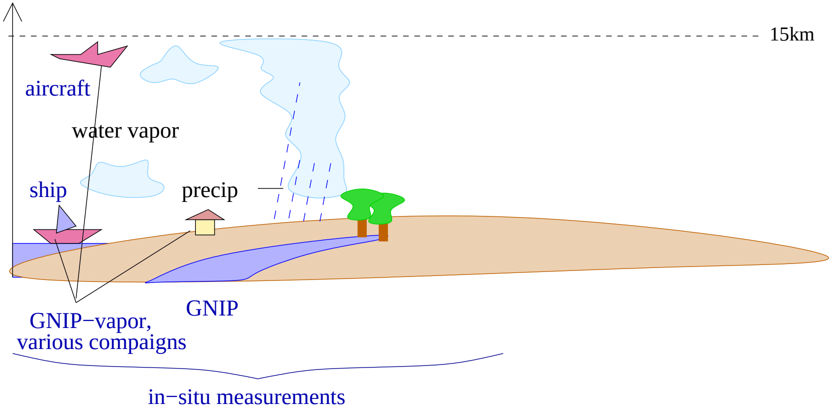
atmospheric model LMDZ

land surface model ORCHIDEE

- 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



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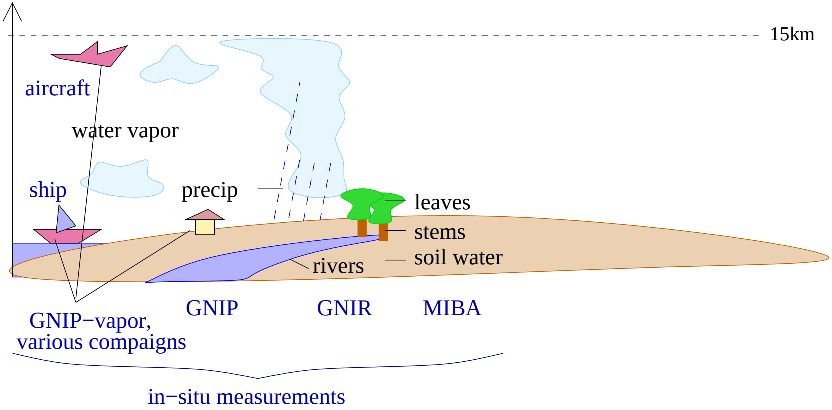

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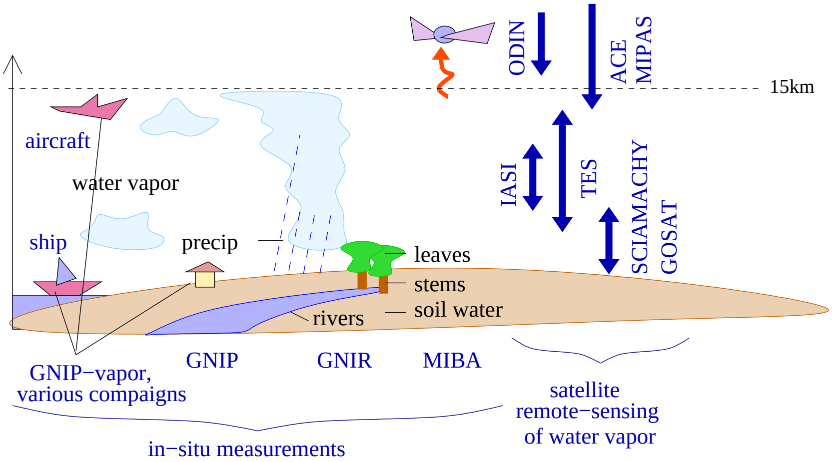

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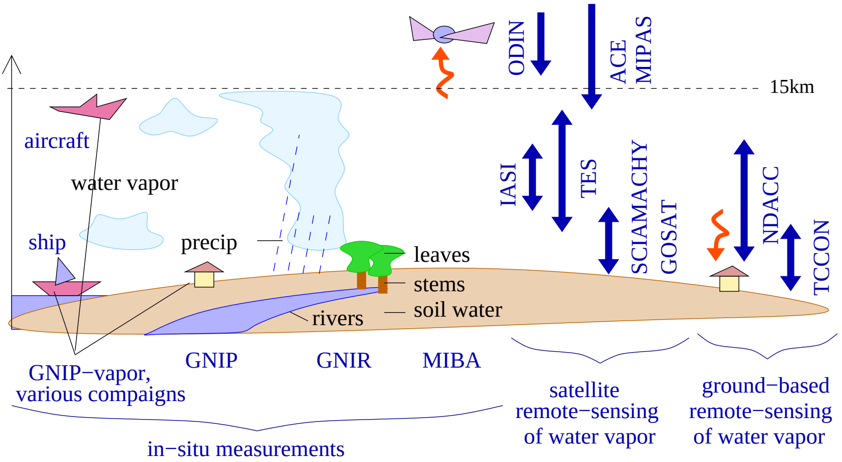

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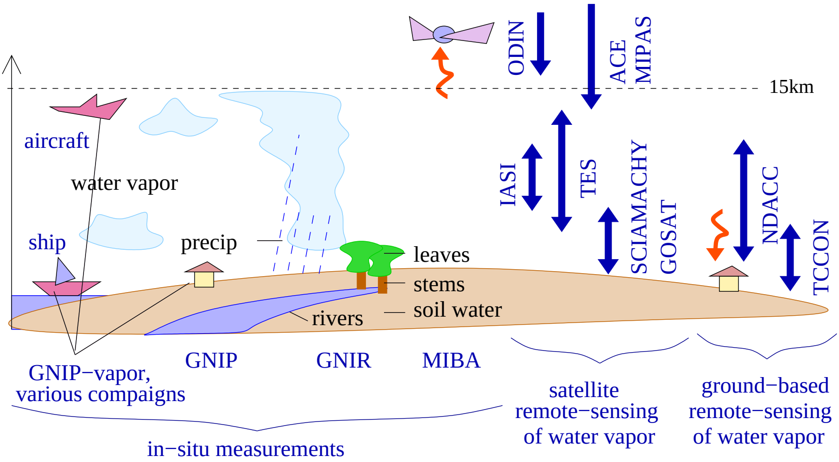
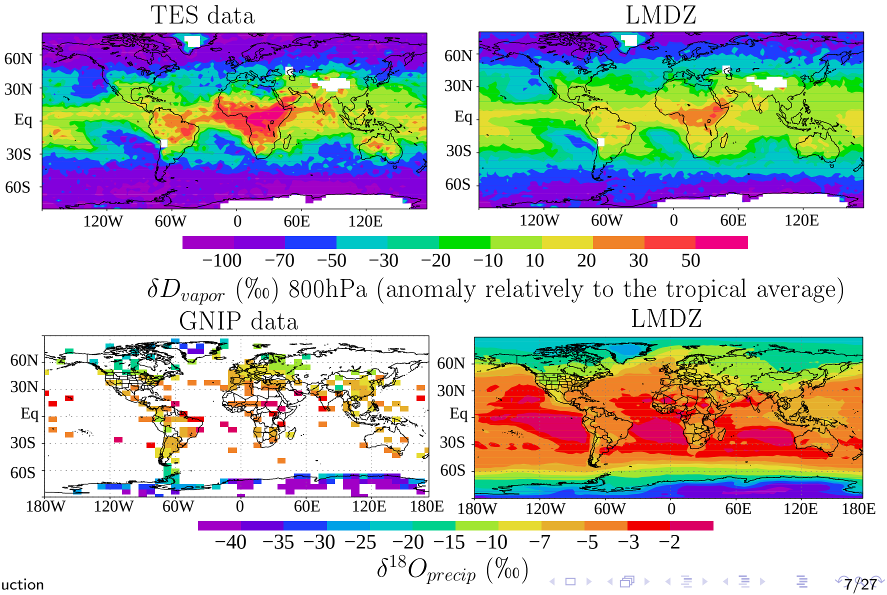


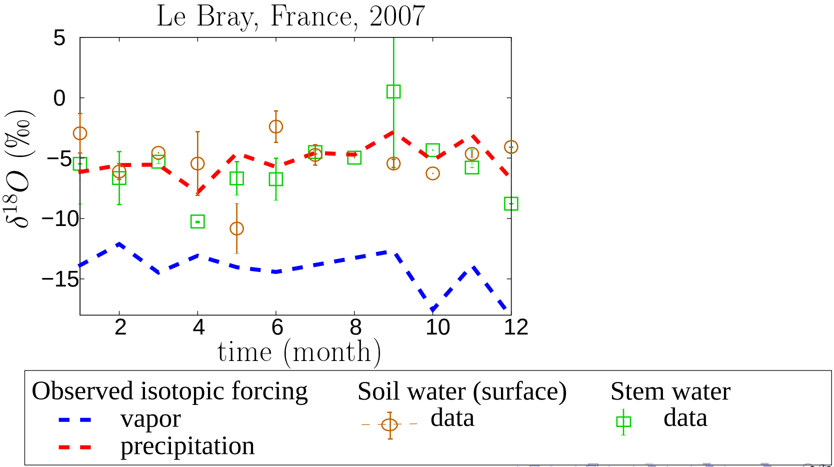
- for remote-sensing : focus on spatio-temporal variations
- account for sampling and instrument sensitivity

Evaluation of LMDZ water vapor and precip



Evaluation of ORCHIDEE land surface isotopes

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



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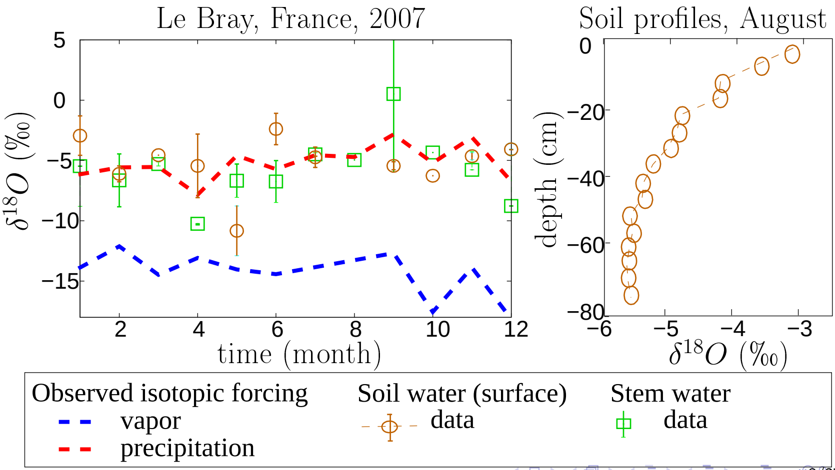

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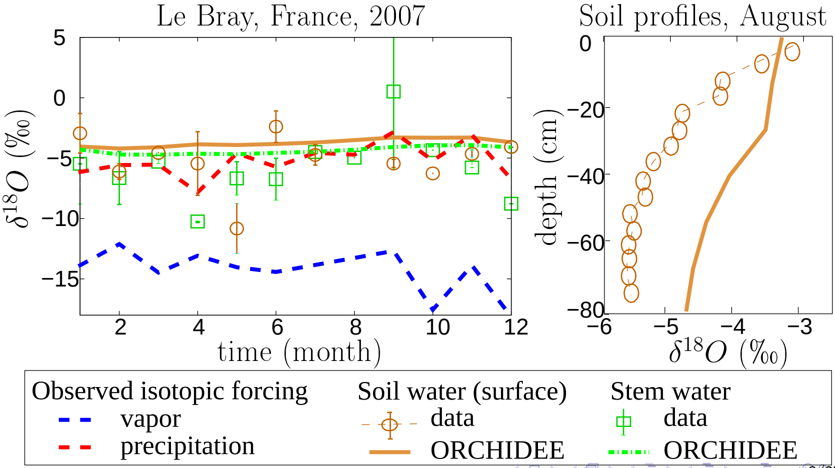
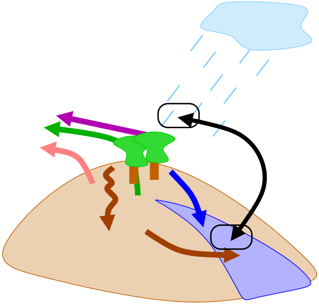
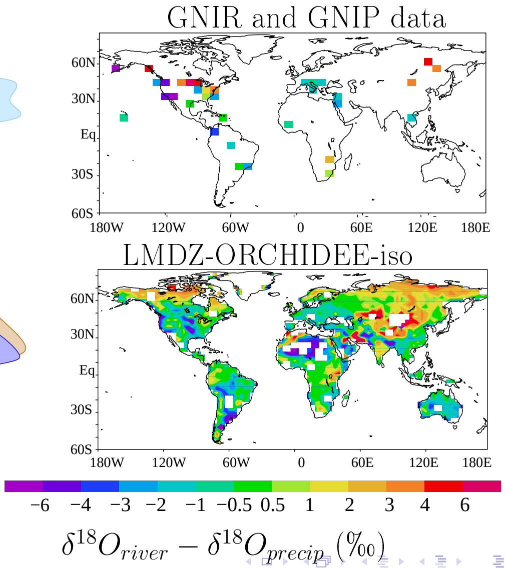


Evaluation of LMDZ-ORCHIDEE precipitation and rivers



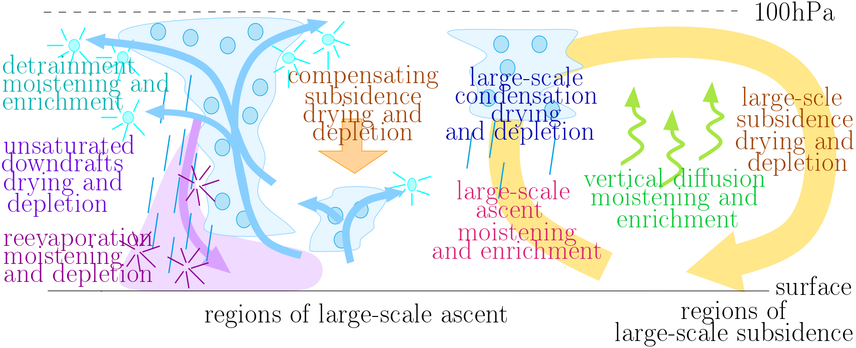


I) Using water vapor measurements to evaluate atmospheric processes

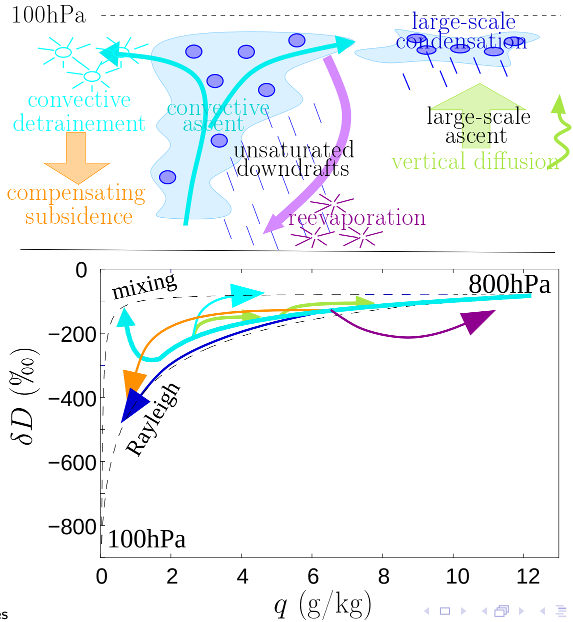
- what controls the water vapor composition
- 3 examples

Atmospheric processes controlling isotopic composition

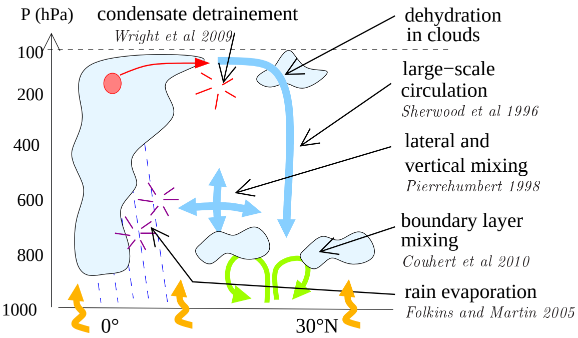
- observational studies (Risi et al 2008b), in particular at intra-event time scales (Risi et al 2010c, Tremoy et al 2012)
- modeling studies (Risi et al 2008, 2010b, 2012b)



q-δD complementarity



1) Processes controlling subtropical humidity



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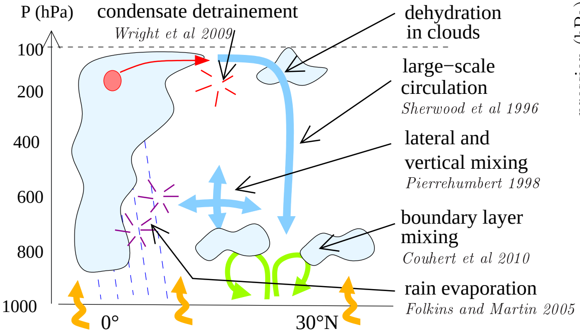
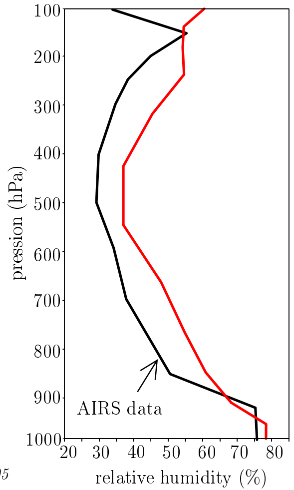
LMDZ−iso (Risi et al 2010a):

control: AR4 version (19 levels)





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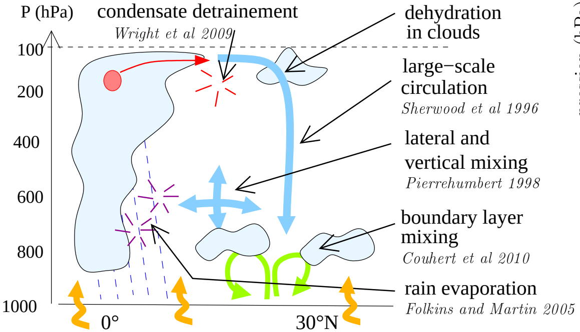
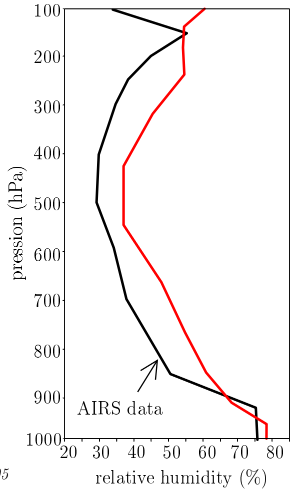
3 reasons for a moist bias





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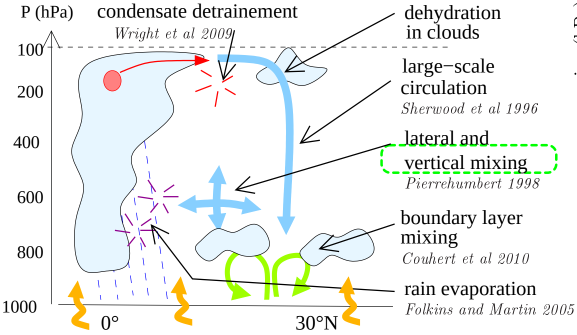

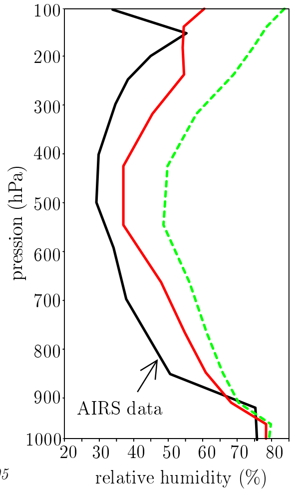

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- diffusive vertical advection
- $\sigma_q/10$

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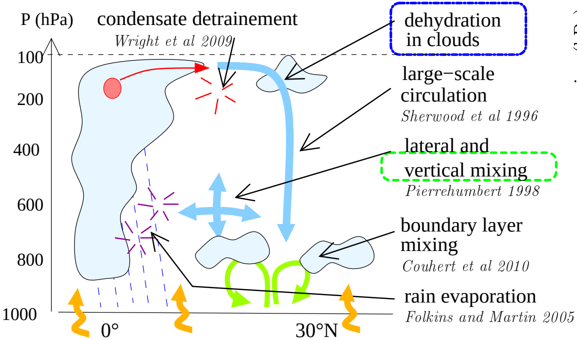

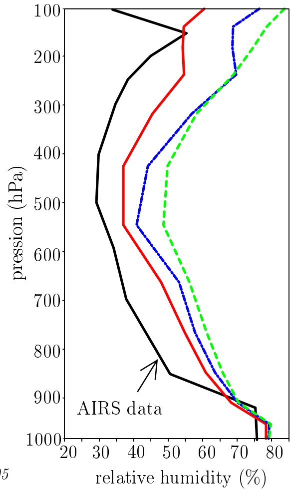

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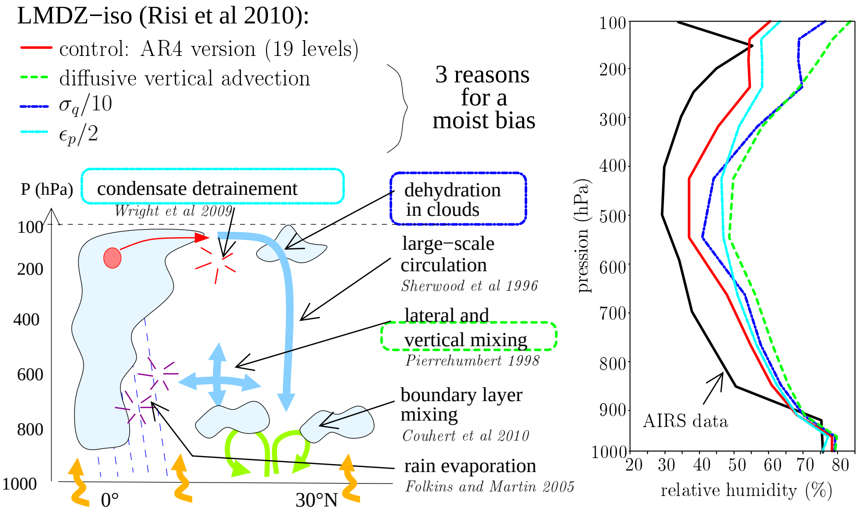
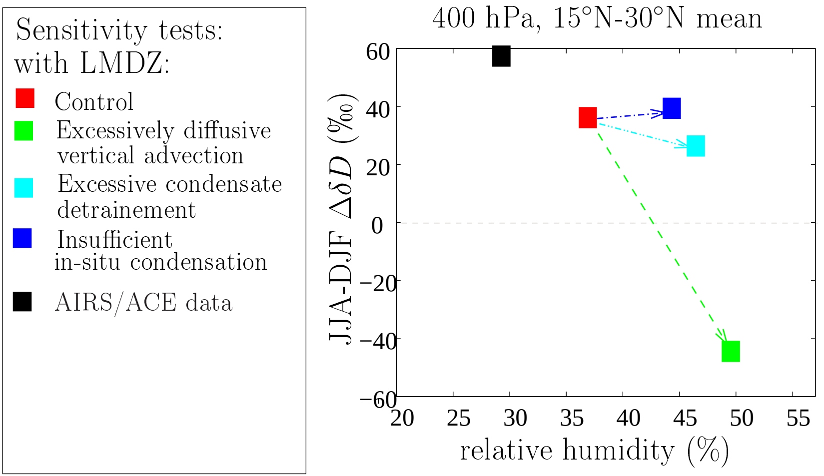


What causes the moist biases in GCMs ?



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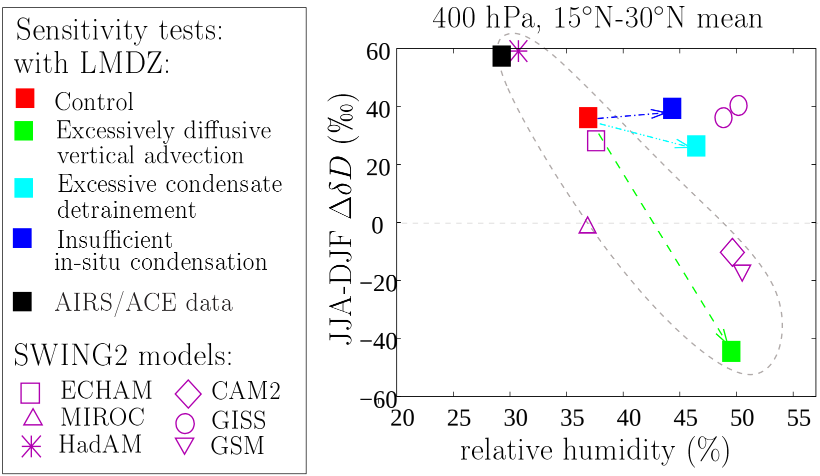
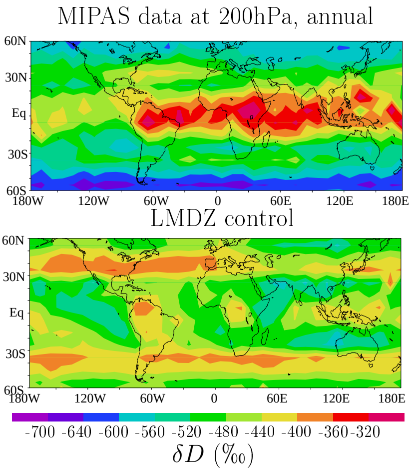


- frequent reason for moist bias=excessively diffusive advection

2) Upper tropospheric convective moistening



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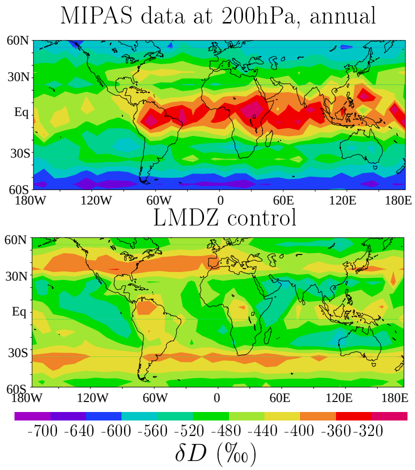

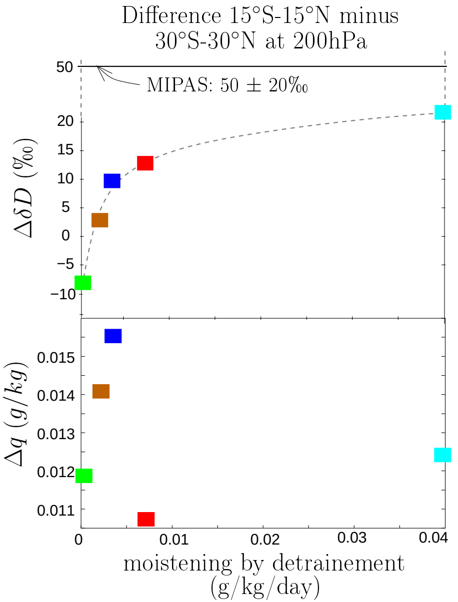

- control
- vertical advection more diffusive
- stronger condensate detrainment
- less in-situ codnensation
- less in-situ precipitation

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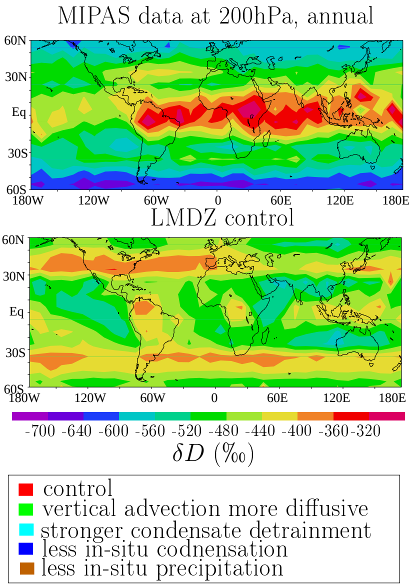
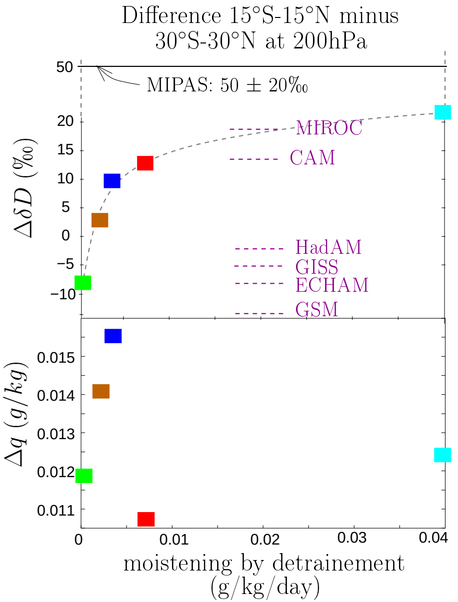
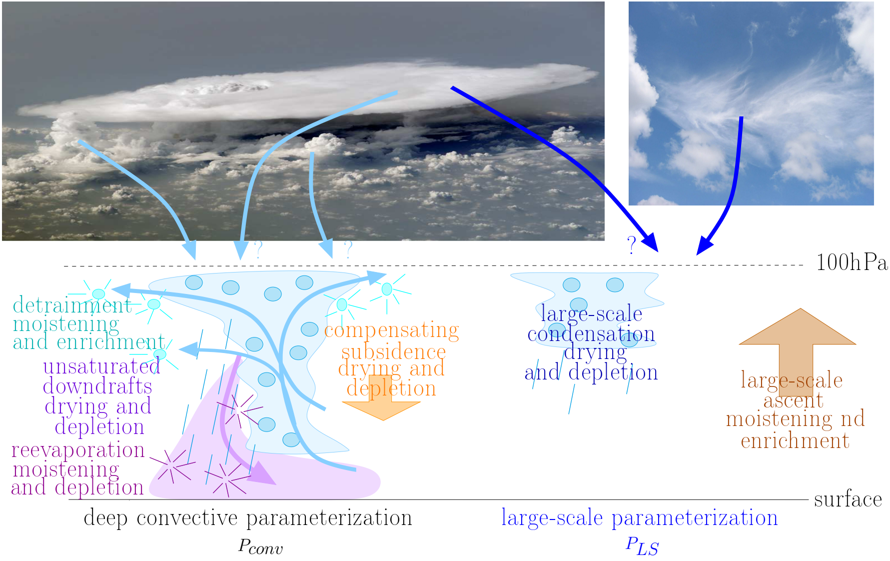




3) Interplay convection - large-scale schemes



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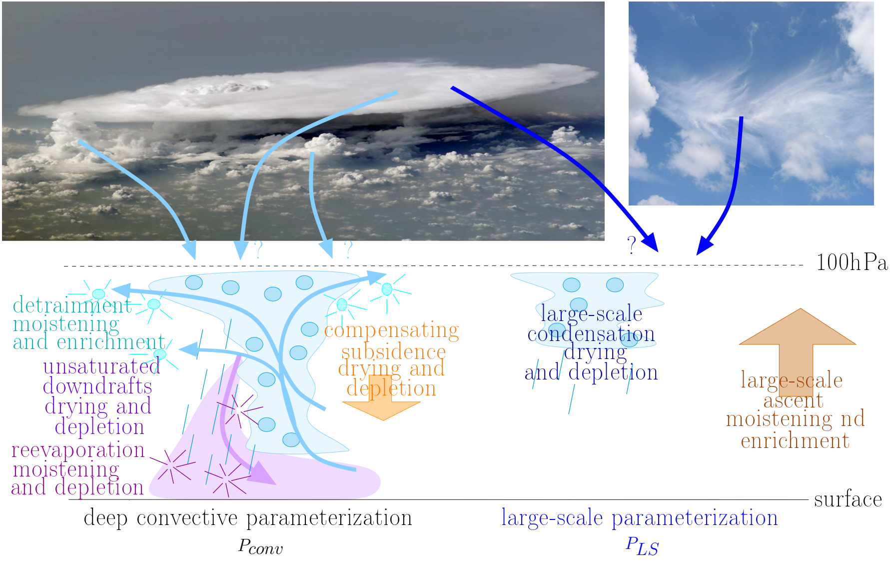
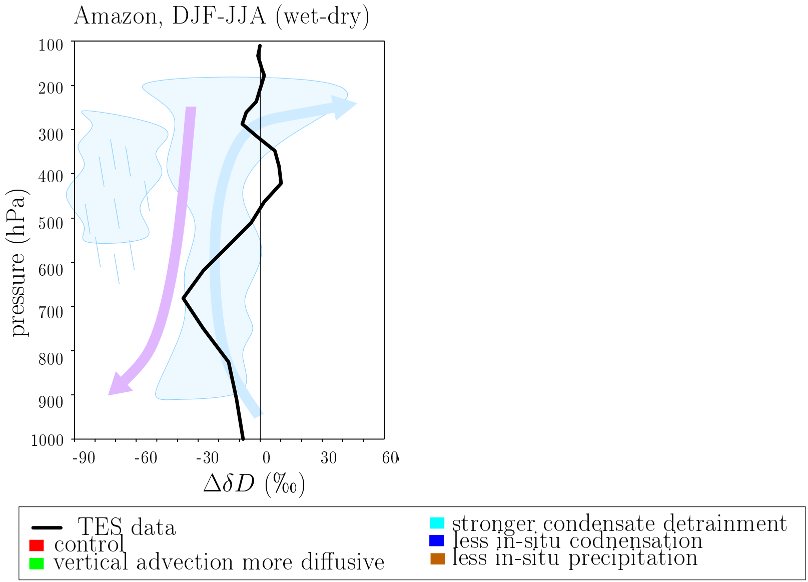


- P_{LS}/P_{tot} arbitrary, but influences cloudiness, intra-seas. variability, chemical tracor transport

Convection vs large-scale precip



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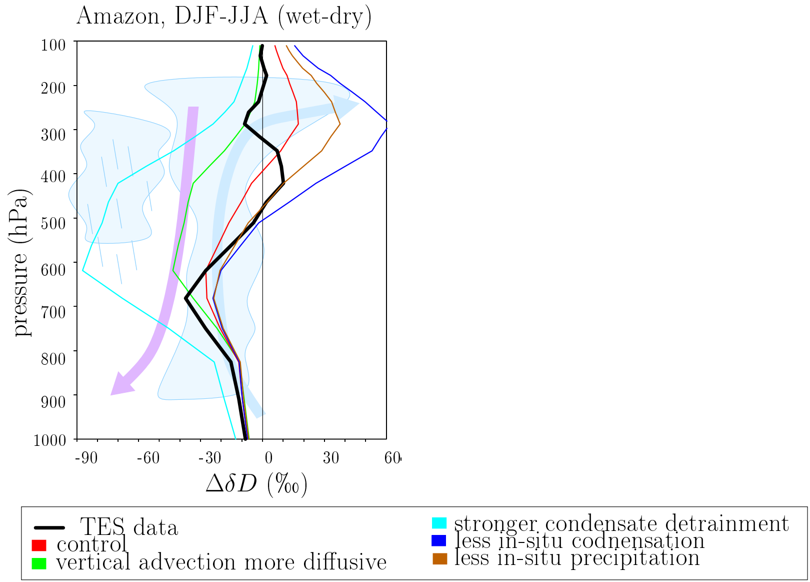

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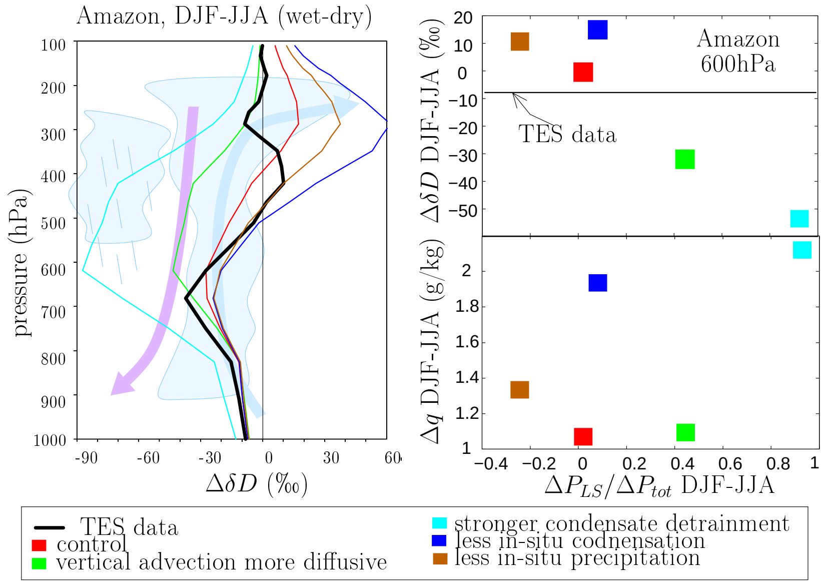

Perspectives on convection

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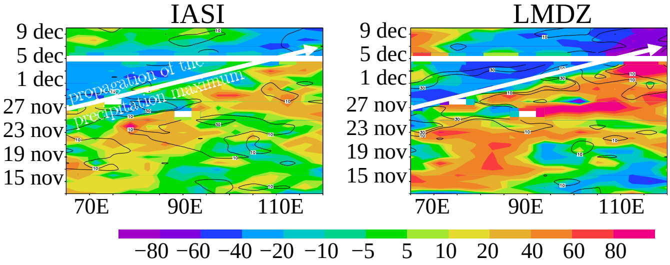
- Combine q, δD + chemical tracers : CO, O_3, ^{10}Be $\Rightarrow$ better characterize fluxes
- MJO project : cause of models' difficulties ? $\Rightarrow$ Relate MJO biases to specific problems in parameterizations, isotopes as additional diagnostic.
- IASI data : daily global coverage $\Rightarrow$convective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

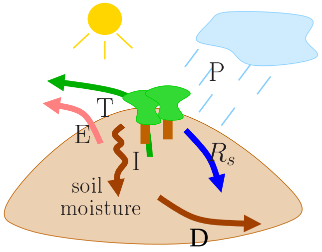


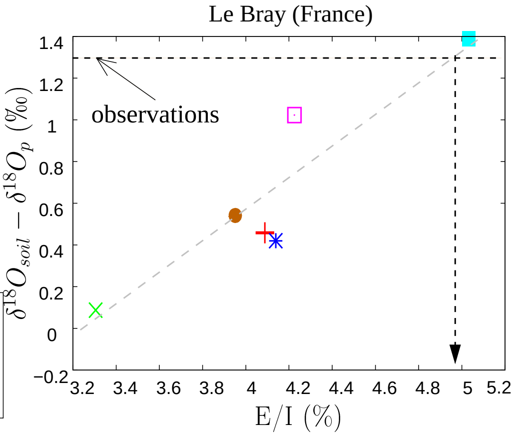
colors: δD anomaly (‰)
contours: q anomalies (%)

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

- 4 examples

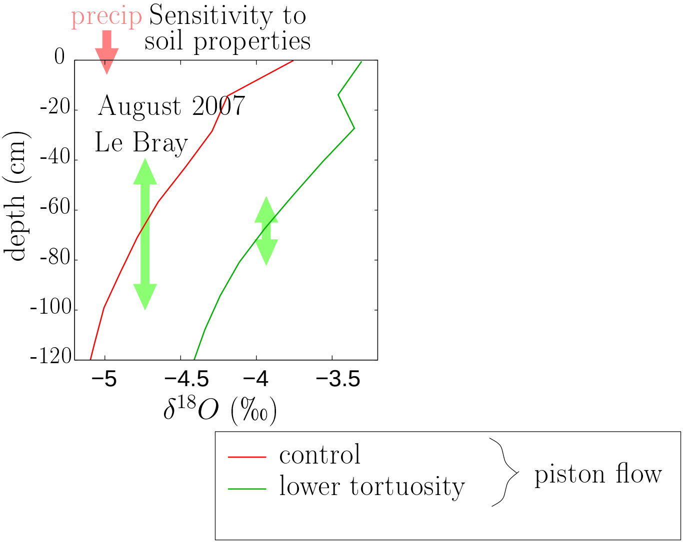
1) Surface water budget



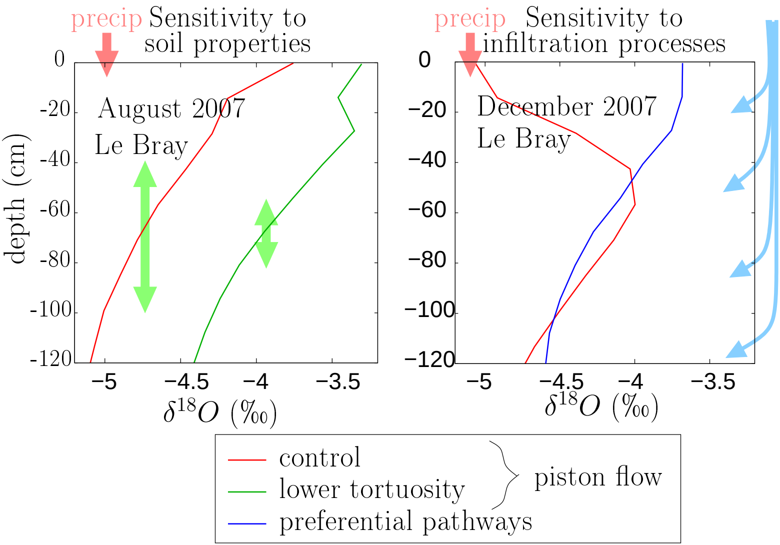


- soil water isotopic measurements -> bare soil evaporation ratio

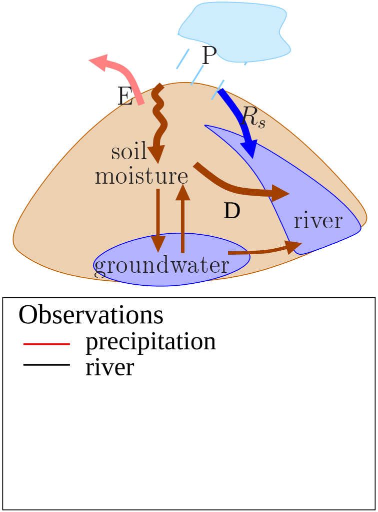
2) Diffusion/infiltration in soils

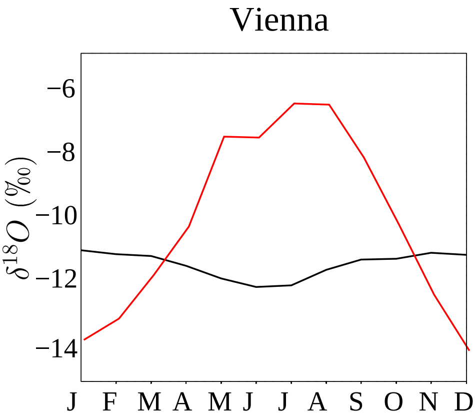


2) Diffusion/infiltration in soils



3) Pathways from precipitation to rivers





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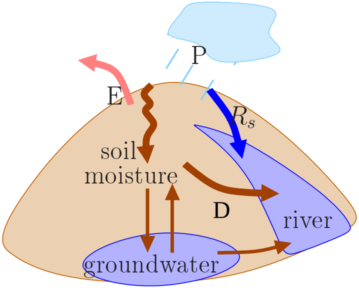

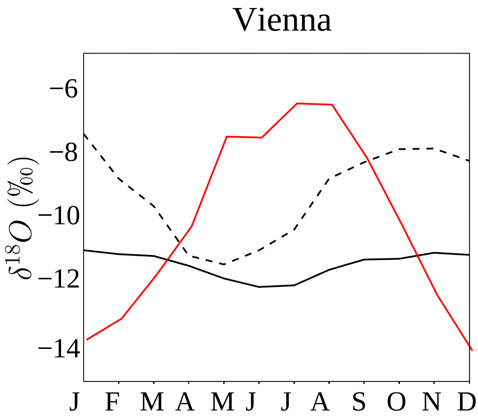

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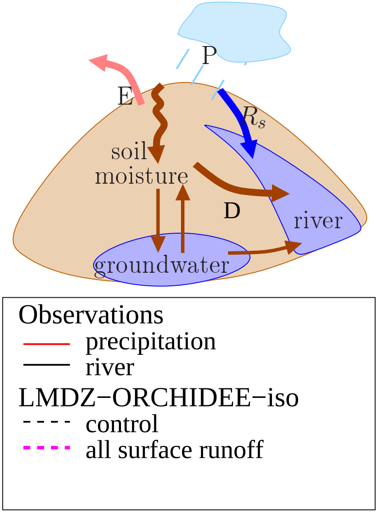

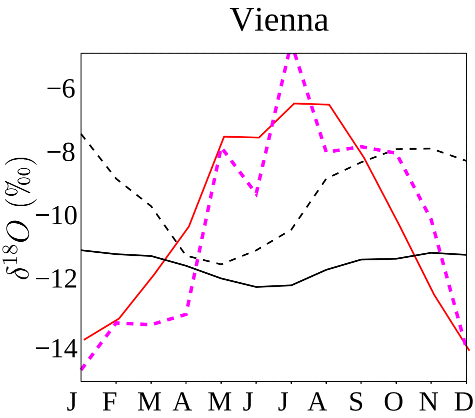

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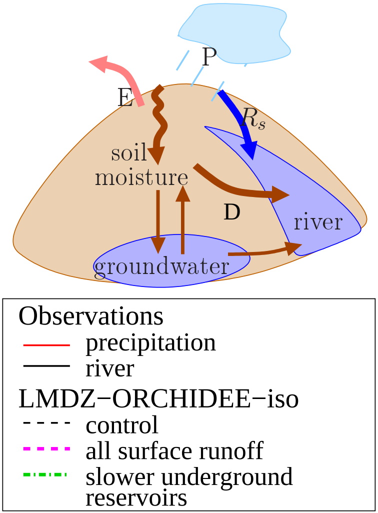
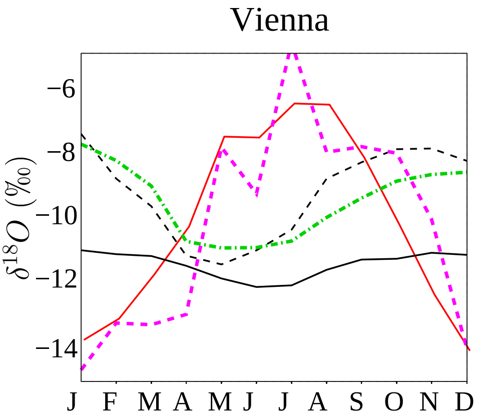
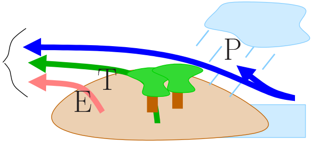




4) Continental recycling

Water tagging:



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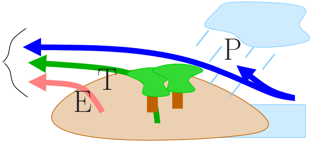

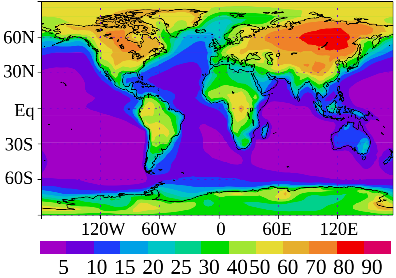

% vapor from continental evapo-transpiration (r_{con})

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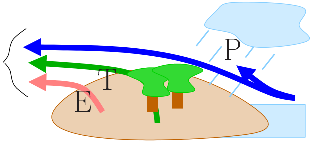
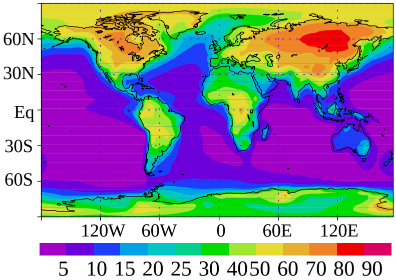
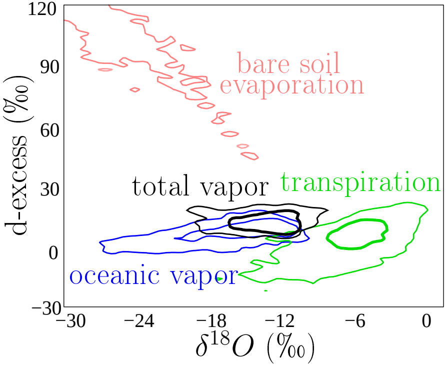


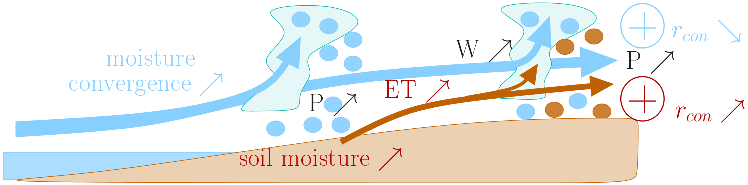


% vapor from continental evapo-transpiration (r_{con})

PDF of vapor composition monthly, all tropical land points



Continental recycling feedbacks



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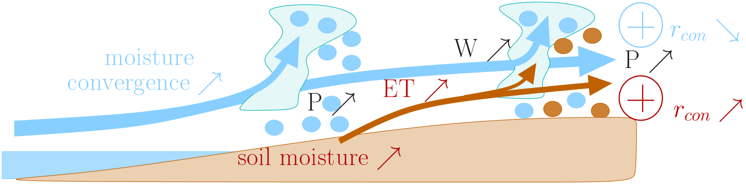
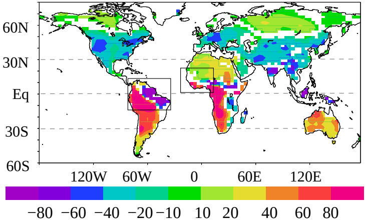
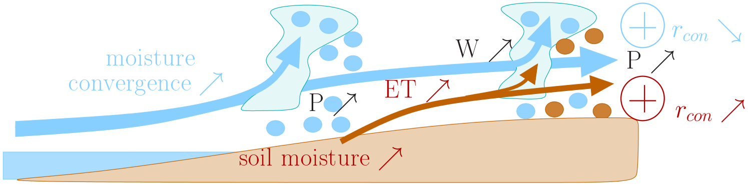
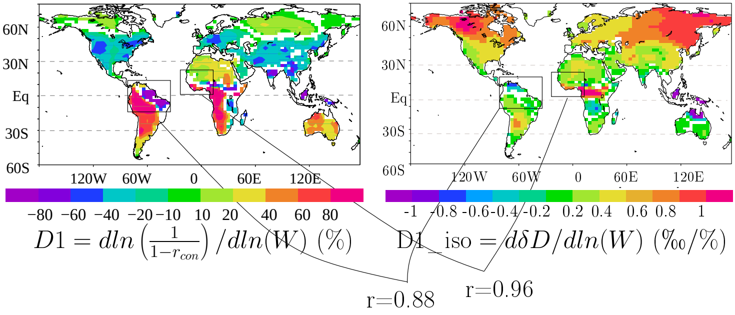




$$D1 = dln\left(\frac{1}{1-r_{con}}\right)/dln(W)\ (\%)$$

Continental recycling feedbacks

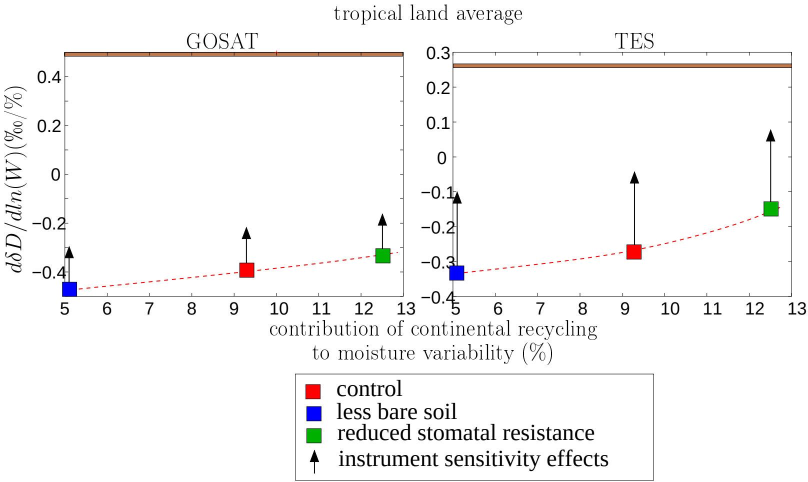




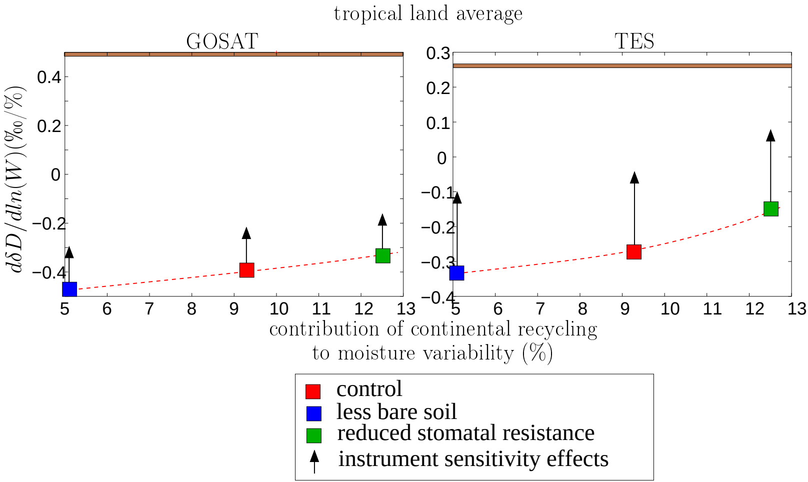
$D1 = dln\left(\frac{1}{1-r_{con}}\right)/dln(W)$ (%) D1_iso $= d\delta D/dln(W)$ (‰/%)

- use D1_iso to evaluate role of cont recycling *(Risi et al in rev)*

Evaluating continental recycling feedbacks



Evaluating continental recycling feedbacks



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

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

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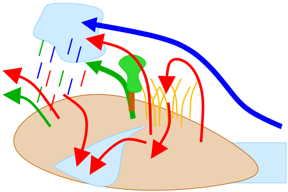
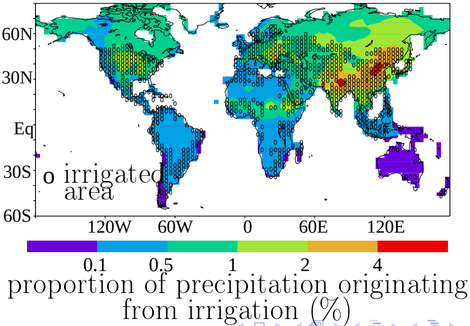
- irrigation changes using water tagging





Conclusion

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