Using water stable isotopic measurements to better evaluate the atmospheric and land surface components of climate models

Camille Risi

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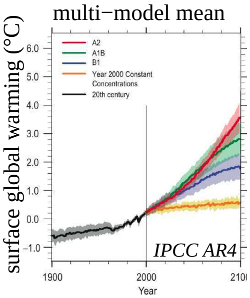
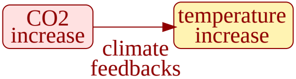
MIPAS:ACE: G Stiller, M Kiefer, B Funke, K Walker, P Bernath,
FTIR: M Schneider, D Wunch, P Wennberg, V Sherlock, N Deutscher, D Griffith
in-situ/MIBA: R Uemura, J. Ogée, T. Bariac, L. Wingate, N. Raz-Yaseef
SWING2: C Sturm

Hydrologic Sciences and Water Resources Engineering Seminar Series, 27 April 2011

Uncertainties in climate projections





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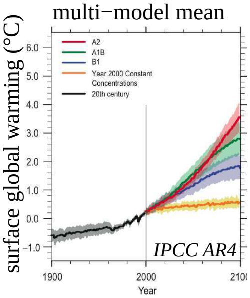

CO2 increase → temperature increase

climate feedbacks

atmospheric processes

Key uncertainties in climate models:

- clouds
- atmospheric convection
- boundary layer
- relative humidity

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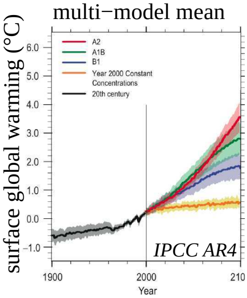

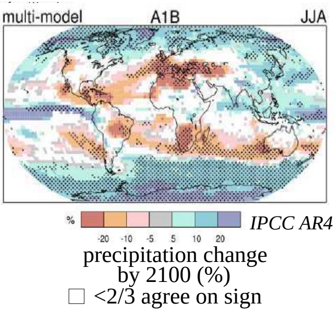

CO2 increase → temperature increase → regional precipitation changes

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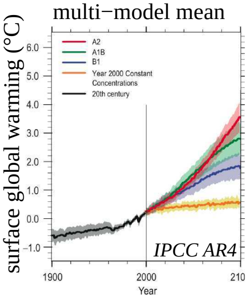

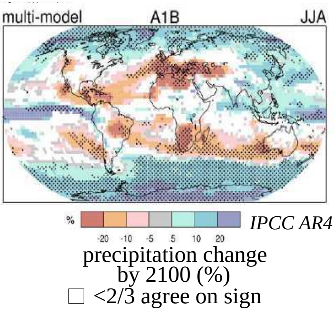

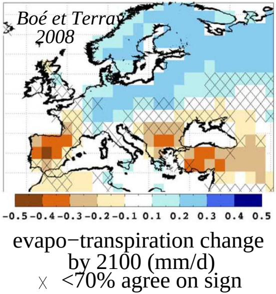

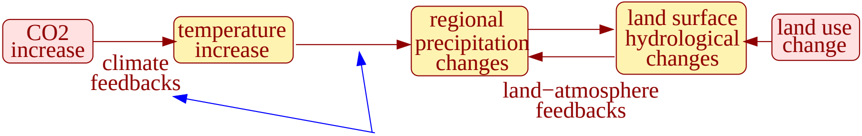

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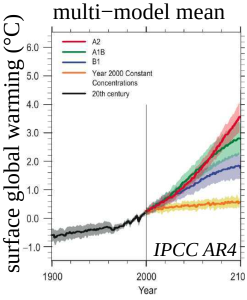
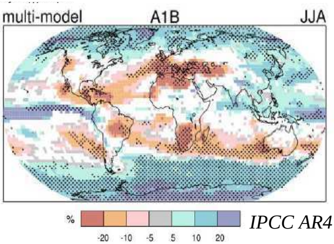
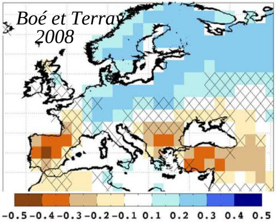




precipitation change by 2100 (%)
☐ <2/3 agree on sign



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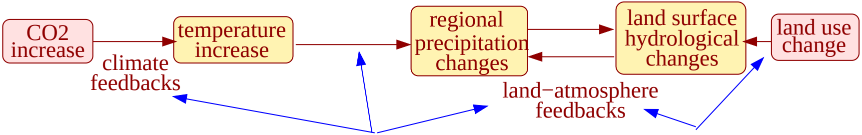

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- sensitivity of surface fluxes to soil moisture
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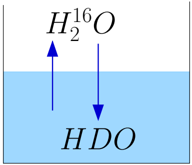
- spatial heterogeneities

Water isotopic composition

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



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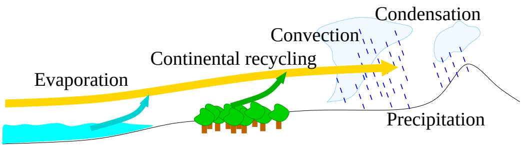

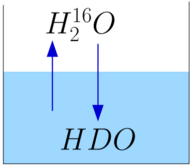

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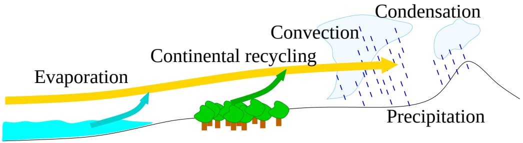

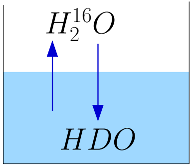

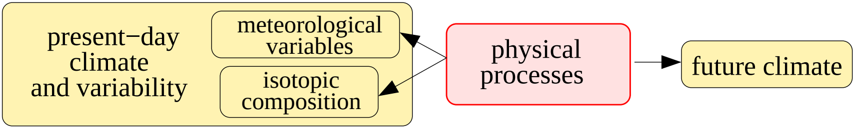

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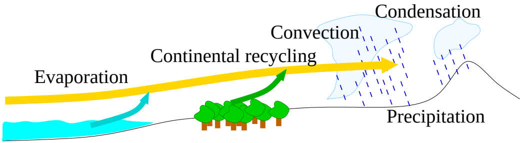

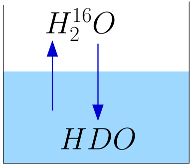

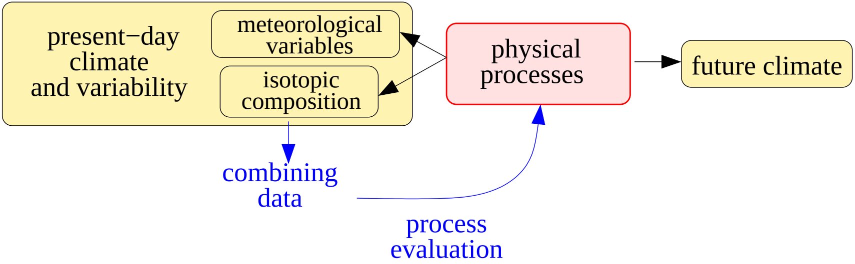

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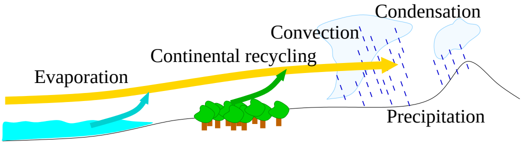
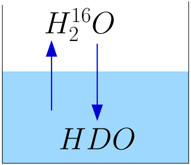
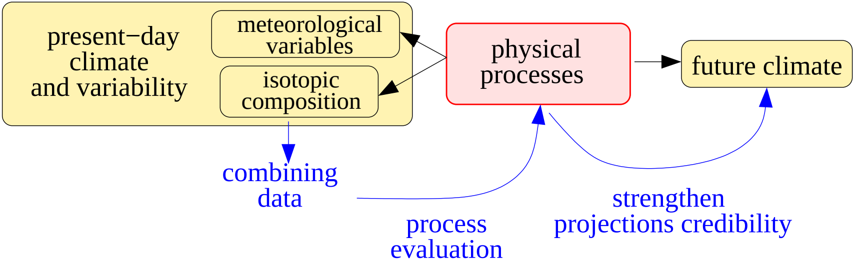


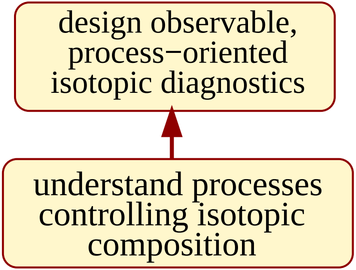




General strategy

understand processes controlling isotopic composition

General strategy



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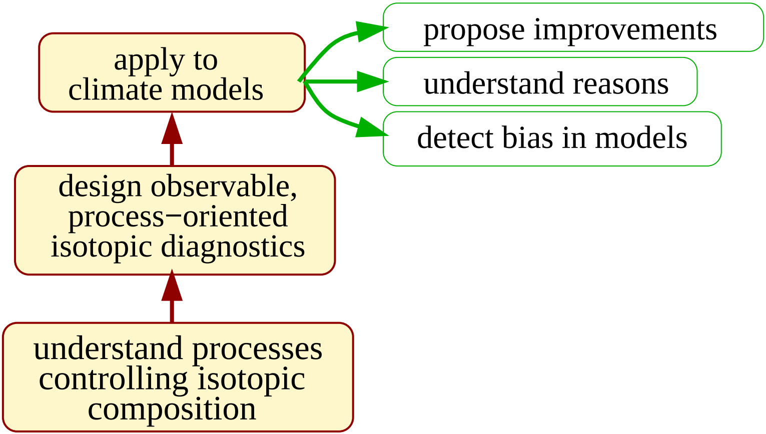

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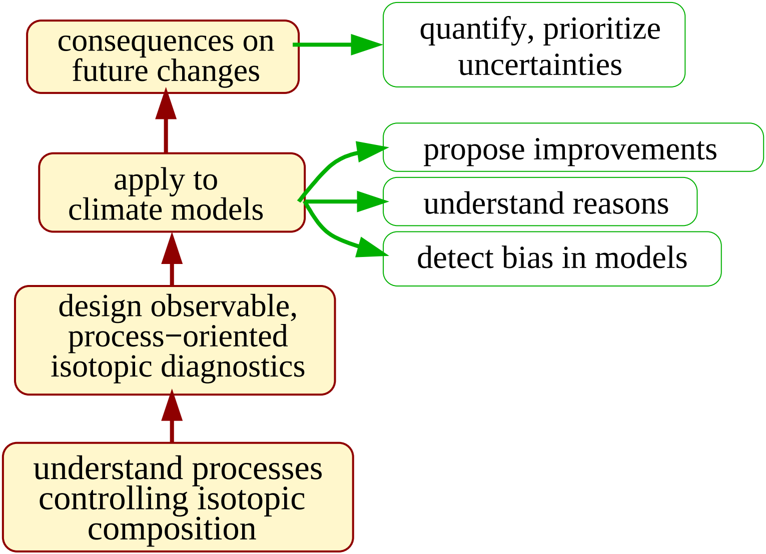
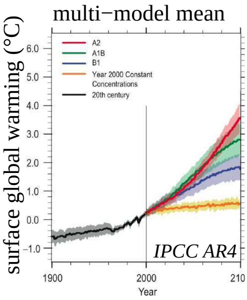
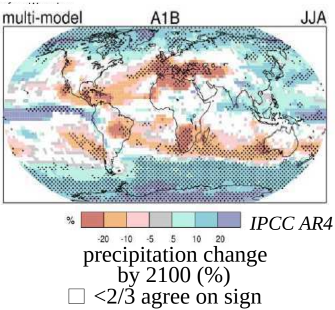
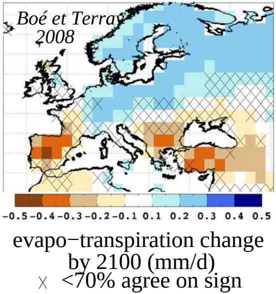
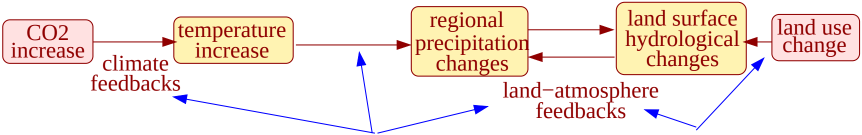


Outline









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- clouds
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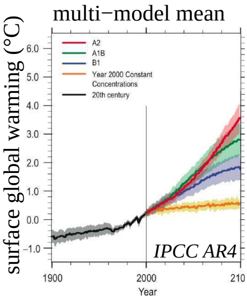
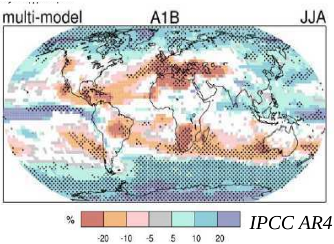
Key uncertainties in climate models:

Outline





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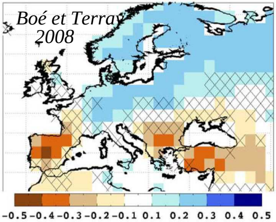

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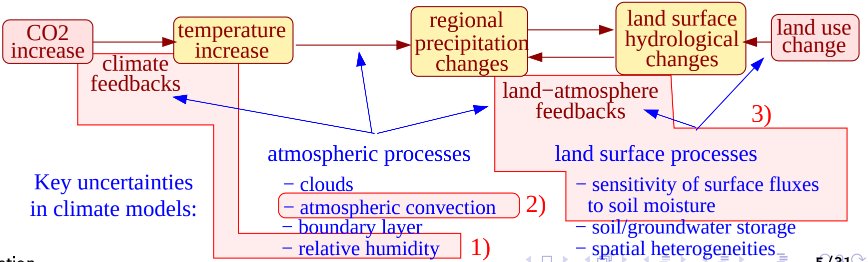

1) Processes controlling relative humidity

- tropical/subtropical free tropospheric relative humidity (RH) impacts:
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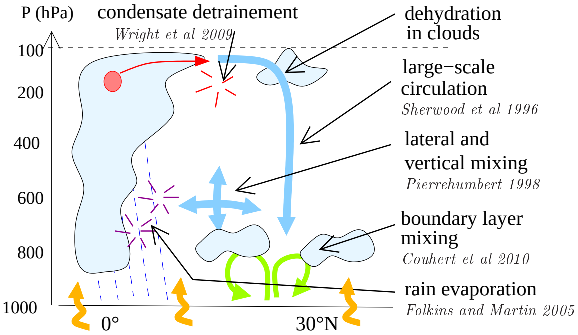
$\Longrightarrow$ need process-based evaluation of RH in climate models

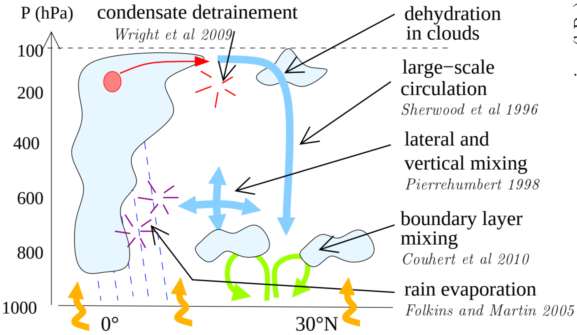
Sensitivity tests to RH processes

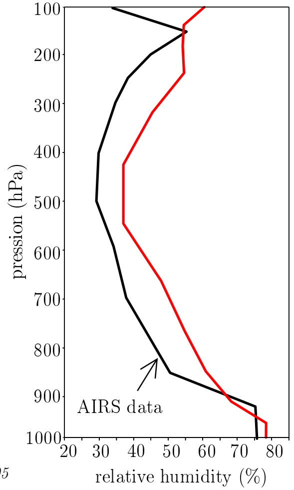


Sensitivity tests to RH processes

LMDZ−iso (Risi et al 2010a):

— control: AR4 version (19 levels)





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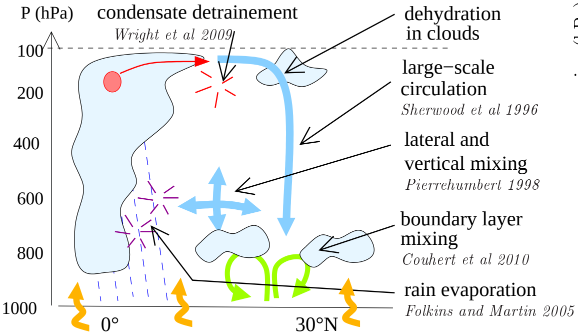
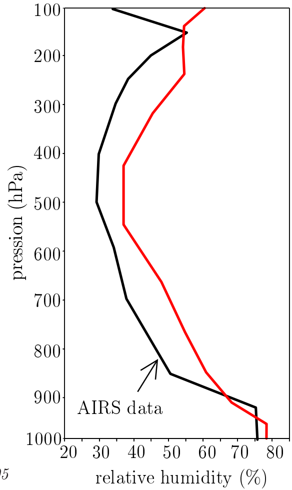
3 reasons for a moist bias





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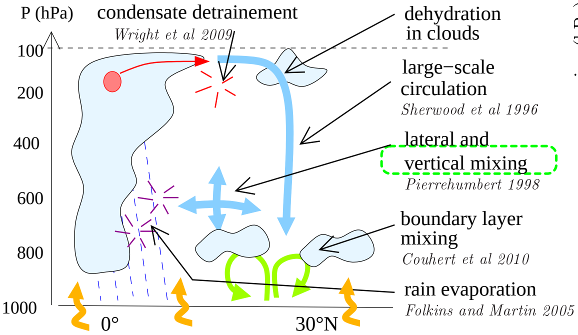

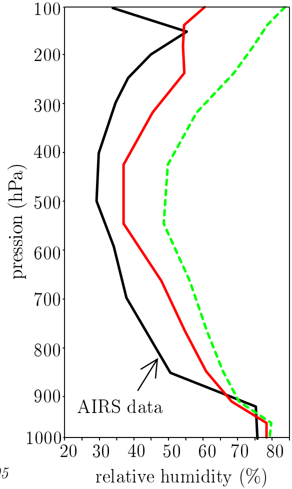

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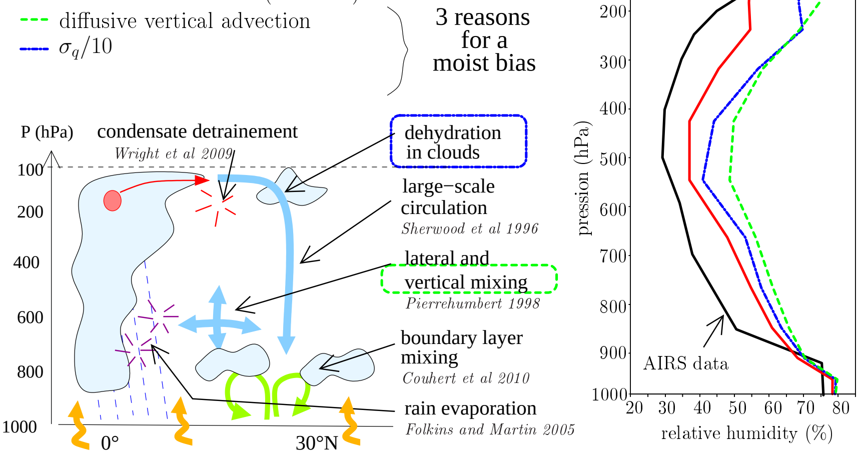

Sensitivity tests to RH processes

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- $\epsilon_p/2$

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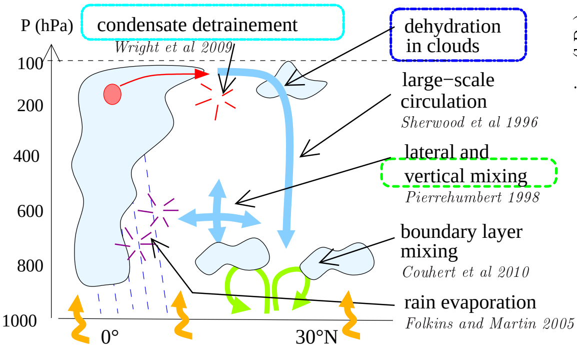
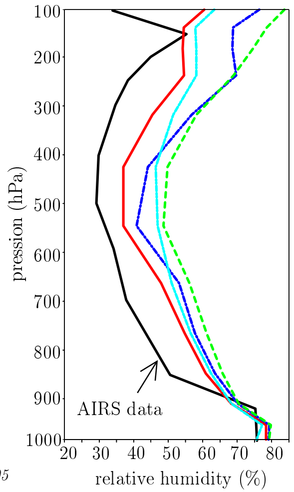
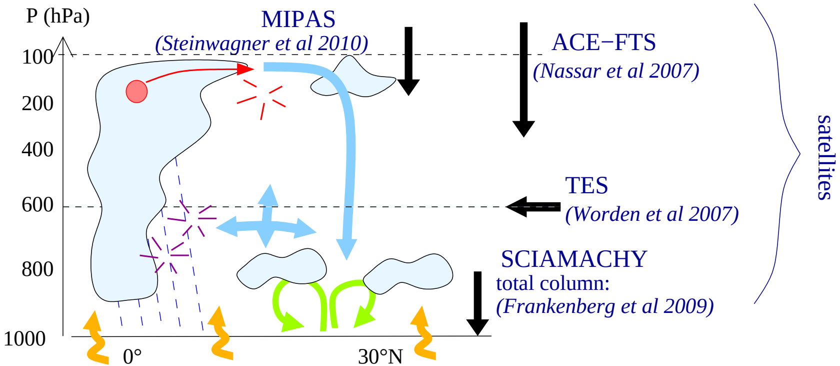




Isotopic measurements



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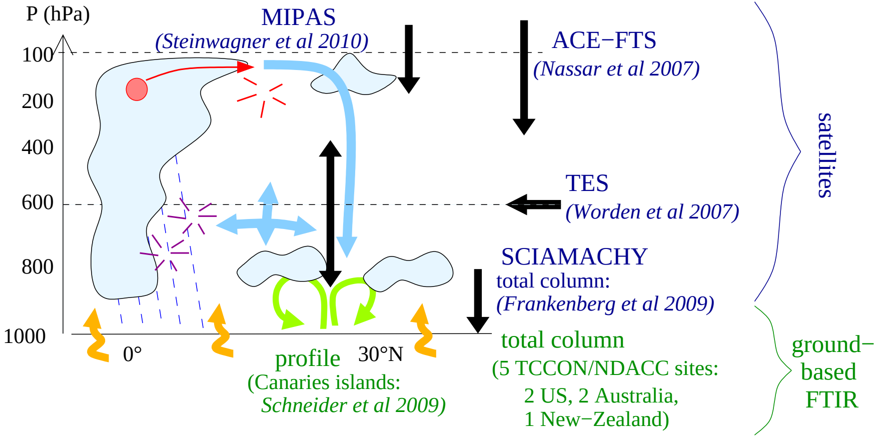

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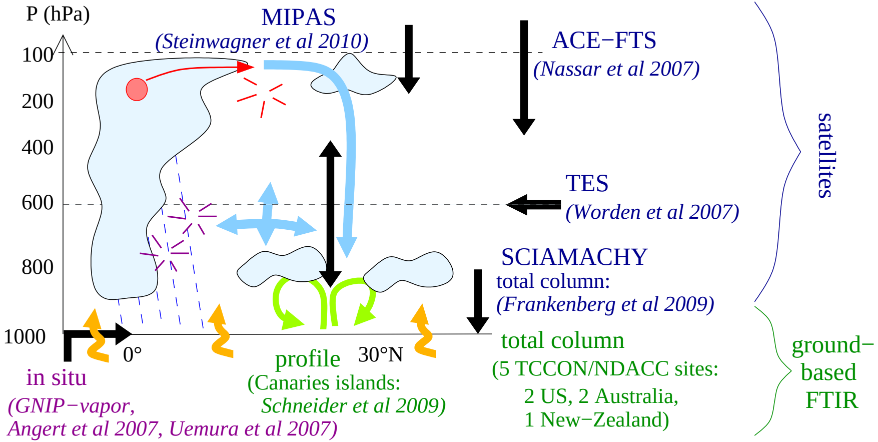

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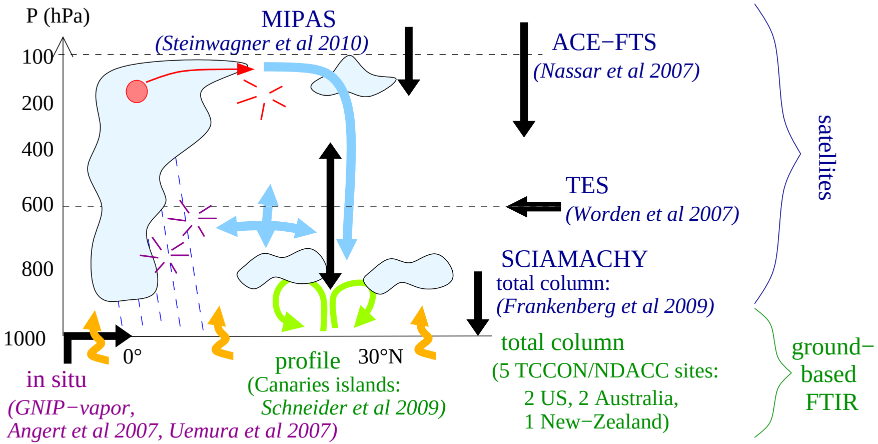
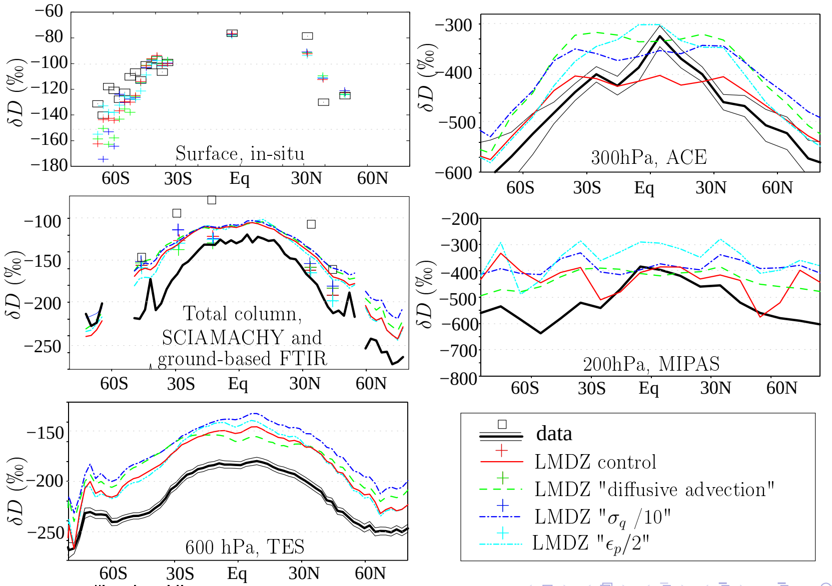
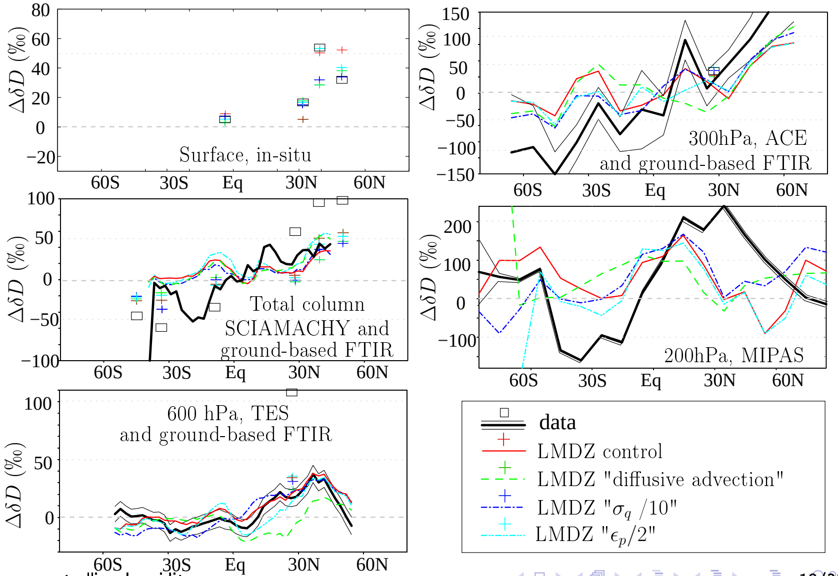


- model-data comparison: collocation; simulations nudged by ECMWF; averaging kernels; spatial/temporal variations

Zonal anual mean



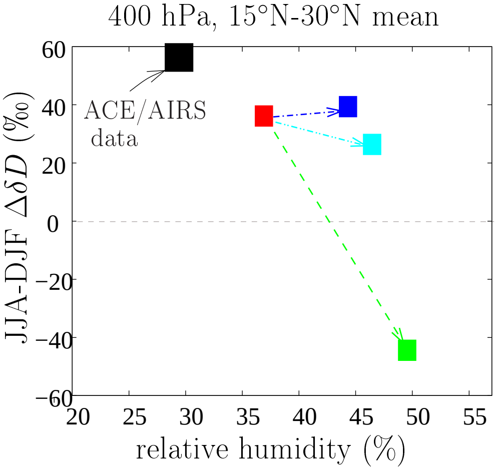
Zonal Seasonal variations (JJA-DJF)



What causes the moist biases in GCMs?

Sensitivity tests:
with LMDZ:

- Control
- Excessively diffusive vertical advection
- Excessive condensate detrainement
- Insufficient in-situ condensation



What causes the moist biases in GCMs?

Sensitivity tests:
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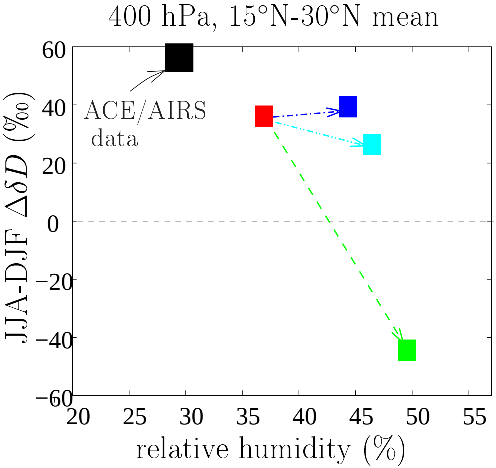
- Control (red)
- Excessively diffusive vertical advection (green)
- Excessive condensate detrainement (cyan)
- Insufficient in-situ condensation (blue)



- robustness? additional tests, theoretical understanding

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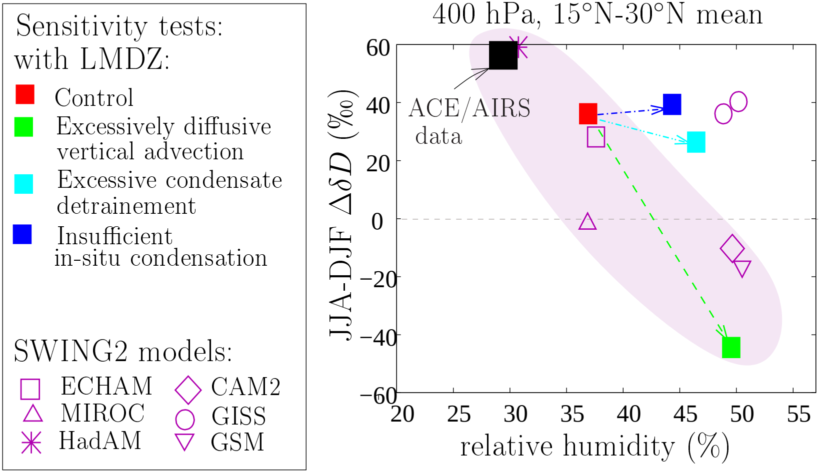
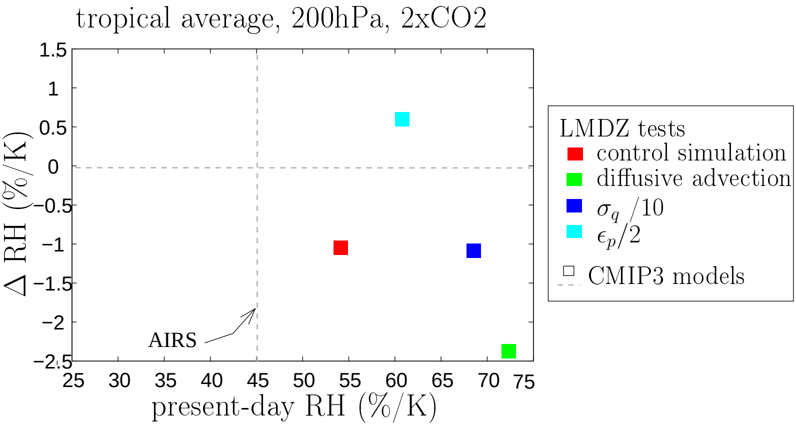


- robustness? additional tests, theoretical understanding
- frequent reason for moist bias=excessively diffusive advection

What impact on humidity projections?



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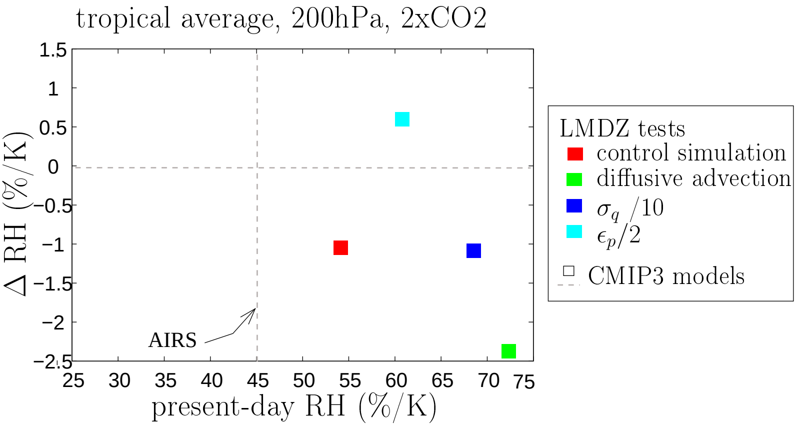

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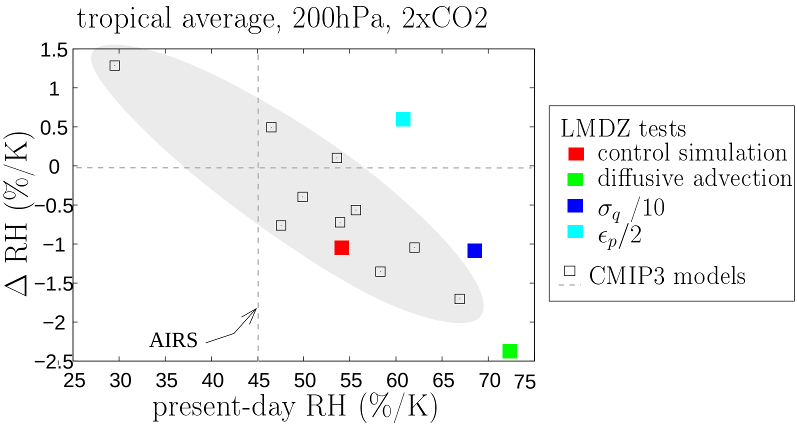

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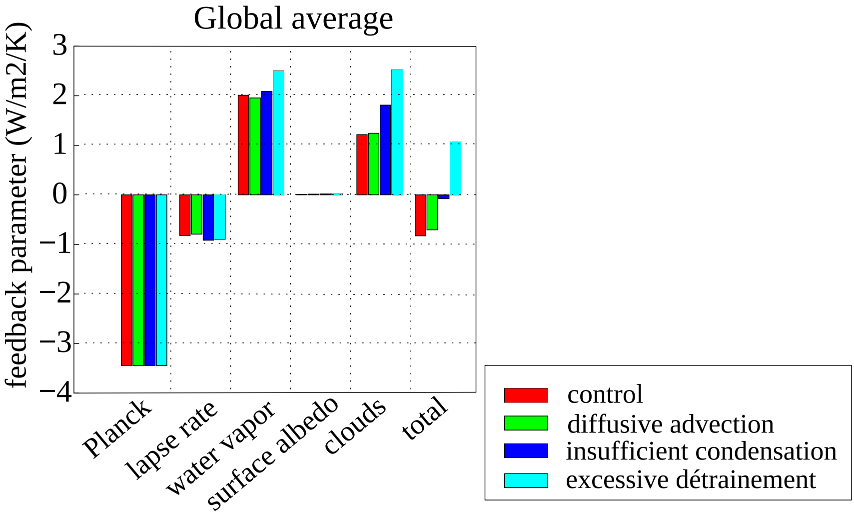
What impact on climate sensitivity?

- radiative kernel decomposition (*Soden et al 2008*)



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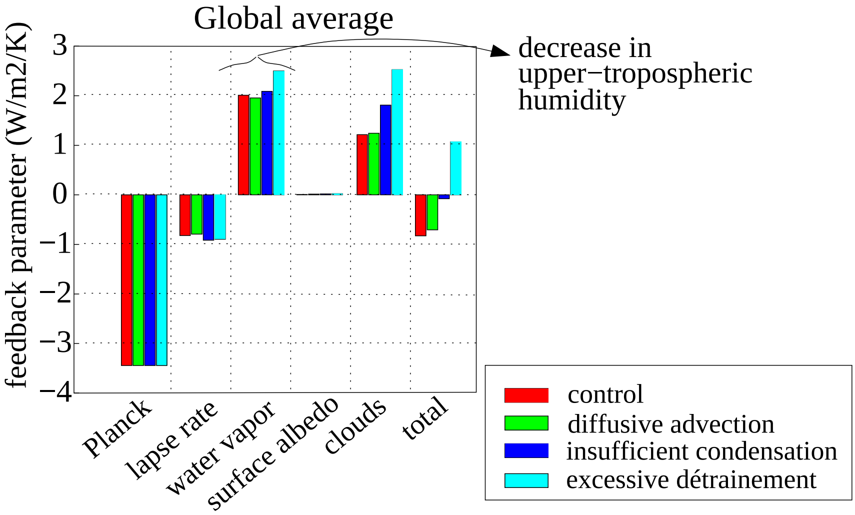

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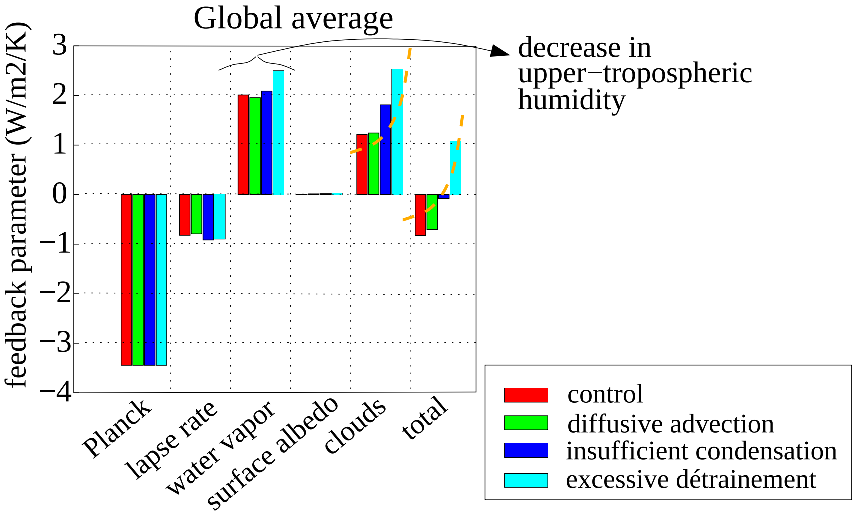

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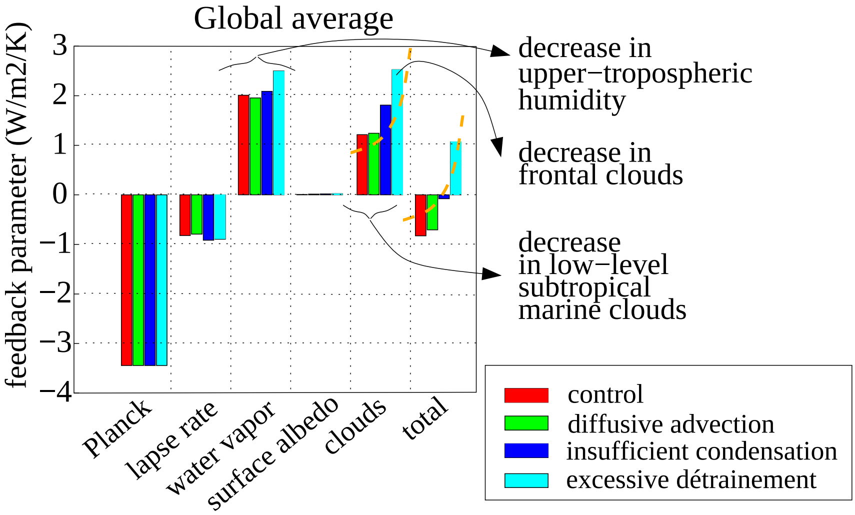

Summary on relative humidity

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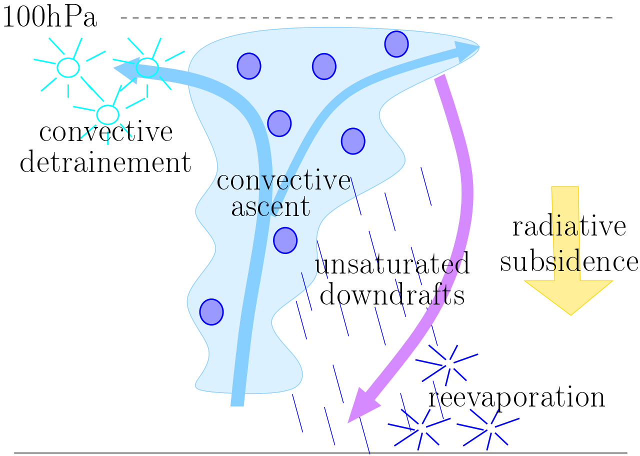
- Consequences on climate change complicated by dynamical and cloud feedbacks

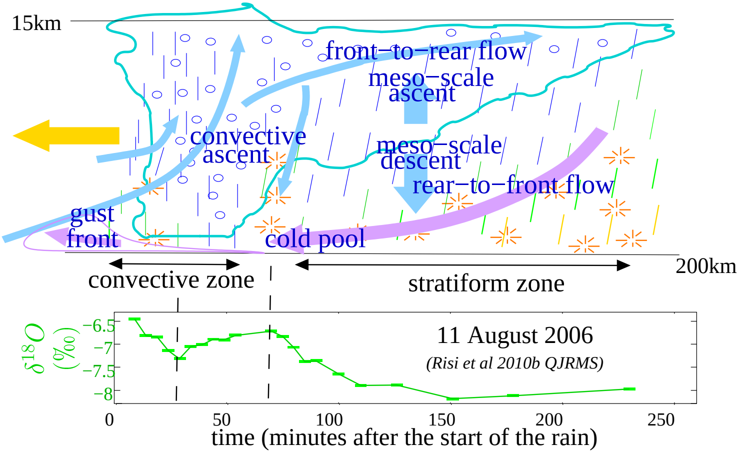
2) Convective processes

- microphysical processes? (*Emanuel and Pierrehumbert 1996*)



Processes along squall lines

- rain sampled every 5 mins in Niamey during AMMA campaign



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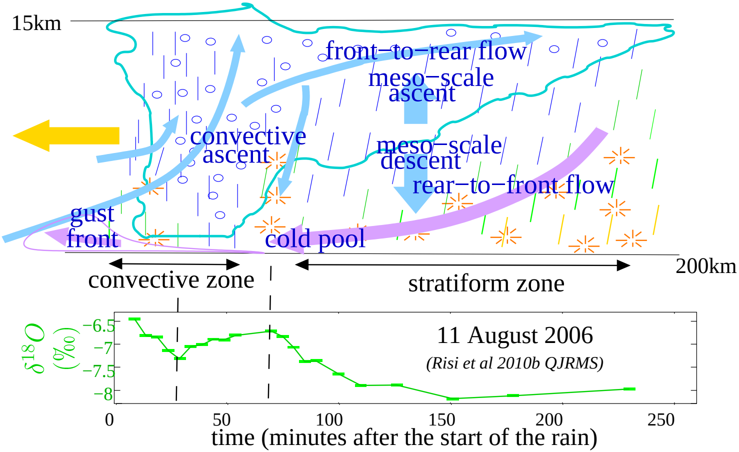

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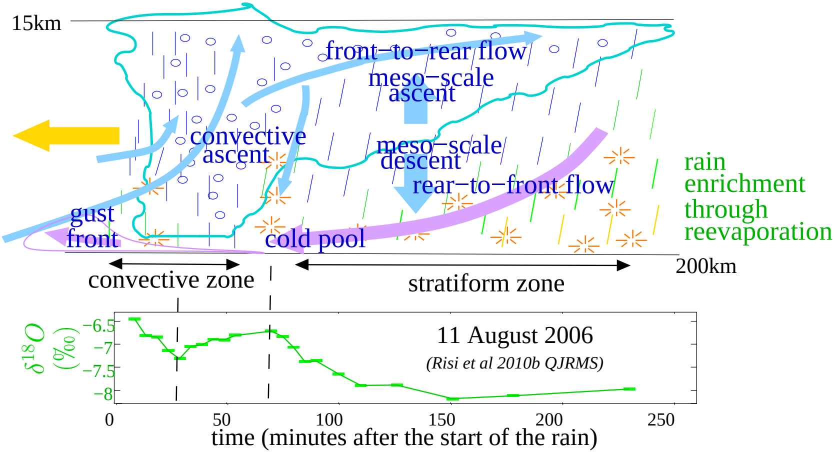

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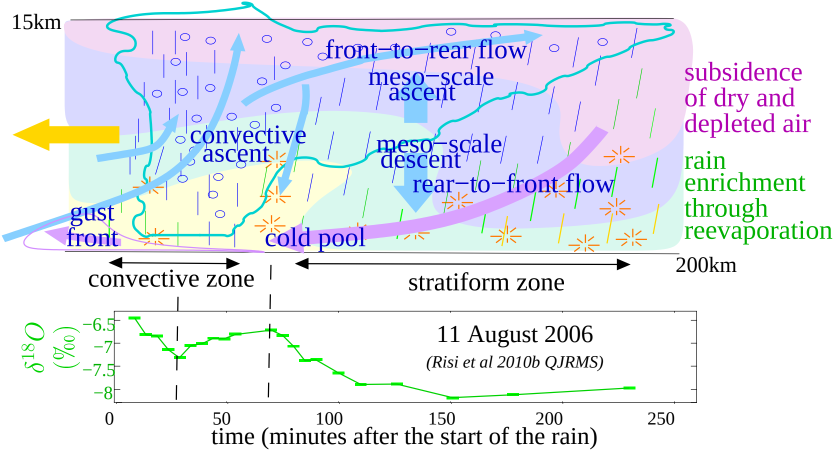
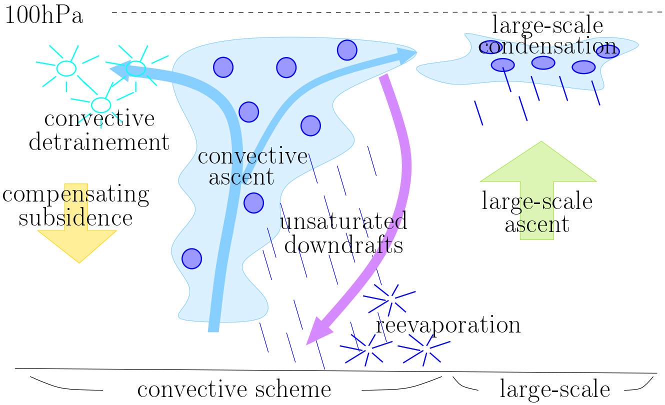


Convective/large-scale fluxes



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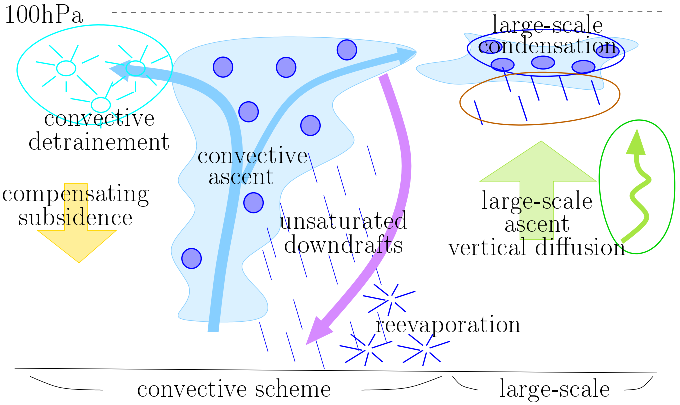
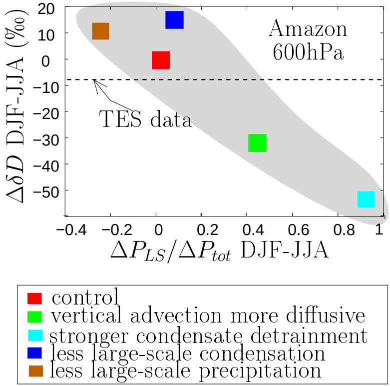


Sensitivity tests with LMDZ:
- control: AR4
- more diffusive vertical advection
- stronger condensate detrainement
- less large-scale condensation
- less large-scale precipitation

Convective contribution to water budget



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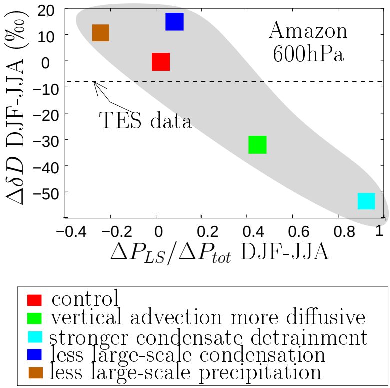

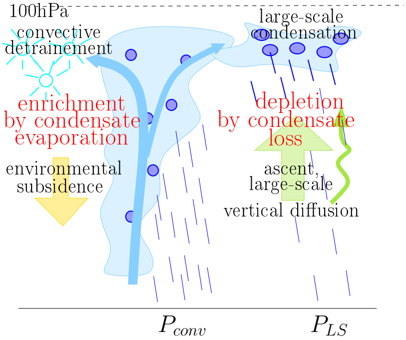

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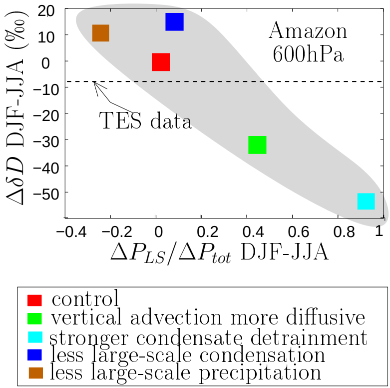
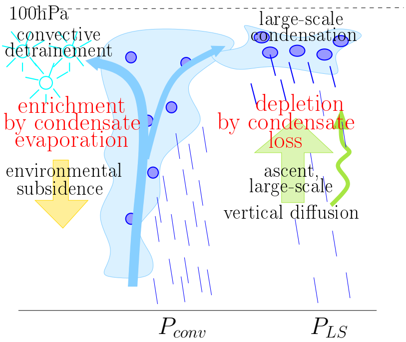
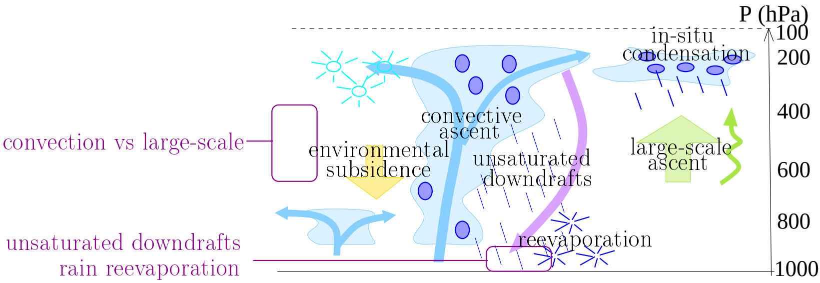




- P_{LS}/P_{tot} ill-defined quantity, but influences cloudiness, intra-seasonal variability, chemical tracor transport

Summary on convection



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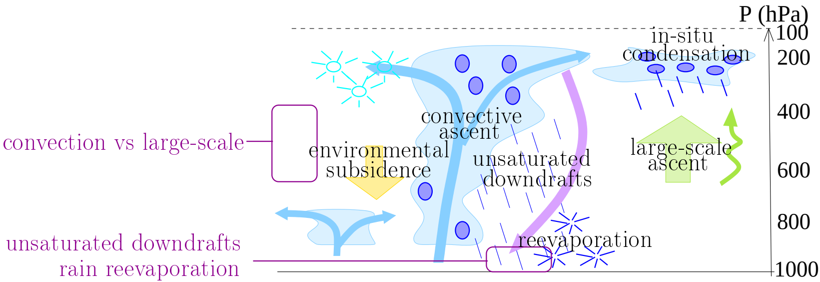

- Perspectives:
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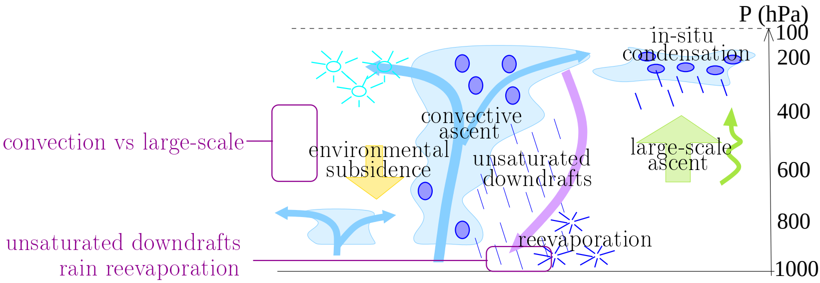

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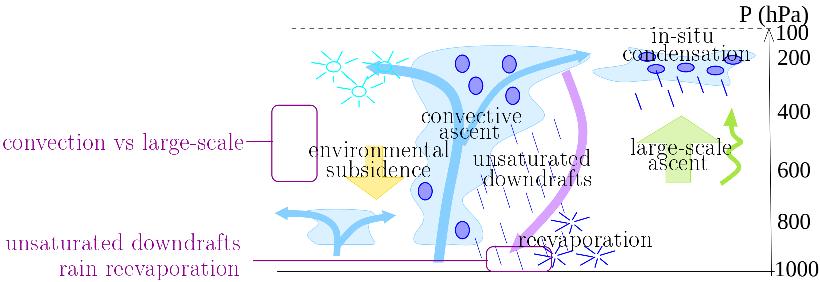

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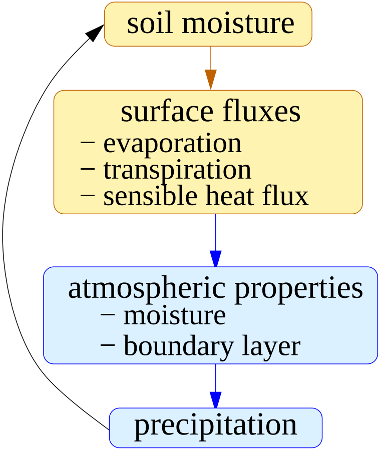
  - impact of misrepresentation of convective processes on precipitation changes?

3) Land atmosphere feedbacks



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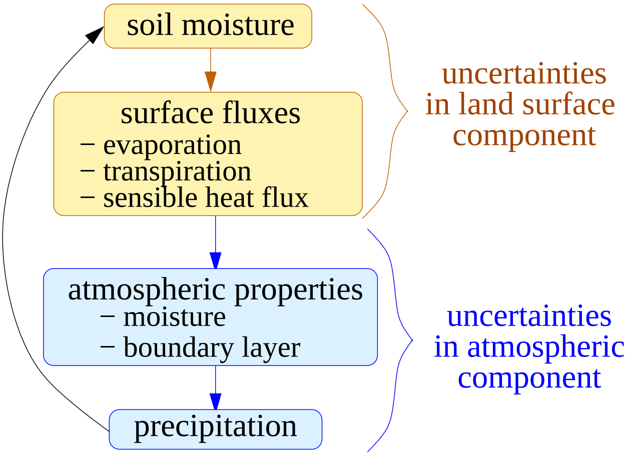

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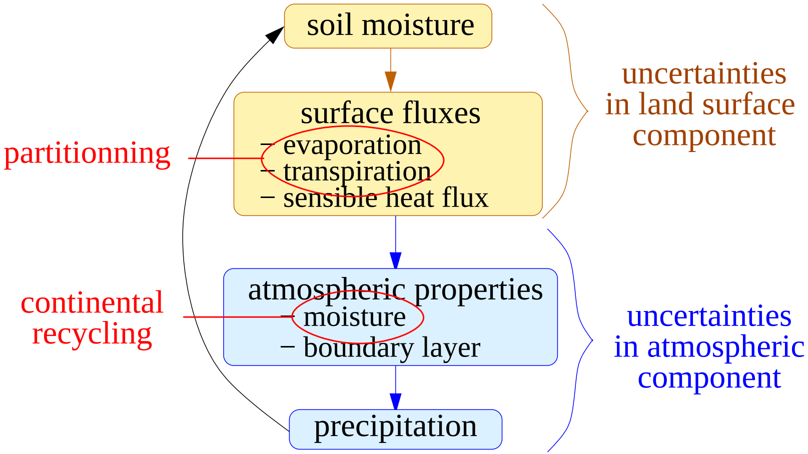
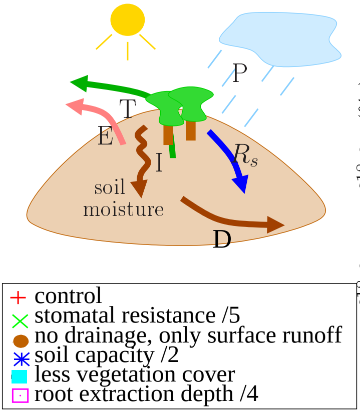
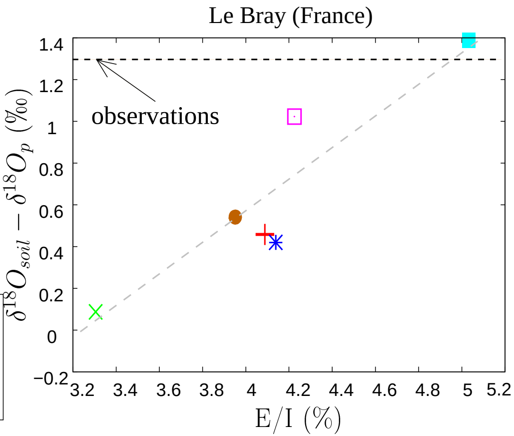


Evapo-transpiration partitioning

- ORCHIDEE-iso land surface model *(Risi et al in rev,a)*





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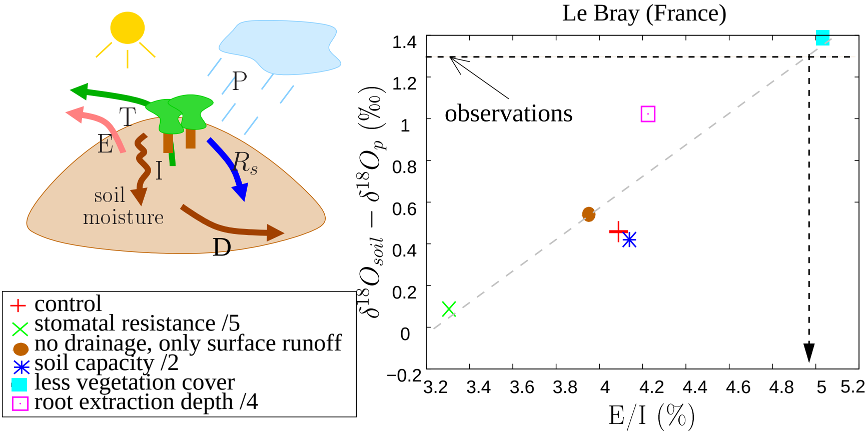

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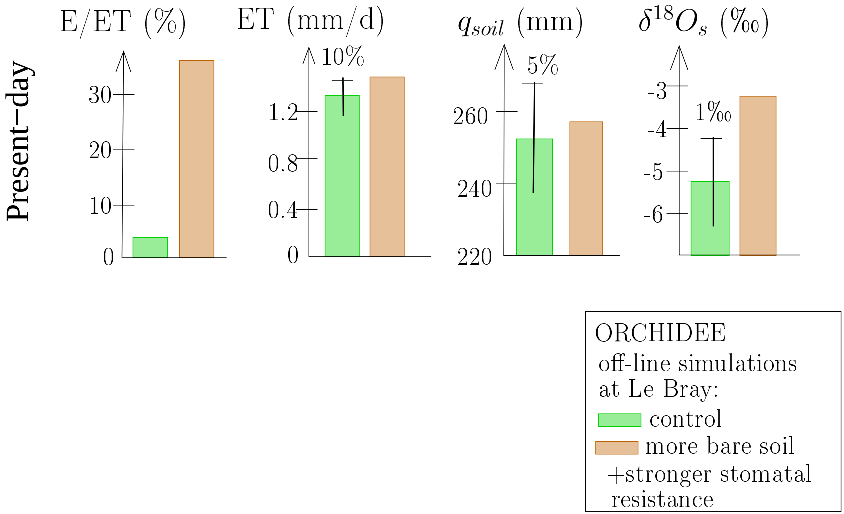

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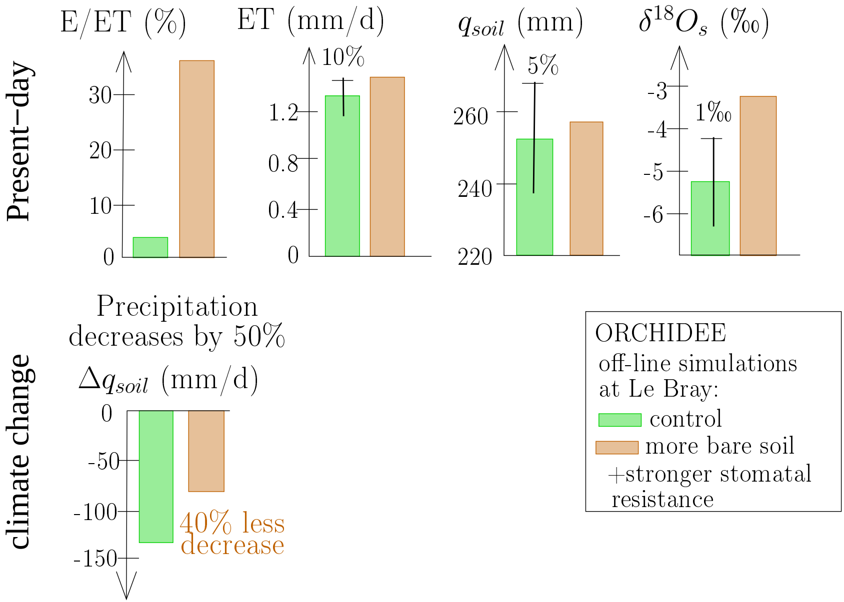

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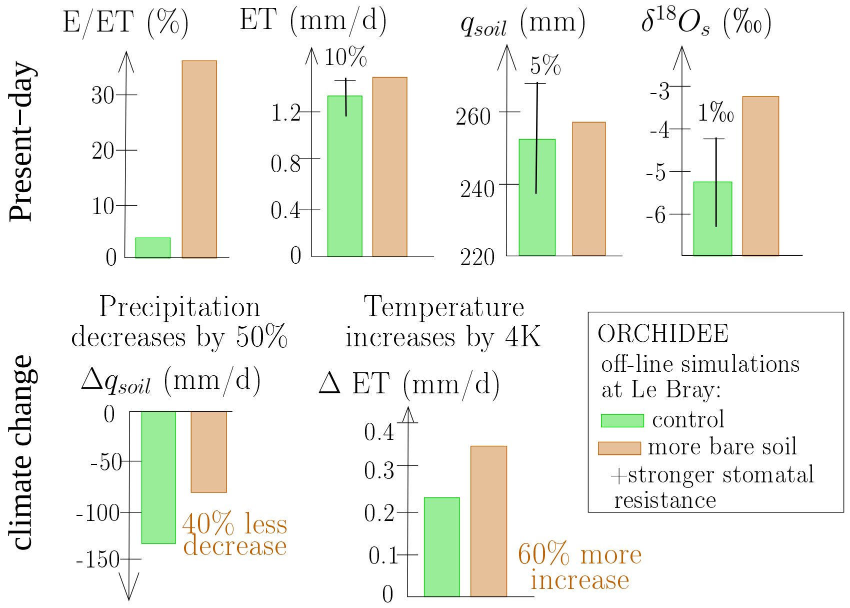
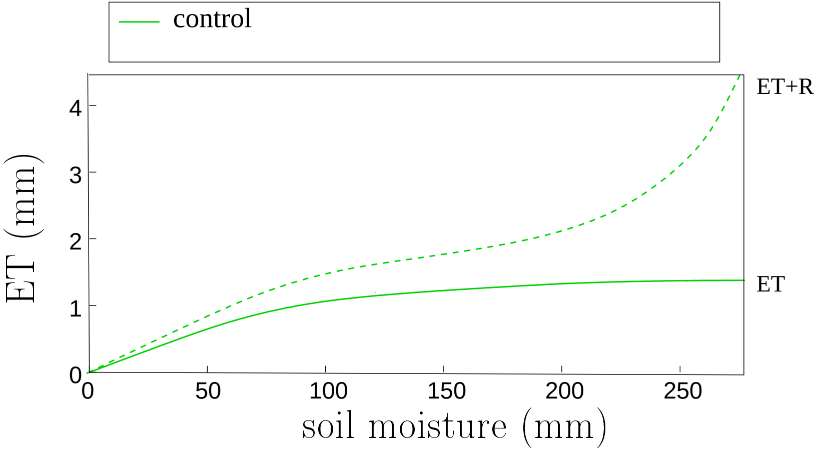


Impact on response to precipitation

Functional relationships (*Koster and Milly 1996*)



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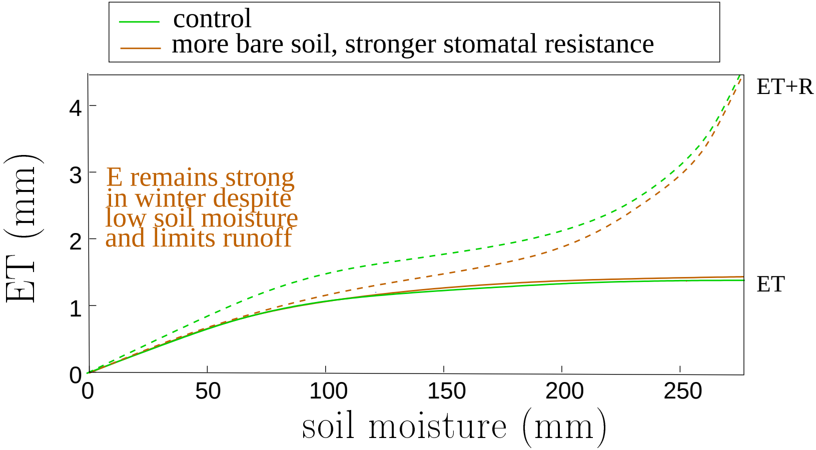

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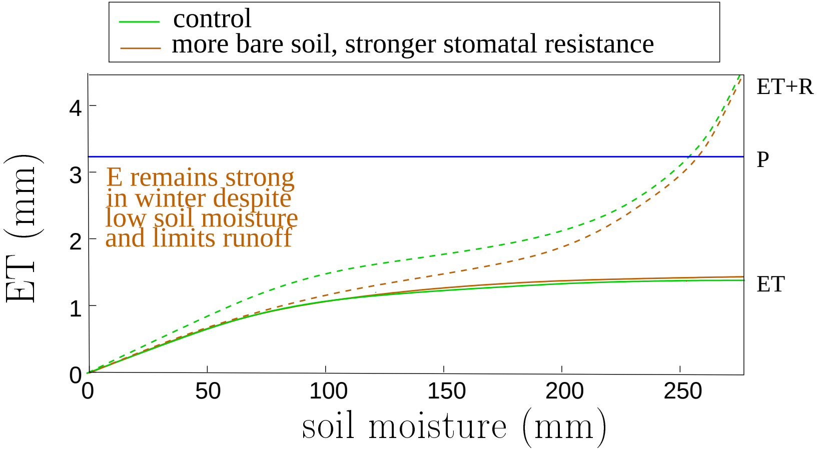

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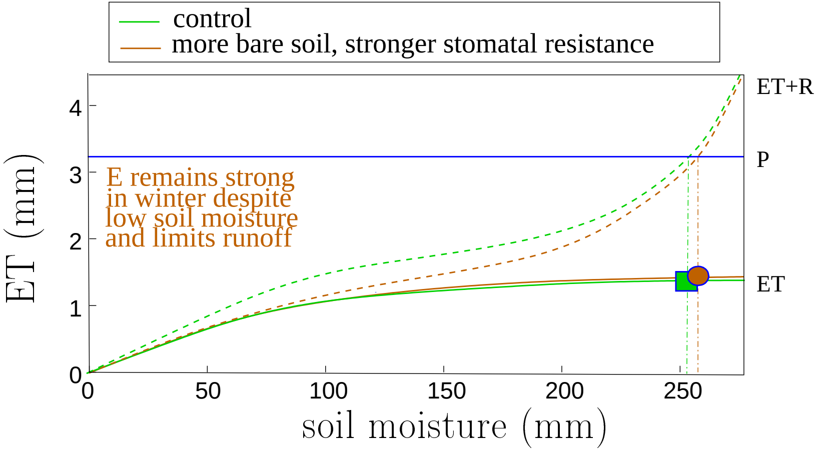

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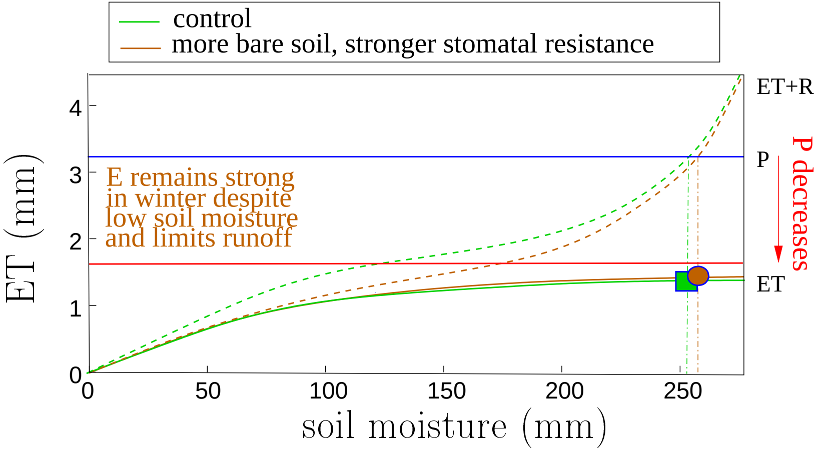

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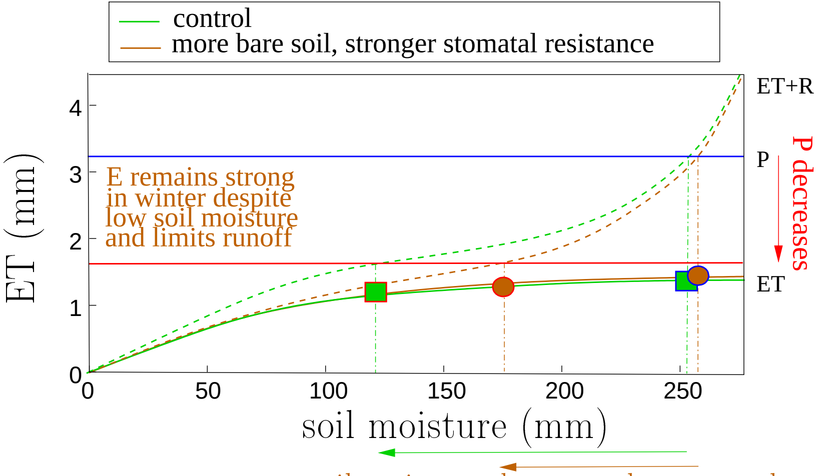

soil moisture decreases less strongly

Summary on evapo-transpiration partitioning

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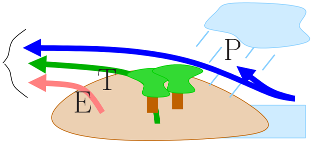
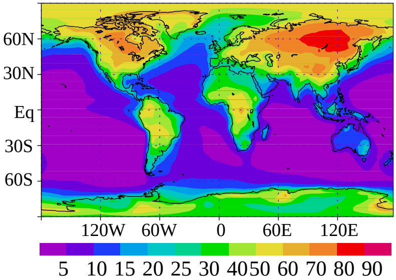
  - To what extent does it feedback on precipitation changes?

Isotopic signature of evaporative origin

Water tagging:





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

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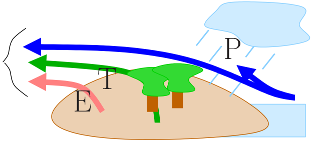

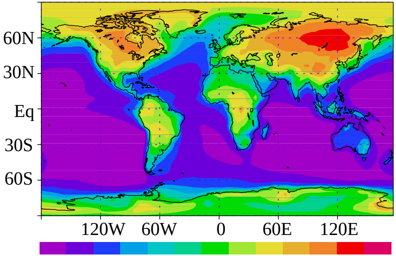

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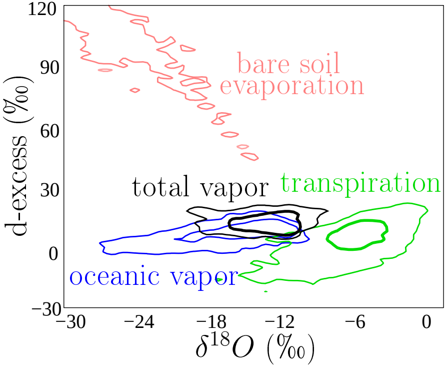
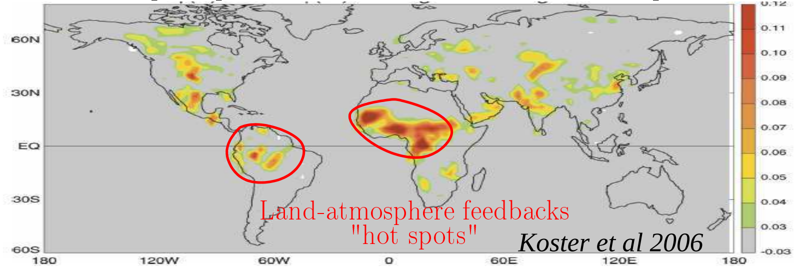


Water isotopes and continental recycling

decrease in precip variance when soil moisture is prescribed



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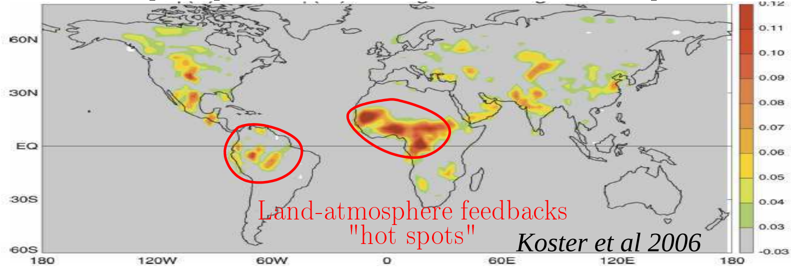
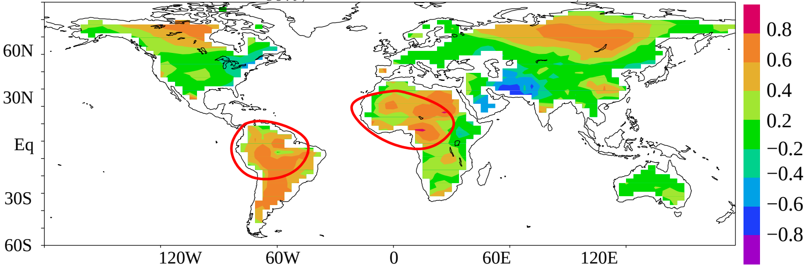
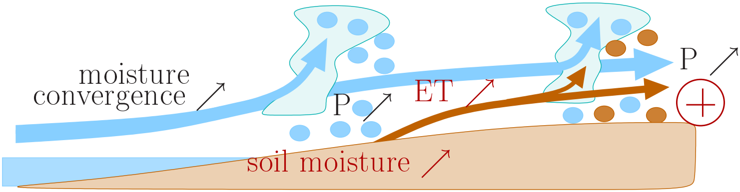


correlation $\delta^{18}O$ - r_{con}, intra-seasonal scale, annual mean



Diagnosing land-atmosphere feedbacks



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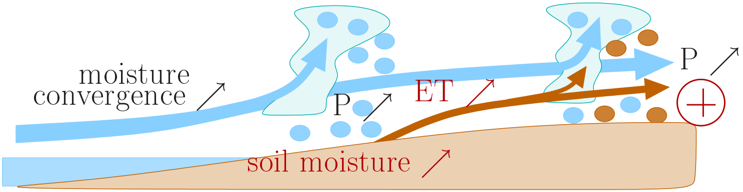

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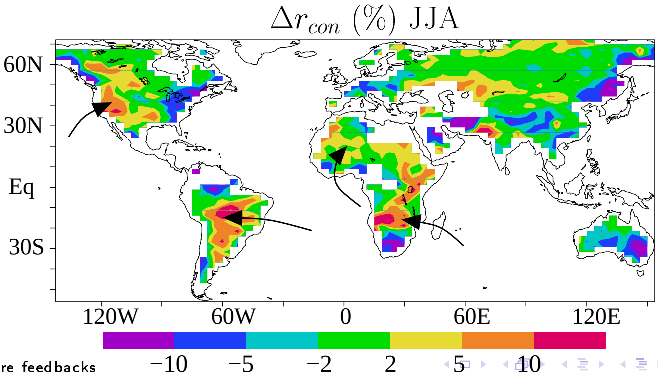
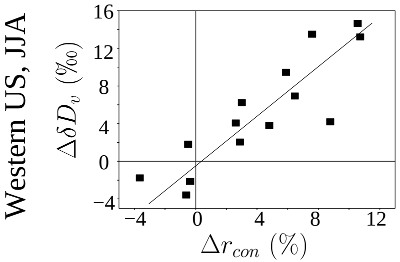
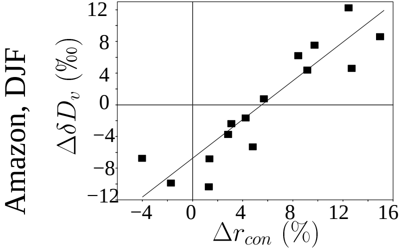


Isotopic signature of feedbacks





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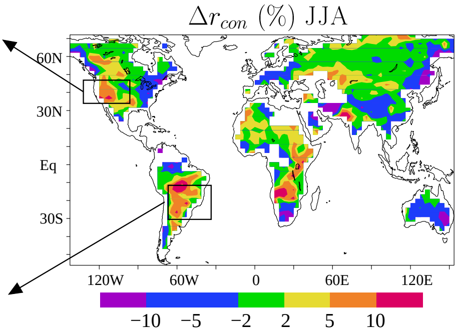
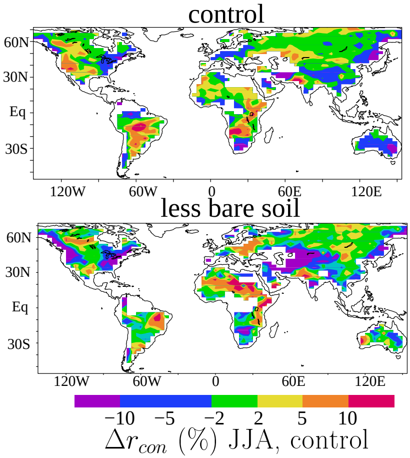


control by large-scale convergence

positive land-atmosphere feedback

Could we discriminate bewteen different simulated feedbacks?



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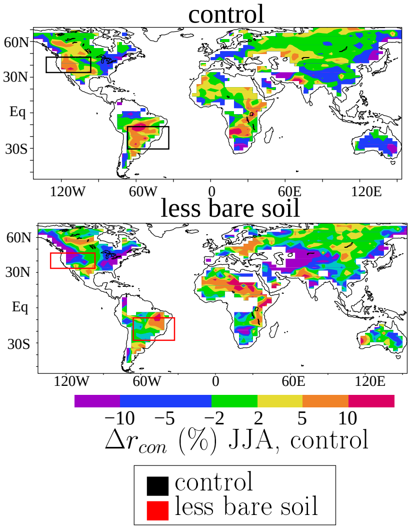

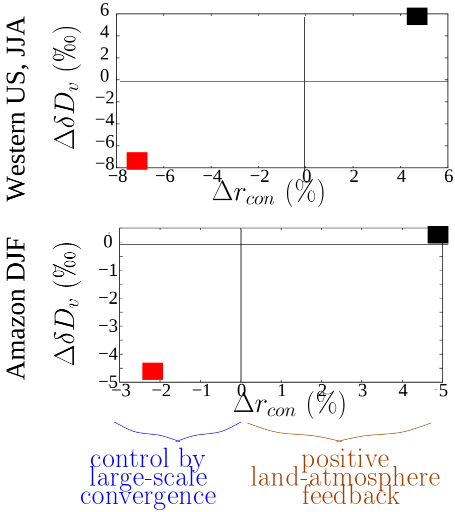

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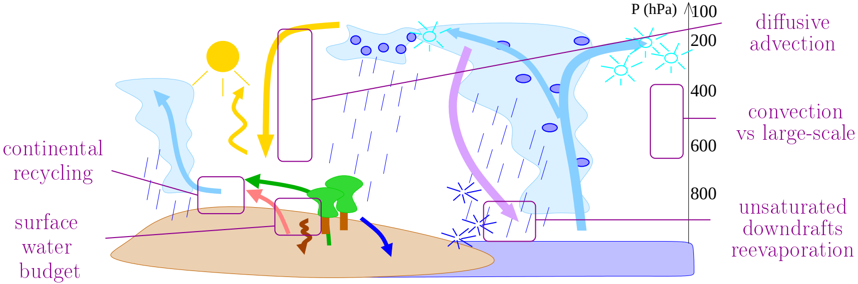
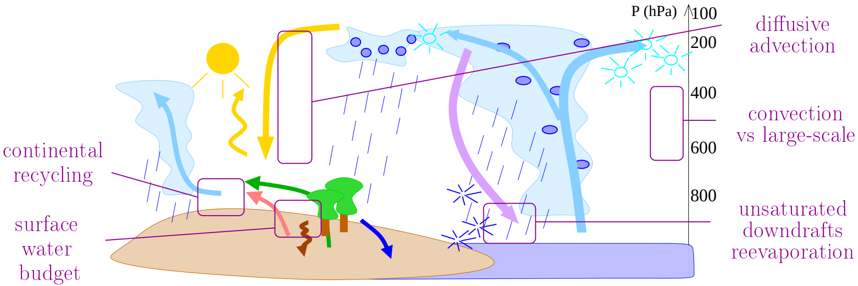
  - Relevance for hydrological projections?
    - Do some processes determine behavior at intra-seasonal scales, and in context of
      - global warming
      - land use change (deforestation, irrigation)

Conclusion



continental recycling
surface water budget
P (hPa)
100
200
400
600
800
diffusive advection
convection vs large-scale
unsaturated downdrafts reevaporation

Conclusion



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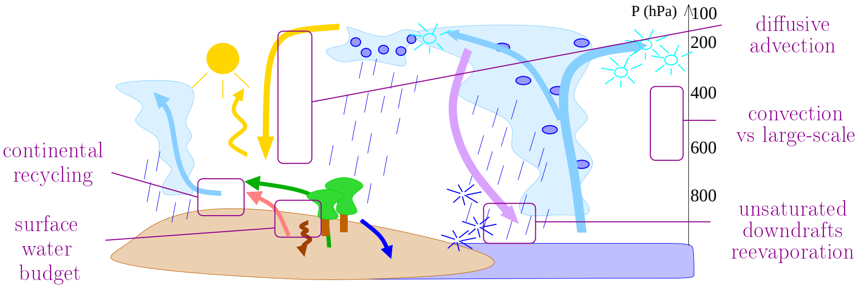
Conclusion



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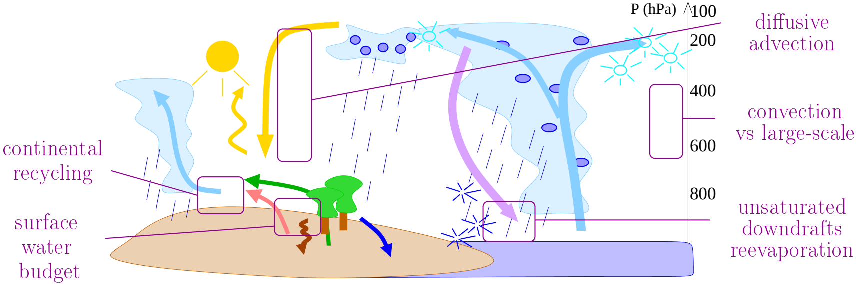

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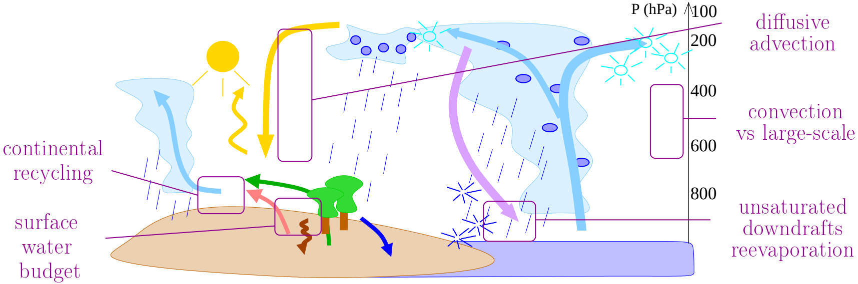

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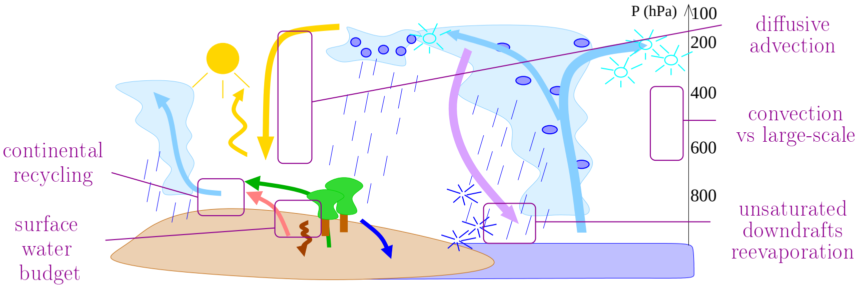

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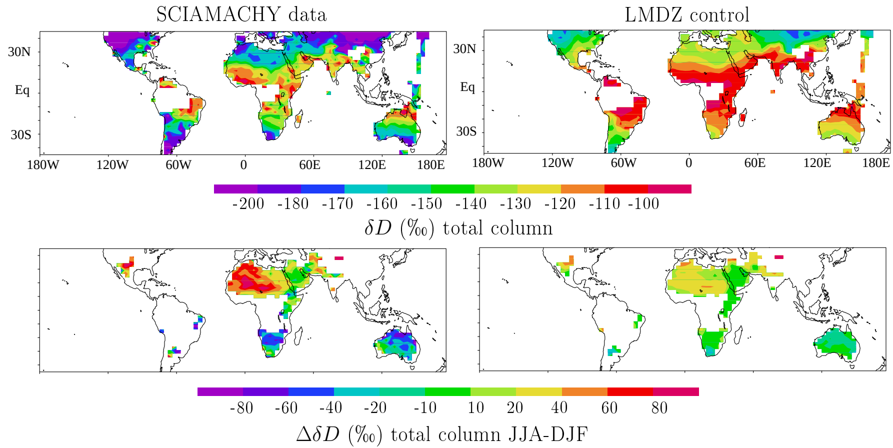
  - model inter-comparisons
  - process/feedbacks studies comparing models behavior for present climate and for projections

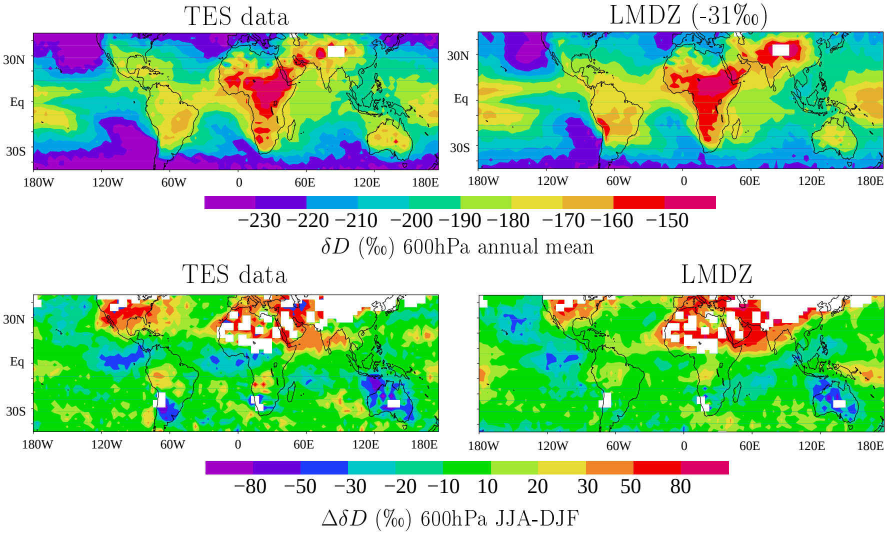
Suplementary material

Evaluation against SCIAMACHY

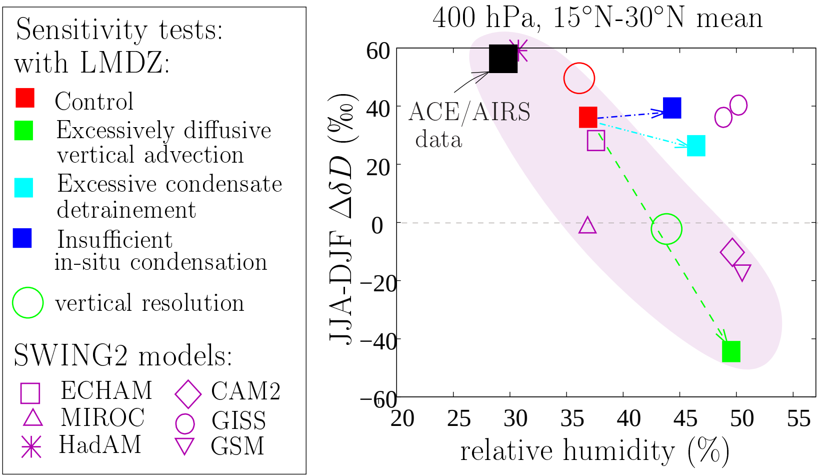


Risi et al in rev,b

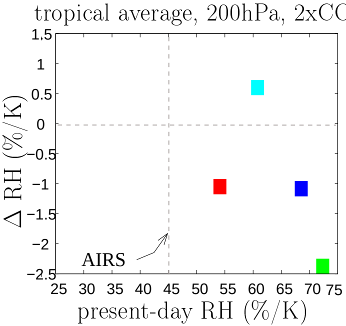
Evaluation against TES

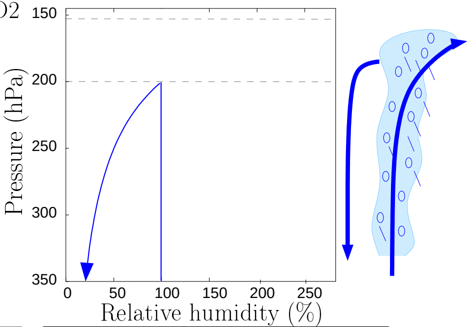


What causes the moist bias?



Consequences on projections



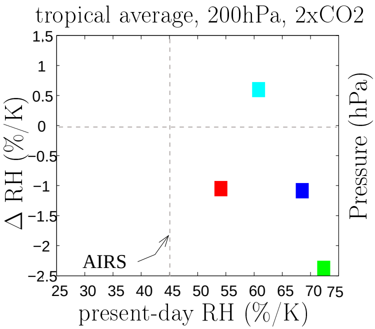


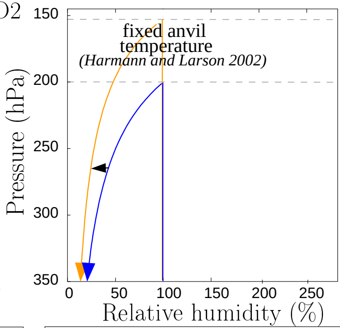
LMDZ tests
- control simulation
- diffusive advection
- σ_q /10
- $\epsilon_p/2$

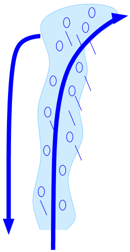
Everything precipitates:

— present

Consequences on projections



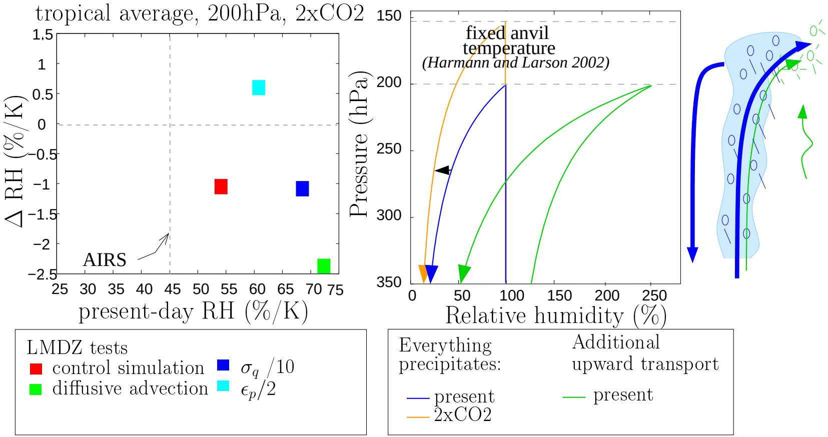




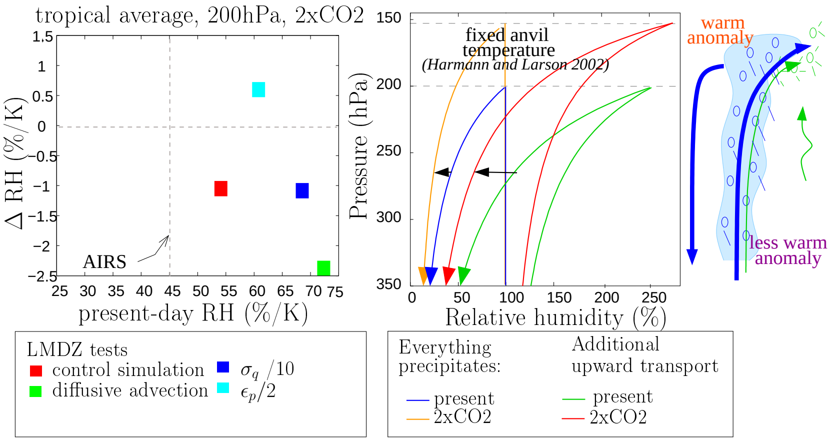
LMDZ tests
- control simulation
- diffusive advection
- σ_q /10
- $\epsilon_p/2$

Everything precipitates:
- present
- 2xCO2

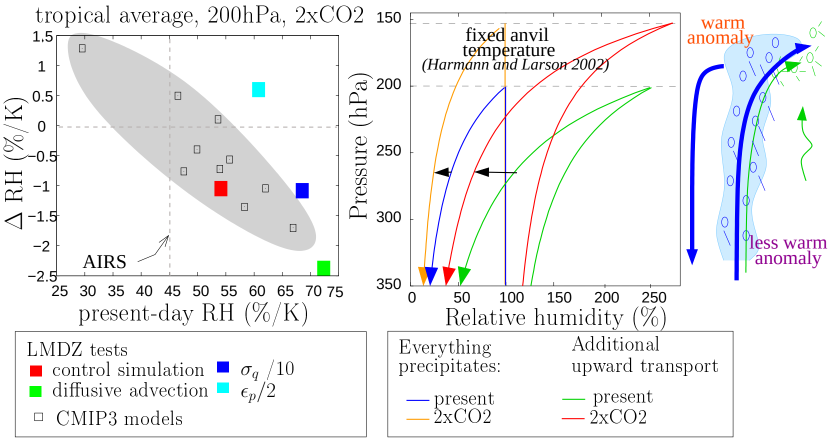
Consequences on projections



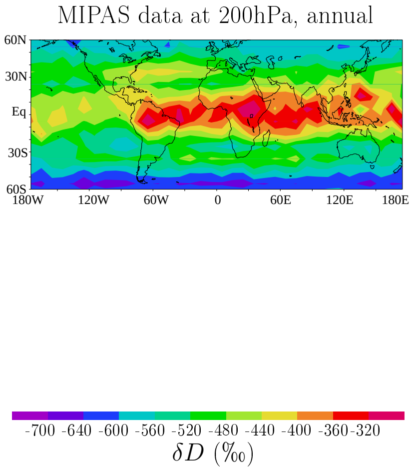
Consequences on projections



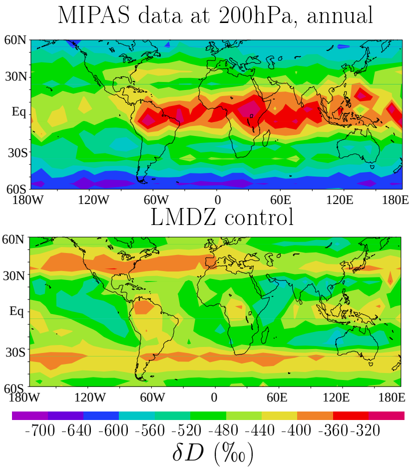
Consequences on projections



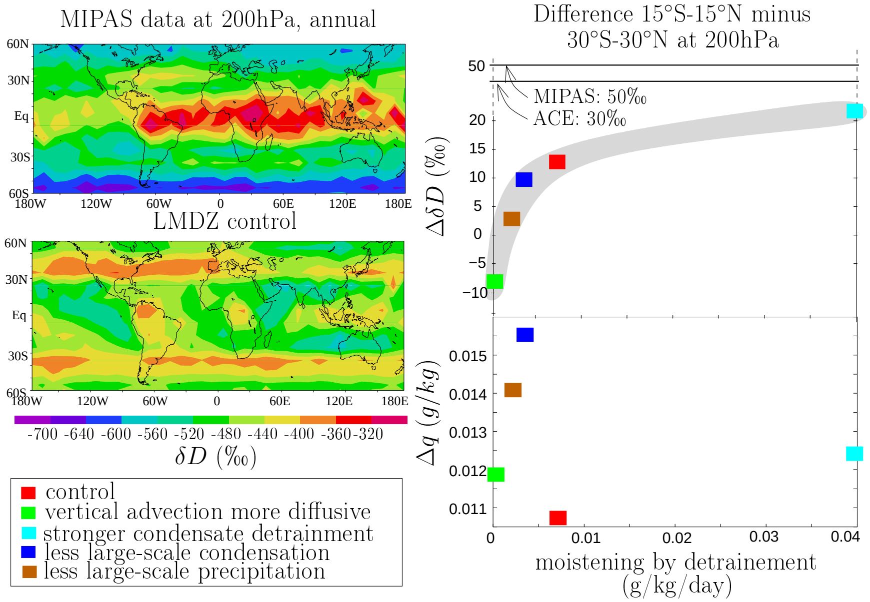
Upper troposphere detrainment



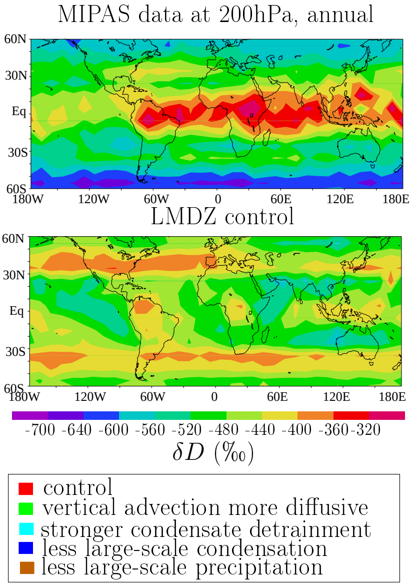
Upper troposphere detrainment

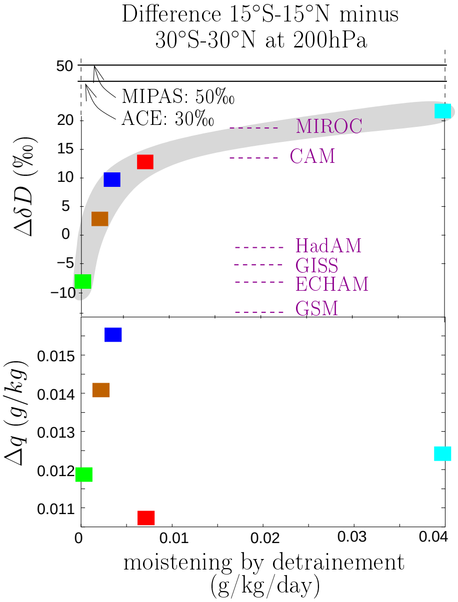


Upper troposphere detrainment

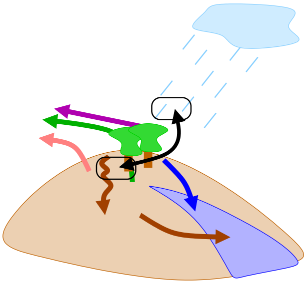


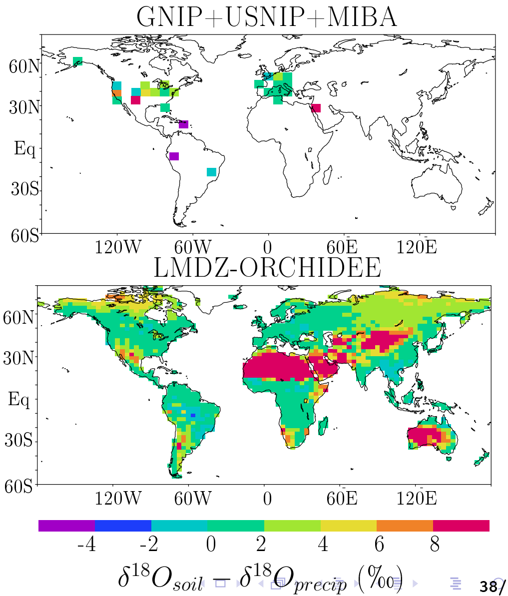
Upper troposphere detrainment





Soil water isotopes





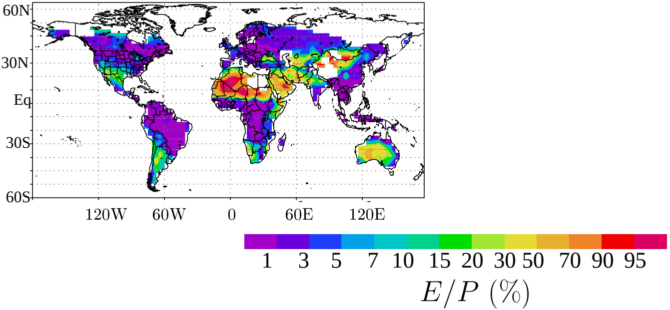
Estimating evapotranspiration partitioning

$\delta^{18}O_{soil} - \delta^{18}O_p$

$\delta^{18}O_v$

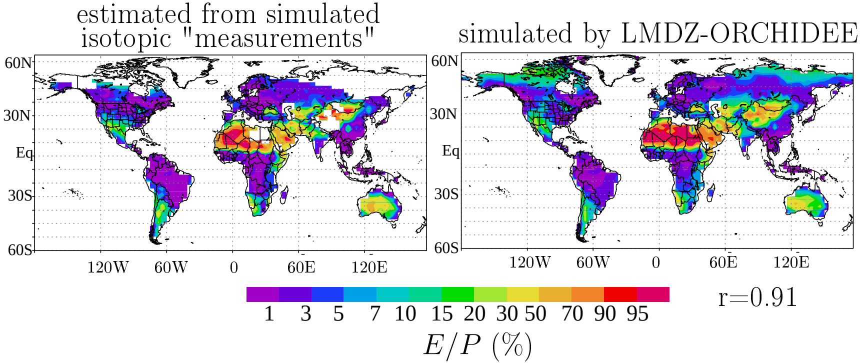
RH, T

estimated from simulated isotopic "measurements"

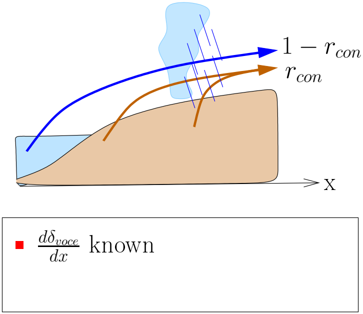


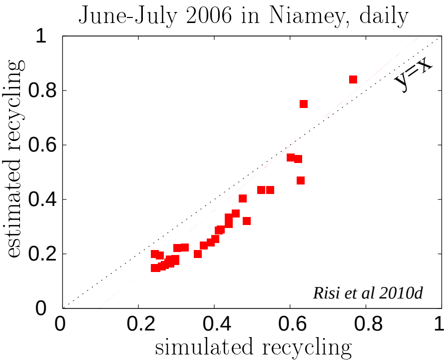
Estimating evapotranspiration partitioning

$$\delta^{18}O_{soil} - \delta^{18}O_p$$
$$\delta^{18}O_v$$
RH, T



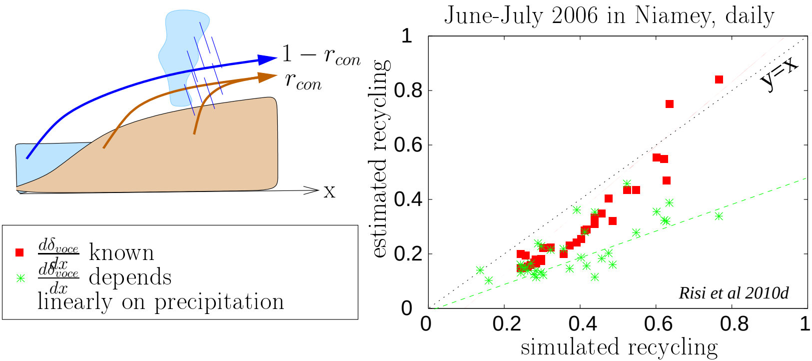
Estimating continental recycling





$$d\left(\frac{r_{con}}{1-r_{con}}\right)/dx = \frac{d\delta_v/dx - d\delta_{voce}/dx}{\delta_p - \delta_v}$$

Estimating continental recycling



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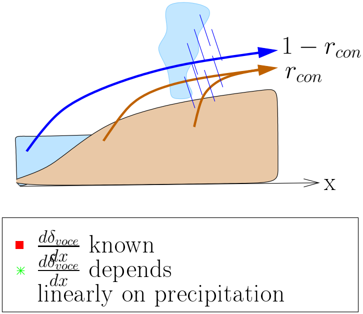
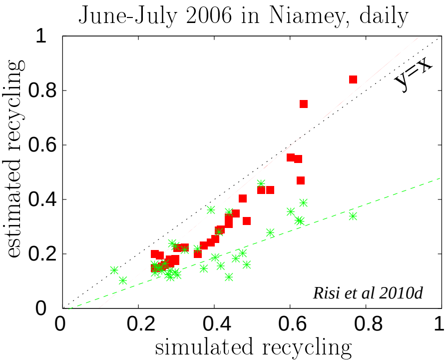
Estimating continental recycling

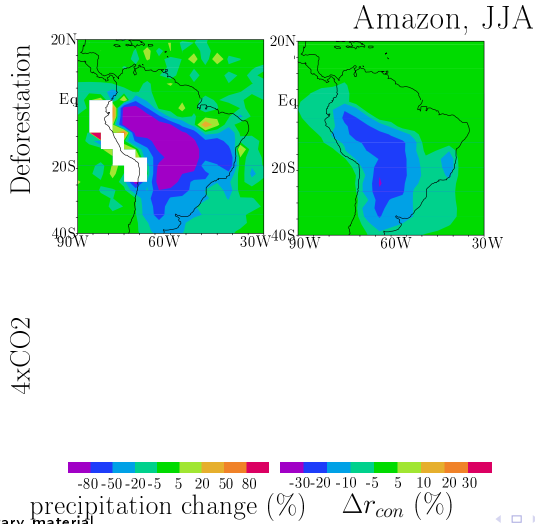




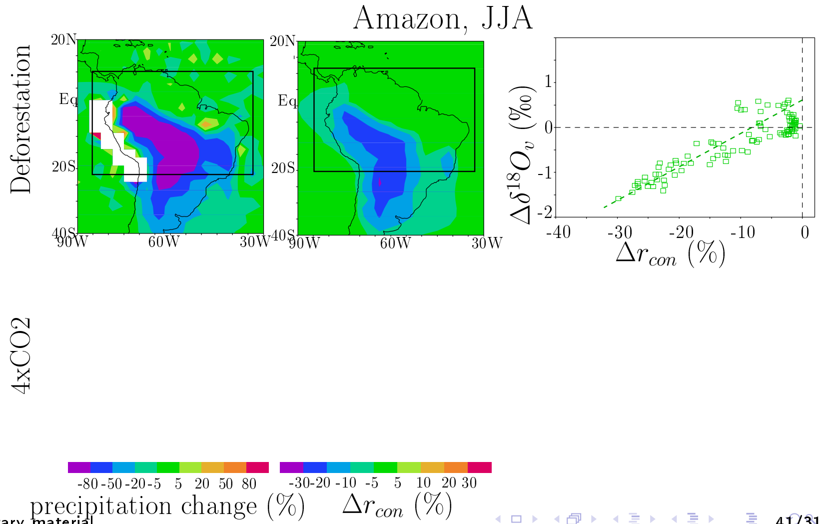
$$d\left(\frac{r_{con}}{1 - r_{con}}\right)/dx = \frac{d\delta_v/dx - d\delta_{voce}/dx}{\delta_p - \delta_v}$$

- Main limitation in using vapor isotopic measurements for continental recycling: understanding atmospheric controls

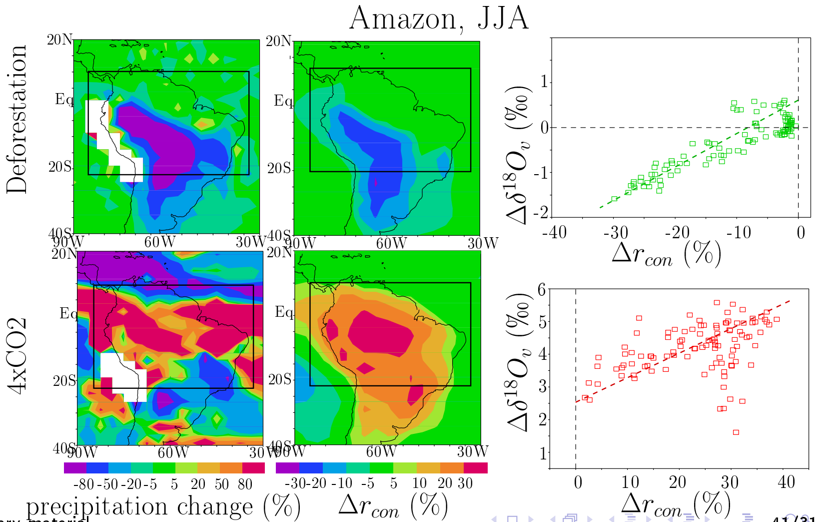
Monitoring land-atmosphere feedbacks related to land use change or global warming



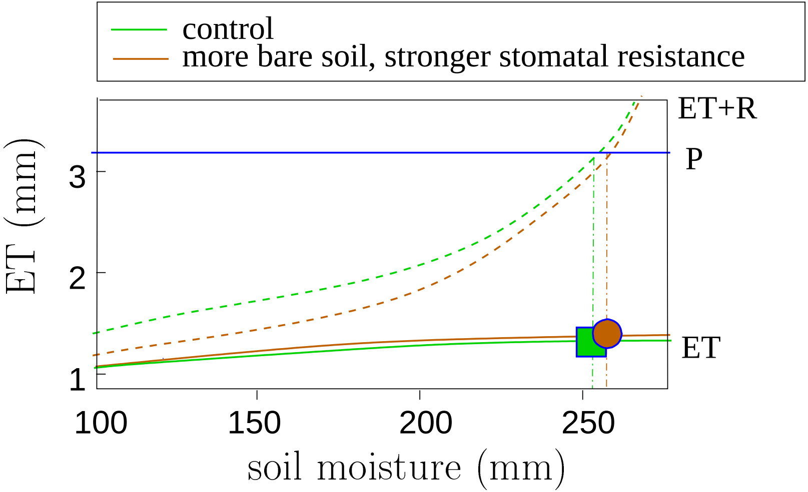
Monitoring land-atmosphere feedbacks related to land use change or global warming



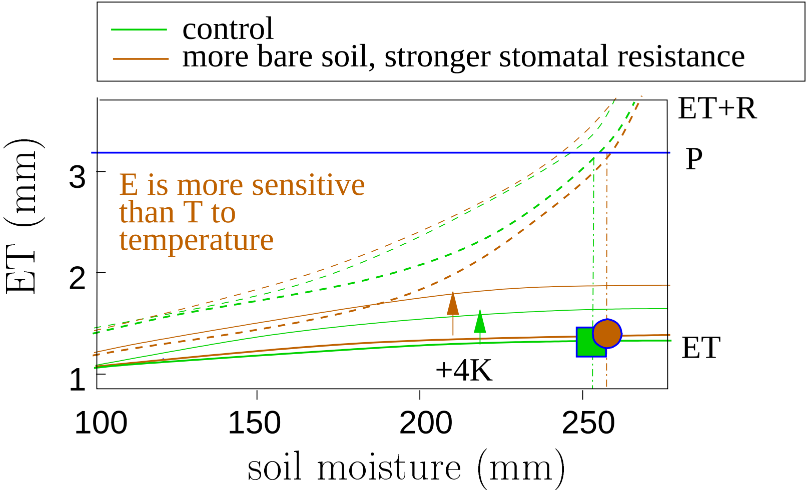
Monitoring land-atmosphere feedbacks related to land use change or global warming



Impact on response to temperature



Impact on response to temperature



Impact on response to temperature