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

Camille Risi

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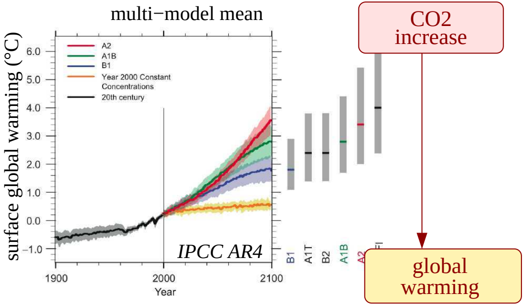
SCIAMACHY: C Frankenberg,
MIPAS: G Stiller, M Kiefer, B Funke
ACE-FTS: K Walker, P Bernath,
FTIR: M Schneider, D Wunch, P Wennberg,
V Sherlock, N Deutscher, D Griffith
in-situ: R Uemura, D Yakir
SWING2: C Sturm
MIBA: J. Ogée, T. Bariac, L. Wingate, N. Raz-Yaseef

CDG seminar at NCAR, 5 April 2011

Uncertainties in climate projections



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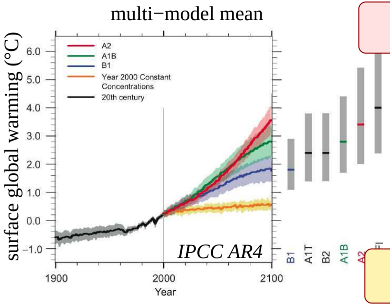


CO2 increase

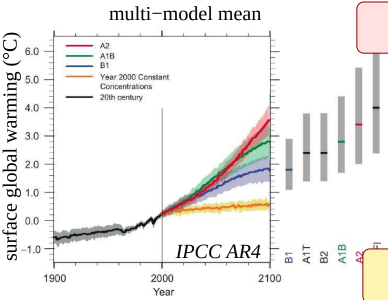
climate feedbacks (clouds, water vapor)

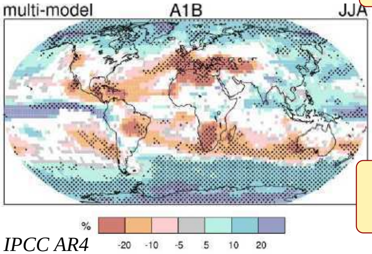
global warming

Uncertainties in climate models

- clouds
- relative humidity
- deep convection
- shallow convection
- boundary layer

Uncertainties in climate projections





precipitation change by 2099 (%)

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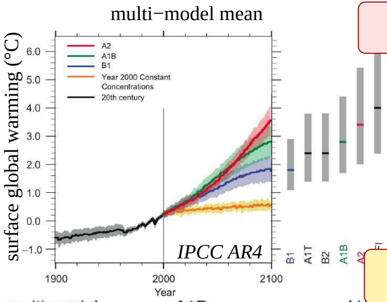
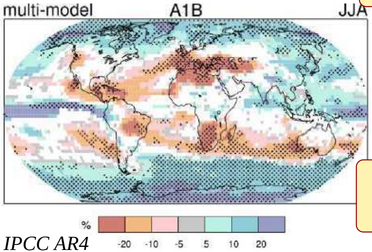
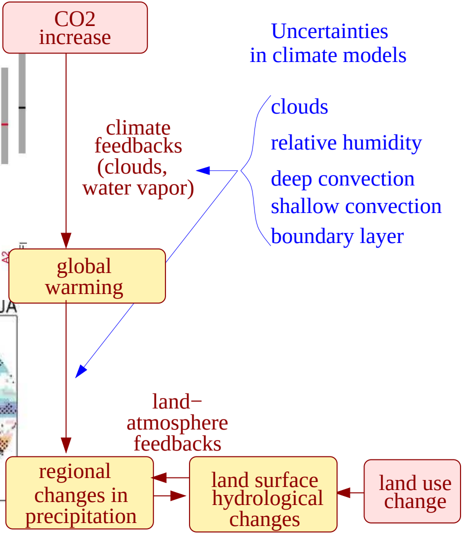




IPCC AR4
precipitation change by 2099 (%)



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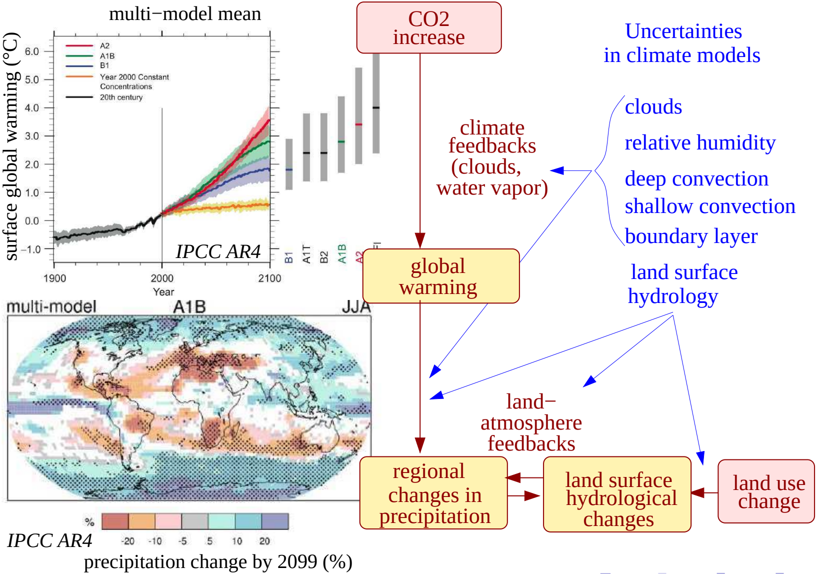
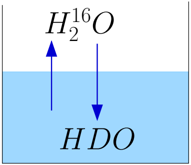


Water isotopic composition

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



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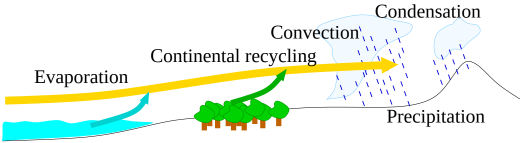

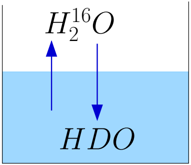

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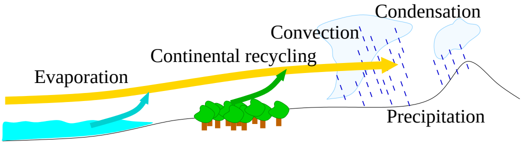

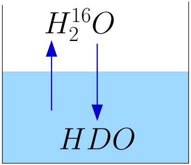

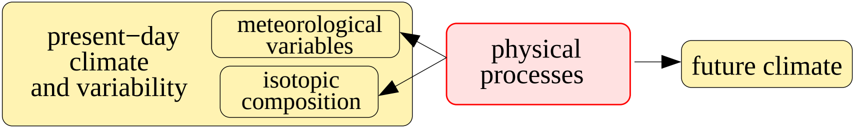

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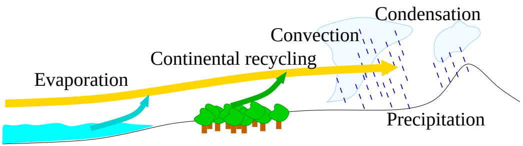

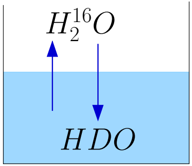

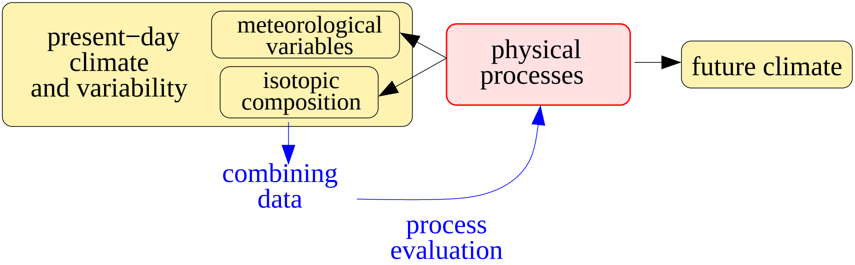

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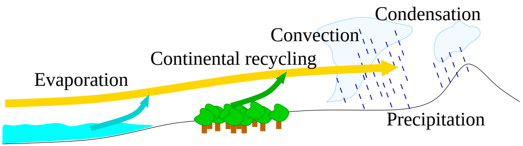
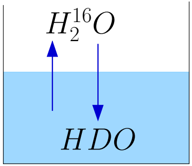
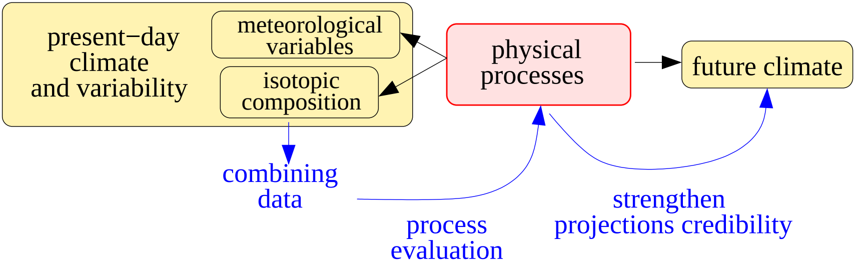


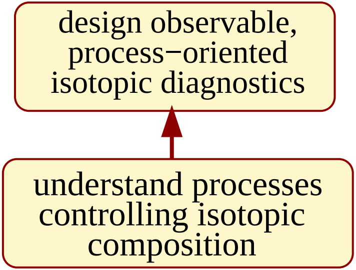




General strategy

understand processes controlling isotopic composition

General strategy



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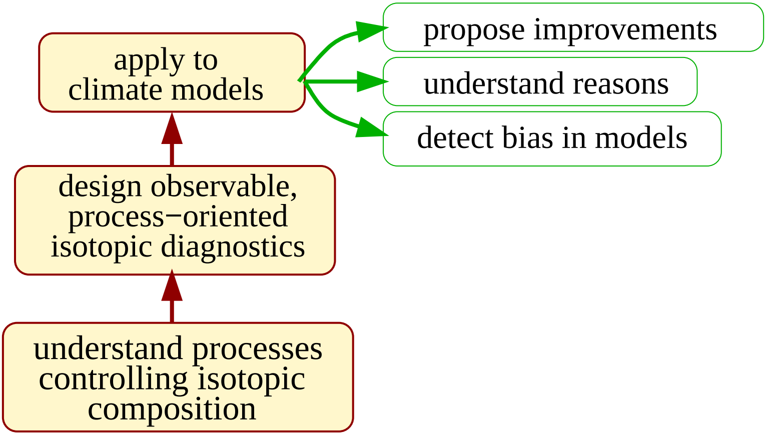

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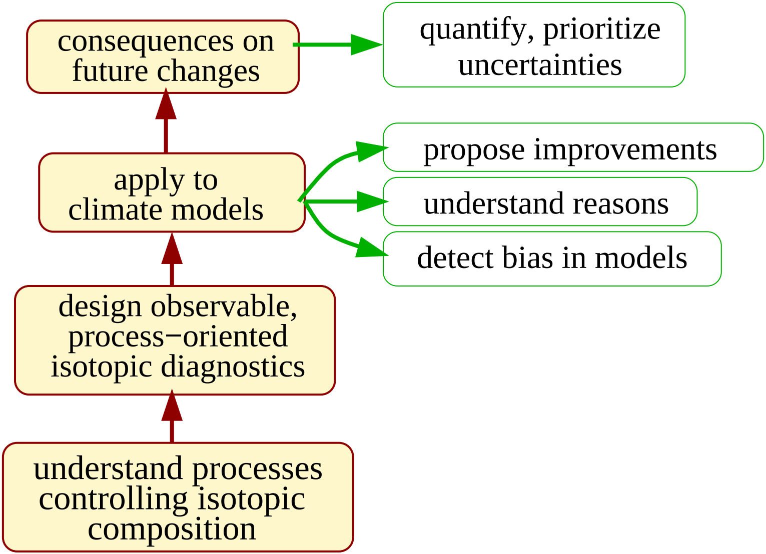
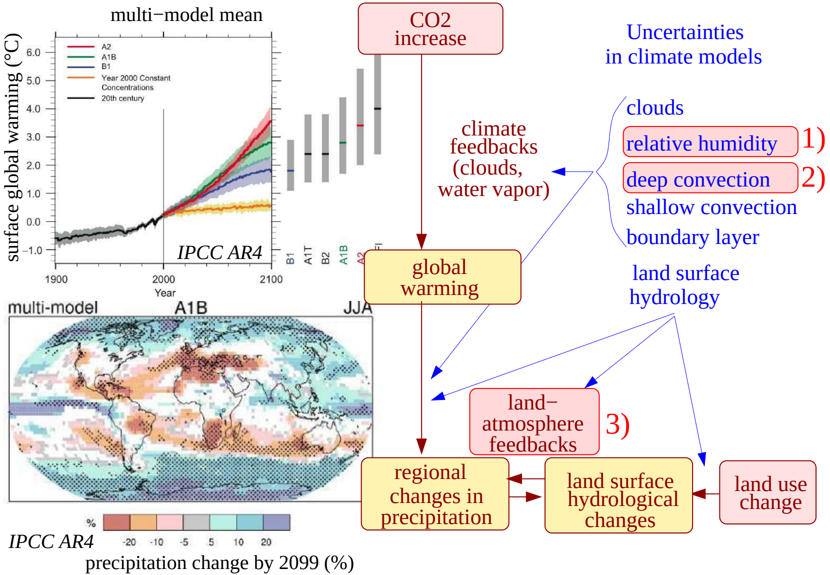


Outline



multi−model mean
surface global warming (°C)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
−1.0
A2
A1B
B1
Year 2000 Constant Concentrations
20th century
IPCC AR4
1900
2000
2100
Year
B1
A1T
B2
A1B
A2
multi-model
A1B
JJA
%
-20
-10
-5
5
10
20
IPCC AR4
precipitation change by 2099 (%)
CO2 increase
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Uncertainties in climate models
clouds
relative humidity
1)
deep convection
2)
shallow convection
boundary layer
land surface hydrology
land−atmosphere feedbacks
3)
regional changes in precipitation
land surface hydrological changes
land use change

1) Processes controlling relative humidity

- tropical/subtropical free tropospheric relative humidity (RH) impacts:
  - water vapor feedback (*Soden et al 2008*)
  - clouds feedbacks (*Sherwood et al 2010*)
  - deep convection (*Derbyshire 2004*)

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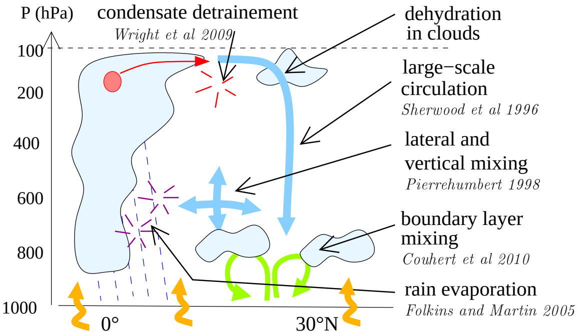
$\Longrightarrow$ need process-based evaluation of RH in climate models
$\Longrightarrow$ Goal: design observational diagnostics to evaluate processes controlling RH, detect and understand biases?

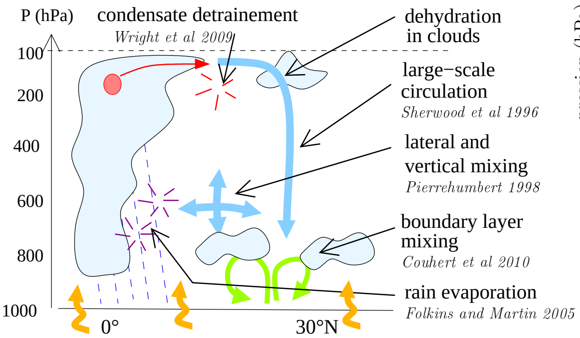
Sensitivity tests to RH processes

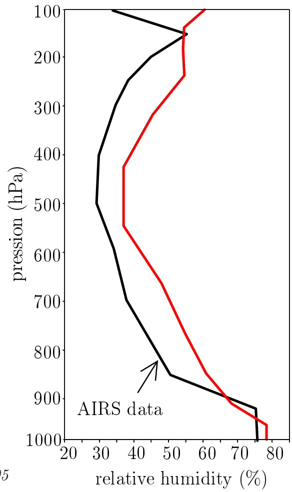


Sensitivity tests to RH processes

LMDZ−iso (Risi et al 2010a):

— control: AR4 version (19 levels)





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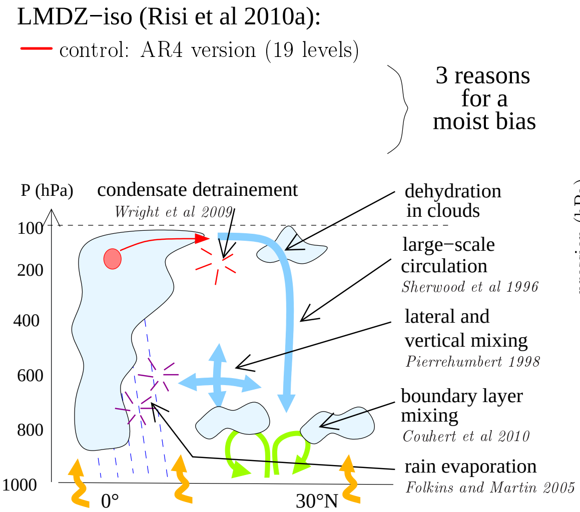

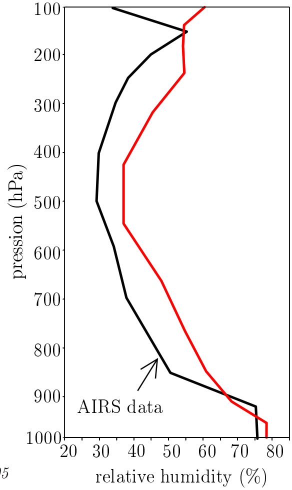

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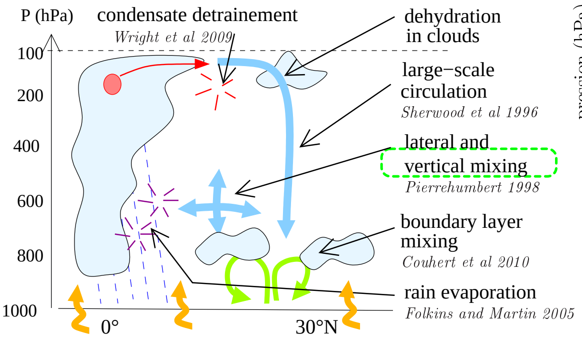
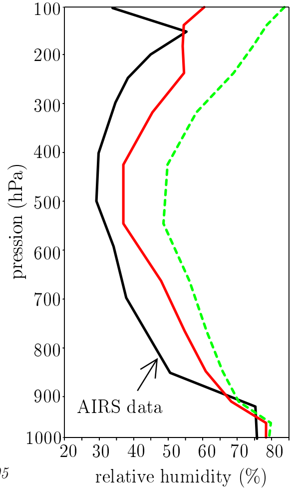
3 reasons for a moist bias





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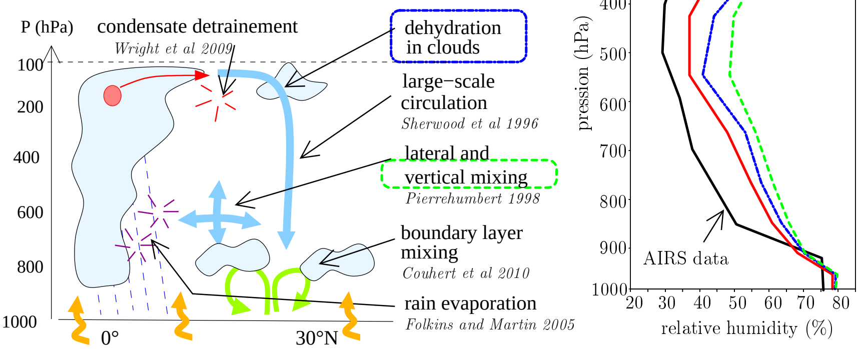

Sensitivity tests to RH processes

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- $\epsilon_p/2$

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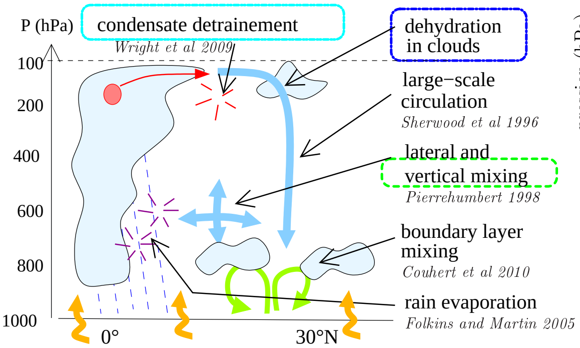
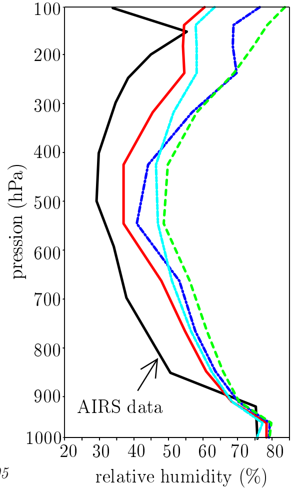
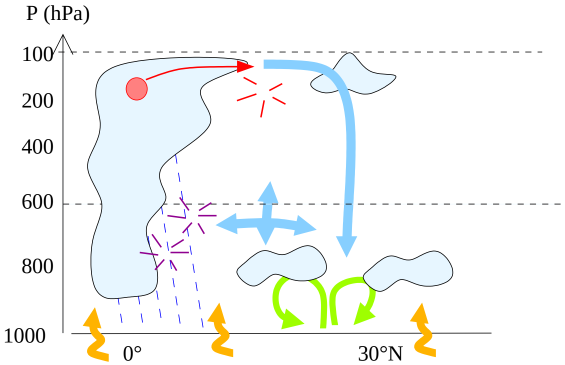




Isotopic measurements



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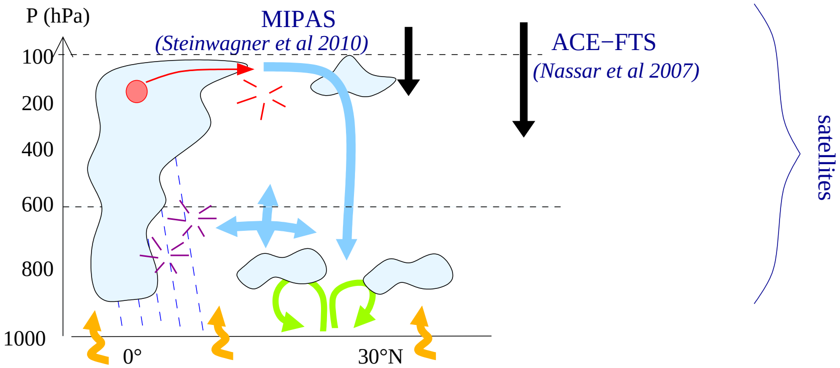

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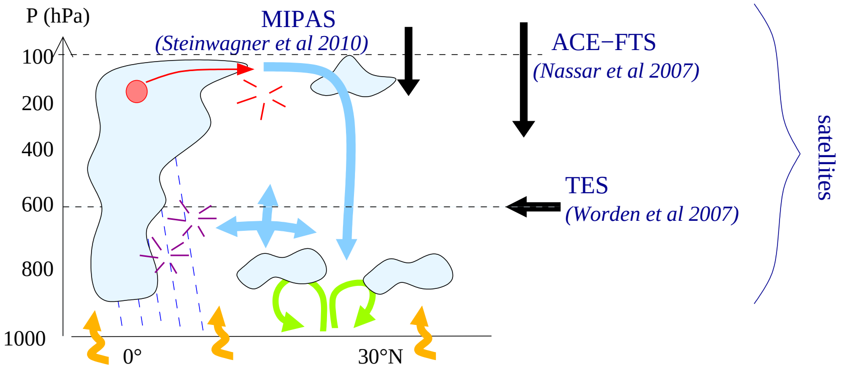

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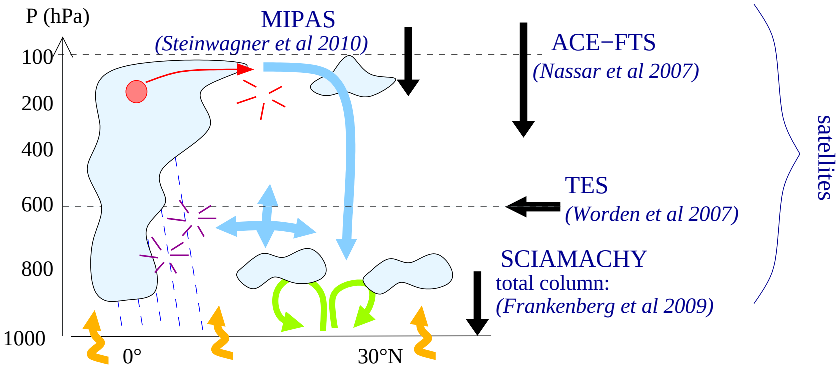

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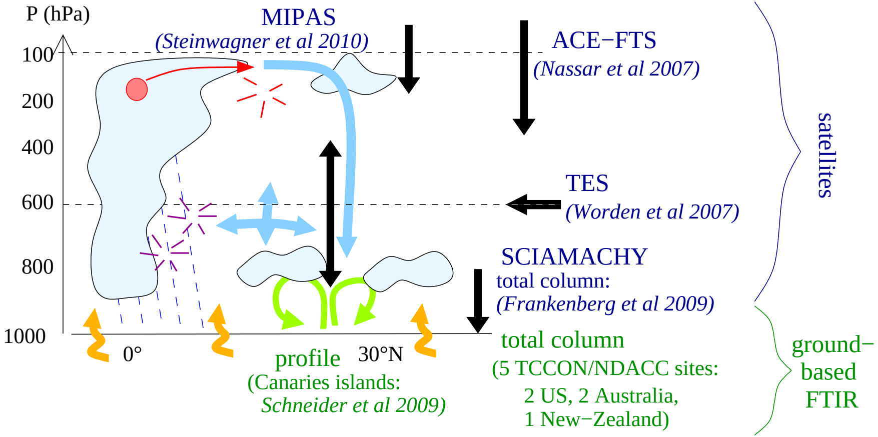

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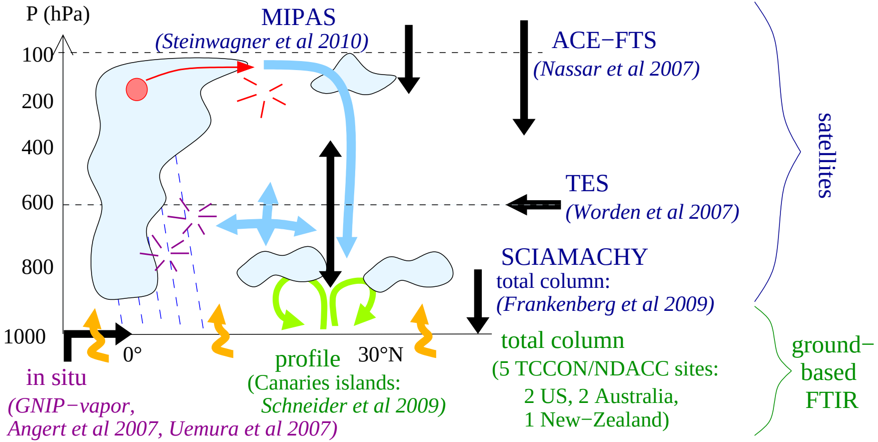

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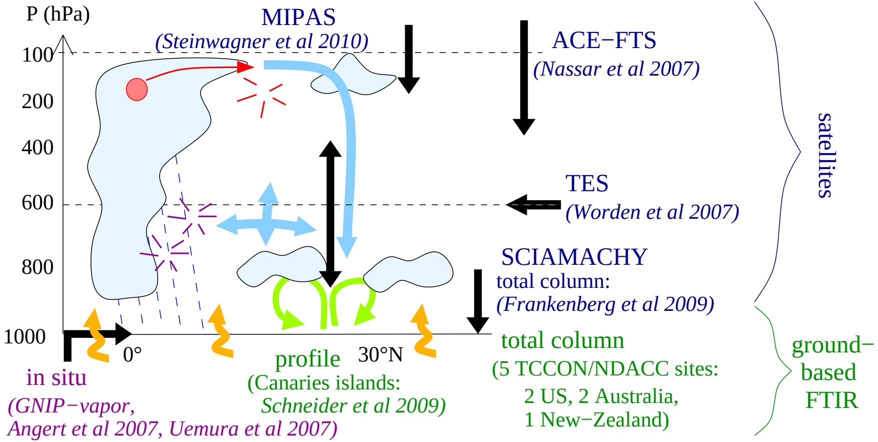
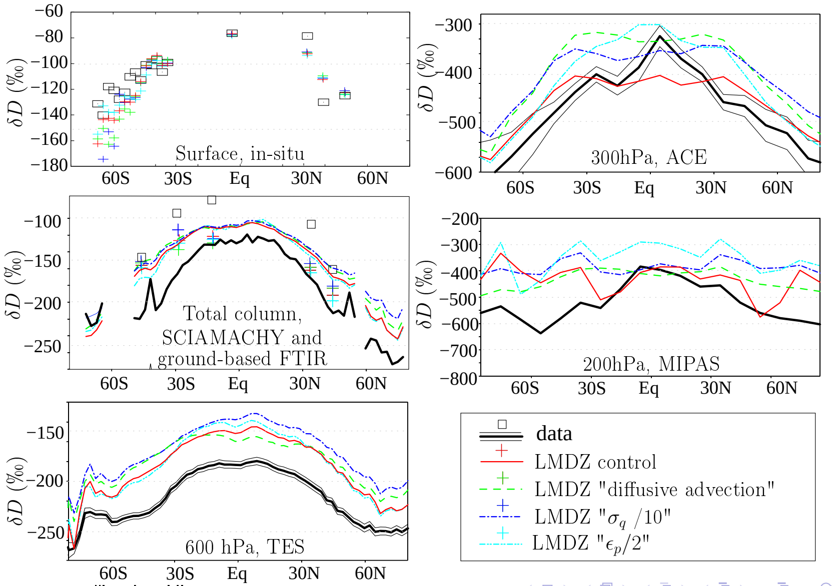
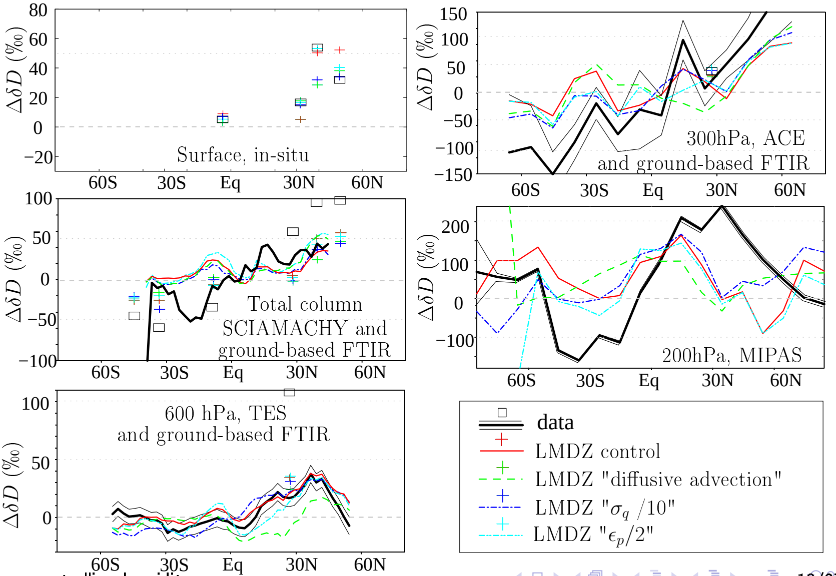


- model-data comparison: collocation; simulations nudged by ECMWF; averaging kernels; spatial/temporal variations

Zonal anual mean



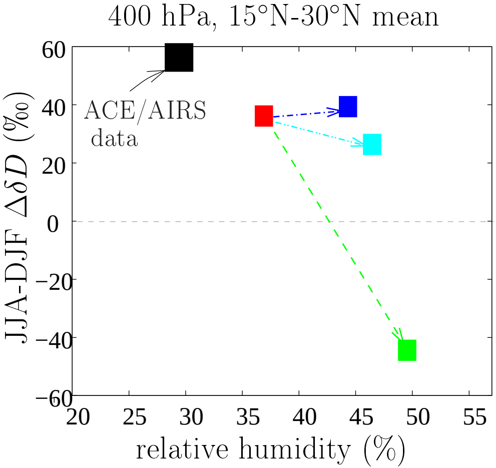
Zonal Seasonal variations (JJA-DJF)



What causes the moist biases in GCMs?

Sensitivity tests:
with LMDZ:

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



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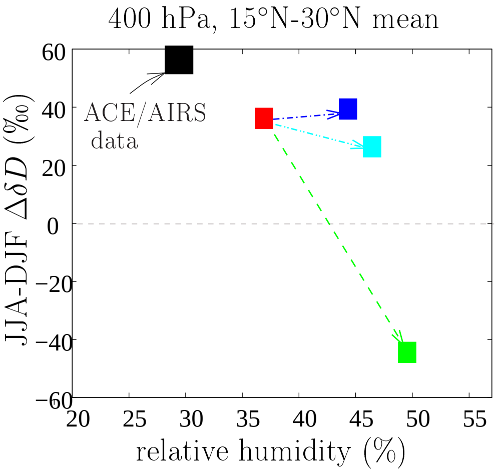

- robustness? additional tests, theoretical understanding

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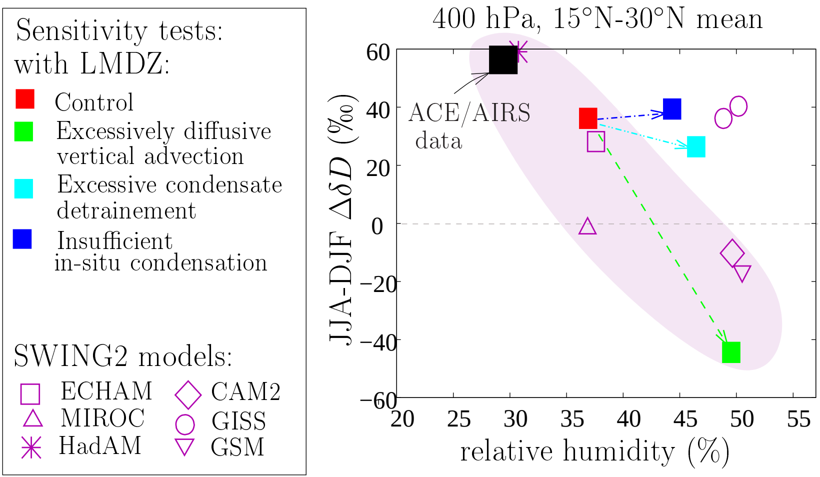

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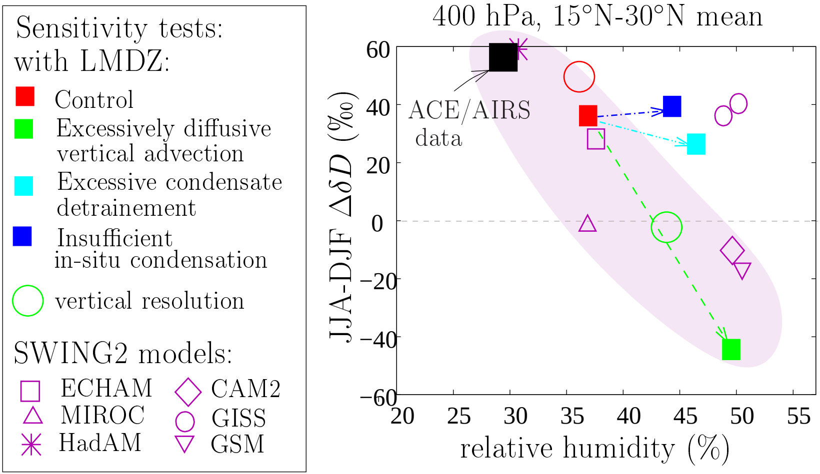

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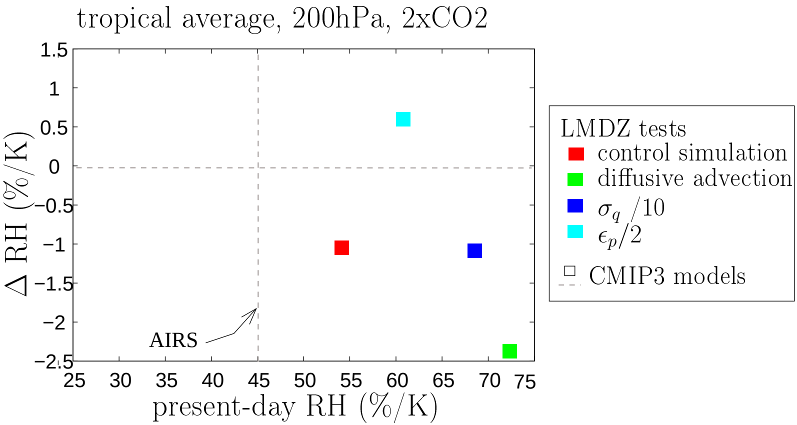
What impact on humidity projections?



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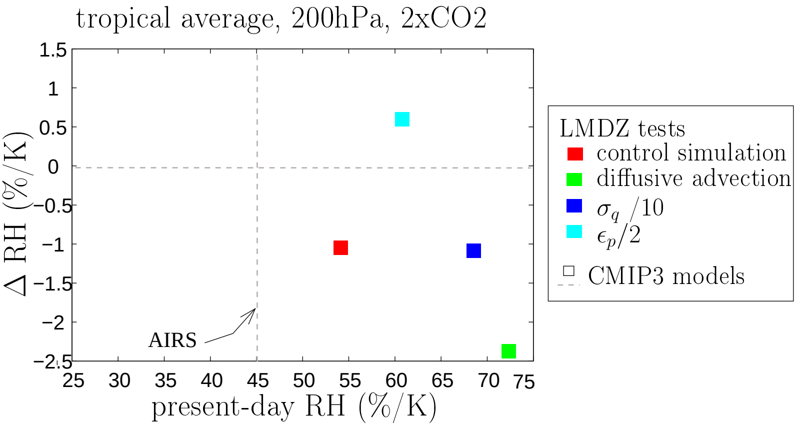

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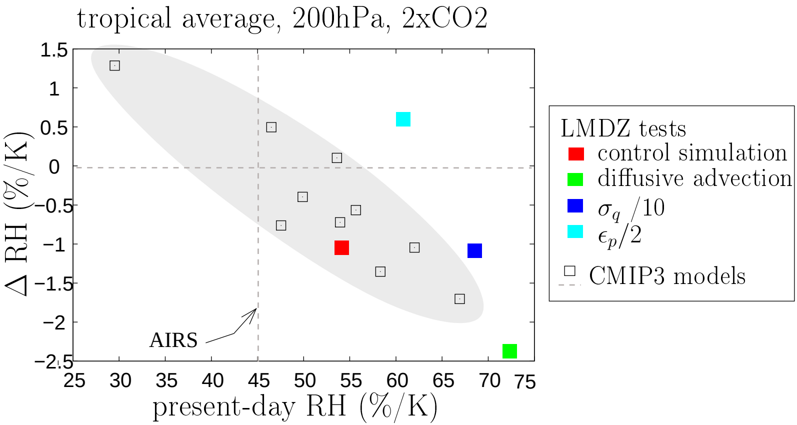

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Summary on relative humidity

- Water vapor isotope measurements as observational diagnostics to understand the reasons for a moist bias in climate models

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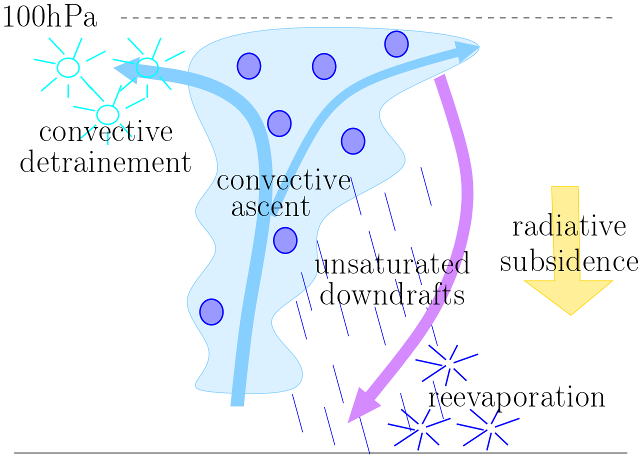
- Excessive vertical diffusion during water vapor transport/insufficient vertical resolution is a widespread cause of moist bias in climate models
- Understanding this reason is all the more important as humidity change projections depends on the reason for the moist bias
- Consequences on climate change? -> study feedbacks using radiative kernel decomposition (*Soden et al 2008*)

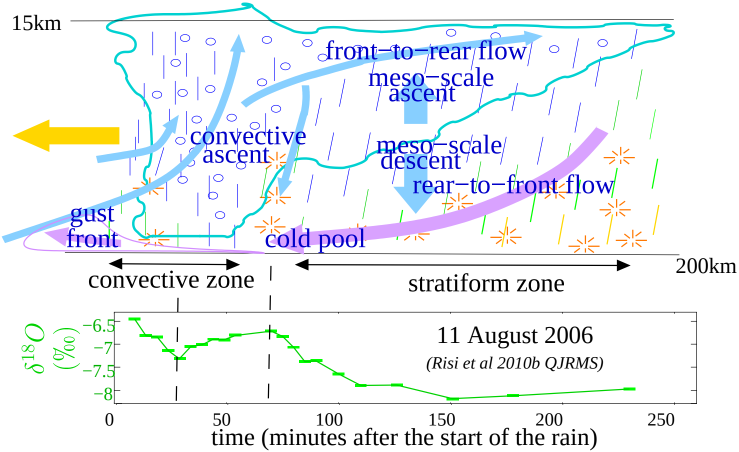
2) Convective processes

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



Processes along squall lines

- rain sampled every 5 mins in Niamey during AMMA campaign



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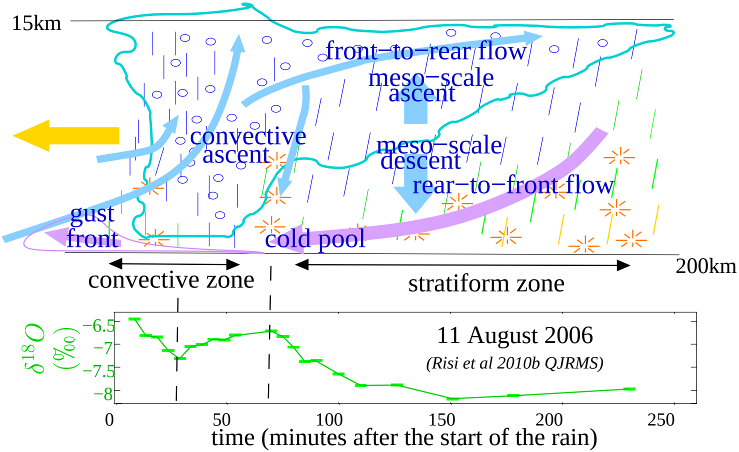

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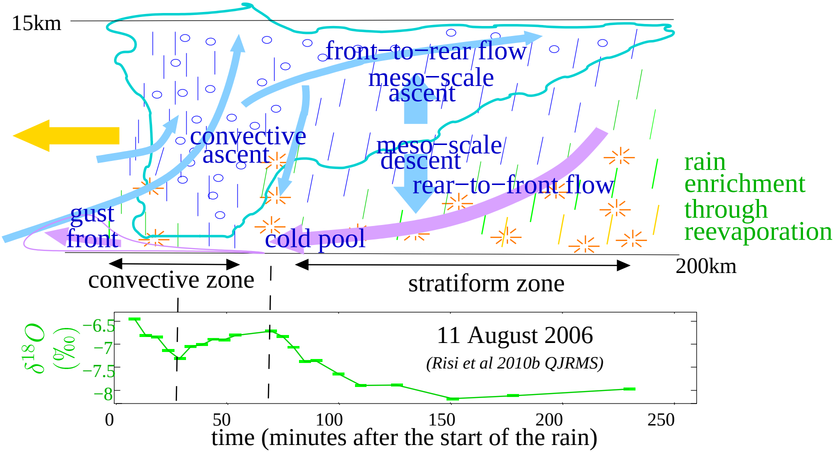

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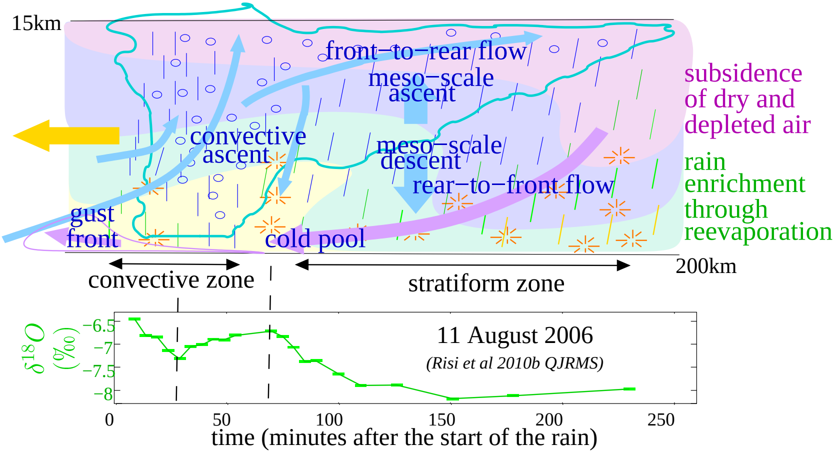
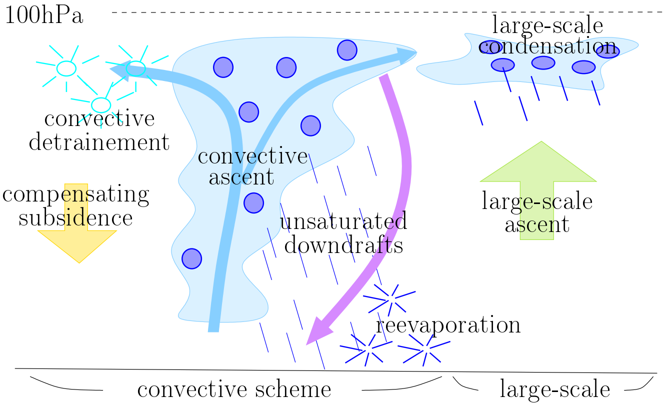


Convective/large-scale fluxes



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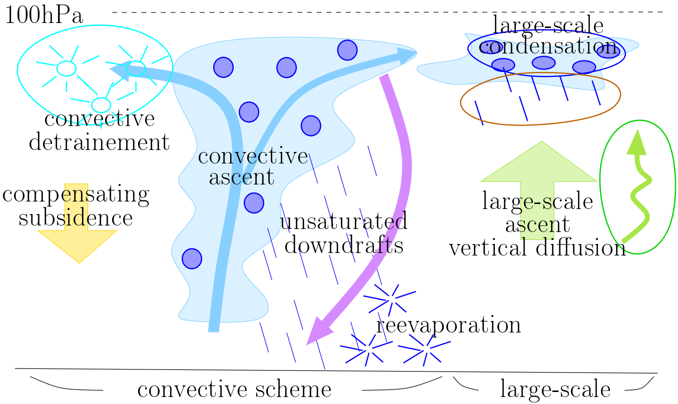
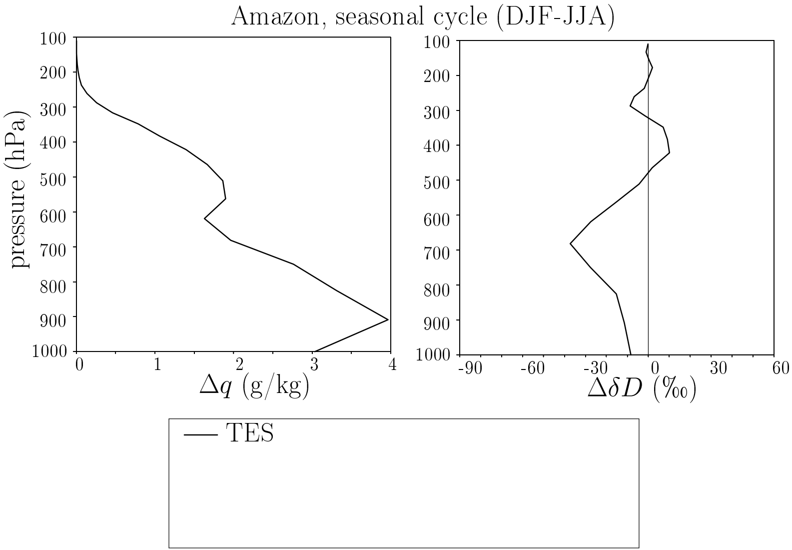


Sensitivity tests with LMDZ:

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

New TES profiles



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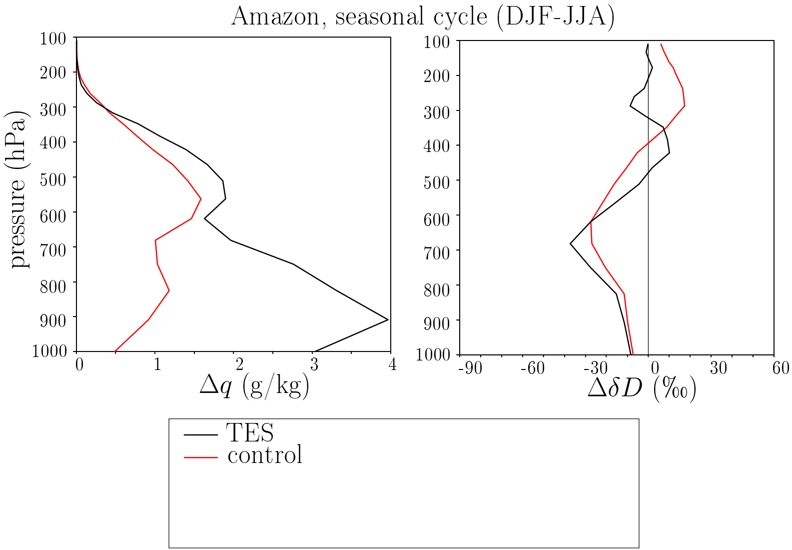

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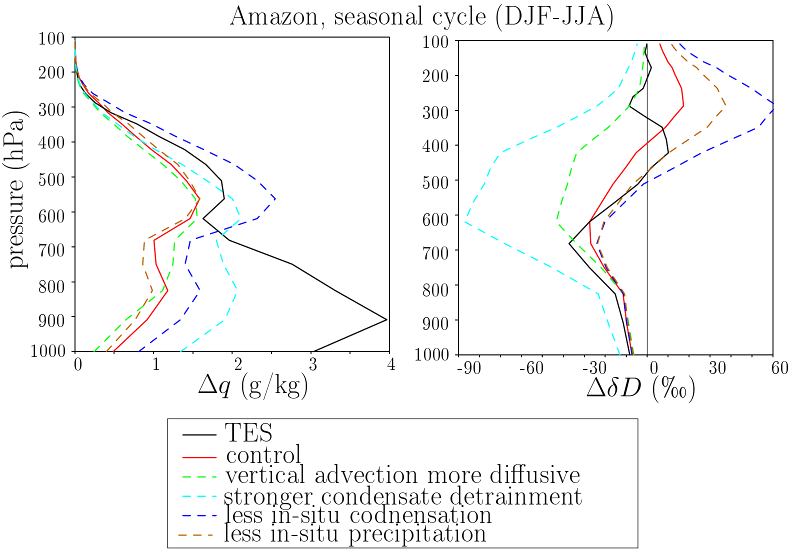
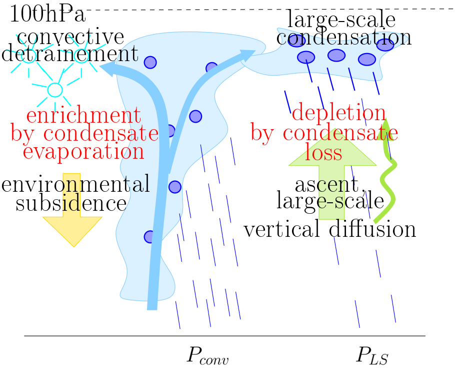


Convective contribution to water budget



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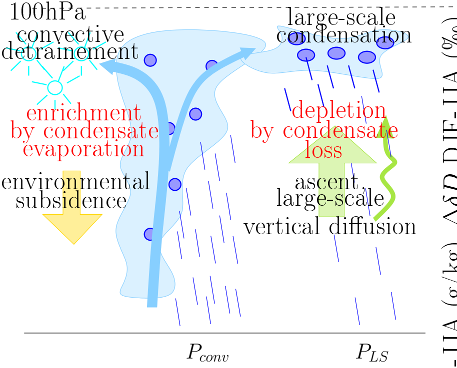

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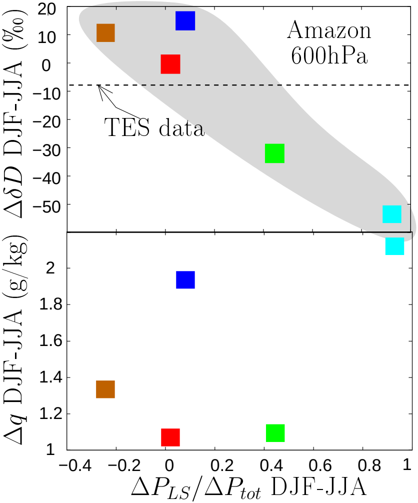

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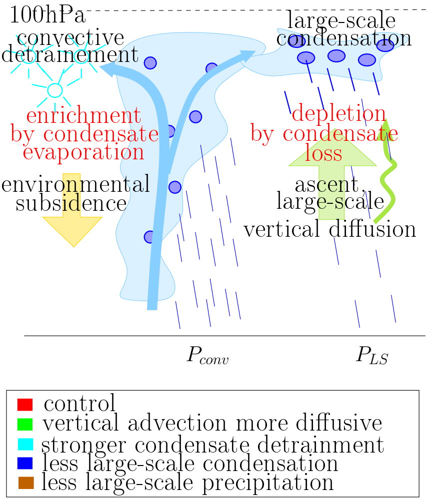
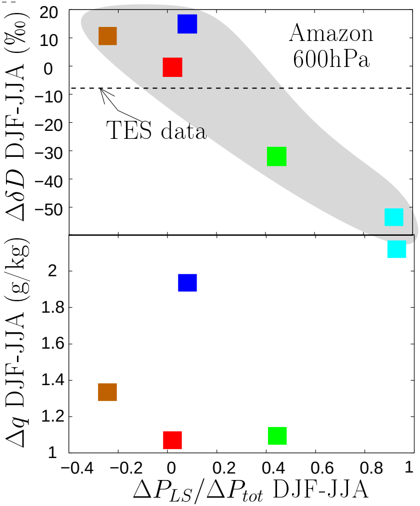
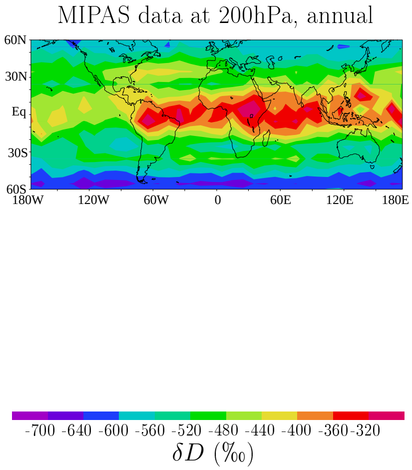




- P_{LS}/P_{tot} ill-defined quantity, but influences cloudiness, intra-seas. variability, chemical tracor transport

Upper troposphere detrainment



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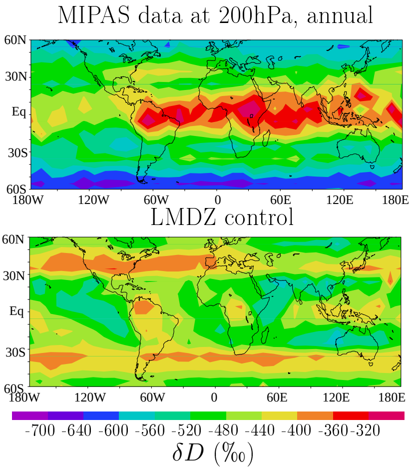

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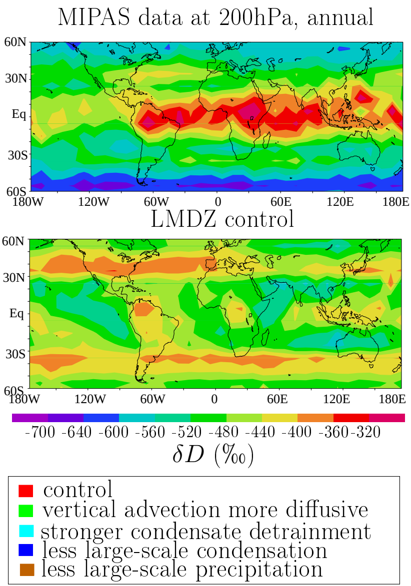

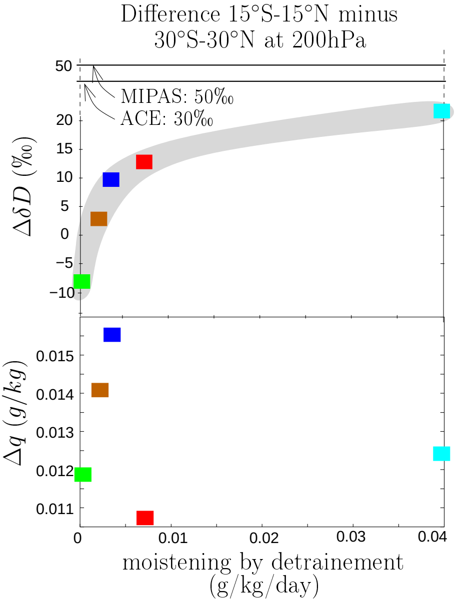

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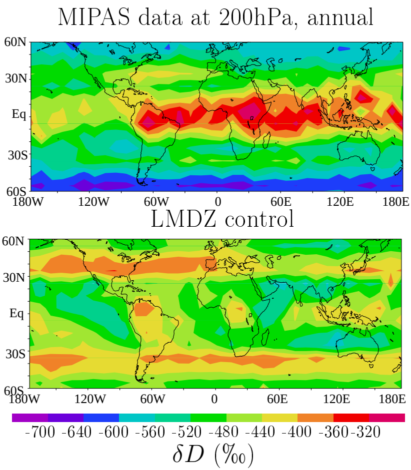

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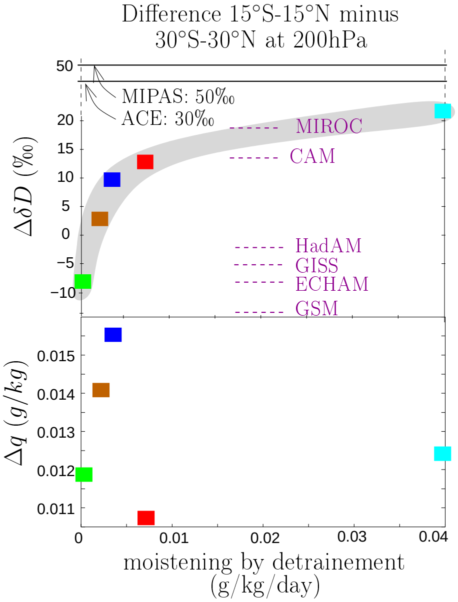
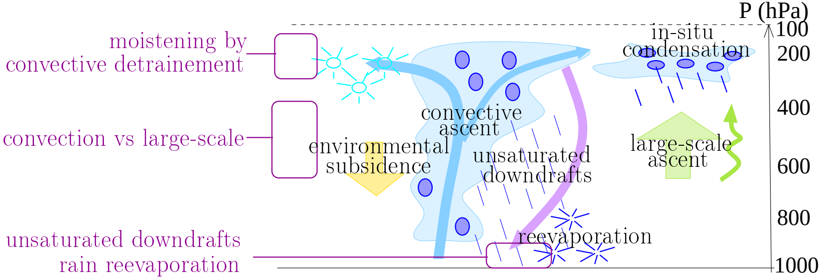


Summary on convection



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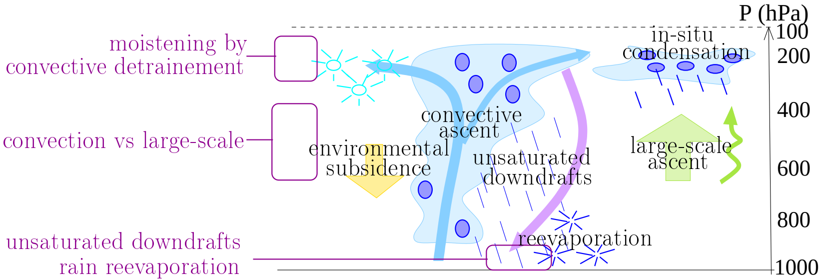

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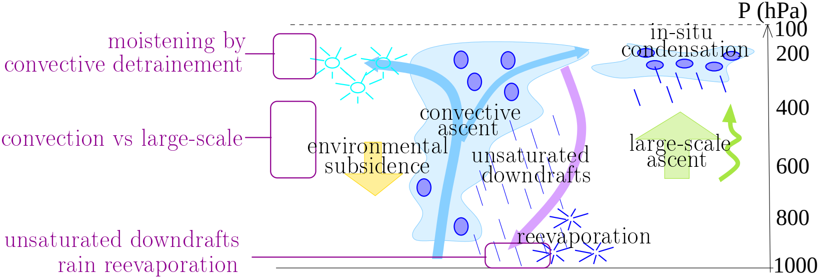
Summary on convection



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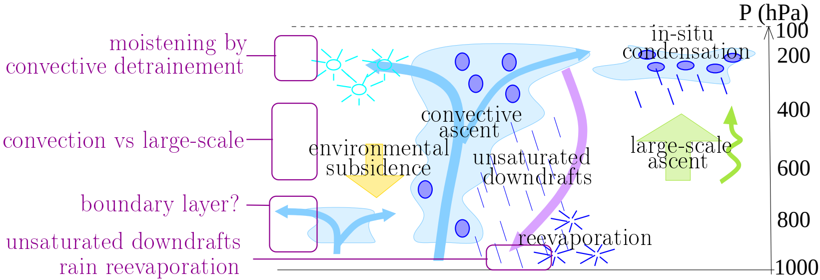

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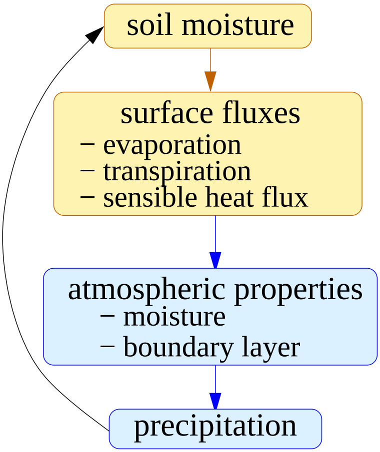
  - A-train synergy: TES+CALIPSO/Cloudsat
  - New physics of LMDZ for AR5 *(Rio et al 2009)*

3) Land atmosphere feedbacks



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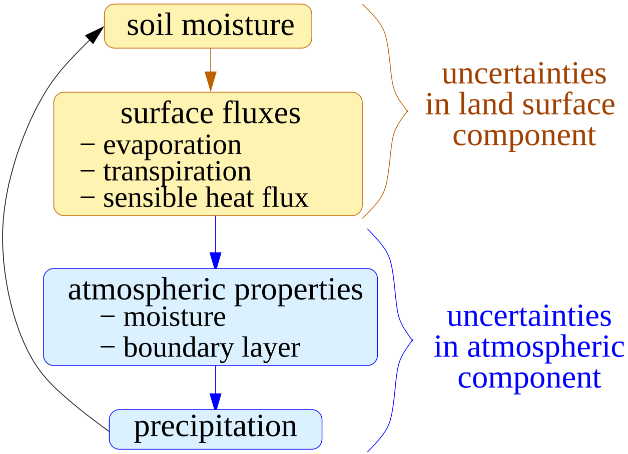

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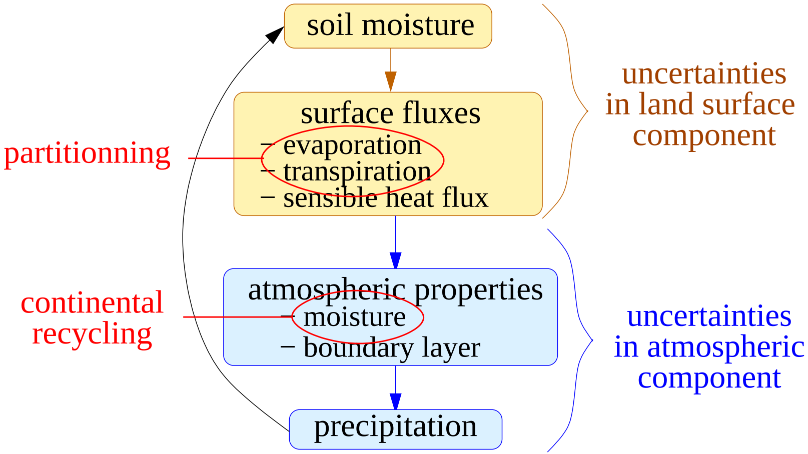
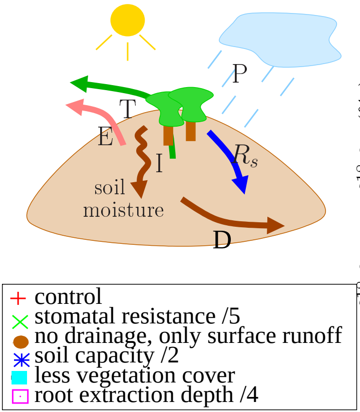
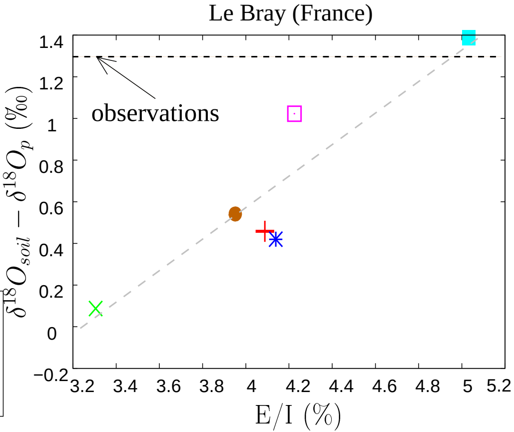


Partitionning surface fluxes

- ORCHIDEE-iso (*Risi et al in rev*)





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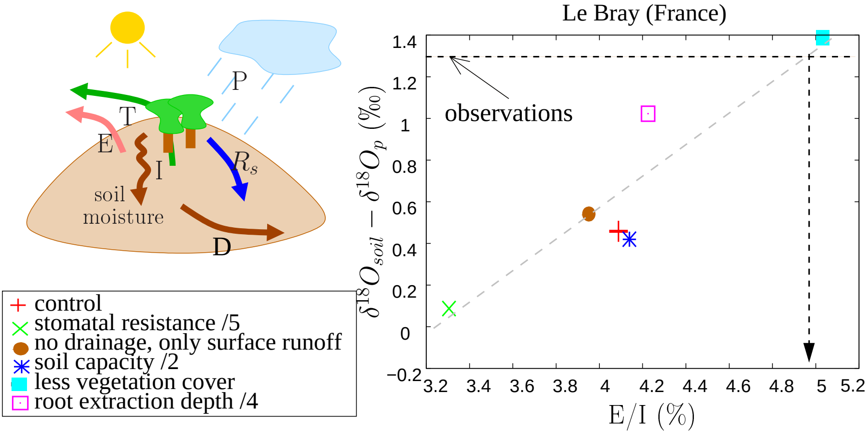
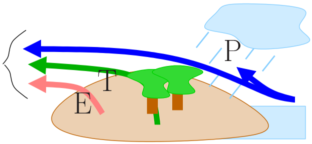
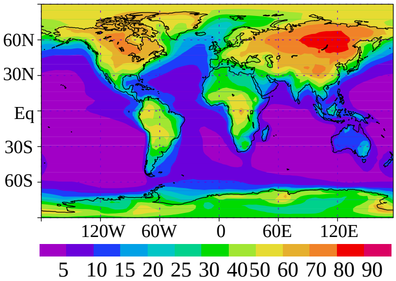


Isotopic signature of evaporative origin

Water tagging:





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

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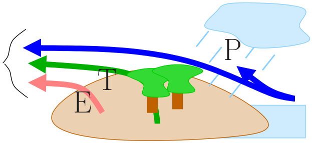
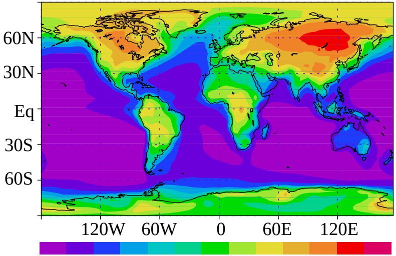
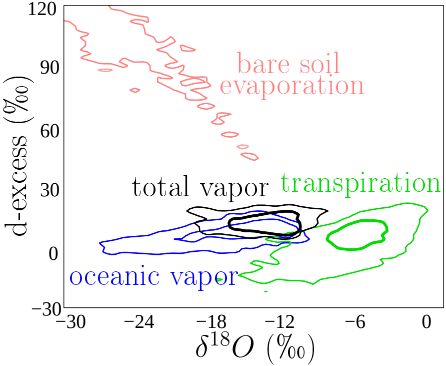




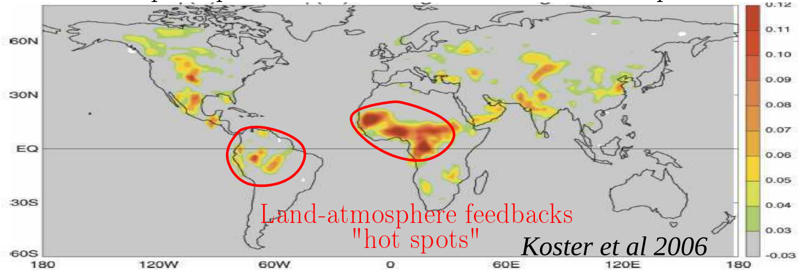
% vapor from continental evapo-transpiration (r_{con})

PDF of vapor composition monthly, all tropical land points



Water isotopes and continental recycling

decrease in precip variance when soil moisture is prescribed



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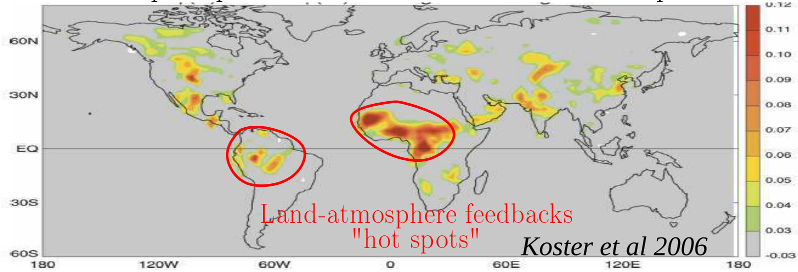
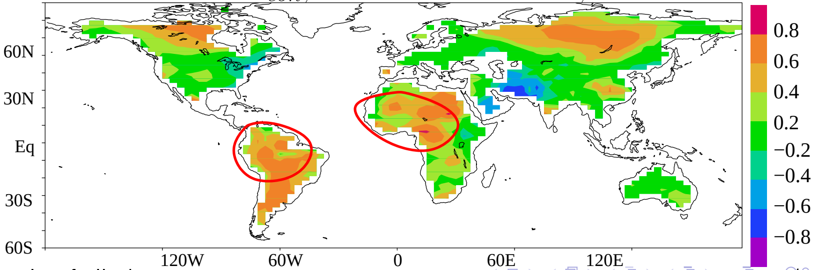
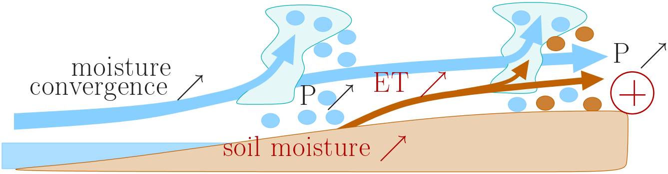


correlation $\delta^{18}O$ - r_{con}, intra-seasonal scale, annual mean



Isotopic signature of land-atmosphere feedbacks



strong precipitation composite minus seasonal average:

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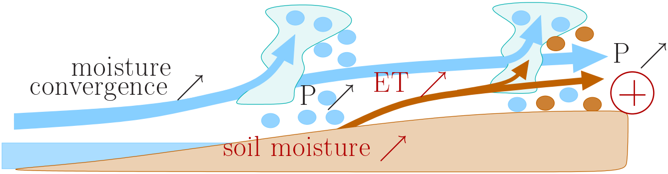

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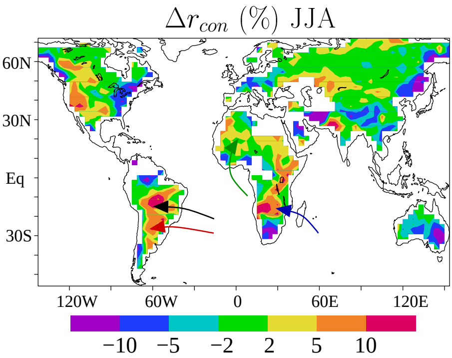

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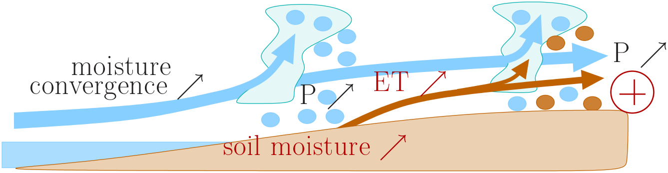

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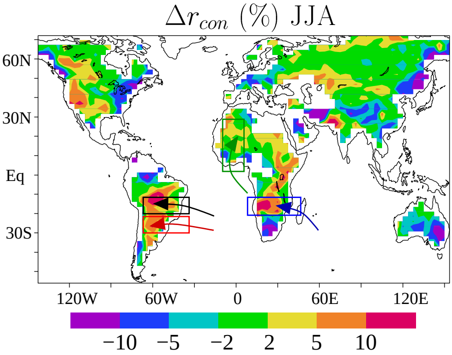

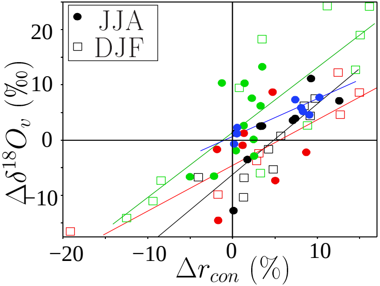

control by large-scale convergence

positive land-atmosphere feedback

Summary on land-atmosphere feedbacks

- work in progress:
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  - sensitivity tests: physics-discriminating diagnostics?

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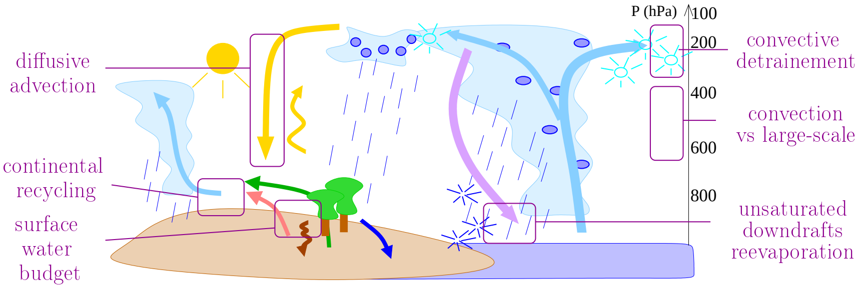
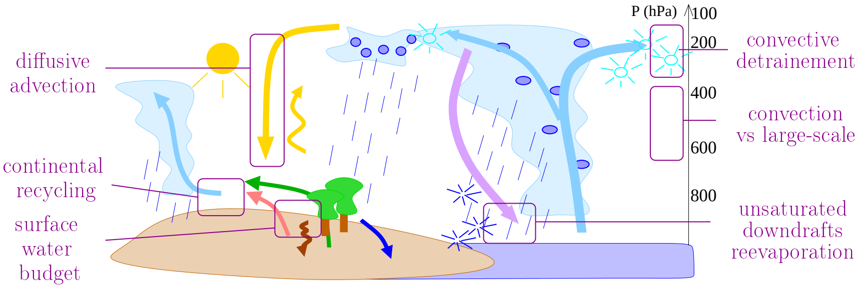
- relevance for hydrological projections
  - Global warming, land use change (deforestation, irrigation)

Conclusion



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

Conclusion



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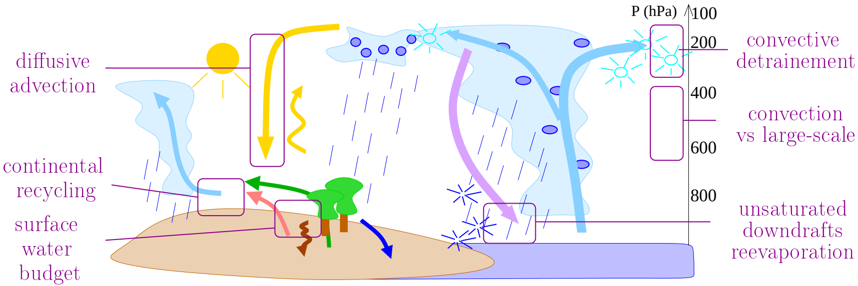

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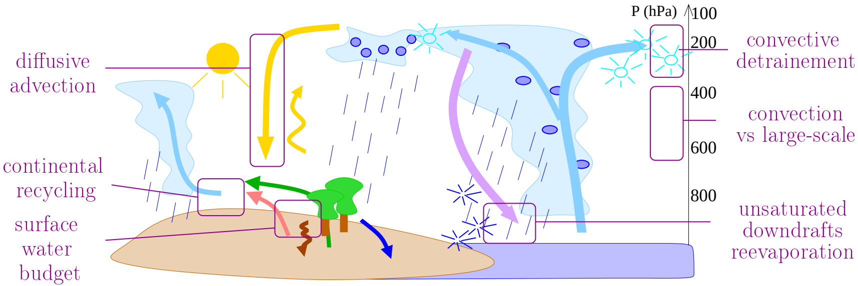

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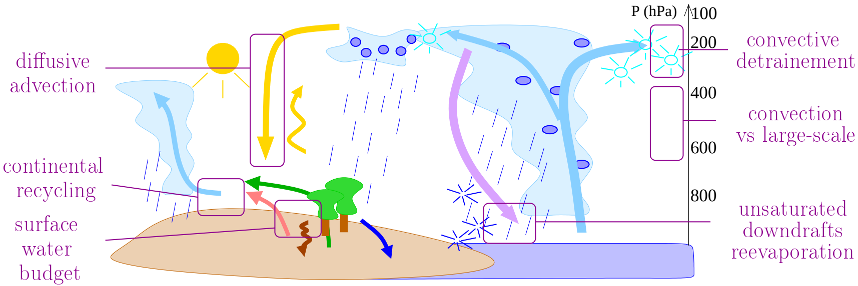

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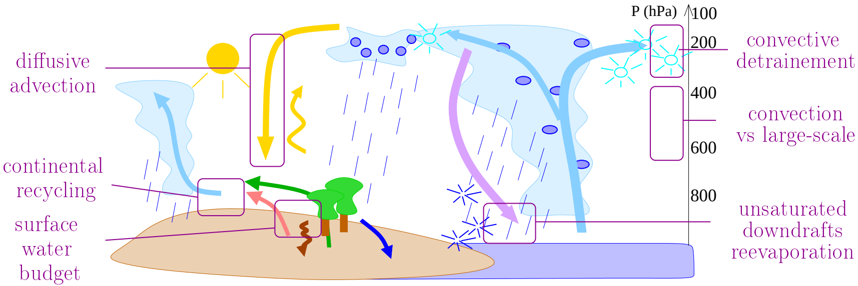

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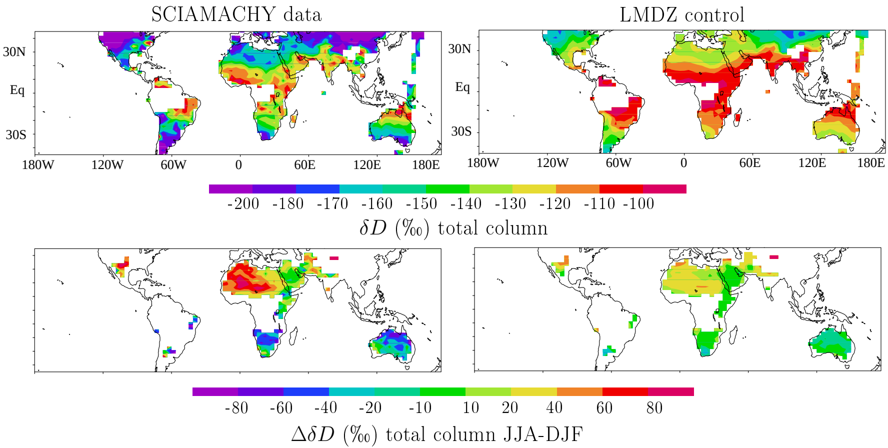
  - process/feedbacks studies comparing models behavior for present climate and for projections

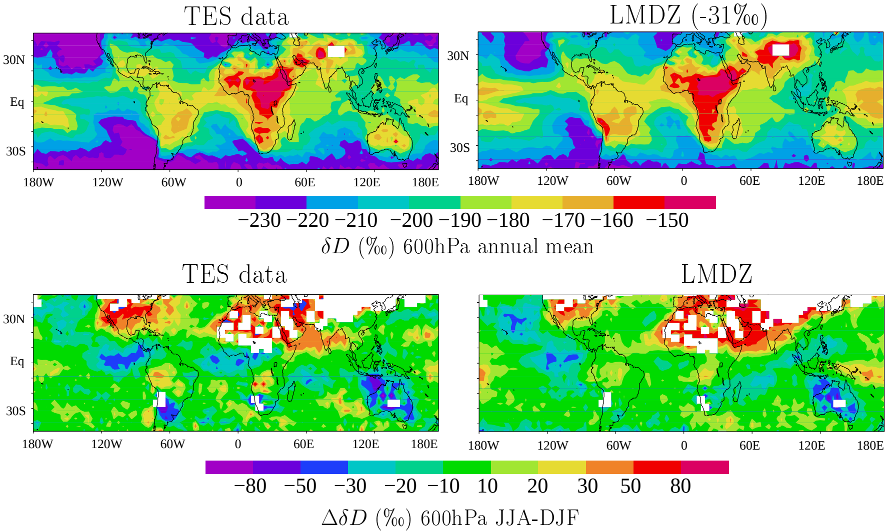
Supl material

Evaluation against SCIAMACHY



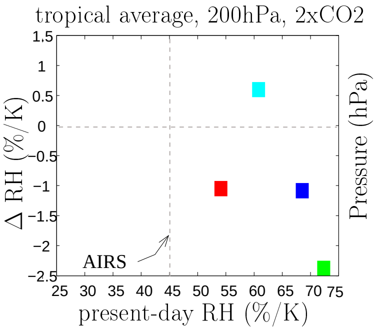
Risi et al in rev,b

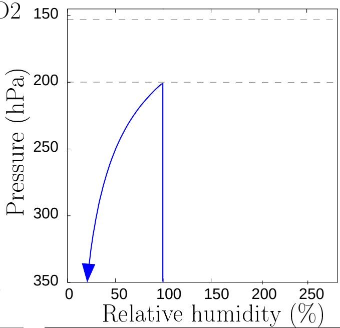
Evaluation against TES

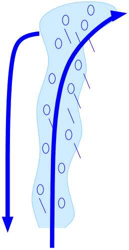


Risi et al in rev,b

Consequences on projections





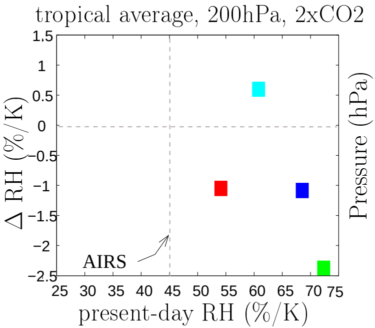


LMDZ tests
control simulation
diffusive advection
σ_q /10
$\epsilon_p/2$

Everything precipitates:

present

Consequences on projections



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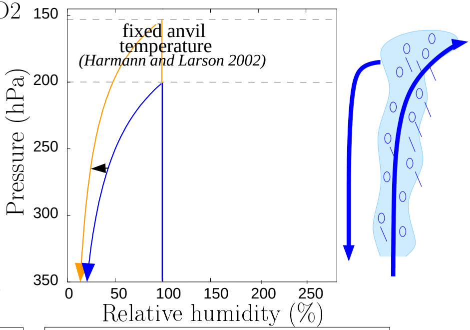

Everything precipitates:

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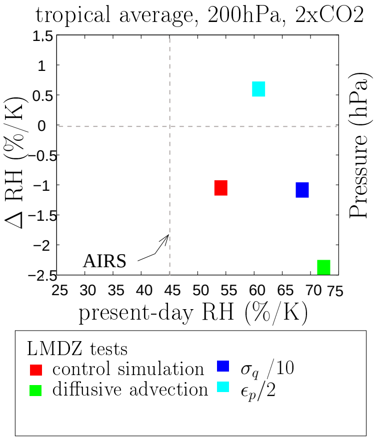
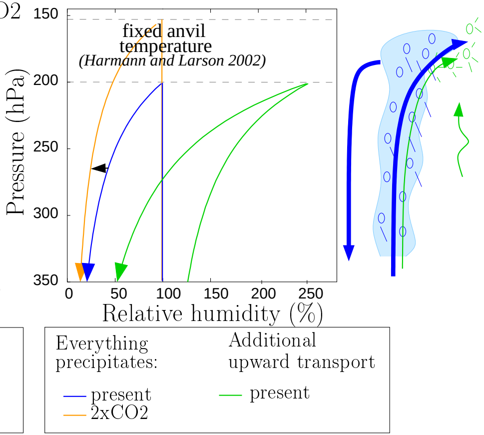
2xCO2

Consequences on projections





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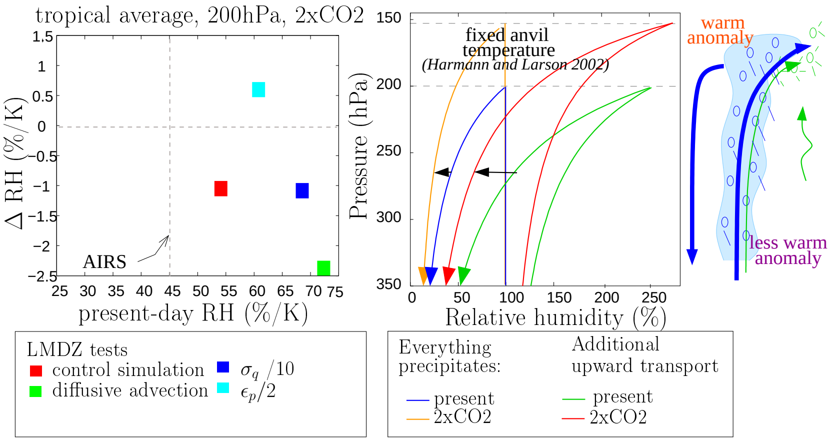

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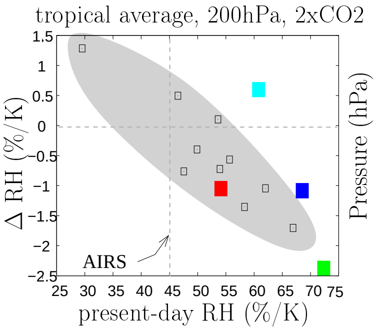

LMDZ tests
control simulation
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σ_q /10
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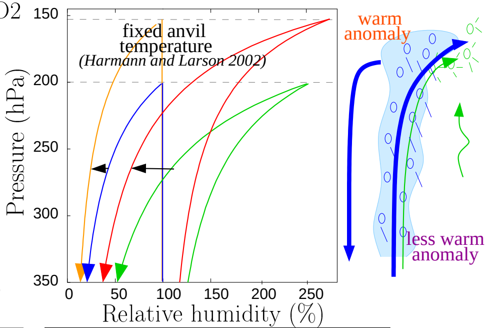
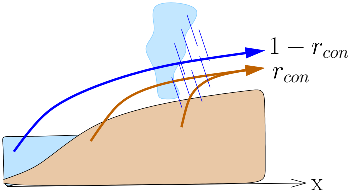
CMIP3 models



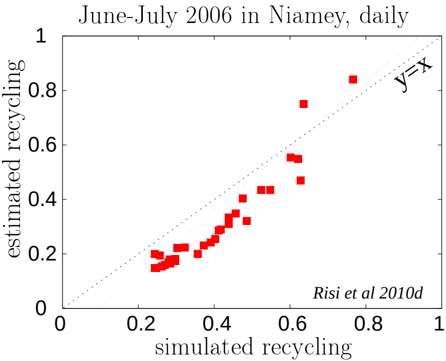
Everything precipitates:
present
2xCO2

Additional upward transport
present
2xCO2

Estimating continental recycling

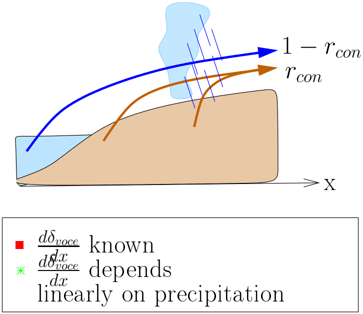


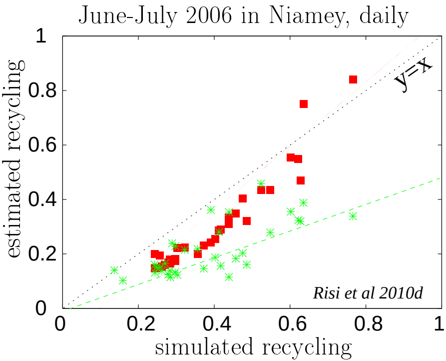
$\frac{d\delta_{voce}}{dx}$ known



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

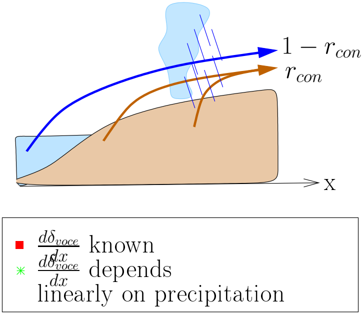
Estimating continental recycling

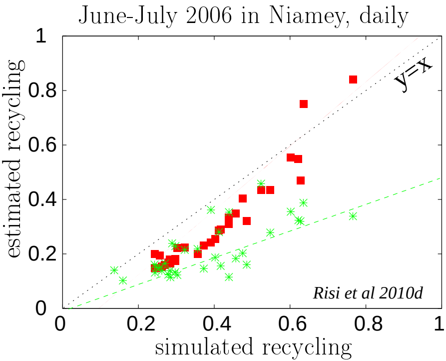




$$d\left(\frac{r_{con}}{1 - r_{con}}\right)/dx = \frac{d\delta_v/dx - d\delta_{voce}/dx}{\delta_p - \delta_v}$$

Estimating continental recycling





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

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