The added value of water isotopic measurements to better evaluate climate models and their climate change projections

Camille Risi

LMD/IPSL/CNRS (Paris, France) and CIRES/University of Colorado (Boulder, USA)

with the contribution of: S. Bony, F. Vimeux, D. Noone, J. Worden, C. Frankenberg, G. Stiller, B. Funke, M. Kieffer, C. Castet

Studium Conference: Hydrogen Isotopes as Environmental Recorders- Orléans, 15 September 2011
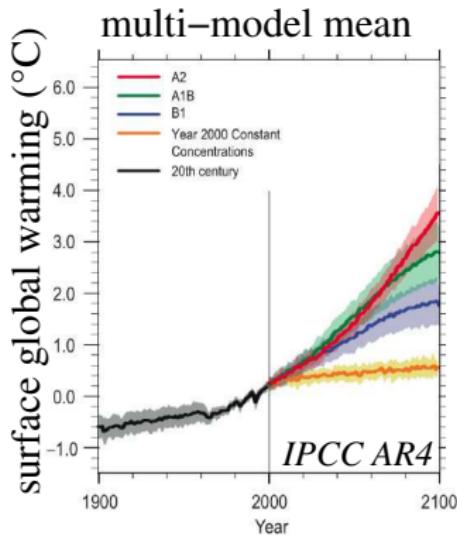
Dipersion in climate projections

Dipersion in climate projections

CO2 increase → temperature increase → regional precipitation changes

Dipersion in climate projections

multi-model mean

IPCC AR4

precipitation change
by 2100 (%)
□ <2/3 agree on sign
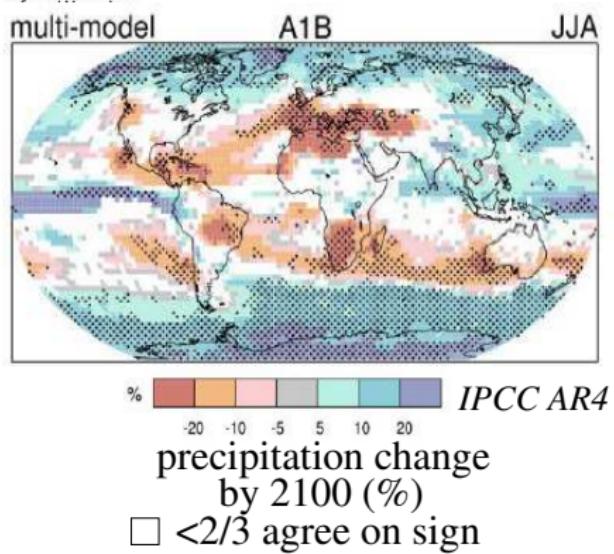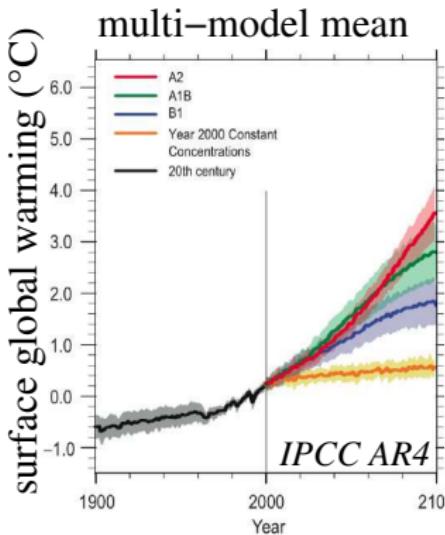
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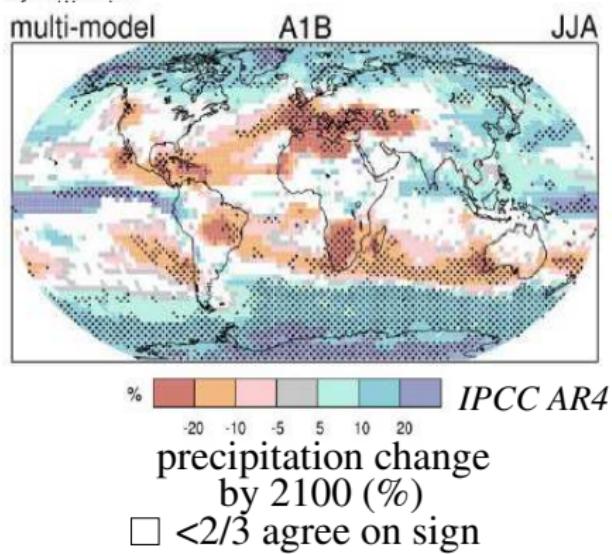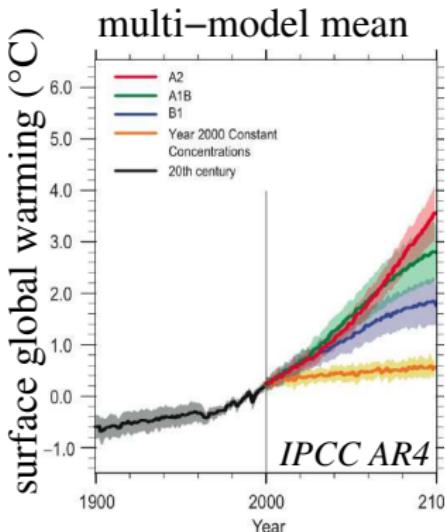
▶ dispersion due to different representations of key processes

Key processes in the tropics
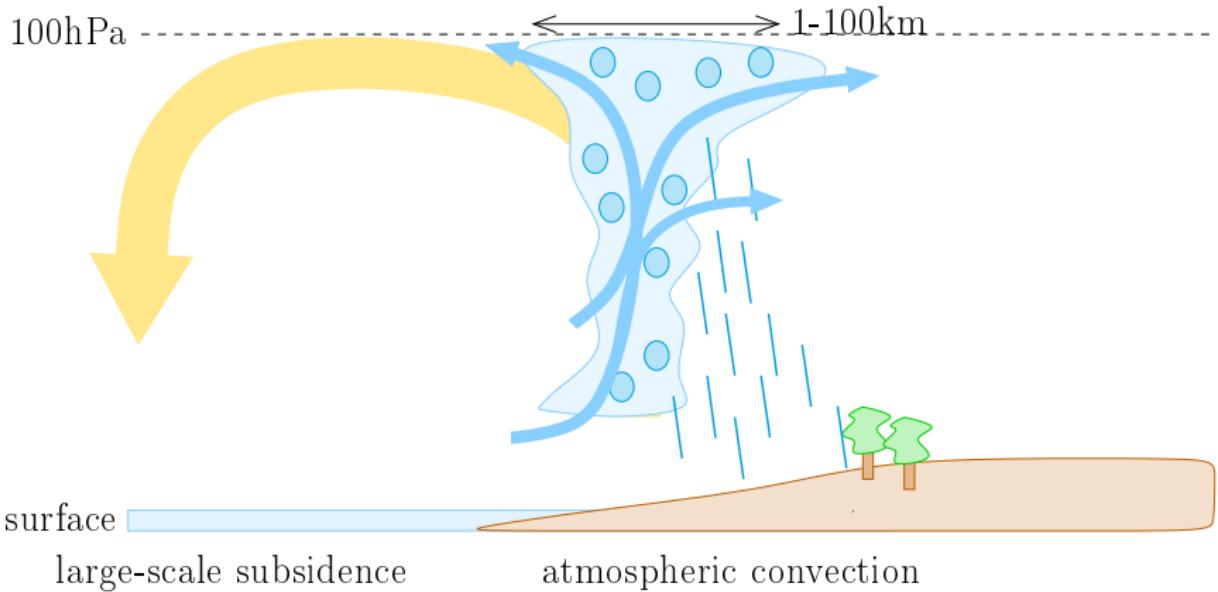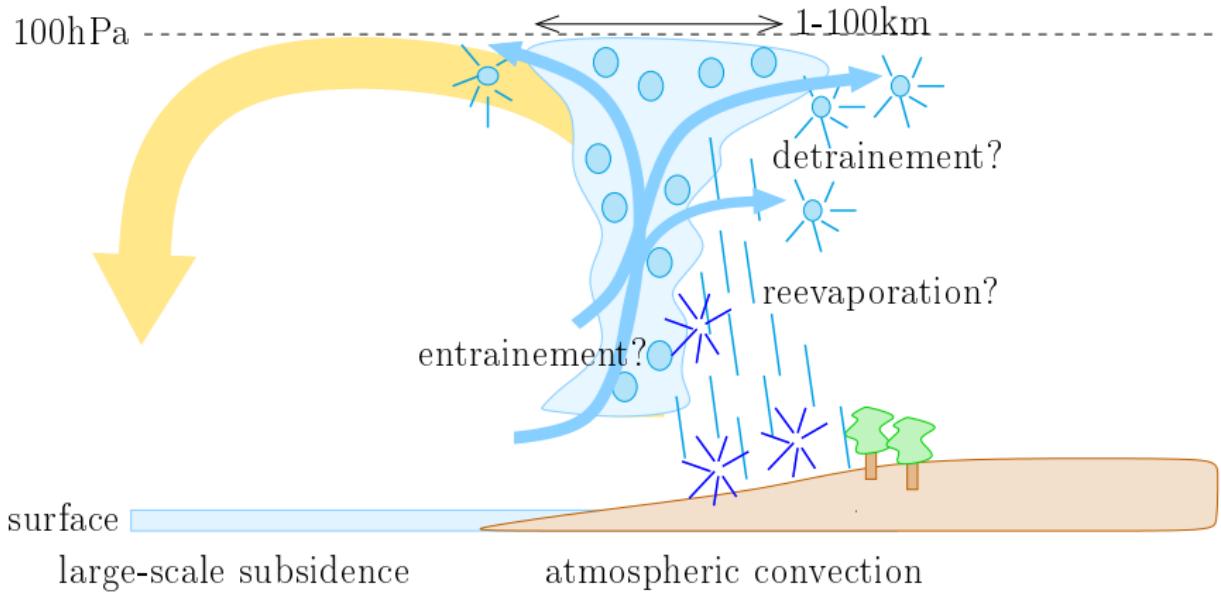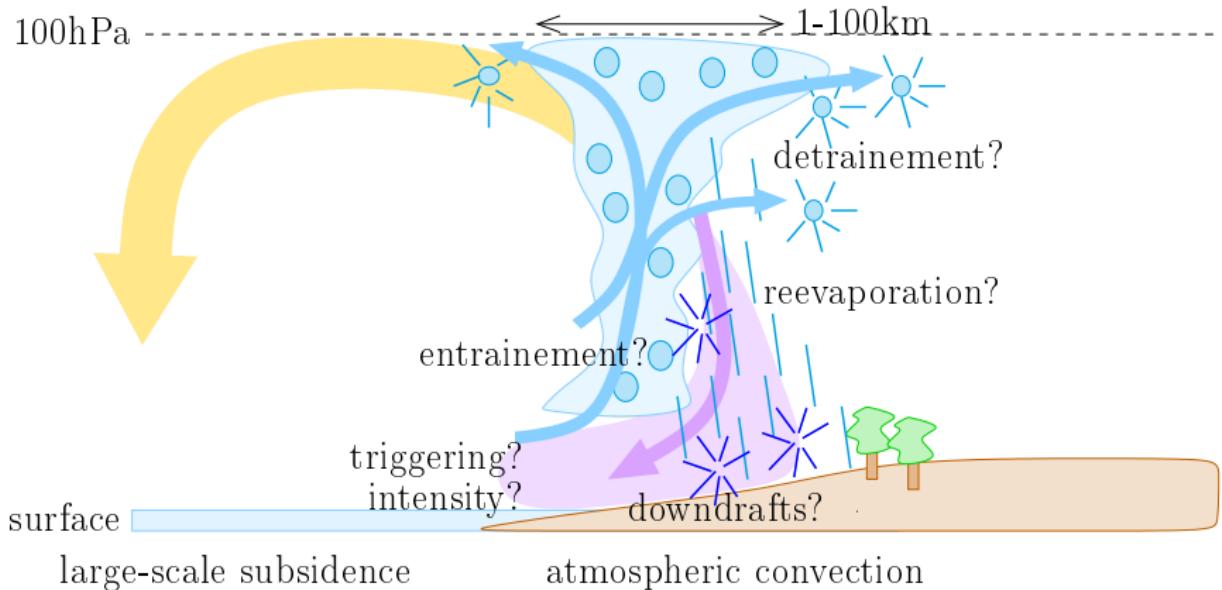
Key processes in the tropics

Key processes in the tropics

100hPa

1-100km

detrainement?

reevaporation?

entrainement?

triggering?
intensity?

downdrafts?

surface

large-scale subsidence

atmospheric convection

Key processes in the tropics
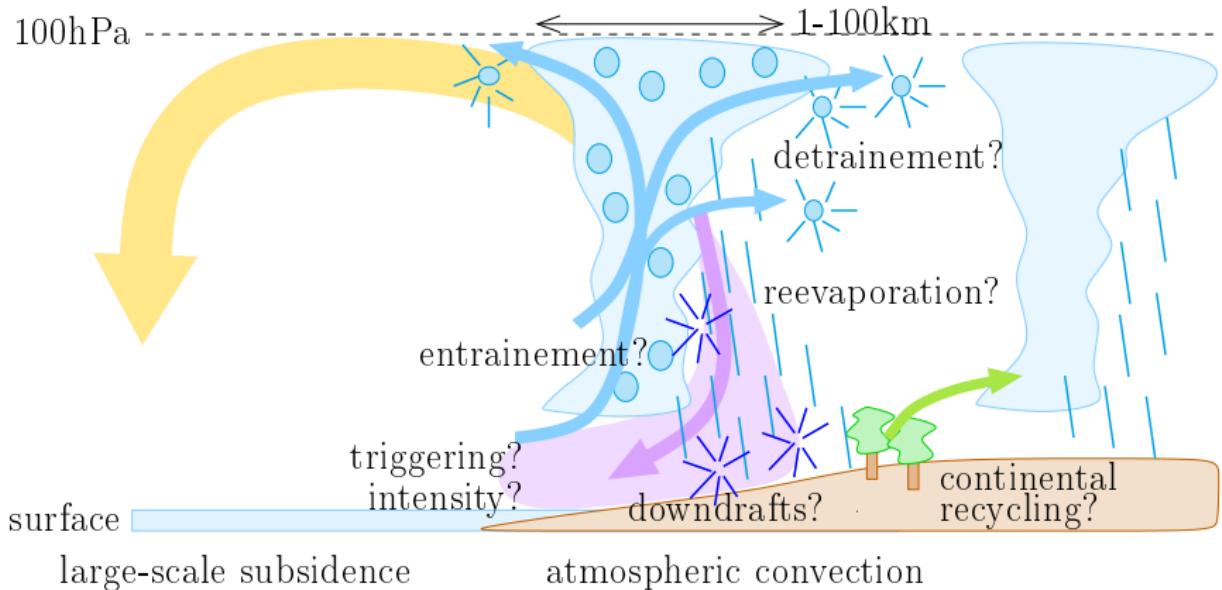
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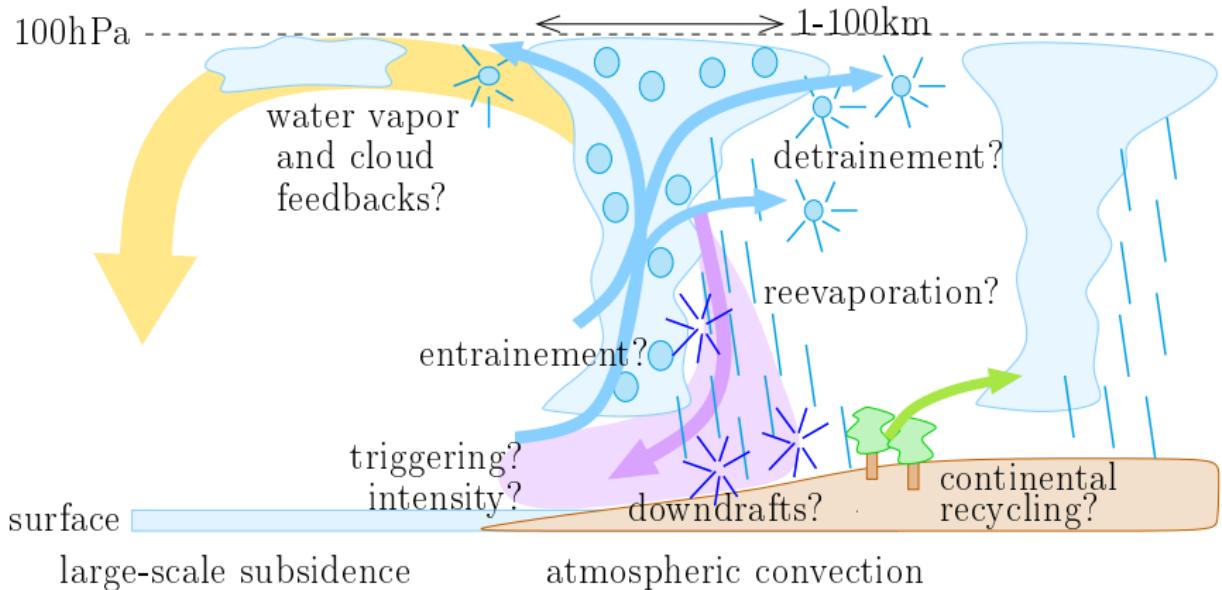
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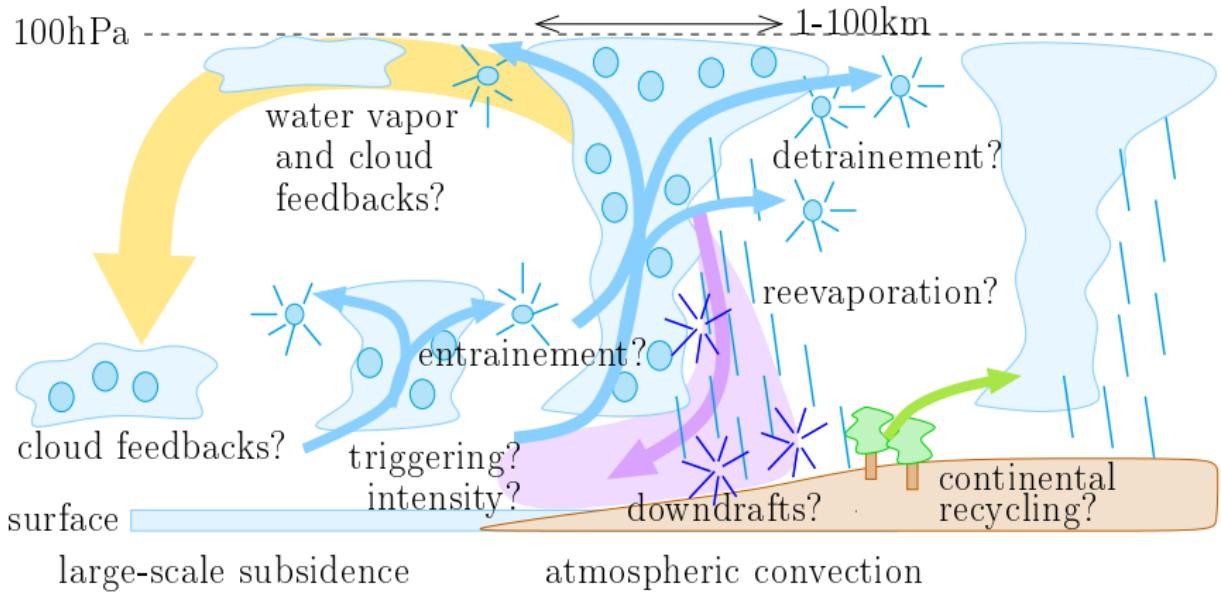
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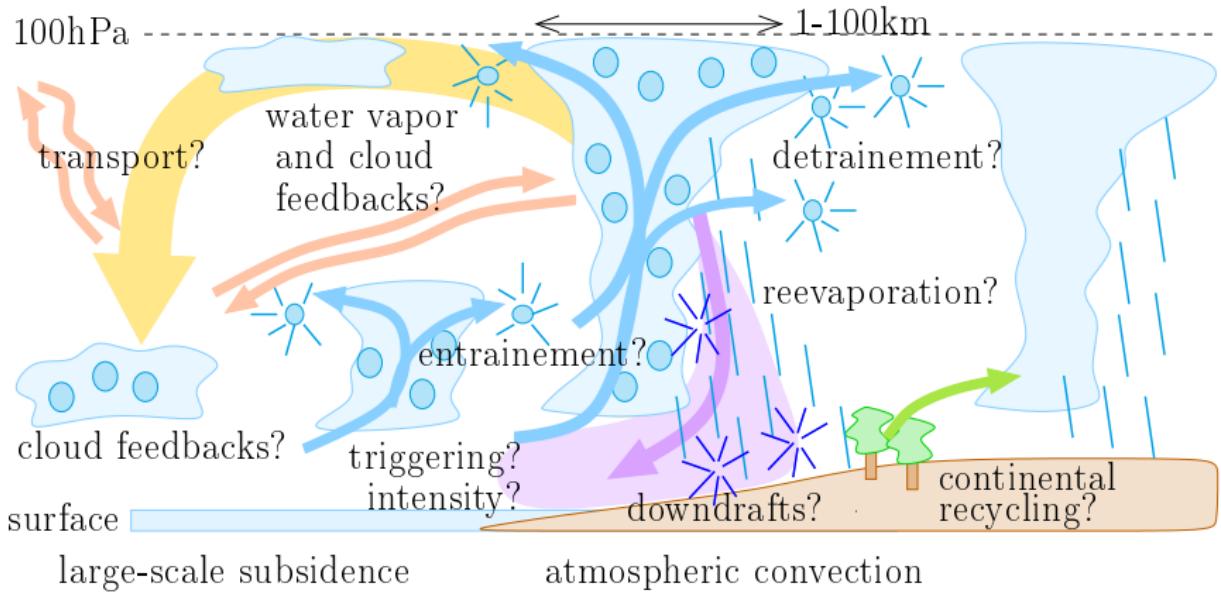
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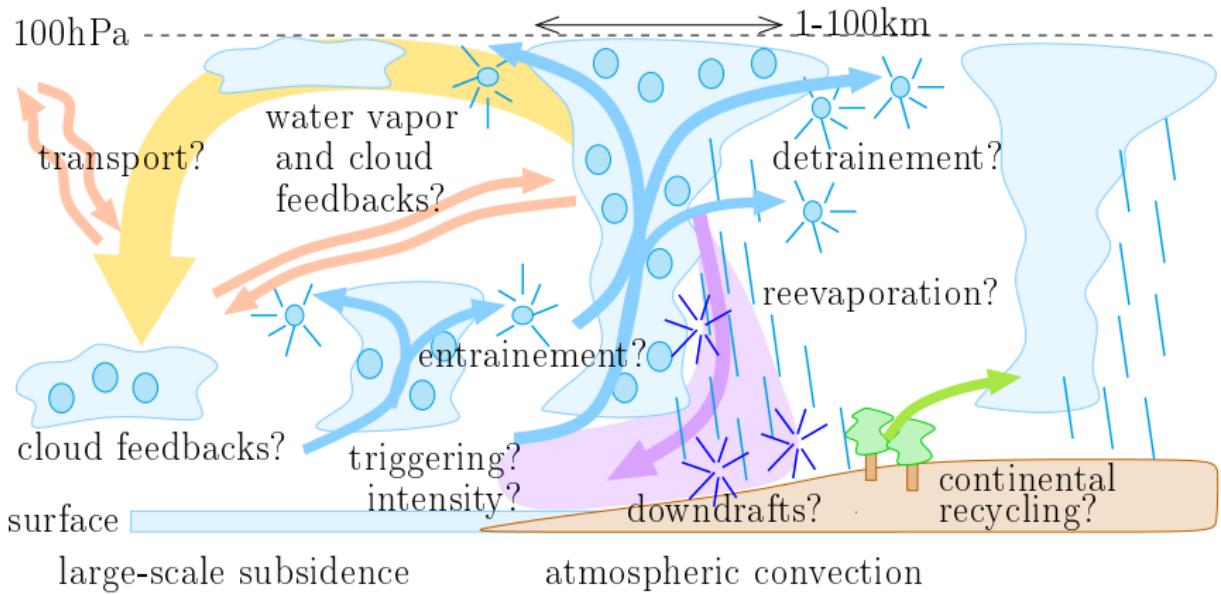
▶ better evaluate representation of these processes in models

Key processes in the tropics
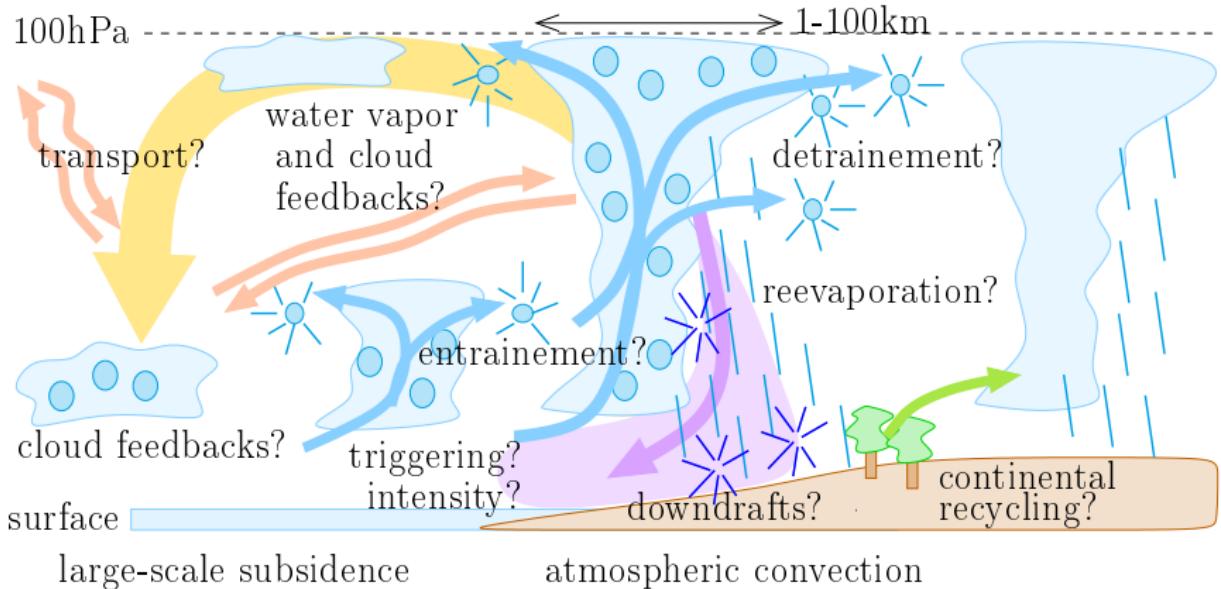
- ▶ better evaluate representation of these processes in models
- ▶ water isotopes (HDO, $H_2^{18}O$) $\leftrightarrow$ combination of these processes $\implies$ could help evaluate these processes?

General strategy
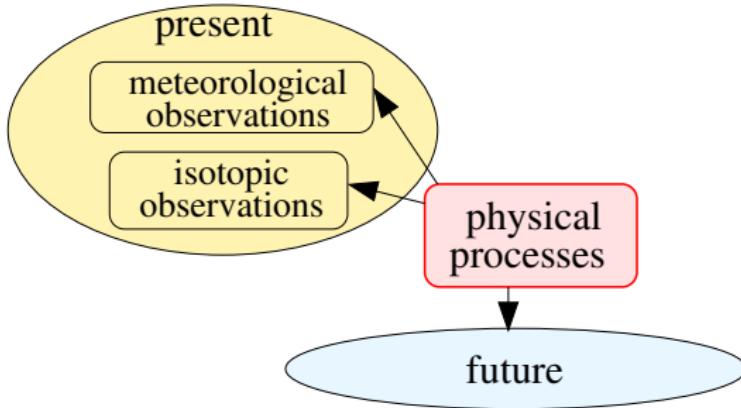
General strategy
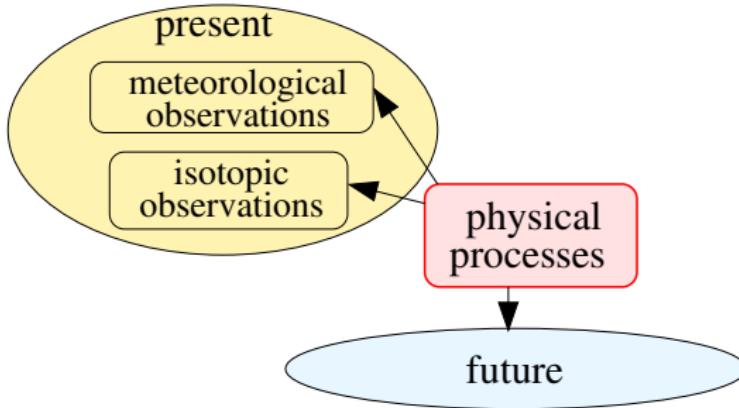
Outline:

1. Convection and tropical transport
   $\implies$ implications for feedbacks in climate change
2. Continental recycling
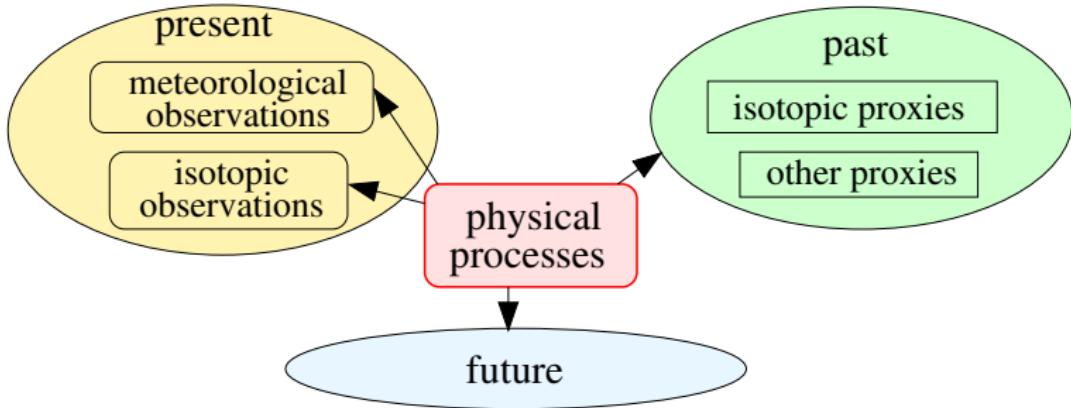
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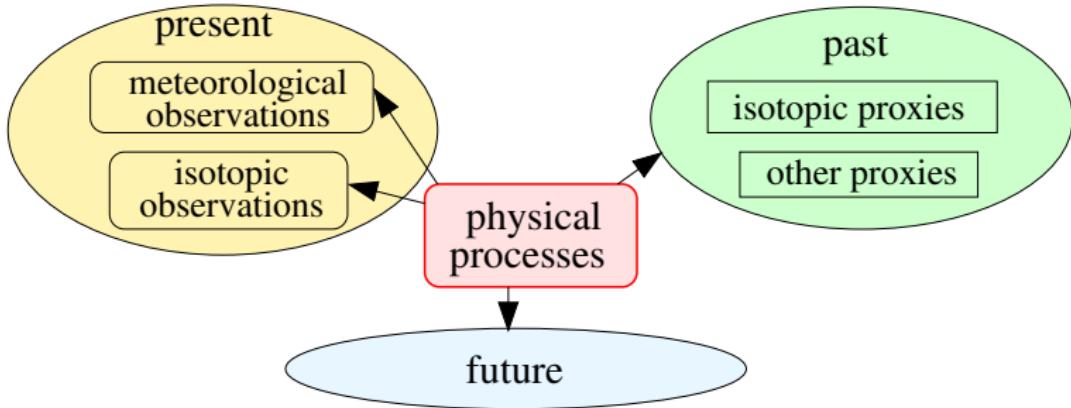
Outline:

1. Convection and tropical transport
   $\Longrightarrow$ implications for feedbacks in climate change
2. Continental recycling
3. Past tropical precipitation changes

1. Convective processes

▶ rain sampled every 5 mins in Niamey during squall lines

1. Convective processes

- rain sampled every 5 mins in Niamey during squall lines

11 August 2006
(Risi et al 2010b QJRMS)
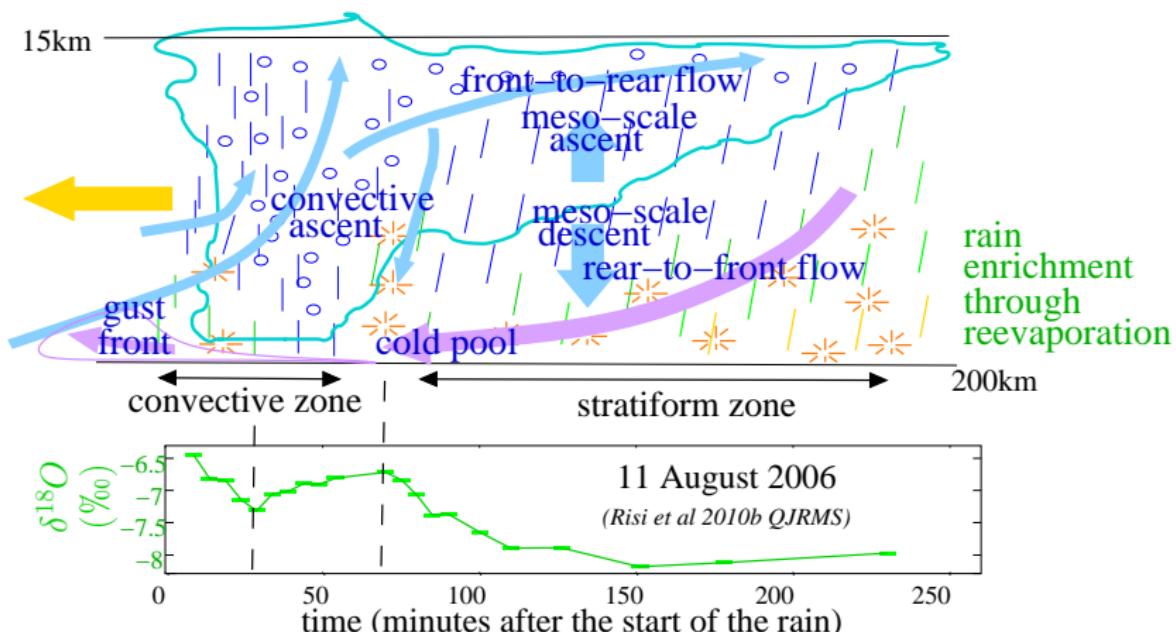
- modelling study: reevaporation, downdrafts

1. Convective processes

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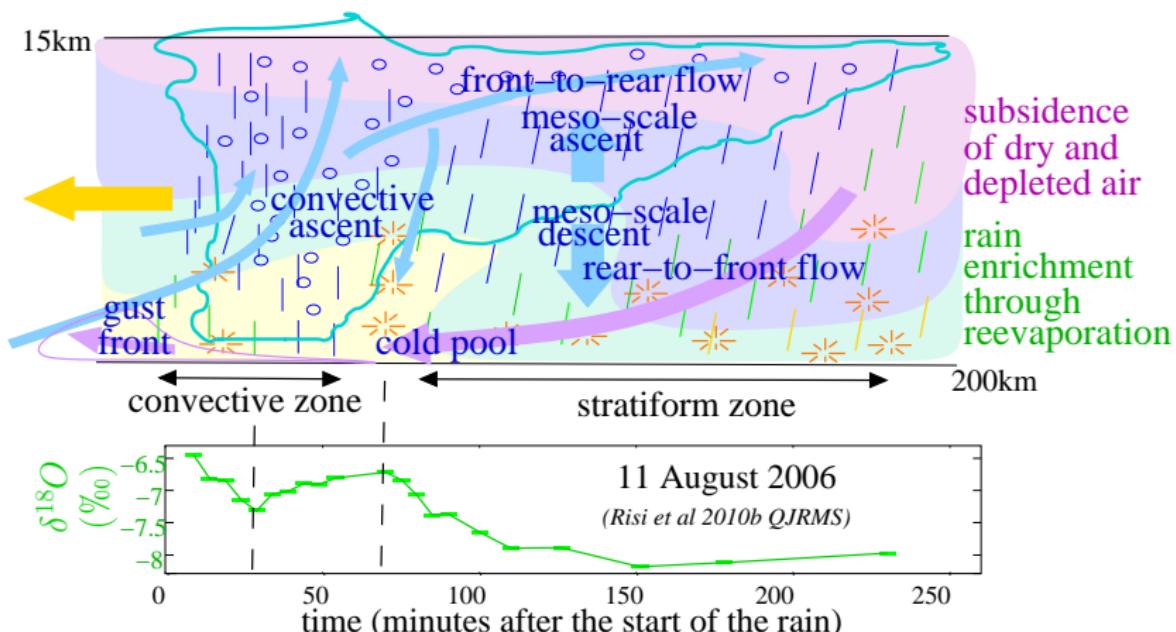
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Precipitation-isotopes relationship

- observations + modelling *(Risi et al 2008 JGR,GRL, 2010b JGR)*
- amount effect: precip $\nearrow \Longrightarrow \delta \searrow$ *(Dansgaard 1964)*

Niamey (Niger), precipitation samples

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Niamey (Niger), precipitation samples

Before onset

After onset

Monsoon onset

$\delta^{18}O$ (‰) P (mm/d)

1 June 2006   1 July   1 August   1 September

stronger precipitation

less reevaporation

$H_2^{16}O$

more depleted precipitation

# Precipitation-isotopes relationship

- observations + modelling *(Risi et al 2008 JGR,GRL, 2010b JGR)*
- amount effect: precip $\nearrow \Longrightarrow \delta \searrow$ *(Dansgaard 1964)*

Niamey (Niger), precipitation samples

New isotopic measurements

New isotopic measurements

1. Convection and tropical dynamics   7/22
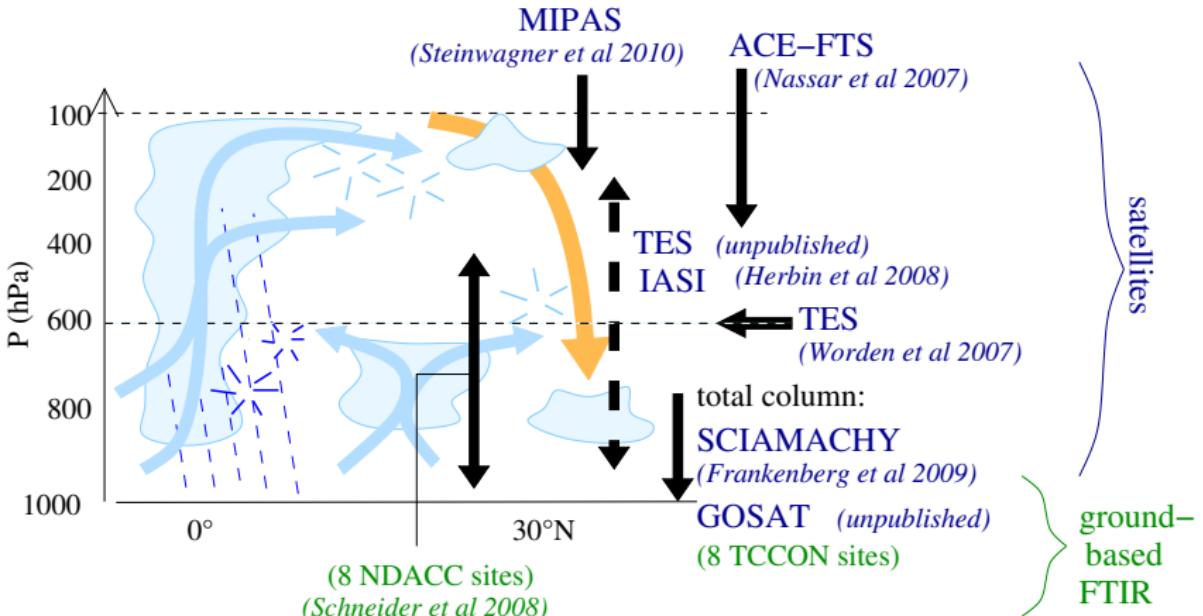
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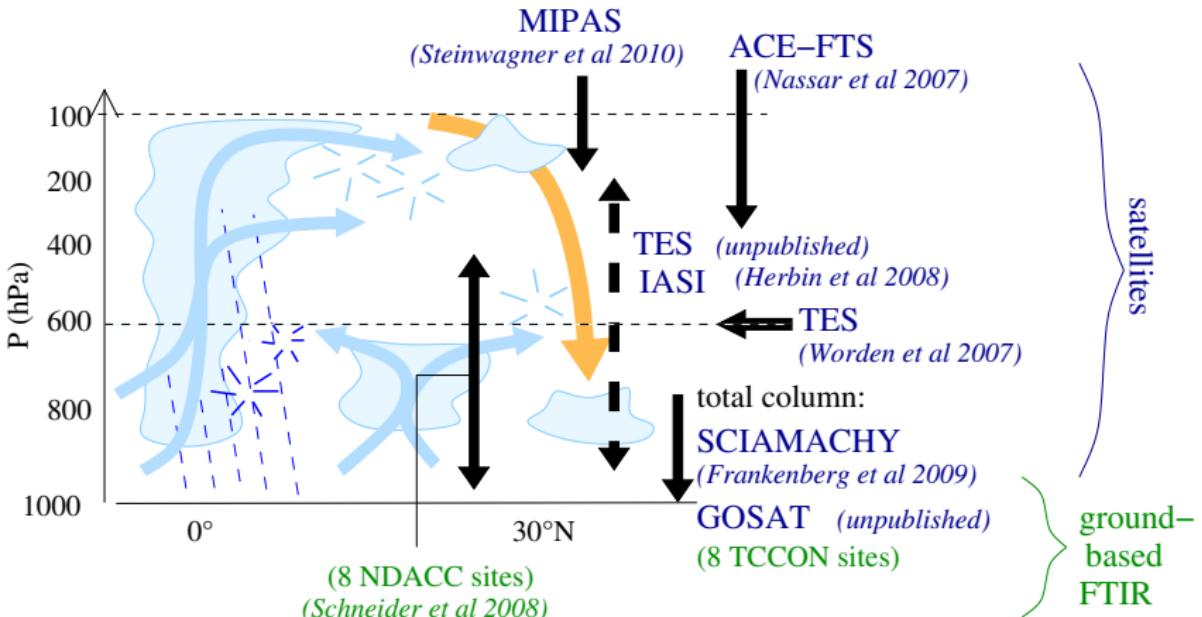
► focus on spatio-temporal variations

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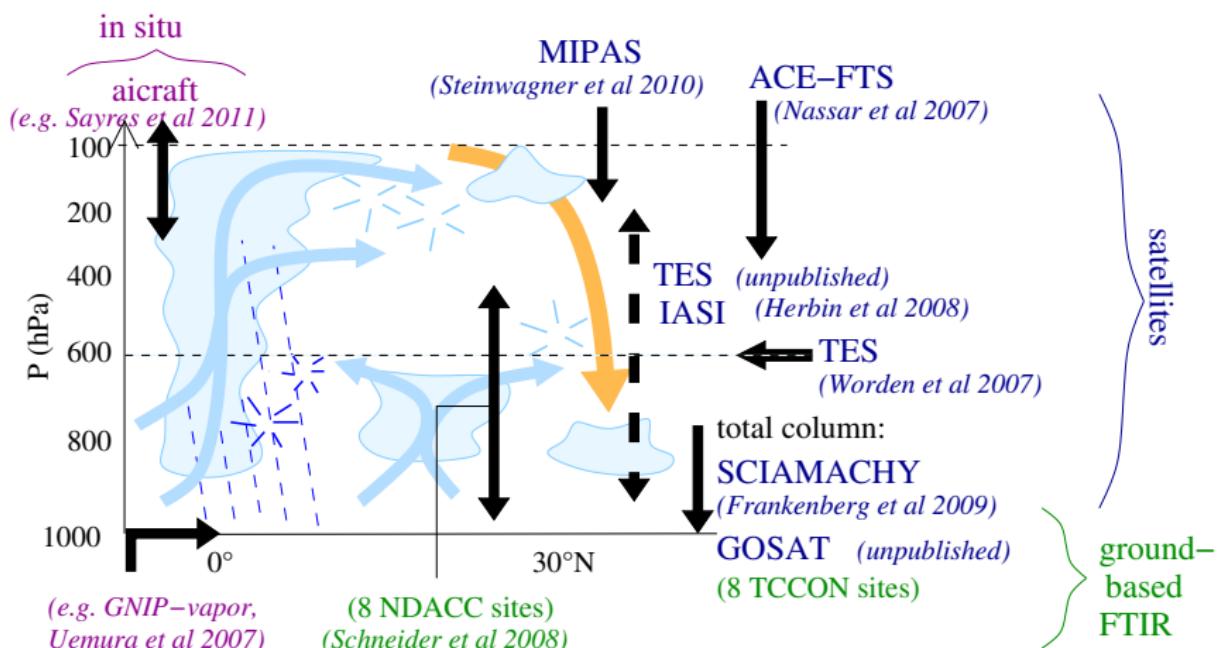
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3D water vapor isotopic distribution
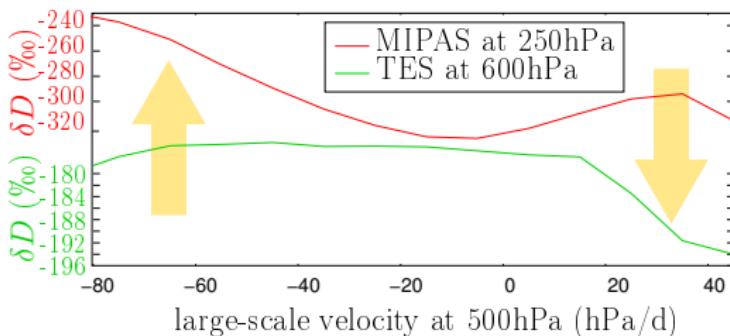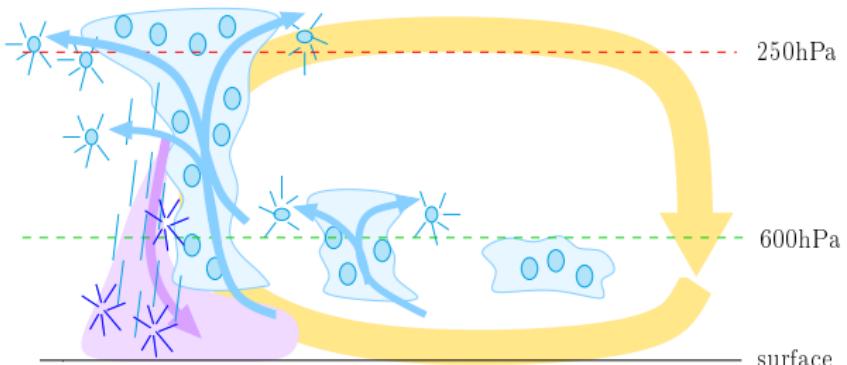
Risi et al submitted

3D water vapor isotopic distribution

Amazon, DJF-JJA
TES

large-scale velocity at 500hPa (hPa/d)

MIPAS at 250hPa
TES at 600hPa
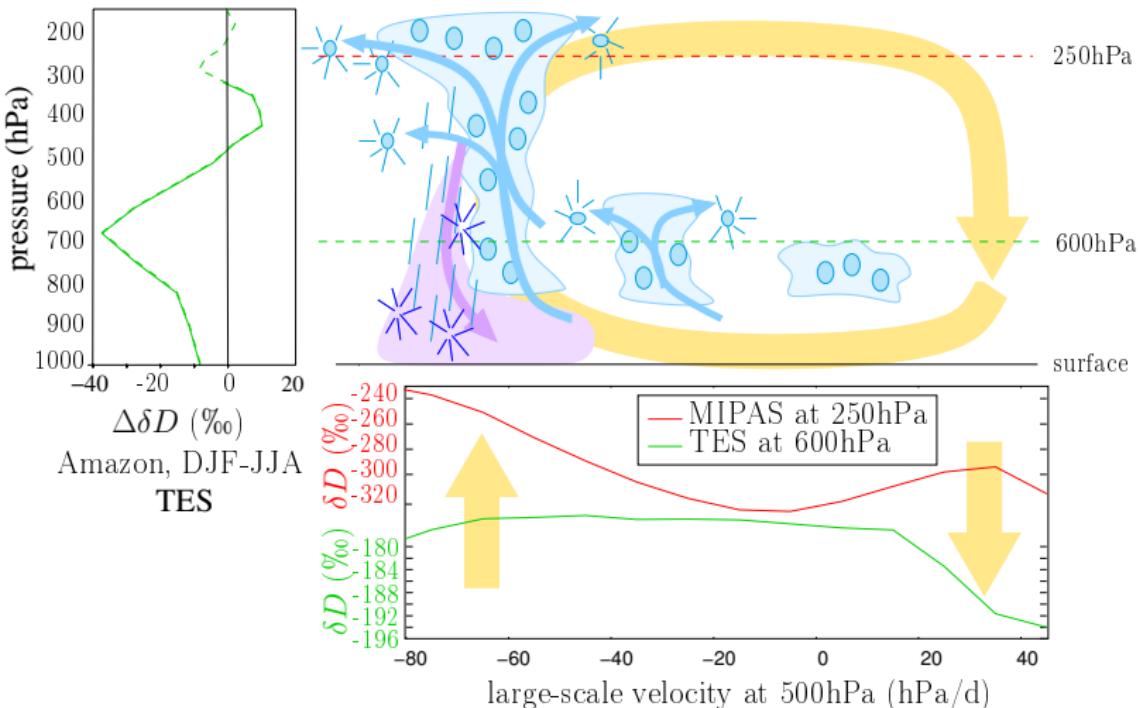
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Do IPCC models capture the isotopic distribution?

TES 600hPa
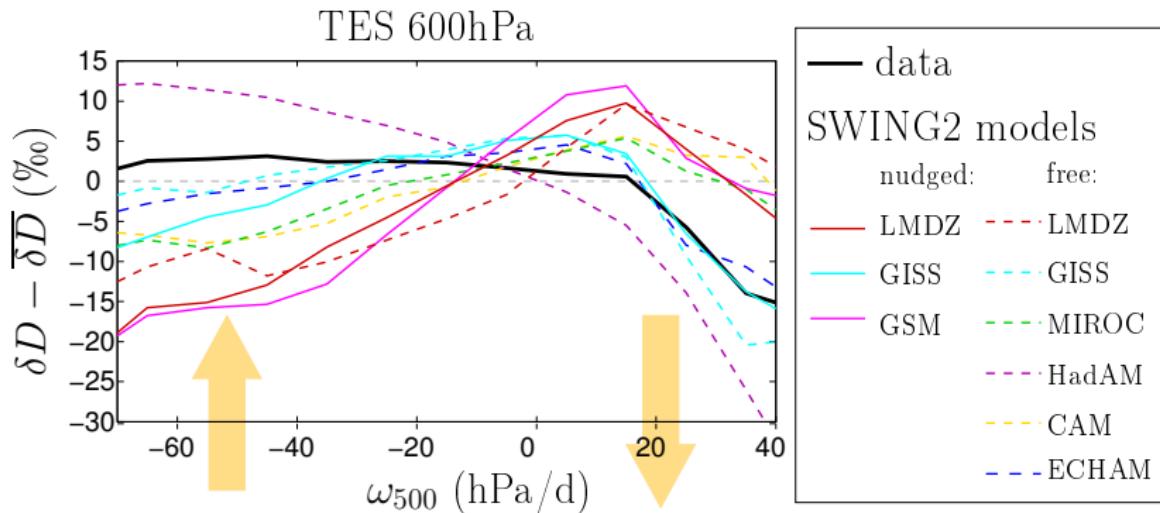
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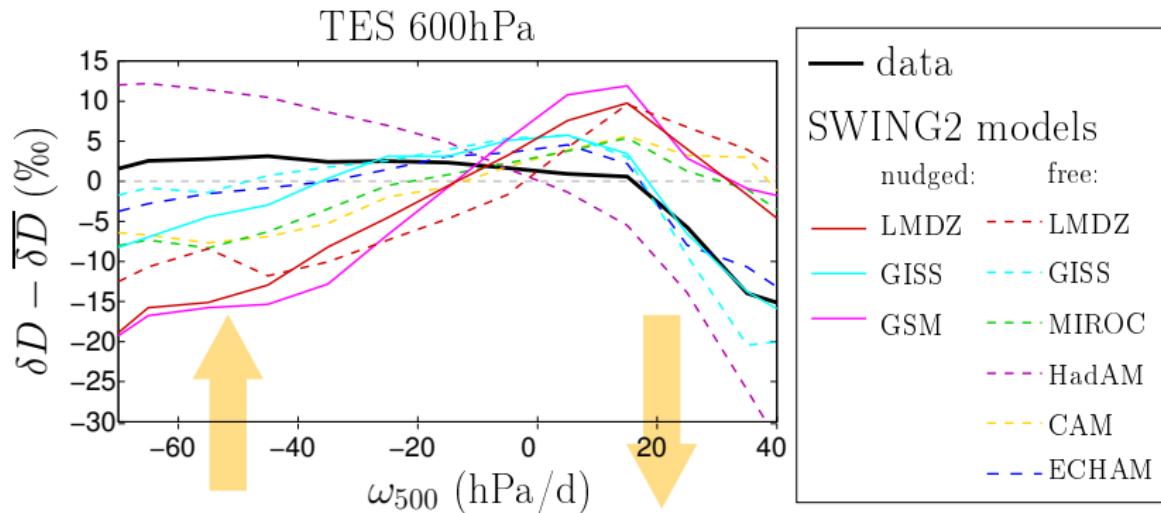
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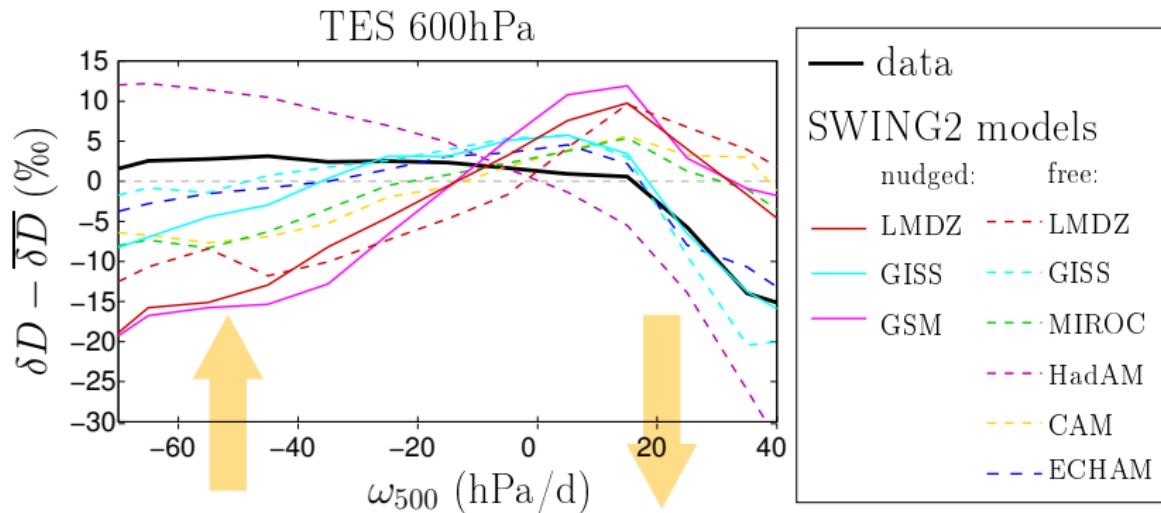
TES 600hPa

- ▶ Large dispersion between models, large model-data differences
- ▶ No obvious link with dispersion in meteorological variables.
- ▶ Reflect differences in key tropical processes? Which one? Can we design observational tests to evaluate models?

Sensitivity tests with LMDZ
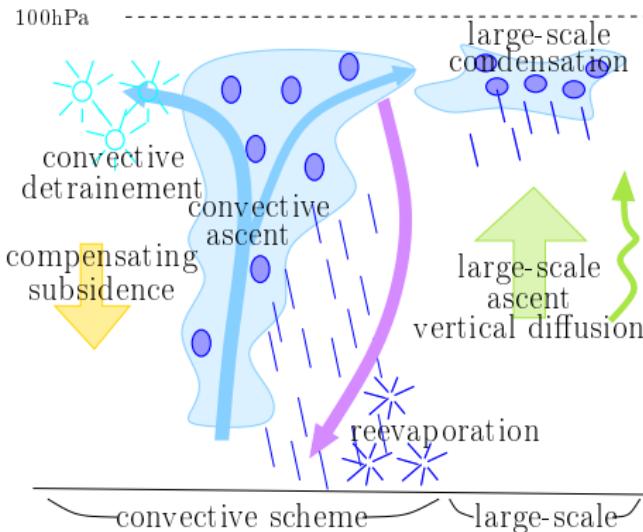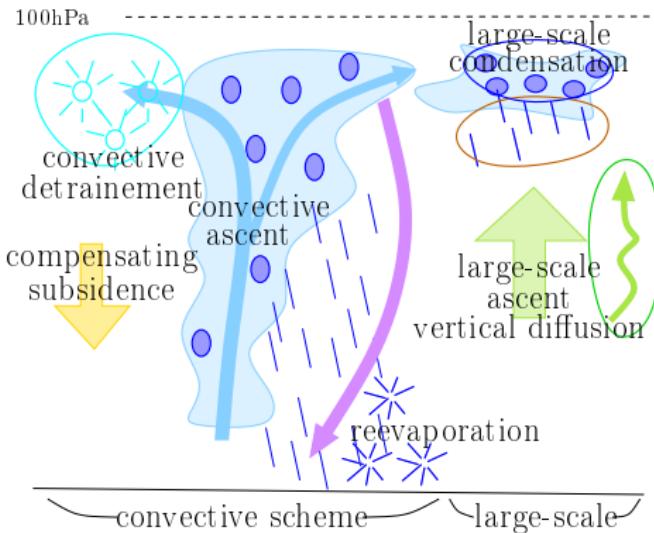
▶ LMDZ (IPSL) with isotopes (*Risi et al 2010a JGR*), nudged

Sensitivity tests with LMDZ

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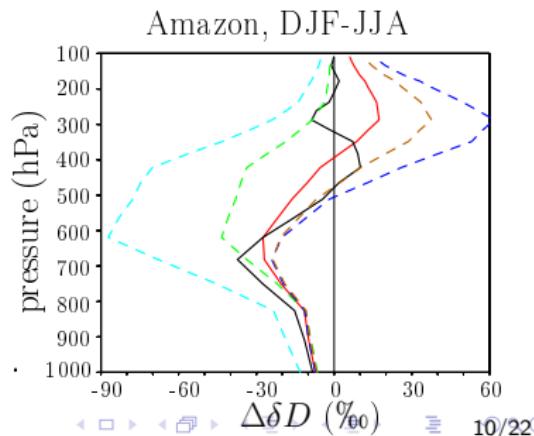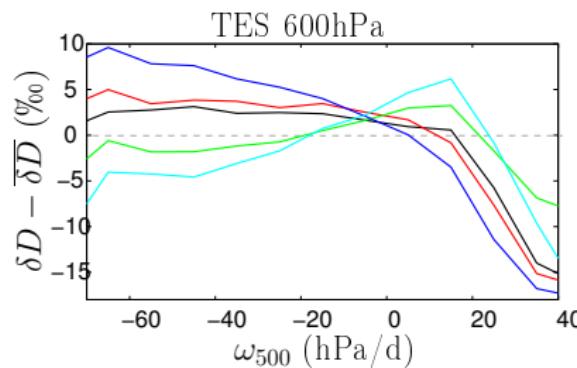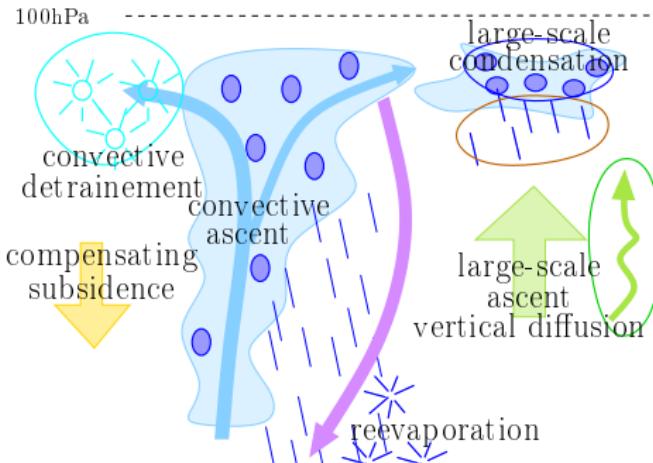
Convective contribution to water budget
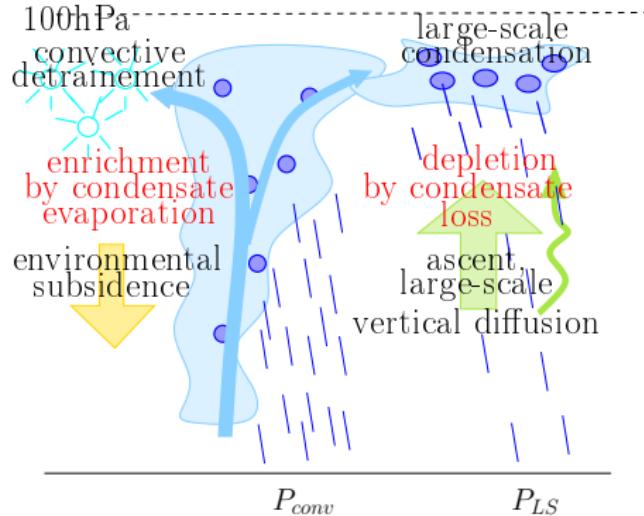
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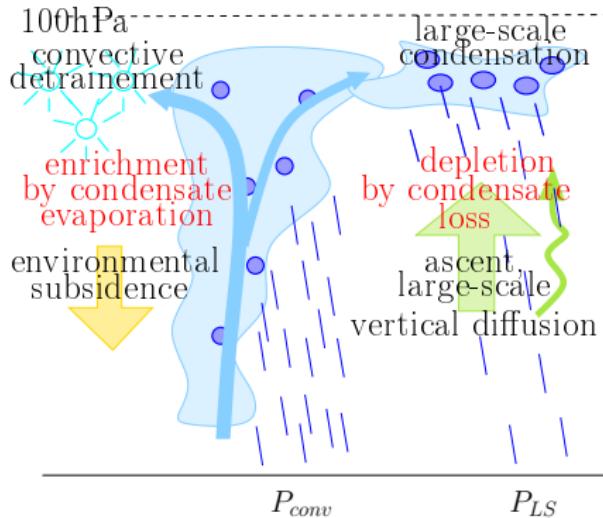
Role of vertical transport in dry regions

400 hPa, 15°N-30°N mean

ACE/AIRS data

JJA-DJF $\Delta\delta D$ (‰)

relative humidity (%)

100hPa

diffusion

surface

atmospheric convection
summer

large-scale subsidence
winter
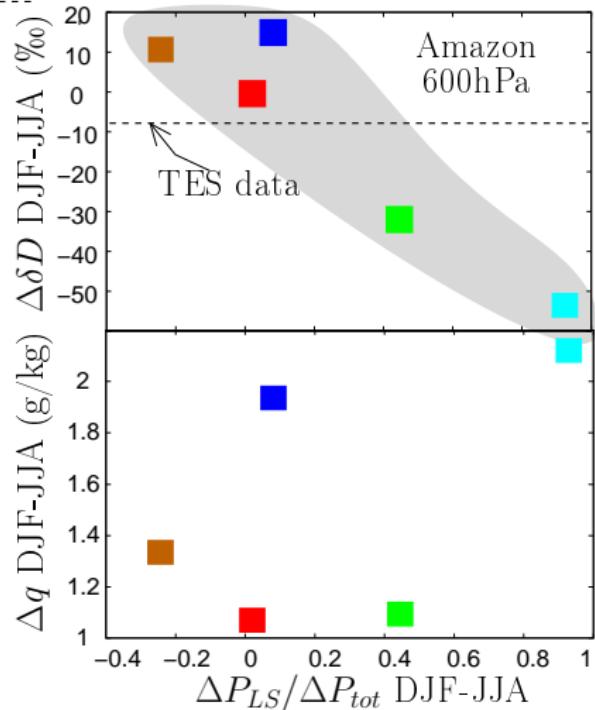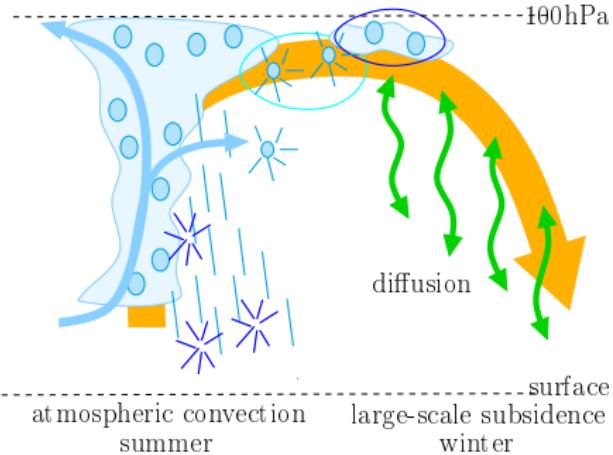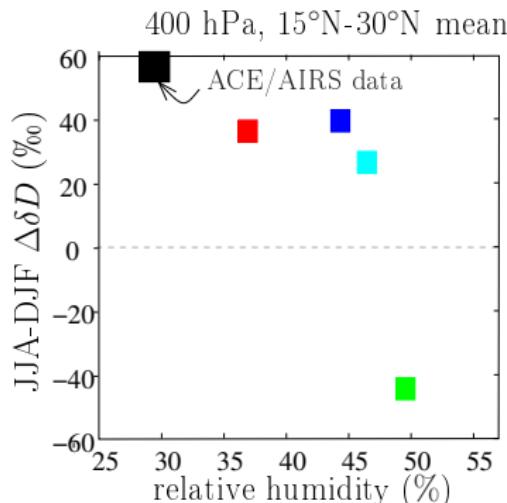
Sensitivity tests:
- Control
- Excessively diffusive vertical advection
- Excessive condensate detrainement
- Insufficient in-situ condensation

Role of vertical transport in dry regions

400 hPa, 15°N-30°N mean

subtropical isotopic seasonality=diagnostic for reason for moist bias

Role of vertical transport in dry regions

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ACE/AIRS data

100hPa

diffusion

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

SWING2 models:
- □ ECHAM
- △ MIROC
- ✳ HadAM
- ◇ CAM2
- ○ GISS
- ▽ GSM

▶ subtropical isotopic seasonality=diagnostic for reason for moist bias

Role of vertical transport in dry regions

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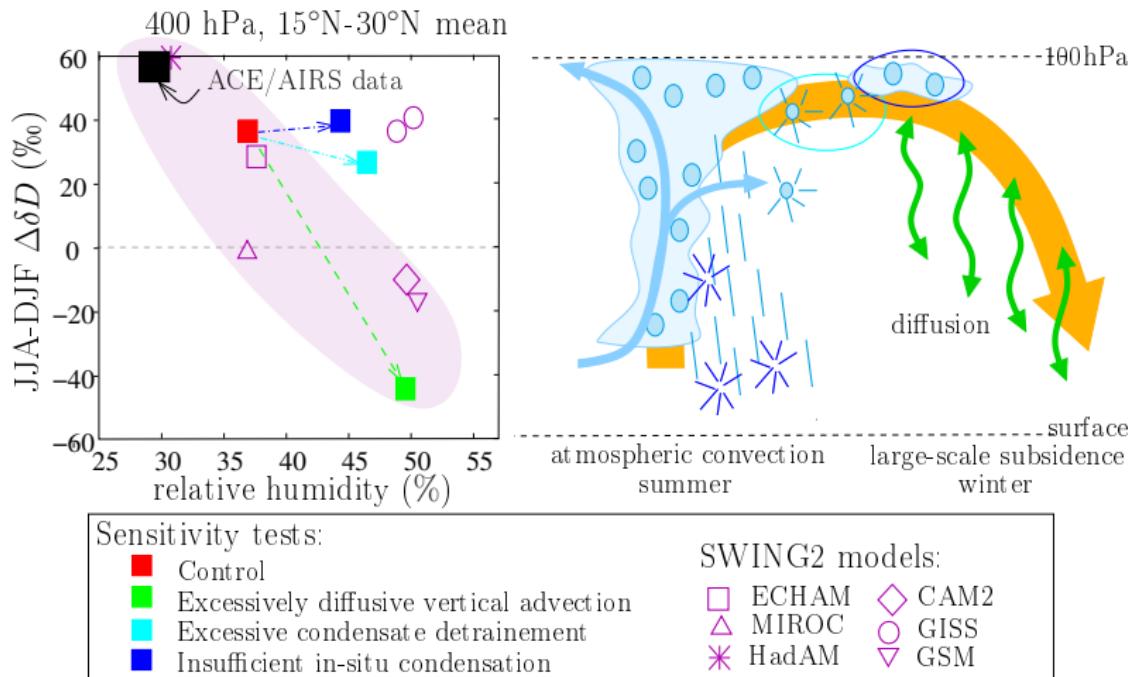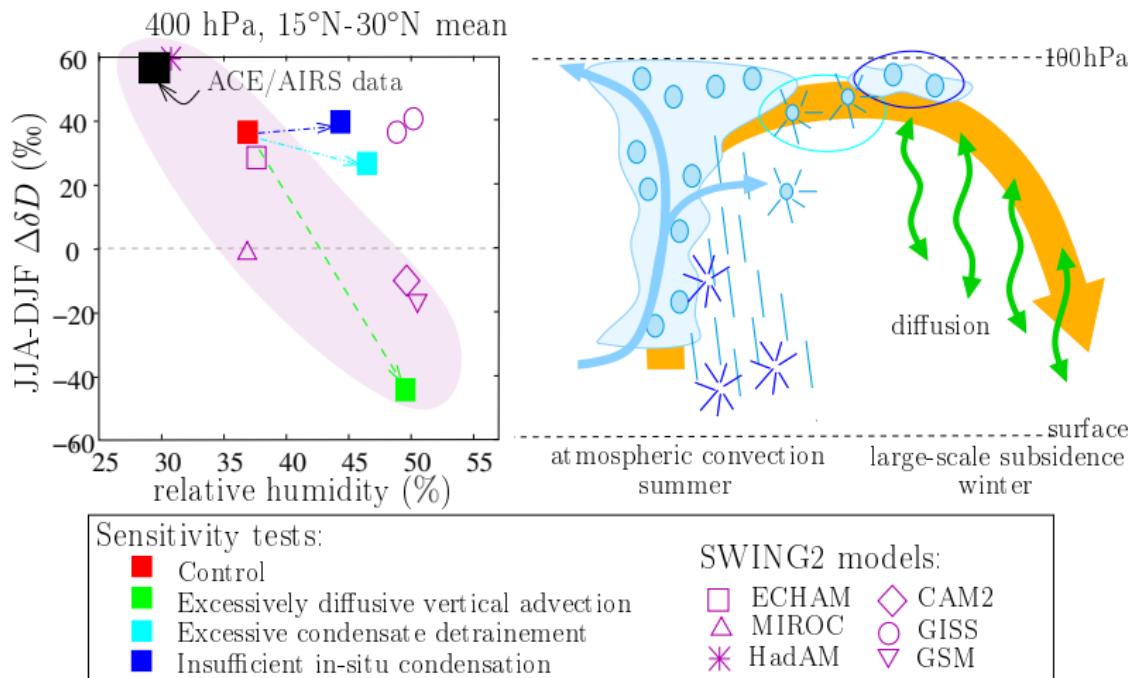
- subtropical isotopic seasonality=diagnostic for reason for moist bias
- frequent reason for moist bias=excessive diffusion

What impact on humidity projections?
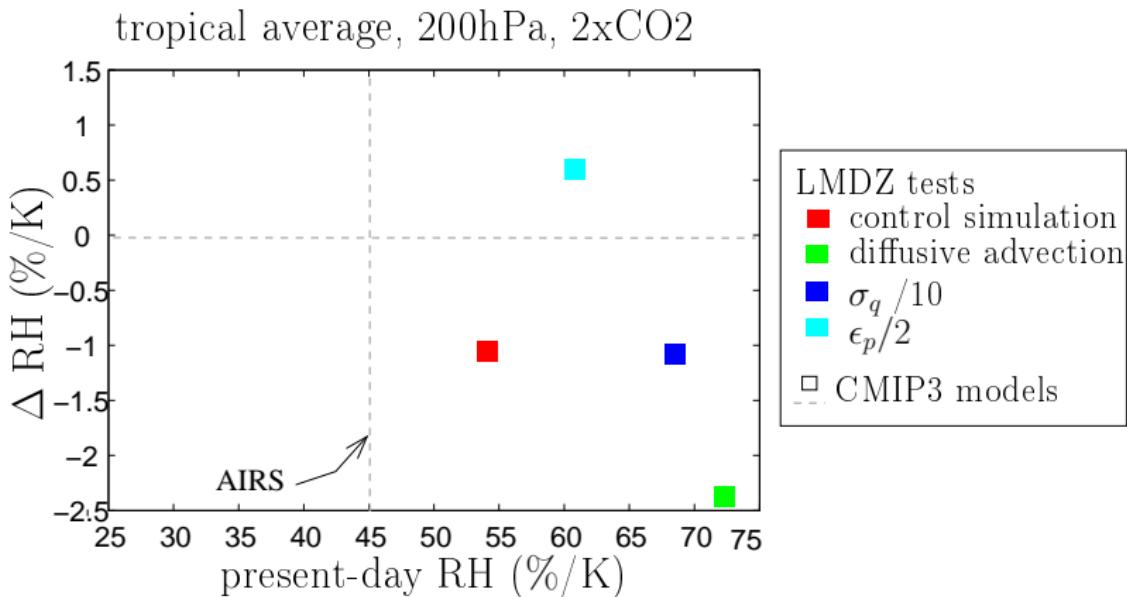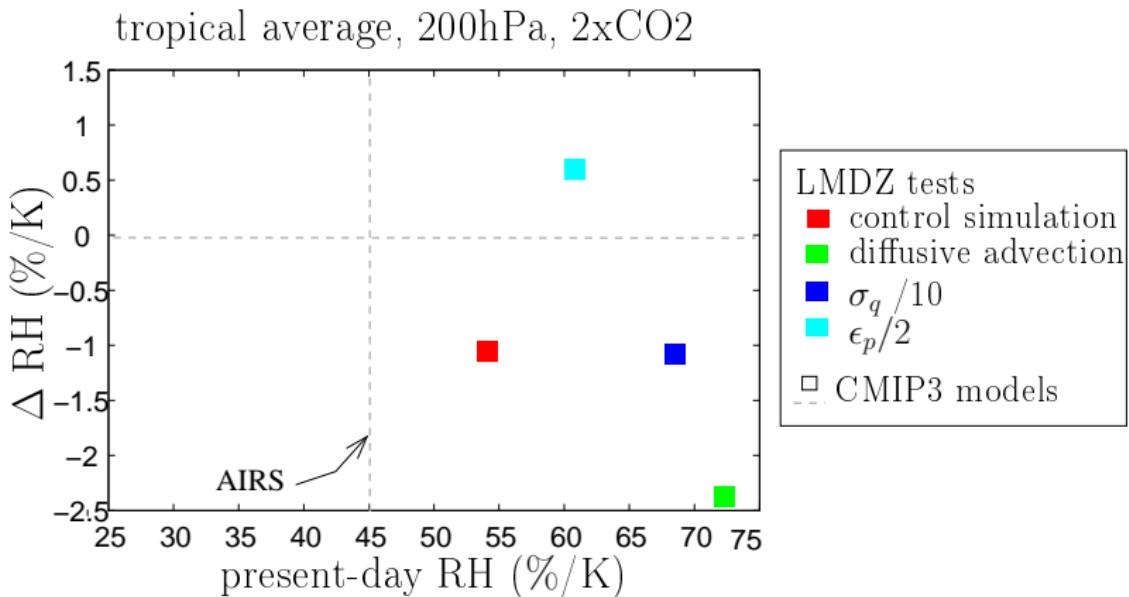
tropical average, 200hPa, 2xCO2

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

□ CMIP3 models

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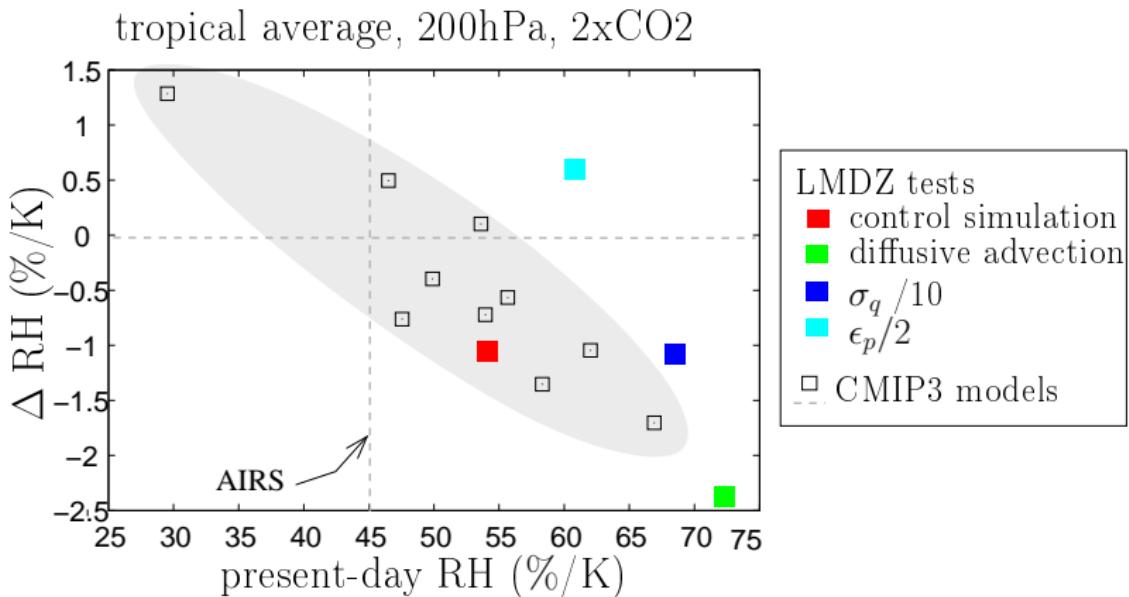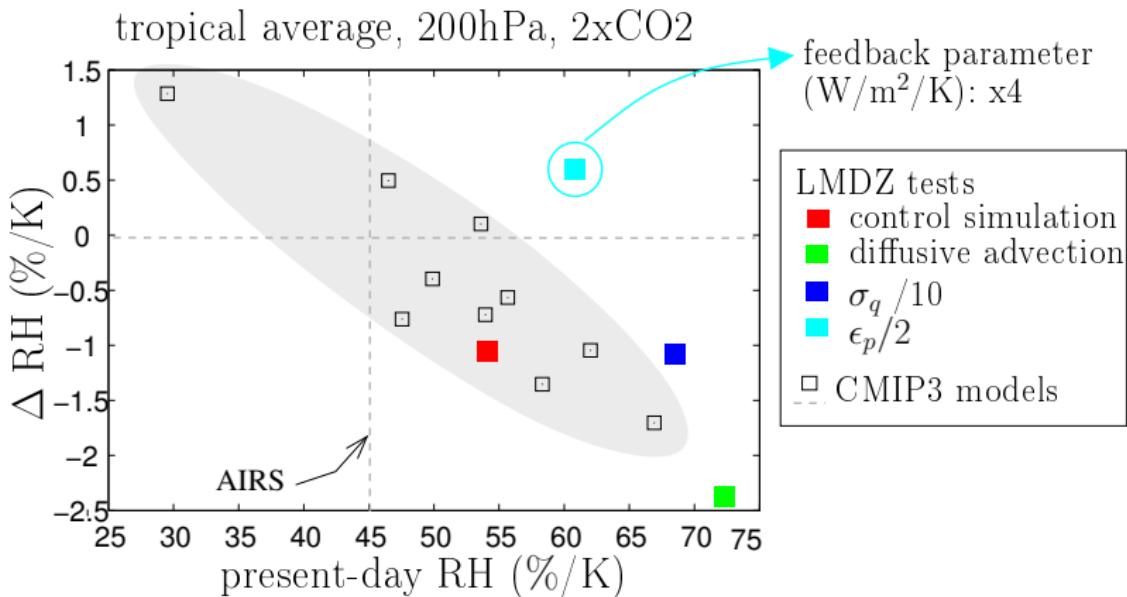
- How a moist bias affect RH change projections depends on reason for bias
- Climate sensitivity: water vapor/high cloud feedbacks

Summary on convection

- In convective regions:
    - precip and surface vapor $\rightarrow$ reevaporation, downdrafts
    - mid tropospheric vapor $\rightarrow$ contribution of convection in water budget

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    - mid and upper tropospheric vapor $\rightarrow$ vertical diffusion

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- subtropical isotopic seasonality=observable diagnostic to identify reason for moist bias in models
  $\Longrightarrow$ excessive vertical diffusion

Summary on convection

- ► In convective regions:
    - ► precip and surface vapor $\rightarrow$ reevaporation, downdrafts
    - ► mid tropospheric vapor $\rightarrow$ contribution of convection in water budget
- ► In dry regions
    - ► mid and upper tropospheric vapor $\rightarrow$ vertical diffusion
- ► subtropical isotopic seasonality=observable diagnostic to identify reason for moist bias in models
  $\implies$ excessive vertical diffusion
- ► Using water isotopes to understand reasons for present-day biases is useful to discriminate between different simulated water vapor and cloud feedbacks.

2. Continental recycling

- LMDZ coupled to ORCHIDEE + water tagging

PDF of vapor composition
monthly, all tropical land points

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Niamey (Niger), annual mean

PDF of vapor composition
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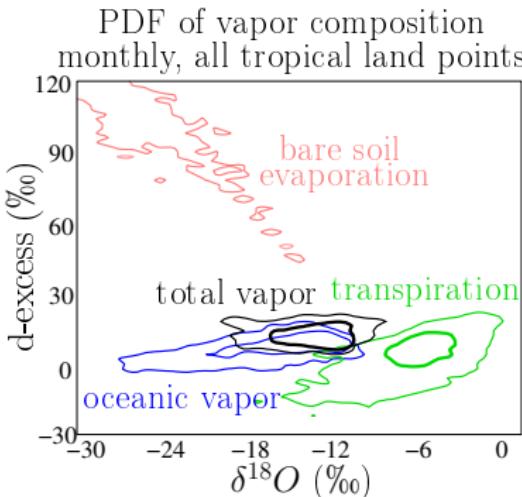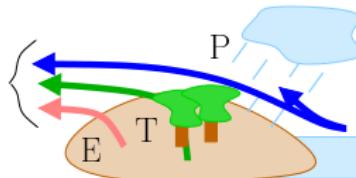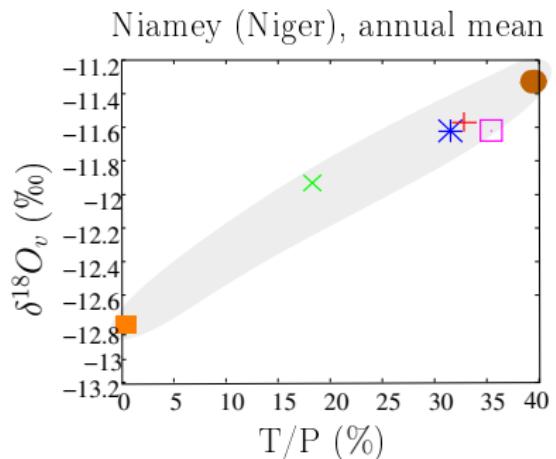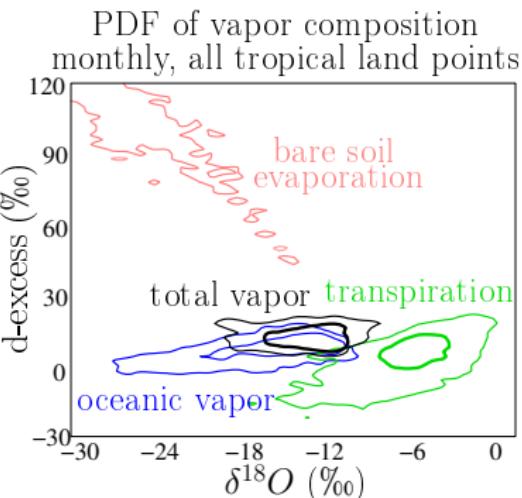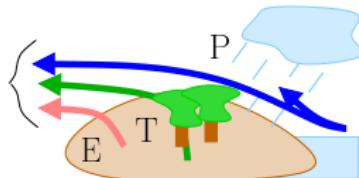
Tests in ORCHIDEE
- $+$ control
- $\times$ stomatal resistance/5
- ● more surface runoff
- ✳ soil capacity/2
- ■ more bare soil
- □ rooting depth /4

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Tests in ORCHIDEE	Tests in LMDZ
+ control	
× stomatal resistance/5	
● more surface runoff	▬ control
✳ soil capacity/2	▬ more diffusion
■ more bare soil	▬ less condensation
□ rooting depth /4	▬ more detrainment

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Tests in ORCHIDEE	Tests in LMDZ
+ control	
× stomatal resistance/5	red control
● more surface runoff	green more diffusion
✳ soil capacity/2	blue less condensation
■ more bare soil	cyan more detrainment
□ rooting depth /4	

- How to extract recycling from atmospheric processes?

Diagnosing land-atmosphere feedbacks

▶ feedbacks on precipitation at intra-seasonal scale
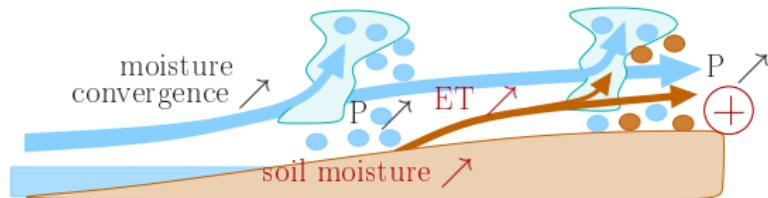
strong precipitation composite minus seasonal average:

Diagnosing land-atmosphere feedbacks

▶ feedbacks on precipitation at intra-seasonal scale

moisture convergence

ET

soil moisture

P

P

Amazon, DJF

Δr_{con} (%)

strong precipitation composite minus seasonal average:

Δr_{con} (%) JJA

control by large-scale convergence

positive land-atmosphere feedback

Diagnosing land-atmosphere feedbacks

▶ feedbacks on precipitation at intra-seasonal scale

strong precipitation composite minus seasonal average:

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Amazon, DJF

Δr_{con} (%)
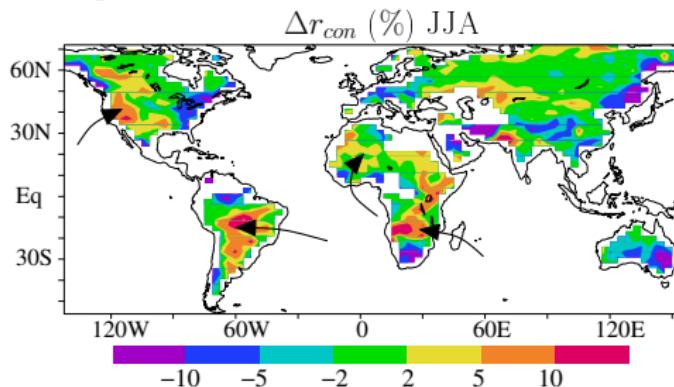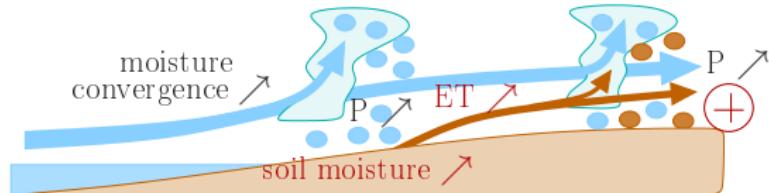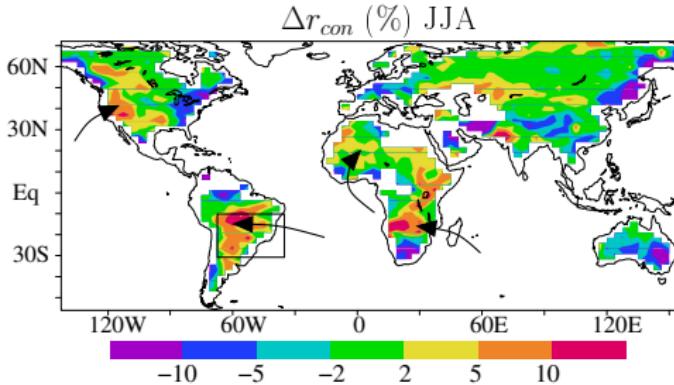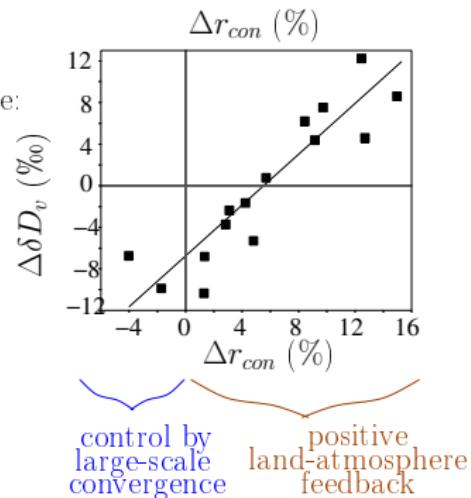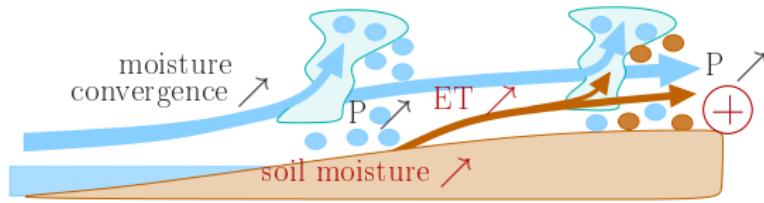
positive land-atmosphere feedback
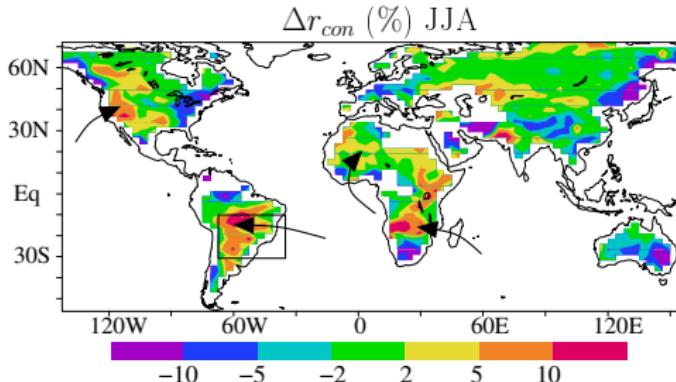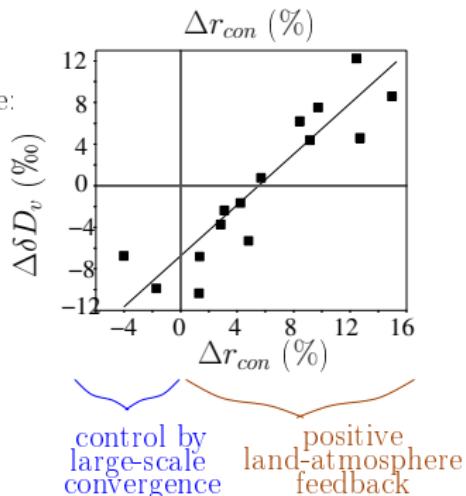
▶ link $\delta D \leftrightarrow$ humidity=proxy for land-atmosphere feedbacks

Diagnosing land-atmosphere feedbacks

▶ feedbacks on precipitation at intra-seasonal scale

moisture convergence

ET

P

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P

Amazon, DJF

Δr_{con} (%)

strong precipitation composite minus seasonal average:
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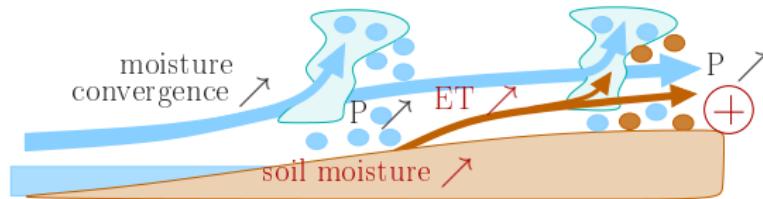
positive land-atmosphere feedback
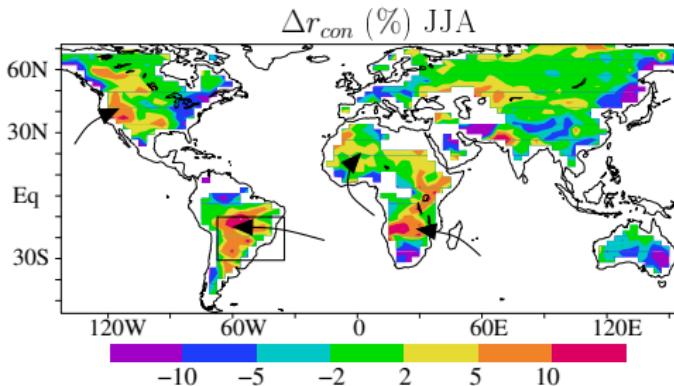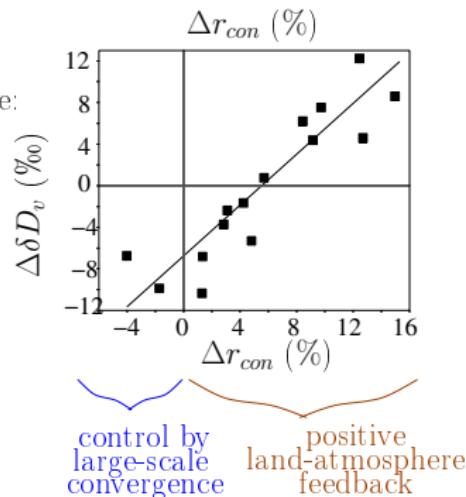
▶ link $\delta D \leftrightarrow$ humidity=proxy for land-atmosphere feedbacks

▶ but again: also sensitive to the atmospheric physics.

Evaluating land-atmosphere feedbacks using satellite datasets

► Hypothesis: compare land versus ocean
► Total column water vapor (GOSAT), intra-seasonal scale
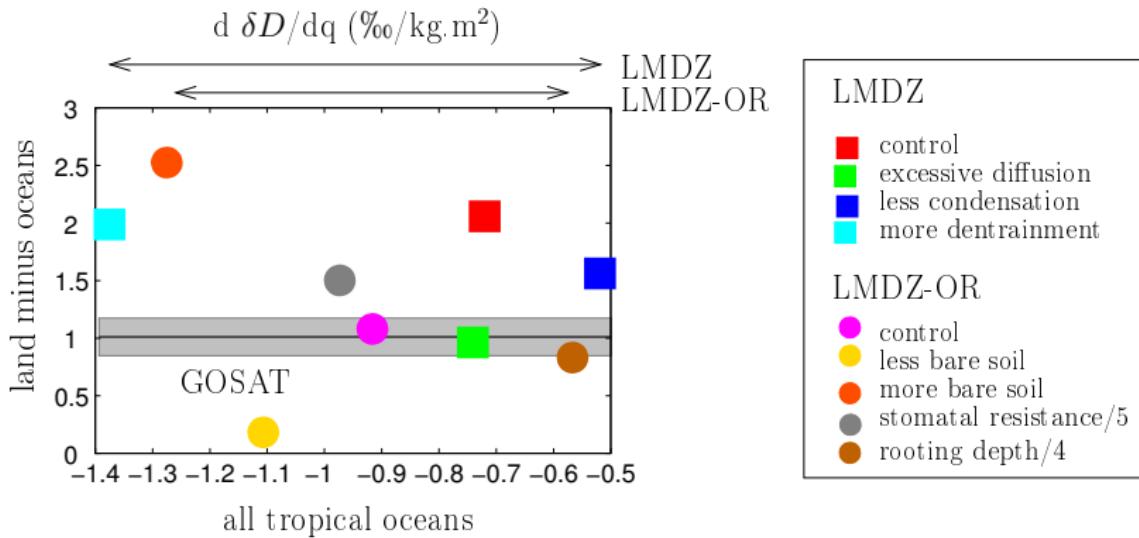
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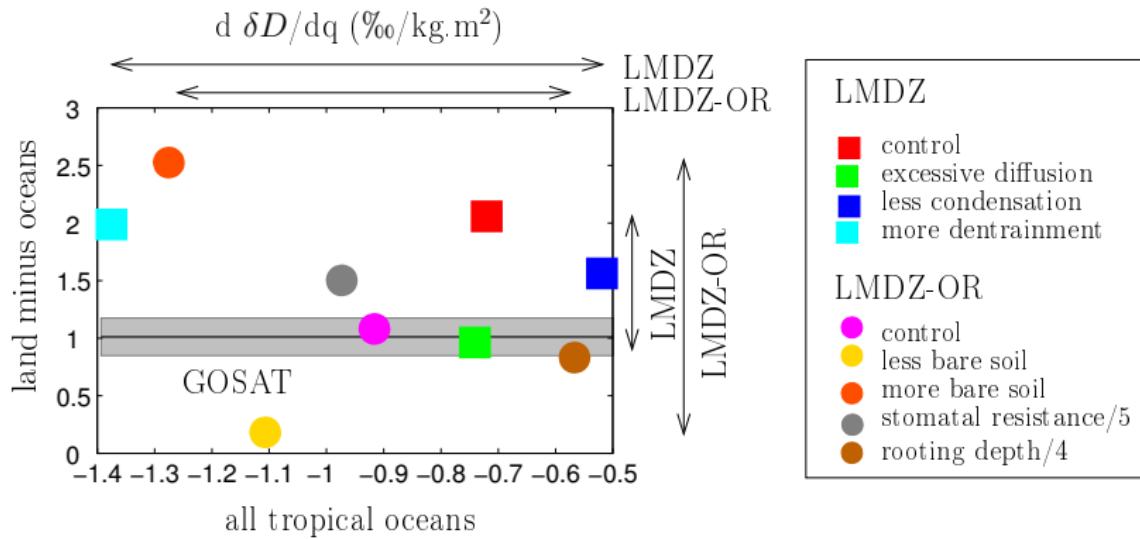
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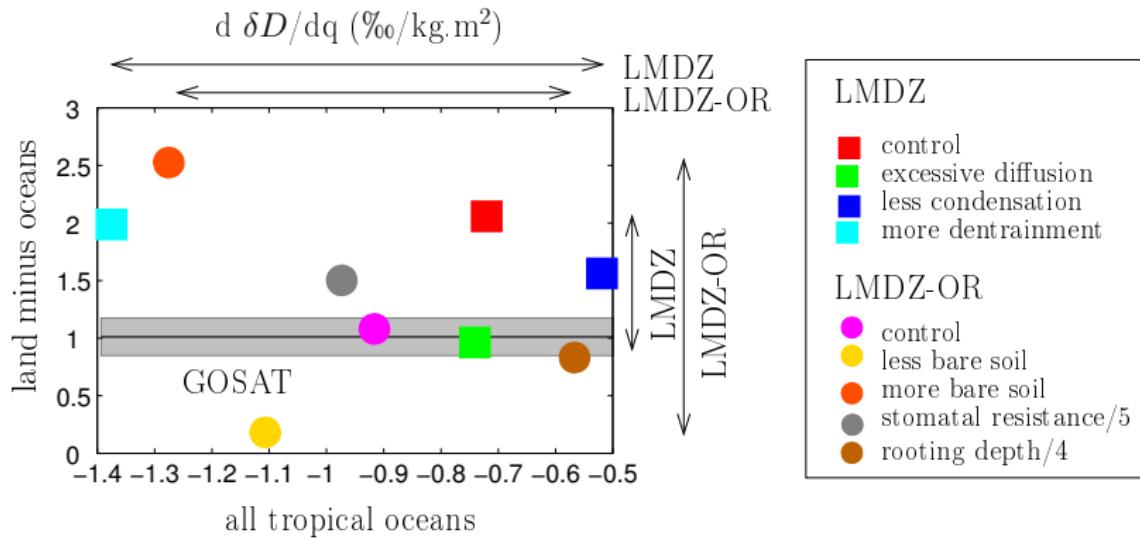
▶ compare land/ocean to discriminate land/atm feedbacks
▶ work in progress to refine diagnostics

Summary on land-atmosphere feedbacks

► link $\delta D \leftrightarrow$ humidity: sensitive to

1. atmospheric physics (e.g. convection)
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- compare link over land versus ocean
 $\Longrightarrow$ evaluate intensity of land-atmosphere feedbacks
- work in progress:
    - refine diagnostics
    - understand processes
    - to what extent evaluating land-atmosphere feedbacks at intra-seasonal scale helps for constraining projections?

3. Isotopic records of past precipitation

▶ ice cores, speleothems, ground water, shells

Correlation $\delta^{18}O_p$ - P

Guliya ice core

$\Delta\delta^{18}O_p$ (‰)

regional ΔP (mm/d)
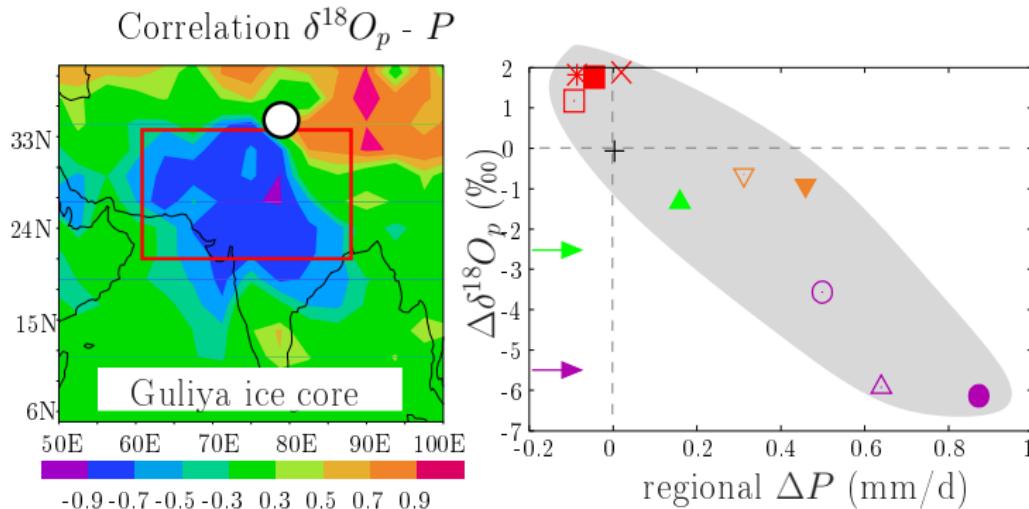
Climates:
+ present-day
× 4xCO2 IPSL
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▶ $\delta^{18}O$ = robust proxy for past regional precipitation changes

Precipitation response to SST changes

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- precipitation response depends strongly on the physics (e.g. *Kang et al 2008*)

Summary on precipitation changes
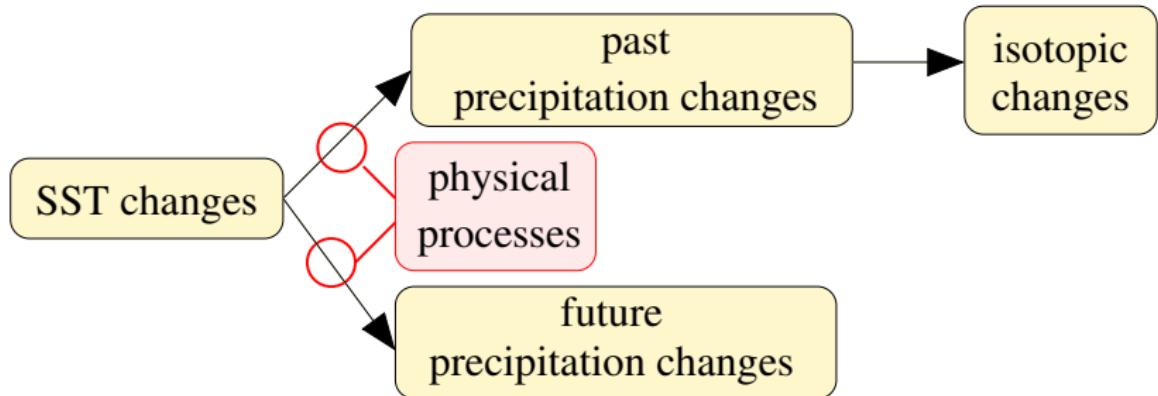
Summary on precipitation changes
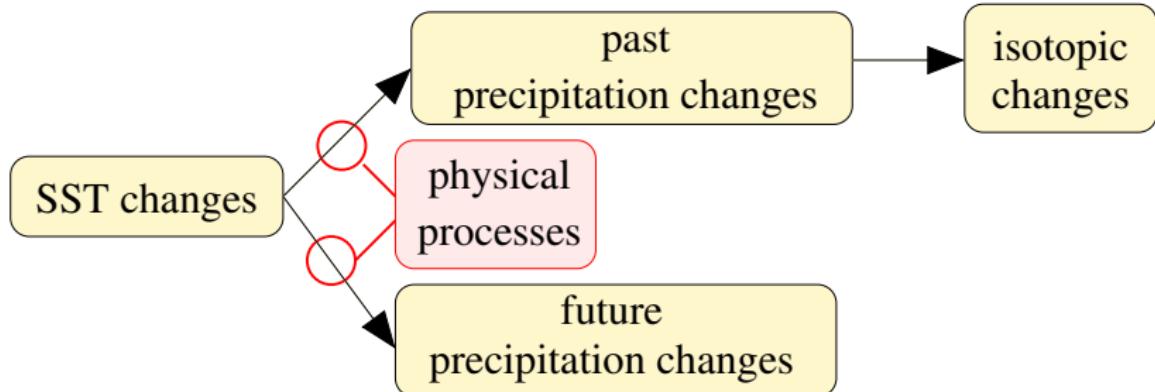
- difficulties:
  - link SST $\longleftrightarrow$ precipitation changes more complex over land
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Summary on precipitation changes
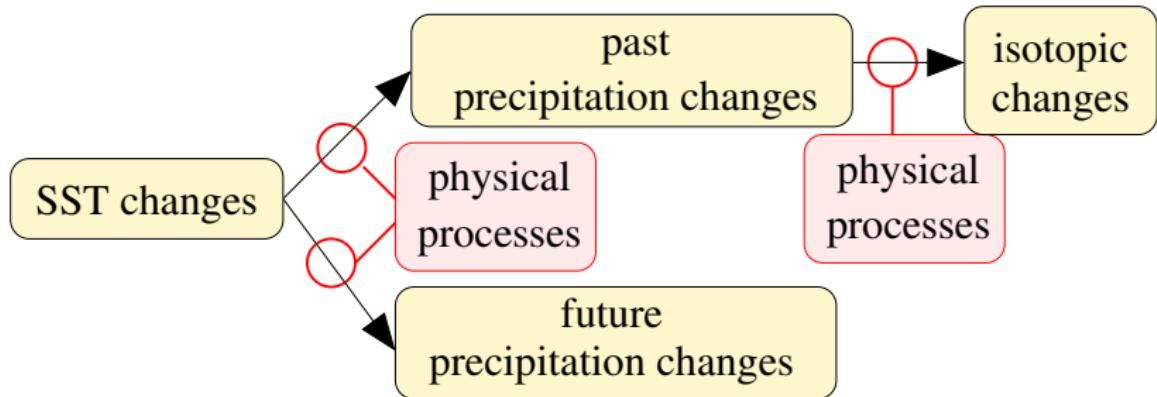
- difficulties:
  - link SST ⟷ precipitation changes more complex over land
    ⟹work in progress to identify robust regional controls
  - link isotopic records ⟷ precipitation changes: also depend
    on the physics
    ⟹need careful calibration

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    - CMIP5: link between physical processes at present, past changes and future projections
   (but isotopes missing)

Supplementary

# Isotopic distribution in water vapor

TES data at 600hPa
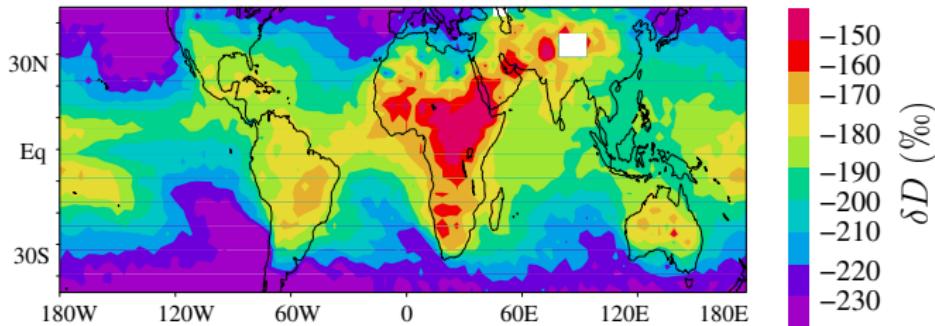
MIPAS data at 250hPa
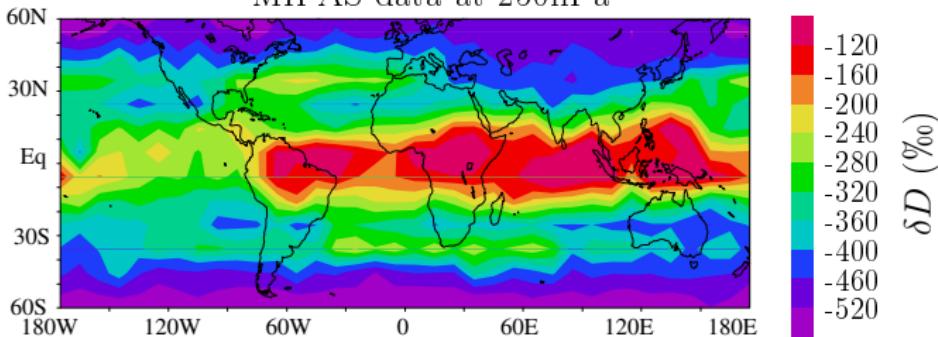
What impact on climate sensitivity?
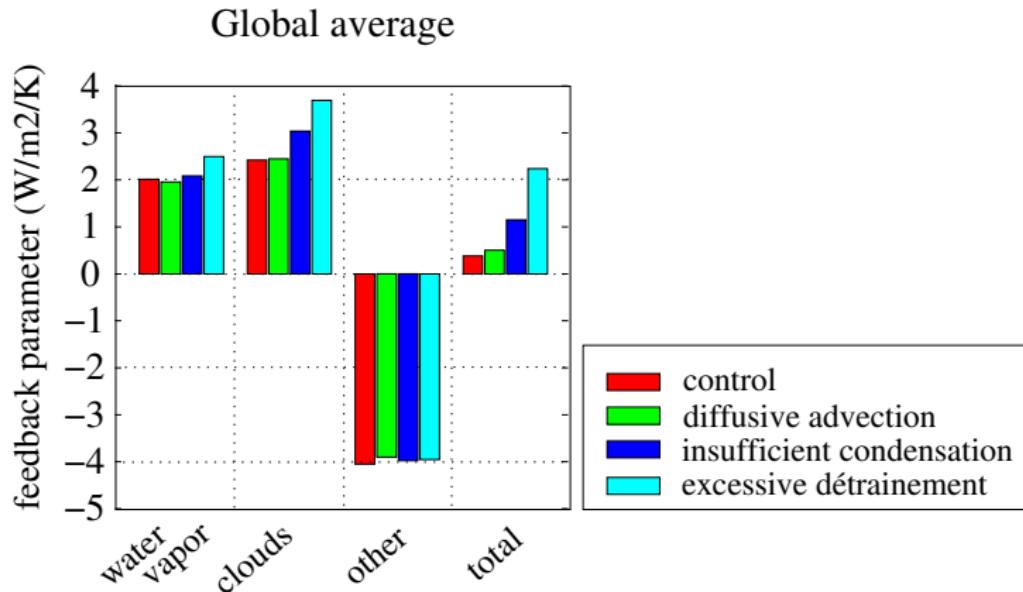
▶ radiative kernel decomposition (*Soden et al 2008*)

Global average

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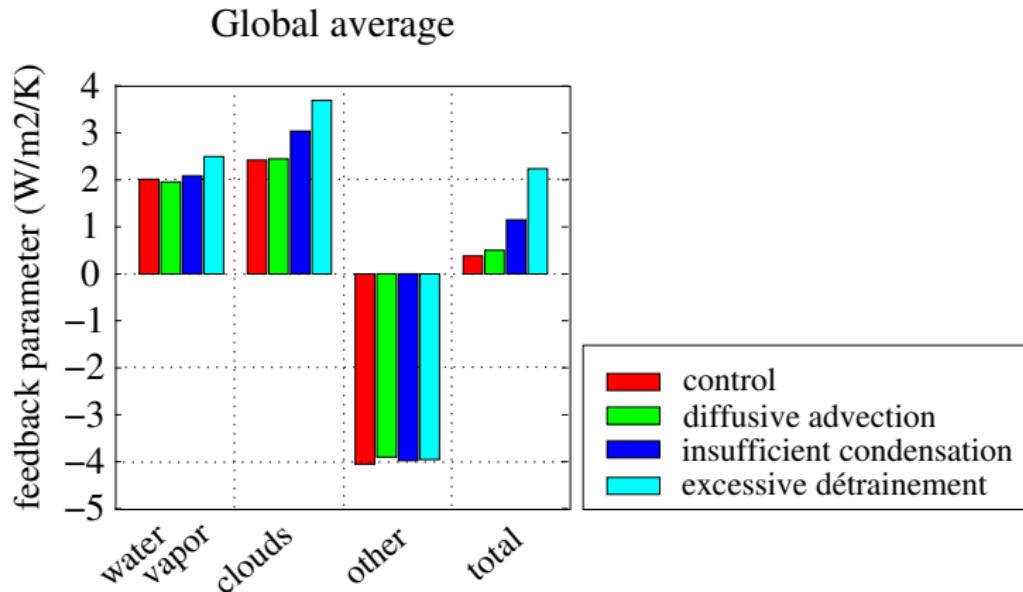
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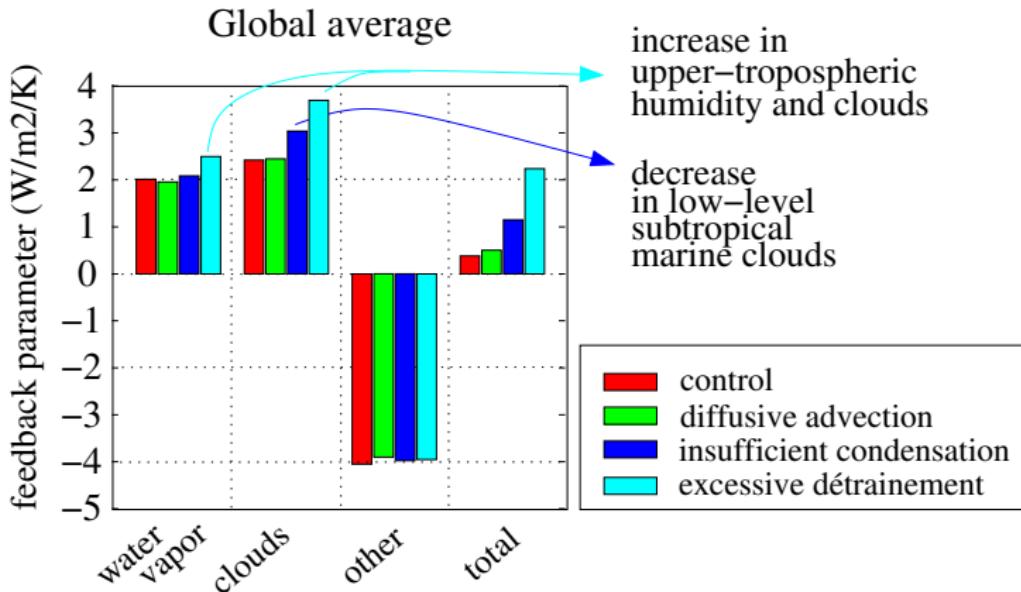
▶ RH change has small impact on water vapor feedbacks
▶ depending on cause for moist bias, impact on cloud feedbacks