# The added value of tropospheric water vapor isotopic measurements for process-oriented evaluation of convective, cloud and transport processes in climate models
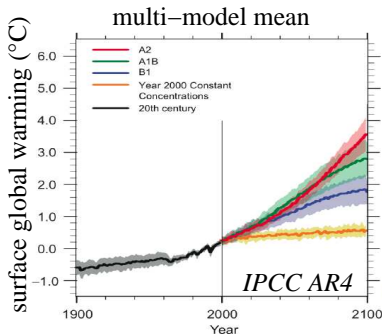
Camille Risi

LMD/IPSL

IMI seminar, October 2 2012

# Outline

0) general introduction on my research goals, overview of my activities
1) tropical upper tropospheric humidity (*Risi et al 2012a,b*)
2) pieces of work, on-going work on atmospheric convection

# Inter-model spread in climate projections



multi−model mean

surface global warming (°C)

A2
A1B
B1
Year 2000 Constant Concentrations
20th century
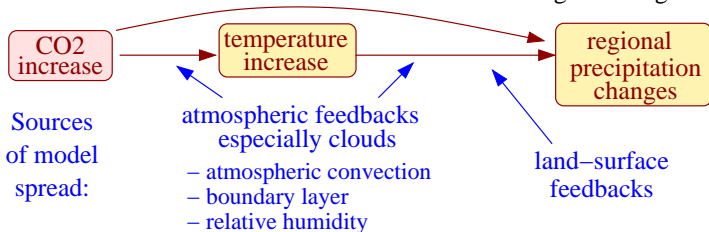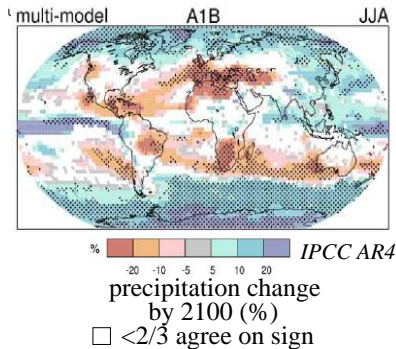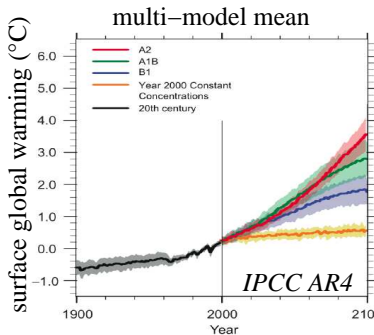
*IPCC AR4*

Year

CO2 increase → temperature increase

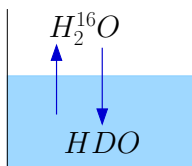**Sources of model spread:**

atmospheric feedbacks especially clouds

– atmospheric convection
– boundary layer
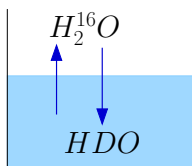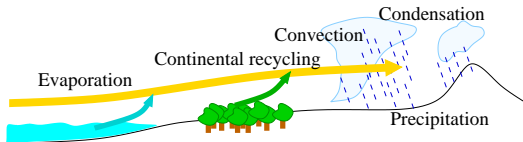– relative humidity

# Inter-model spread in climate projections

# Water isotopic composition

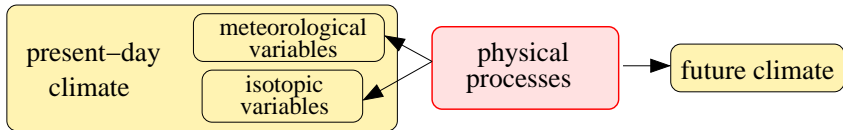- $H_2^{16}O$, $HDO$, $H_2^{18}O$, $H_2^{17}O$, fractionation

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- records phase changes

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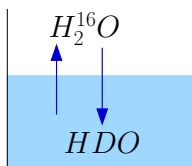- $H_2^{16}O$, $HDO$, $H_2^{18}O$, $H_2^{17}O$, fractionation
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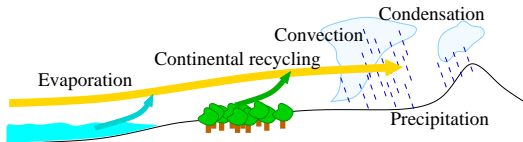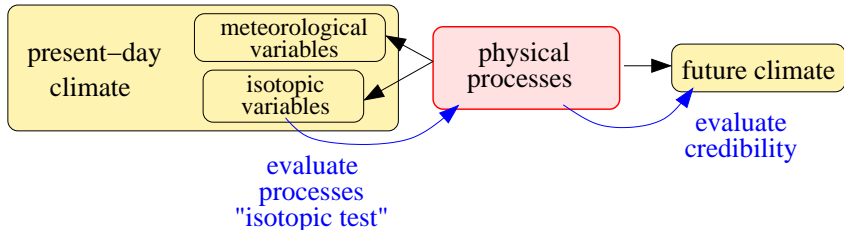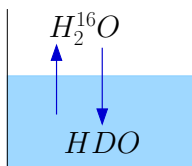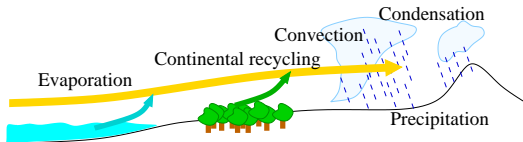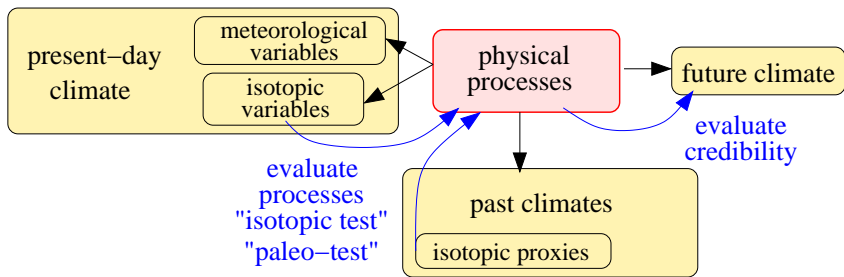- $H_2^{16}O$, $HDO$, $H_2^{18}O$, $H_2^{17}O$, fractionation
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# Overview of my activities

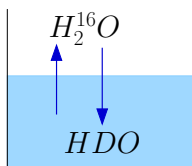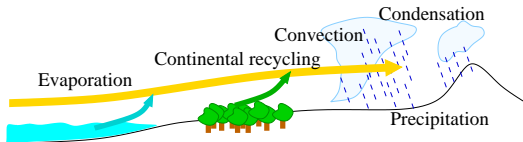1. evaluation of atmospheric processes
   - understand what controls water vapor and precip isotopic composition
   - **processes controlling humidity** (1st part of seminar)
   - **atmospheric deep convection** (2nd part of seminar)

# Overview of my activities

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2. evaluation of land surface processes
   - ▶ partitionning of water fluxes at land surface
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   - ▸ partitionning of water fluxes at land surface
   - ▸ continental recycling

3. evaluation of past tropical precipitation changes
   - ▸ what do tropical water isotopic proxies record
   - ▸ link between past and future behavior (CMIP5)

# The LMDZ model

- atmospheric GCM, component of IPSL model
- isotope-enabled (*Risi et al 2010a*) + water tagging
- can be coupled with isotope-enabled LSM ORCHIDEE

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- zoom capability down to 30km $\implies$ regional applications
- stratospheric capability $\implies$ stratospheric applications

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- stratospheric capability $\Longrightarrow$ stratospheric applications
- "new physics"



Rio et al 2009
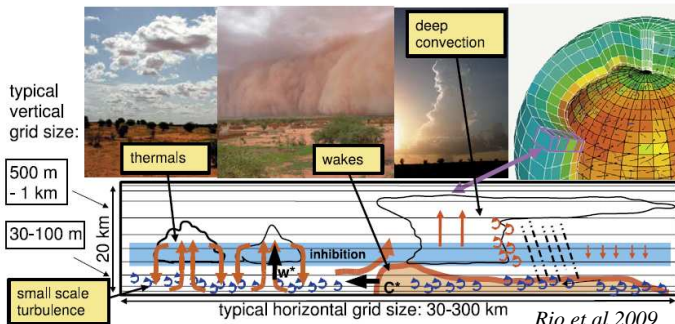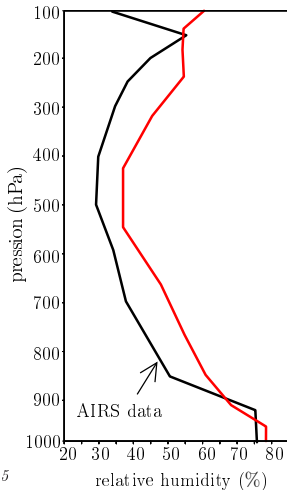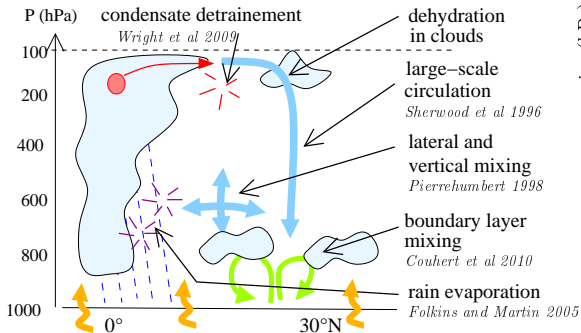
# 1) Processes controlling humidity
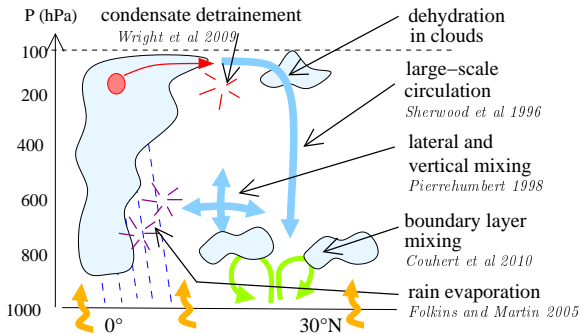
# 1) Processes controlling humidity

**LMDZ–iso (Risi et al 2010a):**
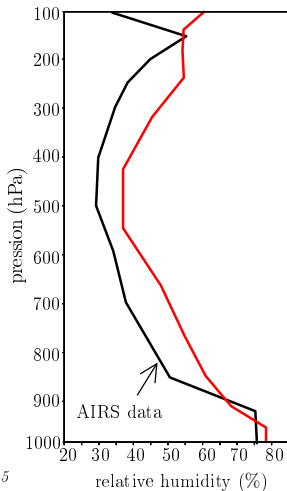— control: AR4 version (19 levels)

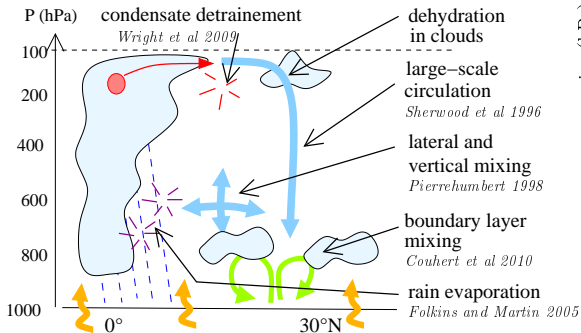# 1) Processes controlling humidity



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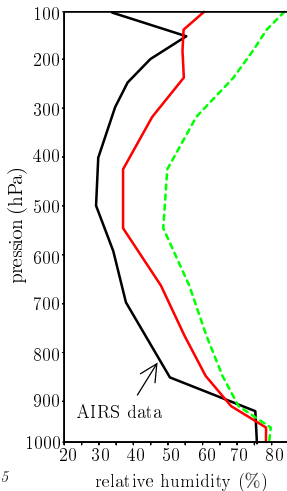
3 reasons
for a
moist bias

P (hPa)    condensate detrainement
           *Wright et al 2009*

dehydration
in clouds

large–scale
circulation
*Sherwood et al 1996*

lateral and
vertical mixing
*Pierrehumbert 1998*

boundary layer
mixing
*Couhert et al 2010*

rain evaporation
*Folkins and Martin 2005*

AIRS data
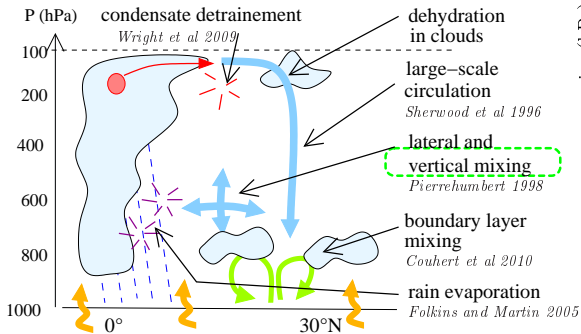
0°          30°N

pression (hPa)

relative humidity (%)

# 1) Processes controlling humidity



LMDZ–iso (Risi et al 2010a):
— control: AR4 version (19 levels)
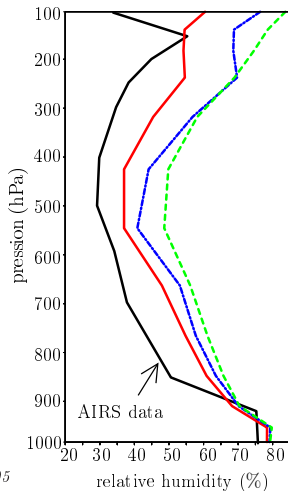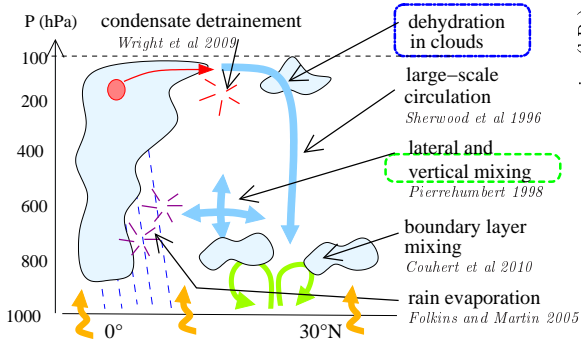-- diffusive vertical advection

3 reasons for a moist bias

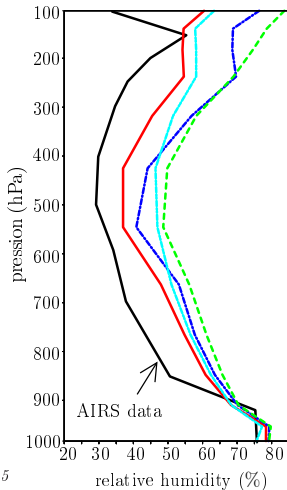P (hPa)   condensate detrainement
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# 1) Processes controlling humidity



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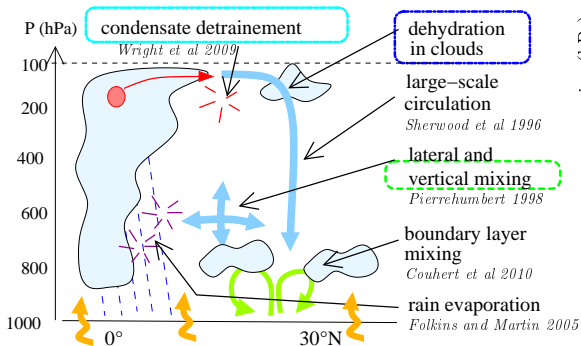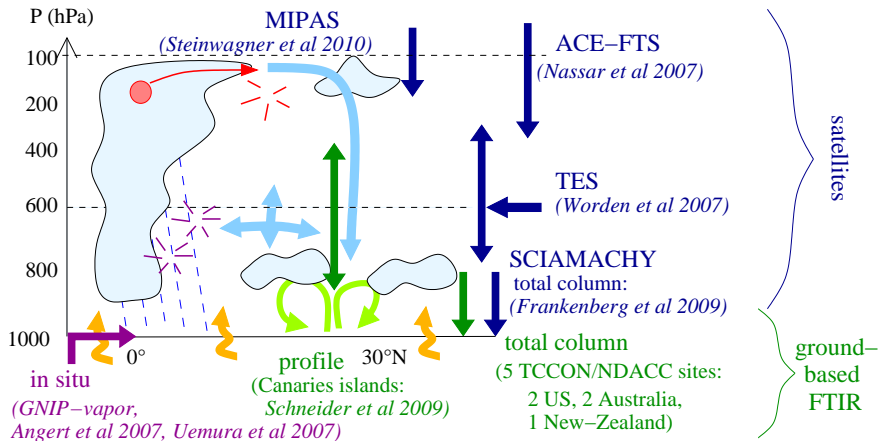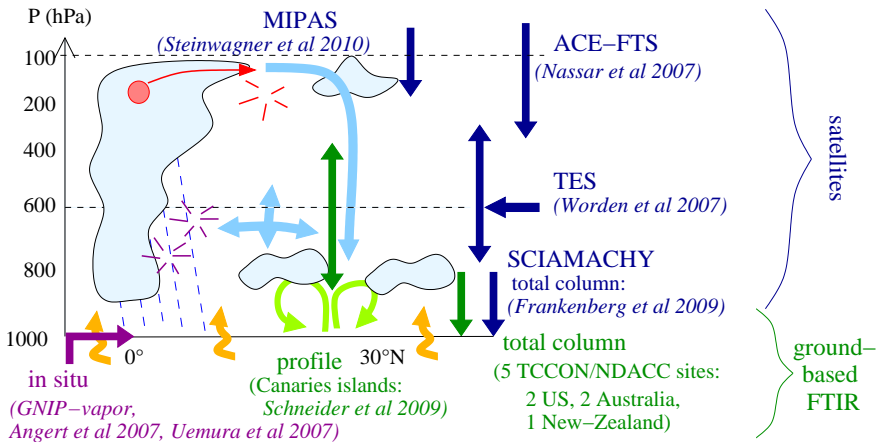-·-· $\sigma_q/10$

3 reasons
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AIRS data

relative humidity (%)

# 1) Processes controlling humidity



LMDZ–iso (Risi et al 2010):
— control: AR4 version (19 levels)
-- diffusive vertical advection
-- $\sigma_q/10$
— $\epsilon_p/2$

3 reasons
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P (hPa)

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0°          30°N

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relative humidity (%)

# Vapor isotope measurements

# Vapor isotope measurements



- model-data comparison: collocation, nudging by ECMWF, averaging kernelss

# Zonal anual mean
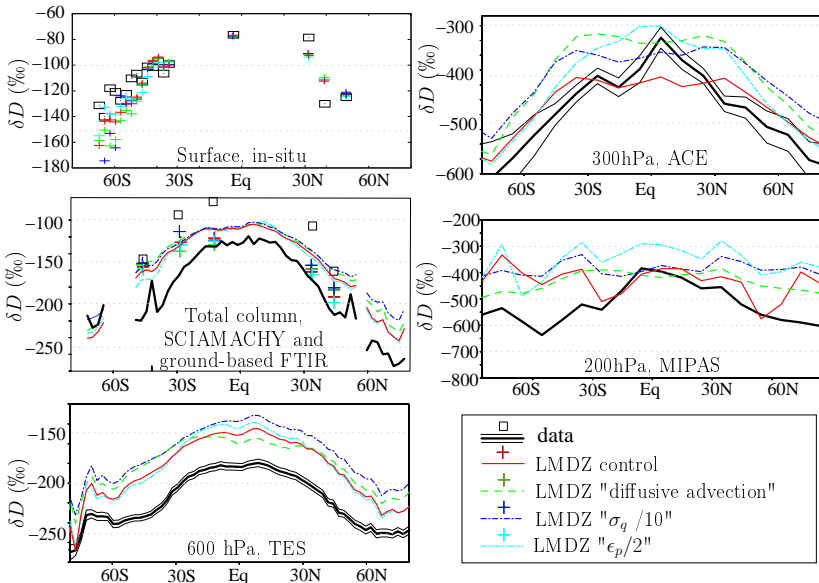
# Zonal Seasonal variations (JJA-DJF)
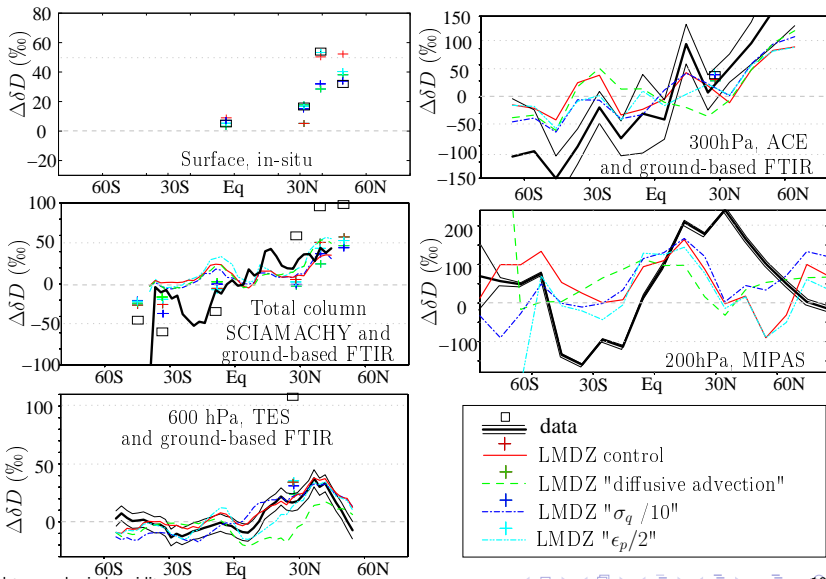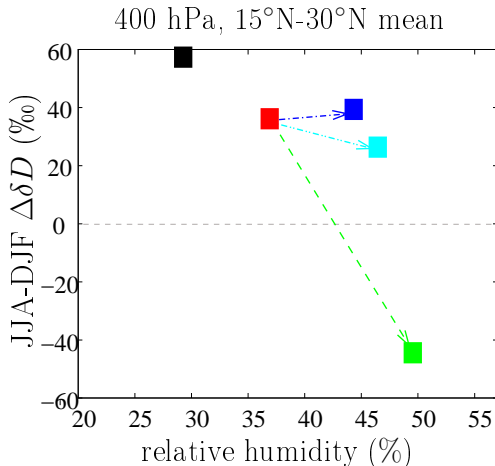
# Diffusion effect on seasonality
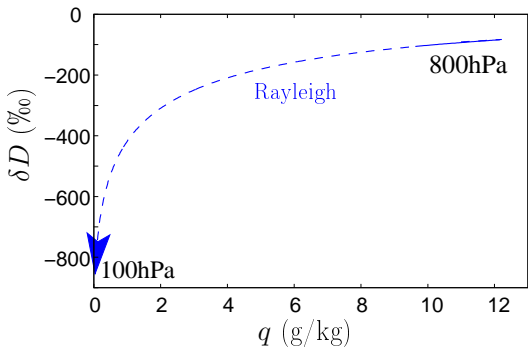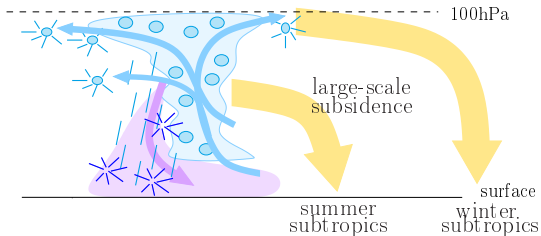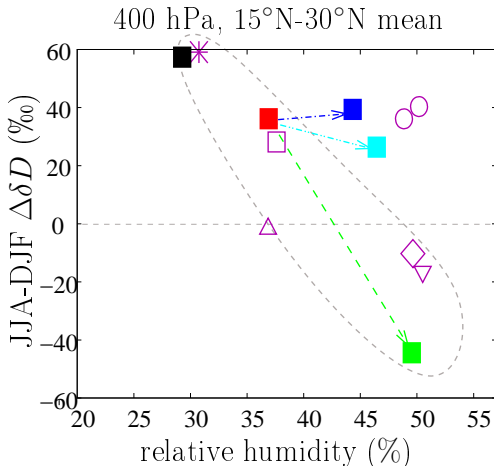
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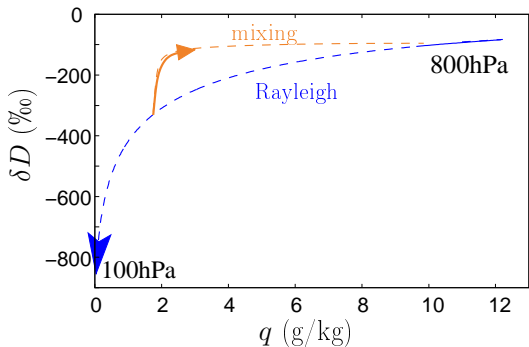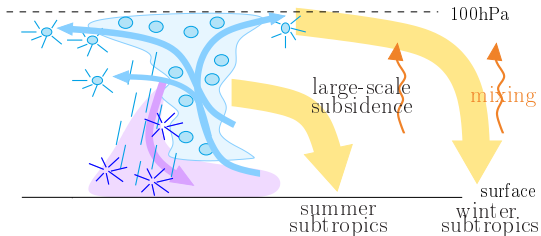
# What causes the moist biases in GCMs?



Sensitivity tests:
with LMDZ:

- Control
- Excessively diffusive vertical advection
- Excessive condensate detrainement
- Insufficient in-situ condensation
- AIRS/ACE data

400 hPa, 15°N-30°N mean

JJA-DJF $\Delta\delta D$ (‰) vs relative humidity (%)

# What causes the moist biases in GCMs?



Sensitivity tests:
with LMDZ:
- ■ (red) Control
- ■ (green) Excessively diffusive vertical advection
- ■ (cyan) Excessive condensate detrainement
- ■ (blue) Insufficient in-situ condensation
- ■ (black) AIRS/ACE data

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

400 hPa, 15°N-30°N mean

Plot axes: JJA-DJF $\Delta\delta D$ (‰) versus relative humidity (%)

▶ frequent reason for moist bias=excessively diffusive advection

# Consequences on future projections
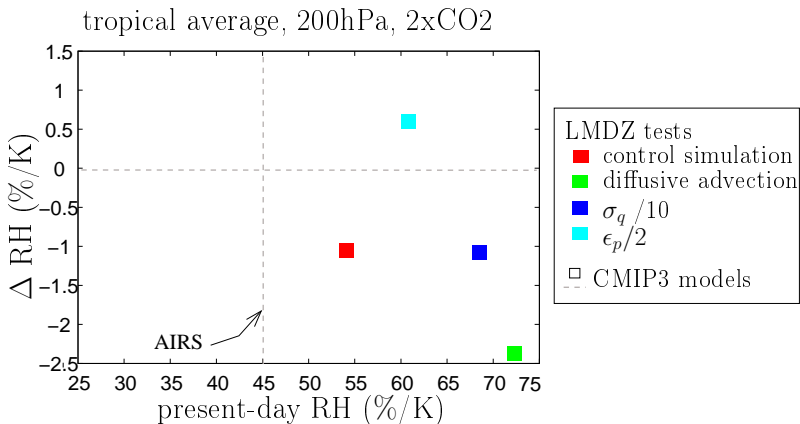


tropical average, 200hPa, 2xCO2

# Consequences on future projections



tropical average, 200hPa, 2xCO2
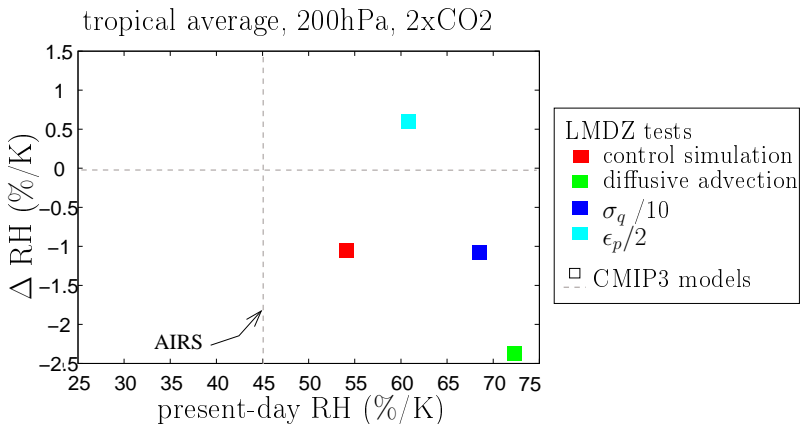
▶ How a moist bias affect humidity change projections depends on the reason for the bias

# Consequences on future projections



tropical average, 200hPa, 2xCO2
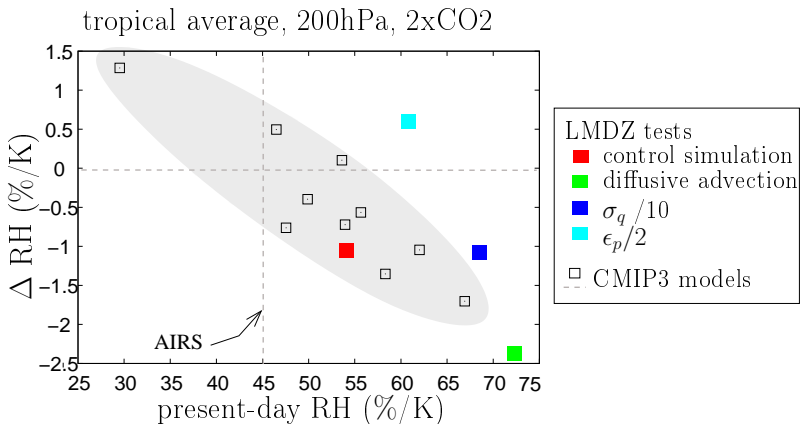
► How a moist bias affect humidity change projections depends on the reason for the bias

# 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 is a widespread cause of moist bias in climate models

# Summary on relative humidity

- Water vapor isotope measurements as observational diagnostics to understand the reasons for a moist bias in climate models
- Excessive vertical diffusion during water vapor transport 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

# 2) Convective processes
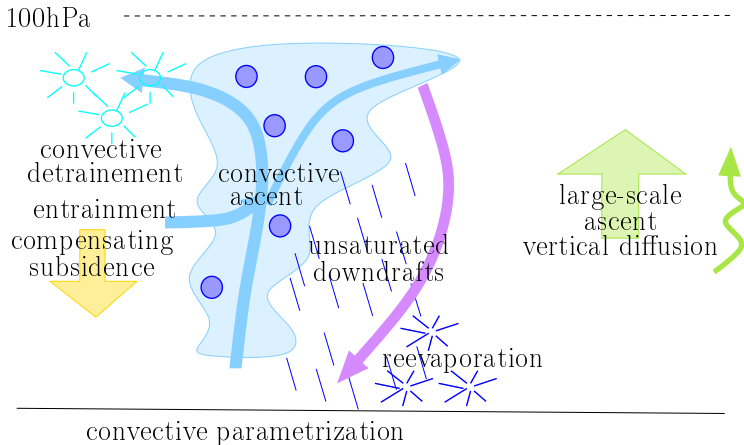
▶ microphysical processes

# 2) Convective processes

- microphysical processes
- closure + competition between parametrizations
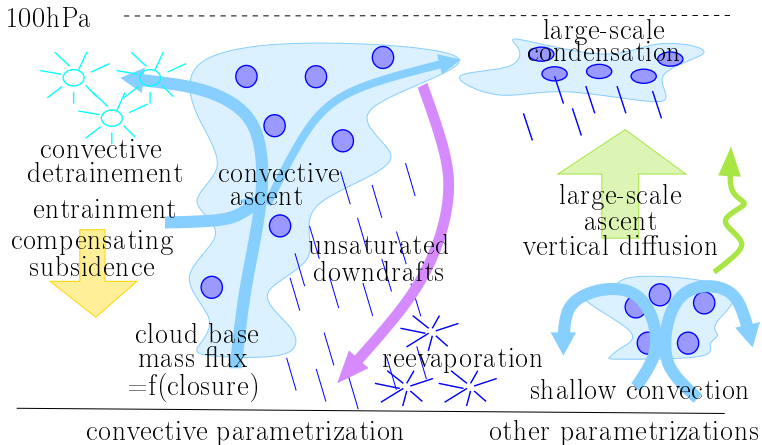
# 2) Convective processes

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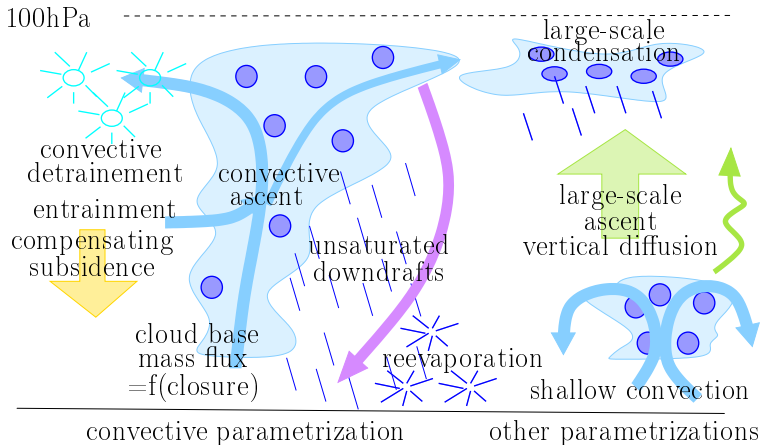


- $P_{LS}/P_{tot}$ arbitrary, but influences cloudiness, intra-seas. variability, chemical tracor transport

# Complementarity between $q$ and $\delta D$
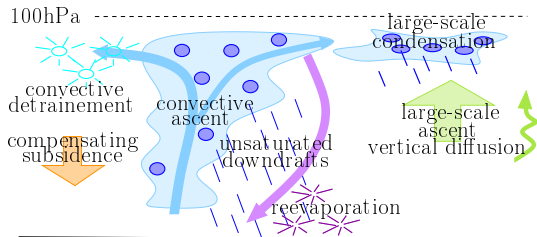
# Complementarity between $q$ and $\delta D$



curves fn altitude:
- ⟶ Rayleigh
- ⟶ cumulated condensate
- ⟶ convective ascent
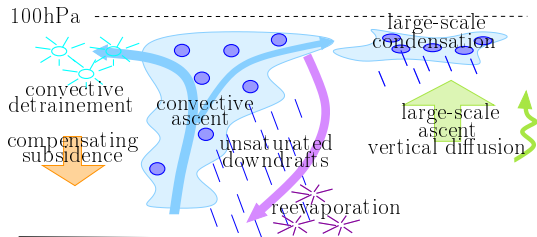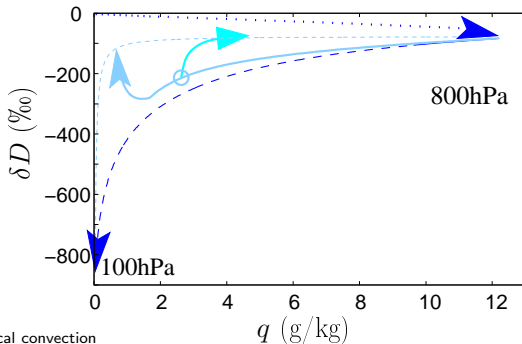
curves fn process:
- ⟶ detrainment

# Complementarity between $q$ and $\delta D$
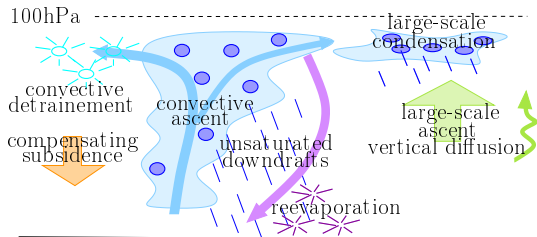


large-scale condensation

100hPa

convective detrainement

convective ascent

compensating subsidence

unsaturated downdrafts

large-scale ascent

vertical diffusion

reevaporation

**curves fn altitude:**
- Rayleigh
- cumulated condensate
- convective ascent
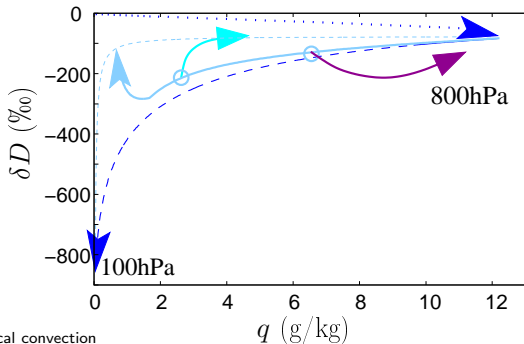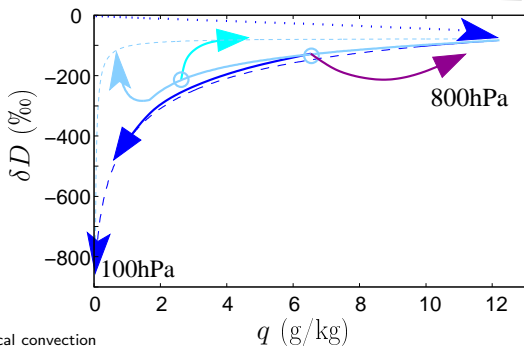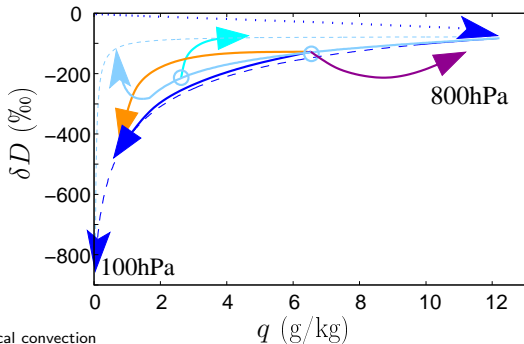
**curves fn process:**
- detrainment
- rain reevaporation

$\delta D$ (‰)

$q$ (g/kg)

800hPa

100hPa

# Complementarity between $q$ and $\delta D$

# Complementarity between $q$ and $\delta D$

# Sensitivity tests in LMDZ

# New TES profiles



Amazon, DJF-JJA (wet-dry)
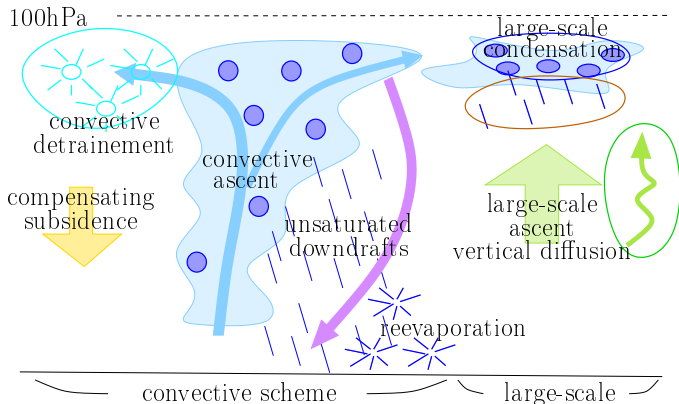
# New TES profiles



Amazon, DJF-JJA (wet-dry)

Legend:
- TES
- control
- more diffusive vertical advection
- stronger condensate detrainment
- less in-situ condensation
- less in-situ precipitation
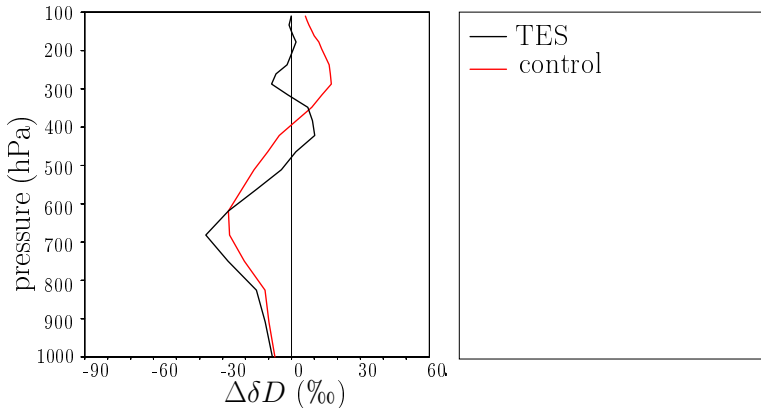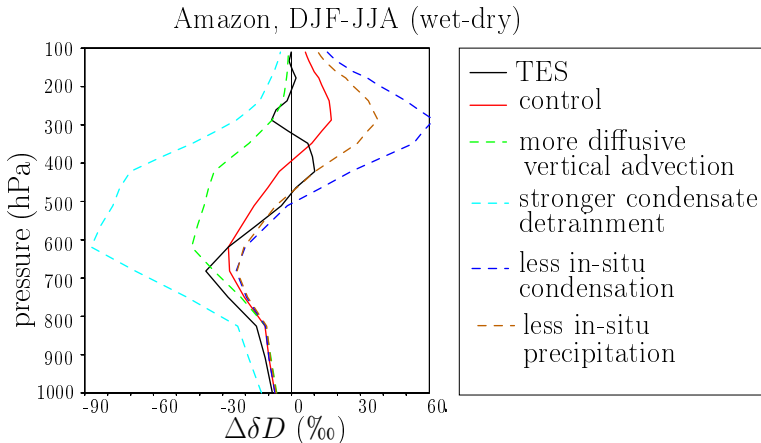
# Convective contribution to water budget

# Upper troposphere detrainment
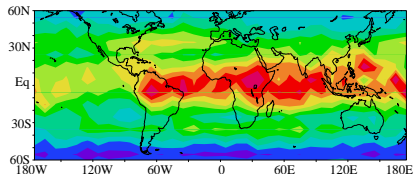
MIPAS data at 200hPa, annual



LMDZ control



$\delta D$ (‰)

# Upper troposphere detrainment



MIPAS data at 200hPa, annual

LMDZ control

$\delta D$ (‰)

Difference 15°S-15°N minus 30°S-30°N at 200hPa

MIPAS: 50 ± 20‰

$\Delta \delta D$ (‰)

$\Delta q$ (g/kg)

moistening by detrainement (g/kg/day)

- **control** (red)
- **vertical advection more diffusive** (green)
- **stronger condensate detrainment** (cyan)
- **less in-situ codnensation** (blue)
- **less in-situ precipitation** (brown)

# Upper troposphere detrainment



MIPAS data at 200hPa, annual

LMDZ control

$\delta D$ (‰)

- **control** (red)
- **vertical advection more diffusive** (green)
- **stronger condensate detrainment** (cyan)
- **less in-situ codnensation** (blue)
- **less in-situ precipitation** (brown)

Difference 15°S-15°N minus 30°S-30°N at 200hPa

MIPAS: $50 \pm 20$‰

MIROC
CAM

HadAM
GISS
ECHAM
GSM

$\Delta \delta D$ (‰)

$\Delta q$ (g/kg)

moistening by detrainement (g/kg/day)

# LMDZ-1D



100−300 km

LMDZ−3D          LMDZ−1D

- same physics, similar behavior

# LMDZ-1D
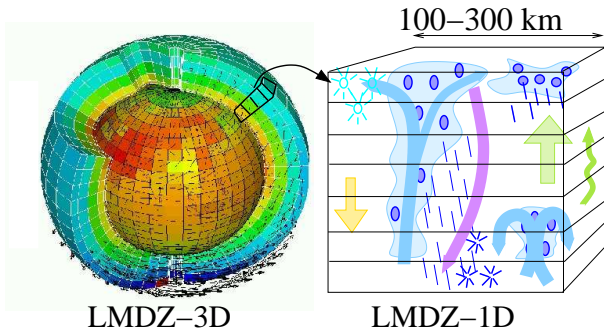


100–300 km

LMDZ–3D        LMDZ–1D

- same physics, similar behavior
- imposed dynamics $\Longrightarrow$ focus on physical biases
- computationally lighter $\Longrightarrow$ more sensitivity tests
- can be compared to CRM simulations

# LMDZ-1D
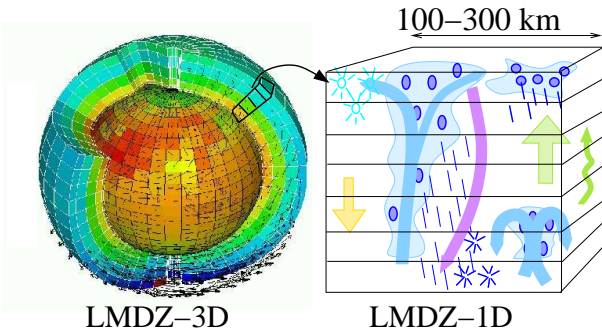


LMDZ–3D          LMDZ–1D

- ▶ same physics, similar behavior
- ▶ imposed dynamics $\implies$ focus on physical biases
- ▶ computationally lighter $\implies$ more sensitivity tests
- ▶ can be compared to CRM simulations
- ▶ idealized experiments: radiative-convective equilibrium
- ▶ realistic experiments: campaign simulations: e.g. TWP-ice

# Sensitivity to rain reevaporation
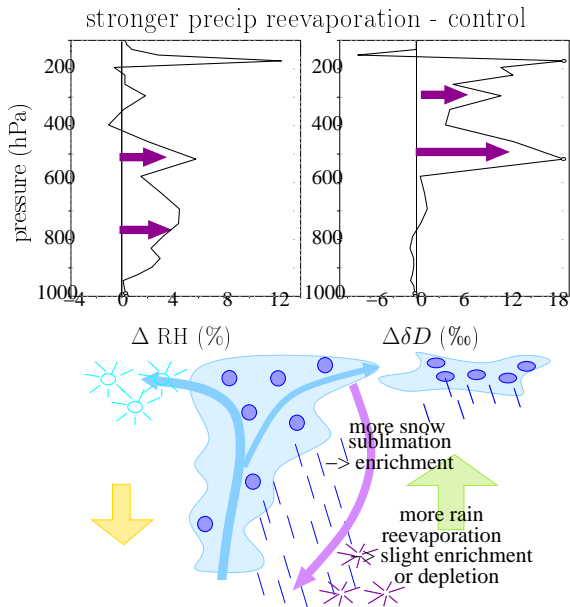


stronger precip reevaporation - control
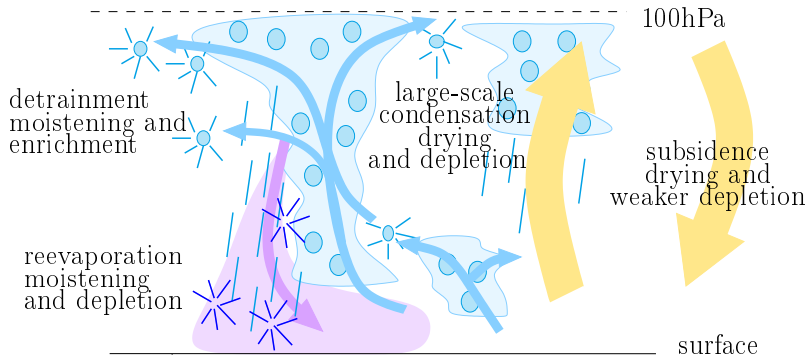
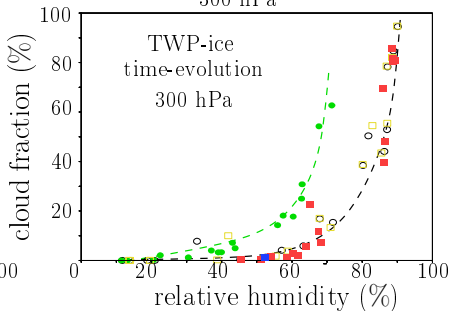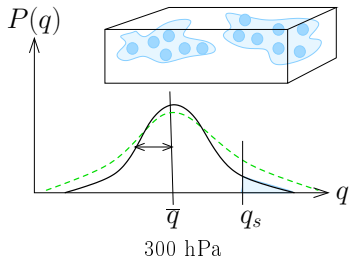# Summary: complementarity $q$-$\delta D$-clouds
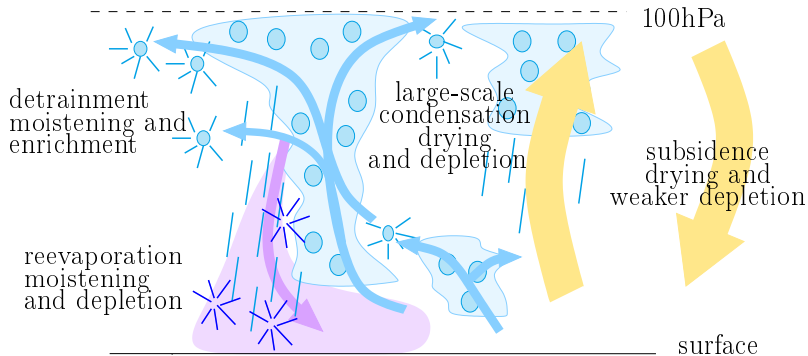
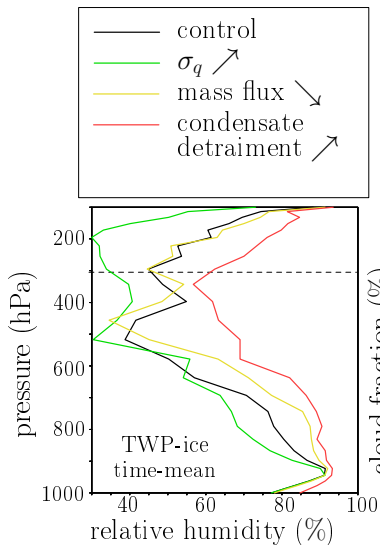# Summary: complementarity $q$-$\delta D$-clouds

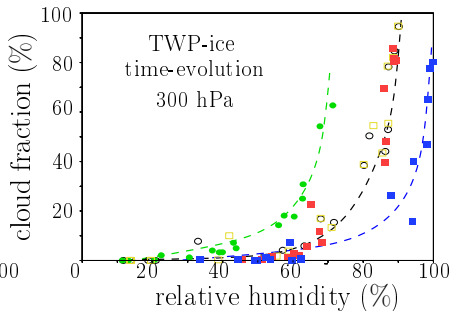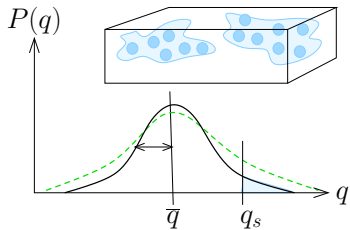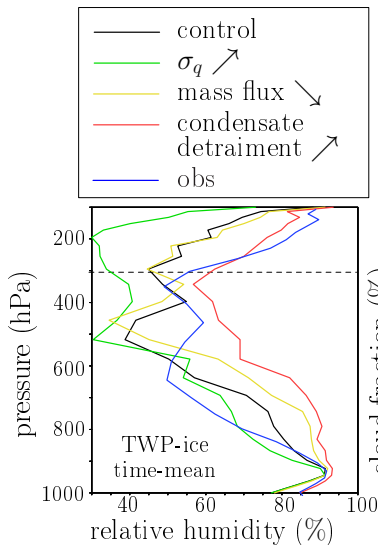# Constrain on large-scale condensation
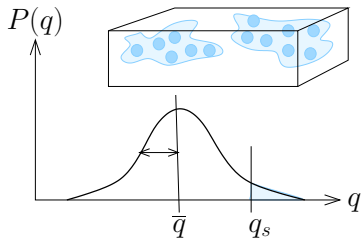
# Constrain on large-scale condensation
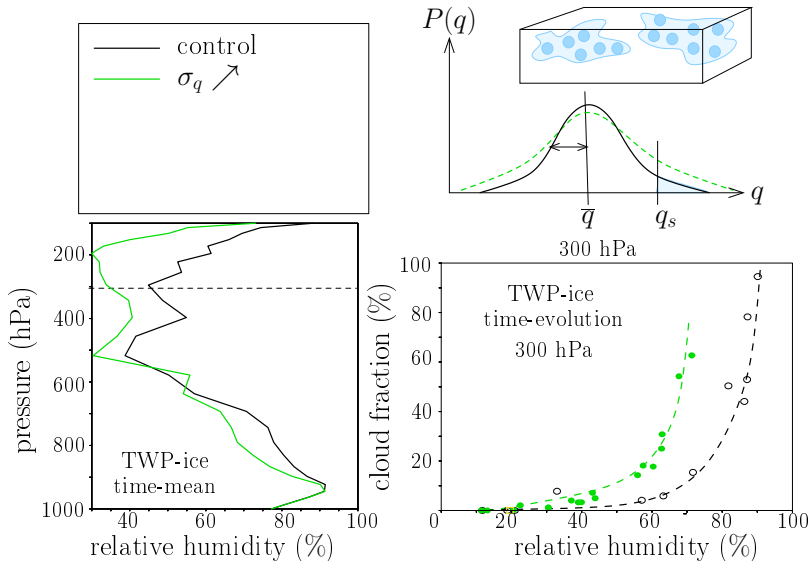
# Constrain on large-scale condensation

# Constrain on large-scale condensation

# Perspective: 4-year project on MJO

- ▶ MJO:
    - ▶ main mode of intra-seasonal convective variability in the tropics
    - ▶ models have trouble to simulate it
    - ▶ convective/clouds processes: same dispersion source in projections
- ▶ Goal: understand/disentangle physical biases responsible for model problems
  combining isotopes+humidity+clouds measurements