How can convection affect low-level clouds ?

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Introduction

- ***Low cloud feedback :*** ***leading source of uncertainty in climate sensitivity estimates***

- ***Several studies show strong link between low cloud feedbacks and shallow convection***

- ***Lower tropospheric mixing*** ***explains ~ 50 % of inter-model spread in climate sensitivity by affecting low cloud feedbacks***

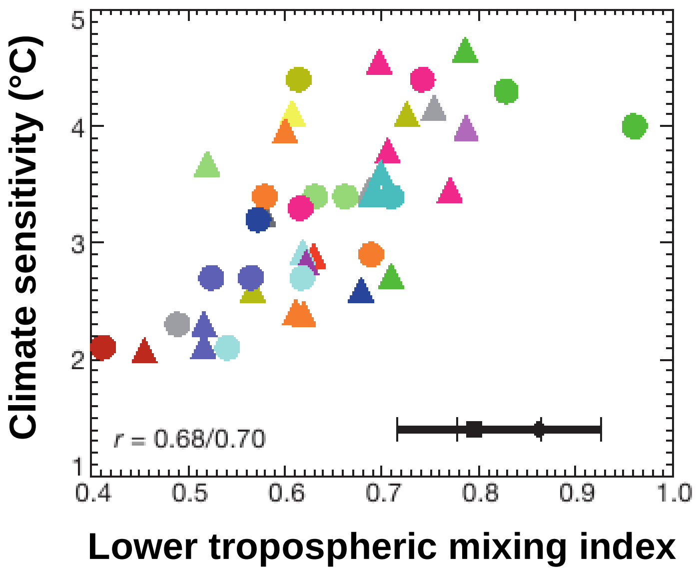
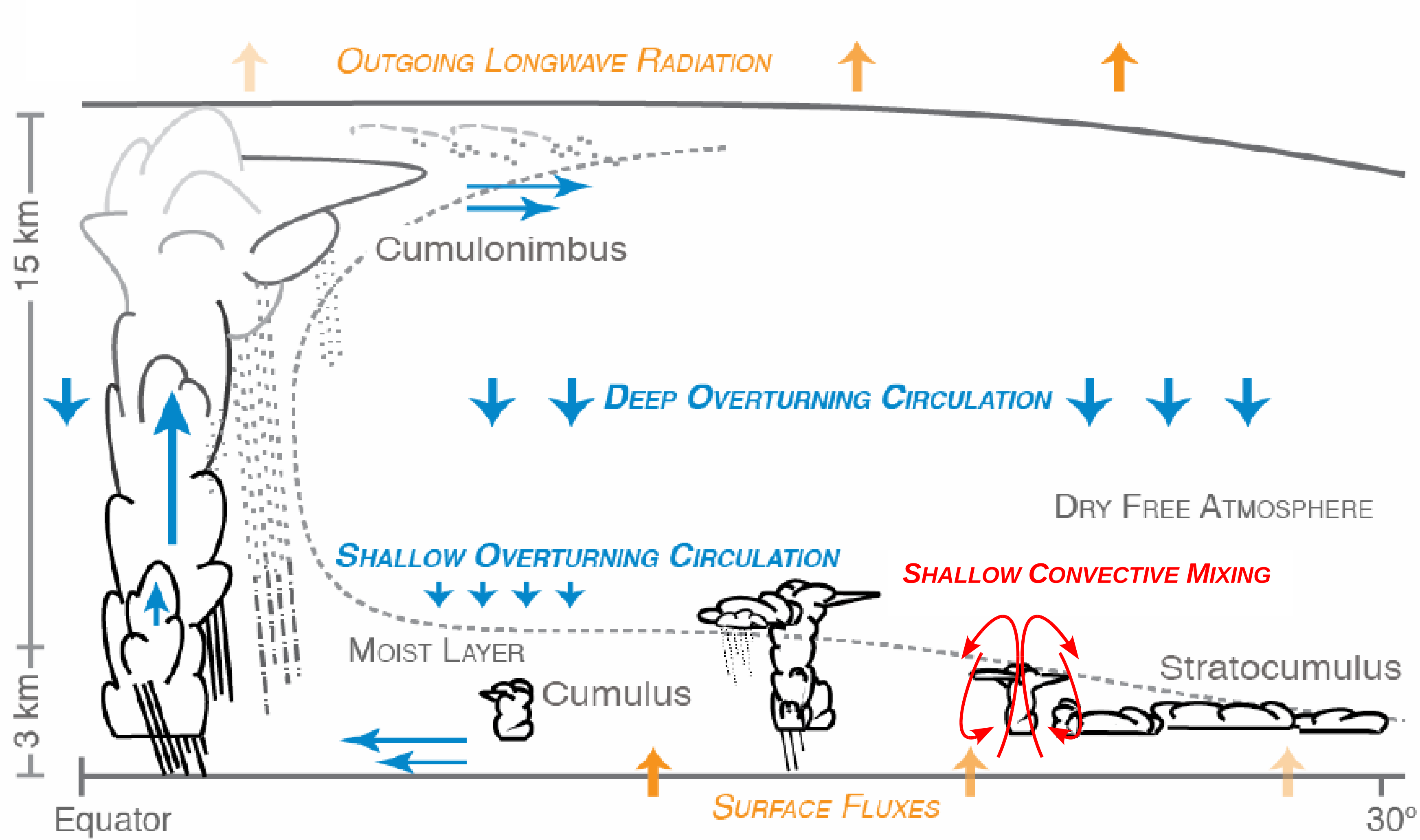


Fig. Relation of lower-tropospheric mixing to climate sensitivity for 43 CMIP3/CMIP5 coupled climate models

(Sherwood et al., 2014)

Lower tropospheric mixing



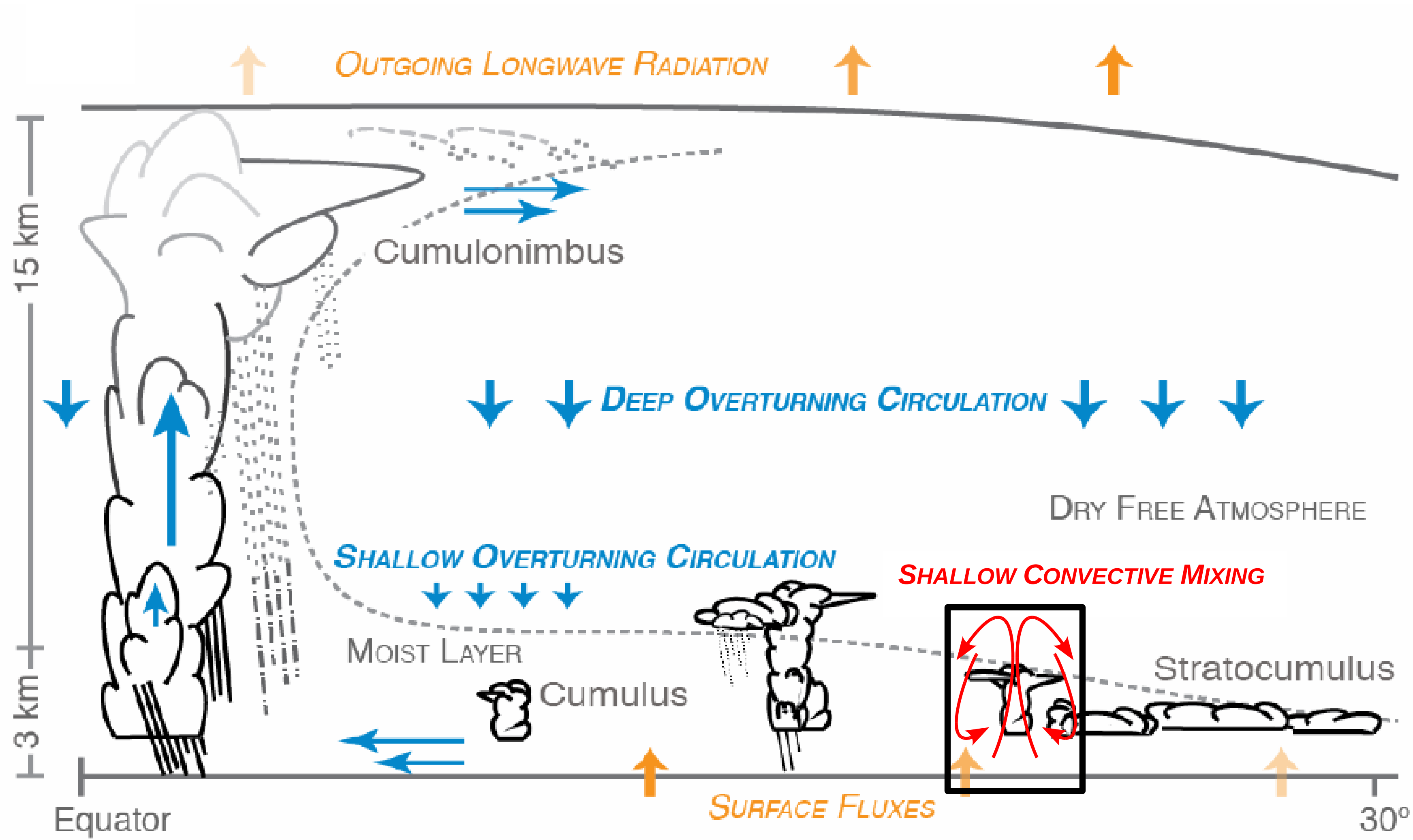
[Idealized tropical circulation]

Adapted from Bony et al., 2015

- Large-scale shallow overturning circulation
- Local shallow convective mixing

- **It reduces the lower tropospheric humidity gradient**
- **Expected to strengthen in a warmer climate, dry the PBL, reduce low clouds and amplify warming**

Aim of the study



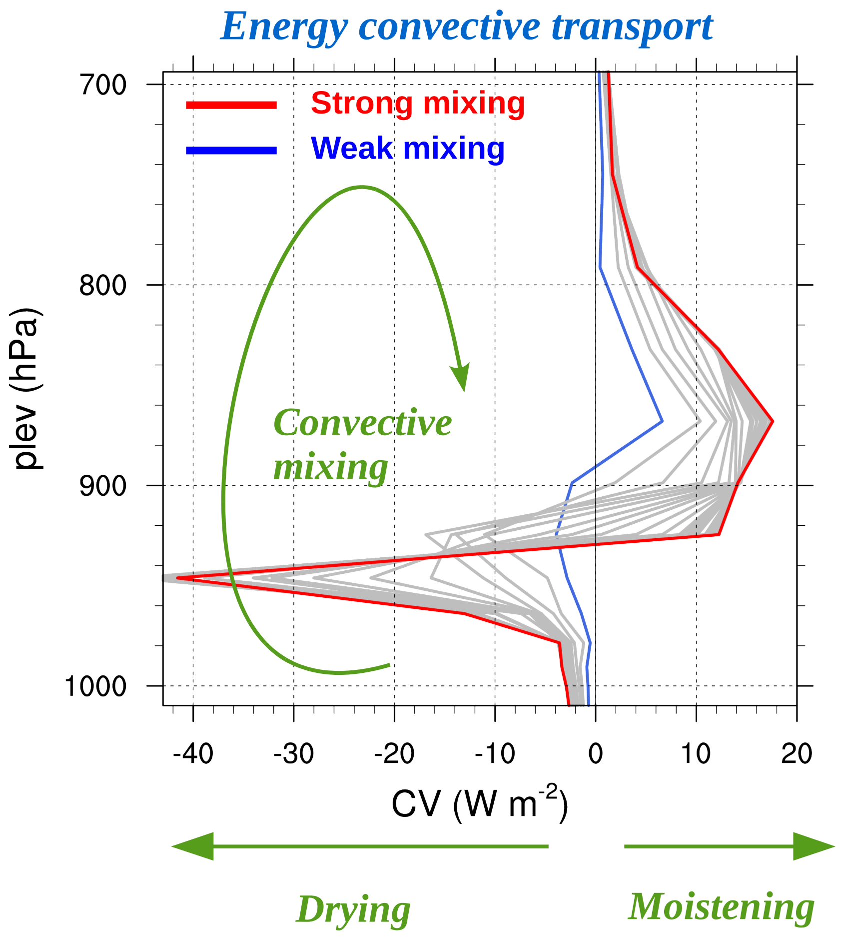
- Understand the mecanisms linking **local shallow mixing by parametrized convection** to **low cumulus clouds** in the present-day climate
- Implication for low cloud feedbacks ?

Experimental protocol

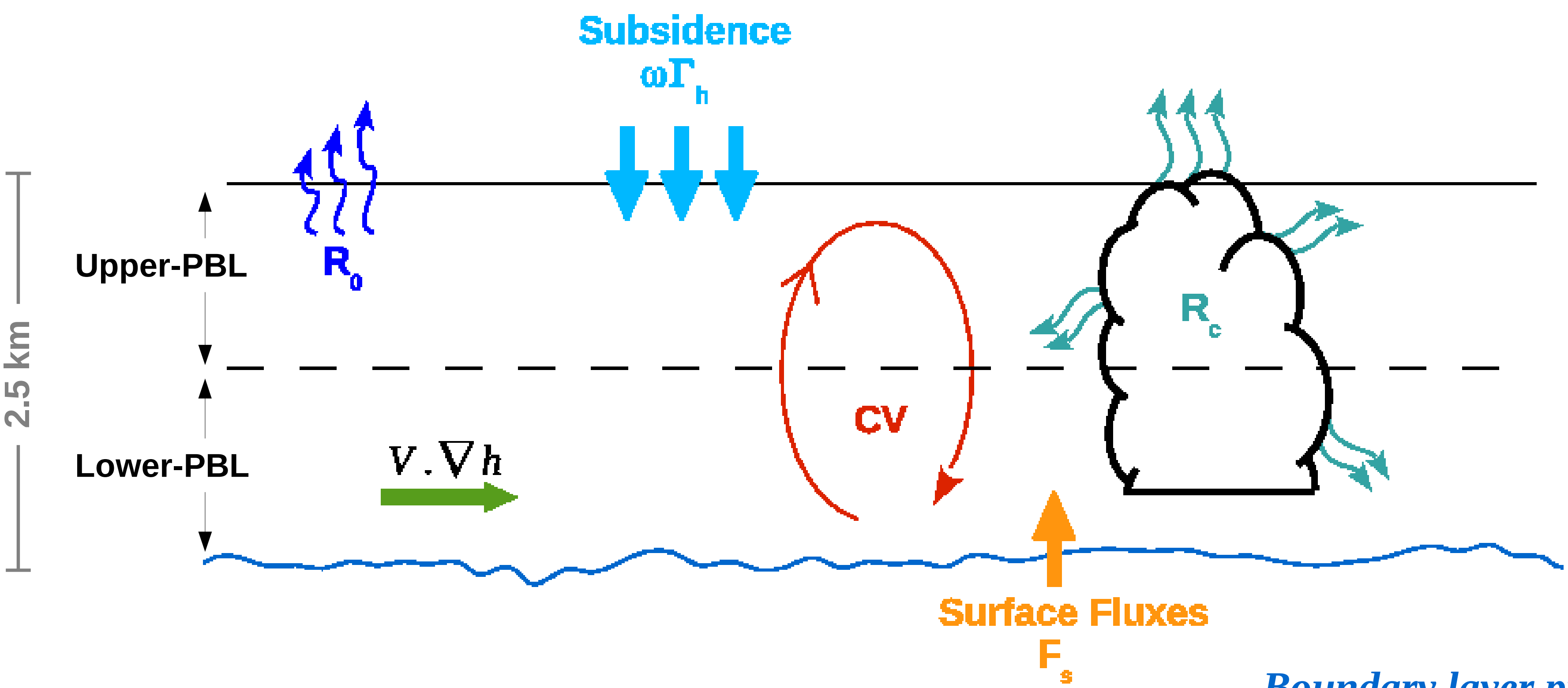
- **IPSL-CM5A model**
  - **Single-column configuration** (useful to study parametrized processes)

- **Parameter-perturbed experiments**
  - **To control the strenght of the convective mixing**
  - **Two convective parametrization schemes are tested**

- **CGILS s6 case studies**
  - **Region of shallow cumulus clouds**



A moist Static Energy analysis



Boundary layer processes

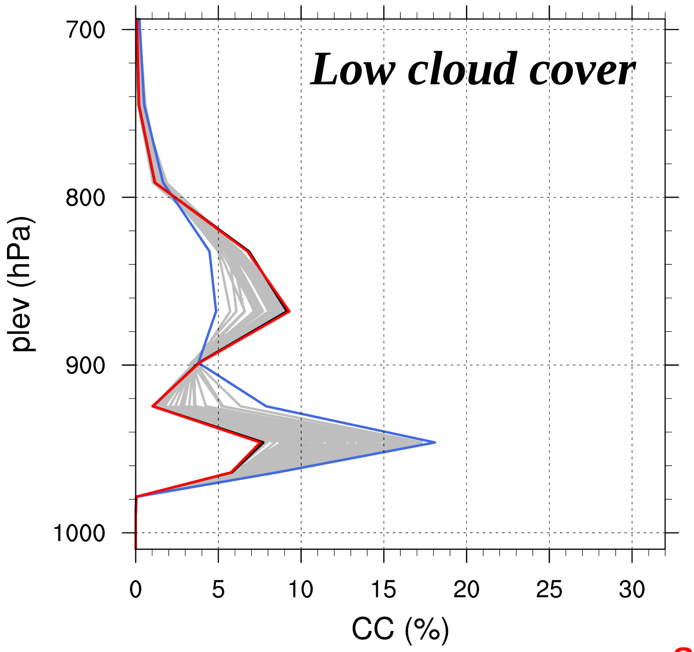
- **Equilibrium between all processes :**

$$R_c + R_0 - F_s - CV - \omega \Gamma_h - V.\nabla h = 0$$

  - Dominant processes linking mixing to low clouds : **surface fluxes**

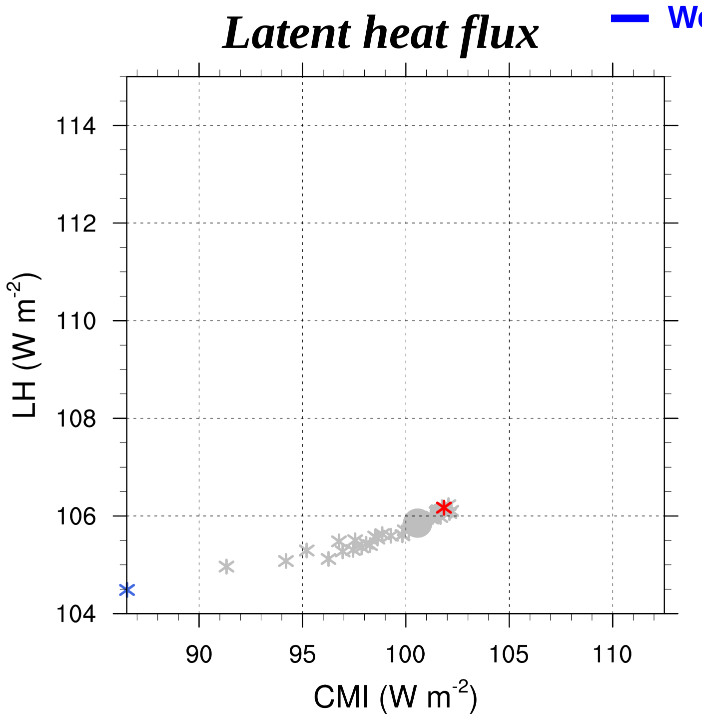
- **Convective mixing index (CMI) :**
  - derived from convective transport of energy between lower and upper part of boundary layer

The role of mixing on low clouds



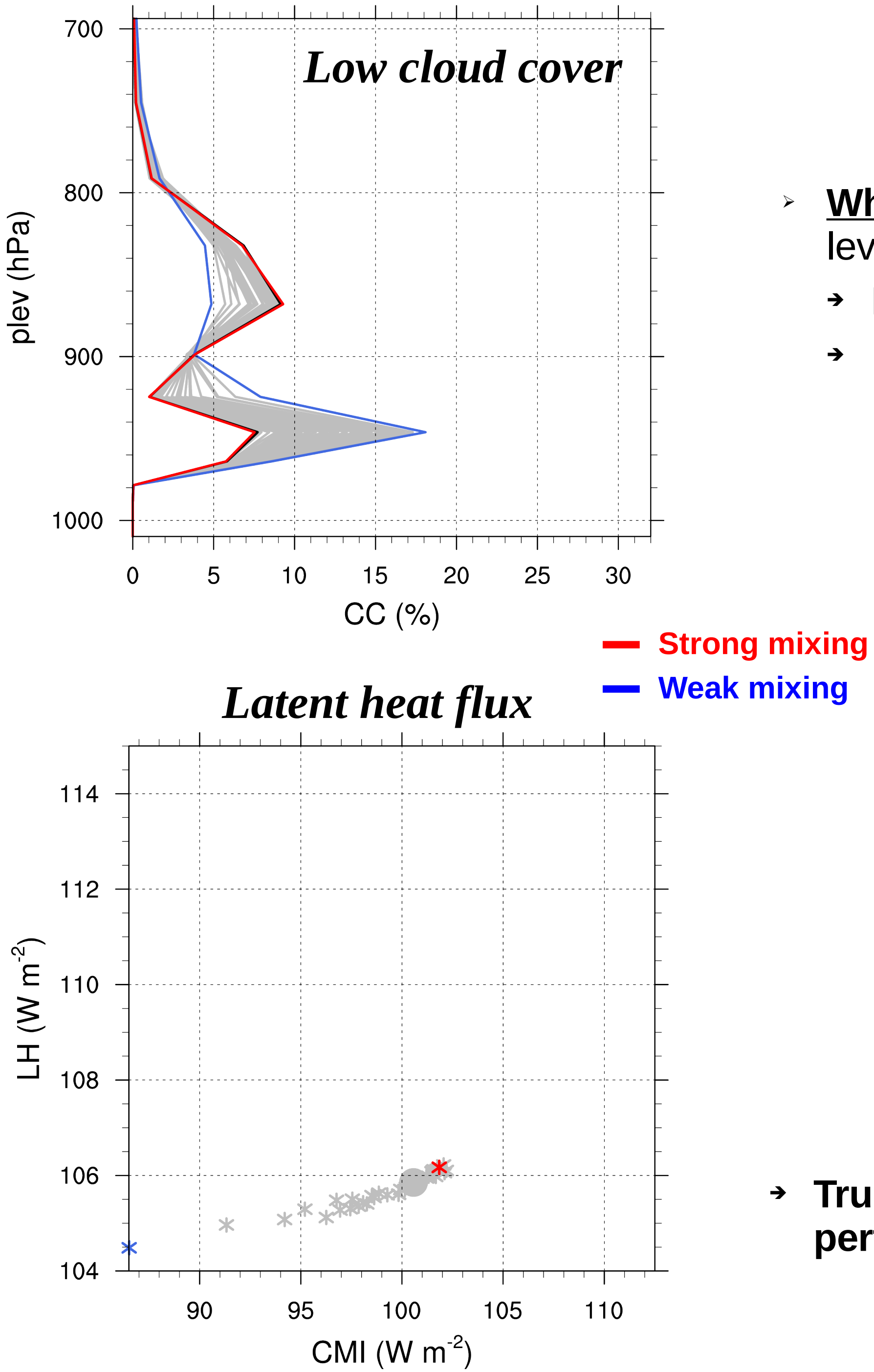
Strong mixing

Weak mixing



- **<u>When the CMI increases</u>**, low-level drying increases and upper-level moistening increases
  - Deeper clouds, with decreased cloud cover at lowest levels
  - Increased latent heat flux

The role of mixing on low clouds



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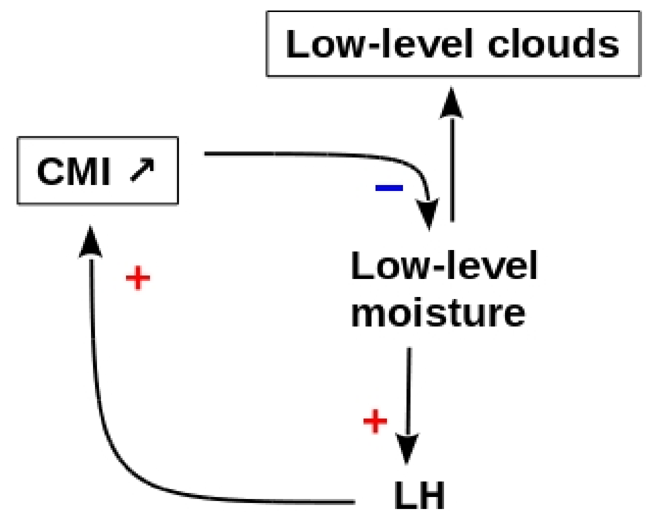

- **True for both convective schemes and with all the other perturbed-parameter experiments**

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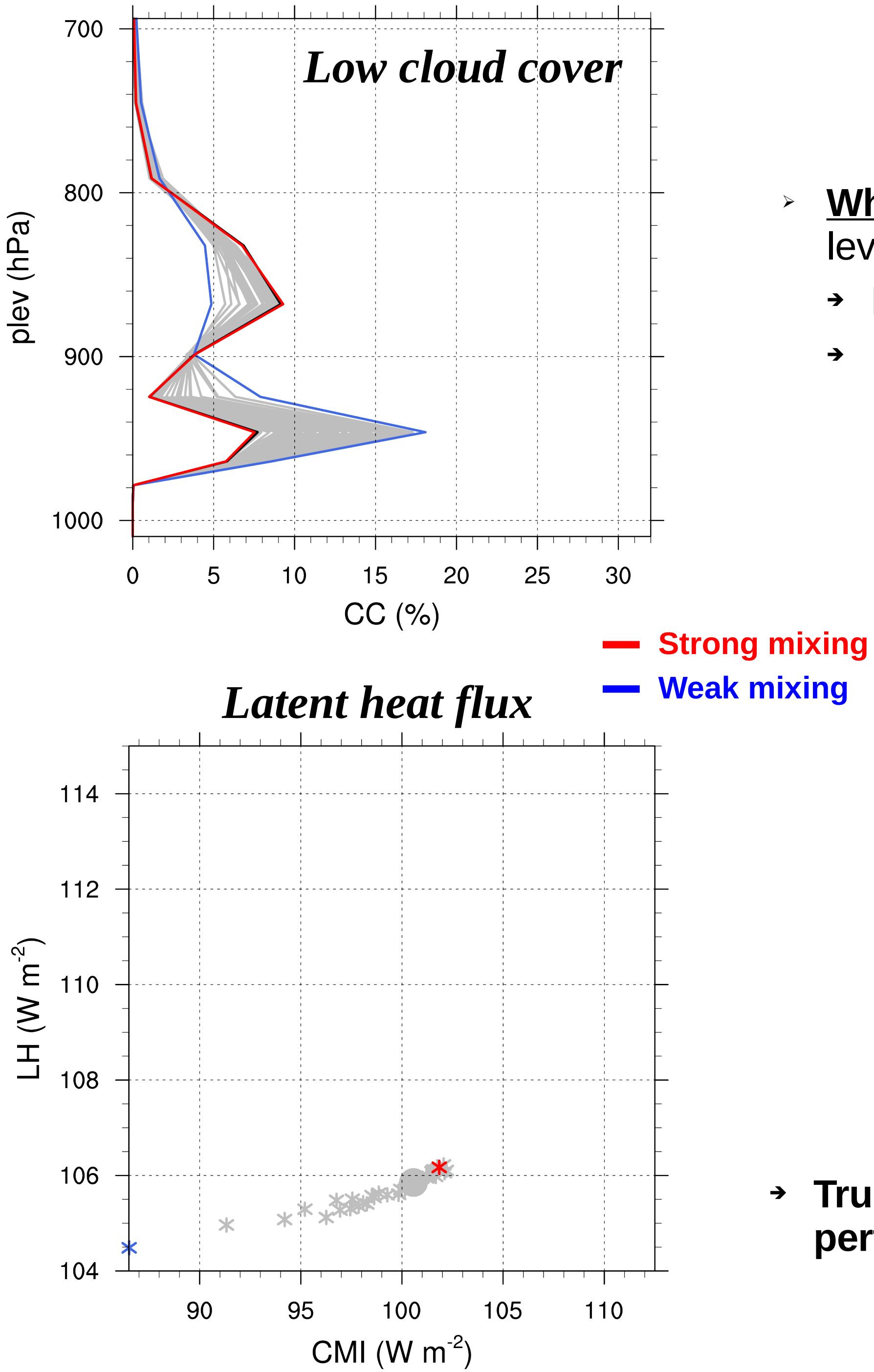

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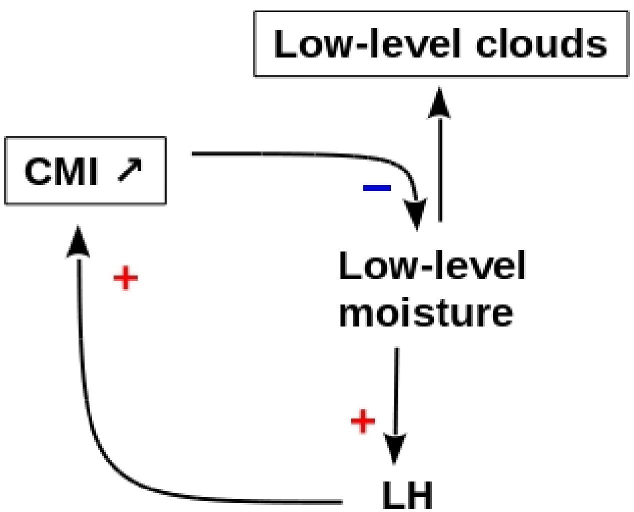
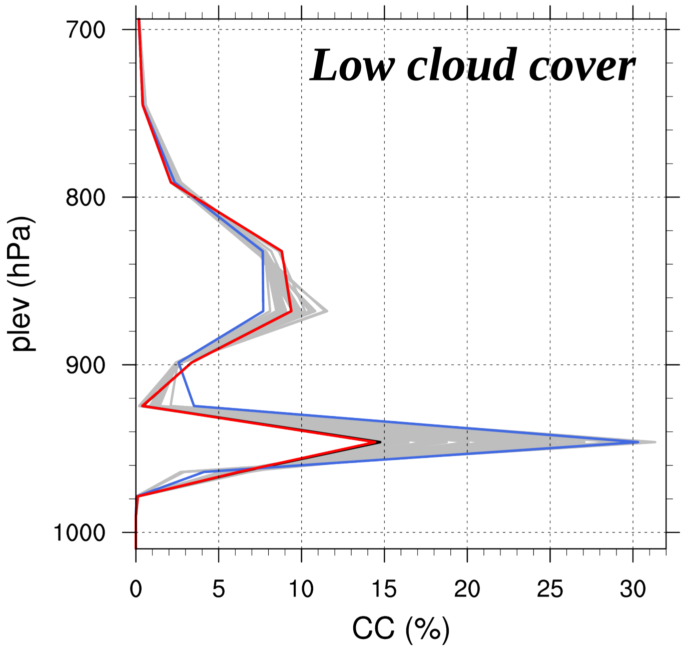
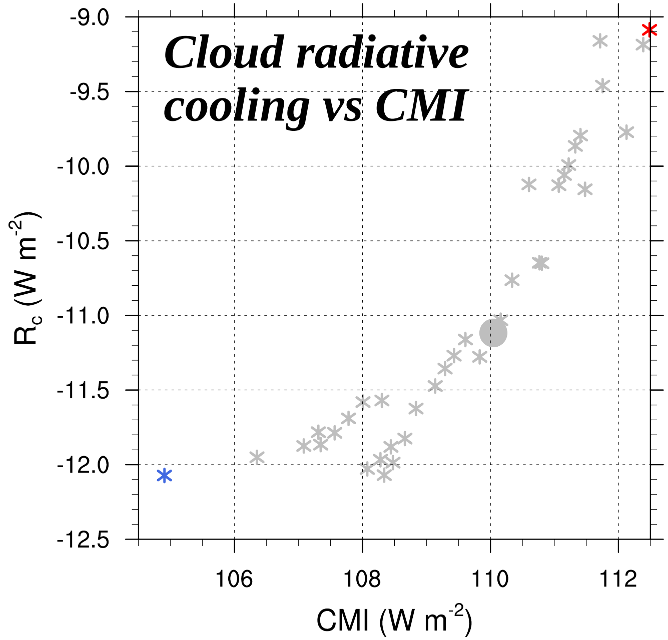


- **True for both convective schemes and with all the other perturbed-parameter experiments**

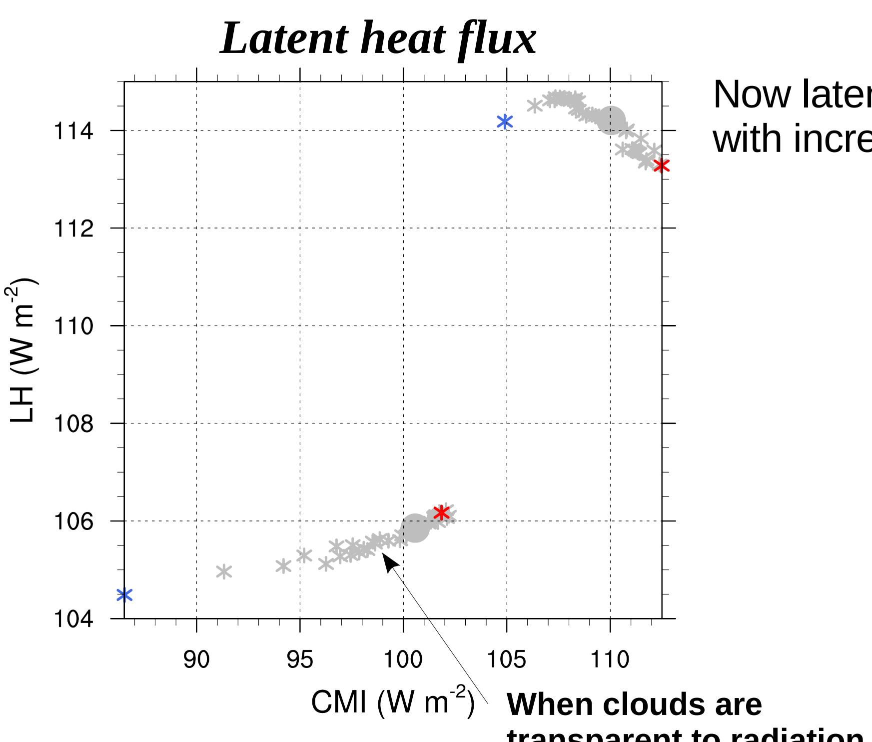
BUT clouds are transparent to radiation !

The role of mixing on low clouds when clouds radiatively cool the boundary layer





Cloud radiative cooling decreases with decreasing cloud cover



Now latent heat flux decreases with increasing CMI

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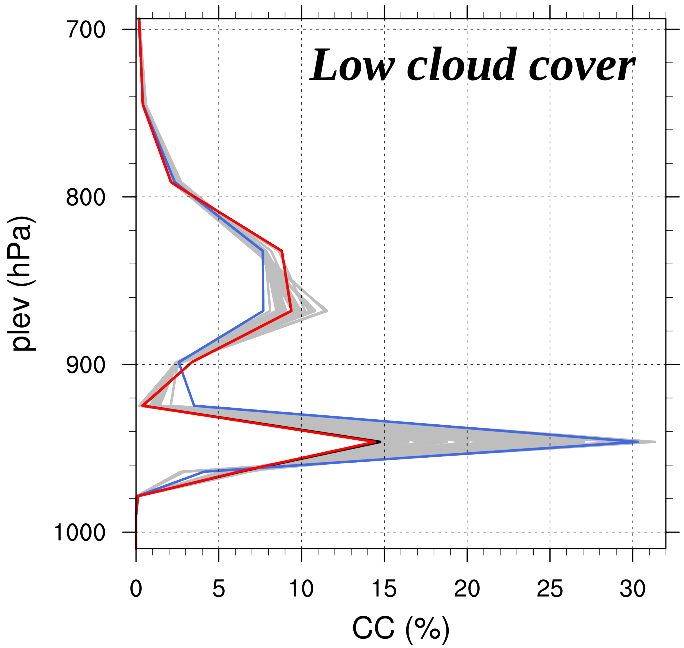

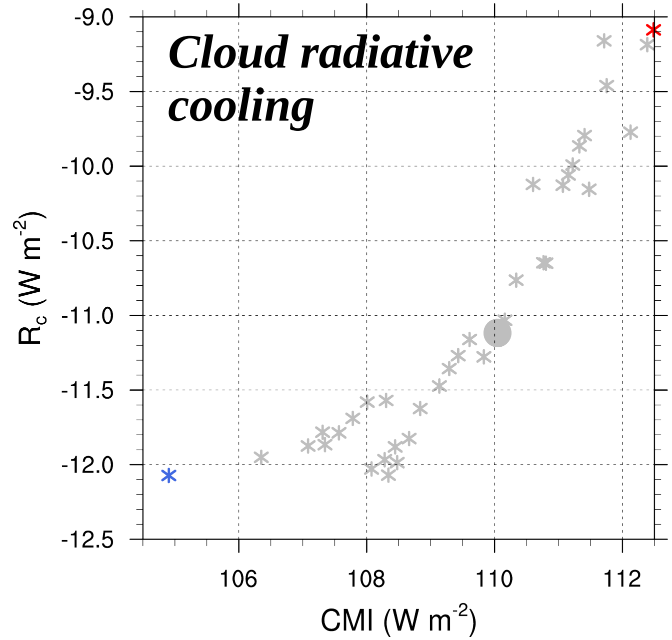

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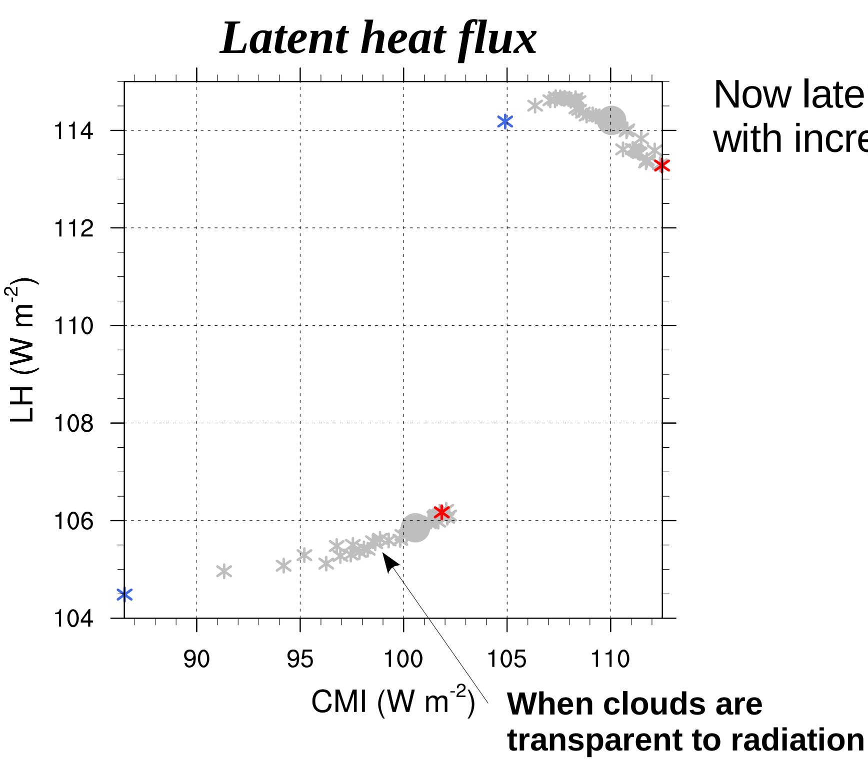

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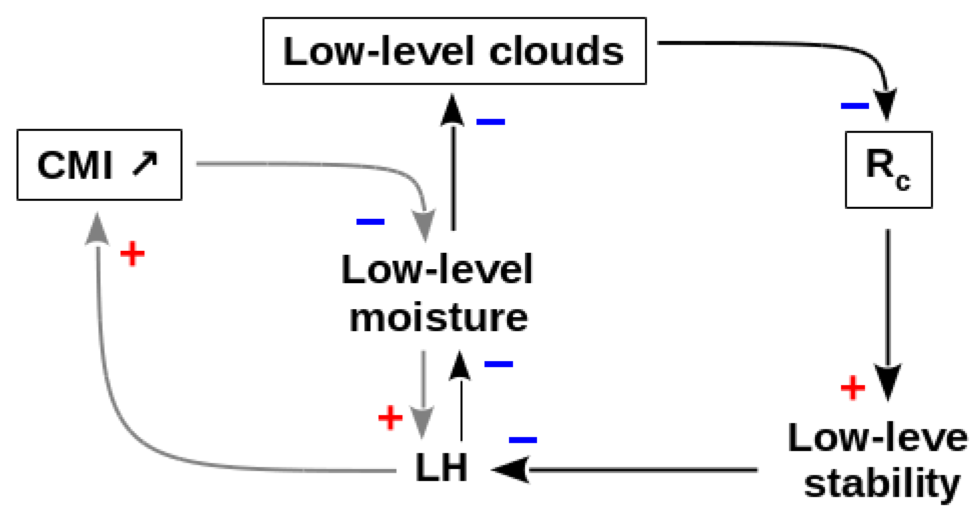
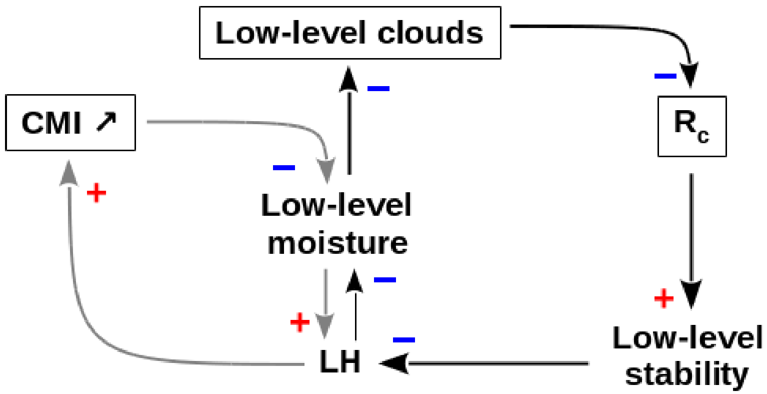


Summary

Mecanisms linking mixing to low clouds



1) <u>Control on low-level moisture via CMI</u>

- **When the sensitivity of clouds to CMI is <u>weaker</u> than the direct effect of mixing**

2) <u>Control on low-level moisture via cloud radiative effects</u>

- **When the sensitivity of clouds to CMI is <u>stronger</u> than the direct effect of mixing**

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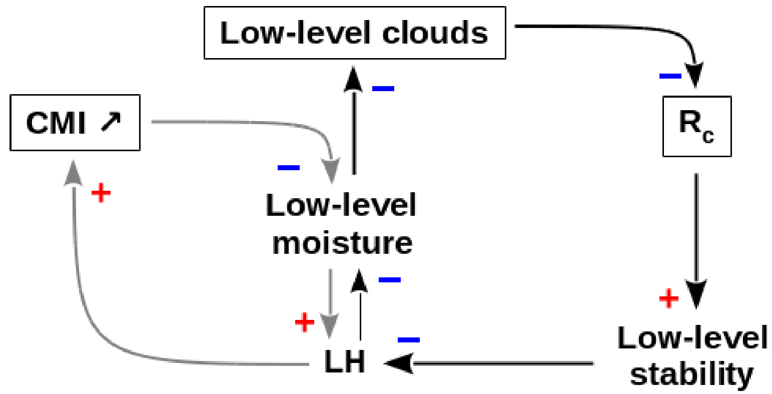

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- **When the sensitivity of clouds to CMI is weaker than the direct effect of mixing**

2) Control on low-level moisture via cloud radiative effects

- **When the sensitivity of clouds to CMI is stronger than the direct effect of mixing**

Link with closure

- Closure in **moisture convergence**

strong sensitivity to latent heat flux

$$\Downarrow$$

$$\frac{\partial R_c}{\partial CMI}$$ **weak**

- Closure in **CAPE**

strong sensitivity to thermal stratification : surface fluxes, profile of cloud radiative forcing

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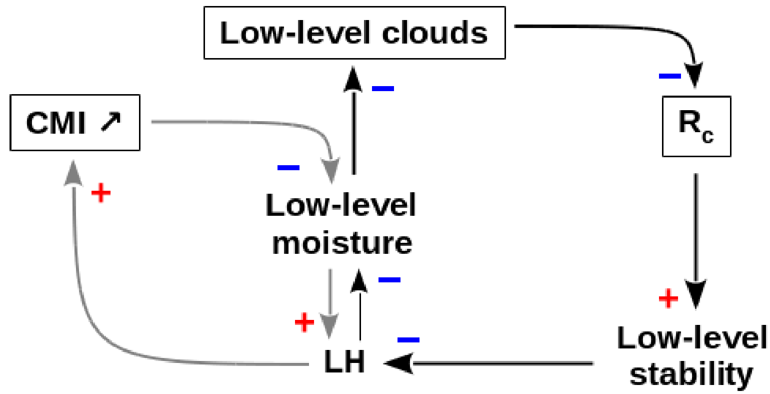

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⇓

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Implication for cloud feedbacks

$$\frac{\partial R_c}{\partial CMI}\Delta CMI$$

Weak cloud response to increased mixing in a warmer climate

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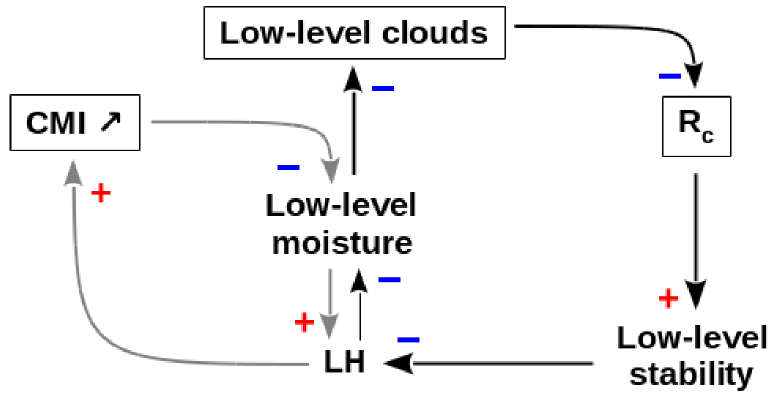

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strong sensitivity to thermal stratification : surface fluxes, profile of cloud radiative forcing

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$$\frac{\partial R_c}{\partial CMI}$$ **<u>strong</u>**

Implication for cloud feedbacks

$$\frac{\partial R_c}{\partial CMI}\Delta CMI = 1.1 \text{ W m}^{-2}\text{ K}^{-1}$$

<u>Weak</u> cloud response to increased mixing in a warmer climate

$$\frac{\partial R_c}{\partial CMI}\Delta CMI = 8.6 \text{ W m}^{-2}\text{ K}^{-1}$$

<u>Strong</u> cloud response to increased mixing in a warmer climate

Perspectives

- **Test these mecanisms using other single-climate models**
  - The CNRM-CM5 model very soon
- **Run 3D experiments**
  - To account for the large-scale circulation
  - To study the interplay between lower tropospheric mixing and low cloud feedbacks
- **Use observations**
  - To explore the mecanisms by analysing co-variations between all involved variables on monthly, seasonal or inter-annual time-scale (analysis by regime or in specific regions)
  - To constrain low cloud feedbacks

Thank you !

Implication for cloud feedbacks

$$\Delta R_c = \Delta R_c^{off} + \frac{\partial R_c}{\partial CMI}\Delta CMI + CMI\,\Delta\frac{\partial R_c}{\partial CMI} + \Delta\frac{\partial R_c}{\partial CMI}\Delta CMI$$

1 2 3 4

1 – Change in cloud radiative forcing independant of convection
2 – Change due to change in CMI + dependance on present-day sensitivity parameter
3 – Change due to change in the sensitivity parameter + dependance on present-day CMI
4 – Covariance term

$$\left.\begin{array}{l}\Delta R_c = 0.95\,W\,m^{-2}K^{-1}\\ \Delta CMI = \quad .\,W\,m^{-2}K^{-}\end{array}\right] \quad \frac{\Delta R_c}{\Delta CMI} = \quad .$$

$$\left.\begin{array}{l}\Delta R_c = 2.78\,W\,m^{-2}K^{-1}\\ \Delta CMI = 13.2\,W\,m^{-2}K^{-1}\end{array}\right] \quad \frac{\Delta R_c}{\Delta CMI} = 0.21$$