Interpretation of the positive low-cloud feedback predicted by the IPSLCM5A model : *An energetic analysis*

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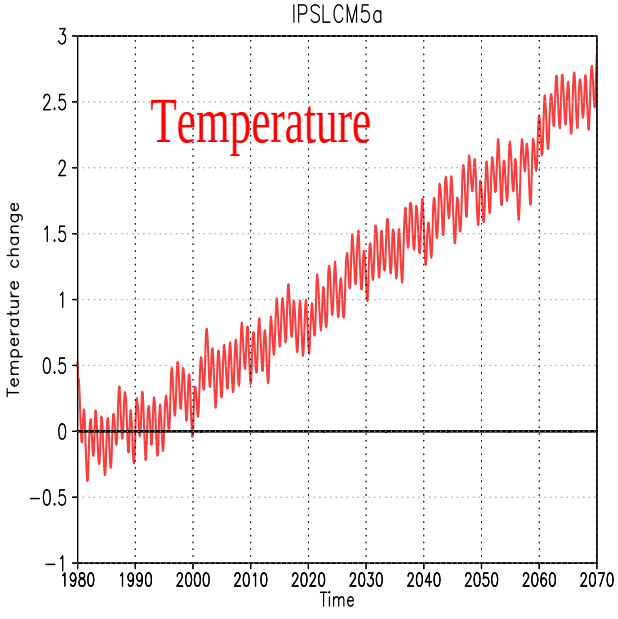
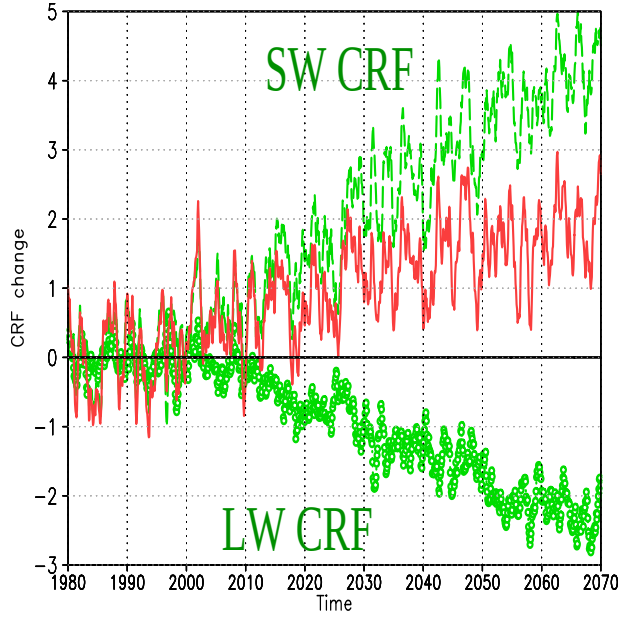
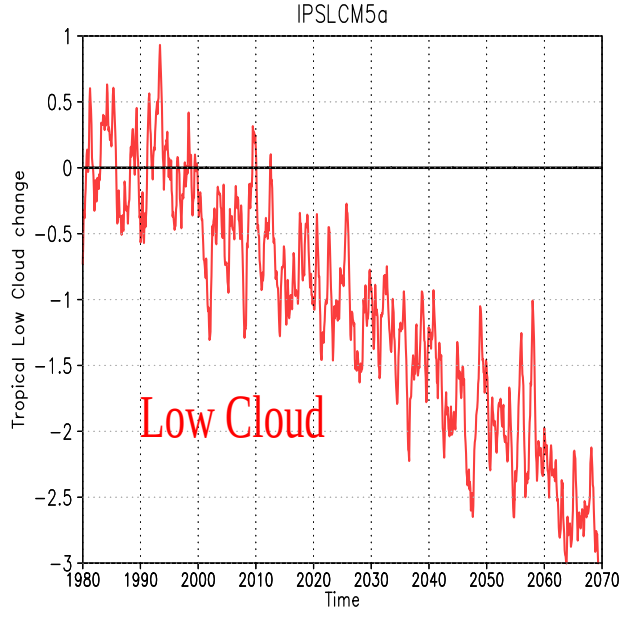
IPSL-CM5a Model

IPSLCM5a : +1pct CO_2 / year

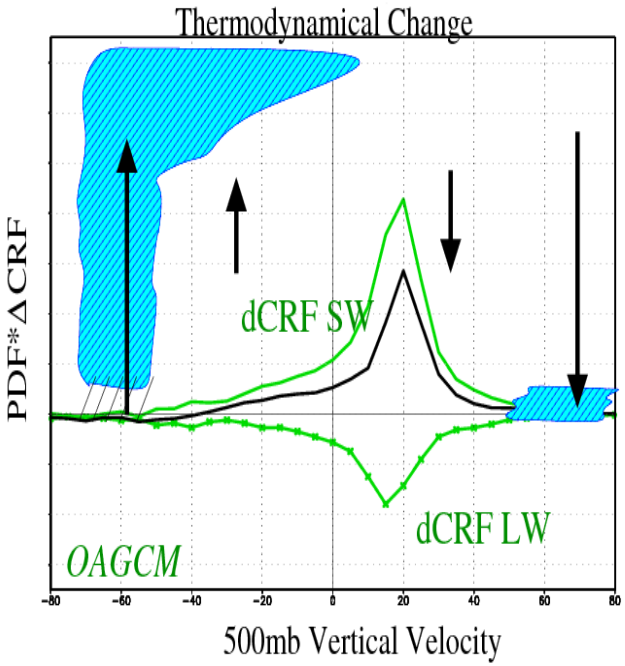


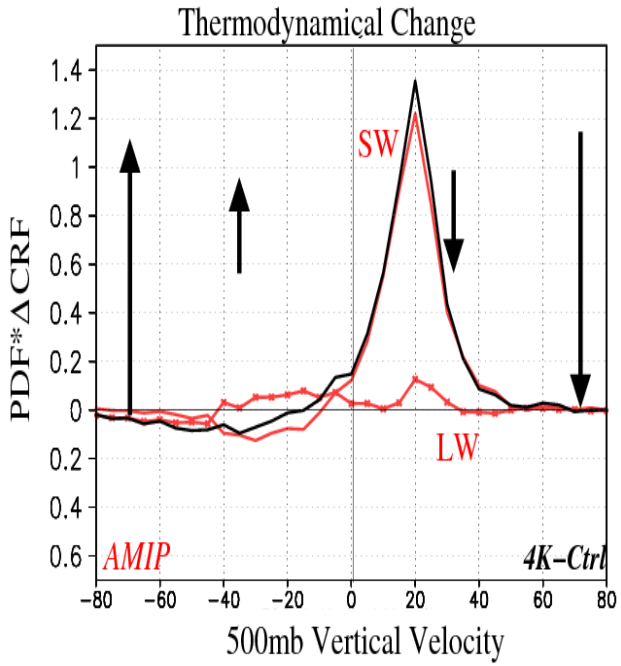


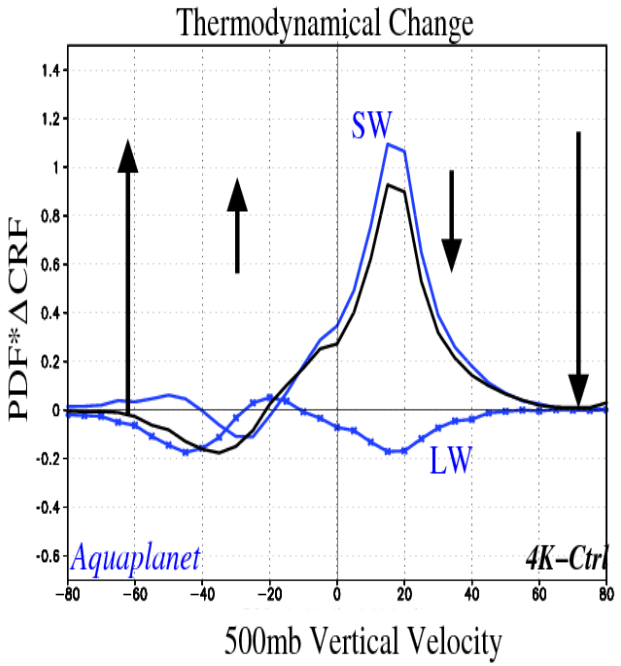


- CO_2 increase : Equilibrium Climate Sensitivity of +4.4K (High sensitivity model)
- Tropical Cloud Radiative Forcing : ΔCRF SW gives the sign of ΔCRF Net (less negative, less cooling)
- Positive feedback associated to the tropical low cloud decrease
- Difficulty to understand the mechanisms involved in a coupled model → Using a model hierarchy of different configurations.

Model Hierarchy

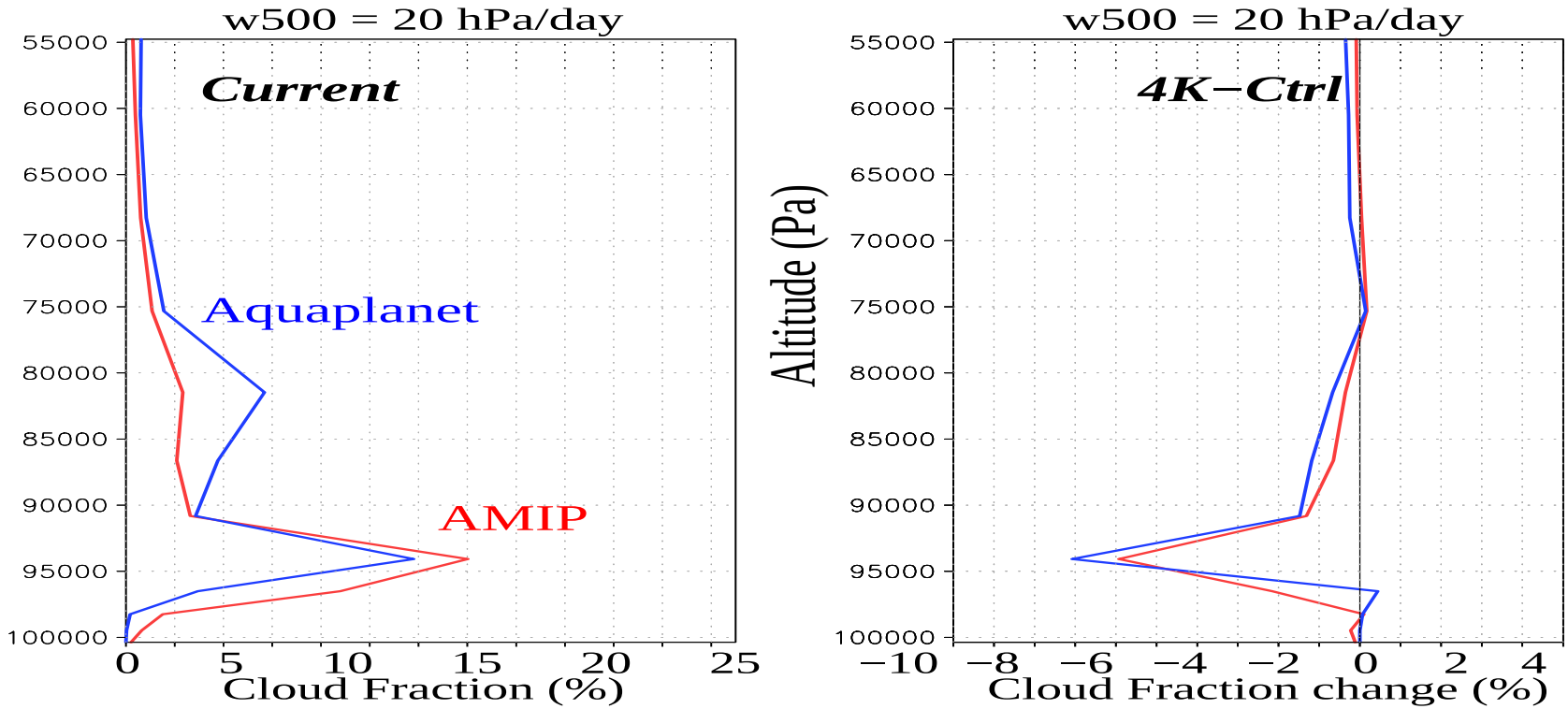






- Model Hierarchy with IPSLCM5A atmospheric physics
- Same response between coupled models and atmospheric models (idealized atmospheric circulations using w_{500})
- Tropical ΔCRF controlled by ΔSWCRF in weak subsidence regimes (w_{500}=0-30hPa/day)
- What controls the SW CRF increase on this regime ?

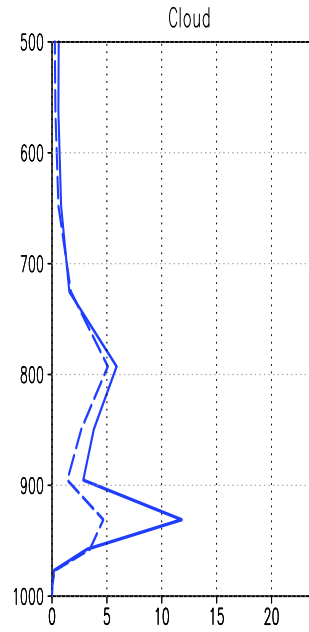
Zoom on weak subsidence regimes



- Cloud profile on a weak subsidence area (w_{500}=20 hPa/day)
- Decrease of cloud fraction in the 950mb layer
- Responsible for the positive cloud feedback of IPSLCM5a model (amplified by the large statistical weight of this regime)
- May we reproduce the 3D behaviour using a SCM ?

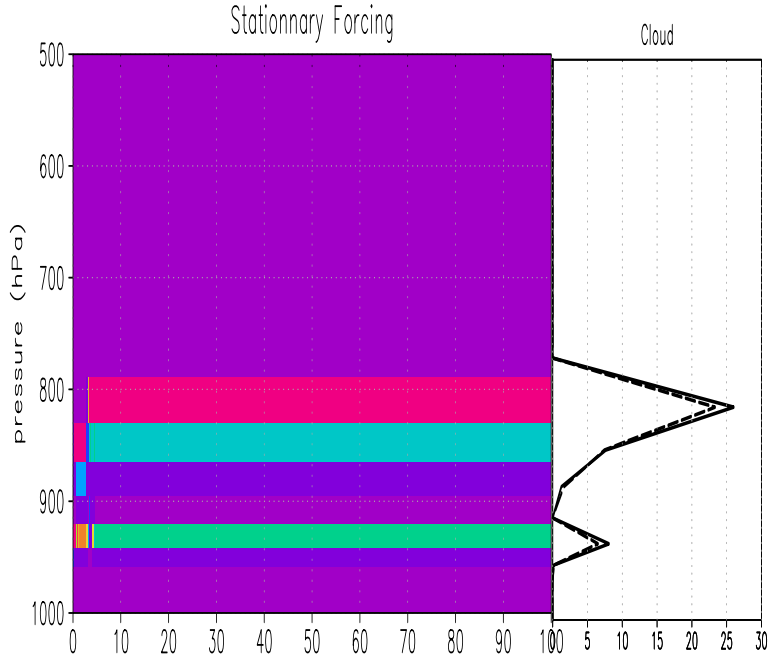
Model Hierarchy

3D

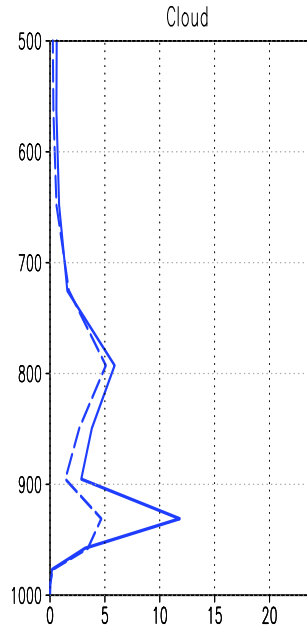


Model Hierarchy

s6 CGILS case

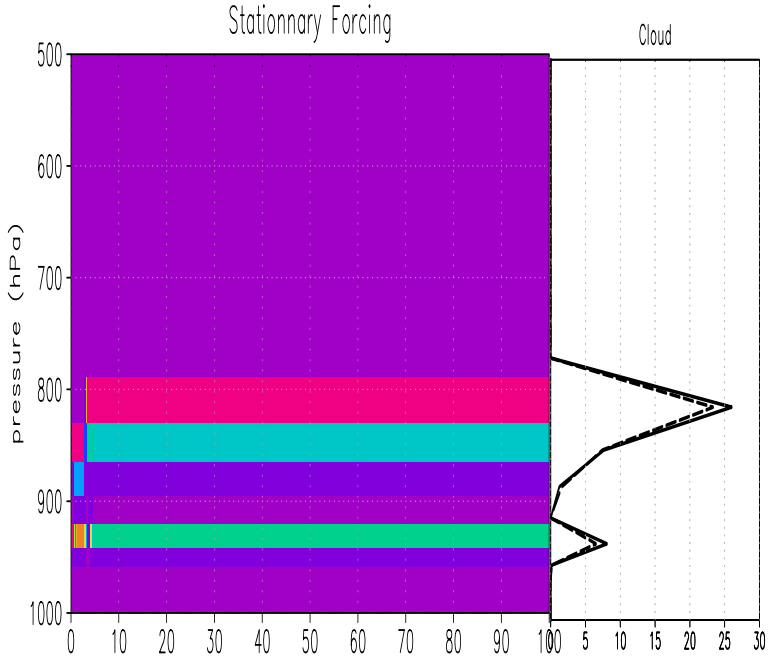


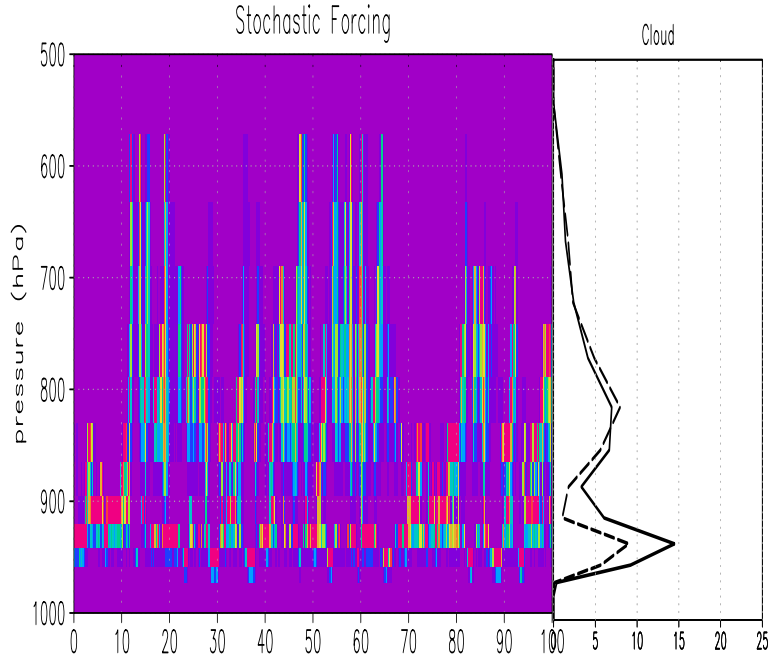
3D

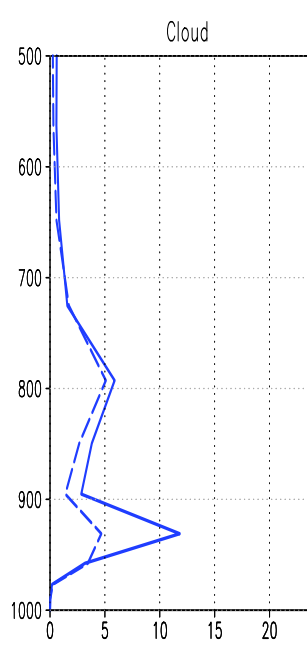


Model Hierarchy

s6 CGILS case ———————— s6 ω-stochastic (σ=σ_{GCM}) —— **3D**





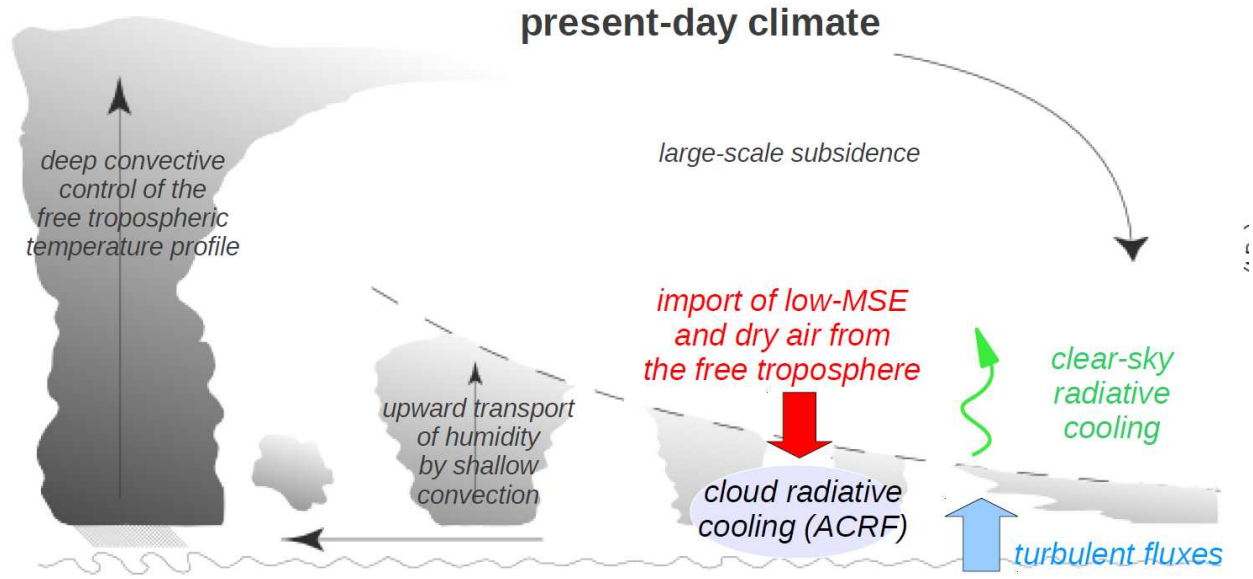


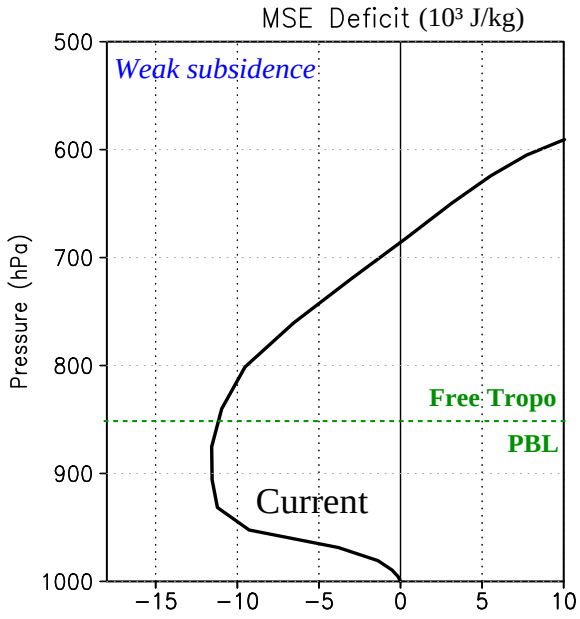
- SCM able to reproduce cloud profile both in present and future climate by adding a stochastic variability on large-scale vertical velocity
- Stochastic forcing allows a alternance of strong convective and subsidence states (characteristics of weak subsidence case)
- What processes control the low cloud decrease ?

Model Hierarchy

- Test of the SCM cloud response over a range a different perturbation applied alone :
  $\rightarrow \Delta$SST, $\Delta\omega$, ΔCO_2...
- Strong influence of the change in the vertical atmospheric stratification in response to a given radiative perturbation
- Analysing the energy budget of the troposphere to understand this behaviour

Positive Low Cloud feedback





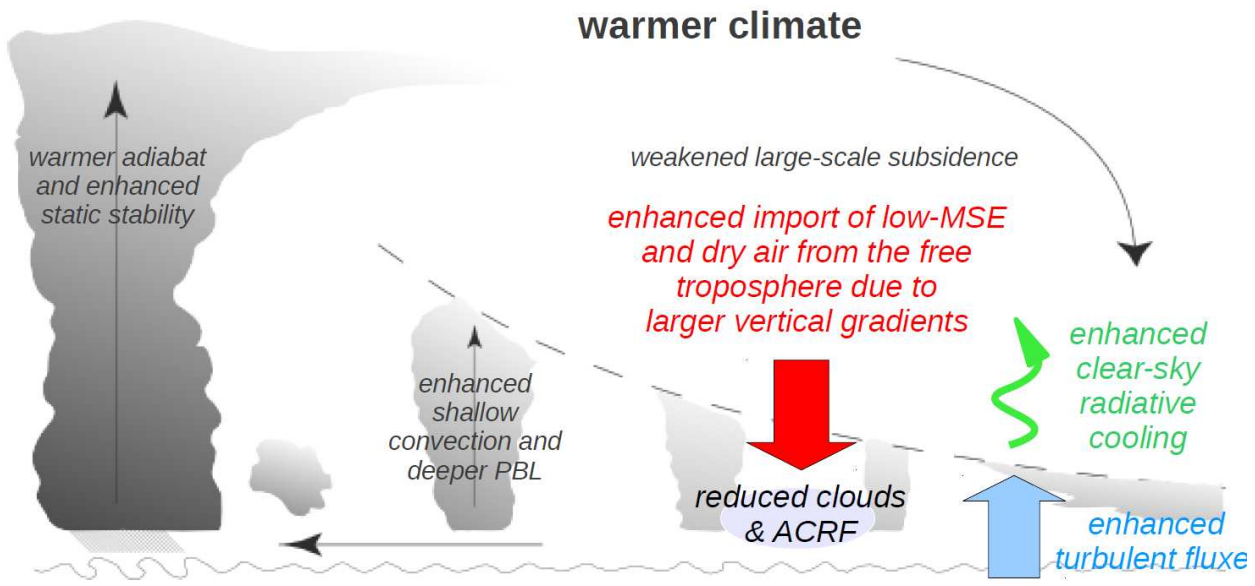
Brient and Bony, submitted to Clim. Dyn.

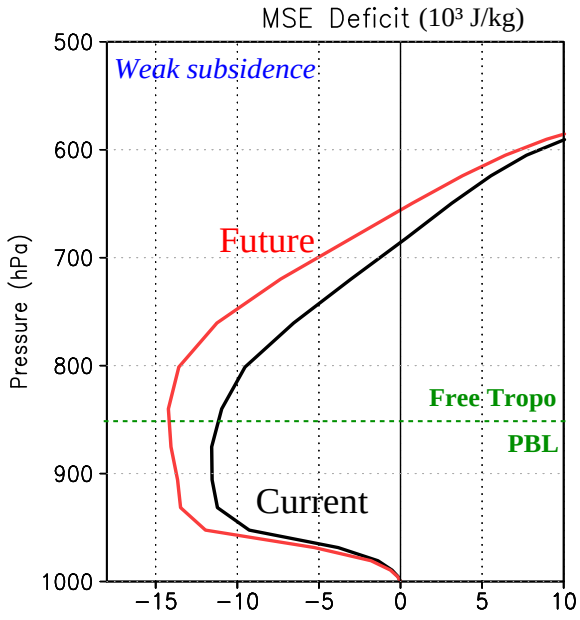
$$[ACRF] = -[R_0] - (LH + SH) + [\vec{V}.\vec{\nabla}h] + [\omega\frac{\partial h}{\partial P}]$$

Energetic analysis of the **PBL MSE** budget on current climate (W/m^2)

- Increased by surface turbulent fluxes $(LH + SH)$
- Decreased by clear-sky radiative cooling ($[R_0]$), Cloud radiative cooling ($[ACRF]$) and vertical advection of MSE ($[-\omega\frac{\partial h}{\partial P}]$)

Positive Low Cloud feedback





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Change of energetic analysis for a **Future Climate** (W/m^2)

- Enhanced import of low-MSE into the PBL $\rightarrow$ Reduced clouds

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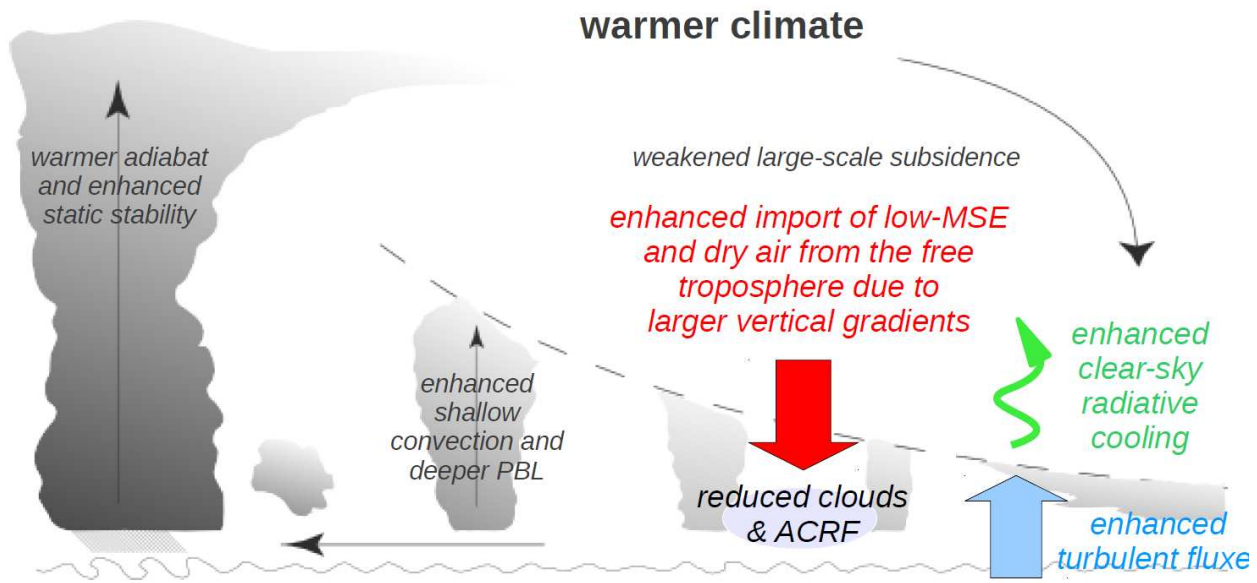

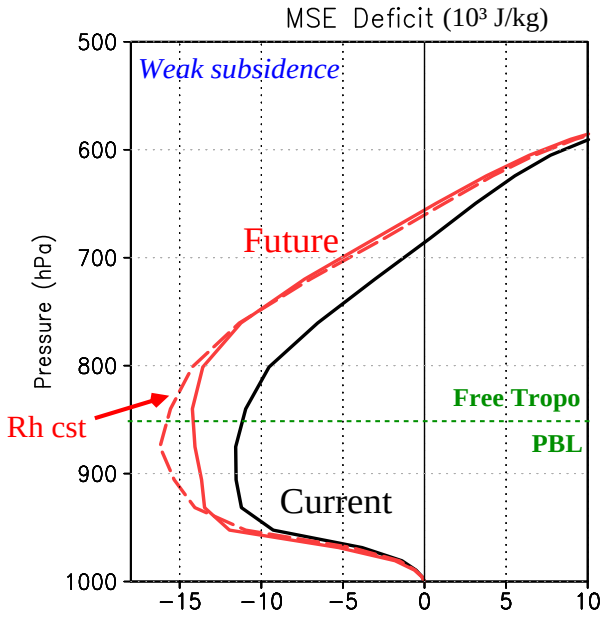

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Change of energetic analysis for a **Future Climate** (W/m^2)

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- At first order, due to Clausius-Clapeyron relationship : $\Delta q(z)$ larger at higher temperature (surface) than at altitude

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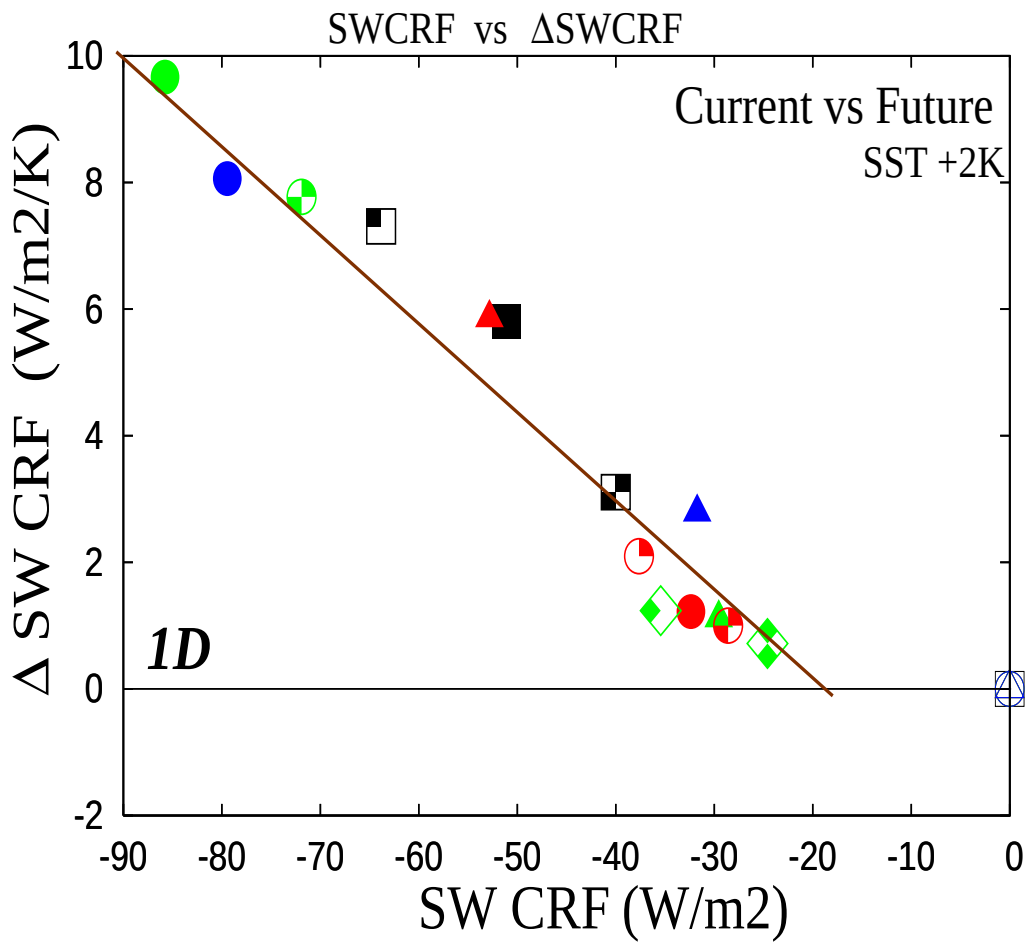
- Playing with uncertain model parameters ("tuning") mostly affecting low clouds to test GCM cloud feedback.
- Always Positive cloud feedback :
  The larger the current cloud cooling, the larger the cloud sensitivity



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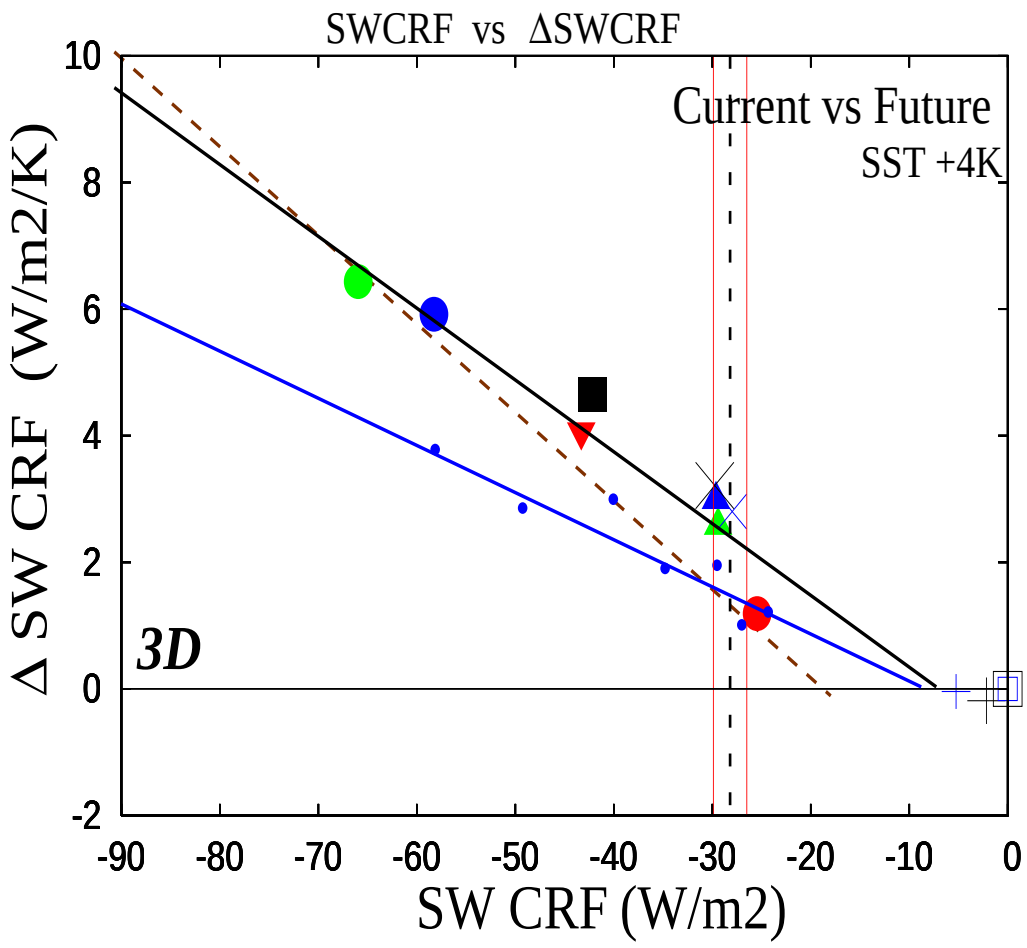

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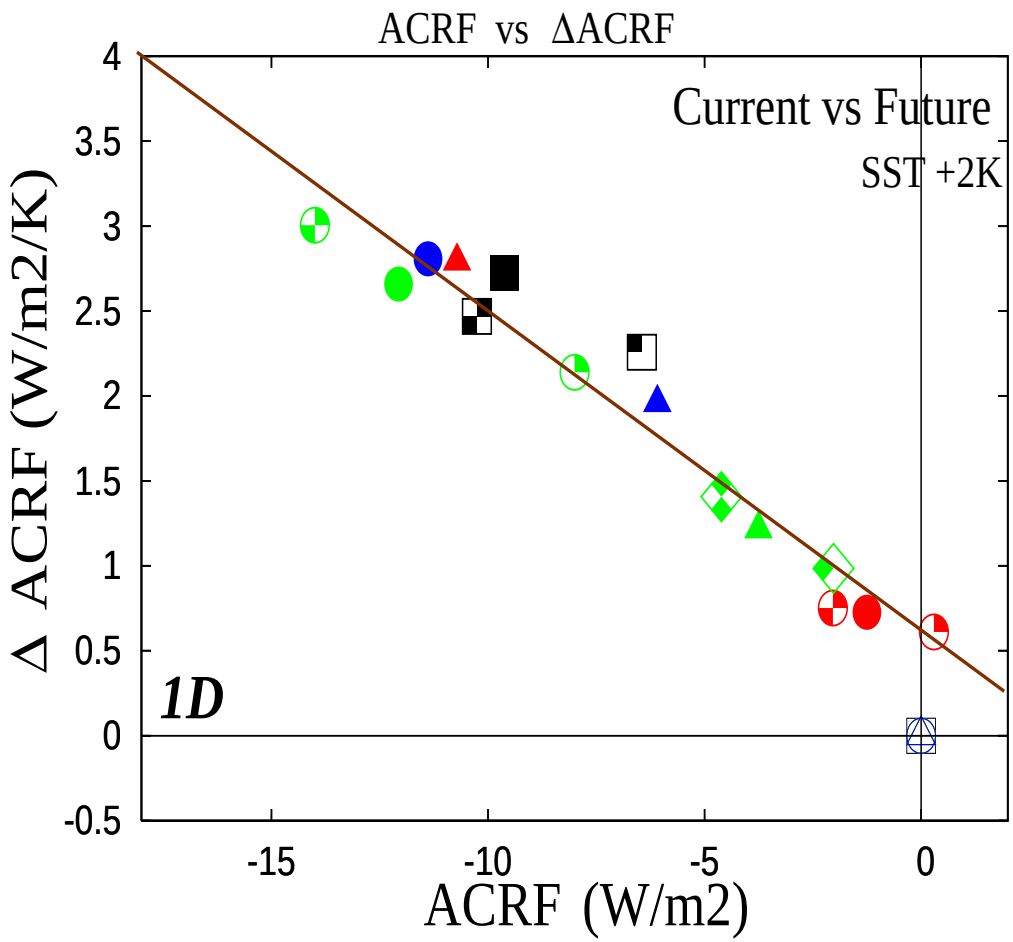

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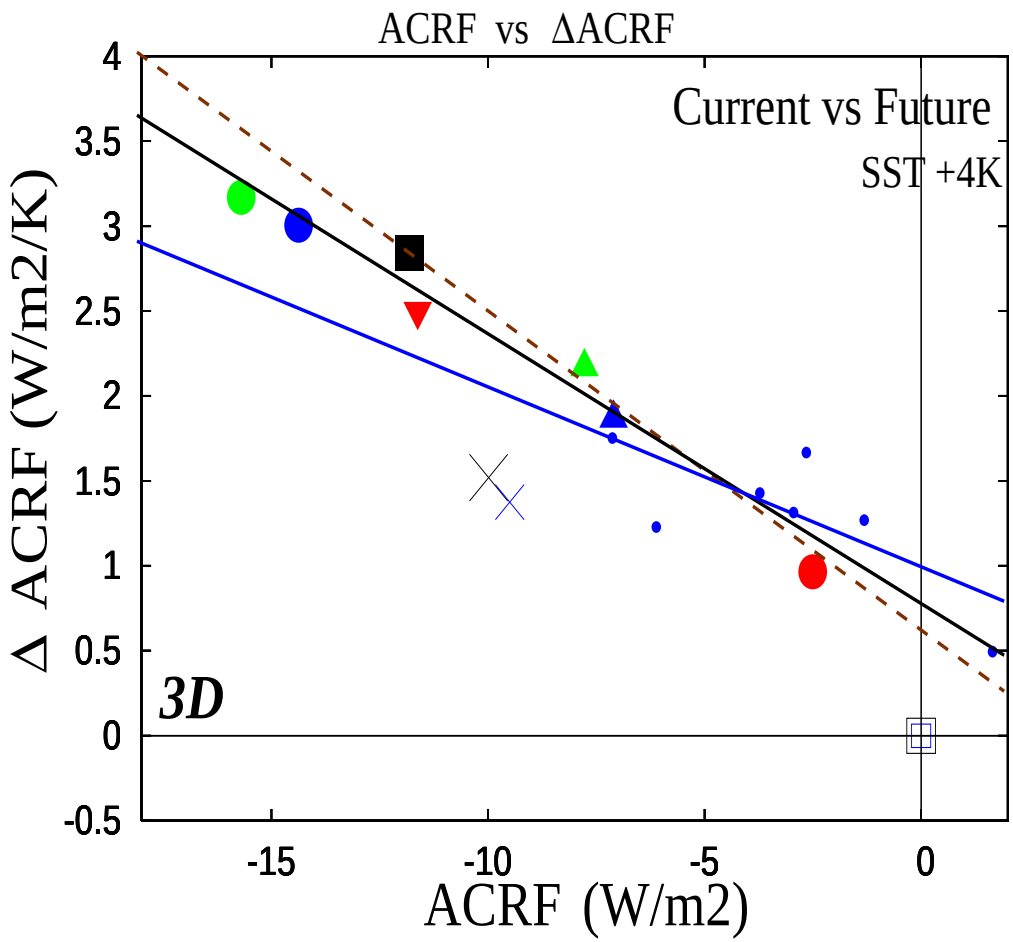

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Physical Interpretation

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- In all cases : Mechanism previously described is at work (enhanced vertical advection of MSE)
  $\Longrightarrow$ Explains the positive sign of the feedback
- Magnitude of the positive feedback related to more local feedback mechanism

Physical Interpretation

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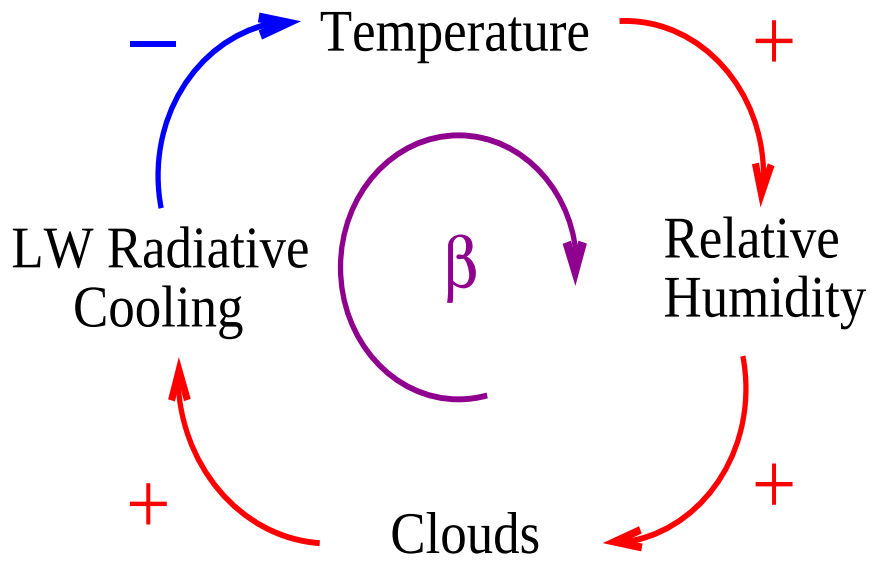
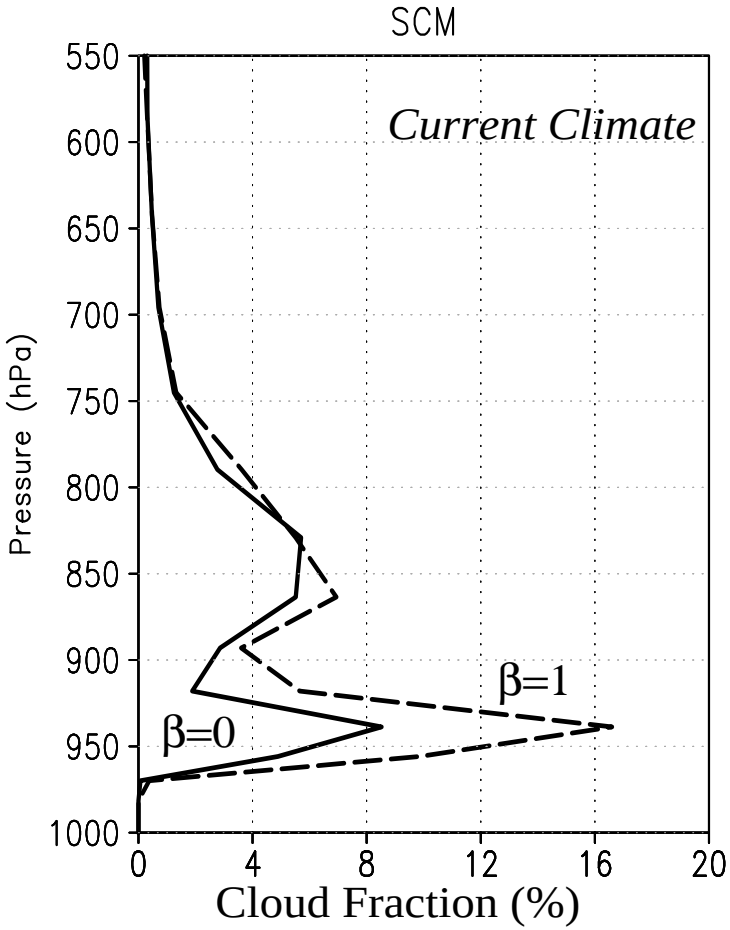
• Local Feedback between cloud radiative effects and RH
$\Longrightarrow$ Clouds contribute to their own maintenance (so-called β effect)

• May this explain the relationship current/future climate ?



Brient and Bony, in prep.

Radiative feedback



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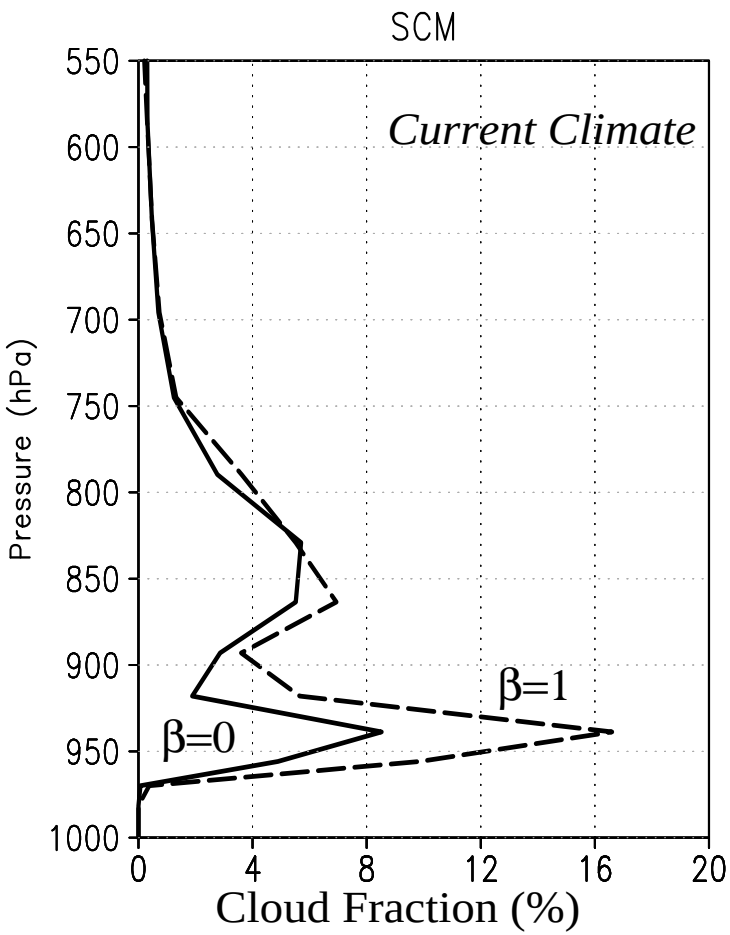
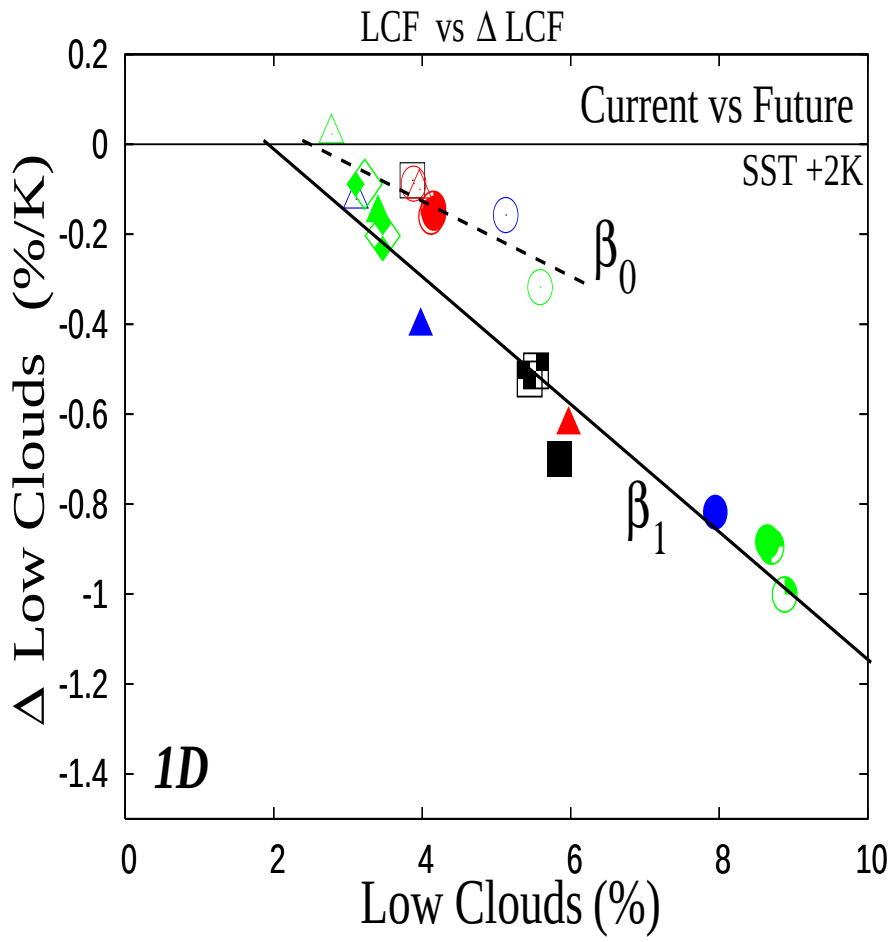
$\Longrightarrow$ Less Clouds in the PBL

Radiative feedback





- Test of this hypothesis by removing cloud radiative effets (β=0)

$\Longrightarrow$ Less Clouds in the PBL

$\Longrightarrow$ Weaker Cloud decrease in a future climate

Conclusions

In the IPSL-CM5A model :

- Positive low cloud feedback due to the decrease of the low cloud fraction over weak subsidence regimes
- Robust across a hierarchy of model configurations (OAGCM, AGCM, Aquaplanet, SCM)
- Low cloud decrease due to a enhanced advection of low-MSE from the free troposphere to the PBL $\longrightarrow$ related to the robust Clausius-Clapeyron mechanism
- Magnitude related to local positive feedback between cloud radiative effects and relative humidity (β effect) $\Longrightarrow$ Interpretation of the relationship current climat cloudiness vs cloud response under a climate change

To do :

- Look at CMIP5 models (same mechanims at work ?)
- Propose process-oriented observational tests (ex : *Kubar et. al 11*)

Thank You