# Using a Moist Static Energy budget to analyse low-cloud feedback simulated by a SCM

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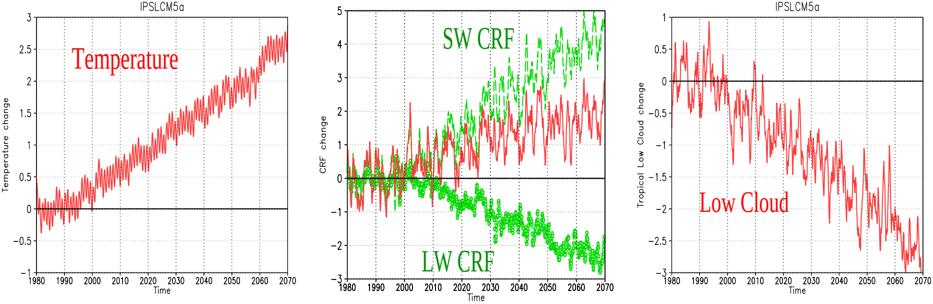
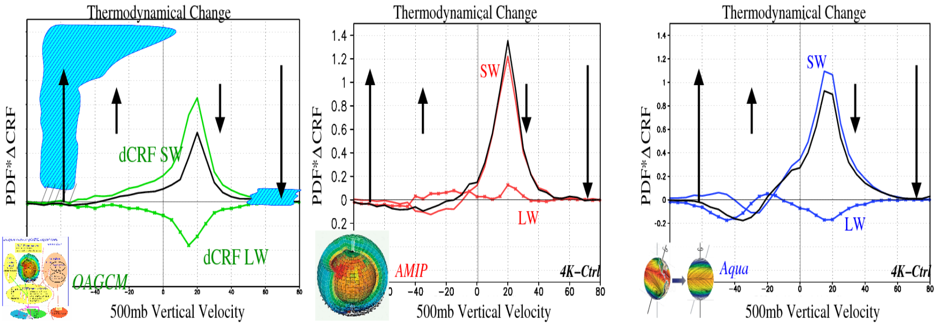
# IPSL-CM5a Model

IPSLCM5a : +1pct $CO_2$ / year



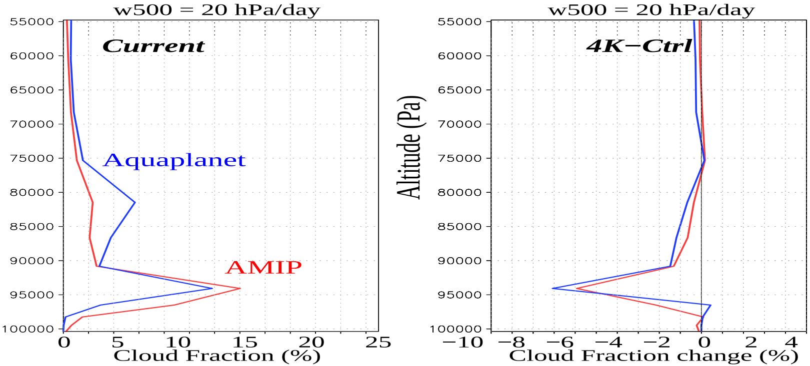

- $CO_2$ increase : Equilibrium Climate Sensitivity of +4.4K (High sensitivity model)
- Tropical Cloud Radiative Forcing : $\Delta$CRF SW gives the sign of $\Delta$CRF Net (less negative, less cooling)
- Positive feedback associated to the tropical low cloud decrease
- Difficulty to understand the mechanisms involved in a coupled model $\rightarrow$ 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 ?

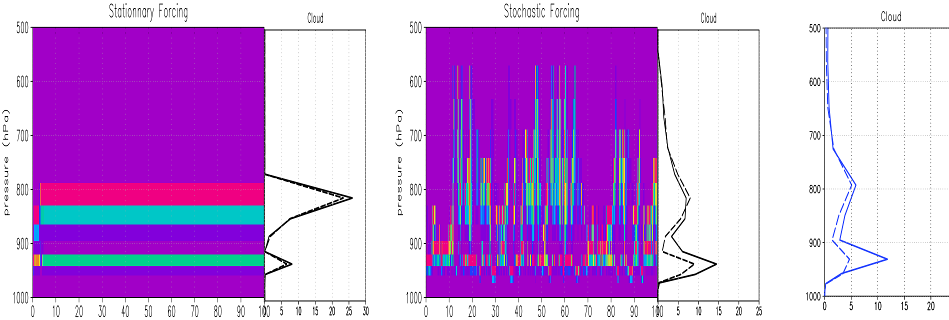
# Zoom on weak subsidence regimes




- 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 ?

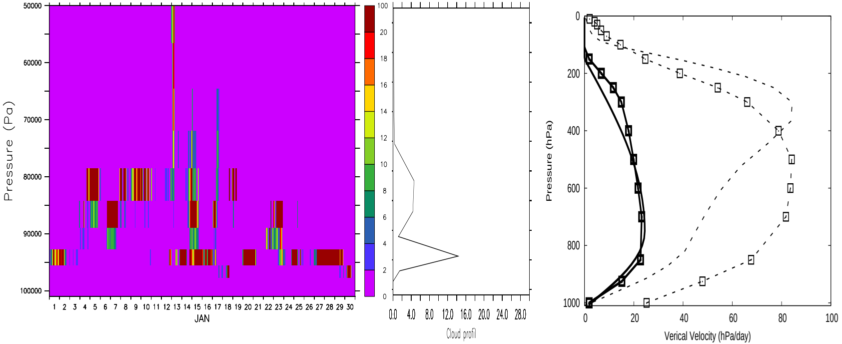
# Model Hierarchy

s6 CGILS case ———————— s6 $\omega$-stochastic ($\sigma$=$\sigma_{GCM}$) —— **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)
- How had the stochastic forcing been created ?

# Framework of Stochastic Forcing

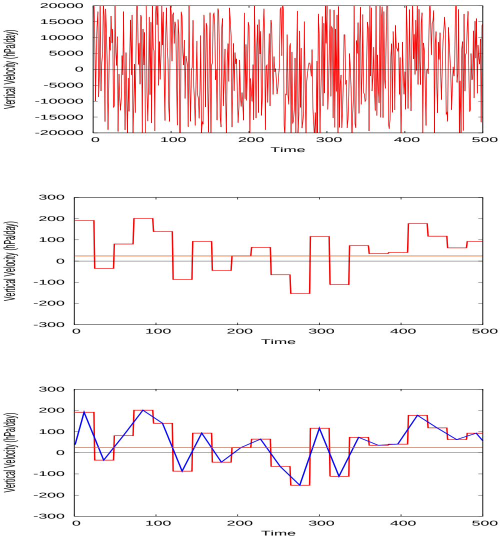



- Using 4xdaily outputs of a Aquaplanet model over w=20 hPa/day to extract **variance profile** (dashed line) : Max at 300 hPa
- In agreement with NCEP2 re-analysis

# Framework of Stochastic Forcing

Creation of stochastic forcing with imposed aquaplanet variance

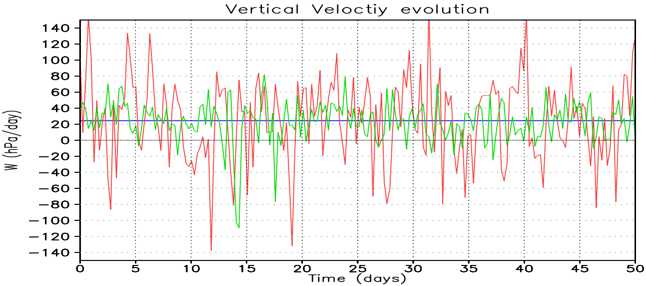
- (1) Full random stochastic forcing $\longrightarrow$ Wrong range of vertical velocity values
- (2) 6-hourly averaged values $\longrightarrow$ Good range, 25 hPa/day as averaged $\omega$
- (3) Smoothing by linear interpolation $\longrightarrow$ Reality-like evolution (memory of the previous step)

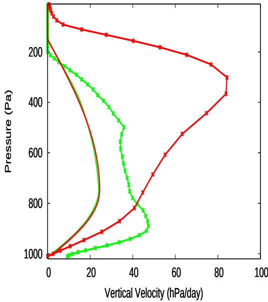


# CGILS Transient Forcing

Transient Forcing created by Chris Bretherton and Minghua Zhang for CGILS protocol

Based on 3-hourly variability of the ECMWF analysis




For $\omega$=750 hPa Stochastic vs Transient

- Less high variation, lower variance
- Smoother

# Understand cloud feedback through a MSE budget

Description of conservative MSE budget ($W/m^2$) :

$$MSE = C_p T + gz + Lq = s + Lq \quad (1)$$

$$< \frac{\partial MSE}{\partial P} >=< \frac{\partial s}{\partial P} > + < \frac{\partial Lq}{\partial P} >= 0 \quad (2)$$

$<>$ represent integration over the entire atmosphere

$\rightarrow$ *Dry static energy budget (s)* :

$$-(\overrightarrow{V}.\overrightarrow{\nabla} s)_{hor} - < \omega \frac{\partial s}{\partial P} > + SH + L * P + ACRF + < R_0 >= 0 \quad (3)$$

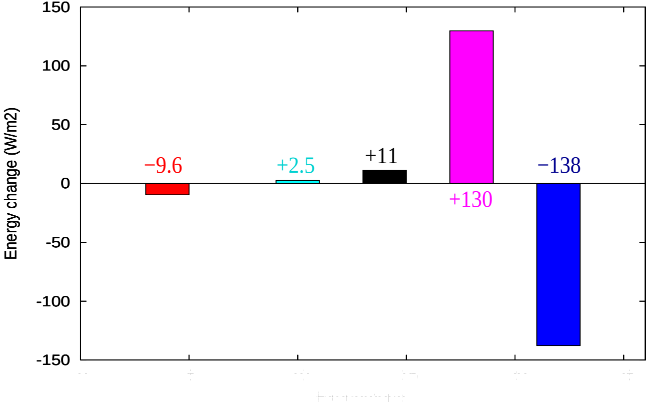
$\rightarrow$ *Water budget :*

$$-L * (\overrightarrow{V}.\overrightarrow{\nabla} q)_{hor} - L* < \omega \frac{\partial q}{\partial P} > + LH - L * P = 0 \quad (4)$$

$\rightarrow$ *Moist Static Energy budget (equations 3 + 4) :*

$$-(\overrightarrow{V}.\overrightarrow{\nabla} MSE)_{hor} - < \omega \frac{\partial MSE}{\partial P} > + SH + LH + ACRF + < R_0 >= 0 \quad (5)$$

# Understand cloud feedback through a MSE budget




ACRF decomposition for stochastic s6 CGILS SCM :

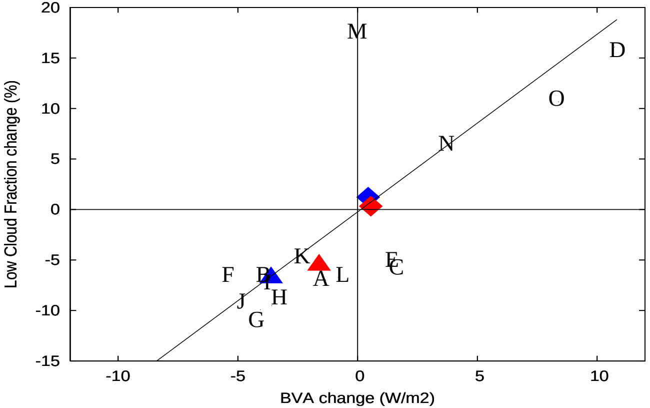
$$ACRF = -(\overrightarrow{V}.\overrightarrow{\nabla} MSE)_{hor} - < \omega \frac{\partial MSE}{\partial P} > + SH + LH + < R_0 >$$

# Understand cloud feedback through a MSE budget

$\Delta$ACRF for stoch s6 CGILS SCM over a range of sensitivity tests (*Brient and Bony, 12*) :

$$\Delta ACRF = -\Delta(\overrightarrow{V}.\overrightarrow{\nabla} MSE)_{hor} - \Delta < \omega \frac{\partial MSE}{\partial P} > + \Delta(SH + LH) + \Delta < R_0 >$$

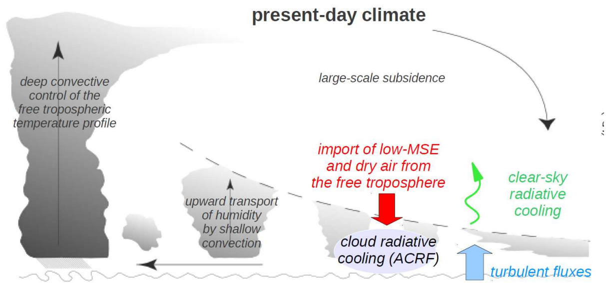
# Understand cloud feedback through a MSE budget

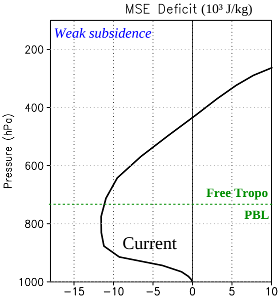



$\Delta$ACRF for stoch s6 CGILS SCM over a range of sensitivity tests (*Brient and Bony, 12*) + 3D colored points :

$$\Delta ACRF \approx \Delta\left(\int_{P=900}^{P=700} -\omega \frac{\partial MSE}{\partial P} \frac{dP}{g}\right)$$

# Positive Low Cloud feedback



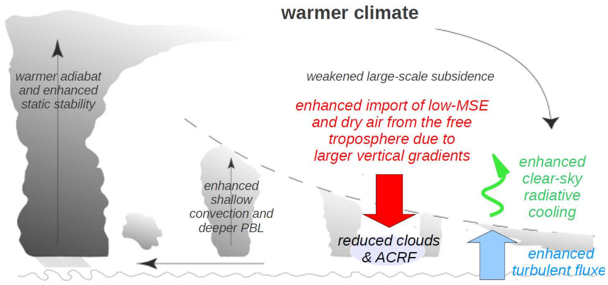

*Brient and Bony, Clim. Dyn., 2012*

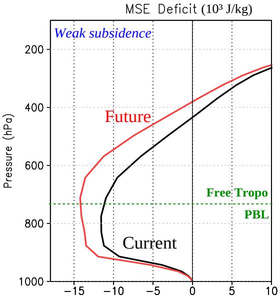
$$[ACRF] = -[R_0] - (LH + SH) + [\overrightarrow{V}.\overrightarrow{\nabla}h] + [\omega\frac{\partial h}{\partial P}]$$

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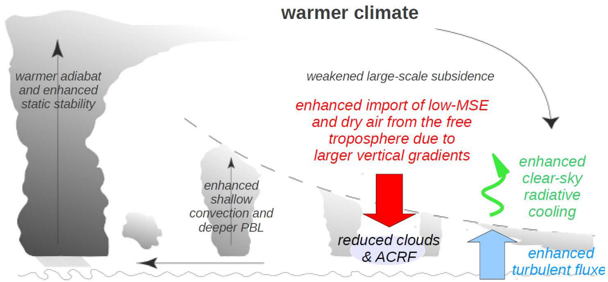
$$\Delta[ACRF] = -\Delta[R_0] - \Delta(LH + SH) + \Delta[\vec{V}.\vec{\nabla}h] + \Delta[\omega\frac{\partial h}{\partial P}]$$

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

- Enhanced import of low-MSE into the PBL → Reduced clouds

# Positive Low Cloud feedback

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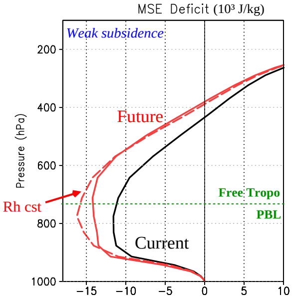


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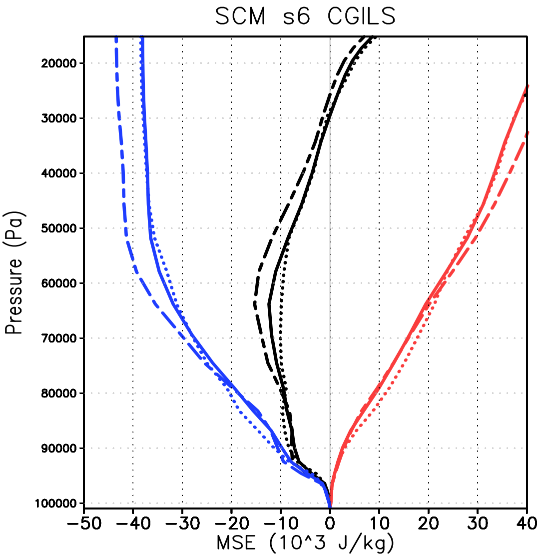
Change of energetic analysis for a **Future Climate** ($W/m^2$)

- Enhanced import of low-MSE into the PBL → Reduced clouds
- At first order, due to Clausius-Clapeyron relationship : Δq(z) larger at higher temperature (surface) than at altitude

# Decomposition of MSE vertical profile

- **MSE deficit vertical profile** decomposed into $C_p$*T+gz and L*q parts
- Dashed lines for +2K and Dotted lines for 4xCO2 experiments
- $\Delta$ MSE due to "Lq" for +2K ($\Delta$CF<0)
- $\Delta$ MSE due to "$C_p$*T+gz" for 4xCO2 ($\Delta$CF>0)



# 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)
- Adding a stochastic forcong on vertical velocity is necessary to reproduce both present and future cloud fraction
- 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

Perspectives :

- Sensitivity of the SCM cloud fraction to variance profile (stochastic, transient, others...) ?
- Sensitivity of the SCM cloud response to potential changes of variance profile under global warming ?
- Less necessary on others (more subsident) points ?

Thank You

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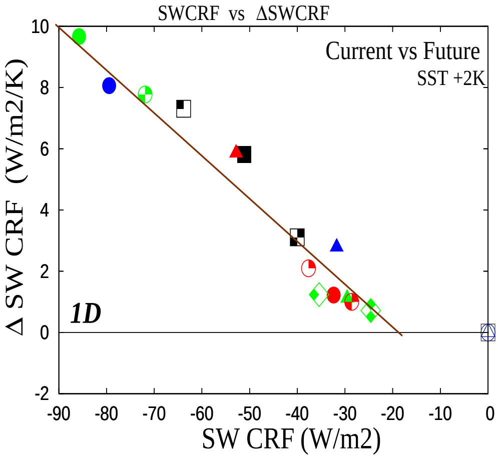
- Playing with uncertain model parameters ("tuning") mostly affecting low clouds to test GCM cloud feedback.
- Always Positive cloud feedback :
  The larger the current cloud cooling, the larger the cloud sensitivity



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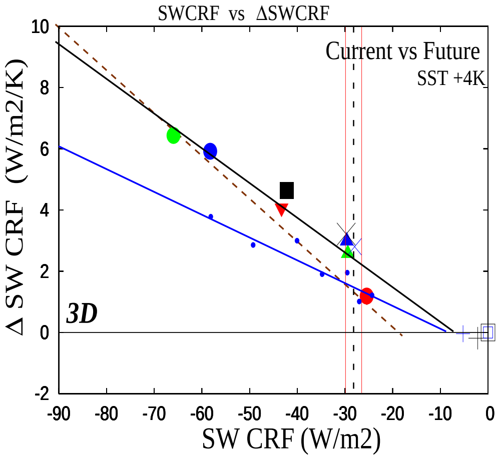

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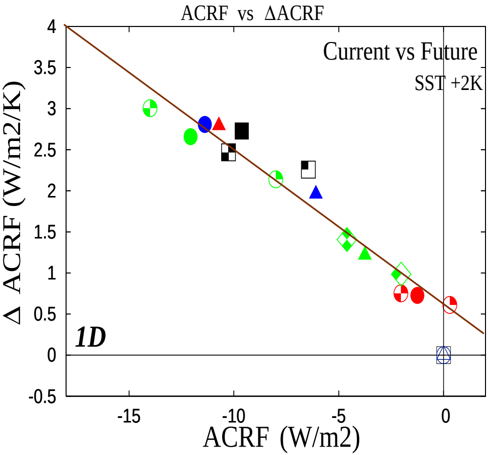
- Range of different $\Delta$ACRF for a same perturbation
  $\rightarrow$ Why ?

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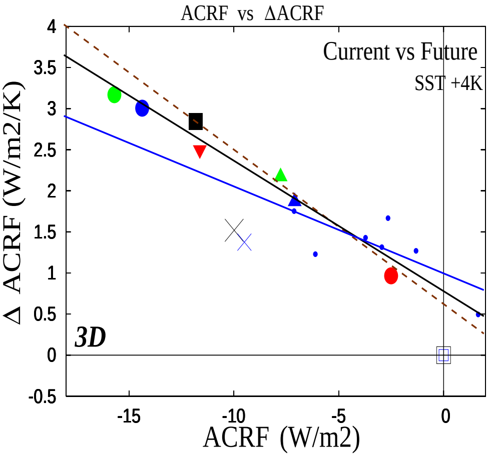


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# Physical Interpretation

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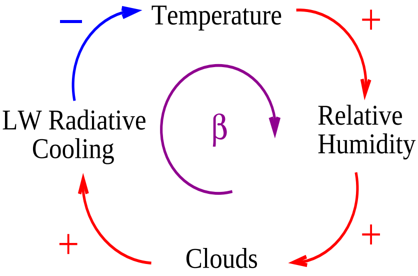
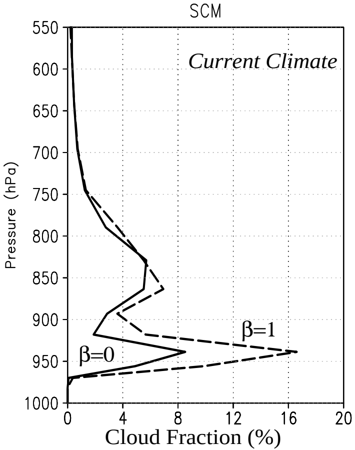
• Local Feedback between cloud radiative effects and RH
$\Longrightarrow$ Clouds contribute to their own maintenance (so-called $\beta$ effect)

• May this explain the relationship current/future climate ?




*Brient and Bony, in prep.*

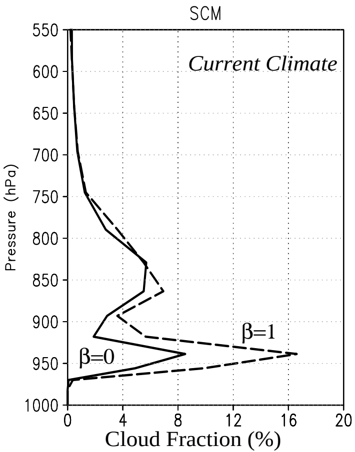
# Radiative feedback

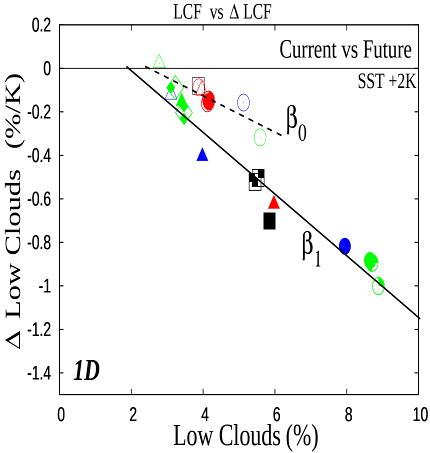



- Test of this hypothesis by removing cloud radiative effets ($\beta$=0)

$\Longrightarrow$ Less Clouds in the PBL

# Radiative feedback




- Test of this hypothesis by removing cloud radiative effets ($\beta$=0)

$\Longrightarrow$ Less Clouds in the PBL

$\Longrightarrow$ Weaker Cloud decrease in a future climate