Interpretation of tropical low-clouds feedbacks in CMIP5 models

Florent Brient, Sandrine Bony

Laboratoire de Meteorologie Dynamique / IPSL (Paris, France)

May, 30th 2012

Objectives of CMIP5 analysis

$\Longrightarrow$ What is the relative role of clouds ajustment to CO_2 and SST change ?

$\Longrightarrow$ Which type of clouds contributes the most to the spread of tropical cloud response ?

$\Longrightarrow$ Are there some robust mechanisms of low-cloud feedback ?

$\Longrightarrow$ Is it possible to link the behaviours of clouds under global warming and under present-day natural variability ?

Objectives of CMIP5 analysis

$\Longrightarrow$ What is the relative role of clouds ajustment to CO_2 and SST change ?

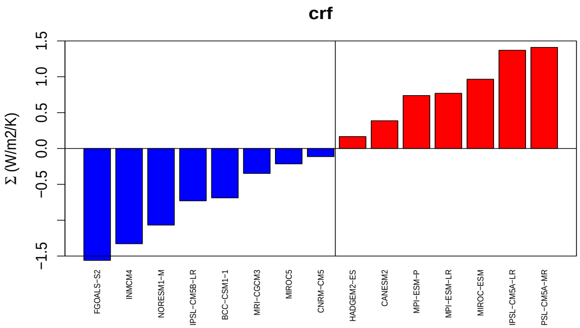
$\Longrightarrow$ Which type of clouds contributes the most to the spread of tropical cloud response ?

$\Longrightarrow$ Are there some robust mechanisms of low-cloud feedback ?

$\Longrightarrow$ Is it possible to link the behaviours of clouds under global warming and under present-day natural variability ?

- Spectrum of configurations and sensitivity experiments
- Overall behaviour and physical mechanisms
- Comparison with observations and re-analysis

Spread of cloud responses in CMIP5 models

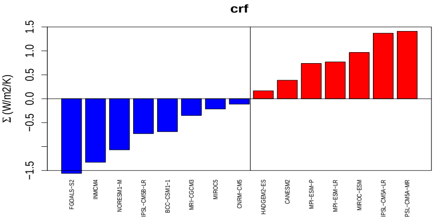


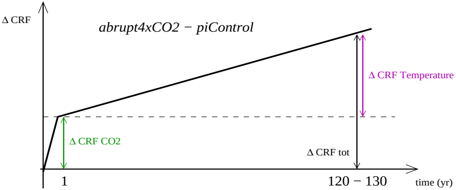
15 CMIP5 OAGCMs Abrupt4xCO_2 - piControl

Update of Bony and Dufresne, 05

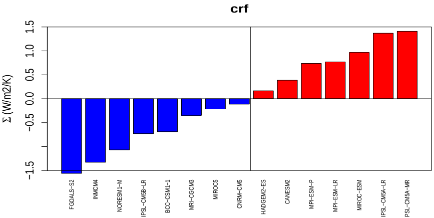
- Large range of tropical cloud radiative response
- As in *BD05*, low-sensitivity and high-sensitivity groups of models defined from CRF change.

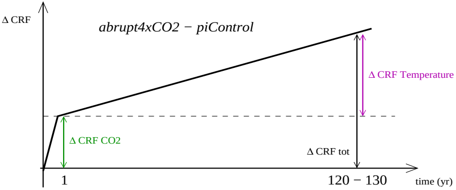
CO_2 vs SST response (ocean)

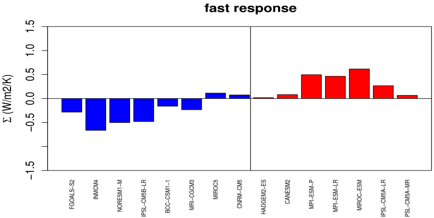


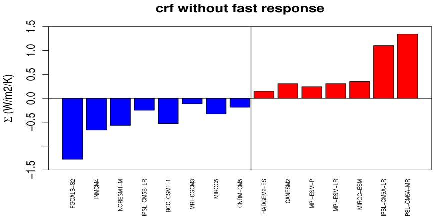


CO_2 vs SST response (ocean)



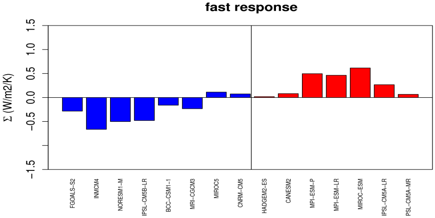




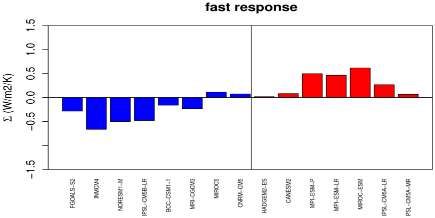


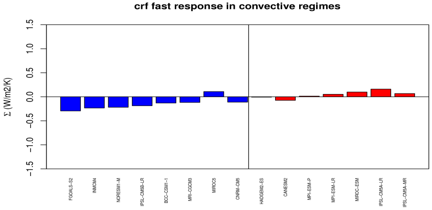
- Spread of CRF change due to both fast (CO_2) and slow (temperature) responses
- However the spread of Temperature dominates

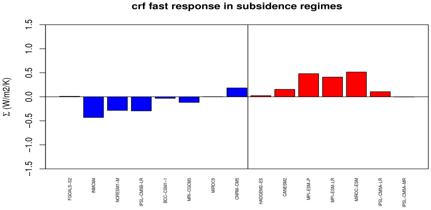
(1) CO_2 response (Fast)



(1) CO_2 response (Fast)

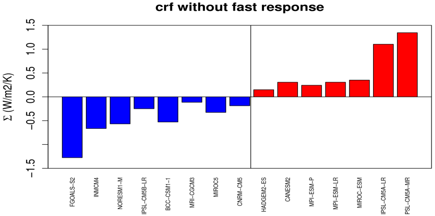




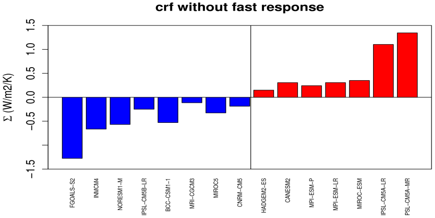


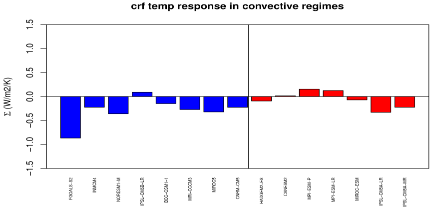
- Separation between Convective (left) and Subsidence (right) regimes
- Spread of fast response in subsidence regimes

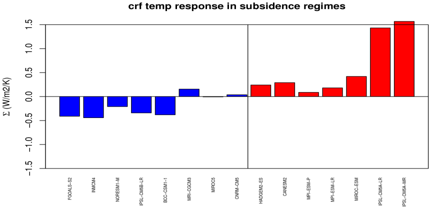
(2) Temperature response (Slow)



(2) Temperature response (Slow)

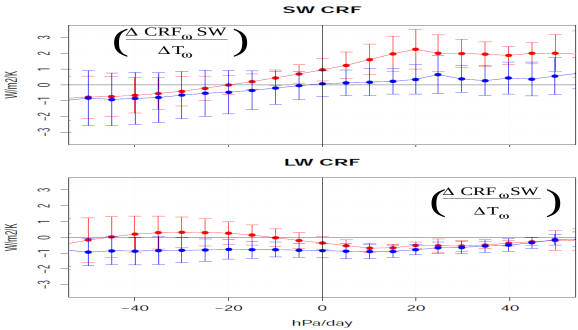


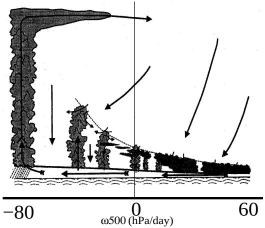




- Spread of slow response also in <u>subsidence</u> regimes

Spread of cloud responses in CMIP5 models

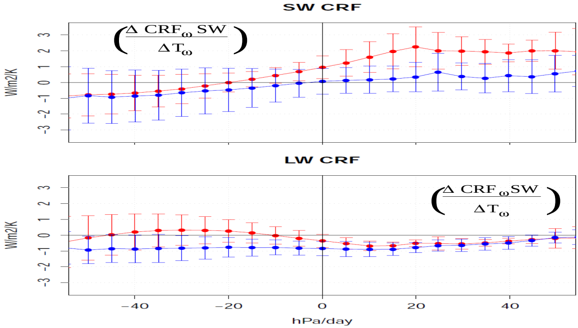


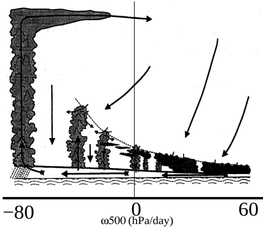


Update of Bony and Dufresne, 05

- As in *BD05*, low-sensitivity and high-sensitivity groups of models defined from CRF change.
- Spread of the SW CRF response in *subsidence* regimes, of LW CRF response in convective regimes.
- However, the overall spread in NET response dominated by **subsidence** regimes (σ=0.74 W/m^2 vs σ=0.33 W/m^2/K in convective regimes)

Spread of cloud responses in CMIP5 models





Update of Bony and Dufresne, 05

- As in *BD05*, low-sensitivity and high-sensitivity groups of models defined from CRF change.
- Spread of the SW CRF response in *subsidence* regimes, of LW CRF response in convective regimes.
- However, the overall spread in NET response dominated by **subsidence** regimes (σ=0.74 W/m^2 vs σ=0.33 W/m^2/K in convective regimes)
- Zoom on some atmospheric models to study temperature response over subsidence regimes

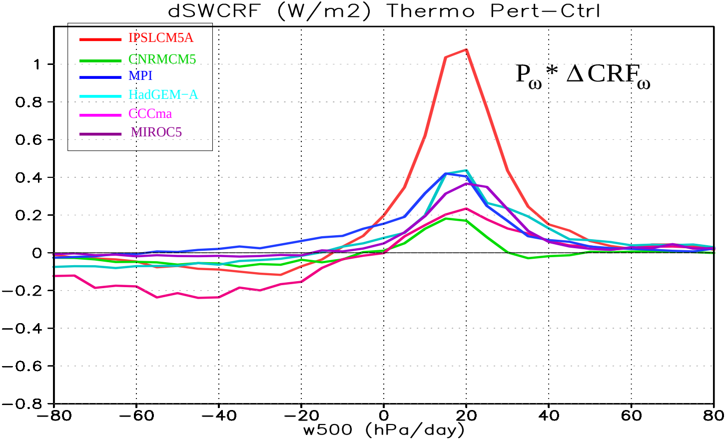
Focus on 6 models

Change in Tropical SW CRF

(AMIP4K-AMIP)

AMIP models	Δ SW CRF (W/m^2)	
IPSL-CM5A-LR	4.5	
MPI-ESM-LR	2.6	
HadGEM2-A	1.2	
MIROC5	0.4	
CNRM-CM5	-0.5	
CanAM4	-1.7	

Thermodynamical CMIP5 cloud feedback



- **Robust positive** SW CRF change over <u>weak subsidence</u> regimes → Max on $w_{500} = 20 \pm 5$ hPa/day

Focus on 6 models

Change in Tropical SW CRF

(AMIP4K-AMIP)

AMIP models	Δ SW CRF (W/m^2)	WS/Thermo (%)
IPSL-CM5A-LR	4.5	**97**
MPI-ESM-LR	2.6	**95**
HadGEM2-A	1.2	**88**
MIROC5	0.4	**97**
CNRM-CM5	-0.5	**82**
CanAM4	-1.7	50

$\Longrightarrow$ Contribution of thermodynamical SW CRF change over Weak Subsidence (**WS** 0-30 hPa/day) compared to Thermo change

• Importance of thermodynamical WS change to understand tropical SW CRF change

Focus on 6 models

Change in Tropical SW CRF

(AMIP4K-AMIP)

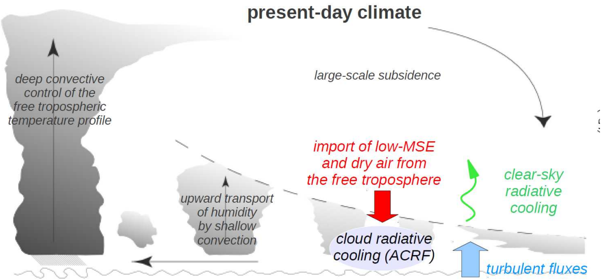
AMIP models	Δ SW CRF (W/m^2)	WS/Thermo (%)
IPSL-CM5A-LR	4.5	**97**
MPI-ESM-LR	2.6	**95**
HadGEM2-A	1.2	**88**
MIROC5	0.4	**97**
CNRM-CM5	-0.5	**82**
CanAM4	-1.7	50

$\Longrightarrow$ Contribution of thermodynamical SW CRF change over Weak Subsidence (**WS** 0-30 hPa/day) compared to Thermo change

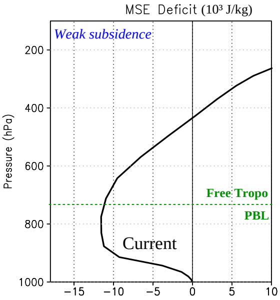
• Importance of thermodynamical WS change to understand tropical SW CRF change

• Most of ACGMs simulate a SW CRF increase with differents amplitudes → Interpretation of the robustness of this sign (IPSL Model)

Positive Low Cloud feedback



Brient and Bony 2012, Clim. Dyn. (in press)

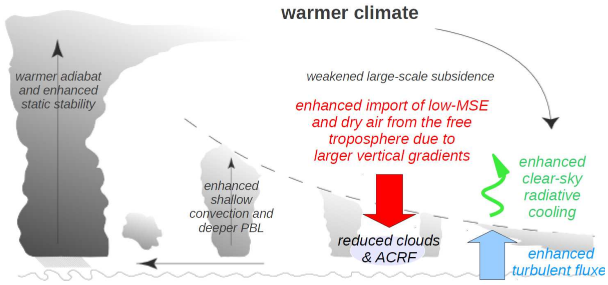


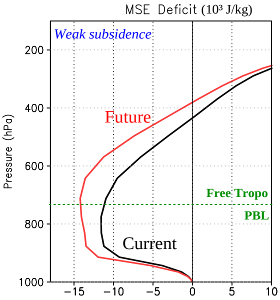
$$[ACRF] = -[R_0] - (LH + SH) + [\overrightarrow{V}.\overrightarrow{\nabla}h] + [\omega \frac{\partial h}{\partial P}] \qquad (W/m^2)$$

Energetic analysis of the **tropo MSE** budget on current climate *($h=c_p T+gz+Lq$)*

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

Positive Low Cloud feedback





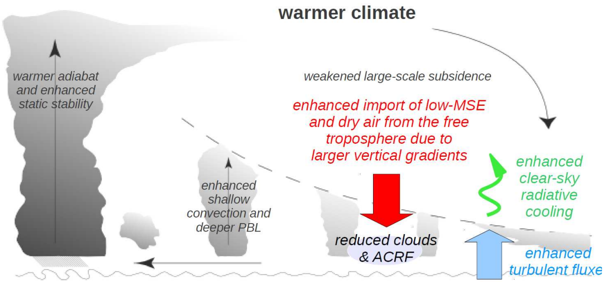
Brient and Bony 2012, Clim. Dyn. (in press)

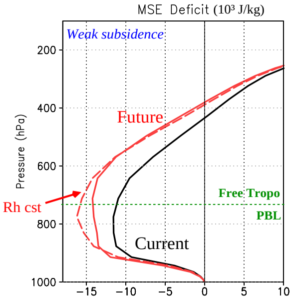
$$\Delta[ACRF] = -\Delta[R_0] - \Delta(LH + SH) + \Delta[\vec{V}.\vec{\nabla}h] + \Delta[\omega\frac{\partial h}{\partial P}] \qquad (W/m^2)$$

Change in energetic analysis for a **Future Climate**

- Enhanced import of low-MSE into the PBL

Positive Low Cloud feedback





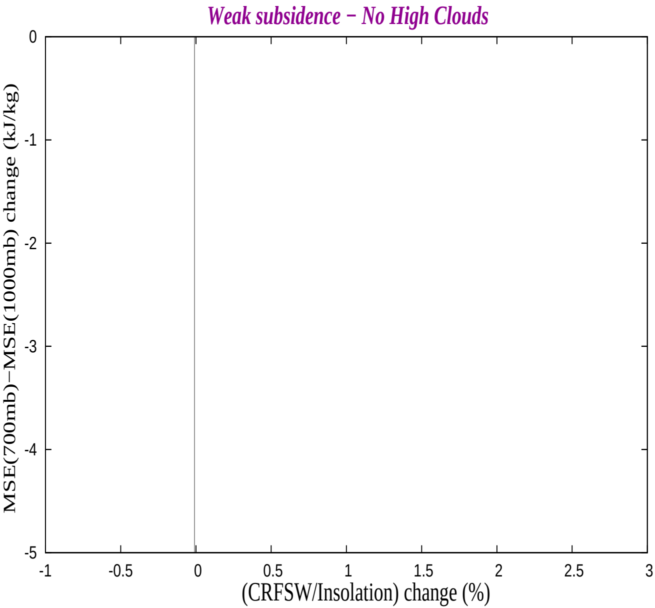
Brient and Bony 2012, Clim. Dyn. (in press)

$$\Delta[ACRF] = -\Delta[R_0] - \Delta(LH + SH) + \Delta[\overrightarrow{V}.\overrightarrow{\nabla} h] + \Delta[\omega \frac{\partial h}{\partial P}] \qquad (\mathrm{W/m^2})$$

Change in energetic analysis for a **Future Climate**

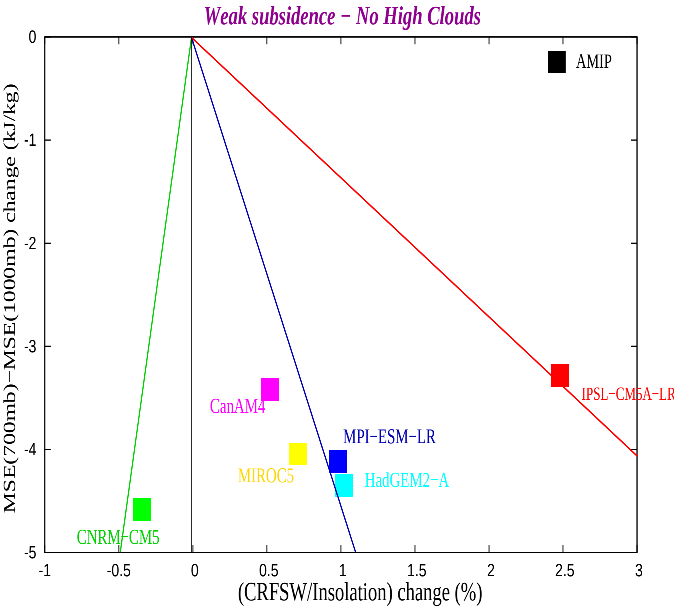
- Enhanced import of low-MSE into the PBL
- At first order, due to Clausius-Clapeyron relationship : Δq(z) larger at higher temperature (surface) than at altitude
- Weaker ACRF needed to balance the energy budget → **Less** low-level clouds

MSE vs Normalized CRFSW change



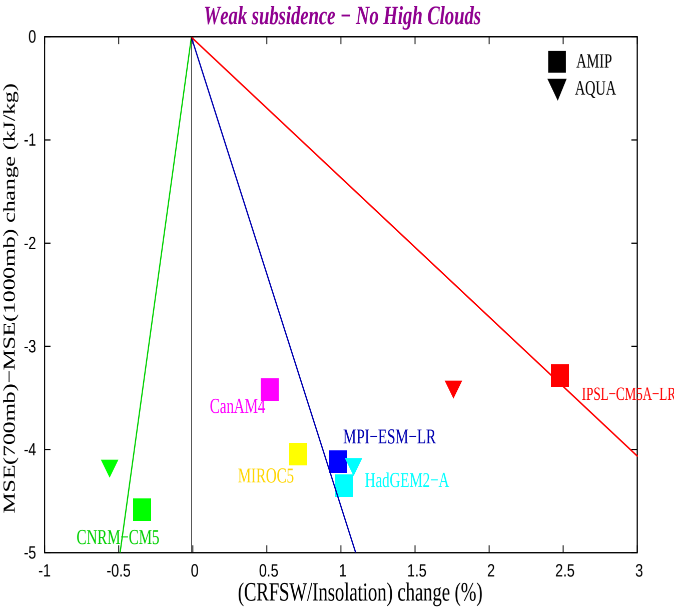
- *Weak sub - No High Clouds*

MSE vs Normalized CRFSW change



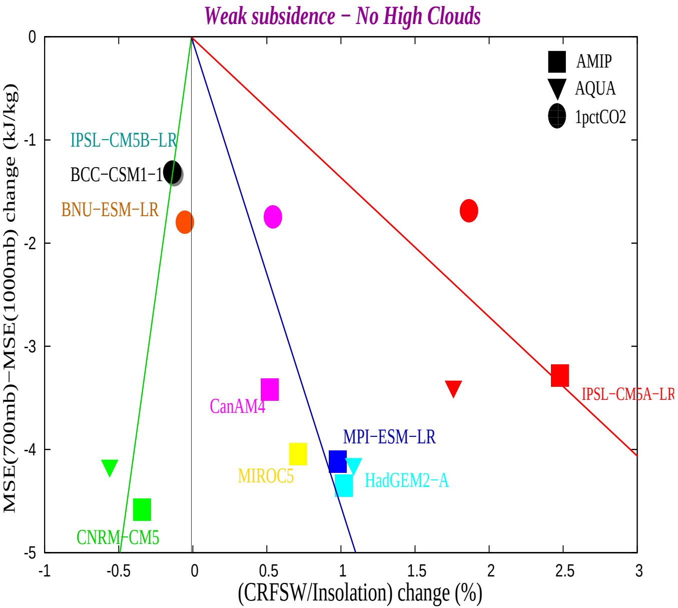
- *Weak sub - No High Clouds*
- Δ δMSE $\nearrow$ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)

MSE vs Normalized CRFSW change



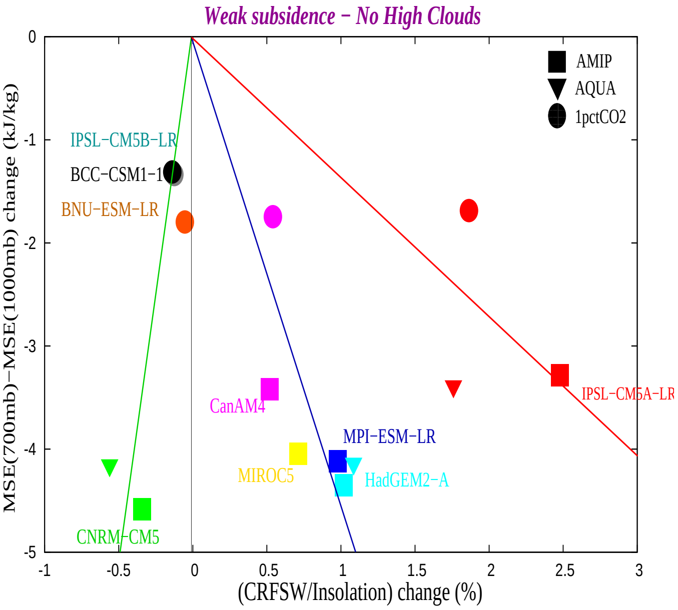
- *Weak sub - No High Clouds*
- $\Delta\ \delta$MSE $\nearrow$ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼)

MSE vs Normalized CRFSW change



- *Weak sub - No High Clouds*
- Δ δMSE $\nearrow$ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼) + 1pctCO2 sim (●)

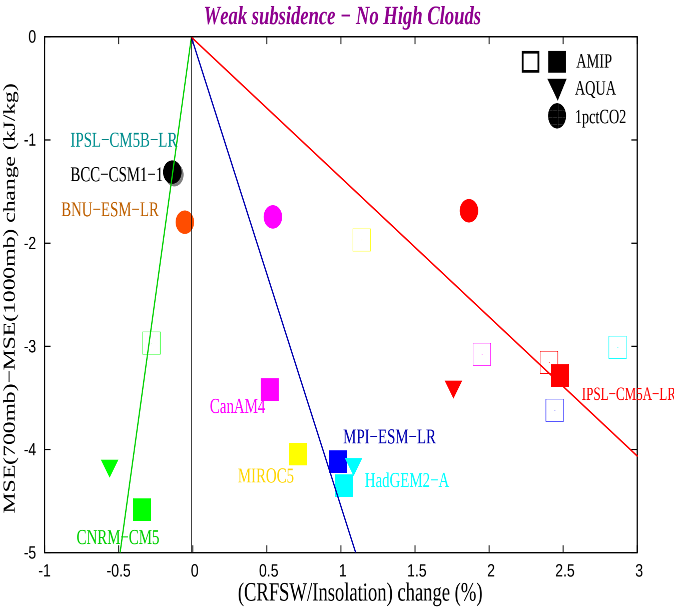
MSE vs Normalized CRFSW change



- *Weak sub - No High Clouds*
- Δ δMSE $\nearrow$ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼) + 1pctCO2 sim (●)

- Seasonal variability (25% warmest- 25% coldest)

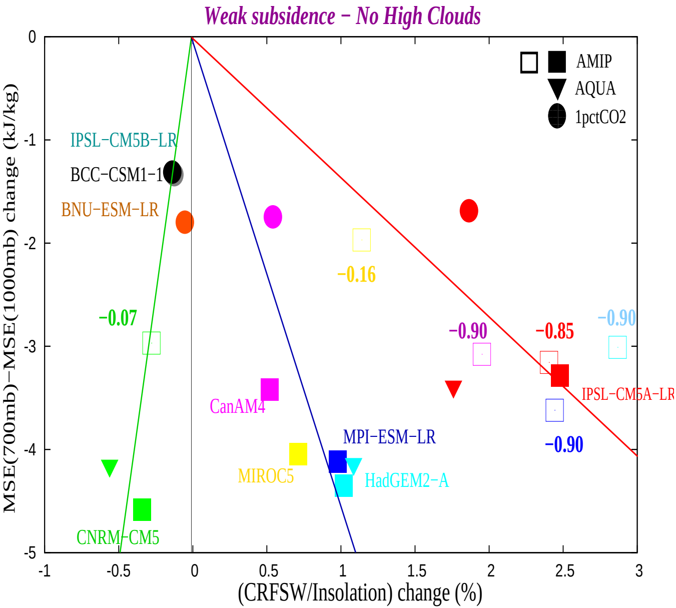
MSE vs Normalized CRFSW change



- *Weak sub - No High Clouds*
- Δ δMSE ↗ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼) + 1pctCO2 sim (●)

- Seasonal variability (25% warmest- 25% coldest)

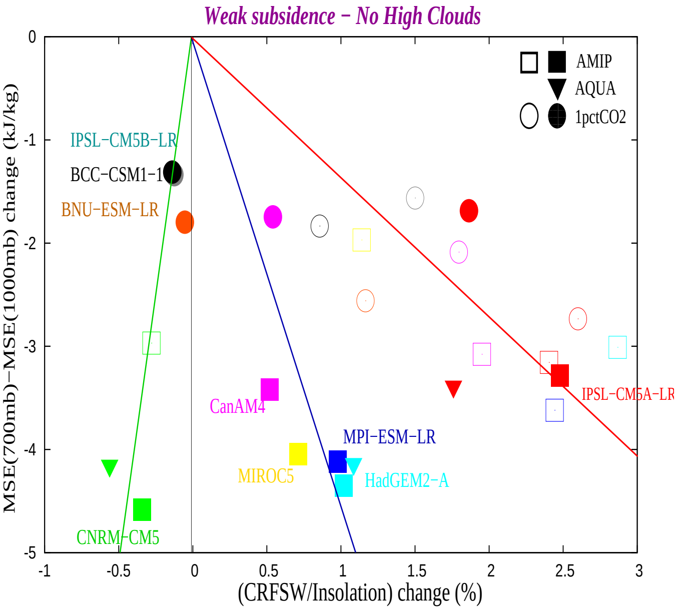
MSE vs Normalized CRFSW change



- *Weak sub - No High Clouds*
- Δ δMSE ↗ in all models (**CI-CI**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼) + 1pctCO2 sim (●)

- Seasonal variability (25% warmest- 25% coldest)

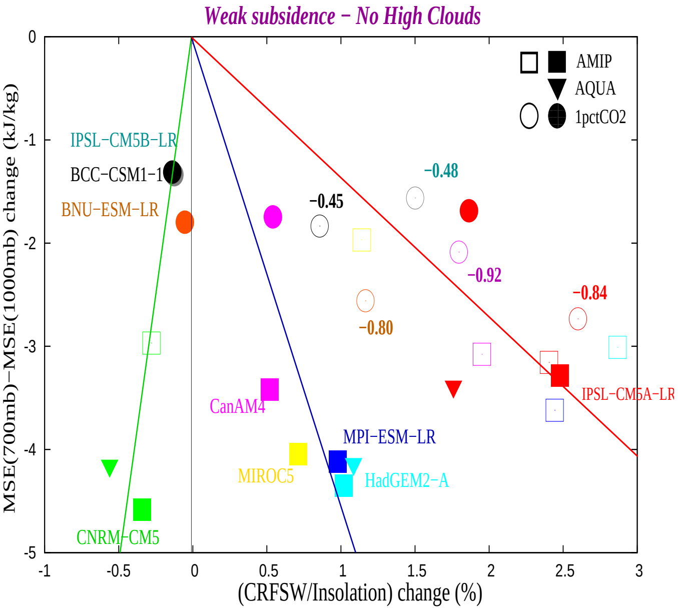
MSE vs Normalized CRFSW change



- *Weak sub - No High Clouds*
- Δ δMSE ↗ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼) + 1pctCO2 sim (●)

- Seasonal variability (25% warmest- 25% coldest)

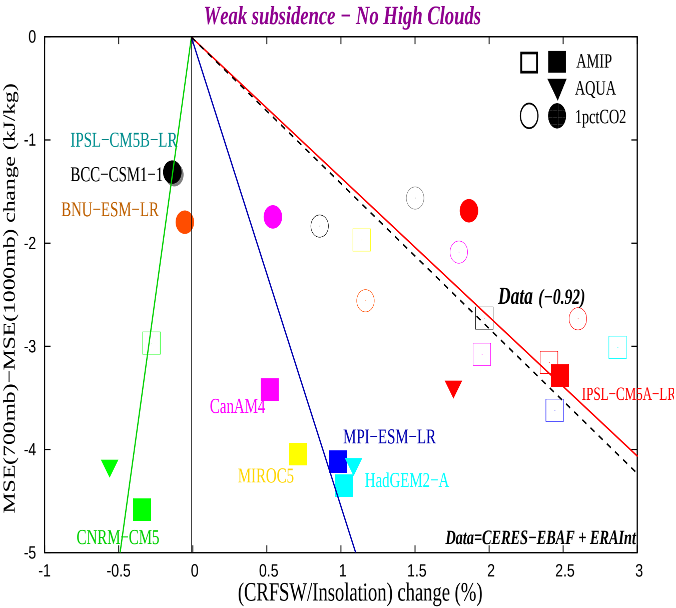
MSE vs Normalized CRFSW change



- *Weak sub - No High Clouds*
- Δ δMSE $\nearrow$ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼) + 1pctCO2 sim (●)

- Seasonal variability (25% warmest- 25% coldest)

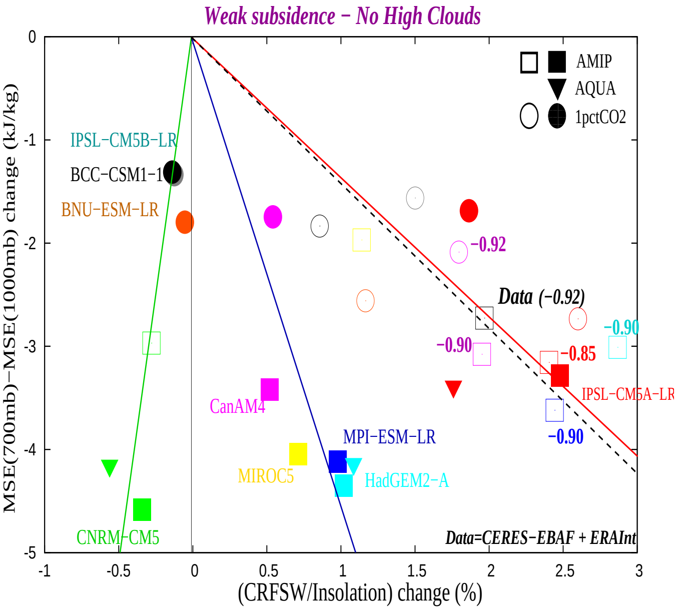
MSE vs Normalized CRFSW change



- *Weak sub - No High Clouds*
- Δ δMSE ↗ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼) + 1pctCO2 sim (●)

- Seasonal variability (25% warmest- 25% coldest)
- Good Correlation δMSE/NSWCRF *(Kawai and Teixeira 10, Kubar et al 11)*

MSE vs Normalized CRFSW change



- *Weak sub - No High Clouds*
- Δ δMSE ↗ in all models (**Cl-Cl**)
- But δMSE not discriminating for a given perturb (+4K)
- Aqua config (▼) + 1pctCO2 sim (●)

- Seasonal variability (25% warmest- 25% coldest)
- Good Correlation δMSE/NSWCRF *(Kawai and Teixeira 10, Kubar et al 11)*

Conclusions

$\Longrightarrow$ *CO_2 vs T response ?*

- Both contributes. Mostly influenced by SW CRF change

$\Longrightarrow$ *Spread of tropical cloud response ?*

- Weak subsidence regimes
- Convective regimes to lesser extent

$\Longrightarrow$ *Robust mecanism of cloud feedback ?*

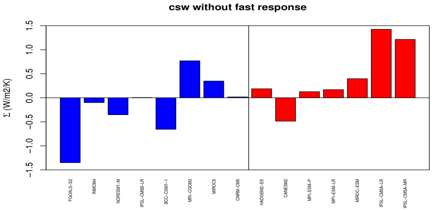
- 3 groups of Low-Cloud feedbacks (weak negative, moderate positive and highly positive) for same δMSE change (**Cl-Cl**)

$\Longrightarrow$ *Observationnal tests ?*

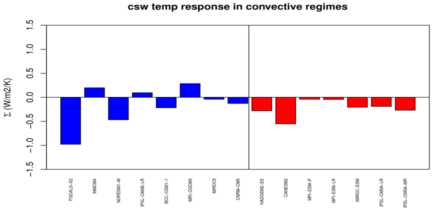
- Seasonal variability also suggests positive low-cloud radiative response, but **not discriminating** of climate change low-cloud feedback (except IPSL-CM5A model)
- What about interannual variability ?

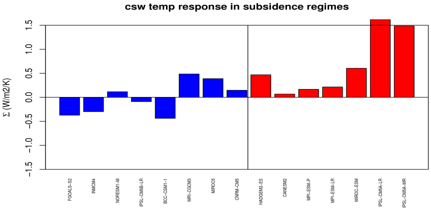
Thank you for your attention

(2) Temperature response for ΔSW (Slow)



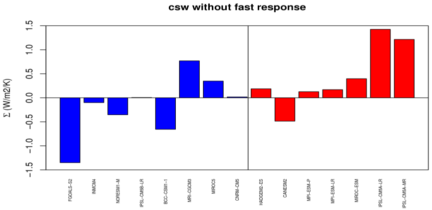
SW only



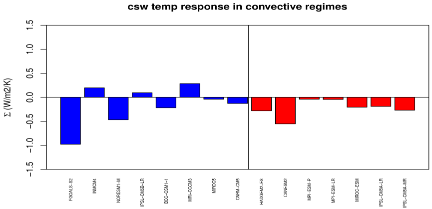


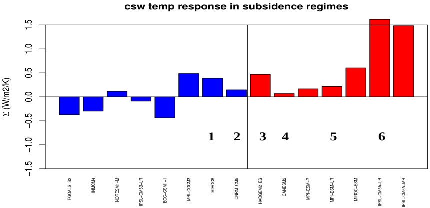
- Spread of slow response in subsidence regimes especially in SW CRF change
- Zoom on some atmospheric models to study temperature response over subsidence regimes

(2) Temperature response for ΔSW (Slow)



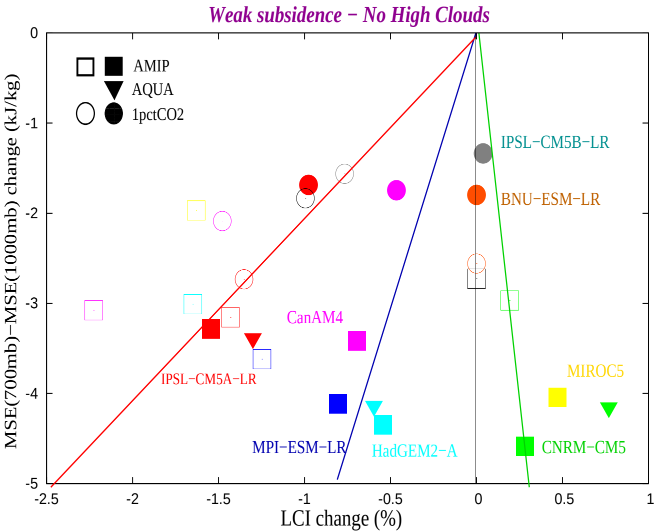
SW only





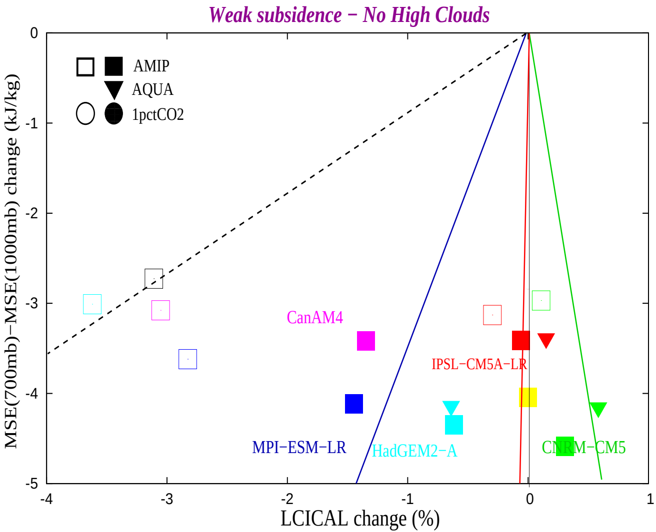
- Spread of slow response in subsidence regimes especially in SW CRF change
- Zoom on some atmospheric models to study temperature response over subsidence regimes

MSE vs LCI change



$$LCI = \frac{\int_{P_0}^{P_{top}} CF(P)\frac{dP}{g}}{\int_{P_0}^{P_{top}} \frac{dP}{g}} \quad (1)$$

MSE vs LCICAL change



$$LCICAL = \frac{\int_{P_0}^{P_{top}} CF_{calispo}(P) \frac{dP}{g}}{\int_{P_0}^{P_{top}} \frac{dP}{g}} \quad (2)$$