On the interpretation of inter-model spread in CMIP5 climate sensitivity estimates

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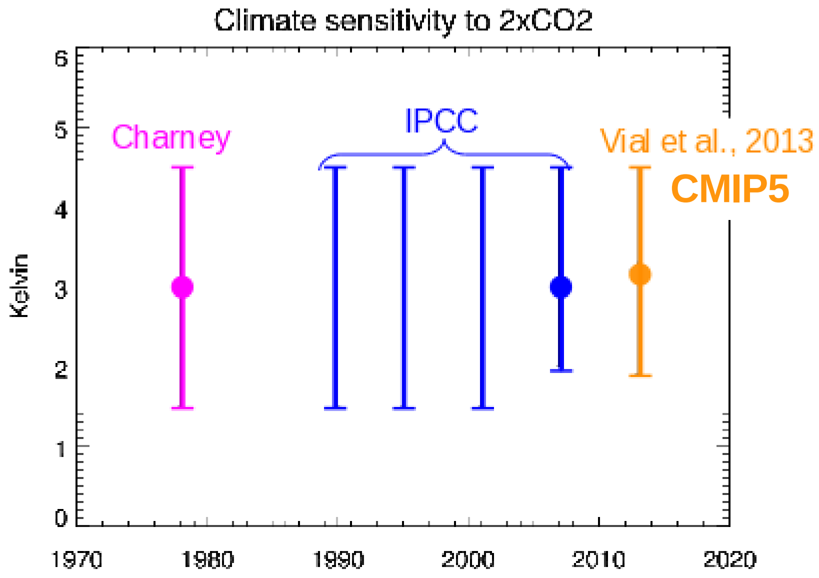
Global warming is known for long but its magnitude is still uncertain

Since the 19th Century
Theory and climate models predict global warming as a response to increased CO_2



Climate model predictions are the same as 40 years ago

► Equilibrium climate sensitivity ranges from **2 to 4.5°C** with no reduction in inter-model spread

What are the causes of this irreducible range ?

► **Cloud feedbacks** have long been identified as the leading source of spread of climate sensitivity estimates

► Recent studies suggest that **direct cloud adjustments to increased CO_2** could also influence climate sensitivity estimates

► **Uncertainty associated with cloud feedbacks may have been misdirected**

Aim :

Revisit the concept of forcing and feedback and the interpretation of inter-model spread in climate sensitivity estimates

► **Isolate the role of CO_2 and surface warming in the climate response to increased CO_2**

Questions :

1) How does the method affect the quantification of individual feedback and forcing terms?

2) Which components influence the most the spread of climate sensitivity estimates?

Are cloud feedbacks still the leading source of spread?

Response of the climate system to a radiative perturbation (4 x CO2)

1) Classical approach:

$$\Delta X \equiv \Delta X(T_s)$$

$$\Delta R \approx \underbrace{\boxed{\frac{\partial R}{\partial CO_2}\Delta CO_2}}_{F} + \boxed{\underbrace{\frac{\partial R}{\partial X}\frac{\partial X}{\partial T_s}}_{\lambda}\underbrace{\Delta T_s}_{\Delta T_s}}$$

CO2 forcing

Temperature
Water vapor
Albedo
clouds

Feedbacks :
responses to global mean surface temperature change

Response of the climate system to a radiative perturbation (4 x CO2)

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F: CO2 forcing

Feedbacks : responses to global mean surface temperature change

2) Revisited approach:

$\Delta X \equiv \Delta X(\mathrm{CO}_2, T_s)$

$$\Delta R \approx \frac{\partial R}{\partial CO_2}\Delta CO_2 + \frac{\partial R}{\partial X}\frac{\partial X}{\partial CO_2}\Delta CO_2 + \frac{\partial R}{\partial X}\frac{\partial X}{\partial T_s}\Delta T_{s,0} + \frac{\partial R}{\partial X}\frac{\partial X}{\partial T_s}\Delta T_{s,\Delta SST}$$

Response of the climate system to a radiative perturbation (4 x CO2)

1) Classical approach:

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Feedbacks :
responses to global mean surface temperature change

2) Revisited approach:

$\Delta X \equiv \Delta X(\mathrm{CO}_2, T_s)$

$$\Delta R \approx \underbrace{\frac{\partial R}{\partial CO_2}\Delta CO_2}_{\text{CO2 forcing}} + \underbrace{\frac{\partial R}{\partial X}\frac{\partial X}{\partial CO_2}\Delta CO_2 + \frac{\partial R}{\partial X}\frac{\partial X}{\partial T_s}\Delta T_{s,0}}_{\text{Tropospheric adjustments to CO2 and land surface warming}} + \underbrace{\frac{\partial R}{\partial X}\frac{\partial X}{\partial T_s}\Delta T_{s,\Delta SST}}_{\text{Responses to subsequent temperature change when SST warms}}$$

CO2 forcing

Tropospheric adjustments to CO2 and land surface warming

Responses to subsequent temperature change when SST warms

$\lambda\ \Delta T_{s,\Delta SST}$

$\Delta T_s \approx 0$

Forcing:

- $sstClim_{4xCO2} - sstClim_{1xCO2}$
- CO2 and land surface temperature vary
- SST is fixed

Feedbacks:

- $Abrupt_{4xCO2} - sstClim_{4xCO2}$
- T varies with warming SST
- CO2 is fixed at 4xCO2

Using the radiative kernels to decompose the TOA radiation change

- **x = CO2, temperature, water vapor, albedo:**

  Use NCAR model's kernels

  Change from model output

$$F_x = \frac{\partial R}{\partial x}\Delta x \qquad \lambda_x = \frac{\partial R}{\partial x}\frac{\Delta x}{\Delta T_{s,\Delta SST}}$$

  Kernel for x

- **For clouds:**

  Changes in CRE corrected for changes in non-cloud variables

$$F_{cl} = \Delta R - \Delta R_0 - \sum_x (F_x - F_x^0) \qquad \lambda_{cl} = \frac{\Delta R - \Delta R_0}{\Delta T_{s,\Delta SST}} - \sum_x (\lambda_x - \lambda_x^0)$$

- **A residual term:**

  Difference between model- and kernel-derived clear-sky fluxes

$$Re^f = \Delta R_0 - \sum_x F_x^0 \qquad Re^\lambda = \frac{\Delta R_0}{\Delta T_{s,\Delta SST}} - \sum_x \lambda_x^0$$

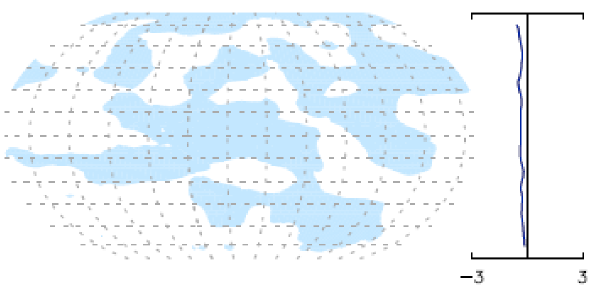
It measures the accuracy of the kernel approximation for model-derived clear-sky flux changes

What is the relative contribution of increased CO_2 and land surface warming to tropospheric adjustments ?

- Compare adjustments estimated from:
  - fixed-SST experiments (CO_2 & land surface temperature vary)
  - aquaplanet experiments (CO_2 only varies, no change in land/sea contrast)

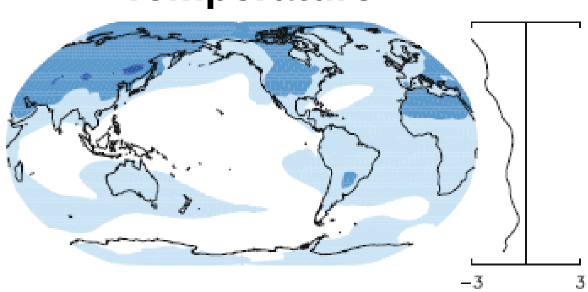
Aquaplanet experiments: no response to increased CO2

Temperature | Water vapor | albedo

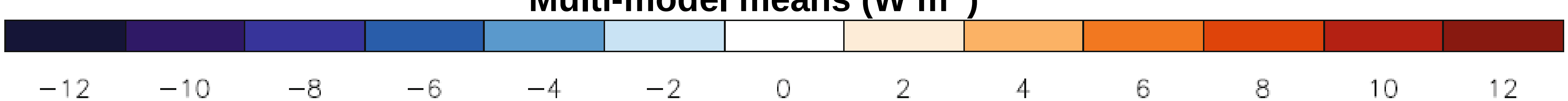


Fixed-SST experiments

Temperature | Water vapor | albedo

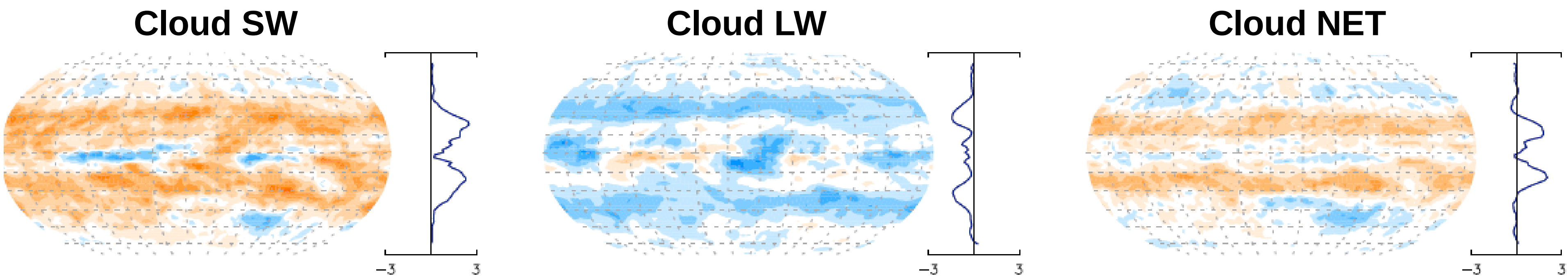


Multi-model means ($W\ m^{-2}$)

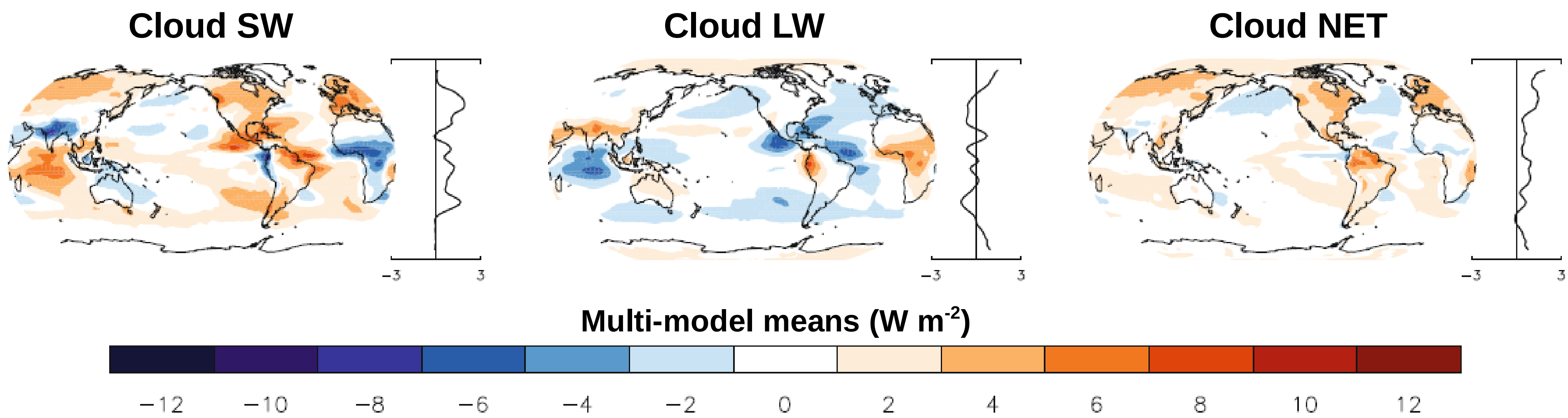


- **Non-cloud adjustments arise from land surface warming only**
- **Non-cloud feedbacks are unchanged when tropospheric adjustments are taken into account**

Aquaplanet experiments: cloud responses to increased CO2



Fixed-SST experiments: cloud responses to land surface warming



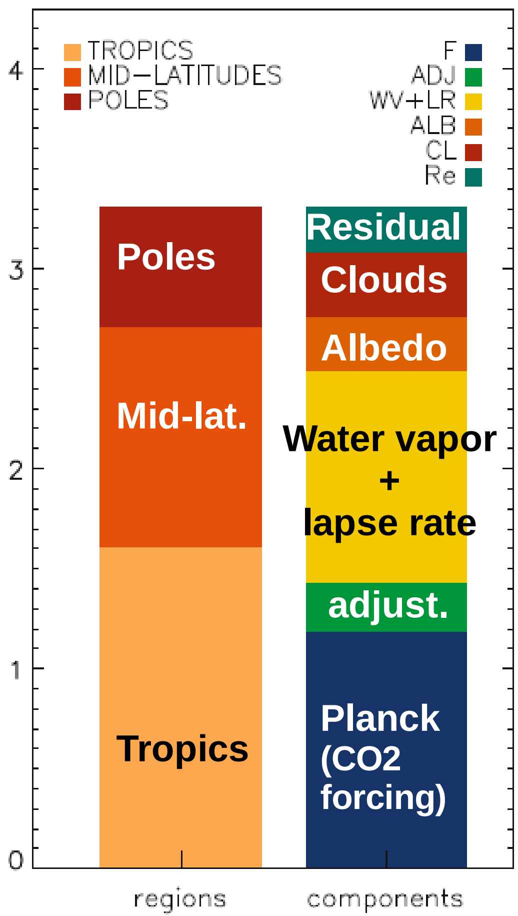
- **Cloud adjustments arise from change in CO2 and land surface warming**
- **Net cloud adjustments are positive for all models, and dominated by SW component**
- **Multi-model mean cloud feedback is reduced by 33% when tropospheric adjustments are taken into account**

Decomposition of CMIP5 climate sensitivity estimates

<u>Equilibrium climate sensitivity</u> ranges from 1.9° to 4.4°C

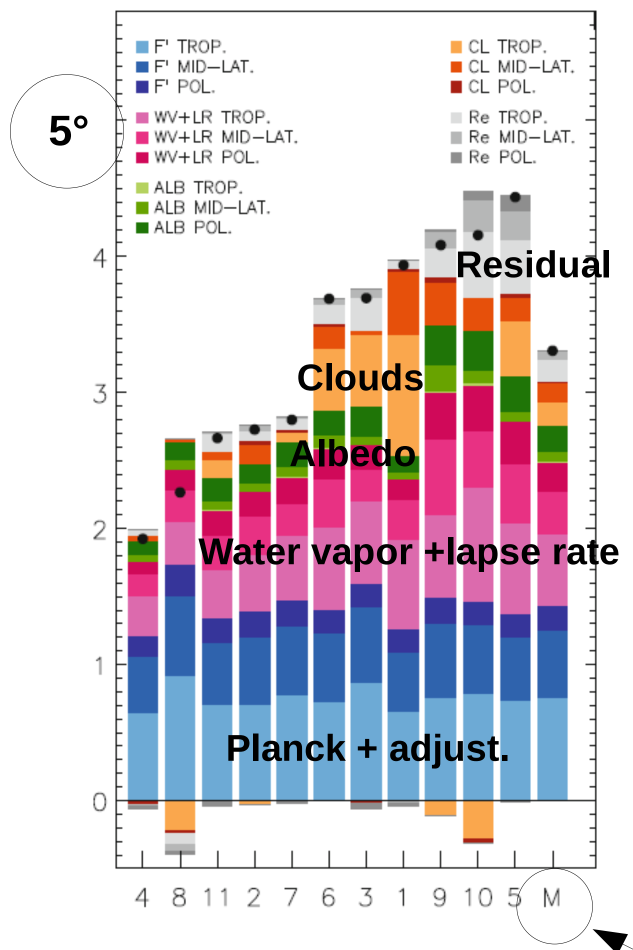
multi-model mean = 3.2°C

Multi-model mean amplitude

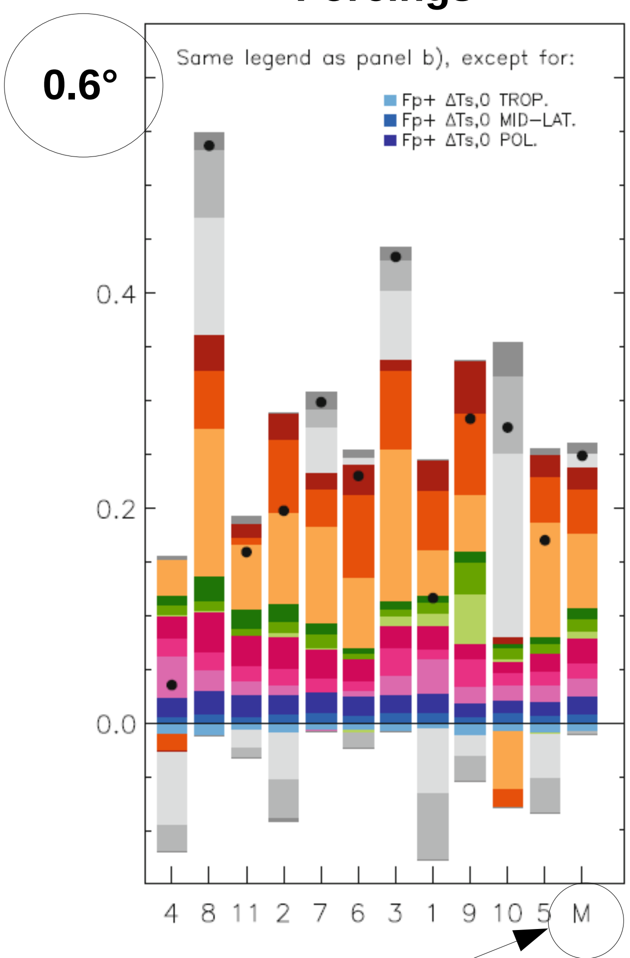


Decomposition for each model

Forcings + feedbacks



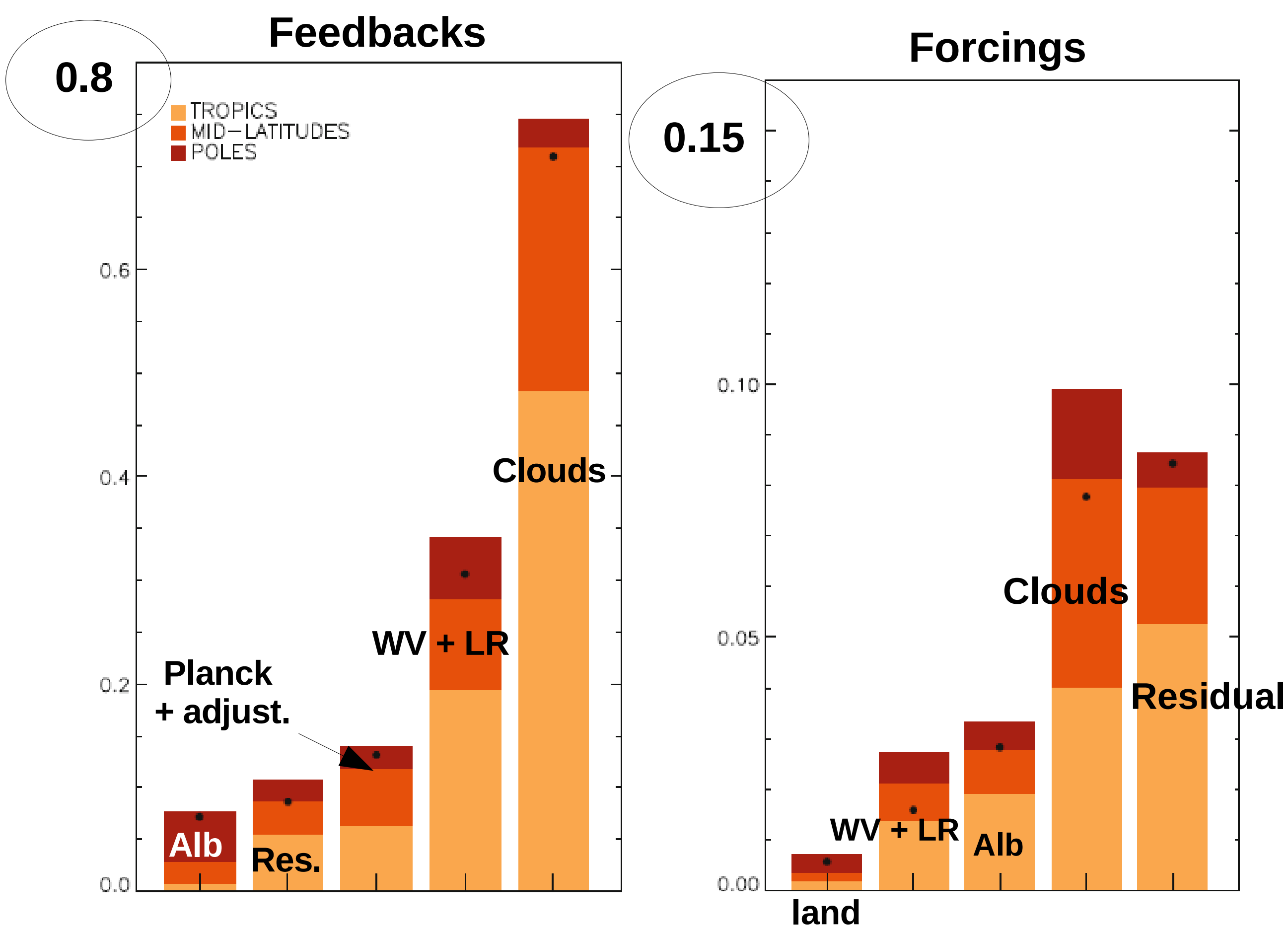
Forcings



Multi-model mean

Decomposition of the inter-model spread

- Inter-model standard deviation of the temperature change associated with each component, normalized by the inter-model standard deviation of the total temperature change



- Cloud feedback represents 70% of the total spread; the spread is the largest in tropics
- WV+LR feedback is the second most important source of spread (30%); largest spread in tropics
- The residual is the largest source of spread among all forcing terms (< 10%, less than for any feedback)

The inter-model spread of climate sensitivity arises <u>primarily from the spread of feedbacks rather than adjustments</u>, and particularly from the <u>tropical cloud feedback</u>.

Summary

- **Considering tropospheric adjustments to CO2 and land surface warming:**

It does affect the quantification of feedbacks

→ **cloud adjustments are positive, and multi-model cloud feedback is reduced by 33%**

→ **non-cloud adjustments are better understood as responses to land surface warming, with no change in non-cloud feedbacks**

It does not affect the spread of feedbacks neither

→ **cloud feedbacks remain the main contribution to the spread of climate sensitivity (70%), especially the tropical cloud feedback**

→ **the tropical WV+LR feedback is the second most important source of spread**

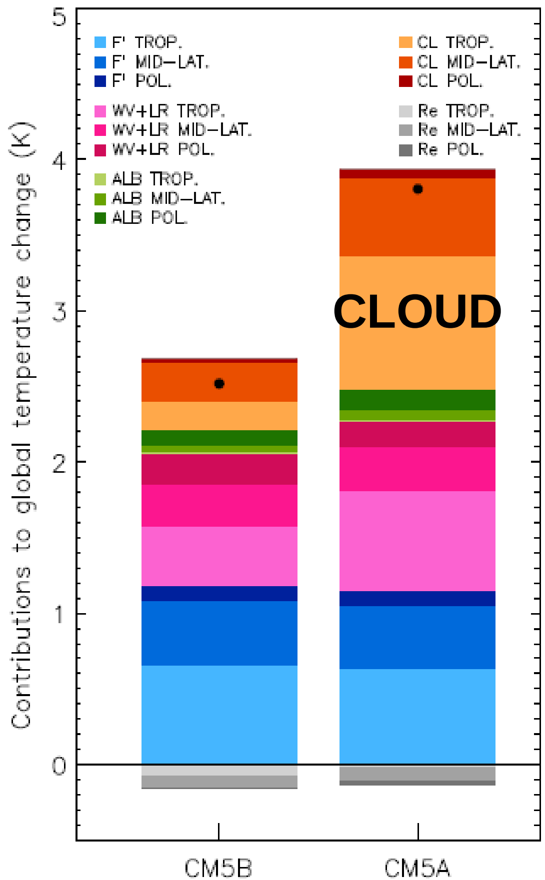
- **Substantial role of the residual term in the calculation of adjustments and feedbacks**

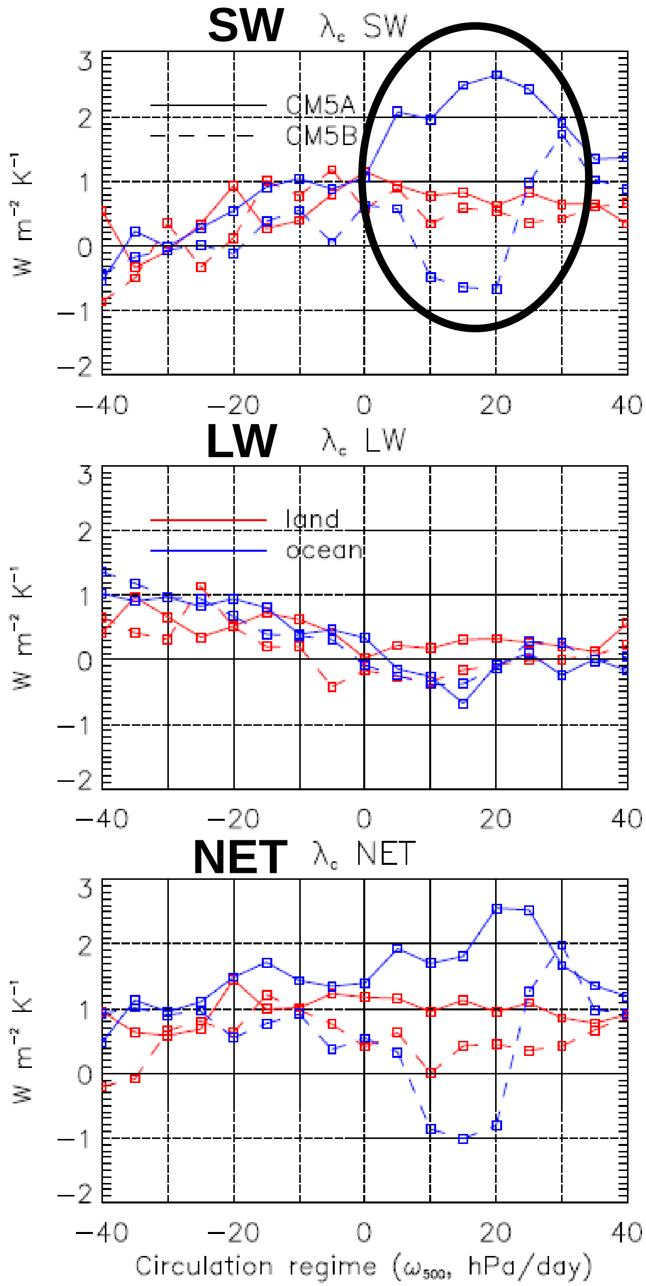
→ **the kernel method underestimates the multi-model mean and inter-model spread temperature change associated with the cloud feedback**

Current work

→ **Analyse differences in <u>tropical low-cloud feedback</u> between IPSL-CM5A and IPSL-CM5B (which cover a large part of the inter-model spread) using SCM and CGILS protocole (subsidence region on the Californian cost)**

Differences in climate sensitivity arise from the cloud feedback



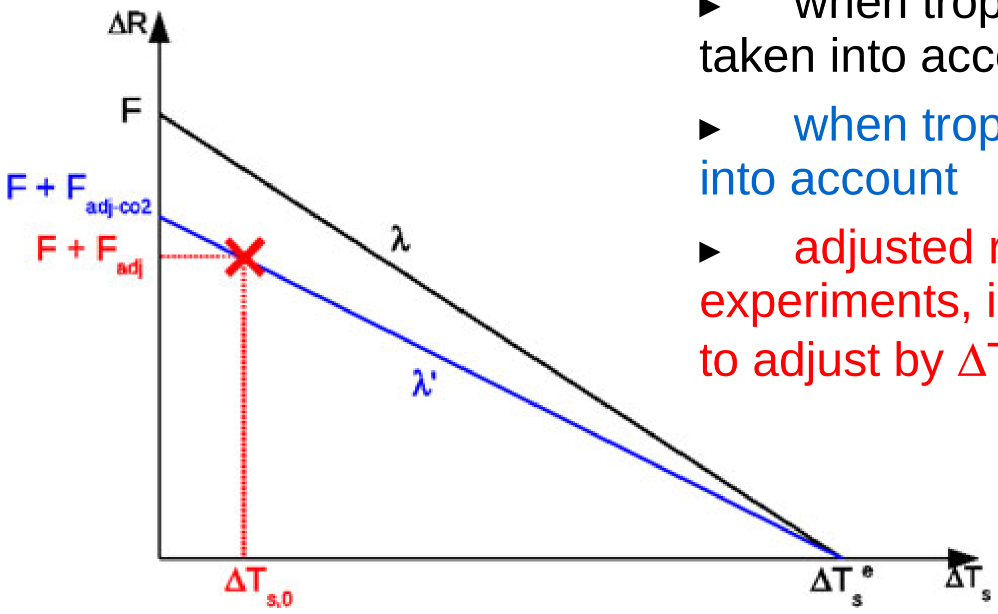


Décomposition of the <u>tropical cloud feedback</u> into dynamical regimes

Difference is the largest over <u>ocean</u> in <u>weak subsidence</u> region

Thank you !

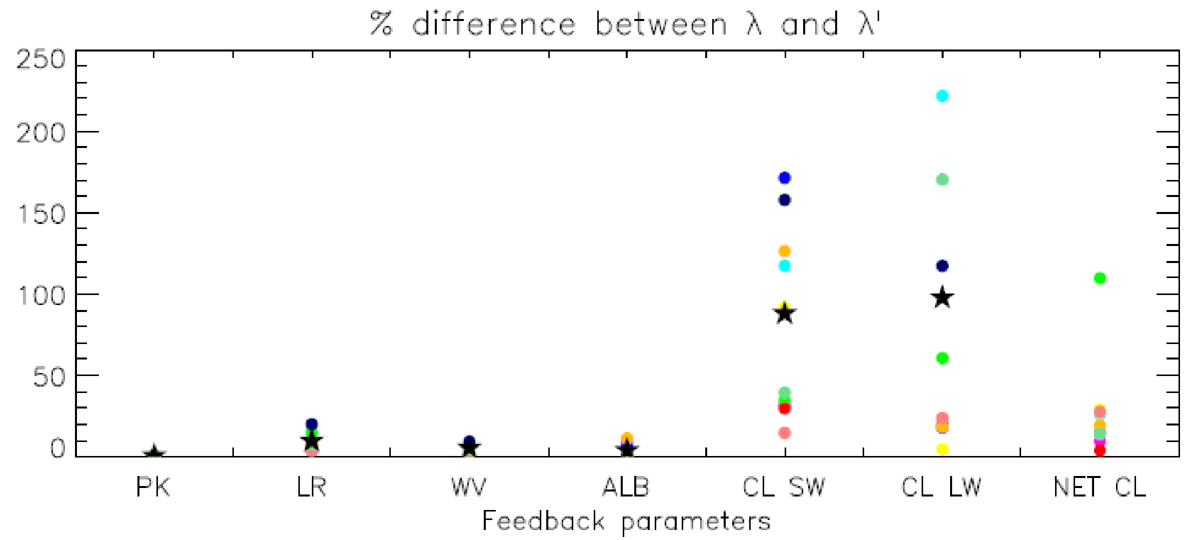
Relationships between the forcings, the feedback parameters and the equilibrium global mean surface temperature



- when tropospheric adjustments to CO_2 forcing are NOT taken into account (classical approach)
- when tropospheric adjustments to CO_2 forcing are taken into account
- adjusted radiative forcing estimated from fixed-SST experiments, in which the land surface temperature is allowed to adjust by $\Delta T_{s,0}$

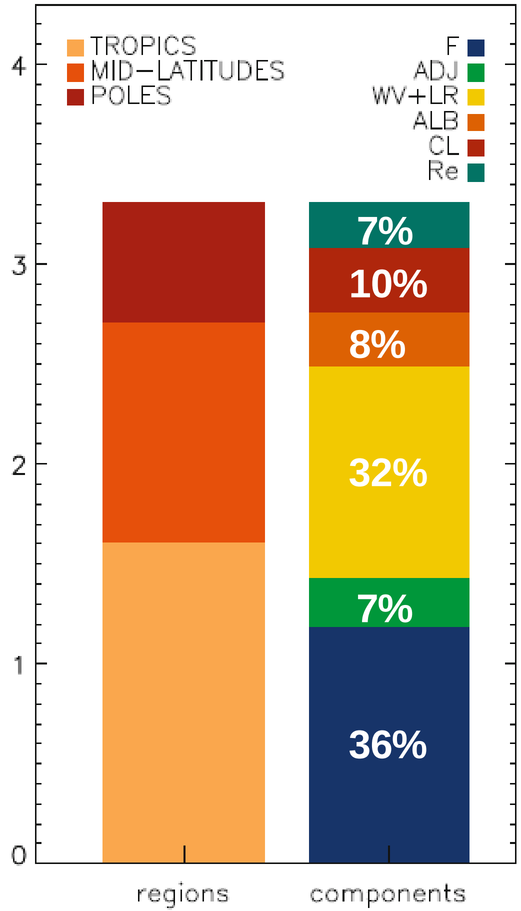
- We assume ΔT_s^e unchanged; this is true with an uncertainty to within ±3%

If $F_{adj} \neq 0$ and $\lambda = \lambda'$ then $F_{adj\text{-}co2} = 0$, and climate responses evolves linearly with global mean temperature

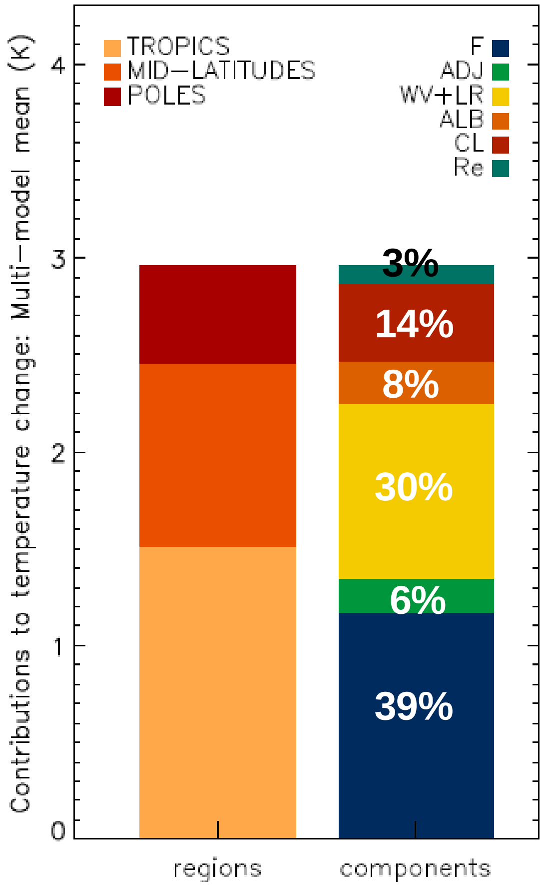


The kernel method underestimates the multi-model mean temperature change associated with the cloud feedback

All models



6 models with residual < 10%



The kernel method underestimates the inter-model spread in temperature change associated with the cloud feedback and overestimate that of all other components