Evaluation of Cloud and Heating Rate Profiles in Eight GCMs Using A-train Satellite Observations

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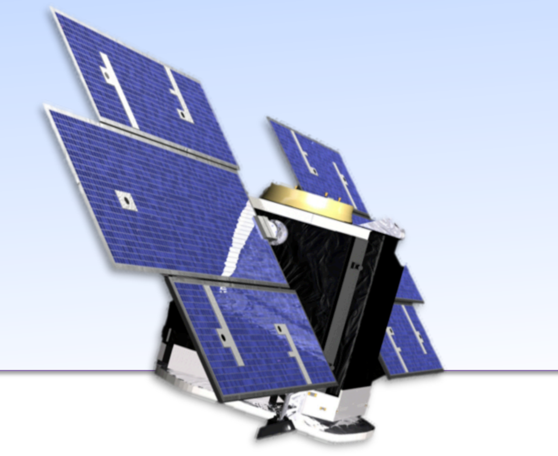


Context and Objectives

1. Context

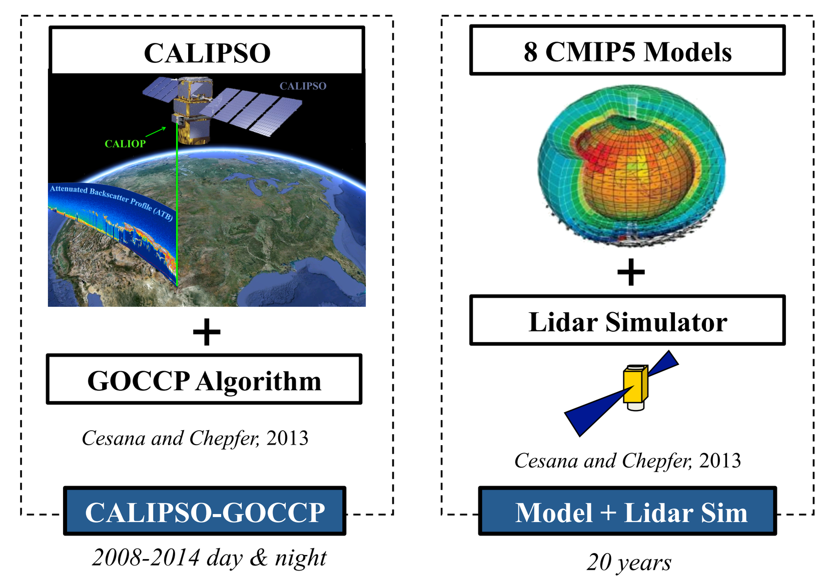
Clouds strongly interact with radiation and modulate the amount of energy reflected, emitted and absorbed by the Earth system. The redistribution of energy within the troposphere has implications for climate prediction, as it impacts the large-scale circulation, the convection and precipitation. While passive sensor satellites have been monitoring outgoing and incoming radiative fluxes at the top of the atmosphere for years (CERES, TRMM), the vertical dimension is still missing and affects our ability to better understand the present climate and the climate response to a global warming as well.

2. Objectives

In this study, we take advantage of two modeling experiments (CMIP5 and GASS-YoTC) and A-train satellite observations (CloudSat/CALIPSO) to assess and characterize the vertical distribution of clouds in eight GCMs and their link with the radiative heating rate profiles.

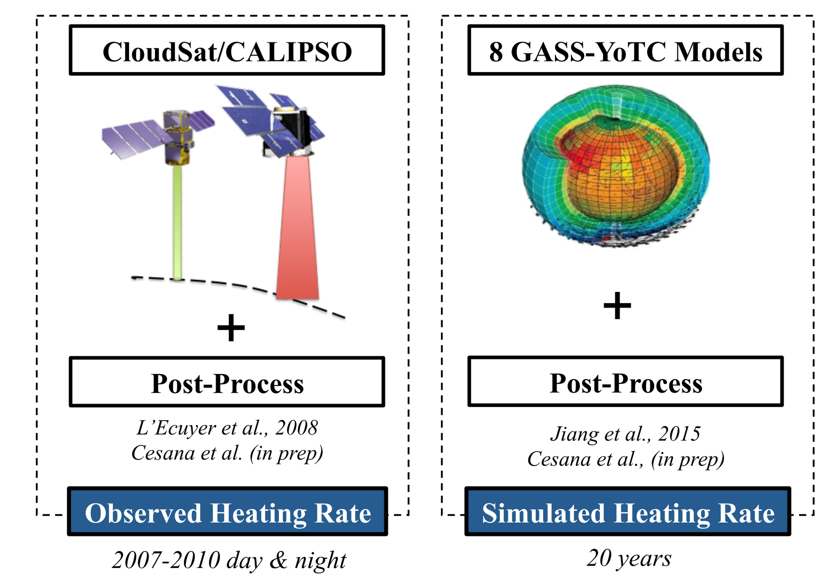
Method

Simulator for Cloud Evaluation



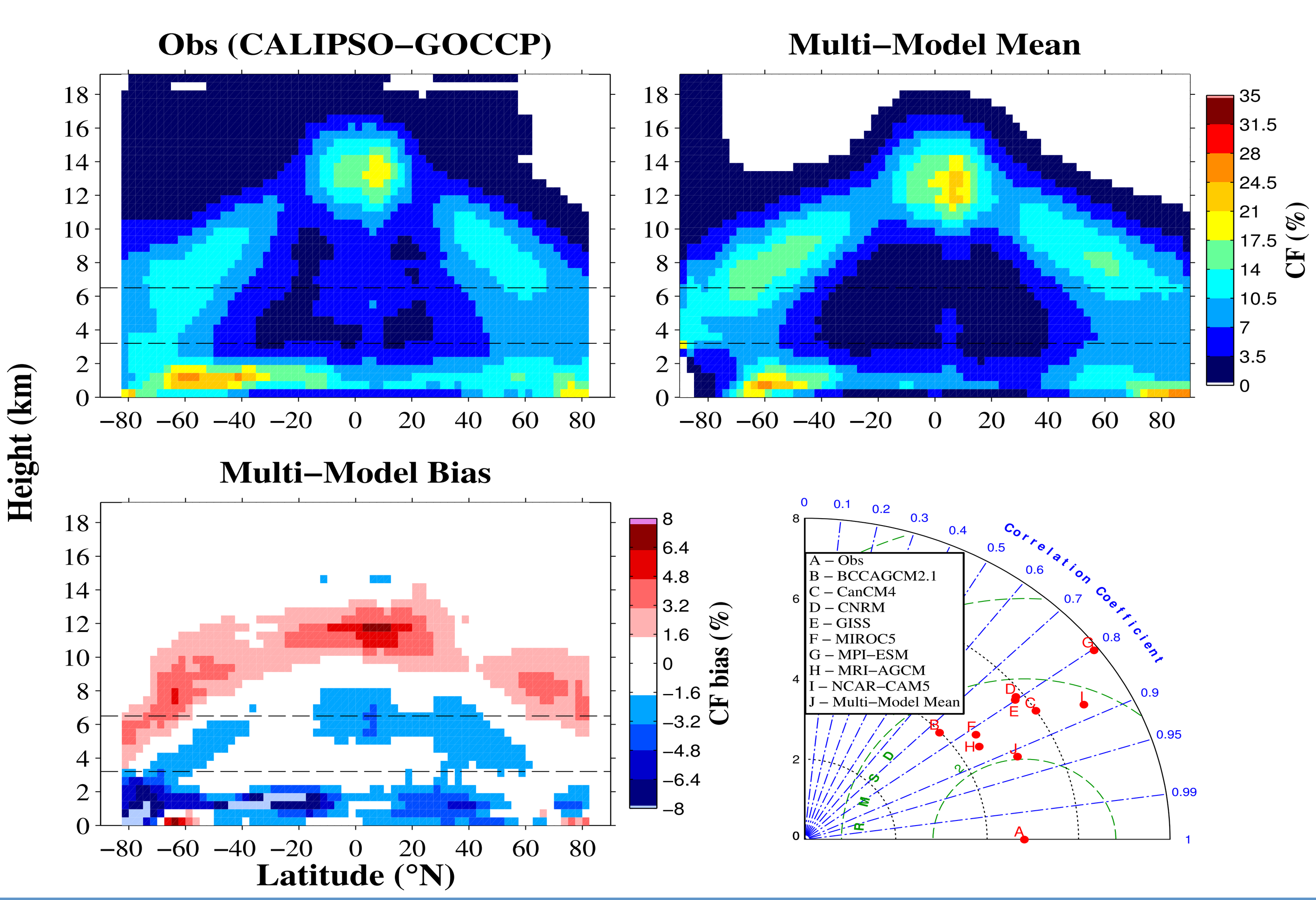
Using the lidar simulator allows:
- Taking into account the instrument limitations
- Using the same cloud definition (threshold, grid, sampling)

Direct Comparison of Heating Rates



- All observations / simulations are projected on the same grid
- SW heating rate are normalized by SW_{toa} fluxes to reduce uncertainties due to observation time sampling.

Zonal Mean Cloud Profile

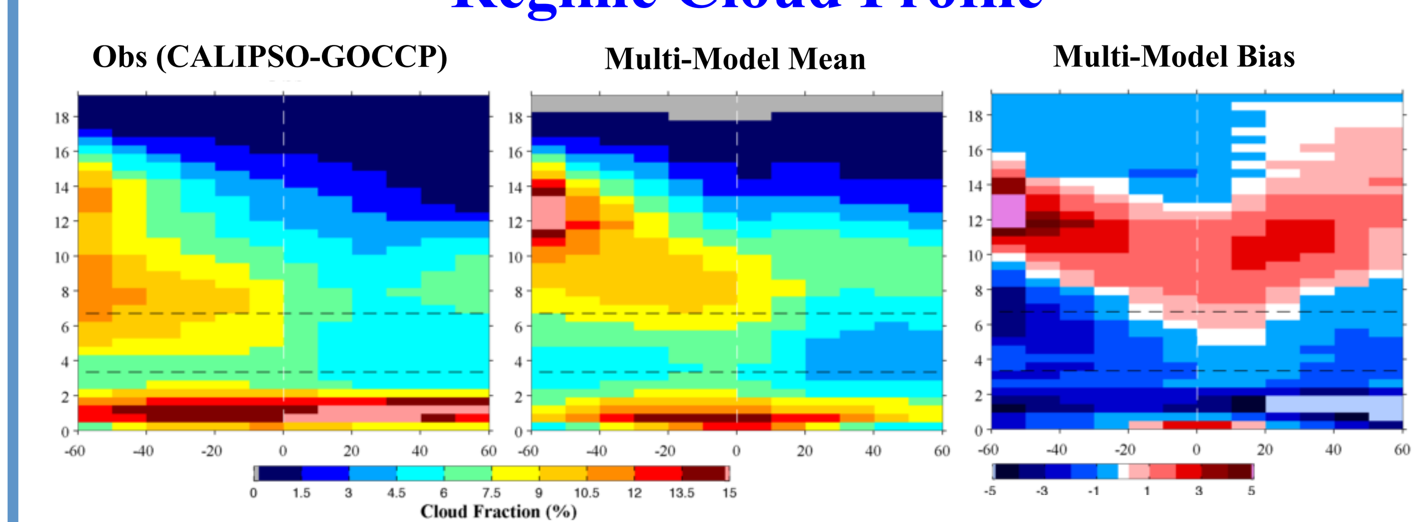


Except one model, all the models have two main biases: they simulated **too many high-level clouds** particularly in the tropics (*up to +15*), and **too few low- and mid-level clouds** (*up to -15%*).

Another common bias is the height of low-level clouds which is too low compared to CALIPSO-GOCCP observations.

The overall pattern of clouds is well simulated though (Multi-model mean correlation is higher than 0.9).

Regime Cloud Profile

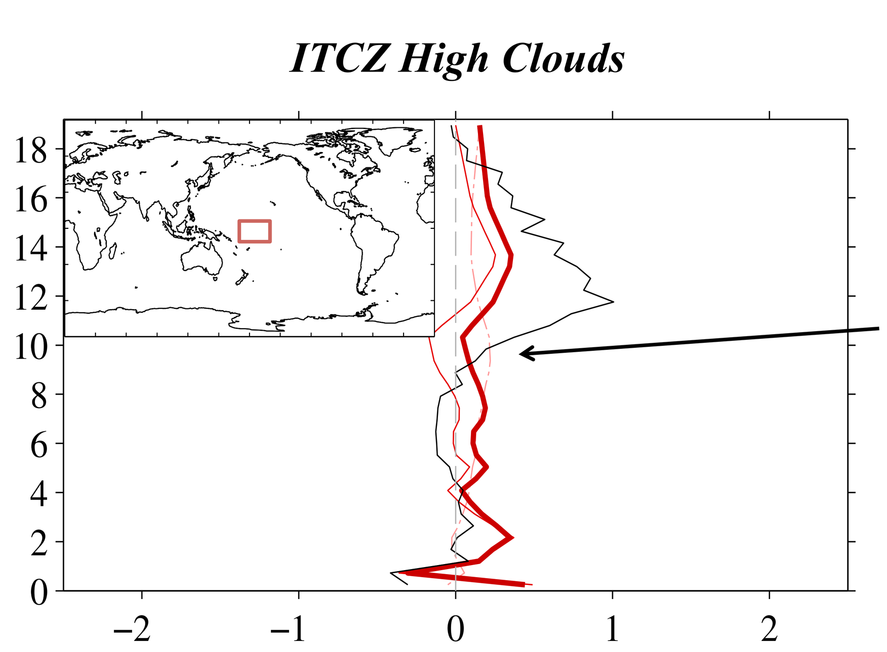


The multi-model mean (middle) is consistent with the previous results: an excess of high-level clouds and a lack of low- and mid-level clouds.

The high-level (low-level) cloud bias remains significant in all regime, although it is larger in large-scale convective (subsident) regimes. These results suggest that the cloud parameterization has more influence in the cloud biases than the large-scale circulation.

Heating Rate Profile: Case Study

ITCZ High Clouds

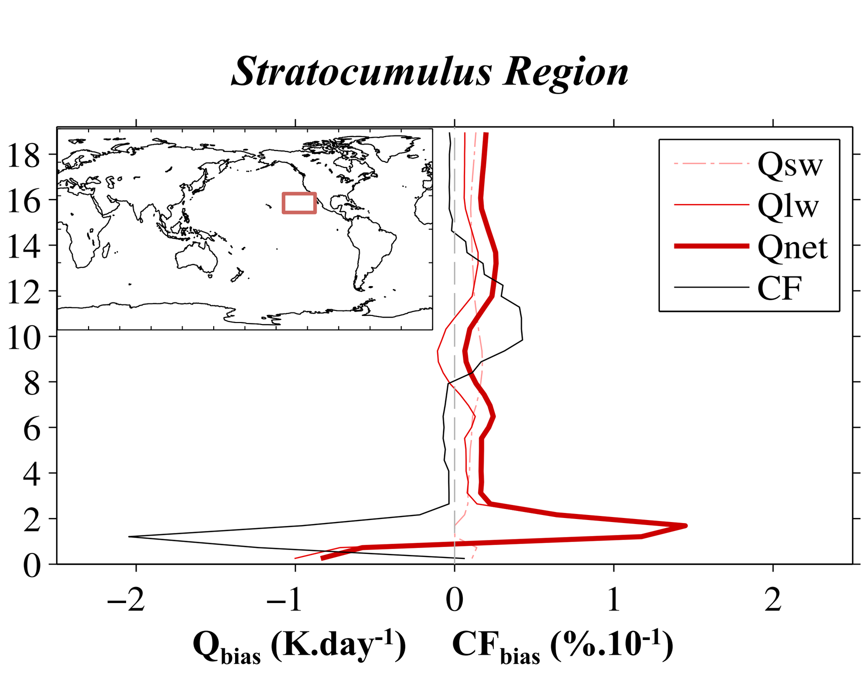


The large positive bias in the high-level clouds (**black line**) generates less LW cooling above 10km and more cooling below 10km (red thin line).

The relation with the cloud bias below this height is subject to caution as CALIPSO and the simulator lidar do not penetrate farther in these clouds.

In the SW (red dashed-line), the absorption is higher toward the cloud base - where the optical depth is maximum - and then diminishes almost linearly until the ground.

Stratocumulus Region

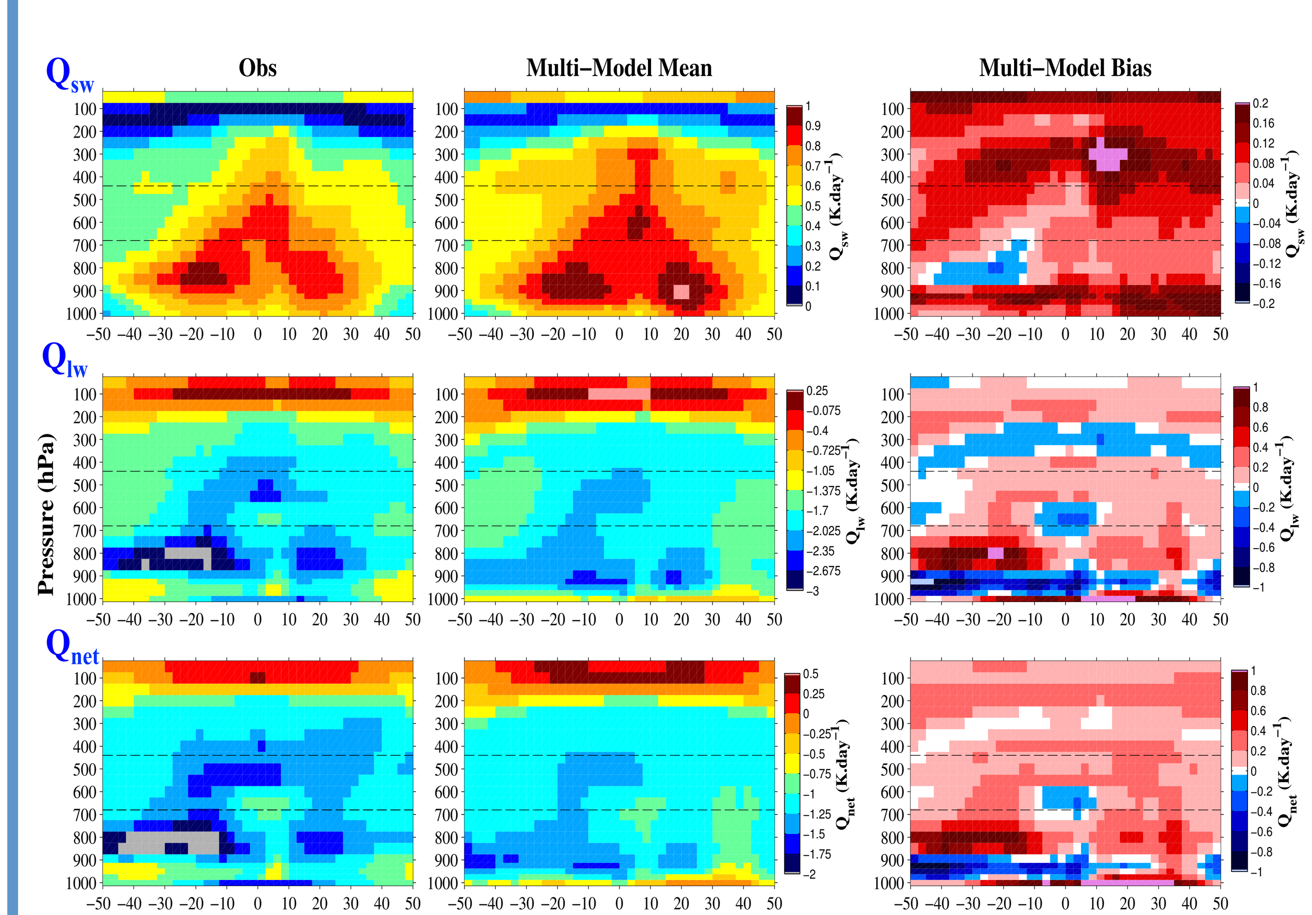


The models produce too many clouds between 8 km and 14 km (up to 5%), generating opposite effects on the LW heating rate bias depending on the cloud height:
- too little cooling by 0.2 K/day > 10km
- too much cooling by 0.1 K/day < 10km

In the mid-troposphere (3 - 7 km), the small lack of modeled clouds (1 to 2%) is coincident with a lack of LW cooling (0.1 K/day) and a slight excess of shortwave heating.

In the boundary layer, the significant deficit of clouds (up to 20%) causes a large overestimation of the modeled LW heating rate (2.5 K/day).

Zonal Mean Heating Rate Profile



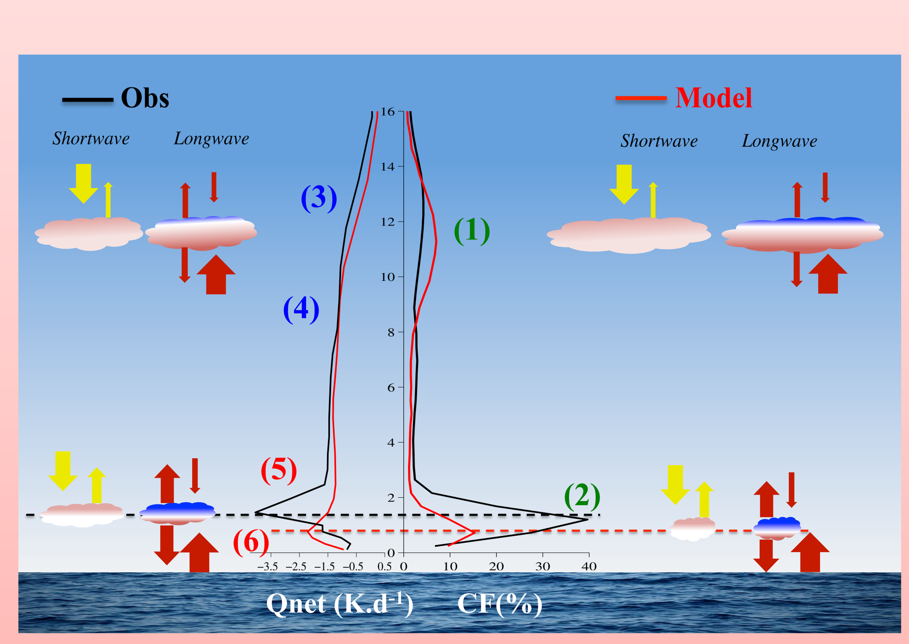
The shortwave heating rate (Qsw) is globally overestimated by the models, which absorb too much solar radiation, especially in the high-level clouds.

The longwave heating rate (Qlw) bias is quite different depending on the height.

Radiative heating rates are primarily driven by the LW radiation. However, the net bias is globally positive, which means that the cooling is too small in climate models.

Summary

We address systematic biases in the representation of cloud profiles and their effects on the heating rate profiles in recent climate models, using vertically resolved satellite measurements.



- Most climate models simulate too many high-level clouds **(1)** and too few low-level clouds **(2)**, no matter the cloud regime, suggesting that cloud parameterization is most likely to be the cause rather than large-scale dynamics.
- While the excess of high-cloud increases the solar absorption and thus enhance the SW heating, it may generate either too little (>10km **(3)**) or to much LW cooling (<10km **(4)**) depending on the height.
- The lack of low-cloud reduces the solar absorption, but results in both a strong reduction of the LW cooling **(5)** and an increase of the cooling close to the surface **(6)**.

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National Aeronautics and Space Administration

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