A process oriented evaluation of clouds simulated by the LMDZ5 GCM using A-train high spatial resolution observations (CALIPSO-PARASOL-CERES)

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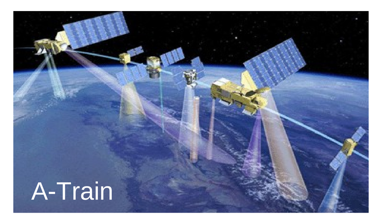
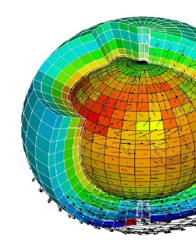
Abstract

The representation of clouds in climate model is usually evaluated using monthly mean top of the atmosphere (TOA) fluxes. Nevertheless a correct simulation of TOA fluxes can be associated to error compensation between key cloud variables: the cloud cover, vertical distribution, and optical depth and/or their spatial and temporal variability. To improve the reliability on cloud feedbacks in climate models, we need to evaluate independently these cloud properties as well as the correlation between them. The use of data with high temporal resolution facilitates the link with parametrizations of clouds in climate models. Here we use the CERES fluxes, the CALIPSO cloud cover and vertical structure, the PARASOL visible directional reflectance (a drop for the cloud optical depth) and the CFMIP Observation Simulation Package (COSP) to evaluate the representation of cloudiness in two versions of the LMDZ5 GCM, the atmospheric component of the IPSL-CM5 climate model.

Method of comparing A-train observations with climate models





Observational Data (level 1)
- Radiometer CERES (Cloud Radiative Forcing)
- Lidar CALIPSO (Cloud Fraction, Cloud Vertical Distribution)
- Radiometer PARASOL (Cloud Optical Depth)

Data processing diagnostics and statistical analysis consistent with the simulator

Observed Dataset
CALIPSO-GOCCP
- PARASOL-Reflectance

consistency

LMDZ5A:
Standard version of IPSL coupled model

LMDZ5B:
- New boundary layer and low level cloud scheme
- Modified version of the convective scheme of Emanuel
- Wakes created from reevaporation or convective rainstorms

Observational Simulator COSP
Subgrid Cloud Simulator SCOPS
- Lidar Simulator
- PARASOL Simulator

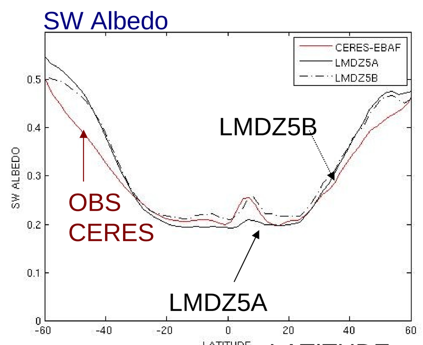
Simulated Dataset
CALIPSO-like
PARASOL-like

Evaluation of Cloud Properties using Monthly Mean Statistics

Evaluation of Monthly Mean Zonal Cloud Properties

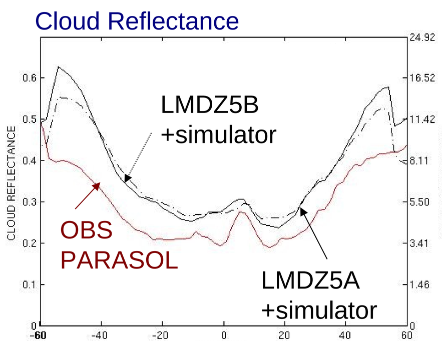
The general structure of Monthly Mean TOA Fluxes is well simulated

SW Albedo

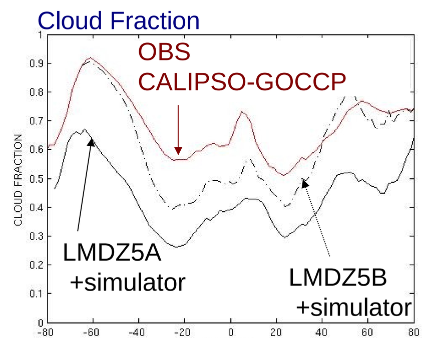


Cloud Radiative Forcing depends on the Reflectance and the Cloud Fraction

Cloud Reflectance



Cloud Fraction



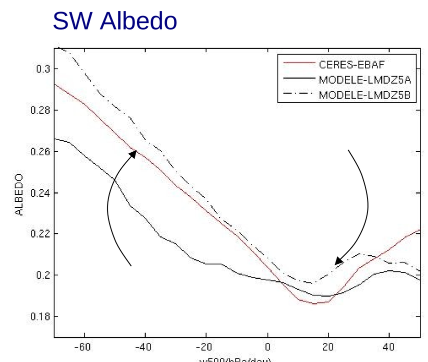
Cloud Reflectance is a surrogate of Cloud Optical Thickness

→ Error compensation between the monthly mean vertically integrated values of cloud cover and cloud optical depth

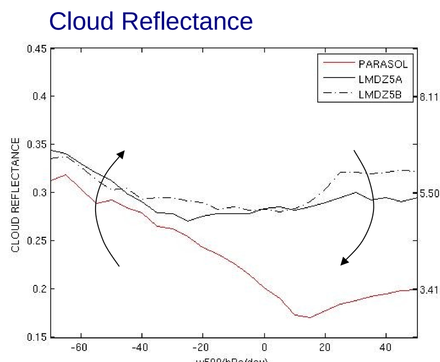
Evaluation of Monthly Mean Cloud Properties in the tropical oceans in circulation regimes

Monthly mean vertical velocity at 500hPa (ω_{500}): an effective proxy of the dynamical regimes

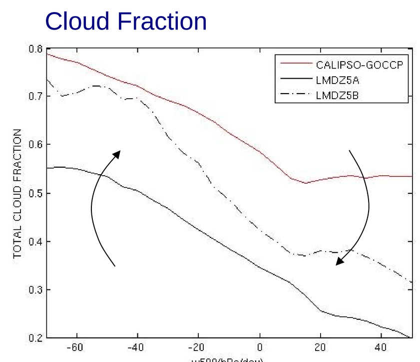
SW Albedo



Cloud Reflectance



Cloud Fraction

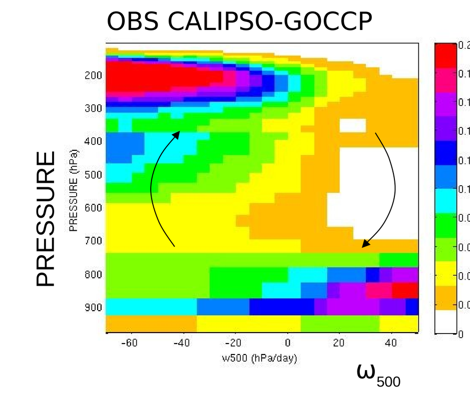


→Subsidence regions
models simulate well the albedo as a result of two combined errors : models create clouds optiacally too thick but they are too few.

→Convective regions
underestimation of cloud fraction (more from LMDZ5A), slight overestimation of cloud reflectance : underestimation of cloud albedo by LMDZ5A and overstimation by LMDZ5B

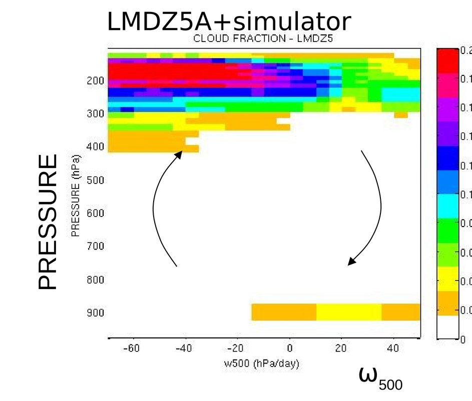
Evaluation of Monthly Mean Cloud Vertical Distribution in the tropical oceans in circulation regimes

OBS CALIPSO-GOCCP

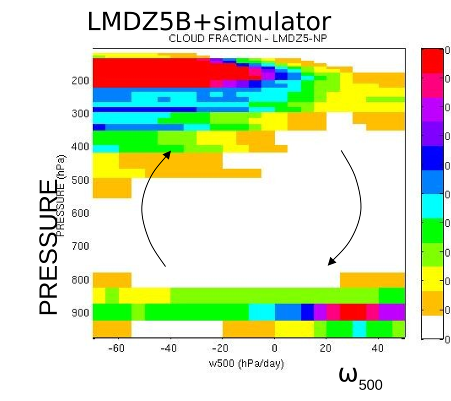


High level clouds dominate in convective regimes and low level clouds are mainly found in subsidence regimes

LMDZ5A+simulator



LMDZ5B+simulator



→LMDZ5A
underestimates significantly low and mid level clouds

→LMDZ5B
new boundary layer and low level cloud scheme improve boundary layer clouds modified version of covective scheme impoves the properties of high level clouds and simulates some mid-level clouds in tropics

The added value of evaluating the model using instantaneous cloud properties

Classical study of cloud properties using monthly mean climatologies

First conclusions:

- correct simulation of SW albedo results from error compensations between cloud cover and cloud optical depth

- the cloud vertical structure is poorly reproduced by the model... too much high clouds, lack of mid and low level clouds

- LMDZ5B leads to significant improvements compared to LMDZ5A, but still far from observations

Can we use the A-train to learn more about clouds in climate modes?

How cloud properties vary with environment variables around the cloud?

is analyzed by various studies at inter-annual time scales.

But the temporal scale of monthly mean statistics

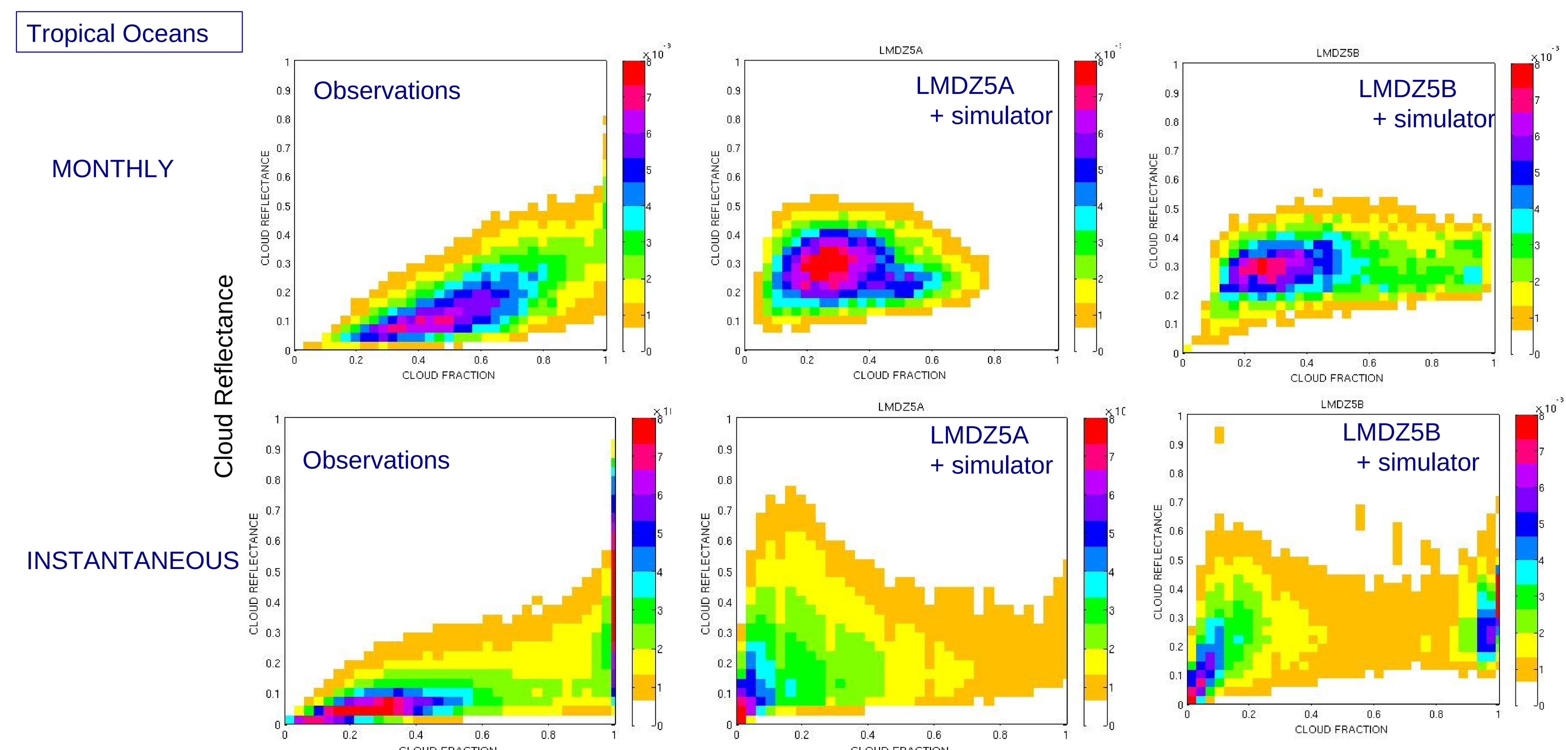
1) precludes to make direct link between these results and the model parametrizations. In parametrizations cloud properties vary instantaneously with variables describing the environment (e.g. atmospheric stability, humidity etc..)

2) the monthly or seasonal mean relationships between cloud variables can be very different from the instantaneous relationships as these dependencies are highly non-linear.

How do Cloud Fraction and Cloud Reflectance vary instantaneously?

Instantaneous and Monthly Correlation between Cloud Fraction and Cloud Optical Depth

Tropical Oceans



The relationship between Cloud Fraction and Cloud Optical Depth is significantly dependent on the spatio-temporal resolution in observations and in the model

→Monthly Correlation CF - CRef:

- Obs: linear relationship; as the cloud fraction increases the cloud optical depth increases too

- Mod: flat relationship; the cloud optical depth remains almost the same when the cloud fraction increases. LMDZ5B simulates some clouds with high CF and CRef.

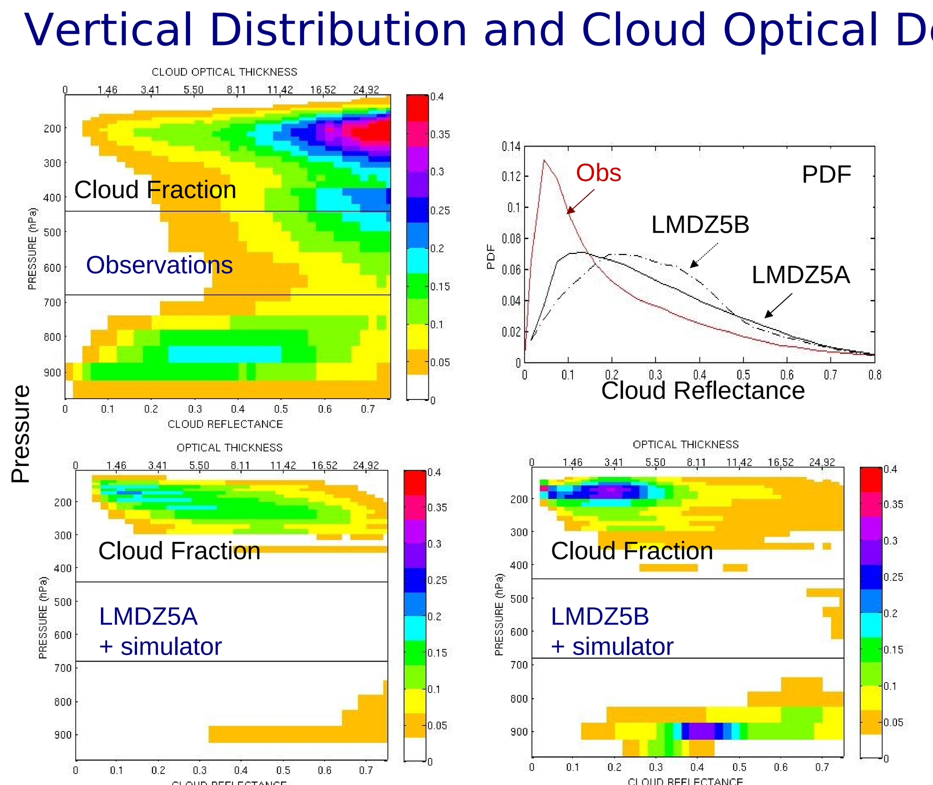
→Instantaneous Correlation CF - CRef:

- Obs: one cloud type with low CF and low CRef and one with CF≈1 and high CRef

- Mod: difficulties in reproducing instantaneous cloud properties. Opposite physical picture to the obs: cloud optical depth decreases as the cloud extends horizontally. LMDZ5B simulates better the relationship.

Evaluation of Tropical Clouds using Instantaneous Clouds Properties

Instantaneous Relation between Cloud Vertical Distribution and Cloud Optical Depth



Observations:

- optically thin clouds: mainly low level clouds with low values of cloud fraction.

- optically intermediate clouds: cloud fraction increases with cloud reflectance

- optically thick clouds: mainly high clouds with low occurrences

Model biases:

- more optically thin high clouds

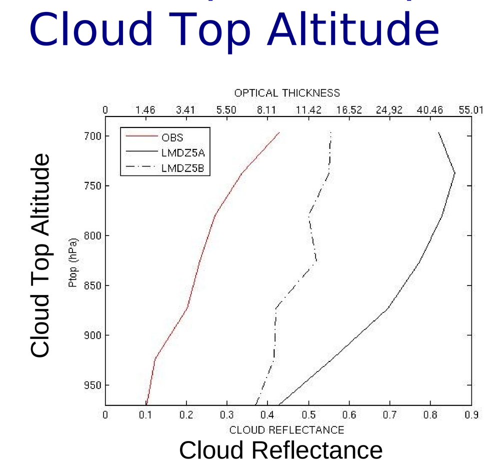
- few optically thick high clouds

- no mid level clouds (or not well simulated)

- overestimation of optically thick low clouds

Focus on tropical boundary layer clouds

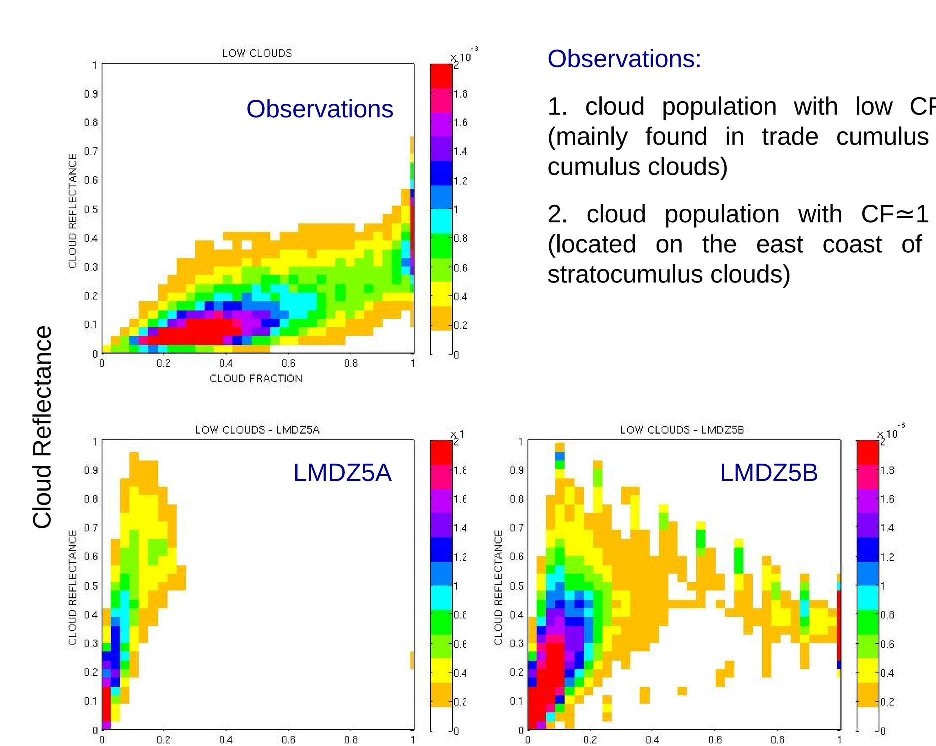
Cloud Optical Depth and Cloud Top Altitude



- Cloud optical depth increases with cloud altitude

- Model needs more liquid water to form clouds

Cloud Fraction and Cloud Optical Depth



Observations:

1. cloud population with low CF and low CRef (mainly found in trade cumulus regions - small cumulus clouds)

2. cloud population with CF≈1 and high CRef (located on the east coast of tropical oceans-stratocumulus clouds)

LMDZ5A:

Underestimation of cloud fraction and overestimation of cloud reflectance

LMDZ5B:

Simulation of clouds with higher cloud fraction but strong overestimation of cloud optical depth

Conclusions

⇒ A-train observations allow to build pictures of cloud properties containing information at the cloud scale. It shows how the cloud properties (cloud cover, cloud optical depth and cloud vertical distribution) vary together under a same change of environment around the cloud
- cloud optical depth increases with the cloud horizontal extent, both the cloud fraction and the in-cloud liquid water content increase (or decrease) at the same time
- for tropical boundary layer clouds cloud optical depth increases with cloud top altitude and with cloud fraction

⇒ The study of cloud properties at high spatial and temporal resolution enables to evaluate the ability of models to reproduce the instantaneous relation between cloud properties and thus to constrain cloud description at the process scale in climate models

⇒ The model evaluated here has difficulties in reproducing instantaneous cloud properties
- in model cloud optical depth decreases when the cloud extends horizontally (CF increases), whereas in the observations the cloud optical depth increases with the cloud horizontal extent
- error compensations in the model are identified: underestimation of high optically thick clouds and overestimation of high thin clouds, the model simulates too few low clouds but they are optically too thick

References

Konsta D., H. Chepfer, and J.-L. Dufresne, 2012: A process oriented characterization of tropical oceanic clouds for climate model evaluation based on a statistical analysis of daytime A-train high spatial resolution observations, Climate Dynamics, submitted.

Konsta D., J.-L. Dufresne, H. Chepfer, A. Idelkadi, and G. Cesana, 2012: Evaluation of clouds simulated by the LMDZ5 GCM using A-train satellite observations (CALIPSO, PARASOL, CERES), Climate Dynamics, submitted.