Parameterization and tuning of cloud and precipitation overlap in LMDz

A case study to explore what it means to improve parameterizations and how HIGH-TUNE may guide this improvement

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Clouds in models - 2021

What does it mean to improve parameterizations?

Epistemological thoughts on the notion of scientific progress

Kuhn in *the Structure of Scientific Revolutions* (1962, p. 169) gives two criteria to replace a scientific paradigm by another:

1. *"The new candidate must seem to* ***resolve some outstanding and generally recognized problem*** *that can be met in no other way."*
2. *"Second, the new paradigm must promise* ***to preserve a relatively large part of the concrete problem-solving ability*** *that has accrued to science through its predecessors".*

<u>Are Kuhn's criteria applicable to parameterizations?</u>

Not directly because:

- The ability of a new parameterization to solve outstanding anomalies and to preserve previous model abilities depends on the tuning of model parameters.
- Even after a tuning phase, a new parameterization often deteriorates some aspects of the model, thus Kuhn's second criteria must be relaxed.
- The conceptual progress brought by a parameterization also have to be taken into account.

What does it mean to improve parameterizations?

Defining scientific progress for parameterizations

The scientific progress brought by a parameterization in a given GCM depends on the pre-existing parameterizations in this GCM. In the following, we therefore do not give criteria to compare two parameterizations, but to **compare two versions of a model containing different parameterizations**.

We will distinguish progress for parameterizations at two levels: **conceptually** and in terms of **model results**.

<u>Conceptually</u>

To compare conceptually a version of a GCM with a new parameterization to the original GCM, we introduce 4 criteria:

- its **Consistency**
- its **Interpretability**
- its **Simplicity**
- its **Comprehensiveness**

In the following, we will call these criteria the **CISC criteria**.

What does it mean to improve parameterizations?

Defining scientific progress for parameterizations

In terms of model results

To compare the results of a GCM with a new parameterization to those given by the original GCM, different choices have to be made:

- The conditions in which the GCM simulation is carried out (SCM case studies, atmospheric GCM, coupled GCM, etc.)
- A standardized tuning protocol to differentiate the improvements or deteriorations associated with the parameterization itself to those associated with the tuning process.
- Target variables of the model and associated references and metrics in order to define which aspects of the model we want to improve

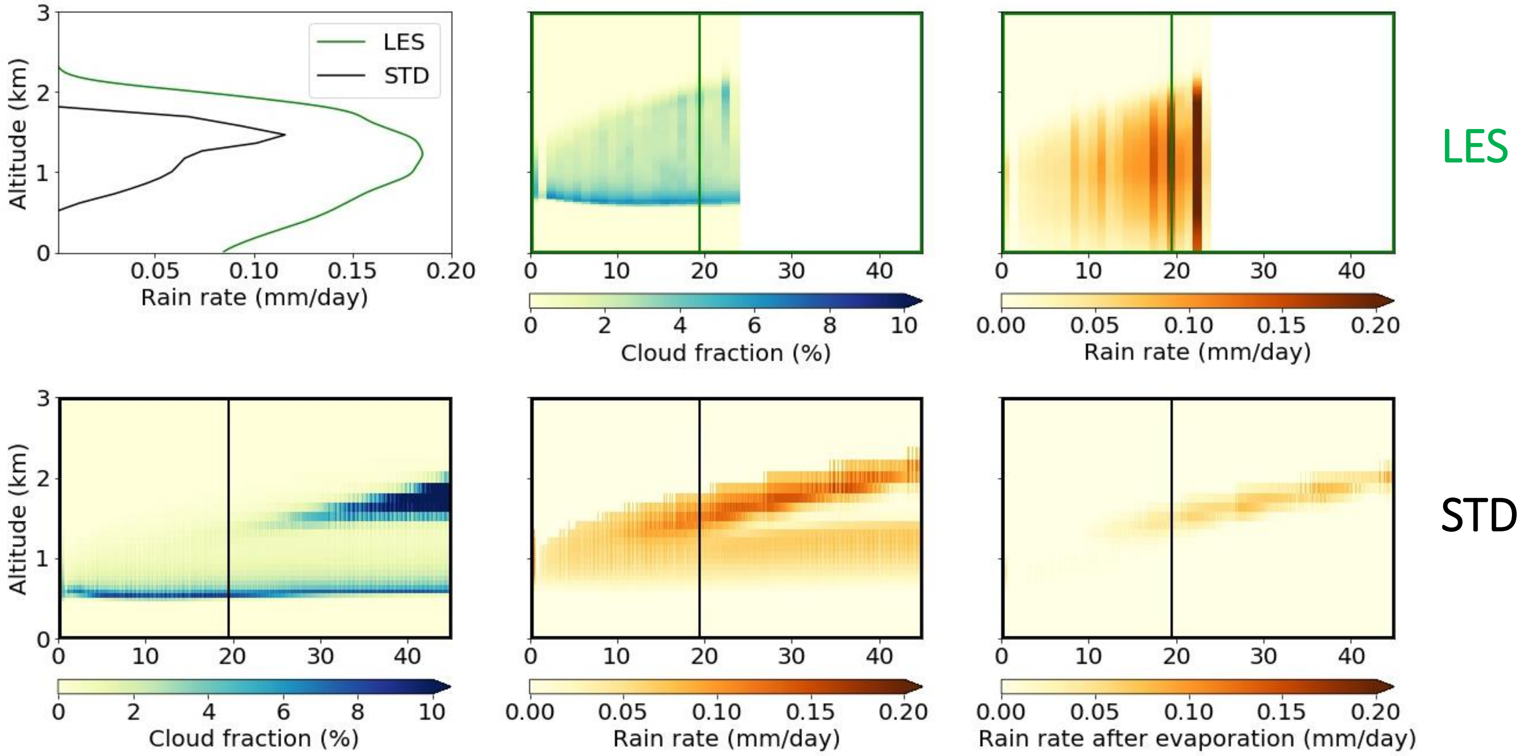
→ even then, whether a new parameterization improves or not a given GCM is not obvious as improvements in some model results will often be associated with deteriorations in others.

→ In the following, we will look at these issues in practice by introducing a cloud and precipitation overlap parameterization in LMDz and examine whether it improves the model or not

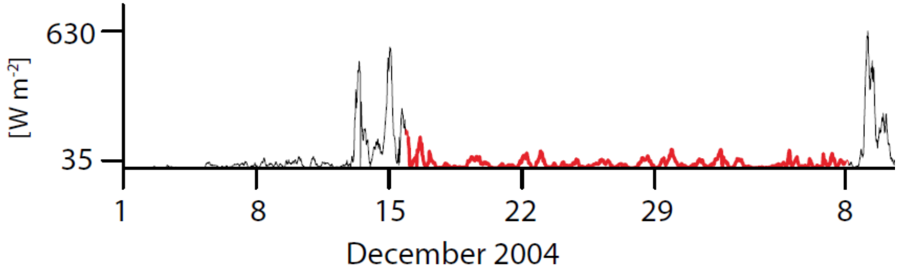
Motivations for the new parameterization

The RICO (Rain in Shallow Cumulus over the Ocean, Nov. 2004 – Jan. 2005) field campaign, has been designed to study **the formation and the effect of rain in trade-wind shallow cumuli.**

Data from the campaign have been used to build a composite case based on a three week period with typical trade wind cumuli and a fair amount of precipitation, about **0.3 mm/day**.




Rauber et al. (2007)



vanZanten et al. (2011)

Contrary to LES and observations, all the rain in the standard version of LMDz **(STD)** evaporates in the cloud layer or immediately below → no precipitation at the surface

Motivations for the new parameterization

Why so much evaporation in the cloud layer in LMDz?

In LMDz, in the large-scale condensation and precipitation scheme (Fisrtilp), at each vertical level, from top to bottom:

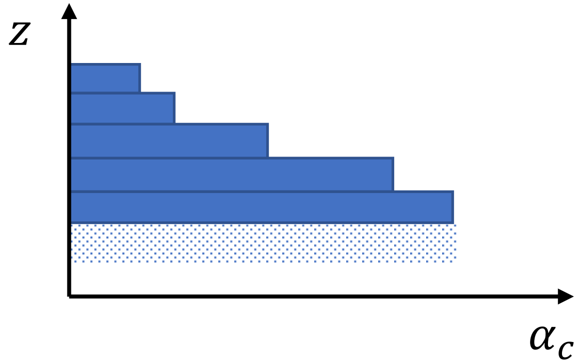
1. Part of the precipitation flux coming from above is evaporated
2. The cloud fraction and content at that level is calculated
3. Part of the newly formed cloud is converted to rain or snow, thus increasing the precipitation flux

The formula used to calculate the evaporation is based on **Sundqvist (1988):**

$$\frac{\partial P_{l,i}}{\partial z} = \beta \left(1 - \frac{q_t}{q_{sat}}\right)\sqrt{P_{l,i}}$$

But: Sundqvist applies this formula in the clear air area only, whereas in LMDz, the formula is applied over the whole cell.

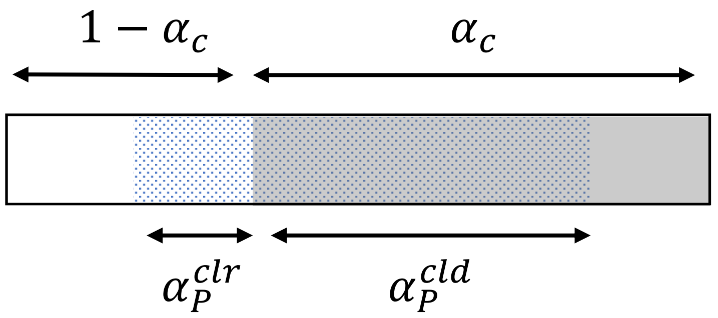
<u>Consequence:</u> in LMDz, almost all the precipitation flux is evaporated in the cloud layer, whereas we would expect little evaporation in this layer since the cloudy air is saturated.



In this example, under a max-random overlap assumption, we would expect no evaporation until cloud base as the cloudy air is assumed to be saturated.

Proposition – inspired from Jakob and Klein (2000)

As in Jakob (2000), we distinguish the clear and cloudy precipitation mass flux density (in $kg.m^{-2}.s^{-1}$) and corresponding fractions:



$$P_{l,s} = P_{l,s}^{clr} + P_{l,s}{}^{cld}$$
$$\alpha_{P_{l,s}} = \alpha_{P_{l,s}}^{clr} + \alpha_{P_{l,s}}^{cld}$$

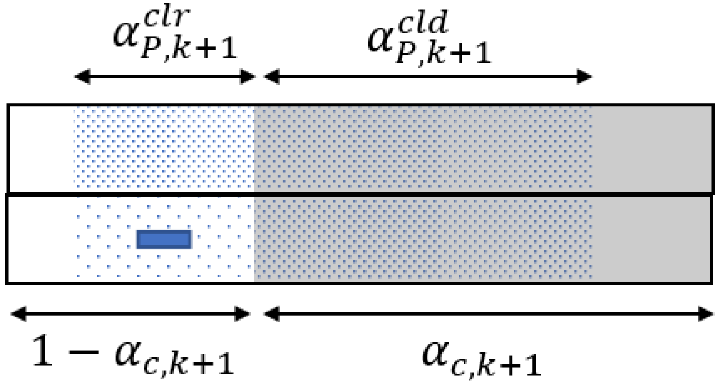
The objective of the parameterization is to calculate P^{clr}, P^{cld}, α_P^{cld} and α_P^{clr} at each level, from top to bottom.

At each level k, we have, in the following order:

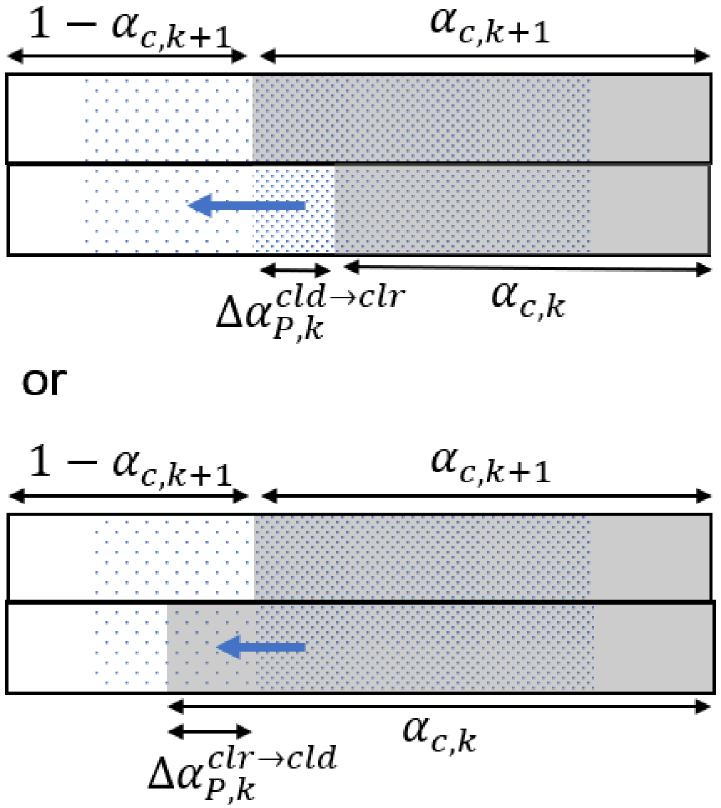
1. **Evaporation of precipitation**
2. **Cloud formation**
3. **Partitioning of precipitation**
4. **Autoconversion**

Sketch of the parameterization

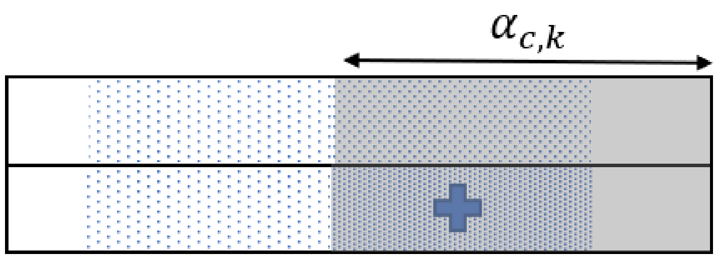
1. Rain evaporation



2. 3. Formation of clouds and partitioning of precipitation



4. Formation of precipitation



Does the new parameterization improve LMDz conceptually?

Assessing conceptual progress using the CISC criteria

- **Consistency:** the new parameterization helps to solve an inconsistency in the application of the formula from Sundqvist (1988)
- **Interpretability:** the variables introduced $P^{clr}, P^{cld}, \alpha_P^{clr}, \alpha_P^{cld}$ and the different equations used are easy to interpret physically → the new parameterization does not make the model less interpretable.
- **Simplicity:** the parameterization involves only 4 variables and 1 tuning parameter and is based on simple geometrical considerations → it does not complicate the model much.
- **Comprehensiveness:** the parameterization takes into account an important process for the evaporation of precipitation absent from the standard version of LMDz: the fact that part of the precipitation flux falls in cloudy air and is thus not evaporated.

Assessing progress in terms of model results in 1D case studies

First results without retuning

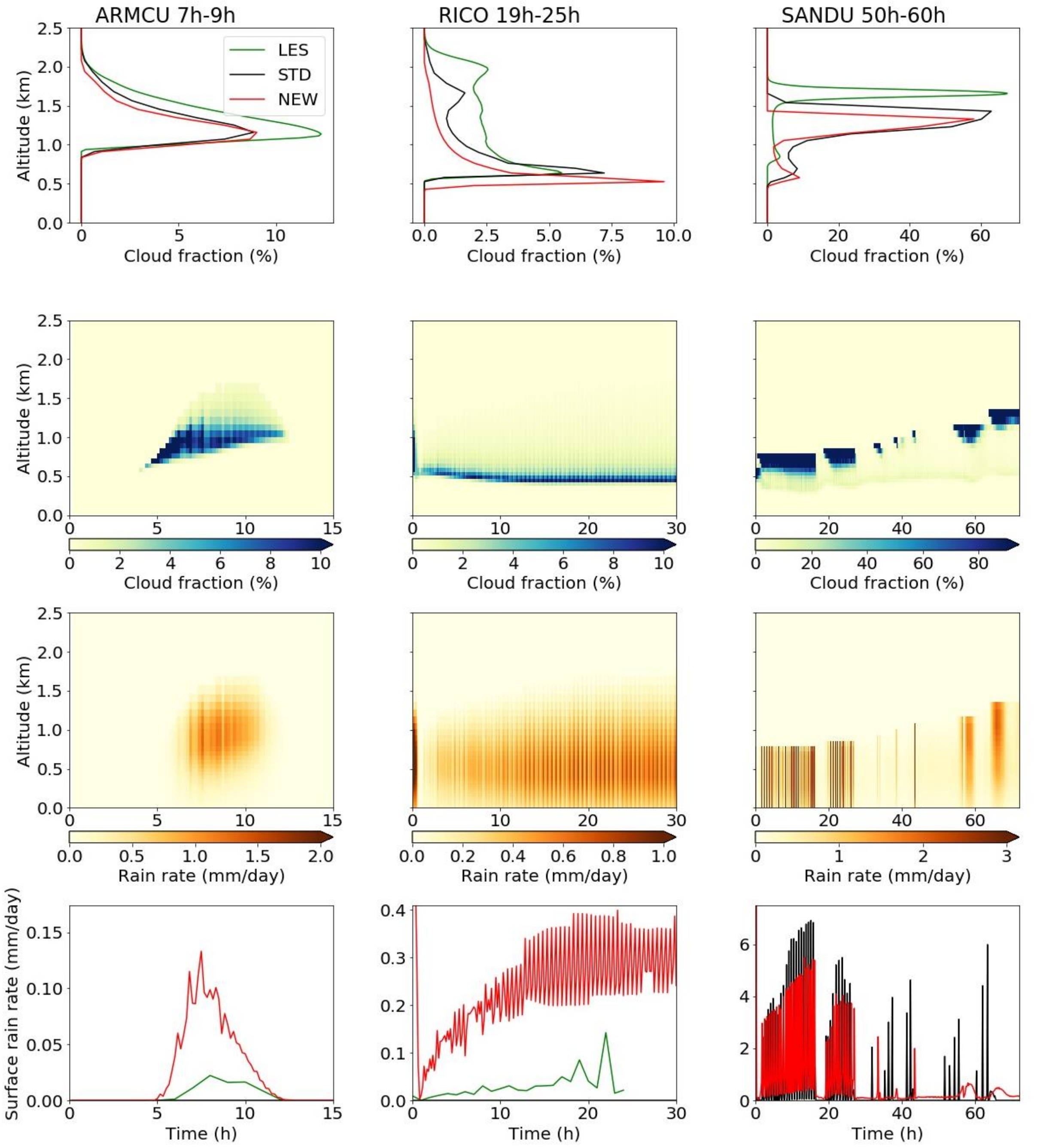
<u>1D Cases</u>

- ARMCU: continental shallow cumulus case
- RICO: precipitating shallow cumulus over oceans in trade wind regions
- SANDU: stratocumulus to cumulus transition over sub-tropical oceans

<u>Results</u>

- Significant increase of the surface rain rate in ARMCU and RICO
- Little changes in the SANDU case
- Diminution of the cloud base height and mid-level cloud fraction in the RICO case

→ A standardized tuning protocol is necessary to assess progress in terms of model results in 1D.



Tuning process using the High-Tune explorer – 1D

One has to choose…

Parameters

Parameter	min	max	std	Controls
FALLV	0.3	2	0.8	speed of fall of ice crystals
RQSP0	40000	60000	45000	standard deviation of the subgrid scale water distribution
RQSDP	7000	25000	10000	standard deviation of the subgrid scale water distribution
RQSH	0.05	0.6	0.4	standard deviation of subgrid scale water distribution
OMEPMX	0.0005	0.01	0.001	maximum efficiency of cloud water -> precipitation conversion
REI	0.5	1.3	1	effective radius of cloud particles
DZ	0.07	0.15	0.07	environmental air altitude shift for buoyancy computation
EVAP	5e-5	5e-3	1e-4	reevaporation of rainfall
CLC	8e-5	1.2e-3	6.5e-4	autoconversion of cloud liquid water to rainfall
CLTAU	4000	15000	900	characteristic time for the formation of rain
RI	5e-6	2e-3	5e-4	minimum rain intensity before linear decrease of the precipitation fraction
A1	0.5	1.2	0.66667	Contribution of buoyancy to the plume acceleration
A2	1.5e-3	4.e-3	2.e-3	drag term in the plume acceleration
B1	0	1	0.95	scaling factor for entrainment and detrainment
BG1	0.4	2	1.1	width of the environmental subgrid scale water distribution

+ range of values for each parameter

Metrics

Case	IHOP	ARMCU	RICO	SANDU	SANDU	SANDU
Subcase	REF	REF	REF	REF	SLOW	FAST
time	7-9	7-9	19-25	50-60	50-60	50-60
$\theta_{400-600hPa}$	X	X	X			
$q_{v,400-600hPa}$		X				
$f_{cld,max}$		X	X			
$z_{cld,ave}$		X		X		
$z_{cld,max}$		X		X	X	X

+ References and tolerances to error for each metric

See Hourdin et al. (2020)

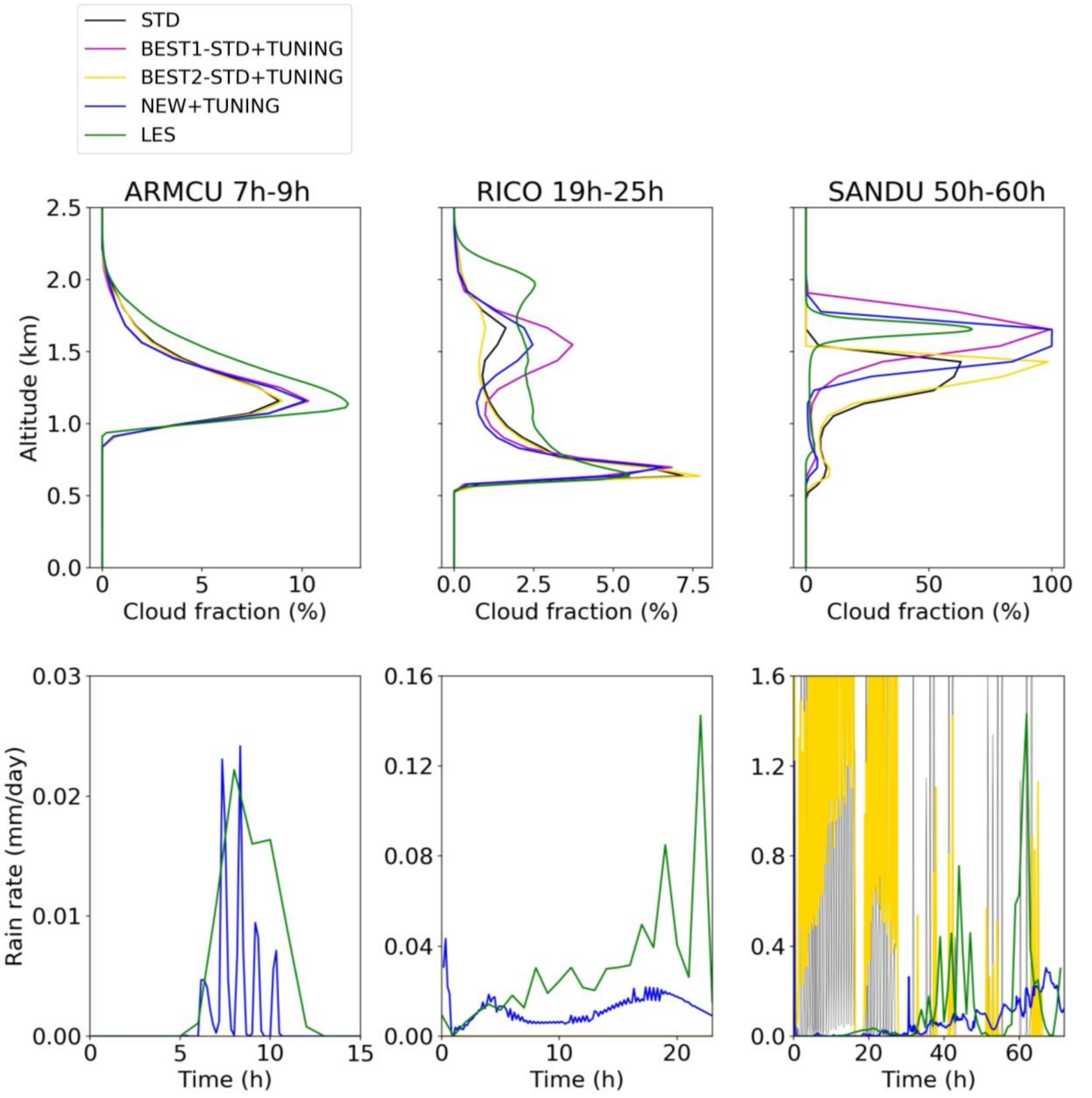
Assessing progress in terms of model results in 1D case studies

Results after 1D tuning

- Comparable results in terms of cloud fraction between the best simulation after tuning using the new version (**NEW+TUNING**) and the best simulations after tuning using the STD version of LMDz (**BEST1-STD+TUNING**, **BEST2-STD+TUNING**).
- Major improvements in terms of surface rain rate in the new version :

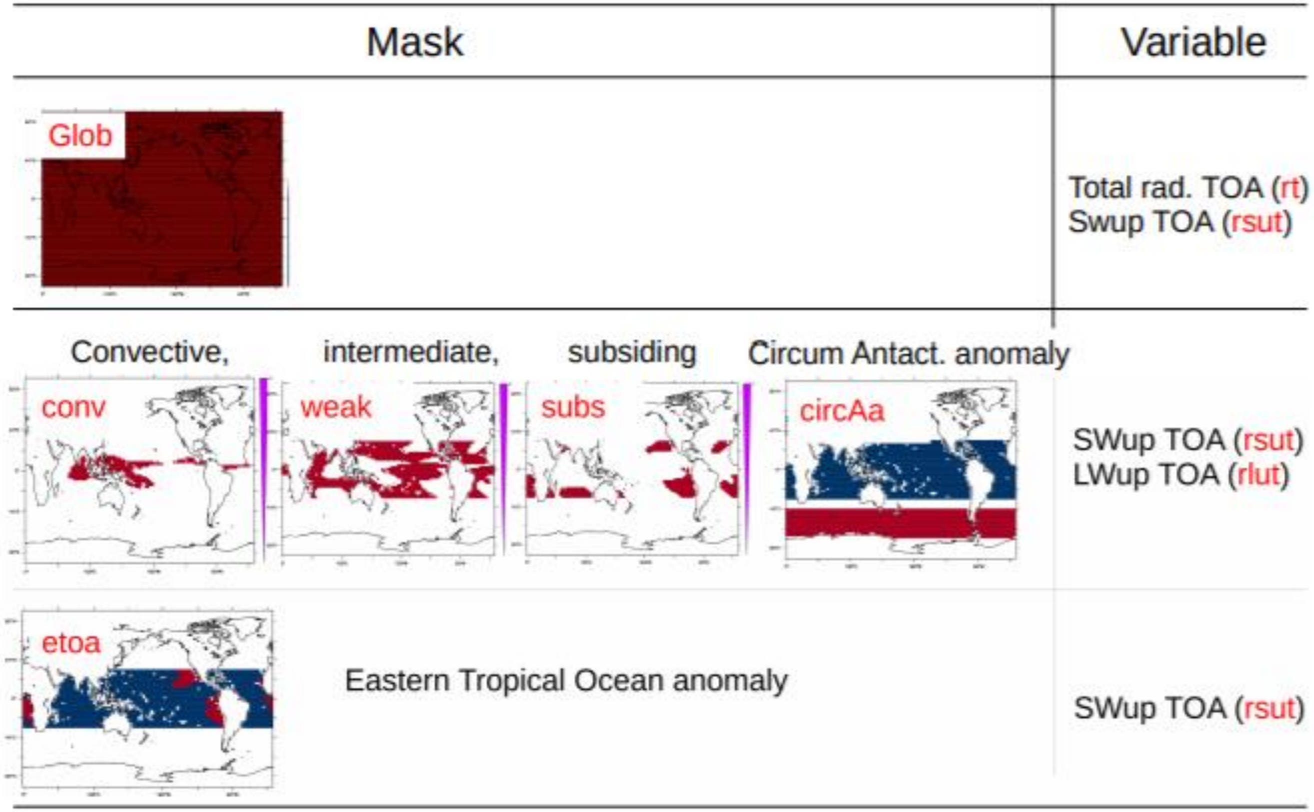
1. In ARMCU and RICO, surface rain rate relatively consistent with LES in **NEW+TUNING,** , whereas no precipitation at all in the best simulations using the standard version of LMDz.
2. In SANDU, surface rain rate with an evolution consistent with those given by LES, whereas there is either no precipitation at the surface (**BEST1-STD+TUNING**), or an overestimation of surface rain rate (**STD**, **BEST2-STD+TUNING**) in the standard version.

→ Kuhn's criteria do apply, we see a progress in terms of model results in the 1D case studies considered.



Tuning process using HighTune tools – 3D

Same parameters but new metrics…



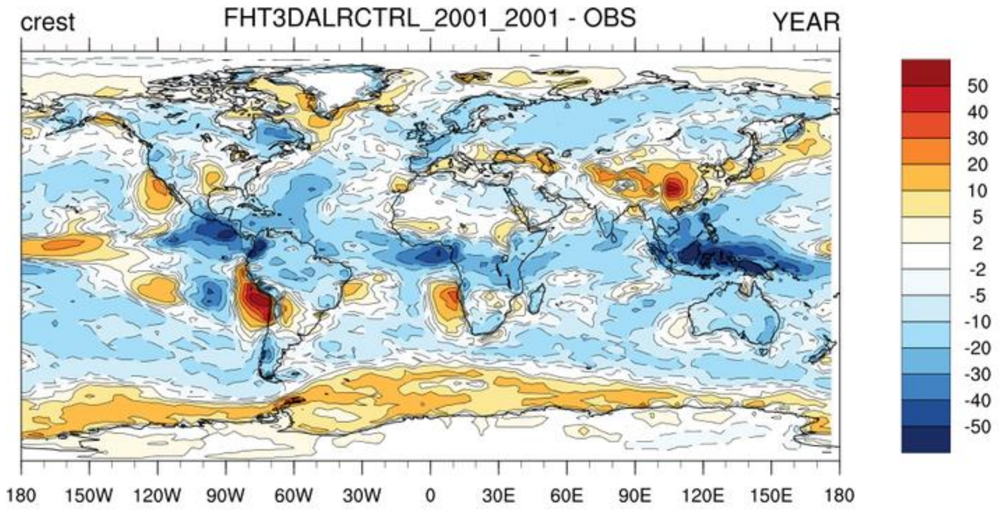
Metrics	target $W\ m^{-2}$	error $W\ m^{-2}$
glob.rt	2.5	0.2
glob.rsut	99.6	5
circAa.rsut	24.0	5
circAa.rlut	-48.6	5
subs.rsut	84.9	5
weak.rsut	81.8	5
conv.rsut	103.2	5
subs.rlut	274.6	5
weak.rlut	264.3	5
conv.rlut	235.8	5
etoa.rsut	11.0	5

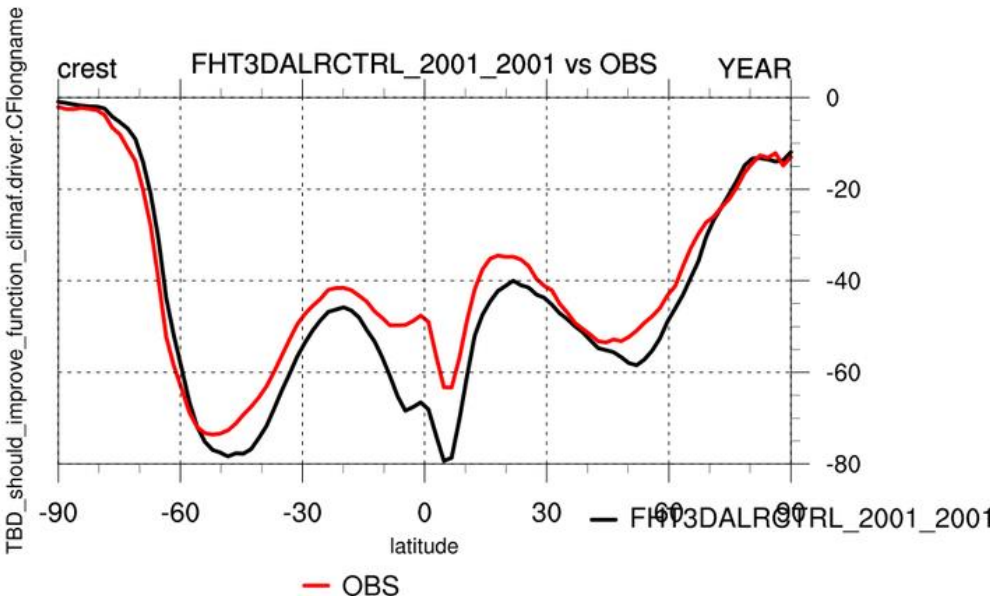
Hourdin et al. (2020)

53 waves in total: 50 waves in 1D, then 3 waves in 3D

Ongoing work - Assessing progress in terms of model results in the 3D GCM

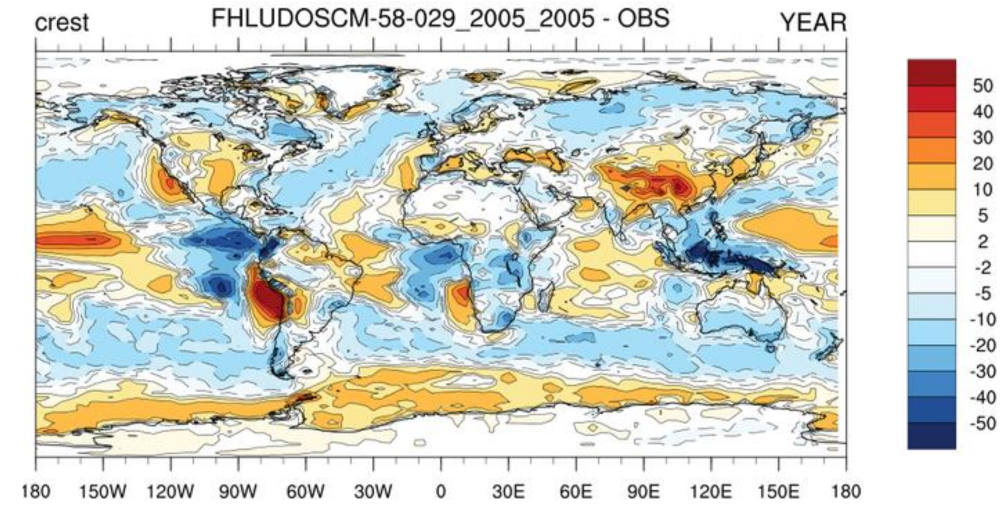
Shortwave Cloud Radiative effect at the top of the atmosphere $(W.m^{-2})$

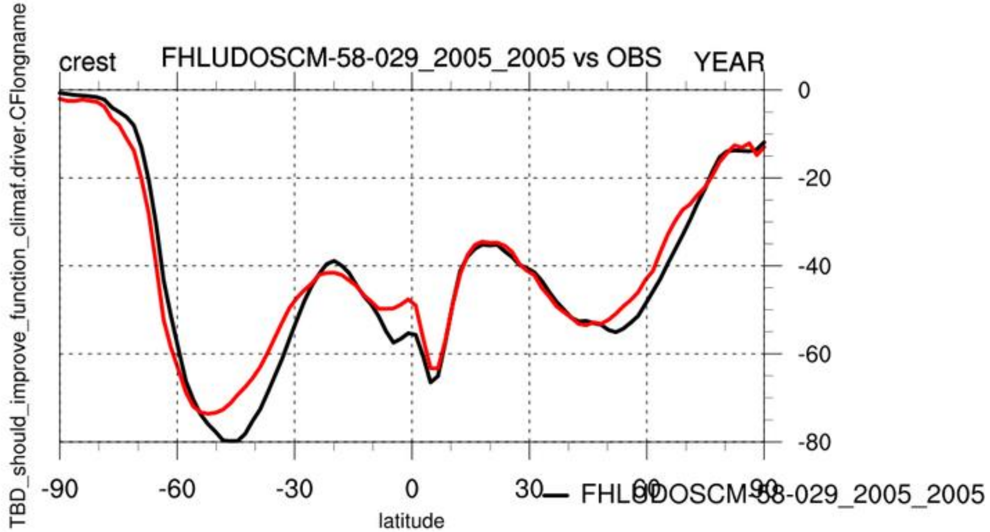




STD

- Bias -6.3
- RMSE 14



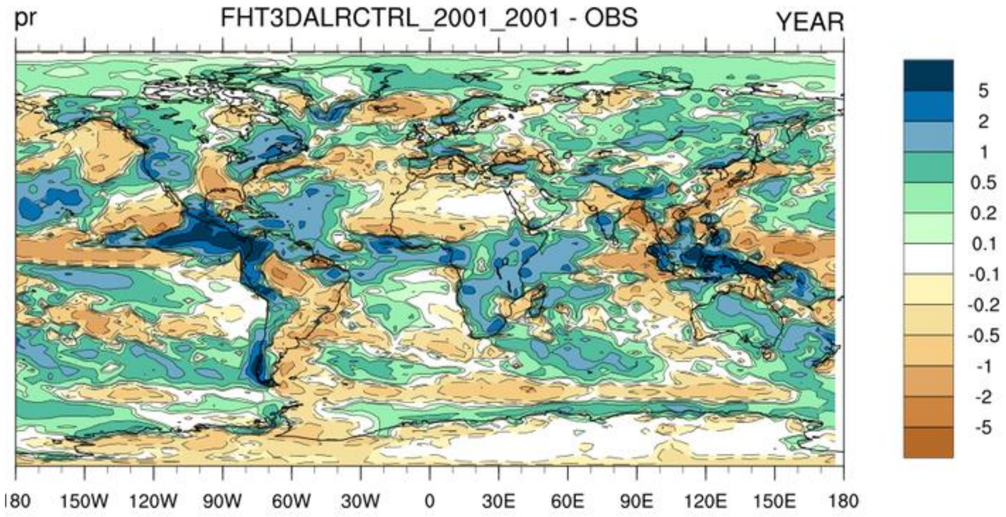


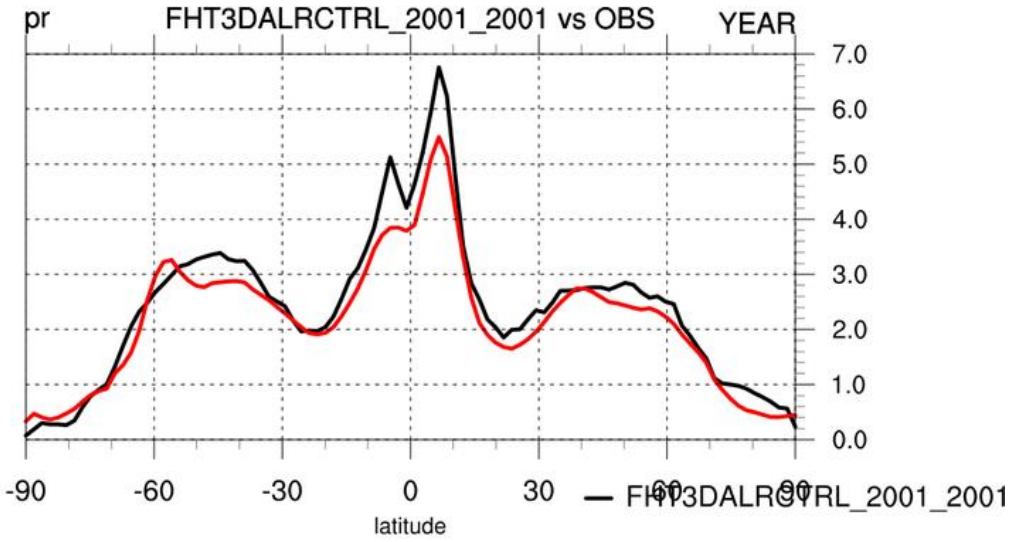
NEW+3D TUNING

- Bias -2
- RMSE 13

Ongoing work - Assessing progress in terms of model results in the 3D GCM

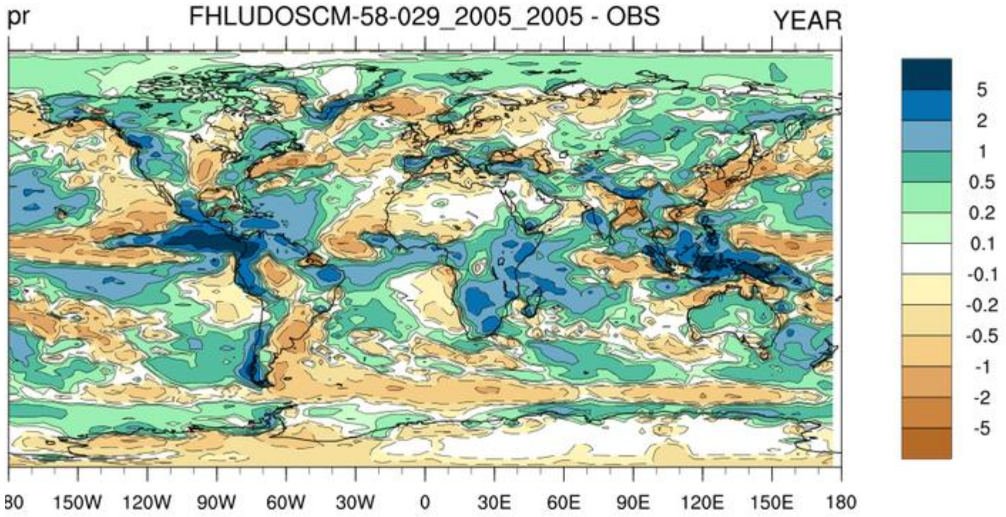
Precipitation (mm/day)

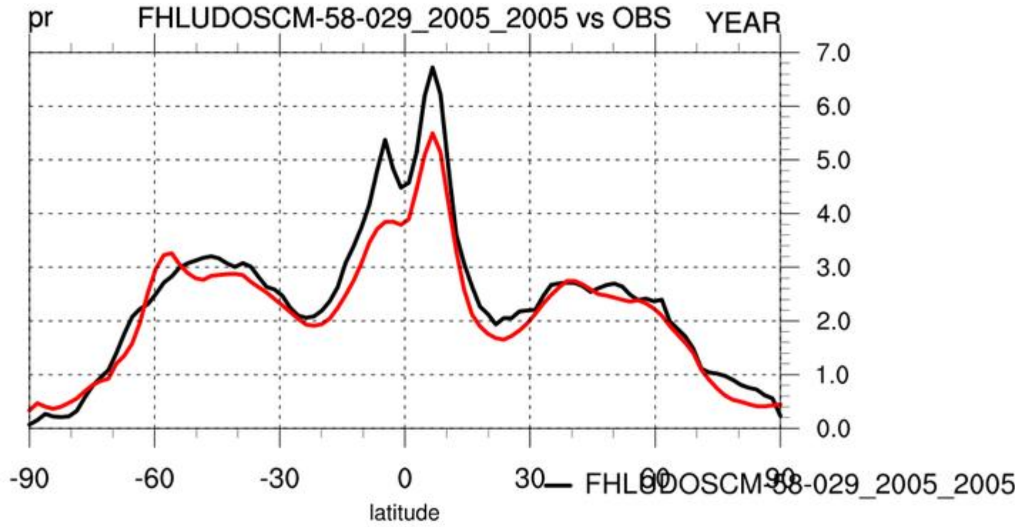




STD

- Bias 0.32
- RMSE 1.47





NEW+3D TUNING

- Bias 0.34
- RMSE 1.3

Ongoing work - Assessing progress in terms of model results in the 3D GCM

To be continued

- In 3D, Kuhn's criteria does not apply. Some improvements are observed, but also some degradations of model results. Previous model results are not entirely preserved.

- In theory, we could define the meaning of progress by choosing a set of normalized metrics and associated weights and by using the following proposition:

→ In terms of model results, a version of a model V_1 is better than another V_2 if and only if there is a set of parameters S_1 in the parameter space P_1 such that the weighted average of the scores of V_1 given by the defined metrics is lower than the weighted average of the scores of V_2 given by the same metrics for any set of parameters in the parameter space P_2. Mathematically, we can write:

$$V_1 > V_2 \leftrightarrow \exists\, S_{1,0} \in P_1, \forall\, S_2 \in P_2, \sum_i \alpha_i m_i\left(V_1, S_{1,0}\right) < \sum_i \alpha_i\, m_i(V_2, S_2)$$

- Difficult in practice to agree on the metrics and weights and to ensure that the whole parameter space has been adequately sampled.