Parameterization and tuning of cloud and precipitation overlap in LMDz

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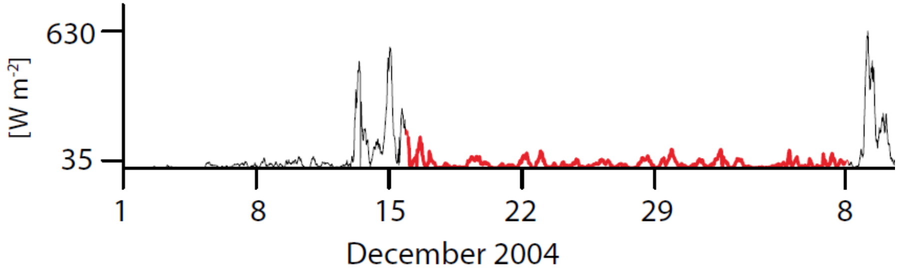
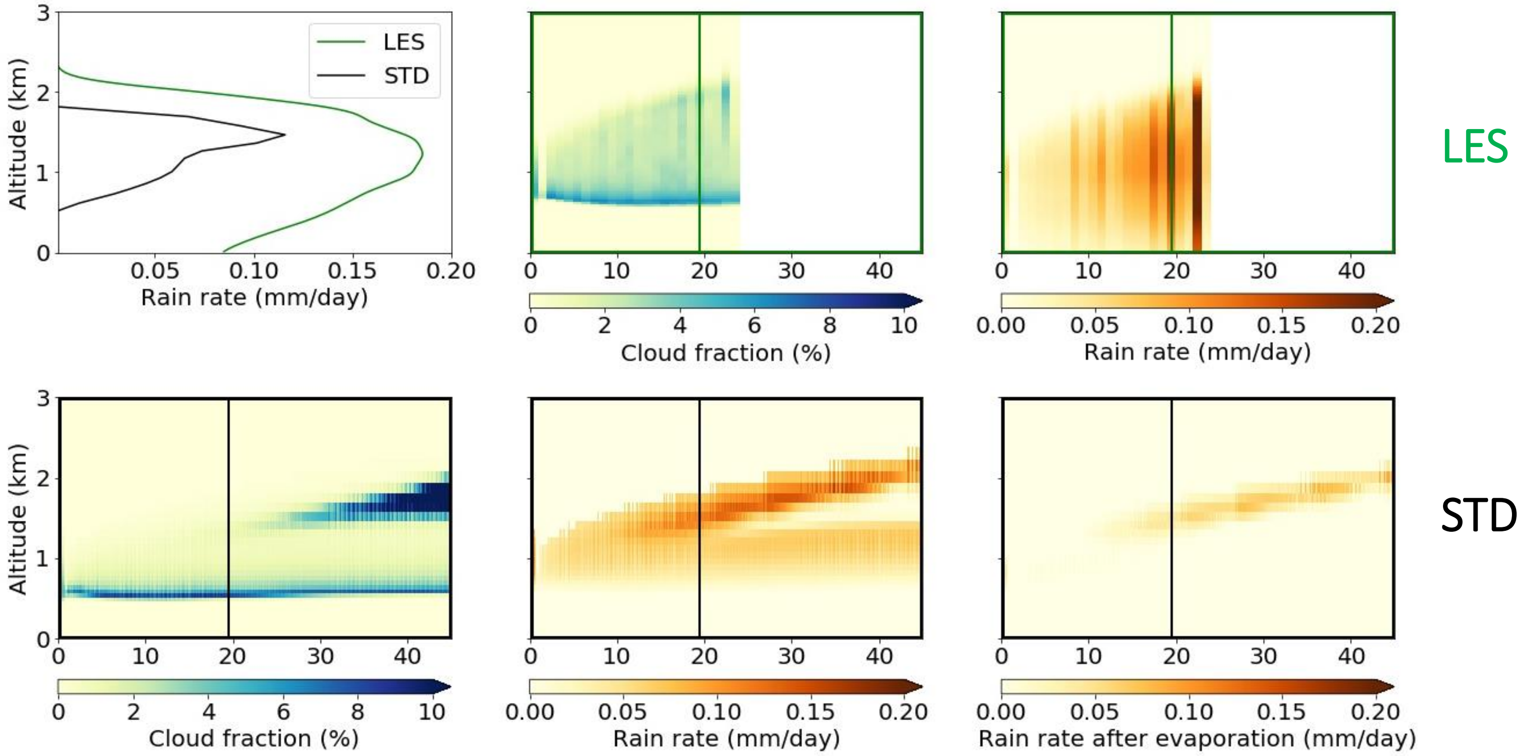
How it all started – rain in RICO

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**.



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

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:

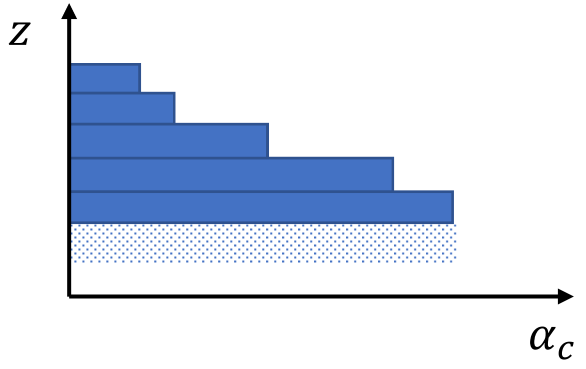
1. Part of the precipitation flux coming from above is evaporated
2. The cloud fraction and content at that level is calculated
3. Part of the newly formed cloud is converted to rain or snow, thus increasing the precipitation flux

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.

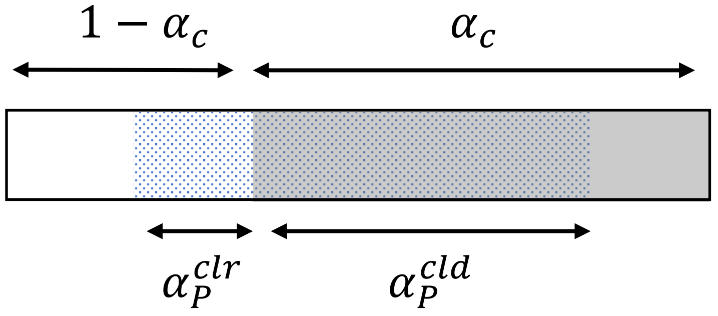
<u>Consequence:</u> in LMDz, almost all the precipitation flux is evaporated in the cloud layer, whereas we would expect little evaporation in this layer since the cloudy air is saturated.



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



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

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:

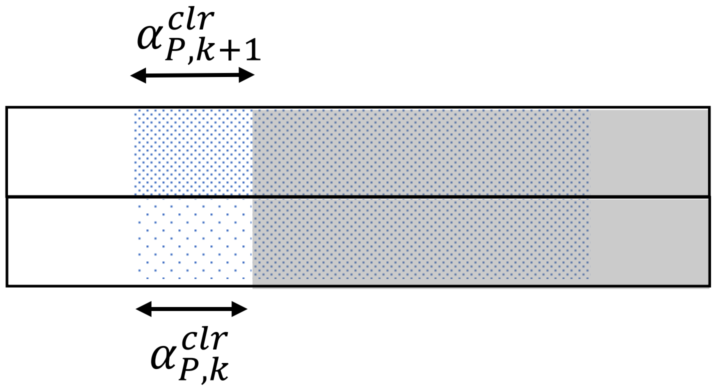
1. **Evaporation of precipitation**
2. **Cloud formation**
3. **Partitioning of precipitation**
4. **Autoconversion**

Proposition – inspired from Jakob and Klein (2000)

1. Evaporation of precipitation

- Only the clear precipitation flux evaporates
- Evaporation does not alter its area $\alpha_{P,k}^{clr} = \alpha_{P,k+1}^{clr}$
- The formula used is the one given in Sundqvist (1988):

$$\Delta P_k^{clr} = \beta \left(1 - \frac{q_{clr}}{q_{sat}}\right) \sqrt{P_{k+1}^{clr}} * \Delta z$$



From which we deduce $P_k^{clr} = P_{k+1}^{clr} - \Delta P_k^{clr}$

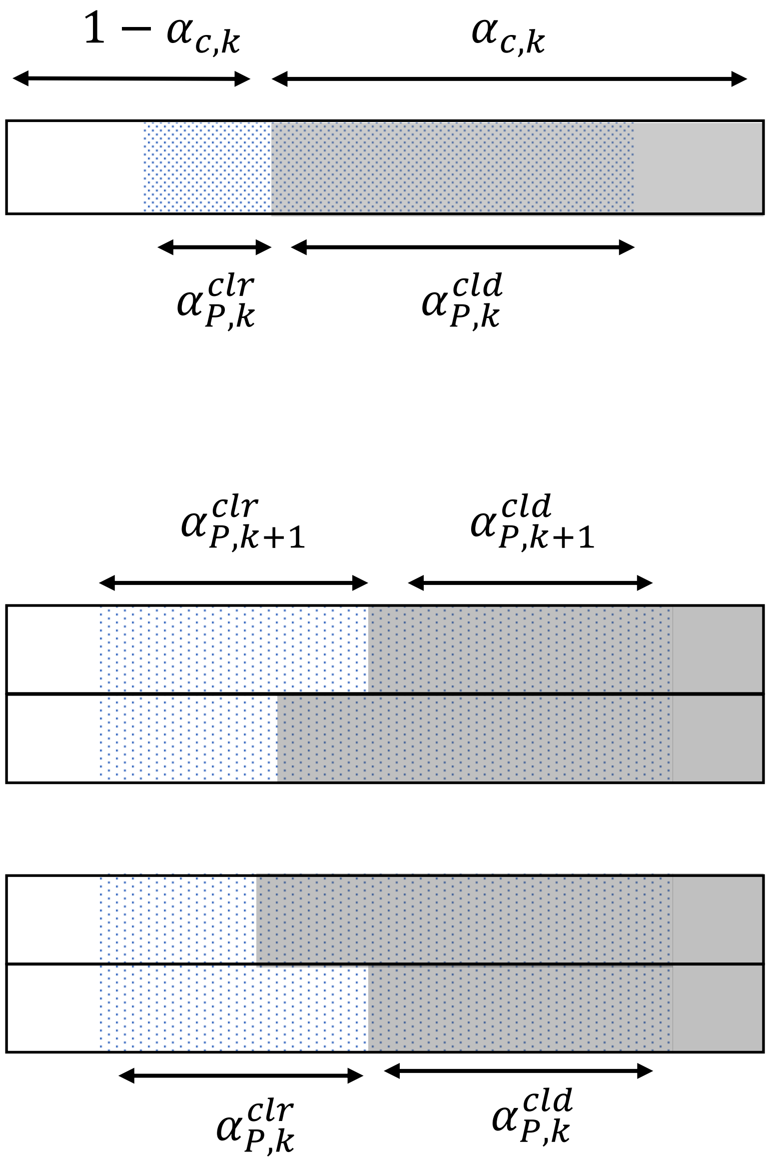
Note

- If all the precipitation flux evaporates at level k, $\alpha_{P,k}^{clr} = 0$
- There is no evaporation in the cloudy part: $\alpha_{P,k}^{cld} = \alpha_{P,k+1}^{cld}$ and $P_k^{cld} = P_{k+1}^{cld}$

Proposition – inspired from Jakob and Klein (2000)

2. Cloud formation

- The cloud formation itself doesn't change (see Madeleine et al. 2020) and gives access to the cloud liquid water content q_c^{in} and to the cloud fraction α_c.
- It defines therefore a new partition between cloudy and clear air at k and we need to calculate the new $\alpha_{\mathrm{P,k}}^{cld}$, $\alpha_{P,k}^{clr}$, P_k^{cld} and P_k^{clr} since precipitation mass that was in cloud in upper level may fall into clear air of the lower level and vice versa.
- There are four cases:
  - Precip in cloud → precip in clear air
  - Precip in cloud → precip in cloud
  - Precip in clear air → precip in cloud
  - Precip in clear air → precip in clear air



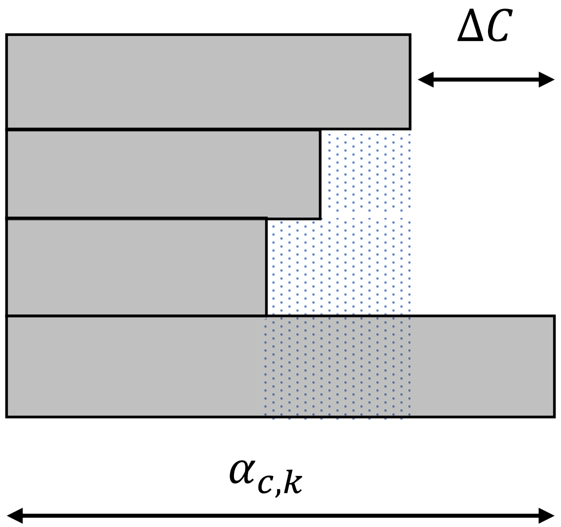
Proposition – inspired from Jakob and Klein (2000)

3. Partitioning of precipitation

- Under a maximum-random overlap assumption, it can be shown that the total fraction covered by clouds from k to k_{top} satisfies the relation :

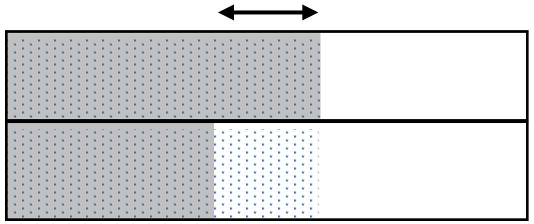
$$(1 - C_k) = (1 - C_{k+1}) * \frac{1 - \max(\alpha_{c,k}, \alpha_{c,k+1})}{1 - \min(\alpha_{c,k+1}, 1 - \delta)}$$

Where $\delta = 10^{-6}$ to prevent division by zero.



Cloudy to clear air:

$\Delta\alpha_{P,k}^{cld\rightarrow clr}$



Clear to cloudy air:

$$\Delta\alpha_{P,k}^{cld\rightarrow clr} = \alpha_{P,k+1}^{cld} - \min(\alpha_{c,k}, \alpha_{P,k+1}^{cld})$$

$$\Delta\alpha_{P,k}^{clr\rightarrow cld} = \max(0, \min(\alpha_{P,k+1}^{clr}, \alpha_{c,k} - \Delta C - \alpha_{c,k+1}))$$

$$\Delta P_k^{cld\rightarrow clr} = \frac{\Delta\alpha_{P,k}^{cld\rightarrow clr}}{\alpha_{P,k+1}^{cld}} * P_{k+1}^{cld}$$

$$\Delta P_k^{clr\rightarrow cld} = \frac{\Delta\alpha_{P,k}^{clr\rightarrow cld}}{\alpha_{P,k+1}^{cld}} * P_{k+1}^{cld}$$

Proposition – inspired from Jakob and Klein (2000)

3. Partitioning of precipitation

Finally, after the formation of clouds, we can update all variables describing the partitioning of precipitation:

$$\tilde{\alpha}_{P,k}^{cld} = \alpha_{P,k+1}^{cld} + \Delta\alpha_{P,k}^{clr\rightarrow cld} - \Delta\alpha_{P,k}^{cld\rightarrow clr}$$

$$\tilde{\alpha}_{P,k}^{clr} = \alpha_{P,k+1}^{clr} - \Delta\alpha_{P,k}^{clr\rightarrow cld} - \Delta\alpha_{P,k}^{cld\rightarrow clr}$$

$$\tilde{P}_{k}^{cld} = P_{k+1}^{cld} + \ \Delta P_{k}^{clr\rightarrow cld} - \ \Delta P_{k}^{cld\rightarrow clr}$$

$$\tilde{P}_{k}^{clr} = P_{k+1}^{clr} - \ \Delta P_{k}^{clr\rightarrow cld} + \ \Delta P_{k}^{cld\rightarrow clr}$$

Proposition – inspired from Jakob and Klein (2000)

4. Autoconversion

Part of cloud water is converted into precipitation:

- For liquid clouds

$$\frac{dq_l}{dt} = -\frac{q_l}{\tau_{conv}}\left(1 - e^{-\left(\frac{\frac{q_l}{\alpha_c}}{q_{clw}}\right)^2}\right)$$

It increases the cloudy liquid precipitation flux by $\Delta P_{k,l}^{cld} = \frac{dq_l}{dt} \times \Delta z \times \alpha_c,$ thus at the base of level k:

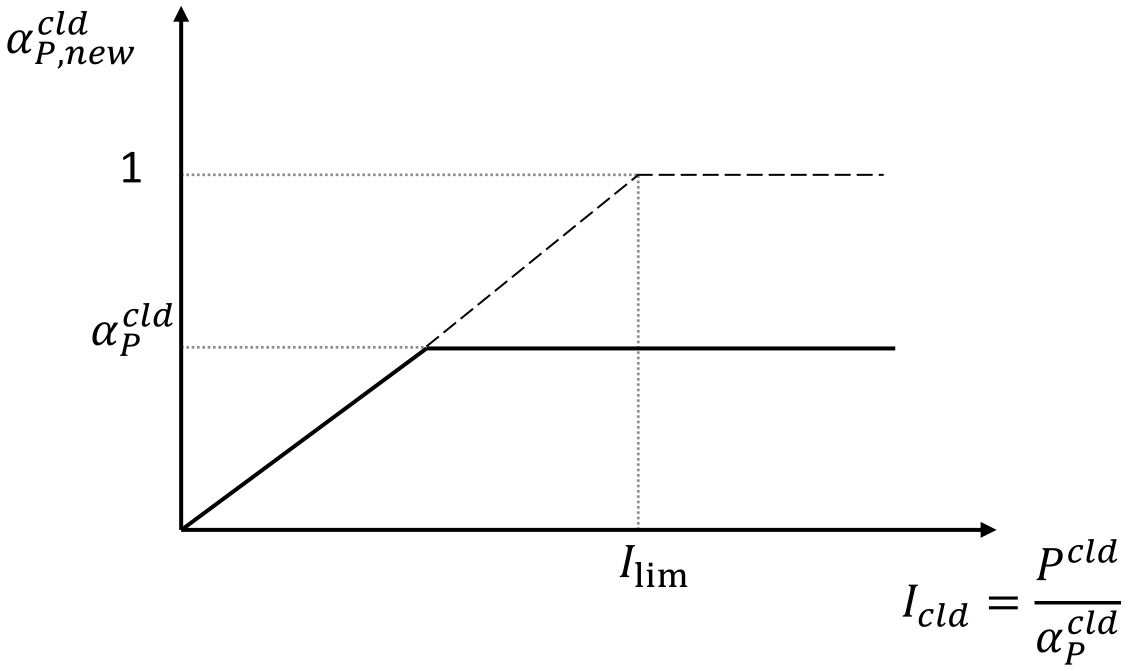
$$\alpha_{P,k}^{cld} = \alpha_{c,k}$$

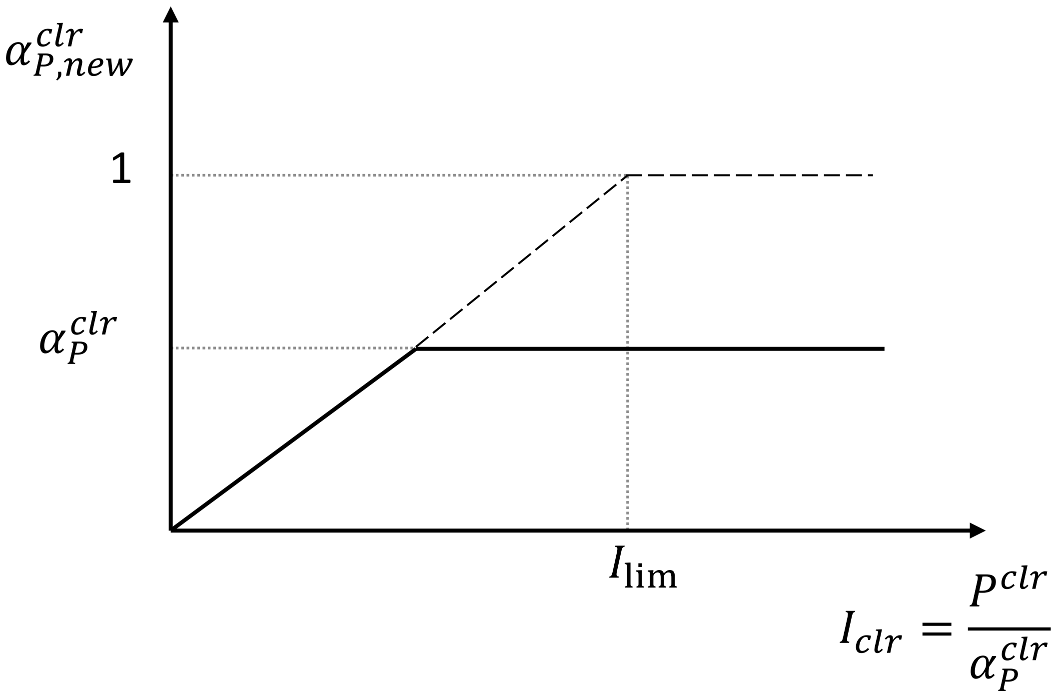
$$P_k^{cld} = \tilde{P}_k^{cld} + \Delta P_k^{cld}$$

- For ice clouds: $\frac{dq_i}{dt} = \frac{1}{\rho}\frac{\partial}{\partial z}(\rho\, w_{iw} q_i)$ increases similarly the cloudy solid precipitation flux by $\Delta P_{k,i}^{cld} = \frac{dq_i}{dt} \times \Delta z \times \alpha_c$.

Proposition – inspired from Jakob and Klein (2000)

5. Limitation of precipitation fraction





At each level, after the autoconversion, we limit the precipitation fraction when the intensity of precipitation becomes smaller than I_{lim}:

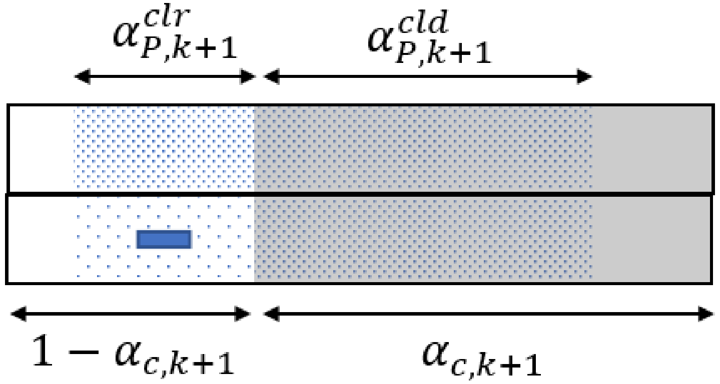
$$I_{cld} = \frac{P_{cld}}{\alpha_P^{cld}}, \qquad \alpha_{P,new}^{cld} = \min(\alpha_P^{cld}, \frac{1}{I_{\lim}} \times I_{cld})$$

and

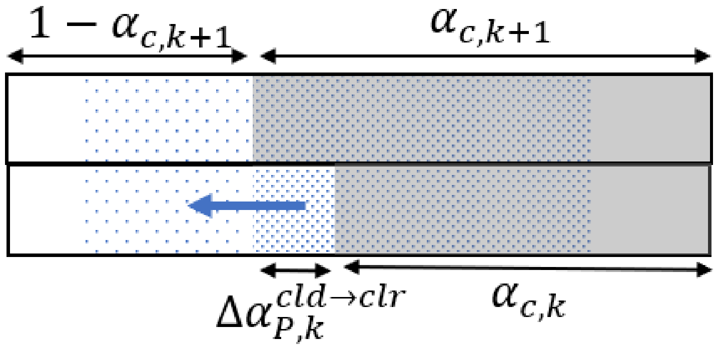
$$I_{clr} = \frac{P_{clr}}{\alpha_P^{clr}}, \qquad \alpha_{P,new}^{clr} = \min(\alpha_P^{clr}, \frac{1}{I_{\lim}} \times I_{clr})$$

Summary

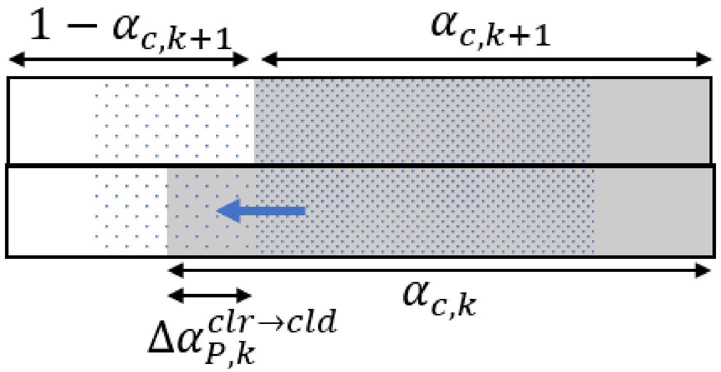
1. Rain evaporation



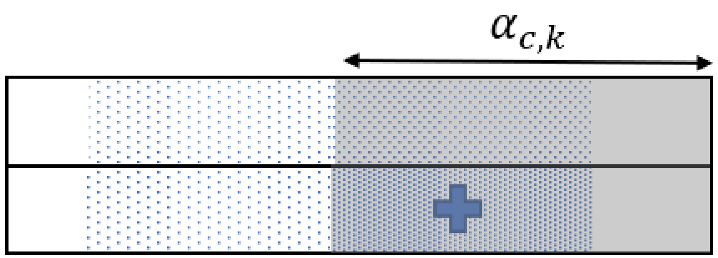
2. 3. Formation of clouds and partitioning of precipitation



or



4. Formation of precipitation



+ 5. Limitation of precipitation fraction

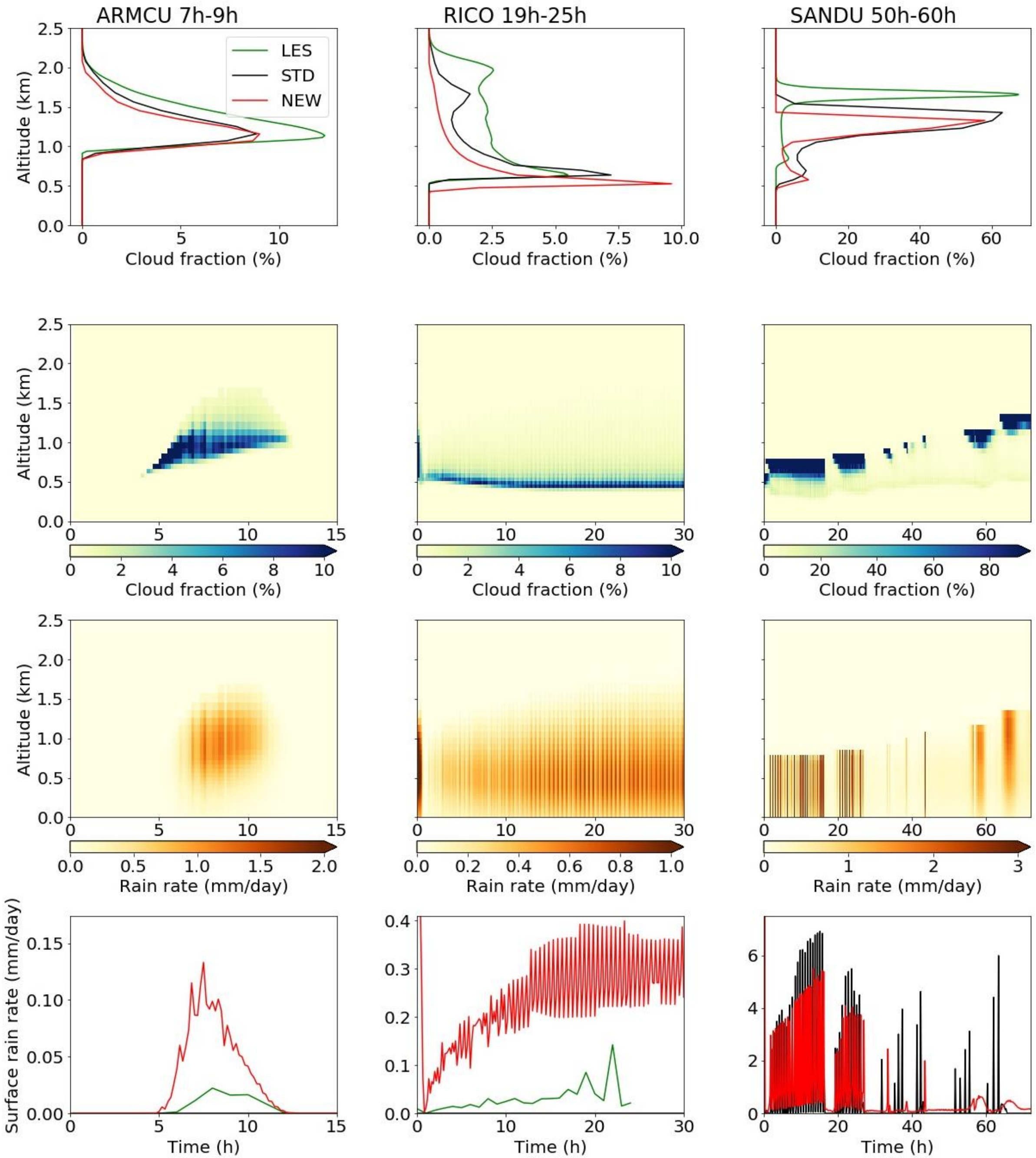
First results without retuning

1D Cases

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

Results

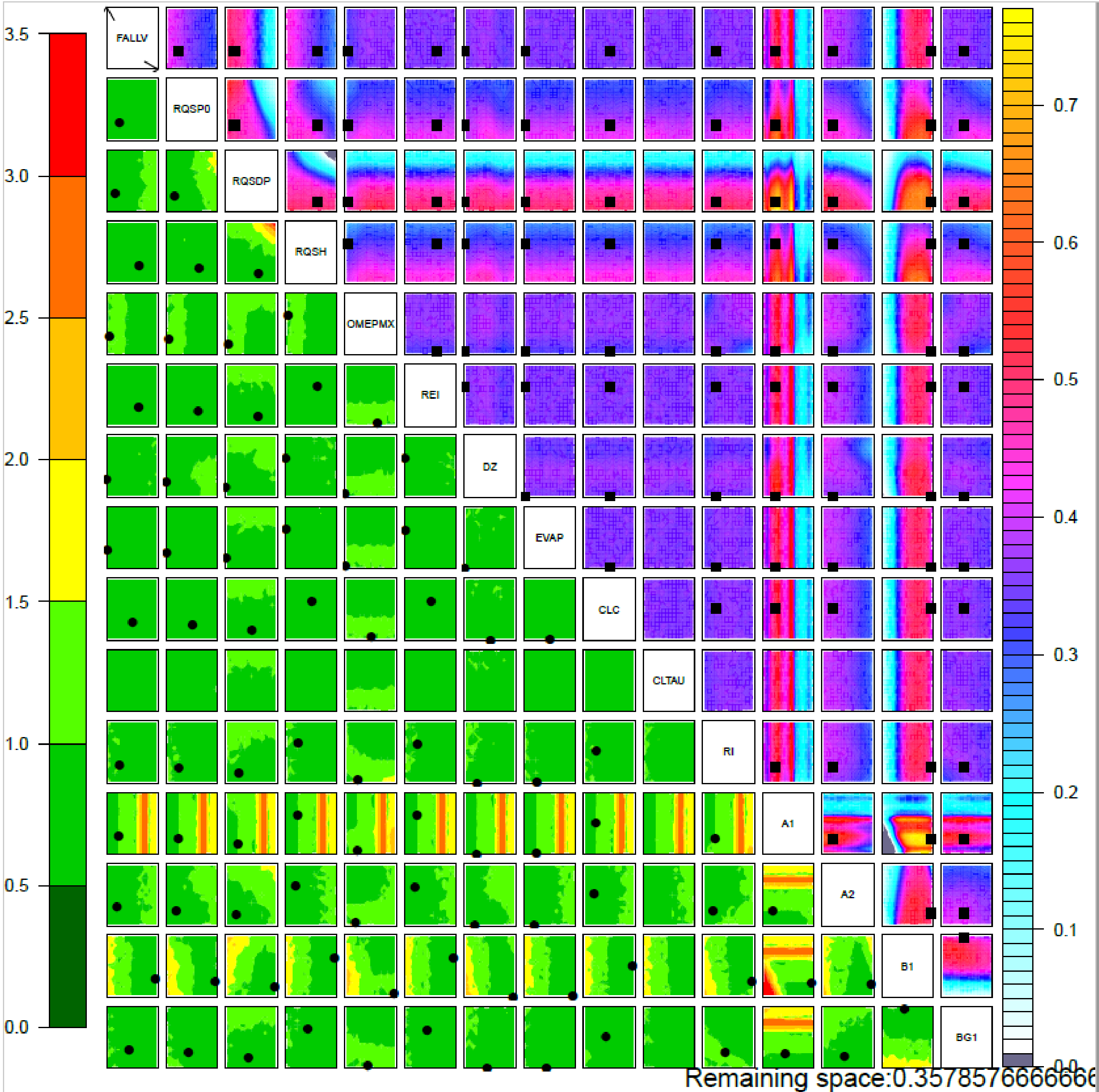
- Significant increase of the surface rain rate in ARMCU and RICO
- Little changes in the SANDU case
- Diminution of the cloud base height and mid-level cloud fraction in the RICO case



Tuning process using HighTune tools

WAVE 1

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



Tuning process using HighTune tools

WAVE 3

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
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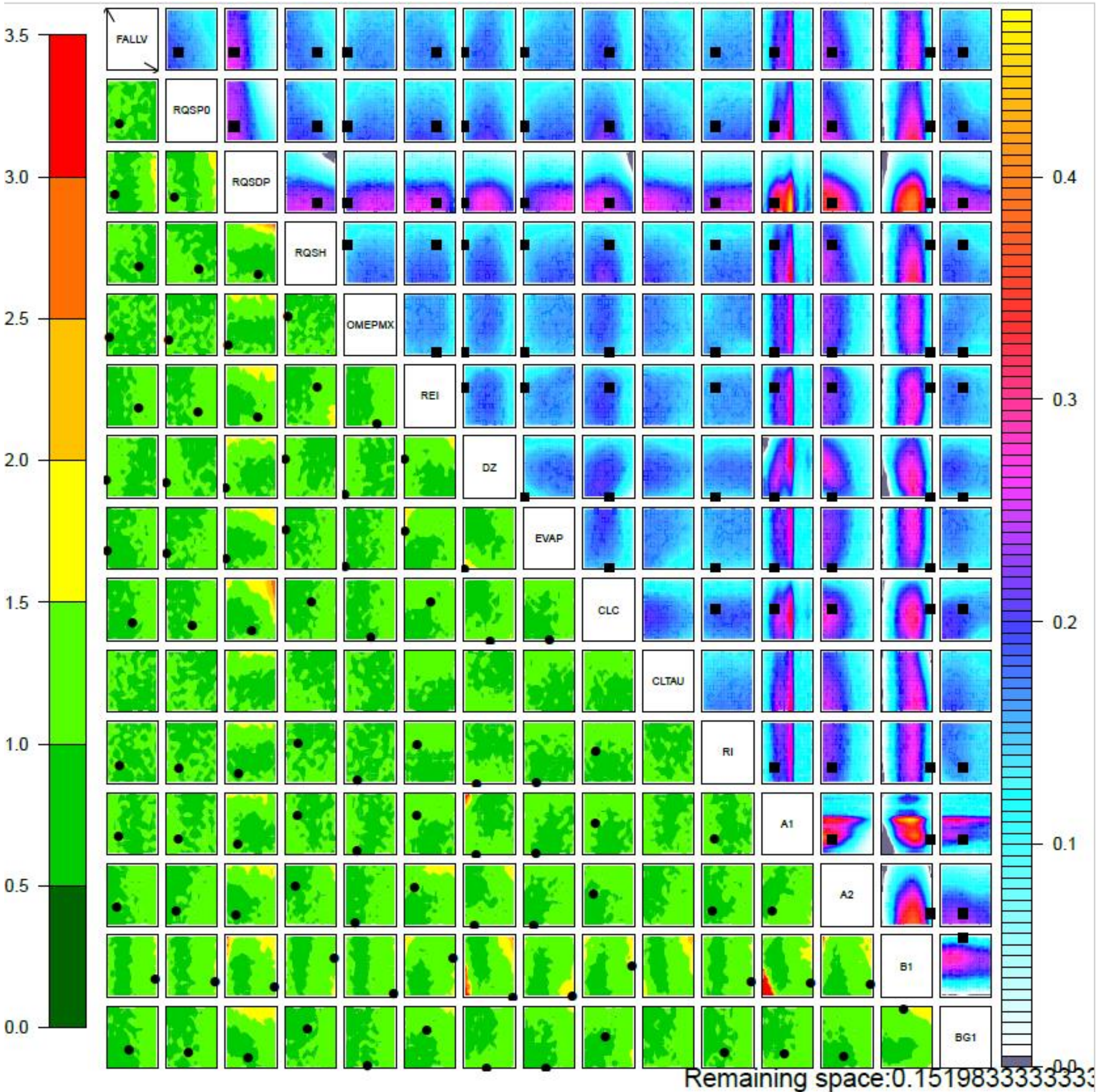
A2	1.5e-3	4.e-3	2.e-3	drag term in the plume acceleration
B1	0	1	0.95	scaling factor for entrainment and detrainment
BG1	0.4	2	1.1	width of the environmental subgrid scale water distribution



Tuning process using HighTune tools

WAVE 5

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
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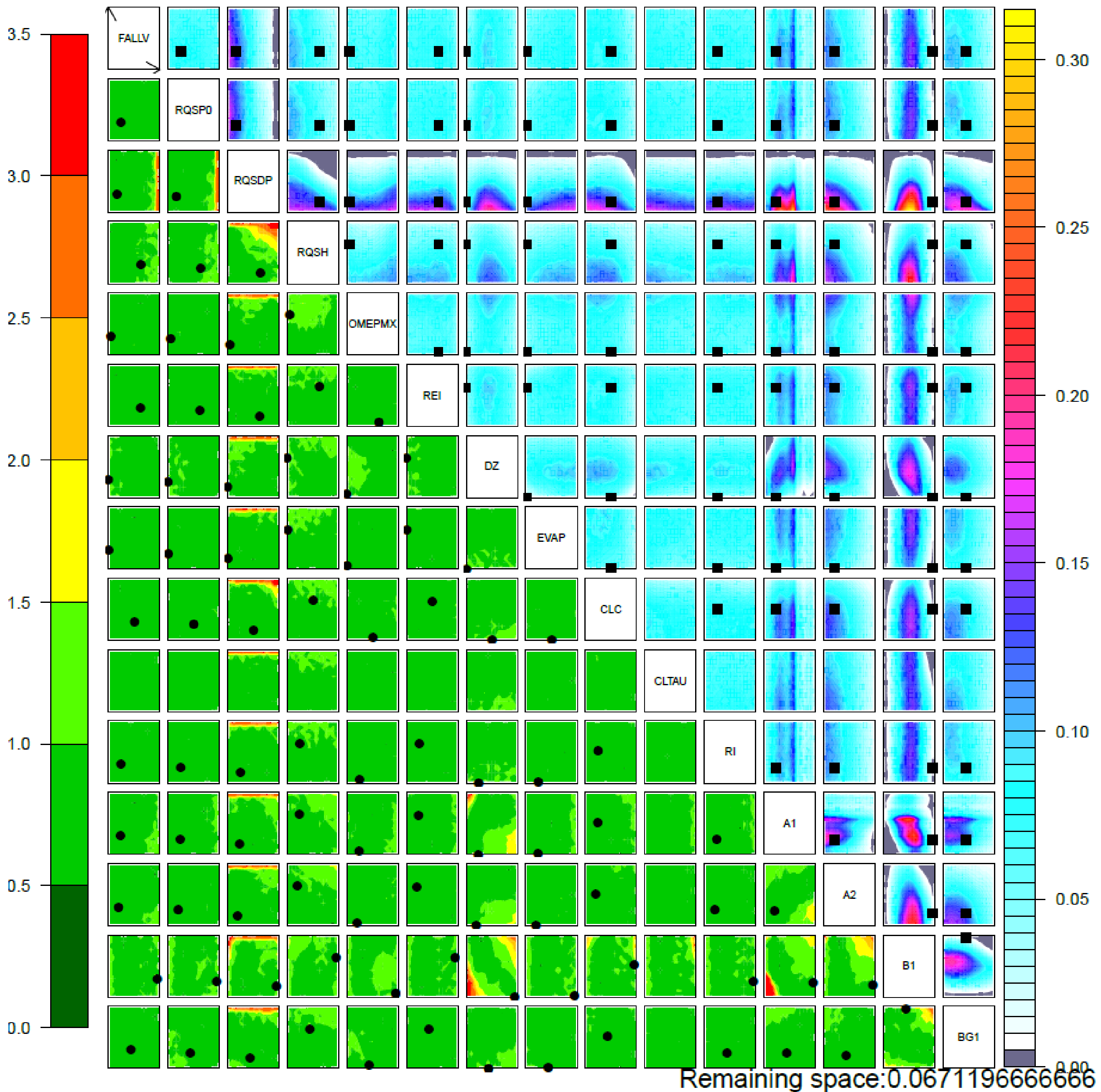
RI	5e-6	2e-3	5e-4	minimum rain intensity before linear decrease of the precipitation fraction
A1	0.5	1.2	0.66667	Contribution of buoyancy to the plume acceleration
A2	1.5e-3	4.e-3	2.e-3	drag term in the plume acceleration
B1	0	1	0.95	scaling factor for entrainment and detrainment
BG1	0.4	2	1.1	width of the environmental subgrid scale water distribution



Tuning process using HighTune tools

WAVE 10

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
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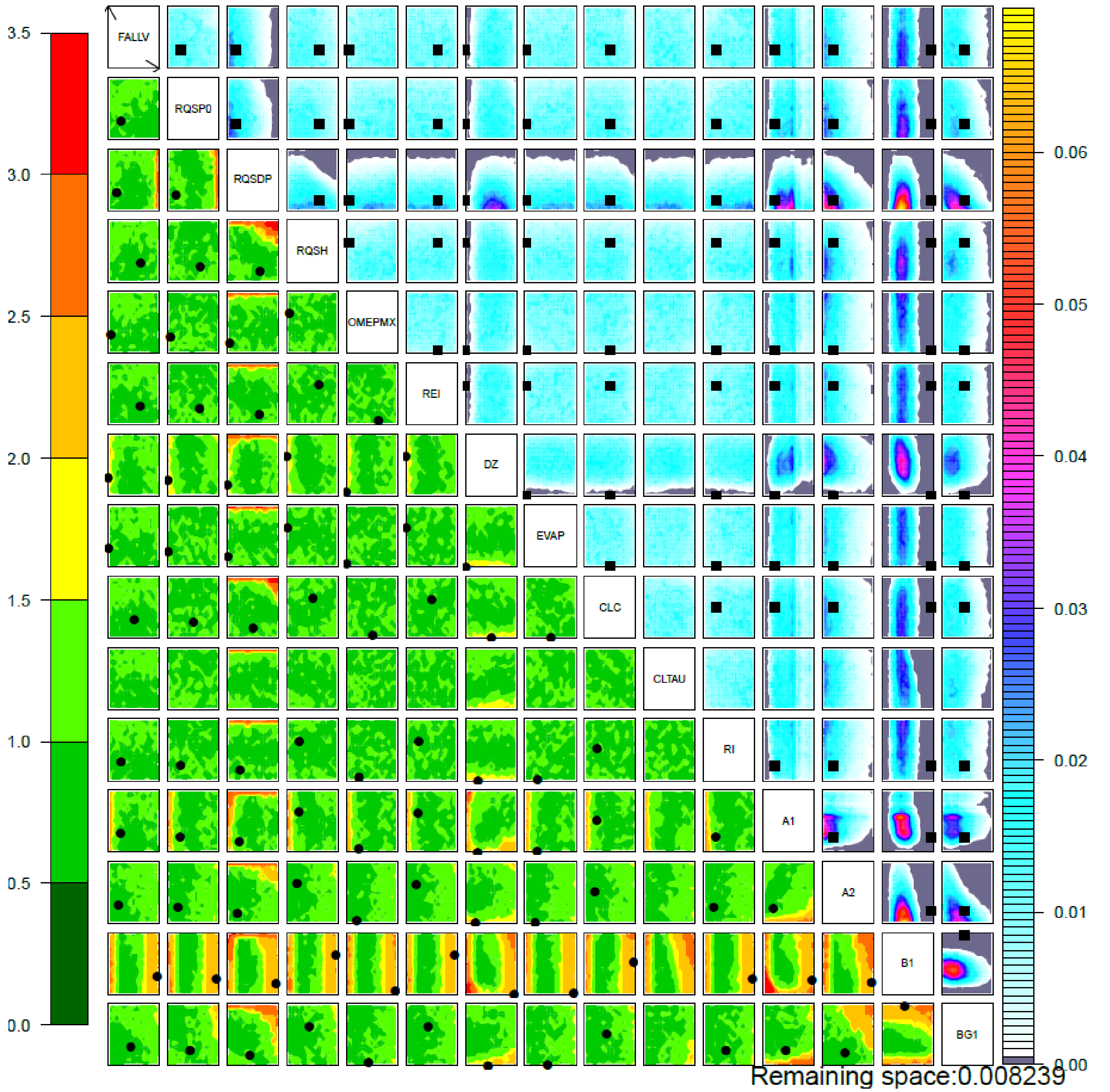
A1	0.5	1.2	0.66667	Contribution of buoyancy to the plume acceleration
A2	1.5e-3	4.e-3	2.e-3	drag term in the plume acceleration
B1	0	1	0.95	scaling factor for entrainment and detrainment
BG1	0.4	2	1.1	width of the environmental subgrid scale water distribution



Tuning process using HighTune tools

WAVE 20

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
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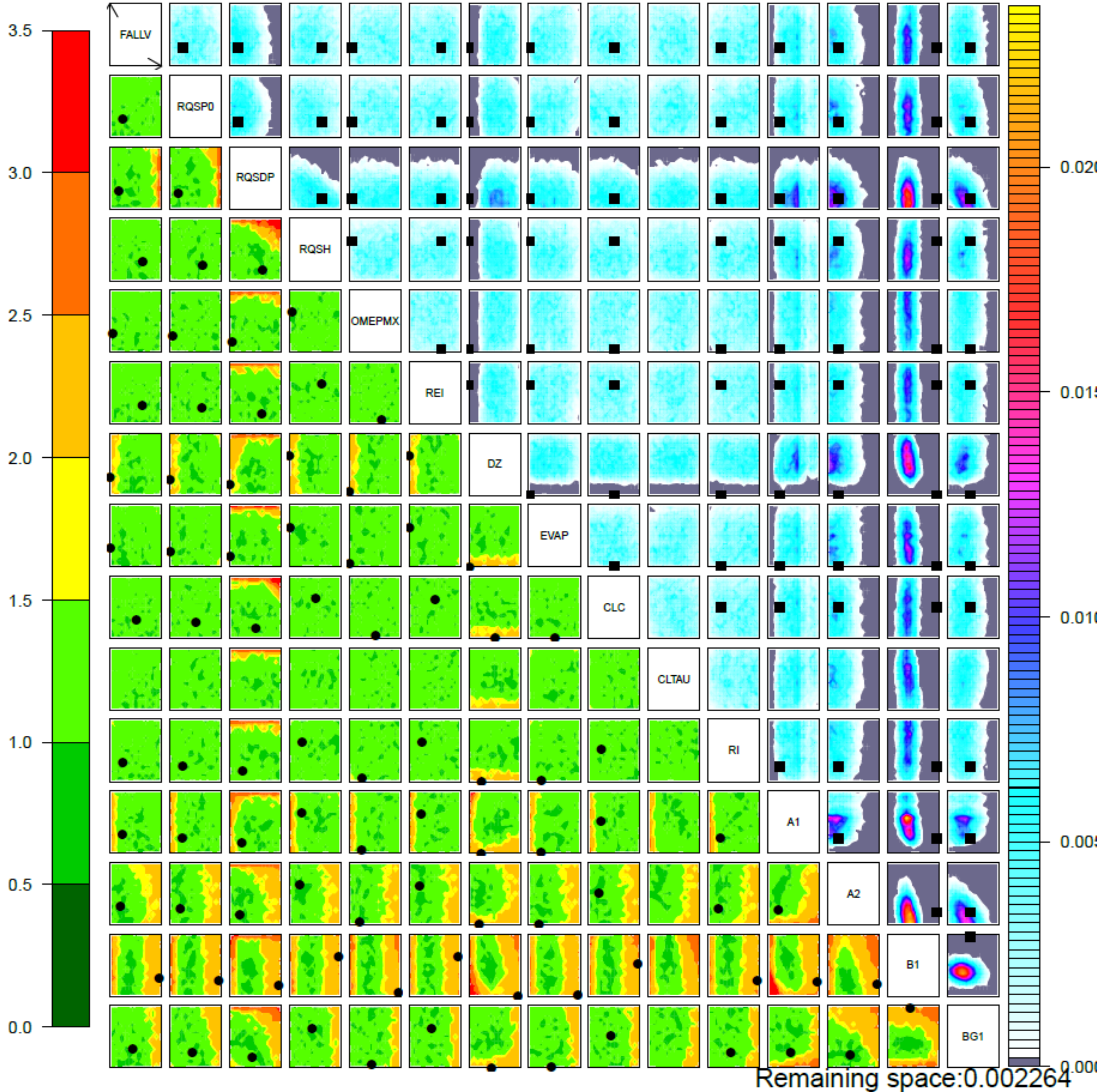

Tuning process using HighTune tools

WAVE 40

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
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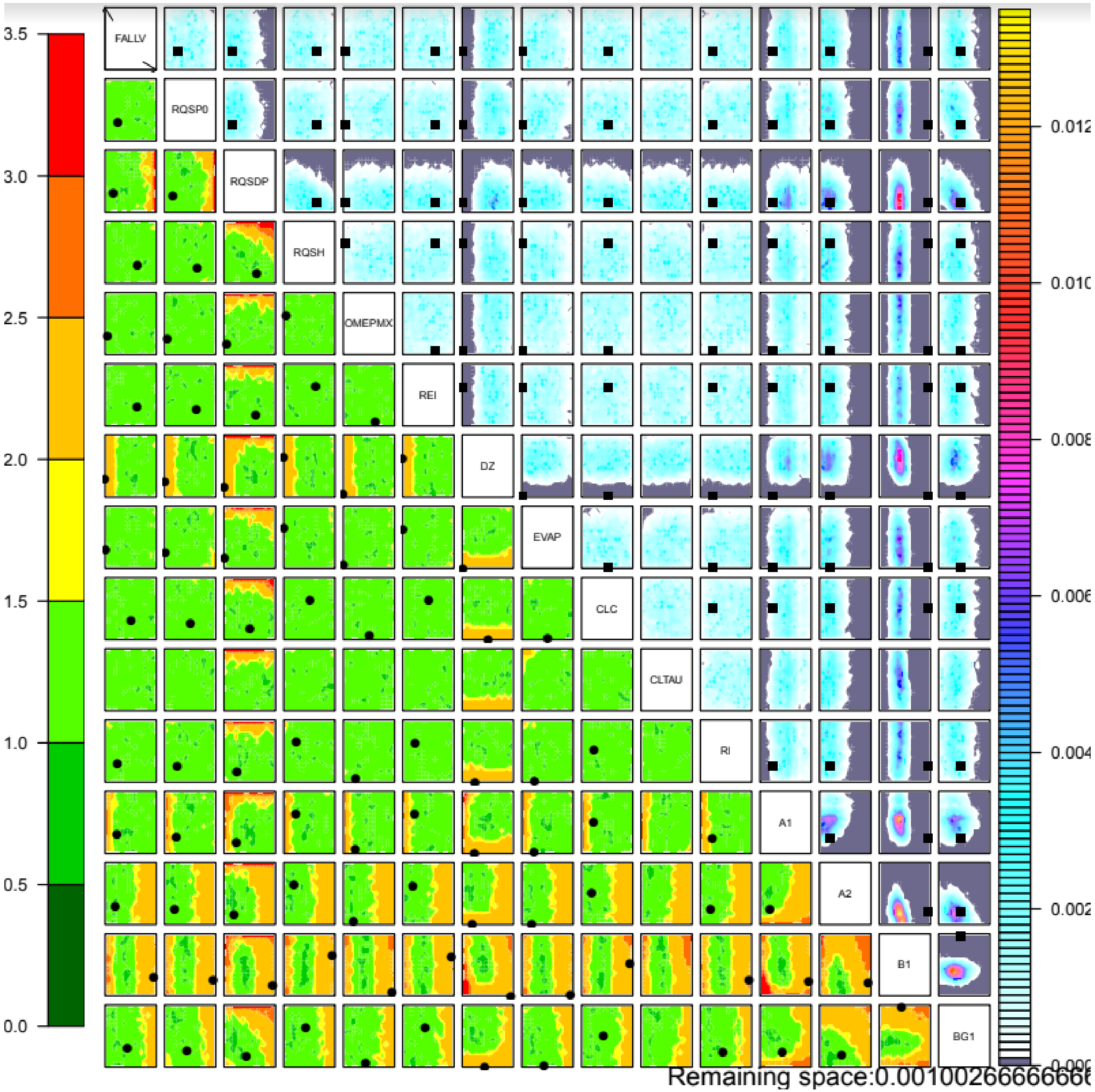
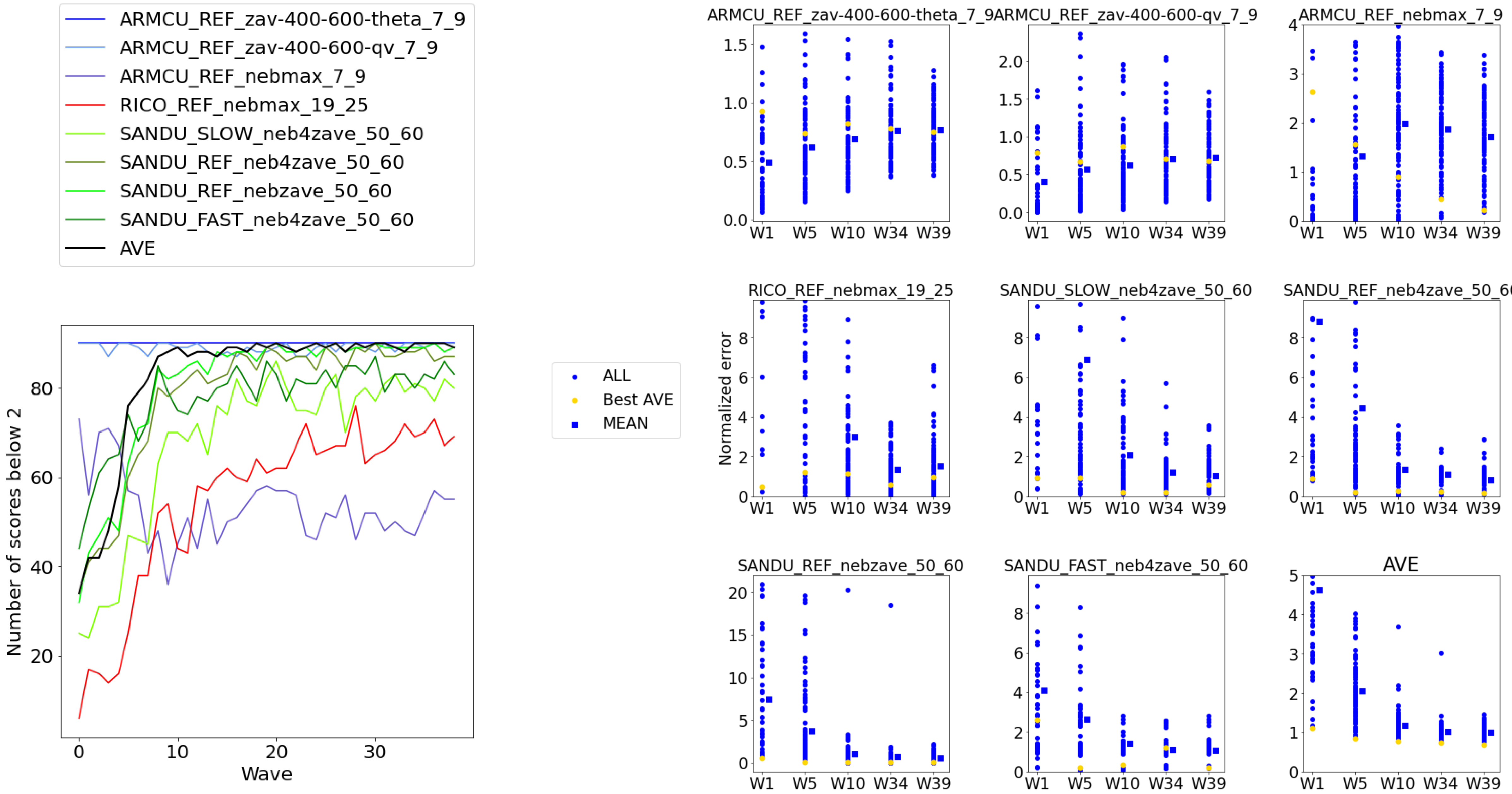


Tuning process using HighTune tools



Test of one "best simulation" after tuning

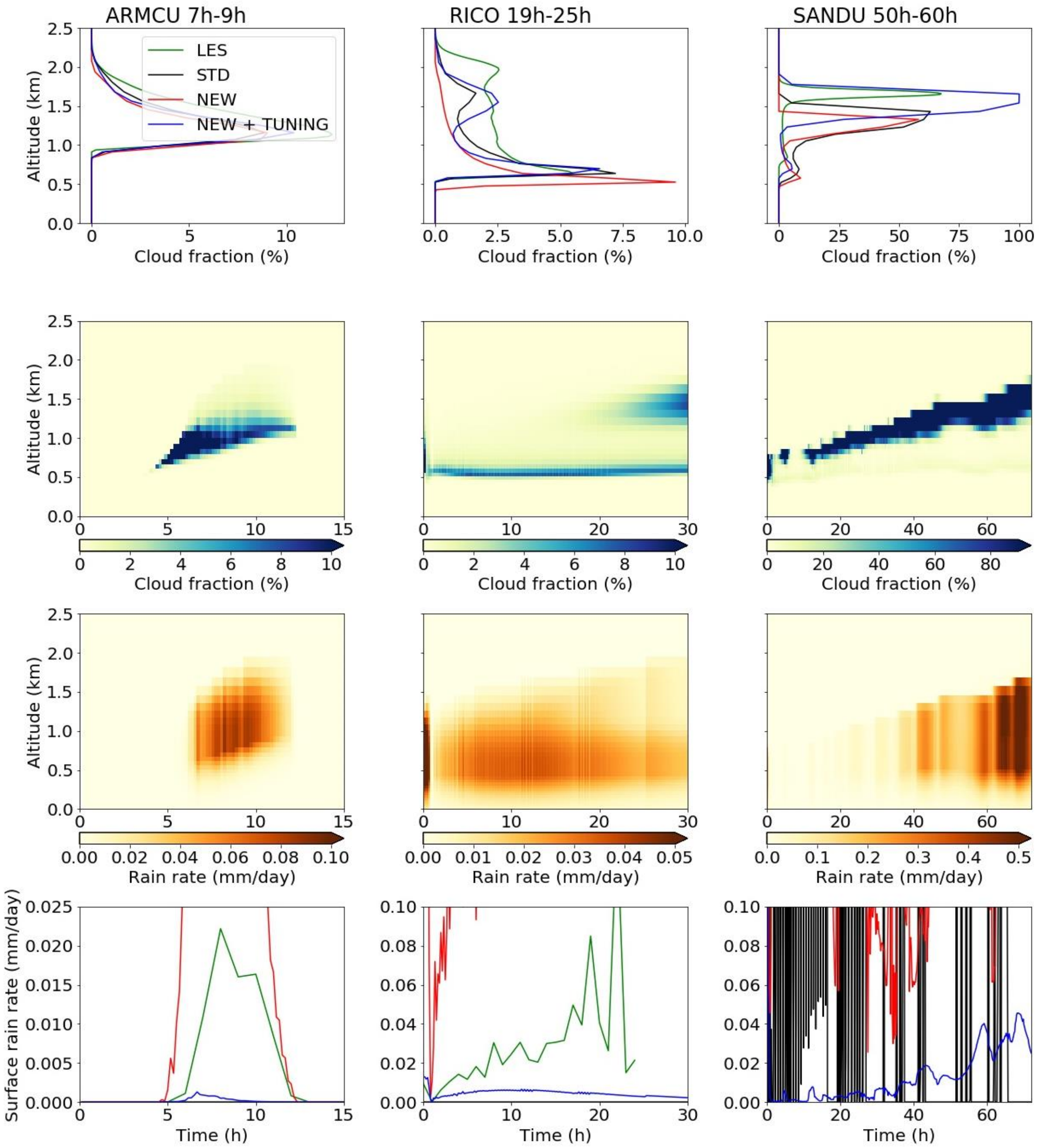
<u>Results</u>

- Comparable results in terms of cloud fraction between "best simulations" (**NEW+TUNING**) and the standard version of LMDz (**STD**).

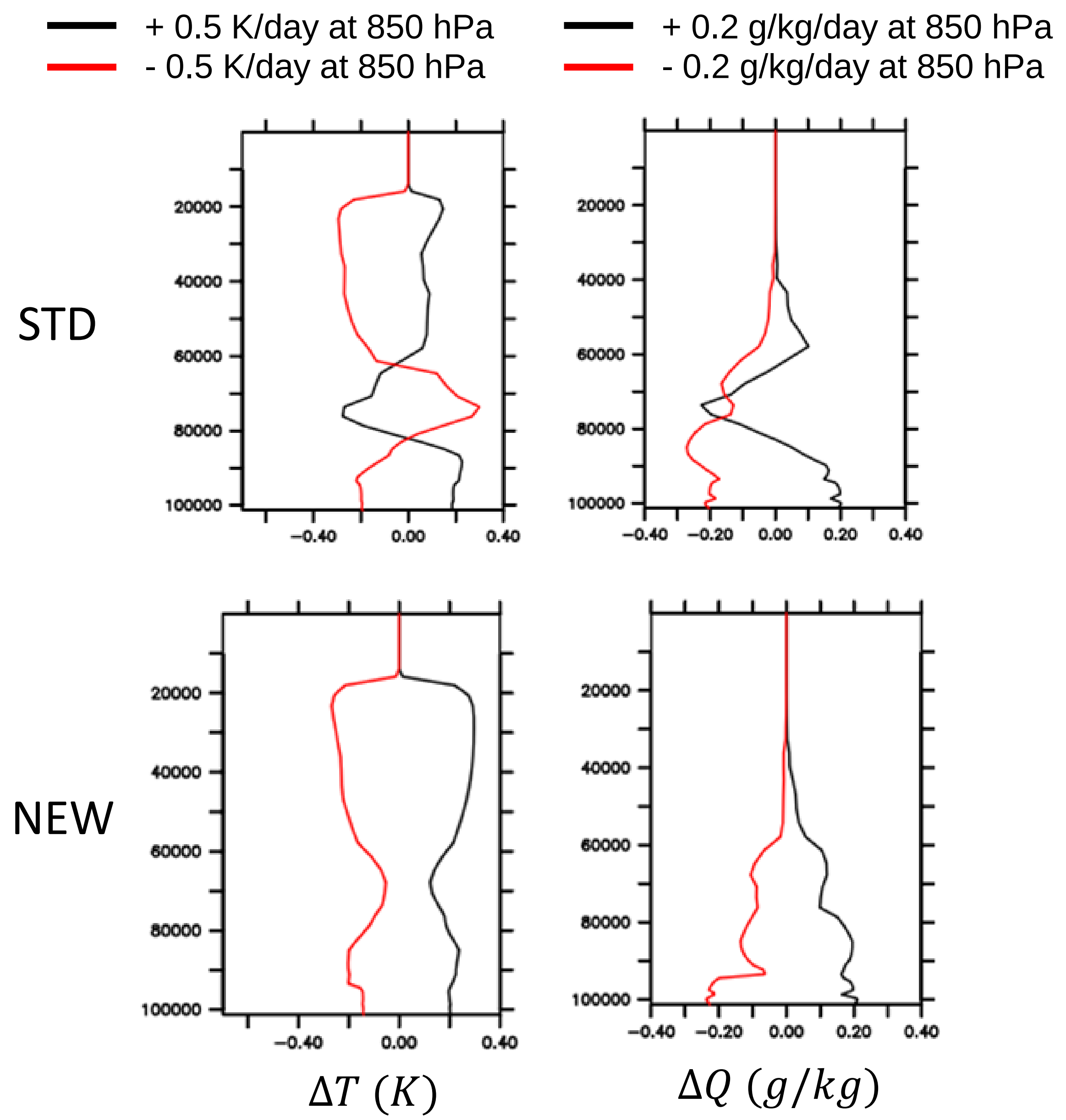
- The rain rate is much weaker after tuning (**NEW+TUNING**) than before (**NEW**).

- Two important differences between **NEW+TUNING** and **STD**:

1. Presence of some precipitation at the surface in the ARMCU and RICO cases in **NEW+TUNING**, whereas no precipitation at all in **STD.**
2. Surface rain rate loses two orders of magnitude in the SANDU case in **NEW+TUNING** compared to **STD.**



Complementary Test in RCE



Setup

- Temperature and humidity tendency perturbations are applied to a Radiative Convective Equilibrium state at 850 hPa
- The new equilibrium state is compared to the native RCE state (see Hwong et al., 2021, for more details)

Results

- Strange non linearity around 700 hPa in the standard version of LMDz (STD).
- The response of the NEW version is more linear and shows better agreement with the CRMs.

Conclusions

- A new parameterization inspired from Jakob and Klein (2000) is introduced to take into account **cloud and precipitation overlap** in the large-scale condensation scheme in LMDz.

- The **HighTune tools** are used with a selected set of metrics to tune the version of LMDz containing this new parameterizations. Tests of the new parameterization shows promising results both in 1D and in RCE experiments.

- <u>More coming soon:</u> 3D waves are currently being performed to assess the impact of the new parameterization in the GCM version of LMDZ.