Coupling aerosols to (cirrus) clouds in a global aerosol-climate model

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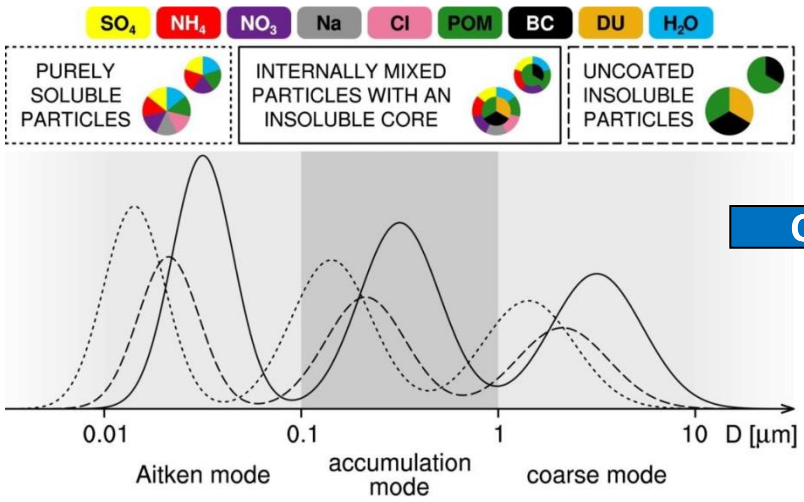
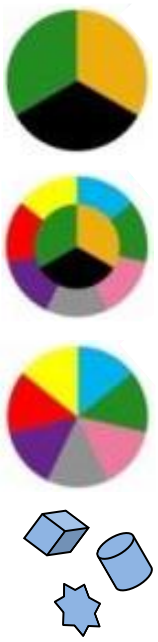
Aerosol submodel MADE3 and coupling to cirrus parametrization in EMAC



COUPLING



Externally mixed DU and BC
→ deposition nucleation

DU and BC with soluble coating
→ immersion freezing

Supercooled solution droplets
→ homogeneous freezing

Pre-existing ice crystals

Dynamical forcing
(updraft)

Nucleation and growth of ice crystals

Ice formation processes

Competition for supersaturated water vapor

Ice crystals
(number concentration and size)

MADE3 aerosol submodel in EMAC

- **9 aerosol types**
- **3 mixing states** (soluble, insoluble and mixed) in 3 log-normal size modes ⇨ **9 modes**
- Explicit simulation of aerosol **mass and number** concentrations
- Microphysical processes: **new particle formation**, **coagulation**, **condensation** and gas-aerosol **partitioning**

Kaiser et al. (2014, 2019)

Cirrus parametrization

- Competition between **homogeneous** and **heterogeneous** freezing
- Consideration of **pre-existing ice crystals**
- Ice nucleating particles: **black carbon** (BC) and **mineral dust** (DU)

Kärcher et al. (2006)
Hendricks et al. (2011)
Kuebbeler et al. (2014)

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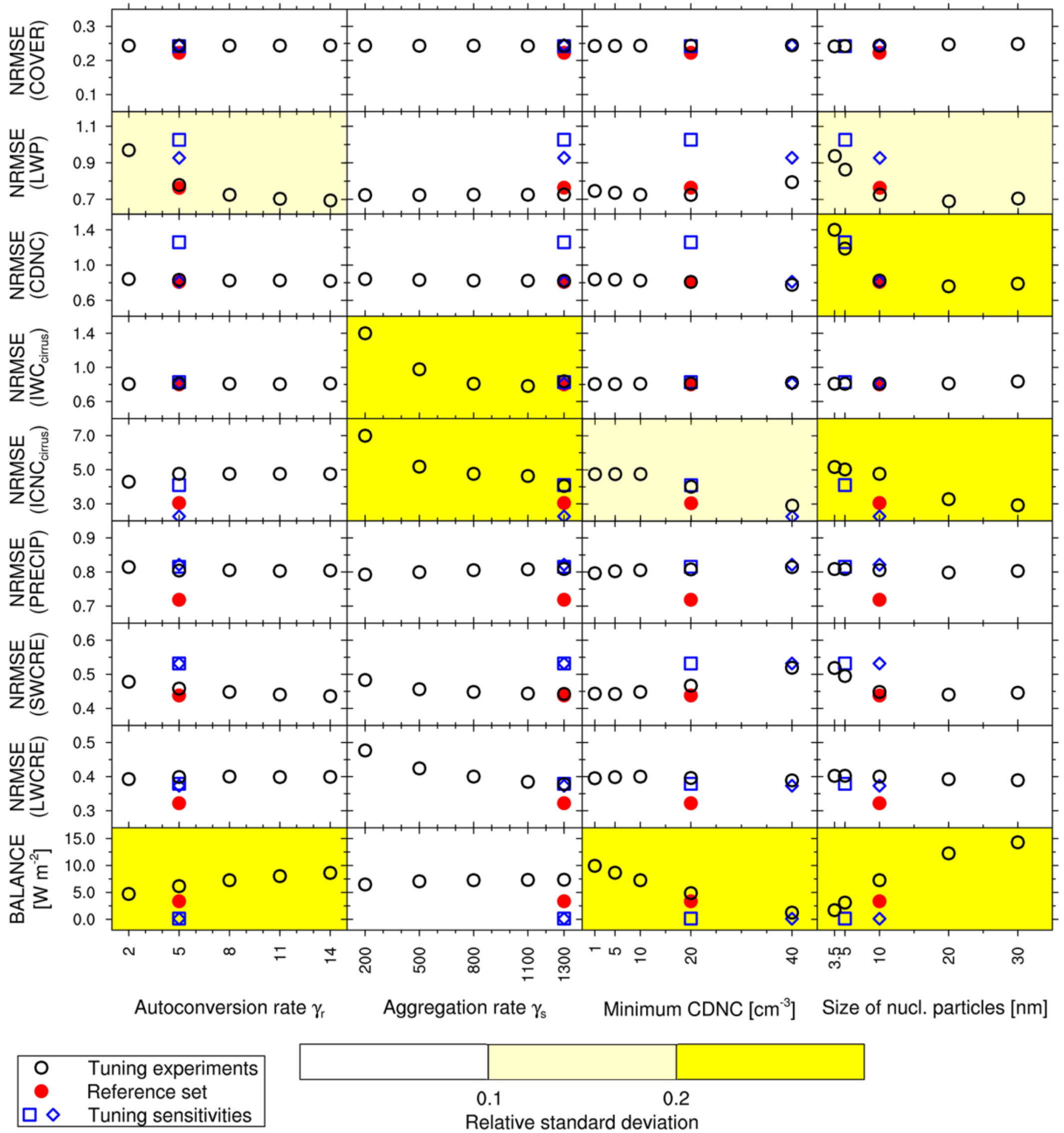
Tuning of the new model configuration



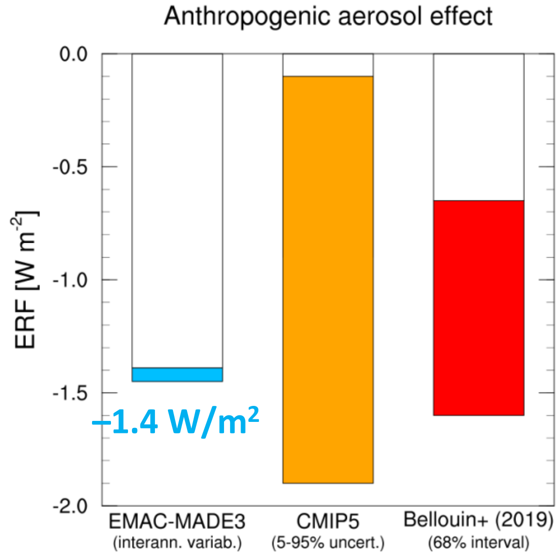
- Focus on **4 tuning parameters**:
  - Autoconversion rate
  - Aggregation rate
  - Minimum CDNC
  - Size of newly nucleated aerosol particles
- For each tuning parameter **5 different values** are tested.
- This results in **17** tuning simulations + **3** additional sensitivities.
- The impact of a specific tuning parameter on the model (cloud and radiation) variables is **quantitatively assessed** by means of the **normalized RMSE** between model and observations:

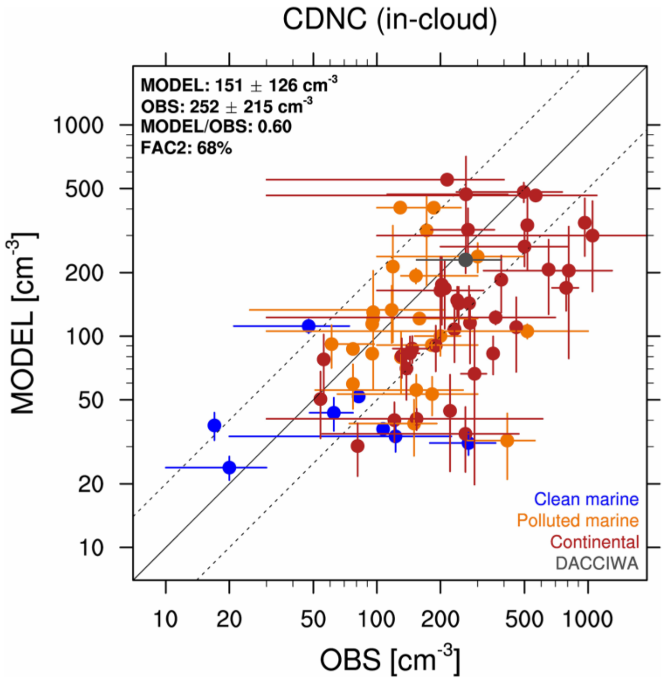
$$\mathrm{NRMSE} = \sqrt{\frac{\sum_i (M_i - O_i)^2}{n}} \Bigg/ \frac{\sum_i O_i}{n}$$

- The sensitivity of a given model variable to the variation of a specific tuning parameter is then quantified with the **relative standard deviation** (RSD).
- This method allows to identify the most important **parameter-variable combinations** and optimally tune them.

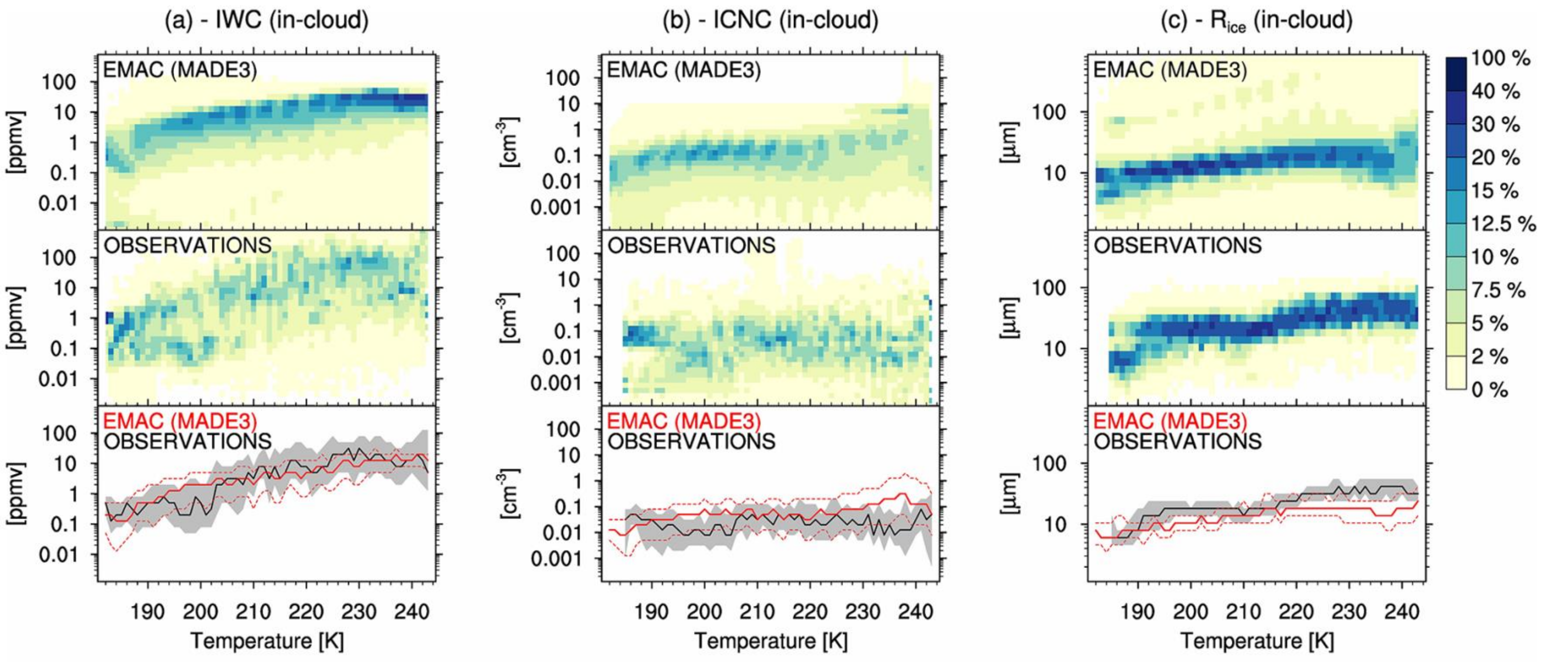
Model evaluation

	This study	Observations	ECHAM5-HAM	ECHAM6-HAM2	EMAC-GMXe	NCAR-CAM5.3	ECHAM6.3-HAM2.3
Cloud cover (%)	66.0	64.5 ± 17.4	62.3	68.1	[69.0; 70.0]	[69.3; 72.2]	[64; 69]
LWP oceans ($g\,m^{-2}$)	84.1	83.0 ± 10.2	55.6	70.6	[72.7; 76.6]	[45.7; 57.7]	[71; 94]
CDNC (cm^{-3})	89.9	74.0 ± 41.1	–	–	–	–	[76, 80]
IWC_{cirrus} (ppmv)	5.7	7.2 [1.7; 29.2]	–	–	–	–	–
$ICNC_{cirrus}$ (cm^{-3})	0.08	0.03 [0.006; 0.10]	–	–	–	–	–
Precipitation ($mm\,d^{-1}$)	3.1	2.7 ± 0.2	2.87	2.99	[2.89; 3.03]	[2.73; 2.80]	3.0
SWCRE ($W\,m^{-2}$)	−53.1	−45.9 ± 5.5	−54.8	−49.9	[−58.1; −54.8]	[−66.3; −58.5]	[−53; −50]
LWCRE ($W\,m^{-2}$)	27.4	28.1 ± 4.4	28.8	24.1	[28.9; 34.4]	[32.1; 36.7]	[24; 28]
Radiative balance ($W\,m^{-2}$)	3.4	–	−0.6	–	[1.53; 4.65]	–	[−0.1; 0.4]





Data collection by Karydis et al. (2017)



Climatology of aircraft measurements by Krämer et al. (2016, 2020)

Conclusions and future applications of the model

1. EMAC-MADE3 is able to reproduce the **global pattern** of the main **cloud** and **radiation** variables in comparison with satellite and in-situ data.

2. Specific **deviations**, in particular in the representation of **liquid water path** which could point to **an overestimated cloud lifetime**, mostly confirm **known biases** of the ECHAM5 model and can therefore not be attributed to the new cloud scheme introduced in this work.

3. A more detailed evaluation of cloud variables in the cirrus regime against an **aircraft based** climatology of in-situ measurements demonstrates the ability of EMAC-MADE3 to adequately represent **ice water content** and **ice crystal number concentration** in cirrus clouds over a wide range of temperatures, albeit with a **positive bias** for the ice crystal number at higher temperatures.

4. The overall performance of EMAC-MADE3 in simulating global cloud and radiation variables is **in line with the results of the CMIP5 models**.

5. Model **biases** in the representation of cirrus clouds are **common to other models**, such as ECHAM5-HAM, EMAC-GMXe, and NCAR-CAM3.5, using various parametrizations for aerosol-induced ice formation in cirrus clouds.

6. Further work is ongoing to characterize the role of **aerosol-induced ice formation on climate**.

Righi et al., *Geosci. Model Dev.*, doi:10.5194/gmd-13-1635-2020, 2020