Satellite-derived warm rain fraction as constraint on cloud lifetime effect in GCMs

Johannes Mülmenstädt,¹ Amund Søvde,² Gunnar Myhre,² Shipeng Zhang,³ Minghuai Wang,³ Takuro Michibata,⁴ Toshi Takemura,⁴ Ivy Tan,⁵ Philip Stier,⁶ Stefan Kinne,⁷ Tristan L’Ecuyer,⁸ Johannes Quaas¹

¹Universität Leipzig ²CICERO ³Nanjing University ⁴Kyushu University ⁵NASA ⁶University of Oxford ⁷MPI ⁸University of Wisconsin

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Precipitation
High radar reflectivity of rain drops

→ CloudSat CPR via 2C-PRECIP-COLUMN or DARDAR_MASK

Liquid-topped clouds
High lidar backscatter at cloud top from liquid droplets

→ CALIOP via DARDAR_MASK

Ice clouds
High radar reflectivity of ice particles

→ CPR via DARDAR_MASK

after Rosenfeld et al. (2008), Science
Rain from pure liquid clouds ("warm rain") is very rare over the extratropical continents.
Warm rain fraction can serve as a process-based observational constraint on parameterized precipitation

- Warm rain fraction can be diagnosed in models

- Warm rain fraction means the same thing in models and satellite

- Warm rain fraction allows us to draw conclusions on precipitation processes active in the model and in reality

- Warm rain fraction has not been tuned to death
Outline

Motivation

Warm rain fraction in observations and GCMs

Tuning the warm rain fraction in ECHAM–HAM
Compare satellite climatology to CMIP5 cfSites
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Warm rain fraction (%)

GCM
Modeled warm rain fraction is diverse

![Image of world map with color-coded warming fractions]

Legend:
- $f_{\text{warm}}$:
  - 0.05
  - 0.1
  - 0.2
  - 0.4
  - 0.6
  - 0.8
  - 1
Outline

Motivation

Warm rain fraction in observations and GCMs

Tuning the warm rain fraction in ECHAM–HAM
Scale factor on autoconversion rate: $10^{-4} \times Q_{\text{aut}}$ reproduces observations
Threshold on autoconversion: $r_e > 17\ \mu m$ reproduces observations
These modifications are related

Khairoutdinov and Kogan (2000):

\[ \frac{\partial q_r}{\partial t} \propto q_l^\alpha N^\beta, \quad \alpha = 2.47, \beta = -1.79 \]  

\[ (1) \]

Since

\[ q_l \propto r_e^3 N \]  

\[ (2) \]

the autoconversion rate can be rewritten as a function of \( r_e \) and either of \( q_l \) or \( N \):

\[ \frac{\partial q_r}{\partial t} \propto \begin{cases} r_e^{3\alpha} N^{\alpha+\beta} \\ r_e^{-3\beta} q_l^{\alpha+\beta} \end{cases} \]  

\[ (3) \]

Under the simplifying assumption that \( r_e \) is uncorrelated with either of \( q_l \) or \( N \), we expect the autoconversion rate to scale with \( r_e^{5.5 \sim 7.5} \), which effectively sets an \( r_e \) threshold.
Retuning TOA radiative balance — accretion comes to the rescue

TOA balance ($W m^{-2}$)

Threshold $r_e$ ($\mu m$)

$Q_{acc} \times$

- 1
- 10
- 100
Links to mixed-phase parameterizations

![Map showing different parameterizations](image)

- **Control**
- **SLF1**
- **SLF2**
- **Satellite**

The color scale represents $f_{\text{warm}}$ with values ranging from 0.05 to 1.0.
Effect on precipitation intensity distribution

- Reducing the warm rain fraction also increases the intensity spectrum.
- Shown here are large-scale precipitation intensity spectra at different latitude bands.
- Decreasing the warm rain fraction increases the probability of intense large-scale precipitation.
Effect on precipitation intensity distribution — probably consistent across CMIP5 models

▶ In most cfSites models, warm rain is less intense than cold rain
▶ Decreasing the warm rain fraction would therefore probably increase the probability of intense precipitation in these models as well

![Graph showing precipitation intensity distribution across different models](image-url)
Tuning the warm rain fraction in ECHAM–HAM: conclusions

- Warm rain fraction is very low over continents (especially extratropical NH)

- Warm rain fraction can be diagnosed in GCMs and may serve as a process-based observational constraint on parameterized precipitation

- Satellite warm rain fraction can be reproduced in ECHAM–HAM by multiplying the Khairoutdinov and Kogan (2000) autoconversion rate by $10^{-4}$ (default ECHAM–HAM tuning factor: 4) or imposing an $r_e > 17 \mu m$ threshold on autoconversion

- TOA radiative budget is strongly affected (large increase in low cloud), but balance can be restored by tuning up accretion

- Reducing the warm rain fraction to match the satellite climatology also increases the intensity spectrum; most other CMIP5 models would likely respond similarly
Hypothesis: warm-rain fraction can serve as an observational constraint on the cloud lifetime effect

- Aerosol influence mainly acts on autoconversion in liquid-water clouds in current models

- The more precipitating warm clouds are simulated in a model, the more opportunity aerosols have to influence the precipitation microphysics

- We hypothesize that the strength of the cloud lifetime effect in models is therefore related to the warm-rain fraction

- This hypothesis can be tested in GCMs with parameterized cloud lifetime effect

- Comparing warm-rain fraction in models against satellites may provide an observational constraint on the cloud lifetime effect
Influence of the warm-rain fraction on $\text{ERF}_{\text{aer}}$

Results for ECHAM6.1–HAM2.2, AeroCom II 1850/2000 emissions

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<th>SW PD − PI (W m$^{-2}$)</th>
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As hypothesized, the configuration with lower warm-rain fraction has a smaller $\text{ERF}_{\text{aer}}$. The change is $−0.5$ W m$^{-2}$ SW offset by $0.3$ W m$^{-2}$ LW $⇒$ plausible that $\text{ERF}_{\text{aer}}$ change is a large contribution $⇒$ (Low-ccraut configuration has not been retuned and $\text{ERF}_{\text{aci}}$ has not been diagnosed separately from $\text{ERF}_{\text{aer}}$ yet)
Influence of the warm-rain fraction on ERF_{aer}

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Comparison to Golaz et al. (2011)

- In GFDL AM3, higher critical $r_e$ leads to stronger ERF, in contrast to our results.
- In AM3, the decrease in $q_l$ due to autoconversion during a time step is limited to

$$q_l \geq q_{\text{crit}} = \frac{4}{3} \pi \frac{\rho l}{\rho} r_{\text{crit}}^3 N_d$$  \hspace{1cm} (4)

- In practice, this limit almost always applies, so that $q_l \approx q_{\text{crit}}$
- The anthropogenic perturbation to $N_d$ therefore results in a change in $q_l$ is therefore

$$\Delta q_l \approx \frac{4}{3} \pi \frac{\rho l}{\rho} r_{\text{crit}}^3 \Delta N_d,$$  \hspace{1cm} (5)

i.e., the perturbation grows with the threshold $r_e$

- In ECHAM-HAM, the combined autoconversion and accretion can deplete $q_l$ beyond threshold $r_e$, so that (5) does not apply

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Golaz et al. (2011), J. Climate
Preliminary conclusions on the relationship between warm-rain fraction and aerosol effects

- Changing the warm-rain fraction (in ECHAM–HAM) changes the ERF_{aci}
  ⇒ As anticipated, aerosol effects are sensitive to the warm-rain fraction

- Plenty of model diversity
  ⇒ Useful as an observational constraint

- Next step: investigate relationship between warm-rain fraction and ERF_{aci} across models
  ⇒ Multiple CAM flavors, SPRINTARS, IFS, ECHAM-HAM, HadGEM(?) are on board as part of an AeroCom experiment

- Participation by other models welcome!
  ⇒ Required output: snow and rain mixing ratio/flux/path, non-accumulated field, ideally 3h; preferably for a model configuration with known ERF_{aci}