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

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Monitoring atmospheric composition & climate – II

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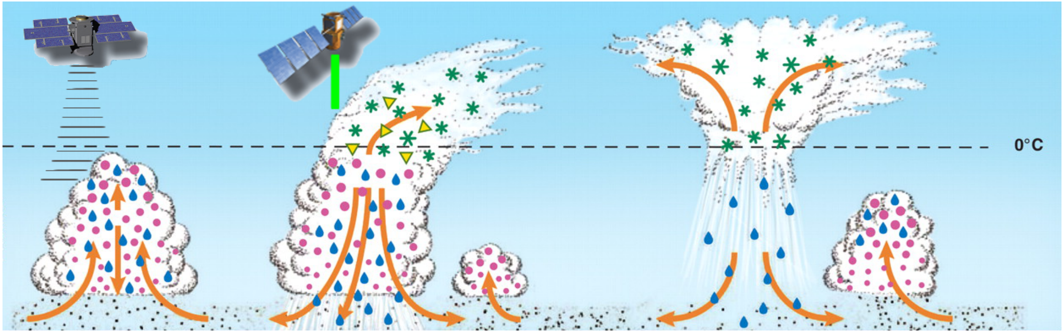

Precipitation

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

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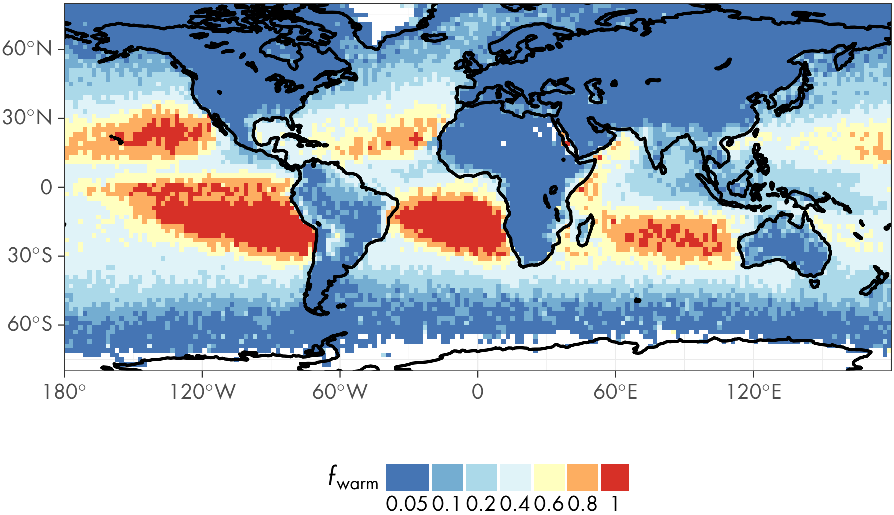
after Rosenfeld et al. (2008), *Science*

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

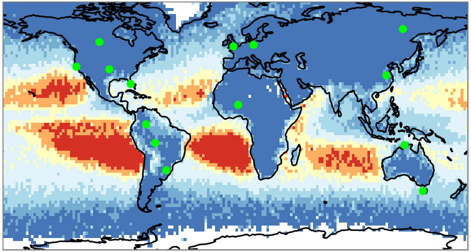
Outline

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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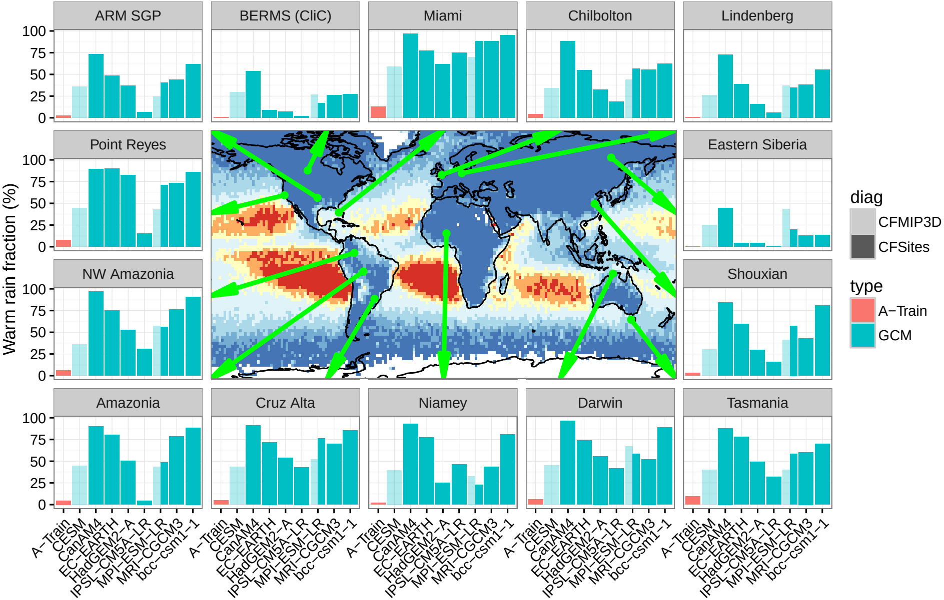

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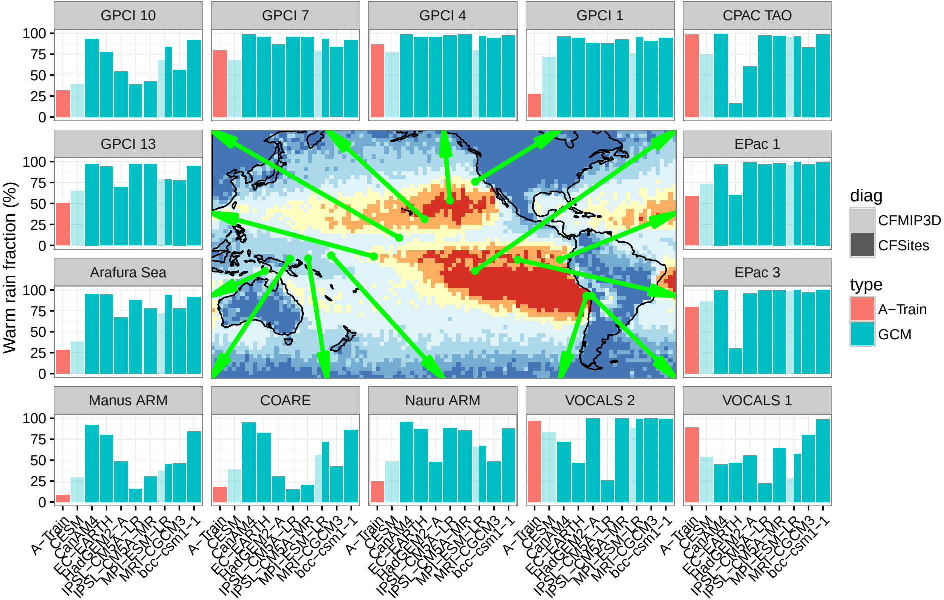
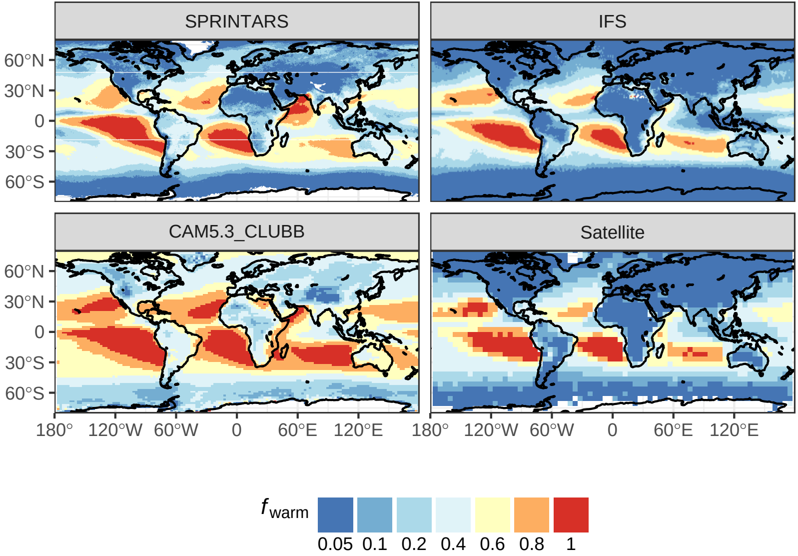


Modeled warm rain fraction is diverse



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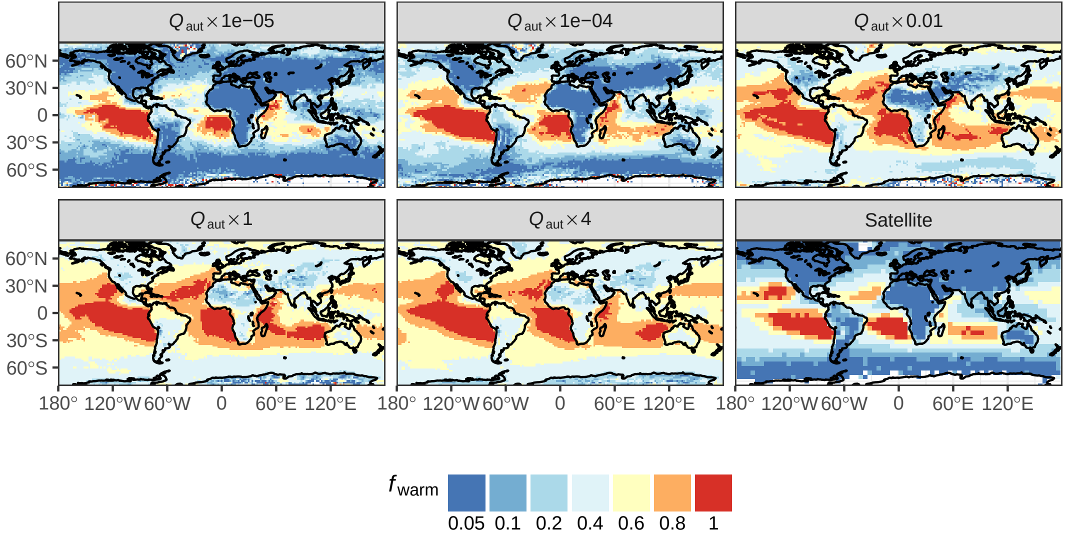
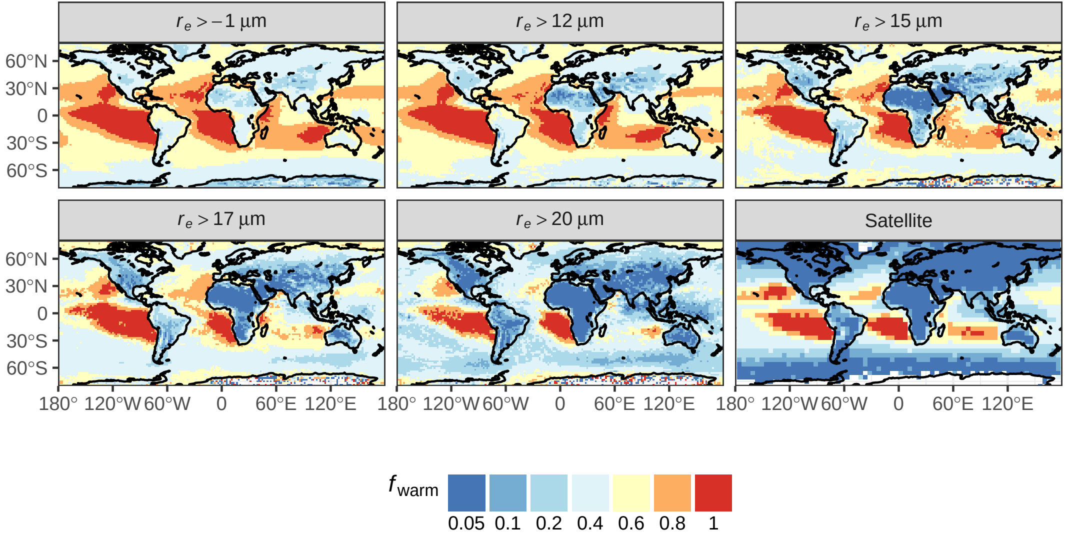
Scale factor on autoconversion rate: $10^{-4} \times Q_{\mathrm{aut}}$ reproduces observations



Threshold on autoconversion: $r_e > 17\ \mu m$ reproduces observations



These modifications are related

Khairoutdinov and Kogan (2000):

$$\frac{\partial q_r}{\partial t} \propto q_l^{\alpha} N^{\beta}, \quad \alpha = 2.47, \beta = -1.79 \tag{1}$$

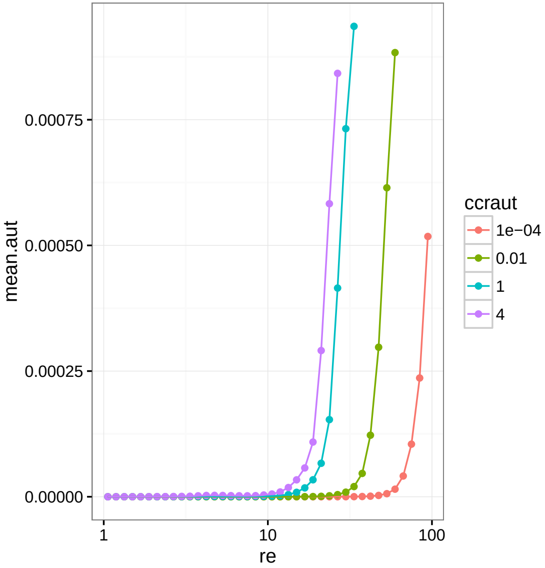
Since

$$q_l \propto r_e^3 N \tag{2}$$

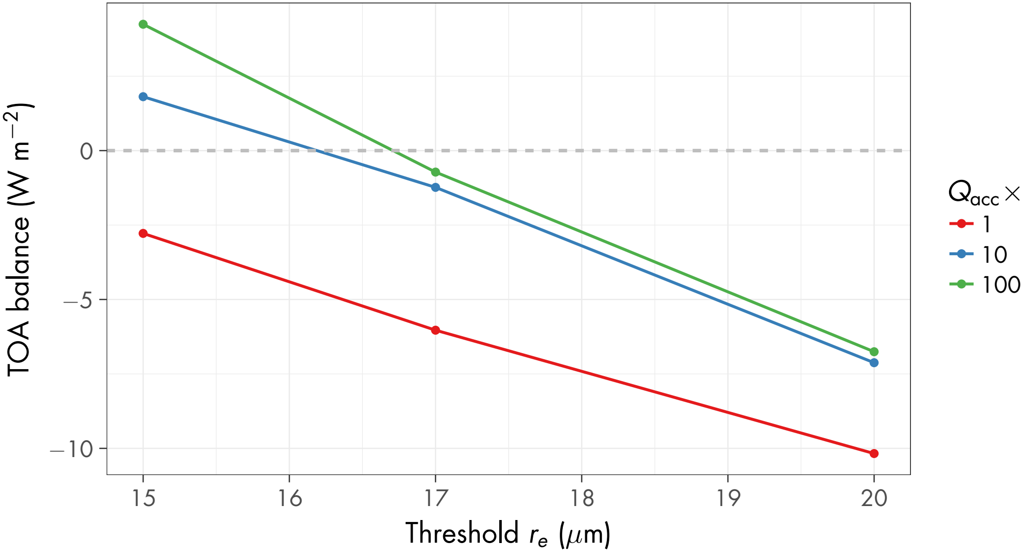
the autoconversion rate can be rewritten as a function of r_e and either of q_l or N:

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

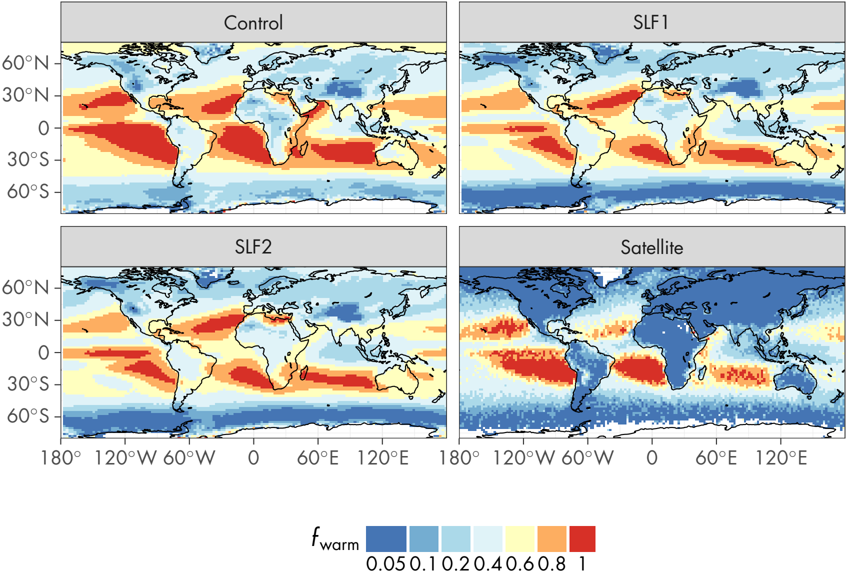
Under the simplifying assumption that r_e is uncorrelated with either of q_l or N, we expect the autoconversion rate to scale with $r_e^{5.5 \sim 7.5}$, which effectively sets an r_e threshold.



Retuning TOA radiative balance — accretion comes to the rescue

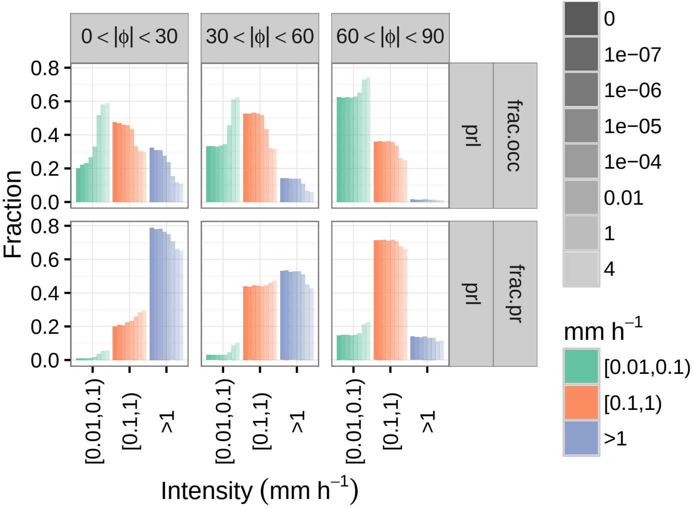


Links to mixed-phase parameterizations



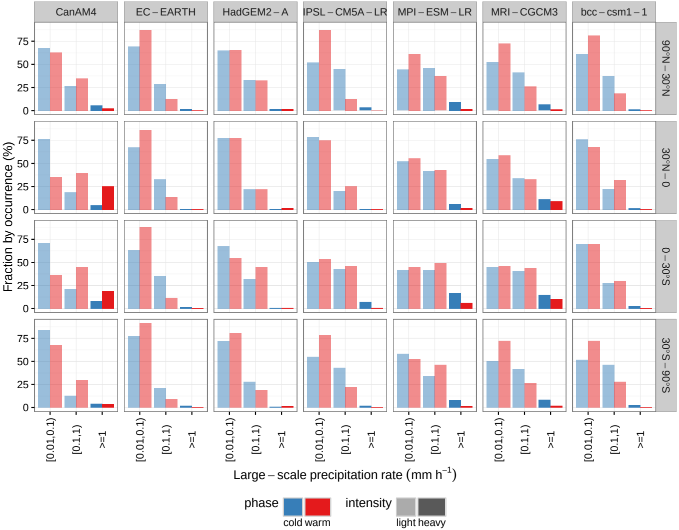
Effect on precipitation intensity distribution

- 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



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 ERF$_{aer}$

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

	SW PD − PI (W m^{-2})	LW PD − PI (W m^{-2})	SW + LW PD − PI (W m^{-2})
Reference	−2.1	1.0	−1.1

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- As hypothesized, the configuration with lower warm-rain fraction has a smaller $\mathrm{ERF}_{\mathrm{aer}}$
- The change is −0.5 W m^{-2} SW offset by 0.3 W m^{-2} LW ⇒ plausible that $\mathrm{ERF}_{\mathrm{aci}}$ change is a large contribution
- (Low-`ccraut` configuration has not been retuned and $\mathrm{ERF}_{\mathrm{aci}}$ has not been diagnosed separately from $\mathrm{ERF}_{\mathrm{aer}}$ yet)

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

$$q_l \geq q_{\text{crit}} = \frac{4}{3}\pi\frac{\rho_l}{\rho}r_{\text{crit}}^3 N_d \tag{4}$$

- 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

$$\Delta q_l \approx \frac{4}{3}\pi\frac{\rho_l}{\rho}r_{\text{crit}}^3 \Delta N_d, \tag{5}$$

  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$_{\mathrm{aci}}$
  - ⇒ 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$_{\mathrm{aci}}$ 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$_{\mathrm{aci}}$