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

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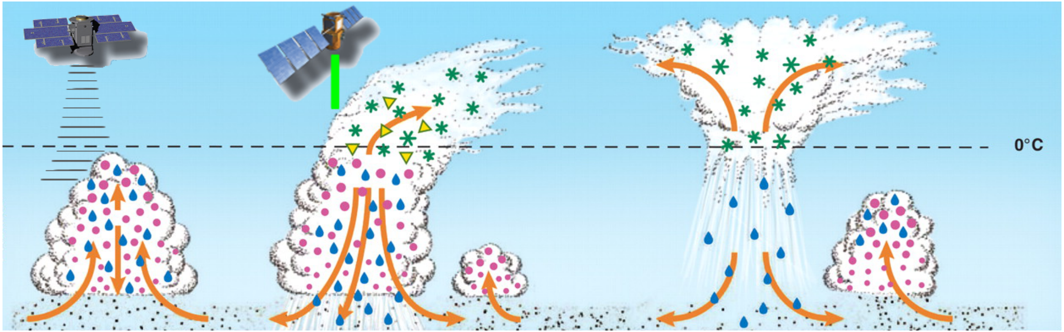


Precipitation

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

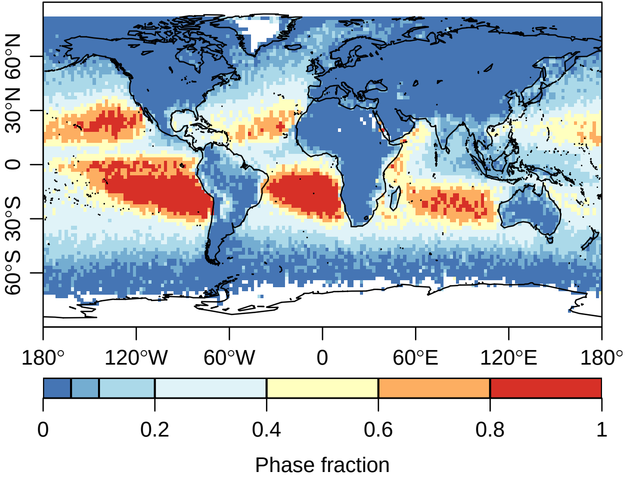
Ice clouds

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



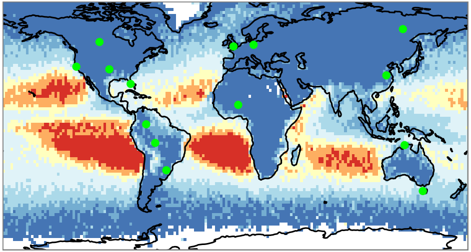
Mülmenstädt et al. (2015), *Geophys. Res. Lett.*

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

Outline

Compare satellite climatology to CMIP5 cfSites



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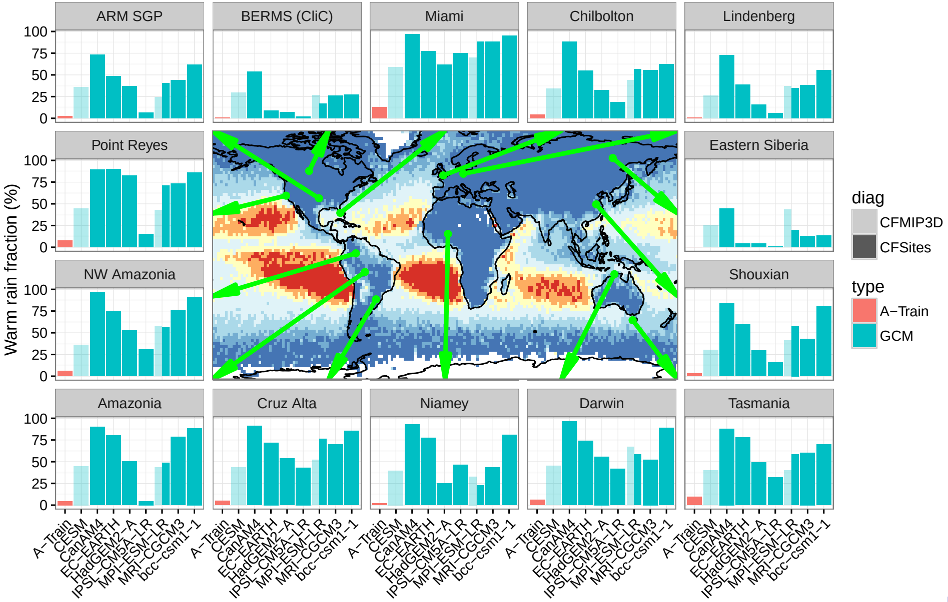

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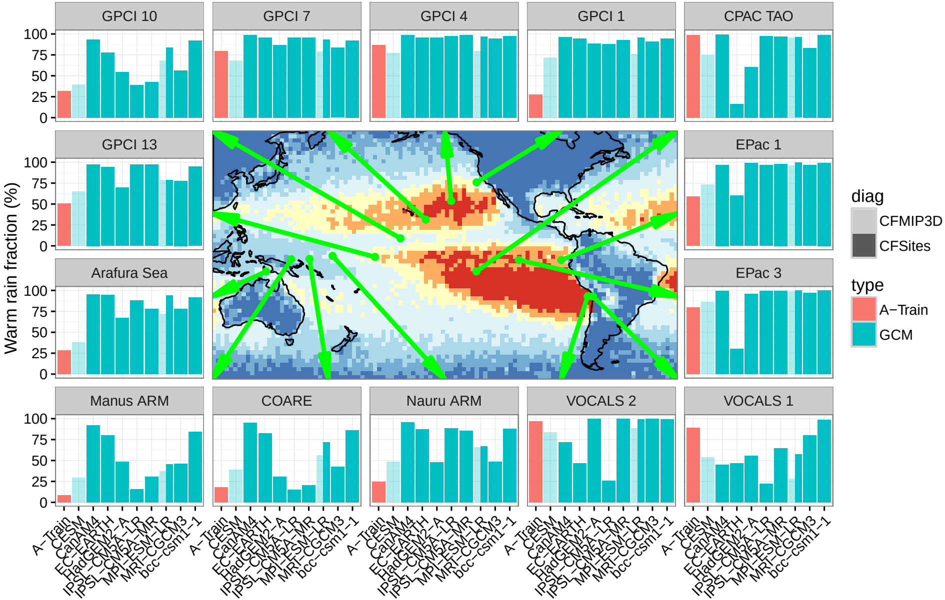
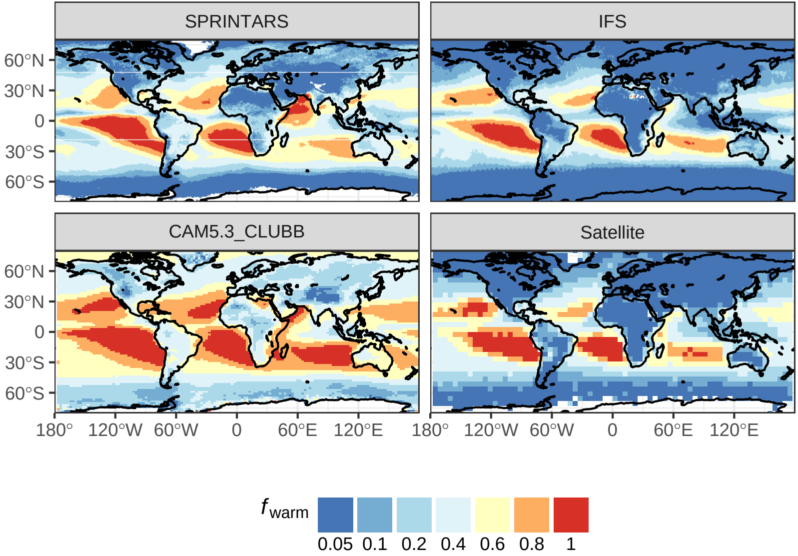
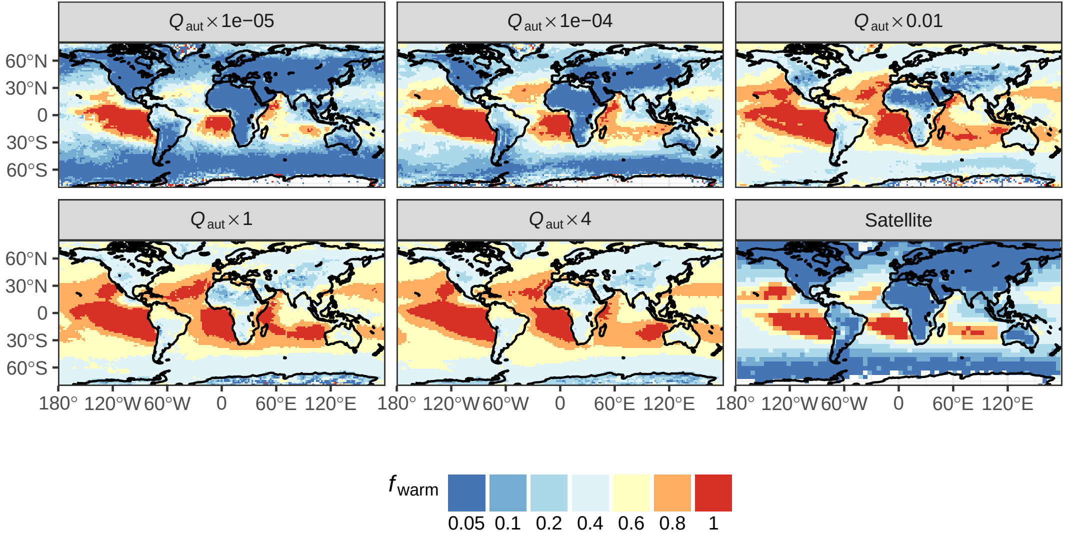


Modeled warm-rain fraction is diverse

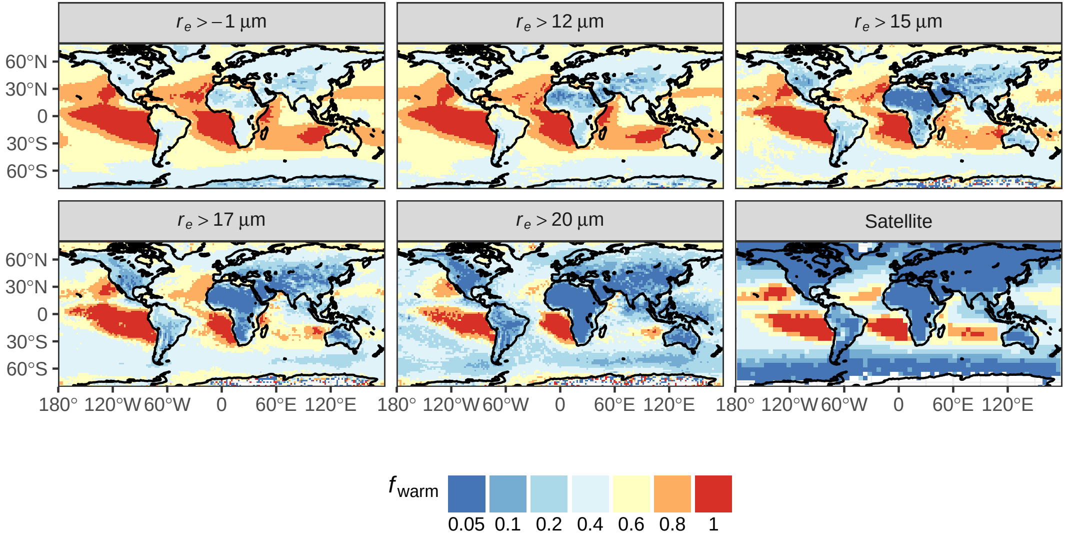


Outline

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



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



These modifications are related

Khairoutdinov and Kogan (2000):

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

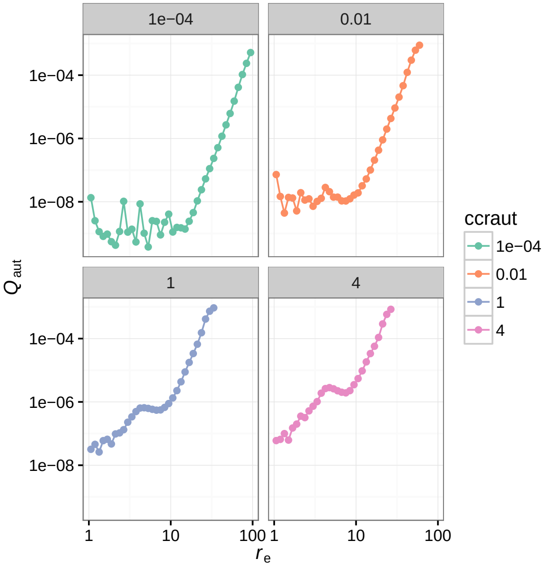
Since

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

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

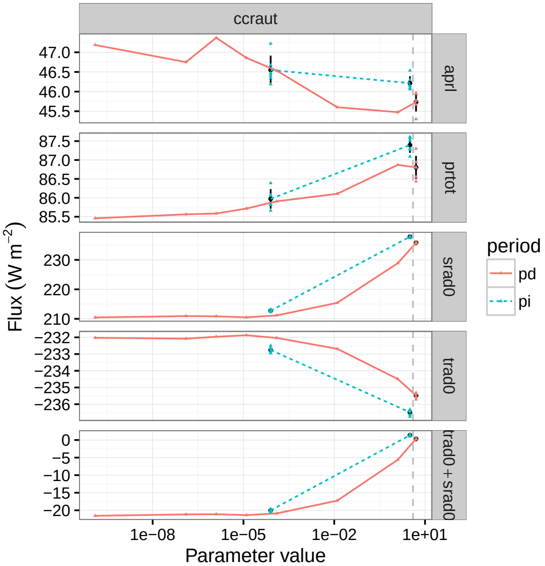
$$\frac{\partial q_r}{\partial t} \propto \begin{cases} r_e^{3\alpha} N^{\alpha+\beta} \\ r_e^{-3\beta} q_l^{\alpha+\beta} \end{cases} \tag{3}$$

Under the simplifying assumption that r_e is uncorrelated with either of q_l or N, we expect the autoconversion rate to scale with $r_e^{5.5\sim7.5}$, which effectively sets an r_e threshold.



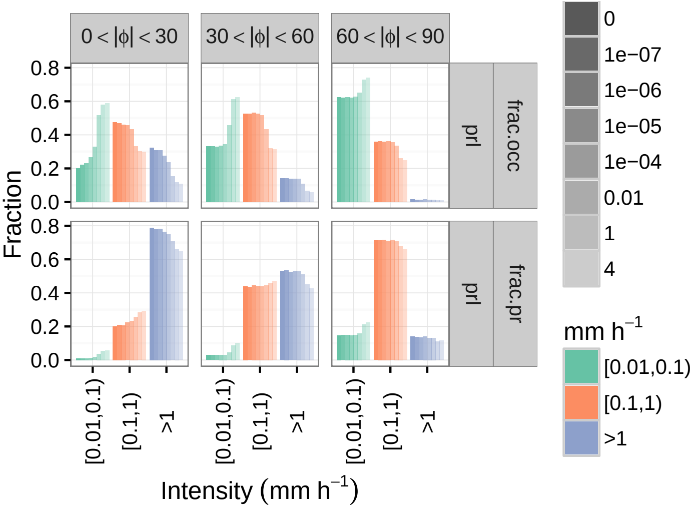
Effect on energy fluxes

- Reducing the warm-rain fraction significantly detunes the TOA energy balance → retuning is required (primarily SW)
- (Reducing warm-rain fraction increases large-scale precipitation)



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



Tuning the warm rain fraction in ECHAM–HAM: conclusions

- 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)
- Alternative to this drastic scale factor: $r_e > 17\mu$m threshold on autoconversion
- Effect on radiative balance is large (large increase in cloud lifetime)
- Reducing the warm-rain fraction to match the satellite climatology also increases the intensity spectrum
- (Some remaining uncertainty on these numbers because of parameter choices in diagnosis of warm-rain fraction)

Outline

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 ERF_{aer}
- The change is $-0.5\ W\ m^{-2}$ SW offset by $0.3\ W\ m^{-2}$ LW $\Rightarrow$ plausible that ERF_{aci} change is a large contribution
- (Low-`ccraut` configuration has not been retuned and ERF_{aci} has not been diagnosed separately from ERF_{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

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

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

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

  i.e., the perturbation grows with the threshold r_e
- In ECHAM-HAM, the combined autoconversion and accretion can deplete q_l without such a restriction, 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
- Lots of model diversity; this observable has not been tuned to death
  - ⇒ May be 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 (potentially as part of an AeroCom intercomparison)
- 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} (protocol will be sent to AeroCom mailing list soon)

Summary

- Warm-rain fraction is very low over continents (especially extratropical NH); details: Mülmenstädt et al. (2015), *Geophys. Res. Lett.* 42 (15), 6502–6509, doi:10.1002/2015GL064604
- Warm-rain fraction can be diagnosed in GCMs and may serve as an observational constraint on precipitation-related processes (including aerosol cloud lifetime effect)
- In ECHAM–HAM, agreement with satellite warm-rain fraction can be achieved with either a drastic rescaling of KK2000 autoconversion or a less drastic r_e threshold
- Either method of tuning the warm-rain fraction intensifies the precipitation intensity spectrum and decreases the ERF_{aci}
- Space-borne active remote sensing is essential for (this and other) studies trying to derive observational constraints on parameterized convection