Observations and Modeling of Shallow Convective Clouds: Implications for the Indirect Aerosol Effects

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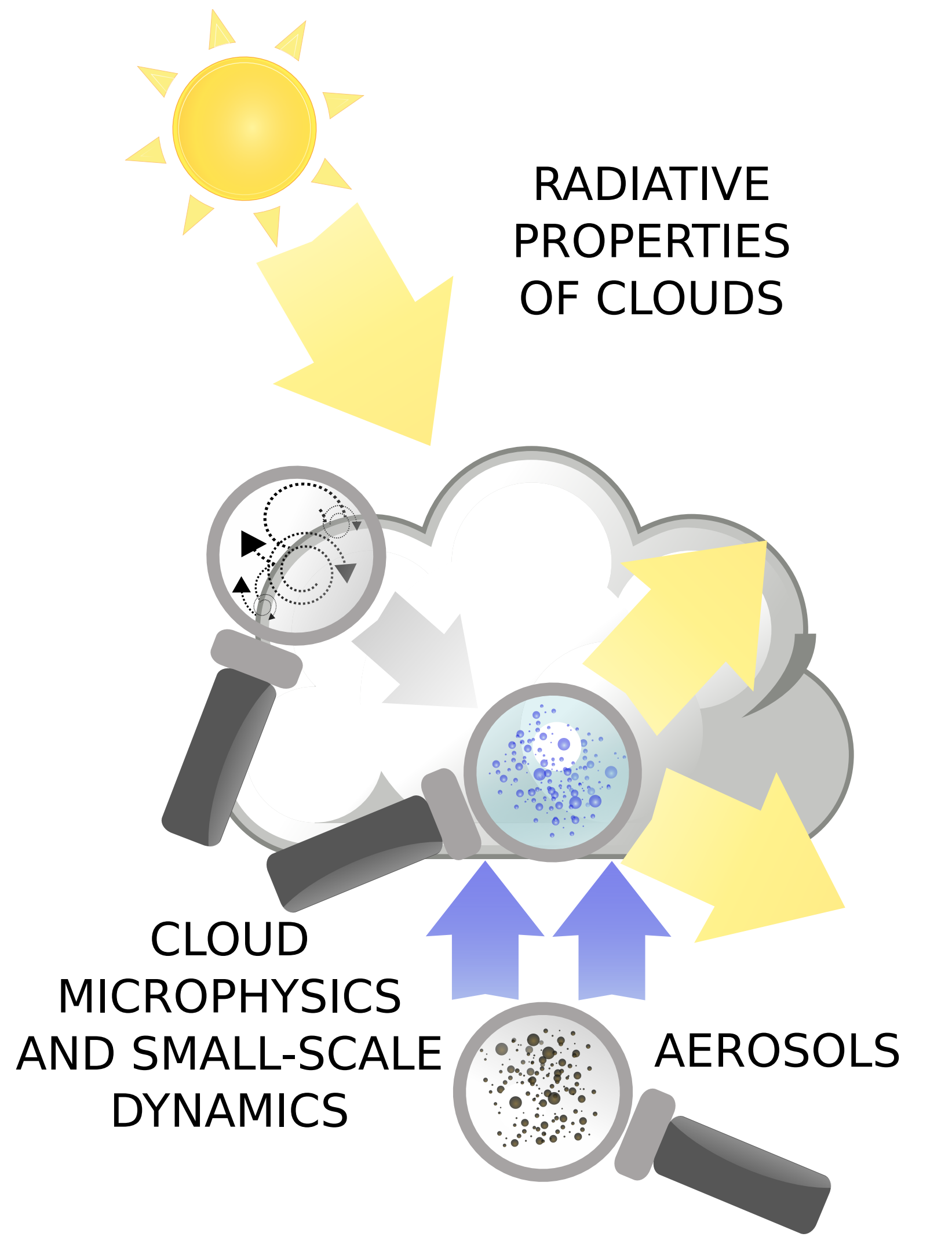
Motivation



Previous modeling studies (e.g. Chosson et al., 2007; Slawinska et al., 2008) have shown that assumptions about microphysical transformations during entrainment and mixing (i.e., the homogeneous versus inhomogeneous mixing) have a significant impact on the albedo of a field of shallow convective clouds. This is because of dilution of these clouds due to entrainment of dry environmental air and the complexity of the small-scale mixing and homogenization. This aspect is especially relevant for the estimate of the indirect aerosol effects, that is, the change of the mean albedo (either through the changes of cloud properties or changes of the cloud fraction) as a result of a change in the cloud condensation nuclei.

Nomenclature

N	cloud droplet number concentration
LWC	liquid water content
LWC_{ad}	adiabatic LWC
AF	adiabatic fraction (LWC/LWC_{ad})
r	droplet radius
r_{eff}	effective radius ($<r^3> / <r^2>$)
d	relative dispersion ($\sqrt{<r>^2 - <r^2>} / <r>$)

homogeneous mixing scenario in which all droplets are exposed to the same evaporation ($N \approx$ const, $r\downarrow$)

extremely inhomogeneous mixing scenario in which a fraction of droplets is totally evaporated ($N\downarrow$, $r \approx$ const)

$$r_{eff} \sim \sqrt[3]{LWC/N} \cdot f(d, \ldots) \quad (1)$$

References

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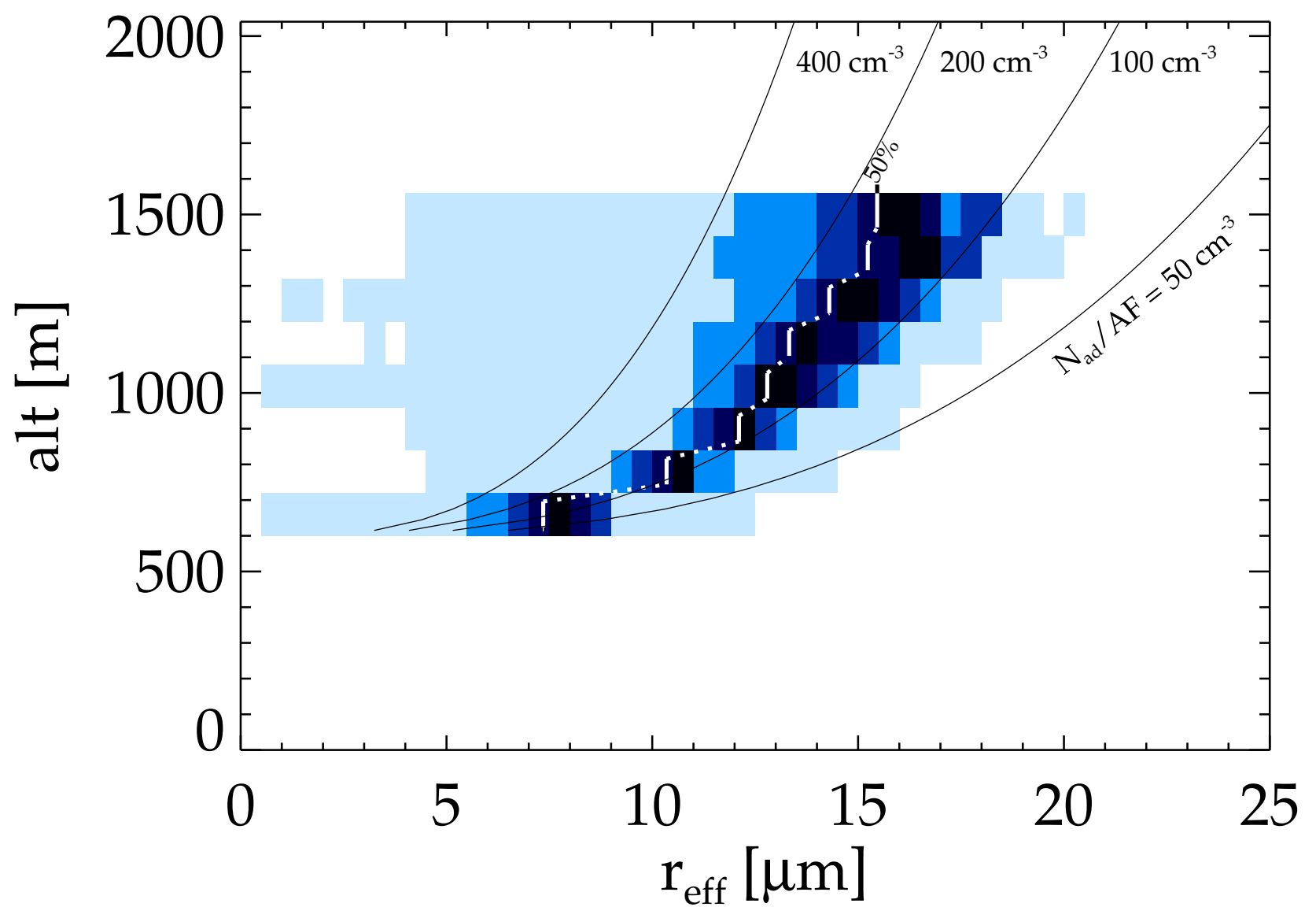
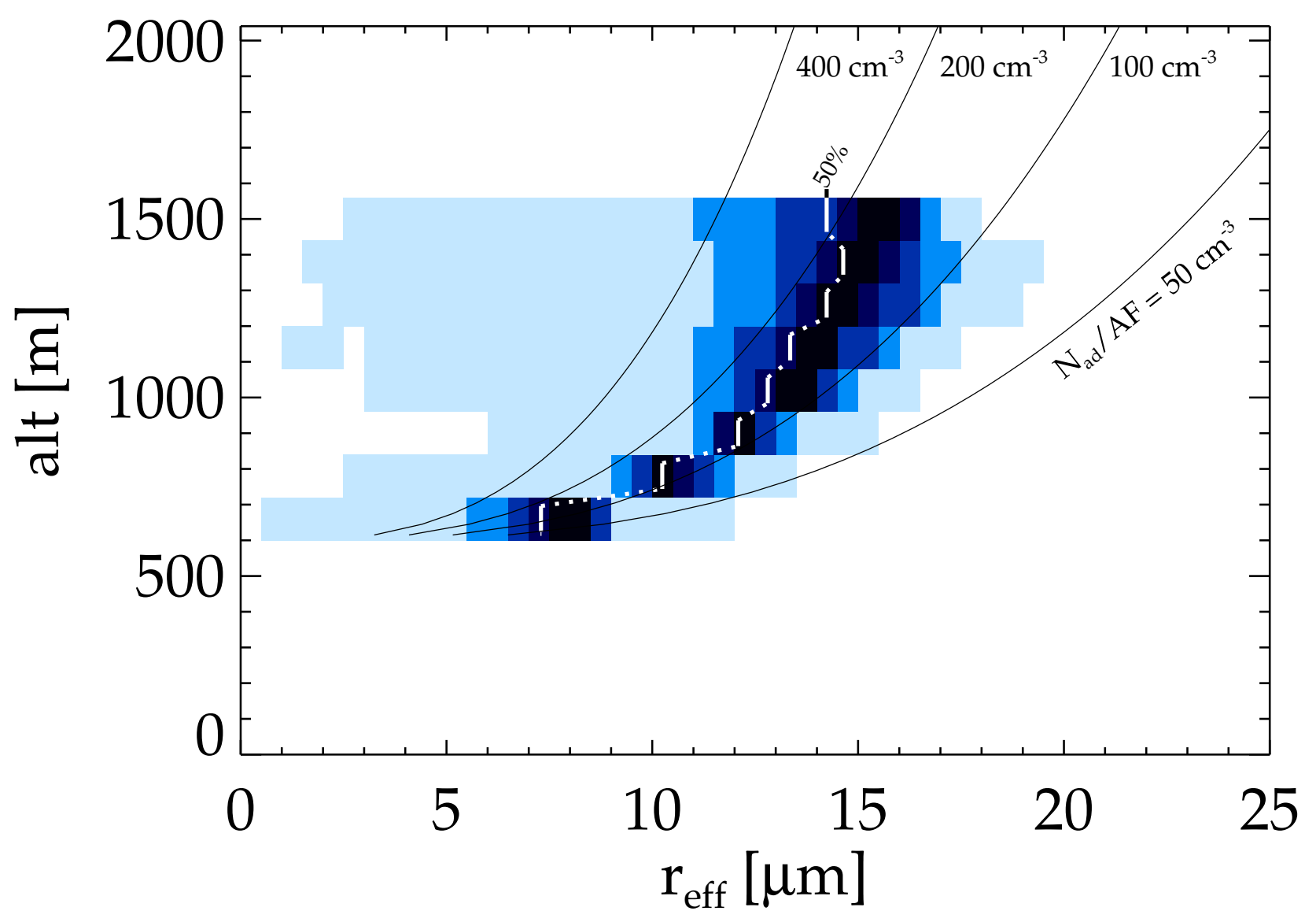
Cloud microphysical observations during RICO

The Rain in Cumulus over the Ocean (RICO) field project (Rauber et al., 2007) took place in the Antilles in December 2004 and January 2005. The campaign included airborne, ground-based, and shipboard measurements. The analysis presented here is based on cloud microphysical in-situ observations aboard the NSF/NCAR C-130Q research aircraft. The cloud microphysical properties are derived from measurements performed using the Fast-FSSP optical cloud droplet spectrometer (Brenguier et al., 1998; Burnet and Brenguier, 2002). The key reason for choosing the Fast-FSSP for the present analysis is the high spectral resolution of the instrument (255-bin description of the 1 to 24 μm range of droplet radius spectrum).

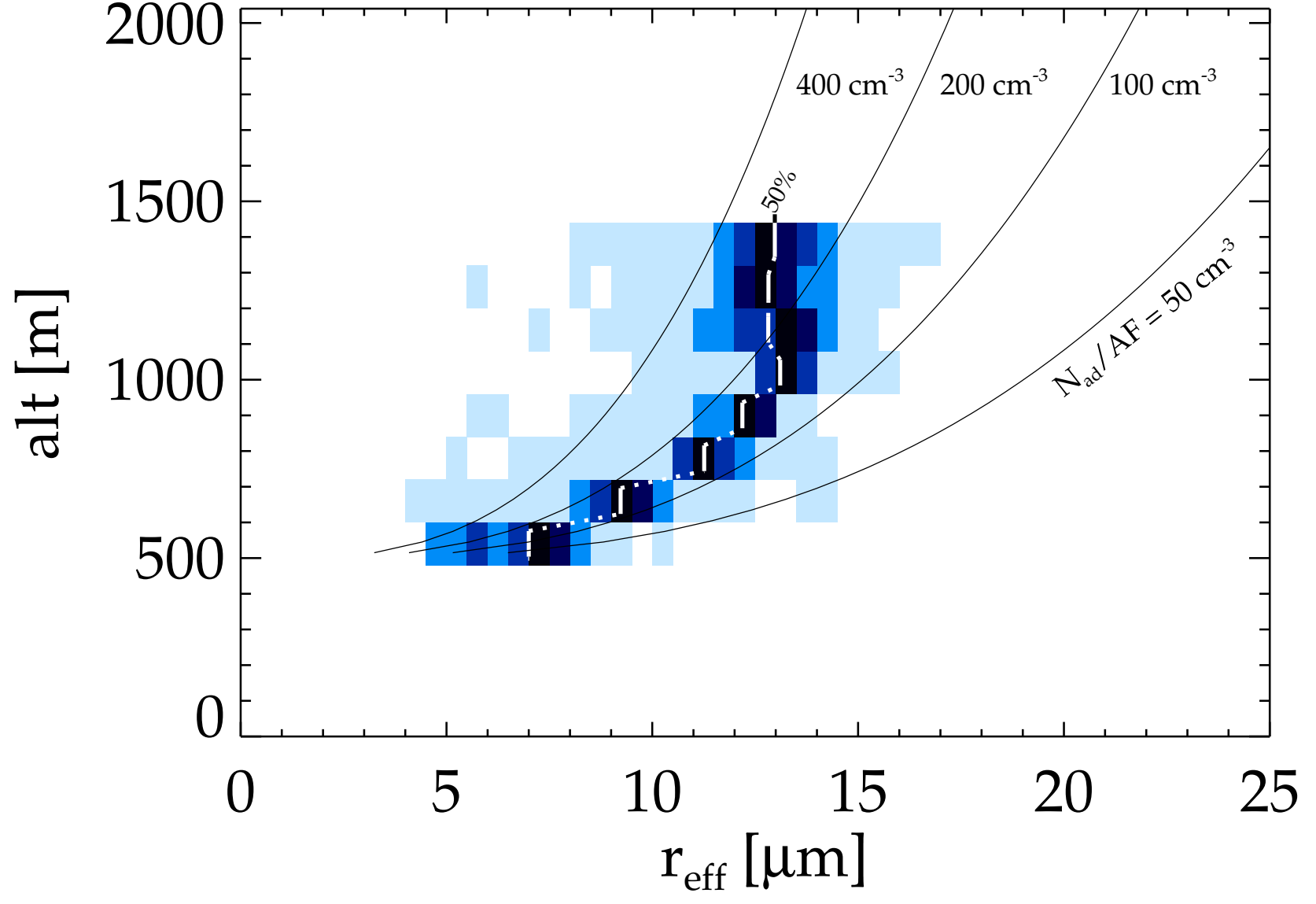
LES simulation
(extremely inhomogeneous mixing)



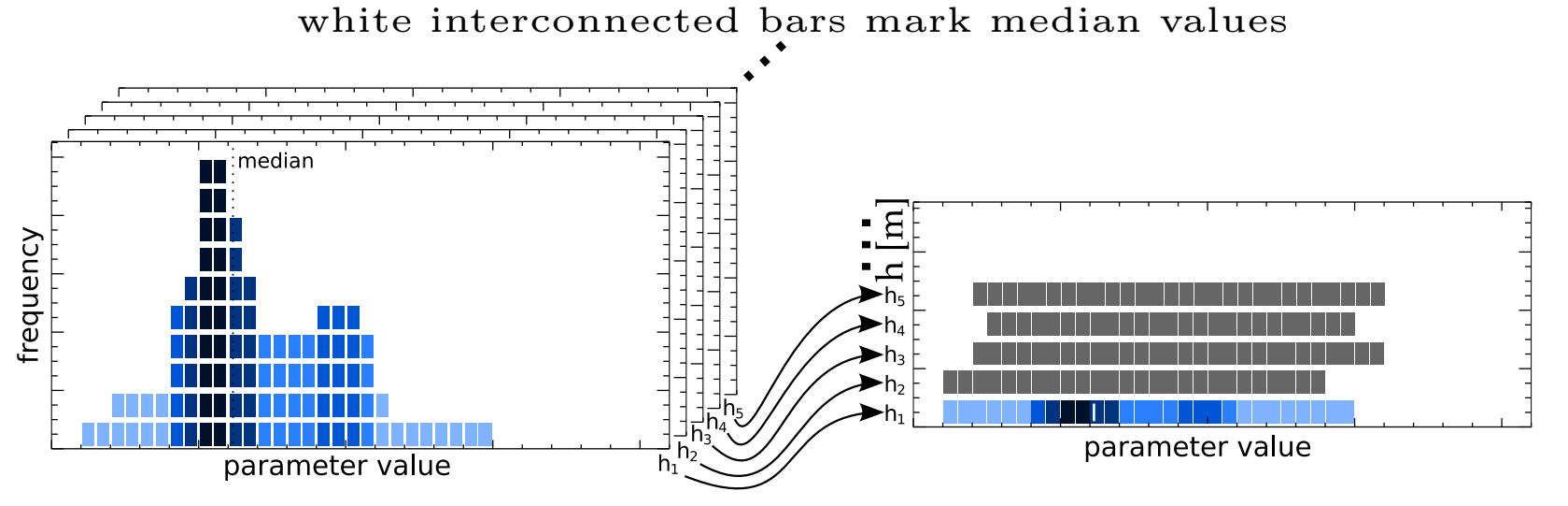
LES simulation
(homogeneous mixing)



RICO Fast-FSSP observations
(C-130 research flight 09)



colors represent ranges of frequency of occurence at a given altitude, each color marks 20% of datapoints ordered by frequency of occurence



white interconnected bars mark median values

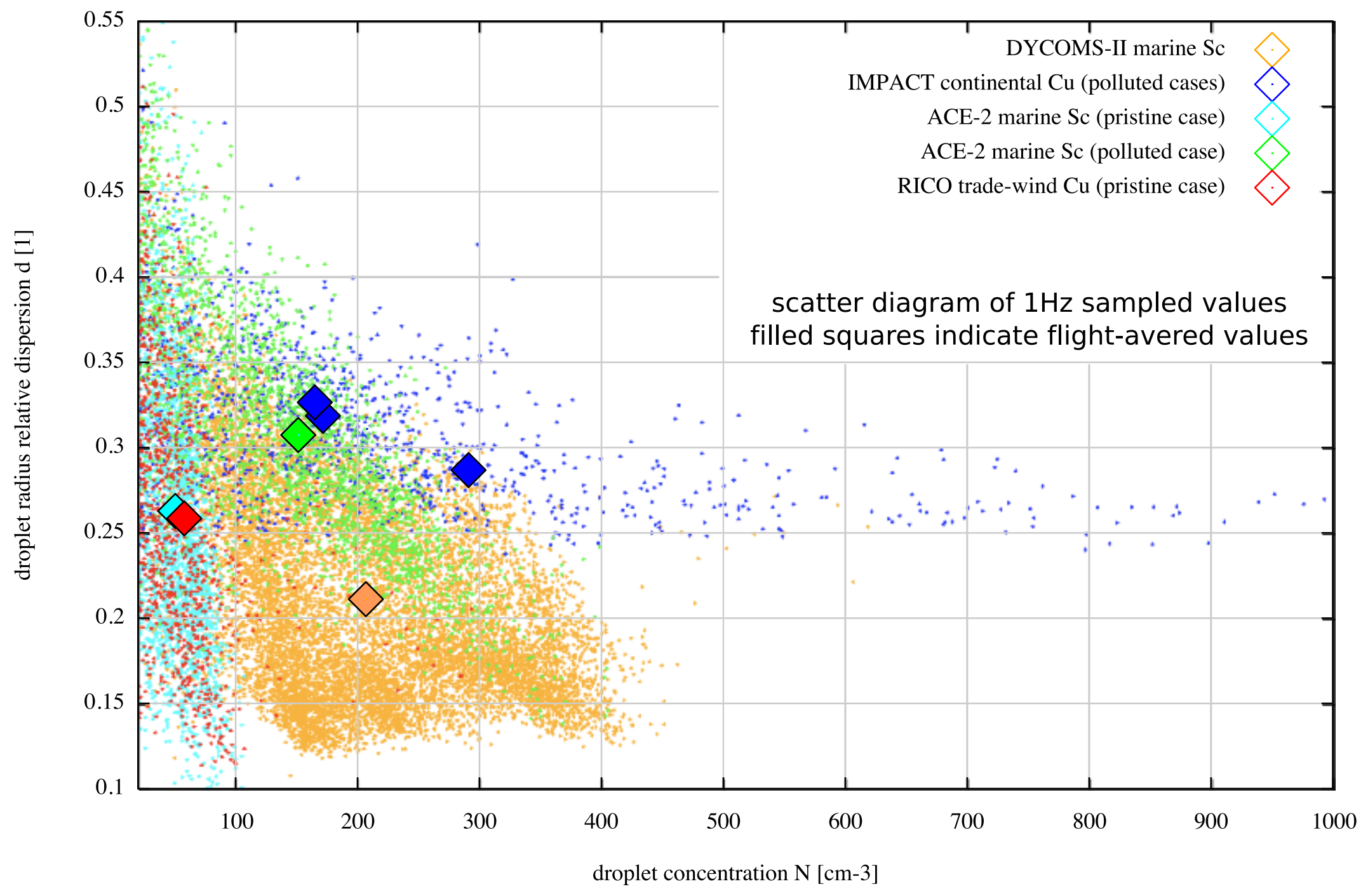
Double-moment bulk microphysics in the EULAG LES model

The double-moment bulk microphysics scheme in the EULAG model (http://www.mmm.ucar.edu/eulag) predicts the number concentrations and mixing ratios for cloud droplets and for drizzle/rain drops, and the evolution of the supersaturation field (Morrison and Grabowski, 2007, 2008). A novel feature of the scheme is that it allows one to prescribe the homogeneity of the mixing, from the homogeneous to extremely inhomogeneous. The model was used to simulate shallow convection observed during the RICO field project, assuming maritime aerosol with concentration of 100 mg^{-1}. The modelling setup follows the model intercomparison case based on RICO observations (see http://www.knmi.nl/samenw/rico/). Two simulations are compared, with subgrid-scale mixing following either homogeneous or extremely inhomogeneous mixing (with domain of 6.4×6.4×4 km; gridlengths of 50×50×20 m).
The analysis is for hours 3-6 of the simulations here.

Results: model simulations and observations

The three diagrams on the left present statistics of effective radius r_{eff} as a function of height. The two upper plots are based on model results for the two extreme types of mixing (domain-wide statistics). The bottom plot is based on the observations from Fast-FSSP during one of the RICO flights. (flight rf09 of about 8 hours, 10 Hz data, $\sim$ 10 m spatial resolution). Only in-cloud datapoints are analysed (threshold of 20 droplets per cm^{-3}).

The calculation of effective radius from the double-moment microphysics requires further assumptions on the spectral shape (see eq. 1). Usually the key parameter is the relative dispersion d, typically parametrized as a function of N (e.g. Liu and Daum, 2002). The scatter diagram to the right illustrates aircraft observations of d vs. N from several field campaigns.



Conclusions

- The double-moment warm-rain microphysics allows prediction of the effective radius vertical profiles.
- Both the modeled and observed distributions of effective radius are monomodal and narrow.
- Effective radius statistics from the model simulations depend on the subgrid scale mixing, especially in the upper half of the cloud field.
- There are discrepancies between model and observations: model features wider histograms, shifted toward larger droplet sizes. The differences may come from model limitations; however, model setup, comparison methodology and observational limitations play a role as well.
- The multi-campaign $d(N)$ scatter plot based on high spectral resolution Fast-FSSP data suggest that accurate parametrization of relative dispersion should consider other parameters besides N (e.g., representing cloud dilution).

Acknowledgements

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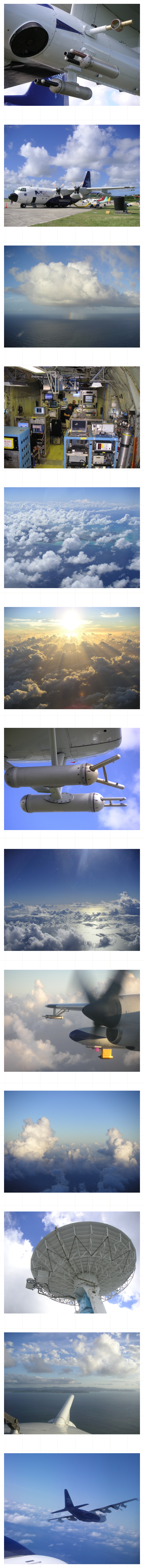

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