Condensation - Mass Flux Connection in Shallow Cu Clouds

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Abstract

The system of trade wind cumulus clouds observed during the RICO field project was simulated by an LES model over a 50x50 km2 domain size. Parameters of latent heat release were analyzed with the goal of parameterizing their effects on grids typical for NWP and large-scale models. Over 2000 clouds were examined focusing on relationship between parameters of latent heat release (phase transition rates) and dynamical/microphysical cloud characteristics. The phase transition rates (Tr), which in warm tropical clouds are represented by processes of condensation/evaporation, were analyzed by stratifying the clouds by their size/stage of maturity. The analyzed parameters included, among others, integral mass and buoyancy fluxes, cloud and rain water parameters. In our previous investigation we found that a remarkably strong correlation exists between Tr and upward mass flux (M). The strong dependence of phase transition rates on M, as well as linear relationship between Tr and M, was explained by applying the condensation theory and the concept of "quasi-steady" supersaturation. The LES derived slope of the linear fit agreed with its theoretically predicted value with an error less than 5%. This result implies that supersaturation in clouds, on average, varies within a few percentage points of its quasi-steady value. The theory, as well as LES data, show that the Tr - M linear fit is valid for local variables, and, therefore, may be integrated to obtain horizontal mean parameters. Expanding the Tr - M relationship for vertically dependent horizontal mean variables, may provide the framework for development of sub-grid scale (SGS) latent heat release parameterization. It was also suggested that calculating the slope of the linear fit from concurrent measurements of temperature and vertical velocity, and comparing it with the theoretical slope based on the quasi-steady supersaturation assumption, may offer a method for estimating the supersaturation in clouds.

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Objective:

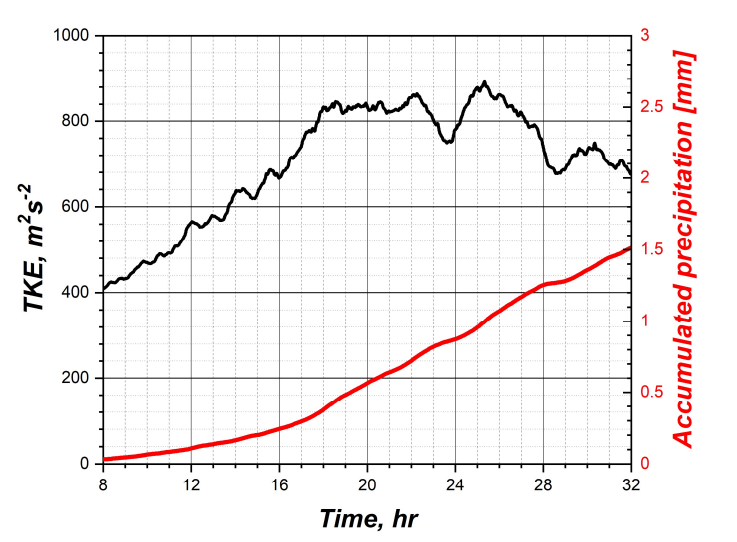
- Evaluating correlations between phase transition rates (CR/ER) and up/down mass/buoyancy flux
- Finding relationships between CR/ER and upward mass flux (MFP)

LES model and Simulations

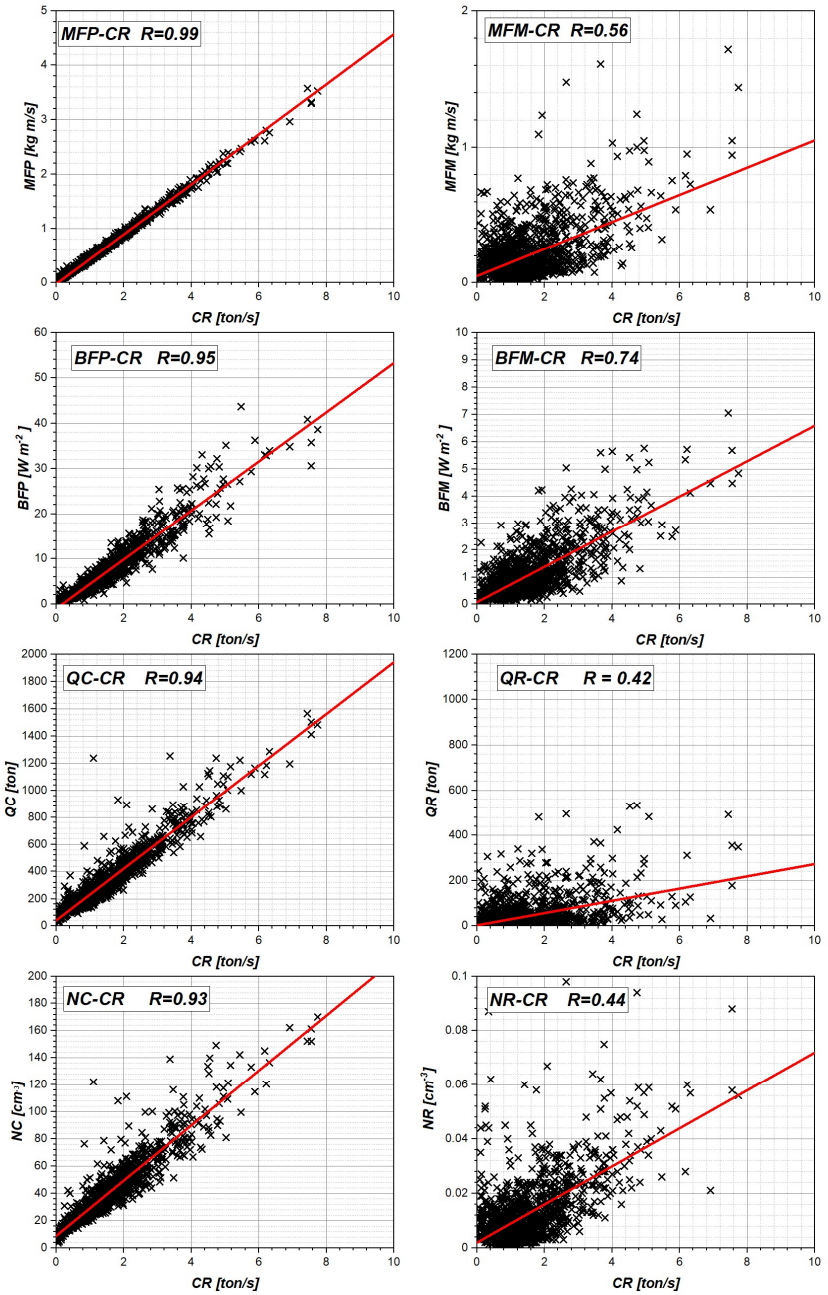
SAM-BM: SAM Bulk Microphysics (BM)

Δh=100 m; Δz=40 m; L ~ 51 km 512x512x100

RICO : Trade wind shallow Cu



8-32 hours
2031 clouds
Four Groups G1-G4

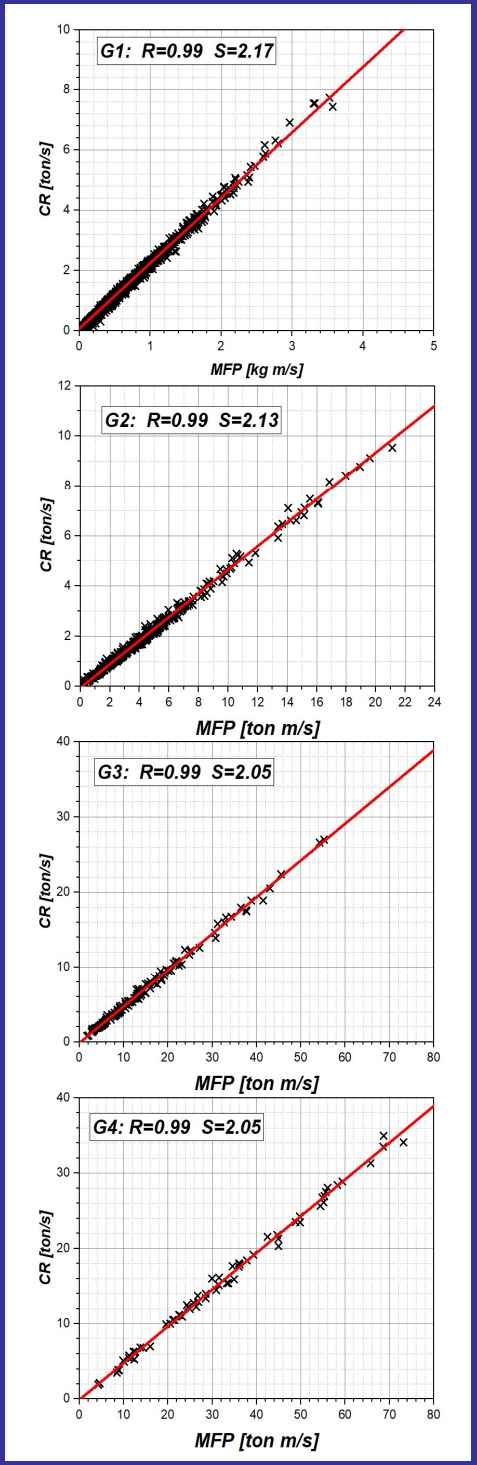


CR correlations

CR-MFP R=0.99

CR-BFP R=0.95

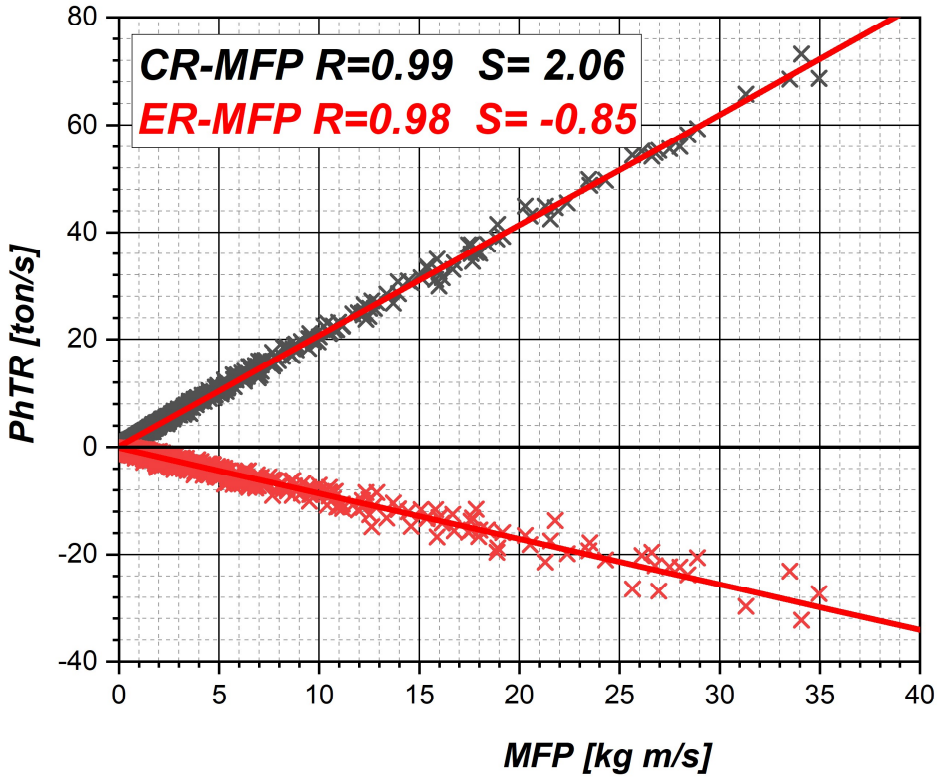
Low R's for downward fluxes



Correlation between condensation rate (CR) and upward mass flux (MFP)

Four Groups G1-G4
R=0.99

High correlation with MFP, both for condensation and evaporation rates



$$\frac{dq_l}{dt} = \alpha_{les}\rho_a W$$

$\alpha_{les} = 2.06 \text{ x}10^{-6}$ [s^{-1}] for $q_v > q_{vs}$

$\alpha_{les} = -0.85 \text{ x}10^{-6}$ for $q_v < q_{vs}$.

Lagrangian air parcel model

$$\frac{dS}{dt} = A_1 W - A_2 S R_i$$

Supersaturation equation

$$S_{qs} = \frac{A_1 W}{A_2 R_i}$$

Quasi-steady solution for S

$$S = \kappa S_{qs}$$

Kappa-- supersaturation in "quasi-steady" units

$$\frac{dq_l}{dt} = \kappa \alpha_{qs} \rho_a W \qquad \alpha_{qs} = \frac{A_1}{A_3}$$

CR linear function of mass flux

LES vs Theory

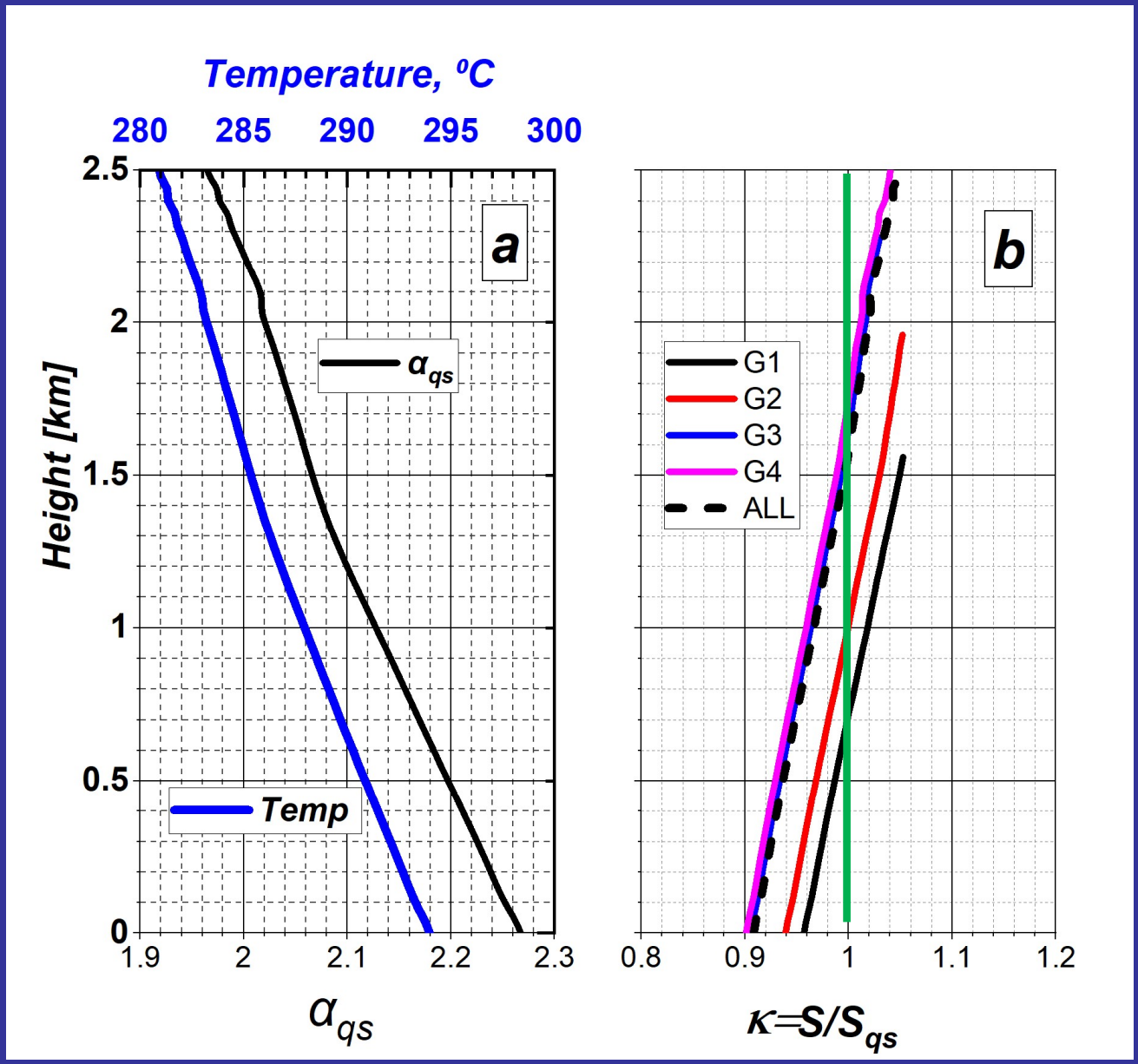
$$\frac{dq_l}{dt} = \alpha_{les}\rho_a W \qquad \frac{dq_l}{dt} = \kappa\alpha_{qs}\,\rho_a W$$

$$\kappa = \alpha_{les}/\alpha_{qs}$$

LES vs Theory

Case	G1	G2	G3	G4	All
LES	2.17	2.13	2.052	2.048	2.06
QS	2.20	2.17	2.15	2.14	2.09
Error, %	1.4	1.9	4.8	4.5	1.5

Kappa profiles - a tool to explore supersaturation in clouds



Conclusions

1. Phase transition rates are highly correlated with upward mass flux (R=0.99)
2. Linear dependence of CR on MFP is supported by condensation theory
3. Linear fit can form a basis for parameterization of latent heat release in NWP models
4. It also implies that supersaturation in clouds, on average, is close to its "quasi-steady" value