Development of a physically based autoconversion parameterization and its application to cloud modeling

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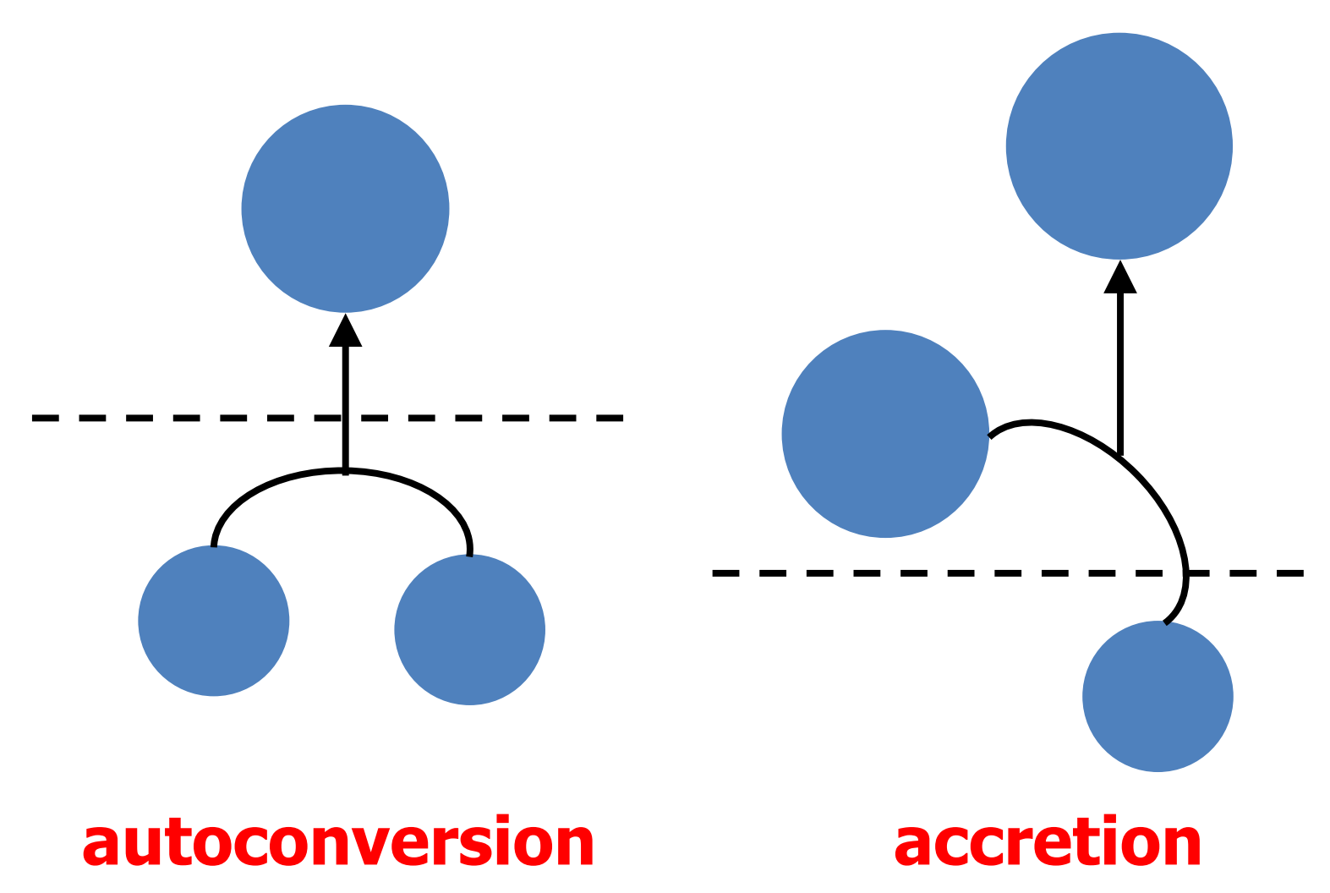
Introduction

- **Autoconversion**: collisional growth of cloud droplet into raindrop in bulk microphysics schemes
- Most of the bulk microphysics schemes have parameterized the autoconversion based on the simple fitting to the observation data or to the results of bin microphysics schemes.



- This study parameterizes the autoconversion in terms of the collision between cloud droplets due to **the difference in terminal velocities** of the cloud droplets, and the accurate cloud droplet **collision efficiency** obtained using a particle trajectory model (Pinsky et al. 2001) is adopted.

Previous parameterizations

1. Kessler-type $\left.\frac{\partial L_r}{\partial t}\right|_{\text{au}} = a_{\text{K}}(L_c - L_{c0})H(L_c - L_{c0})$ LD04: Liu and Daum (2004)

2. Time scale $\left.\frac{\partial L_r}{\partial t}\right|_{\text{au}} = \frac{L_{\text{BR}}(L_c, N_c)}{T_{\text{BR}}(L_c, N_c)}$ BR74: Berry and Reinhardt (1974)

3. Power law $\left.\frac{\partial L_r}{\partial t}\right|_{\text{au}} = c_{\text{KK}}\rho_a^{1-a_{\text{KK}}} L_c^{a_{\text{KK}}} N_c^{b_{\text{KK}}}$ KK00: Khairoutdinov and Kogan (2000)

4. Solving SCE $\left.\frac{\partial L_r}{\partial t}\right|_{\text{au}} = \frac{k_{\text{SB}}}{20m^*}\frac{(\nu+2)(\nu+4)}{(\nu+1)^2} L_c^2 \bar{m}_c^2 \left[1 + \frac{\Phi(\tau)}{(1-\tau)^2}\right]\frac{\rho_{a0}}{\rho_a}$

SB06: Seifert and Beheng (2006)

Derivation of a new autoconversion parameterization

- Start with the stochastic collection equation:

$$\frac{\partial f(m)}{\partial t} = \int_0^{m/2} \underbrace{f(m')}_{①} \underline{\underline{K(m', m-m')}} f(m-m')dm' - \int_0^{\infty} f(m)K(m,m')f(m')dm'$$

- Collection Kernel: $\underline{\underline{K(r,r')}} = \pi(r+r')^2 \underbrace{|v_t(r) - v_t(r')|}_{②}\underbrace{\eta}_{③}$

- Autoconversion rate can be expressed as:

$$\left.\frac{\partial L_r}{\partial t}\right|_{\text{au}} \approx \frac{4}{3}\pi\rho_w \int_0^{\infty}\int_0^{R}(R^3 + r^3)f(r)K(r,R)f(R)drdR$$
$$-\alpha\frac{4}{3}\pi\rho_w \int_0^{r^*}\int_0^{R}(R^3 + r^3)f(r)K(r,R)f(R)drdR$$

1. size distribution: $f(r) = N_0 r^{\mu}\exp(-\lambda r), \quad \mu = \mu(N_c)$
2. terminal velocity: $v = v_0 r^2$
3. collision efficiency: $\eta = k_c \frac{r}{R}\left(1 - \frac{r}{R}\right)\left(\frac{r}{R} + a\right)(R^3 + bR^4)$

Final form

$$\left.\frac{\partial L_r}{\partial t}\right|_{\text{au}} = \frac{4}{3}\pi^2\rho_w N_0^2 v_0 k_c (L_1 - \alpha L_2)$$

$$L_1 = \sum_{i=1}^{10} a_i \Gamma_1(\lambda, i)\left[\Gamma_1(\lambda, 10-i) - \sum_{j=0}^{\mu+i}\frac{\lambda^j}{j!}\Gamma_1(2\lambda, 10-i+j) + b\left\{\Gamma_1(\lambda, 11-i) - \sum_{j=0}^{\mu+i}\frac{\lambda^j}{j!}\Gamma_1(2\lambda, 11-i+j)\right\}\right]$$

$$L_2 = \sum_{i=1}^{10} a_i \Gamma_1(\lambda, i)\left[\Gamma_2(\lambda, 10-i) - \sum_{j=0}^{\mu+i}\frac{\lambda^j}{j!}\Gamma_2(2\lambda, 10-i+j) + b\left\{\Gamma_2(\lambda, 11-i) - \sum_{j=0}^{\mu+i}\frac{\lambda^j}{j!}\Gamma_2(2\lambda, 11-i+j)\right\}\right]$$

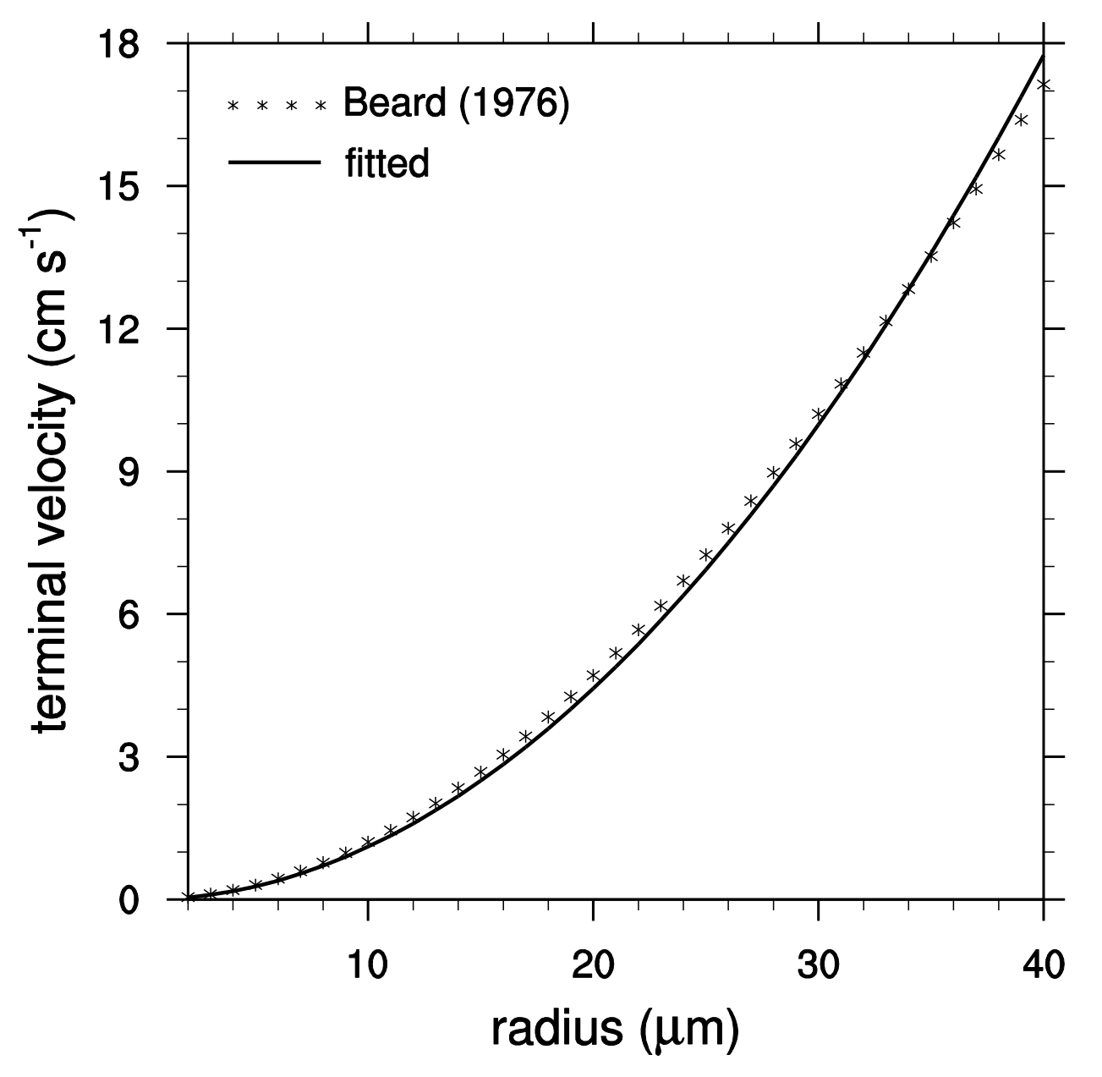
$$\left.\frac{\partial N_c}{\partial t}\right|_{\text{au}} = -\pi N_0^2 v_0 k_c (2N_1 - \alpha N_2), \quad \left.\frac{\partial N_r}{\partial t}\right|_{\text{au}} = \pi N_0^2 v_0 k_c (N_1 - \alpha N_2)$$

$$N_1 = \sum_{i=1}^{7} a_i' \Gamma_1(\lambda, i)\left[\Gamma_1(\lambda, 7-i) - \sum_{j=0}^{\mu+i}\frac{\lambda^j}{j!}\Gamma_1(2\lambda, 7-i+j) + b\left\{\Gamma_1(\lambda, 8-i) - \sum_{j=0}^{\mu+i}\frac{\lambda^j}{j!}\Gamma_1(2\lambda, 8-i+j)\right\}\right]$$

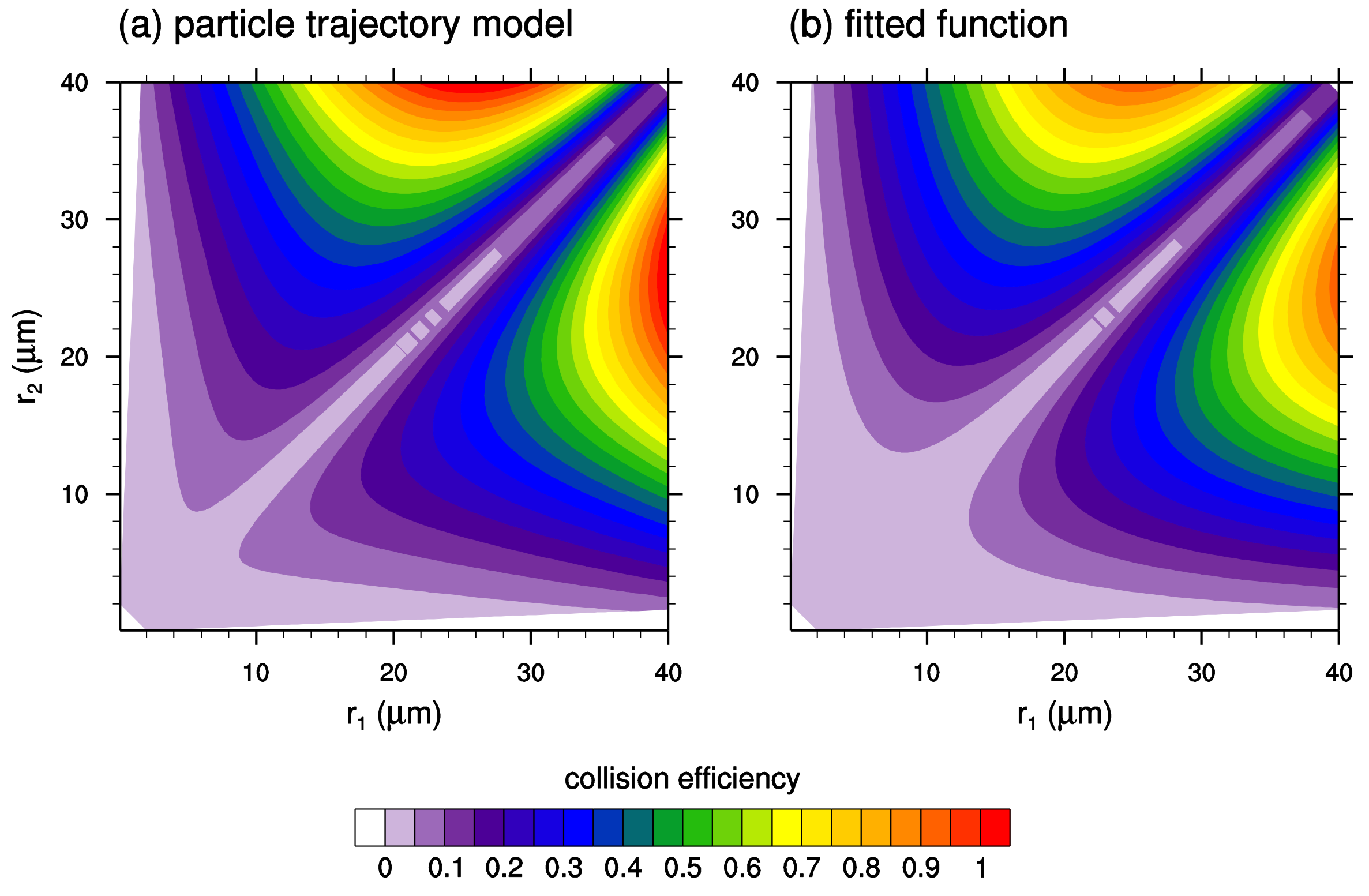
$$N_2 = \sum_{i=1}^{7} a_i' \Gamma_1(\lambda, i)\left[\Gamma_2(\lambda, 7-i) - \sum_{j=0}^{\mu+i}\frac{\lambda^j}{j!}\Gamma_2(2\lambda, 7-i+j) + b\left\{\Gamma_2(\lambda, 8-i) - \sum_{j=0}^{\mu+i}\frac{\lambda^j}{j!}\Gamma_2(2\lambda, 8-i+j)\right\}\right]$$

$$\Gamma_1(\lambda, n) = \frac{(\mu+n)!}{\lambda^{\mu+n+1}}, \quad \Gamma_2(\lambda, n) = \Gamma_1(\lambda, n)\left(1 - e^{-\lambda r^*}\sum_{k=0}^{\mu+n}\frac{(\lambda r^*)^k}{k!}\right)$$

terminal velocity



collision efficiency



Summary and conclusions

- A new physically based autoconversion parameterization is derived by solving SCE.
- The new parameterization results show one of the best agreements with that obtained using the bin microphysics scheme both in the box model simulations and in the cloud-resolving simulations.
- Significant effects of autoconversion parameterization on the cloud properties: Changes in cloud optical thickness and cloud fraction due to autoconversion are up to ~40% and ~20%, respectively.

References

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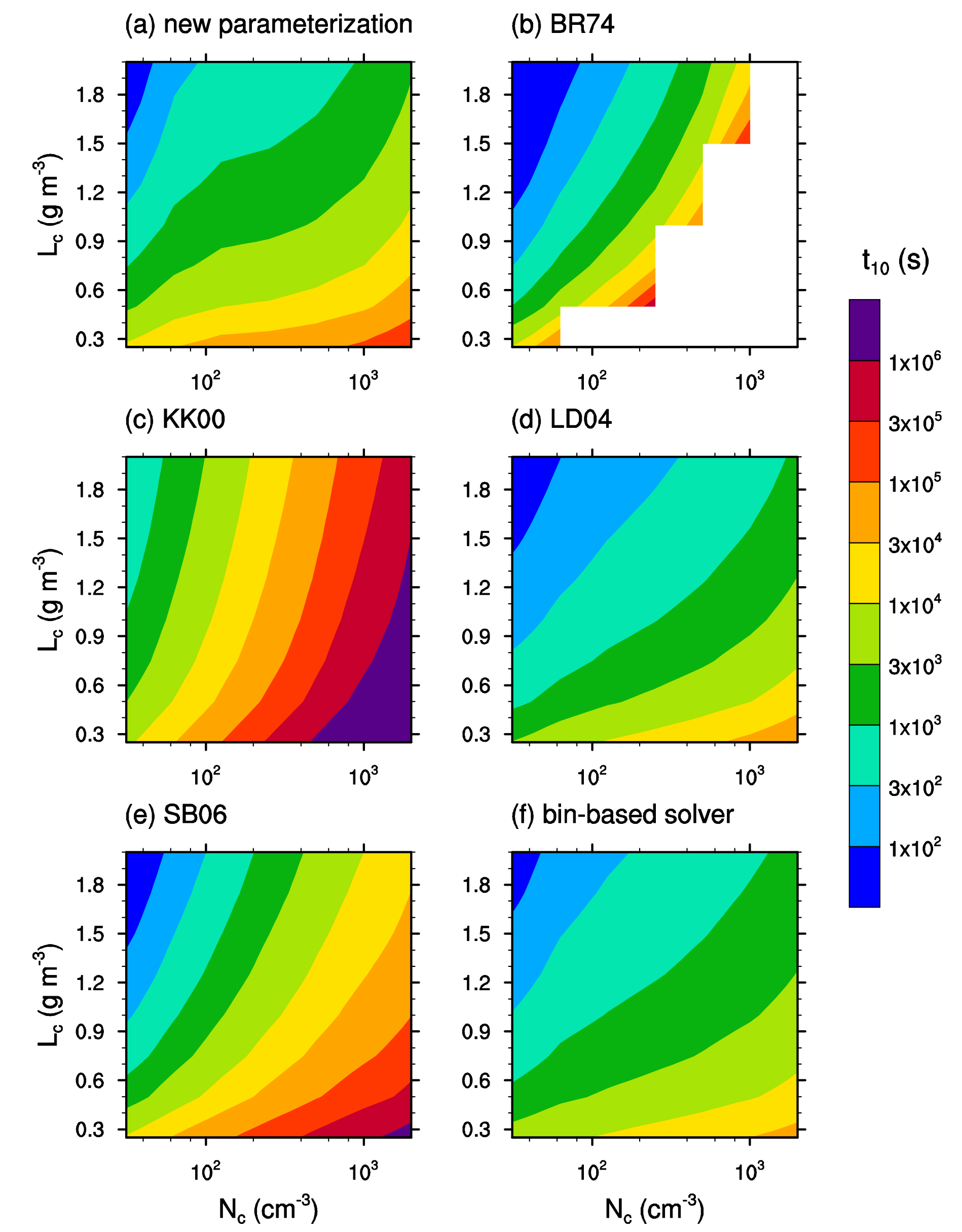
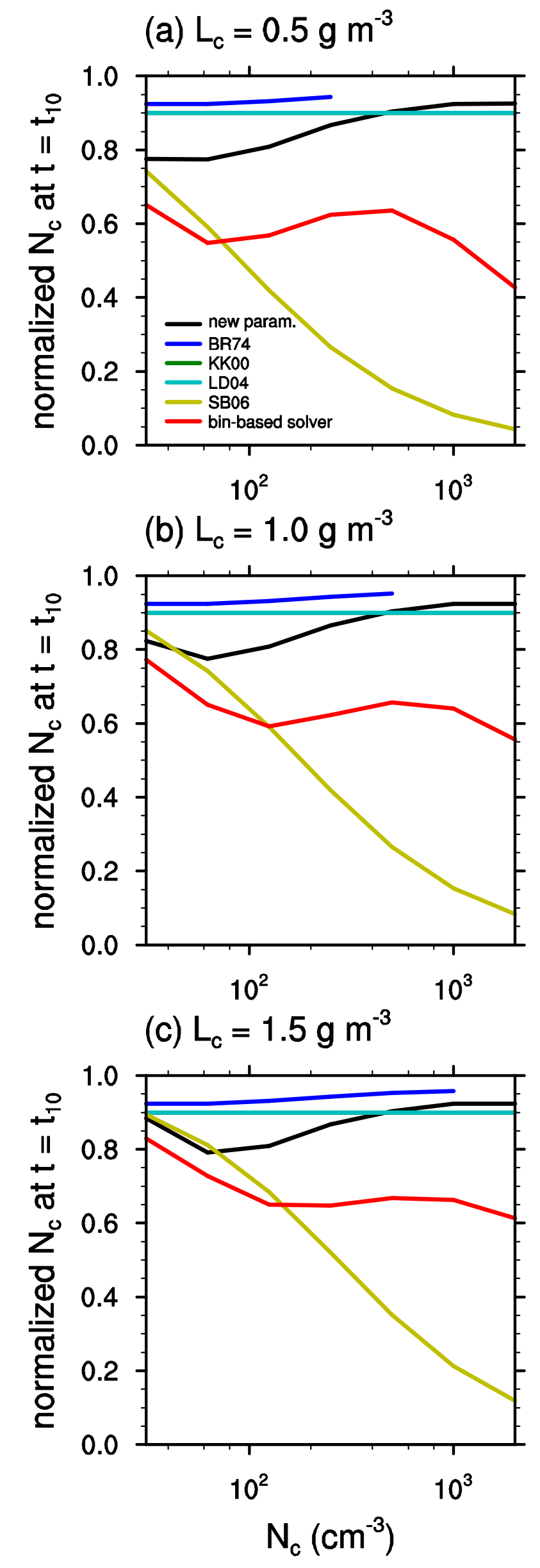
Box model results

t_{10}: the time required for 10% of the initial cloud water content to be converted into rainwater content via the autoconversion



cloud droplet number concentration at t = t_{10} normalized by its initial value



Cloud-resolving model results

- The WRF model v3.7.1
- 3-D idealized warm clouds with Δx = Δy = 100 m and Δz = 30 m