Evaluation of water vapor diffusion equation solving schemes for use in forward simulation of cloud radar Doppler spectra of drizzling stratocumulus

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Introduction

- Bin microphysics models develop particle size distributions more organically than bulk microphysics models, but they face the difficulty of numerical diffusion leading to overly rapid large drop formation.
- Cloud radar Doppler spectra provide rich information for evaluating the fidelity of particle size distributions from cloud models.
- Recently, Morrison et al. (2018) showed that numerical diffusion in solving condensation using a two-moment bin microphysics model can cause serious spectral broadening in a specific condition (continuous activation and condensation along the vertical direction).

Questions

1. In a one-moment bin microphysics model, which scheme can be recommended to solve the vapor diffusion equation? How much refined a bin grid is needed?
2. Does numerical diffusion in solving condensation matter when it is combined with other processes (e.g., collision, activation, etc.)?
3. What are the aspects of solving evaporation (instead of condensation)?

Experimental setup

Schemes for solving the vapor diffusion equation

✓ 2mom: conserving number (0th) and mass (3rd)

✓ 3mom: conserving number, mass, and Rayleigh-regime radar reflectivity factor (6th)

✓ PPM: piecewise parabolic method (Colella and Woodward 1984)

✓ **dynamic**: moving mass bin grid (no numerical diffusion)

Parcel model

✓ dynamic model time step: 5 s

✓ adiabatic heating or cooling according to the prescribed vertical velocity

✓ activation: an implicit method, $\Delta t = 10^{-5}$ s

✓ collision: an exponential flux method (Bott 2000, Lee et al. 2019), $\Delta t = 5$ s

✓ vapor diffusion: $\Delta t = 0.1$ s

✓ drop mass bin grid

geometric grid (doubled at every *s* bins) or

arithmetic grid (increased by 1/*d* μm at every bin)

Conclusions

✓ In a one moment bin microphysics model, the PPM and 3mom schemes yield reasonable solutions of the vapor diffusion equation using an arithmetic mass grid (# of bin ~ 100–200 in a mixture mass grid).

✓ In solving condensation and collision, all of the numerical schemes show hastened DSD broadening compared to the dynamic mass grid (maximum difference ~ 0.2 m s⁻¹).

✓ All of the schemes yield quite good solutions in solving evaporation even at a relatively coarse mass bin grid.

✓ All of these results will be re-examined in a column model framework (Morrison et al. 2018) at the next step.

References

- Bott, A., 2000. doi:10.1175/1520-0469(2000)057<0284:AFMFTN>2.0.CO;2
- Colella, P., and P. R. Woodward, 1984. doi:10.1016/0021-9991(84)90143-8
- Lee, H., et al., 2019. doi:10.1175/JAS-D-18-0174.1
- Morrison, H., et al. 2018. doi: 10.1175/JAS-D-18-0055.1

Condensation: schemes, grids, and convergence

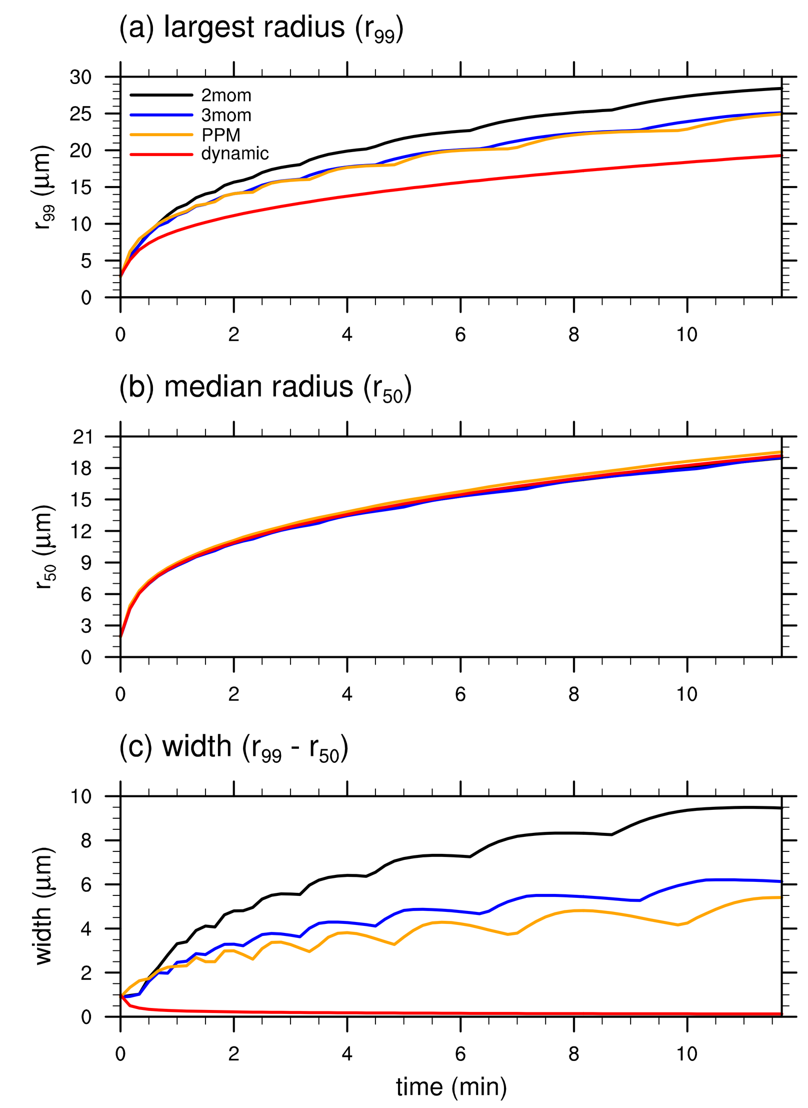
Initial conditions: the same as in Morrison et al. (2018)

- T = 15°C, p = 900 hPa, S = 0.6 %
- w = 1 m s⁻¹ throughout the integration
- N_d = 50 mg⁻¹, constant dN/dr within r = 1–3 μm

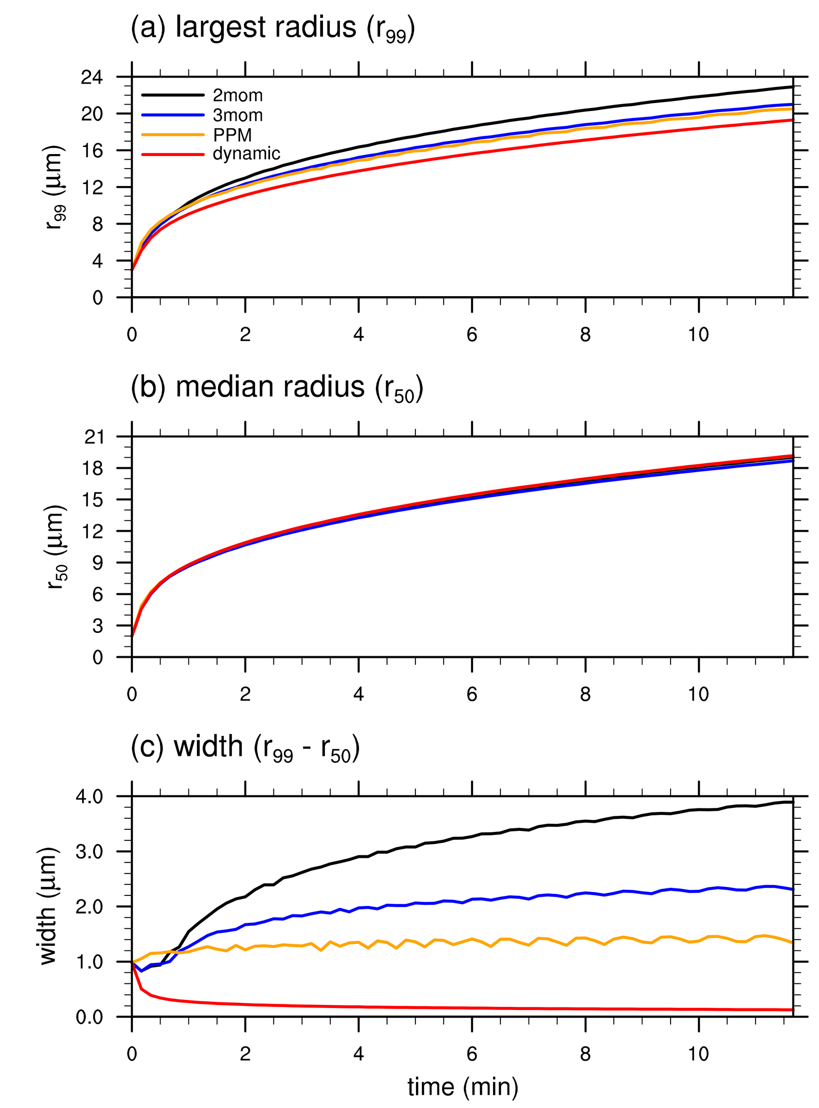
✓ An arithmetic grid is usually advantageous over a geometric grid in solving condensation.

✓ While all of the schemes yield a converged solution, the PPM yields the narrowest (closest to the reference) DSD among the examined schemes.

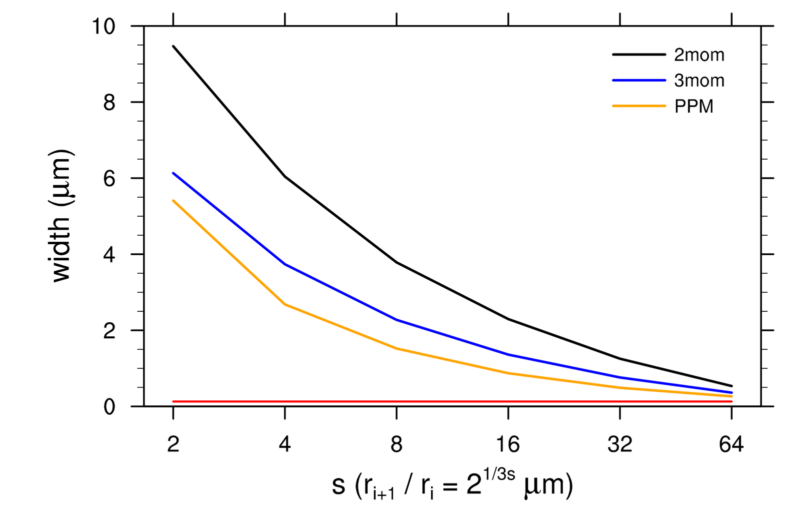
geometric grid, s = 3.16



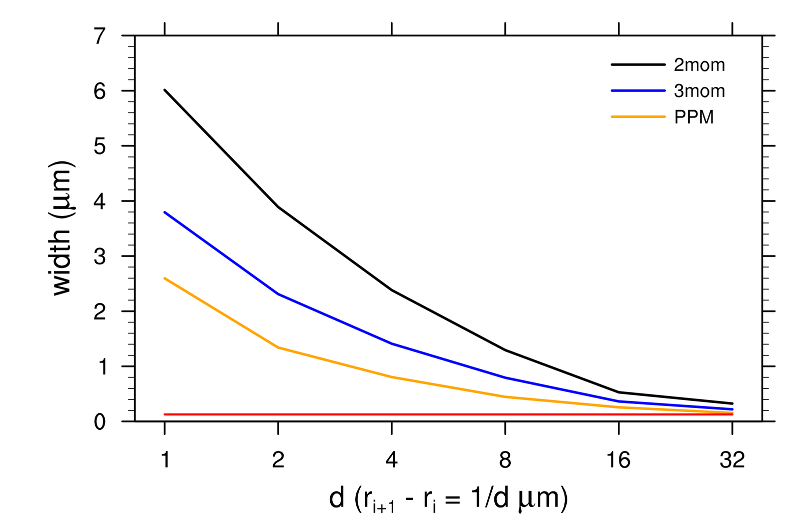
arithmetic grid, d = 2



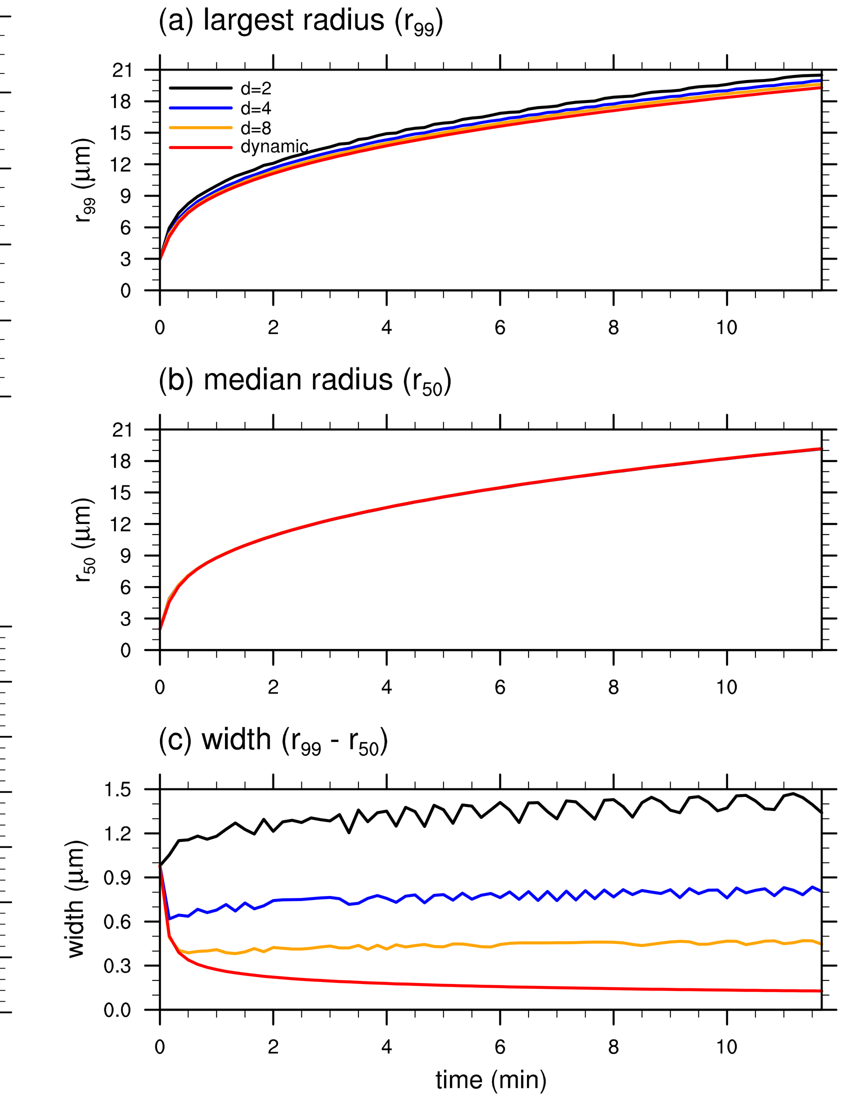
DSD width (r_{99} - r_{50}) **geometric**



DSD width (r_{99} - r_{50}) **arithmetic**



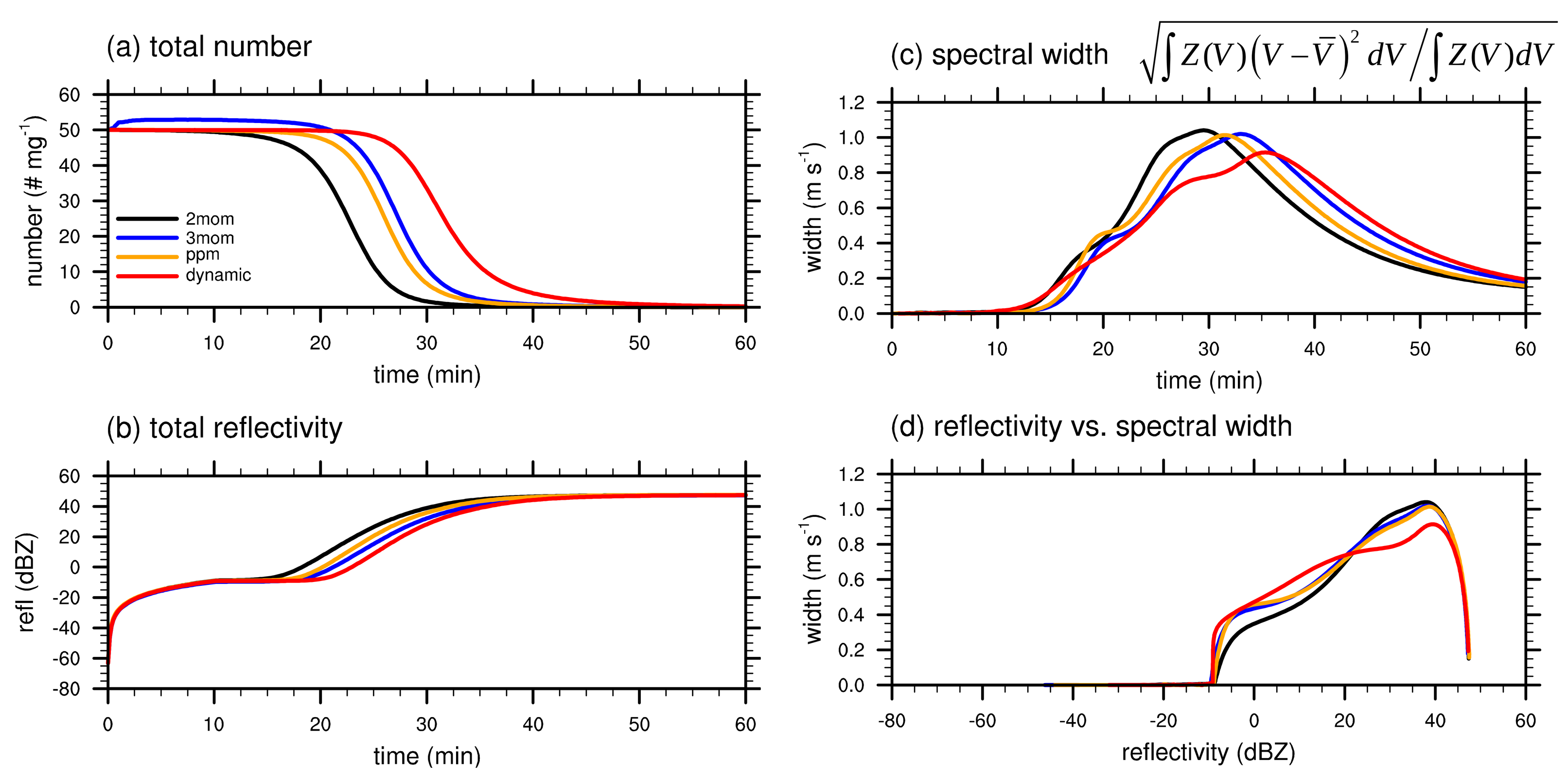
PPM with arithmetic grids



Condensation + Collision

✓ As in the condensation case, but w = 1 m s⁻¹ for the first 10 min and zero afterwards.

✓ **A mixture grid**: d = 2 (r = 1–26 μm), s = 2 (r = 26 μm – 1.5 mm), # of bin = 100



✓ Time scales of collision differ by up to ~10 min in this grid refinement depending on the condensation scheme choice.

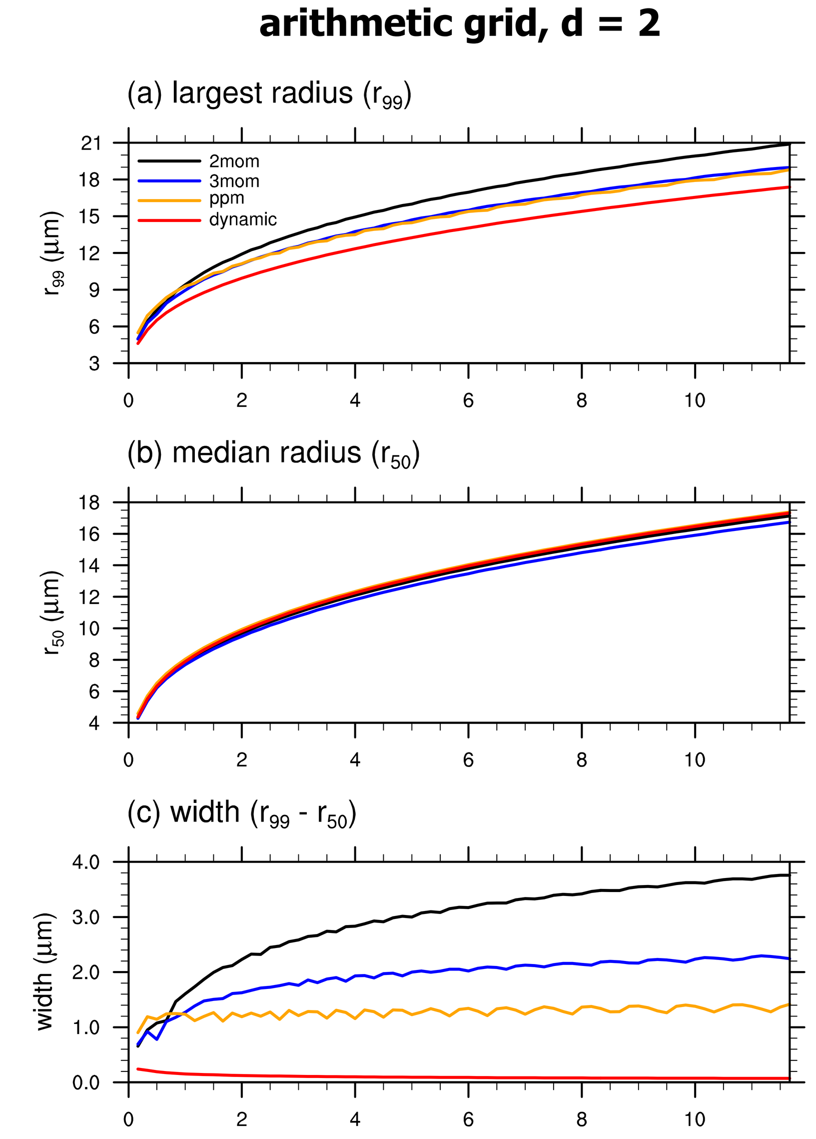
✓ The 3mom scheme yields the time series that are the closest to those of the reference solution, but the scheme slightly overestimates the number concentrations.

✓ Spectral widths of terminal velocity as a function of reflectivity are differ by up to ~ 0.2 m s⁻¹ in this grid refinement depending on the condensation scheme choice.

Activation + Cond.

As in the condensation case, but a bimodal aerosol distribution for the initial condition.

arithmetic grid, d = 2

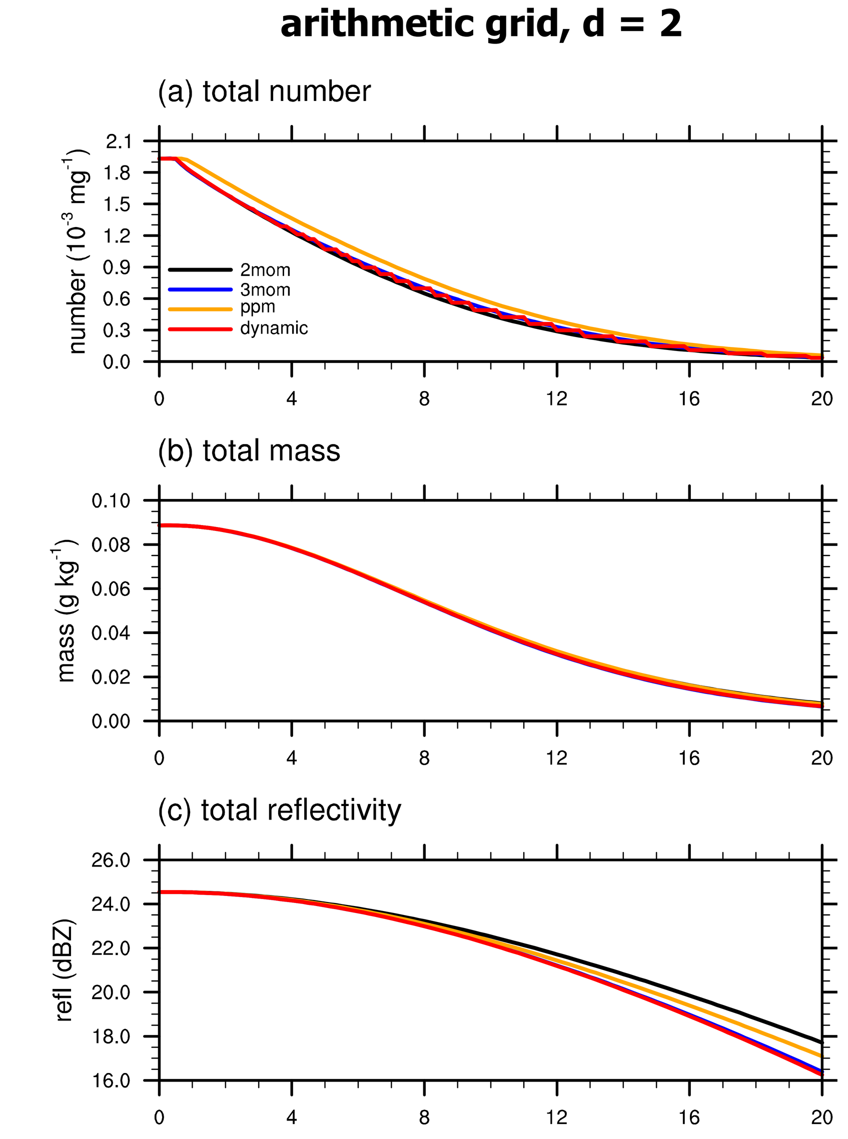


very similar to the condensation only case → less sensitive to the initial DSD

Evaporation

- w = −1 m s⁻¹ throughout the integration
- The Marshall-Palmer distribution (R = 1 mm h⁻¹)

arithmetic grid, d = 2



almost the same result regardless of the scheme choice even at a relatively coarse grid refinement