Toward a better representation of clouds and precipitation: size-resolved microphysics model and cloud Doppler radar

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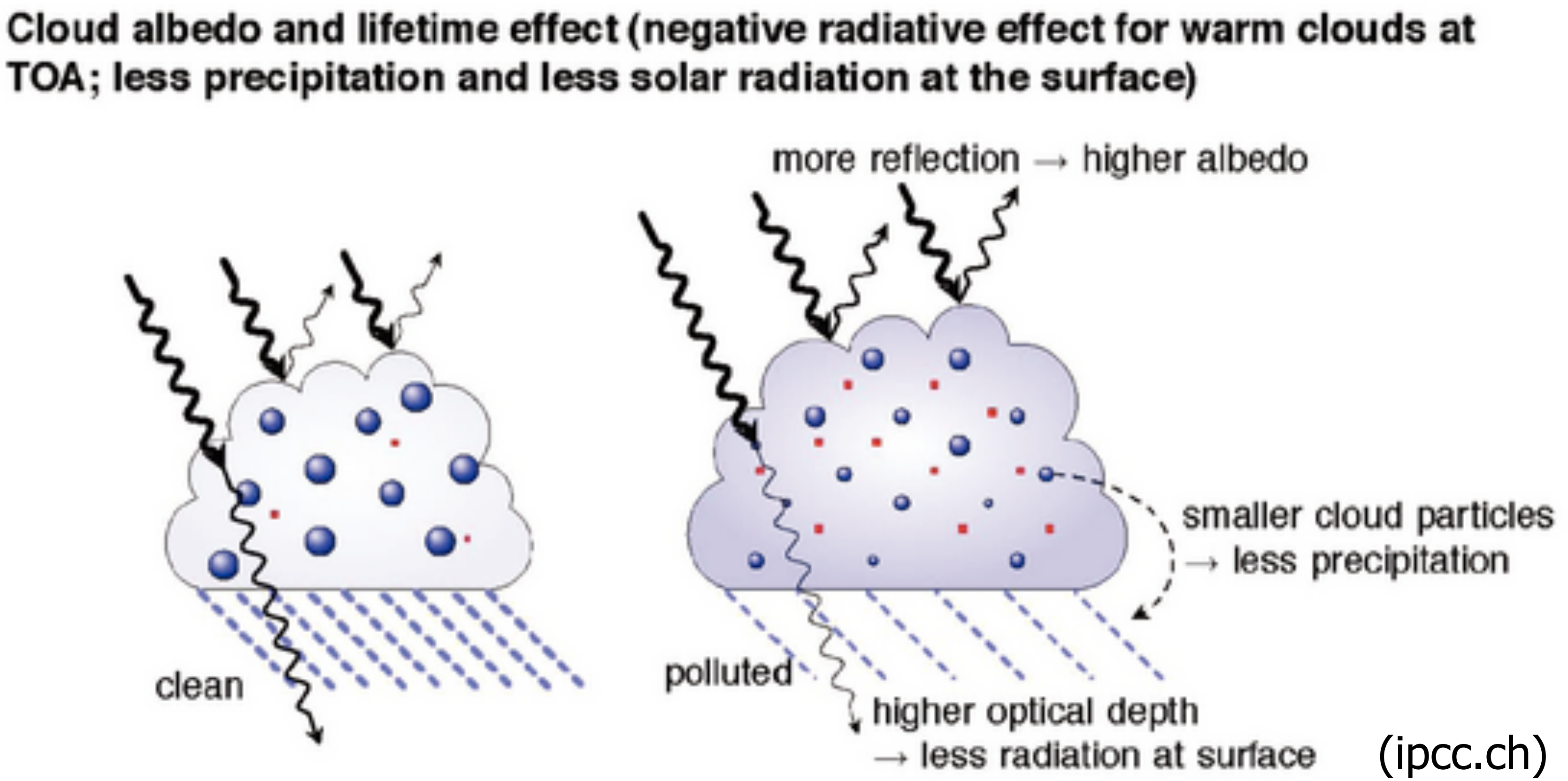
HYUNHO LEE

CO-WORK WITH ANN FRIDLIND AND ANDREW ACKERMAN

Introduction

Aerosol indirect effects and cloud-aerosol interactions



(ipcc.ch)

These interactions are affected by collision of drops and precipitation formation.

Introduction

Theoretically, droplets grow by condensation and form drizzles via collision, but…

Condensation: radii of drops become **similar** to each other.

Collision: collision becomes **rare** as drop radii become similar to each other.

Then, what are the leading mechanism for drizzle formation?

turbulence, giant aerosols, …

How can we evaluate their effects?

One of popular ways is to utilize numerical models!

Cloud microphysics model

What is a cloud microphysics model?

It solves

1) activation (nucleation)
2) vapor diffusion (condensation, evaporation)
3) collision and coalescence
4) breakup
5) sedimentation

in every model grid box (note: only warm processes are listed).

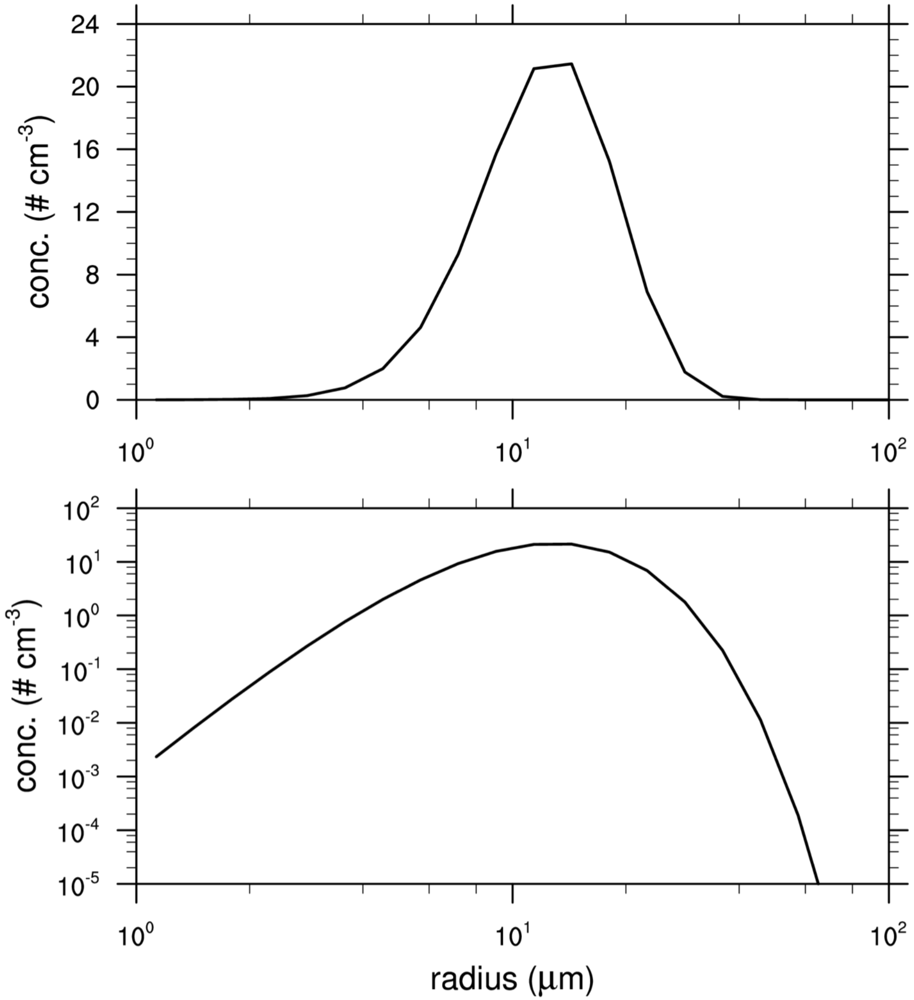
Cloud microphysics model

- ✓ All the microphysical processes depend on “**size**” of cloud particles.
- ✓ Therefore, representing **drop size distributions** is the key to evaluate microphysical processes.

Bulk microphysics scheme

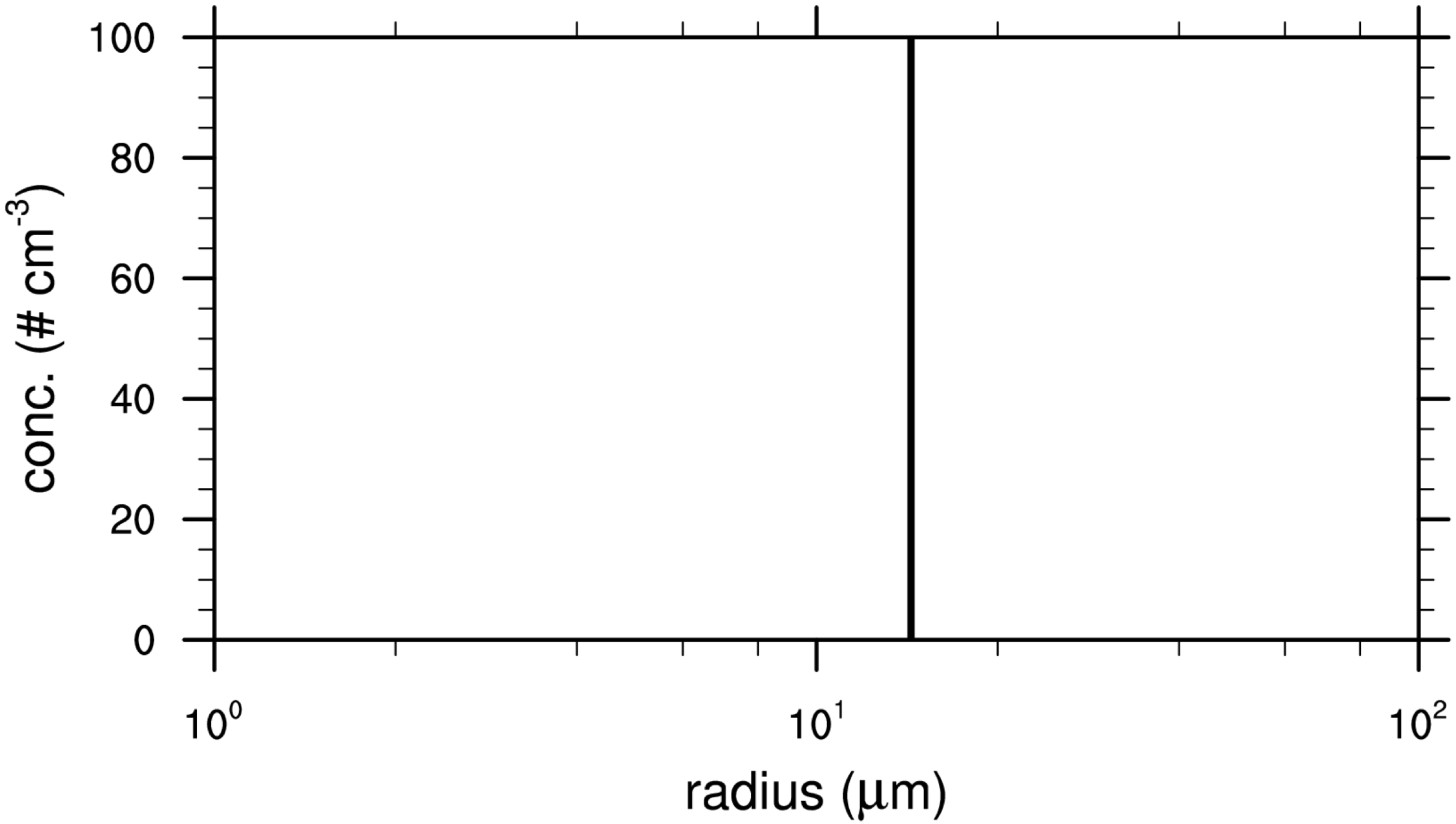
A bulk microphysics scheme parameterizes drop size distributions using a few parameters.

For example, there are 100/cm^3 drops whose radius is 15 μm. How will they be represented in a typical bulk scheme?



Bin microphysics scheme

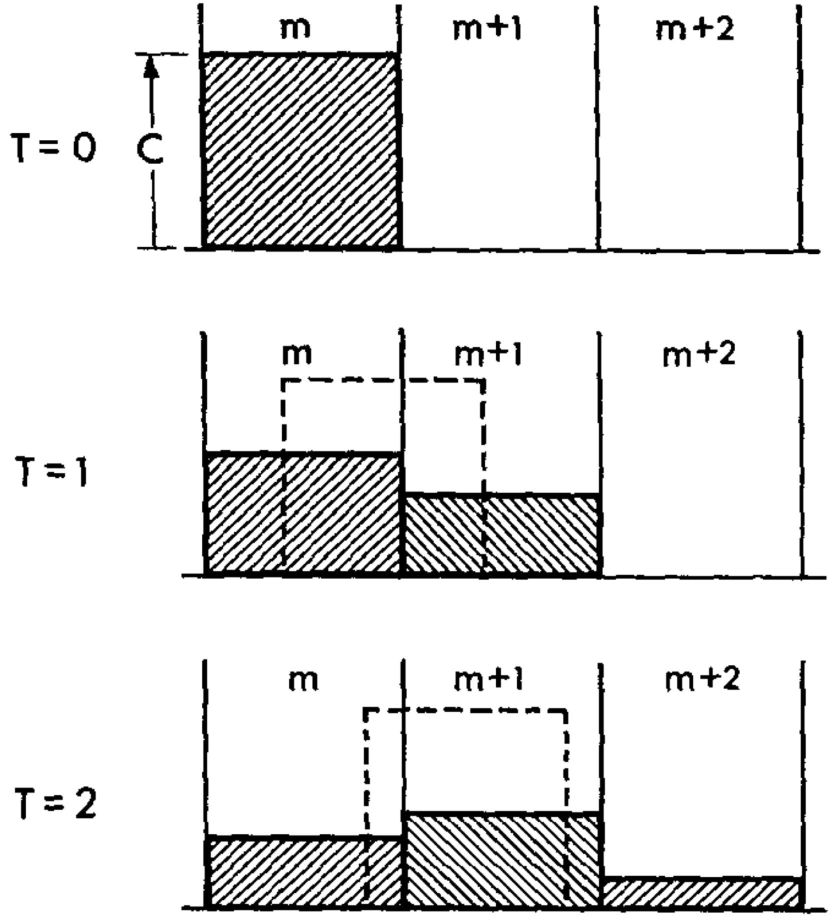
A size-resolved (bin) microphysics scheme
predicts number concentration of drops in “each size bin”.



Numerical diffusion in bin schemes

Q: There are two bins; 1 g and 2 g.
If there are 10 drops whose mass is 1.2 g,
how can we treat them in a bin scheme?

If we places 8 drops in the 1 g bin and 2 drops in the 2 g bin, number and mass are exact. But radar reflectivity is overestimated, and moreover, collision will be overly accelerated (owing to its high non-linearity).



(Egan and Mahoney 1972)

Subject of this study

- ✓ Can we get a **reliable solution** using a bin microphysics scheme?
- ✓ What **numerics** should be used under what **resolutions**?
- ✓ Can the results be **evaluated** using **observations**?

Part I: Collision-coalescence (accepted Monday!)

Collision-coalescence

Stochastic collection equation (SCE)

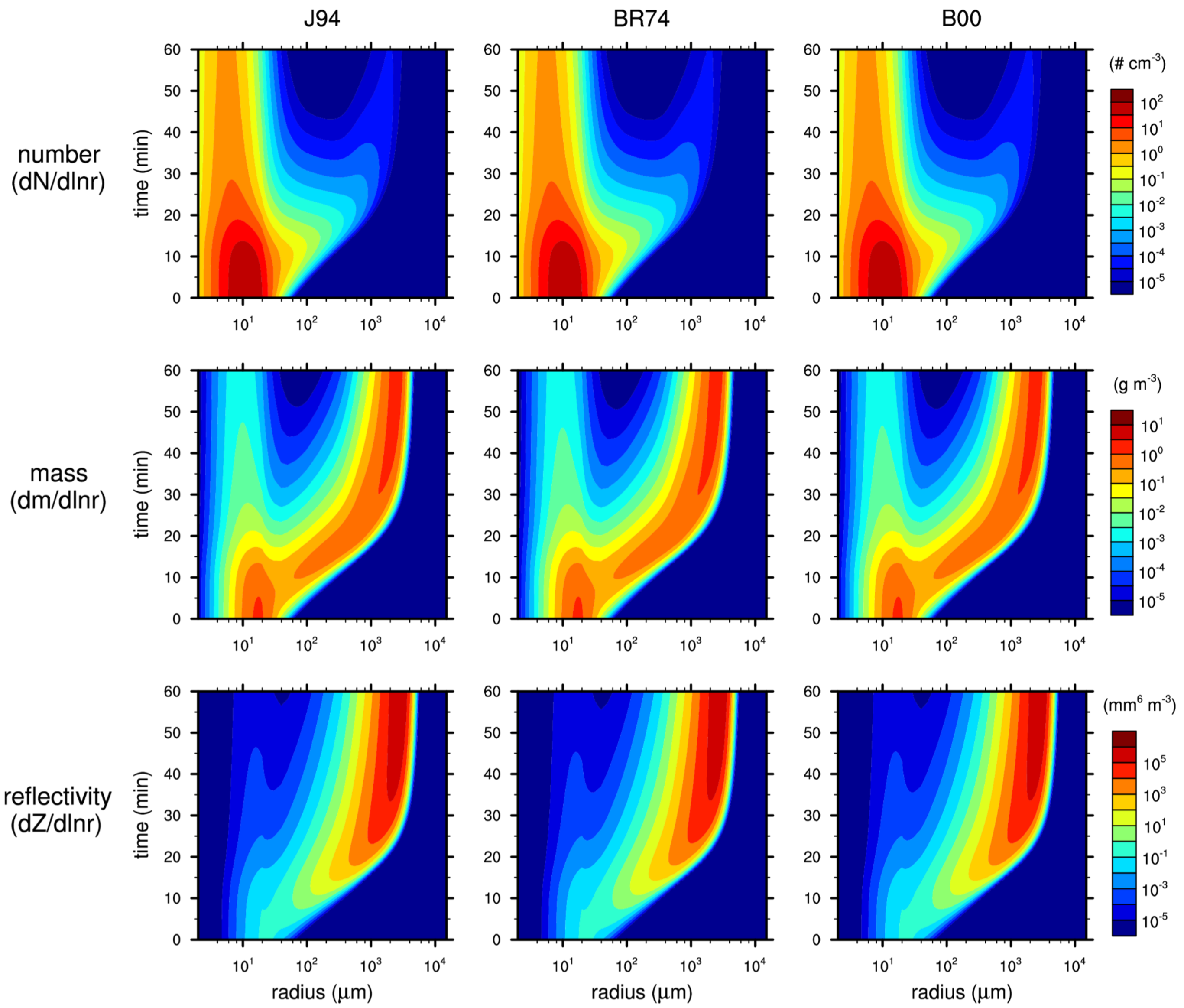
$$\frac{\partial n(m)}{\partial t} = \frac{1}{2}\int_0^m n(m-m')n(m')K(m-m',m')dm' \qquad \text{(source term)}$$

$$-\int_0^\infty n(m)n(m')K(m,m')dm' \qquad \text{(sink term)}$$

Collision-coalescence solving schemes

- ✓ **BR74**: Berry and Reinhardt (1974)
- ✓ **J94**: Jacobson et al. (1994)
- ✓ **B00**: Bott (1998, 2000)
- ✓ Wang et al. (2007)
- ✓ …

Converged solution

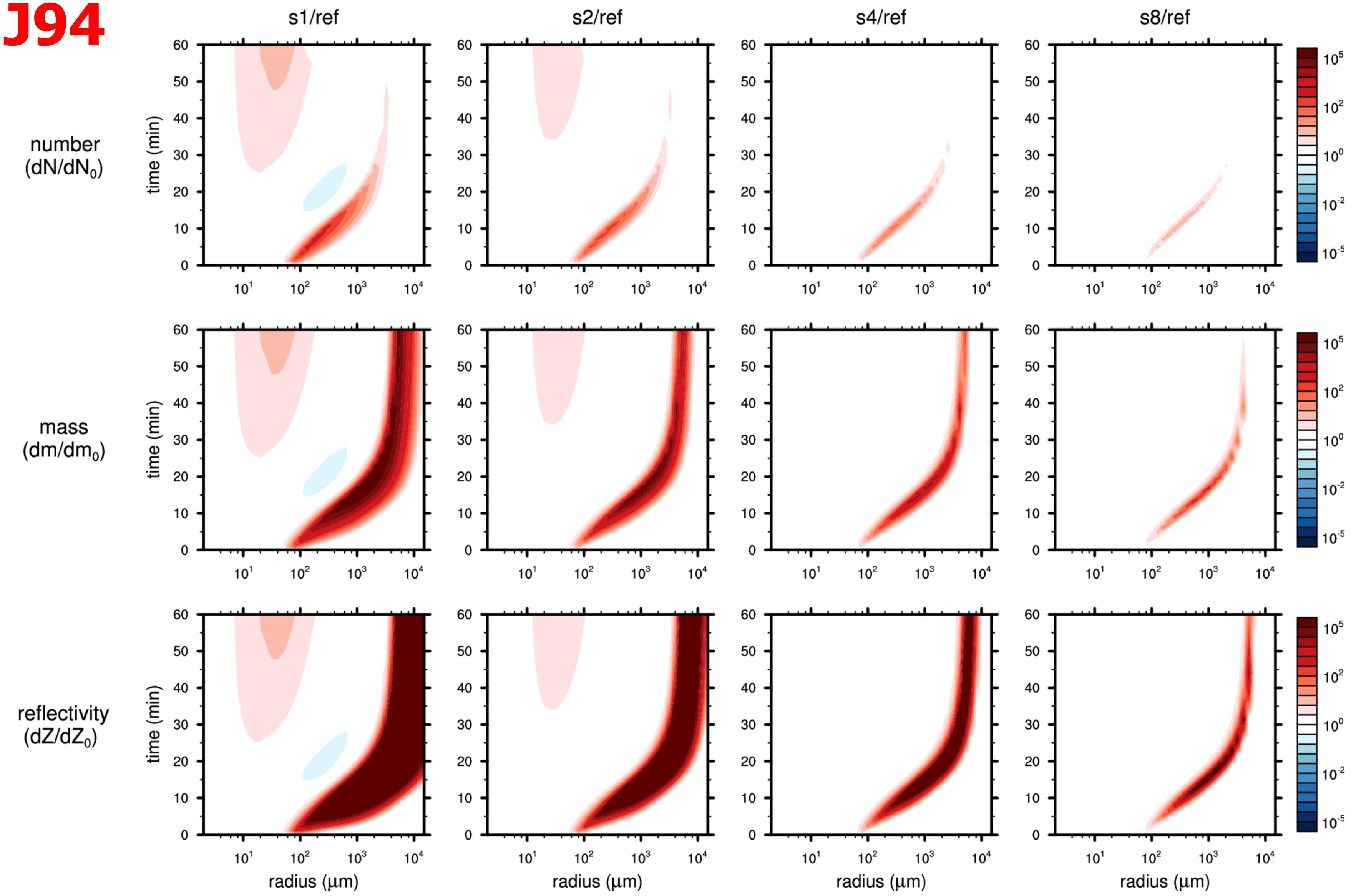


All the (converged) solutions are identical. However, we can obtain this solution only at a very high resolution.

(# of bins = 2560)

Convergence rate

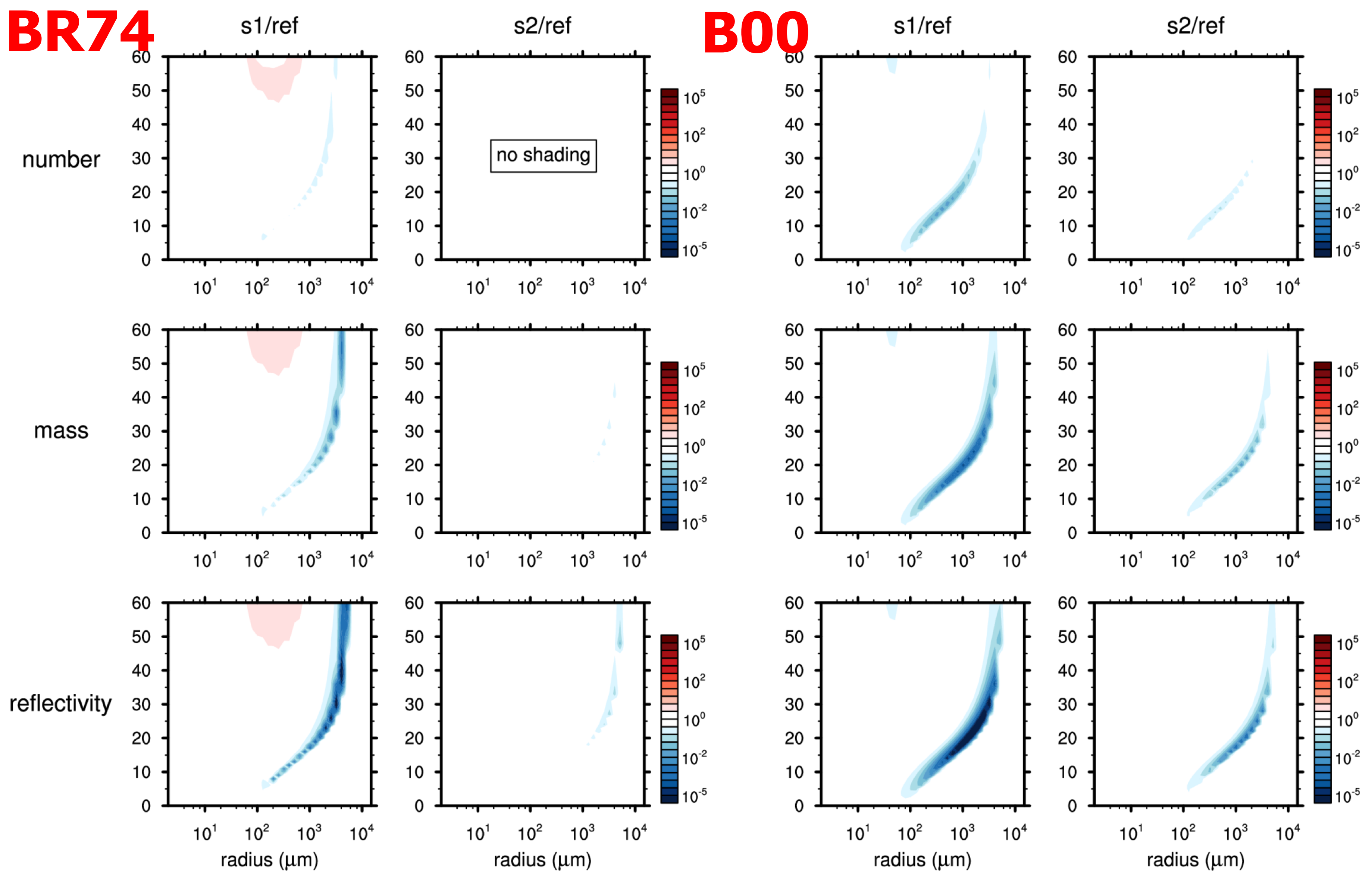
J94



- ✓ Even at a fine grid along the mass axis, J94 shows distinct numerical diffusion.
- ✓ Numerical diffusion is more distinct as the moment of distribution increases.

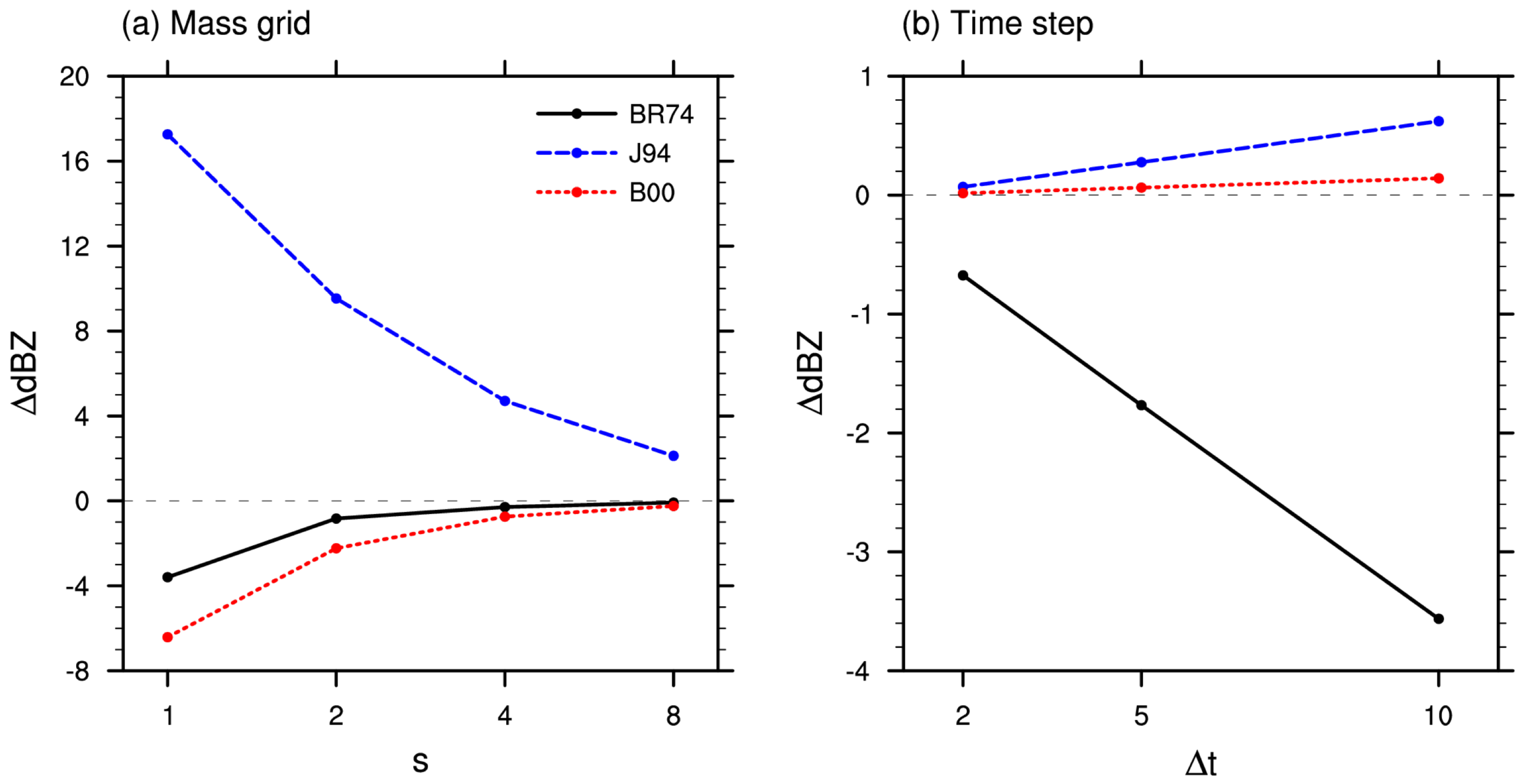
(# of bins = 40 x s)

Convergence rate



Both BR74 and B00 show comparatively suppressed deviations from the reference solution even at a relatively coarse mass grid.

Convergence rate

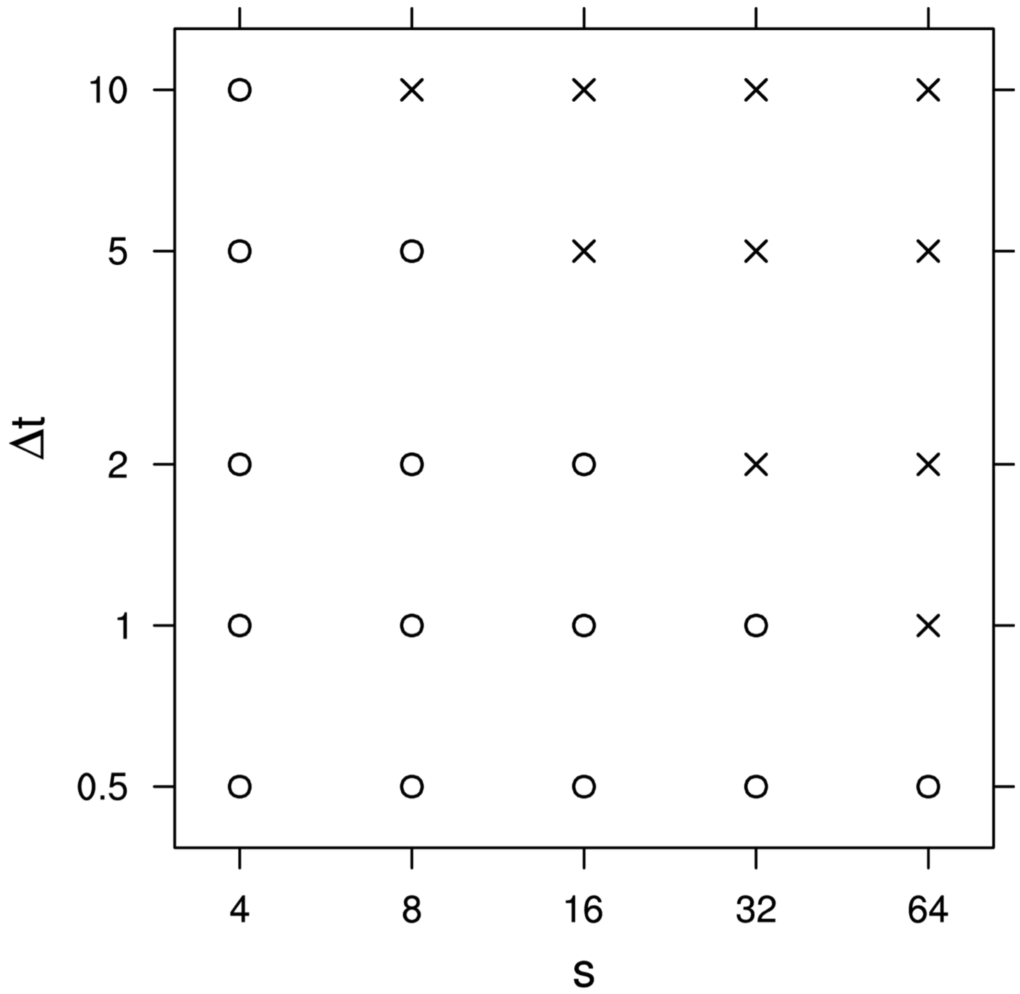


BR74 > B00 >> J94

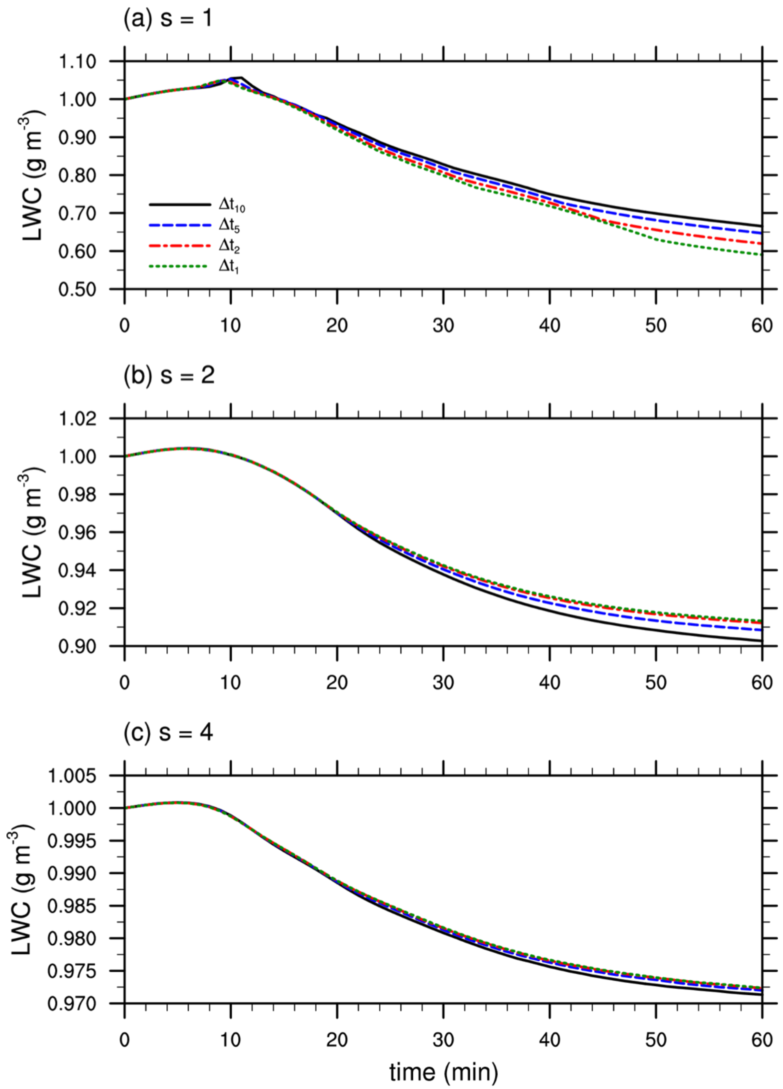
B00 > J94 >> BR74

Numerical tests on BR74

stability w.r.t. time step and mass grid width



mass conservation



3-D LES

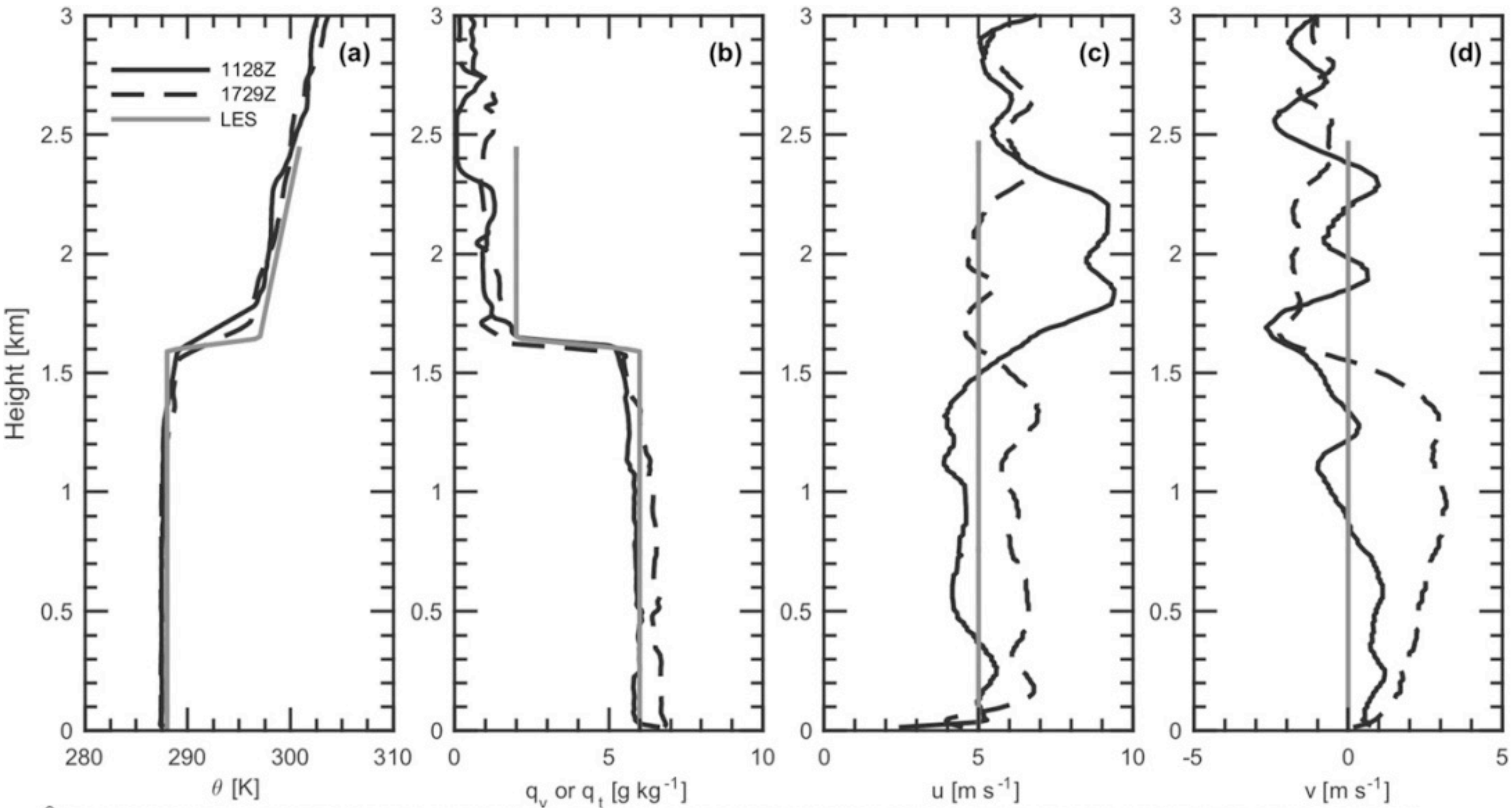
DHARMA (Distributed Hydrodynamic Aerosol and Radiative Modeling Application)

(Ackerman et al. 2004)

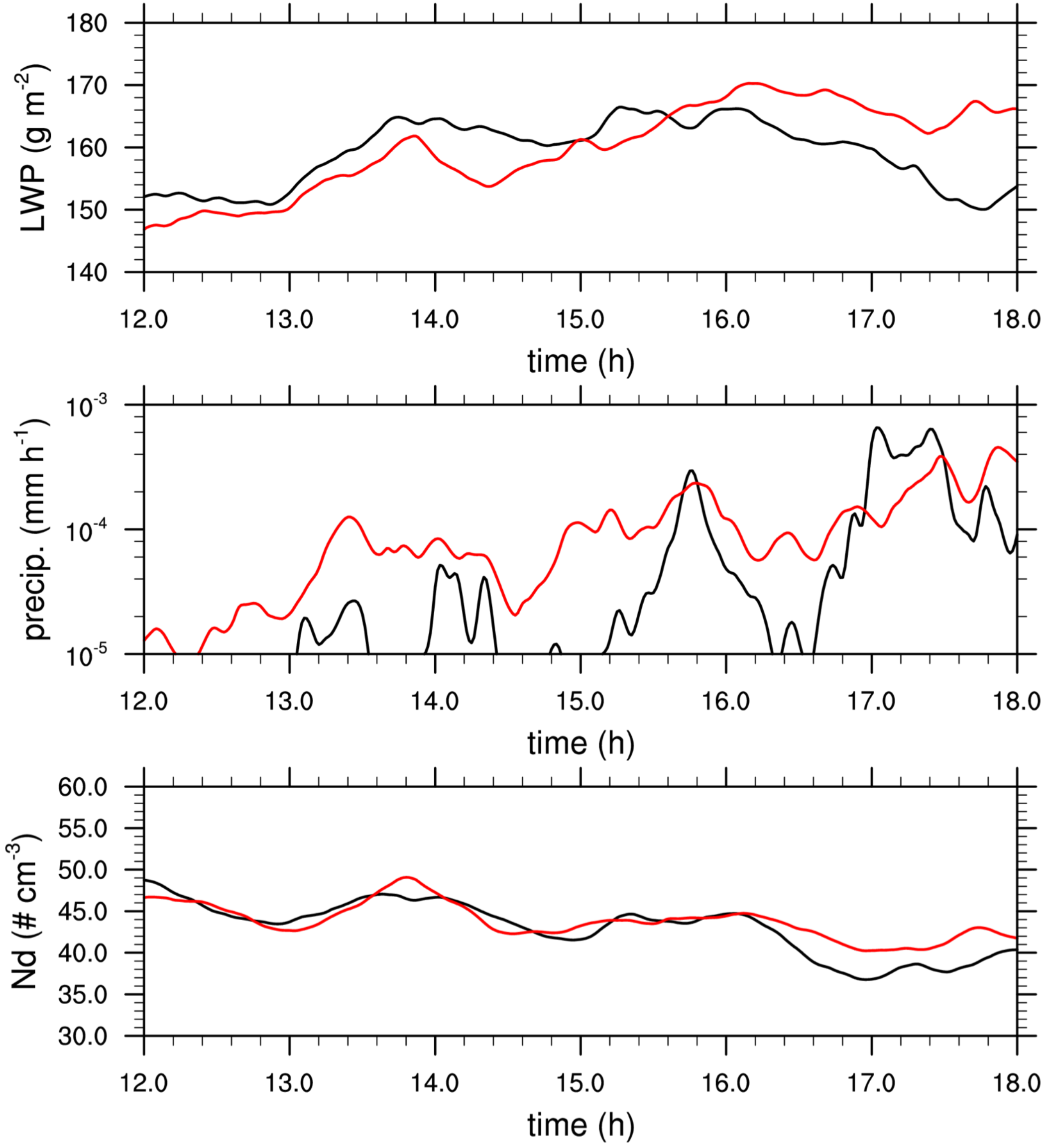
- ✓ $\Delta x = \Delta y = 75$ m, $\Delta z = 10–20$ m in the boundary layer
- ✓ Lx = Ly = 4.8 km, Lz = 2.5 km
- ✓ Number of bins = 70
- ✓ Initial aerosol concentration = 65 cm^{-3}

3-D LES

A case from the CAP-MBL campaign (Wood et al. 2015, Rémillard et al. 2017)



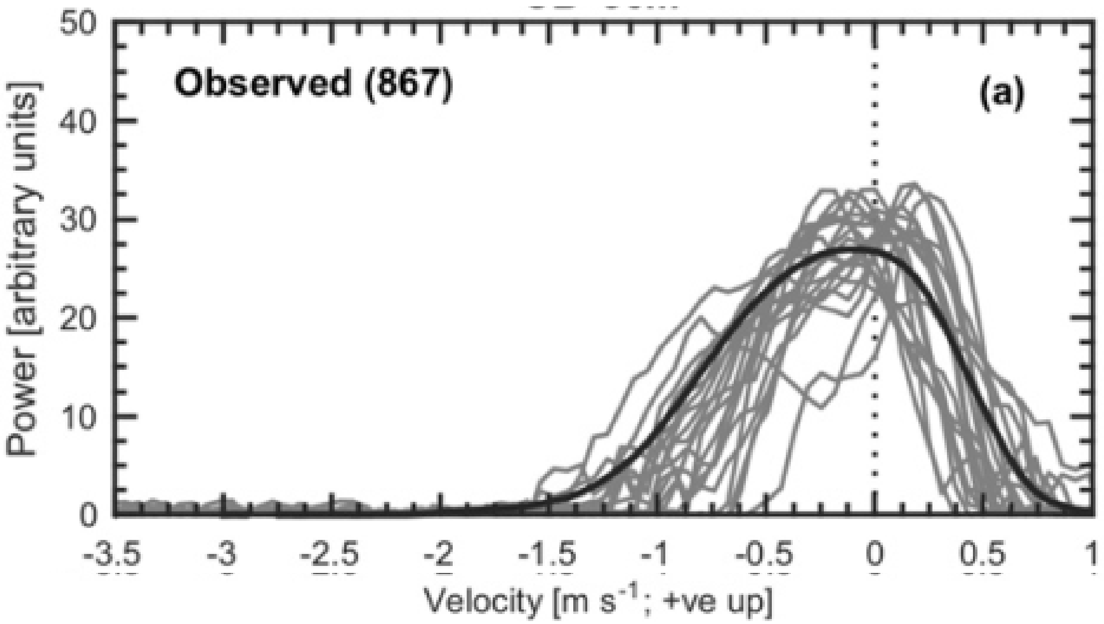
First results



Hard to assess the differences!

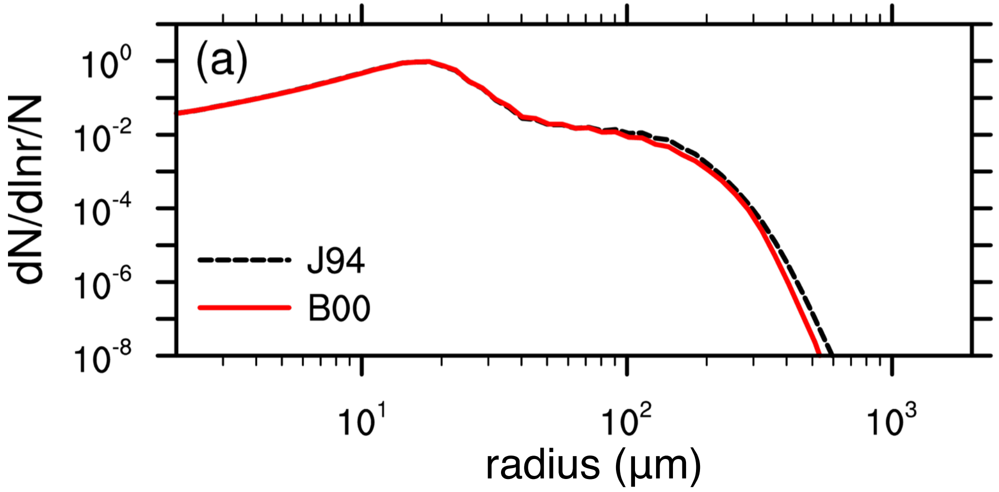
Forward simulator

A cloud Doppler radar yields Doppler spectra.

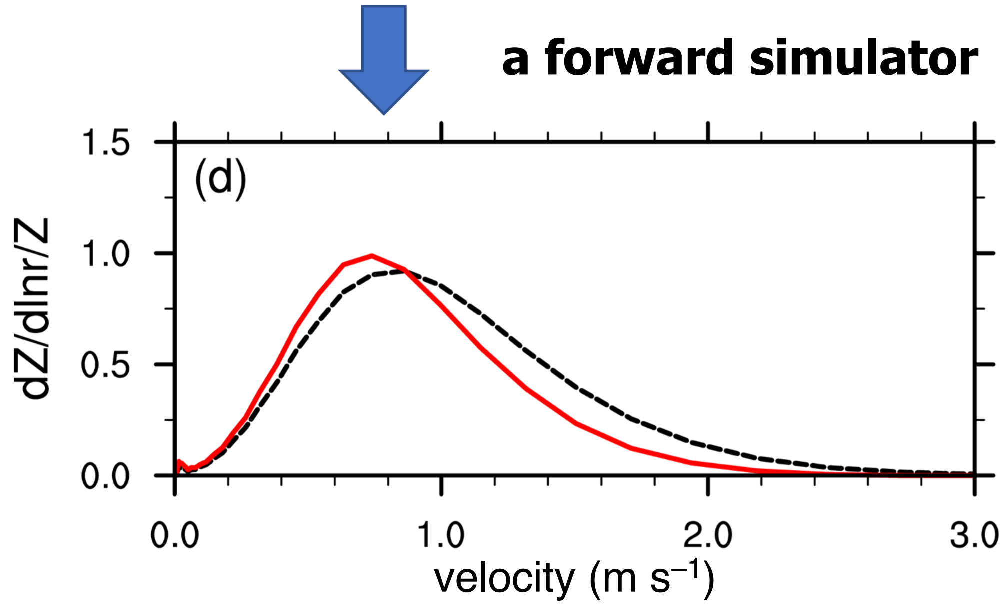


(Rémillard et al. 2017)

From LES-bin model,

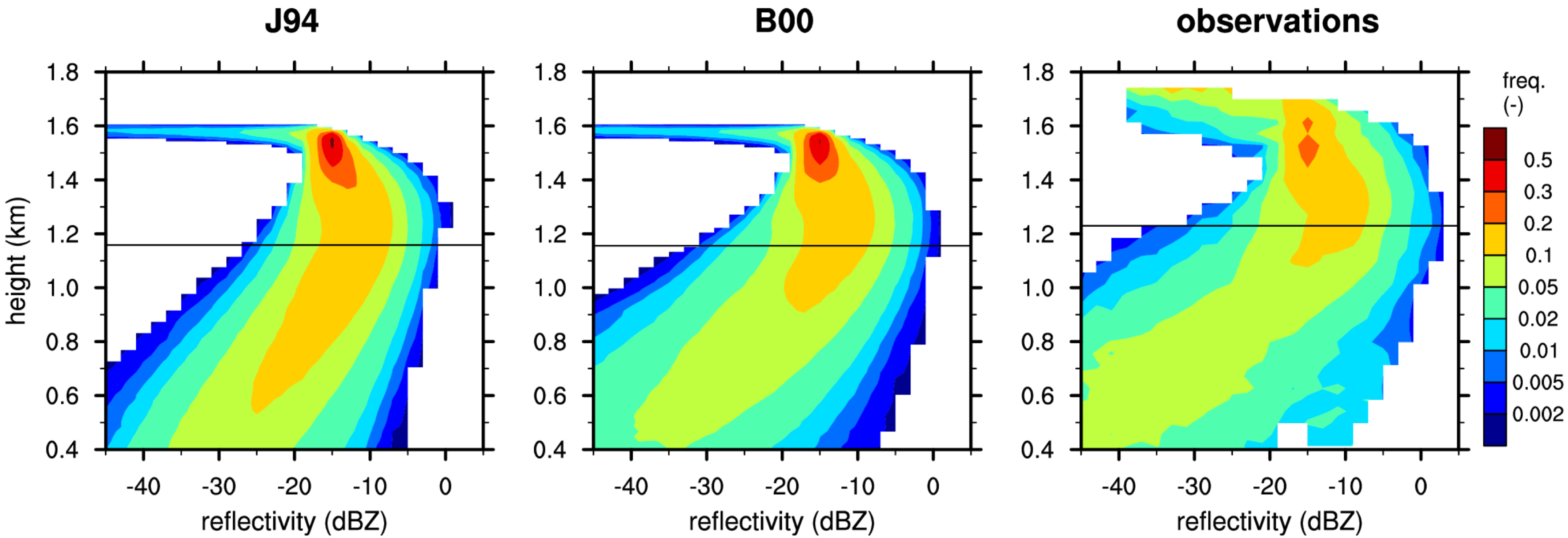


a forward simulator



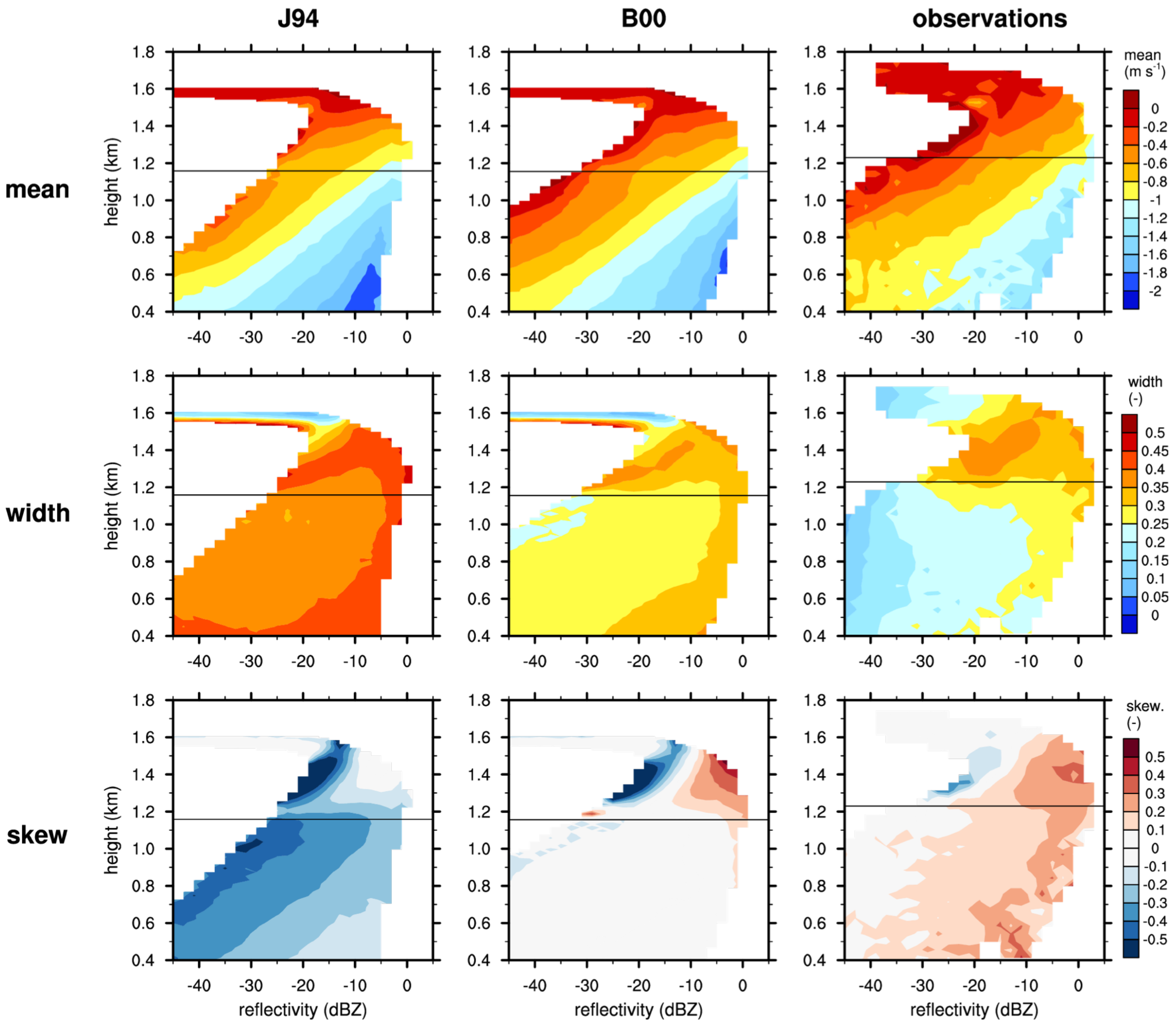
Radar reflectivity

CFAD (contoured frequency-altitude diagram) for radar reflectivity



- ✓ The peaks appear at lower reflectivity in B00 than J94
- ✓ Results from B00 are closer to observations than those from J94.

Doppler spectra



median values of
mean, width, and skewness of
Doppler spectra

J94 (diffusive scheme) yields too large mean Doppler velocity, and too wide and too negatively (toward large values) Doppler spectra.

B00 (better scheme) reduces those biases considerably!

Conclusions

- ✓ Can we get a **reliable solution** using a bin microphysics scheme?

  → It seems to YES!

- ✓ What **numerics** should be used under what **resolutions**?

  → For collision-coalescence, B00 with ~80 bins is satisfactory.

- ✓ Can the results be **evaluated** using **observations**?

  → Cloud Doppler radar and forward simulator are good tools to evaluate model performance.

Future works

- ✓ Are other numerics on processes in a bin microphysics scheme sufficiently accurate?
- ✓ What are the leading mechanisms for drizzle formation?
- ✓ How does increasing aerosols perturb cloud development?

Thank you for your attention!