EarthCARE 2026 Science and Validation workshop

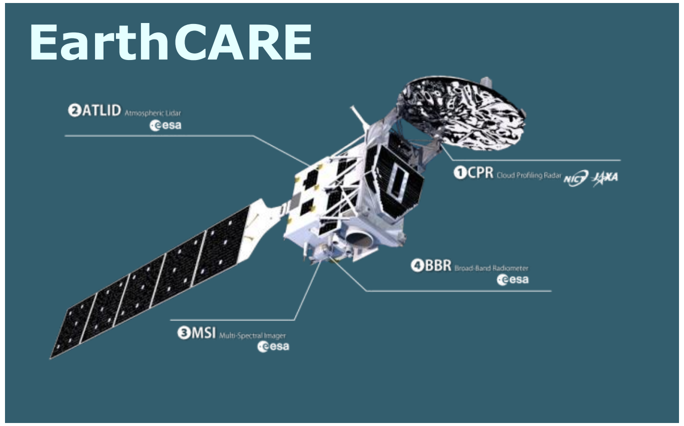
8–12 June 2026 | Rhodes House | Oxford, UK

Revisiting the representation of ice particles in cirrus clouds in numerical weather prediction models using EarthCARE CPR

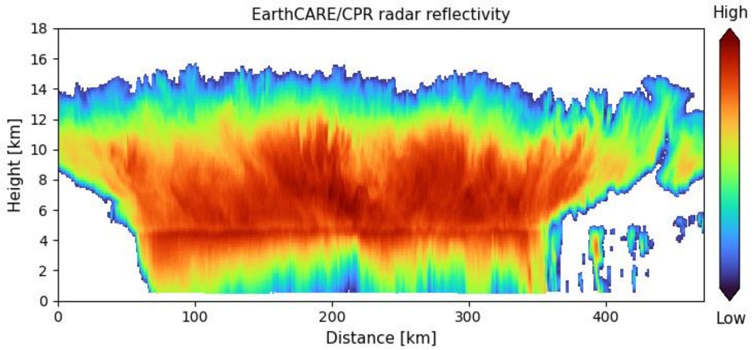
Yasutaka Ikuta

Meteorological Research Institute / Japan Meteorological Agency

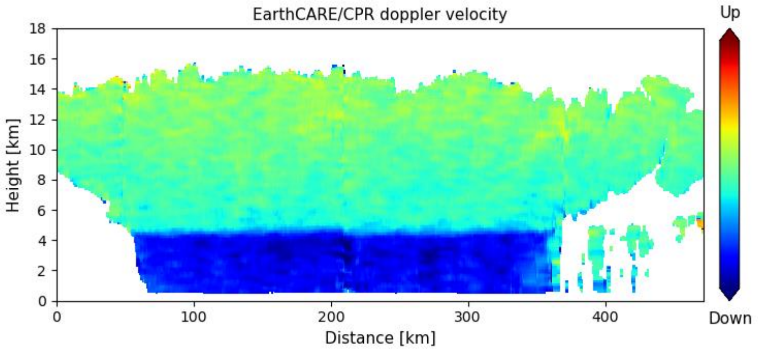
Model validation of EarthCARE/CPR



Reflectivity



Doppler velocity



https://www.satnavi.jaxa.jp/ja/news/2024/10/04/9923/index.html

EarthCARE/CPR (W-band cloud profiling radar)

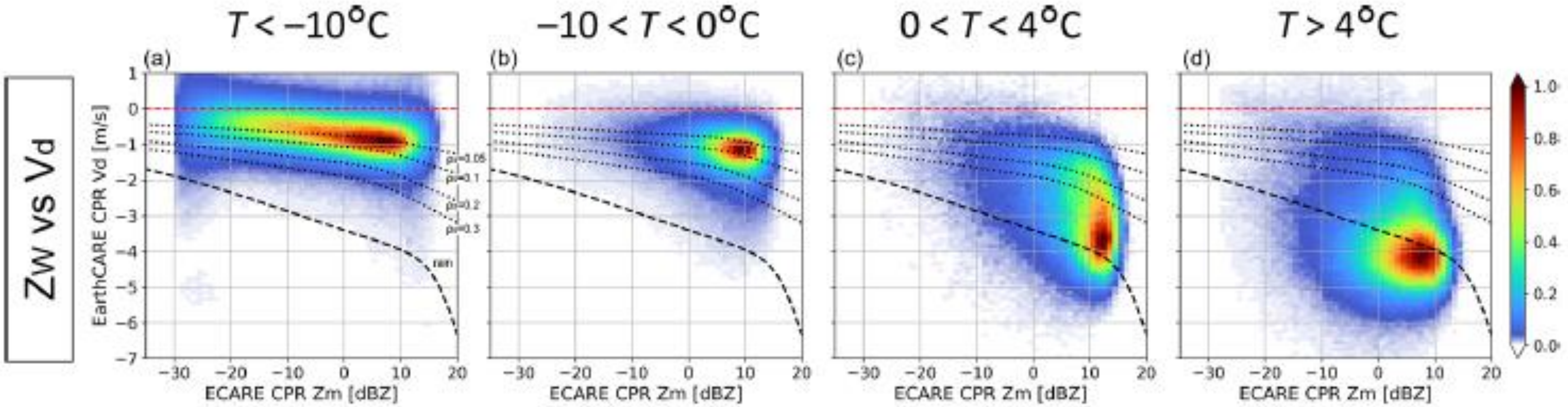
✓ Reflectivity and Doppler velocity

CPR provides detailed vertical information on clouds and precipitation.

→ Comparing CPR observations with simulations enables evaluation of model physics.

Diagnosing microphysics using Z–Vr

EarthCARE provides relationship between reflectivity (Z) and Doppler velocity (Vr)



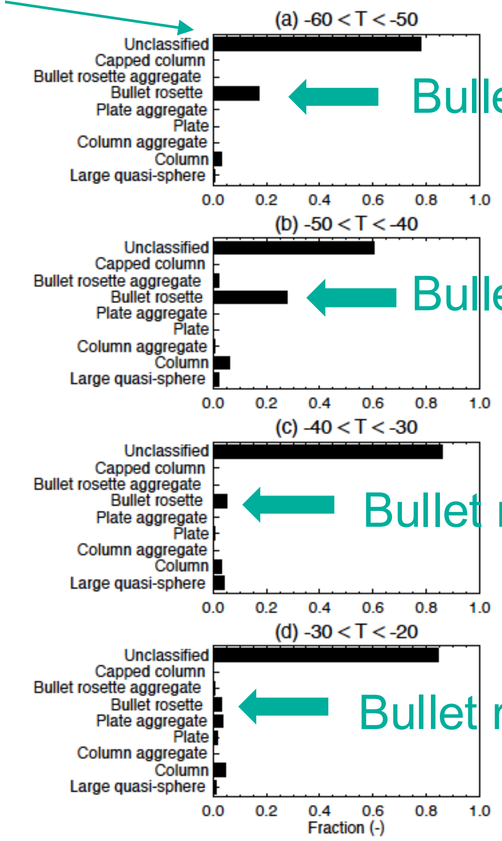
Aoki et al. (2026)

- Z–Vr relation constrains hydrometeor type and terminal velocity
  - ✓ Sensitive to model microphysics
  - ✓ Process-level diagnostic for evaluation

Temperature dependence of shape

JAXA esa EUROPEAN SPACE AGENCY

Unclassified particles



Bullet rosette

Bullet rosette

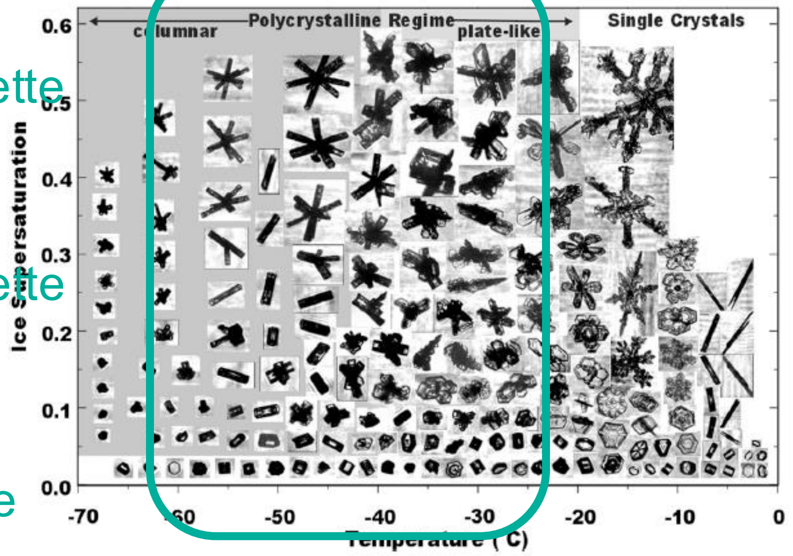
Bullet rosette

Bullet rosette

Figure 8. Fraction of imaged ice crystals with D_{max} greater than 100 µm in four temperature ranges in degrees Celsius.

Fridlind et al. (2016)

Bullet rosette



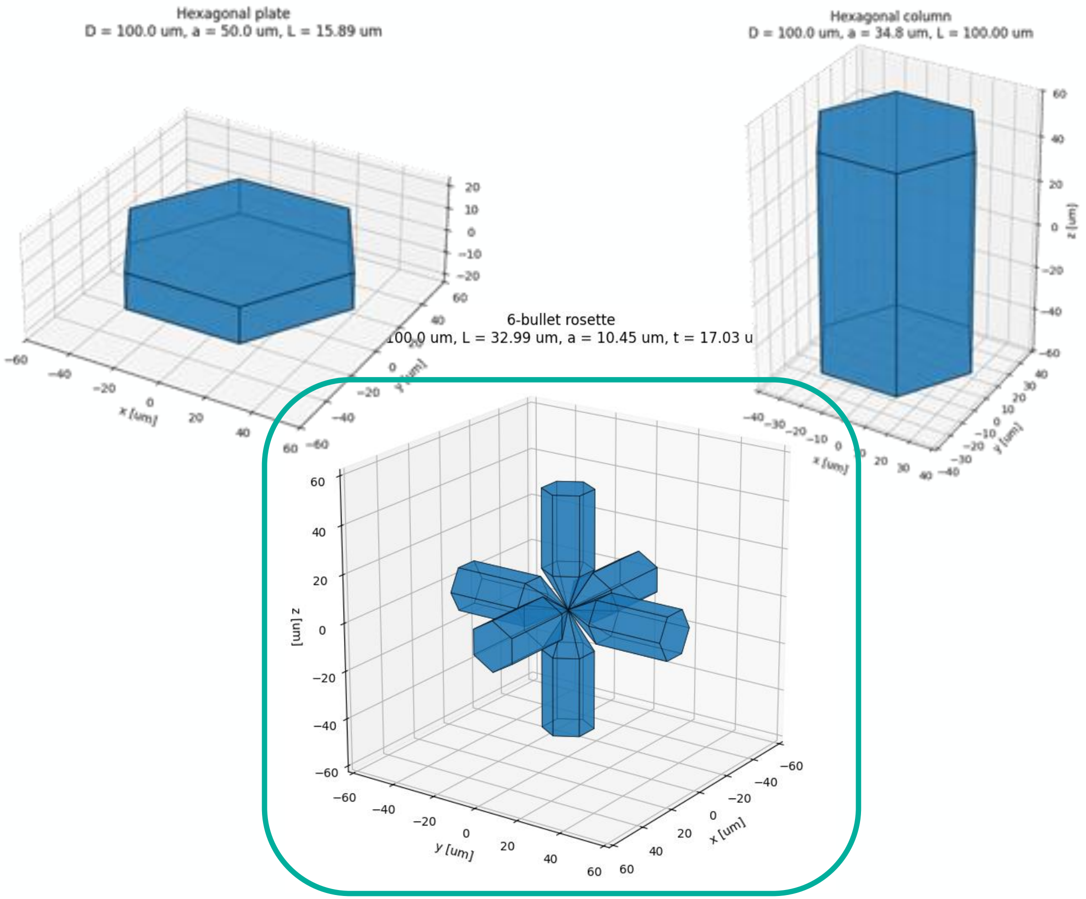
Bailey and Hallett (2008)

Ice particle shape strongly depends on temperature

Cold regime (< -30℃):

- A large fraction of particles remain unclassified
- Bullet rosette is the dominant identified habit

Consistent definition of cloud ice



✓ Ice crystal models follow Yang et al. (2000)
✓ Random orientation is assumed

- Cloud ice particle assumptions are often ambiguous in NWP models. We explicitly define particle types.

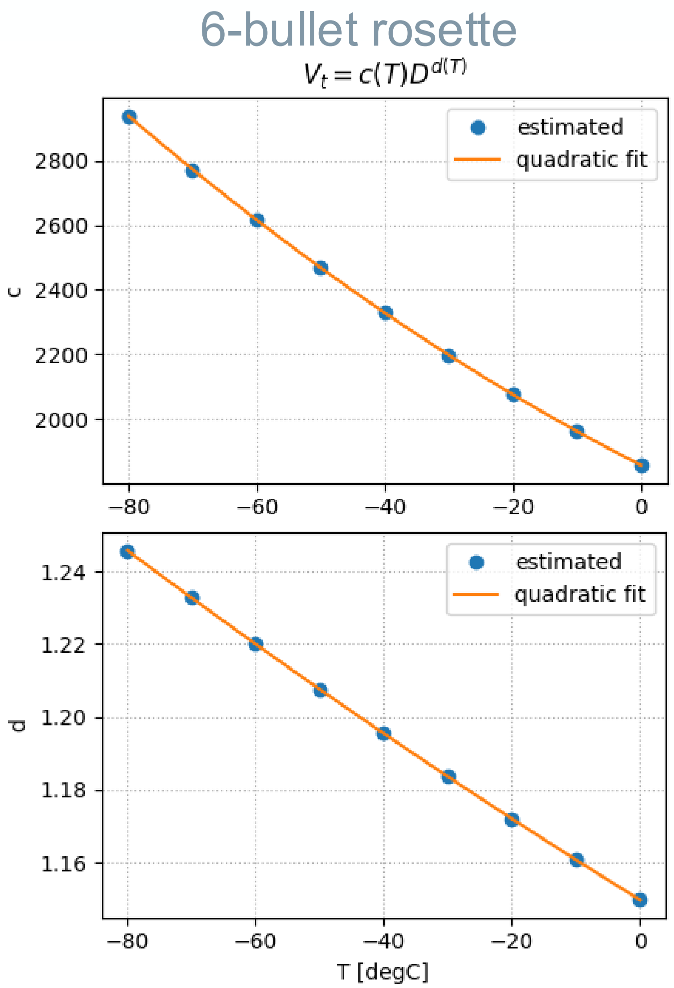
- We define three particle types:
  - ➢ Plate
  - ➢ Column
  - ➢ 6-bullet rosette

In this presentation, we focus on bullet rosette.

- For each type:
  - ➢ Geometric structure
    → mass and terminal velocity are **automatically determined**.

- **Same definition** used in NWP model and CPR simulation

Temperature-dependent Vt



Temperature dependence of c(T), d(T)

Terminal velocity is computed based on Heymsfield and Westbrook (2010)

→ Function of mass and projected area

1. Reynolds number is given by mass and projected area
2. Terminal velocity is given as

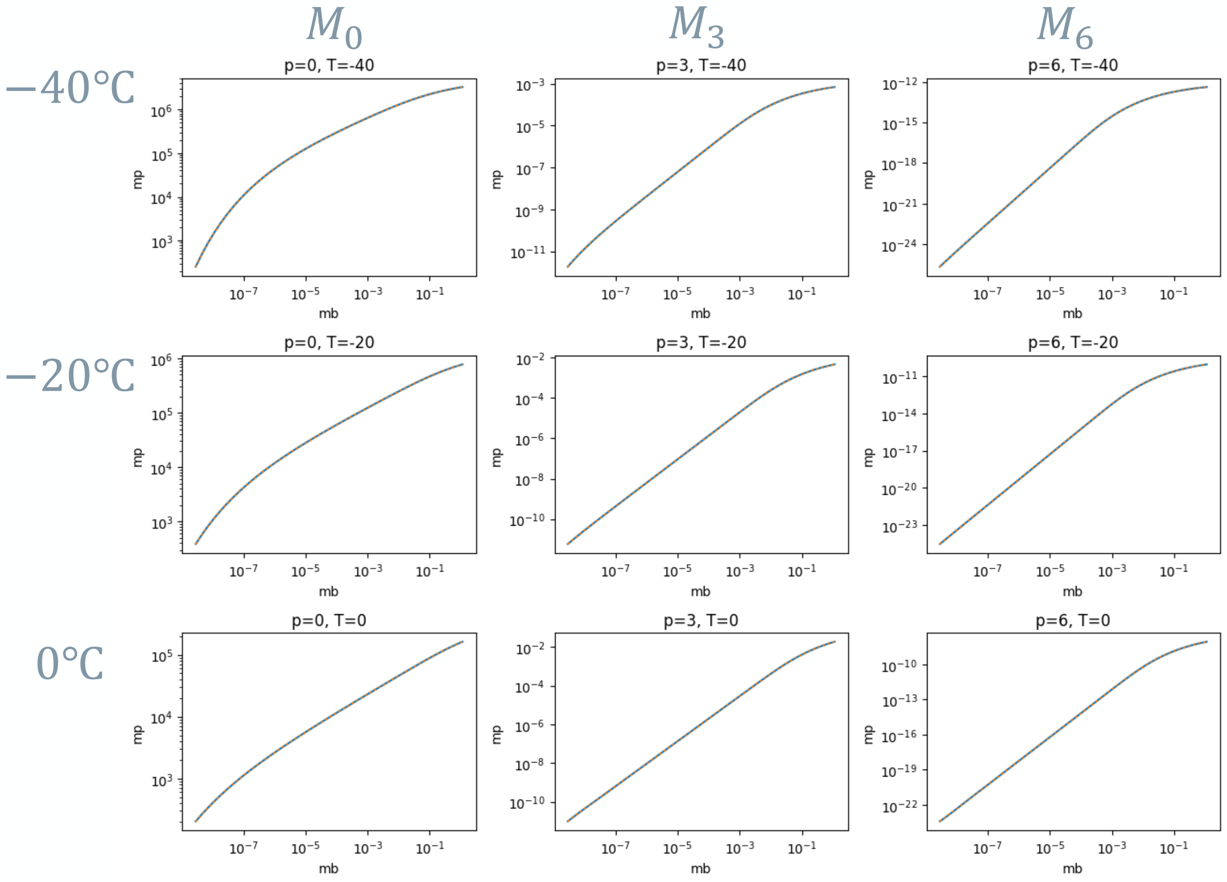
$$v_t = \frac{\eta Re}{\rho_a D}$$

We parameterize terminal velocity as:

$$v_t = c(T) D^{d(T)} \sqrt{\rho_0/\rho_a}$$

Coefficients c and d are fitted as functions of temperature

Inconsistency of size assumption



mass-moment relationship

We revisit how bulk microphysics computes moments.
Conventional approach:

$$M_n = \int_0^\infty D^n N(D,T)\,dD$$

- ➢ assumes infinite particle size range
- ➢ inconsistent with particle definition

This study:

$$M_n = \int_{D_{min}}^{D_{max}(T)} D^n N(D,T)\,dD$$

- ➢ finite and temperature-dependent size range
- ➢ Dmax is given by Heymsfield et al. (2013)

Moments cannot be represented by simple power-law

- ➢ Strong temperature dependence
- ➢ Implemented using LUT

Dmax constrained by observations

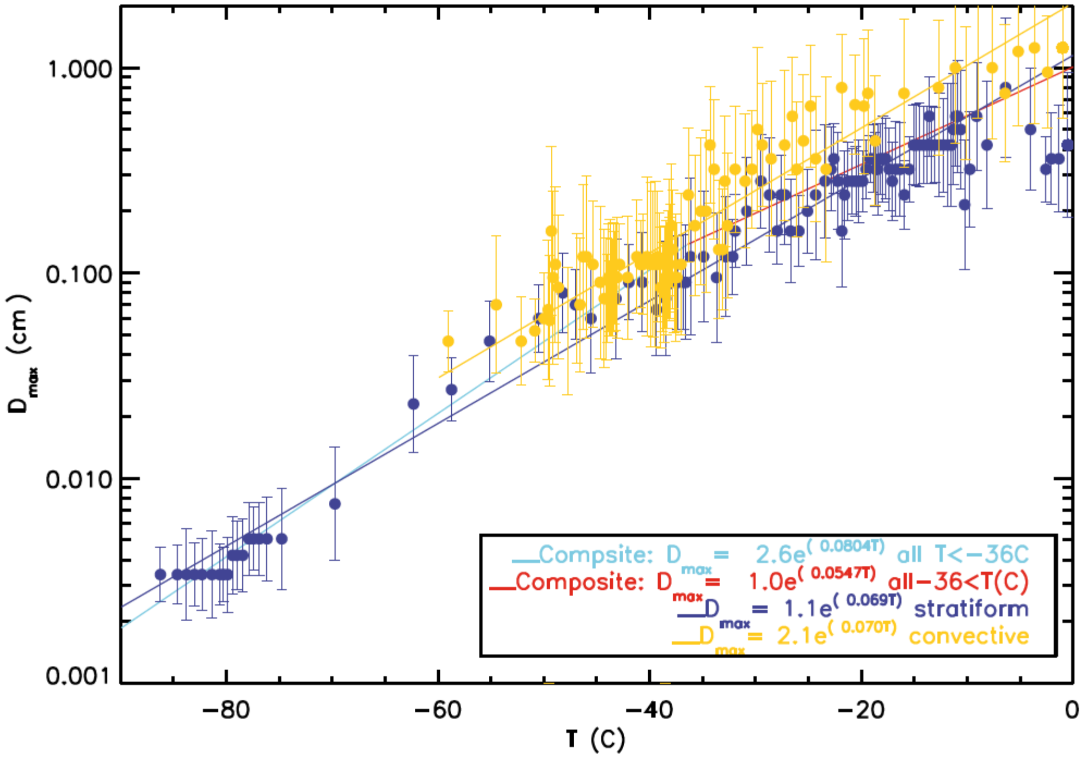


FIG. 6. Maximum diameter in each PSD as a function of temperature, shown as median values in temperature intervals given by an equal number of points as derived from the individual PSDs as a function of temperature; median values shown separately for $T < -60°C$ and $T > -60°C$. Exponential curve fits to the field program data identified as convective clouds, stratiform clouds, and for all clouds combined are shown.

Heymsfield et al. (2013)

- ✓ Dmax increases with temperature
- ✓ Used as upper bound of moment integration in this study

Sensitivity experiments: particle size

Evaluate the impact of assumed particle size on simulated radar observables.

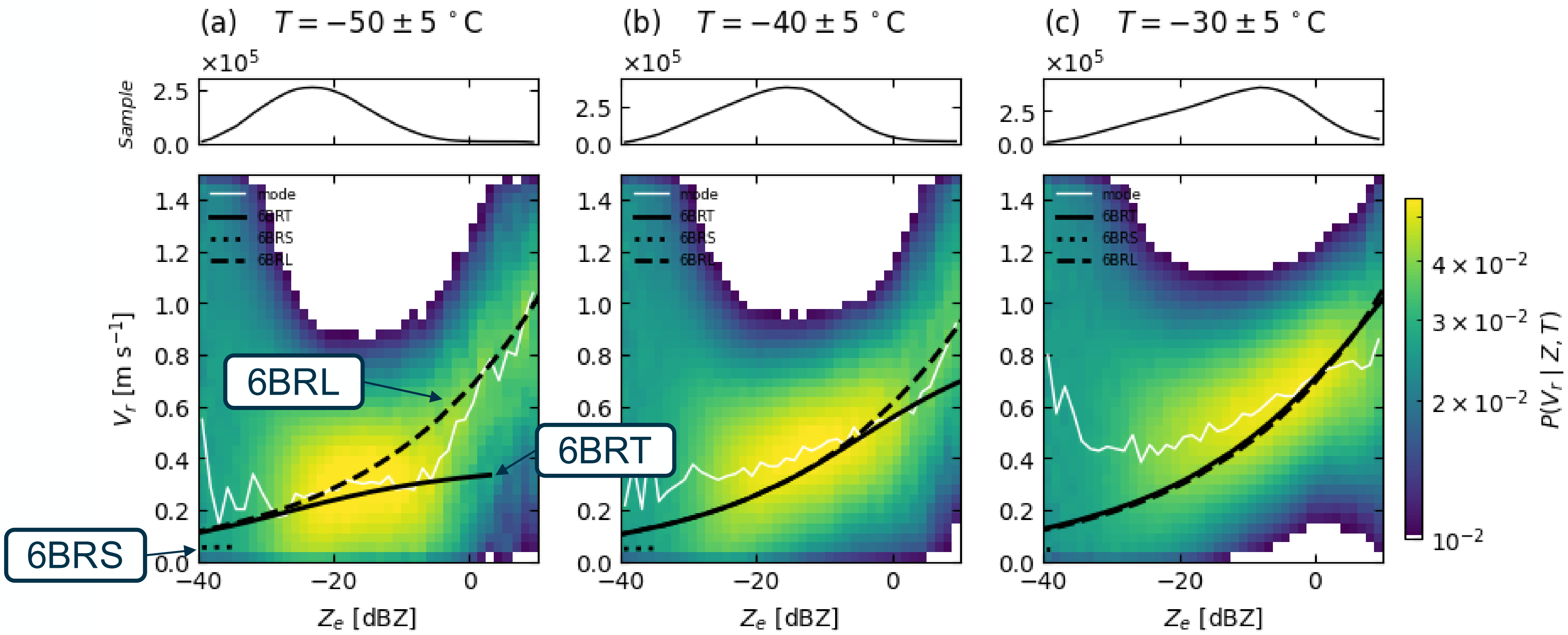
The conventional approach is internally inconsistent:

- Particle properties are defined for Dmax = 100 μm
- PSD moments are integrated over 0–inf.

Experiments

- 6BRT: 6-bullet rosette, temperature-dependent Dmax
- 6BRS: 6-bullet rosette, small Dmax (100 μm)
- 6BRL: 6-bullet rosette, large Dmax (10,000 μm)

Dmax controls Z–Vr relationship

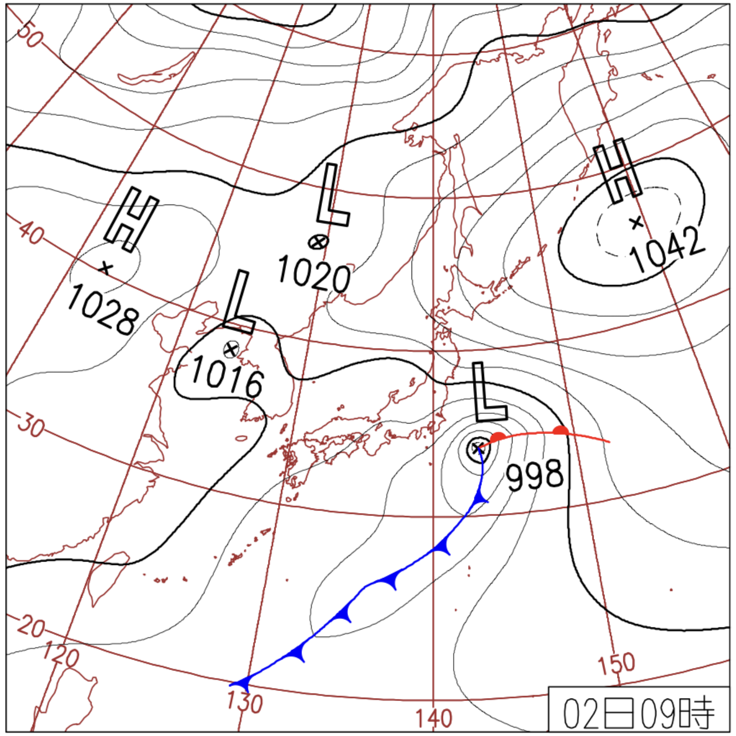


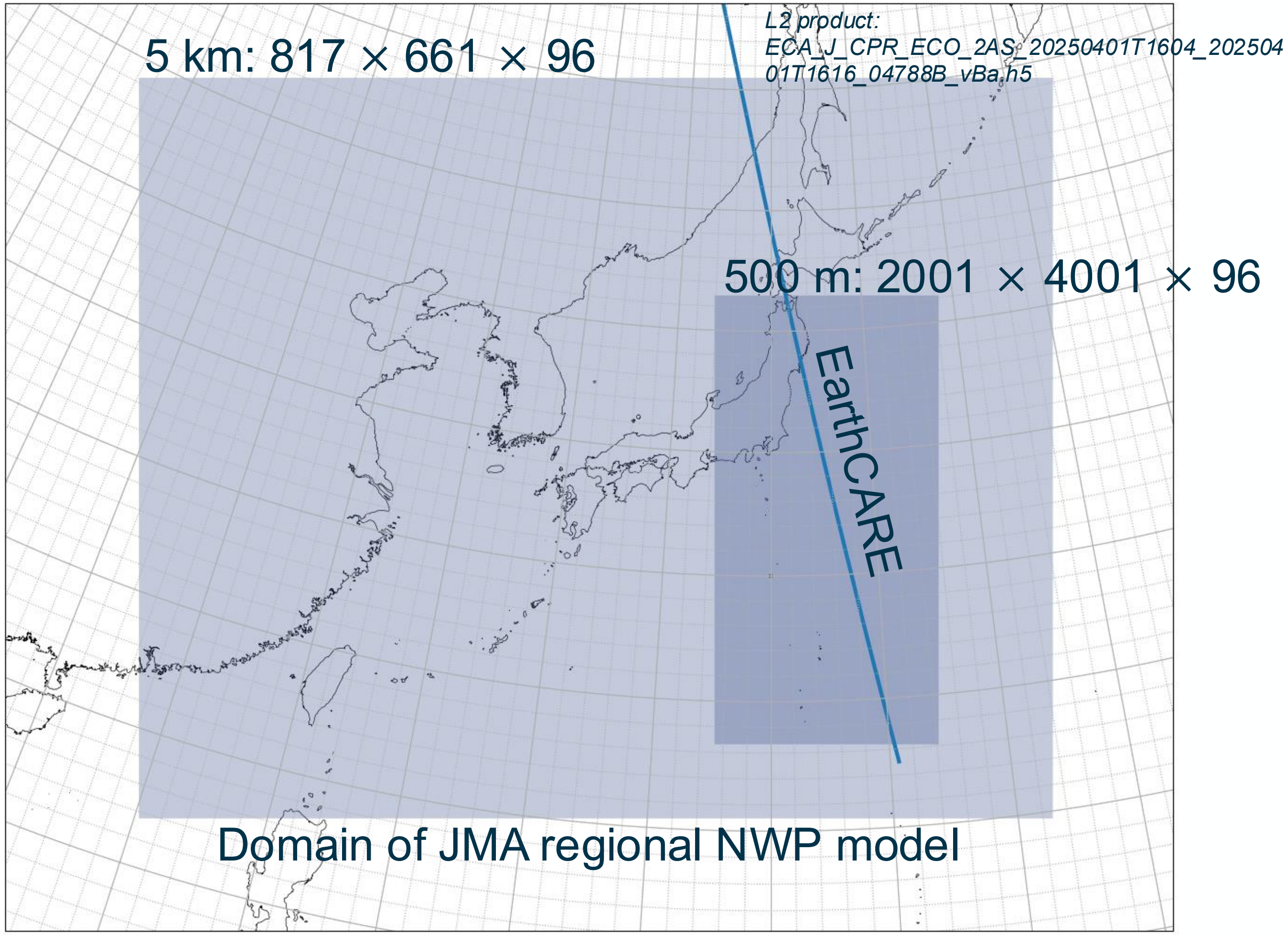
Dmax strongly controls Vr for a given Z

- ✓ Large Dmax → overestimation of Vr
- ✓ Small Dmax → strong deviation
- ✓ Temperature-dependent Dmax → best agreement

6BRT: Temp-dependent
6BRS: Small Dmax
6BRL: Large Dmax

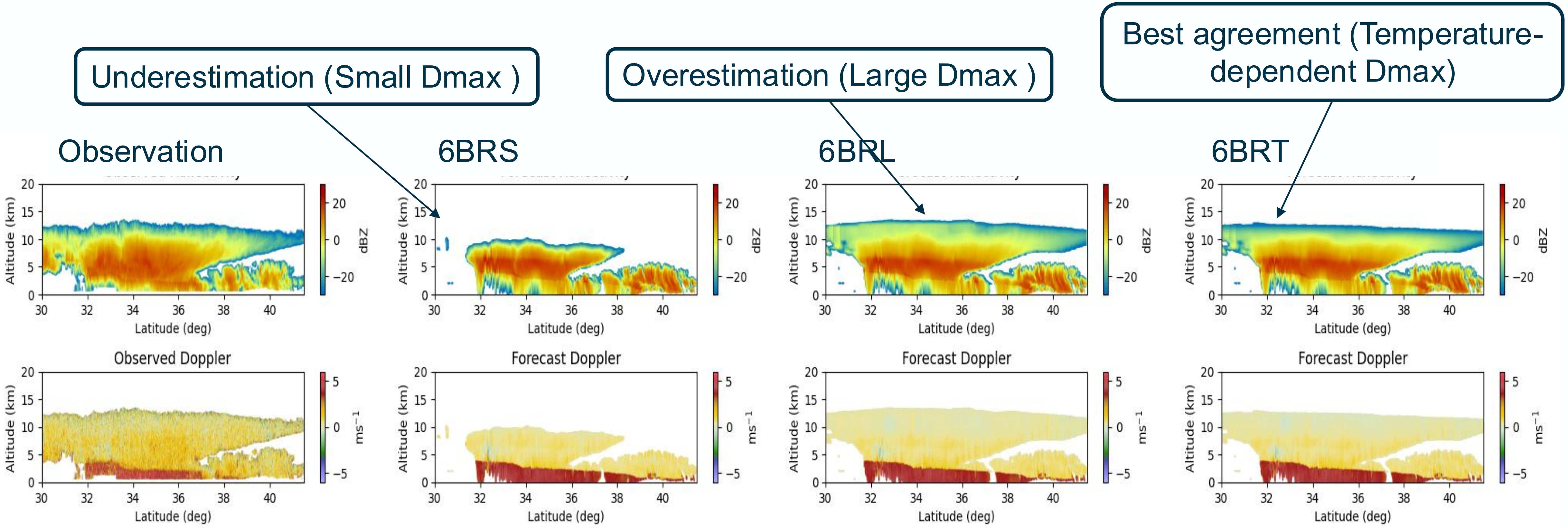
Evaluation case: Midlatitude cyclone





Comparison

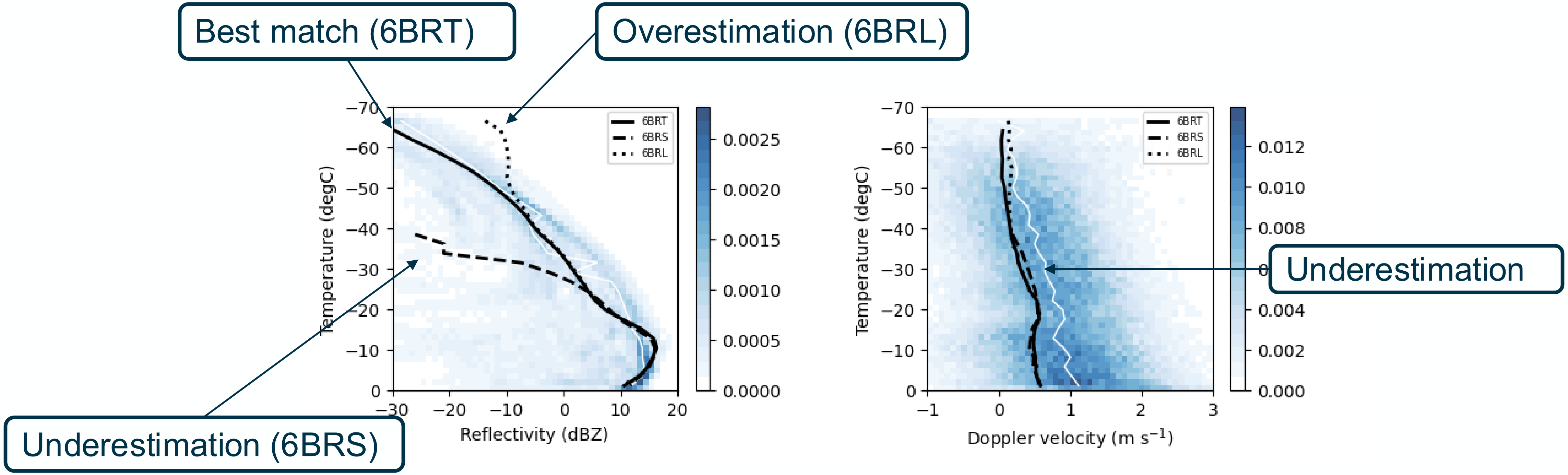
Temperature-dependent Dmax is required to reproduce CPR observations



- ✓ Small Dmax (6BRS) underestimates signal near 10 km
- ✓ Large Dmax (6BRL) overestimates reflectivity aloft
- ✓ Temperature-dependent Dmax (6BRT) shows best agreement

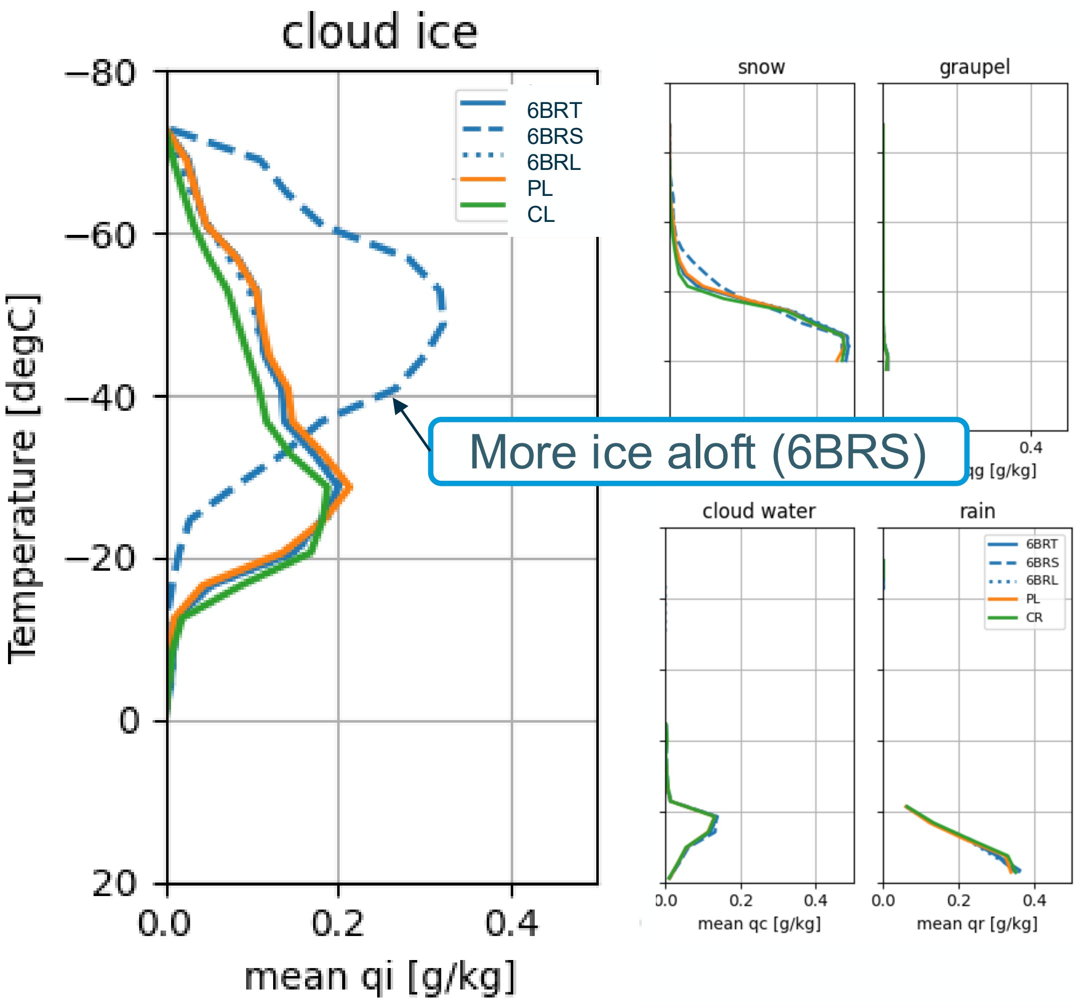
Impact of Dmax on Z–T and V–T

Dmax controls reflectivity–temperature structure



- ✓ Temperature-dependent case (6BRT) best matches observed mode
- ✓ Large Dmax (6BRL) shifts distribution toward higher reflectivity
- ✓ Small Dmax (6BRS) underestimates reflectivity
- ✓ Doppler velocity is generally underestimated

Impact of particle assumptions



- Effect of Dmax:
  - ✓ Small Dmax (6BRS): slower fall → more ice aloft
  - ✓ Large Dmax (6BRL): little difference from 6BRT

→ Vertical ice distribution biases directly translate into CPR signal differences

Summary

- Issue
  - ✓Conventional assumptions (e.g., fixed Dmax = 100 μm) are inconsistent with CPR observations.
- Approach
  - ✓Built a physically consistent framework between NWP and CPR simulator
  - ✓Introduced temperature-dependent Dmax based on observations
- Results
  - ✓Dmax strongly controls Z–Vr relationship
  - ✓Bullet rosette with temperature-depended Dmax → best agreement with observation
- Implication
  - ✓Inconsistent particle assumptions can lead to misleading model evaluation
  - ✓Physically consistent frameworks are required for reliable interpretation of observations
- Remaining issue
  - ✓Doppler velocity is generally underestimated → likely due to missing vertical air motion or terminal velocity bias
  - ✓Snow microphysics remains uncertain