# Assimilation of radar reflectivity and Doppler velocity observations from EarthCARE/CPR

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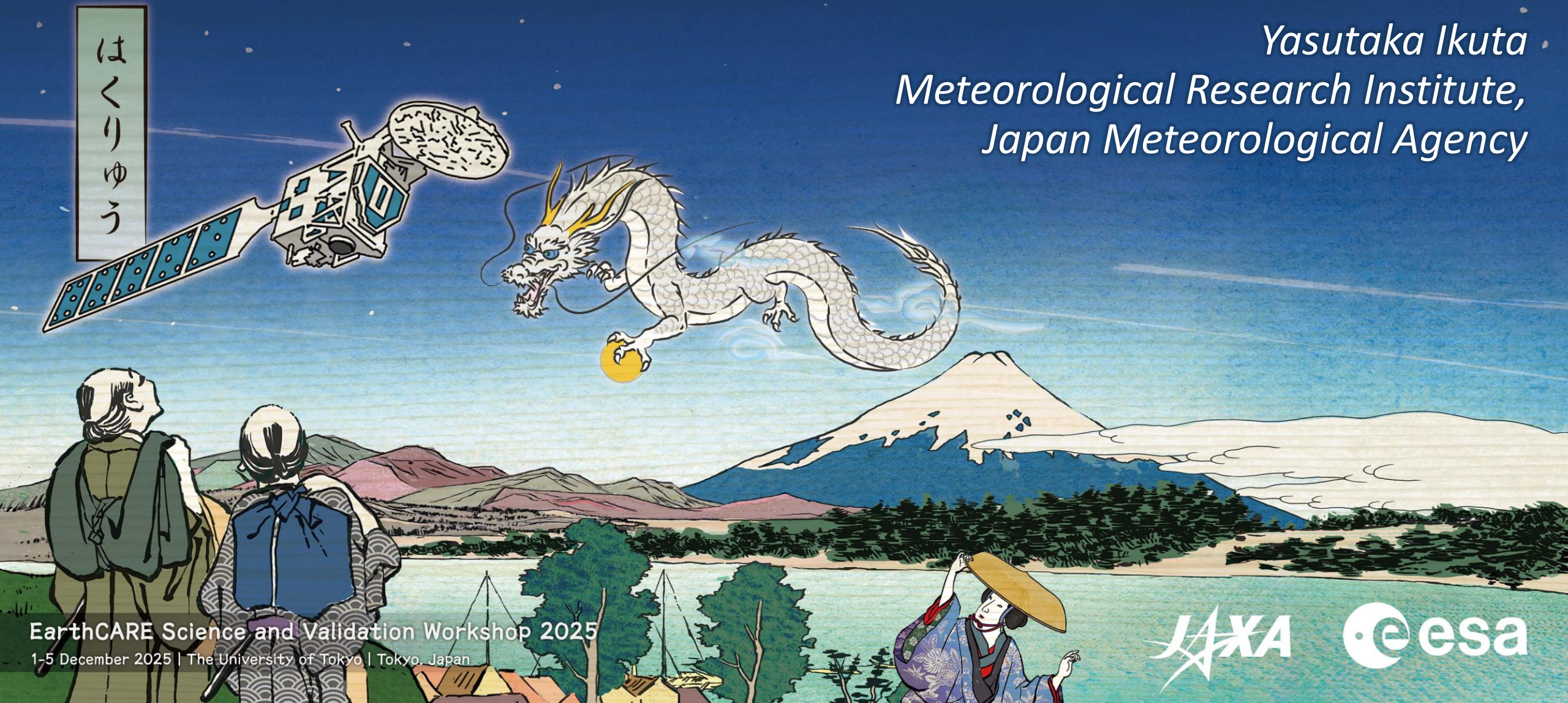


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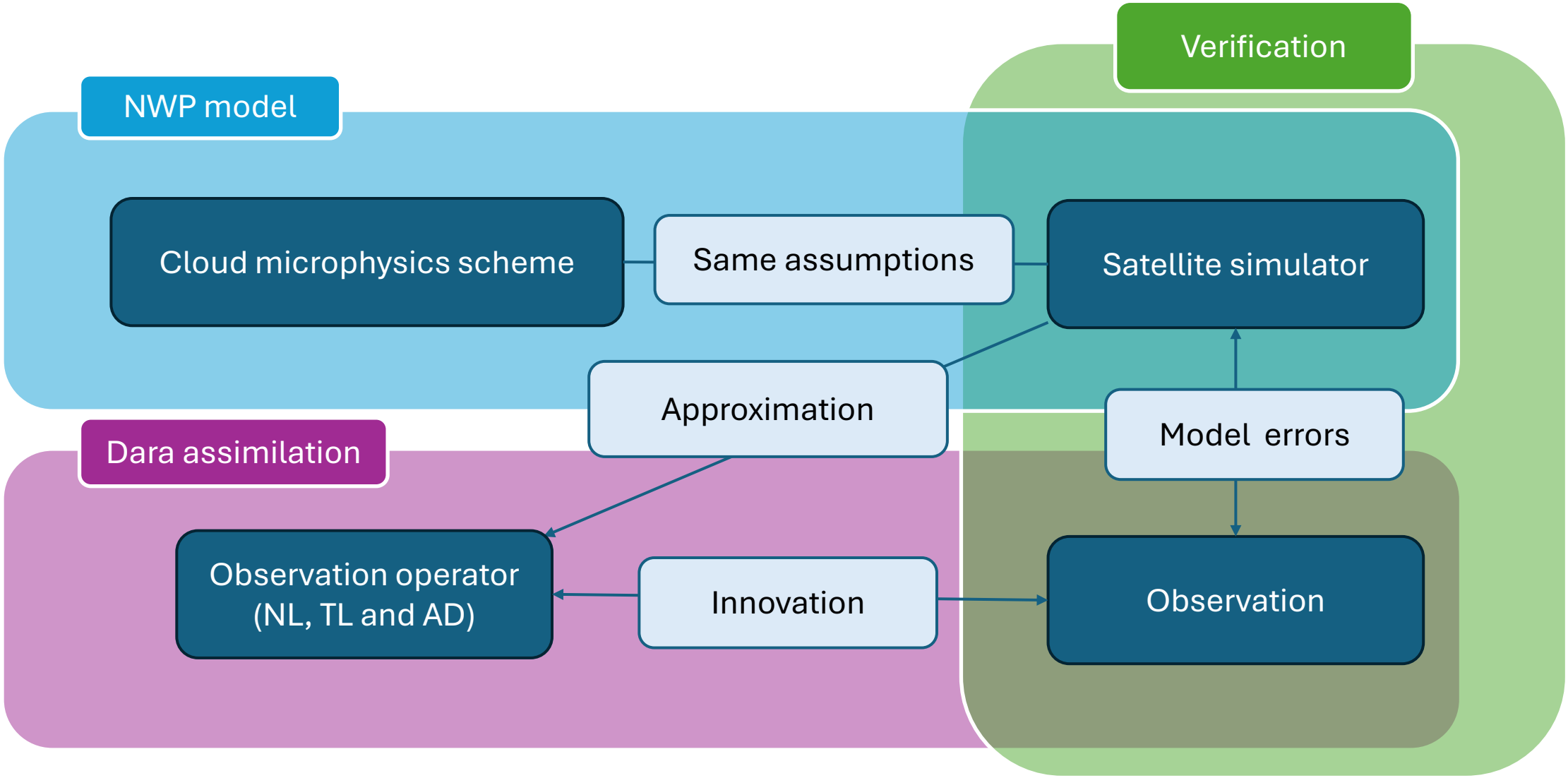
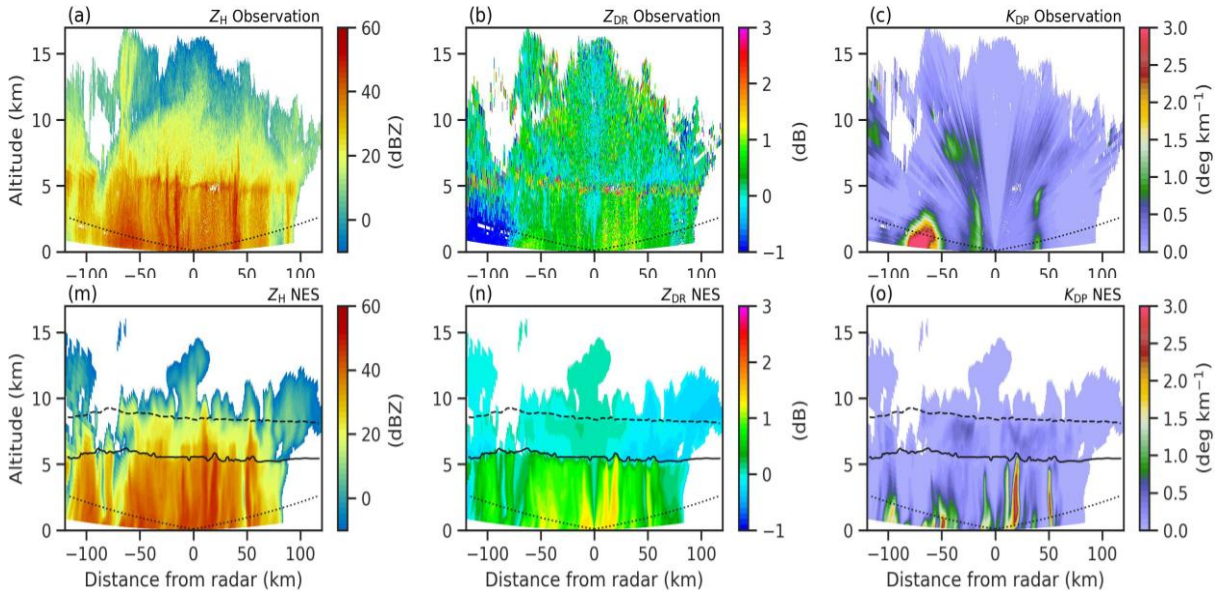
# Introduction

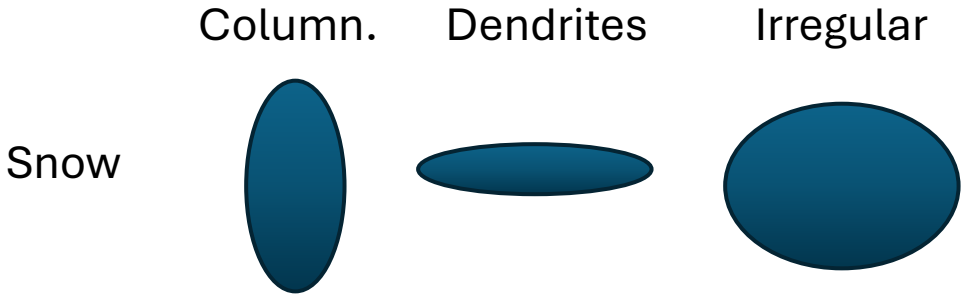
1. Reduce model biases in cloud microphysics schemes to ensure unbiased background fields
   - Bias reduction is essential for reliable evaluation of data assimilation impact.
2. Develop a data assimilation system for Cloud Profiling Radar (CPR) observations
   - Assimilating vertical cloud structure is expected to improve cloud and precipitation forecasts.

# Requirement of microphysics scheme improvement



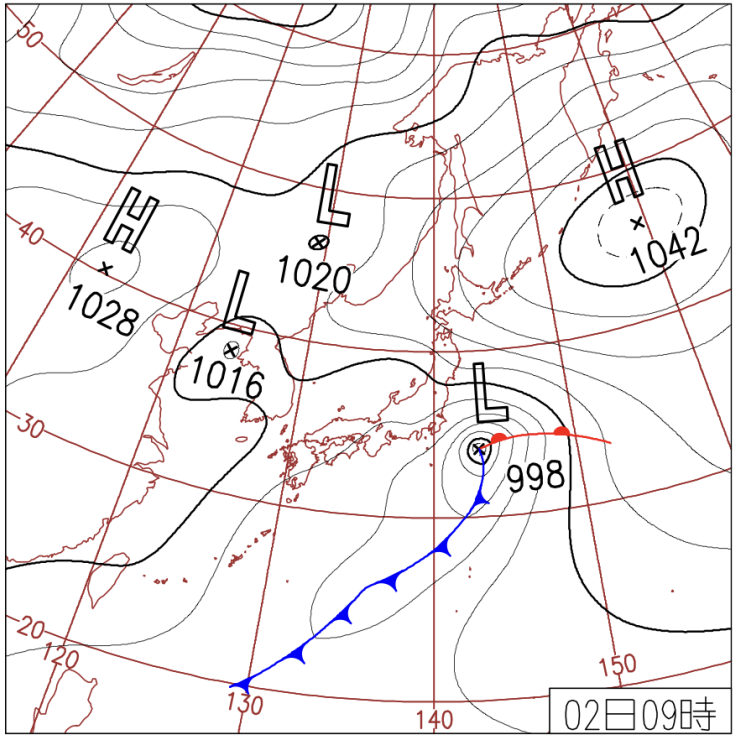
# Developments of cloud microphysics scheme

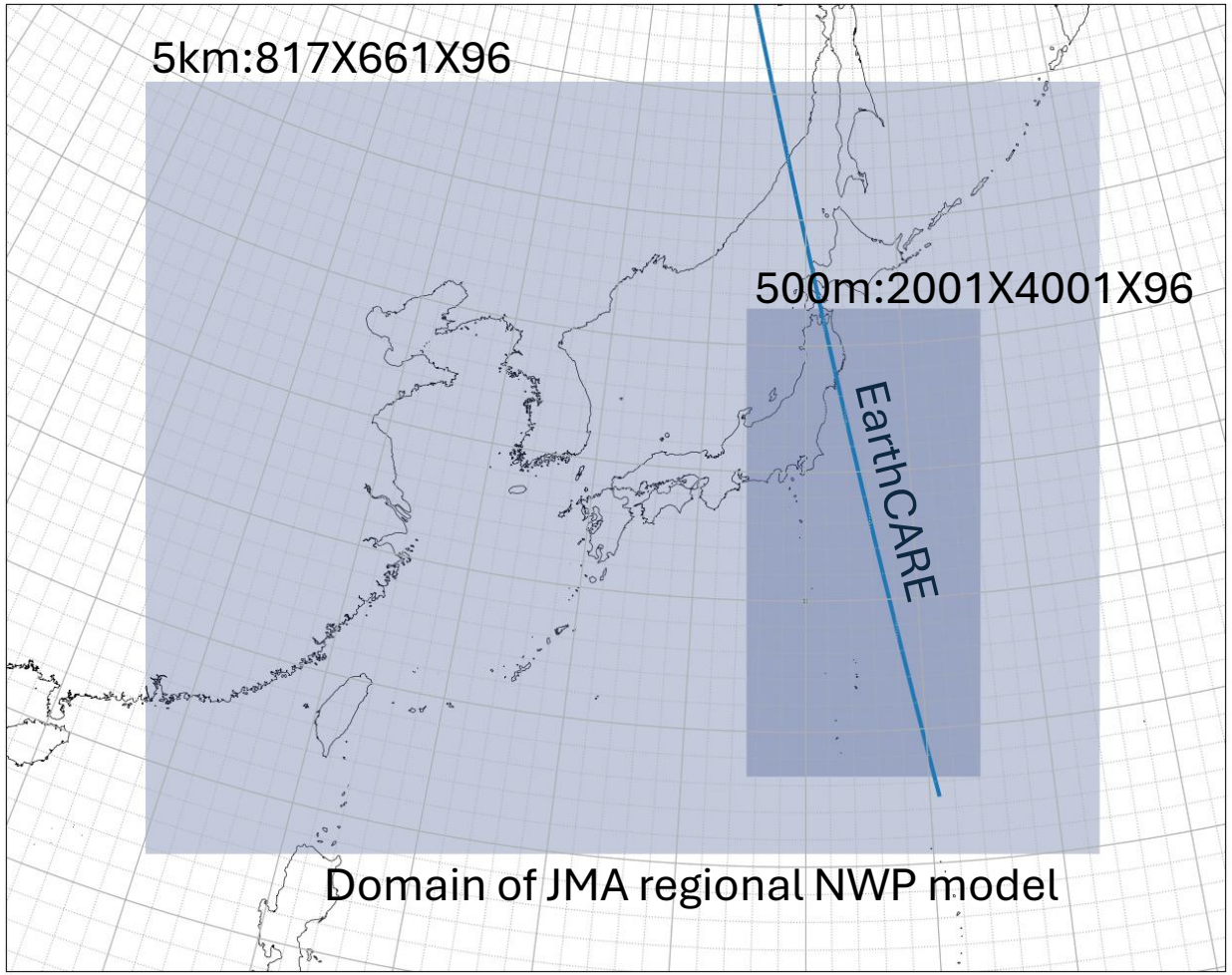



- Current bulk scheme configuration
  - Scheme type: 6-class single moment bulk scheme
  - Snow category is specifically divided into three species: column, dendrites, and irregular
  - Particle shapes are approximated as rotational ellipsoids
- Validation and improvement history
  - Using GPM/DPR (Ikuta et al. 2021)
  - Using dual-polarization radar (Ikuta et al. 2025)
  - Improvement targets: Snow and rain
- Current limitation
  - The accuracy of cloud Ice has not yet been verified using active remote sensing data.

# Case study: Midlatitude low-pressure system

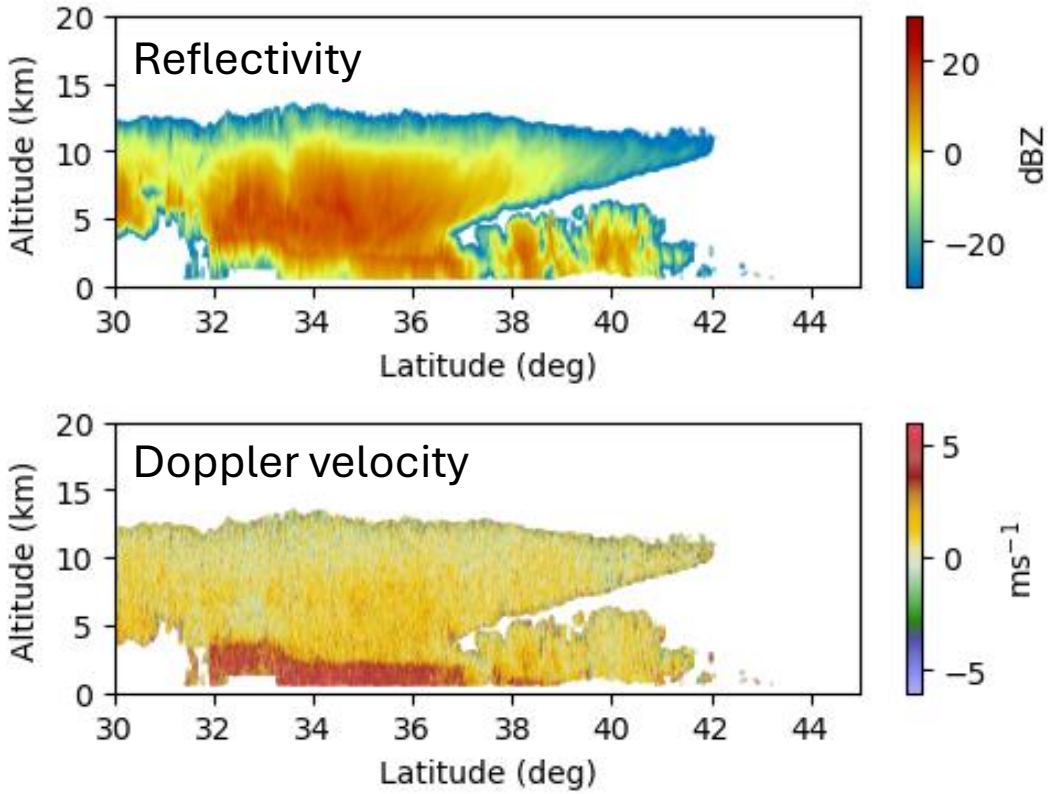


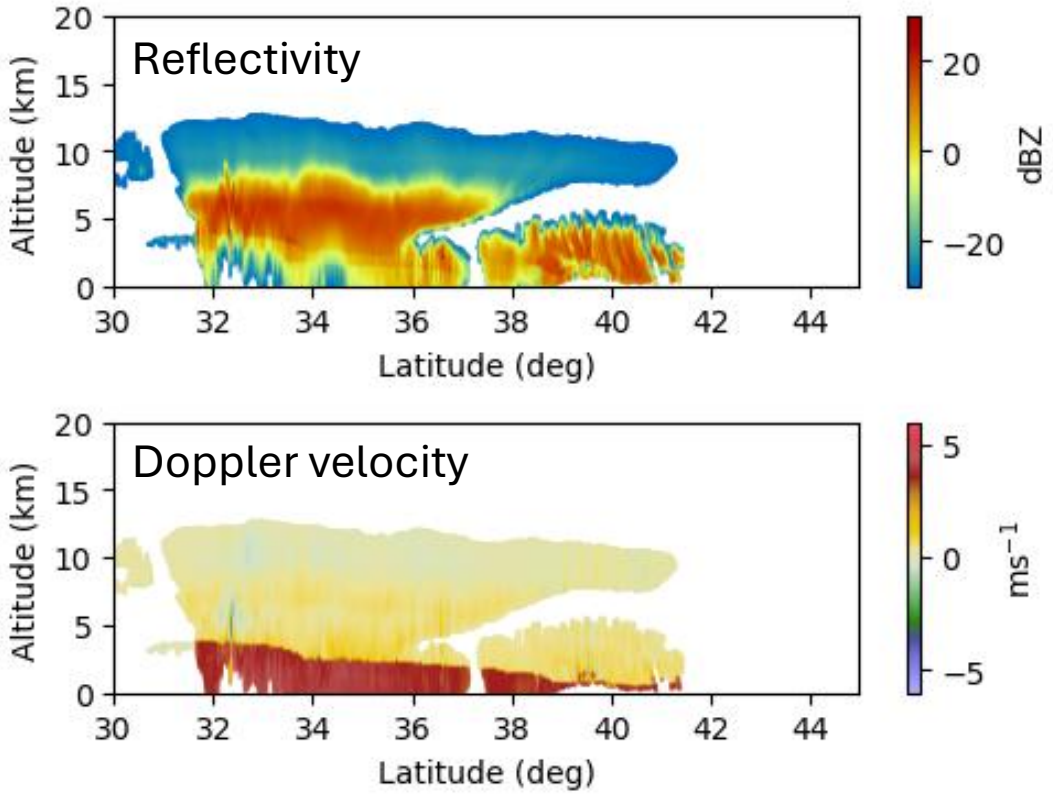

L2 product: ECA_J_CPR_ECO_2AS_20250401T1604_20250401T1616_04788B_vBa.h5
Initial and boundary condition: JMA operational model (Meso-Analysis and GSM)

# Observation and simulation of EarthCARE/CPR

## Observation




## Simulation

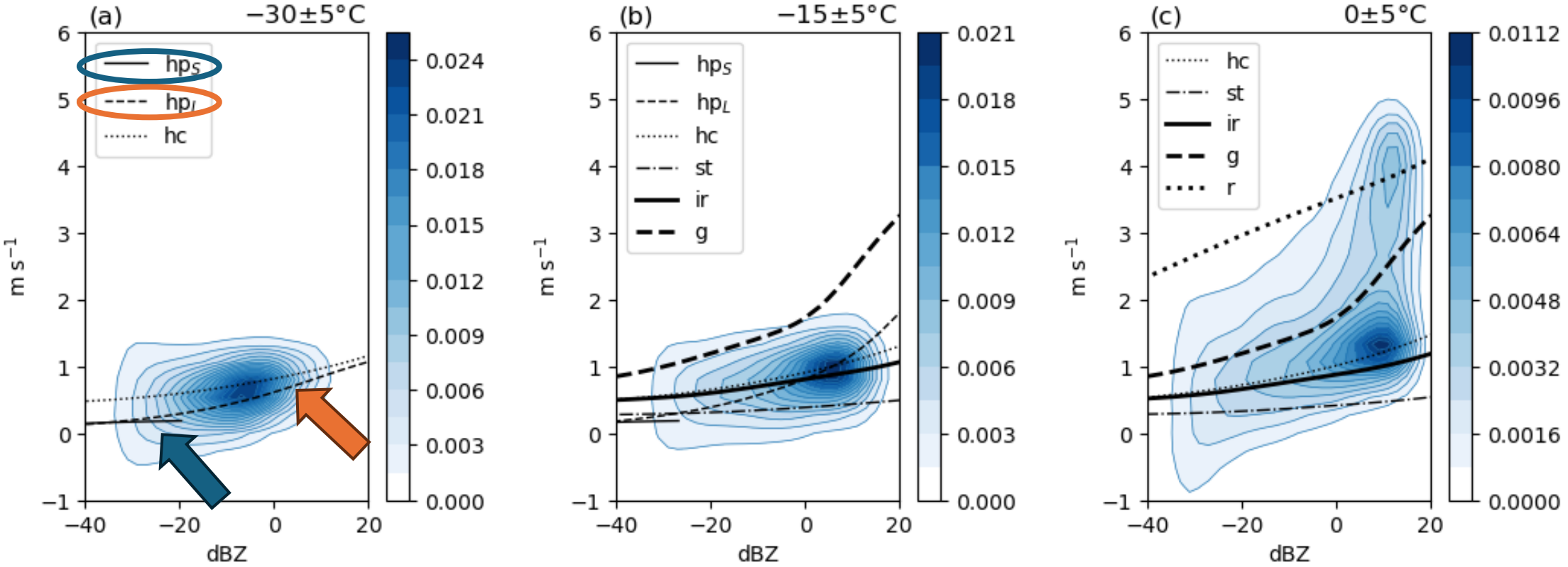



Underestimation of predicted reflectivity near cloud top

# Joint histograms of Reflectivity and Doppler velocity

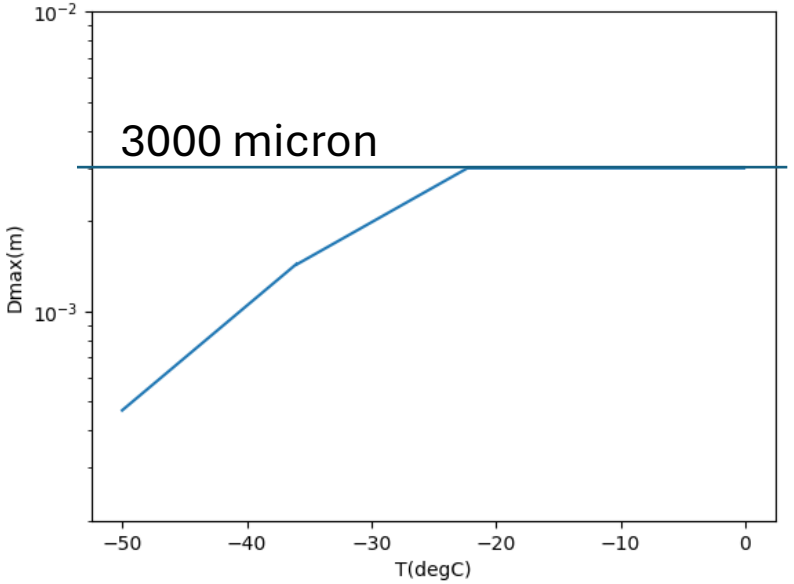
Current scheme: Small hexagonal plate（hps）
New scheme: Large hexagonal plate（hpl）

$15\ \mu\mathrm{m} \leqq D \leqq 100\ \mu\mathrm{m}$
$100\ \mu\mathrm{m} < D \leqq 3000\ \mu\mathrm{m}$



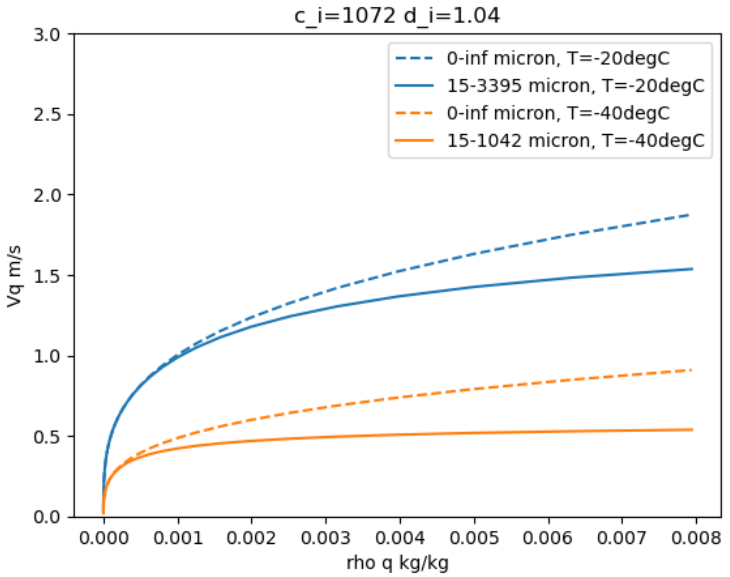
# Temperature-dependent maximum diameter

Maximum diameter




Heymsfield (2013)

Mass-weighted terminal velocity




Moment

Infinite integration

$$M_p(\rho q_i, T) = \int_0^{\infty} D^p N_i(D,T) dD$$

Finite integration

$$M_p(\rho q_i, T) = \int_{D_{min}}^{D_{max}(T)} D^p N_i(D,T) dD$$

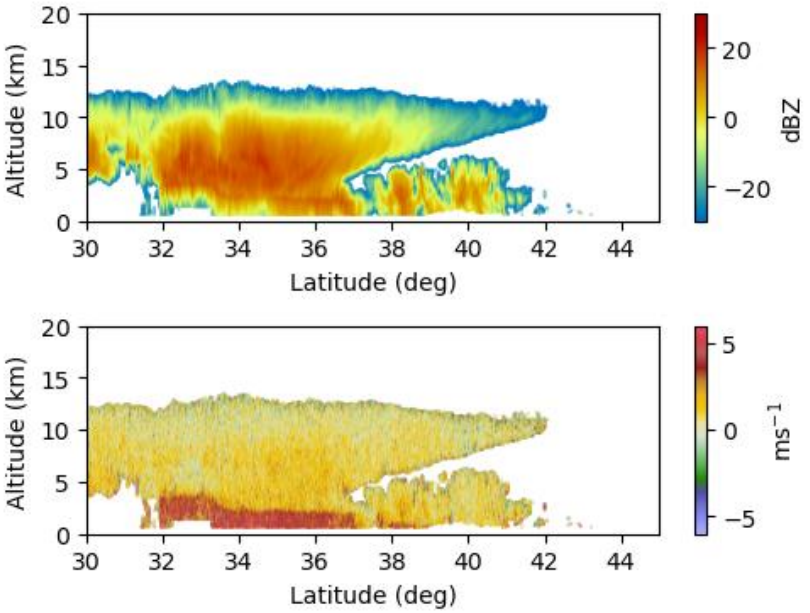
$$D_{min} = 15 \times 10^{-6}\text{m}$$

| Particle type | Mass $\alpha$ | Mass $\beta$ | Area $\gamma$ | Area $\sigma$ |
|---|---|---|---|---|
| Hexagonal plates | | | | |
| $15\ \mu\text{m} \leqslant D \leqslant 100\ \mu\text{m}$ | 0.00739 | 2.45 | 0.24 | 1.85 |
| $100\ \mu\text{m} < D \leqslant 3000\ \mu\text{m}$ | 0.00739 | 2.45 | 0.65 | 2.00 |

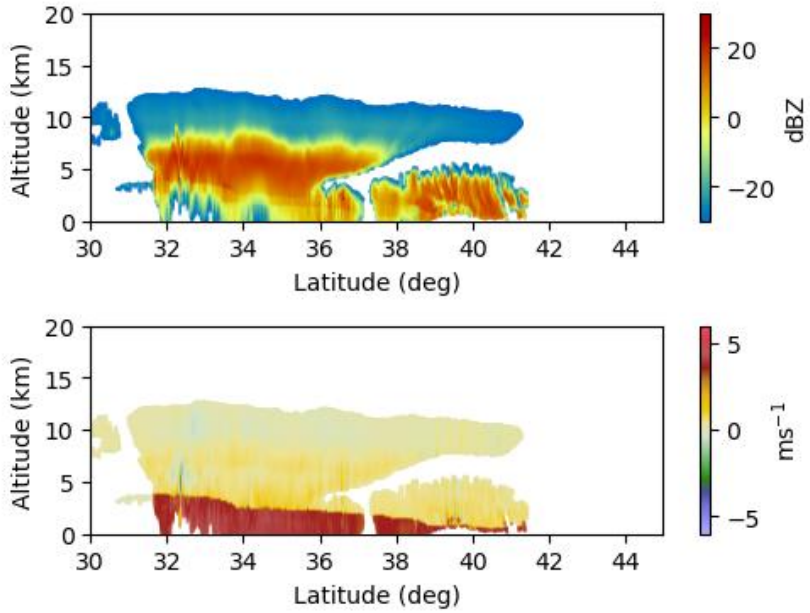
Mitchel (1990)

# Observation and simulation of EarthCARE/CPR

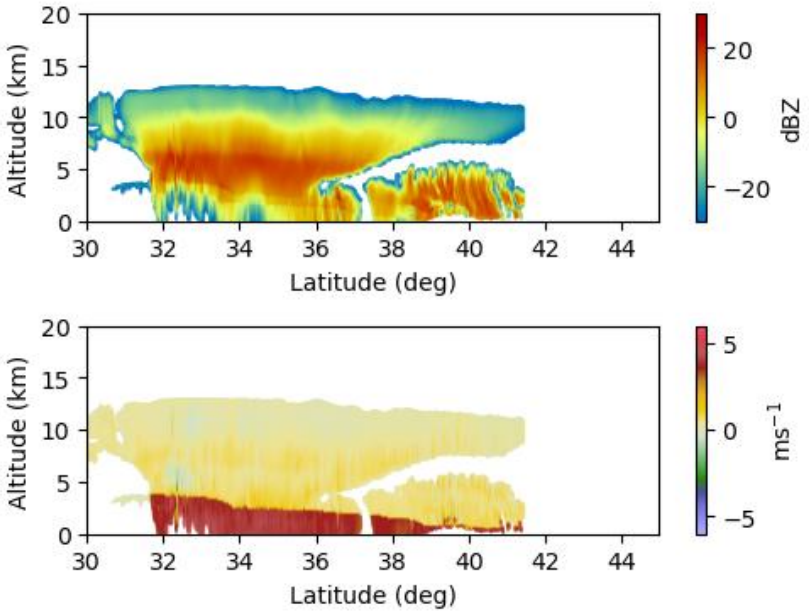
Observation




Old simulation

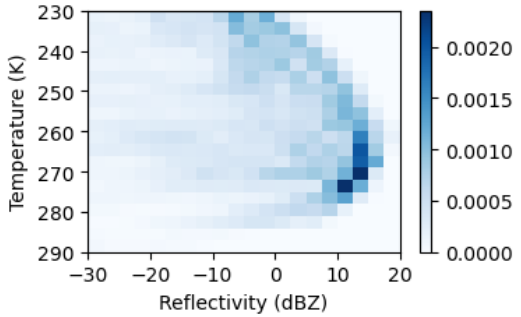
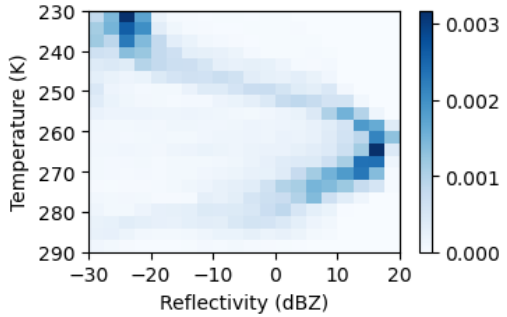
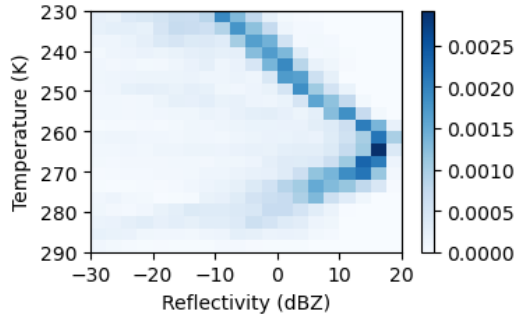
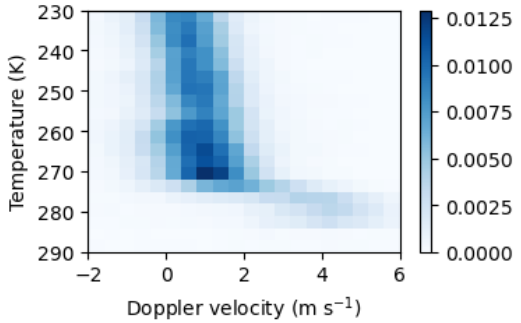
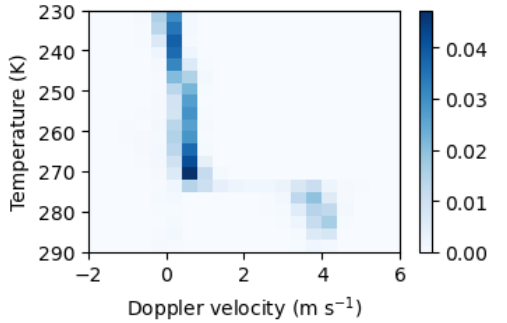
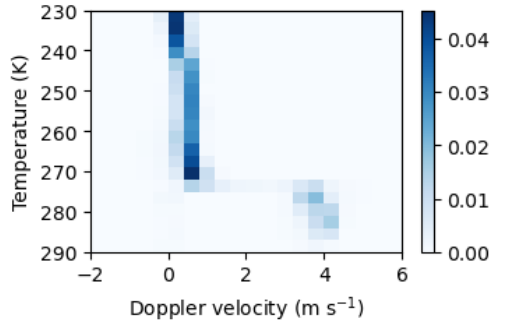
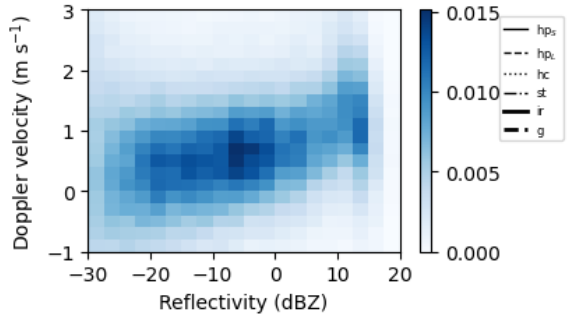
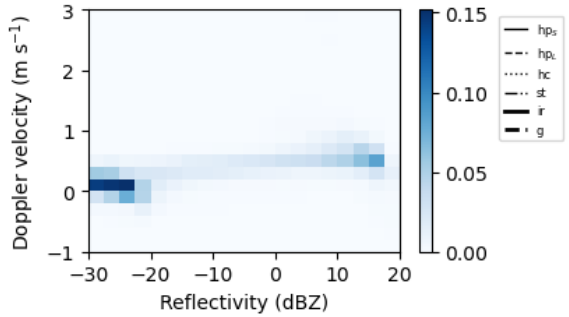
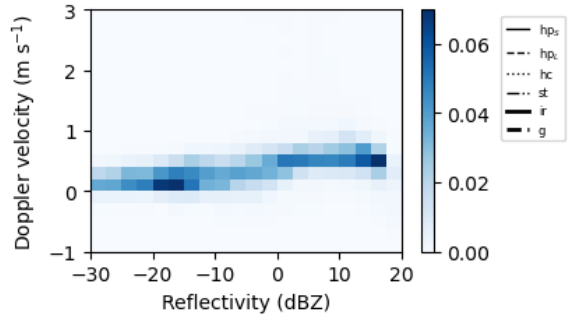



New simulation

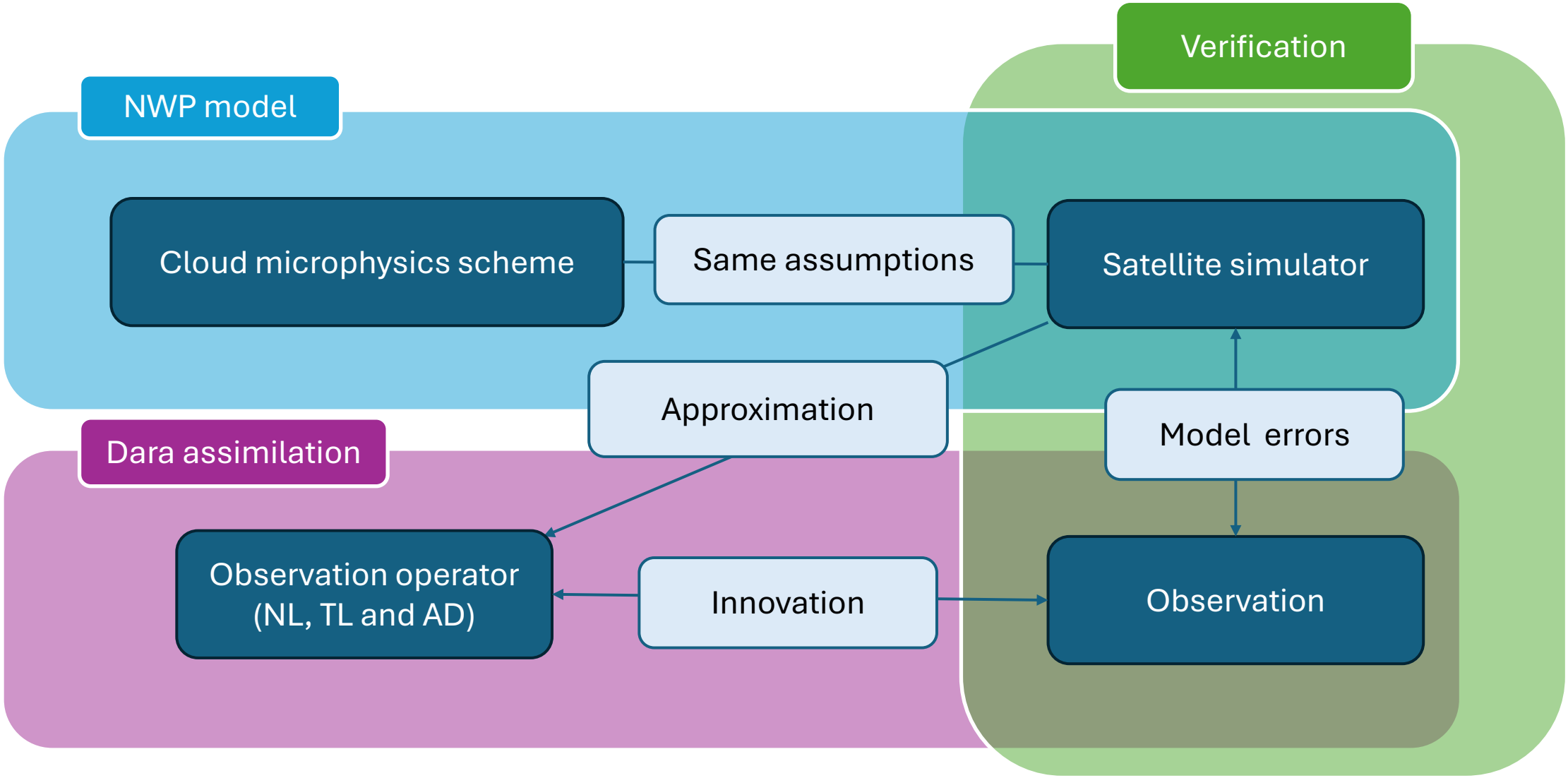



The new scheme reduces the bias in near cloud-top radar reflectivity, showing closer agreement with observations.

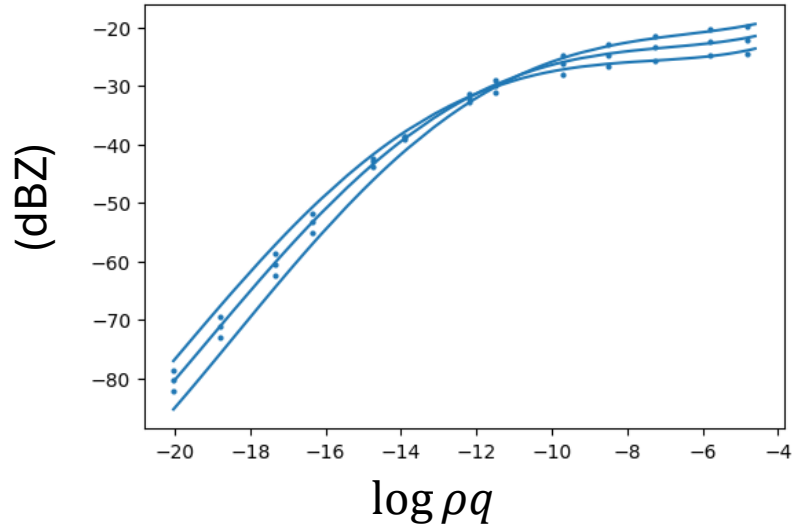
# Joint histogram

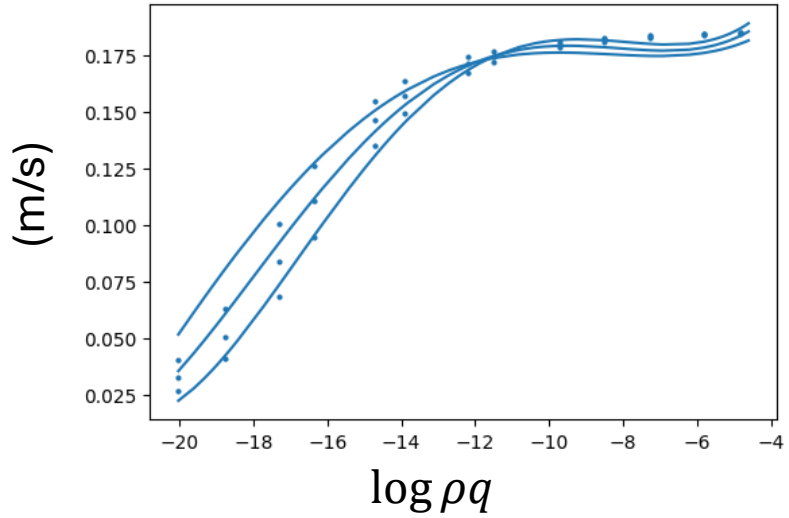
| | Observation | Old simulation | New simulation |
|---|---|---|---|
| Reflectivity-Temperature space |  |  |  |
| Doppler velocity-Temperature space |  |  |  |
| Reflectivity-Doppler velocity space |  |  |  |

# Requirement of microphysics scheme improvement



# Data assimilation




Approximation of the observation operator for reflectivity and Doppler velocity

$$H(T, \rho Q) = \sum_{i=0}^{3} a_i(T)(\log \rho Q)^i$$

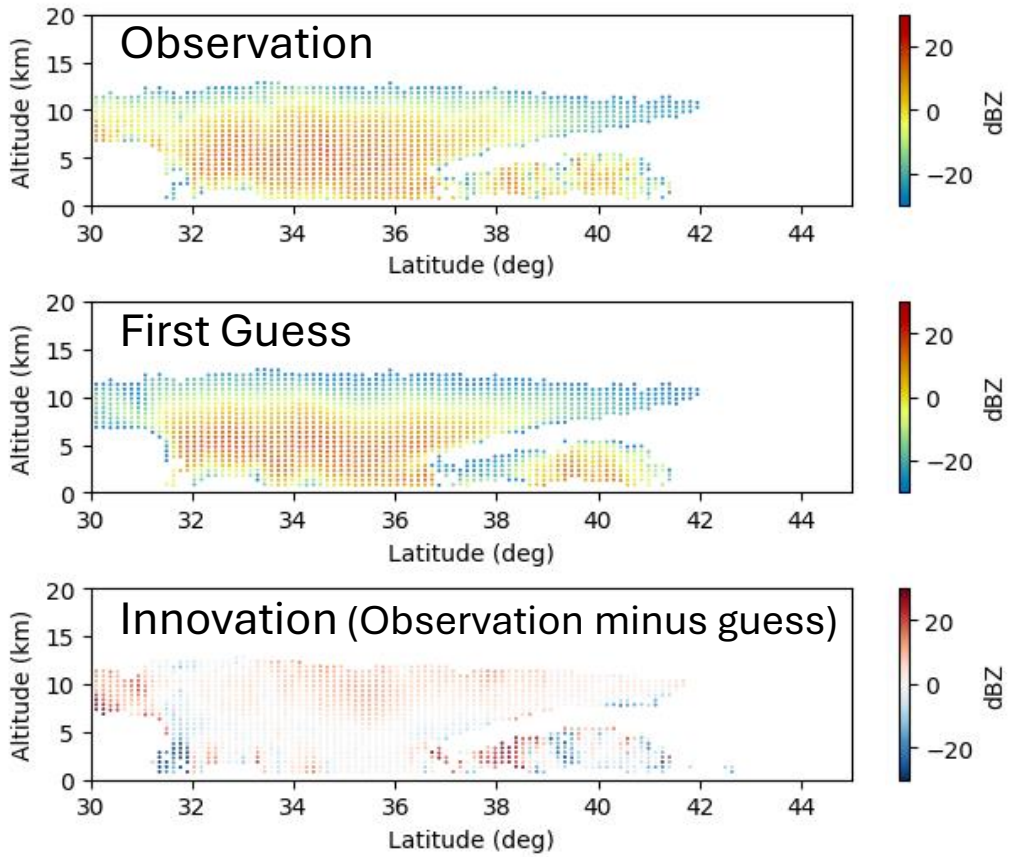
$$a_i = \sum_{j=0}^{3} b_j T^j$$

- The observation operator is represented as a polynomial function of temperature and hydrometeor mass.
- The polynomial coefficients are estimated by fitting to simulated observations from the ARTS database.

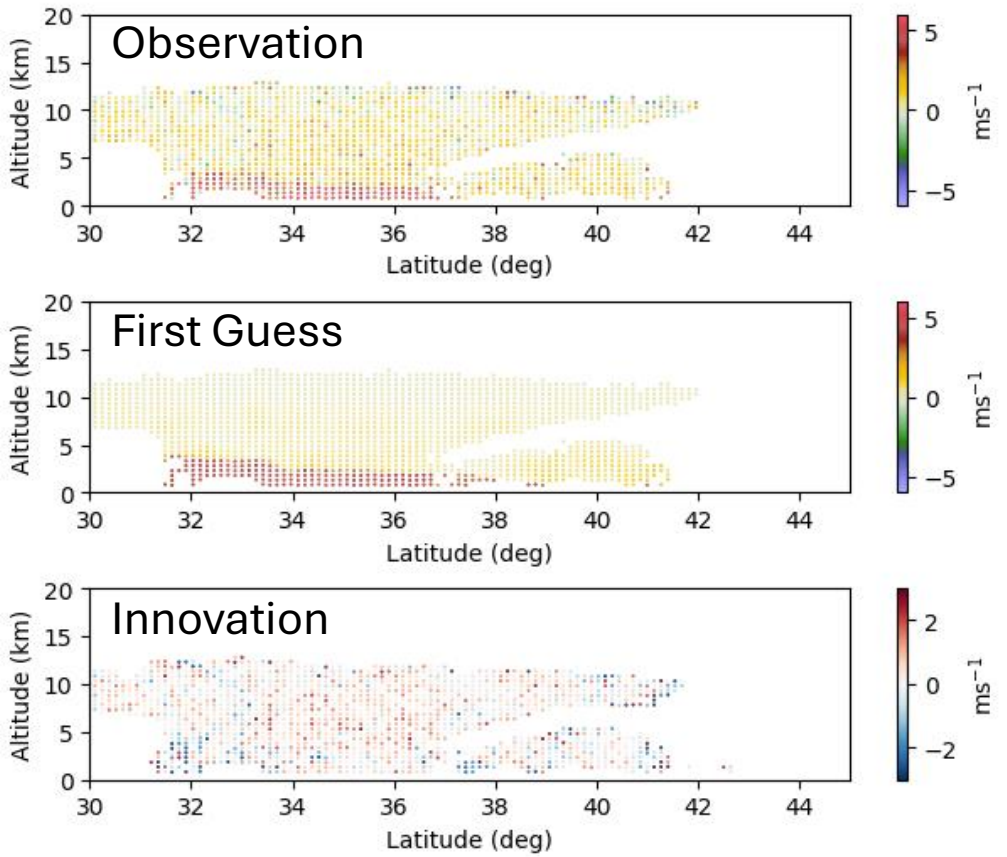
# Thinned observation, first guess, and innovation

Horizontal thinning: 15 km; Vertical thinning: 500m

## Reflectivity




## Doppler velocity

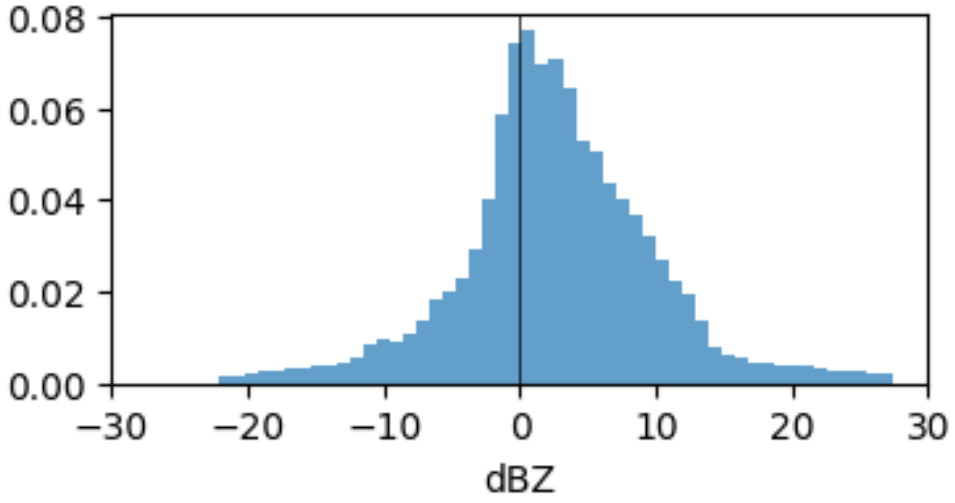



The spatial distribution of Doppler velocity innovations does not exhibit any clearly identifiable structures.

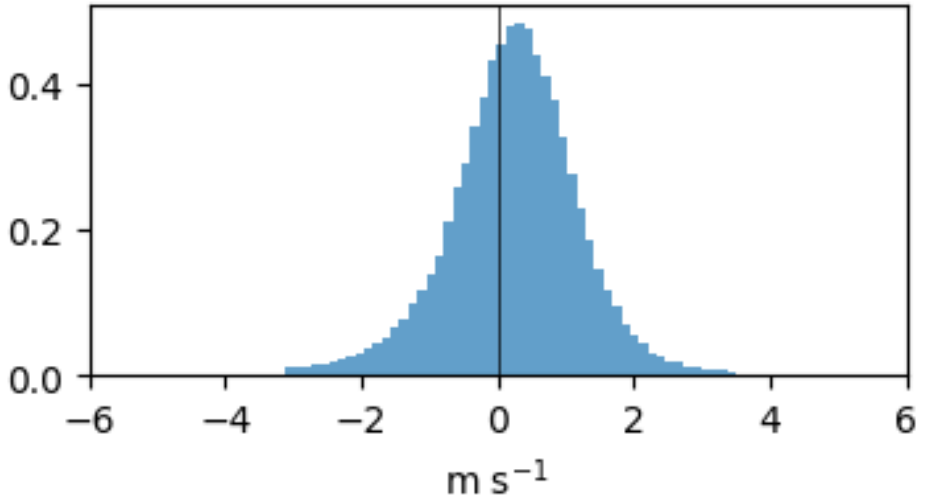
# Observation minus first guess

Histograms of Observation–First Guess — Bias Correction *Not Applied*

Reflectivity



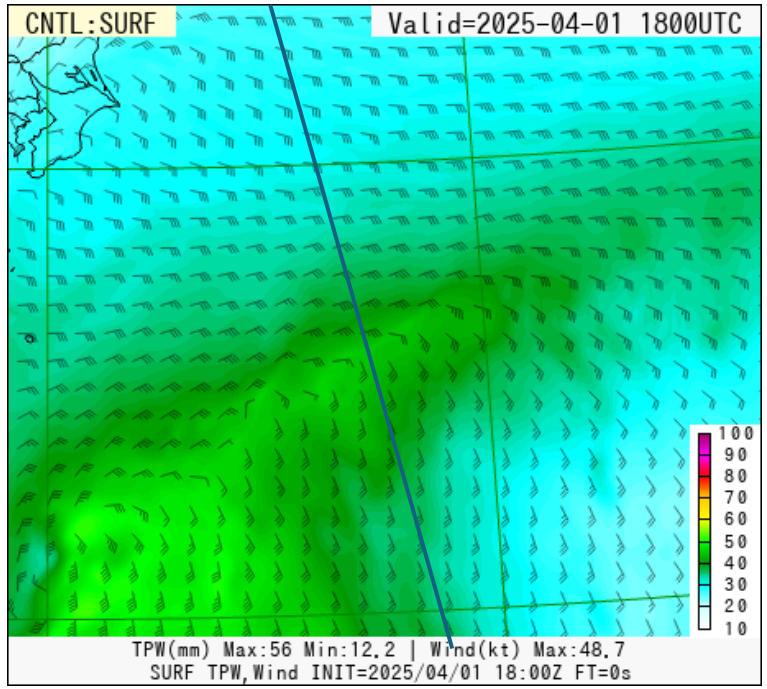

Doppler velocity



# Results

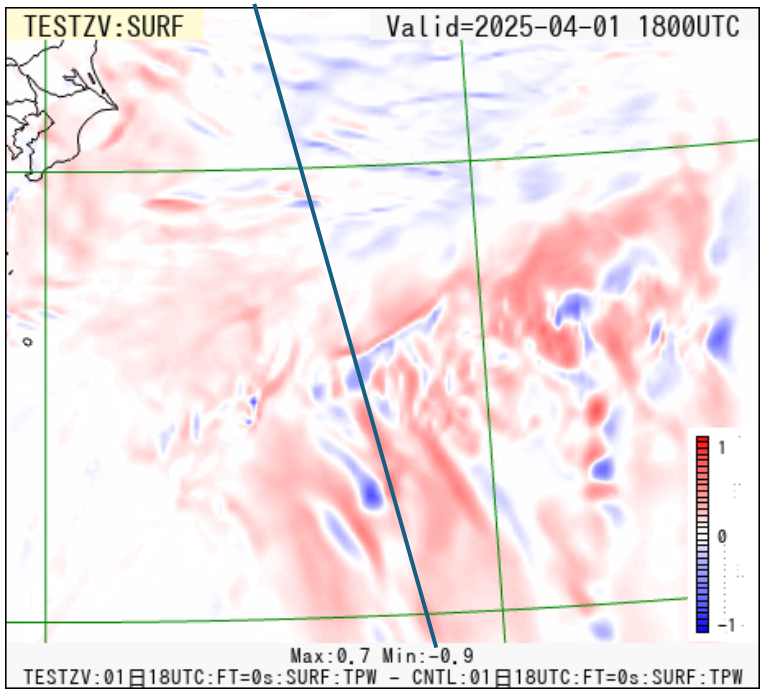
Total precipitable water vapor at the initial forecast time

## First guess



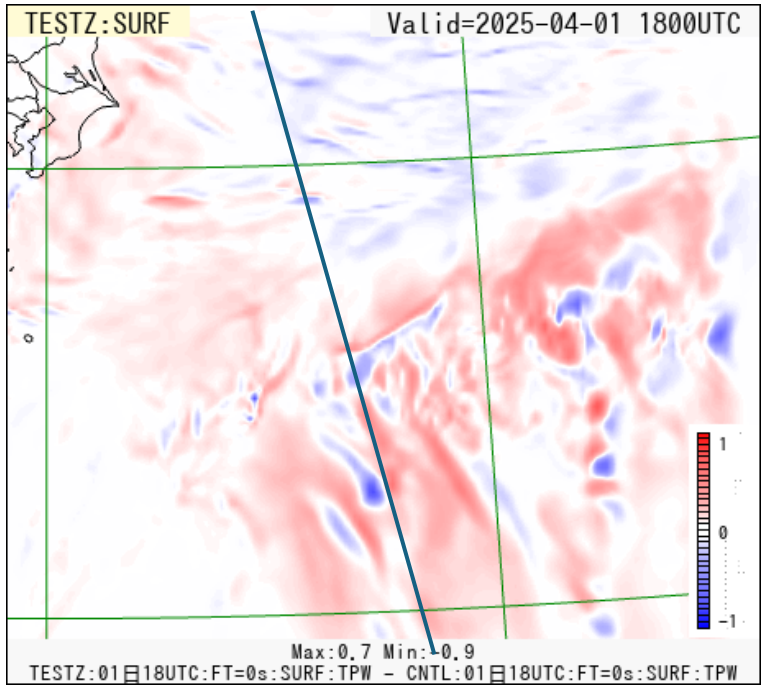

## Analysis — First guess.

with reflectivity and Doppler velocity




## Analysis — First guess

with reflectivity

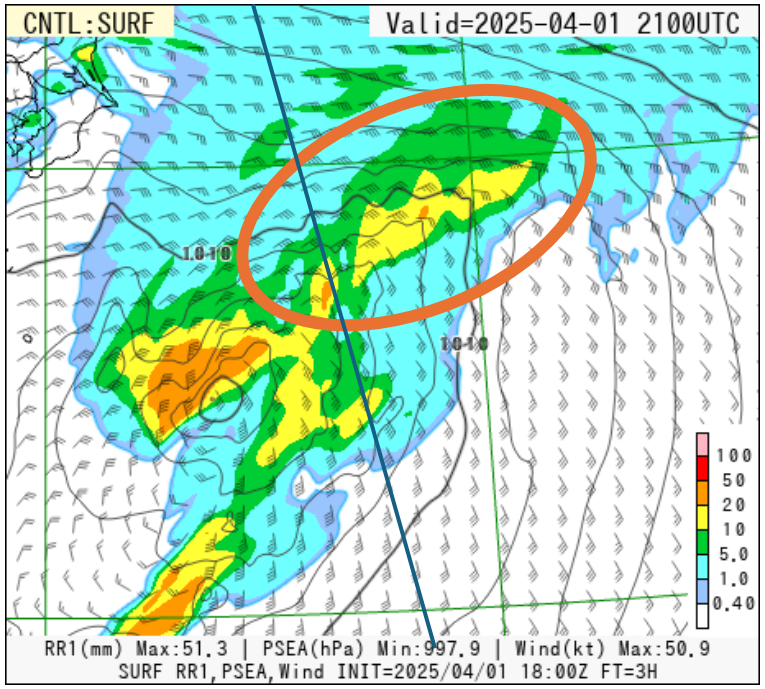



Impact of Doppler velocity is smaller than that of reflectivity

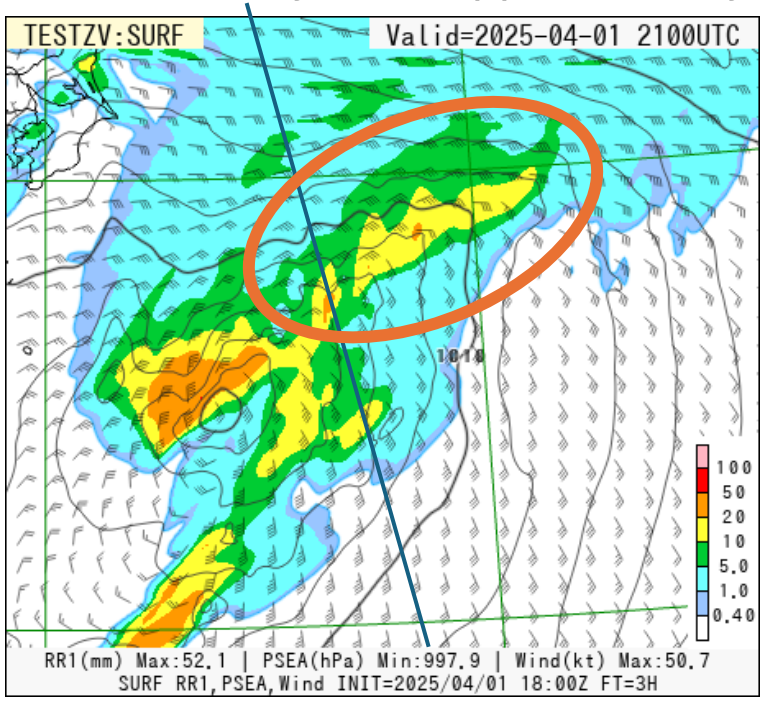
# Results

## Forecast of 1-hour accumulated precipitation

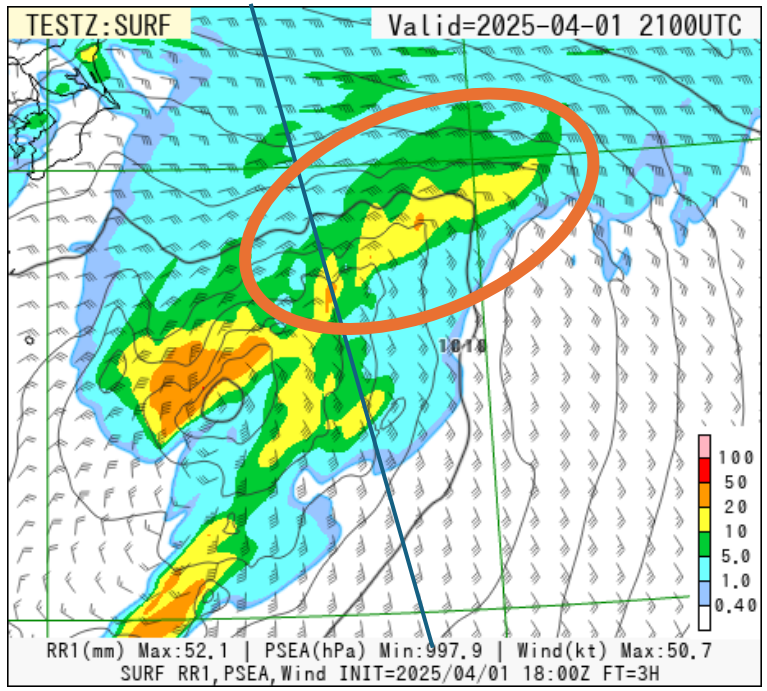
without CPR




with reflectivity and Doppler velocity




with reflectivity




The impact on precipitation forecasts is highly limited.

# Summary

- Improvement of cloud microphysics
  - Re-definition of cloud ice in NWP
  - Introduction of the temperature-dependent maximum diameter for cloud-ice particles
  - Significant reduce the bias of reflectivity
- Development of CPR data assimilation
  - Use of both reflectivity and Doppler velocity
  - Limited impact on precipitation forecasts
  - Impact of Doppler velocity is smaller than that of reflectivity
    - Small differences between observation and first guess reduce the potential impact of assimilation
- Future Work
  - Investigate the atmospheric impact through cycling data assimilation experiments