Investigation of the Optimal Degree of Snow Particle Riming in Dual-Frequency Radar Retrievals Using a GPM/DPR–EarthCARE/CPR Coincidence Dataset

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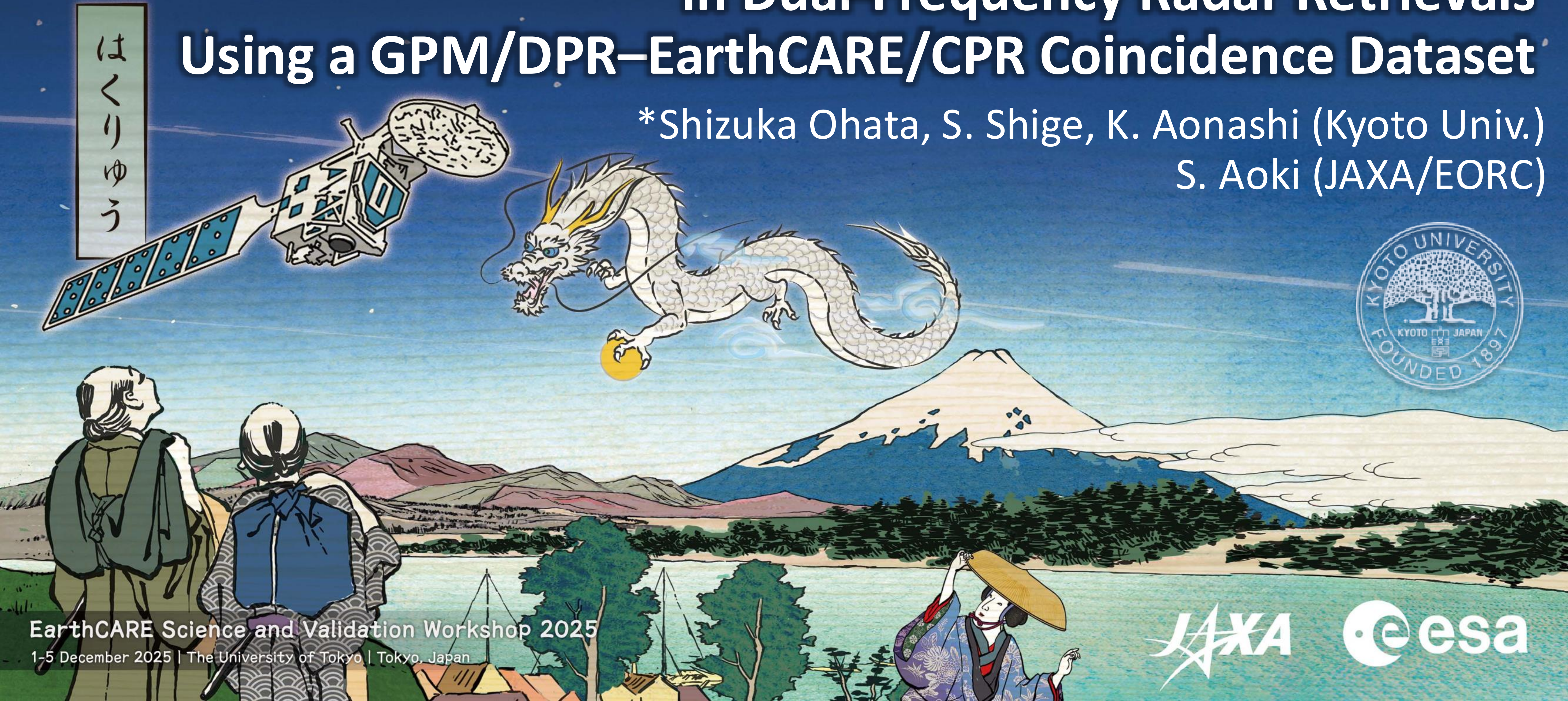

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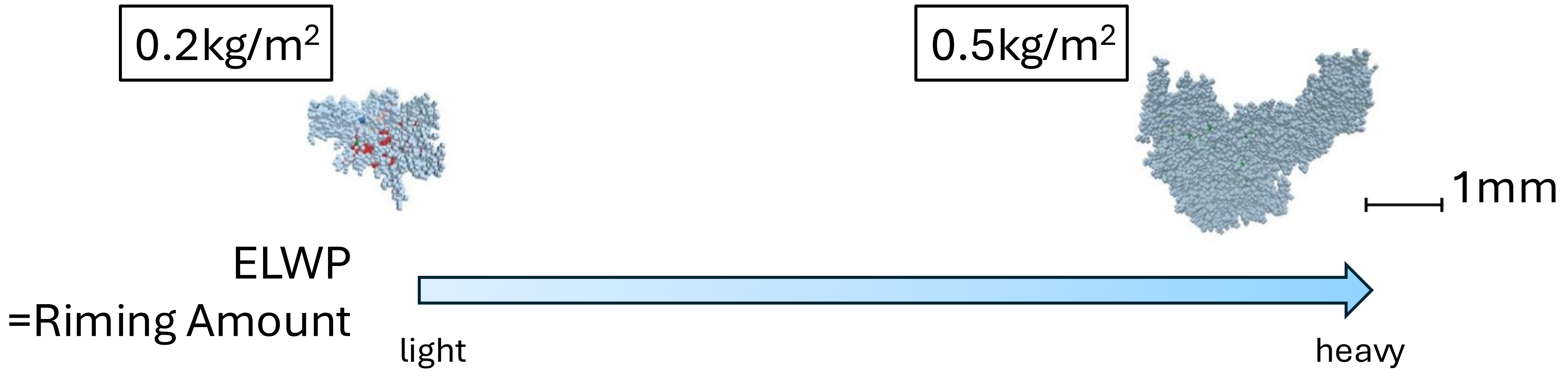
Challenges in GPM/DPR Snowfall Estimation

- **GPM/DPR (Ku, Ka-band radar) observes moderate or heavy snowfall**
- **Current Methods & Issues:**
  - **Standard Product (Seto et al., 2024):**
    - Uses mainly ZmKu.
    - Assumes homogeneous spherical particles.
    - Uses R-Dm relation as constraint.
    - **Issue:** Underestimation of snowfall intensity (e.g, Casella et al., 2017).
  - **Dual-frequency Method (Akiyama et al., 2025):**
    - Uses ZmKu and DFRm(=ZmKu/ZmKa).
    - Considers rimed and aggregated particles (Leinonen & Szyrmer, 2015).
    - Independently estimates Dms (mean diameter) and Nt (concentration).
    - **Key Factor:** Nt and SWC depend on **Riming Amount.**

Concept of Riming Amount & Sensitivity Test

- **Particle Model & Riming Amount in this study**
  - **Database:** Reproduces aggregation & riming (Leinonen & Szyrmer, 2015)
  - **Parameter: ELWP (Effective Liquid Water Path)**
    Amount of rime mass per unit cross-sectional area ($kg\ m^{-2}$)
  - Higher ELWP → **Graupel-like particles**.



(particle images from Leinonen & Szyrmer, 2015)

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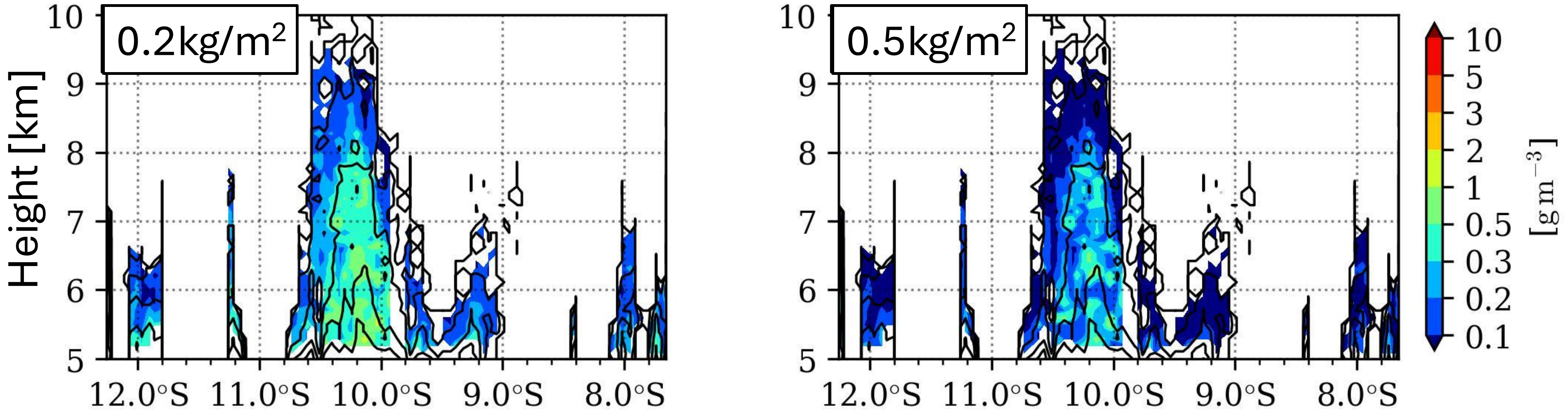
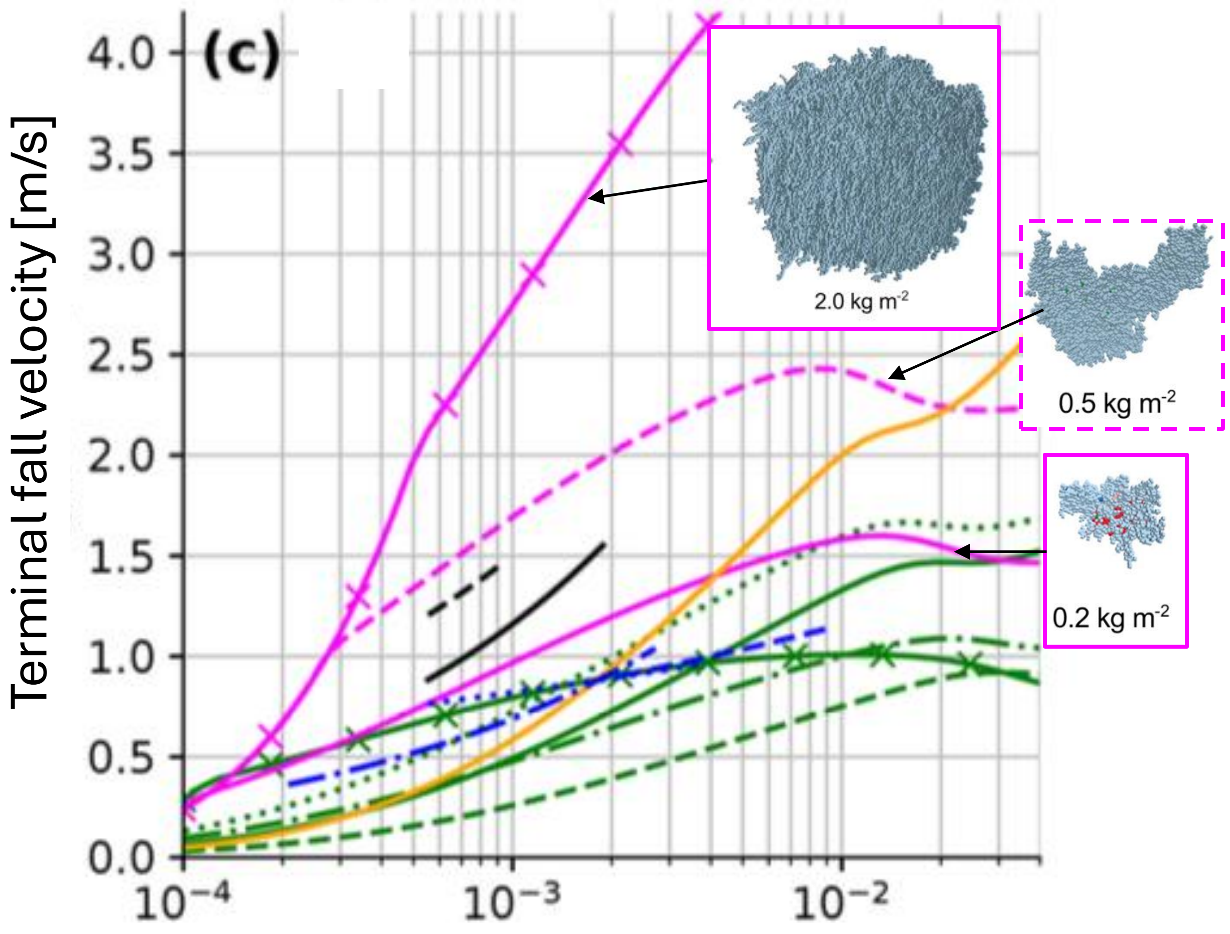
SWC vertical distribution



- **Significant difference** in estimated SWC. **Optimal ELWP** is essential.

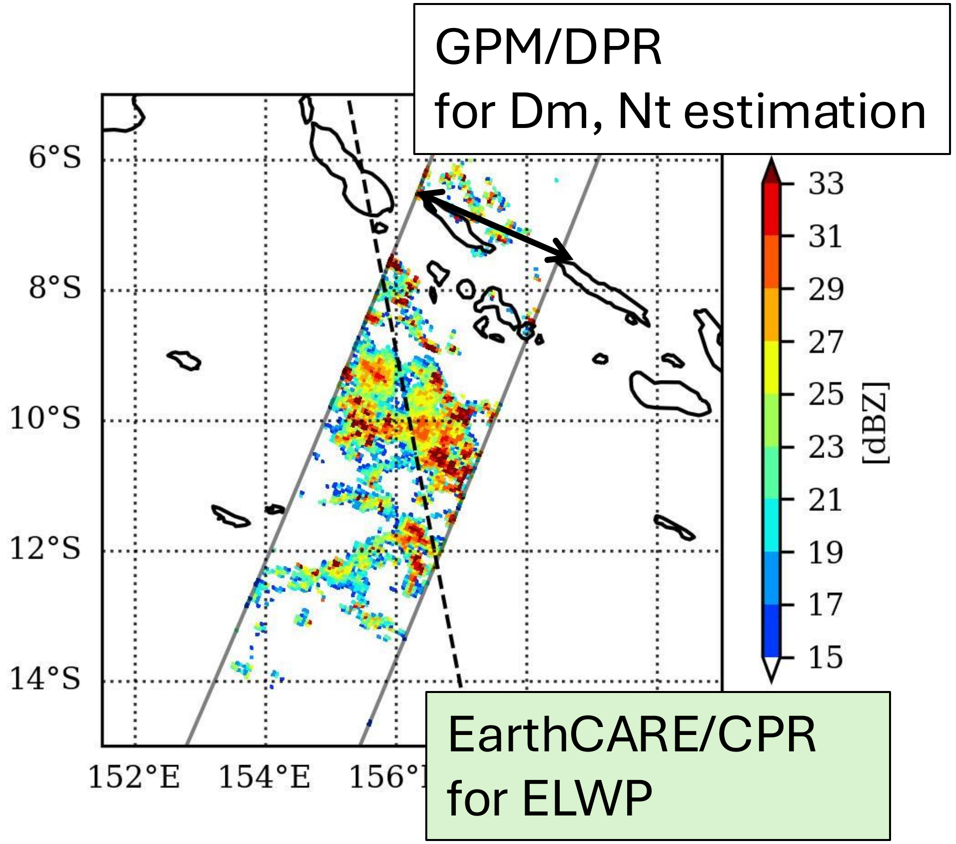
Our purpose: Determining optimal riming amount (ELWP)

Riming amount strongly affects fall velocity.



Ori et al.(2021)

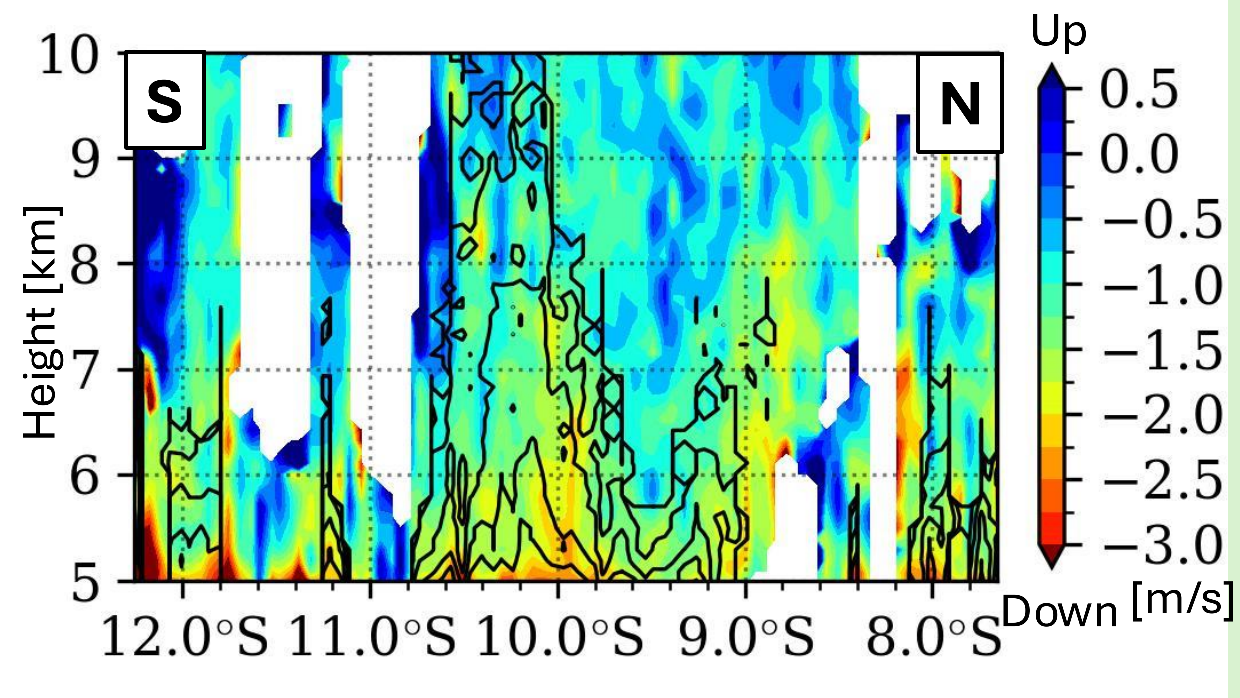
Dataset: EarthCARE-GPM Simultaneous Observation Dataset (Aoki et al., 2025).



Case Study

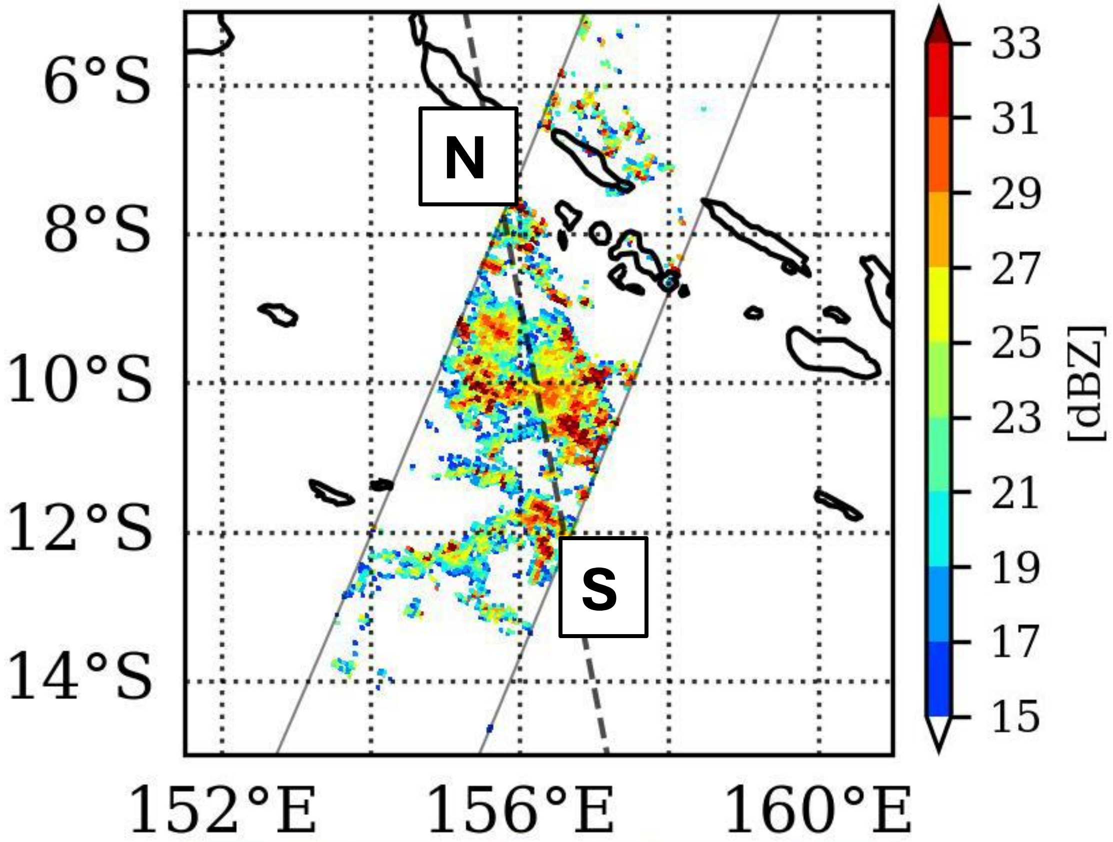
Simultaneous Observation Case (Feb 5, 2025) over east sea of Papua New Guinea

CPR Bias-corrected Doppler velocity (Vd), 10km integration (vBa)



*Line is ZmKu (Shown from 14dBZ, every 4dB).

DPR ZmKu @5km alt.



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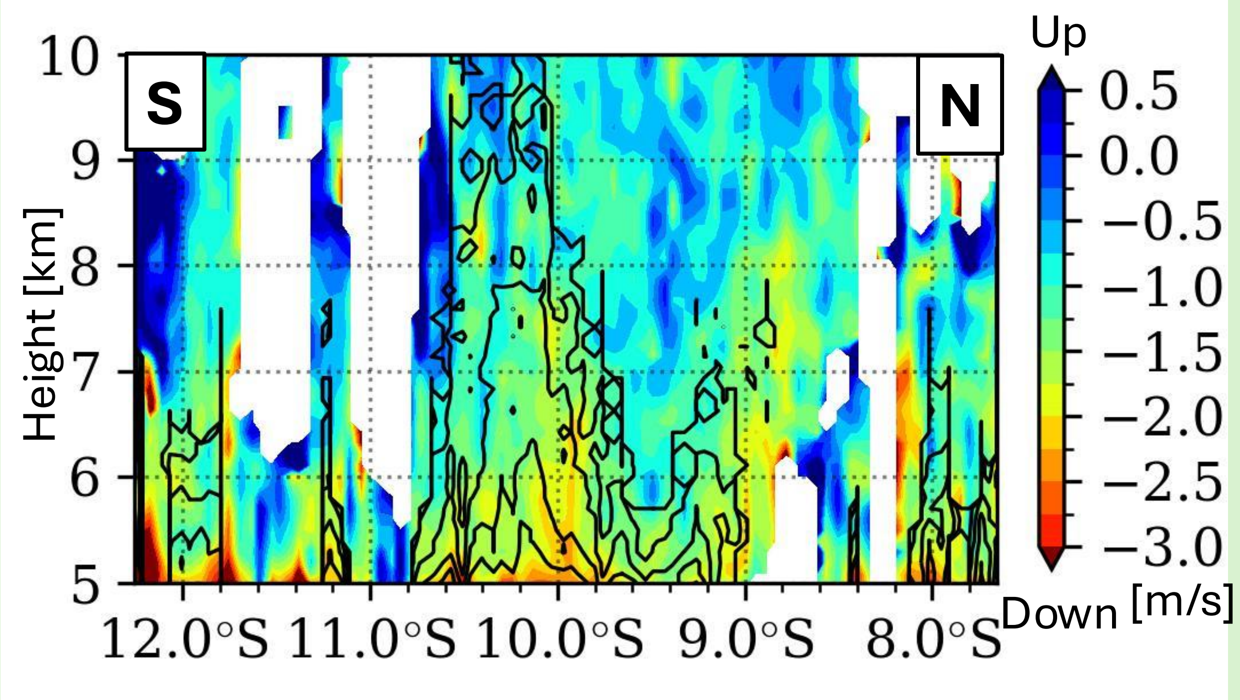

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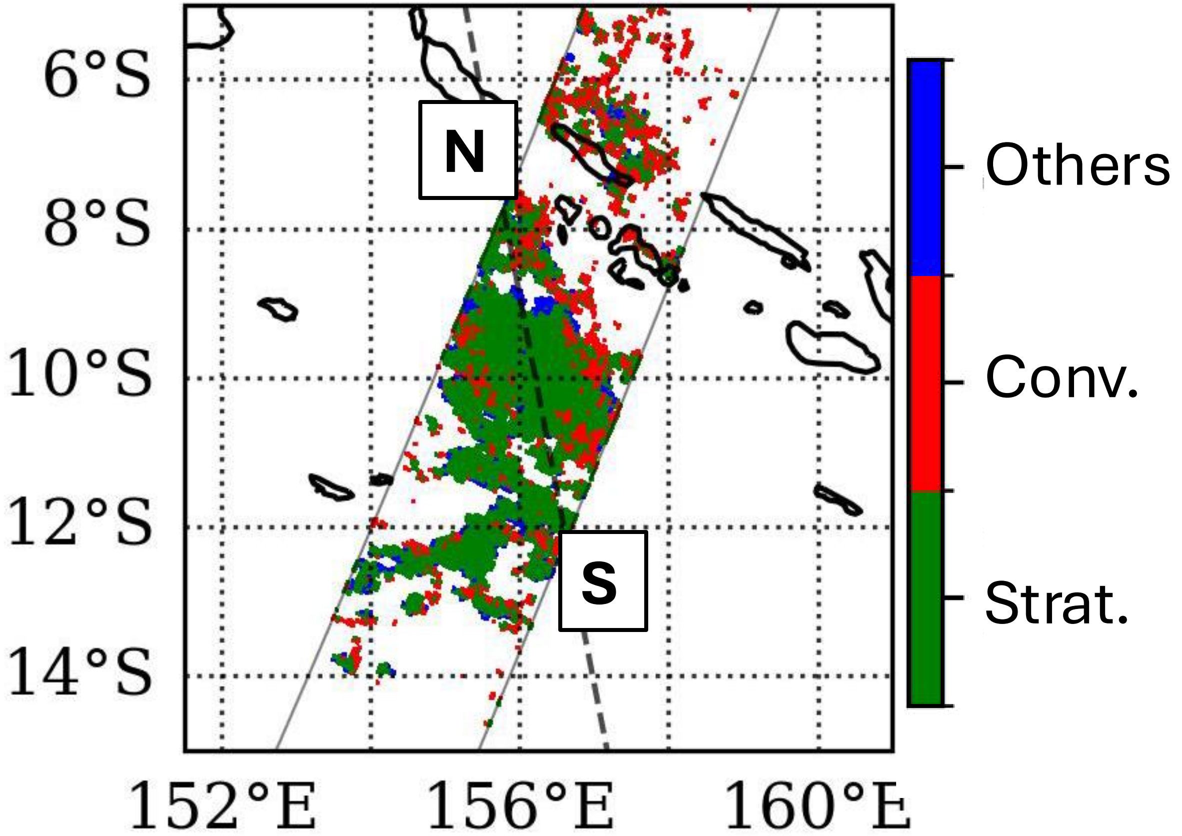
DPR precipitation type



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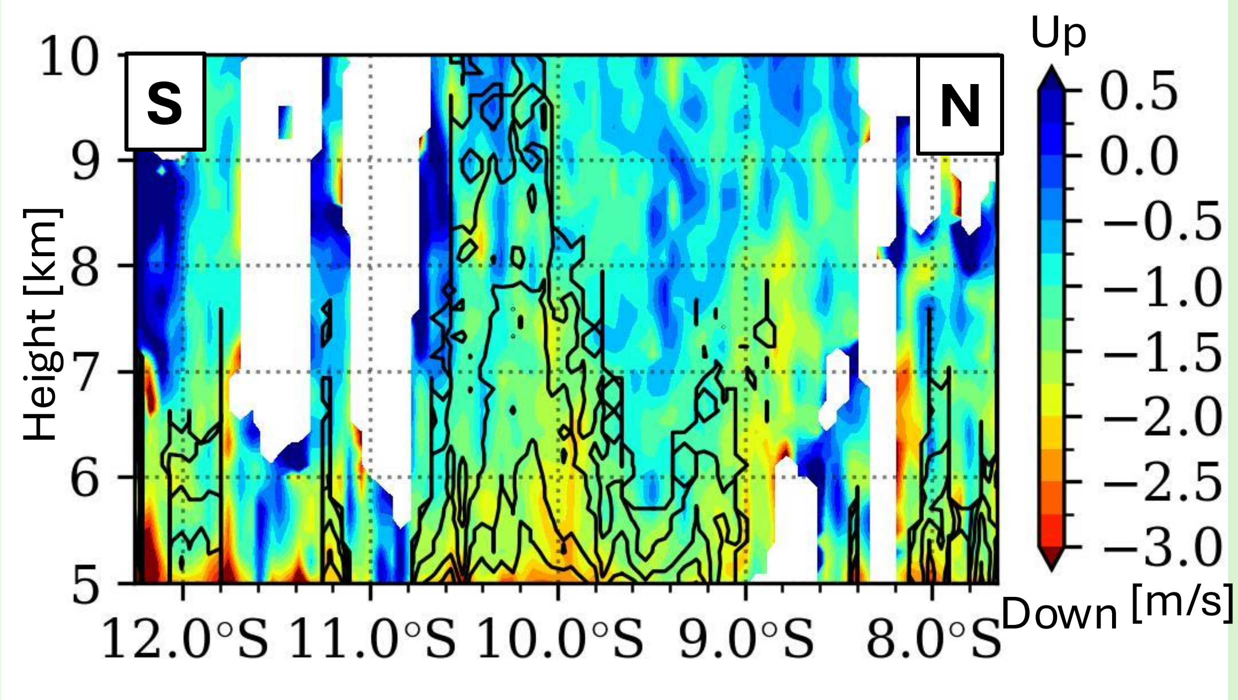

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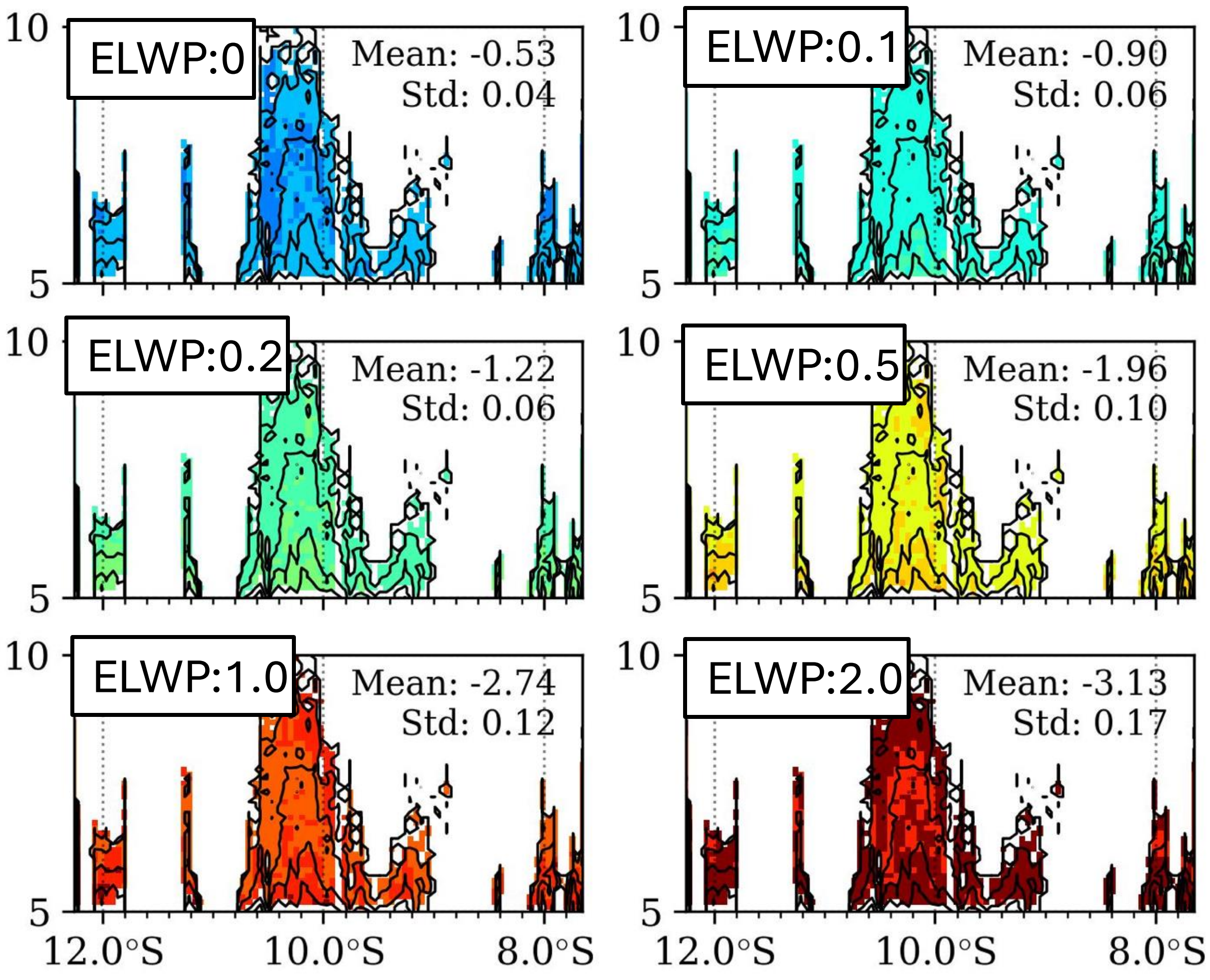
DPR terminal velocity estimates

*correlated by pressure of ECMWF.AUX-2D version vBb



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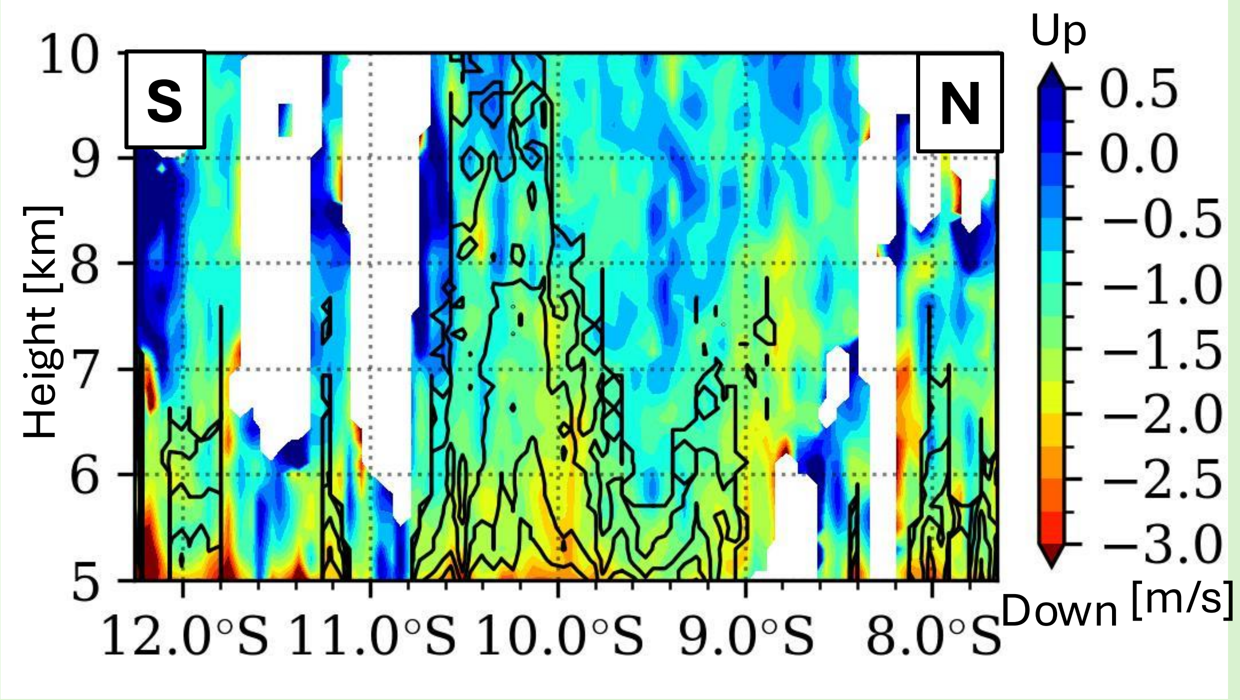

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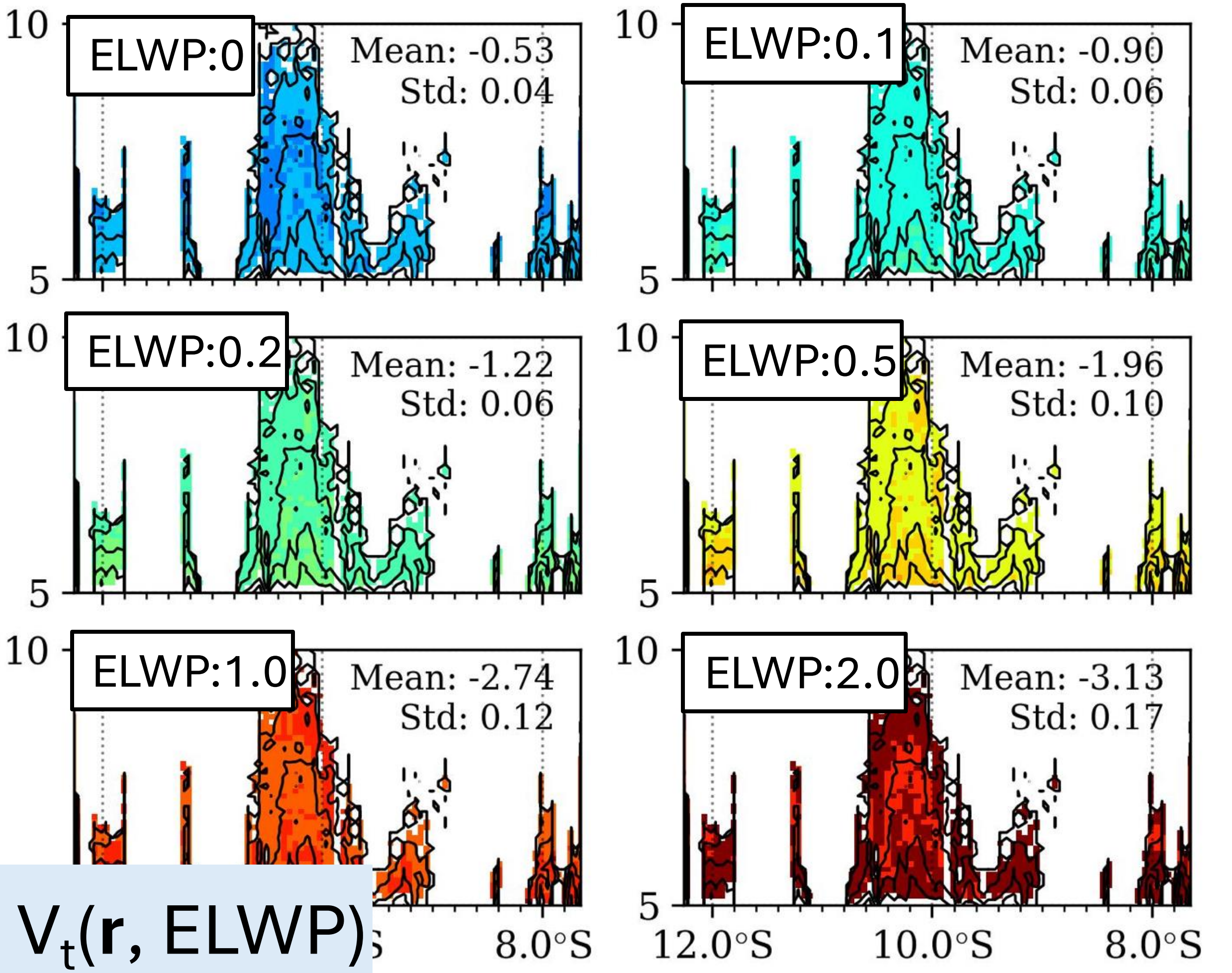
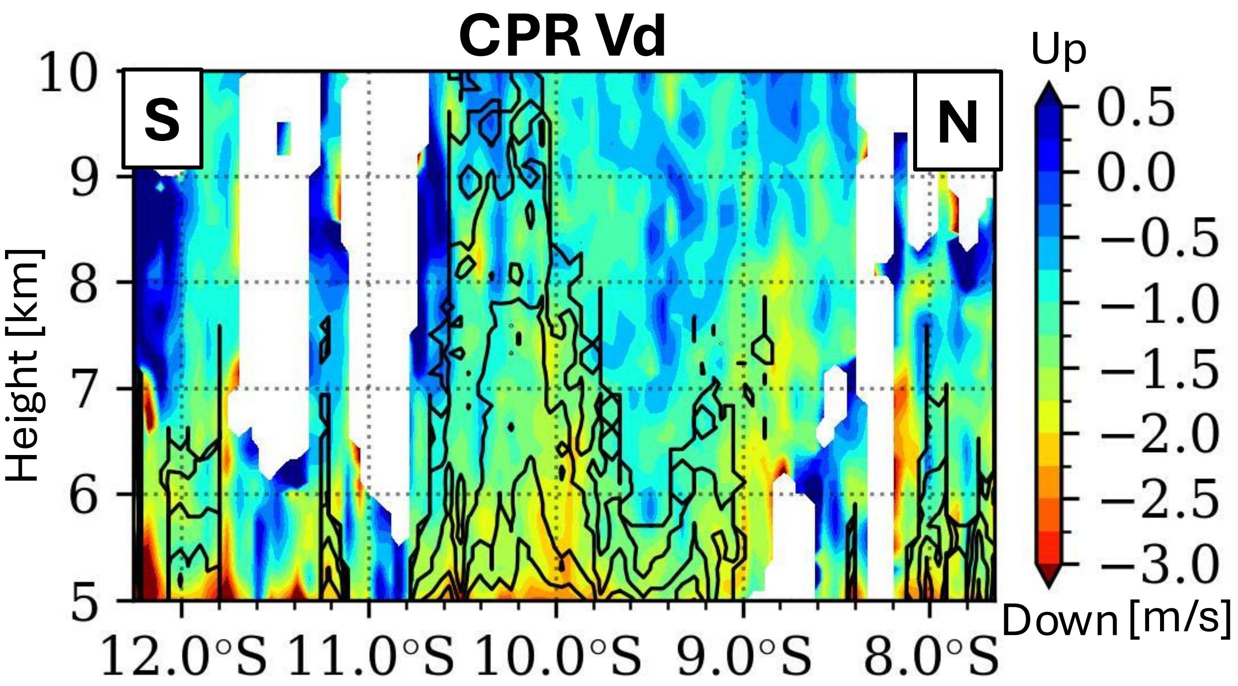
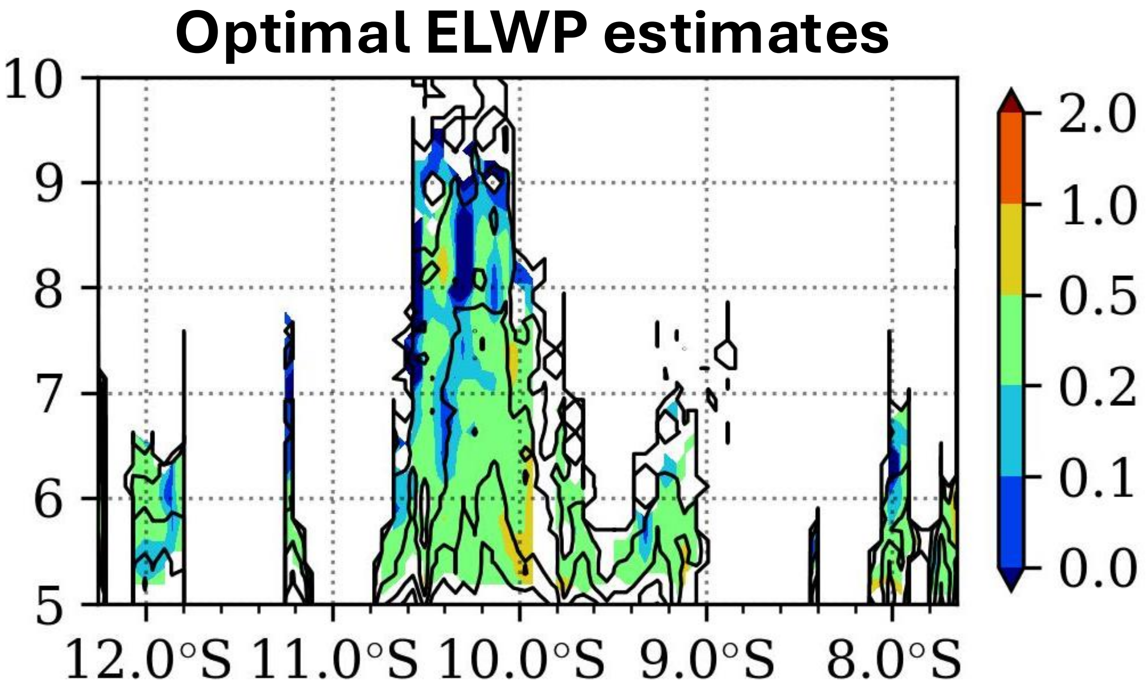


$$V_d(\mathbf{r}) = \cancel{V_{air}}(\mathbf{r}) + V_t(\mathbf{r}, \mathrm{ELWP})$$

Simultaneous Observation Case (Feb 5, 2025)





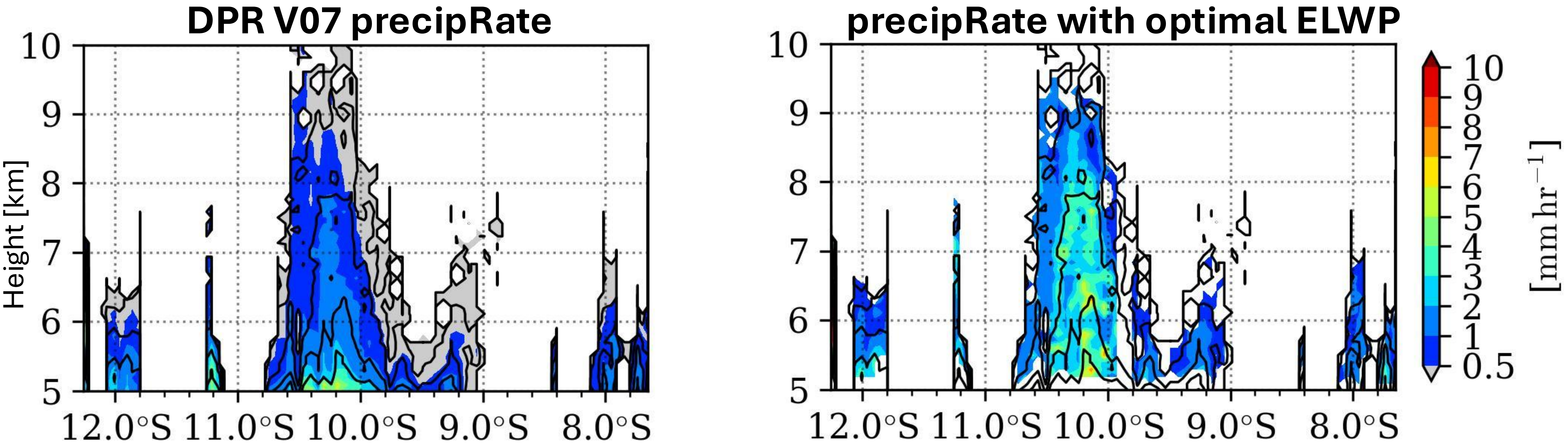
Condition for ELWP estimation

- •Comparison of nearest CPR and DPR beams
- •Dm, Nt are estimated using DPR DF-method (Akiyama et al., 2025)
- •If Vd > Vt(ELWP=0), then ELWP sets 0.

Main Data

- •**CPR(vBa):** Bias-corrected Doppler velocity (Vd), 10km integration
- •**DPR (V07) :** ZmKu, ZmKa, phase

Simultaneous Observation Case (Feb 5, 2025)

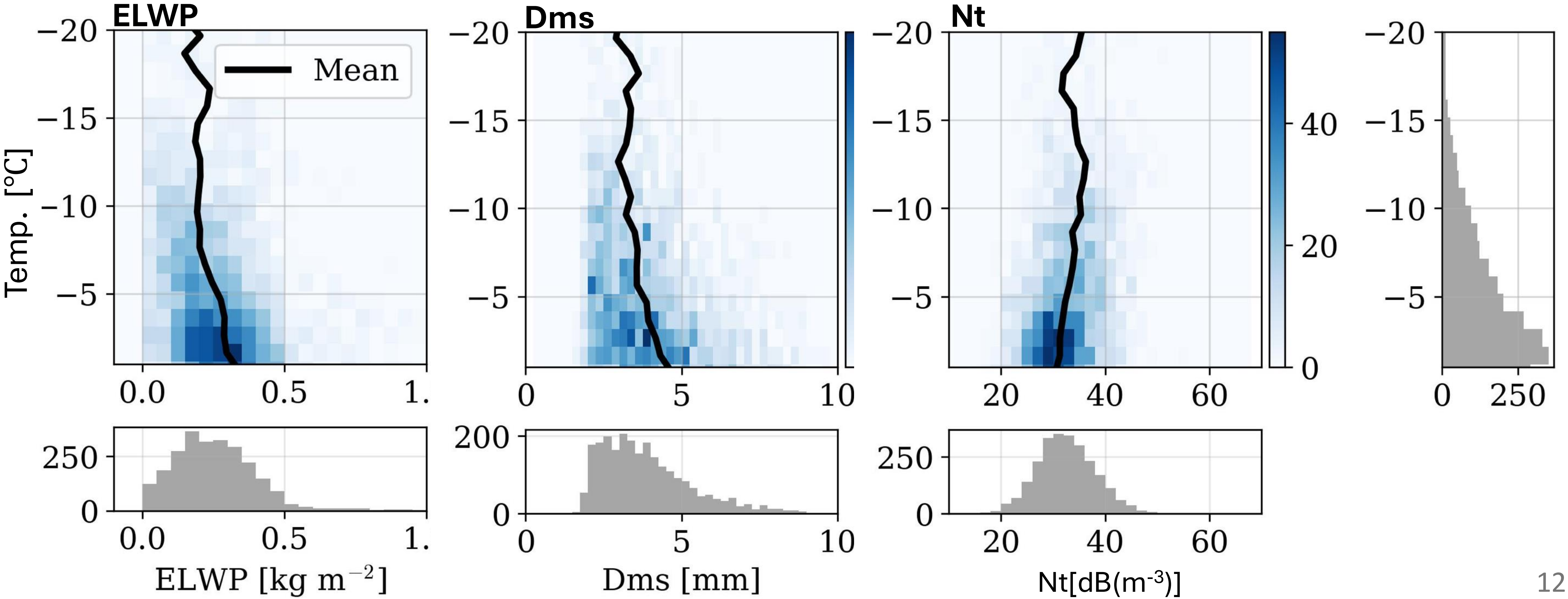


- the snowfall intensity from our new method is about three times higher.
- optimizing ELWP improves the known underestimation issue with DPR.

Statistical Analysis of Snowfall Microphysics

- **Period:** August 2024 – July 2025
- **Target:** Stratiform with BB
- **Conditions:** CPR-DPR time difference < 7.5 min
- **Exclusions:** Optimal ELWP < 0, ELWP > 2, DFR < 1.

2D Histograms (vs. Temperature)



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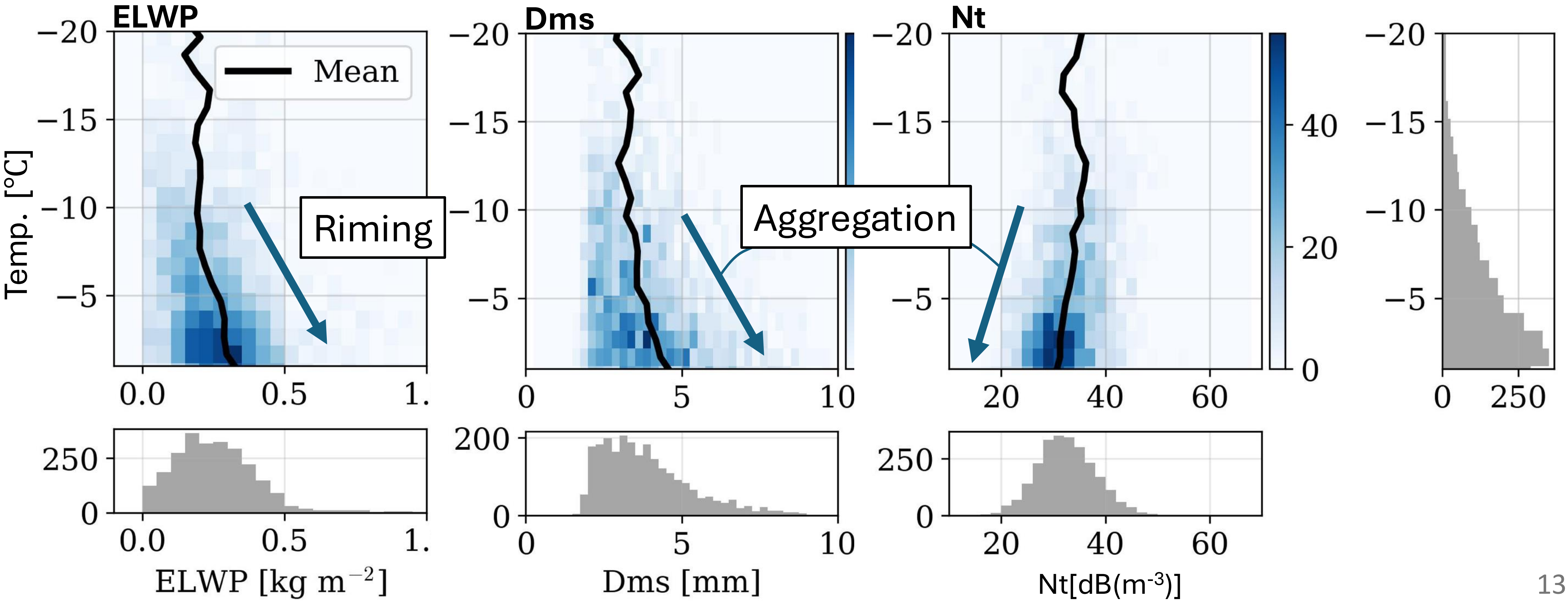
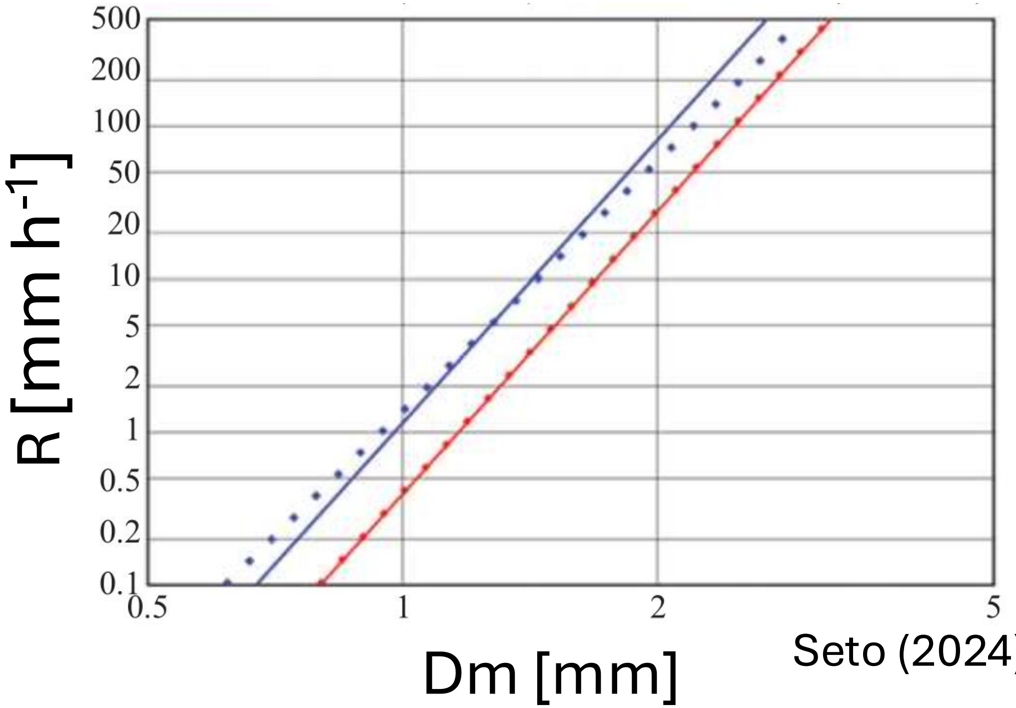


Validity of R-Dm Relationship for Snowfall

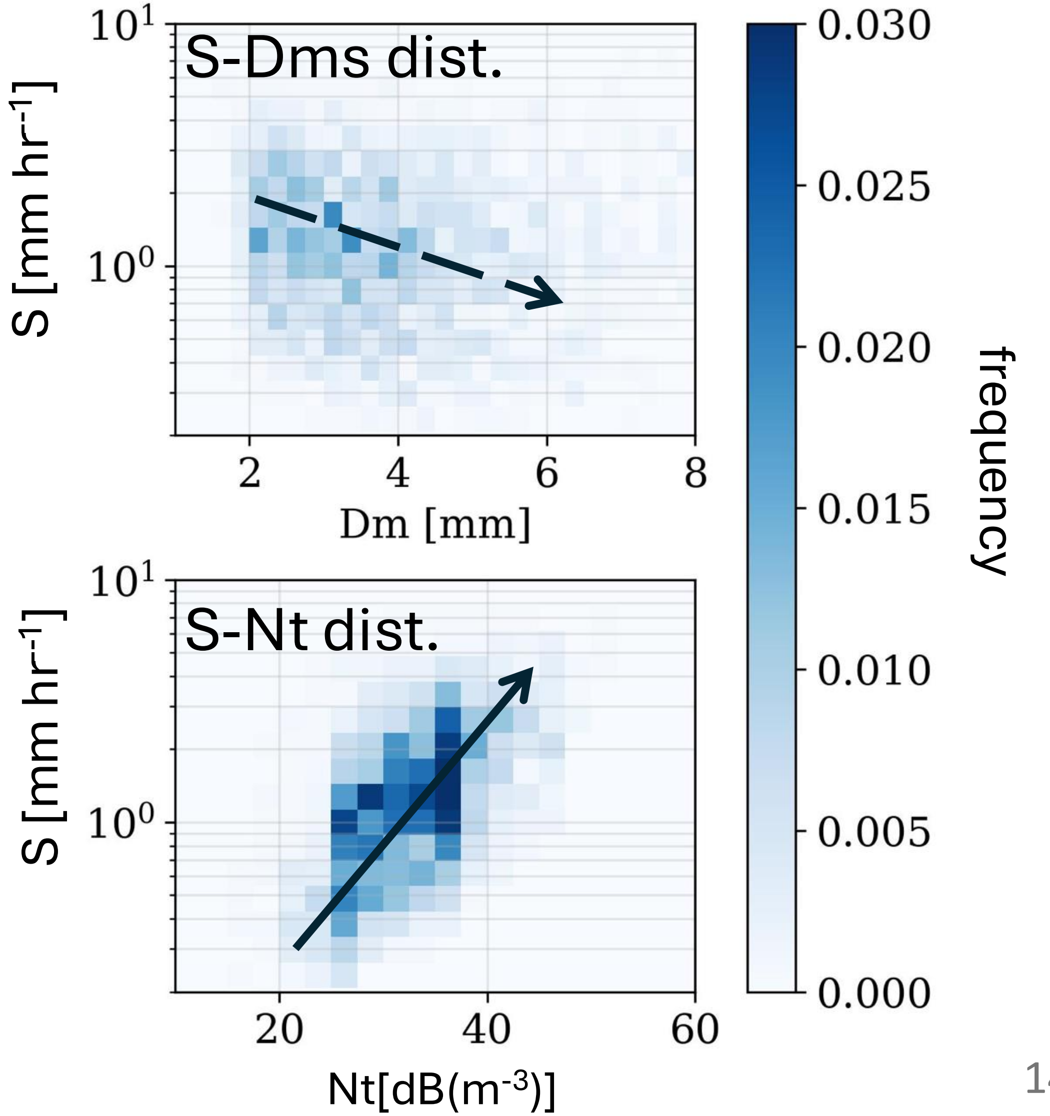
DPR Standard Algorithm

Assumes **Monotonically Increasing** R-Dm.



Seto (2024)

Observed Relationship (This Study):



- Our results are consistent with previous studies (e.g., Harimaya et al., 2004)
- For single-frequency like TRMM/PR, using **Nt constraint** is more effective than Dm.

Summary

Objective:
- Address the ELWP dependency issue in GPM/DPR Dual-frequency method.
- Estimate consistent ELWP using EarthCARE-GPM coin. dataset.

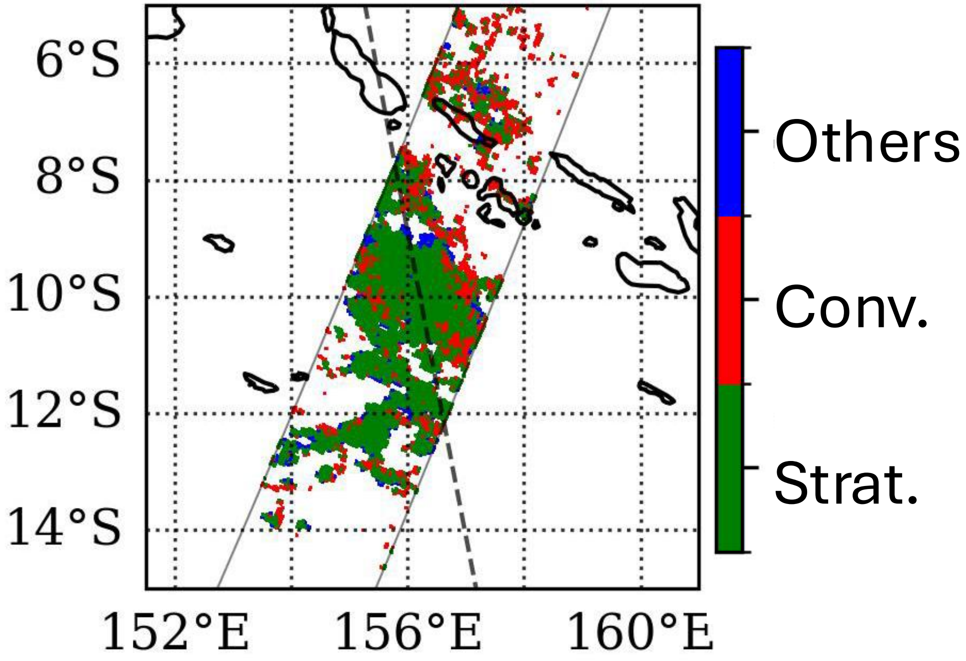
Method:
- Compare terminal velocity estimated from GPM/DPR with Doppler velocity from EarthCARE/CPR.
- Optimize ELWP based on velocity consistency at each altitude.

Results:
- Optimal ELWP peaked at 0.2 kg m^{-2}.
- Snowfall intensity using optimal ELWP increased by approx. 3 times compared to DPR standard product (improving underestimation).
- Statistical analysis showed characteristics of aggregation and riming growth towards lower layers.
- Positive correlation found between snow intensity and number conc., consistent with previous studies.

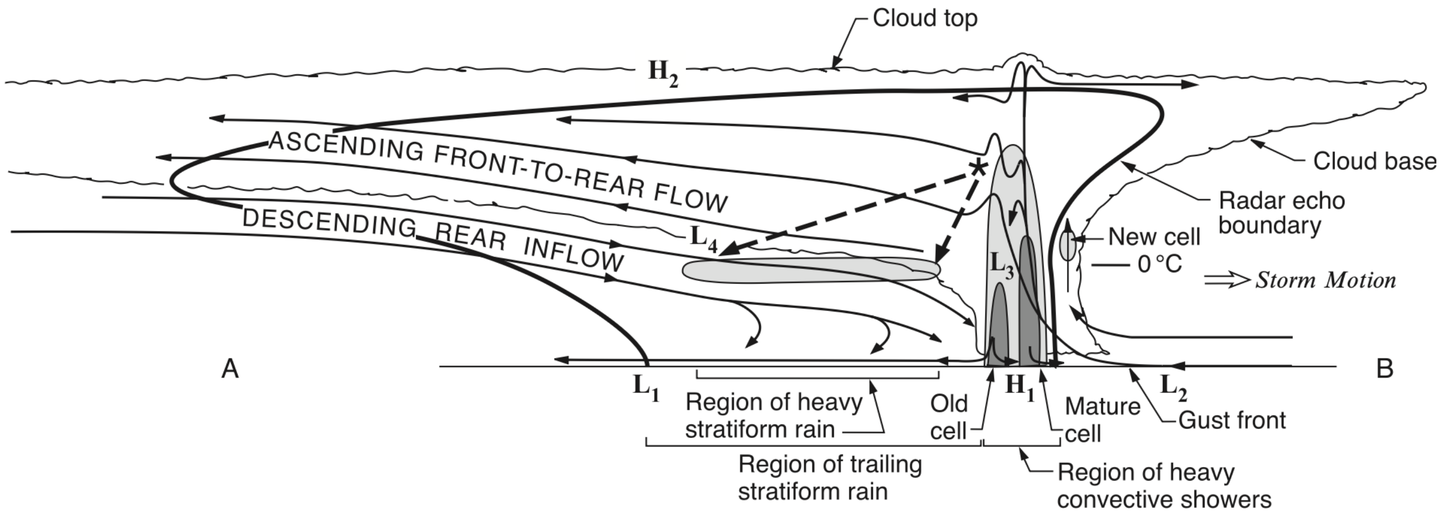
Future work:
- Investigate the consistency between our Vd-based results and CPR radar reflectivity
- Extend the analysis to convective precipitation systems

Appendix: Where cloud liquid water comes from?

DPR precipitation type



Concept model of flow and microphysics in Mesoscale Convective System



Houze et al. (1989)

- Stratiform precipitation of MCS exists with slightly ascending rear flow.
- Upstream supplies cloud water.