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Exploring vertical motion in global clouds and precipitation through combined EarthCARE and Global Precipitation Measurement (GPM) observations

Shunsuke Aoki[1], Takuji Kubota[1], Joe Turk[2] , and Shoichi Shige[3]

1. JAXA/EORC, 2. the JIFRESSE at the UCLA, 3. Kyoto University

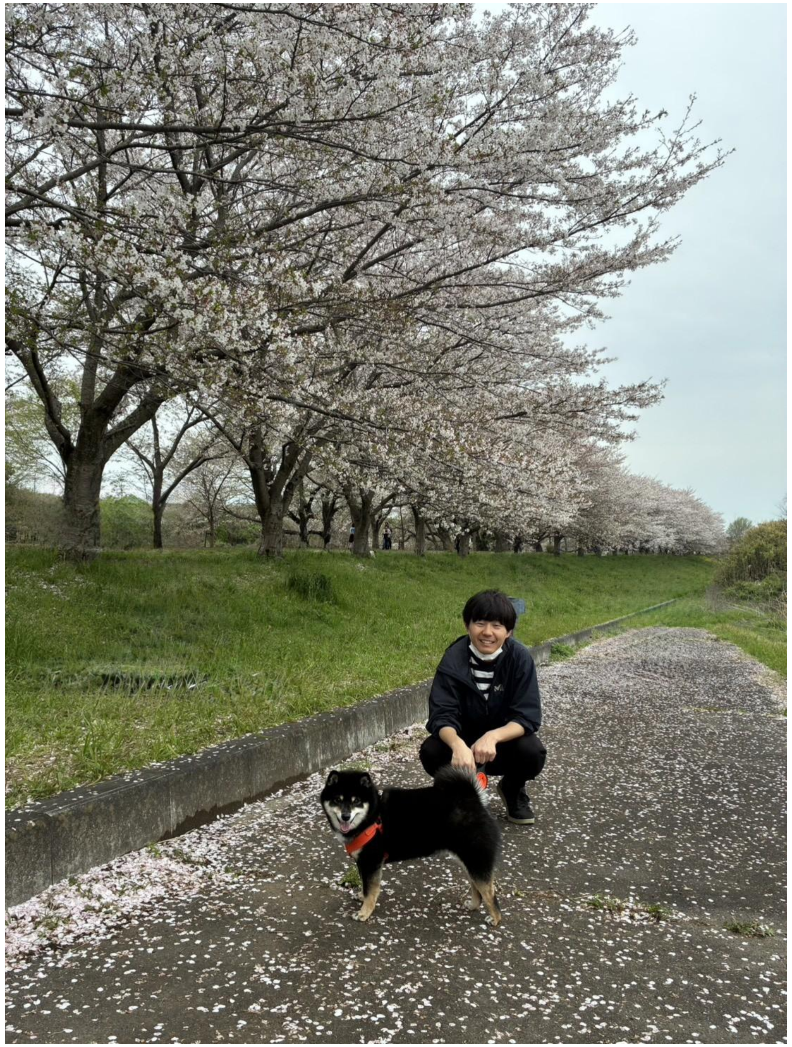
EarthCARE Science Seminar on Apr 15, 2026

Who am I?

Shunsuke Aoki

- ■ Postdoc researcher (Boss: Dr. Takuji Kubota)
- ■ Earth Observation Research Center (EORC), JAXA

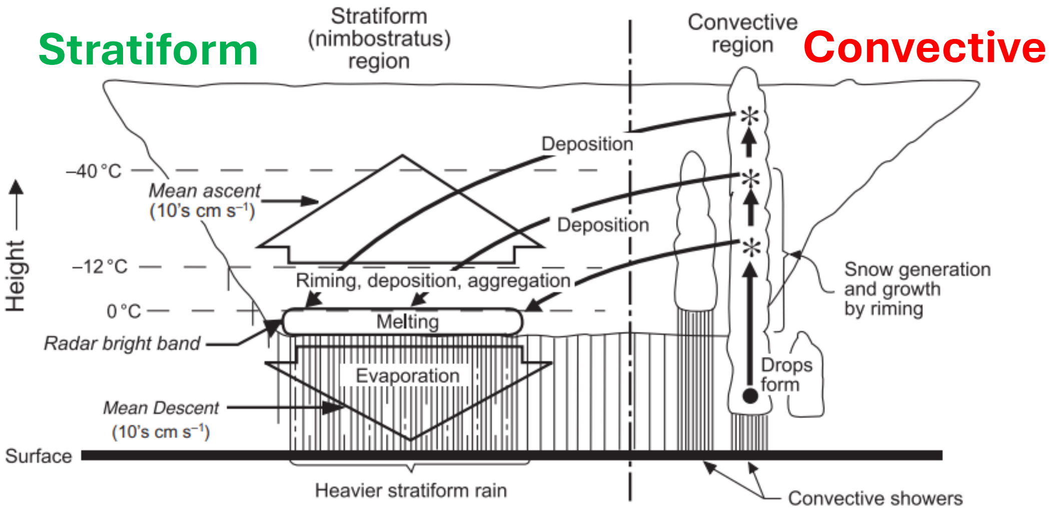
- ■ - Mar 2024: Earth and Planetary Sciences, Kyoto University
  - B.S. (Mar 2019), M.S (Mar 2021), Ph.D. (Mar 2024)
  - Supervisor: Prof. Shoichi Shige
  - Diurnal cycle of precipitation, orographic effects
  - Spaceborne radar (TRMM, GPM, CloudSat)
- ■ Apr 2024-present: EORC, JAXA
  - EarthCARE team
    - JAXA's Level 2 data (one of the developer of CPR_ECO)
  - GPM Spectral Latent Heating product team
  - EarthCARE-GPM coincidence dataset



Cherry blossoms in Tsukuba

Vertical Motions inside Clouds and Precipitation

- Precipitation is fundamental to the global water cycle, latent heating, and the radiation budget.
- Dynamical and microphysical processes within clouds remain one of the major unsolved problems in weather and climate science.
- Precipitating systems are broadly classified into 2 types:
  - **Convective**: intense, narrow updrafts that promote the formation of large hydrometeors through riming and coalescence.
  - **Stratiform**: mesoscale ascent above the melting layer with growth by vapor deposition and aggregation, and subsidence below cloud base due to rain evaporation.
- Ground-based Doppler radars have provided important insights, but because precipitation structures vary substantially with geographic and environmental conditions, **satellite observations are essential for understanding their global characteristics**.

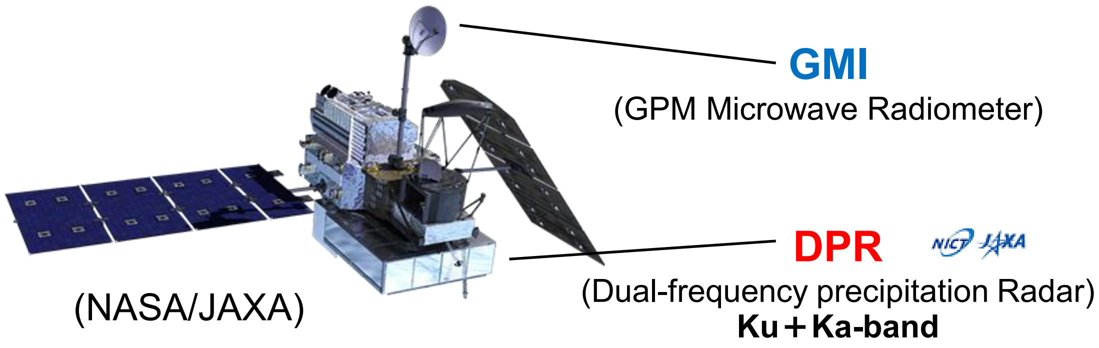


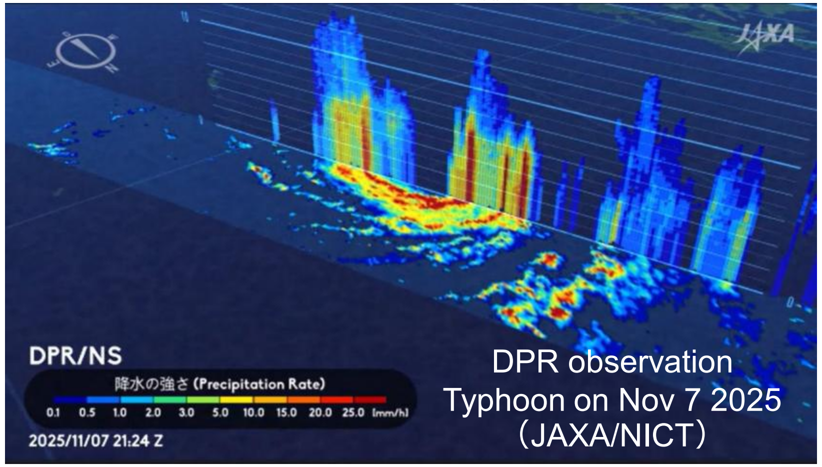
Schematic of the precipitation mechanisms in a mesoscale convective system (Houze 1989)

Cloud and Precipitation Measurements by EarthCARE and GPM

Global Precipitation Measurement (**GPM**) Core Observatory have continued precipitation observations for more than 11 years. It carries the **Dual-frequency Precipitation Radar (DPR; Ku & Ka-band)** and the **Microwave Imager (GMI)**.

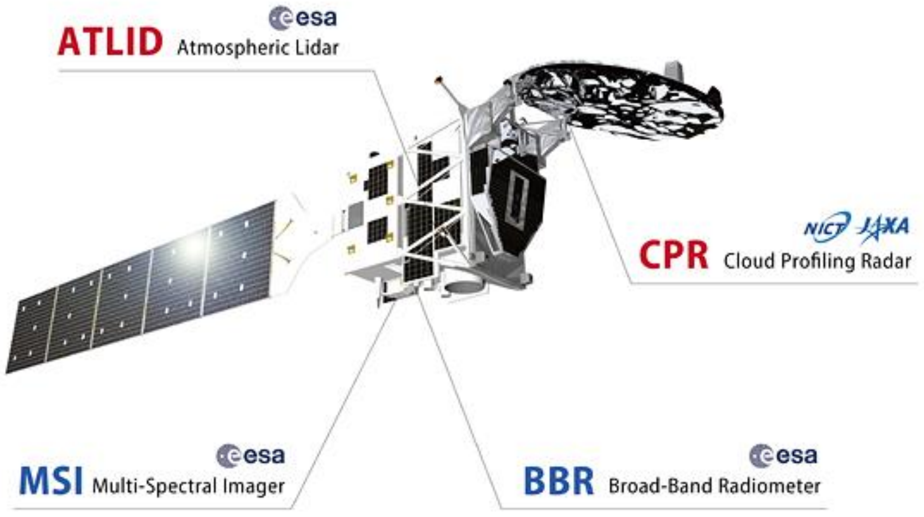
Estimate precipitation and latent heating in convective and stratiform systems

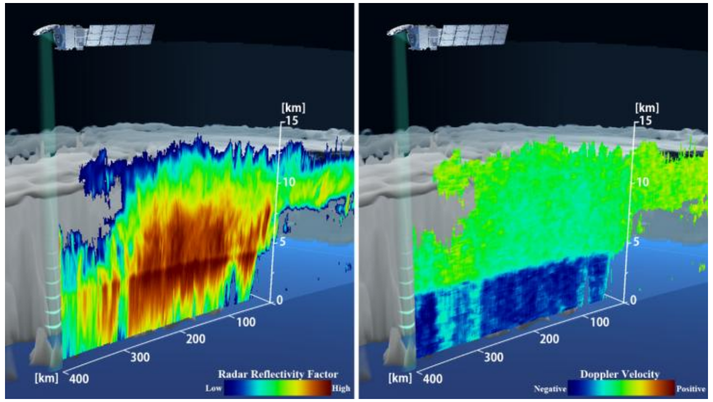




DPR observation
Typhoon on Nov 7 2025
(JAXA/NICT)

EarthCARE's Cloud Profiling Radar (CPR) launched in May 2024 continues CloudSat's W-band cloud observations with **the world's first spaceborne Doppler velocity measurements**.





CPR first images
(JAXA/NICT)

Doppler

↓

Vertical air motion!

(CPR_CLP, CPR_CD)

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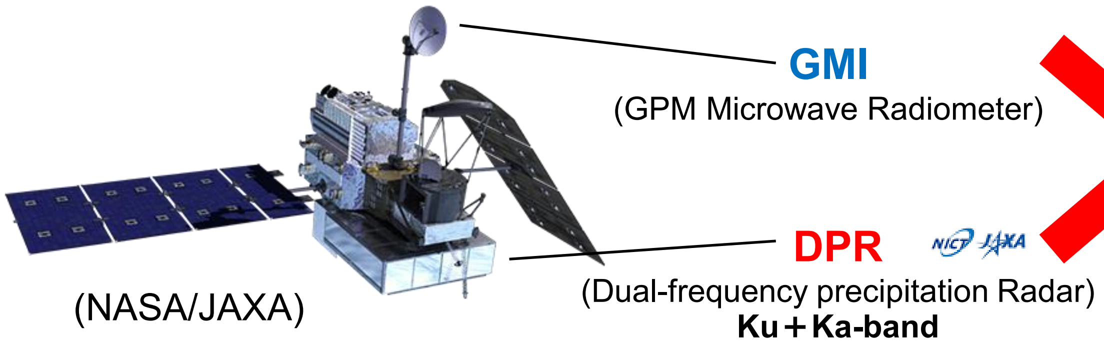
<u>Estimate precipitation and latent heating in convective and stratiform systems</u>



(NASA/JAXA)

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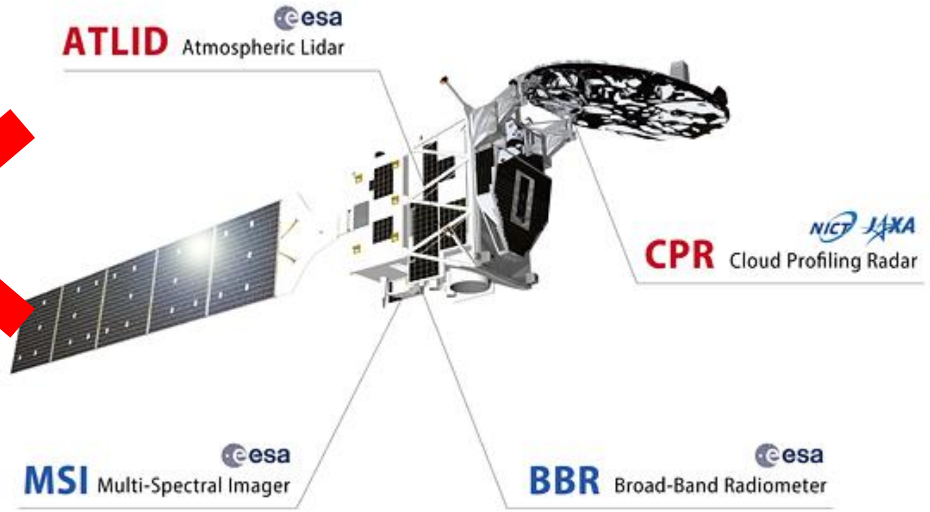
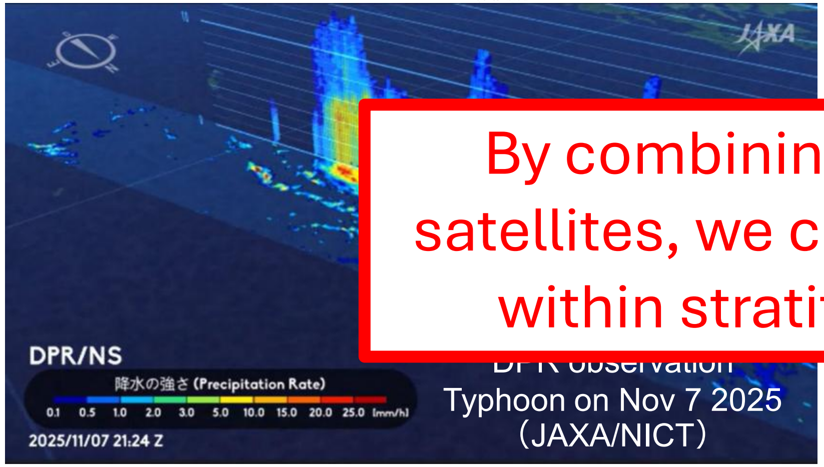
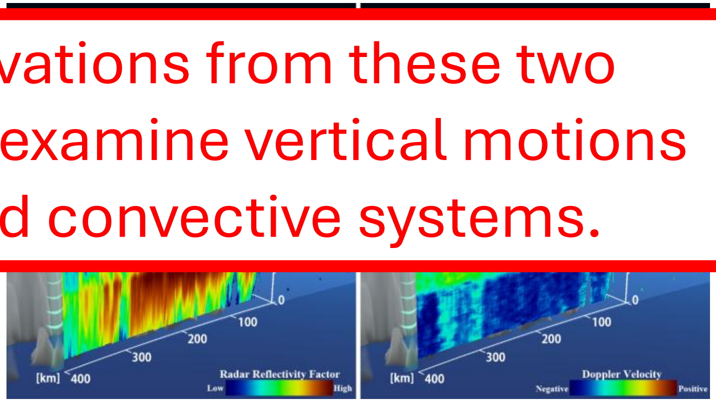




DPR observation
Typhoon on Nov 7 2025
(JAXA/NICT)

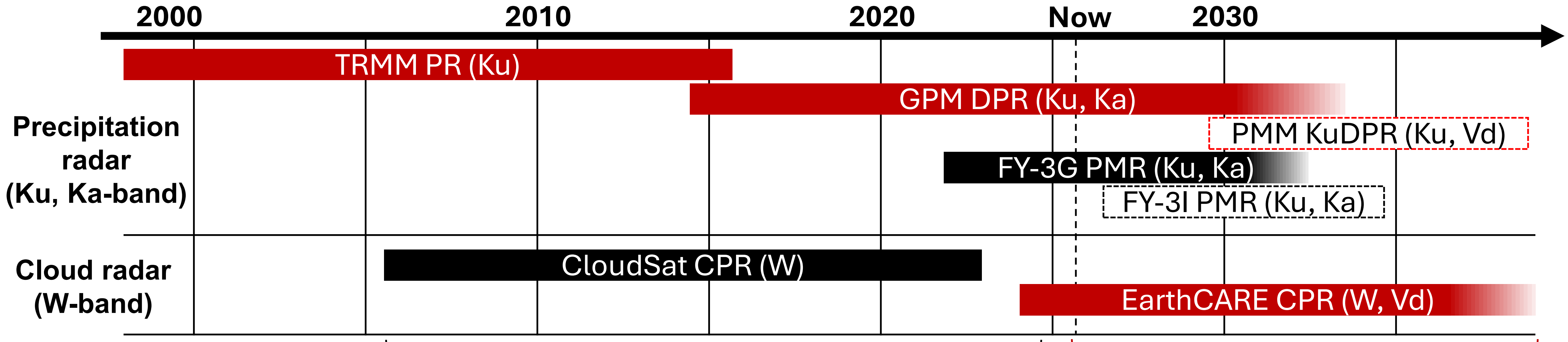
By combining observations from these two satellites, we can now examine vertical motions within stratiform and convective systems.



CPR first images
(JAXA/NICT)

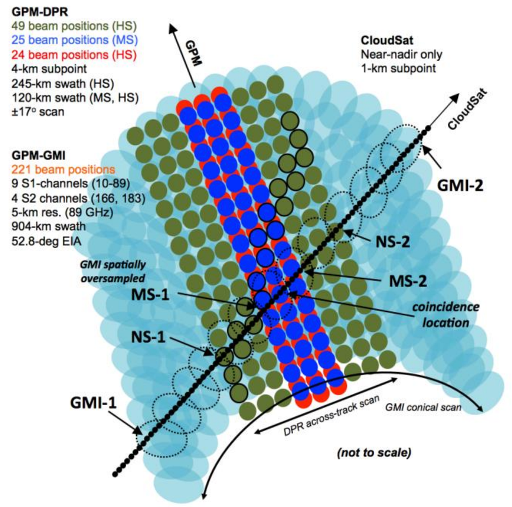
Doppler
↓
Vertical air motion!
(CPR_CLP, CPR_CD)

Synergistic use of cloud and precipitation radar



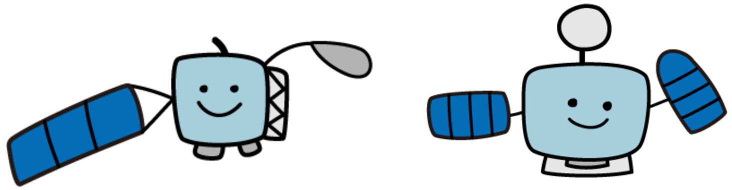
CloudSat-TRMM/GPM coincidence dataset (Turk et al. 2021)

EarthCARE – GPM coincidence dataset (Aoki et al. 2025)



Schematics of CloudSat-GPM coincidence (Turk et al. 2021)

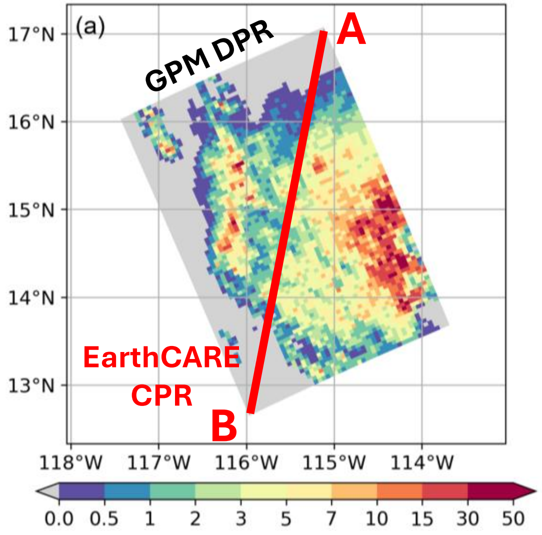
- The **CloudSat–TRMM/GPM Coincident Dataset** (by Dr. Joe Turk), which compiles orbit-crossing cases, has been widely used for studies on ice microphysics, light rainfall, and snowfall, etc.



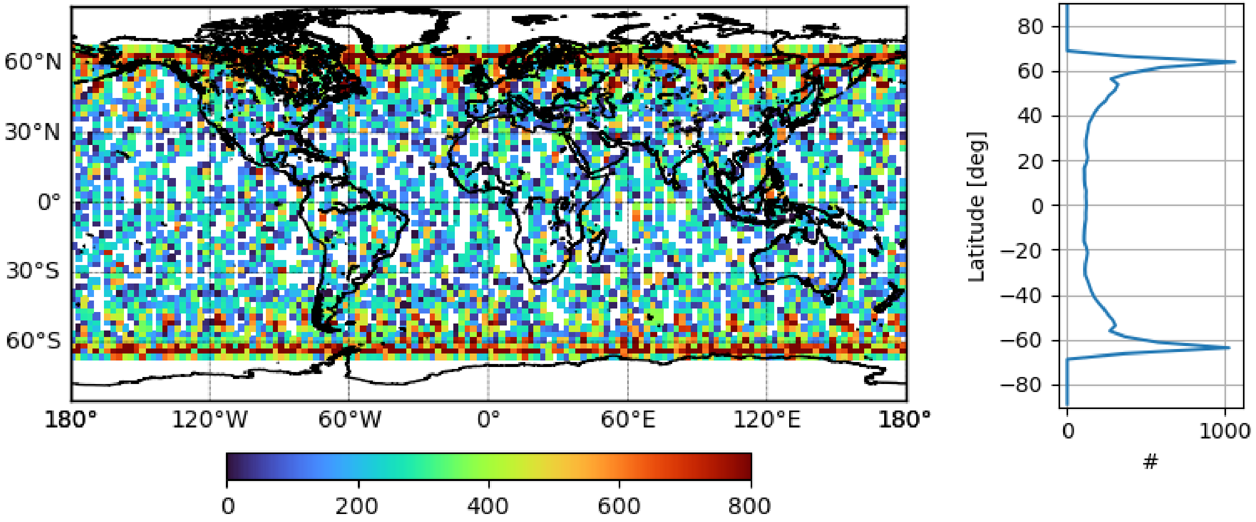
Deveolpment of EarthCARE-GPM coincidence dataset

- Compiles orbit-crossing cases between EarthCARE and GPM within ±15 minutes.
- **Publicly available with the Data DOI on the JAXA website:**
  - ✓ Aoki. S., T. Kubota, and F. J. Turk, 2025, https://doi.org/10.57746/EO.01ka7xakvwj6pcthxkvgt0vr0y.
- Extracts data within the coincident sections while preserving the original data structure as it is.
- Dataset for more than 1-year since Aug 2024 (**>4500 cases**), and more in the future.

GPM DPR
Precip rate [mm/h]

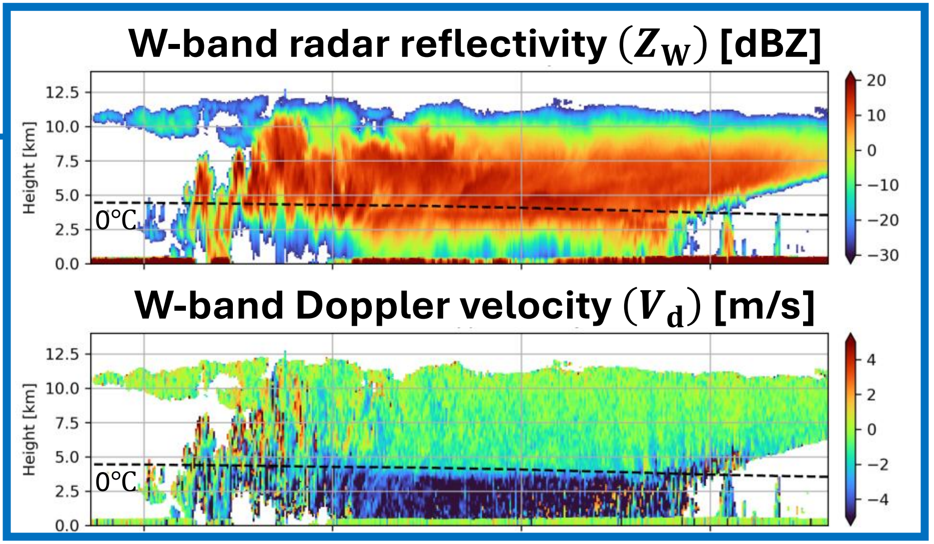


Number of EarthCARE-GPM coincident footprints
(Aug. 2024 – Feb. 2026)



Analysis on EarthCARE/CPR-GPM/DPR coincidence

- Mainly focuses on matchup analysis between
  - **EarthCARE/CPR: W-band Doppler radar**
  - **GPM/DPR: Ku,Ka-band Precipitation radar**
- How do the characteristics of vertical motion differ among precipitation types?
- Is the CPR Doppler velocity consistent with particle sizes estimated from DPR?



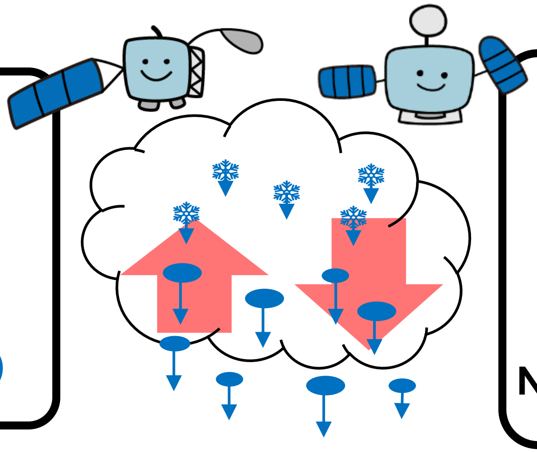
EarthCARE/CPR

Doppler velocity

$$V_d = V_{air} + V_{tz}$$

Vertical air motion

Particle fall speed (reflectivity weighted)



GPM/DPR

Radar reflectivity

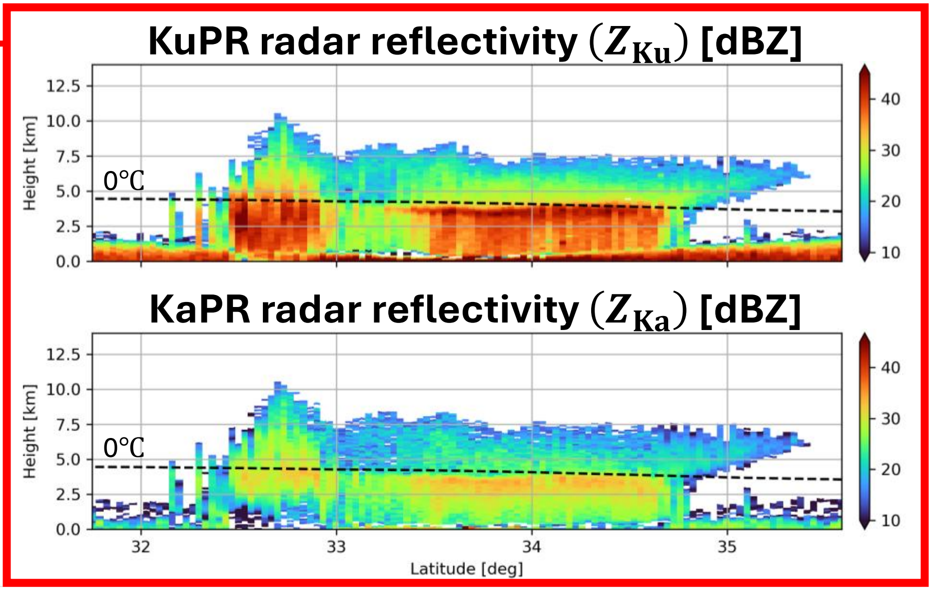
$$Z_{Ku}, Z_{Ka}$$

$$\downarrow$$

$$N_w, D_m \rightarrow R$$

Diameter

Number concentration



Coincidence in US around 7:30 (UTC) on October 19, 2025.

Aoki, S., Kubota, T., and Turk, F. J. (2026): Exploring vertical motions in convective and stratiform precipitation using spaceborne radar observations: insights from EarthCARE and GPM coincidence dataset, *Atmos. Meas. Tech.*, **19**, 79–100, https://doi.org/10.5194/amt-19-79-2026.

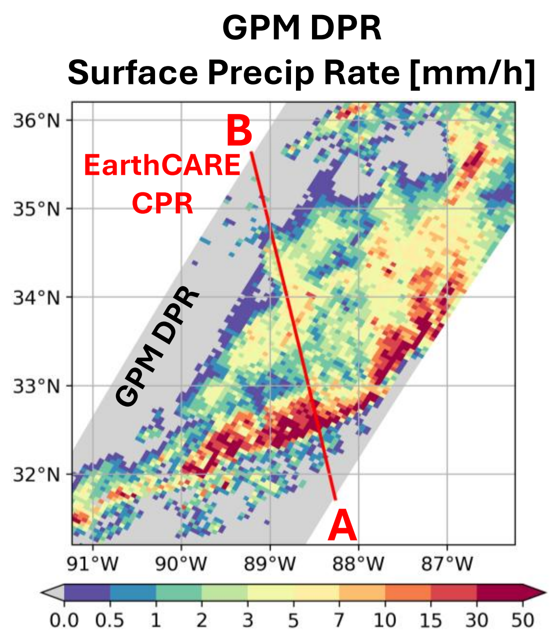
A case study

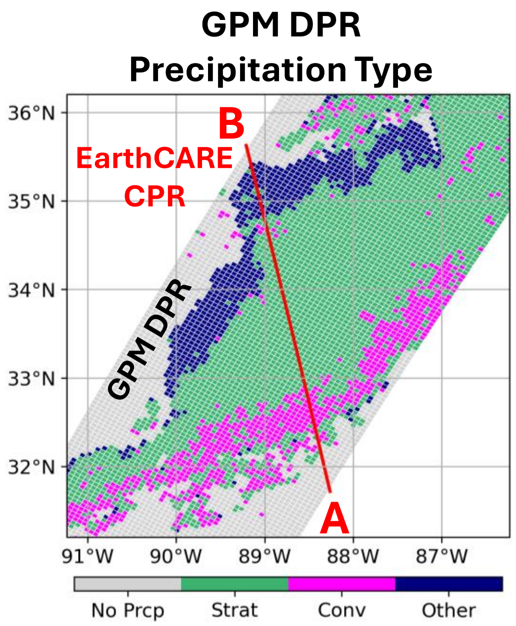
Stratiform

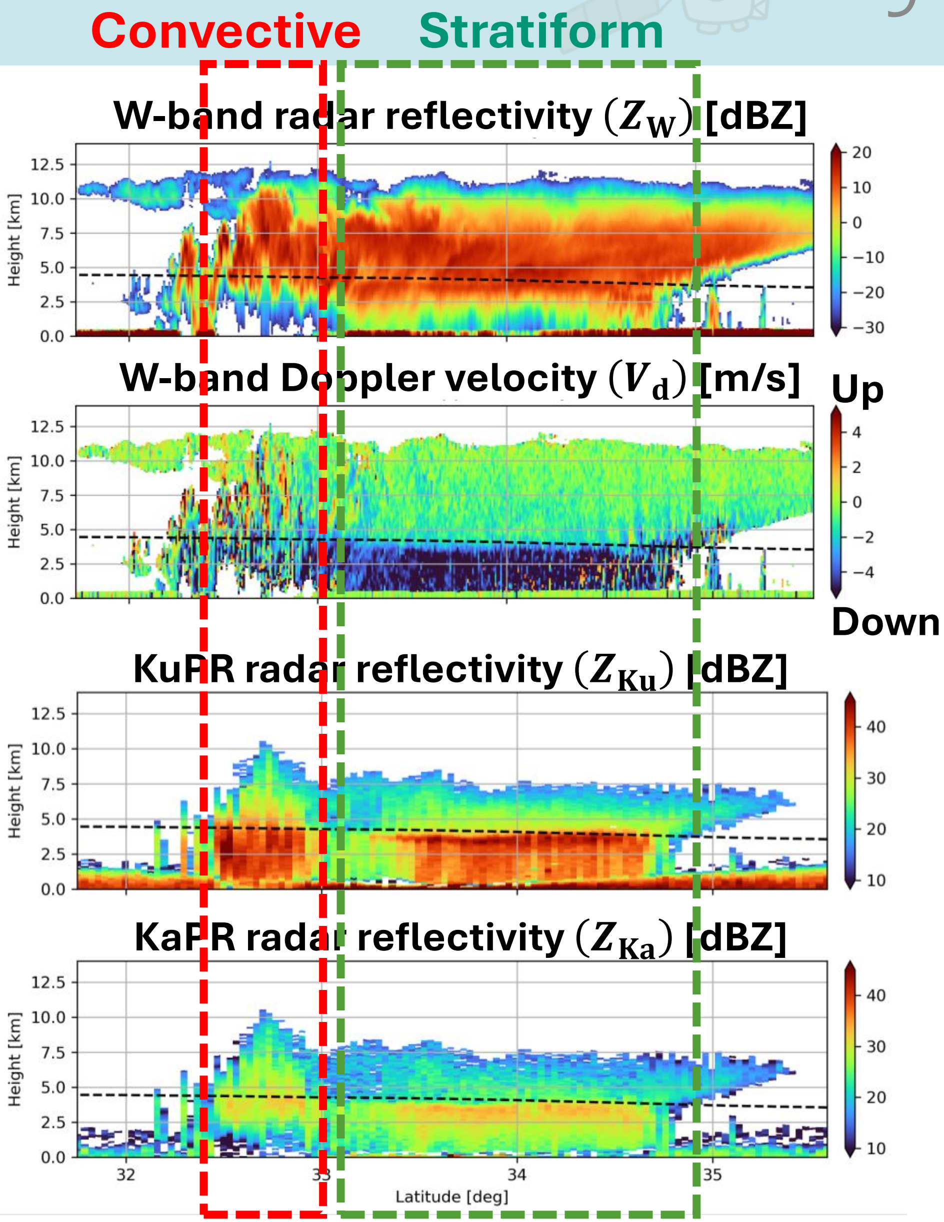
- Doppler velocity differs significantly above and below the melt layer (rain or snow).
- Even with some attenuation occurring in CPR, Doppler velocity can still be measured in the rain layers.

Convective

- Indicates more turbulent vertical air motion, strong wind shear and greater microphysical variability. Severe attenuation.
- The difference in Vd above and below the 0°C is unclear.







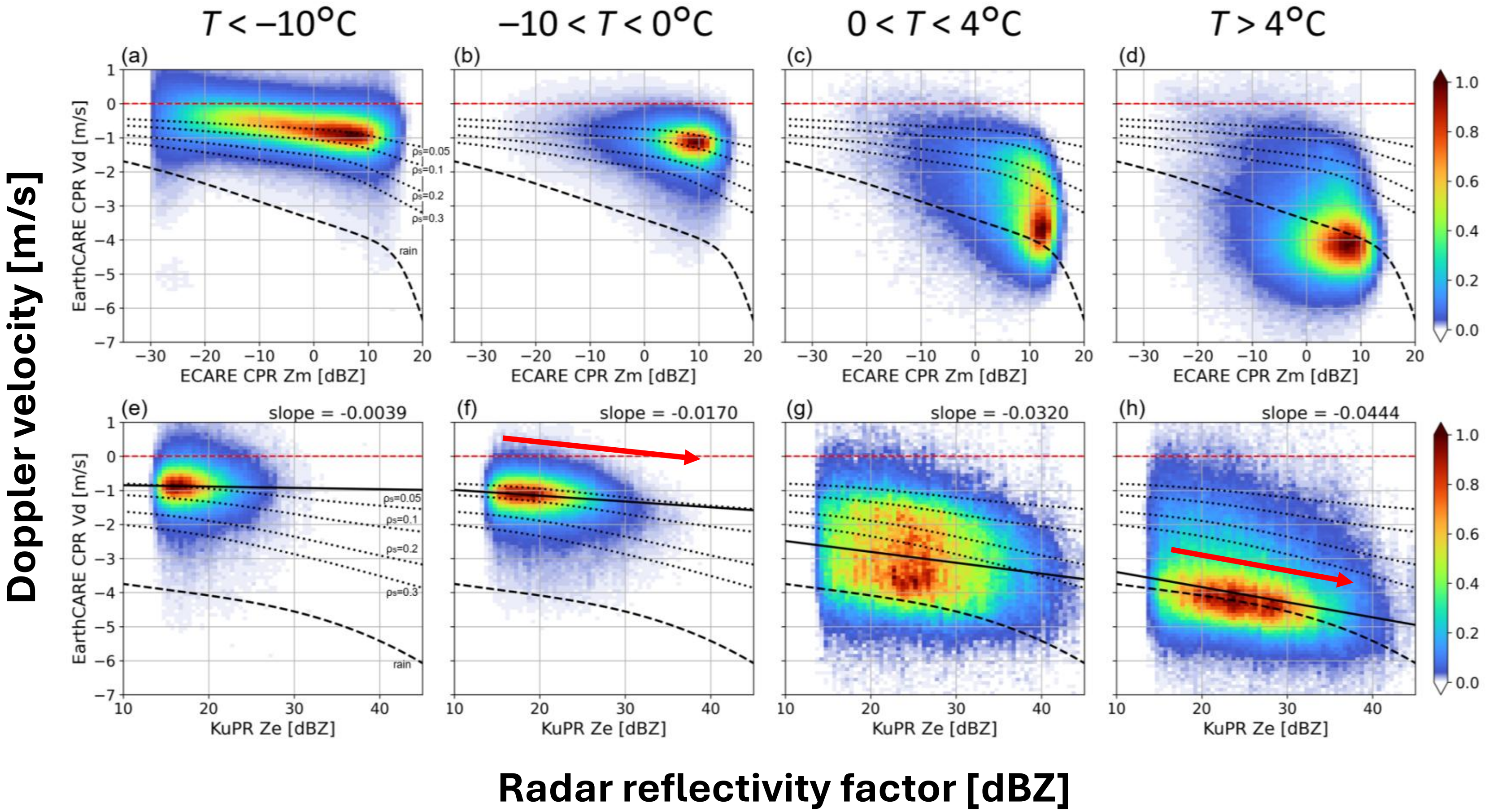
Coincidence in US around 7:30 (UTC) on October 19, 2025.

Z-Vd relationship

- Statistical analysis of coincidence case from Aug 2024 to Jun 2025
- For the upper-level ice: CPR Z increases with Vd, but KuPR has no sensitivity.
- For grown snow and rain (Below the −10 °C level): CPR Z reaches saturation due to the attenuation and Mie effect, while KuPR Z increases with Vd.

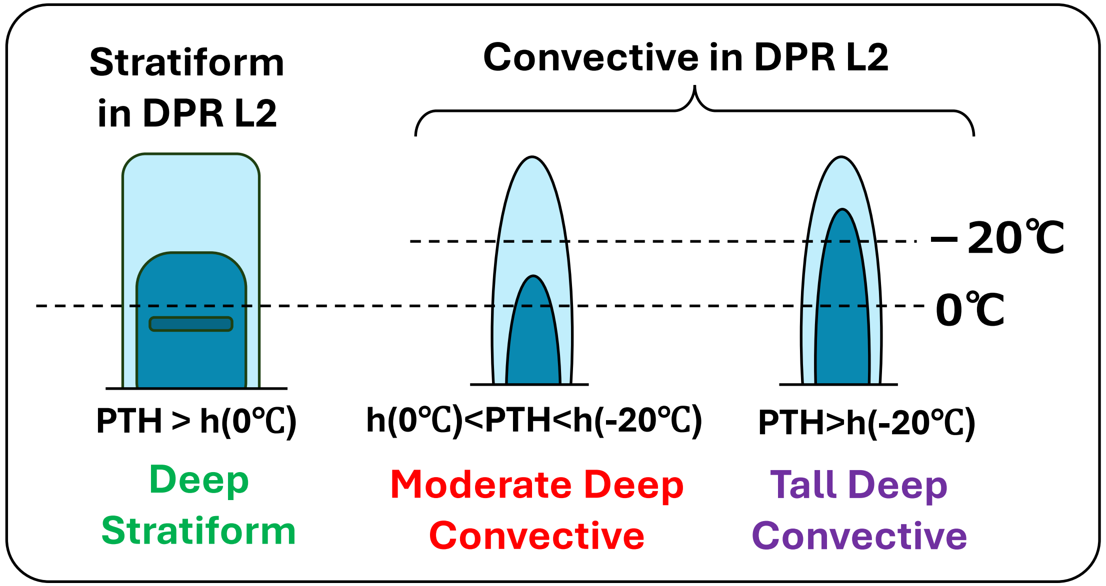
EarthCARE CPR Z (W)

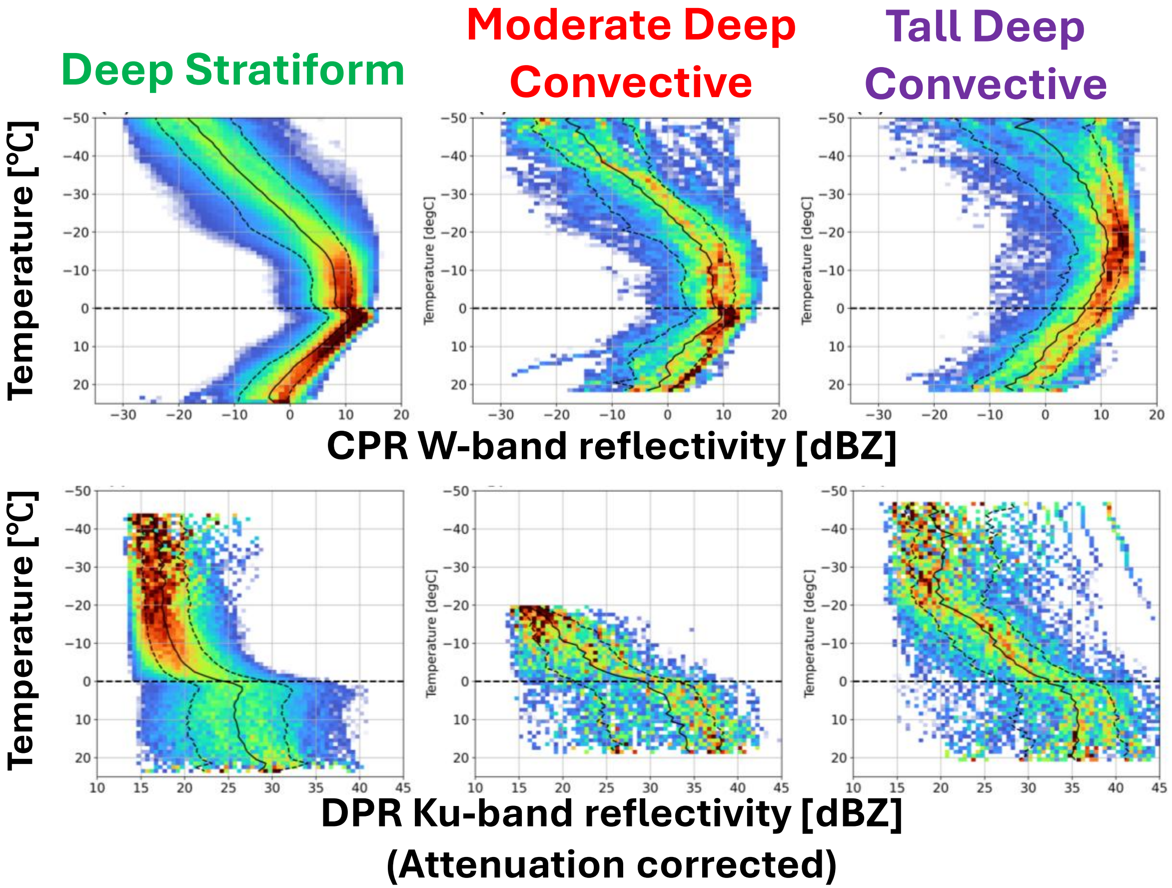
GPM KuPR Z (Ku)



Convective/Stratiform Classification of EC-GPM coincidence

- Classified deep clouds (with DPR precipitation top height (PTH) > 0℃ level) into one of 3 types.
- For precipitation-rate estimation, the GPM/DPR Level 2 algorithm classifies each footprints into a precipitation type (conv/strat /other) according to spatial patterns of Z, such as bright-band and horizontal peakedness.
- In addition, convective cases are further classified according to whether the DPR echo extends to upper levels, resulting in two branches in the ice layer.

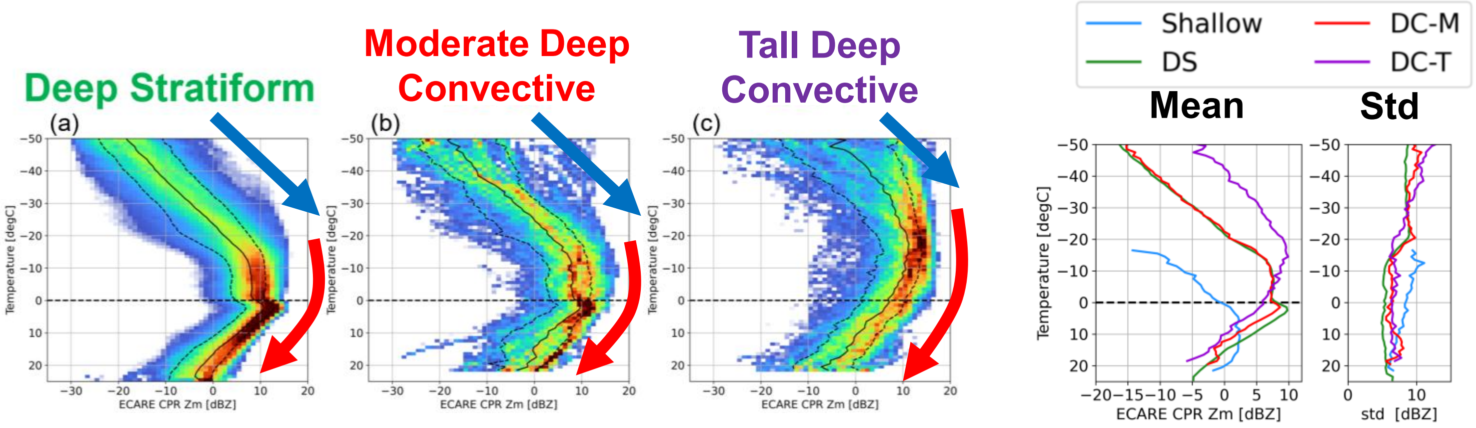




Vertical Profiles of Z and Vd for Each Type

■ Classification into four precipitation types showed distinct differences in vertical profiles.

CPR W-band Reflectivity



Zw is strongly affected by attenuation below the −10 °C level

- For the upper-level ice: CPR Z increases with temperature.
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Vertical Profiles of Z and Vd for Each Type

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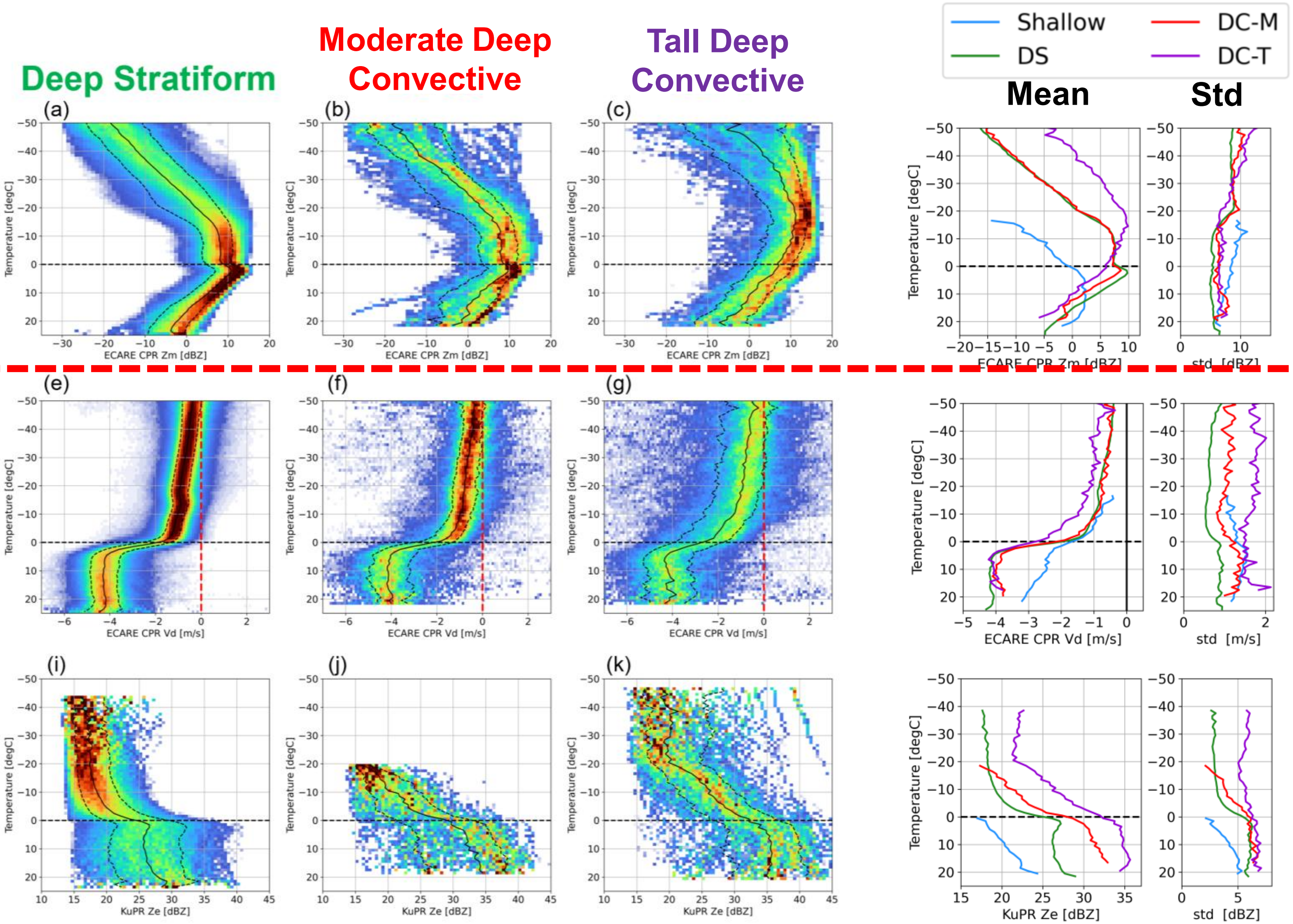
CPR W-band Reflectivity

CPR W-band Doppler velocity

DPR Ku-band Reflectivity



Zw is strongly affected by attenuation below the −10 °C level

Doppler velocity and Z_{Ku} is less affected by attenuation

We can get information on rain and heavy snow

Relationship between Z_{Ku} and Vd?

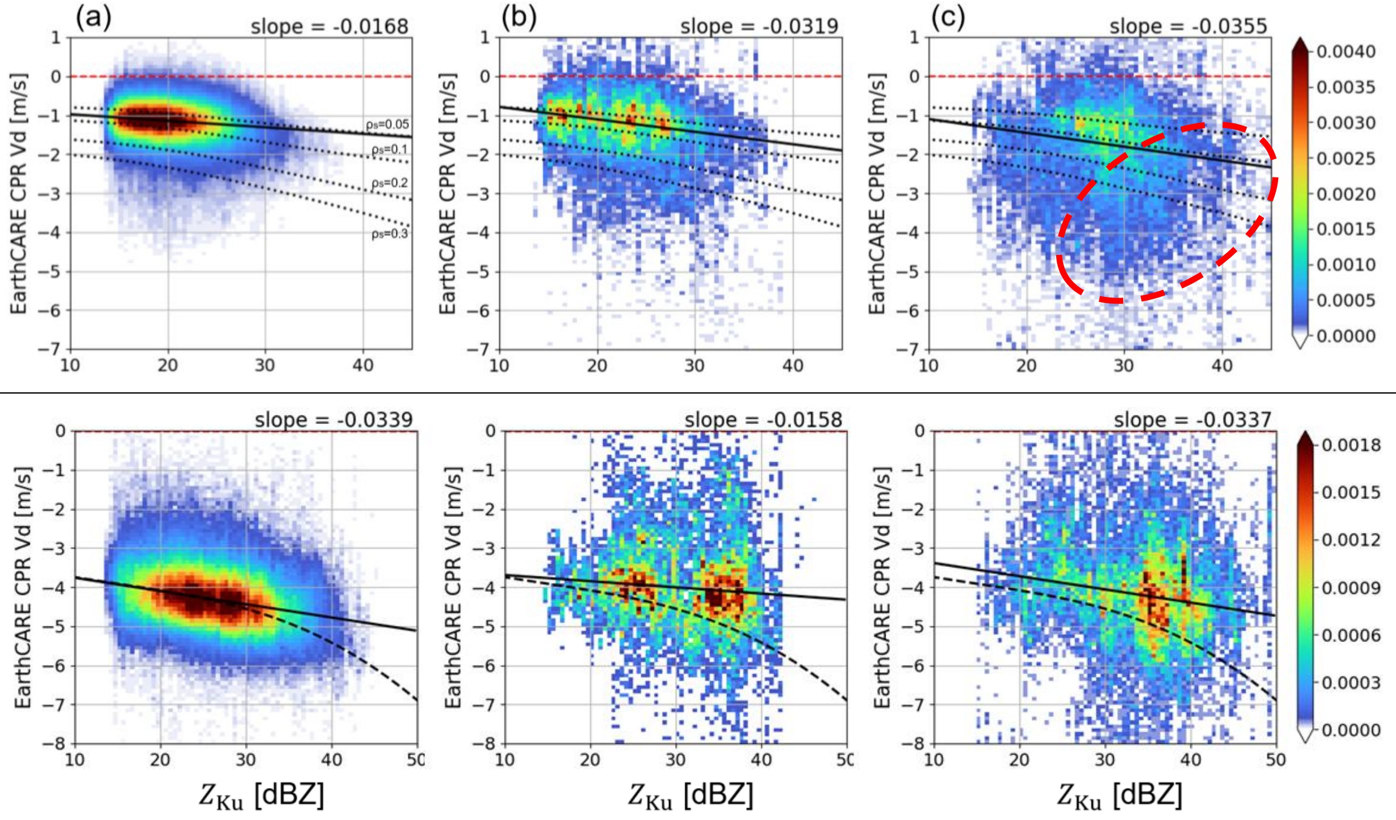
Z_{Ku} – V_d Diagrams for convective/stratiform types

- Stratiform precipitation shows a concentrated distribution.
- Convective precipitation exhibits a broader spread, indicating more turbulent vertical air motion, stronger wind shear, and greater microphysical variability.

Deep Stratiform | **Moderate Deep Convective** | **Tall Deep Convective**

Snow (−10 < *T* < 0℃)

Rain (*T* > 4℃)



Higher Z(Ku) and faster downward Vd in **Convective** than in **Stratiform**

⇒ Dense and large snow and ice particles (graupels or hails)

The Z-dependence of V_d will be further examined by comparison with the DPR-derived particle size distribution.

Calculate particle fall speed from GPM/DPR

CPR Doppler velocity $\boldsymbol{V}_{\mathbf{d}}$ is expressed as

$$\boldsymbol{V}_{\mathbf{d}} = \boldsymbol{V}_{\mathbf{air}} + \boldsymbol{V}_{\mathbf{tz}} + \boldsymbol{\varepsilon}$$

Vertical air motion ($\boldsymbol{V}_{\mathbf{air}}$)

Measurement error ($\boldsymbol{\varepsilon}$)

Reflectivity weighted terminal velocity ($\boldsymbol{V}_{\mathbf{tz}}$)

$$\boldsymbol{V}_{\mathbf{tz}} = \frac{\int \boldsymbol{v}_{\mathbf{t}}(\boldsymbol{D})\boldsymbol{N}(\boldsymbol{D})\boldsymbol{\sigma}_{\mathbf{b}}(\boldsymbol{D})\, \boldsymbol{dD}}{\int \boldsymbol{N}(\boldsymbol{D})\boldsymbol{\sigma}_{\mathbf{b}}(\boldsymbol{D})\, \boldsymbol{dD}}$$

We can calculate $\boldsymbol{V}_{\mathbf{tz}}$ from DPR L2 outputs:

In the DPR Level-2 algorithm, the drop size distribution, $N(D)$ are estimated under the assumption of a gamma distribution to derive precipitation rate from radar reflectivity.

$$N(D) = N_w f(D; D_m) = N_w \frac{6(\mu+4)^{\mu+4}}{4^4\Gamma(\mu+4)}\left(\frac{D}{D_m}\right)^{\mu} \exp\left(\frac{(\mu+4)D}{D_m}\right)$$

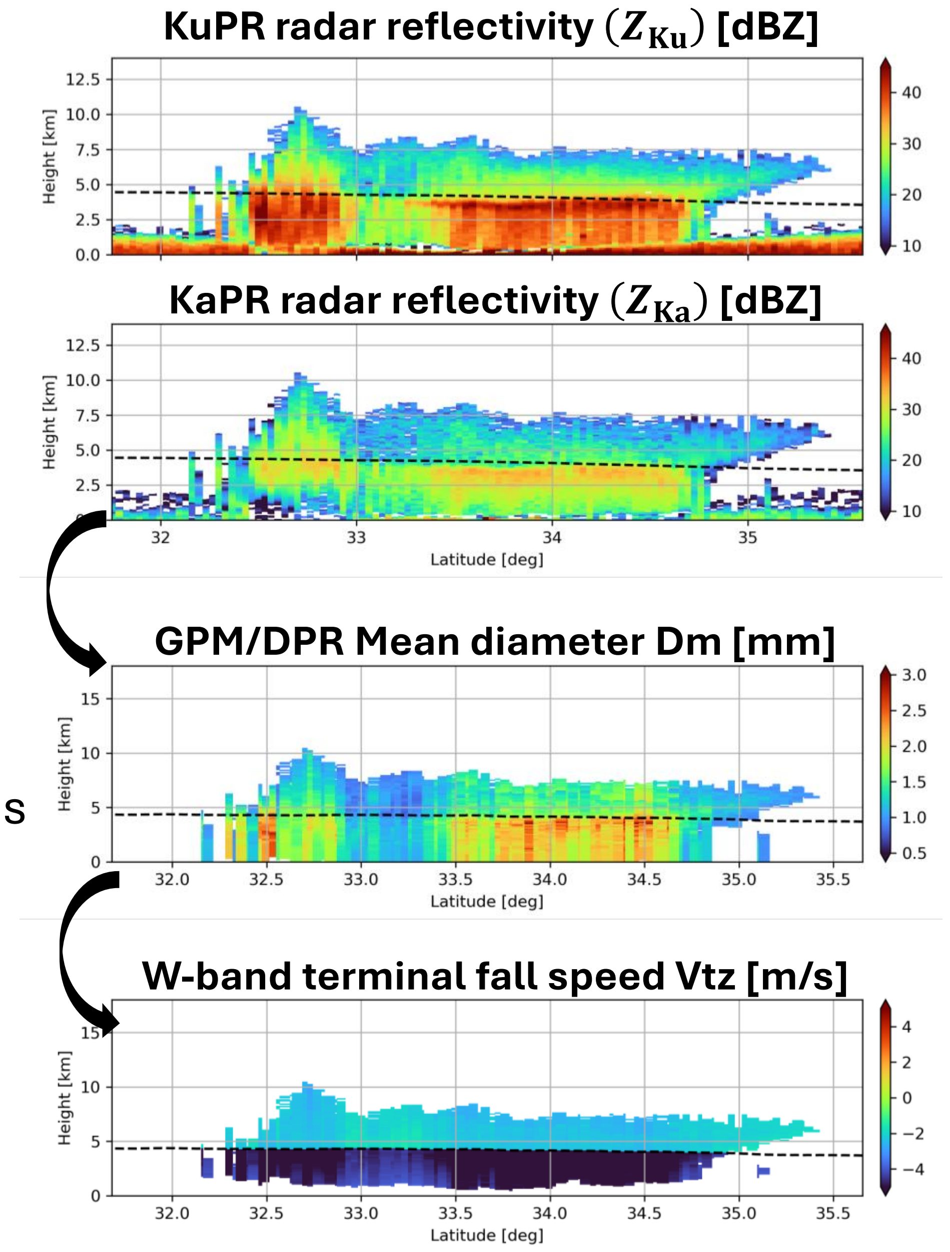
σ_b is derived from Mie scattering calculations for spherical raindrops at the W-band frequency. v_t is given by

- For rain: Atlas and Ulbrich (1977)

$$v_t(D) = -3.78D^{0.67}\sqrt{\rho_0/\rho}$$

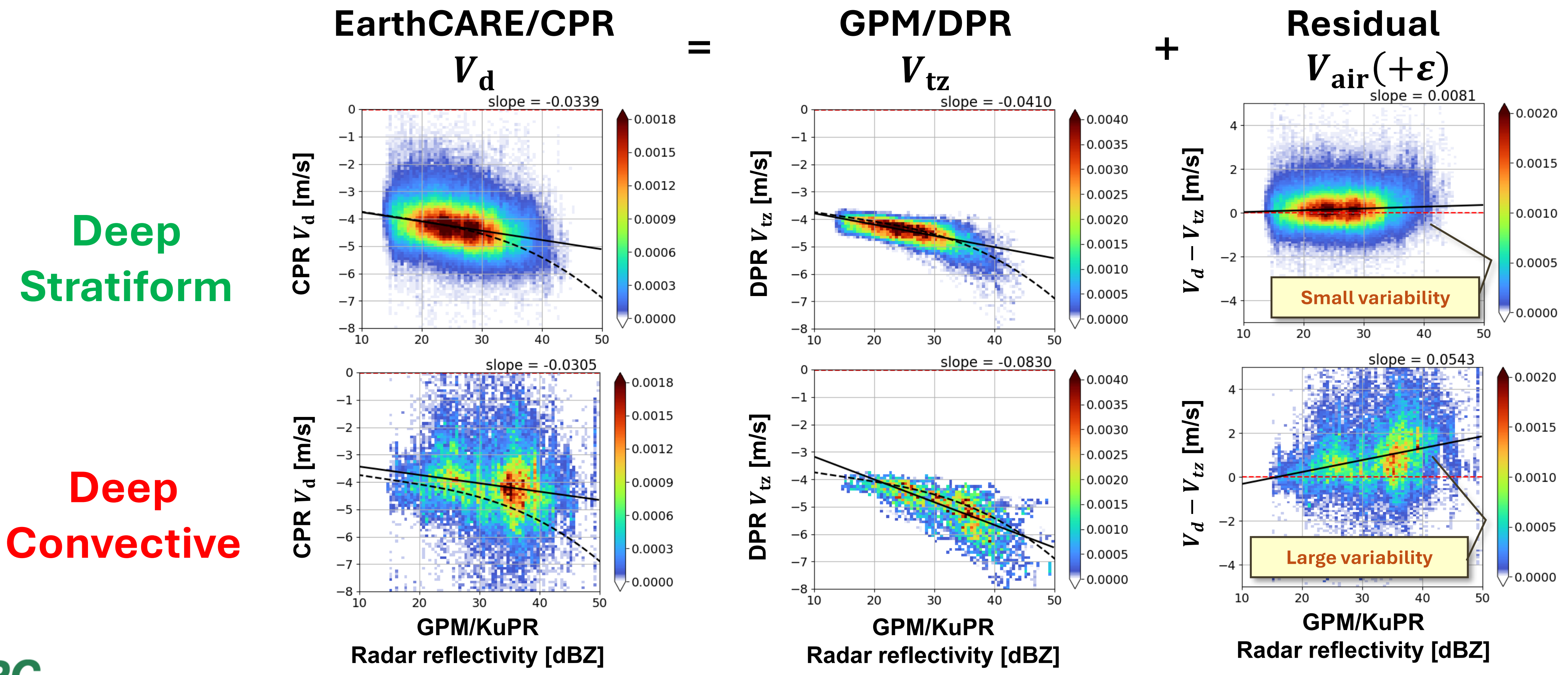
- For snow: Magono and Nakamura (1965)

$$v_t(D_s) = -8.8(0.1D_s\rho_s)^{0.5}\sqrt{\rho_0/\rho}$$



Vd and DPR-based Vtz (Rain; T>4℃)

- DPR-Vtz is broadly consistent with CPR-Vd, particularly in Deep Stratiform type.
- Variability in Vair is small in stratiform, but increases with Z in convective, consistent with the typical characteristics of stratiform and convective systems.



Future work: Linking Vair to diabatic heating

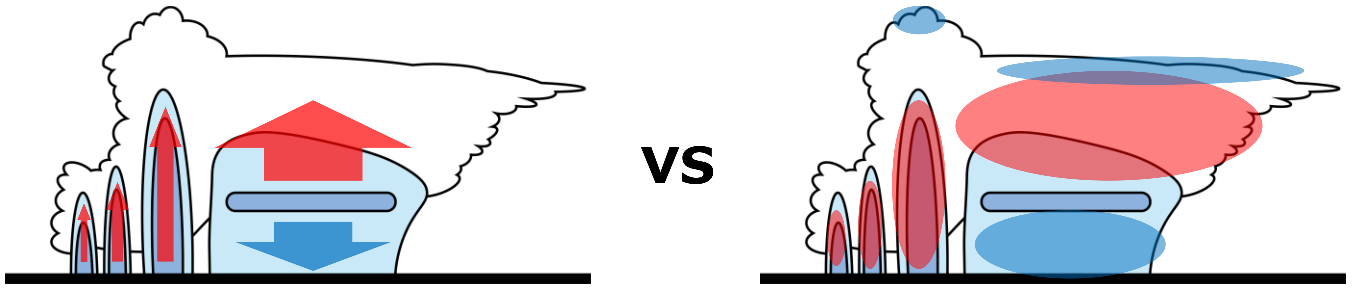
- The characteristics of Vair in stratiform and convective systems likely reflect latent heating (LH) from precipitation and radiative heating (Q_r) associated with surrounding clouds.
- Thermal budget equation in large scale (Yanai et al. 1973):

$$Q_1 \equiv \frac{\partial \bar{s}}{\partial t} + \bar{v} \cdot \nabla \bar{s} + \bar{\omega} \frac{\partial \bar{s}}{\partial p} = Q_R + LH - \nabla \cdot (\overline{s'v'}) - \frac{\partial \overline{s'w'}}{\partial p}$$

CPR Doppler Velocity

A-train/EarthCARE

TRMM/GPM SLH



- Previous GPM studies have attempted to infer latent heating from precipitation to better understand large-scale circulation (e.g. Spectral Latent Heating (SLH) product by Shige et al.).
- This raises the question of whether V_{air} ,newly available from EarthCARE, is consistent with diabatic heating estimates from GPM.

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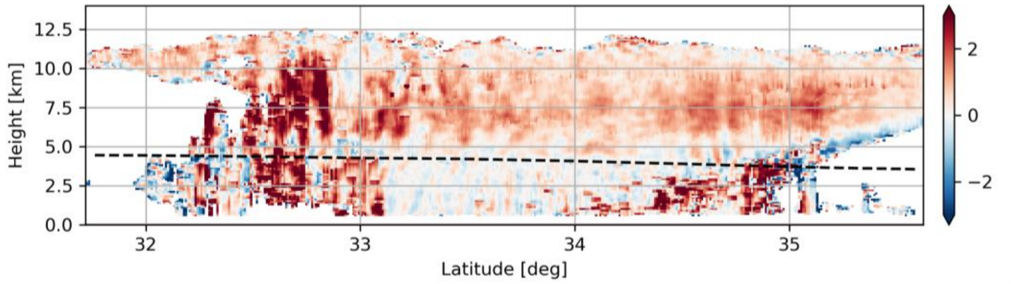
CPR Doppler Velocity ($\bar{\omega}$)

A-train/EarthCARE (Q_R)

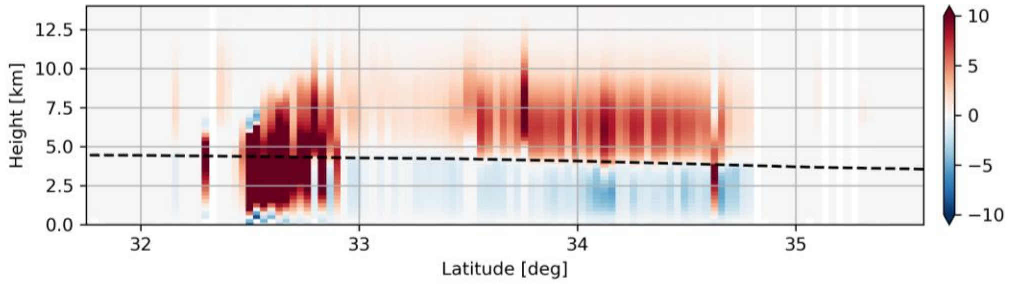
TRMM/GPM SLH ($LH - \nabla \cdot (\overline{s'v'}) - \frac{\partial \overline{s'w'}}{\partial p}$)

Vertical air motion (AC_CLP) [m/s]



VS

Latent heating rate (GPM/SLH) [K/h]



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- This raises the question of whether V_air ,newly available from EarthCARE, is consistent with diabatic heating estimates from GPM. →More in EGU26 and EarthCARE Workshop at Oxford.

Summary

- We investigated the vertical motions inside stratiform and convective precipitation systems by using the coincidence dataset of the EarthCARE/CPR and the GPM/DPR.

- The Vd from CPR enable us to obtain fall speed information even in rain and heavy snowfall layers where CloudSat's reflectivity-only observations suffered from attenuation.
- By combining Vd with DPR, we demonstrate the potential to retrieve particle properties and vertical air motion.

- The synergy between EarthCARE and GPM is expected to provide new insight into the global characteristics of vertical motion in clouds and precipitation.

Thank you!

Email: aoki.shunsuke [at] jaxa.jp