Evaluation of cloud microphysics on MIROC6 utilizing Doppler CPR observation

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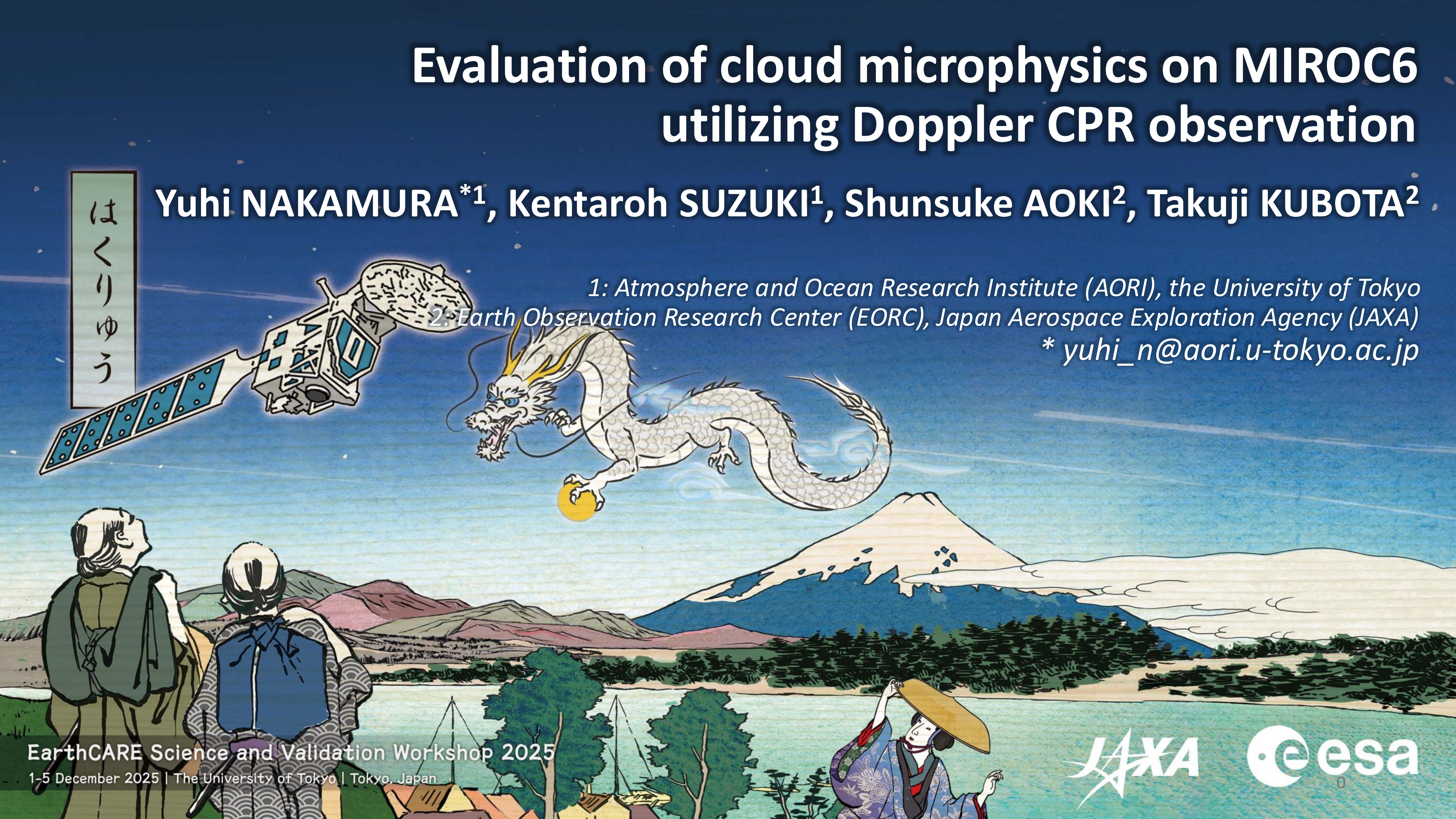


Doppler velocity by EarthCARE, and its component

- Doppler velocity v_d is net vertical motion weighted by radar backscatter.
- net vertical motion
  $=$ vertical air motion w + droplet fall velocity v_f
- The dynamics of cloud/precipitation can be observed more directly.

size distribution

fall velocity

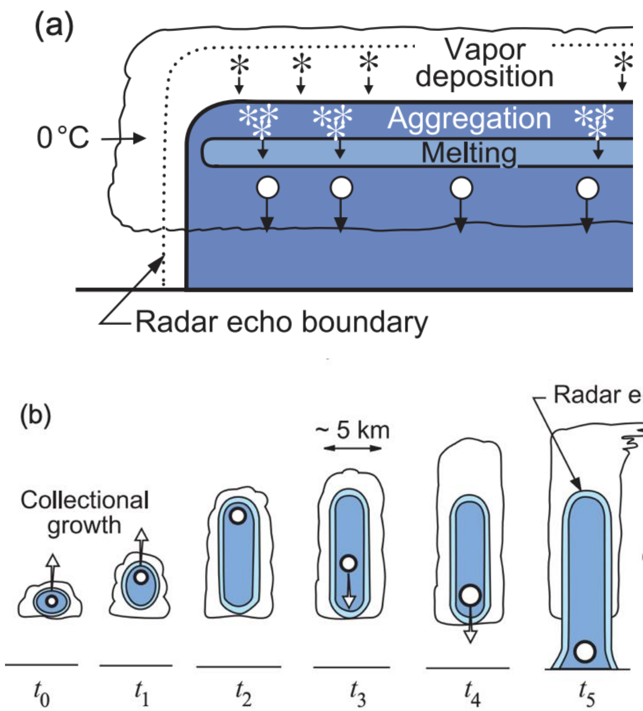
$$v_d = w + \frac{\int_{r_{\min}}^{r_{\max}} dn(r)/dr \cdot C_{\mathrm{bk}}(r)\, v_f(r)\, dr}{\int_{r_{\min}}^{r_{\max}} dn(r)/dr \cdot C_{\mathrm{bk}}(r)\, dr},$$

vertical air motion

radar reflectivity factor

The role of w and v_f depends on by cloud type.

	Observation	GCM
stratiform	**cirrus/stratus/nimbostratus**	**large-scale condensation**
	cloud droplet growth while falling (v_f) mesoscale / turbulence (w)	cloud microphysics (v_f) falling of cloud/rain droplet
convective	**cumulus/cumulonimbus**	**cumulus parameterization**
	cumulus updraft (w) raindrop/graupel fall (v_f)	cumulus updraft (w) diagnosed by instability



Current issues and potential contributions to GCMs

Stratiform clouds:

- Droplet fall velocity v_f was often considered as a tuning parameter.
  v_f strongly affects the performance of GCM.
  → Risk of a physically meaningless setting

✓ New Doppler observation is expected to constrain GCMs.

Convective clouds:

- Observations of cumulus mass flux itself were very limited.
  → Conceptual assumptions are employed.

✓ Quantitative estimation would be provided by Doppler velocity.

1. **Develop a new simulator for Doppler velocity on COSP2 for GCMs.**
2. **Compare GCM with observation and estimate droplet fall velocity.**
3. **Further discussion on potential impact of droplet fall velocity constraint by EarthCARE Doppler velocity on climate modeling.**

Satellite observation

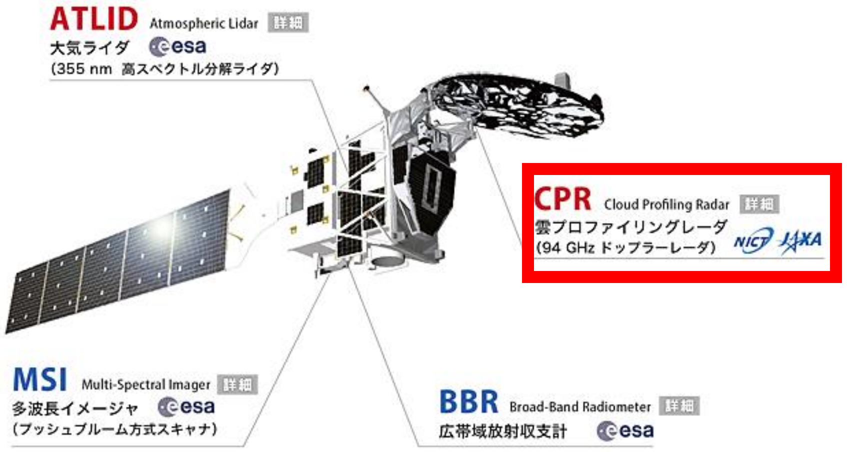
EarthCARE L2

from MAR to SEP 2025

- **CPR-CLP: vBa, vBb**

  Z_e, v_d with our cloud classification
  v_d: 1km-integrated, bias_corrected, unfolded
  T: air temperature

Available at JAXA G-Portal
https://gportal.jaxa.jp/gpr/index/index?lang=en



GCM setup

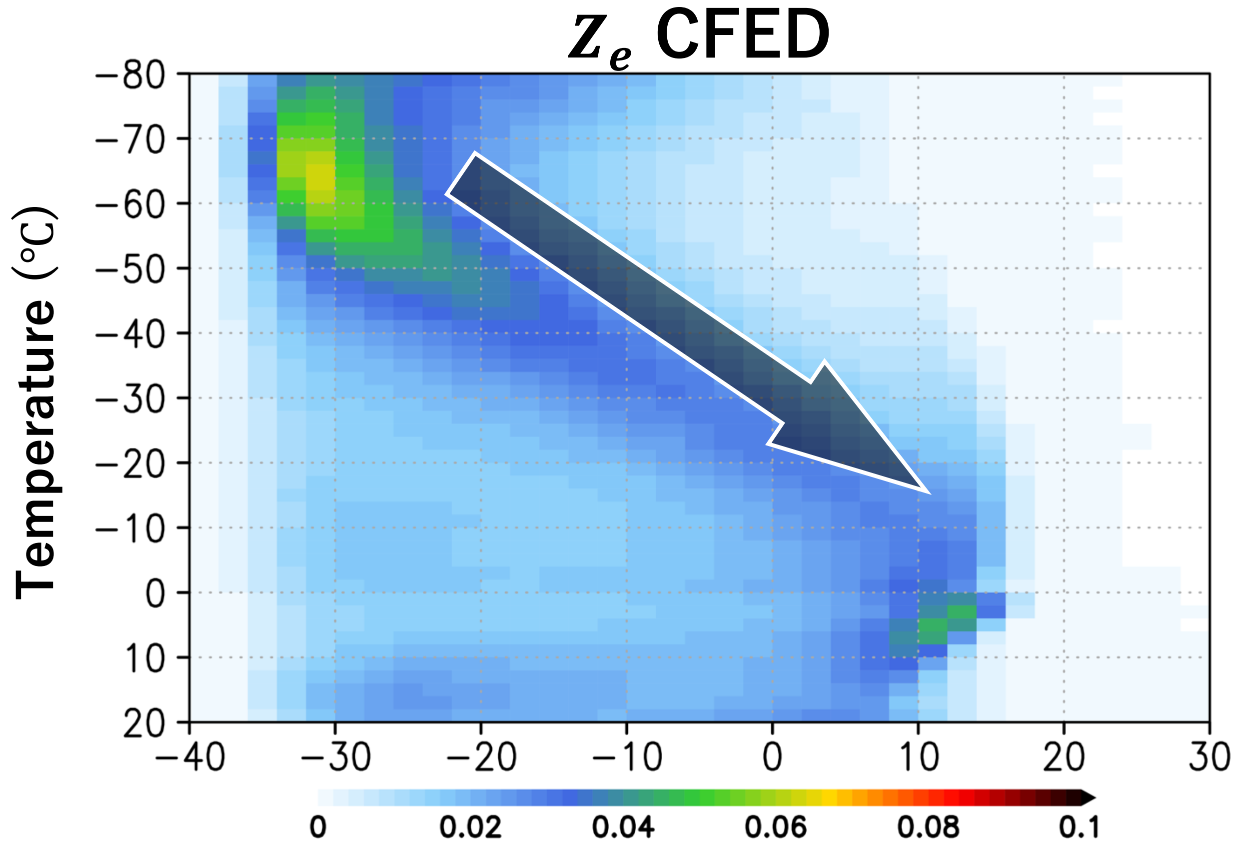
MIROC6 (Tatebe et al. 2019; *GMD*)

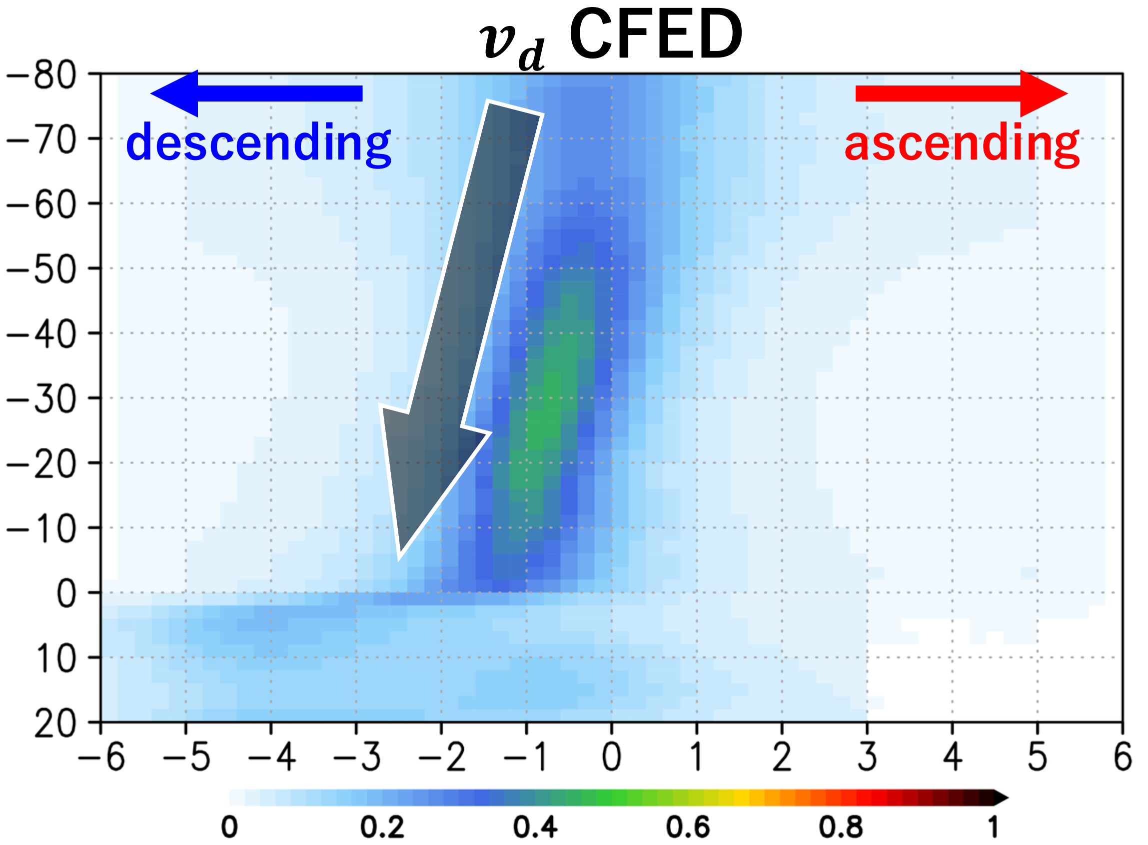
- <u>Prognostic precipitation scheme</u>
  (Michibata et al. 2019; *JAMES*)
  2-moment bulk scheme
  <u>explicit representation of falling particles</u>;
  cloud ice, snowflake, and raindrop
- about 1.4 deg resolution (t85 l40h)
- <u>**MAR-SEP 2025**</u>
  - 7-month run
  - ✓ corresponding period to EarthCARE

COSP2 (Swales et al. 2018; *GMD*)

- CFMIP Observation Simulator Package
- <u>**New Doppler simulator** is implemented.</u>
- Little sensitivity to number of subcolumns

Global statistics of EarthCARE Z_e and v_d





Above the melting level:

Z_e increase and v_d decrease → ice particle growth

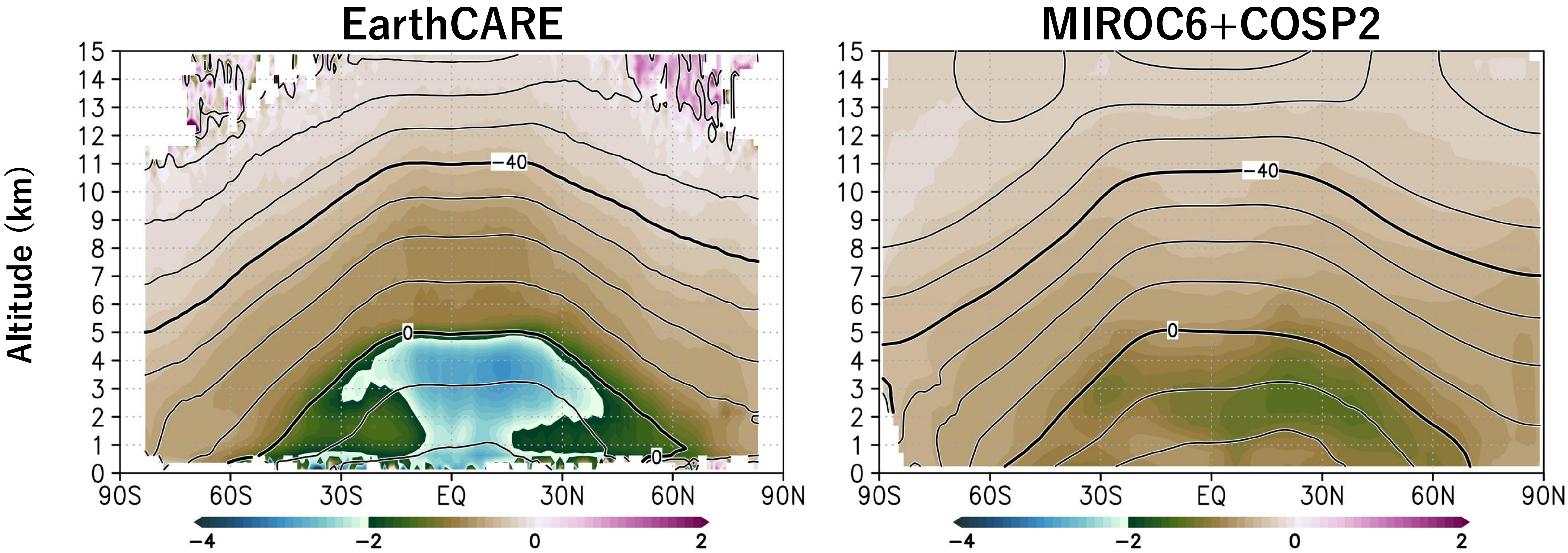
Below the melting level:

two Z_e regimes: raindrop and non-precipitating

clear gap of v_d: slow falling snow / fast falling raindrop

mixture signal among various clouds
precipitating / non-precipitating
stratiform / convective

Comparison of v_d zonal mean



Above the melting level:

Slightly underestimated, especially in Tropics

Below the melting level:

Significantly underestimated: too much drizzle

What kind of cloud is causing this bias?

- Different schemes in GCMs
- Different cloud regimes observed

✓ **mainly due to Stratiform clouds** because of large fraction

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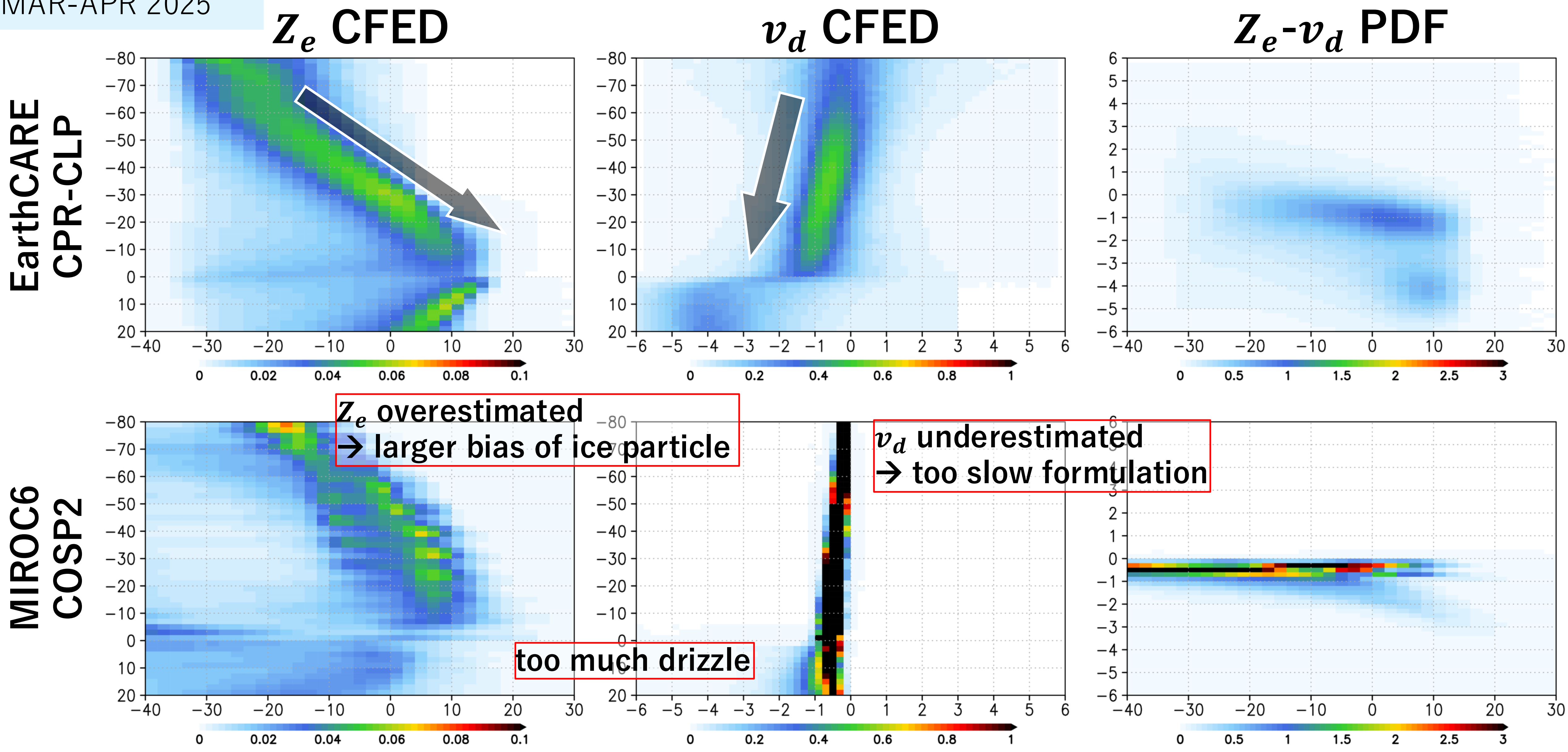
20S-20N
MAR-APR 2025

Comparison of stratiform clouds



Tuning of v_f formulation based on EarthCARE

In Rayleigh scattering limit,

$$v_d = \cancel{w} - \frac{\int v_f(D)\, D^6\, n(D)\, dD}{\int D^6\, n(D)\, dD}$$

w is weak in stratiform cloud

$$Z_e = \int D^6\, n(D)\, dD$$

- **v_f formulation in MIROC6**

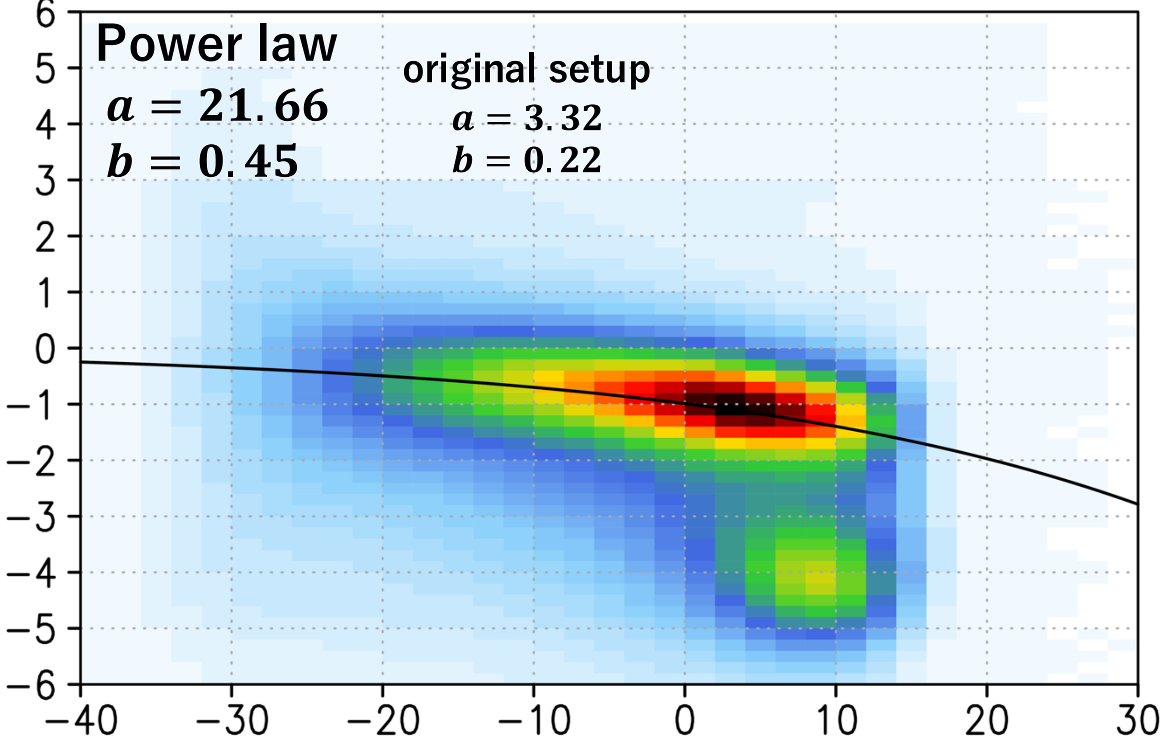
  2 types functions of droplet diameter

  1. **Power law: aD^b**
  2. **PL08: $b_1 - b_2 \exp(-b_3 D) + (b_2 - b_1)\exp(-5 b_3 D)$**

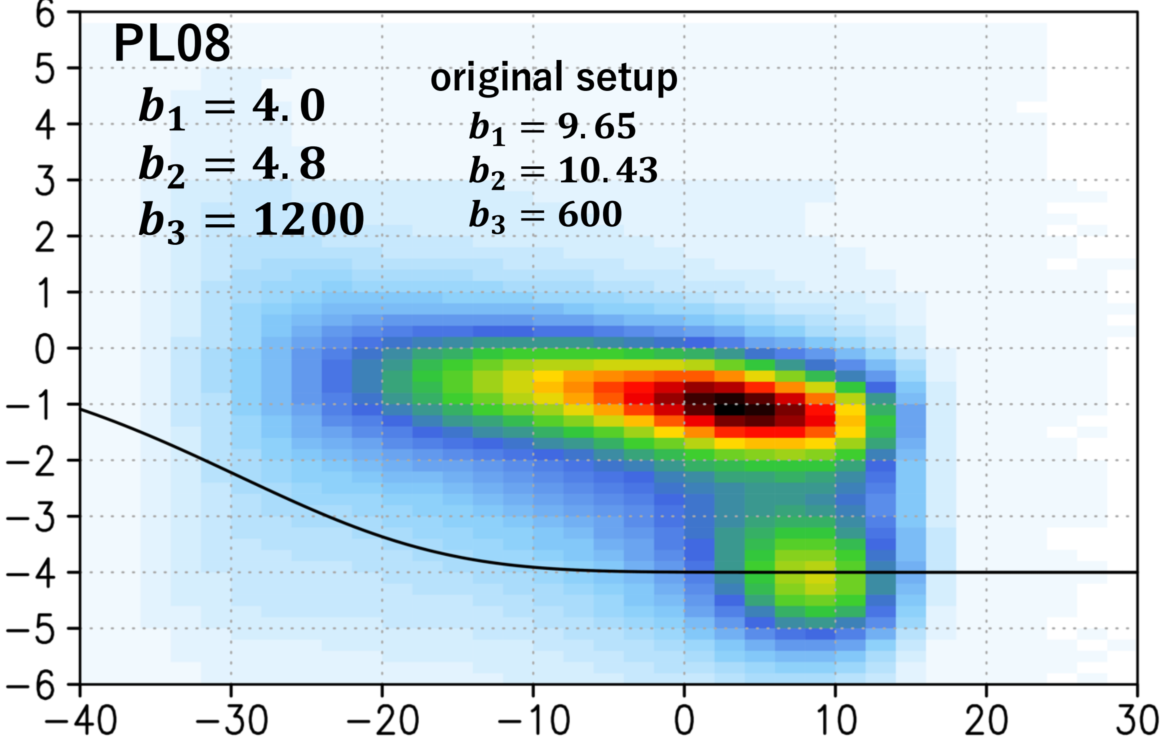
  Posselt and Lohmann (2008; *ACP*)

→ Z_e-v_d relation to estimate parameters

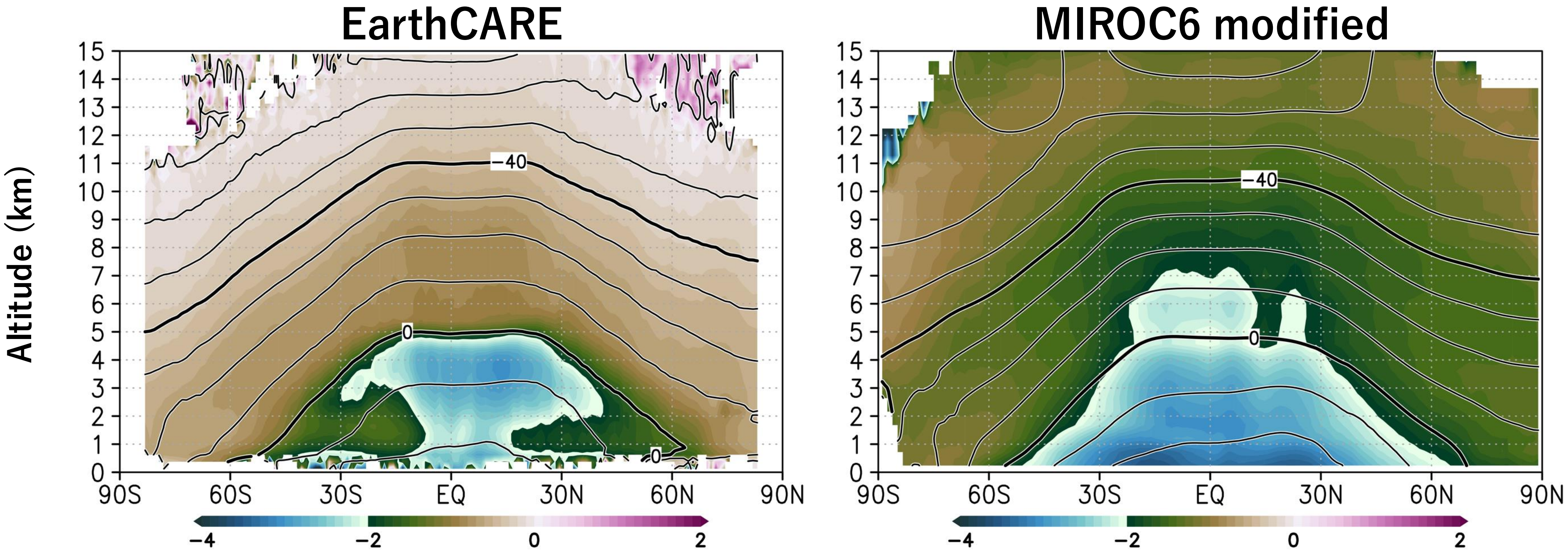
for clouds



for rain



v_f modified results: zonal mean v_d

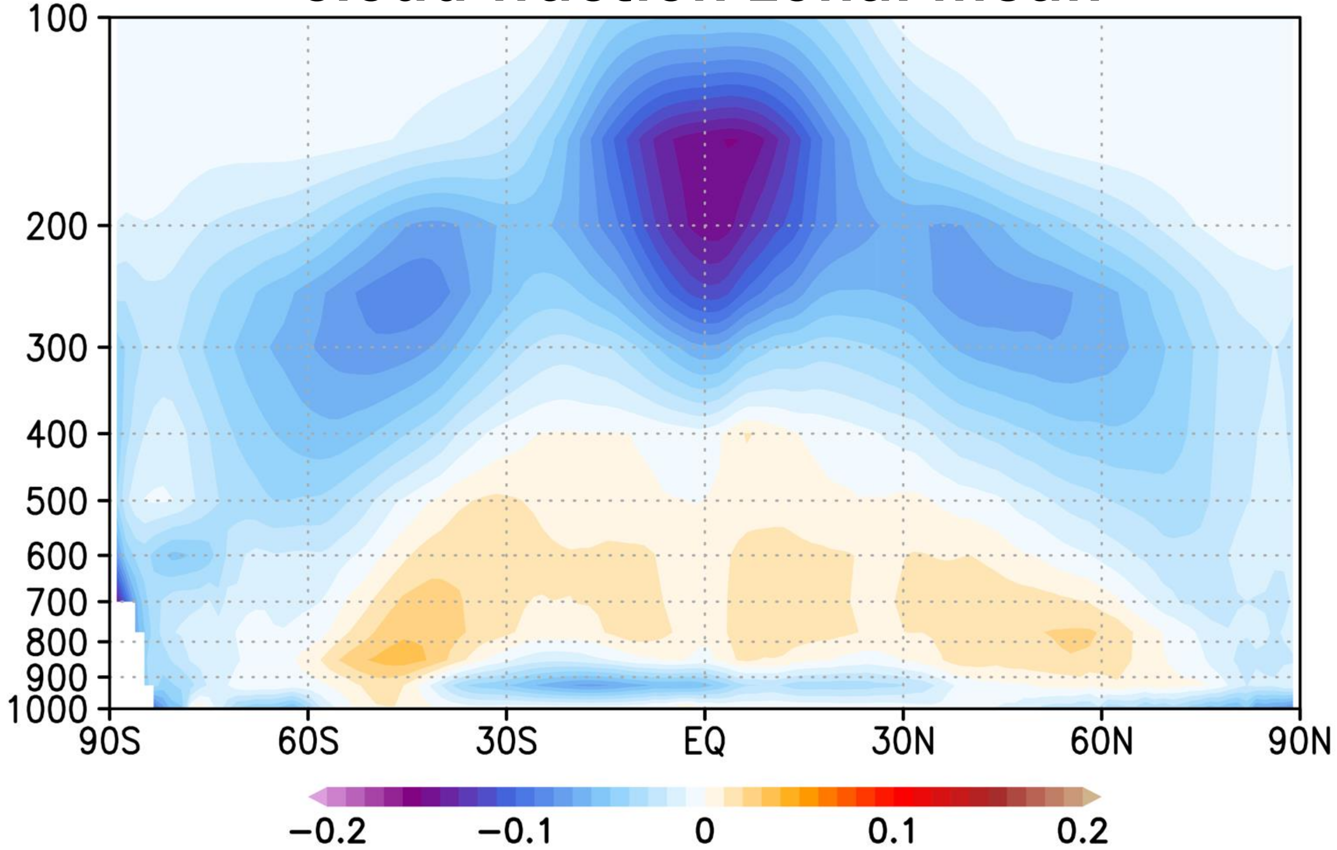


- Signals of rain particles **below the melting level are improved**.
- Fall speed of **ice particles is overestimated** (although parameters are modified).
  → **Droplet size is also biased**.

Changes v_f params based on EarthCARE does not improve MIROC6.

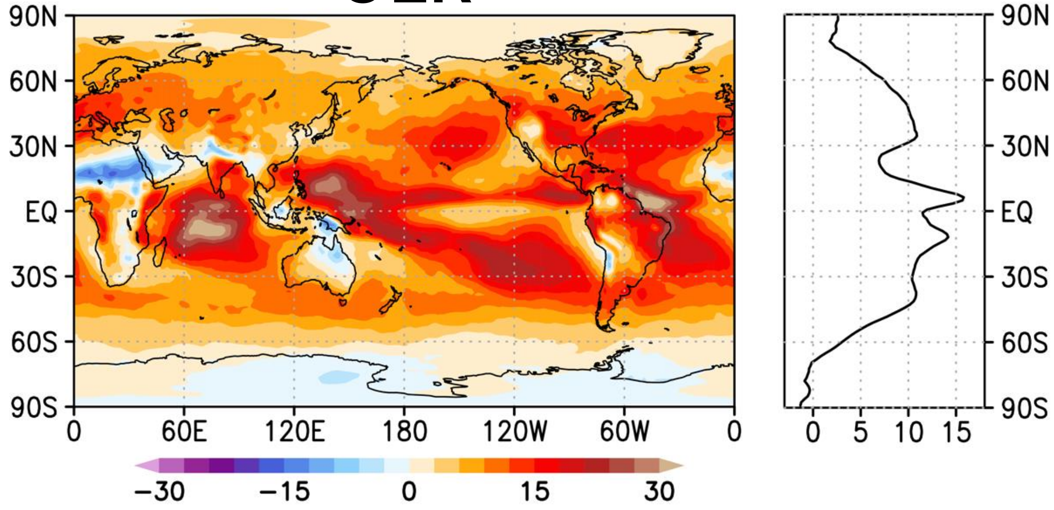
Impact on climate of v_d modification

cloud fraction zonal mean

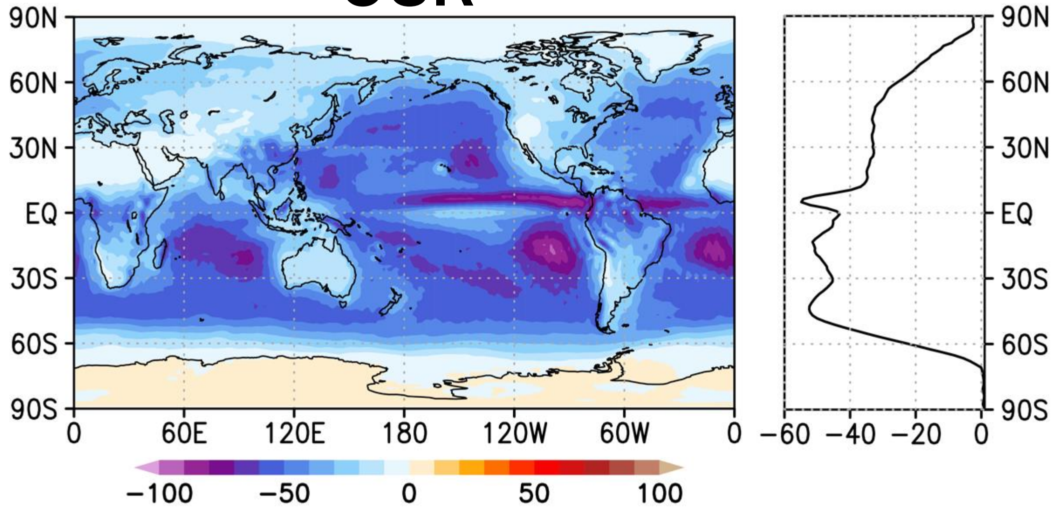


Long-term run, mean of 10-14th year
Anomalies of tuned run from control run

OLR



OSR



- Upper-cloud is reduced: due to faster fall speed.
- Lower-cloud slightly increases.
- Radiative budget is strongly perturbed.

cloud and radiation strongly modified

There might be some error compensation factors.

Summary

1. New simulator for doppler velocity is developed on COSP2

- Droplet fall velocity and vertical air motion are newly handled.

2. Distribution of v_d in MIROC6 is not good, actually

- MIROC6 underestimates v_d, and overestimates Z_e.
- Simply adjusting the parameters does not achieve agreement with the observation.
- Although MIROC6 has good performance on reproducibility of present climate state.
- Vertical Doppler velocity is new constraint factor to refine microphysics modules.

➢ As a next step ..

1. Investigate hidden error compensation factor

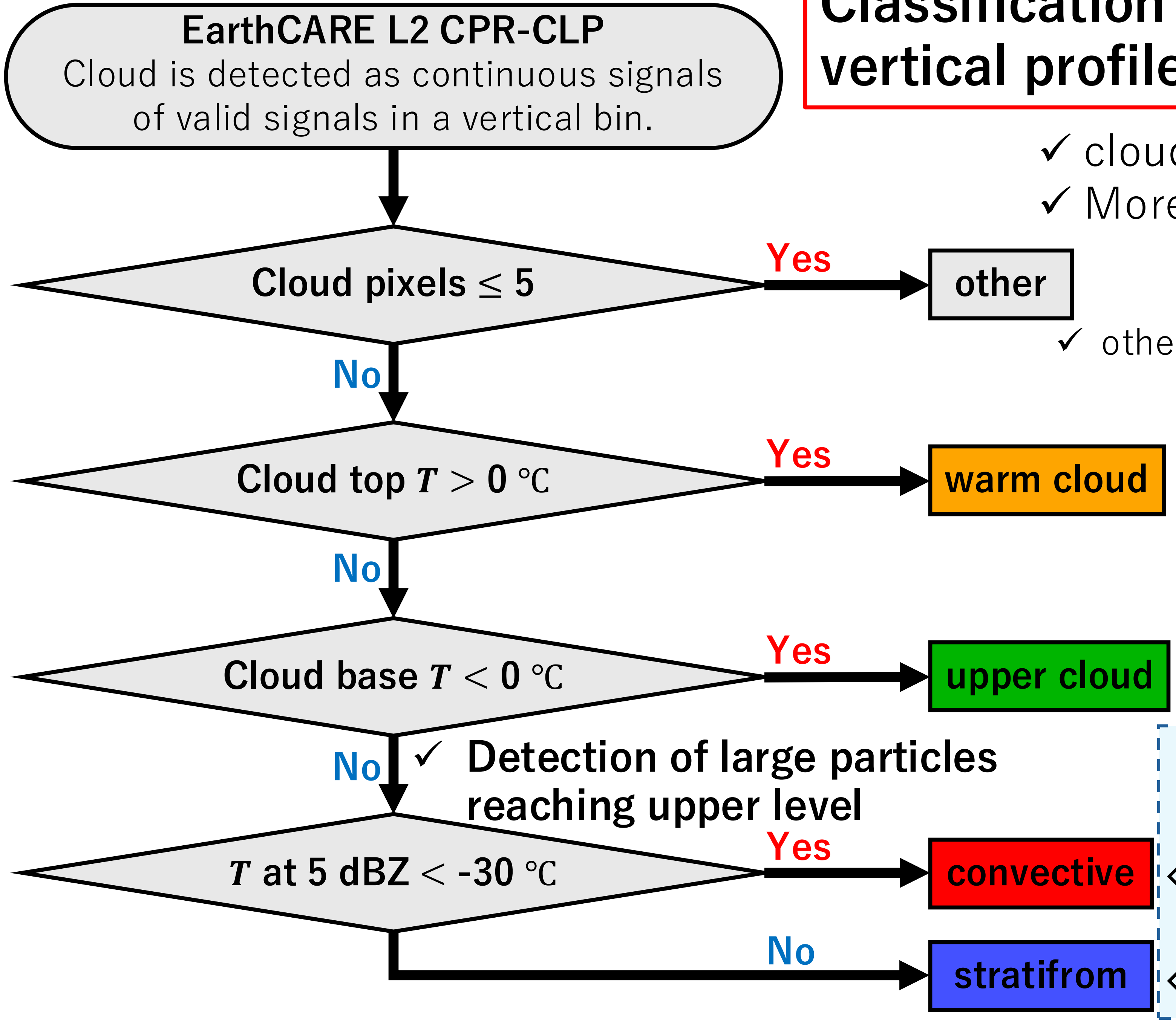
- Impact on climate state of v_f modification
- For good results by good reasons

2. Update cumulus parameterization in GCMs

- Separate retrieval of vertical motion from droplet fall velocity

Classification based on vertical profile of Z_e

✓ cloud mask ≥ 20
✓ More than 500 m above ground surface



✓ other type is excluded from statistics

✓ Detection of large particles reaching upper level

Corresponding schemes of GCMs

⇔ Cumulus parameterization scheme

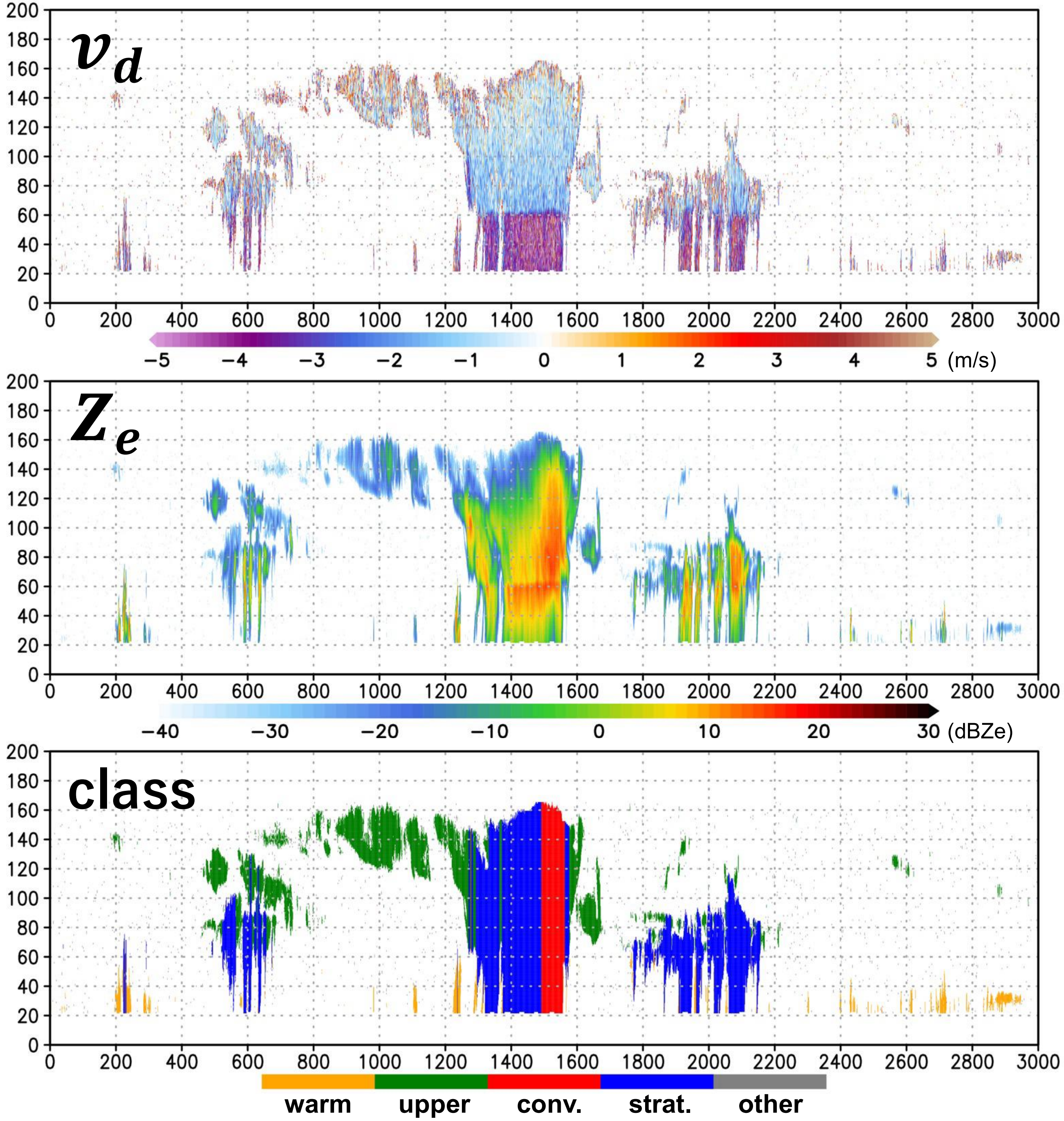
⇔ Large-scale condensation scheme

Example of EarthCARE observation

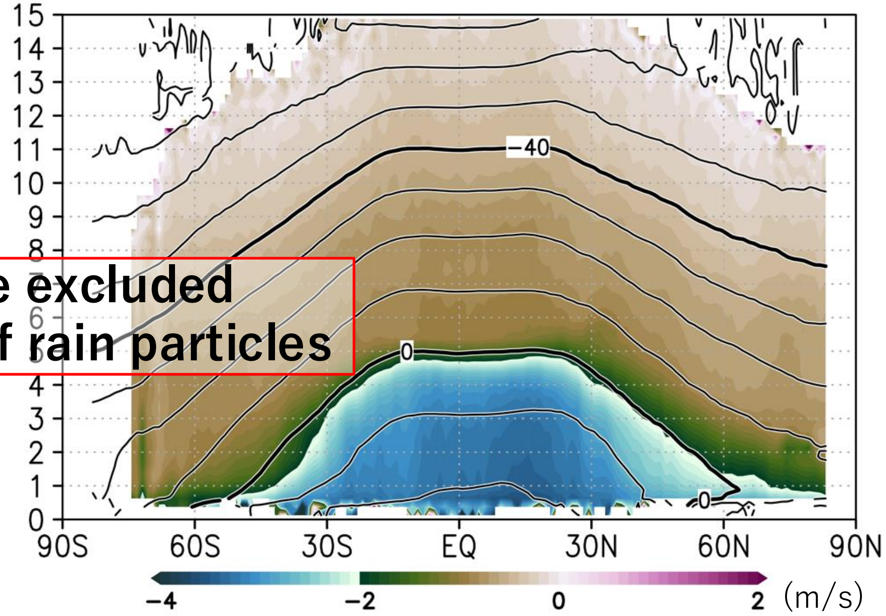
EarthCARE L2a CPR-ECO 04771A
X-axis: number of ray
Y-axis: number of bin

v_d: 1km-integrated, bias-corrected

- Sharp increase of Z_e, corresponding to bright band
- Rapid increase of v_d due to melting of snowflake to raindrop

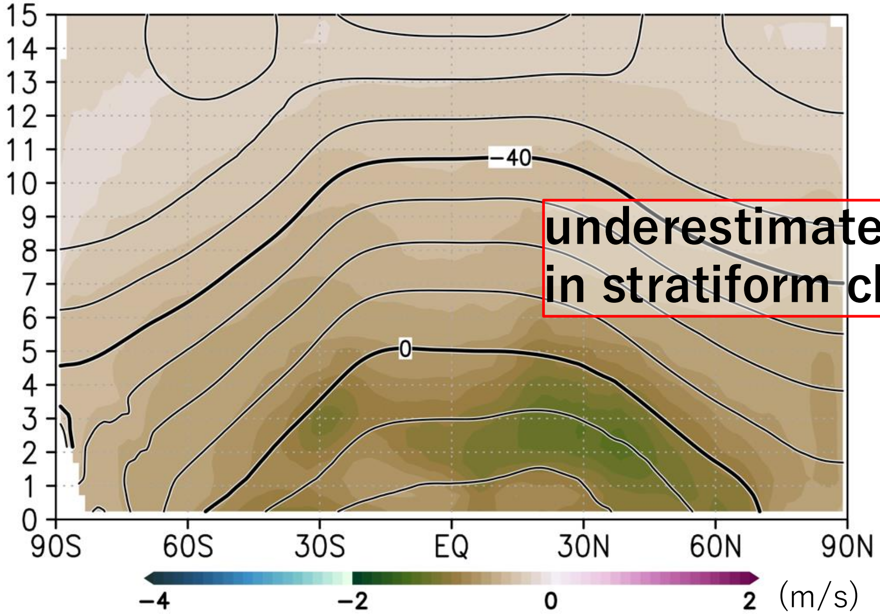


EarthCARE stratiform



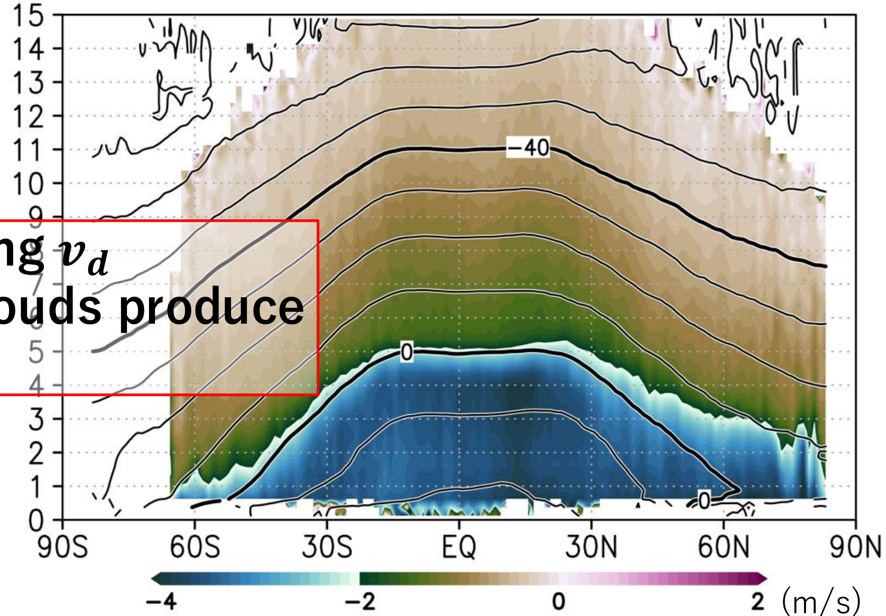
warm clouds are excluded
→ clear signal of rain particles

MIROC6 stratiform



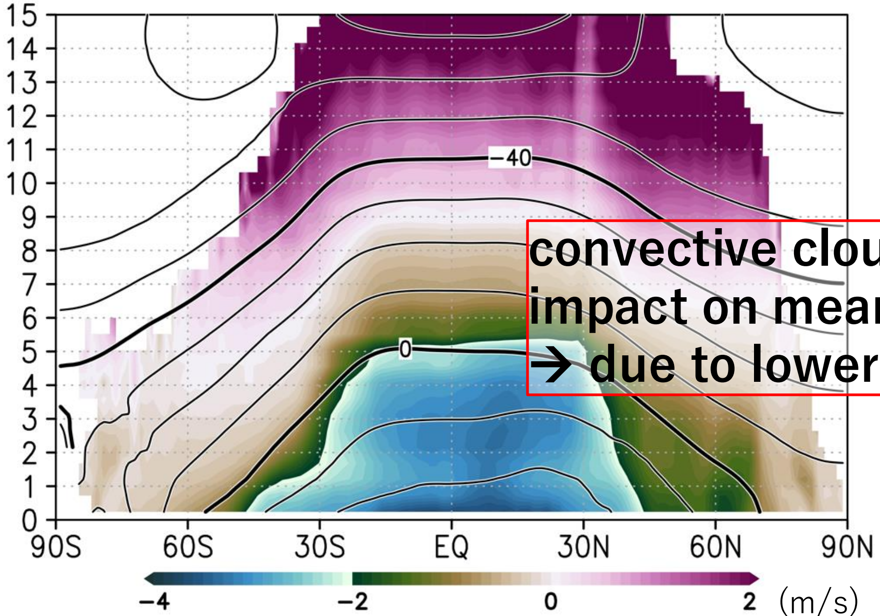
underestimated v_d is found
in stratiform clouds

EarthCARE convective



faster descending v_d
→ convective clouds produce
more heavy rain

MIRCO6 convective



convective clouds have small
impact on mean state
→ due to lower cloud fraction

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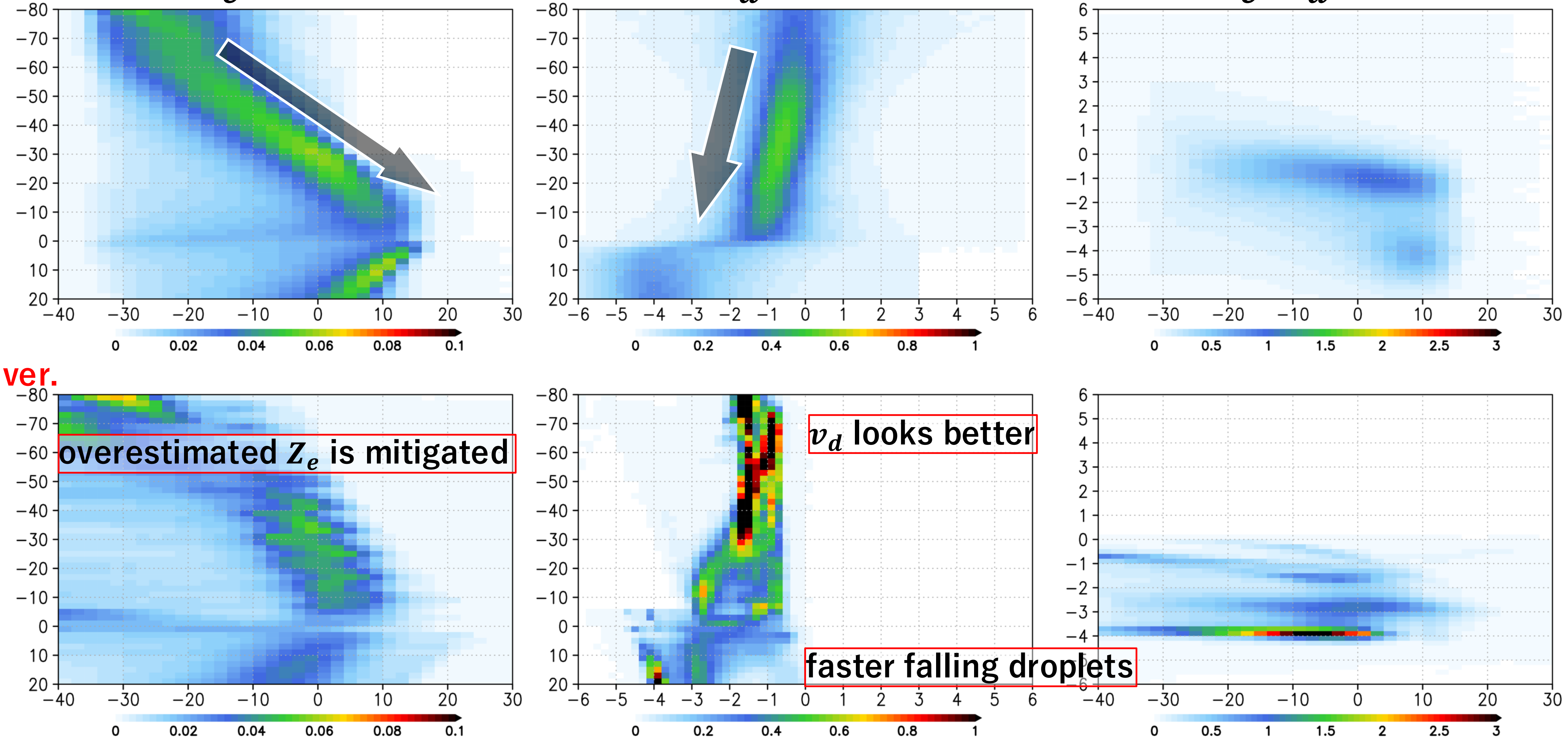
v_f tuning results: CFED analysis

Z_e CFED | v_d CFED | Z_e-v_d PDF

EarthCARE CPR-CLP

tuned ver.

MIROC6 COSP2



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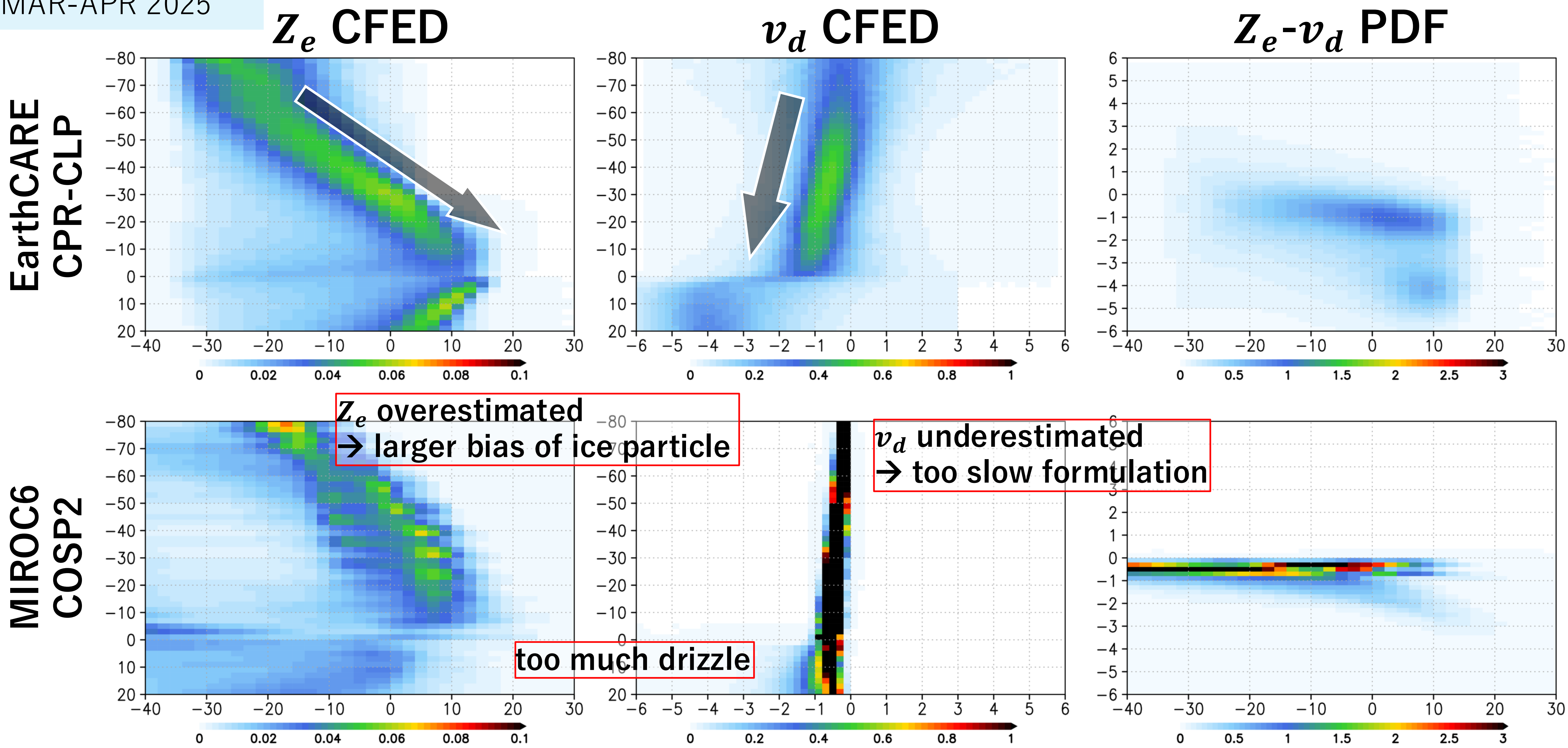
Comparison of stratiform clouds



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Comparison of convective clouds