ESA-JAXA Pre-Launch EarthCARE
Science and Validation Workshop
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# Development of a new simulator on COSP2 for vertical doppler velocity of EarthCARE CPR

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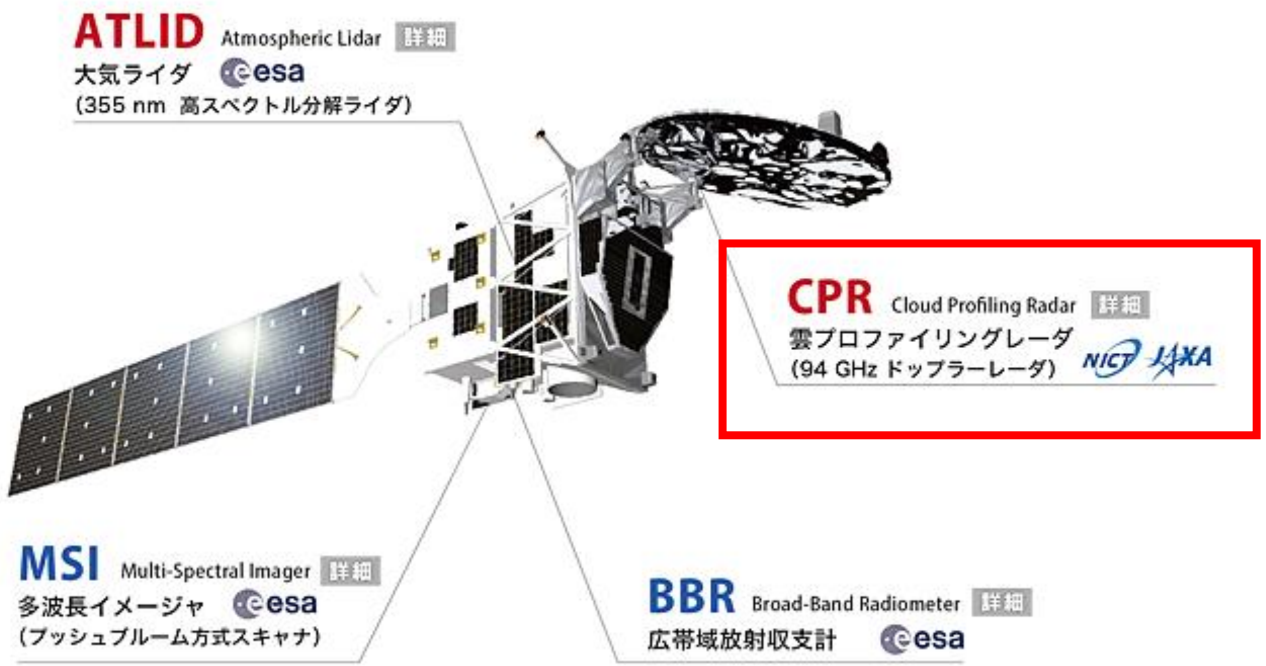
**See also Poster #11**

# Newer observation by EarthCARE CPR and satellite simulator on COSP2




Picture from JAXA webpage (14 Nov. 2022 browsed)
https://www.eorc.jaxa.jp/EARTHCARE/about/hardware_j.html

- **Higher sensitivity than CloudSat**
- **Doppler velocity observation**
  **→ Dynamics of cloud microphysics**

size distribution | back scatter | fall velocity

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

vertical air motion

radar reflectivity factor

- **Retrieval formulation**
- **What is needed for the new simulator…**
  **→ droplet fall velocity**
  **→ vertical air motion**
- For size distribution and back scatter, use codes already implemented in COSP2.

# Contributions to climate models expected from new doppler velocity observation

- Droplet fall velocity was often considered as a tuning parameter.
  It affected the performance of models, both GCMs and CRMs.
  → Risk of a physically meaningless setting.

✓ New observation is expected to constraint the fall velocity of microphysics.

- Observations of cumulus mass flux itself were very limited.

✓ Quantitative estimation will be provided by EarthCARE doppler velocity.
  → But CPR attenuation would be a difficult issue…

To maximize these benefits from EarthCARE,
it is necessary to ensure a basis for comparing models with observation.

1. **To develop a new simulator for doppler velocity on COSP2.**
2. **To compare ground-based doppler radar and GCM.**
3. **Further discussion of an impact for climate from droplet fall velocity and use of doppler velocity statistics.**

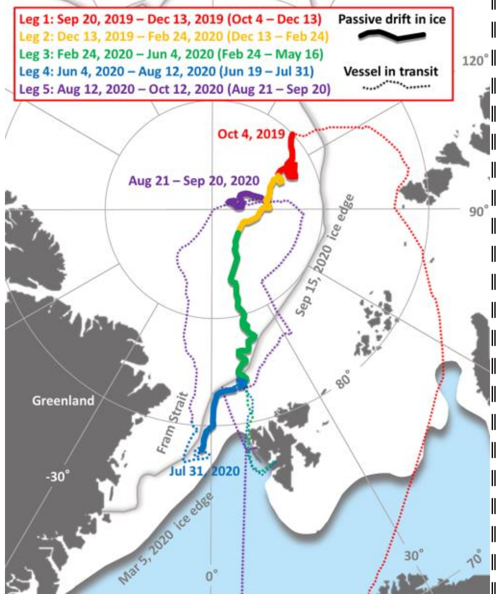
# Ground-based radar

## 1. NICT

(National Institute of Information and Communications Technology)
provided by Horie-san (NICT).
In Koganei City, Tokyo. (30km west of Senso-ji temple, Asakusa)


## 2. MOSAiC

(Multidisciplinary drifting Observatory for the Study of Arctic Climate)
details: [https://mosaic-expedition.org](https://mosaic-expedition.org)
provided by ARM, ship-borne
drifting on sea ice in Arctic Sea




Both datasets are
**in Aug. 2020.**

# GCM setup

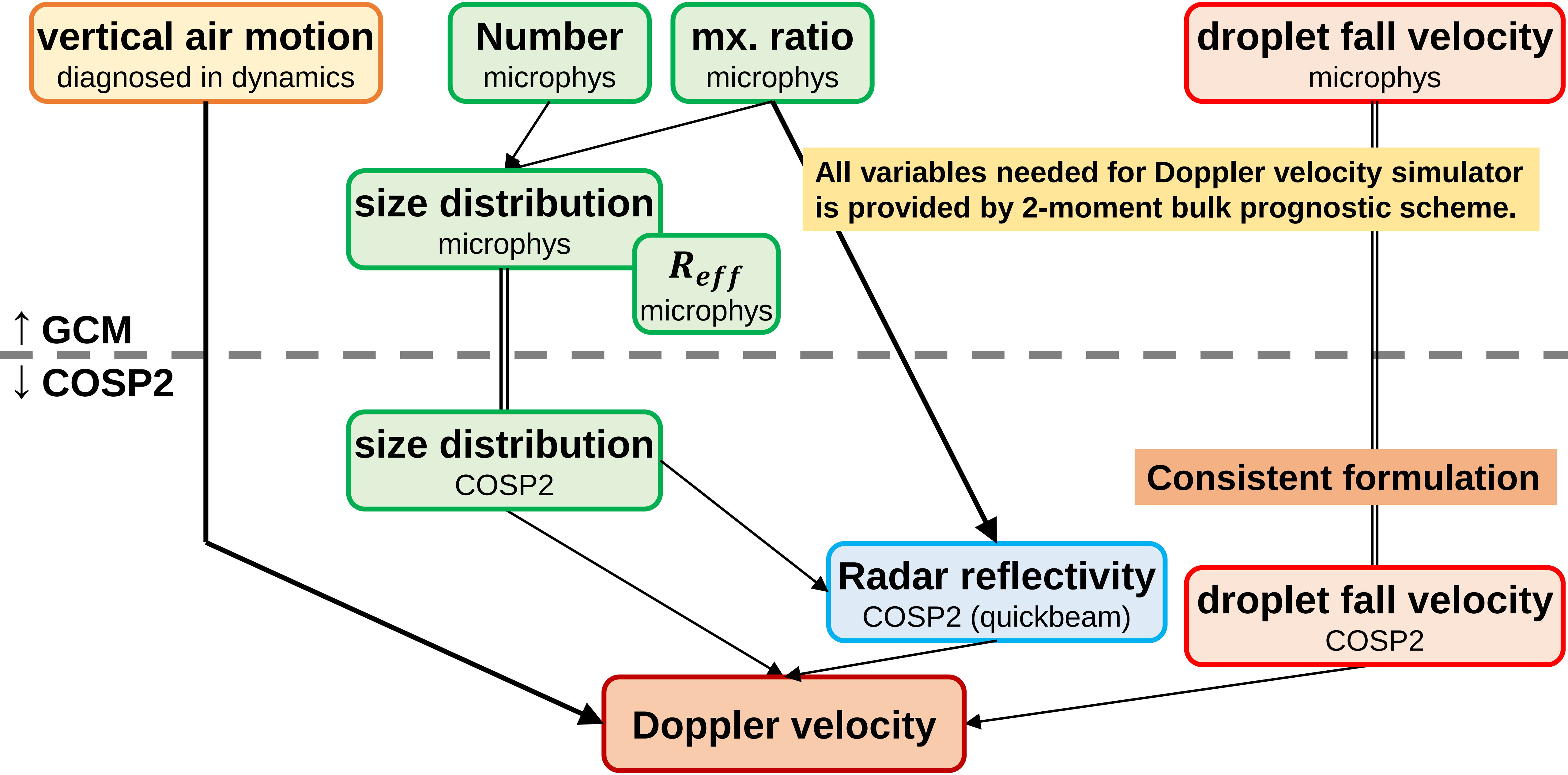
## MIROC6 (Tatebe et al. 2019; *GMD*)

- Prognostic precipitation scheme
  (Michibata et al. 2019; *JAMES*)
  This bulk scheme prognoses mass and number of falling hydrometeors: cloud, rain, and snow.
- about 100 km resolution (t85 l40h)
- **JJA 2020**
  - ✓ 5×5 grids centered on Tokyo (NICT)
  - ✓ 30W-20E, 75N-88N (MOSAiC)

## COSP2

- CFMIP Observation Simulator Package
- Doppler velocity simulator is developed.
- #subcolumn = 140

# Simulator design: prognostic precipitation scheme



# Construction of droplet fall velocity $v_f$

$$v_f = \text{viscous drag} \times \text{formulation}$$

- **viscous drag**
  The higher the air density, the greater the viscous drag and the slower the fall speed.
  $\sqrt{\rho_0/\rho}$: Square root of the ratio of air density $\rho$ to the standard value ($\rho_0$; 1013 hPa, 0℃)
  on/off switchable

- **formulation**
  2 types of functions of droplet diameter $D$ for $v_f$ formulation
  1. **Power law: $aD^b$**
  2. **PL08: $b_1 - b_2\exp(-b_3 D) + (b_2 - b_1)\exp(-5b_3 D)$**
     Posselt and Lohmann (2008; *ACP*)

| **ctrl** | **large-scale condensation** | | | | | **cumulus convection** | | | |
|---|---|---|---|---|---|---|---|---|---|
| droplet | cloud liq. | cloud ice | rain | snow | graupel | cloud liq. | cloud ice | rain | snow |
| viscous drag | × | × | × | × | × | × | × | ○ | ○ |
| PL08 | ○ | × | ○ | × | × | ○ | × | × | × |
| Power law; $a$ | - | 1.107 | - | 3.321 | 19.3 | - | 1.107 | 842 | 4.84 |
| Power law; $b$ | - | 0.22 | - | 0.22 | 0.37 | - | 0.22 | 0.8 | 0.25 |

**PL08: $b_1 = 9.65, b_2 = 10.43, b_3 = 600$**

# Comparison between NICT obs. and MIROC6

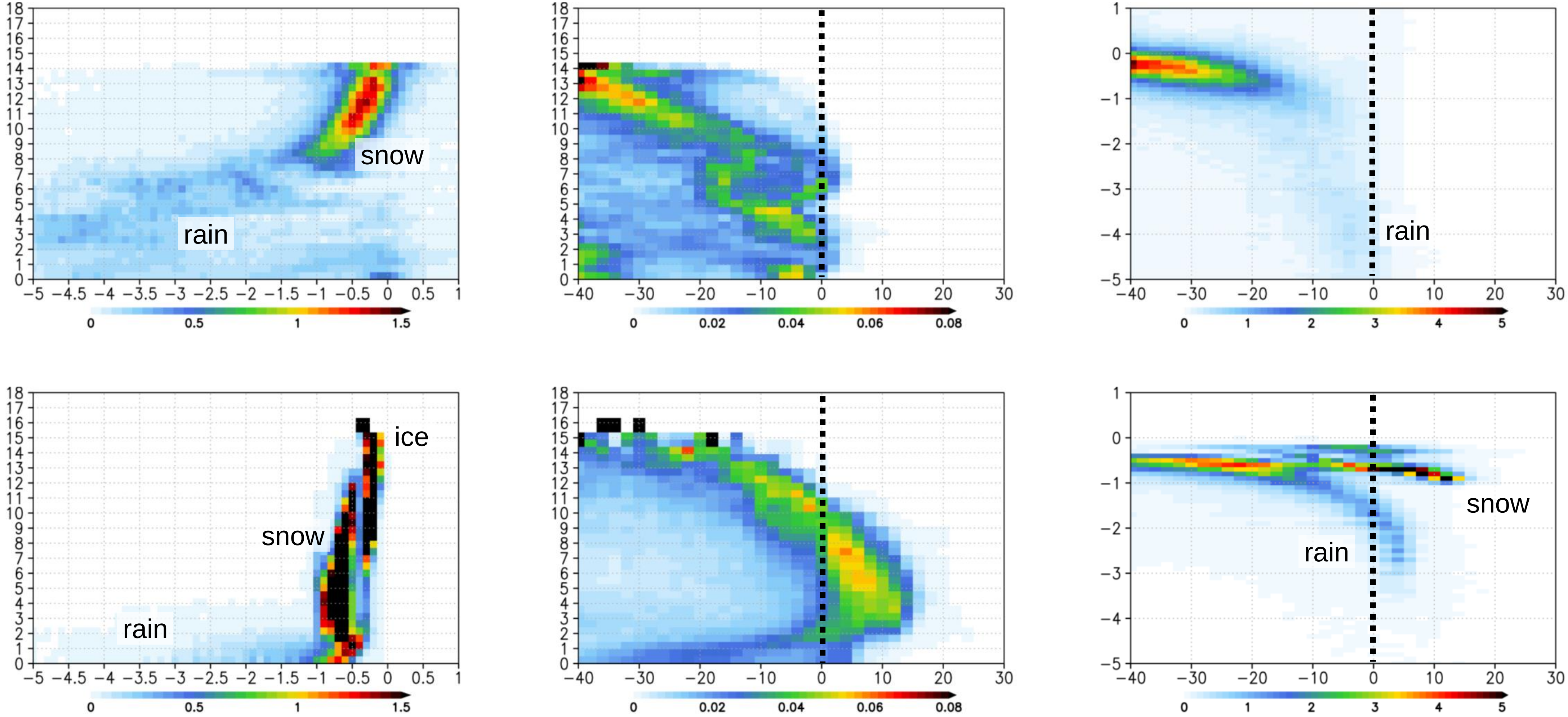
**2020/08 observation**

**$v_d$ CFAD** | **$Z_e$ CFAD** | **$Z_e$-$v_d$ 2dPDF**

**NICT**

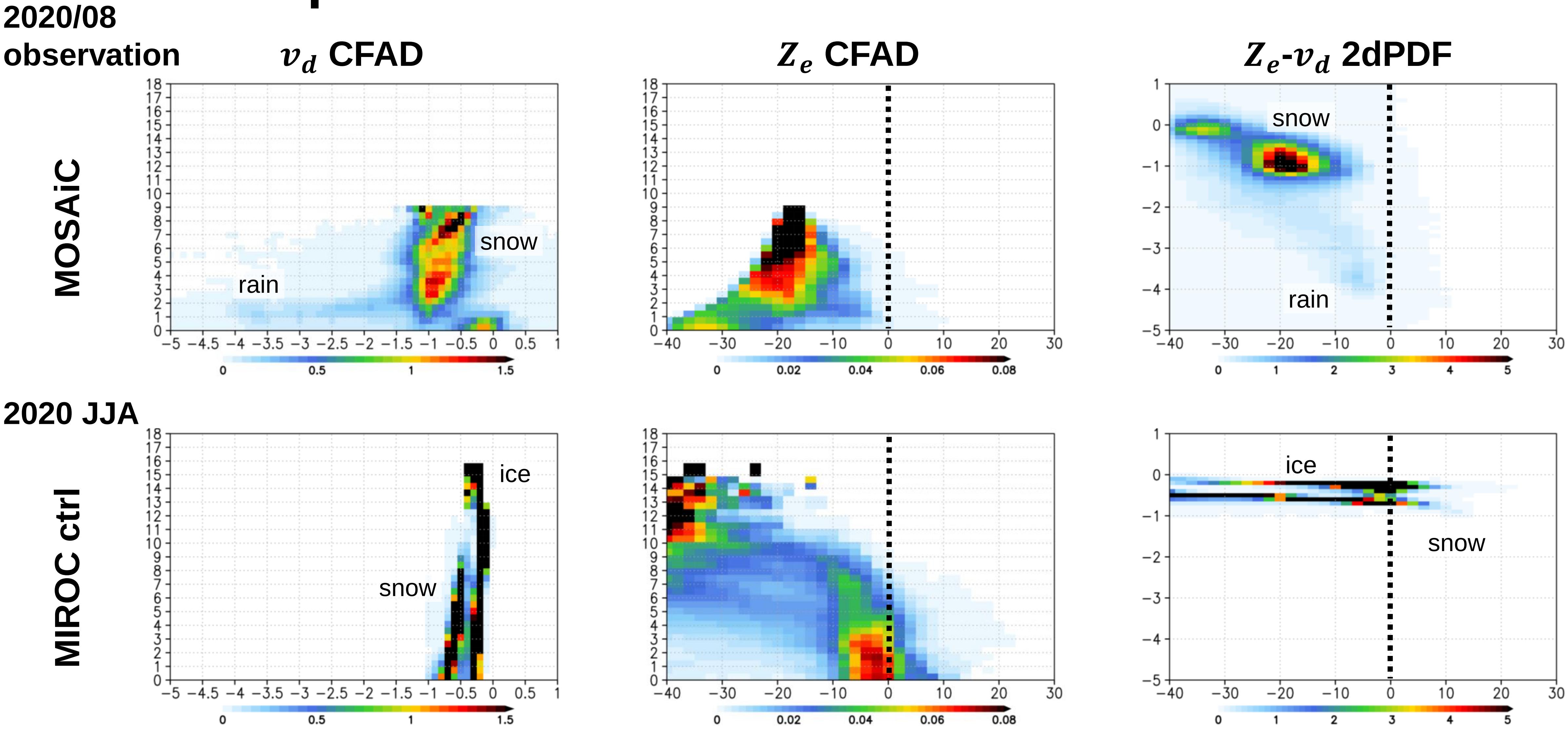
**2020 JJA**

**MIROC ctrl**




- Slower $v_d$ in MIROC6, especially rain particle
- Discrete distribution, ice-snow
- Overestimating $Z_e$
  - ✓ Often seen bias

# Comparison between MOSAiC obs. and MIROC6




- Slower $v_d$, smaller variance in MIROC6.
- Lack of faster falling droplets below 2km
- Overestimating $Z_e$
- Distribution is quite different.

# Tuning to match $v_d$ in MIROC6 with NICT obs.

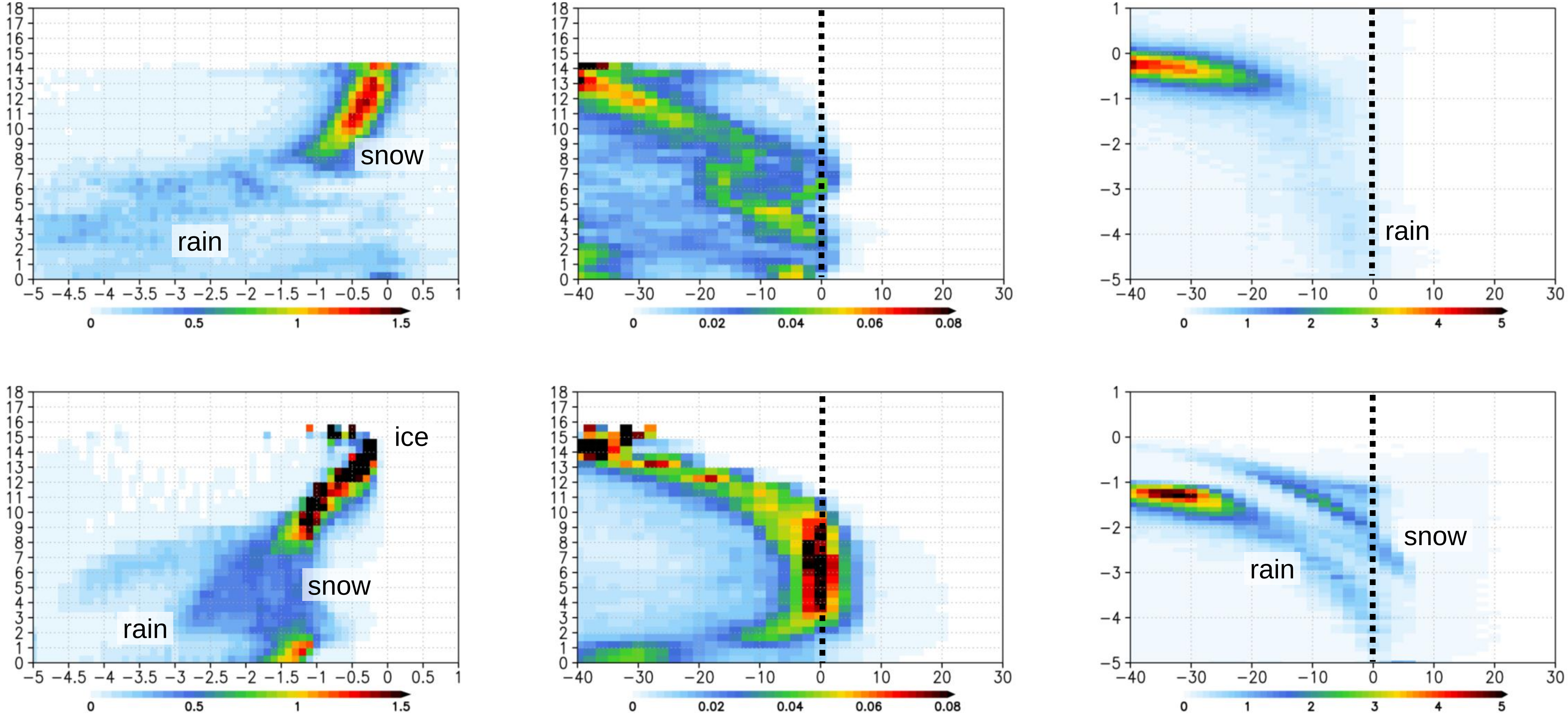
**2020/08 observation**

$v_d$ CFAD | $Z_e$ CFAD | $Z_e$-$v_d$ 2dPDF

NICT

**2020 JJA**

MIROC ctrl

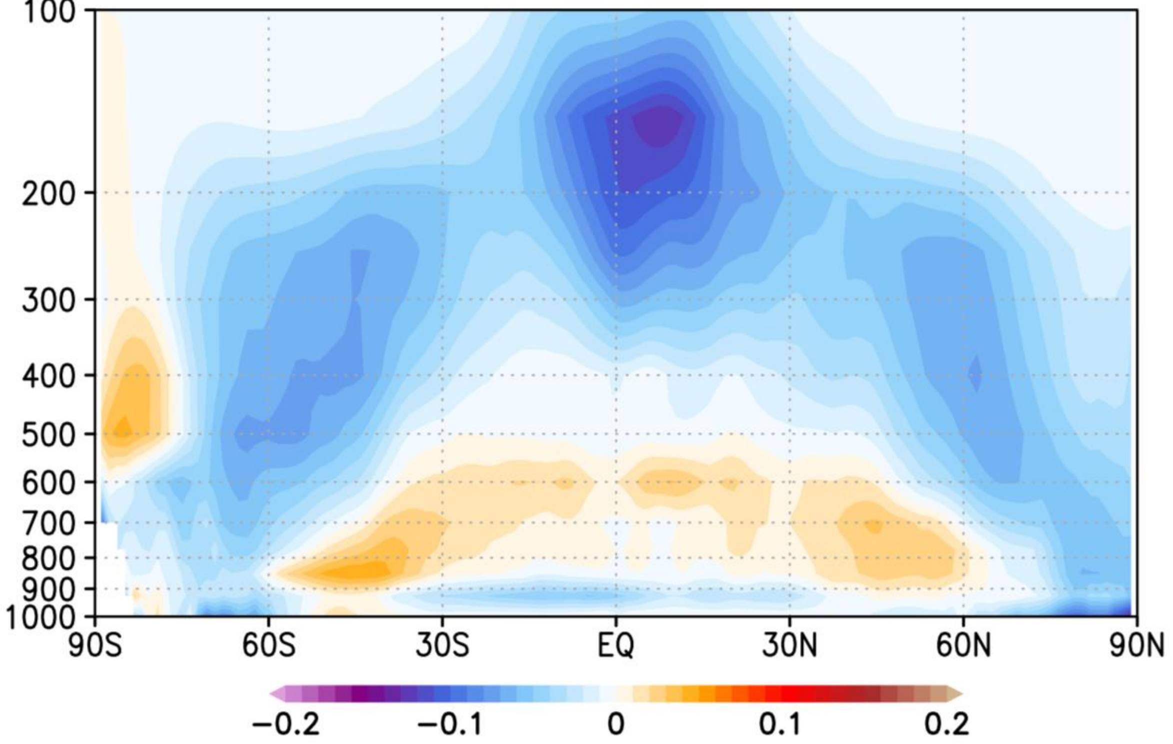



- Tuned to faster $v_d$ and larger variance
- $Z_e$ becomes decreased
- better 2dPDF, but separated

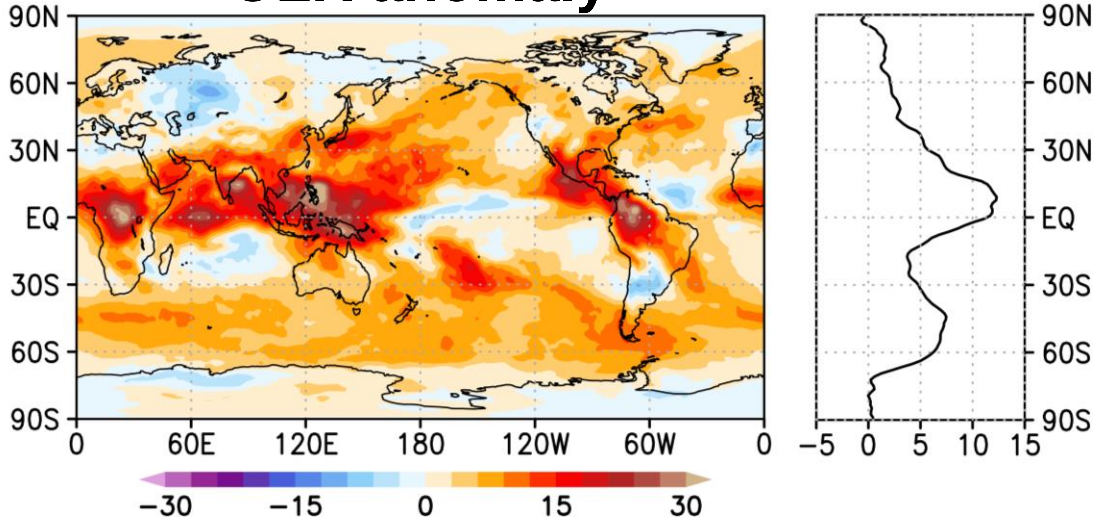
# Impact on climate of $v_d$ tuning

5-year run from Jun. 2020
Anomalies from control run are shown.

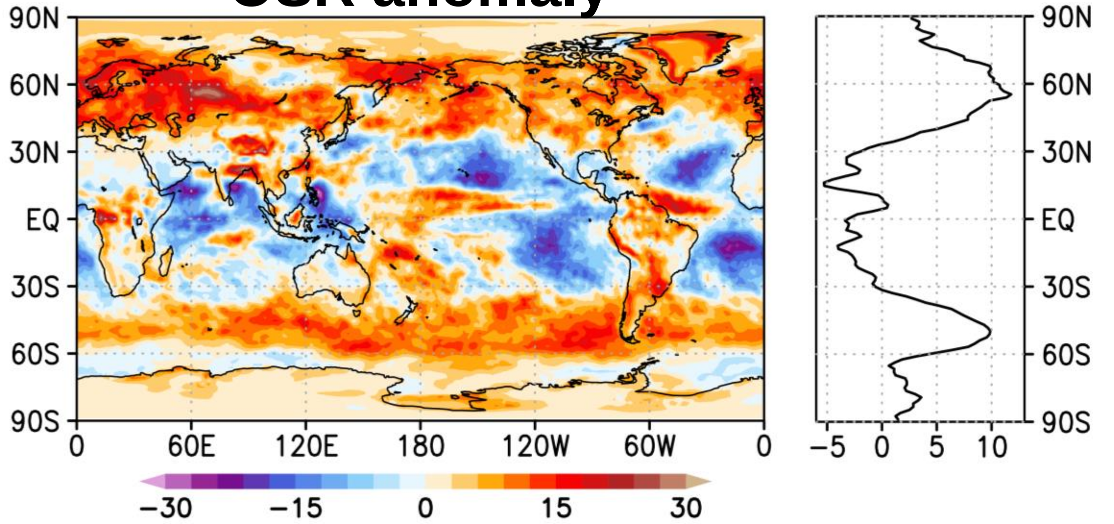
## anomaly of cloud fraction




## OLR anomaly




## OSR anomaly




- Upper clouds strongly decreased.
  → Due to faster fall and shorter lifetime.
- Lower clouds increased.

→ Cooling

**How to reduce this perturbation?**

for liquid: autoconversion ratio, background CCN
for ice: INP, shape, WBF process and mode…

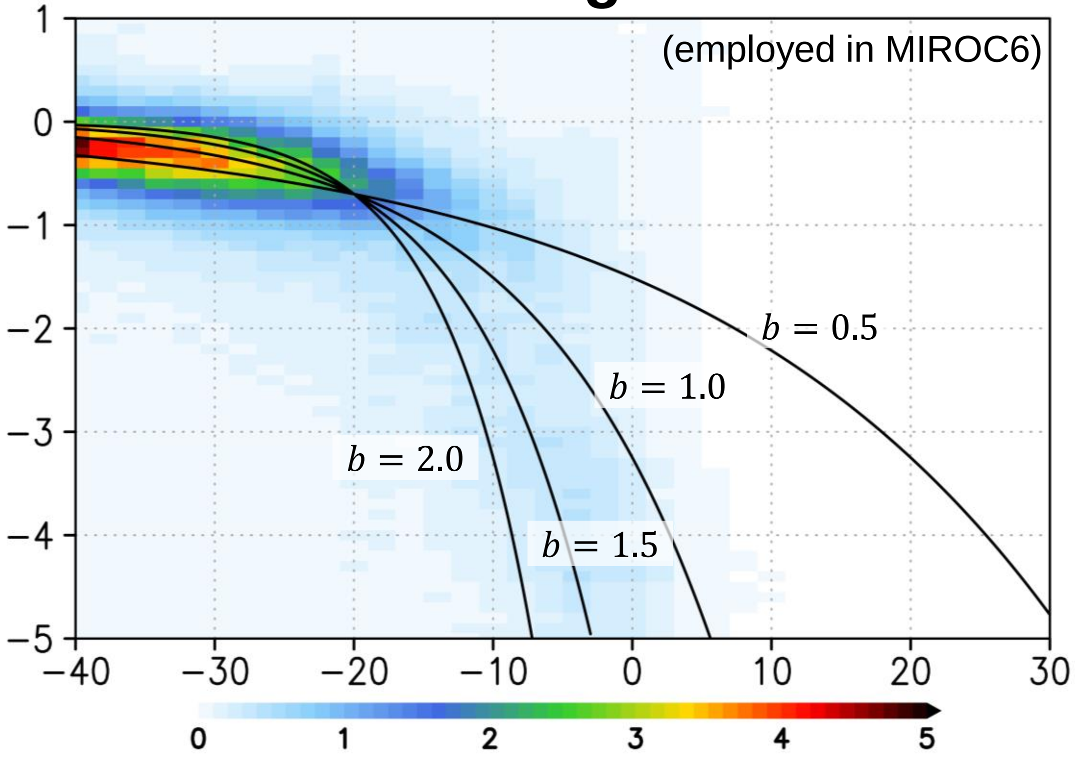
# $Z_e$-$v_d$ relation on 2dPDF of NICT observation

✓ $Z_e$-$v_d$ relation can be made in the similar way as $Z$-$R$ relation.

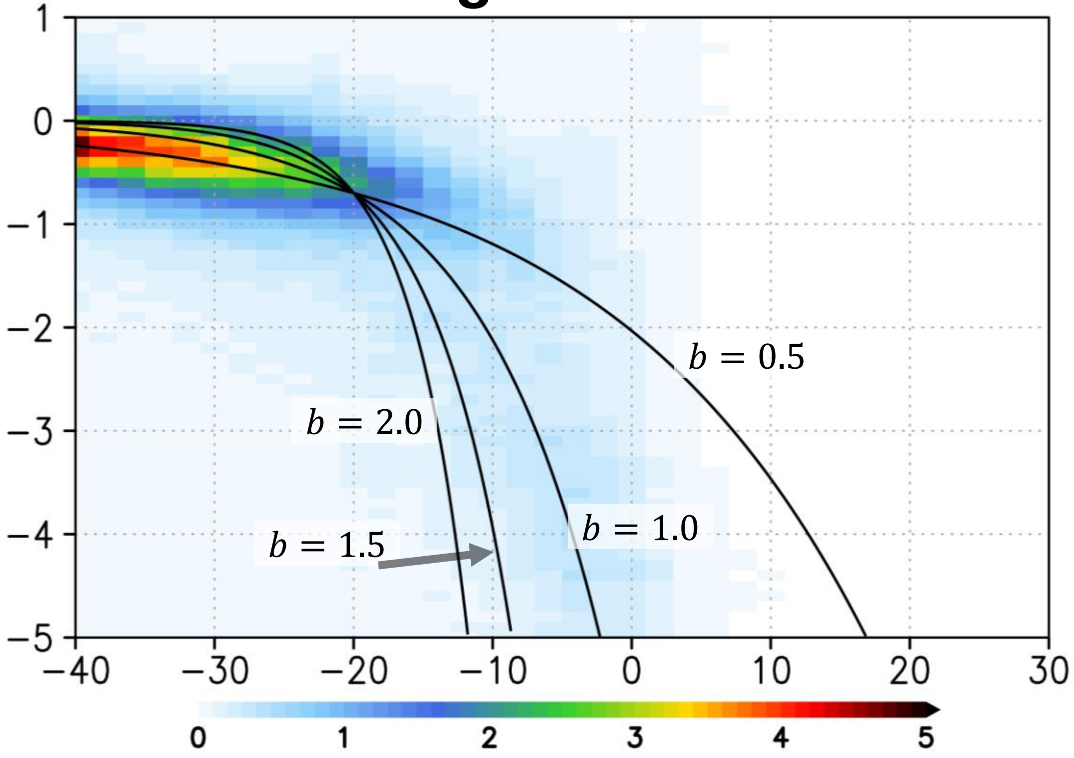
- with **Rayleigh scattering limit** and **power law** for droplet fall velocity

$$v_f = aD^b$$

**modified gamma**




**log normal**




- This line fitting contributes to estimate the scale $b$ of droplet fall velocity.
- Different scale is suggested: $b \approx 0.5$ for snow, $b \approx 1.0$ or $1.5$ for rain.

# 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.**
    - slower $v_d$ and smaller its variance, overestimated $Z_e$
    - separated by categories of cloud/precipitation droplet

3. **Significant impact on climate by tuning of droplet fall velocity**
    - Large modification of cloud fraction and strong cooling effect.
    - Cloud microphysics schemes still have much room for improvement.

4. **Estimation of scale of fall velocity by $Z_e$-$v_d$ relation**
    - Different scale among cloud, rain, snow droplets?
    - Implication for shape of ice particles?

- ✓ **We are now preparing to publish this new simulator for COSP2.**
- ✓ **I'd like to see this simulator used with EarthCARE observation to understand model variability and to improve schemes related to clouds.**

# Supplement

# Details of tuning setup

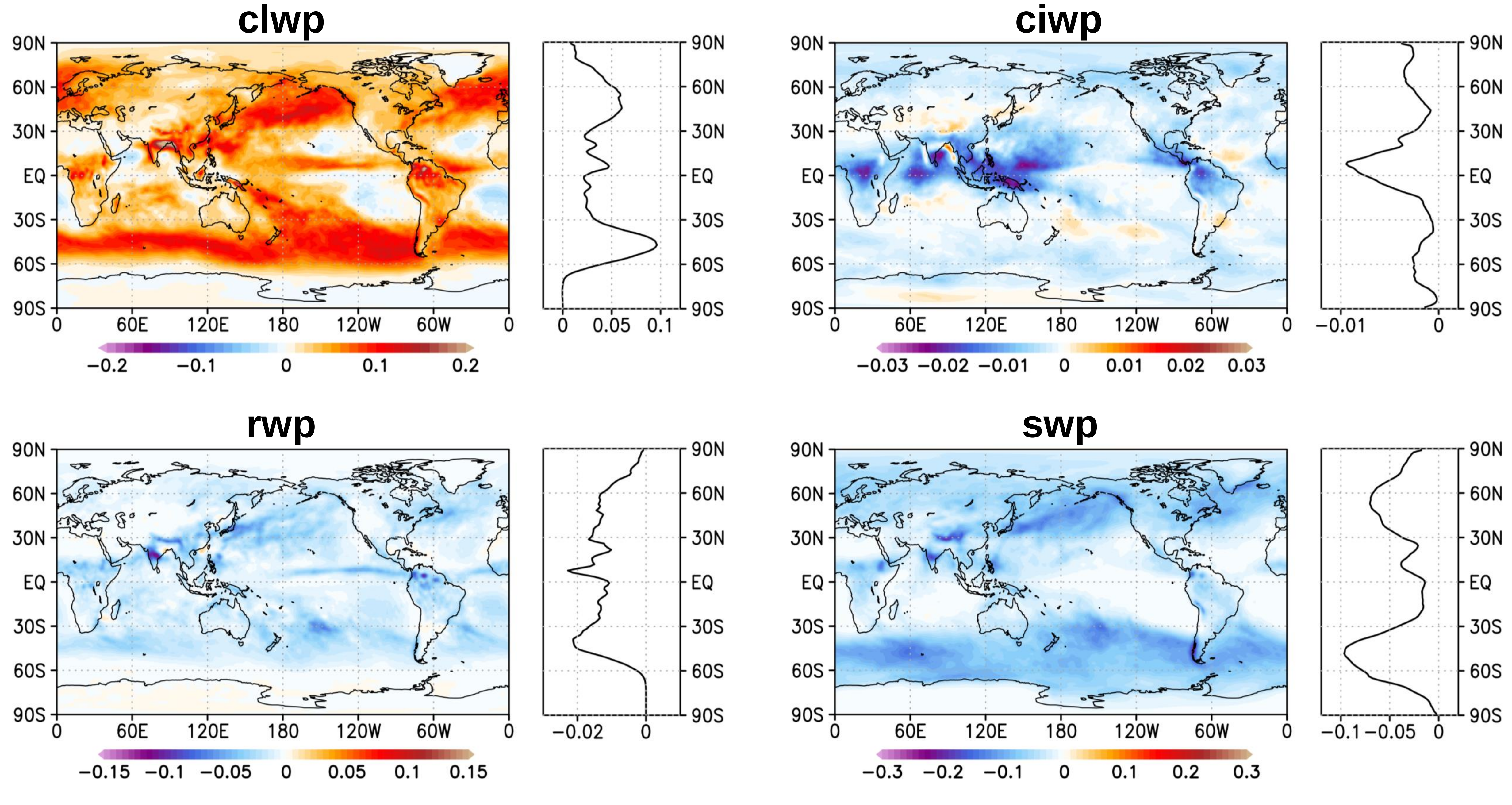
**PL08:** $b_1 - b_2\exp(-b_3 D) + (b_2 - b_1)\exp(-5 b_3 D)$ or **Power law:** $aD^b$

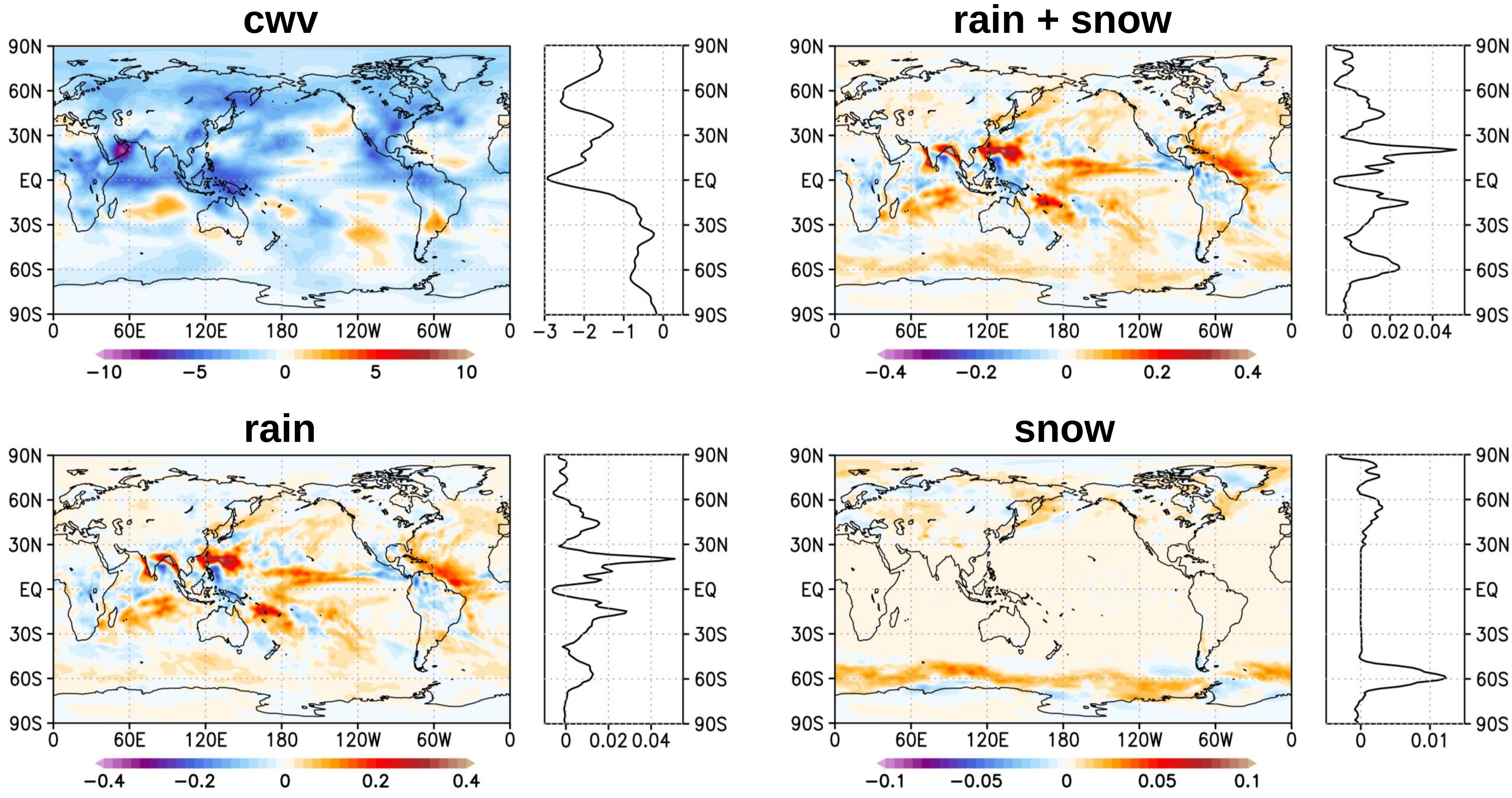
| **ctrl** | **large-scale condensation** | | | | **cumulus convection** | | | |
|---|---|---|---|---|---|---|---|---|
| droplet | cloud liq. | cloud ice | rain | snow | cloud liq. | cloud ice | rain | snow |
| viscous drag | × | × | × | × | × | × | ○ | ○ |
| PL08 | ○ | × | ○ | × | ○ | × | × | × |
| Power law; $a$ | - | 1.107 | - | 3.321 | - | 1.107 | 842 | 4.84 |
| Power law; $b$ | - | 0.22 | - | 0.22 | - | 0.22 | 0.8 | 0.25 |

$$b_1 = 9.65, b_2 = 10.43, b_3 = 600$$

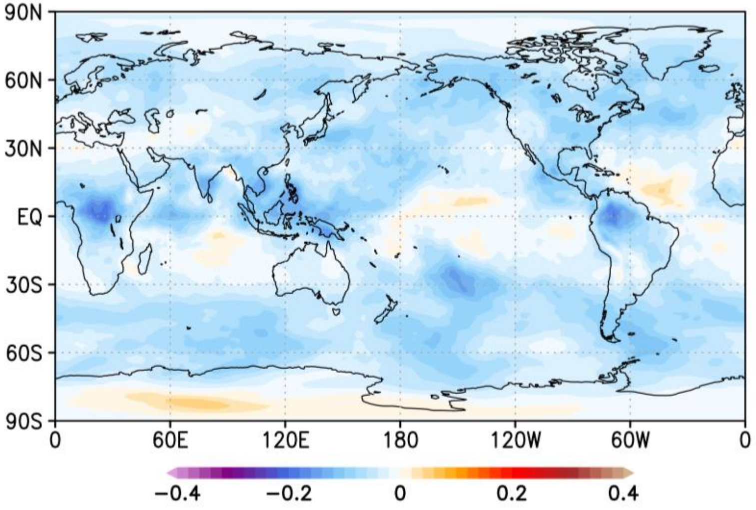
| **tuning** | **large-scale condensation** | | | | **cumulus convection** | | | |
|---|---|---|---|---|---|---|---|---|
| droplet | cloud liq. | cloud ice | rain | snow | cloud liq. | cloud ice | rain | snow |
| viscous drag | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PL08 | ○ | × | ○ | × | ○ | × | × | × |
| Power law; $a$ | - | 300 | - | 100 | - | 300 | 842 | 4.84 |
| Power law; $b$ | - | 0.8 | - | 0.5 | - | 0.8 | 0.8 | 0.25 |

$$b_1 = 10.0, b_2 = 10.43, b_3 = 1500$$

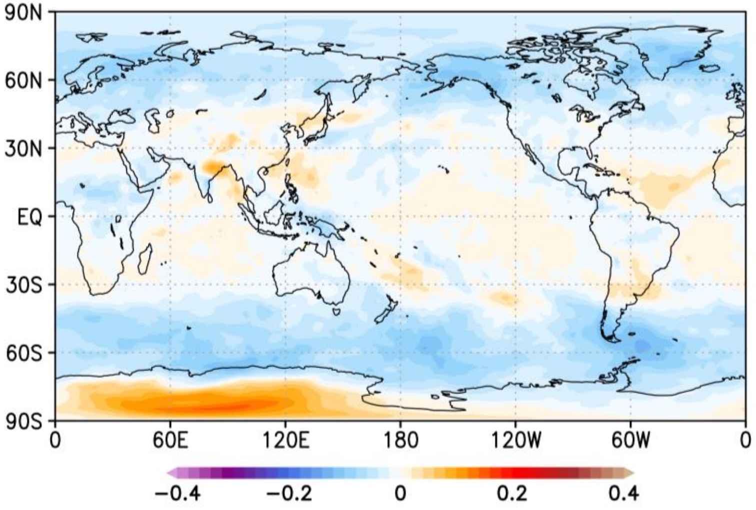

clwp
ciwp
rwp
swp
90N 60N 30N EQ 30S 60S 90S
0 60E 120E 180 120W 60W 0
0 0.05 0.1
−0.2 −0.1 0 0.1 0.2
−0.01 0
−0.03 −0.02 −0.01 0 0.01 0.02 0.03
−0.02 0
−0.15 −0.1 −0.05 0 0.05 0.1 0.15
−0.1 −0.05 0
−0.3 −0.2 −0.1 0 0.1 0.2 0.3


cwv
rain + snow
rain
snow
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
−3 −2 −1 0
0 0.02 0.04
0 0.01
−10 −5 0 5 10
−0.4 −0.2 0 0.2 0.4
−0.1 −0.05 0 0.05 0.1

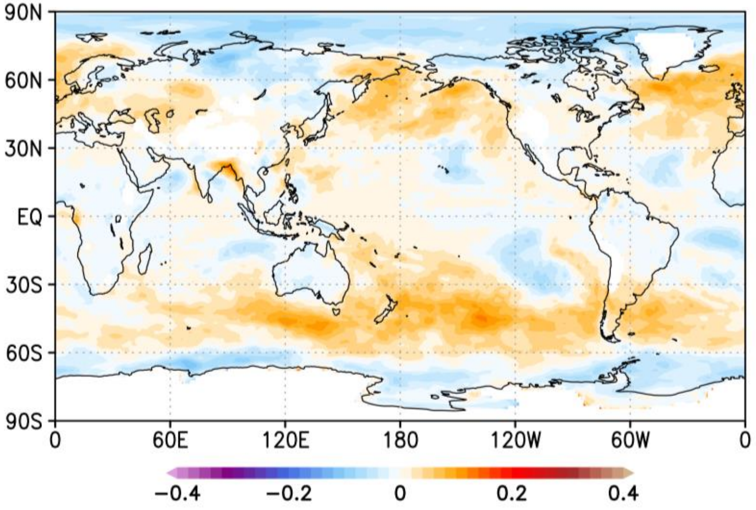
cloud fraction @ 300hPa



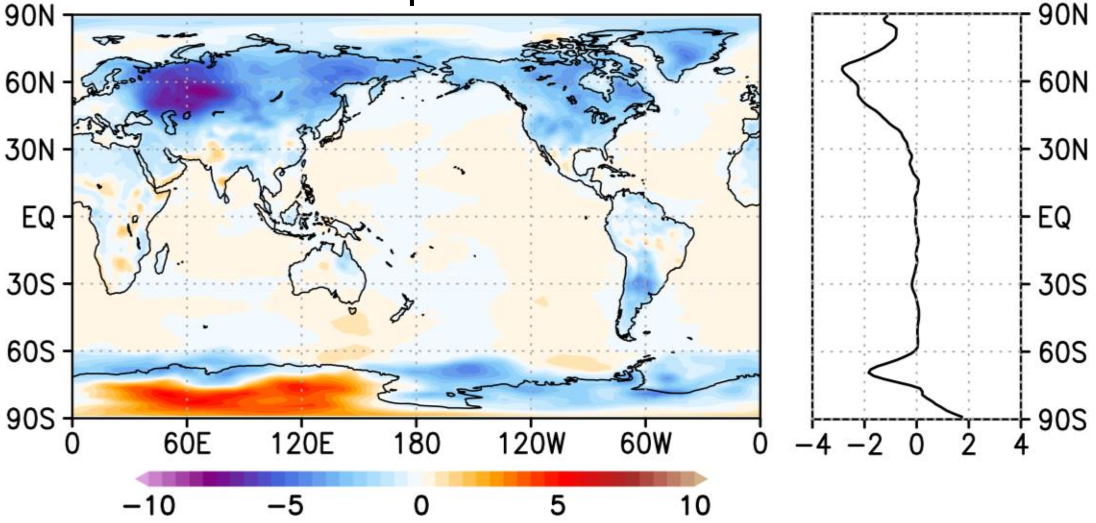

cloud fraction @ 500hPa



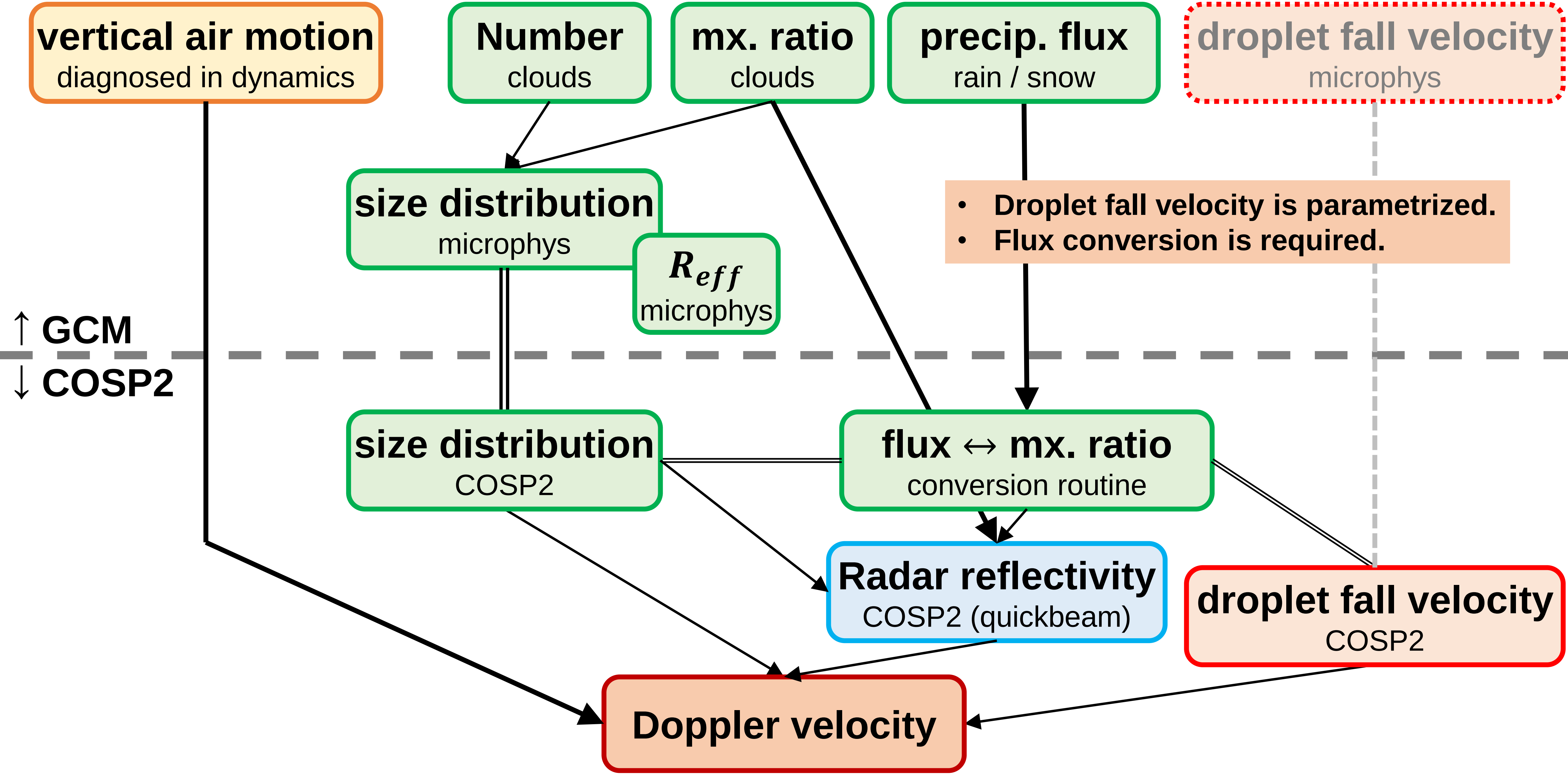

cloud fraction @ 850hPa



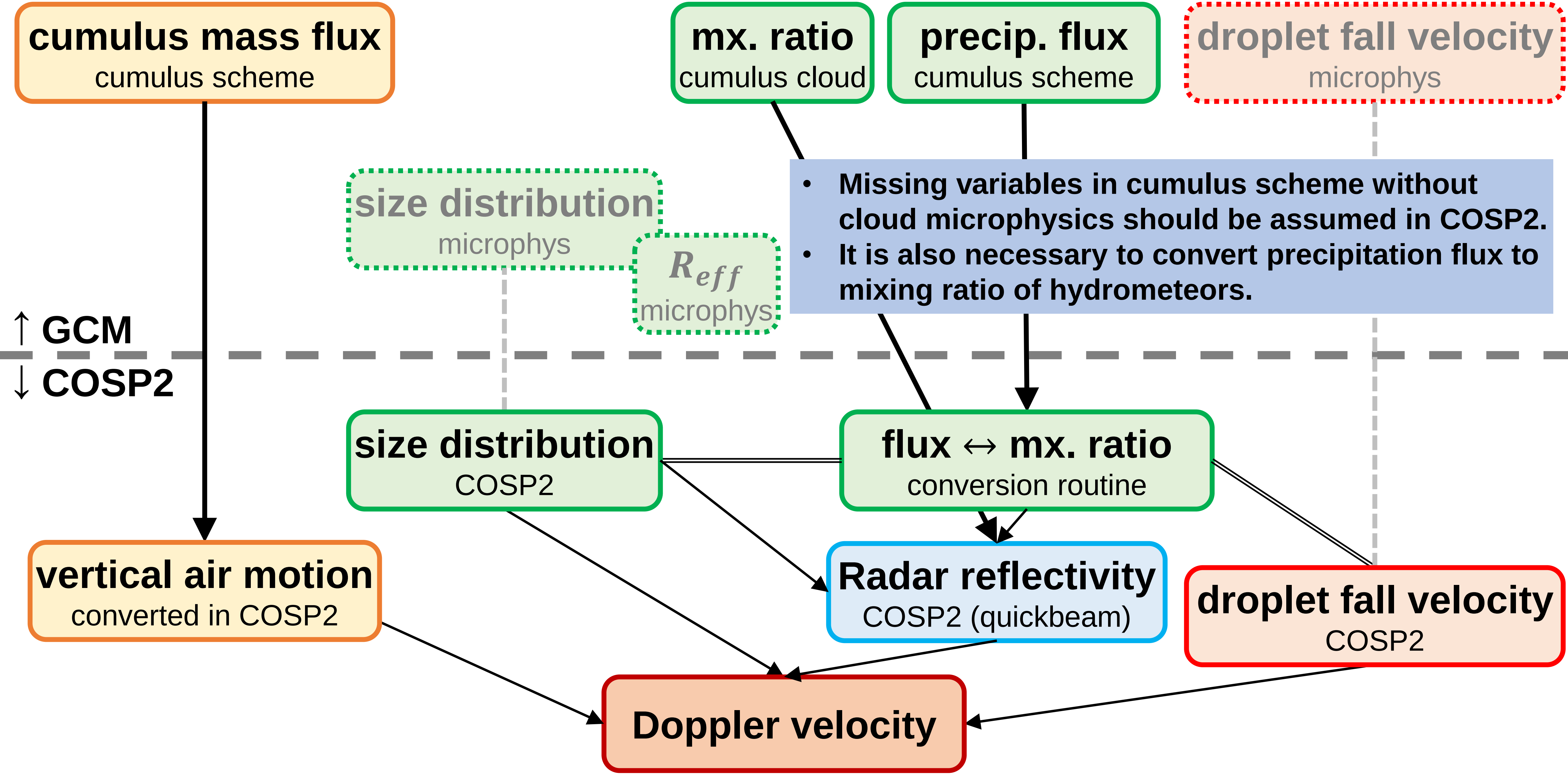

2m temperature



# Simulator design: diagnostic precipitation scheme



# Simulator design: cumulus scheme

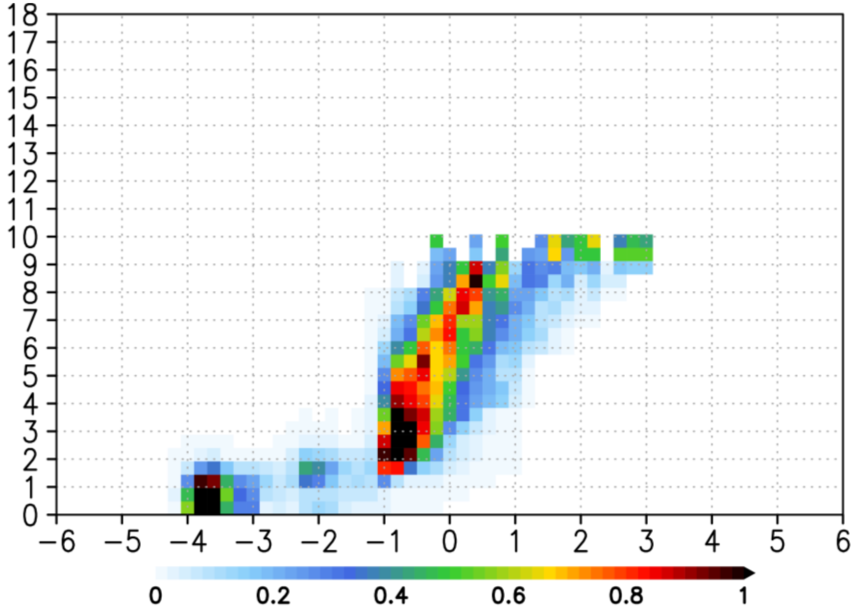



- **Missing variables in cumulus scheme without cloud microphysics should be assumed in COSP2.**
- **It is also necessary to convert precipitation flux to mixing ratio of hydrometeors.**

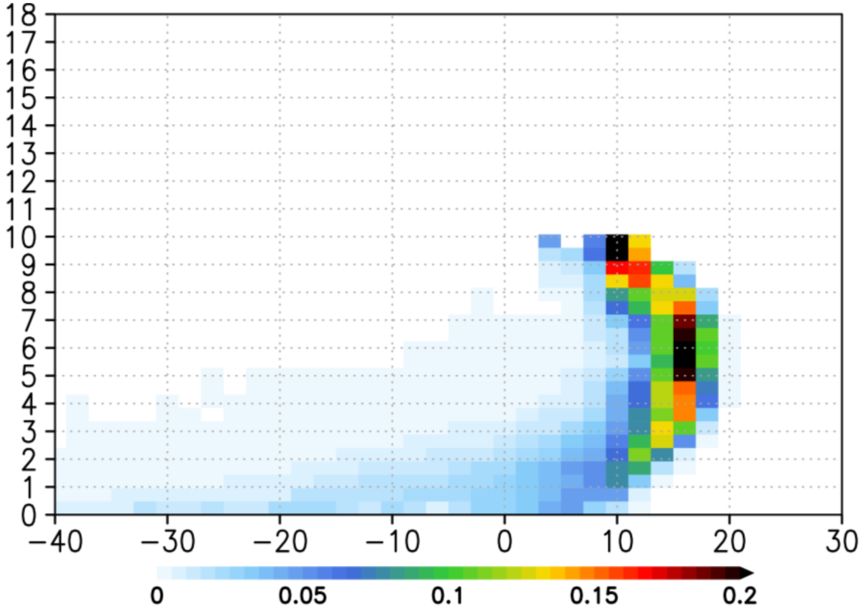
# $v_d$ simulator on cumulus precipitation in MIROC6

MIROC6

$v_d$ CFAD




$Z_e$ CFAD




corresponding area to NICT obs.

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

cumulus mass flux

Not comparable to NICT monthly statistics.
We should pick up cumulus cloud case.

$Z_e$ in COSP2 ...

$$Z_e = 10^{18}\frac{\lambda^4}{\pi^5 K}\int C_{bk} n(D)\, dD$$

Rayleigh Limit ...

$$C_{bk} = \frac{\pi^5 K}{\lambda^4} D^6$$

$$\rightarrow \quad Z_e = 10^{18}\int D^6 n(D)\, dD = 10^{18} N M_6$$

$$M_k = \frac{1}{N}\int D^k n(D)\, dD$$

$$m = \frac{\pi}{6}\rho N M_3$$

$$\frac{1}{N} = \frac{\pi}{6}\rho\frac{M_3}{m}$$

$$N = \frac{6}{\pi}\frac{m}{\rho}\frac{1}{M_3}$$

$$\boxed{Z_e = 10^{18}\frac{6}{\pi}\frac{M_6}{M_3}\frac{m}{\rho}}$$

$$v_d = \not{w} + \frac{\int_{r_{\min}}^{r_{\max}} dn(r)/dr \cdot C_{\mathrm{bk}}(r) v_f(r)\, dr}{\int_{r_{\min}}^{r_{\max}} dn(r)/dr \cdot C_{\mathrm{bk}}(r)\, dr},$$

$$v_f = aD^b$$

$$v_d = \frac{aM_{6+b}}{M_6}$$

$$dBZ_e = 10\log_{10} Z_e$$

$$Ze = 10^{\frac{dBZ_e}{10}}$$

mod. gamma

$$n(D) = \frac{N}{\Gamma(\mu) D}\left(\frac{D}{D_0}\right)^{\mu} \exp\left(-\frac{D}{D_0}\right)$$

$$NM_k = \int D^k n(D)\, dD$$

$$M_k = D_0^k \frac{\Gamma(\mu+k)}{\Gamma(\mu)}$$

$$\begin{aligned} v_d &= \frac{aM_{6+b}}{M_6} \\ &= aD_0^b \frac{\Gamma(\mu+6+b)}{\Gamma(\mu+6)} \end{aligned}$$

$$D_0^b = \frac{v_d}{a} \frac{\Gamma(\mu+6)}{\Gamma(\mu+6+b)}$$

$$\begin{aligned} v_d &= aM_{6+b}\; 10^{18} \frac{1}{Z_e} \frac{6}{\pi} \frac{m}{M_3} \\ &= \frac{6 \times 10^{18}}{\pi}\; am \frac{M_{6+b}}{M_3} \frac{1}{Z_e} \\ &= \frac{6 \times 10^{18}}{\pi}\; aD_0^{3+b} m \frac{\Gamma(\mu+6+b)}{\Gamma(\mu+3)} \frac{1}{Z_e} \end{aligned}$$

$$\begin{aligned} Z_e &= 10^{18} \frac{6}{\pi} \frac{M_6}{M_3} \frac{m}{\rho} \\ &= 10^{18} \frac{6}{\pi} \frac{m}{\rho}\; D_0^3 \frac{\Gamma(\mu+6)}{\Gamma(\mu+3)} \end{aligned}$$

$$D_0^3 = 10^{-18} \frac{\pi}{6} \frac{\rho}{m} \frac{\Gamma(\mu+3)}{\Gamma(\mu+6)}\; Z_e$$

$$v_d = a \frac{\Gamma(\mu+6+b)}{\Gamma(\mu+6)} \left(10^{-18} \frac{\pi}{6} \frac{\rho}{m} \frac{\Gamma(\mu+3)}{\Gamma(\mu+6)}\; Z_e\right)^{\frac{b}{3}}$$

log normal

$$n(D) = \frac{1}{D}\frac{N}{\sqrt{2\pi}\log\sigma}\exp\left[-\frac{(\log D - \log\mu)^2}{2(\log\sigma)^2}\right]$$

$$NM_k = \int D^k n(D)\, dD$$

$$M_k = \exp\left(k\log\mu + \frac{k^2(\log\sigma)^2}{2}\right)$$

$$2R_{eff} = \frac{M_3}{M_2} = \mu\exp\left[\frac{5}{2}(\log\sigma)^2\right]$$

$$(\log\sigma)^2 = \frac{2}{5}\log\left(\frac{2R_{eff}}{\mu}\right)$$

$$M_k = \exp\left(k\log\mu + \frac{k^2}{5}\log\left(\frac{2R_{eff}}{\mu}\right)\right)$$

$$= \mu^k \cdot \left(\frac{2R_{eff}}{\mu}\right)^{\frac{k^2}{5}} = \mu^{k-\frac{k^2}{5}} D_{eff}^{\frac{k^2}{5}}$$

$$v_d = \frac{aM_{6+b}}{M_6} = a\,\mu^{b-\frac{(6+b)^2-6^2}{5}}\left(D_{eff}\right)^{\frac{(6+b)^2-6^2}{5}}$$

$$= a\mu^{-\frac{b(b+7)}{5}} D_{eff}^{\frac{b(b+12)}{5}}$$

$$Z_e = 10^{18}\frac{6}{\pi}\frac{M_6}{M_3}\frac{m}{\rho} = 10^{18}\frac{6}{\pi}\frac{m}{\rho}\,\mu^{-\frac{12}{5}}\left(D_{eff}\right)^{\frac{27}{5}}$$

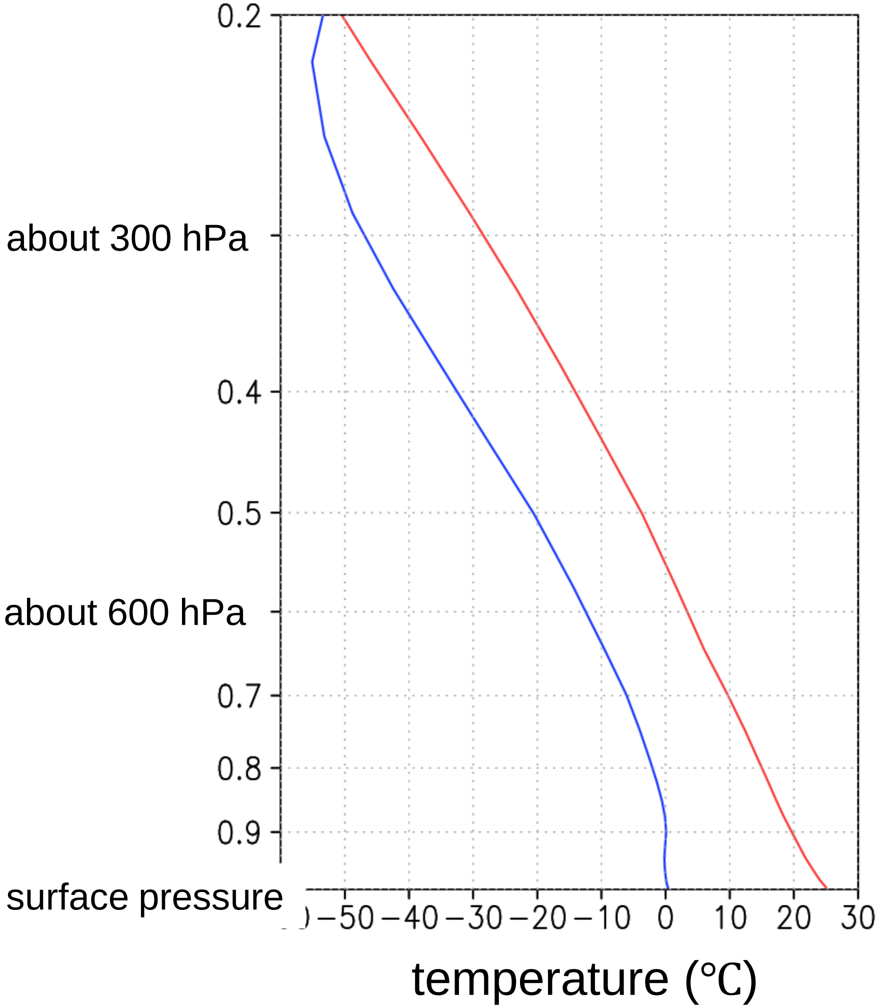
$$v_d = a\mu^{-\frac{b(b+7)}{5}}\left(10^{-18}\frac{\pi}{6}\frac{\rho}{m}\mu^{\frac{12}{5}}Z_e\right)^{\frac{b(b+12)}{27}}$$

$$= a\mu^{-\frac{b(b+3)}{9}}\left(10^{-18}\frac{\pi}{6}\frac{\rho}{m}\right)^{\frac{b(b+12)}{27}} Z_e^{\frac{b(b+12)}{27}}$$

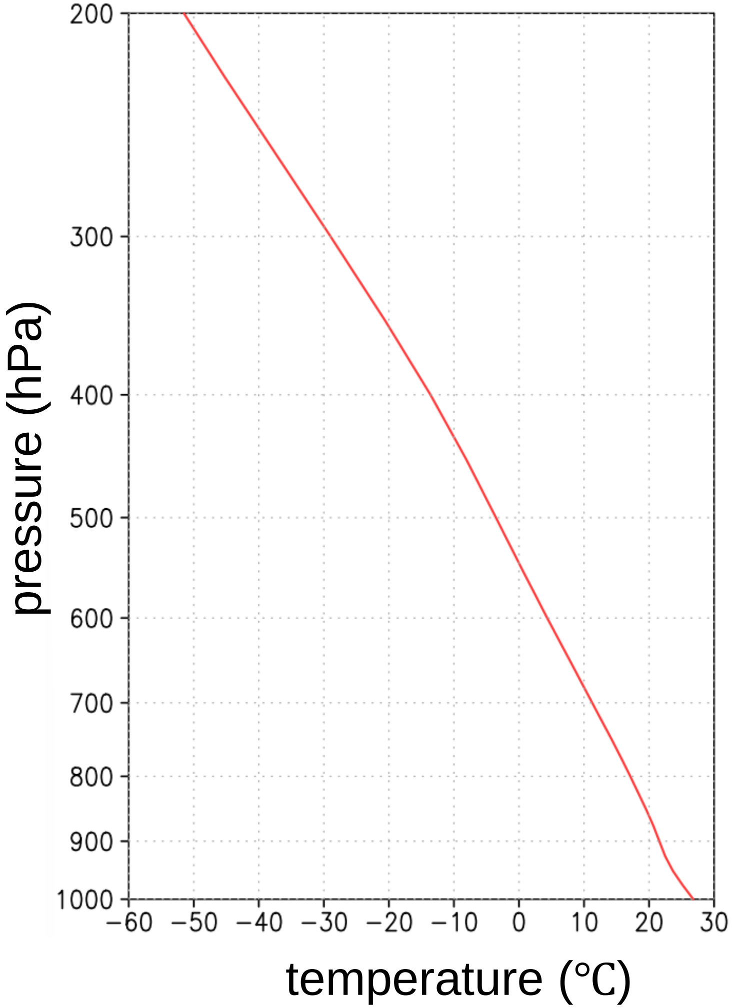
$$v_d = aD_{eff}^{\frac{b(b+12)}{5}}\left(10^{-18}\frac{\pi}{6}\frac{\rho}{m}D_{eff}^{-\frac{27}{5}}Z_e\right)^{\frac{b(b+7)}{12}}$$

$$= aD_{eff}^{-\frac{b(b+3)}{4}}\left(10^{-18}\frac{\pi}{6}\frac{\rho}{m}\right)^{\frac{b(b+7)}{12}} Z_e^{\frac{b(b+7)}{12}}$$

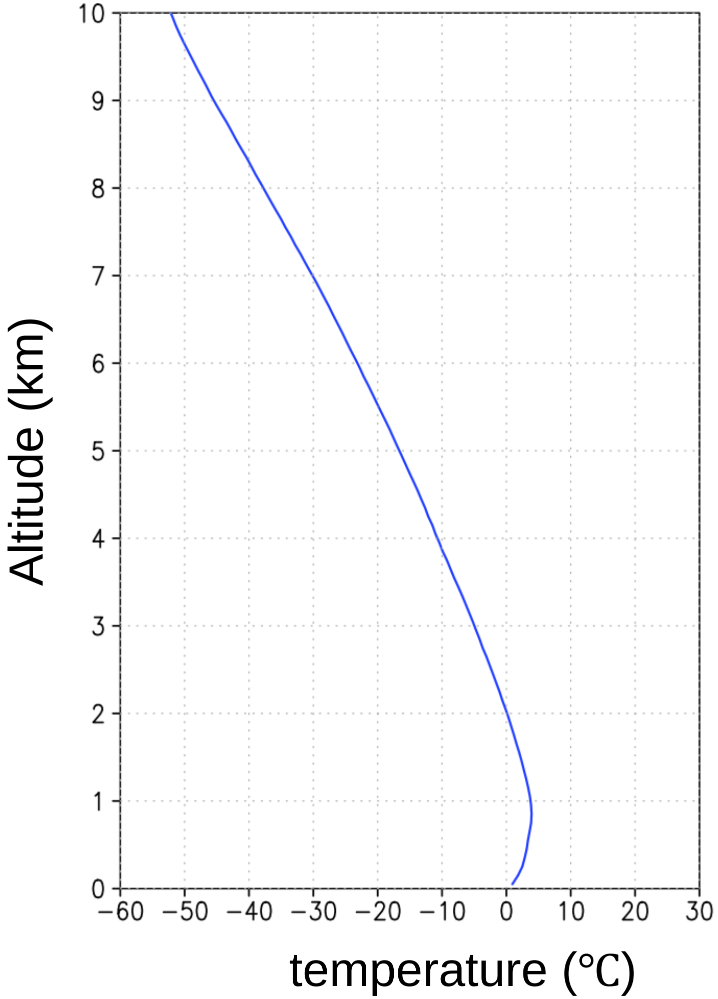
MIROC6 ctrl
red: NICT
blue: MOSAiC



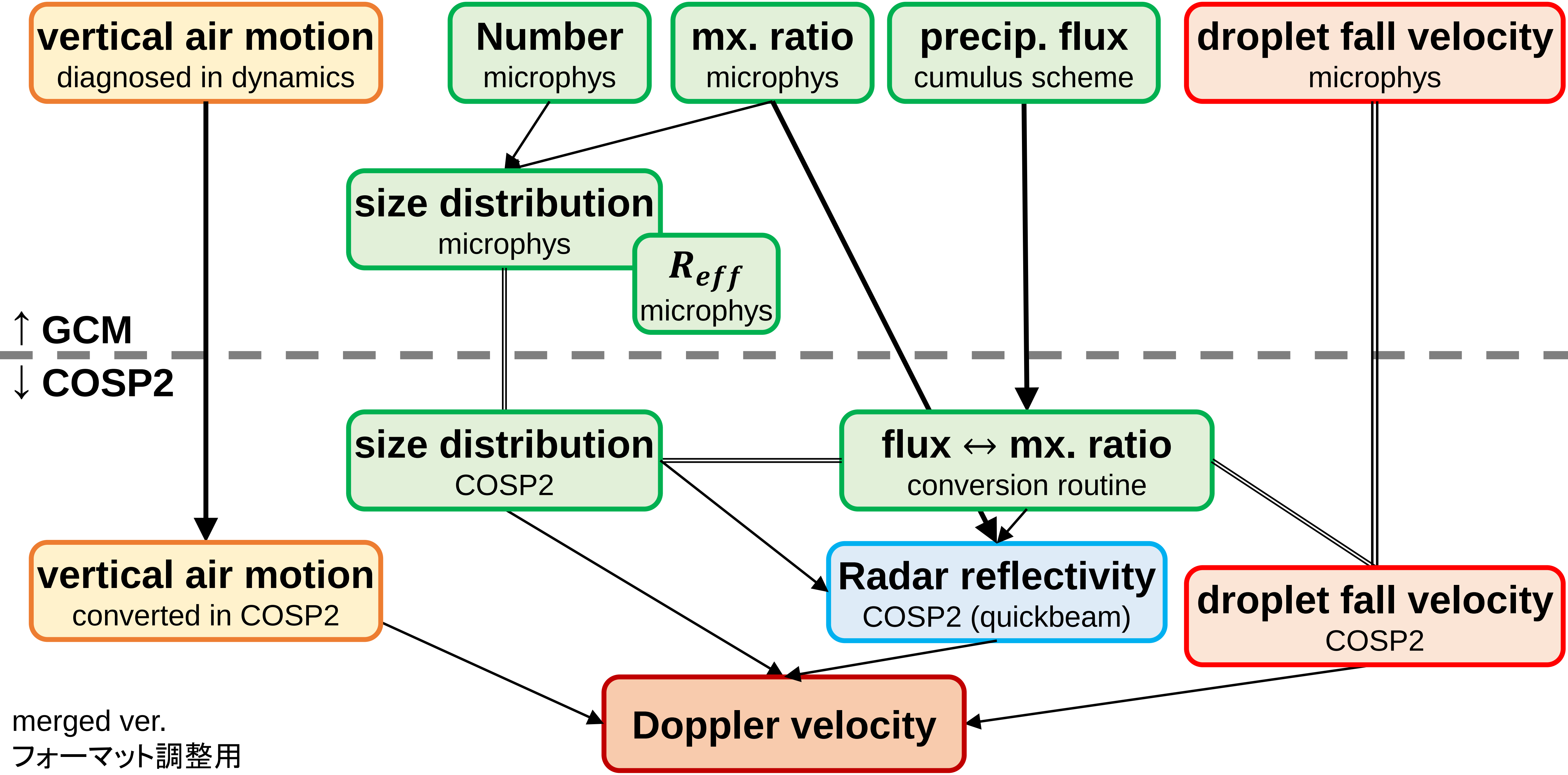

JRA3Q (reanalysis)
NICT
Aug. 2020 monthly




MOSAiC
Sounding
Aug. 2020 monthly



# Simulator design: *****




merged ver.
フォーマット調整用