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Evaluation of cloud micro- and macrophysical properties in the MIROC6 with A-Train observations and COSP simulator

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- **What can be done using satellite observations to constrain the model uncertainty?**
- **How can we improve model biases in cloud and precipitation processes using a simulator?**

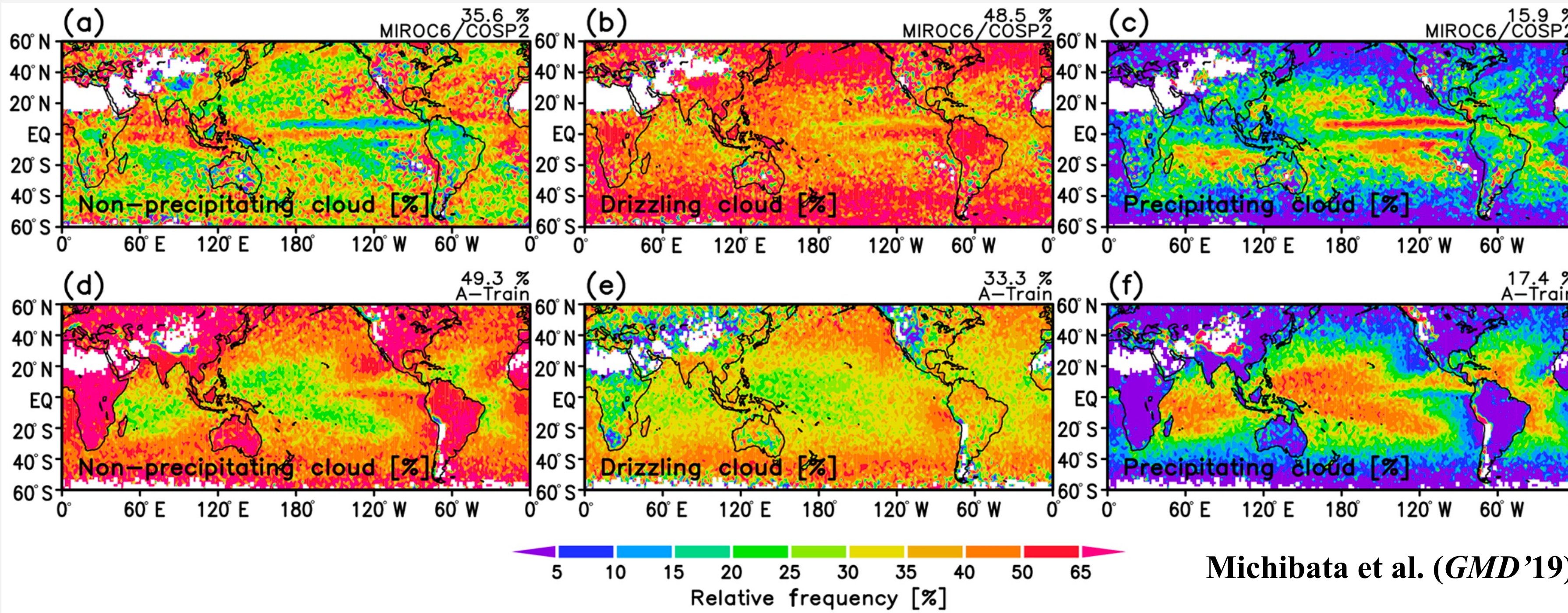
Simulations using MIROC6-SPRINTARS were executed with the SX-Aurora supercomputer system of the National Institute for Environmental Studies, Japan. This study was supported by JSPS KAKENHI Grant Numbers JP19K14795 and JP19H05669.

Common biases in GCMs

Nonprecip (dBZ < -15) Drizzling (-15 < dBZ < 0) Raining (0 < dBZ)

MIROC6

CloudSat

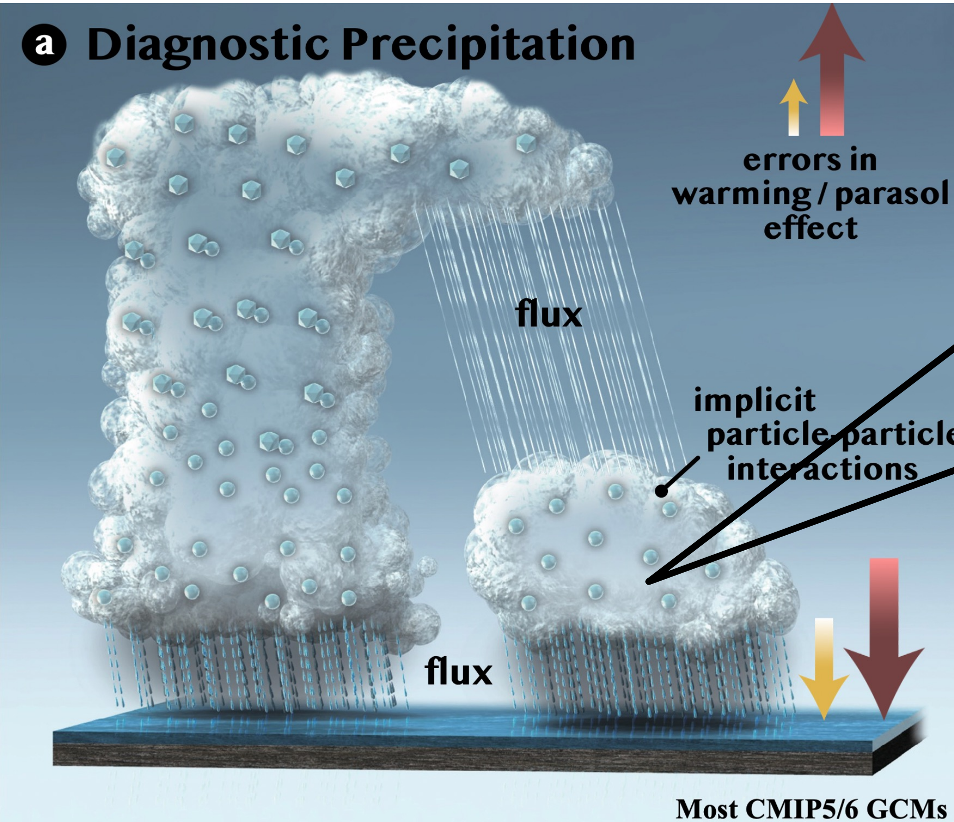


Michibata et al. (*GMD'*19)

► **Various common biases among GCMs, and still suffering...**
– **"Too frequent and too light" rain formation (Stephens et al., 2010)**
– **"Too few" low-cloud bias (Nam et al., 2012)**
– **"Too strong" cloud response to aerosol perturbations (M. Wang et al., 2012)**

► **Developing cloud-precipitation processes in models using satellite information**

Diagnostic-vs-Prognostic precipitation



autoconversion: $P_{aut} \sim f(q_c, N_c)$ — link to aerosols

cloud + cloud → rain

accretion: $P_{acc} \sim g(q_c, q_r)$

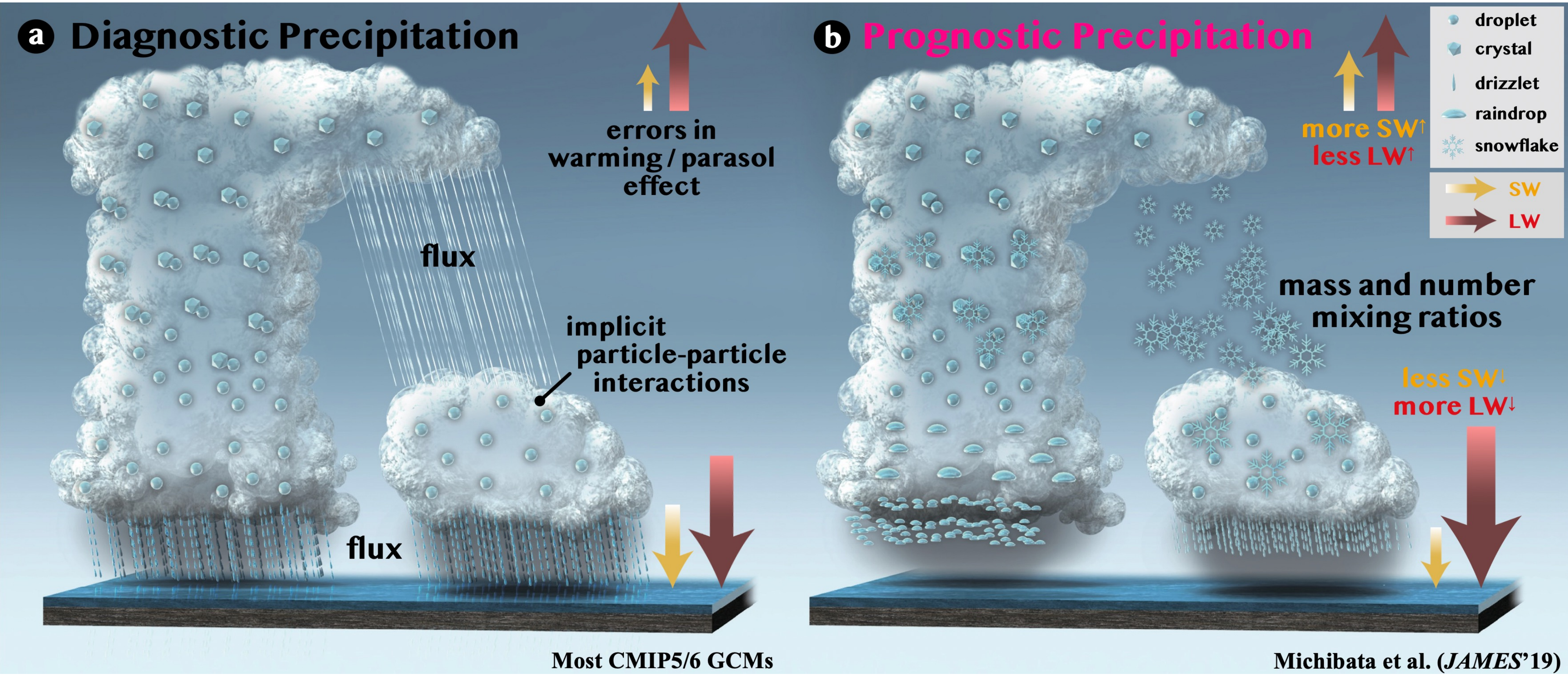
rain + cloud → rain

► **accretion << autoconversion**

► **overestimate of the ACI**

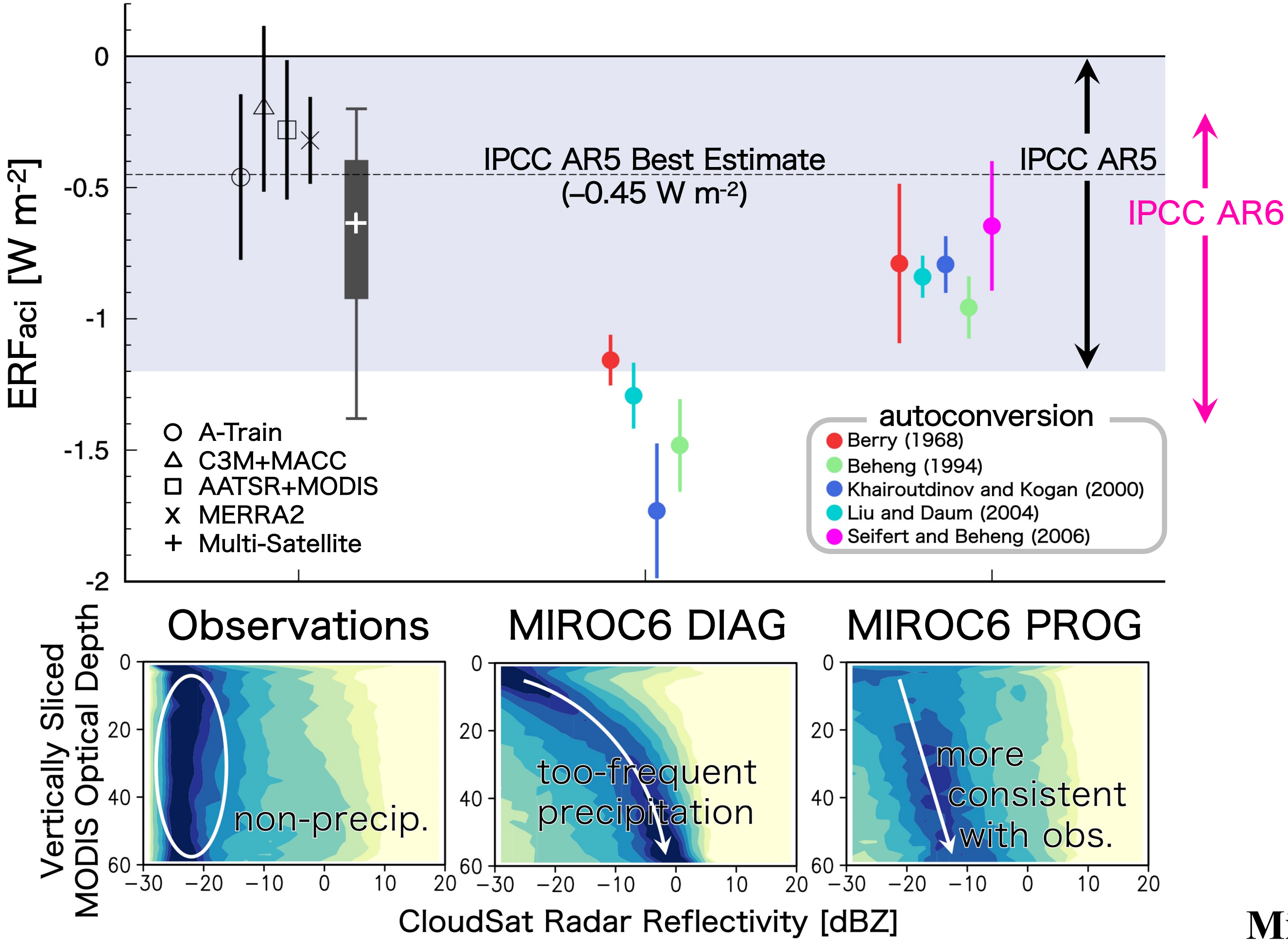
► **Most GCMs treat precipitation diagnostically**
- **instantaneously removed from the atmosphere**
- **overestimate of the magnitude of ACI**
- **bias in warm rain frequency and intensity**

Diagnostic-vs-Prognostic precipitation



- **Prognostic precipitation in MIROC6**
  - mass and number mixing ratios of rain (q_r, N_r) and snow (q_s, N_s)
  - precipitation in the atmosphere across model timesteps
  - improved representation of radiation by considering precipitating hydrometeors
- **Other GCMs including prognostic precipitation**
  - CAM MG2/3; ECHAM6-HAM; GISS-ModelE3; ECMWF-IFS; HadGEM3; E3SM

Improved warm-rain formation and ACI

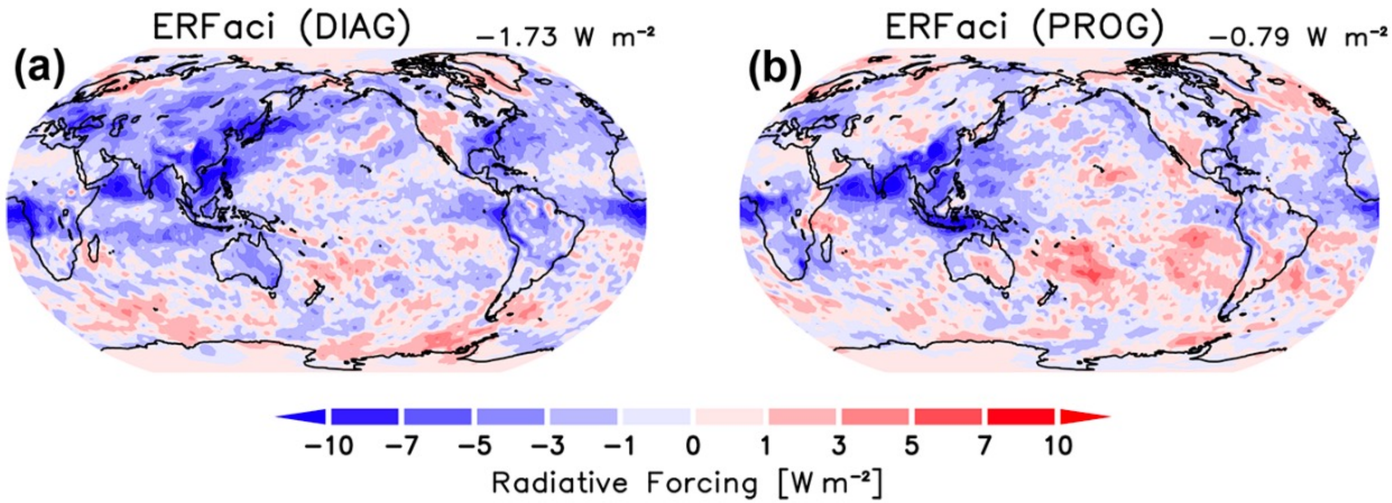


Michibata and Suzuki (*GRL*'20)

- ► **Improved "too frequent" warm rain bias in the PROG scheme**
  – **time-evolution of the raindrop size, by controlling the relative contribution of the autoconversion and accretion depending on the cloud regime**

- ► **Improved "too strong" ACI in PROG, but not in DIAG**

Mechanisms of the weakening ERF$_{aci}$



► **<u>Diagnostic precipitation</u>**

aerosol↑ => cloud water↑ => stronger SW ERF$_{aci}$ (cloud lifetime effect)

► **<u>Prognostic precipitation</u>**

1) Liquid microphysics (Michibata and Suzuki, *GRL'*20)

aerosol↑ => cloud water↑ => stronger SW ERF$_{aci}$

accretion↑ => droplet number↓ => weakening of cloud lifetime effect

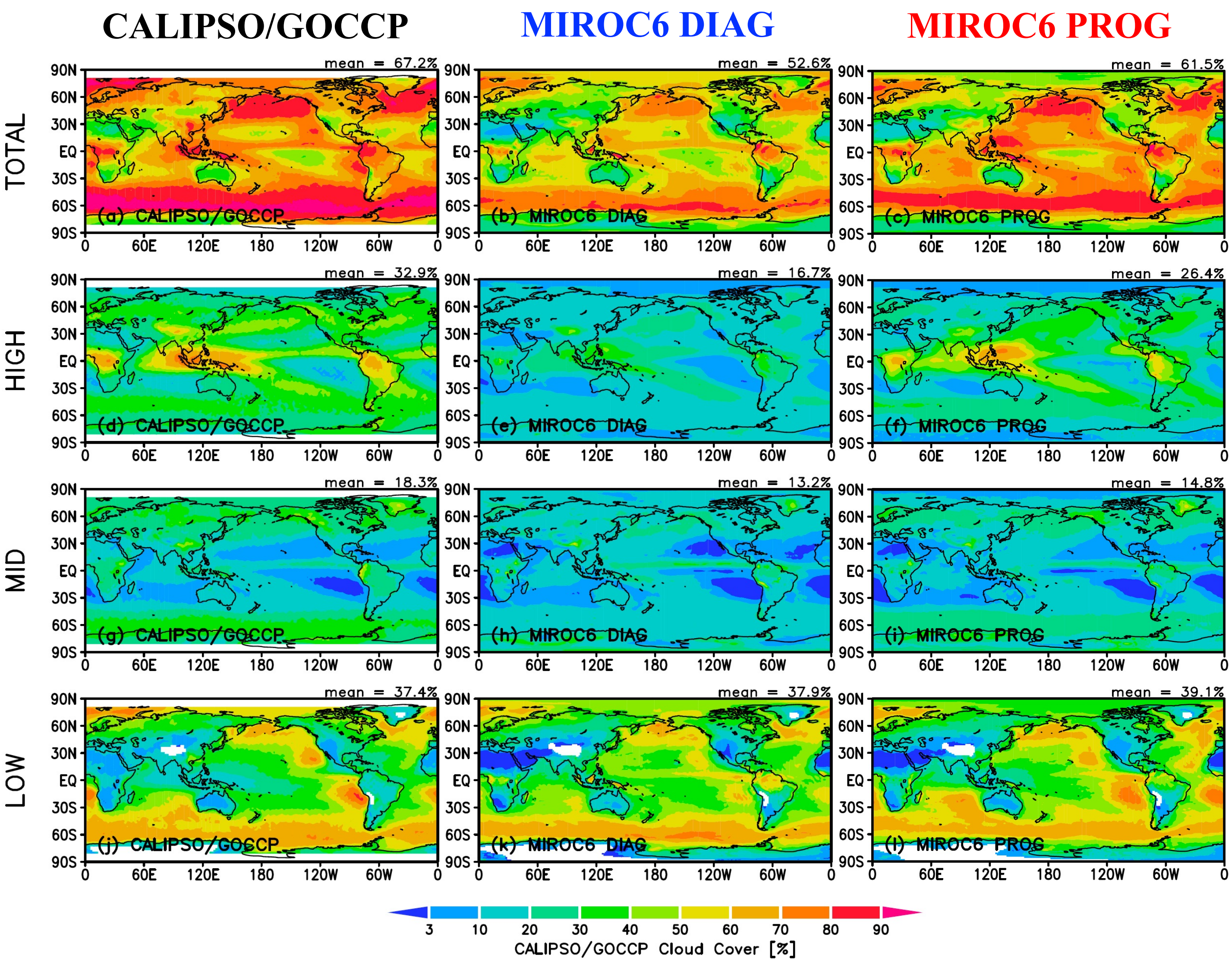
2) Ice microphysics (Michibata et al., *ACP'*20)

aerosol↑ => cloud water↑ => stronger SW ERF$_{aci}$

cloud water↑ => riming↑ => weakening of cloud lifetime effect

(Snow-induced ACI buffering)

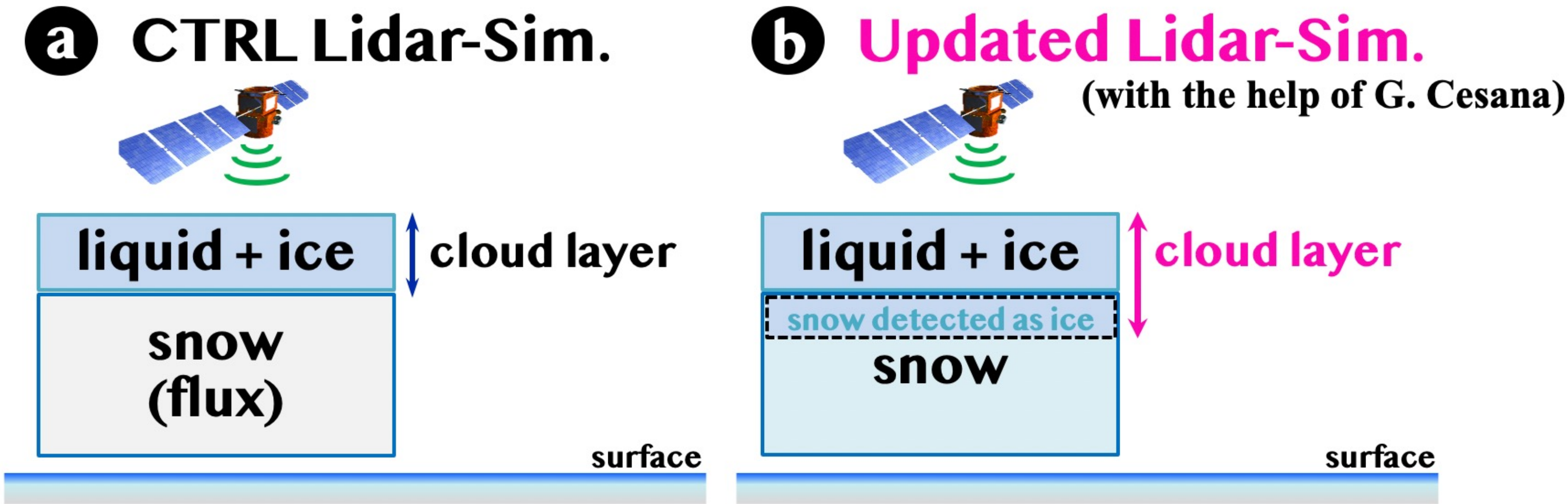
CALIPSO-GOCCP cloud fraction



still large biases, or not?

► **The underestimation is not always the model bias, but inconsistency of model - simulator. The effect of the treatment of snow on cloud coverage is very large.**

Model-vs-Observation inconsistency



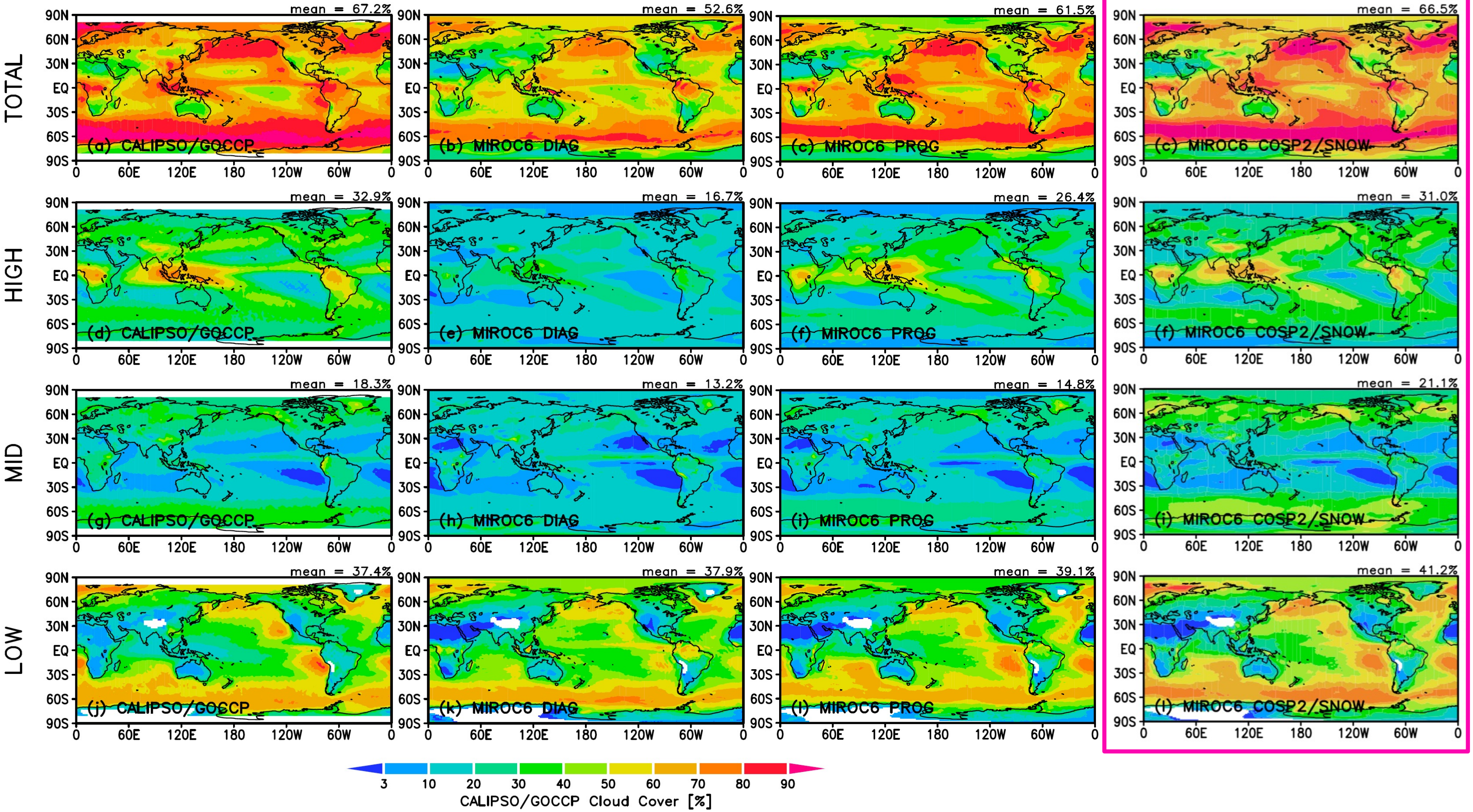
► **a) Old MIROC scheme w/ default lidar simulator**
- cloud layer is detected by the lidar backscattering from cloud droplet and ice crystals.
- lidar does not feel raindrop and snowflake because precipitation is instantaneously remove from the atmosphere.

► **b) Actual retrieval process (updated lidar simulator)**
- lidar cannot separate ice crystals and snowflake as done in bulk microphysics models.
- lidar observation partly includes the snow layer as the cloud layer.

► **Note: this is currently not the official version of the COSP**

CALIPSO-GOCCP cloud fraction

CALIPSO/GOCCP | MIROC6 DIAG | MIROC6 PROG | PROG New LidarSim



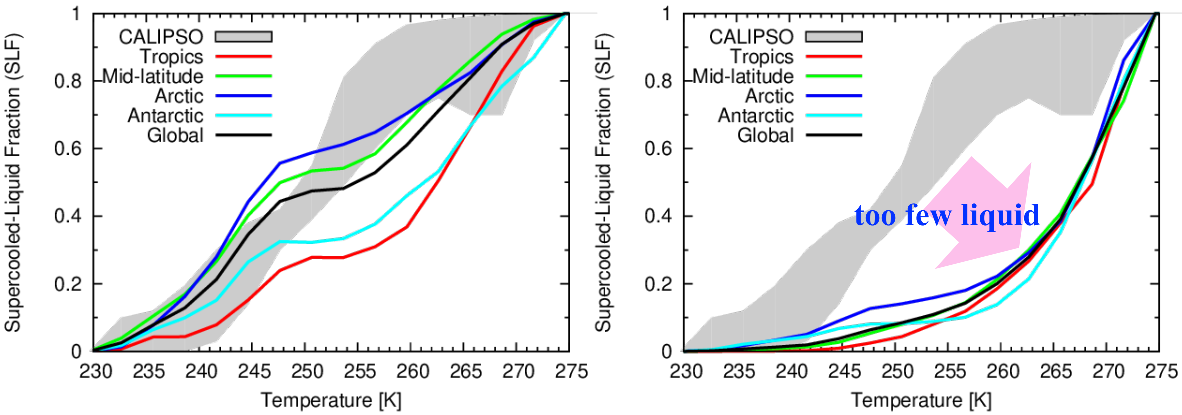
► **Note: The two use the same model outputs but only the lidar simulator is different.**

► **Mid- and high- clouds are sensitive to the lidar update.**

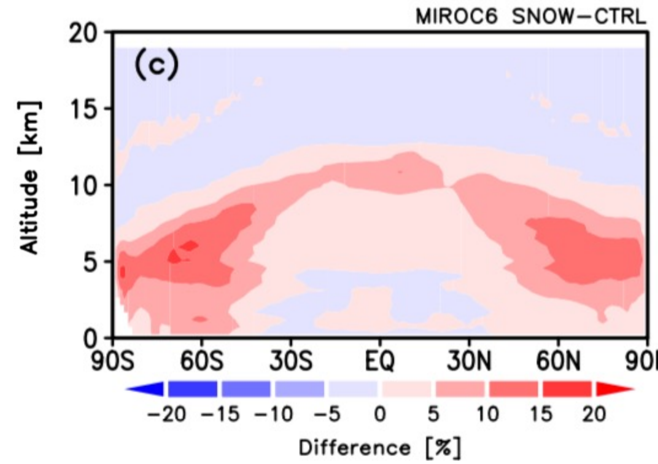
Cloud phase partitioning by temperature

SLF dependence on temperature

a CTRL Lidar-Sim. **b Updated Lidar-Sim.**



3D Cloud Fraction (w/ Snow – w/o Snow)



- ► **Supercooled Liquid Fraction (SLF) = Liquid / (Liquid + Ice)**
- ► **The impact of lidar update on cloud-phase partitioning is also significant.**
- ► **The denominator is increased by a part of snow detected as ice cloud.**
  – apparent liquid fraction is decreased.
  – If other GCMs incorporate prognostic precipitation, same problem will occur.
  – Underestimating SLF means higher potential of ice-to-liquid phase change.
  – larger negative cloud feedback and smaller climate sensitivity (Tan et al, 16)

Summary and next step

- ► **Recent advances in cloud and precipitation modeling in MIROC6**
  - – How can we improve model biases using satellite simulator?
    - – Combined use of MODIS and CloudSat observations helped to understand the discrepancy between model and observation.
    - – Prognostic precipitation is one of the desirable solutions for improving compensating errors between precipitation and energy budget.

- ► **Simulator is essential, but must be careful with its configuration.**
  - – consistent with model physics and retrieval processes?

- ► **EarthCARE simulator into global models**
  - – have to develop process-oriented metrics for model evaluation.
    - – Multiple sensor diagnosis (Suzuki et al., 2011)
    - – New dimensions from doppler CPR
      - – cloud-dynamics interactions; updraft velocity (Takahashi et al., 2017)
      - – regime-dependent aerosol-cloud interactions (Zhang et al., 2016)
  - – cloud-phase partitioning and precipitation-phase partitioning (Kay et al., 2018)
  - – retrievals of rain, snow, graupel/hail to evaluate model performance