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Process representations of cloud and precipitation in MIROC6 with prognostic precipitation: Evaluation against A-Train observations

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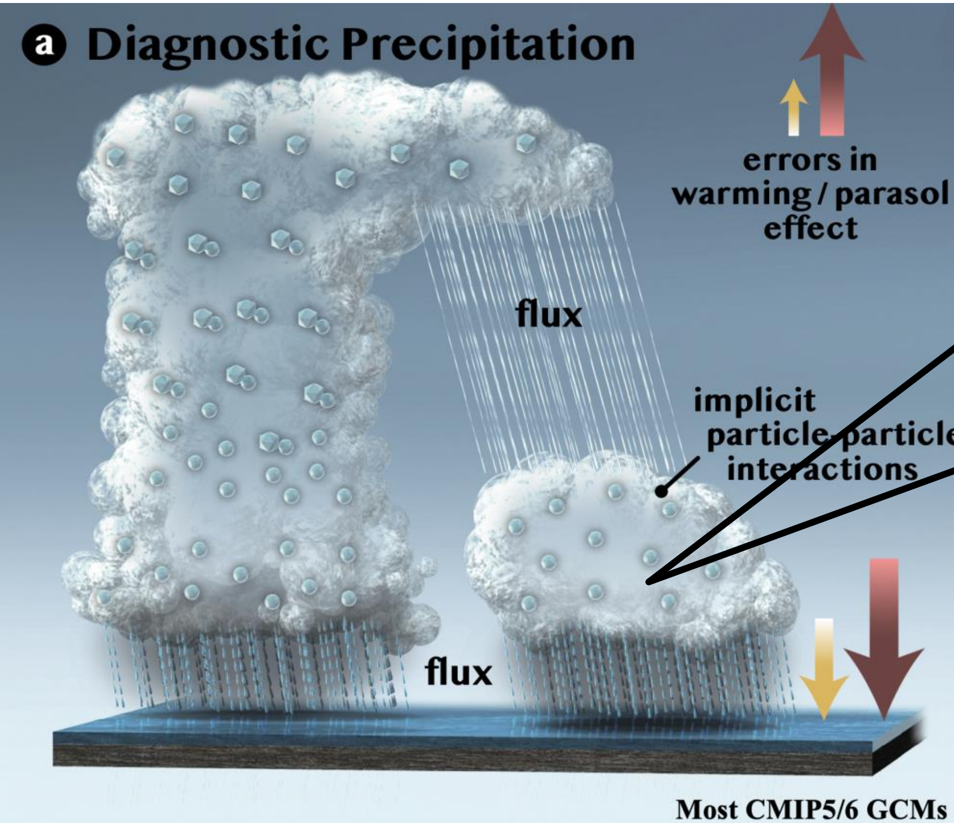
- **What can be done using satellite observations to constrain the model uncertainty?**
- **How can we improve model biases in cloud and precipitation processes using a simulator?**

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.

Diagnostic-vs-Prognostic precipitation



autoconversion: $P_{aut} \sim \mathrm{f}(q_c, N_c)$

cloud + cloud → rain

link to aerosols

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

rain + cloud → rain

► **accretion << autoconversion**

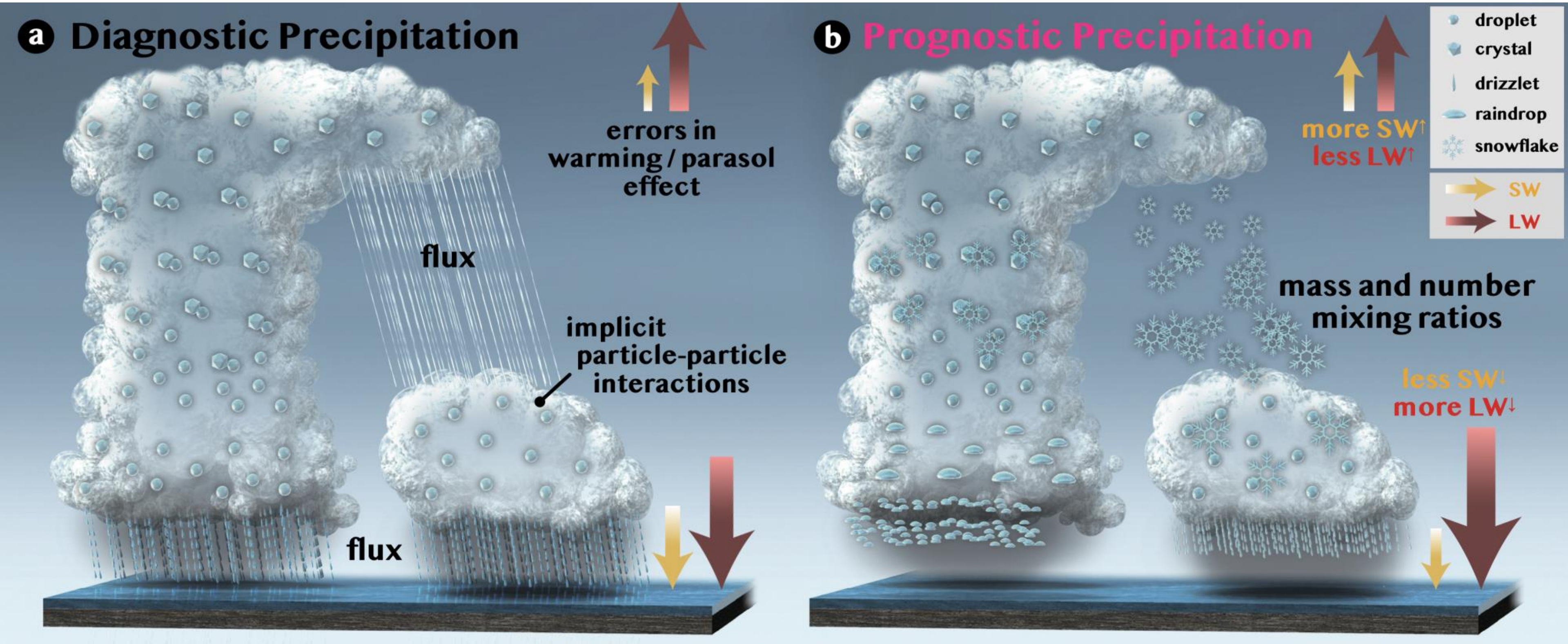
► **Most GCMs treat precipitation diagnostically**

– **instantaneously removed from the atmosphere (Ghan and Easter, 1992)**

– **overestimate of the magnitude of ACI (Quaas et al., 2009; Wang et al., 2012)**

– **bias in warm rain frequency and intensity (Stephens et al., 2010)**

Diagnostic-vs-Prognostic precipitation

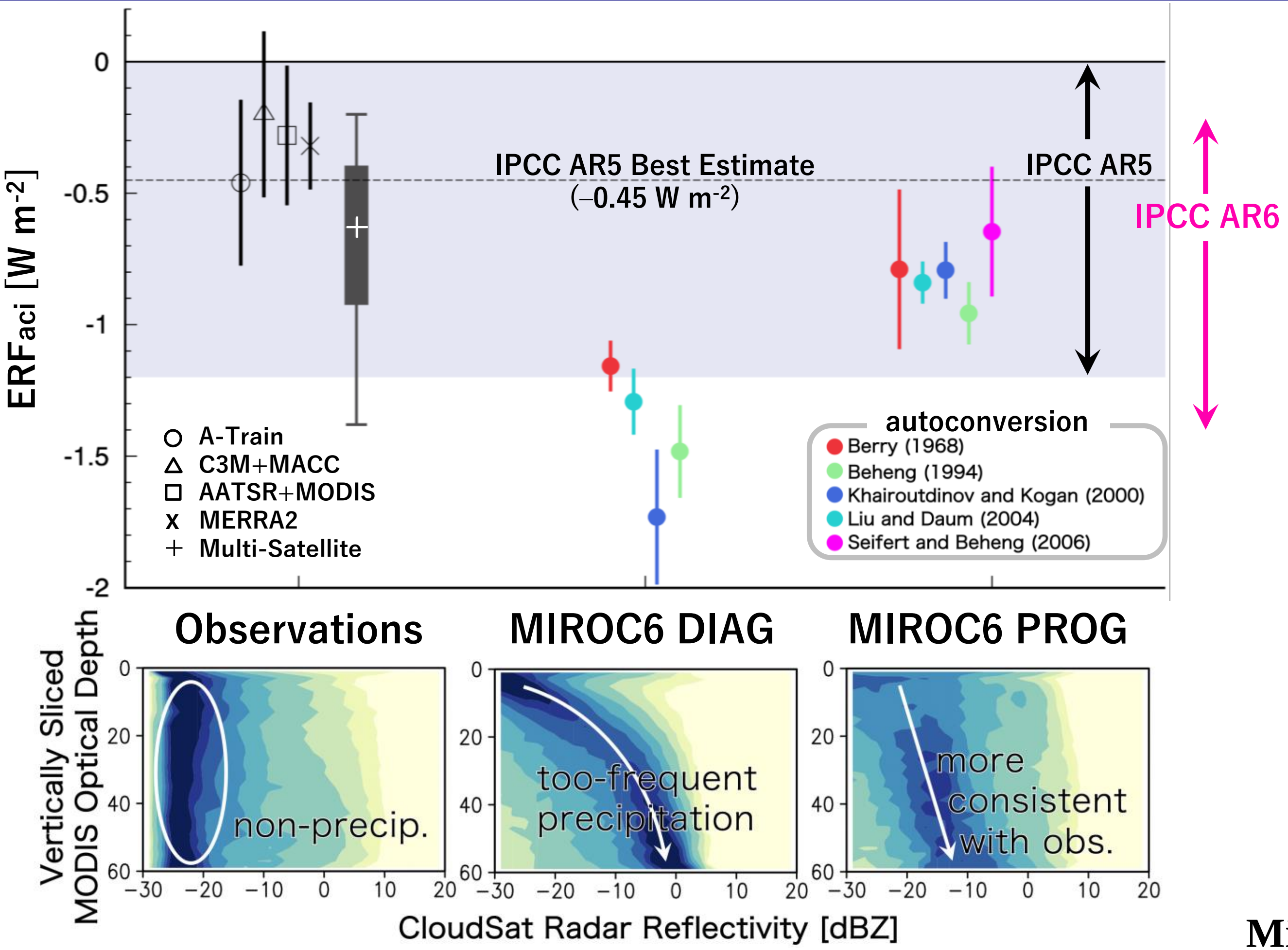


Most CMIP5/6 GCMs

Michibata et al. (*JAMES*'19)

- **Prognostic precipitation in MIROC6**
  - prognoses mass and number mixing ratios of rain (q_r, N_r) and snow (q_s, N_s)
  - keeps precipitation in the atmosphere across model timesteps
  - explicitly considers radiative effects of precipitating hydrometeors
- **Other some (but still limited) GCMs including PROG**
  - CAM MG2/3; ECHAM6-HAM; GISS-ModelE3; ECMWF-IFS; HadGEM3; E3SM

Improved warm-rain formation and ACI

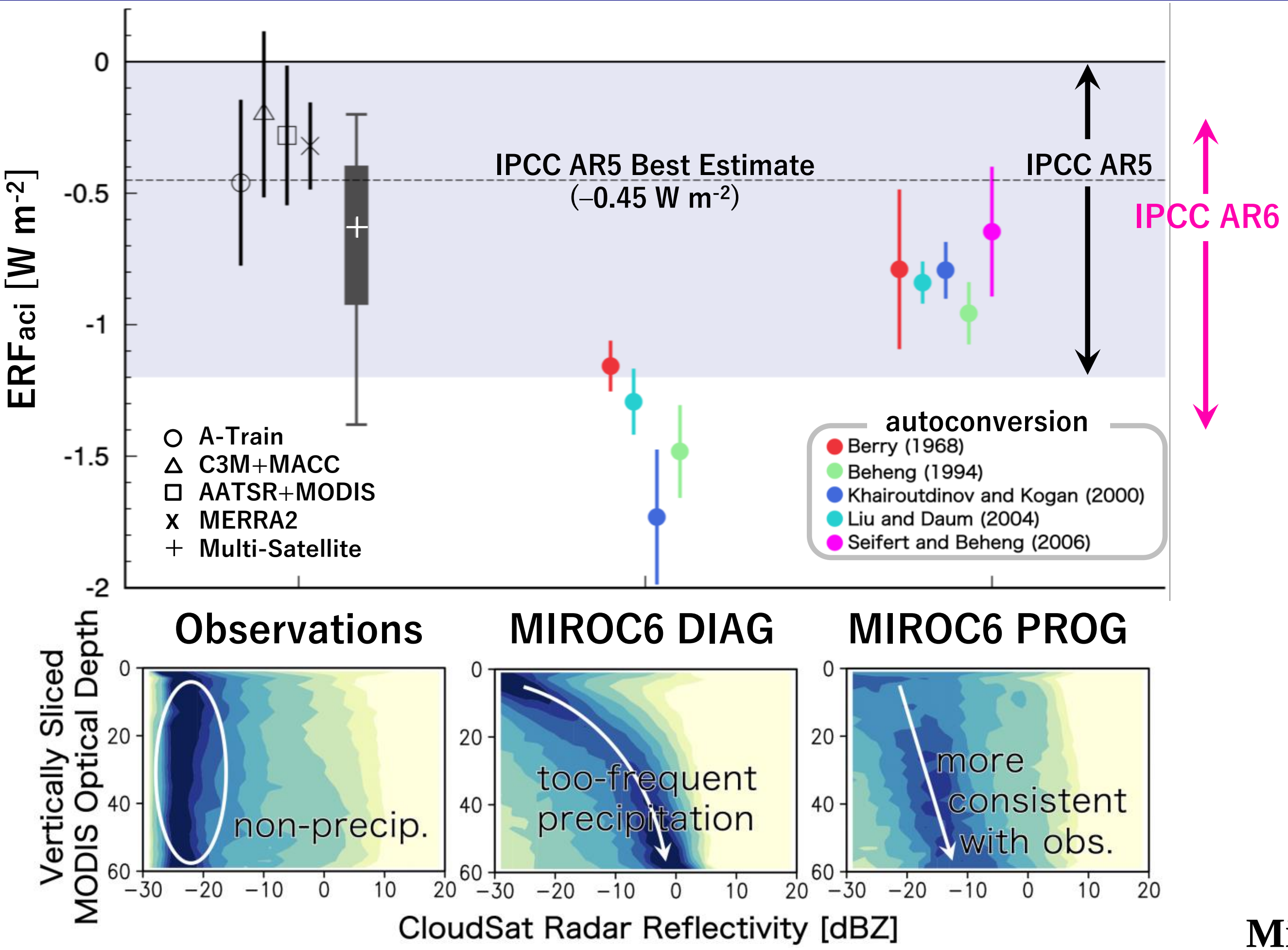


Michibata and Suzuki (*GRL*'20)

- ► **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

- ► **The new scheme also improves the magnitude of aerosol-cloud interactions**

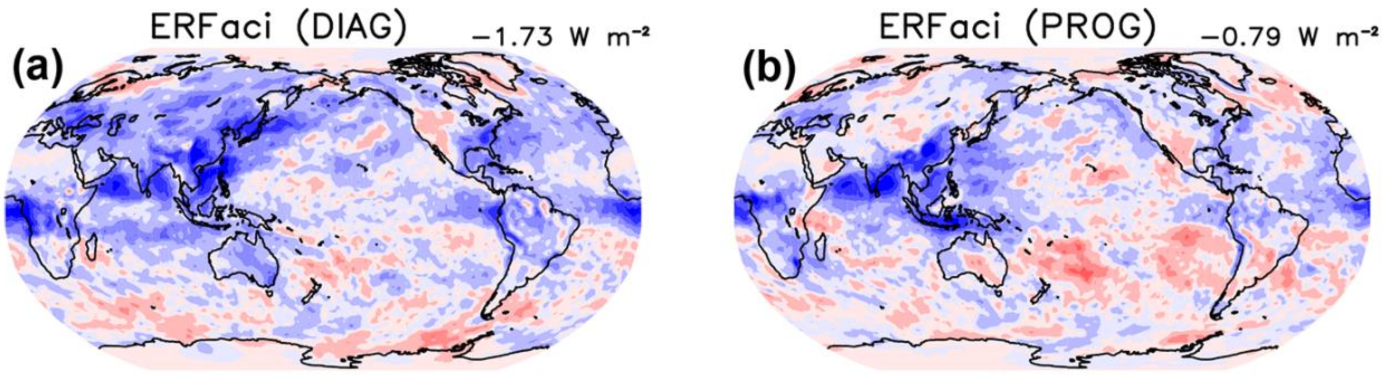
Improved warm-rain formation and ACI

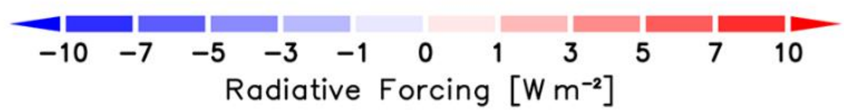


Michibata and Suzuki (*GRL*'20)

Prognostic precipitation can keep a good balance of precipitation and the required energy budget.

Mechanisms of the weakening ERF_{aci}





Michibata et al. (2020, *ACP*)

DIAG

PI aerosol → PD aerosol

ERF_{aci} = –1.73 W m^{-2}

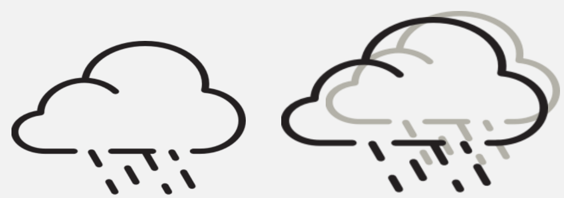
cloud lifetime effect

Larger dLWP

PROG Rain DIAG Snow

PI aerosol → PD aerosol

ERF_{aci} = –1.57 W m^{-2} (– 10%)



cloud lifetime effect
+ explicit accretion (rain)

Smaller dLWP

PROG Rain+Snow

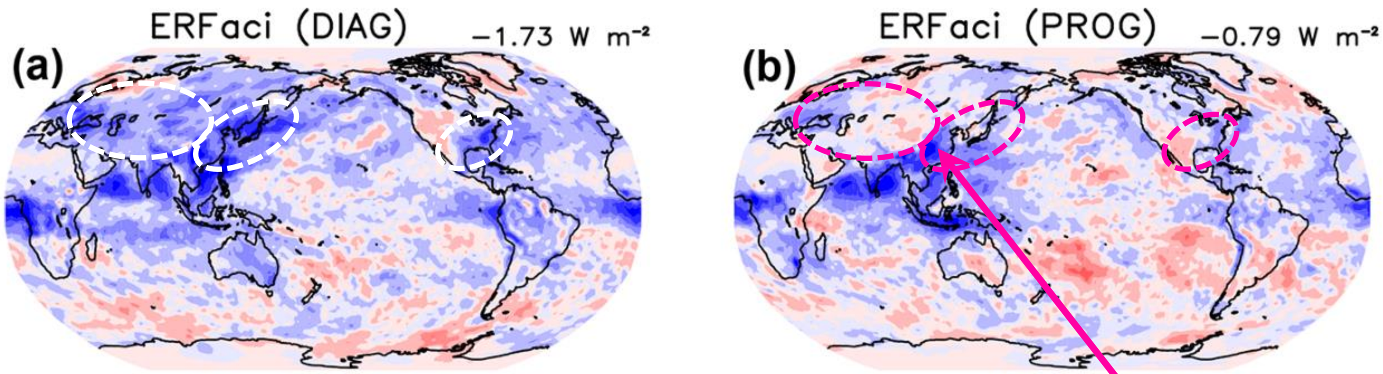
PI aerosol → PD aerosol

ERF_{aci} = –0.79 W m^{-2} (– 54%)

cloud lifetime effect
+ explicit accretion (rain)
+ explicit accretion (snow)

dLWP ~ 0 g m^{-2}

Mechanisms of the weakening ERF$_{aci}$



Research article

Snow-induced buffering in aerosol–cloud interactions

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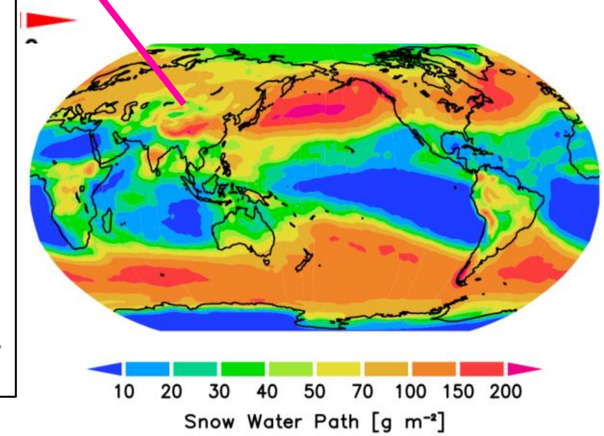


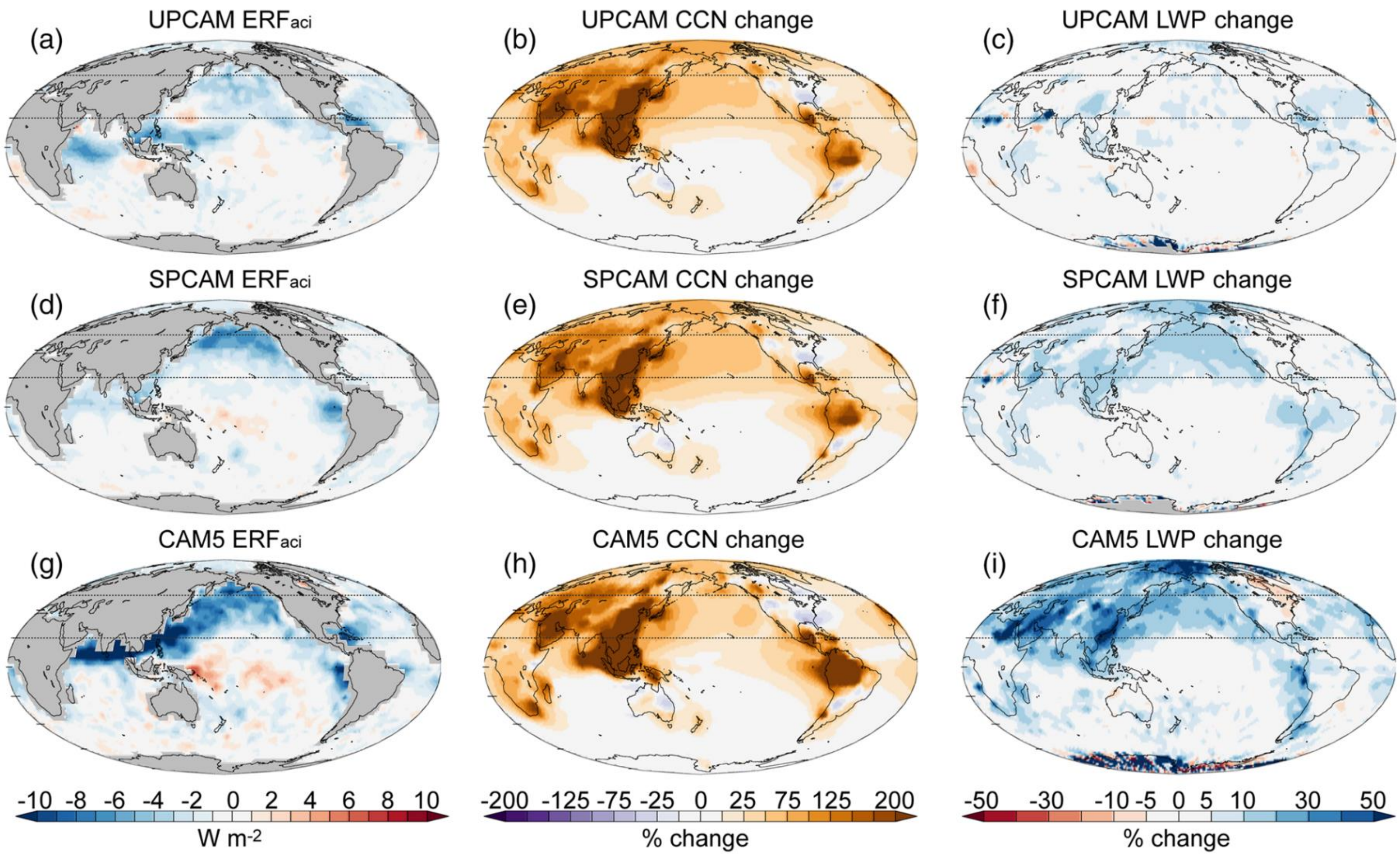
- ► **Regions where ERF$_{aci}$ reduction can be found has abundant snow water path.**
- ► **The falling snow over the midlatitude effectively accretes low-level liquid clouds through the riming process.**

ERF_{aci} in other (high-reso) models

► **Different LWP response in CAM5, SPCAM, and UPCAM**

High-reso (UPCAM)

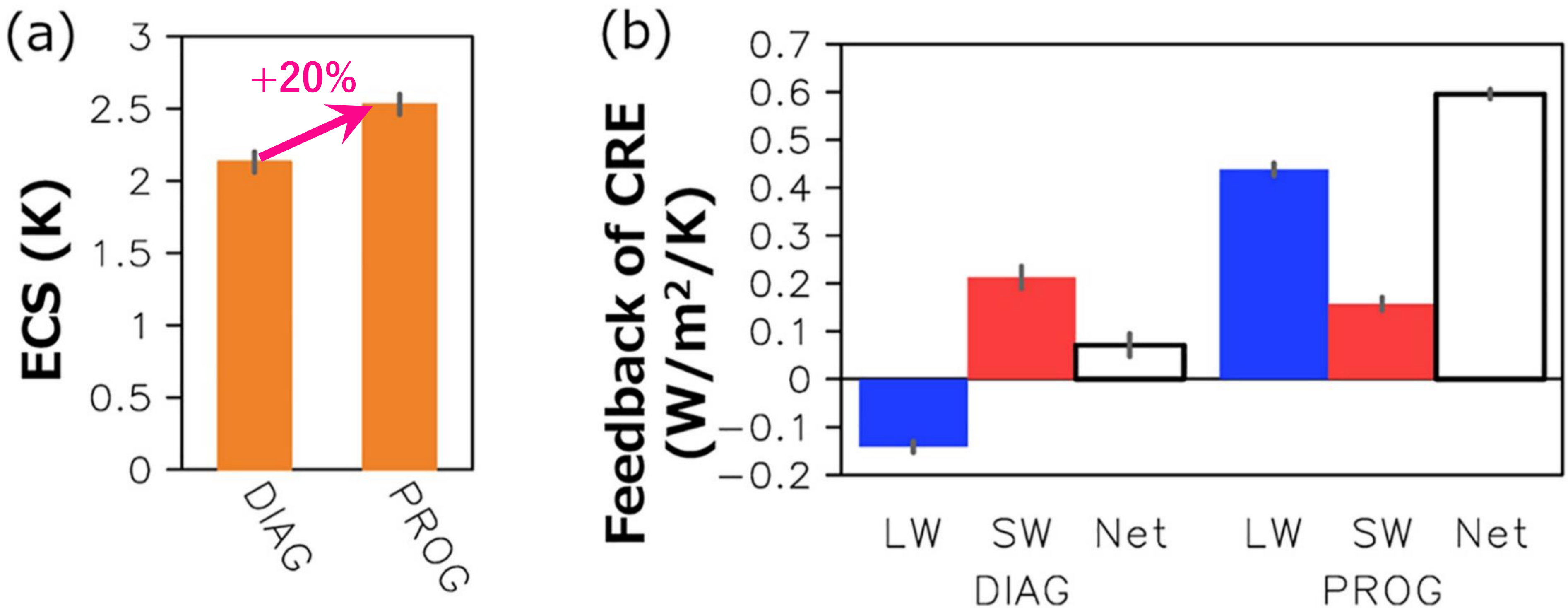
Low-reso (GCMs)



Chris Terai et al. (2020, *JAMES*)

► **LWP change seems less evident in more high-reso models.**

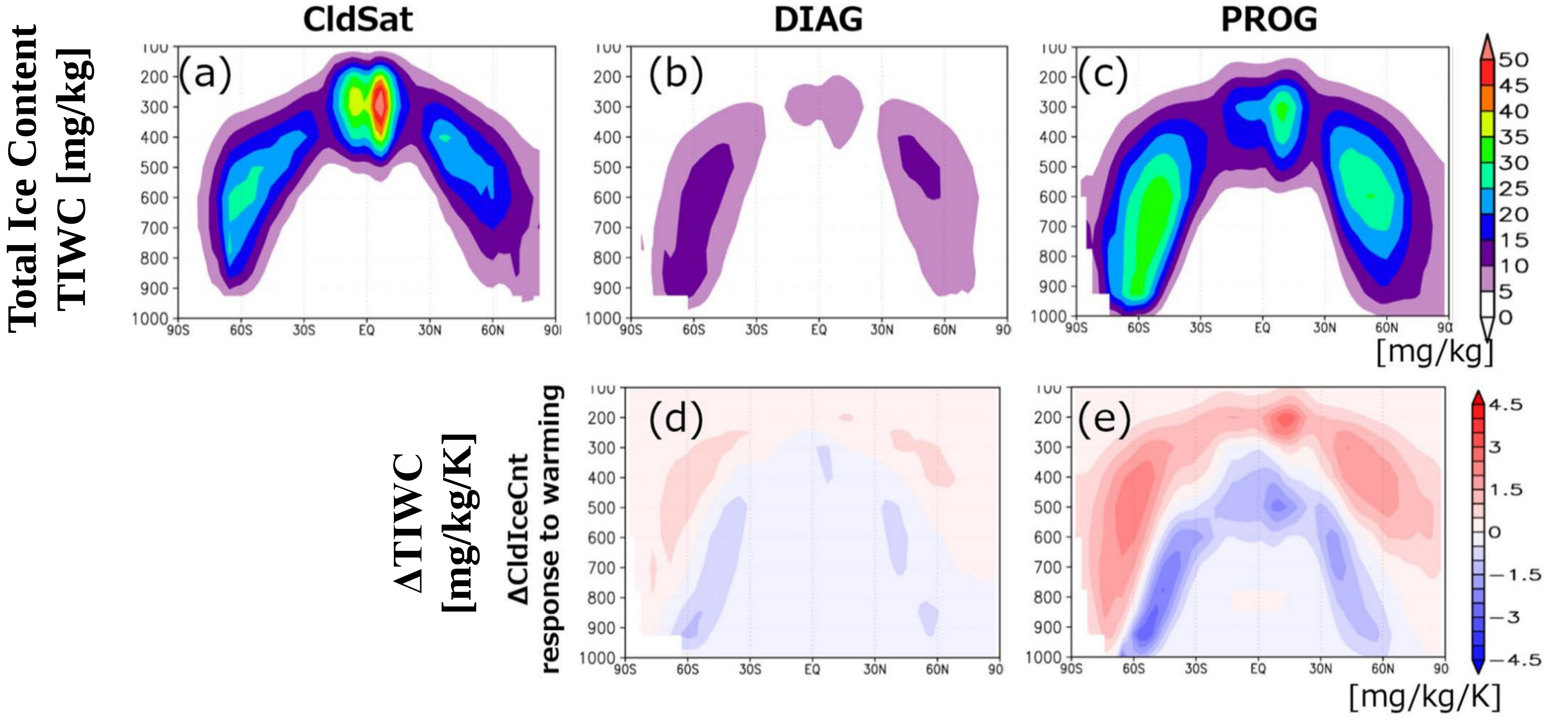
Changes in ECS and cloud feedback



Hirota et al. (2022, *GRL*)

- **The PROG model represents more warming due to increased LW cloud feedback compared to DIAG model.**
- **The increased LW feedback is linked to increased (realistic) cloud ice and snow in the PROG, resulting in enhanced warming.**

Changes in ECS and cloud feedback



- ► **The PROG model represents more warming due to increased LW cloud feedback compared to DIAG model.**
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Use of satellite simulator: Precipitation flag

AGU100 ADVANCING EARTH AND SPACE SCIENCE

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2017JD028213

Key Points:
- Study provides tools to evaluate model rain and snow frequency at a range of intensities using CloudSat (94-GHz) radar reflectivities
- Applying tools shows that the Community Earth System Model has excessive near-surface rain and snow frequency, especially for light rain
- Projected precipitation frequency changes in a warmer world are detectable but contain imprints of present-day model biases

Scale-Aware and Definition-Aware Evaluation of Modeled Near-Surface Precipitation Frequency Using CloudSat Observations

Jennifer E. Kay[1,2], Tristan L'Ecuyer[3], Angeline Pendergrass[4], Helene Chepfer[5], Rodrigo Guzman[5], and Vineel Yettella[1,2]

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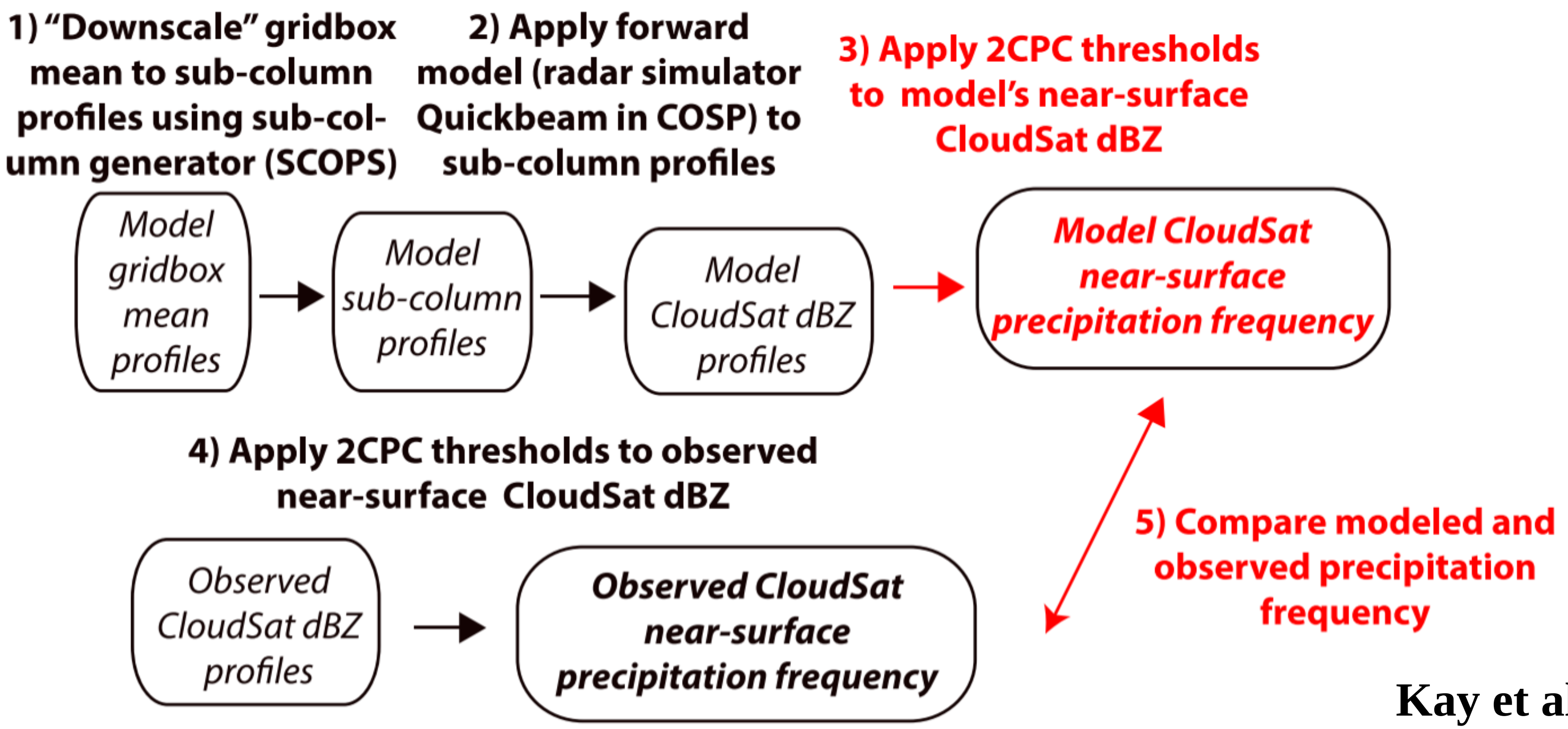
Kay et al. (2018, *JGR*)

- **We must be careful about differences in resolution and definition.**
- **The precipitation flag provides information on the precipitation phase and intensity, in a manner that is consistent with the algorithms of the CloudSat product.**

Use of satellite simulator: Precipitation flag



Kay et al. (2018, *JGR*)

- **We must be careful about differences in resolution and definition.**
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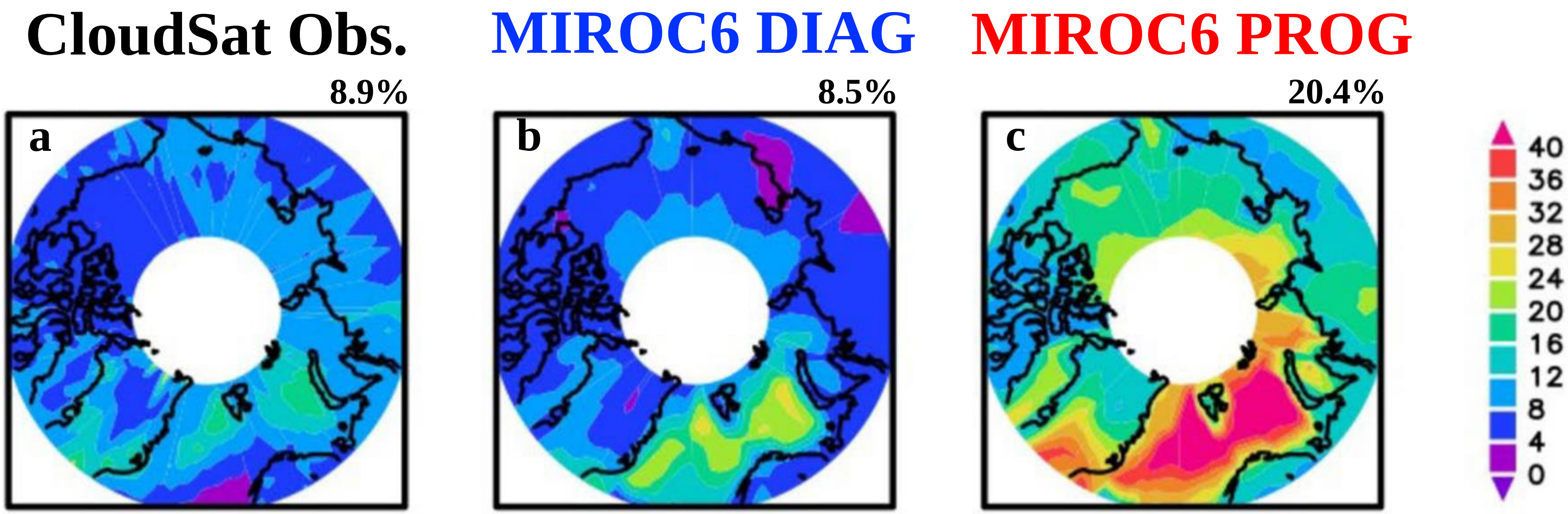
Regional bias in snowfall occurrence

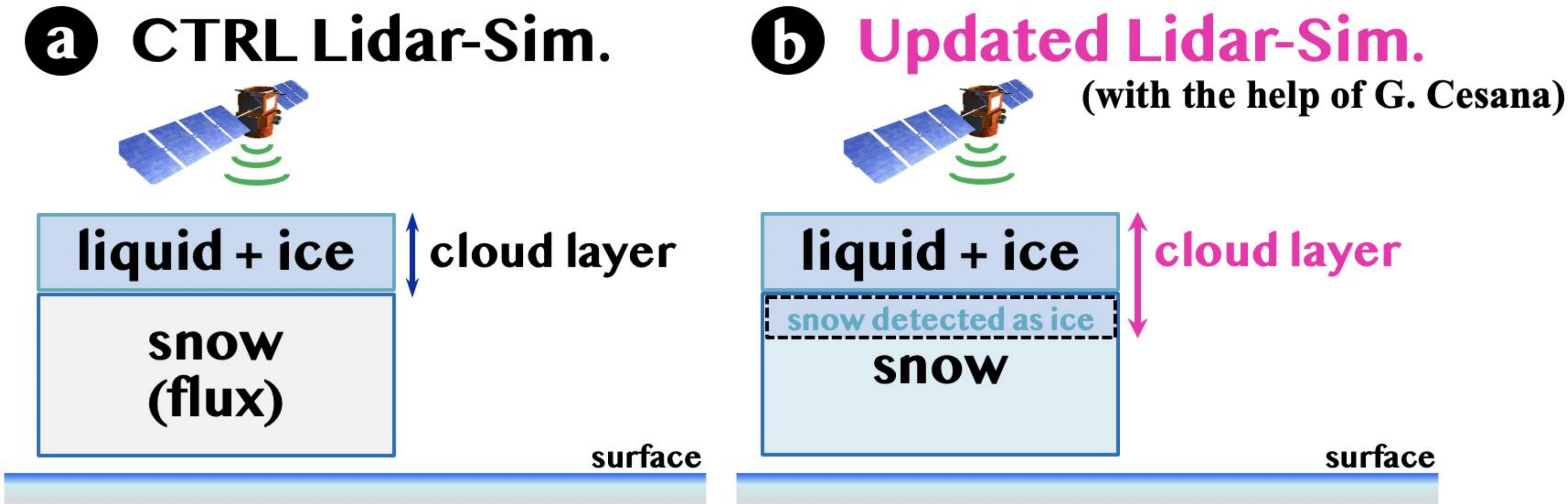
- **PrecipFlag: Occurrence frequency of surface snowfall from CloudSat and MIROC6**



Imura and Michibata (2022, *JAMES*)

- **MIROC6 PROG produces the Arctic snowfall "too-frequently".**
- **The too-frequent snowfall bias compensates by too-light intensity.**
- **The error compensation can be related to biases in the polar climate projection.**

Model-vs-Observation inconsistency



Imura and Michibata (*JAMES*'22)

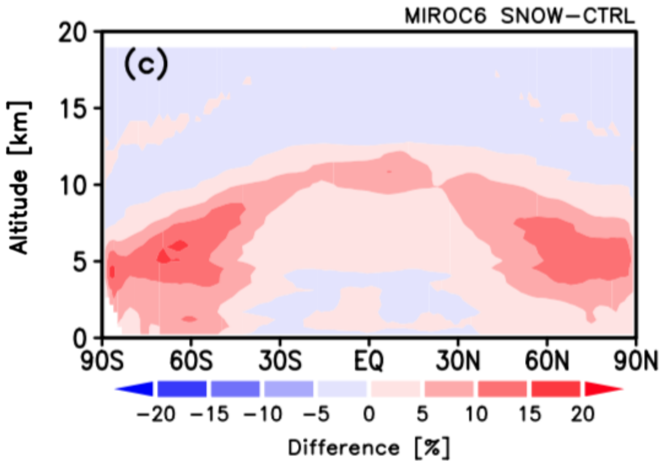
- ► **a) Old MIROC scheme w/ default lidar simulator**
  – cloud layer is detected by the lidar backscattering from cloud droplet and ice crystals.
  – lidar does not feel raindrop and snowflake because precipitation is instantaneously remove from the atmosphere.

- ► **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.

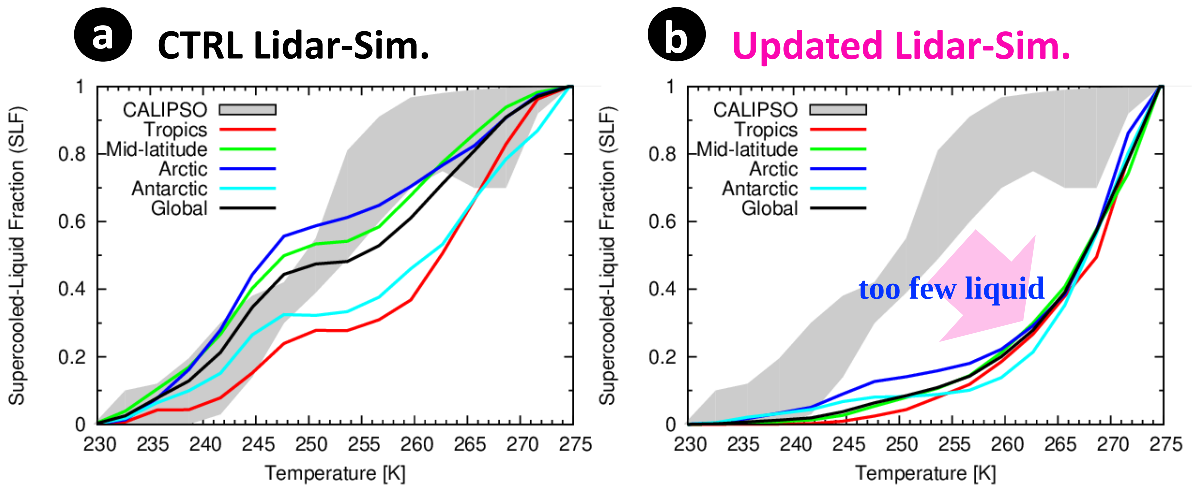
- ► **Note: this is currently not the official version of the COSP**

Cloud phase partitioning by temperature

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



SLF dependence on temperature



Imura and Michibata (*JAMES*'22)

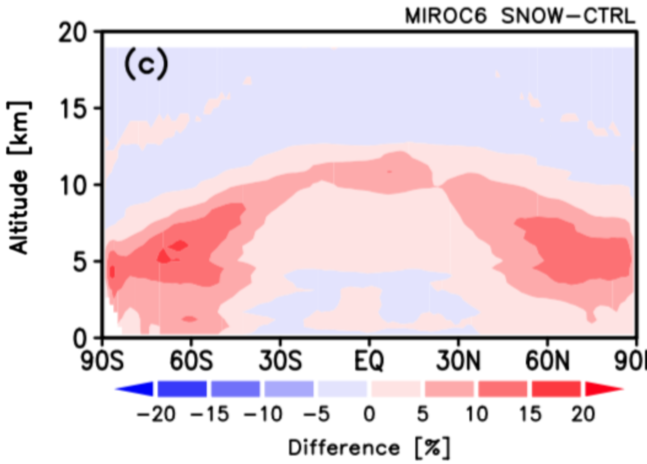
► **Supercooled Liquid Fraction (SLF) = Liquid / (Liquid + Ice)**

► **The impact of lidar update on cloud-phase partitioning is also significant.**

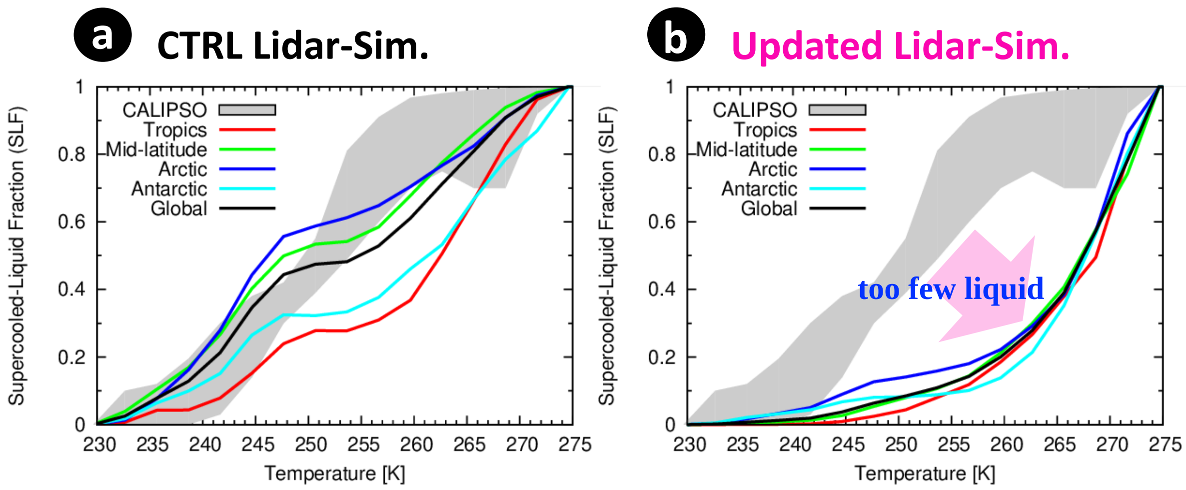
► **The denominator is increased by a part of snow detected as ice cloud, resulting in the apparent SLF being decreased.**
- **If other GCMs incorporate prognostic precipitation, same problem will occur.**
- **Underestimating SLF means higher potential of ice-to-liquid phase change.**
  - **larger negative cloud feedback and smaller climate sensitivity (Tan et al, 16)**

Cloud phase partitioning by temperature

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



SLF dependence on temperature



Imura and Michibata (*JAMES*'22)

– depend on how much precipitation is within the clouds
– EarthCARE and/or GPM missions for process improvement

– The model may have potential bias in the phase partitioning of cloud and precipitation.

Summary and next step

► Recent advances in cloud and precipitation modeling in MIROC6

- How can we improve model biases using satellite simulator?
- Prognostic precipitation: one of the desirable solutions, but not perfect.
- Inter-model comparison among PROG GCMs and GCRMs.
- How the model resolution and dynamics control ACI and cloud feedback

► EarthCARE and process studies with satellite simulator

- satellite simulator is an essential tool
- consistent with model physics and retrieval processes?
- synergistic use of CloudSat/CALIPSO/MODIS/GPM will also be useful

to

?