Improvement of a representation of mixed-phase clouds, and its impact on a global cloud-system-resolving simulation

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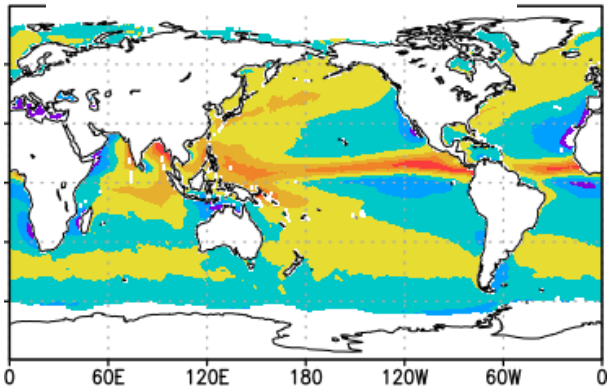
統合的気候モデル高度化研究プログラム Integrated Research Program for Advancing Climate Models (TOUGOU)

Background: Global distributions

Need improvement of Mixed-phase clouds in one-moment scheme

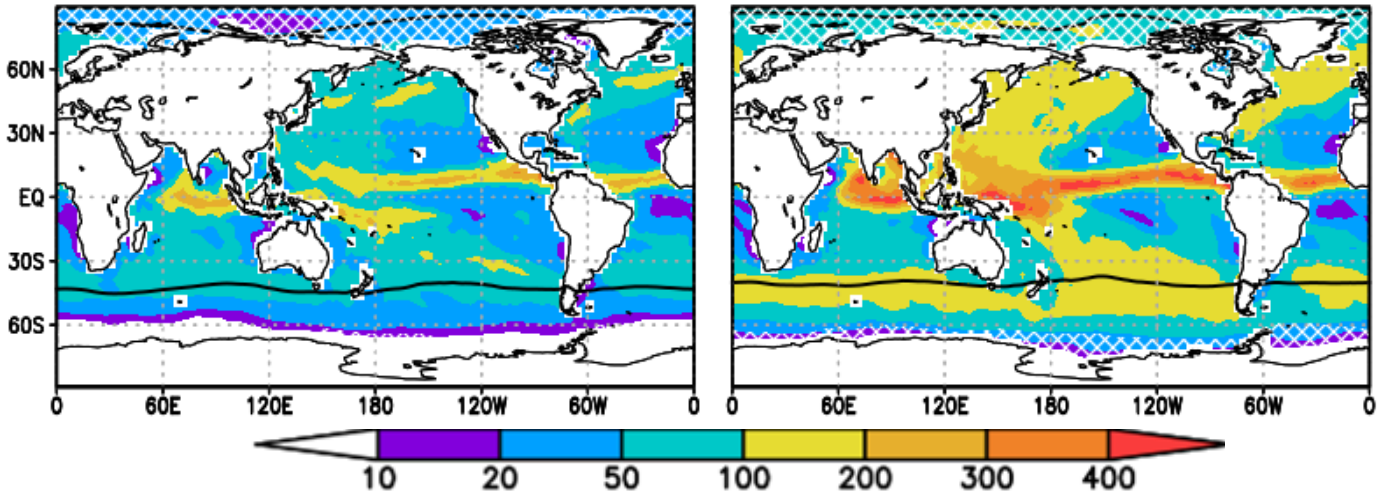
Overestimations of the Bergeron-Findeisen and riming processes and a growth rate from cloud water to rain lead to a fewer LWP

Obs (MAC-LWP)



LWP: one moment microphys)

two-moment microphys



Tomita (2008,JMSJ)

Seiki and Nakajima (2014,JAS)

Background: Vertical structures

backscatter (1/(m sr))

Need improvement of Mixed-phase clouds in one-moment scheme

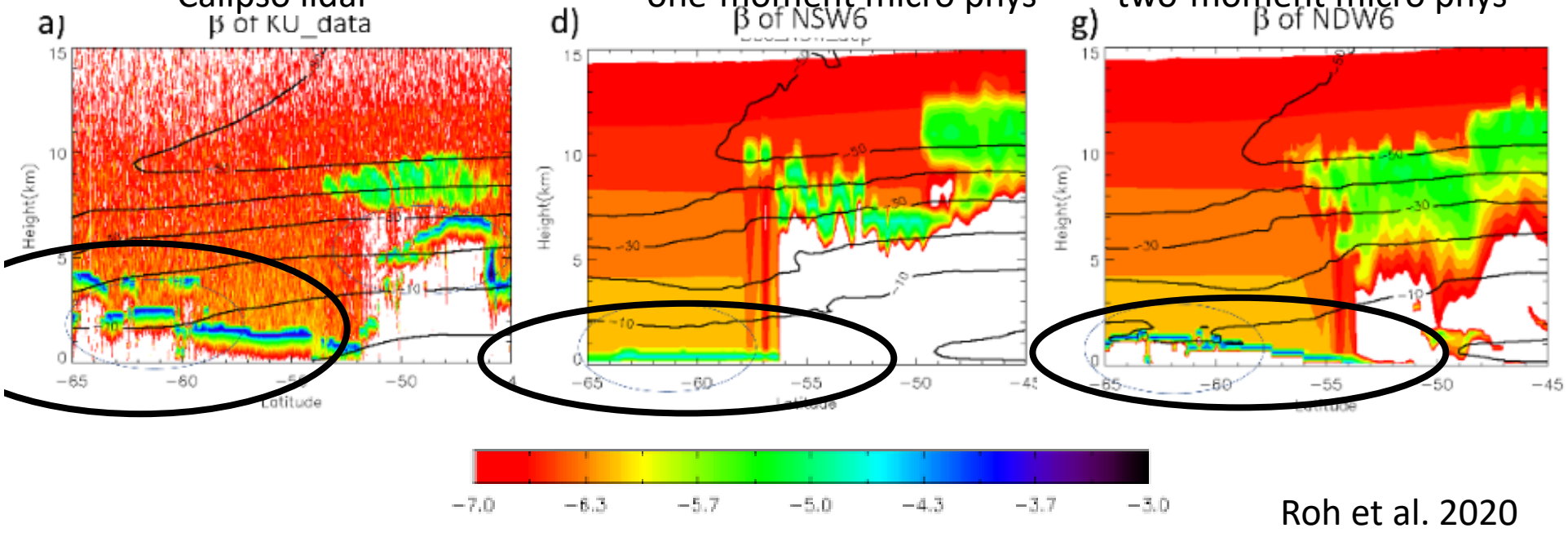
Table 2. Cloud fractions for the three temperature regimes.

	Clouds for only $T > 0°C$ (%)	Clouds for only $-20°C < T < 0°C$ (%)	Clouds for only $T < -20°C$ (%)
KU data	6.6	60.2	33.2
NSW6	0.2	33.7	60.1
NDW6	0.4	67.0	32.6

Calipso lidar

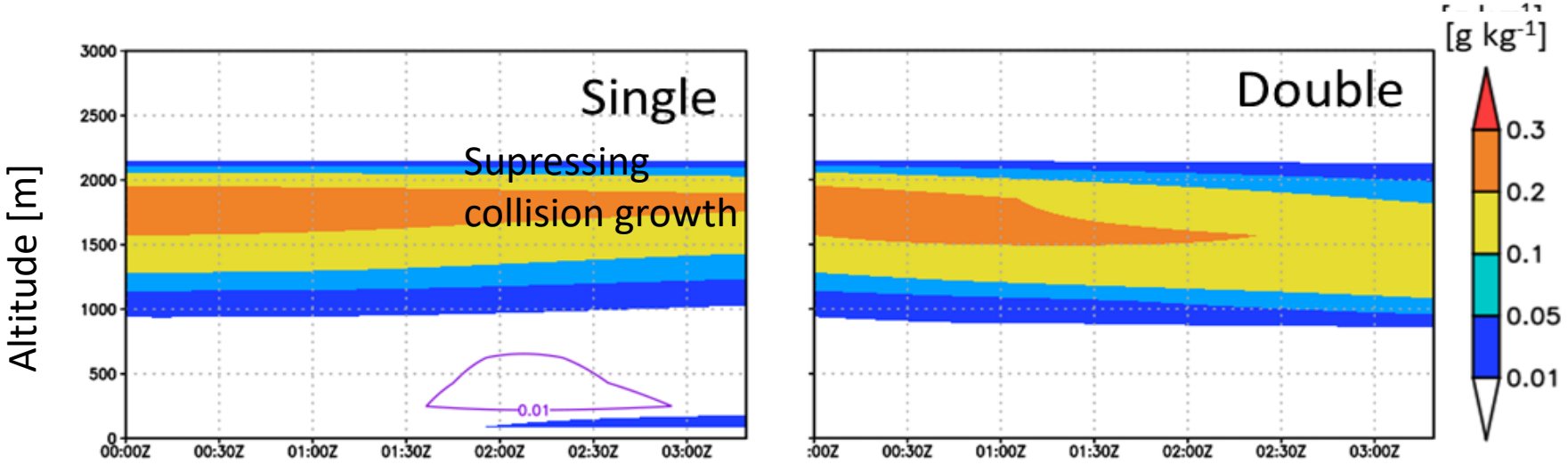
one-moment micro phys

two-moment micro phys



Roh et al. 2020

Background : Improving supercooled droplets with SCM



Time (HH:MM)

- Key physics
- Conversion from cloudwater to rain (Berry, 1968 ➔ Khairoutdinov and Kogan, 2000)
- Diagnostics of ice nucleation (Hong et al., 2014 ➔ Phillips et al., 2007)
- Suppressing Sublimation and ventilation growth of Snow and graupel

<u>Low-level mixed-phase clouds succssesfully maintained after the improvement based on detailed two-moment microphys</u>

Seiki and Roh 2020, JAS

Purpose

- As in most GCMs, a NICAM one-moment microphys has suffered from a representation of supercooled water, which bias has led to weaker reflection of solar incident
- Roh et al. (2020, JAS), Seiki and Roh (2020, JAS) recently improved the one-moment microphysics scheme using Satellite data and two-moment microphys result, and verified in single-column simulations

- This study examines impacts of the improved one-moment microphys scheme in a global NICAM simulation,
  - Cloud coverages, radiative budgets, Spatial structures of mixed phase clouds, etc…

Physics schemes in recent NICAM simulations

Model	NICAM16-S (NICAM.16 for CMIP6)
Cloud microphysics	NICAM Single-moment Water 6 (NSW6) (Tomita, 2008; Roh and Satoh, 2014; Roh et al., 2017)
Cumulus convection and laege-scale condensation	Not used
Radiation	MstrnX (Sekiguchi and Nakajima, 2008), updated radiation table (Seiki et al., 2014), and coupling with cloud microphysics
Turbulence	Mellor-Yamada Nakanishi-Niino (MYNN2) (Nakanishi and Niino, 2006; Noda et al., 2010)
Gravity wave	Orographic gravity wave drag (McFarlane, 1987)
Land surface	Minimal Advanced Treatments of Surface Interaction and RunOff (MATSIRO) (Takata et al., 2003) with wetland scheme (Nitta et al., 2017) and albedo modification
Ocean surface flux	Bulk surface scheme (Louis, 1979); surface roughness is evaluated following Fairall et al. (2003) and Moon et al. (2007)
Ocean model	Fixed to observation (or single layer slab ocean with a nudging toward observation)

→ Seiki and Roh (2020)
+
Fall of ice crystals

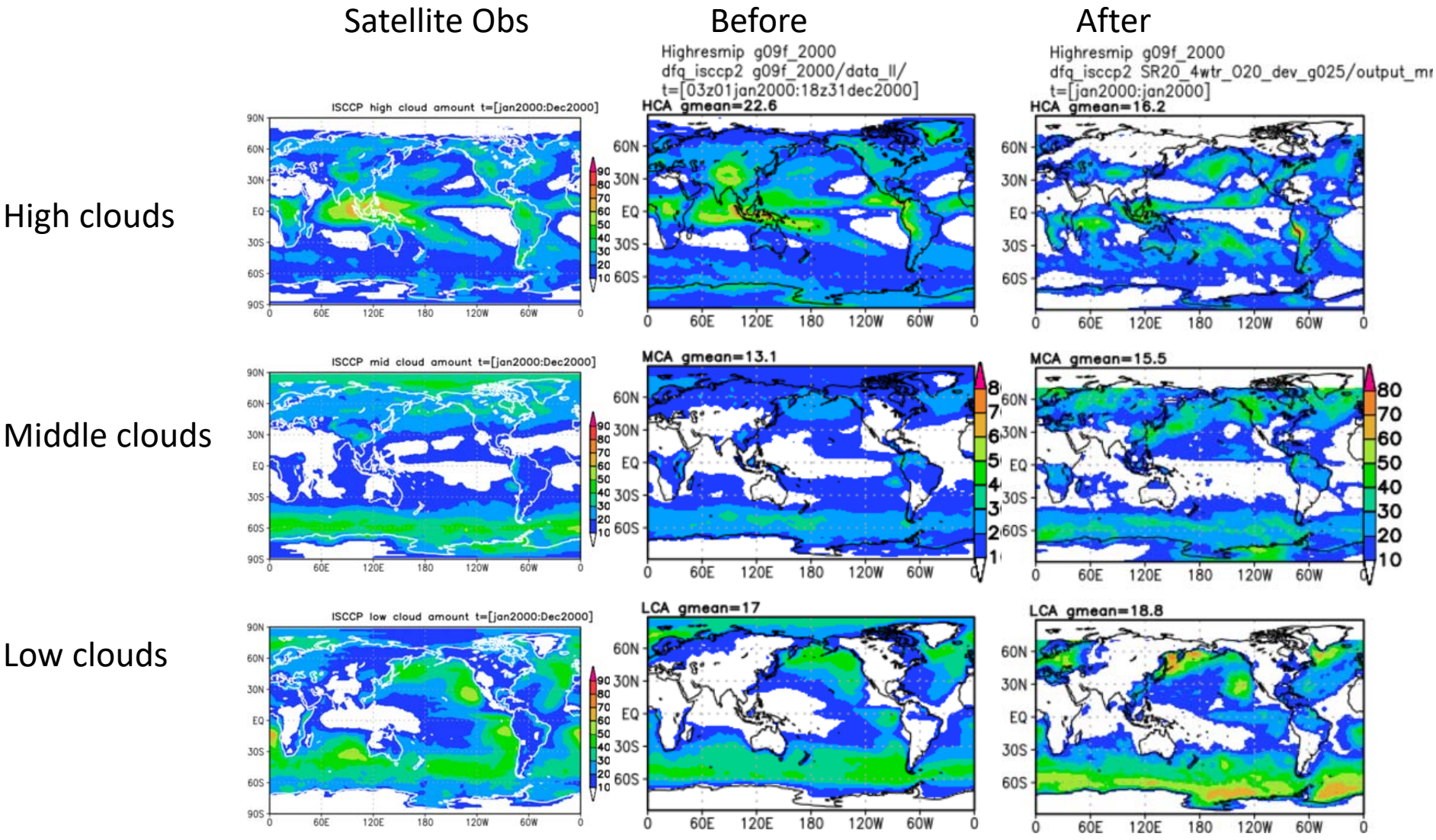
→ Ohno et al. (2020)

- ✓ Setup following the HighResMIP (Roberts et al. 2018)
- ✓ All simulations shown here are performed with a 14-km mesh
- ✓ One-year simulation (yr. 2000)

Kodama et al. 2021, GMD

Cloud coverages

(evaluated by an ISCCP satellite simulator)



Zonal-means of Condensates

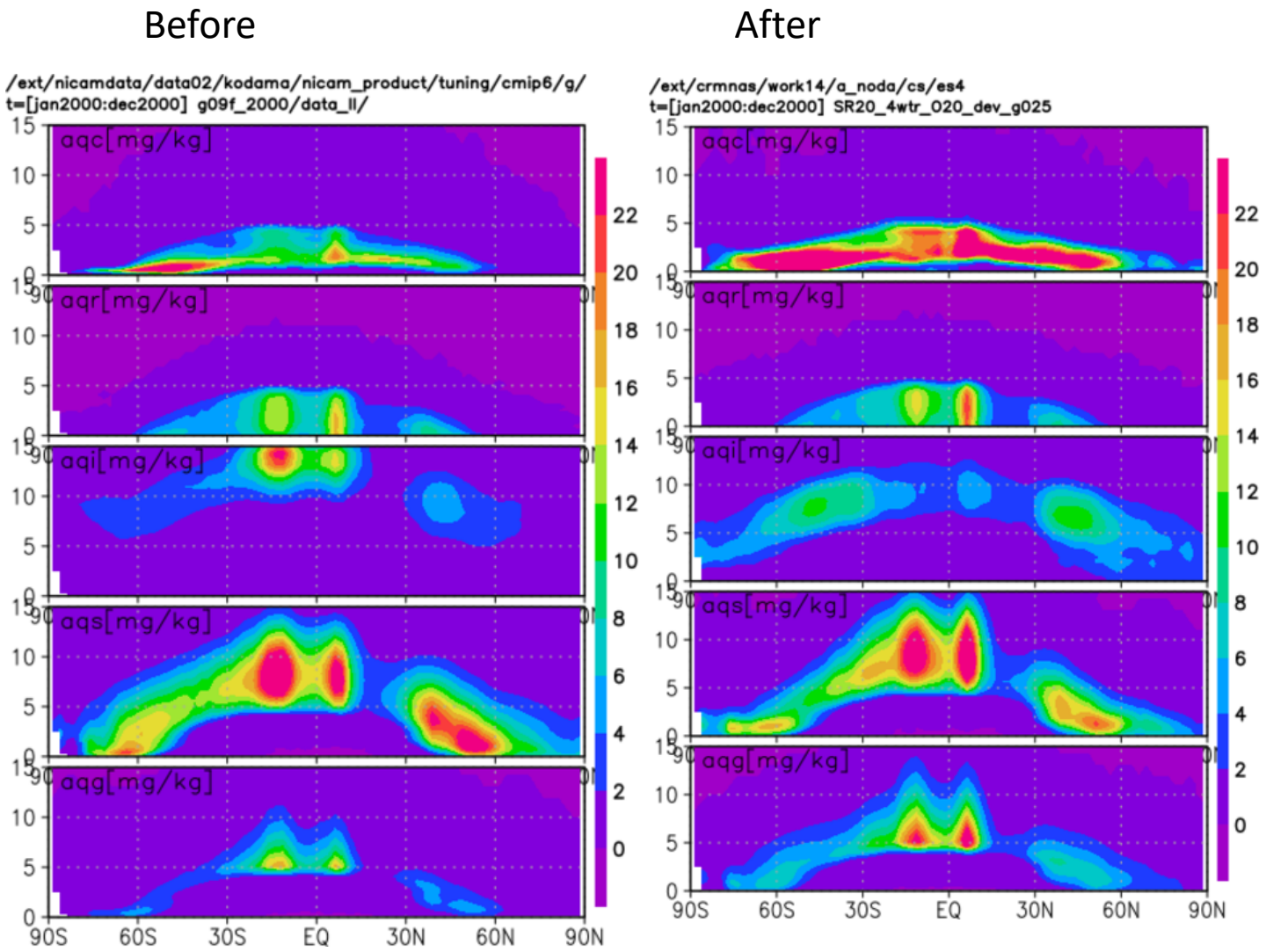
Cloud water

Rain

Cloud ice

Snow

Graupel



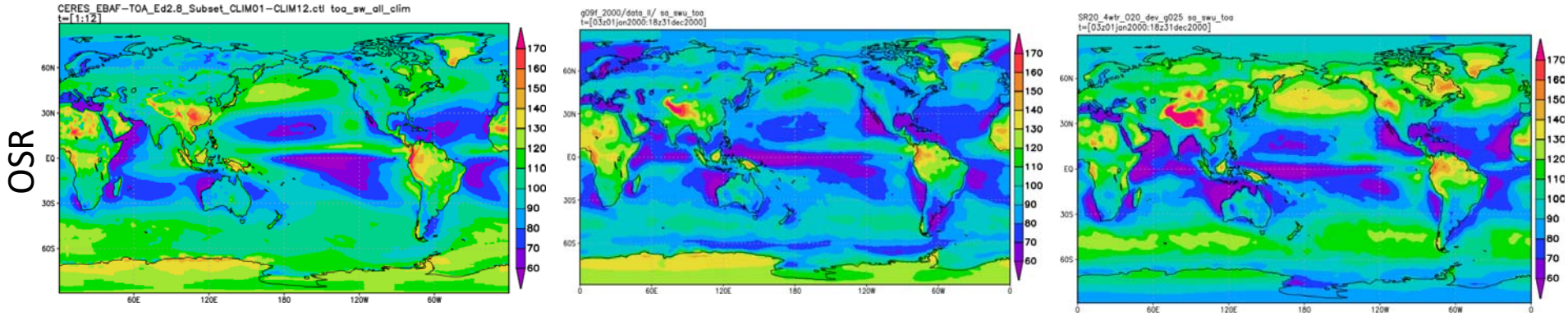
TOA Solar radiation & Liquid water path

CERES

Before

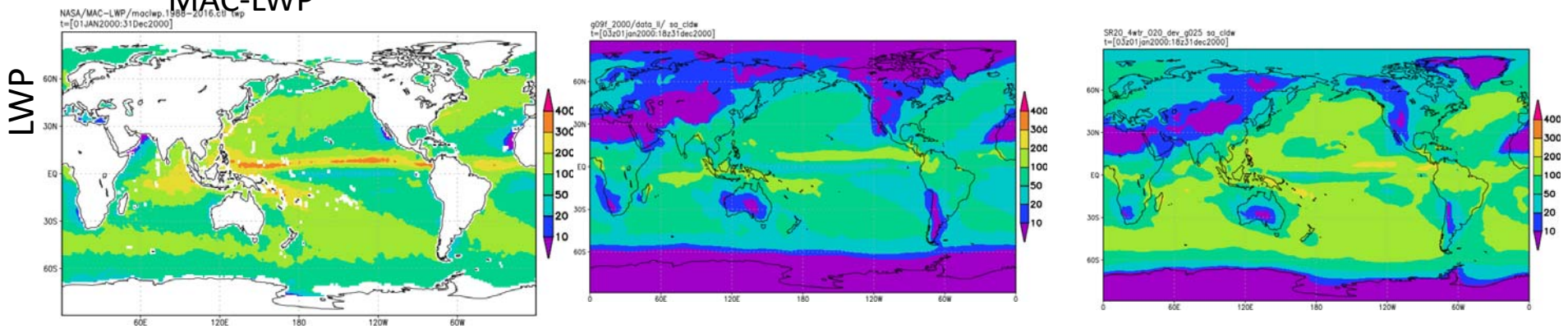
After

OSR



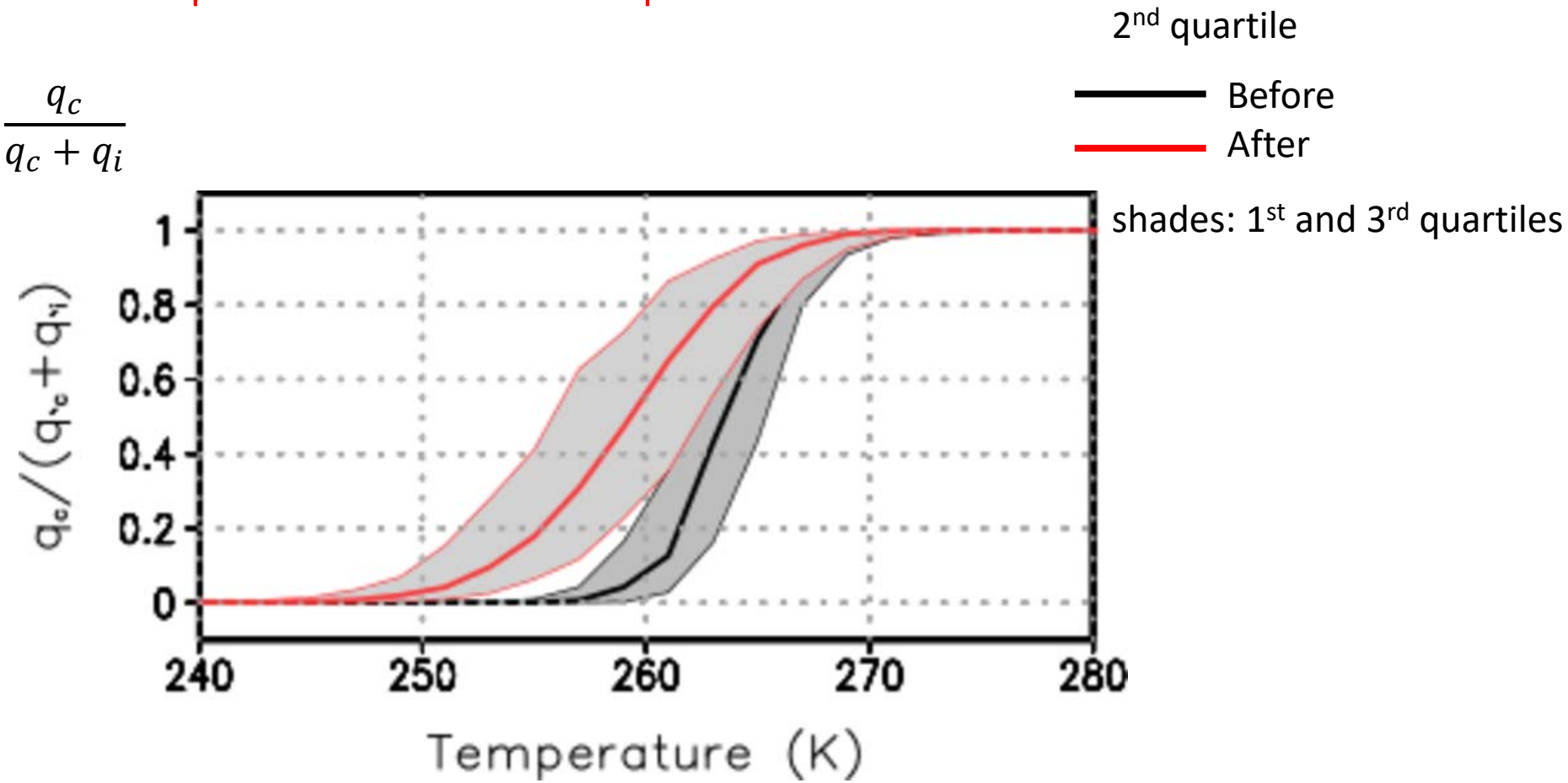
MAC-LWP

LWP



Temperature vs fraction of cloud water

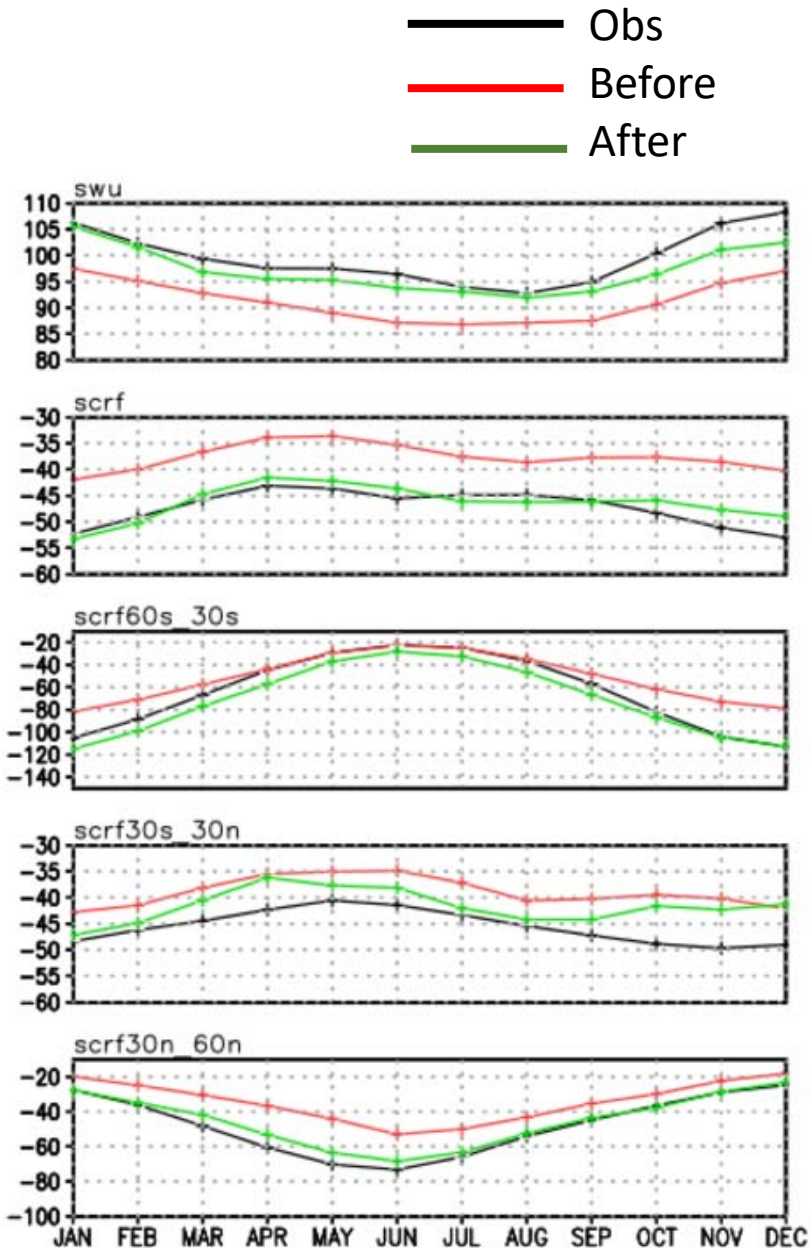
- ✓ Larger fraction of liquid phase in lower temperature
- ✓ Probability of occurrence of mixed-phase clouds becomes larger at the same temperature or fraction of liquid cloud



calculated from roughened data to 2.5deg grid

Seasonal Variation of Shortwave radiation @ TOA

- ✓ Solar Refection and SW CRF greatly improved not only over global means, but in each latitude bands
- ✓ Need future improvement: positive bias left in SH mid-latitudes, which partly compensates negative biases in tropics and NH midlatitudes

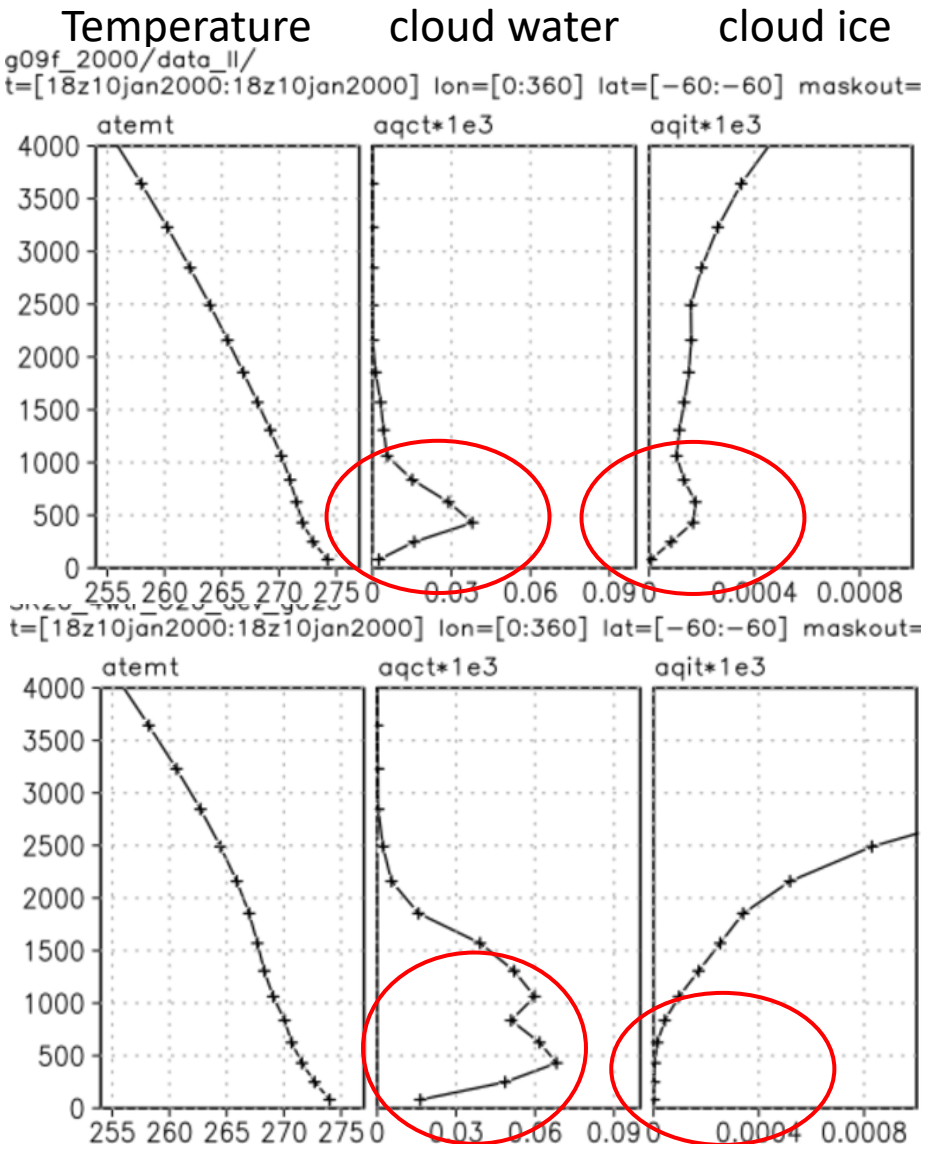


Vertical structures of Mixed-phase clouds in Higher latitude (60 ° S-mean)

- ✓ New one-moment microphysics by Seiki and Roh (2000) leads to more liquid and less ice in boundary-layer clouds due to
  - ✓ suppression of liquid clouds to grow to be rain
  - ✓ suppression of liquid clouds to grow to be ice crystals

Before

After



Conclusion

- Test of a new one-moment microphysics scheme developed by Roh et al. 2020, JAS; Seiki and Roh 2020, JAS)
- Suppression of conversions
  - from cloud water to rain
  - from cloud water to cloud ice
- are major key factors for a better representation of mixed-phase low clouds
- The former also greatly contributes to improve longevity of liquid low clouds
- Those lead to improve solar reflectance and SW cloud radiative forcing almost over the globe

- Further improvement is needed for high clouds
  - more liquid droplets may relate to underestimation of high clouds, and thus, introducing homogeneous nucleation would help reduce this bias in future