Clouds in Models WS: Online, Apr 2021

Realities of Developing and Improving Parameterizations Related to Clouds in GCMs

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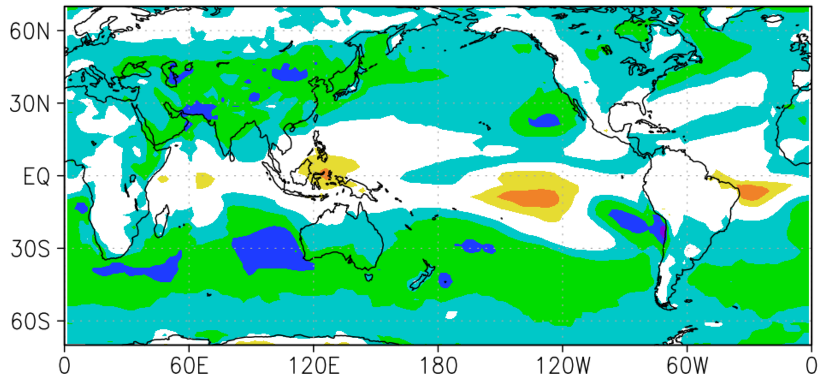
Kawai, H., et al., 2019: Significant Improvement of Cloud Representation in Global Climate Model MRI-ESM2. *Geosci. Model Dev.*, **12**, 2875-2897.

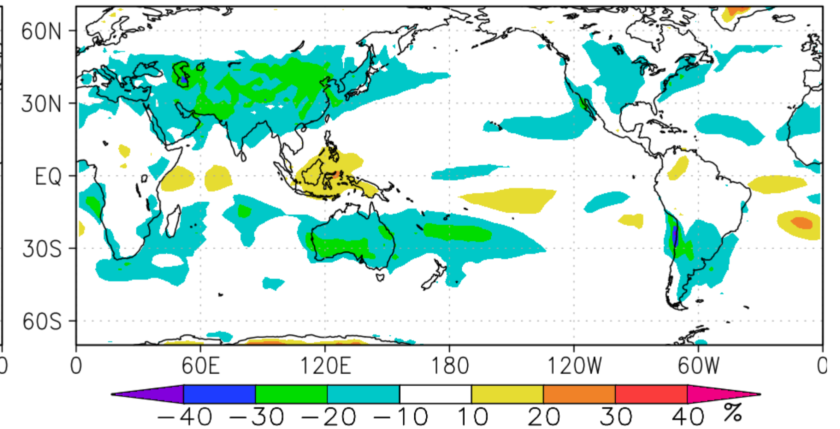
Improvement in clouds in MRI-ESM2

Old model: MRI-CGCM3 **New model: MRI-ESM2**

TCC bias

obs.: ISCCP



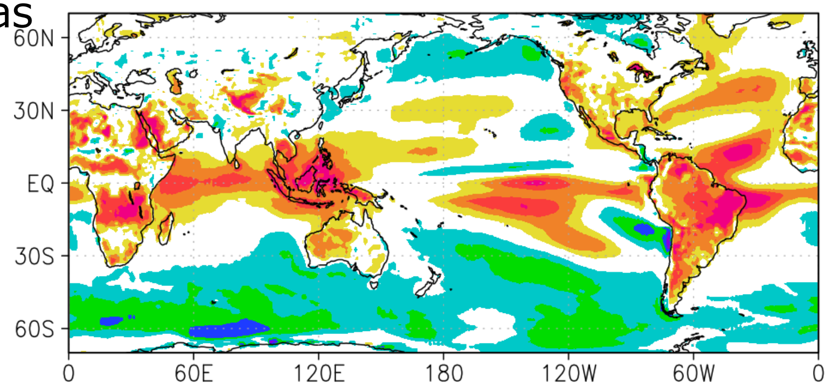


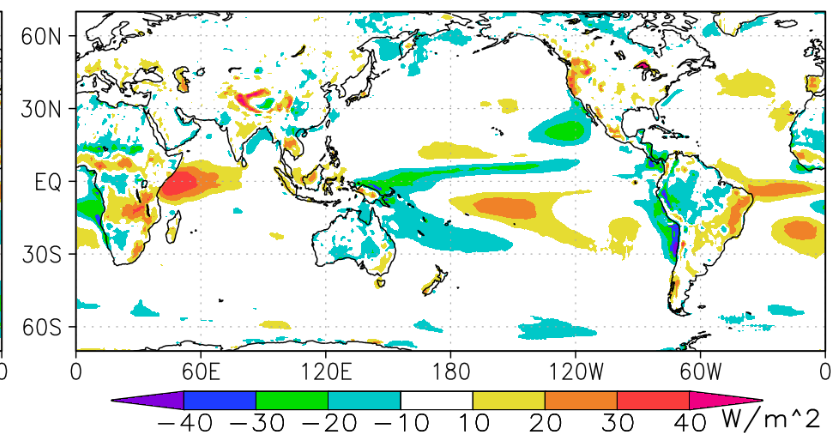
* much less over the Southern Ocean

* Much Improved over the SO and off Peru

TOA SW bias (upward)

obs: CERES-EBAF





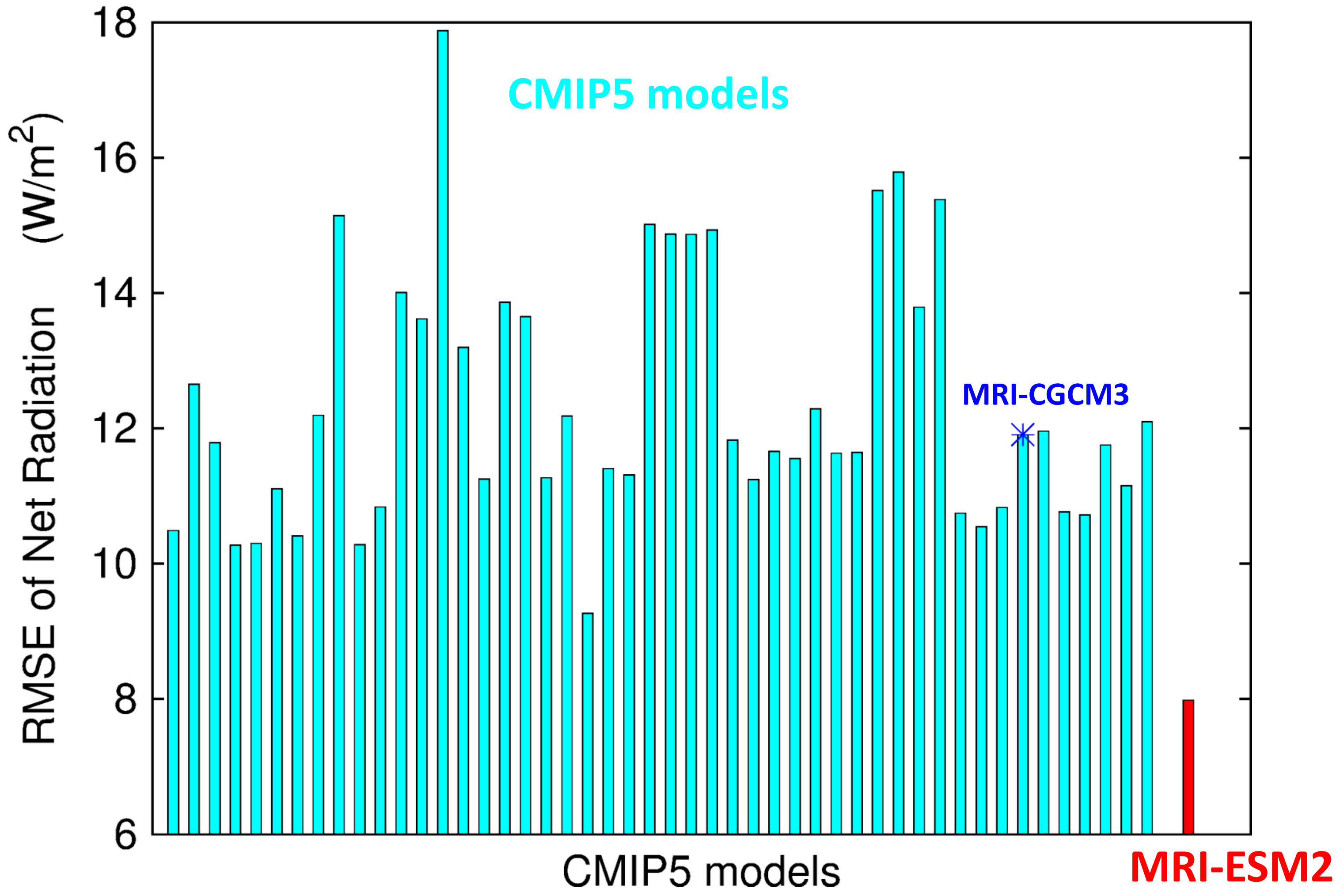
* Too much SW reflection over Tropics
* Much less SW reflection over the SO

* Improved over Tropics
* Improved over the SO and off Peru

Yukimoto et al. (2019), Kawai et al. (2019)

historical 1986-2005 (Annual mean)

Error in Net Radiation (SW+LW, TOA)



New model MRI-ESM2: Best among CMIP5 models

7th among 47 CMIP6 models (5th for 2m Temperature)

(SW is also the best among CMIP5 models. Taylor diagrams show similar results.)

Various improvements related to clouds…

Kawai et al. (2019, *GMD*)

i. Stratocumulus parameterization (turbulence scheme)

ii. Cloud microphysics

iii. Vertical resolution

iv. Convection scheme (shallow convection)

v. Cloud overlap scheme for radiation

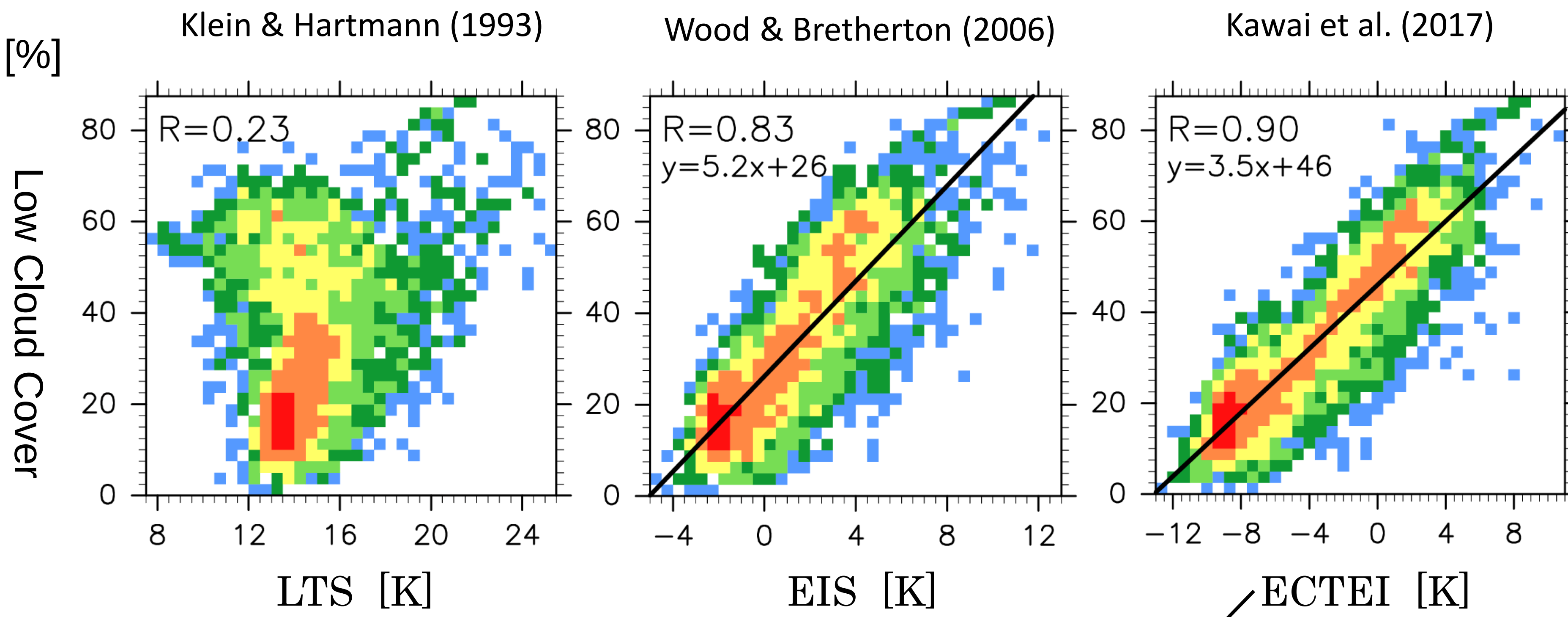
vi. Radiation process

vii. Bug

viii. Aerosol mode radii

ix. Cloud ice fall calculation

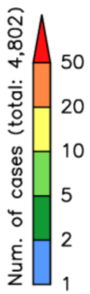
Impact of Stratocumulus parameterization



Not only temperature but also water vapor profile is taken into account.

$$\mathrm{ECTEI} = \mathrm{EIS} - \beta \frac{L}{c_p}\left(q_{\mathrm{surf}} - q_{700}\right)$$

Highest correlation!



Cloud Obs. Data: EECRA Ship Obs. Climatology

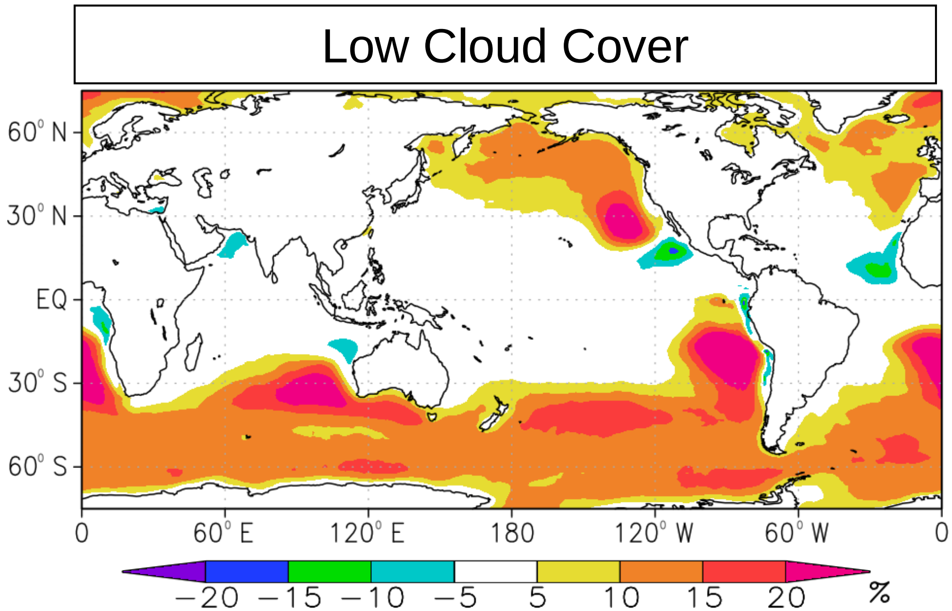
Meteo. Field Data: ERA40

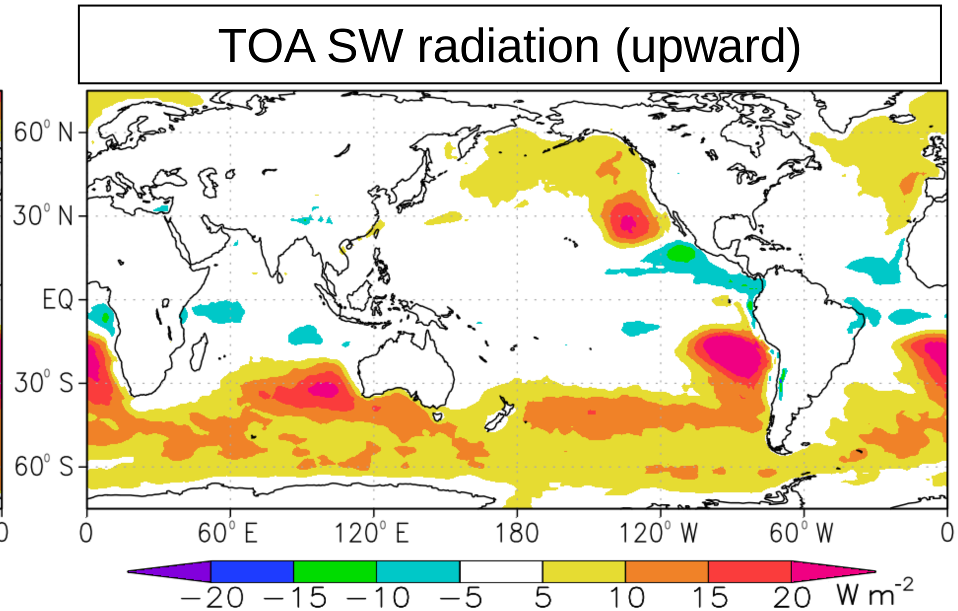
Using Global Ocean Data

Impact of introduction of new stratocumulus scheme

Cloud top mixing is suppressed for ECTEI > −2 K.
(ECTEI-LCC relationship is not used explicitly.)

New stratocumulus scheme − Old scheme





LCC is increased over the SO, the North Pac., and west coast of the continents

(Closer to Obs.)

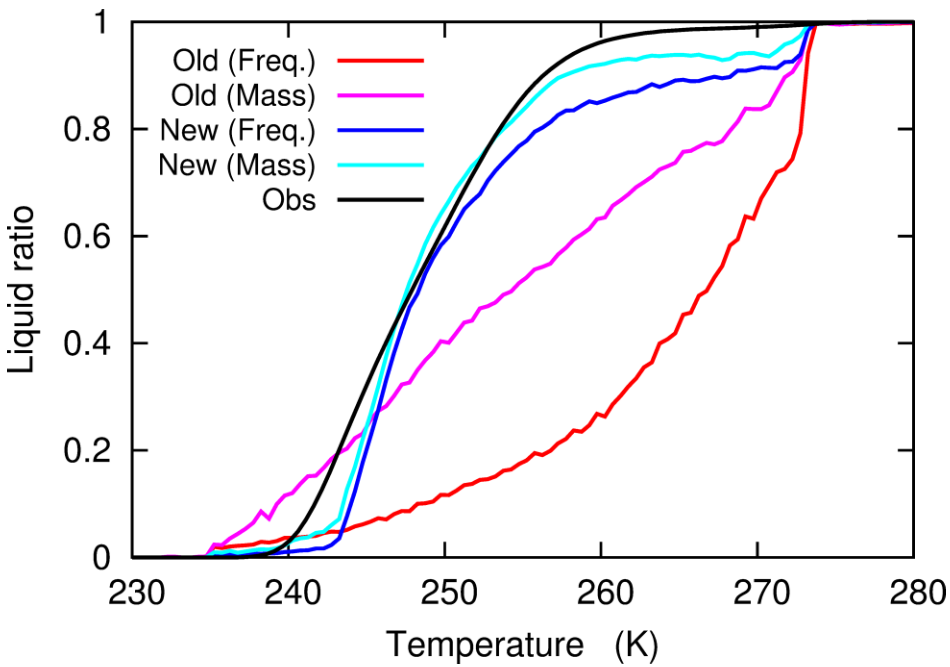
SW reflection is increased over these regions

(Closer to obs.)

10-yr mean

Impact of modified cloud microphysics

Liquid Water Ratio



Model（Improved WBF effect）

Model（Old WBF effect）

Observation: CALIPSO (Hu et al., 2010)

Snapshot (10 days, July)　　800-500 hPa

Observation: High liquid water ratio

Modified treatment of WBF effect in the model cloud microphysics:

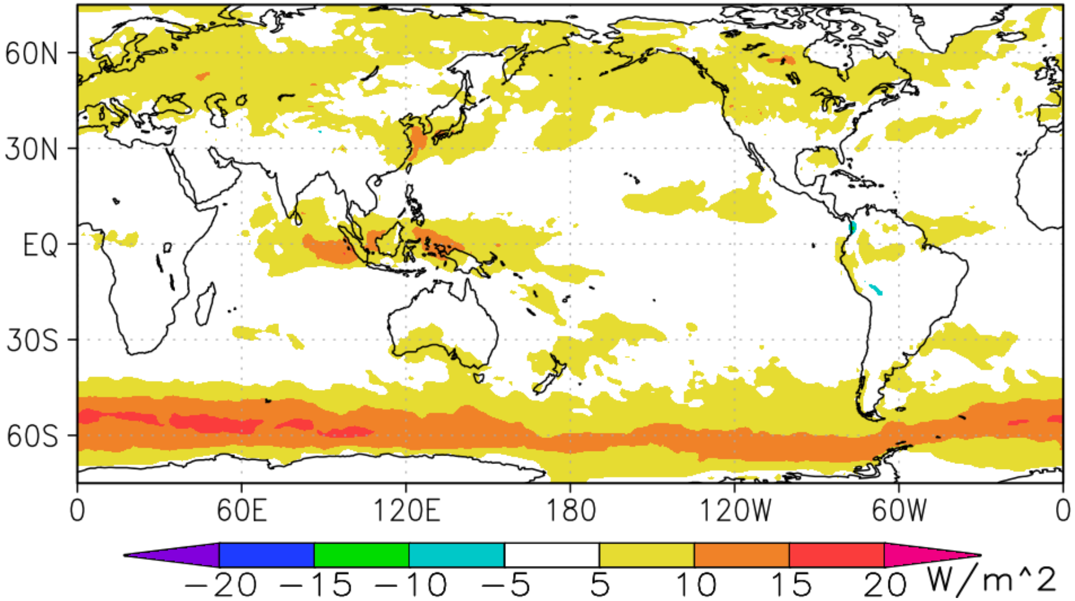
Supercooled water was increased. ➡ Optical thickness of clouds increased.

（Cloud droplets are smaller than ice crystals.）

Impact of modified treatment of WBF effect on SW radiation

TOA SW radiation (upward)

New WBF effect ー Old WBF effect



SW reflection is increased over the Southern Ocean

(Closer to obs.)

10-yr mean

Suppression of Shallow Convection

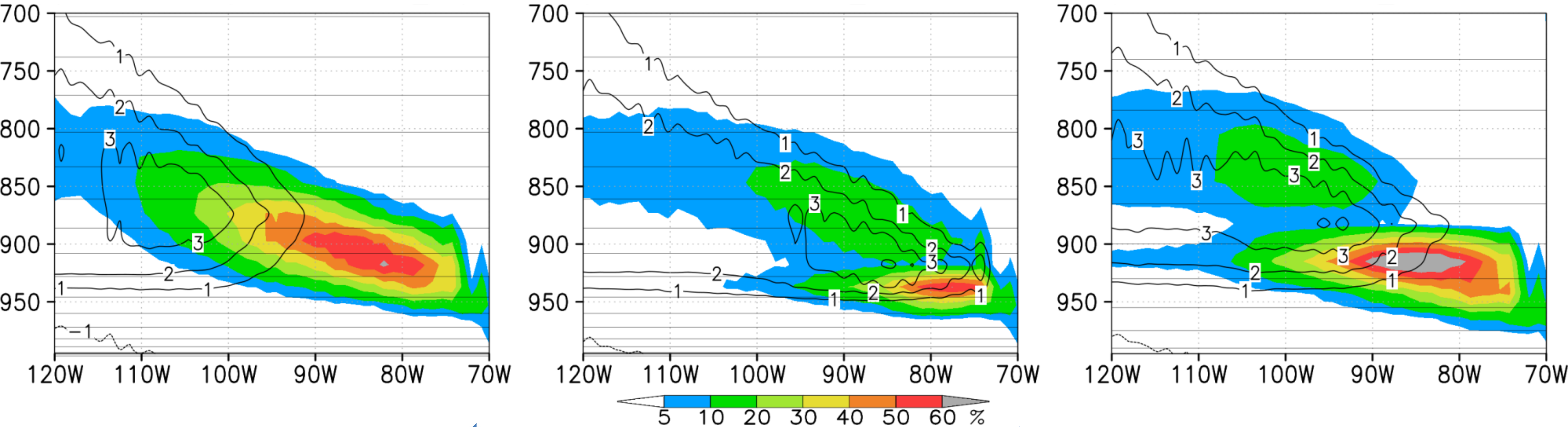
Increased Vertical Resolution

Cross sections of cloud fraction along 20ºS

Shallow Cu conditionally off — L80

Shallow Cu on — L80

Shallow Cu on — L48



Low-level cloud transition from stratocumulus to cumulus became more realistic when shallow convection is suppressed over the area where stratocumulus forms.

Geometrically thin boundary layer clouds became more realistic in L80.

10-yr mean

Various improvements related to clouds…

Kawai et al. (2019, *GMD*)

i. Introduction of a new stratocumulus parameterization based on CTE (cloud top entrainment) criterion (Kawai 2013, Kawai et al. 2017)
   Cloud shortage over the Southern Ocean & Northern Pacific was alleviated.
ii. The modification of the treatment of the Wegener–Bergeron–Findeisen process in cloud microphysics, etc.
   Supercooled water was increased. Then, cloud optical thickness also increased.
iii. Increased vertical resolution from L48 to L80 (Especially in BL.)
   Geometrically thin boundary layer clouds became more realistic.
iv. Suppression of shallow convection under condition of stratocumulus occurrence
   Low-level cloud transition from stratocumulus to cumulus became more realistic.
v. Improvement of a cloud overlap scheme (introduction of PICA; Nagasawa 2012)
   An excess reflection of shortwave radiation over the tropics was drastically alleviated.

Various improvements related to clouds…

Kawai et al. (2019, *GMD*)

vi. Abolishment of spatially reduced calculation of a radiation process

  The low-level clouds in the subtropics and mid-latitudes slightly increased.

vii. A bug associated with the prognostic equations of number concentrations of cloud particles was fixed.

  Too large number concentrations of cloud particles, particularly, for Sc and St were dissolved.

viii. Modification of aerosol mode radii based on recent observations

  Number concentrations of cloud particles became more appropriate.

ix. Improved calculation of cloud ice fall (based on Kawai 2005)

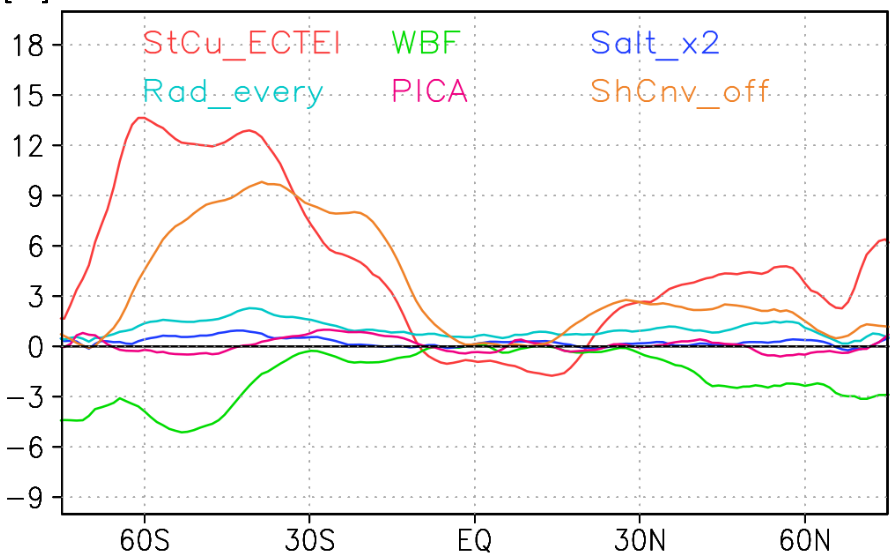
  The calculation became more realistic & the time-step dependency of IWC was alleviated.

Others * Improvement in the aerosol model (MASINGAR) etc.

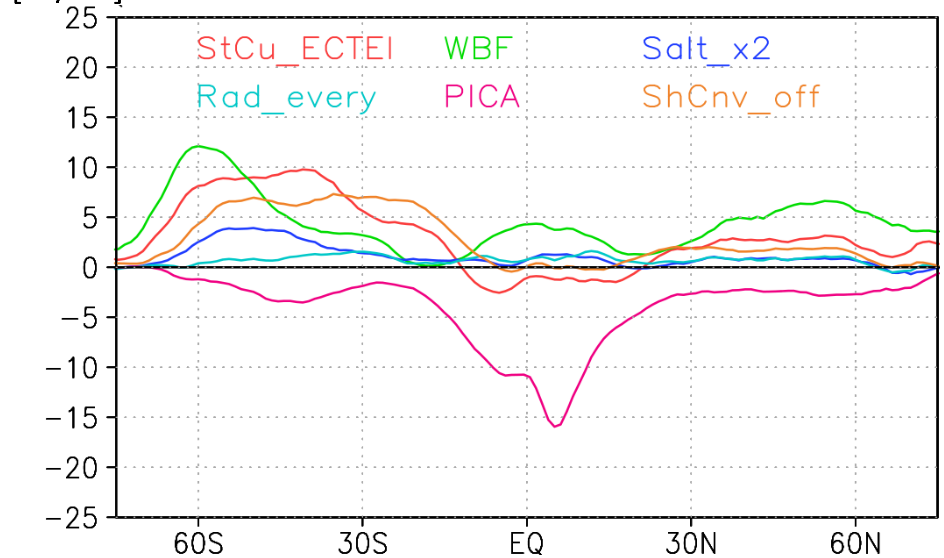
Tuning for total performance (in a convention scheme etc…)

Contribution from various modifications (based on on-off exp.)

Contribution to LCC



Contribution to TOA SW radiation



Stratocumulus scheme

Cloud microphysics (WBF effect)

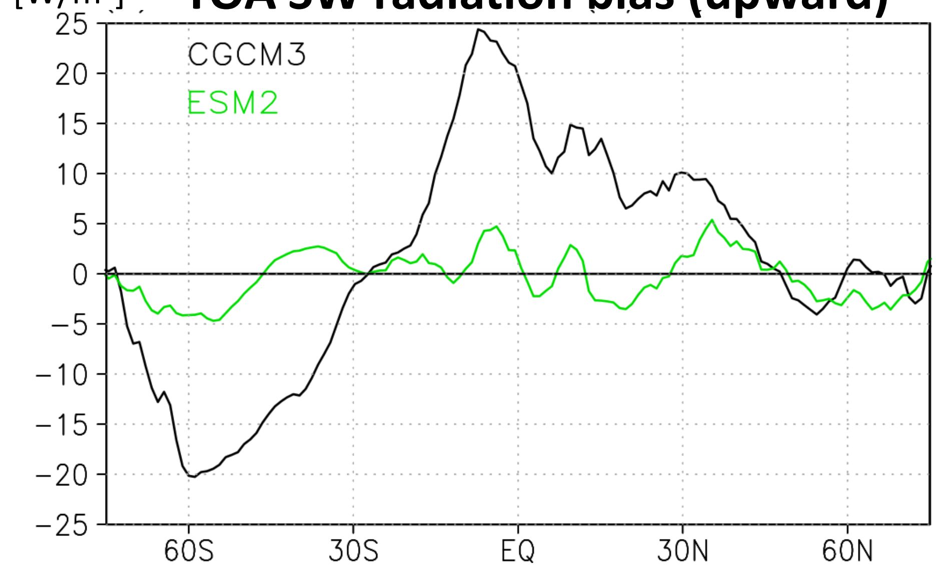
Fine maritime aerosols

Radiation spatial resolution

Cloud overlap

Shallow Conv. off over Sc condition

TOA SW radiation bias (upward)



Kawai et al. (2019, *GMD*)

Summary

Kawai et al. (2019, *GMD*)

- The representations of clouds in climate model MRI-ESM2 (for CMIP6) are significantly improved from the previous version MRI-CGCM3 (for CMIP5).
- The significant improvement is not attributed to the introduction of a new advanced scheme but to the cumulative effect of many "minor" modifications.

Acknowledgements

These improvements were achieved owing to the valuable information obtained from multiple model intercomparison studies and projects.

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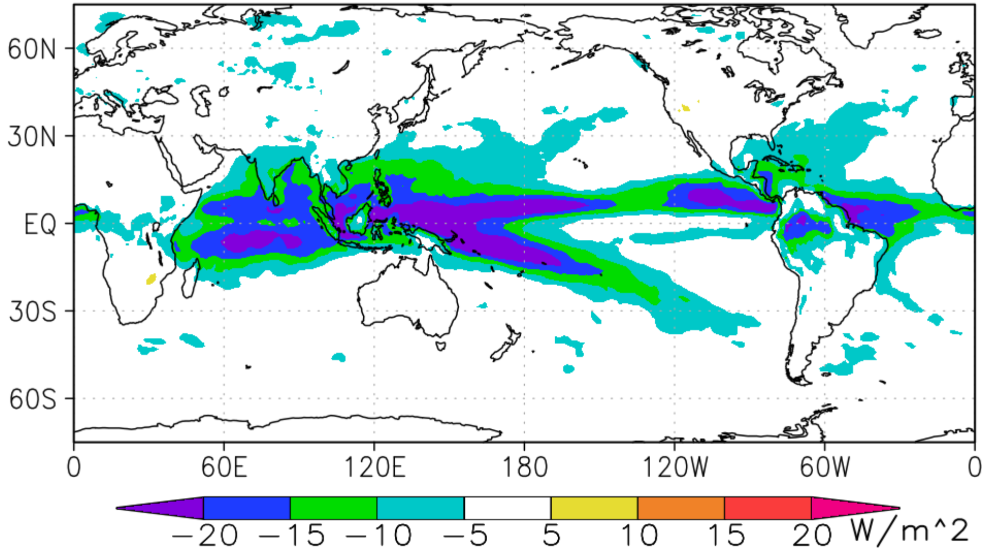
Backup Slides

Impact of new cloud overlap scheme

closer to Maximum-random ovlp — closer to random ovlp

New cloud overlap scheme － Old scheme

TOA SW radiation (upward)



Too much reflection is reduced over the tropics.

(Closer to Obs.)

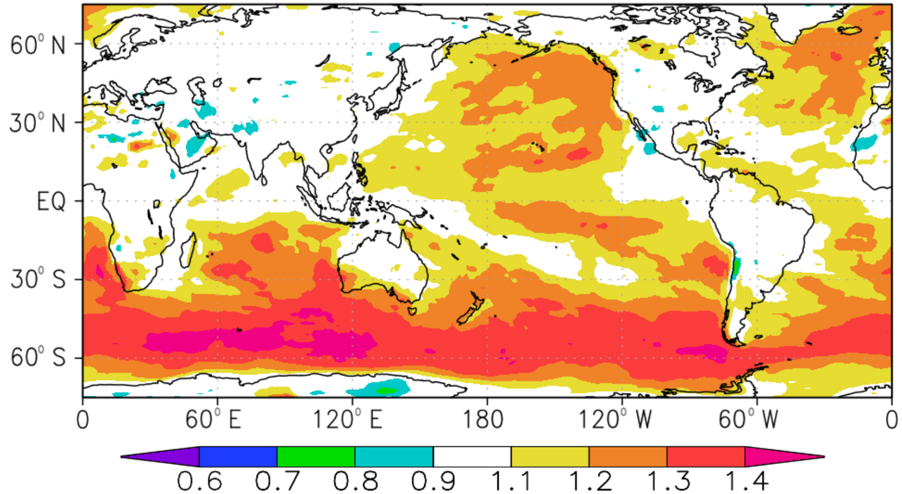
New scheme: PICA (Nagasawa 2012)

10-yr mean

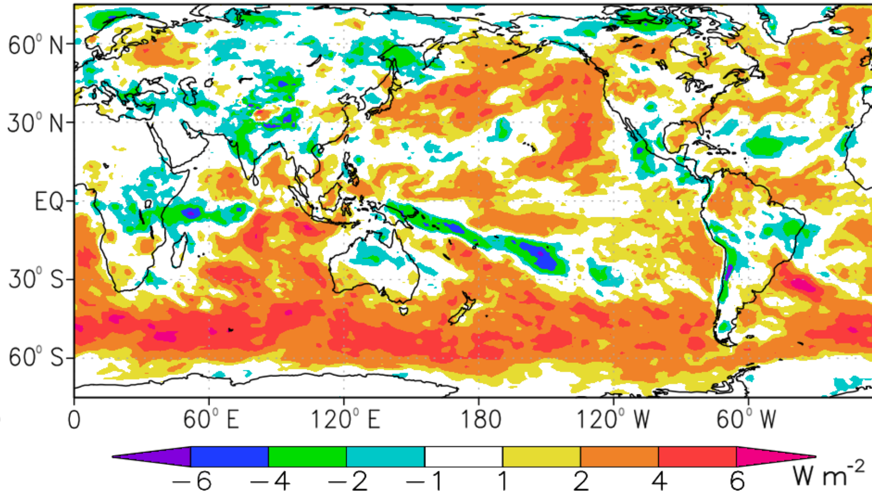
Impact of considering fine maritime aerosols

CCN from maritime aerosols is doubled to consider fine maritime aerosols

Column cloud droplet number concentration (ratio)



TOA SW radiation (upward)



N_c is increased over the Southern Ocean

SW reflection is increased over the SO

(Closer to obs.)

Lower bound of N_c that affects a lot 20C radiation forcing by aerosols (Hoose et al. 2009) is not used in MRI-ESM2.

10-yr mean