Improvements and Reductions in Systematic Errors Associated with Clouds in the MRI Climate Model

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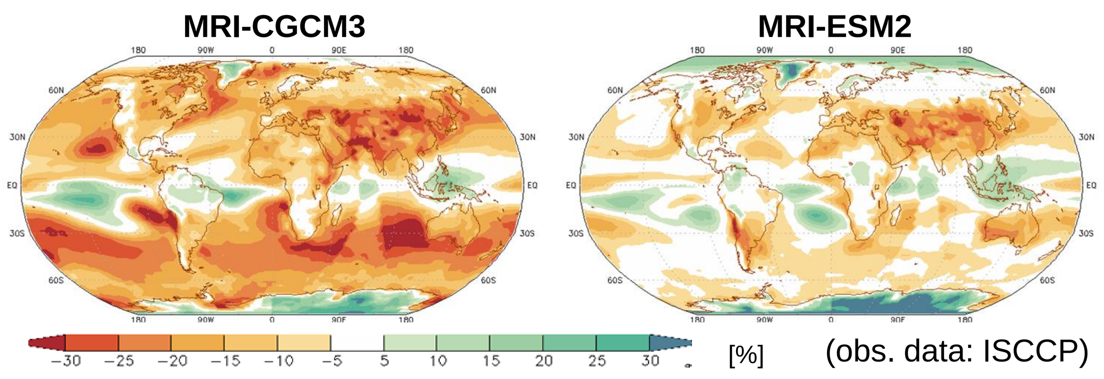
Introduction

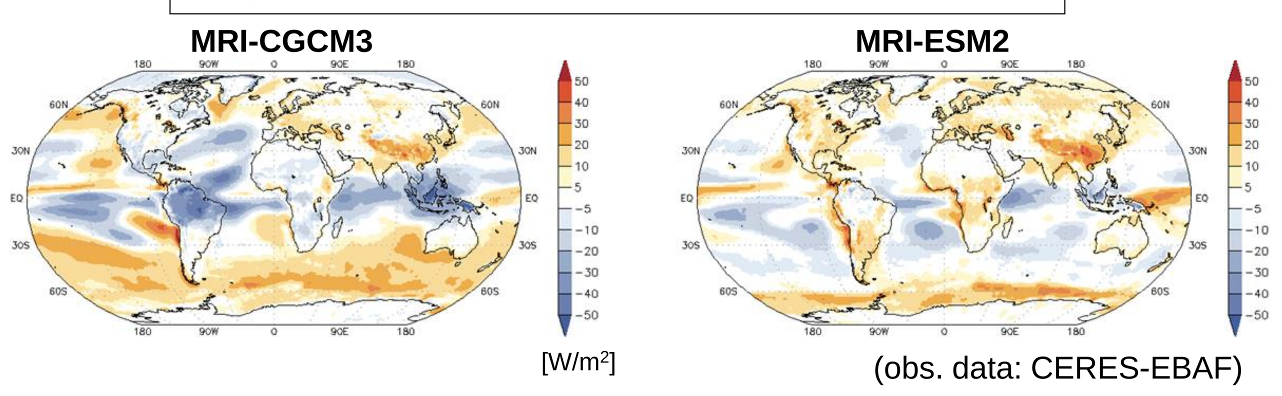
The previous version of the climate model of MRI MRI-CGCM3 (Yukimoto et al. 2012; TL159L48 in the standard configuration), which was used for CMIP5 simulations, had various systematic errors associated with clouds. In the updated version of our climate model, MRI-ESM2 (TL159L80), which is planned for use in CMIP6 simulations, some of such errors are reduced, and the representations of clouds and aerosol–cloud interactions are improved. Figures show that the biases in total cloud cover and shortwave cloud radiative effect are substantially reduced in the new version. The main improvements are briefly summarized herein.

Biases in total cloud cover



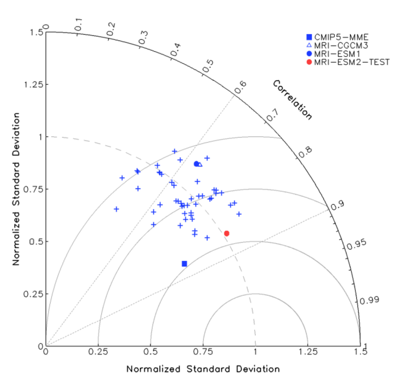
(obs. data: ISCCP)

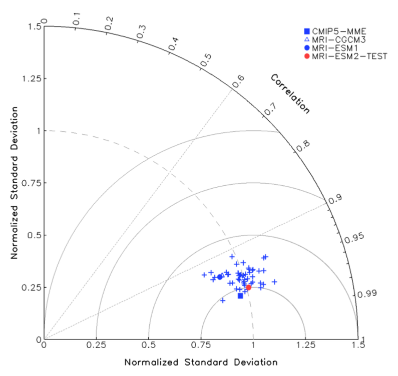
Biases in shortwave cloud radiative effect



(obs. data: CERES-EBAF)

Taylor diagrams





Summary

The major improvements are as follows: Kawai et al. (2017)

i. Introduction of a new stratocumulus parameterization based on CTE (cloud top entrainment) criterion (Kawai 2013)
   -> 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
   -> 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.

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.

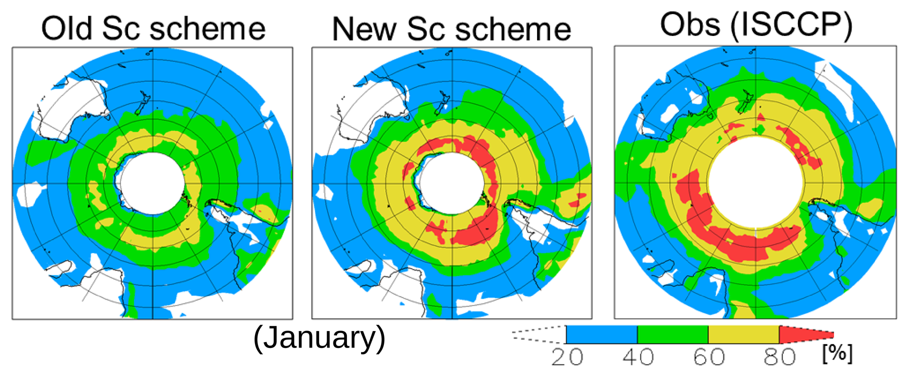
viii. Modification of aerosol mode radii based on recent observations
   -> Number concentrations of cloud particles became more appropriate.

ix. Improved calculation of cloud ice fall (based on Kawai 2005)
   -> The calculation became more realistic & the time-step dependency of ice water content was alleviated.

Examples of Improvements & the Results

New stratocumulus parameterization (i.)

Low Cloud Cover

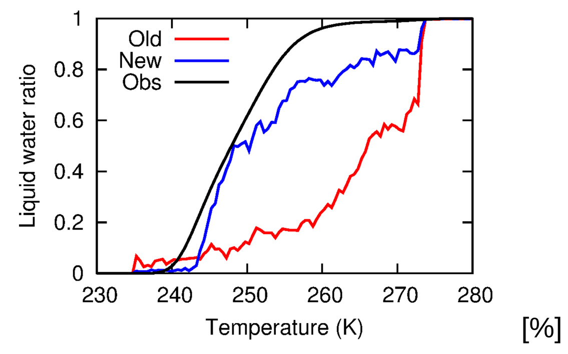


New stratocumulus parameterization based on a stability index that considers a cloud-top entrainment criterion (Kawai 2013) was introduced in the new version.

Cloud shortage over Southern Ocean was alleviated.

Cloud Microphysics (ii.)

Liquid Water Ratio



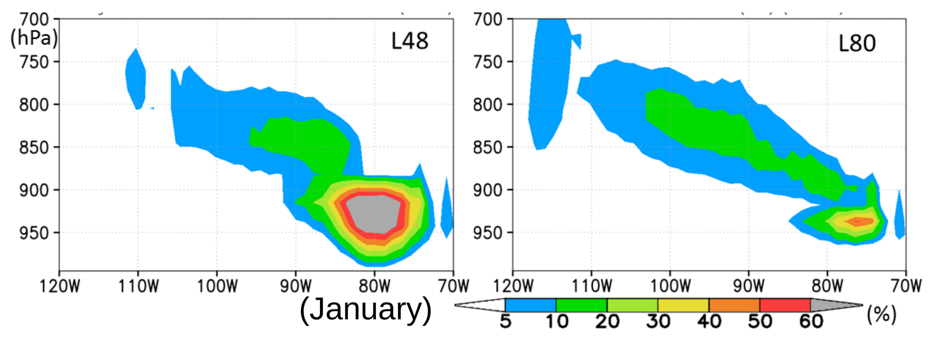
(Global mean at 700 hPa for January)

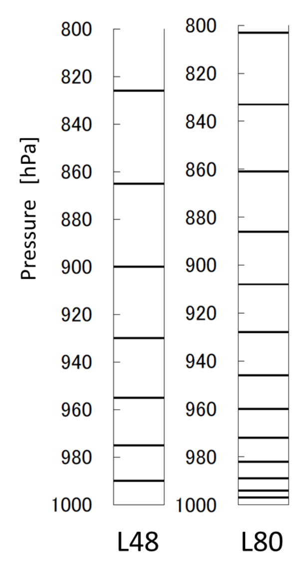
In the new version, WBF process is improved. Observation: Hu et al. (2010)

Supercooled water was increased.
-> Optical thickness of clouds increased.

Increased Vertical Resolution (iii.)

Cross sections of cloud fraction along 20°S

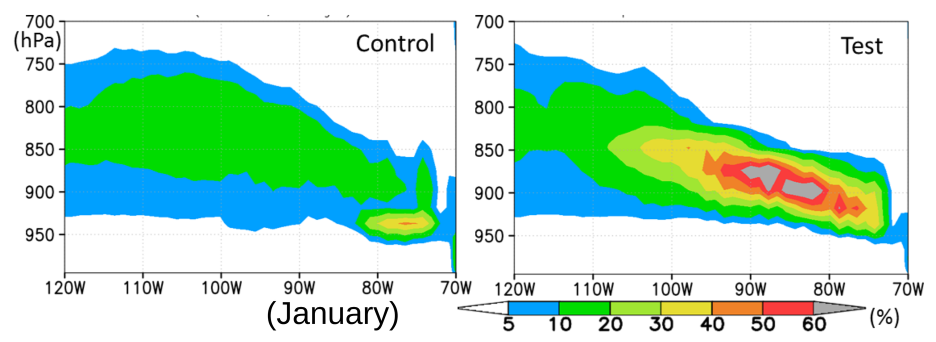




Geometrically thin boundary layer clouds became more realistic in the new version.

Suppression of Shallow Convection (iv.)

Cross sections of cloud fraction along 20°S

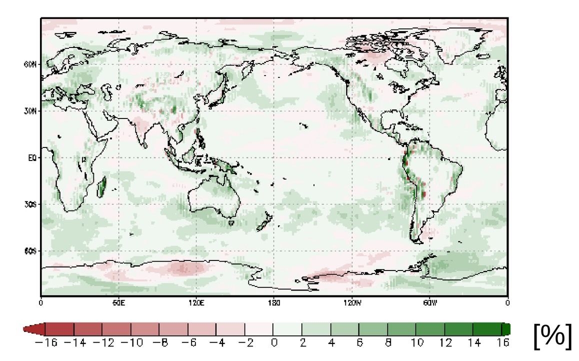


Test: Occurrence of shallow convection is suppressed over the area where the conditions for stratocumulus occurrence are met.

Low-level cloud transition from stratocumulus to cumulus became more realistic in the new version (a model with L80 vertical resolution is used).

Radiation Calculation (vi.)

Impact on low-level cloud cover

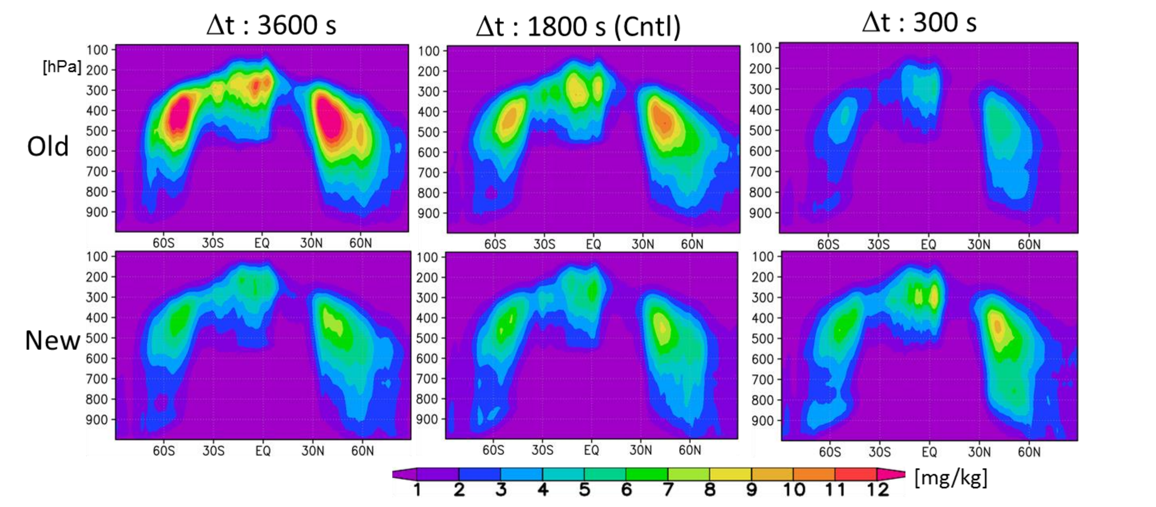


Impact on the low-level cloud cover due to a change in radiation computation from every two grids to every grid in the zonal direction

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

Calculation of Cloud Ice Fall (ix.)

Ice water content



The treatment of cloud ice fall was improved based on the study of Kawai (2005).

The time-step dependency of ice water content was alleviated.

Acknowledgements

These improvements were achieved owing to the valuable information obtained from multiple model intercomparison studies and projects. This work was supported in part by the Integrated Research Program for Advancing Climate Models (TOGO) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan. Additionally, it was supported by the Japan Society for the Promotion of Science (JSPS) and the Global Environment Research Fund (2-1403 and 2-1703) of the Ministry of the Environment, Japan.

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