

## Consistent evaluation of MIROC cloud properties with satellite observations and simulators

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Many of CMIP5 models, including MIROC, share common biases in cloud radiative effect (CRE) such as too large shortwave cooling effect in subtropical ocean and too small cooling effect in Southern Ocean and subtropical west coasts. Diagnosing inherent cloud biases is critical to mitigate the CRE biases. Such model diagnostics, particularly on the global scale, are enabled by comparisons to satellite observations. Notable in this regard is the recent emergence of active sensors on board satellites, i.e. CALIPSO and CloudSat, that provide vertical measurement of clouds, bringing unprecedented information for model evaluations. This is further facilitated by recent development of satellite simulators, such as COSP (CFMIP Observational Simulator Package), which enable consistent comparisons between the models and satellite observations. This study utilizes these tools to quantitatively assess cloud properties and relevant radiative fields in MIROC in comparison to satellite observations. For this purpose, atmospheric component of MIROC5 was used to simulate climatological fields of clouds and radiation with T85 horizontal resolution and 40 vertical levels. The simulation was equipped with inline COSP to diagnose cloud phase and cloud fraction in the manner consistent with what is observed by CALIPSO. The simulated cloud properties and radiative fluxes were then evaluated against the satellite-observed cloud product (CALIPSO GOCCP v2.X) and radiative flux product (CERES-EBAF), respectively. A particular focus of this study is placed on evaluation of cloud phase, which is represented in MIROC5 through parameterizations of microphysical processes, not a prescribed function of temperature. We analyzed how ice cloud ratio (ICR), defined as relative occurrence of ice clouds to total clouds, varies with temperature based on both the native model outputs and COSP-derived diagnostics in comparison to CALIPSO observations. The results show that while the original outputs from MIROC overestimate ICR at a given temperature, the ICR from COSP outputs well fitted to the satellite observation. This underscores the importance of using satellite simulators to make consistent model comparisons to satellite observations and thus to better characterize the inter-model spread of cloud phase dependence on temperature recently reported. Our result also suggests that the too negative CRE at high latitudes in MIROC5 is more like attributed to the less total cloud fraction than observed, rather than to cloud phase biases.

Keywords: cloud radiative effect, global climate model, satellite simulator, cloud phase