Cloud feedbacks in MRI-CGCM3

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1. Introduction

The cloud feedbacks in the MRI-CGCM3 (Yukimoto et al. 2012), which was used for CMIP5 simulations, were investigated. Changes in vertical profiles of cloud radiative effect (CRE), cloud cover, liquid and ice water content (LWC and IWC), and number concentrations of cloud droplets and ice crystals were examined. These profile changes were examined for several areas in which typical cloud regimes are dominant, to understand the contributions from each cloud regime to the global cloud feedback.

2. Model and Experiments

The model resolution is TL159L48 and the prognostic variables are cloud cover, LWC, IWC, and number concentrations of cloud droplets and ice crystals.

31 years averages (1979−2009) of data from AMIP and AMIP+4K runs are used for the analysis. AMIP and AMIP+4K run data of experiments with the convection scheme switched off, which was run under a project SPOOKIE (Webb et al. 2015b), are also examined to understand the roles of convection schemes for the cloud feedback in MRI-CGCM3.

The cloud feedback in MRI-CGCM3 for shortwave radiation is +0.43, for the longwave is −0.31, and the sum is +0.12 W/m^2/K. Figure 1 shows the CRE change for the sum of shortwave and longwave radiation at the top of the atmosphere.

3. Results

3.1. Global Mean

To understand the cloud feedback, the vertical profile of the CRE change was examined. The top left panel in Fig. 2 shows the CRE profile change for upward shortwave radiation. The CRE change is negative for 230 – 100 hPa, positive for 450 – 230hPa, negative for 900 – 700 hPa, and positive for surface – 900hPa, and the sum produces a positive shortwave cloud feedback in total. To understand the contribution of changes in cloud properties, vertical profiles of cloud cover, in-cloud LWC and IWC, in-cloud cloud droplet and ice crystal number concentrations were examined.

Above 230 hPa, the increases in cloud cover and in-cloud IWC contribute to the negative CRE change. The increase in cloud cover is mainly caused by higher top of deep convection, and the increase in in-cloud IWC is partly attributed to larger saturation specific humidity in AMIP+4K. For 450 – 230 hPa, decreases in cloud cover and in-cloud ice crystal number concentration, which overcome the increase in in-cloud IWC, contribute to the positive CRE change. It is plausible that the large increase in in-cloud LWC without significant change in cloud cover contributes to the negative CRE change at 900 – 700 hPa. The increase in in-cloud LWC is partly caused by the larger saturation specific humidity and the phase change of ice crystals to liquid droplets near 0 ºC

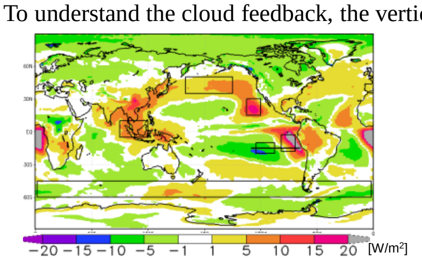

Fig. 1: CRE change for the sum of shortwave and longwave radiation at the top of the atmosphere (AMIP+4K – AMIP).

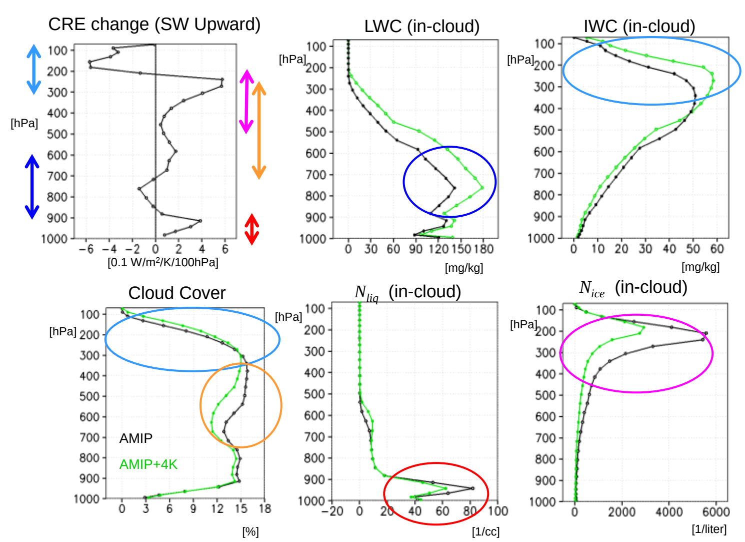

Fig. 2: From the top left, vertical profiles of CRE change for upward shortwave radiation from AMIP to AMIP+4K, in-cloud LWC and IWC, cloud cover, in-cloud cloud droplet and ice crystal number concentrations (black: AMIP, green: AMIP+4K). Global average for 31 years data.

altitude in AMIP+4K. Below 900 hPa, the positive CRE change is likely caused by reduction in the number concentration of cloud droplets. Some of these characteristics of changes related to clouds in MRI-CGCM3 are briefly mentioned in Webb et al. (2015a).

3.2. Changes in typical areas

To understand contributions from typical cloud regimes to the global average profiles, results from some areas are described below.

3.2.1. Deep convection area

Figure 3 shows that cloud cover is significantly reduced for 700 – 170 hPa in the AMIP+4K experiment in the Indochina area shown in Fig.1. This decrease is consistent with a reduction in relative humidity (figure not shown). The stronger drying by convective processes plausibly contributes to the change. Though the convection-off experiment shows similar characteristics to some extent, the change is much smaller than in the convection-on experiment.

3.2.2. Mid-latitudes

Figure 4 shows that cloud cover is reduced for 950 – 300 hPa in AMIP+4K experiment in the North Pacific area shown in Fig.1. The Convection-off experiment shows similar characteristics (except below 750hPa). Therefore, probably processes other than convection cause these changes. The results from the Southern Ocean area also shows similar characteristics (figure not shown).

3.2.3. Stratocumulus to Shallow Convection Area

Figure 5 shows that cloud cover associated with the shallow convection regime increases and stratocumulus cloud cover decreases in AMIP+4K. These changes are consistent with those in relative humidity, which are partly attributed to more intensive transport of humidity by shallow convection in AMIP+4K. When the convection scheme is switched off, the increase in cloud cover corresponding to shallow convection does not occur (figure not shown).

A large decrease in number concentration of cloud droplet is found in stratocumulus clouds, and this decrease contributes to the global average decrease shown in Fig.2. However, a bug related to number concentration equations could affect this large decrease, and so we will not discuss this change further. Note that the decrease in number concentration of cloud droplets is also found in a test run using a bug fix version, though the decrease is much less than in CMIP5 simulation.

3.3. Changes in aerosol concentrations

A large reduction in aerosol mass concentration is found in the AMIP+4K simulation at higher than 400hPa (figure not shown), which causes a reduction in calculated aerosol and ice nuclei number concentrations, contributing to a reduction in ice crystal number concentration. The reduction in aerosol can presumably be attributed to the increase in precipitation and decrease in convective mass flux over tropics in AMIP+4K simulation.

Acknowledgements

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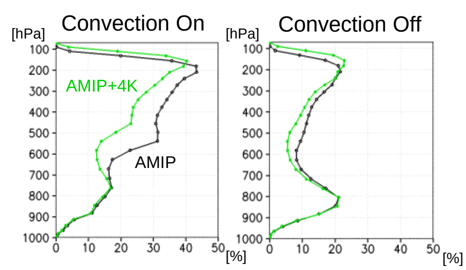

Fig. 3: Cloud cover profile for AMIP (black) and AMIP+4K (green) for the Indochina area shown in Fig. 1. Results of the normal model (left) and the convection switched off version are shown.

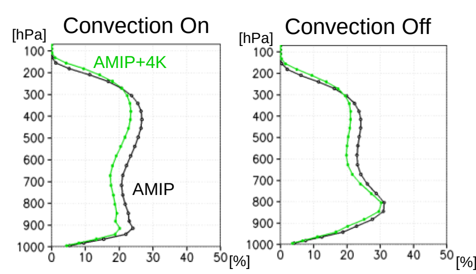

Fig. 4: Same as Fig. 3 but for the North Pacific area.

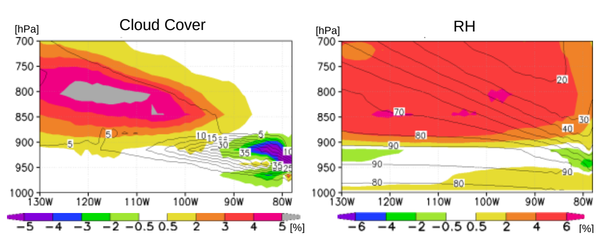

Fig. 5: Cross-sections of cloud cover (left) and relative humidity (right) along 15ºS shown in Fig.1 (shade: difference between AMIP+4K and AMIP, contour: AMIP climatology).