The impact of the cloud overlap and cloud horizontal inhomogeneity assumptions on radiation calculation in JMA global NWP model

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1. Introduction

In low-resolution atmospheric models, the Cloud Overlap Assumption (COA) and the Cloud Horizontal Inhomogeneity Assumption (CHIA) in radiation calculation have a strong impact on the cloud radiative effect. In the past, the radiation calculation of the Japan Meteorological Agency's (JMA's) global Numerical Weather Prediction (NWP) model (JMA, 2024) has not included the effects of the CHIA (Harshvardhan and Randall, 1985). In addition, only a simple COA, which is hard-coded into the radiation calculation, has been used. Consequently, Independent Column Approximation (ICA; e.g., Barker et al., 2003) using the Stochastic Cloud Generator (SCG; Räisänen et al., 2004) was incorporated into the radiation calculation of JMA global NWP model to stochastically handle more realistic versions of the COA and CHIA. This paper reports the results of sensitivity experiments with respect to the radiative effects of the COA and CHIA.

2. Development of the SCG

The SCG was developed to perform radiation calculation using the ICA and to handle various COAs and CHIAs stochastically. Using this approach, cloud existence and cloud water content in each subcolumn are determined from the grid-scale cloud fraction, the grid-scale cloud water content, and a pseudorandom number in each subcolumn. In the present study, the SCG was tested under various conditions (i.e., cloud fraction profile, COA, CHIA, and Fractional Standard Deviation (FSD) of the horizontal fluctuation of the cloud water content). If the number of subcolumns was large enough, this confirmed that the SCG worked without problems under a range of conditions. These results were close to the deterministic reference results. When the number of subcolumns was small, deviation from the deterministic reference results was large, but there was no statistical bias from the deterministic reference results, given the stochastic behavior of the SCG.

3. Settings for the sensitivity experiments

The settings for the sensitivity experiments with respect to the impact of the COA and CHIA on the radiation calculation performed using JMA global NWP model are described below. The number of the ICA subcolumns was set to 10. We tested runs with the Maximum-Random Overlap (MRO; Geleyn and Hollingsworth, 1979) and Exponential-Random Overlap (ERO; Hogan and Illingworth, 2000) as the COA. We also tested runs with and without the CHIA. When the CHIA was considered, we used the ERO for vertical correlation of the horizontal inhomogeneity of the cloud water content. In addition, we used a gamma distribution with an expected value of 1.0 as the probability density function for the horizontal fluctuation of the cloud water content. The FSD value was set to 1.0 uniformly across the globe. The decorrelation lengths of the ERO for the COA and CHIA were set to 2.0 and 1.0 km, respectively. For these sensitivity experiments, time integrations of 120 hours were performed using JMA global NWP model whose model configuration was TL479L100 with a horizontal resolution of about 40 km.

4. Results of the sensitivity experiments

Figures 1 and 2 show the 5-day average of the upward shortwave radiation flux at the top of the atmosphere (OSR) and the upward longwave radiation flux at the top of the atmosphere (OLR), respectively, from the results of the sensitivity experiments on the COA and CHIA. Figures 1a and 2a show the results from the control run, in which the MRO was used as the COA and the CHIA was not considered. When the COA was changed from the MRO to the ERO to make the COA more realistic, the total cloud cover increases and the cloud radiative effect also increases (Figs 1b and 2b). When considering the CHIA in the radiation calculation, the cloud radiative effect decreases due to the horizontal fluctuations in the cloud water content within the cloudy area in the grid (Figs 1c and 2c). When considering both the ERO as the COA and CHIA within the radiation calculation, whether the effect of the former exceeds the opposite effect of the latter depends on the region (Figs 1d and 2d). The sensitivity experiments on the FSD, and those on the vertical correlation of the CHIA, show that an increasing FSD value results in increasing horizontal fluctuation of the cloud water content within the cloudy area in the grid, and reduced cloud radiative effect (not shown). Furthermore, with increasing vertical correlation of the horizontal inhomogeneity of the cloud water content, the effect of the CHIA becomes larger and the cloud radiative effect becomes smaller (not shown).

5. Summary and future plans

ICA using the SCG was incorporated into the radiation calculation of JMA global NWP model to stochastically handle the COA and CHIA in a more realistic manner.

Future work will develop the Monte Carlo Independent Column Approximation (McICA; Pincus et al., 2003), a faster version of the ICA. However, because the results generated using the McICA contain more noise relative to those from the ICA, we will also investigate the impact of this noise on the forecast accuracy.

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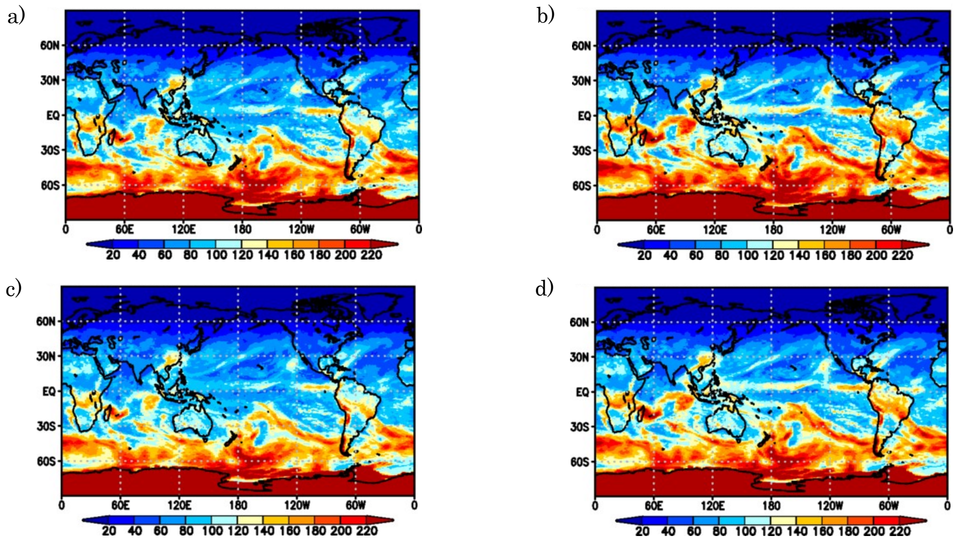

Fig. 1 5-day average OSR (Wm^{-2}) from the results of the sensitivity experiments on the COA and CHIA. a) MRO is used as the COA, and CHIA is not considered (CNTL). b) ERO is used as the COA. c) CHIA is considered. d) ERO is used as the COA, and CHIA is considered. Initial time is 12 UTC 2 January 2018.

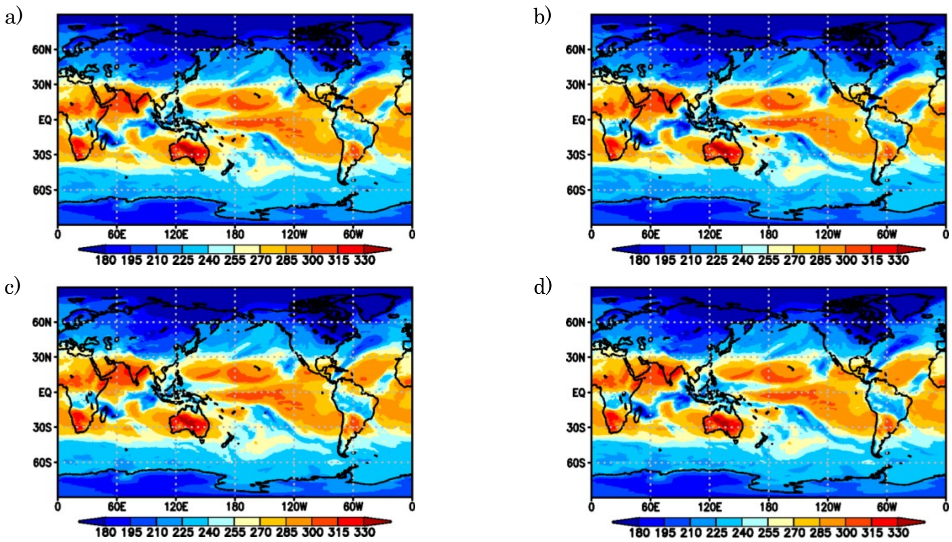

Fig. 2 As for Fig. 1, but for the OLR (Wm^{-2}).