Impact of ice cloud treatment on the OLR in the radiation calculation of JMA global NWP model

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1. Introduction

There is a positive bias in outgoing longwave radiation (OLR) of the JMA global NWP model (Yonehara et al. 2020) (Fig. 1). There are several possible causes, one of which is the treatment of ice clouds in radiation calculations. To estimate the radiative forcing of an ice cloud, it is necessary to estimate its single scattering properties, for which an ice cloud optical property parameterization and an ice cloud effective size parameterization are required.

An accurate ice cloud optical property parameterization is contingent on high quality reference results. To fit the reference results with accuracy, it is necessary to use the definition of the effective size of ice clouds, which is more directly related to the formulation of the single scattering calculation of ice crystals. Since ice clouds are composed of nonspherical ice crystals, various definitions of the ice cloud effective size are used. For example, in the radiation scheme of atmospheric models, the definition of the ice cloud effective size in the ice cloud optical property parameterization may be different to that in the ice cloud effective size parameterization. The single scattering calculation depends strongly on the ice cloud effective size and it is therefore important that the definition is consistent.

Here we consolidate the definition of the ice cloud effective size in the radiation calculations of the JMA global NWP model, and test the improved ice cloud optical property parameterization and ice cloud effective size parameterization.

2. Ice cloud optical property parameterization

The current shortwave and longwave ice cloud optical property parameterization used in the JMA global NWP model is described by Ebert and Curry (1992) (hereafter EC92). In EC92, the reference calculation for the single scattering properties of ice crystals is based on the assumption that the shape of the ice crystals is a hexagonal column. The geometric optics approximation (for shortwave radiation) and the Mie scattering calculation (for longwave radiation) are employed. In EC92, the reference results are fitted using the ice cloud effective radius (ReEC), which is the radius of the sphere having the same surface area as the hexagonal column.

In this study, the ice cloud optical property parameterization of Fu (1996) used for shortwave radiation and Fu et al. (1998) used for longwave radiation are tested (hereafter collectively referred to as FU). The single scattering property reference results of FU are improved compared with EC92. This improvement arises from several factors, including the use of the improved imaginary part of the refractive ice index, more aircraft observations of the particle size distribution of ice clouds, a highly accurate geometric optics approximation, and the adoption of a composite method in the longwave radiation calculation through a combination of the geometric optics approximation and the Mie scattering calculation. In FU, the reference results are fitted using the generalized effective size (Dge). The fitting accuracy of the reference results is higher in Dge than in ReEC, because the definition of Dge is more directly related to the formulation of the reference calculation than is the definition of ReEC.

The accuracy of FU is higher than that of EC92. We find that the radiative forcing of ice clouds calculated using the FU scheme is smaller than that using the EC92 scheme (Fig. 2).

3. Ice cloud effective size parameterization

The current effective size parameterization for ice clouds used in the JMA global NWP model is described by Wyser (1998) (hereafter WY98). The WY98 scheme is based on the particle size distribution obtained from aircraft observations of midlatitude cirrus. The shape of ice crystals is assumed to be a hexagonal column and the effective radius of the ice cloud is based on the average radius of hexagonal columns randomly oriented in space (ReLiou). We note that ReLiou is inconsistent with ReEC.

In this study, the ice cloud effective size parameterization of Sun (2001) is tested (hereafter SUN01). The SUN01 scheme is based on the particle size distribution obtained from aircraft observations of anvil outflow in deep tropical convection (McFarquhar and Heymsfield 1997). The shape of ice crystals is also assumed to be a hexagonal column. The SUN01 scheme has been extended to be applicable to midlatitude cirrus through a comparison with observations. The definition of the ice cloud effective size in SUN01 is Dge, which is consistent with FU but not with EC92, so it is necessary to convert Dge to ReEC for use with EC92.

SUN01 is slightly more accurate than WY98. We find that the radiative forcing of ice clouds when using the SUN01 scheme is larger because the effective size of ice clouds tends to be smaller (Fig. 3).

4. Sensitivity experiments

When changing the ice cloud optical property parameterization from EC92 to FU, the positive bias of

OLR increases and the outgoing shortwave radiation (OSR) decreases in regions with many high-altitude clouds. This is because the radiative forcing of ice clouds calculated using the FU scheme is smaller than that using the EC92 scheme (Fig. 4, left panel).

When changing the ice cloud effective size parameterization from WY98 to SUN01, the positive bias of OLR is reduced and the OSR increases in regions with many high-altitude clouds. This is due to the larger radiative forcing of ice clouds in the SUN01 scheme compared to the WY98 scheme (Fig. 4, middle panel).

When combining the FU and SUN01 schemes (FUSUN01), their impacts have opposing effects and offset each other to some extent. As a result, the OLR increases only slightly in regions with many high-altitude clouds (Fig. 4, right panel).

5. Summary and outlook

We tested different ice cloud optical property parameterizations and ice cloud effective size parameterizations in the radiation scheme of the JMA global NWP model, ensuring that the definition of the ice cloud effective size was consistent in both parameterizations. The improved treatment of ice clouds in the FU and SUN01 schemes could not eliminate the positive OLR bias in the model. In future, we plan to investigate other causes of the OLR bias, such as the representation of high-altitude clouds.

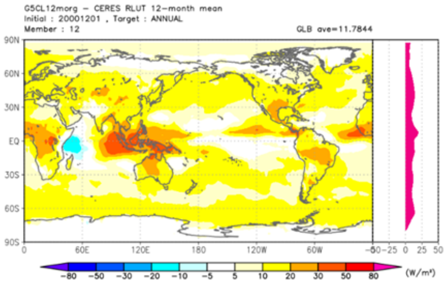

Fig. 1 The OLR bias (Wm^{-2}) in the JMA global NWP model after a 1-year integration (TL159L100, 12member) (CNTL-CERES).

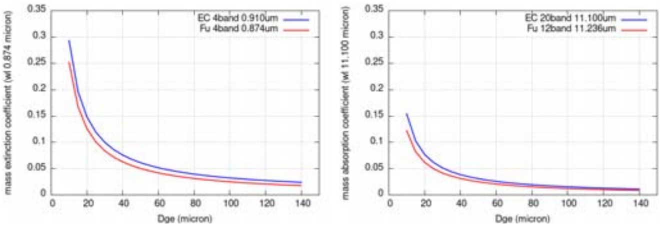

Fig. 2 Dge dependence of ice cloud optical properties using the FU scheme (red) and the EC92 scheme (blue); (left panel) mass extinction coefficient (m^2/g) near the wavelength of 0.9 µm, (right panel) mass absorption coefficient (m^2/g) near the wavelength of 11 µm.

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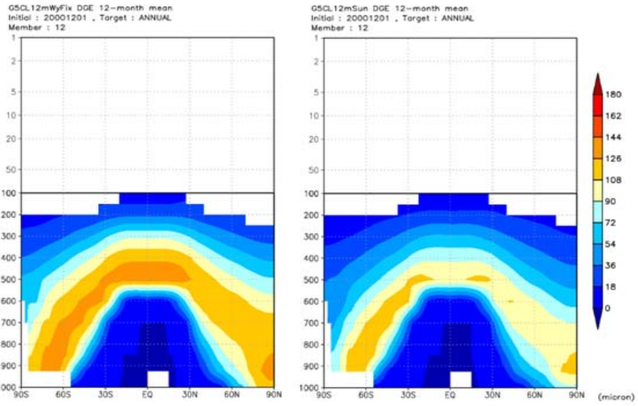

Fig. 3 Zonal mean generalized effective size, Dge (µm), in the JMA global NWP model after a 1-year integration (TL159L100, 12member). (left panel) WY98, (right panel) SUN01.

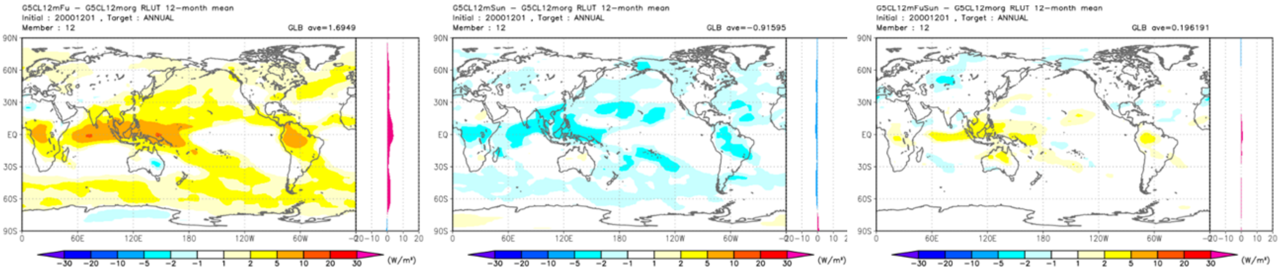

Fig. 4 The impact on the OLR (Wm^{-2}) in the JMA global NWP model after a 1-year integration (TL159L100, 12member); (left panel) FU-CNTL, (middle panel) SUN01-CNTL, (right panel) FUSUN01-CNTL.