Improved SST–shortwave radiation feedback using an updated stratocumulus parameterization

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1 Introduction

The Japan Meteorological Agency (JMA) is developing the next-generation seasonal ensemble prediction system (JMA/MRI-CPS3; CPS3) to support three-month, warm-/cold-season and El Niño forecasts. The atmospheric physical processes of CPS3 are based on the operational JMA Global Spectral Model (GSM; JMA 2019) as of 2020, and an updated stratocumulus parameterization will be implemented to represent stratocumulus clouds in the atmospheric boundary layer. This report outlines the stratocumulus parameterization and presents the results of experiments focused on the feedback between sea surface temperature (SST) and shortwave radiation (SW) flux at the surface.

2 Stratocumulus parameterization

In a general circulation model it is difficult to represent explicitly the complex processes related to stratocumulus clouds, so our approach to tackling this issue involves diagnosing the inversion strength. Kawai and Inoue (2006) (K06) reported some simple conditions that are implemented in the current version of the GSM. A well-known index that corresponds reasonably well to low-level cloud amount is Estimated Inversion Strength (EIS; Wood and Bretherton, 2006). Kawai et al. (2017) proposed the Estimated Cloud Top Entrainment Index (ECTEI), which considers the water vapor profile in addition to EIS.

$$\mathrm{ECTEI} = \mathrm{EIS} - \beta L / C_\mathrm{p} \left(q_\mathrm{surf} - q_{700}\right) \quad (1)$$

$$\beta = (1 - k) C_\mathrm{qgap} \quad (2)$$

where L is latent heat of evaporation; C_p is specific heat at constant pressure; q_surf and q_{700} are the specific humidity at the surface and 700 hPa, respectively; and k and C_qgap are constants.

In our new stratocumulus parameterization, when ECTEI is higher than a threshold, vertical diffusivity is weakened at the top of the boundary layer. As a result, the atmospheric boundary layer becomes wetter, and low clouds are then formed. The ECTEI corresponds more closely than EIS to the observed low-level cloud amount, and a reasonable cloud amount is represented, especially over the Southern Ocean, when the ECTEI is used in a parameterization (Kawai et al. 2019).

3 Experimental design

We conducted free-run experiments using an atmosphere–ocean coupled model. The resolution of the atmospheric model is TL319L100 (Δx ~ 55 km, top ~ 0.01 hPa); the resolution of the ocean model (MRI.COM ver4; Tsujino et al. 2017) is 0.25° × 0.25° with 60 vertical layers. We tested two stratocumulus schemes: one is similar to K06 (CNTL) and the other uses ECTEI (TEST). Calculation of the climatology and the correlation coefficient is based on the monthly mean value of a 30-year integration, excluding the first year as spin-up. Model output is evaluated against CERES-EBAF, COBE-SST and ISCCP data.

4 Results

Climatological low-level cloud amount during June–July–August (JJA) was higher in the TEST experiment than in CNTL, especially off the west coast of continents and over the Southern Ocean (Figure 1), which is consistent with Kawai et al. (2019).

Figure 2 shows the SST–SW feedback; shaded areas in warm (cold) colours indicate positive (negative) feedback. For example, in the positive-feedback region, when SST becomes higher the surface downward SW flux increases as a result of the decrease in cloud amount. CNTL failed to reproduce the widespread positive feedback over the subtropical ocean, whereas TEST represented it well. This is because for higher (lower) SST, q_surf in the second term on the right side of Equation (1) is generally larger (smaller); therefore, ECTEI is smaller (larger) and as a result the parameterization gives less (more) low cloud. Kawai et al. (2017) proposed this mechanism to explain the spatial distribution of low cloud and the changes in different climates. This report confirms that the mechanism also works for the monthly variations in the present climate.

Negative feedback in the NINO.3 region seems to be better represented in TEST. It is, however, necessary to conduct much longer free-run experiments to evaluate phenomena related to El Niño–Southern Oscillation.

Acknowledgements

This work was supported in part by the Japan Society for the Promotion of Science (JSPS) KAKENHI (Grant Nos. JP18H03363, JP19K03977 and JP19H05699).

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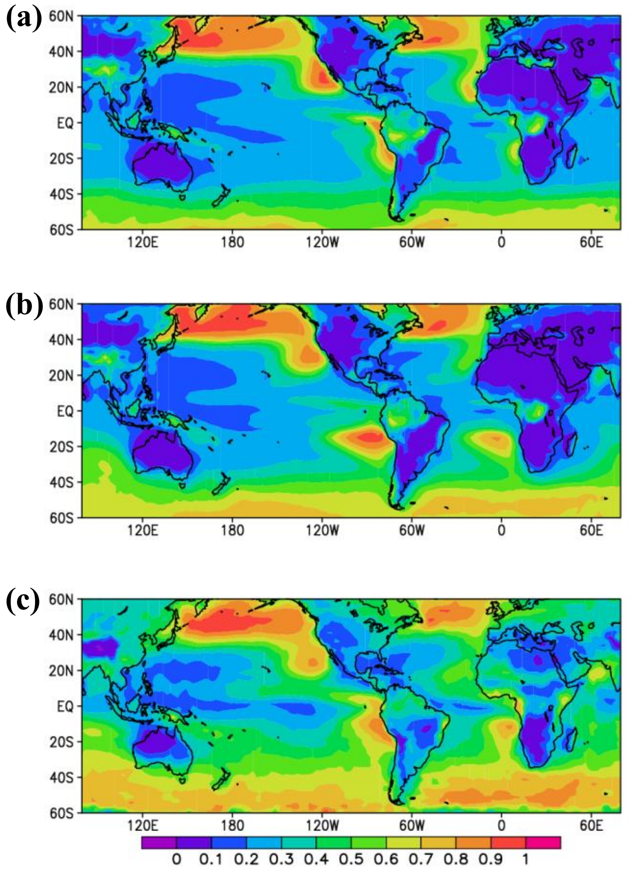

Figure 1 Climatology of low-level cloud amount during JJA for **(a)** CNTL **(b)** TEST and **(c)** ISCCP (1983–2008). ISCCP low-level cloud amount is calculated for areas free of middle- or upper-level clouds.

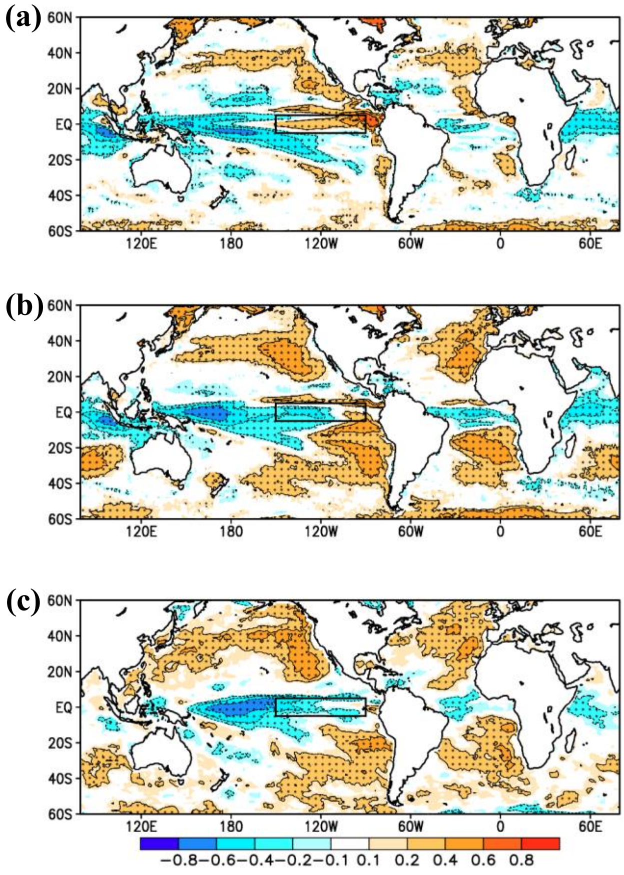

Figure 2 Correlation coefficient between SST and SW anomalies for all months. Anomalies are calculated with respect to the monthly climatology for **(a)** CNTL **(b)** TEST and **(c)** using COBE-SST and CERES-EBAF (2001–2015). Dotted areas are statistically significant at the 99% level. The black box is the NINO.3 region.