Improvement of a Stratocumulus Scheme for Mid-latitude Marine Low Clouds

Hideaki Kawai
Meteorological Research Institute, Japan Meteorological Agency
(e-mail: h-kawai@mri-jma.go.jp)

1. Introduction

In the operational global model of the JMA (Japan Meteorological Agency); i.e., the GSM (Global Spectral Model), mid-latitude marine low clouds are not adequately represented, and there is a longstanding issue that shortwave radiation flux excessively penetrates into the mid-latitude oceans, especially during the summer. A similarly serious excess shortwave radiation flux (negative bias of reflection) is also found in the Japanese 25-year reanalysis dataset (JRA25) (Trenberth and Fasullo 2010), which is the result of the use of the GSM as the forecast model for JRA25. This report presents a development of the stratocumulus scheme (Sc scheme) aimed at reducing the negative bias in both marine low cloud cover and the reflection of solar radiation at mid-latitudes.

2. Problems in previous versions of the Sc scheme

Kawai (2012a, 2012b) reported that the Sc scheme used in the operational JMA-GSM (Kawai and Inoue 2006) has been improved. The representation of the vertical structure of the subtropical boundary layer clouds was improved, and some of the problems associated with the original version of the scheme were resolved, without recognizable deterioration of the radiation budget.

In the improved scheme, the model conditions necessary to produce Sc are: (1) $\theta_{700} - \theta_{surf} > 20$ [K] (based on Klein and Hartmann 1993); and (2) not stable layer near the surface (to guarantee the existence of a mixed layer). When these two conditions are met, mixing at the top of the cloud layer is completely suppressed to prevent the entrainment of dry air in the free atmosphere into the mixed layer; Additional mixing at the top of the mixed layer, which has been used in the operational model for a long time to prevent the unrealistic formation of clouds at the top of the boundary layer, is not applied, and the lower limit of vertical diffusivity is set to be almost zero at the top of the cloud layer. (Hereafter, this scheme is called the LTS (Lower Tropospheric Stability) Sc scheme.)

However, mid-latitude marine low clouds easily dissipate in this scheme, because LTS cannot have large values in mid-latitudes, so the conditions for the scheme are not met. The left panels in Fig. 1 show the low cloud cover and the TOA shortwave radiation bias of applying the LTS Sc scheme (for January). The mid-latitude low cloud cover is underestimated and the shortwave radiation bias is large, as is

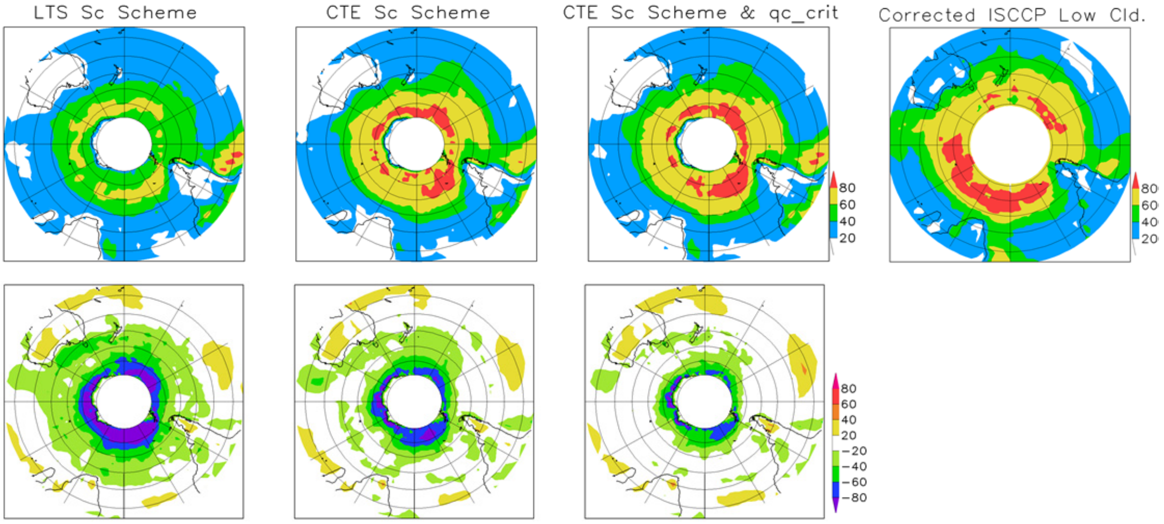

Fig. 1: Top panels: Low cloud cover (%). Bottom panels: Error of TOA upward shortwave flux (W/m^2). The observation data are ERBE. Based on TL159 for January (1987–1989) calculated using the LTS Sc scheme (first from the right), the CTE Sc scheme (second from the right), and with the CTE Sc scheme and the modification of q_{c_crit} (third). The top right panel shows low cloud cover from the ISCCP data, calculated only over areas with no upper clouds.

the case in the operational Sc scheme in the GSM. In addition, the use of LTS in a cloud parameterization can cause an inevitable negative cloud feedback when the model is used for global warming simulations (Wood and Bretherton 2006).

3. Improvement of the Sc scheme

An index EIS (Estimated Inversion Strength) proposed by Wood and Bretherton (2006), which shows relatively large values in mid-latitudes compared with LTS, is basically used in the improved scheme. However, EIS is related only to the inversion strength of (potential) temperature at the cloud top. Consequently, a modified EIS is used here to include the effect of cloud top entrainment (CTE) instability at the cloud top. The most important condition, which is a substitute for the condition (1) of the LTS Sc scheme, is as follows (hereafter, this revised scheme is referred to as the CTE Sc scheme):

$$\mathrm{EIS}_{\mathrm{CTE}} = \mathrm{EIS} - (1 - k)\,(L/C_p)\,(q_{surf} - q_{700})C_{\Delta q} > 0$$

This is a modification of a criterion of non-CTE instability, $\Delta\theta_e > k(L/C_p)\,\Delta q_t$ (Δ: difference between the values above and below the entrainment zone), which is based on an idea similar to CGLMSE in Kawai and Teixeira (2010). A value of 0.7 is used for k (MacVean 1993), and $C_{\Delta q}$ is the correction factor for the humidity difference whose value is less than 1.0, because Δq_t is actually less than ($q_{surf} - q_{700}$), and $C_{\Delta q} = 0.8$ is assumed here. Fig. 2 shows scatter diagrams of optically thick low cloud cover (presumably, stratocumulus or stratus) and LTS, EIS, and $\mathrm{EIS}_{\mathrm{CTE}}$. $\mathrm{EIS}_{\mathrm{CTE}}$ has a very high correlation with low cloud cover, at least, at the same level as EIS.

The second panels from the left in Fig. 1 show the results of applying the CTE Sc scheme: mid-latitude low cloud cover increases, being closer to the observation, while the shortwave radiation error decreases. However, there is still a substantial radiation error.

Therefore, the critical cloud water content, from which autoconversion of cloud water to precipitation starts, is increased from 0.2 to 0.4 g/kg in the boundary layer to suppress the excessive conversion of cloud water into precipitation. This change further decreased the radiation error (third panels from the left in Fig. 1).

The impacts of these changes are limited to almost over the mid-latitude oceans where there were large biases of cloud cover and radiation. Furthermore, these changes in the scheme bring the same improvement for Northern Hemisphere mid-latitudes during the summer, which also had the same bias. These improvements can probably be attributed to the fact that the excessive dissipation of cloud water is prevented, and the overly vigorous conversion of cloud water to precipitation is suppressed by these changes.

Acknowledgements

This work was partly supported by the SOUSEI Program of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and the Research Program on Climate Change Adaptation (RECCA).

References

Kawai, H., 2012a: Examples of mechanisms for negative cloud feedback of stratocumulus and stratus in cloud parameterizations. *SOLA*, **8**, 150-154.

Kawai, H., 2012b: Results of ASTEX and Composite model intercomparison cases using two versions of JMA-GSM SCM. *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling/WMO*, **42**, 0411-0412.

Kawai, H., and T. Inoue, 2006: A simple parameterization scheme for subtropical marine stratocumulus. *SOLA*, **2**, 17–20.

Kawai, H., and J. Teixeira, 2010: Probability Density Functions of Liquid Water Path and Cloud Amount of Marine Boundary Layer Clouds: Geographical and Seasonal Variations and Controlling Meteorological Factors. *J. Climate*, **23**, 2079–2092.

Klein, S. A., and D. L. Hartmann, 1993: The seasonal cycle of low stratiform clouds. *J. Climate*, **6**, 1587–1606.

MacVean, M., 1993: A Numerical Investigation of the Criterion for Cloud-Top Entrainment Instability. *J. Atmos. Sci.*, **50**, 2481–2495.

Trenberth, K. E., and J. T. Fasullo, 2010: Simulation of Present-Day and Twenty-First-Century Energy Budgets of the Southern Oceans. *J. Climate*, **23**, 440–454.

Wood, R., and C.S. Bretherton, 2006: On the Relationship between Stratiform Low Cloud Cover and Lower-Tropospheric Stability. *J. Climate*, **19**, 6425–6432.

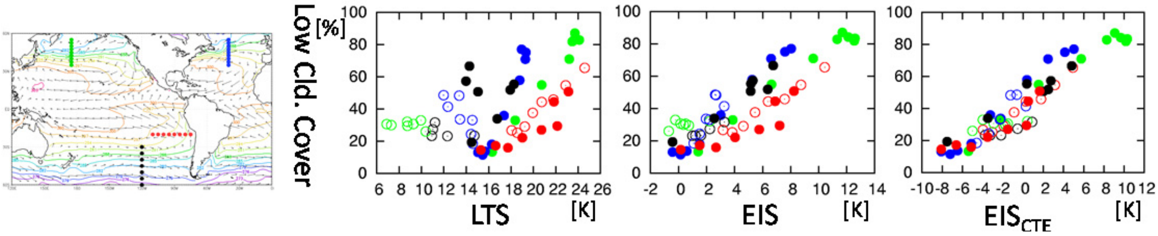

Fig. 2: Left panel shows the data locations. Other panels show scatter diagrams of low cloud cover (%) and LTS (second from the left), EIS (third), and $\mathrm{EIS}_{\mathrm{CTE}}$ (fourth). Low cloud cover in these panels is calculated from the ISCCP low cloud data whose optical depth is greater than 3.55 only over areas with no upper clouds. Data are from January and July 1999–2001. Solid circles correspond to summer data, and open circles to winter. For $\mathrm{EIS}_{\mathrm{CTE}}$, k = 0.7 and $C_{\Delta q} = 0.8$ are used.