Application of delta-four-stream approximation to the JMA-GSM shortwave radiation scheme: preliminary results

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1. Introduction

The current operational shortwave radiation (SW) scheme implemented in the Japan Meteorological Agency Global Spectral Model (JMA-GSM, Yonehara et al. 2014) uses the delta-Eddington two-stream approximation method for the computation of radiative transfer with absorption and multiple scattering processes. This method is computationally efficient under clear-sky and cloudy-sky conditions, and is widely used in SW schemes for global models. However, as the two-stream approximation may cause large computational errors in the calculation of shortwave flux and the heating rate under cloudy-sky conditions, there is a need for higher-order approximation in the model's SW scheme. Against such a background, a delta-four-stream approximation method was tested with the JMA-GSM SW scheme. In this study, the delta-four-stream discrete ordinate method (Liou et al. 1988; Zhang et al. 2013) was applied as an alternative to the currently used delta-Eddington approximation method.

2. Experiment configuration

The accuracy of the delta-four-stream approximation method was investigated using a single column model (SCM). The current SW scheme was used in the control experiment (CNTL), and the delta-four-stream discrete ordinate method was used in the test experiment (TEST). The results of both experiments were compared with the delta-32-stream discrete ordinate method (Stamnes et al. 1988) as a benchmark.

Mid-latitude summer standard atmosphere was chosen to represent a typical vertical profile for temperature, humidity and ozone as given in the SCM. Clear-sky case, low-cloud case with thick cloud lying around 850-hPa height, and high-cloud case with thin cloud lying around 250-hPa height were considered. The surface albedo and the cosine of the solar zenith angle were set to 0.2 and 0.8, respectively. The effects of aerosols were neglected for simplicity.

3. Verification of the delta-four-stream approximation method

Tables 1 and 2 show the results of the SCM experiments for shortwave fluxes. Compared with the corresponding benchmark results in the high-cloud case, CNTL shows negative errors up to 5 W/m^2 for downward flux at the surface and positive errors up to 7 W/m^2 for upward flux at the top of the atmosphere. This suggests that reflection tends to be overestimated with the current SW scheme in this case. The application of delta-four-stream approximation is expected to improve the accuracy of calculation for multiple scattering processes, especially in the optically thin case where the scattering field differs significantly from the two-stream assumption. The shortwave flux errors seen in CNTL were reduced as expected in TEST to less than 0.5 W/m^2.

In the low-cloud case, the accuracy of shortwave fluxes calculated in CNTL was comparable to that of TEST, but a large difference in the shortwave heating rate was observed. This error as compared to the benchmark results is shown in the panel on the right of Figure 1. CNTL (shown by the blue line) exhibits negative shortwave heating error at the cloud top and positive error at the cloud base; notably, the error at the cloud top exceeds 0.9 K/day. It is possible that absorption due to cloud is underestimated with the current SW scheme, meaning that shortwave flux absorption in the upper part of the cloud layer weakens and the energy that should be absorbed there reaches the lower part of the cloud layer. These errors are also reduced by the application of the delta-four-stream method (TEST, red line) to about 0.1 K/day.

Accuracy improvement for shortwave flux and the heating rate was also observed with other atmospheric profiles and solar zenith angles (not shown).

4. Summary and future plans

In this study, the delta-four-stream approximation method was tested in the JMA-GSM SW scheme and its accuracy was investigated. Idealized SCM experiments showed that the delta-four-stream approximation method reduces the shortwave flux and heating rate errors observed with the operational delta-Eddington approximation method, especially in cloudy-sky conditions. The results presented here are preliminary; the impact of this method on the operational JMA-GSM will be investigated as the next step. For operational use, the computational efficiency of the scheme should also be evaluated.

Table 1: Calculated downward shortwave flux at the surface in the SCM (unit: W/m^2). CNTL, TEST, and benchmark represent each experiment. Differences of CNTL and TEST results from the benchmark are also shown.

	benchmark	CNTL	CNTL – benchmark	TEST	TEST – benchmark
clear-sky	841.09	838.53	–2.56	841.56	+0.47
low-cloud	168.98	168.56	–0.42	169.39	+0.41
high-cloud	820.66	815.02	–5.64	820.69	+0.03

Table 2: As per Table 1, but for upward shortwave flux at the top of the atmosphere.

	benchmark	CNTL	CNTL – benchmark	TEST	TEST – benchmark
clear-sky	190.20	192.79	+2.59	189.83	–0.37
low-cloud	653.88	654.60	+0.72	652.64	–1.24
high-cloud	204.04	211.18	+7.14	203.59	–0.45

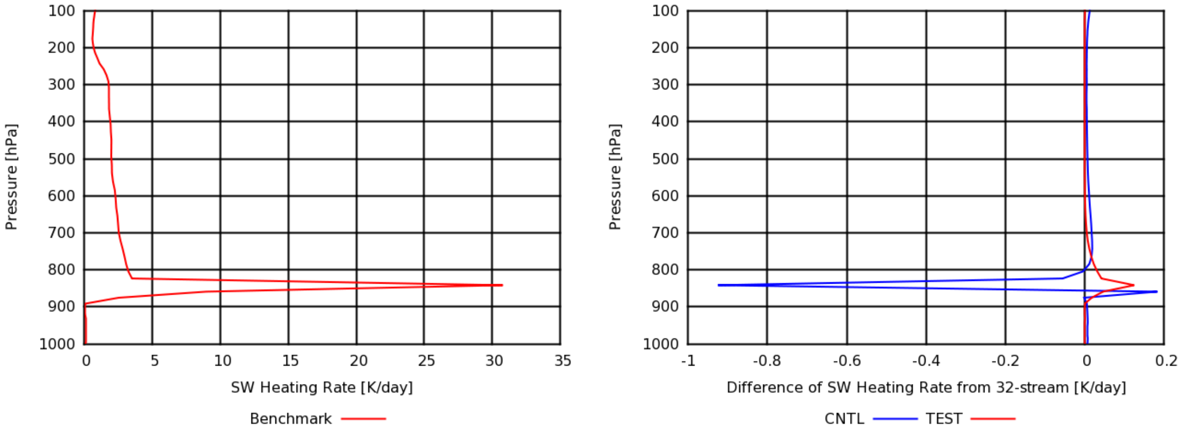

Figure 1: Calculated shortwave heating rate profile in the SCM (unit: K/day). Left: benchmark results; right: differences in CNTL (blue line) and TEST (red line) from the benchmark

References

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