# Development of longwave radiation scheme with consideration of scattering by clouds in JMA global model

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**1. Introduction**

Current version of longwave radiation (LW) scheme in the MRI/JMA global atmospheric model calculates only absorption and emissivity process due to the atmospheric molecules, aerosol particles and clouds. Clouds, including thin ice clouds, are approximated with black bodies (Räisänen,1998) in this scheme. In addition, it is used band-emissivity method to calculate the LW radiative transfer, which takes computational cost proportional to almost square of number of vertical layers of the model, so it makes a matter in increasing the vertical resolution of the model. In order to improve these drawbacks, new LW scheme has developed which is able to consider LW scattering by clouds and is also able to calculate the radiative transfer more efficiently.

**2. New longwave radiation scheme**

2 or 4-stream radiation transfer method is applied in the new LW scheme. According to Li & Fu (2000), two types of schemes are implemented; one is the absorption approximation version, referred as AA, which do not consider scattering process like as the current JMA LW scheme, and the other is a version considering scattering process, referred as AAS. In the radiative transfer equation of the AAS version, the source term by scattering is evaluated with using the radiative intensity of the AA solution. As Li & Fu argued, it is confirmed that this treatment of LW scattering has advantages in both the efficiency and the accuracy of the calculation.

In the new LW scheme, absorptions due to the atmospheric molecules are calculated by two types of k-distribution methods. One is the correlated k-distribution method (i.e. Fu and Liou,1992) where the absorption coefficients at 51 pressure levels between 1000 and 0.01hPa are tabulated by using the HITRAN(2000) absorption line database. The other is referred as a "scaling" k-distribution method (i.e. Chou et al.,2001), used also in the current JMA LW scheme, where the Lorentzian line absorption (pressure broadening) is assumed and only one absorption coefficient at a specified pressure level (500hPa) is prepared.

Table 1 shows calculation bands and variation of absorption gas molecules in the new scheme, with denoting k-distribution types and number of sub-bands, also denoting the overlap assumption of absorptions in the same band. The correlated k-distribution method (C-k, or blue colored) is applied to the absorptions important in the stratosphere, that is $CO_2$ in the 15 micron band, $O_3$ in the 9.6 micron band and $H_2O$ in the three bands. The "scaling" k-distribution method (S-k, or yellow colored) is applied to the other absorptions, including $H_2O$ continuum based on MT-CKD continuum model and Zhong & High (1995) scaling parameters. Number of sub-bands used in S-k is not larger than 6, enough to approximate absorptions in the troposphere, whereas number of sub-bands used in C-k is set to 16, required to represent a sharp peak of the Doppler type absorption line appeared in the stratosphere or higher atmosphere. Overlap assumption of each band/absorption is selected from the following three types: perfect, random and partly correlated (Zhang et al.,2003), except for overlap between $CO_2$ and $H_2O$ in the 15-micron band (band3a-3c) treated by considering $CO_2$ and $H_2O$ as one combined virtual gas.

**3. Verification of the new scheme**

Figure 1 shows heating rate profiles calculated by the new LW scheme compared to the current JMA scheme and Line by Line reference calculation. Observed atmospheric profiles used here are taken from CIRC project (Oreopoulos & Mlawer 2010). Upper two figures indicate that the new scheme has better calculation accuracy for clear sky conditions than the current scheme in general, especially in the upper troposphere and the higher region. From the right figure (high precipitable water case), there may be room for improvement on the scheme in the lower troposphere (evaluation of water vapor continuum absorption). Lower two figures are for the case of existing liquid cloud layer (no scattering condition). It is ascertained generally good calculation is performed for the two cases. Although slightly strong radiative cooling is seen around the top of cloud layers, it may be caused by the parameterization to derive optical depth of cloud layers from the effective radius of cloud particles.

**4. Application to the global atmospheric model**

New LW scheme has implemented to the JMA global atmospheric model (GSAM). 2AA (2-stream AA) version of the scheme has larger effect on the shortwave radiation (SW) field in the model than on the LW field. Figure 2 indicates the effect about SW radiative flux at the surface (in July). The red shade in the center figure indicates 2AA model improves insufficiency of the downward SW flux on the subtropical ocean of GSAM, shown in the left figure. Although 2AA and the GSAM LW scheme are the same as to having no scattering process, 2AA tends to give weaker cooling in the clear-sky lower troposphere than GSAM. It brings to decrease of low cloud amount (the right figure) and contributes to weaken the reflection of SW by clouds. Another difference has confirmed in the atmospheric temperature in the stratosphere (not shown here), due to the difference of heating rates in the clear-sky condition (already shown in Fig.1).

On the other hand, LW scattering has smaller effect on the model climate than expected. From 10 case model experiment, monthly mean OLR difference between 4AAS (4-stream AAS) and 4AA (4-stream AA) version is less than 5 W/m$^2$ in the globe, though difference of estimated OLR for the same atmospheric field is often seen larger than 10 W/m$^2$, especially around Japan and west of the continents. Finally, computation speed has measured with TL159L60 resolution model on Hitachi SR16000 supercomputer system. The result is that 2AA model is about 10% faster than GSAM (55% of computational time of GSAM for the radiation section) and even for 4AAS model, it takes almost the same computational time as GSAM.

Table 1: band configuration of new LW scheme
(pf,pt and no in each parenthesis denote perfect, partly and random overlap assumption, respectively)

| # band | 1 | 2 | 3a | 3b | 3c | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| wave no. (/cm) | (25-340) | (340-540) | (540-620) | (620-720) | (720-800) | (800-980) | (980-1100) | (1100-1215) | (1215-1380) | (1380-1900) | (1900-3000) |
| Major absorption gas | | | | | | | | | | | |
| H2O (line) | C-k (16) | | C-k (16,cg) | | | S-k (6) | S-k (6,pf) | S-k (16,pf) | S-k (4) | C-k (16) | S-k (6) |
| CO2 | | | | | | | | | | | |
| O3 | | | | | | | C-k (16) | C-k (16) | | | |
| H2O (continuum) | S-k (16,pt) | | | | | S-k (6,pf) | | S-k (16,pf) | S-k (4,pf) | S-k (pt,16) | S-k (6,pf) |
| minor absorption gas | | | | | | | | | | | |
| CO2 | | | | | | S-k (6,pf) | | | | | |
| N2O | | | S-k (6,pf) | | | | | S-k (16,pf) | S-k (2,no) | | |
| CH4 | | | | | | | | | S-k (2,no) | | |
| CFCs | | | | | | S-k (6,pf) | | | | | |
| # of sub-bands | 16 | 16 | 16 | 16 | 16 | 6 | 16 | 16 | 16(=4x2x2) | 16 | 6 |

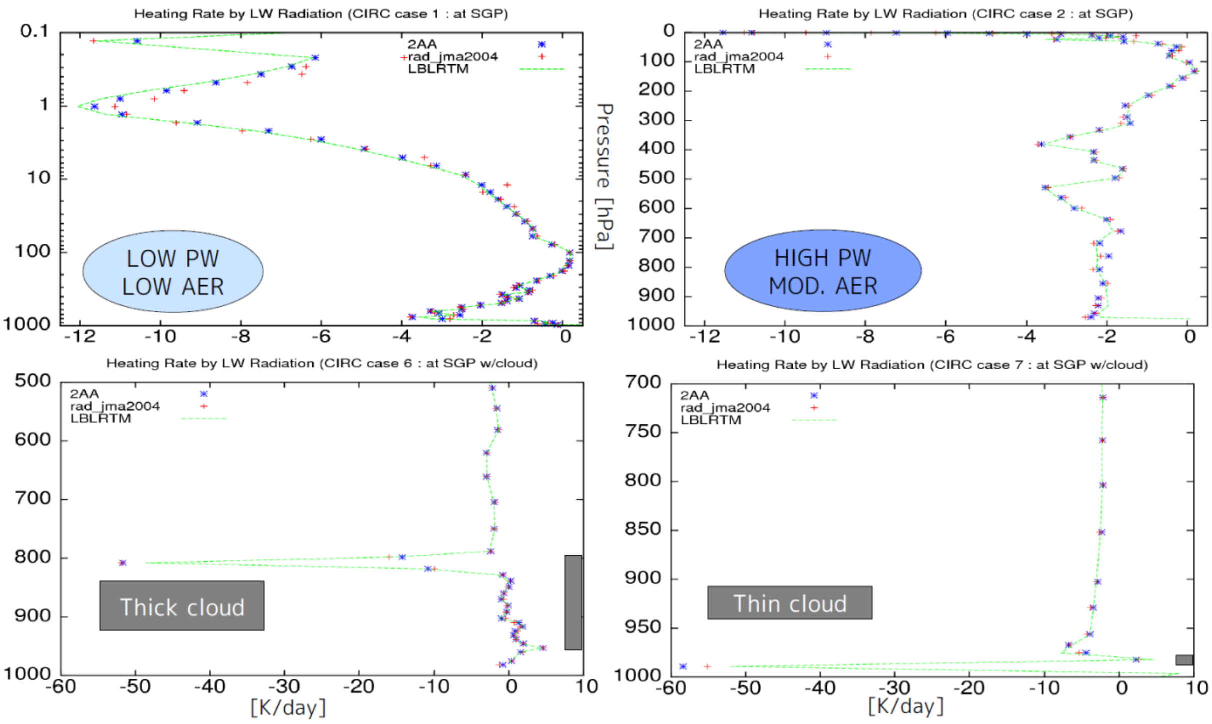


Figure 1: Heating rate profiles for the CIRC atmospheric profiles. PW and AER denotes precipitable water and aerosol. Blue and red dots are calculated by 2AA and the current scheme. Green lines indicate LBL reference calculations. Water cloud layers are located in the heights illustrated by the gray boxes at the far right of the lower two figures.

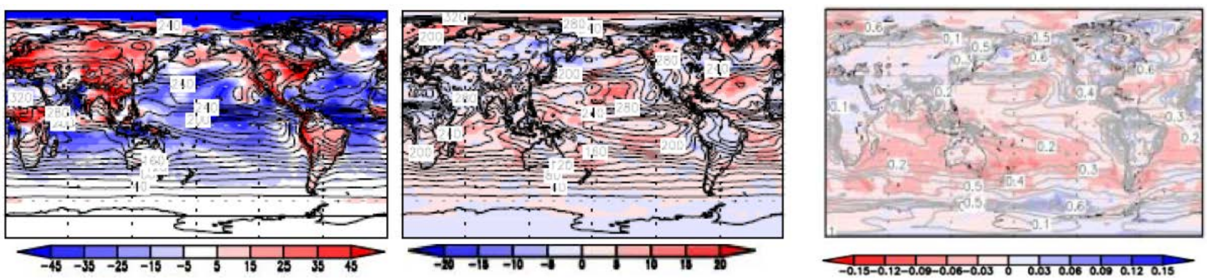

Figure 2: Downward SW flux at the surface in July. (left) flux difference of GSAM from observed(CERES) climatology. (center) flux difference of 2AA from GSAM. (right) difference of modeled low cloud amount between 2AA and GSAM. Unit of SW flux is W/m². The model forecasts (2AA and GSAM) are an average on 10 year cases.