P1.66

DEVELOPMENT OF A NEW RADIATION SCHEME FOR THE GLOBAL ATMOSPHERIC NWP MODEL

Shigeki MURAI *, Syoukichi YABU and Hiroto KITAGAWA
Japan Meteorological Agency, Tokyo, JAPAN

1 INTRODUCTION

A radiation scheme plays an important role in global atmospheric models. As not only its accuracy but also its computing efficiency is important, Japan Meteorological Agency (JMA) developed a more accurate and efficient radiation scheme for a global atmospheric model, as a part of the RR2002 project funded by MEXT (Ministry of Education, Culture, Sports, Science and Technology).

2 CHANGES IN LONGWAVE RADIATION SCHEME

2.1 Outline of changes

The following refinements were carried out based on Chou et al. (2001), in order to calculate radiative flux accurately both in the troposphere and in the stratosphere.

First refinement is on calculation method of transmittance for line absorption. K-distribution method and table look-up method are newly used instead of statistical band model.

Secondly, treatment of water vapor continuum is revised. Parameterization used in the previous scheme is based on Roberts et al. (1976) which tekes account of only self broadening (e-type) absorption. In the new scheme, effect of foreign broadening (P-type) absorption is introduced based on Zhong and Haigh (1995). Variation of absorption coefficient due to water vapor mass change is also considered.

Thirdly, longwave spectrum is divided into 9 bands instead of previous 4 bands. Radiative flux is calculated in each band separately, in order to improve accuracy of band-averaged transmittance. In addition, water vapor absorption are taken into account in entire longwave spectrum. Effects of absorption by trace gases such as CH_4, N_2O and 3 CFCs are also introduced. Figure 1 shows spectral ranges for these bands and absorbers involved in each band.

* *Corresponding author address:* Shigeki MURAI, Japan Meteorological Agency, 1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122, JAPAN; e-mail: murai@met.kishou.go.jp

2.2 K-distribution method

Transmittance in most of spectral bands are calculated by k-distribution method which has advantage of computing efficiently. The basic assumption of this method is that an integration over wavenumber ν can be replaced by an integration over the absorption coefficient k, for a narrow spectral interval where the Planck function can be considered almost constant. If the normalized probability distribution function for k is given by $f(k)$, transmittance can be expressed by

$$T = \int_0^\infty f(k)\exp\left[-\frac{k\,u}{\bar{\mu}}\right]dk = \int_0^1 \exp\left[-\frac{k(g)\,u}{\bar{\mu}}\right]dg, \qquad (1)$$

where u is absorber amount, $1/\bar{\mu}$ is diffusivity factor, and $g(k)$ is a cumulative probability density function. This integration can be replaced by a finite sum of exponential terms.

Considering a homogeneous atmosphere in a spectral band, transmittance is expressed as

$$T(p,\theta,u) = \sum_n \exp\left[-\frac{k_n(p,\theta)\,u}{\bar{\mu}}\right]\Delta g_n, \qquad (2)$$

where Δg_n is a cumulative probability density function weighted by the Planck function.

For calculation for a nonhomogeneous atmospheric path, a pressure scaling method is adopted. We introduce scaled absorber amount defined by

$$\tilde{u} = \int \left(\frac{p'}{p_r}\right)^m h(\theta',\theta_r)\,du', \qquad (3)$$

where p_r and θ_r are the reference pressure and temperature, m is an empirical constant, and $h(\theta,\theta_r)$ is temperature scaling factor given by

$$h(\theta,\theta_r) = 1 + \alpha(\theta-\theta_r) + \beta(\theta-\theta_r)^2, \qquad (4)$$

where α and β are regression coefficients. Using this scaling method, a nonhomogeneous atmosphere is regarded as a homogeneous atmosphere with pressure p_r, temperature θ_r and absorber amount $\tilde{u}$.

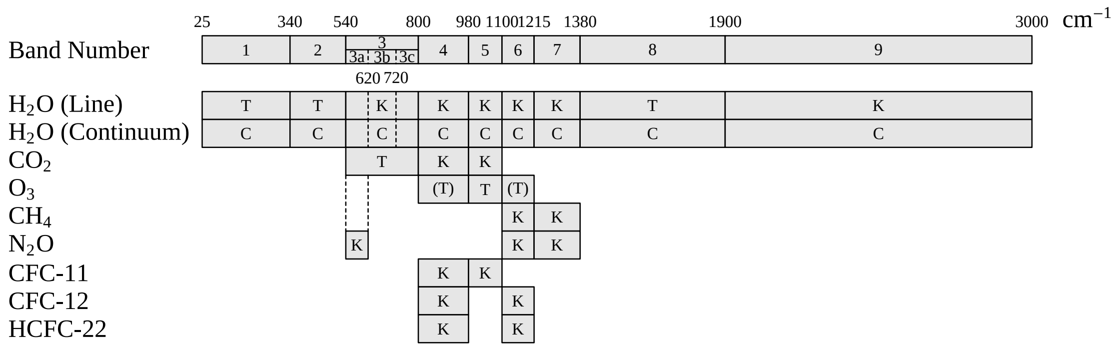

Fig. 1. Longwave spectral bands and absorbers. Letters in the figure represent methods for calculating transmittance; K: k-distribution method, T: table look-up method, C: parameterization of water vapor continuum absorption. Absorptions by ozone noted as (T) mean that these effects are included in the 5th band.

2.3 Table look-up method

K-distribution method described above is a very efficient method, but its accuracy in the upper stratosphere is not enough because pressure scaling technique cannot deal with effects of Doppler absorption adequately. In order to compute transmittance in the upper stratosphere accurately, a pre-computed table look-up technique is used for spectral bands where radiative cooling in the stratosphere is significant.

Transmittance in a homogeneous layer is calculated in advance for some combinations of pressure, temperature and absorber amount by line-by-line method. Temperature dependency is expressed in a form of quadratic fit. Transmittance is given by

$$\begin{aligned} T(p,\theta,u) &= \mathcal{A}(p,u) + \mathcal{B}(p,u)\,(\theta-250) \\ &\quad + C(p,u)\,(\theta-250)^2 . \end{aligned} \tag{5}$$

Coefficients of the tables ($\mathcal{A}$, $\mathcal{B}$, C) are determined using HITRAN2000 (Rothman et al. 2003) as a line parameter database and LBLRTM (Clough et al. 1992, Clough and Iacono 1995) as a line-by-line model.

Transmittance in a nonhomogeneous layer with pressure and temperature varying with height is computed as a homogeneous layer with an effective pressure and temperature defined by

$$p_{eff} = \frac{\int p\,du}{\int du}, \quad \theta_{eff} = \frac{\int \theta\,du}{\int du}, \tag{6}$$

where u is the absorber amount.

2.4 Parameterization of water vapor continuum absorption

Parameterization of water vapor continuum absorption is based on Zhong and Haigh (1995). Optical depth by water vapor continuum in a spectral band is described as

$$\tau_c = \overline{k^e}\,(\overline{ue})\;\overline{ue} + \overline{k^P}\left(\overline{u\,(p-e)}\right)\overline{u\,(p-e)}, \tag{7}$$

where $\overline{ue}$ and $\overline{u\,(p-e)}$ are scaled wator vapor mass for e-type and P-type absorption respectively, defined as

$$\overline{ue} = \int e' f^e(\theta')\,du' \tag{8}$$

$$\overline{u\,(p-e)} = \int (p'-e')\,f^P(\theta')\,du'. \tag{9}$$

In the equations above, e' and p' are water vapor partial pressure and total pressure respectively, f^e and f^P represent temperature dependency described as

$$f^e(\theta) = \exp\left[\Theta\left(1-\frac{\theta}{296}\right)\right] \tag{10}$$

$$f^P(\theta) = \frac{296}{\theta}, \tag{11}$$

where θ is temperature in K, Θ is a constant defined for each spectral band using CKD model (Clough et al. 1989).

$\overline{k^e}$ and $\overline{k^P}$ are absorption coefficients when temperature is 296 K and are functions of scaled water vapor mass. These are fit by

$$\overline{k^e} = a^e\frac{1+c^e\overline{ue}}{1+b^e\overline{ue}} + d^e, \quad \overline{k^P} = a^P\frac{1+c^P\overline{u\,(p-e)}}{1+b^P\overline{u\,(p-e)}} + d^P, \tag{12}$$

where a^e, b^e, c^e, d^e, a^P, b^P, c^P and d^P are fitting parameters determined by comparison with calculation by MT-CKD model. An example of fitting is shown in Figure 2.

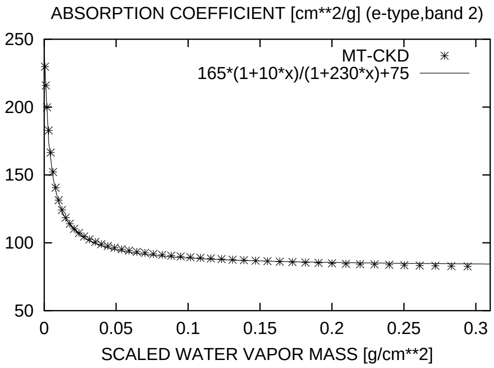

Fig. 2. Absorption coefficient for e-type absorption in the 2nd band. Results by MT-CKD model (∗) and by fitting (solid line) are shown. Abscissa represents scaled water vapor mass divided by 1013 hPa.

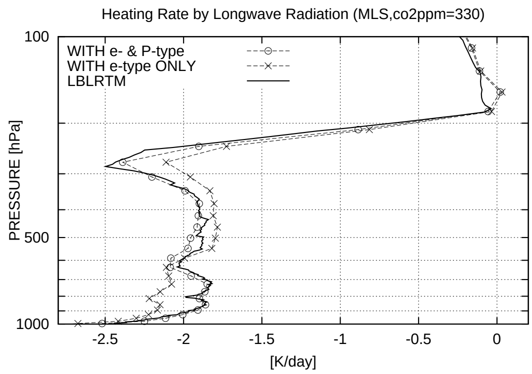

Fig. 3. Heating rate by longwave radiation for midlatitude summer profile. Results by calculation with (◯) and without (×) P-type absorption and line-by-line method (solid line) are shown.

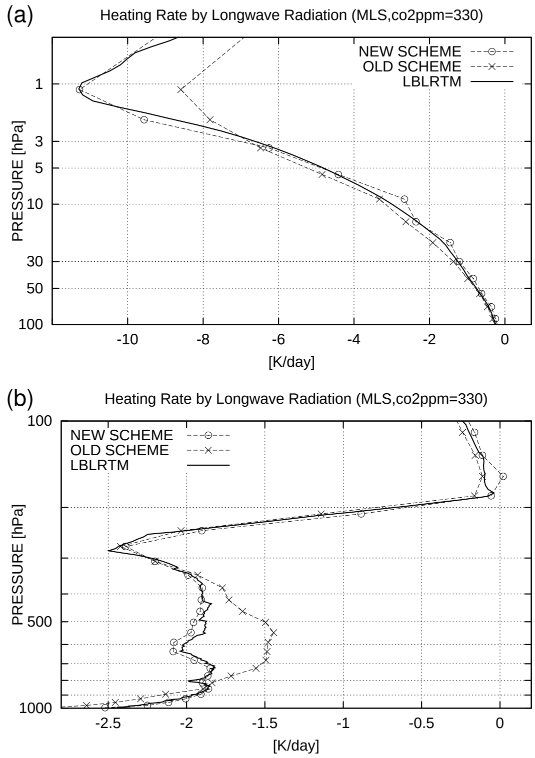

Fig. 4. Heating rate by longwave radiation for midlatitude summer profile. (a) Above 100 hPa, (b) below 100 hPa.

3 CHANGES IN SHORTWAVE RADIATION SCHEME

Shortwave scattering and absorption are modeled by a two-stream formulation using the delta-Eddington approximation. Absorptions by O_3, CO_2 and O_2 are refined in order to improve forecast for temperature in the stratosphere based on Freidenreich and Ramaswamy (1999).

For O_3 absorption, the number of spectral bands is increased from 8 to 15 and we use newer absorption cross section data.

For CO_2 and O_2, absorption bands are added. All absorptions in near-infrared spectrum for CO_2 and absorption in Schumann-Runge band in the ultraviolet spectrum for O_2 are taken into account. In addition, optical depth parameterization is also refined. Although the old scheme does not express variation of absorption coefficient with height sufficiently, the new scheme is able to take account of this effect more adequately. These changes will be more important when the uppermost level in the model will be higher to the mesosphere in the near future.

4 CHARACTERISTIC OF THE SCHEME

Figure 3 shows the effect of P-type absorption to heating rate by longwave radiation. Calculation which takes account of only e-type absorption (×) overestimates radiative cooling in the lower troposphere and underestimates that in the upper troposphere. With the effect of P-type absorption, calculated cooling rate profile is quite similar to the line-by-line calculation.

Figure 4 shows the longwave heating rate profiles calculated for the midlatitude summer profile. The old scheme underestimates the cooling around the stratopause (near 1hPa), and the new scheme reduces the error (Figure 4(a)). This changes were brought mainly by taking account of the Doppler absorption effect properly. Heating rate profiles for the troposphere are shown in Figure 4(b). The old scheme underestimates the cooling in the middle troposphere and overestimates that near the surface. These errors are reduced by the revision of transmittance calculation of water vapor line absorptions and the introduction of P-type continuum absorption.

5 FORECAST PERFORMANCE OF THE MODEL

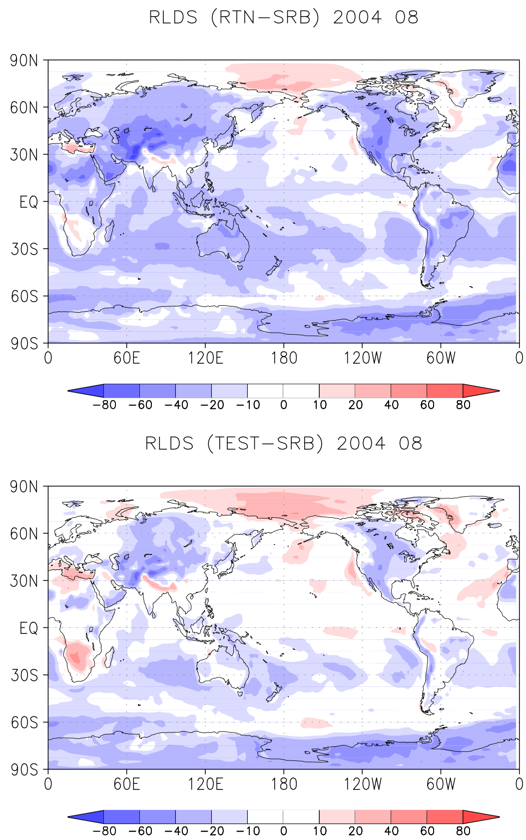

Fig. 5. Error in downward longwave radiative flux at the surface against SRB. Unit is W/m^2. Upper panel is for old scheme, lower is for new scheme.

Figure 5 shows a difference in downward longwave radiative flux at the surface between forecasts and the Surface Radiation Budget (SRB). We used averages of SRB data from 1984 to 1994 as a verifying climatology. The old scheme underestimates the downward longwave flux at the surface over the nearly whole globe. Flux expressed by the new scheme increases especially over the tropical region and over land. A difference between forecasts and SRB is smaller than 10 W/m^2 over most area.

Figure 6 shows vertical profile of temperature bias against sonde observations at the Northern hemisphere (20°N–90°N) in August 2004. Colored lines in the figure represent errors for each forecast time (FT00–216 hours). It is obvious that the new scheme improves temperature forecast in the stratosphere. In the troposphere, bias near 300, 700 hPa and the surface are reduced. In addition, though bias near the surface is increased at the beginning of forcast with the old scheme, the new scheme almost reduces this characteristic. This means that imbalance between initial field and forecast field is reduced.

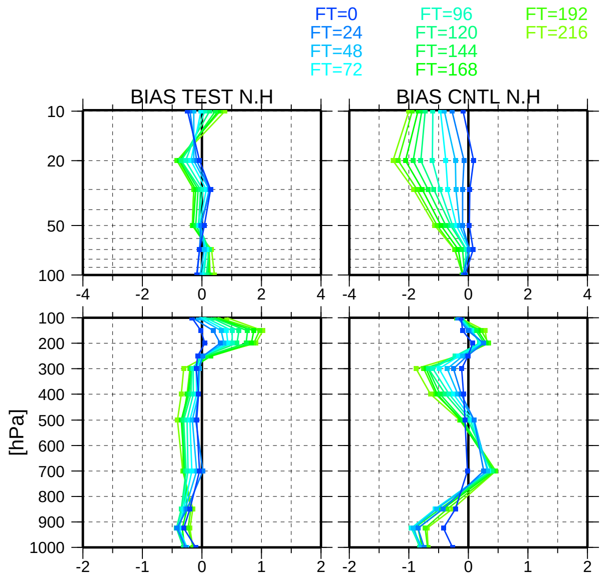

Fig. 6. Vertical profile of temperature bias against sonde observations at the Northern hemisphere (20°N–90°N) in August 2004. Left panel is by the new scheme, right is by the old scheme. Each line represents bias for forecast time from FT00 to FT216 hours.

6 SUMMARY

JMA developed a more accurate and efficient radiation scheme for a global atmospheric model. In this new radiation scheme, a longwave spectrum is divided into 9 bands. Considering a trade-off between accuracy and efficiency, gaseous transmittance is computed using three different approaches depending on the absorber and the spectral band. These are a k-distribution method and a precomputed table look-up method for line absorption, and a parameterization for water vapor continuum absorption. Effects of absorption by trace gases are also introduced. In addition to above changes in the longwave scheme, the parameterization of absorption coefficient is refined in the new shortwave scheme.

By taking account of the Doppler absorption effect properly, errors in longwave cooling around the stratopause are reduced. Errors in cooling of the troposphere are also reduced by improvement of transmittance calculation of line absorption and introduction of P-type absorption of water vapor continuum. Accuracy of downward longwave flux at the ground expressed with the new scheme is also improved. A difference between forecasts and data derived from satellite observations is less than 10 W/m^2 over most area.

REFERENCES

Chou, M. D., M. J. Suarez, X. Z. Liang and M. M.-H. Yan, 2001: A thermal infrared radiation parameterization for atmospheric studies. Technical report series on global modeling and data assimilation Volume **19**, NASA Goddard Space Flight Center.

Clough, S. A. and M. J. Iacono, 1995: Line-by-line calculation of atmospheric fluxes and cooling rates II: Application to carbon dioxide, ozone, methane, nitrous oxide, and the halocarbons. *J. Geophys. Res.*, **100**, 16519–16535.

Clough, S. A., M. J. Iacono and J.-L. Moncet, 1992: Line-by-line calculations of atmospheric fluxes and cooling rates: Application to water vapor. *J. Geophys. Res.*, **97**, 15761–15785.

Clough, S. A., F. X. Kneizys and R. W. Davies, 1989: Line shape and the water vapor continuum. *Atmos. Res.*, **23**, 229–241.

Freidenreich, S. M. and V. Ramaswamy, 1999: A new multiple-band solar radiative parameterization for general circulation models. *J. Geophys. Res.*, **104**, 31389–31409.

Rothman, L. S., A. Barbe, D. C. Benner, L. R. Brown, C. Camy-Peyret, M. R. Carleer, K. Chance, C. Clerbaux, V. Dana, V. M. Devi, A. Fayt, J.-M. Flaud, R. R. Gamache, A. Goldman, D. Jacquemart, K. W. Jucks, W. J. Lafferty, J.-Y. Mandin, S. T. Massie, V. Nemtchinov, D. A. Newnham, A. Perrin, C. P. Rinsland, J. Schroeder, K. M. Smith, M. A. H. Smith, K. Tang, R. A. Toth, J. Vander Auwera, P. Varanasi and K. Yoshino, 2003: The HITRAN molecular spectroscopic database: edition of 2000 including updates through 2001. *J. Quant. Spectrosc. Radiat. Transfer*, **82**, 5–44.

Zhong, W. and J. D. Haigh, 1995: Improved broadband emissivity parameterization for water vapor cooling rate calculations. *J. Atmos. Sci.*, **52**, 124–138.