An accurate calculation scheme of radiative flux transfer for general circulation model studies

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1. Background and objectives

Accurate estimation of the radiative forcing due to greenhouse gases and particulate matters is crucially important for studying global warming processes. In this context, an accurate yet efficient radiative transfer code is a key-tool for successful numerical simulations by general circulation models and for earth radiation budget studies by satellite remote sensing techniques. For these purposes existing radiation codes are not enough to fulfill the demand, especially for cloudy atmosphere simulations. Some codes use emissivity parameterization to introduce cloud effects. In the present study we have developed an accurate and efficient radiative transfer code, which is pertinent to calculate the radiative heating rate in the realistic atmospheres including clouds, aerosols and gaseous constituents.

2. Methods

The absorption coefficient (k-value) of gaseous constituents has a strong and complex wavelength dependence as compared with the scattering coefficient and Plank function. Therefore we have to integrate the transfer equation with respect to wavelength by setting up fine wavelength grids for accurate estimation of radiative fluxes. This method (Line-by-line method, LBL-method) is accurate but takes inhibitively large computing time for applying to general circulation and remote sensing problems.

In this study we adopted a k-distribution method (KD-method) to reduce the computational amount without reducing the accuracy of radiative flux calculations. We further implemented this method in a discrete ordinate method to take into account the multiple scattering effect by aerosols and clouds (Nakajima and Tanaka, 1986). As for gaseous absorption coefficient calculations, we adopted line absorption parameters of HITRAN 1992 database and continuous absorption parameterization of LOWTRAN-7. In this study we will show case studies with the US-standard atmosphere without scattering constituents for demonstrating the accuracy of our method.

We have calculated k-values for several prescribed values of pressure and temperature by making use of an accurate line-by-line integration code (Uchiyama, 1992). And further we get k-distribution functions by sampling k-values from this large table (the data volume is about 1.5G bytes) and by sorting the sampled k-values in terms of the magnitude of k-values.

3. Results

We first of all should demonstrate that the introduction of KD-method does not reduce the computational accuracy noticeably as compared with the LBL-method. For this purpose we have estimated errors involved in two approximations on which we rest in the KD-method, i. e., (1) the approximation of independence of absorption coefficients of different values of pressure and temperature in

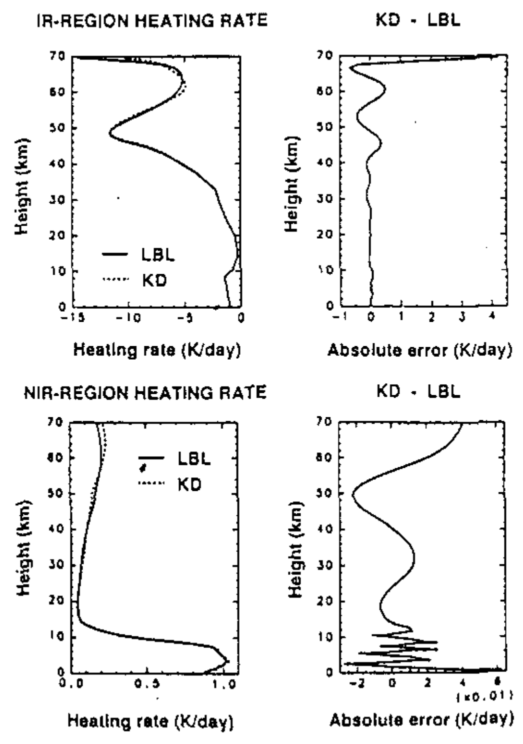

Fig. 1 A comparison of heating rates calculated by KD- and LBL-methods. Results for an infrared band (50-2500 cm^{-1},upper panel), and for a near-infrared band (2500-14500 cm^{-1}, lower panel).

	バンド (1/cm)	大気分子	channel 数
赤外	50-550	H_2O	22
	550-800	H_2O, CO_2	80 (5,16)
	800-980	H_2O	5
	980-1100	H_2O, O_3	32 (4,8)
	1100-2500	H_2O	14
近赤外	2500-14500	H_2O	13

Table 1 The range of wavelength bands, molecular species, and number of channels used in the present calculations.

the process of sorting; (2) independence of absorption coefficients of different gases when these are mixed.

Extensive numerical tests have shown that these two approximations introduce an error less than several percent if the number of equivalent wavelengths (channel) is large enough.

It is observed that the error involved in the KD-method increases relatively slowly with decreasing number of channels. The number of channels about 40 - 150 in the entire region of spectrum will be enough to retain the error less than 10% in radiative heating rate calculations. It is found the number of channels depends on the maximum height of the model atmosphere. Some tentative numbers of channels are listed in Table 1 for the maximum height of 70 km. Figure 1 shows an example of heating rate and its error with this channel selection for two bands. The absolute error is less than 0.02 K/day in the near infrared band and less than 1 K/day in the infrared bands.

4. Future prospects

We have demonstrated our KD-method is promising for general circulation modelling. The channel selection in this study has been done by subjective analyses of absorption coefficient spectra. This process should be improved by introducing an automatic optimization algorithm. We are now working in this direction to produce more efficient k-value selection than reported here (Tsukamoto and Nakajima, 1993). A large computational resources are needed for such extensive numerical calculations

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