A NEW TECHNIQUE FOR DEVELOPING K-DISTRIBUTIONS

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ABSTRACT

This work is devoted to a new technique, which finds the shortest k-distribution series achievable in practice. Its novelty consists in the use of real atmospheric flux calculations to guide both the position of spectral bands and the k terms within each band. Wavenumber subintervals which have similar atmospheric absorption behavior are chosen, then a representative absorption coefficient is set to the value which best fit the results of line-by-line calculations of fluxes. This method of choosing one absorption coefficient to represent a large number of wavenumber subinterval contrasts with other published methods, and is responsible in large part for the improved computational efficiency. Moreover this technique works as well in the stratosphere as the troposphere and it permits a more accurate treatment of cloud scattering and absorption properties than other methods.

1. INTRODUCTION

Despite on essential efforts, up to now, huge computational resources are required for the calculation of radiative transfer in the atmosphere, for weather and climate prediction, and the processing of radiance data retrieved by satellites. So a number of radiation codes have been developed in the past decade. But all these codes are based on the same correlated-k distribution method [*e.g.*, *Lacis and Oinas*, 1991], which has been developed more than a dozen years ago. Consequently, all these codes have the same well-known difficulties in a treatment of overlapping absorption by different species and in cooling/heating rate simulation in upper atmosphere. For example, in the longwave codes by *Mlawer et al.* [1997] and *Cusack et al.* [1999] 256 and 33 k-distribution terms are used, respectively. But the both codes have comparable accuracy: cooling rate errors in stratosphere are 0.75 and 1.5 K day^{-1}.

It should be mentioned that in all these codes cloud absorption is treated separately from the gas absorption. For this a few broad spectral bands are used with effective scattering and absorption coefficients of cloud media in each band. Unfortunately, the absorption coefficient and, consequently, the single-scattering co-albedo of cloudy media, **1-ω**, strongly depend on wavenumber and vary by several orders of magnitude within these bands. So, as it should be stressed, "no optimal method has been found for deriving **ω** over a broad band" [*Chou and Suarez*, 2002].

A new k-distribution technique, which is free of these difficulties, has been developed recently. Moreover it finds the shortest k-distribution series achievable in practice. By means of this technique a fast k-distributions model (FKDM) suitable for use in weather and climate prediction has been created using 23 and 15 k-distribution terms for the longwave and shortwave regions, respectively. The molecule species represented in the model are H_2O, CO_2, O_2, O_3, N_2O, CH_4, and CFC-11, 12, 113.

2. TECHNIQUE APPLICATIONS

The technique and FKDM are described in detail in [*Fomin*, 2004; *Fomin and Correa*, 2005]. Here we consider its some applications. Figure 1, where CO_2 cooling rate in the 15μm band for the midlatitude summer atmosphere up to 120 km is calculated, illustrates its possibility to create vertically unrestricted fast and accurate parameterization of the radiation. Figure 2 shows each k-term weight detailed in previous figure. It should be stressed that none other method can obtain such kind of weights from ~10^{-5} up to ~10^{-1}.

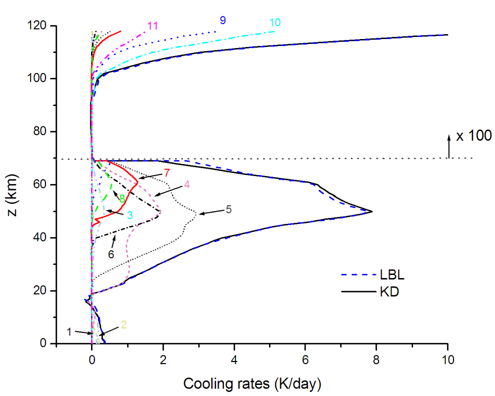

Figure 1 - CO_2 cooling rate in the 15μm band

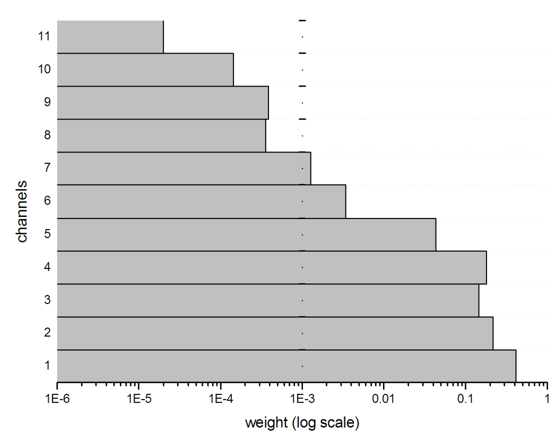

Figure 2 – band weights detailed in previous figure

Figure 3, where erythemal UV fluxes (0.2-0.4 µm) are considered, illustrates the technique efficiency. Ozone absorption and molecular scattering are considered in these calculations. The fluxes were calculated using line-by-line and one-term fit approximation for tropical and subarctic-summer clear-sky conditions and three different ozone concentrations (150, 300 and 600 DU). Representative ozone absorption cross-sections for this fit as a function of ozone amount along the direct solar radiation is shown in Figure 4 The fit accuracy is better than 10% for different conditions (surface albedo between 0.0 – 1.0, ozone amounts between 150 – 600 DU, tropical, midlatitude and subarctic atmospheres). This simple one-term fit may be useful for medical applications.

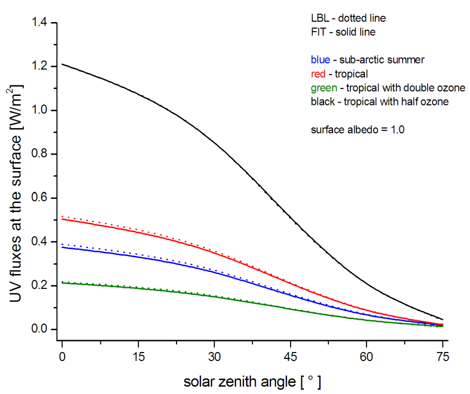

Figure 3 – erythemal UV fluxes (0.2–0.4 µm) for several solar zenital angles

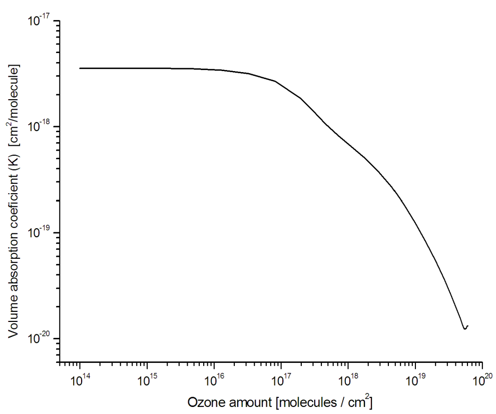

Figure 4 – representative ozone absorption cross-section

As mentioned above the technique is effective for taking into account overlapping absorption by different species. It also gives a possibility to consider radiation absorption by cloud droplets and ice crystals similarly to absorption by molecular species. This feature provides more accurate treatment of cloud optical properties by taking into account correlation between water vapor and liquid water or ice absorption (Figure 5). It has been found that “the neglect this correlation in a radiation model can essentially distort simulated fluxes and heating rates” *[Fomin and Correa*, 2005].

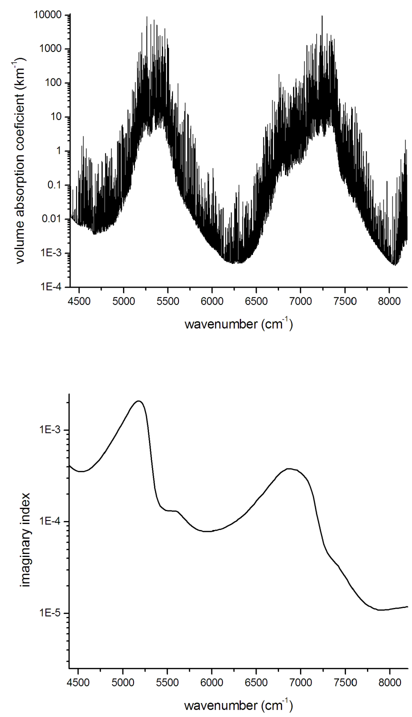

Figure 5 – correlation between water vapor and liquid water or ice absorption

3. CONCLUSIONS

An assessment of this technique accuracy and speed has shown it to be a more efficient technique than the correlated-k method. Moreover this technique works as well in the stratosphere as the troposphere and it permits a more accurate treatment of cloud scattering and absorption properties than other methods. So it is recommended for radiation flux and heating/cooling rate calculations in GCMs and for simulations radiations in the on-line data processing systems for sattelite experiments.

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REFERENCES

Chou, M.-D., and M.J. Suares, 2002: A solar radiation parameterization for atmospheric studies, Technical report series on global modeling and data assimilation, *NASA/TM-1999-10460*, 15, 42-42.

Cusack, S., J.M. Edwards and J.M. Crowther, 1999: Investigating k distributing method for parametrizing gaseos absorption in the Hadley Centre Climate Model, *Journal of Geophysical Research*, 104, 2051-2057.

Fomin, B.A., 2004: A k-distribution technique for radiative transfer simulation in inhomogeneous atmosphere I: FKDM, fast k-distribution model for the longwave, *Journal of Geophysical Research*, 109, D02110, doi: 10.1029/2003 JD003802.

Fomin, B.A. and Correa, M.P., 2005: A k-distribution technique for radiative transfer simulation in inhomogeneous atmosphere: 2. FKDM, fast k-distribution model for the shortwave. *Journal of Geophysical Research*, 110, D02106, doi:10.1029/2004JD005613.

Lacis, A.A., and V. Oinas, 1991: A description of the correlated k-distribution method for modeling nongray gaseous absorption, thermal emission, and multiple scattering in vertically inhomogeneous atmospheres, *Journal of Geophysical Research,* 96, 9027-9074.

Mlawer, E.J., J. Taubman, P.D. Brown, M.J. Iacono and S.A. Clough, 1997: Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave, *Journal of Geophysical Research, 102*, 16663-16682.