

**THE USE OF CORRELATED k -DISTRIBUTIONS TO ACCOUNT
FOR THE RADIATIVE EFFECT OF MOLECULAR ABSORPTION
UPON SATELLITE MEASURED RADIANCES**

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1. INTRODUCTION

Establishing the radiative effect of molecular absorption (emission) in the atmosphere is critical to the proper interpretation of satellite retrieved radiances. Without an accurate accounting for molecular absorption, the assignment of radiative transfer processes to observed radiative effects could be fraught errors. Moreover, since the spectral characteristics of molecular absorption can change quickly with wavenumber, the adaptation of climate model parameterizations has the potential to lead to dubious results unless the chosen spectral range corresponds closely to the response function of the satellite instrument. Thus, an initiative has been undertaken to construct parameterizations that will account for the molecular absorption found in the spectral ranges of several satellite radiometers. Because of its efficiency and accuracy in calculating the molecular absorption for nonhomogeneous paths, the correlated k -distribution procedure has proven to be the most effective parameterization (Fu and Liou, 1992, and Kratz, 1995). A further advantage of the correlated k -distribution procedure is its ability to be incorporated directly into multiple scattering routines that consider scattering, as well as absorption, by clouds and aerosol particles.

2. PROCEDURE

The present study focuses upon the production of correlated k -distribution routines to account for the molecular absorption found within the spectral range from 835 to 1250 cm^{-1} (12 to 8 micrometers), an interval which corresponds to the CERES (Clouds and the Earth's Radiant Energy System) window channel (see Figure 1). The wavenumber range of the CERES window channel covers the portion of the thermal infrared spectrum where a substantial fraction of the outgoing flux for clear sky conditions originates at or near the Earth's surface. Thus, the CERES window channel is critical to the retrieval of surface fluxes from satellite measured radiances (Inamdar and Ramanathan, 1995).

The most important molecular absorption features located within the spectral range of the CERES window channel have been attributed to H_2O and O_3 ; however,

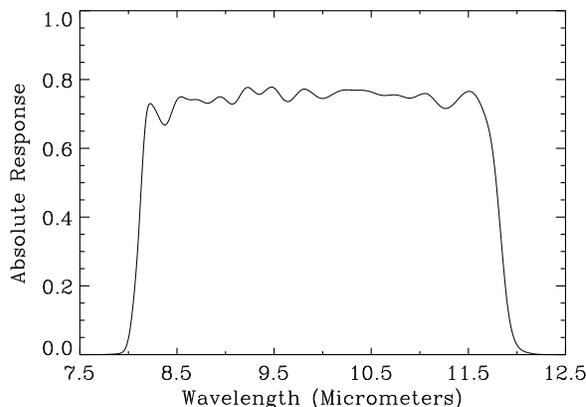


Figure 1. *The spectral response function for the CERES window channel adapted from Lee et al, 1996.*

several minor trace gases, most notably CO_2 , N_2O , CH_4 , F-11, F-12 and F-22, also possess important absorption features within this spectral range. The highly nonuniform distribution of the molecular absorption features found within the CERES window channel necessitated splitting the 835 to 1250 cm^{-1} spectral range into three sections (see Table 1). The first section, the 835 to 980 cm^{-1} spectral range, is dominated by H_2O absorption, although a smaller yet significant contribution from the 10.4 micron band of CO_2 is also present. For the section covering the 980 to 1100 cm^{-1} spectral range, the upwelling TOA (top of atmosphere) flux is dominated by the 9.6 micron band of O_3 while the downwelling surface flux is dominated by H_2O absorption. CO_2 also contributes a small yet significant absorption within the 980 to 1100 cm^{-1} spectral range. The most prominent absorption in the section covering the 1100 to 1250 cm^{-1} spectral range is attributed to H_2O , although significant absorption is also contributed by N_2O and CH_4 . In addition, the chlorofluorocarbons, F-11, F-12 and F-22, possess relatively weak absorption features which pervade the entire spectral range of the CERES window channel. During the course of the present investigation a troublesome problem was encountered involving the CH_4 absorption within the 1100 to 1250 cm^{-1} spectral range. Specifically, the CH_4 absorption within this spectral region was found to be anti-correlated with the CERES window channel spectral response function and with the Planck function. This problem necessitated creating a correlated k -distribution for CH_4 which

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was specifically tailored for use with the CERES window channel spectral response function.

An ESFT (exponential-sum fitting of transmissions) technique was applied to reference line-by-line calculations to produce the k -distributions which represent the observed molecular absorption features within the CERES window channel. The present ESFT procedure has been fully described by Kratz (1995). To accommodate nonhomogeneous pathlengths the absorption coefficients were then taken to possess the same cumulative probability regardless of pressure or temperature. This, of course, leads to the concept of the correlated k -distribution. To account for the H₂O continuum, both the ckd-2.1 (Clough *et al*, 1992) and Roberts *et al* (1976) formulations have been employed. The overlap of spectral features from different molecular species was taken into account by using the multiplication transmissivity property which allows for considerable flexibility, especially when altering relative mixing ratios of the various molecular species.

3. RESULTS

To establish the accuracy of the correlated k -distribution technique as compared with the line-by-line procedure, atmospheric flux calculations have been obtained for a wide variety of atmospheric conditions, as well as for cases both including and neglecting the CERES window channel spectral response function (see Figure 1). Since the focus of the present study is directed at the radiative effects of molecular absorption, only clear sky cases have been considered. In addition, the surface has been taken to be a perfect emitter. Since the results of the comparisons for the McClatchey *et al* (1972) midlatitude summer profile are representative of the other atmospheric profiles, and since the models compare equally well whether the spectral response function is or is not considered, only the midlatitude summer flux calculations considering the spectral response function are presented in Table 1. An examination of the results reported in Table 1 reveals that the current correlated k -distribution routines have the capability of representing the molecular absorption for the entire CERES window channel to an accuracy of 1%. Indeed, the difference between the line-by-line and correlated k -distribution procedures for the calculated upwelling TOA flux for the entire CERES window channel is less than 0.1%. Neglecting the contributions from all the species except H₂O and O₃ yields an upwelling TOA flux of 66.0481 Wm⁻², a 1.4% overestimation. Under circumstances where rapid processing is extremely critical, this error may be deemed acceptable. Neglecting the contributions from all of the species yields an upwelling TOA flux of 76.439 Wm⁻², a 17.4% overestimation which is certainly not acceptable but does emphasize the need to account for molecular absorption within the spectral range of the CERES window channel instrument.

TABLE 1. Comparisons of line-by-line (LbL) and correlated k -distribution (ckd) calculations for the reduction in the flux from the surface to the top of the atmosphere $\Delta F^\uparrow(70)$, the upward flux at the top of the atmosphere $F^\uparrow(70)$, and the downward flux at the surface $F^\downarrow(0)$. The calculations utilized the McClatchey *et al* (1972) midlatitude summer profile and included the CERES window channel instrument response function. The interval range is given in units of cm⁻¹ while the fluxes are given in units of Wm⁻².

Interval	Model	$\Delta F^\uparrow(70)$	$F^\uparrow(70)$	$F^\downarrow(0)$
835–980	LbL	1.995	31.345	14.465
	ckd	1.986	31.354	14.471
980–1100	LbL	7.065	16.710	10.177
	ckd	6.918	16.856	10.088
1100–1250	LbL	2.262	17.062	8.954
	ckd	2.413	16.911	9.297
835–1250	LbL	11.322	65.117	33.596
	ckd	11.318	65.121	33.855

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