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Ming-Dah Chou and Louis Kouvaris

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by

Ming-Dah Chou
Goddard Laboratory for Atmospheric Sciences
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

and

Louis Kouvaris
Applied Research Corporation
Landover, Maryland 20785
and
Goddard Laboratory for Atmospheric Sciences
NASA/Goddard Space Flight Center
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ABSTRACT

This report is the documentation of a FORTRAN program that calculates the atmospheric cooling rate and infrared fluxes for partly cloudy atmospheres based upon the fast but accurate methods of Chou and Arking (1978, 1980). The IR fluxes in the water bands and the 9.6 and 15 μm bands are calculated at 15 levels ranging from 1.39mb to the surface.

The program is generalized to accept any arbitrary atmospheric temperature and humidity profiles and clouds as input and return the cooling rate and fluxes as output. Sample calculations for various atmospheric profiles and cloud situations are demonstrated in the report.

A digital magnetic tape containing the computer codes and the precomputed transmission functions of the radiation routine can be made available upon request.

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1. INTRODUCTION

Radiative heating and cooling play a crucial role on our climate system. The need for a fas yet accurate radiation routine has become more and more demanding as large-scale numerical models are now commonly used as a powerful tool to understand atmospheric processes and to study climatic problems. It has been a fact that the calculation of the radiative terms takes a large percentage, sometimes up to 90%, of the computing time spent in a numerical experiment. Usually, the percentage increases with the accuracy of a radiation routine that leads to the painful choice of a crude radiation routine in long-term climate studies.

Fast yet accurate radiation routines which include both water vapor and carbon dioxide bands have recently been developed by Chou and Arking (1978,[1] 1980[2]). These routines for clear atmospheres are extended to include partly cloudy situations under the assumption that clouds are either black or gray. The computer codes of the radiation routine are described in detail in this report. Radiative transfer equations for fluxes are first presented in Section 2, simplifications of the transmission functions are then given in Section 3. Section 4 depicts the model structure and the approach to the vertical integration of the transfer equations. Section 5 describes the computer codings of the radiation routine. The computer program is listed in Appendix A with arrays and variables tabulated in Appendix B. Some sample calculations are demonstrated in Appendix C.

2. RADIATIVE TRANSFER EQUATIONS

In this radiation routine, the infrared spectrum is divided into four regions: the 15μm CO_2 band, the 9.6μm O_3 band, the water vapor band center region and the band wing region. Clouds

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[1] Chou, M. D. and A. Arking, 1978. An infrared radiation routine for use in numerical atmospheric models. Preprint, Third Conference on Atmospheric Radiation, American Meteorological Society, 303-305.

[2] Chou, M. D. and A. Arking, 1980: Computation of infrared cooling rates in the water vapor bands. J. Atmospheric Sciences, 37, 855-867.

are treated as either black or gray, and scattering due to molecules and particulates is neglected. Fluxes in each spectral region are computed for clear and cloudy atmospheres. These fluxes are then weighted by the fraction of sky cover to obtain the total flux.

For a clear atmosphere, the upward and downward fluxes at pressure level p integrated over the spectral range $\Delta\nu$ can be computed respectively from

$$F^{clr} \uparrow (p) = \int_{\Delta\nu} d\nu \left[B_\nu(T_s)\, \tau_\nu(p, p_s) + \int_{p_s}^{p} B_\nu(T(p'))\, \frac{d\tau_\nu(p, p')}{dp'}\, dp' \right] \tag{1a}$$

and

$$F^{clr} \downarrow (p) = \int_{\Delta\nu} d\nu \left[\int_{p_t}^{p} B_\nu(T(p'))\, \frac{d\tau_\nu(p')}{dp'}\, dp' \right] \tag{1b}$$

where $B_\nu(T)$ is the blackbody flux at temperature T and wavenumber ν and is equal to π times the Planck radiance, $\tau_\nu(p, p')$ the diffuse transmittance between the levels p and p', and the subscripts s and t denote the surface and the top of the atmosphere, respectively.

Because of the rapid variation of transmittance with wavenumber, the use of Eqs. (1a) and (1b) to compute fluxes is a very time-consuming process. Simplifications of Eqs. (1a) and (1b) are applied to different spectral bands. In the 9.6 and 15μm bands, the transmittance τ_ν is replaced by its average value over $\Delta\nu$ which reduces the equations for fluxes to

$$F^{clr} \uparrow (p) = B(T_s)\, \tau(p, p_s) + \int_{p_s}^{p} B(T(p'))\, \frac{d\tau(p, p')}{dp'}\, dp' \tag{2a}$$

and

$$F^{clr} \downarrow (p) = \int_{p_t}^{p} B(T(p'))\, \frac{d\tau(p, p')}{dp'}\, dp', \tag{2b}$$

where

$$B(T) = \int_{\Delta\nu} B_\nu(T)\, d\nu. \tag{2c}$$

and

$$\tau(p, p') = \frac{1}{\Delta\nu} \int_{\Delta\nu} \tau_\nu(p, p')\, d\nu. \tag{2d}$$

In the water vapor bands, the flux computations are simplified by integrating Eqs. (1a) and (1b) by parts and reducing them to

$$F^{clr}\uparrow(p) = B(T(p)) + G(p, p_s, T_s) - G(p, p_s, T(p_s)) + \int_{T(p)}^{T(p_s)} \partial G(p, p', T(p'))/\partial T\, dT(p'), \tag{3a}$$

and

$$F^{clr}\downarrow(p) = B(T(p)) - G(p, p_t, T(p_t)) + \int_{T(p)}^{T(p_t)} \partial G(p, p', T(p'))/\partial T\, dT(p'), \tag{3b}$$

where

$$G(p, p', T) = \int_{\Delta\nu} \tau_\nu(p, p')\, B_\nu(T)\, d\nu. \tag{3c}$$

and

$$\partial G(p, p', T)/\partial T = \int_{\Delta\nu} \tau_\nu(p, p')\, \partial B_\nu(T)/\partial T\, d\nu. \tag{3d}$$

It is noticed that the Planck function varies significantly within a wide spectral interval. The use of Eqs. (2a) and (2b) to compute fluxes would introduce significant errors unless the water vapor bands are divided into a number of intervals ($\gtrsim 10$). With the G-function computed from Eq. (3c) using the line-by-line method, the effect of the variation of Planck function with wavenumber is correctly taken into account. The reason that Eqs. (3a) and (3b) are applied only to the water vapor bands is that we have not yet developed methods for precomputing the G-function in the CO_2 and O_3 bands. This will become clear in Section 3.

For a cloudy atmosphere, Eq. (2a) is used to compute fluxes in the 9.6 and 15μm bands except that the subscript s is replaced by CT for upward fluxes and CB for downward fluxes, where CT denotes the cloud top and CB the cloud base. Similarly, Eq. (3a) is used to compute fluxes in the water vapor bands with the subscript s replaced by CT and CB respectively for upward and downward fluxes.

For a partly cloudy atmosphere, the infrared flux is computed from

$$F(p) = (1 - C)F^{clr}(p) + \sum_{i=1}^{n} C_i F_i^{cld}(p), \tag{4}$$

where F^{cld} is the flux for a cloudy atmosphere, C the total fractional cloud cover, C_i the cloud cover of type i, and n the number of cloud types. The cooling rate is proportional to the flux divergence given by

$$-\frac{dT}{dt} = \frac{g}{C_p} \frac{d}{dp} (F\downarrow - F\uparrow), \tag{5}$$

where C_p is the heat capacity of air and g the acceleration of gravity.

3. COMPUTATION OF TRANSMISSION FUNCTIONS

The most difficult part in computing radiative fluxes in the atmosphere is the integration over the entire spectrum. Usually the absorption coefficient changes several orders of magnitude within a spectral interval of $100\,cm^{-1}$, and the transmittance τ_ν in Eq. (1) must be computed at every $\lesssim 0.01\,cm^{-1}$ interval, which results in a total of 10^5–10^6 points along the spectrum. Since we are interested in the total flux but not the flux at individual wavenumber, the point-by-point calculation is commonly replaced by wide band (or emissivity) or narrow band approximations. In this section, we describe the method used in our radiation routine to eliminate the difficulty in computing transmission functions in various parts of the spectrum.

a. Basic Equations

The beam transmittance between any two pressure levels p_1 and p_2 at wavenumber ν in the direction from the vertical $\theta = \cos^{-1}\mu$ is

$$\tau_\nu(\mu) = \exp\left(-\sum_i u_\nu(i)/\mu\right) \tag{6}$$

where $u_\nu(i)$ is the optical depth of the ith absorber given by

$$u_\nu(i) = \frac{1}{g} \int_{p_1}^{p_2} k_\nu(i) \ q(i)dp, \tag{7}$$

k_ν the absorption coefficient and q the mixing ratio.

The diffuse transmittance in Eqs. (1) and (3c) is related to the beam transmittance by

$$\tau_\nu = 2 \int_0^1 \tau_\nu(\mu) \ \mu \ d\mu, \tag{8}$$

b. Absorption Coefficients

The absorbers considered in this radiation routine include water vapor, carbon dioxide, and ozone. The parameters needed for computing the molecular line absorption are the position, ν_0, strength, S, width, α, and shape of molecular lines. Using the parameters compiled by McClatchey et al. (1973[3]) and assuming a Voigt line function, the absorption coefficients are computed using the line-by-line method at every 0.01 cm^{-1} interval for individual absorbers.

The e-type continuum absorption due to water vapor in the spectral region between 340 and 1200 cm^{-1} is also included. The regression curve given in Roberts et al. (1976[4]) which fits laboratory data is used to compute the absorption coefficient at 296K.

c. Scaling Approximation for Water Vapor Absorption

In the water vapor bands, the efficiency of the flux computation can be further increased by taking advantage of the nature of water vapor distribution. Generally the water vapor decreases logarithmically with height. The lower troposphere is too opaque to have significant cooling for the spectral intervals near the center of the absorption bands, whereas the upper troposphere is too transparent to have significant cooling for the band wings. As shown in Chou and Arking (1980) that the cooling rate has a relatively narrow vertical profile that peaks at the upper

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[3] McClatchey, R. A., W. S. Benedict, S. A. Clough, D. E. Burch, R. F. Calfee, K. Fox, L. S. Rothman and J. S. Garing, 1973: AFCRL atmospheric absorption line parameters compilation. Environ. Res. Pap., No. 434, AFCRL-TR-73-0096.

[4] Roberts, R. E., J. E. A. Selby, and L. M. Biberman, 1976: Infrared continuum absorption by atmospheric water vapor in the 8–12μm window. Applied Optics, 15, 2085-2090.

troposphere for the band center region and at the lower troposphere for the band wing region. By scaling the absorption coefficient (or alternatively the water vapor amount) separately for the band center region and the band wing region based on the temperature and pressure at the height where the cooling rate is a maximum, the difficulty in computing the absorption coefficient for various temperature and pressure can be greatly reduced.

At the levels where cooling is significant, absorption quickly saturates near the center of most of the molecular lines, and the cooling rate is mainly due to the region in line wings. In the far wings, where $|\nu - \nu_0| \gg \alpha$, the water vapor molecular line absorption, ℓ_ν, can be written as

$$\ell_\nu(p, T) = \ell_\nu(p_r, T_r) \frac{p}{p_r} R(T, T_r) \tag{9}$$

where R is the spectrally averaged value of R_ν given by

$$R_\nu(T, T_r) = \left(\frac{T_r}{T}\right)^{1/2} \frac{\sum_i \left[\dfrac{S_i(T)\ \alpha_i\ (p_r, T_r)}{(\nu - \nu_{oi})^2}\right]}{\sum_i \left[\dfrac{S_i(T_r)\ \alpha_i\ (p_r, T_r)}{(\nu - \nu_{oi})^2}\right]} \tag{10}$$

and the index i denotes absorption lines.

In Eq. (9), the absorption coefficient at the reference conditions, $\ell_\nu(p_r, T_r)$, is "exactly" computed using line-by-line method. The error in $\ell_\nu(p, T)$ using the far-wing scaling approximation depends upon the departure of p and T from p_r and T_r. Since the water vapor cooling profile spans only a narrow region in the vertical, the error in cooling rate arising from the use of Eq. (9) is minimal if we choose the reference temperature and pressure to be in the region of maximum cooling. Table 1 shows the spectral regions, the reference temperature and pressure, and the mean values of R_ν for the band center region and the band wing region. The reference temperature and pressure are chosen to correspond to conditions at the level of maximum cooling rate in the U.S. Standard Atmosphere. In Table 1, the temperature scaling term R is given only at two temperatures. Values of R at other temperatures are computed using a quadratic fit to the R-values at $T = T_r \pm 40K$ and $T = T_r$ (for which $R = 1$).

Table 1

The reference temperature T_r and pressure p_r, are specified for the center and the wing regions of the water vapor absorption bands. The effect of temperature on the absorption coefficient is indicated by $R(T, T_r)$, which is the mean value of the function $R_\nu(T, T_r)$ defined by Eq. (10).

	Wavenumber (cm^{-1})	T_r(K)	p_r(mb)	$R(T_r - 40, T_r)$	$R(T_r + 40, T_r)$
Center	0-340 1380-1900	225	275	0.90	1.16
Wing	340-580 760-980 1100-1380 1900-3000	256	550	0.58	1.78

d. Diffuse Transmittance in the 15μm Band

The absorption in the 15μm band from 580 to 760 cm^{-1} is due primarily to CO_2 and secondarily to water vapor. The overlapping of diffuse transmittances is approximated by

$$\tau_{15\mu} = \tau_{CO_2} \cdot \tau_\ell \cdot \tau_e, \tag{11}$$

where τ_{CO_2}, τ_ℓ, and τ_e are the transmittances averaged over the 15μm band due to CO_2 molecular line absorption, H_2O line absorption and H_2O e-type absorption, respectively.

The atmospheric CO_2 content can practically be considered as constant, and the transmittance τ_{CO_2} between any pressure levels is a function of temperature only. Since the relative change in atmospheric temperature is not large, Arking (1976[5]) used a linear expansion method to correct for small variation in the beam transmittance for temperature retrievals. This method introduces an error $\lesssim 0.005$ in the mean diffuse transmittance averaged over the entire 15μm band (Chou and Arking, 1978). In this infrared radiation routine, the transmittance τ_{CO_2} between p_1 and p_2 is computed using the linear expansion method from

$$\tau_{CO_2}(p_1, p_2) = \mathring{\tau}_{CO_2}(p_1, p_2) + \sum_{i=1}^{m} a_i(p_1, p_2)\, \Delta T_i, \tag{12}$$

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[5] Arking, A., 1976: The proper weighting function for deriving temperatures from satellite measured radiances. GSFC X-document X-911-76-48.

where the superscript o denotes the transmittance for a reference temperature profile, m the layers between p_1 and p_2, and ΔT the deviation of temperature from the reference temperature. The coefficient a_i is given by

$$a_i(p_1, p_2) = \partial\tau(p_1, p_2)/\partial T_i. \tag{13}$$

The e-type continuum absorption coefficient, C_ν, increases with vapor pressure but decreases with temperature according to (see Roberts et al., 1976)

$$C_\nu(T) = C_\nu(T_0)\, e \cdot \exp\left[-\frac{1800}{T_0} + \frac{1800}{T}\right], \tag{14}$$

where $C_\nu(T_0)$ is the absorption coefficient at $p = 1$ atm and $T = T_0$, and e the vapor pressure in atms.

With the use of Eq. (14) and the far-wing scaling approximation, Eq. (9), the transmittances τ_ℓ and τ_e are computed from

$$\tau_\ell(w) = \frac{2}{\Delta\nu}\int_{\Delta\nu} d\nu \int_0^1 \exp(-\ell_\nu(p_r, T_r)w/\mu)\,\mu\, d\mu, \tag{15}$$

$$\tau_e(u) = \frac{2}{\Delta\nu}\int_{\Delta\nu} d\nu \int_0^1 \exp(-C_\nu(T_0)u/\mu)\,\mu\, d\mu, \tag{16}$$

where the scaled water vapor amounts are given by

$$w(p_1, p_2) = \frac{1}{g}\int_{p_1}^{p_2} \left(\frac{p}{p_r}\right) R(T, T_r)\, q\, dp, \tag{17}$$

$$u(p_1, p_2) = \frac{1}{g}\int_{p_1}^{p_2} e \cdot \exp\left(-\frac{1800}{T_0} + \frac{1800}{T}\right) q\, dp. \tag{18}$$

Values of $\tau^o_{CO_2}(p_1, p_2)$, $a_i(p_1, p_2)$, $\tau_\ell(w)$, and $\tau_e(u)$ are precomputed using the line-by-line method and stored in tables for later use. The reference conditions are chosen to be the same as the water vapor band wing region, i.e., $p_r = 550$ mb and $T_r = 256$K. Values of R are approximated by that given in Table 1 for the band wing region.

e. Diffuse Transmittance in the 9.6μm Band

In the 9.6μm band from 980 to 1100cm^{-1}, the absorption is mostly due to ozone in the stratosphere. The water vapor e-type absorption contributes somewhat to the cooling in the lower tropical atmosphere, but the effect of line absorption is negligible. Applying the multiplication approximation, the diffuse transmittance is computed from

$$\tau_{9.6\mu} = \tau_{O_3} \cdot \tau_e . \tag{19}$$

The ozone transmittance, τ_{O_3}, is precomputed using the line-by-line method for the three latitude zones, 0-30, 30-60, 60-90°N. Annual mean ozone content and temperature profile at 15, 45, and 75°N are used to compute τ_{O_3} for the respective latitude zones. No attempts have been made to correct for the change in τ_{O_3} due to changes in the ozone content and temperature profile. The transmittance τ_e is precomputed from Eq. (16) and stored in a table as a function of the scaled water vapor amount, u.

f. The G-Function for the Water Vapor Bands

Utilizing the far-wing scaling approximation, the water vapor transmittance between p_1 and p_2 can be written as

$$\tau_\nu(p_1, p_2) = 2\int_0^1 \exp - [(\ell_\nu(p_r, T_r)\, w(p_1, p_2) + C_\nu(T_0)\, u(p_1, p_2))/\mu]\, \mu\, d\mu ; \tag{20}$$

where $w(p_1, p_2)$ and $u(p_1, p_2)$ are given by Eqs. (17) and (18). The error introduced in $\tau_\nu(p_1, p_2)$ by using Eq. (20) was shown in Chou and Arking (1980) to be small with a magnitude $\lesssim 0.01$.

Since $\ell_\nu(p_r, T_r)$ and $C_\nu(T_0)$ are functions of wavenumbers only, the G-function defined in Eq. (3c) depends on w, u, and T, but not on the detailed temperature and humidity profiles. The function G(p, p′, T) in Eqs. (3a) and (3b) can then be approximated by G(w, u, T) with w and u being the scaled water vapor amounts in the column between p and p′. It is now possible to precompute the three-dimensional function of G(w, u, T) using the line-by-line method and the results stored in tables. The G-function defined in Eq. (3c) is computed for the band wing region and the band center region with spectral interval $\Delta\nu$ listed in Table 1. A table look-up for the G-function makes the computations of fluxes very fast from Eqs. (3a) and (3b).

4. VERTICAL INTEGRATION FOR FLUXES

a. Model Structure

Since the functions B, τ, and G in Eqs. (2) and (3) are highly non-linear with respect to height, the vertical integrations cannot be performed analytically. The continuous atmosphere is therefore discretized by dividing it into a number of layers, and the integrations approximated by summations. The fluxes are computed at 15 levels (designated as flux levels hereafter) separated by $\Delta \ln p = 0.828$ above the 200mb level and $\Delta p = 100$mb below. Since the layers are too thick (in terms of the differences in the Planck and transmission functions at the boundaries) for flux computations, each layer is further divided into 3 sublayers with equal $\Delta \ln p$ above the 200mb level and equal Δp below. Thus, there are 43 sublevels and 42 sublayers in the vertical. Fig. 1 illustrates the pressure at these levels.

b. Temperature and Humidity Interpolations

Given temperature and humidity at any pressure levels as inputs to the radiation routine, they are interpolated (or extrapolated) to the 43 sublevels and the middle of each of the 42 sublayers. Temperature and the logarithm of specific humidity are interpolated linearly in ln p.

c. Vertical Integrations

Let j be the index for sublevels increasing downward and $j + \frac{1}{2}$ for the sublayer immediately below, then the following approximations are made in computing fluxes at the level p_i in the 9.6 and 15μm bands (see Fig. 1 for the locations of i and j),

$$B(T(p')) \, d\tau(p_i, p') \simeq B(T_{j-\frac{1}{2}}) \, [\tau(p_i, p_{j-1}) - \tau(p_i, p_j)] \, , \; j = i+1, \ldots, 43, \text{ for upward flux;} \qquad (21a)$$

$$\simeq B(T_{j+\frac{1}{2}}) \, [\tau(p_i, p_{j+1}) - \tau(p_i, p_j)] \, , \; j = 1, \ldots, i-1, \text{ for downward flux.} \qquad (21b)$$

Similarly, the following approximations are made in computing water vapor infrared fluxes,

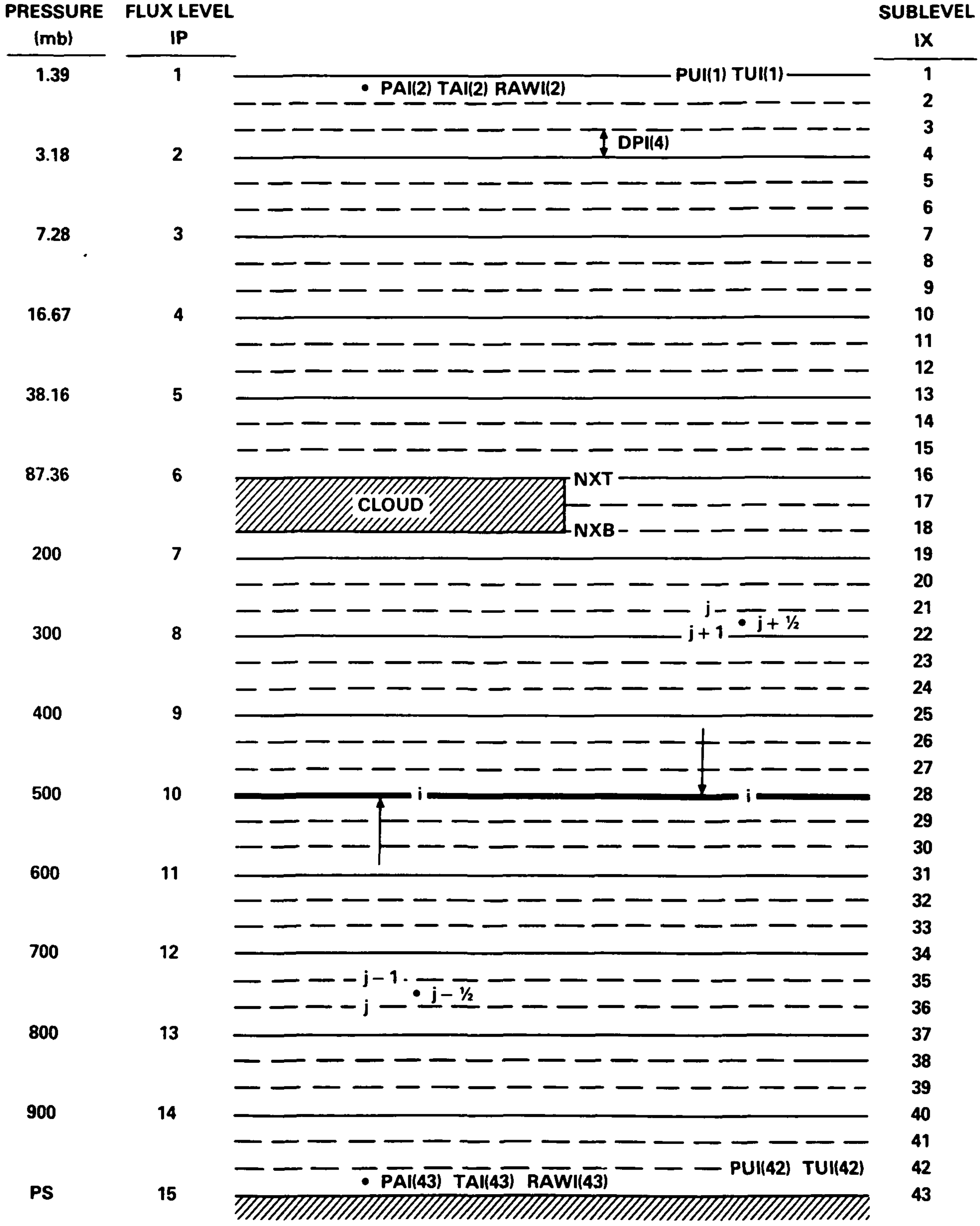

Figure 1. Model Vertical Structure. Sublevels are Used for Computing Fluxes at the Flux Levels.

$$
\begin{aligned}
&[\partial G(p_i, p', T(p'))/\partial T(p')]\, dT(p') \\
&\quad \simeq G(w(p_i, p_{j-1/2}), u(p_i, p_{j-1/2}), T_j) \\
&\qquad - G(w(p_i, p_{j-1/2}), u(p_i, p_{j-1/2}), T_{j-1}), j = i + 1, \ldots, 43, \\
&\qquad\quad \text{for upward flux;} \qquad\qquad (22a) \\
&\quad \simeq G(w(p_{j+1/2}, p_i), u(p_{j+1/2}, p_i), T_j) \\
&\qquad - G(w(p_{j+1/2}, p_1), u(p_{j+1/2}, p_i), T_{j+1}), j = 1, \ldots, i - 1, \\
&\qquad\quad \text{for downward flux.} \qquad\qquad (22b)
\end{aligned}
$$

5. INFRARED RADIATION CODE

The program is divided into 6 sections. The main routine is for specifying the input data and for returning the fluxes and the cooling rate . The fixed data that accompany the program are read in the subroutine INDATA. The third routine GAMOTO interpolates the input data of cloud heights, temperature, and humidity to the model levels and computes the scaled water vapor amounts for each layer. The subroutine IRH2O interpolates the G-function in the water vapor bands which is used in the subroutine FDIVER to compute fluxes in the water vapor bands. Finally, the subroutine RCO2O3 computes the fluxes in the 9.6 and 15μm bands. Subroutines IRH2O and RCO2O3 are independent of each other. In the following, variables and arrays in the routines are all denoted by capital letters.

a. Main Program

The main program is to accept the input data and return the computed fluxes and cooling rate. The users must specify the following input data

Input Data	Unit	Code
Pressure	mb	PA
Temperature	K	TA
Humidity	gm/gm	WA
Surface temperature	K	TS
Surface pressure	mb	PS

Input Data	Unit	Code
Cloud top pressure	mb	CLTOP
Cloud base pressure	mb	CLBOT
Fractional cloud amount		CSS
Number of pressure levels		NDATA
Number of cloud types		NC
Latitude	degree	RLAT

The user's input of pressure, temperature and humidity define the atmospheric profiles. These data must be arranged in order of increasing pressure. The surface pressure, PS, must be greater than 900mb. Different cloud types are treated as non-overlapping. For cloud-free atmospheres, the parameter NC is set to zero.

The following parameters are the outputs of the infrared radiation routine:

Parameter	Unit	Code
Downward flux in the water vapor bands	ergs/(cm^2 sec)	FLUXHD
Upward flux in the water vapor bands	ergs/(cm^2 sec)	FLUXHU
Downward flux in the 9.6 and 15μm bands	ergs/(cm^2 sec)	FLUXCD
Upward flux in the 9.6 and 15μm bands	ergs/(cm^2 sec)	FLUXCU
Cooling rate	°C/day	COOLR

Fluxes are computed at the 15 levels denoted by the running variable IP in Fig. 1, and cooling rates are computed for the layers defined by the flux levels. The spectral ranges for water vapor bands are listed in Table 1. The cooling rate is computed from Eq. (5) with C_p = 1.003×10^7 ergs/(gm K).

b. Subroutine INDATA

This subroutine reads in the model pressure sublevels and the precomputed data for transmission and G-functions. As mentioned in Sec. 4, fluxes are computed at 15 levels (NP = 15) and cooling rates for 14 layers. For proper vertical integration of the transfer equations, each layer is further divided into 3 sublayers (NSB = 3). Therefore we have 43 sublevels (NPT = 43) defining 42 sublayers. The pressure of the first 40 sublevels (PUI) are read in this subroutine and fixed in the model. The last 3 sublevels are computed in subroutine GAMOTO, which depends on the surface pressure.

The G-function is stored in the 3-dimensional array GFH2O. The first index runs from 1 to 25 (NT = 25) corresponding to temperatures of 190K (TEMP1 = 190) to 310K incremented in steps of 5K (DT = 5). The second index corresponding to log w runs from 1 to 22 (NW = 22) where the first value corresponds to log w = -6 (SW = -6) for the band center absorption and to -5.4 (SW = - 5.4) for the band wing absorption. It is incremented in steps of Δ log w = 0.3 (DW = 0.3). The third index corresponding to u runs from 1 to 11 (NUP1 = 11). Index values from 1 to 10 refer to the band wing region given at $\Delta u = 0.006$ (DU = 0.006) intervals starting from u = 0. The last index value is for the band center region which does not include e-type absorption.

The following table summarizes the information in GFH2O (IT, IW, IU) for computing fluxes in the water vapor bands. The units are K for T and gm/cm^2 for w and u.

Table 2

Information in the Precomputed G-Function

Index	Corresponding Parameter	Initial Value		Increment
		Band-Center	Band-Wing	
IT	T	190	190	5
IW	log w	-6.0	-5.4	0.3
IU	u	-	0	0.006

In the 15μm band, the CO_2 transmission function, τ_{CO_2}, is stored in TRE as a two-dimensional array. The first index refers to sublevels and the second index to flux levels. The coefficients for the linear expansion, a_i in Eq. (12), are stored in the one-dimensional array FSN only for the region above the 200 mb level. FSN is ordered in a way as shown in Fig. 2. Values of TRE and FSN are computed for the U.S. Standard Atmosphere. The transmittance due to water vapor line absorption, τ_ℓ, is stored in TAUW for 65 values of log w (NW = 65) starting from -4.0 (SW = -4) incremented by 0.1 (DW = 0.1). The transmittance due to e-type absorption, τ_e, is stored in TAUU. Values of TAUU are given at Δ log u = 0.04 (DU = 0.04) intervals starting from log u = -3.301 (SU = -3.301).

For the 9.6μm band, the ozone transmittance, τ_{O_3}, is given by the three-dimensional array, TOZON. The first index refers to sublevels, the second index to flux levels, and the last to

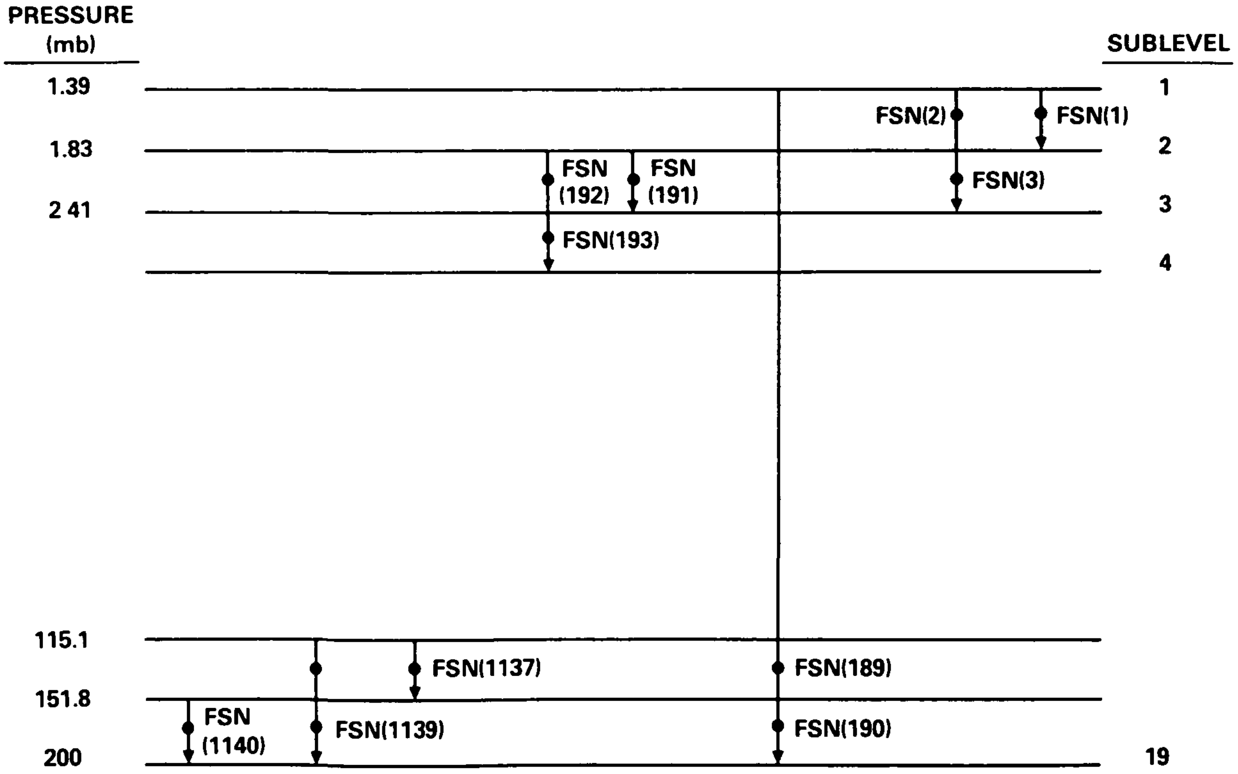

Figure 2. Ordering of the Coefficients FSN's for the Correction of CO_2 Transmittance in the Stratosphere.

latitude zones. In computing ozone transmittance, annual mean ozone mixing ratios representative of 30°-latitude zones are used. The last index (LAT) is equal to 1, 2, and 3 for the latitude zones 0–30, 30–60, and 60–90°, respectively. The transmittance due to e-type absorption, τ_e, is stored in TWIN as a function of log u. It is given at Δ log u = 0.04 (DU = 0.04) intervals starting from log u = -3.301 (SU = -3.301).

The following table summarizes the information in TAUW, TAUU, and TWIN. The units for w and u are gm/cm^2.

Table 3

Information in the Precomputed Transmittances due to Water Vapor Absorption

Transmittance	Spectral Band	Index	Corresponding Parameter	Initial Value	Increment
TAUW	$15\mu m$	IW	log w	–4.0	0.1
TAUU	$15\mu m$	IU	log u	-3.301	0.04
TWIN	$9.6\mu m$	IU	log u	-3.301	0.04

c. Subroutine GAMOTO

This subroutine is to

i) Interpolate user's atmospheric profiles onto the model grids;

ii) Compute scaled water vapor amounts;

iii) Compute indices for cloud top and cloud base;

iv) Call subroutines IRH2O and RCO2O3.

The two sublevels between 900 mb and the surface are computed by dividing the layer into three sublayers with equal Δp, i.e. $\Delta p = (p_s - 900)/3$. The center pressure (PAI) and the air mass (DPI) of each sublayer are then computed. The temperature at each sublevel (TUI) and the temperature and humidity in the middle of each sublayer (TAI and RAWI) are interpolated from the input values of pressure (PA), temperature (TA), and specific humidity (WA). Temperature and the logarithm of the specific humidity are interpolated linearly in ln p. The same parameter

RAWI designated for specific humidity in line 01800 is later redesignated for water vapor content in line 01840.

The scaled water vapor amounts w (WBAR) and u (UBAR) in a column above any pressure level are computed in lines 01910–02000 from the above parameters using Eqs. (17) and (18). The reference pressure p_r is coded as PRE and is equal to 225mb for the band center region and to 550mb for the band wing region. The mean effect of temperature on the absorption coefficient, R, coded as SZ2, is computed from the R-values in Table 1 using a quadratic fit. The coefficients for the quadratic fit are coded as RR. The index KB for the arrays WBAR, RR, and PRE is equal to 1 for the band center absorption and equal to 2 for the band wing absorption. In computing values of u, the following relationship is used

$$eq/g\ dp = \left(\frac{p'q}{0.622\ P}\right)\ (1.02\ q)\ dp' = (1.02/630)\ p'q^2\ dp',$$

where the units are dynes/cm^2 for p and mb for p', and P is the standard pressure equal to 1013mb. The temperature T_0 in Eq. (18) is equal to 296K.

The pressure corresponding to the cloud levels are changed to the nearest sublevel numbers of the model grids. The cloud top pressure (CLTOP) is changed to NXT, the cloud base (CLBOT) to NXB, and the cloud amount (CSS) is just redefined to CS.

d. Subroutine IRH2O

This subroutine computes the terms on the right hand sides of Eqs. (3a) and (3b), which are then used in the subroutine FDIVER for computing fluxes in the water vapor bands. The Planck flux is either coded as SH at each sublevels or as FLUXUS at the surface. $G(p, p_t, T(p_t))$ is coded as SHT, $[G(p, p_s, T_s) - G(p, p_s, T(p_s))]$ as SHS, and $(\partial G/\partial T)\ dT$ as SG. These terms are all computed from the discretized G-values using linear interpolation.

Before discussing the computation of the Planck flux, it is noticed from Eq. (3c) that

$$B(T) = G(w = 0, u = 0, T) = G(w_1, u_1, T) + \delta(T)$$

where w_1 and u_1 are, respectively, the starting values of w and u for the precomputed G-function, and δ (DELTA) the correction term.

The subroutine starts in lines 02560–02670 by interpolating the G-values, corresponding to the surface temperature and the values of w_1 and u_1, for the band wing region (NZ = 1) and the band center region (NZ = NUP1). The upward flux at the surface (FLUXUS) is then the sum of the two G-values and the term DELTA. A similar approach is later applied in computing the Planck flux at each sublevel (SH) in lines 03190–03260.

Following the computation of FLUXUS is the computations of the index value for the temperature nearest to the sublevel temperature and the difference between the sublevel temperature and the temperature at the nearest index value. They are stored in IH and DH for later use.

The rest of the subroutine is used to compute SG with SHT and SHS as by-products. Given values of w, u, and T, the G-function is computed from

$$G(w, u, T) = G(w_i, u_j, T_k) + \frac{\partial G}{\partial \log w}(\log w - \log w_i) + \frac{\partial G}{\partial u}(u - u_j) + \frac{\partial G}{\partial T}(T - T_k) \quad (23)$$

where i (KW), j (KU), and k (IT) are the indices for the precomputed G-function nearest to log w, u, and T, respectively. The term log w – log w_i is coded as FW, u – u_j as FU, and T – T_k as DH. The computation of G-function using (23) is coded in lines 03030–03080. Values of SG are then computed from Eq. (22) and that of SHS from

$$G(w, u, T_s) - G(w, u, T(p_s)) = \frac{\partial G}{\partial T}(T_s - T(p_s))$$

$$\simeq [G(w_i, u_j, T_{k+1}) - G(w_i, u_j, T_k)]/(T_{k+1} - T_k) \cdot (T_s - T(p_s)).$$

Values of SG are computed in lines 03080 and 03120, SHT in 03090 and SHS in 03100.

e. Subroutine FDIVER

This subroutine computes upward and downward fluxes in the water vapor bands (FLUXU and FLUXD) from Eqs. (3a) and (3b) using the parameters SH, FLUXUS, SHT, SHS, and SG computed in the subroutine IRH2O. Treatments of various cloud situations are given in Sec. 4g.

f. Subroutine RCO2O3

This subroutine computes the upward and downward fluxes in the 9.6μm band (FLUXUW and FLUXDW), the 15μm band (FLUXUC and FLUXDC), and the total in these two absorption bands (FLUXU and FLUXD).

The Planck fluxes integrated over the 9.6μm band and the 15μm band are interpolated in lines 04340–04470 from the precomputed Planck fluxes. At the middle of each sublayer, the Planck fluxes are coded as BAI for the 15μm band and BWI for the 9.6μm band. The corresponding Planck fluxes at the surface are coded as BS and BSS, respectively. The precomputed Planck flux in the 9.6μm band is stored in BLKWIN and that in the 15μm band in BLKCO2 at 5K intervals starting from 190K.

The transmittances due to the ozone line absorption (TOZON) and the CO_2 absorption (TRE) are first transferred to the arrays TXUF and TAUF, respectively, in lines 04520–04550. The correction for the CO_2 transmittance above the 200mb level due to the departure of the temperature profile from the U.S. Standard Atmosphere (TR) is then coded in lines 04570–04780. (Note that no correction is made if the parameter LINEXP is set to FALSE). The transmittance due to water vapor line absorption (X) is computed in lines 04830–04960, and the transmittances due to e-type absorption are computed in lines 04980–05090 for both the 15μm band (Y) and the 9.6μm band (YY). Finally, the total transmittances are computed from Eqs. (11) and (19) and are coded in lines 05110 and 05120.

With the computed Planck and transmission functions, fluxes in the 9.6 and 15μm bands are computed from Eqs. (2a) and (2b) in the rest of the subroutine. The treatments of various clouds are explained below.

g. Treatments of Clouds

Clouds are assumed to be black in the infrared. The routine can be easily extended to a gray cloud with a constant emissivity. It can be shown that a gray cloud with emissivity ϵ and amount C is radiatively equivalent to a black cloud with amount ϵC. Although the radiative transfer equations used for computing fluxes in the water vapor bands and in the 9.6 and 15μm bands are different, the treatments of clouds are similar. Fig. 3 illustrates an atmosphere with 5 possible cloud situations. The indices NXT and NXB refer to the cloud top and cloud base, respectively, and C the fractional cloud cover. In the H_2O bands, the computation of the downward flux at the pressure level IP is coded in lines 03450–03710 according to the following relationships,

$$\mathrm{FLUXD(IP)} = \mathrm{SH(IP)} - \mathrm{SHT(IP)} + \sum_{I=1}^{IS-1} \mathrm{SG(I, IP)}$$

$$\text{for clear atmospheres or } \mathrm{IS} \leqslant \mathrm{NXT}$$

$$= \mathrm{SH(IP)} + \sum_{I=NXB}^{IS-1} \mathrm{SG(I, IP)} \qquad \text{for } \mathrm{IS} > \mathrm{NXB}$$

$$= \mathrm{SH(IP)} \qquad \text{for } \mathrm{IS} = \mathrm{NXB} \qquad \text{or } \mathrm{NXB} < \mathrm{IS} < \mathrm{NXT}$$

The total flux is the sum of these fluxes weighted by respective fractions of sky cover. For the case shown in Fig. 3, the fraction of the clear sky for the downward flux at IP is $1 - (C_2 + C_3 + C_4)$ which is coded as 1 - SUMC.

At each flux level, IP, a one-dimensional array of FLUX is computed from

$$\mathrm{FLUX(IX)} = \sum_{I=IX}^{IS-1} \mathrm{SG(I, IP)}, \; \mathrm{IX} = 1, \ldots \mathrm{IS} - 1,$$

which is used for computing fluxes in various cloud situations. Computations of upward fluxes are treated similarly and are not shown here.

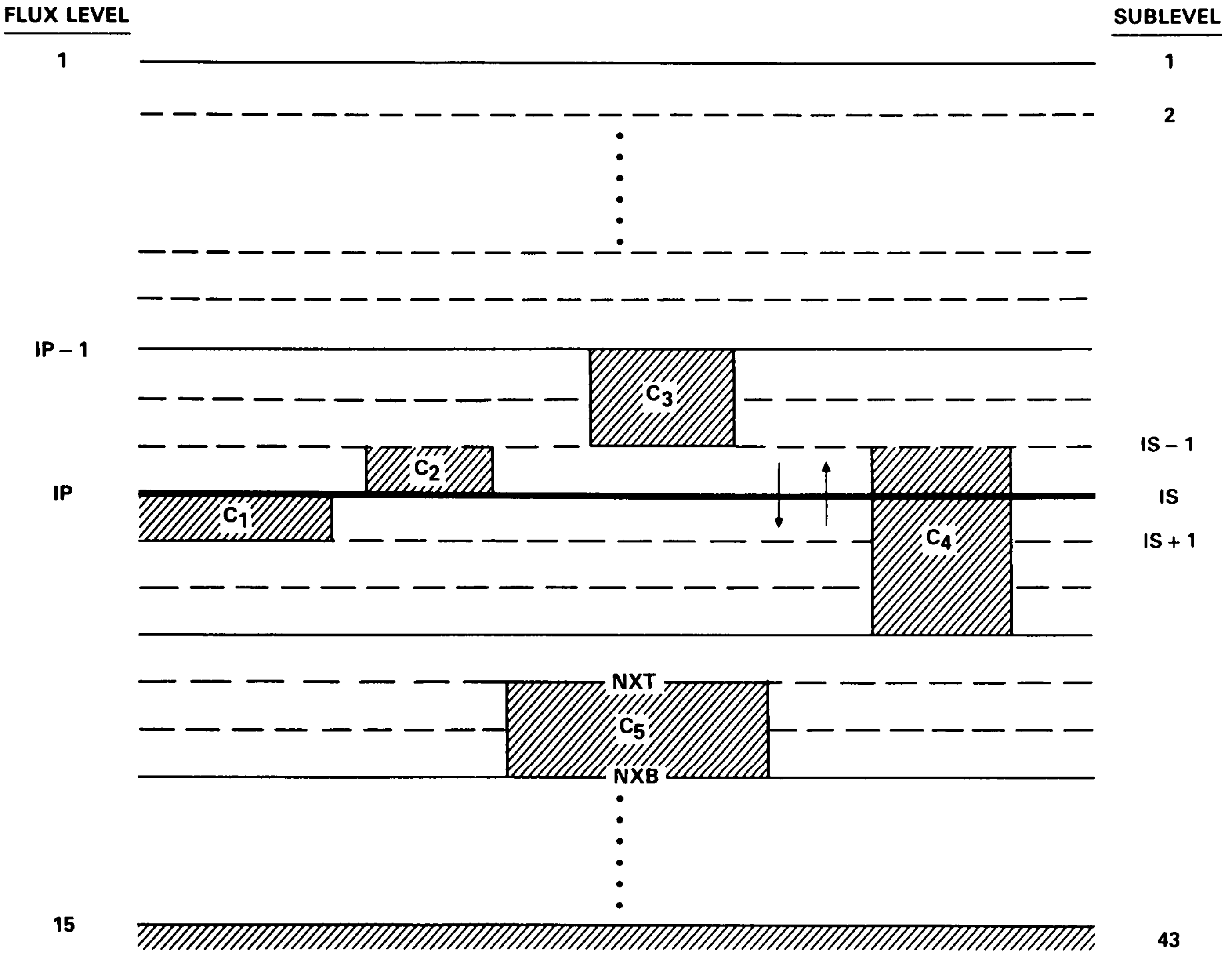

Figure 3. Possible Cloud Situations for Computing Fluxes at the Flux Level IP. NXT and NXB are Indices for Cloud Top and Cloud Base, Respectively, and the C's are Cloud Amount.

With the aid of Fig. 3, the computation of the upward flux in the 15μm band coded in lines 05160–05560 is explained below. The upward flux at the level IP is computed from

$$\begin{aligned}
\text{FLUXUC(IP)} &= \text{BS} * \text{TAUF(NPT, IP)} \\
&+ \sum_{\text{I=IS+1}}^{\text{NPT}} \text{BAI(I)} * [\text{TAUF(I - 1, IP)} - \text{TAUF(I, IP)}] \\
&\qquad \text{for a clear atmosphere or IS} \geqslant \text{NXB} \\
&= \text{BAI(NXT + 1)} * \text{TAUF(NXT, IP)} \\
&+ \sum_{\text{I=IS+1}}^{\text{NXT}} \text{BAI(I)} * [\text{TAUF(I - 1, IP)} - \text{TAUF(I, IP)} \\
&\qquad \text{for IS} < \text{NXT} \\
&= \text{BAI(IS + 1)} \quad \text{for IS = NXT or NXB} < \text{IS} < \text{NXT}
\end{aligned}$$

An intermediate one-dimensional array FLUXC is computed from

$$\text{FLUXC(IX)} = \sum_{\text{I=IS+1}}^{\text{IX}} \text{BAI(I)} * [\text{TAUF(I - 1, IP)} - \text{TAUF(I, IP)}],$$

$$\text{IX} = \text{IS} + 1, \ldots, \text{NPT}$$

and is used for computing fluxes in different cloud situations. The fraction of clear sky for the case shown in Fig. 3 is $1 - (C_1 + C_4 + C_5)$ and is also coded as 1 - SUMC.

6. ACKNOWLEDGMENT

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APPENDIX A

PROGRAM LIST

```
      DIMENSION FLUXHU(15),FLUXHD(15),FLUXCU(15),FLUXCD(15)              IR 00010
      DIMENSION FXWAV(15),FX15C(15),COOLR(15),PUI(43)                    IR 00020
      COMMON/FLUXH/FLUXHU,FLUXHD                                         IR 00030
      COMMON/FLUXC/FLUXCU,FLUXCD                                         IR 00040
      COMMON/AMHN/TA(55),PA(55),WA(55),CSS(10),NDATA,RLAT,TS,PS          IR 00050
      COMMON/PRESS/PUI                                                   IR 00060
      COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT                               IR 00070
      COMMON/CLOU/CLTOP(10),CLBOT(10)                                    IR 00080
      READ(4,26)NDATA,NC,RLAT,TS,PS                                      IR 00090
   26 FORMAT(I2,2X,I2,2X,F4.2,2X,F5.1,2X,F6.1)                           IR 00100
      READ(4,32)DUMMY                                                    IR 00110
      READ(4,21)(PA(I),I=1,NDATA)                                        IR 00120
   21 FORMAT(5F6.1)                                                      IR 00130
      READ(4,32)DUMMY                                                    IR 00140
      READ(4,23)(TA(I),I=1,NDATA)                                        IR 00150
   23 FORMAT(8F7.2)                                                      IR 00160
      READ(4,32)DUMMY                                                    IR 00170
      READ(4,24)(WA(I),I=1,NDATA)                                        IR 00180
   24 FORMAT(5E9.7)                                                      IR 00190
      READ(4,32)DUMMY                                                    IR 00200
      READ(4,25)(CLTOP(I),CLBOT(I),CSS(I),I=1,5)                         IR 00210
   25 FORMAT(5(2F4.0,F4.2))                                              IR 00220
      PRINT 10                                                           IR 00230
   10 FORMAT(12X,'NDATA',2X,'NC',2X,'RLAT',3X,'TS',6X,'PS')              IR 00240
      PRINT 12,NDATA,NC,RLAT,TS,PS                                       IR 00250
   12 FORMAT(13X,I2,4X,I2,2X,F4.1,2X,F5.1,2X,F6.1)                       IR 00260
      PRINT 14                                                           IR 00270
   14 FORMAT(/,10X,'PRESSURE LEVELS(MB) OF SAMPLE PROFILE')              IR 00280
      PRINT 15,(PA(I),I=1,NDATA)                                         IR 00290
   15 FORMAT(5(2X,F6.1,6X))                                              IR 00300
      PRINT 16                                                           IR 00310
   16 FORMAT(/,10X,'TEMPERATURES(K)AT THE ABOVE PRESSURE LEVELS')        IR 00320
      PRINT 11,(TA(I),I=1,NDATA)                                         IR 00330
   11 FORMAT(5(1X,F8.2,5X))                                              IR 00340
      PRINT 17                                                           IR 00350
   17 FORMAT(/,10X,'HUMIDITY(GM/GM) AT THE ABOVE PRESSURE LEVELS')       IR 00360
      PRINT 13,(WA(I),I=1,NDATA)                                         IR 00370
   13 FORMAT(5(1X,E9.3,4X))                                              IR 00380
      PRINT 19                                                           IR 00390
   19 FORMAT(/,10X,'CLOUD TOP',2X,'CLOUD BOTTOM',2X,'CLOUD PERCENT')     IR 00400
      PRINT 18,(CLTOP(IC),CLBOT(IC),CSS(IC),IC=1,NC)                     IR 00410
   18 FORMAT(14X,F4.0,7X,F4.0,9X,F4.2)                                   IR 00420
   32 FORMAT(A1,/,A1)                                                    IR 00430
      CALL INDATA                                                        IR 00440
      CALL GAMOTO                                                        IR 00450
      PRINT 3                                                            IR 00460
    3 FORMAT(//,3X,'PRESSURE',4X,'FLUXES IN H2O BANDS',3X,'FLUXES IN 9.  IR 00470
     $6 & 15 MICRON BANDS')                                              IR 00480
      PRINT 4                                                            IR 00490
    4 FORMAT(5X,'(MB)',7X,'(ERGS/CM**2/SEC)',11X,'(ERGS/CM**2/SEC)')     IR 00500
      PRINT 5                                                            IR 00510
    5 FORMAT(15X,'DOWN',8X,'UP',14X,'DOWN',8X,'UP')                      IR 00520
      DO 2 IP=1,NP                                                       IR 00530
      IPM1=IP-1                                                          IR 00540
      IDD=(IPM1*NSB)+1                                                   IR 00550
    2 PRINT 1,PUI(IDD),FLUXHD(IP),FLUXHU(IP),FLUXCD(IP),FLUXCU(IP)       IR 00560
    1 FORMAT(1X,F8.2,2F12.2,4X,2F12.2)                                   IR 00570
      FAC=3.6*24./10030.*.98                                             IR 00580
      DO 69 IP=1,NP                                                      IR 00590
      FXWAV(IP)=FLUXHD(IP)-FLUXHU(IP)                                    IR 00600
```

```
69 FX15C(IP)=FLUXCD(IP)-FLUXCU(IP)                                    IR 00610
   PRINT 6                                                            IR 00620
 6 FORMAT(//16X,'PRESSURE',10X,'COOLING RATE')                        IR 00630
   PRINT 7                                                            IR 00640
 7 FORMAT(16X,'(MBAR)',7X,'(DEGREE CELCIUS/DAY)')                     IR 00650
   PRINT 8                                                            IR 00660
 8 FORMAT(12X,'FROM',6X,'TO')                                         IR 00670
   DO 90 IP=2,NP                                                      IR 00680
   IPM1=IP-1                                                          IR 00690
   IDD=(IPM1*NSB)+1                                                   IR 00700
   IDE=IDD-NSB                                                        IR 00710
   DP=PUI(IDD)-PUI(IDE)                                               IR 00720
   X1=FXWAV(IP)+FX15C(IP)                                             IR 00730
   X2=FXWAV(IPM1)+FX15C(IPM1)                                         IR 00740
   FXNET=X1-X2                                                        IR 00750
   COOLR(IP)=FXNET*FAC/DP                                             IR 00760
90 CONTINUE                                                           IR 00770
   DO 92 IP=2,NP                                                      IR 00780
   IPM1=IP-1                                                          IR 00790
   IDD=(IPM1*NSB)+1                                                   IR 00800
   IDE=IDD-NSB                                                        IR 00810
92 PRINT 91,PUI(IDE),PUI(IDD),COOLR(IP)                               IR 00820
91 FORMAT(10X,2F8.2,4X,F10.2)                                         IR 00830
   STOP                                                               IR 00840
   END                                                                IR 00850
```

```
      SUBROUTINE INDATA
C***  READ IN DATA
      DIMENSION GFH2O(25,22,11),TRE(43,15)
      DIMENSION TAUW(65),TWIN(100),TAUU(100),ITX(50)
      DIMENSION TOZON(43,15,3),PUI(43)
      DIMENSION ISN(1140),FSN(1140)
      COMMON/H2O/GFH2O
      COMMON/PRESS/PUI
      COMMON/CO2/TAUW,TAUU,TOZON,TWIN,TRE,FSN
      COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT
      NUP1=11
      NP=15
      NPT=43
      NW=22
      NSB=3
      NT=25
      READ(5,32)DUMMY
      READ(5,32)DUMMY
      READ(5,31)(PUI(IX),IX=1,40)
   31 FORMAT(9F8.3)
      READ(5,32)DUMMY
   32 FORMAT(A1,/,A1,/)
      DO 30 IU=1,NUP1
      DO 30 IW=1,NW
      READ(5,35) (ITX(IT),IT=1,NT)
   35 FORMAT(13I6)
      DO 40 IT=1,NT
      GFH2O(IT,IW,IU)=ITX(IT)
   40 CONTINUE
   30 CONTINUE
      READ(5,32)DUMMY
      DO 41 IP=1,NP
      READ(5,42) (ITX(IX),IX=1,NPT)
   42 FORMAT(24I3)
      DO 43 IX=1,NPT
   43 TRE(IX,IP)=ITX(IX)/1000.
   41 CONTINUE
      READ(5,32)DUMMY
      READ(5,45)(ISN(I),I=1,1140)
   45 FORMAT(40I2)
      DO 50 I=1,1140
      F=ISN(I)
   50 FSN(I)=-1.E-5*F
C***  READ TAUW,TAUU
      READ(5,32)DUMMY
      READ(5,81) (TAUW(IW),IW=1,65)
      READ(5,32)DUMMY
      READ(5,81) (TAUU(IU),IU=1,100)
   81 FORMAT(10F8.5)
      READ(5,32)DUMMY
      READ(5,10)(((TOZON(IX,IP,LAT),IP=1,NP),IX=1,NPT),LAT=1,3)
   10 FORMAT(15F5.3)
      READ(5,32)DUMMY
      READ(5,1)(TWIN(IU),IU=1,100)
    1 FORMAT(20F4.2)
      RETURN
      END
```

```
      SUBROUTINE GAMOTO                                                 IR 01430
      DIMENSION RR(2,3),PRE(2)                                          IR 01440
      DIMENSION NXT(10),NXB(10),CS(10)                                  IR 01450
      DIMENSION PUI(43),TUI(43),PAI(43),RAWI(43),DPI(43),TAI(43)        IR 01460
      COMMON/CLOUD/CS,NXB,NXT                                           IR 01470
      COMMON/TEMP/TSS                                                   IR 01480
      COMMON/PRESS/PUI                                                  IR 01490
      COMMON/CLOU/CLTOP(10),CLBOT(10)                                   IR 01500
      COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT                              IR 01510
      COMMON/AGIOS/TUI,PAI,TAI,RAWI,UBAR(43),WBAR(2,43)                 IR 01520
      COMMON/AMHN/TA(55),PA(55),WA(55),CSS(10),NDATA,RLAT,TS,PS         IR 01530
      DATA PRE/275.,550./                                               IR 01540
      DATA RR/1.216414,4.62111,-0.517625E-2,-0.4321E-1,0.1875E-4,       IR 01550
     $.11344E-3/                                                        IR 01560
      TSS=TS                                                            IR 01570
      DP=(PS-PUI(40))/3.                                                IR 01580
      DO 10 IX=41,43                                                    IR 01590
   10 PUI(IX)=PUI(IX-1)+DP                                              IR 01600
      DO 1010 IX=2,NPT                                                  IR 01610
      DPI(IX)=(PUI(IX)-PUI(IX-1))*1.02                                  IR 01620
      PAI(IX)=0.5*(PUI(IX)+PUI(IX-1))                                   IR 01630
 1010 CONTINUE                                                          IR 01640
C                                                                       IR 01650
C****** TEMPERATURE AND HUMIDITY INTERPOLATIONS *************           IR 01660
C                                                                       IR 01670
      NCK=2                                                             IR 01680
      DO 1030 IX=2,NPT                                                  IR 01690
 1040 IF( PAI(IX) .LT. PA(NCK)) GO TO 1042                              IR 01700
      IF(NCK .EQ. NDATA) GO TO 1042                                     IR 01710
      NCK=NCK+1                                                         IR 01720
      GO TO 1040                                                        IR 01730
 1042 CONTINUE                                                          IR 01740
      XX=ALOG(WA(NCK-1))                                                IR 01750
      X1=ALOG(PAI(IX)/PA(NCK-1))                                        IR 01760
      X2=ALOG(PUI(IX)/PA(NCK-1))                                        IR 01770
      X3=ALOG(WA(NCK)/WA(NCK-1))                                        IR 01780
      X4=ALOG(PA(NCK)/PA(NCK-1))                                        IR 01790
      RAWI(IX)=EXP(XX+X1*X3/X4)                                         IR 01800
      IF (RAWI(IX) .LT. 0.0) RAWI(IX)=0.0                               IR 01810
      TAI(IX)=TA(NCK-1)+X1/X4*(TA(NCK)-TA(NCK-1))                       IR 01820
      TUI(IX)=TA(NCK-1)+X2/X4*(TA(NCK)-TA(NCK-1))                       IR 01830
      RAWI(IX)=RAWI(IX)*DPI(IX)                                         IR 01840
 1030 CONTINUE                                                          IR 01850
      TAI(1)=TAI(2)                                                     IR 01860
      TUI(1)=TAI(2)                                                     IR 01870
C                                                                       IR 01880
C**********  COMPUTE SCALED WATER VAPOR AMOUNTS **************          IR 01890
C                                                                       IR 01900
      UBAR(1)=0.                                                        IR 01910
      WBAR(1,1)=0.0                                                     IR 01920
      WBAR(2,1)=0.0                                                     IR 01930
      DO 14 IX=2,NPT                                                    IR 01940
      DO 12 KB=1,2                                                      IR 01950
      SZ2=RR(KB,1)+RR(KB,2)*TAI(IX)+RR(KB,3)*TAI(IX)*TAI(IX)            IR 01960
   12 WBAR(KB,IX)=WBAR(KB,IX-1)+RAWI(IX)*SZ2*(PAI(IX)/PRE(KB))          IR 01970
      XX=(PAI(IX)/630.)*RAWI(IX)*RAWI(IX)/DPI(IX)                       IR 01980
      XX=XX*EXP(1800./TAI(IX)-6.0811)                                   IR 01990
   14 UBAR(IX)=UBAR(IX-1)+XX                                            IR 02000
```

```
C                                                                       IR 02010
C*********** COMPUTE INDEX LEVELS FOR CLOUDS ******************          IR 02020
C                                                                       IR 02030
      DO 20 IC=1,NC                                                     IR 02040
   20 CS(IC)=CSS(IC)                                                    IR 02050
      DO 3 IC=1,NC                                                      IR 02060
      DO 2 IX=16,42                                                     IR 02070
      IF(PUI(IX).LE.CLTOP(IC).AND.PUI(IX+1).GE.CLTOP(IC))GOTO 4         IR 02080
    5 IF(PUI(IX).LE.CLBOT(IC).AND.PUI(IX+1).GE.CLBOT(IC))GOTO 6         IR 02090
      GOTO 2                                                            IR 02100
    4 UT=CLTOP(IC)-PUI(IX)                                              IR 02110
      UB=PUI(IX+1)-CLTOP(IC)                                            IR 02120
      IF(UT.LT.UB)GOTO 7                                                IR 02130
      NXT(IC)=IX+1                                                      IR 02140
      GOTO 5                                                            IR 02150
    7 NXT(IC)=IX                                                        IR 02160
      GOTO 5                                                            IR 02170
    6 UT=CLBOT(IC)-PUI(IX)                                              IR 02180
      UB=PUI(IX+1)-CLBOT(IC)                                            IR 02190
      IF(UT.LT.UB)GOTO 8                                                IR 02200
      NXB(IC)=IX+1                                                      IR 02210
      GOTO 2                                                            IR 02220
    8 NXB(IC)=IX                                                        IR 02230
    2 CONTINUE                                                          IR 02240
    3 CONTINUE                                                          IR 02250
      CALL IRH20                                                        IR 02260
      CALL RCO203(RLAT)                                                 IR 02270
      RETURN                                                            IR 02280
      END                                                               IR 02290
```

```
      SUBROUTINE IRH2O                                                  IR 02300
      DIMENSION IH(43),DH(43),SW(2)                                     IR 02310
      DIMENSION GFH2O(25,22,11),DELTA(25)                               IR 02320
      DIMENSION SG(43,15),SH(15),SHT(15),SHS(15)                        IR 02330
      DIMENSION RAWI(43),TAI(43),PAI(43),TUI(43)                        IR 02340
      COMMON/AGIOS/TUI,PAI,TAI,RAWI,UBAR(43),WBAR(2,43)                 IR 02350
      COMMON/H2O/GFH2O                                                  IR 02360
      COMMON/TEMP/TS                                                    IR 02370
      COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT                              IR 02380
      COMMON/FDIV/SH,SG,SHT,SHS,FLUXUS                                  IR 02390
      DATA TEMP1/190./,SW/-6., -5.4/                                    IR 02400
      DATA DW/0.3/, DU/0.006/,DT/5./                                    IR 02410
      DATA DELTA/160.,168.,179.,189.,199.,211.,219.,232.,242.,254.,     IR 02420
     $268.,279.,292.,307.,320.,335.,350.,365.,382.,397.,415.,           IR 02430
     $432.,451.,471.,492./                                              IR 02440
      NU=NUP1-1                                                         IR 02450
C***  COMPUTE SHS,SHT,SG                                                IR 02460
      FLUXUS=0.                                                         IR 02470
      DO 43 IP=1,NP                                                     IR 02480
      SH(IP)=0.                                                         IR 02490
      SHS(IP)=0.                                                        IR 02500
      SHT(IP)=0.                                                        IR 02510
      DO 44 IX=1,NPT                                                    IR 02520
      SG(IX,IP)=0.                                                      IR 02530
   44 CONTINUE                                                          IR 02540
   43 CONTINUE                                                          IR 02550
      FH=(TS-TEMP1)/DT+1.501                                            IR 02560
      IG=FH                                                             IR 02570
      IF(IG .GE. NT) IG=NT-1                                            IR 02580
      IF(IG .LT. 1) IG=1                                                IR 02590
      DS=TS-(TEMP1+FLOAT(IG-1)*DT)                                      IR 02600
      NZ=1                                                              IR 02610
      DO 41 KB=1,2                                                      IR 02620
      X=GFH2O(IG,1,NZ)+(GFH2O(IG+1,1,NZ)-GFH2O(IG,1,NZ))/DT*DS          IR 02630
      FLUXUS=FLUXUS+X                                                   IR 02640
      NZ=NUP1                                                           IR 02650
   41 CONTINUE                                                          IR 02660
      FLUXUS=FLUXUS+DELTA(IG)                                           IR 02670
      DO 47 IX=1,NPT                                                    IR 02680
      FH=(TUI(IX)-TEMP1)/DT+1.5                                         IR 02690
      IH(IX)=FH                                                         IR 02700
      IF (IH(IX) .LT. 1) IH(IX)=1                                       IR 02710
      IF (IH(IX) .GE. NT) IH(IX)=NT-1                                   IR 02720
      F1=IH(IX)-1                                                       IR 02730
      DH(IX)=TUI(IX)-(TEMP1+F1*DT)                                      IR 02740
   47 CONTINUE                                                          IR 02750
      DO 42 IP=1,NP                                                     IR 02760
      IS=(IP-1)*NSB+1                                                   IR 02770
      DO 40 IX=1,NPT                                                    IR 02780
      IF(IS.EQ.IX)GOTO 40                                               IR 02790
      IF(IX .LT. IS ) IC=IX+1                                           IR 02800
      IF(IX .GT. IS ) IC=IX-1                                           IR 02810
      DY=ABS(UBAR(IS)-0.5*(UBAR(IC)+UBAR(IX)))                          IR 02820
      KU=DY/DU+1.5                                                      IR 02830
      IF (KU .GE. NU) KU=NU-1                                           IR 02840
      FU=DY-FLOAT(KU-1)*DU                                              IR 02850
```

```
C***  KB=1,FOR BAND CENTER REGION, KB=2, FOR BAND WING REGION
      DO 45 KB=1,2
      DX=ABS(WBAR(KB,IS)-0.5*(WBAR(KB,IC)+WBAR(KB,IX)))
      IF(DX .GT. 30.) GO TO 40
      IF(DX .LT. 1.E-6) DX=1.E-6
      DX=ALOG10(DX)
      IF(DX.LT.SW(KB))DX=SW(KB)
      KW=(DX-SW(KB))/DW+1.5001
      IF(KW .GE. NW) KW=NW-1
      FW=DX-(SW(KB)+FLOAT(KW-1)*DW)
      NZ=NUP1
      IF(KB .EQ. 2) NZ=KU
      IK=IX
      DO 50 I=1,2
      IF (I .EQ. 2) IK=IC
      IT=IH(IK)
      DH1=DH(IK)
      DGDT=(GFH2O(IT+1,KW,NZ)-GFH2O(IT,KW,NZ))/DT
      TDEL=DGDT*DH1
      WDEL=(GFH2O(IT,KW+1,NZ)-GFH2O(IT,KW,NZ))/DW*FW
      IF(KB.EQ.2)WDEL=WDEL+(GFH2O(IT,KW,NZ+1)-GFH2O(IT,KW,NZ))/
     *DU*FU
      X=GFH2O(IT,KW,NZ)+TDEL+WDEL
      IF(IK.EQ.1)SHT(IP)=SHT(IP)+X
      IF(IK.EQ.NPT)SHS(IP)=SHS(IP)+DGDT*(TS-TUI(NPT))
      IF (I.EQ.2) X=-X
      SG(IX,IP)=SG(IX,IP)+X
   50 CONTINUE
   45 CONTINUE
   40 CONTINUE
C
C********  COMPUTE SH(IP)
C
      IT=IH(IS)
      NZ=1
      DO 46 KB=1,2
      X=GFH2O(IT,1,NZ)+(GFH2O(IT+1,1,NZ)-GFH2O(IT,1,NZ))/DT*DH(IS)
      SH(IP)=SH(IP)+X
      NZ=NUP1
   46 CONTINUE
      SH(IP)=SH(IP)+DELTA(IT)
   42 CONTINUE
      CALL FDIVER
      RETURN
      END
```

```
      SUBROUTINE FDIVER                                     IR 03310
      DIMENSION FLUXU(15),FLUXD(15),FLUX(43)                IR 03320
      DIMENSION SHT(15),SHS(15),SH(15),SG(43,15)            IR 03330
      DIMENSION CS(10),NXB(10),NXT(10)                      IR 03340
      COMMON/CLOUD/CS,NXB,NXT                               IR 03350
      COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT                  IR 03360
      COMMON/FDIV/SH,SG,SHT,SHS,FLUXUS                      IR 03370
      COMMON/FLUXH/FLUXU,FLUXD                              IR 03380
      NPM1=NP-1                                             IR 03390
      DO 100 I=1,NP                                         IR 03400
      FLUXU(I)=0.                                           IR 03410
      FLUXD(I)=0.                                           IR 03420
  100 CONTINUE                                              IR 03430
C***  COMPUTE DOWNWARD FLUXES                               IR 03440
      DO 185 IP=2,NP                                        IR 03450
      IS=(IP-1)*NSB+1                                       IR 03460
      ISM1=IS-1                                             IR 03470
      SUM=0.                                                IR 03480
      DO 190 LP=1,ISM1                                      IR 03490
      IX=IS-LP                                              IR 03500
      SUM=SUM+SG(IX,IP)                                     IR 03510
      FLUX(IX)=SUM                                          IR 03520
  190 CONTINUE                                              IR 03530
      FLUX(1)=FLUX(1)-SHT(IP)+SH(IP)                        IR 03540
      IF(NC.NE.0)GOTO 75                                    IR 03550
      FLUXD(IP)=FLUX(1)                                     IR 03560
      GOTO 185                                              IR 03570
   75 CONTINUE                                              IR 03580
      SUMC=0.                                               IR 03590
      DO 60 IC=1,NC                                         IR 03600
      NCBX=NXB(IC)                                          IR 03610
      IF(IS.LE.NXT(IC))GOTO 60                              IR 03620
      IF(IS.LE.NCBX)GOTO 62                                 IR 03630
      FLUXD(IP)=FLUXD(IP)+(FLUX(NCBX)+SH(IP))*CS(IC)        IR 03640
      GOTO 63                                               IR 03650
   62 CONTINUE                                              IR 03660
      FLUXD(IP)=FLUXD(IP)+SH(IP)*CS(IC)                     IR 03670
   63 SUMC=SUMC+CS(IC)                                      IR 03680
   60 CONTINUE                                              IR 03690
      FLUXD(IP)=FLUXD(IP)+FLUX(1)*(1.-SUMC)                 IR 03700
  185 CONTINUE                                              IR 03710
C***  COMPUTE UPWARD FLUXES                                 IR 03720
      DO 200 IP=1,NPM1                                      IR 03730
      IS=(IP-1)*NSB+1                                       IR 03740
      ISP1=IS+1                                             IR 03750
      SUM=0.                                                IR 03760
      DO 205 IX=ISP1,NPT                                    IR 03770
      SUM=SUM+SG(IX,IP)                                     IR 03780
      FLUX(IX)=SUM                                          IR 03790
  205 CONTINUE                                              IR 03800
      FLUX(NPT)=FLUX(NPT)+SHS(IP)+SH(IP)                    IR 03810
      IF(NC.NE.0)GOTO 76                                    IR 03820
      FLUXU(IP)=FLUX(NPT)                                   IR 03830
      GOTO 200                                              IR 03840
   76 CONTINUE                                              IR 03850
```

```
      SUMC=0.                                                           IR 03860
      DO 70 IC=1,NC                                                     IR 03870
      NCTX=NXT(IC)                                                      IR 03880
      IF(IS.GE.NXB(IC))GOTO 70                                          IR 03890
      IF(IS.GE.NCTX)GOTO 72                                             IR 03900
      FLUXU(IP)=FLUXU(IP)+(FLUX(NCTX)+SH(IP))*CS(IC)                    IR 03910
      GOTO 73                                                           IR 03920
   72 CONTINUE                                                          IR 03930
      FLUXU(IP)=FLUXU(IP)+SH(IP)*CS(IC)                                 IR 03940
   73 SUMC=SUMC+CS(IC)                                                  IR 03950
   70 CONTINUE                                                          IR 03960
      FLUXU(IP)=FLUXU(IP)+FLUX(NPT)*(1.-SUMC)                           IR 03970
  200 CONTINUE                                                          IR 03980
      FLUXU(NP)=FLUXUS                                                  IR 03990
      RETURN                                                            IR 04000
      END                                                               IR 04010
```

```
      SUBROUTINE RCO2O3(RLAT)
      DIMENSION PAI(43),TAI(43),RAWI(43),BAI(44)
      DIMENSION TUI(43),TOZON(43,15,3)
      DIMENSION TAUU(100),TWIN(100),TAUW(65)
      DIMENSION BWI(44),BLKWIN(25),BLKCO2(25)
      DIMENSION TRE(43,15),TAUF(43,15),TXUF(43,15)
      DIMENSION FLUXD(15),FLUXU(15),FLUXC(43),FLUXW(43)
      DIMENSION FLUXDC(15),FLUXDW(15),FLUXUC(15),FLUXUW(15)
      DIMENSION CS(10),NXB(10),NXT(10)
      DIMENSION TR(19),DTAI(19),DTF(19,19),FSN(1140)
      COMMON/TEMP/TS
      COMMON/FLUXC/FLUXU,FLUXD
      COMMON/CLOUD/CS,NXB,NXT
      COMMON/AGIOS/TUI,PAI,TAI,RAWI,UBAR(43),WBAR(2,43)
      COMMON/CO2/TAUW,TAUU,TOZON,TWIN,TRE,FSN
      COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT
      DATA TR/266.6,262.82,257.13,251.35,245.54,239.95,234.54,
     $229.81,227.06,225.19,223.38,221.6,219.8,218.05,216.49,
     $4*216.65/
      DATA BLKCO2/12825., 14598., 16512., 18568., 20768., 23113.,
     1 25603., 28237., 31015., 33937., 37001., 40207., 43552.,
     2 47036., 50656., 54412., 58300., 62318., 66465., 70738.,
     3 75136., 79655., 84293., 89048., 93918./
      DATA BLKWIN/1944.,2377.,2877.,3450.,4102.,4838.,5664.,6585.,
     *             7606.,8733.,9969.,11320.,12788.,14380.,16097.,
     *             17944.,19923.,22038.,24292.,26685.,29221.,31902.,
     *             34729.,37703.,40825./
      DATA SW/-4./,DW/0.1/,NK/65/,SU/-3.301/,DU/.04/
      DATA TEMP1/190./,DT/5.0/
      LOGICAL LINEXP/.TRUE./
      NPTP1=NPT+1
      LAT=IFIX(RLAT/30.+1.)
      TAI(NPTP1)=TS
      DO 15 IP=1,NPTP1
      DX=TAI(IP)-TEMP1
      IT=DX/DT+1.5
      IF(IT .LT. 2) IT=2
      IF(IT .GT. NT) IT=NT
      ITM1=IT-1
      X=TEMP1+DT*FLOAT(ITM1)
      DS=TAI(IP)-X
      BAI(IP)=BLKCO2(IT)+(BLKCO2(IT)-BLKCO2(ITM1))*DS/DT
      BWI(IP)=BLKWIN(IT)+(BLKWIN(IT)-BLKWIN(ITM1))*DS/DT
   15 CONTINUE
      BS=BAI(NPTP1)
      BSS=BWI(NPTP1)
C
C********* COMPUTE TRANSMITTANCES IN THE 15 MICRON(TAUF) AND
C********* 9.6 MICRON (TXUF) BANDS.
C
      DO 25 IP=1,NP
      DO 25 LP=1,NPT
      TXUF(LP,IP)=TOZON(LP,IP,LAT)
   25 TAUF(LP,IP)=TRE(LP,IP)
      IF(.NOT.LINEXP)GOTO 23
      NSTRA=19
      NSM1=NSTRA-1
      DO 21 LP=1,NSTRA
   21 DTAI(LP)=TAI(LP)-TR(LP)
      LL=0
      DO 20 LP=1,NSM1
      LPP1=LP+1
      DO 20 IX=LPP1,NSTRA
      SUM=0.
      IY=IX-LP
```

```
      DO 22 L=1,IY                                                      IR 04670
      LL=LL+1                                                           IR 04680
      SUM=SUM+FSN(LL)*DTAI(LP+L)                                        IR 04690
   22 CONTINUE                                                          IR 04700
      DTF(IX,LP)=SUM                                                    IR 04710
      DTF(LP,IX)=SUM                                                    IR 04720
   20 CONTINUE                                                          IR 04730
      DO 23 IP=1,7                                                      IR 04740
      IX=(IP-1)*NSB+1                                                   IR 04750
      DO 24 LP=1,NSTRA                                                  IR 04760
   24 TAUF(LP,IP)=TAUF(LP,IP)+DTF(LP,IX)                                IR 04770
   23 CONTINUE                                                          IR 04780
      DO 28 IP=1,NP                                                     IR 04790
      IS=(IP-1)*NSB+1                                                   IR 04800
      DO 32 IX=1,NPT                                                    IR 04810
      IF(IS .EQ. IX) GO TO 32                                           IR 04820
      DX=ABS(WBAR(2,IS)-WBAR(2,IX))                                     IR 04830
      IF(DX.LT.1.E-7)DX=1.E-7                                           IR 04840
      IF(DX .LT. 40.) GO TO 35                                          IR 04850
      X=0.                                                              IR 04860
      YY=0.                                                             IR 04870
      GO TO 40                                                          IR 04880
   35 CONTINUE                                                          IR 04890
      DX=ALOG10(DX)                                                     IR 04900
      IF(DX .LT. SW) GO TO 34                                           IR 04910
      KW=(DX-SW)/DW+1.5                                                 IR 04920
      IF(KW .GT. NK) KW=NK                                              IR 04930
      X=TAUW(KW)                                                        IR 04940
      GO TO 36                                                          IR 04950
   34 X=1.                                                              IR 04960
   36 CONTINUE                                                          IR 04970
      DX=ABS(UBAR(IS)-UBAR(IX))                                         IR 04980
      IF (DX.LT.1.E-7) GO TO 38                                         IR 04990
      DX=ALOG10(DX)                                                     IR 05000
      IF(DX .LT. SU) GO TO 38                                           IR 05010
      KU=(DX-SU)/DU+1.5                                                 IR 05020
      IF(KU .GT. 100) KU=100                                            IR 05030
      Y=TAUU(KU)                                                        IR 05040
      YY=TWIN(KU)                                                       IR 05050
      GO TO 40                                                          IR 05060
   38 CONTINUE                                                          IR 05070
      Y=1.                                                              IR 05080
      YY=1.                                                             IR 05090
   40 CONTINUE                                                          IR 05100
      TAUF(IX,IP)=TAUF(IX,IP)*X*Y                                       IR 05110
      TXUF(IX,IP)=TXUF(IX,IP)*YY                                        IR 05120
   32 CONTINUE                                                          IR 05130
   28 CONTINUE                                                          IR 05140
C***  COMPUTE DOWNWARD FLUXES                                           IR 05150
      FLUXDC(1)=0.                                                      IR 05160
      FLUXDW(1)=0.                                                      IR 05170
      DO 70 IP=2,NP                                                     IR 05180
      FLUXDC(IP)=0.                                                     IR 05190
      FLUXDW(IP)=0.                                                     IR 05200
      TAY=1.                                                            IR 05210
      TAYY=1.                                                           IR 05220
      IS=(IP-1)*NSB+1                                                   IR 05230
      ISM1=IS-1                                                         IR 05240
      XC=0.                                                             IR 05250
      XW=0.                                                             IR 05260
```

```
      DO 75 LP=1,ISM1
      IX=IS-LP
      XC=XC+BAI(IX+1)*(TAY-TAUF(IX,IP))
      XW=XW+BWI(IX+1)*(TAYY-TXUF(IX,IP))
      FLUXC(IX)=XC
      FLUXW(IX)=XW
      TAY=TAUF(IX,IP)
      TAYY=TXUF(IX,IP)
   75 CONTINUE
      IF(NC.NE.0)GOTO 69
      FLUXDC(IP)=FLUXC(1)
      FLUXDW(IP)=FLUXW(1)
      GOTO 70
   69 CONTINUE
      SUMC=0.
      DO 60 IC=1,NC
      NCBX=NXB(IC)
      IF(IS.LE.NXT(IC))GOTO 60
      IF(IS.LE.NCBX)GOTO 62
      FLUXDC(IP)=FLUXDC(IP)+(FLUXC(NCBX)+BAI(NCBX)*TAUF(NCBX,IP))*CS(IC)
      FLUXDW(IP)=FLUXDW(IP)+(FLUXW(NCBX)+BWI(NCBX)*TXUF(NCBX,IP))*CS(IC)
      GOTO 63
   62 CONTINUE
      FLUXDC(IP)=FLUXDC(IP)+BAI(IS)*CS(IC)
      FLUXDW(IP)=FLUXDW(IP)+BWI(IS)*CS(IC)
   63 SUMC=SUMC+CS(IC)
   60 CONTINUE
      FLUXDC(IP)=FLUXDC(IP)+FLUXC(1)*(1.-SUMC)
      FLUXDW(IP)=FLUXDW(IP)+FLUXW(1)*(1.-SUMC)
   70 CONTINUE
C***  COMPUTE UPWARD FLUXES
      NPM1=NP-1
      DO 80 IP=1,NPM1
      FLUXUC(IP)=0.
      FLUXUW(IP)=0.
      TAY=1.
      TAYY=1.
      IS=(IP-1)*NSB+1
      ISP1=IS+1
      XC=0.
      XW=0.
      DO 85 IX=ISP1,NPT
      XC=XC+BAI(IX)*(TAY-TAUF(IX,IP))
      XW=XW+BWI(IX)*(TAYY-TXUF(IX,IP))
      FLUXC(IX)=XC
      FLUXW(IX)=XW
      TAY=TAUF(IX,IP)
      TAYY=TXUF(IX,IP)
   85 CONTINUE
      FLUXC(NPT)=FLUXC(NPT)+BS*TAY
      FLUXW(NPT)=FLUXW(NPT)+BSS*TAYY
      IF(NC.NE.0)GOTO 68
      FLUXUC(IP)=FLUXC(NPT)
      FLUXUW(IP)=FLUXW(NPT)
      GOTO 80
   68 CONTINUE
      SUMC=0.
      DO 64 IC=1,NC
      NCTX=NXT(IC)
      IF(IS.GE.NXB(IC))GOTO 64
      IF(IS.GE.NCTX)GOTO 66
```

```
      FLUXUC(IP)=FLUXUC(IP)+(FLUXC(NCTX)+BAI(NCTX+1)*TAUF(NCTX,IP))
     1*CS(IC)
      FLUXUW(IP)=FLUXUW(IP)+(FLUXW(NCTX)+BWI(NCTX+1)*TXUF(NCTX,IP)
     1)*CS(IC)
      GOTO 67
   66 CONTINUE
      FLUXUC(IP)=FLUXUC(IP)+BAI(IS+1)*CS(IC)
      FLUXUW(IP)=FLUXUW(IP)+BWI(IS+1)*CS(IC)
   67 SUMC=SUMC+CS(IC)
   64 CONTINUE
      FLUXUC(IP)=FLUXUC(IP)+FLUXC(NPT)*(1.-SUMC)
      FLUXUW(IP)=FLUXUW(IP)+FLUXW(NPT)*(1.-SUMC)
   80 CONTINUE
      FLUXUC(NP)=BS
      FLUXUW(NP)=BSS
C
C********* TOTAL FLUXES IN THE 9.6 AND 15 MICRON BANDS *************
C
      DO 97 1P=1,NP
      FLUXU(IP)=FLUXUC(IP)+FLUXUW(IP)
      FLUXD(IP)=FLUXDC(IP)+FLUXDW(IP)
   97 CONTINUE
      RETURN
      END
```

APPENDIX B

ARRAY AND VARIABLE LIST

1. Main Program

Code	Meaning	Unit
PA	Input pressure level	mb
TA	Input temperature	K
WA	Input specific humidity	gm/gm
CLTOP	Cloud top pressure	mb
CLBOT	Cloud base pressure	mb
CSS	Fractional cloud amount	
NDATA	Number of input data in PA, TA, WA	
NC	Number of cloud types	
RLAT	Latitude	degree
PS	Surface pressure	mb
TS	Surface temperature	K
PUI	Pressure sublevel	mb
FLUXHD	Downward flux in the H_2O bands	ergs/(cm^2 sec)
FLUXHU	Upward flux in the H_2O bands	ergs/(cm^2 sec)
FLUXCD	Downward flux in the 9.6 and 15μm bands	ergs/(cm^2 sec)
FLUXCU	Upward flux in the 9.6 and 15μm bands	ergs/(cm^2 sec)
FXWAV	Net flux in the H_2O bands	ergs/(cm^2 sec)
FX15C	Net flux in the 9.6 and 15μm bands	ergs/(cm^2 sec)
FAC	Conversion factor for cooling rate	
COOLR	Cooling rate	°C/day

2. Subroutine INDATA

Code	Meaning	Unit
PUI	See main program	
GFH2O	G-function	ergs/(cm^2 sec)
TRE	CO_2 transmission function	
FSN	Coefficients for correcting CO_2 transmittance	K^{-1}
TAUW	Transmittance in the 15μm band due to H_2O line absorption	
TAUU	Transmittance in the 15μm band due to H_2O e–type absorption	
TOZON	Ozone transmission function	
TWIN	Transmittance in the 9.6μm band due to e–type absorption	
NP	Number of flux levels	
NPT	Total number of sublevels	
NSB	Number of sublayers between neighboring flux levels	
NT	Number of temperature values in GFH2O	
NW	Number of log w values in GFH2O	
NUP1	Number of u values in GHF2O	

3. Subroutine GAMOTO

Code	Meaning	Unit
PA	See main program	
TA	See main program	
WA	See main program	
PUI	See main program	
PAI	Pressure at the middle of sublayers	mb
DPI	Air mass in a sublayer	gm/cm^2
TUI	Temperature at sublevels	K
TAI	Temperature at the middle of sublayers	K
RAWI	Specific humidity in a sublayer (01800)	gm/gm
RAWI	Water vapor content in a sublayer (01840)	gm/cm^2
TS, TSS	Surface temperature	K
WBAR	Scaled water vapor amount for line absorption	gm/cm^2
UBAR	Scaled water vapor amount for e–type absorption	gm/cm^2
PRE	Reference pressure	mb
RR	Coefficients for computing R	
CS, CSS	Fractional cloud cover	
NXT	Index for cloud top pressure	
NXB	Index for cloud base pressure	
CLTOP	See main program	
CLBOT	See main program	
NC	See main program	

4. Subroutine IRH2O

Code	Meaning	Unit
TEMP1	Initial temperature value for array GFH2O	K
SW	Initial value of log w for array GFH2O	
DT	Increment in temperature values in GFH2O	K
DW	Increment in log w in GFH2O	
DU	Increment in u in GFH2O	gm/cm^2
IH	Temperature index for GFH2O	
KW	Index of log w for GFH2O	
KU	Index of u for GFH2O	
DH	Difference between the sublevel temperature and the temperature at the nearest index value.	K
FW	Difference between the value of log w and that at the nearest index value.	
FU	Difference between the value of u and that at the nearest index value.	gm/cm^2
SH	Planck flux at sublevels	$ergs/(cm^2\ sec)$
FLUXUS	Upward flux at the surface	$ergs/(cm^2\ sec)$
SHT	$G(p, p_t, T_t)$	$ergs/(cm^2\ sec)$
SHS	$G(p, p_s, T_s) - G(p, p_s, T(p_s))$	$ergs/(cm^2\ sec)$
SG	$(\partial G/\partial T)\ \Delta T$	$ergs/(cm^2\ sec)$
GFH2O	See subroutine INDATA	
DELTA	Correction term for Planck fluxes	$ergs/(cm^2\ sec)$
DGDT	$\partial G/\partial T$	$ergs/(cm^2\ sec\ K)$
TDEL	$(\partial G/\partial T)\ \Delta T$	$ergs/(cm^2\ sec)$
WDEL	$(\partial G/\partial \log w)\ \Delta \log w$, $(\partial G/\partial u)\ \Delta u$	$ergs/(cm^2\ sec)$
NUP1	See subroutine INDATA	
NP	See subroutine INDATA	

4. Subroutine IRH2O (Continued)

Code	Meaning	Unit
NPT	See subroutine INDATA	
NSB	See subroutine INDATA	
NW	See subroutine INDATA	
NT	See subroutine INDATA	
TS	See main program	
TUI	See subroutine GAMOTO	
WBAR	See subroutine GAMOTO	
UBAR	See subroutine GAMOTO	

5. Subroutine FDIVER

Code	Meaning	Unit
FLUX	Σ SG	ergs/(cm^2 sec)
FLUXU	Upward flux in the water vapor bands	ergs/(cm^2 sec)
FLUXD	Downward flux in the water vapor bands	ergs/(cm^2 sec)
SUMC	Total cloud cover	
NP	See subroutine INDATA	
NPT	See subroutine INDATA	
NSB	See subroutine INDATA	
NC	See main program	
CS	See subroutine GAMOTO	
NXT	See subroutine GAMOTO	
NXB	See subroutine GAMOTO	
SG	See subroutine GAMOTO	
SH	See subroutine GAMOTO	
SHS	See subroutine GAMOTO	
SHT	See subroutine GAMOTO	
FLUXUS	See subroutine GAMOTO	

6. Subroutine RCO2O3

Code	Meaning	Unit
TEMP1	Initial temperature value for arrays BLKCO2 and BLKWIN	K
SW	Initial value of log w for TAUW	
SU	Initial value of log u for TAUU and TWIN	
DT	Increment in temperature values in BLKCO2 and BLKWIN	K
DW	Increment in log w in TAUW	
DU	Increment in log u in TAUU and TWIN	
NT	Number of temperature values in BLKCO2 and BLKWIN	
NK	Number of log w values in TAUW	
LINEXP	Flag for correcting CO_2 transmittance due to temperature variations	
RLAT	Latitude	degree
LAT	Index for latitude	
TAI	See subroutine GAMOTO	
TR	U.S. Standard Temperature profile	K
DTAI	Temperature deviation from TR	K
WBAR	See subroutine GAMOTO	
UBAR	See subroutine GAMOTO	
BLKCO2	Precomputed Planck flux in the 15μm band	ergs/(cm^2 sec)
BLKWIN	Precomputed Planck flux in the 9.6μm band	ergs/(cm^2 sec)
BAI	Planck flux in the middle of sublayers in the 15μm band	ergs/(cm^2 sec)
BWI	Planck flux in the middle of sublayers in the 9.6μm band	ergs/(cm^2 sec)
BS	Upward flux at the surface in the 15μm band	ergs/(cm^2 sec)
BSS	Upward flux at the surface in the 9.6μm band	ergs/(cm^2 sec)
FSN	See subroutine INDATA	
TOZON	See subroutine INDATA	

6. Subroutine RCO2O3 (Continued)

Code	Meaning	Unit
TRE	See subroutine INDATA	
TAUW	See subroutine INDATA	
TAUU	See subroutine INDATA	
TWIN	See subroutine INDATA	
TAUF	Transmittance in the 15μm band	
TXUF	Transmittance in the 9.6μm band	
FLUXC	$\Sigma B \Delta \tau$ in the 15μm band	ergs/(cm^2 sec)
FLUXW	$\Sigma B \Delta \tau$ in the 9.6μm band	ergs/(cm^2 sec)
FLUXDC	Downward flux in the 15μm band	ergs/(cm^2 sec)
FLUXUC	Upward flux in the 15μm band	ergs/(cm^2 sec)
FLUXDW	Downward flux in the 9.6μm band	ergs/(cm^2 sec)
FLUXUW	Upward flux in the 9.6μm band	ergs/(cm^2 sec)
FLUXU	Total upward flux in the 9.6 and 15μm bands	ergs/(cm^2 sec)
FLUXD	Total downward flux in the 9.6 and 15μm bands	ergs/(cm^2 sec)
NC	See main program	
NXT	See subroutine GAMOTO	
NXB	See subroutine GAMOTO	
CS	See subroutine GAMOTO	
SUMC	Total cloud cover	
NP	See subroutine INDATA	
NPT	See subroutine INDATA	
NSB	See subroutine INDATA	

APPENDIX C

SAMPLE OUTPUT

1. Clear Mid-Latitude Winter Atmosphere (NC = 0)

```
                    NDATA   NC   KLAT    TS        PS
                     40      0   15.0   270.0   1013.0

               PRESSURE LEVELS(MB) OF SAMPLE PROFILE
      0.2           0.3           0.5           0.7           1.0
      2.0           3.0           4.0           5.0           6.0
      7.0           8.5          10.0          12.5          15.0
     17.5          20.0          25.0          30.0          35.0
     40.0          50.0          60.0          70.0          85.0
    100.0         125.0         150.0         175.0         200.0
    250.0         300.0         350.0         400.0         500.0
    600.0         700.0         850.0         920.0        1000.0

               TEMPERATURES(K)AT THE ABOVE PRESSURE LEVELS
   240.64        252.60        258.73        264.03        263.21
   255.07        243.47        236.23        230.82        226.98
   224.70        222.30        219.89        217.36        216.80
   216.33        215.93        215.42        215.20        215.20
   215.20        215.20        215.20        215.31        215.87
   216.43        217.05        217.69        218.23        218.69
   219.27        222.39        229.03        234.55        242.40
   251.24        258.73        264.69        268.32        270.57

               HUMIDITY(GM/GM) AT THE ABOVE PRESSURE LEVELS
 0.285E-05     0.439E-05     0.548E-05     0.663E-05     0.820E-05
 0.111E-04     0.118E-04     0.127E-04     0.135E-04     0.143E-04
 0.155E-04     0.169E-04     0.185E-04     0.202E-04     0.193E-04
 0.186E-04     0.180E-04     0.173E-04     0.138E-04     0.105E-04
 0.853E-05     0.700E-05     0.512E-05     0.468E-05     0.415E-05
 0.400E-05     0.400E-05     0.453E-05     0.745E-05     0.195E-04
 0.195E-04     0.244E-04     0.500E-04     0.100E-03     0.272E-03
 0.574E-03     0.102E-02     0.166E-02     0.210E-02     0.242E-02

               CLOUD TOP  CLOUD BOTTOM  CLOUD FRACTION
                  210.        300.            0.18

   PRESSURE    FLUXES IN H2O BANDS    FLUXES IN 9. 6 & 15 MICRON BANDS
     (MB)       (ERGS/CM**2/SEC)             (ERGS/CM**2/SEC)
                DOWN          UP              DOWN          UP
      1.39        0.0      185444.37            0.0      46202.96
      3.18      267.87     185390.31         2061.45     47522.17
      7.28      287.19     185349.50         2958.25     46955.96
     16.67      632.25     185324.37         4343.21     47013.10
     38.16     1855.69     185351.94         6837.71     48156.27
     87.36     2985.56     185424.69        10492.16     50072.78
    200.00     6850.19     185616.37        14897.36     51975.02
    300.00    14780.50     187467.50        17737.02     54861.20
    400.00    28260.62     190267.00        23370.52     59365.65
    500.00    47726.87     194613.50        29131.07     63406.77
    600.00    69482.19     201[illegible]69.56        35585.37     67895.44
    700.00    92101.81     208026.37        42254.19     71718.94
    800.00   110372.37     213865.00        47685.18     74349.87
    900.00   128086.00     219744.00        52466.74     77[illegible]83.87
   1013.00   147111.94     223182.00        57425.71     78223.00

                 PRESSURE           COOLING RATE
                  (MBAR)        (DEGREE CELCIUS/DAY)
              FROM      TO
              1.39     3.18            14.55
              3.18     7.28             3.09
              7.28    16.67             1.71
             16.67    38.16             0.92
             38.16    87.36             0.48
             87.36   200.00             0.46
            200.00   300.00             0.51
            300.00   400.00             1.00
            400.00   500.00             1.42
            500.00   600.00             1.44
            600.00   700.00             1.58
            700.00   800.00             1.29
            800.00   900.00             1.16
            900.00  1013.00             1.46
```

2. Cloudy Mid-Latitude Winter Atmosphere (NC = 5)

```
                 NDATA   NC   RLAT    TS       PS
                  40      5   15.0   270.0   1013.0

               PRESSURE LEVELS(MB) OF SAMPLE PROFILE
     0.2            0.3            0.5            0.7            1.0
     2.0            3.0            4.0            5.0            6.0
     7.0            8.5           10.0           12.5           15.0
    17.5           20.0           25.0           30.0           35.0
    40.0           50.0           60.0           70.0           85.0
   100.0          125.0          150.0          175.0          200.0
   250.0          300.0          350.0          400.0          500.0
   600.0          700.0          850.0          920.0         1000.0

               TEMPERATURES(K)AT THE ABOVE PRESSURE LEVELS
   240.64         252.60         258.73         264.03         263.21
   255.07         243.47         236.23         230.82         226.98
   224.70         222.30         219.89         217.36         216.80
   216.33         215.93         215.42         215.20         215.20
   215.20         215.20         215.20         215.31         215.87
   216.43         217.05         217.69         218.23         218.69
   219.27         222.39         229.03         234.55         242.40
   251.24         258.73         264.69         268.32         270.57

               HUMIDITY(GM/GM) AT THE ABOVE PRESSURE LEVELS
 0.285E-05      0.439E-05      0.548E-05      0.663E-05      0.820E-05
 0.111E-04      0.118E-04      0.127E-04      0.135E-04      0.143E-04
 0.155E-04      0.169E-04      0.185E-04      0.202E-04      0.193E-04
 0.186E-04      0.180E-04      0.173E-04      0.138E-04      0.105E-04
 0.653E-05      0.700E-05      0.512E-05      0.468E-05      0.415E-05
 0.400E-05      0.400E-05      0.453E-05      0.745E-05      0.195E-04
 0.195E-04      0.244E-04      0.500E-04      0.100E-03      0.272E-03
 0.574E-03      0.102E-02      0.166E-02      0.210E-02      0.242E-02

               CLOUD TOP  CLOUD BOTTOM  CLOUD FRACTION
                  210.        300.          0.18
                  505.        600.          0.06
                  801.        901.          0.15
                  600.        900.          0.06
                  204.        902.          0.04


  PRESSURE     FLUXES IN H2O BANDS    FLUXES IN 9. 6 & 15 MICRON BANDS
    (MB)        (ERGS/CM**2/SEC)             (ERGS/CM**2/SEC)
                DOWN         UP                DOWN         UP
     1.39        0.0      160269.50             0.0      43336.52
     3.18      267.87     160215.44          2081.45     42645.90
     7.28      287.19     160174.56          2958.25     42049.80
    16.67      832.25     160148.75          4343.21     41992.21
    38.16     1855.69     160173.62          6037.71     42797.15
    87.36     2985.56     160240.19         10492.16     44245.09
   200.00     6550.19     160410.25         14697.36     45780.01
   300.00    34820.18     177958.44         20919.61     52523.17
   400.00    46781.64     181566.06         26296.43     57142.21
   500.00    63775.48     186278.69         31799.63     61207.65
   600.00    89371.12     196293.62         39297.41     66551.94
   700.00   115026.87     204333.69         46916.08     70682.81
   800.00   130624.25     210515.56         51979.39     73420.44
   900.00   159386.06     219744.00         59768.91     77283.87
  1013.00   173253.37     223182.00         63878.33     78223.00


                  PRESSURE            COOLING RATE
                   (MBAR)       (DEGREE CELCIUS/DAY)
               FROM      TO
                1.39     3.18          14.59
                3.18     7.28           3.16
                7.28    16.67           1.81
               16.67    38.16           1.06
               38.16    87.36           0.56
               87.36   200.00           0.49
              200.00   300.00           0.82
              300.00   400.00           0.77
              400.00   500.00           1.16
              500.00   600.00           1.50
              600.00   700.00           1.78
              700.00   800.00           0.99
              800.00   900.00           1.98
              900.00  1013.00           1.02
```

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3. Clear Tropical Atmosphere (NC = 0)

```
               NDATA  NC   RLAT    TS      PS
                40     0   15.0   297.8   1013.1

            PRESSURE LEVELS(MB) OF SAMPLE PROFILE
     0.2            0.3            0.5            0.7            1.0
     2.0            3.0            4.0            5.0            6.0
     7.0            8.5           10.0           12.5           15.0
    17.5           20.0           25.0           30.0           35.0
    40.0           50.0           60.0           70.0           85.0
   100.0          125.0          150.0          175.0          200.0
   250.0          300.0          350.0          400.0          500.0
   600.0          700.0          850.0          920.0         1000.0

            TEMPERATURES(K)AT THE ABOVE PRESSURE LEVELS
   229.36         246.72         255.63         263.31         269.91
   265.47         257.36         251.76         247.68         244.41
   241.76         239.03         236.29         233.26         230.23
   227.77         225.66         222.96         220.12         217.96
   216.11         212.61         207.66         203.59         199.42
   195.30         197.54         205.47         211.85         218.32
   226.22         235.13         243.39         249.66         259.20
   269.24         278.52         286.72         292.90         297.17

            HUMIDITY(GM/GM) AT THE ABOVE PRESSURE LEVELS
 0.200E-05      0.314E-05      0.395E-05      0.482E-05      0.570E-05
 0.870E-05      0.990E-05      0.107E-04      0.117E-04      0.124E-04
 0.134E-04      0.149E-04      0.166E-04      0.187E-04      0.191E-04
 0.184E-04      0.178E-04      0.171E-04      0.147E-04      0.109E-04
 0.871E-05      0.692E-05      0.498E-05      0.435E-05      0.368E-05
 0.336E-05      0.327E-05      0.349E-05      0.437E-05      0.755E-05
 0.255E-04      0.919E-04      0.239E-03      0.458E-03      0.936E-03
 0.196E-02      0.319E-02      0.794E-02      0.116E-01      0.141E-01

            CLOUD TOP  CLOUD BOTTOM  CLOUD FRACTION
               200.        300.          0.45


   PRESSURE     FLUXES IN H2O BANDS     FLUXES IN 9. 6 & 15 MICRON BANDS
    (MB)        (ERGS/CM**2/SEC)             (ERGS/CM**2/SEC)
                DOWN        UP               DOWN       UP
     1.39        0.0     236907.69            0.0     62255.73
     3.18      306.94    236876.50         2649.86    61631.22
     7.28      307.37    236827.25         4193.17    60845.29
    16.67      953.00    236673.75         6140.75    60214.68
    38.16     2034.50    236570.31         8116.90    60730.78
    87.36     2685.94    236504.87         8774.48    62061.51
   200.00     5388.50    237562.12        12586.56    69809.12
   300.00    20093.37    240090.44        20464.41    76473.31
   400.00    51892.06    246632.06        29464.14    82664.81
   500.00    81082.94    255275.69        37862.09    88353.25
   600.00   113158.37    266878.50        46950.80    94578.75
   700.00   146335.19    282323.06        56815.86   100479.94
   800.00   179883.44    294606.62        65878.81   105042.31
   900.00   219928.56    312925.06        76076.56   111535.56
  1013.10   269846.69    329867.37        91195.87   115737.44


              PRESSURE            COOLING RATE
              (MBAR)         (DEGREE CELCIUS/DAY)
           FROM      TO
            1.39     3.18            17.04
            3.18     7.28             4.90
            7.28    16.67             3.04
           16.67    38.16             1.03
           38.16    87.36             0.01
           87.36   200.00            -0.17
          200.00   300.00             1.13
          300.00   400.00             2.37
          400.00   500.00             1.96
          500.00   600.00             1.97
          600.00   700.00             1.83
          700.00   800.00             2.18
          800.00   900.00             2.15
          900.00  1013.10             3.28
```

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16. Abstract

This report is the documentation of a FORTRAN program that calculates the atmospheric cooling rate and infrared fluxes for partly cloudy atmospheres based upon the fast but accurate methods of Chou and Arking (1978, 1980). The IR fluxes in the water bands and the 9.6 and 15 μm bands are calculated at 15 levels ranging from 1.39mb to the surface.

The program is generalized to accept any arbitrary atmospheric temperature and humidity profiles and clouds as input and return the cooling rate and fluxes as output. Sample calculations for various atmospheric profiles and cloud situations are demonstrated in the report.

A digital magnetic tape containing the computer codes and the precomputed transmission functions of the radiation routine can be made available upon request.

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Infrared Radiation, Cooling Rate, Far-Wing Scaling, Water Vapor, Carbon Dioxide, Ozone

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