AN EFFICIENT ROUTINE FOR INFRARED RADIATIVE TRANSFER IN A CLOUDY ATMOSPHERE

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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 fast 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, 1980). 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

---

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

$$F_{clr} \uparrow (p) = \int_{\Delta \nu} d\nu \left[ B_{p}(T_{s}) \tau_{\nu}(p, p_{3}) + \int_{p_{3}}^{p} B_{p}(T(p')) \frac{d\tau_{\nu}(p, p')}{dp'} dp' \right]$$  (1a)

and

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

where $B_{p}(T)$ is the blackbody flux at temperature $T$ and wavenumber $\nu$ and is equal to $\pi$ 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 15$\mu$m bands, the transmittance $\tau_{\nu}$ is replaced by its average value over $\Delta \nu$ which reduces the equations for fluxes to

$$F_{clr} \uparrow (p) = B(T_{s}) \tau(p, p_{3}) + \int_{p_{3}}^{p} B(T(p')) \frac{d\tau(p, p')}{dp'} dp'$$  (2a)

and

$$F_{clr} \downarrow (p) = \int_{p_{t}}^{p} B(T(p')) \frac{d\tau(p', p)}{dp'} dp'$$  (2b)

where

$$B(T) = \int_{\Delta \nu} B_{p}(T) d\nu.$$  (2c)
\[ \tau(p, p') = \frac{1}{\Delta \nu} \int_{\Delta \nu}^{} \tau_{\nu}(p, p') \, d\nu. \] (2d)

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

\[ F_{\text{clr}} \uparrow (p) = B(T(p)) + G(p, p_s, T_s) - G(p, p_s, T(p_s)) + \int_{T(p)}^{T(p_s)} \partial G(p, p', T(p'))/\partial T \, dT(p'), \] (3a)

and

\[ F_{\text{clr}} \downarrow (p) = B(T(p)) - G(p, p_t, T(p_t)) + \int_{T(p)}^{T(p_t)} \partial G(p, p', T(p'))/\partial T \, dT(p'), \] (3b)

where

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

and

\[ \partial G(p, p', T)/\partial T = \int_{\Delta \nu}^{} \tau_{\nu}(p, p') \, \partial B_{\nu}(T)/\partial T \, d\nu. \] (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 (\( \geq 10 \)). 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 15\(\mu\)m 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

\[ F(p) = (1 - C)F_{\text{clr}}(p) + \sum_{i=1}^{n} C_i F_{i,\text{cld}}(p), \]  

(4)

where \( F_{\text{cld}} \) 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

\[ -\frac{dT}{dt} = \frac{g}{C_p} \frac{d}{dp} (F_\uparrow - F_\downarrow), \]  

(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 \( \tau_\nu \) in Eq. (1) must be computed at every \( \leq 0.01 \) cm\(^{-1}\) interval, which results in a total of \( 10^5 \text{ to } 10^6 \) 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 \( \nu \) in the direction from the vertical \( \theta = \cos^{-1}\mu \) is

\[ \tau_\nu(\mu) = \exp \left(-\sum_i u_\nu(i)/\mu \right) \]  

(6)

where \( u_\nu(i) \) is the optical depth of the \( i \)th absorber given by
\[ u_p(i) = \frac{1}{g} \int_{P_1}^{P_2} k_p(i) q(i) dp, \]  

\( k_p \) the absorption coefficient and \( q \) the mixing ratio.

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

\[ \tau_\nu = 2 \int_0^1 \tau_\nu(\mu) \mu d\mu, \]  

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, \( \nu_0 \), strength, \( S \), width, \( \alpha \), 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 296 K.

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


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, \(\ell_\nu\), can be written as

\[
\ell_\nu(p, T) = \ell_\nu(p_r, T_r) \frac{p}{p_f} R(T, T_r)
\]  

(9)

where \(R\) is the spectrally averaged value of \(R_\nu\) given by

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

(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 \(R_\nu\) 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 \(T = T_r \pm 40\text{K}\) and \(T = T_r\) (for which \(R = 1\)).
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 $R_p(T, T_r)$ defined by Eq. (10).

<table>
<thead>
<tr>
<th>Wavenumber (cm$^{-1}$)</th>
<th>$T_r$ (K)</th>
<th>$p_r$ (mb)</th>
<th>$R(T_r - 40, T_r)$</th>
<th>$R(T_r + 40, T_r)$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Center</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-340</td>
<td>225</td>
<td>275</td>
<td>0.90</td>
<td>1.16</td>
</tr>
<tr>
<td>1380-1900</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>340-580</td>
<td>256</td>
<td>550</td>
<td>0.58</td>
<td>1.78</td>
</tr>
<tr>
<td>760-980</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1100-1380</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1900-3000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

$$
\tau_{15\mu} = \tau_{CO_2} \cdot \tau_{H_2O} \cdot \tau_e,
$$

where $\tau_{CO_2}$, $\tau_{H_2O}$, and $\tau_e$ are the transmittances averaged over the 15μm band due to CO$_2$ molecular line absorption, H$_2$O line absorption and H$_2$O e-type absorption, respectively.

The atmospheric CO$_2$ content can practically be considered as constant, and the transmittance $\tau_{CO_2}$ 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 $\leq 0.005$ in the mean diffuse transmittance averaged over the entire 15μm band (Chou and Arking, 1978). In this infrared radiation routine, the transmittance $\tau_{CO_2}$ between $p_1$ and $p_2$ is computed using the linear expansion method from

$$
\tau_{CO_2}(p_1, p_2) = \tau_{CO_2}^0(p_1, p_2) + \sum_{i=1}^{m} a_i(p_1, p_2) \Delta T_i,
$$

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

\[
a_i(p_1, p_2) = \frac{\partial \tau(p_1, p_2)}{\partial T_1}.
\] (13)

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

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

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

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

\[
\tau_g(w) = \frac{2}{\Delta \nu} \int_{\Delta \nu} \int_0^1 \exp(-C_\nu(p_r, T_r)w/\mu) \mu \, d\mu,
\] (15)

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

where the scaled water vapor amounts are given by

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

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

Values of \( \tau_\nu(T_o)(p_1, p_2) \), \( a_i(p_1, p_2) \), \( \tau_g(w) \), 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 9.6 \mu m Band**

In the 9.6 \mu m band from 980 to 1100 cm\(^{-1}\), 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

\[ T_{9.6} \approx T_{c6} \cdot T_{e}. \]  

The ozone transmittance, \( T_{o3} \), 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 \( T_{o3} \) for the respective latitude zones. No attempts have been made to correct for the change in \( T_{o3} \) due to changes in the ozone content and temperature profile. The transmittance \( T_{e} \) 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 \( \rho_1 \) and \( \rho_2 \) can be written as

\[ \tau_{\rho}(\rho_1, \rho_2) = 2 \int_{0}^{1} \exp \left\{ (\xi_{\rho}(\rho_1, T) \cdot w(\rho_1, \rho_2) + C_{\rho}(T_0) \cdot u(\rho_1, \rho_2))/\mu \right\} \mu \, d\mu; \]  

where \( w(\rho_1, \rho_2) \) and \( u(\rho_1, \rho_2) \) are given by Eqs. (17) and (18). The error introduced in \( \tau_{\rho}(\rho_1, \rho_2) \) by using Eq. (20) was shown in Chou and Arking (1980) to be small with a magnitude \( \lesssim 0.01 \).

Since \( \xi_{\rho}(\rho_1, T) \) and \( C_{\rho}(T_0) \) 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 \( G(\rho, \rho', T) \) 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 \( \rho \) and \( \rho' \). 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 $B$, $\tau$, 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 $\Delta p$ 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 sub-
layers. 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 15$\mu$m bands (see Fig. 1 for the locations of $i$ and $j$).

\begin{align*}
B(T(p')) \, d\tau(p_i, p') &\approx B(T_{j+\frac{1}{2}}) \left[ \tau(p_i, p_{j+1}) - \tau(p_i, p_j) \right], \quad j = i + 1, \ldots, 43, \text{ for upward flux}; \quad (21a) \\
&\approx B(T_{j+\frac{1}{2}}) \left[ \tau(p_i, p_{j+1}) - \tau(p_i, p_j) \right], \quad j = 1, \ldots, i - 1, \text{ for downward flux}. \quad (21b)
\end{align*}

Similarly, the following approximations are made in computing water vapor infrared fluxes,
<table>
<thead>
<tr>
<th>PRESSURE (mb)</th>
<th>FLUX LEVEL</th>
<th>SUBLEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.39</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3.18</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7.28</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>16.67</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>38.16</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>87.36</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>200</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>300</td>
<td>8</td>
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</tr>
<tr>
<td>400</td>
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<td>500</td>
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<td>600</td>
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<td>14</td>
</tr>
<tr>
<td>PS</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

Figure 1. Model Vertical Structure. Sublevels are Used for Computing Fluxes at the Flux Levels.
\[
[\partial G(p_i, p', T(p'))/\partial T(p')] \, dT(p')
\]

\[
\simeq G(w(p_i, p_{j-\frac{1}{2}}), u(p_i, p_{j-\frac{1}{2}}), T_j)
\]
\[- G(w(p_i, p_{j-\frac{1}{2}}), u(p_i, p_{j-\frac{1}{2}}), T_{j-1}), j = i + 1, \ldots, 43,
\]
for upward flux; \hspace{1cm} (22a)

\[
\simeq G(w(p_{j+\frac{1}{2}}, p_i), u(p_{j+\frac{1}{2}}, p_i), T_j)
\]
\[- G(w(p_{j+\frac{1}{2}}, p_i), u(p_{j+\frac{1}{2}}, p_i), T_{j+1}), j = 1, \ldots, i - 1,
\]
for downward flux. \hspace{1cm} (22b)

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 15\,\mu m 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

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Unit</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>mb</td>
<td>PA</td>
</tr>
<tr>
<td>Temperature</td>
<td>K</td>
<td>TA</td>
</tr>
<tr>
<td>Humidity</td>
<td>gm/gm</td>
<td>WA</td>
</tr>
<tr>
<td>Surface temperature</td>
<td>K</td>
<td>TS</td>
</tr>
<tr>
<td>Surface pressure</td>
<td>mb</td>
<td>PS</td>
</tr>
<tr>
<td>Input Data</td>
<td>Unit</td>
<td>Code</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Cloud top pressure</td>
<td>mb</td>
<td>CLTOP</td>
</tr>
<tr>
<td>Cloud base pressure</td>
<td>mb</td>
<td>CLBOT</td>
</tr>
<tr>
<td>Fractional cloud amount</td>
<td></td>
<td>CSS</td>
</tr>
<tr>
<td>Number of pressure levels</td>
<td></td>
<td>NDATA</td>
</tr>
<tr>
<td>Number of cloud types</td>
<td></td>
<td>NC</td>
</tr>
<tr>
<td>Latitude</td>
<td>degree</td>
<td>RLAT</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downward flux in the water vapor bands</td>
<td>ergs/(cm² sec)</td>
<td>FLUXHD</td>
</tr>
<tr>
<td>Upward flux in the water vapor bands</td>
<td>ergs/(cm² sec)</td>
<td>FLUXHU</td>
</tr>
<tr>
<td>Downward flux in the 9.6 and 15μm bands</td>
<td>ergs/(cm² sec)</td>
<td>FLUXCD</td>
</tr>
<tr>
<td>Upward flux in the 9.6 and 15μm bands</td>
<td>ergs/(cm² sec)</td>
<td>FLUXCU</td>
</tr>
<tr>
<td>Cooling rate</td>
<td>°C/day</td>
<td>COOLR</td>
</tr>
</tbody>
</table>

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 \( C_p = 1.003 \times 10^7 \text{ ergs/(gm K)} \).
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 Δu = 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/cm² for w and u.

<table>
<thead>
<tr>
<th>Index</th>
<th>Corresponding Parameter</th>
<th>Initial Value</th>
<th>Increment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Band–Center</td>
<td>Band–Wing</td>
</tr>
<tr>
<td>IT</td>
<td>T</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>IW</td>
<td>log w</td>
<td>−6.0</td>
<td>−5.4</td>
</tr>
<tr>
<td>IU</td>
<td>u</td>
<td>−</td>
<td>0</td>
</tr>
</tbody>
</table>
In the 15\,\mu m band, the \text{CO}_2 transmission function, $\tau_{\text{CO}_2}$, 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, $\tau_w$, 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, $\tau_e$, is stored in TAUU. Values of TAUU are given at $\Delta \log u = 0.04$ (DU = 0.04) intervals starting from $\log u = -3.301$ (SU = -3.301).

For the 9.6\,\mu m band, the ozone transmittance, $\tau_{\text{O}_3}$, 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.](image)
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, $\tau_e$, is stored in TWIN as a function of log $u$. It is given at $\Delta \log u = 0.04$ (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

<table>
<thead>
<tr>
<th>Transmittance</th>
<th>Spectral Band</th>
<th>Index</th>
<th>Corresponding Parameter</th>
<th>Initial Value</th>
<th>Increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAUW</td>
<td>15$\mu$m</td>
<td>IW</td>
<td>log $w$</td>
<td>-4.0</td>
<td>0.1</td>
</tr>
<tr>
<td>TAUU</td>
<td>15$\mu$m</td>
<td>IU</td>
<td>log $u$</td>
<td>-3.301</td>
<td>0.04</td>
</tr>
<tr>
<td>TWIN</td>
<td>9.6$\mu$m</td>
<td>IU</td>
<td>log $u$</td>
<td>-3.301</td>
<td>0.04</td>
</tr>
</tbody>
</table>

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 $\Delta p$, 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 225 mb for the band center region and to 550 mb 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 1013 mb. The temperature $T_0$ in Eq. (18) is equal to 296 K.

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 N XB, 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. $G(p, p_r, T(p_t))$ 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 \( \delta \) (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

\[
G(w, u, T) = G(w_j, u_j, T_k) + \frac{\partial G}{\partial \log w} (\log w - \log w_i) + \frac{\partial G}{\partial u} (u - u_j) + \frac{\partial G}{\partial T} (T - T_k)
\]

(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 9.6 μm band (FLUXUW and FLUXDW), the 15 μm band (FLUXUC and FLUXDC), and the total in these two absorption bands (FLUXU and FLUXD).

The Planck fluxes integrated over the 9.6 μm band and the 15 μm 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 15 μm band and BWI for the 9.6 μm band. The corresponding Planck fluxes at the surface are coded as BS and BSS, respectively. The precomputed Planck flux in the 9.6 μm band is stored in BLKWIN and that in the 15 μm band in BLKCO2 at 5 K intervals starting from 190 K.

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 200 mb 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 15 μm band (Y) and the 9.6 μm 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 15 μm 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 $e$ and amount $C$ is radiatively equivalent to a black cloud with amount $eC$. Although the radiative transfer equations used for computing fluxes in the water vapor bands and in the 9.6 and 15 $\mu$m 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,

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

for clear atmospheres or $IS \leq NXT$

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

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

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 $1 - \text{SUMC}$.

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

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

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

\[
\text{FLUXUC}(IP) = BS \times \text{TAUF}(NPT, IP) + \sum_{I=IS+1}^{NPT} \text{BAI}(I) \times [\text{TAUF}(I - 1, IP) - \text{TAUF}(I, IP)]
\]

for a clear atmosphere or \( IS \geq NXB \)

\[
= \text{BAI}(NXT + 1) \times \text{TAUF}(NXT, IP)
\]

\[
+ \sum_{I=IS+1}^{NXT} \text{BAI}(I) \times [\text{TAUF}(I - 1, IP) - \text{TAUF}(I, IP)]
\]

for \( IS < NXT \)

\[
= \text{BAI}(IS + 1) \quad \text{for } IS = NXT \text{ or } NXB < IS < NXT
\]

An intermediate one-dimensional array FLUXC is computed from

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

\( IX = IS + 1, \ldots, NPT \)

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 \( 1 - \text{SUMC} \).

6. ACKNOWLEDGMENT

The authors would like to thank Dr. M. L. C. Wu for her critical review of the manuscript and helpful suggestions.
APPENDIX A

PROGRAM LIST

DIMENSION FLUXHU(15), FLUXHD(15), FLUXCU(15), FLUXCD(15),
DIMENSION FXWAV(15), FX15(15), COOLRU(15), PUU(15),
COMMON/FLUXH/FLUXHU, FLUXHD
COMMON/FLUXC/FLUXCU, FLUXCD
COMMON/AMHN/TA(.55), PA(.55), WAl(.55), CSSU(5), NDATA, RLAT, TS, PS
COMMON/PRESS/PUI
COMMON/INIT/NUP1, NP, NSB, NC, NPT, NW, NT
COMMON/CLOU/CLTOP(10), CLBOT(10)
READ(4, 26) NDATA, RC, PS
26 FORMAT(12, 2X, 12, 2X, F4.2, 2X, F5.1, 2X, F6.1)
READ(4, 21) PM(1), MP(1), I=1, NDATA
21 FORMAT(5F6.1)
READ(4, 22) TR(1), I=1, NDATA
22 FORMAT(SF7.2)
READ(4, 24) WA(1), I=1, NDATA
24 FORMAT(SF7.2)
READ(4, 25) CLTOP(1), CLBOT(1), CSS(1), I=1, 5
25 FORMAT(5F6.1)
PRINT 10
PRINT 12, NDATA, RLAT, TS, PS
12 FORMAT(.13X, I2, 4X, I2, 2X, F4.1, 2X, F5.1, 2X, F6.1)
PRINT 14
14 FORMAT(10X, "PRESSURE LEVELS(MB) OF SAMPLE PROFILE")
PRINT 15, (PA(I), I=1, NDATA)
15 FORMAT(5F6.1)
PRINT 16
16 FORMAT(10X, "TEMPERATURES(K) AT THE ABOVE PRESSURE LEVELS")
PRINT 11, (TA(I), I=1, NDATA)
11 FORMAT(5(I, F8.2, 5X))
PRINT 17
17 FORMAT(10X, "HUMIDITY(GM/GM) AT THE ABOVE PRESSURE LEVELS")
PRINT 13, WA(1), I=1, NDATA
13 FORMAT(5(I, F9.3, 4X))
PRINT 19
19 FORMAT(10X, "CLOUD TOP", 2X, "CLOUD BOTTOM", 2X, "CLOUD PERCENT")
PRINT 18, (CLTOP(1), CLBOT(1), CSS(1), I=1, NC)
18 FORMAT(4X, F4.0, 7X, F4.0, 9X, F4.2)
32 FORMAT(A1, .A1)
CALL INDATA
CALL GAMOTO
PRINT 3
PRINT 4
3 FORMAT(1, X, "PRESSURE", 4X, "FLUXES IN H2O BANDS", 3X, "FLUXES IN 9. 
6 & 15 MICRON BANDS")
PRINT 5
4 FORMAT(1, X, "MB")
PRINT 5
5 FORMAT(1, X, "DOWN", 8X, "UP", 14X, "DOWN", 8X, "UP")
DO 2 IP=1, NP
IPMP=IP-1
F=.C=J.6*24./10030.*.98
DO 69 IP=1, NP
FXWAV(IP)=FLUXHD(IP)-FLUXHU(IP)
2 FORMAT(1, MP(IP), FLUXHD(IP), FLUXHU(IP), FLUXCD(IP), FLUXCU(IP)
1 FORMAT(1, F8.2, 2F12.2, 4X, 2F12.2)
F=G.J.6*24./10030.*.98
DO 69 IP=1, NP
FXWAV(IP)=FLUXHD(IP)-FLUXHU(IP)

A-1
69  FX15C(IP) = FLUXCD(IP) - FLUXCU(IP)
  PRINT 6
6  FORMAT(16X, 'PRESSURE', 10X, 'COOLING RATE',
  PRINT 7
7  FORMAT(16X, '(MBAR)', 7X, '(DEGREE CELCIUS/DAY)')
  PRINT 8
8  FORMAT(12X, 'FROM', 6X, 'TO',
  DO 90 IP = 2, NP
   IPM1 = IP - 1
   IDD = (IPM1*NSB) + 1
   IDE = IDD - NSB
   DP = PUI(IDD) - PUI(IDE)
   X1 = FXWAV(IP) + FX15C(IP)
   X2 = FXWAV(IPM1) + FX15C(IPM1)
   FXNET = X1 - X2
   COOLR(IP) = FXNET*FAC/DP
90  CONTINUE
  DO 92 IP = 2, NP
   IPM1 = IP - 1
   IDD = (IPM1*NSB) + 1
   IDE = IDD - NSB
   PUI(IDE) = PUI(IPM1) + COOLR(IP)
92  PRINT 91, PUI(IDE), PUI(IPM1), COOLR(IP)
91  FORMAT(10X, 2F8.2, 4X, F10.2)
STOP
END
SUBROUTINE INDATA
C*** READ IN DATA
DIMENSION GFH20(25,22,11),TRE(43,15)
DIMENSION TAUW(100),TAUU(100),ITX(50)
DIMENSION TOZON(43,15,3),PUI(43)
DIMENSION ISN(1140),FSN(1140)
COMMON/H20/GFH20
COMMON/PRESS/PUI
COMMON/CO2/TAUW,TAUU,TOZON,TWIN,TRE,ISN
COMMON/INIT/NUP1,NP,NSB,NPT,NW,NT
NUP1=44
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(1316)
DO 40 IT=1,NT
GFH20(IT,IX,IX)=ITX(IT)
40 CONTINUE
30 CONTINUE
READ(5,33);DUMMY
READ(5,32);DUMMY
DO 41 IP=1,NP
DO 41 IX=1,NPT
READ(5,35); (ITX(IT),IT=1,NT)
42 FORMAT(2413)
DO 43 IX=1,NPT
43 TRE(IX,IP)=ITX(IX)/1000.
41 CONTINUE
READ(5,32);DUMMY
READ(5,45);ISN(IX),IX=1,1140)
45 FORMAT(4012)
DO 50 I=1,1140
F=ISN(I)
50 FSN(I)=-1.0+5*F
C*** READ TAUW,TAUU
READ(5,32);DUMMY
READ(5,81); (TAUW(IX),IX=1,65)
READ(5,32);DUMMY
READ(5,81); (TAUW(IX),IX=1,100)
81 FORMAT(10F8.5)
READ(5,32);DUMMY
READ(5,10); (TOZON(IX,IP,IX),IX=1,NPT,IP=1,IP=1,IP=1,IP=1)
10 FORMAT(15F5.3)
READ(5,32);DUMMY
READ(5,10); (TWIN(IX,IX),IX=1,100)
1 FORMAT(20F4.2)
RETURN
END
SUBROUTINE GAMETO
DIMENSION RR(2,3),PRE(2),
DIMENSION NXT(10),NXB(10),CS(10)
DIMENSION PUU,PUU(43),TUI(43),PAI(43),RAWI(43),DPI(43),TAI(43)
COMMON/CLOUD/CS,NXB,NXT
COMMON/TEMP/TSS
COMMON/PRESS/PUI
COMMON/AGIOS/TUI,PAI,TAI,RAWI,UBAR(43),WBAR(2,43)
COMMON/AMHN/TAO5,PAI55,WA(55),CSS(10),NDATA,RLAT,TS,PS
DATA PRE/275.,550./
DATA RR/1.216414,4.62111,-0.517625E-2,-0.4321E-1,0.1875E-4,
$.11344E-3/
TSS=TS
DP=PUI-40,1)/3.
DO 10 IX=41,43
10 PUI(IX)=PUI(IX-1)+DP
DO 10 IX2=2,NPT
DPI(IX)=-PUI(IX)/PUI(IX-1)*1.02
PAI(IX)=-PAI(IX)+PUI(IX-1)
1010 CONTINUE
C
C****** TEMPERATURE AND HUMIDITY INTERPOLATIONS *************
C
NCK=2
DO 1030 IX=2,NPT
1040 IF( PAI(IX).LT. PAI(NCK)) GO TO 1042
IF( NCK .EQ. NDATA) GO TO 1042
NCK=NCK+1
GO TO 1040
1042 CONTINUE
XX=ALOG(WA(IX)/WANCK-1)
X1=ALOG(PAIR(IX)/PAI(NCK-1))
X2=ALOG(PUI(IX)/PUI(NCK-1))
X3=ALOG(WA(NCK)/WA(NCK-1))
X4=ALOG(PAI(NCK)/PAI(NCK-1))
RAWI(IX)=EXPVXX+X1*X3/X4
IF (RAWI(IX) .LT. 0.0, RAWI(IX)=0.0
TAI(IX)=TAI(NCK-1)+X1*X2*TAI(NCK)-TAI(NCK-1))
TUI(IX)=TAI(NCK-1)+X2*X4*TAI(NCK)-TAI(NCK-1))
RAWI(IX)=RAWI(IX)*DPI(IX)
1030 CONTINUE
C
C********** COMPUTE SCALED WATER VAPOR AMOUNTS ***************
C
UBAR=U.
WBAR(1,1)=0.0
WBAR(2,1)=0.0
DO 14 IX=2,NPT
DO 12 KB=1,2
S2=RR(KB,1)+RR(KB,2)*TAI(IX)+RR(KB,3)*TAI(IX)
12 WBAR(KB,IX)=WBAR(KB,IX-1)+RAWI(IX)*S2*PAI(IX)/PRE(KB)
XX=PAI(IX)/630.*RAWI(IX)/DPI(IX)
XX=XX*EXP(1.0/TAI(IX)-6.0811)
14 UBAR(IX)=UBAR(IX-1)+XX

A-4
C********** COMPUTE INDEX LEVELS FOR CLOUDS **************

C
DO 20 IC=1,NC
20 CS(IC)=CSS(IC)
DO 3 IC=1,NC
DO 2 IX=16,42
IF(PUI(IX).LE.CLTOP(IC).AND.PUI(IX+1).GE.CLTOP(IC))GOTO 4
5 IF(PUI(IX).LE.CLBOT(IC).AND.PUI(IX+1).GE.CLBOHCI,IC)GOTO 6
GOTO 2
4 UT=CLTOP(IC)-PUI(IX)
UB=PUI(IX+1)-CLTOP(IC)
IF(UT.LT.UB)GOTO 7
NXT(IC)=IX+1
GOTO 5
7 NXT(IC)=IX
GOTO 5
6 UT=CLBOT(IC)-PUI(IX)
UB=PUI(IX+1)-CLBOHCI,IC)
IF(UT.LT.UB)GOTO 8
NXB(IC)=IX+1
GOTO 2
8 NXB(IC)=IX
2 CONTINUE
3 CONTINUE
CALL IRH20
CALL RCO203(RLAT)
RETURN
END
SUBROUTINE IRH20
DIMENSION IH(43),DH(43),SW(2)
DIMENSION GFH20(25,22,11),DELTA(25)
DIMENSION SGH20,SH(15),SHS(15),SH(15),SHS(15),SH(15)
DIMENSION RAWI(3),TAI(43),PAI(43),TUL(43)
COMMON/AGIOS/TUL,PAI,TAI,RAWI,UBAR(43),WBAR(2,43)
COMMON/H20/GFH20
COMMON/TEMP/TS
COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT
COMMON/FU IV/SH,SG,SH,SHS,FLUXUS
DATA TEMPI/190./,SW/-6.,-5.4/
DATA DW/0.3/, DU/0.006/, DT/5./
$432.,451.,471.,492./
NU=NUP1-1
*** COMPUTE SHS, SHT, SG
FLUXUS=0.
DO 43 IP=1,NP
SH(IP)=0.
SH(IP)=0.
SHT(IP)=0.
DO 44 IX=1,NPT
SG(IX,IP)=0.
44 CONTINUE
43 CONTINUE
FH=(TS-TEMPI)/DT+1.501
IG=FH
IF (IG .GE. NT) IG=NT-1
IF (IG .LT. 1), IG=1
DS=TS-(TEMP1+FLOAT(IG-1)*DT)
NZ=1
DO 41 KB=1,2
X=GFH20(IG,1,NZ)+GFH20(IG+1,1,NZ)-GFH20(IG,1,NZ)/DT*DS
FLUXUS=FLUXUS+X
NZ=NUP1
41 CONTINUE
FLUXUS=FLUXUS+DELTA(IG)
DO 47 IX=1,NPT
FH=(TUL(IX)-TEMPI)/DT+1.5
IH(IX)=FH
IF (IH(IX) .LT. 1), IH(IX)=1
IF (IH(IX) .GE. NT), IH(IX)=NT-1
FH=IH(IX)-1
DH(IX,TUL(IX))=(TEMP1+FH)*DT
47 CONTINUE
DO 42 IP=1,NP
IS=(IP-1)*NSB+1
DO 40 IX=1,NPT
IF (IX.EQ.IX) GOTO 40
IF (IX .LT. IS), IC=IX+1
IF (IX .GT. IS), IC=IX-1
DY=ABS(UBAR(IS))-.5*(UBAR(IC)+UBAR(IX))
KD=DY/DU+1.5
IF (KD .GE. NU) KD=NU-1
FY=DY-FLOAT(KD-1)*DU
A-6
C*** KB=1, FOR BAND CENTER REGION, KB=2, FOR BAND WING REGION

DO 45 KB=1,2
DX=ABS(WBAR(KB,1S)-0.5*WBAR(KB,1C)+WBAR(KB,1X))
IF(DX .GT. 30.) GO TO 40
IF(DX .LT. 1.E-6, DX=1.E-6
DX=ALOG10(DX)
KW=SW(KB); DX=SW(KB)
IF(KW .GE. NW) KW=NW-1
FW=SW(KB)+FUAT(KW-1, *DW)
NZ=NUP1
IF(KB .EQ. 2) NZ=KW
IK=IX
DO 50 I=1,2
IF (I .EQ. 2) IK=1C
IT=IH(IK)
DH1=DH(IK)
DGD1=(GF20(I+1, KW,NZ)-GF20(1T, KW,NZ)) / DT
TDEL=DGD1*DH1
WDEL=(GF20(I+1, KW,NZ)-GF20(I, KW,NZ)) / DW*FW
IF(KB.EQ.2)WDEL=GF20(I, KW,NZ+1)-GF20(I, KW,NZ); /
*DU*FU
X=GF20(I, KW,NZ)+TDEL+WDEL
IF(1K.EQ.1) SHT(IP)=SHT(IP)+X
IF (I .EQ. NPT) SHS(IP)=SHS(IP)+DGD1*(TS-TUI(NPT))
IF (I .EQ. 2) X=X
SG(IK,IP)=SG(IK,IP)+X
50 CONTINUE
45 CONTINUE
40 CONTINUE

C
C********** COMPUTE SH(IP)
C
IT=IH(IK)
NZ=1
DO 46 KB=1,2
X=GF20(I, 1T, 1, NZ)+GF20(I+1, 1, NZ)-GF20(1T, 1, NZ) / DT*DH(IK)
SH(IP)=SH(IP)+X
NZ=NUP1
46 CONTINUE
SH(IP)=SH(IP)+DELTA(IT)
42 CONTINUE
CALL FDIVER
RETURN
END
SUBROUTINE FDIVER
DIMENSION FLUXU(15),FLUXD(15),FLUXU(43)
DIMENSION SHT(15),SHS(15),SH(15),SG(43,15)
DIMENSION CS(10),NXB(10),NXT(10),
COMMON/CLOUD/CS,NXB,NXT
COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT
COMMON/FDIV/SH,SG,SHT,SHS,FLUXU
COMMON/FLUXH/FLUXU,FLUXD
NPM1=NP-1
DO 100 I=1,NP
FLUXU(I)=0.
FLUXD(I)=0.
100 CONTINUE
C*** COMPUTE DOWNWARD FLUXES
DO 185 IP=2,NP
IS=(IP-1)*NSB+1
ISM1=IS-1
SUM=0.
DO 190 LP=1,ISM1
IX=IS-LP
SUM=SUM+SGU(IP,IX)
FLUXU(IP)=SUM
190 CONTINUE
FLUXU(IP)=FLUXU(IP)-SHT(IP)+SH(IP)
IF(NC.NE.0)GOTO 75
FLUXU(IP)=FLUXU(IP)
GOTO 185
75 CONTINUE
SUMC=0.
DO 60 IC=1,NC
NCBX=NXB(IC)
IF(IS.LE.NXT(IC))GOTO 60
IF(IS.LE.NCBX)GOTO 62
FLUXD(IP)=FLUXD(IP)+(FLUXU(IP)+SH(IP))*CS(IC)
GOTO 63
62 CONTINUE
FLUXD(IP)=FLUXD(IP)+SH(IP)*CS(IC)
63 SUMC=SUMC+CS(IC)
60 CONTINUE
FLUXD(IP)=FLUXD(IP)+FLUXU(IP)*(1.-SUMC)
185 CONTINUE
C*** COMPUTE UPWARD FLUXES
DO 200 IP=1,NPM1
ISP1=IS+1
SUM=0.
DO 205 IX=ISP1,NPT
SUM=SUM+SGU(IX,IP)
FLUXU(IX)=SUM
205 CONTINUE
FLUXU(NPT)=FLUXU(NPT)+SHS(IP)+SH(IP)
IF(NC.NE.0)GOTO 76
FLUXU(IP)=FLUXU(NPT)
GOTO 200
76 CONTINUE
SUMC=0.
DO 70 IC=1,NC
NCTX=NXT(IC)
IF(IS.GE.NXB(IC))GOTO 70
IF(IS.GE.NCTA,GOTO 72
FLUXU(IP)=FLUXU(IP)+FLUX(NCTX)+SH(IP)*CS(IC)
GOTO 73
72 CONTINUE
FLUXU(IP)=FLUXU(IP)+SH(IP)*CS(IC)
73 SUMC=SUMC+CS(IC)
70 CONTINUE
FLUXU(IP)=FLUXU(IP)+FLUX(NPT)*CSU(1-SUMC)
200 CONTINUE
FLUXU(NP)=FLUXU
RETURN
END
SUBROUTINE RC0203(LRLAT)
DIMENSION PAU43;,TAIl43,,RAWIl43>)
DIMENSION TUU43J.TOZON 143,15,31
DIMENSION TAUUUOO>,TWINUOO>,TAUW165j
DIMENSION BWU44;,BLKWINl25>,BLKC02t25>
DIMENSION TRE(.43,15/,TAUF(43,15>,TXUFi43,15>)
DIMENSION FLUXDU5.l,FLUXUU5.»,FLUXC<.43>,FLUXWl43>
DIMENSION FLUXDCU5>,FLUXDWl.l5;,FLUXUCU5),FUJXUWU5y
DIMENSION CSUO>,NXBUO>,NXTUOj
DIMENSION TRU9>,DTAIU9j,DTFU9,19>,FSNU140) COMMON/TEMP/TS
COMMON/FLUXC/FLUXU.FLUXD
COMMON/CLOUD/CS.NXB.NXT
COMMON/AGIOS/TUI,PAI,TAU,RAWI,UBARl43;,WBAKU43>
COMMON/C02/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,
$229.81,227.06,225.19,223.38,221.6,219.8,218.05,216.49,216.65/
DATA BLKC02/12825., 14598., 16512., 18568., 20768., 23113.,
1 25603., 28237., 31015., 3450., 4102., 4838., 5664., 6585.,
 2 7606., 8733., 9969., 11320., 12788., 14380., 16097.,
 3 17944., 19923., 22038., 24292., 26685., 29221., 31902.,
 $34729., 37703., 40825./
DATA SW/-4./,DW/0.1/,NK/65/,SU/-3.301/,DU/.04/ DATA TEMPI/190./.DT/5.0/
LOGICAL LINEXP/.TRUE./
NPTP1=NPT+1 LAT=IFIXlRLAT/30.+1./
LAT=IFIX(lRLAT/30.+1.,)
TAI(NPTPl)=TS
DO 15 IP=1,NPTPl DX=TAI(IP)-TEMP1
do 15 IT=DX/DT+1.5
IT=DX/DT+1.5 IP(IT .LT. 2) IT=2
IF(IT .GT. NT) IT=NT
ITM1=IT-1
X=TEMP1+DT*FLOATUTM1;
DS=TAIUP;-.X
BAI(IP)=BLKC02(IT)+BLKC02(1T)+BLKC02(1T)+BLKC02(ITM1)/.DS/DT
BI(IP)=BLKWIN(IT)+BLKWIN(IT)+BLKWIN(ITM1)/.DS/DT
15 CONTINUE
BS=BAI(NPTPl)
BSS=BI(NPTPl)
C
** COMPUTE TRANSMITTANCES IN THE 15 MICRON(LAUF; AND
** 9.6 MICRON (TXUF; BANDS.
C
DO 25 IP=1,LP DO 25 LP=1,LP 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
DTA1(LP)=TA1(LP)-TR(LP)
LL=0
DO 20 LP=1,NSM1 LP1=LP+1
DO 20 IX=LP1,NSTRA SUM=0.
S1M=0.
11=1-IX- LP
A-10
DO 22 L=1,IY
   LL=LL+1
   SUM=SUM+FSN(aL)*DTAI(LP*L)
22 CONTINUE
   DTF(LP,IX)=SUM
   DTF(LP,IX)=SUM
20 CONTINUE
   DO 23 IP=1,7
      IX=(IP-1)*NSB+1
   DO 24 LP=1,NSTRA
      TAUFL(IP,LP)=TAUFL(IP,LP)+DTF(LP,IX)
23 CONTINUE
   DO 28 IP=1,NP
      IS=IP-1)*NSB+1
      DO 29 IX=IP,NPT
      IF(IS.EQ. IX) GO TO 32
      DX=ABS(WBAR(2,IX)-WBAR(IP))
      IF(DX.LT.1.E-7) DX=1.E-7
      IF(DX.LT.40.) GO TO 35
      X=0.
      YY=0.
      GO TO 40
32 CONTINUE
   DX=ALOG10(DX)
   IF(DX.LT.30) GO TO 34
   KW=(DX-SW)/DW+1.5
   IF(KW.GT.100) KW=100
   Y=TAUW(KW)
   YY=TWIN(KW)
   GO TO 40
34 X=1.
36 CONTINUE
   DX=ABS(WBAR(IS)-WBAR(IP))
   IF(DX.LT.1.E-7) GO TO 38
   DX=ALOG10(DX)
   IF(DX.LT.30) GO TO 36
   KW=(DX-SW)/DW+1.5
   IF(KW.GT.100) KW=100
   Y=TAUW(KW)
   YY=TWIN(KW)
   GO TO 40
38 CONTINUE
   Y=1.
   YY=1.
40 CONTINUE
   TAUFL(IP,IP)=TAUFL(IP,IP)*X*Y
   TXUF(IP,IP)=TXUF(IP,IP)*YY
32 CONTINUE
28 CONTINUE
*** COMPUTE DOWNWARD FLUXES
   FLUXC(IP)=0.
   FLUXD(IP)=0.
   DO 70 IP=2,NP
      FLUXC(IP)=0.
      FLUXD(IP)=0.
   TA=1.
   TATY=1.
   IS=(IP-1)*NSB+1
   ISM=IS-1
   XC=0.
   XW=0.
70 CONTINUE
DO 75 LP=1,ISM1
   IX=IS-LP
   XC=XC+BAI(I)+TAY+TAUF(I,LP)
   XM=XM+BW1(I)+TAYY+TXUF(I,LP)
   FLUXC(I)=XC
   FLUXM(I)=XM
   TAY=TAUF(I,LP)
   TA=TAY+TXUF(I,LP)
75 CONTINUE
   IF(NC.NE.0)GOTO 69
   FLUXDC(IP)=FLUXC(IP)
   FLUXDM(IP)=FLUXM(IP)
   GOTO 70
69 CONTINUE
   SUMC=0.
   DO 60 IC=1,NC
      NCBX=NXTB(IP)
      IF(NC.GE.NCBX)GOTO 60
      IF(IS.LE.NCBX)GOTO 66
      FLUXDC(IP)=FLUXDC(IP)+BAI(IP)*CSUC
      FLUXDM(IP)=FLUXDM(IP)+BW1(IP)*CSUC
      GOTO 63
66 CONTINUE
   FLUXDC(IP)=FLUXDC(IP)+BAI(IP)*CSUC
   FLUXDM(IP)=FLUXDM(IP)+BW1(IP)*CSUC
   SUMC=0.
   DO 64 IC=1,NC
      NCBX=NXTB(IP)
      IF(IS.LE.NCBX)GOTO 64
      IF(IS.GE.NCBX)GOTO 66
      NCTX=NXTB(IP)
      IF(IS.LE.NCTX)GOTO 64
      IF(IS.GE.NCTX)GOTO 66
   DO 84 IX=1,NPT
      XC=XC+BAI(I)*TAY+TAUF(I,LP)
      XM=XM+BW1(I)*TAYY+TXUF(I,LP)
      FLUXC(I)=XC
      FLUXM(I)=XM
      TAY=TAUF(I,LP)
      TA=TAY+TXUF(I,LP)
84 CONTINUE
   FLUXC(NPT)=FLUXC(NPT)+BS*TAY
   FLUXM(NPT)=FLUXM(NPT)+BS*TAYY
   IF(NC.NE.0)GOTO 68
   FLUXDC(IP)=FLUXC(IP)
   FLUXDM(IP)=FLUXM(IP)
   GOTO 80
68 CONTINUE
   SUMC=0.
   DO 64 IC=1,NC
      NCBX=NXTB(IP)
      IF(IS.LE.NCBX)GOTO 64
      IF(IS.GE.NCBX)GOTO 66
   GOTO 66
C*** COMPUTE UPWARD FLUXES
NP1=NP-1
   DO 80 IP=1,NP1
      FLUXDC(IP)=0.
      FLUXDM(IP)=0.
   TAY=1.
   TA=TAY+TXUF(I,LP)
80 CONTINUE
FLUXUC(IP) = FLUXUC(IP) + (FLUXC(NCTX) + BAI(NCTX+1) * TAUF(NCTX, IP)) * CS(IC)
GOTO 67
66 CONTINUE
FLUXUC(IP) = FLUXUC(IP) + BAI(1S+1) * CS(IC)
64 CONTINUE
SUMC = SUMC + CS(IC)
67 SUMC = SUMC + CS(IC)
67 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
********** TOTAL FLUXES IN THE 9.6 AND 15 MICRON BANDS **********
C
DO 97 IP=1, NP
FLUXU(IP) = FLUXUC(IP) + FLUXUW(IP)
FLUXW(IP) = FLUXDC(IP) + FLUXDW(IP)
97 CONTINUE
RETURN
END
## APPENDIX B

### ARRAY AND VARIABLE LIST

1. **Main Program**

<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>Input pressure level</td>
<td>mb</td>
</tr>
<tr>
<td>TA</td>
<td>Input temperature</td>
<td>K</td>
</tr>
<tr>
<td>WA</td>
<td>Input specific humidity</td>
<td>gm/gm</td>
</tr>
<tr>
<td>CLTOP</td>
<td>Cloud top pressure</td>
<td>mb</td>
</tr>
<tr>
<td>CLBOT</td>
<td>Cloud base pressure</td>
<td>mb</td>
</tr>
<tr>
<td>CSS</td>
<td>Fractional cloud amount</td>
<td></td>
</tr>
<tr>
<td>NDATA</td>
<td>Number of input data in PA, TA, WA</td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>Number of cloud types</td>
<td></td>
</tr>
<tr>
<td>RLAT</td>
<td>Latitude</td>
<td>degree</td>
</tr>
<tr>
<td>PS</td>
<td>Surface pressure</td>
<td>mb</td>
</tr>
<tr>
<td>TS</td>
<td>Surface temperature</td>
<td>K</td>
</tr>
<tr>
<td>PUI</td>
<td>Pressure sublevel</td>
<td>mb</td>
</tr>
<tr>
<td>FLUXHD</td>
<td>Downward flux in the H$_2$O bands</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>FLUXHU</td>
<td>Upward flux in the H$_2$O bands</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>FLUXCD</td>
<td>Downward flux in the 9.6 and 15$\mu$m bands</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>FLUXCU</td>
<td>Upward flux in the 9.6 and 15$\mu$m bands</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>FXWAV</td>
<td>Net flux in the H$_2$O bands</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>FX15C</td>
<td>Net flux in the 9.6 and 15$\mu$m bands</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>FAC</td>
<td>Conversion factor for cooling rate</td>
<td></td>
</tr>
<tr>
<td>COOLR</td>
<td>Cooling rate</td>
<td>°C/day</td>
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</table>
2. Subroutine INDATA

<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning</th>
<th>Unit</th>
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<td>PUI</td>
<td>See main program</td>
<td></td>
</tr>
<tr>
<td>GFH2O</td>
<td>G-function</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>TRE</td>
<td>CO₂ transmission function</td>
<td></td>
</tr>
<tr>
<td>FSN</td>
<td>Coefficients for correcting CO₂ transmittance</td>
<td>K⁻¹</td>
</tr>
<tr>
<td>TAUW</td>
<td>Transmittance in the 15μm band due to H₂O line absorption</td>
<td></td>
</tr>
<tr>
<td>TAUU</td>
<td>Transmittance in the 15μm band due to H₂O e-type absorption</td>
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</tr>
<tr>
<td>TOZON</td>
<td>Ozone transmission function</td>
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<tr>
<td>TWIN</td>
<td>Transmittance in the 9.6μm band due to e-type absorption</td>
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<tr>
<td>NP</td>
<td>Number of flux levels</td>
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<tr>
<td>NPT</td>
<td>Total number of sublevels</td>
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<tr>
<td>NSB</td>
<td>Number of sublayers between neighboring flux levels</td>
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<tr>
<td>NT</td>
<td>Number of temperature values in GFH2O</td>
<td></td>
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<tr>
<td>NW</td>
<td>Number of log w values in GFH2O</td>
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</tr>
<tr>
<td>NUP1</td>
<td>Number of u values in GHF2O</td>
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</tbody>
</table>
3. Subroutine GAMOTO

<table>
<thead>
<tr>
<th>Code</th>
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<th>Unit</th>
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<tr>
<td>PA</td>
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<td></td>
</tr>
<tr>
<td>TA</td>
<td>See main program</td>
<td></td>
</tr>
<tr>
<td>WA</td>
<td>See main program</td>
<td></td>
</tr>
<tr>
<td>PUI</td>
<td>See main program</td>
<td></td>
</tr>
<tr>
<td>PAI</td>
<td>Pressure at the middle of sublayers</td>
<td>mb</td>
</tr>
<tr>
<td>DPI</td>
<td>Air mass in a sublayer</td>
<td>gm/cm²</td>
</tr>
<tr>
<td>TUI</td>
<td>Temperature at sublevels</td>
<td>K</td>
</tr>
<tr>
<td>TAI</td>
<td>Temperature at the middle of sublayers</td>
<td>K</td>
</tr>
<tr>
<td>RAWI</td>
<td>Specific humidity in a sublayer (01800)</td>
<td>gm/gm</td>
</tr>
<tr>
<td>RAWI</td>
<td>Water vapor content in a sublayer (01840)</td>
<td>gm/cm²</td>
</tr>
<tr>
<td>TS, TSS</td>
<td>Surface temperature</td>
<td>K</td>
</tr>
<tr>
<td>WBAR</td>
<td>Scaled water vapor amount for line absorption</td>
<td>gm/cm²</td>
</tr>
<tr>
<td>UBAR</td>
<td>Scaled water vapor amount for e-type absorption</td>
<td>gm/cm²</td>
</tr>
<tr>
<td>PRE</td>
<td>Reference pressure</td>
<td>mb</td>
</tr>
<tr>
<td>RR</td>
<td>Coefficients for computing R</td>
<td></td>
</tr>
<tr>
<td>CS, CSS</td>
<td>Fractional cloud cover</td>
<td></td>
</tr>
<tr>
<td>NXT</td>
<td>Index for cloud top pressure</td>
<td></td>
</tr>
<tr>
<td>NXB</td>
<td>Index for cloud base pressure</td>
<td></td>
</tr>
<tr>
<td>CLTOP</td>
<td>See main program</td>
<td></td>
</tr>
<tr>
<td>CLBOT</td>
<td>See main program</td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>See main program</td>
<td></td>
</tr>
</tbody>
</table>
### 4. Subroutine 1RH2O

<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMP1</td>
<td>Initial temperature value for array GFH2O</td>
<td>K</td>
</tr>
<tr>
<td>SW</td>
<td>Initial value of log w for array GFH2O</td>
<td>K</td>
</tr>
<tr>
<td>DT</td>
<td>Increment in temperature values in GFH2O</td>
<td>K</td>
</tr>
<tr>
<td>DW</td>
<td>Increment in log w in GFH2O</td>
<td>gm/cm²</td>
</tr>
<tr>
<td>DU</td>
<td>Increment in u in GFH2O</td>
<td>gm/cm²</td>
</tr>
<tr>
<td>IH</td>
<td>Temperature index for GFH2O</td>
<td>K</td>
</tr>
<tr>
<td>KW</td>
<td>Index of log w for GFH2O</td>
<td>K</td>
</tr>
<tr>
<td>KU</td>
<td>Index of u for GFH2O</td>
<td>K</td>
</tr>
<tr>
<td>DH</td>
<td>Difference between the sublevel temperature and the temperature at the nearest index value.</td>
<td>K</td>
</tr>
<tr>
<td>FW</td>
<td>Difference between the value of log w and that at the nearest index value.</td>
<td>K</td>
</tr>
<tr>
<td>FU</td>
<td>Difference between the value of u and that at the nearest index value.</td>
<td>gm/cm²</td>
</tr>
<tr>
<td>SH</td>
<td>Planck flux at sublevels</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>FLUXUS</td>
<td>Upward flux at the surface</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>SHT</td>
<td>G(p, p₁, T₁)</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>SHS</td>
<td>G(p, p₂, T₂) - G(p, p₃, T(p₃))</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>SG</td>
<td>(⧿G/⧿T) ΔT</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>GFH2O</td>
<td>See subroutine INDATA</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>DELTA</td>
<td>Correction term for Planck fluxes</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>DGDT</td>
<td>⧿G/⧿T</td>
<td>ergs/(cm² sec K)</td>
</tr>
<tr>
<td>TDEL</td>
<td>(⧿G/⧿T) ΔT</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>WDEL</td>
<td>(⧿G/⧿ log w) Δ log w, (⧿G/⧿u) Δu</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>NUP1</td>
<td>See subroutine INDATA</td>
<td>ergs/(cm² sec)</td>
</tr>
<tr>
<td>NP</td>
<td>See subroutine INDATA</td>
<td>ergs/(cm² sec)</td>
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</table>
4. Subroutine IRH2O (Continued)

<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning</th>
<th>Unit</th>
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<tr>
<td>NPT</td>
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<td></td>
</tr>
<tr>
<td>NSB</td>
<td>See subroutine INDATA</td>
<td></td>
</tr>
<tr>
<td>NW</td>
<td>See subroutine INDATA</td>
<td></td>
</tr>
<tr>
<td>NT</td>
<td>See subroutine INDATA</td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>See main program</td>
<td></td>
</tr>
<tr>
<td>TUI</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>WBAR</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>UBAR</td>
<td>See subroutine GAMOTO</td>
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</tr>
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5. Subroutine FDIVER

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<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLUX</td>
<td>$\Sigma$ SG</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>FLUXU</td>
<td>Upward flux in the water vapor bands</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>FLUXD</td>
<td>Downward flux in the water vapor bands</td>
<td>ergs/(cm$^2$ sec)</td>
</tr>
<tr>
<td>SUMC</td>
<td>Total cloud cover</td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>See subroutine INDATA</td>
<td></td>
</tr>
<tr>
<td>NPT</td>
<td>See subroutine INDATA</td>
<td></td>
</tr>
<tr>
<td>NSB</td>
<td>See subroutine INDATA</td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>See main program</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>NXT</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>NXB</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>SH</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>SHS</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>SHT</td>
<td>See subroutine GAMOTO</td>
<td></td>
</tr>
<tr>
<td>FLUXUS</td>
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### 6. Subroutine RCO2O3

<table>
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<th>Meaning</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMPI</td>
<td>Initial temperature value for arrays BLKCO2 and BLKWIN</td>
<td>K</td>
</tr>
<tr>
<td>SW</td>
<td>Initial value of log w for TAUW</td>
<td>K</td>
</tr>
<tr>
<td>SU</td>
<td>Initial value of log u for TAUU and TWIN</td>
<td>degree</td>
</tr>
<tr>
<td>DT</td>
<td>Increment in temperature values in BLKCO2 and BLKWIN</td>
<td>K</td>
</tr>
<tr>
<td>DW</td>
<td>Increment in log w in TAUW</td>
<td>degree</td>
</tr>
<tr>
<td>DU</td>
<td>Increment in log u in TAUU and TWIN</td>
<td>degree</td>
</tr>
<tr>
<td>NT</td>
<td>Number of temperature values in BLKCO2 and BLKWIN</td>
<td>degree</td>
</tr>
<tr>
<td>NK</td>
<td>Number of log w values in TAUW</td>
<td>degree</td>
</tr>
<tr>
<td>LINEXP</td>
<td>Flag for correcting CO\textsubscript{2} transmittance due to temperature variations</td>
<td>degree</td>
</tr>
<tr>
<td>RLAT</td>
<td>Latitude</td>
<td>degree</td>
</tr>
<tr>
<td>LAT</td>
<td>Index for latitude</td>
<td>degree</td>
</tr>
<tr>
<td>TAI</td>
<td>See subroutine GAMOTO</td>
<td>degree</td>
</tr>
<tr>
<td>TR</td>
<td>U.S. Standard Temperature profile</td>
<td>K</td>
</tr>
<tr>
<td>DTAI</td>
<td>Temperature deviation from TR</td>
<td>K</td>
</tr>
<tr>
<td>WBAR</td>
<td>See subroutine GAMOTO</td>
<td>degree</td>
</tr>
<tr>
<td>UBAR</td>
<td>See subroutine GAMOTO</td>
<td>degree</td>
</tr>
<tr>
<td>BLKCO2</td>
<td>Precomputed Planck flux in the 15\textmu m band</td>
<td>ergs/(cm\textsuperscript{2} sec)</td>
</tr>
<tr>
<td>BLKWIN</td>
<td>Precomputed Planck flux in the 9.6\textmu m band</td>
<td>ergs/(cm\textsuperscript{2} sec)</td>
</tr>
<tr>
<td>BAI</td>
<td>Planck flux in the middle of sublayers in the 15\textmu m band</td>
<td>ergs/(cm\textsuperscript{2} sec)</td>
</tr>
<tr>
<td>BWI</td>
<td>Planck flux in the middle of sublayers in the 9.6\textmu m band</td>
<td>ergs/(cm\textsuperscript{2} sec)</td>
</tr>
<tr>
<td>BS</td>
<td>Upward flux at the surface in the 15\textmu m band</td>
<td>ergs/(cm\textsuperscript{2} sec)</td>
</tr>
<tr>
<td>BSS</td>
<td>Upward flux at the surface in the 9.6\textmu m band</td>
<td>ergs/(cm\textsuperscript{2} sec)</td>
</tr>
<tr>
<td>FSN</td>
<td>See subroutine INDATA</td>
<td>degree</td>
</tr>
<tr>
<td>TOZON</td>
<td>See subroutine INDATA</td>
<td>degree</td>
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</table>
6. Subroutine RCO2O3 (Continued)

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

### SAMPLE OUTPUT

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

<table>
<thead>
<tr>
<th>DATA</th>
<th>NC</th>
<th>RLAT</th>
<th>TS</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0</td>
<td>15.0</td>
<td>270.0</td>
<td>1013.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRESSURE LEVELS (MB) OF SAMPLE PROFILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEMPERATURES (K) AT THE ABOVE PRESSURE LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>240.64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HUMIDITY (G/M^2) AT THE ABOVE PRESSURE LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.125E-05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CLOUD TOP</th>
<th>CLOUD BOTTOM</th>
<th>CLOUD FRACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>210.00</td>
<td>300.00</td>
<td>0.18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRESSURE (MB)</th>
<th>FLUXES IN 4.2 MICRON BANDS</th>
<th>FLUXES IN 9, 6 &amp; 15 MICRON BANDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRESSURE (MB)</th>
<th>COOLING RATE (DEGREES CELSIUS/DAY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
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</tbody>
</table>

C-1
2. Cloudy Mid-Latitude Winter Atmosphere (NC = 5)

<table>
<thead>
<tr>
<th>DATA</th>
<th>NC</th>
<th>RLAT</th>
<th>TS</th>
<th>PS</th>
<th>40</th>
<th>5</th>
<th>15.0</th>
<th>270.0</th>
<th>1u13.0</th>
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</table>

### PRESSURE LEVELS (MB) OF SAMPLE PROFILE

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>0.2</th>
<th>0.3</th>
<th>0.5</th>
<th>0.7</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>0.574E-03</td>
<td>0.195E-04</td>
<td>0.053E-05</td>
<td>0.186E-04</td>
<td>0.155E-04</td>
</tr>
<tr>
<td>2.5</td>
<td>9.00</td>
<td>8.00</td>
<td>6.00</td>
<td>4.00</td>
<td>2.00</td>
</tr>
<tr>
<td>3.0</td>
<td>1.13</td>
<td>1.00</td>
<td>0.80</td>
<td>0.60</td>
<td>0.40</td>
</tr>
<tr>
<td>3.5</td>
<td>1.25</td>
<td>1.20</td>
<td>1.15</td>
<td>1.10</td>
<td>1.00</td>
</tr>
<tr>
<td>4.0</td>
<td>1.37</td>
<td>1.30</td>
<td>1.25</td>
<td>1.20</td>
<td>1.15</td>
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</table>

### TEMPERATURES (K) AT THE ABOVE PRESSURE LEVELS

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>246.64</th>
<th>252.60</th>
<th>258.73</th>
<th>264.03</th>
<th>263.21</th>
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<tbody>
<tr>
<td>224.70</td>
<td>253.47</td>
<td>259.23</td>
<td>263.82</td>
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<tr>
<td>221.33</td>
<td>215.93</td>
<td>215.42</td>
<td>215.20</td>
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<tr>
<td>221.43</td>
<td>217.05</td>
<td>217.69</td>
<td>218.3</td>
<td>218.69</td>
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<tr>
<td>219.27</td>
<td>222.39</td>
<td>229.03</td>
<td>234.55</td>
<td>242.40</td>
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<tr>
<td>231.24</td>
<td>258.73</td>
<td>264.69</td>
<td>268.32</td>
<td>270.37</td>
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### HUMIDITY (G./CM.) AT THE ABOVE PRESSURE LEVELS

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>0.285E-05</th>
<th>0.439E-05</th>
<th>0.548E-05</th>
<th>0.663E-05</th>
<th>0.820E-05</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.118E-04</td>
<td>0.118E-04</td>
<td>0.123E-04</td>
<td>0.129E-04</td>
<td>0.135E-04</td>
<td>0.143E-04</td>
</tr>
<tr>
<td>0.155E-04</td>
<td>0.169E-04</td>
<td>0.185E-04</td>
<td>0.202E-04</td>
<td>0.193E-04</td>
<td></td>
</tr>
<tr>
<td>0.186E-04</td>
<td>0.188E-04</td>
<td>0.173E-04</td>
<td>0.138E-04</td>
<td>0.105E-04</td>
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</tr>
<tr>
<td>0.233E-05</td>
<td>0.700E-05</td>
<td>0.512E-05</td>
<td>0.468E-05</td>
<td>0.415E-05</td>
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</tr>
<tr>
<td>0.400E-05</td>
<td>0.600E-05</td>
<td>0.653E-05</td>
<td>0.763E-05</td>
<td>0.193E-04</td>
<td></td>
</tr>
<tr>
<td>0.195E-04</td>
<td>0.244E-04</td>
<td>0.500E-04</td>
<td>0.100E-03</td>
<td>0.272E-03</td>
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</tr>
<tr>
<td>0.574E-03</td>
<td>0.102E-02</td>
<td>0.168E-02</td>
<td>0.21Ue-02</td>
<td>0.242E-02</td>
<td></td>
</tr>
</tbody>
</table>

### CLOUD TOP CLOUD BOTTOM CLOUD FRACTION

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>210.0</th>
<th>300.0</th>
<th>0.18</th>
</tr>
</thead>
<tbody>
<tr>
<td>305.0</td>
<td>600.0</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>801.0</td>
<td>901.0</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>600.0</td>
<td>901.0</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>204.0</td>
<td>902.0</td>
<td>0.04</td>
<td></td>
</tr>
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</table>

### PRESSURE FLUXES IN 920 BANDS FLUXES IN 9, 6 & 15 MICRON BANDS

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### PRESSURE (KBAR) COALIC RATE (DEGREE C.LATTUDE/DAY)

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3. Clear Tropical Atmosphere (NC = 0)

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**PRESSURE LEVELS (hPa) OF SAMPLE PROFILE**

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<tr>
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<td>6.0</td>
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**TEMPERATURE (K) AT THE ABOVE PRESSURE LEVELS**

<table>
<thead>
<tr>
<th>229.36</th>
<th>246.72</th>
<th>265.47</th>
<th>284.13</th>
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<tr>
<td>229.36</td>
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<td>229.36</td>
<td>246.72</td>
<td>265.47</td>
<td>284.13</td>
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**HUMIDITY (gm/kg) AT THE ABOVE PRESSURE LEVELS**

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<tr>
<th>0.2000E-05</th>
<th>0.314E-05</th>
<th>0.395E-05</th>
<th>0.482E-05</th>
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<tr>
<td>0.570E-05</td>
<td>0.679E-05</td>
<td>0.786E-05</td>
<td>0.895E-05</td>
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**PRESSURE**

- **H2O BANDS**
  - **DOWN**
    - 26.72: 235.63
    - 26.72: 235.63
    - 26.72: 235.63
    - 26.72: 235.63

- **9.6 & 15 MICRON BANDS**
  - **DOWN**
    - 26.72: 235.63
    - 26.72: 235.63
    - 26.72: 235.63
    - 26.72: 235.63

**PRESSURE (hPa)**

- **COOLING RATE (DEGREE CELSIUS/DAY)**
  - FROM 1.39 TO 3.18: 17.04
  - FROM 3.18 TO 7.28: 4.90
  - FROM 7.28 TO 11.36: 3.04
  - FROM 11.36 TO 16.67: 1.03
  - FROM 16.67 TO 23.03: 0.01
  - FROM 23.03 TO 30.00: -0.17
  - FROM 30.00 TO 40.00: 1.13
  - FROM 40.00 TO 50.00: 2.37
  - FROM 50.00 TO 60.00: 1.96
  - FROM 60.00 TO 70.00: 1.97
  - FROM 70.00 TO 80.00: 2.20
  - FROM 80.00 TO 90.00: 2.15
  - FROM 90.00 TO 100.00: 3.28

C-3
**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.