Air Mass Computer Program for Atmospheric Transmittance/Radiance Calculation: FSCATM

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Air Mass Computer Program for Atmospheric Transmittance/Radiance Calculation: FSCATM

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Calculations of atmospheric transmittance and radiance require the knowledge of the integrated amounts of the absorbing gases along the path. This report describes the calculation of the integrated amounts ("air mass" or "column density") for various infrared absorbing gases for an arbitrary slant path through the atmosphere, including the effects of both curvature and refraction, and presents a Fortran program, FSCATM, to perform the calculation. Among the features of FSCATM are: → con't

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1. It calculates the layer-by-layer integrated absorber amounts and density-weighted pressure and temperature for an arbitrary slant path through the atmosphere.

2. It assumes a spherically symmetric atmosphere with exponential profiles of density and refractivity between layer boundaries.

3. It allows a variety of options for specifying the slant path.

4. It includes six representative atmospheric profiles of pressure and temperature, and of density for the gases H_2O, CO_2, O_3, N_2O, CO, CH_4, and O_2 and has provision for user-supplied profiles of up to 20 gases.

5. The output layering may either be generated internally or supplied by the user.

6. It is portable to 32 bit word computers in single precision and compatible with both ANSI Standard FORTRAN 66 and 77.

7. It is modular and easily modified to suit the users' particular needs. A discussion of atmospheric profile data and a survey of the literature are included in appendices.

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1. INTRODUCTION

Calculations of atmospheric transmittance and radiance require knowledge of the amount and distribution of the absorbing gases along the optical path. The integrated amount of gas along a path compared to the amount for a vertical path from ground to space is generally referred to as "air mass". Under some circumstances, air mass can be calculated simply by assuming a plane parallel atmosphere and using the secant approximation. For other cases, for example, large zenith angles or tangent paths, curvature and refraction must be taken into account, requiring a more elaborate integration along the path.

This report presents the Fortran program FSCATM, which calculates the integrated absorber amounts for an arbitrary slant path through the atmosphere, including the effects of both curvature and refraction. FSCATM is specifically designed to create the atmosphere inputs to the AFGL line-by-line atmospheric transmittance and radiance program FASCODE,[1] but the program is general enough to be useful to others working in the field of infrared radiative transfer in the atmosphere.

(Received for publication 1 March 1983)

1. Clough, S.A., Kneizys, F.X., Rothman, L.S., and Gallery, W.O. (1981) Atmospheric spectral transmittances and radiance: FASCOD1B, SPIE, Atmospheric Transmission 277:152-166.

Among the features of FSCATM are:

1. It calculates the layer-by-layer integrated absorber amounts and density-weighted pressure and temperature for an arbitrary slant path through the atmosphere,

2. It assumes a spherically symmetric atmosphere with exponential profiles of density and refractivity between layer boundaries,

3. It allows a variety of options for specifying the slant path,

4. It includes six representative atmospheric profiles of pressure and temperature, and of density for the gases H_2O, CO_2, O_3, N_2O, CO, CH_3 and O_2, and has provision for user-supplied profiles of up to 20 gases,

5. The output layering may either be generated internally or supplied by the user,

6. It is portable to 32 bit word computers in single precision and compatible with both ANSI Standard FORTRAN 66 and 77, and

7. It is modular and easily modified to suit the users' particular needs.

As distributed FSCATM is a subroutine called by FASCODE. However, it may very easily be converted to a self-contained program (see Section 3.4 for details). References to FSCATM in this report will assume that it is being run in the stand-alone mode. FSCATM is available as part of the FASCOD1C package (see Section 3.5 for details).

Section 2 of this report provides background on the calculation of air mass, including atmospheric refraction, the numerical algorithm used here, and some examples of the effects of curvature and refraction on air mass. Section 3 documents the program FSCATM, including usage and sample input and output.

Appendix A discusses the six standard atmospheric profiles included in FSCATM and describes other sources of atmospheric profile data. Appendix B describes the formula for the index of refraction of air used in FSCATM. Finally, Appendix C gives a brief survey of the literature on air-mass calculation and atmospheric refraction.

2. AIR MASS

2.1 Definitions

The integrated absorber amount, m, along a slant path through the atmosphere is given by

$$m = \int \rho ds \quad , \tag{1}$$

where ρ is the mass or number density of the gas and ds is the element of length along the path (m is also sometimes referred to as the "column density"). For vertical path from ground to space for the U.S. Standard Atmosphere 1962, m for the total air density is 2.15×10^{25} molecules $cm^{-2} = m_o$. This quantity m_o is sometimes referred to as "one air mass". The term air mass is somewhat ambiguous; in this report the term air mass for a particular path will refer to the relative air mass or m/m_o. For example, the air mass for a path from ground to space, where the zenith angle at the ground is 90.0^o, is 38.1. The term air mass applies specifically to total amount of air along the path. For non-uniformly mixed gases, such as H_2O or O_3, the relative amount of gas along a slant path compared to a vertical path may differ greatly from the (total) air mass.

These calculations assume a spherically-symmetric layered atmosphere with the pressure, temperature, and absorbing gas densities defined at a suitable number of layer boundaries. For any path through the atmosphere, the integrated absorber amounts, m, are calculated individually for each layer and summed over the layers. This discussion will be confined to the calculation for a single layer.

Figure 1 illustrates the geometry of a path through a single layer. The layer is bounded by the radii r_1 and r_2, α and ϕ are the zenith angles at r_1 and r_2 respectively, s is the curved path length, β is the earth centered angle, and ψ is the bending along the path. The radius of the earth is r_e while the radius to any point is r. The height z above the lower boundary equals $r - r_e$.

The pressure P, temperature T, and absorbing gas density ρ are given at r_1 and r_2. Inside the layer, temperature is interpolated linearly, while pressure and density are assumed to follow an exponential distribution. For pressure,

$$P(z) = P_1 \exp[-z/H_p] \tag{2}$$

$$H_p = -(\Delta z)/\ln(P_2/P_1) \quad , \tag{3}$$

where H_p is called the pressure scale height and Δz is $r_2 - r_1$. Equation (2) is exact for an isothermal layer and is an excellent approximation for a non-isothermal layer if the layer is thin compared to a scale height.

Similarly, the density is given by:

$$\rho(z) = \rho_1 \exp[-z/H_\rho] \tag{4}$$

$$H_\rho = -\Delta z/\ln(\rho_2/\rho_1) \quad . \tag{5}$$

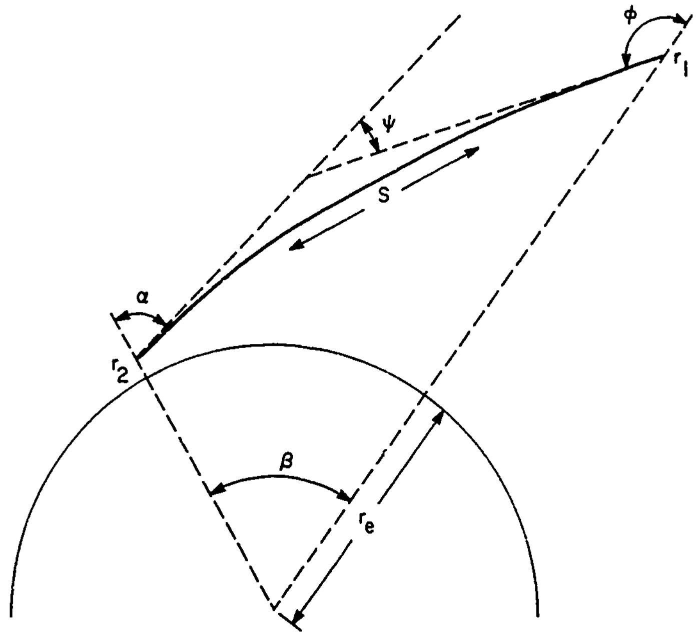

Figure 1. Geometry of the Refracted Path Through a Single Layer

For a uniformly mixed gas in an isothermal layer, Eq. (4) is again exact and for a non-isothermal layer is a good approximation. For a non-uniformly mixed gas, the density will not follow an exponential distribution. In such cases it is necessary to make the spacing between boundaries small enough so that the calculated density between layers does not depend significantly upon the particular interpolation scheme used.

The integrated amount m of the absorbing gas for the layer can be rewritten from Eq. (1) as

$$m = \int_1^2 \rho(z) \frac{ds}{dz} dz \quad . \tag{6}$$

From small zenith angles, ds/dz is essentially constant over the layer and equals sec θ, where θ is the incident angle of the path at z (see Figure 2). In this case, Eq. (6) can be approximated as:

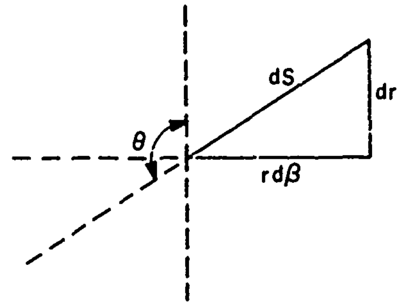

Figure 2. The Differential Path Quantities at a Point

$$m = \sec\theta \int_1^2 \rho \, dz \quad . \tag{7}$$

This approximation is the same as assuming a plane parallel atmosphere. The vertical integral of the density has a particularly simple analytic solution when the profile is exponential:

$$\int_1^2 \rho \, dz = H_\rho(\rho_1 - \rho_2) \quad . \tag{8}$$

For larger zenith angles where the earth's curvature is important but where refraction is still not significant, Eq. (6) can be solved analytically using the Chapman functions. (See Appendix C for references to the Chapman functions.) For even larger zenith angles, refraction must be taken into account. In this later case the layer can be divided into a number of sublayers bounded by $z_1, z_2, \cdots z_J$, which need not be uniformly spaced. The spacing between sublayers $\Delta z_j = z_j + 1 - z_j$ is determined by the requirement that the integral in Eq. (6) can be adequately represented by the sum over the sublayers j:

$$m = \sum \rho_j \frac{ds}{dz_j} \Delta z_j \quad , \tag{9}$$

where

$$\overline{\rho_j} = \frac{1}{\Delta z_j} \int_j^{j+1} \rho \, dz = \frac{1}{\Delta z_j} H_\rho (\rho(z_j) - \rho(z_j + 1)) \qquad (10)$$

$$\overline{\frac{ds}{dz_j}} = \frac{1}{\Delta z_j} \int_j^{j+1} ds = \frac{\Delta s_j}{\Delta z_j} \qquad (11)$$

$$\Delta z_j = z_{j+1} - z_j \quad . \qquad (12)$$

The problem now is to determine the number and spacing of the sublayers and the path length Δs_j through each sublayer, including the effects of refraction. This problem is discussed in the next section.

In addition to the absorber amount, atmospheric transmittance calculations require an effective pressure and temperature for a layer. The effective pressure is required to calculate the halfwidth and the effective temperature is used to calculate the line intensity halfwidth, and, in emission, blackbody source function for a layer. The effective values are those that make the absorption and/or emission of an equivalent homogeneous layer equal to that of the nonhomogeneous layer. There is no single definition of the effective pressure or temperature: the effective values depend upon many factors such as the path, the density distribution, and the spectral region, and will in general be different for different absorbing gases. The most generally applicable definition, however, is the density weighted average:

$$\overline{P} = \int P \rho^* ds \Big/ \int \rho^* ds \qquad (13)$$

$$\overline{T} = \int T \rho^* ds \Big/ \int \rho^* ds \quad , \qquad (14)$$

where ρ^* is the total air density. For a uniformly mixed gas with no temperature dependence in the line intensities, the mean pressure given by Eq. (13) is essentially the Curtis-Godson approximation.

The effective pressure $\overline{P}$ and temperature $\overline{T}$ are calculated in a way similar to the absorber amount in Eq. (9), using

$$\overline{P}m^* = \int P\rho^* ds = \sum \frac{\overline{\Delta s}_i}{\Delta z_i} \int_i^{i+1} P(z)\,\rho^*(z)dz \tag{15}$$

$$\overline{T}m^* = \int T\rho^* ds = \sum \frac{\overline{\Delta s}_i}{\Delta z_i} \int_i^{i+1} T(z)\,\rho^*(z)dz \tag{16}$$

$$m^* = \int \rho^* ds = \sum \frac{\overline{\Delta s}_i}{\Delta z_i} \int_i^{i+1} \rho^* dz \quad . \tag{17}$$

The pressure and total air density are both assumed to follow an exponential profile with scale heights H_p and $H_\rho*$ respectively. The integral in Eq. (15) can be written as

$$\int_i^{i+1} P\rho^* dz = \frac{H_p H_\rho *}{H_p + H_\rho *} \left(P(z_i)\,\rho^*(z_i) - P(z_{i+1})\,\rho^*(z_{i+1})\right) \tag{18}$$

From the ideal gas law

$$P = G\rho^* T \quad , \tag{19}$$

where G is the gas constant for air. Using this equation, the integral in Eq. (16) becomes

$$\int_i^{i+1} T\rho^* dz = \frac{1}{G}\int_i^{i+1} P dz = \frac{H_p}{G}\left(P(z_i) - P(z_{i+1})\right) \quad . \tag{20}$$

The density integral in Eq. (17) is the same as in Eq. (10):

$$\int_i^{i+1} \rho^* dz = H_\rho * (\rho^*(z_i) - \rho^*(z_{i+1})) \quad . \tag{21}$$

The next section will describe the method used to calculate the refracted path Δs_j through each sublayer.

2.2 Atmospheric Refraction

The refraction of a light ray is due to the gradient of the index of refraction n, with the ray refracted in the direction of increasing n. To a close approximation, the refractivity $N = n - 1$ is proportional to the air density. See Appendix B for a discussion of the index of refraction of air. In a spherically symmetric atmosphere, grad n is directed radially, and except in unusual circumstances, downward. The trajectory of the ray is determined by Snells law for a spherically symmetric medium:[2]

$$n(r)\, r \sin \theta = c \quad , \tag{22}$$

where θ is the angle of incidence at r and c is a constant that depends upon the particular path. If the ray is horizontal at r_T then $z_T = r_T - r_e$ is the tangent height and $c = n(r_T)r_T$. The curvature K of the refracted ray can be shown to be[3]

$$K = - \sin \theta \frac{n'}{n} \quad , \tag{23}$$

where $n' = dn/dr$.

It is useful to define the quantity R(r) as

$$R(r) = - \frac{r}{n/n'} \quad . \tag{24}$$

R is simply the ratio of r to the radius of curvature of a ray tangent at r. R is a property of the atmospheric profile (not the particular path) and is a good measure of the importance of refraction at a given altitude. For example, for the U.S. Standard Atmosphere 1962, R is 0.16 at the ground and decreases approximately exponentially with a scale height of about 10 km. As an extreme example, if $R = 1.0$, a ray tangent at r will continue indefinitely to follow a circular path of radius r.

Consider now a point moving along the path within the layer defined by r_1 and r_2 as shown in Figure 1. At a point defined by the radius r and with an incidence angle θ as shown in Figure 2, the differential path length ds is

$$ds = - \frac{1}{\cos \theta}\, dr \quad . \tag{25}$$

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2. Born, M., and Wolf, E. (1964) Principals of Optics, Pergamon Press, Inc., N.Y., pp 121-123.
3. Meyer-Arendt, J.R., and Emmanuel, C.B. (1965) Optical Scintillation: A Survey of the Literature, National Bureau of Standards, Tech Note 225.

Eq. (22) can be used to eliminate θ in Eq. (25) giving:

$$ds = \left(1 - \frac{c^2}{n^2 r^2}\right)^{-1/2} dr \quad . \tag{26}$$

Eq. (26) can be integrated numerically to obtain s for a layer or sublayer.

The drawback with using Eq. (26) is that in the region near a tangent height (that is, $\sin \theta = c/nr$ approaches 1), the right-hand side of Eq. (26) goes to infinity and a different numerical algorithm must be used. An alternative formulation of this equation that avoids this problem is as follows. Define a new independent variable x as

$$x = - r \cos \theta \tag{27}$$

$$dx = - \left(\cos \theta - r \sin \theta \frac{d\theta}{dr} \right) dr \quad . \tag{28}$$

Differentiating Eq. (22) and using Eq. (24) gives

$$\frac{d\theta}{dr} = - \frac{\tan \theta}{r} (1 - R) \quad . \tag{29}$$

Substituting Eq. (29) into Eq. (28) gives

$$dx = - (1 - R \sin^2 \theta) \frac{dr}{\cos \theta} \quad . \tag{30}$$

Comparing Eq. (30) with Eq. (25) gives

$$ds = (1 - R \sin^2 \theta)^{-1} dx \quad . \tag{31}$$

In this form of the equation for ds, the right-hand side is a well-behaved function of r for all paths, including vertical and horizontal paths (except in the unusual circumstances that $R \geq 1$). The intermediate variable x is related to r by

$$x = - r \cos \theta = r \left(1 - \frac{c^2}{n^2 r^2}\right)^{1/2} \tag{32}$$

which is also a well-behaved function of r for all paths. In practice, the numerical integration of Eq. (31) is driven in terms of steps in r, from r to $r + \Delta r$. The corresponding increment in x is calculated using Eq. (32). The integration of s from Eq. (31) is then straightforward.

It is also useful to calculate the values of the earth centered angle β and the bending ψ for the layer. From Figure 2, again,

$$\frac{d\beta}{dr} = \frac{\tan\theta}{r} \quad . \tag{33}$$

In terms of x:

$$\frac{d\beta}{dx} = \frac{d\beta}{dr}\,\frac{dr}{dx} \quad .$$

$$\frac{d\beta}{dx} = (1 - R\sin^2\theta)^{-1}\,\frac{\sin\theta}{r} \quad . \tag{34}$$

ψ is related to the other path quantities by

$$\psi = \pi + \beta - \alpha - \theta \tag{35}$$

so that

$$\frac{d\psi}{dx} = \frac{d\beta}{dx} - \frac{d\theta}{dx} \tag{36}$$

giving

$$\frac{d\psi}{dx} = (1 - R\sin^2\theta)^{-1}\,\frac{R}{r}\sin\theta \quad . \tag{37}$$

In practice ψ is integrated along the path along with s and β is calculated from Eq. (35).

It is useful to examine Eq. (31) in some detail. It can be shown geometrically that dx equals ds in the case of a straight line, that is, no refraction. Correspondingly, the right-hand side of Eq. (31) approaches 1 as refraction becomes less important, that is, as either R or $\sin\theta$ goes to zero. At the other extreme, in the case of very strong refraction of a horizontal ray where the curvature due to refraction equals the curvature of the earth, R and $\sin\theta$ both equal 1 and the right-hand side of Eq. (31) becomes infinite. The path in this case is a circle for which $x = r\cos\theta$ is constant. For even stronger refraction where $R > 1$, the light ray is bent back toward the earth and the right-hand side of Eq. (31) becomes negative.

In this case, dx is also negative along the p .h. Finally, in the presence of a density inversion ($n' > 0$), R is negative and the ray is bent upwards.

2.3 Numerical Algorithm

This section will describe the numerical algorithm used to calculate the slant path and the absorber amounts through a single layer.

The integration of the slant path parameters s, β, and ψ and the absorber amounts is performed by dividing the layer into sublayers bounded by the altitudes z_j, j = 1 to J. The spacing of the sublayers is chosen so that the path increments are approximately equal to a nominal path increment $\widetilde{\Delta s}$, where $\widetilde{\Delta s}$ is determined by the required accuracy of the results. The integration always proceeds from the bottom of the layer to the top: the incidence angle θ at the bottom of the layer is assumed known as is the value of c [Eq. (22)].

The values of N, P, ρ, and ρ^* are interpolated exponentially from the values at the layer boundaries with scale heights H_N, H_p, H_ρ, and $H_\rho{}^*$ respectively.

R is given by

$$R = \frac{r}{n/n'}$$

$$= \frac{r\, N_1\, e^{-z/H_N}}{H_N\left(1 + N_1\, e^{-z/H_N}\right)} , \qquad (38)$$

where N_1 is the value of N at z = 0.

The numerical integration scheme proceeds as follows:

1. $\Delta r_j = \widetilde{\Delta s} \cos \theta_{j-1}$
2. $r_j = r_{j-1} + \Delta r_j$
3. $\sin \theta_j = c/(n(r_j) r_j)$
4. $\cos \theta_j = -(1 - \sin^2 \theta_j)^{1/2}$
5. $x_j = -r_j \cos \theta_j$
6. $\Delta x_j = x_j - x_{j-1}$
7. $\left.\frac{ds}{dx}\right|_j = (1 - R_j \sin^2 \theta_j)$

8. $s_j = s_{j-1} + \frac{1}{2}\left(\frac{ds}{dx}\bigg|_{j-1} + \frac{ds}{dx}\bigg|_j\right)\Delta x_j$

9. $\frac{d\psi}{dx}\bigg|_j = \frac{ds}{dx}\bigg|_i \frac{R_j}{r_j} \sin\theta_j$

10. $\psi_j = \psi_{j-1} + \frac{1}{2}\left(\frac{d\psi}{dx}\bigg|_{j-1} + \frac{d\psi}{dx}\bigg|_j\right)\Delta x_j$

11. $m_j = m_{j-1} + \frac{\Delta s_j}{\Delta r_j} H_\rho(\rho(r_j) - \rho(r_{j-1}))$

12. $j = j + 1$

13. Go to 1.

Near a tangent height where $\cos\theta$ approaches zero, this scheme must be modified. First, Step 1 breaks down for $\cos\theta_1 = 0$ and is replaced by

$$\Delta r_1 = \frac{\Delta\tilde{s}^2}{2r_1} \quad . \tag{39}$$

Secondly, the truncation error for $\cos\theta_j$ in Step 4 is excessive for computers with seven decimal digits of precision when $\sin\theta_j$ is greater than about 0.99999. To avoid this problem, $\cos\theta_j$ is calculated for $\sin\theta_j > 0.99999$ from:

$$\cos\theta(r) = -(2\,y(r) - y^2(r))^{1/2} \tag{40}$$

and

$$y(r) = \int_{r_T}^{r} (1 - R(r))\,\frac{\sin\theta}{r}\,dr \quad , \tag{41}$$

where r_T is the radius at the tangent height. [Eq. (40) and Eq. (41) are obtained by integrating Eq. (29).]

Note that the steps are driven in increments of r although the nominal independent variable is x. There are two reasons for this procedure. First, it is necessary to stop the integration at the upper boundary; this is done most conveniently when r drives the integration. Secondly, x is an analytic function of r so that x_j can be calculated simply from r_j. The opposite is not true; an iterative scheme would be required to calculate r_j given x_j.

2.4 Examples of Air Mass Calculations

This section will present some examples of air mass calculations for total air, water vapor, and ozone for various geometries and atmospheric profiles using the program FSCATM. The cases were chosen to broadly represent the range of conditions likely to meet in spectroscopic observations of the atmosphere. In general, the results are presented both with and without the effects of refraction so that the reader may judge for himself under which circumstances refraction can be neglected.

The three atmosphere profiles used here are taken from McClatchey et al[4*] and were chosen to represent mean and extremes of temperature and of water-vapor and ozone concentrations found in the atmosphere. The profiles of temperature, total air density, water-vapor density, and ozone density up to 70 km are shown in Figure 3. The surface pressure for all three profiles is the same, 1013 mb.

The paths are described in terms of the following parameters: H1 is the observer's altitude, ANGLE is the zenith angle at the observer, and H2 is the altitude of the other end of the path. For a path out to space, H2 is the top of the atmospheric profile (here 100 km). Three geometries are presented here: (1) H1 = 0, H2 = 100 km, ANGLE varies from 0 to 90°, (2) H2 = 100 km, ANGLE = 90°, H1 varies from 0 to 50 km, and (3) H1 = 30 km, H2 = 100 km, ANGLE varies from 85° to about 95.5° at which point the path intersects the earth. Path 1 is relevant for ground-based observations, while paths 2 and 3 correspond to observations from balloon or aircraft. Path 2 is also relevant to satellite observations scanning the limb, where H1 is the tangent height and the integrated absorber amounts must, of course, be doubled.

These calculations were all performed with the index of refraction calculated at 2000 cm^{-1} (5 μm). The effect on air mass of variations of the index of refraction with wavenumber are negligible between 500 and 20,000 cm^{-1} (20 to 0.5 μm).

Although the term air mass refers properly only to the amount of air along a path, it will be applied here loosely to water vapor and ozone to refer to the integrated amount relative to a vertical path from ground to space for the same

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*See Appendix A regarding the water vapor profiles.

4. McClatchey, R.A., Fenn, R.W., Selby, J.E.A., Volz, F.E., and Garing, J.S. (1972) Optical Properties of the Atmosphere (Third Edition), AFCRL-TR-72-0497, AD 679996.

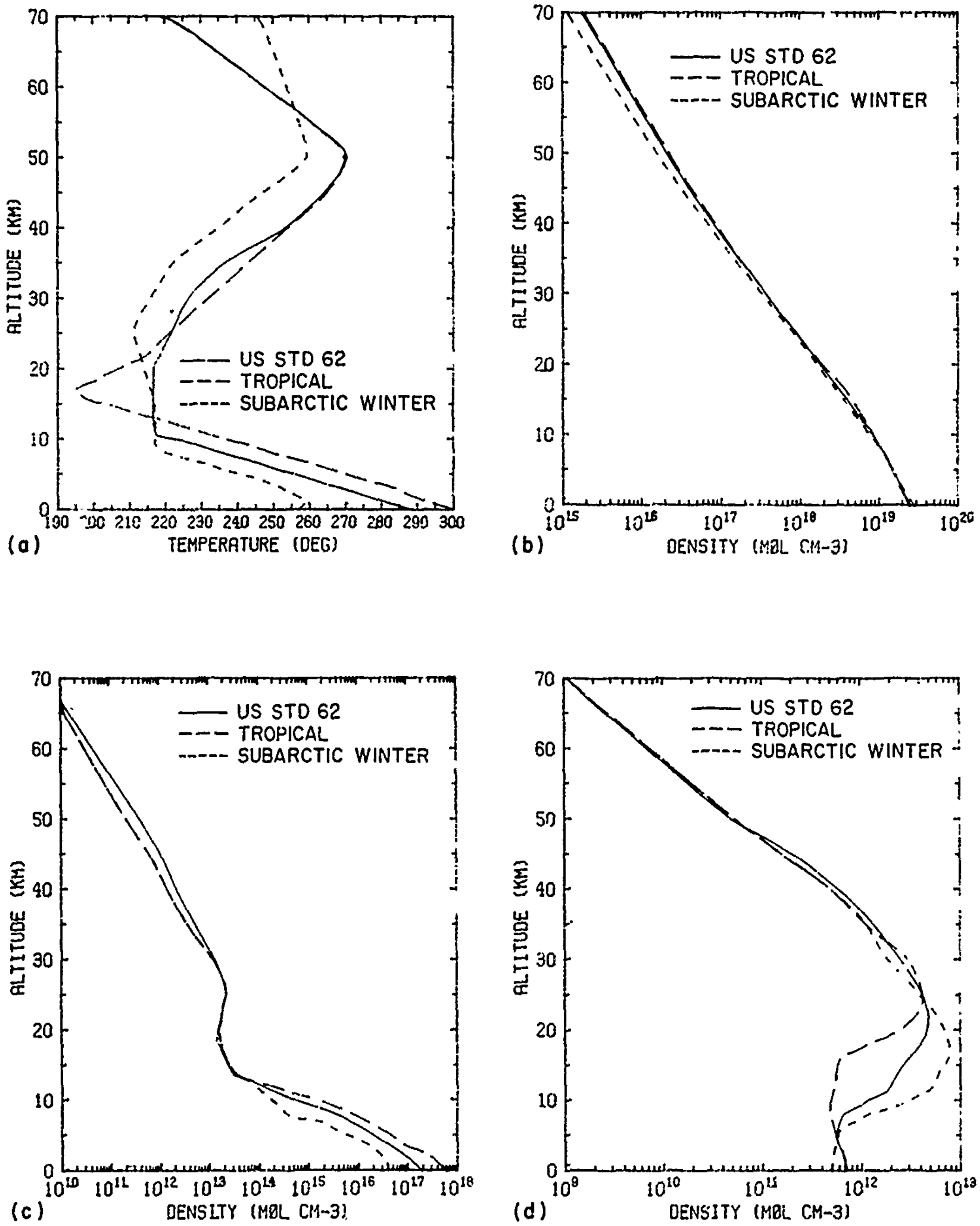


Figure 3. Profiles of Three Atmospheric Models of (a) Temperature, (b) Total Air Density, (c) Water Vapor, and (d) Ozone

vertical distribution. For the U.S. Standard Atmosphere 1962, one air mass refers to the following integrated absorber amounts:

air	2.15×10^{25} molecules cm^{-2}
water vapor	4.74×10^{22} molecules cm^{-2}
ozone	9.24×10^{18} molecules cm^{-2} .

In the following graphs, U and $\tilde{U}$ will represent the air mass for a refracted path and an unrefracted path respectively.

Figures 4 and 5 show the effect of the earth's curvature on air mass for a ground-based observer by comparing the air mass computed without refraction with the secant of the zenith angle. Figure 5 shows that the secant approximation is good to within 1 percent up to a zenith angle of 72° for a uniformly mixed gas, up to 80° for water vapor, but only up to 60° for ozone.

Figure 6 shows the same calculations as Figure 4 except that refraction is included. At 90° the air mass values for the three components are:

	With Refraction	No Refraction
air	38.1	35.1
H_2O	72.2	66.1
O_3	14.4	13.8

These values depend upon the atmospheric profile used; in this case it is the U.S. Standard Atmosphere 1962. Water vapor has the highest value since it is concentrated near the ground where the effective secant [ds/dz in Eq. (6)] is the highest. Conversely, ozone has the smallest air mass value since the ozone density profile peaks near 20 km, where the effective secant is relatively small.

Comparing Figure 7 with Figure 5 shows that the effect of refraction is smaller than that of the earth's curvature. At 90°, refraction increases the air mass by less than 10 percent, and the air mass can be computed neglecting refraction to better than 1 percent up to 86° for water vapor, 84° for a uniformly mixed gas, and 82° for ozone.

The air mass vs altitude for an observer looking out horizontally is shown in Figure 8. These curves mimic the density profiles of the components themselves, since for this path the bulk of the absorber is located within a few kilometers (vertically) of the observer's altitude. From Figure 9, the effect of refraction an air mass becomes less than 1 percent at 20 km for all three components.

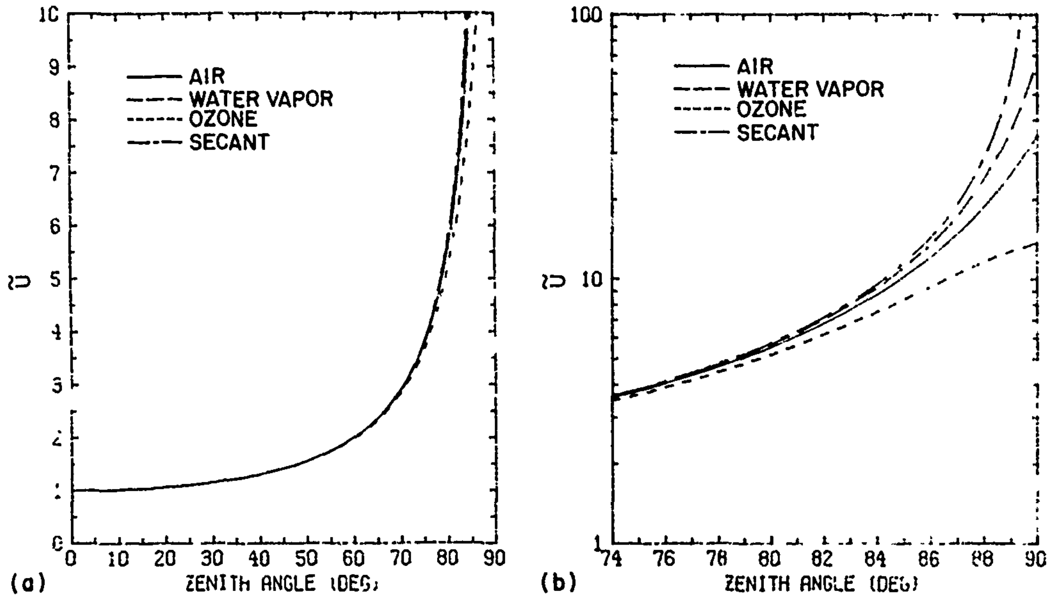


Figure 4. Air Mass ($\tilde{U}$) vs Zenith Angle for the Case: H1 = 0, H2 = 100 km U.S. Standard Atmosphere 1962, No Refraction. For reference, the secant of the angle is also shown: (a) 0 to 90^{o} and (b) 74 to 90^{o}

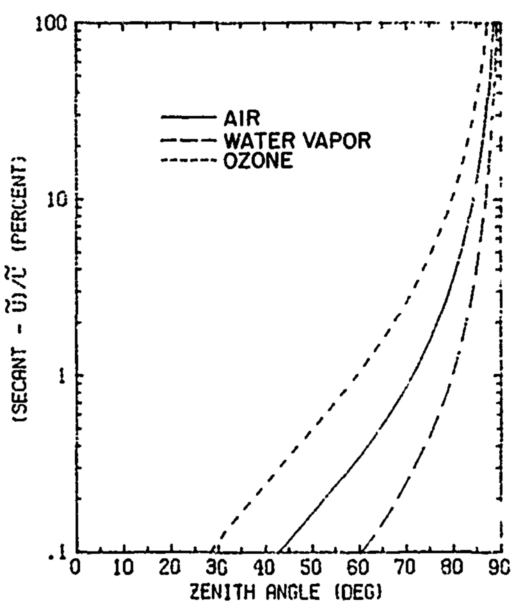


Figure 5. Relative Air Mass Error Due to the Secant Approximation vs Zenith Angle for the Case Shown in Figure 4

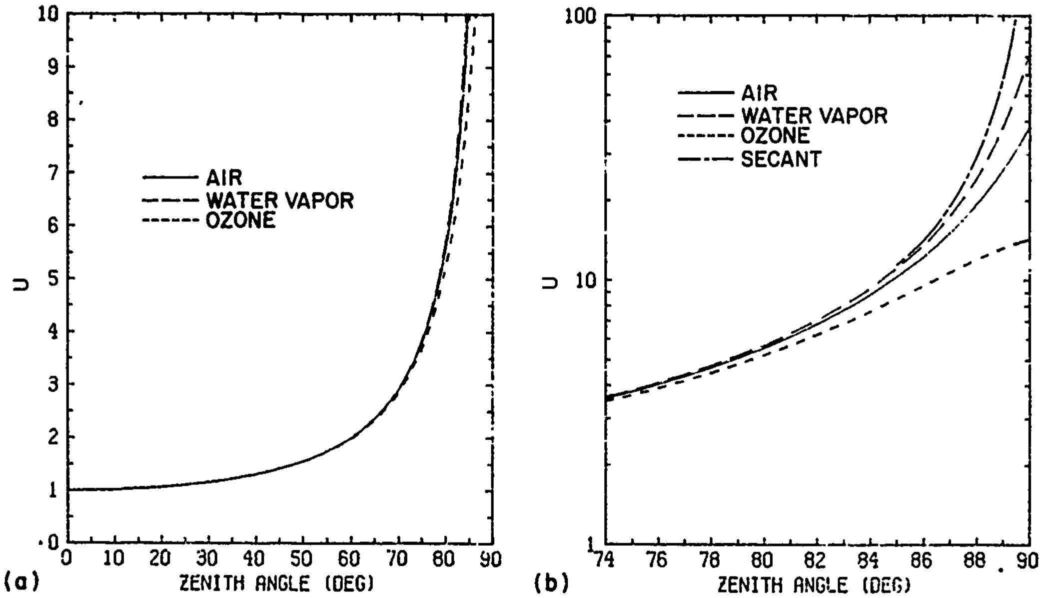


Figure 6. Air Mass (U) vs Zenith Angle for the Case H1 = 0, H2 = 100 km, U.S. Standard Atmosphere 1962, Including Refraction: (a) 0 to 90° and (b) 74 to 90°

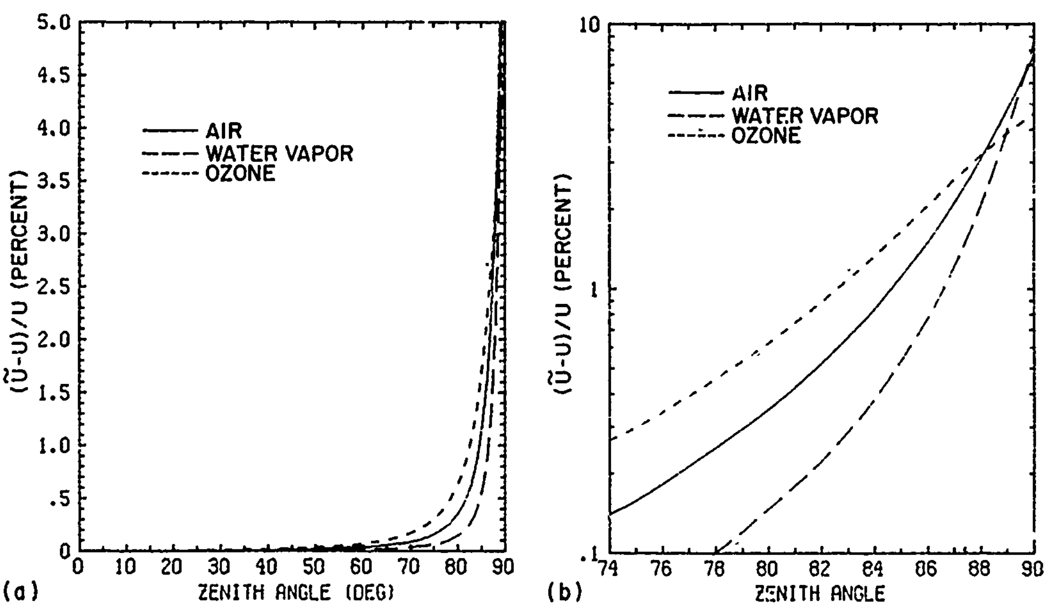


Figure 7. Relative Air Mass Error Due to Neglecting Refraction vs Zenith Angle for the Case in Figure 6: (a) 0 to 90° and (b) 74 to 90°

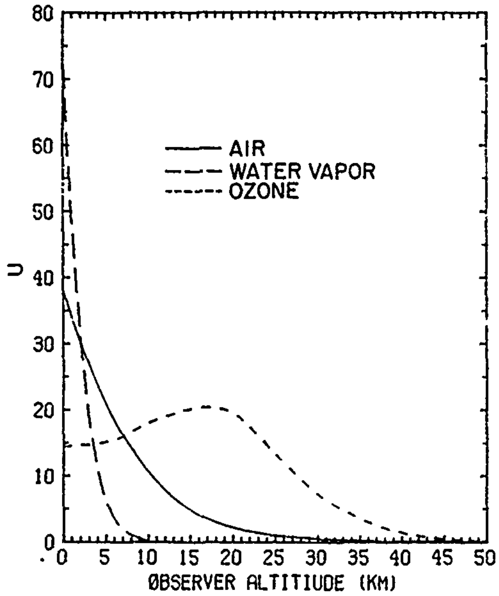


Figure 8. Air Mass (U) vs Observer Altitude (H1) for the Case H2 = 100 km, ZENITH ANGLE = 90°, U.S. Standard Atmosphere 1962, Including Refraction

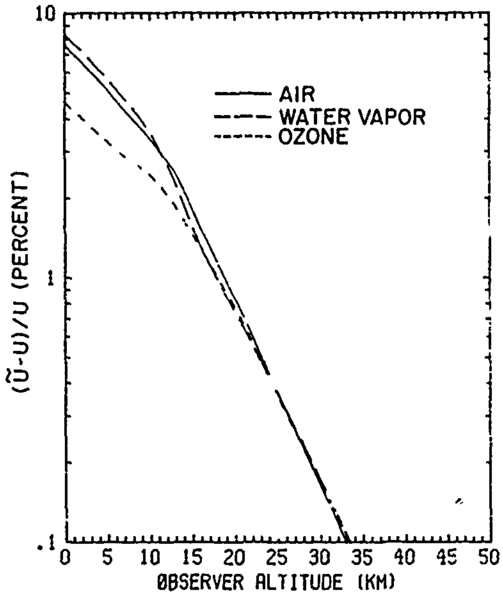
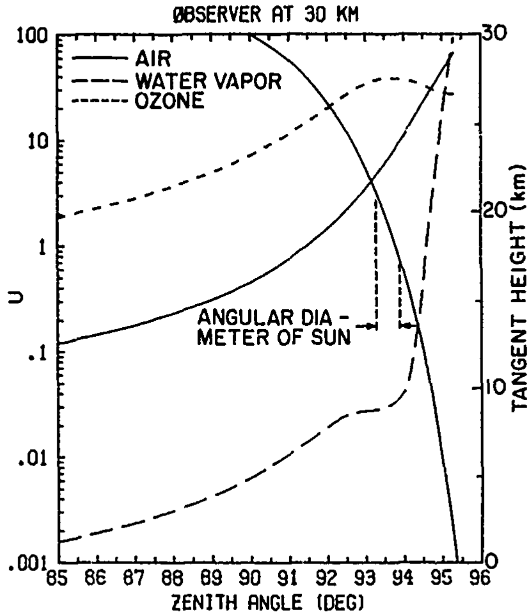


Figure 9. Relative Air Mass Error Due to Neglecting Refraction vs Observer Altitude for the Case in Figure 8

The variation of air mass with zenith angle for a typical stratospheric balloon-borne spectroscopic experiment is shown in Figure 10, with the error due to neglecting refraction in Figure 11. The zenith angle shown is the apparent zenith angle of the refracted ray such as would be measured at the observer. The tangent height vs zenith angle is shown on the right-hand axis of Figure 10. Also shown on Figure 10 is the sun's angular diameter for comparison (after Sneider[5]). If the sun is used as a source for a measurement, the air mass to different points in the sun can vary by more than a factor of 2 for large zenith angles. This effect is due to curvature: by comparison of the effect of refraction shown in Figure 11 is much less. The variation in air mass due to this effect can be the major source of uncertainty in a measurement and must be considered carefully.

Sneider's[5] Figures 4 and 5 show comparisons similar to Figures 10 and 11 here; however, they are not directly comparable since his refracted and unrefracted paths do not have the same zenith angle at the observer. His calculations involve an observer looking at the sun: the unrefracted path follows a straight line to the sun with the zenith angle at the observer equal to the astronomical

5. Sneider, D. (1975) Refractive effects in remote sounding of the atmosphere with infrared transmission spectroscopy, J. Atmos. Sci. 32:2178-2184.



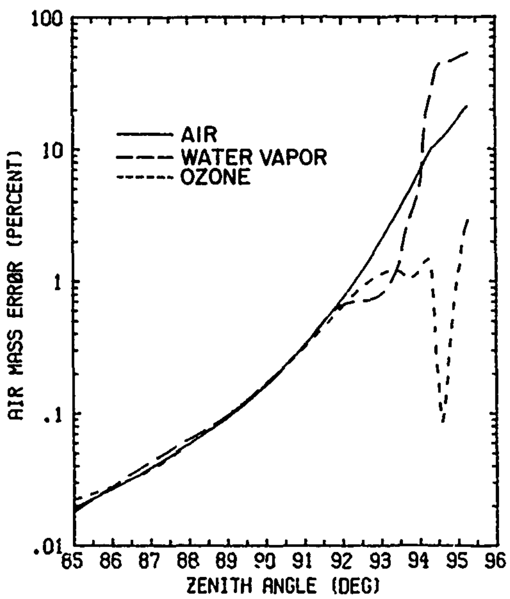


Figure 10. Air Mass (U) vs Zenith Angle for the Case H1 = 30 km, H2 = 100 km, U.S. Standard Atmosphere 1962, Including Refraction. Also shown are the tangent height vs zenith angle and the angular diameter of the sun

Figure 11. Relative Air Mass Error Due to Neglecting Refraction vs Zenith Angle for the Case in Figure 10

zenith angle. For the refracted path, the zenith angle at the observer is the apparent zenith angle, which is less than the astronomical zenith angle. It turns out that the effect of refraction appears greater for the geometry presented in Sneider's report than in this one.

Figures 12 and 13 demonstrate the effect of different atmospheric profiles on the absorber amount for two different paths. In Figure 12(a) the integrated amount for a uniformly mixed gas for a path from ground to space at 90° varies only 10 percent from a tropical to a Subarctic Winter atmosphere (assuming the same surface pressure). The water vapor amount, however, differs by a factor of 10 and the ozone amount by a factor of 2, due to different density profiles. For the path in Figure 13 (tangent height to space) the pressure at a given altitude is different for the three profiles so that the amounts for a uniformly mixed gas become equal at 3 km. The water amounts above 13 km become equal because the water vapor profiles above that altitude are about the same [see Figure 3(c)].

Different atmospheric profiles also produce different amounts of refraction. The difference in the tangent height between a refracted and an unrefracted ray coming in from space is shown as a function of the refracted tangent height in

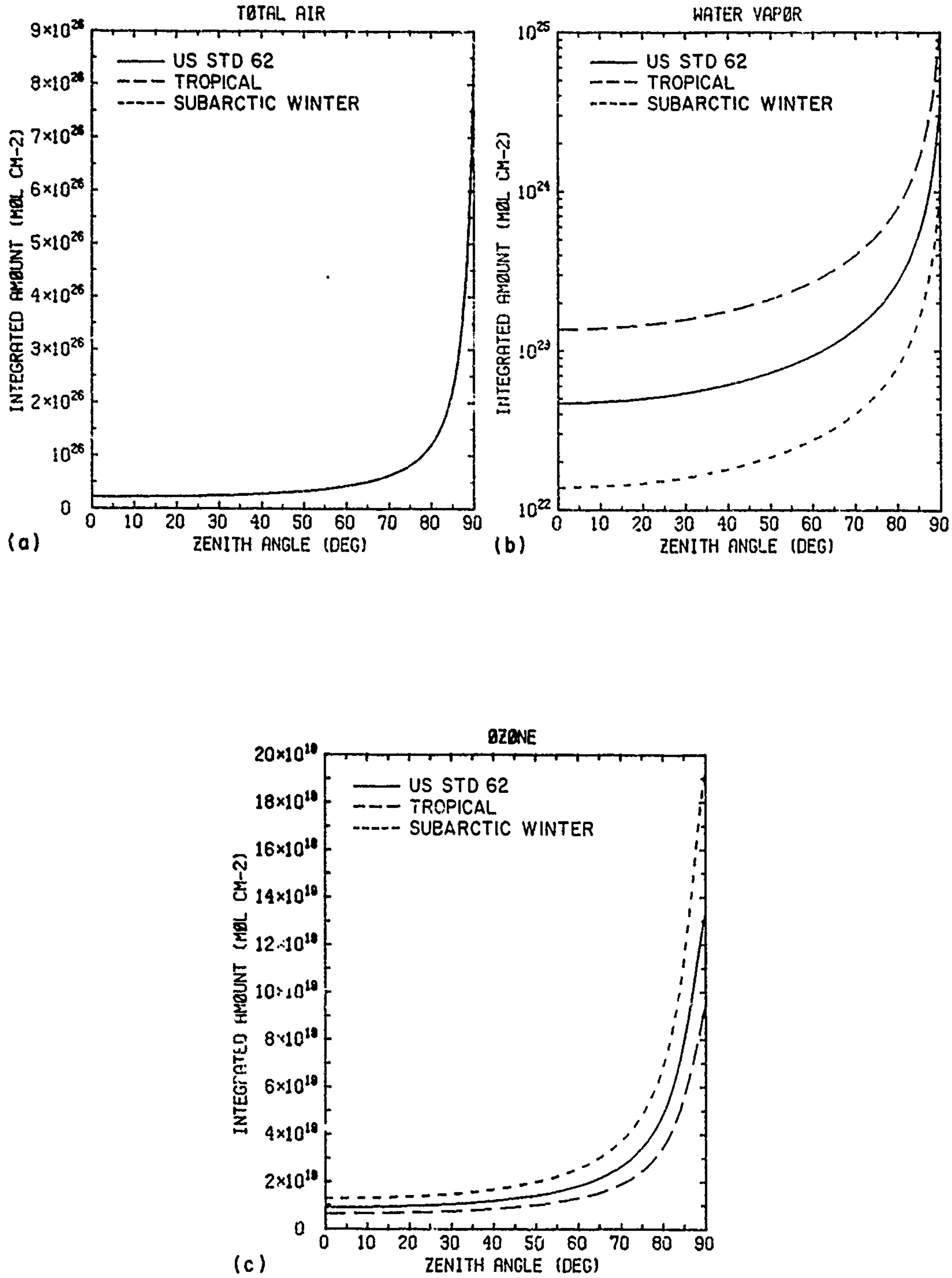


Figure 12. Integrated Absorber Amounts vs Zenith Angle for Three Atmospheric Profiles for the Case of H1 = 0, H2 = 100 km, Including Refraction: (a) Total Air (the Three Curves are Indistinguishable), (b) Water Vapor, and (c) Ozone

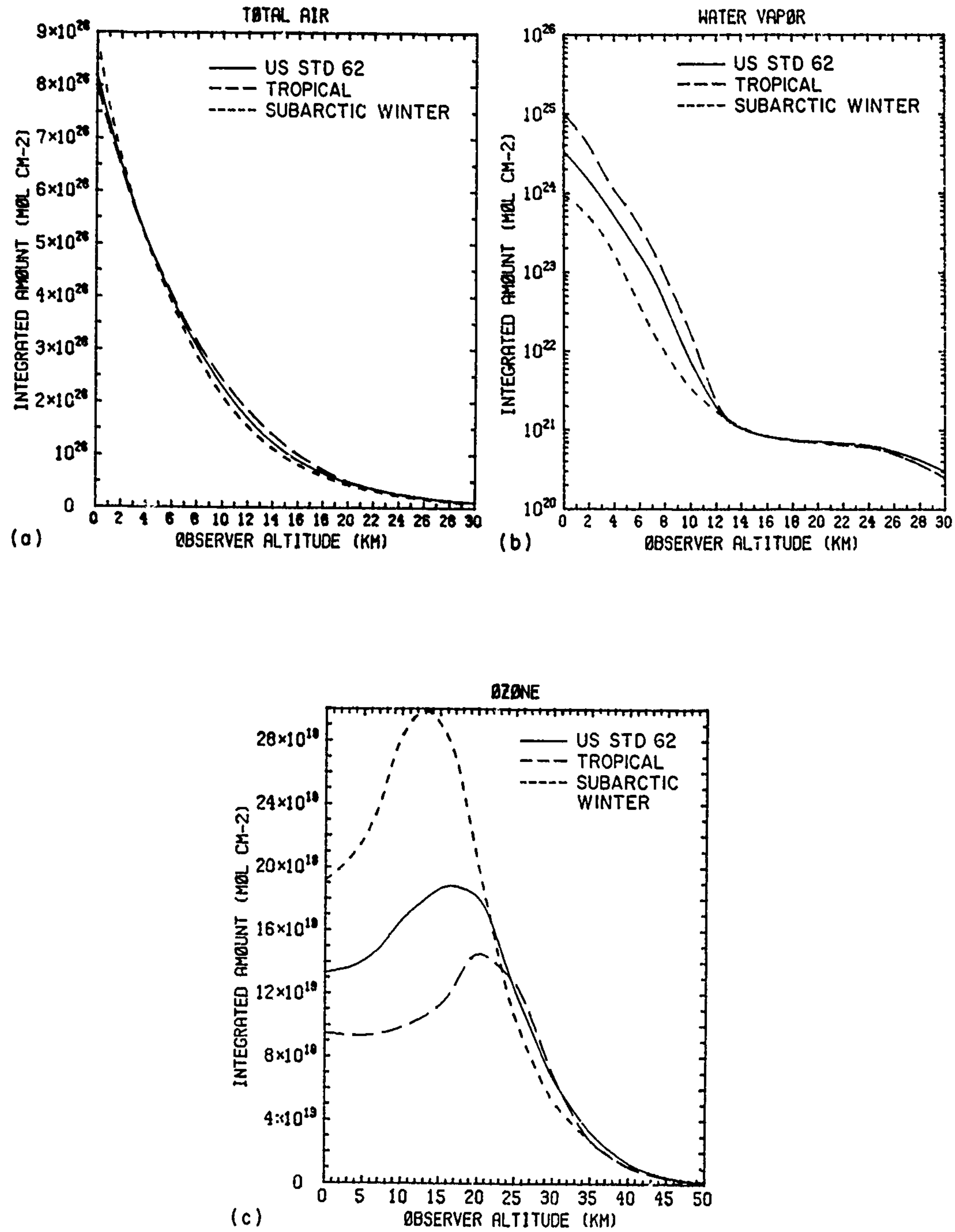


Figure 13. Integrated Absorber Amounts vs Observer Altitude for Three Atmospheric Profiles for the Case of ZENITH ANGLE = 90, H2 = 100 km, Including Refraction: (a) Total Air, (b) Water Vapor, and (c) Ozone

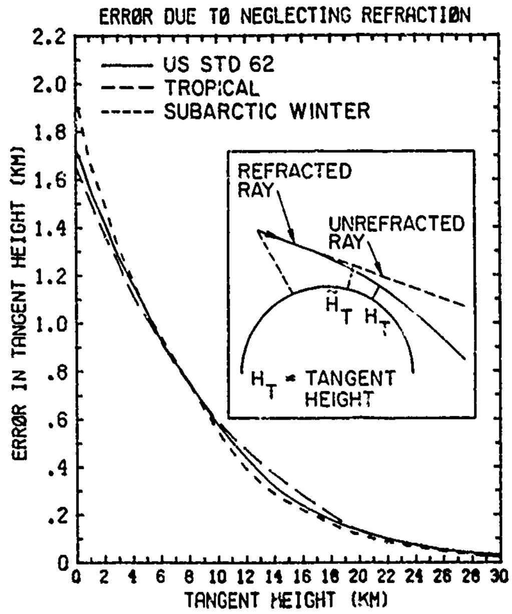


Figure 14. Unrefracted Tangent Height Minus Refracted Tangent Height vs Refracted Tangent Height for Three Atmospheric Profiles. The diagram illustrates the geometry involved

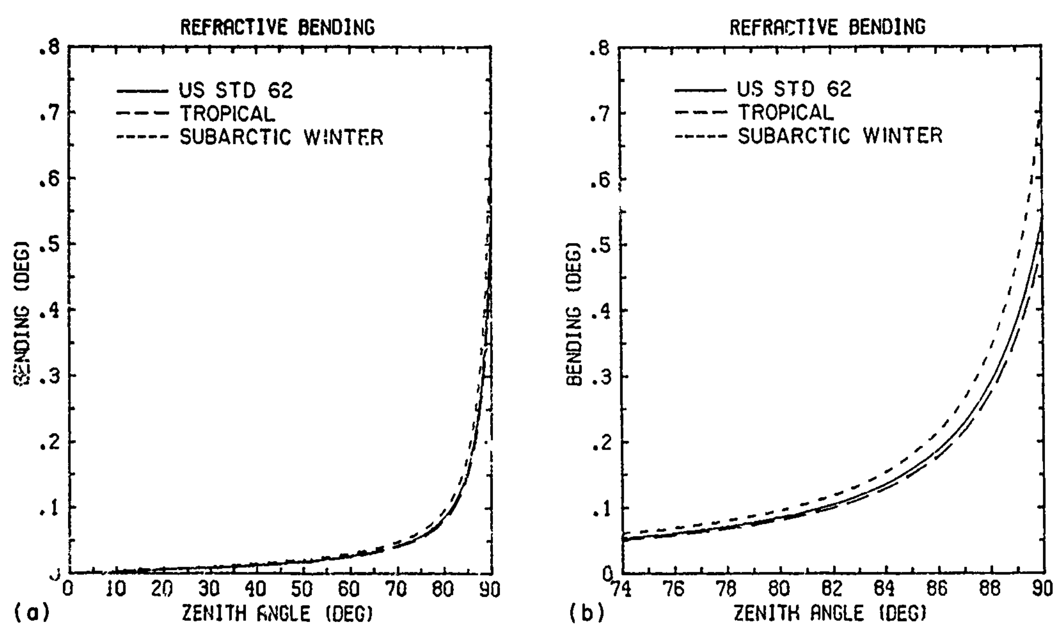


Figure 15. Refractive Bending vs Zenith Angle for Three Atmospheric Profiles for the Case H1 = 0, H2 = 100 km: (a) 0 to 90° and (b) 74 to 90°

Figure 14 for the three atmospheric profiles (the geometry is shown schematically in the inset). The total refractive bending is shown in Figure 15 vs zenith angle for a path from ground to space and in Figure 16 vs observer altitude for a path tangent at that altitude. Note that the total bending for a path from the ground at 90° for the U.S. Standard Atmosphere 1962 and for the tropical atmosphere is about 0.5°, which is the same as the solar diameter of 0.5°.

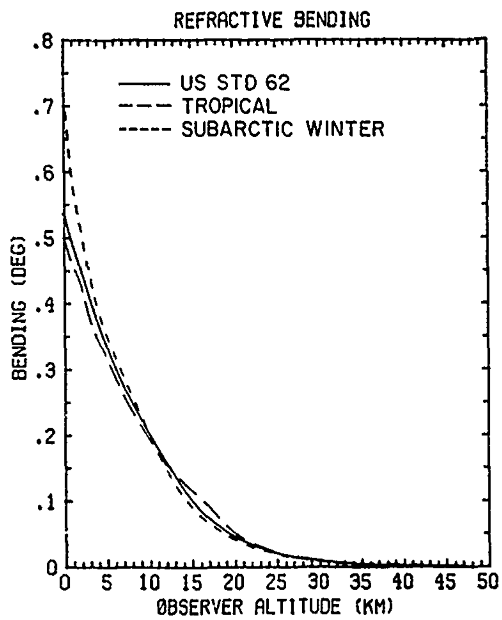


Figure 16. Refractive Bending vs Observer Altitude for Three Atmospheric Profiles for the Case H2 = space, ZENITH ANGLE = 90°

3. FSCATM: A PROGRAM TO CALCULATE AIR MASS

FSCATM calculates the integrated absorber amounts and density-weighted pressure and temperature for an arbitrary slant path through the atmosphere. FSCATM is specifically designed to calculate and format the atmospheric inputs for the atmospheric transmittance/radiance program FASCODE.[2] The form of the input parameters mimics as closely as possible the input parameters to the well known low resolution atmospheric transmittance/radiance program

LOWTRAN.[6] In fact, the core subroutines from FSCATM will replace the geometry subroutines in the next version of LOWTRAN. The six representative atmospheric profiles included in FSCATM are the same as in LOWTRAN although the densities are in different units.

3.1 Program Usage

Four standard control cards control the operation of FSCATM while other cards may be required to define non-standard conditions. The program input consists of a set of control cards read in on UNIT = 5 defining the atmospheric profile, the path, and the output layer boundaries. Output consists of a report written to UNIT = 6 providing a complete description of the profile, path, and absorber amounts and describing any error conditions encountered. Optionally, the mean pressure and temperature and the integrated absorber amounts for each layer are written to UNIT = 7. Examples of program input and output will be shown later in this section.

3.1.1 INPUT

The four standard atmospheric input control cards are shown in Table 1 and are discussed below.

3.1.1.1 Card 1 Model Parameters: MODEL, ITYPE, IBND, NOZERO, NOPRNT, KMAX, IPUNCH, RE

The parameter MODEL selects one of the six standard atmospheric profiles (1 to 6)* or allows the user to read in either a profile (MODEL = 7) or a set of horizontal path parameters (MODEL = 0). (See the section on non-standard conditions for the use of MODEL = 0 or 7.) ITYPE selects one of three types of path: (1) a horizontal path at constant temperature and pressure, (2) a slant path from H1 to H2, (3) a slant path from H1 to space (equal to the highest level in the atmospheric profile, 100 km for MODEL = 1 to 6). IBND controls the layering of the final output: If IBND = 0, the program automatically selects a set of output layers based on user-supplied parameters from Card 4. If IBND is greater than 0, the user directly inputs the output layer boundaries on Card 4.

Normally, the program will zero out the absorber amounts of a gas for a layer if the amount for that layer and those above it are less than 0.1 percent of the total amount. NOZERO = 1 suppresses this option. This option is used to

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*See Appendix A for a discussion of these atmospheric profiles.

6. Kneizys, F.X., Shettle, E.P., Gallery, W.O., Chetwynd, J.H., Jr., Abreu, L.W., Selby, J.E.A., Fenn, R.W., and McClatchey, R.A. (1980) Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 5, AFGL-TR-80-0067, AD A088215.

Table 1. FSCATM Control Cards

Control Card 1: MODEL, ITYPE, IBND, NOZERO, NOPRNT, KMAX, IPUNCH, RE
(7I5, 5X, F10. 4)

MODEL =	0: user-supplied horizontal path parameters
	1: tropical atmospheric model
	2: midlatitude summer
	3: midlatitude winter
	4: subarctic summer
	5: subarctic winter
	6: U. S. Standard Atmosphere 1962
	7: user-supplied atmospheric profile
ITYPE =	1: horizontal path (constant pressure)
	2: slant path from H1 to H2
	3: slant path from H1 to space
IBND	number of boundary altitudes for the FASOCD1 layers: IF IBND . GT. 0, user-supplied boundaries IF IBND . EQ. 0, auto layering is selected
NOZERO =	1: suppresses zeroing of small amounts Default = 0
NOPRNT =	1: selects short printout. Default = 0
KMAX	number of molecular species. Default = 7, max = 20. IF KMAX . LT. 0, a ray trace is done but no amounts are calculated.
IPUNCH =	1: write layer amounts to unit IPU=7. Default = 0.
RE	radius of the earth, defaults: MODEL = 1, RE = 6378.39 km; 2, 3, 6, 7, RE = 6371.23 km; 4, 5, RE = 6356.91 km

The formats for the remaining control cards are different depending on whether the path is horizontal (ITYPE=1) or slant (ITYPE=2 or 3).

For a slant path (ITYPE=2 or 3):

Control Card 2: H1, H2, ANGLE, RANGE, BETA, LEN
(5F10. 4, I5)

H1	altitude of the observer or receiver (km)
H2	altitude of the other endpoint of the path (ITYPE=2) or the tangent height (ITYPE=3)
ANGLE	zenith angle at H1 (degrees)
RANGE	length of the path from H1 to H2 (km):
BETA	earth centered angle for the path H1 to H2 (deg)
LEN	=0, short path; =1, long path through a tangent height. LEN is used only when ANGLE is greater than 90. 0 and H1 is greater than H2. Default = 0.

Control Card 3: V1, V2
(2F10. 3)

V1, V2	initial and final wavenumbers for use in calculating the Doppler halfwidth used in creating the FASCODE layers and in calculating the index of refraction (cm^{-1})

Table 1. FSCATM Control Cards (Contd)

Control Card 4:

IF IBND . EQ. 0 (autolayering selected)

AVTRAT, TDIFF1, TDIFF2 (3F10.3)
AVTRAT = max Voigt width ratio across a layer. Default = 2.0
TDIFF1 = max temp difference (K) across a layer at HMIN (=lowest altitude along the path). Default = 15.0 K
TDIFF2 = max temp difference (K) across a layer at HMAX (=highest altitude along the path). Default = 30.0 K

IF IBND . NE. 0 (user-supplied FASCOD1 layer boundaries)

(ZBND(IB), IB=1, IBND) (8F10.3)
ZBND altitudes of FASCOD1 layer boundaries

If MODEL=7, the input atmospheric profile is read in after Control Card 4 in the following format:

IMOD, HEADER(I5, /, 3A8)
IMOD = number of levels in the profile
HEADER = 24-character describing the profile

Z, P, T, TD, RH, PPH20, DENH10, AMSMIX (8F10.3)
(VMIX(K), K=1, KMAX) (8E10.3)
two (or more) card images for each of the IMOD levels. See the text for the definition and usages of TP, RH, PPH20, DENH20, AMSMIX, and VMIX.

For a horizontal path (ITYPE=1):

Control Card 2:

For MODEL = 1 to 7:
Z, RANGE (2F10.3)

For MODEL = 0:
RANGE, P, T, TD, RH, PPH20, DENH20, AMSMIX (8F10.3)
(VMIX(K), K=1, KMAX) (8E10.3)
where Z and RANGE are the altitude and range of the path, both in km. For MODEL = 1 to 7, the pressure, temperature, and densities are interpolated from the model atmosphere. For MODEL = 0, see the text for the definition and usages of TP, RH, PPH20, DENH20, AMSMIX, and VMIX. If the volume mixing ratio of O_3 is not supplied for MODEL = 0, it is computed using a value for the volume mixing ratio of 40. E-9.

Control Cards 3 and 4: not used

For MODEL = 7, the input atmospheric profile is read in after Control Card 2 as for a slant path.

save computation time in the line-by-line computation since the computation time is proportional to the number of spectral lines in the calculation. NOPRNT = 1 selects a short form of the output on UNIT = 6 by suppressing the printing of the tables of the atmospheric profile, the slant path, and the layer amounts. KMAX is the number of molecular species for which the amounts are calculated and defaults to 7. The order of the molecules corresponds to the order on the AFGL Atmospheric Line Parameters Compilation[7*] and the Trace Gas Compilation[8] and is listed in Table 2. To calculate amounts for molecules other than the first seven, the user must select the MODEL = 7 option and read in an atmospheric profile including the profiles of the desired molecules, up to at most 20. If KMAX is less than zero, a ray trace is performed but no amounts are calculated. RE is the radius of the earth in KM. It can be changed to account for variations in the radius with latitude or to model the atmosphere of other planets.

3.1.1.2 Card 2 Slant Path Parameters: H1, H2, ANGLE, RANGE, BETA, LEN

The format for Card 2 and following are different depending on whether ITYPE is 1 (horizontal path) or 2 or 3 (slant paths). The slant paths will be discussed first.

The slant path parameters are illustrated in Figure 17. Only two or three of the first five parameters on Card 2 need be specified to define the slant path. See Table 3 for the allowable combinations of slant path parameters. The distinction between H1 and H2 is important when calculating radiance, since the radiance for the path from H1 to H2 is not the same as that from H2 to H1. ANGLE is the apparent or measured zenith angle at H1 and is different from the astronomical or unrefracted zenith angle. Note from Table 3 that when RANGE is a supplied parameter, H2 or ANGLE is calculated assuming no refraction and the refracted path is followed using that value. The resulting path will have a value of RANGE different from the input value, and if the path goes through a tangent height, the difference can be substantial. The parameter LEN is demonstrated in Figure 18.

Certain combinations of slant path parameters represent impossible geometries, for example, H1 = 10 km, H2 = 5 km, ANGLE = 60 deg. These cases are flagged as errors and the program stops. If a slant path intersects the earth, for

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*For current version see Rothman, L. S. (1981) AFGL atmospheric absorption line parameters compilation: 1980 version, Appl. Opt. 20:791.

7. McClatchey, R.A., Benedict, W.S., Clough, S.A., Burch, D.E., Calfee, R.F., Fox, K., Rothman, L.S., and Garing, J.S. (1973) AFCRL Atmospheric Absorption Line Parameters Compilation, AFCRL-TR-73-0096, AD 762904.

8. Rothman, L.S., Goldman, A., Gillis, J.R., Tipping, R.H., Brown, L.R., Margolis, J.S., Maki, A.G., and Young, L.D.G. (1981) AFGL trace gas compilation: 1980 version, Appl. Opt. 20:1323-1328.

Table 2. Molecular Species

	Molecule	Mwt*	V†		Molecule	Mwt*	V†
1	H_2O	18.015	0	11	NH_3	17.03	0
2	CO_2	44.010	322	12	HNO_3	63.01	0
3	O_3	47.998	0	13	OH	17.00	0
4	N_2O	44.01	0.27	14	HF	20.01	0
5	CO	28.011	0.19	15	HCl	36.46	0
6	CH_4	16.043	1.5	16	HBr	80.92	0
7	O_2	31.999	2.0948×10^5	17	HI	127.91	0
8	NO	30.01	0	18	ClO	51.45	0
9	SO_2	64.06	0	19	OCS	60.08	0
10	NO_2	46.01	0	20	H_2CO	30.03	0

*Molecular weight, from CRC, Handbook of Chemistry and Physics, 1971. The molecular weight is the average for the various isotopes weighted by their natural abundance.

†Default volume-mixing ratio in parts per million used for MODEL = 7 from U.S. Standard Atmosphere 1976.[9]

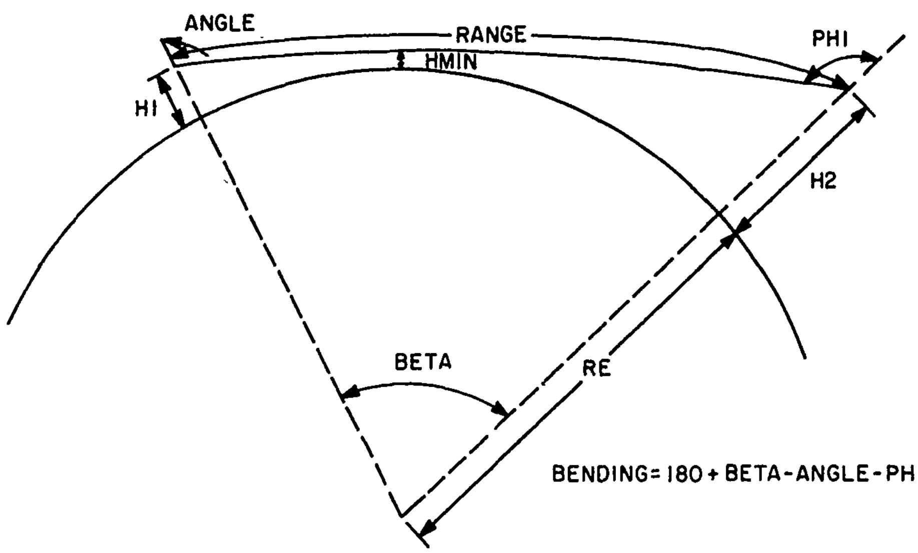

Figure 17. The Slant Path Parameters H1, H2, ANGLE, PHI, RANGE, BETA, and HMIN

9. (1976) U.S. Standard Atmosphere 1976, NOAA - S/T 76-1562, U.S. Government Printing Office.

Table 3. Allowable Combinations of Slant Path Parameters

Case	ITYPE	H1	H2	ANGLE	RANGE	BETA	LEN (Optional)
2A	2	*	*	*			(*)
2B	2	*		*	*		
2C	2	*	*		*		
2D	2	*	*			*	
3A	3	*		*			
3B	3	*	* (HMIN)				

2A: LEN option is available only when H1 > H2 and ANGLE > 90. Otherwise, LEN is set in the program.

2B: H2 calculated assuming no refraction. Calculated RANGE will differ from the input value.

2C: ANGLE calculated assuming no refraction. Calculated RANGE will differ from the input value.

2D: Exact ANGLE is calculated by iteration of the path calculation.

3B: H2 is interpreted as HMIN = tangent height. H2 is reset to highest profile boundary.

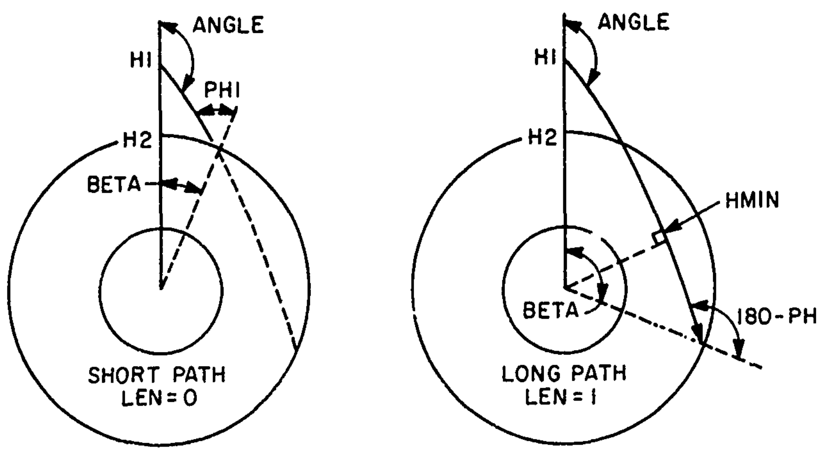

Figure 18. Demonstration of the Parameter LEN

example, H1 = 10 km, H2 = 20 km, ANGLE = 100 deg, the action of the program depends upon ITYPE. If ITYPE = 2, an error is flagged and the program stops. If ITYPE = 3, H2 is reset to 0, a message is printed, and the program continues.

It is possible to specify a value for H1 and/or H2 that is greater than the highest altitude in the atmospheric profile, for example, H1 might be a satellite altitude (for MODEL = 1 through 6, the highest boundary is at 100 km). In this case, the program resets H1 and/or H2 to the highest profile altitude ZMAX and recomputes ANGLE at ZMAX, assuming no refraction. This procedure is necessary because the density profiles above the top of the atmosphere are poorly defined and because the calculation time for the path above the atmosphere may be excessive (for example, for geosynchronous altitudes). Note also that for the Case 2D in Table 2 (H1, H2, BETA) H1 and H2 are not reset in the iterative calculation of ANGLE so this case can be relatively time-consuming.

3.1.1.3 Card 3 Frequency Range: V1, V2

The average of V1 and V2 is used to calculate the Doppler halfwidth used in creating the output layers and to calculate the index of refraction. V1 and V2 need not correspond to the range of the spectral calculation, if for example the user wants to run cases in two different spectral regions with identical paths and output layers.

3.1.1.4 Card 4 Output Layering

If IBND = 0 on Card 1, the program generates its own set of output layer boundaries based on the values of AVTRAT, TDIFF1, and TDIFF2. AVTRAT specifies the maximum allowable ratio of the Voigt halfwidth from one output boundary to the next highest for a molecule of molecular weight 36 and Lorentz halfwidth at 1013 mb and 296K of 0.1 cm^{-1}. TDIFF1 and TDIFF2 define the maximum allowable temperature difference across an output layer for a layer at HMIN and HMAX respectively. The actual temperature difference for a particular layer is determined by exponentially interpolating TDIFF1 and TDIFF2 to the altitude of bottom of the layer. The layers produced by this procedure will satisfy approximately both constraints. The defaults provided (AVTRAT = 2.0, TDIFF1 = 15K and TDIFF2 = 30K) will produce a set of output layers generally suitable for general survey calculations. The user should, however, experiment with finer layering and critically examine the results in view of his accuracy requirements.

If IBND is greater than zero, the user supplies its own output layer boundaries. These need not include the path endpoints and may extend above and below the endpoints. The program will edit this set of output boundaries to one that extends from the lowest to the highest altitude along the path and includes H1 or H2 if they fall in the middle. The zeroing option on Card 1 may further reduce this set of layers under certain circumstances.

3.1.1.5 Horizontal Path: Z, RANGE, P, T, TD, PPH20, DENH20, AMSMIX, VMIX

For a horizontal path (ITYPE = 1, MODEL = 0 or MODEL = 1 to 7), Card 2 contains the cnly remaining parameters that need be specified and the format is different for the two cases. For an ITYPE = 1, MODEL = 1 through 7 case, only the altitude Z and path length RANGE need be specified. The program will interpolate the pressure, temperature, and densities to the given altitude. For a MODEL = 0 case, the user must supply the path length, pressure P, temperature T, water vapor amount, and volume mixing ratios for the other gases. See the next section on non-standard profiles for the definitions and usages of the various water vapor parameters and the conventions regarding the uniformly mixed gases. If no value for the ozone volume-mixing ratio is supplied, the surface value of 40×10^{-9} ppmv is assumed, taken from U.S. Standard Atmosphere 1976.[9]

3.1.1.6 Non-Standard Profiles

The MODEL = 7 option on Card 1 allows the user to read in an atmospheric profile, for example, from a radiosonde ascent. The profile is read in after Card 4 for ITYPE = 2 or 3 and after Card 2 for ITYPE = 1. The necessary parameters for each level are: the altitude, pressure, temperature, water vapor amount, and volume mixing ratios of the other gases. The water vapor amount can be specified in any one of six ways: VMIX = volume mixing ratio (ppm), AMSMIX = mass mixing ratio (gm kg^{-1}), DENH20 = mass density (gm m^{-3}), PPH20 = partial pressure (mb), RH = relative humidity (percent), or TD = dew point (^{o}C). If more than one of these values is given for the same level, the first non-zero value in the above list is used. A dew-point temperature of zero is a valid input and is assumed if all the water vapor parameters are left zero. To specify no water vapor, specify any negative value for the volume mixing ratio. (The dew point temperature should not be confused with the wet bulb temperature of a wet and dry bulb thermometer.)

If the volume mixing ratios for the uniformly mixed gases (K = 2 = CO_2, 4 = N_2O, 5 = CO, 6 = CH_4, 7 = O_2) are not supplied, then the following values are used:

Default Volume-mixing Ratios

CO_2	N_2O	CO	CH_4	O_2
322×10^{-6}	0.27×10^{-6}	0.19×10^{-6}	1.5×10^{-6}	0.20948

These default values, especially for CO, are different from those used to calculate the densities for models 1 through 6 taken from Optical Properties of the Atmosphere, Third Edition.[4] If no profile for ozone is supplied, the ozone density is left at zero. To specify a zero density for a gas, read in any negative value for the volume mixing ratio.

3.1.2 OUTPUT

The program output consists of a descriptive report written to UNIT = 6 and optionally, the layer-by-layer results written to UNIT = 7. See the sample output following for examples of both outputs. The report on UNIT = 6 is largely self-explanatory. It should be noted, however, that the absorber amounts for a layer are for a single pass through the layer even if the path passes through the layer twice, as for a tangent path. The total amount listed does account for the two passes through a layer. Also, the parameter ZETA in the table of FASCODE output layer boundaries is defined as the ratio of the Lorentz to the Lorentz plus Doppler halfwidths (at half height).

The file written to UNIT = 7 consists of, first of all, a card with the number of layers to follow and 70 characters describing the atmospheric profile and the path. Next is the layer-by-layer data on two cards or more per layer. Card 1 contains the mean pressure, temperature, ICNTRL, and a 20-character layer description field. Card 2 contains the molecular absorber amounts in the order shown in Table 2 with the following exception. The amount in the eighth position is for N_2, which is used by FASCODE to calculate foreign broadened water-vapor continuum. The amounts for the remaining molecules start in position 9 beginning with molecule number 8 (NO). The ICNTRL parameter is used to describe the relationship between that layer and the rest of the path and is illustrated in Figure 19. For a tangent path, the layers that the path traverses twice (the symmetric layers) have ICNTRL = 2. The asymmetric layers (if any) on the near side of H1 have ICNTRL = 1, while the asymmetric layers (if any) on the far side

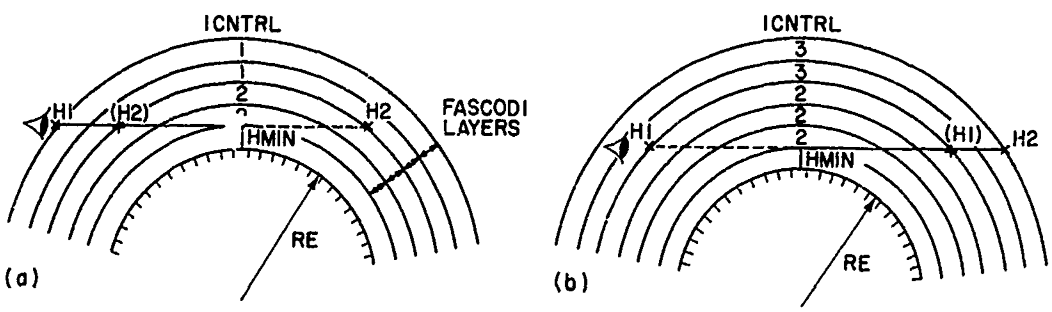

Figure 19. The Parameter ICNTRL for Two Tangent Paths

of H1 have ICNTRL = 3. For a path that is not a tangent path, then for a looking up case (H1 less the H2) ICNTRL = 3 and for a looking down case, ICNTRL = 1. For a horizontal path ICNTRL = 0.

3.2 Sample Input and Output

The input and output for four sample cases is listed in Table 4. Case 1, shown in Table 4a, models the conditions of a set of measurements taken at the South Pole.[10] These measurements were taken by a ground based instrument at 2.9 km elevation looking at the sun, with a solar zenith angle of 67.7°. On Card 1, the Subarctic Winter Atmosphere (MODEL = 5) was selected because it contains the least amount of water vapor. ITYPE = 3 selects a slant path from H1 to the top of the atmosphere profile, here 100 km. The remaining parameters on Card 1 are left zero to select the defaults. In particular, IBND = 0 causes the program to generate its own output layers on the basis of the parameters on Card 4.

On Card 2, H1 is the altitude of the observer, here 2.9 km, and ANGLE is the measured zenith angle at H1. The other parameters are left blank and are calculated by the program. On Card 3, the initial and final wavenumbers are simply averaged and the average value is used to calculate the index of refraction and to produce the output layering. Card 4 is left blank to select the defaults that are 2.0, 15.0, and 30.0 for AVTRAT, TDIFF1 and TDIFF2 respectively.

The first page of the output for this case simply echoes the input cards and shows the supplied default values. A list of the atmospheric profiles follows. Next the path parameters are shown reduced to the standard form H1, H2, ANGLE, PHI, HMIN, and LEN: any allowed set of parameters (see Table 3) is reduced to this form. The output layer boundaries generated internally are shown next. These boundaries satisfy the requirements that: (1) the ratio of the average Voigt width across a layer is less than AVTRAT and, (2) the temperature difference across a layer is less than TDIFF. The value of TDIFF at any altitude is found by exponentially interpolating TDIFF1 and TDIFF2 to that altitude. A selected boundary is always rounded down to the nearest 0.1 km. In this case the temperature criterion determines the thickness of the first two layers while the Voigt ratio determines the next five. The Voigt ratio algorithm is only approximate so that the actual Voigt ratio may be slightly more than AVTRAT. The parameter ZETA is the ratio of the Lorentz to the Lorentz plus Doppler halfwidths.

---

10. Blatherwick, R.D., Murcray, F.J., Murcray, F.H., Goldman, A., and Murcray, D.G. (1982) Atlas of south pole IR solar spectra, Appl. Opt. 21:2658-2659.

Table 4a. Sample Input and Output - Case 1

```
*****INPUT CASE 1*************************************************************************************************
   5    3
      2.9                  67.7
    880.0       890.0
      0.0         0.0       0.0

*****OUTPUT CASE 1************************************************************************************************

1                     *****PROGRAM FSCATM*****       01/11/83       11.03.08.


 CONTROL CARD 1: MODEL AND OPTIONS

          MODEL     =      5
          ITYPE     =      3
          IBND      =      0
          NOZERO    =      0
          NOPRNT    =      0
          KMAX      =      0
          IPUNCH    =      0
          RE        =       0.000 KM


 CONTROL CARD 1 PARAMETERS WITH DEFAULTS:

          MODEL     =      5
          ITYPE     =      3
          IBND      =      0
          NOZERO    =      0
          NOPRNT    =      0
          KMAX      =      7
          IPUNCH    =      0
          RE        =   6356.910 KM


 SLANT PATH SELECTED, ITYPE =     3


 CONTROL CARD 2:  SLANT PATH PARAMETERS

          H1        =      2.9000 KM
          H2        =      0.0000 KM
          ANGLE     =     67.7000 DEG
          RANGE     =      0.0000 KM
          BETA      =      0.0000 DEG
          LEN       =           0
```

Table 4a. Sample Input and Output - Case 1 (Contd)

```
CONTROL CARD 3

         V1     =     880.000 CM-1
         V2     =     890.000 CM-1
         VBAR   =     885.000 CM-1


AUTOLAYERING SELECTED

         AVTRAT    =     2.00
         TDIFF1    =    15.00
         TDIFF2    =    30.00
1ATMOSPHERIC PROFILE SELECTED IS: M =   5     SUBARCTIC WINTER
```

I	Z (KM)	P (MB)	T (K)	REFRACT INDEX-1 *1.0E6	DENSITY (MOLS CM-3) AIR	H2O	CO2	O3	N2O	CO	CH4	O2
1	0.000	1013.000	257.100	305.153	2.85E+19	4.01E+16	9.41E+15	5.15E+11	7.98E+12	2.14E+12	4.56E+13	5.97E+18
2	1.000	887.800	259.100	265.366	2.48E+19	4.01E+16	8.18E+15	5.15E+11	6.94E+12	1.86E+12	3.97E+13	5.19E+18
3	2.000	777.500	255.900	235.010	2.20E+19	3.14E+16	7.25E+15	5.15E+11	6.16E+12	1.65E+12	3.52E+13	4.07E+18
4	3.000	679.800	252.700	208.354	1.95E+19	2.27E+16	6.43E+15	5.40E+11	5.45E+12	1.46E+12	3.12E+13	4.08E+18
5	4.000	593.200	247.700	185.492	1.73E+19	1.37E+16	5.72E+15	5.65E+11	4.86E+12	1.30E+12	2.77E+13	3.63E+18
6	5.000	515.800	240.900	165.051	1.55E+19	6.69E+15	5.12E+15	5.90E+11	4.34E+12	1.16E+12	2.48E+13	3.25E+18
7	6.000	446.700	234.100	147.808	1.38E+19	3.28E+15	4.56E+15	6.15E+11	3.87E+12	1.04E+12	2.21E+13	2.90E+18
8	7.000	385.300	227.300	131.307	1.23E+19	1.81E+15	4.05E+15	8.91E+11	3.44E+12	9.21E+11	1.97E+13	2.57E+18
9	8.000	330.800	220.600	116.160	1.09E+19	3.68E+14	3.59E+15	1.13E+12	3.04E+12	8.15E+11	1.74E+13	2.28E+18
10	9.000	282.900	217.200	100.895	9.43E+18	2.81E+14	3.11E+15	2.01E+12	2.64E+12	7.08E+11	1.51E+13	1.98E+18
11	10.000	241.800	217.200	86.237	8.06E+18	1.84E+14	2.66E+15	3.01E+12	2.26E+12	6.05E+11	1.29E+13	1.69E+18
12	11.000	206.700	217.200	73.719	6.89E+18	1.27E+14	2.28E+15	4.02E+12	1.93E+12	5.17E+11	1.10E+13	1.44E+18
13	12.000	176.600	217.200	62.984	5.89E+18	8.69E+13	1.94E+15	5.40E+12	1.65E+12	4.42E+11	9.43E+12	1.23E+18
14	13.000	151.000	217.200	53.854	5.04E+18	6.02E+13	1.66E+15	5.90E+12	1.41E+12	3.78E+11	8.06E+12	1.06E+18
15	14.000	129.100	217.200	46.043	4.31E+18	3.34E+13	1.42E+15	6.15E+12	1.21E+12	3.23E+11	6.89E+12	9.02E+17
16	15.000	110.300	217.200	39.338	3.68E+18	2.54E+13	1.21E+15	7.03E+12	1.03E+12	2.76E+11	5.89E+12	7.71E+17
17	16.000	94.310	216.600	33.728	3.15E+18	2.14E+13	1.04E+15	7.78E+12	8.83E+11	2.37E+11	5.05E+12	6.61E+17
18	17.000	80.580	216.000	28.893	2.70E+18	1.87E+13	3.92E+14	7.78E+12	7.57E+11	2.03E+11	4.33E+12	5.66E+17
19	18.000	68.820	215.400	24.749	2.31E+18	1.67E+13	7.64E+14	7.78E+12	6.48E+11	1.74E+11	3.70E+12	4.85E+17
20	19.000	58.750	214.800	21.187	1.98E+18	1.64E+13	6.54E+14	7.53E+12	5.55E+11	1.49E+11	3.17E+12	4.15E+17
21	20.000	50.140	214.100	18.141	1.70E+18	1.51E+13	5.60E+14	7.03E+12	4.75E+11	1.27E+11	2.72E+12	3.56E+17
22	21.000	42.770	213.600	15.511	1.45E+18	1.71E+13	4.79E+14	6.40E+12	4.06E+11	1.09E+11	2.32E+12	3.04E+17
23	22.000	36.470	213.000	13.263	1.24E+18	1.71E+13	4.09E+14	5.90E+12	3.47E+11	9.30E+10	1.99E+12	2.60E+17
24	23.000	31.090	212.400	11.339	1.06E+18	1.81E+13	3.50E+14	5.40E+12	2.97E+11	7.95E+10	1.70E+12	2.22E+17
25	24.000	26.490	211.800	9.688	9.06E+17	2.01E+13	2.99E+14	4.52E+12	2.54E+11	6.80E+10	1.45E+12	1.90E+17
26	25.000	22.560	211.200	8.274	7.74E+17	2.24E+13	2.55E+14	4.02E+12	2.17E+11	5.80E+10	1.24E+12	1.62E+17
27	30.000	10.200	216.000	3.658	3.42E+17	1.20E+13	1.13E+14	1.66E+12	9.58E+10	2.57E+10	5.47E+11	7.17E+16
28	35.000	4.701	222.200	1.639	1.53E+17	3.68E+12	5.06E+13	1.16E+12	4.29E+10	1.15E+10	2.45E+11	3.21E+16
29	40.000	2.243	234.700	.740	6.92E+16	1.44E+12	2.29E+13	5.15E+11	1.94E+10	5.19E+09	1.11E+11	1.45E+16
30	45.000	1.113	247.000	.349	3.26E+16	6.35E+11	1.08E+13	1.63E+11	9.14E+09	2.45E+09	5.22E+10	6.84E+15
31	50.000	.572	259.300	.171	1.60E+16	2.11E+11	5.27E+12	5.40E+10	4.47E+09	1.20E+09	2.56E+10	3.35E+15
32	70.000	.040	245.700	.013	1.18E+15	4.69E+09	3.91E+11	1.08E+09	3.32E+08	8.88E+07	1.90E+09	2.49E+14
33	100.000	.000	210.000	.000	1.03E+13	3.34E-07	3.42E+09	5.40E+05	2.90E+06	7.76E+05	1.66E+07	2.17E+12

Table 4a. Sample Input and Output - Case 1 (Contd)

```
CASE 3A: GIVEN H1,H2=SPACE,ANGLE


SLANT PATH PARAMETERS IN STANDARD FORM

        H1      =     2.900 KM
        H2      =   100.000 KM
        ANGLE   =    67.700 DEG
        PHI     =   114.288 DEG
        HMIN    =     2.900 KM
        LEN     =         0


FASCODE LAYER BOUNDARIES PRODUCED BY THE AUTOMATIC LAYERING ROUTINE AUTLAY
THE USER SHOULD EXAMINE THESE BOUNDARIES AND MODIFY THEM IF APPROPRIATE
THE FOLLOWING PARAMETERS ARE USED:

        AVTRAT  =     2.00        = MAX RATIO OF VOIGT WIDTHS
        TDIFF1  =    15.00        = MAX TEMP DIFF AT HMIN
        TDIFF2  =    30.00        = MAX TEMP DIFF AT HMAX
        ALZERO  =      .100 CM-1  = AVERAGE LORENTZ WIDTH AT STP
        AVMWT   =    36.00        = AVERAGE MOLECULAR WEIGHT
        VBAR    =   885.00  CM-1  = AVERAGE WAVENUMBER
```

I	Z (KM)	P (MB)	T (K)	LORENTZ (CM-1)	DOPPLER (CM-1)	ZETA	VOIGT (CM-1)	VOIGT RATIO	TEMP DIFF (K)
1	2.900	698.990	253.020	.07355	.00084	.989	.07356	1.37	14.8
2	5.400	486.962	238.160	.05358	.00082	.985	.05359	1.34	14.9
3	7.600	351.608	223.280	.03995	.00079	.981	.03997	1.99	6.1
4	12.100	173.856	217.200	.02003	.00078	.963	.02006	1.98	.9
5	16.500	87.175	216.300	.01006	.00078	.928	.01012	1.99	2.7
6	21.000	42.770	213.600	.00497	.00077	.866	.00509	2.02	1.5
7	25.900	19.556	212.064	.00228	.00077	.748	.00252	2.04	7.7
8	33.000	6.408	219.720	.00073	.00078	.484	.00123	1.33	18.4
9	41.400	1.843	238.144	.00020	.00082	.199	.00092	1.05	19.7
10	49.400	.619	257.824	.00007	.00085	.072	.00088	1.08	20.8
11	77.300	.012	237.013	.00000	.00081	.002	.00081	1.06	25.5
12	98.700	.000	211.547	.00000	.00077	.000	.00077	1.00	1.5
13	100.000	.000	210.000	.00000	.00077	.000	.00077	0.00	0.0

1CALCULATION OF THE REFRACTED PATH THROUGH THE ATMOSPHERE

I	ALTITUDE FROM (KM)	ALTITUDE TO (KM)	THETA (DEG)	DRANGE (KM)	RANGE (KM)	DBETA (DEG)	BETA (DEG)	PHI (DEG)	DBEND (DEG)	BENDING (DEG)	PBAR (MB)	TBAR (K)	RHOBAR (MOL CM-3)
	H1 TO H2												
1	2.900	3.000	67.700	.264	.264	.002	.002	112.302	.000	.000	684.394	252.860	1.96E+19
2	3.000	4.000	67.698	2.634	2.898	.022	.024	112.321	.003	.004	636.356	250.240	1.84E+19

Table 4a. Sample Input and Output - Case 1 (Contd)

3	4.000	5.000	67.679	2.632	5.530	.022	.046	112.340	.003	.006	554.321	244.348	1.64E+19
4	5.000	5.400	67.660	1.052	5.582	.009	.055	112.348	.001	.007	501.354	239.548	1.52E+19
5	5.400	6.000	67.652	1.578	8.159	.013	.068	112.359	.001	.009	466.773	236.158	1.43E+19
6	6.000	7.000	67.641	2.628	10.787	.022	.090	112.379	.002	.011	415.849	230.750	1.30E+19
7	7.000	7.600	67.621	1.576	12.363	.013	.103	112.391	.001	.012	368.404	225.309	1.18E+19
8	7.600	8.000	67.609	1.050	13.413	.009	.112	112.399	.001	.013	341.183	221.948	1.11E+19
9	8.000	9.000	67.601	2.623	16.036	.022	.134	112.418	.002	.015	306.788	218.936	1.01E+19
10	9.000	10.000	67.582	2.621	18.657	.022	.155	112.438	.002	.017	262.350	217.200	8.73E+18
11	10.000	11.000	67.562	2.619	21.276	.022	.177	112.458	.002	.019	224.250	217.200	7.46E+18
12	11.000	12.000	67.542	2.617	23.892	.022	.199	112.478	.001	.021	191.650	217.200	6.38E+18
13	12.000	12.100	67.522	.262	24.154	.002	.201	112.480	.000	.021	175.228	217.200	5.84E+18
14	12.100	13.000	67.520	2.353	26.507	.020	.221	112.499	.001	.022	162.428	217.200	5.41E+18
15	13.000	14.000	67.501	2.612	29.119	.022	.242	112.519	.001	.023	140.050	217.200	4.66E+18
16	14.000	15.000	67.481	2.610	31.729	.022	.264	112.540	.001	.024	119.700	217.200	3.98E+18
17	15.000	16.000	67.460	2.608	34.336	.022	.286	112.561	.001	.025	102.301	216.908	3.41E+18
18	16.000	16.500	67.439	1.303	35.639	.011	.296	112.571	.000	.025	90.742	216.452	3.03E+18
19	16.500	17.000	67.429	1.302	36.942	.011	.307	112.582	.000	.025	83.877	216.152	2.81E+18
20	17.000	18.000	67.418	2.603	39.545	.022	.329	112.603	.001	.026	74.697	215.708	2.50E+18
21	18.000	19.000	67.397	2.601	42.145	.022	.350	112.624	.000	.026	63.783	215.108	2.14E+18
22	19.000	20.000	67.376	2.598	44.744	.022	.372	112.645	.000	.027	54.443	214.459	1.83E+18
23	20.000	21.000	67.355	2.596	47.340	.022	.394	112.666	.000	.027	46.454	213.856	1.57E+18
24	21.000	22.000	67.334	2.594	49.934	.021	.415	112.688	.000	.027	39.619	213.308	1.34E+18
25	22.000	23.000	67.312	2.592	52.525	.021	.436	112.709	.000	.028	33.779	212.708	1.15E+18
26	23.000	24.000	67.291	2.589	55.114	.021	.458	112.730	.000	.028	28.789	212.108	9.81E+17
27	24.000	25.000	67.270	2.587	57.701	.021	.479	112.751	.000	.028	24.524	211.508	8.38E+17
28	25.000	25.900	67.249	2.326	60.027	.019	.499	112.770	.000	.028	21.059	211.621	7.20E+17
29	25.900	30.000	67.230	10.574	70.602	.087	.586	112.857	.000	.029	14.894	213.807	4.87E+17
30	30.000	33.000	67.143	7.713	78.315	.064	.650	112.921	.000	.029	8.310	217.705	2.71E+17
31	33.000	35.000	67.079	5.131	83.446	.042	.692	112.963	.000	.029	5.556	220.891	1.81E+17
32	35.000	40.000	67.037	12.788	96.234	.105	.798	113.068	.000	.029	3.484	227.571	1.06E+17
33	40.000	41.400	66.932	3.571	99.805	.029	.827	113.098	.000	.029	2.044	236.357	6.24E+16
34	41.400	45.000	66.902	9.162	108.967	.075	.902	113.173	.000	.029	1.481	242.146	4.33E+16
35	45.000	49.400	66.827	11.160	120.127	.092	.994	113.265	.000	.029	.868	251.807	2.42E+16
36	49.400	50.000	66.735	1.519	121.646	.012	1.007	113.278	.000	.029	.596	258.551	1.67E+16
37	50.000	70.000	66.722	50.191	171.837	.411	1.418	113.689	.000	.029	.305	255.121	5.70E+15
38	70.000	77.300	66.311	18.117	189.954	.148	1.565	113.836	.000	.029	.026	242.153	7.02E+14
39	77.300	98.700	66.164	52.512	242.465	.426	1.992	114.263	.000	.029	.006	230.191	1.07E+14
40	98.700	100.000	65.737	3.162	245.627	.026	2.017	114.288	.000	.029	.000	210.799	1.15E+13

1INTEGRATED ABSORBER AMOUNTS BY LAYER

I	LAYER BOUNDARIES		INTEGRATED AMOUNTS (MOL CM-2)							
	FROM	TO	AIR	H2O	CO2	O3	N2O	CO	CH4	O2
1	2.900	3.000	5.166E+23	6.091E+20	1.703E+20	1.419E+16	1.445E+17	3.871E+16	8.259E+17	1.075E+23
2	3.000	4.000	4.845E+24	4.701E+21	1.598E+21	1.454E+17	1.356E+18	3.631E+17	7.747E+18	1.014E+24
3	4.000	5.000	4.319E+24	2.575E+21	1.425E+21	1.519E+17	1.209E+18	3.238E+17	6.908E+18	9.046E+23
4	5.000	5.400	1.595E+24	6.121E+20	5.262E+20	6.258E+16	4.465E+17	1.196E+17	2.551E+18	3.341E+23
5	5.400	6.000	2.257E+24	6.452E+20	7.450E+20	9.581E+16	6.321E+17	1.694E+17	3.613E+18	4.730E+23
6	6.000	7.000	3.425E+24	6.487E+20	1.130E+21	1.956E+17	9.590E+17	2.569E+17	5.481E+18	7.177E+23
7	7.000	7.600	1.865E+24	1.833E+20	6.155E+20	1.508E+17	5.223E+17	1.399E+17	2.985E+18	3.908E+23
8	7.600	8.000	1.169E+24	5.399E+19	3.858E+20	1.131E+17	3.273E+17	8.768E+16	1.870E+18	2.449E+23
9	8.000	9.000	2.658E+24	8.457E+19	8.772E+20	4.005E+17	7.443E+17	1.994E+17	4.253E+16	5.569E+23
10	9.000	10.000	2.288E+24	6.002E+19	7.554E+20	6.490E+17	6.408E+17	1.717E+17	3.663E+18	4.796E+23
11	10.000	11.000	1.954E+24	4.027E+19	6.451E+20	9.140E+17	5.474E+17	1.466E+17	3.128E+18	4.095E+23
12	11.000	12.000	1.669E+24	2.767E+19	5.508E+20	1.223E+18	4.674E+17	1.252E+17	2.671E+18	3.496E+23

Table 4a. Sample Input and Output - Case 1 (Contd)

13	12.000	12.100	1.528E+23	2.232E+18	5.045E+19	1.418E+17	4.279E+16	1.146E+16	2.446E+17	3.202E+22
14	12.100	13.000	1.272E+24	1.678E+19	4.200E+20	1.334E+18	3.563E+17	9.546E+16	2.036E+18	2.666E+23
15	13.000	14.000	1.217E+24	1.189E+19	4.018E+20	1.573E+18	3.410E+17	9.134E+16	1.948E+18	2.551E+23
16	14.000	15.000	1.040E+24	7.632E+18	3.431E+20	1.717E+18	2.912E+17	7.800E+16	1.664E+18	2.179E+23
17	15.000	16.000	8.890E+23	6.088E+18	2.934E+20	1.929E+18	2.490E+17	6.670E+16	1.423E+18	1.863E+23
18	16.000	16.500	3.954E+23	2.697E+18	1.305E+20	1.014E+18	1.108E+17	2.967E+16	6.328E+17	8.287E+22
19	16.500	17.000	3.659E+23	2.521E+18	1.208E+20	1.013E+18	1.025E+17	2.745E+16	5.856E+17	7.668E+22
20	17.000	18.000	6.515E+23	4.608E+18	2.151E+20	2.025E+18	1.825E+17	4.868E+16	1.043E+18	1.366E+23
21	18.000	19.000	5.574E+23	4.304E+18	1.840E+20	1.991E+18	1.561E+17	4.181E+16	8.922E+17	1.168E+23
22	19.000	20.000	4.768E+23	4.081E+18	1.574E+20	1.891E+18	1.335E+17	3.577E+16	7.632E+17	9.993E+22
23	20.000	21.000	4.076E+23	4.161E+18	1.345E+20	1.742E+18	1.142E+17	3.058E+16	6.524E+17	8.542E+22
24	21.000	22.000	3.482E+23	4.422E+18	1.149E+20	1.594E+18	9.752E+16	2.612E+16	5.573E+17	7.297E+22
25	22.000	23.000	2.975E+23	4.549E+18	9.820E+19	1.462E+18	8.330E+16	2.232E+16	4.761E+17	6.234E+22
26	23.000	24.000	2.540E+23	4.931E+18	8.385E+19	1.280E+18	7.113E+16	1.906E+16	4.066E+17	5.323E+22
27	24.000	25.000	2.168E+23	5.486E+18	7.156E+19	1.103E+18	6.072E+16	1.626E+16	3.470E+17	4.542E+22
28	25.000	25.900	1.674E+23	4.930E+18	5.525E+19	8.733E+17	4.688E+16	1.256E+16	2.678E+17	3.507E+22
29	25.900	30.000	5.150E+23	1.660E+19	1.700E+20	2.760E+18	1.442E+17	3.863E+16	8.241E+17	1.079E+23
30	30.000	33.000	2.094E+23	6.645E+18	6.911E+19	1.258E+18	5.864E+16	1.571E+16	3.351E+17	4.388E+22
31	33.000	35.000	9.271E+22	2.415E+18	3.060E+19	6.544E+17	2.597E+16	6.958E+15	1.484E+17	1.943E+22
32	35.000	40.000	1.352E+23	3.051E+18	4.464E+19	1.013E+18	3.788E+16	1.015E+16	2.165E+17	2.834E+22
33	40.000	41.400	2.229E+22	4.590E+17	7.357E+18	1.571E+17	6.243E+15	1.672E+15	3.568E+16	4.672E+21
34	41.400	45.000	3.968E+22	7.925E+17	1.310E+19	2.325E+17	1.112E+16	2.977E+15	6.352E+16	8.317E+21
35	45.000	49.400	2.704E+22	4.537E+17	8.925E+18	1.164E+17	7.574E+15	2.029E+15	4.329E+16	5.668E+21
36	49.400	50.000	2.533E+21	3.420E+16	8.361E+17	8.763E+15	7.094E+14	1.900E+14	4.055E+15	5.309E+20
37	50.000	70.000	2.862E+22	2.727E+17	9.447E+18	6.814E+16	8.016E+15	2.147E+15	4.581E+16	5.998E+21
38	70.000	77.300	1.272E+21	4.936E+15	4.204E+17	8.914E+14	3.567E+14	9.554E+13	2.038E+15	2.669E+20
39	77.300	98.700	5.617E+20	2.042E+15	1.658E+17	1.645E+14	1.576E+14	4.222E+13	9.007E+14	1.179E+20
40	98.700	100.000	3.631E+18	1.179E+13	1.199E+15	2.021E+11	1.017E+12	2.725E+11	5.813E+12	7.610E+17
0TOTAL	2.900	100.000	3.834E+25	1.036E+22	1.265E+22	3.307E+19	1.074E+19	2.876E+18	6.136E+19	8.033E+24

```
1 SUMMARY OF THE GEOMETRY CALCULATION

         MODEL    =     SUBARCTIC WINTER
         H1       =       2.900 KM
         H2       =     100.000 KM
         ANGLE    =      67.700 DEG
         RANGE    =     245.627 KM
         BETA     =       2.017 DEG
         PHI      =     114.298 DEG
         HMIN     =       2.900 KM
         BENDING  =        .029 DEG
         LEN      =           0
         AIRMAS   =    1.78     RELATIVE TO A VERTICAL PATH , GROUND TO SPACE
0FINAL SET OF LAYERS FOR INPUT TO FASCOD1
 A LAYER AMOUNT MAY BE SET TO ZERO IF THE CUMULATIVE AMOUNT FOR THAT LAYER AND ABOVE IS LESS THAN 0.1 PERCENT
 OF THE TOTAL AMOUNT. THIS IS DONE ONLY FOR THE FOLLOWING CASES
     1.  IEMIT = 0 (TRANSMITTANCE)
     2.  IEMIT = 1 (RADIANCE) AND ICNTRL = 3 (PATH LOOKING UP)
 O2 IS NOT INCLUDED
 IF THE AMOUNTS FOR ALL THE MOLECULES BUT O2 ARE ZEROED, THE REMAINING LAYERS ARE ELIMINATED


    L   LAYER BOUNDARIES ICNTRL  PBAR     TBAR               INTEGRATED AMOUNTS (MOLS CM-2)
          FROM       TO
          (KM)      (KM)          (MB)     (K)     AIR    H2O     CO2     O3     N2O     CO     CH4     O2
```

Table 4a. Sample Input and Output - Case 1 (Contd)

1	2.900	5.400	3	589.04	246.59	1.13E+25	8.50E+21	3.72E+21	3.74E+17	3.16E+18	8.45E+17	1.80E+19	2.36E+24
2	5.400	7.600	3	419.36	231.02	7.55E+24	1.48E+21	2.49E+21	4.42E+17	2.11E+18	5.66E+17	1.21E+19	1.56E+24
3	7.600	12.100	3	262.80	218.23	9.89E+24	2.69E+20	3.26E+21	3.44E+18	2.77E+18	7.42E+17	1.58E+19	2.07E+24
4	12.100	16.500	3	130.55	217.08	4.81E+24	4.51E+19	1.59E+21	7.57E+18	1.35E+18	3.61E+17	7.70E+18	1.01E+24
5	16.500	21.000	3	64.98	215.09	2.46E+24	1.97E+19	8.12E+20	8.66E+18	6.89E+17	1.84E+17	3.94E+18	5.15E+23
6	21.000	25.900	3	31.15	212.41	1.28E+24	2.43E+19	4.24E+20	6.31E+18	3.60E+17	9.63E+16	2.05E+18	2.69E+23
7	25.900	33.000	3	12.99	214.93	7.24E+23	2.32E+19	2.39E+20	4.02E+18	2.03E+17	5.43E+16	1.16E+18	1.52E+23
8	33.000	41.400	3	4.12	225.88	2.50E+23	0.	8.26E+19	1.82E+18	7.01E+16	1.88E+16	4.01E+17	5.24E+22	
9	41.400	49.400	3	1.23	246.06	6.67E+22	0.	2.20E+19	3.49E+17	1.87E+16	5.01E+15	1.07E+17	1.40E+22	
10	49.400	77.300	3	.32	254.88	3.24E+22	0.	0.	7.78E+16	0.	0.	0.	6.80E+21	

Table 4b. Sample Input and Output - Case 2

```
*****INPUT CASE 2*******************************************************************************************
    7    3                  20
     33.0                94.87
    820.0      830.0
      2.0       50.0      50.0
   36
S  7G + TRACE GASES
   0.0000  1013.2500  288.1500
 .100E+05  .322E+03  .330E-01  .320E+00  .150E+00  .170E+01  .209E+06  .300E-03
 .300E-03  .300E-03  .130E-02  .300E-04  .440E-07  .100E-07  .100E-03  .170E-05
 .300E-05  .100E-06  .600E-03  .240E-02
   2.0000  795.0100  275.1540
 .970E+04  .322E+03  .330E-01  .320E+00  .140E+00  .170E+01  .209E+06  .300E-03
 .250E-03  .300E-03  .120E-02  .400E-04  .440E-07  .100E-07  .650E-04  .170E-05
 .300E-05  .100E-06  .580E-03  .300E-03
   4.0000  616.6000  262.1660
 .380E+04  .322E+03  .340E-01  .320E+00  .130E+00  .170E+01  .209E+06  .300E-03
 .140E-03  .300E-03  .100E-02  .500E-04  .440E-07  .300E-07  .330E-04  .170E-05
 .300E-05  .100E-06  .560E-03  .130E-03
   6.0000  472.1700  249.1870
 .150E+04  .322E+03  .410E-01  .320E+00  .130E+00  .170E+01  .209E+06  .300E-03
 .950E-04  .300E-03  .850E-03  .700E-04  .440E-07  .900E-07  .260E-04  .170E-05
 .300E-05  .120E-06  .550E-03  .700E-04
   8.0000  356.5100  236.2150
 .650E+03  .322E+03  .600E-01  .320E+00  .120E+00  .160E+01  .209E+06  .300E-03
 .700E-04  .300E-03  .700E-03  .800E-04  .440E-07  .230E-06  .220E-04  .170E-05
 .300E-05  .150E-06  .530E-03  .500E-04
  10.0000  264.9900  223.2520
 .200E+02  .322E+03  .130E+00  .320E+00  .100E+00  .160E+01  .209E+06  .300E-03
 .600E-04  .300E-03  .550E-03  .900E-04  .470E-07  .600E-06  .240E-04  .170E-05
 .300E-05  .200E-06  .520E-03  .340E-04
  12.0000  193.9900  216.6500
 .600E+01  .322E+03  .310E+00  .310E+00  .800E-01  .160E+01  .209E+06  .300E-03
 .550E-04  .300E-03  .400E-03  .100E-03  .490E-07  .200E-05  .300E-04  .170E-05
 .300E-05  .400E-06  .500E-03  .330E-04
  14.0000  141.7000  216.6500
 .290E+01  .322E+03  .500E+00  .300E+00  .500E-01  .150E+01  .209E+06  .300E-03
 .560E-04  .330E-03  .300E-03  .200E-03  .530E-07  .450E-05  .100E-04  .170E-05
 .300E-05  .700E-06  .470E-03  .370E-04
  16.0000  103.5200  216.6500
 .320E+01  .322E+03  .850E+00  .290E+00  .300E-01  .150E+01  .209E+06  .270E-03
 .600E-04  .350E-03  .100E-03  .300E-03  .810E-07  .100E-04  .250E-03  .170E-05
 .300E-05  .130E-05  .390E-03  .360E-04
  18.0000   75.6520  216.6500
 .340E+01  .322E+03  .160E+01  .270E+00  .200E-01  .140E+01  .209E+06  .230E-03
 .500E-04  .400E-03  .100E-04  .110E-02  .130E-06  .250E-04  .400E-03  .170E-05
 .300E-05  .250E-05  .310E-03  .340E-04
  20.0000   55.2930  216.6500
 .350E+01  .322E+03  .260E+01  .240E+00  .150E-01  .130E+01  .209E+06  .250E-03
 .310E-04  .900E-03  .100E-05  .200E-02  .190E-06  .600E-04  .500E-03  .170E-05
 .300E-05  .600E-05  .240E-03  .330E-04
  22.0000   40.4750  218.5740
```

Table 4b. Sample Input and Output - Case 2 (Contd)

.350E+01	.322E+03	.360E+01	.200E+00	.160E-01	.110E+01	.209E+06	.300E-03
.220E-04	.120E-02	.100E-06	.300E-02	.520E-06	.100E-03	.550E-03	.170E-05
.300E-05	.100E-04	.190E-03	.400E-04				
24.0000	29.7170	220.5600					
.350E+01	.322E+03	.470E+01	.160E+00	.170E-01	.100E+01	.209E+06	.400E-03
.190E-04	.220E-02	.100E-06	.400E-02	.100E-05	.150E-03	.600E-03	.170E-05
.300E-05	.200E-04	.140E-03	.500E-04				
26.0000	21.8830	222.5440					
.370E+01	.322E+03	.570E+01	.130E+00	.180E-01	.930E+00	.209E+06	.800E-03
.170E-04	.310E-02	.100E-06	.350E-02	.290E-05	.200E-03	.650E-03	.170E-05
.300E-05	.500E-04	.110E-03	.600E-04				
28.0000	16.1610	224.5270					
.390E+01	.322E+03	.620E+01	.110E+00	.190E-01	.860E+00	.209E+06	.150E-02
.150E-04	.450E-02	.100E-06	.300E-02	.610E-05	.250E-03	.700E-03	.170E-05
.300E-05	.100E-03	.700E-04	.800E-04				
30.0000	11.9700	226.5090					
.410E+01	.322E+03	.660E+01	.900E-01	.200E-01	.800E+00	.209E+06	.250E-02
.130E-04	.750E-02	.100E-06	.200E-02	.100E-04	.300E-03	.100E-02	.180E-05
.300E-05	.200E-03	.300E-04	.900E-04				
32.0000	8.8910	228.4900					
.420E+01	.322E+03	.720E+01	.700E-01	.220E-01	.730E+00	.209E+06	.400E-02
.120E-04	.700E-02	.100E-06	.100E-02	.280E-04	.320E-03	.120E-02	.210E-05
.300E-05	.400E-03	.170E-04	.100E-02				
34.0000	6.6340	233.7430					
.430E+01	.322E+03	.770E+01	.500E-01	.240E-01	.660E+00	.209E+06	.700E-02
.110E-04	.550E-02	.100E-06	.600E-03	.580E-04	.340E-03	.160E-02	.240E-05
.300E-05	.500E-03	.600E-05	.110E-03				
36.0000	4.9950	239.2820					
.440E+01	.322E+03	.810E+01	.320E-01	.270E-01	.570E+00	.209E+06	.900E-02
.110E-04	.500E-02	.100E-06	.350E-03	.130E-03	.360E-03	.180E-02	.310E-05
.300E-05	.600E-03	.250E-05	.120E-03				
38.0000	3.7710	244.8180					
.440E+01	.322E+03	.780E+01	.220E-01	.300E-01	.480E+00	.209E+06	.100E-01
.120E-04	.450E-02	.100E-06	.200E-03	.220E-03	.380E-03	.170E-02	.390E-05
.300E-05	.700E-03	.100E-05	.120E-03				
40.0000	2.8710	250.3500					
.450E+01	.322E+03	.730E+01	.160E-01	.300E-01	.400E+00	.209E+06	.120E-01
.130E-04	.350E-02	.100E-06	.100E-03	.310E-03	.400E-03	.150E-02	.510E-05
.300E-05	.720E-03	.500E-06	.110E-03				
42.0000	2.1200	255.8780					
.450E+01	.322E+03	.640E+01	.100E-01	.300E-01	.320E+00	.209E+06	.110E-01
.150E-04	.300E-02	.100E-06	.700E-04	.400E-03	.410E-03	.140E-02	.640E-05
.300E-05	.600E-03	.200E-06	.950E-04				
44.0000	1.6950	261.4030					
.450E+01	.322E+03	.580E+01	.700E-02	.300E-01	.250E+00	.209E+06	.100E-01
.190E-04	.250E-02	.100E-06	.400E-04	.500E-03	.420E-03	.130E-02	.700E-05
.300E-05	.300E-03	.800E-07	.800E-04				
46.0000	1.3130	266.9250					
.460E+01	.322E+03	.470E+01	.400E-02	.300E-01	.200E+00	.209E+06	.100E-01
.230E-04	.200E-02	.100E-06	.200E-04	.600E-03	.430E-03	.130E-02	.730E-05
.300E-05	.170E-03	.250E-07	.650E-04				
48.0000	1.0230	270.6500					
.480E+01	.322E+03	.380E+01	.200E-02	.300E-01	.150E+00	.209E+06	.100E-01
.310E-04	.150E-02	.100E-06	.100E-04	.700E-03	.440E-03	.130E-02	.740E-05
.300E-05	.130E-03	.100E-07	.510E-04				

Table 4b. Sample Input and Output - Case 2 (Contd)

```
   50.0000      .7980   270.6500
  .500E+01   .322E+03   .310E+01   .100E-02   .300E-01   .100E+00   .209E+06   .100E-01
  .350E-04   .100E-02   .100E-06   .500E-05   .800E-03   .450E-03   .130E-02   .740E-05
  .300E-05   .100E-03   .100E-07   .400E-04
   55.0000      .4253   260.7710
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
   60.0000      .2196   247.0210
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
   65.0000      .1093   233.2920
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
   70.0000      .0522   219.5850
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
   75.0000      .0239   208.3990
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
   80.0000      .0105   198.6390
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
   85.0000      .0045   188.8930
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
   90.0000      .0018   196.8700
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
   95.0000      .0008   188.4200
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.
  100.0000      .0003   195.0800
       5.0         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.         0.         0.         0.         0.
        0.         0.         0.         0.

*****OUTPUT CASE 2*****************************************************************************

1                  *****PROGRAM FSCATM*****      01/11/83      11.03.37.


 CONTROL CARD 1: MODEL AND OPTIONS

        MODEL   =     7
```

Table 4b. Sample Input and Output - Case 2 (Contd)

```
        ITYPE    =     3
        IBND     =     0
        NOZERO   =     0
        NOPRNT   =     0
        KMAX     =    20
        IPUNCH   =     0
        RE       =       0.000 KM


CONTROL CARD 1 PARAMETERS WITH DEFAULTS:

        MODEL    =     7
        ITYPE    =     3
        IBND     =     0
        NOZERO   =     0
        NOPRNT   =     0
        KMAX     =    20
        IPUNCH   =     0
        RE       =  6371.230 KM


SLANT PATH SELECTED, ITYPE =     3


CONTROL CARD 2:  SLANT PATH PARAMETERS

        H1       =   33.0000 KM
        H2       =    0.0000 KM
        ANGLE    =   94.8700 DEG
        RANGE    =    0.0000 KM
        BETA     =    0.0000 DEG
        LEN      =         0


CONTROL CARD 3

        V1   =    820.000 CM-1
        V2   =    830.000 CM-1
        VBAR =    825.000 CM-1


AUTOLAYERING SELECTED

        AVTRAT     =     2.00
        TDIFF1     =    50.00
        TDIFF2     =    50.00


READING IN USER SUPPLIED MODEL ATMOSPHERE
```

Table 4b. Sample Input and Output - Case 2 (Contd)

IMOD = 36
PROFILE = US 76 + TRACE GASES

	I	Z (KM)	P (MB)	T (K)	TD (C)	RH (PERCNT)	PPH2O (MB)	DENH2O (GM M-3)	AMSMIX (GM/KG)
VOL MIX RAT (PPMV)		H2O SO2 HI	CO2 NO2 CLO	O3 NH3 OCS	N2O HNO3 H2CO	CO OH	CH4 HF	O2 HCL	NO HBR
	1	0.000	1013.250	288.150	-0.000	0.000	0.000	0.000	0.000
		1.000E+04	3.220E+02	3.300E-02	3.200E-01	1.500E-01	1.700E+00	2.090E+05	3.000E-04
		3.000E-04	3.000E-04	1.300E-03	3.000E-05	4.400E-08	1.000E-08	1.000E-04	1.700E-06
		3.000E-06	1.000E-07	6.000E-04	2.400E-03				
	2	2.000	795.010	275.154	0.000	0.000	0.000	0.000	0.000
		9.700E+03	3.220E+02	3.300E-02	3.200E-01	1.400E-01	1.700E+00	2.090E+05	3.000E-04
		2.500E-04	3.000E-04	1.200E-03	4.000E-05	4.400E-08	1.000E-08	6.500E-05	1.700E-06
		3.000E-06	1.000E-07	5.800E-04	3.000E-04				
	3	4.000	616.600	262.166	0.000	0.000	0.000	0.000	0.000
		3.800E+03	3.220E+02	3.400E-02	3.200E-01	1.300E-01	1.700E+00	2.090E+05	3.000E-04
		1.400E-04	3.000E-04	1.000E-03	5.000E-05	4.400E-08	3.000E-08	3.300E-05	1.700E-06
		3.000E-06	1.000E-07	5.600E-04	1.300E-04				
	4	6.000	472.170	249.187	0.000	0.000	0.000	0.000	0.000
		1.500E+03	3.220E+02	4.100E-02	3.200E-01	1.300E-01	1.700E+00	2.090E+05	3.000E-04
		9.500E-05	3.000E-04	8.500E-04	7.000E-05	4.400E-08	9.000E-08	2.600E-05	1.700E-06
		3.000E-06	1.200E-07	5.500E-04	7.000E-05				
	5	8.000	356.510	236.215	0.000	0.000	0.000	0.000	0.000
		6.500E+02	3.220E+02	6.000E-02	3.200E-01	1.200E-01	1.600E+00	2.090E+05	3.000E-04
		7.000E-05	3.000E-04	7.000E-04	8.000E-05	4.400E-08	2.300E-07	2.200E-05	1.700E-06
		3.000E-06	1.500E-07	5.300E-04	5.000E-05				
	6	10.000	264.990	223.252	0.000	0.000	0.000	0.000	0.000
		2.000E+01	3.220E+02	1.300E-01	3.200E-01	1.000E-01	1.600E+00	2.090E+05	3.000E-04

Table 4b. Sample Input and Output - Case 2 (Contd)

	6.000E-05	3.000E-04	5.500E-04	9.000E-05	4.700E-08	6.000E-07	2.400E-05	1.700E-06
	3.000E-06	2.000E-07	5.200E-04	3.400E-05				
7	12.000	193.990	216.650	0.000	0.000	0.000	0.000	0.000
	6.000E+00	3.220E+02	3.100E-01	3.100E-01	8.000E-02	1.600E+00	2.090E+05	3.000E-04
	5.500E-05	3.000E-04	4.000E-04	1.000E-04	4.900E-08	2.000E-06	3.000E-05	1.700E-06
	3.000E-06	4.000E-07	5.000E-04	3.300E-05				
8	14.000	141.700	216.650	0.000	0.000	0.000	0.000	0.000
	2.900E+00	3.220E+02	5.000E-01	3.000E-01	5.000E-02	1.500E+00	2.090E+05	3.000E-04
	5.600E-05	3.300E-04	3.000E-04	2.000E-04	5.300E-08	4.500E-06	1.000E-05	1.700E-06
	3.000E-06	7.000E-07	4.700E-04	3.700E-05				
9	16.000	103.520	216.650	0.000	0.000	0.000	0.000	0.000
	3.200E+00	3.220E+02	8.500E-01	2.900E-01	3.000E-02	1.500E+00	2.090E+05	2.700E-04
	6.000E-05	3.500E-04	1.000E-04	3.000E-04	8.100E-08	1.000E-05	2.500E-04	1.700E-06
	3.000E-06	1.300E-06	3.900E-04	3.600E-05				
10	18.000	75.652	216.650	0.000	0.000	0.000	0.000	0.000
	3.400E+00	3.220E+02	1.600E+00	2.700E-01	2.000E-02	1.400E+00	2.090E+05	2.300E-04
	5.000E-05	4.000E-04	1.000E-05	1.100E-03	1.300E-07	2.500E-05	4.000E-04	1.700E-06
	3.000E-06	2.500E-06	3.100E-04	3.400E-05				
11	20.000	55.293	216.650	0.000	0.000	0.000	0.000	0.000
	3.500E+00	3.220E+02	2.600E+00	2.400E-01	1.500E-02	1.300E+00	2.090E+05	2.500E-04
	3.100E-05	9.000E-04	1.000E-06	2.000E-03	1.300E-07	6.000E-05	5.000E-04	1.700E-06
	3.000E-06	6.000E-06	2.400E-04	3.300E-05				
12	22.000	40.475	218.574	0.000	0.000	0.000	0.000	0.000
	3.500E+00	3.220E+02	3.600E+00	2.000E-01	1.600E-02	1.100E+00	2.090E+05	3.000E-04
	2.200E-05	1.200E-03	1.000E-07	3.000E-03	5.200E-07	1.000E-04	5.500E-04	1.700E-06
	3.000E-06	1.000E-05	1.900E-04	4.000E-05				
13	24.000	29.717	220.560	0.000	0.000	0.000	0.000	0.000

Table 4b. Sample Input and Output - Case 2 (Contd)

	3.500E+00	3.220E+02	4.700E+00	1.600E-01	1.700E-02	1.000E+00	2.090E+05	4.000E-04
	1.900E-05	2.200E-03	1.000E-07	4.000E-03	1.000E-06	1.500E-04	6.000E-04	1.700E-06
	3.000E-06	2.000E-05	1.400E-04	5.000E-05				
14	26.000	21.883	222.544	0.000	0.000	0.000	0.000	0.000
	3.700E+00	3.220E+02	5.700E+00	1.300E-01	1.800E-02	9.300E-01	2.090E+05	8.000E-04
	1.700E-05	3.100E-03	1.000E-07	3.500E-03	2.900E-06	2.000E-04	6.500E-04	1.700E-06
	3.000E-06	5.000E-05	1.100E-04	6.000E-05				
15	28.000	16.161	224.527	0.000	0.000	0.000	0.000	0.000
	3.900E+00	3.220E+02	6.200E+00	1.100E-01	1.900E-02	8.600E-01	2.090E+05	1.500E-03
	1.500E-05	4.500E-03	1.000E-07	3.000E-03	6.100E-06	2.500E-04	7.000E-04	1.700E-06
	3.000E-06	1.000E-04	7.000E-05	8.000E-05				
16	30.000	11.970	226.509	0.000	0.000	0.000	0.000	0.000
	4.100E+00	3.220E+02	6.600E+00	9.000E-02	2.000E-02	8.000E-01	2.090E+05	2.500E-03
	1.300E-05	7.500E-03	1.000E-07	2.000E-03	1.000E-05	3.000E-04	1.000E-03	1.800E-06
	3.000E-06	2.000E-04	3.000E-05	9.000E-05				
17	32.000	8.891	228.490	0.000	0.000	0.000	0.000	0.000
	4.200E+00	3.220E+02	7.200E+00	7.000E-02	2.200E-02	7.300E-01	2.090E+05	4.000E-03
	1.200E-05	7.000E-03	1.000E-07	1.000E-03	2.800E-05	3.200E-04	1.200E-03	2.100E-06
	3.000E-06	4.000E-04	1.700E-05	1.000E-04				
18	34.000	6.634	233.743	0.000	0.000	0.000	0.000	0.000
	4.300E+00	3.220E+02	7.700E+00	5.000E-02	2.400E-02	6.600E-01	2.090E+05	7.000E-03
	1.100E-05	5.500E-03	1.000E-07	6.000E-04	5.800E-05	3.400E-04	1.600E-03	2.400E-06
	3.000E-06	5.000E-04	6.000E-06	1.100E-04				
19	36.000	4.985	239.282	0.000	0.000	0.000	0.000	0.000
	4.400E+00	3.220E+02	8.100E+00	3.200E-02	2.700E-02	5.700E-01	2.090E+05	9.000E-03
	1.100E-05	5.000E-03	1.000E-07	3.500E-04	1.300E-04	3.600E-04	1.800E-03	3.100E-06
	3.000E-06	6.000E-04	2.500E-06	1.200E-04				
20	38.000	3.771	244.818	0.000	0.000	0.000	0.000	0.000

Table 4b. Sample Input and Output - Case 2 (Contd)

	4.400E+00	3.220E+02	7.800E+00	2.200E-02	3.000E-02	4.800E-01	2.090E+05	1.000E-02
	1.200E-05	4.500E-03	1.000E-07	2.000E-04	2.200E-04	3.800E-04	1.700E-03	3.900E-06
	3.000E-06	7.000E-04	1.000E-06	1.200E-04				
21	40.000	2.871	250.350	0.000	0.000	0.000	0.000	0.000
	4.500E+00	3.220E+02	7.300E+00	1.600E-02	3.000E-02	4.000E-01	2.090E+05	1.200E-02
	1.300E-05	3.500E-03	1.000E-07	1.000E-04	3.100E-04	4.000E-04	1.500E-03	5.100E-06
	3.000E-06	7.200E-04	5.000E-07	1.100E-04				
22	42.000	2.120	255.878	0.000	0.000	0.000	0.000	0.000
	4.500E+00	3.220E+02	6.400E+00	1.000E-02	3.000E-02	3.200E-01	2.090E+05	1.100E-02
	1.500E-05	3.000E-03	1.000E-07	7.000E-05	4.000E-04	4.100E-04	1.400E-03	6.400E-06
	3.000E-06	6.000E-04	2.000E-07	9.500E-05				
23	44.000	1.695	261.403	0.000	0.000	0.000	0.000	0.000
	4.500E+00	3.220E+02	5.800E+00	7.000E-03	3.000E-02	2.500E-01	2.090E+05	1.000E-02
	1.300E-05	2.500E-03	1.000E-07	4.000E-05	5.000E-04	4.200E-04	1.300E-03	7.000E-06
	3.000E-06	3.000E-04	8.000E-08	8.000E-05				
24	46.000	1.313	266.925	0.000	0.000	0.000	0.000	0.000
	4.600E+00	3.220E+02	4.700E+00	4.000E-03	3.000E-02	2.000E-01	2.090E+05	1.000E-02
	2.300E-05	2.000E-03	1.000E-07	2.000E-05	6.000E-04	4.300E-04	1.300E-03	7.300E-06
	3.000E-06	1.700E-04	2.500E-08	6.500E-05				
25	48.000	1.023	270.650	0.000	0.000	0.000	0.000	0.000
	4.800E+00	3.220E+02	3.800E+00	2.000E-03	3.000E-02	1.500E-01	2.090E+05	1.000E-02
	3.100E-05	1.500E-03	1.000E-07	1.000E-05	7.000E-04	4.400E-04	1.300E-03	7.400E-06
	3.000E-06	1.300E-04	1.000E-08	5.100E-05				
26	50.000	.798	270.650	0.000	0.000	0.000	0.000	0.000
	5.000E+00	3.220E+02	3.100E+00	1.000E-03	3.000E-02	1.000E-01	2.090E+05	1.000E-02
	3.500E-05	1.000E-03	1.000E-07	5.000E-06	8.000E-04	4.500E-04	1.300E-03	7.400E-06
	3.000E-06	1.000E-04	1.000E-08	4.000E-05				

Table 4b. Sample Input and Output - Case 2 (Contd)

```
27    55.000      .425   250.771    0.000     0.000     0.000     0.000     0.000
   5.000E+00 0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.
28    60.000      .220   247.021    0.000     0.000     0.000     0.000     0.000
   5.000E+00 0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.
29    65.000      .109   233.292    0.000     0.000     0.000     0.000     0.000
   5.000E+00 0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.
30    70.000      .052   219.585    0.000     0.000     0.000     0.000     0.000
   5.000E+00 0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.
31    75.000      .024   209.399    0.000     0.000     0.000     0.000     0.000
   5.000E+00 0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.
32    80.000      .011   198.639    0.000     0.000     0.000     0.000     0.000
   5.000E+00 0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.
33    85.000      .005   188.893    0.000     0.000     0.000     0.000     0.000
   5.000E+00 0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.        0.        0.        0.        0.
   0.        0.         0.         0.
```

Table 4b. Sample Input and Output - Case 2 (Contd)

34	90.000	.002	166.870	0.000	0.000	0.000	0.000	0.000
	5.000E+00	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.				
35	95.000	.001	188.420	0.000	0.000	0.000	0.000	0.000
	5.000E+00	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.				
36	100.000	.000	195.080	0.000	0.000	0.000	0.000	0.000
	5.000E+00	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.				

1ATMOSPHERIC PROFILE SELECTED IS: M = 7 US 76 + TRACE GASES

I	Z (KM)	P (MB)	T (K)	REFRACT INDEX-1 *1.0E6	AIR	DENSITY (MOLS CM-3) H2O SO2 HI	CO2 NO2 CLO	O3 NH3 OCS	N2O HNO3 H2CO	CO OH	CH4 HF	O2 HCL	NO HBR
1	0.000	1013.250	288.150	271.956	2.55E+19	2.55E+17	8.20E+15	8.40E+11	8.15E+12	3.82E+12	4.33E+13	5.32E+18	7.64E+09
						7.64E+09	7.64E+09	3.31E+10	7.64E+08	1.12E+06	2.55E+05	2.55E+09	4.33E+07
						7.64E-07	2.55E+06	1.53E+10	6.11E+10				
2	2.000	795.010	275.154	223.485	2.09E+19	2.03E+17	6.74E+15	6.91E+11	6.70E+12	2.93E+12	3.56E+13	4.37E+18	6.28E+09
						5.23E+09	6.28E+09	2.51E+10	8.37E+08	9.21E+05	2.09E+05	1.30E+09	3.56E+07
						6.28E+07	2.09E+06	1.21E+10	5.28E+09				
3	4.000	616.600	262.166	182.088	1.70E+19	6.47E+16	5.49E+15	5.79E+11	5.45E+12	2.21E+12	2.90E+13	3.56E+18	5.11E+09
						2.38E+09	5.11E+09	1.70E+10	8.52E+08	7.50E+05	5.11E+05	5.62E+08	2.90E+07
						5.11E+07	1.70E+06	9.54E+09	2.21E+09				
4	6.000	472.170	249.167	146.750	1.37E+19	2.06E-16	4.42E+15	5.63E+11	4.39E+12	1.78E+12	2.33E+13	2.87E+18	4.12E+09
						1.30E+09	4.12E+09	1.17E+10	9.61E+08	6.04E+05	1.24E+06	3.57E+08	2.33E+07
						4.12E+07	1.65E+06	7.55E+09	9.61E+08				
5	8.000	356.510	236.215	116.902	1.09E+19	7.11E+15	3.52E+15	6.56E+11	3.50E+12	1.31E+12	1.75E+13	2.28E+18	3.28E+09
						7.65E+08	3.28E+09	7.65E+09	8.75E+08	4.81E+05	2.51E+06	2.40E+08	1.86E+07
						3.28E+07	1.64E+06	5.79E+09	5.47E+08				
6	10.000	264.990	223.252	91.945	8.60E+18	1.72E+14	2.77E+15	1.12E+12	2.75E+12	8.60E+11	1.38E+13	1.80E+18	2.58E+09
						5.16E+08	2.58E+09	4.73E+09	7.74E+08	4.04E+05	5.16E+06	2.06E+08	1.46E+07
						2.58E+07	1.72E+06	4.47E+09	2.92E+08				
7	12.000	193.990	216.650	69.361	6.49E+18	3.89E+13	2.09E+15	2.01E+12	2.01E+12	5.19E+11	1.04E+13	1.36E+18	1.95E+09
						3.57E+08	1.95E+09	2.59E+09	6.49E+08	3.18E+05	1.30E+07	1.95E+08	1.10E+07
						1.95E+07	2.59E+06	3.24E+09	2.14E+08				
8	14.000	141.700	216.650	50.665	4.74E+18	1.37E+13	1.53E+15	2.37E+12	1.42E+12	2.37E+11	7.11E+12	9.90E+17	1.42E+09

Table 4b. Sample Input and Output - Case 2 (Contd)

						2.65E-08	1.56E+09	1.42E+09	9.47E+08	2.51E+05	2.13E+07	4.74E+07	8.05E+06
						1.42E-07	3.32E+06	2.23E+09	1.75E+08				
9	16.000	103.520	216.650	37.014	3.46E+18	1.11E+13	1.11E+15	2.94E+12	1.00E+12	1.04E+11	5.19E+12	7.23E+17	9.34E+08
						2.09E+08	1.21E+09	3.46E+06	1.04E+09	2.80E+05	3.46E+07	3.65E+08	5.88E+06
						1.04E+07	4.50E+06	1.35E+09	1.25E+08				
10	18.000	75.652	216.650	27.049	2.53E+18	8.60E+12	8.14E+14	4.05E+12	6.83E+11	5.06E+10	3.54E+12	5.29E-17	5.62E+08
						1.26E+08	1.01E+09	2.53E+07	2.78E+09	3.29E+05	6.32E+07	1.01E+09	4.30E+06
						7.59E+06	6.32E+06	7.84E+08	8.60E+07				
11	20.000	55.293	216.650	19.770	1.85E+18	6.47E+12	5.95E+14	4.81E+12	4.44E+11	2.77E+10	2.40E+12	3.86E+17	4.62E+08
						5.73E+07	1.66E+09	1.85E+06	3.70E+09	3.51E+05	1.11E+08	3.24E+08	3.14E+06
						5.55E+06	1.11E+07	4.44E+08	6.10E+07				
12	22.000	40.475	218.574	14.344	1.34E+18	4.69E+12	4.32E+14	4.83E+12	2.68E+11	2.15E+10	1.48E+12	2.80E+17	4.02E+08
						2.95E+07	1.61E+09	1.34E+05	4.02E+09	6.97E+05	1.34E+08	7.38E+08	2.28E+06
						4.02E+06	1.34E+07	2.55E+08	5.36E+07				
13	24.000	29.717	220.560	10.437	9.76E+17	3.42E+12	3.14E+14	4.59E+12	1.56E+11	1.66E+10	9.76E+11	2.04E+17	3.90E+08
						1.85E+07	2.15E+09	9.76E+04	3.90E+09	9.76E+05	1.46E+08	5.86E+08	1.66E+06
						2.93E+06	1.95E+07	1.37E+08	4.88E+07				
14	26.000	21.883	222.544	7.617	7.12E+17	2.64E+12	2.29E+14	4.06E+12	9.26E+10	1.28E+10	6.62E+11	1.49E+17	5.70E+08
						1.21E-07	2.21E+09	7.12E+04	2.49E+09	2.07E+06	1.42E+08	4.63E+08	1.21E+06
						2.14E-06	3.56E+07	7.83E+07	4.27E+07				
15	28.000	16.161	224.527	5.576	5.21E+17	2.03E+12	1.68E+14	3.23E+12	5.73E+10	9.91E+09	4.48E+11	1.09E+17	7.82E+08
						7.82E-06	2.35E+09	5.21E+04	1.56E+09	3.18E+06	1.30E+08	3.65E+08	8.86E+05
						1.58E-06	5.21E+07	3.65E+07	4.17E+07				
16	30.000	11.970	226.509	4.094	3.83E+17	1.57E+12	1.23E+14	2.53E+12	3.44E+10	7.66E+09	3.06E+11	3.00E+16	9.57E+08
						4.98E+06	2.87E+09	3.83E+04	7.66E+08	3.83E+06	1.15E+08	3.83E+08	6.89E+05
						1.15E-06	7.66E+07	1.15E+07	3.44E+07				
17	32.000	8.891	228.490	3.014	2.82E+17	1.18E+12	9.08E+13	2.03E+12	1.97E+10	6.20E+09	2.06E+11	5.89E+16	1.13E+09
						3.38E-06	1.97E+09	2.82E+04	2.82E+08	7.09E+06	9.02E+07	3.38E+08	5.92E+05
						8.46E+05	1.13E+08	4.79E+06	2.82E+07				
18	34.000	6.634	233.743	2.199	2.06E+17	8.84E+11	6.62E+13	1.58E+12	1.03E+10	4.93E+09	1.36E+11	4.30E+16	1.44E+09
						2.26E+06	1.13E+09	2.06E+04	1.23E+08	1.19E+07	6.99E+07	3.29E+08	4.93E+05
						6.17E-05	1.03E+08	1.23E+06	2.26E+07				
19	36.000	4.985	239.282	1.614	1.51E+17	6.64E+11	4.86E+13	1.22E+12	4.83E+09	4.07E+09	8.60E+10	3.15E+16	1.36E+09
						1.66E-06	7.54E+08	1.51E+04	5.28E+07	1.96E+07	5.43E+07	2.72E+08	4.68E+05
						4.53E+05	9.05E+07	3.77E+05	1.81E+07				
20	38.000	3.771	244.818	1.193	1.12E+17	4.91E+11	3.59E+13	8.70E+11	2.45E+09	3.35E+09	5.36E+10	2.33E+16	1.12E+09
						1.34E+06	5.02E+08	1.12E+04	2.23E+07	2.45E+07	4.24E+07	1.90E+08	4.35E+05
						3.35E+05	7.81E+07	1.12E+05	1.34E+07				
21	40.000	2.871	250.350	.888	8.31E+16	3.74E+11	2.67E+13	6.06E+11	1.33E+09	2.49E+09	3.32E+10	1.74E+16	9.97E+08
						1.08E-06	2.91E+08	8.31E+03	8.31E+06	2.57E+07	3.32E+07	1.25E+08	4.24E+05
						2.49E-05	5.98E+07	4.15E+04	9.14E+06				
22	42.000	2.120	255.878	.642	6.00E+16	2.70E+11	1.93E+13	3.84E+11	6.00E+08	1.80E+09	1.92E+10	1.25E+16	6.60E+08
						9.00E-05	1.80E+08	6.00E+03	4.20E+06	2.40E+07	2.46E+07	8.40E+07	3.84E+05
						1.80E+05	3.60E+07	1.20E+04	5.70E+06				
23	44.000	1.695	261.403	.502	4.70E+16	2.11E+11	1.51E+13	2.72E+11	3.29E+08	1.41E+09	1.17E+10	9.82E+15	4.70E+08
						8.45E+05	1.17E+08	4.70E+03	1.88E+06	2.35E+07	1.97E+07	6.11E+07	3.29E+05
						1.41E+05	1.41E+07	3.76E+03	3.76E+06				
24	46.000	1.313	266.925	.381	3.56E+16	1.64E+11	1.15E+13	1.67E+11	1.43E+08	1.07E+09	7.13E+09	7.45E+15	3.56E+08
						8.19E+05	7.13E+07	3.56E-03	7.13E+05	2.14E+07	1.53E+07	4.63E+07	2.60E+05
						1.07E+05	6.06E+06	8.91E+02	2.32E+06				
25	48.000	1.023	270.650	.293	2.74E+16	1.31E+11	8.62E+12	1.04E+11	5.48E+07	8.21E+08	4.11E+09	5.72E+15	2.74E+08
						8.49E+05	4.11E+07	2.74E+03	2.74E+05	1.32E+07	1.20E+07	3.56E+07	2.03E+05
						8.21E+04	3.56E+06	2.74E+02	1.40E+06				
26	50.000	[illegible]	270.650	.228	2.14E+16	1.07E+11	6.88E+12	6.62E+10	2.14E+07	6.41E+08	2.14E+09	4.46E+15	2.14E+08
						7.47E+05	2.14E+07	2.14E+03	1.07E+05	1.71E+07	9.61E+06	2.78E+07	1.58E+05

Table 4b. Sample Input and Output - Case 2 (Contd)

```
                                                         6.41E+04 2.14E+06 2.14E+02 8.54E+05
 27    55.000      .425    260.771       .126 1.18E+16 5.91E+10 3.80E+12 0.        3.19E+09 2.24E+09 1.77E+10 2.47E+15 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.
 28    60.000      .220    247.021       .069 6.44E+15 3.22E+10 2.07E+12 0.        '.74E+09 1.22E+09 9.66E+09 1.35E+15 0.
                                                         0.       0.       0.        (        0.       0.       0.       0.
                                                         0.       0.       0.        0.
 29    65.000      .109    233.292       .036 3.39E+15 1.70E+10 1.09E+12 0.        9.16E+08 6.45E+08 5.09E+09 7.11E+14 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.
 30    70.000      .052    219.585       .018 1.72E+15 8.61E+09 5.54E+11 0.        4.65E+08 3.27E+08 2.58E+09 3.61E+14 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.
 31    75.000      .024    208.399       .009 8.31E+14 4.15E+09 2.67E+11 0.        2.24E+08 1.58E+08 1.25E+09 1.74E+14 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.
 32    80.000      .011    198.639       .004 3.83E+14 1.91E+09 1.23E+11 0.        1.03E+08 7.27E+07 5.74E+08 8.02E+13 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.
 33    85.000      .005    188.893       .002 1.73E+14 8.63E+08 5.56E+10 0.        4.66E+07 3.28E+07 2.59E+08 3.61E+13 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.
 34    90.000      .002    186.870       .001 6.98E+13 3.49E+08 2.25E+10 0.        1.88E+07 1.33E+07 1.05E+08 1.46E+13 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.
 35    95.000      .001    188.420       .000 3.08E+13 1.54E+08 9.90E+09 0.        8.30E+06 5.84E+06 4.61E+07 5.44E+12 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.
 36   100.000      .000    195.080       .000 1.11E+13 5.57E+07 3.59E+09 0.        3.01E+06 2.12E+06 1.67E+07 2.33E+12 0.
                                                         0.       0.       0.        0.       0.       0.       0.       0.
                                                         0.       0.       0.        0.

CASE 3A: GIVEN H1,H2=SPACE,ANGLE


SLANT PATH PARAMETERS IN STANDARD FORM

          H1       =      33.000 KM
          H2       =     100.000 KM
          ANGLE    =      94.870 DEG
          PHI      =      99.572 DEG
          HMIN     =       9.255 KM
          LEN      =           1


FASCODE LAYER BOUNDARIES PRODUCED BY THE AUTOMATIC LAYERING ROUTINE AUTLAY
THE USER SHOULD EXAMINE THESE BOUNDARIES AND MODIFY THEM IF APPROPRIATE
THE FOLLOWING PARAMETERS ARE USED:

          AVTRAT   =      2.00         = MAX RATIO OF VOIGT WIDTHS
          TDIFF1   =     50.00         = MAX TEMP DIFF AT HMIN
          TDIFF2   =     50.00         = MAX TEMP DIFF AT HMAX
```

Table 4b. Sample Input and Output - Case 2 (Contd)

```
ALZERO   =     .100 CM-1 = AVERAGE LORENTZ WIDTH AT STP
AVMWT    =    36.00      = AVERAGE  MOLECULAR WEIGHT
VBAR     =   825.00  CM-1 = AVERAGE WAVENUMBER
```

I	Z (KM)	P (MB)	T (K)	LORENTZ (CM-1)	DOPPLER (CM-1)	ZETA	VOIGT (CM-1)	VOIGT RATIO	TEMP DIFF (K)
1	9.255	295.960	228.082	.03327	.00074	.978	.03329	1.97	11.4
2	13.800	146.221	216.650	.01687	.00072	.959	.01690	1.98	0.0
3	18.200	73.317	216.650	.00646	.00072	.921	.00652	1.99	2.6
4	22.700	36.326	219.269	.00417	.00073	.851	.00429	2.00	5.1
5	27.800	16.658	224.329	.00189	.00074	.719	.00214	2.00	15.5
6	36.200	4.848	239.836	.00053	.00076	.411	.00107	1.58	50.0
7	84.500	.005	189.868	.00000	.00068	.001	.00068	.99	5.2
8	100.000	.000	195.080	.00000	.00069	.000	.00069	0.00	0.0

1CALCULATION OF THE REFRACTED PATH THROUGH THE ATMOSPHERE

I	ALTITUDE FROM (KM)	TO (KM)	THETA (DEG)	DRANGE (KM)	RANGE (KM)	DBETA (DEG)	BETA (DEG)	PHI (DEG)	DBEND (DEG)	BENDING (DEG)	PBAR (MB)	TBAR (K)	RHOBAR (MOL CM-3)
	TANGENT HEIGHT	H1											
1	9.255	10.000	90.000	101.441	101.441	.911	.911	90.843	.068	.068	285.647	226.502	9.13E+18
2	10.000	12.000	89.157	93.235	194.677	.837	1.748	91.618	.061	.129	233.072	220.435	7.60E+18
3	12.000	13.800	88.382	55.690	250.367	.500	2.247	92.087	.030	.160	171.107	216.650	5.68E+18
4	13.800	14.000	87.913	5.431	255.798	.049	2.296	92.134	.003	.162	143.963	216.650	4.81E+18
5	14.000	16.000	87.866	48.925	304.723	.439	2.735	92.553	.019	.181	123.174	216.650	4.08E+18
6	16.000	18.000	87.447	41.922	346.644	.376	3.110	92.917	.012	.193	89.890	216.650	2.98E+18
7	18.000	18.200	87.083	3.908	350.552	.035	3.145	92.951	.001	.194	74.485	216.650	2.49E+18
8	18.200	20.000	87.049	33.325	383.877	.298	3.443	93.242	.007	.201	64.443	216.650	2.14E+18
9	20.000	22.000	86.758	33.816	417.693	.303	3.746	93.539	.005	.207	48.001	217.546	1.58E+18
10	22.000	22.700	86.461	11.183	428.876	.100	3.846	93.638	.001	.208	38.410	218.914	1.27E+18
11	22.700	24.000	86.352	20.002	448.878	.179	4.025	93.815	.002	.210	33.049	219.887	1.08E+18
12	24.000	26.000	86.185	29.081	477.959	.260	4.265	94.072	.002	.212	25.847	221.488	8.39E+17
13	26.000	27.800	85.928	24.684	502.643	.220	4.505	94.291	.001	.214	19.296	223.386	6.22E+17
14	27.800	28.000	85.709	2.665	505.308	.024	4.529	94.315	.000	.214	16.410	224.427	5.30E+17
15	28.000	30.000	85.685	25.893	531.201	.231	4.760	94.545	.001	.215	14.086	225.457	4.49E+17
16	30.000	32.000	85.455	24.646	555.847	.220	4.980	94.764	.001	.216	10.444	227.440	3.30E+17
17	32.000	33.000	85.236	11.908	567.755	.106	5.086	94.870	.000	.216	8.289	229.762	2.61E+17
0	DOUBLE RANGE, BETA, BENDING FOR SYMMETRIC PART OF PATH				1135.511		10.172			.432			
	H1 TO H2												
18	33.000	34.000	85.130	11.656	1147.166	.104	10.276	94.974	.000	.432	7.160	232.389	2.23E+17
19	34.000	36.000	85.026	22.613	1169.779	.201	10.478	95.175	.000	.433	5.818	236.342	1.77E+17
20	36.000	36.200	84.825	2.213	1171.992	.020	10.497	95.194	.000	.433	4.916	239.557	1.49E+17
21	36.200	38.000	84.806	19.555	1191.548	.174	10.671	95.368	.000	.433	4.314	242.193	1.28E+17
22	38.000	40.000	84.632	21.013	1212.561	.187	10.858	95.555	.000	.433	3.325	247.423	9.67E+16
23	40.000	42.000	84.445	20.331	1232.892	.181	11.039	95.736	.000	.433	2.499	252.941	7.10E+16
24	42.000	44.000	84.264	19.712	1252.604	.175	11.214	95.911	.000	.434	1.909	258.505	5.33E+16

Table 4b. Sample Input and Output - Case 2 (Contd)

25	44.000	46.000	84 089	19.147	1271.751	.170	11.394	96.081	.000	.434	1.506	264.015	4.11E+16
26	46.000	48.000	83.919	18.628	1290.379	.165	11.550	96.246	.000	.434	1.169	268.694	3.13E+16
27	48.000	50.000	83.754	13.150	1308.529	.161	11.711	93.407	.000	.434	.911	270.650	2.43E+16
28	50.000	55.000	83.593	43.504	1352.033	.385	12.096	96.792	.000	.434	.612	266.211	1.62E+16
29	55.000	60.000	83.208	41.176	1393.209	.364	12.460	97.157	.000	.434	.322	254.583	8.88E+15
30	60.000	65.000	82.843	39.191	1432.401	.346	12.807	97.503	.000	.434	.164	240.871	4.77E+15
31	65.000	70.000	82.497	37.472	1469.872	.330	13.137	97.833	.000	.434	.081	227.186	2.47E+15
32	70.000	75.000	82.167	35.964	1505.836	.317	13.454	98.150	.000	.434	.038	214.652	1.23E+15
33	75.000	80.000	81.850	34.528	1540.464	.304	13.758	98.454	.000	.434	.017	204.132	5.79E+14
34	80.000	34.500	81.546	30.140	1570.603	.265	14.023	98.719	.000	.434	.008	194.762	2.74E+14
35	84.500	85.000	81.281	3.293	1573.896	.029	14.052	98.748	.000	.434	.005	189.386	1.80E+14
36	85.000	90.000	81.252	32.356	1606.252	.284	14.335	99.031	.000	.434	.003	188.035	1.14E+14
37	90.000	95.000	80.969	31.379	1637.631	.275	14.610	99.306	.000	.434	.001	187.536	4.77E+13
38	95.000	100.000	80.694	30.488	1668.119	.266	14.876	99.572	.000	.434	.001	191.163	1.94E+13

1INTEGRATED ABSORBER AMOUNTS BY LAYER

I	LAYER BOUNDARIES FROM (KM)	TO (KM)	AIR	INTEGRATED AMOUNTS (MOL CM-2) H2O SO2 HI	CO2 NO2 CLO	O3 NH3 OCS	N2O HNO3 H2CO	CO OH	CH4 HF	O2 HCL	NO HBR
1	9.255	10.000	9.258E+25	4.747E+21	2.982E+22	9.949E+18	2.963E+19	9.696E+18	1.482E+20	1.935E+25	2.778E+16
				5.776E+15	2.778E+16	5.413E+16	8.092E+15	4.281E+12	4.392E+13	2.174E+15	1.574E+14
				2.778E+14	1.724E+13	4.838E+16	3.472E+15				
2	10.000	12.000	7.089E+25	9.004E+20	2.283E+22	1.375E+19	2.238E+19	6.462E+18	1.134E+20	1.482E+25	2.127E+16
				4.100E+15	2.127E+16	3.420E+16	6.675E+15	3.391E+12	7.533E+13	1.874E+15	1.205E+14
				2.127E+14	1.941E+13	3.626E+16	2.380E+15				
3	12.000	13.800	3.165E+25	1.434E+20	1.019E+22	1.203E+19	9.680E+18	2.103E+18	4.932E+19	6.614E+24	9.494E+15
				1.754E+15	9.876E+15	1.128E+16	4.274E+15	1.602E+12	9.024E+13	6.294E+14	5.380E+13
				9.494E+13	1.609E+13	1.543E+16	1.095E+15				
4	13.800	14.000	2.614E+24	7.863E+18	8.415E+20	1.276E+18	7.853E+17	1.338E+17	3.933E+18	5.462E+23	7.841E+14
				1.462E+14	8.583E+14	7.955E+14	5.049E+14	1.380E+11	1.129E+13	2.763E+13	4.443E+12
				7.841E+12	1.779E+12	1.232E+15	9.615E+13				
5	14.000	16.000	1.998E+25	6.066E+19	6.435E+21	1.290E+19	5.903E+18	7.987E+17	2.998E+19	4.177E+24	5.715E+15
				1.155E+15	6.776E+15	3.800E+15	4.848E+15	1.297E+12	1.332E+14	1.327E+15	3.307E+13
				5.995E+13	1.889E+13	8.633E+15	7.302E+14				
6	16.000	18.000	1.250E+25	4.113E+19	4.024E+21	1.447E+19	3.507E+18	3.128E+17	1.816E+19	2.612E+24	3.136E+15
				6.900E+14	4.656E+15	5.275E+14	7.339E+15	1.272E+12	1.978E+14	3.919E+15	2.124E+13
				3.749E+13	2.238E+13	4.392E+15	4.382E+14				
7	18.000	18.200	9.730E+23	3.313E+18	3.133E+20	1.595E+18	2.612E+17	1.918E+16	1.357E+18	2.034E+23	2.247E+14
				4.751E+13	4.053E+14	8.696E+12	1.103E+15	1.289E+11	2.542E+13	3.936E+14	1.654E+12
				2.919E+12	2.542E+12	2.978E+14	3.303E+13				
8	18.200	20.000	7.132E+24	2.462E+19	2.297E+21	1.482E+19	1.812E+18	1.231E+17	9.608E+18	1.491E+24	1.714E+15
				2.800E+14	4.454E+15	2.536E+13	1.085E+16	1.136E+12	2.890E+14	3.211E+15	1.213E+13
				2.140E+13	2.890E+13	1.939E+15	2.388E+14				
9	20.000	22.000	5.360E+24	1.876E+19	1.729E+21	1.629E+19	1.183E+18	8.286E+16	6.453E+18	1.120E+24	1.461E+15
				1.423E+14	5.535E+15	2.247E+12	1.304E+16	1.698E+12	4.125E+14	2.803E+15	9.111E+12
				1.608E+13	4.125E+13	1.156E+15	1.938E+14				
10	22.000	22.700	1.420E+24	4.969E+18	4.571E+20	5.351E+18	2.734E+17	2.295E+16	1.537E+18	2.967E+23	4.476E+14
				3.046E+13	1.893E+15	1.420E+11	4.476E+15	8.275E+11	1.523E+14	7.926E+14	2.414E+12
				4.259E+12	1.602E+13	2.561E+14	5.901E+13				
11	22.700	24.000	2.170E+24	7.595E+18	6.987E+20	9.330E+18	3.748E+17	3.614E+16	2.242E+18	4.535E+23	7.386E+14
				4.334E+13	3.913E+15	2.170E+11	7.886E+15	1.752E+12	2.846E+14	1.264E+15	3.689E+12
				6.510E+12	3.461E+13	3.374E+14	1.007E+14				
12	24.000	26.000	2.438E+24	8.761E+18	7.852E+20	1.256E+19	3.545E+17	4.258E+16	2.357E+18	5.096E+23	1.377E+15

Table 4b. Sample Input and Output - Case 2 (Contd)

				4.400E+13	6.331E+15	2.[illegible]8E+11	9.169E+15	4.209E+12	4.200E+14	1.519E+15	4.145E+12
				7.315E+12	7.758E+13	3.056E+14	1.330E+14				
13	26.000	27.800	1.535E+24	5.807E+18	4.941E+20	9.067E+18	1.860E+17	2.927E+16	1.381E+18	3.207E+23	1.525E+15
				2.475E+13	5.600E+15	1.535E+11	5.034E+15	6.220E+12	3.380E+14	1.030E+15	2.509E+12
				4.604E+12	1.047E+14	1.402E+14	1.043E+14				
14	27.800	28.000	1.411E+23	5.490E+17	4.545E+19	6.714E+17	1.566E+16	2.675E+15	1.219E+17	2.950E+22	2.052E+14
				2.131E+12	6.234E+14	1.411E+10	4.267E+14	8.296E+11	3.489E+13	9.844E+13	2.400E+11
				4.234E+11	1.363E+13	1.011E+13	1.113E+13				
15	28.000	30.000	1.163E+24	4.643E+18	3.744E+20	7.425E+18	1.166E+17	2.263E+16	9.667E+17	2.430E+23	2.242E+15
				1.632E+13	6.725E+15	1.163E+11	2.902E+15	9.040E+12	3.171E+14	9.676E+14	2.031E+12
				3.486E+12	1.643E+14	5.627E+13	9.837E+13				
16	30.000	32.000	8.136E+23	3.374E+18	2.620E+20	5.526E+18	6.522E+16	1.702E+16	6.236E+17	1.700E+23	2.561E+15
				1.019E+13	5.908E+15	8.136E+10	1.197E+15	1.381E+13	2.516E+14	8.877E+14	1.576E+12
				2.441E+12	2.301E+14	1.893E+13	7.698E+13				
17	32.000	33.000	3.105E+23	1.312E+18	1.000E+20	2.273E+18	2.006E+16	6.979E+15	2.213E+17	6.491E+22	1.428E+15
				3.649E+12	2.052E+15	3.106E+10	2.751E+14	1.043E+13	1.009E+14	4.000E+14	6.738E+11
				9.317E+11	1.312E+14	4.147E+12	3.179E+13				
18	33.000	34.000	2.596E+23	1.110E+18	8.359E+19	1.965E+18	1.417E+16	6.093E+15	1.759E+17	5.425E+22	1.579E+15
				2.920E+12	1.520E+15	2.596E+10	1.781E+14	1.255E+13	8.690E+13	3.860E+14	6.021E+11
				7.788E+11	1.226E+14	2.059E+12	2.787E+13				
19	34.000	36.000	4.002E+23	1.740E+18	1.289E+20	3.157E+18	1.635E+16	1.016E+16	2.467E+17	8.365E+22	3.162E+15
				4.403E+12	2.105E+15	4.002E+10	1.885E+14	3.489E+13	1.398E+14	6.773E+14	1.087E+12
				1.201E+12	2.184E+14	1.640E+12	4.588E+13				
20	36.000	36.200	3.290E+22	1.447E+17	1.059E+19	2.660E+17	1.033E+15	8.929E+14	1.859E+16	6.876E+21	2.976E+14
				3.634E+11	1.636E+14	3.290E+09	[illegible].120E+13	4.391E+12	1.187E+13	5.905E+13	1.032E+11
				9.869E+10	1.989E+13	7.861E+10	3.948E+12				
21	36.200	38.000	2.509E+23	1.104E+18	8.078E+19	1.992E+18	6.619E+15	7.163E+15	1.307E+17	5.243E+22	2.388E+15
				2.890E+12	1.187E+15	2.509E+10	6.605E+13	4.344E+13	9.293E+13	4.382E+14	8.793E+11
				7.526E+11	1.634E+14	3.978E+11	3.010E+13				
22	38.000	40.000	2.032E+23	9.035E+17	6.542E+19	1.536E+18	3.861E+15	6.095E+15	8.959E+16	4.246E+22	2.218E+15
				2.533E+12	8.140E+14	2.032E+10	2.986E+13	5.282E+13	7.911E+13	3.258E+14	9.022E+11
				5.095E+11	[illegible].441E+14	1.493E+11	2.341E+13				
23	40.000	42.000	1.443E+23	6.493E+17	4.646E+19	9.908E+17	1.868E+15	4.329E+15	5.207E+16	3.016E+22	1.563E+15
				2.008E+12	4.701E+14	1.443E+10	1.226E+13	5.056E+13	5.839E+13	2.096E+14	8.206E+11
				4.329E+11	9.548E+13	4.651E+10	1.483E+13				
24	42.000	44.000	1.050E+23	4.724E+17	3.380E+19	6.412E+17	8.901E+14	3.149E+15	2.993E+16	2.194E+22	1.104E+15
				1.720E+12	2.831E+14	1.050E+10	5.699E+12	4.680E+13	4.354E+13	1.419E+14	7.014E+11
				3.149E+11	4.614E+13	1.403E+10	9.198E+12				
25	44.000	46.000	7.862E+22	3.575E+17	2.532E+19	4.134E+17	4.274E+14	2.359E+15	1.772E+16	1.643E+22	7.362E+14
				1.594E+12	1.772E+14	7.662E+09	2.308E+12	4.292E+13	3.339E+13	1.022E+14	5.614E+11
				2.359E+11	1.825E+13	3.825E+09	5.709E+12				
26	46.000	48.000	5.838E+22	2.741E+17	1.880E+19	2.484E+17	1.712E+14	1.751E+15	1.022E+16	1.220E+22	5.338E+14
				1.553E+12	1.022E+14	5.838E+09	8.562E+11	3.773E+13	2.538E+13	7.589E+13	4.289E+11
				1.751E+11	8.761E+12	9.765E+08	3.389E+12				
27	48.000	50.000	4.402E+22	2.155E+17	1.417E+19	1.520E+17	6.450E+13	1.321E+15	5.478E+15	9.200E+21	4.402E+14
				1.447E+12	5.478E+13	4.402E+09	3.225E+11	3.287E+13	1.958E+13	5.722E+13	3.257E+11
				1.321E+11	5.063E+12	4.402E+08	2.004E+12				
28	50.000	55.000	7.031E+22	3.515E+17	2.264E+19	1.454E+17	2.705E+15	5.533E+15	3.174E+16	1.471E+22	4.690E+14
				1.641E+12	4.690E+13	4.690E+09	2.345E+11	3.752E+13	2.110E+13	6.097E+13	3.470E+11
				1.407E+11	4.690E+12	4.690E+08	1.876E+12				
29	55.000	60.000	3.656E+22	1.828E+17	1.177E+19	0.	9.871E+15	6.946E+15	5.484E+16	7.658E+21	0.
				0.	0.	0.	0.	0.	0.	0.	0.
				0.	0.	0.	0.				
30	60.000	65.000	1.868E+22	9.340E+16	6.015E+18	0.	5.044E+15	3.549E+15	2.802E+16	3.913E+21	0.
				0.	0.	0.	0.	0.	0.	0.	0.

Table 4b. Sample Input and Output - Case 2 (Contd)

```
                                 0.         0.         0.          0.
   31    65.000     70.000 9.254E+21 4.627E+16 2.980E+18 0.          2.499E+15 1.758E+15 1.388E+16 1.939E+21 0.
                                 0.         0.         0.          0.         0.         0.         0.         0.
                                 0.         0.         0.          0.
   32    70.000     75.000 4.407E+21 2.204E+16 1.419E+18 0.          1.190E+15 8.373E+14 6.611E+15 9.232E+20 0.
                                 0.         0.         0.          0.         0.         0.         0.         0.
                                 0.         0.         0.          0.
   33    75.000     80.000 2.007E+21 1.003E+16 6.461E+17 0.          5.418E+14 3.812E+14 3.010E+15 4.203E+20 0.
                                 0.         0.         0.          0.         0.         0.         0.         0.
                                 0.         0.         0.          0.
   34    80.000     84.500 8.250E+20 4.125E+15 2.656E+17 0.          2.227E+14 1.567E+14 1.237E+15 1.728E+20 0.
                                 0.         0.         0.          0.         0.         0.         0.         0.
                                 0.         0.         0.          0.
   35    84.500     85.000 5.914E+19 2.957E+14 1.904E+16 0.          1.597E+13 1.124E+13 8.872E+13 1.239E+19 0.
                                 0.         0.         0.          0.         0.         0.         0.         0.
                                 0.         0.         0.          0.
   36    85.000     90.000 3.681E+20 1.841E+15 1.185E+17 0.          9.939E+13 6.994E+13 5.522E+14 7.711E+19 0.
                                 0.         0.         0.          0.         0.         0.         0.         0.
                                 0.         0.         0.          0.
   37    90.000     95.000 1.497E+20 7.487E+14 4.821E+16 0.          4.043E+13 2.845E+13 2.246E+14 3.137E+19 0.
                                 0.         0.         0.          0.         0.         0.         0.         0.
                                 0.         0.         0.          0.
   38    95.000    100.000 5.901E+19 2.951E+14 1.900E+16 0.          1.593E+13 1.121E+13 8.852E+13 1.236E+19 0.
                                 0.         0.         0.          0.         0.         0.         0.         0.
                                 0.         0.         0.          0.
0TOTAL   33.000    100.000 5.090E+26 1.198E+22 1.639E+23 3.106E+20 1.532E+20 3.988E+19 7.806E+20 1.064E+26 1.792E+17
                                     2.856E+16 2.362E+17 2.096E+17 1.767E+17 5.206E+14 6.968E+15 4.917E+16 8.701E+14
                                     1.527E+15 2.728E+15 2.377E+17 1.875E+16
1 SUMMARY OF THE GEOMETRY CALCULATION

          MODEL    =     US 76 + TRACE GASES
          H1       =       33.000 KM
          H2       =      100.000 KM
          ANGLE    =       94.870 DEG
          RANGE    =     1668.119 KM
          BETA     =       14.876 DEG
          PHI      =       99.572 DEG
          HMIN     =        9.255 KM
          BENDING  =         .434 DEG
          LEN      =            1
          AIRMAS   =     23.6      RELATIVE TO A VERTICAL PATH , GROUND TO SPACE
0FINAL SET OF LAYERS FOR INPUT TO FASCOD1
 A LAYER AMOUNT MAY BE SET TO ZERO IF THE CUMULATIVE AMOUNT FOR THAT LAYER AND ABOVE IS LESS THAN 0.1 PERCENT
 OF THE TOTAL AMOUNT. THIS IS DONE ONLY FOR THE FOLLOWING CASES
     1.  IEMIT = 0 (TRANSMITTANCE)
     2.  IEMIT = 1 (RADIANCE) AND ICNTRL = 3 (PATH LOOKING UP)
 O2 IS NOT INCLUDED
 IF THE AMOUNTS FOR ALL THE MOLECULES BUT O2 ARE ZEROED, THE REMAINING LAYERS ARE ELIMINATED


     L    LAYER BOUNDARIES ICNTRL  PBAR     TBAR                INTEGRATED AMOUNTS (MOLS CM-2)
           FROM       TO
           (KM)      (KM)          (MB)      (K)      AIR       H2O       CO2       O3        N2O       CO        CH4       O2        NO
                                                                SO2       NO2       NH3       HNO3      OH        HF        HCL       HBR
                                                                HI        CLO       OCS       H2CO
```

Table 4b. Sample Input and Output - Case 2 (Contd)

1	9.255	13.800	2	247.97	222.70	1.95E+26	5.79E+21	6.28E+22	3.57E+19	6.17E+19	1.83E+19	3.11E+20	4.08E+25	5.85E+16
							1.16E+16	5.89E+16	9.96E+16	1.90E+16	9.27E+12	2.09E+14	4.68E+15	3.32E+14
							5.85E+14	5.27E+13	1.00E+17	6.95E+15				
2	13.800	18.200	2	111.83	216.65	3.61E+25	1.13E+20	1.16E+22	3.02E+19	1.05E+19	1.26E+18	5.34E+19	7.54E+24	9.86E+15
							2.04E+15	1.27E+16	5.13E+15	1.38E+16	2.84E+12	3.68E+14	5.67E+15	6.13E+13
							1.08E+14	4.56E+13	1.46E+16	1.30E+15				
3	18.200	22.700	2	55.45	217.23	1.39E+25	4.83E+19	4.48E+21	3.65E+19	3.27E+18	2.29E+17	1.76E+19	2.91E+24	3.62E+15
							4.53E+14	1.19E+16	0.	2.84E+16	3.66E+12	8.54E+14	6.81E+15	2.37E+13
							4.17E+13	8.62E+13	3.35E+15	4.92E+14				
4	22.700	27.800	2	26.75	221.40	6.14E+24	2.22E+19	1.98E+21	3.10E+19	9.15E+17	1.07E+17	5.98E+19	1.28E+24	3.79E+15
							1.12E+14	1.58E+16	0.	2.21E+16	1.22E+13	1.04E+15	3.81E+15	1.04E+13
							1.84E+13	2.17E+14	7.83E+14	3.38E+14				
5	27.800	33.000	2	12.26	226.61	2.43E+24	9.88E+18	7.82E+20	1.62E+19	2.18E+17	4.93E+16	1.93E+18	5.07E+23	6.44E+15
							3.23E+13	1.53E+16	0.	4.80E+15	3.41E+13	7.05E+14	2.35E+15	4.52E+12
							7.28E+12	5.39E+14	0.	2.18E+14				
6	33.000	36.200	3	6.28	235.01	6.93E+23	0.	2.23E+20	5.39E+18	0.	1.71E+16	4.41E+17	1.45E+23	5.04E+15
							0.	3.79E+15	0.	3.78E+14	5.18E+13	2.39E+14	1.12E+15	1.79E+12
							2.08E+12	3.61E+14	0.	7.77E+13				
7	36.200	84.500	3	2.54	252.50	1.03E+24	0.	3.30E+20	6.12E+18	0.	4.53E+16	0.	2.15E+23	9.65E+15
							0.	3.14E+15	0.	0.	3.45E+14	3.73E+14	1.41E+15	4.97E+12
							2.79E+12	4.86E+14	0.	9.05E+13				

Table 4c. Sample Input and Output - Case 3

```
*****INPUT CASE 3**********************************************************************************************
    6    2    25     1     1
    100.0      0.0      180.0
    690.0      700.0
      2.0        4.0        6.0        8.0       10.0       12.0       14.0       16.0
     18.0       20.0       22.0       24.0       26.0       28.0       30.0       32.0
     34.0       36.0       38.0       40.0       42.0       44.0       46.0       48.0
     50.0

*****OUTPUT CASE 3*********************************************************************************************

1                    *****PROGRAM FSCATM*****       01/11/83       11.03.55.


 CONTROL CARD 1: MODEL AND OPTIONS

          MODEL    =      6
          ITYPE    =      2
          IBND     =     25
          NOZERO   =      1
          NOPRNT   =      1
          KMAX     =      0
          IPUNCH   =      0
          RE       =       0.000 KM


 CONTROL CARD 1 PARAMETERS WITH DEFAULTS:

          MODEL    =      6
          ITYPE    =      2
          IBND     =     25
          NOZERO   =      1
          NOPRNT   =      1
          KMAX     =      7
          IPUNCH   =      0
          RE       =   6371.230 KM


 SLANT PATH SELECTED, ITYPE =      2


 CONTROL CARD 2:  SLANT PATH PARAMETERS

          H1       =   100.0000 KM
          H2       =     0.0000 KM
          ANGLE    =   180.0000 DEG
          RANGE    =     0.0000 KM
```

Table 4c. Sample Input and Output - Case 3 (Contd)

```
        BETA    =     0.0000 DEG
        LEN     =          0


 CONTROL CARD 3

        V1   =    690.000 CM-1
        V2   =    700.000 CM-1
        VBAR =    695.000 CM-1


 USER DEFINED BOUNDARIES FOR FASCOD1 LAYERS
        I     Z (KM)

         1     2.0000
         2     4.0000
         3     6.0000
         4     8.0000
         5    10.0000
         6    12.0000
         7    14.0000
         8    16.0000
         9    18.0000
        10    20.0000
        11    22.0000
        12    24.0000
        13    26.0000
        14    28.0000
        15    30.0000
        16    32.0000
        17    34.0000
        18    36.0000
        19    38.0000
        20    40.0000
        21    42.0000
        22    44.0000
        23    46.0000
        24    48.0000
        25    50.0000
1ATMOSPHERIC PROFILE SELECTED IS: M =   6     U. S. STANDARD, 1962

 CASE 2A: GIVEN H1, H2, ANGLE

 EITHER A SHORT PATH (LEN=0) OR A LONG PATH THROUGH A TANGENT HEIGHT (LEN=1) IS POSSIBLE: LEN =   0


 SLANT PATH PARAMETERS IN STANDARD FORM

        H1      =    100.000 KM
        H2      =      0.000 KM
```

Table 4c. Sample Input and Output - Case 3 (Contd)

```
        ANGLE    =     180.000 DEG
        PHI      =       -.000 DEG
        HMIN     =       0.000 KM
        LEN      =           0


HALFWIDTH INFORMATION ON THE USER SUPPLIED FASCOD1 BOUNDARIES
THE FOLLOWING VALUES ARE ASSUMED:
        ALZERO   =        .100 CM-1 = AVERAGE LORENTZ WIDTH AT STP
        AVMWT    =     36.00        = AVERAGE  MOLECULAR WEIGHT
        VBAR     =    695.00   CM-1 = AVERAGE WAVENUMBER
```

I	Z (KM)	P (MB)	T (K)	LORENTZ (CM-1)	DOPPLER (CM-1)	ZETA	VOIGT (CM-1)	VOIGT RATIO	TEMP DIFF (K)
1	2.000	795.000	275.100	.08139	.00069	.992	.08139	1.26	12.9
2	4.000	616.600	262.200	.06466	.00067	.990	.06466	1.27	13.0
3	6.000	472.200	249.200	.05079	.00065	.987	.05080	1.29	13.0
4	8.000	356.500	236.200	.03939	.00064	.984	.03940	1.31	13.0
5	10.000	265.000	223.200	.03012	.00062	.980	.03013	1.35	6.6
6	12.000	194.000	216.600	.02238	.00061	.973	.02240	1.37	0.0
7	14.000	141.700	216.600	.01635	.00061	.964	.01637	1.37	0.0
8	16.000	103.500	216.600	.01194	.00061	.951	.01197	1.37	0.0
9	18.000	75.650	216.600	.00873	.00061	.935	.00877	1.36	0.0
10	20.000	55.290	216.600	.00638	.00061	.913	.00644	1.36	2.0
11	22.000	40.470	218.600	.00465	.00061	.883	.00473	1.35	2.0
12	24.000	29.720	220.600	.00340	.00062	.846	.00351	1.33	2.0
13	26.000	21.914	222.580	.00249	.00062	.801	.00264	1.30	2.0
14	28.000	16.196	224.540	.00184	.00062	.747	.00203	1.27	2.0
15	30.000	11.970	226.500	.00135	.00062	.684	.00159	1.22	4.0
16	32.000	8.925	230.500	.00100	.00063	.613	.00130	1.18	4.0
17	34.000	6.654	234.500	.00074	.00064	.537	.00110	1.13	5.4
18	36.000	5.001	239.880	.00055	.00064	.460	.00097	1.10	6.8
19	38.000	3.789	246.640	.00041	.00065	.386	.00089	1.07	6.8
20	40.000	2.871	253.400	.00031	.00066	.317	.00083	1.05	4.3
21	42.000	2.209	257.720	.00023	.00067	.260	.00079	1.03	4.3
22	44.000	1.700	262.040	.00018	.00067	.210	.00077	1.02	3.4
23	46.000	1.316	265.420	.00014	.00068	.169	.00075	1.02	2.6
24	48.000	1.025	268.040	.00011	.00068	.135	.00073	1.01	2.6
25	50.000	.798	270.600	.00008	.00068	.108	.00072	0.00	0.0

```
1 SUMMARY OF THE GEOMETRY CALCULATION

        MODEL    =     U. S. STANDARD, 1962
        H1       =    100.000 KM
        H2       =      0.000 KM
        ANGLE    =    180.000 DEG
        RANGE    =    100.000 KM
        BETA     =       .000 DEG
        PHI      =      -.000 DEG
        HMIN     =      0.000 KM
        BENDING  =      -.000 DEG
        LEN      =          0
        AIRMAS   =     1.00     RELATIVE TO A VERTICAL PATH , GROUND TO SPACE
```

Table 4c. Sample Input and Output - Case 3 (Contd)

```
FINAL SET OF LAYERS FOR INPUT TO FASCOD
 A LAYER AMOUNT MAY BE SET TO ZERO IF THE CUMULATIVE AMOUNT FOR THAT LAYER AND ABOVE IS LESS THAN 0.1 PERCENT
 OF THE TOTAL AMOUNT. THIS IS DONE ONLY FOR THE FOLLOWING CASES
     1.  IEMIT = 0 (TRANSMITTANCE)
     2.  IEMIT = 1 (RADIANCE) AND ICNTRL = 3 (PATH LOOKING UP)
 O2 IS NOT INCLUDED
 IF THE AMOUNTS FOR ALL THE MOLECULES BUT O2 ARE ZEROED, THE REMAINING LAYERS ARE ELIMINATED
```

L	LAYER BOUNDARIES FROM (KM)	TO (KM)	ICNTRL	PBAR (MB)	TBAR (K)	INTEGRATED AMOUNTS (MOLS CM-2) AIR	H2O	CO2	O3	N2O	CO	CH4	O2
1	0.000	2.000	1	903.76	281.80	4.63E+24	2.85E+22	1.52E+21	1.36E+17	1.29E+18	3.45E+17	7.36E+13	9.64E+23
2	2.000	4.000	1	705.62	268.88	3.78E+24	1.25E+22	1.25E+21	1.25E+17	1.06E+18	2.83E+17	6.04E+13	7.91E+23
3	4.000	6.000	1	544.24	255.92	3.07E+24	4.51E+21	1.01E+21	1.15E+17	8.57E+17	2.30E+17	4.90E+13	6.42E+23
4	6.000	8.000	1	414.24	242.93	2.46E+24	1.50E+21	8.11E+20	1.22E+17	6.88E+17	1.84E+17	3.93E+13	5.15E+23
5	8.000	10.000	1	310.64	229.94	1.95E+24	3.58E+20	6.42E+20	1.77E+17	5.45E+17	1.46E+17	3.11E+13	4.08E+23
6	10.000	12.000	1	229.45	218.49	1.51E+24	6.06E+19	4.98E+20	3.18E+17	4.23E+17	1.13E+17	2.42E+13	3.16E+23
7	12.000	14.000	1	167.85	216.60	1.11E+24	1.30E+19	3.67E+20	4.33E+17	3.12E+17	8.35E+16	1.78E+13	2.33E+23
8	14.000	16.000	1	122.60	216.60	8.13E+23	4.62E+18	2.68E+20	5.33E+17	2.28E+17	6.10E+16	1.30E+13	1.70E+23
9	16.000	18.000	1	89.58	216.60	5.94E+23	3.49E+18	1.96E+20	7.02E+17	1.66E+17	4.46E+16	9.51E+17	1.25E+23
10	18.000	20.000	1	65.47	216.60	4.34E+23	2.94E+18	1.43E+20	8.78E+17	1.22E+17	3.26E+16	6.95E+17	9.10E+22
11	20.000	22.000	1	47.88	217.55	3.16E+23	3.21E+18	1.04E+20	9.60E+17	8.86E+16	2.37E+16	5.06E+17	6.63E+22
12	22.000	24.000	1	35.10	219.55	2.30E+23	3.79E+18	7.58E+19	9.47E+17	6.43E+16	1.72E+16	3.68E+17	4.81E+22
13	24.000	26.000	1	25.81	221.54	1.67E+23	4.21E+18	5.53E+19	8.44E+17	4.69E+16	1.26E+16	2.68E+17	3.51E+22
14	26.000	28.000	1	19.06	223.51	1.23E+23	3.55E+18	4.05E+19	6.91E+17	3.43E+16	9.20E+15	1.96E+17	2.57E+22
15	28.000	30.000	1	14.09	225.47	8.98E+22	2.84E+18	2.97E+19	5.59E+17	2.51E+16	6.74E+15	1.44E+17	1.88E+22
16	30.000	32.000	1	10.45	228.39	6.58E+22	2.15E+18	2.17E+19	4.46E+17	1.84E+16	4.94E+15	1.05E+17	1.38E+22
17	32.000	34.000	1	7.79	232.39	4.82E+22	1.52E+18	1.59E+19	3.51E+17	1.35E+16	3.62E+15	7.72E+15	1.01E+22
18	34.000	36.000	1	5.82	236.71	3.54E+22	1.08E+18	1.17E+19	2.74E+17	9.90E+15	2.65E+15	5.66E+15	7.41E+21
19	36.000	38.000	1	4.40	243.0[illegible]	[illegible].60E+22	7.59E+17	8.60E+18	2.01E+17	7.29E+15	1.95E+15	4.17E+15	5.46E+21
20	38.000	40.000	1	3.33	249.83	1.92E+22	5.36E+17	6.34E+18	1.45E+17	5.37E+15	1.44E+15	3.07E+15	4.02E+21
21	40.000	42.000	1	2.54	255.45	1.43E+22	3.88E+17	4.73E+18	1.00E+17	4.01E+15	1.07E+15	2.29E+15	3.00E+21

Table 4c. Sample Input and Output - Case 3 (Contd)

22	42.000	44.000	1	1.96	259.77	1.08E+22	2.89E+17	3.58E+18	6.56E+16	3.04E+15	8.13E+14	1.73E+15	2.27E+21
23	44.000	46.000	1	1.51	263.90	8.22E+21	2.12E+17	2.71E+18	4.23E+16	2.30E+15	6.17E+14	1.32E+16	1.72E+21
24	46.000	48.000	1	1.17	266.70	6.32E+21	1.45E+17	2.09E+18	2.43E+16	1.77E+15	4.74E+14	1.01E+15	1.33E+21
25	48.000	50.000	1	.91	269.26	4.88E+21	9.83E+16	1.61E+18	1.36E+16	1.37E+15	3.66E+14	7.81E+15	1.02E+21
26	50.000	100.000	1	.39	251.62	1.69E+22	1.84E+17	5.58E+18	2.60E+16	4.74E+15	1.27E+15	2.71E+16	3.55E+21

Table 4d. Sample Input and Output - Case 4

```
*****INPUT CASE 4*************************************************************************************************
    2    2                  1           1
      8.0       10.0                     450.0
    800.0     1200.0
      1.6       10.0        15.0


*****OUTPUT CASE 4************************************************************************************************
1                    *****PROGRAM FSCATM*****      01/11/83       11.04.18.


 CONTROL CARD 1: MODEL AND OPTIONS

          MODEL    =       2
          ITYPE    =       2
          IBND     =       0
          NOZERO   =       0
          NOPRNT   =       1
          KMAX     =       0
          IPUNCH   =       1
          RE       =        0.000 KM


 CONTROL CARD 1 PARAMETERS WITH DEFAULTS:

          MODEL    =       2
          ITYPE    =       2
          IBND     =       0
          NOZERO   =       0
          NOPRNT   =       1
          KMAX     =       7
          IPUNCH   =       1
          RE       =    6371.230 KM


 SLANT PATH SELECTED, ITYPE =      2


 CONTROL CARD 2:  SLANT PATH PARAMETERS

          H1       =       8.0000 KM
          H2       =      10.0000 KM
          ANGLE    =       0.0000 DEG
          RANGE    =     450.0000 KM
          BETA     =       0.0000 DEG
          LEN      =            0
```

Table 4d. Sample Input and Output - Case 4 (Contd)

```
CONTROL CARD 3

        V1   =    800.000 CM-1
        V2   =   1200.000 CM-1
        VBAR =   1000.000 CM-1


AUTOLAYERING SELECTED

        AVTRAT    =     1.60
        TDIFF1    =    10.00
        TDIFF2    =    15.00
1ATMOSPHERIC PROFILE SELECTED IS: M =   2     MIDLATITUDE SUMMER


CASE 2C: GIVEN H1, H2, RANGE

        NOTE: ANGLE IS COMPUTED FROM H1, H2, AND RANGE ASSUMING NO REFRACTION


SLANT PATH PARAMETERS IN STANDARD FORM

        H1       =      8.000 KM
        H2       =     10.000 KM
        ANGLE    =     91.786 DEG
        PHI      =     92.241 DEG
        HMIN     =      4.647 KM
        LEN      =          1


FASCODE LAYER BOUNDARIES PRODUCED BY THE AUTOMATIC LAYERING ROUTINE AUTLAY
THE USER SHOULD EXAMINE THESE BOUNDARIES AND MODIFY THEM IF APPROPRIATE
THE FOLLOWING PARAMETERS ARE USED:

        AVTRAT    =     1.60        = MAX RATIO OF VOIGT WIDTHS
        TDIFF1    =    10.00        = MAX TEMP DIFF AT HMIN
        TDIFF2    =    15.00        = MAX TEMP DIFF AT HMAX
        ALZERO    =      .100 CM-1  = AVERAGE LORENTZ WIDTH AT STP
        AVMWT     =    36.00        = AVERAGE  MOLECULAR WEIGHT
        VBAR      =  1000.00   CM-1 = AVERAGE WAVENUMBER
```

I	Z (KM)	P (MB)	T (K)	LORENTZ (CM-1)	DOPPLER (CM-1)	ZETA	VOIGT (CM-1)	VOIGT RATIO	TEMP DIFF (K)
1	4.647	579.076	269.119	.05994	.00098	.984	.05995	1.21	9.9
2	6.300	467.835	259.200	.04934	.00096	.981	.04936	1.23	11.2
3	8.000	372.000	248.000	.04011	.00094	.977	.04013	1.27	12.3
4	9.900	285.030	235.700	.03152	.00092	.972	.03155	1.01	.7
5	10.000	281.000	235.000	.03112	.00091	.971	.03115	0.00	0.0

Table 4d. Sample Input and Output - Case 4 (Contd)

```
1 SUMMARY OF THE GEOMETRY CALCULATION

         MODEL    =     MIDLATITUDE SUMMER
         H1       =       8.000 KM
         H2       =      10.000 KM
         ANGLE    =      91.766 DEG
         RANGE    =     494.451 KM
         BETA     =       4.441 DEG
         PHI      =      92.241 DEG
         HMIN     =       4.647 KM
         BENDING  =        .434 DEG
         LEN      =           1
         AIRMAS   =    30.9     RELATIVE TO A VERTICAL PATH , GROUND TO SPACE
0FINAL SET OF LAYERS FOR INPUT TO FASCOD1
 A LAYER AMOUNT MAY BE SET TO ZERO IF THE CUMULATIVE AMOUNT FOR THAT LAYER AND ABOVE IS LESS THAN 0.1 PERCENT
 OF THE TOTAL AMOUNT. THIS IS DONE ONLY FOR THE FOLLOWING CASES
     1.   IEMIT = 0 (TRANSMITTANCE)
     2.   IEMIT = 1 (RADIANCE) AND ICNTRL = 3 (PATH LOOKING UP)
 O2 IS NOT INCLUDED
 IF THE AMOUNTS FOR ALL THE MOLECULES BUT O2 ARE ZEROED, THE REMAINING LAYERS ARE ELIMINATED


    L   LAYER BOUNDARIES ICNTRL  PBAR      TBAR                 INTEGRATED AMOUNTS (MOLS CM-2)
          FROM       TO
          (KM)      (KM)          (MB)       (K)      AIR      H2O      CO2      O3       N2O      CO       CH4      O2

    1    4.647     6.300   2    542.59    265.96 2.26E+26 4.89E+23 7.46E+22 1.29E+19 6.33E+19 1.69E+19 3.62E+20 4.73E+25

    2    6.300     8.000   2    422.54    254.30 7.79E+25 7.77E+22 2.57E+22 6.12E+18 2.18E+19 5.84E+18 1.25E+20 1.63E+25

    3    8.000     9.900   3    330.11    242.52 5.36E+25 2.39E+22 1.77E+22 5.81E+18 1.50E+19 4.02E+18 8.58E+19 1.12E+25

    4    9.900    10.000   3    283.01    235.35 2.24E+24 0.       7.39E+20 2.89E+17 6.27E+17 1.68E+17 3.58E+18 4.69E+23

****TAPE7  CASE4*************************************************************************************************

   4      MIDLATITUDE SUMMER        H1=     8.00 H2=    10.00 ANGLE=   91.766 LEN= 1
5.426E+02    265.96                  2                        4.65 TO    6.30 KM
 4.89E+23  7.46E+22  1.29E+19  6.33E+19  1.69E+19  3.62E+20  4.73E+25
4.225E+02    254.30                  2                        6.30 TO    8.00 KM
 7.77E+22  2.57E+22  6.12E+18  2.18E+19  5.84E+18  1.25E+20  1.63E+25
3.301E+02    242.52                  3                        8.00 TO    9.90 KM
 2.39E+22  1.77E+22  5.81E+18  1.50E+19  4.02E+18  8.58E+19  1.12E+25
2.830E+02    235.35                  3                        9.90 TO   10.00 KM
 0.        7.39E+20  2.89E+17  6.27E+17  1.68E+17  3.58E+18  4.69E+23
```

The following two pages trace the refracted path through the atmosphere, starting from the lowest point along the path. The layer boundaries for this calculation are the result of merging the atmospheric profile boundaries with the output layer boundaries, from HMIN to HMAX. The column labeled THETA shows the path zenith angle at the bottom of that layer, while DRANGE is the curved path length through the layer. DBETA is the earth-centered angle subtended by that layer. PHI is the arrival angle at the top of the layer, while DBEND is the refractive bending in the layer. PBAR and TBAR are the density-weighted pressure and temperatures for the layer, while RHOBAR is the average density. The next table lists the amounts for each gas for each layer, plus the total for the path.

The last page prints a summary of the path calculation then the amounts for the output layers. Note that the amounts for H_2O are zeroed out above 32.3 km because less than 0.1 percent of the total H_2O amount for this path lies above 32.3 km. The amounts for all the other molecules except O_3 are zeroed out above 49.0 km for the same reason. Finally, the layers above 78.1 km are eliminated entirely since 99.9 percent of the amounts for all the molecules lie below this altitude. This zeroing option can reduce the computation time for a line-by-line calculation. The option can be suppressed by specifying NOZERO = 1 on Card 1.

Case 2, shown in Table 4b, models the conditions of a stratospheric balloon-borne experiment looking at the sun as it sets.[11] On Card 1, MODEL = 7 selects a user-supplied atmospheric profile, ITYPE = 3 selects a slant path to space, and KMAX = 20 selects 20 molecular species, the maximum allowed. On Card 2, H1 = 33 km is the altitude of the balloon and ANGLE = 94.88 deg is the apparent or measured zenith angle of the sun. The reported zenith angle of 95.3 deg is the astronomical zenith angle for a straight line to the sun. The apparent zenith angle was found by iteration of the program until the apparent zenith angle (ANGLE) plus the total bending (BENDNG) equaled the astronomical zenith angle.

Autolayering is again selected but now the parameters AVTRAT, TDIFF1, and TDIFF2 are supplied on Card 4 as 2.0, 50.0, and 50.0 respectively. The large values of TDIFF1 and TDIFF2 will generate a relatively small number of thick output layers. This layering is useful for initial or survey line-by-line calculations since the time of the calculation is related to the number of layers. More accurate calculations may require more layers: the user must experiment with different layerings to determine the minimum number of layers consistent with his accuracy requirements.

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11. Goldman, A., Blatherwick, R.D., Murcray, F.J., Van Allen, J.W., Murcray, F.H., and Murcray, D.G. (1982) Atlas of stratospheric IR absorption spectra, Appl. Opt. 21:1163-1164.

Using a value of AVTRAT larger than 2.0 will also generate thick output layers. However, due to the layer to layer merging scheme used in FASCODE, layers generated by a value of AVTRAT greater than 2.0 may be inconsistent with FASCODE.

The user-supplied atmospheric profile is read in after Card 4. In this case, the temperature profile is from the U.S. Standard Atmosphere 1976 while the volume mixing ratios up to 50 km for the various gases, except CO_2, are from Smith[12] (see also Appendix A). Above the 50 km only a water vapor concentration is given: the mixing ratios for the "uniformly mixed gases" CO_2, N_2O, CO, CH_4, and O_2 revert to their default values. Note: the program does not check whether the atmosphere is in hydrostatic equilibrium.

Following the atmospheric profile are the slant path parameters in standard form. This path passes through a tangent height of 9.152 km. Next comes the internally-generated FASCODE output layer boundaries; note that the ratio of the Voigt halfwidths controls the layering up to 40 km. The rest of the output is straight forward and self-explanatory.

Case 3, shown in Table 4c, illustrates the use of user-supplied output layers, the NOZERO option, and of the short form of the output. On Card 1, IBND is set to the number of user-supplied output boundaries, 25 in this case. The altitudes are then read in after Card 3. The NOPRNT = 1 option suppresses the printing of the tables of the atmospheric profile and ray trace calculation. The NOZERO = 1 option preserves the amounts for all the molecules for all the layers. This option is important, for example, when calculating the radiance measured looking down from space, where the contribution from a high but sparse layer can be significant. The particular case run here applies to calculating weighting functions for temperature sounding from a satellite looking straight down from space. Note also that the program resets H1 from the input value 500 km to 100 km, which is the altitude of the highest boundary in the atmospheric profile.

The last case, shown in Table 4d, illustrates the use of H1, H1, and RANGE to describe the path. The program calculates ANGLE from H1, H2, and RANGE assuming no refraction, and then traces out the path using H1, H2, and ANGLE. Due to refraction the resultant RANGE is significantly larger than the input value. Also shown is the output on TAPE7 selected by the IPU=1 option on Card 1. This output is in a form suitable for direct input to FASCODE.

---

12. Smith, M.A.H. (1982) Compilation of Atmospheric Gas Concentration Profiles From 0 to 50 km, NASA TM-83289.

3.3 Program Structure

The program consists of a simple driver program, called FSCATM, and 20 subroutines. Table 5 lists the program units and their functions and Figure 20 shows the relationship among the principal ones. Each subroutine contains comment cards describing its function. The comments in ATMPTH contain a concise description of the program usage. The program is modular so that the user may easily modify it to suit any particular needs.

Table 5. Program Units and Their Functions

Program Unit	Function
FSCATM	Interface between FASCODE and ATMPTH
ATMCON	Block data: Initializes various program constants
ATMPTH	Main subroutine: Handles I/O
MLATMB	Block data: Stores reference profiles
MLATM	Model atmosphere: Sets up atmospheric profile
NSMDL	Non-standard model: Inputs user profiles
WATVAP	Calculates the water vapor number density for non-standard conditions
GEOINP	Reduces the input slant path parameters to the standard form: H1, H2, ANGLE, LEN
REDUCE	Eliminates slant path segments that extend about the highest profile altitude
FDBETA	Calculates angle given the input parameters H1, H2, BETA
EXPINT	Exponential interpolation
FNDHMN	Calculates HMIN = Minimum altitude along the path (Tangent altitude if any)
FINDSH	Finds the layer containing a given altitude
SCALHT	Calculates the scale height of the refractivity
ANDEX	Calculates the index of refraction at a given altitude
RADREF	Calculates the radius of curvature due to refraction
RFPATH	Drives the path calculation over all the layers
FILL	Sets up a profile extending from HMIN to HMAX
ALAYER	Calculates the path and the amounts through one layer
AUTLAY	Layers the atmosphere from HMIN to HMAX based on AVTRAT, TDIFF1, and TDIFF2
HALFWD	Calculates LORENTZ, DOPPLER, and VOIGT half-widths and ZETA given P, T, and VBAR

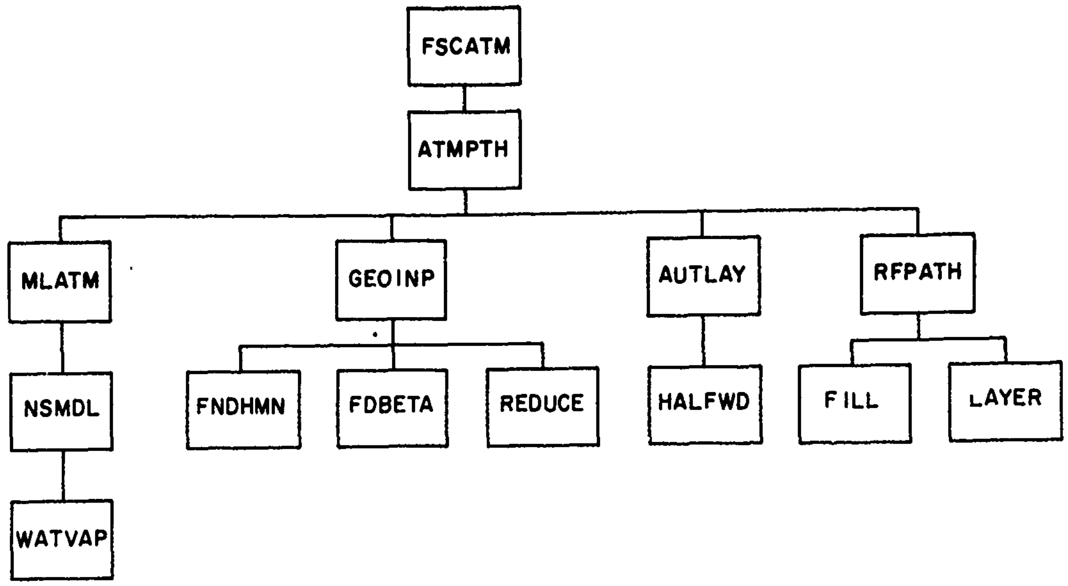

Figure 20. Structure Chart Showing the Major Subroutines

3.4 Portability

The program FSCATM runs on a CDC 6600 computer (a 60 bit word computer) with a FORTRAN 77 (FORTRAN V) compiler. It is also designed to be compatible with minor modifications with 32 bit word computer in single precision and with FORTRAN 66 (FORTRAN IV). To run on a 32 bit word computer, variables containing character data must be declared DOUBLE PRECISION (CHARACTER *8 will not work since some of these variables are carried in COMMON along with non-character variables). The required statements for this are supplied in the program with the characters 'C&' in Columns 1 to 3. To compile under CDC FORTRAN IV, all single quotes ' must be replaced with double quotes ". To convert the subroutine FSCATM to a stand-along program, enable the statements in FSCATM with the characters 'CP' in Columns 1 and 2, and include the subroutines from ATMPTH to HALFWD. The user must also supply subroutines DATE and TIME, which return the date and time in A8 format.

When the sample cases described in Section 3.2 are run on a 32 bit word computer in single precision, the results may be different in the third or fourth decimal place compared with the sample output. This precision is generally sufficient considering the accuracy of the models and of the data.

3.5 Availability

FSCATM is available as a part of the FASCOD1C package. This package includes the program FASCOD1C plus various other associated programs and sample input and output. The package is available on tape from

National Climatic Center, NOAA
Environmental Data Service
Federal Building
Asheville, NC 28801
(704)-258-2850, ex 682 (Ms Yolanda Goodge)

and presently costs $98.00. The users guide for FASCOD1C is available from

S.A. Clough
AFGL/OPI
Hanscom AFB MA 01731

An earlier version of FSCATM, called FSCDATM, was distributed as a part of the FASCOD1B package. FSCATM is a revision of FSCDATM with a number of improvements and fixes. In particular, FSCDATM would not work properly on a 32 bit word computer in single precision for tangent paths. This bug has been fixed in FSCATM.

3.6 Errata for FSCATM

As distributed with FASCOD1C, FSCATM contained six known errors. The corrections are as follows:

1. Line 24740 (line 420 of ATMPTH)

   IF(VMIX(I).GT.0.0) DENSTY(K, 1) = VMIX(K)*RHOBAR*1.0E-6

   should read

   IF(VMIX(K).GT.0.0) DENSTY(K, 1) = VMIX(K)*RHOBAR*1.0E-6

2. After line 25300 (line 476 of ATMPTH), insert

   NLAYERS = 1

   WN2L(1) = AMTAIR * VMIXN2 * 1.0 E-6

3. Line 25240 (line 488 of ATMPTH)

   1 (AMOUNT(K, 1), K=1, KMAX)

   should read

   1 (AMOUNT(K, 1), K=1, 7), WN2L(1), (AMOUNT(K, 1), K=8, KMAX)

4. Lines 28540 to 28550 (lines 800 to 801 of ATMPTH)

```
IF(IPUNCH.EQ.1) WRITE(IPU, 70)(AMOUNT(K, L), K=1, KMAX)
70 FORMAT(1P8E10.2)
```

should read

```
IF(IPUNCH.NE.1) GO TO 470
WRITE(IPU, 70)(AMOUNT(K, L), K=1, 7), WN2L(L)
70 FORMAT (1P8E10.2)
IF(KMAX.GT.7)WRITE(IPU, 70)(AMOUNT(K, L), K=8, KMAX)
```

5. In FORMAT statements 30, 35, and 37 of ATMPTH, the '20X' should be changed to 'T20'.

6. Line 44970 (line 143 of ALAYER)

```
TPSUM(J) = TPSUM(J) + 0.5*DS*(PA+PB)
```

should read

```
TPSUM(J) = TPSUM(J) + 0.5*DS*(PA+PB)/GCAIR
```

Corrections 1 and 2 are required for the program to run a horizontal path properly. Corrections 3 and 4 are required to write the proper layer information to TAPE7. Correction 5 affects only the printed output of the total air amounts. Correction 6 fixes an error in the calculation of the average temperature for a very thin layer: most paths are unaffected by this error. These corrections have been incorporated into the listing contained in this report, with an '!' in column 74.

3.7 Program Listing

```
      SUBROUTINE FSCATM
CP    PROGRAM FSCATM
C**********************************************************************
C
C     FSCATM IS AN ATMOSPHERIC RAY TRACE PROGRAM.
C     IT CREATES AND FORMATS THE ATMOSPHERIC INPUTS FOR THE AFGL
C     LINE-BY-LINE TRANSMITTANCE/RADIANCE PROGRAM FASCODE.
C
C     SEE THE COMMENTS IN SUBROUTINE ATMPTH FOR DETAILED INSTRUCTIONS ON
C     THE USAGE OF THE ATMOSPHERIC INPUTS.
C
C     TO CONVERT THE AIR MASS MODULE TO A STAND ALONE PROGRAM,
C     INCLUDE THE SUBROUTINES FROM FSCATM TO HALFWD, AND
C     ENABLE THE CARDS THAT BEGIN WITH 'CP  '.
C
C     TO RUN THE PROGRAM ON A 32 BIT WORD MACHINE, ENABLE THE CARDS
C     THAT BEGIN WITH 'C& '.
C
C**********************************************************************
      COMMON /PATHD/ PBAR(37),TBAR(37),AMOUNT(20,37),WN2L(37),
     C    DVL(37),WTOTL(37),ALBL(37),ADBL(37),AVBL(37),H2OSL(37),
     C    ICNTRL(37),ITYL(37),SECNTA(37),ALTB(37),ALTT(37),HT1,HT2
      COMMON /MAIN/ NWDFIL,KFILE,KPANEL,LINFIL,P0,TEMPO,NLAYRS,
     C               H2OSLF,WTOT,ALBAR,ADBAR,AVBAR,AVFIX,LAYRFX,SECNTO,
     C   SAMPLE,ALFALO,AVMASS
C&    DOUBLE PRECISION XID,SECANT,HMOLID,YID ,HMOL
      COMMON /FILHDR/ XID(10),SECANT,PAVE,TAVE,HMOLID(20),WK(20),WN2,
     C               DV,V1,V2,TBOUND,EMISIV,FSCDID(17),NMOL,LAYER,
     C               YI1,YID(10)
      EQUIVALENCE (FSCDID(5),IEMIT)
C&    DOUBLE PRECISION HMOLS
      COMMON /HMOLS/ HMOLS(20)
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1     ICUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
C&    DOUBLE PRECISION HDATE,HTIME
C*****IRD, IPP, IPU ARE UNIT NUMBERS FOR INPUT, OUTPUT, PUNCH
CP    DATA IRD/5/,IPR/6/,IPU/7/,IEMIT/0/
CP    OPEN(UNIT=5,FILE='INPUT',STATUS='OLD')
CP    OPEN(UNIT=6,FILE='OUTPUT')
      CALL DATE(HDATE)
      CALL TIME(HTIME)
      WRITE(IPR,900)  HDATE,HTIME
900   FORMAT('1',20X,'*****PROGRAM FSCATM*****      ',A10,5X,A10,///)
C*****
      CALL ATMPTH(IEMIT)
C*****
      SECANT = 1.0
      NMOL = KMAX
      DO 30 M=1,KMAX
30    HMOLID(M)=HMOLS(M)
      RETURN
CP    STOP
C
      END
```

```
      SUBROUTINE ATMPTH(IEMIT)
C*********************************************************************
C
C
C
C
C                 ATMPTH   (ATMOSPHERIC PATH)
C
C
C
C
C                              WILLIAM O. GALLERY
C                              FRANCIS X. KNEIZYS
C                              SHEPARD A. CLOUGH
C
C
C
C                                         AIR FORCE GEOPHYSICS LAB
C                                         OPTICAL PHYSICS DIVISION
C                                         HANSCOM AFB
C                                         BEDFORD, MA.  01731
C                                         617-861-4774
C
C
C                                         REVISED    JULY, 1982
C
C*********************************************************************
C
C
C     USER INSTRUCTIONS:
C
C     ATMPTH CALCULATES THE DENSITY WEIGHTED MEAN TEMPERATURE AND
C     PRESSURE AND THE INTEGRATED ABSORBER AMOUNTS (IN MOLECULES
C     CM-2) FOR EACH LAYER ALONG A PATH THROUGH A LAYERED
C     ATMOSPHERE, INCLUDING THE EFFECTS OF REFRACTION AND THE  EARTH'S
C     CURVATURE.  ATMPTH IS DESIGNED TO PREPARE THE ATMOSPHERIC INPUTS
C     TO THE PROGRAM FASCOD1 WHICH DOES A LINE-BY-LINE CALCULATION OF
C     ATMOSPHERIC TRANSMITTANCE OR RADIANCE AND IS DESCRIBED IN
C     REFERENCE (1).  THE CONTROL CARDS REQUIRED TO RUN ATMPTH ARE
C     DESCRIBED LATER IN THESE COMMENTS.  A DETAILED DESCRIPTION OF
C     OF THE ALGORITHM USED HERE AND A DISCUSSION OF THE EFFECTS OF
C     THE EARTH'S CURVATURE AND REFRACTION ARE GIVEN IN REFERENCE (2).
C
C     THE DEFINITIONS AND USES OF THE PATH PARAMETERS ITYPE, H1, H2,
C     ANGLE, RANGE, BETA, AND LEN ARE THE SAME AS THOSE DESCRIBED IN
C     REFERENCE (3): HOWEVER THE SUBROUTINES WHICH CALCULATE THE
C     REFRACTED PATH ARE COMPLETELY DIFFERENT FROM THOSE IN THE
C     VERSIONS OF LOWTRAN, UP TO LOWTRAN 5.
C
C     THERE ARE SIX BUILT IN ATMOSPHERIC PROFILES WHICH DEFINE THE
C     PRESSURE, TEMPERATURE, AND THE DENSITIES OF THE SEVEN MOLECULAR
C     SPECIES H2O, CO2, O3, N2O, CO, CH4, AND O2 ON THE AFGL
C     ATMOSPHERIC LINE PARAMETERS COMPILATION AT 33 STANDARD
C     ALTITUDES.  THESE MODEL ATMOSPHERES ARE THE SAME AS THOSE
C     DESCRIBED IN REFERENCE (4), ALTHOUGH THE DENSITIES ARE IN
C     DIFFERENT UNITS.  THE USER MAY ALSO INPUT AN ATMOSPHERIC
C     PROFILE AS DESCRIBED LATER (SEE ALSO THE COMMENTS IN
C     THE SUBROUTINE NSMOL) AND INCLUDE UP TO 13 ADDITIONAL
C     SPECIES CORRESPONDING TO THE MOLECULES ON THE AFGL TRACE GAS
C     COMPILATION.
```

```
C
C     THE PRINCIPAL OUTPUT CONSISTS OF THE INTEGRATED ABSORBER AMOUNTS
C     FOR A SET OF LAYERS TO BE INPUT TO THE LINE-BY-LINE CALCULATION.
C     THE NUMBER OF THESE LAYERS REPRESENTS A TRADEOFF BETWEEN ACCURACY
C     AND COMPUTATIONAL SPEED OF THE LINE-BY-LINE CALCULATION.  THE
C     USER HAS THE OPTION OF INPUTTING HIS OWN SET OF LAYER BOUNDARIES
C     OR OF LETTING THE SUBROUTINE AUTLAY GENERATE THESE LAYERS
C     AUTOMATICALLY.  IF THE USER INPUTS HIS OWN BOUNDARIES,  THEY NEED
C     NOT FALL ON THE ATMOSPHERIC PROFILE BOUNDARIES OR INCLUDE THE
C     PATH ENDPOINTS. IF AUTOMATIC LAYERING IS SELECTED, THE USER MAY
C     SPECIFY THE MAXIMUM HALFWIDTH RATIO ACROSS A LAYER AND THE
C     MAXIMUM TEMPERATURE DIFFERENCE ACROSS A LAYER.
C
C     IT IS DIFFICULT TO SPECIFY APRIORI THE RELATIONSHIP BETWEEN
C     THE NUMBER OF LAYERS AND THE ACCURACY:  THE ACCURACY DEPENDS UPON
C     SUCH FACTORS AS THE SPECTRAL REGION, THE DISTRIBUTION OF THE
C     MOLECULES OF INTEREST, THE PARTICULAR PATH TAKEN, AND WHETHER
C     TRANSMITTANCE OR RADIANCE IS CALCULATED. THE LAYERING CREATED
C     BY THE DEFAULT VALUES OF AVTRAT (2.0) AND TDIFF1 (15.0 K) AND
C     TDIFF2 (30.0 K) SHOULD BE CONSIDERED A POINT OF DEPARTURE FOR
C     SUBSEQUENT CALCULATIONS. THE USER SHOULD THEN EXPERIMENT WITH
C     DIFFERENT LAYERING UNTIL THE RESULTS ARE CONSISTENT WITH
C     HIS ACCURACY REQUIREMENTS.
C
C     TO SAVE COMPUTER TIME IN FASCOD1, THE LAYER AMOUNTS ARE ZEROED
C     OUT WHEN
C         1.  THE CUMULATIVE AMOUNT FOR THAT LAYER AND ABOVE IS LESS
C             THAN 0.1 PERCENT OF THE TOTAL,
C        AND
C         2.  A. TRANSMITTANCE IS CALCUALTED (IEMIT = 0)
C                OR
C             B. RADIANCE IS CALCULATED (IEMIT = 1) AND THE PATH IS
C                LOOKING UP (ICNTRL = 3)
C     O2 IS  NOT CONSIDERED IN THIS SCHEME.  IF THE ABSORBER
C     FOR A LAYER FOR ALL THE MOLECULES (EXCEPT O2) ARE ZEROED
C     OUT, THEN THAT LAYER AND THOSE ABOVE ARE ELIMINATED
C
C     TO CALCULATE THE AMOUNTS FOR THE TRACE GASES (MOLECULES 8 THROUGH
C     20) THE USER MUST INCREASE KMAX ON CARD 1 AND READ IN AN
C     ATMOSPHERIC PROFILE (MODEL = 7) INCLUDING THE VOLUME MIXING RATIOS
C     OF THE ADDITIONAL MOLECULES.
C
C-----------------------------------------------------------------------
C     CONTROL CARDS:
C
C     FOUR  CONTROL CARDS CONTROL THE OPERATION OF THE PROGRAM WHILE
C     OTHER CARDS MAY BE READ IN TO DEFINE NON-STANDARD CONDITIONS. THE
C     FORMATS OF THESE CARDS AND THE MEANING OF THE PARAMETERS ARE
C     DESCRIBED AS FOLLOWS:
C
C        CONTROL CARD 1: MODEL, ITYPE, IBND, NOZERO, NOPRNT, KMAX,
C                        IPUNCH, RE
C                        (7I5,5X,F10.4)
C             MODEL = 0: USER SUPPLIED HORIZONTAL PATH PARAMETERS
C                     1: TROPICAL MODEL ATMOSPHERE
C                     2: MIDLATITUDE SUMMER
C                     3: MIDLATITUDE WINTER
C                     4: SUBARCTIC SUMMER
C                     5: SUBARCTIC WINTER
C                     6: U.S. STANDARD, 1962
```

```
C                 7: USER SUPPLIED ATMOSPHERIC PROFILE
C          ITYPE = 1: HORIZONTAL PATH (CONSTANT PRESSURE)
C                 2: SLANT PATH FROM H1 TO H2
C                 3: SLANT PATH FROM H1 TO SPACE
C          IBND    NUMBER OF BOUNDARY ALTITUDES FOR THE FASCOD1
C                  LAYERS: IF IBND GT 0, USER SUPPLIES BOUNDARIES
C                          IF IBND = 0, AUTO LAYERING IS SELECTED
C          NOZERO =1: SUPRESSES ZEROING OF SMALL AMOUNTS.
C                  DEFAULT = 0
C          NOPRNT =1: SELECTS SHORT PRINTOUT. DEFAULT = 0
C          KMAX    NUMBER OF MOLECULAR SPECIES. DEFAULT = 7
C                  IF KMAX LT 0, A RAY TRACE IS DONE BUT NO AMOUNTS
C                  ARE CALCULATED
C          IPUNCH =1: WRITE LAYER AMOUNTS TO UNIT IPU=7. DEFAULT = 0
C          RE      RADIUS OF THE EARTH. DEFAULTS:
C                  MODEL = 1, RE = 6378.39 KM
C                          2,3,6,7, RE = 6371.23 KM
C                          4,5, RE = 6356.91 KM
C
C     THE FORMATS FOR THE REMAINING CONTROL CARDS ARE DIFFERENT
C     DEPENDING ON WHETHER THE PATH IS HORIZONTAL (ITYPE = 1)
C     OR SLANT (ITYPE = 2 OR 3)
C
C----------------------------------------------------------------------
C
C     FOR A SLANT PATH (ITYPE = 2 OR 3):
C
C        CONTROL CARD 2: H1,H2,ANGLE,RANGE,BETA,LEN
C                           (5F10.4,I5)
C             H1      ALTITUDE OF THE OBSERVER OR RECIEVER (KM)
C             H2      ALTITUDE OF THE OTHER ENDPOINT OF THE PATH (KM):
C             ANGLE   ZENITH ANGLE AT H1 (DEGREES)
C             RANGE   LENGTH OF THE PATH FROM H1 TO H2 (KM):
C             BETA    EARTH CENTERED ANGLE FOR THE PATH H1 TO H2 (DEG)
C             LEN     =0, SHORT PATH; =1, LONG PATH THROUGH A TANGENT:
C                     HEIGHT.  LEN IS USED ONLY WHEN ANGLE IS GT 90.0
C                     AND H1 IS GT H2.  DEFAULT = 0.
C
C     ONLY THREE OF THE FIRST FIVE PARAMETERS NEED BE SPECIFIED;
C     FOR EXAMPLE, H1, H2, ANGLE, OR H1, H2, BETA, OR H1, ANGLE, RANGE.
C     SEE THE COMMENTS IN THE SUBROUTINE GEOINP OR SEE REFERENCE (2)
C     FOR MORE DETAILS ON THE POSSIBLE COMBINATIONS OF THESE PARAMETERS
C
C        CONTROL CARD 3: V1, V2
C                           (2F10.3)
C             V1,V2   INITIAL AND FINAL WAVENUMBERS FOR USE
C                     IN CALCULATING THE DOPPLER HALFWIDTH USED IN
C                     CREATING THE FASCODE LAYERS AND IN CALCULATING
C                     THE INDEX OF REFRACTION  (CM-1)
C
C        CONTROL CARD 4: (LAYERING)
C
C        IF IBND = 0 (AUTOLAYERING SELECTED)
C
C             AVTRAT,TDIFF1,TDIFF2  (3F10.3)
C             AVTRAT = MAX VOIGT WIDTH RATIO ACROSS A LAYER
C                      DEFAULT - 2.0
C             TDIFF1 = MAX TEMP DIFFERENCE (K) ACROSS A LAYER AT HMIN
C                      (=LOWEST ALTITUDE ALONG THE PATH).
C                      DEFAULT - 15.0 K
```

```
C           TDIFF2 = MAX TEMP DIFFERENCE (K) ACROSS A LAYER AT HMAX
C                    (=HIGHEST ALTITUDE ALONG THE PATH).
C                    DEFAULT = 30.0 K
C
C       IF IBND NE 0 (USER SUPPLIED FASCOD1 LAYER BOUNDARIES)
C
C           (ZBND(IB),IB=1,IBND)  (8F10.3)
C           ZBND      ALTITUDES OF FASCOD1 LAYER BOUNDARIES
C
C     IF MODEL = 7, THE INPUT ATMOSPHERIC PROFILE IS READ IN AFTER
C     CONTROL CARD 4 IN THE FOLLOWING FORMAT:
C
C           IMOD, HEADER  (I5,/,3A8)
C                IMOD   = NUMBER OF LEVELS IN THE PROFILE
C                HEADER = 24 CHARACTER HEADER DESCRIBING THE PROFILE
C
C           Z,P,T,TD,RH,PPH2O,DENH2O,AMSMIX    (8F10.3)
C           (VMIX(K),K=1,KMAX)      (8E10.3)
C                    TWO (OR MORE) CARD IMAGES FOR EACH OF THE IMOD
C                    LEVELS.  SEE COMMENTS  FOR THE SUBROUTINE NSMDL
C                  , REGARDING  THE DEFINITIONS AND USAGES OF THESE
C                    PARAMETERS.
C
C----------------------------------------------------------------------
C
C     FOR A HORIZONTAL PATH (ITYPE = 1):
C        CONTROL CARD 2:
C           FOR MODEL = 1 TO 7:
C           Z,RANGE      (2F10.3)
C
C           FOR MODEL = 0:
C           RANGE,P,T,TD,RH,PPH2O,DENH2O,AMSMIX  (8F10.3)
C           (VMIX(K),K=1,KMAX)      (8E10.3)
C                    WHERE Z AND RANGE ARE THE ALTITUDE AND RANGE OF
C                    THE PATH, BOTH IN KM.  FOR MODEL = 1 TO 7, THE
C                    PRESSURE, TEMPERATURE, AND DENSITIES ARE
C                    INTERPOLATED FROM THE MODEL ATMOSPHERE.  FOR
C                    MODEL = 0, SEE THE NOTES FOR THE SUBROUTINE
C                    NSMDL FOR THE DEFINITIONS AND USAGES OF THE
C                    PARAMETERS IN THIS CASE.  IF THE VOLUME MIXING
C                    RATIO OF O3 IS NOT SUPPLIED FOR MODEL = 0, IT IS
C                    COMPUTED USING A VALUE FOR THE VOLUME
C                    MIXING RATIO OF 40.E-9.
C
C        CONTROL CARDS 3 AND 4: NOT USED
C
C     FOR MODEL 7, THE INPUT ATMOSPHERIC PROFILE IS READ IN AFTER
C     CONTROL CARD 2 AS FOR A SLANT PATH.
C
C----------------------------------------------------------------------
C
C     OUTPUT :
C
C     THE PRINTED OUTPUT IS ON FILE IPR (DEFAULT=6). SELECTING
C     NOPPNT=1 SUPRESSES THE PRINTING OF THE ATMOSPHERIC PROFILES
C     AND THE LAYER-BY-LAYER RESULTS FOR THE REFRACTED PATH.
C     IF IPUNCH = 1, THEN THE FASCOD1 INPUT DATA IS ALSO PUT ON FILE
C     IPU (DEFAULT=7) AND CONSISTS OF A SINGLE CARD IMAGE GIVING THE
C     NUMBER OF LAYERS LMAX AND A 70 CHARACTER FIELD DESCRIBING THE
C     PROFILE AND THE PATH, FOLLOWED BY TWO (OR MORE) CARD IMAGES FOR
```

```
C     EACH OF THE LMAX LAYERS
C
C        CARD 1: LMAX,LABEL  (I5,5X,A70)
C               LMAX   = NUMBER OF FASCOD1 LAYERS, MAY DIFFER FROM
C                        IBND DEPENDING ON THE PATH.
C               LABEL  = 70 CHARACTER FIELD.
C
C        CARD 2: PAVE,TAVE,ICNTRL,LAYRID
C                (2F10.4,10X,I5,25X, A20)
C               PAVE   =  AVERAGE PRESSURE (MB)
C               TAVE   =  AVERAGE TEMPERATURE (K)
C               ICNTRL : IF THE PATH DOES NOT GO THROUGH A TANGENT HEIGHT,
C                           IF H1.LT.H2  ICNTRL = 3
C                           IF H1.GT.H2  ICNTRL = 1
C                        IF THE PATH GOES THROUGH A TANGENT HEIGHT, THEN
C                           FOR THE LAYERS FROM THE TANGENT HEIGHT TO
C                           MIN(H1,H2),  ICNTRL = 2
C                           FOR THE LAYERS (IF ANY) FROM MIN(H1,H2)
C                           TO H1, ICNTRL = 1
C                           FOR THE LAYERS (IF ANY) FROM MIN(H1,H2)
C                           TO H2, ICNTRL = 3
C                        FOR A HORIZONTAL PATH, ICNTRL = 0
C               LAYRID:  20 CHARACTER FIELD GIVING THE BOUNDARY
C                        ALTITUDES (ITYPE 2 OR 3) OR RANGE AND
C                        ALTITUDE (ITYPE 1)
C
C        CARD 3: (AMOUNT(K),K=1,KMAX)
C                (1P8E10.2)
C               AMOUNT(K)   INTEGRATED ABSORBER AMOUNT FOR THE K'TH
C                           MOLECULAR SPECIES (MOLECULES CM-2)
C
C        CARDS 2 AND 3 ARE REPEATED UNITL LMAX LAYERS ARE SPECIFIED.
C
C-----------------------------------------------------------------------
C
C     REFERENCES:
C
C     (1)  FASCOD1 - A USERS' GUIDE (AVAILABLE FROM S.A. CLOUGH AT
C                    THE ABOVE ADDRESS)
C          SEE ALSO:
C          FASCODE - FAST ATMOSPHERIC SIGNATURE CODE
C          (SPECTRAL TRANSMITTANCE AND RADIANCE)
C                                                       AFGL-TR-78-0081
C
C     (2)  FSCATM - A FORTRAN PROGRAM TO CALCULATE AIR MASS FOR
C          INFRARED RADIATIVE TRANSFER (AFGL REPORT- IN PREPERATION)
C
C
C     (3)  ATMOSPHERIC TRANSMITTANCE/RADIANCE:
C          COMPUTER CODE LOWTRAN 5
C                                                       AFGL-TR-80-0067
C
C     (4)  OPTICAL PROPERTIES OF THE ATMOSPHERE (THIRD EDITION)
C                                                       AFGL-TR-72-0497
C
C
C***********************************************************************
C
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
```

```
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
      COMMON /CONSTN/ PZERO,TZERO,AVOGAD,ALOSMT,GASCON,PLANK,BOLTZ,
     1    CLIGHT,ADCON,ALZERO,AVMWT,AIRMWT,AMWT(20),VMIXST(20),VMIXN2
C&    DOUBLE PRECISION HMOD
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
C&    DOUBLE PRECISION HMOLS
      COMMON /HMOLS/ HMOLS(20)
      COMMON /PATHD/ PBAR(37),TBAR(37),AMOUNT(20,37),WN2L(37),
     C    DVL(37),WTOTL(37),ALBL(37),ADBL(37),AVBL(37),H2OSL(37),
     C    ICNTRL(37),ITYL(37),SECNTA(37),ALTB(37),ALTT(37),HT1,HT2
      COMMON /MAIN/ NWDFIL,KFILE,KPANEL,LINFIL,PO,TEMPO,NLAYRS,
     C               H2OSLF,WTOT,ALBAR,ADBAR,AVBAR,AVFIX,LAYRFX,SECNTO,
     C    SAMPLE,ALFALO,AVMASS
      COMMON /BNDRY/ ZBND(34),PBND(34),TBND(34),ALORNZ(34),ADOPP(34),
     1    AVOIGT(34)
      COMMON /ZOUTP/ ZOUT(37),SOUT(37),RHOSUM(37),AMTTOT(20),AMTCUM(20),
     C ISKIP(20)
      DIMENSION VMIX(20)
      DIMENSION XZM(6312),XPBAR(1258),XZOUT(171)
      EQUIVALENCE (ZM(1),XZM(1)),(PBAR(1),XPBAR(1)),(ZOUT(1),XZOUT(1))
C&    DOUBLE PRECISION HORIZ
      DIMENSION HORIZ(3)
      DATA AVRATS/2.0/,TDIF1S/15.0/,TDIF2S/30.0/
      DATA HORIZ/8HHORIZONT, 8HAL PATH , 8H        /
      DATA HT1HRZ/4H AT /,HT2HRZ/4H KN /,HT1SLT/4H TO /,HT2SLT/4H KM /
      DATA IERROR/0/
C*****IAMT = 1:CALCULATE AMOUNTS, IAMT = 2:DO NOT CALCULATE AMOUNTS
      DATA IAMT/1/
C*****O3VMIX IS THE MEAN SURFACE VOLUME MIXING RATIO OF OZONE,
C*****PARTS PER MILLION, FROM U. S. STANDARD ATMOSPHERE, 1976
      DATA O3VMIX/40.0E-3/
C*****AIRMS1 IS ONE AIRMASS OR THE TOTAL AMOUNT FOR A VERTICAL PATH
C*****FROM GROUND TO SPACE
      DATA AIRMS1/2.153E25/
      PI = ASIN(1.0)*2.0
      DEG = 180.0/PI
C*****GCAIR IS THE GAS CONSTANT FOR RHO IN MOL CM(-3), P IN MB, AND
C*****T IN K
      GCAIR = 1.0E-3*GASCON/AVOGAD
C*****ADCON IS THE CONSTANT FOR THE DOPPLER HALFWIDTH
      ADCON = SQRT(2.0*ALOG(2.0)*GASCON/CLIGHT**2)
C*****ZERO OUT COMMON BLOCKS
      NXZM = IMODMX*(4+KDIM)+IDIM*(12+3*KDIM)
      NXPBAR = IOUTMX*(14+KDIM)
      NXZOUT = IOUTMX*3+KDIM*3
      DO 90 N=1,NXZM
   90 XZM(N) = 0.0
      DO 91 N=1,NXPBAR
   91 XPBAR(N) = 0.0
      DO 92 N=1,NXZOUT
   92 XZOUT(N) = 0.0
C*****
C*****
C*****READ CONTROL CARD 1
      READ(IRD,20) MODEL,ITYPE,IBND,NOZERO,NOPRNT,KMAX,IPUNCH,RE
   20 FORMAT(7I5,5X,F10.3)
      WRITE(IPR,21)
```

```
   21 FORMAT(' CONTROL CARD 1: MODEL AND OPTIONS ')
      WRITE(IPR,22) MODEL,ITYPE,IBND,NOZERO,NOPRNT,KMAX,IPUNCH,RE
   22 FORMAT(/,10X,'MODEL   = ',I5,/,10X,'ITYPE   = ',I5,/,
     1     10X,'IBND    = ',I5,/,10X,'NOZERO  = ',I5,/,
     2     10X,'NOPRNT  = ',I5,/,10X,'KMAX    = ',I5,/,
     3     10X,'IPUNCH  = ',I5,/,
     3     10X 'RE      = ',F10.3,' KM')
      M = MODEL
      IF(ITYPE.LT.1 .OR. ITYPE.GT.3) GO TO 900
      IF(M.LT.0 .OR. M.GT.7)  GO TO 900
      IF(IBND.GT.IBMAX) GO TO 900
      IF(KMAX.GT.KDIM) GO TO 900
      IF(KMAX.EQ.0) KMAX = KMXNOM
      IF(IPUNCH.EQ.1) OPEN(UNIT=IPU,FILE='TAPE7')
      IF(RE.NE.0.0) GO TO 95
      RE = 6371.23
      IF(M.EQ.1) RE = 6378.39
      IF(M.EQ.4 .OR. M.EQ.5) RE = 6356.91
   95 CONTINUE
      WRITE(IPR,24)
   24 FORMAT(///,' CONTROL CARD 1 PARAMETERS WITH DEFAULTS:')
      WRITE(IPR,22) MODEL,ITYPE,IBND,NOZERO,NOPRNT,KMAX,IPUNCH,RE
      IF(ITYPE.NE.1) GO TO 200
C*****
C*****
C*****HORIZONTAL PATH SELECTED
C*****
C*****
      WRITE(IPR,25)
   25 FORMAT(///,' HORIZONTAL PATH SELECTED')
      DO 103 I=1,3
      HMOD(I) =  HORIZ(I)
  103 CONTINUE
      IF(M.NE.0)  GO TO 120
C*****READ IN PARAMETERS FOR A HORIZONTAL PATH, MODEL 0
      READ(IRD,26) RANGE,PH,TH,TD,RH,PPH2O,DENH2O,AMSMIX,
     1     (VMIX(K),K=1,KMAX)
   26 FORMAT(8F10.3,/,(8E10.3))
      WRITE(IPR,27) RANGE,PH,TH,TD,RH,PPH2O,DENH2O,AMSMIX,(HMOLS(K),
     1     K=1,KMAX)
   27 FORMAT(//,' ECHO INPUT PARAMETERS FOR MODEL 0',//,
     1  10X,'RANGE   = ',F10.3,' KM',/,10X,'P       = ',F10.3,' MB',/,
     2  10X,'T       = ',F10.3,' K',/,10X,'DEW PT  = ',F10.3,' C',/,
     3  10X,'REL HUM = ',F10.3,' %',/,10X,'PART PR = ',F10.3,' MB',/,
     4  10X,'MASS DEN= ',F10.3,' GM/M3',/,
     5  10X,'MASS MIX= ',F10.3,' GM/KG',//,
     6  40X,'VOLUME MIXING RATIO ( PARTS PER MILLION)',/,
     7  10X,8A10)
      WRITE(IPR,28) (VMIX(K),K=1,KMAX)
   28 FORMAT(10X,1P8E10.3)
      ZH = -999.0
      RHOBAR = ALOSMT*(PH/PZERO)*(TZERO/TH)
      DENSTY(1,1) = 0.0
      IF(VMIX(1).EQ.0.0)  CALL WATVAP(PH,TH,TD,RH,PPH2O,DENH2O,
     1     AMSMIX,DENSTY(1,1))
      IF(VMIX(1).GT.0.0) DENSTY(1,1) = VMIX(1)*RHOBAR*1.0E-6
      DO 105 K=2,KMAX
      DENSTY(K,1) = 0.0
      IF(VMIX(K).EQ.0.0) DENSTY(K,1) = VMIXST(K)*RHOBAR*1.0E-6
      IF(VMIX(K).GT.0.0) DENSTY(K,1) = VMIX(K)*RHOBAR*1.0E-6
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  105 CONTINUE                                                            024750
      IF(VMIX(3).EQ.0.0)  DENSTY(3,1) = O3VMIX*RHOBAR*1.0E-6              024760
      WRITE(IPR,29)RANGE,PH,TH,(HMOLS(K),K=1,KMAX)                        024770
   29 FORMAT(///,' PARAMETERS FOR A HORIZONTAL PATH, MODEL 0:',//         024780
     1    10X,'RANGE    = ',F10.3,' KM',/,10X,'P        = ',F10.3,' KM',/, 024790
     2    10X,'T        = ',F10.3,' K',//,                                024800
     3    10X,'DENSITY ',T26,'AIR',(T33,8A10))                            024810
      WRITE(IPR,30) RHOBAR,(DENSTY(K,1),K=1,KMAX)                         024820
   30 FORMAT(T63,'(MOL CM-3)',//,(T20,1PE10.3,(T30,8E10.3)))             !024830
      GO TO 160                                                           024840
C*****MODEL 1 TO 7                                                        024850
  120 CONTINUE                                                            024860
C*****READ IN CONTROL CARD 2                                              024870
      READ(IRD,31)  ZH,RANGE                                              024880
   31 FORMAT(F10.3,F10.3)                                                 024890
      WRITE(IPR,32) ZH,RANGE                                              024900
   32 FORMAT(///,' CONTROL CARD 2:',//,10X,'Z      = ',F10.3,' KM',/,     024910
     1     10X,'RANGE = ',F10.3,' KM')                                    024920
C*****SET UP THE ATMOSPHERIC PROFILE                                      024930
      CALL MLATM(M)                                                       024940
C*****INTERPOLATE ATMOSPHERIC PROFILE DENSITIES TO ZH                     024950
      DO 130 IM= 2,IMOD                                                   024960
      IF(ZH.LT.ZM(IM))  GO TO 140                                         024970
  130 CONTINUE                                                            024980
      IM = IMOD                                                           024990
  140 CONTINUE                                                            025000
      A = (ZH-ZM(IM-1))/(ZM(IM)-ZM(IM-1))                                 025010
      CALL EXPINT(PH,PM(IM-1),PM(IM),A)                                   025020
      TH = TM(IM-1)+(TM(IM)-TM(IM-1))*A                                   025030
      RHOBAR = ALOSMT*PH*TZERO/(PZERO*TH)                                 025040
      DO 150 K=1,KMAX                                                     025050
      CALL EXPINT(DENSTY(K,1),DENM(K,IM-1),DENM(K,IM),A)                  025060
  150 CONTINUE                                                            025070
      WRITE(IPR,34)  HMOD,ZH,PH,TH,(HMOLS(K),K=1,KMAX)                    025080
   34 FORMAT(///' PRESSURE, TEMPERATURE, AND DENSITIES INTERPOLATED',     025090
     1     ' FROM THE FOLLOWING ATMOSPHERIC MODEL: ',//,10X, 3A8,//       025100
     2     10X,'Z      = ',F10.3,' KM',/,10X,'P      = ',F10.3,' MB',/,   025110
     3    10X,'T      = ',F10.3,' K',//,                                  025120
     4     10X,'DENSITIES :',T26,'AIR',(T30,8A10))                        025130
      WRITE(IPR,35) RHOBAR,(DENSTY(K,1),K=1,KMAX)                         025140
   35 FORMAT(T63,'(MOL CM-3)',//,T20,1PE10.3,(T30,8E10.3))               !025150
  160 CONTINUE                                                            025160
C*****COMPUTE AMOUNTS FOR A HORIZONTAL PATH                               025170
      DO 170 K=1,KMAX                                                     025180
      AMOUNT(K,1) = DENSTY(K,1)*RANGE*1.0E+5                              025190
  170 CONTINUE                                                            025200
      AMTAIR = RHOBAR*RANGE*1.0E-5                                        025210
      WRITE(IPR,36) HMOD,ZH,PH,TH,RANGE,(HMOLS(K),K=1,KMAX)               025220
   36 FORMAT('0SINGLE LAYER INPUT TO FASCOD1',//,10X,'MODEL = ',3A8,/,    025230
     1     10X,'Z      = ',F10.3,' KM',/,10X,'P      = ',F10.3,' MB',/,   025240
     2     10X,'T      = ',F10.3,' K',/,10X,'RANGE = ',F10.3,' KM',//,    025250
     4     10X,'AMOUNTS:',T26,'AIR',(T30,8A10))                           025260
      WRITE(IPR,37) AMTAIR, (AMOUNT(K,1),K=1,KMAX)                        025270
   37 FORMAT(T63,'(MOL CM-2)',//,T20,1PE10.2,(T30,8E10.2))               !025280
      ICNTRL(1)=0                                                         025290
      LMAX = 1                                                            025300
      NLAYRS = 1                                                         !025303
      WN2L(1) = AMTAIR*VMIXN2*1.0E-6                                     !025306
      PBAR(1)=PH                                                          025310
      TBAR(1)=TH                                                          025320
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      ALTB(1)=RANGE
      ZOUT(1)=ZH
      SECNTA(1)=1.
      ALTT(1)=ZH
      HT1 = HT1HRZ
      HT2 = HT2HRZ
      IF(IPUNCH.EQ.1) WRITE(IPU,38)  LMAX,HMOD
   38 FORMAT(I5,5X,3A8)
      IF(IPUNCH.EQ.1) WRITE(IPU,39)  PH,TH,ICNTRL(1),RANGE,ZH,
     1     (AMOUNT(K,1),K=1,7),WN2L(1),(AMOUNT(K,1),K=8,KMAX)
   39 FORMAT(2F10.4,10X,I5,25X,F7.2,' AT',F7.2,' KM',/,
     1     (1P8E10.2))
      RETURN
C*****
C*****
C*****SLANT PATH SELECTED
C*****
C*****
  200 CONTINUE
C*****ITYPE = 2 OR 3: SLANT PATH THROUGH THE ATMOSPHERE
      WRITE(IPR,40) ITYPE
   40 FORMAT(///,' SLANT PATH SELECTED, ITYPE = ',I5)
C***** READ IN CONTROL CARD 2 CONTAINING SLANT PATH PARAMETERS
      READ(IRD,46)  H1,H2,ANGLE,RANGE,BETA,LEN
   46 FORMAT(5F10.4,I5)
      WRITE(IPR,48)  H1,H2,ANGLE,RANGE,BETA,LEN
   48 FORMAT(///' CONTROL CARD 2:  SLANT PATH PARAMETERS',//,
     1     10X,'H1       = ',F10.4,' KM',/,10X,'H2      = ',F10.4,' KM',/,
     2     10X,'ANGLE    = ',F10.4,' DEG',/,10X,'RANGE   = ',F10.4,' KM',/
     3     10X,'BETA     = ',F10.4,' DEG',/,10X,'LEN     = ',I10)
C*****READ IN CONTROL CARD 3 GIVING THE FREQUENCY RANGE IN WAVENUMBERS
      READ(IRD,50) V1,V2
   50 FORMAT(2F10.3)
      VBAR = 0.5*(V1+V2)
      WRITE(IPR,51) V1,V2,VBAR
   51 FORMAT(///,' CONTROL CARD 3',//,10X,'V1   = ',F10.3,' CM-1',/,
     1     10X,'V2   = ',F10.3,' CM-1',/,10X,'VBAR = ',F10.3,' CM-1')
C*****GENERATE OR READ IN FASCOD1 BOUNDARY LAYERS
      IF(IBND.NE.0) GO TO 210
C*****SELECT AUTOMATIC LAYERING
      READ(IRD,56) AVTRAT,TDIFF1,TDIFF2
   56 FORMAT(3F10.3)
      IF(AVTRAT.EQ.0.0) AVTRAT = AVRATS
      IF(TDIFF1.EQ.0.0) TDIFF1 = TDIF1S
      IF(TDIFF2.EQ.0.0) TDIFF2 = TDIF2S
      WRITE(IPR,57)  AVTRAT,TDIFF1,TDIFF2
   57 FORMAT(///,' AUTOLAYERING SELECTED',//,
     1     10X,'AVTRAT    = ',F8.2,/,10X,'TDIFF1    = ',F8.2,/,
     2     10X,'TDIFF2    = ',F8.2)
      IF(AVTRAT.LE.1.0 .OR. TDIFF1.LE.0.0 .OR. TDIFF2.LE.0.0) GO TO 906
      GO TO 220
  210 CONTINUE
C*****READ IN FASCOD1 BOUNDARY LAYERS
      READ(IRD,58) (ZBND(IB),IB=1,IBND)
   58 FORMAT(8F10.3)
      WRITE(IPR,59) (IB,ZBND(IB),IB=1,IBND)
   59 FORMAT(///,' USER DEFINED BOUNDARIES FOR FASCOD1 LAYERS',/,
     1     10X,'I',4X,'Z (KM)',//,(10X,I2,F10.4))
      IF(ZBND(1).LT.0) GO TO 902
      DO 215 IB=2,IBND
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      IF(ZBND(IB).LE.ZBND(IB-1)) GO TO 902
  215 CONTINUE
  220 CONTINUE
C*****SET UP ATMOSPHERIC PROFILE
      CALL  MLATM(M)
C*****COMPUTE THE REFRACTIVE INDEX PROFILE
C*****RFNDXM IS 1.0-INDEX
C*****EQUATION FOR RFNDXM IS FROM LOWTRAN (REF 3)
      DO 225 IM=1,IMOD
      PPH2O = DENM(1,IM)*PZERO*TM(IM)/(TZERO*ALOSMT)
      RFNDXM(IM) = ((77.46+0.459E-8*VBAR**2)*PM(IM)/TM(IM)
     1    -(PPH2O/1013.0)*(43.49-0.347E-8*VBAR**2))*1.0E-6
  225 CONTINUE
C*****PRINT ATMOSPHERIC PROFILE
      WRITE(IPR,52) M,HMOD
   52 FORMAT('1ATMOSPHERIC PROFILE SELECTED IS: M = ',I3,5X, 3A8)
      IF(NOPRNT.NE.0)  GO TO 230
      WRITE(IPR,53) (HMOLS(K),K=1,KMAX)
   53 FORMAT(/,T5,'I',T12,'Z',T22,'P',T32,'T',T38,'REFRACT',
     1     T70,'DENSITY  (MOLS CM-3)',/,
     2     T38,'INDEX*1',T50,/,
     3     T11,'(KM)',T21,'(MB)',T31,'(K)',T38,'*1.0E6',
     4     T50,'AIR',(T55,8A9))
      WRITE(IPR,55)
   55 FORMAT(/)
      DO 228 IM=1,IMOD
      DENAIR = ALOSMT*(PM(IM)/PZERO)*(TZERO/TM(IM))
      WRITE(IPR,54)    IM,ZM(IM),PM(IM),TM(IM),RFNDXM(IM),DENAIR,
     1     (DENM(K,IM),K=1,KMAX)
   54 FORMAT(I4,3F10.3,6PF10.3,1P9E9.2,/,(53X,1P8E9.2))
  228 CONTINUE
  230 CONTINUE
C*****REDUCE SLANT PATH PARAMETERS TO STANDARD FORM
      CALL GEOINP(H1,H2,ANGLE,RANGE,BETA,ITYPE,LEN,HMIN,PHI,IERROR)
      IF(IERROR.NE.0) GO TO 904
C*****SET UP FASCOD1 LAYER BOUNDARIES
      IF(IBND.NE.0)  GO TO 235
C*****AUTOMATIC LAYERING SELECTED
      HMAX = AMAX1(H1,H2)
      CALL AUTLAY(HMIN,HMAX,VBAR,AVTRAT,TDIFF1,TDIFF2,IBND,IERROR)
      GO TO 238
  235 CONTINUE
C*****USER SUPPLIED LAYERING
      WRITE(IPR,80)
   80 FORMAT(///,' HALFWIDTH INFORMATION ON THE USER SUPPLIED ',
     1     'FASCOD1 BOUNDARIES',/,' THE FOLLOWING VALUES ARE ASSUMED:')
      DO 237 IB=1,IBND
      CALL HALFWD(ZBND(IB),VBAR,PBND(IB),TBND(IB),ALORNZ(IB),ADOPP(IB),
     1     AVOIGT(IB))
  237 CONTINUE
  238 CONTINUE
      WRITE(IPR,82) ALZERO,AVMWT,VBAR
   82 FORMAT(10X,'ALZERO    = ',F9.3,' CM-1 = AVERAGE LORENTZ WIDTH ',
     1     'AT STP',/,
     2   10X,'AVMWT     = ',F8.2,'        = AVERAGE  MOLECULAR WEIGHT',/,
     3   10X,'VBAR      = ',F8.2,'  CM-1 = AVERAGE WAVENUMBER',///,
     4     T5,'I',T12,'Z',T22,'P',T32,'T',T39,'LORENTZ',
     5     T49,'DOPPLER',T61,'ZETA',T70,'VOIGT',T80,'VOIGT',T90,'TEMP',/,
     6     T11,'(KM)',T21,'(MB)',T31,'(K)',T40,'(CM-1)',
     7     T50,'(CM-1)',T70,'(CM-1)',T80,'RATIO',T90,'DIFF (K)',/)
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      DO 239 IB=1,IBND
      ZETA = ALORNZ(IB)/(ALORNZ(IB)+ADOPP(IB))
      RATIO = 0.0
      DTEMP = 0.0
      IF(IB.NE.IBND) RATIO = AVOIGT(IB)/AVOIGT(IB+1)
      IF(IB.NE.IBND) DTEMP = ABS(TBND(IB)-TBND(IB+1))
      WRITE(IPR,84) IB,ZBND(IB),PBND(IB),TBND(IB),ALORNZ(IB),ADOPP(IB),
     1     ZETA,AVOIGT(IB),RATIO,DTEMP
   84 FORMAT(I5,3F10.3,2F10.5,F10.3,F10.5,F10.2,F10.1)
  239 CONTINUE
      IF(IERROR.NE.0)  STOP  06
C*****MERGE FASCOD1 LAYER BOUNDARIES WITH ATMOSPHEREIC PROFILE LEVELS
      I = 0
      IM = 1
      IB = 1
  240 CONTINUE
      I = I+1
      IF(I.GT.IDIM) GO TO 908
      IF(IB.GT.IBND)  GO TO 250
      IF(ZBND(IB).LT.ZM(IM)) GO TO 260
C*****INSERT A LEVEL FROM THE ATMOSPHERIC PROFILE
      IF(ZBND(IB).EQ.ZM(IM)) IB = IB+1
  250 CONTINUE
      Z(I) = ZM(IM)
      P(I) = PM(IM)
      T(I) = TM(IM)
      RFNDX(I) = RFNDXM(IM)
      DO 255 K=1,KMAX
      DENSTY(K,I) = DENM(K,IM)
  255 CONTINUE
      IF(IM.GE.IMOD)  GO TO 270
      IM = IM+1
      GO TO 240
  260 CONTINUE
C*****INSERT A LEVEL FROM THE FASCOD1 BOUNDARIES AND INTERPOLATE
C*****PRESSURE, TEMPERATURE, AND DENSITIES
      Z(I) = ZBND(IB)
      IF(IM.EQ.1)  IM = 2
      A = (Z(I)-ZM(IM-1))/(ZM(IM,-ZM(IM-1))
      CALL EXPINT(P(I),PM(IM-1),PM(IM),A)
      T(I) = TM(IM-1)+(TM(IM)-TM(IM-1))*A
      CALL EXPINT(RFNDX(I),RFNDXM(IM-1),RFNDXM(IM),A)
      DO 265 K=1,KMAX
      CALL EXPINT(DENSTY(K,I),DENM(K,IM-1),DENM(K,IM),A)
  265 CONTINUE
      IB = IB+1
      GO TO 240
  270 CONTINUE
      IMAX = I
C*****CALCULATE THE REFRACTED PATH THROUGH THE ATMOSPHERE
      CALL RFPATH(H1,H2,ANGLE,PHI,LEN,HMIN,IAMT,RANGE,BETA,BENDNG)
C*****PRINT AMOUNTS BY LAYER AND ACCUMULATE TOTALS
      IF(NOPRNT.NE.1) WRITE(IPR,60) (HMOLS(K),K=1,KMAX)
   60 FORMAT('1INTEGRATED ABSORBER AMOUNTS BY LAYER',///,
     1     T5,'I  LAYER BOUNDARIES',T55,'INTEGRATED AMOUNTS (MOL CM-2)',
     2     /,T11,'FROM',T22,'TO',T30,'AIR',T36,8(1X,A8,1X),/,
     4     T11,'(KM)',T21,'(KM)',(T37,8A10))
      I2 = IPATH-1
      AIRTOT = 0.0
      DO 280 K=1,KMAX
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  280 AMTTOT(K) = 0.0
      HMID = AMIN1(H1,H2)
      DO 290 I=1,I2
      FAC = 1.0
      IF(LEN.EQ.1 .AND. ZP(I+1).LE.HMID)  FAC = 2.0
      AMTAIR = RHOPSM(I)*1.0E5
      AIRTOT = AIRTOT+FAC*AMTAIR
      DO 285 K=1,KMAX
      AMTTOT(K) = AMTTOT(K)+FAC*AMTP(K,I)
  285 CONTINUE
      IF(NOPRNT.NE.1) WRITE(IPR,61) I,ZP(I),ZP(I+1),AMTAIR,(AMTP(K,I),
     1    K=1,KMAX)
   61 FORMAT(I5,2F10.3,1P9E10.3,/,(35X,1P8E10.3))
  290 CONTINUE
      IF(NOPRNT.NE.1) WRITE(IPR,62) H1,H2,AIRTOT,(AMTTOT(K),K=1,KMAX)
   62 FORMAT('0TOTAL',F9.3,F10.3,1P9E10.3,/,(35X,1P8E10.3))
  300 CONTINUE
C*****PRINT SUMMARY OF PATH
      AIRMAS = AIRTOT/AIRMS1
      WRITE(IPR,63) HMOD,H1,H2,ANGLE,RANGE,BETA,PHI,HMIN,BENDNG,LEN,
     1   AIRMAS
   63 FORMAT('1 SUMMARY OF THE GEOMETRY CALCULATION',//,
     1    10X,'MODEL    = ',4X,3A8,/
     1    10X,'H1       = ',F10.3,' KM',/,10X,'H2       = ',F10.3,' KM',/,
     2  10X,'ANGLE    = ',F10.3,' DEG',/,10X,'RANGE    = ',F10.3,' KM',/,
     3  10X,'BETA     = ',F10.3,' DEG',/,10X,'PHI      = ',F10.3,' DEG',/,
     4    10X,'HMIN     = ',F10.3,' KM',/,10X,'BENDING = ',F10.3,' DEG',/
     5    10X,'LEN      = ',I10,/,10X,'AIRMAS  = ',G10.3,
     6    'RELATIVE TO A VERTICAL PATH , GROUND TO SPACE')
C*****RETRIEVE THE LAYERS FROM HMIN TO MAX(H1,H2)' DEFINED BY THE
C*****BOUNDARIES HMIN,H1,H2 AND ZBND
      I = 1
      I2 = IPATH-1
      ZOUT(I) = ZP(I)
C*****FIND SMALLEST ZBND.GT.HMIN
      DO 305 IB=1,IBND
      IF(ZBND(IB).GT.HMIN)  GO TO 310
  305 CONTINUE
      IB = IBND
  310 CONTINUE
      DO 360 IP=1,I2
      PBAR(I) = PBAR(I)+PPSUM(IP)
      TBAR(I) = TBAR(I)+TPSUM(IP)
      RHOSUM(I) = RHOSUM(I)+RHOPSM(IP)
      SOUT(I) = SOUT(I)+SP(IP)
      DO 320 K=1,KMAX
      AMOUNT(K,I) = AMOUNT(K,I)+AMTP(K,IP)
  320 CONTINUE
      IF(ZOUT(I).EQ.HMID)  IHMID = I
      IF(IP.EQ.I2)  GO TO 360
C*****TEST FOR JUMP UP TO THE NEXT LAYER OF ZOUT
      IF(ZP(IP+1).EQ.ZBND(IB))  GO TO 330
      IF(LEN.EQ.1 .AND. ZP(IP+1).EQ.HMID)  GO TO 340
      GO TO 360
C*****JUMP TO THE NEXT LAYER OF ZBND
  330 IB = IB+1
      IF(IB.GT.IBND)  IB = IBND
C*****JUMP TO THE NEXT LAYER IN ZOUT
  340 I = I+1
      ZOUT(I) = ZP(IP+1)
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  360 CONTINUE
      IOUTMX = I+1
      ZOUT(IOUTMX) = ZP(IPATH)
      IF(ZOUT(IOUTMX).EQ.HMID)  IHMID = IOUTMX
C*****CALCULATE THE DENSITY WIEGHTED PRESSURE AND TEMPERATURE AND
C*****ZERO OUT LAYER AMOUNTS AFTER 99.9 PERCENT OF THE TOTAL
      DO 405 K=1,KMAX
      AMTCUM(K) = 0.0
      ISKIP(K) = 0
      IF(AMTTOT(K).EQ.0.0) ISKIP(K) = 1
  405 CONTINUE
      L2 = IOUTMX-1
      LMAX = L2
      DO 450 L=1,L2
      PBAR(L) = PBAR(L)/RHOSUM(L)
      TBAR(L) = TBAR(L)/RHOSUM(L)
C*****ADJUST RHOSUM FOR THE PATH LENGTH IN CM NOT KM
      RHOSUM(L) = RHOSUM(L)*1.0E+5
C*****CALCULATE THE AMOUNT OF N2 TO DETERMINE THE PRESSURE BROADENING
      WN2L(L) = RHOSUM(L)*VMIXN2*1.0E-6
C*****CALCULATE 'EFFECTIVE SECANT' SECNTA
      SECNTA(L) = SOUT(L)/(ZOUT(L+1)-ZOUT(L))
      ALTB(L) = ZOUT(L)
      ALTT(L) = ZOUT(L+1)
C*****SET ICNTRL
      IF(LEN.EQ.1) GO TO 410
          IF(H1.LT.H2)  ICNTRL(L) = 3
          IF(H1.GT.H2)  ICNTRL(L) = 1
          GO TO 415
  410 CONTINUE
          IF(ZOUT(L).LT.HMID) ICNTRL(L) = 2
          IF(ZOUT(L).GE.HMID .AND. H1.GT.H2) ICNTRL(L) = 1
          IF(ZOUT(L).GE.HMID .AND. H1.LT.H2) ICNTRL(L) = 3
  415 CONTINUE
C*****TEST FOR ZEROING OF AMOUNTS
      ISKPT = 0
      FAC = 1
      IF(ICNTRL(L).EQ.2) FAC = 2
      DO 440 K=1,KMAX
      IF(ISKIP(K).EQ.1)  GO TO 420
      IF(NOZERO.EQ.1 .OR. K.EQ.7 .OR.
     1    (IEMIT.EQ.1 .AND. ICNTRL(L).NE.3))  GO TO 430
      IF(((AMTTOT(K)-AMTCUM(K))/AMTTOT(K)).GT.0.001)  GO TO 430
  420 CONTINUE
C*****ZERO OUT THIS AMOUNT
      ISKIP(K) = 1
      AMOUNT(K,L) = 0.0
      ISKPT = ISKPT+1
C*****IF ALL BUT O2 ARE ZEROED, ELIMINATE ALL HIGHER LAYERS
      IF(ISKPT.GE.(KMAX-1))  GO TO 460
  430 CONTINUE
      AMTCUM(K) = AMTCUM(K)+FAC*AMOUNT(K,L)
  440 CONTINUE
      LMAX = L
  450 CONTINUE
  460 CONTINUE
C*****OUTPUT THE PROFILE
      WRITE(IPR,64) (HMOLS(K),K=1,KMAX)
   64 FORMAT('0FINAL SET OF LAYERS FOR INPUT TO FASCOD1',/,
     1     ' A LAYER AMOUNT MAY BE SET TO ZERO IF THE CUMULATIVE ',
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     2    'AMOUNT FOR THAT LAYER AND ABOVE IS LESS THAN 0.1 PERCENT',/,    028330
     3    ' OF THE TOTAL AMOUNT. THIS IS DONE ONLY FOR THE ',              028340
     4    'FOLLOWING CASES',/,5X,'1.  IEMIT = 0 (TRANSMITTANCE)',/,5X,     028350
     5    '2.  IEMIT = 1 (RADIANCE) AND ICNTRL = 3 (PATH LOOKING UP)',/,  028360
     6    ' O2 IS NOT INCLUDED',/,' IF THE AMOUNTS FOR ALL THE',           028370
     7    ' MOLECULES BUT O2 ARE ZEROED, THE REMAINING LAYERS ARE ',       028380
     8    'ELIMINATED',////,T5,'L    LAYER BOUNDARIES',T26,'ICNTRL',T34,   028390
     9    'PBAR',T43,'TBAR',T65,'INTEGRATED AMOUNTS (MOLS CM-2)',/,        028400
     *    T11,'FROM',T22,'TO',/,                                           028410
     1    T11,'(KM)',T21,'(KM)',T34,'(MB)',T44,'(K)',T52,'AIR',            028420
     2    (T57,8A9))                                                       028430
      IF(IPUNCH.EQ.1) WRITE(IPU,65) LMAX,HMOD,H1,H2,ANGLE,LEN              028440
   65 FORMAT(I5,5X,3A8,' H1=',F8.2,' H2=',F8.2,' ANGLE=',F8.3,             028450
     1    ' LEN=',I2)                                                      028460
      DO 470 L=1,LMAX                                                      028470
      WRITE(IPR,66)  L,ZOUT(L),ZOUT(L+1),ICNTRL(L),PBAR(L),TBAR(L),        028480
     1    RHOSUM(L),(AMOUNT(K,L),K=1,KMAX)                                 028490
   66 FORMAT(/,I4,2F10.3,I4,2F9.2,1P9E9.2,/,(55X,1P8E9.2))                028500
      IF(IPUNCH.EQ.1) WRITE(IPU,68)  PBAR(L),TBAR(L),ICNTRL(L),           028510
     1    ZOUT(L),ZOUT(L+1)                                                028520
   68 FORMAT(1PG10.3,0PF10.2,10X,I5,25X,F7.2,' TO',F7.2,' KM')            028530
      IF(IPUNCH.NE.1) GO TO 470                                           !028540
      WRITE(IPU,70) (AMOUNT(K,L),K=1,7),WN2L(L)                           !028545
   70 FORMAT(1P8E10.2)                                                    !028550
      IF(KMAX.GT.7) WRITE(IPU,70) (AMOUNT(K,L),K=8,KMAX)                  !028555
  470 CONTINUE                                                             028560
      NLAYRS = LMAX                                                        028570
      HT1 = HT1SLT                                                         028580
      HT2 = HT2SLT                                                         028590
      RETURN                                                               028600
C*****                                                                     028610
C*****                                                                     028620
C*****ERROR MESSAGES                                                       028630
C*****                                                                     028640
  900 WRITE(IPR,901) MODEL,ITYPE,KMAX                                      028650
  901 FORMAT(///,' ERROR IN INPUT, CONTROL CARD 1: ONE OF THE ',           028660
     1    'PARAMETERS MODEL, ITYPE, KMAX IS OUT OT RANGE',//,              028670
     2    10X,'MODEL   = ',I5,/,10X,'ITYPE   = ',I5,/,                     028680
     3    10X,'KMAX    = ',I5)                                             028690
      STOP 10                                                              028700
  902 WRITE(IPR,903)                                                       028710
  903 FORMAT(///,' ERROR: BOUNDARY ALTITUDES FOR FASCOD1 LAYERS ',         028720
     1    'ARE NEGATIVE OR NOT IN ASCENDING ORDER')                        028730
      STOP 12                                                              028740
  904 WRITE(IPR,905)                                                       028750
  905 FORMAT('0ERROR FLAG RETURNED FROM GEOINP:  AN ERROR OCCURED ',       028760
     1    'IN PROCESSING THE SLANT PATH PARAMETERS',/,                     028770
     2    '0PROGRAM STOP')                                                 028780
      STOP 14                                                              028790
  906 WRITE(IPR,907)                                                       028800
  907 FORMAT(///,' ERROR: EITHER AVTRAT.LE.1.0 OR TDIFF.LE.0',/,          028810
     1    '0PROGRAM STOP')                                                 028820
      STOP 05                                                              028830
  908 WRITE(IPR,909) IDIM                                                  028840
  909 FORMAT(//,' ERROR: THE MERGING OF THE ATMOSPHERIC PROFILE ',         028850
     1    'AND THE FASCODE BOUNDARIES ',/,T10,'EXCEEDS THE AVAILABLE',     028860
     2    ' DIMENSION IDIM = ',I3)                                         028870
      STOP 16                                                              028880
      END                                                                  028890
```

```
      BLOCK DATA ATMCON
C***********************************************************************
C     THIS SUBROUTINE INITIALIZES THE CONSTANTS  USED IN THE
C     PROGRAM. CONSTANTS RELATING TO THE ATMOSPHERIC PROFILES ARE STORED
C     IN BLOCK DATA MLATMB.
C***********************************************************************
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1     IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
      COMMON /CONSTN/ PZERO,TZERO,AVOGAD,ALOSMT,GASCON,PLANK,BOLTZ,
     1     CLIGHT,ADCON,ALZERO,AVMWT,AIRMWT,AMWT(20),VMIXST(20),VMIXN2
C&    DOUBLE PRECISION HMOLS
      COMMON /HMOLS/ HMOLS(20)
C*****IMODMX IS THE MAX NUMBER OF LEVELS IN THE ATMOSPHERIC PROFILE
C*****     STORED IN ZM
C*****IOUTMX IS THE MAXIMUN NUMBER OF OUTPUT LAYERS
C*****IDIM IS THE MAXIMUM NUMBER OF LEVELS IN THE PROFILE Z OBTAINED
C*****     BY MERGING ZM AND ZBND
C*****KDIM ID THE MAXIMUM NUMBER OF MOLECULES, KMXNOM IS THE DEFAULT
C*****IBMAX IS THE MAXIMUM NUMBER OF INPUT FASCODE LAYERS
      DATA IMODMX/50/,IOUTMX/37/,IDIM/71/,KDIM/20/,KMXNOM/7/
      DATA IBMAX/34/
C*****DELTAS IS THE NOMINAL SLANT PATH INCREMENT IN KM.
      DATA DELTAS/5.0/
      DATA PZERO/1013.25/,TZERO/273.15/
      DATA AVOGAD/6.022045E+23/,ALOSMT/2.68675E+19/,
     1     GASCON/8.31441E+7/,PLANK/6.626176E-27/,BOLTZ/1.380662E-16/,
     2     CLIGHT/2.99792458E10/
C*****ALZERO IS THE MEAN LORENTZ HALFWIDTH AT PZERO AND 296.0 K.
C*****AVMWT IS THE MEAN MOLECULAR WEIGHT USED TO AUTOMATICALLY
C*****GENERATE THE FASCOD1 BOUNDARIES IN AUTLAY
      DATA ALZERO/0.1/,AVMWT/36.0/
C*****ORDER OF MOLECULES H2O(1), CO2(2), O3(3), N2O(4), CO(5), CH4(6),
C*****     O2(7), NO(8), SO2(9), NO2(10), NH3(11), HNO3(12), OH(13).
C*****     HF(14 ), HCL(15), HBR(16), HI(17), CLO(18), OCS(19), H2CO(20)
      DATA HMOLS/  8H   H2O    ,  8H   CO2    ,  8H   O3     ,
     1        8H   N2O    ,  8H   CO     ,  8H   CH4    ,
     2        8H   O2     ,  8H   NO     ,  8H   SO2    ,
     3        8H   NO2    ,  8H   NH3    ,  8H   HNO3   ,
     4        8H   OH     ,  8H   HF     ,  8H   HCL    ,
     5        8H   HBR    ,  8H   HI     ,  8H   CLO    ,
     6        8H   OCS    ,  8H   H2CO   /
C*****MOLECULAR WEIGHTS
      DATA AIRMWT/28.964/,AMWT/18.015,44.010,47.998,44.01,28.011,
     1     16.043,31.999,30.01,64.06,46.01,17.03,63.01,17.00,20.01,
     2     36.46,80.92,127.91,51.45,60.08,30.03/
C*****VMIXN2 IS THE VOLUME MIXING RATIO OF N2
      DATA VMIXN2/7.8084E5/
C*****DEFAULT VOLUME MIXING RATIOS FOR THE UNIFORMILY MIXED GASES
C*****FOR USER SUPPLIED ATMOSPHERIC PROFILES,
C*****IN PARTS PER MILLION, FROM THE U. S. STANDARD ATMOSPHERE, 1976.
C*****THESE ARE NOT THE SAME VALUES AS USED IN MODELS 1 TO 6
      DATA VMIXST/0.0,322., 0.0,0.27,0.19,1.5,2.0948E+5,13*0.0/
      END
```

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      BLOCK DATA MLATMB
C**********************************************************************
C     THIS SUBROUTINE INITIALIZES THE 6 BUILT-IN ATMOSPHERIC PROFILES
C     (FROM 'OPTICAL PROPERTIES OF THE ATMOSPHERE, THIRD EDITION'
C     AFCRL-72-0497 (AD 753 075) AND 'U.S. STANDARD ATMOSPHERE 1976)
C     AND SETS OTHER CONSTANTS RELATED TO THE ATMOSPHERIC PROFILES
C**********************************************************************
C&    DOUBLE PRECISION ATMNA1,ATMNA2,ATMNA3,ATMNA4,ATMNA5,ATMNA6
      COMMON /MLATMC/ ALT(34),P1(34),P2(34),P3(34),P4(34),P5(34),P6(34)
     +,T1(34),T2(34) T3(34),T4(34),T5(34),T6(34)
     +,AMOL11(34),AM  12(34),AMOL13(34),AMOL14(34),AMOL15(34),AMOL16(34)
     +,AMOL17(34),AMOL18(34)
     +,AMOL21(34),AMOL22(34),AMOL23(34),AMOL24(34),AMOL25(34),AMOL26(34)
     +,AMOL27(34),AMOL28(34)
     +,AMOL31(34),AMOL32(34),AMOL33(34),AMOL34(34),AMOL35(34),AMOL36(34)
     +,AMOL37(34),AMOL38(34)
     +,AMOL41(34),AMOL42(34),AMOL43(34),AMOL44(34),AMOL45(34),AMOL46(34)
     +,AMOL47(34),AMOL48(34)
     +,AMOL51(34),AMOL52(34),AMOL53(34),AMOL54(34),AMOL55(34),AMOL56(34)
     +,AMOL57(34),AMOL58(34)
     +,AMOL61(34),AMOL62(34),AMOL63(34),AMOL64(34),AMOL65(34),AMOL66(34)
     +,AMOL67(34),AMOL68(34)
     +,ATMNA1(3),ATMNA2(3),ATMNA3(3),ATMNA4(3),ATMNA5(3),ATMNA6(3)
      DATA ATMNA1  /8HTROPICAL,8H        ,8H        /
      DATA ATMNA2  /8HMIDLATIT,8HUDE SUMM,8HER      /
      DATA ATMNA3  /8HMIDLATIT,8HUDE WINT,8HER      /
      DATA ATMNA4  /8HSUBARCTI,8HC SUMMER ,8H       /
      DATA ATMNA5  /8HSUBARCTI,8HC WINTER ,8H       /
      DATA ATMNA6  /8HU. S. ST,8HANDARD,  ,8H1962    /
      DATA ALT /
     *       0.,        1.,        2.,        3.,        4.,        5.,
     *       6.,        7.,        8.,        9.,       10.,       11.,
     *      12.,       13.,       14.,       15.,       16.,       17.,
     *      18.,       19.,       20.,       21.,       22.,       23.,
     *      24.,       25.,       30.,       35.,       40.,       45.,
     *      50.,       70.,      100.,        0./
      DATA P1 /
     * 1.013E+03, 9.040E+02, 8.050E+02, 7.150E+02, 6.330E+02, 5.590E+02,
     * 4.920E+02, 4.320E+02, 3.780E+02, 3.290E+02, 2.860E+02, 2.470E+02,
     * 2.130E+02, 1.820E+02, 1.560E+02, 1.320E+02, 1.110E+02, 9.370E+01,
     * 7.890E+01, 6.660E+01, 5.650E+01, 4.800E+01, 4.090E+01, 3.500E+01,
     * 3.000E+01, 2.570E+01, 1.220E+01, 6.000E+00, 3.050E+00, 1.590E+00,
     * 8.540E-01, 5.790E-02, 3.000E-04, 0.        /
      DATA P2 /
     * 1.013E+03, 9.020E+02, 8.020E+02, 7.100E+02, 6.280E+02, 5.540E+02,
     * 4.870E+02, 4.260E+02, 3.720E+02, 3.240E+02, 2.810E+02, 2.430E+02,
     * 2.090E+02, 1.790E+02, 1.530E+02, 1.300E+02, 1.110E+02, 9.500E+01,
     * 8.120E+01, 6.950E+01, 5.950E+01, 5.100E+01, 4.370E+01, 3.760E+01,
     * 3.220E+01, 2.770E+01, 1.320E+01, 6.520E+00, 3.330E+00, 1.760E+00,
     * 9.510E-01, 6.710E-02, 3.000E-04, 0.        /
      DATA P3 /
     * 1.018E+03, 8.973E+02, 7.897E+02, 6.938E+02, 6.081E+02, 5.313E+02,
     * 4.627E+02, 4.016E+02, 3.473E+02, 2.992E+02, 2.568E+02, 2.199E+02,
     * 1.882E+02, 1.610E+02, 1.378E+02, 1.178E+02, 1.007E+02, 8.610E+01,
     * 7.350E+01, 6.280E+01, 5.370E+01, 4.580E+01, 3.910E+01, 3.340E+01,
     * 2.860E+01, 2.430E+01, 1.110E+01, 5.180E+00, 2.530E+00, 1.290E+00,
     * 6.820E-01, 4.670E-02, 3.000E-04, 0.        /
      DATA P4 /
     * 1.010E+03, 8.960E+02, 7.929E+02, 7.000E+02, 6.160E+02, 5.410E+02,
     * 4.730E+02, 4.130E+02, 3.590E+02, 3.107E+02, 2.677E+02, 2.300E+02,
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* 1.977E+02, 1.700E+02, 1.460E+02, 1.250E+02, 1.080E+02, 9.280E+01,
* 7.980E+01, 6.860E+01, 5.890E+01, 5.070E+01, 4.360E+01, 3.750E+01,
* 3.227E+01, 2.780E+01, 1.340E+01, 6.610E+00, 3.400E+00, 1.810E+00,
* 9.870E-01, 7.070E-02, 3.000E-04, 0.       /
 DATA P5 /
* 1.013E+03, 8.878E+02, 7.775E+02, 6.798E+02, 5.932E+02, 5.158E+02,
* 4.467E+02, 3.853E+02, 3.308E+02, 2.829E+02, 2.418E+02, 2.067E+02,
* 1.766E+02, 1.510E+02, 1.291E+02, 1.103E+02, 9.431E+01, 8.058E+01,
* 6.882E+01, 5.875E+01, 5.014E+01, 4.277E+01, 3.647E+01, 3.109E+01,
* 2.649E+01, 2.256E+01, 1.020E+01, 4.701E+00, 2.243E+00, 1.113E+00,
* 5.719E-01, 4.016E-02, 3.000E-04, 0.       /
 DATA P6 /
* 1.013E+03, 8.986E+02, 7.950E+02, 7.012E+02, 6.166E+02, 5.405E+02,
* 4.722E+02, 4.111E+02, 3.565E+02, 3.080E+02, 2.650E+02, 2.270E+02,
* 1.940E+02, 1.658E+02, 1.417E+02, 1.211E+02, 1.035E+02, 8.850E+01,
* 7.565E+01, 6.467E+01, 5.529E+01, 4.729E+01, 4.047E+01, 3.467E+01,
* 2.972E+01, 2.549E+01, 1.197E+01, 5.746E+00, 2.871E+00, 1.491E+00,
* 7.978E-01, 5.520E-02, 3.008E-04, 0.       /
 DATA T1 /
* 3.000E+02, 2.940E+02, 2.880E+02, 2.840E+02, 2.770E+02, 2.700E+02,
* 2.640E+02, 2.570E+02, 2.500E+02, 2.440E+02, 2.370E+02, 2.300E+02,
* 2.240E+02, 2.170E+02, 2.100E+02, 2.040E+02, 1.970E+02, 1.950E+02,
* 1.990E+02, 2.030E+02, 2.070E+02, 2.110E+02, 2.150E+02, 2.170E+02,
* 2.190E+02, 2.210E+02, 2.320E+02, 2.430E+02, 2.540E+02, 2.650E+02,
* 2.700E+02, 2.190E+02, 2.100E+02, 1.900E+02/
 DATA T2 /
* 2.940E+02, 2.900E+02, 2.850E+02, 2.790E+02, 2.730E+02, 2.670E+02,
* 2.610E+02, 2.550E+02, 2.480E+02, 2.420E+02, 2.350E+02, 2.290E+02,
* 2.220E+02, 2.160E+02, 2.160E+02, 2.160E+02, 2.160E+02, 2.160E+02,
* 2.160E+02, 2.170E+02, 2.180E+02, 2.190E+02, 2.200E+02, 2.220E+02,
* 2.230E+02, 2.240E+02, 2.340E+02, 2.450E+02, 2.580E+02, 2.700E+02,
* 2.760E+02, 2.180E+02, 2.100E+02, 1.900E+02/
 DATA T3 /
* 2.722E+02, 2.687E+02, 2.652E+02, 2.617E+02, 2.557E+02, 2.497E+02,
* 2.437E+02, 2.377E+02, 2.317E+02, 2.257E+02, 2.197E+02, 2.192E+02,
* 2.187E+02, 2.182E+02, 2.177E+02, 2.172E+02, 2.167E+02, 2.162E+02,
* 2.157E+02, 2.152E+02, 2.152E+02, 2.152E+02, 2.152E+02, 2.152E+02,
* 2.152E+02, 2.152E+02, 2.174E+02, 2.278E+02, 2.432E+02, 2.585E+02,
* 2.657E+02, 2.307E+02, 2.102E+02, 1.900E+02/
 DATA T4 /
* 2.870E+02, 2.820E+02, 2.760E+02, 2.710E+02, 2.660E+02, 2.600E+02,
* 2.530E+02, 2.460E+02, 2.390E+02, 2.320E+02, 2.250E+02, 2.250E+02,
* 2.250E+02, 2.250E+02, 2.250E+02, 2.250E+02, 2.250E+02, 2.250E+02,
* 2.250E+02, 2.250E+02, 2.250E+02, 2.250E+02, 2.250E+02, 2.250E+02,
* 2.260E+02, 2.280E+02, 2.350E+02, 2.470E+02, 2.620E+02, 2.740E+02,
* 2.770E+02, 2.160E+02, 2.100E+02, 1.900E+02/
 DATA T5 /
* 2.571E+02, 2.591E+02, 2.559E+02, 2.527E+02, 2.477E+02, 2.409E+02,
* 2.341E+02, 2.273E+02, 2.206E+02, 2.172E+02, 2.172E+02, 2.172E+02,
* 2.172E+02, 2.172E+02, 2.172E+02, 2.172E+02, 2.166E+02, 2.160E+02,
* 2.154E+02, 2.148E+02, 2.141E+02, 2.136E+02, 2.130E+02, 2.124E+02,
* 2.118E+02, 2.112E+02, 2.160E+02, 2.222E+02, 2.347E+02, 2.470E+02,
* 2.593E+02, 2.457E+02, 2.100E+02, 1.900E+02/
 DATA T6 /
* 2.881E+02, 2.816E+02, 2.751E+02, 2.687E+02, 2.622E+02, 2.557E+02,
* 2.492E+02, 2.427E+02, 2.362E+02, 2.297E+02, 2.232E+02, 2.168E+02,
* 2.166E+02, 2.166E+02, 2.166E+02, 2.166E+02, 2.166E+02, 2.166E+02,
* 2.166E+02, 2.166E+02, 2.166E+02, 2.176E+02, 2.186E+02, 2.196E+02,
* 2.206E+02, 2.216E+02, 2.265E+02, 2.365E+02, 2.534E+02, 2.642E+02,
* 2.706E+02, 2.197E+02, 2.100E+02, 1.900E+02/
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      DATA AMOL11 /
     * 6.353E+17, 4.347E+17, 3.110E+17, 1.571E+17, 7.356E+16, 5.015E+16,
     * 2.842E+16, 1.571E+16, 8.359E+15, 4.012E+15, 1.672E+15, 5.684E+14,
     * 2.006E+14, 6.018E+13, 3.344E+13, 2.541E+13, 2.140E+13, 1.872E+13,
     * 1.672E+13, 1.638E+13, 1.505E+13, 1.705E+13, 1.705E+13, 1.806E+13,
     * 2.006E+13, 2.240E+13, 1.204E+13, 3.678E+12, 1.438E+12, 6.353E+11,
     * 2.106E+11, 4.681E+09, 3.344E+07, 0.        /
      DATA AMOL12 /
     * 7.864E+15, 7.208E+15, 6.580E+15, 5.968E+15, 5.440E+15, 4.934E+15,
     * 4.447E+15, 4.014E+15, 3.612E+15, 3.223E+15, 2.885E+15, 2.568E+15,
     * 2.273E+15, 2.005E+15, 1.776E+15, 1.547E+15, 1.347E+15, 1.149E+15,
     * 9.480E+14, 7.844E+14, 6.526E+14, 5.439E+14, 4.548E+14, 3.856E+14,
     * 3.275E+14, 2.780E+14, 1.257E+14, 5.903E+13, 2.871E+13, 1.435E+13,
     * 7.562E+12, 6.321E+11, 3.416E+09, 0.        /
      DATA AMOL13 /
     * 7.028E+11, 7.028E+11, 6.777E+11, 6.400E+11, 5.898E+11, 5.647E+11,
     * 5.396E+11, 5.145E+11, 4.894E+11, 4.894E+11, 4.894E+11, 5.145E+11,
     * 5.396E+11, 5.647E+11, 5.647E+11, 5.898E+11, 5.898E+11, 8.659E-11,
     * 1.129E+12, 1.757E+12, 2.384E+12, 3.012E+12, 3.514E+12, 4.016E+12,
     * 4.267E+12, 4.267E+12, 3.012E+12, 1.155E+12, 5.145E+11, 1.631E+11,
     * 5.396E+10, 1.079E+09, 5.396E+05, 0.        /
      DATA AMOL14 /
     * 6.672E+12, 6.116E+12, 5.583E+12, 5 063E+12, 4.615E+12, 4.186E+12,
     * 3.773E+12, 3.406E+12, 3.065E+12, 2.734E+12, 2.448E+12, 2.178E+12,
     * 1.929E+12, 1.701E+12, 1.507E+12, 1.313E+12, 1.143E+12, 9.748E+11,
     * 8.043E+11, 6.656E+11, 5.537E+11, 4.615E+11, 3.859E+11, 3.272E+11,
     * 2.779E+11, 2.359E+11, 1.067E+11, 5.009E+10, 2.436E+10, 1.217E+10,
     * 6.417E+09, 5.364E+08, 2.898E+06, 0.        /
      DATA AMOL15 /
     * 1.787E+12, 1.638E+12, 1.496E+12, 1.356E+12, 1.236E+12, 1.121E+12,
     * 1.011E+12, 9.122E+11, 8.210E+11, 7.324E+11, 6.556E+11, 5.835E+11,
     * 5.167E+11, 4.558E+11, 4.037E+11, 3.516E+11, 3.062E+11, 2.611E+11,
     * 2.154E+11, 1.783E+11, 1.483E+11, 1.236E+11, 1.034E+11, 8.764E+10,
     * 7.444E+10, 6.319E+10, 2 857E+10, 1.342E+10, 6.525E+09, 3.260E+09,
     * 1.719E+09, 1.437E+08, 7.763E+05, 0.        /
      DATA AMOL16 /
     * 3.813E+13, 3.495E+13, 3.191E+13, 2.893E+13, 2.637E+13, 2.392E+13,
     * 2.156E+13, 1.946E+13, 1.751E+13, 1.562E+13, 1.399E+13, 1.245E+13,
     * 1.102E+13, 9.723E+12, 8.612E+12, 7.501E+12, 6.532E+12, 5.570E+12,
     * 4.596E+12, 3.803E+12, 3.164E+12, 2.637E+12, 2.205E+12, 1.870E+12,
     * 1.588E+12, 1.348E+12, 6.096E+11, 2.862E+11, 1.392E+11, 6.955E+10,
     * 3.6[illegible]7E+10, 3.065E+09, 1.656E+07, 0.        /
      DATA AMOL17 /
     * 4.992E+18, 4.576E+18, 4.178E+18, 3.789E+18, 3.453E+18, 3.132E+18,
     * 2.823E+18, 2.548E+18, 2.293E+18, 2.046E+18, 1.831E+18, 1.630E+18,
     * 1.443E+18, 1.273E+18, 1.128E+18, 9.822E+17, 8.553E+17, 7.294E+17,
     * 6.018E+17, 4.980E+17, 4.143E+17, 3.453E+17, 2.887E+17, 2.448E+17,
     * 2.079E+17, 1.765E+17, 7.982E+16, 3.748E+16, 1.823E+16, 9.107E+15,
     * 4.801E+15, 4.013E+14, 2.168E+12, 0.        /
      DATA AMOL18 /
     * 1.861E+19, 1.706E+19, 1.557E+19, 1.412E+19, 1.287E+19, 1.167E+19,
     * 1.052E+19, 9.498E+18, 8.548E+18, 7.626E+18, 6.826E+18, 6.076E+18,
     * 5.380E+18, 4.745E+18, 4.203E+18, 3.661E+18, 3.188E+18, 2.719E+18,
     * 2.243E+18, 1.856E+18, 1.544E+18, 1.287E+18, 1.076E+18, 9.125E+17,
     * 7.750E+17, 6.579E+17, 2.975E+17, 1.397E+17, 6.794E+16, 3.395E+16,
     * 1.790E+16, 1.496E+15, 8.083E+12, 0.        /
      DATA AMOL21 /
     * 4.681E+17, 3.110E+17, 1.973E+17, 1.103E+17, 6.353E+16, 3.344E+16,
     * 2.040E+16, 1.237E+16, 7.022E+15, 4.012E+15, 2.140E+15, 7.356E+14,
     * 2.006E+14, 6.018E+13, 3.344E+13, 2.541E+13, 2.140E+13, 1.872E+13,
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     * 1.672E+13, 1.638E+13, 1.505E+13, 1.705E+13, 1.705E+13, 1.806E+13,
     * 2.006E+13, 2.240E+13, 1.204E+13, 3.678E+12, 1.438E+12, 6.353E+11,
     * 2.106E+11, 4.681E+09, 3.344E+07, 0.        /
      DATA AMOL22 /
     * 8.084E+15, 7.334E+15. 6.663E+15, 6.048E+15, 5.479E+15, 4.950E+15,
     * 4.455E+15, 3.990E+15, 3.584E+15, 3.203E+15, 2.858E+15, 2.537E+15,
     * 2.251E+15, 1.981E+15, 1.694E+15, 1.439E+15, 1.223E+15, 1.052E+15,
     * 8.988E+14, 7.658E+14, 6.526E+14, 5.568E+14, 4.749E+14, 4.049E+14,
     * 3.452E+14, 2.957E+14, 1.349E+14, 6.363E+13, 3.086E+13, 1.559E+13,
     * 8.238E+12, 7.359E+11, 3.416E+09, 0.        /
      DATA AMOL23 /
     * 7.530E+11, 7.530E+11, 7.530E+11, 7.781E+11, 8.032E+11, 8.283E+11,
     * 8.659E+11, 9.412E+11, 9.914E+11, 1.079E+12, 1.129E+12, 1.380E+12,
     * 1.506E+12, 1.882E+12, 2.259E+12, 2.384E+12, 2.635E+12, 3.012E+12,
     * 3.514E+12, 4.016E+12, 4.267E+12, 4.518E+12, 4.518E+12, 4.267E+12,
     * 4.016E+12, 3.765E+12, 2.510E+12, 1.155E+12, 5.145E+11, 1.631E+11,
     * 5.396E+10, 1.079E+09, 5.396E+05, 0.        /
      DATA AMOL24 /
     * 6.859E+12, 6.223E+12, 5.654E+12, 5.132E+12, 4.649E+12, 4.200E+12,
     * 3.780E+12, 3.386E+12, 3.041E+12, 2.715E+12, 2.425E+12, 2.153E+12,
     * 1.910E+12, 1.681E+12, 1.437E+12, 1.221E+12, 1.043E+12, 8.922E+11,
     * 7.626E+11, 6.497E+11, 5.537E+11, 4.724E+11, 4.030E+11, 3.436E+11,
     * 2.929E+11, 2.509E+11, 1.144E+11, 5.399E+10, 2.618E+10, 1.322E+10,
     * 6.990E+09, 6.244E+08, 2.898E+06, 0.        /
      DATA AMOL25 /
     * 1.837E+12, 1.667E+12, 1.514E+12, 1.375E+12, 1.245E+12, 1.125E+12,
     * 1.012E+12, 9.069E+11, 8.146E+11, 7.272E+11, 6.496E+11, 5.766E+11,
     * 5.116E+11, 4.503E+11, 3.849E+11, 3.270E+11, 2.792E+11, 2.390E+11,
     * 2.043E+11, 1.740E+11, 1.483E+11, 1.265E+11, 1.079E+11, 9.203E+10,
     * 7.846E+10, 6.720E+10, 3.065E+10, 1.446E+10, 7.014E+09, 3.542E+09,
     * 1.872E+09, 1.673E+08, 7.763E+05, 0.        /
      DATA AMOL26 /
     * 3.919E+13, 3.556E+13, 3.231E+13, 2.932E+13, 2.657E+13, 2.400E+13,
     * 2.160E+13, 1.935E+13, 1.738E+13, 1.551E+13, 1.386E+13, 1.230E+13,
     * 1.091E+13, 9.607E+12, 8.211E+12, 6.977E+12, 5.957E+12, 5.099E+12,
     * 4.358E+12, 3.713E+12, 3.164E+12, 2.700E+12, 2.303E+12, 1.963E+12,
     * 1.674E+12, 1.434E+12, 6.539E+11, 3.085E+11, 1.496E+11, 7.557E+10,
     * 3.994E+10, 3.568E+09, 1.656E+07, 0.        /
      DATA AMOL27 /
     * 5.132E+18, 4.656E+18, 4.230E+18, 3.840E+18, 3.478E+18, 3.142E+18,
     * 2.828E+18, 2.533E+18, 2.275E+18, 2.031E+18, 1.815E+18, 1.611E+18,
     * 1.429E+18, 1.258E+18, 1.075E+18, 9.135E+17, 7.800E+17, 6.676E+17,
     * 5.706E+17, 4.861E+17, 4.143E+17, 3.535E+17, 3.015E+17, 2.571E+17,
     * 2.192E+17, 1.877E+17, 8.562E+16, 4.039E+16, 1.959E+16, 9.894E+15,
     * 5.230E+15, 4.672E+14, 2.169E+12, 0.        /
      DATA AMOL28 /
     * 1.913E+19, 1.726E+19, 1.577E+19, 1.431E+19, 1.297E+19, 1.171E+19,
     * 1.054E+19, 9.442E+18, 8.481E+18, 7.572E+18, 6.764E+18, 6.003E+18,
     * 5.326E+18, 4.689E+18, 4.008E+18, 3.405E+18, 2.908E+18, 2.489E+18,
     * 2.127E+18, 1.812E+18, 1.544E+18, 1.318E+18, 1.124E+18, 9.583E+17,
     * 8.170E+17, 6.996E+17, 3.192E+17, 1.506E+17, 7.302E+16, 3.688E+16,
     * 1.949E+16, 1.741E+15, 8.083E+12, 0.        /
      DATA AMOL31 /
     * 1.170E+17, 8.359E+16, 6.018E+16, 4.012E+16, 2.207E+16, 1.271E+16,
     * 7.022E+15, 2.842E+15, 1.170E+15, 5.350E+14, 2.508E+14, 2.307E+14,
     * 2.006E+14, 6.018E+13, 3.344E+13, 2.541E+13, 2.140E+13, 1.872E+13,
     * 1.672E+13, 1.638E+13, 1.505E+13, 1.705E+13, 1.705E+13, 1.806E+13,
     * 2.006E+13, 2.240E+13, 1.204E+13, 3.678E+12, 1.438E+12, 6.353E+11,
     * 2.106E+11, 4.681E+09, 3.344E+07, 0.        /
      DATA AMOL32 /
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     * 8.903E+15, 7.957E+15, 7.100E+15, 6.326E+15, 5.679E+15, 5.083E+15,
     * 4.537E+15, 4.039E+15, 3.583E+15, 3.169E+15, 2.795E+15, 2.399E+15,
     * 2.057E+15, 1.764E+15, 1.513E+15, 1.297E+15, 1.111E+15, 9.522E+14,
     * 8.147E+14, 6.977E+14, 5.966E+14, 5.089E+14, 4.344E+14, 3.711E+14,
     * 3.178E+14, 2.700E+14, 1.221E+14, 5.437E+13, 2.487E+13, 1.193E+13,
     * 6.137E+12, 4.840E+11, 3.412E+09, 0.          /
      DATA AMOL33 /
     * 7.530E+11, 6.777E+11, 6.149E+11, 6.149E+11, 6.149E+11, 7.279E+11,
     * 8.032E+11, 9.663E+11, 1.129E+12, 1.506E+12, 2.008E+12, 2.635E+12,
     * 3.263E+12, 3.765E+12, 4.016E+12, 4.267E+12, 4.518E+12, 4.894E+12,
     * 5.145E+12, 5.396E+12, 5.647E+12, 5.396E+12, 5.396E+12, 4.894E+12,
     * 4.518E+12, 4.267E+12, 2.384E+12, 1.155E+12, 5.145E+11, 1.631E+11,
     * 5.396E+10, 1.079E+09, 5.396E+05, 0.          /
      DATA AMOL34 /
     * 7.554E+12, 6.751E+12, 6.024E+12, 5.367E+12, 4.818E+12, 4.313E+12,
     * 3.850E+12, 3.427E+12, 3.041E+12, 2.689E+12, 2.371E+12, 2.035E+12,
     * 1.746E+12, 1.497E+12, 1.284E+12, 1.100E+12, 9.427E+11, 8.079E+11,
     * 6.913E+11, 5.920E+11, 5.062E+11, 4.318E+11, 3.686E+11, 3.149E+11,
     * 2.696E+11, 2.291E+11, 1.036E+11, 4.613E+10, 2.110E+10, 1.012E+10,
     * 5.207E+09, 4.107E+08, 2.895E+06, 0.          /
      DATA AMOL35 /
     * 2.023E+12, 1.808E+12, 1.614E+12, 1.438E+12, 1.291E+12, 1.155E+12,
     * 1.031E+12, 9.179E+11, 8.144E+11, 7.203E+11, 6.351E+11, 5.451E+11,
     * 4.676E+11, 4.009E+11, 3.440E+11, 2.947E+11, 2.525E+11, 2.164E+11,
     * 1.852E+11, 1.586E+11, 1.356E+11, 1.156E+11, 9.873E+10, 8.434E+10,
     * 7.222E+10, 6.136E+10, 2.774E+10, 1.236E+10, 5.653E+09, 2.712E+09,
     * 1.395E+09, 1.100E+08, 7.755E+05, 0.          /
      DATA AMOL36 /
     * 4.317E+13, 3.858E+13, 3.442E+13, 3.067E+13, 2.753E+13, 2.465E+13,
     * 2.200E+13, 1.958E+13, 1.737E+13, 1.537E+13, 1.355E+13, 1.163E+13,
     * 9.976E+12, 8.554E+12, 7.338E+12, 6.287E+12, 5.387E+12, 4.617E+12,
     * 3.950E+12, 3.383E+12, 2.893E+12, 2.467E+12, 2.106E+12, 1.799E+12,
     * 1.541E+12, 1.309E+12, 5.919E+11, 2.636E+11, 1.206E+11, 5.785E+10,
     * 2.976E+10, 2.347E+09, 1.654E+07, 0.          /
      DATA AMOL37 /
     * 5.652E+18, 5.051E+18, 4.507E+18, 4.016E+18, 3.605E+18, 3.227E+18,
     * 2.880E+18, 2.564E+18, 2.275E+18, 2.012E+18, 1.774E+18, 1.523E+18,
     * 1.306E+18, 1.120E+18, 9.608E+17, 8.232E+17, 7.054E+17, 6.045E+17,
     * 5.172E+17, 4.430E+17, 3.788E+17, 3.230E+17, 2.758E+17, 2.356E+17,
     * 2.017E+17, 1.714E+17, 7.750E+16, 3.451E+16, 1.579E+16, 7.575E+15,
     * 3.896E+15, 3.073E+14, 2.166E+12, 0.          /
      DATA AMOL38 /
     * 2.107E+19, 1.883E+19, 1.680E+19, 1.497E+19, 1.344E+19, 1.203E+19,
     * 1.074E+19, 9.557E+18, 8.480E+18, 7.500E+18, 6.613E+18, 5.676E+18,
     * 4.869E+18, 4.175E+18, 3.581E+18, 3.069E+18, 2.629E+18, 2.253E+18,
     * 1.928E+18, 1.651E+18, 1.412E+18, 1.204E+18, 1.028E+18, 8.781E+17,
     * 7.519E+17, 6.389E+17, 2.889E+17, 1.287E+17, 5.886E+16, 2.823E+16,
     * 1.452E+16, 1.145E+15, 8.075E+12, 0.          /
      DATA AMOL41 /
     * 3.043E+17, 2.006E+17, 1.404E+17, 9.028E+16, 5.684E+16, 3.344E+16,
     * 1.806E+16, 9.696E+15, 4.347E+15, 1.404E+15, 5.015E+14, 3.143E+14,
     * 2.006E+14, 6.018E+13, 3.344E+13, 2.541E+13, 2.140E+13, 1.872E+13,
     * 1.672E+13, 1.638E+13, 1.505E+13, 1.705E+13, 1.705E+13, 1.806E+13,
     * 2.006E+13, 2.240E+13, 1.204E+13, 3.678E+12, 1.438E+12, 6.353E+11,
     * 2.106E+11, 4.681E+09, 3.344E+07, 0.          /
      DATA AMOL42 /
     * 8.314E+15, 7.531E+15, 6.822E+15, 6.146E+15, 5.518E+15, 4.964E+15,
     * 4.464E+15, 4.011E+15, 3.590E+15, 3.202E+15, 2.845E+15, 2.444E+15,
     * 2.101E+15, 1.806E+15, 1.551E+15, 1.328E+15, 1.148E+15, 9.861E+14,
     * 8.480E+14, 7.290E+14, 6.259E+14, 5.388E+14, 4.633E+14, 3.985E+14,
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* 3.414E+14, 2.915E+14, 1.363E+14, 6.398E+13, 3.103E+13, 1.579E+13,
* 8.519E+12, 7.826E+11, 3.416E+09, 0.        /
 DATA AMOL43 /
* 6.149E+11, 6.777E+11, 7.028E+11, 7.279E+11, 7.530E+11, 8.032E+11,
* 8.910E+11, 9.412E+11, 9.914E+11, 1.380E+12, 1.631E+12, 2.259E+12,
* 2.635E+12, 3.263E+12, 3.514E+12, 4.016E+12, 4.267E+12, 4.894E+12,
* 5.145E+12, 5.145E+12, 4.894E+12, 4.518E+12, 4.016E+12, 3.765E+12,
* 3.514E+12, 3.263E+12, 1.757E+12, 1.155E+12, 5.145E+11, 1.631E+11,
* 5.396E+10, 1.079E+09, 5.396E+05, 0.        /
 DATA AMOL44 /
* 7.054E+12, 6.390E+12, 5.789E+12, 5.215E+12, 4.682E+12, 4.212E+12,
* 3.788E+12, 3.403E+12, 3.046E+12, 2.716E+12, 2.414E+12, 2.074E+12,
* 1.782E+12, 1.533E+12, 1.316E+12, 1.127E+12, 9.738E+11, 8.367E+11,
* 7.195E+11, 6.185E+11, 5.311E+11, 4.571E+11, 3.931E+11, 3.381E+11,
* 2.897E+11, 2.474E+11, 1.157E+11, 5.429E+10, 2.633E+10, 1.340E+10,
* 7.229E+09, 6.640E+08, 2.898E+06, 0.        /
 DATA AMOL45 /
* 1.889E+12, 1.712E+12, 1.551E+12, 1.397E+12, 1.254E+12, 1.128E+12,
* 1.015E+12, 9.116E+11, 8.159E+11, 7.276E+11, 6.465E+11, 5.555E+11,
* 4.775E+11, 4.106E+11, 3.526E+11, 3.019E+11, 2.608E+11, 2.241E+11,
* 1.927E+11, 1.657E+11, 1.422E+11, 1.224E+11, 1.053E+11, 9.057E+10,
* 7.759E+10, 6.625E+10, 3.098E+10, 1.454E+10, 7.052E+09, 3.590E+09,
* 1.936E+09, 1.779E+08, 7.763E+05, 0.        /
 DATA AMOL46 /
* 4.031E+13, 3.651E+13, 3.308E+13, 2.980E+13, 2.675E+13, 2.407E+13,
* 2.164E+13, 1.945E+13, 1.741E+13, 1.552E+13, 1.379E+13, 1.185E+13,
* 1.019E+13, 8.759E+12, 7.522E+12, 6.440E+12, 5.564E+12, 4.781E+12,
* 4.111E+12, 3.534E+12, 3.035E+12, 2.612E+12, 2.246E+12, 1.932E+12,
* 1.655E+12, 1.413E+12, 6.610E+11, 3.102E+11, 1.504E+11, 7.658E+10,
* 4.131E+10, 3.794E+09, 1.656E+07, 0.        /
 DATA AMOL47 /
* 5.278E+18, 4.781E+18, 4.331E+18, 3.902E+18, 3.503E+18, 3.151E+18,
* 2.834E+18, 2.546E+18, 2.279E+18, 2.033E+18, 1.806E+18, 1.552E+18,
* 1.334E+18, 1.147E+18, 9.849E+17, 8.433E+17, 7.286E+17, 6.260E+17,
* 5.383E+17, 4.628E+17, 3.973E+17, 3.420E+17, 2.941E+17, 2.530E+17,
* 2.167E+17, 1.851E+17, 8.655E+16, 4.062E+16, 1.970E+16, 1.003E+16,
* 5.408E+15, 4.968E+14, 2.168E+12, 0.        /
 DATA AMOL48 /
* 1.967E+19, 1.782E+19, 1.614E+19, 1.454E+19, 1.306E+19, 1.175E+19,
* 1.056E+19, 9.491E+18, 8.495E+18, 7.576E+18, 6.731E+18, 5.783E+18,
* 4.971E+18, 4.275E+18, 3.671E+18, 3.143E+18, 2.716E+18, 2.334E+18,
* 2.007E+18, 1.725E+18, 1.481E+18, 1.275E+18, 1.096E+18, 9.430E+17,
* 8.079E+17, 6.898E+17, 3.226E+17, 1.514E+17, 7.342E+16, 3.737E+16,
* 2.016E+16, 1.852E+15, 8.083E+12, 0.        /
 DATA AMOL51 /
* 4.012E+16, 4.012E+16, 3.143E+16, 2.274E+16, 1.371E+16, 6.687E+15,
* 3.277E+15, 1.806E+15, 3.678E+14, 2.809E+14, 1.839E+14, 1.271E-14,
* 8.693E+13, 6.018E+13, 3.344E+13, 2.541E+13, 2.140E+13, 1.872E+13,
* 1.672E+13, 1.638E+13, 1.505E+13, 1.705E+13, 1.705E+13, 1.806E+13,
* 2.006E+13, 2.240E+13, 1.204E+13, 3.678E+12, 1.438E+12, 6.353E+11,
* 2.106E+11, 4.681E+09, 3.344E+07, 0.        /
 DATA AMOL52 /
* 9.407E+15, 8.179E+15, 7.254E+15, 6.425E+15, 5.721E+15, 5.117E+15,
* 4.561E+15, 4.052E+15, 3.585E+15, 3.114E+15, 2.662E+15, 2.275E+15,
* 1.944E+15, 1.662E+15, 1.421E+15, 1.214E+15, 1.041E+15, 8.920E+14,
* 7.639E+14, 6.539E+14, 5.599E+14, 4.787E+14, 4.094E+14, 3.500E+14,
* 2.990E+14, 2.554E+14, 1.129E+14, 5.058E+13, 2.285E+13, 1.077E+13,
* 5.273E+12, 3.908E+11, 3.416E+09, 0.        /
 DATA AMOL53 /
* 5.145E+11, 5.145E+11, 5.145E+11, 5.396E+11, 5.647E+11, 5.898E+11,
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* 6.149E+11, 8.910E+11, 1.129E+12, 2.008E+12, 3.012E+12, 4.016E+12,   033030
* 5.396E+12, 5.898E+12, 6.149E+12, 7.028E+12, 7.781E+12, 7.781E+12,   033040
* 7.781E+12, 7.530E+12, 7.028E+12, 6.400E+12, 5.898E+12, 5.396E+12,   033050
* 4.518E+12, 4.016E+12, 1.882E+12, 1.155E+12, 5.145E+11, 1.631E+11,   033060
* 5.396E+10, 1.079E+09, 5.396E+05, 0.        /                        033070
 DATA AMOL54 /                                                         033080
* 7.982E+12, 6.940E+12, 6.155E+12, 5.431E+12, 4.855E+12, 4.342E+12,   033090
* 3.870E+12, 3.438E+12, 3.042E+12, 2.642E+12, 2.258E+12, 1.931E+12,   033100
* 1.649E+12, 1.410E+12, 1.206E+12, 1.030E+12, 8.833E+11, 7.568E+11,   033110
* 6.482E+11, 5.549E+11, 4.751E+11, 4.062E+11, 3.473E+11, 2.969E+11,   033120
* 2.537E+11, 2.167E+11, 9.580E+10, 4.292E+10, 1.939E+10, 9.141E+09,   033130
* 4.474E+09, 3.316E+08, 2.898E+06, 0.        /                        033140
 DATA AMOL55 /                                                         033150
* 2.138E+12, 1.859E+12, 1.649E+12, 1.460E+12, 1.300E+12, 1.163E+12,   033160
* 1.037E+12, 9.210E+11, 8.148E+11, 7.078E+11, 6.049E+11, 5.171E+11,   033170
* 4.418E+11, 3.778E+11, 3.230E+11, 2.760E+11, 2.366E+11, 2.027E+11,   033180
* 1.736E+11, 1.486E+11, 1.273E+11, 1.088E+11, 9.304E+10, 7.954E+10,   033190
* 6.796E+10, 5.804E+10, 2.566E+10, 1.150E+10, 5.193E+09, 2.449E+09,   033200
* 1.198E+09, 8.882E+07, 7.763E+05, 0.        /                        033210
 DATA AMOL56 /                                                         033220
* 4.561E+13, 3.966E+13, 3.517E+13, 3.115E+13, 2.774E+13, 2.481E+13,   033230
* 2.212E+13, 1.965E+13, 1.738E+13, 1.510E+13, 1.291E+13, 1.103E+13,   033240
* 9.425E+12, 8.059E+12, 6.890E+12, 5.887E+12, 5.047E+12, 4.325E+12,   033250
* 3.704E+12, 3.171E+12, 2.715E+12, 2.321E+12, 1.985E+12, 1.697E+12,   033260
* 1.450E+12, 1.238E+12, 5.474E+11, 2.453E+11, 1.108E+11, 5.224E+10,   033270
* 2.557E+10, 1.895E+09, 1.656E+07, 0.        /                        033280
 DATA AMOL57 /                                                         033290
* 5.972E+18, 5.193E+18, 4.065E+18, 4.079E+18, 3.632E+18, 3.249E+18,   033300
* 2.896E+18, 2.573E+18, 2.276E+18, 1.977E+18, 1.690E+18, 1.444E+18,   033310
* 1.234E+18, 1.055E+18, 9.022E+17, 7.708E+17, 6.609E+17, 5.663E+17,   033320
* 4.850E+17, 4.152E+17, 3.555E+17, 3.039E+17, 2.599E+17, 2.222E+17,   033330
* 1.898E+17, 1.621E+17, 7.168E+16, 3.211E+16, 1.451E+16, 6.840E+15,   033340
* 3.348E+15, 2.481E+14, 2.168E+12, 0.        /                        033350
 DATA AMOL58 /                                                         033360
* 2.226E+19, 1.936E+19, 1.717E+19, 1.520E+19, 1.354E+19, 1.211E+19,   033370
* 1.079E+19, 9.589E+18, 8.484E+18, 7.369E+18, 6.299E+18, 5.384E+18,   033380
* 4.600E+18, 3.933E+18, 3.363E+18, 2.873E+18, 2.463E+18, 2.111E+18,   033390
* 1.808E+18, 1.547E+18, 1.325E+18, 1.133E+18, 9.687E+17, 8.282E+17,   033400
* 7.076E+17, 6.043E+17, 2.672E+17, 1.197E+17, 5.407E+16, 2.549E+16,   033410
* 1.248E+16, 9.248E+14, 8.083E+12, 0.        /                        033420
 DATA AMOL61 /                                                         033430
* 1.973E+17, 1.404E+17, 9.696E+16, 6.018E+16, 3.678E+16, 2.140E+16,   033440
* 1.271E+16, 7.022E+15, 4.012E+15, 1.538E+15, 6.018E+14, 2.742E+14,   033450
* 1.237E+14, 6.018E+13, 2.809E+13, 2.407E+13, 2.040E+13, 1.739E+13,   033460
* 1.471E+13, 1.471E+13, 1.471E+13, 1.605E+13, 1.739E+13, 1.906E+13,   033470
* 2.040E+13, 2.207E+13, 1.271E+13, 5.350E+12, 2.240E+12, 1.070E+12,   033480
* 4.012E+11, 5.015E+09, 3.344E+07, 0.        /                        033490
 DATA AMOL62 /                                                         033500
* 8.342E+15, 7.583E+15, 6.878E+15, 6.220E+15, 5.611E+15, 5.047E+15,   033510
* 4.526E+15, 4.048E+15, 3.607E+15, 3.205E+15, 2.839E+15, 2.503E+15,   033520
* 2.141E+15, 1.830E+15, 1.564E+15, 1.337E+15, 1.142E+15, 9.769E+14,   033530
* 8.351E+14, 7.139E+14, 6.103E+14, 5.196E+14, 4.426E+14, 3.775E+14,   033540
* 3.221E+14, 2.750E+14, 1.264E+14, 5.809E+13, 2.709E+13, 1.349E+13,   033550
* 7.049E+12, 6.007E+11, 3.425E+09, 0.        /                        033560
 DATA AMOL63 /                                                         033570
* 6.777E+11, 6.777E+11, 6.777E+11, 6.275E+11, 5.773E+11, 5.773E+11,   033580
* 5.647E+11, 6.149E+11, 6.526E+11, 8.910E+11, 1.129E+12, 1.631E+12,   033590
* 2.008E+12, 2.133E+12, 2.384E+12, 2.635E+12, 3.012E+12, 3.514E+12,   033600
* 4.016E+12, 4.392E+12, 4.769E+12, 4.769E+12, 4.894E+12, 4.769E+12,   033610
* 4.518E+12, 4.267E+12, 2.510E+12, 1.380E+12, 6.149E+11, 2.133E+11,   033620
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     * 5.020E+10, 1.079E+09, 5.396E+05, 0.        /
      DATA AMOL64 /
     * 7.078E+12, 6.434E+12, 5.836E+12, 5.277E+12, 4.760E+12, 4.282E+12,
     * 3.8[illegible]1E+12, 3.434E+12, 3.061E+12, 2.720E+12, 2.408E+12, 2.124E+12,
     * 1.8[illegible]E+12, 1.553E+12, 1.327E+12, 1.134E+12, 9.694E+11, 8.289E+11,
     * 7.08[illegible]E+11, 6.057E+11, 5.178E+11, 4.409E+11, 3.756E+11, 3.203E+11,
     * 2.733E+11, 2.333E+11, 1.072E+11, 4.929E+10, 2.298E+10, 1.145E+10,
     * 5.981E+09, 5.097E+08, 2.906E+06, 0.        /
      DATA AMOL65 /
     * 1.896E+12, 1.723E+12, 1.563E+12, 1.414E+12, 1.275E+12, 1.147E+12,
     * 1.029E+12, 9.199E+11, 8.199E+11, 7.285E+11, 6.451E+11, 5.689E+11,
     * 4.867E+11, 4.160E+11, 3.555E+11, 3.038E+11, 2.597E+11, 2.220E+11,
     * 1.898E+11, 1.622E+11, 1.387E+11, 1.181E+11, 1.006E+11, 8.579E+10,
     * 7.321E+10, 6.250E+10, 2.872E+10, 1.320E+10, 6.156E+09, 3.067E+09,
     * 1.602E+09, 1.365E+08, 7.784E+05, 0.        /
      DATA AMOL66 /
     * 4.045E+13, 3.677E+13, 3.335E+13, 3.016E+13, 2.720E+13, 2.447E+13,
     * 2.195E+13, 1.962E+13, 1.749E+13, 1.554E+13, 1.376E+13, 1.214E+13,
     * 1.038E+13, 8.874E+12, 7.584E+12, 6.481E+12, 5.539E+12, 4.737E+12,
     * 4.049E+12, 3.461E+12, 2.959E+12, 2.519E+12, 2.146E+12, 1.830E+12,
     * 1.562E+12, 1.333E+12, 6.126E+11, 2.816E+11, 1.313E+11, 6.542E+10,
     * 3.418E+10, 2.913E+09, 1.660E+07, 0.        /
      DATA AMOL67 /
     * 5.296E+18, 4.814E+18, 4.366E+18, 3.949E+18, 3.562E+18, 3.204E+18,
     * 2.874E+18, 2.570E+18, 2.290E+18, 2.035E+18, 1.802E+18, 1.589E+18,
     * 1.359E+18, 1.162E+18, 9.930E+17, 8.486E+17, 7.253E+17, 6.202E+17,
     * 5.301E+17, 4.532E+17, 3.875E+17, 3.299E+17, 2.810E+17, 2.396E+17,
     * 2.045E+17, 1.746E+17, 8.021E+16, 3.686E+16, 1.720E+16, 8.566E+15,
     * 4.475E+15, 3.814E+14, 2.174E+12, 0.        /
      DATA AMOL68 /
     * 1.974E+19, 1.794E+19, 1.627E+19, 1.472E+19, 1.328E+19, 1.194E+19,
     * 1.071E+19, 9.578E+18, 8.536E+18, 7.585E+18, 6.717E+18, 5.924E+18,
     * 5.067E+18, 4.331E+18, 3.701E+18, 3.163E+18, 2.704E+18, 2.312E+18,
     * 1.976E+18, 1.689E+18, 1.444E+18, 1.230E+18, 1.047E+18, 8.932E+17,
     * 7.622E+17, 6.508E+17, 2.990E+17, 1.375E+17, 6.410E+16, 3.193E+16,
     * 1.668E+16, 1.422E+15, 8.104E+12, 0.        /
      END
```

```
      SUBROUTINE  MLATM(M)
C*********************************************************************
C     THIS SUBROUTINE LOADS ONE OF THE 6 BUILT IN ATMOSPHERIC PROFILES
C     OR CALLS NSMDL TO READ IN A USER SUPPLIED PROFILE.
C*********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
C&    DOUBLE PRECISION HMOD
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
C&    DOUBLE PRECISION ATMNAM
      COMMON /MLATMC/ ALT(34),PMDL(34,6),TMDL(34,6),AMOL(34,8,6),
     1    ATMNAM(3,6)
      IF(M.EQ.7) GO TO 200
      IF(M.GE.1 .OR. M.LE.6) IMOD = 33
      DO 100 I=1,IMOD
      ZM(I) = ALT(I)
      PM(I) = PMDL(I,M)
      TM(I) = TMDL(I,M)
C*****AMOL(I,8,M) IS N2 AND IS NO LONGER USED
      DO 100 K=1,7
      DENM(K,I) = AMOL(I,K,M)
  100 CONTINUE
      DO 110 L=1,3
  110 HMOD(L) = ATMNAM(L,M)
      GO TO 210
  200 CONTINUE
      CALL NSMDL
  210 CONTINUE
      ZMIN = ZM(1)
      ZMAX = ZM(IMOD)
      RETURN
      END
```

```
      SUBROUTINE NSMOL
C*********************************************************************
C
C
C     NOTES TO USER:
C
C     THIS SUBROUTINE IS FOR READING IN AN ATMOSPHERIC PROFILE
C     CORRESPONDING TO MODEL = 7.  THE PROFILE IS READ IN AFTER
C     CONTROL CARD 4 IN THE FOLLOWING FORMAT
C             IMOD    (I5)
C                     THE NUMBER OF LAYER BOUNDARIES TO FOLLOW
C             (HEADER(I),I=1,3)      ( 3A8)
C                     A 24 CHARACTER HEADER DESCRIBING THE PROFILE
C        FOR EACH OF THE IMOD LEVELS-
C             Z,P,T,TD,RH,PPH2O,DENH2O,AMSMIX      (8F10.3)
C             (VMIX(K),K=1,KMAX)      (8E10.3)
C                     Z       ALTITUDE (KM
C                     P       PRESSURE (MB)
C                     T       TEMPERATURE (K)
C                     TD      DEW POINT (DEG C)
C                     RH      RELATIVE HUMIDITY (PER CENT)
C                     PPH2O   H2O PARTIAL PRESSURE (MB)
C                     DENH2O  H2O MASS DENSITY (GM M-3)
C                     AMSMIX  H2O MASS MIXING RATIO (GM KG-1)
C                     VMIX    VOLUME MIXING RATIO OF THE K'TH
C                             MOLECULAR SPECIES, PARTS PER MILLION
C
C     THE WATER VAPOR DENSITY MAY BE SPECIFIED IN ANY OF 6 WAYS-
C     IF VMIX(1) IS NOT SUPPLIED, THEN THE DENSITY OF H2O, DENSTY(1),
C     IS COMPUTED
C     IN THE SUBROUTINE WATVAP FROM THE GIVEN VALUE OF TD, RH,
C     PPH2O, DENH2O, OR ASMIX.  IF MORE THAN ONE OF THESE IS GIVEN,
C     THEN THE LAST ONE GIVEN IS USED.  (NOTE THAT TD = 0 IS
C     A VALID INPUT AND THAT TD SHOULD NOT BE CONFUSED WITH THE
C     WETBULB TEMPERATURE OF A WET AND DRY BULB THERMOMETER)
C     IF THE VOL MIX RATIOS OF THE UNIFORMLY MIXED GASES (K=2=CO2,
C     4=N2O,5=CO,6=CH4,7=O2,8=N2) ARE NOT SUPPLIED, THEY ARE
C     CALCULATED USING THE VALUE OF THE VOLUME MIXING RATIO
C     VMIXST(K) TAKEN FROM THE U.S. STANDARD ATMOSPHERE, 1976.
C     NOTE THAT THESE VALUES OF VMIXST (ESP FOR CO) ARE DIFFERENT
C     FROM THOSE USED IN MODELS 1 TO 6, WHICH ARE TAKEN FROM
C     OPTICAL PROPERTIES OF THE ATMOSPHERE (THIRD EDITION).
C     IF AN O3 PROFILE IS NOT SUPPLIED, IT IS SET EQUAL TO ZERO.
C*********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
      COMMON /CONSTN/ PZERO,TZERO,AVOGAD,ALOSMT,GASCON,PLANK,BOLTZ,
     1    CLIGHT,ADCON,ALZERO,AVMWT,AIRMWT,AMWT(20),VMIXST(20),VMIXN2
C&    DOUBLE PRECISION HMOD
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
C&    DOUBLE PRECISION HMOLS
      COMMON /HMOLS/ HMOLS(20)
      DIMENSION VMIX(20)
C&    DOUBLE PRECISION HD1,HD2
      DIMENSION HD1(9),HD2(9)
      DATA HD1/  8H       I,  8H    Z   ,  8H    P   ,  8H    T   ,
```

```
     1      8H    TD  ,  8H     RH  ,  8H   PPH2O  ,  8H DENH2O  ,
     2      8H AMSMIX  /
      DATA HD2/  8H          ,  8H    (KM)  ,  8H    (MB)  ,  8H     (K)   ,
     1      8H    (C)   ,  8H(PERCNT)  ,  8H    (MB)  ,  8H(GM M-3)  ,
     2      8H(GM/KG)  /
      WRITE(IPR,20)
   20 FORMAT(///,' READING IN USER SUPPLIED MODEL ATMOSPHERE')
      READ(IRD.21) IMOD
   21 FORMAT(I5)
      READ(IRD,22) HMOD
   22 FORMAT(3A8)
      WRITE(IPR,24) IMOD, HMOD
   24 FORMAT(//,10X,'IMOD     = ',I5,/,10X,'PROFILE = ',3A8)
      IF(IMOD.GT.IMODMX) GO TO 900
      WRITE(IPR,26) HD1,HD2
   26 FORMAT(/,(3X,9(1X,A8,1X)))
      WRITE(IPR,28) HMOLS
   28 FORMAT(/,' VOL MIX RAT' ,8(1X,A8,1X),/,' (PPMV)',
     1     (T14,8A10))
      DO 110 IM=1,IMOD
      READ(IRD,30) ZM(IM),PM(IM),TM(IM),TD,RH,PPH2O,DENH2O,AMSMIX
   30 FORMAT(8F10.3)
      WRITE(IPR,32) IM,ZM(IM),PM(IM),TM(IM),TD,RH,PPH2O,DENH2O,AMSMIX
   32 FORMAT(/,I11,8F10.3)
      READ(IRD,34)  (VMIX(K),K=1,KMAX)
   34 FORMAT(8E10.3)
      WRITE(IPR,36)  (VMIX(K),K=1,KMAX)
   36 FORMAT(/,11X,1P8E10.3)
      RHOAIR = ALOSMT*(PM(IM)/PZERO)*(TZERO/TM(IM))
      DENM(1,IM) = 0.0
      IF(VMIX(1).GT.0.0) DENM(1,IM) = VMIX(1)*RHOAIR*1.0E-6
      IF(VMIX(1).EQ.0.0) CALL WATVAP(PM(IM),TM(IM),TD,RH,PPH2O,
     1     DENH2O,AMSMIX,DENM(1,IM))
      DO 100 K=2,KMAX
      DENM(K,IM) = 0.0
      IF(VMIX(K).GT.0.0) DENM(K,IM) = VMIX(K)*RHOAIR*1.0E-6
      IF(VMIX(K).EQ.0.0) DENM(K,IM) = VMIXST(K)*RHOAIR*1.0E-6
  100 CONTINUE
  110 CONTINUE
      RETURN
  900 CONTINUE
      WRITE(IPR,902) IMOD,IMODMX
  902 FORMAT(/,' NUMBER OF PROFILE LEVELS IMOD = ',I5,' EXCEEDS THE ',
     1     'MAXIMUM ALLOWED = ',I5)
      END
```

```
      SUBROUTINE WATVAP(P,T,TD,RH,PPH2O,DENH2O,AMSMIX,DENNUM)
C**********************************************************************
C     THIS SUBROUTINE COMPUTES THE WATERVAPOR NUMBER DENSITY (MOL CM-3)
C     GIVEN : TD = DEW POINT TEMPERATURE (DEG C), RH = RELATIVE HUMIDITY
C     (PERCENT), PPH2O = WATER VAPOR PARTIAL PRESSURE (MB), DENH2O =
C     WATER VAPOR MASS DENSITY (GM M-3),AMSMIX = MASS MIXING RATIO
C     (GM/KG).
C     IF MORE THAN ONE OF THESE QUANTITIES IS GIVEN, THE LAST ONE
C     GIVEN IS USED.  THE FUNCTION DENSAT FOR THE SATURATION
C     WATER VAPOR DENSITY OVER WATER IS ACCURATE TO BETTER THAN 1
C     PERCENT FROM -50 TO +50 DEG C. (SEE THE LOWTRAN3 OR 5 REPORT)
C**********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
      COMMON /CONSTN/ PZERO,TZERO,AVOGAD,ALOSMT,GASCON,PLANK,BOLTZ,
     1    CLIGHT,ADCON,ALZERO,AVMWT,AIRMWT,AMWT(20),VMIXST(20),VMIXN2
      DATA C1/18.9766/,C2/-14.9595/,C3/-2.4388/
      DENSAT(ATEMP) = ATEMP*B*EXP(C1+C2*ATEMP+C3*ATEMP**2)*1.0E-6
C*****
      RHOAIR = ALOSMT*(P/PZERO)*(TZERO/T)
      A = TZERO/T
      B = AVOGAD/AMWT(1)
      IF(AMSMIX.LE.0.0) GO TO 110
C*****GIVEN MASS MIXING RATIO (GM KG-1)
      DENNUM = B*AMSMIX*1.0E-3*RHOAIR
      GO TO 200
  110 CONTINUE
      IF(DENH2O.LE.0.0) GO TO 120
C*****GIVEN MASS DENSITY (GM M-3)
      DENNUM = B*DENH2O*1.0E-6
      GO TO 200
  120 CONTINUE
      IF(PPH2O.LE.0.0) GO TO 130
C*****GIVEN WATER VAPOR PARTIAL PRESSURE (MB)
      DENNUM = ALOSMT*(PPH2O/PZERO)*(TZERO/T)
      GO TO 200
  130 CONTINUE
      IF(RH.LE.0.0) GO TO 140
C*****GIVEN RELATIVE HUMIDITY (PERCENT)
      DENNUM = DENSAT(A)*(RH/100.0)/(1.0-(1.0-RH/100.0)*DENSAT(A)/
     1    RHOAIR)
      GO TO 200
  140 CONTINUE
C*****GIVEN DEWPOINT (DEG C)
      ATD = TZERO/(TZERO+TD)
      DENNUM = DENSAT(ATD)*(TZERO+TD)/T
  200 CONTINUE
      DENST = DENSAT(A)
      RHP = 100.0*(DENNUM/DENST)*((RHOAIR-DENST)/(RHOAIR-DENNUM))
      WRITE(IPR,12) RHP
   12 FORMAT('+',95X,'RH = ',F10.2)
      IF(RHP.LE.100.0) GO TO 230
      WRITE(IPR,10) RHP
   10 FORMAT(/,' ********WARNING (FROM WATVAP): RELATIVE HUMIDITY = ',
     1    G10.3,' IS GREATER THAN 100 PERCENT')
  230 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GEOINP(H1,H2,ANGLE,RANGE,BETA,ITYPE,LEN,HMIN,PHI,
     1    IERROR)
C*********************************************************************
C     GEOINP INTERPRETS THE ALLOWABLE COMBINATIONS OF INPUT PATH
C     PARAMETERS INTO THE STANDARD SET H1,H2,ANGLE,PHI,HMIN, AND LEN.
C     THE ALLOWABLE COMBINATIONS OF INPUT PARAMETERS ARE- FOR ITYPE = 2,
C     (SLANT PATH H1 TO H2) A. H1, H2, AND ANGLE, B. H1, ANGLE, AND
C     RANGE, C. H1, H2, AND RANGE, D. H1, H2, AND BETA -
C     FOR ITYPE = 3 (SLANT PATH H1 TO SPACE, H2 = ZMAX(=100 KM,M=1 TO 6)
C     A. H1 AND ANGLE, B. H1 AND HMIN (INPUT AS H2).
C     THE SUBROUTINE ALSO DETECTS BAD INPUT (IMPOSSIBLE GEOMETRY) AND
C     ITYPE = 2 CASES WHICH INTERSECT THE EARTH, AND RETURNS THESE
C     CASES WITH ERROR FLAGS.
C     THE SUBROUTINE FNDHMN IS CALLED TO CALCULATE HMIN, THE MINIMUM
C     HEIGHT ALONG THE PATH, AND PHI, THE ZENITH ANGLE AT H2, USING THE
C     ATMOSPHERIC PROFILE STORED IN /MDATA/
C*********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
      ITER = 0
      IF(ITYPE.NE.3) GO TO 120
C*****SLANT PATH TO SPACE
C*****NOTE: IF BOTH HMIN AND ANGLE ARE ZERO, THEN ANGLE IS
C*****ASSUMED SPECIFIED
      IF(H2.NE.0.0)  GO TO 110
C*****CASE 3A: H1,SPACE,ANGLE
      WRITE(IPR,10)
   10 FORMAT(//,' CASE 3A: GIVEN H1,H2=SPACE,ANGLE')
      H2 =  ZMAX
      CALL FNDHMN(H1,ANGLE,H2,LEN,ITER,HMIN,PHI,IERROR)
      GO TO 200
  110 CONTINUE
C*****CASE 3B: H1,HMIN,SPACE
      WRITE(IPR,12)
   12 FORMAT(//,' CASE 3B: GIVEN H1, HMIN, H2=SPACE')
      HMIN = H2
      H2 = ZMAX
      IF(H1.LT.HMIN) GO TO 9001
      CALL FNDHMN(HMIN,90.0,H1,LEN,ITER,HMIN,ANGLE,IERROR)
      CALL FNDHMN(HMIN,90.0,H2,LEN,ITER,HMIN,PHI,IERROR)
      IF(HMIN.LT.H1) LEN = 1
      GO TO 200
  120 CONTINUE
      IF(ITYPE.NE.2) GO TO 9002
      IF(RANGE.NE.0.0.OR.BETA.NE.0.0) GO TO 130
C*****CASE 2A: H1, H2, ANGLE
      WRITE(IPR,16)
   16 FORMAT(//, ' CASE 2A: GIVEN H1, H2, ANGLE')
      IF(H1.GE.H2.AND.ANGLE.LE.90.0) GO TO 9004
      IF(H1.EQ.0.0 .AND. ANGLE.GT.90.0) GO TO 9007
      IF(H2.LT.H1 .AND. ANGLE.GT.90.0)  WRITE(IPR,15) LEN
   15 FORMAT(//,' EITHER A SHORT PATH (LEN=0) OR A LONG PATH ',
     1    'THROUGH A TANGENT HEIGHT (LEN=1) IS POSSIBLE: LEN = ',
     2    I3)
      H2ST = H2
      CALL FNDHMN(H1,ANGLE,H2,LEN,ITER,HMIN,PHI,IERROR)
      IF(H2.NE.H2ST)  GO TO 9007
      GO TO 200
  130 CONTINUE
```

```
      IF(BETA.NE.0.0) GO TO 150
      IF(ANGLE.EQ.0.0) GO TO 140
C*****CASE 2B: H1, ANGLE, RANGE
C*****ASSUME NO REFRACTION
      WRITE(IPR,18)
   18 FORMAT(//,' CASE 2B:, GIVEN H1, ANGLE, RANGE',//
     1    10X,'NOTE: H2 IS COMPUTED FROM H1, ANGLE, AND RANGE ',
     2    'ASSUMING NO REFRACTION')
      R1 = RE+H1
      R2 = SQRT(R1**2+RANGE**2+2.0*R1*RANGE*COS(+ANGLE/DEG))
      H2 = R2-RE
      IF(H2.GE.0.0)  GO TO 135
      H2 = 0.0
      R2 = RE+H2
      RANGE = -R1*COS(ANGLE/DEG)-SQRT(R2**2-R1**2*(SIN(ANGLE/DEG))**2)
      WRITE(IPR,17) RANGE
   17 FORMAT(//,10X,'CALCULATED H2 IS LESS THAN ZERO:',/,
     1    10X,'RESET H2 = 0.0 AND RANGE = ',F10.3)
  135 CONTINUE
C*****NOTE: GEOMETRIC PHI IS NEEDED TO DETERMINE LEN(0 OR 1).
C*****PHI IS THEN RECOMPUTED IN FNDHMN
      PHI = 180.0-ACOS((R2**2+RANGE**2-R1**2)/(2.0*R2*RANGE))*DEG
      LEN = 0
      IF(ANGLE.GT.90.0.AND.PHI.GT.90.0) LEN = 1
      CALL FNDHMN(H1,ANGLE,H2,LEN,ITER,HMIN,PHI,IERROR)
      GO TO 200
  140 CONTINUE
C*****CASE 2C: H1, H2, RANGE
      WRITE(IPR,19)
   19 FORMAT(//,' CASE 2C: GIVEN H1, H2, RANGE',//,
     1    10X,'NOTE: ANGLE IS COMPUTED FROM H1, H2, AND RANGE ',
     2    'ASSUMING NO REFRACTION')
      IF(ABS(H1-H2).GT.RANGE) GO TO 9003
      R1 = H1+RE
      R2 = H2+RE
      ANGLE = 180.0-ACOS((R1**2+RANGE**2-R2**2)/(2.0*R1*RANGE))*DEG
      PHI = 180.0-ACOS((R2**2+RANGE**2-R1**2)/(2.0*R2*RANGE))*DEG
      LEN = 0.
      IF(ANGLE.GT.90.0.AND.PHI.GT.90.0) LEN = 1
      CALL FNDHMN(H1,ANGLE,H2,LEN,ITER,HMIN,PHI,IERROR)
      GO TO 200
C*****CASE 2D: H1, H2, BETA
  150 CONTINUE
      CALL FDBETA(H1,H2,BETA,ANGLE,PHI,LEN,HMIN,IERROR)
      GO TO 200
C*****END OF ALLOWED CASES
C*****
  200 CONTINUE
C*****TEST IERROR AND RECHECK LEN
      IF(IERROR.NE.0)  RETURN
      LEN = 0
      IF(HMIN.LT.AMIN1(H1,H2)) LEN = 1
C*****REDUCE PATH ENDPOINTS ABOVE ZMAX TO ZMAX
      IF(HMIN.GE.ZMAX) GO TO 9003
      IF(H1.GT.ZMAX .OR. H2.GT.ZMAX)  CALL REDUCE(H1,H2,ANGLE,PHI,ITER)
C*****AT THIS POINT THE FOLLOWING PARAMETERS ARE DEFINED-
C*****     H1,H2,ANGLE,PHI,HMIN,LEN
      WRITE(IPR,20)  H1,H2,ANGLE,PHI,HMIN,LEN
   20 FORMAT(///,' SLANT PATH PARAMETERS IN STANDARD FORM',//,
     1  10X,'H1      = ',F10.3,' KM',/,10X,'H2      = ',F10.3,' KM',/,
```

```
     2  10X,'ANGLE    = ',F10.3,' DEG',/,10X,'PHI      = ',F10.3,' DEG',/,
    ,3     10X,'HMIN     = ',F10.3,' KM',/,10X,'LEN      = ',I10)
      RETURN
C*****
C*****ERROR MESAGES
C*****
 9001 CONTINUE
      WRITE(IPR,40) H1,HMIN
   40 FORMAT('0GEOINP: CASE 3B (H1,HMIN,SPACE): ERROR IN INPUT DATA',
     1     //,10X,'H1 = ',F12.6,'     IS LESS THAN HMIN = ',F12.6)
      GO TO 9900
 9002 WRITE(IPR,42) ITYPE,ITYPE
   42 FORMAT('0GEOINP: ERROR IN INPUT DATA, ITYPE NOT EQUAL TO ',
     1     ' 2, OR 3.   ITYPE = ',I10,E23.14)
      GO TO 9900
 9003 WRITE(IPR,43) H1,H2,RANGE
   43 FORMAT('0GEOINP: CASE 2C (H1,H2,RANGE): ERROR IN INPUT DATA',//,
     110X,'ABS(H1-H2) GT RANGE;  H1 = ',F12.6,'     H2 = ',F12.6,
     2    '      RANGE = ',F12.6)
      GO TO 9900
 9004 CONTINUE
      WRITE(IPR,44)  H1,H2,ANGLE
   44 FORMAT('0GEOINP: CASE 2A (H1,H2,ANGLE): ERROR IN INPUT DATA',
     1  //,10X,'H1 = ',F12.6,'     IS GREATER THAN OR EQUAL TO H2 = ',
     2     F12.6,/,10X,'AND ANGLE = ',F12.6,'     IS LESS THAN OR ',
     3     'EQUAL TO 90.0')
      GO TO 9900
 9007 WRITE(IPR,48)
   48 FORMAT('0GEOINP: ITYPE = 2: SLANT PATH INTERSECTS THE EARTH',
     1     ' AND CANNOT REACH H2')
      GO TO 9900
 9008 WRITE(IPR,50) ZMAX,H1,H2,HMIN
   50 FORMAT(' GEOINP:  THE ENTIRE PATH LIES ABOVE THE TOP ZMAX ',
     1     'OF THE ATMOSPHERIC PROFILE',//,10X,'ZMAX = ',G12.6,5X,
     2     ' H1 = ',G12.6,5X,'  H2 = ',G12.6,'  HMIN = ',G12.6)
 9900 IERROR = 1
      RETURN
      END
```

```
      SUBROUTINE REDUCE(H1,H2,ANGLE,PHI,ITER)
C*********************************************************************
C     ZMAX IS THE HIGHEST LEVEL IN THE ATMOSPHERIC PROFILE STORED IN
C     COMMON /MDATA/.  IF H1 AND/OR H2 ARE GREATER THAN ZMAX, THIS
C     SUBROUTINE REDUCES THEM TO ZMAX AND RESETS ANGLE AND/OR PHI
C     AS NECESSARY. THIS REDUCTION IS NECESSARY,FOR EXAMPLE FOR
C     SATELLITE ALTITUDES, BECAUSE (1) THE DENSITY PROFILES ARE
C     POORLY DEFINED ABOVE ZMAX AND (2) THE CALCULATION TIME FOR
C     PATHS ABOVE ZMAX CAN BE EXCESSIVE ( EG. FOR GEOSYNCRONOUS
C     ALTITUDES)
C*********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
      IF(H1.LE.ZMAX .AND. H2.LE.ZMAX)  RETURN
      CALL FINDSH(H1,SH,GAMMA)
      CPATH = ANDEX(H1,SH,GAMMA)*(RE+H1)*SIN(ANGLE/DEG)
      CALL FINDSH(ZMAX,SH,GAMMA)
      CZMAX = ANDEX(ZMAX,SH,GAMMA)*(RE+ZMAX)
      ANGMAX = 180.0-ASIN(CPATH/CZMAX)*DEG
      IF(H1.LE.ZMAX) GO TO 120
      H1 = ZMAX
      ANGLE = ANGMAX
  120 CONTINUE
      IF(H2.LE.ZMAX)  GO TO 130
      H2 = ZMAX
      PHI = ANGMAX
  130 CONTINUE
      IF(ITER.EQ.0) WRITE(IPR,20) ZMAX,ANGMAX
   20 FORMAT(///,  FROM SUBROUTINE REDUCE : ',/,
     1    10X,'ONE OR BOTH OF H1 AND H2 ARE ABOVE THE TOP OF THE ',
     2    'ATMOSPHERIC PROFILE ZMAX = ',F10.3,'  AND HAVE BEEN RESET ',
     3    'TO ZMAX.',/,10X,'ANGLE AND/OR PHI HAVE ALSO BEEN RESET TO ',
     4    'THE ZENITH ANGLE AT ZMAX = ',F10.3,' DEG')
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FDBETA(H1,H2,BETA,ANGLE,PHI,LEN,HMIN,IERROR)
C**********************************************************************
C     GIVEN H1,H2,AND BETA (THE EARTH CENTERED ANGLE) THIS SUBROUTINE
C     CALCULATES THE INITIAL ZENITH ANGLE AT H1 THROUGH AN ITERATIVE
C     PROCEEDURE
C**********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
C&    DOUBLE PRECISION HMOD
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
      DATA TOLRNC/1.0E-4/,ITERMX/10/
      IFLAG = 0
      IF(H1.GT.H2) GO TO 100
      IORDER = 1
      HA = H1
      HB = H2
      GO TO 120
  100 CONTINUE
      IORDER = -1
      HA = H2
      HB = H1
  120 CONTINUE
C*****LOAD ATMOSPHERIC PROFILE INTO /MODEL/
      IMAX = IMOD
      DO 130 IM=1,IMOD
      Z(IM) = ZM(IM)
      P(IM)=PM(IM)
      T(IM) = TM(IM)
      RFNDX(IM) = RFNDXM(IM)
  130 CONTINUE
C*****SET PARAMETER TO SUPRESS CALCULATION OF AMOUNTS
      IAMTB = 2
C*****GUESS AT ANGLE, INTEGRATE TO FIND BETA, TEST FOR
C*****CONVERGENCE, AND ITERATE
C*****FIRST GUESS AT ANGLE: USE THE GEOMETRIC SOLUTION(NO REFRACTION)
      ITER = 1
      RA = RE+HA
      RB = RE+HB
      SG = SQRT(RA**2+RB**2-2.0*RA*RB*COS(BETA/DEG))
      ANGLE1 = 180.0-ACOS((RA**2+SG**2-RB**2)/(2.0*RA*SG))*DEG
      HMIN = HA
      IF(ANGLE1.GT.90.0)  HMIN = RA*SIN(ANGLE1/DEG)-RE
      IF(HMIN.GE.0.0) GO TO 310
      IFLAG = 1
      HMIN = 0.0
      CALL FNDHMN(HMIN,90.0,HA,LEN,ITER,HMIN,ANGLE1,IERROR)
  310 CONTINUE
      WRITE(IPR,24)
   24 FORMAT(///,' CASE 2D: GIVEN H1, H2,  BETA:',//,
     1     ' ITERATE AROUND ANGLE UNTIL BETA CONVERGES',//,
     2     ' ITER    ANGLE',T21,'BETA',T30,'DBETA',T40,'RANGE',
     3     T51,'HMIN',T61,'PHI',T70,'BENDING',/,
     4     T10,'(DEG)',T21,'(DEG)',T30,'(DEG)',T41,'(KM)',
     5     T51,'(KM)',T60,'(DEG)',T71,'(DEG)',/)
      LEN = 0
      IF(ANGLE1.GT.90.0) LEN = 1
```

```
      CALL FNDHMN(HA,ANGLE1,HB,LEN,ITER,HMIN,PHI,IERROR)
      LEN = 0
      IF(HMIN.LT.HA) LEN = 1
      CALL RFPATH(HA,HB,ANGLE1,PHI,LEN,HMIN,IAMTB,RANGE,BETA1,BENDNG)
      DBETA = BETA-BETA1
      WRITE(IPR,26)  ITER,ANGLE1,BETA1,DBETA,RANGE,HMIN,PHI,BENDNG
   26 FORMAT(I5,3F10.4,2F10.3,2F10.4)
      IF(IFLAG.EQ.1 .AND. BETA1.LT.BETA) GO TO 9005
      ITER = 2
      DANG = (BETA/25.0)**2
      IF(DANG.LT.0.001) DANG = 0.001
      ANGLE2 = ANGLE1-DANG
      IF(ANGLE2.LT.0.0)  ANGLE2 = 0.0
      LEN = 0
      IF(ANGLE2.GT.90.0) LEN = 1
      CALL FNDHMN(HA,ANGLE2,HB,LEN,ITER,HMIN,PHI,IERROR)
      LEN = 0
      IF(HMIN.LT.HA) LEN = 1
      CALL RFPATH(HA,HB,ANGLE2,PHI,LEN,HMIN,IAMTB,RANGE,BETA2,BENDNG)
      DBETA = BETA-BETA2
      WRITE(IPR,26)  ITER,ANGLE2,BETA2,DBETA,RANGE,HMIN,PHI,BENDNG
      IF(ABS(DBETA).LE.TOLRNC) GO TO 340
  320 CONTINUE
      ITER = ITER+1
      ANGLE3 = ANGLE2+(ANGLE2-ANGLE1)*(BETA-BETA2)/(BETA2-BETA1)
      LEN = 0
      IF(ANGLE3.GT.90.0) LEN = 1
      CALL FNDHMN(HA,ANGLE3,HB,LEN,ITER,HMIN,PHI,IERROR)
      LEN = 0
      IF(HMIN.LT.HA) LEN = 1
      CALL RFPATH(HA,HB,ANGLE3,PHI,LEN,HMIN,IAMTB,RANGE,BETA3,BENDNG)
      DBETA = BETA-BETA3
      WRITE(IPR,26)  ITER,ANGLE3,BETA3,DBETA,RANGE,HMIN,PHI,BENDNG
      IF(BETA3.LT.BETA.AND.HMIN.LT.0.0) GO TO 9005
      ANGLE1 = ANGLE2
      ANGLE2 = ANGLE3
      BETA1 = BETA2
      BETA2 = BETA3
      IF(ABS(BETA-BETA3).LT.TOLRNC) GO TO 340
      IF(ITER.GT.ITERMX) GO TO 9006
      GO TO 320
  340 CONTINUE
      IF(HMIN.LT.0.0) GO TO 9005
C*****CONVERGED TO A SOLUTION
      ANGLE = ANGLE3
      BETA = BETA3
C*****ASSIGN ANGLE AND PHI TO PROPER H1 AND H2
      IF(IORDER.EQ.1) GO TO 350
      TEMP = PHI
      PHI = ANGLE
      ANGLE = TEMP
  350 CONTINUE
      RETURN
C*****
C*****ERROR MESSAGES
C*****
 9005 CONTINUE
      WRITE(IPR,45)
   45 FORMAT('OFDBETA, CASE 2D(H1,H2,BETA): REFRACTED TANGENT ',
     1    'HEIGHT IS LESS THAN ZERO-PATH INTERSECTS THE EARTH',
```

```
     2    //,10X,'BETA IS TOO LARGE FOR THIS H1 AND H2')
      GO TO 9900
 9006 CONTINUE
      WRITE(IPR,46) H1,H2,BETA,ITER,ANGLE1,BETA1,ANGLE2,BETA2,
     1    ANGLE3,BETA3
   46 FORMAT('OFDBETA, CASE 2D (H1,H2,BETA): SOLUTION DID NOT ',
     1    ' CONVERGE',//,10X,'H1 = ',F12.6,'    H2 = ',F12.6,
     2    '    BETA = ',F12.6,'    ITERATIONS = ',I4,//,
     3    10X,'LAST THREE ITERATIONS ',//,
     4    (10X,'ANGLE = ',F15.9,'    BETA = ',F15.9))
 9900 IERROR = 1
      RETURN
      END
```

```
      SUBROUTINE EXPINT(X,X1,X2,A)
C***********************************************************************
C     THIS SUBROUTINE EXPONENTIALLY INTERPOLATES X1 AND X2 TO X BY
C     THE FACTOR A
C***********************************************************************
      IF(X1.EQ.0.0 .OR. X2.EQ.0.0)  GO TO 100
      X = X1*(X2/X1)**A
      RETURN
  100 X = X1+(X2-X1)*A
      RETURN
      END
```

```
      SUBROUTINE FNDHMN(H1,ANGLE,H2,LEN,ITER,HMIN,PHI,IERROR)
C**********************************************************************
C     THIS SUBROUTINE CALCULATES THE MINIMUM ALTITUDE HMIN ALONG
C     THE REFRACTED PATH AND THE FINAL ZENITH ANGLE PHI.
C     THE PARAMETER LEN INDICATES WHETHER THE PATH GOES THROUGH
C     A TANGENT HEIGHT (LEN=1) OR NOT (LEN=0).  IF ANGLE > 90 AND
C     H1 > H2, THEN LEN CAN EITHER BE 1 OR 0, AND THE CHOICE IS
C     LEFT TO THE USER.
C     THE (INDEX OF REFRACTION - 1.0) IS MODELED AS AN EXPONENTIAL
C     BETWEEN THE LAYER BOUNDARIES, WITH A SCALE HEIGHT SH AND AN
C     AMOUNT AT THE GROUND GAMMA.
C     CPATH IS THE REFRACTIVE CONSTANT FOR THIS PATH AND
C     EQUALS  INDEX(H1)*(RE+H1)*SIN(ANGLE).
C**********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    ICUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,IPRINT
      DATA DH/1.0/,ETA/5.0E-8/
C*****ETA MAY BE TOO SMALL FOR SOME COMPUTERS. TRY 1.0E-7 FOR 32 BIT
C*****WORD MACHINES
      CRFRCT(H) = (RE+H)*ANDEX(H,SH,GAMMA)
      N = 0
      CALL FINDSH(H1,SH,GAMMA)
      CPATH = CRFRCT(H1)*SIN(ANGLE/DEG)
      CALL FINDSH(H2,SH,GAMMA)
      CH2 = CRFRCT(H2)
      IF(ABS(CPATH/CH2).GT.1.0) GO TO 200
      IF(ANGLE.GT.90.0)  GO TO 100
      LEN = 0
      HMIN = H1
      GO TO 160
  100 CONTINUE
      IF(H1.LE.H2)  LEN = 1
      IF(LEN.EQ.1)  GO TO 110
      LEN = 0
      HMIN = H2
      GO TO 160
  110 CONTINUE
C*****LONG PATH THROUGH A TANGENT HEIGHT.
C*****SOLVE ITERATIVELY FOR THE TANGENT HEIGHT HT.
C*****HT IS THE HEIGHT FOR WHICH  INDEX(HT)*(RE+HT) = CPATH.
      CALL FINDSH(0.0,SH,GAMMA)
      CMIN = CRFRCT(0.0)
C*****FOR BETA CASES (ITER>0), ALLOW FOR HT < 0.0
      IF(ITER.EQ.0 .AND. CPATH.LT.CMIN)  GO TO 150
      HT1 = (RE+H1)*SIN(ANGLE/DEG)-RE
      CALL FINDSH(HT1,SH,GAMMA)
      CT1 = CRFRCT(HT1)
      HT2 = HT1-DH
      CALL FINDSH(HT2,SH,GAMMA)
      CT2 = CRFRCT(HT2)
C*****ITERATE TO FIND HT
      N = 2
  120 CONTINUE
      N = N+1
      HT3 = HT2+(HT2-HT1)*(CPATH-CT2)/(CT2-CT1)
      CALL FINDSH(HT3,SH,GAMMA)
      CT3 = CRFRCT(HT3)
      DC = CPATH-CT3
      IF(ABS((CPATH-CT3)/CPATH).LT.ETA)  GO TO 130
```

```
      IF(N.GT.15) GO TO 210
      HT1 = HT2
      CT1 = CT2
      HT2 = HT3
      CT2 = CT3
      GO TO 120
  130 CONTINUE
      HT = HT3
      HMIN = HT
      GO TO 160
  150 CONTINUE
C*****TANGENT PATH INTERSECTS EARTH
      H2 = 0.0
      HMIN = 0.0
      LEN = 0
      CH2 = CMIN
      WRITE(IPR,22) H1,ANGLE
   22 FORMAT(///,' TANGENT PATH WITH H1 = ',F10.3,' AND ANGLE = ',
     1    F10.3,' INTERSECTS THE EARTH',//,10X,'H2 HAS BEEN RESET ',
     2    'TO 0.0 AND LEN TO 0')
  160 CONTINUE
C*****CALCULATE THE ZENITH ANGLE PHI AT H2
      PHI = ASIN(CPATH/CH2)*DEG
      IF(ANGLE.LE.90.0 .OR. LEN.EQ.1)  PHI = 180.0-PHI
      RETURN
C*****H2 LT TANGENT HEIGHT FOR THIS H1 AND ANGLE
  200 CONTINUE
      WRITE(IPR,20)
   20 FORMAT('0H2 IS LESS THAN THE TANGENT HEIGHT FOR THIS PATH ',
     1    'AND CANNOT BE REACHED')
      IERROR = 2
      RETURN
  210 CONTINUE
      DC = CPATH-CT3
      WRITE(IPR,24)  N,CPATH,CT3,DC,HT3
   24 FORMAT(///,'0FROM SUBROUTINE FNDHMN :',//,
     1    10X,'THE PROCEEDURE TO FIND THE TANGENT HEIGHT DID NOT ',
     2    'CONVERG AFTER ',I3,'  ITERATIONS',//,
     3    10X,'CPATH   = ',F12.5,' KM',//,10X,'CT3     = ',F12.5,' KM',
     4    //,10X,'DC      = ',E12.3,' KM',//,
     5    10X,'HT3     = ',F12.5,' KM')
      STOP 05
      END
```

```
      SUBROUTINE FINDSH(H,SH,GAMMA)
C**********************************************************************
C     GIVEN AN ALTITUDE H, THIS SUBROUTINE FINDS THE LAYER BOUNDARIES
C     Z(I1) AND Z(I2) WHICH CONTAIN H,  THEN CALCULATES THE SCALE
C     HEIGHT (SH) AND THE VALUE AT THE GROUND (GAMMA+1) FOR THE
C     REFRACTIVITY (INDEX OF REFRACTION -1)
C********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
C&    DOUBLE PRECISION HMOD
      COMMON  HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON  ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON  Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
      DO 100 IM=2,IMOD
      I2 = IM
      IF(ZM(IM).GE.H)  GO TO 110
  100 CONTINUE
      I2 = IMOD
  110 CONTINUE
      I1 = I2-1
      CALL SCALHT(ZM(I1),ZM(I2),RFNDXM(I1),RFNDXM(I2),SH,GAMMA)
      RETURN
      END
```

```
      SUBROUTINE SCALHT(Z1,Z2,RFNDX1,RFNDX2,SH,GAMMA)
C*********************************************************************
C     THIS SUBROUTINE CALCULATES THE SCALE HEIGHT SH OF THE (INDEX OF
C     REFRACTION-1.0) FROM THE VALUES OF THE INDEX AT THE ALTITUDES Z1
C     AND Z2 ( Z1 < Z2). IT ALSO CALCULATES THE EXTRAPOLATED VALUE
C     GAMMA OF THE (INDEX-1.0) AT Z = 0.0
C*********************************************************************
      RF1 = RFNDX1+1.0E-20
      RF2 = RFNDX2+1.0E-20
      RATIO = RF1/RF2
      IF(ABS(RATIO-1.0).LT.1.0E-05)  GO TO 100
      SH = (Z2-Z1)/ALOG(RATIO)
      GAMMA = RF1*(RF2/RF1)**(-Z1/(Z2-Z1))
      GO TO 110
  100 CONTINUE
C*****THE VARIATION IN THE INDEX OF REFRACTION WITH HEIGHT IS
C*****INSIGNIFICANT OR ZERO
      SH = 0.0
      GAMMA = RFNDX1
  110 CONTINUE
      RETURN
      END
```

```
      FUNCTION ANDEX(H,SH,GAMMA)
C*********************************************************************
C     COMPUTES THE INDEX OF REFRACTION AT HEIGHT H, SH IS THE
C     SCALE HEIGHT, GAMMA IS THE VALUE AT H=0 OF THE REFRACTIVITY =
C     INDEX-1
C*********************************************************************
      IF(SH.EQ.0.0) GO TO 10
      ANDEX = 1.0+GAMMA*EXP(-H/SH)
      RETURN
   10 ANDEX = 1.0+GAMMA
      RETURN
      END
```

```
      FUNCTION RADREF(H,SH,GAMMA)
C**********************************************************************
C     COMPUTES THE RADIUS OF CURVATURE OF THE REFRACTED RAY FOR
C     A HORIZONTAL PATH.  RADREF = ANDEX/ D(ANDEX)/D(RADIUS)
C**********************************************************************
      DATA BIGNUM/1.0E36/
      IF(SH.EQ.0.0) GO TO 20
      RADREF = SH*(1.0+EXP(H/SH)/GAMMA)
      RETURN
   20 RADREF = BIGNUM
      RETURN
      END
```

```
      SUBROUTINE RFPATH(H1,H2,ANGLE,PHI,LEN,HMIN,IAMT,RANGE,BETA,BENDNG)
C**********************************************************************
C     THIS SUBROUTINE TRACES THE REFRACTED RAY FROM H1 WITH A
C     INITIAL ZENITH ANGLE ANGLE TO H2 WHERE THE ZENITH ANGLE IS PHI,
C     AND CALCULATES THE ABSORBER AMOUNTS (IF IAMT.EQ.1) ALONG
C     THE PATH.  IT STARTS FROM THE LOWEST POINT ALONG THE PATH
C     (THE TANGENT HEIGHT HMIN IF LEN = 1 OR HA = MIN(H1,H2) IF LEN = 0)
C     AND PROCEEDS TO THE HIGHEST POINT.  BETA AND RANGE ARE THE
C     EARTH CENTERED ANGLE AND THE TOTAL DISTANCE RESPECTIVELY
C     FOR THE REFRACTED PATH FROM H1 TO H2, AND BENDNG IS THE TOTAL
C     BENDING ALONG THE PATH
C**********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
C&    DOUBLE PRECISION HMOD                                             C&
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
      DIMENSION HLOW(2)
      DATA HLOW/2HH1,2HH2/
      IF(H1.GT.H2) GO TO 90
      IORDER = 1
      HA = H1
      HB = H2
      ANGLEA = ANGLE
      GO TO 95
   90 CONTINUE
      IORDER = -1
      HA = H2
      HB = H1
      ANGLEA = PHI
   95 CONTINUE
      JNEXT = 1
      IF(IAMT.EQ.1 .AND. NOPRNT.NE.1)  WRITE(IPR,20)
   20 FORMAT('1CALCULATION OF THE REFRACTED PATH THROUGH THE ',
     1    'ATMOSPHERE',///,
     4    T5,'I',T14,'ALTITUDE',T30,'THETA',T38,'DRANGE',T47,'RANGE',
     5    T57,'DBETA',T65,'BETA',T76,'PHI',T84,'DBEND',T91,'BENDING',
     6    T102,'PBAR',T111,'TBAR',T119,'RHOBAR',/,
     7    T11,'FROM',T22,'TO',/,T11,'(KM)',T21,'(KM)',T30,'(DEG)',
     8    T39,'(KM)',T48,'(KM)',T57,'(DEG)',T65,'(DEG)',T75,'(DEG)',
     9    T84,'(DEG)',T92,'(DEG)',T102,'(MB)',T112,'(K)',
     1    T117,'(MOL CM-3)',/)
      IF(LEN.EQ.0) GO TO 100
C*****LONG PATH: FILL IN THE SYMETRIC PART FROM THE TANGENT HEIGHT
C*****TO HA
      CALL FILL(HMIN,HA,JNEXT)
      JHA = JNEXT
  100 CONTINUE
C*****FILL IN THE REMAINING PATH FROM HA TO HB
      IF(HA.EQ.HB) GO TO 110
      CALL FILL(HA,HB,JNEXT)
  110 CONTINUE
      JMAX = JNEXT
      IPATH = JMAX
C*****INTEGRATE EACH SEGMENT OF THE PATH
C*****CALCULATE CPATH SEPERATELY FOR LEN = 0,1
      IF(LEN.EQ.1) GO TO 115
```

```
      CALL FINDSH(HA,SH,GAMMA)
      CPATH = (RE+HA)*ANDEX(HA,SH,GAMMA)*SIN(ANGLEA/DEG)
      GO TO 116
  115 CONTINUE
      CALL FINDSH(HMIN,SH,GAMMA)
      CPATH = (RE+HMIN)*ANDEX(HMIN,SH,GAMMA)
  116 CONTINUE
      BETA = 0.0
      S = 0.0
      BENDNG = 0.0
      IF(LEN.EQ.0) GO TO 140
C*****DO SYMETRIC PART, FROM TANGENT HEIGHT(HMIN) TO HA
      IHLOW = 1
      IF(IORDER.EQ.-1)  IHLOW = 2
      IF(IAMT.EQ.1 .AND. NOPRNT.NE.1) WRITE(IPR,24) HLOW(IHLOW)
   24 FORMAT(' ',T10,'TANGENT',T20,A2,/,T10,'HEIGHT',/)
      SINAI = 1.0
      COSAI = 0.0
      THETA = 90.0
      J2 = JHA-1
      DO 120 J=1,J2
      CALL SCALHT(ZP(J),ZP(J+1),RFNDXP(J),RFNDXP(J+1),SH,GAMMA)
      CALL ALAYER(J,SINAI,COSAI,CPATH,SH,GAMMA,IAMT,DS,DBEND)
      DBEND = DBEND*DEG
      PHI = ASIN(SINAI)*DEG
      DBETA = THETA-PHI+DBEND
      PHI = 180.0-PHI
      S = S+DS
      BENDNG = BENDNG+DBEND
      BETA = BETA+DBETA
      IF(IAMT.NE.1) GO TO 118
      PBAR = PPSUM(J)/RHOPSM(J)
      TBAR = TPSUM(J)/RHOPSM(J)
      RHOBAR = RHOPSM(J)/DS
      IF(IAMT.EQ.1 .AND. NOPRNT.NE.1) WRITE(IPR,22) J,ZP(J),ZP(J+1),
     1    THETA,DS,S,DBETA,BETA,PHI,DBEND,BENDNG,PBAR,TBAR,RHOBAR
   22 FORMAT(' ',I4,2F10.3,10F9.3,1PE9.2)
  118 CONTINUE
      THETA = 180.0-PHI
  120 CONTINUE
C*****DOUBLE PATH QUANTITIES FOR THE OTHER PART OF THE SYMETRIC PATH
      BENDNG = 2.0*BENDNG
      BETA = 2.0*BETA
      S = 2.0*S
      IF(IAMT.EQ.1 .AND. NOPRNT.NE.1) WRITE(IPR,26) S,BETA,BENDNG
   26 FORMAT('0',T10,'DOUBLE RANGE, BETA, BENDING',/,
     1    T10,'FOR SYMMETRIC PART OF PATH',T44,F9.3,T62,F9.3,
     2    T89,F9.3,/)
      JNEXT = JHA
      GO TO 150
  140 CONTINUE
C*****SHORT PATH
      JNEXT = 1
C*****ANGLEA IS THE ZENITH ANGLE AT HA IN DEG
C*****SINAI IS SIN OF THE INCIDENCE ANGLE
C*****COSAI IS CARRIED SEPERATELY TO AVOID A PRECISION PROBLEM
C*****WHEN SINAI IS CLOSE TO 1.0
      THETA = ANGLEA
      IF(ANGLEA.GT.45.0) GO TO 145
      SINAI = SIN(ANGLEA/DEG)
```

```
      COSAI = -COS(ANGLEA/DEG)
      GO TO 150
  145 CONTINUE
      SINAI = COS((90.0-ANGLEA)/DEG)
      COSAI = -SIN((90.0-ANGLEA)/DEG)
  150 CONTINUE
C*****DO PATH FROM HA TO HB
      IF(HA.EQ.HB) GO TO 170
      J1 = JNEXT
      J2 = JMAX-1
      IHLOW = 1
      IF(IORDER.EQ.-1)  IHLOW = 2
      IHIGH = MOD(IHLOW,2)+1
      IF(IAMT.EQ.1 .AND. NOPRNT.NE.1) WRITE(IPR,28) HLOW(IHLOW),
     1    HLOW(IHIGH)
   28 FORMAT(' ',T14,A2,' TO ',A2,/)
      DO 160 J=J1,J2
      CALL SCALHT(ZP(J),ZP(J+1),RFNDXP(J),RFNDXP(J+1),SH,GAMMA)
      CALL ALAYER(J,SINAI,COSAI,CPATH,SH,GAMMA,IAMT,DS,DBEND)
      DBEND = DBEND*DEG
      PHI = ASIN(SINAI)*DEG
      DBETA = THETA-PHI+DBEND
      PHI = 180.0-PHI
      S = S+DS
      BENDNG = BENDNG+DBEND
      BETA = BETA+DBETA
      IF(IAMT.NE.1) GO TO 158
      PBAR = PPSUM(J)/RHOPSM(J)
      TBAR = TPSUM(J)/RHOPSM(J)
      RHOBAR = RHOPSM(J)/DS
      IF(IAMT.EQ.1 .AND. NOPRNT.NE.1) WRITE(IPR,22) J,ZP(J),ZP(J+1),
     1    THETA,DS,S,DBETA,BETA,PHI,DBEND,BENDNG,PBAR,TBAR,RHOBAR
  158 CONTINUE
      THETA = 180.0-PHI
  160 CONTINUE
  170 CONTINUE
      IF(IORDER.EQ.-1) PHI = ANGLEA
      RANGE = S
      RETURN
      END
```

```
      SUBROUTINE FILL(HA,HB,JNEXT)
C*********************************************************************
C     THIS SUBROUTINE DEFINES THE ATMOSPHERIC BOUNDARIES OF THE PATH
C     FROM HA TO HB AND INTERPOLATES (EXTRAPOLATES) THE DENSITIES TO
C     THESE BOUNDARIES ASSUMING THE DENSITIES VARY EXPONENTIALLY
C     WITH HEIGHT.
C*********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
C&    DOUBLE PRECISION HMOD
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
      IF(HA.LT.HB) GO TO 90
      WRITE(IPR,22) HA,HB,JNEXT
   22 FORMAT('0SUBROUTINE FILL- ERROR, HA .GE. HB',//,
     1    10X,'HA, HB, JNEXT = ',2E25.15,I6)
      STOP 06
   90 CONTINUE
C*****FIND Z(IA)- THE SMALLEST Z(I).GT.HA
      DO 100 I=1,IMAX
      IF(HA.GE.Z(I)) GO TO 100
      IA = I
      GO TO 110
  100 CONTINUE
      IA = IMAX+1
      IB = IA
      GO TO 130
C*****FIND Z(IB)- THE SMALLEST Z(I).GE.HB
  110 CONTINUE
      DO 120 I=IA,IMAX
      IF(HB.GT.Z(I)) GO TO 120
      IB = I
      GO TO 130
  120 CONTINUE
      IB = IMAX+1
  130 CONTINUE
C*****INTERPOLATE DENSITIES TO HA, HB
      ZP(JNEXT) = HA
      I2 = IA
      IF(I2.EQ.1) I2 = 2
      IF(I2.GT.IMAX) I2 = IMAX
      I1 = I2-1
      A = (HA-Z(I1))/(Z(I2)-Z(I1))
      CALL EXPINT(PP(JNEXT),P(I1),P(I2),A)
      TP(JNEXT) = T(I1)+(T(I2)-T(I1))*A
      CALL EXPINT(RFNDXP(JNEXT),RFNDX(I1),RFNDX(I2),A)
      DO 140 K=1,KMAX
      CALL EXPINT(DENP(K,JNEXT),DENSTY(K,I1),DENSTY(K,I2),A)
  140 CONTINUE
      IF(IA.EQ.IB) GO TO 160
C*****FILL IN DENSITIES BETWEEN HA AND HB
      I1 = IA
      I2 = IB-1
      DO 150 I=I1,I2
      JNEXT = JNEXT+1
      ZP(JNEXT) = Z(I)
      PP(JNEXT) = P(I)
```

```
      TP(JNEXT) = T(I)
      RFNDXP(JNEXT) = RFNDX(I)
      DO 150 K=1,KMAX
      DENP(K,JNEXT) = DENSTY(K,I)
  150 CONTINUE
  160 CONTINUE
C*****INTERPOLATE THE DENSITIES TO HB
      JNEXT = JNEXT+1
      ZP(JNEXT) = HB
      I2 = IB
      IF(I2.EQ.1) I2 = 2
      IF(I2.GT.IMAX) I2 = IMAX
      I1 = I2-1
      A = (HB-Z(I1))/(Z(I2)-Z(I1))
      CALL EXPINT(PP(JNEXT),P(I1),P(I2),A)
      TP(JNEXT) = T(I1)+(T(I2)-T(I1))*A
      CALL EXPINT(RFNDXP(JNEXT),RFNDX(I1),RFNDX(I2),A)
      DO 170 K=1,KMAX
      CALL EXPINT(DENP(K,JNEXT),DENSTY(K,I1),DENSTY(K,I2),A)
  170 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ALAYER(J,SINAI,COSAI,CPATH,SH,GAMMA,IAMT,S,BEND)
C**********************************************************************
C     THIS SUBROUTINE TRACES THE OPTICAL RAY THROUGH ONE LAYER FROM
C     Z1 TO Z2 AND IF IAMT.NE.2 CALCULATES THE INTEGRATED ABSORBER
C     AMOUNTS FOR THE LAYER. SINAI IS THE SIN OF THE INITIAL INCIDENCE
C     ANGLE (= 180 - ZENITH ANGLE). COSAI IS CARRIED SEPERATELY TO
C     AVOID A PRECISION PROBLEM NEAR SINAI = 1. CPATH IS THE CONSTANT
C     OF REFRACTION FOR THE PATH = INDEX*RADIUS*SINAI, SH AND GAMMA ARE
C     THE SCALE HEIGHT AND THE AMOUNT AT THE GROUND FOR THE REFRACTIVITY
C     (= 1-INDEX OF REFRACTION), S IS THE REFRACTED PATH LENGTH THROUGH
C     THE LAYER, BETA IS THE EARTH CENTERED ANGLE, AND BEND IS THE
C     BENDING THROUGH THE LAYER. IAMT CONTROLS WHETHER AMOUNTS ARE
C     CALCULATED OR NOT.
C**********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
C&    DOUBLE PRECISION HMOD
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
      DIMENSION HDEN(20),DENA(20),DENB(20)
      DATA EPSILN/1.0E-5/
      N = 0
      Z1 = ZP(J)
      Z2 = ZP(J+1)
      H1 = Z1
      R1 = RE+H1
      DHMIN = DELTAS**2/(2.0*R1)
      SINAI1 = SINAI
      COSAI1 = COSAI
      IF((1.0-SINAI).LT.EPSILN)  Y1 = COSAI1**2/2.0+COSAI1**4/8.0+
     1    COSAI1**6*3.0/48.0
      Y3 = 0.0
      X1 = -R1*COSAI1
      RATIO1 = R1/RADREF(H1,SH,GAMMA)
      DSDX1 = 1.0/(1.0-RATIO1*SINAI1**2)
      DBNDX1 = DSDX1*SINAI1*RATIO1/R1
      S = 0.0
      BEND = 0.0
      IF(IAMT.EQ.2) GO TO 110
C*****INITIALIZE THE VARIABLES FOR THE CALCULATION OF THE
C*****ABSORBER AMOUNTS
      PA = PP(J)
      PB = PP(J+1)
      TA = TP(J)
      TB = TP(J+1)
      RHOA = PA/(GCAIR*TA)
      RHOB = PB/(GCAIR*TB)
      DZ = ZP(J+1)-ZP(J)
      HP = -DZ/ALOG(PB/PA)
      IF(ABS(RHOB/RHOA-1.0).LT.EPSILN)  GO TO 90
      HRHO = -DZ/ALOG(RHOB/RHOA)
      GO TO 95
   90 HRHO = 1.0E30
   95 CONTINUE
      DO 105 K=1,KMAX
      DENA(K) = DENP(K,J)
      DENB(K) = DENP(K,J+1)
```

```
      IF(DENA(K).EQ.0.0 .OR. DENB(K).EQ.0.0)  GO TO 100
      IF(ABS(1.0-DENA(K)/DENB(K)).LE.EPSILN)  GO TO 100
C*****USE EXPONENTIAL INTERPOLATION
      HDEN(K) = -DZ/ALOG(DENB(K)/DENA(K))
      GO TO 105
C*****USE LINEAR INTERPOLATION
  100 HDEN(K) = 0.0
  105 CONTINUE
  110 CONTINUE
C*****
C*****LOOP THROUGH PATH
C*****INTEGRATE PATH QUANTITIES USING QUADRATIC INTEGRATION WITH
C*****UNEQUALLY SPACED POINTS
C*****
  115 CONTINUE
      N = N+1
      DH = -DELTAS*COSAI1
      IF(DH.LT.DHMIN) DH = DHMIN
      H3 = H1+DH
      IF(H3.GT.Z2) H3 = Z2
      DH = H3-H1
      R3 = RE+H3
      H2 = H1+DH/2.0
      R2 = RE+H2
      SINAI2 = CPATH/(ANDEX(H2,SH,GAMMA)*R2)
      SINAI3 = CPATH/(ANDEX(H3,SH,GAMMA)*R3)
      RATIO2 = R2/RADREF(H2,SH,GAMMA)
      RATIO3 = R3/RADREF(H3,SH,GAMMA)
      IF((1.0-SINAI2).GT.EPSILN)  GO TO 116
C*****NEAR A TANGENT HEIGHT, COSAI = -SQRT(1-SINAI**2) LOSES
C*****PRECISION. USE THE FOLLOWING ALGORITHM TO GET COSAI.
      Y3 = Y1+(SINAI1*(1.0-RATIO1)/R1+4.0*SINAI2*(1.0-RATIO2)/R2+
     1    SINAI3*(1.0-RATIO3)/R3)*DH/6.0
      COSAI3 = -SQRT(2.0*Y3-Y3**2)
      X3 = -R3*COSAI3
      DX = X3-X1
      W1 = 0.5*DX
      W2 = 0.0
      W  = 0.5*DX
      GO TO 118
C*****
  116 CONTINUE
      COSAI2 = -SQRT(1.0-SINAI2**2)
      COSAI3 = -SQRT(1.0-SINAI3**2)
      X2 = -R2*COSAI2
      X3 = -R3*COSAI3
C*****CALCULATE WEIGHTS
      D31 = X3-X1
      D32 = X3-X2
      D21 = X2-X1
      IF(D32.EQ.0.0 .OR. D21.EQ.0.0) GO TO 117
      W1 = (2.0-D32/D21)*D31/6.0
      W2 = D31**3/(D32*D21*6.0)
      W3 = (2.0-D21/D32)*D31/6.0
      GO TO 118
  117 CONTINUE
      W1 = 0.5*D31
      W2 = 0.0
      W3 = 0.5*D31
C*****
```

```
  118 CONTINUE
      DSDX2 = 1.0/(1.0-RATIO2*SINAI2**2)
      DSDX3 = 1.0/(1.0-RATIO3*SINAI3**2)
      DBNDX2 = DSDX2*SINAI2*RATIO2/R2
      DBNDX3 = DSDX3*SINAI3*RATIO3/R3
C*****INTEGRATE
      DS = W1*DSDX1+W2*DSDX2+W3*DSDX3
      S = S+DS
      DBEND = W1*DBNDX1+W2*DBNDX2+W3*DBNDX3
      BEND = BEND+DBEND
      IF(IAMT.EQ.2)  GO TO 150
C*****CALCULATE AMOUNTS
      DSDZ = DS/DH
      PB = PA*EXP(-DH/HP)
      RHOB = RHOA*EXP(-DH/HRHO)
      IF((DH/HRHO).LT.EPSILN)  GO TO 120
      PPSUM(J) = PPSUM(J)+DSDZ*(HP/(1.0+HP/HRHO))*(PA*RHOA-PB*RHOB)
      TPSUM(J) = TPSUM(J)+DSDZ*HP*(PA-PB)/GCAIR
      RHOPSM(J) = RHOPSM(J)+DSDZ*HRHO*(RHOA-RHOB)
      GO TO 125
  120 CONTINUE
      PPSUM(J) = PPSUM(J)+0.5*DS*(PA*RHOA+PB*RHOB)
      TPSUM(J) = TPSUM(J)+0.5*DS*(PA+PB)/GCAIR
      RHOPSM(J) = RHOPSM(J)+0.5*DS*(RHOA+RHOB)
  125 CONTINUE
      DO 140 K=1,KMAX
      IF(HDEN(K).EQ.0.0) GO TO 130
      IF(ABS(DH/HDEN(K)).LT.EPSILN) GO TO 130
C*****EXPONENTIAL INTERPOLATION
      DENB(K) = DENP(K,J)*EXP(-(H3-Z1)/HDEN(K))
C*****1.0E5 FACTOR CONVERTS FROM KM TO CM
      AMTP(K,J) = AMTP(K,J)+DSDZ*HDEN(K)*(DENA(K)-DENB(K))*1.0E5
      GO TO 140
  130 CONTINUE
C*****LINEAR INTERPOLATION
      DFN3(K) = DENP(K,J)+(DENP(K,J+1)-DENP(K,J))*(H3-Z1)/DZ
      AMTP(K,J) = AMTP(K,J)+0.5*(DENA(K)+DENB(K))*DS*1.0E5
  140 CONTINUE
      PA = PB
      RHOA = RHOB
      DO 145 K=1,KMAX
  145 DENA(K) = DENB(K)
  150 CONTINUE
      IF(H3.GE.Z2) GO TO 160
      H1 = H3
      R1 = R3
      SINAI1 = SINAI3
      RATIO1 = RATIO3
      Y1 = Y3
      COSAI1 = COSAI3
      X1 = X3
      DSDX1 = DSDX3
      DBNDX1 = DBNDX3
      CC TO 115
  160 CONTINUE
      SINAI = SINAI3
      COSAI = COSAI3
      SP(J) = S
      RETURN
      END
```

```
      SUBROUTINE AUTLAY(HMIN,HMAX,VBAR,AVTRAT,TDIFF1,TDIFF2,IBND,
     1     IERROR)
C**********************************************************************
C     THIS SUBROUTINE AUTOMATICALLY SELECTS A SET OF FASCODE BOUNDARY
C     LEVELS WHICH SATISFY THE FOLLOWING TWO TESTS:
C          1. THE RATIO OF THE VOIGT HALFWIDTHS BETWEEN BOUNDARIES
C             IS LESS THAN OR EQUAL TO AVTRAT, AND
C          2. THE TEMPERATURE DIFFERENCE BETWEEN BOUNDARIES IS
C             LESS THAN OR EQUAL TO TDIFF
C     TDIFF VARIES FROM TDIFF1 AT HMIN TO TDIFF2 AT HMAX,
C     WITH EXPONENTIAL INTERPOLATION BETWEEN
C     THESE BOUNDARIES ARE ROUNDED DOWN TO THE NEAREST TENTH KM
C     NOTE THAT THESE TESTS APPLY TO THE LAYER BOUNDARIES
C     NOT TO THE AVERAGE VALUES FROM ONE LAYER TO THE NEXT.
C**********************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1     IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
      COMMON /CONSTN/ PZERO,TZERO,AVOGAD,ALOSMT,GASCON,PLANK,BOLTZ,
     1     CLIGHT,ADCON,ALZERO,AVMWT,AIRMWT,AMWT(20),VMIXST(20),VMIXN2
C&    DOUBLE PRECISION HMOD
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1     PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON Z(71),P(71),T(71),RFNDX(71),DENSTY(20,71)
      COMMON /BNDRY/ ZBND(34),PBND(34),TBND(34),ALORNZ(34),ADOPP(34),
     1     AVOIGT(34)
      DIMENSION AVTM(50)
C*****FUNCTION ZROUND ROUNDS THE ALTITUDE Z DOWN TO THE
C*****NEAREST TENTH KM
      ZROUND(ZX) = 0.1*FLOAT(IFIX(10.0*ZX))
C*****
      DO 100 IM=2,IMOD
      IHMIN = IM
      IF(ZM(IM).GT.HMIN) GO TO 120
  100 CONTINUE
  120 CONTINUE
      HTOP = HMAX
      IF(HTOP.GT.ZMAX) HTOP = ZMAX
      IM = IHMIN-1
      ZZ = ZM(IM)
      CALL HALFWD(ZZ,VBAR,P,T,AL,AD,AVTM(IM))
      IB = 1
      ZBND(IB) = HMIN
      IM = IHMIN
      CALL HALFWD(ZBND(IB),VBAR,PBND(IB),TBND(IB),ALORNZ(IB),
     1     ADOPP(IB),AVOIGT(IB))
      IB = 2
C*****BEGIN LOOP
  200 CONTINUE
      IPASS = 0
      ZBND(IB) = ZM(IM)
      IF(ZBND(IB).GE.HTOP)  ZBND(IB) = HTOP
      CALL HALFWD(ZBND(IB),VBAR,PBND(IB),TBND(IB),ALORNZ(IB),
     1     ADOPP(IB),AVOIGT(IB))
      AVTM(IM) = AVOIGT(IB)
C*****TEST THE RATIO OF THE VOIGT WIDTHS AGAINST AVTRAT
      IF((AVOIGT(IB-1)/AVOIGT(IB)).LT.AVTRAT)  GO TO 220
C*****ZM(IM) FAILS THE HALFWIDTH RATIO TEST
      IPASS = 1
```

```
      AVOIGT(IB) = AVOIGT(IB-1)/AVTRAT
      ZBND(IB) = ZM(IM-1)+(ZM(IM)-ZM(IM-1))*ALOG(AVOIGT(IB)/AVTM(IM-1))/
     1     ALOG(AVTM(IM)/AVTM(IM-1))
      IF(ZBND(IB).NE.HTOP) ZBND(IB) = ZROUND(ZBND(IB))
      CALL HALFWD(ZBND(IB),VBAR,PBND(IB),TBND(IB),ALORNZ(IB),
     1     ADOPP(IB),AVOIGT(IB))
  220 CONTINUE
C*****TEST THE TEMPERATURE DIFFERENCE AGAINST TDIFF
      FAC = (ZBND(IB-1)-HMIN)/(HMAX-HMIN)
      CALL EXPINT(TDIFF,TDIFF1,TDIFF2,FAC)
      IF(ABS(TBND(IB)-TBND(IB-1)).LE.TDIFF)  GO TO 230
C*****ZBND(IB) FAILS THE TERPERATURE DIFFERENCE TEST
      IPASS = 2
      TBND(IB) = TBND(IB-1)+SIGN(TDIFF,TM(IM)-TM(IM-1))
      ZBND(IB) = ZM(IM-1)+(ZM(IM)-ZM(IM-1))*
     1     (TBND(IB)-TM(IM-1))/(TM(IM)-TM(IM-1))
      IF(ZBND(IB).NE.HTOP)  ZBND(IB) = ZROUND(ZBND(IB))
      CALL HALFWD(ZBND(IB),VBAR,PBND(IB),TBND(IB),ALORNZ(IB),
     1     ADOPP(IB),AVOIGT(IB))
  230 CONTINUE
      IF(ZBND(IB).GE.HTOP)  GO TO 300
      IF(IPASS.NE.0)  GO TO 240
C*****BOTH HALFWIDTH AND TEMPERATURE TEST PASS FOR ZBND(IB) = ZM(IM),
C*****NOW TRY ZBND(IB) = ZM(IM+1)
      IM = IM+1
      GO TO 200
  240 CONTINUE
C*****ONE OF THE TESTS FAILED AND A NEW BOUNDRY ZBND WAS PRODUCED
C*****TEST FOR THE NEXT BOUNDARY AT THE PREVIOUS ZM(IM)
      IB = IB+1
      IF(IB.GT.IBMAX)  GO TO 900
      GO TO 200
  300 CONTINUE
      IBND = IB
      WRITE(IPR,10)  AVTRAT,TDIFF1,TDIFF2
   10 FORMAT(///,' FASCODE LAYER BOUNDARIES PRODUCED BY THE AUTOMATIC ',
     1     'LAYERING ROUTINE AUTLAY',/,' THE USER SHOULD EXAMINE ',
     2     'THESE BOUNDARIES AND MODIFY THEM IF APPROPRIATE',/,
     3     ' THE FOLLOWING PARAMETERS ARE USED:',//,
     4 10X,'AVTRAT    = ',F8.2,'      = MAX RATIO OF VOIGT WIDTHS',/,
     5 10X,'TDIFF1    = ',F8.2,'      = MAX TEMP DIFF AT HMIN',/,
     6 10X,'TDIFF2    = ',F8.2,'      = MAX TEMP DIFF AT HMAX')
      RETURN
  900 CONTINUE
      WRITE(IPR,901) IBMAX
  901 FORMAT(///,' ERROR IN AUTLAY:',/,5X,'THE NUMBER OF ',
     1     'GENERATED LAYER BOUNDARIES EXCEEDS THE DIMENSION IBMAX ',
     2     'OF THE ARRAY ZBND.  IBMAX = ',I5,/,
     3 5X,'PROBABLE CAUSE: EITHER AVTRAT AND/OF TDIFF ARE TOO SMALL',
     4     /,5X,'THE GENERATED LAYERS FOLLOW')
      IBND = IBMAX
      IERROR = 5
      RETURN
      END
```

```
      SUBROUTINE HALFWD(Z,VBAR,P,T,ALORNZ,ADOPP,AVOIGT)
C*******************************************************************
C     GIVEN AN ALTITUDE Z AND AN AVERAGE WAVENUMBER VBAR, THIS
C     SUBROUTINE INTERPOLATES P AND T FROM THE PROFILE IN ZM  AND
C     CALCULATES THE LORENTZ, THE DOPPLER, AND THE VOIGT HALFWIDTHS
C     (AT HALFHEIGHT) ALORNZ, ADOPP, AND AVOIGT RESPECTIVELY FOR
C     THE ALTITUDE Z
C     AN AVERAGE LORENTZ WIDTH ALZERO AND AN AVERAGE MOLECULAR
C     WEIGHT AVMWT ARE ASSUMED
C*******************************************************************
      COMMON /IFIL/ IRD,IPR,IPU
      COMMON /PARMTR/ PI,DEG,GCAIR,RE,DELTAS,ZMIN,ZMAX,IMAX,IMOD,IBMAX,
     1    IOUTMX,IPATH,IMODMX,IDIM,KDIM,KMXNOM,KMAX,NOPRNT
      COMMON /CONSTN/ PZERO,TZERO,AVOGAD,ALOSMT,GASCON,PLANK,BOLTZ,
     1    CLIGHT,ADCON,ALZERO,AVMWT,AIRMWT,AMWT(20),VMIXST(20),VMIXN2
C&    DOUBLE PRECISION HMOD
      COMMON HMOD(3),ZM(50),PM(50),TM(50),RFNDXM(50),DENM(20,50)
      COMMON ZP(71),PP(71),TP(71),RFNDXP(71),SP(71),
     1    PPSUM(71),TPSUM(71),RHOPSM(71),DENP(20,71),AMTP(20,71)
      COMMON ZX(71),PX(71),TX(71),RFNDX(71),DENSTY(20,71)
C*****FUNCTIONS
C*****ALZERO IS AT 1013.25 MB AND 296.0 K
      ALPHAL(P,T) = ALZERO*(P/PZERO)*SQRT(296.0/T)
      ALPHAD(T,V) = ADCON*V*SQRT(T/AVMWT)
      ALPHAV(AL,AD) = 0.5*(AL+SQRT(AL**2+4.0*AD**2))
C*****
      DO 100 I2=2,IMOD
      IM = I2
      IF(ZM(IM).GE.Z)  GO TO 110
  100 CONTINUE
      IM = IMOD
  110 CONTINUE
      FAC = (Z-ZM(IM-1))/(ZM(IM)-ZM(IM-1))
      CALL EXPINT(P,PM(IM-1),PM(IM),FAC)
      T = TM(IM-1)+(TM(IM)-TM(IM-1))*FAC
      ALORNZ = ALPHAL(P,T)
      ADOPP = ALPHAD(T,VBAR)
      AVOIGT = ALPHAV(ALORNZ,ADOPP)
      RETURN
      END
```

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12. Smith, M.A.H. (1982) Compilation of Atmospheric Gas Concentration Profiles From 0 to 50 km, NASA TM-83289.

Appendix A

Atmospheric Profiles

Six atmospheric profiles are included in FSCATM as a convenience to the user. These profiles consist of the pressure and temperature, and the number densities of H_2O, CO_2, O_3, N_2O, CO, CH_4, and O_2, vs altitude at 1-km steps from 0 to 25 km, 5-km steps from 25 to 50 km, and at 70 and 100 km. These profiles, taken from McClatchey et al[A1] correspond to the 1962 U.S. Standard Atmosphere[A2] and five supplementary models:[A3] Tropical (15°N), Midlatitude Summer (45°N, July), Midlatitude Winter (45°, Jan), Subarctic Summer (60°N, July), and Subarctic Winter (60°N, Jan). These profiles are identical to the ones contained in LOWTRAN.[A4] The water vapor and ozone altitude profiles added to the 1962 U.S. Standard Atmosphere by McClatchey et al[A1] were obtained from Sissenwine et al[A5] and Hering et al[A6] respectively, and correspond to mean annual values. The water vapor densities for the 1962 U.S. Standard Atmosphere correspond to relative humidities of approximately 50 percent for altitudes up to 10 km, whereas the relative humidity values for the other supplementary models tend to decrease with altitude from approximately 80 percent at sea level to approximately 30 percent at 10-km altitude. Above 12 km, the water-vapor number densities of models 1 to 5 are identical and represent volume mixing ratios that reach a minimum of about 6.5 ppmv at 17 km, increase to 30 ppmv at 30 km, and then decrease to 10 ppmv at 50 km. For all models, the gases CO_2, N_2O, CO, CH_4, and O_2

Because of the large number of references cited above, they will not be listed here. See References, page 139.

are considered uniformly mixed with volume mixing ratios of 330, 0.28, 0.075, 1.6, and 2.095×10^5 ppm respectively.

The temperature profiles as a function of altitude for the six atmospheric models are shown in Figure A1. Figure A2 shows the water-vapor density vs altitude for 0 to 100 km and an expanded profile from 0 to 30 km. Figure A3 shows similar profiles for ozone.

In the almost 20 years since these profiles were constructed, our knowledge of the state of the atmosphere has increased enormously. This is particularly true regarding the stratosphere and above, and the concentration of minor constituents. For example, the stratospheric water-vapor concentrations for the six profiles given here are now known to be too large by a factor of 5 at 30 km. Models 1 through 6 may still be considered representative of their respective conditions up to about 50 km for temperature, up to 30 km for ozone densities, and up to the tropopause (~ 15 km in the Tropics to 8 km in the Arctic) for water vapor. Users may still use these models for cases dominated by the conditions in the troposphere. For cases dominated by stratospheric conditions or where the distribution of minor constituents is significant, the user should supply his own profile read in under the MODEL = 7 option.

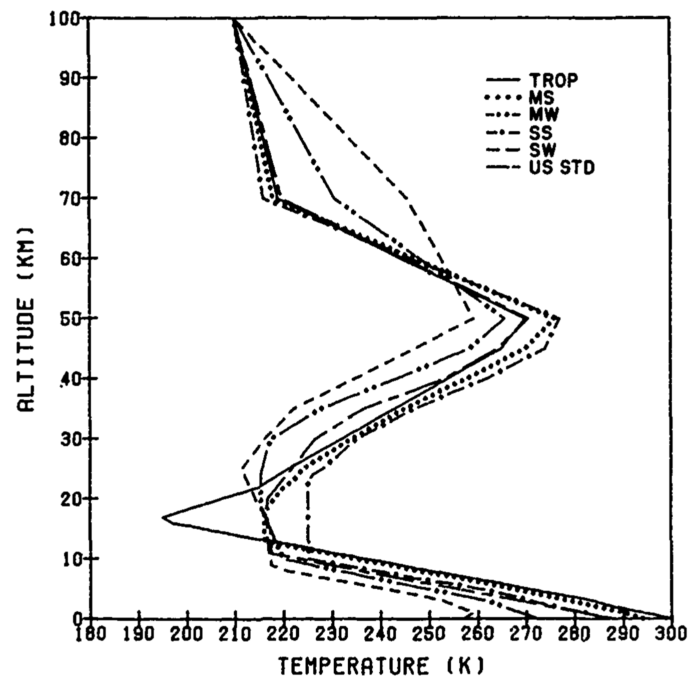

Figure A1. Temperature vs Altitude for the Six Model Atmospheres

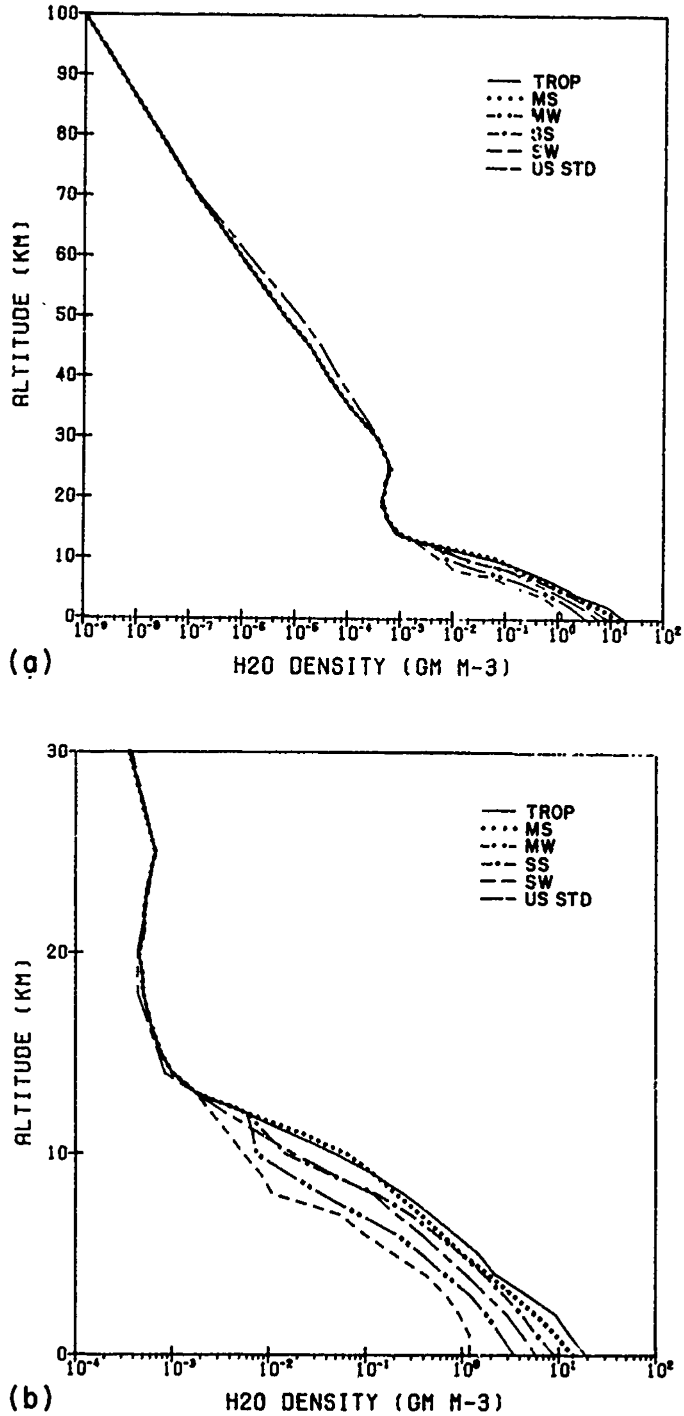

Figure A2. Water Vapor Density Profiles vs Altitude for the Six Model Atmospheres: (a) From 0 to 100 km and (b) From 0 to 30 km

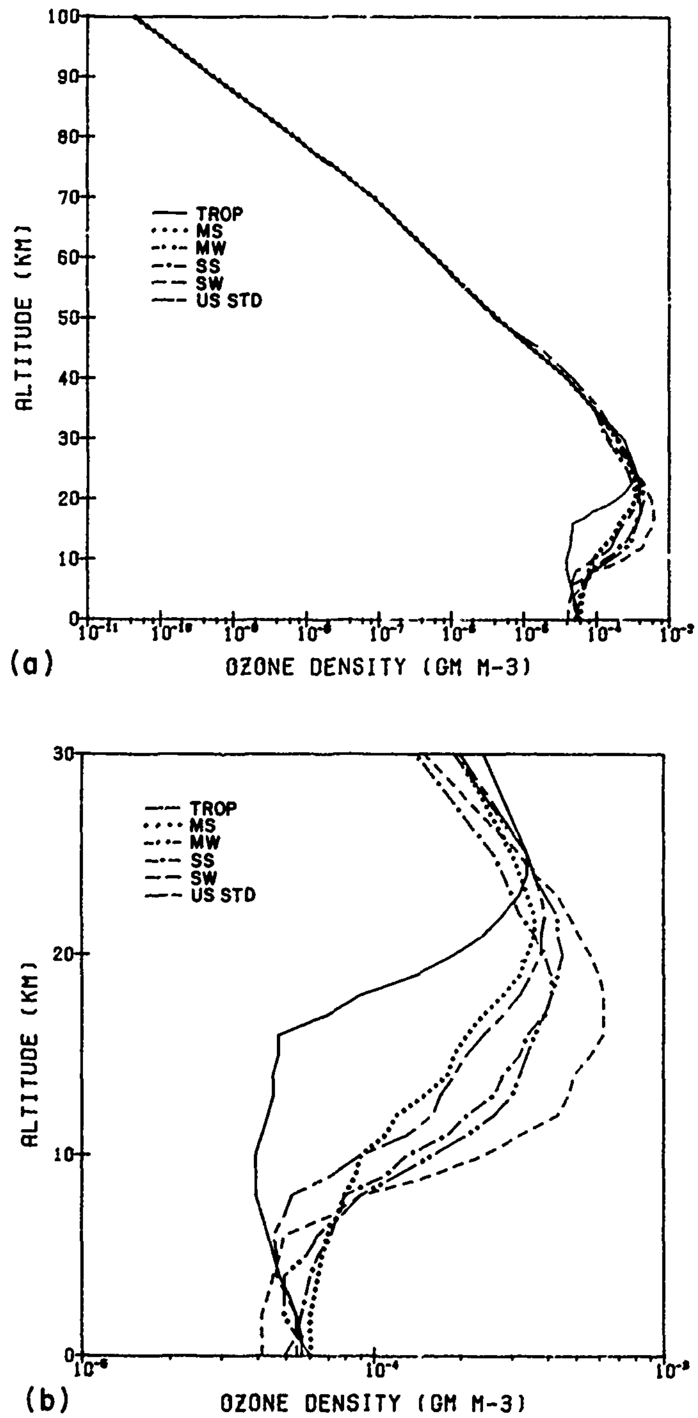

Figure A3. Ozone Profile vs Altitude for the Six Model Atmospheres: (a) From 0 to 100 km and (b) From 0 to 30 km

There are several recent sources for profiles of temperature and minor constituent density. The U.S. Standard Atmosphere 1976[A7] updates the 1962 U.S. Standard Atmosphere for temperature above 50 km and provides revised estimates for the surface concentrations of what was termed previously "uniformly mixed gases". The new values for the volume mixing ratios of CO_2, N_2O, CO, and CH_4 are 322, 0.27, 0.19, and 1.50 ppmv respectively. These values are used as the default mixing ratios for MODEL = 7 if the user-supplied values are zero. Actually the concentration of these gases do show significant variations from these values, particularly with altitude in the stratosphere.

Cole and Kantor[A8] provide sets of monthly mean temperature profiles up to 90 km at 15° intervals between the Equator and the pole. Along with statistics on the variability of these profiles, they also provide models that portray the longitudinal variations in monthly mean values of temperature during winter months and the vertical variation which occurs during stratospheric warming and cooling events in the winter arctic and subarctic. Houghton[A9] provides seasonal profile temperature at 10°N, 40°N and 70°N up to 105 km plus the original references for the data (this by the way is a marvelous little book that I strongly recommend as both an introduction and a refresher in atmospheric physics).

For profiles of the minor constituants including ozone and stratosphere water vapor, Hudson et al[A10] provides an up-to-date (June 1981) and exhaustive source. This volume is available from

Stratospheric Chemistry and Physics Branch
Code 963
NASA Goddard Space Flight Center
Greenbelt, MD 20771

or

Word Meteorological Center
Case Postule No. 5
Geneva 20, Switzerland

Much of the profile data from this source plus some more recent measurements have been compiled as annual averages in 2 km steps in Smith.[A11]

Finally a new edition of the Handbook of Geophysics[A12] is in preparation, which will include seasonal profiles of temperature, water vapor, and ozone plus a wealth of other data. This volume should be available in 1984.

Because of the large number of references cited above, they will not be listed here. See References, page 139.

References

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A9. Houghton, J.T. (1977) The Physics of Atmospheres, Cambridge University Press, Cambridge.

A10. (1982) The Stratosphere 1981 Theory and Measurements, WMO Global Ozone Research and Monitoring Project Report 11.

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A12. Handbook of Geophysics, AFGL (in preparation).

Appendix B

Index of Refraction

The expression for the index of refraction of air is:

$$n - 1 = 10^{-6} \times (77.46 + 0.479 \times 10^{-8} * \tilde{\nu}^2) \times \frac{P}{T}$$

$$- \frac{P_{H_2O}}{P_o} * (43.49 - 0.347 \times 10^{-8} \tilde{\nu}^2)$$

where $\tilde{\nu}$ is the wavenumber, c is the speed of light, P and T the pressure and temperature, P_{H_2O} is the water-vapor partial pressure, and P_o is 1013.25 mb. This expression is the same as is in the program LOWTRAN[B1] and is a simplified version of the expression by Edlen.[B2] For further references on the index of refraction of air, the reader is referred to References B3 and B4.

B1. Kneizys, F.X., Shettle, E.P., Gallery, W.O., Chetwynd, J.H., Jr., Abreu, L.W., Selby, J.E.A., Fenn, R.W., and McClatchey, R.A. (1980) Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 5, AFGL-TR-80-0067, AD A088215.

B2. Edlen, B. (1966) The refractive index of air, Metrologia 2:12.

B3. Peck, E.R., and Reeder, K. (1972) Dispersion of air, J. Opt. Soc. Am. 62:958.

B4. Owens, J.C. (1972) Optical refractive index of air dependence on pressure, temperature and composition, Appl. Opt. 6:51.

Appendix C

A Brief Survey of the Literature

The subject of air mass calculation and the associated subject of astronomical refraction go back to Laplace and have generated a large body of literature. This brief survey is meant only to point out a few references to which the interested reader can turn to for further references.

The theory of atmospheric refraction and of air mass calculation is discussed in some detail in Kondratyev, K. (1969) Radiation in the Atmosphere, Academic Press, New York, Chapter 4 and in Zuev, V. E. (1982) Laser Beams in the Atmosphere, Consultants Bureau, New York, Chapter 1.

The following paper has a fairly extensive list of references on the calculation of air mass along with graphs showing the effect of neglecting refraction for occultation geometries: Sneider, D. (1975) Refractive effects in remote sounding of the atmosphere with infrared transmission spectroscopy, J. Atmos. Sci. **32**: 2178-2184.

Essentially the same paper but with tables of air mass for observer altitudes ranging from 10 to 50 km in steps of 1 km, with zenith angles ranging from 80° to 97° is Sneider, D. E., and Goldman, A. (1974) Refractive Effects in Remote Sensing of the Atmosphere With Infrared Transmission Spectroscopy, Ballistic Res. Labs, Report 1790, Aberdeen Md, DTIC No. AD-A011253.

A more recent paper with references is Wang, P.-H., Deepak, A., and Hong, S.-S. (1981) General formulation of optical paths or large zenith angles in the earth's curved atmosphere, J. Atmos. Sci. **38**:650-658.

One of the earliest tabulations of air mass was by Bemporad and is reprinted in List, R.J. (1968) Smithsonian Meteorological Tables (6th Revised Edition), Smithsonian Institute Press, Washington.

In the case where refraction can be neglected and where the density profile is exponential, the air mass can be calculated analytically using the "Chapman function". The original reference is Chapman, S. (1931) The absorption and dissociative or ionizing effect of monochromatic radiation in an atmosphere on a rotating earth II. Grazing incidence, Proc. Phys. Soc. (London) **43**:483-501.

Since then numerous simplifications and approximations to the Chapman functions have appeared. Among them are: (1) Fitzmaurice, J.A. (1964) Simplification of the Chapman function for atmospheric attenuation, Appl. Opt. **3**:640; (2) Swider, W., Jr., and Gardner, M.E. (1967) On the Accuracy of Certain Approximations to the Chapman Functions, AFCRL-67-0468, AD 658826; (3) Swider, W., Jr., and Gardner, M.E. (1969) On the accuracy of Chapman function approximations, Appl. Opt. **3**:1725; and (4) Smith, F.L. III, and Smith, C. (1972) Numerical evaluation of Chapman's grazing incidence integral, Ch (x, ψ), J. Geophys. Res. **77**:3592-3597.

An analytic approximation to the calculation of air mass that includes the effect of earth's curvature and refraction is in Uplinger, W.G. (1981) A Simple Model for Relative Air Mass, in preprint volume for the Fourth Conference on Atmospheric Radiation, June 1981, Toronto, Canada (American Meteorological Society).

The case in which the density scale height varies with altitude (that is, temperature) is discussed in Swider, W., Jr. (1964) The determination of the optical depth at large solar zenith distances, Planet Space Sci. **12**:761-782.

Another method for dealing with non-exponential density distributions is found in Green, A.E.S., and Martin, J.D. (1966) A generalized Chapman Function, The Middle Ultraviolet: Its Science and Technology, A.E.S. Green, Ed., Wiley, New York, pp 140-157.

The following paper applies the Chapman function to a solar occultation measurement of the absorption by trace gases in the stratosphere: Menzies, R.J., Rutledge, C.W., Zanteson, R.A., and Spears, D.L. (1981) Balloonborne laser heterodyne radiometer for measurements of stratospheric trace species, Appl. Opt. **20**:536-544.

Astronomical refraction refers to the bending of a ray along a path from an observer to a very distant source outside the atmosphere, for instance a star. The effect was recognized in ancient times and is still the subject of active investigation among astronomers. The following paper gives a review of the subject plus an extensive list of references: Mahan, A.I. (1962) Astronomical refraction - some history and theories, Appl. Opt. **4**:497-511.

The following report gives an even more complete derivation of the mathematics of refraction plus extensive references covering refraction of visible, IR, and radio waves: Meyer-Arendt, J.R., and Emmanuel, C.B. (1965) Optical Scintillation, a Survey of the Literature, National Bureau of Standards Tech Note 225.

Analyt.. solutions for astronomical refraction for several vertical distributions of the refractive index are given in White, R. (1975) New solutions to the refraction integral, J. Opt. Soc. Am. 65:676-678.

Terrestrial refraction applies to cases in which the whole path lies near the surface of the earth and is of importance in geodesy and surveying. A recent volume devoted to both astronomical and terrestrial refraction is Tengstrom, E., and Teliki, R., Ed. (1979) Refractional Influences in Astronomy and Geodesy, IAU Symposium No. 89, D. Reidel Publishing Co., Holland.

The following report describes an atmospheric ray tracing computer program capable of handling complex problems such as mirages and ducting, for frequencies from the microwave to the visible: Able, M., Mill, J.D., and Lenn, L. (1982) The Theory and Use of a Raytracing Model Developed at USAFETAC., USAFETAC-TN-82-002.

Since this report went to press, the following two papers have come to my attention: Thompson, D.A., Pepin, T.J., and Simon, F.W. (1982) Ray tracing in a spherically symmetric atmosphere, J. Opt. Soc. 72:1498-1501 and Chu, W.P. (1983) Calculation of atmospheric refraction for spacecraft remote-sensing applications, Appl. Opt. 22:721-725.