ATMOSPHERIC TRANSMITTANCE FROM 0.25 TO 28.5 MICRONS: COMPUTER CODE LOWTRAN 3

J. E. A. Selby, et al

Air Force Cambridge Research Laboratories
Hanscom Air Force Base, Massachusetts

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J. E. A. SELBY
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Errata

1. Pages 38 through 44—The transmittance curves presented in Figures 5 through 11 should be terminated at 0.25 μm. The figures show an increase in transmittance due to ozone absorption as the wavelength approaches 0.2 μm. However, absorption due to oxygen becomes important below 0.25 μm and has not been taken into account in LOWTRAN 3.

2. Page 69—Line number A 126B and A 134 should read as follows:

```
IF (VIS.GT.0.0) PRINT 417, VIS                                  A 126B
IF (VIS.LE.0.0.AND.IHAZE.GT.0) PRINT 416, IHAZE,HZ(IHAZE)       A 134
```

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A Fortran computer program, LOWTRAN 3, is described for calculating the transmittance of the atmosphere in the spectral region from 0.25 to 28.5 μm at a spectral resolution of 20 cm^{-1}. The program provides a choice of six atmospheric models covering seasonal and latitudinal variations from sea level to 100 km, two haze models, and accounts for molecular absorption, molecular scattering, and aerosol extinction. Refraction and earth curvature effects are also included. This program provides some modifications to the molecular absorption and aerosol extinction data provided in an earlier LOWTRAN 2

20. (Cont)

report. In addition, input modifications have been made, making the LOWTRAN 3 program considerably more flexible in terms of the input of meteorological data.

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Atmospheric Transmittance From 0.25 to 28.5 μm: Computer Code LOWTRAN 3

1. INTRODUCTION

The need for predicting the transmittance of the atmosphere over a broad spectral interval at low resolution is not a new one, and many methods have been proposed to do this. A major problem with most of the techniques is that they are difficult to apply. In order to alleviate this situation and to provide a fairly accurate, simple, and rapid way of estimating atmospheric transmittance in the 0.25 to 28.5 μm region, an empirical graphical prediction scheme was devised using some techniques originally suggested by Altshuler.[1] The prediction scheme is based mainly on recent laboratory transmittance measurements complemented by using available the theoretical molecular line constants in line-by-line transmittance calculations, and is presented by McClatchey et al.[2]

Because of the large amount of interest shown in this work, it was decided to computerize the prediction scheme and to digitize the spectral curves, transmittance functions, and model atmospheres contained in McClatchey et al,[2] which forms the basis of LOWTRAN 3.

(Received for publication 6 May 1975)

1. Altshuler, T.L. (1961) Infrared Transmission and Background Radiation by Clear Atmospheres, GE Report 61SD199, AD-401923.
2. 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-72-0497.

The Fortran computer code LOWTRAN 3 is designed to calculate the transmittance (averaged over a 20 cm^{-1} interval) for a given atmospheric path at steps of 5 cm^{-1} from 350 to 40,000 cm^{-1} (0.25 to 28.5 μm). A choice of six model atmospheres is given with an option for a seventh model which can be inserted as a set of radiosonde data. Aerosol attenuation is calculated for a given visual range based on an interpolation/extrapolation scheme using two aerosol models (see Section 3.4).

The computer code LOWTRAN 3 supersedes two earlier versions of the program, namely LOWTRAN 1[3] and LOWTRAN 2.[4] LOWTRAN 3 is a modification of the LOWTRAN 2 computer code, and provides an updating of the original data as well as giving more flexibility to the user. The differences between the two programs will be described in detail in the following sections.

For horizontal path transmittance calculations under nonstandard conditions, the user can specify his own meteorological conditions. The amount of water vapor in the path is calculated in LOWTRAN 3 using either dew point temperature or ambient temperature and relative humidity, whichever the user specifies (see Section 3.1).

The card sequence numbering system used in LOWTRAN 2 has been preserved so that workers who are already using LOWTRAN 2 can update their card decks with a minimum of effort. All changes and additions to the latter program have been indicated by a symbol, (for example, , A, B, C, etcetera) against an original sequence number (see Appendix A).

We will first briefly describe the theory and input data used in the program. General instructions for using LOWTRAN 3 are given in Section 5. A series of examples illustrating the input data necessary for making a variety of typical atmospheric transmittance calculations is given in Section 6. A listing of the computer code and data is given in Appendix A, supplemented by a flow chart (Appendix B) and a definition of symbols (Appendix D). An iterative refraction scheme used for one particular application of the program (see Section 6.6) is described in Appendix C. Examples of atmospheric transmittance spectra obtained from LOWTRAN 3 together with comparisons with laboratory and field measurements are given in Section 7.

If any discrepancies are encountered in the program, we would appreciate notification in writing.

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3. Manley, O.P., Smith, H.J.P., Treve, Y.M., Carpenter, J.W., Degges, T.C., Doan, L.R. (1971) OPTIR II, AFCRL-71-0528 (Vol. 2 & 3)
(1973) OPTIR III, AFCRL-TR-73-0217 and 0491
(1974) OPTIR IIIB, AFCRL-TR-74-0319.

4. Selby, J.E.A., and McClatchey, R.A. (1972) Atmospheric Transmittance from 0.25 to 28.5 μm: Computer Code LOWTRAN 2, AFCRL-72-0745.

2. MODEL ATMOSPHERES

The altitude, pressure, temperature, water vapor density, and ozone density for the U.S. Standard Atmosphere and five seasonal model atmospheres, as well as the number of particles per cm^3 for two haze models – corresponding to sea level visual ranges of 5 and 23 km – are provided as basic input data for LOWTRAN 3. The model atmospheres correspond to the 1962 U.S. Standard Atmosphere[5] and the five supplementary models: that is, Tropical (15°N), Midlatitude Summer (45°N, July), Midlatitude Winter (45°, January), Subarctic Summer (60°N, July), and Subarctic Winter (60°N, January). The different models are digitized in 1 km steps from 0 to 25 km, 5 km steps from 25 to 50 km, then at 70 km and 100 km directly as given by McClatchey et al.[2]

The water vapor and ozone altitude profiles added to the 1962 U.S. Standard Atmosphere by McClatchey et al were obtained from Sissenwine et al[6] and Herring et al[7] 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.

In addition to the model atmospheres provided in this report, the user has the option of inserting his own model atmosphere [specifically designed for direct insertion of radiosonde data (see Section 6.9)], or of building another model by combining various parts of the six standard models (see Section 6.10).

One major difference between LOWTRAN 3 and LOWTRAN 2 is that the reader no longer has to look up the saturation vapor density of water (from Table 1 in Selby and McClatchey[4]) when using meteorological data as input to the program. In LOWTRAN 3 the actual water vapor density is calculated for a given ambient temperature and relative humidity or dew point temperature using the following empirical expression for the saturation vapor density:

$$F(t) = A \exp\left(18.9766 - 14.9595A - 2.4388A^2\right) \text{ gm m}^{-3}$$

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[5] Valley, S. L., Ed. (1965) Handbook of Geophysics and Space Environments, AFCRL.

[6] Sissenwine, N., Grantham, D. D., Salmela, H. A. (1968) Humidity Up to the Mesopause, AFCRL-68-0550.

[7] Herring, W. S., and Borden, T. R. (1964) Ozone Observations Over North America, AFCRL-64-30, Vol. 2.

where

$A = 273.15/(273.15 + t)$

and

t is given in °C.

The above expression was found to give a good fit to published values of saturation water vapor density measured over water[8] to better than 1 percent for temperatures between -50°C and 50°C.

If t is the dew point temperature then F(t) gives the actual water vapor density directly at the corresponding ambient temperature. If t is the ambient temperature then the water vapor density is given by F(t) × RH/100 where RH is the percent relative humidity.

Thus the user has a choice of meteorological parameters necessary to specify the amount of water vapor, that is, ambient temperature and relative humidity, or dew point temperature, or water vapor density. The procedure for inserting radiosonde data into the program and the necessary formats are described in Sections 5.3 and 6.8.

3. ATMOSPHERIC CONSTITUENTS

3.1 Atmospheric Gases

It is assumed in this report that mixing ratios of the gases, CO_2, N_2O, CH_4, CO, N_2, and O_2 remain constant at all altitudes at the following values: 330, 0.28, 1.6, 0.075, 7.905×10^5, and 2.095×10^5 parts per million respectively. These gases as a whole, with the exception of nitrogen, will be referred to as the uniformly mixed gases.

Absorption coefficients for water vapor, ozone, and the combined effects of the uniformly mixed gases were digitized from the spectral curves (Figures 16-25)[2] by McClatchey et al and are included as data for LOWTRAN 3. The transmittance spectra from which the coefficients were derived were first degraded in resolution to 20 cm^{-1} and the data points were digitized at steps of 5 cm^{-1}. For the ultraviolet and visible ozone bands (see McClatchey et al, Figure 26),[2] the absorption coefficients were digitized at 200 cm^{-1} and 500 cm^{-1} intervals respectively.

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8. List, R.J. (1968) Smithsonian Meteorological Tables (6th revised edition), Smithsonian Institute Press, Washington.

There has been one modification to the spectral data for water vapor* in the 2.7 μm region (since LOWTRAN 2 was published) based on a more recent review of available experimental measurements. The above modification leads to slightly higher atmospheric absorption by water vapor in the 2.2 to 3.4 μm spectral region than given by LOWTRAN 2.

3.2 Continuum Absorption

Absorption coefficients for the water vapor continuum near 10 μm and 4 μm in LOWTRAN 3 are based on measurements of Burch et al, McCoy and Rensch, and Bignell.[9-13] The effect of absorption by the water vapor continuum between 14 μm and 28.5 μm has not been included at this time because there is insufficient data in this region.

The continuum due to collision induced absorption by nitrogen in the 4 μm region is included in LOWTRAN 3 based on the measurements of Reddy and Cho[14] and Shapiro and Gush[15] (see also McClatchey et al[2]).

In all cases the transmittance due to continuum absorption is assumed to follow a simple exponential law.

3.3 Molecular Scattering

The absorption coefficient due to molecular scattering, C6, is introduced into LOWTRAN 3 via the following expression:

$$C6 = 9.87 \times 10^{-20} \nu^4 \text{ km}^{-1}$$

where ν is in wavenumbers (cm^{-1}).

The above expression was obtained as a best fit to molecular scattering coefficients published by Penndorf[16] and is shown in Figure 1 together with the aerosol extinction coefficient.

3.4 Aerosol Models

Two aerosol models are incorporated into LOWTRAN 3 and correspond to visual ranges of approximately 5 km and 23 km at sea level. However, an aerosol attenuation for any visual range is calculated by LOWTRAN 3 using an interpolation/extrapolation procedure (described in Section 3.5) which utilizes these two models. As these aerosol models are based on measurements of continental aerosol under moderate visibility conditions, they may not be valid for very low

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*Not included in LOWTRAN 2.

NOTE: For references 9-16, see list of References on page 63.

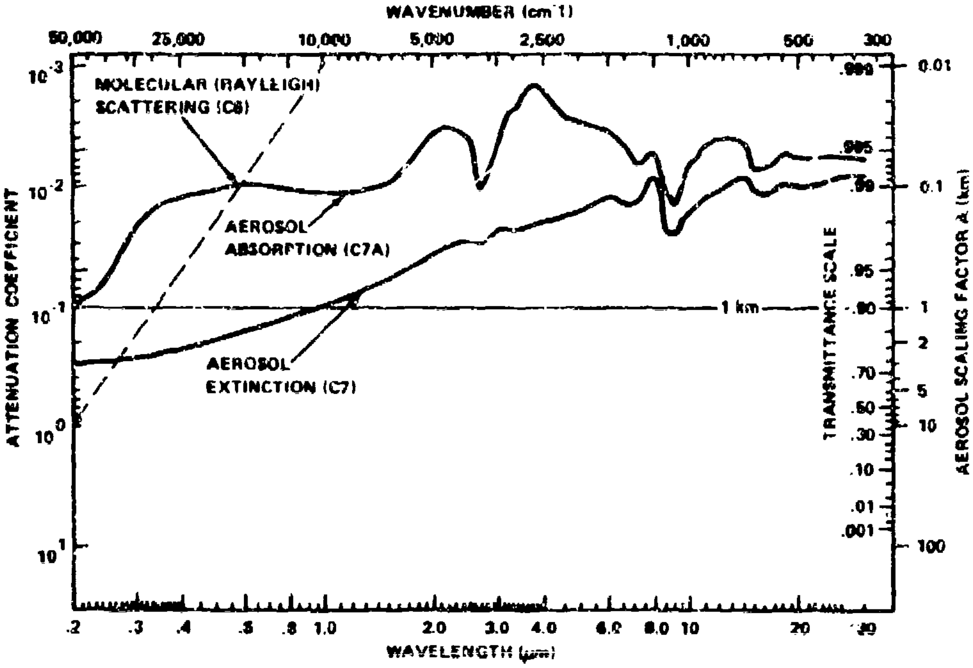

Figure 1. Attenuation Coefficients for Aerosol Transmittance (Absorption and Total Extinction)

visibility conditions less than 2 km. Reported low visibility conditions less than 2 km are probably representative of fog conditions. In this case, the LOWTRAN 3 results will tend to underestimate the attenuation (overestimate the transmittance) in the infrared and overestimate the attenuation in the ultraviolet. A more realistic result can be obtained by assuming the attenuation to be wavelength independent (see McClatchey, et al, 1972, p. 79)[2] and assuming that the aerosol attenuation provided by LOWTRAN 3 at 5500 Å is also valid throughout the infrared and near ultraviolet. The application of this "fog model" should only be applied to the lowest few hundred meters above the surface. In LOWTRAN 3, a message will be printed out to warn the user in the event that results are required for sea level visual ranges less than 2 km. The two aerosol models are based on the following assumptions.

(1) A particle size distribution similar to Deirmendjian's Haze Model C,[17, 18] but where the large particle radius cutoff has been extended to 100 μm (compared

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17. Deirmendjian, D. (1964) Appl. Opt. 3:187.

18. Deirmendjian, D. (1969) Electromagnetic Scattering on Spherical Polydispersions, American Elsevier Pub. Co., N.Y.

to 5 μm in Deirmendjian[17] and 10 μm in McClatchey et al[2] and Selby and McClatchey[4]).

(2) The particle size distribution is assumed to remain constant with altitude.

(3) The variation of aerosol number density with altitude is assumed to be the same as previously given by McClatchey et al[2] for the 23 km visual range model. The latter aerosol number densities were adjusted to give extinction coefficients at a wavelength of 0.55 μm that corresponded to those obtained by Elterman[19,20] at each altitude.

(4) The variation of aerosol refractive index with wavelength has been obtained from measurements by Volz[21] (see also McClatchey and Selby[22]), who has found that aerosols are composed of water-soluble substances as well as dust like material.

Aerosol extinction (C7) and aerosol absorption (C7A) values were calculated based on single scattering Mie theory using the above aerosol size distribution and refractive index values (assuming the aerosols to be composed of 70 percent water-soluble substance and 30 percent dust-like substance, which appears to be representative of continental aerosol). Figure 1 shows the variation of the calculated aerosol extinction and absorption coefficients with wavelength. In LOWTRAN 3, (C7) and (C7A) were digitized directly from Figure 1 at discrete wavelengths (see Appendix A and Table A2).

The above aerosol model replaces the empirical function previously used in LOWTRAN 2. Figure 1 can be used to calculate aerosol extinction and absorption in the same way as described in McClatchey et al[2] and replaces Figure 22 in the latter reference.

3.5 Aerosol Interpolation/Extrapolation Scheme

The total extinction coefficient σ_T at 0.55 μm is inversely proportional to visual range, VIS, and can be written as follows (Middleton[23]):

$$\sigma_T = \sigma_a + \sigma_m = \frac{3.91}{VIS} .$$

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19. Elterman, L. (1968) UV, Visible and IR Attenuation for Altitudes up to 50 km, AFCRL-68-0153.
20. Elterman, L. (1970) Vertical Attenuation Model with Eight Surface Meteorological Ranges 2 to 13 km, AFCRL-70-0200.
21. Volz, F.E. (1972) Appl.Opt. **11**:755.
22. McClatchey, R.A., and Selby, J.E.A. (1974) Atmospheric Attenuation of Laser Radiation from 0.76 to 31.25 μm, AFCRL-TR-74-0003.
23. Middleton, W.E.K. (1952) Vision Through the Atmosphere, Univ. of Toronto Press.

assuming a 2 percent contrast threshold where the suffixes a and m refer to the aerosol and molecular components respectively. The aerosol extinction coefficient can thus be written as

$$\sigma_a = \frac{3.91}{VIS} - \sigma_m .$$

Since the aerosol extinction coefficient σ_a is directly proportional to the aerosol number density N(z), we can write

$$N(z) = \frac{a(z)}{VIS} - b(z) ,$$

where a(z) and b(z) are constants for a given altitude z. It will be noted that b(z) is proportional to the molecular scattering coefficient at 0.55 μm at altitude z, where molecular absorption has been assumed negligible at $\lambda = 0.55\,\mu m$.

The above equation forms the basis for the interpolation/extrapolation procedure used in LOWTRAN 3 to determine aerosol attenuation at any given visual range.

The coefficients a and b are determined from the above equation at each altitude using the two aerosol models, that is,

$$a(z) = \left|N_5(z) - N_{23}(z)\right| \Big/ \left|1/5 - 1/23\right|$$

$$b(z) = \left|N_{23}(z)/5 - N_5(z)/23\right| \Big/ \left|1/5 - 1/23\right|$$

where N_5 and N_{23} refer to the number densities for the 5-km and 23-km sea level visual ranges. Note that the above procedure is used only in the lower 5 km of the atmosphere since the two aerosol models are identical above 5 km altitude.

4. THEORY

4.1 Basic Assumptions

The computer program LOWTRAN 3 follows almost exactly the procedures outlined by McClatchey et al.[2] The main assumptions made are that the atmosphere can be represented by a 33-layer model, and that the average transmittance $\bar{\tau}$ over a 20 cm^{-1} interval (due to molecular absorption) can be represented by a single parameter model of the form

$$\bar{\tau} = f\,(C_\nu \omega^*) \qquad (1)$$

where C_ν is a wavelength (or wavenumber) dependent absorption coefficient and ω^* is an "equivalent absorber amount" for the atmospheric path, which is defined in terms of the pressure $P(z)$, temperature $T(z)$, concentration of absorber ΔL, and an empirical constant n as follows:

$$\omega^* = \Delta L \left\{ \frac{P(z)}{P_o} \sqrt{\frac{T_o}{T(z)}} \right\}^n . \qquad (2)$$

If Eq. (2) is substituted in Eq. (1) and n is set equal to zero and unity, respectively, Eq. (1) reverts to the well known weak line and strong line approximations common to most band models.

The form of the function f and parameter n was determined empirically using both laboratory transmittance data and available molecular line constants. In both cases, the transmittance was degraded in resolution to 20 cm^{-1} throughout the entire spectral range covered here. It was found that the functions f for H_2O and the combined contributions of the uniformly mixed gases were essentially identical, although the parameter n differed in the two cases. Mean values of n were determined to be 0.9 for H_2O, 0.75 for the uniformly mixed gases, and 0.4 for ozone.

4.2 Earth Curvature and Refraction

In general, earth curvature has a greater influence on the path length (and hence on the transmittance) than atmospheric refraction. For long slant paths with zenith angles close to 90° in the lower layers of the atmosphere, however, refractive effects can cause a significant increase in the path length (up to 30 percent for a 90° path to space from ground level). Figure 2 shows the effect of atmospheric refraction on defining the minimum height of a path trajectory from space. The minimum height referred to here is also known as the tangent height. In Figure 2, the difference between the geometrical (no refraction) and the actual minimum height is plotted against the actual minimum height for three different model atmospheres. The sketch in the upper right-hand corner of Figure 2 indicates that there is also a discrepancy in the earth center angle β subtended by the trajectory, when refraction is significant. The difference $\beta - \beta'$ shown in Figure 2 is equal to the total angular deviation ψ of the trajectory due to refraction.

For many applications it is necessary to account not only for the effect of refraction and earth curvature on the transmittance over a given path trajectory, but also on the purely geometrical aspects of the trajectory itself. For example, the total deviation ψ, angle of arrival ϕ, or angle β subtended by the path trajectory may be required as illustrated in Figure 3. LOWTRAN 3 calculates the quantities ψ, ϕ, β and slant range on the basis of a layered atmosphere in the following paragraphs.

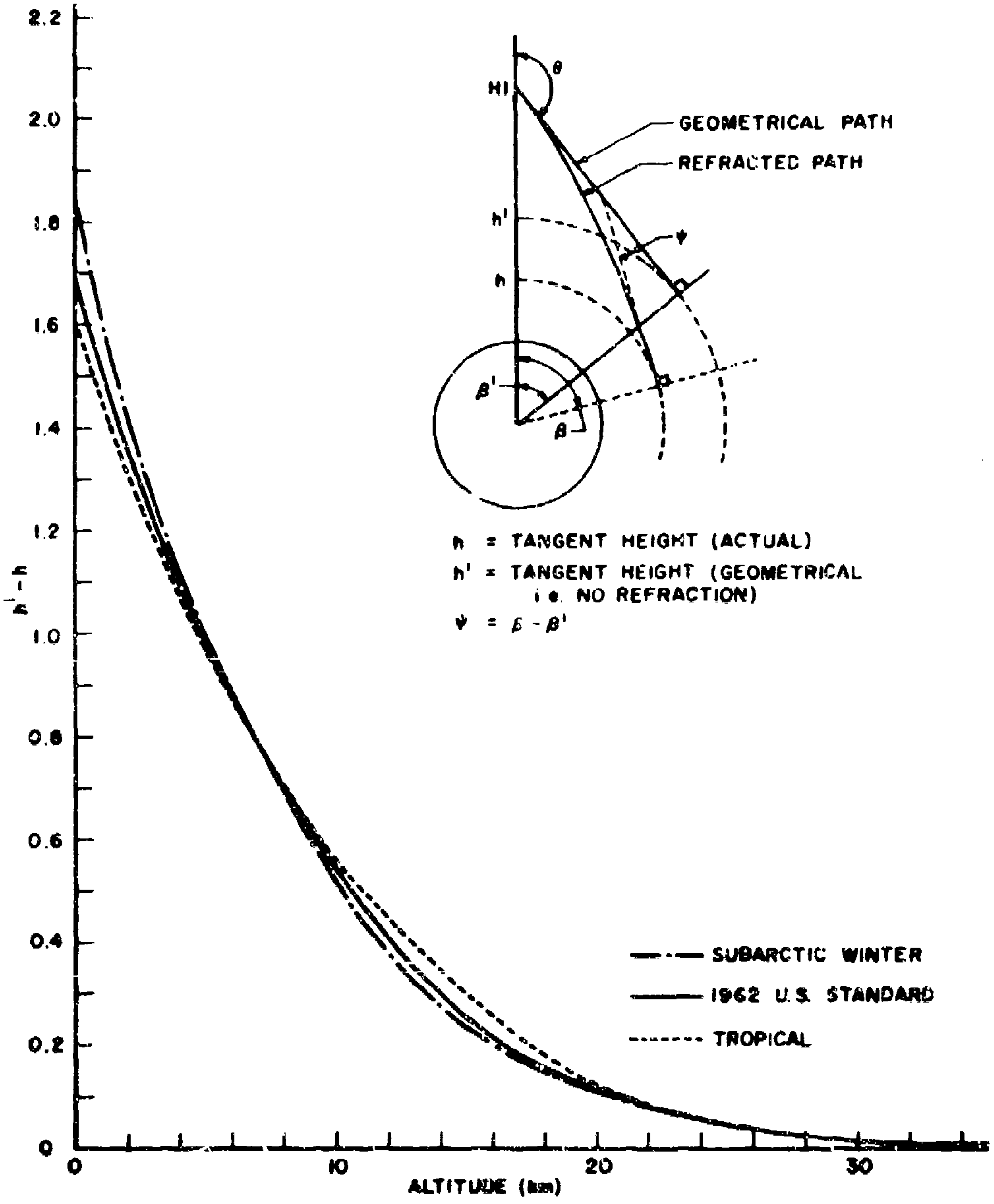

Figure 2. The Difference Between Unrefracted and Refracted Tangent Height Positions as a Function of Altitude for Three Model Atmospheres Based on the 33-Layer Model

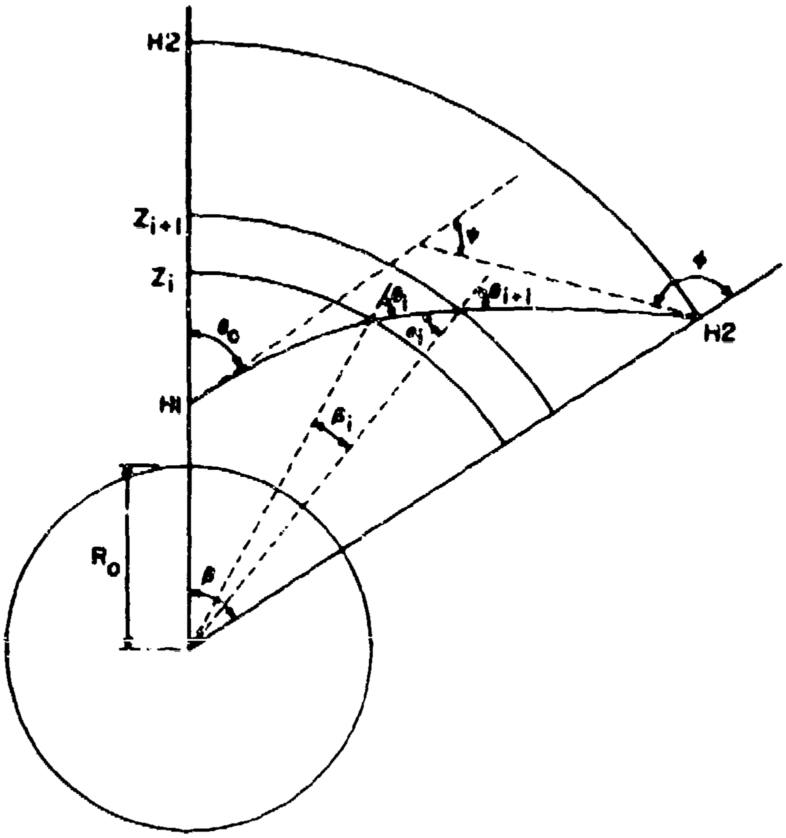

Figure 3. General Schematic of a Refracted Path From Altitudes H1 to H2 Showing the Angles Defining the Trajectory. Initial zenith angle θ_0 at H1, angle of arrival ϕ at H2, total angular deviation ψ, and angle subtended by path at the earth's center, β

The earth's atmosphere is assumed to be divided into a series of concentric spherical layers for each of which a mean refractive index is defined. However, the non-sphericity of the earth is taken into account to some extent by using a different earth radius for each latitude (associated with a given model atmosphere).

Consider the trajectory of a ray passing from heights H1 to H2 at an initial zenith angle θ_0. Let z_i and z_{i+1} define the boundary heights of a given layer, and let θ_i and θ_{i+1} be the local zenith angles at the respective boundaries (see Figure 3). Then at a height of z_{i+1}, the angle of refraction is θ_{i+1}. The angle of incidence α_i at height z_{i+1} can be defined as

$$\sin \alpha_i = (R_0 + z_i) \sin \theta_i / (R_0 + z_{i+1}) . \qquad (3)$$

Applying Snell's law at boundary z_{i+1}, we have

$$n_i \sin \alpha_i = n_{i+1} \sin \theta_{i+1} \tag{4}$$

where n_i and n_{i+1} are the mean refractive indices of the layers above z_i and z_{i+1} respectively.

Substituting for $\sin \alpha_i$ in Eq. (4), we have

$$n_i (R_o + z_i) \sin \theta_i = n_{i+1} (R_o + z_{i+1}) \sin \theta_{i+1} . \tag{5}$$

It follows from symmetry that

$$\begin{aligned} n_i (R_o + z_i) \sin \theta_i &= n_{i-1} (R_o + z_{i-1}) \sin \theta_{i-1} \\ &= n_o (R_o + H1) \sin \theta_o \\ &= \text{const.} \end{aligned} \tag{6}$$

Therefore, the angle of refraction at any level z can be written in terms of the initial input conditions and the refractive index n_o of the layer above H1 as

$$\sin \theta = n_o (R_o + H1) \sin \theta_o / n (R_o + z) . \tag{7}$$

The angle β_i subtended at the center of the earth by the intersection of the ray with the layer z_i to z_{i+1} is given by

$$\beta_i = \theta_i - \alpha_i . \tag{8}$$

Thus the total earth center angle subtended by the ray when traversing the atmosphere from H1 to H2 is

$$\beta = \sum_i^{m-1} (\theta_i - \alpha_i) \tag{9}$$

$$= \sum_i^{m-1} \left| \sin^{-1} \left\{ A / n_i (R_o + z_i) \right\} - \sin^{-1} \left\{ A / n_i (R_o + z_{i+1}) \right\} \right| \tag{10}$$

where m is the number of levels between H1 and H2, and $A = n_o (R_o + H1) \sin \theta_o$.

The angle of arrival ϕ of the ray at H_2 is given by

$$\phi = 180° - \sin^{-1} \left\{ A / n_{m-1} (R_o + H2) \right\} . \tag{11}$$

The total angular deviation of the trajectory Ψ is given by

$$\Psi = \beta - \phi - \theta_0 + 180 \, . \tag{12}$$

The effective path length between levels z_i and z_{i+1} is given by

$$DS_i = (R_o + z_{i+1}) \sin \beta_i / \sin \theta_i \quad \text{for } 0° < \theta < 180° \tag{13}$$

for $\theta = 0°$ and $180°$, $DS_i = a_{i+1} - z_i$. If we assume that the equivalent absorber amount per unit path length ω (see Section 4.1) for a given gas varies exponentially with altitude, we can write

$$\int_{z_i}^{z_{i+1}} \omega \, dz = H_i \left[\omega(z_i) - \omega(z_{i+1}) \right] \tag{14}$$

where $H_i = (z_{i+1} - z_i) / \log_e \left[\omega(z_i) / \omega(z_{i+1}) \right]$. The amount of absorber W_i along a path of length DS_i between altitudes z_i and z_{i+1} is therefore given by:

$$\begin{aligned} W_i &= \int_0^{DS_i} \omega \, ds \\ &= \frac{DS_i}{z_{i+1} - z_i} \int_{z_i}^{z_{i+1}} \omega \, dz \\ &= \frac{DS_i \left[\omega(z_i) - \omega(z_{i+1}) \right]}{\log_e \left[\omega(z_i) / \omega(z_{i+1}) \right]} \, . \end{aligned} \tag{15}$$

The total equivalent absorber amount W for a given atmospheric path is given by the sum of the W_i values for all layers; that is, $W = \sum_{i=1}^{m-1} W_i$ where m is the number of levels traversed by the path.

4.3 Refractive Index of Air

The following simplified version of Edlen's[24] expression for the refractive index of air is used in LOWTRAN 3:

$$\left(n_a - 1 \right) 10^{+6} = \left(77.46 + \frac{0.459}{\lambda^2} \right) \frac{P}{T} - \frac{P_{H_2O}}{1013} \left(43.49 - \frac{0.347}{\lambda^2} \right).$$

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[24] Edlen, B. (1966) Metrologia 2:12.

where p_{H_2O} and P refer respectively to the partial pressure of water vapor and atmospheric pressure in millibars, T is atmospheric temperature in degrees Kelvin, and λ is the wavelength in micrometers (μm).

The above expression has been used over the entire wavelength range 0.2 to 28.5 μm in LOWTRAN 3. Although Edlen's expression for the refractive index of air is widely used in both the visible and infrared spectral regions, it is questionable how far it should be used into the ultraviolet and into the far infrared since the formula is based primarily on measurements made in the visible part of the spectrum from 0.43 to 0.8 μm.

4.4 Geometrical Path Configurations

When using LOWTRAN 3, the type of atmospheric path for which a calculation is to be made must be specified according to one of the three broad categories listed below.

TYPE 1. Horizontal path: that is, a constant pressure path where the effects of earth curvature and refraction are negligible.

TYPE 2. Slant paths between two altitudes from H1 to H2.

TYPE 3. Slant paths to space from initial altitude H1.

The variations within the latter two categories for both upward and downward path trajectories can be seen from Figure 4.

It will be noted that two trajectories are possible for a given set of input parameters, H1, H2, and θ for a downward looking path (TYPE 2), provided that H2 lies between H1 and the minimum height, HMIN.

In most instances, the reader will not be aware that two paths are possible for a given set of input conditions. For such a case, LOWTRAN 3 will execute the shorter path condition [Figure 4(d)] and print out a message to the effect that the case shown in Figure 4(e) does exist. Should the reader decide to run the latter case, he need only set the parameter LEN equal to unity and resubmit the case. This will be seen more clearly from the following section (also Section 6.4).

5. INSTRUCTIONS FOR USING LOWTRAN 3

The input data for LOWTRAN 3 are given in Appendix A. In general, it is only necessary to change the last four cards (referred to here as Nos. 1-4)† in order to run the program for a given problem. The formats for the last four cards and their application will next be discussed.

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† These four cards were referred to as Nos. 470-473 in the LOWTRAN 2 report.

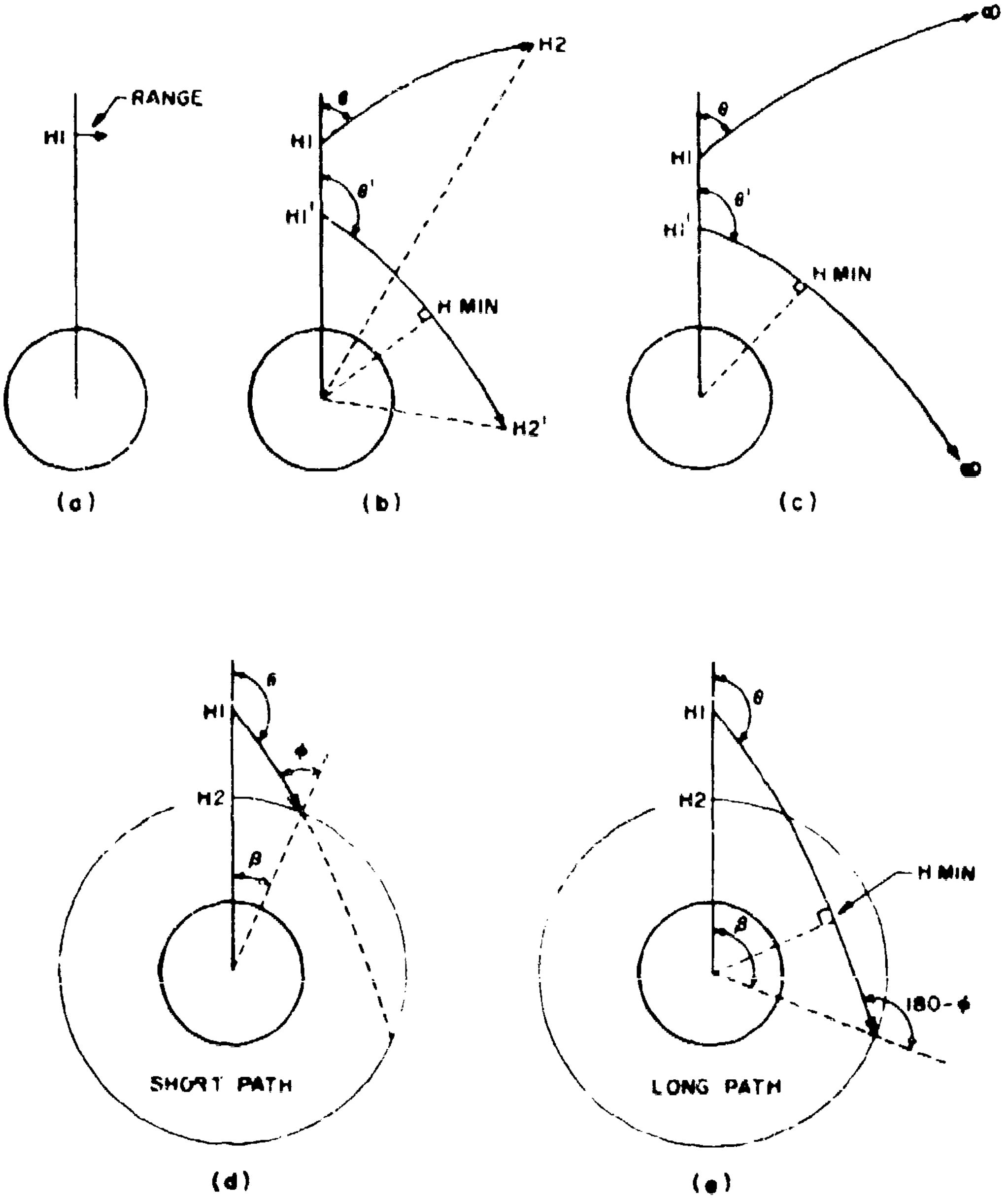

Figure 4. Geometrical Path Configuration for: (a) Horizontal Paths (Type 1), (b) Slant Paths Between Two Altitudes H1 and H2 (Type 2), and (c) Slant Paths to Space (Type 3). For downward looking paths where HMIN < H2 < H1, two trajectories are possible as indicated in (d) and (e).

5.1 Input Data and Formats

The data necessary to specify a given problem are given on the last four cards as follows

CARD 1 MODEL, IHAZE, ITYPE, LEN, JP, IM, M1, M2, M3, ML, R0 {FORMAT (10I3, F10.3)}
CARD 2 H1, H2, ANGLE, RANGE, BETA, VIS {FORMAT (6F10.3)}
CARD 3 V1, V2, DV {FORMAT (3F10.3)}
CARD 4 IXY {FORMAT (I3)}.

Definitions of the above quantities will be discussed in Section 5.2.

If the quantity MODEL given on CARD 1 is set equal to 0 or 7 (which is the case if meteorological data are used as input to the program), then the above card sequence (and format for CARD 2) is changed. These cases will be described in Section 5.3 and examples for some typical problems will be given in Sections 6.7 and 6.8.

5.2 Basic Instructions

The various quantities to be specified on each of the four control cards (summarized in Section 5.1) will be discussed in this section.

5.2.1 CARD 1 MODEL, IHAZE, ITYPE, LEN, JP, IM, M1, M2, M3, ML, R0

The parameter MODEL selects one of the six geographical model atmospheres or specifies that meteorological data are to be used in place of the standard models. IHAZE specifies whether aerosol attenuation is to be included in the calculation or not. For any problem the atmospheric path must be specified as one of three types according to ITYPE and LEN. The rest of the quantities given on CARD 1† (which can be left blank if not required) provide the user with options to suppress printing (JP), to intermix the six standard model atmospheres (M1, M2, M3) and to input a new model atmosphere (IM, ML). The options for the above parameters and their uses are stated and described in detail below:

MODEL = 0 if meteorological data are specified (for horizontal paths only)‡
= 1 selects TROPICAL MODEL ATMOSPHERE
= 2 selects MIDLATITUDE SUMMER
= 3 selects MIDLATITUDE WINTER
= 4 selects SUBARCTIC SUMMER
= 5 selects SUBARCTIC WINTER
= 6 selects 1962 US STANDARD
= 7 if a new model atmosphere (or radiosonde data) is to be inserted.‡

---

† The parameters JP, IM, etc. given on CARD 1 were not included in LOWTRAN 2.
‡ In these cases the format for CARD 2 changes (see nonstandard conditions) Section 5.3 and examples 7 and 8 (Section 6.7 and 6.8).

IHAZE = 0 means no aerosol attenuation included in the calculations.

IHAZE = 1 or 2 if aerosol attenuation is required (see also CARD 2).

If IHAZE is set equal to 1 or 2 and visual range (VIS) is not specified on CARD 2, then the program will automatically select visual ranges of 23 km or 5 km respectively.

ITYPE = 1 for a horizontal (constant pressure) path.
= 2 for a vertical or slant path between two altitudes.
= 3 for a vertical or slant path to space.

The TYPE 1 path should not be confused with a long 90° path where the local height of the end of the trajectory is at a significantly different height. In such a case, specify the path according to ITYPE = 2 (see Section 5.2.2).

LEN = 0 for normal operation of program.

LEN = 1 selects the downward TYPE 2 path shown in Figure 4(e).

The parameter LEN can be ignored (that is, left blank) for the majority of cases. It need only be used for a downward looking path (H2 < H1) when two paths are possible for the same input parameters (see Section 4.4). In such a case, a computer printout statement will be given indicating that the user has two choices for the problem and that the shorter path [see Figure 4(d)] has been executed. Set LEN = 1 for the longer case (an example of this is given in Section 6.4).

JP = 0 for normal operation of program.

JP = 1 to suppress printing of transmittance table (see Table 1)

IM = 1 when radiosonde data are to be read in initially

IM = 0 for normal operation of program or when subsequent calculations are to be run with MODEL = 7

ML = number of levels to be read in for MODEL = 7

Note that IM and ML are only used when MODEL = 7 and then only on the first calculation when the data are read in.

M1 = M2 = M3 = 0 for normal operation of program.

The parameters M1, M2, and M3 can each take integral values between 0 and 6 and are used to modify or supplement the altitude profiles of temperature, water vapor, and ozone respectively, for any given atmospheric model specified by MODEL. For example:

M1 = 1 selects the TROPICAL temperature altitude profile

M1 = 2 selects the MIDLATITUDE SUMMER temperature altitude profile

M1 = 6 selects the 1962 US STANDARD temperature altitude profile

M2 = 1 selects the TROPICAL water vapor altitude profile

M2 = 2 selects the MIDLATITUDE SUMMER water vapor altitude profile

M2 = 6 selects the 1962 US STANDARD water vapor altitude profile

M3 = 1 selects the TROPICAL ozone altitude profile

M3 = 2 selects the MIDLATITUDE SUMMER ozone altitude profile

M3 = 6 selects the 1962 US STANDARD ozone altitude profile

R0 = radius of the earth (km) at the particular geographical location at which the calculation is to be performed.

If R0 is left blank, the program will use the midlatitude value of 6371.23 km if MODEL is set equal to zero or 7. Otherwise the earth radius for the appropriate standard model atmosphere (specified by MODEL) will be used.

The use of the parameters defined above will become more apparent by referring to the examples given in Section 6.

In the case where MODEL = 7, the new atmosphere (model or radiosonde data) is inserted between CARDS 1 and 2 (see Section 5.3).

5.2.2 CARD 2 H1, H2, ANGLE, RANGE, BETA, VIS

Card 2 is used to define the geometrical path parameters for a given problem.

H1 = initial altitude (km)

H2 = final altitude (km)

ANGLE = initial zenith angle (degrees) as measured from H1

RANGE = path length (km)

BETA = earth centre angle subtended by H1 and H2 (degrees)

VIS = sea level visual range (km)

It is not necessary to specify every quantity given above; only those that adequately describe the problem according to the parameter ITYPE (as described below).

(1) Horizontal Paths (ITYPE = 1)

(a) specify H1, RANGE and VIS only

(b) if nonstandard meteorological data are to be used, that is, if MODEL = 0 on CARD 1), then the following parameters must be specified on CARD 2: H1, P, T, DP, RH, WH, WO, VIS, RANGE according to FORMAT (3F10.3, 2F5.1, 2E10.3, 2F10.3), where P, T, DP, RH, WH and WO are the pressure (mb), temperature (°C), dew point temperature (°C), relative humidity (%), H_2O density (gm m^{-3}) and ozone density (gm m^{-3}) respectively.

Note that it is necessary to specify all of the quantities underlined with a full line and one of the quantities underlined with a dashed line. If the ozone density (WO) is not known, a value can be chosen from one of the standard atmospheric models by using the parameter M3 on CARD 1 (see Section 5.2.1 above).

Some examples of typical horizontal path calculations are given in Sections 6.1 and 6.8.

(2) Slant Paths to Space (ITYPE = 3)

(a) specify H1, ANGLE and VIS

(b) specify H1, HMIN and VIS (for limb viewing problem where HMIN is the required tangent height or minimum altitude of the path trajectory.

(3) Slant Paths Between Two Altitudes (ITYPE = 2)

(a) specify H1, H2, ANGLE and VIS

(b) specify H1, ANGLE, RANGE and VIS

(c) specify H1, H2, RANGE and VIS

For cases (b) and (c), the program will calculate H2 and ANGLE respectively, assuming no refraction; then proceed as for case (a). This method of defining the problem should be used when refraction effects are not important; for example, for ranges of a few tens of km at zenith angles less than 80°. It can also be used for larger angles (including 90°) provided that the path lies within one atmospheric layer.

(d) Specify H1, H2, BETA and VIS. Leave ANGLE and RANGE blank in this case. This method can be used when the geometrical configuration of the source and receiver is known accurately, but the initial zenith angle is not known precisely due to atmospheric refraction effects. Beta is most frequently determined by the user from ground range information.

In the cases of 2(b) and 3(d) above, the subroutine ANGLE is called in the program to determine the appropriate input zenith angle by an iterative technique taking into account atmospheric refraction (see Appendix C).

In the case where MODEL = 7, the new model atmosphere (or radiosonde data) is inserted between CARDS 1 and 2 (see Section 5.3).

5.2.3 CARD 3 V1, V2, DV

The spectral range over which transmittance data are required and the spectral increments at which the data are to be printed out is determined by CARD 3.

V1 = initial frequency in wavenumbers (cm^{-1})

V2 = final frequency in wavenumbers (cm^{-1}) where V2 > V1

DV = frequency increment (or step size) (cm^{-1})

(Note that $\nu = 10^4/\lambda$ where ν is the frequency in cm^{-1} and λ is the wavelength in microns, and that DV can only take values which are a multiple of 5.)

5.2.4 CARD 4 IXY

The control parameter IXY can cause the program to recycle, so that a series of problems can be run with one submission of LOWTRAN 3. Five values of IXY can be used to provide the options given below.

IXY = 0 or blank card to end of program

= 1 to select a new CARD 3 and CARD 4 only (assuming other parameters are unchanged)

= 2 to select a new data sequence (CARDS 1, 2, 3, and 4)

= 3 to select a new CARD 2 and CARD 4 only (assuming other parameters are unchanged)

= 4 to select a new CARD 3 and CARD 4 only (assuming other parameters are unchanged)

Thus, if for the same model atmosphere and type of atmospheric path the reader wishes to make further transmittance calculations in different spectral intervals V1' to V2' etc. and for a different step size (DV' etc.), then IXY is set equal to 1. In this case, the card sequence is as follows and can be repeated as many times as required:

CARD 4 IXY = 1
CARD 5 V1' V2' DV'
CARD 6 IXY = 1
CARD 7 V1'' V2'' DV''
CARD 8 IXY = 0

The final IXY card should always be a blank or zero (see also Section 6.2). When using the IXY = 1 option, the wavelength dependence of the refractive index is not changed (use IXY = 2 option if this is required).

To make successive transmittance computations where just the geographical model atmosphere is changed and/or with or without aerosol attenuation, set IXY = 4 and construct a data card sequence along the same lines as given above. This sequence of recycling can be repeated successively, and several examples are given in Section 6.

5.2.5 PROBLEM SEQUENCING

When a series of problems is to be executed (with one submission of LOWTRAN 3) involving the standard atmospheric models (MODEL = 1 to 6) as well as cases involving MODEL = 0 and MODEL = 7, then the order in which the data are set up becomes very important. Note the following sequence.

1. Run all problems using MODEL = 1 through 6 first.
2. Secondly, run all problems involving the use of MODEL = 0.
3. Run all problems involving the use of MODEL = 7 last. The reason for running MODEL = 7 cases last is that when a new atmospheric model is read in, the altitudes may not correspond with those given in the standard models (see Section 2.1) and the program will erase them. Similarly, if a MODEL = 0 case is run following a MODEL = 7 case, the first level of MODEL 7 is erased.

5.3 Non-Standard Conditions

Three options are available if atmospheric transmittance calculations are required for non-standard conditions. Here non-standard refers t conditions other than those specified by the six model atmospheres provided by LOWTRAN 3 (see Section 2.1), which are selected by the parameter MODEL on CARD 1 (see Section 5.2.1). The three options enable the reader to insert:

(1) his own model atmopshere(s) in place of any (or all) of the six standard models, provided that the data are in exactly the same format and are specified at the same altitudes as the latter. In this case the appropriate print statements in LOWTRAN 3 (that identify the atmospheric model used) must be changed correspondingly.

(2) an additional atmospheric model (MODEL 7), which can be in the form of radiosonde data. The data need not be specified at the same altitudes as in the standard models.

(3) meteorological conditions for a given horizontal path calculation (MODEL = 0 case).

The first of these options requires the most effort and needs no further discussion here, other than a reference to Appendix A for a summary of the standard model atmosphere parameters, units and formats (see also Table A2).

5.3.1 ADDITIONAL ATMOSPHERIC MODEL (MODEL = 7)

As stated in Section 5.2.2 a new model atmosphere can be inserted between CARDS 1 and 2 provided the parameters MODEL and IM are set equal to 7 and 1 respectively on CARD 1. The number of atmospheric levels to be inserted (ML) must also be specified on CARD 1. The appropriate meteorological parameters and format for the atmospheric data are given below.

Z, P, T, DP, RH, WH, WO, AHAZE [FORMAT (3F10.3, 2F5.1, 2E10.3, 2F10.3)] where

Z = altitude (km)
P = pressure
T = ambient temperature (°C)
DP = dew point temperature (°C)
RH = relative humidity (%)
WH = water vapor density (gm m^{-3})
WO = ozone density (gm m^{-3})
AHAZE = aerosol number density (cm^{-3})

Note that it is only necessary to specify those quantities underlined with a full line and either of the quantities underlined with the dashed line.

If the ozone density (WO) is not known then a value can be obtained from one of the standard atmospheric models (for the appropriate latitude and season) by using the parameter M3 on CARD 1 (see Section 5.2.1).

If the aerosol number density was not measured as a function of altitude and the reader wishes to include aerosol attenuation in the calculation, set IHAZE = 1 on CARD 1. In this case (as with the M1, N2, and M3 options) LOWTRAN 3 will use the aerosol models already contained in the program and interpolate to give aerosol number density values at the same altitudes as the radiosonde (or new model atmosphere) data.[†] The program will then look for a sea level visual range (VIS) to be specified on CARD 2. If VIS is not specified, a 23 km sea level visual range will be assumed. If aerosol attenuation is not required, set IHAZE = 0 on CARD 1 as before.

5.3.2 HORIZONTAL PATHS (MODEL = 0)

If meteorological data are to be used for horizontal path atmospheric transmittance calculations, then set MODEL = 0 on CARD 1. The following parameters can then be specified on CARD 2:

CARD 2 H1, P, T, DP, RH, WH, WO, VIS, RANGE [FORMAT (3F10.3, 2F5.1, 2E10.3, 2F10.3)] where the above parameters refer to altitude (km), pressure (mb) ambient temperature (°C),[‡] dew point temperature (°C), relative humidity (%), water vapor density (gm m^{-3}), ozone density (gm m^{-3}), visual range (km) and path length (km) respectively (as previously defined in Sections 5.3.1 and 5.2.2).

The format for the above card is similar to that for inputting radiosonde data (MODEL = 7) described in Section 5.3.1 above. Again, it is only necessary to specify the quantities underlined with the solid line and one of the quantities underlined with the dashed line. The ozone density WO can be specified using the parameter M3 on CARD 1 if measurements are not available. In the latter case, a value will be calculated at altitude H1 based on the appropriate model atmosphere selected by M3.

6. EXAMPLES

The following examples explain the problem parameters that need to be specified and card formats necessary for using LOWTRAN 3 to make a wide range of atmospheric transmittance calculations. Example 9 describes how the reader may insert an additional model atmosphere (for example, a set of radiosonde or rawinsonde data) into the program.

As mentioned earlier, only the last four data cards (see Table A2 in Appendix A) are necessary to specify a given problem. It should be noted that the

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[†] A similar interpolation scheme is applied when the M1, M2 and M3 options are used to supplement MODEL 7 (and also for MODEL = 0) using the standard atmospheric models.

[‡] Note that temperature is given in °C for MODEL = 0 option and not °K as previously used in LOWTRAN 2.

terms "CARD 1, CARD 2, etc." are used for convenience to denote these important control cards in their correct sequence, and do not refer to the actual first, second, etc. data cards in LOWTRAN 3 (described in Appendix A).

6.1 Example 1 - Horizontal Path Calculations (ITYPE = 1)

PROBLEM AND CARD FORMAT

Calculate the transmittance from 500 cm^{-1} to 1000 cm^{-1} in steps of 5 cm^{-1} for a horizontal path of range 10 km at an altitude of 2.5 km. for a midlatitude summer model atmosphere and the 5 km (sea level) visual range haze model.

CARD 1 **2**1**1
CARD 2 *****2.500**************************10.000***************5.000
CARD 3 ***500.000**1000.000*****5.000
CARD 4 ***

or alternatively

CARD 1 **2**2**1
CARD 2 *****2.500**************************10.0
CARD 3 ***500.000**1000.000*******5.0
CARD 4 Blank

(* represents a space on the card.)

Note that setting IHAZE = 2 can select a 5 km visual range at sea level without setting VIS on CARD 2.

6.2 Example 2 - Slant Path Calculation to Space (ITYPE = 3) for Two Spectral Intervals

PROBLEM AND CARD FORMAT

Calculate the transmittance from 3 to 5 μm and 8 to 14 μm in steps of ~0.05 μm for a 45° slant path to space from 12.2 km, for a midlatitude winter model atmosphere and a 23 km visual range haze model.

In this case V1 = 2000 cm^{-1}, V2 = 3335 cm^{-1}, and DV varies from 20 cm^{-1} to 55.5 cm^{-1}. Let us choose the lower value, that is, DV = 20 cm^{-1}; also, V1' = 714 cm^{-1} and V2' = 1250 cm^{-1} with DV' varying from 2.55 cm^{-1} to 7.81 cm^{-1}. Thus DV' = 5 cm^{-1}, since this is the nearest multiple of 5 cm^{-1}.

CARD 1 **3**1**3
CARD 2 ****12.200****************45.0
CARD 3 **2000.000**3335.000******20.0
CARD 4 **1
CARD 5 ***714.000**1250.000******5.00
CARD 6 Blank

Note setting IHAZE = 1 on CARD 1 will select a 23 km sea level visual range if VIS is not set on CARD 2.

6.3 Example 3 - Upward Looking Slant Path Calculation (ITYPE = 2)

PROBLEM AND CARD FORMAT

Calculate the transmittance from 4 to 5 μm in steps of ~0.01 μm for a slant path from 2.25 km to 22.8 km at zenith angle of 65°, for a subarctic winter model atmosphere and a 15 km (sea level) visual range haze model.

In this case V1 = 2000 cm^{-1}, V2 = 2500 cm^{-1}, and DV varies from 4 cm^{-1} to 6.26 cm^{-1}. Therefore, set DV = 5 cm^{-1} since this is the nearest multiple of 5 cm^{-1}.

CARD 1 **5**1**2

CARD 2 ******2.25******8.50******65.0************************15.000

CARD 3 **2000.000**2500.000*******5.0

CARD 4 Blank

6.4 Example 4 - Slant Path Between Two Altitudes Looking Downward (ITYPE = 2)

PROBLEM AND CARD FORMAT

Suppose the transmittance from 10 to 20 μm is required for a downward path from 10 km to 8 km at a zenith angle of 92°, using the 1962 US Standard Model Atmosphere and no haze.

In this case set V1 = 500 cm^{-1} (20 μm), V2 = 1000 cm^{-1} (10 μm) and DV = 5 cm^{-1}.

CARD 1 **6**0**2

CARD 2 ****10.000*****8.000****92.000

CARD 3 ***500.000**1000.000*****5.000

CARD 4 Blank

When this case is executed, however, there will be a message printed out to the effect that a longer path is also possible for the same input conditions [for example, see Figures 3(d) and 3(e)]. If you wish to rerun the conditions for the longer path, the card sequence is as follows;

CARD 1 **6**0**2**1

CARD 2 ****10.000*****8.000****92.000

CARD 3 ***500.000**1000.000*****5.000

CARD 4 Blank

6.5 Example 5 - Repeated Problems in Sequence

PROBLEM AND CARD FORMAT

Calculate the transmittance for the 4 to 8 μm region for (1) a 75° zenith angle slant path from 0.23 km to 8.55 km for tropical, midlatitude summer and subarctic summer conditions, and (2) for horizontal paths of 1, 5, and 10 km at

5 km altitude for midlatitude summer conditions. In both cases, assume the sea level visual range to be 15 km.

The set up cards for the above problems are as follows:

```
CARD 1   **1**1**2
CARD 2   *****0.230*****8.550****75.000************************15.000
CARD 3   **1250.000**2500.000*****5.000
CARD 4   **4
CARD 5   **2**1**2
CARD 6   **4
CARD 7   **4**1**2
CARD 8   **2
CARD 9   **2**1**1
CARD 10  *****5.000*************************1.000†
CARD 11  **1250.000**2500.000*****5.000
CARD 12  **3
CARD 13  *****5.000*************************5.000†
CARD 14  **3
CARD 15  *****5.000************************10.000†
CARD 16  ***
```

6.6 Example 6 - To Calculate Viewing Angle, Taking Into Account the Effect of Refraction

PROBLEM AND CARD FORMAT

Suppose the exact position of a source and receiver is known; that is, H1, H2, and geometrical range. From this, one can calculate the apparent zenith angle (assuming no refraction) and the total angle subtended by the path at the center of the earth, β (see Figure 3).. If the apparent zenith angle is such that atmospheric refraction could cause appreciable bending of the path trajectory, then the receiver could be considerably off target. To take into account the effect of atmospheric refraction, one can use the subroutine ANGLE (with H1, H2, and BETA as inputs) which is called by the program to determine the correct zenith angle.

Suppose Example 4 was the above case where $\beta = 5.3715°$ is known specifically for the shorter path. The card sequence would then be:

```
CARD 1   **6**0**2
CARD 2   ****10.000*****8.000************************5.3715
CARD 3   ***500.000**1000.000*****5.000
CARD 4   Blank
```

---

† Since the aerosol attenuation models are independent of sea level visual range above 5 km altitude, it is not necessary to specify VIS in this case.

6.7 Example 7 - Earth Limb Viewing Case

PROBLEM AND CARD FORMAT

Consider an earth limb viewing problem where it is required to calculate the atmospheric transmittance from, say, an altitude of 100 km to space passing through a tangent height (HMIN) of 12 km (see Figure 4(, .. the 2 to 5 μm region for a subarctic winter model atmosphere. In this case let us assume that aerosol attenuation is required. As described in Section 5.2.2, only the quantities H1 and HMIN are specified on CARD 2. The appropriate zenith angle (taking into account atmospheric refraction) is calculated by the program using the subroutine ANGL.

CARD 1 **5**1**3
CARD 2 ***100.000****12,000
CARD 3 **2000.000**2500,000*****5.000
CARD 4 ***

6.8 Example 8 - Horizontal Path with Non-Standard Conditions

If the appropriate conditions are known for the horizontal path, then a different procedure to that given in Examples 1 to 7 can be used. For this case, CARD 2 (see Sections 5.1 and 5.2) contains the following information:† altitude (km), pressure (mb), ambient temperature (°C), dew point temperature (°C), relative humidity (%), water vapor density (gm.m^{-3}), ozone density (gm.m^{-3}), sea level visual range (km), and path length (km) according to format (3F10.3, 2F5.2, 2E10.3, 2F10.3).

PROBLEM AND CARD FORMAT

Calculate the transmittance from 3 to 5 μm for a 10 km path at sea level (midlatitude winter environment) for the following conditions: Pressure = 1000 mb, ambient temperature - 10°C, relative humidity = 40%, and sea level visual range = 50 km.

CARD 1 **0**1**1**0**0**0**0**0**3
CARD 2 *****0.000**1000.000****10.000*****40.00************************
50.000****10.000
CARD 3 **2000.000**3330.000*****5.000
CARD 4 ***

The index 3 on CARD 1 corresponds to the parameter M3 (see Section 5.2) and selects the ozone density corresponding to the midlatitude winter model atmosphere, since the latter quantity is not specified in the above problem. If M3

---

† Note that this problem is specified differently in LOWTRAN 2.

were left blank, then ozone attenuation would not be included in the transmittance calculation.

If a number of different problems are being run with one submission of the program involving the standard model atmospheres as well as problems similar to Example 6.8, then the order in which the problems are run becomes important (see Section 5.3).

6.9 Example 9 - To Insert or Change Model Atmosphere Data

If the reader wishes to include his own model atmosphere data in LOWTRAN 3 two options are available. Either replace one or more of the standard models by the new data or use the MODEL = 7 option which is more convenient. If the former approach is taken, it is recommended that the new atmospheric data be digitized at the same altitudes and according to the same format as the remaining standard models (see Appendix A and Table A2). Note that each of the standard model atmosphere data cards contain the following: altitude (km), pressure (mb), temperature (°K), water vapor density (gm.m^{-3}), and ozone density (gm.m^{-3}) with two models specified on one card (see Table A2) according to format (F6.1, 2E10.3, F6.1, 2E10.7).

In the above case, the reader should modify the appropriate print statements in the program accordingly in order to identify the new model atmospheres, otherwise the printout from LOWTRAN 3 will identify them according to the standard atmospheric models which they replaced.

If the reader wishes to make a limited number of atmospheric transmittance calculations for one or more sets of radiosonde (or rawinsonde) data, it is more convenient to use the MODEL = 7 option; an example of which is given below.

PROBLEM AND CARD FORMAT

Calculate for a given set of radiosonde data the transmittance in the 4 to 8 μm region for (1) a slant path from 0.21 km to 8.55 km at a zenith angle of 35.5° and (2) horizontal paths of 1, 5, and 10 km at 0.21 km altitude. Assume the sea level visual range to be 15 km and the ozone distribution to be representative of midlatitude summer conditions. In this example, the radiosonde data consists of 21 levels and only the following parameters are given: altitude (km), pressure (mb), ambient temperature (°C), and dew point temperature (°C).

The set up cards for the above problem are as follows:

```
**7**1**2**0**0**1**0**0**2*21
*****0.000**1015.000****24.4***21.4
     0.136  1000.000     22.0    19.4
     0.560   950.000     17.8    16.1
```

```
         1.080    892.000     14.8    11.9
         1.526    850.000     12.8     5.8
         1.650    832.000     12.8    -6.2
         2.270    775.000     11.8   -18.2
         3.140    700.000      7.2   -20.8
         5.820    500.000    -10.1   -28.1
         5.990    488.000    -11.5   -27.5
         7.510    400.000    -19.5   -31.5
         8.720    338.000    -28.5   -41.5
         9.180    318.000    -32.7   -39.7
         9.590    300.000    -35.3   -43.3
         9.720    294.000    -34.7   -42.7
        10.020    281.000    -38.7   -45.7
        10.830    250.000    -44.7   -50.0
        12.290    200.000    -57.1   -50.0
        13.600    161.000    -69.5   -50.0
        14.050    150.000    -71.1   -50.0
        16.450    100.000    -70.9   -50.0
*****0.210*****8.550****35.500************************15.000
**1250.000**2500.000*****5.000
**2
**7**1**1**0**0**0**0**0**0*21
*****0.210*************************1.000**************15.000
**1250.000**2500.000*****5.000
**3
*****0.210*************************5.000**************15.000
**3
*****0.210************************10.000**************15.000
***
```

Note that problems utilizing the standard model atmospheres must precede problems similar to Example 9 (see Section 5.3).

6.10 Typical Output from LOWTRAN 3

The output for a problem similar to Example 3 (Section 6.3) is given in Table 1. The parameters defining the atmospheric path, model atmospheres and frequency range will first be printed out. Following the heading HORIZONTAL PROFILES there are 12 columns. The first column gives a running integer associated with each level (level indicator). The second column gives the level altitude in km. The next 8 columns give the equivalent absorber amounts per km for the following absorbing species: water vapor, uniformly mixed gases, ozone, nitrogen continuum, water vapor continuum, molecular scattering, aerosol extinction, and UV ozone, respectively. The last two columns give the mean refractive index modulus from that level to the level above and the refractive index modulus (multiplied by 10^6) at that level.

A heading VERTICAL PROFILES is then printed followed by 15 columns. The first and second columns give the integer associated with the levels traversed by the path and the height of the level. Then follow 8 columns which give the integrated equivalent absorber amounts from the initial altitude to the level above (in the same order as indicated above). The next 4 columns are labelled PSI, PHI, BETA, and THETA, and correspond to the angles similar to ψ, ϕ, β, and θ given in Figure 3 (Section 4.2). Columns PSI and BETA give the accumulated values of ψ and β to the level above. Columns THETA and PHI give the local zenith angle θ_i corresponding to that level and the angle of arrival at the level above, respectively. The accumulated slant range is printed out in the last column under RANGE.

The total equivalent absorber amounts for each absorber species are then summarized below in their appropriate units.

A transmittance table, containing 12 columns, now follows. The first 3 columns give the frequency (cm^{-1}), wavelength (microns), and total transmittance. The next 7 columns show the individual transmittance due to water vapor, uniformly mixed gases, ozone, nitrogen (4 μm) continuum, water vapor (10 μm) continuum, molecular scattering, and aerosol extinction. The last 2 columns give the absorption due to aerosols and the cumulative total integrated absorption. The latter quantity can be used to determine the average transmittance over any given spectral interval within the spectral range covered by the calculation. Finally, the total integrated absorption from V1 to V2 is printed out (units are cm^{-1}) together with the average transmittance over the band.

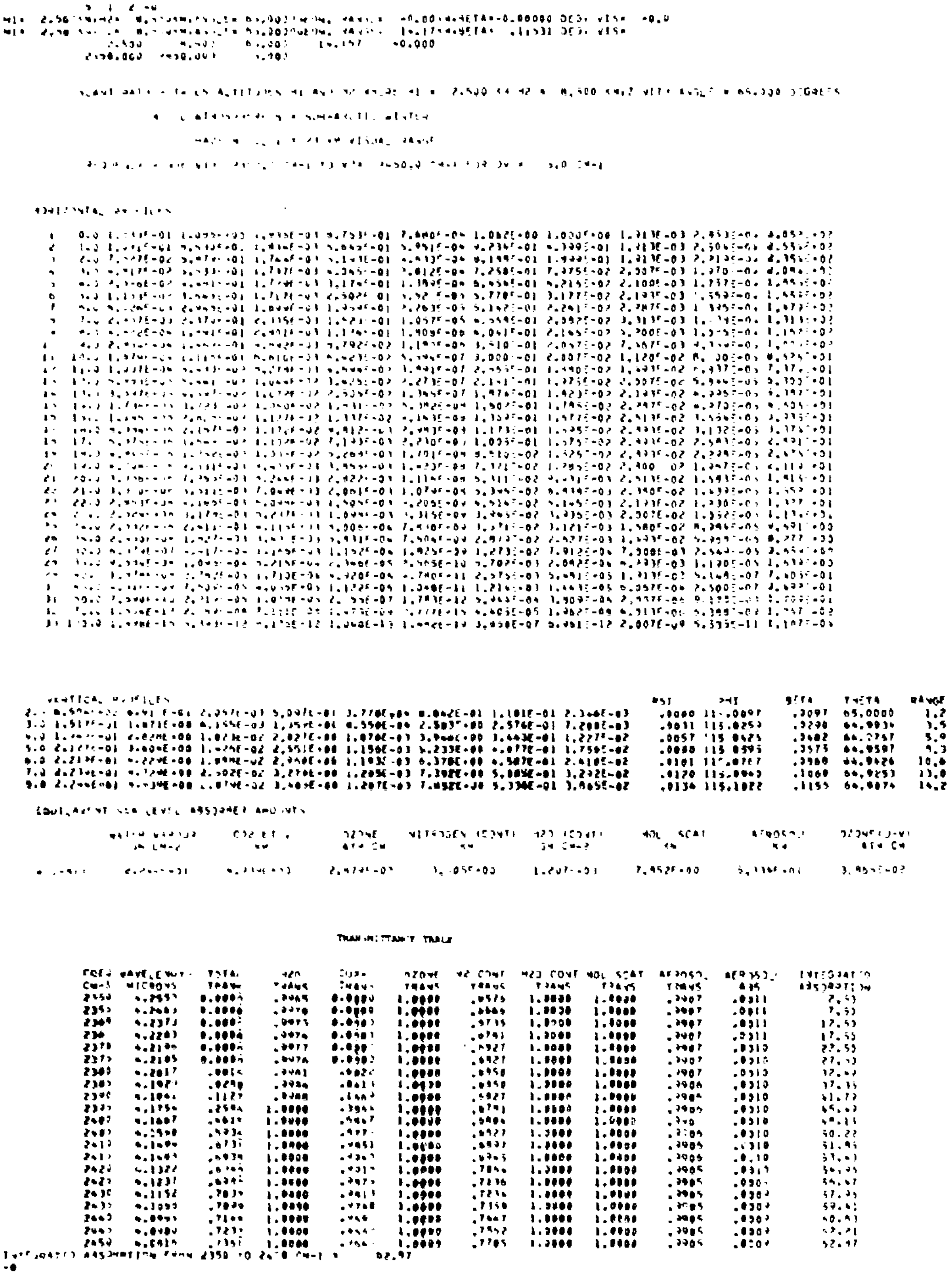
7. LIMITATION AND COMMENTS

It should be remembered that the transmittance values obtained from LOWTRAN 3 are at a spectral resolution of 20 cm^{-1}, although the output can be obtained at 5 cm^{-1} intervals.

The program will round off input frequencies to the nearest frequency at which spectral data are given.

The overall accuracy in transmittance, which this technique provides, is better than 10 percent. The largest errors may occur in the distant wings of strongly absorbing bands in regions where such bands overlap appreciably.

Table 1. Typical Output From LOWTRAN 3



```
                                        TRANSMITTANCE TABLE

        FREQ  WAVELENGTH  TOTAL    H2O     CO2+    OZONE   N2 CONT H2O CONT MOL SCAT AEROSOL  AEROSOL   INTEGRATED
        CM-1   MICRONS    TRANS   TRANS   TRANS    TRANS   TRANS    TRANS    TRANS   TRANS     ABS     ABSORPTION
        2350   4.2553    0.0000   .9965   0.0000  1.0000   .9575   1.0000   1.0000   .9907    .0311        2.50
        2355   4.2463    0.0000   .9970   0.0000  1.0000   .9669   1.0000   1.0000   .9907    .0311        7.50
        2360   4.2373    0.0000   .9975   0.0000  1.0000   .9735   1.0000   1.0000   .9907    .0311       12.50
        2365   4.2283    0.0000   .9976   0.0000  1.0000   .9741   1.0000   1.0000   .9907    .0311       17.50
        2370   4.2194    0.0000   .9977   0.0000  1.0000   .9927   1.0000   1.0000   .9907    .0310       22.50
        2375   4.2105    0.0000   .9978   0.0000  1.0000   .9921   1.0000   1.0000   .9907    .0310       27.50
        2380   4.2017     .0015   .9981    .0022  1.0000   .9950   1.0000   1.0000   .9907    .0310       32.49
        2385   4.1929     .0290   .9984    .0413  1.0000   .9950   1.0000   1.0000   .9906    .0310       37.35
        2390   4.1841     .1127   .9988    .1663  1.0000   .9927   1.0000   1.0000   .9906    .0310       41.77
        2395   4.1754     .2594  1.0000    .3944  1.0000   .9791   1.0000   1.0000   .9905    .0310       45.43
        2400   4.1667     .4615  1.0000    .5467  1.0000   .9804   1.0000   1.0000   .990     .0310       48.11
        2405   4.1580     .5934  1.0000    .997   1.0000   .9927   1.0000   1.0000   .9905    .0310       50.22
        2410   4.1494     .6735  1.0000    .9451  1.0000   .9937   1.0000   1.0000   .9905    .0310       51.95
        2415   4.1408     .6939  1.0000    .9367  1.0000   .9765   1.0000   1.0000   .9905    .0310       53.43
        2420   4.1322     .6965  1.0000    .9315  1.0000   .7854   1.0000   1.0000   .9905    .0310       54.95
        2425   4.1237     .6992  1.0000    .9975  1.0000   .7136   1.0000   1.0000   .9905    .0309       55.67
        2430   4.1152     .7039  1.0000    .9611  1.0000   .7236   1.0000   1.0000   .9905    .0309       57.35
        2435   4.1068     .7090  1.0000    .9748  1.0000   .7150   1.0000   1.0000   .9905    .0309       59.41
        2440   4.0984     .7144  1.0000    .956   1.0000   .7447   1.0000   1.0000   .9905    .0309       60.53
        2445   4.0900     .7232  1.0000    .9547  1.0000   .7552   1.0000   1.0000   .9905    .0309       62.21
        2450   4.0816     .7351  1.0000    .976   1.0009   .7705   1.0000   1.0000   .9905    .0309       62.97
INTEGRATED ABSORPTION FROM 2350 TO 2450 CM-1 =     62.97
-0
```

The reason for this error is twofold. First, a unique spectral curve in Figures 16 to 18, McClatchey et al,[2] is based on a single absorber parameter and cannot be defined for a wide range of atmospheric paths without some loss in accuracy.

Secondly, the transmittance in the window regions between strong bands generally lies in the weak line approximation region, where the transmittance is a function of the quantity of absorber present and not of the product of absorber amount and pressure. The one-dimensional prediction scheme presented in this report is not accurate for such conditions, which in general give transmittance values greater than 0.99. The digitized data were obtained for conditions representative of moderate atmospheric paths and will tend to overestimate the transmittance for very long paths and underestimate the transmittance for very short paths, in the spectral regions described above.

As the transmittance approaches 1.0, the percentage error in transmittance decreases toward zero but the uncertainty in the absorptance (or emittance) increases greatly.

Because of the nature of the program - which uses a layered atmosphere - errors can be introduced into the refraction calculation, since we assume each layer to have a mean refractive index associated with it. This is particularly true for a long path in one layer near ground level where one would expect refraction to be a maximum. But in fact, for such a condition the program may indicate no refraction at all. If problems like these are encountered, the number of levels must be increased in the altitude region of interest.

The effect of wavelength on refraction has been included (see Section 4.3). When a particular problem is set up for a frequency range V1 to V2, however, the average frequency is used in the refractive index calculation. If the reader is using LOWTRAN 3 for trajectory analysis where wavelength dependence of refractive index may be important, it is recommended that dummy values for V1 and V2 be used such that the average frequency corresponds to the frequency of interest.

If LOWTRAN 3 is to be used for trajectory analysis, it is recommended that the number of levels in the model atmospheres be increased substantially between the altitudes of interest. The computer program (with 34 levels) will tend to underestimate the refraction of the atmosphere by as much as 20 percent for the worst case (that is, a 90° path to space from sea level).

If LOWTRAN 3 is not being used for problems similar to Examples 6 and 7 it is recommended that the subroutine ANGL be removed from the program, thereby reducing the size of the card deck by approximately one-third.

Some examples of transmittance spectra obtained from LOWTRAN 3 are presented in Figures 5 through 11. From Figure 5 one can see the separate contributions to the total transmittance due to the various absorbing gases, molecular scattering and aerosol attenuation. The other figures show the variation of atmospheric transmittance with (1) model atmosphere for fixed paths, (2) altitude and path for a fixed model atmosphere, and (3) range and zenith angle for a fixed altitude. In Figures 6 through 11 the aerosol attenuation is calculated on the basis of a 23 km sea level visual range.

In general, fairly good agreement has been found between experimental field measurements and LOWTRAN 3 predictions although a lack of accurate meteorological data (including visual range and actual aerosol characteristics) gives rise to some uncertainty.

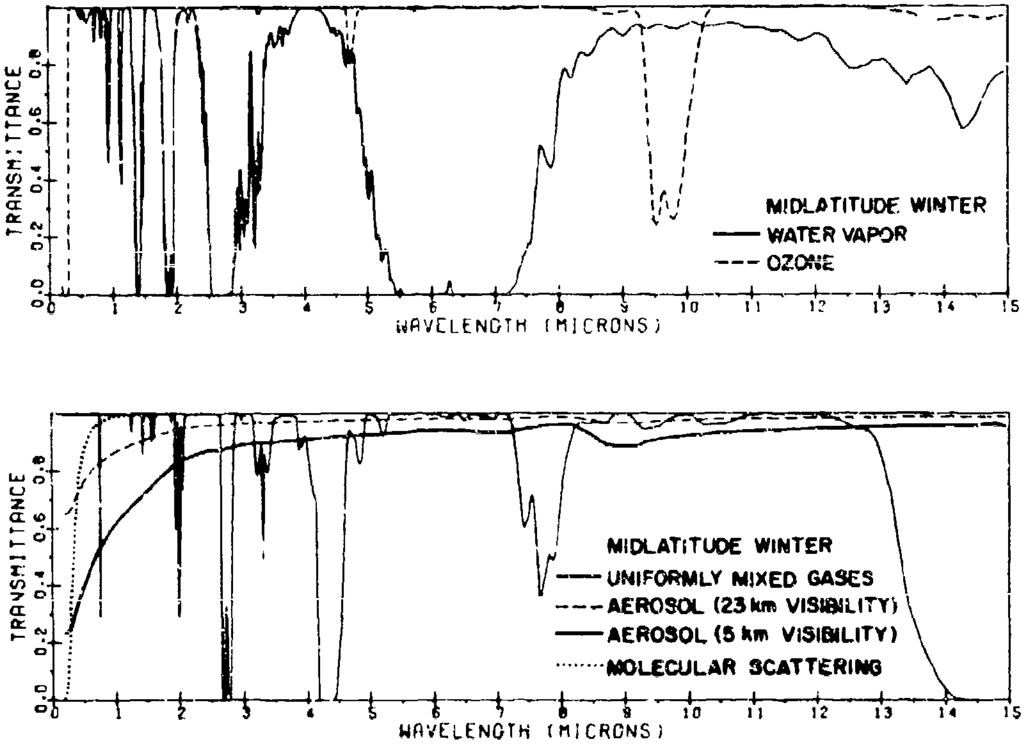


Figure 5. Vertical Path to Space From Sea Level for the Midlatitude Winter Model Atmosphere Showing the Separate Contributions to the Total Transmittance

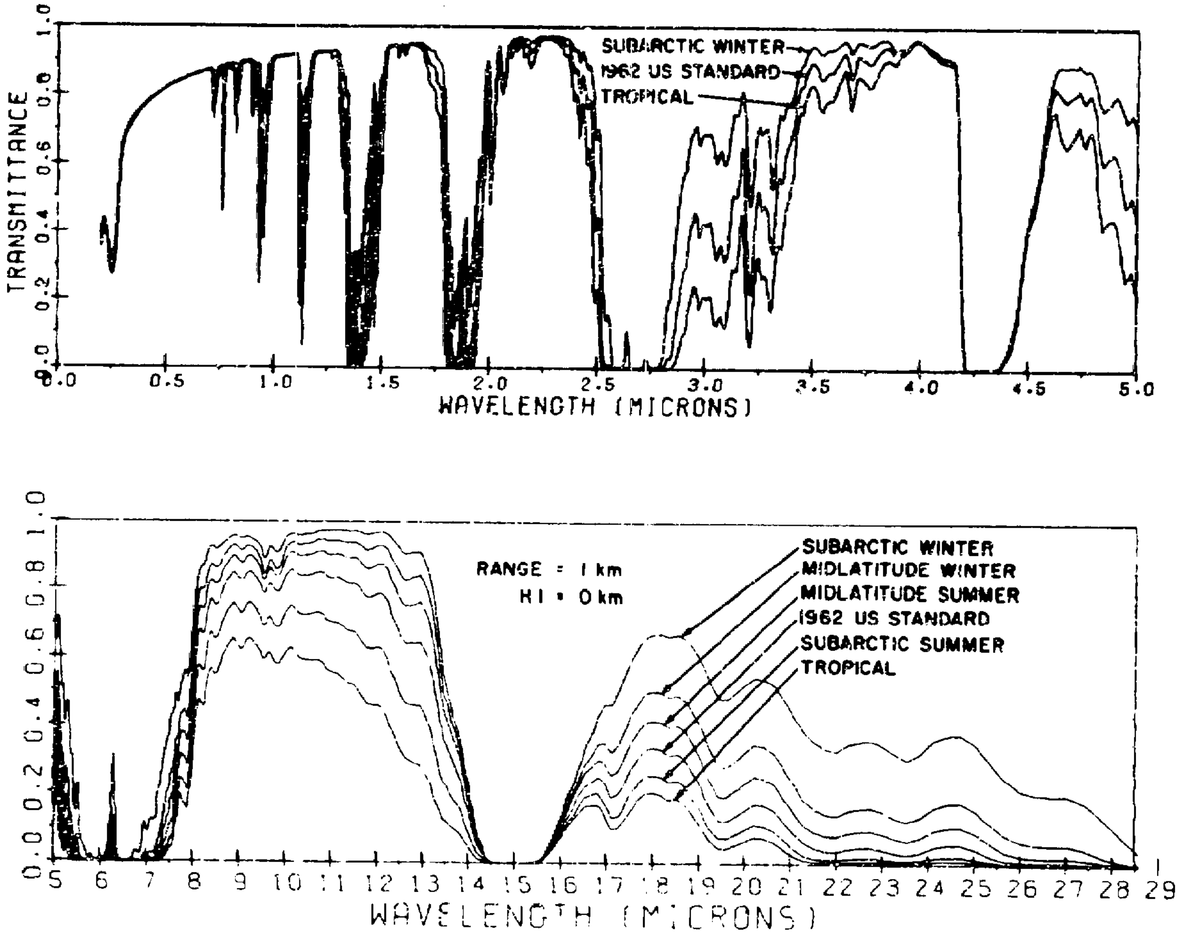


Figure 6. Atmospheric Transmittance for a 1 km Path at Sea Level for Six Model Atmospheres

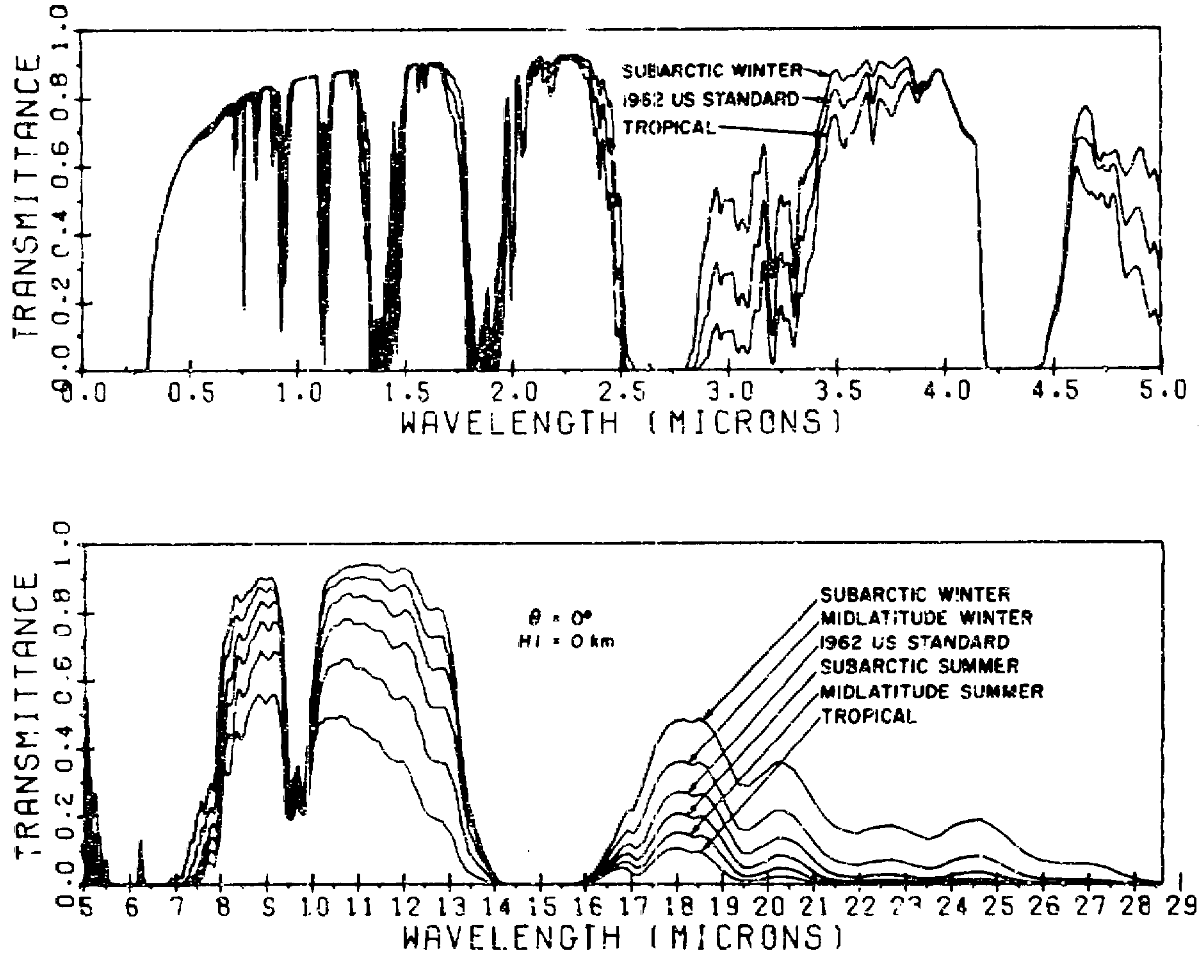


Figure 7. Atmospheric Transmittance for a Vertical Path to Space From Sea Level for Six Model Atmospheres

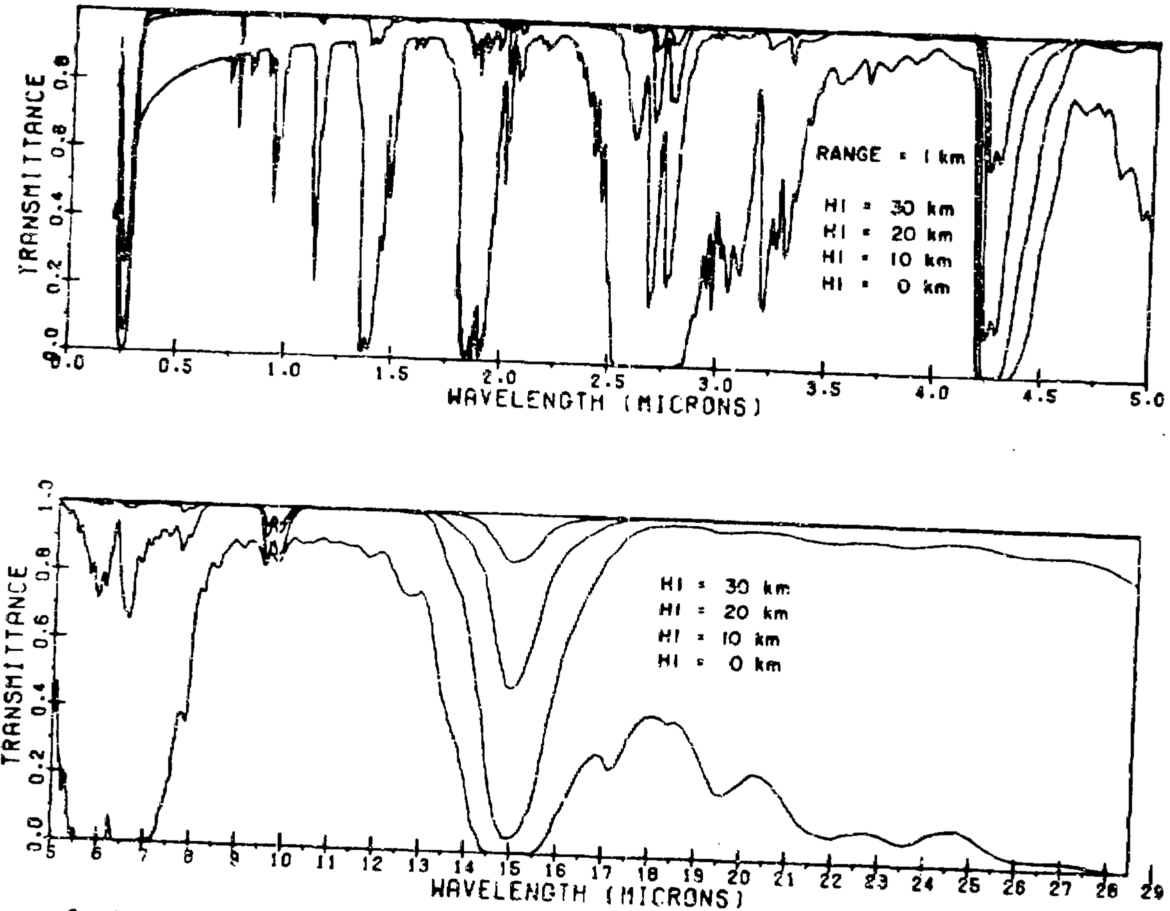


Figure 8. Variation of Transmittance With Altitude for a 1 km Path for the 1962 U.S. Standard Atmosphere

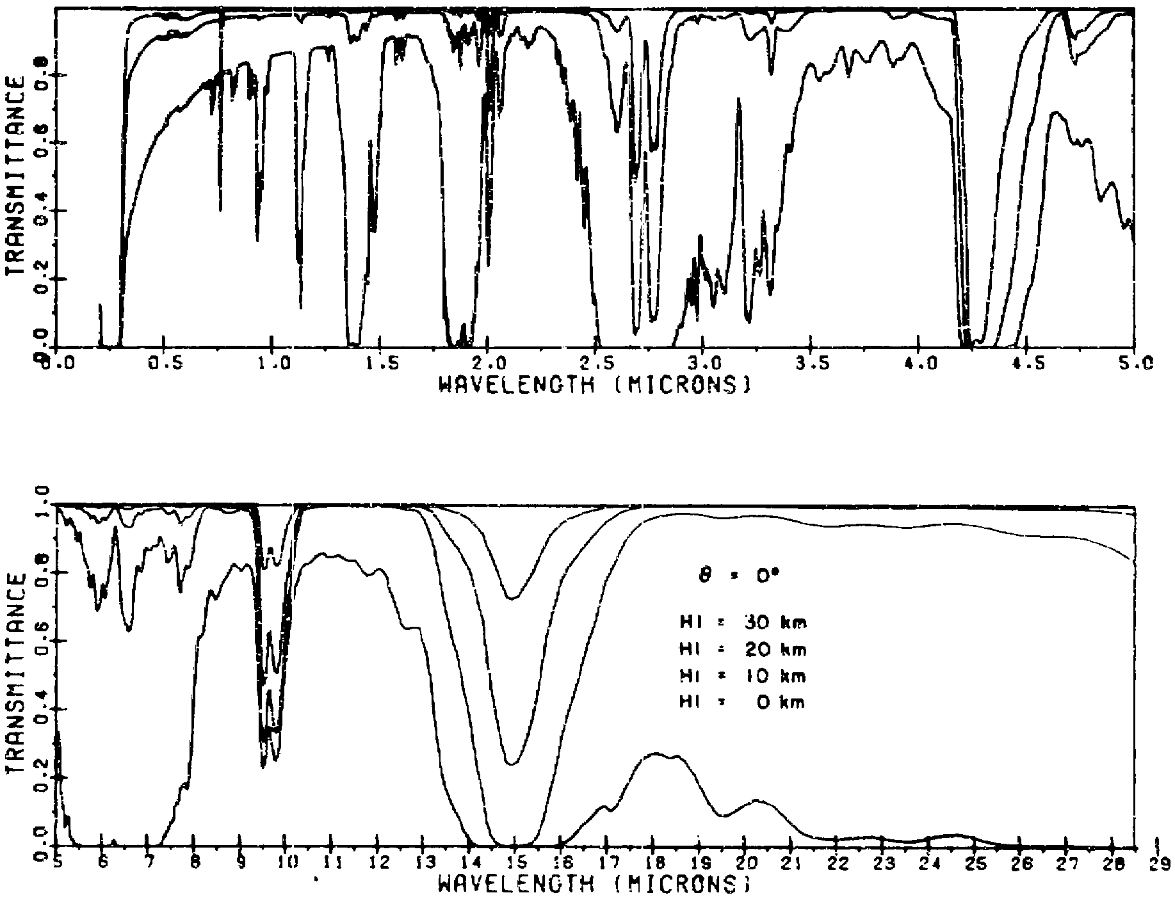


Figure 9. Variation of Transmittance With Altitude for a Vertical Path to Space for the 1962 U.S. Standard Atmosphere

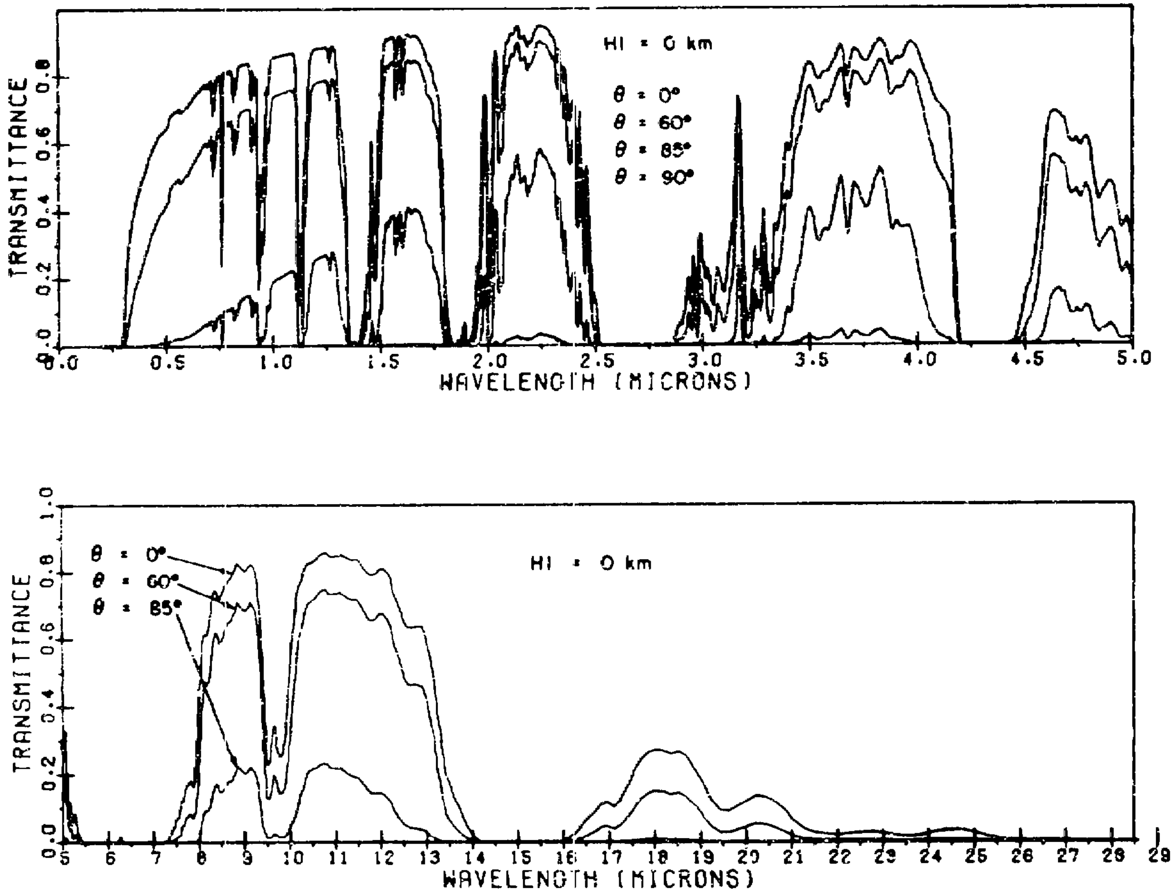


Figure 10. Variation of Transmittance With Zenith Angle for a Path From Sea Level to Space for the 1962 U.S. Standard Atmosphere

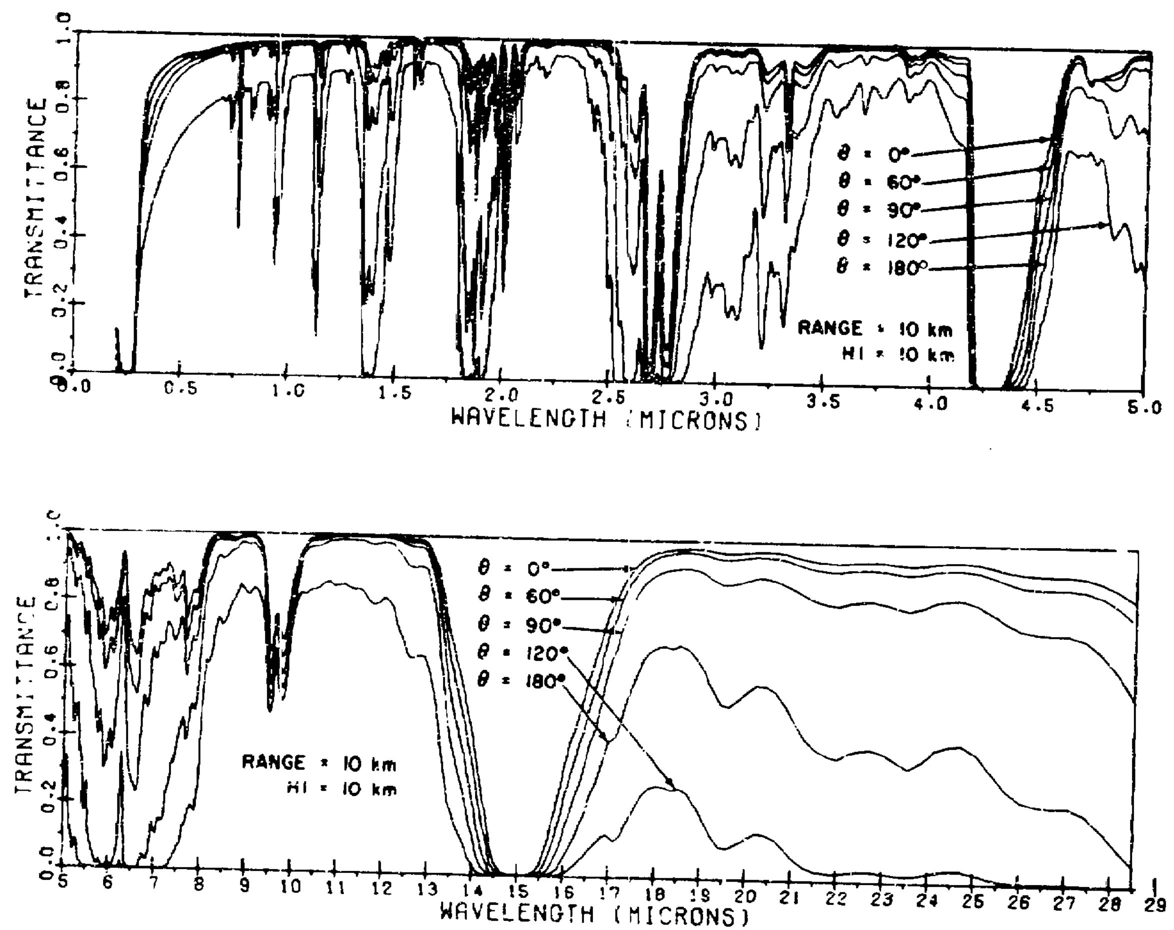


Figure 11. Variation of Transmittance With Zenith Angle for a Fixed 10 km Range at an Altitude of 10 km for the 1962 U.S. Standard Atmosphere

8. COMPARISONS OF LOWTRAN 3 PREDICTIONS WITH MEASUREMENTS

Figures 12 - 14 show some comparison of LOWTRAN 3 predictions with laboratory measurements of Howard, Burch and Williams[25] and Burch[26] for some important water vapor and carbon dioxide bands. It will be seen that the LOWTRAN 3 calculations agree closely both spectrally and in integrated absorption.

In Table 2 a comparison is made between five integrated absorption measurements of HBW[25] in the 2.7 μm H_2O band and those predicted using LOWTRAN 3. The measurements were chosen to be representative of conditions occurring in the first 50 km of the atmosphere.

Table 2. Comparison of LOWTRAN 3 Predicted and Measured Integrated Absorptions in the 2.7 μm Water Vapor Band

A = Integrated Absorption (3450 - 3850 cm^{-1})				
	Pressure (mb)	H_2O (pr cm)	$A_{LOWTRAN\ 3}$ (cm^{-1})	$A_{Meas.}$ (cm^{-1})
Case No. 1	1073	1.68	399	399
Case No. 2	997	0.21	382	374
Case No. 3	413	0.034	273	258
Case No. 4	413	0.017	133	131
Case No. 5	90.6	0.017	226	206

Figure 15 shows a transmittance spectrum measured by Gebbie et al[27] for a 1 nautical mile path over water, covering the 0.5 to 15 μm region. In the LOWTRAN 3 simulation of the spectrum the visual range was assumed to be 13 km which gives a transmittance of 60 percent at 0.6 μm. The effect of ozone absorption in the 10 μm region can be seen in the LOWTRAN 3 comparison, which shows a midlatitude winter concentration in one case and no ozone in the other. The no-ozone case appears to agree better with Gebbie's measurements.

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25. Howard, J.N., Burch, D.L., and Williams, D. (1955) Near-Infrared Transmission Through Synthetic Atmospheres, AFCRL-TR-55-213, Geophysical Research Papers No. 40.

26. Burch, D.E., Gryvnak, D., Singleton, E.B., France, W.L., and Williams, D. (1962) Infrared Absorption by Carbon Dioxide, Water Vapor, and Minor Atmospheric Constituents, AFCRL-62-698.

27. Gebbie, H.A., Harding, W.R., Hilsum, C., Pryce, A.W., Roberts, V. (1951) Proc. Roy. Soc. **206A**:87.

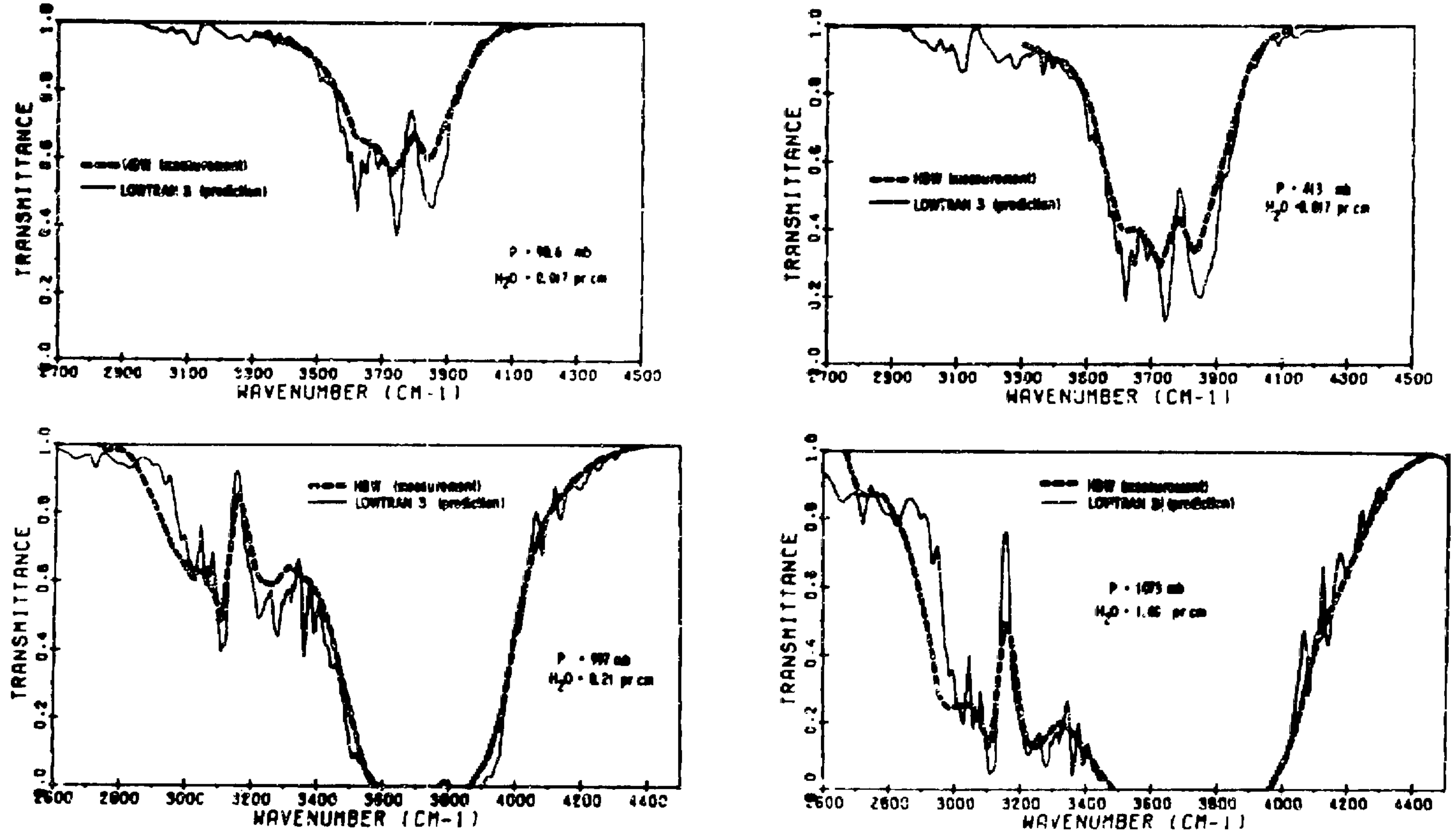

Figure 12. Comparison of LOWTRAN 3 Calculations and Howard, Burch and Williams Measurements for 2.7 μm Water Vapor Band

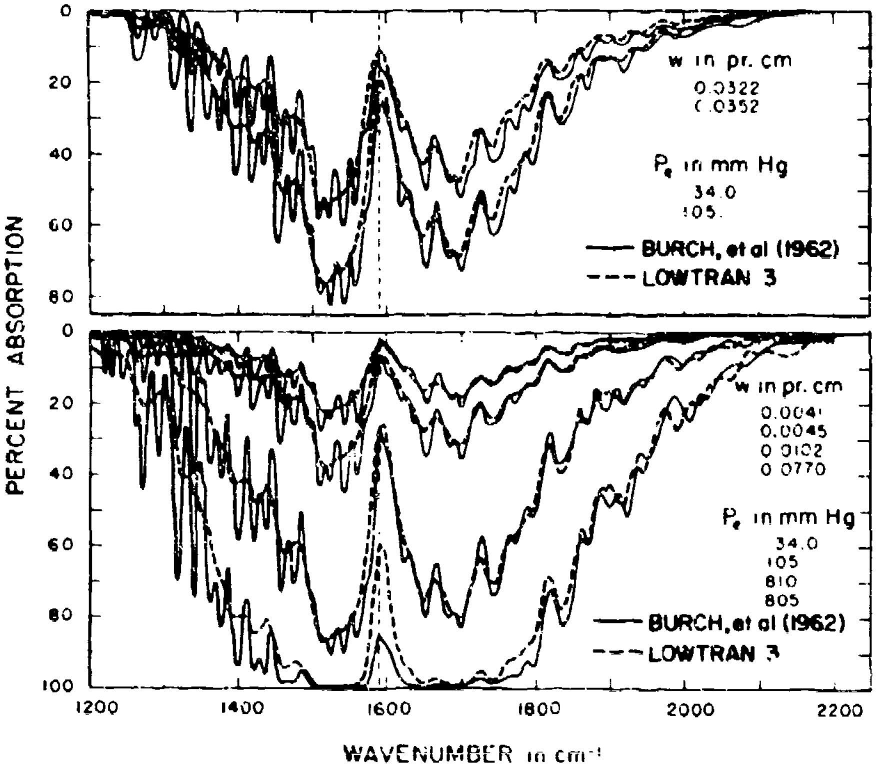

Figure 13. Representative Absorption Curves for the 6.3 μm H_2O Band. Spectral slit width equals approximately 6 cm^{-1}

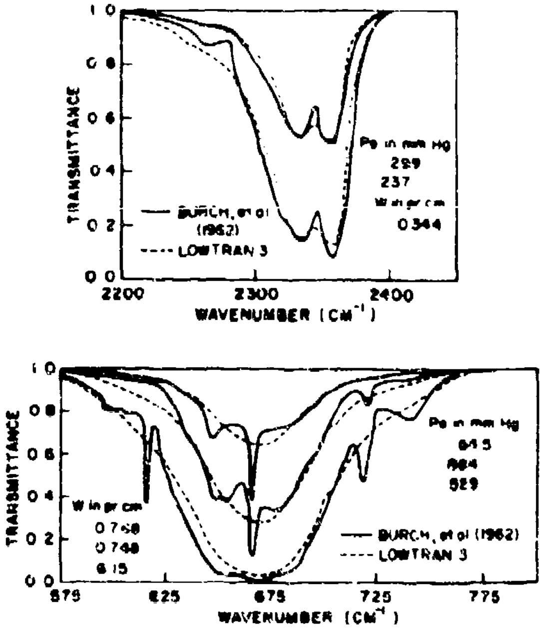

Figure 14. Comparison of LOWTRAN 3 Calculations and Measurements of Burch et al (1962) for CO_2 Bands at 4.3 μm and 15 μm

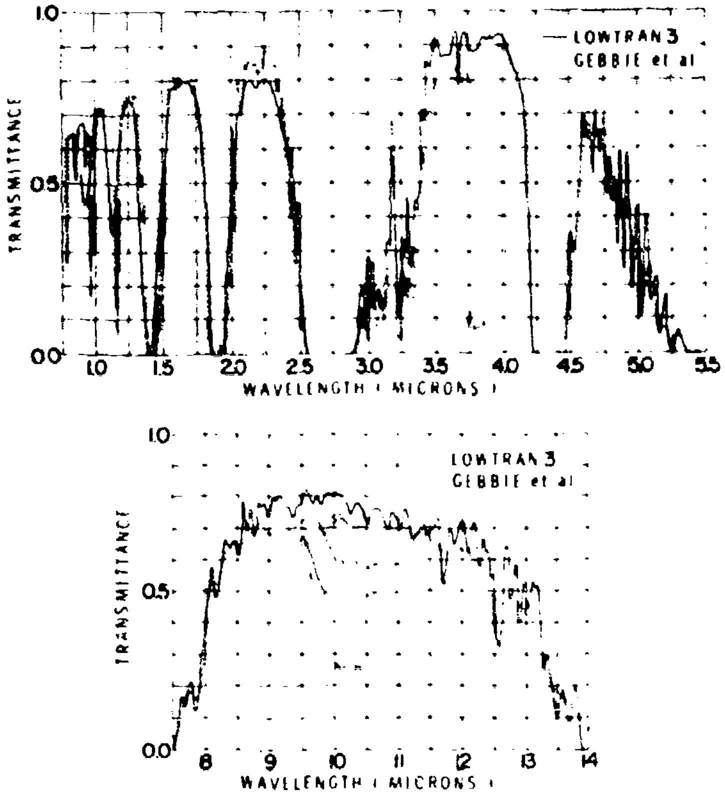

Figure 15. Atmospheric Transmittance for a 1 Nautical Mile Path (Water Content 1.7 pr cm)

Figures 16 - 22 show a series of measurements by Yates and Taylor[28] covering a wide spectral interval. The path lengths in these measurements are 0.3, 5.5, 16.25 and 27.7 km and were made at sea level (over water) with the exception of the 27.7 km path, which was at altitude of 10,000 feet. No aerosol attenuation was used in simulating the 0.3 km path using LOWTRAN 3. The apparent wavelength shift at short wavelengths in Figure 16 is due to a calibration error in Yates and Taylor's measurements. The obvious discrepancy between prediction and measurement in the 10 μm is due to the fact that Yates and Taylor artificially set the transmittance level to be 100 percent in this window region (since they were unable to estimate the water vapor continuum contribution). The water vapor continuum given in LOWTRAN 3 extends from 7 to 15 μm. There is evidence that the effect of continuum absorption by H_2O extends to longer wavelengths (Bignell,[12] Burch et al[13]), and this is currently being investigated.

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[28] Yates, H. W., Taylor, J. H. (1960) Infrared Transmission of the Atmosphere, NR Report 5453, U.S. Naval Research Laboratory, Washington, D.C.

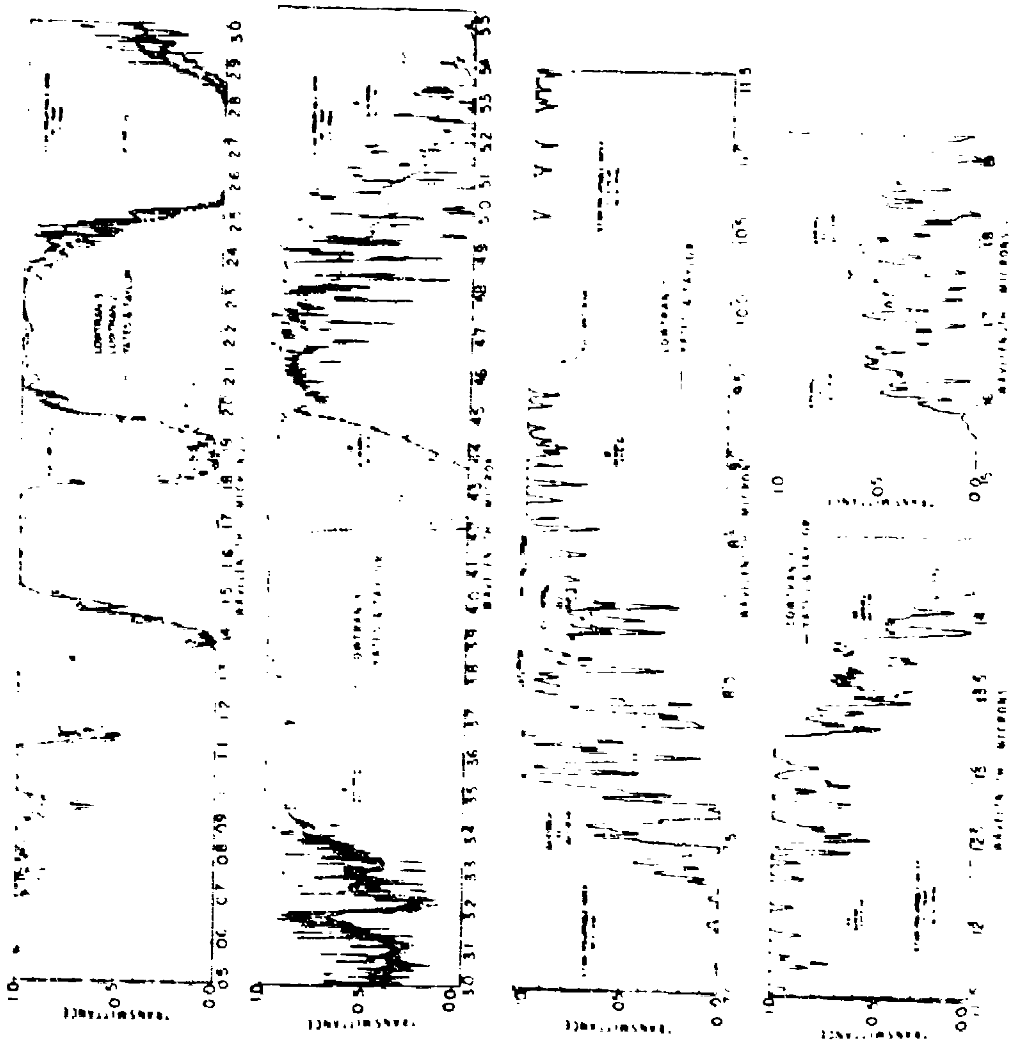
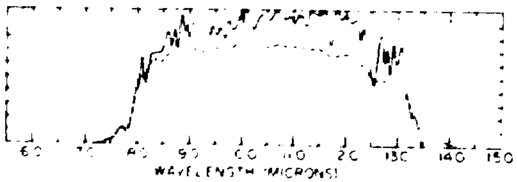
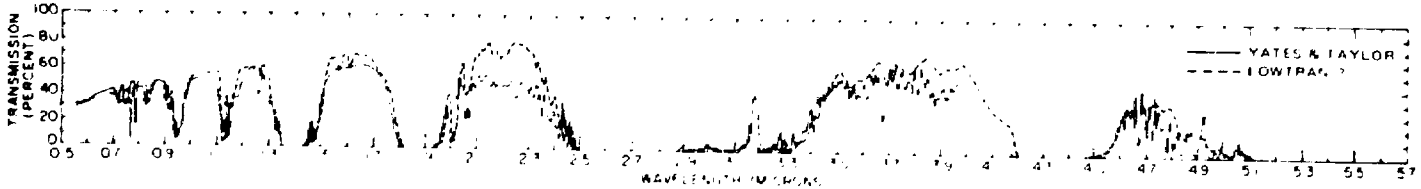


Figure 16. Atmospheric Transmittance Over a 0.3 km Path in the Chesapeake Bay Area

Path Length	5.5 km	Relative Humidity	66%
Time		H_2O in Path	2.2 cm
Temperature	38°F	Transmittance at 0.55 μm	40%
		LOWTRAN 3 visual range	23.5 km





Path Length	16.25 km	Relative Humidity	41%
Time		H_2O in Path	6.5 - 6.9 cm
Temperature	53 °F	Transmittance at 0.55 μm	20%
		LOWTRAN 3 visual range	51 km

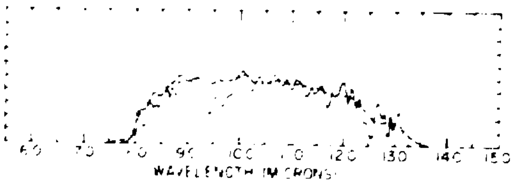
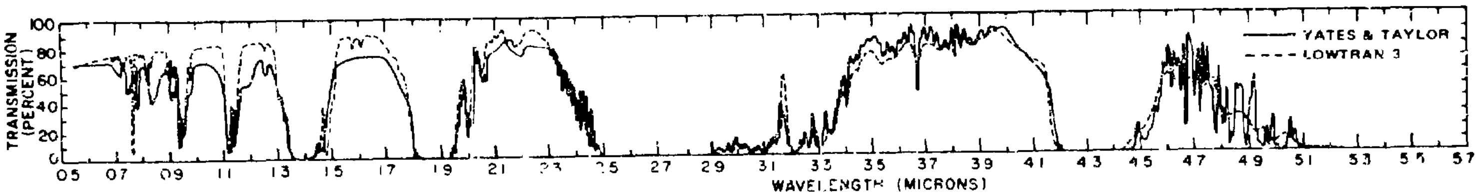
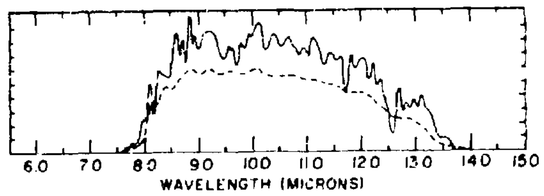


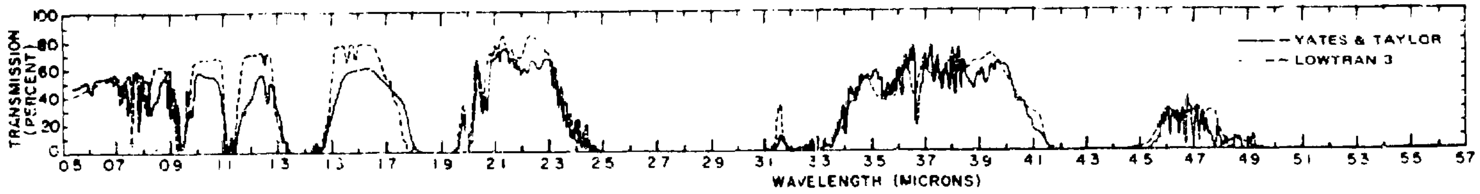
Figure 17. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over (a) 5.5 km; (b) 16.25 km in the Chesapeake Bay Area on 19 April 1956



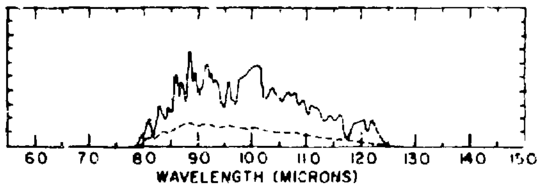
Path Length	5.5 km	Relative Humidity	51%
Time	2100 hr	H_2O in Path	4.18 cm
Temperature	64°F	Transmittance at 0.55 μm	70%
		LOWTRAN 3 visual range	60 km



(a)

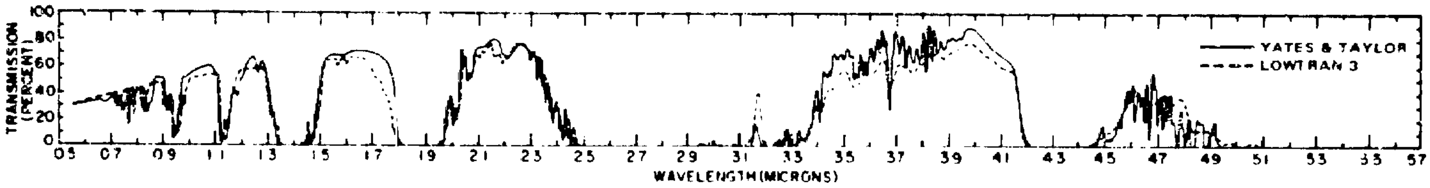


Path Length	16.25 km	Relative Humidity	53%
Time	1600 hr	H_2O in Path	15.1 cm
Temperature	69.7°F	Transmittance at 0.55 μm	43%
		LOWTRAN 3 visual range	75 km

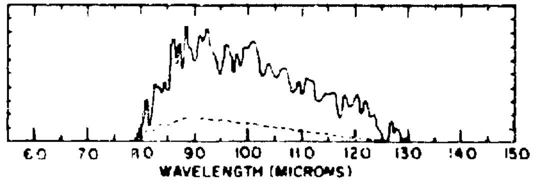


(b)

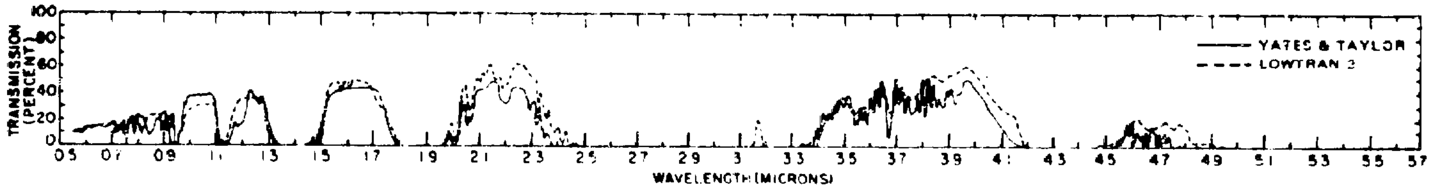
Figure 18. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over: (a) 5.5 km; (b) 16.25 km in the Chesapeake Bay Area on 19 June 1956



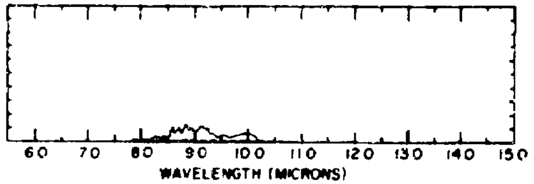
Path Length	5.5 km	Relative Humidity	73%
Time	1800 hr	H_2O in Path	9.4 cm
Temperature	78°F	Transmittance at 0.55 μm	30%
		LOWTRAN 3 visual range	18 km



(a)

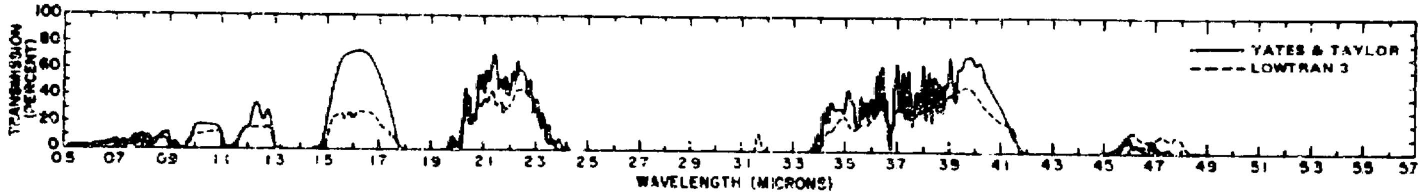


Path Length	16.25 km	Relative Humidity	82 %
Time	1100 hr	H_2O in Path	27.7 cm
Temperature	74°F	Transmittance at 0.55 μm	10%
		LOWTRAN 3 visual range	28 km



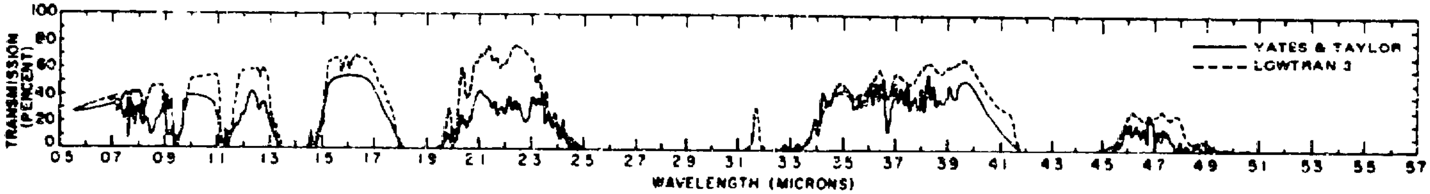
(b)

Figure 19. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over: (a) 5.5 km; (b) 16.25 km in the Chesapeake Bay Area on 27 August 1956



Path Length	16.25 km	Relative Humidity	59%	LOWTRAN 3 visual range	16.2 km
Time	1900 hr	H_2O in Path	36 - 38 cm		
Temperature	87.5°F	Transmittance at 0.55 µm	2%		

Figure 20. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over 16.25 km in the Chesapeake Bay Area on 16 June 1957



Path Length	27.7 km	Relative Humidity	100%
Altitude	10,000 ft	H_2O in Path	20 cm
Time	1130 hr	Transmittance at 0.55 µm	26.5%
Temperature	43°F	LOWTRAN 3 visual range	50 km

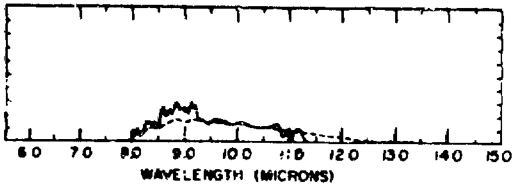
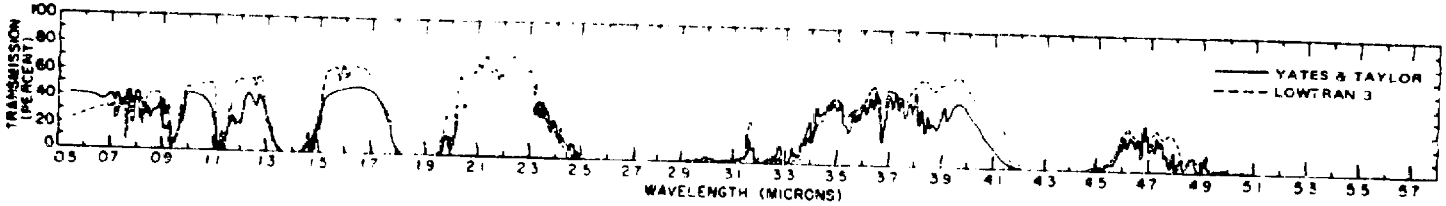


Figure 21. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over 27.7 km in the Hawaiian Islands on 1 September 1957



Path Length	27.7 km		
Altitude	10,000 ft	H_2O in Path	8 - 13 cm
Time	2300 hr	Transmittance at 0.55 μm	41%

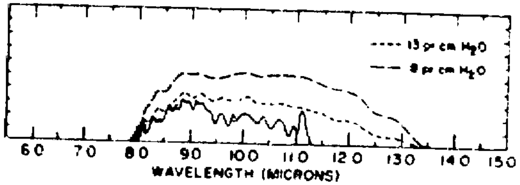


Figure 22. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over 27.7 km in the Hawaiian Islands 6 - 7 September 1957

In Figures 17 - 22 the transmittance values at 0.55 μm given by Yates and Taylor were used to estimate the visual range used in the LOWTRAN 3 simulations. In some cases (see Figure 22 for example), choosing a lower visual range gives far better agreement between the measurements and LOWTRAN 3 predictions. Generally, the predictions and measurements disagree most in the 10 μm region, where it is extremely difficult to obtain absolute transmittance values from long path measurements in the atmosphere. Because of the importance of the 10 μm window region in many applications, it is strongly suggested that future field measurements of this kind be carried out with extreme care, in order to obtain reliable atmospheric transmittance data against which a model such as LOWTRAN 3 can be tested.

It is also apparent that there are some inconsistencies in the measurements shown in Figures 16 - 22 which are the cause of some apparent deviations between the LOWTRAN 3 predictions, and the measurements.

Figures 23 - 26 show some more recent sea level measurements made by Ashley et al[29] (General Dynamics). These measurements have been made at somewhat higher resolution (~ 4 cm^{-1}) and cover the spectral regions 1.8 - 5.4 μm and 4.8 - 14 μm using two interferometers with different detectors. In Figures 23 and 24 the transmittance measurements were made over short and medium path lengths (that is, ~ 0.045 km and 3.25 km) and covered the spectral region from 1.8 to 5.4 μm. A 1.3 km sea level path transmittance spectrum covering the 1.8 to 14 μm region is shown in Figure 25. In the latter spectrum the transmittance was normalized to unity in the 10 μm region. The anomalous spike shown at ~ 13 μm was due to electrical noise. Figure 26 shows a long slant path measurement (~ 12 km) from 800 ft to 3187 ft altitude. Again the agreement between these measurements and LOWTRAN 3 predictions is good. The improvement of LOWTRAN 3 over LOWTRAN 2 in the 2 - 3.5 μm region can be seen from Figure 25.

Figure 27 shows three aircraft measurements made by Cumming et al[30] (CARDE) in the 2.7 μm region at an altitude of 13.7 km. The measurements were made over Florida using the sun as a radiation source.

In the LOWTRAN 3 predictions shown in Figure 27 the sensitivity of the transmittance to atmospheric conditions is indicated. For example the upper figure shows the transmittance obtained from LOWTRAN 3 using the tropical and 1962 U.S. Standard Atmospheres compared with the CARDE measurement. The second

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[29] Ashley, G.W., Gastineau, L., and Blay, D. (1973) Private Communication.

[30] Cumming, C., Hawkins, G.R., McKinnon, D.J.G., Rollins, J., and Stephenson, W.R. (1965) Quantitative Atlas of Infrared Stratospheric Transmission in the 2.7 Micron Region, Canadian Armament Research and Development Establishment, CARDE T.R. 546/65, Project D46-38-01-19.

figure shows a LOWTRAN 3 comparison using the Tropical Model Atmosphere with and without aerosol attenuation. The latter curve appears to agree better with the measurement.

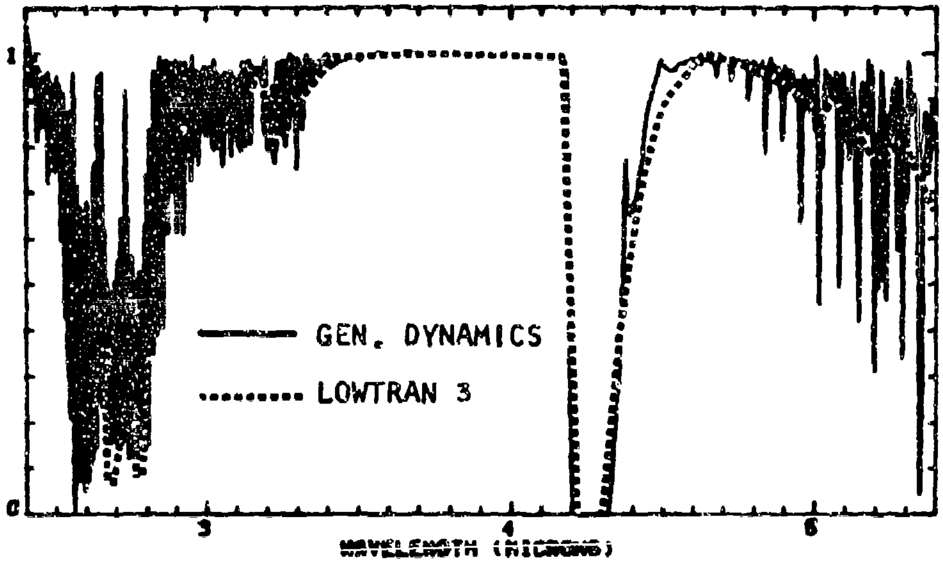

Figure 23. Comparison Between LOWTRAN 3 and General Dynamics Measurements 150 ft (45 m) Path at Sea Level (H_2O = 0.35 pr cm/km)

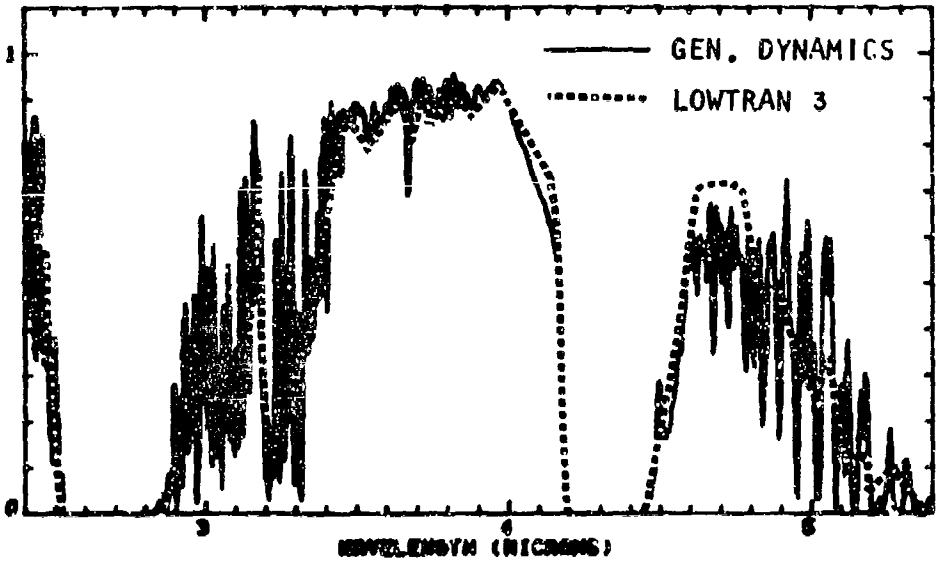

Figure 24. Comparison Between LOWTRAN 3 and General Dynamics Measurements; 10,679 ft (3.25 km) Path at Sea Level (H_2O = 0.35 pr cm/km)

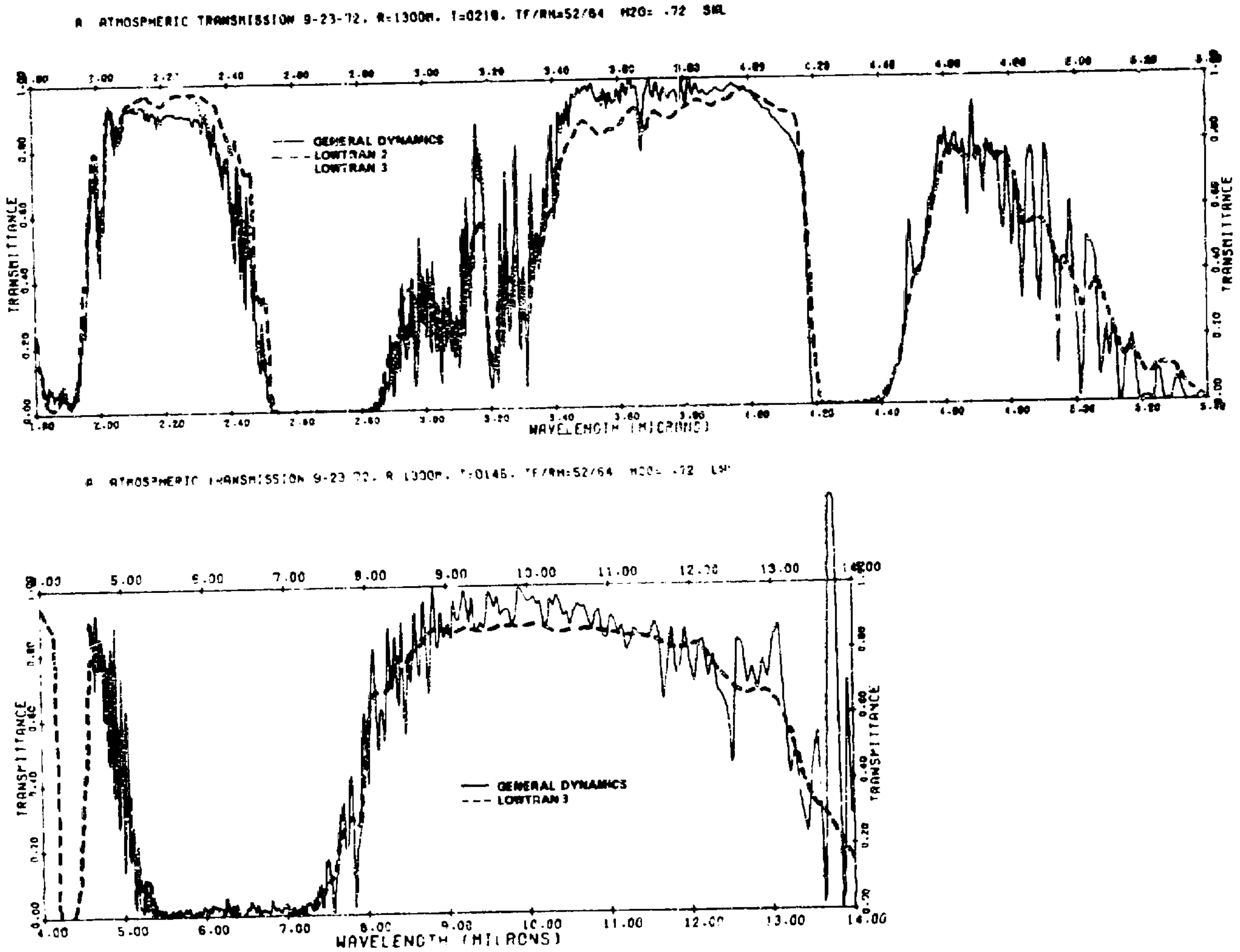

Figure 25. Comparison Between LOWTRAN 3, LOWTRAN 2, and General Dynamics Measurements; Range = 1.3 km at Sea Level (H_2O = 0.72 pr cm/km)

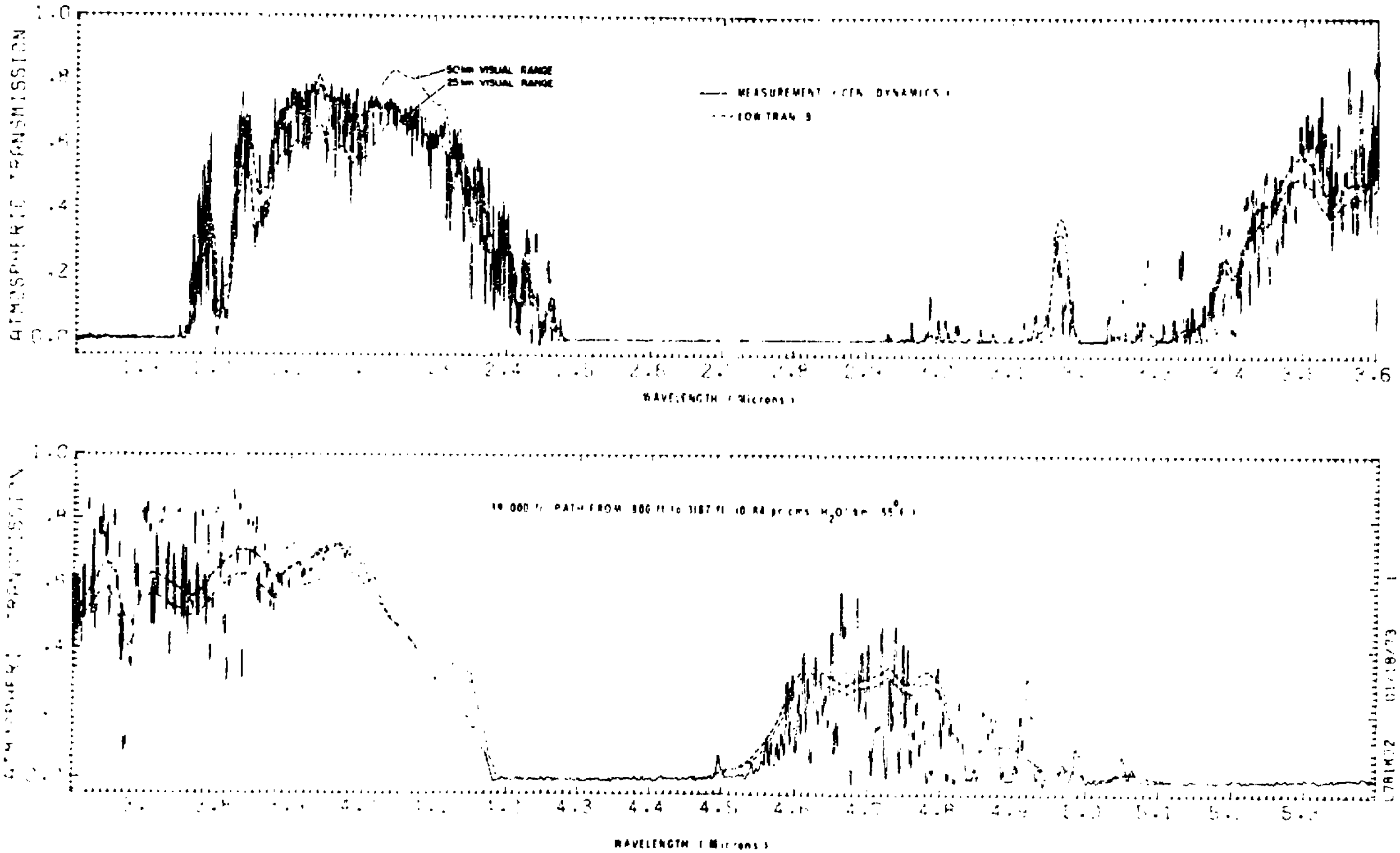

Figure 26. Comparison Between LOWTRAN 3 and General Dynamics Measurements; 39,000-ft path from 800 ft to 3187 ft (0.84 pr cm H_2O/km)

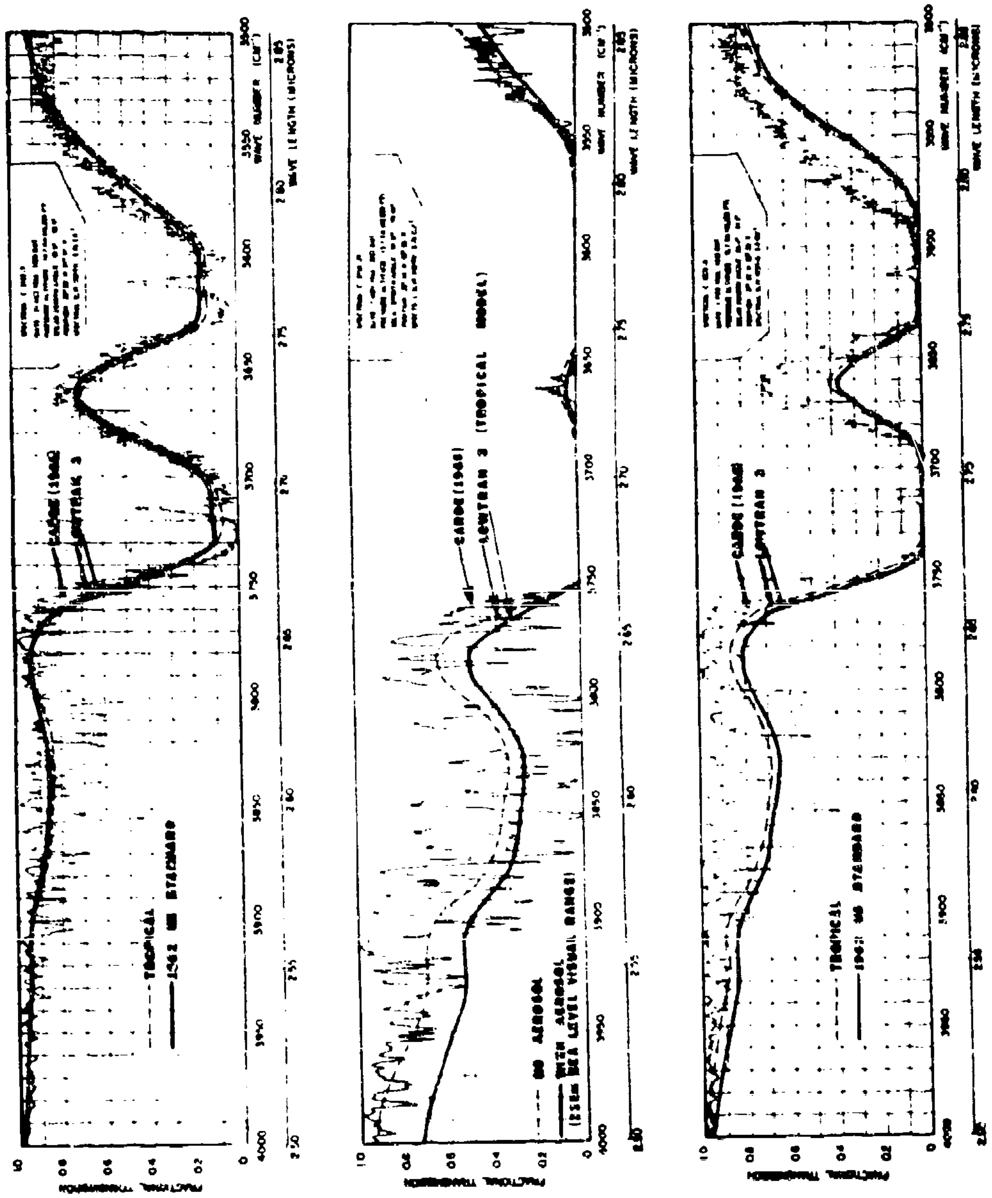

Figure 27. Comparison Between LOWTRAN 3 and CARDE (1965) Measurements Through an Atmospheric Slant Path

Figure 28 shows two atmospheric transmittance measurements made by Farmer et al[31] (EMI) for horizontal paths at 5.2 km altitude in the Bolivian Andes. The measurements were made over path lengths of 1.9 and 8.4 km and covered the 4 μm spectral region.

In general, LOWTRAN 3 predictions compare fairly well with available atmospheric transmittance measurements. Further laboratory studies will be conducted to determine more accurately the effect of continuum absorption by water vapor primarily in the 10 μm and 18 - 30 μm regions. It is hoped that further refined atmospheric transmittance measurements over long atmospheric paths will be made in the near future, with much attention payed to obtaining accurate absolute transmittance measurements in the window regions.

As more measurements become available, it is planned to update LOWTRAN. A version of the program which is also capable of predicting atmospheric "clear sky" and earth backgrounds will be published in the near future. Two examples of some typical radiance calculations using a modified LOWTRAN program are shown in Figure 29. Figure 29a gives the clear sky radiance for a vertical path from sea level to space for six model atmospheres and Figure 29b shows both the upward spectral radiance (as viewed from space) for a midlatitude winter model atmosphere and the downward radiance at sea level. The back body spectral radiance curve, superimposed on Figure 29b corresponds to a ground temperature of 272°K (assuming a ground emissivity of unity).

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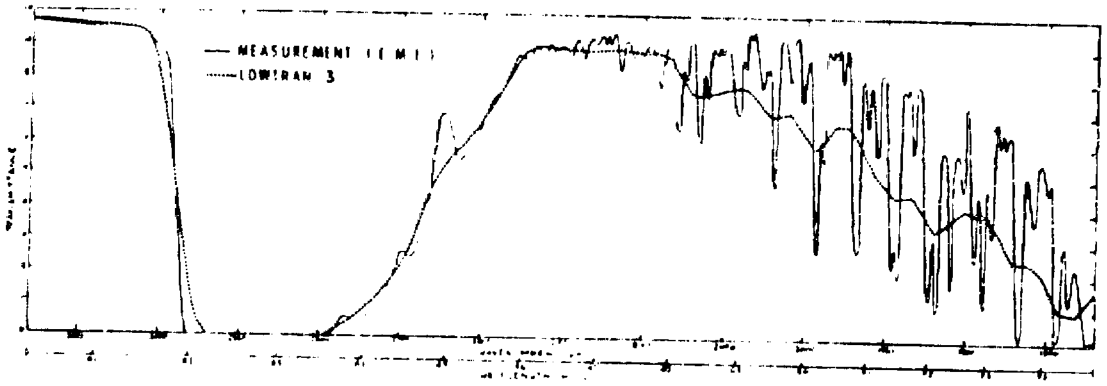
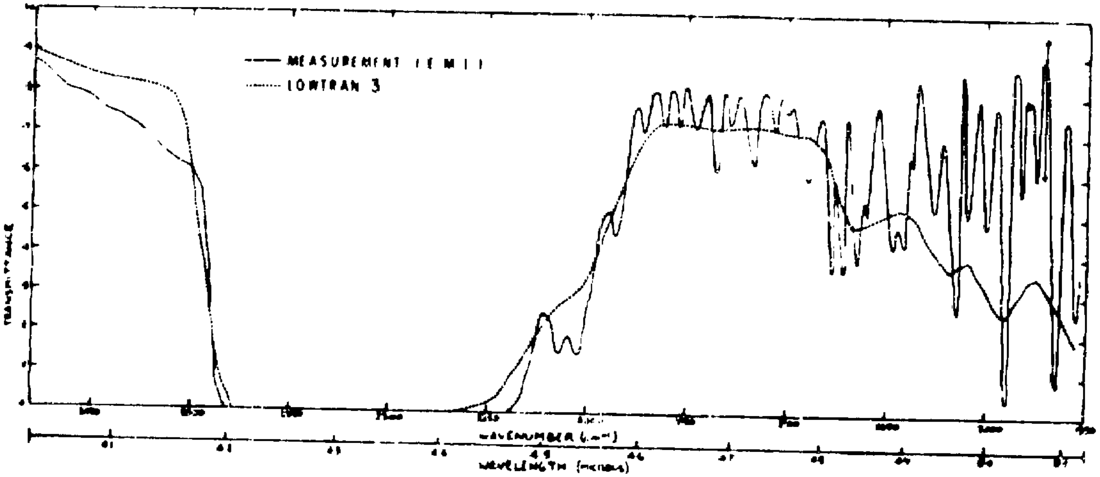
[31] Farmer, C. B., Berry, P. J., and Lloyd, D. B. (1963) Atmospheric Transmission Measurements in the 3.5 to 5.5 Micron Band at 5200 Meters Altitude, EMI Electronics Limited, Hayes, Middlesex, England, Report No. DMP 1578.



1.9 km PATH at 5.2 km ALTITUDE (0.32 pr cm H_2O)



8.4 km PATH at 5.2 km ALTITUDE (1.9 pr cm H_2O)

Figure 28. Comparison Between LOWTRAN 3 and EMI Measurements for a 1.9 km and 8.4 km Path

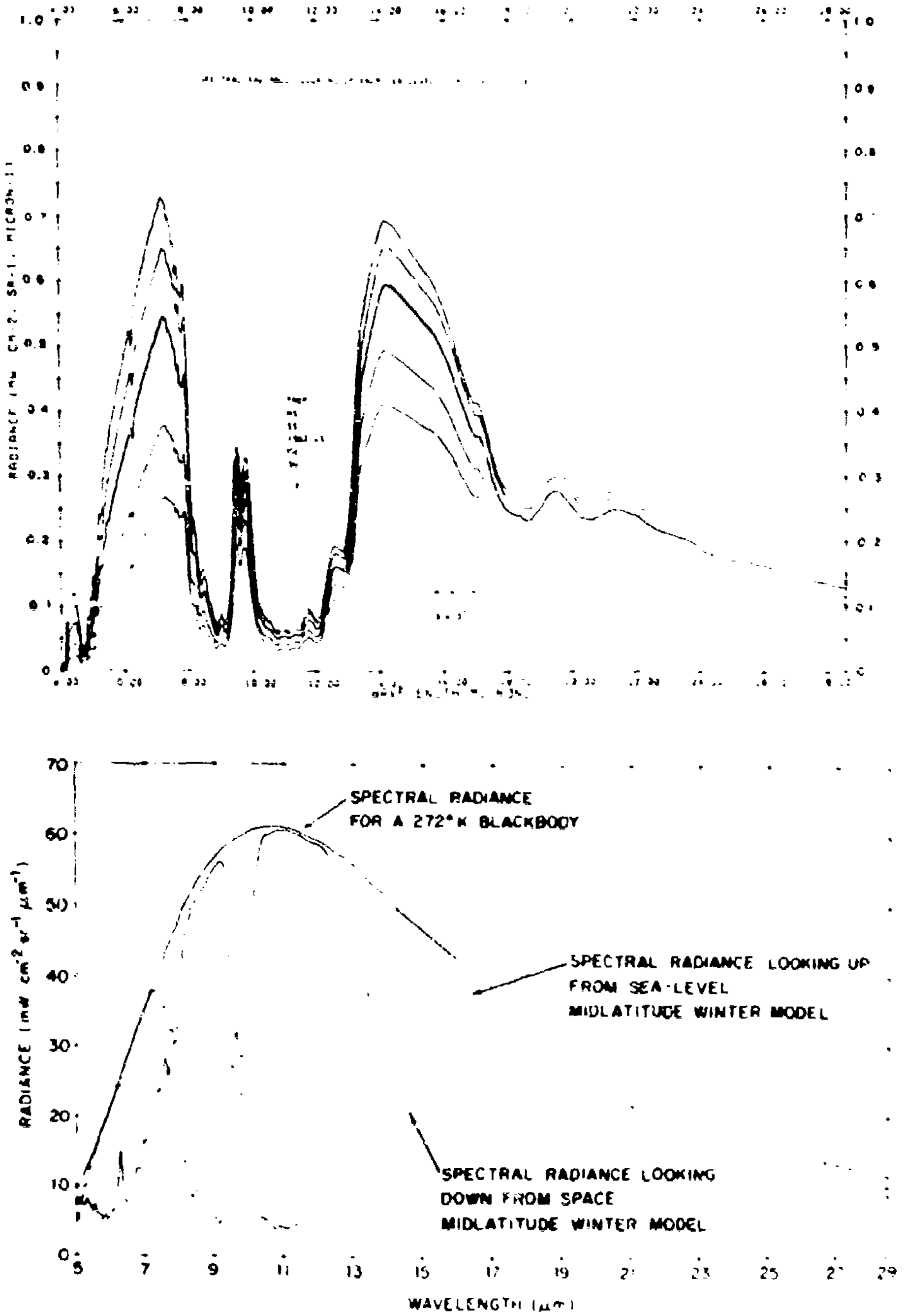


Figure 29. Two Examples of Some Typical Radiance Calculations Using a Modified LOWTRAN Program

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Appendix A

Listing of Program and Data

A listing of the Fortran program LOWTRAN 3 is given in Table A1 together with the two subroutines POINT and ANGL (see Appendix C for an explanation of subroutine ANGL). The input data for the program is given in Table A2. A general flow chart for the main program is presented in Appendix B, and definitions of the symbols used in the computer codes are summarized in Appendix D.

The subroutine POINT has a twofold purpose. When the subroutine is called for a given altitude X, it is used to determine the mean refractive index (1) in the layer between X and the level above, TX(9), and (2) in the layer between X and the level below, YN. In addition, an interpolation scheme is used to determine the effective absorber amounts per km at altitude X for each absorber. When the parameter IP is set equal to zero, only the mean refractive index above and below altitude X is determined from POINT.

The subroutine ANGL is used solely for the purpose of calculating the initial zenith angle (θ_o or ANGL) by an iterative scheme taking into account refraction, given (1) the initial and final altitudes of the path (H1 and H2 respectively) and the angle subtended at the earth's center (β or BETA) by the trajectory, or (2) the initial altitude and tangent height (H1 and HMIN respectively). Examples of two typical problems involving the use of the subroutine ANGL are given in Sections 6.6 and 6.7. An explanation of the iteration scheme is given in Appendix C.

The changes necessary to update LOWTRAN 2 to LOWTRAN 3 are indicated by the symbols *, +, A, B, C etc. against the card sequence numbers in Table A1. The - symbol indicates that the following card (in LOWTRAN 2) has been removed.

Table A1. Listing of Fortran Code LOWTRAN 3

```
      PROGRAM LOWTRAN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)            A   1
      COMMON Z(34),P(7,34),T(7,34),FH(10,34),WH(7,34),M,NL,RE,DH,CO,PI  A   2*
      DIMENSION WO(7,34),HZ1(34),HZ2(5),AHAZE(34),AHZ2(20)              A   3*
      DIMENSION TP(57),FH(67),FD(67),HZ(2),TX(10),VH(10),W(10),E(10)    A   4
      DIMENSION C1(2580), C2(1575), C3(540), C4(133), C5(15), C8(102)   A   5A
      DIMENSION VX(45),C7(45),C7A(45)                                   A   5B
      F(A)=EXP(18.9766-14.9595*A-2.43882*A*A)*A                         A   5C
      DATA HZ(1)/5H23 KM/,HZ(2)/5H 5 KM/                                A   6
C*******************************************************************     A   7
C     PROGRAM LOWTRAN3 CALCULATES THE TRANSMITTANCE OF THE ATMOSPHERE   A   8
C     FROM 350 CM-1 TO 40000 CM-1 (0.25 TO 28.57 MICRONS) AT 20 CM-1    A   9
C     SPECTRAL RESOLUTION ON A LINEAR WAVENUMBER SCALE.                 A  10
C     REFRACTION AND EARTH CURVATURE EFFECTS ARE INCLUDED.   ATMOSPHERE A  11
C     IS LAYERED IN ONE KM. INTERVALS BETWEEN 0 AND 25 KM., 5 KM. INTER- A  12
C     VALS TO 50 KM., A TWENTY KM. INTERVAL TO 70 KM., AND A THIRTY KM. A  13
C     INTERVAL TO 100 KM.                                               A  14
C*******************************************************************     A  15
C     PROGRAM ACTIVATED BY SUBMISSION OF FOUR CARD SEQUENCE AS FOLLOWS  A  16
C                                                                       A  17
C   CARD 1 MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO  FORMAT(10I3,F10.3) A  18*
C   CARD 2 H1,H2,ANGLE,RANGE,BETA,VIS                  FORMAT(7F10.3)   A  19
C   CARD 3 V1, V2, DV                                  FORMAT(7F10.3)   A  20
C   CARD 4 IXY                                         FORMAT(I3)       A  21
C                                                                       A  22
C     MODEL=1,2,3,4,5 OR 6 SELECTS ONE OF THE FOLLOWING MODEL ATMOSPHERE A  23
C     TROPICAL,MIDLATITUDE SUMMER,MIDLATITUDE WINTER,SUBARCTIC SUMMER,  A  24
C     SUBARCTIC WINTER,OR THE 1962 U.S.  STANDARD RESPECTIVELY          A  25
C     MODEL=0 FOR HORIZ. PATH WHEN METEOROL. DATA USED:INSTEAD OF CARD 2 A  26*
C     READ H1,P(MB),T(DEG C),DEW PT.TEMP(DEG C),%REL HUMIDITY,H2O DENSITY A  27*
C     (GM.M-3),O3 DENSITY(GM.M-3), VIS(KM),RANGE(KM) WITH FORMAT 429.   A  28*
C     MODEL=7 WHEN NEW MODEL ATMOSPHERE(E.G. RADIOSONDE DATA) USED.     A  29A
C     DATA CARDS ARE READ IN BETWEEN CARDS 1 AND 2, AND SHOULD CONTAIN: A  29B
C     ALTITUDE(KM.),PRESSURE,TEMP,DEW PT.TEMP,REL. HUMIDITY,H2O DENSITY, A  29C
C     O3 DENSITY,AEROSOL NO. DENSITY(CM-3) ACCORDING TO FORMAT 429.     A  29D
C     NOTE THAT EITHER DEW PT. TEMP.OR REL. HUMIDITY CAN BE USED.       A  29E
C                                                                       A  29F
C     M1,M2,M3, ARE USED TO CHANGE TEMP,H2O, AND O3 ALTITUDE PROFILES.  A  29G
C                                                                       A  30
C     IF IHAZE=0 NO AEROSOL SCATTERING IS COMPUTED                      A  31
C     IHAZE =1 IF AEROSOL ATTENUATION REQUIRED (THIS IS USED IN         A  32
C     CONJUNCTION WITH VISUAL RANGE(SEE CARD 2))                        A  33
C     IHAZE = 1 OR 2 ALSO GIVE AEROSOL ATTENUATION FOR 23KM AND 5KM VIS. A  34
C     HAZE MODELS RESPECTIVELY IF VIS =0 ON CARD 2                      A  35
C                                                                       A  36
C     ITYPE=1,2  OR 3 INDICATES THE TYPE OF ATMOSPHERIC PATH            A  37
C     ITYPE=3,VERTICAL OR SLANT PATH TO SPACE                           A  38
C     ITYPE=2,VERTICAL OR SLANT PATH BETWEEN TWO ALTITUDES              A  39
C     ITYPE=1, CORRESPONDS TO A HORIZONTAL (CONSTANT PRESSURE) PATH     A  40
C                                                                       A  41
C     H1=OBSERVER ALTITUDE (KM)                                         A  42
C     H2=SOURCE  ALTITUDE (KM)                                          A  43
C     ANGLE= ZENITH ANGLE AT H1 (DEGREES)                               A  44
C     RANGE=PATH LENGTH (KM)                                            A  45
C     BETA=EARTH CENTRE ANGLE                                           A  46
C     VIS = VISUAL RANGE AT SEA LEVEL (KM)                              A  47
C     (IF ITYPE=1 READ H1 AND RANGE:IF ITYPE=3 READ H1 AND ANGLE.       A  48
C     IF ITYPE=2 READ H1 AND TWO OTHER PARAMETERS E.G. H2 AND ANGLE)    A  49
C                                                                       A  50
C     V1=INITIAL FREQUENCY (WAVENUMBER CM-1 ) INTEGER VALUE             A  51
C     V2=FINAL FREQUENCY(WAVENUMBER CM-1 ) INTEGER VALUE                A  52
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
C     DV= FREQUENCY INTERVALS AT WHICH TRANSMITTANCE IS PRINTED          A  53
C     NOTE: DV MUST BE A MULTIPLE OF 5 CM-1                              A  54
C                                                                        A  55
C     IXY=0  TO END DATA ,=1 FOR NEW V1,V2,DV ONLY , =2 TO CONTINUE DATA A  56
C     IXY=3 FOR NEW CARD 2 ONLY,=4 FOR NEW CARD 1 ONLY.                  A  57A
C*********************************************************************** A  57B
      IXY=0                                                              A  57C
      READ (5,400) IATM,NL                                               A  58
      READ (5,401) (HZ1(I),I=1,NL)                                       A  59
      READ (5,401) (HZ2(I),I=1,5)                                        A  60
      DO 1 J=1,3                                                         A  61
      K2=2*J                                                             A  62
      K1=K2-1                                                            A  63
      DO 1 I=1,NL                                                        A  64
1     READ (5,402) Z(I),(P(K,I),T(K,I),WH(K,I),WO(K,I),K=K1,K2)          A  65
      READ (5,431) (VX(I),C7(I),C7A(I),I=1,44)                           A  66*
      READ (5,403) (TR(I),FH(I),FO(I),I=1,67)                            A  67
      READ (5,404) (C1(I),I=1,2580)                                      A  68
      READ (5,404) (C2(I),I=1,1575)                                      A  69
      READ (5,404) (C3(I),I=1,540)                                       A  70
      READ (5,405) (C4(I),I=1,133)                                       A  71
      READ (5,406) (C5(I),I=1,15)                                        A  72
      READ (5,405) (C8(I),I=1,102)                                       A  73
      PI=2.0*ASIN(1.0)                                                   A  74*
      CA=PI/180.                                                         A  75
      IP=0                                                               A  76
2     CONTINUE                                                           A  77
      RE=6371.23                                                         A  78
      IFIND=0                                                            A  79
C     JP NE 0  SUPRESS PRINT                                             A  79+
      READ 400,MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO                A  80
      PRINT400,MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO                A  81
C     PRINT 424, MODEL,IHAZE,ITYPE,LEN                                   A  81
 200  M=MODEL                                                            A  82
      IF (M.EQ.1) RE=6370.39                                             A  83
      IF (M.EQ.4) RE=6356.91                                             A  84
      IF (M.EQ.5) RE=6356.91                                             A  85A
      IF(IXY.GT.3) GO TO 8                                               A  85B
      IF(RO.NE.0.0) RE=RO                                                A  85C
      IF(M.EQ.7.AND.IM.NE.0)GO TO 4                                      A  85D
      IF (MODEL.EQ.0) GO TO 4                                            A  86
 300  READ 406, H1,H2,ANGLE,RANGE,BETA,VIS                               A  87*
      PRINT 425, H1,H2,ANGLE,RANGE,BETA,VIS                              A  88
      X1=RE+H1                                                           A  89
      IF (ITYPE.EQ.3) GO TO 560                                          A  90*
      IF (ITYPE.EQ.1) GO TO 8                                            A  91
      X2=RE+H2                                                           A  92
      IF (RANGE.EQ.0.) GO TO 5                                           A  93
      PRINT 428, H1,H2,ANGLE,RANGE,BETA,VIS                              A  94
      IF (H2.EQ.0.AND.ANGLE.NE.0) GO TO 3                                A  95
      ANGLE=ACOS(0.5*((H2-H1)*(1.+X2/X1)/RANGE-RANGE/X1))/CA             A  96
      GO TO 7                                                            A  97
 3    X2=SQRT((X1/RANGE+RANGE/X1+2.0*COS(ANGLE*CA))*X1*RANGE)            A  98
      H2=X2-RE                                                           A  99
      GO TO 7                                                            A 100
 4    CONTINUE                                                           A 101*
      IF(ML.LE.0)ML=1                                                    A 102*
      DO 540 K=1,ML                                                      A 103A
      AHAZE(K)=0.0                                                       A 103B
      IF(M.EQ.0)READ 429,H1,P(7,1),TMP,DP,RH,WH(7,K),WO(7,K),VIS,RANGE   A 103C
      IF(M.EQ.0)PRINT 430,H1,P(7,1),TMP,DP,RH,WH(7,K),WO(7,K),VIS,RANGE  A 103D
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF(M.GT.0)READ 429,Z(K),P(7,K),TMP,DP,RH,WH(7,K),WO(7,K),AHAZE(K)    A 103E
      J=IFIX(Z(K)+1.0E-6)+1.                                               A 103F
      IF(M.EQ.0)Z(K)=H1                                                    A 103G
      IF(Z(K).GE.25.0) J=(Z(K)-25.0)/5.0+26.                               A 103H
      IF(Z(K).GE.50.0) J=(Z(K)-50.0)/20.0+31.                              A 103I
      IF(Z(K).GE.70.0) J=(Z(K)-70.0)/30.0+32.                              A 103J
      IF(J.GT.33)J=33                                                      A 103K
      FAC=Z(K)-FLOAT(J-1)                                                  A 103L
      IF(J.LT.26) GO TO 500                                                A 103M
      FAC=(Z(K)-5.0*FLOAT(J-26)-25.)/5.                                    A 103N
      IF(J.GE.31) FAC=(Z(K)-50.0)/20.                                      A 103O
      IF(J.GE.32) FAC=(Z(K)-70.0)/30.                                      A 103P
      IF(FAC.GT.1.0) FAC=1.0                                               A 103Q
  500 L=J+1                                                                A 103R
      T(7,K)=TMP+273.15                                                    A 103S
      IF(M1.GT.0)T(7,K)=T(M1,J)*(T(M1,L)/T(M1,J))**FAC                     A 103T
      TT=273.15/T(7,K)                                                     A 103U
      IF(RH.LE.0.0) TT=273.15/(273.15+DP)                                  A 103V
      IF(WH(7,K).LE.0.0) WH(7,K)=F(TT)                                     A 103W
      IF(M2.GT.0)WH(7,K)=WH(M2,J)*(WH(M2,L)/WH(M2,J))**FAC                 A 103X
      IF(RH.GT.0.0) WH(7,K)=0.01*RH*WH(7,K)                                A 103Y
      IF(M3.GT.0)WO(7,K)=WO(M3,J)*(WO(M3,L)/WO(M3,J))**FAC                 A 103Z
      IF(Z(K).GE.5.0)GO TO 520                                             A 104A
      IF(AHAZE(K).EQ.0.0)AHAZE(K)=HZ2(J)*(HZ2(L)/HZ2(J))**FAC              A 104B
  520 IF(AHAZE(K).EQ.0.0)AHAZE(K)=HZ1(J)*(HZ1(L)/HZ1(J))**FAC              A 104C
      IF(MODEL.EQ.0)GO TO 8                                                A 104D
      IF(K.EQ.1)PRINT 441                                                  A 104E
      PRINT 429,Z(K),P(7,K),TMP,DP,RH,WH(7,K),WO(7,K),AHAZE(K)             A 104F
  540 CONTINUE                                                             A 104G
      IM=6                                                                 A 104H
      NL=ML                                                                A 104I
      M1=0                                                                 A 104J
      M2=0                                                                 A 104K
      M3=0                                                                 A 104L
C     NOTE THAT Z(I) MAY NOT CORRESPOND TO THE VALUES GIVEN FOR STANDARD   A 104M
C     MODEL ATMOSPHERES                                                    A 104N
      GO TO 300                                                            A 104O
  560 IF (RANGE.GT.0.0) GO TO 580                                          A 104P
      IF (H2.GT.0.0.AND.H2.LT.H1) IFIND=1                                  A 104Q
      GO TO 8                                                              A 104R
  580 ITYPE=2                                                              A 104S
      BETA=ACOS(0.5*(RANGE*RANGE/(X1*X2)-X2/X1-X1/X2))/CA                  A 104T
    5 IF (BETA.EQ.0.) GO TO 6                                              A 105
      IFIND=1                                                              A 106
      BET=CA*BETA                                                          A 107
      X2=RE+H2                                                             A 108
      ANGLE=ATAN(X2*SIN(BET)/(X2*COS(BET)-X1))/CA                          A 109
      RANGE=X2*SIN(BET)/SIN(ANGLE*CA)                                      A 110
      BET=BETA                                                             A 111
      GO TO 8                                                              A 112
    6 RANGE=(X2/X1)**2-(SIN(ANGLE*CA))**2                                  A 113
      IF (RANGE.GE.0.0) RANGE=X1*(SQRT(RANGE)-ABS(COS(ANGLE*CA)))          A 114
    7 IF (ANGLE.NE.0..OR.ANGLE.NE.180.) BET=ASIN(RANGE*SIN(ANGLE*CA)/X2)   A 115
      IF (ANGLE.LT.0.) ANGLE=ANGLE+PI                                      A 116
      IF (RANGE.LT.0.0) RANGE=-RANGE                                       A 117
      BET=BET/CA                                                           A 118
      PRINT 428, H1,H2,ANGLE,RANGE,BET,VIS                                 A 119
    8 CONTINUE                                                             A 120A
      SUMA=0.                                                              A 120B
      IF(IXY.LE.2) READ 406,V1,V2,DV                                       A 121*
      IF(IXY.LE.2)PRINT 406,V1,V2,DV                                       A 122*
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF (ITYPE.EQ.1) PRINT 407, H1,RANGE                                A 123
      IF (ITYPE.EQ.2) PRINT 408, H1,H2,ANGLE                             A 124
      IF (ITYPE.EQ.3) PRINT 409, H1,ANGLE                                A 125
      IF (MODEL.EQ.0) M=7                                                A 126A
      IF (M.EQ.7) PRINT 417, VIS                                         A 126B
      IF(VIS.LT.2.0.AND.VIS.GT.0.0) PRINT 442                            A 126C
      IF (M.EQ.1) PRINT 410, M                                           A 127
      IF (M.EQ.2) PRINT 411, M                                           A 128
      IF (M.EQ.3) PRINT 412, M                                           A 129
      IF (M.EQ.4) PRINT 413, M                                           A 130
      IF (M.EQ.5) PRINT 415, M                                           A 131
      IF (M.EQ.6) PRINT 414, M                                           A 132
      IF (IHAZE.EQ.0.) PRINT 426                                         A 133
      IF (M.NE.7.AND.IHAZE.GT.0) PRINT 416, IHAZE,VZ(IHAZE)              A 134*
      AVW=10000./V1                                                      A 135
      ALAM=10000./V2                                                     A 136
      PRINT 418, V1,V2,DV,ALAM,AVW                                       A 137
      AVW=0.5E-4*(V1+V2)                                                 A 138
      AVW=AVW*AVW                                                        A 139
      CO=77.46+.459*AVW                                                  A 140
      CW=43.487-0.3473*AVW                                               A 141
      IF (IFIND.EQ.1) GO TO 15                                           A 142
9     IF (IFIND.EQ.1) CALL ANGL (H1,H2,ANGLE,BETA,LEN,ML)                A 143*
      IFIND=0                                                            A 144
      IF (JP.EQ.0) PRINT 427                                             A 146*
      IF (ITYPE.EQ.1) GO TO 15                                           A 147
      DO 11 K=1,10                                                       A 148
      VH(K)=0.0                                                          A 149
11    CONTINUE                                                           A 150
      BETA=0.0                                                           A 151-
      SR=0.0                                                             A 153
      IP=0                                                               A 154-
C****  NOW DEFINE CONSTANT PRESSURE PATH QUANTITES  EH(1-8)              A 156
      Y=CA*ANGLE                                                         A 157
      SPHI=SIN(Y)                                                        A 158
      R1=(RE+H1)*SPHI                                                    A 159
      IF (H1.GT.Z(NL)) GO TO 13                                          A 160
      GO TO 15                                                           A 161
13    X=(RE+Z(NL))/(RE+H1)                                               A 162
      IF (SPHI.GT.X) GO TO 14                                            A 163
      H1=Z(NL)                                                           A 164
      J1=NL                                                              A 165
      SPHI=SPHI/X                                                        A 166
      ANGLE=180.0-ASIN(SPHI)/CA                                          A 167
      R1=(RE+H1)*SPHI                                                    A 168
      GO TO 15                                                           A 170
14    HMIN=R1-RE                                                         A 171
      PRINT 433, HMIN                                                    A 172
      GO TO 95                                                           A 173
15    DO 17 I=1,NL                                                       A 174
      PS=P(M,I)/1013.0                                                   A 175
      TS=273.15/T(M,I)                                                   A 176A
      IF(M1.GT.0.AND.M.LT.7)TS=273.15/T(M1,I)                            A 176B
      X=PS*TS                                                            A 177
      PT=PS*SQRT(TS)                                                     A 178
      D=0.1*WH(M,I)                                                      A 179
      IF(M2.GT.0.AND.M.LT.7) D=0.1*WH(M2,I)                              A 180*
      EH(1,I)=D*PT**0.9                                                  A 181*
      EH(2,I)=X*PT**0.75                                                 A 182*
      EH(4,I)=0.8*PT*X                                                   A 183
      PPW=4.56E-5*D*273.15/TS                                            A 184*
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      EH(5,I)=(PPW+0.005*(PS-PPW))*D                                    A 185
      EH(6,I)=X                                                         A 186
      HAZE=HZ1(I)                                                       A 187
      IF(M.EQ.7) HAZE=AHAZE(I)                                          A 188*
      IF(Z(I).GE.5.0) GO TO 150                                         A 189*
      IF(IHAZE.EQ.2)HAZE=HZ2(I)                                         A 190A
      IF(IHAZE.EQ.2.AND.M.EQ.7)HAZE=AHZ2(I)                             A 190B
      IF(VIS.LE.0.0) GO TO 150                                          A 190C
      HAZE= 6.389*((HZ2(I)-HZ1(I))/VIS+HZ1(I)/5.0-HZ2(I)/23.0)          A 190D
      IF (M.NE.7) GO TO 150                                             A 190E
      HAZE=6.389*((AHZ2(I)-AHAZE(I))/VIS+AHAZE(I)/5.0-AHZ2(I)/23.0)     A 190F
 150  IF(HAZE.LT.0.0) HAZE=0.0                                          A 190G
      EH(7,I)=3.5336E-4*HAZE                                            A 191
      EH(8,I)=46.6667*WO(M,I)                                           A 192
      IF(M3.GT.0.AND.M.LT.7) EH(8,I)=46.667*WO(M3,I)                    A 193A
      EH(8,I)=EH(8,I)*PT**0.4                                           A 193B
      EH(9,I)=1.0                                                       A 193C
      EH(10,I)=1.0E-6*(CO*X*1013.0/273.15-PPW*CW)                       A 193D
      IF (I.EQ.NL) GO TO 16                                             A 194
      IF (MODEL.EQ.0.AND.I.GE.1) GO TO 26                               A 195A
      T2=T(M,I+1)                                                       A 195B
      W2=WH(M,I+1)                                                      A 195C
      IF(M1.GT.0)T2=T(M1,I+1)                                           A 195D
      IF(M2.GT.0)W2=WH(M2,I+1)                                          A 195E
      PPW=4.56E-6*W2*T2                                                 A 196*
      EH(9,I)=0.5*(EH(10,I)+1.0E-6*(CO*P(M,I+1)/T2-PPW*CW))             A 197*
16    IF (I.EQ.NL) EH(9,I)=0.                                           A 198*
      IF (H1.GE.Z(I)) J1=I                                              A 199*
      IF (IFIND.EQ.0.OR.JP.EQ.0) PRINT 434, I,Z(I),(EH(K,I),K=1,10)     A 200*
      EH(9,I)=EH(9,I)+1.0                                               A 201
17    CONTINUE                                                          A 202

      IP=1                                                              A 204
      IK=0                                                              A 205
      X1=H1                                                             A 206
      CALL POINT (H1,YN,N,NP1,TX,IP)                                    A 207
      J1=N                                                              A 208
      TX1=TX(9)                                                         A 209
      DO 18 K=1,8                                                       A 210
18    F(K)=TX(K)                                                        A 211
      IF (ITYPE.EQ.1) GO TO 26                                          A 212
      IF (ITYPE.EQ.2) H2=Z(NL)                                          A 213
      IF (ANGLE.GT.90.0) GO TO 28                                       A 214
19    IF (ANGLE.GT.90.0.AND.NP1.GT.0) J1=J1+1                           A 215
      J2=NL                                                             A 216
      IF (ITYPE.EQ.3) GO TO 20                                          A 217
      CALL POINT (H2,YN,N,NP,TX,IP)                                     A 218
      J2=N                                                              A 219
      IF (NP.GT.0) J2=J2-1                                              A 220
20    DO 21 K=1,8                                                       A 221
      EH(K,J1)=F(K)                                                     A 222
      IF (ITYPE.EQ.3) GO TO 21                                          A 223
      EH(K,J2+1)=TX(K)                                                  A 224
21    CONTINUE                                                          A 225
      IF (J1.EQ.J2) TX1=TX1+YN-EH(9,J1)                                 A 226
C****  NOW DEFINE VERTICAL PATH QUANTITIES VH(1-8)                      A 227
      IF (JP.EQ.0) PRINT 420                                            A 228*
      DO 29 I=J1,J2                                                     A 229
      X1=Z(I)                                                           A 230
      X2=Z(I+1)                                                         A 231
      IF (I.EQ.J1) X1=H1                                                A 232
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF (I.EQ.J2) X2=H2
      DZ=X2-X1
      IF (I.EQ.NL) DZ=Z(I)-Z(I-1)
      DS=DZ
C*****  UPWARD TRAJECTORY
      RX=(RE+X1)/(RE+X2)
      THETA=ASIN(SPHI)/CA
      PHI=ASIN(SPHI*RX)/CA
      BET=THETA-PHI
      SALP=RX*SPHI
      IF (SPHI.GT.1.E-10) DS=(RE+X2)*SIN(BET*CA)/SPHI
      BETA=BETA+BET
      PSI=BETA+PHI-ANGLE
      PHI=180.-PHI
      SR=SR+DS
      DO 24 K=1,8
      EV=DS*EH(K,I)
      IF (I.EQ.NL) GO TO 22
      IF (EH(K,I).EQ.0.0.OR.EH(K,I+1).EQ.0.0) GO TO 23
      IF (EH(K,I).EQ.EH(K,I+1)) GO TO 24
      EV=DS*(EH(K,I)-EH(K,I+1))/ALOG(EH(K,I)/EH(K,I+1))
      GO TO 24
22    IF (EH(K,I).EQ.0.0) GO TO 23
      IF (EH(K,I-1).EQ.0.0) GO TO 23
      IF (EH(K,I).EQ.EH(K,I-1)) GO TO 24
      EV=EV/ALOG(EH(K,I-1)/EH(K,I))
      GO TO 24
23    EV=0.
24    VH(K)=VH(K)+EV
      IF (JP.EQ.0) PRINT 435, I,X1,(VH(L),L=1,8),PSI,PHI,BETA,THETA,SR
      IF (I.GE.NL) GO TO 25
      IF (I+1.EQ.J2) EH(9,I+1)=YN
      IF (I.EQ.J1) EH(9,I)=TX1
      RN=EH(9,I+1)/EH(9,I)
      SPHI=SPHI*RX/RN
      IF (SALP.GE.RN) SPHI=SALP
25    CONTINUE
      GO TO 47
C**** HORIZONTAL PATH
26    DO 27 K=1,8
      W(K)=RANGE*EH(K,1)
      IF (MODEL.GT.0) W(K)=RANGE*TX(K)
27    CONTINUE
      GO TO 49
28    CONTINUE
C****   DOWNWARD TRAJECTORY
      K2=0
      IF (NP1.EQ.1) J1=J1-1
      J2=J1+1
      YN1=YN
      J=J1+1
      IF (H2.GT.Z(J1+1).OR.H1.EQ.H2) GO TO 30
      IF (NP1.EQ.1.AND.H2.GE.Z(J1+1)) GO TO 30
      CALL POINT (H2,YN,N,NP2,TX,IP)
      DO 29 K=1,8
29    W(K)=TX(K)
      TX2=TX(9)
      YN2=YN
      IF (H2.LT.H1) H=H2
      J2=N
      IF (J1.EQ.J2) TX2=TX1+YN2-EH(9,N)
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF (H2.GT.H1) TX1=TX2
      IF (J1.EQ.J2.AND.H2.LT.H1) YN1=TX2
   30 A0=(RE+H1)*SPHI*YN1
      IF (H2.GE.H1) YN2=YN1
      DO 31 I=1,J1
      HMIN=A0/EH(9,I)-RE
      IF (I.EQ.J1) HMIN=A0/YN1-RE
      JMIN=I
      IF (HMIN.LE.Z(I+1)) GO TO 32
   31 CONTINUE
   32 X=HMIN
      IF (HMIN.LE.0) GO TO 34
      CALL POINT (X,YN,N,NP,TX,IP)
      JMIN=N
      TX3=TX(9)
      IF (J2.EQ.N.OR.J1.EQ.N) TX3=YN2+TX(9)-EH(9,N)
      IF (J1.EQ.N.AND.H2.GE.H1) GO TO 33
      HMIN=A0/TX3-RE
      IF (ABS(X-HMIN).GT.0.0001) GO TO 32
   33 IF (J1.EQ.N.AND.H2.GE.H1) YN1=TX3
      IF (J2.EQ.N.AND.J1.NE.J2) YN2=TX3
      IF (H2.GE.H1) TX2=TX3
      IF (H2.GE.H1) J2=N
      IF (H2.GE.H1.OR.H2.LT.HMIN) H=HMIN
      PRINT 436, HMIN
      IF (H2.LT.HMIN) PRINT 440, HMIN
      GO TO 35
   34 PRINT 436, HMIN
      IF (H2.LT.H1) GO TO 35
      IF (ITYPE.EQ.3.OR.H2.GE.H1) PRINT 437
      ITYPE=2
      TX2=EH(9,1)
      JMIN=0
      J2=1
      H2=0.0
      H=0.0
C****  NOW DEFINE VERTICAL PATH QUANTITIES VH(1-8)
   35 IF (JP.EQ.0) PRINT 420
      DO 40 I=1,NL
      J=J-1
      REF=EH(9,J)
      IF (I.EQ.1) REF=YN1
      IF (I.EQ.1.AND.K2.EQ.1) REF=YN2
      IF (J.EQ.J2.AND.K2.EQ.0) REF=TX2
      IF (I.NE.1) X1=Z(J+1)
      X2=Z(J)
      IF (J.EQ.J2.AND.K2.EQ.0) X2=H
      IF (J.EQ.JMIN.AND.K2.EQ.1) X2=HMIN
      HM=(RE+X1)*SPHI-RE
      IF (HM.GT.Z(J).AND.HM.GT.X2) X2=HM
      RX=(RE+X1)/(RE+X2)
      DS=X1-X2
      ALP=90.0
      THET=ASIN(SPHI)/CA
      SALP=RX*SPHI
      IF (ABS(X2-HM).GT.1.0E-5) ALP=ASIN(SALP)/CA
      BET=ALP-THET
      IF (SPHI.GT.1.0E-10) DS=(RE+X2)*SIN(BET*CA)/SPHI
      THETA=180.0-THET
      BETA=BETA+BET
      PSI=BETA-ALP-ANGLE+180.0
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      SR=SR+DS
      DO 39 K=1,8
      AJ=EH(K,J)
      BJ=EH(K,J+1)
      IF (J.EQ.J1) BJ=E(K)
      IF (J.EQ.J2.AND.H2.LT.H1.AND.H2.GT.0.0) AJ=W(K)
      IF (J.EQ.JMIN.AND.H2.GE.H1) AJ=TX(K)
      IF (J.EQ.JMIN.AND.ABS(H2-HH).LT.1.0E-5) AJ=TX(K)
      IF (K2.EQ.0) GO TO 36
      IF (J.EQ.J2) BJ=W(K)
      IF (J.EQ.JMIN) AJ=TX(K)
36    IF (AJ.EQ.0.0.OR.BJ.EQ.0.0) GO TO 38
      IF (AJ.EQ.BJ) GO TO 37
      EV=DS*(AJ-BJ)/ALOG(AJ/BJ)
      GO TO 39
37    EV=DS*AJ
      GO TO 39
38    EV=0.0
39    VH(K)=VH(K)+EV
      IF (JP.EQ.0) PRINT 435, J,X1,(VH(L),L=1,8),PSI,ALP,BETA,THETA,SR
      IF (J.EQ.J2.AND.H2.GE.H1) GO TO 45
      IF (J.EQ.JMIN.AND.K2.EQ.1) GO TO 43
      IF (J.NE.1) RN=REF/EH(9,J-1)
      IF (J.EQ.J2+1) RN=REF/TX2
      IF (J.EQ.J2.AND.K2.EQ.0) RN=REF/YN2
      IF (J.EQ.(JMIN+1).AND.K2.EQ.1) RN=REF/TX3
      IF (SALP.GE.RN) RN=1.0
      SPHI=SALP*RN
      IF (J.EQ.J2.AND.K2.EQ.0) GO TO 41
40    CONTINUE
41    IF (HMIN.LE.0) GO TO 47
      IF (LEN.EQ.0) PRINT 438
      IF (LEN.EQ.0) GO TO 47
      IF (LEN.EQ.1) PRINT 439
      K2=1
      X1=X2
      IF (ABS(X1-HMIN).LE.0.001) GO TO 47
      H=HMIN
      J=J2+1
      IF (NP2.EQ.1) J=J-1
      B=BETA
      PH=180.0-ASIN(SPHI)/CA
      TS=SR
      PS=PSI
      DO 42 K=1,8
42    E(K)=VH(K)
      GO TO 35
43    BETA=2.*BETA-B
      PSI=2.*PSI-PS
      SR=2.*SR-TS
C      LONG PATH  TAKEN
      PHI=PH
      DO 44 K=1,8
44    VH(K)=2.*VH(K)-E(K)
      GO TO 47
45    DO 46 K=1,10
46    VH(K)=2.0*VH(K)
      BETA=2.0*BETA
      SR=2.0*SR
      IF (H2.EQ.H1) GO TO 47
      RN=TX1/YN1
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      SPHI=SIN(ANGLE*CA)                                                A 416
      IF (SPHI.LT.RN) SPHI=SPHI/RN                                      A 417
      GO TO 19                                                          A 418
47    CONTINUE                                                          A 419
      PRINT 406, HM                                                     A 419*
      DO 48 K=1,10                                                      A 420
      W(K)=VH(K)                                                        A 421
48    CONTINUE                                                          A 422
49    WRITE (6,419)                                                     A 423
      WRITE (6,421) (W(I),I=1,8)                                        A 424
      I=1                                                               A 425
      L=1                                                               A 426
      IV1=V1/5.0                                                        A 427
      IV2=V2/5.+.99                                                     A 428
      IV1=5*IV1                                                         A 429
      IV2=5*IV2                                                         A 430
      IF (IV1.LT.350) IV1=350                                           A 431
      IF (IV2.GT.50000) IV2=50000                                       A 432
      IF (DV.LT.5.) DV=5.                                               A 433
      IDV=DV                                                            A 434
      IV=IV1-IDV                                                        A 435
      ICOUNT=0                                                          A 436
C****  BEGINING OF TRANSMITTANCE CALCULATIONS                           A 437
50    IV=IV+IDV                                                         A 438A
      IF(JP.NE.0) GO TO 52                                              A 438B
      IF (ICOUNT.EQ.0) GO TO 51                                         A 439
      IF (ICOUNT.EQ.50) GO TO 51                                        A 440
      GO TO 52                                                          A 441
51    ICOUNT=0                                                          A 442
      PRINT 422                                                         A 443
52    DO 53 K=1,10                                                      A 444*
      TX(K)=0.0                                                         A 445
      IF (K.LT.4) TX(K)=1.0                                             A 446
53    CONTINUE                                                          A 447
      ICOUNT=ICOUNT+1                                                   A 448
      SUM=0.0                                                           A 449
      V=IV                                                              A 450
      I=(IV-350)/5+1                                                    A 451
      IF (IV.LT.1400) GO TO 61                                          A 452
      IF (IV.LT.2740) GO TO 68                                          A 453
C********   MOLECULAR SCATTERING                                        A 454
      C6=9.807E-20*(V**4.0117)                                          A 455
      TX(6)=C6*W(6)                                                     A 456
      SUM=SUM+TX(6)                                                     A 457
      IF (IV.LT.9200) GO TO 72                                          A 458
      IF (IV.LT.13000) GO TO 69                                         A 459
C*********  UV OZONE                                                    A 460
      IF (IV.LE.23400) GO TO 54                                         A 461
      IF (IV.GE.27500) GO TO 55                                         A 462
      GO TO 87                                                          A 463
54    XX=200.0                                                          A 464
      XI=(V-13000.0)/XX+1.0                                             A 465
      L1=1                                                              A 466
      L2=53                                                             A 467
      GO TO 56                                                          A 468
55    XX=500.0                                                          A 469
      XI=(V-27500.0)/XX+57.0                                            A 470
      L1=57                                                             A 471
      L2=102                                                            A 472
56    DO 57 N=L1,L2                                                     A 473
      XD=XI-FLOAT(N)                                                    A 474
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF (XD) 59,58,57                                                  A 475
57    CONTINUE                                                          A 476
58    TX(8)=W(8)*C8(N)                                                  A 477
      GO TO 60                                                          A 478
59    TX(8)=C8(N)+XD*(C8(N)-C8(N-1))                                    A 479
      TX(8)=W(8)*TX(8)                                                  A 480
60    SUM=SUM+TX(8)                                                     A 481
      IF(IV.GT.14500)GO TO 97                                           A 482*
      GO TO 69                                                          A 483
C********     WATER VAPOUR CONTINUUM                                    A 484
61    IF (IV.LE.670) GO TO 72                                           A 485
      IF (IV.LT.700) GO TO 66                                           A 486
      XI=(V-700.)/50.+1.                                                A 487
      DO 63 NH=1,15                                                     A 488
      XH=XI-FLOAT(NH)                                                   A 489
      IF (XH) 65,64,63                                                  A 490
63    CONTINUE                                                          A 491
64    TX(5)=C5(NH)                                                      A 492
      GO TO 67                                                          A 493
65    TX(5)=C5(NH)+XH*(C5(NH)-C5(NH-1))                                 A 494
      GO TO 67                                                          A 495
66    TX(5)=(V-670.)*0.09                                               A 496
67    TX(5)=W(5)*TX(5)                                                  A 497
      SUM=SUM+TX(5)                                                     A 498
      GO TO 72                                                          A 499
C********    NITROGEN CONTINUUM                                         A 500
68    IF (IV.LT.2080) GO TO 72                                          A 501
      K4=I-346                                                          A 502
      TX(4)=C4(K4)*W(4)                                                 A 503
      SUM=SUM+TX(4)                                                     A 504
      GO TO 72                                                          A 505
C******** WATER VAPOUR                                                  A 506
69    IF (IV.LT.12800.AND.IV.GE.9875) GO TO 70                          A 507
      IF (IV.LE.14520.AND.IV.GE.13400) GO TO 71                         A 508
      GO TO 76                                                          A 509
70    I=I-135                                                           A 510
      GO TO 72                                                          A 511
71    I=I-255                                                           A 512
72    K1=1                                                              A 513
      IF (W(1).LT.1.0E-20) GO TO 76                                     A 514
      WS1=ALOG10(W(1))+C1(I)                                            A 515
      IF (WS1.LT.-2.3468) GO TO 76                                      A 516
      IF (WS1.GT.2.0) K1=40                                             A 518
      IF (WS1.GT.3.5682) GO TO 75                                       A 517
      DO 73 K=K1,67                                                     A 519
      IF (WS1.LE.FW(K)) GO TO 74                                        A 520
73    CONTINUE                                                          A 521
74    TX(1)=TR(K)+(TR(K-1)-TR(K))*(FW(K)-WS1)/(FW(K)-FW(K-1))           A 522
      GO TO 76                                                          A 523
75    TX(1)=0.0                                                         A 524
76    CONTINUE                                                          A 525
C********    UNIFORMLY MIXED GASES                                      A 526
      IF (IV.LT.8060.AND.IV.GE.500) GO TO 77                            A 527
      IF (IV.LT.13190.AND.IV.GT.12970) GO TO 78                         A 528
      GO TO 83                                                          A 529
77    J=I-38                                                            A 530
      GO TO 79                                                          A 531
78    J=(IV-12950)/5+1516                                               A 532
79    IF(W(2).LT.1.0E-20) GO TO 83                                      A 533*
      K1=1                                                              A 534
      WS2=ALOG10(W(2))+C2(J)                                            A 535
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF (WS2.LT.-2.3468) GO TO 83                                      A 536
      IF (WS2.GT.3.5682) GO TO 82                                       A 537
      IF (WS2.GT.2.0) K1=40                                             A 538
      DO 80 K=K1,67                                                     A 539
      IF (WS2.LE.FW(K)) GO TO 81                                        A 540
80    CONTINUE                                                          A 541
81    TX(2)=TR(K)+(TR(K-1)-TR(K))*(FW(K)-WS2)/(FW(K)-FW(K-1))           A 542
      GO TO 83                                                          A 543
82    TX(2)=0.0                                                         A 544
83    CONTINUE                                                          A 545
C********  OZONE                                                        A 546
      IF (IV.LT.575.OR.IV.GT.3270) GO TO 87                             A 557
      L=I-45                                                            A 547
      K1=1                                                              A 548
      IF (W(3).LT.1.0E-20) GO TO 87                                     A 549
      WS3=ALOG10(W(3))+C3(L)                                            A 550
      IF (WS3.LT.-1.6778) GO TO 87                                      A 551
      IF (WS3.GT.3.9345) GO TO 86                                       A 552
      IF (WS3.GT.1.5) K1=36                                             A 553
      DO 84 K=K1,67                                                     A 554
      IF (WS3.LE.FO(K)) GO TO 85                                        A 555
84    CONTINUE                                                          A 556
85    TX(3)=TR(K)-(TR(K)-TR(K-1))*(FO(K)-WS3)/(FO(K)-FO(K-1))           A 558
      GO TO 87                                                          A 559
86    TX(3)=0.0                                                         A 560
87    CONTINUE                                                          A 561
C********   AEROSOL EXTINCTION                                          A 562
      ALAM=1.0E+4/V                                                     A 563A
      XX=0.0                                                            A 563B
      YY=0.0                                                            A 563C
      IF (IHAZE.EQ.0.) GO TO 90                                         A 564
      DO 88 N=1,44                                                      A 565*
      XD=ALAM-VX(N)                                                     A 566*
      IF(XD)89,88,88                                                    A 567*
88    CONTINUE                                                          A 568A
89    XX=(C7(N)-C7(N-1))*XD/(VX(N)-VX(N-1))+C7(N)                       A 568B
      YY=(C7A(N)-C7A(N-1))*XD/(VX(N)-VX(N-1))+C7A(N)                    A 568C
90    TX(10)=YY*W(7)                                                    A 568D
      TX(7)=XX*W(7)                                                     A 569*
      SUM=SUM+TX(7)                                                     A 570
      TX(9)=SUM                                                         A 571
      DO 94 K=4,10                                                      A 572*
      IF (TX(K).EQ.0.0) GO TO 92                                        A 573
      IF (TX(K).LE.0.1) GO TO 91                                        A 574
      IF (TX(K).GT.70.) GO TO 93                                        A 575
      TX(K)=EXP(-TX(K))                                                 A 576
      GO TO 94                                                          A 577
91    TX(K)=1.0-TX(K)+0.5*TX(K)*TX(K)                                   A 578
      GO TO 94                                                          A 579
92    TX(K)=1.0                                                         A 580
      GO TO 94                                                          A 581
93    TX(K)=0.                                                          A 582
94    CONTINUE                                                          A 583
      TX(10)=1.0-TX(10)                                                 A 583*
      TX(9)=TX(1)*TX(2)*TX(3)*TX(9)                                     A 584
      IF (IV.GE.13000) TX(3)=TX(8)                                      A 585
      IF(JP.EQ.1)TX(9)=TX(7)                                            A 586A
      AB=1.-TX(9)                                                       A 586B
      IF(IV.EQ.IV1.OR.IV.EQ.IV2) AB=0.5*AB                              A 586C
      SUMA=SUMA+AB*DV                                                   A 586D
      IF(JP.EQ.0) WRITE(6,423) IV,ALAM,TX(9),(TX(K),K=1,7),TX(10),SUMA  A 587*
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF (IV.GE.IV2) GO TO 95                                           A 588
      GO TO 50                                                          A 589
95    READ 400, IXY                                                     A 590
      AB=1.-SUMA/V2-V1                                                  A 591A
      PRINT 424, IV1,IV2,SUMA,AB                                        A 591B
      PRINT 400,IXY                                                     A 591C
      IF(IXY.EQ.0) GO TO 100                                            A 591D
      GO TO (96,2,97,98,100),IXY                                        A 591E
96    READ 406, V1,V2,DV                                                A 592
      AVW=10000./V1                                                     A 593
      ALAM=10000./V2                                                    A 594
      PRINT 418, V1,V2,DV,ALAM,AVW                                      A 595
      SUMA=0.0                                                          A 596*
      GO TO 49                                                          A 597
97    IF(MODEL.EQ.0) GO TO 200                                          A 598A
      GO TO 300                                                         A 598B
98    READ 400,MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO               A 598C
      PRINT 400,MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO              A 598D
      GO TO 200                                                         A 598E
100   STOP                                                              A 599*
400   FORMAT(10I3,F10.3)                                                A 600*
401   FORMAT (8E10.3)                                                   A 601
402   FORMAT (F6.1,2(E10.3,F6.1,2E10.1))                                A 602
403   FORMAT (4(F6.3,2F7.4))                                            A 603
404   FORMAT (15F5.2)                                                   A 604
405   FORMAT (8E9.2)                                                    A 605
406   FORMAT (7F10.3)                                                   A 606
407   FORMAT (//10X,28H HORIZONTAL PATH, ALTITUDE =,F7.3,11H KM,RANGE =, A 607
     1F7.3,3H KM)                                                       A 608
408   FORMAT (//10X,50H SLANT PATH BETWEEN ALTITUDES H1 AND H2 WHERE H1  A 609
     1=,F7.3,8H KM H2 =,F7.3,18H KM,ZENITH ANGLE =,F7.3,8H DEGREES)     A 610
409   FORMAT (//10X,39H SLANT PATH TO SPACE FROM ALTITUDE H1 =,F7.3,19H  A 611
     1KM, ZENITH ANGLE =,F7.3,8H DEGREES)                               A 612
410   FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,11H = TROPICAL)             A 613
411   FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = MIDLATITUDE SUMMER)   A 614
412   FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = MIDLATITUDE WINTER)   A 615
413   FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = SUB-ARCTIC SUMMER )   A 616
414   FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = 1962 US STANDARD  )   A 617
415   FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = SUB-ARCTIC WINTER )   A 618
416   FORMAT (/30X,18H        HAZE MODEL ,I1,3H = ,A5,13H VISUAL RANGE) A 619
417   FORMAT (/25X*HAZE MODEL  =*,F5.1,* KM VISUAL RANGE AT SEA LEVEL*) A 620
418   FORMAT (/10X,21H FREQUENCY RANGE V1= ,F7.1,13H CM-1 TO V2= ,F7.1,1 A 621
     14H CM-1 FOR DV =,F6.1,9H CM-1   (,F6.2,* - *,F5.2,* MICRONS )*)   A 622
419   FORMAT (/10X,38H EQUILAVENT SEA LEVEL ABSORBER AMOUNTS//21X113HWAT A 623
     1ER VAPOUR     CO2 ETC.       OZONE     NITROGEN (CONT)  H2O (CONT) A 624
     2    MOL  SCAT      AEROSOL     OZONE(U-V)/24X,7HGM CM-2,10X,2HKM,1 A 625
     30X,6HATM CM,10X,2HKM,9X,7HGM CM-2,10X,2HKM,13X,2HKM,10X,6HATM CM) A 626
420   FORMAT (1H1,///10X,*  VERTICAL PROFILES  *,64X,*PSI*,6X,*PHI*,6X,* A 627
     1BETA*,4X,*THETA    RANGE*)                                        A 628
421   FORMAT (/10X,9H W(1-8)=8(F14.3)/)                                 A 629
422   FORMAT (1H1,/10X,32H  FREQ WAVELENGTH  TOTAL     H2O,5X4HCO2+,5X,6 A 630*
     14HOZONE  N2 CONT  H2O CONT MOL SCAT  AEROSOL  AEROSOL   INTEGRATED A 631*
     2 /11X,14H CM-1  MICRONS,8(4X5HTRANS),4X,20H ABS     ABSORPTION )  A 632*
423   FORMAT (10X,I6,10F9.4,F12.2)                                      A 633*
424   FORMAT (* INTEGRATED ASORPTION FROM*,I5,* TO*,I5,* CM-1 =*,F10.2, A 634A
     1*,AVERAGE TRANSMITTANCE =*,F6.4)                                  A 634B
425   FORMAT (10X,7F10.3)                                               A 635
426   FORMAT (/20X,*AEROSOL SCATTERING NOT COMPUTED,IHAZE=0*)           A 636
427   FORMAT (1H1,///10X,20H HORIZONTAL PROFILES/)                      A 637
428   FORMAT (10X,* H1=*,F7.3,*KM,H2=*,F7.3,*KM,ANGLE=*,F8.4,*GEOM. RANG A 638
     1E =*,F7.2,*KM,BETA=*,F8.5,*,VIS=*,F5.1)                           A 639
429   FORMAT(3F10.3,2F5.1,2F10.3,2F10.3)                                A 640*
430   FORMAT(10X,*INPUT METEOROLOGICAL DATA:*/10X,*Z=*,F7.2,* KM, P=*,F7 A 641*
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
     1.2,* MB,T=*,F5.1,* C, DEW PT.TEMP*,F5.1,* C, REL HUMIDITY=*,F5.1,   A 642*
     2* %, H2O DENSITY=*,1PE9.2,* GM M-3*/10X,* OZONE DENSITY=*,E9.2,* G  A 643*
     3M-3, VISUAL RANGE=*,0PF6.1,* KM,RANGE=*,F10.3,* KM *  )             A 644*
 431  FORMAT(4(F6.2,2F7.5))                                               A 645*
 432  FORMAT (* STARTING PARAMETERS H1 AND ANGLE HAVE BEEN REDEFINED;H1=  A 646
     1 *,F10.3,*ANGLE =*,F10.6)                                           A 647
 433  FORMAT (* TRAJECTORY MISSES EARTHS ATMOSPHERE. CLOSEST DISTANCE OF  A 648
     1 APPROACH IS*,F10.3,1X,/,1X,*END OF CALCULATION*)                   A 649
 434  FORMAT (10X,I4,F6.1,11(F10.3))                                      A 650
 435  FORMAT (I5,F7.1,8E10.3,4F9.4,F7.1)                                  A 651
 436  FORMAT (* HMIN = *,F10.3)                                           A 652
 437  FORMAT (* PATH INTERSECTS EARTH - PATH CHANGED TO TYPE 2 WITH H2 =  A 653
     1 0.0 KM*)                                                           A 654
 438  FORMAT (* CHOICE OF TWO PATHS FOR THIS CASE -SHORTEST PATH TAKEN.   A 655
     1 FOR LONGER PATH SET LEN=1.*)                                       A 656
 439  FORMAT (* CHOICE OF TWO PATHS FOR THIS CASE -LONGEST PATH TAKEN.    A 657
     1 FOR SHORT PATH SET LEN = 0 *)                                      A 658
 440  FORMAT (* H2 WAS SET LESS THAN HMIN AND HAS BEEN RESET EQUAL TO     A 659
     1  HMIN I.E. H2 = *,F10.3)                                           A 660
 441  FORMAT(*  MODEL ATMOSPHERE NO. 7*,/ 4X,*Z (KM)*,3X,*P (MB)*,4X,     A 661*
     1 *T (C) DEW PT %RH  H2O(GM.M-3) O3(GM.M-3) NO  DEN.*)               A 662*
 442  FORMAT(*  FOG CONDITIONS MAY EXIST AT SEA LEVEL FOR THIS VISUAL RA  A 663*
     1NGE*,/,*  IF SO THEN ASSUME THE TRANSMITTANCE DUE TO FOG IS GIVEN   A 644*
     1BY THE TRANSMITTANCE AT 0.55 MICRONS*)                              A 665*
      END                                                                 A 666*


      SUBROUTINE POINT (X,YN,N,NP,TX,IP)                                  B   1
      COMMON Z(34),P(7,34),T(7,34),EH(10,34),WH(7,34),M,NL,RE,DW,CO,PI    B   2*
      DIMENSION TX(10)                                                    B   3
C*********************************************************************** B   4
C     SUBROUTINE POINT COMPUTES THE MEAN REFRATIVE INDEX ABOVE AND BELOW  B   5
C     A GIVEN ALTITUDE AND INTERPOLATES EXPONENTIALLY TO DETERMINE THE    B   6
C     EQUIVALENT ABSORBER AMOUNTS AT THAT ALTITUDE.                       B   7
C                                                                         B   8
C*********************************************************************** B   9
C                                                                         B  10
C      X IS THE HEIGHT IN QUESTION                                        B  11
C      TX(9) AND YN ARE THE MEAN REFRACTIVE INDICES ABOVE AND BELOW X     B  12
C      N IS THE LEVEL INTEGER CORRESPONDING TO X OR THE LEVEL BELOW X     B  13
C      NP =1 IF X COINCIDES WITH MODEL ATMOSPHERE LEVEL ,IF NOT NP = 0    B  14
C      TX(1-8) ARE ABSORBER  AMOUNTS PER KM AT HEIGHT X                   B  15
C*********************************************************************** B  16*
      N=NL                                                                B  17*
      NP=0                                                                B  18
      IF (X.LT.0.0) X=0.                                                  B  19A
      IF (X.GT.Z(NL)) GO TO 4                                             B  19B
      DO 1 I=1,NL                                                         B  20
      N=I                                                                 B  21
      IF (X-Z(I)) 2,4,1                                                   B  22
1     CONTINUE                                                            B  23-
2     J2=N                                                                B  25
      N=N-1                                                               B  26
      FAC=(X-Z(N))/(Z(J2)-Z(N))                                           B  27
      PX1=P(M,N)*(P(M,J2)/P(M,N))**FAC                                    B  28
      TX1=T(M,N)*(T(M,J2)/T(M,N))**FAC                                    B  29
      WX1=WH(M,N)*(WH(M,J2)/WH(M,N))**FAC                                 B  30
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      TX(3)=CO*PX1/TX1-4.56E-6*HX1*TX1*CW                               B  31
      TX(2)=CO*P(M,J2)/T(M,J2)-4.56E-5*WH(M,J2)*T(M,J2)*CW              B  32
      TX(1)=CO*P(M,N)/T(M,N)-4.56E-6*WH(M,N)*T(M,N)*CW                  B  33
      TX(9)=0.5E-6*(TX(2)+TX(3))                                        B  34
      YN=0.5E-6*(TX(1)+TX(3))                                           B  35
      IF (IT.EQ.0) GO TO 9                                              B  36
      DO 3 K=1,8                                                        B  37A
      TX(K)=0.0                                                         B  37B
      IF (EH(K,N).EQ.0.0) GO TO 3                                       B  38
      IF (EH(K,N).GT.1000.0) GO TO 3                                    B  39
      TX(K)=EH(K,N)*(EH(K,J2)/EH(K,N))**FAC                             B  40
3     CONTINUE                                                          B  41
      GO TO 9                                                           B  42
4     NP=1                                                              B  43
      IF (IP.EQ.0) GO TO 6                                              B  44
      DO 5 K=1,8                                                        B  45
5     TX(K)=EH(K,N)                                                     B  46
6     TX(9)=EH(9,N)-1.                                                  B  47
      YN=0.0                                                            B  48
C*****  CARDS B 24 AND 50 THROUGH 59 ARE NO LONGER REQUIRED             B  48+
      IF (N.GT.1) YN=EH(9,N-1)-1.0                                      B  49
9     CONTINUE                                                          B  60
      IF (IP.EQ.1) PRINT 400, X,N,NP,TX(3),YN,IP,(TX(K),K=1,8)          B  61
      TX(9)=TX(9)+1.                                                    B  62
      YN=YN+1.                                                          B  63
      RETURN                                                            B  64
C                                                                       B  65
400   FORMAT (/,* FROM POINT* HEIGHT=*,F10.4,* KM,N=*,I3,*,NP=*,I2,*,REF B  66
     1. INDEX ABOVE & BELOW X=*,2E11.4,*,IP=*,I3,/,12X,*EQUIV. ABSORBER B  67
     2AMOUNTS PER KM AT X=*,8E10.3)                                     B  68
      END                                                               B  69



      SUBROUTINE ANGL (H1,H2,ANGLE,B1,LEN,ML)                           C   1*
      COMMON Z(34),P(7,34),T(7,34),EH(10,34),WH(7,34),M,NL,RE,CW,CO,PI  C   2*
      DIMENSION TX(10)                                                  C   3
C*******************************************************************   C   4
C                                                                       C   5
C     THIS SUBROUTINE CALCULATES THE INITIAL ZENITH ANGLE (ANGLE)       C   6
C     TAKING INTO ACCOUNT REFRACTION EFFECTS GIVEN H1,H2, AND BETA      C   7
C     (WHERE BETA IS THE EARTH CENTRE ANGLE SUBTENDED BY H1 AND H2 ).   C   8
C     ASSUMING THE REFRACTIVE INDEX TO BE CONSTANT IN A GIVEN LAYER.    C   9
C     FOR GREATER ACCURACY INCREASE THE NUMBER OF LEVELS IN THE MODEL   C  10
C     ATMOSPHERE.                                                       C  11
C                                                                       C  12
C     THIS SUBROUTINE CAN BE REMOVED FROM THE PROGRAM IF NOT REQUIRED.  C  13
C*******************************************************************   C  14
      IP=99                                                             C  15
      CA=PI/180.                                                        C  16
      X1=RE+H1                                                          C  17
      X2=RE+H2                                                          C  18
      LEN=0.                                                            C  19
      IT=0                                                              C  20
      B1=B1*CA                                                          C  21
      IF(B1.EQ.0.0) B1=ACOS(X2/X1)                                      C  21B
      TANG=X2*SIN(B1)/(X2*COS(B1)-X1)                                   C  22
      THET=ATAN(TANG)                                                   C  23
      IF (THET.LT.0.0) THET=THET+PI                                     C  24
      SPHI=SIN(THET)                                                    C  25
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      ANG=THET/CA
C     PRINT 404, B1,ANG,TANG
      TN=THET
      TM=TN-0.5*CA
1     ANGLE=THET
      FBT=0.
      BETA=0.
      BET1=0
      BET2=0
      FBT1=0
      FBT2=0
      FBT3=0.0
      IF(B1.LE.0.0) GO TO 2
C     PRINT 400, IT
      Y=2.*THET
      IF (Y-PI.GT.1.0E-8) GO TO 9
      IF (IP.EQ.100) GO TO 6
      XMIN=X2*COS(B1)-RE
      IF (XMIN-H1) 3,4,4
2     HMIN=H2
      H2=H1
      H1=MIN
3     ANGLE=0.5*PI
      THET=ANGLE
      SPHI=1.0
      ANG=ANGLE/CA
C     PRINT 404, B1,ANG,SPHI
4     IP=100
      CALL POINT (H1,YN,N,NP,TX,IP)
      J1=N
      TX1=TX(9)
5     CALL POINT (H2,YN,N,NP,TX,IP)
      IF (NP.EQ.1) N=N-1
      J2=N
      IF (J1.EQ.J2) TX1=TX1+YN-EH(9,J1)
6     DO 7 J=J1,J2
      X1=RE+Z(J)
      X2=RE+Z(J+1)
      IF (J.EQ.J1) X1=RE+H1
      IF (J.EQ.J2) X2=RE+H2
      SALP=X1*SPHI/X2
      ALP=ASIN(SALP)
      RN=EH(9,J+1)/EH(9,J)
      IF ((J+1).EQ.J2) RN=YN/EH(9,J)
      IF (J.EQ.J1) RN=EH(9,J+1)/TX1
      IF ((J+1).EQ.J2.AND.J.EQ.J1) RN=YN/TX1
      BET=THET-ALP
      FB=-TAN(ALP)
      IF (J.NE.J1) FB=FB+TAN(THET)
      FBT=FBT+FB
      BETA=BETA+BET
      TH1=THET/CA
      BE=BET/CA
      C=ALP/CA
C     PRINT 402, J,Z(J),THET,ALP,BET,BETA,FBT,FB,TH1,BE,C
      IF (X2.EQ.RE+H2) C=PI-ALP
      IF (SALP.GE.RN) RN=1.
      SPHI=SALP/RN
      THET=ASIN(SPHI)
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
7       CONTINUE                                                        C  81
        IF(B1.LE.0.0) GO TO 29                                          C  81+
        GO TO 26                                                        C  82
8       CONTINUE                                                        C  83
        TANG=-TANG                                                      C  84
        ANGLE=PI-ANGLE                                                  C  85
        TN=ANGLE                                                        C  86
        ANG=ANGLE/CA                                                    C  87
C       PRINT 404, B1,ANG,TANG                                          C  88
        IF (H1.LE.0.0) GO TO 3                                          C  89
9       CONTINUE                                                        C  90
        IP=101                                                          C  91
        CALL POINT (H1,YN,N,NP1,TX,IP)                                  C  92
        TX1=TX(9)                                                       C  93
        YN1=YN                                                          C  94
        IF (NP1.EQ.1) N=N-1                                             C  95
        J2=NL                                                           C  96A
        IF (N.EQ.7) J2=ML                                               C  96B
        J1=N                                                            C  97
        J=J1+1                                                          C  98
        IF (H2.GE.H1) GO TO 13                                          C  99
        CALL POINT (H2,YN,N,NP,TX,IP)                                   C 100
        TX2=TX(9)                                                       C 101
        YN2=YN                                                          C 102
        J2=N                                                            C 103
        IF (J1.EQ.J2) TX2=YN1+TX(9)-EH(9,J1)                            C 104
10      J=J-1                                                           C 105
        X1=RE+Z(J+1)                                                    C 106
        X2=RE+Z(J)                                                      C 107
        IF (J.EQ.J1) X1=RE+H1                                           C 108
        IF (J.EQ.J2) X2=RE+H2                                           C 109
        SALP=X1*SPHI/X2                                                 C 110
        HMIN=X1*SPHI-RE                                                 C 111
C       PRINT 402, J,X1,Z(J),SPHI,SALP,HMIN,RE                          C 112
        IF (SALP.LE.1.0) GO TO 11                                       C 113
        SALP=SPHI                                                       C 114
        IF (HMIN.GT.H2) GO TO 10                                        C 115
11      ALP=ASIN(SALP)                                                  C 116
        THET=ASIN(SPHI)                                                 C 117
        BET=ALP-THET                                                    C 118
        BET1=BET1+BET                                                   C 119
        FB=TAN(ALP)                                                     C 120
        IF (J.NE.J1) FB=FB-TAN(THET)                                    C 121
        FBT1=FBT1+FB                                                    C 122
        TH1=THET/CA                                                     C 123
        BE=BET/CA                                                       C 124
        AL=ALP/CA                                                       C 125
C       PRINT 402, J,X2,THET,ALP,BET1,BET,BMIN,HMIN,FBT1,TH1,BE,AL      C 126
        IF (X2.EQ.RE+H2) C=PI-ALP                                       C 127
        REF=EH(9,J)                                                     C 128
        IF (J.EQ.J1) REF=YN1                                            C 129
        IF (J.EQ.J2) REF=TX2                                            C 130
        IF (J.EQ.1) GO TO 12                                            C 131
        RN=EH(9,J)/EH(9,J-1)                                            C 132
        IF (J.EQ.J1) RN=YN1/EH(9,J-1)                                   C 133A
        IF(J.EQ.J2+1) RN=REF/TX2                                        C 133B
        IF(J.EQ.J2) RN=REF/YN2                                          C 133C
        IF (SALP.GE.RN) RN=1.                                           C 134
        SPHI=SALP*RN                                                    C 135
        IF (Z(J).LE.H2) GO YO 12                                        C 136
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      GO TO 19                                                          C 137
12    X1=X2                                                             C 138
      IF (ABS(Z(J)-H2).LT.1.0E-10.AND.J.NE.1) GO TO 13                  C 139
      GO TO 14                                                          C 140
13    J=J-1                                                             C 141
      X1=RE+Z(J+1)                                                      C 142
      IF (J.EQ.J1) X1=RE+H1                                             C 143
      IF (J.EQ.J2.AND.J.NE.J1) X1=RE+H2                                 C 144
14    X2=RE+Z(J)                                                        C 145
      HMIN=X1*SPHI-RE                                                   C 146
      IF (HMIN.LE.0.0) GO TO 25                                         C 147
      IF (Z(J).LT.HMIN) GO TO 18                                        C 148
      REF=EH(9,J)                                                       C 149
      IF (J.EQ.J2) REF=YN                                               C 150
      SALP=X1*SPHI/X2                                                   C 151
      ALP=ASIN(SALP)                                                    C 152
      THET=ASIN(SPHI)                                                   C 153
      BET=ALP-THET                                                      C 154
      FB=TAN(ALP)-TAN(THET)                                             C 155
      FBT2=FBT2+FB                                                      C 156
      BET2=BET2+BET                                                     C 157
      BMIN=BET1+BET2                                                    C 158
      AL=ALP/CA                                                         C 159
      TH1=THET/CA                                                       C 160
C     PRINT 402, J,X2,THET,ALP,BET2,BET,BMIN,HMIN,FBT2,TH1,BE,AL        C 161
      RN=REF/EH(9,J-1)                                                  C 162
      IF (SALP.GE.RN) RN=1.0                                            C 163
      SPHI=SALP*RN                                                      C 164
      GO TO 13                                                          C 165
17    TX3=YN1+TX(9)-EH(9,J1)                                            C 166
      YN1=TX3                                                           C 167
      IF (ABS(H2-Z(J+1)).LE.1.0E-5) YN1=TX(9)                           C 168
      IF (ABS(H1-Z(J+1)).LE.1.0E-5) YN1=TX(9)                           C 169
      RN=1.0                                                            C 170
      GO TO 19                                                          C 171
18    CALL POINT (HMIN,YN,N,NP,TX,IP)                                   C 172
      IP=102                                                            C 173
      TX3=TX(9)                                                         C 174
      IF (J.EQ.J1.AND.H2.GE.H1) GO TO 17                                C 175
      IF (J.EQ.J1.OR.J.EQ.J2) TX3 YN2+TX(9)-EH(9,J)                     C 176
      IF (HMIN.GT.H2) TX3=TX(9)                                         C 177
      IF (J.EQ.J1.AND.HMIN.GT.H2) GO TO 17                              C 178
      RN=REF/TX3                                                        C 179
      IF (SALP.GE.RN) RN=1.                                             C 180
      SPHI=SALP*RN                                                      C 181
      X=X1*SPHI-RE                                                      C 182
      DIF=ABS(HMIN-X)                                                   C 183
      HMIN=X                                                            C 184
      IF (DIF-1.0E-5) 19,19,18                                          C 185
19    X2=RE+HMIN                                                        C 186
C     PRINT 403, HMIN,DIF,RN                                            C 187
      THET=ASIN(SPHI)                                                   C 188
      IF(RN.EQ.1.0) FBT3=-TAN(THET)                                     C 188B
      IF (RN.EQ.1) GO TO 20                                             C 189
      DNX=(TX3-1.0)*ALOG((TX3-1.0)/(REF-1.0))/(X2-X1)                   C 190
      FBT3=-TAN(THET)*(1.0-1.0/(1.0+TX3/(X2*DNX)))                      C 191
20    BET=0.5*PI-THET                                                   C 192
      BET2=BET2+BET                                                     C 193
      BMIN=BET1+BET2                                                    C 194
      IF (H2.GE.H1) GO TO 23                                            C 195
      BET=BET1+2.*BET2                                                  C 196
      DB1=B1-BET1
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
                                                                C 197
      DB2=BET-B1                                                C 198
21    DB3=ABS(BMIN-B1)                                          C 199A
      IF(DB3.GT.DB1.AND.DB2.GT.DB1) GO TO 25                    C 199B
      IF(DB2.GT.DB3) GO TO 22                                   C 199C
      IF(DB2.GT.DB1)  GO TO 25                                  C 200
      BETA=BET                                                  C 201
      FBT=FBT1+2.0*(FBT2+FBT3)                                  C 202
      LEN=1.                                                    C 203
      GO TO 26                                                  C 204
22    BETA=BET1+BET2                                            C 205
      FBT=FBT1+FBT2+FBT3                                        C 206
C     PRINT 401, J,BETA,FBT,FBT1,FBT2,FBT3,TX1,YN1              C 207
      GO TO 26                                                  C 208
23    BETA=2.0*(BET1+BET2)                                      C 209
      LEN=1.                                                    C 210
      FBT=2.0*(FBT1+FBT2+FBT3)                                  C 211
      PRINT 401, J,BETA,FBT,FBT1,FBT2,FBT3,TX1,YN1              C 212
      IF (H2.EQ.H1) GO TO 26                                    C 213
      IP=103                                                    C 214
      IF (NP1.EQ.1) J1=J1+1                                     C 215
      SPHI=SIN(ANGLE)                                           C 216
      IF (Z(J1+1).LE.H2) GO TO 24                               C 217
      RN=TX1/YN1                                                C 218
      IF (SPHI.GE.RN) RN=1.                                     C 219
      SPHI=SPHI/RN                                              C 220
      THET=ASIN(SPHI)                                           C 221
      GO TO 5                                                   C 222
24    CALL POINT (H2,YN,N,NP,TX,IP)                             C 223
      TX1=TX1+YN-EH(9,J1)                                       C 224
      RN=TX1/YN1                                                C 225
      J2=J1                                                     C 226
      IF (SPHI.GE.RN) RN=1.                                     C 227
      SPHI=SPHI/RN                                              C 228
      THET=ASIN(SPHI)                                           C 229
      GO TO 5                                                   C 230
25    BETA=BET1                                                 C 231
      LEN=0.                                                    C 232
      FBT=FBT1                                                  C 233
26    THET=ANGLE+(B1-BETA)/(1.+FBT/TANG)                        C 234
      DBETA=BETA/CA                                             C 235
      B=BET1/CA                                                 C 236
      TH1=THET/CA                                               C 237
      PRINT 404, BETA,DBETA,FBT,TH1,TANG                        C 238
      IF (THET.GT.TN.OR.THET.LT.TM) THET=(TN+TM)/2.             C 239
      TH1=THET/CA                                               C 241
      PRINT 404, BET1,B,FBT,TH1                                 C 240
      TN1=TN/CA                                                 C 242
      TM1=TM/CA                                                 C 243
      PRINT 405, TN,TM,TN1,TM1                                  C 244
      SPHI=SIN(THET)                                            C 245
      TANG=TAN(THET)                                            C 246
      IT=IT+1                                                   C 247
      DBE=ABS(B1-BETA)                                          C 248
      DTH=ABS(ANGLE-THET)                                       C 249
      IF (IT.EQ.10)  THET=0.5*(ANGLE+THET)                      C 250*
      IF (IT.EQ.10) GO TO 28                                    C 251
      IF (DBE.GT.1.0E-7.AND.DTH.GT.1.0E-7) GO TO 1              C 252
28    ANGLE=THET/CA                                             C 253
      PRINT 406, ANGLE,IT                                       C 254
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      RETURN                                                            C 255A
29    H1=H2                                                             C 255B
      ANGLE=C/CA                                                        C 255C
      PRINT 406, ANGLE,IT                                               C 255D
      RETURN                                                            C 255E
C                                                                       C 256
400   FORMAT (//* ITTERATION NUMBER *,I3,//)                            C 257
401   FORMAT (I6,E16.7,8F13.3)                                          C 258
402   FORMAT (I4,F10.4,6E13.4,4F10.4/)                                  C 259
403   FORMAT (*  HMIN=*,F14.6,*  DIF=*E14.6,*  PR=*,E16.8)              C 260
404   FORMAT (* TOTAL BETA = *,F14.6,F15.5,*,FBT = *,E14.6,* THET =*,F10 C 261
     1.6,*TANG=*,F10.6,*)                                               C 262
405   FORMAT (5F12.6)                                                   C 263
406   FORMAT (8X,/1H*,*ZENITH ANGLE =*,F7.3,* DEGREES :  RECOMPUTED     C 264
     1 FROM SUBROUTINE ANGL (ITTERATION*,I3,*)*)                        C 265
      END                                                               C 266
```

The input data given in Table A2 can be summarized as follows:

(1) The first card gives the number of model atmospheres IATM to be read in and the number of levels NL.

(2) The next six cards contain the haze number densities (HAZE 1 and HAZE 2). Units: cm^{-3}.

(3) The next 102 cards contain the model atmosphere data for the six geographical models (with two models for each altitude on one card). Units: altitude (km), pressure (mb), temperature (°K), H_2O density (gm m^{-3}), O_3 density (gm m^{-3}).

(4) The next 11 cards contain the aerosol extinction (C7) and absorption (C7A) coefficients as a function of wavelength VX. The order and units are as follows: VX (μm), C7 (km^{-1}) and C7A (km^{-1}).

(5) The next 17 cards contain the transmittance scale (TR) and logarithmic scaling factors for water vapor and the uniformly mixed gases (FW), and for ozone (FO). Units: H_2O ($\log_{10}$ gm cm^{-2}), uniformly mixed gases ($\log_{10}$ km), O_3 ($\log_{10}$ atm cm) respectively.

(6) The next 344 cards contain the spectral data for the various molecules in the following order: C1 (H_2O), C2 (uniformly mixed gases), C3 (ozone), C4 (nitrogan continuum), C5 (H_2O continuum), C8 (UV and visible ozone). The parameters C1, C2 and C3 are in the form of logarithmic absorption coefficients, with units $\log_{10}$ (gm^{-1} cm^2), $\log_{10}$ (km^{-1}) and $\log_{10}$ (atm^{-1} cm^{-1}), respectively. The units of C4 to C8 are km^{-1}.

(7) The last four cards contain the operational instructions for executing the program and are discussed in detail in Section 5.

A wavenumber (cm^{-1}) identification is given in the last 5 columns of the spectral data cards described above. Labels identifying the various card groups are also given in Table A2.

Table A2. Listing of Data for LOWTRAN 3

```
 6 34                                                                                *
2.830E+03 1.245E+03 5.374E+02 2.257E+02 1.193E+02 8.992E+01 6.341E+01 5.593E+01
6.073E+01 5.822E+01 5.679E+01 5.320E+01 5.589E+01 5.159E+01 5.052E+01 4.747E+01
4.514E+01 4.460E+01 4.317E+01 3.636E+01 2.663E+01 1.935E+01 1.456E+01 1.114E+01
8.831E+00 7.434E+00 2.239E+00 5.893E-01 1.551E-01 4.084E-02 1.078E-02 5.553E-05
1.970E-08-0.
1.379E+04 5.034E+03 1.845E+03 6.735E+02 2.454E+02
   0.0 1.013E+03 300.0    1.9E 01    5.6E-05 1.013E+03 294.0    1.4E 01    6.0E-05
   1.0 9.040E+02 294.0    1.3E+01    5.6E-05 9.020E+02 290.0    9.3E+00    6.0E-05
   2.0 8.050E+02 288.0    9.3E+00    5.4E-05 8.020E+02 285.0    5.9E+00    6.0E-05
   3.0 7.150E+02 284.0    4.7E+00    5.1E-05 7.100E+02 279.0    3.3E+00    6.2E-05
   4.0 6.330E+02 277.0    2.2E+00    4.7E-05 6.280E+02 273.0    1.9E+00    6.4E-05
   5.0 5.590E+02 270.0    1.5E+00    4.5E-05 5.540E+02 267.0    1.0E+00    6.6E-05
   6.0 4.920E+02 264.0    8.5E-01    4.3E-05 4.670E+02 261.0    6.1E-01    6.9E-05
   7.0 4.320E+02 257.0    4.7E-01    4.1E-05 4.260E+02 255.0    3.7E-01    7.5E-05
   8.0 3.780E+02 250.0    2.5E-01    3.9E-05 3.720E+02 248.0    2.1E-01    7.9E-05
   9.0 3.290E+02 244.0    1.2E-01    3.9E-05 3.240E+02 242.0    1.2E-01    8.6E-05
  10.0 2.860E+02 237.0    5.0E-02    3.9E-05 2.810E+02 235.0    6.4E-02    9.0E-05
  11.0 2.470E+02 230.0    1.7E-02    4.1E-05 2.430E+02 229.0    2.2E-02    1.1E-04
  12.0 2.130E+02 224.0    6.0E-03    4.3E-05 2.090E+02 222.0    6.0E-03    1.2E-04
  13.0 1.820E+02 217.0    1.8E-03    4.5E-05 1.790E+02 216.0    1.8E-03    1.5E-04
  14.0 1.560E+02 210.0    1.0E-03    4.5E-05 1.530E+02 216.0    1.0E-03    1.8E-04
  15.0 1.320E+02 204.0    7.6E-04    4.7E-05 1.300E+02 216.0    7.6E-04    1.9E-04
  16.0 1.110E+02 197.0    6.4E-04    4.7E-05 1.110E+02 216.0    6.4E-04    2.1E-04
  17.0 9.370E+01 195.0    5.6E-04    6.9E-05 9.500E+01 216.0    5.6E-04    2.4E-04
  18.0 7.890E+01 199.0    5.0E-04    9.0E-05 8.120E+01 216.0    5.0E-04    2.8E-04
  19.0 6.660E+01 203.0    4.9E-04    1.4E-04 6.950E+01 217.0    4.9E-04    3.2E-04
  20.0 5.650E+01 207.0    4.5E-04    1.9E-04 5.950E+01 218.0    4.5E-04    3.4E-04
  21.0 4.800E+01 211.0    5.1E-04    2.4E-04 5.100E+01 219.0    5.1E-04    3.6E-04
  22.0 4.090E+01 215.0    5.1E-04    2.8E-04 4.370E+01 220.0    5.1E-04    3.6E-04
  23.0 3.500E+01 217.0    5.4E-04    3.2E-04 3.760E+01 222.0    5.4E-04    3.4E-04
  24.0 3.000E+01 219.0    6.0E-04    3.4E-04 3.220E+01 223.0    6.0E-04    3.2E-04
  25.0 2.570E+01 221.0    6.7E-04    3.4E-04 2.770E+01 224.0    6.7E-04    3.0E-04
  30.0 1.220E+01 232.0    3.6E-04    2.4E-04 1.320E+01 234.0    3.6E-04    2.0E-04
  35.0 6.000E+00 243.0    1.1E-04    9.2E-05 6.520E+00 245.0    1.1E-04    9.2E-05
  40.0 3.050E+00 254.0    4.3E-05    4.1E-05 3.330E+00 258.0    4.3E-05    4.1E-05
  45.0 1.590E+00 265.0    1.9E-05    1.3E-05 1.760E+00 270.0    1.9E-05    1.3E-05
  50.0 8.540E-01 270.0    6.3E-06    4.3E-06 9.510E-01 276.0    6.3E-06    4.3E-06
  70.0 5.790E-02 219.0    1.4E-07    8.6E-08 6.710E-02 218.0    1.4E-07    8.6E-08
 100.0 3.000E-04 210.0    1.0E-09    4.3E-11 3.000E-04 210.0    1.0E-09    4.3E-11
99999.           210.0                                  210.0                       *
   0.0 1.018E+03 272.2    3.5E+00    6.0E-05 1.010E+03 287.0    9.1E+00    4.9E-05
   1.0 8.973E+02 268.7    2.5E+00    5.4E-05 8.960E+02 282.0    6.0E+00    5.4E-05
   2.0 7.897E+02 265.2    1.8E+00    4.9E-05 7.929E+02 276.0    4.2E+00    5.6E-05
   3.0 6.938E+02 261.7    1.2E+00    4.9E-05 7.000E+02 271.0    2.7E+00    5.8E-05
   4.0 6.081E+02 255.7    6.6E-01    4.9E-05 6.160E+02 266.0    1.7E+00    6.0E-05
   5.0 5.313E+02 249.7    3.8E-01    5.8E-05 5.410E+02 260.0    1.0E+00    6.4E-05
   6.0 4.627E+02 243.7    2.1E-01    6.4E-05 4.730E+02 253.0    5.4E-01    7.1E-05
   7.0 4.016E+02 237.7    8.5E-02    7.7E-05 4.130E+02 246.0    2.9E-01    7.5E-05
   8.0 3.473E+02 231.7    3.5E-02    9.0E-05 3.590E+02 239.0    1.3E-01    7.9E-05
   9.0 2.992E+02 225.7    1.6E-02    1.2E-04 3.107E+02 232.0    4.2E-02    1.1E-04
  10.0 2.568E+02 219.7    7.5E-03    1.6E-04 2.677E+02 225.0    1.5E-02    1.3E-04
  11.0 2.199E+02 219.2    6.9E-03    2.1E-04 2.300E+02 225.0    9.4E-03    1.8E-04
  12.0 1.882E+02 218.7    6.0E-03    2.6E-04 1.977E+02 225.0    6.0E-03    2.1E-04
  13.0 1.610E+02 218.2    1.8E-03    3.0E-04 1.700E+02 225.0    1.8E-03    2.6E-04
  14.0 1.378E+02 217.7    1.0E-03    3.2E-04 1.460E+02 225.0    1.0E-03    2.8E-04
  15.0 1.178E+02 217.2    7.6E-04    3.4E-04 1.250E+02 225.0    7.6E-04    3.2E-04
  16.0 1.007E+02 216.7    6.4E-04    3.6E-04 1.080E+02 225.0    6.4E-04    3.4E-04
  17.0 8.610E+01 216.2    5.6E-04    3.9E-04 9.280E+01 225.0    5.6E-04    3.9E-04
  18.0 7.350E+01 215.7    5.0E-04    4.1E-04 7.980E+01 225.0    5.0E-04    4.1E-04
  19.0 6.280E+01 215.2    4.9E-04    4.3E-04 6.860E+01 225.0    4.9E-04    4.1E-04
```

HAZE MODELS

MODEL ATMOSPHERES 1 & 2

MODEL ATMOSPHERES 3 & 4

Table A2. Listing of Data for LOWTRAN 3 (Cont)

```
  20.0 5.370E+01 215.2   4.5E-04   4.3E-04 5.090E+01 225.0   4.5E-04   3.9E-04
  21.0 4.580E+01 215.2   5.1E-04   4.3E-04 5.070E+01 225.0   5.1E-04   3.5E-04
  22.0 3.910E+01 215.2   5.1E-04   4.3E-04 4.360E+01 225.0   5.1E-04   3.2E-04
  23.0 3.340E+01 215.2   5.4E-04   3.9E-04 3.750E+01 225.0   5.4E-04   3.0E-04
  24.0 2.860E+01 215.2   6.0E-04   3.5E-04 3.227E+01 226.0   6.0E-04   2.9E-04
  25.0 2.430E+01 215.2   6.7E-04   3.4E-04 2.780E+01 228.0   6.7E-04   2.5E-04
  30.0 1.110E+01 217.4   3.6E-04   1.9E-04 1.360E+01 235.0   3.6E-04   1.4E-04
  35.0 5.180E+00 227.8   1.1E-04   9.2E-05 6.610E+00 247.0   1.1E-04   9.2E-05
  40.0 2.530E+00 243.2   4.3E-05   4.1E-05 3.400E+00 262.0   4.3E-05   4.1E-05
  45.0 1.290E+00 258.5   1.9E-05   1.3E-05 1.810E+00 274.0   1.9E-05   1.3E-05
  50.0 6.820E-01 265.7   6.3E-06   4.3E-06 9.870E-01 277.0   6.3E-06   4.3E-06
  70.0 4.670E-02 230.7   1.4E-07   8.5E-08 7.070E-02 216.0   1.4E-07   8.5E-08
 100.0 3.000E-04 210.2   1.0E-09   4.3E-11 3.000E-04 210.0   1.0E-09   4.3E-11
99999.           210.0                               210.0                       *
   0.0 1.013E+03 257.1   1.2E+00   4.1E-05 1.013E+03 288.1   5.9E+00   5.4E-05
   1.0 8.878E+02 259.1   1.2E+00   4.1E-05 8.986E+02 281.6   4.2E+00   5.4E-05
   2.0 7.775E+02 255.9   9.4E-01   4.1E-05 7.950E+02 275.1   2.9E+00   5.4E-05
   3.0 6.798E+02 252.7   6.8E-01   4.3E-05 7.012E+02 268.7   1.8E+00   5.0E-05
   4.0 5.932E+02 247.7   4.1E-01   4.5E-05 6.166E+02 262.2   1.1E+00   4.6E-05
   5.0 5.158E+02 240.9   2.0E-01   4.7E-05 5.405E+02 255.7   6.4E-01   4.5E-05
   6.0 4.467E+02 234.1   9.8E-02   4.9E-05 4.722E+02 249.2   3.8E-01   4.5E-05
   7.0 3.853E+02 227.3   5.4E-02   7.1E-05 4.111E+02 242.7   2.1E-01   4.9E-05
   8.0 3.308E+02 220.6   1.1E-02   9.0E-05 3.565E+02 236.2   1.2E-01   5.2E-05
   9.0 2.829E+02 217.2   8.4E-03   1.5E-04 3.080E+02 229.7   4.6E-02   7.1E-05
  10.0 2.418E+02 217.2   5.5E-03   2.4E-04 2.650E+02 223.2   1.8E-02   9.0E-05
  11.0 2.067E+02 217.2   3.8E-03   3.2E-04 2.270E+02 216.8   8.2E-03   1.3E-04
  12.0 1.766E+02 217.2   2.6E-03   4.3E-04 1.940E+02 216.6   3.7E-03   1.5E-04
  13.0 1.510E+02 217.2   1.8E-03   4.7E-04 1.658E+02 216.6   1.8E-03   1.7E-04
  14.0 1.291E+02 217.2   1.0E-03   4.9E-04 1.417E+02 216.6   8.4E-04   1.9E-04
  15.0 1.103E+02 217.2   7.6E-04   5.5E-04 1.211E+02 216.6   7.2E-04   2.1E-04
  16.0 9.431E+01 216.6   6.4E-04   6.2E-04 1.035E+02 216.6   6.1E-04   2.4E-04
  17.0 8.058E+01 216.0   5.6E-04   6.2E-04 8.850E+01 216.6   5.2E-04   2.8E-04
  18.0 6.882E+01 215.4   5.0E-04   6.2E-04 7.565E+01 216.6   4.4E-04   3.2E-04
  19.0 5.875E+01 214.8   4.9E-04   6.0E-04 6.467E+01 216.6   4.4E-04   3.5E-04
  20.0 5.014E+01 214.1   4.5E-04   5.5E-04 5.529E+01 216.6   4.4E-04   3.8E-04
  21.0 4.277E+01 213.6   5.1E-04   5.1E-04 4.729E+01 217.6   4.8E-04   3.8E-04
  22.0 3.647E+01 213.0   5.1E-04   4.7E-04 4.047E+01 218.6   5.2E-04   3.9E-04
  23.0 3.109E+01 212.5   5.4E-04   4.3E-04 3.457E+01 219.6   5.7E-04   3.8E-04
  24.0 2.649E+01 211.8   6.0E-04   3.5E-04 2.972E+01 220.6   6.1E-04   3.5E-04
  25.0 2.256E+01 211.2   6.7E-04   3.2E-04 2.549E+01 221.6   6.6E-04   3.4E-04
  30.0 1.020E+01 216.0   3.6E-04   1.5E-04 1.197E+01 226.5   3.8E-04   2.0E-04
  35.0 4.701E+00 222.2   1.1E-04   9.2E-05 5.746E+00 236.5   1.6E-04   1.1E-04
  40.0 2.243E+00 234.7   4.3E-05   4.1E-05 2.871E+00 253.4   6.7E-05   4.3E-05
  45.0 1.113E+00 247.0   1.9E-05   1.3E-05 1.491E+00 264.2   3.2E-05   1.7E-05
  50.0 5.719E-01 259.3   6.3E-06   4.3E-06 7.978E-01 270.6   1.2E-05   4.9E-06
  70.0 4.016E-02 245.7   1.4E-07   8.5E-08 5.520E-02 219.7   1.5E-07   8.5E-08
 100.0 3.800E-04 210.0   1.0E-09   4.3E-11 3.000E-04 210.0   1.0E-09   4.3E-11
99999.           210.0                               210.0                       *
   .20 .28600 .04530   .25 .28000 .05660   .31 .26200 .02060   .34 .24500 .01450*
   .49 .18500 .01050   .51 .17600 .01000   .63 .14600 .00914   .69 .13400 .00914*
   .86 .10800 .01020  1.06 .08910 .01380  1.54 .05790 .00924  2.00 .03510 .01348*
  2.50 .02660 .00369  2.70 .02670 .00388  3.00 .02240 .00487  3.20 .02150 .00232*
  3.39 .02390 .00222  3.50 .02100 .00171  3.75 .01950 .00143  4.00 .01820 .00154*
  4.50 .01670 .00249  5.50 .01360 .00295  6.00 .01190 .00360  6.50 .01210 .00423*
  7.20 .01330 .00629  7.90 .00784 .00504  8.20 .00809 .00702  8.50 .01530 .01160*
  8.70 .02190 .01180  9.00 .02380 .01310  9.20 .02350 .01430  9.50 .01850 .00937*
 10.00 .01570 .00698 10.59 .01350 .00549 11.00 .01220 .00439 13.00 .00938 .00386*
 14.80 .00827 .00464 15.00 .01010 .00691 17.20 .01100 .00607 18.50 .00823 .00506*
 20.00 .01010 .00567 25.00 .00878 .00565 27.90 .00821 .00562 30.00 .00838 .00581*
 0.999-2.3468-1.6778 0.998-2.0362-1.3980 0.996-1.6930-1.1192 0.994-1.4815-0.9506
 0.992-1.3279-0.8239 0.990-1.2007-0.7250 0.980-0.7825-0.4318 0.970-0.5229-0.2366
```

MODEL ATMOSPHERES 3 & 4 continued

MODEL ATMOSPHERES 5 & 6

AEROSOL SPECTRAL DATA

Table A2. Listing of Data for LOWTRAN 3 (Cont)

TRANSMITTANCE FUNCTIONS

```
0.960-0.3468-0.1074 0.950-0.1938-0.       0.940-0.0655 0.0969 0.930 0.0414 0.1761
0.920 0.1553 0.2304 0.910 0.2430 0.3310 0.900 0.3324 0.3522 0.880 0.4342 0.4624
0.860 0.6128 0.5563 0.840 0.7243 0.6435 0.820 0.8261 0.7243 0.800 0.9191 0.7324
0.780 1.0090 0.8573 0.760 1.0757 0.9191 0.740 1.1461 0.9731 0.720 1.2122 1.0253
0.700 1.2672 1.0719 0.680 1.3254 1.1173 0.660 1.3892 1.1614 0.640 1.4403 1.2095
0.620 1.4955 1.2480 0.600 1.5441 1.2900 0.580 1.5966 1.3263 0.560 1.6435 1.3617
0.540 1.6857 1.3979 0.520 1.7340 1.4393 0.500 1.7792 1.4698 0.480 1.8261 1.4983
0.460 1.8692 1.5314 0.440 1.9191 1.5682 0.420 1.9638 1.6021 0.400 2.0086 1.6335
0.380 2.0607 1.6721 0.360 2.1038 1.7376 0.340 2.1461 1.7482 0.320 2.1875 1.7924
0.300 2.2304 1.8325 0.280 2.2788 1.8865 0.260 2.3263 1.9395 0.240 2.3717 2.0000
0.220 2.4183 2.0607 0.200 2.4698 2.1206 0.180 2.5159 2.1903 0.160 2.5740 2.2552
0.140 2.6284 2.3385 0.120 2.6922 2.4313 0.100 2.7559 2.5185 0.080 2.8261 2.6435
0.060 2.9031 2.7853 0.040 3.0000 2.9777 0.030 3.0607 3.1072 0.020 3.1461 3.2553
0.015 3.2041 3.3617 0.010 3.2718 3.4771 0.008 3.3054 3.5563 0.006 3.3444 3.6233
0.004 3.3979 3.7076 0.002 3.4916 3.8325 0.001 3.5682 3.9345
```

SPECTRAL DATA: H_2O

```
3.93 3.72 3.54 3.42 3.37 3.37 3.36 3.33 3.25 3.13 3.02 2.96 2.97 3.08 3.18  350
3.12 3.08 3.03 3.00 3.01 3.03 3.07 3.05 3.01 2.94 2.83 2.71 2.62 2.58 2.57  425
2.62 2.67 2.72 2.71 2.60 2.46 2.35 2.26 2.22 2.23 2.19 2.17 2.17 2.20 2.26  500
2.34 2.42 2.39 2.20 2.01 1.92 1.83 1.78 1.79 1.81 1.84 1.83 1.80 1.71 1.51  575
1.39 1.38 1.25 1.18 1.19 1.18 1.21 1.33 1.47 1.53 1.54 1.36 1.12 0.89 0.59  650
0.49 0.60 0.71 0.79 0.99 0.86 0.73 0.53 0.43 0.51 0.52 0.67 0.73 0.80 0.33  725
0.80 0.63 0.47 0.32-0.08-0.21-0.29-0.21-0.01 0.08 0.16 0.09-0.03-0.21-0.37  800
-0.35-0.30-0.31-0.37-0.42-0.48-0.42-0.40-0.39-0.43-0.77-0.83-0.88-0.79-0.60  875
-0.50-0.42-0.39-0.38-0.37-0.40-0.51-0.67-0.62-0.56-0.40-0.32-0.21-0.09-0.16  950
-0.16-0.19-0.28-0.33-0.35-0.28-0.22-0.10-0.05-0.11-0.13-0.27-0.27-0.18-0.06 1025
0.11 0.23 0.26 0.19 0.11-0.00-0.09 0.02 0.08 0.12 0.22 0.28 0.39 0.54 0.58 1100
0.75 0.79 0.79 0.71 0.69 0.76 0.80 1.01 1.16 1.18 1.14 1.05 1.02 1.11 1.23 1175
1.41 1.75 1.83 1.99 2.05 2.03 2.00 1.96 1.90 1.86 1.91 2.08 2.24 2.41 2.53 1250
2.68 2.67 2.73 2.79 2.81 2.91 2.93 3.02 3.16 3.23 3.30 3.34 3.43 3.57 3.59 1325
3.59 3.58 3.57 3.61 3.71 3.71 3.69 3.64 3.60 3.58 3.80 3.95 4.05 4.05 4.12 1400
3.99 3.96 4.01 4.13 4.22 4.35 4.49 4.58 4.62 4.63 4.61 4.57 4.56 4.56 4.53 1475
4.49 4.46 4.40 4.28 4.16 3.92 3.63 3.35 3.16 3.10 3.24 3.47 3.66 3.86 3.93 1550
4.00 4.04 4.15 4.23 4.31 4.35 4.31 4.23 4.20 4.24 4.28 4.35 4.42 4.42 4.44 1625
4.46 4.40 4.30 4.22 4.13 4.07 4.12 4.19 4.22 4.23 4.16 4.04 3.99 3.94 3.93 1700
3.91 3.86 3.83 3.90 3.78 3.70 3.54 3.40 3.30 3.31 3.42 3.52 3.52 3.49 3.41 1775
3.21 3.14 3.10 3.08 3.11 2.98 2.88 2.78 2.74 2.76 2.72 2.76 2.82 2.85 2.86 1850
2.75 2.64 2.60 2.61 2.66 2.56 2.49 2.37 2.25 2.14 2.08 2.11 2.20 2.31 2.28 1925
2.15 2.06 1.99 2.03 2.05 1.96 1.84 1.72 1.64 1.59 1.57 1.57 1.60 1.63 1.51 2000
1.38 1.07 0.91 0.87 0.92 1.04 1.01 0.92 0.84 0.92 0.97 1.01 1.06 1.10 1.36 2075
1.01 0.91 0.73 0.55 0.47 0.41 0.39 0.38 0.34 0.33 0.36 0.43 0.48 0.45 0.38 2150
0.27 0.21 0.22 0.29 0.37 0.38 0.37 0.29 0.19 0.13 0.11 0.03-0.05-0.12-0.24 2225
-0.31-0.39-0.43-0.50-0.59-0.68-0.73-0.80-0.92-1.06-1.14-1.22-1.27-1.28-1.33 2300
-1.32-1.43-1.51-1.63-1.74-1.82-1.98-2.09-2.21-2.21-2.24-2.27-2.36-2.51-2.55 2375
-2.70-2.63-2.57-2.56-2.59-2.67-2.69-2.67-2.68-2.62-2.52-2.42-2.29-2.14-2.00 2450
-1.87-1.71-1.51-1.39-1.27-1.12-1.01-0.89-0.75-0.66-0.57-0.47-0.42-0.32-0.27 2525
-0.26-0.19-0.13-0.11-0.01 0.05 0.08 0.17 0.25 0.31 0.41 0.43 0.44 0.63 0.36 2600
0.35 0.31 0.25 0.25 0.22 0.21 0.33 0.49 0.65 0.76 0.71 0.51 0.38 0.13 0.10 2675
0.17 0.24 0.31 0.35 0.45 0.51 0.56 0.60 0.63 0.62 0.63 0.64 0.66 0.69 0.76 2750
0.75 0.74 0.70 0.62 0.53 0.46 0.39 0.38 0.37 0.36 0.42 0.47 0.50 0.58 0.59 2825
0.67 0.62 0.64 0.68 0.76 0.90 1.11 1.13 1.10 0.97 0.98 1.17 1.38 1.52 1.70 2900*
1.76 1.84 1.92 1.90 1.87 1.91 2.02 2.13 2.10 2.18 2.22 2.25 2.03 2.01 1.77 2975*
1.93 2.19 2.28 2.14 2.15 2.22 2.01 2.14 2.26 2.36 2.51 2.66 2.73 2.68 2.59 3050*
2.64 2.22 1.95 1.61 1.11 0.88 0.83 0.89 1.28 1.62 1.62 1.99 2.01 2.14 2.16 3125*
2.21 2.30 2.33 2.42 2.50 2.51 2.49 2.46 2.42 2.37 2.37 2.33 2.31 2.43 2.56 3200*
2.61 2.63 2.60 2.50 2.38 2.41 2.34 2.31 2.32 2.40 2.27 2.32 2.22 2.09 2.60 3275*
2.17 2.51 2.77 2.68 2.49 2.29 2.23 2.42 2.61 2.58 2.49 2.40 2.39 2.51 2.50 3350*
2.68 2.68 2.70 2.82 2.83 2.82 2.81 2.84 2.86 2.91 2.96 3.03 3.08 3.21 3.30 3425*
3.40 3.52 3.49 3.46 3.51 3.54 3.56 3.55 3.57 3.61 3.71 3.80 3.92 3.99 4.06 3500*
4.02 4.06 4.12 4.28 4.38 4.22 4.32 4.42 4.53 4.64 4.55 4.40 4.28 4.32 4.38 3575*
4.37 4.24 4.13 4.14 4.20 4.25 4.32 4.35 4.31 4.27 4.25 4.27 4.31 4.36 4.41 3650*
4.52 4.59 4.71 4.79 4.81 4.73 4.61 4.42 4.28 4.08 4.00 3.88 3.86 3.92 3.98 3725*
```

Table A2. Listing of Data for LOWTRAN 3 (Cont)

```
 4.12 4.18 4.31 4.37 4.42 4.50 4.53 4.58 4.59 4.61 4.61 4.59 4.53 4.49 4.44 3800
 4.41 4.40 4.34 4.30 4.26 4.09 3.98 3.87 3.78 3.77 3.79 3.75 3.72 3.62 3.56 3875
 3.51 3.49 3.32 3.15 3.07 2.96 2.87 2.80 2.68 2.53 2.53 2.51 2.59 2.57 2.50 3950
 2.42 2.32 2.20 2.12 2.00 1.92 1.79 1.63 1.60 1.69 1.78 2.04 2.08 1.81 1.70 4025
 1.63 1.61 1.60 1.49 1.14 1.35 1.64 1.69 1.70 1.59 1.45 1.29 1.19 1.08 1.02 4100
 1.04 1.10 1.16 1.28 1.23 1.22 1.08 1.08 1.06 0.89 0.93 0.73 0.58 0.54 0.77 4175
 0.81 0.74 0.71 0.57 0.49 0.43 0.38 0.12 0.18 0.20 0.41 0.37 0.31 0.31-0.13 4250
-0.21-0.32-0.36-0.39-0.33-0.39-0.45-0.50-0.56-0.62-0.68-0.77-0.84-0.91-1.00 4325
-1.11-1.19-1.26-1.31-1.39-1.43-1.48-1.52-1.57-1.60-1.61-1.60-1.58-1.51-1.42 4400
-1.32-1.26-1.16-1.00-0.83-0.71-0.61-0.52-0.43-0.36-0.30-0.21-0.19-0.17-0.15 4475
-0.13-0.17-0.19-0.12-0.06-0.01 0.00-0.11-0.23-0.32-0.44-0.51-0.48-0.47-0.42 4550
-0.48-0.40-0.39-0.37-0.35-0.48-0.75-1.13-1.58-1.80-1.66-1.52-1.35-1.19-1.02 4625
-0.88-0.66-0.65-0.63-0.62-0.66-0.73-0.79-0.88-0.84-0.70-0.59-0.43-0.39-0.58 4700
-0.61-0.74-0.79-0.76-0.69-0.62-0.59-0.52-0.48-0.48-0.42-0.39-0.38-0.33-0.29 4775
-0.26-0.29-0.22-0.28-0.37-0.50-0.60-0.60-0.51-0.46-0.42-0.43-0.45-0.35-0.24 4850
-0.14-0.08-0.09 0.00 0.11 0.32 0.43 0.42 0.32 0.23 0.22 0.29 0.45 0.55 0.52 4925
 0.65 [illegible] 0.75 0.85 0.83 0.85 0.87 0.90 0.93 1.00 1.04 1.15 1.22 1.32 1.31 5000
 1.32 1.33 1.48 1.78 1.87 2.01 1.92 1.86 1.89 1.92 1.98 2.03 2.39 2.31 2.48 5075
 2.78 2.72 2.76 2.78 2.70 2.77 3.08 2.94 3.05 2.94 3.23 3.20 3.19 3.32 3.11 5150
 3.41 3.31 3.36 3.46 3.36 3.39 3.50 3.41 3.22 3.19 2.98 2.78 2.98 3.02 2.92 5225
 2.98 2.06 2.92 2.92 3.05 3.22 3.60 3.78 3.61 3.96 3.76 3.62 3.54 3.08 3.31 5300
 3.16 3.37 3.41 3.30 3.33 3.53 3.51 3.40 3.43 3.52 3.31 3.40 3.58 3.61 3.49 5375
 3.46 3.42 3.19 3.18 3.30 3.08 2.99 3.21 3.11 3.14 3.10 2.72 2.81 2.95 2.59 5450
 2.73 2.72 2.47 2.51 2.60 2.42 2.37 2.73 1.91 1.87 1.81 1.78 1.53 1.51 1.52 5525
 1.59 1.50 1.42 1.32 1.22 1.12 1.08 1.02 [illegible] 0.92 0.90 0.87 0.84 0.82 0.79 5600
 0.78 0.76 0.75 0.72 0.71 0.71 0.70 0.69 0.67 0.61 0.59 0.52 0.48 0.41 0.39 5675
 0.38 0.33 0.32 0.30 0.30 0.30 0.29 0.28 0.27 0.26 0.25 0.23 0.22 0.21 0.20 5750
 0.18 0.14 0.13 0.06 0.01-0.03-0.07-0.11-0.16-0.21-0.24-0.29-0.32-0.38-0.41 5825
-0.45-0.50-0.54-0.61-0.69-0.76-0.84-0.90-0.97-1.01-1.10-1.13-1.19-1.22-1.28 5900
-1.30-1.33-1.36-1.39-1.43-1.48-1.50-1.52-1.57-1.61-1.66-1.70-1.72-1.78-1.81 5975
-1.89-1.92-2.00-2.09-2.16-2.24-2.31-2.40-2.48-2.54-2.61-2.71-2.83-2.95-3.10 6050
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 6125
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 6200
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 6275
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 6350
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 6425
-3.78-3.33-3.01-2.82-2.68-2.49-2.30-2.13-2.00-1.81-1.60-1.41-1.23-0.99-0.79 6500
-0.63-0.48-0.36-0.28-0.16-0.06 0.08 0.20 0.28 0.41 0.54 0.69 0.80 0.92 1.04 6575
 1.19 1.19 1.0[illegible] 0.99 1.02 1.19 1.29 1.30 1.29 1.38 1.19 1.33 1.42 1.43 1.70 6650
 1.62 1.54 1.41 1.53 1.86 1.96 1.97 2.02 2.01 1.94 1.94 1.83 2.03 2.21 2.42 6725
 2.30 2.16 2.02 2.02 2.02 2.13 1.90 1.71 2.01 1.56 1.56 1.51 1.30 1.63 1.54 6800
 1.67 1.70 2.22 2.39 2.38 2.30 1.93 2.39 2.49 2.52 2.57 2.21 2.19 2.40 2.41 6875
 2.45 2.51 2.23 2.49 2.30 2.61 2.72 2.52 2.63 2.56 2.51 2.70 2.62 2.62 2.90 6950
 2.74 2.79 2.74 2.70 2.88 2.81 2.72 2.76 2.84 2.92 2.98 2.83 2.86 3.02 3.08 7025
 3.26 3.03 3.14 3.29 3.03 3.11 3.15 3.30 3.31 3.22 3.30 3.06 3.34 3.40 3.37 7100
 3.32 3.08 3.09 3.09 3.01 3.07 3.07 3.[illegible]1 3.21 3.[illegible]1 3.67 3.59 3.79 3.70 3.69 7175
 3.39 3.11 3.13 3.01 3.10 3.01 3.18 3.42 3.43 3[illegible]5 3.40 3.39 3.39 3.51 3.54 7250
 3.42 3.58 3.67 3.59 3.63 3.66 3.48 3.39 3.29 3.31 3.41 3.23 3.32 3.12 2.91 7325
 2.91 2.75 2.78 2.72 2.62 2.58 2.32 2.22 2.08 1.97 1.68 1.62 1.64 1.53 1.56 7400
 1.51 1.52 1.48 1.42 1.42 1.40 1.41 1.43 1.56 1.52 1.51 1.52 1.39 1.39 1.30 7475
 1.09 1.16 1.21 1.20 1.22 1.20 1.18 1.20 1.19 1.17 1.18 1.10 1.09 1.10 1.11 7550
 1.04 0.98 0.90 0.85 0.93 0.90 0.90 0.86 0.71 0.79 0.70 0.71 0.67 0.62 0.53 7625
 0.42 0.31 0.20 0.01-0.08-0.17-0.26-0.35-0.44-0.53-0.63-0.73-0.83-0.93-1.04 7700
-1.14-1.24-1.34-1.44-1.54-1.64-1.74-1.84-1.94-2.04-2.14-2.24-2.34-2.44-2.54 7775
-2.64-2.74-2.84-2.94-3.04-3.14-3.24-3.34-3.44-3.54-3.64-3.74-3.84-3.94-4.04 7850
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 7925
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 8000
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 8075
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 8150
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 8225
-4.15-4.06-3.97-3.88-3.79-3.70-3.61-3.52-3.43-3.34-3.25-3.16-3.07-2.98-2.89 8300
```

SPECTRAL DATA: H_2O

Table A2. Listing of Data for LOWTRAN 3 (Cont)

SPECTRAL DATA: H_2O

```
-2.80-2.71-2.62-2.53-2.44-2.35-2.26-2.18-2.09-2.00-1.91-1.82-1.73-1.64-1.55 8375
-1.46-1.37-1.28-1.19-1.10-1.01-0.92-0.83-0.74-0.65-0.56-0.47-0.38-0.29-0.20 8450
-0.14-0.09-0.02 0.03 0.10 0.17 0.22 0.30 0.35 0.41 0.45 0.42 0.40 0.43 0.46 8525
 0.50 0.55 0.71 0.84 0.93 1.01 1.06 1.07 1.02 1.01 1.12 1.23 1.24 1.28 1.34 8600
 1.43 1.52 1.56 1.59 1.56 1.51 1.61 1.50 1.70 1.02 1.32 1.34 1.09 1.01 1.45 8675
 1.30 1.28 1.43 1.50 1.49 1.55 1.40 1.32 1.39 1.53 1.82 2.23 2.61 2.51 2.20 8750
 1.66 1.61 1.19 1.32 1.52 1.70 1.90 2.01 1.92 1.91 2.12 2.10 2.01 2.18 1.39 8825
 2.11 2.20 2.21 2.13 2.00 1.91 1.92 1.97 1.88 1.91 1.91 1.92 1.93 1.74 1.51 8900
 1.50 1.27 1.20 1.18 1.11 0.99 0.86 0.71 0.60 0.46 0.31 0.17 0.03-0.07-0.21 8975
-0.35-0.49-0.64-0.79-0.94-1.11-1.24-1.41-1.57-1.73-1.91-2.09-2.27-2.45-2.63 9050
-2.81-2.99-3.18-3.37-3.56-3.75-3.94-4.13-4.31-4.49-4.66-4.83-4.99-5.14-5.28 9125
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.60-4.26-3.89-3.57-3.32-3.11-2.91 9875
-2.89-2.79-2.74-2.63-2.47-2.29-2.20-2.17-2.23-2.27-2.32-2.12-2.00-2.07-2.07 9950
-2.07-1.90-1.77-1.70-1.63-1.60-1.59-1.43-1.21-1.15-1.09-1.13-1.29-1.19-0.3810025
-0.93-0.87-0.91-0.89-0.71-0.62-0.59-0.50-0.63-0.58-0.39-0.22-0.14-0.06-0.3110100
-0.01-0.00-0.20-0.16-0.02 0.10 0.32 0.42 0.37 0.23 0.12 0.15 0.28 0.43 0.5910175
 0.58 0.53 0.44 0.39 0.38 0.35 0.23 0.26 0.19 0.08 0.10 0.19 0.27 0.39 0.6310250
 0.32 0.37 0.58 0.64 0.87 0.98 1.00 1.02 1.13 1.08 1.08 1.16 1.16 1.30 1.6110325
 1.40 1.32 1.32 1.37 1.42 1.50 1.42 1.30 1.36 1.38 1.49 1.63 1.62 1.62 1.7010400
 1.60 1.60 1.56 1.56 1.63 1.64 1.56 1.49 1.49 1.52 1.58 1.62 1.62 1.61 1.5110475
 1.62 1.63 1.71 1.72 1.70 1.70 1.67 1.62 1.66 1.70 1.67 1.56 1.49 1.42 1.3810550
 1.26 1.20 1.13 1.14 1.19 1.29 1.50 1.72 1.86 1.70 1.82 1.88 1.82 1.89 1.3910625
 2.00 2.14 2.04 2.02 2.02 1.98 1.90 1.83 1.81 1.72 1.69 1.59 1.50 1.36 1.2010700
 0.98 0.63 0.43 0.29 0.16 0.05 0.02 0.03 0.00 0.01-0.08-0.18-0.20-0.11-0.0610775
-0.03-0.14-0.21-0.08-0.06 0.10 0.18 0.11 0.32 0.42 0.44 0.38 0.28 0.42 0.4310850
 0.41 0.33 0.32 0.41 0.50 0.46 0.31 0.18 0.08 0.20 0.21 0.34 0.35 0.29 0.3510925
 0.39 0.42 0.38 0.32 0.30 0.16-0.01-0.23-0.41-0.52-0.48-0.53-0.61-0.45-0.2311000
-0.03 0.21 0.36 0.39 0.47 0.44 0.40 0.51 0.59 0.53 0.69 0.57 0.48 0.52 0.6211075
 0.59 0.55 0.50 0.32 0.26 0.11-0.08-0.10-0.16-0.43-0.62-0.88-1.09-1.16-1.3111150
-1.45-1.49-1.70-1.91-2.01-1.97-1.97-1.97-1.97-2.26-2.20-2.01-1.99-2.00-2.0411225
-2.37-2.49-2.44-2.36-2.32-2.19-2.10-2.25-2.16-2.36-2.44-2.40-2.49-2.46-2.4311300
-2.40-2.36-2.40-2.49-2.59-2.68-2.89-3.28-3.51-3.74-3.97-4.20-4.43-4.66-4.8911375
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.0011450
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-0.91-1.01-0.99-0.87-0.92-0.79-0.42-0.54-0.38-0.42-0.48-0.34-0.27-0.17-0.2811900
-0.30-0.22-0.30-0.09-0.01-0.20 0.06 0.10 0.06 0.14-0.12-0.02-0.02-0.13-0.1111975
-0.10-0.06-0.05-0.04-0.10-0.04-0.06-0.21-0.38-0.61-0.40-0.31-0.42-0.58-0.5712050
-0.54-0.24 0.11 0.51 0.81 0.79 0.62 0.26-0.31-0.67-0.80-0.88-0.58-0.39-0.1012125
 0.09 0.06 0.08 0.16 0.21 0.13 0.32 0.35 0.51 0.60 0.51 0.51 0.40 0.40 0.4312200
 0.42 0.33 0.43 0.34 0.22 0.13-0.11-0.31-0.31-0.41-0.41-0.39-0.53-0.69-0.3412275
-0.88-1.01-1.10-1.13-1.29-1.45-1.49-1.67-1.67-1.51-1.66-1.60-1.69-1.83-1.5812350
-1.42-1.40-1.24-1.38-1.31-1.30-1.30-1.28-1.39-1.33-1.40-1.35-1.37-1.39-1.4112425
-1.49-1.48-1.56-1.47-1.46-1.41-1.42-1.40-1.41-1.31-1.15-1.13-1.20-1.41-1.0812500
-2.08-2.08-2.22-2.35-2.35-1.98-1.92-1.78-1.57-1.69-1.70-1.70-1.66-1.84-1.5012575
-1.56-1.42-1.29-1.39-1.20-1.68-1.58-1.44-1.53-1.48-1.43-1.58-1.58-1.69-1.7912650
-2.00-2.16-1.99-2.23-2.04-2.04-2.39-2.74-3.09-3.44-3.79-4.14-4.49-4.84-5.1912725
-2.46-2.26-1.99-2.01-2.14-2.31-2.15-2.01-1.99-2.14-2.41-2.12-1.99-1.84-1.7913400
-1.71-1.78-1.72-1.68-1.78-1.52-1.38-1.29-1.22-0.91-0.90-1.01-0.76-0.90-0.9013475
-0.98-1.19-1.00-0.79-0.68-0.60-0.73-0.95-0.85-0.61-0.61-0.43-0.51-0.97-0.9313550
-0.61-0.41-0.29-0.29-0.61-0.74-0.19-0.18 0.   0.19-0.18 0.20 0.20 0.02  .2013625
-0.91 0.10 0.25 0.11 0.   -0.37-0.10 0.02 0.16 0.20 0.   0.09 0.09 0.09 0.0713700
 0.22 0.11 0.11 0.21 0.09 0.21 0.20 0.37 0.20 0.07 0.09-0.29-0.69-0.69-0.7413775
-0.00-1.01-0.06-0.54-0.19 0.19 0.23 0.21 0.29 0.20 0.29 0.52 0.54 0.51  .6013850
 0.40 0.49 0.40 0.46 0.49 0.27 0.06-0.33-0.81-1.17-1.11-1.37-1.52-1.54-1.9613925
-2.06-2.06-2.14-1.96-2.00-2.00-2.00-2.23-2.31-2.31-2.53-2.31-2.31-2.31-2.2014000
-2.34-2.34-1.91-1.82-1.69-1.56-1.84-1.91-1.75-1.83-1.76-1.54-1.90-1.80-1.6814075
-1.69-1.56-1.60-1.71-1.36-1.36-1.44-1.40-1.40-1.40-1.36-1.45-1.49-1.85-1.3914150
```

Table A2. Listing of Data for LOWTRAN 3 (Cont)

SPECTRAL DATA: H_2O cont.

SPECTRAL DATA: UNIFORMLY MIXED GASES

```
-1.23-1.18-1.18-1.34-1.36-1.23-1.23-1.37-1.30-1.43-1.28-1.27-1.37-1.32-1.3214225
-1.22-1.28-1.38-1.63-2.07-2.42-2.58-2.59-2.88-2.54-2.43-1.88-1.60-1.26-1.1614300
-1.23-1.18-1.23-1.10-0.83-0.80-0.80-0.90-0.98-0.97-0.97-0.91-0.92-1.13-1.2414375
-1.50-1.89-2.18-2.32-2.63-3.91-4.20-4.49-4.78-5.07-5.37-5.07-5.07-5.07-5.0714450
-4.95-3.70-3.20-2.75-1.90-1.73-1.51-1.29-1.11-0.91-0.71-0.51-0.30-0.06 0.22   500
 0.49 0.76 1.08 1.23 1.56 1.76 1.91 2.08 2.23 2.36 2.51 2.72 2.90 3.12 3.37   575
 3.56 3.69 3.79 3.86 3.88 3.86 3.73 3.58 3.38 3.17 2.86 2.73 2.52 2.31 2.17   650
 2.01 1.89 1.77 1.63 1.47 1.21 0.92 0.53 0.23-0.17-0.53-0.74-0.81-0.84-0.98   725
-1.08-1.18-1.42-1.61-1.86-2.10-2.29-2.51-2.72-2.91-3.14-5.00-5.00-5.00-5.00   800
-5.00-5.00-5.00-5.00-5.00-5.00-2.68-2.47-2.19-1.97-1.71-1.50-1.32-1.21-1.13   875
-1.09-1.11-1.10-1.09-1.01-1.01-1.11-1.33-1.66-2.13-2.51-2.83-2.71-2.39-2.19   950
-1.78-1.59-1.33-1.18-1.01-0.96-0.91-0.90-0.87-0.80-0.79-0.86-1.07-1.28-1.69  1025
-2.11-2.74-3.09-3.50-3.03-2.58-2.23-1.89-1.54-1.28-1.13-1.11-1.16-1.28-1.23  1100
-1.21-1.17-1.12-1.15-1.19-1.20-1.17-1.02-0.89-0.68-0.42-0.24-0.01 0.18 0.40  1175
 0.57 0.77 0.96 1.07 1.13 1.11 1.08 1.15 1.27 1.33 1.44 1.40 1.13 0.89 0.53  1250
 0.54 0.65 0.78 0.81 0.86 0.82 0.68 0.47 0.14-0.12-0.48-0.92-1.43-1.89-2.32  1325
-2.81-5.00-5.00-5.00-3.14-2.47-2.00-1.71-1.59-1.61-1.69-1.82-1.87-1.90-1.94  1400
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-1.70-2.01-2.41-2.64-2.63-2.49-2.38-2.27-2.16-2.05-1.94-1.63-1.76-1.71-1.70  1550
-1.72-1.81-1.92-2.03-2.27-2.61-3.21-4.01-5.00=5.00-5.00-5.00-5.00-5.00-5.00  1625
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-2.83-2.71-2.67-2.67-2.68-2.58-2.33-2.01-1.64-1.32-0.97-0.76-0.63-0.59-0.50  1850
-0.63-0.69-0.87-1.05-1.26-1.53-1.87-1.91-1.93-2.02-2.21-2.48-2.80-3.08-3.11  1925
-3.09-2.93-2.76-2.39-2.01-1.69-1.36-0.99-0.63-0.28 0.00 0.08 0.11 0.12 0.12  2000
 0.07 0.01-0.08-0.23-0.40-0.51-0.53-0.57-0.60-0.61-0.73-0.81-0.95-1.05-1.32  2075
-0.91-0.68-0.41-0.03 0.19 0.41 0.76 1.00 1.18 1.39 1.51 1.58 1.68 1.71 1.93  2150
 1.91 2.02 2.18 2.32 2.58 2.61 2.69 2.81 2.89 2.96 3.04 3.14 3.27 3.41 3.55  2225
 3.72 3.90 4.03 4.22 4.42 4.61 4.71 4.73 4.65 4.63 4.72 4.78 4.79 4.50 3.62  2300
 3.28 2.79 2.30 1.85 1.35 0.62-0.24-1.69-2.18-2.01-1.79-1.53-1.32-1.20-1.15  2375
-1.12-1.19-1.25-1.26-1.20-1.17-1.20-1.32-1.54-1.84-2.16-2.30-2.26-2.01-1.71  2450
-1.38-1.06-0.81-0.61-0.49-0.45-0.47-0.49-0.46-0.37-0.31-0.34-0.49-0.73-1.11  2525
-1.43-2.01-2.60-2.89-2.87-2.74-2.51-2.42-2.38-2.39-2.42-2.46-2.48-2.49-2.63  2600
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-2.26-2.23-2.20-2.09-2.02-1.96-1.85-1.94-1.86-1.66-1.57-1.65-1.79-1.73-1.59  2750
-1.64-1.69-1.74-1.79-1.87-1.78-1.63-1.50-1.37-1.21-1.00-0.83-0.69-0.53-0.41  2825
-0.30-0.19-0.09-0.04 0.02 0.10 0.16 0.18 0.23 0.26 0.27 0.26 0.24 0.22 0.17  2900
 0.12 0.07-0.01-0.07-0.09 0.32 0.72 0.91 1.12 1.03 0.67 0.17-0.11-0.39-0.29  2975
-0.17-0.08-0.08 0.03 0.13 0.18 0.24 0.27 0.29 0.30 0.29 0.26 0.23 0.21 0.13  3050
 0.09 0.02-0.04-0.19-0.32-0.51-0.72-0.98-1.18-1.50-1.62-1.81-2.04-2.29-2.49  3125
-2.62-2.87-3.03-3.21-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00  3200
-5.00-4.01-3.38-3.01-2.63-2.32-2.09-1.98-1.94-2.00-2.14-2.26-2.20-2.02-1.82  3275
-1.59-1.43-1.38-1.45-1.64-1.90-2.09-2.54-2.91-3.28-3.61-3.72-3.64-3.50-3.41  3350
-3.37-3.30-3.16-3.01-2.76-2.51-2.20-1.80-1.49-1.22-0.97-0.72-0.49-0.20 0.03  3425
 0.20 0.36 0.51 0.61 0.67 0.83 1.00 1.22 1.38 1.56 1.70 1.86 2.01 2.20 2.31  3500
 2.47 2.61 2.76 2.92 3.01 3.05 3.02 2.98 2.98 3.01 3.03 2.97 2.78 2.44 2.13  3575
 1.83 1.59 1.49 1.50 1.67 1.94 2.22 2.50 2.71 2.93 3.12 3.19 3.17 3.15 3.21  3650
 3.26 3.19 2.98 2.59 2.14 1.70 1.22 0.55-0.27-1.09-2.54-3.03-2.94-2.73-2.63  3725
-2.61-2.60-2.63-2.60-2.57-2.53-2.57-2.64-2.77-3.04-3.38-3.98-5.00-5.00-5.00  3800
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-4.07-3.89-3.76-3.67-3.56-3.42-3.35-3.26-3.18-3.14-3.11-3.09-3.10-3.12-3.23  4175
-3.30-3.38-3.37-3.29-3.14-3.08-3.00-2.93-2.89-2.91-3.06-3.08-3.16-3.31-3.48  4250
-3.71-3.98-5.00-5.00-5.00-5.00-4.52-3.98-3.69-3.42-3.10-2.95-2.77 2.61-2.48  4325
-2.41-2.41-2.48-2.38-2.34-2.27-2.21-2.31-2.48-2.73-3.21-4.13-5.00-5.00-5.00  4400
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-5.00-5.00-4.13-4.02-3.99-3.96-3.87-3.73-3.51-3.29-3.13-2.99-2.84-2.73-2.59  4550
-2.68-2.69-2.65-2.62-2.59-2.57-2.62-2.81-3.04-3.21-3.39-3.42-3.36-3.21-3.13  4625
-2.93-2.80-2.64-2.52-2.37-2.28-2.20-2.13-2.07-2.02-1.96-1.85-1.78-1.63-1.44  4700
```

Table A2. Listing of Data for LOWTRAN 3 (Cont)

SPECTRAL DATA: UNIFORMLY MIXED GASES

```
-1.31-1.20-1.08-0.99-0.94-0.86-0.76-0.52-0.31-0.06 0.13 0.30 0.37 0.36 0.36 4775
 0.35 0.35 0.39 0.46 0.48 0.61 0.23-0.08-0.38-0.67-0.88-0.96-0.98-0.87-0.57 4850
-0.36-0.12 0.14 0.44 0.68 0.90 1.11 1.19 1.24 1.25 1.26 1.27 1.51 1.59 1.60 4925
 1.78 0.71 0.11-0.29-0.67-1.32-1.61-1.58-1.42-1.18-0.91-0.59-0.27-0.05 0.29 5000
 0.57 0.73 0.92 0.81 0.73 0.79 0.91 1.01 1.03 0.86 0.72 0.63 0.38 0.12-0.21 5075
-0.47-0.67-1.23-1.67-2.31-2.76-3.24-3.49-3.51-3.47-3.39-3.37-3.43-3.53-3.50 5150
-3.36-3.18-3.07-2.96-3.08-3.14-3.12-3.23-3.07-2.83-2.47-2.25-2.07-1.91-1.78 5225
-1.63-1.46-1.27-1.28-1.76-1.40-1.57-1.98-2.28-2.87-3.74-5.00-5.00-5.00-5.00 5300
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 5375
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 5450
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 5525
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 5600
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-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.91-4.79-4.51 5900
-4.48-4.40-4.29-4.17-3.90-3.77-3.59-3.62-3.72-3.73-3.69-3.31-3.12-2.91-2.53 5975
-2.41-2.27-2.16-2.11-2.28-2.29-2.21-2.06-1.91-1.99-2.27-2.59-2.96-3.35-3.59 6050
-3.79-3.68-3.53-3.45-3.39-3.31-3.18-2.97-2.69-2.39-2.11-1.83-1.59-1.49-1.22 6125
-1.08-0.99-0.68-0.54-0.71-0.79-0.78-0.66-0.49-0.54-0.86-1.37-2.08-2.44-3.46 6200
-3.72-3.74-3.59-3.22-2.95-2.52-2.21-1.64-1.34-1.09-0.86-0.72-0.61-0.70-0.72 6275
-0.67-0.57-0.38-0.51-0.97-1.36-1.89-2.76-3.18-4.21-4.57-4.62-4.78-4.87-5.00 6350
-5.00-5.00-5.00-5.00-5.00-4.93-4.46-3.99-3.45-2.99-2.63-2.30-2.09-2.02-2.12 6425
-2.18-2.13-2.04-1.79-1.83-2.08-2.28-2.51-3.01-3.15-3.22-3.29-3.58-3.89-4.46 6500
-4.99-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 6575
-4.81-4.57-4.11-3.63-3.09-2.99-2.91-2.89-3.19-3.20-3.36-3.62-3.89-3.92-3.73 6650
-3.53-3.37-3.19-3.07-2.79-2.52-2.36-2.24-2.19-2.32-2.41-2.27-2.86-2.83-2.15 6725
-2.47-2.91-3.57-4.89-5.00-5.00-5.00-5.00-5.00-4.61-4.18-3.89-3.57-3.33-3.32 6800
-2.74-2.51-2.20-1.99-1.73-1.57-1.38-1.21-1.11-0.98-0.87-0.79-0.60-0.37-0.18 6875
-0.04-0.04-0.06-0.15-0.18-0.19-0.23-0.45-1.02-1.97-2.78-3.71-4.01-4.20-4.35 6950
-4.58-4.73-4.81-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 7025
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 7100
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 7175
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 7250
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 7325
-5.00-5.00-5.00-4.71-4.31-3.99-3.68-3.50-3.34-3.22-3.23-3.25-3.24-3.18-3.10 7400
-3.07-3.18-3.41-3.67-4.12-4.68-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.51-4.18 7475
-3.73-3.49-3.17-2.96-2.73-2.63-2.58-2.59-2.57-2.49-2.42-2.39-2.48-2.62-3.02 7550
-3.49-4.16-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.87-4.50 7625
-4.21-3.90-3.66-3.56-3.51-3.51-3.51-3.49-3.41-3.34-3.34-3.47-3.60-3.87-4.23 7700
-4.59-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.93 7775
-4.51-4.10-3.78-3.32-3.03-2.74-2.43-2.08-1.83-1.59-1.29-1.02-0.81-0.70-0.73 7850
-0.98-1.09-1.19-1.35-1.47-1.57-1.66-1.80-1.91-2.04-2.18-2.33-2.47-2.61-2.78 7925
-2.97-3.10-3.29-3.44-3.63-3.81-3.98-4.15-4.32-4.61-4.71-4.83-5.00-5.00-5.00 8000
-5.00-5.00-5.00-5.00-4.32-3.24-2.59-2.12-1.62-1.57-1.34-1.15-1.02-0.82-0.6412950
-0.48-0.33-0.14-0.06 0.08 0.21 0.39 0.52 0.61 0.72 0.85 0.96 1.02 1.12 1.1813025
 1.21 1.17 1.00 0.99 0.90 0.97 1.13 1.37 1.58 1.74 1.70 1.49 1.13 0.73 0.2213100
-0.51-1.57-3.49-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.0013175
```

SPECTRAL DATA: OZONE

```
-4.15-3.51-3.00-2.54-2.12-1.76-1.50-1.21-0.86-0.49-0.29-0.13 0.02 0.12 0.24   575
 0.32 0.43 0.52 0.59 0.65 0.72 0.79 0.76 0.72 0.68 0.64 0.68 0.79 0.83 0.93   650
 0.80 0.78 0.68 0.56 0.49 0.42 0.34 0.26 0.14 0.02-0.14-0.35-0.51-0.74-0.98   725
-1.17-1.40-1.58-2.11-2.47-2.83-3.24-3.59-3.94-5.00-5.00-5.00-5.00-5.00-5.0    800
-5.00-5.00-5.00-5.00-5.00-4.46-4.08-3.50-3.14-2.78-2.41-2.10-1.78-1.49-1.23   875
-0.20 0.15 0.35 0.57 0.70 0.95 1.20 1.40 1.65 1.80 1.97 2.10 2.21 2.31 2.38   950*
 2.40 2.42 2.58 2.52 2.20 2.48 2.56 2.45 2.30 2.00 1.20 0.95 0.92 0.93 0.90 1025*
 0.89 0.90 0.92 0.96 0.95 0.96 0.95 0.90 0.80 0.65 0.55 0.40 0.30 0.19 0.09 1100*
-0.02-0.11-0.22-0.41-0.56-0.71-0.89-1.03-1.18-1.33-1.60-1.76-1.90-2.02-2.21 1175
-2.46-2.59-2.79-3.00-3.22-3.61-4.16-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 1250
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 1325
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 1400
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 1475
```

Table A2. Listing of Data for LOWTRAN 3 (Cont)

SPECTRAL DATA: OZONE

N_2 CONTINUUM (H_2O CONTINUUM) OZONE UV AND VISIBLE

```
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.16-3.91-3.66-3.41-3.05-2.69 1550
-2.44-2.19-2.03-1.86-1.71-1.56-1.48-1.39-1.26-1.13-0.97-0.81-0.65-0.48-0.35 1625
-0.22-0.14-0.06-0.02-0.09-0.18-0.14 0.06 0.26-0.02-0.42-0.50-0.82-0.90-0.74 1700
-0.74-0.79-0.84-0.89-0.85-0.81-0.76-0.70-0.68-0.64-0.65-0.66-0.72-0.78-0.94 1775
-0.96-1.02-1.14-1.24-1.33-1.47-1.61-1.77-1.92-1.96-2.04-2.04-2.09-2.06-2.03 1850
-1.98-1.93-1.87-1.82-1.76-1.71-1.65-1.59-1.51-1.44-1.36-1.24-1.18-1.08-0.98 1925
-0.88-0.78-0.69-0.59-0.49-0.37-0.25-0.18-0.10 0.00 0.16 0.27 0.39 0.57 0.75 2000
 0.93 1.11 1.20 1.33 1.44 1.46 1.48 1.48 1.64 1.58 1.49 1.23 0.66 0.38-0.33 2075
-0.71-0.66-0.58-0.49-0.44-0.40-0.40-0.46-0.53-0.64-0.76-0.88-1.01-1.14-1.26 2150
-1.48-1.55-1.69-1.83-1.98-2.13-2.20-2.45-2.64-2.86-3.07-3.24-3.53-3.72-3.94 2225
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 2300
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 2375
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 2450
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 2525
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.16-3.97-3.77-3.58-3.38-3.07-2.75 2600
-2.44-2.12-1.85-1.57-1.30-1.07-0.98-0.94-0.89-0.85-0.81-0.77-0.72-0.69-0.63 2675
-0.58-0.53-0.48-0.41-0.35-0.26-0.19-0.17-0.18-0.19-0.46-0.79-1.12-1.45-1.75 2750
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-1.94-1.73-1.63-1.57-1.41-1.33-1.25-1.17-1.09-1.02-0.96-0.83-0.82-0.73-0.63 2900
-0.54-0.42-0.27-0.12 0.03 0.18 0.25 0.31 0.39 0.47 0.48 0.49 0.50 0.52 0.40 2975
 0.46 0.23 0.01-0.11-0.33-0.55-0.77-0.83-0.88-0.94-0.92-0.91-0.90-0.85-0.80 3050
-0.76-0.71-0.69-0.67-0.66-0.65-0.65-0.66-0.67-0.69-0.70-0.72-0.82-0.93-1.13 3125
-1.14-1.24-1.34-1.51-1.65-2.13-2.57-2.92-3.26-3.71-4.16-5.00-5.00-5.00-5.00 3200
 2.93E-04 3.86E-04 5.09E-04 6.56E-04 8.85E-04 1.06E-03 1.31E-03 1.73E-03    2080
 2.27E-03 2.73E-03 3.36E-03 3.95E-03 5.46E-03 7.19E-03 9.00E-03 1.13E-02    2120
 1.36E-02 1.66E-02 1.96E-02 2.16E-02 2.36E-02 2.63E-02 2.90E-02 3.15E-02    2160
 3.40E-02 3.66E-02 3.92E-02 4.26E-02 4.60E-02 4.95E-02 5.30E-02 5.65E-02    2200
 6.00E-02 6.30E-02 6.60E-02 6.89E-02 7.15E-02 7.39E-02 7.60E-02 7.84E-02    2240
 8.08E-02 8.39E-02 8.70E-02 9.17E-02 9.56E-02 1.04E-01 1.20E-01 1.38E-01    2280
 1.52E-01 1.60E-01 1.69E-01 1.63E-01 1.51E-01 1.37E-01 1.23E-01 1.18E-01    2320
 1.16E-01 1.14E-01 1.12E-01 1.12E-01 1.11E-01 1.11E-01 1.12E-01 1.14E-01    2360
 1.13E-01 1.12E-01 1.09E-01 1.07E-01 1.02E-01 9.90E-02 9.50E-02 9.03E-02    2400
 8.65E-02 8.29E-02 7.65E-02 7.05E-02 6.50E-02 6.10E-02 5.50E-02 4.95E-02    2440
 4.50E-02 4.90E-02 3.75E-02 3.50E-02 3.10E-02 2.65E-02 2.50E-02 2.20E-02    2480
 1.95E-02 1.75E-02 1.60E-02 1.42E-02 1.20E-02 1.05E-02 9.50E-03 9.00E-03    2520
 8.00E-03 7.00E-03 6.50E-03 6.00E-03 5.50E-03 4.75E-03 4.20E-03 3.75E-03    2560
 3.50E-03 3.00E-03 2.50E-03 2.25E-03 2.00E-03 1.85E-03 1.70E-03 1.60E-03    2600
 1.50E-03 1.50E-03 1.54E-03 1.50E-03 1.47E-03 1.34E-03 1.25E-03 1.06E-03    2640
 9.06E-04 7.57E-04 6.41E-04 5.04E-04 4.06E-04 3.36E-04 2.56E-04 2.32E-04    2680
 1.94E-04 1.57E-04 1.31E-04 1.02E-04 5.07E-05                              2720
26.7 20.7 14.8 11.7  9.02 7.68 6.68 5.68 5.34 5.34 5.34 4.34 3.56 1.74 [illegible]  700
 4.50E-03 8.00E-03 1.07E-02 1.10E-02 1.27E-02 1.71E-02 2.00E-02 2.45E-02   13000
 3.07E-02 3.84E-02 4.78E-02 5.67E-02 6.54E-02 7.62E-02 9.15E-02 1.00E-01   14600
 1.09E-01 1.20E-01 1.28E-01 1.12E-01 1.11E-01 1.16E-01 1.19E-01 1.13E-01   16200
 4.06E-02 3.87E-02 3.62E-02 2.94E-02 2.09E-02 1.80E-02 1.91E-02 1.66E-02   19400
 1.03E-01 9.24E-02 8.20E-02 7.57E-02 7.07E-02 6.58E-02 5.56E-02 4.77E-02   17800
 1.17E-02 7.70E-03 6.10E-03 5.57E-03 5.40E-03 3.70E-03 3.20E-03 3.10E-03   21000
 2.55E-03 1.98E-03 1.40E-03 9.25E-04 2.50E-04 0.00E-04 0.00E-04 0.00E-04   22600
 5.65E-04 2.04E-03 7.35E-03 2.03E-02 4.98E-02 1.18E-01 2.46E-01 5.18E-01   27600
 1.02E-00 1.95E-00 3.79E-00 6.65E-00 1.24E+01 2.20E+01 3.67E+01 5.95E+01   31500
 8.50E+01 1.26E+02 1.68E+02 2.06E+02 2.42E+02 2.71E+02 2.91E+02 3.02E+02   35500
 3.03E+02 2.94E+02 2.77E+02 2.54E+02 2.26E+02 1.92E+02 1.68E+02 1.44E+02   39500
 1.17E+02 9.75E+01 7.65E+01 6.14E+01 4.62E+01 3.46E+01 2.52E+01 2.03E+01   43500
 1.57E+01 1.20E+01 1.00E+01 8.80E-00 8.30E-00 8.60E-00                     47500
  5  1  2
    2.500      9.585     65.000
 2350.000  2450.000      5.000
```

Appendix B

Basic Flow Chart for LOWTRAN 2

A general flow chart for LOWTRAN 3 is given in Figure B1 which shows the overall mode of operation of the program. More detailed flow charts are also given for the two main blocks in the program, that is, where the equivalent absorber amounts and refraction calculations are made (Figure B2) and for the transmittance calculation (Figure B3).

The notation used in the flow charts is as follows:

(1) If a condition stated within a given block is fulfilled, then the direction of flow is sideways as indicated by the direction in which the block points (for example, → for the following block ⭔).

(2) If the condition stated within a block is not fulfilled, the flow is downwards.

The numbers appearing on the flow charts correspond to the statement numbers given in the main program (see Table A1).

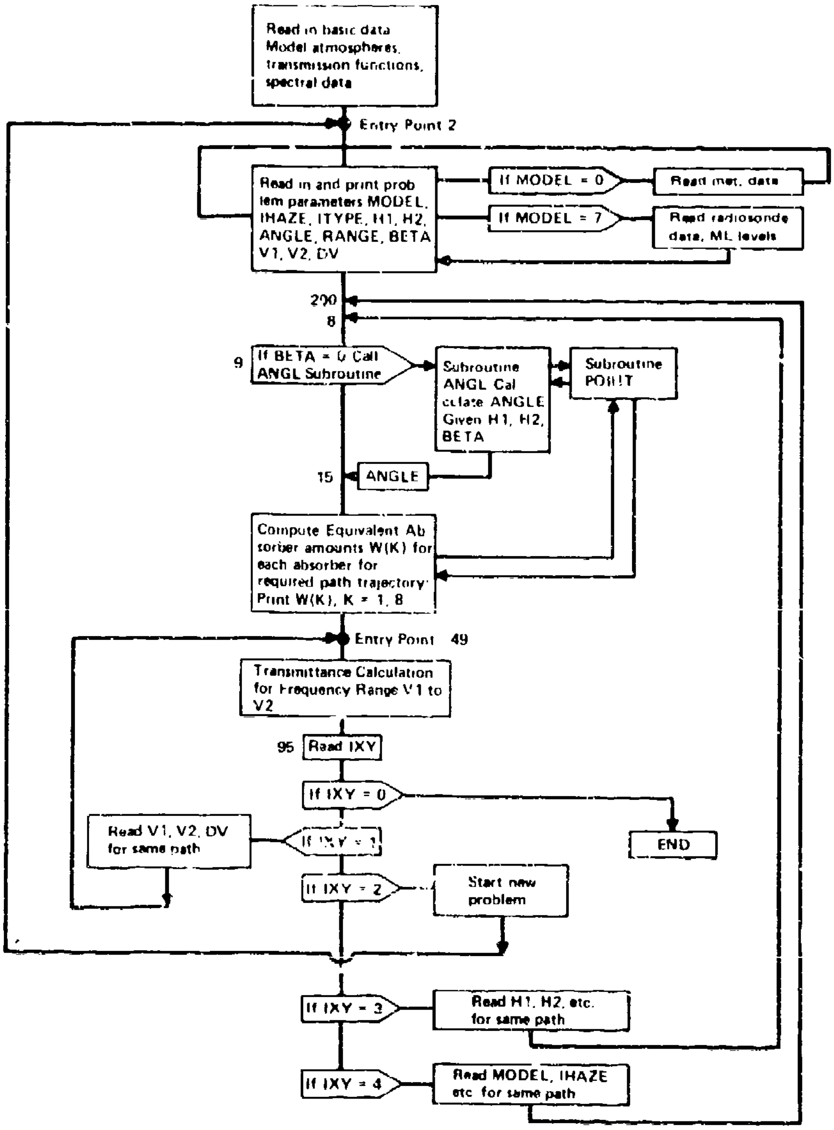

Figure B1. General Flow Chart for LOWTRAN 3

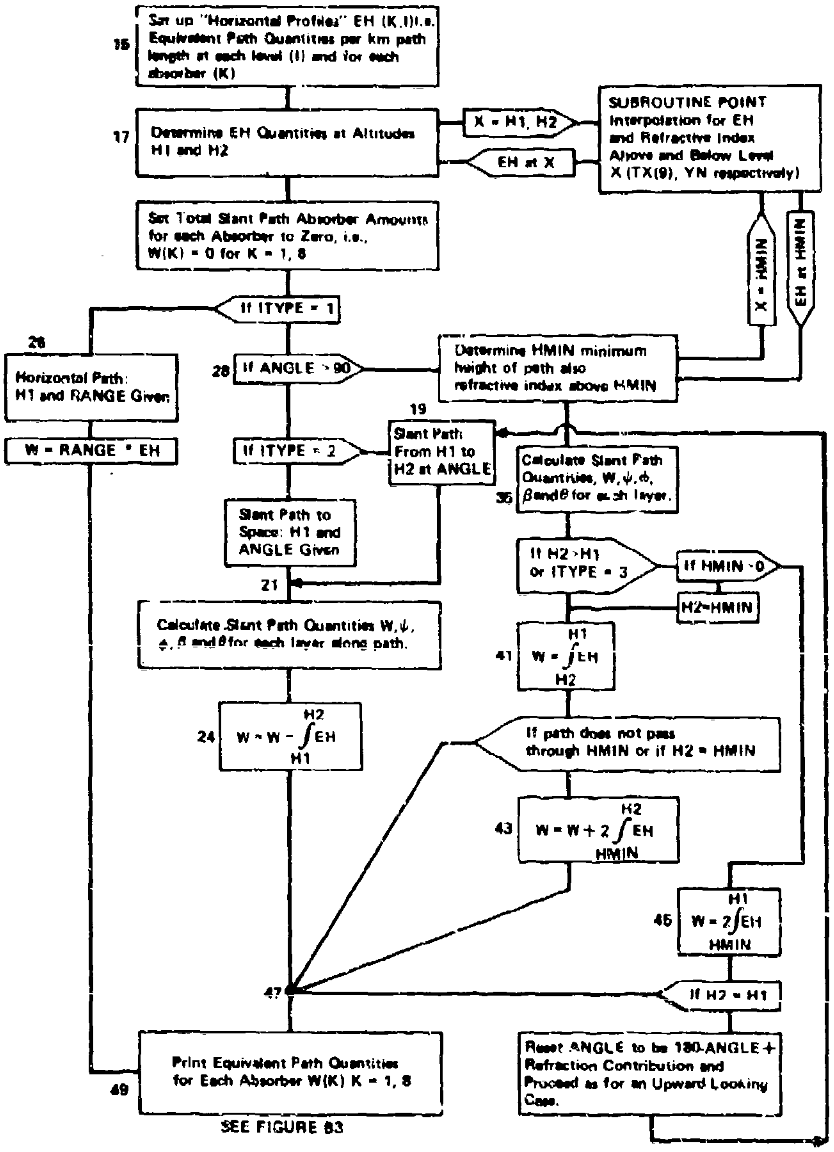

Figure B2. Flow Chart for Calculation of Equivalent Path Quantities

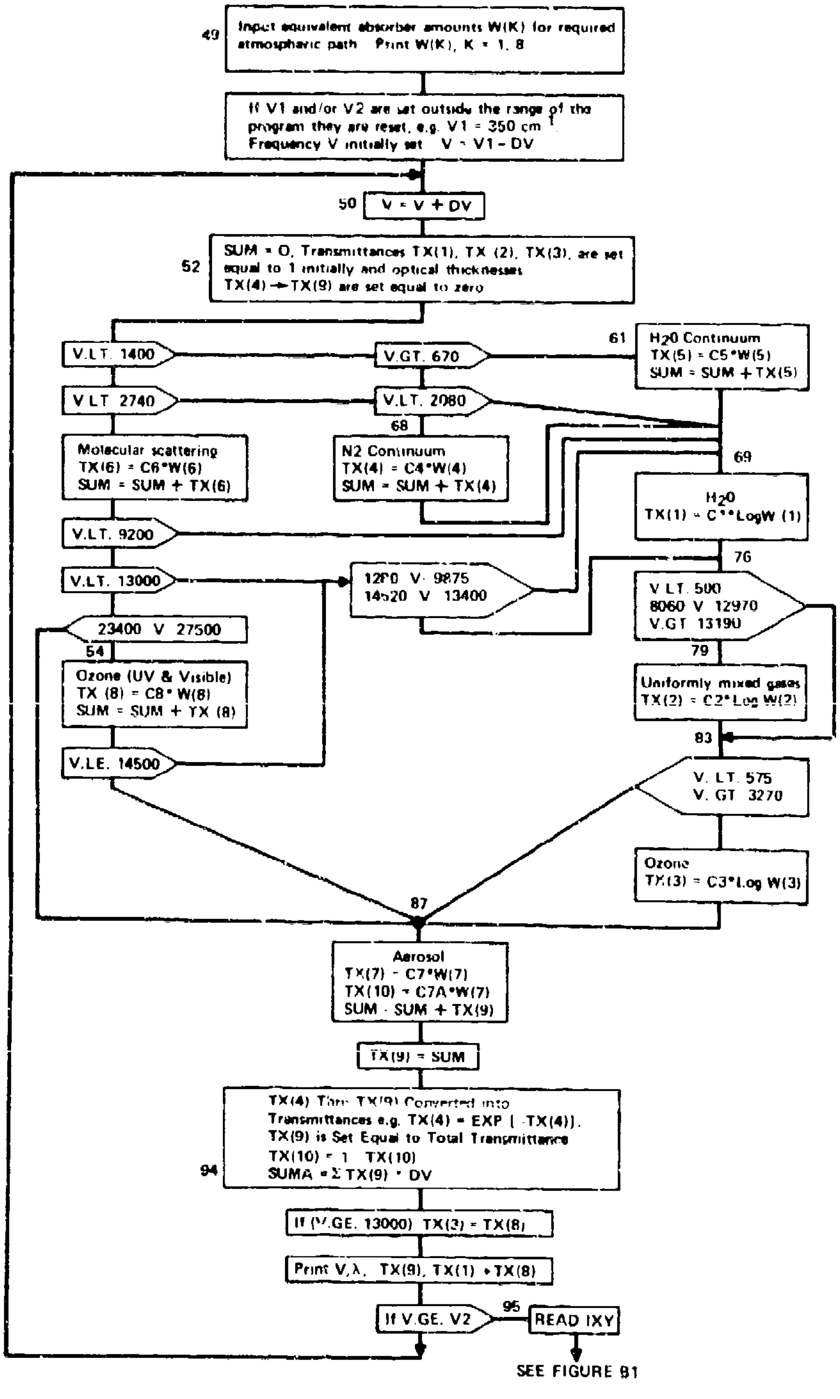

Figure B3. Flow Chart for Transmittance Calculations

Appendix C

Iterative Refraction Scheme Used in Subroutine ANGL

1. INTRODUCTION

An iterative scheme is presented here for determining the initial zenith angle θ_o required for a path trajectory from altitude H1 to H2 for a given earth center angle β_o (see Figure C1), taking into account refraction. The theoretical background for the scheme can be conveniently divided into upward- and downward-looking path trajectories.

2. UPWARD TRAJECTORIES ($\theta_o \leq 90°$)

If we let the geometrical angle θ in Figure C1 be our initial guess for θ_o and use this in the LOWTRAN 3 program, we can calculate the corresponding β, taking refraction into account ($\beta \geq \beta_o$ for upward looking paths). It is apparent that β is a function of θ for a given H1, H2 and model atmosphere. That is:

$$\beta = f(\theta) \quad . \tag{C1}$$

We can then differentiate β with respect to θ and write the differential $d\beta = f'(\theta)d\theta$ in the form

$$d\theta = d\beta/f'(\theta) \quad . \tag{C2}$$

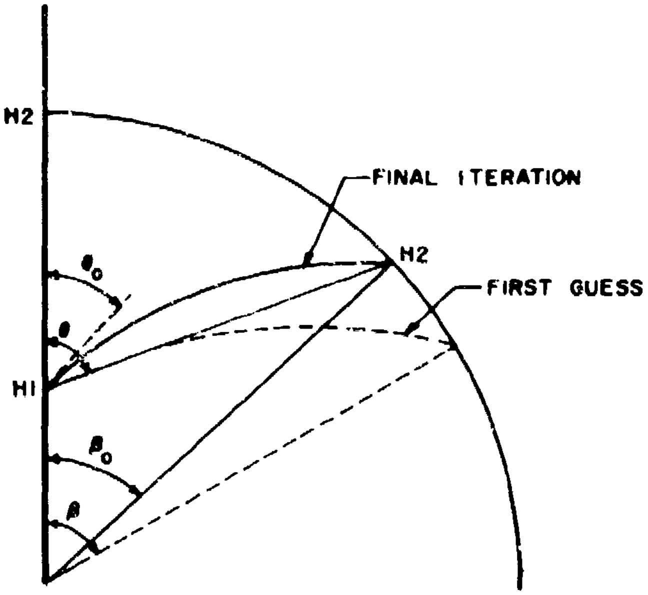

Figure C1. Schematic for Upward Looking Paths Showing: (a) The first guess at the trajectory using the geometrical angle θ from H1 to H2, and (b) the final iteration where $\theta = \theta_o$ and $\beta = \beta_o$

Replacing the differentials by differences, we have

$$\theta' - \theta = (\beta_o - \beta)/f'(\theta) \tag{C3}$$

where θ' is the next guess at θ_o. That is:

$$\theta' = \theta + (\beta_o - \beta)/f'(\theta) . \tag{C4}$$

Thus we can substitute θ' in Eq. (C1) and go through the same procedure described above to obtain successive iterations, until θ' converges finally to θ_o when $\beta_o - \beta$ is negligibly small (for example, $< 10^{-7}$ radians). The major unknowns in the above equation are $f(\theta)$ and $f'(\theta)$. From Eqs. (9) and (10) of Section 4.2, it was seen that

$$\beta = \sum_{i}^{m-1} (\theta_i - \alpha_i) = f(\theta) . \tag{C5}$$

Thus

$$f'(\theta) = \sum_{i}^{m-1} \left(\frac{d\theta_i}{d\theta} - \frac{d\alpha_i}{d\theta} \right) \qquad \text{(C6)}$$

where m is the number of levels between H1 and H2. Also from Eq. (7)

$$\sin \theta_i = n_o (R_o + H1) \sin \theta / n_i (R_o + z_i) . \qquad \text{(C7)}$$

Differentiating the above equation with respect to θ, we have

$$\cos \theta_i \frac{d\theta_i}{d\theta} = n_o (R_o + H1) \cos \theta / n_i (R_o + z_i) .$$

Therefore

$$\frac{d\theta_i}{d\theta} = \frac{\tan \theta_i}{\tan \theta} \qquad \text{(C8)}$$

assuming that n_i and z_i are independent of θ †. Similarly, it can be shown that

$$\frac{d\alpha_i}{d\theta} = \frac{\tan \alpha_i}{\tan \theta} \qquad \text{(C9)}$$

so that

$$f'(\theta) = \frac{1}{\tan \theta} \sum_{i}^{m-1} (\tan \theta_i - \tan \alpha_i) . \qquad \text{(C10)}$$

Equations (C4) and (C10) form the basis for the iteration scheme provided in the subroutine ANGL which contains all the angular calculations given in the main LOWTRAN 2 program for both upward- and downward-looking paths. For an initial guess θ, the quantities β and $f'(\theta)$ are calculated by summing β_i and $\tan \theta_i - \tan \alpha_i$ (defined in Figures 2 and C1) for each layer along the total extent of the path trajectory. Using Eq. (C4), a second guess θ' is obtained and is used to obtain successive θ's until the final value of β is sufficiently close to β_o (for example, to within 10^{-7} radians). When the latter condition is satisfied, the final iteration gives the required initial zenith angle θ_o.

---

† This assumption holds for upward looking trajectories but not for some downward looking cases where the trajectory passes through the minimum height HMIN (see Figure 3). The latter case will be discussed in the following section.

3. DOWNWARD TRAJECTORIES ($\theta_c > 90^\circ$)

The iteration scheme for determining θ_o for downward looking trajectories is identical to that described above, provided that the path does not pass through the minimum height HMIN [that is, see Figure 3(d)]. If the path does pass through HMIN, however, it is apparent that the refractive index between HMIN and the level above (say, n_m) and HMIN are both dependent on successive guesses of θ.

Consider the case shown in Figure C2 where $H2 < H1$. For a given initial guess θ, let us divide the contribution to the total angle β into three parts:

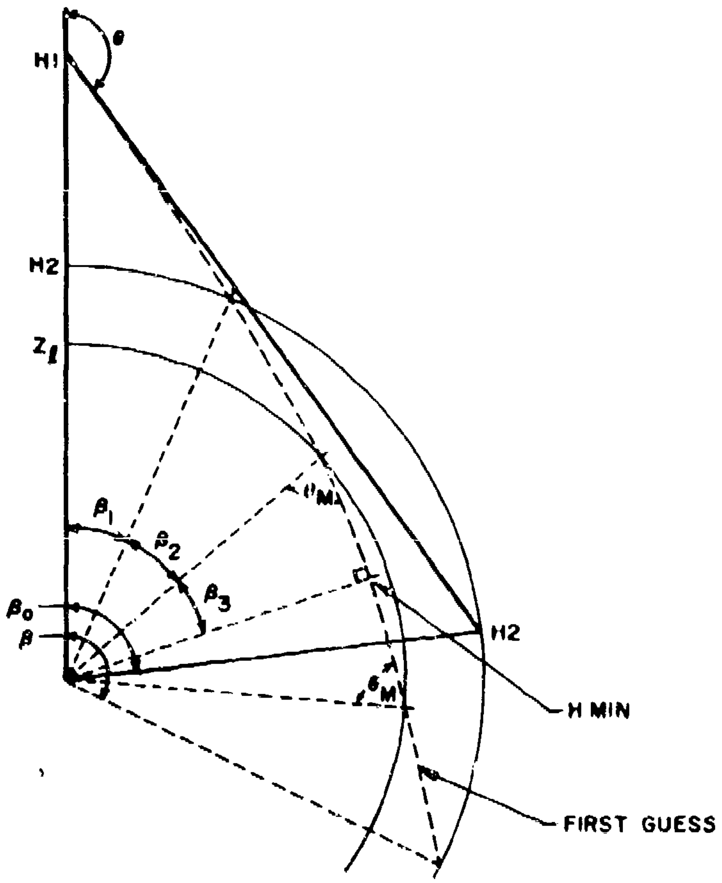

Figure C2. Schematic for Downward Looking Paths Showing the First Guess at the Trajectory Using the Geometrical Angle θ. HMIN is the minimum height for the first iteration, which will be lower than the final value when $\theta = \theta_o$ and $\beta = \beta_o$

β_1, β_2 and β_3. Here β_1 is the angle between H1 and H2 (on the short side of the path), β_2 is the angle between H_2 and the level z_ℓ above HMIN, and β_3 is the angle from z_ℓ to HMIN. That is, $\beta = \beta_1 + 2\beta_2 + 2\beta_3 = f(\theta)$. Then

$$f'(\theta) = \frac{d\beta_1}{d\theta} + \frac{2d\beta_2}{d\theta} + \frac{2d\beta_3}{d\theta}. \tag{C11}$$

Following the same procedure outlined in the previous section, and defining

$$\sin \theta_i = n_o \left(R_o + H_1\right) \sin \theta / n_i \left(R_o + z_i\right) \tag{C12}$$

where n_o now refers to the mean refraction from H1 to the level <u>below</u> H1, we can show that

$$\frac{d\beta_1}{d\theta} = \frac{1}{\tan \theta} \sum_{j}^{k-1} \left(\tan \theta_i - \tan \alpha_i\right) = F_1 \tag{C13}$$

$$\frac{d\beta_2}{d\theta} = \frac{1}{\tan \theta} \sum_{k}^{\ell-1} \left(\tan \theta_i - \tan \alpha_i\right) = F_2 \tag{C14}$$

$$\frac{d\beta_3}{d\theta} = -\frac{d\theta_m}{d\theta} = F_3 \tag{C15}$$

(where $\theta_m = 90 - \beta_3$). Now

$$\sin \theta_m = n_o(R_o + H_1) \sin \theta / n_m(R_o + z_\ell) \tag{C16}$$

where n_m is the refractive index between HMIN and z_ℓ. Differentiating Eq. (C16) with respect to θ and dividing by $\cos \theta_m$, we have

$$\frac{d\theta_m}{d\theta} = \frac{\tan \theta_m}{\tan \theta} - \frac{\tan \theta_m}{n_m} \left(\frac{dn_m}{d\theta}\right). \tag{C17}$$

We will now digress for a moment to show some relationships between HMIN, n_m and θ, which will assist us in defining the quantity $dn_m/d\theta$. If we let $X = R_o + \text{HMIN}$ and write

$$\frac{dn_m}{d\theta} = \frac{dn_m}{dX} \cdot \frac{dX}{d\theta} \tag{C18}$$

then clearly dn_m/dX is the mean refractive index gradient above HMIN, which we can specify for a given model atmosphere. The other parameter $dX/d\theta$ defines the variation of HMIN with θ.

Applying Eq. (C12) and replacing n_i, z_i and θ_i by n_m, HMIN and $\pi/2$ respectively, we have

$$n_m X = n_o (R_o + H1) \sin\theta . \tag{C19}$$

Differentiating Eq. (C19) with respect to θ and using Eq. (18), it will be seen that

$$\frac{dX}{d\theta} = \left[\left(\frac{1}{X} + \frac{1}{n_m} \frac{dn_m}{dX} \right) \tan\theta \right]^{-1} . \tag{C20}$$

Also, if we assume that $n - 1$ varies exponentially with altitude where n is the mean refractive index, then the refractive index gradient is given by

$$\frac{dn}{dX} = -\frac{n-1}{H}$$

where H is a scale height parameter which can be defined as follows:

$$H = (z_i - z_{i-1})/\log_e \left\{ (n_{i-1} - 1)/(n_i - 1) \right\} .$$

Therefore

$$\frac{dn_m}{dX} = -\left(\frac{n_m - 1}{z_i - \text{HMIN}} \right) \log_e \left(\frac{n_m - 1}{n_i - 1} \right) . \tag{C21}$$

Using Eqs. (C18) through (C20) and substituting for $dn_m/d\theta$ in Eq. (C17), we have

$$\frac{d\theta_m}{d\theta} = \frac{\tan\theta_m}{\tan\theta} \left[1 - \frac{1}{n_m} \frac{dn}{dX} \bigg/ \left(\frac{1}{X} + \frac{1}{n_m} \frac{dn}{dX} \right) \right] . \tag{C22}$$

Thus we can now write Eq. (C15) in terms of known quantities:

$$F_3 = -\frac{\tan\theta_m}{\tan\theta} \left[1 - \left(1 + n_m \big/ X \frac{dn_m}{dX} \right)^{-1} \right] . \tag{C23}$$

The final expression for the iteration scheme for the general case where H2 < H1 and $\theta > 90^{\circ}$ is

$$\theta' = \theta + (\beta_o - \beta)/(F_1 + 2F_2 + 2F_3) \qquad \text{(C24)}$$

where F_1, F_2 and F_3 are defined in Eqs. (C13), (C14) and (C23). For the case where $\theta > 90^{\circ}$ and H2 > H1, the above expression would become

$$\theta' = \theta + (\beta_o - \beta)/(2F1 + 2F3 + F)$$

where F refers to the upward looking contribution from H1 to H2 and is given by

$$F = \frac{1}{\tan \theta_r} \sum_{i=r}^{m=1} (\tan \theta_i - \tan \alpha_i) .$$

In the above expression, θ_r is the angle of refraction at H1. That is

$$\theta_r = \sin^{-1} (n_o \sin \theta / n_o')$$

where n_o' and n_o are the mean refractive indices of the layers above and below H1 respectively, and θ is the current initial zenith angle guess.

Appendix D

Symbols and Definitions

AB	Absorption at frequency ν, also average transmittance
AHAZE	Aerosol number density for MODEL = 7
AHZZ	Aerosol number density for MODEL = 7
AJ	Equivalent absorber amount per km at level J
ALAM	Wavelength (μm)
ALP	Angle of arrival at adjacent level
ANGLE	Input zenith angle (degrees) [compare with θ_0 in the text]
AO	Constant A defined in Eq. (10); that is, $(R_0 + H1)n_0 \sin \theta_0$
AVW	Average wavelength used in refractive index expression
BET	Angle subtended at the earth's center as path traverses adjacent levels [cf β_i in Eq. (8)]
BETA	Total angle subtended by path at earth's center [compare β in Eq. (9)]
BJ	Equivalent absorber amount per km at level J + 1
CA	Conversion factor from degrees to radians
CO	Wavelength dependent coefficient used in refractive index expression
CW	Wavelength dependent coefficient used in refractive index expression
C1	Log absorption coefficient for water vapor
C2	Log absorption coefficient for uniformly mixed gases
C3	Log absorption coefficient for ozone
C4	Absorption coefficient for nitrogen (~4 μm)
C5	Absorption coefficient for water vapor continuum (~10 μm)
C6	Extinction coefficient for molecular scattering

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C7	Extinction coefficient for aerosol models
C7A	Aerosol absorption coefficient
C8	Absorption coefficient for ozone (UV and visible regions)
D	Water vapor amount (pr. cm/km) at level I
DP	Dew point temperature (°C)
DS	Path length from level I to Level I + 1
DV	Wavenumber increment at which transmittance is calculated
DZ	Height increment from level I to level I + 1
E(K)	Equivalent absorber amounts per km at height H1 [see ω^* in Eq. (2)]
EH(1, I)	Equivalent absorber amount per km for H_2O at level Z(I)
EH(2, I)	Equivalent absorber amount per km for $CO_2 + N_2O$ etc at level Z(I)
EH(3, I)	Equivalent absorber amount per km for O_3 at level Z(I)
EH(4, I)	Equivalent absorber amount per km for N_2 at level Z(I)
EH(5, I)	Equivalent absorber amount per km for H_2O continuum at level Z(I)
EH(6, I)	Equivalent absorber amount per km for molecular scattering at level Z(I)
EH(7, I)	Equivalent absorber amount per km for aerosol extinction at level Z(I)
EH(8, I)	Equivalent absorber amount per km for ozone (UV and visible) at level Z(I)
EH(9, I)	Mean refractive index of layer above level Z(I)
EV	Integrated absorber amount from level I to level I + 1 [cf W_i defined in Eq. (15)]
F	Function for determining saturation vapor density of water (gm m^{-3})
FO	Transmission function logarithmic absorber amount scale for O_3
FW	Transmission function logarithmic absorber amount scale for H_2O and the uniformly mixed gases
H1	Initial altitude (km)
H2	Final altitude (km)
HAZE	Aerosol number density (no. cm^{-3})
HM	Estimated tangent height (km)
HMIN	Minimum altitude of path trajectory (km)
HZ1	Aerosol number density (no. cm^{-3}) for 23 km visual range
HZ2	Aerosol number density (no. cm^{-3}) for 5 km visual range
I	Running integer used as altitude (level) indicator and frequency indicator
IATM	Number of levels in model atmosphere
IDV	Frequency increment (cm^{-1})
IFIND	Indicator for using subroutine ANGL
IHAZE	Aerosol model indicator
IM	Parameter used when reading in a new atmospheric model (see Section 5.2.1)
IP	Indicator for using subroutine POINT to calculate refractive index only (IP = 0) or equivalent absorber amounts also (IP ≠ 0).

ITYPE	Indicator for type of atmospheric path (see Section 5.1)
IV	Frequency at which transmittance is calculated
IV1	Starting frequency (equivalent to V1—see Section 5.1)
IV2	Last frequency (equivalent to V2—see Section 5.1)
IXY	Parameter for terminating program and cycling indicator (see Section 5.1)
J	Running integer for altitude identification
JMIN	Altitude indicator for minimum height of path
JP	Print option parameter
J1	Level indicator for altitude H1
J2	Level indicator for altitude H2
K	Absorber indicator, K = 1, 2, 3, etc., corresponds to H_2O, uniformly mixed gases, O_3 etc. respectively
K1	Integer used in reading two model atmospheres on one card
K2	Integer used in reading two model atmospheres on one card and cycling parameter for downward looking paths
K4	Frequency indicator for nitrogen continuum transmittance calculation
L	Frequency indicator for ozone transmittance calculation
LEN	Parameter used for defining longest of two paths (see Section 5.1)
L1	Frequency identifier for UV and visible ozone transmittance calculation
L2	Frequency identifier for UV and visible ozone transmittance calculation
M	Integer used to identify required model atmosphere
ML	Number of levels in radiosonde data input (MODEL = 7)
MODEL	Integer used to identify required model atmosphere (see Section 5.1)
M1	Integer for selecting H_2O altitude profile for (M=M1)
M2	Integer for selecting temperature altitude profile for (M=M2)
M3	Integer for selecting O_3 altitude profile for (M=M3)
N	Indicator for level below given input altitude used in POINT subroutine; also as frequency indicator in UV and visible ozone transmittance calculation
NH	Frequency indicator for water vapor continuum transmittance calculation
NL	Number of levels in model atmosphere data
NP	Indicator for determining whether H1 or H2 coincide with levels in the model atmosphere
NP1	Value of NP for altitude H1
NP2	Value of NP for altitude H2
P(M,I)	Pressure (mb) at level I for model atmosphere M

PHI	Angle of arrival at H2
PI	3.141592654 that is (π)
PPW	Partial pressure of water vapor (in atmospheres)
PS	Total pressure in atmospheres
PSI	Angular deviation of path from initial direction [cf ψ in Eq. (12)]
PT	Product of total pressure (atm) and the square root of 273/T(M, I)
RANGE	Path length (km)
RE	Earth radius (km) (cf R_o in text)
REF	Refractive index of air at level I
RH	Relative humidity (%)
RN	Ratio of refractive indices of air above and below a given level
RO	Earth radius (km) read in as input (= RE)
RX	Ratio of earth center distances between adjacent levels
R1	The product of the sine of the initial zenith angle and the earth center distance to starting altitude
SALP	Sine of angle of arrival at adjacent level (cf sin α)
SPHI	Sine of the local zenith angle at a given level (cf sin θ)
SR	Slant range (km)
SUM	Sum of the optical thicknesses of absorbers 4 through 8
SUMA	Accumulated integrated absorption
T(M, I)	Temperature (°K) for model atmosphere M at level I
THET	Zenith angle at a given level (in radians)
THETA	Zenith angle at a given level (in degrees)
TMP	Ambient temperature (°C)
TR	Transmittance scales for transmission functions
TS	Ratio of standard temperature (273.0°K) to temperature at level I
TT	Ratio 273.15/(TMP + 273.15)
TX(K)	Equivalent absorber amounts per km at a given altitude obtained from POINT; also transmittance values at a given wavelength for each absorber type (K = 1, 8)
TX(9)	Total transmittance at frequency V
TX(10)	Absorption due to aerosol only at frequency V
TX1	Refractive index of layer above initial altitude H1
TX2	Refractive index of layer above final altitude H2
TX3	Refractive index of layer above minimum altitude HMIN
V	Running frequency (cm^{-1})
VH(K)	Integral of the equivalent absorber amounts from H1 to level I
VIS	Visual range (km) at sea level
VX	Wavelength at which aerosol coefficients are read in (μm)
V1	Initial frequency for transmittance calculation, cm^{-1}
V2	Final frequency for transmittance calculation, cm^{-1}

W(K)	Total equivalent absorber amount for entire path
WH(M, I)	Water vapor density for atmospheric model M at level I (gm m^{-3})
WO(M, I)	Ozone density for atmospheric model M at level I (gm m^{-3})
WS1	Transmission function scaling factor for H_2O at given wavelength
WS2	Transmission function scaling factor for CO_2, etc., at given wavelength
WS3	Transmission function scaling factor for O_3 at given wavelength
W2	Water vapor density for atmospheric model M at level I + 1 (gm m^{-3})
X	Input height to POINT subroutine
XD	Wavenumber interpolation parameter in UV ozone transmittance calculation
XH	Wavenumber interpolation parameter in H_2O continuum calculation
XI	Wavenumber interpolation parameter
XX	Wavenumber identification parameter for UV ozone transmittance calculation
X1	Earth center distance of level I
X2	Earth center distance of level I + 1
Y	Input zenith angle in radians
YN	Refractive index of layer below input height from POINT subroutine
YN1	Refractive index of layer below initial altitude H1.
YN2	Refractive index of layer below final altitude H2
YY	Aerosol absorption coefficient at frequency V
Z(I)	Altitude at level I in km

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