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ATMOSPHERIC TRANSMITTANCE/RADIANCE COMPUTER CODE FASCOD2

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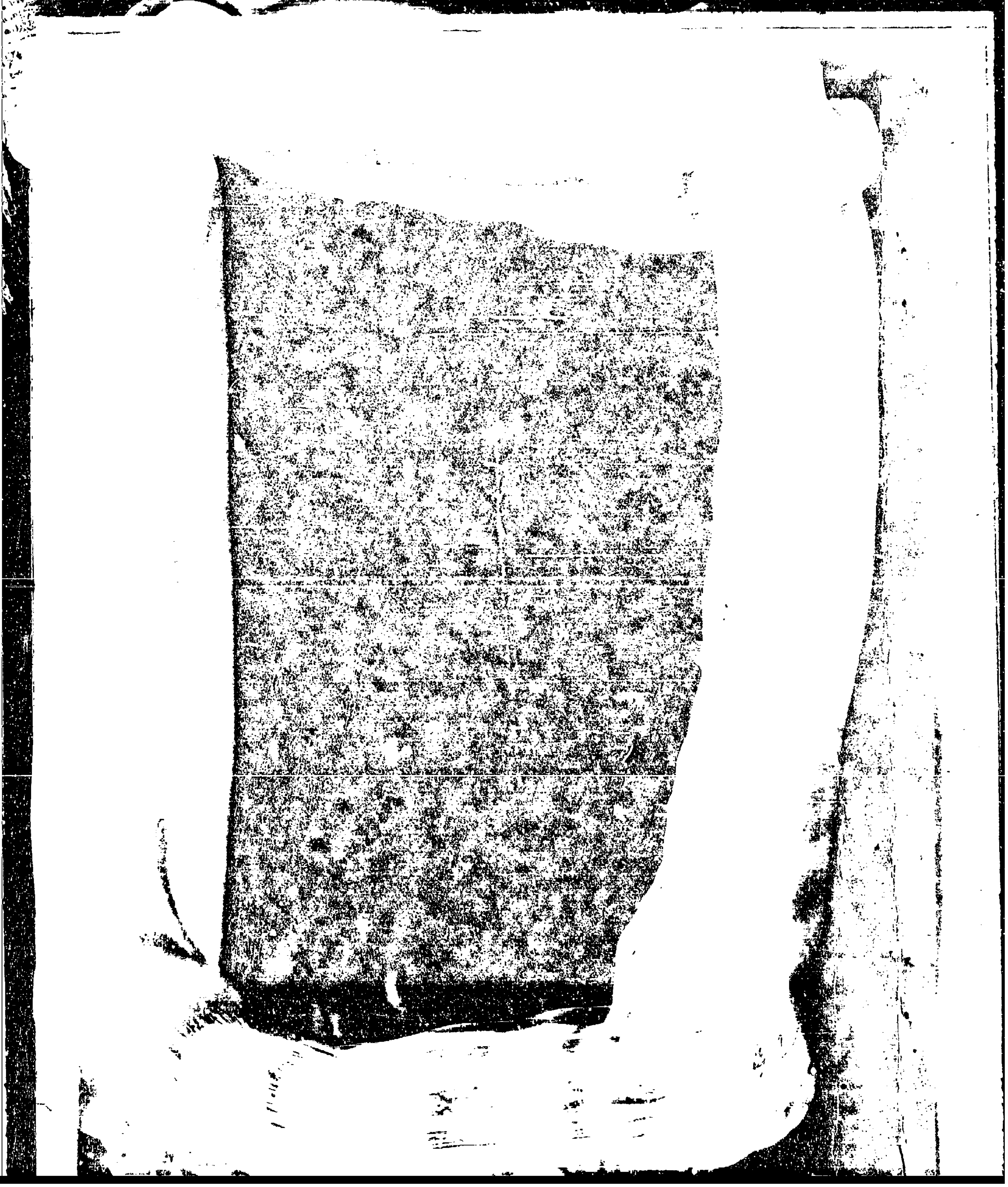

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The fast line-by-line transmittance and radiance code FASCOD1 has been changed to include the AFGL geometry routine ATMPTH and the aerosol models of the lower resolution code LOWTRAN 5. The code utilizes an optical path subject to continuous refraction and accounts for losses due to molecular and aerosol absorption and scattering. The problem of non-LTE radiance and transmission has been studied and code changes proposed. Absorption from the sub-Lorentzian CO2 far line wings is also discussed.

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1. INTRODUCTION

This report describes work completed and in progress on the development of a Fortran computer code FASCOD2 to calculate atmospheric transmittance and/or radiance for any given path at high spectral resolution. The present code is based on FASCODE[1] and FASCOD1[2] computer codes that use the AFGL line compilations[3] and an approximation to the Voigt line profile based on the HIRACC[4] algorithm. All aspects of this code that are independent of spectral resolution are to be the same as those found in the moderate spectral resolution code LOWTRAN5[5], once it has been modified to accept the improved geometry routine discussed here. Most importantly, the two codes have a common set of model (gas and aerosol) atmospheres and are run by similar sets of control cards.

Section 2 describes how the code has been modified to calculate atmospheric paths for a spherical, refracting medium using a new AFGL geometry routine[6] along with the six representative model atmospheres found in the LOWTRAN codes. Following this, the code has been changed to include zeroth-order scattering and absorption due to the aerosol models used in the LOWTRAN 5 code[8]. These last changes are detailed in Section 3 and the resulting interim code i documented in the Appendix.

FASCODE's radiative transfer assumes the atmospheric layers are in local thermodynamic equilibrium (LTE). For higher altitudes, the photon-driven chemistry and reduced molecular collision rate cause this assumption to be invalid. Degges[9] has modelled the kinetics of this phenomena and produced selected single-transition population densities for given sun angles (season and time of day). Section 4 discusses how the results from Degges computations can be used to include upper atmospheric non-LTE effects in FASCODE's transmittance and radiance calculations.

The Voigt line shape model predicts a Lorenzian profile for the line wings. It has been established that this is incorrect for CO_2. The far wings are sub-Lorentzian. This error becomes important near band heads located next to window regions in the atmosphere where the background continuum constitutes the only absorption. The focus in the present work is the CO_2 continuum. Section 5 outlines this problem and discusses possible ways the line profiles can be modified in the far wing to account for this aspect of atmospheric radiative transfer.

The inhomogeneous model atmospheres are approximated in FASCODE by a user-specified number of homogeneous layers to simplify the radiative transfer. Consequently, line strengths and half widths are evaluated at a defined average therodynamic state in each layer. This approach produces errors that can only be decreased by increasing the number of layers and therefore increasing the computational time. The proposed study outlined in Section 6 is to develop some knowledge concerning how layering produces errors so that they can be controlled. The goal of this work is to produce guidelines for selecting layer boundaries to minimize the error while keeping the number of layers and thus computational time acceptable.

2. OPTICAL PATHS AND ATMOSPHERIC MODELS

Program ATMPTH[6] and its subroutines, as supplied by AFGL, eliminate the need for offline programs such as LAYER[6] and DRIVER[6] in the preparation of the atmospheric information for FASCOD1. The program is capable of determining optical paths through the atmosphere, and includes the effects due to spherical geometry and refraction. ATMPTH calculates the molecular density-weighted average temperature and pressure, along with the integrated molecular absorber amounts in each of the homogeneous layers used to approximate the atmosphere. The user can choose between six representative atmospheres, or supply his own. The number and placement of layer boundaries is also specified by the user. The goal is to incorporate ATMPTH as a subroutine to FASCOD1, eliminating the need for off-line programs. Description of the ATMPTH Program: A brief description of the ATMPTH program will be presented here for those users who may require a more complete understanding of the overall calculation procedure. The first control card specifies the choice of model atmosphere. There are six built-in representative atmospheres which are specified by the pressure, temperature, and molecular densities of H_2O, CO_2, O_3, N_2O, CO, CH_4, O_2, and N_2 at 34 altitudes. These model atmospheres are essentially the same as those in LOWTRAN[5], except that the densities are in different units. One of the six model atmospheres stored in subroutine MDLATM, or a non-standard user-supplied atmosphere as read by subroutine NSMDL, is selected and stored in the common block /MDATA/.

The second control card must contain three of the following five path parameters: H1, H2, ANGLE, RANGE, and BETA. See the LOWTRAN report[5] for allowable combinations of these parameters. Next, the desired FASCODE layer boundaries are read in. These need not correspond to the altitudes contained in the model atmospheres or include H1 or H2, the altitudes of the path endpoints. The only restriction on the choice of boundaries is that they be chosen such that the ratio of the mean half-widths in adjacent layers is not greater than 2 to 1[1]. A new atmospheric profile containing both the previous altitudes and the desired FASCODE boundaries is formed. Pressures, temperatures, and molecular densities at the FASCODE boundaries are found by interpolation of the model atmosphere.

Subroutine GMTRY is called to calculate the refracted path through the atmosphere, and integrate the amounts of the absorbers along that path. Subroutine RFRPTH (which drives the integration) requires as input the set H1, ANGLE, H2 and LEN. These are determined by GMTRY using the three path parameters supplied. A final atmospheric profile, generated by RFRPTH, starts at HMIN (tangent height if any) and goes up the MAX (H1, H2) (the larger of H1 and H2). The profile is specified at H1, H2 and all of the model atmosphere altitudes and FASCODE layer boundaries between HMIN and MAX (H1, H2).

The determination of the refracted path, integration of the absorber amounts, and formation of the homogeneous layers is done using as layer boundaries all of the altitudes in the final profile. Once the path and integrated amounts are known, layers are merged in ATMPTH to form the desired FASCODE layers defined by the boundaries HMIN, H1, H2, and the FASCODE boundaries between HMIN and MAX (H1, H2). Finally, the layers are compared. If the ratio of the geometric thicknesses of two adjacent layers is greater than 10 or less than .1, the two layers are combined to form a single layer with a properly weighted average pressure and temperature and combined absorber amounts.

Note that the calculation of the refracted path and the absorber amounts is done using the model atmosphere altitudes as additional layer boundaries. Only after the calculation procedure is complete is the number of layers reduced. This is done so that model atmosphere data is not degraded in the process of performing the path integrals. A general flow diagram of ATMPTH is given in Figure 1.

ATMPTH As A Subroutine Of FASCOD1: ATMPTH and its subroutines have been added to FASCOD1 as subroutines. ATMPTH is called only once to generate the layer pressures and temperatures, integrated amounts of molecules and aerosols, and the mean halfwidths associated with each of the FASCODE layers. This information is stored in arrays in common block /OUTPUT/, and is passed to the FASCODE subroutine PATH. PATH is called as before in FASCODE, once for each layer, except that instead of reading the layer data from a file generated by an offline program, the data is assigned using the array values in /OUTPUT/ and /PATH/ as

PAVE = PBAR(L)

TAVE = TBAR(L)

etc.

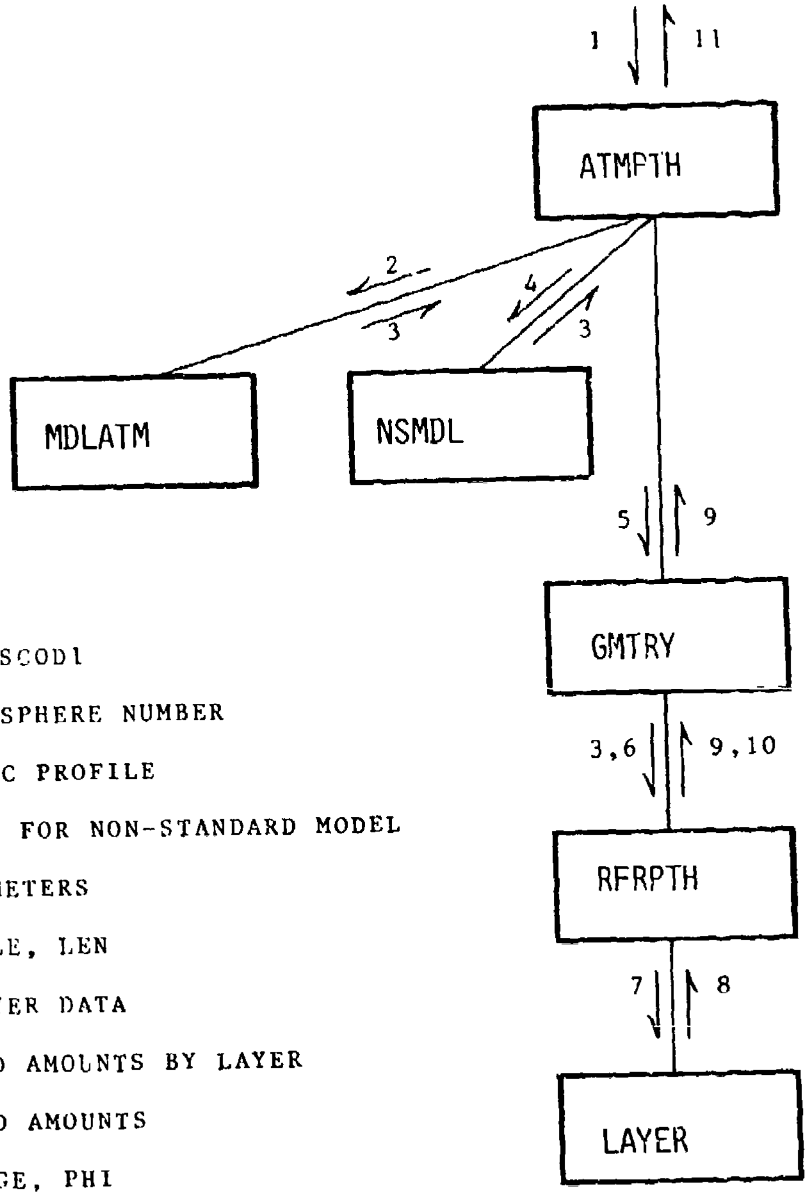
Due to the number of times that they are referenced and central memory considerations, simple variables are preferred over subscripted variables for use in the calculation procedures.

The following gives the sequence and format of the ATMPTH control cards. These now appear as a portion of the FASCOD2 control cards and will be mentioned again, but only briefly, in the FASCOD2 users guide.

Three cards control the operation of the program while other cards must be read in to define the FASCODE boundary levels, and possibly to define non-standard conditions. The formats of these cards and the meaning of the parameters are described as follows:

CARD 1: MODEL, ITYPE, I1N, IMOD, KMAX, RE
(5I5, 5X, F10.4)

MODEL = 0: USER SUPPLIED HORIZONTAL PATH PARAMETERS
1: TROPICAL MODEL ATMOSPHERE
2: MIDLATITUDE SUMMER



1. CALL BY FASCOD1
2. MODEL ATMOSPHERE NUMBER
3. ATMOSPHERIC PROFILE
4. IMOD, CALL FOR NON-STANDARD MODEL
5. PATH PARAMETERS
6. H1,H2,ANGLE, LEN
7. SINGLE LAYER DATA
8. INTEGRATED AMOUNTS BY LAYER
9. INTEGRATED AMOUNTS
10. BETA, RANGE, PHI
11. INTEGRATED AMOUNTS FOR FASCOD1 LAYERS

<u>FIGURE 1</u> ATMPTH FLOW DIAGRAM

3: MIDLATITUDE WINTER
4: SUBARCTIC SUMMER
5: SUBARCTIC WINTER
6: U.S. STANDARD, 1962
7: USER SUPPLIED ATMOSPHERIC PROFILE

ITYPE = 1: HORIZONTAL PATH (CONSTANT PRESSURE)
2: SLANT PATH FROM H1 TO H2
3: SLANT PATH FROM H1 TO SPACE (100 KM)

IIN	NUMBER OF BOUNDARY ALTITUDES FOR THE FASCOD1 LAYERS (REQUIRED FOR ITYPE = 2 OR 3)
IMOD	NUMBER OF BOUNDARY ALTITUDES FOR USER SUPPLIED ATMOSPHERIC PROFILE (MODEL 7) DEFAULT = 34
KMAX	NUMBER OF MOLECULAR SPECIES FOR WHICH THE AMOUNTS ARE TO BE CALCULATED. DEFAULT = 8
RE	RADIUS OF THE EARTH. DEFAULTS: MODEL = 1, RE = 6378.39 KM 2,3,6,7, RE = 6371.23 KM 4,5, RE = 6356.91 KM

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

For a slant path:

CARD 2: H1, H2, ANGLE, RANGE, BETA, LEN
(5F10, 4, 15)

H1	ALTITUDE OF THE OBSERVER OR RECEIVER (KM)
H2	ALTITUDE OF THE OTHER ENDPOINT OF THE PATH (KM)
ANGLE	ZENITH ANGLE AT H1 (DEGREES)
RANGE	LENGTH OF THE PATH FROM H1 to H2 (KM)
BETA	EARTH CENTERED ANGLE FOR THE PATH H1 TO H2 (DEG)
LEN	= 0, SHORT PATH; = 1, LONG PATH THROUGH A TANGENT HEIGHT. LEN IS USED ONLY WHEN ANGLE IS GT 90.0 AND H1 IS GT H2. DEFAULT = 0.

Only three of the first five parameters need be specified; for example, H1, H2, ANGLE, or H1, H2, BETA, or H1, ANGLE, RANGE. See the comments in the subroutine GMTRY or see Reference (5) for more details on the possible combinations of these parameters. Next read in the boundary altitudes for the FASCODE layers (required). Format (8F10.3)

CARD 3: V1, V2
(2F10.3)

V1,V2	INITIAL AND FINAL WAVENUMBERS FOR USE IN CALCULATING THE INDEX OF REFRACTION (CM-1)

IF MODEL = 7, THE INPUT ATMOSPHERIC PROFILE IS READ IN AFTER CONTRAL CARD 1 IN THE FOLLOWING FORMAT

(HEADER(I), I = 1,2) (2A10)
A 20 CHARACTER HEADER DESCRIBING THE PROFILE
Z,P,T (3F10.3)
(DENSITY(K), K = 1, KMAX) (8E10.3):
TWO CARDS FOR EACH OF THE IMOD LEVELS GIVING THE ALTITUDE (KM), PRESSURE (MB), TEMPERATURE (K), AND DENSITIES OF THE MOLECULAR SPECIES (MOLECULES CM-3) AT EACH LEVEL)

For a horizontal path:

CARD 2: Z, P, T, RANGE (DEN(K), K = 1, KMAX)
(4F10.3,/,(8E10.3))

Z	ALTITUDE (KM)
P	PRESSURE (MB)
T	TEMPERATUARE (K)
RANGE	PATH LENGTH (KM)
DEN(K)	DENSITY OF THE K'TH MOLECULAR SPECIES (MOLEUCLES CM-3)

For MODEL = 1 to 7, only Z and RANGE are used and P, T, and DEN are interpolated.

CARD 3: NOT USED

For model 7, the input model atmosphere is read in after control card 1 as for a slant path.

Sample ATMPTH input control card sequences are given as part of the FASCOD2 users guide in the Appendix.

Verification of ATMPTH As A Subroutine Of Fascode: ATMPTH as supplied by AFGL was capable of being run as an off-line program whose output, consisting of atmospheric information, could be read directly by FASCOD1. To verify that ATMPTH has been successfully interfaced with FASCODE as a subroutine, comparison runs for horizontal, vertical, and slant (long and short) paths were made using the latest version of FASCOD2 with ATMPTH as a subroutine and an original version of FASCOD1 using ATMPTH as an off-line program. The codes produced identical output in all cases, indicating that the atmospheric information was being properly transferred to FASCOD2 from the newly added ATMPTH subroutine.

3. ATMOSPHERIC AEROSOL MODELS

FASCODE performs a line by line calculation of molecular transmittance and radiance through a layered atmosphere. Outside the microwave region[7], it does not include the effects of molecular scattering or aerosol scattering and absorption. These extinction mechanisms have now been added as part of the development of FASCOD2. A new subroutine, AERSOL, gives the FASCOD2 user the option of choosing any of the aerosol models developed by AFGL for the LOWTRAN 5[5] code. The user is referred to Reference 8 for a complete description of the available aerosol models. Molecular scattering is also accounted for in AERSOL using an expression for the attenuation coefficient taken directly from LOWTRAN.

Description of the AERSOL Subroutine: The AERSOL subroutines AERPRF, PRFDTA, EXABIN, EXTDTA, and AEREXT have been taken directly from LOWTRAN 5. The only changes that have been made to the LOWTRAN routines have been the reduction in size and number of common blocks wherever LOWTRAN variables were not used by FASCODE.

AERSOL is called initially to generate the aerosol densities at the 34 altitudes of the model atmospheres. During this first call the single aerosol control card, which contains IHAZE, ISEASN, IVULCN, and VIS, is read. Subroutine AERPRF is then called 34 times (once for each altitude) to load the desired aerosol density from the data stored in subroutine PRFDTA. These densities are unitless and used to obtain equivalent sea level absorber amounts. The chosen profile is then stored in the array EHM(34) in the common block /PROF/. At this point control returns to FASCOD2, where ATMPTH is called to generate the layer data. EHM(34) is passed to ATMPTH where it is handled in the same way as the molecular density profiles. The integrated aerosol amounts are stored in the array AWKAER(L) and are assigned to the simple variable name WKAER in subroutine PATH.

AERSOL is subsequently called once for each layer. Its function then is to load molecular scattering and aerosol scattering and absorption "effective optical depths" into the FASCOD2 array ABSRB(J), over the frequency range of V1ABS to V2ABS in increments of DVABS, as specified by FASCOD2. Note that this array was previously used by FASCODE for molecular continuum data such as H_2O and N_2. It now contains in addition to the continuum data, molecular scattering and aerosol extinction which are also relatively slow functions of frequency.

The effective optical depths are given by the product of the integrated amount and the appropriate attenuation coefficient. For aerosol scattering or absorption, the amount WKAER is known from ATMPTH. The coefficients are a function of the aerosol model chosen, the relative humidity (for altitudes between 0 and 2 km), the altitude region, and the frequency. During AERSOL's first call within the layer loop EXABIN is called to obtain a set of altitude and frequency dependent attenuation coefficients using the data stored in subroutine EXTDTA. These are stored in the arrays ABSC(4,40) and EXTC(4,40), corresponding to the 4 altitude regions and 40 wavelengths contained in VX2(40).

The frequency loop in aersol calls AEREXT to obtain the coefficients at each frequency by interpolation of the ABSC and EXTC arrays. The aerosol optical depths are then simply:

$$\tau_{A,S} = (\mathrm{EXT-ABS}) * \mathrm{WKAER}$$

$$\tau_{A,A} = \mathrm{ABS} * \mathrm{WKAER}$$

The expression for the molecular scattering optical depth was taken directly from LOWTRAN as:

$$\tau_{m,s} = \nu^4/(9.26799 \cdot 10^{18} - 1.07123 \cdot 10^9 \cdot \nu^2) \left(\frac{P}{P_o}\right)\left(\frac{T_o}{T}\right) S. \qquad (3.1)$$

For the case where the current FASCOD2 layer is not totally contained within one of the aerosol regions, 0-2 km, 2-10 km, 10-30 km, or 30-100 km, a linear combination of the altitude dependent aerosol attenuation coefficients is used.

The overall flow of the aerosol routine is shown in Figure 2.

AERSOL As A Subroutine Of FASCODE: As mentioned earlier, AERSOL is called once to initialize the aerosol density profile and then once for each layer to calculate the effective optical depths and load them into the ABSORB array. The R1 array, which eventually has ABSORB merged into it, now contains total extinction data rather than just molecular absorption data. The calculation procedure in FASCOD2 is correct for transmittance but must be modified for emission calculations. Emission is proportional to absorption, not extinction, therefore the statement in subroutine EMIN which calculates blackbody radiation must be modified by the scattering albedo. The original equation,

$$\mathrm{BBRAD(I) = (1-TR(I)) * BB} \qquad (3.2)$$

has been changed to

$$\mathrm{BBRAD(I) = (1-TR(I)) * (1-ALB) * BB.} \qquad (3.3)$$

where

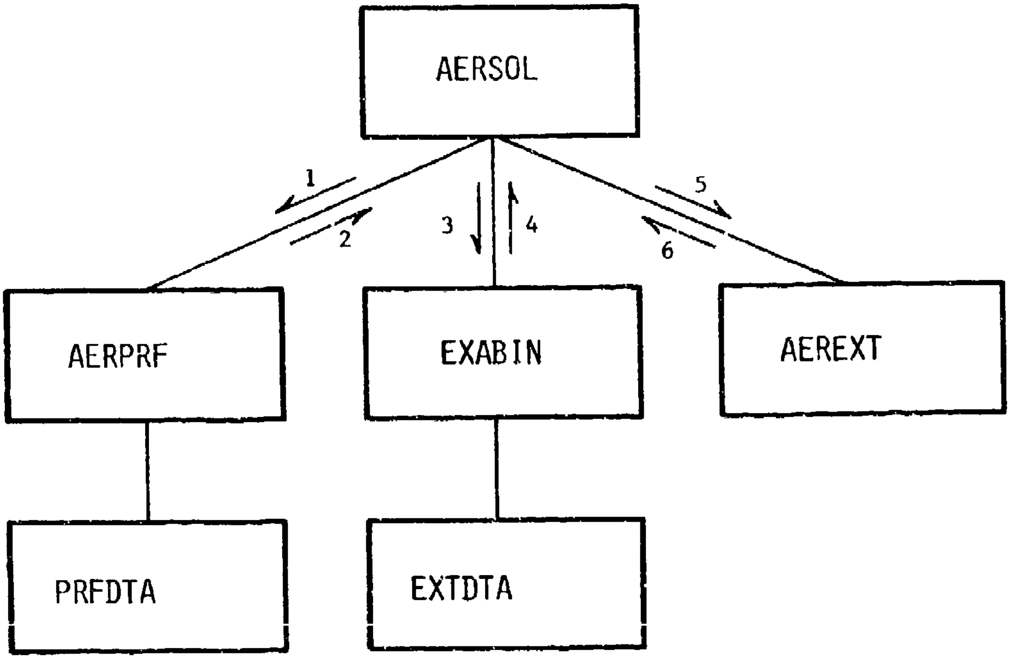
$$\mathrm{ALB} = \frac{k_S}{k_E} .$$

The user is referred to References 5 and 8 for guidance in choosing the proper aerosol model for his particular problem. Once the choice is made, a single aerosol control card, having the following format, controls the aersol routine:

```
IHAZE, ISEASN, IVULCN, JP, VIS

FORMAT (4(4x,I1), 5x, E10.3)
```

where,



1. CONTROL PARAMETERS
2. PROFILE EHM(34)
3. CONTROL PARAMETERS
4. ABSC(4,40),EXTC(4,40)
5. ABSC(4,40),EXTC(4,40)
6. ABSV(4),EXTV(4)

FIGURE 2 AERSOL FLOW DIAGRAM

IHAZE = 0 no aerosol attenuation included in the calculation.

= 1 RURAL extinction, 23 km VIS.

= 2 RURAL extinction, 5 km VIS.

= 3 MARITIME extinction, 23 km VIS.

= 4 MARITIME extinction, 5 km VIS.

= 5 URBAN extinction, 5 km VIS.

= 6 TROPOSPHERIC extinction, 50 km VIS.

= 7 USER DEFINED extinction, 23 km VIS. (Read into the program immediately after CARD1. Refer to the main program LOWEM in Appendix A^5 for the input format of the coefficients).

= 8 FOG1 (Advection Fog) extinction, 0.2 km VIS.

= 9 FOG2 (Radiation Fog) extinction, 0.5 km VIS.

ISEASN = 0 season determined by the value of MODEL;
SPRING-SUMMER for MODEL = 0,1,2,4,6,7
FALL-WINTER for MODEL = 3,5

= 1 SPRING-SUMMER

= 2 FALL-WINTER

IVULCN = 0,1 BACKGROUND STRATOSPHERIC profile and extinction

= 2 MODERATE VOLCANIC profile and AGED VOLCANIC extinction

= 3 HIGH VOLCANIC profile and FRESH VOLCANIC extinction

= 4 HIGH VOLCANIC profile and AGED VOLCANIC extinction

= 5 MODERATE VOLCANIC profile and FRESH VOLCANIC extinction

JP = print option parameter to be used in the final version of the code; JP may be ignored at this time.

VIS = meteorological range (km)
(when specified, supercedes default value set by IHAZE).

Verification Of The AERSOL Routine: To verify that the aerosol routines function properly as subroutines of FASCOD2, comparisons were made with LOWTRAN results. LOWTRAN 5 gives separate aerosol contributions to transmittance. FASCOD2 does not do this, so statements were added to artificially suppress molecular absorption by dividing molecular absorber amounts by 10^{20}. FASCOD2 was then run for transmittance, and the results checked with LOWTRAN 5 results for aerosol absorber amounts, attenuation coefficients, and transmittance. Vertical paths were used to eliminate any differences caused by the different geometry routines now used in these two codes.

The comparisons made are convincing evidence that FASCOD2 handles the aerosol models and calculations correctly. The improved geometry routine now used in FASCOD2 uses a slightly different humidity calculation for the 0-2 km region than used in LOWTRAN 5. This causes some very small differences in the numbers returned by the two codes for aerosols only. Since the improved geometry routine is being added to LOWTRAN by AFGL, a common humidity claculation will be agreed upon and put into both codes.

4. NON-LTE TRANSMISSION AND RADIANCE

Introduction And Formalism: The FASCODE algorithm constructs molecular spectral absorption functions using an approximate Voigt line-shape profile for each active transition between molecular vibrational-rotational (VR) states. The line-strength and half-width associated with each transition are evaluated at the density-weighted average temperature and pressure of each of the homogeneous layers that together approximate the inhomogeneous atmosphere. The line broadening is principally determined by collisions in the higher-pressure lower atmosphere (Lorentz region) and by the thermal equilibrium velocity distribution in the upper atmosphere (Doppler region). Line-strengths, on the other hand, are mainly determined by the populations of the two VR states which each transition connects.

Under conditions of local thermodynamic equilibrium (LTE), collisions cause the molecular VR states to have a Boltzman population distribution. In this case, line-strengths can be calculated in terms of the strengths at a reference temperature T_o, since one knows how the upper and lower state populations vary with temperature. FASCODE performs this calculation together with the half-width calculation as explained in Ref. 1. Reference line-strengths and half-widths, as given by the line parameters compilation[3] at a reference temperature (296°K) and pressure (1013mb), are modified to give the actual strength and both Doppler and Lorentz widths according to the average layer temperature and pressure. Under LTE conditions, the layer transmission spectral function is calculated line-by-line by HIRAC and LBLF4. The layer radiance is then directly calculated from the optical depth for molecular absorption using the Planck function, which represents thermal equilibrium population ratios, evaluated at the average temperature of the layer T.

The transmittance and radiance in the lower atmosphere can be represented quite adequately in terms of the LTE model outlined above. However, at altitudes above 30-50 km, the lower gas density enhances the characteristic time between collisions and slows the rate of VR state 'mixing'. The molecular VR state populations tend to be driven from equilibrium by the local radiation field. Although collisions are not sufficient to bring about a thermal population distribution among the vibrational states, both translational and rotational degrees of freedom largely remain in thermal equilibrium at the kinetic temperature T. Thus, the line half-widths and line-shapes are not significantly altered in the higher altitude non-LTE case.

A computer code capable of modeling the principal non-equilibrium vibrational populations of H_2O, CO_2, O_3 and NO has been previously developed[9]. We are adding to FASCODE the capability to use this high-altitude vibrational state population data in order to allow for a more realistic calculation of both transmission and radiance in this region. Minor modifications can be made to the basic FASCODE algorithm to allow for the line-by-line construction of the spectral absorptance function for non-equilibrium vibrational populations. Several more extensive changes will allow the code to handle non-LTE radiance.

In the non-LTE case, the general expression for the strength of a single line in terms of the line-strength at the reference temperature is

$$S = S(T_o) \left[\frac{\rho_\ell - \rho_u}{\rho_\ell^o - \rho_u^o} \right] \qquad (4.1)$$

where the ρ's are upper and lower single VR state populations for the homogeneous layer and the superscript 'o' refers to equilibrium conditions at the reference temperature T_o. The total optical depth τ_ν is obtained by summing the single line absorption coefficients K_ν^i, weighted by the absorber amounts W_i, over all of the active lines for all molecules:

$$\tau_\nu = \sum_i W_i \, K_\nu^i \, . \qquad (4.2)$$

The spectral radiance per line R^i_ν for a thin layer of gas (no self-absorption) is related to the absorption coefficient for that line by

$$\bar{R}^i_\nu = \frac{2h\nu^3}{c^2}\left[\frac{\rho^i_u}{\rho^i_\ell - \rho^i_u}\right] K^i_\nu \, , \qquad (4.3)$$

giving a total emission $R_\nu = \sum_i \bar{R}^i_\nu W_i$ for all lines in a thin layer. Note that *at equlibrium*, the ratio of emission to absorption $\bar{R}^i_\nu / K^i_\nu$ reduces to the Planck function

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\left[\frac{1}{e^{\frac{h\nu}{kT}} - 1}\right] \qquad (4.4)$$

for each line. The Planck function then also similarly relates total LTE emission and absorption. This general relationship does not apply in the non-LTE case.

It will be assumed that the line-shapes for absorption and radiance in the non-LTE problem are the same as they would be at equilibrium, so the K^i_ν and $\bar{R}^i_\nu$ differ from their equilibrium counterparts only by factors which depend on VR single state populations. The actual populations ρ_ℓ and ρ_u for a particular layer can be calculated from the vibrational state population data of the Degges model, assuming the rotational sub-states follow the Boltzman distribution. Reference single state populations ρ^o_ℓ and ρ^o_u can also be calculated for the thermal equilibrium distribution at T_o. Therefore, both K^i_ν and $\bar{R}^i_\nu$ can be calculated line-by-line and properly summed to give the total optical depth and radiance.

The model we then have is one containing an equilibrium gas A and a non-equilibrium gas B. At lower altitudes, only gas A is active. Above 30-50 km., the majority of lines are still in equilibrium, but some lines must be included in gas B rather than A. The total optical depth is

$$\tau_\nu = \tau_\nu^A + \tau_\nu^B , \qquad (4.5)$$

where both τ_ν^A and τ_ν^B must be calculated line-by-line. The total radiance for a thin layer is

$$R_\nu = R_\nu^A + R_\nu^B , \qquad (4.6)$$

where $R_\nu^A = \tau_\nu^A B_\nu(T)$, and R_ν^B is calculated line-by-line. The total radiant intensity including self-absorption for a finite homogeneous layer is

$$I_\nu^{RAD} = \frac{R_\nu}{\tau_\nu} \left[1 - e^{-\tau_\nu}\right]. \qquad (4.7)$$

A Preliminary Outline Of Planned Code Modifications For Non-LTE Transmission and Radiance: We describe somewhat schematically in this section a series of code changes which will serve to provide FASCODE with the capability to use non-equilibrium vibrational level populations for improved radiance and transmission calculations. Every effort will be made to have the code function as it does presently for calculations under LTE conditions. This will be accomplished by constructing new routines when necessary rather than modifying existing ones.

The non-LTE calculation will require two new data bases. Vibrational level population data of Degges and Smith[9] will be read and stored for those levels which are not at thermal equilibrium. The data should cover an altitude range appropriate to FASCODE and it can be expected to vary with the solar angle under daylight conditions and with the change to night conditions. The second data base will consist of a line parameters file which will have an expanded format to include a vibrational transition ID or some additional labels to facilitate matching lines with corresponding non-LTE levels.

Along with the new data bases, several new routines are being created. A new routine will read the non-LTE line data and vibrational level populations. It will prepare two new sets of line-strengths for use in the non-LTE absorptance and radiance calculations. Another routine will later calculate the total radiance for each completed layer.

The complete program will function as follows. At lower altitudes, HIRAC1 will ignore the non-LTE data in the revised line file and proceed without modification. The non-LTE routines will be triggered above a certain altitude. At this altitude and above, HIRAC1 will calculate absorptance line-by-line using the appropriate non-LTE line-strengths where necessary. A second line-by-line calculation will be performed and the results stored on a second file for later use in the radiance calculation. This second calculation can be done by HIRAC1, using specially modified line-strengths. The radiance routines will be modified to give the prop · ' total layer transmittance and radiance using the two stored spectral functions. The single layer results will then be merged with those of previous layers using the current algorithm.

5. A MODEL FOR THE CO_2 CONTINUUM

The line-shapes of CO_2 and most other molecules are usually taken to be Lorentzian in the high pressure, collision-broadened limit. The two-parameter Lorentzian shape function is completely specified by a strength S, which is the integral of the shape function, and the line width at half maximum α. The experimental evidence suggests that the actual shape function for CO_2 is approximately Lorentzian within about 15 half-widths of the line center[10], but becomes sharply sub-Lorentzian at greater distances from the central peak[11,12]. This effect can be understood in light of the limitations of collisional models that give the Lorentzian line-shape. A simple impact approximation which assumes that collisions occur instantaneously gives the Lorentzian shape with a half-width $\alpha \sim \tau^{-1}$, where τ is the average time between collisions[13,14]. The large frequency separations $(\nu - \nu_o)$ typical of the far wings correspond to very short time scales which may be shorter than the actual average collision duration. Therefore, it is not surprising that the impact approximation and the Lorentzian shape associated with it should not properly describe behavior in the far wings.

The initial approach that we will use to better model the real line-shape in the far wings is to replace the Lorentzian shape function f_L by the more general multiparameter shape function f in the far wings:

$$f = f_L e^{-a\left[|\nu-\nu_o| - \nu_{min}\right]^b} \; ; \text{ if } |\nu-\nu_o| > \nu_{min} . \qquad (5.1)$$

The parameters a, b, and ν_{min} can be determined from the experimental data of Winters[11] and Burch[12]. Winters has used this shape function to fit measurements of the far wings above the 2400 cm^{-1} band head. The data of Burch suggests that the same form may also be used for the 3800 cm^{-1} and 7000 cm^{-1} bands. We will make the further assumption (consistent with the limited data which is available) that all of the atmospheric CO_2 lines can be modelled with the same shape function f, with only S, and α to be specified for each line.

The modification of the far wing CO_2 line-shape in FASCODE is presently in its preliminary stages. (Since the FASCODE report of January '78, the problem of water vapor continuum absorption is being addressed through work at AFGL[2]). The sub-Lorentzian shape function will be used to construct a function representing the CO_2 continuum, in a fashion similar to the way the water vapor continuum has been modelled. An AFGL routine is available which combines lines to considerably reduce the computational time required to construct a continuum function line-by-line[15]. The problem of how one can properly 'match' the pressure-dependent continuum functions to an efficient line-by-line calculation of the other four functions which represent the line center remains to be more adequately addressed.

6. ATMOSPHERIC LAYERING

The interim code, FASCOD2, models the inhomogeneous atmosphere with a series of homogeneous layers. The user is required to specify, in addition to the path and model atmosphere parameters, the altitudes where the layer boundaries are to be placed. The geometry package ATMPTH then 'traces' the (generally) curved path through each layer and computes an average pressure $\bar{P}$ and temperature $\bar{T}$ plus molecular and aerosol amounts for each layer. Presently, the user has no guidelines to aid in choosing layer boundaries. To ensure that the result is sufficiently accurate, a large number of layers can be used, but only at the expense of computational time, which is particularly disadvantageous if a large range of wave numbers is to be studied. Another problem can arise if too few layers are used. Aside from having to deal with a somewhat uncontrollable error, it is possible to violate the requirement that the ratio of average pressures in consecutive layers be less than two (2). If this happens, execution will stop in mid-program.

We have planned several kinds of changes to overcome these problems. This work has not been completed, but we will outline the planning that has taken place in the last year. We plan to make code modifications in several stages. The first and most obvious change will be to construct a routine that prepares the set of layer boundaries based on one or two conditions which the user can specify. A condition suggested by AFGL is that the maximum pressure and temperature variations within each layer be fixed by the user. This kind of condition can guarantee that the approximation of homogeneity within each layer is a good one.

If it proves feasible, the layering routine may be expanded to base the choice of layer boundaries on a wider set of criteria. For instance, the allowable error in any single layer should depend on what part of the total absorption or radiance is due to that layer. Because this error can vary with the kind of path involved and with the wavenumber region of interest, it is very difficult to decide how the layer boundaries should be chosen in order to minimize the total error. Based on these kind of considerations, we will undertake a study of the error which results when running the code, by using the same path and varying the layering scheme. The 'error' can be calculated by comparison with a reference run which has a sufficiently large number of layers. A measure of the error in the transmission for the frequency interval from ν_1 to ν_2 is, for example,

$$\frac{1}{|\nu_1 - \nu_2|} \int_{\nu_1}^{\nu_2} \left| \frac{T_\nu - T_\nu^{ref}}{T_\nu^{ref}} \right| d\nu \; . \qquad (6.1)$$

We have written a short routine to evaluate this error by comparing a statistical sample of the output of the two runs. The error can be studied as a function of the number and position of layer boundaries, the type of path specified, and the wavenumber region. The goal of this parametric study will be to develop a more adequate set of criteria for the specification of layer boundaries. The end product may be either a set of guidelines for the user, or a more sophisticated layering algorithm which will function side-by-side with the geometry package.

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APPENDIX - FASCODE USERS GUIDE

Introduction: In the course of adding the ATMPTH and AERSOL routines to FASCOD1 several new control cards were introduced. In addition, some of the original FASCOD1 control cards have been consolidated to simplify the entire control deck structure.

The complete input card sequence is listed below. The routine with which the card is associated is also given.

Card 1 from FASCOD1 main

XID(I), I = 1,7
(10A10)

Card 2 from FASCOD 1 main

IHIRAC, ILBLF4, ICNTHM, IAERSL, IEMIT,
ISCAN, IFILTR, IPLOT, IATM, MPTS, NPTS
(9(4X,I1), 25X, 2I5)

Card 3 from FASCOD1 main

V1, V2, TBOUND, EMISIV
(10E10.3)

Card 4 from AERSOL, included only if aerosol attenuation is to be included, i.e., IAERSL = 1

IHAZE, ISEASN, IVULCN, JP, VIS
(4,(4X,I1), 5X, E10.3)

Card, 5, 6, 7 and the layer boundaries pertain to ATMPTH, and are included only if IATM = 0

Card 5 MODEL, ITYPE, IIN, IMOD, KMAX, RE
(5I5, 5X, F10.4)

The formats for control cards 6 and 7 are different depending on whether the path is horizontal (ITYPE = 1) or slant (ITYPE = 2 or 3).

For a slant path-

Card 6 H1, H2, ANGLE, RANGE, BETA, LEN
(5F10.4, I5)

Next read in the boundary altitudes for the FASCOD1 layers, with format (8F10.3).

Card 7 V1, V2,
(2F10.3)

For a horizontal path-

Card 6 Z, P, T, RANGE (DEN(K), K = 1, KMAX)
(4F10.3,/, (8E10.3)

For a model = 1 to 7, only Z and RANGE are used and P, T and DEN are interpolated. For model = 0, P and T are included.

Card 7 not used

For model 7, the input model atmosphere is read in after control card 5 as for a slant path;

(HEADER(I) I = 1,2)   (2A10)

Z,P, T   (3F10.3)

DENSITY (K), K = 1, KMAX (8E10.3)

Repeat the last two cards for each of the IMOD levels.

Card 8 from the scanning routine; this card is included
only if ISCAN ≠ 0

HWHM, V1, V2, JEMIT, JFN, JVAR
(3F10.3, 3(9X,I1)

Card 9, 10, 11, 12 are plotting cards, and are included
only if IPLOT ≠ 0

Card 9 NAME, PHONE, EXTENSION, ID
(3A10)

Card 10 V1, V2, XSIZE, DELV, NUMSBX, NOENDX, LFILE,
LSKIPF, SCALE, IP4
(4F10.3, 4I5, F10.3, I5)

Card 11 YMIN, YMAX, YSIZE, DELY, NUMSBY, NOENDY, IDEC,
JEMIT, JPLOT, LOGPLT
(4F10.3, 6I5)

Card 12 Repeat card 10

If the user is supplying layer data (IATM ≠ 0) then FILE 7 must contain the following information to be read by PATH.

NLAYRS (I5)

The next two cards are repeated for J layers

PBAR(J), TBAR(J), DUMMY, ICNTRK(J)
(3F10.4, I5)
(AMOUNT(I,J) I = 1,8)
(8E10.3)

If aerosol attenuation is to be included it must also be supplied by repeating the following card for J layers

AWKAER(J)   (E10.3)

Sample Input Sequence: The following smaple input card sequency corresponds to a FASCOD1 run in the emission mode, including aerosols for a vertical path from 0 to 20 km, with a layer boundary every 1 km. Note that the scanning routine is used (ISCAN = 1), while the plotting routine which is machine dependent is not used (IPLOT = 0).

```
   DATA FOR FASCOD2 REPORT, GROUND TO 20 KM, VERTICAL,AEROSOLS ON
HI=1 F4=1 CN=1 AE=1 EM=1 SC=1 FI=0 PL=0                                          2    2
2.095E+03 2.105E+03 0.000E+00 0.000E+00 0.000E+C0
IH=1 IS=1 IV=1 JF=1        2.30E+01
   6    2   21
  00.0       20.0       00.0
  0.         1.         2.         3.         4.         5.         6.         7.
  8.         9.         10.        11.        12.        13.        14.        15.
 16.         17.        18.        19.        20.        21.        22.        23.
 2090.       2110.
  1.         2095.1     2104.95               0          3
 -1.
```

Sample Output: The output has been truncated to include only output up to the second layer, plus the final layer and the results of the scanning routine. This should be sufficient for a user to verify that his copy of the code is functioning properly.

```
0    DATA FOR FASCOD2 REPORT, GROUND TO 20 KM, VERTICAL,AEROSOLS ON       FASCOD1  80/08/01. 14.43.04.
0 HIRAC      LBLF4      CNTNM      AERSL      EMISS      SCNFN      FILTR      PLOT
    1          1          1          1          1          1          0          0
  JH=       1  IS=       1  IV=        1,  VIS=    .230E+02
  ICH       1     6   10   15
  AEROSOL PROFILE
        .15800E+00
        .99100E-01
        .62100E-01
        .34600E-01
        .18500E-01
        .93100E-02
        .77100E-02
        .62300E-02
        .33700E-02
        .18200E-02
        .11400E-02
        .79900E-03
        .64100E-03
        .51700E-03
        .44200E-03
        .39500E-03
        .38200E-03
        .42500E-03
        .52000E-03
        .58100E-03
        .58900E-03
        .50200E-03
        .42000E-03
        .30000E-03
        .19800E-03
        .13100E-03
        .33200E-04
        .16400E-04
        .79900E-05
        .40100E-05
        .21000E-05
        .16000E-06
        .93100E-09
      0.
1CONTROL CARD 1:


           MODEL    =      6
           ITYPE    =      2
           IIN      =     21
           IMOD     =      0
           NMAX     =      0
           RE       =        0.000


  CONTROL CARD 1 PARAMETERS WITH DEFAULTS:
```

```
MODEL   =      6
ITYPE   =      2
IIN     =     21
IMOD    =     34
KMAX    =      8
RE      =   6371.230


SLANT PATH SELECTED, ITYPE =      2


MODEL ATMOSPHERE SELECTED IS:  M =      6

        U. S. STANDARD, 1962

  I       Z          P          T                                            DENSITY
                                       H2O       CO2        O3         N2O        CH4        CO         O2         N2
        (KM)       (MB)       (K)                                            (MOL CM-3)

  1     0.000   1013.000   288.100 1.973E+17 8.342E+15 6.777E+11 7.078E+12 1.896E+12 4.045E+13 5.296E+18 1.974E+19
  2     1.000    898.600   281.600 1.404E+17 7.583E+15 6.777E+11 6.434E+12 1.723E+12 3.677E+13 4.814E+18 1.794E+19
  3     2.000    795.000   275.100 9.696E+16 6.878E+15 6.777E+11 5.836E+12 1.563E+12 3.335E+13 4.366E+18 1.627E+19
  4     3.000    701.200   268.700 6.018E+16 6.220E+15 6.275E+11 5.277E+12 1.414E+12 3.016E+13 3.949E+18 1.472E+19
  5     4.000    616.600   262.200 3.678E+16 5.611E+15 5.773E+11 4.760E+12 1.275E+12 2.720E+13 3.562E+18 1.328E+19
  6     5.000    540.500   255.700 2.140E+16 5.047E+15 5.773E+11 4.282E+12 1.147E+12 2.447E+13 3.204E+18 1.194E+19
  7     6.000    472.200   249.200 1.271E+16 4.526E+15 5.647E+11 3.841E+12 1.027E+12 2.195E+13 2.874E+18 1.071E+19
  8     7.000    411.100   242.700 7.022E+15 4.048E+15 6.149E+11 3.434E+12 9.199E+11 1.962E+13 2.570E+18 9.578E+18
  9     8.000    356.500   236.200 4.012E+15 3.607E+15 6.526E+11 3.061E+12 8.199E+11 1.749E+13 2.290E+18 8.536E+18
 10     9.000    308.000   229.700 1.538E+15 3.205E+15 8.910E+11 2.720E+12 7.285E+11 1.554E+13 2.035E+18 7.585E+18
 11    10.000    265.000   223.200 6.018E+14 2.839E+15 1.129E+12 2.408E+12 6.451E+11 1.376E+13 1.802E+18 6.717E+18
 12    11.000    227.000   216.600 2.742E+14 2.503E+15 1.631E+12 2.124E+12 5.689E+11 1.214E+13 1.559E+18 5.924E+18
 13    12.000    194.000   216.600 1.237E+14 2.141E+15 2.008E+12 1.817E+12 4.867E+11 1.038E+13 1.359E+18 5.067E+18
 14    13.000    165.800   216.600 6.018E+13 1.830E+15 2.133E+12 1.553E+12 4.160E+11 8.874E+12 1.162E+18 4.331E+18
 15    14.000    141.700   216.600 2.809E+13 1.564E+15 2.384E+12 1.327E+12 3.535E+11 7.584E+12 9.930E+17 3.701E+18
 16    15.000    121.100   216.600 2.407E+13 1.337E+15 2.635E+12 1.134E+12 3.038E+11 6.481E+12 8.486E+17 3.163E+18
 17    16.000    103.500   216.600 2.040E+13 1.142E+15 3.012E+12 9.694E+11 2.597E+11 5.539E+12 7.253E+17 2.704E+18
 18    17.000     88.500   216.600 1.739E+13 9.769E+14 3.514E+12 8.209E+11 2.220E+11 4.737E+12 6.202E+17 2.312E+18
```

```
 19    18.000     75.650    216.600 1.471E+13 8.351E+14 4.016E+12 7.085E+11 1.898E+11 4.049E+12 5.301E+17 1.976E+18

 20    19.000     64.670    216.600 1.471E+13 7.139E+14 4.392E+12 6.057E+11 1.622E+11 3.461E+12 4.532E+17 1.689E+18

 21    20.000     55.290    216.600 1.471E+13 6.103E+14 4.769E+12 5.178E+11 1.387E+11 2.959E+12 3.875E+17 1.444E+18

 22    21.000     47.290    217.600 1.605E+13 5.196E+14 4.769E+12 4.409E+11 1.181E+11 2.519E+12 3.299E+17 1.230E+18

 23    22.000     40.470    218.600 1.739E+13 4.426E+14 4.894E+12 3.756E+11 1.006E+11 2.146E+12 2.310E+17 1.047E+18

 24    23.000     34.670    219.600 1.906E+13 3.775E+14 4.769E+12 3.203E+11 8.579E+10 1.830E+12 2.396E+17 8.932E+17

 25    24.000     29.720    220.600 2.040E+13 3.221E+14 4.518E+12 2.733E+11 7.321E+10 1.562E+12 2.045E+17 7.622E+17

 26    25.000     25.490    221.600 2.207E+13 2.750E+14 4.267E+12 2.333E+11 6.250E+10 1.333E+12 1.746E+17 6.508E+17

 27    30.000     11.970    226.500 1.271E+13 1.264E+14 2.510E+12 1.072E+11 2.872E+10 6.126E+11 8.021E+16 2.990E+17

 28    35.000      5.746    236.500 5.350E+12 5.809E+13 1.380E+12 4.929E+10 1.320E+10 2.816E+11 3.686E+16 1.375E+17

 29    40.000      2.871    253.400 2.240E+12 2.709E+13 6.149E+11 2.293E+10 6.156E+09 1.313E+11 1.720E+16 6.410E+16

 30    45.000      1.491    264.200 1.070E+12 1.349E+13 2.133E+11 1.145E+10 3.067E+09 6.542E+10 8.566E+15 3.193E+16

 31    50.000       .798    270.600 4.012E+11 7.049E+12 5.020E+10 5.981E+09 1.602E+09 3.418E+10 4.475E+15 1.668E+16

 32    70.000       .055    219.700 5.015E+09 6.007E+11 1.079E+09 5.097E+08 1.365E+08 2.913E+09 3.814E+14 1.422E+15

 33   100.000       .000    210.000 3.344E+07 3.425E+09 5.396E+05 2.706E+06 7.784E+05 1.660E+07 2.174E+12 8.104E+12

 34 99999.000      0.000    190.000 0.        0.        0.        0.        0.        0.        0.        0.
1CONTROL CARD 2:  SLANT PATH PARAMETERS

          H1        =     0.0000 KM
          H2        =    20.0000 KM
          ANGLE     =     0.0000 DEG
          RANGE     =     0.0000 KM
          BETA      =     0.0000 DEG
          LEN       =          0


          BOUNDARY ALTITUDES FOR FASCOD1 LAYERS

           I     Z (KM)

           1     0.0000
           2     1.0000
           3     2.0000
           4     3.0000
           5     4.0000
           6     5.0000
           7     6.0000
           8     7.0000
           9     8.0000
          10     9.0000
```

```
      11   10.0000
      12   11.0000
      13   12.0000
      14   13.0000
      15   14.0000
      16   15.0000
      17   16.0000
      18   17.0000
      19   18.0000
      20   19.0000
      21   20.0000


 CONTROL CARD 3

       V1   =    2090.000 CM-1
       V2   =    2110.000 CM-1
       VBAR =    2100.000 CM-1
1MERGED ATMOSPHERIC PROFILE:  MODEL ATMOSPHERE  PLUS FASCOD1 LAYER BOUNDARIES

 THIS PROFILE IS THE INPUT ATMOSPHERE TO THE GEOMETRY CALCULATION

  I     Z         P          T       REFRACT                                      DENSITY
                                     INDEX-1     H2O        CO2        O3          N2O        CO         CH4        O2         N2
      (KM)      (MB)        (K)      *1.0E+6                                   (MOL CM-3)

  1     0.000  1013.000    288.100    272.098 1.973E+17 8.342E+15 6.777E+11 7.078E+12 1.896E+12 4.045E+13 5.296E+18 1.974E+19

  2     1.000   895.600    281.600    247.012 1.404E+17 7.533E+15 6.777E+11 6.434E+12 1.723E+12 3.677E+13 4.814E+18 1.794E+19

  3     2.000   795.000    275.100    223.751 9.696E+16 6.878E+15 6.777E+11 5.836E+12 1.563E+12 3.335E+13 4.366E+18 1.627E+19

  4     3.000   701.200    268.700    202.099 6.018E+16 6.220E+15 6.275E+11 5.277E+12 1.414E+12 3.016E+13 3.949E+18 1.472E+19

  5     4.000   616.600    262.200    182.151 3.678E+16 5.611E+15 5.773E+11 4.760E+12 1.275E+12 2.720E+13 3.562E+18 1.328E+19

  6     5.000   540.500    255.700    163.749 2.140E+16 5.047E+15 5.773E+11 4.282E+12 1.147E+12 2.447E+13 3.204E+18 1.194E+19

  7     6.000   472.200    249.200    146.797 1.271E+16 4.526E+15 5.647E+11 3.841E+12 1.027E+12 2.175E+13 2.874E+18 1.071E+19

  8     7.000   411.100    242.700    131.232 7.022E+15 4.048E+15 6.149E+11 3.434E+12 9.199E+11 1.962E+13 2.570E+18 9.578E+18

  9     8.000   356.500    236.200    116.938 4.012E+15 3.607E+15 6.526E+11 3.061E+12 8.197E+11 1.749E+13 2.290E+18 8.536E+18

 10     9.000   308.000    229.700    103.891 1.538E+15 3.205E+15 8.910E+11 2.720E+12 7.285E+11 1.554E+13 2.035E+18 7.585E+18

 11    10.000   265.000    223.200     91.991 6.018E+14 2.839E+15 1.127E+12 2.408E+12 6.451E+11 1.376E+13 1.802E+18 6.717E+18

 12    11.000   227.000    216.800     81.126 2.742E+14 2.503E+15 1.631E+12 2.124E+12 5.689E+11 1.214E+13 1.589E+18 5.924E+18

 13    12.000   194.000    216.600     69.397 1.237E+14 2.141E+15 2.008E+12 1.817E+12 4.867E+11 1.038E+13 1.359E+18 5.067E+18

 14    13.000   165.800    216.600     59.309 6.018E+13 1.830E+15 2.133E+12 1.553E+12 4.160E+11 8.874E+12 1.162E+18 4.331E+18

 15    14.000   141.700    216.600     50.688 2.809E+13 1.564E+15 2.384E+12 1.327E+12 3.535E+11 7.534E+12 9.930E+17 3.701E+18
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 16    15.000   121.100   216.600    43.319 2.407E+13 1.337E+15 2.635E+12 1.134E+12 3.038E+11 6.401E+12 8.486E+17 3.163E+18
 17    16.000   103.500   216.600    37.024 2.040E+13 1.142E+15 3.012E+12 9.694E+11 2.597E+11 5.539E+12 7.252E+17 2.704E+18
 18    17.000    88.500   216.600    31.658 1.739E+13 9.769E+14 3.514E+12 8.289E+11 2.220E+11 4.737E+12 6.202E+17 2.319E+18
 19    18.000    75.650   216.600    27.061 1.471E+13 8.351E+14 4.016E+12 7.035E+11 1.393E+11 4.049E+12 5.301E+17 1.976E+18
 20    19.000    64.670   216.600    23.133 1.471E+13 7.139E+14 4.392E+12 6.057E+11 1.622E+11 3.461E+12 4.532E+17 1.683E+18
 21    20.000    55.290   216.600    19.778 1.471E+13 6.103E+14 4.769E+12 5.178E+11 1.387E+11 2.959E+12 3.875E+17 1.444E+18
 22    21.000    47.290   217.600    16.039 1.605E+13 5.196E+14 4.769E+12 4.409E+11 1.181E+11 2.519E+12 3.299E+17 1.230E+18
 23    22.000    40.470   218.600    14.344 1.739E+13 4.426E+14 4.894E+12 3.756E+11 1.004E+11 2.146E+12 2.810E+17 1.047E+18
 24    23.000    34.670   219.600    12.233 1.906E+13 3.775E+14 4.769E+12 3.203E+11 8.579E+10 1.830E+12 2.396E+17 8.932E+17
 25    24.000    29.720   220.600    10.439 2.040E+13 3.221E+14 4.518E+12 2.732E+11 7.321E+10 1.562E+12 2.045E+17 7.422E+17
 26    25.000    25.490   221.600     8.912 2.207E+13 2.750E+14 4.267E+12 2.333E+11 6.250E+10 1.333E+12 1.745E+17 6.530E+17
.27    30.000    11.970   226.500     4.095 1.271E+13 1.264E+14 2.510E+12 1.072E+11 2.872E+10 6.126E+11 8.021E+16 2.990E+17
 28    35.000     5.746   236.500     1.882 5.350E+12 5.809E+13 1.380E+12 4.929E+10 1.320E+10 2.816E+11 3.688E+16 1.375E+17
 29    40.000     2.871   253.400      .878 2.240E+12 2.709E+13 6.149E+11 2.290E+10 6.156E+09 1.313E+11 1.720E+16 6.412E+16
 30    45.000     1.491   264.200      .437 1.070E+12 1.349E+13 2.133E+11 1.145E+10 3.067E+09 6.542E+10 8.566E+15 3.193E+16
 31    50.000      .798   270.600      .228 4.012E+11 7.049E+12 5.020E+10 5.981E+09 1.602E+09 3.415E+10 4.475E+15 1.663E+16
 32    70.000      .055   219.700      .019 5.015E+09 6.007E+11 1.079E+09 5.097E+08 1.365E+08 2.913E+09 3.814E+14 1.422E+15
 33   100.000      .000   210.000      .000 3.344E+07 3.425E+09 5.396E+05 2.906E+06 7.784E+05 1.660E+07 2.174E+12 8.104E-12
 34 99999.000     0.000   190.000     0.000 0.        0.        0.        0.        0.        0.        0.        0.
1SLANT PATH PARAMETERS AFTER INPUT PROCESSING

           H1     =      0.000 KM
           H2     =     20.000 KM
           ANGLE  =      0.000 DEG
           HMIN   =      0.000 KM
           LEN    =          0
1CALCULATION OF THE REFRACTED PATH THROUGH THE ATMOSPHERE

    I        ALTITUDE         THETA    DRANGE    RANGE      DBETA    BETA        PHI      DBEND  BENDING     PBAR       TBAR    RHOBAR
           FROM        TO
           (KM)       (KM)    (DEG)     (KM)      (KM)      (DEG)    (DEG)      (DEG)     (DEG)   (DEG)      (MB)       (K)   (MOL CM-2)
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0          H1  TO  H2
0   1    0.000     1.000     .000     1.000     1.000    -.000    -.000  180.000    0.000    0.000  955.533  284.890 2.435E+19
0   2    1.000     2.000     .000     1.000     2.000    -.000    -.000  180.000    0.000    0.000  846.598  278.391 2.202E+19
0   3    2.000     3.000     .000     1.000     3.000    -.000    -.000  180.000    0.000    0.000  747.916  271.942 1.972E+19
0   4    3.000     4.000     .000     1.000     4.000    -.000    -.000  180.000    0.000    0.000  658.727  265.473 1.801E+19
0   5    4.000     5.000     .000     1.000     5.000    -.000    -.000  180.000    0.000    0.000  578.391  258.994 1.625E+19
0   6    5.000     6.000     .000     1.000     6.000    -.000    -.000  180.000    0.000    0.000  506.204  252.495 1.455E+19
0   7    6.000     7.000     .000     1.000     7.000    -.000    -.000  180.000    0.000    0.000  441.516  245.976 1.302E+19
0   8    7.000     8.000     .000     1.000     8.000    -.000    -.000  180.000    0.000    0.000  384.677  239.497 1.155E+19
0   9    8.000     9.000     .000     1.000     9.000    -.000    -.000  180.000    0.000    0.000  332..37  232.998 1.035E+19
0  10    9.000    10.000     .000     1.000    10.000    -.000    -.000  180.000    0.000    0.000  285.397  226.500 9.141E+18
0  11   10.000    11.000     .000     1.000    11.000    -.000    -.000  180.000    0.000    0.000  245.908  220.052 8.082E+18
0  12   11.000    12.000     .000     1.000    12.000    -.000    -.000  180.000    0.000    0.000  210.497  216.703 7.022E+18
0  13   12.000    13.000     .000     1.000    13.000    -.000    -.000  180.000    0.000    0.000  179.900  216.600 6.002E+18
0  14   13.000    14.000     .000     1.000    14.000    -.000    -.000  180.000    0.000    0.000  153.750  216.600 5.132E+18
0  15   14.000    15.000     .000     1.000    15.000     .000    -.000  180.000    0.000    0.000  131.400  216.600 4.385E+18
0  16   15.000    16.000     .000     1.000    16.000    -.000    -.000  180.000    0.000    0.000  112.300  216.600 3.752E+18
0  17   16.000    17.000     .000     1.000    17.000    -.000    -.000  180.000    0.000    0.000   96.000  216.600 3.205E+18
0  18   17.000    18.000     .000     1.000    18.000    -.000    -.000  180.000    0.000    0.000   82.075  216.600 2.746E+18
0  19   18.000    19.000     .000     1.000    19.000    -.000    -.000  180.000    0.000    0.000   70.160  216.600 2.346E+18
0  20   19.000    20.000     .000     1.000    20.000    -.000    -.000  180.000    0.000    0.000   59.980  216.600 2.006E+18


ORESULTS OF THE GEOMETRY CALCULATION

          H1       =      0.000 KM
          H2       =     20.000 KM
          ANGLE    =      0.000 DEG
          RANGE    =     20.000 KM
          BETA     =     -.000 DEG
          PHI      =    180.000 DEG
          HMIN     =      0.000 KM
          BENDING  =       .000 DEG
          LEN      =          0
1INTEGRATED ABSORBER AMOUNTS BY LAYER


    I  LAYER BOUNDARIES                                  INTEGRATED AMOUNTS
        FROM        TO       H2O       CO2        O3       N2O        CO       CH4        O2        N2
        (KM)       (KM)                                    (MOL  CM-2)
0   1    0.000     1.000 1.672E+22 7.956E+20 6.777E+16 6.751E+17 1.808E+17 3.859E+18 5.051E+23 1.883E+24

0   2    1.000     2.000 1.173E+22 7.225E+20 6.777E+16 6.130E+17 1.642E+17 3.503E+18 4.506E+23 1.709E+24

0   3    2.000     3.000 7.711E+21 6.543E+20 6.523E+16 5.552E+17 1.497E+17 3.173E+18 4.154E+23 1.548E+24

0   4    3.000     4.000 4.752E+21 5.910E+20 6.021E+16 5.014E+17 1.343E+17 2.865E+18 3.752E+23 1.399E+24

0   5    4.000     5.000 2.840E+21 5.324E+20 5.773E+16 4.517E+17 1.210E+17 2.581E+18 3.386E+23 1.260E+24

0   6    5.000     6.000 1.668E+21 4.782E+20 5.710E+16 4.058E+17 1.057E+17 2.319E+18 3.036E+23 1.131E+24

0   7    6.000     7.000 9.586E+20 4.283E+20 5.894E+16 3.634E+17 9.734E+16 2.076E+18 2.719E+23 1.013E+24

0   8    7.000     8.000 5.377E+20 3.823E+20 6.336E+16 3.244E+17 8.689E+16 1.853E+18 2.427E+23 9.047E+23
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0   9     8.000     9.000 2.580E+20 3.402E+20 7.656E+16 2.887E+17 7.733E+16 1.650E+18 2.160E+23 8.051E+23
0  10     9.000    10.000 9.977E+19 3.018E+20 1.005E+17 2.561E+17 6.860E+16 1.463E+18 1.916E+23 7.142E+23
0  11    10.000    11.000 4.140E+19 2.667E+20 1.365E+17 2.263E+17 6.062E+16 1.293E+18 1.693E+23 6.312E+23
0  12    11.000    12.000 1.891E+19 2.317E+20 1.813E+17 1.967E+17 5.267E+16 1.124E+18 1.471E+23 5.484E+23
0  13    12.000    13.000 8.816E+18 1.903E+20 2.070E+17 1.682E+17 4.504E+16 9.607E+17 1.258E+23 4.699E+23
0  14    13.000    14.000 4.212E+18 1.694E+20 2.256E+17 1.437E+17 3.850E+16 8.212E+17 1.075E+23 4.008E+23
0  15    14.000    15.000 2.603E+18 1.448E+20 2.507E+17 1.228E+17 3.290E+16 7.018E+17 9.189E+22 3.425E+23
0  16    15.000    16.000 2.218E+18 1.237E+20 2.219E+17 1.050E+17 2.812E+16 5.998E+17 7.853E+22 2.929E+23
0  17    16.000    17.000 1.885E+18 1.057E+20 3.257E+17 8.973E+16 2.404E+16 5.128E+17 6.714E+22 2.503E+23
0  18    17.000    18.000 1.601E+18 9.041E+19 3.759E+17 7.671E+16 2.055E+16 4.384E+17 5.740E+22 2.140E+23
0  19    18.000    19.000 1.471E+18 7.729E+19 4.201E+17 6.558E+16 1.756E+16 3.747E+17 4.906E+22 1.829E+23
0  20    19.000    20.000 1.471E+18 6.607E+19 4.578E+17 5.606E+16 1.501E+16 3.203E+17 4.195E+22 1.563E+23
1FINAL SET OF LAYERS FOR INPUT TO FASCOD1
 IF THE RATIO OF THE THICKNESSES OF TWO ADJACENT LAYERS IS GREATER THAN 10.0,
 THEN MERGE THESE LAYERS

  L  LAYER BOUNDARIES  ICNTRL  PBAR     TBAR                                   INTEGRATED AMOUNTS
        FROM      TO                             AIR      H2O      CO2       O3       N2O       CO       CH4       O2       N2
        (KM)     (KM)           (MB)     (K)                                           (MOL CM-2)

  1     0.000    1.000    1   955.58   284.89 2.43E+24 1.67E+22 7.96E+20 6.78E+16 6.75E+17 1.81E+17 3.86E+18 5.05E+23 1.88E+24

  2     1.000    2.000    1   846.60   278.39 2.20E+24 1.17E+22 7.22E+20 6.78E+16 6.13E+17 1.64E+17 3.50E+18 4.59E+23 1.71E+24

  3     2.000    3.000    1   747.92   271.94 1.99E+24 7.71E+21 6.54E+20 6.52E+16 5.55E+17 1.49E+17 3.17E+18 4.15E+23 1.55E+24

  4     3.000    4.000    1   658.73   265.49 1.80E+24 4.75E+21 5.91E+20 6.02E+16 5.01E+17 1.34E+17 2.87E+18 3.75E+23 1.40E+24

  5     4.000    5.000    1   578.39   258.99 1.62E+24 2.84E+21 5.32E+20 5.77E+16 4.52E+17 1.21E+17 2.58E+18 3.38E+23 1.26E+24

  6     5.000    6.000    1   506.20   252.50 1.45E+24 1.67E+21 4.78E+20 5.71E+16 4.06E+17 1.09E+17 2.32E+18 3.04E+23 1.13E+24

  7     6.000    7.000    1   441.82   246.00 1.30E+24 9.59E+20 4.28E+20 5.89E+16 3.63E+17 9.73E+16 2.08E+18 2.72E+23 1.01E+24
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  8     7.000     8.000  1   380.68   239.50 1.16E+24 5.38E+20 3.82E+20 6.34E+16 3.24E+17 8.69E+16 1.95E+18 2.43E+23 9.05E+23

  9     8.000     9.000  1   332.14   233.00 1.03E+24 2.59E+20 3.40E+20 7.66E+16 2.89E+17 7.73E+16 1.65E+18 2.16E+23 8.05E+23

 10     9.000    10.000  1   286.40   226.50 9.14E+23 9.98E+19 3.02E+20 1.01E+17 2.56E+17 6.86E+16 1.46E+18 1.92E+23 7.14E+23

 11    10.000    11.000  1   245.91   220.05 8.05E+23 4.17E+19 2.67E+20 1.36E+17 2.26E+17 6.06E+16 1.29E+18 1.69E+23 6.31E+23

 12    11.000    12.000  1   210.50   216.70 7.02E+23 1.87E+19 2.32E+20 1.81E+17 1.97E+17 5.27E+16 1.12E+18 1.47E+23 5.48E+23

 13    12.000    13.000  1   179.90   216.60 6.00E+23 6.82E+18 1.98E+20 2.07E+17 1.68E+17 4.50E+16 9.61E+17 1.26E+23 4.69E+23

 14    13.000    14.000  1   153.75   216.60 5.13E+23 4.21E+18 1.69E+20 2.26E+17 1.44E+17 3.85E+16 8.21E+17 1.08E+23 4.01E+23

 15    14.000    15.000  1   131.40   216.60 4.38E+23 2.60E+18 1.45E+20 2.51E+17 1.23E+17 3.29E+16 7.02E+17 9.19E+22 3.42E+23

 16    15.000    16.000  1   112.30   216.60 3.75E+23 2.22E+18 1.24E+20 2.82E+17 1.05E+17 2.81E+16 6.00E+17 7.85E+22 2.92E+23

 17    16.000    17.000  1    96.00   216.60 3.20E+23 1.89E+18 1.06E+20 3.26E+17 8.97E+16 2.40E+16 5.13E+17 6.71E+22 2.50E+23

 18    17.000    18.000  1    82.07   216.60 2.74E+23 1.60E+18 9.04E+19 3.76E+17 7.67E+16 2.05E+16 4.38E+17 5.74E+22 2.14E+23

 19    18.000    19.000  1    70.16   216.60 2.34E+23 1.47E+18 7.73E+19 4.20E+17 6.56E+16 1.76E+16 3.75E+17 4.91E+22 1.83E+23

 20    19.000    20.000  1    59.98   216.60 2.00E+23 1.47E+18 6.61E+19 4.58E+17 5.61E+16 1.50E+16 3.20E+17 4.19E+22 1.56E+23

  AVERAGE RELATIVE HUMIDITY FROM 0 TO 2 KM IS      .296E+02
0 V1(CM-1) =     2095.0000
0 V2(CM-1) =     2105.0000
0 TBOUND   =        0.0000     BOUNDARY EMISSIVITY =     0.00000

0                    LINE FILE INFORMATION
0LINE PARAMETERS TAPE IS ONLY SOURCE FOR FACCOD1                              BCDMRG1   79/11/12. 10.38.40.
0

       H2O  =     65              4.1993E-25
       CO2  =    333              1.6437E-25
        O3  =    402              1.9995E-22
       N2O  =      0              0.
        CO  =     23              6.6488E-22
       CH4  =      0              0.
        O2  =      0              0.
0 LOWEST LINE =    2090.042      HIGHEST LINE =    2109.990      TOTAL NUMBER OF LINES =      823
1
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0    DATA FOR FASCOD2 REPORT, GROUND TO 20 KM, VERTICAL,AEROSOL: ON       FASCOD1  80/08/01. 14.43.04.
0 LAYER =          1
0 PRESS(MB) =   955.53254
0 TEMP(K) =     284.89
0 SECANT =         1.00000

      H2O  =  1.672E+22
      CO2  =  7.956E+20
       O3  =  6.777E+16
      N2O  =  6.751E+17
       CO  =  1.808E+17
      CH4  =  3.858E+18
       O2  =  5.051E+23

       N2  =  1.883E+24
0 WKAER =        .12855E+00
0 SELF BROADENING FACTOR FOR H2O IS      1.02781
0 COMPUTED DV BEFORE MODIFICATION =     .02471832
  TYPE OF PATH =      1
  RATIO OF PREVIOUS DV TO CURRENT DV =      0.0000
  TYPE OF MERGE         99
0 DV FOR THE LAYER     .02470000
  ICH        1    5   10   15
  EXTINCTION AND ABSORPTION COEFFICIENTS
     .2000    2.69397    .65394   2.21519     .65000   1.48671   0.00000   1.05019     .00063
     .3000    1.74607    .11455   1.87266     .08791   1.55462   0.00000   1.05850     .00152
     .3371    1.60283    .08146   1.66557     .05816   1.51506   0.00000   1.05759     .00184
     .5500    1.00000    .05693   1.00000     .03652   1.00000   0.00000   1.00000     .00506
     .6943     .75250    .04951    .72525     .02994    .70673   0.00000    .94249     .00791
    1.0600     .42038    .05610    .38401     .03278    .28867   0.00000    .81456     .01829
    1.5360     .24176    .04038    .15449     .02557    .09994    .00019    .66051     .03728
    2.0000     .14675    .01909    .08475     .00810    .04184    .00127    .54860     .06158
    2.2500     .13430    .01997    .04044     .00842    .02728    .00138    .49133     .07553
    2.5000     .12316    .02042    .03082     .00867    .01843    .00291    .44677     .08943
    2.7000     .13237    .05599    .04620     .03139    .01335    .00405    .41671     .10051
    3.0000     .12228    .04050    .05271     .03947    .06513    .03080    .38063     .11614
    3.3923     .10700    .01447    .01067     .00646    .08950    .03297    .34773     .13310
    3.7500     .10108    .00867    .01266     .00316    .01532    .06019    .32804     .14348
    4.5000     .09308    .01496    .01127     .00395    .04766    .04119    .29732     .14633
    5.0000     .08365    .01336    .01056     .00519    .04278    .04133    .27506     .13709
    5.5000     .07950    .01627    .01086     .00646    .05010    .05703    .25082     .12482
    6.0000     .07276    .02342    .01449     .01304    .05367    .05266    .22620     .11134
    6.2000     .07377    .02421    .01499     .01247    .04372    .04304    .21652     .10709
    6.5000     .07353    .02435    .01228     .01095    .03342    .03285    .20253     .10076
    7.2000     .07954    .03517    .01778     .01620    .04456    .04137    .17265     .09605
    7.9000     .04651    .02828    .01475     .01449    .11867    .11816    .14905     .08734
    8.2000     .04451    .03916    .02285     .02278    .14709    .14633    .14234     .09000
    8.7000     .12176    .06739    .03215     .02730    .12734    .12639    .14082     .10304
    9.0000     .12693    .07280    .03474     .03104    .09291    .09215    .15057     .11905
    9.2000     .12808    .08086    .04285     .04023    .08778    .03722    .16399     .13437
   10.0000     .09102    .04013    .01652     .01544    .05019    .04968    .20608     .17551
   10.5910     .06028    .03206    .01304     .01234    .04070    .04044    .24481     .20095
   11.0000     .07424    .02662    .01101     .01014     05734    .05709    .27791     .22494
   11.5000     .06800    .02530    .01120     .01076    .03576    .03551    .25076     .18418
   12.5000     .06155    .02524    .01297     .01272    .01975    .01962    .15272     .09265
   14.8000     .05285    .03046    .01753     .01741    .01892    .01892    .09601      06665
   15.0000     .05173    .04292    .02468     .02462    .01956    .01949    .07456     .06033
```

```
  16.4000    .06260    .03469    .01741    .01722    .03665    .03665    .14576    .12329
  17.2000    .07159    .03975    .01766    .01747    .04152    .04146    .12373    .10551
  18.3000    .05959    .03260    .01513    .01506    .01715    .01709    .18348    .16154
  21.3000    .06212    .03684    .01557    .01551    .01620    .01620    .12150    .07835
  25.0000    .05325    .03307    .01104    .01456    .00835    .00835    .12924    .10532
  30.0000    .04703    .03391    .01532    .01532    .00633    .00633    .08538    .06757
  40.0000    .04393    .03455    .01582    .01502    .00589    .00589    .04108    .03247
0*********** CONTINUUMS ARE INTERIM (04/24/79) ********
0        * LBLF4 *
 DV FOR LBLF4 =      1.58080      BOUND FOR LBLF4 =   25.2928
0 FIRST LINE USED IN RDLIN4--- CHECK THE LINEFIL
 EOF ON LINFIL IN RDLIN4 -- CHECK THE LINFIL
0           TIME                READ    CONVOLUTION             PANEL
           1.247                .009            .007            0.000
0     * HIRAC1 *                                                      BOUNDF3(CM-1) =    6.3232
 OUTPUT ON FILE     10                DV =     .02470000
 FIRST LINE ON LINFIL USED (MORE LINES MAY BE REQUIRED)
 EOF ON LINFIL (MORE LINES MAY BE REQUIRED)
      1025 2095.000000  .21251300E+00
      1026 2095.024700  .23875292E+00
      1429 2104.973300  .71545700E-01
      1430 2105.003500  .72624964E-01
0           TIME                READ    CONVOLUTION             PANEL
           1.606                .003            .308            .004
                                                                     NO. LINES =        823    NO. CHANGES =              0
0  AVERAGE WIDTH =       .08651    AVERAGE ZETA =       .97602
         1 2095.000000  .50661152E-07  .60854974E+00
         2 2095.024700  .56718727E-07  .78709463E+00
       405 2104.978500  .16037268E-07  .93055420E+00
       406 2105.003500  .16308452E-07  .92994953E+00
 TIME REQUIRED FOR --EMINIT--         .013
1
0    DATA FOR FASCOD2 REPORT. GROUND TO 20 KM, VERTICAL,AEROSOLS ON      FASCOD1  80/08/01. 14.43.04.
0 LAYER =            2
0 PRESS(MB) =    846.59847
0 TEMP(K) =      279.39
0 SECANT =          1.00000

        H2O   =  1.173E+22
        CO2   =  7.225E+20
         O3   =  6.777E+16
        N2O   =  6.130E+17
         CO   =  1.642E+17
        CH4   =  3.303E+18
         O2   =  4.506E+23

         N2   =  1.709E+24
0 WKAER =          .79164E-01
0 SELF BROADENING FACTOR FOR H2O IS     1.02153
0 COMPUTED DV BEFORE MODIFICATION =     .02202022
  TYPE OF PATH =       1
  RATIO OF PREVIOUS DV TO CURRENT DV =      1.1217
  TYPE OF MERGE            0
0 DV FOR THE LAYER      .02470000
0*********** CONTINUUMS ARE INTERIM (04/24/79) ********
0        * LBLF4 *

 DV FOR LBLF4 =      1.58080      BOUND FOR LBLF4 =   25.2928
0 FIRST LINE USED IN RDLIN4--- CHECK THE LINEFIL
 EOF ON LINFIL IN RDLIN4 -- CHECK THE LINFIL
0           TIME                READ    CONVOLUTION             PANEL
           1.672                .007            .006            .001
0     * HIRAC1 *
```

```
 OUTPUT ON FILE    10              DV =    .02470000          BOUNDF3(CM-1) =   6.3232
 FIRST LINE ON LINFIL USED (MORE LINES MAY BE REQUIRED)
  EOF ON LINFIL (MORE LINES MAY BE REQUIRED)
      1025 2095.000000  .13798026E+00
      1026 2095.024700  .15373386E+00
      1429 2104.978600  .45239849E-01
      1430 2105.003500  .45928005E-01
0          TIME              READ    CONVOLUTION            PANEL
          1.986             0.000          .272              .003
0  AVERAGE WIDTH =      .07752   AVERAGE ZETA =     .97360   NO. LINES =        823    NO. CHANGES =          0
0 THE TIME AT THE START OF RADMRG IS          1.987
         1 2095.000000  .71114184E-07  .70435462E+00
         2 2095.024700  .78416337E-07  .67537528E+00
       405 2104.978900  .23376408E-07  .88977643E+00
       406 2105.003500  .23763079E-07  .88820477E+00
0 THE TIME AT THE END OF RADMRG IS          2.002
        .015 SECS WERE REQUIRED FOR THIS MERGE

1
0    DATA FOR FASCOD2 REPORT, GROUND TO 20 KM, VERTICAL,AEROSOLS ON
  FASCOD1  80/08/01. 14.43.04.
0 LAYER =         20
0 PRESS(MB) =      57.98000
0 TEMP(K) =       216.60
0 SECANT =          1.00000

       H2O   =  1.471E+18
       CO2   =  6.097E+19
        O3   =  4.579E+17
       N2O   =  5.606E+16
        CO   =  1.501E+16
       CH4   =  7.203E+17
        O2   =  4.195E+22

        N2   =  1.563E+23
0 WNAER =          .53499E-03
0 SELF BROADENING FACTOR FOR H2O IS     1.00003
0 COMPUTED DV BEFORE MODIFICATION =     .00184575
  TYPE OF PATH =      1
  RATIO OF PREVIOUS DV TO CURRENT DV =      1.3549
  TYPE OF MERGE         3
0 DV FOR THE LAYER     .00187566
0********** CONTINUUMS ARE INTERIM (04/24/79) ********
0       * LBLF4 *
 DV FOR LBLF4 =      .12004      BOUND FOR LBLF4 =     1.9207
0           TIME              READ    CONVOLUTION            PANEL
          9.406              .005          .044              .001
0       * HIRAC1 *
 OUTPUT ON FILE    10              DV =    .00187566            BOUNDF3(CM
-1) =     .4802
      1025 2095.000000  .97030616E-01
      1026 2095.001876  .91536800E-01
      2431 2097.637173  .23443367E-02
      2432 2097.639048  .24933910E-02
        33 2097.640924  .26649310E-02
        34 2097.642800  .28632146E-02
      2431 2102.138748  .31801572E-02
      2432 2102.140623  .34120511E-02
        33 2102.142499  .37119442E-02
        34 2102.144375  .41323181E-02
      1555 2104.997248  .91792734E-02
      1556 2104.999123  .75420034E-02
0           TIME              READ    CONVOLUTION            PANEL
          9.653              .002          .183              .032
0  AVERAGE WIDTH =      .00682   AVERAGE ZETA =     .77955   NO. LINES
=          454    NO. CHANGES =          0
```

```
O THE TIME AT THE START OF RADMRG IS          9.654
          1 2095.000000  .55446851E-07  .35885728E+00
          2 2095.001876  .56321966E-07  .36444128E+00
       1407 2097.637173  .76589018E-07  .59110297E+00
       1408 2097.639048  .75904442E-07  .59297272E+00
          1 2097.640924  .75220149E-07  .59467820E+00
          2 2097.642800  .74333068E-07  .59618769E+00
       2399 2102.138748  .24917037E-07  .82871025E+00
       2400 2102.140623  .24882769E-07  .82770311E+00
          1 2102.142499  .24842629E-07  .82634540E+00
          2 2102.144375  .24795136E-07  .82455650E+00
       1523 2104.997248  .27755935E-07  .79083859E+00
       1524 2104.999123  .27840110E-07  .79446629E+00
O THE TIME AT THE END OF RADMRG IS            9.898
      .244 SECS WERE REQUIRED FOR THIS MERGE
1    DATA FOR FASCOD2 REPORT, GROUND TO 20 KM, VERTICAL,AEROSOLS ON
  FASCOD1  80/08/01. 14.43.04.
O SECANT =         0.00000
O PRESS(MB) =     59.98000
O TEMP(K) =      216.60
O DV(CM-1) =      .00187566
O V1(CM-1) =  2095.000000
O V2(CM-1) =  2105.000000
O LAYER =   20
O COLUMN DENSITY (MOLECULES/CM**2)

       H2O  =  4.737E+22
       CO2  =  6.701E+21
        O3  =  3.538E+18
       N2O  =  5.685E+18
        CO  =  1.523E+18
       CH4  =  3.249E+19
        O2  =  4.254E+24
O***  SINCSQ  ***

       INPUT FILE NUMBER = 12, JEMIT = 0 JFN = 3
       HWHM OF INSTRUMENT FUNCTION =  1.00000000 CM-1
      BOUND OF INSTRUMENT FUNCTION =  4.52000000 CM-1
       OUTPUT FILE NUMBER = 11,    V1 =  2095.10000,   V2 =  2104.95000
       DV OUT    .25000000
O      NF =  226,  DXF = .02000,     SUM =  .997436312531470
   SHRINK RATIO =     16
           END OF FILE ENCOUNTERED
O      TIME =  9.769,  READ =  .004,  CONV. =   .052,  PANEL  = 0.000
O  SUMIN =  .641322358E+01
1
O V1P =  2095.10000 V2P =  2104.85000 DVOUT =   .25000000 NLIM =
   40
O
  .36382E+00  .44527E+00  .51555E+00  .56811E+00  .59998E+00  .61144E+
00  .60729E+00  .59449E+00  .58093E+00  .57293E+00
O
  .68123E+00  .67046E+00  .66034E+00  .65088E+00  .63952E+00  .62191E+
00  .59326E+00  .54947E+00  .49009E+00  .41674E+00
 SUMOUT  .589029948E+01
```