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A MODULAR RADIATIVE TRANSFER PROGRAM FOR GAS FILTER CORRELATION RADIOMETRY

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16. Abstract

The fundamentals of a computer program, Simulated Monochromatic Atmospheric Radiative Transfer (SMART), which calculates atmospheric path transmission, solar radiation, and thermal radiation in the 4.6 μm spectral region are described. A brief outline of atmospheric absorption properties and line-by-line transmission calculations is explained in conjunction with an outline of the SMART computational procedures. Program flexibility is demonstrated by simulating the response of a Gas Filter Correlation Radiometer (GFCR) as one example of an atmospheric infrared sensor. Program limitations, input data requirements, program listing, and comparison of SMART transmission calculations are presented.

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A MODULAR RADIATIVE TRANSFER PROGRAM FOR GAS FILTER CORRELATION RADIOMETRY

By

Joseph C. Casas[1] and Shirley A. Campbell[2]

SUMMARY

A line-by-line radiative transfer program that simulates the response of a Gas Filter Correlation Radiometer (GFCR) as a function of altitude is presented and discussed. The program was developed to specifically solve downward viewing GFCR simulation problems, but can be easily adapted to many different infrared sensor requirements. The overlaid structure and specific task subroutines permit desired modifications to be made with ease.

The program performs the task of calculating atmospheric transmittance and upwelling radiance as a function of wavenumber, altitude, and primary gas concentration, and writes the results on a temporary storage disk. The program then uses these results to calculate the output response of the GFCR.

Both input and output of the program are described, as well as a sample test case. The FORTRAN variables, subroutines, and overlaid programs are listed and explained. A flowchart is also furnished.

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INTRODUCTION

The use in recent years of high sensitivity and high effective spectral resolution (less than 0.1 cm^{-1}) instrumentation in the remote measurement of trace atmospheric gases has required refinements in the computational methods utilized in evaluating the atmospheric transmittance in the infrared spectral region. The principle of detection of trace atmospheric gases, specifically gaseous pollutants, has been described by Ludwig (ref. 1). The success of this principle not only depends upon the ability of the instrument technique to discriminate between the pollutant and interfering spectral lines, but also requires an accurate knowledge of high resolution pollutant and atmospheric spectra. This can only be accomplished by applying a line-by-line atmospheric radiative transfer program.

The high resolution of the GFCR instrument requires the usage of a line-by-line program for the purpose of analyzing long path trace atmospheric gas measurements. The program presented in this paper is a combination of an improved version of the line-by-line program described in reference 2 and several desirable characteristics from other line-by-line radiative transfer programs (refs. 3 and 4). The objective was to develop an efficient, generalized line-by-line atmospheric radiative transfer program, which could be readily adapted to many different infrared sensor research needs. The program currently accomodates nadir viewing sensors but can be modified for limb scan sensors via the appropriate geometrical interpretation of atmospheric layer transmission values. This paper describes the program and the basic analytical concepts upon which it is based, as well as its operation.

SYMBOLS

c_i	concentration of absorbing gas, parts per million (ppm)
C8	Boltzmann distribution constant, cm Kelvin
E	monochromatic upwelling radiance, watts $cm^{-2}sr^{-1}$
E'	energy of the lower state, cm^{-1}
f	Chapman function, dimensionless
h	sensor altitude index, dimensionless
h'	uppermost layer altitude index, dimensionless
H_s	wavenumber dependent sun irradiance at the top of the atmosphere, watts $cm^{-1}sr^{-2}cm^{-1}$
k	atmospheric layer index, dimensionless
l	thickness of layer, cm
m	constant, 1.5 for water vapor and 1.0 for all other molecules, dimensionless
N^O	Planck blackbody radiation, watts $cm^{-2}sr^{-1}$
p	mean pressure of layer, atm (1 atm = 1.01325 E+5 Newtons/meter^2)
p_e	equivalent pressure, atm
S_{in}	adjusted spectral line intensity, $atm^{-1}cm^{-2}$
S_0	spectral line intensity, $atm^{-1}cm^{-2}$
T	layer temperature, Kelvin
T_0	reference temperature corresponding to spectral line parameters, Kelvin
T_s	surface temperature, Kelvin
z	altitude index, dimensionless
α_{in}	adjusted spectral line half-width, cm^{-1}
α_0	line half-width, cm^{-1}

β_{in}	Lorentz line shape, dimensionless
ε	wavenumber dependent surface emittance, dimensionless
κ_{in}	wavenumber dependent absorption coefficient, $atm^{-1}cm^{-1}$
τ	gaseous transmittance at a particular altitude, dimensionless
θ	sun zenith angle, degrees
ω	wavenumber (inverse wavelength), cm^{-1}
$\overline{\omega}$	averaged wavenumber, cm^{-1}

SUBSCRIPTS:

i	gas species number
n	spectral line number

DICTIONARY OF FORTRAN VARIABLES

ABSCOF1	Absorption coefficient for primary gas at OMEGA (($cm^{-1}atm^{-1}$)/cm^{-1}).
ABSCOF2	Absorption coefficient for interfering gases at OMEGA (($cm^{-1}atm^{-1}$)/cm^{-1}).
ABSCOFT	Total absorption coefficient for all active infrared gases (ABSCOF1 + ABSCOF2) ((cm^{-1} atm^{-1})/cm^{-1}).
ADJALPH	Adjusted half-width of WZ (cm^{-1}).
ALPHA	Half-width value at half maximum of WX from spectral line parameter tape (cm^{-1}).
ALPHAD (I,NLAY)	Half-width values at half maximum of WZ for a Doppler spectral line for species I (cm^{-1}).
ALPHAL (I,NLAY)	Adjusted half-width values at half maximum of WZ for a Lorentz spectral line for species I (cm^{-1}).
ALPHAV (I,NLAY)	Adjusted half-width values at half maximum of WZ for a Voigt spectral line for species I (cm^{-1}).

ATMTAU (NLAY,NXM)	For atmospheric layers, calculated transmission of atmosphere at the top of the layer at OMEGA; for instrumentation and calibration layers, calculated transmission of that layer at OMEGA.
BBCNEW (NLAYI)	Radiation of the cold blackbody calibration source attenuated by the vacuum cell at OMEGA.
BBCNEWC (NLAYI)	Radiation of the cold blackbody calibration source attenuated by the calibration cell and the gas cell at OMEGA.
BBCNEWG (NLAYI)	Radiation of the cold blackbody calibration source attenuated by the gas cell at OMEGA.
BBCNEWV (NLAYI)	Radiation of the cold blackbody calibration source attenuated by the calibration cell and the vacuum cell at OMEGA.
BBCOLD (NLAYI)	Radiation of the cold blackbody calibration source attenuated by the vacuum cell at the previous OMEGA.
BBCOLD1 (NLAYI)	Temperature of the cold blackbody calibration source (Kelvin).
BBCOLDC (NLAYI)	Radiation of the cold blackbody calibration source attenuated by the calibration cell and the gas cell at the previous OMEGA.
BBCOLDG (NLAYI)	Radiation of the cold blackbody calibration source attenuated by the gas cell at the previous OMEGA.
BBCOLDV (NLAYI)	Radiation of the cold blackbody calibration source attenuated by the calibration cell and the vacuum cell at the previous OMEGA.
BBHNEW (NLAYI)	Radiation of the hot blackbody calibration source attenuated by the vacuum cell at OMEGA.
BBHNEWC (NLAYI)	Radiation of the hot blackbody calibration source attenuated by the calibration cell and the gas cell at OMEGA.
BBHNEWG (NLAYI)	Radiation of the hot blackbody calibration source attenuated by the gas cell at OMEGA.
BBHNEWV (NLAYI)	Radiation of the hot blackbody calibration source attenuated by the calibration cell and the vacuum cell at OMEGA.

BBHOLD (NLAYI)	Radiation of the hot blackbody calibration source attenuated by the vacuum cell at the previous OMEGA.
BBHOLDC (NLAYI)	Radiation of the hot blackbody calibration source attenuated by the calibration cell and the gas cell at the previous OMEGA.
BBHOLDG (NLAYI)	Radiation of the hot blackbody calibration source attenuated by the gas cell at the previous OMEGA.
BBHOLDV (NLAYI)	Radiation of the hot blackbody calibration source attenuated by the calibration cell and the vacuum cell at the previous OMEGA.
BBHOT (NLAYI)	Temperature of the hot blackbody calibration source (Kelvin).
BLCKIN (NLAYI)	Instrument's internal blackbody temperature (Kelvin).
BRDFAC	Primary gas pressure broadening factor.
BROAD	Primary gas pressure broadening coefficient.
C	2 * CMINV.
C7	First radiation constant (1.1908E-12 watts $cm^{-2} sr^{-1} cm^{-1}$).
C8	Boltzmann's constant (1.439 cm K).
C9	Doppler coefficient (6.7675E-8).
CHAPZEN	Exponential component of the Chapman transmission function of the atmosphere for the solar zenith angle.
CMINV	Distance above and below OMEGA considered as center line absorption in the transmittance calculation at wavenumber OMEGA (cm^{-1}).
COMPABS (I,NLAY)	Line profile component of absorption coefficient at OMEGA.
COSS	Cosine of the solar zenith angle.
DELTAW	Minimum allowable integrating wavenumber increment (cm^{-1}).
DIST	Width of the spectral band pass.

DV(JJ,NEMIS,NSURF)	Differential signal resulting from the transmission of external energy between the gas and vacuum cell (watts $cm^{-2} sr^{-1}$).
EL	Energy of lower state of transition of WZ from spectral line parameter tape (cm^{-1}).
EMISBB	Emissivity of the instrument internal blackbody.
EMISS (NEMIS)	Thermal emissivity of the earth's surface within the effective field of view.
ERFC	Error function describing the correction for the Voigt profile approximation.
ERRDN (NLAYI)	Error in the signal resulting from an imbalance between the optical paths (%).
FCD	Doppler intensity function.
FCERR	Error function for the Voigt intensity approximation.
FCL	Lorentz intensity function.
FCV	Voigt intensity function.
FILTERW (NOC)	Instrument filter wavenumber at which input transmission values are located (cm^{-1}).
GASANEW (JJ,NEMIS, NSURF)	Total upwelling atmospheric radiation attenuated by the gas cell at OMEGA.
GASAOLD (JJ,NEMIS, NSURF)	Total upwelling atmospheric radiation attenuated by the gas cell at the previous OMEGA.
GASBNEW (NLAYI)	Radiation of the internal blackbody attenuated by the gas cell at the previous OMEGA.
GASBOLD (NLAYI)	Radiation of the internal blackbody attenuated by the gas cell at the previous OMEGA.
GASCONC (ILINE{L}, NLAY)	Concentration of gas ILINE (L) in layer (ppm).
GASENEW (JJ,NEMIS, NSURF)	Total upwelling atmospheric radiation attenuated by the gas cell including gas cell thermal emission at OMEGA.

GASEOLD (JJ,NEMIS, NSURF)	Total upwelling atmospheric radiation attenuated by the gas cell including gas cell thermal emission at the previous OMEGA.
GBALDIF (NLAYI)	Difference of the radiation from the hot and cold blackbody balance sources attenuated by the gas cell path.
GCLTAIN (NLAYI)	Average transmission of the gas cell for the internal blackbody radiation.
IDENT (16)	Identification numbers corresponding to active infrared gas. 1 - Carbon Monoxide (CO) 2 - Water (H_2O) 3 - Sulfur Dioxide (SO_2) 4 - Ammonia (NH_3) 5 - Methane (CH_4) 7 - Nitrous Oxide (N_2O) 10 - Nitric Oxide (NO) 12 - Carbon Dioxide (CO_2)
ILINE (NOMEG)	Array of identification numbers corresponding to spectral lines in OMEGSTR.
IPOINT	Working pointer for OMEGSTR.
IPOLLUT	Identification number of primary gas.
IS	Identification number of species WZ from spectral line parameter tape.
JCOUNT	Number of integration steps.
JPROF (NLAY)	Line profile array: 1 if Lorentzian, 2 if Voigt.
KBI	Number of atmospheric layers.
MOLWT(IS)	Array of molecular weights corresponding to the IDENT array.
MOLWTIS	Molecular weight of species IS (grams/ molecules).
NEMIS	Number of earth's emissivities to be considered.
NLAY	Total number of input homogeneous layers (atmospheric + instrument + calibration).

NLAYI	Number of instrument layers.
NOC	Number of input FILTERW values.
NOMEG	Number of spectral lines in OMEGSTR.
NSPEC	Number of active infrared gases being considered.
NSTORW	Number of spectral lines in WSTOR.
NSUN	Number of input SUNW values.
NSURF	Number of surface temperatures to be considered.
NXM	Number of primary gas concentration multipliers (XMULT).
OMEGA	The center wavenumber of the subinterval being considered for transmittance calculations (cm^{-1}).
OMEGSTR(NOMEG)	Array of spectral lines from OMEGA-CMINV to OMEGA + CMINV.
OPATH (NLAY)	Optical path of layer (atm-cm).
PLANCK	Thermal emission of layer at OMEGA (watts $cm^{-2}sr^{-1}$).
PLANK (NLAYI)	Thermal emission of the instrument's internal blackbody at OMEGA (watts $cm^{-2}sr^{-1}$).
PRES (NLAY)	Pressure of layer (atm).
PROFAC1 (I,NLAY)	Multiplicative variable for line profile.
PROFAC2 (I,NLAY)	Multiplicative variable for line profile ($\|\omega-\omega_0\|$/ALPHA).
RADATM (NLAY,NXM)	For atmospheric layers, the radiation upwelling from the atmosphere as a result of atmospheric gaseous molecular emission at OMEGA; for instrument and calibration layers, the radiation as a result of gaseous molecular emission of that layer at OMEGA ((watts $cm^{-2}sr^{-1}$)/cm^{-1}).

RADCOLC (NLAYI)	Integrated radiation of the cold blackbody calibration source attenuated by the calibration cell and the gas cell.
RADCOLD (NLAYI)	Integrated radiation of the cold blackbody calibration source attenuated by the vacuum cell.
RADCOLG (NLAYI)	Integrated radiation of the cold blackbody calibration source attenuated by the gas cell.
RADCOLV (NLAYI)	Integrated radiation of the cold blackbody calibration source attenuated by the calibration and vacuum cells.
RADGASA (JJ,NEMIS, NSURF)	Integrated total upwelling atmospheric radiation attenuated by the gas cell.
RADGASB (NLAYI)	Integrated radiation of the internal blackbody attenuated by the gas cell.
RADGASE (JJ,NEMIS, NSURF)	Integrated total upwelling atmospheric radiation attenuated by the gas cell including gas cell thermal emission.
RADHOT (NLAYI)	Integrated radiation of the hot blackbody calibration source attenuated by the vacuum cell.
RADHOTC (NLAYI)	Integrated radiation of the hot blackbody calibration source attenuated by the calibration cell and the gas cell.
RADHOTG (NLAYI)	Integrated radiation of the hot blackbody calibration source attenuated by the gas cell.
RADHOTV (NLAYI)	Integrated radiation of the hot blackbody calibration source attenuated by the calibration cell and the vacuum cell.
RADOLD (NLAY,NXM)	For atmospheric layers, the radiation upwelling from the atmosphere as a result of atmospheric gaseous molecular emission at the previous OMEGA; for instrument and calibration layers, the radiation as a result of gaseous molecular emission of that layer at the previous OMEGA.
RADOTOT (JJ,NEMIS, NSURF)	Total upwelling radiation at the previous OMEGA.

RADSOLD (JJ,NEMIS, NSURF)	Radiation upwelling from the atmosphere as a result of earth surface emission at the previous OMEGA.
RADSUN (NLAY,NEMIS, NXM)	Radiation upwelling from the atmosphere as a result of incident solar energy at OMEGA ((watts $cm^{-2}sr^{-1})/cm^{-1}$).
RADSUNO (NLAY,NEMIS, NXM)	Radiation upwelling from the atmosphere as a result of incident solar energy at the previous OMEGA.
RADSURF (JJ,NEMIS, NSURF)	Radiation upwelling from the atmosphere as a result of earth surface emission at OMEGA ((watts $cm^{-2}sr^{-1})/cm^{-1}$).
RADTOT (JJ,NEMIS NSURF)	Total upwelling radiation at OMEGA (RADSUN + RADSURF + RADATM) ((watts $cm^{-2}sr^{-1})/cm^{-1}$).
RADVACA (JJ,NEMIS, NSURF)	Integrated total upwelling atmospheric radiation attenuated by the vacuum cell.
RADVACB (NLAYI)	Integrated radiation of the internal blackbody attenuated by the vacuum cell.
RATLV (I,NLAY)	Ratio of Lorentz to Voigt half-widths for species I.
REFTEMP (I)	Reference temperature corresponding to identification numbers of spectral line parameters from tape (Kelvin).
RESPG (NOC)	Normalized transmission values for gas cell given at FILTERW.
RESPIN	Instrument detector response.
RESPV (NOC)	Normalized transmission values for vacuum cell given at FILTERW.
ROOTEMP (NLAY)	Square root of layer temperature.
S	Adjusted line strength of WZ ($atm^{-1}cm^{-2}$).
SIGAV (JJ,NEMIS, NSURF)	Signal resulting from external blackbody radiation attenuated by the vacuum cell and the aperture (watts $cm^{-2}sr^{-1}$).
SIGBV (NLAYI)	Signal resulting from the internal blackbody radiation attenuated by the vacuum cell and the aperture (watts $cm^{-2}sr^{-1}$).

SUNCOM (NEMIS)	Component of solar energy unattenuated by the atmosphere (watts $cm^{-2}sr^{-1}$).
SUNFLUX (NSUN)	Wavenumber dependent solar energy incident at the top of the atmosphere (watts $cm^{-2}sr^{-1}$).
SUNINTP	Interpolated solar energy at OMEGA.
SUNW (NSUN)	Wavenumbers corresponding to the SUNFLUX input values.
SURFCOM (NEMIS, NSURF)	Component of surface energy contribution unattenuated by the atmosphere (watts $cm^{-2}sr^{-1}$).
SZ	Line strength values of WZ from spectral line parameter tape ($atm^{-1}cm^{-2}$).
TAU (NXM)	Transmission of layer at OMEGA.
TAUA (NLAYI)	Calculated average transmission coefficient for the vacuum cell aperture required to balance the optical paths for two external blackbody temperatures.
TAUGFIL	Interpolated transmittance of gas cell filter at OMEGA.
TAUOLD (NLAY,NXM)	For atmospheric layers, the calculated transmission of the atmosphere at the top of the layer at the previous OMEGA; for instrument and calibration layers, the transmission of that layer at the previous OMEGA.
TAUSLAT (NXM)	Total atmospheric slant path coefficient.
TAUVFIL	Interpolated transmittance of vacuum cell filter at OMEGA.
TCONSQ	Temperature dependence of the rotational partition function; $(TEMPCON)^2$ unless water, which is $(TEMPCON)^{5/2}$.
TEMP (NLAY)	Temperature of layer (Kelvin).
TEMPCON	Reference temperature of gas/temperature of layer (temperature adjustment for line half-width).
TERFC	Error function term for Voigt profile.

TERFC2	TERFC squared.
THICK (NLAY)	Thickness of layer (cm).
TINV (NLAY)	Inverse of layer temperature.
TOTATM (NLAY,NXM)	For atmospheric layers, the integrated radiation upwelling from the atmosphere as a result of atmosphere gaseous molecular emission; for instrument and calibration layers, the integrated radiation as a result of gaseous molecular emission of that layer.
TOTRAD (JJ,NEMIS, NSURF)	Total integrated upwelling radiation.
TOTSUN (NLAY,NEMIS, NXM)	Integrated radiation upwelling from the atmosphere as a result of incident solar energy.
TOTSURF (JJ,NEMIS, NSURF)	Integrated radiation upwelling from the atmosphere as a result of earth surface emission.
TRANS (NLAY,NXM)	For atmospheric layers, the calculated integrated transmission of the atmosphere at the top of the layer; for instrument and calibration layers, the integrated transmission of that layer.
TSURF (NSURF)	Temperature of the earth's surface within the effective field of view (Kelvin).
V (JJ,NEMIS,NSURF)	Average signal resulting from the transmission of external energy between the gas and vacuum cells (watts $cm^{-2} sr^{-1}$).
VACANEW (JJ,NEMIS, NSURF)	Total upwelling atmospheric radiation attenuated by the vacuum cell at OMEGA.
VACAOLD (JJ,NEMIS, NSURF)	Total upwelling atmospheric radiation attenuated by the vacuum cell at the previous OMEGA.
VACBNEW (NLAYI)	Radiation of the internal blackbody attenuated by the vacuum cell at OMEGA (watts $cm^{-2} sr^{-1}$).
VACBOLD (NLAYI)	Radiation of the internal blackbody attenuated by the vacuum cell at the previous OMEGA (watts $cm^{-2} sr^{-1}$).

VBALDIF (NLAYI)	Difference of the radiation from the hot and cold blackbody balance sources attenuated by the vacuum cell path.
VGTPAR	A Voigt parameter.
VGTPAR2	Reciprocal of the Voigt parameter squared.
VGTPAR4	VGTPAR squared.
W3	OMEGA cubed.
WI	Initial wavenumber used for transmittance calculation (cm^{-1}).
WF	Final wavenumber used for transmittance calculation (cm^{-1}).
WRATLV	Ratio of Lorentz to Voigt half-widths for WZ.
WRATV1	1 - WRATLV.
WSTOR (NSTORW)	Array of spectral lines, the first of which is $\leq$ OMEGA and the remainder are $\geq$ OMEGA but $\leq$ OMEGA + CMINV.
WZ	Wavenumber values from spectral line parameter tape (cm^{-1}).
XMULT (NXM)	Primary gas concentration multipliers.
ZENITH	Sun zenith angle (degrees).

PROBLEM DEFINITION AND METHOD OF SOLUTION

A line-by-line radiative transfer computer program was needed to efficiently perform the task of data reduction for several versions of the GFCR which are being developed by NASA/Langley Research Center (LaRC). The writing of the SMART program was undertaken to minimize data reduction cost by the efficient utilization of computer storage through overlaying, by reducing execution time, and by combining several phases of the previous data reduction procedure, i.e., instrument balance and calibration (ref. 1) and data signal simulation. The modular structure of the program was designed to permit modifications of the computational algorithms without affecting the program framework. The individual overlaid programs and subroutines are explained in the Program Organization and Description section. In addition, thorough documentation was necessary for program clarity.

In order to minimize computation time without a loss in accuracy, certain assumptions were made concerning the atmosphere and radiative transfer processes in the algorithms used to perform transmittance calculations. To compute the transmittance from the earth's surface to a sensor altitude, h, the modeled atmosphere between these points is divided into a number of homogeneous layers, i.e., regions within which the temperature, total pressure, and concentrations of the primary and interfering molecular absorbers are uniform. The error in this approximation may be made as small as desired by subdividing the atmosphere into a sufficiently large number of layers. The total radiance incident on a sensor at altitude h is given by

$$E(h) = \int_{\Delta\omega} E(\omega)\,d\omega \tag{1}$$

where $\Delta\omega$ is the spectral bandpass of interest and $E(\omega)$ is the total monochromatic upwelling radiance.

For a cloud-free, non-scattering atmosphere under local thermodynamic equilibrium, the atmospheric radiative transfer equation for the total monochromatic upwelling radiant energy, $E(\omega)$, as viewed by a nadir type of sensor can be written as

$$
\begin{aligned}
E(\omega) = {} & \varepsilon(\omega)\ N^{o}(\omega,T_s)\ \tau(\omega,h) \\
& + \int_0^h N^{o}\Big(\omega,T(z)\Big)\ \frac{d\tau(\omega,z)}{dz}\ dz \\
& + \frac{1}{\pi}\ [1 - \varepsilon(\omega)]\ \cos\theta\ H_s(\omega) \\
& \cdot\ [\tau(\omega,h)][\tau(\omega,h')]\ f(\theta)
\end{aligned}
\tag{2}
$$

where $\varepsilon(\omega)$ is the wavenumber dependent surface emittance, $N^{o}(\omega,T_s)$ is the Planck blackbody function which is dependent on wavenumber and surface temperature, T_s, or radiating gas temperature at a particular altitude, $T(z)$. The monochromatic transmittance of the atmosphere between the emitting surface z and the altitude of the sensor, h, is represented by $\tau(\omega,h)$, and the monochromatic vertical transmission of the entire modeled atmosphere is represented by $\tau(\omega,h')$. The solar zenith angle is θ and the wavenumber dependent sun irradiance at the top of the atmosphere is H_s. The Chapman function (ref. 1), $f(\theta)$, is equal to $\sec\theta$ for $0^{o} \leq \theta \leq 60^{o}$ and is equal to the Chapman polynomial for $\theta > 60^{o}$. The three terms on the right-hand side of equation (2) represent, respectively, the earth's surface emission, the atmospheric emission, and the solar reflected energy (see figure 1). All of these components must be considered in the solar-thermal overlap region at 4.6 μm. These terms are represented in SMART by RADSURF, RADATM, and RADSUN, respectively.

A closer examination of the form of equations (1) and (2) indicates two very distinct differences between the methodology of SMART and other conventional line-by-line radiative transfer programs. The first difference is the order in which the integrals over $\Delta\omega$ and over the change in altitude, Δh, are performed. By initially integrating over Δh monochromatically, the inflexibility of transmittance averaging is eliminated, i.e.,

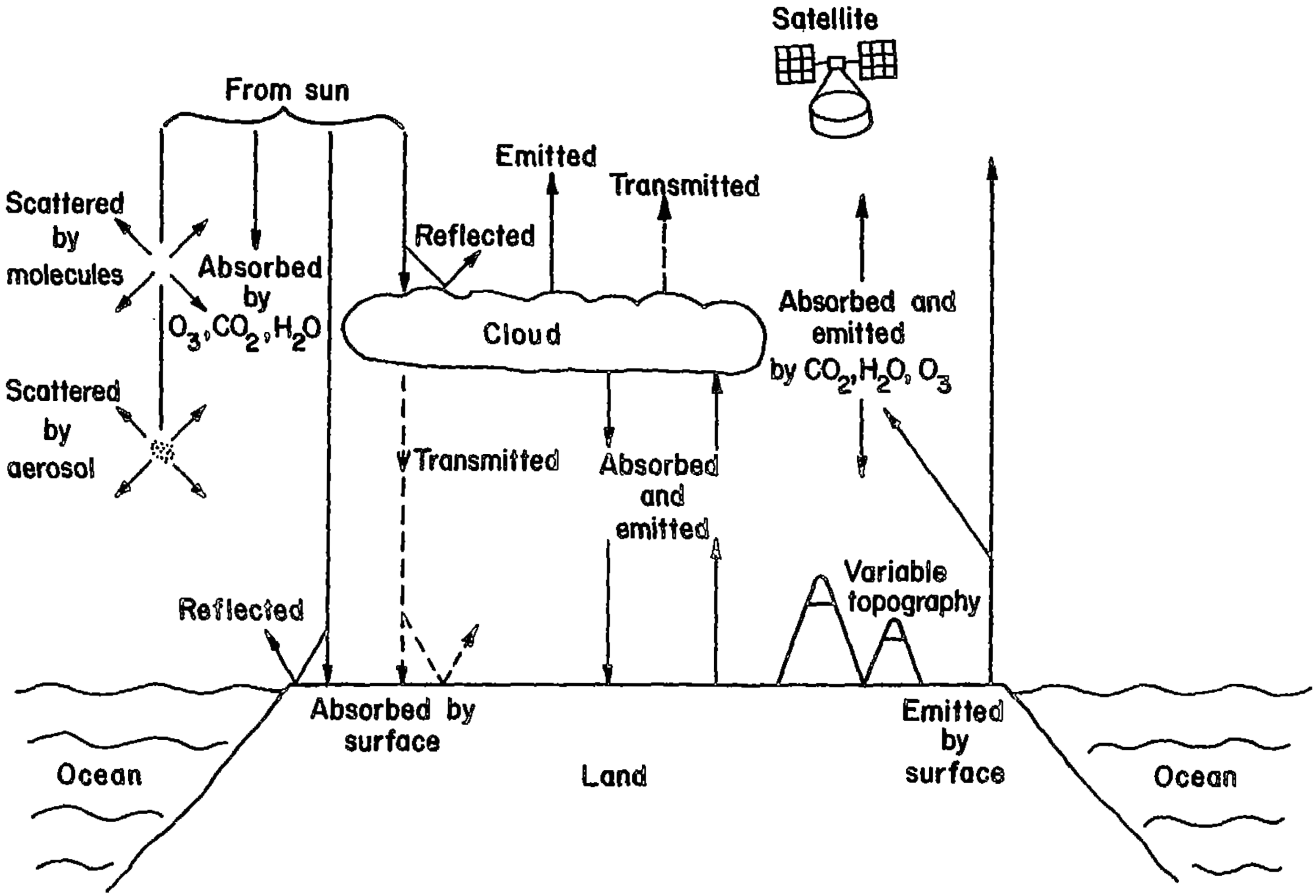

Figure 1. Interaction of radiation with the atmosphere.

the monochromatic transmission at any altitude h is given by

$$\tau(\omega,h) = \prod_{z=1}^{h} \tau(\omega,z) \tag{3}$$

and not by

$$\bar{\tau}(\Delta\omega,h) = \frac{1}{\Delta\omega} \sum_{\Delta\omega} \left[\prod_{z=1}^{h} \tau(\omega,z) \right]. \tag{4}$$

The spectral resolution of the transmittance values, i.e., the number of ω's at which the absorption coefficient is calculated, is defined by the user in subroutine GETW. The algorithm used for our CO calculations is explained later in this section.

The second difference between SMART and most other line-by-line radiative transfer programs is the specification of the order of limits of integration over altitude. The lower limit of integration is the radiating source and the upper limit is the sensor altitude which allows for practical computation of the monochromatic and total integrated transmission at the top of each atmospheric layer as seen by equation (3). This eliminates redundant calculations of atmospheric transmittance in evaluating signals from aircraft platform sensors at various altitudes.

Theoretically, the total absorption coefficient at any wavenumber, ω , consists of contributions from all spectral lines; however, for practical computational purposes, only lines within the vicinity of ω are considered for calculation in SMART. The contribution to the absorption coefficient of lines in the vicinity of ω can be divided into two parts, direct and wing. Those lines which lie within an interval defined by approximately 100 half-widths of the primary gas to each side of ω are considered to be the direct contributors to the absorption coefficient, while those lines lying outside of this interval result in wing absorption. In the SMART calculation of direct line absorption contribution, at each incremented step a symmetric interval (CMINV) is considered about the center wavenumber. This interval is constant throughout the entire band. For atmospheric carbon monoxide using the Lorentzian line profile, an interval of 5 cm^{-1} was selected since this value was approximately 100 times the line half-width of CO. For spectral lines beyond 5 cm^{-1}, the direct contribution to the absorption coefficient is very small (ref. 8). Presently, the SMART program does not include wing contribution.

The SMART program is divided into two primary level overlays (see figure 2). The first lower level overlay, as described in the Program Organization and Description section, performs initialization of all variables required for the calculation of the monochromatic gas transmission (TAU) for each atmospheric, instrument cell, and instrument calibration layer. The procedure for the computation of TAU is initiated by a call of the READTP subroutine, which reads all spectral reference information; i.e., line position (WZ), half-width (ALPHA), intensity (SZ), lower energy level (EL), and species identification number (IS) from the spectral line parameter reference tape for the band interval WI - CMINV to WF + CMINV. To analyze the GFCR sensor carbon monoxide data measurements in the 4.6 μm region, the McClatchey spectral line parameter tape (ref. 5) was used to obtain all spectral reference information. The parameters read should be under room temperature and standard pressure (296.0 K and 1 atm) conditions or the appropriate conversion must be performed prior to reading these parameters in subroutine READTP (see Appendix C).

The gaseous transmittance at a particular altitude as a function of wavenumber is given by

$$TAU(\omega) = \tau(\omega) = \exp\left[- \sum_i \kappa_i(\omega) p\, c_i \ell\right] \qquad (5)$$

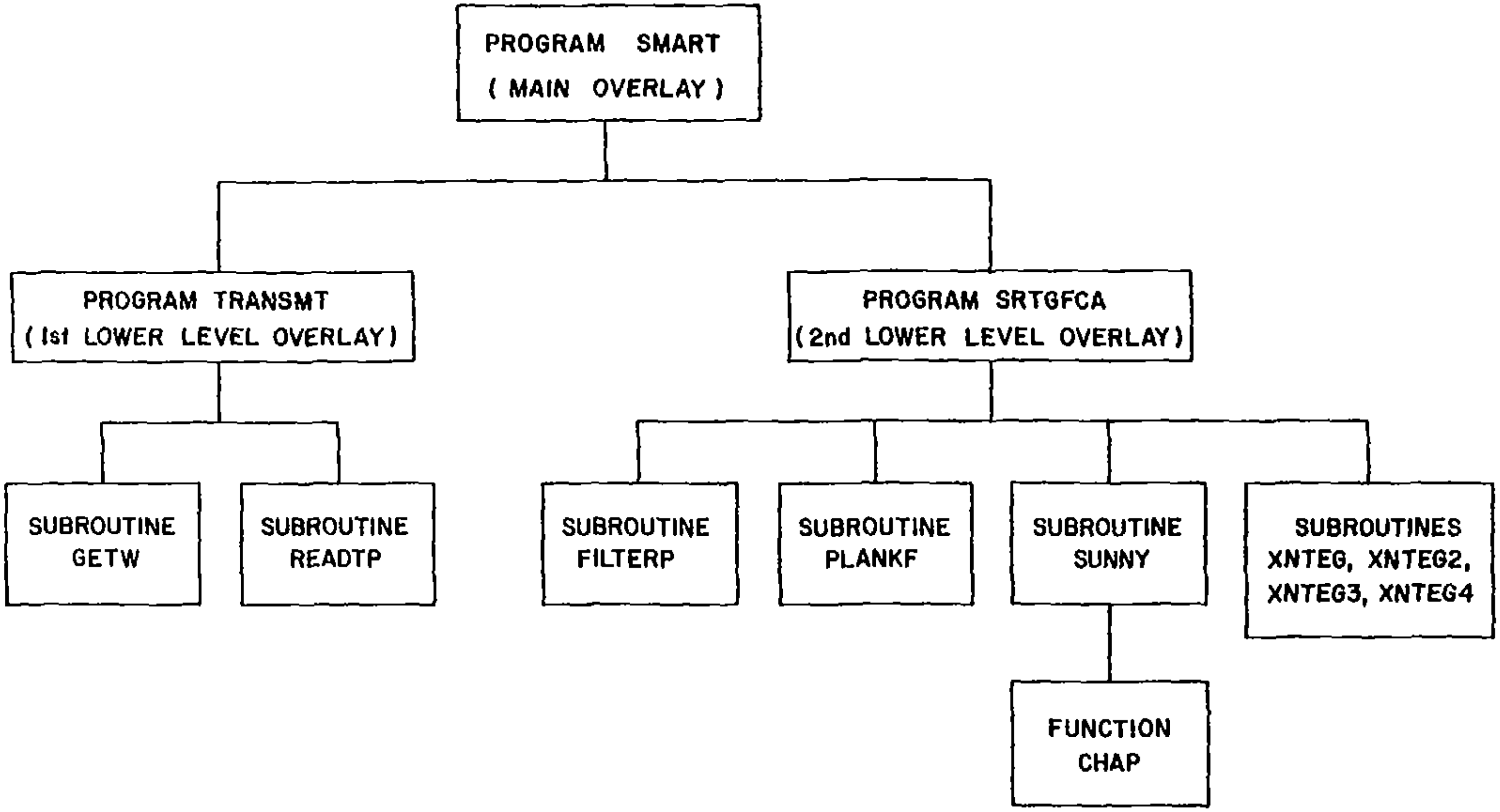

Figure 2. SMART program structure.

where $\kappa_i(\omega)$ is the wavenumber dependent absorption coefficent of gas species i (their sum being ABSCOFT), p (PRES) is the total mean pressure of layer k, c_i (GASCONC) is the concentration of absorbing gas i, and ℓ (THICK) is the thickness of the kth layer.

In general, the absorption coefficient of the nth line of species i is described by

$$\kappa_{in}(\omega) = S_{in}\beta_{in}(\omega) \tag{6}$$

where S_{in} is the layer temperature (TEMP) corrected line intensity and β_{in} is the line shape function, i.e., Lorentz, Voigt, or Doppler. The Lorentz line shape is given by

$$\beta_{in}(\omega) = \frac{1}{\pi}\frac{\alpha_{in}}{(\omega - \omega_{in})^2 + (\alpha_{in})^2} \tag{7}$$

where α_{in} (ADJALPH) is the temperature and pressure dependent line half-width for layer k and is calculated by

$$\text{ADJALPH} = \alpha_{in} = \alpha_o p_e \left(\frac{T_o}{T}\right)^{1/2} . \tag{8}$$

The reference line half-width, α_o (ALPHA), is read from the spectral line parameter tape at temperature T_o (REFTEMP). The equivalent pressure, p_e, is a function of the ratio of self-broadening to the nitrogen-broadening efficiency (BROAD), the total pressure (PRES), and the concentration of the absorbing gas (GASCONC) as given by

$$p_e = [\text{GASCONC} * (\text{BROAD} - 1) + 1] * \text{PRES} . \tag{9}$$

In the case of trace gases in the atmosphere, the equivalent pressure is set equal to the total atmospheric pressure since self-broadening is insignificant. For instrument and calibration layers, self-broadening is assumed and the corresponding equivalent pressure for BROAD is calculated.

The line intensity (S) depends upon the temperature through the Boltzman distribution factor (ref. 6) and is expressed as

$$S_{in} = S_o \left(\frac{T_o}{T}\right)^m \exp\left[-C8\left(\frac{T_o}{T} - 1\right)\frac{E'}{T_o}\right] \tag{10}$$

or

S = SZ *TCONSQ * EXP [-C8*(TEMPCON - 1)*EL/REFTEMP] (11)

where m is 1.5 for water vapor and ozone and 1.0 for other infrared active molecules, such as CO, CO_2, N_2C, and C8 is the Boltzman distribution constant. At this point, the user has the option of calculating ABSCOFT as determined by the Lorentz function or as determined by an approximation to the Voigt function detailed by Kielkopf (ref. 7). The flexibility of SMART allows easy insertion of the Doppler line profile calculation by the addition of an option as defined by JPROF in the same program location as the Lorentz and Voigt function. The line shape for each layer (JPROF) must be designated in the input and need not be the same for each layer. The direct contribution to the absorption coefficient from all infrared active lines whose center positions lies within CMINV of the wavenumber under consideration (OMEGA), i.e., the interval OMEGA - CMINV to OMEGA + CMINV, constitutes the total direct absorption at OMEGA. For additional spectral line information, the interval of direct contribution can easily be extended by increasing the dimensions of the appropriate variables. The total absorption at OMEGA for this interval is determined by the summation of the absorption coefficients for all lines within the interval. In addition, the user can automatically obtain the total absorption coefficient (ABCOFT) that corresponds to a maximum of ten different primary gas vertical mixing ratio profiles as defined by XMULT. Each value of XMULT is multiplied by the volume mixing ratio of the primary gas in every layer resulting in a bias shifting of the input vertical mixing ratio profile. ABSCOFT is calculated as the sum of two components, ABSCOF1, which is the absorption coefficient for the primary gas, and ABSCOF2, which is the absorption coefficient for all other interfering gases. The absorption effects of continua, such as nitrogen and water vapor, could easily be considered in the form of an added third term to ABSCOFT after the necessary algorithms for accurately calculating the continuum absorption in the spectral region under consideration have been developed.

After completion of the monochromatic calculation of ABSCOFT at OMEGA for the first layer, the transmittance is calculated as shown by equation (5). This procedure is repeated resulting in a TAU value for each layer k. The self-emission (RADATM) of each layer is then calculated via the wavenumber dependent energy described by the Planck blackbody function used in subroutine PLANKF. The temperature used in PLANKF is the mean temperature (TEMP) of the emitting layer. The emissivity (EMISS) of the layer is determined by the calculated transmittance of that layer as given by

$$\text{EMISS} = 1 - \text{TAU} . \tag{12}$$

The total monochromatic transmittance (ATMTAU) at the top of each atmospheric layer is then calculated as

$$\text{ATMTAU}(\omega) = \Pi_k \ \text{TAU}_k(\omega) \tag{13}$$

and written on temporary storage disk 6 with the corresponding wavenumber and self-emission component.

The next operation performed by SMART is the determination of the wavenumber increment step size for the purpose of repeating the transmittance calculations for the entire spectral band being considered, i.e., WI - CMINV to WF + CMINV. This task is accomplished by the GETW subroutine. The size of the wavenumber increment used in absorption coefficient calculations is arbitrary and depends upon the spectral resolution required by the user, since the absorption coefficient varies rapidly as a function of relative position to the spectral line centers. Subroutine GETW can be replaced by any of several schemes (refs. 4, 8, and 9) proposed for selection of wavenumber positions for line-by-line absorption calculations. For applications of SMART to the GFCR carbon monoxide sensor, a minimum mesh size (DWMIN) of .01 cm^{-1} and a maximum mesh size of .5 cm^{-1}, which is 1/8 of the average distance between CO spectral lines, was determined to most efficiently describe the wavenumber dependent absorption coefficient. When the spectral line density being examined is high, a large number of integration points are calculated; however, if the spectral line density is low, fewer points of integration are considered. The transmittance calculation for a new OMEGA is performed and the corresponding results, i.e., ATMTAU (ω) and RADATM (ω), are written on temporary storage disk 6. This procedure is repeated until ATMTAU and RADATM for the entire spectral band are written.

The second lower level overlay is comprised of four sections. The first section of the overlay reads the input data required for computation of instrument parameters, and the remaining variables of the RADSURF and RADSUN contributions given by equation (2). After initialization of variables, subroutine FILTERP is called to evaluate by interpolation the wavenumber dependent variables, i.e., instrument filter functions and solar irradiance values. The second section calculates the earth's monochromatic emission (RADSURF) as a function of one or more surface temperatures and emissivities. This task is accomplished by employing subroutine PLANKF in the calculation of the wavenumber dependent Planck distribution of energy.

The solar contribution (RADSUN) is calculated in accordance with equation (2) by subroutine SUNNY, where the Chapman function is employed in determining the slant path transmittance of incident solar radiance. The three terms of equation (2), i.e., RADSURF, RADATM, and RADSUN, are then obtained by attenuating each component by the appropriate atmospheric transmittance (ATMTAU) value for an altitude corresponding to the top of each atmospheric layer.

The third section calculates the internal radiance values for the GFCR sensor and the necessary parameters for balance and calibration. [A detailed description of instruments based on the gas filter correlation technique is presented in references 1 and 2]. In addition, the simulated signals (DV and V) corresponding to the sensor detection of total upwelling radiance (RADTOT) are calculated. For convenience, the trapezoidal rule is used for integration of all variables over the spectral band being examined. This process is performed by the subroutines XNTEG, XNTEG2, XNTEG3, and XNTEG4. The dimensions of the variables to be integrated determines which of the four subroutines is called. The required output parameters, both atmospheric and sensor, are then stored and are readily accessible for output listing in section four.

PROGRAM ORGANIZATION AND DESCRIPTION

The SMART program is written in FORTRAN IV for the Control Data Cyber series computer systems and is overlaid. For our sample test case using 17 input layers, the storage required is 130300 octal words. The storage is dependent upon the number of atmospheric and instrument layers required for calculations. Each additional layer requires approximately 2000 octal words.

Each overlaid program and its subroutines are listed on the following pages. For each program or subroutine, the required number of octal words of storage and an explanation of the function are presented. A dictionary of FORTRAN variables used was given in a previous section. A flow chart showing the logic flow and the interrelation of the various programs and subroutines is shown in figure 3.

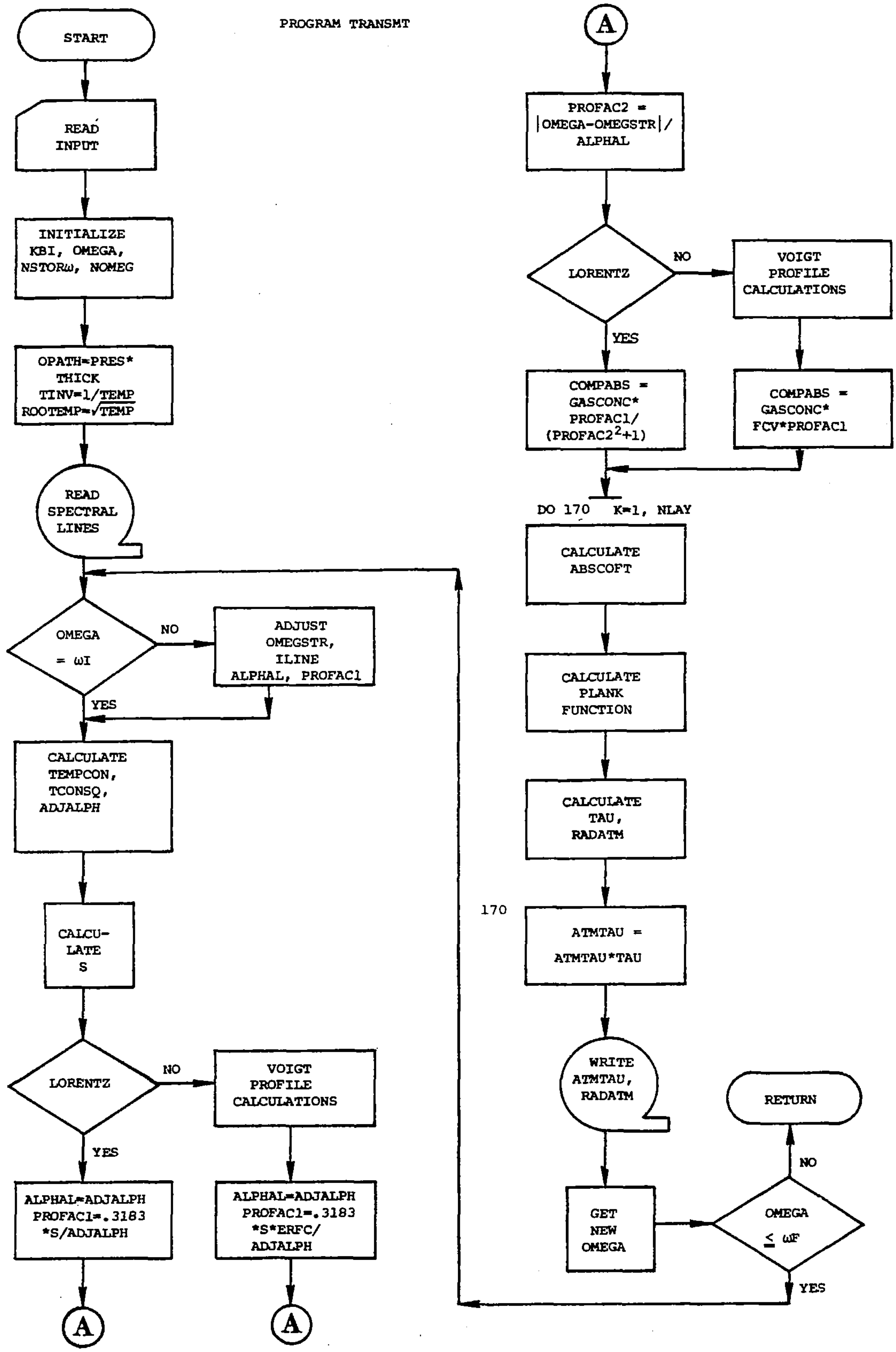

Figure 3. Flowchart of SMART program.

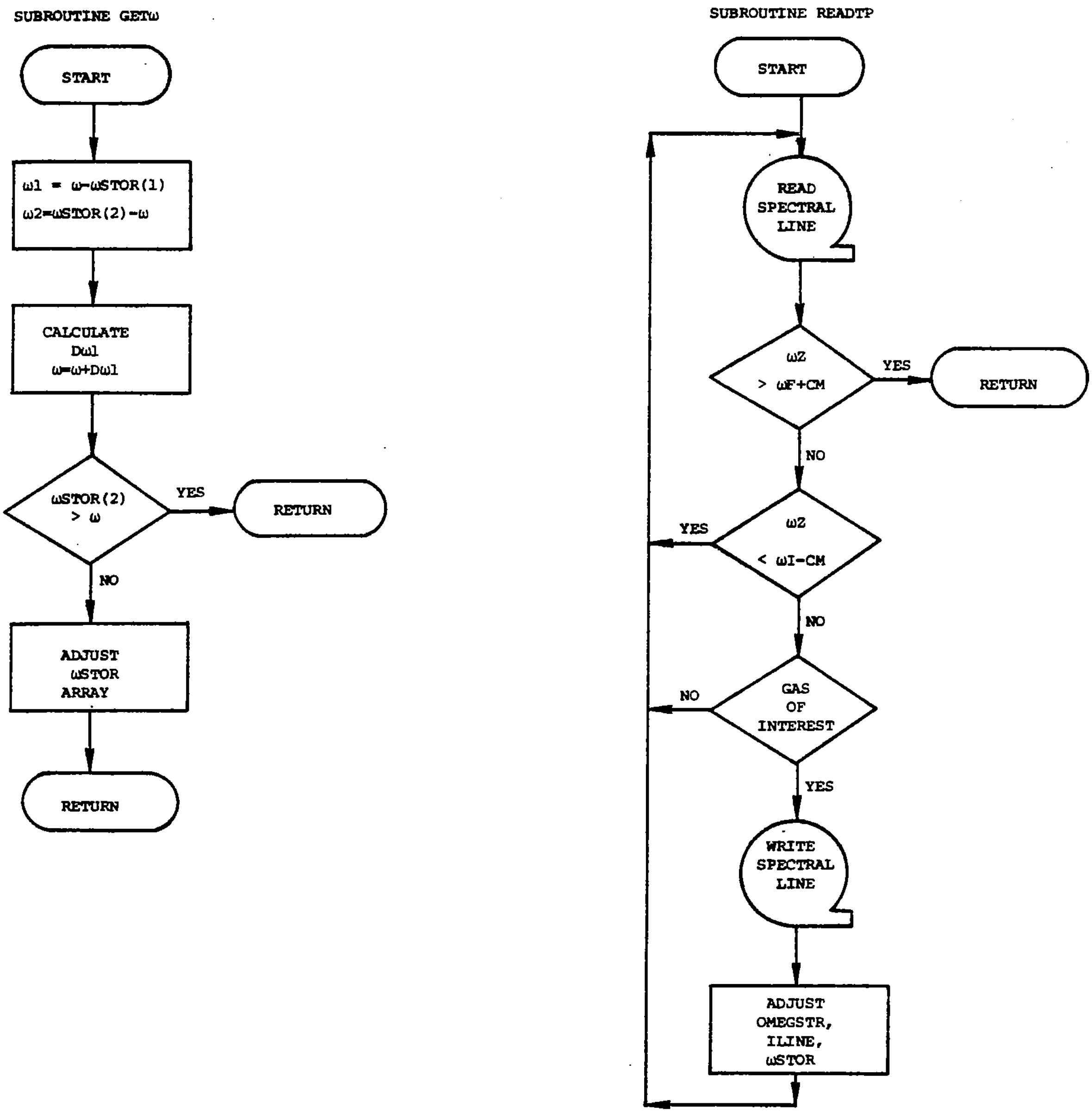

Figure 3. Flowchart of SMART program (continued).

PROGRAM SRTGFCA

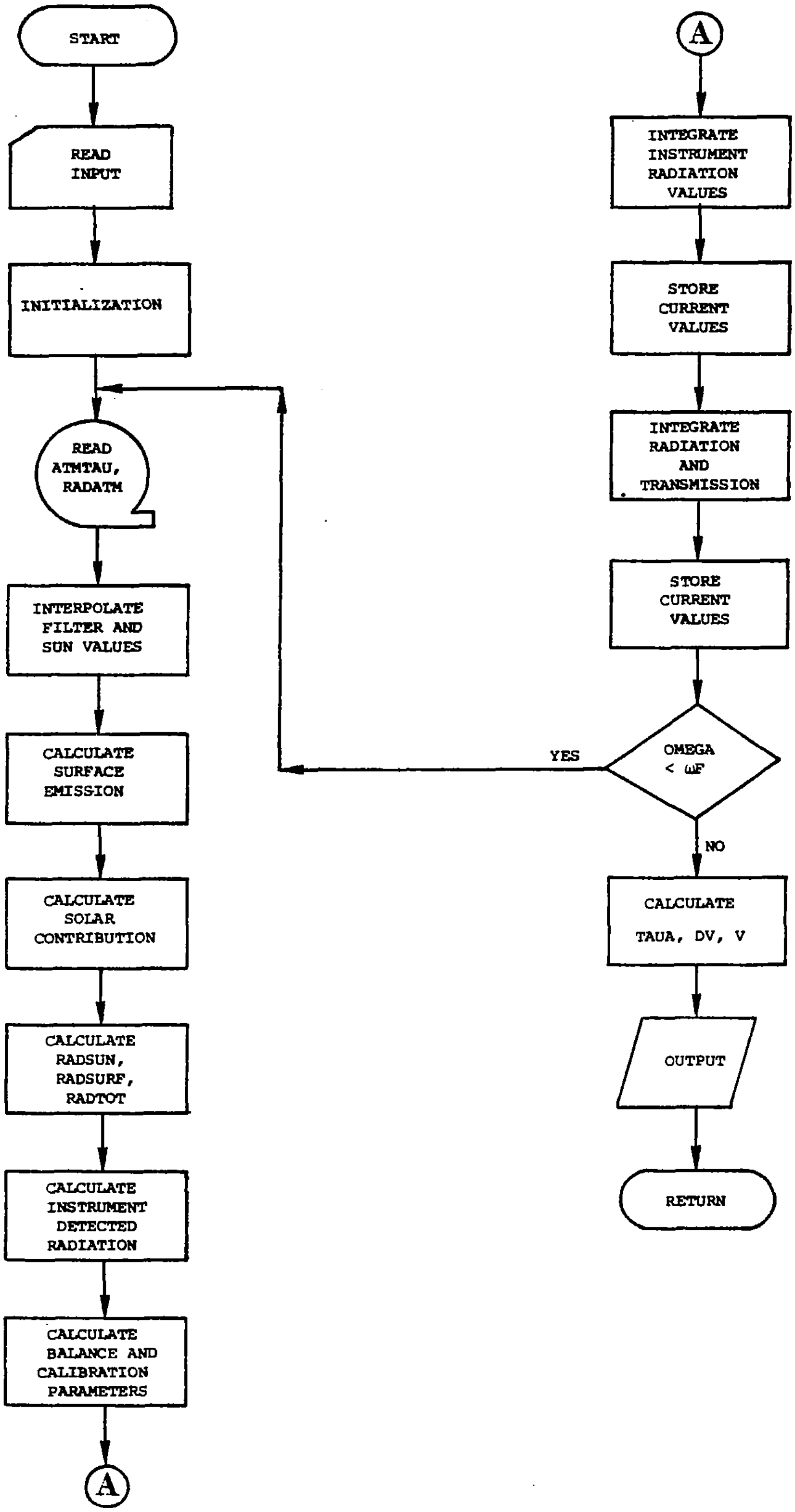

Figure 3. Flowchart of SMART program (continued).

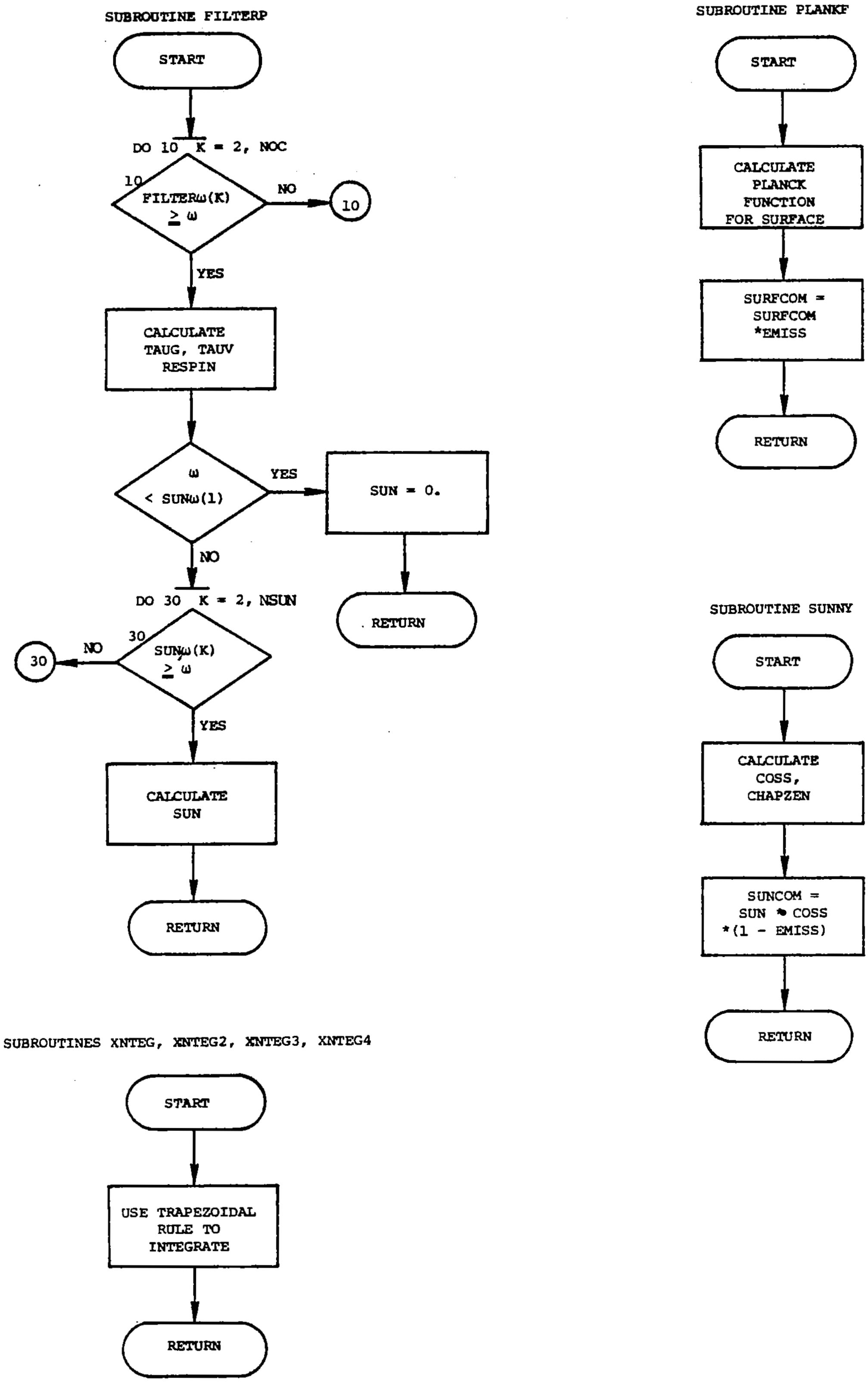

Figure 3. Flowchart of SMART program (concluded).

PROGRAM SMART

SMART, the program executive, has two main functions. First, it supervises the execution of the two lower level overlays. Second, storage for each array and program constant, which is common to each overlay, is set aside. The storage required, i.e., program length + buffer length + labeled common length + blank common length, is 13241_8 .

```
      OVERLAY(MAIN,0,0)
      PROGRAM SMART(INPUT,OUTPUT,TAPE7,TAPE2,TAPE6)
C *** THIS PROGRAM PERFORMS LINE-BY-LINE RADIATIVE TRANSFER CALCULATIONS FOR
C     NON-HOMOGENEOUS ATMOSPHERIC MODELS AS A FUNCTION OF ALTITUDE
C *** THE SECOND SECTION SIMULATES THE RESPONSE OF THE GAS FILTER CORRELATION
C     INSTRUMENT AT THE VARIOUS ALTITUDES ***
      COMMON/AB/TEMP(17),PRES(17),THICK(17),OPATH(17),GASCONC(20,17),
     1          IDENT(20),XMULT(10),JPROF(17)
      COMMON/AA/NXM,NLAY,NLAYI,NOC,KBI,NSPEC,DELTAW,CMINV,IPOLLUT,
     1          BROAD,WI,WF
      CALL OVERLAY(4HMAIN,1,0)
      REWIND 6
      CALL OVERLAY(4HMAIN,2,0)
      STOP
      END
```

PROGRAM TRANSMT

TRANSMT is the first overlay subordinate to SMART. TRANSMT reads the atmospheric profile information and the integration processing parameters from cards. From the spectral line parameter tape, wavenumbers, half-widths, intensities, energies of the lower state, and identification species numbers are read. For our calculations, McClatchey's spectral line parameter tape (ref. 5) was used with appropriate unit conversions applied. TRANSMT performs line-by-line radiative transfer calculations and writes on temporary storage disk 6 center wavenumber, transmittance, and radiance as a function of altitude and primary gas concentration. Storage required is 112274_8 .

```
      OVERLAY(MAIN,1,0)
      PROGRAM TRANSMT
      DIMENSION REFTEMP(30),ALPHAL(300,17),PROFAC1(300,17),
     1          PROFAC2(300,17),TAU(10),COMPABS(300,17),TINV(17),
     1          ROOTEMP(17),ATMTAU(17,10),RADATM(17,10),
     2          ALPHAV(300,17),RATLV(300,17),ALPHAD(300,17)
      REAL MOLWT(20),MOLWTIS
      COMMON/AB/TEMP(17),PRES(17),THICK(17),OPATH(17),GASCONC(20,17),
     1          IDENT(20),XMULT(10),JPROF(17)
      COMMON/AA/NXM,NLAY,NLAYI,NOC,KBI,NSPEC,DELTAW,CMINV,IPOLLUT,
     1          BROAD,WI,WF
      COMMON WSTOR(300),OMEGSTR(300),ILINE(300)
      DATA C7/1.1906E-12/,C8/1.439/,C9/6.7675E-8/,C10/109./,NSUN/41/
      DATA (REFTEMP=30*296.)
      DATA(MOLWT=28.,18.,64.,17.,16.,44.,44.,28.,17.,30.,46.,4*44.,64.,
     1           46.,44.,17.,30.)
C ***INPUT PARAMETERS READ FROM CARDS ***
      READ 1010, NLAY,NLAYI,NOC,NXM,NSPEC,IDENT
 1010 FORMAT(5I5,5X,20I2)
      READ 1020,(JPROF(K),K=1,NLAY)
 1020 FORMAT(40I2)
      READ 1030, WI,WF,DELTAW,CMINV,IPOLLUT,BROAD
 1030 FORMAT(4F10.4,I5,F10.4)
      READ 1040, (XMULT(J),J=1,NXM)
 1040 FORMAT(8F10.4)
      READ 1050, (TEMP(J),PRES(J),THICK(J),J=1,NLAY)
 1050 FORMAT(3F10.4)
      READ 1060, ((GASCONC(J,K),J=1,16),K=1,NLAY)
 1060 FORMAT(8E10.3)
C *** INITIALIZATION ***
      KBI=NLAY-2*NLAYI
      OMEGA=WI
      DW1=0.
      NSTORW=NOMEG=0
      I=0
```

```
      DO 10 K=1,NLAY
        OPATH(K)=PRES(K)* THICK(K)
        TINV(K)=1./TEMP(K)
        ROOTEMP(K)=SQRT(TEMP(K))
        BRDFAC=(BROAD-1.)*GASCONC(IPOLLUT,K)+1.
        IF (NLAY.EQ.1) PRES(K)=PRES(K)*BRDFAC
        IF (K.GT.KBI) PRES(K)=PRES(K)*BRDFAC
   10 CONTINUE
C *** READ SPECTRAL LINE PARAMETER TAPE FOR ALL LINES INCLUDED IN WI-CMINV TO
C     WF +CMINV ***
      CALL READTP(WI,CMINV,WF,IDENT,NSTORW,NOMEG)
   20 W3=OMEGA *OMEGA *OMEGA
C *** DETERMINE SPECTRAL LINES TO BE INCLUDED IN SUBINTERVAL OF INTEGRATION
C     AND ADJUST CORRESPONDING LINE PARAMETERS ***
      IF (OMEGA .EQ. WI) GO TO 50
      IF (OMEGSTR(1) .GE. (OMEGA-CMINV)) GO TO 45
      DO 25 K=2,NOMEG
        IPOINT=K
        IF (OMEGSTR(K) .GE. (OMEGA-CMINV)) GO TO 30
   25 CONTINUE
   30 NOMEG=NOMEG -IPOINT +1
      I=I -IPOINT +1
      DO 35 J=1,NOMEG
        ILINE(J)=ILINE(J +IPOINT-1)
        OMEGSTR(J)=OMEGSTR(J +IPOINT-1)
   35 CONTINUE
      DO 40 K=1,NLAY
       DO 40 J=1,NOMEG
        ALPHAL(J,K)=ALPHAL(J +IPOINT-1,K)
        PROFAC1(J,K)=PROFAC1(J +IPOINT-1,K)
        IF (JPROF(K).EQ.1) GO TO 40
        RATLV(J,K)=RATLV(J+IPOINT-1,K)
   40 CONTINUE
   45 IF (WZ .GT. (OMEGA +CMINV)) GO TO 100
      GO TO 65
   50 I=0
C *** READ SPECTRAL LINES FOR SUBINTERVAL OF INTEGRATION ***
      REWIND 2
   55 READ(2,1000) WZ,ALPHA,SZ,EL,IS
 1000 FORMAT(F10.4,F5.3,E15.8,F12.4,I2)
      IF (EOF(2)) 100,60
   60 IF (WZ .GT. (OMEGA +CMINV)) GO TO 100
   65 I=I+1
      IF (OMEGA .EQ. WI) GO TO 70
      NOMEG=NOMEG +1
      OMEGSTR(NOMEG)=WZ
      ILINE(NOMEG)=IS
      NSTORW=NSTORW +1
      WSTOR(NSTORW) =WZ
C *** DETERMINE LINE PROFILE PARAMETERS AND ADJUST FOR LAYER TERPERATURE ***
   70 DO 95 K=1,NLAY
        TEMPCON=REFTEMP(IS) *TINV(K)
        TCONSQ=TEMPCON *TEMPCON
        IF (IS .EQ. 2) TCONSQ= TCONSQ *SQRT(TEMPCON)
        ADJALPH=ALPHA *PRES(K)* SQRT(TEMPCON)
        S=SZ *TCONSQ *EXP(-C8 *(TEMPCON -1.) * EL/REFTEMP(IS))
        IF (JPROF(K).EQ.1) GO TO 85
        MOLWTIS=MOLWT(IS)
        ALPHAD(I,K)=C9*WZ*ROOTEMP(K)*SQRT(28./MOLWTIS)
        TSTALPH=ADJALPH/ALPHAD(I,K)
        ALPHAV(I,K)=.53431*ADJALPH+SQRT(.21687*ADJALPH*ADJALPH
     1            + ALPHAD(I,K)*ALPHAD(I,K))
        VGTPAR=.83255*ADJALPH/ALPHAD(I,K)
        VGTPAR2=1./(VGTPAR*VGTPAR)
        RATLV(I,K)=1./(1.+ADJALPH*VGTPAR2/ALPHAV(I,K))
        IF (VGTPAR.LT.1.5) GO TO 75
        VGTPAR4=VGTPAR2*VGTPAR2
        ERFC=(1.+4.5*VGTPAR2+2.*VGTPAR4)/(1.+5.*VGTPAR2
     1    + 3.75*VGTPAR4)
        GO TO 80
   75   TERFC=1./(1.+.47047*VGTPAR)
        TERFC2=TERFC*TERFC
        ERFC=VGTPAR*TERFC*(.61686-.16994*TERFC+1.32554*TERFC2)
```

```
   80   CONTINUE
   85   ALPHAL(I,K)= ADJALPH
        IF (JPROF(K).EQ.2) GO TO 90
        PROFAC1(I,K)= .3183 *S/ADJALPH
        GO TO 95
   90   PROFAC1(I,K)=.3183*S*ERFC/ADJALPH
   95 CONTINUE
      GO TO 55
C *** CALCULATE ABSORPTION COEFFIENT AS DETERMINED BY LINE PROFILE ***
  100 DO 120 K=1,NLAY
       DO 120 J=1,NOMEG
        PROFAC2(J,K)=ABS(OMEGA- OMEGSTR(J))/ALPHAL(J,K)
        IF (JPROF(K).EQ.1) GO TO 115
        WRATLV=RATLV(I,K)
        WRATLV1=1.-WRATLV
        FCL=1./(1.+(PROFAC2(J,K)*PROFAC2(J,K)))
        TSTPROF=ALPHAL(J,K)/ALPHAD(J,K)
        IF (TSTPROF.GT.1) GO TO 105
        EXPTST=-.693147*PROFAC2(J,K)*PROFAC2(J,K)
        IF (EXPTST.LT.-675.84) GO TO 105
        FCD=EXP(EXPTST)
        GO TO 110
  105   FCD=0.
  110   FCERR=((.8029/PROFAC2(J,K))-(.4207*PROFAC2(J,K)))/
     1       ((1./PROFAC2(J,K)) + (PROFAC2(J,K)*PROFAC2(J,K))*
     2(.2030 + (.07355*(PROFAC2(J,K)*PROFAC2(J,K)))))
        FCV=WRATLV1*FCD+WRATLV*FCL+
     1    WRATLV*WRATLV1*FCERR*(FCL - FCD)
        COMPABS(J,K)=GASCONC(ILINE(J),K)*FCV*PROFAC1(J,K)
        GO TO 120
  115   CONTINUE
        COMPABS(J,K)=GASCONC(ILINE(J),K)*PROFAC1(J,K)/(1.+PROFAC2(J,K)*
     1    PROFAC2(J,K))
  120 CONTINUE
      DO 125 K=1,NLAY
      DO 125 J=1,NXM
       RADATM(K,J)=0.
       ATMTAU(K,J)=1.
  125 CONTINUE
      DO 170 K=1,NLAY
      IF (K.EQ.1) GO TO 135
      DO 130 J=1,NXM
       ATMTAU(K,J)=ATMTAU(K-1,J)
       RADATM(K,J)=RADATM(K-1,J)
  130 CONTINUE
  135 ABSCOF2=ABSCOF1=0.
      IF (K.LE.KBI) GO TO 145
      DO 140 J=1,NXM
       ATMTAU(K,J)=1.
       RADATM(K,J)=0.
  140 CONTINUE
  145  DO 160 L=1,NOMEG
         IF (ILINE(L) .EQ. IPOLLUT) GO TO 150
         ABSCOF2= ABSCOF2 + COMPABS(L,K)
         GO TO 155
  150    ABSCOF1=ABSCOF1 +COMPABS(L,K)
  155    CONTINUE
  160 CONTINUE
       PLANCK=C7*W3/(EXP(C8*OMEGA/TEMP(K))-1.)
       ABSCOFT=ABSCOF1 +ABSCOF2
C *** CALCULATE MONOCHROMATIC ATMOSPHERIC TRANSMITTANCE AND EMISSION AND WRITE
C     RESULTS ON DISC 6 ***
        DO 165 J=1,NXM
         IF (K.LE.KBI) ABSCOFT= ABSCOF1 *XMULT(J) +ABSCOF2
         TAU(J)= EXP(-ABSCOFT *OPATH(K))
         RADATM(K,J)=RADATM(K,J)*TAU(J)+PLANCK*(1.-TAU(J))
         ATMTAU(K,J)=ATMTAU(K,J)*TAU(J)
  165   CONTINUE
  170 CONTINUE
      WRITE(6)OMEGA,((ATMTAU(K,J),J=1,NXM),K=1,NLAY),((RADATM(K,J),
     1            J=1,NXM),K=1,NLAY),DW1
C *** CALCULATE NEW OMEGA ***
      CALL GETW(OMEGA,DELTAW,NSTORW,DW1)
      IF (OMEGA .LE. WF) GO TO 20
      RETURN
      END
```

SUBROUTINE GETW

GETW is a subroutine of TRANSMT. GETW determines the wavenumber mesh for integration. The algorithm 1) determines the distance from OMEGA to the closest spectral line, 2) calculates 1/4 of that distance, 3) determines the maximum (DW) between DWMIN and the value calculated in step 2, and 4) sets the new integration point equal to OMEGA plus DW. The minimum integration stepping size is read in TRANSMT. Storage required is 1644_8 .

```
      SUBROUTINE GETW(W,DW,NSTORW,DW1)
C *** DETERMINE THE WAVENUMBER MESH FOR INTEGRATION ***
      COMMON WSTOR(300),OMEGSTR(300),ILINE(300)
      W1=W-WSTOR(1)
      W2=WSTOR(2)-W
      DW1=AMAX1(AMIN1(W1,W2)*.25,DW)
      W=W +DW1
      IF (WSTOR(2) .GT. W) RETURN
      K=3
    5 IF (WSTOR(K).GT.W) GO TO 10
      K=K+1
      GO TO 5
   10 NSTORW=NSTORW-K+2
      DO 15 J=1,NSTORW
   15 WSTOR(J)=WSTOR(J+K-2)
      RETURN
      END
```

SUBROUTINE READTP

READTP is a subroutine of TRANSMT. READTP reads the spectral line parameter tape for all lines in the interval WI - CMINV to WF + CMINV and writes them on temporary storage disk 2. Storage required is 2000_8 .

```
              SUBROUTINE READTP(WI,CM,WF,IDENT,K,L)
      C ***   READ SPECTRAL LINE PARAMETER TAPE FOR ALL LINES FROM WI-CMINV TO WF +
      C       CMINV
      C       VARIABLES INCLUDE LINE LOCATION (WZ),HALF-WIDTH (BL),LINE STRENGTH (S),
      C       GROUND STATE ENERGY (E),SPECIES IDENTIFICATION NUMBER (IS) ***
              DIMENSION IDENT(20)
              COMMON WSTOR(300),OMEGSTR(300),ILINE(300)
              REWIND 2
              K=1
              L=0
            5 READ(7,1000) WZ,BL,S,E,IS
              IF (WZ .GT. (WF +CM)) GO TO 25
              IF (WZ .LT. (WI- CM)) GO TO 5
              DO 10 J= 1,16
                IF (IDENT(J) .EQ. IS) GO TO 15
           10 CONTINUE
              GO TO 5
           15 WRITE(2,1000) WZ,BL,S,E,IS
              PRINT 1010, WZ,BL,S,E,IS
         1010 FORMAT(1H ,F10.4,1X,F5.3,1X,E15.8,1X,F12.4,1X,I2)
              IF (WZ .LT. WI) WSTOR(1)=WZ
              IF (WZ .GT. (WI +CM)) GO TO 5
              L= L+1
              ILINE(L)=IS
              OMEGSTR(L)= WZ
           20 IF (WZ.LT.WI) GO TO 5
              K=K +1
              WSTOR(K) =WZ
              GO TO 5
         1000 FORMAT(F10.4,F5.3,E15.8,F12.4,I2)
           25 WRITE(2,1000)WZ,BL,S,E,IS
              RETURN
              END
```

PROGRAM SRTGFCA

SRTGFCA is the second overlay subordinate to SMART. SRTGFCA reads from cards surface tèmperatures and emissivities, and optical and thermal parameters as required for instrument simulation. SRTGFCA reads from temporary storage disk 6 the transmittance and radiance calculations performed by TRANSMT, and computes instrument response parameters. It is again emphasized that any infrared instrument requiring atmospheric transmittance and radiance information as input may be substituted for SRTGFCA. Storage required is 27342_8 .

```
      OVERLAY(MAIN,2,0)
      PROGRAM SRTGFCA
      DIMENSION ATMTAU(17,10),RADATM(17,10),RADSUN(10,2,10),TAUSLAT(10),
     1          SUNCOM(10),RADSURF(100,2,2),SURFCOM(10,10),
     2          RADTOT(100,2,2),SUNW(41),SUNFLUX(41),CONC1(10),
     3          CONC(10),ID(10)
      DIMENSION PLANK(10),BLCKIN(10),VACBNEW(10),GASBNEW(10),BBHNEW(10),
     1          GASANEW(100,2,2),VACANEW(100,2,2),GASENEW(100,2,2),
     2          BBCNEW(10),BBHOT(10),BBCOLD1(10),BBHNEWG(10),BBCNEWG(10)
     3          ,BBHNEWC(10),BBCNEWC(10),BBHNEWV(10),BBCNEWV(10),
     4          BBHOLD(10),BBCOLD(10),BBHOLDG(10),BBCOLDG(10),
     5          BBHOLDC(10),BBCOLDC(10),VACBOLD(10),GASBOLD(10),
     6          GASAOLD(100,2,2),VACAOLD(100,2,2),GASEOLD(100,2,2),
     7          RADHOT(10),RADCOLD(10),RADHOTG(10),RADCOLG(10),
     8          RADHOTC(10),RADCOLC(10),RADVACB(10),RADGASB(10),
     9          RADGASA(100,2,2),RADVACA(100,2,2),RADGASE(100,2,2),
     A          BBHOLDV(10),BBCOLDV(10),RADHOTV(10),RADCOLV(10)
      DIMENSION TOTSUN(10,2,10),TOTSURF(100,2,2),RADSUNO(10,2,10),
     1          TOTRAD(100,2,2),RADSOLD(100,2,2),RADOLD(17,10),
     2          RADOTOT(100,2,2),TAUOLD(17,10),TRANS(17,10),TOTATM(17,10
     3          ),GBALDIF(10),VBALDIF(10),TAUA(10),SIGBV(10),
     4          GCLTAIN(10),ERRDN(10),SIGAV(100,2,2),DV(100,2,2),
     5          GCLTAAT(100,2,2),V(100,2,2)
      COMMON/AB/TEMP(17),PRES(17),THICK(17),OPATH(17),GASCONC(20,17),
     1          IDENT(20),XMULT(10),JPROF(17)
      COMMON/AA/NXM,NLAY,NLAYI,NOC,KBI,NSPEC,DELTAW,CMINV,IPOLLUT,
     1          BROAD,WI,WF
      COMMON/CA/RESPG(35),FILTERW(35),RESPV(35),RESP(35)
      COMMON/CB/EMISS(10),TSURF(10)
      DATA(SUNW=1941.75,1980.20,2020.20,2061.86,2105.26,2150.54,2197.80,
     1          2247.19,2298.85,2352.94,2409.64,2469.14,2531.64,2597.40,
     2          2666.67,2739.73,2816.90,2898.55,2985.07,3076.92,3174.60,
     3          3278.69,3389.83,3508.77,3636.36,3773.58,3921.57,4081.63,
     4          4255.32,4444.44,4651.16,4878.05,5128.21,5405.41,5714.29,
     5          6060.61,6451.61,6896.55,7407.41,8000.00,8695.65)
      DATA(SUNFLUX=.274E-6,.284E-6,.296E-6,.307E-6,.323E-6,.330E-6,
     1              .343E-6,.359E-6,.362E-6,.391E-6,.411E-6,.439E-6,
     2              .462E-6,.481E-6,.501E-6,.526E-6,.554E-6,.580E-6,
     3              .607E-6,.639E-6,.673E-6,.708E-6,.748E-6,.789E-6,
     4              .835E-6,.883E-6,.938E-6,.995E-6,1.058E-6,1.128E-6,
     5              1.204E-6,1.286E-6,1.376E-6,1.474E-6,1.581E-6,
     6              1.699E-6,1.826E-6,1.964E-6,2.110E-6,2.250E-6,
```

```
     7                2.322E-6)
      DATA C7/1.1906E-12/,C8/1.439/,C9/6.7675E-8/,C10/109./,NSUN/41/
      READ 1080,NEMIS,NSURF,NOC,ZENITH
 1080 FORMAT(3I5,F10.3)
      READ 1090,(TSURF(J),J=1,NSURF)
 1090 FORMAT(8E10.3)
      READ 1090,(EMISS(J),J=1,NEMIS)
      READ 1100,(FILTERW(J),RESPV(J),RESPG(J),RESP(J),J=1,NOC)
 1100 FORMAT(F10.3,F10.6,F10.6,F10.3)
      READ 1090,(BLCKIN(K),K=1,NLAYI)
      READ 1090,(BBHOT(K),BBCOLD1(K),K=1,NLAYI)
      READ 1090, EMISBB
      IF ((WI.LT.FILTERW(1)).OR.(WF.GT.FILTERW(NOC))) GO TO 500
      JCOUNT=0
      DO 5 K=1,NLAY
      DO 5 J=1,NXM
        RADATM(K,J)=TRANS(K,J)=TOTATM(K,J)=0.
    5 CONTINUE
      DO 10 K=1,NLAYI
       RADHOT(K)=RADCOLD(K)=RADHOTG(K)=RADCOLG(K)=RADHOTC(K)=RADCOLC(K)=
     1  RADVACB(K)=RADGASB(K)=RADHOTV(K)=RADCOLV(K)=0.
   10 CONTINUE
      DO 15 K=1,NLAY
       DO 15 L=1,NEMIS
       DO 15 M=1,NSURF
       DO 15 J=1,NXM
        TOTSUN(K,L,J)=0.
        JJ=J+(K-1)*10
        RADGASA(JJ,L,M)=RADVACA(JJ,L,M)=RADGASE(JJ,L,M)=0.
        TOTRAD(JJ,L,M)=TOTSURF(JJ,L,M)=0.
   15 CONTINUE
C *** READ DISC 6 ***
   20 READ(6)OMEGA,((ATMTAU(K,J),J=1,NXM),K=1,NLAY),((RADATM(K,J),
     1             J=1,NXM),K=1,NLAY),DW1
      IF (EOF(6)) 185,25
   25 JCOUNT=JCOUNT+1
C *** INTERPOLATE WAVENUMBER DEPENDENT INPUT VALUES ***
      CALL FILTERP(OMEGA,TAUVFIL,TAUGFIL,SUNINTP,NOC,NSUN,SUNW,SUNFLUX,
     1RESPIN)
C ***CALCULATE UNATTENUATED SURFACE EMISSION ***
      CALL PLANKF(OMEGA,SURFCOM,NEMIS,NSURF)
C *** CALCULATE UNATTENUATED SOLAR RADIATION REFLECTED BY THE EARTH SURFACE ***
      IF (ZENITH.GE.90.) GO TO 30
      CALL SUNNY(OMEGA,NEMIS,SUNCOM,ZENITH,SUNINTP,CHAPZEN)
      GO TO 40
   30 CHAPZEN=0.
      DO 35 L=1,NEMIS
   35  SUNCOM(L)=0.
C *** CALCULATE TOTAL ATTENUATED RADIATION AT THE TOP OF EACH ATMOSPHERIC
C     LAYER ***
   40 DO 130 K=1,KBI
       DO 130 L=1,NEMIS
        DO 130 M=1,NSURF
         DO 130 J=1,NXM
          JJ=J+(K-1)*10
          TAUSLAT(J)=ATMTAU(KBI,J)**CHAPZEN
          RADSUN(K,L,J)=SUNCOM(L) *TAUSLAT(J)* ATMTAU(K,J)
          RADSURF(JJ,L,M)=SURFCOM(L,M)* ATMTAU(K,J)
          RADTOT(JJ,L,M)=RADATM(K,J) + RADSURF(JJ,L,M) + RADSUN(K,L,J)
  130  CONTINUE
      IF (NLAYI.EQ.0) GO TO 160
      W3= OMEGA *OMEGA *OMEGA
C *** CALCULATE INSTRUMENT DETECTED RADIATION ***
      DO 140 K=1,NLAYI
      PLANK(K) =C7 *W3/(EXP(C8 *OMEGA/BLCKIN(K))-1.) *EMISBB
      VACBNEW(K) =PLANK(K)*TAUVFIL *RESPIN
      GASBNEW(K) =PLANK(K)*ATMTAU(K +KBI,1) *TAUGFIL *RESPIN
       DO 135 L=1,NEMIS
        DO 135 M=1,NSURF
         DO 135 J=1,NXM
```

```
          JJ=J +(K-1) *10
          GASANEW(JJ,L,M)=RADTOT(JJ,L,M) *ATMTAU(K+KBI,1) *TAUGFIL*RESPIN
          VACANEW(JJ,L,M)=RADTOT(JJ,L,M) *TAUVFIL *RESPIN
          GASENEW(JJ,L,M)=(RADTOT(JJ,L,M) *ATMTAU(K+KBI,1) +RADATM(K+KBI,
     1         1)) *TAUGFIL*RESPIN
  135  CONTINUE
C *** CALCULATE BALANCE AND CALIBRATION PARAMETERS ***
      BBHNEW(K)=(C7 *W3/(EXP(C8 *OMEGA/BBHOT(K))-1.)) *TAUVFIL *RESPIN
      BBCNEW(K)=(C7 *W3/(EXP(C8 *OMEGA/BBCOLD1(K))-1.)) *TAUVFIL*RESPIN
      BBHNEWG(K)=(C7*W3/(EXP(C8*OMEGA/BBHOT(K))-1.))*ATMTAU(K+KBI,1)*
     1 TAUGFIL*RESPIN
      BBCNEWG(K)=(C7*W3/(EXP(C8*OMEGA/BBCOLD1(K))-1.))*ATMTAU(K+KBI,1)*
     1 TAUGFIL*RESPIN
      BBHNEWC(K)=BBHNEWG(K)*ATMTAU(K+KBI+NLAYI,1)+(RADATM(K+KBI+NLAYI,1)
     *            *TAUGFIL*RESPIN)*ATMTAU(K+KBI,1)
      BBCNEWC(K)=BBCNEWG(K)*ATMTAU(K+KBI+NLAYI,1)+(RADATM(K+KBI+NLAYI,1)
     *            *TAUGFIL*RESPIN)*ATMTAU(K+KBI,1)
      BBHNEWV(K)=BBHNEW(K)*ATMTAU(K+KBI+NLAYI,1)+(RADATM(K+KBI+NLAYI,1)
     *            *TAUVFIL*RESPIN)
      BBCNEWV(K)=BBCNEW(K)*ATMTAU(K+KBI+NLAYI,1)+(RADATM(K+KBI+NLAYI,1)
     *            *TAUVFIL*RESPIN)
  140 CONTINUE
      IF (OMEGA.EQ.WI) GO TO 145
C *** INTEGRATE INSTRUMENT RADIATION VALUES ***
      CALL XNTEG(DW1,BBHNEW,BBHOLD,RADHOT,NLAYI)
      CALL XNTEG(DW1,BBCNEW,BBCOLD,RADCOLD,NLAYI)
      CALL XNTEG(DW1,BBHNEWG,BBHOLDG,RADHOTG,NLAYI)
      CALL XNTEG(DW1,BBCNEWG,BBCOLDG,RADCOLG,NLAYI)
      CALL XNTEG(DW1,BBHNEWC,BBHOLDC,RADHOTC,NLAYI)
      CALL XNTEG(DW1,BBCNEWC,BBCOLDC,RADCOLC,NLAYI)
      CALL XNTEG(DW1,VACBNEW,VACBOLD,RADVACB,NLAYI)
      CALL XNTEG(DW1,GASBNEW,GASBOLD,RADGASB,NLAYI)
      CALL XNTEG(DW1,BBHNEWV,BBHOLDV,RADHOTV,NLAYI)
      CALL XNTEG(DW1,BBCNEWV,BBCOLDV,RADCOLV,NLAYI)
      CALL XNTEG2(DW1,GASANEW,GASAOLD,RADGASA,NLAYI,NEMIS,NSURF,NXM)
      CALL XNTEG2(DW1,VACANEW,VACAOLD,RADVACA,NLAYI,NEMIS,NSURF,NXM)
      CALL XNTEG2(DW1,GASENEW,GASEOLD,RADGASE,NLAYI,NEMIS,NSURF,NXM)
C *** STORE CURRENT INSTRUMENT RADIATION VALUES FOR INTEGRATION PURPOSES ***
  145 DO 155 K=1,NLAYI
       BBHOLD(K)=BBHNEW(K)
       BBCOLD(K)=BBCNEW(K)
       BBHOLDG(K)=BBHNEWG(K)
       BBCOLDG(K)=BBCNEWG(K)
       BBHOLDC(K)=BBHNEWC(K)
       BBCOLDC(K)=BBCNEWC(K)
       BBHOLDV(K)=BBHNEWV(K)
       BBCOLDV(K)=BBCNEWV(K)
       VACBOLD(K)=VACBNEW(K)
       GASBOLD(K)=GASBNEW(K)
        DO 150 L=1,NEMIS
         DO 150 M=1,NSURF
          DO 150 J=1,NXM
           JJ= J+(K-1) *10
           GASAOLD(JJ,L,M)=GASANEW(JJ,L,M)
           VACAOLD(JJ,L,M)=VACANEW(JJ,L,M)
           GASEOLD(JJ,L,M)=GASENEW(JJ,L,M)
  150   CONTINUE
  155 CONTINUE
  160 IF (OMEGA.EQ.WI) GO TO 165
C *** INTEGRATE ATMOSPHERIC RADIATION AND TRANSMITTANCE AND INSTRUMENT
C     TRANSMITTANCE ***
      CALL XNTEG3(DW1,ATMTAU,TAUOLD,TRANS,NLAY,NXM)
      CALL XNTEG3(DW1,RADATM,RADOLD,TOTATM,NLAY,NXM)
      CALL XNTEG2(DW1,RADTOT,RADOTOT,TOTRAD,KBI ,NEMIS,NSURF,NXM)
      CALL XNTEG2(DW1,RADSURF,RADSOLD,TOTSURF,KBI ,NEMIS,NSURF,NXM)
      CALL XNTEG4(DW1,RADSUN,RADSUNO,TOTSUN,KBI ,NEMIS,NXM)
C *** STORE CURRENT TRANSMISSION AND ATMOSPHERIC RADIATION VALUES FOR
C     INTEGRATION PURPOSES ***
  165 DO 170 K=1,NLAY
       DO 170 J=1,NXM
```

```
      TAUOLD(K,J)=ATMTAU(K,J)
      RADOLD(K,J)=RADATM(K,J)
  170 CONTINUE
      DO 180 K=1,KBI
       DO 175 L=1,NEMIS
        DO 175 M=1,NSURF
         DO 175 J=1,NXM
         JJ=J+(K-1)*10
         RADOTOT(JJ,L,M)=RADTOT(JJ,L,M)
         RADSOLD(JJ,L,M)=RADSURF(JJ,L,M)
         RADSUNO(K,L,J)=RADSUN(K,L,J)
  175  CONTINUE
  180 CONTINUE
      GO TO 20
C *** CALCULATE INSTRUMENT OUTPUT RESPONSE PARAMETERS ***
  185 IF (NLAYI.EQ.0) GO TO 200
      DO 195 K=1,NLAYI
      GBALDIF(K)=RADHOTG(K)-RADCOLG(K)
      VBALDIF(K)=RADHOJ(K)-RADCOLD(K)
      TAUA(K)=GBALDIF(K)/VBALDIF(K)
      SIGBV(K)=RADVACB(K)* TAUA(K)
      GCLTAIN(K)=RADGASB(K)/RADVACB(K)
      ERRDN(K)=RADGASB(K)-TAUA(K)* RADVACB(K)
       DO 190 L=1,NEMIS
        DO 190 M=1,NSURF
         DO 190 J=1,NXM
         JJ=J+ (K-1)* 10
         SIGAV(JJ,L,M)=RADVACA(JJ,L,M)* TAUA(K)
         DV(JJ,L,M)=RADGASA(JJ,L,M)- SIGAV(JJ,L,M)
         GCLTAAT(JJ,L,M)=RADGASA(JJ,L,M)/RADVACA(JJ,L,M)
         V(JJ,L,M)=(RADGASA(JJ,L,M) + SIGAV(JJ,L,M))/2.
  190  CONTINUE
  195 CONTINUE
C *** OUTPUT ***
 200  J=0
      DO 250 LL=1,16
       IF (IDENT(LL).EQ. 0) GO TO 250
       J=J+1
       IF (IDENT(LL).EQ. 1) ID(J)=2HCO
       IF (IDENT(LL).EQ. 2) ID(J)=3HH2O
       IF (IDENT(LL).EQ. 7) ID(J)=3HN2O
       IF (IDENT(LL).EQ.12) ID(J)=3HCO2
  250 CONTINUE
      IF (IPOLLUT.EQ.1) IPOLT=2HCO
      IF (IPOLLUT.EQ.2) IPOLT=3HH2O
      IF (IPOLLUT.EQ.3) IPOLT=3HSO2
      IF (IPOLLUT.EQ.4) IPOLT=3HNH3
      IF (IPOLLUT.EQ.5) IPOLT=3HCH4
      IF (IPOLLUT.EQ.7) IPOLT=3HN2O
      IF (IPOLLUT.EQ.12) IPOLT=3HCO2
      C= 2.*CMINV
      DIST=WF-WI
      DO 255 K=1,NLAY
      DO 255 J=1,NXM
      TRANS(K,J)=TRANS(K,J)/DIST
  255 CONTINUE
      PRINT 2000,IPOLT,WI,WF,C,DELTAW,JCOUNT
 2000 FORMAT(1H1,*THE INVESTIGATED POLLUTANT IS *,A3/* THE WAVENUMBER IN
     1TERVAL IS *,F10.3,* TO *,F10.3/* THE SUBINTERVAL OF INTEGRATION IS
     2 *,F10.3,* CM-1*/* THE MINIMUM INTEGRATING INCREMENT IS *,F6.3,* C
     3M-1*/* THE NUMBER OF POINTS OF INTEGRATION IS *,I6)
      PRINT 2010
 2010 FORMAT(1H0,*FILTER FUNCTION*/* WAVENUMBER   VACUUM RESP   GAS CELL
     1 RESP   DETECTOR RESP*)
      PRINT 2020,(FILTERW(J),RESPV(J),RESPG(J),RESP(J),J=1,NOC)
 2020 FORMAT(1H ,F10.3,4X,F10.4,4X,F10.4,6X,F10.4)
      DO 300 J=1,NXM
       CONC1(J)=XMULT(J) *GASCONC(IPOLLUT,1)
  300 CONTINUE
      PRINT 2030
```

```
2030 FORMAT(1H1,*ATMOSPHERIC PARAMETERS*)
     PRINT 2040,(ID(J),J=1,NSPEC)
2040 FORMAT(1H ,*LAYER  TEMP (K)  PRESS (ATM)  THICK (CM)  PATH (ATM-CM
    1)        *,4(A3,8X))
     DO 310 K=1,NLAY
      BRDFAC=(BROAD-1.) *GASCONC(IPOLLUT,1) +1.
      IF (K.LE.KBI) PRES(K)=PRES(K) *BRDFAC
      IF (K.GT.KBI) PRES(K)=PRES(K)/BRDFAC
 310 CONTINUE
     DO 330 K=1,NLAY
     J=0
     DO 320 LL=1,16
      IF (IDENT(LL).EQ. 0) GO TO 320
      J=J+1
      CONC(J)=GASCONC(IDENT(LL),K)
 320 CONTINUE
     PRINT 2050,K,TEMP(K),PRES(K),THICK(K),OPATH(K),(CONC(J),J=1,NSPEC)
2050 FORMAT(1H ,I2,5X,F7.2,3X,F8.5,5X,1PE12.5,1X,E12.5,3X,4(E10.3,1X))
 330 CONTINUE
     PRINT 2060,ZENITH
2060 FORMAT(1H0,*THE SUN ZENITH ANGLE IS *,0PF7.3,* DEGREES*)
     LOOP=NLAY
     IF (NLAYI.GT.0) LOOP=NLAYI
     DO 400 K=1,LOOP
     PRINT 2070,K
2070 FORMAT(1H1,*LAYER *,I2)
     IF (JPROF(K).EQ.1) IPROF=7HLORENTZ
     IF (JPROF(K).EQ.2) IPROF=5HVOIGT
     PRINT 2075, IPROF
2075 FORMAT(1H ,*THE SPECTRAL LINE PROFILE IS *,A7)
     PRINT 2080
2080 FORMAT(1H0,*ATMOSPHERIC OUTPUT PARAMETERS*)
     PRINT 2090,(CONC1(J),J=1,NXM)
2090 FORMAT(1H ,*THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSI
    1DERED ARE*/10X,1P10E12.4)
     PRINT 2100,(TRANS(K,J),J=1,NXM),(TOTATM(K,J),J=1,NXM)
2100 FORMAT(1H ,*TRANS    =*,1P10E12.4,/* TOTATM   =*,10E12.4)
     DO 340 L=1,NEMIS
     PRINT 2110,EMISS(L)
2110 FORMAT(1H ,*SURFACE EMISSIVITY =*,0PF6.3)
     PRINT 2120,(TOTSUN(K,L,J),J=1,NXM)
2120 FORMAT(1H ,*TOTSUN   =*,1P10E12.4)
 340 CONTINUE
     JJ=1+(K-1)*10
     JK=JJ+9
     DO 350 L=1,NEMIS
     DO 350 M=1,NSURF
     PRINT 2130,EMISS(L),TSURF(M)
2130 FORMAT(1H ,*SURFACE EMISSIVITY = *,0PF6.3,/* SURFACE TEMPERATURE =
    1 *,F8.3)
     PRINT 2140,(TOTSURF(J,L,M),J=JJ,JK),(TOTRAD(J,L,M),J=JJ,JK)
2140 FORMAT(1H ,*TOTSURF =*,1P10E12.4,/* TOTRAD   =*,10E12.4)
 350 CONTINUE
     IF (NLAYI.EQ.0) GO TO 400
     PRINT 2150
2150 FORMAT(1H0,*INSTRUMENT OUTPUT PARAMETERS*)
     PRINT 2160,RADVACB(K),RADGASB(K),TAUA(K),ERRDN(K)
2160 FORMAT(1H ,*RADVACB =*,1PE12.4,/* RADGASB =*,E12.4/* TAUA    =*,E
    112
    1.4/* ERRDN   =*,E12.4)
     PRINT 2090,(CONC1(J),J=1,NXM)
     PRINT 2170,(TRANS(K+KBI,J),J=1,NXM)
2170 FORMAT(1H ,*TRANS    =*,1P10E12.4)
     DO 360 L=1,NEMIS
     DO 360 M=1,NSURF
     PRINT 2130,EMISS(L),TSURF(M)
     PRINT 2180,(RADVACA(J,L,M),J=JJ,JK),(RADGASA(J,L,M),J=JJ,JK),
    1(RADGASE(J,L,M),J=JJ,JK),(DV(J,L,M),J=JJ,JK),(V(J,L,M),J=JJ,JK)
2180 FORMAT(1H ,*RADVACA =*,1P10E12.4/* RADGASA =*,10E12.4/* RADGASE =*
    1,10E12.4/* DV      =*,10E12.4/* V       =*,10E12.4)
 360 CONTINUE
     PRINT 2190
```

```
 2190 FORMAT(1HO,*CALIBRATION OUTPUT PARAMETERS*)
      DVHOT=RADHOTC(K)-TAUA(K)*RADHOTV(K)
      DVCOLD=RADCOLC(K)-TAUA(K)*RADCOLV(K)
      VHOT=(RADHOTC(K) + TAUA(K)*RADHOTV(K))/2.
      VCOLD=(RADCOLC(K) +TAUA(K)*RADCOLV(K))/2.
      PRINT 2200, TRANS(K+KBI+NLAYI,1),RADHOTC(K),RADCOLC(K),RADHOTV(K),
     1RADCOLV(K),DVHOT,DVCOLD,VHOT,VCOLD
 2200 FORMAT(1H ,*TRANS    =*,1PE12.4,/* RADHOTC =*,E12.4,/* RADCOLC =*,
     1E12.4,/* RADHOTV =*,E12.4,/* RADCOLV =*,E12.4,/* DVHOT   =*,E12.4,
     2/* DVCOLD  =*,E12.4,/* VHOT    =*,E12.4,/* VCOLD   =*,E12.4)
      PRINT 2210
 2210 FORMAT(1H ,*BALANCE OUTPUT PARAMETERS*)
      DVHOTB=RADHOTG(K)-TAUA(K)*RADHOT(K)
      DVCOLDB=RADCOLG(K)-TAUA(K)*RADCOLD(K)
      VHOTB=(RADHOTG(K) +TAUA(K)*RADHOT(K))/2.
      VCOLDB=(RADCOLG(K) +TAUA(K)*RADCOLD(K))/2.
      PRINT 2220,RADHOT(K),RADCOLD(K),RADHOTG(K),RADCOLG(K),DVHOTB,
     1DVCOLDB,VHOTB,VCOLDB
 2220 FORMAT(1H ,*RADHOT  =*,1PE12.4,/* RADCOLD =*,E12.4,/* RADHOTG =*,
     1E12.4,/* RADCOLG =*,E12.4,/* DVHOTB  =*,E12.4,/* DVCOLDB =*,E12.4,
     2/* VHOTB   =*,E12.4,/* VCOLDB  =*,E12.4)
  400 CONTINUE
      GO TO 550
  500 PRINT 3000
 3000 FORMAT(1H1,*THE WAVENUMBER INTERVAL IS OUTSIDE OF THE FILTER RANGE
     1*)
  550 RETURN
      END
```

SUBROUTINE FILTERP

FILTERP is a subroutine of SRTGFCA. FILTERP interpolates linearly the wavenumber-dependent vacuum cell and gas cell filter transmission, detector response, and solar flux values. Input filter parameters are read from cards in SRTGFCA while solar flux parameters are found in DATA statements in SRTGFCA. Storage required is 272_8 .

```
      SUBROUTINE FILTERP(W,TAUV,TAUG,SUN,NOC,NSUN,SUNW,SUNFLUX,RESPIN)
C *** INTERPOLATE WAVENUMBER DEPENDENT VACUUM CELL RESPONSE, GAS CELL RESPONSE,
C     DETECTOR RESPONSE, AND SOLAR FLUX FROM INPUTTED PARAMETERS ***
      DIMENSION SUNW(41),SUNFLUX(41)
      COMMON/CA/RESPG(35),FILTERW(35),RESPV(35),RESP(35)
      DO 10 K=2,NOC
       K2=K
       IF (FILTERW(K).GE.W) GO TO 20
   10 CONTINUE
   20 K1=K2-1
      COM=(W-FILTERW(K1))/(FILTERW(K2)-FILTERW(K1))
      RESPIN=RESP(K1)+ COM* (RESP(K2)-RESP(K1))
      TAUV=RESPV(K1) +COM *(RESPV(K2)-RESPV(K1))
      TAUG=RESPG(K1) +COM *(RESPG(K2)-RESPG(K1))
      IF (W.LT.SUNW(1)) GO TO 50
      DO 30 K=2,NSUN
       K2=K
       IF (SUNW(K).GE.W) GO TO 40
   30 CONTINUE
   40 K1=K2-1
      COM=(W-SUNW(K1))/(SUNW(K2)-SUNW(K1))
      SUN=SUNFLUX(K1) +COM*(SUNFLUX(K2)-SUNFLUX(K1))
      RETURN
   50 SUN=0.
      RETURN
      END
```

SUBROUTINE PLANKF

PLANKF is a subroutine of SRTGFCA. PLANKF calculates unattenuated surface emission using Planck's blackbody function. The surface temperatures and emissivities are read in SRTGFCA. The storage required is 106_8 .

```
      SUBROUTINE PLANKF(W,SURFCOM,NEMIS,NSURF)
C *** CALCULATE UNATTENUATED SURFACE EMISSION USING PLANCK FUNCTION
C     MONOCHROMATICALLY ***
      DIMENSION SURFCOM(10,10)
      COMMON/CB/EMISS(10),TSURF(10)
      DATA C7/1.1906E-12/,C8/1.439/
      W3=W*W*W
      DO 10 I=1,NEMIS
       DO 10 K=1,NSURF
        SURFCOM(I,K)=C7 *W3/(EXP(C8*W/TSURF(K))-1.)
        SURFCOM(I,K)=SURFCOM(I,K) *EMISS(I)
   10 CONTINUE
      RETURN
      END
```

SUBROUTINE SUNNY

SUNNY is a subroutine of SRTGFCA. SUNNY calculates attenuated solar radiation reflected by the earth's surface using the Chapman function. The sun zenith angle is an input to SRTGFCA. The storage required is 60_8 .

```
      SUBROUTINE SUNNY(W,NEMIS,SUNCOM,THETA,SUN,CHAPZEN)
C *** CALCULATE UNATTENUATED SOLAR RADIATION REFLECTED BY THE EARTH SURFACE
C     MONOCHROMATICALLY ***
      DIMENSION SUNCOM(10)
      COMMON/CB/EMISS(10),TSURF(10)
      COSS=COS(THETA/57.2957795)
      CHAPZEN= CHAP(THETA)
      DO 10 I=1,NEMIS
       SUNCOM(I)=SUN *COSS *(1.-EMISS(I))
   10 CONTINUE
      RETURN
      END
```

FUNCTION CHAP

CHAP is a function of SRTGFCA called by subroutine SUNNY. CHAP determines slant path transmission by use of the Chapman polynomial. The storage required is 53_8 .

```
      FUNCTION CHAP(THETA)
C *** DETERMINE SLANT PATH TRANSMISSION
C     FOR THETA .GT. 60. DEGREES, THE NATURAL LOG OF THE CHAPMAN FUNCTION IS
C     GIVEN BY AN 8 TH DEGREE POLYNOMIAL IN THETA ***
      DATA PI/3.1415926535/
      IF (THETA.GT.60.) GO TO 20
      CHAP=1.0/COS(PI *THETA/180.)
      RETURN
   20 XX=THETA
      POLY=(((((((-8.39732633E-13*XX +2.12740023E-10)*XX-9.45994657E-9)
     1     *XX-1.37255804E-6)*XX +3.30591581E-5)*XX +2.30546152E-2)*XX
     2     -2.44211940)*XX +9.78869273E+1)*XX -1.43635200E+3
      CHAP=EXP(-POLY)
      RETURN
      END
```

SUBROUTINES XNTEG, XNTEG2, XNTEG3, XNTEG4

XNTEG, XNTEG2, XNTEG3, and XNTEG4 are subroutines of SRTGFCA. They each integrate monochromatic values using the trapezoidal rule, and differ by the dimensions of the variables involved in the integration. The storage required for XNTEG, XNTEG2, XNTEG3, and XNTEG4 is 21_8, 123_8, 31_8, and 77_8, respectively.

```
      SUBROUTINE XNTEG(DW1,VALNEW,VALOLD,SUM,K)
C *** INTEGRATE MONOCHROMATIC VALUES USING TRAPEZOIDAL RULE ***
      DIMENSION VALNEW(10),VALOLD(10),SUM(10)
       DO 50 IK=1,K
        SUM(IK)=SUM(IK) +(DW1/2) *(VALNEW(IK) +VALOLD(IK))
   50  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE XNTEG2(DW1,VALNEW,VALOLD,SUM,KBI,NEMIS,NSURF,NXM)
C *** INTEGRATE MONOCHROMATIC VALUES USING TRAPEZOIDAL RULE ***
      DIMENSION VALNEW(100,2,2),VALOLD(100,2,2),SUM(100,2,2)
       DO 50 K=1,KBI
        DO 50 L=1,NEMIS
         DO 50 M=1,NSURF
          DO 50 J=1,NXM
          JJ=J +(K-1) *10
          SUM(JJ,L,M) =SUM(JJ,L,M) +(DW1/2)* (VALNEW(JJ,L,M) +VALOLD(JJ,
     1                L,M))
   50  CONTINUE
       RETURN
       END
```

```
      SUBROUTINE XNTEG3(DW1,VALNEW,VALOLD,SUM,K,NXM)
C *** INTEGRATE MONOCHROMATIC VALUES USING TRAPEZOIDAL RULE ***
      DIMENSION VALNEW(17,10),VALOLD(17,10),SUM(17,10)
      DO 50 IK=1,K
       DO 50 J=1,NXM
       SUM(IK,J)=SUM(IK,J)+ (DW1/2)* (VALNEW(IK,J)+ VALOLD(IK,J))
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE XNTEG4(DW1,VALNEW,VALOLD,SUM,K,NEMIS,NXM)
C *** INTEGRATE MONOCHROMATIC VALUES USING TRAPEZOIDAL RULE ***
      DIMENSION VALNEW(10,2,10),VALOLD(10,2,10),SUM(10,2,10)
      DO 50 IK=1,K
       DO 50 L=1,NEMIS
        DO 50 J=1,NXM
        SUM(IK,L,J)=SUM(IK,L,J) + (DW1/2)* (VALNEW(IK,L,J)+ VALOLD(IK,L
     1               ,J))
   50 CONTINUE
      RETURN
      END
```

OPERATING INSTRUCTIONS

Input

The input from cards is divided into two sections. One section is the atmospheric data used by TRANSMT and its associated routines. The other section is the instrument data used by SRTGFCA and its associated routines.

The physical set-up for the TEMP, PRES, and THICK data is arranged such that all atmospheric layers are read in first, followed by the instrument cell layers to be considered, followed by an equal number of calibration cell layers. An option for no instrument and calibration layers is explained later.

In order to avoid unnecessary calculations, one should be careful in choosing the values of DELTAW and CMINV. For our sample case using carbon monoxide as the primary gas, 2070-2220 cm^{-1} as the band width, DELTAW of .01 cm^{-1}, and CMINV of 5 cm^{-1}, a total of 12628 points of integration were considered. If DELTAW were chosen smaller and/or CMINV were chosen larger this total would be significantly greater causing execution time to increase.

Caution should be exercised concerning the units of the line parameters read from the spectral line tape. These units must be as specified in the dictionary of FORTRAN variables, and the reference temperature of the spectral lines must be 296.0K or the appropriate change to REFTEMP in the DATA statement in TRANSMT must be performed. A sample case input is listed in Appendix A.

Options

Presently, one may choose either Lorentzian or Keilkopf's approximation to the Voigt (ref. 7) profile in the calculation of spectral line shape in program TRANSMT. The Doppler line profile will be added in order to more accurately describe atmospheric conditions of low pressure and high temperature. It should be mentioned here that the Voigt profile requires a significant increase in calculation time.

By setting the value of NLAYI to zero, only atmospheric transmittance and radiance calculations are performed.

The program is currently set up to perform carbon monoxide calculations in the 4.6 μm spectral band. Any other primary pollutant gas may be considered by setting the value of IPOLLUT to the identification number of that specie and by making necessary adjustments to band widths and filters. The gas broadening coefficient, BROAD, must also be changed to correspond to the gas being considered.

Program SRTGFCA simulates a gas filter correlation radiometer. Any infrared instrument using atmospheric transmittance and radiance information as input may be substituted for SRTGFCA.

It should be mentioned here that a routine to plot transmittance versus wavenumber as a function of altitude may be incorporated following the writing of the transmittance values on temporary storage disk 6 in TRANSMT.

The trapezoidal rule is used as the integration approximation in routines XNTEG, XNTEG2, XNTEG3, and XNTEG4. Should the user wish to incorporate a different integration process, these routines may be easily replaced. Similarly, that subroutine that determines the wavenumber mesh for integration may be replaced by an algorithm more suitable to the user.

Output

The program output is in two sections. The first section lists the spectral lines used in the calculations, and the input data such as atmospheric profile and filter parameters. The second section is divided into two parts. Atmospheric output parameters, i.e., band integrated transmission and total upwelling radiance as well as the band integrated components of the total radiance (solar, surface, and atmospheric), as a function of surface temperatures and emissivities are listed for the top of each atmospheric layer. The second part lists the corresponding instrument output responses in addition to calibration and balance output parameters as required by input instructions. If one sets NLAYI to zero, the instrument calibration will not be performed.

A sample case output is listed in Appendix B.

SAMPLE PROBLEM

The input listed in Appendix A and output in Appendix B correspond to a problem of determining the GFCR response of the instrument flying at the top of each of the first four modeled atmospheric layers. The model chosen is a 45° North Latitude July atmosphere with a corresponding water vapor profile (ref. 10). The sun zenith angle is 45°. The pollutant is carbon monoxide calculated at 10 different concentrations in each layer, with interferent constituent concentrations of water vapor and carbon dioxide held constant in each layer. The spectral band is 4.6 μm, and the filter parameters simulate those of a NASA/LaRC version of a GFCR.

COMPARISONS AND CONCLUSIONS

Obviously, any computer program is only as accurate as the theoretical model on which it is based and the accuracy of the numerical algorithms coded into program instructions. As outlined previously in the Problem Definition and Method of Solution section, the accuracy of this model is dictated by the assumptions made in our application to a specific problem.

In order to verify the results of the SMART calculated absorption coefficients, several comparisons were made with existing experimental and theoretical absorption results in the CO fundamental band. The SMART program's algorithms for computing transmittance were checked against hand calculations for several wavenumbers and were shown to be correct. The high resolution absorption measurements, .05 cm^{-1}, reported by Chaney and Drayson (refs. 11 and 12) for the R20 line of the 4.6 μm CO band was simulated by the SMART program, degraded, and compared. The absorption was computed at .01 cm^{-1} intervals using the AFCRL line parameter data (ref. 5), then convoluted with a triangular slit transmission function whose width was .12 cm^{-1} at half-maximum. The discrepancy found between the higher values of line strengths by Drayson (ref. 12) which were calculated from the measurements of Chaney (ref. 11), and the lower line strengths from the AFCRL line parameter tape, i.e., 1.11 and 0.80 $(atm^{-1}cm^{-1})_{STP}$, respectively, for the R20 line, will be investigated further in the future. A preliminary comparison has shown no discrepancy between Drayson's line strengths near the CO fundamental band center, e.g., the R0 and P1 line. As the distance of a line from the band center increases, the discrepancy increases between the higher values of Drayson's line strengths and the lower AFCRL data line strengths (refs. 13, 14, 15, and 16). The SMART calculated spectrum is in excellent agreement with the experimental spectrum near the line center, and has only slightly higher values of absorption in the line wings. This deviation in the wings is probably due to the difference between the actual line profile (ref. 17) and the Lorentz line profile employed in our calculations. The absorption in the line wings calculated by SMART is in agreement with Burch and Gryvnak (ref. 18), who have shown that the extreme wings of the spectral lines are sub-Lorentzian. Despite the line wing shape differences, a comparison between the equivalent line width calculation using the Ladenberg and Reiche function (ref. 19) as described by Kondrat'Yev (ref. 20), and the SMART integrated absorption reveals less than 0.5 percent discrepancy in the total absorption by the R20 line under Chaney's test conditions.

SMART calculations of the entire CO fundamental band were performed and compared to the integrated absorption reported by the experimental work of Burch and Gryvnak (ref. 21). The SMART integrated absorption differed from the value reported by Burch by only 6.0 percent. This difference is probably due to a combination of an uncertainty in the reported experimental conditions and Burch's reported ±5.0 percent instrumentation measurement error (ref. 21).

A line-by-line radiative transfer program that simulates a gas filter correlation radiometer has been developed and described. The overlaid structure allows for the substitution of the instrument simulation program with one that describes any infrared sensor. Any of the specific task subroutines may easily be substituted by algorithms that are more suitable and convenient to the user.

The program is currently constructed to perform carbon monoxide calculations in the fundamental 4.6 μm spectral band, but by making necessary adjustments, other gas species transmittance calculations may be made. Future additions to the program will include the Doppler profile option (Lorentz and Voigt are presently incorporated), a sub-Lorentzian wing absorption algorithm, the water vapor and nitrogen continuum absorption algorithms, and a routine to plot transmittance as a function of wavenumber.

The storage required for the program is dependent upon the number of layers (atmospheric, instrument cell, and calibration cell) desired for consideration. For our sample case, 17 layers required 130300 octal words of storage and 838 seconds of execution time. Although this may appear to be a large amount of time and storage, the present program is equivalent to 32 separate computer runs of an earlier version of a radiative transfer program used at LaRC. By simultaneously performing several functions, such as balancing and calibrating, program efficiency increased, and a cost savings factor of five was realized.

A sample problem was processed. The resulting computer listing of input and output is shown.

APPENDIX A

Input Parameters for a Sample Test Case Listed as Card Images

```
   17     4    31    10     3        1  2                          12
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
2070.          2220.          .01          5.                1     1.00
0.             .1             .2           .3         .4          .5          .6          .7
.8             1.0
293.5          .9831          30480.
292.1          .9497          30480.
290.7          .9163          30480.
289.3          .8837          30480.
288.0          .8532          30480.
286.6          .8228          30480.
285.1          .7927          30480.
283.4          .7649          30480.
281.6          .7375          30480.
311.5          .92105         1.
311.5          .92105         1.
311.5          .92105         1.
311.5          .92105         1.
298.5          .92105         2.
298.5          .92105         2.
298.5          .92105         2.
298.5          .92105         2.
    1.0E-06 1.844E-02
                                              3.2E-04
    1.0E-06 1.676E-02
                                              3.2E-04
    1.0E-06 1.498E-02
                                              3.2E-04
    1.0E-06 1.331E-02
                                              3.2E-04
    1.0E-06 1.213E-02
                                              3.2E-04
    1.0E-06 1.092E-02
                                              3.2E-04
    1.0E-06 9.675E-03
                                              3.2E-04
    1.0E-06 8.606E-03
                                              3.2E-04
    1.0E-06 7.528E-03
                                              3.2E-04
.35

.35
```

```
.35

.35

.08143

.08143

.08143

.08143

   2      2    31     45.
300.        296.
.98         .88
    2070.0          0.0          0.0          1.
    2075.0        .0050        .0050          1.
    2080.0        .0250        .0250          1.
    2085.0        .1060        .1060          1.
    2090.0        .1000        .1000          1.
    2095.0        .1550        .1550          1.
    2100.0        .2300        .2300          1.
    2105.0        .3500        .3500          1.
    2110.0        .4850        .4850          1.
    2115.0        .6250        .6250          1.
    2120.0        .7750        .7750          1.
    2125.0        .8700        .8700          1.
    2130.0        .9300        .9300          1.
    2135.0        .9700        .9700          1.
    2140.0        .9950        .9950          1.
    2145.0        1.000        1.000          1.
    2150.0        .9950        .9950          1.
    2155.0        .9650        .9650          1.
    2160.0        .9050        .9050          1.
    2165.0        .8100        .8100          1.
    2170.0        .6800        .6800          1.
    2175.0        .5350        .5350          1.
    2180.0        .4100        .4100          1.
    2185.0        .2850        .2850          1.
    2190.0        .1900        .1900          1.
    2195.0        .1400        .1400          1.
    2200.0        .0950        .0950          1.
    2205.0        .0650        .0650          1.
    2210.0        .0350        .0350          1.



    2215.0        .0150        .0150          1.
    2220.0        .0050        .0050          1.
311.8      311.8      311.8      311.8
308.8      284.7      308.8      284.7      308.8      284.7      308.8      284.7
1.
```

APPENDIX B

Output Listing for a Sample Test Case

```
THE INVESTIGATED POLLUTANT IS CO
THE WAVENUMBER INTERVAL IS   2070.000 TO   2220.000
THE SUBINTERVAL OF INTEGRATION IS     10.000 CM-1
THE MINIMUM INTEGRATING INCREMENT IS   .010 CM-1
THE NUMBER OF POINTS OF INTEGRATION IS  12628
```

FILTER FUNCTION

WAVENUMBER	VACUUM RESP	GAS CELL RESP	DETECTOR RESP
2070.000	0.0000	0.0000	1.0000
2075.000	.0050	.0050	1.0000
2080.000	.0250	.0250	1.0000
2085.000	.1060	.1060	1.0000
2090.000	.1000	.1000	1.0000
2095.000	.1550	.1550	1.0000
2100.000	.2300	.2300	1.0000
2105.000	.3500	.3500	1.0000
2110.000	.4850	.4850	1.0000
2115.000	.6250	.6250	1.0000
2120.000	.7750	.7750	1.0000
2125.000	.8700	.8700	1.0000
2130.000	.9300	.9300	1.0000
2135.000	.9700	.9700	1.0000
2140.000	.9950	.9950	1.0000
2145.000	1.0000	1.0000	1.0000
2150.000	.9950	.9950	1.0000
2155.000	.9650	.9650	1.0000
2160.000	.9050	.9050	1.0000
2165.000	.8100	.8100	1.0000
2170.000	.6800	.6800	1.0000
2175.000	.5350	.5350	1.0000
2180.000	.4100	.4100	1.0000
2185.000	.2850	.2850	1.0000
2190.000	.1900	.1900	1.0000
2195.000	.1400	.1400	1.0000
2200.000	.0950	.0950	1.0000
2205.000	.0650	.0650	1.0000
2210.000	.0350	.0350	1.0000
2215.000	.0150	.0150	1.0000
2220.000	.0050	.0050	1.0000

ATMOSPHERIC PARAMETERS

LAYER	TEMP (K)	PRESS (ATM)	THICK (CM)	PATH (ATM-CM)	CO	H2O	CO2
1	293.50	.98310	3.04800E+04	2.99649E+04	1.000E-06	1.844E-02	3.200E-04
2	292.10	.94970	3.04800E+04	2.89469E+04	1.000E-06	1.676E-02	3.200E-04
3	290.70	.91630	3.04800E+04	2.79288E+04	1.000E-06	1.498E-02	3.200E-04
4	289.30	.88370	3.04800E+04	2.69352E+04	1.000E-06	1.331E-02	3.200E-04
5	288.00	.85320	3.04800E+04	2.60055E+04	1.000E-06	1.213E-02	3.200E-04
6	286.60	.82280	3.04800E+04	2.50789E+04	1.000E-06	1.092E-02	3.200E-04
7	285.10	.79270	3.04800E+04	2.41615E+04	1.000E-06	9.675E-03	3.200E-04
8	283.40	.76490	3.04800E+04	2.33142E+04	1.000E-06	8.608E-03	3.200E-04
9	281.60	.73750	3.04800E+04	2.24790E+04	1.000E-06	7.528E-03	3.200E-04
10	311.50	.92105	1.00000E+00	9.21050E-01	3.500E-01	0.	0.
11	311.50	.92105	1.00000E+00	9.21050E-01	3.500E-01	0.	0.
12	311.50	.92105	1.00000E+00	9.21050E-01	3.500E-01	0.	0.
13	311.50	.92105	1.00000E+00	9.21050E-01	3.500E-01	0.	0.
14	298.50	.92105	2.00000E+00	1.84210E+00	8.143E-02	0.	0.
15	298.50	.92105	2.00000E+00	1.84210E+00	8.143E-02	0.	0.
16	298.50	.92105	2.00000E+00	1.84210E+00	8.143E-02	0.	0.
17	298.50	.92105	2.00000E+00	1.84210E+00	8.143E-02	0.	0.

THE SUN ZENITH ANGLE IS 45.000 DEGREES

```
LAYER  1
THE SPECTRAL LINE PROFILE IS LORENTZ

ATMOSPHERIC OUTPUT PARAMETERS
THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE
                 0.          1.0000E-07  2.0000E-07  3.0000E-07  4.0000E-07  5.0000E-07  6.0000E-07  7.0000E-07  8.0000E-07  1.0000E-06
TRANS    =  9.0869E-01  9.0450E-01  9.0053E-01  8.9676E-01  8.9318E-01  8.8976E-01  8.8650E-01  8.8337E-01  8.8038E-01  8.7476E-01
TOTATM   =  4.7195E-06  4.9182E-06  5.1066E-06  5.2856E-06  5.4559E-06  5.6183E-06  5.7733E-06  5.9217E-06  6.0638E-06  6.3314E-06
SURFACE EMISSIVITY =  .980
TOTSUN   =  4.8823E-07  4.6696E-07  4.5384E-07  4.4404E-07  4.3596E-07  4.2897E-07  4.2273E-07  4.1705E-07  4.1180E-07  4.0231E-07
SURFACE EMISSIVITY =  .880
TOTSUN   =  2.9294E-06  2.8017E-06  2.7230E-06  2.6642E-06  2.6158E-06  2.5738E-06  2.5364E-06  2.5023E-06  2.4708E-06  2.4139E-06
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  300.000
TOTSURF  =  5.3556E-05  5.3311E-05  5.3079E-05  5.2859E-05  5.2649E-05  5.2449E-05  5.2259E-05  5.2076E-05  5.1901E-05  5.1572E-05
TOTRAD   =  5.8763E-05  5.8696E-05  5.8640E-05  5.8588E-05  5.8541E-05  5.8497E-05  5.8455E-05  5.8415E-05  5.8377E-05  5.8306E-05
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  296.000
TOTSURF  =  4.6617E-05  4.6404E-05  4.6202E-05  4.6010E-05  4.5828E-05  4.5654E-05  4.5488E-05  4.5329E-05  4.5177E-05  4.4890E-05
TOTRAD   =  5.1824E-05  5.1789E-05  5.1763E-05  5.1740E-05  5.1720E-05  5.1701E-05  5.1684E-05  5.1668E-05  5.1653E-05  5.1624E-05
SURFACE EMISSIVITY =   .880
SURFACE TEMPERATURE =  300.000
TOTSURF  =  4.8091E-05  4.7871E-05  4.7663E-05  4.7465E-05  4.7277E-05  4.7097E-05  4.6926E-05  4.6762E-05  4.6605E-05  4.6309E-05
TOTRAD   =  5.5740E-05  5.5591E-05  5.5493E-05  5.5415E-05  5.5349E-05  5.5290E-05  5.5236E-05  5.5186E-05  5.5140E-05  5.5055E-05
SURFACE EMISSIVITY =   .880
SURFACE TEMPERATURE =  296.000
TOTSURF  =  4.1860E-05  4.1669E-05  4.1488E-05  4.1315E-05  4.1152E-05  4.0995E-05  4.0846E-05  4.0704E-05  4.0567E-05  4.0310E-05
TOTRAD   =  4.9509E-05  4.9389E-05  4.9317E-05  4.9265E-05  4.9223E-05  4.9188E-05  4.9156E-05  4.9128E-05  4.9102E-05  4.9055E-05

INSTRUMENT OUTPUT PARAMETERS
RADVACB =  4.0824E-05
RADGASB =  3.3833E-05
TAUA     =  8.2869E-01
ERRDN    =  2.6392E-09
THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE
                 0.          1.0000E-07  2.0000E-07  3.0000E-07  4.0000E-07  5.0000E-07  6.0000E-07  7.0000E-07  8.0000E-07  1.0000E-06
TRANS    =  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  300.000
RADVACA =  2.6875E-05  2.6840E-05  2.6810E-05  2.6784E-05  2.6759E-05  2.6736E-05  2.6714E-05  2.6693E-05  2.6674E-05  2.6637E-05
RADGASA =  2.2270E-05  2.2263E-05  2.2256E-05  2.2249E-05  2.2243E-05  2.2236E-05  2.2230E-05  2.2223E-05  2.2217E-05  2.2205E-05
RADGASE =  2.9195E-05  2.9187E-05  2.9180E-05  2.9174E-05  2.9167E-05  2.9161E-05  2.9154E-05  2.9148E-05  2.9142E-05  2.9129E-05
DV       = -1.2146E-09  2.0897E-08  3.8468E-08  5.3762E-08  6.7548E-08  8.0173E-08  9.1835E-08  1.0267E-07  1.1278E-07  1.3111E-07
V        =  2.2271E-05  2.2253E-05  2.2237E-05  2.2222E-05  2.2209E-05  2.2196E-05  2.2184E-05  2.2172E-05  2.2161E-05  2.2139E-05
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  296.000
RADVACA =  2.3686E-05  2.3668E-05  2.3654E-05  2.3642E-05  2.3632E-05  2.3622E-05  2.3613E-05  2.3605E-05  2.3597E-05  2.3582E-05
RADGASA =  1.9630E-05  1.9626E-05  1.9622E-05  1.9618E-05  1.9615E-05  1.9611E-05  1.9608E-05  1.9605E-05  1.9602E-05  1.9595E-05
RADGASE =  2.6554E-05  2.6550E-05  2.6546E-05  2.6543E-05  2.6539E-05  2.6536E-05  2.6532E-05  2.6529E-05  2.6526E-05  2.6520E-05
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DV       =  1.0087E-09  1.2503E-08  2.0183E-08  2.6247E-08  3.1405E-08  3.5952E-08  4.0042E-08  4.3766E-08  4.7184E-08  5.3273E-08
V        =  1.9629E-05  1.9619E-05  1.9612E-05  1.9605E-05  1.9599E-05  1.9593E-05  1.9588E-05  1.9583E-05  1.9578E-05  1.9569E-05
SURFACE EMISSIVITY =   .880
SURFACE TEMPERATURE =  300.000
RADVACA =  2.5501E-05  2.5422E-05  2.5371E-05  2.5331E-05  2.5296E-05  2.5266E-05  2.5238E-05  2.5212E-05  2.5188E-05  2.5144E-05
RADGASA =  2.1127E-05  2.1110E-05  2.1094E-05  2.1078E-05  2.1063E-05  2.1049E-05  2.1035E-05  2.1022E-05  2.1009E-05  2.0985E-05
RADGASE =  2.8052E-05  2.8034E-05  2.8018E-05  2.8003E-05  2.7988E-05  2.7973E-05  2.7960E-05  2.7946E-05  2.7934E-05  2.7909E-05
DV       = -4.8932E-09  4.2747E-08  6.8951E-08  8.6792E-08  1.0041E-07  1.1146E-07  1.2079E-07  1.2884E-07  1.3592E-07  1.4786E-07
V        =  2.1130E-05  2.1089E-05  2.1059E-05  2.1035E-05  2.1013E-05  2.0993E-05  2.0975E-05  2.0958E-05  2.0941E-05  2.0911E-05
SURFACE EMISSIVITY =   .880
SURFACE TEMPERATURE =  296.000
RADVACA =  2.2637E-05  2.2574E-05  2.2536E-05  2.2510E-05  2.2488E-05  2.2469E-05  2.2453E-05  2.2439E-05  2.2425E-05  2.2401E-05
RADGASA =  1.8756E-05  1.8742E-05  1.8728E-05  1.8716E-05  1.8704E-05  1.8692E-05  1.8681E-05  1.8671E-05  1.8661E-05  1.8641E-05
RADGASE =  2.5681E-05  2.5666E-05  2.5653E-05  2.5640E-05  2.5628E-05  2.5617E-05  2.5606E-05  2.5595E-05  2.5585E-05  2.5566E-05
DV       = -2.8968E-09  3.5210E-08  5.2532E-08  6.2084E-08  6.7951E-08  7.1757E-08  7.4280E-08  7.5948E-08  7.7018E-08  7.7969E-08
V        =  1.8758E-05  1.8724E-05  1.8702E-05  1.8685E-05  1.8670E-05  1.8656E-05  1.8644E-05  1.8633E-05  1.8622E-05  1.8602E-05

CALIBRATION OUTPUT PARAMETERS
TRANS    =  8.9319E-01
RADHOTC  =  3.0296E-05
RADCOLC  =  1.3627E-05
RADHOTV  =  3.5813E-05
RADCOLV  =  1.7151E-05
DVHOT    =  6.1833E-07
DVCOLD   = -5.8639E-07
VHOT     =  2.9987E-05
VCOLD    =  1.3920E-05
BALANCE OUTPUT PARAMETERS
RADHOT   =  3.7086E-05
RADCOLD  =  1.5933E-05
RADHOTG  =  3.0736E-05
RADCOLG  =  1.3206E-05
DVHOTB   =  2.8268E-09
DVCOLDB  =  2.8268E-09
VHOTB    =  3.0734E-05
VCOLDB   =  1.3205E-05
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LAYER  2
THE SPECTRAL LINE PROFILE IS LORENTZ

ATMOSPHERIC OUTPUT PARAMETERS
THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE
            0.          1.0000E-07  2.0000E-07  3.0000E-07  4.0000E-07  5.0000E-07  6.0000E-07  7.0000E-07  8.0000E-07  1.0000E-06
TRANS    =  8.6540E-01  8.5771E-01  8.5079E-01  8.4450E-01  8.3875E-01  8.3346E-01  8.2856E-01  8.2400E-01  8.1972E-01  8.1190E-01
TOTATM   =  6.7130E-06  7.0666E-06  7.3850E-06  7.6738E-06  7.9377E-06  8.1804E-06  8.4051E-06  8.6142E-06  8.8099E-06  9.1678E-06
SURFACE EMISSIVITY =  .980
TOTSUN   =  4.7743E-07  4.5535E-07  4.4200E-07  4.3205E-07  4.2387E-07  4.1677E-07  4.1043E-07  4.0466E-07  3.9934E-07  3.8970E-07
SURFACE EMISSIVITY =  .880
TOTSUN   =  2.8646E-06  2.7321E-06  2.6520E-06  2.5923E-06  2.5432E-06  2.5006E-06  2.4626E-06  2.4280E-06  2.3960E-06  2.3382E-06
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  300.000
TOTSURF  =  5.0853E-05  5.0406E-05  5.0003E-05  4.9637E-05  4.9302E-05  4.8993E-05  4.8708E-05  4.8441E-05  4.8192E-05  4.7736E-05
TOTRAD   =  5.8043E-05  5.7928E-05  5.7830E-05  5.7742E-05  5.7663E-05  5.7590E-05  5.7523E-05  5.7460E-05  5.7401E-05  5.7293E-05
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  296.000
TOTSURF  =  4.4262E-05  4.3873E-05  4.3522E-05  4.3203E-05  4.2912E-05  4.2643E-05  4.2395E-05  4.2163E-05  4.1946E-05  4.1549E-05
TOTRAD   =  5.1452E-05  5.1394E-05  5.1349E-05  5.1309E-05  5.1273E-05  5.1241E-05  5.1210E-05  5.1182E-05  5.1156E-05  5.1107E-05
SURFACE EMISSIVITY =   .880
SURFACE TEMPERATURE =  300.000
TOTSURF  =  4.5664E-05  4.5262E-05  4.4900E-05  4.4572E-05  4.4271E-05  4.3994E-05  4.3737E-05  4.3498E-05  4.3275E-05  4.2865E-05
TOTRAD   =  5.5241E-05  5.5061E-05  5.4937E-05  5.4838E-05  5.4752E-05  5.4675E-05  5.4605E-05  5.4541E-05  5.4480E-05  5.4371E-05
SURFACE EMISSIVITY =   .880
SURFACE TEMPERATURE =  296.000
TOTSURF  =  3.9745E-05  3.9396E-05  3.9081E-05  3.8795E-05  3.8533E-05  3.8292E-05  3.8069E-05  3.7861E-05  3.7666E-05  3.7309E-05
TOTRAD   =  4.9323E-05  4.9194E-05  4.9118E-05  4.9061E-05  4.9014E-05  4.8973E-05  4.8936E-05  4.8903E-05  4.8872E-05  4.8815E-05

INSTRUMENT OUTPUT PARAMETERS
RADVACB  =  4.0824E-05
RADGASB  =  3.3833E-05
TAUA     =  8.2869E-01
ERRDN    =  2.6392E-09
THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE
            0.          1.0000E-07  2.0000E-07  3.0000E-07  4.0000E-07  5.0000E-07  6.0000E-07  7.0000E-07  8.0000E-07  1.0000E-06
TRANS    =  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  300.000
RADVACA  =  2.6562E-05  2.6501E-05  2.6450E-05  2.6404E-05  2.6363E-05  2.6325E-05  2.6290E-05  2.6257E-05  2.6227E-05  2.6171E-05
RADGASA  =  2.2007E-05  2.1995E-05  2.1983E-05  2.1971E-05  2.1960E-05  2.1949E-05  2.1938E-05  2.1927E-05  2.1916E-05  2.1895E-05
RADGASE  =  2.8931E-05  2.8919E-05  2.8907E-05  2.8896E-05  2.8884E-05  2.8873E-05  2.8862E-05  2.8851E-05  2.8841E-05  2.8820E-05
DV       = -4.8006E-09  3.3529E-08  6.4283E-08  9.0468E-08  1.1330E-07  1.3347E-07  1.5144E-07  1.6758E-07  1.8215E-07  2.0746E-07
V        =  2.2009E-05  2.1978E-05  2.1951E-05  2.1926E-05  2.1903E-05  2.1882E-05  2.1862E-05  2.1843E-05  2.1825E-05  2.1792E-05
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  296.000
RADVACA  =  2.3524E-05  2.3494E-05  2.3470E-05  2.3449E-05  2.3430E-05  2.3413E-05  2.3398E-05  2.3383E-05  2.3369E-05  2.3344E-05
RADGASA  =  1.9494E-05  1.9487E-05  1.9481E-05  1.9475E-05  1.9470E-05  1.9464E-05  1.9459E-05  1.9453E-05  1.9448E-05  1.9438E-05
RADGASE  =  2.6418E-05  2.6412E-05  2.6406E-05  2.6400E-05  2.6394E-05  2.6389E-05  2.6383E-05  2.6378E-05  2.6373E-05  2.6363E-05
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DV       = -5.1766E-10  1.8340E-08  3.2138E-08  4.3463E-08  5.3190E-08  6.1731E-08  6.9334E-08  7.6165E-08  8.2348E-08  9.3129E-08
V        =  1.9494E-05  1.9478E-05  1.9465E-05  1.9454E-05  1.9443E-05  1.9433E-05  1.9424E-05  1.9415E-05  1.9407E-05  1.9392E-05
SURFACE EMISSIVITY =    .880
SURFACE TEMPERATURE =  300.000
RADVACA =  2.5283E-05  2.5188E-05  2.5123E-05  2.5071E-05  2.5027E-05  2.4987E-05  2.4951E-05  2.4917E-05  2.4886E-05  2.4830E-05
RADGASA =  2.0945E-05  2.0924E-05  2.0904E-05  2.0885E-05  2.0867E-05  2.0850E-05  2.0833E-05  2.0817E-05  2.0801E-05  2.0771E-05
RADGASE =  2.7869E-05  2.7848E-05  2.7829E-05  2.7810E-05  2.7792E-05  2.7774E-05  2.7757E-05  2.7741E-05  2.7725E-05  2.7695E-05
DV       = -6.8533E-09  5.1010E-08  8.4677E-08  1.0872E-07  1.2760E-07  1.4319E-07  1.5642E-07  1.6787E-07  1.7791E-07  1.9474E-07
V        =  2.0948E-05  2.0898E-05  2.0862E-05  2.0831E-05  2.0803E-05  2.0778E-05  2.0755E-05  2.0733E-05  2.0712E-05  2.0674E-05
SURFACE EMISSIVITY =    .880
SURFACE TEMPERATURE =  296.000
RADVACA =  2.2555E-05  2.2487E-05  2.2447E-05  2.2418E-05  2.2394E-05  2.2372E-05  2.2354E-05  2.2336E-05  2.2320E-05  2.2291E-05
RADGASA =  1.8688E-05  1.8672E-05  1.8658E-05  1.8644E-05  1.8631E-05  1.8619E-05  1.8607E-05  1.8596E-05  1.8585E-05  1.8564E-05
RADGASE =  2.5612E-05  2.5597E-05  2.5582E-05  2.5568E-05  2.5556E-05  2.5543E-05  2.5531E-05  2.5520E-05  2.5509E-05  2.5489E-05
DV       = -3.0074E-09  3.7371E-08  5.5812E-08  6.6507E-08  7.3629E-08  7.8775E-08  8.2694E-08  8.5784E-08  8.8285E-08  9.2072E-08
V        =  1.8689E-05  1.8654E-05  1.8630E-05  1.8611E-05  1.8594E-05  1.8579E-05  1.8566E-05  1.8553E-05  1.8541E-05  1.8518E-05

CALIBRATION OUTPUT PARAMETERS
TRANS    =  8.9319E-01
RADHOTC  =  3.0296E-05
RADCOLC  =  1.3627E-05
RADHOTV  =  3.5813E-05
RADCOLV  =  1.7151E-05
DVHOT    =  6.1833E-07
DVCOLD   = -5.8639E-07
VHOT     =  2.9987E-05
VCOLD    =  1.3920E-05
BALANCE OUTPUT PARAMETERS
RADHOT   =  3.7086E-05
RADCOLD  =  1.5933E-05
RADHOTG  =  3.0736E-05
RADCOLG  =  1.3206E-05
DVHOTB   =  2.8268E-09
DVCOLDB  =  2.8268E-09
VHOTB    =  3.0734E-05
VCOLDB   =  1.3205E-05
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LAYER  3
THE SPECTRAL LINE PROFILE IS LORENTZ

ATMOSPHERIC OUTPUT PARAMETERS
THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE
                0.           1.0000E-07  2.0000E-07  3.0000E-07  4.0000E-07  5.0000E-07  6.0000E-07  7.0000E-07  8.0000E-07  1.0000E-06
TRANS    =  8.3636E-01  8.2564E-01  8.1643E-01  8.0838E-01  8.0123E-01  7.9481E-01  7.8898E-01  7.8362E-01  7.7865E-01  7.6966E-01
TOTATM   =  7.9081E-06  8.3869E-06  8.7973E-06  9.1550E-06  9.4715E-06  9.7553E-06  1.0013E-05  1.0249E-05  1.0468E-05  1.0863E-05
SURFACE EMISSIVITY =  .980
TOTSUN   =  4.6891E-07  4.4607E-07  4.3250E-07  4.2242E-07  4.1411E-07  4.0692E-07  4.0049E-07  3.9463E-07  3.8922E-07  3.7945E-07
SURFACE EMISSIVITY =  .880
TOTSUN   =  2.8135E-06  2.6764E-06  2.5950E-06  2.5345E-06  2.4847E-06  2.4415E-06  2.4029E-06  2.3678E-06  2.3353E-06  2.2767E-06
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  300.000
TOTSURF  =  4.9047E-05  4.8425E-05  4.7890E-05  4.7422E-05  4.7006E-05  4.6633E-05  4.6293E-05  4.5982E-05  4.5693E-05  4.5169E-05
TOTRAD   =  5.7424E-05  5.7258E-05  5.7119E-05  5.6999E-05  5.6892E-05  5.6795E-05  5.6707E-05  5.6625E-05  5.6549E-05  5.6412E-05
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  296.000
TOTSURF  =  4.2688E-05  4.2147E-05  4.1681E-05  4.1274E-05  4.0912E-05  4.0588E-05  4.0292E-05  4.0021E-05  3.9769E-05  3.9314E-05
TOTRAD   =  5.1065E-05  5.0980E-05  5.0911E-05  5.0851E-05  5.0798E-05  5.0750E-05  5.0706E-05  5.0664E-05  5.0626E-05  5.0556E-05
SURFACE EMISSIVITY =   .880
SURFACE TEMPERATURE =  300.000
TOTSURF  =  4.4042E-05  4.3484E-05  4.3003E-05  4.2583E-05  4.2210E-05  4.1875E-05  4.1570E-05  4.1290E-05  4.1030E-05  4.0560E-05
TOTRAD   =  5.4764E-05  5.4547E-05  5.4395E-05  5.4272E-05  5.4166E-05  5.4071E-05  5.3985E-05  5.3906E-05  5.3833E-05  5.3700E-05
SURFACE EMISSIVITY =   .880
SURFACE TEMPERATURE =  296.000
TOTSURF  =  3.8332E-05  3.7846E-05  3.7428E-05  3.7062E-05  3.6738E-05  3.6446E-05  3.6181E-05  3.5937E-05  3.5711E-05  3.5302E-05
TOTRAD   =  4.9054E-05  4.8909E-05  4.8820E-05  4.8752E-05  4.8694E-05  4.8643E-05  4.8597E-05  4.8554E-05  4.8514E-05  4.8442E-05

INSTRUMENT OUTPUT PARAMETERS
RADVACB =  4.0824E-05
RADGASB =  3.3833E-05
TAUA    =  8.2869E-01
ERRON   =  2.6392E-09
THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE
                0.           1.0000E-07  2.0000E-07  3.0000E-07  4.0000E-07  5.0000E-07  6.0000E-07  7.0000E-07  8.0000E-07  1.0000E-06
TRANS    =  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01  8.4226E-01
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  300.000
RADVACA  =  2.6297E-05  2.6209E-05  2.6136E-05  2.6073E-05  2.6017E-05  2.5967E-05  2.5921E-05  2.5879E-05  2.5839E-05  2.5768E-05
RADGASA  =  2.1784E-05  2.1767E-05  2.1750E-05  2.1733E-05  2.1717E-05  2.1701E-05  2.1685E-05  2.1670E-05  2.1654E-05  2.1625E-05
RADGASE  =  2.8709E-05  2.8691E-05  2.8674E-05  2.8658E-05  2.8641E-05  2.8625E-05  2.8610E-05  2.8594E-05  2.8579E-05  2.8549E-05
DV       = -7.5854E-09  4.7781E-08  9.1044E-08  1.2663E-07  1.5662E-07  1.8231E-07  2.0460E-07  2.2415E-07  2.4145E-07  2.7076E-07
V        =  2.1788E-05  2.1743E-05  2.1704E-05  2.1670E-05  2.1638E-05  2.1610E-05  2.1583E-05  2.1558E-05  2.1534E-05  2.1489E-05
SURFACE EMISSIVITY =   .980
SURFACE TEMPERATURE =  296.000
RADVACA  =  2.3357E-05  2.3312E-05  2.3276E-05  2.3245E-05  2.3217E-05  2.3192E-05  2.3169E-05  2.3148E-05  2.3128E-05  2.3092E-05
RADGASA  =  1.9354E-05  1.9345E-05  1.9336E-05  1.9327E-05  1.9319E-05  1.9311E-05  1.9302E-05  1.9295E-05  1.9287E-05  1.9272E-05
RADGASE  =  2.6278E-05  2.6269E-05  2.6260E-05  2.6252E-05  2.6243E-05  2.6235E-05  2.6227E-05  2.6219E-05  2.6211E-05  2.6196E-05
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DV       = -2.1434E-09  2.6095E-08  4.7206E-08  6.4440E-08  7.9026E-08  9.1621E-08  1.0265E-07  1.1241E-07  1.2113E-07  1.3607E-07
V        =  1.9355E-05  1.9331E-05  1.9312E-05  1.9295E-05  1.9279E-05  1.9265E-05  1.9251E-05  1.9238E-05  1.9226E-05  1.9204E-05
SURFACE EMISSIVITY =    .880
SURFACE TEMPERATURE =  300.000
RADVACA =  2.5077E-05  2.4962E-05  2.4883E-05  2.4819E-05  2.4764E-05  2.4714E-05  2.4670E-05  2.4629E-05  2.4591E-05  2.4522E-05
RADGASA =  2.0772E-05  2.0747E-05  2.0723E-05  2.0701E-05  2.0679E-05  2.0658E-05  2.0638E-05  2.0618E-05  2.0599E-05  2.0563E-05
RADGASE =  2.7697E-05  2.7672E-05  2.7648E-05  2.7625E-05  2.7603E-05  2.7582E-05  2.7562E-05  2.7543E-05  2.7524E-05  2.7487E-05
DV       = -8.7233E-09  6.1094E-08  1.0302E-07  1.3348E-07  1.5750E-07  1.7725E-07  1.9392E-07  2.0824E-07  2.2071E-07  2.4141E-07
V        =  2.0777E-05  2.0717E-05  2.0672E-05  2.0634E-05  2.0600E-05  2.0569E-05  2.0541E-05  2.0514E-05  2.0489E-05  2.0442E-05
SURFACE EMISSIVITY =    .880
SURFACE TEMPERATURE =  296.000
RADVACA =  2.2437E-05  2.2361E-05  2.2315E-05  2.2279E-05  2.2249E-05  2.2223E-05  2.2199E-05  2.2177E-05  2.2156E-05  2.2118E-05
RADGASA =  1.8590E-05  1.8572E-05  1.8556E-05  1.8540E-05  1.8526E-05  1.8512E-05  1.8498E-05  1.8486E-05  1.8473E-05  1.8450E-05
RADGASE =  2.5514E-05  2.5496E-05  2.5480E-05  2.5465E-05  2.5450E-05  2.5436E-05  2.5423E-05  2.5410E-05  2.5398E-05  2.5374E-05
DV       = -3.8366E-09  4.1621E-08  6.3659E-08  7.7635E-08  8.7821E-08  9.5818E-08  1.0238E-07  1.0791E-07  1.1267E-07  1.2048E-07
V        =  1.8592E-05  1.8551E-05  1.8524E-05  1.8501E-05  1.8482E-05  1.8464E-05  1.8447E-05  1.8432E-05  1.8417E-05  1.8390E-05

CALIBRATION OUTPUT PARAMETERS
TRANS    =  8.9319E-01
RADHOTC  =  3.0296E-05
RADCOLC  =  1.3627E-05
RADHOTV  =  3.5813E-05
RADCOLV  =  1.7151E-05
DVHOT    =  6.1833E-07
DVCOLD   = -5.8639E-07
VHOT     =  2.9987E-05
VCOLD    =  1.3920E-05
BALANCE OUTPUT PARAMETERS
RADHOT   =  3.7086E-05
RADCOLD  =  1.5933E-05
RADHOTG  =  3.0736E-05
RADCOLG  =  1.3206E-05
DVHOTB   =  2.8268E-09
DVCOLDB  =  2.8268E-09
VHOTB    =  3.0734E-05
VCOLDB   =  1.3205E-05
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LAYER 4
THE SPECTRAL LINE PROFILE IS LORENTZ

ATMOSPHERIC OUTPUT PARAMETERS
THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

	0.	1.0000E-07	2.0000E-07	3.0000E-07	4.0000E-07	5.0000E-07	6.0000E-07	7.0000E-07	8.0000E-07	1.0000E-06
TRANS =	8.1524E-01	8.0183E-01	7.9079E-01	7.8146E-01	7.7336E-01	7.6620E-01	7.5976E-01	7.5388E-01	7.4846E-01	7.3868E-01
TOTATM =	8.6745E-06	9.2558E-06	9.7314E-06	1.0132E-05	1.0478E-05	1.0782E-05	1.1056E-05	1.1305E-05	1.1534E-05	1.1946E-05
SURFACE EMISSIVITY =	.980									
TOTSUN =	4.6215E-07	4.3857E-07	4.2480E-07	4.1458E-07	4.0616E-07	3.9887E-07	3.9235E-07	3.8641E-07	3.8093E-07	3.7101E-07
SURFACE EMISSIVITY =	.880									
TOTSUN =	2.7729E-06	2.6314E-06	2.5488E-06	2.4875E-06	2.4370E-06	2.3932E-06	2.3541E-06	2.3184E-06	2.2856E-06	2.2261E-06
SURFACE EMISSIVITY =		.980								
SURFACE TEMPERATURE =		300.000								
TOTSURF =	4.7735E-05	4.6958E-05	4.6318E-05	4.5777E-05	4.5307E-05	4.4891E-05	4.4517E-05	4.4175E-05	4.3860E-05	4.3292E-05
TOTRAD =	5.6872E-05	5.6653E-05	5.6475E-05	5.6323E-05	5.6190E-05	5.6072E-05	5.5965E-05	5.5866E-05	5.5775E-05	5.5610E-05
SURFACE EMISSIVITY =		.980								
SURFACE TEMPERATURE =		296.000								
TOTSURF =	4.1545E-05	4.0869E-05	4.0312E-05	3.9841E-05	3.9432E-05	3.9070E-05	3.8745E-05	3.8448E-05	3.8174E-05	3.7679E-05
TOTRAD =	5.0682E-05	5.0563E-05	5.0469E-05	5.0387E-05	5.0316E-05	5.0251E-05	5.0193E-05	5.0139E-05	5.0088E-05	4.9997E-05
SURFACE EMISSIVITY =		.880								
SURFACE TEMPERATURE =		300.000								
TOTSURF =	4.2864E-05	4.2167E-05	4.1592E-05	4.1106E-05	4.0684E-05	4.0310E-05	3.9974E-05	3.9668E-05	3.9385E-05	3.8874E-05
TOTRAD =	5.4311E-05	5.4054E-05	5.3872E-05	5.3725E-05	5.3598E-05	5.3486E-05	5.3384E-05	5.3291E-05	5.3204E-05	5.3047E-05
SURFACE EMISSIVITY =		.880								
SURFACE TEMPERATURE =		296.000								
TOTSURF =	3.7306E-05	3.6699E-05	3.6199E-05	3.5776E-05	3.5408E-05	3.5084E-05	3.4791E-05	3.4524E-05	3.4278E-05	3.3834E-05
TOTRAD =	4.8753E-05	4.8586E-05	4.8479E-05	4.8395E-05	4.8323E-05	4.8259E-05	4.8201E-05	4.8147E-05	4.8098E-05	4.8007E-05

INSTRUMENT OUTPUT PARAMETERS
RADVACB = 4.0824E-05
RADGASB = 3.3833E-05
TAUA = 8.2869E-01
ERRON = 2.6392E-09
THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

	0.	1.0000E-07	2.0000E-07	3.0000E-07	4.0000E-07	5.0000E-07	6.0000E-07	7.0000E-07	8.0000E-07	1.0000E-06
TRANS =	8.4226E-01	8.4226E-01	8.4226E-01	8.4226E-01	8.4226E-01	8.4226E-01	8.4226E-01	8.4226E-01	8.4226E-01	8.4226E-01
SURFACE EMISSIVITY =		.980								
SURFACE TEMPERATURE =		300.000								
RADVACA =	2.6062E-05	2.5946E-05	2.5852E-05	2.5773E-05	2.5704E-05	2.5642E-05	2.5586E-05	2.5535E-05	2.5488E-05	2.5403E-05
RADGASA =	2.1588E-05	2.1565E-05	2.1542E-05	2.1520E-05	2.1499E-05	2.1478E-05	2.1457E-05	2.1437E-05	2.1418E-05	2.1379E-05
RADGASE =	2.8512E-05	2.8489E-05	2.8467E-05	2.8445E-05	2.8423E-05	2.8402E-05	2.8382E-05	2.8362E-05	2.8342E-05	2.8304E-05
DV =	-9.9065E-09	6.3264E-08	1.1850E-07	1.6243E-07	1.9841E-07	2.2852E-07	2.5415E-07	2.7628E-07	2.9563E-07	3.2792E-07
V =	2.1593E-05	2.1533E-05	2.1483E-05	2.1439E-05	2.1400E-05	2.1364E-05	2.1330E-05	2.1299E-05	2.1270E-05	2.1215E-05
SURFACE EMISSIVITY =		.980								
SURFACE TEMPERATURE =		296.000								
RADVACA =	2.3193E-05	2.3131E-05	2.3081E-05	2.3038E-05	2.3001E-05	2.2967E-05	2.2937E-05	2.2909E-05	2.2883E-05	2.2835E-05
RADGASA =	1.9216E-05	1.9204E-05	1.9192E-05	1.9180E-05	1.9168E-05	1.9157E-05	1.9146E-05	1.9135E-05	1.9125E-05	1.9104E-05
RADGASE =	2.6141E-05	2.6128E-05	2.6116E-05	2.6104E-05	2.6093E-05	2.6081E-05	2.6070E-05	2.6060E-05	2.6049E-05	2.6029E-05

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DV       = -3.7740E-09  3.5524E-08  6.4734E-08  8.8169E-08  1.0764E-07  1.2416E-07  1.3843E-07  1.5090E-07  1.6192E-07  1.8059E-07
V        =  1.9218E-05  1.9186E-05  1.9159E-05  1.9136E-05  1.9114E-05  1.9095E-05  1.9077E-05  1.9060E-05  1.9044E-05  1.9014E-05
SURFACE EMISSIVITY =    .880
SURFACE TEMPERATURE =   300.000
RADVACA =  2.4883E-05  2.4747E-05  2.4652E-05  2.4575E-05  2.4509E-05  2.4451E-05  2.4398E-05  2.4350E-05  2.4305E-05  2.4224E-05
RADGASA =  2.0610E-05  2.0581E-05  2.0552E-05  2.0526E-05  2.0500E-05  2.0475E-05  2.0451E-05  2.0428E-05  2.0405E-05  2.0362E-05
RADGASE =  2.7535E-05  2.7505E-05  2.7477E-05  2.7450E-05  2.7424E-05  2.7400E-05  2.7376E-05  2.7352E-05  2.7330E-05  2.7287E-05
DV       = -1.0501E-08  7.2720E-08  1.2342E-07  1.6032E-07  1.8926E-07  2.1288E-07  2.3265E-07  2.4951E-07  2.6410E-07  2.8814E-07
V        =  2.0615E-05  2.0544E-05  2.0491E-05  2.0445E-05  2.0405E-05  2.0369E-05  2.0335E-05  2.0303E-05  2.0273E-05  2.0218E-05
SURFACE EMISSIVITY =    .880
SURFACE TEMPERATURE =   296.000
RADVACA =  2.2307E-05  2.2219E-05  2.2163E-05  2.2119E-05  2.2082E-05  2.2049E-05  2.2019E-05  2.1991E-05  2.1965E-05  2.1918E-05
RADGASA =  1.8481E-05  1.8460E-05  1.8442E-05  1.8424E-05  1.8407E-05  1.8391E-05  1.8376E-05  1.8361E-05  1.8346E-05  1.8319E-05
RADGASE =  2.5405E-05  2.5385E-05  2.5366E-05  2.5348E-05  2.5331E-05  2.5315E-05  2.5300E-05  2.5285E-05  2.5271E-05  2.5244E-05
DV       = -4.9944E-09  4.7811E-08  7.5146E-08  9.3638E-08  1.0775E-07  1.1917E-07  1.2874E-07  1.3692E-07  1.4404E-07  1.5584E-07
V        =  1.8483E-05  1.8437E-05  1.8404E-05  1.8377E-05  1.8353E-05  1.8331E-05  1.8311E-05  1.8292E-05  1.8274E-05  1.8241E-05

CALIBRATION OUTPUT PARAMETERS
TRANS    =  8.9319E-01
RADHOTC  =  3.0296E-05
RADCOLC  =  1.3627E-05
RADHOTV  =  3.5813E-05
RADCOLV  =  1.7151E-05
DVHOT    =  6.1833E-07
DVCOLD   = -5.8639E-07
VHOT     =  2.9987E-05
VCOLD    =  1.3920E-05
BALANCE OUTPUT PARAMETERS
RADHOT   =  3.7086E-05
RADCOLD  =  1.5933E-05
RADHOTG  =  3.0736E-05
RADCOLG  =  1.3206E-05
DVHOTB   =  2.8268E-09
DVCOLDB  =  2.8268E-09
VHOTB    =  3.0734E-05
VCOLDB   =  1.3205E-05
```

APPENDIX C

Unit Conversion

The authors wish to note that in the past various units have been used to define the line intensities; therefore, the following conversion factors may be helpful.

At standard temperature and pressure condition, STP,

$$1\ (\text{cm-atm})_{STP} = 2.69 \times 10^{19}\ \text{molecules/cm}^2\ ;$$

however, at some temperature T' ,

$$1\ (\text{cm-atm})_{T'} = \frac{273.15\ K}{T'\ K} \times 2.69 \times 10^{19}\ \text{molecules/cm}^2$$

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