EOSAEL92

Volume 11

LARGE AREA SCREENING SYSTEMS APPLICATIONS MODULE LASS

R.E. Davis

Science and Technology Corporation
Las Cruces, NM 88005-1229
R.A. Sutherland

Battlefield Environment Directorate
Army Research Laboratory
White Sands Missile Range, New Mexico 88002-5501

DRAFT June 1993 DRAFT

ABSTRACT

The EOSAEL92 large area screening systems applications (LASS) module is an adaptation of a similar model originally developed through the support of the Joint Technical Coordinating Group/Munitions Expenditures Smoke and Aerosol Working Group for use in research on the effectiveness of smoke screens deployed at large fixed and semifixed military installations. The original impetus for the work was to develop a tool for the assessment of smoke screens, employed with other techniques of camouflage, concealment, and deception, as an electro-optical countermeasure against low-level nap-of-the-earth attack by high-performance aircraft. The outputs of the model are symbolic maps displaying the direct and diffuse components of scene transmission as affected by a large-area smoke screen. In principle, the digital maps can be used with appropriately scaled maps of any given fixed installation to asses the effectiveness of a smoke screen under various ambient meteorological an illumination conditions for various attack scenarios. The model is logically divided into two distinct parts: One that applies the Gaussian diffusion approximation to compute obscurant concentration path length, or CL product, and another that applies the plane parallel approximation to compute target-background contrast. The transport and diffusion algorithms are similar to those employed in other EOSAEL92 obscuration models, differing only in minor detail. The radiative transfer algorithms, however, are unique in the use of the extensive radiative transfer tables originally published by Van de Hulst, which are used together with novel scaling algorithms to account for effects of single and multiple scattering along arbitrary slant path and horizontal lines of sight. The model as thus far developed treats scattering processes only and is thus restricted to wavelength regions where absorption and thermal emission are negligible. The obscurant phase function is taken to be of the Henyey-Greenstein form and can account for various degrees of anisotropic scattering as well as isotropic scattering. The model accounts for scattering of the direct solar beam, uniform diffuse sky light, and diffuse reflection from the underlying (earth) surface.

Contents

1 TECHNICAL DOCUMENTATION **6**
1.1 Introduction . . . 6
1.2 Availability . . . 7
1.2.1 Mailing Address . . . 7
1.2.2 Phone and Electronic Mail . . . 7
1.3 Theory . . . 7
1.3.1 Transport and Diffusion . . . 8
1.3.2 Radiative Transfer . . . 10
1.4 Program Description . . . 15
1.4.1 Transport and Diffusion Routines (TD87L) . . . 15
1.4.2 Radiative Transfer Routines (RT87L) . . . 19

2 USER'S GUIDE **31**
2.1 Overveiw . . . 31
2.1.1 Coordinate Convention . . . 32
2.2 Input Data . . . 32
2.2.1 Input For The TDLASS Module . . . 34
2.2.2 Input For The RTLASS Module . . . 38
2.3 Examples of Use . . . 40
2.3.1 Example 1 . . . 41
2.3.2 Example 2 . . . 46
2.3.3 Example 3 . . . 50
2.3.4 Example 4 . . . 54
2.3.5 Example 5 . . . 59
2.3.6 Example 6 . . . 63
2.3.7 Example 7 . . . 67
2.3.8 Example 8 . . . 69
2.3.9 Example 9 . . . 71
2.3.10 Example 10 . . . 73

A RADIATIVE TRANSFER TABLES **75**

EOSAEL MODULES . . . 99

List of Figures

1.1 Coordinate Systems Used in the LASS Model. 10
1.2 Plots of the Henyey-Greenstein Phase Function for Various Values of the Asymmetry Parameter. 13
1.3 Subarray scheme used for mapping the composite grid. 19
1.4 R and T operators for $\mu_i = 0.1$. 23
1.5 R and T operators for $\mu_i = 0.3$. 24
1.6 R and T operators for $\mu_i = 0.5$. 25
1.7 R and T operators for $\mu_i = 0.7$. 26
1.8 R and T operators for $\mu_i = 0.9$. 27
1.9 R and T operators for $\mu_i = 1.0$. 28
1.10 R and T operators first moments, UR and UT. 29
1.11 R and T operators second moments, URU and UTU. 30

2.1 Sketch illustrating relationship between a user coordinate system and the north-east system. . 33

A.1 Sketch demonstrating the format used in generating the radiative transfer tables. 76

List of Tables

2.1 The `SCEN` Card . . . 34
2.2 The `LINE` Card . . . 35
2.3 The `SRCD` Card . . . 35
2.4 The `MET1` Card . . . 35
2.5 The `CMAP` Card . . . 36
2.6 The `PLOT` Card . . . 37
2.7 The `SRCL` Card . . . 37
2.8 The `OPTN` Card . . . 37
2.9 The `OBSC` Card . . . 38
2.10 The `SOLR` Card . . . 38
2.11 The `ALBO` Card . . . 39
2.12 The `RTAZ` Card . . . 39

A.1 Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.000) . . . 77
A.1 Cont. . . . 78
A.2 Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.250) . . . 79
A.2 Cont. . . . 80
A.3 Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.500) . . . 81
A.3 Cont. . . . 82
A.4 Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.750) . . . 83
A.4 Cont. . . . 84
A.5 Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.875) . . . 85
A.5 Cont. . . . 86
A.6 Single-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.000) . . . 87
A.6 Cont. . . . 88
A.7 Single-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.250) . . . 89
A.7 Cont. . . . 90
A.8 Single-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.500) . . . 91
A.8 Cont. . . . 92
A.9 Single-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.750) . . . 93
A.9 Cont. . . . 94

A.10 Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.875) 95
A.10 Cont. 96

Chapter 1

TECHNICAL DOCUMENTATION

1.1 Introduction

The EOSAEL92 LASS module is based upon the physical principles and mathematical techniques outlined in a special report published by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). [Sutherland and Fowler, 1985] The original purpose for developing the model was to assist in modeling the effectiveness of smoke screens used in concert with other conventional methods of camouflage, concealment, and deception (CCD) as employed at large fixed and semifixed military installations such as air bases, air fields, and ammunition supply points.

An earlier version of the model entitled Gaussian Large-Area Screening Systems (GLASS) [Davis, 1984] contained only transport and diffusion algorithms to calculate direct transmittance over arbitrary lines of sight (LOS) through smoke screens created by conventional M3A3 fog oil generators. This earlier version of the model was used as a real-time decision and planning aid at subsequent field tests conducted at the Yakima Firing Center, Washington,[Sutherland, 1985] and at Eglin Air Force Base, Florida. [Farmer *et al.*, 1984] [Williams *et al.*, 1985] The current LASS model contains a more general version of these same transport and diffusion transmission, which in turn is used to compute target-background contrast reduction. The model is unique among smoke models in the treatment of single and multiple scattering based upon an extension and refinement of the radiation tables originally published by Van de Hulst. [de Hulst, 1980]

For cases other than horizontal propagation, the output of the LASS model is a "digital map" giving values of either optical depth, cloud radiance, surface irradiance, or contrast transmission along various vertical or slant path directions. These values are provided over the entire modeled smoke screen produced by an arbitrary deployment of fog oil generators. For the special case of horizontal propagation, no digital map is produced, and the model gives data for only the single target-observer path specified by the user. This single-path option can also be employed for any user-selected LOS. As currently programmed, the model explicitly treats only conventional M3A3 for oil generators but can treat any semicontinuous source provided that the appropriate source characteristics are supplied as input by the user. The model treats only scattering and is thus restricted to wavelengths where absorption and thermal emission are nominally insignificant, that is, to the visible and near-infrared wavelengths. In treating radiative transfer, the model uses the plane-parallel approximation, which in turn implies a smoke screen of large (strictly infinite) horizontal extent. This is a reasonable approximation for a large-area screen.

The LASS computer program is written in two parts. The first part, TD87L, treats only transport and diffusion in the Gaussian approximation and computes the obscurant path-integrated concentration. The second part, RT87L, treats multiple scattering. The TD87L routine can be used in a stand-alone mode to produce a digital map of path-integrated concentration in the wind-aligned coordinate system. These maps can then be rotated for any wind direction and then superimposed over any ground scene of interest. The RT87L model uses the output of TD87L as input and adds the effects of single and multiple scattering by using the scaling laws and the Van de Hulst radiation tables. [de Hulst, 1980] The output of RT87L is a

digital map giving either contrast transmission, cloud radiance, or downward-directed surface irradiance. The RT87L model can be exercised with various optional inputs to determine the effects of solar angle, solar flux density, sky radiance, surface albedo, etc., without needing to rerun the TD87L routine.

Both TD87L and RT87L contain printer plot routines. However, both models output numerical arrays that can be used with a wide variety of commercial plotting software, including video monitors. Software for more sophisticated plotting techniques is not supplied, in order to keep the program machine independent. Both routines can be executed on desktop computers such as the IBM PC or the Zenith Z-100 with little or no program modification, but at least 640 kbytes of memory are required to handle the large data arrays used by the programs.

1.2 Availability

EOSAEL92 is available to U.S. Government Agencies, specified allied organizations, and their authorized contractors at no cost. U.S. Government agencies needing EOSAEL92 should send a letter of request, signed by a branch chief or division director, to US Army Research Laboratory ARL. Contractors should have their Government contract monitor send the letter of request. Allied organizations must request EOSAEL92 through their national representative.

Please include, within security restrictions, your intended use(s). Also, indicate what type of nine-track tape your computer can read. We can make "ASCII" tapes, and UNIX "tar" format tapes in either 1600 or 6250 bpi. We can also make SUN cartridge tapes We can't supply EOSAEL92 on other media. Documentation for the modules is included.

The EOSAEL92 point of contact at ARL is Dr. Alan Wetmore.

1.2.1 Mailing Address

DIRECTOR EXECUTIVE
Battlefield Environment Directorate
Army Research Laboratory
ATTN: AMSRL-BE-M (EOSAEL)
White Sands Missile Range, New Mexico 88002-5501

1.2.2 Phone and Electronic Mail

(505) 678-5563
FAX (505) 678-2432
DSN 258-5563
`awetmore@curie.arl.army.mil`

1.3 Theory

As noted in the previous section, the LASS model is logically divided into two sections: one treating obscurant transport and diffusion and the other treating radiative transfer. The transport and diffusion algorithms are based upon the well-known Gaussian approximation and differ little from algorithms used in other smoke obscuration models such as the EOSAEL combined obscuration model for battlefield-induced contaminants (COMBIC) model. [Hoock *et al.*, 1984] However, the radiative transfer treatment uses specially developed scaling laws and the Van de Hulst radiation tables [de Hulst, 1980] to treat the problem of multiple scattering in the plane-parallel approximation. This treatment is unique to the LASS model. Since specific details of the procedure are given in chapters III and IV of the Joint Technical Coordinating Group (JTCG) special report, [Sutherland and Fowler, 1985] only a cursory description is given here.

1.3.1 Transport and Diffusion

The basic problem addressed in the transport and diffusion methodology is to determine the obscurant path-integrated concentration, or CL product, along a path of propagation defined in terms of some hypothetical target-observer pair. The mathematical expression defining the CL product in terms of the obscurant mass concentration, χ, over a total path of length, or range, R, is written as

$$CL(R;\alpha,\beta,\gamma) = \int_0^R \chi(r;\alpha,\beta,\gamma)dr, \tag{1.1}$$

where $\chi(r;\alpha,\beta,\gamma)$ is the obscurant concentration measured along the direction defined by the line parameters α,β,γ, at a distance r from some suitably chosen origin, usually designated the target location. The line parameters α,β,γ are defined in terms of the observer-target Cartesian coordinated from simple geometry as

$$\alpha = \frac{X_0 - X_t}{R} = \sin(\theta)\sin(\phi) \tag{1.2}$$

$$\beta = \frac{y_0 - y_t}{R} = \sin(\theta)\cos(\phi) \tag{1.3}$$

$$\gamma = \frac{z_0 - z_t}{R} = \cos(\theta), \tag{1.4}$$

where R is the total observer-target range, and θ and ϕ are, respectively, the zenith and azimuth directions of the path of propagation. In equations 1.2,1.3, and 1.4, coordinates subscripted "o" denote the observer location, and coordinates subscripted "t" denote the target location.

The obscurant mass concentration, assuming a continuous source located at the origin, is modeled in the Gaussian approximation as

$$\chi(r;\alpha,\beta,\gamma) = \sum_{i=0}^{N_0} \left[\chi_i^+(r;\alpha,\beta,\gamma) + \chi_i^-(r;\alpha,\beta,\gamma)\right], \tag{1.5}$$

where

$$\chi_i^{\pm}(r;\alpha,\beta,\gamma) = \frac{(2\pi)^{-1}Qf(r')}{u\sigma_y(r')\sigma_z(r')}\exp - \left[\frac{1}{2}\left(\frac{\beta_r + y_t}{\sigma_y(r')}\right)^2 + \frac{1}{2}\left(\frac{\mu_r + z_t \pm z_i}{\sigma_z(r')}\right)^2\right] \tag{1.6}$$

$$r' = \alpha r + x_t - x_0 \tag{1.7}$$

$$z_i = z(r') - 2iH_m, \tag{1.8}$$

where Q is the source mass emission rate, u is the mean windspeed, and H_m is the boundary layer mixing height. In this form, the model accounts for effects of the finite mixing height through the image, or reflection, terms denoted by subscript i. The diffusion functions σ_x and σ_z account for atmospheric diffusion and are modeled using the usual power law parameterization as

$$\sigma_i(r') = \sigma_i(0) + a_i(r')^{b_i}; i = x, y, z, \tag{1.9}$$

where $\sigma_i(0)$, the "source sigma," is related to the source size, and the diffusion coefficients, a_i and b_i, are functions of the atmospheric stability and are well documented elsewhere. [Sutherland and Fowler, 1985] [Hoock *et al.*, 1984]

In equation 1.6, the function $f(r')$ is included to account approximately for atmospheric scavenging and obscurant evaporation and is modeled using the following empirical relationship: [Hoock *et al.*, 1984]

$$f(r') = e^{-gr'/u}\left[a + (1-a)e^{-br'/u}\right]. \tag{1.10}$$

In this equation, the first exponential expression accounts for atmospheric-scavenging, and the expression inside the brackets accounts for obscurant evaporation. For fog oil, the scavenging factor, $g(s^{-1})$, is assumed

zero, and the evaporation parameters, a (dimensionless) and $b(s^{-1})$, are taken to be 0.650 and 0.000333, respectively.

The plume vertical centerline coordinate, $z(r')$, is modeled accounting for momentum rise by the following expression, strictly valid only for neutral stability, as

$$z(r') = z_0 + \frac{kU^* r'}{u}, \tag{1.11}$$

where z_0 is the source height, k is the von Karman constant (~ 0.40), U^* is the friction velocity, and u is the mean windspeed. Effects of source buoyancy are assumed negligible.

As written here, the expression for the Gaussian plume given by equations 1.6, 1.7, and 1.8 refer to a coordinate system aligned such that the positive x-axis is downwind, the y-axis is crosswind, and the z-axis is vertical. The calculations in the LASS model are performed in this "wind-aligned" system. For convenience, however, all user input coordinates can bye referenced with respect to any convenient right-handed Cartesian coordinate system specified by an x-axis heading referenced clockwise from north. A transformation to a north-oriented geographic coordinate system defined with the positive x-axis directed eastward and the positive y-axis directed northward is then made internally. All angular data, including the user-defined x-axis heading, the wind direction azimuth, and the solar azimuth, are referenced positive clockwise with respect to north. An example of the coordinate systems used in the model is sketched in figure 1.1. Note from figure 1.1 that the wind direction azimuth is defined as the direction from which the wind is blowing and should not be confused with the wind vector, which is defined as the direction toward which the wind is blowing.

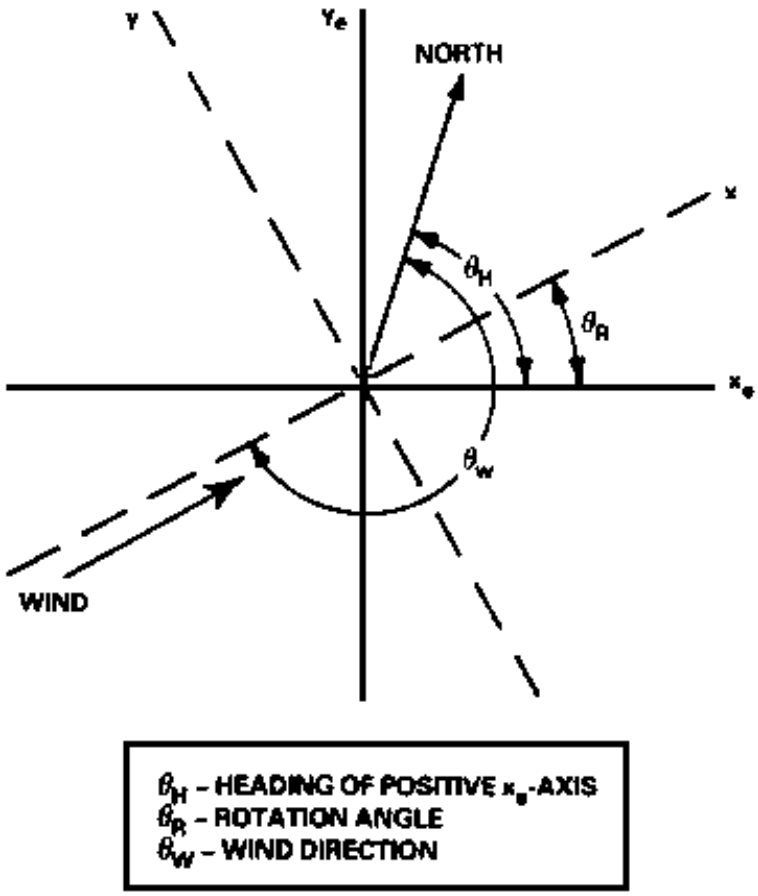


Figure 1.1: Coordinate Systems Used in the LASS Model.

1.3.2 Radiative Transfer

The major problem addressed by the LASS radiative transfer routine is the computation of the total radiance, including both the direct and diffuse components, propagated along some specific target-observer path.

The computation of the direct component is straight forward and requires only an application of the well-known Beer-Bouguer-Lambert law. For computing the directly transmitted component propagated along a straight line between some hypothetical target (or background) and observer, the appropriate expression is

$$I^0(R_0;\mu,\phi) = I(R_t;\mu,\phi)e^{-\tau}, \tag{1.12}$$

where the superscript "0" denotes the direct or "zero order" component, $I(R_t;\mu,\phi)$ is the radiance emanating from the target (or background) surface at location R_t, and $I^0(R_t;\mu,\phi)$ is the directly transmitted radiance received at the observer location, R_0. The angular coordinates θ ($\mu =\mid \cos(\theta) \mid$) and ϕ denote the direction of the target-observer path of propagation, and τ is the obscurant optical thickness between the points denoted by coordinates R_0 and R_t. The optical thickness is computed from the obscurant mass extinction coefficient, α, and the CL product, defined in the previous section, according to the relationship $\tau = \alpha CL$.

The radiance expressed by equation 1.12 represents that portion of the total radiation field that reaches the observer directly without undergoing any interaction with the intervening medium and is hence termed the direct or zeroth-order component. The diffuse component is composed of all single and higher orders

that occur by scattering of ambient radiation from the sun, sky, and surface into the target-observer path of propagation. The remainder of this section describes the method used for computing the diffuse component.

Exact methods for computing the diffuse radiance, even under the simplifying assumption of a Gaussian concentration distribution, are currently beyond the state of the art, except through computer-intensive numerical techniques that are impractical for EOSAEL purposes. To account from these important effects, we employ the plane-parallel approximation, wherein the obscurant concentration is assumed to be horizontally uniform but vertically stratified; this approximation is reasonably valid for actual large-area smoke screens. In the plane-parallel approximation, the equations for computing the diffuse component, accounting for all single and higher orders of scattering, are written in terms of the diffuse transmission and reflection operators (R, T) and moments (UR, UT) for the three distinguishing cases of upward $(+\mu)$, downward $(-\mu)$, and horizontal $(\mu = 0)$ propagation as

UPWARD:

$$I^*(B; +\mu, \phi) = \frac{\mu_0 F_0}{\pi} R(B; \mu, \phi, \mu_0, \phi_0) + \frac{D_0}{\pi} UR(B; \mu) + A_0 \frac{G\downarrow}{\pi} UT(B; \mu) \tag{1.13}$$

DOWNWARD:

$$I^*(B; -\mu, \phi) = \frac{\mu_0 F_0}{\pi} T(B; \mu, \phi, \mu_0, \phi_0) + \frac{D_0}{\pi} UT(B; \mu) + A_0 \frac{G\downarrow}{pi} UR(B; \mu) \tag{1.14}$$

HORIZONTAL

$$I^*(B; 0, \phi) = [1 - e^{-\tau}] \left[\frac{\mu_0 F_0}{\pi} T(B; \mu, \phi, \mu_0, \phi_0) + \frac{D_0}{\pi} UT(B; 0) + \frac{G\downarrow}{pi} UR(B; 0) \right], \tag{1.15}$$

where B is the total vertical optical depth of the screen and, as before, θ $(\mu =| \cos(\theta) |)$ and ϕ are the directional coordinates of the target-observer path of propagation. Other quantities are the solar beam normal irradiance, F_0; the solar zenith θ_0, $(\mu_0 =| \cos(\theta_0) |)$, and azimuth, ϕ, coordinates; the F_0; the solar zenith θ_0, $(\mu_0 =| \cos(\theta_0) |)$, and azimuth, ϕ, coordinates; the diffuse sky irradiance, D_0 (assumed uniform and isotropic); the surface albedo, A_0; and the downward-directed surface irradiance, $G\downarrow$. In each of the above expressions, the first term on the right accounts for scattering of the direct solar beam radiation, the second term accounts for scattering of uniform diffuse sky radiation, and the third term accounts for Lambertian reflection from the underlying (earth) surface. The first two expressions are also understood to apply to propagation through the entire screen, and the third applies to a finite horizontal path of total optical thickness, τ, located at the bottom of the screen.

The downward-directed hemispherical surface irradiance, $G\downarrow$, appearing in the last term of each of the above expressions, must be computed in the presence of the screen and is not assumed to be known beforehand by the user. $G\downarrow$ can be expressed in closed form by introducing the second moments (URU, UTU), in which case we have [Sutherland and Davis, 1986]

$$G\downarrow = \frac{\mu_0 F_0 e^{-B/\mu_0} + 2D_0 E_3(B) + \mu_0 F_0 UT(B; \mu_0)/\pi + D_0 UTU(B)/\pi}{[1 - A_0 URU(B)/\pi]}, \tag{1.16}$$

where $E_3(B)$ is the well-known exponential integral, which can be evaluated by using any of several numerical techniques. [Sutherland and Fowler, 1985] For later purposes, a definition of the total upward hemispherical irradiance incident at the extreme top of the screen is useful:

$$G\uparrow = \frac{\mu_0 F_0}{\pi} UR(B; \mu_0) + \frac{D_0}{\pi} URU(B) + \frac{G\downarrow}{\pi} UTU(B). \tag{1.17}$$

The key in applying the above expressions to practical problems lies in the evaluation of the diffuse transmission and reflection operators and moments $(R, T, UR, UT, URU,$ and $UTU)$. In the most general case, and even in the plane-parallel approximation, the determination of these functions is involved and cumbersome. The approach used in the LASS model lies in the application of precalculated radiative transfer

tables originally conceived by Van de Hulst, [de Hulst, 1980] extended for the single-scattering case by Sutherland [Sutherland, 1986] and for the multiple-scattering case by Durack and Giever, [Durack and Giever, 1987] and summarized in an earlier work by Sutherland and Fowler. [Sutherland and Fowler, 1985] The tables are based upon azimuth-averaged solutions to the radiative transfer equation obtained in the plane parallel approximation assuming a Henyey-Greenstein form for the scattering phase function. The tables are composed of two sets: one treating multiple scattering and the other treating the component due to single scattering. A more complete description and listing of the tables are given in appendix A.

The tables as used here give only azimuth-averaged solutions and contain no information on the azimuth dependence of the diffuse radiance. In the LASS model, unique scaling algorithms are incorporated that essentially extend the utility of the tables to include the azimuth dependence by using the intuitive assumption that all higher order scattering is essentially isotropic, and hence, the azimuth dependence can be approximated as due to the single-scattered component only. This means that the azimuth dependence can be approximated by first subtracting out the azimuth-averaged single-scattering contributions from the tables and then adding back the azimuth-dependent single-scattering contributions. This idea is particularly attractive because the single-scattering azimuth-dependent operators can be easily calculated. With the scaling laws so incorporated, the full azimuth-dependent reflection/transmission operators are given as:

$$R(g,B;\mu,\phi,\mu_0,\phi_0) = R_{ss}(g,B;\mu,\phi,\mu_0,\phi_0) + \left[R^m(g,B;\mu,\mu_0) - R^1(g,B;\mu,\mu_0)\right] \tag{1.18}$$

$$T(g,B;\mu,\phi,\mu_0,\phi_0) = T_{ss}(g,B;\mu,\phi,\mu_0,\phi_0) + \left[T^m(g,B;\mu,\mu_0) - T^1(g,B;\mu,\mu_0)\right] \tag{1.19}$$

where the superscript 1 denotes the first-order azimuth-averaged solutions, and superscript m denotes the full multiple-scattering azimuth-averaged solutions–both of which are obtained from the lookup tables listed in mission operators, R_{ss} and T_{ss}, are given by

$$R_{ss}(g,B;\mu,\phi,\mu_0,\phi_0) = \frac{1}{4}\frac{1}{\mu+\mu_0}P(g,\mu,\phi,\mu_0,\phi_0)\left\{1-\exp\left[-\left(\frac{1}{\mu_0}+\frac{1}{\mu}\right)B\right]\right\} \tag{1.20}$$

$$T_{ss}(g,B;\mu,\phi,\mu_0,\phi_0) = \frac{1}{4}\frac{1}{\mu-\mu_0}P(g,\mu,\phi,\mu_0,\phi_0)e^{-B/\mu_0}\left\{1-\exp\left[-\left(\frac{1}{\mu_0}+\frac{1}{\mu}\right)B\right]\right\} \tag{1.21}$$

where $P(g;\mu,\phi,\mu_0,\phi_0)$ is the azimuth-dependent Henyey-Greenstein form of the optical phase function given by [Sutherland, 1986]

$$P(g;\mu,\phi,\mu_0,\phi_0) = \frac{(1-g)^2}{(1+g^2-2g\cos\psi)^{3/2}}. \tag{1.22}$$

In this expression, g is the asymmetry parameter and ψ is the scattering angle, which in turn is computed from simple geometry as

$$\cos\psi = \left[\mu\mu_0 + \left(1-\mu^2\right)^{\frac{1}{2}}\left(1-\mu_0^2\right)^{\frac{1}{2}}\right]\cos(\phi-\phi_0). \tag{1.23}$$

Several plots of the Henyey-Greenstein phase function for various values of the asymmetry parameter are shown in figure 1.2. Note from figure 1.2 that for $g = 0$ the scattering is isotropic and that the degree of skewness showing increased scattering in the forward direction increased scattering in the forward direction increases with increasing values of the asymmetry parameter. At visible wavelengths, an asymmetry value $g = 0.750$ to $g = 0.875$ is appropriate for most of the inventory screening smokes, including fog oil that is used with the M3A3 generator.

The scaling of the azimuth dependence is surprisingly accurate, and some examples showing the magnitude of the azimuth dependence and a more complete description of the algorithm are reported by Sutherland and Davis. [Sutherland and Davis, 1986]

With the aid of the radiation tables, the azimuth scaling algorithm, and the appropriate user input, the computation of the diffuse component is straight-forward using equations 1.13, 1.14, and 1.15. The total radiance reaching the observer is then the sum of the direct and diffuse components. In the model, the target

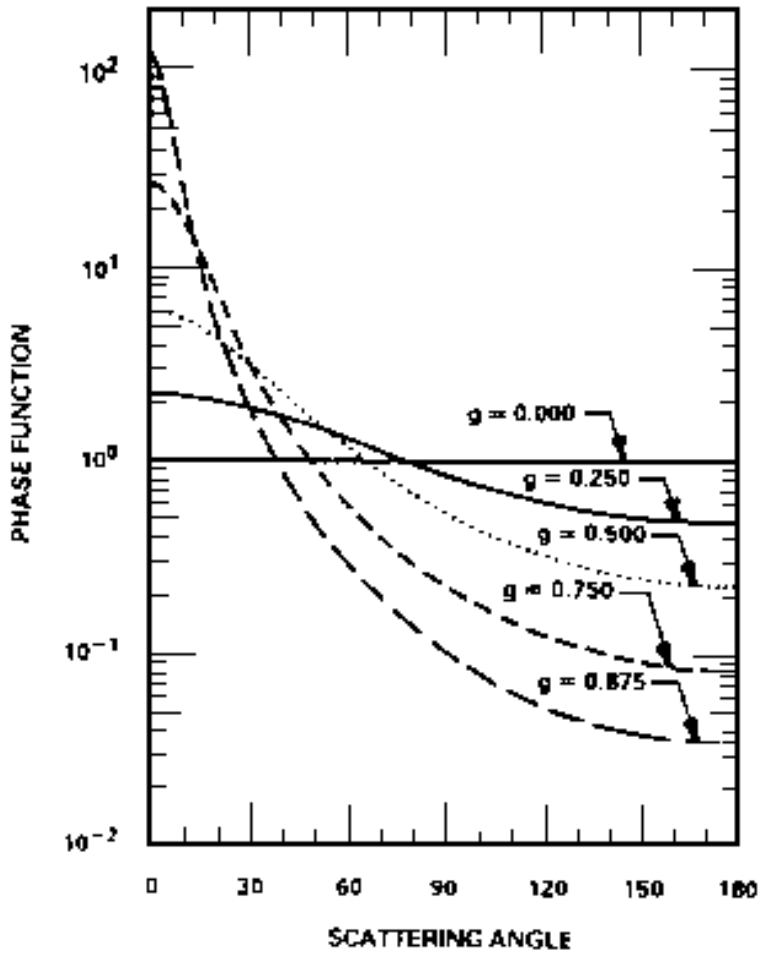


Figure 1.2: Plots of the Henyey-Greenstein Phase Function for Various Values of the Asymmetry Parameter.

(or background) is assumed to be a nonemitting Lambertian reflecting surface, in which case the radiance is due to reflection of the ambient radiation (sun, sky, and surface) and is given simply by:

$$I(R_t;\mu,\phi) = A_t \frac{G(R_t)}{\pi}, \tag{1.24}$$

where A_t is the target reflectivity, or albedo, and $G(R_t)$ is the total hemispherical irradiance at the target surface. As indicated in the notation, the radiance, under the Lambertian assumption, is uniform and isotropic. The total radiance reaching an observer from the direction of a Lambertian surface is now written in the plane-parallel approximation for the three cases of upward, downward, and horizontal propagation as

UPWARD:

$$I(R_0;+\mu,\phi) = A_t \frac{G\downarrow}{\pi} e^{-B/\mu} + I^*(B;+\mu,\phi), \tag{1.25}$$

DOWNWARD:

$$I(R_0;-\mu,\phi) = A_t \frac{G\uparrow}{\pi} e^{-B/\mu} + I^*(B;-\mu,\phi), \tag{1.26}$$

HORIZONTAL:

$$I(R_0;0,\phi) = A_t \frac{G\downarrow}{\pi} e^{-\tau} + I^*(B;0,\phi), \tag{1.27}$$

where the diffuse component, denoted by superscript (*), is calculated by appropriate use of the tables and equations 1.13–1.15 and 1.18–1.19. As before, the first two expressions apply to propagation through the entire screen, and the third expression applies to a finite horizontal path of optical thickness, τ, located at the extreme bottom of the screen. Also, in the first and last expressions, the target is assumed to be located at the extreme bottom of the screen (at the surface). In the second expression, the target is assumed to be located at the extreme top of the screen.

In target acquisition applications, the usual procedure is to apply the above expressions to both a target-observer and a background-observer path of propagation. The resulting expressions are then used to compute a quantity called the contrast transmission, which is essentially the ratio of the target-to-background contrast as perceived at the target location to the contrast perceived at the observer location. After some intermediate manipulation described in the word of Sutherland and Fowler, [Sutherland and Fowler, 1985] the contrast transmission can be expressed as

$$T_c(+\mu,\phi) = \left[1 + \frac{D^*(+\mu,\phi)}{A_b \exp(-\tau)}\right]^{-1}, \tag{1.28}$$

where A_b is the background albedo and τ is the path of propagation optical thickness. The factor $D^*(+\mu,\phi)$ is called the Duntley factor, after the pioneering work of S.Q. Duntley, [Duntley, 1948] and is written in terms of the diffuse radiance and hemispherical irradiance as

$$D^*(+\mu,\phi) = \frac{I^*(+\mu,\phi)}{G\downarrow/\pi} \tag{1.29}$$

$$D^*(-\mu,\phi) = \frac{I^*(-\mu,\phi)}{G\uparrow/\pi} \tag{1.30}$$

$$D^*(0,\phi) = \frac{I^*(0,\phi)}{G\downarrow/\pi}, \tag{1.31}$$

where the various radiation quantities can be calculated from appropriate application of the LASS equation. For a long horizontal path through the natural (unsmoked) atmosphere, the term in the numerator of the last expression of equations 1.29, 1.30, and 1.31 is simply the equilibrium sky radiance; the term in the denominator, multiplied by the surface albedo A_0, is the surface upwelling irradiance and is therefore sometimes referred to as the "sky-to-ground ratio." This quantity is often used as input to military target acquisition models.

1.4 Program Description

The LASS computer model includes two distinct programs:

1. One that treats obscurant transport and diffusion (TD87L) and,
2. One that treats radiative transfer (RT87L).

For slant-path and vertical LOS, these routines produce digital maps of the modeled smoke screen. For the special case of horizontal propagation, or through a user-selected option, the modules produce results for only a single LOS as defined through user input. The transport and diffusion routine, TD87L, can be used as a stand-alone code for calculating either the path-integrated concentration (CL product), the optical thickness, or transmittance along parallel paths. The CL output of TD87L is required for input into RT87L. In principle, any CL map generated by other models providing the appropriate output format could be used by the RT87L program.

Both programs are written in ANSI FORTRAN 77 with particular attention given to operation on a desktop computer using a DOS-type operating system. However, since the programs contain large arrays and produce large data files, a hard disk and at least 640 kbytes of memory are recommended for operation on desktop systems.

Because the output consists of digital maps, the only practical means for displaying the results is by plotting them. Since plotting routines are necessarily hardware/software dependent, only printer plot routines have been included in these modules. This approach, although crude, has the advantage of providing plot outputs to every user with access to a printer. If the user has more sophisticated plotting hardware and software available, the output files can, of course, be used as input to create much higher-resolution gray-level displays or contour plots as the user desires.

1.4.1 Transport and Diffusion Routines (TD87L)

The basic function of the TD87L routine is to perform the line integrations defined by equation 1.1, which essentially defines the obscurant path-integrated concentration or CL product. For the completely general case, this integration can become quite cumbersome and complex since it is dependent upon cloud geometry, terrain, wind variations, and other environmental influences. To make the problem more tractable, a number of simplifying approximations are made. The first of these is that the obscurant dispersion can be described by the steady-state Gaussian diffusion approximation of equations 1.5–1.8 under the assumption of uniform flat terrain and a constant wind field. These simplifying assumptions allow analytical solutions in some restricted scenarios and greatly reduce computer resource requirements.

For the special cases of crosswind and vertical LOS, the integrations can be performed analytically, and the results can be expressed in terms of the well-known error function. [Sutherland and Fowler, 1985] For the more general situations, however, numerical techniques that greatly increase computation time are required.

The model can treat any reasonable number of sources deployed at arbitrary locations and can, in fact, also treat a single source. However, the radiative transfer calculations are most accurate for those scenarios involving a large number of sources deployed along a nearly straight line. For these scenarios, the plane-parallel approximation is most appropriate. Regardless of the number of sources, the TD87L routine begins by calculating a single-source cloud. The single solutions are then superimposed to produce a digital map of the entire screen.

The following sections briefly describe each of the subroutines used by the TD87L routine. The user's guide (chapter 2) provides more detailed information concerning specific inputs and user options.

Subroutine TDLASS (driver)

The subroutine `TDLASS` is called from the `DRV011` program or from your program. It serves as the executive manager for the transport and diffusion calculations, directing the sequence of code progression as defined

by user options. This driver also initializes key variables, opens input and output files, and calls for the execution of relevant subroutines.

Subroutine RDATA

The `RDATA` subroutine reads in all the user-supplied data necessary for creating the example run and directing the TD87L calculations. The user input is accomplished through the standard EOSAEL card image format. Input data for the TD87L calculations include observer, target, and obscurant source locations; meteorological parameters; obscurant definition; source characteristics; desired spatial resolution of calculations; and user options. The user's guide (chapter 2) provides a complete description of the input requirements and variables.

Subroutine CALUSTR

For a passive, that is, nonbuoyant and non-settling obscurant, there will generally be an upward drift of the plume vertical centroid due to wind shear and the vertical gradients of the diffusion coefficients. This upward "momentum rise" velocity is considered to be constant using similarity theory and can be accounted for in the TD87L by using an algorithm given by Sutherland and Fowler. [Sutherland and Fowler, 1985] A key parameter in this algorithm is the friction velocity, usually designated by U^*. The subroutine `CALUSTR` is responsible for computing this parameter using the technique described by Sutherland et al. [Sutherland *et al.*, 1986]

Subroutine VCL

The `VCL` subroutine calculates CL for the special case of vertical LOSs using an analytical solution for a Gaussian plume. Calculations are performed over a number of parallel LOSs up to the 15,000 required by the user-specified spatial resolution and downwind range. If CL calculations are required for more than 15,000 LOSs, the subroutine returns an error message stating that too many values are required for the storage array.

This routine creates a vertical view CL map for a single source. These data, the CL values along the vertical LOSs, are then passed to the subroutine `MLASS` via the array "CL" for construction of the overall LASS. As stated above, it is implicitly assumed that all individual source clouds are identical and that linear superposition of overlapping clouds is valid. The function routines `ACOEFF`, `DCOEFF`, and `CCOEFF` are called by `VCL` for the CL calculations.

Subroutine CLCALC

The `CLCALC` subroutine performs CL calculations for nonvertical LOSs. The CL values in this subroutine are computed with numerical integrations. The subroutine is capable of computing CL along any zenith angles. This restriction is established to ensure that the output is consistent with RT87L input requirements. TD87L could easily be modified to produce data for LASS clouds viewed from any zenith angle if the user so requires.

In performing the calculations, `CLCALC` begins with the LOS termination in the x-y plane at a z coordinate defined by the user-entered z value of the target, usually $z = 0.0$, and on the centerline of the wind-aligned system. The CL computed first is for an LOS terminating one resolution element downwind of the source. The LOS azimuth and zenith angles are defined by the user inputs of target and observer positions on the `SCEN` card. All LOSs are parallel to this initially defined LOS. The observer is always considered completely above the LASS and is, for computational purposes, established at the mixing height.

The CL calculations proceed bye resetting the target one resolution element in the negative y, that is, crosswind direction. The target is repeatedly moved in the negative y direction until a CL is calculated that is below the threshold value defined by the user. The target is then moved one resolution from the centerline in the positive y direction and the calculations are repeated in the same manner in which they were performed on the negative y side of the centerline.

After the threshold CL value is reached in the positive y direction, the next target is then moved on resolution element downwind along the centerline; that is, the x-axis and the procedures are repeated. The downwind limit is defined by the user on the input cards.

As the `VCL`, the CL values calculated by `CLCALC` are passed on a `MLASS` for construction of the overall LASS. `CLCALC` calls subroutine `ROMB` to perform the actual numerical integrations and function routines `ACOEFF`, `DCOEFF`, and `CCOEFF` for the dispersion coefficient calculations.

Subroutine SINGCL

The subroutine `SINGCL` calculated CL if a single LOS, rather than an LASS map, is specified by the user. This subroutine is used the majority of the time for the calculation of CL for a horizontal LOS since no map is generated when this option is selected. `SINGCL` uses the same algorithms as `CLCALC` for computing CLs, calling subroutine `ROMB` for the numerical integrations.

Functions ACOEFF, DCOEFF, and CCOEFF

Functions `ACOEFF`, `DCOEFF`, and `CCOEFF` provide the power law coefficients necessary for the calculation of the atmospheric diffusion functions. The power law coefficients, a_i and b_i, are Functions of the Pasquill stability category and surface roughness and are calculated using techniques identical to those used in EOSAEL COMBIC. [Hoock *et al.*, 1984]

Subroutine ROMB

Subroutine `ROMB` performs the numerical line integrations for CL using a Romberg integration algorithm. [Carnahan *et al.*, 1969] The Romberg integration routine first estimates the value of the integral by using the interval endpoints, that is, the concentration at the target and observer positions. This initial estimate is then refined by making repeated use of the trapezoidal rule in sequential steps as the integration interval is repeatedly divided in half. The computed CL value for a given integration trial, that is, integration performed for a defined interval between points, is compared with the value computed in the previous trial integration in which the integration intervals were twice as large. This procedure is repeated until the difference between computed CLs is equal to or less than 1 percent. This threshold of 1 percent can easily be changed by modifying the conditional comparative statements in `ROMB`.

The repeated halving of the integration step sizes is accomplished by dividing the LOS defined by the target and observer positions by 2^N, where N is increased by 1 each time the integral is reevaluated. Since the target and observer may be widely separated when large zenith angles are considered, no integral value comparisons are made until after the $N = 6$ integration has been made. This procedure prevents premature termination of the integration due to situations in which negligible contributions to the integral are made while the integration intervals are large. If no convergence of the CL value has been accomplished by $N = 14$ integrations, the halving is terminated. This $N = 14$ limit has been set for several reasons. First, most computing machines anticipated to run TD87L will be run in 16-bit modes and will not handle integers larger than 32,768. Secondly, the computation time increases significantly as N increases above 14.

If no convergence is reached with the repeated interval halving, then a Romberg tableau is calculated. This table is constructed from the previously calculated CL values. As each item of the table is calculated, a test for convergence is made. If convergence is found, the table calculations are terminated and a CL value is returned to the calling routine; if no convergence is found, the last CL value of the table is returned to the calling routine. The situation of no convergence is extremely rare and will not be encountered in most calculations.

Subroutine `ROMB` calls function routine `CONC`.

Function CONC

The function `CONC` calculates obscurant concentration at specific points along the given LOS using the Gaussian plume algorithm for cloud mass distribution. All calculations are made in the wind-aligned coordinate system. Obscurant scavenging and evaporation are included in the calculations via the input parameter `GSCAV` entered on the `MET1` card. The diffusion coefficients are computed in this function, using the resulting power law coefficients determined by the functions `ACOEFF`, `DCOEFF`, and `CCOEFF`.

Subroutine MVCL

The `MVCL` computes the mean vertical optical depth for horizontal LOSs. This mean vertical optical depth is required by RT87L for radiative transfer calculations. The computation is accomplished by using the CL algorithm used by the subroutine `VCL`. A vertical CL and optical depth are calculated in intervals that are user-defined resolution elements along the horizontal LOS of interest. These values, along with their coordinates along the LOS, and the arithmetic mean value are stored in the array CL.

Function ERFUN

The `ERFUN` function calculates the well-known error function needed by the analytical CL algorithm using standard approximations. See Sutherland and Fowler for an algorithm description. [Sutherland and Fowler, 1985]

Subroutine MLASS

The purpose of the `MLASS` subroutine is to construct the overall LASS by placing the single-source obscurant cloud image at the designated source locations, thereby producing a composite digital map. This subroutine maps the output into a 200– by 200–resolution element grid composed of four 50– by 200–element storage arrays. As with the single-source cloud, the composite LASS is constructed in the wind-aligned coordinate system. The four storage arrays ensure compatibility of the code with most PC FORTRAN compilers.

This subroutine allows the single-source cloud to be placed in as many as 50 different locations in the grid. When cloud images overlap, the CL values at overlapping locations are summed./ For programming efficiency, all LOSs are parallel, making the overall LASS construction mathematically simple. The algorithms used in constructing the LASS obscurant screen cannot be used for LOSs converging on a single observer location since every LOS has a unique zenith and azimuth angle relative to targets on the ground.

Figure 1.3 presents a graphical display of the overall LASS grid with the storage array locations. In most cases, the full grid is needed to display the calculated LASS. However, it is significant from a computer storage point of view that the TD87L submodule is capable of using and outputting only a portion of the 200– by 200–element grid allowed. For example, given a 40–m resolution and a total downwind screen length of 3000 m, only the first two storage arrays of the grid contain the obscurant. (Recall that the storage arrays are 50 by 200 elements, where the index 50 indicates the number of downwind resolution elements.) Since in this example only 75 downwind storage elements are required, only the first two storage arrays will be used and written to the output files.

Subroutine PLASS

To be properly used, the two-dimensional nature of the TD87L output requires a visual display of the data. However, because plotting and graphics are hardware and software dependent, no attempt has been made to provide TD87L with sophisticated plot routines. Instead, the data are displayed by this subroutine as a line printer digital plot in the standard EOSAEL output file. Data points are presented in a digital format using the numbers 0 through 9 t depict gray-level bins, that is, levels of different CL. The gray scale levels, intervals, and lower limits are specified by the user on the `CMAP` input card. The plot area is internally scaled to 100 by 100 elements to display the LASS in 132-character wide output format. This means if the entire 200– by 200–element grid is used in the calculation of the LASS, only every other row and column of the

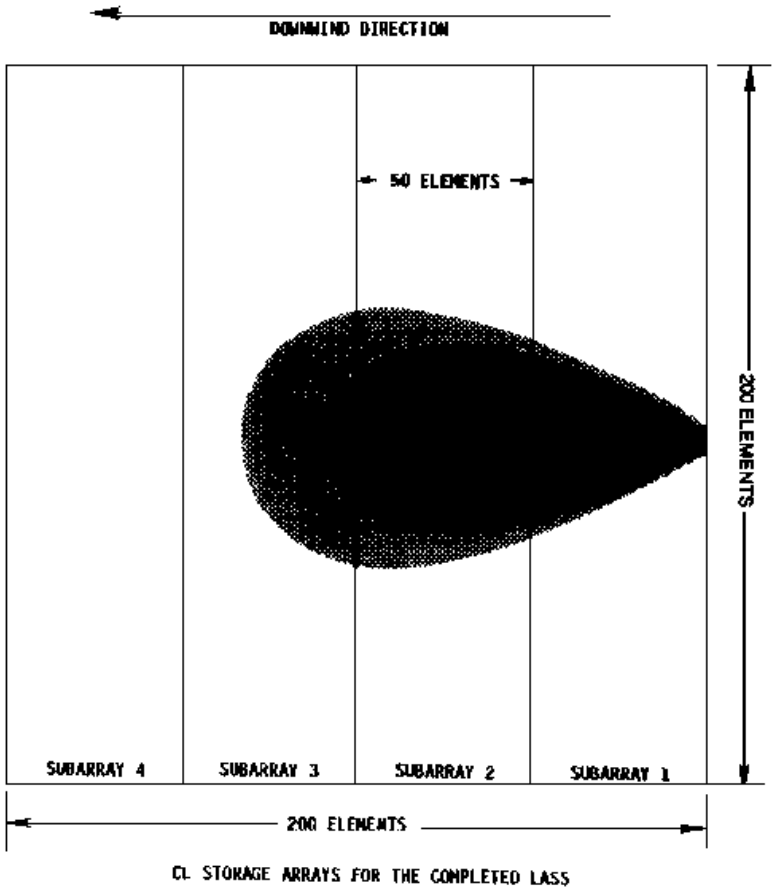


Figure 1.3: Subarray scheme used for mapping the composite grid.

grid is plotted by the printer. If the user wishes a more detailed representation of the data and has plotting hardware and software available, then the `WRTLAS` option should bye used to create an output file of the LASS digital data.

1.4.2 Radiative Transfer Routines (RT87L)

The purpose of the RT87L routines is to perform the radiative transfer calculations required to account for the optical effects due to single and multiple scattering of the ambient radiation into the observer-target LOS and to compute the downward-directed surface irradiance. The final output is a digital map representing either path radiance, contrast transmission, or downward-directed surface irradiance, depending upon user input options. Major inputs required are a digital map of CL as produced by the TD87L routine; the obscurant optical scattering and extinction properties; the ambient radiation levels from the sun and sky; and the reflectivities, or albedos, of the target, background, and earth surface. The radiative transfer calculations are performed along the same parallel LOS as those used by TD87L. This routine can be used with any other transport and diffusion model as long as the proper file format of the output subarrays is maintained and the LOS zenith angles are compatible with those used in the RT87L reflection and transmission operator tables (appendix A).

The model accounts for scattering only; it neglects thermal emission and assumes that the obscurant

screen is of sufficient horizontal extent that the plane-parallel approximation is applicable. Transport and diffusion calculations have shown that the plane-parallel assumption is good for most practical sized screens, breaking down only near the edges. Calculations made by the scattering phase function is described by the Henyey-Greenstein form shown earlier in figure 1.2.

The solutions of the radiative transfer equation are evaluated in terms of the single– and multiple–scattering operators, moments, and bimoments introduced by equations 1.1 through 1.4 of section sec:trans. The RT87L module makes extensive use of the radiative transfer lookup tables discussed in appendix A to evaluate the appropriate single– and multiple–scattering operators and moments. Five sets of tables corresponding to the Henyey-Greenstein asymmetry parameters of $g = 0.0, 0.25, 0.5, 0.75$ and 0.875 are stored internally in the model. Each of these five tables is further segmented by nine values of optical depth: $0.03125, 0.0625, 0.125, 0.25, 0.5, 1.0, 2.0, 4.0$, and 8.0. The operators, moments, and bimoments contained in each table segment are calculated for six discrete angles ($\mu = \mid \cos\theta \mid = 1.0, 0.9, 0.5, 0.5, 0.3$, and 0.1), providing a range of observer/source zenith angles from 0 (directly overhead) to 84° (nearly horizontal). The procedure accounts for contributions from the direct solar beam, uniform diffuse skylight, and reflection from the surface. Because of the nonlinear nature of the operators, RT87L requires the user to specify the asymmetry parameter and zenith angles of observer and sun to precisely match table values (no interpolation is done for these variables). The code does, however, interpolate values for optical depth but does no extrapolate for optical depths less than 0.0325 or greater than 8.0.

The use of discrete values for asymmetry or zenith angle does not place a severe constraint on the usefulness of the model, because the "lookup" tables cover a wide range of scenarios. Some caution is required, however, when defining the LOS zenith angle used in making the CL calculations (TD87L module) to assure compatibility with the discrete angles applicable in the RT87L computations.

The operators contained in the tables are strictly applicable for conservative scattering and yield only azimuth-averaged results. RT87L does allow the user to scale these operators to produce azimuth-dependent results using the approximate expressions of equations 1.18 and 1.19. The model also allows for scaling of nonconservative scattering using approximations that are reasonably accurate as long as the obscurant single-scattering albedo is no far from unity.

The RT87L module includes nine subroutines and five function routines that are described in the following sections.

Subroutine RTLASS (Main Program)

The `RTLASS` subroutine is the coordinating subroutine for the radiative transfer calculations, serving as an executive manager, directing the sequence of code operations, and initializing key variables. After the CL data input file has been read in by the subroutine `READCL`, `RTLASS` proceeds to establish observer and solar azimuth/zenith coordinates. It is called either by `DRV011` or your program. With the zenith values (in terms of $\cos\theta$) and the asymmetry parameter, `RTLASS` calls up all related operators, moments, and bimoments from the radiative transfer lookup tables. Given the observer and solar zenith angles and an asymmetry parameter, there are only nine possible values of the reflection operators that can be taken from the tables, each individual value corresponding to a specific optical depth. The reason for looking up these values before the calculations start is to eliminate the necessity for calling the lookup operator values for each LOS calculation. This procedure can eliminate thousands of calls to the look up subroutines.

After acquiring the necessary table values, RT87L then performs the azimuth-dependent scaling of the operators and performs path radiance calculations. The CL values are converted into optical thickness values by forming the product of the mass extinction coefficient supplied by the user with the CL data. The optical thickness is then used to compute effective vertical optical depth values for the radiative transfer calculations using the plane-parallel approximation.

As contrast transmission values are calculated, so are values of the downward-directed global irradiance and path radiance. Both of these values, as well as the CL for particular LOS in question, are written to an output file.

Subroutine RCARDS

The `RCARDS` subroutine handles most of the user input required for module execution. The specific input cards that must be read by the `RCARDS` routine establish values for solar flux, albedos, solar azimuth and zenith angles, diffuse sky irradiance, and options concerning the scaling of the radiative transfer operators to include azimuth dependence. The input format is that of EOSAEL (that is, card order independent), and a complete description of the input variables is found in the user's guide (2).

Subroutine READCL

The `READCL` subroutine reads in the CL data input files required for the radiative transfer calculations. These input CL files nee not be generated by TD87L as long as the file format is identical to TD87L-generated CL files, and the observer/target zenith angles match one of the six angles used in the lookup tables. Many different combinations of solar angles, fluxes, surface albedos, etc. can be run for a given CL map. (Note that for a given CL map the observer/target coordinates have been set so that the observer zenith angle is fixed.)

Subroutine RTTABL

The `RTTABL` subroutine contains the lookup tables for the transmission and reflection operators given in appendix A (945 entries for each operator). Values of these operators are found by specifying an asymmetry parameter, an optical depth, an observer zenith angle, and a solar (incident radiation) zenith angle. If any of these input values do not exactly match those of the tables, the program will terminate with an error message. Plots of the transmission and reflection operators for an asymmetry parameter of $g = 0.750$ (appropriate for fog oil) and different values of μ_i are displayed in figures 1.4 through 1.9.

Subroutine URTTAB

The `URTTAB` subroutine contains the moments and bimoments of the transmission and reflection operators. As with `RTTABL`, values from the tables are located by specifying optical depth, asymmetry parameter, and observer zenith angle. Plots of all moments and bimoments contained in the tables are displayed in figures 1.10 and 1.11.

Subroutine RTAZ

The `RTAZ` subroutine performs the azimuth scaling by using the algorithms given by Sutherland and Fowler. [Sutherland and Fowler, 1985] This subroutine calls function routines `HGPF` (Henyey-Greenstein phase function) and `HGRF` (Henyey-Greenstein redistribution function).

Function HGPF

The purpose of subroutine `HGPF` is to evaluate the `HGPF`. Inputs required are azimuth and zenith angles for incident and scattered radiation. The calculated function is normalized over 4π steradians.

Function HGRF

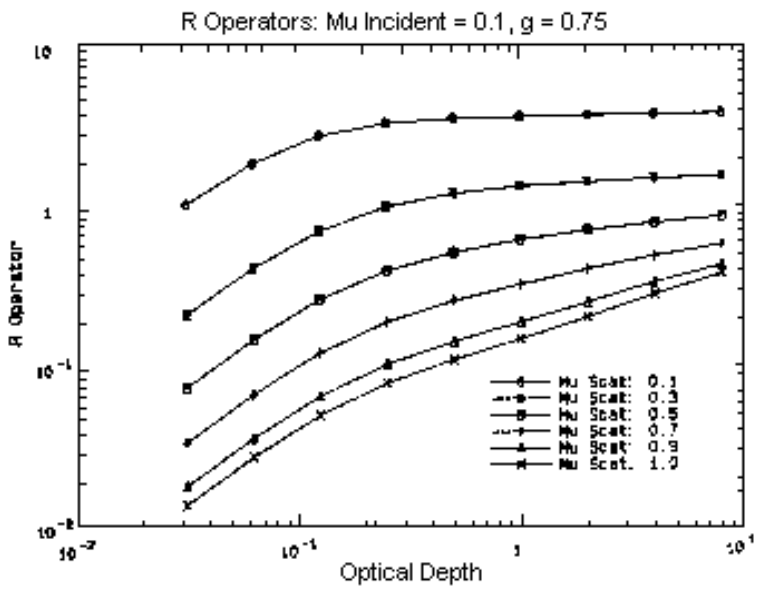
The purpose of subroutine `HGRF` is to calculate the `HGRF`. The redistribution function is azimuth independent and is normalized over 2π steradians. The calculation of the redistribution function requires the evaluation of an elliptical integral, which is done by using a series expansion of 50 terms.

Function EXPINT, E2, and E3

In solving the single-scattering radiative transfer equation, LASS requires values of the third-order exponential integral. These values are calculated in the function E3, which uses a recursion relation on the second-order exponential integral. The second-order value is calculated by using a recursion relation on the first-order exponential integral, which is computed function `EXPINT`. These calculations are quite fast and provide greater accuracy than interpolation from lookup tables.

Subroutine PLASS

As with the TD87L module, a graphic display is needed to interpret the output of RT87L. To avoid hardware and software constraints, the subroutine `PLASS` uses a line printer to display the calculated results. Plot boundaries and gray levels are determined through user input. The output remains in the wind-defined coordinate system such that the values of x increase to the right (downwind direction) and the values of y increase toward the top of the page.



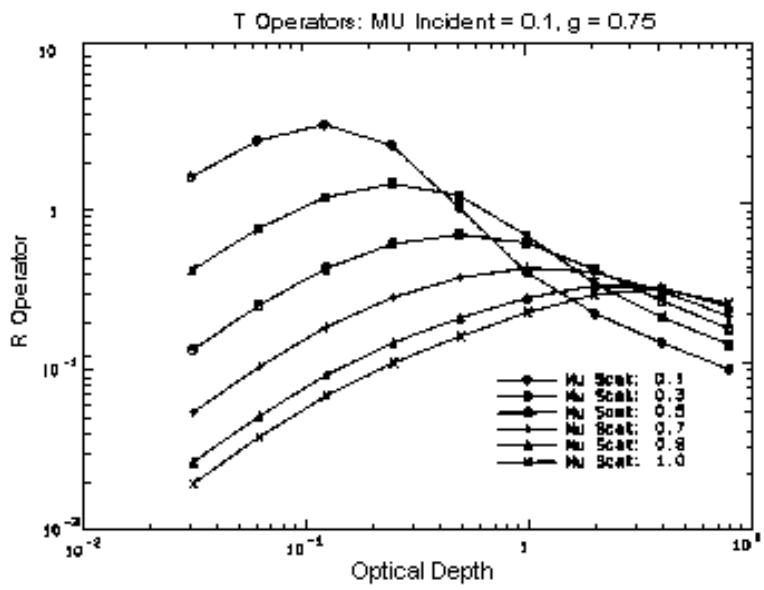


Figure 1.4: R and T operators for $\mu_i = 0.1$.

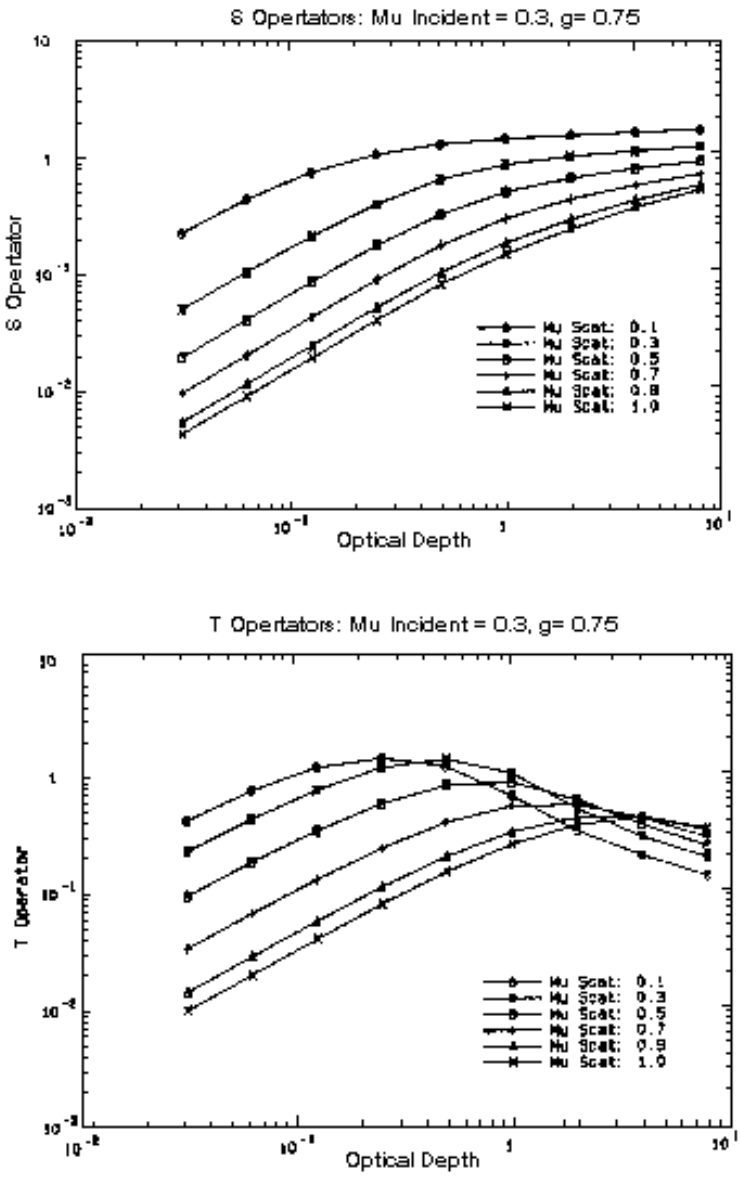


Figure 1.5: R and T operators for $\mu_i = 0.3$.

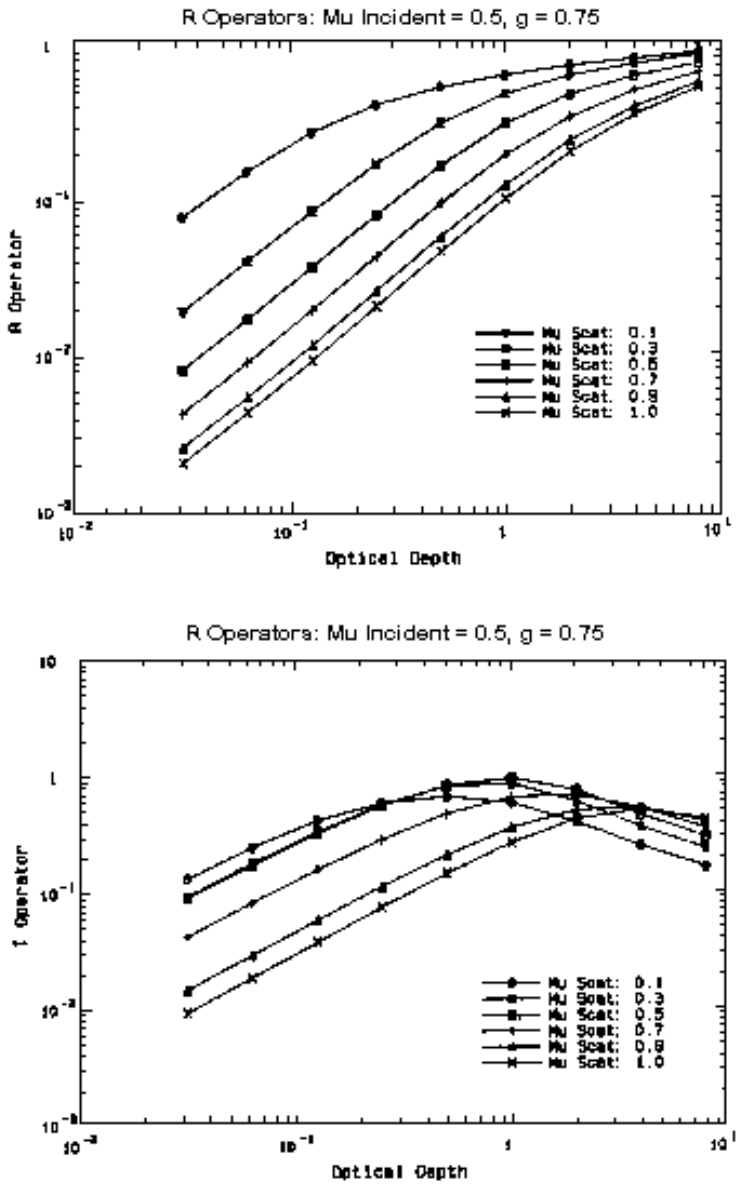


Figure 1.6: R and T operators for $\mu_i = 0.5$.

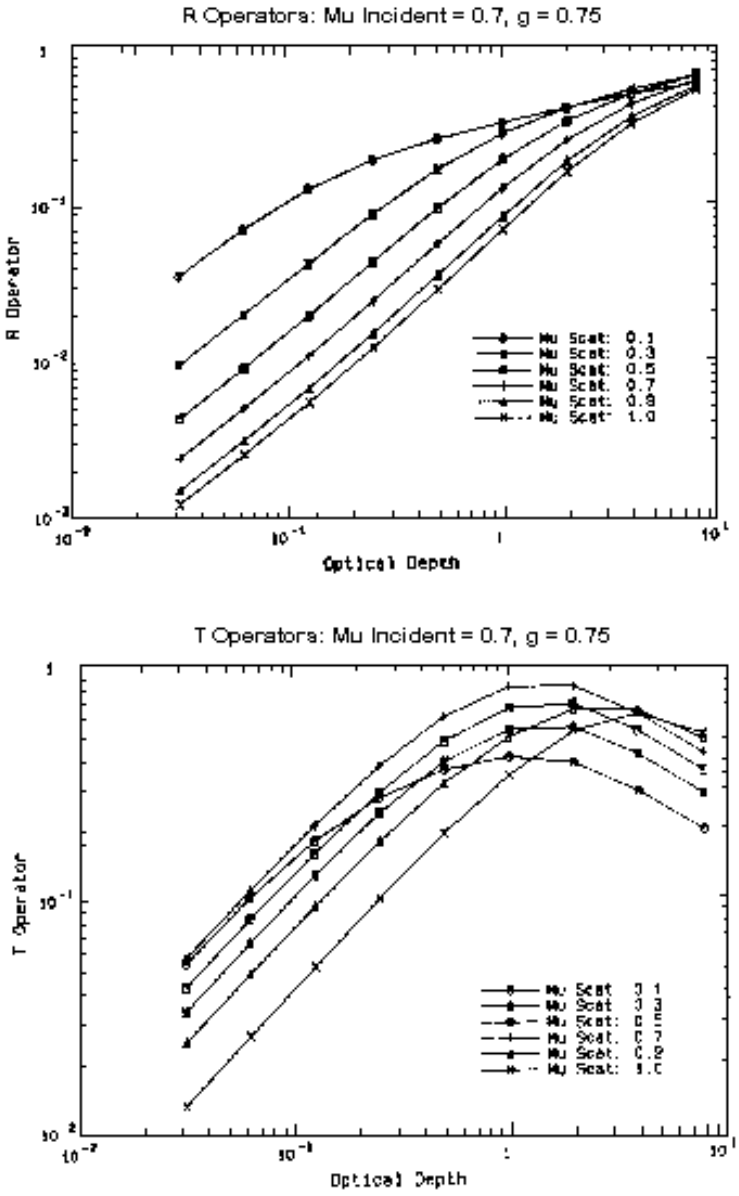


Figure 1.7: R and T operators for $\mu_i = 0.7$.

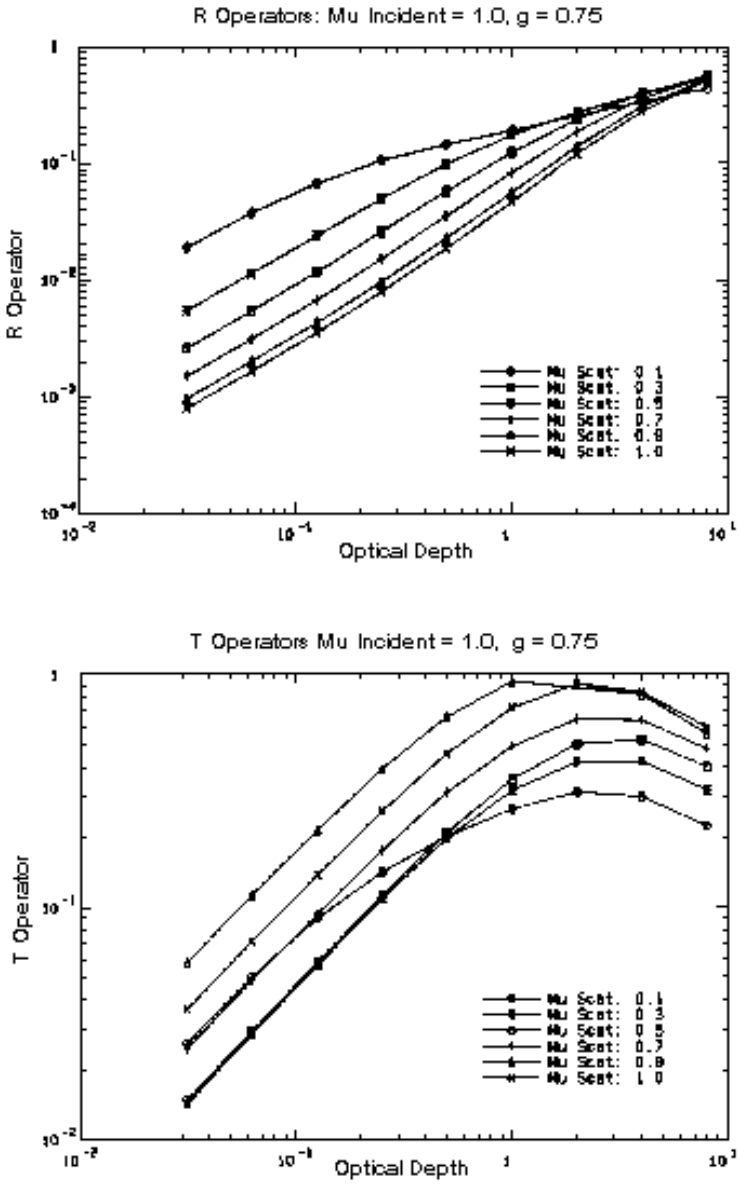


Figure 1.8: R and T operators for $\mu_i = 0.9$.

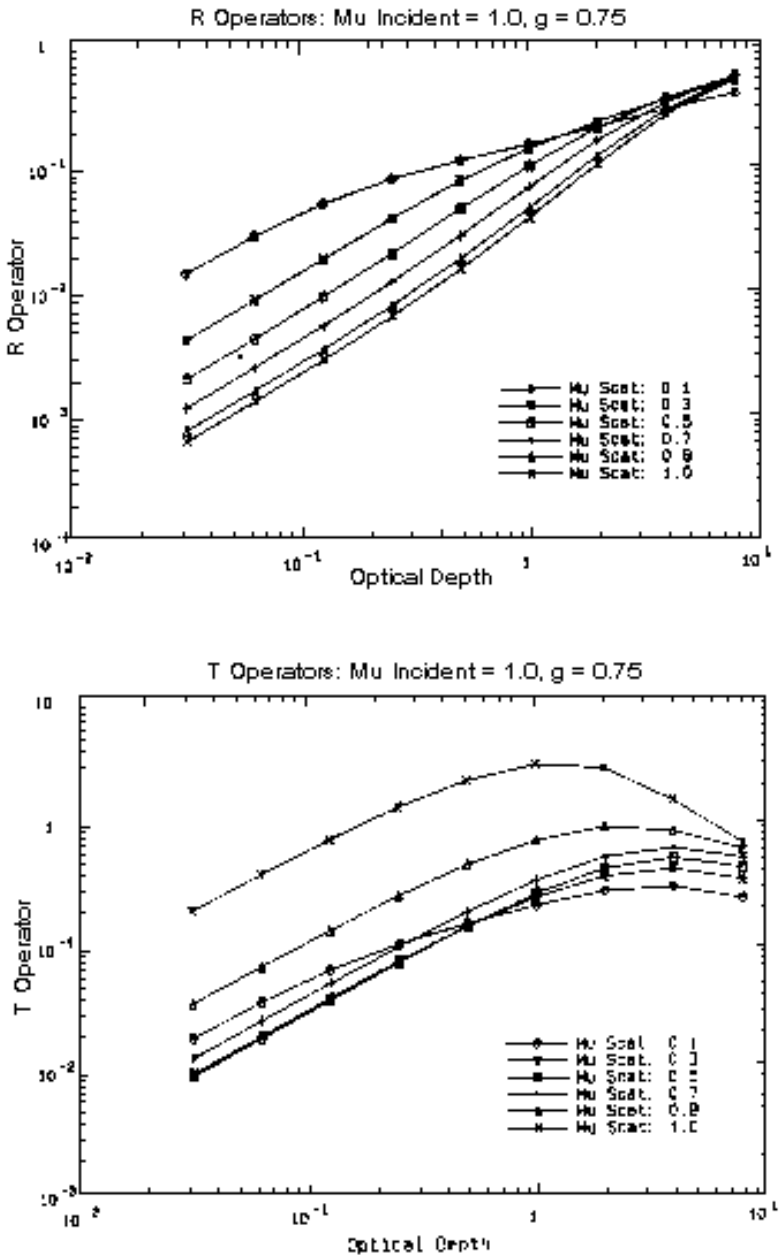


Figure 1.9: R and T operators for $\mu_i = 1.0$.

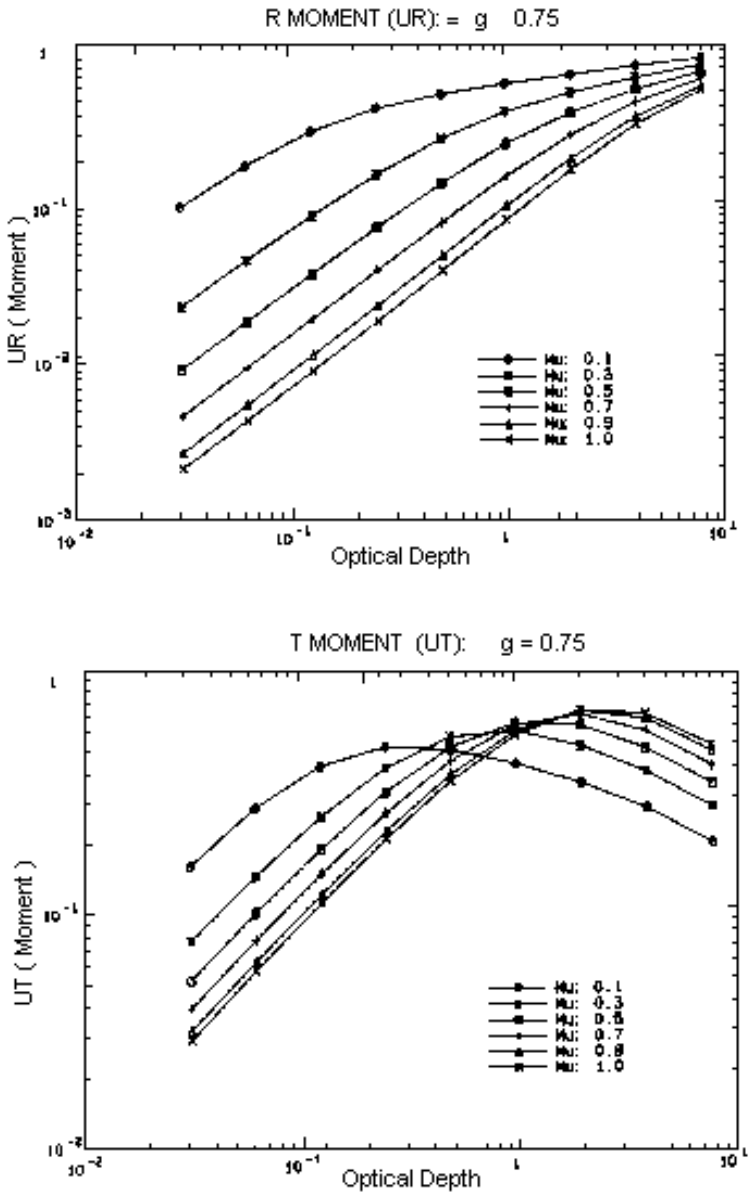


Figure 1.10: R and T operators first moments, UR and UT.

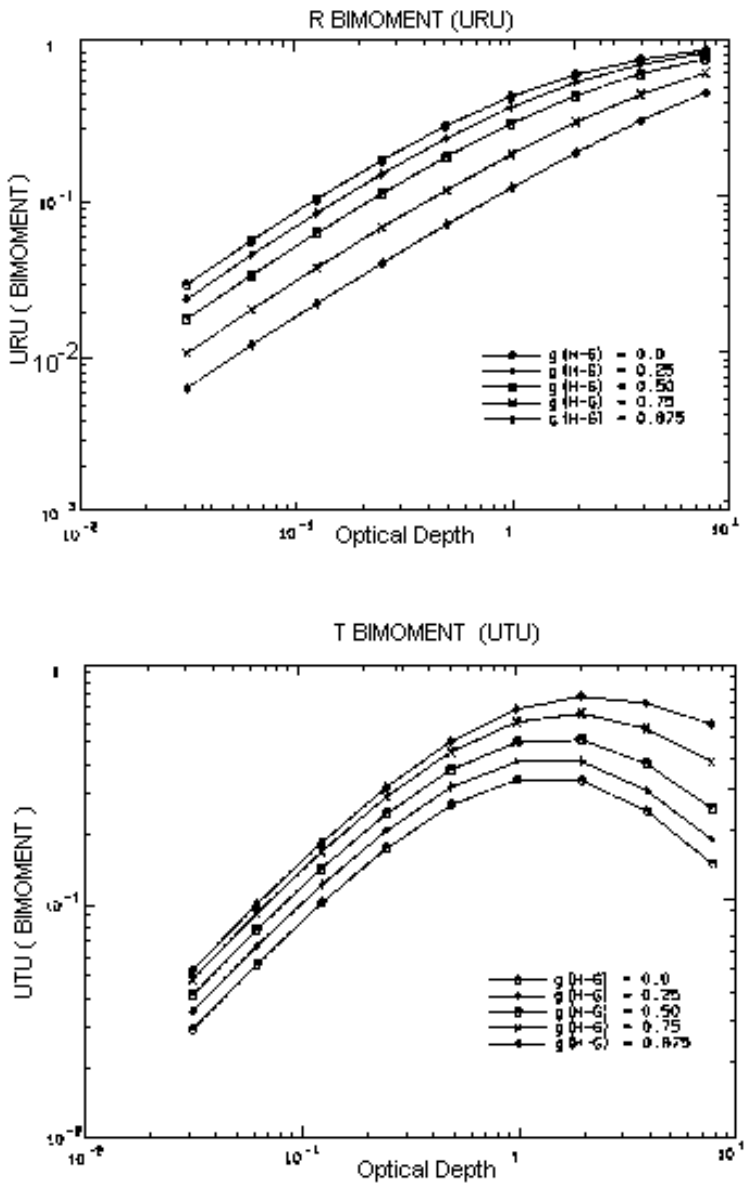


Figure 1.11: R and T operators second moments, URU and UTU.

Chapter 2

USER'S GUIDE

2.1 Overveiw

The LASS computer model provides a tool for the study of large area screening systems applications and effects. The associated computer program, LASS is made up of two models: one that treats transport and diffusion (TD87L) and another that treats radiative transfer (RT87L). The transport and diffusion segment uses a Gaussian formalism to calculate obscurant path-integrated concentration (CL) along parallel LOSs over the extent of the entire screen. The result is a CL digital map of the screen as viewed from above along the defined slant path. (The horizontal LOS option does not create a map of the screen, but yields a single CL value.) With minor modifications, the CL map can be transformed to represent either optical depth or direct transmittance for any spectral band of interest.

The radiative transfer segment performs extensive radiative transfer calculations by using the plane parallel approximation that essentially transforms the CL map into a radiative transfer map of contrast transmission. Since the output of RT87L includes path radiance and downward-directed hemispherical surface irradiance, digital maps of these quantities may also be generated with minor code modifications. The radiative transfer model is currently valid only for the visible and near-infrared wavelengths.

The LASS module is made up of 28 FORTRAN 77 functions and subroutines and is currently operational on a variety of minicomputers and PCs. While care has been taken to ensure machine independence, minor modifications to the code for operation o some types of machines or operating systems may be necessary. Such modifications will most likely involve the I/O portions of LASS. Because plotting routines are extremely machine and software dependent, only printer plot options are provided in the coding. However, the user may use LASS output files as input for specific plotting packages.

Contour plots and color digital plots are often useful display formats for the LASS calculations.

The model is primarily applicable to situations in which the observer (for example, an aircraft) is located above the screen and the target is located on the surface. In the examples that follow, the obscurant is fog oil dispersed by M3A3 generators. However, the user may adapt TD87L to any obscurant and continuous source by providing the appropriate characteristics. For the RT87L calculations to be meaningful, the phase function of any obscurant studied should be well described by an `HGPF` with an asymmetry parameter of 0.0, 0.25, 0.5, 0.75, or 0.875.

LASS currently requires that target-observer LOSs have zenith angles of $0.0°, 45.6°, 60.0°, 72.5°, 84.3°$, or $90°$. These angles are entered by the appropriate code number on the `SCEN` input card (see section 2.2). The zenith angles are restricted to these values for the TD87L output in order to be compatible with the reflection and transmission operators and moments that are tabularized in the RT87L module. If the user desires only CL output and does not need to run RT87L, then TD87L can be easily modified to accept any arbitrary zenith angle for the target-observer LOS. (Note that no map will be calculated for a horizontal LOS, one with a zenith angle of $90.0°$).

2.1.1 Coordinate Convention

All input coordinates for targets and obscurant sources are referenced to a right-handed Cartesian coordinate system with the X-Y plane assumed to be the horizontal surface (the ground) and Z defining the vertical direction. User coordinate systems are rotated to a north-oriented system with positive X directed to the east and positive Y directed north. This rotation is performed in TD87L and requires the user to provide the rotation angle, ϕ_s (`PHNOR` on the `SCEN` card). ϕ_s is the angle between the Y axis of the user coordinate system and true north. This measurement is made clockwise from true north to the Y axis (see figure 2.1). The observer azimuth, the solar azimuth, and the wind direction are all referenced from true north. These angles are also taken to be positive when measured clockwise from true north. The zenith angle is measured positive downward with respect to the zenith: for example, an observer directly above a target has a 0.0° zenith angle, while an observer that is on the ground has a zenith angle of 90°. Figure 2.1 illustrates the LASS coordinate system scheme.

The following two examples show two simple scenarios with the target at the origin.

1. Suppose the Y axis was pointing directly toward true north and the observer was directly overhead of the target. That would mean that the coordinate system is not rotated with respect to true north and $\phi_s = 0.0°$. The zenith angle, θ_0, is 0.0° since the observer is directly overhead. The azimuth angle, ϕ_0, is 0.0° since the observer is aligned with true north.

2. Suppose north points 45.0° counterclockwise from the y axis and the observer is on the ground and on the y axis. That would mean that the y axis is 45° clockwise from true north so $\phi_s = 45.0°$. The zenith angle, θ_0 is 90.0° since the observer is on the ground. The azimuth angle, ϕ_0, is 45.0° since the observer is 45° clockwise from true north.

The wind direction, `UDIR`, is a meteorological direction referring to the direction from which the wind is blowing and NOT the wind vector. For example: a wind blowing from the east has a direction of 90° and a wind blowing from the south has a direction of 180°.

In the standard mode of operation, the model can address up to 50 identical obscurant-generating sources defined by the source characteristics entered on the `SCRD` card and located at the X, Y coordinates entered on the `SRCL` card. The source characteristics and release heights `ZSRC` entered on the `SRCD` card are assumed to be the same for all sources. The model optionally allows for a line source approximation using the `LINE` card. With this option, all sources are assumed deployed along a straight line of total length `SLEN`. The source line is centered at the coordinates `XS(1)`, `YS(1)` specified on the `LINE` card and oriented at an angle `PSI` with respect to the wind direction. `PSI` is defined as the angle between the source line and the wind direction normal.

2.2 Input Data

All input data for LASS are entered in standard EOSAEL format, A4,6X,7E10.4, that is, input data are entered through 80-character, order-independent, "card" images. The first four columns contain characters that indicate the input types that follow. The data are then entered in E10.4 format starting in column 11. The following tables discuss the card image input in detail.

Data are entered through card images primarily to define situations of interest and specify options. Up to seven data variables may be entered on a card image. The following tables display the input variables for LASS. The left-hand column of the tables gives the card identifier names; the central column presents the variable names; and the right-hand column defines the variables.

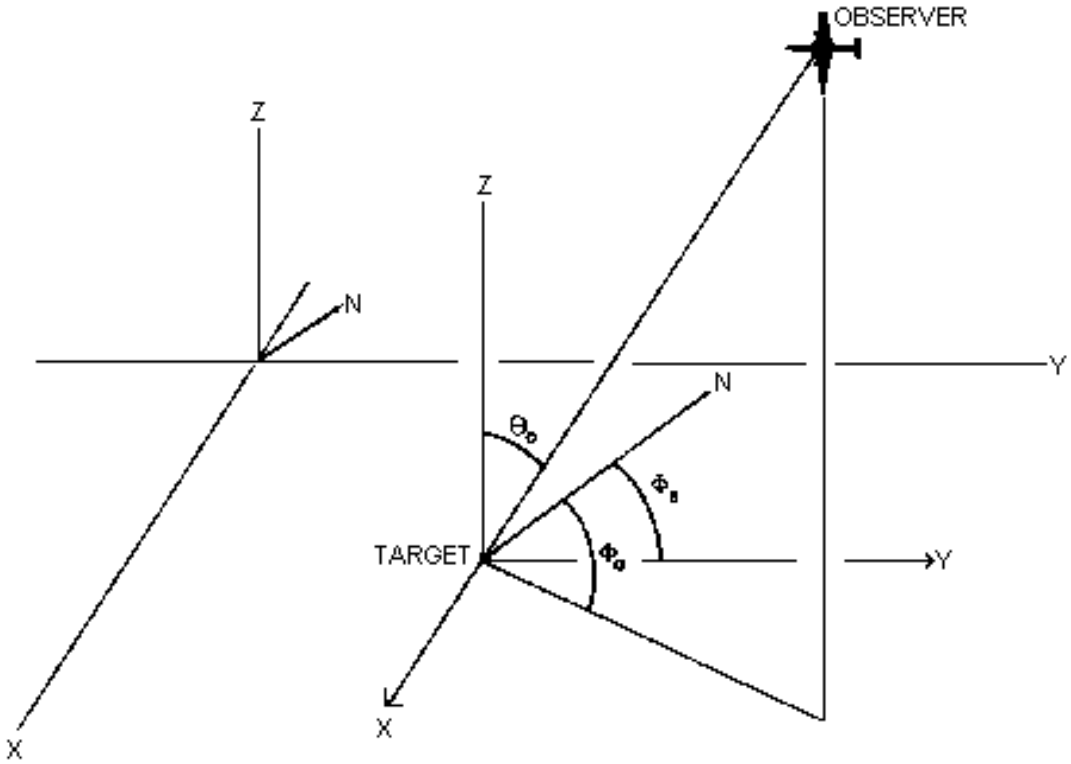


Figure 2.1: Sketch illustrating relationship between a user coordinate system and the north-east system.

2.2.1 Input For The TDLASS Module

Table 2.1: The `SCEN` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SCEN           RT(X)     RT(Y)     RT(Z)     IOBSZ     PHLOS         R     PHNOR
```

NAME	UNITS	LOS definition in north-oriented coordinate system
`RT(X)`	m	Target X coordinate
`RT(Y)`	m	Target Y coordinate
`RT(Z)`	m	Target Z coordinate
`IOBSZ`		Observer zenith angle code

Code	Zenith(Angle)	COS(Angle)
0	Horiz.(90.0)	0.0
1	84.3	0.1
2	72.5	0.3
3	60.0	0.5
4	45.6	0.7
5	25.8	0.9
6	Vert.(0.0)	1.0

Note: For `IOBSZ = 0.0` (Horizontal) the following information is written to hard copy and to LASS output file (Unit `NCLIMT`):

(1) Horizontal observer-target CL, optical depth, and transmittance
(2) Mean vertical CL, optical depth, and transmittance along the LOS
(3) Table of steps along the LOS containing: distance from observer, wind and field coordinates, vertical CL, and vertical optical depth (table is in place of LASS).

No printer map is constructed
No single source output file is written

`PHLOS`	degrees	Observer azimuth angle relative to north
`R`	m	Observer-target range: Required only if horizontal (`IOBSZ = 0`) is selected
`PHNOR`	degrees	Degrees from true north to the Y axis of user coordinate system. Measured clockwise from true north to the Y axis

Table 2.2: The `LINE` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
LINE           XS(1)     YS(1)      XNUM      SLEN       PSI
```

NAME	UNITS	Source centerline coordinates (Used only if "line source" approximation is desired)
`XS(1)`	m	X Coordinate
`YS(1)`	m	Y Coordinate
`XNUM`		Number of sources along the line
`SLEN`	m	Line length
`PSI`	degrees	Angle between wind direction and deployment line normal

Table 2.3: The `SRCD` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SRCD           QEMIS       EFF        YF      ZSRC        F1        F2
```

NAME	UNITS	Munition and obscurant data
`QEMIS`	g/s	Mass emission rate
`EFF`	%	Efficiency
`YF`		Yield factor (default = `1`)
`ZSRC`	m	Source height above surface
`F1`		Evaporation constant (Fog oil: `F1 = 0.65`)
`F2`	s	Evaporation time scale (Fog oil: `F2 = 3003.0`)

Table 2.4: The `MET1` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
MET1            PASQ      USPD      UDIR      ZRUF        HM     GSCAV       SHF
```

NAME	UNITS	Meteorological data
`PASQ`		Pasquill stability category (`1.0--6.0`)
`USPD`	m/s	Mean windspeed
`UDIR`	degrees	Mean wind direction referenced from the North For example: 0.0° is North, 90.0° is East, 180.0° is South, etc.
`ZRUF`	m	Roughness parameter
`HM`	m	Mixing height
`GSCAV`		Scavenging factor (normally = `0.0`)
`SHF`	W/m^2	Sensible heat flux

Table 2.5: The `CMAP` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CMAP            DEL      CMIN      XMAX      YMAX      CFAC
```

NAME	UNITS	Contour map parameters
`DEL`	m	Grid spacing (constant for X, Y directions)
`CMIN`		Minimum value of concentration calculated for a single-source cloud
`XMAX`	m	Downwind distance limit of calculations
`YMAX`	m	Crosswind distance limit as measured from centerline
`CFAC`		Factor to multiply by `CMIN` to give a larger range in `CMIN`. Normally = `1.0`

Table 2.6: The `PLOT` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
PLOT          TAUMIN    TAUINC     EXTCO
```

NAME	UNITS	Plot parameters
`TAUMIN`		Minimum optical thickness to be plotted
`TAUINC`		Optical thickness increment used to create plotting bins (gray levels) that are assigned plot symbols
`EXTCO`	m^2/g	Visual mass extinction coefficient

Table 2.7: The `SRCL` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SRCL           XS(1)     YS(1)
```

NAME	UNITS	The X, Y coordinates of the generator locations
`XS(1)`	m	X Coordinate
`YS(1)`	m	Y Coordinate

Table 2.8: The `OPTN` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
OPTN          PTLASS    WRTSGL    WRTLAS     VCVSW     SLOSW
```

NAME	UNITS	Options
`PTLASS`		`> 0.0`; Printer plot will be made of the LASS
`WRTSGL`		`> 0.0`; Output of single-source file will be written.
`WRTLAS`		`0.0`; CL LASS output file will be written
`VCVSW`		`0.0`; Vertical centroid velocity for LASS to be used Note: if `VCVSW` is turned on (`> 0.0`) a value for `SHF` should be included on the `MET1` card
`SLOSW`		`> 0.0`; Output of CL for a single observer-target LOS

2.2.2 Input For The RTLASS Module

Table 2.9: The `OBSC` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
OBSC            EXTCO       GHG
```

NAME	UNITS	Obscurant optical properties
`EXTCO`	m^2/g	Mass extinction coefficient
`GHG`		Henyey-Greenstein asymmetry parameter code

Code	Parameter, g
0.0	0.0
1.0	0.25
2.0	0.50
3.0	0.75 (fog oil)
4.0	0.875

Table 2.10: The `SOLR` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SOLR            FSOL    ISOLMU    SOLPHI     ALBDO       SKY
```

NAME	UNITS	Solar and sky data
`FSOL`	W/m^2	Solar beam irradiance
`ISOLMU`		Solar zenith angle code

CODE	Zenith(Angle)	COS(Zenith Angle)
0	90.0	0.0
1	84.3	0.1
2	72.5	0.3
3	60.0	0.5
4	45.6	0.7
5	25.8	0.9
6	Vert.(0.0)	1.0

`SOLPHI`	degrees	Solar Azimuth Angle Measured from North
`ALBDO`		Surface ALBEDO (`0.0--1.0`)
`SKY`	W/m^2	Sky diffuse irradiance

Table 2.11: The `ALBO` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
ALBO          TGTALB    BCKALB
```

NAME	UNITS	Target and Background Albedos
`TGTALB`		Target albedo (`0.0-1.0`)
		(`TGTALB`) not used in this release
`BCKALB`		Background albedo (`0.0-1.0`)

Table 2.12: The `RTAZ` Card.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
RTAZ           AZDEP
```

NAME	UNITS	Option to scale R and T functions to include azimuth dependence
`AZDEP`		`=0.0` for azimuth-dependent calculations
		`=1.0` for azimuth-averaged calculations

2.3 Examples of Use

Seven LASS example runs are presented here to illustrate actual use of the program. The user-defined examples are entered via the input card described in section 2.2. The following examples demonstrate the utility of LASS in using a single TD87L CL map to study a variety of radiative transfer situations, that is, changes in solar flux, solar position, diffuse shy irradiance, and background albedo. The user is reminded, however, that the observer/target angles are established when the LASS CL calculations are made.

2.3.1 Example 1

In example 1, a CL map is produced by 17 M3A3 fog oil generators. The scenario establishes an observer directly over the target at an altitude of 100 m (equal to the mixing height). The cloud is mapped by using LOSs parallel to the observer-target LOS. Calculations for a single generator cloud are made 3500 m downwind and up to 800 m on either side of the center-line. The resolution is set to 40 m and the minimum CL to be calculated for the single generator cloud is 0.000001 g/m^2. This value is determined by CMIN multiplied by CFAC. (This minimum CL defines the edge of the calculated LASS.)

In this example, both CL values for the single generator cloud and the total LAS are written to output files, but no radiative transfer calculations are made. Example 2 illustrates how the LASS CL output file is used in the RT calculations.

The input file and the output for example 1, including the CL map generated, are presented in the following pages.

```
WAVL          0.55
TDLASS
NAME
        EXAMPLE 1: LASS(87)
SCEN          0.0       0.0       0.0       6.0       0.0    2000.0      0.0
CMAP         40.0       0.001  3500.000   800.000     0.001
SRCD         37.2     100.0       1.0       2.0       0.65   3003.2
MET1          3.0       4.4      40.0       0.3    1000.000     0.0       0.0
PLOT          0.001     0.05      7.2
OPTN          1.0       1.0       1.0       0.0       0.0
SRCL        361.351  1018.451
SRCL        401.996   946.399
SRCL        740.0    1020.0
SRCL        166.062   942.276
SRCL         73.723   941.151
SRCL        -11.122   940.587
SRCL        770.310   949.936
SRCL        899.781   848.532
SRCL        895.298   798.127
SRCL        878.731   619.976
SRCL        867.795   509.875
SRCL        850.549   302.706
SRCL        840.870   197.992
SRCL        826.507  -199.264
SRCL        825.734   -96.115
SRCL        460.0     640.0
SRCL        816.466  -414.659
DONE
END
STOP
# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) LASS01.DAT 2.1 02/23/90
```

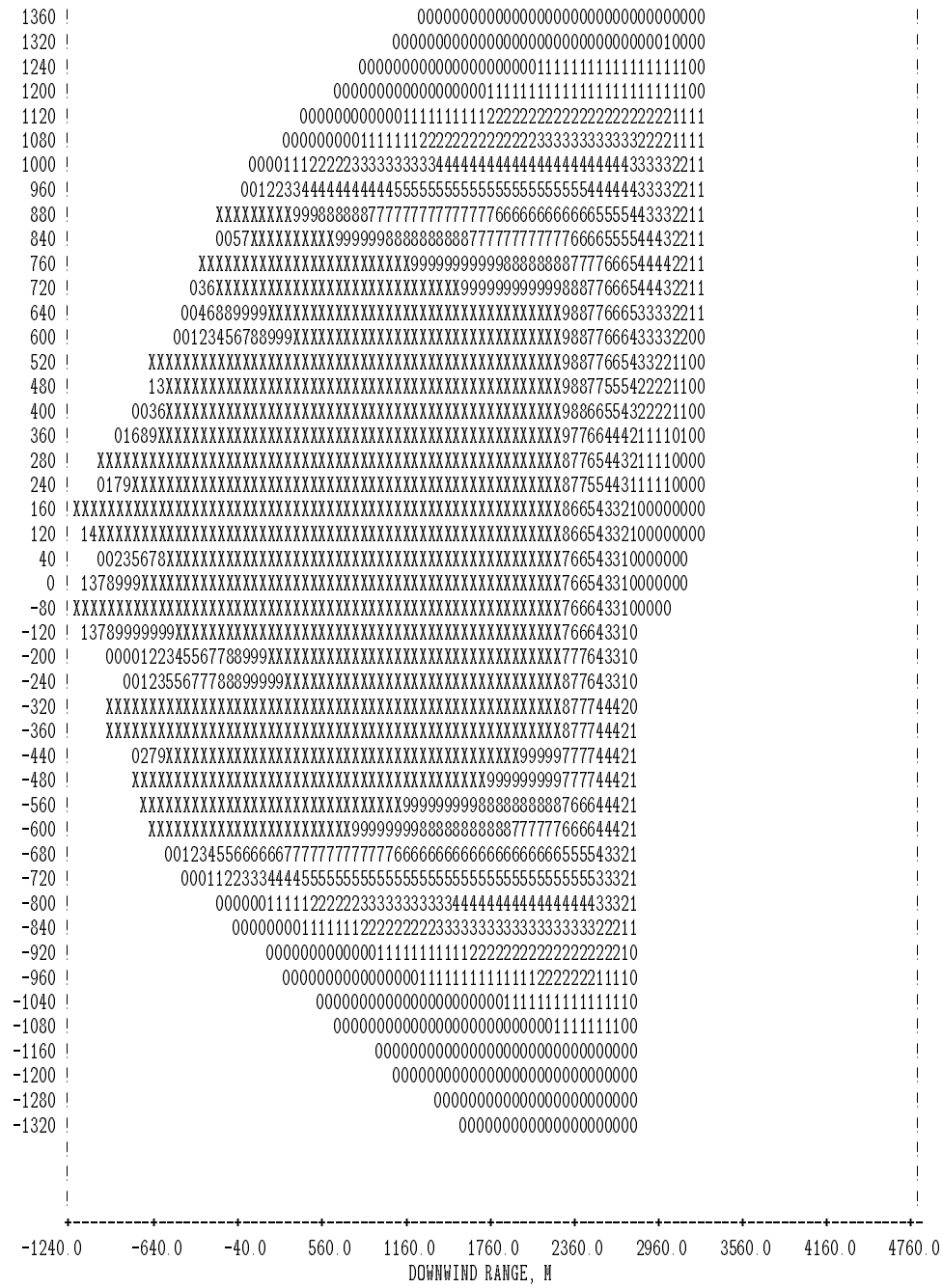

```
*****************************************************************************
  WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
  BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                SEVERE CRIMINAL PENALTIES.
*****************************************************************************
```


```
*******************************
```

```
                    *                            *
                    *    ELECTRO-OPTICAL SYSTEMS   *
                    *                            *
                    *  ATMOSPHERIC EFFECTS LIBRARY *
                    *                            *
                    *    NOT FOR OPERATIONAL USE   *
                    *                            *
                    * EOSAEL87 REV 2.1   02/23/90  *
                    *                            *
                    ********************************


 ERROR       0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
 JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
WAVL          0.55
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .5500E+00 .5500E+00 .0000E+00


                                   BEGINNING           ENDING

            WAVENUMBER (CM**-1)      18181.818          18181.818

            WAVELENGTH (MICROMETERS)      .550               .550

            FREQUENCY (GHZ)         545454.563         545454.563



         **** EOSAEL WARNING ****
 VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM


                                VISIBILITY
                                 10.00 KM


                    ********************************
                    *                            *
                    *        T D L A S S         *
                    *                            *
                    *TRANSPORT AND DIFFUSION  PART *
                    *LARGE AREA SMOKE SCREEN MODULE*
                    *    NOT FOR OPERATIONAL USE   *
                    *                            *
                    * EOSAEL87 REV 2.1   02/23/90  *
                    *                            *
                    ********************************


 TDLASS IS OPENING FILE 'TDLASS.PLT' FOR OUTPUT.
 TDLASS IS OPENING FILE 'TDLASS.AUX' FOR OUTPUT.
```

```
*******************************************************************************
***************************      TDLASS MODULE      ***************************
***************************       CYCLE #    1       ***************************
*******************************************************************************


                          *****CARD INPUT*****
-------------------------------------------------------------------------------
        EXAMPLE 1: LASS(87)
SCEN          .000      .000      .000     6.000      .000  2000.000      .000
CMAP        40.000      .001  3500.000   800.000      .001      .000      .000
SRCD        37.200   100.000     1.000     2.000      .650  3003.200      .000
MET1         3.000     4.400    40.000      .300  1000.000      .000      .000
PLOT          .001      .050     7.200      .000      .000      .000      .000
OPTN         1.000     1.000     1.000      .000      .000      .000      .000
SRCL       361.351  1018.451      .000      .000      .000      .000      .000
SRCL       401.996   946.399      .000      .000      .000      .000      .000
SRCL       740.000  1020.000      .000      .000      .000      .000      .000
SRCL       166.062   942.276      .000      .000      .000      .000      .000
SRCL        73.723   941.151      .000      .000      .000      .000      .000
SRCL       -11.122   940.587      .000      .000      .000      .000      .000
SRCL       770.310   949.936      .000      .000      .000      .000      .000
SRCL       899.781   848.532      .000      .000      .000      .000      .000
SRCL       895.298   798.127      .000      .000      .000      .000      .000
SRCL       878.731   619.976      .000      .000      .000      .000      .000
SRCL       867.795   509.875      .000      .000      .000      .000      .000
SRCL       850.549   302.706      .000      .000      .000      .000      .000
SRCL       840.870   197.992      .000      .000      .000      .000      .000
SRCL       826.507  -199.264      .000      .000      .000      .000      .000
SRCL       825.734   -96.115      .000      .000      .000      .000      .000
SRCL       460.000   640.000      .000      .000      .000      .000      .000
SRCL       816.466  -414.659      .000      .000      .000      .000      .000
DONE          .000      .000      .000      .000      .000      .000      .000
-------------------------------------------------------------------------------

                           *****INPUT*****
-------------------------------------------------------------------------------

METEOROLOGICAL:
   WIND SPEED          4.4  M/S     MIXING HEIGHT      1000.0   M
   WIND DIRECTION     40.0  DEG     SCAVENGING FACTOR       .00
   SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =     .650
   PASQUILL CATEGORY   3.0                       F2 = 3003.2   S



REFERENCE                                  REFERENCE
OBSERVER DATA:                             TARGET COORDINATES:
   X            .0 M                          X            .0 M
   Y            .0 M                          Y            .0 M
   Z        1000.0 M                          Z            .0 M
   OBS. ZENITH ANGLE
                       (W.R.T.TARG.)      .0 DEG
   OBS. AZIMUTH ANGLE                      OBS.-TARG.RANGE    1000.0 M
                       (W.R.T.NORTH)      .0 DEG
   FIELD AZIMUTH ANGLE
                       (W.R.T.NORTH)      .0 DEG



SOURCE DATA:                               OBSCURANT DATA:
```

```
   NO. OF GENERATORS          17              TYPE           FOG OIL
   DEPLOYMENT IS NON-LINEAR                   EMISSION RATE    37.20  G/S
                                              YIELD FACTOR      1.00
                                              EFFICIENCY      100.00  %
                                              MASS EXT.COEFF.   7.200 M**2/G


LASS ARRAY PARAMETERS:
   RESOLUTION                 40.0    M
   MIN. CONCENTRATION        .1000E-05 G/M**3

--------------------------------------------------------------------------------


**** BEGIN CALCULATIONS FOR SINGLE SOURCE CLOUD ****


   **** CL OUTPUT HAS BEEN CALCULATED FOR A SINGLE
        SOURCE CLOUD AND STORED IN A SEPARATE FILE ****


   **** SINGLE SOURCE OUTPUT COMPLETE ****


   **** BEGIN CONSTRUCTION OF OVERALL LASS FOR  17 SOURCES ****


   **** LASS OUTPUT FOR 17 SOURCES COMPLETE ****


--------------------------------------------------------------------------------
                           ***** LASS MAP *****


LEGEND:
   SYMBOL      OPT. DEP.      TRANS.(%)     CONC. LENGTH (G/M**2)

      0        .00 -   .05    99.9 - 95.0     .139E-03 -  .708E-02
      1        .05 -   .10    95.0 - 90.4     .708E-02 -  .140E-01
      2        .10 -   .15    90.4 - 86.0     .140E-01 -  .210E-01
      3        .15 -   .20    86.0 - 81.8     .210E-01 -  .279E-01
      4        .20 -   .25    81.8 - 77.8     .279E-01 -  .349E-01
      5        .25 -   .30    77.8 - 74.0     .349E-01 -  .418E-01
      6        .30 -   .35    74.0 - 70.4     .418E-01 -  .487E-01
      7        .35 -   .40    70.4 - 67.0     .487E-01 -  .557E-01
      8        .40 -   .45    67.0 - 63.7     .557E-01 -  .626E-01
      9        .45 -   .50    63.7 - 60.6     .626E-01 -  .696E-01
      X          >=   .50        =< 60.6            >=  .696E-01

    WIND SYSTEM COORDINATES ARE USED.


            +---------+---------+---------+---------+---------+---------+---------+---------+---------+-
            !                                                                                           !
            !                                                                                           !
            !                                                                                           !
       1600 !                                                 000000000000000000                          !
       1560 !                                               00000000000000000000                          !
       1480 !                                           0000000000000000000000000000                      !
       1440 !                                         000000000000000000000000000000                      !
```



******MODULE TDLASS END******

2.3.2 Example 2

Example 2 illustrates the LASS RT calculation module by using the CL map produced in example 1. This is an early morning scenario with the sun due east (azimuth = 90°) and just above the horizon (zenith code = 1.0° or 84°). The solar flux density is set to 10 W/m^2, and the diffuse sky irradiance is defined to be 40 W/m^2. The background, surface, and target albedos are set to 0.2 (although the target albedo is not used in the current version). The value of **AZDEP** in the card **RTAZ** directs LASS to make azimuth-dependent scaling calculations on the R and T operators. The input file and the output from example 2, including the contrast transmission map produced by the example 2 run, are presented in the following pages.

Note that the observer position in this scenario is directly over the LASS. Therefore, the observer-target (scattered radiation) LOS is nearly perpendicular to the solar-target (incident radiation) LOS. That is, the scattering angle is approximately 90°.

```
WAVL          0.55
RTLASS
NAME
          EXAMPLE 2: LASS(87)
OBSC          7.2       0.75
SOLR         10.0       1.0       90.0       0.2       40.0
ALBO          0.2       0.2
RTAZ          1.0
DONE
END
STOP
# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) LASS02.DAT 2.1 02/23/90
```

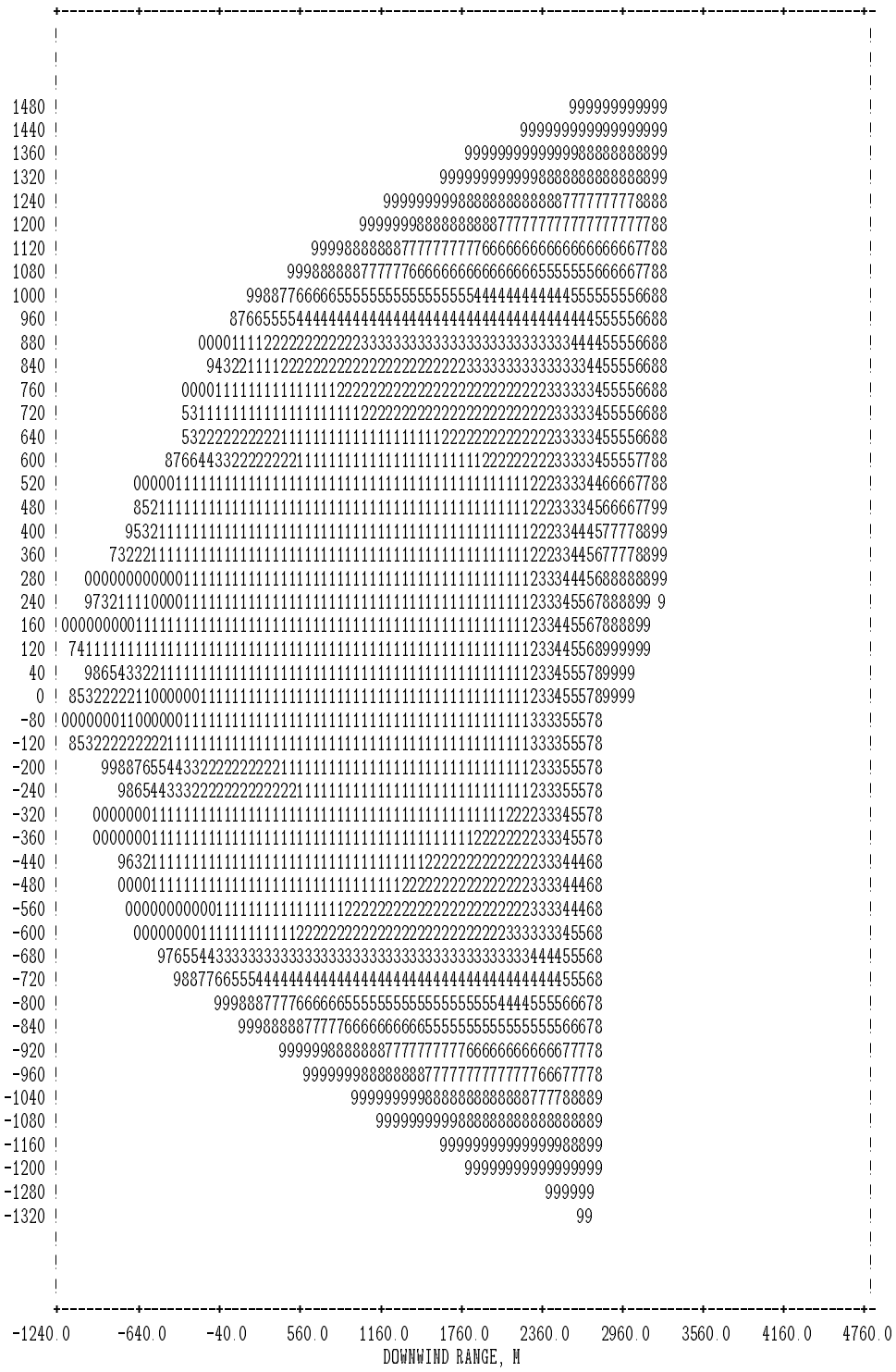
```
*****************************************************************************
  WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
  BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                 SEVERE CRIMINAL PENALTIES.
*****************************************************************************
```

```
                 *******************************
                 *                             *
                 *   ELECTRO-OPTICAL SYSTEMS   *
                 *                             *
                 *  ATMOSPHERIC EFFECTS LIBRARY *
                 *                             *
                 *   NOT FOR OPERATIONAL USE   *
                 *                             *
                 * EOSAEL87 REV 2.1   02/23/90 *
                 *                             *
                 *******************************
```

```
 ERROR       0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
 JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
WAVL          0.55
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .5500E+00 .5500E+00 .0000E+00
```

```
                                BEGINNING          ENDING

          WAVENUMBER (CM**-1)      18181.818         18181.818

          WAVELENGTH (MICROMETERS)      .550              .550

          FREQUENCY (GHZ)         545454.563        545454.563



        **** EOSAEL WARNING ****
VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM



                              VISIBILITY
                               10.00 KM



                  ******************************
                  *                            *
                  *        R T L A S S         *
                  *                            *
                  *  RADIATION TRANSPORT  PART 2 *
                  *LARGE AREA SMOKE SCREEN MODULE*
                  *    NOT FOR OPERATIONAL USE   *
                  *                            *
                  * EOSAEL87 REV 2.1   02/23/90  *
                  *                            *
                  ******************************


** WARNING: FILE TDLASS.PLT NOT OPEN BEFORE ENTRYINTO RTLASS. **


*************************************************************************
************************     RTLASS MODULE     ************************
************************      CYCLE #    1      ************************
*************************************************************************


                          *****CARD INPUT*****
-------------------------------------------------------------------------------
        EXAMPLE 2: LASS(87)
OBSC        7.200      .750      .000      .000      .000      .000      .000
SOLR       10.000     1.000    90.000      .200    40.000      .000      .000
ALBO         .200      .200      .000      .000      .000      .000      .000
RTAZ        1.000      .000      .000      .000      .000      .000      .000
DONE         .000      .000      .000      .000      .000      .000      .000
** WARNING: FILE RTLASS.PLT NOT OPENED BEFORE CALLOF RTLASS.
-------------------------------------------------------------------------------
```

```
                              *****INPUT*****
-------------------------------------------------------------------------------

METEOROLOGICAL:
    WIND SPEED          4.4  M/S     MIXING HEIGHT      1000.0   M
    WIND DIRECTION     40.0  DEG     SCAVENGING FACTOR      .00
    SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =     .650
    PASQUILL CATEGORY   3.0                       F2 = 3003.2   S


SOLAR/SKY DATA:
    SOLAR FLUX          10.00 W/M     SURFACE ALBEDO         .20
    SOLAR ZENITH                      SKY RADIANCE        40.00  W/M**2
    (W.R.T. OBS.)      84.26 DEG
    SOLAR AZIMUTH
    (W.R.T. NORTH)     90.00 DEG


SOURCE DATA:                                  REFERENCE
    TYPE              FOG OIL                OBSERVER DATA:
    NO. OF GENERATORS   17                   OBS. ZENITH ANGLE
    EMISSION RATE      37.20  G/S                 (W.R.T.TARG.)     .0 DEG
    YIELD FACTOR        1.00                 OBS. AZIMUTH ANGLE
    EFFICIENCY        100.00  %                   (W.R.T.NORTH)     .0 DEG
    MASS EXT.COEFF.     7.200 M**2/G         OBS.-TARG.RANGE     1000.0 M
    HEN.-GR. PARAMETER   .00                 FIELD AZIMUTH ANGLE
                                             (W.R.T.NORTH)     .0 DEG
                                             BACKGROUND ALBEDO       .20


LASS ARRAY PARAMETERS:
    RESOLUTION                 40.0    M
    MIN. CONCENTRATION       .1000E-05 G/M**3
    AZIMUTH AVERAGING IS:    ON

-------------------------------------------------------------------------------
1              ---------------------------------------------------------------------------------------

                                          **** CONTRAST TRANSMISSION MAP ****


                  LEGEND:
                            SYMBOL    CONT.TRANS.(%)

                              0        0 =< CT < 10
                              1       10 =< CT < 20
                              2       20 =< CT < 30
                              3       30 =< CT < 40
                              4       40 =< CT < 50
                              5       50 =< CT < 60
                              6       60 =< CT < 70
                              7       70 =< CT < 80
                              8       80 =< CT < 90
                              9       90 =< CT < 100

                            WIND SYSTEM COORDINATES ARE USED.


1
```



******MODULE RTLASS END******

2.3.3 Example 3

In example 3, as in example 2, the CL map generated by example 1 is used for RT calculations but not for a midday scenario. The sun is located nearly overhead (azimuth = 180°, zenith = 26°). The solar flux is set to 950 W/m^2, and the diffuse sky irradiance is 180 W/m^2. All other input parameters remain identical to those established in examples 1 and 2.

The input file and the output for example 3, including the contrast transmission plot produced by the example 3 run, are presented in the following pages.

Recalling that the observer and solar positions set for this example establish a backscatter situation (the scattering angle is 164°), a comparison of the example 2 and 3 contrast transmission maps illustrates the importance of sun-target-observer angles to LASS effectiveness. This comparison reveals that the same LASS viewed by an overhead observer is more effective in obscuring targets in the early morning than it is at midday.

Examples 2 and 3 demonstrate the utility of LASS in using a single LASS CL map to study various RT scenarios, that is, changes in solar flux, solar position, diffuse sky irradiance, and background albedo. The user must remember, however, that the observer-target angles are established when the LASS CL calculations are made.

```
WAVL          0.55
RTLASS
NAME
         EXAMPLE 3: LASS(87)
OBSC          7.2       0.75
SOLR        950.0       5.0     180.0       0.2     180.0
ALBO          0.2       0.2
RTAZ          1.0
DONE
END
STOP
# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) LASS03.DAT 2.1 02/23/90
```

```
*****************************************************************************
  WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
  BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                 SEVERE CRIMINAL PENALTIES.
*****************************************************************************
```

```
*******************************
*                             *
*   ELECTRO-OPTICAL SYSTEMS   *
*                             *
* ATMOSPHERIC EFFECTS LIBRARY *
*                             *
*   NOT FOR OPERATIONAL USE   *
*                             *
* EOSAEL87 REV 2.1   02/23/90 *
*                             *
*******************************
```

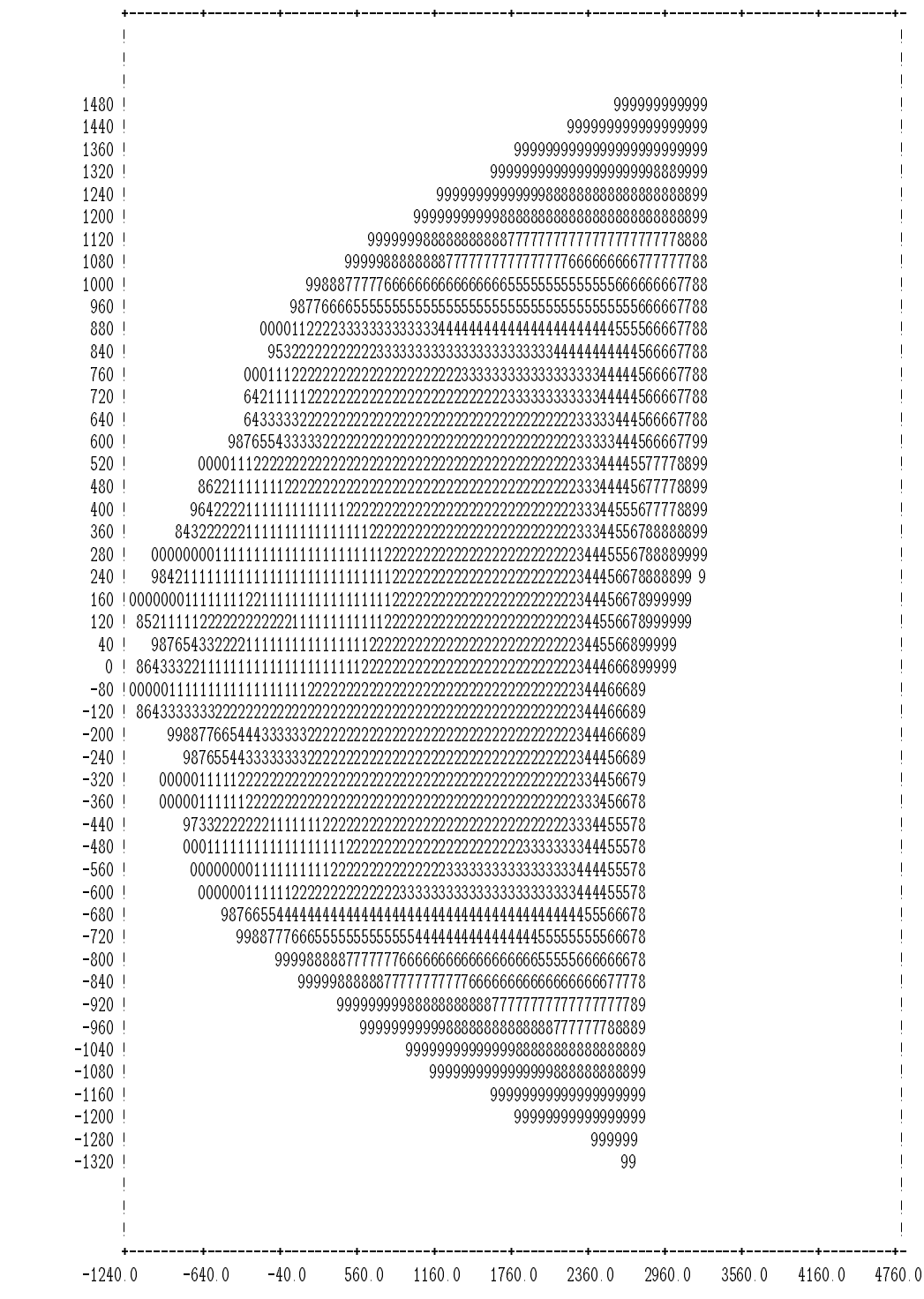
```
 ERROR       0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
 JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
WAVL          0.55
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .5500E+00 .5500E+00 .0000E+00


                                    BEGINNING           ENDING

           WAVENUMBER (CM**-1)       18181.818          18181.818

           WAVELENGTH (MICROMETERS)       .550               .550

           FREQUENCY (GHZ)          545454.563         545454.563



        **** EOSAEL WARNING ****
 VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM



                                VISIBILITY
                                 10.00 KM




                  ********************************
                  *                              *
                  *        R T L A S S           *
                  *                              *
                  *  RADIATION TRANSPORT  PART 2 *
                  *LARGE AREA SMOKE SCREEN MODULE*
                  *    NOT FOR OPERATIONAL USE   *
                  *                              *
                  * EOSAEL87 REV 2.1   02/23/90  *
                  *                              *
                  ********************************


 ** WARNING: FILE TDLASS.PLT NOT OPEN BEFORE ENTRYINTO RTLASS. **


 ***************************************************************************
 *************************      RTLASS MODULE      *************************
 *************************       CYCLE #    1       *************************
 ***************************************************************************


                           *****CARD INPUT*****
 ---------------------------------------------------------------------------
        EXAMPLE 3: LASS(87)
 OBSC        7.200      .750      .000      .000      .000      .000      .000
 SOLR      950.000     5.000   180.000      .200   180.000      .000      .000
```

```
ALBO          .200      .200      .000      .000      .000      .000      .000
RTAZ         1.000      .000      .000      .000      .000      .000      .000
DONE          .000      .000      .000      .000      .000      .000      .000
** WARNING: FILE RTLASS.PLT NOT OPENED BEFORE CALLOF RTLASS.
-------------------------------------------------------------------------------


                          *****INPUT*****
-------------------------------------------------------------------------------

METEOROLOGICAL:
    WIND SPEED          4.4  M/S     MIXING HEIGHT      1000.0   M
    WIND DIRECTION     40.0  DEG     SCAVENGING FACTOR      .00
    SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =     .650
    PASQUILL CATEGORY   3.0                       F2 = 3003.2   S



SOLAR/SKY DATA:
    SOLAR FLUX         950.00 W/M     SURFACE ALBEDO         .20
    SOLAR ZENITH                      SKY RADIANCE        180.00  W/M**2
    (W.R.T. OBS.)      25.84 DEG
    SOLAR AZIMUTH
    (W.R.T. NORTH)    180.00 DEG



SOURCE DATA:                                  REFERENCE
    TYPE              FOG OIL                OBSERVER DATA:
    NO. OF GENERATORS   17                   OBS. ZENITH ANGLE
    EMISSION RATE      37.20  G/S                  (W.R.T.TARG.)     .0 DEG
    YIELD FACTOR        1.00                 OBS. AZIMUTH ANGLE
    EFFICIENCY        100.00  %                    (W.R.T.NORTH)     .0 DEG
    MASS EXT.COEFF.     7.200 M**2/G         OBS.-TARG.RANGE     1000.0 M
    HEN.-GR. PARAMETER   .00                 FIELD AZIMUTH ANGLE
                                             (W.R.T.NORTH)     .0 DEG
                                             BACKGROUND ALBEDO       .20



LASS ARRAY PARAMETERS:
    RESOLUTION                 40.0    M
    MIN. CONCENTRATION       .1000E-05 G/M**3
    AZIMUTH AVERAGING IS:    ON

-------------------------------------------------------------------------------
1              ---------------------------------------------------------------------------------------

                                          **** CONTRAST TRANSMISSION MAP ****


                  LEGEND:
                            SYMBOL    CONT.TRANS.(%)

                              0        0 =< CT < 10
                              1       10 =< CT < 20
                              2       20 =< CT < 30
                              3       30 =< CT < 40
                              4       40 =< CT < 50
                              5       50 =< CT < 60
                              6       60 =< CT < 70
                              7       70 =< CT < 80
                              8       80 =< CT < 90
```

9 90 =< CT < 100

WIND SYSTEM COORDINATES ARE USED.

1



```
                                    DOWNWIND RANGE, M


                ******MODULE RTLASS END******
```

2.3.4 Example 4

In example 4, the scenario is identical to that of example 1 except that the observer is moved to a location due west (azimuth = 270°) of the target and at a zenith of 60°. The input file has been constructed so that the contrast transmission map will also be calculated during the run. The RT scenario is identical to example 2 (early morning).

The input file, the CL map generated by example 4, and the contrast transmission results are presented in the following pages. Comparison of the CL map of this run with that of example 1 reveals how mush denser the LASS appears to an observer with a shallow look-down angle than to an observer directly above the LASS. This is, of course, a result of the greater path length along the former observer's LOS. Similar conclusions may be drawn by comparing the contrast transmission plots of this example and example 2.

```
WAVL          0.55
TDLASS
NAME
        EXAMPLE 4:  LASS(87)
SCEN          0.0       0.0       0.0       3.0     270.0    2000.0      00.0
CMAP         40.0       0.001  3500.000   800.000     0.001
SRCD         37.2     100.0       1.0       2.0       0.65   3003.2
MET1          3.0       4.4      40.0       0.3    1000.000     0.0      00.0
PLOT          0.001     0.05      7.2
OPTN          1.0       1.0       1.0       0.0       0.0
SRCL        361.351  1018.451
SRCL        401.996   946.399
SRCL        740.0    1020.0
SRCL        166.062   942.276
SRCL         73.723   941.151
SRCL        -11.122   940.587
SRCL        770.310   949.936
SRCL        899.781   848.532
SRCL        895.298   798.127
SRCL        878.731   619.976
SRCL        867.795   509.875
SRCL        850.549   302.706
SRCL        840.870   197.992
SRCL        826.507  -199.264
SRCL        825.734   -96.115
SRCL        460.0     640.000
SRCL        816.466  -414.659
DONE
END
RTLASS
NAME
         EXAMPLE 4:  LASS(87)
OBSC          7.2       0.75
SOLR         10.0       1.0      90.0       0.2      40.0
ALBO          0.2       0.2
RTAZ          1.0
DONE
END
STOP
# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) LASS04.DAT 2.1 02/23/90
```

****
WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED

```
  BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                  SEVERE CRIMINAL PENALTIES.
*****************************************************************************


                    *******************************
                    *                             *
                    *    ELECTRO-OPTICAL SYSTEMS  *
                    *                             *
                    *  ATMOSPHERIC EFFECTS LIBRARY *
                    *                             *
                    *    NOT FOR OPERATIONAL USE  *
                    *                             *
                    * EOSAEL87 REV 2.1   02/23/90 *
                    *                             *
                    *******************************


 ERROR       0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
 JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
WAVL          0.55
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .5500E+00 .5500E+00 .0000E+00


                                   BEGINNING           ENDING

            WAVENUMBER (CM**-1)       18181.818          18181.818

            WAVELENGTH (MICROMETERS)       .550               .550

            FREQUENCY (GHZ)          545454.563         545454.563



         **** EOSAEL WARNING ****
 VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM



                                 VISIBILITY
                                  10.00 KM



                    *******************************
                    *                             *
```

```
*        T D L A S S        *
*                           *
*TRANSPORT AND DIFFUSION  PART *
*LARGE AREA SMOKE SCREEN MODULE*
*    NOT FOR OPERATIONAL USE  *
*                           *
* EOSAEL87 REV 2.1   02/23/90 *
*                           *
*****************************
```

```
TDLASS IS OPENING FILE 'TDLASS.PLT' FOR OUTPUT.
TDLASS IS OPENING FILE 'TDLASS.AUX' FOR OUTPUT.
```

```
*******************************************************************************
**************************      TDLASS MODULE      **************************
**************************       CYCLE #    1       **************************
*******************************************************************************
```

*****CARD INPUT*****

```
-------------------------------------------------------------------------------
       EXAMPLE 4:  LASS(87)
SCEN          .000      .000      .000     3.000   270.000  2000.000      .000
CMAP        40.000      .001  3500.000   800.000      .001      .000      .000
SRCD        37.200   100.000     1.000     2.000      .650  3003.200      .000
MET1         3.000     4.400    40.000      .300  1000.000      .000      .000
PLOT          .001      .050     7.200      .000      .000      .000      .000
OPTN         1.000     1.000     1.000      .000      .000      .000      .000
SRCL       361.351  1018.451      .000      .000      .000      .000      .000
SRCL       401.996   946.399      .000      .000      .000      .000      .000
SRCL       740.000  1020.000      .000      .000      .000      .000      .000
SRCL       166.062   942.276      .000      .000      .000      .000      .000
SRCL        73.723   941.151      .000      .000      .000      .000      .000
SRCL       -11.122   940.587      .000      .000      .000      .000      .000
SRCL       770.310   949.936      .000      .000      .000      .000      .000
SRCL       899.781   848.532      .000      .000      .000      .000      .000
SRCL       895.298   798.127      .000      .000      .000      .000      .000
SRCL       878.731   619.976      .000      .000      .000      .000      .000
SRCL       867.795   509.875      .000      .000      .000      .000      .000
SRCL       850.549   302.706      .000      .000      .000      .000      .000
SRCL       840.870   197.992      .000      .000      .000      .000      .000
SRCL       826.507  -199.264      .000      .000      .000      .000      .000
SRCL       825.734   -96.115      .000      .000      .000      .000      .000
SRCL       460.000   640.000      .000      .000      .000      .000      .000
SRCL       816.466  -414.659      .000      .000      .000      .000      .000
DONE          .000      .000      .000      .000      .000      .000      .000
-------------------------------------------------------------------------------
```

*****INPUT*****

```
-------------------------------------------------------------------------------

METEOROLOGICAL:
   WIND SPEED          4.4  M/S     MIXING HEIGHT      1000.0   M
   WIND DIRECTION     40.0  DEG     SCAVENGING FACTOR      .00
   SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =     .650
   PASQUILL CATEGORY   3.0                        F2 = 3003.2   S


REFERENCE                                   REFERENCE
```

```
OBSERVER DATA:                                TARGET COORDINATES:
    X       -1732.1 M                            X            .0 M
    Y            .0 M                            Y            .0 M
    Z        1000.0 M                            Z            .0 M
    OBS. ZENITH ANGLE
                        (W.R.T.TARG.)    60.0 DEG
    OBS. AZIMUTH ANGLE                       OBS.-TARG.RANGE    2000.0 M
                        (W.R.T.NORTH)   270.0 DEG
    FIELD AZIMUTH ANGLE
                        (W.R.T.NORTH)      .0 DEG



SOURCE DATA:                                  OBSCURANT DATA:
    NO. OF GENERATORS          17                TYPE           FOG OIL
    DEPLOYMENT IS NON-LINEAR                     EMISSION RATE    37.20  G/S
                                                 YIELD FACTOR      1.00
                                                 EFFICIENCY      100.00  %
                                                 MASS EXT.COEFF.   7.200 M**2/G



LASS ARRAY PARAMETERS:
    RESOLUTION                  40.0    M
    MIN. CONCENTRATION        .1000E-05 G/M**3

--------------------------------------------------------------------------------


**** BEGIN CALCULATIONS FOR SINGLE SOURCE CLOUD ****


    **** CL OUTPUT HAS BEEN CALCULATED FOR A SINGLE
         SOURCE CLOUD AND STORED IN A SEPARATE FILE ****


    **** SINGLE SOURCE OUTPUT COMPLETE ****


    **** BEGIN CONSTRUCTION OF OVERALL LASS FOR  17 SOURCES ****


    **** LASS OUTPUT FOR 17 SOURCES COMPLETE ****


--------------------------------------------------------------------------------
                              ***** LASS MAP *****


LEGEND:
    SYMBOL      OPT. DEP.      TRANS.(%)     CONC. LENGTH (G/M**2)

       0        .00 -   .05    99.9 - 95.0     .139E-03 -  .708E-02
       1        .05 -   .10    95.0 - 90.4     .708E-02 -  .140E-01
       2        .10 -   .15    90.4 - 86.0     .140E-01 -  .210E-01
       3        .15 -   .20    86.0 - 81.8     .210E-01 -  .279E-01
       4        .20 -   .25    81.8 - 77.8     .279E-01 -  .349E-01
       5        .25 -   .30    77.8 - 74.0     .349E-01 -  .418E-01
       6        .30 -   .35    74.0 - 70.4     .418E-01 -  .487E-01
       7        .35 -   .40    70.4 - 67.0     .487E-01 -  .557E-01
       8        .40 -   .45    67.0 - 63.7     .557E-01 -  .626E-01
       9        .45 -   .50    63.7 - 60.6     .626E-01 -  .696E-01
       X          >=   .50       =< 60.6            >=  .696E-01
```

WIND SYSTEM COORDINATES ARE USED.

```
       +---------+---------+---------+---------+---------+---------+---------+---------+---------+-
       !                                                                                           !
       !                                                                                           !
       !                                                                                           !
  2320 !                                                                  000                      !
  2280 !                                                                0000000                    !
  2200 !                                                             000000000000                  !
  2160 !                                                            00000000000000                 !
  2080 !                                                          000000000000000000               !
  2040 !                                                          000000000000000000               !
  1960 !                                                       00000000000000000000000             !
  1920 !                                                      000000000000000000000000             !
  1840 !                                                   0000000000000000000000000000            !
  1800 !                                                  00000000000000000000000000000            !
  1720 !                                               000000000000000000000000000000000           !
  1680 !                                              0000000000000000000000001101110000           !
  1600 !                                           00000000000000000001111111111111111100          !
  1560 !                                          0000000000000000000011111111111111111100        !
  1480 !                                       000000000000000011111112222222222222222211         !
  1440 !                                      00000000000000111111122222223333333322332211        !
  1360 !                                 0000000000001111122222333334444444444433343311           !
  1320 !                                 0000000000111112222333334444455555555555444443311        !
  1240 !                              00000000111122233344445555666677777777666655553322          !
  1200 !                             000000011222333444555666677778888888888777755554422          !
  1120 !                          00000112234455667778889999XXXXXXXXXXXXXXX999866664422           !
  1080 !                          00012234556677889 9XXXXXXXXXXXXXXXXXXXXXXXXXX877774422           !
  1000 !                        0134789XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX977775422            !
   960 !                       047XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX977775422             !
   880 !                     0XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX77774422              !
   840 !                   017XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX77774422               !
   760 !                 00XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX966664411               !
   720 !                 1XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX966663311               !
   640 !              0135XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX855553311               !
   600 !            0047XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX744442211               !
   520 !          00XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX8633332200               !
   480 !         002XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX8533331100               !
   400 !       002XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX996422221100               !
   360 !      00XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX886311121100               !
   280 ! 00XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX885211110000               !
   240 ! 15XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX9774211110000               !
   160 !XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX9774200000000               !
   120 ! 03XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX9773200000000               !
    40 ! 14XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX8773100000000               !
     0 !1XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX8773100000000               !
   -80 !XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX88841000000                   !
  -120 ! 026799XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX88841000000                   !
  -200 !     00248XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX988420000                     !
  -240 !     14XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX988420000                     !
  -320 !    XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX98842                         !
  -360 !    XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX88842                         !
  -440 !       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX88842                         !
  -480 !       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX87742                         !
  -560 !        XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX77742                         !
  -600 !         XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX999966642                       !
  -680 !           00113345566677777888888888888888888888888888888888777755531                 !
  -720 !             00001122334444555555666666666666666667777777766665443 1                  !
  -800 !                 0000000011112222223333333444444444444555444433321                    !
```

```
 -840 !                 00000000001111112222222233333333334444444433321                                  !
 -920 !                     00000000000000111111111122222222222222222210                                  !
 -960 !                       00000000000000000011111111111222222212210                                  !
-1040 !                            00000000000000000000000011111111111110                                  !
-1080 !                              00000000000000000000000000111111100                                  !
-1160 !                                   00000000000000000000000000000000                                  !
-1200 !                                     00000000000000000000000000000                                  !
-1280 !                                          00000000000000000000000                                  !
-1320 !                                            00000000000000000000                                  !
-1400 !                                                 0000000000000000                                  !
-1440 !                                                    0000000000000                                  !
-1520 !                                                         00000000                                  !
-1560 !                                                           0 000                                  !
      !                                                                                                  !
      !                                                                                                  !
      !                                                                                                  !
      +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+-
 -1240.0     -640.0     -40.0     560.0    1160.0    1760.0    2360.0    2960.0    3560.0    4160.0    4760.0
                                                DOWNWIND RANGE, M


                    ******MODULE TDLASS END******
```

2.3.5 Example 5

Example 5 used the LASS CL map calculated in example 4 to compute a contrast transmission map for the identical scenario except with the sun relocated behind the observer (azimuth = 270°, zenith angle = 84°). That is, the LASS of example 4 is now studied in a backscatter situation. The input file and the output for example 5, including the computed contrast transmission map, are presented in the following pages.

Comparison with the example 4 contrast transmission map for the forward scattering scenario reveals that the LASS is not effective for backscatter situations, although the differences are not as strong as might have been expected. The lack of extreme differences is a result of two factors. First, the solar flux for these runs is quite low (10 W/m^2), so that diffuse sky irradiance dominates. Second, the observer has a zenith angle of nearly 25° less than the solar zenith (scattering angles of 36° and 156° for example 4 and example 5, respectively) so that the observers in the two examples are not receiving full forward or backscatter radiation.

```
WAVL          0.55
RTLASS
NAME
         EXAMPLE 5: LASS(87)
OBSC          7.2       0.75
SOLR         10.0       1.0      270.0        0.2       40.0
ALBO          0.2       0.2
RTAZ          1.0
DONE
END
STOP
# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) LASS05.DAT 2.1 02/23/90


*****************************************************************************
  WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
  BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                 SEVERE CRIMINAL PENALTIES.
*****************************************************************************
```

```
*******************************
*                             *
*    ELECTRO-OPTICAL SYSTEMS  *
*                             *
*  ATMOSPHERIC EFFECTS LIBRARY *
*                             *
*    NOT FOR OPERATIONAL USE  *
*                             *
* EOSAEL87 REV 2.1   02/23/90 *
*                             *
*******************************


 ERROR       0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
 JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
WAVL          0.55
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .5500E+00 .5500E+00 .0000E+00


                                  BEGINNING           ENDING

            WAVENUMBER (CM**-1)       18181.818          18181.818

            WAVELENGTH (MICROMETERS)       .550               .550

            FREQUENCY (GHZ)          545454.563         545454.563



         **** EOSAEL WARNING ****
 VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM



                              VISIBILITY
                               10.00 KM


*******************************
*                             *
*        R T L A S S          *
*                             *
*  RADIATION TRANSPORT  PART 2 *
*LARGE AREA SMOKE SCREEN MODULE*
*    NOT FOR OPERATIONAL USE  *
*                             *
* EOSAEL87 REV 2.1   02/23/90 *
```

```
                    *                              *
                    ******************************


** WARNING: FILE TDLASS.PLT NOT OPEN BEFORE ENTRYINTO RTLASS. **


*************************************************************************
************************      RTLASS MODULE      ************************
************************       CYCLE #    1       ************************
*************************************************************************


                            *****CARD INPUT*****
-----------------------------------------------------------------------------------
        EXAMPLE 5: LASS(87)
OBSC        7.200      .750      .000      .000      .000      .000      .000
SOLR       10.000     1.000   270.000      .200    40.000      .000      .000
ALBO         .200      .200      .000      .000      .000      .000      .000
RTAZ        1.000      .000      .000      .000      .000      .000      .000
DONE         .000      .000      .000      .000      .000      .000      .000
** WARNING: FILE RTLASS.PLT NOT OPENED BEFORE CALLOF RTLASS.
-----------------------------------------------------------------------------------


                            *****INPUT*****
-----------------------------------------------------------------------------------

METEOROLOGICAL:
    WIND SPEED          4.4  M/S     MIXING HEIGHT      1000.0   M
    WIND DIRECTION     40.0  DEG     SCAVENGING FACTOR      .00
    SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =     .650
    PASQUILL CATEGORY   3.0                        F2 = 3003.2   S



SOLAR/SKY DATA:
    SOLAR FLUX          10.00 W/M     SURFACE ALBEDO         .20
    SOLAR ZENITH                      SKY RADIANCE        40.00  W/M**2
    (W.R.T. OBS.)      84.26 DEG
    SOLAR AZIMUTH
    (W.R.T. NORTH)    270.00 DEG



SOURCE DATA:                                REFERENCE
    TYPE             FOG OIL               OBSERVER DATA:
    NO. OF GENERATORS   17                 OBS. ZENITH ANGLE
    EMISSION RATE      37.20  G/S               (W.R.T.TARG.)   60.0 DEG
    YIELD FACTOR        1.00               OBS. AZIMUTH ANGLE
    EFFICIENCY        100.00  %                (W.R.T.NORTH)  270.0 DEG
    MASS EXT.COEFF.     7.200 M**2/G       OBS.-TARG.RANGE    2000.0 M
    HEN.-GR. PARAMETER   .00               FIELD AZIMUTH ANGLE
                                           (W.R.T.NORTH)      .0 DEG
                                           BACKGROUND ALBEDO       .20



LASS ARRAY PARAMETERS:
    RESOLUTION                40.0    M
    MIN. CONCENTRATION      .1000E-05 G/M**3
    AZIMUTH AVERAGING IS:    ON
```

```
 ------------------------------------------------------------------------------
1              ------------------------------------------------------------------------------

                                    **** CONTRAST TRANSMISSION MAP ****


                LEGEND:
                          SYMBOL    CONT.TRANS.(%)

                            0        0 =< CT < 10
                            1       10 =< CT < 20
                            2       20 =< CT < 30
                            3       30 =< CT < 40
                            4       40 =< CT < 50
                            5       50 =< CT < 60
                            6       60 =< CT < 70
                            7       70 =< CT < 80
                            8       80 =< CT < 90
                            9       90 =< CT < 100

                          WIND SYSTEM COORDINATES ARE USED.


1
             +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+-
             !                                                                                                    !
             !                                                                                                    !
             !                                                                                                    !
        1840 !                                                                  88888888                          !
        1800 !                                                                8888888888                          !
        1720 !                                                          888888888888888888                        !
        1680 !                                                        888888888888888888888                        !
        1600 !                                                    8888888888888777777778888                        !
        1560 !                                                  888888888888777777777777788                        !
        1480 !                                              88888888877777776666666666667788                        !
        1440 !                                            888888887777776666666665666666677                        !
        1360 !                                        8888888777766666655555555555555556677                        !
        1320 !                                      88888877776666655555544444444444455556677                        !
        1240 !                                  888887766665555444444443333333333333444445577                        !
        1200 !                                8888777665555444444333333333333333333344445577                        !
        1120 !                            887766554444333333222222222222222222222222333335566                        !
        1080 !                          8876554443333322222222222222222221122222222333334466                        !
        1000 !                        865332222211111111111111111111111111111111111222233334466                        !
         960 !                       532111111111111111111111111111111111111111111222233334466                        !
         880 !                     000000000000000000000000000000000000000111111112233334577                        !
         840 !                    732100000000000000000000000000000000000000011111112233335577                        !
         760 !                   000000000000000000000000000000000000000000011111112233335577                        !
         720 !                  710000000000000000000000000000000000000000000001111112244445577                        !
         640 !                885421110000000000000000000000000000000000000000011112223444446688                        !
         600 !                531111000000000000000000000000000000000000000000011112223444446688                        !
         520 !              000000000000000000000000000000000000000000000000011111223455557788                        !
         480 !             600000000000000000000000000000000000000000000000011112223466667788                        !
         400 !           862100000000000000000000000000000000000000000000000011112223566668888                        !
         360 !           100000000000000000000000000000000000000000000000000011112334577778 8                        !
         280 !         000000000000000000000000000000000000000000000000000000111223346888888                        !
         240 !       741000000000000000000000000000000000000000000000000000011122335688888 8                        !
         160 !      000000000000000000000000000000000000000000000000000000011122335788888                        !
         120 !       852111000000000000000000000000000000000000000000000000011112335788888                        !
          40 !       752111000000000000000000000000000000000000000000000000000111133357                        !
           0 !      700000000000000000000000000000000000000000000000000000000111133357                        !
         -80 !      000000000000000000000000000000000000000000000000000000000111133357                        !
        -120 !       864322222211111100000000000000000000000000000000000000000111123357                        !
```

```
 -200 !      865321111111100000000000000000000000000000000000000000111123357                                  !
 -240 !     752111000000000000000000000000000000000000000000000000111123357                                  !
 -320 !    000000000000000000000000000000000000000000000000111111111111123346                                  !
 -360 !    000000000000000000000000000000000000000000000111111111111111133346                                  !
 -440 !       100000000000000000000000000000000111111111111111111111112233346                                  !
 -480 !       000000000000000000000000000000111111111111111111111111222233346                                  !
 -560 !        000000000000000000011111111111111111111111122222222222222233357                                  !
 -600 !         0000000000111111111111111111122222222222222222222222222233457                                  !
 -680 !             876554443333333333333333333333333333333333333333333344457                                  !
 -720 !               887766655554444444444444433333333333333333333333344457                                  !
 -800 !                     888888777766666655555555555555444444444444455567                                  !
 -840 !                         8888887777776666666666555555555555555566668                                  !
 -920 !                               88888888887777777777666666666666666678                                  !
 -960 !                                   888888888888777777777777777677778                                  !
-1040 !                                          8888888888888888887788888                                  !
-1080 !                                              888888888888888888888                                  !
-1160 !                                                    8888888888888                                    !
-1200 !                                                        888888888                                    !
      !                                                                                                     !
      !                                                                                                     !
      !                                                                                                     !
      +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+-
 -1240.0     -640.0     -40.0     560.0    1160.0    1760.0    2360.0    2960.0    3560.0    4160.0    4760.0
                                                DOWNWIND RANGE, M


              ******MODULE RTLASS END******
```

2.3.6 Example 6

Example 6 illustrates a horizontal scenario, the output of which is quite different from any nonhorizontal scenario.

In this example, the observer's zenith is 90° (zenith code = 0.0) and the azimuth is 270°. The specification of `IOBSZ = 0.0` automatically results in the calculation of a single observer-target horizontal CL, optical depth, and transmission. Also included in the output is a table giving the vertical CLs and optical depths for positions along the horizontal LOS, as well as the mean of these values. The input file and the output for example 6 are presented in the following five pages. No CL map is produced.

For this scenario, the observer's horizontal LOS encounters clouds produced by three generators. Therefore, the calculated CL is large and the transmittance is low. Notice too that the option `VCVSW` is set to `0.0` (`= OFF`). Thus, the generator plumes do not rise as they travel downwind.

A single observer-target CL may be included in the output of any scenario by setting the option `SLOSSW = 1.0`. For a horizontal scenario, however, this single CL will always be included in the output.

This example also included the RT calculations in the same run. The inputs used are identical to those of example 5. However, since the CL input file was for a horizontal scenario, the output from the RT calculations are the horizontal observer-target contrast transmission, path irradiance, and direct irradiance. No contrast transmission map is generated.

```
WAVL          0.55
TDLASS
NAME
        EXAMPLE 6: LASS(87)
SCEN        760.0    1060.0       0.0       0.0     270.0    1000.0      60.0
CMAP         40.0       0.001  3500.000   800.000     0.001
SRCD         37.2     100.0       1.0       2.0       0.65   3003.2
MET1          3.0       4.4       0.0       0.3    1000.000     0.0      20.0
PLOT          0.001     0.05      7.2
OPTN          1.0       1.0       1.0       1.0       1.0
SRCL        361.351  1018.451
SRCL        401.996   946.399
```

```
SRCL        166.062   942.276
DONE
END
RTLASS
NAME

         EXAMPLE 6: LASS(87)
OBSC          7.2       0.75
SOLR         10.0       1.0     270.0       0.2      40.0
ALBO          0.2       0.2
RTAZ          1.0
DONE
END
STOP
# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) LASS06.DAT 2.1 02/23/90
```


```
*****************************************************************************
  WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
  BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                SEVERE CRIMINAL PENALTIES.
*****************************************************************************
```


```
                  ******************************
                  *                            *
                  *   ELECTRO-OPTICAL SYSTEMS  *
                  *                            *
                  * ATMOSPHERIC EFFECTS LIBRARY *
                  *                            *
                  *   NOT FOR OPERATIONAL USE  *
                  *                            *
                  * EOSAEL87 REV 2.1   02/23/90 *
                  *                            *
                  ******************************


 ERROR      0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
 JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
WAVL         0.55
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .5500E+00 .5500E+00 .0000E+00


                                BEGINNING          ENDING

           WAVENUMBER (CM**-1)     18181.818        18181.818

           WAVELENGTH (MICROMETERS)     .550             .550

           FREQUENCY (GHZ)        545454.563       545454.563
```

```
        **** EOSAEL WARNING ****
VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM



                              VISIBILITY
                               10.00 KM




                 ********************************
                 *                              *
                 *        T D L A S S           *
                 *                              *
                 *TRANSPORT AND DIFFUSION  PART *
                 *LARGE AREA SMOKE SCREEN MODULE*
                 *    NOT FOR OPERATIONAL USE   *
                 *                              *
                 * EOSAEL87 REV 2.1   02/23/90  *
                 *                              *
                 ********************************


TDLASS IS OPENING FILE 'TDLASS.PLT' FOR OUTPUT.
TDLASS IS OPENING FILE 'TDLASS.AUX' FOR OUTPUT.


*******************************************************************************
***************************      TDLASS MODULE      ***************************
***************************       CYCLE #    1       ***************************
*******************************************************************************


                          *****CARD INPUT*****
-------------------------------------------------------------------------------
       EXAMPLE 6: LASS(87)
SCEN       760.000  1060.000      .000      .000   270.000  1000.000    60.000
CMAP        40.000      .001  3500.000   800.000      .001      .000      .000
SRCD        37.200   100.000     1.000     2.000      .650  3003.200      .000
MET1         3.000     4.400      .000      .300  1000.000      .000    20.000
PLOT          .001      .050     7.200      .000      .000      .000      .000
OPTN         1.000     1.000     1.000     1.000     1.000      .000      .000
SRCL       361.351  1018.451      .000      .000      .000      .000      .000
SRCL       401.996   946.399      .000      .000      .000      .000      .000
SRCL       166.062   942.276      .000      .000      .000      .000      .000
DONE          .000      .000      .000      .000      .000      .000      .000
-------------------------------------------------------------------------------

                           *****INPUT*****
-------------------------------------------------------------------------------

METEOROLOGICAL:
   WIND SPEED          4.4  M/S     MIXING HEIGHT      1000.0   M
   WIND DIRECTION       .0  DEG     SCAVENGING FACTOR      .00
   SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =     .650
```

```
    PASQUILL CATEGORY   3.0                      F2 = 3003.2   S
                SENSIBLE HEAT FLUX   20.00  WATTS/M**2



REFERENCE                                   REFERENCE
OBSERVER DATA:                              TARGET COORDINATES:
    X         298.0 M                          X        1298.0 M
    Y        -128.2 M                          Y        -128.2 M
    Z            .0 M                          Z            .0 M
    OBS. ZENITH ANGLE
                        (W.R.T.TARG.)    90.0 DEG
    OBS. AZIMUTH ANGLE                      OBS.-TARG.RANGE    1000.0 M
                        (W.R.T.NORTH)   270.0 DEG
    FIELD AZIMUTH ANGLE
                        (W.R.T.NORTH)    60.0 DEG



SOURCE DATA:                                OBSCURANT DATA:
    NO. OF GENERATORS           3               TYPE           FOG OIL
    DEPLOYMENT IS NON-LINEAR                    EMISSION RATE    37.20  G/S
                                                YIELD FACTOR      1.00
                                                EFFICIENCY      100.00  %
                                                MASS EXT.COEFF.   7.200 M**2/G



LASS ARRAY PARAMETERS:
    RESOLUTION                  40.0    M
    MIN. CONCENTRATION         .1000E-05 G/M**3

-------------------------------------------------------------------------------


-------------------------------------------------------------------------------

**** BEGIN CALCULATIONS FOR SINGLE OBSERVER-TARGET LOS FOR  3 SOURCES ****

                              ******OUTPUT******
-------------------------------------------------------------------------------


    HORIZONTAL OBSERVER-TARGET CL:    .600E+00 G/M**2
    HORIZONTAL OPTICAL DEPTH:       4.322
    HORIZONTAL TRANSMISSION:          .01


VERTICAL OBSERVER-TARGET LOS DATA:

DIST. FROM          WIND                FIELD        VERTICAL      VERTICAL
OBSERVER (M)      X         Y         X          Y    CL (G/M**2)      TAU
------------ -------------------  -------------------- ------------   --------
  360.00      128.18    657.99     440.00     505.75    .226E-05       .000
  400.00      128.18    697.99     460.00     540.39    .508E-04       .000
  440.00      128.18    737.99     480.00     575.03    .650E-03       .005
  480.00      128.18    777.99     500.00     609.67    .474E-02       .034
  520.00      128.18    817.99     520.00     644.31    .197E-01       .142
  560.00      128.18    857.99     540.00     678.95    .465E-01       .335
  600.00      128.18    897.99     560.00     713.59    .626E-01       .451
  640.00      128.18    937.99     580.00     748.23    .518E-01       .373
  680.00      128.18    977.99     600.00     782.87    .718E-01       .517
  720.00      128.18   1017.99     620.00     817.52    .156E+00      1.123
```

```
760.00     128.18   1057.99    640.00    852.16    .138E+00     .992
800.00     128.18   1097.99    660.00    886.80    .620E-01     .447
840.00     128.18   1137.99    680.00    921.44    .137E-01     .098
880.00     128.18   1177.99    700.00    956.08    .115E-02     .008
920.00     128.18   1217.99    720.00    990.72    .343E-04     .000


           MEAN VERTICAL CL:                .419E-01 G/M**2
           MEAN VERTICAL OPTICAL DEPTH:     .302
           MEAN VERTICAL TRANSMISSION:      .74

                      ******MODULE TDLASS END******
```

2.3.7 Example 7

Example 7 is another horizontal scenario. The inputs are identical to those of example 6 except that for example 7 the option `VCVSW` has been set to `1.0` (`= ON`), and a sensible heat flux has been specified. That is, the plumes rise as they travel downwind.

The input and output for example 7 are presented in the following pages. The output shows that when the plumes are allowed to rise slightly, the observer's horizontal LOS encounters less dense regions of the plumes than it did in example 6. Hence, the horizontal CL is lower and the transmittance is higher than in example 6.

```
WAVL          0.55
TDLASS
NAME
        EXAMPLE 7:  LASS(87)
SCEN        760.0    1060.0       0.0       0.0     270.0    1000.0      60.0
CMAP         40.0       0.001  3500.000   800.000     0.001
SRCD         37.2     100.0       1.0       2.0       0.65   3003.2
MET1          3.0       4.4       0.0       0.3    1000.000     0.0      20.0
PLOT          0.001     0.05      7.2
OPTN          1.0       1.0       1.0       0.0       1.0
SRCL        361.351  1018.451
SRCL        401.996   946.399
SRCL        166.062   942.276
DONE
END
RTLASS
NAME
       EXAMPLE 7:  LASS(87)
OBSC          7.2       0.75
SOLR         10.0       1.0     270.0       0.2      40.0
ALBO          0.2       0.2
RTAZ          1.0
DONE
END
STOP
# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) LASS07.DAT 2.1 02/23/90

*************************************************************************
  WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
  BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                SEVERE CRIMINAL PENALTIES.
*************************************************************************
                 ******************************
                 *                            *
                 *   ELECTRO-OPTICAL SYSTEMS  *
                 *                            *
                 * ATMOSPHERIC EFFECTS LIBRARY *
                 *                            *
                 *   NOT FOR OPERATIONAL USE  *
                 *                            *
                 * EOSAEL87 REV 2.1   02/23/90 *
                 *                            *
                 ******************************
 ERROR      0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
```

```
 JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
WAVL          0.55
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .5500E+00 .5500E+00 .0000E+00
                                        BEGINNING           ENDING
            WAVENUMBER (CM**-1)        18181.818          18181.818
            WAVELENGTH (MICROMETERS)        .550               .550
            FREQUENCY (GHZ)           545454.563         545454.563
         **** EOSAEL WARNING ****
 VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM
                                   VISIBILITY
                                    10.00 KM
                    ********************************
                    *                              *
                    *        T D L A S S           *
                    *                              *
                    *TRANSPORT AND DIFFUSION  PART *
                    *LARGE AREA SMOKE SCREEN MODULE*
                    *    NOT FOR OPERATIONAL USE   *
                    *                              *
                    * EOSAEL87 REV 2.1   02/23/90  *
                    *                              *
                    ********************************
 TDLASS IS OPENING FILE 'TDLASS.PLT' FOR OUTPUT.
 TDLASS IS OPENING FILE 'TDLASS.AUX' FOR OUTPUT.
 ******************************************************************************
 ***************************      TDLASS MODULE      ***************************
 ***************************       CYCLE #    1       ***************************
 ******************************************************************************
                              *****CARD INPUT*****
 ------------------------------------------------------------------------------
        EXAMPLE 7:  LASS(87)
 SCEN        760.000  1060.000      .000      .000   270.000  1000.000    60.000
 CMAP         40.000      .001  3500.000   800.000      .001      .000      .000
 SRCD         37.200   100.000     1.000     2.000      .650  3003.200      .000
 MET1          3.000     4.400      .000      .300  1000.000      .000    20.000
 PLOT           .001      .050     7.200      .000      .000      .000      .000
 OPTN          1.000     1.000     1.000      .000     1.000      .000      .000
 SRCL        361.351  1018.451      .000      .000      .000      .000      .000
 SRCL        401.996   946.399      .000      .000      .000      .000      .000
 SRCL        166.062   942.276      .000      .000      .000      .000      .000
 DONE           .000      .000      .000      .000      .000      .000      .000
 ------------------------------------------------------------------------------
                              *****INPUT*****
 ------------------------------------------------------------------------------
 METEOROLOGICAL:
     WIND SPEED          4.4  M/S     MIXING HEIGHT      1000.0   M
     WIND DIRECTION       .0  DEG     SCAVENGING FACTOR      .00
     SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =      .650
     PASQUILL CATEGORY   3.0                        F2 = 3003.2   S
 REFERENCE                                      REFERENCE
 OBSERVER DATA:                                 TARGET COORDINATES:
     X         298.0 M                              X        1298.0 M
     Y        -128.2 M                              Y        -128.2 M
     Z            .0 M                              Z            .0 M
     OBS. ZENITH ANGLE
                         (W.R.T.TARG.)    90.0 DEG
     OBS. AZIMUTH ANGLE                      OBS.-TARG.RANGE    1000.0 M
                         (W.R.T.NORTH)   270.0 DEG
     FIELD AZIMUTH ANGLE
                         (W.R.T.NORTH)    60.0 DEG
 SOURCE DATA:                                   OBSCURANT DATA:
     NO. OF GENERATORS            3                TYPE            FOG OIL
     DEPLOYMENT IS NON-LINEAR                      EMISSION RATE    37.20  G/S
                                                   YIELD FACTOR      1.00
                                                   EFFICIENCY      100.00  %
                                                   MASS EXT.COEFF.   7.200 M**2/G
 LASS ARRAY PARAMETERS:
     RESOLUTION                  40.0    M
     MIN. CONCENTRATION         .1000E-05 G/M**3
 ------------------------------------------------------------------------------
 ------------------------------------------------------------------------------
 **** BEGIN CALCULATIONS FOR SINGLE OBSERVER-TARGET LOS FOR  3 SOURCES ****
                              ******OUTPUT******
 ------------------------------------------------------------------------------
     HORIZONTAL OBSERVER-TARGET CL:    .728E+00 G/M**2
     HORIZONTAL OPTICAL DEPTH:        5.241
     HORIZONTAL TRANSMISSION:          .01
 VERTICAL OBSERVER-TARGET LOS DATA:
 DIST. FROM          WIND                  FIELD         VERTICAL      VERTICAL
 OBSERVER (M)      X         Y          X          Y    CL (G/M**2)      TAU
 ------------ ------------------  ------------------- ------------    --------
   360.00      128.18    657.99     440.00     505.75    .226E-05      .000
```

```
   400.00     128.18   697.99    460.00    540.39   .508E-04     .000
   440.00     128.18   737.99    480.00    575.03   .650E-03     .005
   480.00     128.18   777.99    500.00    609.67   .474E-02     .034
   520.00     128.18   817.99    520.00    644.31   .197E-01     .142
   560.00     128.18   857.99    540.00    678.95   .465E-01     .335
   600.00     128.18   897.99    560.00    713.59   .626E-01     .451
   640.00     128.18   937.99    580.00    748.23   .518E-01     .373
   680.00     128.18   977.99    600.00    782.87   .718E-01     .517
   720.00     128.18  1017.99    620.00    817.52   .156E+00    1.123
   760.00     128.18  1057.99    640.00    852.16   .138E+00     .992
   800.00     128.18  1097.99    660.00    886.80   .620E-01     .447
   840.00     128.18  1137.99    680.00    921.44   .137E-01     .098
   880.00     128.18  1177.99    700.00    956.08   .115E-02     .008
   920.00     128.18  1217.99    720.00    990.72   .343E-04     .000
              MEAN VERTICAL CL:                .419E-01 G/M**2
              MEAN VERTICAL OPTICAL DEPTH:     .302
              MEAN VERTICAL TRANSMISSION:      .74
                          ******MODULE TDLASS END******
```

2.3.8 Example 8

```
WAVL          0.55
   TDLASS
   NAME
          EXAMPLE 6: LASS(87)
   SCEN         1000.0   -1000.0     0.0       0.0       0.0    2000.0      0.0
   CMAP         40.0       0.001  3500.000   800.000     0.001
   SRCD         37.2     100.0       1.0       2.0       0.65   3003.2
   MET1          3.0       4.4     270.0       0.3     400.000     0.0      20.0
   PLOT          0.001     0.05      7.2
   OPTN          1.0       1.0       1.0       1.0       1.0
   SRCL          0.0       0.0
   DONE
   END
   # THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
   # SCCS  @(#) LASS08.DAT 2.1 02/23/90

   ****************************************************************************
     WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
     BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
     EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                    SEVERE CRIMINAL PENALTIES.
   ****************************************************************************
                     *******************************
                     *                             *
                     *   ELECTRO-OPTICAL SYSTEMS   *
                     *                             *
                     *  ATMOSPHERIC EFFECTS LIBRARY *
                     *                             *
                     *   NOT FOR OPERATIONAL USE   *
                     *                             *
                     * EOSAEL87 REV 2.1   02/23/90 *
                     *                             *
                     *******************************
    ERROR      0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
    JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
   WAVL         0.55
    NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
   WAVL       .5500E+00 .5500E+00 .0000E+00
                                    BEGINNING          ENDING
              WAVENUMBER (CM**-1)      18181.818         18181.818
              WAVELENGTH (MICROMETERS)      .550              .550
              FREQUENCY (GHZ)        545454.563        545454.563
            **** EOSAEL WARNING ****
    VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM
                                   VISIBILITY
                                    10.00 KM
                     *******************************
                     *                             *
                     *        T D L A S S          *
                     *                             *
                     *TRANSPORT AND DIFFUSION  PART *
                     *LARGE AREA SMOKE SCREEN MODULE*
                     *   NOT FOR OPERATIONAL USE   *
                     *                             *
                     * EOSAEL87 REV 2.1   02/23/90 *
                     *                             *
                     *******************************
    TDLASS IS OPENING FILE 'TDLASS.PLT' FOR OUTPUT.
```

```
TDLASS IS OPENING FILE 'TDLASS.AUX' FOR OUTPUT.
*******************************************************************************
***************************      TDLASS MODULE      ***************************
***************************       CYCLE #    1       ***************************
*******************************************************************************
                              *****CARD INPUT*****
-------------------------------------------------------------------------------
        EXAMPLE 6: LASS(87)
SCEN       1000.000 -1000.000      .000      .000      .000  2000.000      .000
CMAP         40.000      .001  3500.000   800.000      .001      .000      .000
SRCD         37.200   100.000     1.000     2.000      .650  3003.200      .000
MET1          3.000     4.400   270.000      .300   400.000      .000    20.000
PLOT           .001      .050     7.200      .000      .000      .000      .000
OPTN          1.000     1.000     1.000     1.000     1.000      .000      .000
SRCL           .000      .000      .000      .000      .000      .000      .000
DONE           .000      .000      .000      .000      .000      .000      .000
-------------------------------------------------------------------------------
                              *****INPUT*****
-------------------------------------------------------------------------------
METEOROLOGICAL:
    WIND SPEED          4.4  M/S     MIXING HEIGHT       400.0   M
    WIND DIRECTION    270.0  DEG     SCAVENGING FACTOR      .00
    SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =     .650
    PASQUILL CATEGORY   3.0                        F2 = 3003.2   S
                 SENSIBLE HEAT FLUX   20.00  WATTS/M**2
REFERENCE                                      REFERENCE
OBSERVER DATA:                                 TARGET COORDINATES:
    X        1000.0 M                             X        1000.0 M
    Y        1000.0 M                             Y       -1000.0 M
    Z            .0 M                             Z            .0 M
    OBS. ZENITH ANGLE
                        (W.R.T.TARG.)    90.0 DEG
    OBS. AZIMUTH ANGLE                        OBS.-TARG.RANGE    2000.0 M
                        (W.R.T.NORTH)      .0 DEG
    FIELD AZIMUTH ANGLE
                        (W.R.T.NORTH)      .0 DEG
SOURCE DATA:                                   OBSCURANT DATA:
    NO. OF GENERATORS            1                TYPE            FOG OIL
    DEPLOYMENT IS NON-LINEAR                      EMISSION RATE    37.20  G/S
                                                  YIELD FACTOR      1.00
                                                  EFFICIENCY      100.00  %
                                                  MASS EXT.COEFF.   7.200 M**2/G
LASS ARRAY PARAMETERS:
    RESOLUTION                  40.0    M
    MIN. CONCENTRATION         .1000E-05 G/M**3
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
**** BEGIN CALCULATIONS FOR SINGLE OBSERVER-TARGET LOS FOR  1 SOURCES ****
                              ******OUTPUT******
-------------------------------------------------------------------------------
    HORIZONTAL OBSERVER-TARGET CL:    .767E-01 G/M**2
    HORIZONTAL OPTICAL DEPTH:         .552
    HORIZONTAL TRANSMISSION:          .58
VERTICAL OBSERVER-TARGET LOS DATA:
DIST. FROM          WIND                  FIELD          VERTICAL      VERTICAL
OBSERVER (M)      X          Y          X          Y    CL (G/M**2)      TAU
----------- ---------- ---------- ---------- ---------- ----------- ---------
  520.00     1000.00    480.00    1000.00    480.00    .161E-05      .000
  560.00     1000.00    440.00    1000.00    440.00    .776E-05      .000
  600.00     1000.00    400.00    1000.00    400.00    .326E-04      .000
  640.00     1000.00    360.00    1000.00    360.00    .120E-03      .001
  680.00     1000.00    320.00    1000.00    320.00    .382E-03      .003
  720.00     1000.00    280.00    1000.00    280.00    .107E-02      .008
  760.00     1000.00    240.00    1000.00    240.00    .259E-02      .019
  800.00     1000.00    200.00    1000.00    200.00    .550E-02      .040
  840.00     1000.00    160.00    1000.00    160.00    .102E-01      .073
  880.00     1000.00    120.00    1000.00    120.00    .164E-01      .118
  920.00     1000.00     80.00    1000.00     80.00    .231E-01      .166
  960.00     1000.00     40.00    1000.00     40.00    .284E-01      .204
 1000.00     1000.00       .00    1000.00       .00    .304E-01      .219
 1040.00     1000.00    -40.00    1000.00    -40.00    .284E-01      .204
 1080.00     1000.00    -80.00    1000.00    -80.00    .231E-01      .166
 1120.00     1000.00   -120.00    1000.00   -120.00    .164E-01      .118
 1160.00     1000.00   -160.00    1000.00   -160.00    .102E-01      .073
 1200.00     1000.00   -200.00    1000.00   -200.00    .550E-02      .040
 1240.00     1000.00   -240.00    1000.00   -240.00    .259E-02      .019
 1280.00     1000.00   -280.00    1000.00   -280.00    .107E-02      .008
 1320.00     1000.00   -320.00    1000.00   -320.00    .382E-03      .003
 1360.00     1000.00   -360.00    1000.00   -360.00    .120E-03      .001
 1400.00     1000.00   -400.00    1000.00   -400.00    .326E-04      .000
 1440.00     1000.00   -440.00    1000.00   -440.00    .776E-05      .000
 1480.00     1000.00   -480.00    1000.00   -480.00    .161E-05      .000
              MEAN VERTICAL CL:                  .824E-02 G/M**2
              MEAN VERTICAL OPTICAL DEPTH:       .059
```

```
              MEAN VERTICAL TRANSMISSION:      .94
                              ******MODULE TDLASS END******
```

2.3.9 Example 9

```
WAVL          0.55
   TDLASS
   NAME
          Observer at 1 km north of target 1
   SCEN          0.0       0.0       0.0       0.0       0.0    1000.0       0.0
   CMAP         40.0       0.001  3500.000   800.000    0.001
   SRCD         37.2     100.0       1.0       2.0       0.65   3003.2
   MET1          3.0       4.4     180.0       0.3     400.000     0.0      20.0
   PLOT          0.001     0.05      7.2
   OPTN          1.0       1.0       1.0       1.0       1.0
   SRCL          0.0      50.0
   SRCL         50.0       0.0
   SRCL          0.0     -50.0
   SRCL         -50.0      0.0
   DONE
   END
   # THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
   # SCCS  @(#) LASS09.DAT 2.1 02/23/90

   ****************************************************************************
     WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
     BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
     EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                    SEVERE CRIMINAL PENALTIES.
   ****************************************************************************
                     ********************************
                     *                              *
                     *    ELECTRO-OPTICAL SYSTEMS   *
                     *                              *
                     *  ATMOSPHERIC EFFECTS LIBRARY *
                     *                              *
                     *    NOT FOR OPERATIONAL USE   *
                     *                              *
                     * EOSAEL87 REV 2.1   02/23/90  *
                     *                              *
                     ********************************
    ERROR      0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
    JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
   WAVL          0.55
    NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
   WAVL       .5500E+00 .5500E+00 .0000E+00
                                        BEGINNING           ENDING
              WAVENUMBER (CM**-1)       18181.818          18181.818
              WAVELENGTH (MICROMETERS)       .550               .550
              FREQUENCY (GHZ)          545454.563         545454.563
           **** EOSAEL WARNING ****
    VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM
                                   VISIBILITY
                                    10.00 KM
                     ********************************
                     *                              *
                     *         T D L A S S          *
                     *                              *
                     *TRANSPORT AND DIFFUSION  PART *
                     *LARGE AREA SMOKE SCREEN MODULE*
                     *    NOT FOR OPERATIONAL USE   *
                     *                              *
                     * EOSAEL87 REV 2.1   02/23/90  *
                     *                              *
                     ********************************
    TDLASS IS OPENING FILE 'TDLASS.PLT' FOR OUTPUT.
    TDLASS IS OPENING FILE 'TDLASS.AUX' FOR OUTPUT.
    ******************************************************************************
    ***************************      TDLASS MODULE      ***************************
    ***************************       CYCLE #    1      ***************************
    ******************************************************************************
                              *****CARD INPUT*****
    ------------------------------------------------------------------------------
          Observer at 1 km north of target 1
    SCEN          .000      .000      .000      .000      .000  1000.000      .000
    CMAP        40.000      .001  3500.000   800.000      .001      .000      .000
    SRCD        37.200   100.000     1.000     2.000      .650  3003.200      .000
    MET1         3.000     4.400   180.000      .300   400.000      .000    20.000
    PLOT          .001      .050     7.200      .000      .000      .000      .000
```

```
OPTN          1.000     1.000     1.000     1.000     1.000      .000      .000
SRCL           .000    50.000      .000      .000      .000      .000      .000
SRCL         50.000      .000      .000      .000      .000      .000      .000
SRCL           .000   -50.000      .000      .000      .000      .000      .000
SRCL        -50.000      .000      .000      .000      .000      .000      .000
DONE           .000      .000      .000      .000      .000      .000      .000
-------------------------------------------------------------------------------
                              *****INPUT*****
-------------------------------------------------------------------------------
METEOROLOGICAL:
    WIND SPEED          4.4  M/S     MIXING HEIGHT       400.0   M
    WIND DIRECTION    180.0  DEG     SCAVENGING FACTOR      .00
    SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =      .650
    PASQUILL CATEGORY   3.0                       F2 = 3003.2   S
                 SENSIBLE HEAT FLUX   20.00  WATTS/M**2
REFERENCE                                    REFERENCE
OBSERVER DATA:                               TARGET COORDINATES:
    X            .0 M                            X            .0 M
    Y        1000.0 M                            Y            .0 M
    Z            .0 M                            Z            .0 M
    OBS. ZENITH ANGLE
                        (W.R.T.TARG.)    90.0 DEG
    OBS. AZIMUTH ANGLE                       OBS.-TARG.RANGE    1000.0 M
                        (W.R.T.NORTH)      .0 DEG
    FIELD AZIMUTH ANGLE
                        (W.R.T.NORTH)      .0 DEG
SOURCE DATA:                                 OBSCURANT DATA:
    NO. OF GENERATORS            4               TYPE            FOG OIL
    DEPLOYMENT IS NON-LINEAR                     EMISSION RATE    37.20  G/S
                                                 YIELD FACTOR      1.00
                                                 EFFICIENCY      100.00  %
                                                 MASS EXT.COEFF.   7.200 M**2/G
LASS ARRAY PARAMETERS:
    RESOLUTION                  40.0    M
    MIN. CONCENTRATION         .1000E-05 G/M**3
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
**** BEGIN CALCULATIONS FOR SINGLE OBSERVER-TARGET LOS FOR  4 SOURCES ****
                              ******OUTPUT******
-------------------------------------------------------------------------------
    HORIZONTAL OBSERVER-TARGET CL:    .152E+02 G/M**2
    HORIZONTAL OPTICAL DEPTH:      109.496
    HORIZONTAL TRANSMISSION:          .00
VERTICAL OBSERVER-TARGET LOS DATA:
DIST. FROM          WIND                  FIELD         VERTICAL      VERTICAL
OBSERVER (M)      X          Y          X          Y    CL (G/M**2)      TAU
------------ ------------------ ------------------ ------------    --------
   40.00      960.00       .00        .00     960.00    .120E+00      .860
   80.00      920.00       .00        .00     920.00    .124E+00      .891
  120.00      880.00       .00        .00     880.00    .128E+00      .924
  160.00      840.00       .00        .00     840.00    .133E+00      .960
  200.00      800.00       .00        .00     800.00    .139E+00      .998
  240.00      760.00       .00        .00     760.00    .144E+00     1.039
  280.00      720.00       .00        .00     720.00    .150E+00     1.083
  320.00      680.00       .00        .00     680.00    .157E+00     1.131
  360.00      640.00       .00        .00     640.00    .164E+00     1.183
  400.00      600.00       .00        .00     600.00    .172E+00     1.240
  440.00      560.00       .00        .00     560.00    .181E+00     1.301
  480.00      520.00       .00        .00     520.00    .190E+00     1.368
  520.00      480.00       .00        .00     480.00    .200E+00     1.442
  560.00      440.00       .00        .00     440.00    .211E+00     1.522
  600.00      400.00       .00        .00     400.00    .223E+00     1.609
  640.00      360.00       .00        .00     360.00    .237E+00     1.704
  680.00      320.00       .00        .00     320.00    .251E+00     1.809
  720.00      280.00       .00        .00     280.00    .268E+00     1.929
  760.00      240.00       .00        .00     240.00    .288E+00     2.074
  800.00      200.00       .00        .00     200.00    .317E+00     2.284
  840.00      160.00       .00        .00     160.00    .371E+00     2.670
  880.00      120.00       .00        .00     120.00    .497E+00     3.578
  920.00       80.00       .00        .00      80.00    .926E+00     6.669
  960.00       40.00       .00        .00      40.00    .272E+00     1.956
 1000.00         .00       .00        .00        .00    .462E+00     3.323
              MEAN VERTICAL CL:                .253E+00 G/M**2
              MEAN VERTICAL OPTICAL DEPTH:    1.822
              MEAN VERTICAL TRANSMISSION:      .16
                              ******MODULE TDLASS END******
```

2.3.10 Example 10

```
WAVL          0.55
   TDLASS
   NAME
           EXAMPLE 6: LASS(87)
   SCEN          0.0       0.0       0.0       0.0     105.0    1000.0      15.0
   CMAP         40.0       0.001  3500.000   800.000     0.001
   SRCD         37.2     100.0       1.0       2.0       0.65   3003.2
   MET1          3.0       4.4     285.0       0.3     400.000     0.0      20.0
   PLOT          0.001     0.05      7.2
   OPTN          1.0       1.0       1.0       1.0       1.0
   SRCL          0.0       0.0
   DONE
   END
   # THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
   # SCCS  @(#) LASS10.DAT 2.1 02/23/90

   ****************************************************************************
     WARNING - THIS LIBRARY CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED
     BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC 2751 ET SEQ.) OR
     EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
                     SEVERE CRIMINAL PENALTIES.
   ****************************************************************************
                      ******************************
                      *                            *
                      *   ELECTRO-OPTICAL SYSTEMS  *
                      *                            *
                      * ATMOSPHERIC EFFECTS LIBRARY *
                      *                            *
                      *   NOT FOR OPERATIONAL USE  *
                      *                            *
                      * EOSAEL87 REV 2.1   02/23/90 *
                      *                            *
                      ******************************
    ERROR      0 ON ATTEMPT TO OPEN ALTERNATE INPUT FILE.
    JOB.DAT FILE IGNORED, INPUT STANDARD INPUT RESUMED
   WAVL         0.55
    NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
   WAVL       .5500E+00 .5500E+00 .0000E+00
                                    BEGINNING          ENDING
               WAVENUMBER (CM**-1)      18181.818        18181.818
               WAVELENGTH (MICROMETERS)      .550             .550
               FREQUENCY (GHZ)        545454.563       545454.563
            **** EOSAEL WARNING ****
    VISIBILITY AND EXTINCTION = 0.0, VISIBILITY CHANGED TO 10.0 KM
                                     VISIBILITY
                                      10.00 KM
                      ******************************
                      *                            *
                      *        T D L A S S         *
                      *                            *
                      *TRANSPORT AND DIFFUSION  PART *
                      *LARGE AREA SMOKE SCREEN MODULE*
                      *   NOT FOR OPERATIONAL USE  *
                      *                            *
                      * EOSAEL87 REV 2.1   02/23/90 *
                      *                            *
                      ******************************
    TDLASS IS OPENING FILE 'TDLASS.PLT' FOR OUTPUT.
    TDLASS IS OPENING FILE 'TDLASS.AUX' FOR OUTPUT.
    ******************************************************************************
    *************************      TDLASS MODULE      **************************
    *************************      CYCLE #    1       **************************
    ******************************************************************************
                                 *****CARD INPUT*****
    ------------------------------------------------------------------------------
           EXAMPLE 6: LASS(87)
    SCEN          .000      .000      .000      .000   105.000  1000.000    15.000
    CMAP        40.000      .001  3500.000   800.000      .001      .000      .000
    SRCD        37.200   100.000     1.000     2.000      .650  3003.200      .000
    MET1         3.000     4.400   285.000      .300   400.000      .000    20.000
    PLOT          .001      .050     7.200      .000      .000      .000      .000
    OPTN         1.000     1.000     1.000     1.000     1.000      .000      .000
    SRCL          .000      .000      .000      .000      .000      .000      .000
    DONE          .000      .000      .000      .000      .000      .000      .000
    ------------------------------------------------------------------------------
                                 *****INPUT*****
    ------------------------------------------------------------------------------
    METEOROLOGICAL:
        WIND SPEED         4.4  M/S     MIXING HEIGHT       400.0   M
        WIND DIRECTION   285.0  DEG     SCAVENGING FACTOR      .00
```

```
    SURFACE ROUGHNESS    .30 M       EVAP.COEFF.:  F1 =      .650
    PASQUILL CATEGORY   3.0                        F2 = 3003.2   S
                 SENSIBLE HEAT FLUX   20.00  WATTS/M**2
REFERENCE                                      REFERENCE
OBSERVER DATA:                                 TARGET COORDINATES:
    X          965.9 M                            X            .0 M
    Y         -258.8 M                            Y            .0 M
    Z             .0 M                            Z            .0 M
    OBS. ZENITH ANGLE
                         (W.R.T.TARG.)    90.0 DEG
    OBS. AZIMUTH ANGLE                        OBS.-TARG.RANGE    1000.0 M
                         (W.R.T.NORTH)   105.0 DEG
    FIELD AZIMUTH ANGLE
                         (W.R.T.NORTH)    15.0 DEG
SOURCE DATA:                                   OBSCURANT DATA:
    NO. OF GENERATORS            1                TYPE            FOG OIL
    DEPLOYMENT IS NON-LINEAR                      EMISSION RATE    37.20  G/S
                                                  YIELD FACTOR      1.00
                                                  EFFICIENCY      100.00  %
                                                  MASS EXT.COEFF.   7.200 M**2/G
LASS ARRAY PARAMETERS:
    RESOLUTION                   40.0    M
    MIN. CONCENTRATION         .1000E-05 G/M**3
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
**** BEGIN CALCULATIONS FOR SINGLE OBSERVER-TARGET LOS FOR  1 SOURCES ****
                              ******OUTPUT******
-------------------------------------------------------------------------------
    HORIZONTAL OBSERVER-TARGET CL:    .107E+02 G/M**2
    HORIZONTAL OPTICAL DEPTH:       76.823
    HORIZONTAL TRANSMISSION:          .00
VERTICAL OBSERVER-TARGET LOS DATA:
DIST. FROM          WIND                  FIELD          VERTICAL      VERTICAL
OBSERVER (M)      X          Y          X          Y    CL (G/M**2)      TAU
-----------  -----------------  -----------------  -----------    --------
   40.00      960.00       .00     960.00       .00    .316E-01      .227
   80.00      920.00       .00     920.00       .00    .328E-01      .236
  120.00      880.00       .00     880.00       .00    .342E-01      .246
  160.00      840.00       .00     840.00       .00    .357E-01      .257
  200.00      800.00       .00     800.00       .00    .373E-01      .269
  240.00      760.00       .00     760.00       .00    .391E-01      .282
  280.00      720.00       .00     720.00       .00    .411E-01      .296
  320.00      680.00       .00     680.00       .00    .433E-01      .312
  360.00      640.00       .00     640.00       .00    .458E-01      .330
  400.00      600.00       .00     600.00       .00    .486E-01      .350
  440.00      560.00       .00     560.00       .00    .518E-01      .373
  480.00      520.00       .00     520.00       .00    .554E-01      .399
  520.00      480.00       .00     480.00       .00    .596E-01      .429
  560.00      440.00       .00     440.00       .00    .645E-01      .465
  600.00      400.00       .00     400.00       .00    .704E-01      .507
  640.00      360.00       .00     360.00       .00    .775E-01      .558
  680.00      320.00       .00     320.00       .00    .862E-01      .621
  720.00      280.00       .00     280.00       .00    .973E-01      .701
  760.00      240.00       .00     240.00       .00    .112E+00      .806
  800.00      200.00       .00     200.00       .00    .132E+00      .951
  840.00      160.00       .00     160.00       .00    .162E+00     1.163
  880.00      120.00       .00     120.00       .00    .210E+00     1.509
  920.00       80.00       .00      80.00       .00    .302E+00     2.175
  960.00       40.00       .00      40.00       .00    .564E+00     4.063
              MEAN VERTICAL CL:                  .101E+00 G/M**2
              MEAN VERTICAL OPTICAL DEPTH:      .730
              MEAN VERTICAL TRANSMISSION:       .48
                              ******MODULE TDLASS END******
```

Appendix A

RADIATIVE TRANSFER TABLES

The key to applying the solutions of the radiative transfer equation described in the main text, to practical problems lies in the use of lookup tables to obtain numerical values for the various single- and multiple-scattering operators and moments. In this appendix, we document the tables as originally conceived by Van de Hulst [de Hulst, 1980] and recently updated and extended by transfer equation obtained in the plane-parallel approximation, assuming a Henyey-Greenstein form for the scattering phase function (see figure 1.2 and equation 1.22 of the main text).

The tables consist of two sets: one set that treats single scattering only and one set that treats multiple scattering. The tables as originally published by Sutherland and Fowler [Sutherland and Fowler, 1985] for the case of multiple scattering are listed in tables A-1 through A-5 and for the case of single scattering in tables A-6 through A-10. Each of the two sets has a total of five tables, and each table corresponds to a different asymmetry parameter of the Henyey-Greenstein phase function ranging from $g = 0.0$ to 0.875. Each table contains nine matrices, corresponding to nine optical depths ranging from $B = 0.03125$ to 8.0. The multiple-scattering tables were generated by using techniques described by Durack and Giever [Durack and Giever, 1987] and are based upon the radiative transfer model, AGSCAT. The single-scattering tables were generated by using techniques described by Sutherland. [Sutherland, 1986]

Each matrix contains 64 elements, giving numerical values of the reflection/transmission operators and moments for various discrete values of the zenith coordinates ranging from $\mu = 0.0$ to 1.0. The matrices are arranged in the somewhat unconventional format, sketched in figure A.1, order to exploit certain symmetry properties. All elements to the right of the diagonal refer to reflection and those to the left refer to transmission. With the exception of the two extremes, the diagonal elements represent the horizontal transmission operator, $T(B; 0.\mu_0)$. The first element along the diagonal is the horizontal first moment, $UT(B; 0)$, and the last element along the diagonal is the third-order exponential integral, $E3(B)$. The last column of each matrix gives values for the first reflection moment, $UR(B; \mu)$, except for the first element, which is the second moment $URU(B)$. Similarly, the last row in each matrix gives values of the first transmission moment, $UT(B, \mu)$, except for the first value, which is the second moment $UTU(\mu)$. The remaining elements are the discrete reflection/transmission operators $R(\mu_i, \mu_j)$ and $T(\mu_i, \mu_j)$, arranged in conventional matrix notation, except that the first row and first column are the completely symmetric elements, $T(\mu_j, \mu)$ and $R(\mu_i, \mu_i)$, respectively.

The tables as presented here contain all of the information necessary to evaluate the various single- and multiple-scattering azimuth averaged transmission and reflection operators and moments introduced in the main text.

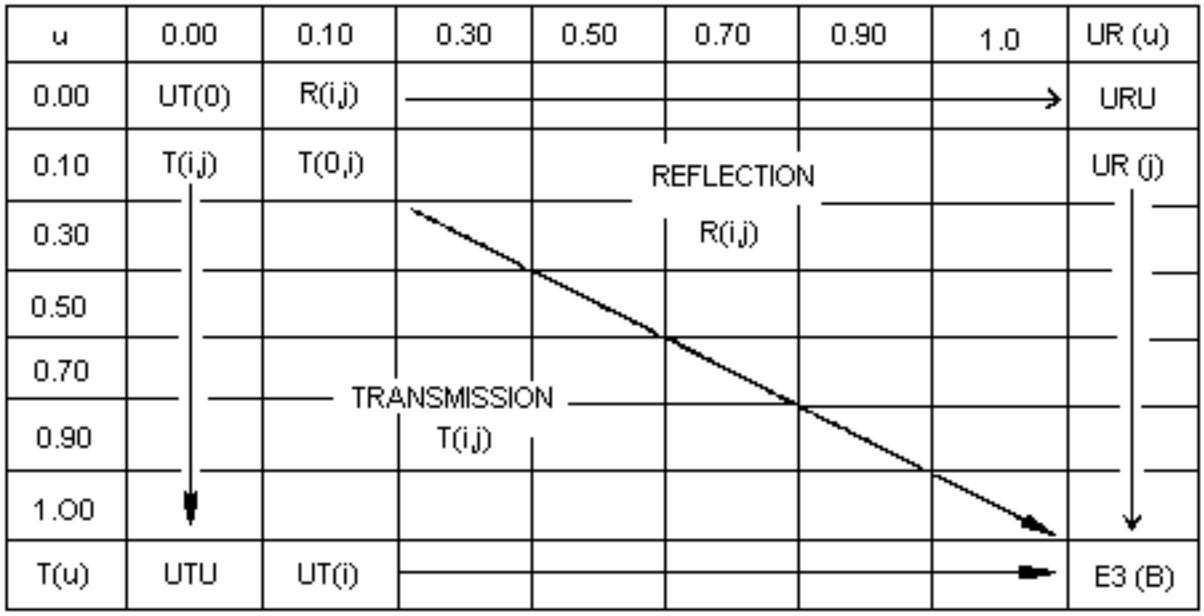


Figure A.1: Sketch demonstrating the format used in generating the radiative transfer tables.

Table A.1: Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.000).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.5207+00	.5771+00	.8369-01	.3150-01	.1638-01	.1001-01	.8133-02	.2914-01
0.10	.5742+00	.2252+01	.2197+00	.1348+00	.9714-01	.7593-01	.6845-01	.1297+00
0.30	.8355+01	.2191+00	.8886+00	.5134+01	.3701-01	.2893-01	.2608-01	.4938-01
0.50	.3148-01	.1345+00	.5129-01	.5538+00	.2271-01	.1775 -01	.1601-01	.3092-01
0.70	.1637-01	.9702-01	.3699-01	.2270-01	.4020+00	.1280-01	.1154-01	.2184-01
0.90	.1000-01	.7585-01	.2892-01	.1775-01	.1280-01	.3155+00	.9021-02	.1707-01
1.00	.8132-02	.6839-01	.2607-01	.1600-01	.1154-01	.9019-02	.2848+00	.1539-01
$UT(U)$	.2906-01	.1292+00	.4928-01	.3025-01	.2182-01	.1706-01	.1538-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.4553+00	.9846+00	.1599+00	.6248-01	.3303-01	.2038-01	.1662-01	.5544-01
0.10	.9522+00	.1627+01	.3957+00	.2469+00	.1794+00	.1408+00	.1271+00	.2330+00
0.30	.1589+00	.3900+00	.7722+00	.9993-01	.7263-01	.5704-01	.5151-01	.9415-01
0.50	.6234-01	.2447+00	.9954-01	.5022+00	.4543-01	.3568-01	.3222-01	.5884-01
0.70	.3299-01	.1782+00	.7243-01	.4535-01	.3713+00	.2594-01	.2343-01	.4276-01
0.90	.2036-01	.1401+00	.5692-01	.3563-01	.2592-01	.2944+00	.1840-02	.3358-01
1.00	.1661-01	.1265+00	.5141-01	.3218-01	.2341-01	.1839-01	.2667+00	.3032-01
$UT(U)$	.5505-01	.2295+00	.9352-01	.5860-01	.4264-01	.3351-01	.3026-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.4130+00	.1393+01	.2895+00	.1213+00	.6620-01	.4159-01	.3414-01	.1022+00
0.10	.1163+00	.9474+01	.6245+00	.4006+00	.2946+00	.2329+00	.2108+00	.3703+00
0.30	.2827+00	.6849+00	.6718+00	.1872+00	.1382+00	.1095+00	.9914-01	.1720+00
0.50	.1201+00	.3850+00	.1845+00	.4707+00	.8958-01	.7099-01	.6431-01	.1113-01
0.70	.6590-01	.2864+00	.1367+00	.8902-01	.3595+00	.5247-01	.4754-01	.8214-01
0.90	.4148-01	.2278+00	.1086-01	.7065-01	.5229-01	.2902+00	.3768-01	.6507-01
1.00	.3407-01	.2067+00	.9842-01	.6403-01	.4739-01	.3759-01	.2647+00	.5894-01
$UT(U)$	.1002+00	.3491+00	.1683+00	.1098+00	.8138-01	.6460-01	.5856-01	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.3731+00	.1624+01	.4753+00	.2242+00	.1297+00	.8434-01	.7009-01	.1798+00
0.10	.8241+00	.4529+00	.8290+00	.5518+00	.4130+00	.3298+00	.2996+00	.5016+00
0.30	.4362+00	.6521+00	.5432+00	.3254+00	.2466+00	.1984+00	.1807+00	.2920+00
0.50	.2173+00	.4771+00	.3089+00	.4328+00	.1704+00	.1373+00	.1251+00	.2006+00
0.70	.1276+00	.3721+00	.2376+00	.1666+00	.3500+00	.1046+00	.9532-01	.1523+00
0.90	.8351-01	.3041+00	.1927+00	.1349+00	.1033+00	.2919+00	.7688-01	.1226+00
1.00	.6953-01	.2785+00	.1760+00	.1232+00	.9424-01	.7621-01	.2692+00	.1117+00
$UT(U)$	.1709+00	.4174+00	.2733+00	.1928+00	.1480-01	.1199-01	.1095+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.3139+00	.1718+01	.6746+00	.3783+00	.2409+00	.1663+00	.1413+00	.2958+00
0.10	.3476+00	.2185+00	.9650+00	.6705+00	.5134+00	.4157+00	.3796+00	.6046+00
0.30	.5084+00	.4936+00	.3639+00	.5004+00	.3949+00	.3255+00	.2990+00	.4438+00
0.50	.3398+00	.4443+00	.4204+00	.3559+00	.3013+00	.2496+00	.2297+00	.3344+00
0.70	.2278+00	.3818+00	.3484+00	.2789+00	.3179+00	.2000+00	.1842+00	.2659+00
0.90	.1606+00	.3300+00	.2951+00	.2349+00	.1915+00	.2808+00	.1532+00	.2201+00
1.00	.1374+00	.3083+00	.2738+00	.2176+00	.1772+00	.1486+00	.2644+00	.2025+00
$UT(U)$	.2610+00	.3878+00	.3677+00	.2978+00	.2446+00	.2062+00	.1910+00	.2216+00

Table A.1: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.2427+00	.1775+00	.8253+00	.5569+00	.4404+00	.3060+00	.2694+00	.4466+00
0.10	.1779+00	.1395+00	.1058+00	.7719+00	.6102+00	.5050+00	.4650+00	.6976+00
0.30	.3816+00	.2737+00	.2087+00	.6641+00	.5511+00	.4694+00	.4367+00	.5939+00
0.50	.4015+00	.3188+00	.4019+00	.2509+00	.4720+00	.4072+00	.3805+00	.4984+00
0.70	.3392+00	.3191+00	.3815+00	.3714+00	.2575+00	.3511+00	.3289+00	.4229+00
0.90	.2744+00	.3033+00	.3515+00	.3372+00	.3058+00	.2489+00	.2870+00	.3651+00
1.00	.2465+00	.2935+00	.3364+00	.3210+00	.2903+00	.2602+00	.2423+00	.3413+00
$UT(U)$	.3340+00	.3024+00	.3704+00	.3663+00	.3375+00	.3057+00	.2908+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.1698+00	.1826+00	.9251+00	.7115+00	.5890+00	.4980+00	.4597+00	.6099+00
0.10	.1158+00	.9293+00	.1129+00	.8606+00	.7071+00	.6038+00	.5633+00	.7888+00
0.30	.2117+00	.1555+00	.1242+01	.7883+00	.6867+00	.6075+00	.5740+00	.7215+00
0.50	.3155+00	.1953+00	.2628+00	.1558+00	.6408+00	.5791+00	.5516+00	.6572+00
0.70	.3629+00	.2235+00	.2936+00	.3421+00	.1794+00	.5393+00	.5162+00	.5965+00
0.90	.3636+00	.2380+00	.3062+00	.3491+00	.3650+00	.1925+00	.4782+00	.5421+00
1.00	.3544+00	.2413+00	.3077+00	.3481+00	.3619+00	.3592+00	.1958+00	.5175+00
$UT(U)$	.3298+00	.2112+00	.2772+00	.3245+00	.3460+00	.3495+00	.3471+00	.3012-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.1069+00	.1869+01	.9996+00	.8258+00	.7461+00	.6920+00	.6685+00	.7540+00
0.10	.7188-01	.5780-01	.1186+01	.9393+00	.7888+00	.6946+00	.6575+00	.8671+00
0.30	.1248+00	.9469-01	.7613-01	.8806+00	.7948+00	.7276+00	.6986+00	.8250+00
0.50	.1888+00	.1163+00	.1535+00	.9348-01	.7749+00	.7280+00	.7060+00	.7855+00
0.70	.2594+00	.1374+00	.1811+00	.2221+00	.1104+00	.7138+00	.6972+00	.7470+00
0.90	.3213+00	.1564+00	.2056+00	.2505+00	.2900+00	.1259+00	.6794+00	.7093+00
1.00	.3456+00	.1648+00	.2160+00	.2623+00	.3023+00	.3335+00	.1327+00	.6909+00
$UT(U)$	.2404+00	.1329+00	.1750+00	.2141+00	.2497+00	.2789+00	.2907+00	.2760-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.6148-01	.1899+01	.1052+01	.9053+00	.8568+00	.8377+00	.8325+00	.8584+00
0.10	.4130-01	.3321-01	.1226+01	.9795+00	.8469+00	.7613+00	.7282+00	.9235+00
0.30	.7159-01	.5437-01	.4373-01	.9454+00	.8713+00	.8154+00	.7917+00	.8993+00
0.50	.1075+00	.6663-01	.8772-01	.5358-01	.8687+00	.8356+00	.8201+00	.8766+00
0.70	.1496+00	.7859-01	.1035+00	.1268+00	.6320-01	.8408+00	.8319+00	.8545+00
0.90	.1975+00	.9039-01	.1190+00	.1458+00	.1720+00	.7269-01	.8340+00	.8326+00
1.00	.2233+00	.9622-01	.1267+00	.1552+00	.1829+00	.2100+00	.7738-01	.8218+00
$UT(U)$	.1414+00	.7645-01	.1006+00	.1233+00	.1455+00	.1672+00	.1778+00	.3114-01

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.2: Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.250).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.5219+00	.6172+00	.8073-01	.2563-01	.1095-01	.5497-02	.4064-02	.2354-01
0.10	.6263+00	.2441+01	.2263+00	.1314+00	.8842-01	.6386-01	.5517-01	.1244+00
0.30	.9396-01	.2383+00	.9451+00	.4585-01	.3037-01	.2170-01	.1869-01	.4369-01
0.50	.3794-01	.1430+00	.5845-01	.5670+00	.1680-01	.1194-01	.1026-01	.2457-01
0.70	.2239-01	.9879-01	.4177-01	.2835-01	.3895+00	.7761-02	.6669-02	.1619-01
0.90	.1734-01	.7275-01	.3163-01	.2241-01	.1885-01	.2853+00	.4727-02	.1155-01
1.00	.1732-01	.6330-01	.2784-01	.2012-01	.1748-01	.1698-01	.2478+00	.9941-02
$UT(U)$	.3466-01	.1344+00	.5497-01	.3597-01	.2746-01	.2258-01	.2083-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.4580+00	.1055+01	.1550+00	.5144-01	.2252-01	.1149-01	.8548-02	.4479-01
0.10	.1039+01	.1767+01	.4088+00	.2419+00	.1644+00	.1195+00	.1035+00	.2241+00
0.30	.1784+00	.4242+00	.8249+00	.8995-01	.6024-01	.4336-01	.3745-01	.8357-01
0.50	.7463-01	.2600+00	.1131+00	.5178+00	.3412-01	.2443-01	.2107-01	.4799-01
0.70	.4452-01	.1815+00	.8147-01	.5612-01	.3636+00	.1609-01	.1387-01	.3196-01
0.90	.3448-01	.1345+00	.6200-01	.4451-01	.3753-01	.2701+00	.9912-02	.2295-01
1.00	.3436-01	.1173+00	.5468-01	.4000-01	.3481-01	.3375-01	.2358+00	.1981-01
$UT(U)$	.6570-01	.2384+00	.1041+00	.6944-01	.5345-01	.4414-01	.4077-01	.4488+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.4189+00	.1494+01	.2827+00	.1016+00	.4649-01	.2444-01	.1840-01	.8279-01
0.10	.1270+01	.1031+01	.6468+00	.3942+00	.2719+00	.1996+00	.1736+00	.3565+00
0.30	.3166+00	.6368+00	.7223+00	.1705+00	.1164+00	.8492-01	.7373-01	.1535+00
0.50	.1426+00	.4099+00	.2087+00	.4908+00	.6889-01	.5003-01	.4339-01	.9165-01
0.70	.8714-01	.2928+00	.1530+00	.1087+00	.3580+00	.3372-01	.2923-01	.6225-01
0.90	.6779-01	.2203+00	.1177+00	.8688-01	.7377-01	.2724+00	.2121-01	.4529-01
1.00	.6734-01	.1933+00	.1042+00	.7829-01	.6850-01	.6629-01	.2402+00	.3930-01
$UT(U)$	.1197+00	.3628+00	.1868+00	.1294+00	.1013+00	.8439-01	.7820-01	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.3839+00	.1739+01	.4679+00	.1925+00	.9515-01	.5273-01	.4051-01	.1468+00
0.10	.9024+00	.4930+00	.8582+00	.5437+00	.3825+00	.2845+00	.2488+00	.4824+00
0.30	.4874+00	.7129+00	.5889+00	.3077+00	.2124+00	.1583+00	.1387+00	.2629+00
0.50	.2546+00	.5121+00	.3477+00	.4585+00	.1355+00	.1009+00	.8833-01	.1679+00
0.70	.1641+00	.3857+00	.2645+00	.2000+00	.3570+00	.7081-01	.6202-01	.1181+00
0.90	.1296+00	.3001+00	.2082+00	.1626+00	.1405+00	.2832+00	.4622-01	.8797-01
1.00	.1284-01	.2669+00	.1861+00	.1475+00	.1309+00	.1267+00	.2538+00	.7705-01
$UT(U)$	.2038+00	.4367+00	.3024+00	.2254+00	.1822+00	.1546+00	.1422+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.3312+00	.1834+01	.6683+00	.3345+00	.1870+00	.1131+00	.8996-01	.2460+00
0.10	.3824+00	.2376+00	.9956+00	.6588+00	.4752+00	.3596+00	.3167+00	.5787+00
0.30	.5684+00	.5449+00	.3990+00	.4695+00	.3485+00	.2687+00	.2386+00	.4041+00
0.50	.3936+00	.4854+00	.4726+00	.3854+00	.2498+00	.1935+00	.1721+00	.2866+00
0.70	.2836+00	.4071+00	.3880+00	.3288+00	.3354+00	.1452+00	.1294+00	.2136+00
0.90	.2333+00	.3391+00	.3205+00	.2774+00	.2493+00	.2857+00	.1008+00	.1654+00
1.00	.2312+00	.3098+00	.2921+00	.2553+00	.2344+00	.2286+00	.2632+00	.1471+00
$UT(U)$	.3108+00	.4137+00	.4037+00	.3455+00	.2968+00	.2609+00	.2464+00	.2216+00

Table A.2: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.2660+00	.1890+00	.8198+00	.5070+00	.3348+00	.2301+00	.1931+00	.3826+00
0.10	.1983+00	.1538+00	.1087+01	.7564+00	.5654+00	.4397+00	.3918+00	.6655+00
0.30	.4315+00	.3077+00	.2327+00	.6310+00	.4975+00	.4010+00	.3626+00	.5476+00
0.50	.4635+00	.3580+00	.4563+00	.2794+00	.4093+00	.3353+00	.3051+00	.4400+00
0.70	.4105+00	.3544+00	.4313+00	.4337+00	.2834+00	.2767+00	.2572+00	.3557+00
0.90	.3699+00	.3301+00	.3914+00	.3941+00	.3815+00	.2683+00	.2107+00	.2917+00
1.00	.3708+00	.3151+00	.3701+00	.3734+00	.3662+00	.3659+00	.2578+00	.2656+00
$UT(U)$	.3980+00	.3345+00	.4168+00	.4247+00	.4047+00	.3791+00	.3665+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.1949+00	.1940+00	.9211+00	.6640+00	.5178+00	.4137+00	.3714+00	.5432+00
0.10	.1334+00	.1060+00	.1158+01	.8452+00	.6613+00	.5356+00	.4862+00	.7553+00
0.30	.2471+00	.1804+00	.1428+00	.7571+00	.6335+00	.5369+00	.4963+00	.6750+00
0.50	.3710+00	.2273+00	.3076+00	.1797+00	.5787+00	.5046+00	.4718+00	.5987+00
0.70	.4356+00	.2598+00	.3438+00	.4044+00	.2066+00	.4599+00	.4331+00	.5271+00
0.90	.4617+00	.2748+00	.3568+00	.4135+00	.4451+00	.2202+00	.3916+00	.4633+00
1.00	.4792+00	.2772+00	.3570+00	.4117+00	.4441+00	.4672+00	.229+00	.4346+00
$UT(U)$	.3965+00	.2447+00	.3237+00	.3829+00	.4145+00	.4283+00	.4300+00	.3012-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.1284+00	.1985+01	.1001+01	.7878+00	.6879+00	.6220+00	.5941+00	.6984+00
0.10	.8620-01	.6869-01	.1218+01	.9199+00	.7488+00	.6324+00	.5863+00	.8389+00
0.30	.1518+00	.1144+00	.9112-01	.8566+00	.7502+00	.6660+00	.6297+00	.7864+00
0.50	.2310+00	.1409+00	.1872+00	.1122+00	.7239+00	.6652+00	.6377+00	.7373+00
0.70	.3188+00	.1667+00	.2213+00	.2722+00	.1328+00	.6481+00	.6276+00	.6896+00
0.90	.4007+00	.1898+00	.2512+00	.3074+00	.3579+00	.1514+00	.6069+00	.6431+00
1.00	.4397+00	.1998+00	.2639+00	.3219+00	.3739+00	.4191+00	.1595+00	.6205+00
$UT(U)$	.2960+00	.1611+00	.2136+00	.2623+00	.3071+00	.3451+00	.3612+00	.2760-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.7647-01	.2020+01	.1062+01	.8804+00	.8173+00	.7924+00	.7859+00	.8203+00
0.10	.5126-01	.4085-01	.1265+01	.9766+00	.8159+00	.7095+00	.6680+00	.9040+00
0.30	.9009-01	.6795-01	.5416-01	.9319+00	.8392+00	.7681+00	.7380+00	.8728+00
0.50	.1361+00	.8354-01	.1107+00	.6657-01	.8333+00	.7908+00	.7710+00	.8436+00
0.70	.1901+00	.9870-01	.1308+00	.1609+00	.7866-01	.7966+00	.7852+00	.8152+00
0.90	.2516+00	.1136+00	.1506+00	.1852+00	.2187+00	.9055-01	.7878+00	.7872+00
1.00	.2848+00	.1210+00	.1604+00	.1971+00	.2328+00	.2677+00	.9642-01	.7734+00
$UT(U)$	.1796+00	.9595-01	.1272+00	.1564+00	.1847+00	.2126+00	.2262+00	.3114-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.3: Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.500).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.5199+00	.7710+00	.7513-01	.1774-01	.6141-02	.2677-02	.1878-02	.1755-01
0.10	.8291+00	.3188+01	.2468+00	.1206+00	.6825-01	.4210-01	.3388-01	.1170+00
0.30	.1241+00	.2986+00	.1117+01	.3633-01	.2079-01	.1308-01	.1064-01	.3612-01
0.50	.5062-01	.1550+00	.7273-01	.5697+00	.1034-01	.6638-02	.5458-02	.1774-01
0.70	.3139-01	.8864-01	.4411-01	.3555-01	.3261+00	.4019-02	.3334-02	.1030-01
0.90	.2961-01	.5382-01	.2687-01	.2299-01	.2478-01	.2006+00	.2239-02	.6574-02
1.00	.4585-01	.4277-01	.2113-01	.1807-01	.2035-01	.3088-01	.1608+00	.5386-02
$UT(U)$	.4065-01	.1418+00	.6254-01	.4280-01	.3335-01	.2755-01	.2538-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.4553+00	.1329+01	.1467+00	.3642-01	.1288-01	.5654-02	.3969-02	.3334-01
0.10	.1380+01	.2323+01	.4515+00	.2258+00	.1293+00	.8037-01	.6486-01	.2117+00
0.30	.2353+00	.5327+00	.9857+00	.7273-01	.4213-01	.2669-01	.2177-01	.6951-01
0.50	.9887-01	.2831+00	.1404+00	.5293+00	.2146-01	.1386-01	.1141-01	.3497-01
0.70	.6171-01	.1643+00	.8609-01	.6984-01	.3115+00	.8463-02	.7027-02	.2056-01
0.90	.5814-01	.1008+00	.5295-01	.4551-01	.4884-01	.1951+00	.4730-02	.1321-01
1.00	.8969-01	.8049-01	.4183-01	.3591-01	.4024-01	.6062-01	.1575+00	.1085-01
$UT(U)$	.7714-01	.2509+00	.1182+00	.8246-01	.6485-01	.5388-01	.4974-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.4174+00	.1894+01	.2736+00	.7447-01	.2748-01	.1229-01	.8665-02	.6166-01
0.10	.1695+01	.1361+01	.7232+00	.3749+00	.2191+00	.1379+00	.1118+00	.3384+00
0.30	.4172+00	.8045+00	.8753+00	.1420+00	.8416-01	.5406-01	.4430-01	.1290+00
0.50	.1870+00	.4517+00	.2586+00	.5143+00	.4487-01	.2932-01	.2424-01	.6785-01
0.70	.1188+00	.2704+00	.1622+00	.1339+00	.3175+00	.1825-01	.1519-01	.4081-01
0.90	.1120+00	.1698+00	.1017+00	.8859-01	.9463-01	.2053+00	.1031-01	.2659-01
1.00	.1715+00	.1368+00	.8106-01	.7051-01	.7843-01	.1167+00	.1677+00	.2194-01
$UT(U)$	.1408+00	.3810+00	.2113+00	.1532+00	.1227+00	.1031+00	.9556-01	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.3860+00	.2207+01	.4647+00	.1480+00	.5924-01	.2766-01	.1975-01	.1101+00
0.10	.1207+01	.6410+00	.9673+00	.5254+00	.3156+00	.2025+00	.1655+00	.4594+00
0.30	.6411+00	.9101+00	.7238+00	.2600+00	.1606+00	.1058+00	.8749-01	.2245+00
0.50	.3299+00	.5778+00	.4306+00	.4962+00	.9292-01	.6223-01	.5187-01	.1275+00
0.70	.2187+00	.3705+00	.2831+00	.2437+00	.3325+00	.4023-01	.3375-01	.7991-01
0.90	.2075+00	.2441+00	.1845+00	.1661+00	.1768+00	.2270+00	.2334-01	.5342-01
1.00	.3138+00	.2005+00	.1496+00	.1344+00	.1484+00	.2161+00	.1893+00	.4450-01
$UT(U)$	.2406+00	.4597+00	.3409+00	.2659+00	.2204+00	.1891+00	.1767+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.3399+00	.2319+01	.6787+00	.2722+00	.1255+00	.6394-01	.4702-01	.1876+00
0.10	.4956+00	.2882+00	.1121+01	.6416+00	.3988+00	.2627+00	.2169+00	.5505+00
0.30	.7455+00	.7005+00	.4917+00	.4223+00	.2776+00	.1907+00	.1603+00	.3521+00
0.50	.5041+00	.5674+00	.5873+00	.4330+00	.1832+00	.1283+00	.1088+00	.2255+00
0.70	.3680+00	.4168+00	.4253+00	.3974+00	.3333+00	.8907-01	.7593-01	.1515+00
0.90	.3564+00	.3015+00	.2989+00	.2877+00	.3073+00	.2496+00	.5478-01	.1060+00
1.00	.5265+00	.2570+00	.2505+00	.2400+00	.2639+00	.3712+00	.2159+00	.8980-01
$UT(U)$	.3692+00	.4418+00	.4593+00	.4066+00	.3590+00	.3203+00	.3037+00	.2216+00

Table A.3: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.2835+00	.2375+01	.8407+00	.4358+00	.2463+00	.1456+00	.1135+00	.3013+00
0.10	.2364+00	.1740+00	.1217+01	.7372+00	.4804+00	.3290+00	.2764+00	.6300+00
0.30	.5583+00	.3861+00	.2783+00	.5846+00	.4156+00	.3027+00	.2605+00	.4865+00
0.50	.5891+00	.4319+00	.5719+00	.3232+00	.3234+00	.2427+00	.2115+00	.3618+00
0.70	.5206+00	.3923+00	.4949+00	.5262+00	.3031+00	.1882+00	.1651+00	.2687+00
0.90	.5315+00	.3297+00	.3989+00	.4260+00	.4640+00	.2613+00	.1284+00	.2020+00
1.00	.7519+00	.2985+00	.3543+00	.3752+00	.4161+00	.5546+00	.2391+00	.1761+00
$UT(U)$	.4793+00	.3701+00	.4778+00	.5029+00	.4917+00	.4688+00	.4560+00	.1097
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.2199+00	.2423+01	.9451+00	.5947+00	.4175+00	.3003+00	.2553+00	.4489+00
0.10	.1556+00	.1188+00	.1287+01	.8243+00	.5708+00	.4146+00	.3581+00	.7138+00
0.30	.3098+00	.2181+00	.1658+00	.7133+00	.5488+00	.4285+00	.3806+00	.6102+00
0.50	.4719+00	.2774+00	.3877+00	.2107+00	.4881+00	.3985+00	.3601+00	.5147+00
0.70	.5508+00	.3085+00	.4192+00	.5031+00	.2365+00	.3507+00	.3204+00	.4276+00
0.90	.6245+00	.3100+00	.4095+00	.4837+00	.5484+00	.2405+00	.2765+00	.3528+00
1.00	.8194+00	.3032+00	.3954+00	.4622+00	.5267+00	.6551+00	.2366+00	.3203+00
$UT(U)$	.4908+00	.2862+00	.3885+00	.4670+00	.5149+00	.5338+00	.5444+00	.3012-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.1547+00	.2468+01	.1029+01	.7275+00	.5977+00	.5124+00	.4759+00	.6105+00
0.10	.1044+00	.8023-01	.1349+01	.9014+00	.6606+00	.5120+00	.4573+00	.7989+00
0.30	.1934+00	.1420+00	.1091+00	.8190+00	.6719+00	.5620+00	.5166+00	.7268+00
0.50	.3003+00	.1768+00	.2410+00	.1358+00	.6428+00	.5662+00	.5309+00	.6611+00
0.70	.4162+00	.2094+00	.2851+00	.3540+00	.1609+00	.5461+00	.5195+00	.5983+00
0.90	.5317+00	.2363+00	.3199+00	.3946+00	.4640+00	.1819+00	.4928+00	.5379+00
1.00	.6342+00	.2465+00	.3325+00	.4084+00	.4795+00	.5630+00	.1901+00	.5090+00
$UT(U)$	.3839+00	.2011+00	.2732+00	.3385+00	.3984+00	.4503+00	.4727+00	.2760-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.9757-01	.2506+01	.1100+01	.8366+00	.7511+00	.7139+00	.7015+00	.7541+00
0.10	.6548-01	.5036-01	.1401+01	.9661+00	.7373+00	.5999+00	.5504+00	.8731+00
0.30	.1208+00	.8893-01	.6839-01	.9069+00	.7762+00	.6815+00	.6430+00	.8277+00
0.50	.1875E+0	.1103E+0	.1498E+0	.8481-01	.7722E+0	.7144E+0	.6878E+0	.7863E+0
0.70	.2610E+0	.1307E+0	.1776E+0	.2202E+0	.1005E+0	.7219E+0	.7055E+0	.7467E+0
0.90	.3465E+0	.1506E+0	.2046E+0	.2537E+0	.3006E+0	.1159E+0	.7059E+0	.7080E+0
1.00	.3945E+0	.1604E+0	.2177E+0	.2699E+0	.3199E+0	.3690E+0	.1233E+0	.6889E+0
$UT(U)$	.2457E+0	.1269E+0	.1723E+0	.2136E+0	.2532E+0	.2918E+0	.3107E+0	.3114-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.4: Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.750).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.5108+00	.1083+01	.4952-01	.8136-02	.2393-02	.9680-03	.6557-03	.1062-01
0.10	.1583+01	.5683+01	.2216+00	.7774-01	.3548-01	.1904-01	.1455-01	.1002+00
0.30	.2258+00	.4137+00	.1257+01	.1925-01	.9533-02	.5448-02	.4272-02	.2292-01
0.50	.9062-01	.1317+00	.9402-01	.4244+00	.4302-02	.2587-02	.2074-02	.9033-02
0.70	.5674-01	.5334-01	.3343-01	.4252-01	.1844+00	.1498-02	.1220-02	.4559-02
0.90	.5785-01	.2605-01	.1420-01	.1484-01	.2465-01	.9490-01	.7984-03	.2659-02
1.00	.2024+00	.1916-01	.9877-02	.9387-02	.1321-01	.3634-01	.7140-01	.2108-02
$UT(U)$	.4758-01	.1587+00	.7574-01	.5151-01	.3910-01	.3147-01	.2866-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.4409+00	.1951+01	.1018+00	.1716-01	.5020-02	.2012-02	.1358-02	.2006-01
0.10	.2660+01	.4225+01	.4274+00	.1531+00	.7027-01	.3771-01	.2880-01	.1842+00
0.30	.4258+00	.7482+00	.1163+01	.4018-01	.1993-01	.1136-01	.8897-02	.4501-01
0.50	.1747+00	.2474+00	.1813+00	.4172+00	.9054-02	.5422-02	.4338-02	.1813-01
0.70	.1103+00	.1022+00	.6596-01	.8306-01	.1855+00	.3128-02	.2543-02	.9203-02
0.90	.1130+00	.5044-01	.2845-01	.2954-01	.4854-01	.9621-01	.1656-02	.5373-02
1.00	.3943+00	.3722-01	.1988-01	.1882-01	.2627-01	.7154-01	.7246-01	.4261-02
$UT(U)$	.9042-01	.2784+00	.1426+00	.9930-01	.7620-01	.6171-01	.5633-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.4015+00	.2890+01	.2048+00	.3688-01	.1083-01	.4296-02	.2889-02	.3702-01
0.10	.3335+01	.2552+01	.7285+00	.2717+00	.1264+00	.6817-01	.5211-01	.3004+00
0.30	.7513+00	.1168+01	.1103+01	.8389-01	.4196-01	.2392-01	.1871-01	.8637-01
0.50	.3243+00	.4169+00	.3353+00	.4388+00	.1953-01	.1165-01	.9301-02	.3628-01
0.70	.2087+00	.1789+00	.1274+00	.1583+00	.2033+00	.6715-02	.5445-02	.1867-01
0.90	.2158+00	.8989-01	.5647-01	.5834-01	.9408-01	.1071+00	.3527-02	.1094-01
1.00	.7485+00	.6668-01	.3981-01	.3767-01	.5192-01	.1386+00	.8096-01	.8677-02
$UT(U)$	.1654+00	.4189+00	.2540+00	.1848+00	.1449+00	.1187+00	.1088+00	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.3720+00	.3441+01	.3840+00	.7980-01	.2423-01	.9575-02	.6414-02	.6640-01
0.10	.2451+01	.1210+01	.1032+01	.4086+00	.1953+00	.1066+00	.8177-01	.4169+00
0.30	.1156+01	.1405+01	.9879+00	.1695+00	.8697-01	.4995-01	.3910-01	.1578+00
0.50	.5584+00	.5884+00	.5682+00	.4702+00	.4307-01	.2576-01	.2053-01	.7171-01
0.70	.3735+00	.2724+00	.2343+00	.2872+00	.2354+00	.1501-01	.1214-01	.3799-01
0.90	.3937+00	.1419+00	.1092+00	.1132+00	.1767+00	.1285+00	.7840-02	.2249-01
1.00	.1349+01	.1063+00	.7824-01	.7490-01	.1012+00	.2601+00	.9795-01	.1787-01
$UT(U)$	.2842+00	.5022+00	.4075+00	.3217+00	.2623+00	.2200+00	.2033+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.3322+00	.3634+01	.6214+00	.1663+00	.5579-01	.2262-01	.1520-01	.1152+00
0.10	.9843+00	.4851+00	.1242+01	.5289+00	.2633+00	.1469+00	.1135+00	.5073+00
0.30	.1358+01	.1171+01	.7240+00	.3102+00	.1683+00	.9904-01	.7803-01	.2632+00
0.50	.8310+00	.6661+00	.8097+00	.4668+00	.9461-01	.5772-01	.4617-01	.1366+00
0.70	.6023+00	.3583+00	.3885+00	.4734+00	.2701+00	.3507-01	.2842-01	.7680-01
0.90	.6577+00	.2014+00	.1985+00	.2106+00	.3124+00	.1588+00	.1854-01	.4669-01
1.00	.2196+01	.1543+00	.1465+00	.1457+00	.1913+00	.4588+00	.1238+00	.3734-01
$UT(U)$	.4416+00	.4850+00	.5483+00	.4955+00	.4336+00	.3796+00	.3561+00	.2216+00

Table A.4: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.2873+00	.3709+01	.8259+00	.3076+00	.1263+00	.5648-01	.3894-01	.1920+00
0.10	.3792+00	.2371+00	.1366+01	.6302+00	.3327+00	.1932+00	.1514+00	.5813+00
0.30	.1016+01	.6548+00	.4091+00	.4781+00	.2835+00	.1757+00	.1407+00	.3857+00
0.50	.9514+00	.5855+00	.8485+00	.3932+00	.1935+00	.1246+00	.1012+00	.2405+00
0.70	.8060+00	.4070+00	.5303+00	.6534+00	.2887+00	.8355-01	.6866-01	.1502+00
0.90	.9346+00	.2656+00	.3193+00	.3573+00	.4933+00	.1957+00	.4685-01	.9672-01
1.00	.2932+01	.2139+00	.2491+00	.2666+00	.3386+00	.7184+00	.1599+00	.7874-01
$UT(U)$	.5886+00	.4187+00	.5786+00	.6242+00	.6102+00	.5741+00	.5534+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.2384+00	.3758+01	.9520+00	.4702+00	.2559+00	.1404+00	.1042+00	.3040+00
0.10	.2097+00	.1414+00	.1444+01	.7192+00	.4115+00	.2555+00	.2057+00	.6548+00
0.30	.5064+00	.3236+00	.2161+00	.6209+00	.4094+00	.2749+00	.2271+00	.5032+00
0.50	.7461+00	.3974+00	.6004+00	.2681+00	.3379+00	.2391+00	.2012+00	.3750+00
0.70	.8120+00	.3802+00	.5402+00	.6794+00	.2630+00	.1873+00	.1597+00	.2707+00
0.90	.1019+01	.3136+00	.4219+00	.5035+00	.6428+00	.2223+00	.1208+00	.1931+00
1.00	.2724+01	.2762+00	.3269+00	.4224+00	.5204+00	.9087+00	.1980+00	.1632+00
$UT(U)$	.6357+00	.3452+00	.4955+00	.6066+00	.6719+00	.6986+00	.7015+00	.3012-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.1852+00	.3800+01	.1042+01	.6133+00	.4286+00	.3058+00	.2564+00	.4500+00
0.10	.1358+00	.9363-01	.1505+01	.7962+00	.4960+00	.3378+00	.2844+00	.7324+00
0.30	.2847+00	.1964+00	.1352+00	.7341+00	.5335+00	.3957+00	.3424+00	.6173+00
0.50	.4577+00	.2486+00	.3608+00	.1710+00	.4949+00	.3919+00	.3471+00	.5193+00
0.70	.6168+00	.2872+00	.4131+00	.5214+00	.1983+00	.3560+00	.3209+00	.4294+00
0.90	.8160+00	.3000+00	.4234+00	.5257+00	.6357+00	.2088+00	.2793+00	.3482+00
1.00	.1487+01	.2962+00	.4134+00	.5082+00	.6125+00	.8405+00	.2071+00	.3116+00
$UT(U)$	.5444+00	.2675+00	.3827+00	.4803+00	.5672+00	.6400+00	.6700+00	.2760-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.1350+00	.3838+01	.1121+01	.7397+00	.6051+00	.5261+00	.4925+00	.6109+00
0.10	.9158-01	.6340-01	.1560+01	.8663+00	.5788+00	.4303+00	.3800+00	.8115+00
0.30	.1873+00	.1309+00	.9064-01	.8346+00	.6522+00	.5282+00	.4795+00	.7306+00
0.50	.2953+00	.1644+00	.2352+00	.1138+00	.6443+00	.5587+00	.5197+00	.6619+00
0.70	.4170+00	.1954+00	.2794+00	.3509+00	.1353+00	.5531+00	.5249+00	.5979+00
0.90	.5547+00	.2238+00	.3196+00	.4009+00	.4772+00	.1550+00	.5073+00	.5364+00
1.00	.6688+00	.2365+00	.3372+00	.4223+00	.5031+00	.5926+00	.1639+00	.5064+00
$UT(U)$	.3890+00	.1885+00	.2694+00	.3381+00	.4020+00	.4634+00	.4932+00	.3114-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.5: Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.875).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.4965+00	.1041+01	.2518-01	.3592-02	.1026-02	.4128-03	.2689-03	.6325-02
0.10	.3191+01	.8876+01	.1396+00	.4117-01	.1741-01	.8987-02	.6786-02	.7540-01
0.30	.4200+00	.3763+00	.9541+00	.8933-02	.4258-02	.2381-02	.1845-02	.1229-01
0.50	.1614+00	.7790-01	.7997-01	.2446+00	.1867-02	.1109-02	.8778-03	.4285-02
0.70	.1013+00	.2717-01	.1809-01	.3277-01	.9504-01	.6403-03	.5257-03	.2062-02
0.90	.1021+00	.1244-01	.6697-02	.7471-02	.1497-01	.4626-01	.3399-03	.1175-02
1.00	.6401+00	.9007-02	.4507-02	.4383-02	.6527-02	.2096-01	.3402-01	.9223-03
$UT(U)$	.5196-01	.1835+00	.8638-01	.5632-01	.4170-01	.3308-01	.2999-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.4190+00	.2105+01	.5360-01	.7524-02	.2115-02	.8434-03	.5487-03	.1189-01
0.10	.5365+01	.7159+01	.2907+00	.8554-01	.3593-01	.1845-01	.1390-01	.1443+00
0.30	.7839+00	.7086+00	.9646+00	.1888-01	.8923-02	.4959-02	.3835-02	.2470-01
0.50	.3094+00	.1530+00	.1559+00	.2551+00	.3878-02	.2290-02	.1810-02	.8669-02
0.70	.1965+00	.5406-01	.3619-01	.6450-01	.9926-01	.1314-02	.1076-02	.4166-02
0.90	.1994+00	.2487-01	.1351-01	.1496-01	.2974-01	.4816-01	.6935-03	.2369-02
1.00	.1248+01	.1803-01	.9112-02	.8804-02	.1306-01	.4171-01	.3537-01	.1858-02
$UT(U)$	.9878-01	.3183+00	.1630+00	.1089+00	.8145-01	.6497-01	.5901-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.3774+00	.3457+01	.1157+00	.1622-01	.4464-02	.1753-02	.1139-02	.2188-01
0.10	.6904+01	.4658+01	.5438+00	.1638+00	.6866-01	.3511-01	.2642-01	.2468+00
0.30	.1366+01	.1201+01	.1027+01	.4084-01	.1911-01	.1053-01	.8120-02	.4936-01
0.50	.5690+00	.2796+00	.2956+00	.2899+00	.8265-02	.4839-02	.3815-02	.1764-01
0.70	.3699+00	.1007+00	.7199-01	.1249+00	.1138+00	.2750-02	.2244-02	.8477-02
0.90	.3804+00	.4656-01	.2730-01	.2993-01	.5869-01	.5505+00	.1438-02	.4807-02
1.00	.2373+01	.3376-01	.1849-01	.1774-01	.2610-01	.8259-01	.4037-01	.3767-02
$UT(U)$	.1809+00	.4727+00	.2910+00	.2037+00	.1555+00	.1254+00	.1143+00	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.3489+00	.4402+01	.2448+00	.3619-01	.9770-02	.3753-02	.2433-02	.3937-01
0.10	.5407+01	.2357+01	.8679+00	.2707+00	.1145+00	.5857-01	.4406-01	.3595+00
0.30	.2081+01	.1672+01	.1069+01	.8921-01	.4156-01	.2269-01	.1744-01	.9619-01
0.50	.9648+00	.4509+00	.5289+00	.3466+00	.1827-01	.1058-01	.8303-02	.3602-01
0.70	.6565+00	.1684+00	.1408+00	.2340+00	.1403+00	.5948-02	.4823-02	.1741-01
0.90	.6927+00	.7849-01	.5493-01	.5972-01	.1142+00	.6813-01	.3066-02	.9855-02
1.00	.4290+01	.5690-01	.3744-01	.3585-01	.5210-01	.1618+00	.4993-01	.7711-02
$UT(U)$	.3120+00	.5597+00	.4693+00	.3578+00	.2837+00	.2337+00	.2146+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.3128+00	.4784+01	.4670+00	.8249-01	.2249-01	.8444-02	.5462-02	.6913-01
0.10	.2299+01	.9290+00	.1145+01	.3845+00	.1667+00	.8604-01	.6482-01	.4550+00
0.30	.2471+01	.1717+01	.9417+00	.1870+00	.8855-01	.4821-01	.3695-01	.1756+00
0.50	.1405+01	.6213+00	.8399+00	.4026+00	.4192-01	.2405-01	.1880-01	.7297-01
0.70	.1041+01	.2530+00	.2624+00	.4108+00	.1772+00	.1353-01	.1089-01	.3613-01
0.90	.1153+01	.1208+00	.1080+00	.1179+00	.2154+00	.8812-01	.6860-02	.2050-01
1.00	.7021+01	.8779-01	.7447-01	.7258-01	.1034+00	.3092+00	.6479-01	.1603-01
$UT(U)$	.4891+00	.5376+00	.6361+00	.5601+00	.4759+00	.4077+00	.3797+00	.2216+00

Table A.5: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.2753+00	.4920+01	.7239+00	.1796+00	.5428-01	.2044-01	.1324-01	.1180+00
0.10	.7719+00	.3851+00	.1330+01	.4930+00	.2242+00	.1182+00	.8952-01	.5319+00
0.30	.1942+01	.1169+01	.6190+00	.3411+00	.1715+00	.9500-01	.7300-01	.2845+00
0.50	.1575+01	.6961+00	.1058+01	.4142+00	.9640-01	.5584-01	.4364-01	.1417+00
0.70	.1345+01	.3452+00	.4361+00	.6357+00	.2202+00	.3275-01	.2618-01	.7498-01
0.90	.1622+01	.1774+00	.1993+00	.2250+00	.3808+00	.1179+00	.1654-01	.4340-01
1.00	.9462+01	.1310+00	.1409+00	.1453+00	.2014+00	.5590+00	.8814-01	.3402-01
$UT(U)$	.6654+00	.4689+00	.6808+00	.7249+00	.6885+00	.6312+00	.6024+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.2374+00	.4987+01	.9072+00	.3319+00	.1290+00	.5348-01	.3547-01	.1947+00
0.10	.3441+00	.1929+00	.1441+01	.5928+00	.2919+00	.1610+00	.1236+00	.6018+00
0.30	.9713+00	.5737+00	.3190+00	.5062+00	.2832+00	.1655+00	.1291+00	.4004+00
0.50	.1226+01	.5792+00	.9210+00	.3352+00	.2017+00	.1235+00	.9785-01	.2494+00
0.70	.1269+01	.4057+00	.5799+00	.7872+00	.2461+00	.8186-01	.6597-01	.1504+00
0.90	.1716+01	.2495+00	.3270+00	.3900+00	.5893+00	.1567+00	.4359-01	.9256-01
1.00	.8845+01	.1937+00	.2451+00	.2757+00	.3699+00	.8887+00	.1233+00	.7369-01
$UT(U)$	.7506+00	.4001+00	.6012+00	.7364+00	.7981+00	.8065+00	.7993+00	.3012-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.1979+00	.5032+01	.1091+01	.4912+00	.2658+00	.1409+00	.1017+00	.3076+00
0.10	.1918+00	.1124+00	.1512+01	.6772+00	.3695+00	.2218+00	.1758+00	.6724+00
0.30	.4624+00	.2967+00	.1733+00	.6397+00	.4056+00	.2611+00	.2110+00	.5114+00
0.50	.7313+00	.3707+00	.5738+00	.2172+00	.3485+00	.2387+00	.1967+00	.3828+00
0.70	.8990+00	.3727+00	.5572+00	.7186+00	.2219+00	.1905+00	.1598+00	.2747+00
0.90	.1282+01	.3089+00	.4403+00	.5473+00	.7253+00	.1877+00	.1196+00	.1911+00
1.00	.4509+01	.2680+00	.3730+00	.4516+00	.5815+00	.1084+01	.1645+00	.1588+00
$UT(U)$	.6982+00	.3321+00	.4950+00	.6258+00	.7338+00	.8113+00	.8386+00	.2760-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.1561+00	.5070+01	.1107+01	.6309+00	.4433+00	.3191+00	.2674+00	.4579+00
0.10	.1259+00	.7491-01	.1570+01	.7504+00	.4519+00	.3040+00	.2547+00	.7482+00
0.30	.2816+00	.1882+00	.1119+00	.7501+00	.5299+00	.3850+00	.3299+00	.6258+00
0.50	.4525+00	.2384+00	.3569+00	.1418+00	.5059+00	.3956+00	.3472+00	.5276+00
0.70	.6239+00	.2788+00	.4159+00	.5271+00	.1661+00	.3679+00	.3302+00	.4380+00
0.90	.8450+00	.2990+00	.4410+00	.5561+00	.6762+00	.1791+00	.2912+00	.3546+00
1.00	.1390+01	.2986+00	.4366+00	.5473+00	.6711+00	.9117+00	.1795+00	.3159+00
$UT(U)$	.5647+00	.2616+00	.3886+00	.4914+00	.5856+00	.6731+00	.7138+00	.3114-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.6: Single-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.000).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.4390+00	.5809+00	.7836-01	.2938-01	.1525-01	.9318-02	.7573-02	.2714-01
0.10	.5716+00	.1829+01	.2130+00	.1303+00	.9385-01	.7334-01	.6611-01	.1254+00
0.30	.7822-01	.2118+00	.7509+00	.4797-01	.3457-01	.2702-01	.2436-01	.4611-01
0.50	.2936-01	.1299+00	.4792-01	.4697+00	.2117-01	.1654-01	.1491-01	.2823-01
0.70	.1525-01	.9363-01	.3454-01	.2116-01	.3416+00	.1192-01	.1075-01	.2034-01
0.90	.9316-02	.7321-01	.2700-01	.1654-01	.1192-01	.2683+00	.8400-02	.1590-01
1.00	.7572-02	.6600-01	.2434-01	.1491-01	.1075-01	.8399-02	.2423+00	.1433-01
$UT(U)$	.2707-01	.1246+00	.4601-01	.2819-01	.2032-01	.1588-01	.1432-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.3992+00	.8919+00	.1420+00	.5530-01	.2920-01	.1801-01	.1469-01	.4902-01
0.10	.8368+00	.1338+01	.3534+00	.2198+00	.1595+00	.1252+00	.1130+00	.2077+00
0.30	.1410+00	.3458+00	.6766+00	.8858-01	.6435-01	.5053-01	.4563-01	.8343-01
0.50	.5516-01	.2170+00	.8820-01	.4412+00	.4018-01	.3145-01	.2850-01	.5205-01
0.70	.2916-01	.1581+00	.6415-01	.4011-01	.3266+00	.2293-01	.2071-01	.3781-01
0.90	.1800-01	.1243+00	.5041-01	.3151-01	.2291-01	.2591+00	.1626-01	.2926-01
1.00	.1468-01	.1123+00	.4553-01	.2846-01	.2069-01	.1625-01	.2349+00	.2681-01
$UT(U)$	.4864-01	.2031+00	.8280-01	.5181-01	.3769-01	.2961-01	.2675-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.3398+00	.1147+01	.2356+00	.9837-01	.5363-01	.3369-01	.2765-01	.8292-01
0.10	.8953+00	.7163+00	.5070+00	.3237+00	.2376+00	.1877+00	.1698+00	.3000+00
0.30	.2289+00	.4659+00	.5494+00	.1521+00	.1121+00	.8880-01	.8043-01	.1398+00
0.50	.9735-01	.3077+00	.1495+00	.3894+00	.7262-01	.5753-01	.5212-01	.9026-01
0.70	.5335-01	.2291+00	.1108+00	.7208-01	.2987+00	.4250-01	.3850-01	.6658-01
0.90	.3358-01	.1824+00	.8795-01	.5720-01	.4233-01	.2418+00	.3052-01	.5273-01
1.00	.2758-01	.1656+00	.7973-01	.5185-01	.3836-01	.3043-01	.2206+00	.4776-01
$UT(U)$	.8105-01	.2783+00	.1362+00	.8888-01	.6585-01	.5228-01	.4739-01	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.2589+00	.1242+01	.3380+00	.1580+00	.9115-01	.5920-01	.4918-01	.1271+00
0.10	.5130+00	.2052+00	.6027+00	.3959+00	.2946+00	.2345+00	.2127+00	.3622+00
0.30	.3018+00	.4406+00	.3622+00	.2301+00	.1740+00	.1398+00	.1272+00	.2070+00
0.50	.1516+00	.3278+00	.2149+00	.3033+00	.1199+00	.9653-01	.8794-01	.1416+00
0.70	.8924-01	.2573+00	.1657+00	.1164+00	.2499+00	.7344-01	.6693-01	.1073+00
0.90	.5845-01	.2111+00	.1345+00	.9433-01	.7224-01	.2104+00	.5396-01	.8628-01
1.00	.4868-01	.1935+00	.1229+00	.8614-01	.6594-01	.5334-01	.1947+00	.7858-01
$UT(U)$	.1190+00	.2854+00	.1898+00	.1344+00	.1034+00	.8381-01	.7655-01	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.1633+00	.1250+01	.4018+00	.2162+00	.1358+00	.9317-01	.7902-02	.1704+00
0.10	.8422-01	.1684-01	.6242+00	.4156+00	.3115+00	.2490+00	.2263+00	.3792+00
0.30	.2623+00	.2277+00	.1574+00	.2908+00	.2269+00	.1858+00	.1703+00	.2592+00
0.50	.1839+00	.2257+00	.2238+00	.1839+00	.1708+00	.1409+00	.1295+00	.1917+00
0.70	.1249+00	.2012+00	.1879+00	.1521+00	.1748+00	.1124+00	.1034+00	.1512+00
0.90	.8854-01	.1772+00	.1604+00	.1287+00	.1053+00	.1594+00	.8579-01	.1246+00
1.00	.7582-01	.1666+00	.1492+00	.1193+00	.9749-01	.8194-01	.1516+00	.1144+00
$UT(U)$	.1411+00	.1966+00	.1954+00	.1611+00	.1334+00	.1130+00	.1048+00	.2216+00

Table A.6: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.7425-01	.1250+01	.4161+00	.2454+00	.1683+00	.1238+00	.1081+00	.1967+00
0.10	.1135-02	.1135-03	.6250+00	.4167+00	.3125+00	.2500+00	.2273+00	.3801+00
0.30	.9909-01	.4454-01	.2973-01	.3110+00	.2479+00	.2059+00	.1898+00	.2782+00
0.50	.1353+00	.8456-01	.1246+00	.6767-01	.2016+00	.1706+00	.1584+00	.2195+00
0.70	.1223+00	.9984-01	.1275+00	.1304+00	.8559-01	.1439+00	.1341+00	.1805+00
0.90	.1016+00	.1029+00	.1223+00	.1212+00	.1119+00	.9144-01	.1156+00	.1529+00
1.00	.9197-01	.1022+00	.1186+00	.1163+00	.1069+00	.9672-01	.9197-01	.1420+00
$UT(U)$	.1162+00	.8755-01	.1185+00	.1255+00	.1198+00	.1108+00	.1062+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.1877-01	.1250+01	.4167+00	.2499+00	.1780+00	.1373+00	.1227+00	.2040+00
0.10	.1031-06	.5153-08	.6250+00	.4167+00	.3125+00	.2500+00	.2273+00	.3801+00
0.30	.7070-02	.1591-02	.1061-02	.3125+00	.2500+00	.2083+00	.1923+00	.2800+00
0.50	.3663-01	.1145-01	.2130-01	.9158-02	.2081+00	.1782+00	.1663+00	.2251+00
0.70	.5860-01	.2393-01	.3510-01	.4890-01	.2051-01	.1553+00	.1459+00	.1889+00
0.90	.6689-01	.3387-01	.4462-01	.5628-01	.6367-01	.3010-01	.1296+00	.1628+00
1.00	.6767-01	.3759-01	.4788-01	.5851-01	.6492-01	.6742-01	.3383-01	.1523+00
$UT(U)$	.5056-01	.2162-01	.3132-01	.4452-01	.5446-01	.6001-01	.6151-01	.3013-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.1599-02	.1250+01	.4167+00	.2500+00	.1786+00	.1389+00	.1250+00	.2046+00
0.10	.4248-15	.1062-16	.6250+00	.4167+00	.3125+00	.2500+00	.2273+00	.3801+00
0.30	.1800-04	.2024-05	.1350-05	.3125+00	.2500+00	.2083+00	.1923+00	.2800+00
0.50	.1342-02	.2097-03	.4173-03	.1677-03	.2083+00	.1786+00	.1667+00	.2253+00
0.70	.6732-02	.1374-02	.2061-02	.3704-02	.1178-02	.1562+00	.1470+00	.1894+00
0.90	.1450-01	.3670-02	.4893-02	.7130-02	.1056-01	.3262-02	.1316+00	.1637+00
1.00	.1832-01	.5088-02	.6541-02	.8990-02	.1251-01	.1643-01	.4579-02	.1534+00
$UT(U)$	.6945-02	.1810-02	.2502-02	.4023-02	.6831-02	.1044-01	.1231-01	.2761-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.1707-04	.1250+01	.4167+00	.2500+00	.1786+00	.1389+00	.1250+00	.2046+00
0.10	.3610-32	.4512-34	.6250+00	.4167+00	.3125+00	.2500+00	.2273+00	.3801+00
0.30	.5829-10	.3279-11	.2186-11	.3125+00	.2500+00	.2083+00	.1923+00	.2800+00
0.50	.9003-06	.7033-07	.1407-06	.5627-07	.2083+00	.1786+00	.1667+00	.2253+00
0.70	.4441-04	.4533-05	.6800-05	.1346-04	.3886-05	.1562+00	.1471+00	.1894+00
0.90	.3405-03	.4310-04	.5746-04	.8613-04	.1588-03	.3831-04	.1316+00	.1638+00
1.00	.6709-03	.9318-04	.1198-03	.1677-03	.2705-03	.4939-03	.8387-04	.1543+00
$UT(U)$	.1114-03	.1895-04	.2558-04	.3882-04	.7856-04	.2003-03	.3138-03	.3118-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.7: Single-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.250).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.4359+00	.6201+00	.7499-01	.2349-01	.9919-02	.4933-02	.3635-02	.2158-01
0.10	.6219+00	.1976+01	.2187+00	.1265+00	.8491-01	.6119-01	.5282-01	.1198+00
0.30	.8813-01	.2299+00	.7943+00	.4232-01	.2793-01	.1989-01	.1710-01	.4033-01
0.50	.3572-01	.1377+00	.5486-01	.4769+00	.1531-01	.1084-01	.9299-02	.2253-01
0.70	.2129-01	.9499-01	.3925-01	.2679-01	.3272+00	.6997-02	.6002-02	.1477-01
0.90	.1671-01	.6985-01	.2974-01	.2124-01	.1802-01	.2391+00	.4234-02	.1049-01
1.00	.1683-01	.6074-01	.2618-01	.1909-01	.1675-01	.1643-01	.2074+00	.9021-02
$UT(U)$	.3263-01	.1292+00	.5153-01	.3385-01	.2597-01	.2145-01	.1984-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.3945+00	.9520+00	.1359+00	.4422-01	.1899-01	.9535-02	.7050-02	.3854-01
0.10	.9099+00	.1446+01	.3628+00	.2134+00	.1443+00	.1044+00	.9028-01	.1978+00
0.30	.1588+00	.3754+00	.7158+00	.7818-01	.5199-01	.3720-01	.3204-01	.7261-01
0.50	.6711-01	.2300+00	.1010+00	.4480+00	.2907-01	.2067-01	.1777-01	.4128-01
0.70	.4072-01	.1603+00	.7290-01	.5079-01	.3129+00	.1346-01	.1157-01	.2727-01
0.90	.3228-01	.1186+00	.5553-01	.4047-01	.3464-01	.2310+00	.8197-02	.1945-01
1.00	.3262-01	.1033+00	.4897-01	.3643-01	.3225-01	.3179-01	.2010+00	.1674-01
$UT(U)$	.5914-01	.2103+00	.9280-01	.6242-01	.4846-01	.4035-01	.3743-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.3335+00	.1225+01	.2255+00	.7865-01	.3487-01	.1783-01	.1327-01	.6417-01
0.10	.9741+00	.7739+00	.5205+00	.3142+00	.2150+00	.1566+00	.1357+00	.2846+00
0.30	.2579+00	.5057+00	.5811+00	.1342+00	.9060-01	.6538-01	.5647-01	.1208+00
0.50	.1184+00	.3261+00	.1711+00	.3954+00	.5254-01	.3768-01	.3249-01	.7097-01
0.70	.7449-01	.2325+00	.1259+00	.9127-01	.2862+00	.2494-01	.2150-01	.4755-01
0.90	.6022-01	.1741+00	.9688-01	.7348-01	.6401-01	.2155+00	.1538-01	.3419-01
1.00	.6128-01	.1523+00	.8576-01	.6637-01	.5980-01	.5951-01	.1889+00	.2951-01
$UT(U)$	.9985-01	.2872+00	.1528+00	.1076+00	.8544-01	.7220-01	.6735-01	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.2516+00	.1325+01	.3235+00	.1264+00	.5928-01	.3134-01	.2361-01	.9641-01
0.10	.5582+00	.2217+00	.6188+00	.3843+00	.2665+00	.1956+00	.1700+00	.3426+00
0.30	.3400+00	.4783+00	.3831+00	.2031+00	.1406+00	.1029+00	.8933-01	.1775+00
0.50	.1845+00	.3474+00	.2460+00	.3079+00	.8676-01	.6322-01	.5483-01	.1102+00
0.70	.1246+00	.2611+00	.1882+00	.1474+00	.2394+00	.4310-01	.3738-01	.7567-01
0.90	.1048+00	.2014+00	.1482+00	.1212+00	.1092+00	.1875+00	.2720-01	.5520-01
1.00	.1082+00	.1781+00	.1322+00	.1103+00	.1028+00	.1043+00	.1667+00	.4790-01
$UT(U)$	.1495+00	.2928+00	.2132+00	.1638+00	.1358+00	.1179+00	.1112+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.1566+00	.1334+01	.3845+00	.1728+00	.8829-01	.4933-01	.3793-01	.1265+00
0.10	.9164-01	.1820-01	.6409+00	.4034+00	.2818+00	.2078+00	.1808+00	.3582+00
0.30	.2956+00	.2471+00	.1665+00	.2566+00	.1833+00	.1368+00	.1196+00	.2208+00
0.50	.2238+00	.2392+00	.2561+00	.1868+00	.1236+00	.9227-01	.8073-01	.1476+00
0.70	.1744+00	.2041+00	.2135+00	.1926+00	.1675+00	.6595-01	.5774-01	.1053+00
0.90	.1588+00	.1691+00	.1767+00	.1653+00	.1592+00	.1420+00	.4324-01	.7854-01
1.00	.1685+00	.1533+00	.1604+00	.1527+00	.1520+00	.1603+00	.1298+00	.6871-01
$UT(U)$	.1823+00	.1997+00	.2196+00	.1980+00	.1782+00	.1629+00	.1566+00	.2216+00

Table A.7: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.6992-01	.1334+01	.3983+00	.1962+00	.1095+00	.6556-01	.5188-01	.1439+00
0.10	.1235-02	.1226-03	.6417+00	.4044+00	.2827+00	.2086+00	.1816+00	.3591+00
0.30	.1117+00	.4834-01	.3145-01	.2745+00	.2002+00	.1516+00	.1333+00	.2361+00
0.50	.1647+00	.8962-01	.1426+00	.6871-01	.1458+00	.1117+00	.9874-01	.1677+00
0.70	.1707+00	.1013+00	.1449+00	.1651+00	.8199-01	.8447-01	.7489-01	.1244+00
0.90	.1822+00	.9814-01	.1347+00	.1556+00	.1693+00	.8150-01	.5828-01	.9530-01
1.00	.2044+00	.9402-01	.1276+00	.1488+00	.1666+00	.1892+00	.7873-01	.8423-01
$UT(U)$	.1560+00	.8758-01	.1330+00	.1559+00	.1634+00	.1648+00	.1646+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.1731-01	.1334+01	.3988+00	.1998+00	.1157+00	.7276-01	.5890-01	.1484+00
0.10	.1121-06	.5568-08	.6417+00	.4044+00	.2827+00	.2086+00	.1816+00	.3591+00
0.30	.7966-02	.1727-02	.1122-02	.2758+00	.2020+00	.1534+00	.1350+00	.2376+00
0.50	.4457-01	.1213-01	.2439-01	.9299-02	.1506+00	.1167+00	.1037+00	.1717+00
0.70	.8183-01	.2428-01	.3988-01	.6192-01	.1965-01	.9113-01	.8149-01	.1297+00
0.90	.1200+00	.3231-01	.4915-01	.7230-01	.9628-01	.2683-01	.6534-01	.1009+00
1.00	.1504+00	.3459-01	.5150-01	.7490-01	.1012+00	.1319+00	.2896-01	.8983-01
$UT(U)$	.7137-01	.2124-01	.3499-01	.5597-01	.7613-01	.9255-01	.9941-01	.3013-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.1444-02	.1334+01	.3988+00	.1999+00	.1161+00	.7352-01	.5998-01	.1487+00
0.10	.4622-15	.1148-16	.6417+00	.4044+00	.2827+00	.2086+00	.1816+00	.3591+00
0.30	.2028-04	.2197-05	.1428-05	.2758+00	.2020+00	.1534+00	.1350+00	.2376+00
0.50	.1633-02	.2222-03	.4777-03	.1703-03	.1507+00	.1170+00	.1039+00	.1719+00
0.70	.9399-02	.1394-02	.2341-02	.4690-02	.1129-02	.9170-01	.8212-01	.1301+00
0.90	.2600-01	.3502-02	.5389-02	.9159-02	.1596-01	.2907-02	.6630-01	.1015+00
1.00	.4070-01	.4682-02	.7035-02	.1151-01	.1951-01	.3213-01	.3920-02	.9041-01
$UT(U)$	.1042-01	.1746-02	.2772-02	.5118-02	.9833-02	.1676-01	.2080-01	.2761-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.1513-04	.1334+01	.3988+00	.1999+00	.1161+00	.7353-01	.6000-01	.1487+00
0.10	.3927-32	.4875-34	.6417+00	.4044+00	.2827+00	.2086+00	.1816+00	.3591+00
0.30	.6568-10	.3559-11	.2312-11	.2758+00	.2020+00	.1534+00	.1350+00	.2376+00
0.50	.1095-05	.7455-07	.1610-06	.5713-07	.1507+00	.1170+00	.1039+00	.1719+00
0.70	.6201-04	.4599-05	.7727-05	.1704-04	.3723-05	.9170-01	.8213-01	.1301+00
0.90	.6108-03	.4112-04	.6330-04	.1106-03	.2401-03	.3414-04	.6632-01	.1014+00
1.00	.1491-02	.8575-04	.1289-03	.2146-03	.4216-03	.9659-03	.7179-04	.9042-01
$UT(U)$	.1787-03	.1796-04	.2807-04	.4973-04	.1169-03	.3356-03	.5532-03	.3118-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.8: Single-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.500).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.4241+00	.7676+00	.6801-01	.1572-01	.5422-02	.2382-02	.1680-02	.1573-01
0.10	.8147+00	.2550+01	.2351+00	.1139+00	.6408-01	.3934-01	.3161-01	.1108+00
0.30	.1164+00	.2851+00	.9232+00	.3253-01	.1852-01	.1163-01	.9465-02	.3251-01
0.50	.4824-01	.1473+00	.6849-01	.4681+00	.9133-02	.5870-02	.4833-02	.1582-01
0.70	.3040-01	.8381-01	.4149-01	.3403-01	.2661+00	.3560-02	.2959-02	.9158-02
0.90	.2907-01	.5062-01	.2516-01	.2197-01	.2407-01	.1626+00	.1998-02	.5842-02
1.00	.4542-01	.4014-01	.1972-01	.1722-01	.1976-01	.3042-01	.1300+00	.4790-02
$UT(U)$	.3852-01	.1345+00	.5855-01	.4055-01	.3191-01	.2657-01	.2455-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.3774+00	.1178+01	.1232+00	.2960-01	.1038-01	.4605-02	.3259-02	.2761-01
0.10	.1192+01	.1866+01	.3902+00	.1923+00	.1089+00	.6715-01	.5403-01	.1813+00
0.30	.2098+00	.4655+00	.8318+00	.6007-01	.3447-01	.2175-01	.1773-01	.5791-01
0.50	.9063-01	.2461+00	.1260+00	.4397+00	.1734-01	.1120-01	.9234-02	.2872-01
0.70	.5814-01	.1415+00	.7707-01	.6451-01	.2544+00	.6848-02	.5703-02	.1678-01
0.90	.5615-01	.8594-01	.4696-01	.4186-01	.4627-01	.1571+00	.3868-02	.1077-01
1.00	.8805-01	.6827-01	.3688-01	.3286-01	.3804-01	.5887-01	.1260+00	.8850-02
$UT(U)$	.7023-01	.2169+00	.1051+00	.7492-01	.5993-01	.5045-01	.4681-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.3111+00	.1516+01	.2045+00	.5265-01	.1907-01	.8613-02	.6135-02	.4491-01
0.10	.1276+01	.9986+00	.5597+00	.2831+00	.1622+00	.1007+00	.8120-01	.2581+00
0.30	.3407+00	.6271+00	.6754+00	.1031+00	.6007-01	.3823-01	.3125-01	.9499-01
0.50	.1600+00	.3489+00	.2136+00	.3881+00	.3133-01	.2041-01	.1689-01	.4874-01
0.70	.1063+00	.2051+00	.1331+00	.1159+00	.2327+00	.1269-01	.1060-01	.2895-01
0.90	.1048+00	.1262+00	.8195-01	.7600-01	.8548-01	.1465+00	.7258-02	.1878-01
1.00	.1654+00	.1007+00	.6459-01	.5987-01	.7053-01	.1102+00	.1184+00	.1550-01
$UT(U)$	.1197+00	.2916+00	.1720+00	.1294+00	.1066+00	.9156-01	.8563-01	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.2263+00	.1640+01	.2933+00	.8459-01	.3241-01	.1514-01	.1091-01	.6564-01
0.10	.7313+00	.2861+00	.6654+00	.3462+00	.2011+00	.1258+00	.1017+00	.3079+00
0.30	.4492+00	.5931+00	.4453+00	.1560+00	.9319-01	.6017-01	.4944-01	.1373+00
0.50	.2491+00	.3717+00	.3071+00	.3022+00	.5174-01	.3425-01	.2850-01	.7449-01
0.70	.1779+00	.2303+00	.1990+00	.1872+00	.1946+00	.2193-01	.1843-01	.4549-01
0.90	.1824+00	.1460+00	.1253+00	.1253+00	.1459+00	.1275+00	.1283-01	.3004-01
1.00	.2920+00	.1177+00	.9957-01	.9946-01	.1212+00	.1932+00	.1045+00	.2496-01
$UT(U)$	.1816+00	.2890+00	.2372+00	.1972+00	.1715+00	.1527+00	.1448+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.1341+00	.1652+01	.3487+00	.1157+00	.4827-01	.2382-01	.1753-01	.8390-01
0.10	.1201+00	.2349-01	.6892+00	.3635+00	.2126+00	.1336+00	.1082+00	.3207+00
0.30	.3905+00	.3064+00	.1935+00	.1972+00	.1215+00	.7997-01	.6617-01	.1683+00
0.50	.3022+00	.2559+00	.3198+00	.1833+00	.7370-01	.4999-01	.4196-01	.9827-01
0.70	.2490+00	.1801+00	.2257+00	.2446+00	.1362+00	.3355-01	.2847-01	.6246-01
0.90	.2763+00	.1225+00	.1494+00	.1709+00	.2126+00	.9660-01	.2040-01	.4232-01
1.00	.4548+00	.1013+00	.1208+00	.1378+00	.1792+00	.2968+00	.8136-01	.3551-01
$UT(U)$	.2260+00	.1877+00	.2392+00	.2380+00	.2284+00	.2171+00	.2112+00	.2216+00

Table A.8: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.5640-01	.1652+01	.3612+00	.1314+00	.5984-01	.3166-01	.2398-01	.9377-01
0.10	.1618-02	.1582-03	.6901+00	.3644+00	.2133+00	.1341+00	.1087+00	.3214+00
0.30	.1475+00	.5995-01	.3655-01	.2109+00	.1328+00	.8864-01	.7375-01	.1789+00
0.50	.2224+00	.9587-01	.1780+00	.6744-01	.8697-01	.6054-01	.5132-01	.1106+00
0.70	.2438+00	.8936-01	.1531+00	.2097+00	.6667-01	.4298-01	.3692-01	.7314-01
0.90	.3170+00	.7113-01	.1139+00	.1610+00	.2206+00	.5543-01	.2750-01	.5096-01
1.00	.5517+00	.6214-01	.9610-01	.1343+00	.1965+00	.3503+00	.4935-01	.4324-01
$UT(U)$	.1993+00	.7692-01	.1393+00	.1857+00	.2128+00	.2279+00	.2323+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.1308-01	.1652+01	.3616+00	.1338+00	.6327-01	.3509-01	.2723-01	.9620-01
0.10	.1469-06	.7184-08	.6901+00	.3644+00	.2134+00	.1341+00	.1087+00	.3214+00
0.30	.1052-01	.2141-02	.1304-02	.2119+00	.1339+00	.8968-01	.7472-01	.1798+00
0.50	.6019-01	.1298-01	.3045-01	.9127-02	.8980-01	.6324-01	.5387-01	.1130+00
0.70	.1168+00	.2142-01	.4216-01	.7864-01	.1598-01	.4637-01	.4018-01	.7602-02
0.90	.2087+00	.2342-01	.4158-01	.7477-01	.1286+00	.1825-01	.3083-01	.5382-01
1.00	.4059+00	.2286-01	.3878-01	.6756-01	.1194-01	.2442+00	.1815-01	.4599-01
$UT(U)$	.9505-01	.1733-01	.3423-01	.6507-07	.1005+00	.1338+00	.1486+00	.3013-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.1026-02	.1652+01	.3616+00	.1338+00	.6348-01	.3551-01	.2773-01	.9636-01
0.10	.6056-15	.1481-16	.6901+00	.3644+00	.2134+00	.1341+00	.1087+00	.3214+00
0.30	.2679-04	.2725-05	.1659-05	.2119+00	.1339+00	.8969-01	.7473-01	.1798+00
0.50	.2205-02	.2377-03	.5964-03	.1672-03	.8989-01	.6336-01	.5401-01	.1131+00
0.70	.1342-01	.1230-02	.2475-02	.5957-02	.9176-03	.4666-01	.4049-01	.7621-01
0.90	.4524-01	.2538-02	.4558-02	.9473-02	.2132-01	.1977-02	.3128-01	.5408-01
1.00	.1099+00	.3094-02	.5298-02	.1038-01	.2301-01	.5951-01	.2457-02	.4627-01
$UT(U)$	.1468-01	.1326-02	.2495-02	.5654-02	.1307-01	.2546-01	.3324-01	.2761-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.1023-04	.1652+01	.3616+00	.1338+00	.6348-01	.3551-01	.2774-01	.9637-01
0.10	.5145-32	.6291-34	.6901+00	.3644+00	.2134+00	.1341+00	.1087+00	.3214+00
0.30	.8677-10	.4413-11	.2687-11	.2119+00	.1339+00	.8969-01	.7473-01	.1798+00
0.50	.1479-05	.7975-07	.2010-06	.5608-07	.8989-01	.6336-01	.5401-01	.1131+00
0.70	.8853-04	.4058-05	.8169-05	.2165-04	.3027-05	.4666-01	.4049-01	.7621-01
0.90	.1062-02	.2980-04	.5354-04	.1144-03	.3207-03	.2322-04	.3129-01	.5408-01
1.00	.4025-02	.5667-04	.9705-04	.1936-03	.4973-03	.1789-02	.4500-04	.4627-01
$UT(U)$	.2710-03	.1279-04	.2359-04	.5115-04	.1536-03	.5371-03	.9489-03	.3118-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.9: Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.750).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.3892+00	.1040+01	.4170-01	.7025-02	.2138-02	.8892-03	.5903-03	.8976-02
0.10	.1505+01	.4296+01	.1985+00	.6878-01	.3133-01	.1685-01	.1294-01	.8994-01
0.30	.2151+00	.3823+00	.9688+00	.1633-01	.8188-02	.4732-02	.3741-02	.1946-01
0.50	.8918-01	.1201+00	.8870-01	.3223+00	.3776-02	.2301-02	.1854-02	.7738-02
0.70	.5652-01	.4810-01	.3126-01	.4082-01	.1395+00	.1357-02	.1107-02	.3956-02
0.90	.5762-01	.2338-01	.1311-01	.1418-01	.2403-01	.7200-01	.7364-03	.2336-02
1.00	.2118+00	.1724-01	.9097-02	.8921-02	.1280-01	.3752-01	.5414-01	.1863-02
$UT(U)$	.4517-01	.1453+00	.7085-01	.4925-01	.3783-01	.3066-01	.2800-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.3295+00	.1596+01	.7555-01	.1322-01	.4094-02	.1719-02	.1145-02	.1534-01
0.10	.2203+01	.3143+01	.3293+00	.1160+00	.5325-01	.2875-01	.2212-01	.1437+00
0.30	.3877+00	.6241+00	.8729+00	.3015-01	.1524-01	.8850-02	.7008-02	.3403-01
0.50	.1675+00	.2007+00	.1633+00	.3028+00	.7168-02	.4389-02	.3542-02	.1389-01
0.70	.1081+00	.8119-01	.5807-01	.7738-01	.1334+00	.2610-02	.2133-02	.7205-02
0.90	.1113+00	.3969-01	.2447-01	.2702-01	.4619-01	.6955-01	.1426-02	.4292-02
1.00	.4106+00	.2933-01	.1701-01	.1703-01	.2465-01	.7261-01	.5247-01	.3433-02
$UT(U)$	.8273-01	.2283+00	.1264+00	.9141-01	.7164-01	.5877-01	.5389-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.2527+00	.2053+01	.1254+00	.2352-01	.7518-02	.3215-02	.2155-02	.2404-01
0.10	.2358+01	.1682+01	.4724+00	.1709+00	.7932-01	.4311-01	.3324-01	.1990+00
0.30	.6295+00	.8408+00	.7088+00	.5176-01	.2656-01	.1555-01	.1235-01	.5452-01
0.50	.2957+00	.2845+00	.2766+00	.2672+00	.1295-01	.8003-02	.6478-02	.2325-01
0.70	.1977+00	.1177+00	.1003+00	.1391+00	.1220+00	.4838-02	.3966-02	.1234-01
0.90	.2077+00	.5827-01	.4270-01	.4905-01	.8534-01	.6488-01	.2675-02	.7456-02
1.00	.7714+00	.4325-01	.2980-01	.3102-01	.4570-01	.1360+00	.4929-01	.5994-02
$UT(U)$	.1417+00	.2928+00	.2041+00	.1586+00	.1290+00	.1082+00	.1000+00	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.1667+00	.2222+01	.1798+00	.3779-01	.1278-01	.5649-02	.3834-02	.3376-01
0.10	.1351+01	.4820+00	.5617+00	.2090+00	.9833-01	.5386-01	.4164-01	.2324+00
0.30	.8300+00	.7952+00	.4672+00	.7833-01	.4121-01	.2448-01	.1954-01	.7683-01
0.50	.4606+00	.3031+00	.3978+00	.2081+00	.2139-01	.1343-01	.1093-01	.3497-01
0.70	.3308+00	.1322+00	.1500+00	.2246+00	.1020+00	.8360-02	.6893-02	.1922-01
0.90	.3615+00	.6741-01	.6531-01	.8089-01	.1457+00	.5647-01	.4730-02	.1187-01
1.00	.1362+01	.5056-01	.4594-01	.5154-01	.7856-01	.2383+00	.4350-01	.9626-02
$UT(U)$	.2169+00	.2671+00	.2737+00	.2423+00	.2110+00	.1845+00	.1731+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.8761-01	.2237+01	.2138+00	.5169-01	.1903-01	.8891-02	.6159-02	.4176-01
0.10	.2218+00	.3957-01	.5817+00	.2194+00	.1040+00	.5721-01	.4431-01	.2403+00
0.30	.7214+00	.4109+00	.2031+00	.9898-01	.5374-01	.3254-01	.2615-01	.9237-01
0.50	.5587+00	.2087+00	.4141+00	.1262+00	.3047-01	.1960-01	.1609-01	.4548-01
0.70	.4629+00	.1033+00	.1701+00	.2934+00	.7140-01	.1279-01	.1065-01	.2615-01
0.90	.5476+00	.5660-01	.7785-01	.1103+00	.2122+00	.4277-01	.7520-02	.1664-01
1.00	.2121+01	.4353-01	.5574-01	.7140-01	.1161+00	.3661+00	.3388-01	.1364-01
$UT(U)$	.2735+00	.1506+00	.2607+00	.2904+00	.2864+00	.2707+00	.2614+00	.2216+00

Table A.9: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.3239-01	.2237+01	.2214+00	.5869-01	.2360-01	.1182-01	.8425-02	.4583-01
0.10	.2989-02	.2666-03	.5824+00	.2199+00	.1043+00	.5743-01	.4449-01	.2407+00
0.30	.2725+00	.8037-01	.3835-01	.1059+00	.5871-01	.3606-01	.2915-01	.9736-01
0.50	.4111+00	.7819-01	.2306+00	.4644-01	.3596-01	.2373-01	.1968-01	.5076-01
0.70	.4532+00	.5129-01	.1154+00	.2516+00	.3495-01	.1638-01	.1381-01	.3043-01
0.90	.6284+00	.3285-01	.5937-01	.1039+00	.2257+00	.2454-01	.1014-01	.1996-01
1.00	.2573+01	.2669-01	.4434-01	.6957-01	.1273+00	.4321+00	.2055-01	.1657-01
$UT(U)$	.2463+00	.5138-01	.1353+00	.2199+00	.2716+00	.2966+00	.3022+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.6686-02	.2237+01	.2217+00	.5976-01	.2495-01	.1310-01	.9565-02	.4679-01
0.10	.2714-06	.1210-07	.5824+00	.2199+00	.1043+00	.5743-01	.4449-01	.2407+00
0.30	.1944-01	.2871-02	.1368-02	.1064+00	.5921-01	.3649-01	.2953-01	.9779-01
0.50	.1113+00	.1059-01	.3943-01	.6285-02	.3712-01	2479-01	.2066-01	.5174-01
0.70	.2172+00	.1229-01	.3177-01	.9434-01	.8376-02	.1767-01	.1503-01	.3157-01
0.90	.4137+00	.1082-01	.2166-01	.4826-01	.1284+00	.8079-02	.1136-01	.2105-01
1.00	.1893+01	.9821-02	.1789-01	.3501-01	.7734-01	.3012+00	.7559-02	.1760-01
$UT(U)$	.1215+00	.9798-02	.2699-01	.7092-01	.1298+00	.1835+00	.2070+00	.3013-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.4810-03	.2237+01	.2217+00	.5978-01	.2503-01	.1325-01	.9741-02	.4685-01
0.10	.1119-14	.2495-16	.5824+00	.2199+00	.1043+00	.5743-01	.4449-01	.2407+00
0.30	.4949-04	.3653-05	.1741-05	.1064+00	.5922-01	.3649-01	.2954-01	.9780-01
0.50	.4076-02	.1939-03	.7724-03	.1151-03	.3716-01	.2484-01	.2072-01	.5178-01
0.70	.2495-01	.7060-03	.1865-02	.7146-02	.4811-03	.1778-01	.1515-01	.3165-01
0.90	.8967-01	.1172-02	.2375-02	.6114-02	.2128-01	.8755-03	.1153-01	.2114-01
1.00	.5123+00	.1329-02	.2444-02	.5379-02	.1491-01	.7341-01	.1023-02	.1770-01
$UT(U)$	.1981-01	.6551-03	.1546-02	.5114-02	.1620-01	.3705-01	.5053-01	.2761-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.4626-05	.2237+01	.2217+00	.5978-01	.2503-01	.1325-01	.9744-02	.4685-01
0.10	.9507-32	.1060-33	.5824+00	.2199+00	.1043+00	.5743-01	.449-01	.2407+00
0.30	.1603-09	.5917-11	.2820-11	.1064+00	.5922-01	.3649-01	.2954-01	.9780-01
0.50	.2735-05	.6504-07	.2604-06	.3861-07	.3716-01	.2484-01	.2072-01	.5178-01
0.70	.1646-03	.2329-05	.6155-05	.2597-04	.1587-05	.1779-01	.1515-01	.3165-01
0.90	.2106-02	.1377-04	.2790-04	.7384-04	.3202-03	.1028-04	.1153-01	.2115-01
1.00	.1877-01	.2434-04	.4477-04	.1003-03	.3223-03	.2207-02	.1874-04	.1770-01
$UT(U)$	.3940-03	.5420-05	.1255-04	.3564-04	.1688-03	.8263-03	.1604-02	.3118-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Table A.10: Multiple-Scattering Reflection and Transmission by Finite Layers Using the Heney-Greenstein Phase Function (Asymmetry Parameter = 0.875).

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 0.03125$								
$R(\mu_i, \mu_j)$	.3375+00	.9329+00	.2075-01	.3178-02	.9412-03	.3856-03	.1688-03	.5001-02
0.10	.2949+01	.6042+01	.1145+00	.3404-01	.1450-01	.7570-02	.5654-02	.6147-01
0.30	.4210+00	.3379+00	.6519+00	.7628-02	.3700-02	.2101-02	.1639-02	.9919-02
0.50	.1742+00	.6791-01	.7461-01	.1679+00	.1687-02	.1010-02	.8381-03	.3602-02
0.70	.1100+00	.2333-01	.1689-01	.3106-01	.6584-01	.5985-03	.4689-03	.1775-02
0.90	.1113+00	.1068-01	.6172-02	.7130-02	.1508-01	.3261-01	.3394-03	.1031-02
1.00	.9070+00	.7603-02	.4073-02	.4151-02	.6323-02	.2368-01	.2387-01	.8183-03
$UT(U)$	.4948-01	.1615+00	.8107-01	.5410-01	.4044-01	.3220-01	.3974-01	.4709+00
$\tau = 0.06250$								
$R(\mu_i, \mu_j)$	.2645+00	.1432+01	.3760-01	.5983-02	.1802-02	.7454-03	.3273-03	.8299-02
0.10	.4314+01	.4421+01	.1900+00	.5743-01	.2464-01	.1292-01	.9664-02	.9607-01
0.30	.7588+00	.5516+00	.5875+00	.1409-01	.6889-02	.3930-02	.3071-02	.1724-01
0.50	.3274+00	.1135+00	.1373+00	.1578+00	.3203-02	.1927-02	.1601-02	.6462-02
0.70	.2104+00	.3937-01	.3138-01	.5889-01	.6296-01	.1151-02	.9036-03	.3236-02
0.90	.2149+00	.1814-01	.1152-01	.1359-01	.2899-01	.3150-01	.6572-03	.1897-02
1.00	.1758+01	.1293-01	.7618-02	.7923-02	.1218-01	.4583-01	.2313-01	.1501-02
$UT(U)$	.9063-01	.2460+00	.1448+00	.1010+00	.7698-01	.6198-01	.7685-01	.4448+00
$\tau = 0.12500$								
$R(\mu_i, \mu_j)$	.1829+00	.1843+01	.6240-01	.1064-01	.3309-02	.1394-02	.6161-03	.1259-01
0.10	.4619+01	.2366+01	.2726+00	.8456-01	.3671-01	.1937-01	.1452-01	.1297+00
0.30	.1232+01	.7431+00	.4770+00	.2418-01	.1200-01	.6907-02	.5413-02	.2736-01
0.50	.5778+00	.1609+00	.2327+00	.1392+00	.5789-02	.3513-02	.2928-02	.1078-01
0.70	.3849+00	.5708-01	.5418-01	.1058+00	.5758-01	.2134-02	.1680-02	.5536-02
0.90	.4010+00	.2663-01	.2011-01	.2466-01	.5356-01	.2938-01	.1233-02	.3295-02
1.00	.3303+01	.1907-01	.1334-01	.1444-01	.2257-01	.8581-01	.2173-01	.2620-02
$UT(U)$	.1553+00	.2971+00	.2329+00	.1764+00	.1397+00	.1149+00	.1438+00	.3988+00
$\tau = 0.25000$								
$R(\mu_i, \mu_j)$	.1068+00	.1994+01	.8951-01	.1710-01	.5625-02	.2450-02	.1096-02	.1717-01
0.10	.2647+01	.6779+00	.3240+00	.1034+00	.4550-01	.2420-01	.1820-01	.1487+00
0.30	.1625+01	.7028+00	.3144+00	.3659-01	.1862-01	.1087-01	.8562-02	.3815-01
0.50	.9000+00	.1714+00	.3346+00	.1084+00	.9560-02	.5895-02	.4941-02	.1615-01
0.70	.6440+00	.6410-01	.8104-01	.1709+00	.4817-01	.3687-02	.2920-02	.8605-02
0.90	.6981+00	.3080-01	.3075-01	.4067-01	.9142-01	.2557-01	.2180-02	.5242-02
1.00	.5830+01	.2229-01	.2057-01	.2398-01	.3880-01	.1504+00	.1918-01	.4201-02
$UT(U)$	.2380+00	.2418+00	.3073+00	.2712+00	.1209+00	.1980+00	.2521+00	.3247+00
$\tau = 0.50000$								
$R(\mu_i, \mu_j)$	.4950-01	.2007+01	.1064+00	.2339-01	.8378-02	.3856-02	.1761-02	.2082-01
0.10	.4345+00	.5565-01	.3356+00	.1086+00	.4812-01	.2571-01	.1936-01	.1530+00
0.30	.1412+01	.3631+00	.1367+00	.4624-01	.2429-01	.1445-01	.1146-01	.4550-01
0.50	.1092+01	.1180+00	.3484+00	.6577-01	.1362-01	.8603-02	.7275-02	.2092-01
0.70	.9011+00	.5011-01	.9192-01	.2233+00	.3370-01	.5641-02	.4511-02	.1169-01
0.90	.1058+01	.2586-01	.3666-01	.5548-01	.1332+00	.1937-01	.3467-02	.7343-02
1.00	.9081+01	.1919-01	.2496-01	.3322-01	.5737-01	.2311+00	.1494-01	.5948-02
$UT(U)$	.3013+00	.1117+00	.2792+000	.3255+00	.3178+00	.2953+00	.3884+00	.2216+00

Table A.10: Cont.

μ_j	$T(\mu_i, \mu_j)$	μ_j						$URU(U)$
		0.10	0.30	0.50	0.70	0.90	1.00	
$\tau = 1.00000$								
$R(\mu_i, \mu_j)$	.1651-01	.2007+01	.1102+00	.2655-01	.1039-01	.5125-02	.2408-02	.2264-01
0.10	.5855-02	.3750-03	.3360+00	.1088+00	.4828-01	.2581-01	.1944-01	.1532+00
0.30	.5334+00	.7103-01	.2581-01	.4945-01	.2653-01	.1601-01	.1277-01	.4781-01
0.50	.8033+00	.4421-01	.1940+00	.2419-01	.1607-01	.1042-01	.8899-02	.2330-01
0.70	.8823+00	.2487-01	.6236-01	.1915+00	.1650-01	.7225-02	.5851-02	.1359-01
0.90	.1213+01	.1501-01	.2796-01	.5224-01	.1416+00	.1111-01	.4673-02	.8805-02
1.00	.1102+02	.1177-01	.1985-01	.3237-01	.6288-01	.2727+00	.9059-02	.7214-02
$UT(U)$	.2737+00	.3011-01	.1285+00	.2421+00	.3055+00	.3310+00	.4634+00	.1097+00
$\tau = 2.00000$								
$R(\mu_i, \mu_j)$	.3188-02	.2007+01	.1104+00	.2704-01	.1098-01	.5681-02	.2734-02	.2307-01
0.10	.5316-06	.1702-07	.3360+00	.1088+00	.4828-01	.2581-01	.1944-01	.1532+00
0.30	.3806-01	.2537-02	.9208-03	.4969-01	.2676-01	.1620-01	.1294-01	.4801-01
0.50	.2174+00	.5986-02	.3317-01	.3274-02	.1659-01	.1088-01	.9342-02	.2374-01
0.70	.4229+00	.5961-02	.1717-01	.7179-01	.3954-02	.7795-02	.6367-02	.1409-01
0.90	.7989+00	.4943-02	.1020-01	.2427-01	.8057-01	.3659-02	.5239-02	.9283-02
1.00	.8105+01	.4330-02	.8012-02	.1629-01	.3820-01	.1901+00	.3333-02	.7657-02
$UT(U)$	.1375+00	.4937-02	.1970-01	.7246-01	.1454+00	.2110+00	.3325+00	.3013-01
$\tau = 4.00000$								
$R(\mu_i, \mu_j)$	.2214-03	.2007+01	.1104+00	.2705-01	.1102-01	.5748-02	.2784-02	.2310-01
0.10	.2192-14	.3509-16	.3360+00	.1088+00	.4828-01	.2581-01	.1944-01	.1532+00
0.30	.9687-04	.3229-05	.1172-05	.4969-01	.2676-01	.1620-01	.1294-01	.4801-01
0.50	.7965-02	.1096-03	.6497-03	.5997-04	.1661-01	.1090-01	.9365-02	.2375-01
0.70	.4857-01	.3424-03	.1008-02	.5438-02	.2271-03	.7844-02	.6416-02	.1412-01
0.90	.1732+00	.5356-03	.1118-02	.3074-02	.1336-01	.3965-03	.5316-02	.9326-02
1.00	.2194+01	.5861-03	.1094-02	.2503-02	.7364-02	.4633-01	.4510-03	.7702-02
$UT(U)$	.2315-01	.3141-03	.8299-03	.4209-02	.1761-01	.4407-01	.8679-01	.2761-02
$\tau = 8.00000$								
$R(\mu_i, \mu_j)$	.2060-05	.2007+01	.1104+00	.2705-01	.1102-01	.5748-02	.2785-02	.2310-01
0.10	.1862-31	.1491-33	.3360+00	.1088+00	.4828-01	.2581-01	.1944-01	.1532+00
0.30	.3138-09	.5230-11	.1898-11	.4969-01	.2676-01	.1620-01	.1294-01	.4801-01
0.50	.5344-05	.3678-07	.2190-06	.2012-07	.1661-01	.1090-01	.9356-02	.2375-01
0.70	.3204-03	.1129-05	.3326-05	.1976-04	.7490-06	.7844-02	.6416-02	.1412-01
0.90	.4067-02	.6290-05	.1314-04	.3713-04	.2009-03	.4656-05	.5317-02	.9326-02
1.00	.8036-01	.1073-04	.2005-04	.4668-04	.1592-03	.1393-02	.8261-05	.7702-02
$UT(U)$	.4866-03	.2796-05	.6025-05	.2054-04	.1573-03	.1009-02	.3025-02	.3118-04

μ_j – Cosine of incident solar angle
$T(\mu_i, \mu_j)$ – Transmission function
μ_i – Cosine of propagation angle
$UR(U)$ – First-order reflection moment
τ – Vertical optical depth
$R(\mu_i, \mu_j)$ – Reflection function
$UT(U)$ – First-order transmission moment

Bibliography

[Carnahan *et al.*, 1969] Carnahan, B., H. A. Luther, and J. O. Wilkes, 1969: *Applied Numerical Methods.* John Wiley and Sons, Inc., New York.

[Davis, 1984] Davis, R. E., 1984: *A Gaussian Large Area Smoke Screen Computer Model: The GLASS Model.* STC Technical Report 2038, Science and Technology Corporation, Hampton, VA.

[de Hulst, 1980] de Hulst, H. C. Van, 1980: *Multiple Light Scattering*, volume 1 and 2. Academic Press, New York.

[Duntley, 1948] Duntley, S. Q., 1948: "The Reduction of Apparent Contrast by the Atmosphere". In *J Opt Soc AM*, chapter 38, pages 179–191.

[Durack and Giever, 1987] Durack, D., and J. Giever, 1987: *AGSCAT Programs.* , Physical Science Laboratory, New Mexico State University, Las Cruce, NM. contractor report being prepared under contract DAAD07-86-C-0034, for the U. S. Army Atmospheric Sciences Laboratory.

[Farmer *et al.*, 1984] Farmer, W. M., R. E. Davis, and E. S. Stallings, 1984: *Summary Report of the Airfield Camouflage with Large Area Smoke Screens Test.* STC Technical Report 2047, Science and Technology Corporation, Hampton, VA.

[Hoock *et al.*, 1984] Hoock, D. W., R. A. Sutherland, and D. Clayton, 1984: "EOSAEL 82, Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC)". U. S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM. ASL-TR-0160-11 vol 11.

[Sutherland and Davis, 1986] Sutherland, R. A., and R. E. Davis, 1986: "A Large Area Screening Systems Applications Model for EOSAEL 87". In *Proceedings of the Fifth EOSAEL/TWI Conference*, White Sands Missle Range, NM. U. S. Army Atmospheric Sciences Laboratory.

[Sutherland and Fowler, 1985] Sutherland, R. A., and B. W. Fowler, 1985: *Standards for Large Area Screening Systems Modeling.* Special Report 61 JTCG/ME-85-4, Aberdeen Proving Ground, MD.

[Sutherland *et al.*, 1986] Sutherland, R. A., F. V. Hansen, and W. D. Bach, 1986: "A Quantative Method for Estimating Pasquill Stability Class from Windspeed and Sensible Heat Flux". In *Boundary Layer Meteorology*, chapter 37, pages 357–369.

[Sutherland, 1985] Sutherland, R. A., 1985: *Large Area Screening Systems Fields Demonstration Test Report: Yakima Mini Demo.* ASL-TR-0167, U. S. Army Atmospheric Sciences Laboratories, White Sands Missle Range, NM.

[Sutherland, 1986] Sutherland, R. A., 1986: *Determination and use of the Chandrasekhar-Van de Hulst F and G Functions Extended to Anisotropic Scattering.* , U. S. Army Atmospheric Sciences Laboratory, White Sands Missle Range, NM. technical report in preparation.

[Williams *et al.*, 1985] Williams, R. R., W. M. Farmer, R. E. Davis, E. S. Stallings, R. E. Hoeferkamp, and M. H. McClendon, 1985: "Demonstration Test Using Camouflage with Large Area Smoke Screens (ACLASS) for Airbase Concealment". In *Proceedings of Smoke/Obscurants Symposium IX*, Aberdeen Proving Ground, MD. OPM Smoke/Obscurants AMCPM-SMK-T.

EOSAEL **MODULES**

AGAUS	(vol 1)	
BITS	(vol 2)	
CLIMAT	(vol 3)	Climatology
COMBIC	(vol 4)	Obscuration Model for Multiple Battlefield-Induced Contaminants
COPTER	(vol 5)	Obscuration due to Helicopter-Lofted Snow and Dust
FASCAT	(vol 6)	Fast Algorithm for Atmospheric Scattering Calculations
FITTE	(vol 7)	Fire-Induced Transmission and Turbulence Effects
GRNADE	(vol 8)	Smoke Munitions Self-Screening Applications
ILUMA	(vol 9)	Natural Illumination under Realistic Weather Conditions
KWIK	(vol 10)	Transmission Threshold Smoke Munitions Expenditures Model
LASS	(vol 11)	Large Area Screening Systems Application
LOWTRN	(vol 12)	Atmospheric Transmittance and Radiance for Broadband Applications
LZTRAN	(vol 13)	Laser Transmittance–Gaseous Absorption Algorithm
MPLUME	(vol 14)	Missile Smoke Plume Obscuration
NBSCAT	(vol 15)	
NMMW	(vol 16)	Near Millimeter Wave, Gaseous Absorption
NOVAE	(vol 17)	Nonlinear Aerosol Vaporization and Breakdown Effects, High Energy Lasers
OVRCST	(vol 18)	Contrast Transmission
PFNDAT	(vol 19)	Aerosol Phase Function Data Base
RADAR	(vol 20)	Millimeter Wave System Performance
REFRAC	(vol 21)	Optical Path Bending Code for Near Earth Paths
TARGAC	(vol 22)	Target Acquisition
UVTRAN	(vol 23)	
XSCALE	(vol 24)	Natural Aerosol Extinction