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FAST ALGORITHM FOR ATMOSPHERIC SCATTERING CALCULATIONS
FASCAT

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User's Guide
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The contents of chapter 1 (technical documentation) of this document were drawn from the report AFGL-TR-84-0168, *The fast atmospheric scattering (FASCAT) Model Performance Under Fractional Cloud Conditions and Related Studies*, by Wayne S. Hering and Richard W. Johnson. The text and equations have, however, received minor editorial changes and all equations have been renumbered. Errors in typing and transcription of the equations and other material from the original report are in no way due to Hering or Johnson since they have not been responsible for any aspect of the preparation of the present manuscript.

The user's guide portion of this document, chapter 2, is based partly on material from appendix B of the source document cited. The coding, input, and output have been revised and updated for easier exchange of information with the other EOSAEL modules.

The original development of FASCAT was under the direct sponsorship of the Air Force Geophysics Laboratory (AFGL) Optical Physics Division. Written permission of AFGL has been obtained for inclusion of significant portions of the source document into this document.

The material contained here is a severe abbreviation of the material contained in the AFGL document cited. Users who wish to delve into the FASCAT methodology and procedures should make every possible effort to obtain a copy of the source document since it contains much more detailed descriptions of the analytical empirical foundations of the FASCAT code, as well as extensive studies, graphs, many other supporting materials, and an extensive set of references.

ABSTRACT

FASCAT is a fast atmospheric scattering model for calculating apparent background and target radiance fields due to scattered sunlight. It is based on research by Wayne S. Hering, Visibility Laboratory, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California 92093, under the sponsorship of the AFGL, Optical Physics Division.

The FASCAT computer code calculates the spectral radiance of distant objects and backgrounds for any designated slant path in the atmosphere. The apparent radiance is the sum of the residual background or target radiance plus the path radiance generated by the scattering of light reaching the path from the sun and the surrounding sky and terrain. Several input options are available for the specification of the vertical profiles of aerosol properties. Cloud information is entered by specification of the cloud type, amount, altitude of base and top, and the relative optical thickness (average, thin, or thick). For designated sensor and target altitudes, the apparent contrast is calculated for cloud free slant paths, which may or may not transverse a fractional cloud layer. Objects in sunlight or shadow may be viewed against sky, cloud, or terrain backgrounds.

This document contains an abbreviated review of the major physical bases for the model and instructions for the preparation of input data files for the code.

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Chapter 1

Technical Documentation

1.1 Introduction

This document is based on a report by Wayne S. Hering and Richard W. Johnson of the Visibility Laboratory at the Scripps Institution of Oceanography, and is directed toward providing users with only superficial descriptions of the foundations of the AFGL FASCAT computer code.[Hering and Johnson, 1984]

Many researchers have conducted studies related to visible and infrared optical properties within the lower troposphere. Among the studies most relevant to this report are those of Hering [Hering, 1981] and others. The subject areas range from the generalized development for equation of transfer formalisms by Gordon [Gordon, 1982] to the specific analyses of experimentally measured aerosol size distributions.[Fitch, 1983]

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.

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1.3 Analytical Techniques for Estimating Image Transmission Properties of the Atmosphere

As set forth by Duntley [Duntley, 1948], the degradation of visible image contrast along viewing path of increasing length is governed by

1. The attenuation of the inherent background and object radiances by air molecule and aerosol particle scattering and absorption and

2. The generation of path radiance by molecular and aerosol scattering of incident light into the path of sight.[Duntley *et al.*, 1978]

Direct field measurements of the basic optical properties, required for determining these factors for selected path segments, are not made simply and inexpensively. Thus, operational estimates of contrast transmittance must be derived from model simulations that relate the aerosol directional scattering and absorption properties to generally available meteorological observations and forecasts.[Shettle and Fenn, 1979] Additional problems stem from the complexity of multiple-scattering processes and the relatively large amount of computer time and capacity required for treating the radiative transfer calculations completely as a physical probe to yield fast yet consistent calculations of the radiance distribution. The successful development of techniques for real-time estimates of the atmospheric effects on visible image transmission requires a reasonable balance between the desired accuracy, the complexity of the modeling procedures, and the reliability and representativeness of the available input data. Since these factors may vary considerably from one application to the next, reasonably good flexibility and completeness in the analytic approximations used for the estimates are important.

The development and testing of field oriented techniques for calculation directional path radiance and the object-background contrast transmittance along inclined paths of sight in clear-hazy atmospheres were described in a previous report.[Hering, 1981] This report addresses extensions and refinements to the modeling procedures and their validation. In particular, techniques are presented for (1) estimating the background radiance and (2) visible image transmission characteristics in overcast sky conditions from conventional observations or forecast of cloud type and altitude. As in the case of prior studies, technique development was based extensively on experimental data, including a broad series of simultaneous optical and meteorological measurements gathered with a specially instrumented aircraft. The high resolution profile measurements were obtained over a period of several years in a wide range of meteorological and geographical conditions in the United States and Western Europe.

Further extensions of the modeling concepts deal with the combined effects of both environmental and target factors on visual detection range. Although an independent assessment can be made of the changes in contrast transmittance that are associated with natural changes in the relevant atmospheric variables, the impact of these changes on target detection distance depends markedly on such factors as inherent target contrast, target size, and glimpse time. Analytic representations of vision experiment data were added to the contrast transmittance model to explore the relative sensitivity of visual detection distance to a selected range of target and atmospheric variables.[Blackwell, 1946][Taylor, 1964] Results are presented for several examples assuming simplified targets and backgrounds.

Section 1.3.2 presents a review of the basic equations and a summary of the analytic approximations used for calculating path radiance and for estimating visible spectrum contrast transmittance in cloudless atmospheres. Section 1.3.3 presents techniques for the representation of the input variable required for calculation background radiance and spectral contrast transmittance. Section 1.3.4 describes extension of the modeling concepts to deal with image transmission characteristics for viewing paths below and overcast cloud layer.

1.3.1 Summary of the Theory and Analytic Approximations

Although some refinements and additions to cloudless-sky modeling procedures are presented, this section is primarily a summary of theory and analytic approximations given in the work of Hering.[Hering, 1981]

Neglecting turbulence effects, the equation for the apparent spectral radiance of the background b at range r along the path of sight specified by zenith angle θ and azimuthal angle ϕ, can be written[Duntley *et al.*, 1957]

$$ {}_bL_r(z,\theta,\phi) = T_r(z,\theta)\ {}_bL_0(z_t,\theta,\phi) + L_r^*(z,\theta,\phi); \tag{1.1} $$

where ${}_bL_0$ is the inherent background radiance at target altitude z_t,

$$ T_r = \exp - \int_0^r \alpha(r)dr \tag{1.2} $$

is the path transmittance; α is the volume attenuation coefficient; and L_r^* is the path radiance produced by the scattering of light from the sun and from the surrounding sky, clouds, and terrain into the path of sight.

The path radiance is given by

$$ L_r^*(z,\theta,\phi) = \int_0^r L_*(z',\theta,\phi)T_r(z',\theta)dr' \tag{1.3} $$

where $L_*(z',\theta,\phi)$ is the path function, defined as the point function component of path radiance generated by the directional scattering of light reaching that point of the path. The expression for the path function can be written in terms of its contributions from the scattering of solar (lunar) scalar irradiance ${}_s\varepsilon(z)$ and from the scattering of sky and earth radiances $L(z,\theta',\phi')$ as follows (for example, Gordon [Gordon, 1969]):

$$ L_*(z,\theta,\phi) = {}_s\varepsilon(z)\sigma(z,\beta_s) + \int_{4\pi} L(z',\theta,\phi)\sigma(z,\beta')d\Omega', \tag{1.4} $$

where $\sigma(z,\beta)$ is the directional volume scattering function at angle β between the path of sight and the direction of the source light, $d\Omega$ is an element of solid angle, and β_s is the scattering angle with respect to the sun.

In turn, the spectral contrast transmittance of the path of sight can be expressed (see Duntley et al.[Duntley *et al.*, 1957]) directly as the product of the path transmittance, $T_r(z,\theta)$, and the ratio of the inherent, ${}_bL_0$, and apparent, ${}_bL_r$, background radiances as follows:

$$ \frac{C_r(z,\theta,\phi)}{C_0(z_t,\theta,\phi)} = \frac{T_r(z,\theta)\ \ {}_bL_0(z_t,\theta,\phi)}{{}_bL_r(z,\theta,\phi)}, \tag{1.5} $$

where $C_r = ({}_tL_r - {}_bL_r)/{}_bL_r$ is the apparent target contrast at path length r, $C_0 = ({}_tL_0 - {}_bL_0)/{}_bL_0$ is the inherent target contrast at altitude z_t, and ${}_tL_0$ is the inherent target radiance. Thus, the contrast transmittance of a given path does not depend upon intrinsic target characteristics but is a function only of the directional radiance distribution in the atmosphere and the path transmittance. The expression is strictly applicable only for monochromatic radiation but may be applied with good approximation to reasonable broad spectral bands in the visible portion of the spectrum.

From equation 1.4, we note that the path function and, in turn, the contrast transmittance as calculated from equation 1.5 depend upon the direction of the viewing path relative to the distribution of light reaching the path. The first term on the right-hand side of equation 1.4 is the contribution of primary scattering of direct solar irradiance. The directional volume scattering function may be expressed

$$ \sigma(z,\beta) = P(z,\beta)s(z), \tag{1.6} $$

where $s(z)$ is the total volume scattering coefficient and $P(z, \beta)$ is the single-scattering phase function for combined Rayleigh plus aerosol particle scattering, which defines the probability that incident radiation will be scattered in the direction given by scattering angle β . The phase function varies significantly with the scattering properties of the aerosol particle distribution in the atmosphere.

By substituting equation 1.6 in equation 1.4, the expression for $L_*(z, \theta, \phi)$ becomes

$$L_*(z,\theta,\phi) = {}_s\varepsilon(z)P(z,\beta)s(z) + \int\int_{4\pi} L(z,\theta',\phi')P(z,\beta)s(z)d\Omega'. \tag{1.7}$$

Modeling techniques for the calculation of the diffuse component of the path function are discussed in the following paragraphs.

1.3.2 Calculation of the Path Function

The second term on the right-hand side of equation 1.7 is the component of the path function resulting from the scattering of diffuse radiance reaching the path from the surrounding sky and terrain. It has a directional dependence due to the asymmetry in the background sky and earth radiance distribution and the scattering phase function asymmetry. Precise numerical calculation of the path radiance resulting from the complex multiple-scattering processes requires large amounts of computer time. For this reason, rapid approximate methods are employed extensively for radiation transfer calculations. The appropriate choice of a computational method from among the variety of available methods depends upon the results desired for the application at hand. Since complete directionality is important for calculating the path radiance component due to single scattering of direct solar radiance, approximate hemispherical two-stream methods can be used effectively for fast calculation of the path radiance component due to scattering of the background sky and terrain radiances at any point and direction, provided that the asymmetric influence of the prominent forward scatter peak and the irradiance profile are managed adequately. The delta-Eddington approximation introduced by Joseph, Wiscombe, and Weinman satisfies the requirement.[Joseph *et al.*, 1976] It extends the standard Eddington approximation, which assumes a simple cosine dependence of the single scattering phase function, through approximation of the phase function, P_d, by a truncated forward scatter peak and a two-term phase function expansion,

$$4\pi P_d(\beta) = 2f'\triangle(1-\cos\beta) + (1-f')(1+3g'\cos\beta), \tag{1.8}$$

where f' is the fractional scattering represented by the forward peak and g' is the asymmetry factor of the truncated phase function. In effect, the delta-Eddington approximation transforms most of the enhanced radiance in the solar aureole into the direct solar flux component, and the general assumption is that

$$f'(z) = g^2(z). \tag{1.9}$$

This assumption is commensurate with representation of the actual phase function with a single term Henyey-Greenstein phase function. Alternate expressions are required[McKellar and Box, 1981] for other phase function representations such as the two-term Henyey-Greenstein functions.[Joseph *et al.*, 1976] show that calculations of radiative transfer with the delta-Eddington approximations can be carried out with the standard Eddington computer code [Shettle and Weinman, 1970] with the following changes of variable

$$\triangle\tau' = (1-\omega f')\triangle\tau, \tag{1.10}$$

$$\omega' = \frac{\omega(1-f')}{1-\omega f'}, \tag{1.11}$$

and

$$g' = \frac{g-f'}{1-f'}, \tag{1.12}$$

where $\triangle\tau$ is the optical thickness of the layer and ω is the single-scattering albedo.

As an integral part of the technique for estimating directional contrast transmittance, the products of the Eddington computer program are used directly to calculated the second term on the right-hand side of equation 1.7. [Shettle and Weinman, 1970]

From the standard Eddington approximation, the diffuse radiance is assumed to be given by

$$L(z,\theta',\phi') = L_D(z) + L_{D'}(z)\cos\theta'. \tag{1.13}$$

As shown by Shettle [Shettle, 1981], if we substitute equation 1.13 and the delta-Eddington approximations given by equations 1.8, 1.9, and 1.12 into the last term of equation 1.7 and integrate over θ' and ϕ', we have

$$\int\int_{4\pi} L(z,\theta',\phi')P(z,\beta)s(z)d\Omega = s(z)\left[L_D(z) + gL_{D'}(z)\cos\theta\right]. \tag{1.14}$$

A recent refinement in the above expression for the diffuse component of the path function consists of an additional term to help account for the effects of the azimuthal asymmetry in the background sky-terrain radiance distribution. The term is introduced as a rough approximation to an iteration of the singly scattered sunlight component of the path function. Its magnitude is assumed proportional to the single-scattering component, ${}_s\epsilon(z)P(z,\beta)$, and proportional to the fractional contribution of the total diffuse energy, $4\pi L_D(z)$, to the sum of the total diffuse energy and singly scattered sunlight component at the level of computation. In other respects, the modification conforms with the extension of the delta-Eddington model introduced by Davies [Davies, 1980]; in particular, the contribution of the asymmetry term is proportional to $\sin\theta$, $\sin\theta_s$, and $\cos\phi$. The modified expression for the diffuse component of the path function is

$$\int\int_{4\pi} L(z,\theta',\phi')P(z,\beta)s(z)d\Omega = s(z)\left[L_D(z) + gL_{D'}(z)\cos\theta + gL_{D''}(z)\cos\phi\right] \tag{1.15}$$

where

$$L_{D''}(z) = \frac{4\pi L_D(z)P(z,\beta)\ {}_s\varepsilon(z)\sin\theta_s\sin\theta}{4\pi L_D(z) + P(z,\beta)\ {}_s\varepsilon(z)} \tag{1.16}$$

Commensurate with the delta-Eddington approximations and equation 1.10, the expression for the solar scalar irradiance at altitude z is

$${}_s\varepsilon(z) = {}_s\varepsilon(\infty)\exp\left(\frac{-\tau_x}{\cos\theta_s}\right), \tag{1.17}$$

where ${}_s\epsilon(\infty)$ is the extraterrestrial solar scalar irradiance. The optical depth τ_x is assumed equal to the delta-Eddington optical depth, τ', everywhere except within the forward peak ($\beta < 25°$) where τ_x is equal to the unmodified value of τ. Substituting equations 1.14 and 1.15 into equation 1.7, the expression for the path function becomes

$$L_*(z,\theta,\phi) = s(z)\left[P(z,\beta_s)\ {}_s\varepsilon(\infty)\exp\left(\frac{-\tau_x}{\cos\theta_s}\right) + L_D(z) + gL_{D'}(z)\cos\theta + gL_{D''}(z)\cos\phi\right] \tag{1.18}$$

1.3.3 Calculation of Sky and Terrain Radiance

For an assumed plane parallel and horizontally homogeneous atmosphere, the directional path radiance, $L(z,\theta,\phi)$, and the radiance $L_r^*(z,\theta,\phi)$, can now be calculated form equations 1.1, 1.3, and 1.18 through finite summation over adjacent atmospheric layers using the trapezoidal rule. For upward paths of sight, the inherent background radiance of clear sky at target altitude is given by

$${}_bL_0(z_t,\theta,\phi) = L_\infty^*(z_t,\theta,\phi), \tag{1.19}$$

where $L_\infty^*(z_t,\theta,\phi)$, is the path radiance as determined at altitude z_t for the slant path from the top of the atmosphere to z_t. Looking downward, the inherent background radiance for the case of uniform Lambertian reflectance and a horizontal surface is given by

$${}_bL_0(z_t,\theta,\phi) = \frac{T_{r0}(z_t,\theta)R(\theta,\phi)E(0,d)}{\pi} + {}_rL_0^*(z_t,\theta,\phi), \tag{1.20}$$

where $R(\theta, \phi)$ is the local surface reflectance; $E(0, d) = \varepsilon_s(0) \cos\theta_s + \pi[L_d(0) + 2/3 L_{D'}(0)]$ is the downwelling irradiance at the surface; and T_{r0} is the transmittance of the slant path from the surface to target altitude z_t.

1.3.4 Application of Analytic Techniques

Environmental data and forecasts relevant to the determination of the background spectral radiance distribution and image transmission characteristics may be available in many forms and with varying degrees of completeness and applicability. Emphasis has been placed on developing a general modular format for requisite data entry, seeking to take full advantage of all available information important for a particular application of the radiance model. A summary of input variables and alternate techniques for the specification of the atmospheric properties is included in Hering.[Hering, 1983] Basic data entries include the wavelength representative of the sensor spectral characteristics, solar zenith angle, and the observational paths of interest for the problem at hand.

Several options are available for the input of specific atmospheric variables. One may introduce as many atmospheric layers as warranted by the accuracy and completeness of the meteorological observations or forecasts available for the specification of the optical parameter profiles. Minimum information for each designated layer includes the altitude limits, the average scattering coefficient, the average absorption coefficient, and the single-scattering phase function for aerosol particle scattering.

Representation of Surface Reflectance

The background surface reflectance contributes to the calculated radiance distribution in two ways. First, the general or broad area average surface reflectance is entered to calculated the component of path radiance that is generated by light reaching the path through scattering from the underlying surface and in turn scattered in the direction of the sensor as given by equation 1.7. For a land surface, the reflectance is assumed to conform with Lambert's law, so that the resultant radiance is independent of observation angle and depends only on the downwelling irradiance and the average surface reflectance.

Second, the local background reflectance, which may differ from the area averaged reflectance discussed above, is entered for the determination of the inherent background radiance and its contribution to the apparent spectral radiance as given by equations 1.1 and 1.20.

The above algorithms deal with surface reflectance over land areas. Another option, for use primarily over an open water surface, assumes specular surface reflection. Here the surface radiance is a function of both the viewing angle and the downwelling radiance distribution. For the water option, the Fresnell reflectance of the water surface as a function of observation angle is set equal to average values for a sea surface roughened by light surface winds (4 m/s). These values as calculated by Gordon [Gordon, 1969], assume that the crosswind and upwind wave slope probabilities of Cox and Munk [Cox and Munk, 1954] may be approximated by a single circular distribution of wave slopes.

Representation of Total Volume Scattering Coefficient

The spatial distribution of total volume scattering coefficient deserves prime consideration since it is the major determinant of visible spectrum contrast transmittance. Techniques for the specification of the scattering coefficient profile have been investigated during the course of the aircraft measurement and analysis program. Some of the results of these studies and their application to operational modeling procedures were summarized by Hering. [Hering, 1981] A brief review is given here for immediate reference.

For profile modeling purposes, it is important to consider a conservative measure of scattering coefficient that in the absence of local aerosol particle sources or sinks does not change appreciably following the air motion. The optical scattering mixing ratio, $Q(z)$, is such a parameter.

As the vertical mixing within an identifiable atmospheric layer becomes more complete, $Q(z)$ becomes more constant with height within the layer.

The optical scattering ratio is defined

$$Q(z) = \frac{s(z)}{S_R(z)}, \tag{1.21}$$

where $S_R(z)$ is the total volume coefficient for Rayleigh scattering at altitude z. Note that

$$S(z) = S_R(z) + S_M(z) = \omega(z)\alpha(z), \tag{1.22}$$

where $\alpha(z)$ is the extinction coefficient and $S_M(z)$ is the aerosol scattering coefficient. It follows that the aerosol scattering ratio is given by

$$\frac{S_M(z)}{S_R(z)} = Q(z) - 1. \tag{1.23}$$

The aerosol scattering ratio also would be constant under conditions of complete aerosol mixing. An additional computational advantage of a scattering ratio representation is that it provides normalization with respect to both density altitude and wavelength.

Profiles of $Q(z)$, derived form the extensive series of airborne optical measurements made by the Visibility Laboratory, reveal large variability, depending upon the aerosol particle source strength and the nature of the convective and turbulent mixing processes. The problem is to model the essential characteristics of the $Q(z)$ profiles in a way that recognizes operational observing and forecasting limitations yet takes maximum advantage of existing capabilities. A prominent feature of the daytime aircraft soundings over inland areas was the marked tendency for $Q(z)$ to remain essentially constant with height within the boundary layer and also in the relatively haze-free region of the upper troposphere above the primary layer. We emphasize that the assumption of constant scattering ratio with height does not hold well for ground-based stable layers with little vertical mixing such as those associated with the nocturnal formation of fog. However, for application to problems of contrast transmittance in hazy atmospheres in the daytime following the dispersion of any surface inversion existing at sunrise, a simple three-layer troposphere model with constant $Q(z)$ in each layer provides in most cases a good first approximation of the aerosol scattering profile. Thus, the forecasting problem is reduced to the prediction of the upper altitude limit of mixed boundary layer and the average scattering ratio within each layer. An evaluation of model representations of the high resolution scattering ratio profiles as measured during several deployments of the instrumented aircraft in Western Europe is given in Hering. [Hering, 1981]

Representation of Single-Scattering Phase Function and Single-Scattering Albedo

The single-scattering phase function $P(z, \beta)$ as employed in equation 1.7 is a bulk parameter of the atmospheric layer, representing the combined aerosol and Rayleigh phase functions. It is given by

$$P(\beta, z) = \frac{P_R(\beta) + [Q(z) - 1]\, P_M(\beta, z)}{Q(z)}, \tag{1.24}$$

where $P_M(\beta, z)$ is the phase function for aerosol scattering, and the theoretical Rayleigh phase function is

$$\frac{P_R(\beta) = 3(1 + \cos^2 \beta)}{16\pi}. \tag{1.25}$$

The phase function for single scattering has a normalized form,

$$\int_{4\pi} P(z, \theta, \phi) d\Omega = 1. \tag{1.26}$$

The computational scheme offers several options for specification of the average single-scattering phase function $P(z, \beta)$ for each designated atmospheric layer. Detailed estimates of $P_M(\beta)$, available from prescribed aerosol models such as those associated with atmospheric transmittance and radiance (LOWTRN), may be entered directly and used in a table lookup format. [Shettle and Fenn, 1979] A second option is the representation of the aerosol phase functions by two-term Henyey-Greenstein functions as follows: [Irvine, 1968]

$$P_M(\beta, g_1, g_2, c) = cP_{HG}(\beta, g_1) + (1-c)P_{HG}(\beta, g_2), \tag{1.27}$$

where

$$P_{HG}(\beta, g) = \frac{1-g^2}{\left[4\pi(1-2g\cos\beta+g^2)^{3/2}\right]}, \tag{1.28}$$

and the asymmetry factor, g, is given by

$$g = \frac{1}{2}\int_0^{\pi} P(\beta)\cos\beta\sin\beta d\beta. \tag{1.29}$$

To the extent that the Henyey-Greenstein asymmetry factors, g_1 and g_2, and the partitioning factor, c, can be estimated from reference atmosphere calculations, they can be entered for the specification of the required scattering phase functions. In the absence of information that may serve to identify the directional scattering properties of individual aerosol layers, yet another option may be used as described in Hering. [Hering, 1981] Empirical functions were developed that prescribe the Henyey-Greenstein function parameters, g_1, g_2, and c, as functions of the scattering ratio $Q(z)$. The derived expressions are based to a large extent on the average phase functions for selected ranges of scattering coefficient as measured by Barteneva. [Irvine, 1960]

The other direct-entry variable for each designated atmospheric layer is the single-scattering albedo, $\omega(z)$. It is defined by the expression

$$\omega(z) = \frac{s(z)}{\alpha(z)}, \tag{1.30}$$

so that the fraction of radiation absorbed for each single photon collision is $1 - \omega(z)$. Commensurate with other variables, $\omega(z)$ is introduced as a bulk parameter and is a measure of the combined absorption effects of both air molecules and aerosol particles. In the visible spectrum, $\omega(z)$ in the boundary layer ranges form 1.0 (no absorption) to less than 0.7 in urban atmospheres with appreciable carbon concentration.

1.4 Review of FASCAT Development and Status

Studies over the past few years have produced a FASCAT model for direct determination of the apparent spectral radiance of distant objects and backgrounds. The development and testing of the basic multiple-scattering model for calculation background radiance fields from conventional meteorological observations and environmental data are described in AFGL reports. [Hering, 1981] [Hering, 1983] Section 1.4 consists, in fact, of excerpts from the latter document and provides a ready reference to the mathematical basis of the FASCAT model. In addition, that report also describes performance tests involving comparisons with calculations derived form other radiative transfer models and comparisons with measure radiance data gathered in a wide range of environmental conditions.

Recent refinements and additions to FASCAT have increased the scope of applications that can be addressed with the modeling procedures. Building upon techniques for radiance field calculations in clear and overcast sky conditions, approximate solutions are introduced for dealing with the determination of image transmission characteristics in partly cloudy atmospheres. As described in section 1.4.1, solutions are obtained as a function of cloud amount for the conventional types of high, middle, and low clouds.

In a model extension described in section 1.4.2, analytic techniques are introduced for the direct calculation of inherent target radiance as determined form the intrinsic target properties and the calculated irradiance distribution. When combined with calculations of directional path radiance and beam transmittance, this model extension provides companion calculations of the apparent spectral radiances of both target and background along any predetermined slant path and, in turn, of the apparent target contrast at the point of observation.

Other modifications to FASCAT involve substantial revisions to data input procedures in an attempt to simplify the entry of meteorological, optical, and target parameters into the computer program. Step-by-step instructions for the input/output data files are included in the user's guide for FASCAT in section 2 of this document. Special input options are briefly discussed in section 1.3.3 of the work of Shettle and Fenn, including the use of LOWTRN aerosol models for the specification of optical property profiles. [Shettle and Fenn, 1979]

1.4.1 Extension of the Radiance Model to Partly Cloudy Atmospheres

Explicit determination of the instantaneous upper and lower hemisphere radiance fields in a partly cloudy atmosphere requires a detailed knowledge of the actual cloud structure, orientation, and illumination that is normally not available. Even if precise determinations were possible, the resultant calculations may be representative for only short periods. However, we can consider the development of computational schemes that provide estimates of the average (most probable) effects of changes in cloud cover on the apparent target and local background radiance fields. For partly cloudy atmospheres, the calculation of both the direct sun contribution to the irradiance incident on the target and the singly scattered sunlight component of the path radiance can be handled as before with the basic FASCAT model. Cloud-free path algorithms define the approximate probability that the target, background, or observation path will be in sunlight or cloud shadow. [Allen and Malick, 1983] The important complicating factor is, of course, the determination of the diffuse components of the irradiance and radiance fields and their dependence on cloud type and amount. After consideration and rejection of many approaches, we settled on a highly simplified method that solves for the diffuse radiance field as the weighted average of clear-sky and overcast-sky diffuse field calculations. The analytical techniques as derived through reference to the SOLMET data base help ensure that the results are consistent with the average observed surface irradiance as a function of cloud type and amount and solar zenith angle. [SOLMET, 1979] The SOLMET data base and its application for the determination of the average optical thickness of overcast cloud layers for individual cloud types are described in AFGL-TR-83-0236. [Hering, 1983] Reference is made also to that report for a discussion of the development and testing of techniques for the determination of the radiance fields in overcast sky conditions. Extension of the techniques for use in partly cloudy atmospheres is discussed in the following paragraphs.

Shapiro uses the SOLMET data differently with the other modeling procedures to determine the average flux transmittance and average albedo for individual layers of partial cloud cover for many cloud types as a function of cloud amount and solar zenith angle. [Shapiro, 1982] With additional simplifying assumptions, the results of these studies can be applied in part for the calculation of the approximate average diffuse irradiance and radiance fields in partly cloudy atmospheres.

Determination of Upward Irradiance

The albedo at altitude z_a at the top of the cloud layer is given by

$$A(z_a) = \frac{E(z_a, u)}{E(z_a, d)}, \tag{1.31}$$

where $E(z_a, u)$ and $E(z_a, d)$ are the upward and downward irradiance, respectively. Shapiro assumed that the albedo of the partly cloudy layer, A_{PC}, is given by the weighted average of the albedo for a corresponding clear atmosphere, A_{CR}, and the albedo for the overcast sky, A_{OV}, having the same cloud form, thus [Shapiro, 1982]

$$A_{PC}(z_a) = F(n, \mu_s) A_{OV}(z_a) + [1 - F(n, \mu_s)]\, A_{CR}(z_a). \tag{1.32}$$

Selecting SOLMET data subsets with a single cloud type and amount present, Shapiro determined weighting factors that define average values of $F(n, \mu_s)$ exhibit a systematic behavior, but depart significantly from a straight linear dependence on n. Shapiro derived biquadratic polynomial expressions that provide close approximations of the derived weighting factors as determined for the individual cloud types. Considering the expected time and space variability of the albedo of partly cloudy layers and the lack of strong systematic variability in $F(n, \mu_s)$ as a function of cloud type, we combined solutions to obtain a general polynomial representation given by

$$F(n, \mu_s) = n(1.43 - 1.21\mu_s - 2.00n + 1.21n\mu_s + 1.57n^2). \tag{1.33}$$

It should be emphasized that while equation 1.4 applies to all cloud types, the albedo of the partly cloudy layer, as calculated from equation 1.3, is dependent upon the actual optical properties of the cloud used for the calculation of A_{OV}. Note also that $F(n, \mu_s)$ is zero for clear sky and one for overcast cloud cover.

Since the total downward (solar plus diffuse) irradiance $E(z_a, d)$ incident on the top of a single cloud layer does not vary significantly with n, we can write approximately through combination of equations 1.31, 1.32, and 1.33.

$$E_{PC}(z_a, u) = F(n, \mu_s) E_{OV}(z_a, u) + [1 - F(n, \mu_s)]\, E_{CR}(z_a, u), \tag{1.34}$$

where $E_{OV}(z_a, u)$ and $E_{CR}(z_a, u)$ are the upward diffuse irradiances as determined for overcast and clear sky, respectively.

Determination of Downward Irradiance

A similar expression can be derived for the total downward irradiance below the cloud layer. The flux transmittance $F_T(1)$ of cloud layer 1 is given by

$$F_T(1) = \frac{E(z_b, d)}{E(z_a, d)}, \tag{1.35}$$

where $E(z_a, d)$ is the downward irradiance at altitude z_b at the base of the cloud layer. Assuming $E_{PC}(z_a, d) = EOV(z_a, d) = ECR(z_a, d)$, we have

$$E_{PC}(z_b, d) = F(n, \mu_s) E_{OV}(z_b, d) + [1 - F(n, \mu_s)]\, E_{CR}(z_b, d). \tag{1.36}$$

The total downward irradiance can be expressed as the sum of the diffuse, $E_D(z_b, d)$, and the direct sun, $E_s(z, d)$, components, hence

$$E(z_b, d) = E_D(z_b, d) + E_s(z_b, d). \tag{1.37}$$

Let us assume that the average overtime of the solar irradiance component in partly cloudy atmospheres is determined by the cloud-free solar path probability, $G(n, \mu_s)$, such that

$$_s\overline{E}_{PC}(z_b, d) = G(n, \mu_s)\ {}_sE_{CR}(z_b, d) + [1 - G(n, \mu_s)]\ {}_sE_{OV}. \tag{1.38}$$

Substituting equations 1.8 and 1.9 in equation 1.10 and assuming that the diffuse irradiance is represented by the time-averaged diffuse irradiance, we have for partly cloudy skies

$$\begin{aligned} {}_DE_{PC}(z_b, d) &= F(n, \mu_s)\ {}_DE_{OV}(z_b, d) + [1 - F(n, \mu_s)]\ {}_DE_{CR}(z_b, d) + \\ &\quad [1 - F(n, \mu_s) - G(n, \mu_s)]\,[\ {}_sE_{CR}(z_b, d) -\ {}_sE_{OV}(z_b, d)]\,. \end{aligned}$$

In the special case where $1 - F = G$, the downward diffuse irradiance below the cloud layer is given by the weighted average of the diffuse irradiance calculated for the corresponding overcast and clear atmospheres as prescribed by equation 1.34 for the upward irradiance above the cloud layer. However, using the approximation of Allen and Malick for $G(n, \mu_s)$ and equation 1.33 for $F(n, \mu_s)$, we find that the quantity $(1 - F)$ is invariably larger than G in association with an additive component to the downwelling diffuse irradiance below the cloud layer. [Allen and Malick, 1983] Likely sources of the enhancement of diffuse irradiance are the forward scatter of direct solar radiance through the thin cloud edges and the reflection downward from the sides of opaque clouds. The additive term increases with increasing solar elevation angle and increases from scattered to broken.

Determination of Average Path Radiance

Conceding for reasons discussed above that detailed calculations of the upper hemisphere radiance fields in partly cloudy atmospheres are not practical, let us introduce assumptions that greatly simplify calculation of the average directional path radiance distribution that is expected to occur with a given cloud cover and aerosol distribution. A necessary step is to develop approximate expressions that specify the expected changes in cloud amount as a function of cloud type and solar angle. The approach here is to establish general expressions for the path function that are consistent with the average behavior of the diffuse irradiance fields in partly cloudy conditions as represented by equations 1.34 and 1.39.

As noted earlier, the spectral path radiance is given by

$$L_r^*(z,\theta,\phi) = \int_0^r L_*(z',\theta,\phi) T_r'(z',\theta) d_r', \tag{1.39}$$

where $L_*(z',\theta,\phi)$ is the path function, defined as the point function component of the path radiance that is generated by the scattering of light reaching that point of the path form all directions. The path function can be expressed in terms of its contributions from the scattering of solar (lunar) scalar irradiance $L_*(z',\theta,\phi)$ and from the scattering of sky, cloud, and earth radiances $L_{*d}(z_s',\theta,\phi)$ thus

$$L_*(z,\theta,\phi) = L_{*s}(z,\theta,\phi) + L_{*d}(z,\theta,\phi), \tag{1.40}$$

where

$$L_{*s}(z,\theta,\phi) = s_\varepsilon(z) P(z,\beta) s(z), \tag{1.41}$$

and

$$L_{*d}(z,\theta,\phi) = \int_{4\pi} L(z,\theta',\phi') P(z,\beta) s(z) d\Omega'. \tag{1.42}$$

$P(z,\beta)$ is the normalized single-scattering phase function at angle β between the path of sight and the direction of the source light, and $s(z)$ is the total volume scattering coefficient. The delta-Eddington approximation is employed to determine the multiple-scattering component of the path function. The resultant expression for the path function can be written

$$L_*(z,\theta,\phi) = s(z)\left[P(z,\beta_s)\ {}_s\varepsilon(z) + L_D(z) + gL_D' \cos\theta + gL_D''(z)\cos\phi\right], \tag{1.43}$$

where g is the asymmetry factor; and L_D, L_D', and L_D'' are the average, vertical asymmetry, and azimuthal asymmetry components, respectively, of the delta-Eddington path function representation.

Given approximate expressions for the calculation of the diffuse component of the path function, $L_{*d}(z,\theta,\phi)$, we can proceed with the FASCAT model to calculate the spectral path radiance distribution in partly cloudy atmospheres in the same way as for clear and overcast atmospheres. Let us specify that the diffuse component of the path function will respond to changes in cloud amount and solar zenith angle in direct correspondence with the changes in the diffuse irradiance above and below the cloud layer. Consistent with equation 1.34, we assume for all points above the cloud layer that

$${}_{PC}L_{*c}(z_a,\theta,\phi) = F(n,\mu_s)\ {}_{OV}L_{*d}(z_a,\theta,\phi) + [1 - F(n,\mu_s)]\ {}_{CR}L_{*d}(z_a,\theta,\phi); \tag{1.44}$$

and by analogy with equation 1.39, we assume for all points below the cloud layer that

$$\begin{aligned} {}_{PC}L_{*d}(z_b,\theta,\phi) \quad = \quad & F(n,\mu_s)\ {}_{OV}L_{*d}(z_b,\theta,\phi) + [1 - F(n,\mu_s)]\ {}_{CR}L_{*d}(z_b,\theta,\phi) + \\ & \frac{1}{\pi}[1 - F(n,\mu_s) - G(n,\mu_s)]\left[\ {}_sE_{CR}(z_b,d) - \ {}_sE_{OV}(z_b,d)\right], \end{aligned}$$

where the weighting factors $F(n,\mu_s)$ are given by equation 1.33. The probability of a cloud free solar path, $G(n,\theta_s)$, can be expressed [Allen and Malick, 1983]

$$\ln G(n,\theta_s) = (1 + c_n \tan\theta_s) \ln p_n, \tag{1.45}$$

where θ_s is the solar zenith angle and

$$p_n = \frac{1 - n(1 + 3n)}{4} \tag{1.46}$$

and

$$c_n = \frac{0.55 - n}{2} \tag{1.47}$$

For completeness, we assume that equation 1.44 also applies at all points along segments of cloud-free viewing paths that are between the base and top of the partly cloudy layer.

For calculations of the time or space averaged values of path function for point below the cloud layer with equation 1.40, the increase in the diffuse component with increasing cloud amount tends to be offset by a decrease in the direct solar component of the path function due to the increased probability that the points along the observation path will be in cloud shadow. The average or most probable value of the solar component of the path function for partly cloudy atmospheres is given by

$${}_{PC}L_{*s}(z,\theta,\phi) = G(n,\mu_s)\ {}_{CR}L_{*s}(z,\theta,\phi) + [1 - G(n,\mu_s)]\ {}_{OV}L_{*s}(z,\theta,\phi). \tag{1.48}$$

Two-Layer Cloud Option

The above system of analytic expressions yields estimates of the average path radiance distribution for atmospheres with a single cloud layer of varying cloud amount. A simple strategy was used to extend the FASCAT model calculations to include a second layer of fractional cloud cover, although the physical basis for the determination of the average diffuse spectral radiance is more tenuous. The assumption is made that the weighting factors $F(n, \mu_s)$, as determined for a single cloud layer, will apply, in general, to conditions where the layer exists in combination with a second layer of variable cloud cover. In the absence of representative experimental data for definitive test of this assumption, the two-layer cloud option is included in FASCAT to obtain rough estimates of the multilayer cloud effects on image transmission. The diffuse path function component is calculated as the weighted average of the corresponding values as calculated for the overcast upper layer, the overcast lower layer, overcast both layers, and for the clear atmosphere. Mathematical details will not be quoted here, but they may be found in AFGL-TR-84-0168. [Hering and Johnson, 1984]

1.4.2 Calculation of Apparent Target and Background Radiances

Equation 1.1 provides an expression for the apparent spectral radiance of distant target t at range r, as given by Duntley et al. [Duntley *et al.*, 1957] For the specific purpose of calculating the inherent target radiance, it is assumed that both the downward and upward diffuse radiance fields are uniform. Now the diffuse component of the irradiance on the target surface can be expressed as

$${}_{D}H_t(z_t,\theta_{Nt}) = \frac{{}_{D}E(z_t,d)\,[1 + \cos\theta_{Nt}]}{2} + \frac{{}_{D}E(z_t,d)\,[1 - \cos\theta_{Nt}]}{2} \tag{1.49}$$

where, as in equations 1.34 and 1.37, $E(z_t, u)$ is the upward irradiance on a horizontal surface, ${}_{D}E(z_t, u)$ is downward diffuse irradiance on a horizontal surface, and the direction of the target surface normal is (θ_{Nt}, ϕ_{Nt}). The total (solar plus diffuse) irradiance on the target surface is

$$H_t(z_t,\theta_{st},\phi_{Nt}) = \varepsilon_s(z_t)\cos\theta_{st} + {}_{D}H_t(z_t,\theta_{Nt}), \tag{1.50}$$

where the angle between the solar direction and the target surface normal direction is given by

$$\cos\theta_{st} = \cos\theta_{Nt}\cos\theta_s + \sin\theta_{Nt}\sin\theta_s\cos(\phi_{Nt} - \phi_s)\,. \tag{1.51}$$

The $\cos\theta_{st}$ is set to zero if $\cos\theta_{st} < 0$ or if the target is in local shadow. Finally it is assumed that the target surfaces reflect in accordance with Lambert's law so that the expression for the inherent spectral radiance of the target becomes

$${}_{t}L_0(z_t,\theta,\phi) = \frac{R_t H_t(z_t,\theta_{st}\theta_{Nt})}{\pi}. \tag{1.52}$$

The expressions corresponding to equations 1.1, 1.49, 1.50, and 1.52 for the apparent spectral radiance of the local background are

$${}_bL_r(z,\theta,\phi) = {}_bL_0(z_b,\theta,\phi)T_r(z,\theta) + L_r^*(z,\theta,\phi), \tag{1.53}$$

$${}_DH_b(z_b,\theta,\phi) = \frac{{}_DE(z_b,d)\,[1+\cos\theta_{Nb}]}{2} + \frac{{}_DE(z_b,d)\,[1-\cos\theta_{Nb}]}{2}, \tag{1.54}$$

$$H_b(z_b,\theta_{sb},\theta_{Nb}) = \varepsilon_s(z_b)\cos\theta_{sb} + {}_DH_b(z_b,\theta_{Nb}), \tag{1.55}$$

and

$${}_bL_0(z_b,\theta,\phi) = \frac{R_bH_b(z_b,\theta_{sb},\theta_{Nb})}{\pi} \tag{1.56}$$

where the subscript b refers to the local background surface that appears in immediate contrast with the designated target surface. As in the case of the target surface, the direction of the normal to the local background is an independent input variable to FASCAT. For objects viewed against a sky background, ${}_bL_0$ is zero. If one selects the sea surface option in FASCAT, R_b is ignored for observing paths directed toward the sea surface, and the inherent radiance is calculated as the Fresnel reflectance of the wind ruffled water surface, assuming the wave slope probabilities of Cox and Munk [Cox and Munk, 1954] and Hering [Hering, 1983].

Chapter 2

User's Guide

FASCAT is a fast atmospheric scattering model for calculating apparent background and target radiance fields. It is based on research by Wayne S. Hering, Visibility Laboratory, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California 92093.

The FASCAT computer code calculates the spectral radiance of distant objects and backgrounds for any designated slant path in the atmosphere. The apparent radiance is the sum of the residual background or target radiance plus the path radiance generated by the scattering of light reaching the path from the sun and the surrounding sky and terrain. Several input options are available for the specification of the vertical profiles of aerosol properties. Cloud information is entered by specification of the cloud type, amount, altitude of base and top and the relative optical thickness (average, thin, or thick). For designated sensor and target altitudes, the apparent contrast is calculated for cloud free slant paths, which may or may not transverse a fractional cloud layer. Objects in sunlight or shadow may be viewed against sky, cloud, or terrain backgrounds.

To calculate the apparent spectral contrast of distant targets, the user must know or estimate a variety of environmental and target factors. The accuracy and suitability of data available for the determinations vary markedly, depending upon the circumstances under which the model is applied. Therefore, emphasis has been placed on developing data input procedures that simplify preparing the required information and that adapt to the amount and variety of available data. An item-by-item list of input data and instruction notes on selection of many of those data may be found in section 2.2 of this report. Users of prior releases of FASCAT should note that the EOSAEL release requires the use of a different set of formats than the AFGL release. The intervening sections contain discussions of the general characteristics and special features of the modeling procedures to help users develop input data sets.

2.1 Program Description

Input data may be separated into four functional categories:

1. general parameters,
2. optical parameters profiles,
3. cloud layer information, and
4. target and local background data.

Each group will be discussed in the following paragraphs.

2.1.1 General Parameters

Wavelength

Although the model calculations are strictly applicable only for monochromatic radiation, the results are suitable with good approximation for reasonable broad spectral bands in the visible and near infrared portions of the spectrum. The designated wavelength should be chosen to conform as closely as possible with the overall spectral characteristics of the sensor. The model is applicable over the range 450 to 1060 nm.

Average Surface Reflectance

The weighted spatial average of the surface reflectance is entered to calculate the component of the path radiance that is generated by light reaching the path through reflection by the underlying surface and subsequent scattering by the atmosphere in the direction in the sensor. Thus, the area comprising the spatial average may be small as in the case of slant observation paths near the earth's surface or large as for paths extending from high altitude to the horizon. As described under target data, section 2.1.4, another data entry is made for the local background reflectance, which often differs from the average reflectance. The local reflectance is used for determining the inherent radiance of the immediate background against which the target appears.

Base Altitude of the Top Layer

This item sets the lower altitude limit of the primary ozone layer and should, in most instances, correspond with the altitude of the tropopause. Stored climatological values of total ozone as a function of latitude and season are used to calculate the ozone optical depth of the top layer for the designated wavelength.; Desired departures from the climatological values can be handled through appropriate changes in the designated single-scattering albedo for the top layer. The single-scattering albedo for the top layer normally is used to define only the absorption by molecular or aerosol constituents other than ozone.

Observation Angles

Up to 20 zenith observing angles may be selected. Default values include every 10°, beginning at 5° and ending at 175° plus zenith angles of 100° and 110°. Three azimuthal observing angles may be selected. They are specified in the input files as departures from the solar azimuthal angle. The default values are 0° (upsun), 90° (cross sun), and 180° (downsun).

2.1.2 Optical Parameters Profiles

Under the revised data entry format, the optical property profiles for the cloud-free atmosphere, above, below, and between cloud elements, are established first. Next the cloud properties are superimposed; and, finally, information with respect to sensor, target, and background factors are entered.

Depending upon the completeness of available measurements and observations, the user may select up to 10 layers to define the vertical distribution of the individual parameters. For each designated layer, the optical scattering ratio, the single-scattering albedo, and the single-scattering phase function and the associated asymmetry factor must be entered. Reference is made to sections 1.3.4 and 1.3.4 for a discussion of these optical parameters and for a description of options for their specification and entry into the computer program.

A recent extension to the FASCAT computer code, developed by Lieutenant Colonel John D. Mill and Eric P. Shettle of the AFGL, enables specification of the optical properties for each layer through use of the LOWTRN aerosol models. [Shettle and Fenn, 1979] Representative optical properties for rural, maritime, urban, and tropospheric atmospheres as well as for advection and radiation fog are supplied through interpolation from stored lookup tables. The aerosol model and associated properties are designated independently for each layer. The operator enters the appropriate aerosol type, the visible (550 nm) extinction coefficient, and the relative humidity; and the corresponding values of optical scattering ratio, single-scattering albedo, and the phase function for the designated wavelength are determined and supplied to the main program for radiance field calculations.

As discussed in section 1.3.4, many options are available in particular for the specification of the single-scattering phase function. For example, the program will accept the coefficient of two-term Henyey-Greenstein functions and calculate the scattering phase function. When other information is lacking, another model option will estimate the Henyey-Greenstein coefficients from the scattering ratio by using algorithms derived from the extensive field measurements of phase function by Barteneva. [Irvine, 1960]

Note that profile information for all atmospheric levels must be entered before specific cloud type and amount information is entered below. For layers of fractional cloud cover, the data entries in all cases define the optical properties of the cloud-free paths between the individual clouds. For overcast cloud layers, the operators have have two choices. First, users can simply make dummy entries for the optical properties for the overcast cloud layer for the initial profiles that will be ignored, and new data will be supplied through entry of cloud information in the input file items discussed below. Second, the users may enter their own cloud optical properties (scattering ratio, using-scattering albedo, and scattering phase function) rather than rely on the average values prescribed as a function of cloud type. If the second option is chosen for overcast cloud representation, the cloud optical properties are entered along with and in the same manner as for the cloud-free layers, and no entry for the cloud layer is made in the cloud layer input file.

2.1.3 Cloud Layer Information

The input for the individual cloud layers (two-layer maximum) consists of the base and top altitudes, the cloud amount in tenths, the cloud type (cirrus/cirrostratus, altostratus/altocumulus, cumulus, stratus/stratocumulus, or nimbostratus/precipitation), and the relative optical depth of the cloud. The relative optical depth has three options: Average, thin (minus standard deviation), and thick (plus standard deviation). In a separate phase of study summarized in Hering [Hering, 1983], the average and the variability of cloud optical depth as a function of cloud type were determined empirically from the SOLMET data base. The model algorithms return the optical depth for the specified cloud type and relative optical thickness (average, thick, or thin) from the table without direct reference to the specified base and top altitude of the layer. In other words, the optical thickness is determined independently of the specified geometric thickness of the cloud. These approximations are, however, likely to be valid only at visible and near-IR wavelengths.

2.1.4 Target and Local Background Data

Data sets consisting of sensor, target, and local background information are entered in the last section of the input file. Once the path function and beam transmittance distributions have been established form prior entry data, the model deals in turn with each of the target/background data sets without need for repeating the basic path function and transmittance calculations. Data entries for all cases where the targets are viewed from above against the earth's surface as the background are listed first, followed by cases where the objects are viewed from below against a sky or cloud background. The number of target/background data entries is unlimited. The input data for each set include the following:

Downward-Looking Observation Paths

- Sensor altitude (kilometers mean sea level)
- Target altitude (kilometers mean sea level)
- Target reflectivity
- Target normal zenith angle (degrees)
- Target normal azimuthal angle (degrees departure from solar azimuth)

- Target illumination (three options)
  1. full sunlight
  2. cloud shadow – includes direct solar beam and forward peak radiance penetration of thin clouds
  3. local shadow
- Local background (against which target appears) reflectivity
- Local background surface normal zenith angle (degrees)
- Local background surface normal azimuthal angel (departure from solar azimuth angle)
- Local background illumination (three options)
  1. full sunlight
  2. cloud shadow
  3. local shadow

Upward-Looking Observation Paths

Data entry items for upward paths are the same as for downward paths of sight except that local background input data are not required. The apparent local background radiance for a clear or partly cloudy atmosphere is the calculated sky radiance for a cloud-free path. For the case of an intervening overcast layer, apparent radiance of the cloud is returned as the local background radiance. A separate data set is employed to calculate the apparent radiance of the local background where that background is an opaque cloud element in a partly cloudy sky. For the second data set, the cloud element is assumed to be the target for the upward path of sight, and the appropriate cloud reflectivity, cloud surface normal direction, and cloud illumination (full sun or shadow) are entered as target data.

Note that for both upward- and downward-looking paths, the choice as to what the target is and what the local background is against which the target appears can be arbitrary in many situations. Model calculations of the apparent radiance of opaque surfaces are the same regardless of the target/background assignment.

2.2 Input Data Descriptions

Except for the first card, which has format (20A4), all the input data are in the EOSAEL format (A4,6X,8F10.4). Each card (except the first one) carries a four-character identifier, six blank "columns," and one to eight data values. The data are always entered in "real" or "floating point" form even though they may appear to be simple integers in the discussions. Note that the numerical data may be entered using alternate format specifications, provided that each value is placed in one of the 10-character wide positions. Thus, data might actually appear in the data file to be some mixture such as F10.4,3(E10.3),E10.4,F10.2,2(F10.1).

SPECIAL NOTE: Unlike many EOSAEL modules, the FASCAT module does not provide card-order independence. All cards must appear in precisely the order in which they are listed below, with the exceptions that some of the cards should not appear at all if certain options are selected. The cards whose presence or absence depends on such options are identified below.

Also note that FASCAT does not support internal cycling implemented via the EOSAEL `GO` cards.

2.2.1 TITLE Card

This must be the first FASCAT data card. It is read under a separate format, and if located elsewhere in the data stream, the program will probably terminate prematurely.

Table 2.1: THE TITLE CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
TITLE
```

NAME	UNITS	Description
		1-80 characters to identify run (Format is 20A4)
		This must be the fist FASCAT data card.

2.2.2 IPRF Card

IPRINT if activated prints a series of tables associated with the calculation of the irradiance and the direct diffuse radiance components reaching each atmospheric layer. The number of table sets depends on the number of cloud layers. For example, if the maximum of two layers of fractional or overcast cloud are prescribed, four sets of tables of four tables each are printed. The first set includes only the upper cloud layer in the calculations, the second set includes the lower cloud layer, and the third set includes both cloud layers. The last set, or fourth set in this case, refers to the cloud free portion of the atmosphere except for instances where overcast is prescribed for a given cloud layer.

The first table in each set lists the Rayleigh and total optical thickness for each sublayer. The second table lists the vertical beam transmittance, the single-scattering albedo, and the combined Rayleigh plus aerosol asymmetry factor for each sublayer. The third table lists the total optical depth profile for the actual and modified delta-Eddington atmosphere. The fourth table in each set lists the components of the irradiance profiles as determined by the delta-Eddington computer code.

ISTORE if activated stores data in unformatted binary form; output handling is system dependent; logical unit number in program FASCAT is 4, unless overridden by an EOSAEL driver (see auxiliary program storecat on distribution tape).

ISEA if activated prescribes lower boundary conditions that conform to a wind ruffled sea surface with light to moderate wind surface. Since Fresnel reflectance is assumed and a matching downwelling radiance and the reflected solar beam component are required, this option is set up to operate only if the 0°, 90°, and 180° azimuthal angle option is used. (see section 2.2.22)

Table 2.2: THE `IPRF` CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
IPRF          IPRINT    ISTORE      ISEA
```

NAME	UNITS	Description
`IPRINT`		print option =0 ignores this option =1 activates this option
`ISTORE`		store option =0 ignore this option =1 activates this option
`ISEA`		reflectance option =0 ignore this option =1 activates this option

2.2.3 ALBF Card

ALB is used to calculate the contribution of the diffuse background component of the path radiance, that is, radiance reflected from the underlying surface and then scattered by the atmosphere in the direction of the sensor or observer. A weighted area average of the background reflectivity is required, giving the most weight to the background within 0° to 25° of the observation angle. ALB will often differ from the local or immediate background reflectivity DBREF, described in connection with the NDLF, DSN1, and DSN2 cards (below).

BAT sets the lower altitude limit of the primary ozone layer. BAT should correspond to the base altitude of the upper layer as entered on the first ZLDF (see ISPF and ZLDF card descriptions) and correspond in general to the tropopause height. Valid limits for this entry are 10 to 15 km. The ozone optical depth is calculated as a function of wavelength, assuming average total ozone as a function of latitude and season. Other contributions to absorption in the top layer should be included in the specified single-scattering albedo for the layer (see also card ISPF notes).

Table 2.3: THE ALBF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
ALBF              ALB     LAMDA       BAT
```

NAME	UNITS	Description
ALB		average surface reflectance
LAMDA	μm	representative wavelength
BAT	km	base altitude of top layer

2.2.4 FACF Card

The extraterrestrial solar irradiance may be entered in any desired units. The resultant radiance will then be in the dame units per steradian. A normal set of units for irradiance would be $w * 10E - 6/nm * cm^2$. Note that apparent contrast and contrast transmittance are independent of FAC.

Table 2.4: THE FACF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
FACF              FAC
```

NAME	UNITS	Description
FAC	$\mu/cm^2 nm$	Extraterrestrial solar irradiance

2.2.5 ZENF Card

If the option to enter a specific solar zenith angle is chosen here, it is entered on THTF (next). Also entered there are the latitude and Julian date, which are required for determination of the average total ozone amount (also see card ALBF).

Table 2.5: THE `ZENF` CARD.

```
           1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
ZENF                IZEN
```

NAME	UNITS	Description
`IZEN`		=0 Option ignored. Use `DAYF` card
		=1 Option accepted. Input solar zenith angle on `THTF` card

2.2.6 THTF Card

Use only if IZEN = 1 on the ZENF card.

Table 2.6: THE THTF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
THTF          THETAS    JULIAN      XLAT
```

NAME	UNITS	Description
THETAS	degrees	solar zenith angle (degrees and tenths)
JULIAN		Julian date
XLAT	degrees	latitude (degrees and tenths)

2.2.7 DAYF Card

Use only if IZEN = 0 on the ZENF card. If location is in the Southern Hemisphere, keep the latitude entry positive, but add 183 to the Julian date.

Table 2.7: THE DAYF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
DAYF            HOUR    JULIAN      XLAT
```

NAME	UNITS	Description
HOUR	hours	local time (hours and tenths)
JULIAN		Julian date
XLAT	degrees	latitude (degrees and tenths)

2.2.8 NTHF Card

Total number of view angles are specified with NTHETA. If NTHETA=0, a set of default angles will be used.

Note that only rough corrections for refraction and earth's curvature are made, so that radiance calculations for observation angles close to the horizon are subject to errors associated with those unresolved effects.

Table 2.8: THE NTHF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
NTHF          NTHETA
```

NAME	UNITS	Description
NTHETA		total number of view angles. If NTHETA=0, a set of default angle will be used.

2.2.9 THF1 Card

Up to eight values for the viewing zenith angles may be entered on one card, and enough cards of type **THF1** must appear to provide precisely **NTHETA** values. They should be in ascending order.

SPECIAL NOTE: No value of **THETA(J)** may be set to 90° since the delta-Eddington method will fail and lead to program termination. **NTHETA** must not exceed 20.

Table 2.9: THE **THF1** CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
THF1         THETA(J)
```

NAME	UNITS	Description
THETA(J)	degrees	Viewing zenith angles Up to eight values may be place on each card. Add cards as necessary to get **NTHETA** values.

2.2.10 NLYF Card

The user may introduce as many layers to define the optical properties of the atmosphere as warranted b;y the completeness and accuracy of the available observations and forecasts. The optical property profiles for the cloud free areas (above, below, and between clouds) are set up in cards **NLYF**, **ISPF**, **ZLDF**, **INDF**, and **TBEF** (below).

Cloud layers are superimposed on the **NCLF** and **ALTF** cards. Sensor and target levels are specified on the **NDLF**, **DSN1**, **DSN2**, **NULF**, and **USN1** cards. Even in the case of an overcast sky, users should initially setup a cloud free atmosphere for the complete vertical profile. For an overcast layer (no cloud free path), the cloud profile initially postulated on the **ZLDF** card for that altitude interval will supersede the previous clear atmosphere data. A clear atmosphere boundary on card **ISPF** *should not be chosen interior to a cloud layer* as specified on card **ALTF**.

SPECIAL NOTE: **NLAY** should not be zero and may not exceed 10, and there must be **NLAY** pairs of cards of types **ISPF** and **ZLDF** (see below) that must be properly ordered as interleaved pairs.

Table 2.10: THE **NLYF** CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
NLYF             NLAY
```

NAME	UNITS	Description
NLAY		Total number of layers for the initial atmospheres

2.2.11 ISPF Card

`ISPF(ILAY)` prescribes the method used to introduce the optical properties for each layer (base altitude `ZL`) in a plane parallel horizontally homogeneous atmosphere. Five methods (options) are available as described below. Optical parameters to be specified are the following:

`A` = single-scattering albedo.
Ratio of total volume scattering coefficient (Rayleigh and aerosol) to total extinction coefficient (Rayleigh and aerosol scattering plus aerosol absorption).
`Q` = scattering ratio.
Ratio of total volume scattering coefficient to Rayleigh scattering coefficient.
`P(BETA)` = aerosol single-scattering phase function.
`G` = aerosol phase function asymmetry factor.

The options for entry of these variables are the following:

1. Data entries for each layer are `Q` and `W` only. `P(BETA)` and `G` are determined by two-term Henyey-Greenstein functions whose coefficients `G1, G2`, and `C` are prescribed in the FASCAT code as a function of `Q`.

2. Data entries are `Q` and `W` only. Option may be used as an alternate general format for fog/clouds. `P` and `G` for average drop size distribution are returned from memory.

3. Data entries are `Q, W, G`, and `P` (see cards `INDF` and `TBEF`). User enters all variables including lookup table for single-scattering phase function (see `INDF` card).

4. Data entries are `Q, W`, and the Henyey-Greenstein phase function coefficients, `G1, G2`, and `C`.

5. Data entries are made for each layer through reference to LOWTRN aerosol models.

Using subroutines by J. MILL/AFGL, operator enters: (a) extinction coefficient (Rayleigh and aerosol scattering plus aerosol absorption but not gaseous absorption); (b) relative humidity; and (c) LOWTRN aerosol model (rural, maritime, urban, troposphere, advection fog, or radiation fog). Requisite optical properties are returned by model algorithms and table interpolation.

Table 2.11: THE `ISPF` CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
ISPF      ISPF(ILAY)
```

NAME	UNITS	Description
`ISPF(ILAY)`		Aerosol type of atmospheric layer
		=1 input ZL, Q, W (calculates phase functions)
		=2 input ZL, Q, W (specifies cloud and fog phase function)
		=31, 32, 33 ZL, Q, W, G (enter phase function calculation)
		=4 $ZL, Q, W, G1, G2$ (H-G phase function calculation)
		=5 ZL, `VEXT`, `RHUMIS`, `NMODEL` (LOWTRN models)

2.2.12 ZLDFF Card

Contents of this card depend on the preceding parameter ISPF.

Type 1=ZL(ILAY), Q(ILAY), W(ILAY)
Type 2=ZL(ILAY), Q(ILAY), W(ILAY)
Type 31,32,33=ZL(ILAY), Q(ILAY), W(ILAY), G(ILAY)
Type 4=ZL(ILAY), Q(ILAY), W(ILAY), G1(ILAY), G2(ILAY), C(ILAY)
Type 5=ZL(ILAY), VEXT, RHUMID, NMODEL

Table 2.12: THE ZLDFF CARD.

```
         1         2         3         4          5         6         7         8
1234567890123456789012345678901234567890 1234567890123456789012345678901234567890
ZLDFF               ZL    Q-VEXT  W-RHUMIDG-G1-NMODEL       G2        C
```

NAME	UNITS	Description
ZL	km	base altitude of layer
Q		scattering ratio
VEXT	km^{-1}	visibility extinction
W		single-scattering albedo
RHUMID		relative humidity
G		aerosol asymmetry parameter
G1		aerosol asymmetry factor (H. G. function)
NMODEL		LOWTRN aerosol model
		1 = Rural
		2 = Maritime
		3 = Urban
		4 = Troposphere
		5–7 = Not used, default to rural
		8 = advection fog
		9 = Radiation fog
G2		aerosol asymmetry factor (H. G. function)
C		partitioning factor (H. G. function)

2.2.13 INDF Card

Used only if aerosol type 31–33 selected for use. Repeat records INDF and TBEF for each 31–33 type chosen.

Table 2.13: THE INDF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
INDF           IENDT
```

NAME	UNITS	Description
IENDT		Total number of BETA/P entries for table.
		Used only if aerosol type 31–33 selected for use.

2.2.14 TBEF Card

TBEF used only if aerosol type 31–33 chosen. This card must be repeated IENDT times.

Table 2.14: THE TBEF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
TBEF           TBETA        TP
```

NAME	UNITS	Description
TBETA	degrees	beta angle
TP		phase function

2.2.15 NCLF Card

A maximum of two cloud layers may be entered. If more layers are observed or reported, approximate the sky condition with a two-layer representation of cloud cover.

Table 2.15: THE NCLF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
NCLF          NCLOUD
```

NAME	UNITS	Description
NCLOUD		Total number of cloud layers (maximum of two)

2.2.16 ALTF Card

For each cloud layer, enter the base and top altitude (kilometers mean sea level) and the fraction of sky covered by the cloud layer in tenths. The cloud type (ICLOUD) is identified by one of the standard cloud forms (cirrus/cirrostratus, altostratus/altocumulus, cumulus, stratus/stratocumulus, and nimbostratus/precipitation). The relative optical thickness (ICLFAC) has three options: average, thick, and thin. Model algorithms return the appropriate optical depth from ICLOUD and ICLFAC without direct reference to the geometric thickness of the cloud. Repeat ALTF NCLOUD times.

Table 2.16: THE ALTF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
ALFT          ALTOP     ALTBT     AMFTR     ICLOUD    ICLFAC
```

NAME	UNITS	Description
ALTOP	km	top altitude of cloud layer (kilometers mean sea level)
ALTBT	km	base altitude of cloud layer (kilometers mean sea level)
AMTFR		amount fraction of cloud layer
ICLOUD		cloud type =1 cirrus/cirrostratus =2 altostratus/altocumulus =3 cumulus =4 stratus/stratocumulus =5 nimbostratus/precipitation
ICLFAC		relative optical thickness (Use if NCLOUD is nonzero) =1 average optical thickness =2 thick =3 thin

2.2.17 NDLF Card

The total number of combinations of sensor-target altitudes and target-background conditions to be dealt with. The maximum value is 10.

Intrinsic properties of local sloping backgrounds and three-dimensional targets for selected downward-looking paths of sight are entered on cards DSN1 and DSN2.

If NDLOOK is nonzero, then NDLOOK ordered pairs of the next two cards (DSN1 and DSN2) are required.

IMPORTANT NOTE: For extraterrestrial sensor position, designate sensor altitude (DSEN) as 100 km.

The zenith angle of the target normal and the zenith angle of the local background normal are entered directly, without regard to the solar zenith angle. However, the azimuthal angles of the target normal and the local background normal are entered as departures–repeat departures–from the solar azimuthal angle, without regard to sign.

The inherent local background and target radiances are determined under the assumption of diffuse or Lambertian reflectance of the irradiance reaching the object and background surface from all directions. Illumination of target and/or background can be designated as

1. in direct sunlight
2. in cloud shadow, which will include direct solar irradiance passing through thin clouds
3. in local shadow with no direct sun illumination.

Table 2.17: THE NDLF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
NDLF          NDLOOK
```

NAME	UNITS	Description
NDLOOK		Total number of combinations of sensor-target altitudes and target-background conditions to be dealt with. maximum value is 10.

2.2.18 DSN1 Card

Table 2.18: THE DSN1 CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
DSN1           DSENS     DTARG    DTAREF    DZNORM    DANORM     IDTRG
```

NAME	UNITS	Description
DSENS	km	sensor altitude path of sight (kilometers mean sea level)
DTARG	km	target altitude path of sight (kilometers mean sea level)
DTAREF		target reflectivity
DZNORM	degrees	target normal zenith angle
DANORM	degrees	target normal azimuth angle (degrees departure form solar azimuth)
IDTRG		target illumination =1 sunlight =2 cloud shadow =3 local shadow

2.2.19 DSN2 Card

Table 2.19: THE DSN2 CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
DSN2           DBREF     DZSLOP    DASLOP     IDLUM
```

NAME	UNITS	Description
DBREF		local background reflectivity
DZSLOP	degrees	background normal zenith angle
DASLOP	degrees	background normal azimuth angle (degrees departure from solar azimuth)
IDLUM		background illumination =1 sunlight =2 cloud shadow =3 local shadow

2.2.20 NULF Card

If NULOOK is nonzero, then NULOOK cards of the type USN1 (next) are required. However, no USN1 cards may appear if NULOOK = 0.

Table 2.20: THE NULF CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
NULF          NULOOK
```

NAME	UNITS	Description
NULOOK		Number of upward sight paths

2.2.21 USN1 Card

These parameters are defined analogously to those appearing on the DSN1 and DSN2 cards (above).

Table 2.21: THE `USN1` CARD.

```
         1         2         3         4         5         6         7         8
12345678909012345678901234567890123456789012345678901234567890123456789012345678 90
USN1              USENS     UTARG     UTAREF    UZNORM    UANORM     IUTRG
```

NAME	UNITS	Description
USENS	km	sensor altitude upward path of sight (kilometers mean sea level)
UTARG	km	target altitude upward path of sight (kilometers mean sea level)
UTAREF		target reflectivity
UZNORM	degrees	target normal zenith angle
UANORM	degrees	target normal azimuth angle (degrees departure from solar azimuth)
IUTRG		target illumination =1 sunlight =2 cloud shadow =3 local shadow

2.2.22 NPHF Card

As opposed to zenith observing angles, the azimuthal observing angles are entered as departures–REPEAT departures–from the solar azimuthal angle.

Option 0 defaults to azimuthal angles of 0° (upsun), 90° (cross sun) and 180° (downsun). This option must be used if `ISEA`=1 (see `IPREF` card).

Option 1 permits selection of any three azimuthal viewing directions, entered as the departures from the solar azimuthal angle without regard to sign.

Table 2.22: THE `NPHF` CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
NPHF           NPHI
```

NAME	UNITS	Description
`NPHI`		Option for user entered azimuth viewing angles
		=0 default azimuths = 0°, 180°, and 90°
		=1 user inputs three azimuth angles
		(degrees departure from solar azimuth)

2.2.23 PHIF Card

Use only if `NPHI`=1. Three values are expected.

Table 2.23: THE `PHIF` CARD.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
PHIF        PHINT(1)  PHINT(2)  PHINT(3)
```

NAME	UNITS	Description
`PHINT(1--3)`	degrees	Azimuth viewing angles
		Three values are expected

2.2.24 DONE Card

Signals that all input data have been read; should be the very last card in a data stream.

2.3 List of Normal Output Quantities

Title
Average Surface Reflectance
Representative Wavelength
Base Altitude of Top Layer
Extraterrestrial Solar Irradiance
Solar Zenith Angle
Julian Date (Solar Azimuth Angle - Local Time)
Latitude
Total Atmospheric Layers
  Layer Number
  Aerosol Type

- Altitude
- Q, W, G, G1, G2, C, VEXT, Humidity, Model Type (According to Aerosol Type)
- Total Cloud Layers
- Cloud Layer
  - Type
  - Top Altitude of Cloud
  - Base Altitude of Cloud
  - Amount Fraction
  - Relative Optical Thickness
- Downward Path of Sight
  - Sensor Altitude
  - Target Altitude
    - Target
      - Reflectivity
      - Normal Zenith Degrees
      - Direction Azimuth Degrees
      - Illumination
    - Local Background
      - Reflectivity
      - Normal Zenith Degrees
      - Direction Azimuth Degrees
      - Illumination
- Upward Path of Sight
  - Sensor Altitude
  - Target Altitude
    - Target
      - Reflectivity
      - Normal Zenith Degrees
      - Direction Azimuth Degrees
      - Illumination
- Sublayer
  - Z, SCALE, HT, DELTATR, DELTAT
- Major Layer Asymmetry Parameters
  - T, W, G, FL, FLP
- Solar Zenith Angle
- L, Z, TAUSL, TAUPSL
- Delta-Eddington Results
- Downward Path of Sight
  - Inherent Background Surface Radiance
  - Apparent Background Radiance Table
  - Inherent Target Radiance
  - Apparent Target Radiance Table
  - Apparent Target Contrast Table
- Upward Path of Sight
  - Apparent Background Radiance Table
  - Inherent Target Radiance
  - Apparent Target Radiance Table
  - Apparent Target Contrast Table

2.4 Summary of Subroutine and Major Variables

Subroutine ADJUST assigns arrays of atmospheric layers.

The parameters are: IOPT = Assignment Choices
INDEXA, INDEXB = Move INDEXB into INDEXA

Subroutine CAL drives fluxes subroutine.

The parameters are: TAU = Optical Depth
M = Index on Layer/Sublayer
IPRINT = Print Option (0=NO, 1=YES)
N = Total Atmospheric Layers
ISTORE = (0=NO, 1=YES)

Subroutine CLDFR combine delta-Eddington variables for diffuse radiance calculation.

The parameters are: CLR = Clear Sky Contribution
A = First Cloud Layer Contribution
B = Second Cloud Layer Contribution
AB = All Cloud Contributions
ANS = Combined Radiance
IOPT...1 = Above Top Cloud, 2 = Below Top Cloud
M = Index on Layer

Subroutine DELETED expands and prints delta-Eddington products.

The parameters are: N = Total Atmospheric Layers
IPRINT = Print Option (0=NO, 1=YES)
ISTORE = Store Option (0=NO, 1=YES)

Subroutine ERRMSG handles fatal error messages.

The parameters are: JERR = Points to Fatal Error

Subroutine FLUXES determines irradiance profiles for N layer atmosphere.

The parameters are: N = Number of Atmospheric Layers
TAU = Optical Depth for Which Fluxes are Calculated
(ERI Shettle, AFGL/OPA, Hanscom AFB, MA 01731)

Subroutine FUNCTION is GL(Q).

The parameters are: GL = Asymmetry Factor for Combined Rayleigh
and Aerosol Scattering Where Q is the
Ratio of Total and Rayleigh Scattering
Coefficients

Subroutine INDATF is used to enter user data. `INDATF` is EOSAEL version of routine `INDATA`.s

The parameters are: LAMBDA = Wavelength
IPRINT = Print Option (0=NO, 1=YES)
N = Total Atmospheric Layers
ISTORE = Store Option (0=NO, 1=YES)
BRO = Surface Rayleigh Scattering Coefficients
at LAMBDA

Subroutine NSTAR computes radiance generated over path from T and N of layers.

The parameters are: ITIN = Top Altitude Level
IBALT = Bottom Altitude Level and Layer
IUD = 1 For Up THETA (0-85)
2 For Down THETA (90-180)
ANS = Result
T = Transmittance for Range
IT = Index on THETA (View Angle)
TT = Diffuse Transmittance
IPHI = Index on Azimuthal Angle

Subroutine OPTIC computes optical thickness.

The parameters are: LAMBDA = Wavelength
N = Total Atmospheric Layers
BRO = Surface Rayleigh Scattering Coefficient
At LAMBDA
KCLOUD = Cloud Layer Index
IPRINT = Print Option...1=YES, 0=NO
ISTORE = Store Option...1=YES, 0=NO

Subroutine PHASEF supplies, via lookup tables, the extinction and scattering coefficients, single-scatter albedo, scattering ratio, single-scatter phase function and asymmetry parameter for any of the LOWTRN 5 aerosol models, for wavelengths between 0.55 and 1.06 μm.

The input parameters are: VEXT = Visible Extinction Coefficient in 1/km.
(Total Extinction, Including Rayleigh an Aerosol
Scattering and Aerosol Absorption, but not Gas
Absorption (see above).
Required, No Default, Range, 1E-2 to 1E-3.)
WAVLEN = Wavelength in Micrometers, Range,
0.55 to 1.06, Defaults to Closest if Out
of Range.
NMODEL = LOWTRN 5 Aerosol Model Number
1 - Rural (Default Mode)
2 - Maritime
3 - Urban
4 - Tropospheric
5–7 - Not Used, Default to 1
8 - Advection Fog
9 - Radiation Fog
RHUMID - Relative Humidity in Percent.
0.0–99.0%. Default is 70% if Too
Small or 99% if To Large. For the
Fog Models, the RH is Ignored
ALT - Altitude in Kilometers (For Rayleigh
Calculation). 0 to 10 km, Defaults
to Nearest if Out of Range
MPHASW - Dimension of Arrays PHANGLE and
PHFUNC, Below

The output parameters are: EXT - Extinction Coefficient in 1/km.

SCATT - Scattering Coefficient in 1/km.
SSLAB - Single-Scattering Albedo (0–1)
SRATIO - Ratio of SCATT to Rayleigh Scattering
Coefficient, Dimensionless
("Scattering Ratio")
PHFUN - Array (1 to NPHASE) of Directional
Scattering Coefficients
in 1/(km*STER). (see IERR)
PHANGL - Angles Associated with PHFUN in Degrees
(Same for All Models)
NPHASE - Number of Elements in PHANGL and PHFUNC
= MIN(MPHASE,NZANG) (see AERMOD subroutine)
ASSYM - Phase Function Asymmetry Parameter (0–1)
IERR - Error Flag
-2 : Fatal, MPHASE is .LE. 0
-1 : Fatal, Visible Extinction not
0 : Normal Execution
1 : Warning, Defaults Used for One
or More Inputs
2 : Warning, Full Phase Function
not Returned (MPHASE too Small)
3 : Both One and Two
4 : Extinction .LT. Rayleigh, Reset
to Rayleigh
5–7 : Combinations of 1,2,4

(Lt. John D. Mill, AFGLOPA, Hanscom AFB, MA 01731)

Subroutine PLTCLD determines multiple-scattered radiance component for partly cloudy skies.

The parameters are: N = Total Atmospheric Layers

Subroutine SCATT determines the scattering ratio of the overcast cloud layer.

The parameters are: SVAR1 = Scattering Variance
SVAR2 = Scattering Variance
BRO = Surface Rayleigh Scattering Coefficient
at Wavelength Lambda
I = Index on Cloud Layer

Subroutine SENSIT finds sensor match with base altitude.

The parameters are: JUD...1 = Down Path, 2 = Up Path
N = Total Atmospheric Layers
JRT...1 = Radiance, 2 = Target Contrast
JTOT = Total Sets

SKYIT is the subroutine for azimuthal angle indexing and for calculation of transmittance and sea surface reflectance.

The parameters are: N = Total Atmospheric Layers
ISEA = Reflectance Option (0=NO, 1=YES)
JUD: 1 = Down Path, 2 = Up Path
JTOT = Total Sets of Computations
JRT: 1 = Radiance, 2 = Target Contrast

Subroutine SKYPRT prints tables for radiance and apparent target contrast.

The parameters are: ISTORE: 0=NO, 1=YES
JUD: 1 = Down Path, 2 = Up Path
JTOT = Total Sets
JRT: 1 = Radiance, 2 = Target Contrast
ISEA: 1 = Sea Reflectance, 0 = No Sea Reflectance

Subroutine SKYRAD calculates apparent background and target radiance fields and apparent target contrast.

The parameters are: N = Total Number of Atmospheric Layers
ALB = Average Surface Reflectance
ALBP = Local Object/Background Reflectance
(If not ALB)
ISEA = Reflectance Option (0=NO, 1=YES)
JUD...1 = Down Path, 2 = Up Path
JTOT... Total Sets
JRT...1 = Radiance, 2 = Target Contrast

Subroutine SPF calculates the single-scattering phase function.

The parameters are: Q = Scattering Ratio
P = Phase Function
IOP: = 1 For P = F(Q)
= 2 For Fog or Cloud
= 3 Input Table and G to Be Specified
By User
= 4 User specified G1, G2, and C for Henyey-
Greenstein Calculation, Aerosol
Scattering Phase Function
G1, G2 are User Input Asymmetry Factors
and Weighting Function

Subroutine SPFTAB interpolates P from IOP option table (BETA, P).

The parameters are: IOP = Index on Beta Table
BETA = Scattering Angles
P = Interpolated Phase Function

Subroutine TANIT calculates T (Transmittance) and SN (Path Radiance) for Each Sublayer.

The parameters are: T = Transmittance
SN = Layer Path Radiance
L = Index for Layer
M = Index for Layer
THETA = Look Angle
A = Single-scattering Albedo for Layer
PHI = Azimuthal Angle
RTS = Solar Zenith Angle in Radians
RT = View Angle in Radians
IT = Index on View Angles
ISEA: 0 = No Reflectance, 1 = Reflectance

Subroutine TBPRA reads in tables to print (TBPRA is EOSAEL version of routine TBPR).

The parameters are: N = Total Atmospheric Layers
ISTORE ... Store Option .. 0=NO, 1=YES

Subroutine TOTLAY reforms tables of atmospheric layers.

The parameters are: NLAY = Total Layers
N = Total Atmospheric Layers
LAMBDA = Wavelength
BRO = Surface Rayleigh Scattering Coefficient
at Lambda

Subroutine TRIDAG solves systems of N simultaneous lines.

The parameters are: N = Number of Atmospheric Layer
SUB, DIA, SUP, CON = System of Equations from
Subroutine FLUXES.
V = Output Vector

Subroutine XRANG determines if X is in range of XMIN and XMAX.
Subroutine ZENITH computes the solar zenith angle.

Chapter 3

Sample Runs of FASCAT

The following are sample input and output files of FASCAT.

3.1 Example 1

3.1.1 Inputs for the first test run.

The following is the sample input file `FASCAT01.DAT`.

```
WAVL    0.55
FASC
IPRF    1.0     0.0      0.0
ALBF    0.07    0.55     15.0
FACF    185.0
ZENF    0.0
DAYF    11.0    190.     40.0
NTHF    0.0
NLYF    7.0
ISPF    5.
ZLDF    15.0    0.00221  70.0    4.
ISPF    5.
ZLDF    10.0     .0047   70.0    4.
ISPF    5.
ZLDF    6.0     .00752   70.0    4.
ISPF    5.
ZLDF    3.0     .01066   70.0    4.
ISPF    5.
ZLDF    1.3     .01280   70.0    4.
ISPF    5.
ZLDF    0.5     .14400   70.0    1.
ISPF    5.
ZLDF    0.0     .15100   70.0    1.
NCLF    2.
ALTF    7.0     6.0      0.6     1.      1.
ALTF    2.5     1.5      0.3     3.      1.
NDLF    4.
DSN1    03.0    0.0      0.15    0.0     0.0     1.
DSN2    0.075   0.0      0.0     1.
DSN1    03.0    0.0      0.15    0.0     0.0     1.
DSN2    0.075   0.0      0.0     3.
DSN1    03.0    0.0      0.15    0.0     0.0     3.
DSN2    0.075   0.0      0.0     3.
DSN1    03.0    0.0      0.15    0.0     0.0     3.
DSN2    0.075   0.0      0.0     1.
NULF    1.
USN1    0.0     15.0     0.25    180.0   0.0     1.
NPHF    1.
PHIF    0.0     90.0     180.0
DONE
```

```
END
STOP
TEST  RUN ON EOSAEL MODIFICATION OF 384 VERSION, LOWTRAN PFN OPTION

# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) FASCAT01.DAT 1.1 03/10/93
```

3.1.2 Output for the first test run.

The following is the sample output file `FASCAT01.OUT`.

```
********************************************************************************
  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.
********************************************************************************

1




                     ********************************
                     *                              *
                     *    ELECTRO-OPTICAL SYSTEMS   *
                     *                              *
                     *  ATMOSPHERIC EFFECTS LIBRARY *
                     *                              *
                     *    NOT FOR OPERATIONAL USE   *
                     *                              *
                     * EOSAEL92 REV 1.1   03/10/93  *
                     *                              *
                     ********************************


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
1




                     ********************************
                     *                              *
                     *        F A S C A T           *
                     *                              *
                     *  ATMOSPHERIC ILLUMINATION    *
                     *                              *
```

```
                    *   NOT FOR OPERATIONAL USE    *
                    *                              *
                    * EOSAEL92 REV 1.1   03/10/93  *
                    *                              *
                    ********************************


  IPRF       1.0       0.0       0.0
  AVERAGE SURFACE REFLECTANCE                      .7000E-01
  REPRESENTATIVE WAVELENGTH                        .5500E+00
  BASE ALTITUDE OF TOP LAYER                       .1500E+02
  EXTRATERRESTRIAL SOLAR IRRADIANCE              .185000E+03
  SOLAR ZENITH ANGLE                               .2163E+02
  LOCAL TIME (HOURS AND TENTHS)                    .1100E+02
  SOLAR AZIMUTHAL ANGLE                            .1396E+03
  JULIAN DATE                                            190
  LATITUDE                                         .4000E+02
   VIEW ANGLES
      .500E+01
      .150E+02
      .250E+02
      .350E+02
      .450E+02
      .550E+02
      .650E+02
      .750E+02
      .850E+02
      .950E+02
      .100E+03
      .105E+03
      .110E+03
      .115E+03
      .125E+03
      .135E+03
      .145E+03
      .155E+03
      .165E+03
      .175E+03
  TOTAL NUMBER OF ATMOSPHERIC LAYERS                       7

                                                              HENYEY GREENSTEIN PARAMETERS            LOWTRAN MODEL INPUT
LAYER  ISPF   ALTITUDE   SCT. RATIO    SS ALBEDO    ASYM. FACTOR    G1          G2          C        VEXT      HUMIDITY  MODEL
  1      5    .1500E+02                                                                            .2210E-02   .7000E+02   4
  2      5    .1000E+02                                                                            .4700E-02   .7000E+02   4
  3      5    .6000E+01                                                                            .7520E-02   .7000E+02   4
  4      5    .3000E+01                                                                            .1066E-01   .7000E+02   4
  5      5    .1300E+01                                                                            .1280E-01   .7000E+02   4
  6      5    .5000E+00                                                                            .1440E+00   .7000E+02   1
  7      5    .0000E+00                                                                            .1510E+00   .7000E+02   1
  TOTAL CLOUD LAYERS                                       2
  TYPE   TOP ALTITUDE       BASE ALTITUDE     AMOUNT        RELATIVE OPTICAL THICKNESS
    1       .7000E+01          .6000E+01     .6000E+00                   1
    3       .2500E+01          .1500E+01     .3000E+00                   1

  APPARENT RADIANCE AND TARGET CONTRAST FOR DOWNWARD PATH

 SENSOR   TARGET                           TARGET                                        LOCAL BACKGROUND
ALTITUDE ALTITUDE     REFLECTIVITY  NORMAL    NORMAL  ILLUMINATION          REFLECTIVITY  NORMAL  DIRECTION      ILLUMINATION
   KM       KM                      ZENITH    AZIMUTH                                     ZENITH   AZIMUTH
                                    DEGREES   DEGREES                                     DEGREES  DEGREES
  3.00      .00          .150         .00       .00   DIRECT SUNLIGHT           .075         .00       .00          DIRECT SUNLIGHT
  3.00      .00          .150         .00       .00   DIRECT SUNLIGHT           .075         .00       .00          LOCAL SHADOW
  3.00      .00          .150         .00       .00   LOCAL SHADOW              .075         .00       .00          LOCAL SHADOW
  3.00      .00          .150         .00       .00   LOCAL SHADOW              .075         .00       .00          DIRECT SUNLIGHT

  APPARENT RADIANCE AND TARGET CONTRAST FOR UPWARD PATH

 SENSOR    TARGET                       TARGET
ALTITUDE  ALTITUDE         REFLECTIVITY  NORMAL DIRECTION  ILLUMINATION
   KM        KM                          ZENITH  AZIMUTH
                                         DEGREES DEGREES
   .00     15.00                .250     180.00     .00    DIRECT SUNLIGHT


   AZIMUTH ANGLES           .0    90.0   180.0
```

TABLE 71 IPRF 1.0 0.0 0.0

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
REFLECTIVITY	.7500E-01
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	DIRECT SUNLIGHT
INHERENT BACKGROUND RADIANCE AT THE SURFACE	.4666E+01

THETA	PHI= .0	90.0	180.0
95.0	.1741E+02	.1551E+02	.1511E+02
100.0	.1276E+02	.1171E+02	.1150E+02
105.0	.1028E+02	.9674E+01	.9571E+01
110.0	.8837E+01	.8476E+01	.8444E+01
115.0	.7928E+01	.7710E+01	.7717E+01
125.0	.6876E+01	.6805E+01	.6862E+01
135.0	.6321E+01	.6316E+01	.6397E+01
145.0	.6008E+01	.6033E+01	.6119E+01
155.0	.5832E+01	.5870E+01	.5971E+01
165.0	.5747E+01	.5781E+01	.5845E+01
175.0	.5727E+01	.5742E+01	.5756E+01

APPARENT TARGET CONTRAST

THETA	PHI= .0	90.0	180.0
95.0	.2011E-01	.2258E-01	.2317E-01
100.0	.1088E+00	.1186E+00	.1208E+00
105.0	.2036E+00	.2164E+00	.2188E+00
110.0	.2889E+00	.3012E+00	.3024E+00
115.0	.3618E+00	.3720E+00	.3716E+00
125.0	.4746E+00	.4795E+00	.4755E+00
135.0	.5525E+00	.5529E+00	.5459E+00
145.0	.6049E+00	.6023E+00	.5939E+00
155.0	.6383E+00	.6342E+00	.6235E+00
165.0	.6569E+00	.6531E+00	.6458E+00
175.0	.6635E+00	.6617E+00	.6601E+00

APPARENT TARGET RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
TARGET ALTITUDE	.0000E+00
REFLECTIVITY	.1500E+00
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	DIRECT SUNLIGHT
INHERENT TARGET RADIANCE	.9331E+01

THETA	PHI= .0	90.0	180.0
95.0	.1777E+02	.1586E+02	.1546E+02
100.0	.1415E+02	.1310E+02	.1288E+02
105.0	.1238E+02	.1177E+02	.1166E+02
110.0	.1139E+02	.1103E+02	.1100E+02
115.0	.1080E+02	.1058E+02	.1059E+02
125.0	.1014E+02	.1007E+02	.1013E+02
135.0	.9813E+01	.9808E+01	.9890E+01
145.0	.9642E+01	.9667E+01	.9752E+01
155.0	.9555E+01	.9593E+01	.9694E+01
165.0	.9522E+01	.9556E+01	.9621E+01
175.0	.9527E+01	.9542E+01	.9556E+01

TABLE 72 IPRF 1.0 0.0 0.0

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
REFLECTIVITY	.7500E-01
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	LOCAL SHADOW
INHERENT BACKGROUND RADIANCE AT THE SURFACE	.1424E+01

THETA PHI=	.0	90.0	180.0
95.0	.1717E+02	.1527E+02	.1487E+02
100.0	.1180E+02	.1074E+02	.1053E+02
105.0	.8827E+01	.8219E+01	.8116E+01
110.0	.7063E+01	.6702E+01	.6669E+01
115.0	.5935E+01	.5717E+01	.5724E+01
125.0	.4608E+01	.4538E+01	.4595E+01
135.0	.3894E+01	.3890E+01	.3971E+01
145.0	.3482E+01	.3508E+01	.3593E+01
155.0	.3245E+01	.3283E+01	.3384E+01
165.0	.3124E+01	.3157E+01	.3222E+01
175.0	.3087E+01	.3102E+01	.3116E+01

APPARENT TARGET CONTRAST

THETA PHI=	.0	90.0	180.0
95.0	.3456E-01	.3887E-01	.3991E-01
100.0	.1995E+00	.2191E+00	.2235E+00
105.0	.4020E+00	.4317E+00	.4372E+00
110.0	.6126E+00	.6457E+00	.6488E+00
115.0	.8190E+00	.8503E+00	.8492E+00
125.0	.1200E+01	.1219E+01	.1204E+01
135.0	.1520E+01	.1522E+01	.1491E+01
145.0	.1769E+01	.1756E+01	.1714E+01
155.0	.1944E+01	.1922E+01	.1864E+01
165.0	.2048E+01	.2027E+01	.1986E+01
175.0	.2086E+01	.2076E+01	.2067E+01

APPARENT TARGET RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
TARGET ALTITUDE	.0000E+00
REFLECTIVITY	.1500E+00
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	DIRECT SUNLIGHT
INHERENT TARGET RADIANCE	.9331E+01

THETA PHI=	.0	90.0	180.0
95.0	.1777E+02	.1586E+02	.1546E+02
100.0	.1415E+02	.1310E+02	.1288E+02
105.0	.1238E+02	.1177E+02	.1166E+02
110.0	.1139E+02	.1103E+02	.1100E+02
115.0	.1080E+02	.1058E+02	.1059E+02
125.0	.1014E+02	.1007E+02	.1013E+02
135.0	.9813E+01	.9808E+01	.9890E+01
145.0	.9642E+01	.9667E+01	.9752E+01
155.0	.9555E+01	.9593E+01	.9694E+01
165.0	.9522E+01	.9556E+01	.9621E+01
175.0	.9527E+01	.9542E+01	.9556E+01

TABLE 73 IPRF 1.0 0.0 0.0

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
REFLECTIVITY	.7500E-01

NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	LOCAL SHADOW
INHERENT BACKGROUND RADIANCE AT THE SURFACE	.1424E+01

THETA	PHI= .0	90.0	180.0
95.0	.1717E+02	.1527E+02	.1487E+02
100.0	.1180E+02	.1074E+02	.1053E+02
105.0	.8827E+01	.8219E+01	.8116E+01
110.0	.7063E+01	.6702E+01	.6669E+01
115.0	.5935E+01	.5717E+01	.5724E+01
125.0	.4608E+01	.4538E+01	.4595E+01
135.0	.3894E+01	.3890E+01	.3971E+01
145.0	.3482E+01	.3508E+01	.3593E+01
155.0	.3245E+01	.3283E+01	.3384E+01
165.0	.3124E+01	.3157E+01	.3222E+01
175.0	.3087E+01	.3102E+01	.3116E+01

APPARENT TARGET CONTRAST

THETA	PHI= .0	90.0	180.0
95.0	.6223E-02	.6998E-02	.7186E-02
100.0	.3592E-01	.3944E-01	.4024E-01
105.0	.7238E-01	.7773E-01	.7872E-01
110.0	.1103E+00	.1162E+00	.1168E+00
115.0	.1474E+00	.1531E+00	.1529E+00
125.0	.2161E+00	.2194E+00	.2167E+00
135.0	.2736E+00	.2740E+00	.2684E+00
145.0	.3184E+00	.3161E+00	.3086E+00
155.0	.3500E+00	.3460E+00	.3357E+00
165.0	.3688E+00	.3649E+00	.3575E+00
175.0	.3756E+00	.3738E+00	.3721E+00

APPARENT TARGET RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
TARGET ALTITUDE	.0000E+00
REFLECTIVITY	.1500E+00
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	LOCAL SHADOW
INHERENT TARGET RADIANCE	.2847E+01

THETA	PHI= .0	90.0	180.0
95.0	.1728E+02	.1538E+02	.1498E+02
100.0	.1222E+02	.1117E+02	.1095E+02
105.0	.9466E+01	.8858E+01	.8755E+01
110.0	.7842E+01	.7481E+01	.7449E+01
115.0	.6811E+01	.6592E+01	.6600E+01
125.0	.5604E+01	.5534E+01	.5591E+01
135.0	.4960E+01	.4955E+01	.5036E+01
145.0	.4591E+01	.4617E+01	.4702E+01
155.0	.4381E+01	.4419E+01	.4520E+01
165.0	.4276E+01	.4309E+01	.4374E+01
175.0	.4246E+01	.4261E+01	.4275E+01

TABLE 74 IPRF 1.0 0.0 0.0

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
REFLECTIVITY	.7500E-01
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	DIRECT SUNLIGHT
INHERENT BACKGROUND RADIANCE AT THE SURFACE	.4666E+01

THETA	PHI= .0	90.0	180.0
95.0	.1741E+02	.1551E+02	.1511E+02
100.0	.1276E+02	.1171E+02	.1150E+02

105.0	.1028E+02	.9674E+01	.9571E+01
110.0	.8837E+01	.8476E+01	.8444E+01
115.0	.7928E+01	.7710E+01	.7717E+01
125.0	.6876E+01	.6805E+01	.6862E+01
135.0	.6321E+01	.6316E+01	.6397E+01
145.0	.6008E+01	.6033E+01	.6119E+01
155.0	.5832E+01	.5870E+01	.5971E+01
165.0	.5747E+01	.5781E+01	.5845E+01
175.0	.5727E+01	.5742E+01	.5756E+01

APPARENT TARGET CONTRAST

THETA	PHI= .0	90.0	180.0
95.0	-.7837E-02	-.8798E-02	-.9030E-02
100.0	-.4241E-01	-.4622E-01	-.4708E-01
105.0	-.7936E-01	-.8435E-01	-.8526E-01
110.0	-.1126E+00	-.1174E+00	-.1178E+00
115.0	-.1410E+00	-.1450E+00	-.1448E+00
125.0	-.1850E+00	-.1869E+00	-.1853E+00
135.0	-.2153E+00	-.2155E+00	-.2127E+00
145.0	-.2357E+00	-.2347E+00	-.2315E+00
155.0	-.2488E+00	-.2472E+00	-.2430E+00
165.0	-.2560E+00	-.2545E+00	-.2517E+00
175.0	-.2586E+00	-.2579E+00	-.2573E+00

APPARENT TARGET RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
TARGET ALTITUDE	.0000E+00
REFLECTIVITY	.1500E+00
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	LOCAL SHADOW
INHERENT TARGET RADIANCE	.2847E+01

THETA	PHI= .0	90.0	180.0
95.0	.1728E+02	.1538E+02	.1498E+02
100.0	.1222E+02	.1117E+02	.1095E+02
105.0	.9466E+01	.8858E+01	.8755E+01
110.0	.7842E+01	.7481E+01	.7449E+01
115.0	.6811E+01	.6592E+01	.6600E+01
125.0	.5604E+01	.5534E+01	.5591E+01
135.0	.4960E+01	.4955E+01	.5036E+01
145.0	.4591E+01	.4617E+01	.4702E+01
155.0	.4381E+01	.4419E+01	.4520E+01
165.0	.4276E+01	.4309E+01	.4374E+01
175.0	.4246E+01	.4261E+01	.4275E+01

TABLE 31 IPRF 1.0 0.0 0.0

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.0000E+00

THETA	PHI= .0	90.0	180.0
5.0	.1830E+02	.1501E+02	.8957E+01
15.0	.2937E+02	.9378E+01	.7229E+01
25.0	.5207E+02	.8440E+01	.6380E+01
35.0	.2565E+02	.7796E+01	.6026E+01
45.0	.2069E+02	.7604E+01	.6119E+01
55.0	.1267E+02	.7944E+01	.6688E+01
65.0	.1296E+02	.9040E+01	.7965E+01
75.0	.1507E+02	.1158E+02	.1064E+02
85.0	.2045E+02	.1699E+02	.1609E+02

APPARENT TARGET CONTRAST

THETA	PHI= .0	90.0	180.0
5.0	.5606E-01	.6994E-01	.1191E+00

```
 15.0    .3271E-01   .1116E+00   .1500E+00
 25.0    .1737E-01   .1224E+00   .1691E+00
 35.0    .3430E-01   .1282E+00   .1739E+00
 45.0    .4001E-01   .1229E+00   .1607E+00
 55.0    .5714E-01   .1037E+00   .1299E+00
 65.0    .4155E-01   .7000E-01   .8392E-01
 75.0    .1449E-01   .2597E-01   .2986E-01
 85.0   -.6295E-02  -.5583E-02  -.6274E-02

APPARENT TARGET RADIANCE

 SOLAR ZENITH ANGLE                                .2163E+02
 SENSOR ALTITUDE                                   .0000E+00
 TARGET ALTITUDE                                   .1500E+02
 REFLECTIVITY                                      .2500E+00
 NORMAL ZENITH ANGLE                               .1800E+03
 NORMAL AZIMUTH ANGLE                              .0000E+00
 ILLUMINATION                                     DIRECT SUNLIGHT
 INHERENT TARGET RADIANCE                          .1763E+01
 THETA   PHI=     .0        90.0       180.0
  5.0    .1933E+02   .1606E+02   .1002E+02
 15.0    .3033E+02   .1042E+02   .8313E+01
 25.0    .5298E+02   .9473E+01   .7459E+01
 35.0    .2653E+02   .8796E+01   .7074E+01
 45.0    .2152E+02   .8539E+01   .7103E+01
 55.0    .1340E+02   .8768E+01   .7557E+01
 65.0    .1350E+02   .9673E+01   .8634E+01
 75.0    .1529E+02   .1189E+02   .1096E+02
 85.0    .2032E+02   .1690E+02   .1599E+02
END OF JOB



                             END EOSAEL RUN
STOP 000
```

3.2 Example 2

3.2.1 Inputs for the second test run.

The following is the sample input file `FASCAT02.DAT`.

```
WAVL      0.55
FASCAT
IPRF      1.        0.        0.
ALBF      0.07      0.55      15.0
FACF      185.0
ZENF      0.
DAYF      11.0      190.      40.0
NTHF      0.
NLYF      7.
ISPF      4.
ZLDF      15.0      1.250     0.99999   0.714     -.613     0.963
ISPF      4.
ZLDF      10.0      1.250     .99999    0.714     -.613     0.963
ISPF      4.
ZLDF      6.0       1.250     .99999    0.714     -.613     0.963
ISPF      4.
ZLDF      3.0       1.250     .99999    0.714     -.613     0.963
ISPF      4.
ZLDF      1.3       1.250     .99999    0.714     -.613     0.963
ISPF      4.
ZLDF      0.5       1.250     .90000    0.714     -.613     0.963
ISPF      4.
ZLDF      0.0       1.250     .90000    0.714     -.613     0.963
NCLF      2.
ALTF      7.0       6.0       0.6       1.        1.
ALTF      2.5       1.5       0.3       3.        1.
NDLF      4.
DSN1      3.0       0.0       .15       0.0       0.0       1.
DSN2      0.075     0.0       0.0       1.
```

```
DSN1     3.0      0.0      .15      0.0      0.0      1.
DSN2     0.075    0.0      0.0      3.
DSN1     3.0      0.0      .15      0.0      0.0      3.
DSN2     0.075    0.0      0.0      3.
DSN1     3.0      0.0      .15      0.0      0.0      3.
DSN2     0.075    0.0      0.0      1.
NULF     1.
USN1     0.0      15.0     .25      180.0    0.0      1.
NPHF     1.
PHIF     0.0      90.0     180.0
DONE
END
STOP
TEST RUN ON 384 VERSION, H-G OPTION, DISTRIBUTION VERSION OF FASCAT
# THE FOLLOWING IS EOSAEL SOURCE CONTROL INFORMATION YOU CAN SAFELY REMOVE IT
# SCCS  @(#) FASCAT02.DAT 1.1 03/10/93
```

3.2.2 Output for the second test run

The following is the sample output file `FASCAT02.OUT`.

```
*******************************************************************************
  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.
*******************************************************************************

1




                    ********************************
                    *                              *
                    *    ELECTRO-OPTICAL SYSTEMS   *
                    *                              *
                    *  ATMOSPHERIC EFFECTS LIBRARY *
                    *                              *
                    *    NOT FOR OPERATIONAL USE   *
                    *                              *
                    * EOSAEL92 REV 1.1   03/10/93  *
                    *                              *
                    ********************************


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
1
```

```
                 *******************************
                 *                             *
                 *          F A S C A T        *
                 *                             *
                 *  ATMOSPHERIC ILLUMINATION   *
                 *                             *
                 *   NOT FOR OPERATIONAL USE   *
                 *                             *
                 * EOSAEL92 REV 1.1   03/10/93 *
                 *                             *
                 *******************************


  IPRF      1.        0.        0.
  AVERAGE SURFACE REFLECTANCE                    .7000E-01
  REPRESENTATIVE WAVELENGTH                      .5500E+00
  BASE ALTITUDE OF TOP LAYER                     .1500E+02
  EXTRATERRESTRIAL SOLAR IRRADIANCE            .185000E+03
  SOLAR ZENITH ANGLE                             .2163E+02
  LOCAL TIME (HOURS AND TENTHS)                  .1100E+02
  SOLAR AZIMUTHAL ANGLE                          .1396E+03
  JULIAN DATE                                          190
  LATITUDE                                       .4000E+02
   VIEW ANGLES
       .500E+01
       .150E+02
       .250E+02
       .350E+02
       .450E+02
       .550E+02
       .650E+02
       .750E+02
       .850E+02
       .950E+02
       .100E+03
       .105E+03
       .110E+03
       .115E+03
       .125E+03
       .135E+03
       .145E+03
       .155E+03
       .165E+03
       .175E+03
  TOTAL NUMBER OF ATMOSPHERIC LAYERS                    7

                                                             HENYEY GREENSTEIN PARAMETERS          LOWTRAN MODEL INPUT
LAYER  ISPF   ALTITUDE   SCT. RATIO    SS ALBEDO    ASYM. FACTOR   G1          G2           C         VEXT     HUMIDITY  MODEL
  1      4    .1500E+02   .1250E+01    .1000E+01                .7140E+00   -.6130E+00   .9630E+00
  2      4    .1000E+02   .1250E+01    .1000E+01                .7140E+00   -.6130E+00   .9630E+00
  3      4    .6000E+01   .1250E+01    .1000E+01                .7140E+00   -.6130E+00   .9630E+00
  4      4    .3000E+01   .1250E+01    .1000E+01                .7140E+00   -.6130E+00   .9630E+00
  5      4    .1300E+01   .1250E+01    .1000E+01                .7140E+00   -.6130E+00   .9630E+00
  6      4    .5000E+00   .1250E+01    .9000E+00                .7140E+00   -.6130E+00   .9630E+00
  7      4    .0000E+00   .1250E+01    .9000E+00                .7140E+00   -.6130E+00   .9630E+00
  TOTAL CLOUD LAYERS                                    2
  TYPE    TOP ALTITUDE       BASE ALTITUDE      AMOUNT       RELATIVE OPTICAL THICKNESS
    1       .7000E+01          .6000E+01      .6000E+00                 1
    3       .2500E+01          .1500E+01      .3000E+00                 1

  APPARENT RADIANCE AND TARGET CONTRAST FOR DOWNWARD PATH

 SENSOR   TARGET                      TARGET                                    LOCAL BACKGROUND
ALTITUDE ALTITUDE    REFLECTIVITY  NORMAL    NORMAL  ILLUMINATION        REFLECTIVITY  NORMAL  DIRECTION     ILLUMINATION
   KM       KM                     ZENITH    AZIMUTH                                   ZENITH   AZIMUTH
                                   DEGREES   DEGREES                                   DEGREES  DEGREES
  3.00      .00        .150          .00       .00   DIRECT SUNLIGHT         .075         .00      .00       DIRECT SUNLIGHT
  3.00      .00        .150          .00       .00   DIRECT SUNLIGHT         .075         .00      .00       LOCAL SHADOW
  3.00      .00        .150          .00       .00   LOCAL SHADOW            .075         .00      .00       LOCAL SHADOW
  3.00      .00        .150          .00       .00   LOCAL SHADOW            .075         .00      .00       DIRECT SUNLIGHT

  APPARENT RADIANCE AND TARGET CONTRAST FOR UPWARD PATH

 SENSOR    TARGET                         TARGET
ALTITUDE  ALTITUDE           REFLECTIVITY  NORMAL DIRECTION  ILLUMINATION
   KM        KM                            ZENITH  AZIMUTH
                                           DEGREES DEGREES
```

.00 15.00 .250 180.00 .00 DIRECT SUNLIGHT

AZIMUTH ANGLES .0 90.0 180.0

TABLE 71 IPRF 1. 0. 0.

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
REFLECTIVITY	.7500E-01
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	DIRECT SUNLIGHT
INHERENT BACKGROUND RADIANCE AT THE SURFACE	.4840E+01

THETA	PHI= .0	90.0	180.0
95.0	.8951E+01	.8635E+01	.8826E+01
100.0	.6894E+01	.6798E+01	.6944E+01
105.0	.6205E+01	.6181E+01	.6310E+01
110.0	.5864E+01	.5874E+01	.5993E+01
115.0	.5665E+01	.5695E+01	.5805E+01
125.0	.5454E+01	.5501E+01	.5597E+01
135.0	.5355E+01	.5406E+01	.5489E+01
145.0	.5308E+01	.5354E+01	.5425E+01
155.0	.5289E+01	.5327E+01	.5383E+01
165.0	.5287E+01	.5313E+01	.5348E+01
175.0	.5298E+01	.5307E+01	.5318E+01

APPARENT TARGET CONTRAST

THETA	PHI= .0	90.0	180.0
95.0	.3271E+00	.3391E+00	.3317E+00
100.0	.5549E+00	.5628E+00	.5509E+00
105.0	.6677E+00	.6703E+00	.6566E+00
110.0	.7343E+00	.7330E+00	.7184E+00
115.0	.7774E+00	.7733E+00	.7586E+00
125.0	.8279E+00	.8209E+00	.8068E+00
135.0	.8544E+00	.8465E+00	.8337E+00
145.0	.8687E+00	.8612E+00	.8499E+00
155.0	.8759E+00	.8697E+00	.8606E+00
165.0	.8786E+00	.8744E+00	.8686E+00
175.0	.8780E+00	.8764E+00	.8745E+00

APPARENT TARGET RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
TARGET ALTITUDE	.0000E+00
REFLECTIVITY	.1500E+00
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	DIRECT SUNLIGHT
INHERENT TARGET RADIANCE	.9681E+01

THETA	PHI= .0	90.0	180.0
95.0	.1188E+02	.1156E+02	.1175E+02
100.0	.1072E+02	.1062E+02	.1077E+02
105.0	.1035E+02	.1032E+02	.1045E+02
110.0	.1017E+02	.1018E+02	.1030E+02
115.0	.1007E+02	.1010E+02	.1021E+02
125.0	.9970E+01	.1002E+02	.1011E+02
135.0	.9931E+01	.9981E+01	.1006E+02
145.0	.9919E+01	.9965E+01	.1004E+02
155.0	.9922E+01	.9959E+01	.1002E+02
165.0	.9933E+01	.9958E+01	.9993E+01
175.0	.9949E+01	.9959E+01	.9970E+01

TABLE 72 IPRF 1. 0. 0.

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
REFLECTIVITY	.7500E-01
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	LOCAL SHADOW
INHERENT BACKGROUND RADIANCE AT THE SURFACE	.1320E+01

THETA	PHI= .0	90.0	180.0
95.0	.6822E+01	.6506E+01	.6697E+01
100.0	.4112E+01	.4016E+01	.4162E+01
105.0	.3192E+01	.3168E+01	.3297E+01
110.0	.2733E+01	.2743E+01	.2862E+01
115.0	.2463E+01	.2492E+01	.2603E+01
125.0	.2171E+01	.2217E+01	.2313E+01
135.0	.2028E+01	.2078E+01	.2161E+01
145.0	.1955E+01	.2001E+01	.2072E+01
155.0	.1920E+01	.1958E+01	.2014E+01
165.0	.1909E+01	.1935E+01	.1970E+01
175.0	.1915E+01	.1925E+01	.1936E+01

APPARENT TARGET CONTRAST

THETA	PHI= .0	90.0	180.0
95.0	.7413E+00	.7773E+00	.7551E+00
100.0	.1607E+01	.1645E+01	.1588E+01
105.0	.2242E+01	.2259E+01	.2170E+01
110.0	.2721E+01	.2711E+01	.2598E+01
115.0	.3089E+01	.3052E+01	.2923E+01
125.0	.3593E+01	.3517E+01	.3372E+01
135.0	.3897E+01	.3803E+01	.3657E+01
145.0	.4074E+01	.3980E+01	.3844E+01
155.0	.4167E+01	.4087E+01	.3973E+01
165.0	.4203E+01	.4147E+01	.4073E+01
175.0	.4194E+01	.4173E+01	.4149E+01

APPARENT TARGET RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
TARGET ALTITUDE	.0000E+00
REFLECTIVITY	.1500E+00
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	DIRECT SUNLIGHT
INHERENT TARGET RADIANCE	.9681E+01

THETA	PHI= .0	90.0	180.0
95.0	.1188E+02	.1156E+02	.1175E+02
100.0	.1072E+02	.1062E+02	.1077E+02
105.0	.1035E+02	.1032E+02	.1045E+02
110.0	.1017E+02	.1018E+02	.1030E+02
115.0	.1007E+02	.1010E+02	.1021E+02
125.0	.9970E+01	.1002E+02	.1011E+02
135.0	.9931E+01	.9981E+01	.1006E+02
145.0	.9919E+01	.9965E+01	.1004E+02
155.0	.9922E+01	.9959E+01	.1002E+02
165.0	.9933E+01	.9958E+01	.9993E+01
175.0	.9949E+01	.9959E+01	.9970E+01

TABLE 73 IPRF 1. 0. 0.

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
REFLECTIVITY	.7500E-01
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	LOCAL SHADOW
INHERENT BACKGROUND RADIANCE AT THE SURFACE	.1320E+01

THETA	PHI= .0	90.0	180.0
95.0	.6822E+01	.6506E+01	.6697E+01
100.0	.4112E+01	.4016E+01	.4162E+01
105.0	.3192E+01	.3168E+01	.3297E+01
110.0	.2733E+01	.2743E+01	.2862E+01
115.0	.2463E+01	.2492E+01	.2603E+01
125.0	.2171E+01	.2217E+01	.2313E+01
135.0	.2028E+01	.2078E+01	.2161E+01
145.0	.1955E+01	.2001E+01	.2072E+01
155.0	.1920E+01	.1958E+01	.2014E+01
165.0	.1909E+01	.1935E+01	.1970E+01
175.0	.1915E+01	.1925E+01	.1936E+01

APPARENT TARGET CONTRAST

THETA	PHI= .0	90.0	180.0
95.0	.1171E+00	.1228E+00	.1193E+00
100.0	.2538E+00	.2599E+00	.2507E+00
105.0	.3541E+00	.3568E+00	.3428E+00
110.0	.4298E+00	.4282E+00	.4104E+00
115.0	.4879E+00	.4820E+00	.4616E+00
125.0	.5676E+00	.5556E+00	.5326E+00
135.0	.6155E+00	.6006E+00	.5776E+00
145.0	.6434E+00	.6286E+00	.6071E+00
155.0	.6582E+00	.6456E+00	.6275E+00
165.0	.6638E+00	.6550E+00	.6433E+00
175.0	.6625E+00	.6591E+00	.6554E+00

APPARENT TARGET RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
TARGET ALTITUDE	.0000E+00
REFLECTIVITY	.1500E+00
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	LOCAL SHADOW
INHERENT TARGET RADIANCE	.2641E+01

THETA	PHI= .0	90.0	180.0
95.0	.7621E+01	.7305E+01	.7496E+01
100.0	.5156E+01	.5060E+01	.5206E+01
105.0	.4322E+01	.4298E+01	.4427E+01
110.0	.3907E+01	.3918E+01	.4037E+01
115.0	.3664E+01	.3694E+01	.3804E+01
125.0	.3402E+01	.3449E+01	.3545E+01
135.0	.3276E+01	.3326E+01	.3409E+01
145.0	.3213E+01	.3259E+01	.3330E+01
155.0	.3184E+01	.3222E+01	.3278E+01
165.0	.3176E+01	.3202E+01	.3237E+01
175.0	.3184E+01	.3194E+01	.3205E+01

TABLE 74 IPRF 1. 0. 0.

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
REFLECTIVITY	.7500E-01
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	DIRECT SUNLIGHT
INHERENT BACKGROUND RADIANCE AT THE SURFACE	.4840E+01

THETA	PHI= .0	90.0	180.0
95.0	.8951E+01	.8635E+01	.8826E+01
100.0	.6894E+01	.6798E+01	.6944E+01
105.0	.6205E+01	.6181E+01	.6310E+01
110.0	.5864E+01	.5874E+01	.5993E+01
115.0	.5665E+01	.5695E+01	.5805E+01
125.0	.5454E+01	.5501E+01	.5597E+01
135.0	.5355E+01	.5406E+01	.5489E+01
145.0	.5308E+01	.5354E+01	.5425E+01
155.0	.5289E+01	.5327E+01	.5383E+01
165.0	.5287E+01	.5313E+01	.5348E+01
175.0	.5298E+01	.5307E+01	.5318E+01

APPARENT TARGET CONTRAST

THETA	PHI= .0	90.0	180.0
95.0	-.1486E+00	-.1541E+00	-.1507E+00
100.0	-.2521E+00	-.2557E+00	-.2503E+00
105.0	-.3034E+00	-.3046E+00	-.2984E+00
110.0	-.3337E+00	-.3330E+00	-.3265E+00
115.0	-.3532E+00	-.3514E+00	-.3447E+00
125.0	-.3762E+00	-.3730E+00	-.3666E+00
135.0	-.3882E+00	-.3846E+00	-.3788E+00
145.0	-.3947E+00	-.3913E+00	-.3862E+00
155.0	-.3980E+00	-.3952E+00	-.3911E+00
165.0	-.3992E+00	-.3973E+00	-.3947E+00
175.0	-.3989E+00	-.3982E+00	-.3974E+00

APPARENT TARGET RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.3000E+01
TARGET ALTITUDE	.0000E+00
REFLECTIVITY	.1500E+00
NORMAL ZENITH ANGLE	.0000E+00
NORMAL AZIMUTH ANGLE	.0000E+00
ILLUMINATION	LOCAL SHADOW
INHERENT TARGET RADIANCE	.2641E+01

THETA	PHI= .0	90.0	180.0
95.0	.7621E+01	.7305E+01	.7496E+01
100.0	.5156E+01	.5060E+01	.5206E+01
105.0	.4322E+01	.4298E+01	.4427E+01
110.0	.3907E+01	.3918E+01	.4037E+01
115.0	.3664E+01	.3694E+01	.3804E+01
125.0	.3402E+01	.3449E+01	.3545E+01
135.0	.3276E+01	.3326E+01	.3409E+01
145.0	.3213E+01	.3259E+01	.3330E+01
155.0	.3184E+01	.3222E+01	.3278E+01
165.0	.3176E+01	.3202E+01	.3237E+01
175.0	.3184E+01	.3194E+01	.3205E+01

TABLE 31 IPRF 1. 0. 0.

APPARENT BACKGROUND RADIANCE

SOLAR ZENITH ANGLE	.2163E+02
SENSOR ALTITUDE	.0000E+00

THETA	PHI= .0	90.0	180.0
5.0	.5379E+01	.4354E+01	.3184E+01
15.0	.8302E+01	.3333E+01	.2619E+01

```
  25.0    .9620E+01   .3028E+01   .2378E+01
  35.0    .7509E+01   .2891E+01   .2319E+01
  45.0    .5887E+01   .2946E+01   .2420E+01
  55.0    .4648E+01   .3232E+01   .2741E+01
  65.0    .5159E+01   .3913E+01   .3470E+01
  75.0    .6859E+01   .5560E+01   .5217E+01
  85.0    .1263E+02   .1099E+02   .1095E+02

APPARENT TARGET CONTRAST
 THETA   PHI=     .0       90.0       180.0
   5.0    .1578E+00   .2238E+00   .3281E+00
  15.0    .5898E-01   .3061E+00   .4309E+00
  25.0    .3380E-01   .3505E+00   .4876E+00
  35.0    .7641E-01   .3710E+00   .4997E+00
  45.0    .1281E+00   .3562E+00   .4660E+00
  55.0    .1665E+00   .3039E+00   .3846E+00
  65.0    .1284E+00   .2148E+00   .2604E+00
  75.0    .5229E-01   .9567E-01   .1107E+00
  85.0   -.2864E-01  -.1856E-01  -.1842E-01

APPARENT TARGET RADIANCE

 SOLAR ZENITH ANGLE                                  .2163E+02
 SENSOR ALTITUDE                                     .0000E+00
 TARGET ALTITUDE                                     .1500E+02
 REFLECTIVITY                                        .2500E+00
 NORMAL ZENITH ANGLE                                 .1800E+03
 NORMAL AZIMUTH ANGLE                                .0000E+00
 ILLUMINATION                                       DIRECT SUNLIGHT
 INHERENT TARGET RADIANCE                            .1628E+01
 THETA   PHI=     .0       90.0       180.0
   5.0    .6229E+01   .5329E+01   .4229E+01
  15.0    .8791E+01   .4353E+01   .3748E+01
  25.0    .9946E+01   .4089E+01   .3538E+01
  35.0    .8083E+01   .3964E+01   .3478E+01
  45.0    .6641E+01   .3995E+01   .3548E+01
  55.0    .5422E+01   .4214E+01   .3795E+01
  65.0    .5821E+01   .4753E+01   .4373E+01
  75.0    .7217E+01   .6092E+01   .5795E+01
  85.0    .1227E+02   .1079E+02   .1075E+02
END OF JOB



                                END EOSAEL RUN
STOP 000
```

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