SINGLE SCATTERING CODE AGAUSX: THEORY, APPLICATIONS, COMPARISONS, AND LISTING

JULY 1980

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function; (2) cycling over a range of wavelengths; (3) treating changes in hygroscopic particle sizes; (4) treating multicomponent aerosols differing in specific gravity and/or optical properties; (5) options whereby users can either input particle number density or mass density and mass concentration; (6) various size distribution models; and (7) automatic look up and/or interpolation of optical constants for liquid water. A comparison of AGAUSX with other Mie codes is also presented.
ACKNOWLEDGEMENTS

The work reported here was supported, in part, by the US Army Atmospheric Sciences Laboratory, Battelle Columbus Laboratories, and the New Mexico State University Computer Center. The authors also acknowledge the indirect assistance provided by Dr. C. W. Querfeld through discussions of the detailed numerical procedures which formed the starting point for the analysis presented above. Discussions with Dr. R. B. Gomez are also gratefully acknowledged. Thanks are also due to C. Amacker, N. Denzler, and S. Gregersen for their aid in constructing this report.
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INTRODUCTION

The increasing need for information concerning the effects of aerosols upon electro-magnetic radiation passing through media containing these aerosols requires continual improvement of existing processes. As our understanding of these processes improves, the need for sophisticated numerical codes capable of accurately representing such theory continually increases. It is to this end that computer program AGAUSX (and its predecessors) has been constructed.

PROGRAM AGAUSX

Experience acquired over a period of several years with various versions of the single scattering codes PGAUSS and AGAUS has revealed that users of such codes often tend to be over conservative in their choice of the number of radii at which Mie calculations are performed. Many single scattering codes require that the user specify some input parameter such as the total number of radii to be used. Unless a user has had a great deal of experience with choosing such parameters for various types of size distributions, there is a tendency to use many more radii than may be needed to obtain results at acceptable levels of accuracy. Since the overall running time of Mie codes may be greatly reduced by reducing the number of particle sizes treated, it is desirable to have a code in which one specifies an acceptable level of accuracy and which then uses only as many particle radius values as are needed to satisfy that requirement. Rather than specifying the number of radii, the user of AGAUSX must specify a "convergence" level DELTA. The quantity DELTA represents the minimum fractional accuracy that is acceptable for certain results of a run. In operation, AGAUSX then runs through the Mie calculations and integrations over size using only a few particle radii and obtains first estimates of extinction coefficients, etc. The size intervals are then reduced to one-half their former value and new estimates are calculated. If the new and old estimates agree to within (DELTA x 100) percent, then AGAUSX ceases to treat additional particle sizes and proceeds to its final calculations. If the new estimate does not agree with the "old" one to within (DELTA x 100) percent, the size interval is again cut in half and the calculations and comparisons are repeated. The cycling occurs repetitively

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until either the convergence criterion is satisfied or until some pre-coded maximum number of values (513 for AGAUSX) for particle radius have been used.

It is believed that AGAUSX will represent a substantial advancement in aerosol modeling because it contains a large variety of size distributions, the possibility of modeling mixtures of aerosols with different optical properties, treats changes in particle size with variable relative humidity, is compatible with ACT+ and will probably provide substantially shorter computation times than most existing aerosol codes. In addition AGAUSX has the capability of producing an analytic phase function when quick results of intermediate accuracy are desired.

In summary, program AGAUSX is a versatile, single scattering, state of the art computer code capable of performing the following:

(1) Provisions for producing (a) phase functions, (b) Legendre coefficients or (c) scattering fractions compatible with ACT.

(2) Provisions for producing an analytic phase function represented by Legendre coefficients.

(3) Provision for automatic cycling over a range of wavelengths and averaging of results over such a range of wavelengths.

(4) Provision for treating changes in hygroscopic particle sizes which may occur with variations in relative humidity.

(5) Provision for treating multicomponent aerosols differing in specific gravity and/or optical properties.

(6) Availability of options whereby users can either define particle number densities or let them be calculated from mass density and mass concentration.

(7) Availability of options whereby users can select various size distribution models, including:

(a) Log Normal

(b) Double Exponential

(c) Dermendjian's Model C

(d) Power Laws

(e) Khirgian - Mazin

(f) Modified Gamma whose control parameters may include liquid water content

(g) Four Bimodal Log-Normal

(h) Marshall - Palmer rain model

(i) User Supplied

(8) Inclusion of an internal subroutine to provide automatic look up and/or interpolation of optical constants for liquid water at wavelengths between 0.35\,\mu m and 200\,\mu m.

(9) Inclusion of built-in internal checks to warn users if certain computed quantities seem to be failing to converge and extended error messages associated with failures in the Mle routine.

Every effort has been made to insure that program AGAUSX is machine independent. To this end AGAUSX has been written in ASCII FORTAN, and is available in the form of BCD punched deck. Should the user have any questions, discover possible inaccuracies, or simply be desirous of a punched deck, please contact R. C. Shirkey, AUTOVON 258-4200 or (505) 678-4200.
MIE THEORY

Mie theory\(^1\) predicts the scattering by and the absorption in an isolated, discrete, homogeneous, isotropic sphere of diameter \(D\) with a known complex refractive index \(n = m - ik\) relative to the surrounding medium and illuminated by monochromatic radiant energy with wavelength \(\lambda\) in the surrounding medium. The theory is given in detail in standard texts and need not be repeated here. Instead, only those elements of theory needed for an understanding of the numerical algorithms used in AGAUSX are included.

Scatterers attenuate beams of radiant energy by scattering some of the energy into directions other than the incident or forward direction and by absorbing some of the incident energy within the body of the particle. The combined effect of pure scattering by the particle and true absorption within the particle is termed extinction. The amount of extinction, scattering and absorption by a single particle is given in terms of corresponding equivalent blocking areas or cross sections, \(C_{\text{ext}}\), \(C_{\text{sca}}\), and \(C_{\text{abs}}\), respectively. These cross sections depend only on the refractive index of the particle \(n = m - ik\) and the size parameter \(\alpha = 2\pi r/\lambda\), where \(r\) is the particle radius, and \(\lambda\) is the wavelength.

The transmission, \(T\), of a cloud of particles of geometric depth, \(d\), and number density, \(N\), is given by

\[T = e^{-t},\]

(1)

\(^1\)G. Mie, 1908, "Considerations on the Optics of Turbid Media, Especially Colloidal Metal Sols," Ann Phys, 25
with the optical depth, $\tau$, given by

$$\tau = K_{\text{ext}} \cdot d,$$  \hspace{1cm} (2)

where

$$K_{\text{ext}} = N e_{\text{ext}}.$$  \hspace{1cm} (3)

The balance between loss by scattering and loss by absorption is frequently characterized by the albedo of single scattering $\omega_o$, given by

$$\omega_o = \frac{C_{\text{sca}}}{C_{\text{sca}} + C_{\text{abs}}} = \frac{C_{\text{sca}}}{C_{\text{ext}}}.$$  \hspace{1cm} (4)

A scatterer with $\omega_o = 1$ has no absorption and is termed a conservative scatterer. The albedo $\omega_o$ gives the probability that a photon encountering the scatterer will be scattered into some direction including the incident direction.

Although the extinction by a cloud of particles is correctly given by equations (1) and (2), two implicit assumptions may lead to improper use of the equations. The optical depth $\tau$ in equation (2) does not include losses caused by absorption in the medium surrounding the particles. This assumption obviously breaks down at wavelengths for which atmospheric gases absorb appreciably. The second assumption is that scattered photons never return to
the incident direction, i.e., that there is no multiple scattering. This effect becomes increasingly important as optical depths exceed $\tau = 0.1$ for broad band propagation.\textsuperscript{2,3} For laser wavelengths the effect is increasingly important as $\tau$ goes beyond a value of 15.\textsuperscript{2,3}

A final caution should be noted in regard to absorption within the particle. Although absorption within the particle is correctly determined by the wavelength-dependent imaginary part $k$ of the refractive index $n$, the explicit mechanism which causes the absorption is usually not specified. Usually the absorption is joule heating and it is sometimes necessary to account for the isotropic black body radiation emitted by the scatterer when its temperature rises above that of its surroundings. There may also be circumstances when quantum transitions occur in the scatterer followed by emission at or near the same wavelengths. It is incumbent on the user of the numerical algorithms presented here to properly include these effects since they are not automatically accounted for in these algorithms.

All scattering properties of spheres are computed from $m$ and $k$, and through the use of the induced electric and magnetic multipole moments of the sphere $a_n$ and $b_n$, respectively. The moments are given by\textsuperscript{*}

\[
a_n = \frac{\psi_n^*(\alpha) \psi_n(\alpha) - n \psi_n(\alpha) \psi_n^*(\alpha)}{\psi_n^*(\alpha) \xi_n(\alpha) - n \psi_n(\alpha) \xi_n^*(\alpha)},
\]

\textsuperscript{2}S. Hoijer, 1974, \textit{Atmospheric Attenuation of a Light Beam Due to Scattering and Absorption}, Research Institute of National Defense, FOA-2-C-2859-E1-E2-E3-E4


\textsuperscript{*}Note that $n$ is used as a subscript, an integer index, and a complex index of refraction when it is not a subscript.
and

\[ b_n = \frac{n\Psi'_n(n\alpha)\Psi_n(\alpha) - \Psi'_n(n\alpha)\Psi_n'(\alpha)}{n\Psi'_n(n\alpha)\xi'_n(\alpha) - \Psi'_n(n\alpha)\xi_n'(\alpha)}. \]  

(6)

The prime denotes differentiation with respect to the argument. The \( \Psi_n(z) \) and \( \xi_n(z) \) functions are Ricatti–Bessel functions of the first and third kind, respectively, and are related to the spherical Bessel functions \( j_n(z) \) and \( n_n(z) \) by

\[ \Psi_n(z) = zj_n(z), \]  

(7)

and

\[ \xi_n(z) = zj_n(z) - izn_n(z) = \Psi_n(z) + i\xi_n(\gamma), \]  

(8)

where

\[ j_n(z) = \left(\frac{\pi}{2z}\right)^{1/2} J_{n+1/2}(z), \]  

(9)
\[ n_n(z) = \left( \frac{\lambda}{2z} \right)^{1/2} N_{n+1/2}(z). \]  

(10)

The function \( J_{n+1/2}(z) \) is the half integral order Bessel function; the function \( N_{n+1/2}(z) \) is the half integral order Neuman function.

The extinction cross section is computed from

\[ C_{\text{ext}} = \frac{\lambda^2}{2\pi} \sum_{n=1}^{\infty} (2n+1) \Re(a_n b_n^*), \]  

(11)

and the scattering cross section from

\[ C_{\text{sca}} = \frac{\lambda^2}{2\pi} \sum_{n=1}^{\infty} (2n+1) |a_n|^2 + |b_n|^2. \]  

(12)

The various cross sections are the basic quantities used in scattering problems, but they are not the quantities usually computed directly from Mie algorithms. Instead, it is more convenient to compute dimensionless efficiency factors \( Q_{\text{ext}} \) and \( Q_{\text{sca}} \), which depend on \( n, k, \) and \( a, \) and which are multiplied by the geometrical sphere cross section to obtain the true cross section \( C_L = \pi r^2 Q_L \). Thus,
\[ Q_{\text{ext}} = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) \Re \left( a_n + b_n \right), \]  
(13)

and

\[ Q_{\text{sca}} = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) \left[ |a_n|^2 + |b_n|^2 \right]. \]  
(14)

Although the cross sections account for the energy removed from the forward beam, they do not give any information about where the scattered photons go. This information is contained in scattering amplitudes and intensity factors which relate the flux density scattered through an angle \( \theta \) relative to the incident flux density. There are two amplitudes, \( S_1(\theta) \) and \( S_2(\theta) \), and the intensity factors \( i_1(\theta) \) and \( i_2(\theta) \), which correspond to light respectively polarized perpendicular and parallel to the plane of the scattering defined by the direction of incidence and the direction of scattering.

The intensity factors are related to the scattering amplitudes by

\[ i_1(\theta) = |S_1(\theta)|^2, \]  
(15)
\[ i_2(\theta) = |S_2(\theta)|^2. \]  \hfill (16)

The amplitudes come from the multipole moments through

\[ S_1(\theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} [a_n \pi_n(\theta) + b_n \tau_n(\theta)], \]  \hfill (17)

and

\[ S_2(\theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} [b_n \pi_n(\theta) + a_n \tau_n(\theta)], \]  \hfill (18)

and angular factors \( \pi_n(\theta) \) and \( \tau_n(\theta) \) defined in terms of associated Legendre functions:

\[ \pi_n(\theta) = \frac{p^l_n(\cos \theta)}{\sin \theta}; \]  \hfill (19)
\[ \tau_n(\theta) = \frac{d\pi_n(\cos \theta)}{d\theta}. \]  

(20)

The amplitudes have relative phase \( \delta = \arg S_1 - \arg S_2 \).

Alternative expressions frequently used are

\[ \pi_n(\theta) = \frac{d\pi_n(\cos \theta)}{d(\cos \theta)}. \]  

(21)

and

\[ \pi_n(\theta) = \cos \theta \cdot \pi_n(\theta) - \sin^2 \theta \cdot \frac{d\pi_n(\theta)}{d(\cos \theta)}. \]  

(22)

where

\[ p_n(\cos \theta) = \frac{1}{2^n n!} \frac{d^n}{d\cos^n \theta} (\cos^2 \theta - 1)^n. \]  

(23)

These functions satisfy the following recurrence relations:
\[ \pi_n(\theta) = \cos \theta \frac{(2n-1)}{(n-1)} \pi_{n-1}(\theta) - \frac{n}{n-1} \pi_{n-2}(\theta), \quad (24) \]

and

\[ \tau_n(\theta) = \cos \theta \left[ \pi_n(\theta) - \pi_{n-2} \right] - (2n-1) \sin^2 \theta \pi_{n-1}(\theta) + \tau_{n-2}(\theta). \quad (25) \]

The scattering cross section measures the ability of a particle to scatter light, and it is to be expected that \( C_{\text{sca}} \) is obtained from an integral over the scattering intensity factors. Equation (12) follows from

\[ C_{\text{sca}} = \frac{\lambda^2}{4\pi} \int_{-1}^{1} [i_1(\theta) + i_2(\theta)] d\cos \theta. \quad (26) \]

Although the intensity factors themselves may be used in scattering calculations, they are primarily suited for computing flux densities, and it is frequently more convenient to measure and compute scattered light in terms of raddiances. Raddiances do not have the \( 1/r^2 \) dependence, and it is therefore unnecessary to know the distance from the scatterer to the detector if the detector field of view is small and is filled by the scattering cloud. The phase function, \( p(\theta) \), gives a radianc, \( I \), scattered into the \( \theta \) direction in terms of the radianc \( I_0 \) incident on the particle. The phase function is dimensionless and is defined here as
\[ p(\theta) = \frac{\lambda^2}{2\pi C_{\text{ext}}} \left[ i_1(\theta) + i_2(\theta) \right]. \quad (27) \]

The normalized phase function \( p(\theta) d\Omega/4 \) gives the probability of a photon being scattered through an angle \( \theta \) into an element of solid angle \( d\Omega = d\phi d(\cos \theta) \). The integral of the normalized phase function is the single scattering albedo \( \bar{\omega}_0 \), which gives the probability that the photon is scattered:

\[ \bar{\omega}_0 = \frac{1}{4\pi} \int_0^{2\pi} \int_{-1}^1 p(\theta) d\phi d\cos \theta = \frac{\lambda^2}{4\pi C_{\text{ext}}} \int_{-1}^1 [i_1(\theta) + i_2(\theta)] d\cos \theta, \quad (28) \]

or

\[ \bar{\omega}_0 = C_{\text{sca}}/C_{\text{ext}}. \quad (29) \]

The phase function contains a sum over the polarization states implicit in the \( i_1 \) and \( i_2 \) intensity factors, and is thus unsuitable for describing the polarization of the scattered light.

The phase function can also be represented by a Legendre series:

\[ p(\theta) = \sum_{\ell=0}^{n-1} \bar{\omega}_\ell P_\ell(\cos \theta), \quad (30) \]
where the Legendre expansion coefficients $\tilde{\omega}_\ell$ are given by

$$
\tilde{\omega}_\ell = \frac{(2\ell+1)}{2} \int_{-1}^{1} P(\theta) P_\ell(\cos \theta) d(\cos \theta),
$$

(31)

and $P_\ell(\cos \theta)$ are the usual Legendre polynomials.

**ANALYTIC PHASE FUNCTION**

A new analytic phase function has been constructed that approximates the computed phase function. This analytic phase function is comprised of two analytic functions; a new function up to angle $\theta_1$ and a modified Henyey-Greenstein analytic function for angles greater than $\theta_1$. This new analytic phase function is called the Goedeke-Henyey-Greenstein analytic phase function and will subsequently be referred to as the GHG phase function.

The GHG phase function has the following analytic form:

$$
\bar{P}(\mu) = \begin{cases} 
\tilde{\omega}_0 \left[ \frac{\alpha}{2} \frac{1-g^2}{(1-2\mu g^2)^{3/2}} + (1-\frac{\alpha}{2}) \frac{1}{(1-2\mu g^2)^{1/2}} \right], & \mu \gg \mu_1, \\
\tilde{\omega}_0 \beta \frac{1-g^2}{(1-2\mu g^2)^{3/2}} & \mu_1 \gg \mu \gg -1,
\end{cases}
$$

(32a,b)

where $\mu = \cos \theta$, $\tilde{\omega}_0$ is the albedo for single scattering, and $\bar{P}(\mu)$ is the phase function at $\mu$. The bar above quantities denotes approximations. Here, $g$, $\alpha$, $\beta$, $\mu_1$ are parameters that must be fixed and are evaluated as follows:
Using equation 32a as a generating function, we may write the equivalent equation

\[ \bar{P}(\mu) = \tilde{\omega}_0 \sum_{N=0}^{\infty} (\alpha N + 1) g^N P_N(\mu), \]  

(33a)

or

\[ \bar{P}(\mu) = \sum_{N=0}^{\infty} \bar{\omega}_N P_N(\mu), \]  

(33b)

where the \( P_N(\mu) \)'s are the Legendre polynomials, and again the bar above the symbols denotes approximations. Making use of equations 32a and 33a we now solve for \( \alpha \) and \( \beta \) by forcing the equations to match at \( \mu = 1 \). This is done because forward scattering is usually dominant for large Mie size parameters. Solve simultaneously

\[ \bar{P}(1) = \frac{\tilde{\omega}_0}{(1-g)^2} \left[ \frac{\alpha}{2} (1+g) + (1- \frac{\alpha}{2})(1-g) \right], \]  

(34a)
\[ \tilde{\omega}_2 = \bar{\omega}_2 = \tilde{\omega}_0 (\alpha + 1)g^2. \]  \hfill (34b)

In equation (34b) we have forced the approximate value, \( \tilde{\omega}_2 \), to equal the exact value, \( \bar{\omega}_2 \). \( \bar{\omega}_2 \) has been used, as opposed to \( \tilde{\omega}_1 \), as it was found that the match produced by \( \tilde{\omega}_1 = \tilde{\omega}_0 (\alpha + 1)g \) will not work for all cases. Since we expect that for \( \mu < \mu_1 \) the actual phase function, and therefore the HG part of the CHG phase function, is small compared to its values for \( \mu > \mu_1 \), we take the values of \( \alpha \) and \( g \), found by simultaneously solving equations 34a and b, as our working values.

Ideally \( \mu_1 \) could be found by setting equation 34a equal to zero; however, using a value of \( \mu_1 \) determined in such a manner would produce an unnatural dip in the phase function where we match 32a to 32b. Therefore we take \( \mu_1 \) to be that value of \( \mu \) for which the phase function represented by equation (32a) first goes negative (the phase function represented by equation 32a may not go negative, but dependent upon the various parameters it may). \( \beta \) is found by matching 32a to 32b at \( \mu = \mu_1 \). This yields

\[ \beta = \frac{\alpha}{2} + (1 - \frac{\alpha}{2})(1 - 2g\mu_1 + g^2)/(1 - g^2) > 0. \]  \hfill (35)

Since \( \mu_1 \) is now known a priori the value of \( \beta \) will be approximate. As \( \beta > 0 \) then \( \tilde{P}(\mu) > 0 \) for all \( \mu \) and is a continuous function of \( \mu \). We must now determine the approximate Legendre coefficients, \( \tilde{\omega}_N \). This is done by using the inversion formula
\[
\bar{\omega}_N = \frac{2N+1}{2} \int_{-1}^{1} P(\mu) P_N(\mu) d\mu.
\] (36)

If \( \mu_1 > -1 \), implying usage of the HG phase function, none of the \( \bar{\omega}_N \) will exactly match the exact or 'true' \( \tilde{\omega}_N \). Since it is most important that an approximate phase function have the correct single scattering albedo, \( \tilde{\omega}_0 \), we redefine

\[
\bar{P}(\mu) \equiv \frac{\tilde{\omega}_0}{\bar{\omega}_0} P(\mu),
\] (37)

and therefore,

\[
\bar{\omega}_N' = \frac{2N+1}{2} \int_{-1}^{1} \bar{P}(\mu) P_N(\mu) d\mu,
\] (38)

\[
= \frac{\tilde{\omega}_0}{\bar{\omega}_0} \bar{\omega}_N'.
\]

This guarantees that \( \bar{\omega}_0 = \tilde{\omega}_0 \), but because \( a, g, \) and \( b \) are approximate, \( \bar{\omega}_2 \) will not match \( \tilde{\omega}_2 \) exactly. As long as the HG part of the GHG phase is small, the mismatch between \( \bar{\omega}_2 \) and \( \tilde{\omega}_2 \) will be small.

In all the above cases it is necessary to calculate only two of the coefficients in the Legendre expansion of the phase function, \( \bar{\omega}_0 \) and \( \bar{\omega}_1 \) or \( \tilde{\omega}_0 \) and \( \tilde{\omega}_1 \). This may be done directly in terms of the \( a_n \) and \( b_n \) coefficients of the Legendre series occurring in Mie theory without evaluating the exact phase function of any angle.
We want the phase function incident for natural light to satisfy

\[
\int_{-1}^{1} \overline{P}(\mu) d\Omega = 4\pi \tilde{\omega}_0 = 2\pi \int_{-1}^{1} P(\mu) d\mu = 4\pi \frac{C_{\text{scat}}}{C_{\text{ext}}},
\]

(39)

where \( C \) is the total cross section for scattering and extinction, respectively. In the notation of van de Hulst\(^4\)

\[
C_{\text{scat}} = \frac{1}{k^2} \int F(\theta, \phi) d\Omega.
\]

(40)

So, if we put

\[
P(\mu) = \frac{K}{2\pi} \int_0^{2\pi} F(\theta, \phi) d\phi,
\]

(41)

then

\[
\int P(\mu) d\Omega = K k^2 C_{\text{scat}}.
\]

(42)

or

\[ K = \frac{4}{k^2 C_{\text{ext}}} \]  \hspace{1cm} (43)

and therefore

\[ P(\mu) = \frac{2}{k^2 C_{\text{ext}}} \int_0^{2\pi} F(\theta, \phi) d\phi. \]  \hspace{1cm} (44)

Now \( F(\theta, \phi) = i_1(\theta)\sin^2 \phi + i_2(\theta)\cos^2 \phi \), hence

\[ P(\mu) = \frac{1}{k^2 C_{\text{ext}}} \left[ i_1(\theta) + i_2(\theta) \right], \]  \hspace{1cm} (45)

where \( i_{1,2}(\theta) = \left| S_{1,2}(\theta) \right|^2 \)

and

\[ S_1(0) = S_2(0) = \frac{1}{2} \sum_{n=1}^{L_{\infty}} (2n+1) \left( a_n^* b_n + a_n b_n^* \right). \]  \hspace{1cm} (46)
Therefore,

\[ P(1) = \frac{1}{k^2 C_{\text{ext}}} \left( \frac{1}{2} \sum_{n=1}^{L} \left| (2n+1)(a_n + b_n) \right|^2 \right) = \frac{2}{k^2 C_{\text{ext}}} |S_1(0)|^2, \quad (47) \]

where

\[ C_{\text{ext}} = \frac{4\pi}{k^2} \text{Re} \left[ \frac{1}{2} \sum_{n=1}^{L} (2n+1)(a_n + b_n) \right] = \frac{4\pi}{k^2} \text{Re} \left[ S_1(0) \right]. \quad (48) \]

This allows direct calculation of \( P(1) \) in terms of \( a_n \) and \( b_n \). We now need expressions for \( \tilde{\omega}_1 \) and/or \( \tilde{\omega}_2 \) in terms of the \( a_n \) and \( b_n \). These are given by Chu and Churchill.\(^5\) In terms of the Mie coefficients \( a_n, b_n \), these expressions are:

\[ \tilde{\omega}_1 = \frac{3}{2} \sum_{n=1}^{\infty} \frac{2(n+2)}{(n+1)} (a_n a_n^* + b_n b_n^* + a_{n+1} a_{n+1}^* + b_{n+1} b_{n+1}^*) + \frac{2(2n+1)}{n(n+1)} (a_n b_n + a_n^* b_n^*), \quad (49) \]


\(^*\)There appears to be a typographical error in Chu and Churchill's work on the bottom of page 961: \( j+k-n = 2r+1 \) should read \( j+k-n = 2r-1 \).
\[ \tilde{\omega}_2 = \frac{4}{x^2 Q_{\text{ext}}} \sum_{n=1}^{\infty} \frac{5}{2} \frac{(n(n+1)-3)^2(2n+1)}{n(n+1)(2n+3)(2n-1)} \text{Re}(a_n^* a_n + b_n^* b_n) + \frac{15}{2} \frac{n(n+3)}{(2n+3)} \text{Re}(a_{n+2}^* a_{n+2} + b_{n+2}^* b_{n+2}) + \frac{15}{n+1} \frac{1}{(n+1)^2} \text{Re}(a_{n+1}^* b_n + b_{n+1}^* a_n) \]

(50)

where \( x = 2\pi r/\lambda \), \( Q_{\text{ext}} = C_{\text{ext}}/(\pi r^2) \), and \( r \) is the particle radius.

RELATIONSHIPS BETWEEN SCATTERING FRACTIONS AND PHASE FUNCTIONS

Among the objectives of the work done here was the conversion of the single scattering code AGAUS into a form which produced the types of data required by the ACT Battlefield/Smoke Obscuration Model while retaining a variety of options previously developed for AGAUS. That conversion required that AGAUS be given the additional capabilities of predicting (a) attenuation coefficients or cross sections in units of square meters per milligram of aerosol material, and (b) so-called "scattering fractions" per unit aerosol mass. In order to avoid possible confusions on the precise relationships between "scattering fractions" and the customary quantities used in Mie theory, those relationships will be summarized below before proceeding to a discussion of the evaluation of AGAUSX.

The so-called "phase functions", denoted here by \( P_f(\mu) \) and "scattering fractions" \( S_f(\theta) \) are both derived from the average scattered intensities \((I_1 + I_2)/2\) defined in Mie theory. The two quantities are related to one another for calculations associated with a single wavelength by a simple multiplicative factor, but they have different interpretations and applications.

Let \( I(\alpha, m, k, \theta) \) be the average of the intensities \( i_1(\theta) \) and \( i_2(\theta) \) for scattering at angle \( \theta \) from a sphere whose Mie-size parameter is \( \alpha = 2\pi r/\lambda \), and whose complex index of refraction is \( n = m+ik \). Furthermore, let \( n(r)dr \) be the relative number of aerosol particles with radii between \( r \) and \( (r+dr) \), and let \( Q_{\text{ext}}(\alpha, m, k) \) and \( Q_{\text{scat}}(\alpha, m, k) \) respectively be the total extinction and
scattering efficiency factors as defined by van de Hulst.⁴

Now, define the quantities \( \overline{I} \), \( \overline{C}_{\text{ext}} \) and \( \overline{C}_{\text{sca}} \) as follows:

\[
\overline{C}_{\text{ext}} = \frac{1}{N_T} \int_{r=0}^{\infty} \pi r^2 n(r) Q_{\text{ext}}(\alpha,m,k)\,dr,
\]  
(51)

\[
\overline{C}_{\text{sca}} = \frac{1}{N_T} \int_{r=0}^{\infty} \pi r^2 n(r) Q_{\text{sca}}(\alpha,m,k)\,dr,
\]  
(52)

\[
\overline{I}(\theta) = \frac{1}{N_T} \int_{r=0}^{\infty} I(\alpha,m,k,\theta)n(r)\,dr,
\]  
(53)

where

\[
N_T = \int_{r=0}^{\infty} n(r)\,dr.
\]  
(54)

The "phase function" as defined in program(s) AGAUS is given by

\[ P_f(\theta) = \frac{2}{\pi} \frac{\lambda}{C_{\text{ext}}} \bar{I}(\theta), \] \hspace{1cm} (55)

as has the property that

\[ \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} P_f(\theta) d\phi d(\cos\theta) = 4\pi \frac{C_{\text{sca}}}{C_{\text{ext}}} \approx 4\pi \bar{\omega}_0, \] \hspace{1cm} (56)

where \( \bar{\omega}_0 \) is called "the albedo for single scattering".

The "scattering fractions" \( S_f(\theta) \) are defined by

\[ S_f(\theta) = \left( \frac{\lambda}{2\pi} \right)^2 N_T \bar{I}(\theta), \] \hspace{1cm} (57)

and \( S_f(\theta) \) has the property

\[ \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} S_f(\theta) d\phi d(\cos\theta) = C_{\text{sca}} \cdot N_T = (C_{\text{sca}})_{\text{total}}, \] \hspace{1cm} (58)

wherein \( (C_{\text{sca}})_{\text{total}} \) is the total scattering cross section per unit mass of aerosol material.
Thus, it will be seen that

\[ S_f(\theta) = \left( \frac{1}{4\pi} N_T \bar{C}_{\text{ext}} \right) P_f(\theta). \]  

(59)

The ACT Model is coded with the assumption that \((C_{\text{Sca})_{\text{total}}} as derived from \(S_f(\theta) will have units of square meters per milligram. Programs AGAUS9 and AGAUSX, (see below) on the other hand are coded in what are basically CGS units. Conversion from \(I(\theta) to \(S_f(\theta) in the ACT normalization therefore requires a unit-conversion factor for \(\lambda^2 from \mu m to m, and for \(N_T from cm^{-3} to m^{-3}, i.e.,

\[ \left[ \lambda(\mu m) \right]^2 N_T (cm^{-3}) \times \left( 10^{-6} \frac{m}{\mu m} \right)^2 \times 10^6 \frac{cm}{m}^{3} \]  

(60)

Thus, a factor \(10^{-6} is required to convert the scattering fractions from the internal units of program AGAUS to the units expected by ACT.

VERIFICATION OF COMPUTER CODES

Evaluation of AGAUS9:* Once the relationships between the Mie intensities, \(i_1 and \(i_2 described above were clearly elucidated, it seemed that it would be a straightforward task to convert AGAUS from the computation of phase functions to the calculation of scattering fractions. When the appropriate conversions were completed, the new version, AGAUS9, was run using, as nearly as could be

*AGAUS9 is the parent code for AGAUSX and they basically differ only in the manner in which the number of radial increments for integration over the size distributions are chosen.
determined, the same aerosol model for which results were found in the ACT documentation.* The particular model used was a log normal distribution for white phosphorus (WP) smoke ($\bar{r} = 0.37\mu m$, $\sigma = 1.54\mu m$), 200 particle radii between minimum and maximum values of 0.005 and 1.0\mu m, respectively, a mass density of 1.87 gm/cc, a particle number density of $1.276345 \times 10^3$ cm$^{-3}$, and complex index of refraction $n = 1.43 - 0i$. Computations were performed at 7 wavelengths (0.40, 0.45, 0.50, 0.55, 0.60, 0.65 and 0.70\mu m), and the scattering fractions were arithmetically averaged over wavelength. Some of the results are presented in table 1. Only a cursory examination of that table is needed to observe that the AGAus9 results were not in very good agreement with those found in the ACT documentation. This comparison was unexpected, because the basic AGAus code had previously been found to give much better agreement with other Mie codes than is seen in table 1.

Because thorough reviews of the program listings failed to shed any light on the reasons for such large apparent discrepancies it was decided that comparisons of computations made at a single wavelength (rather than after averaging over several wavelengths) were highly desirable. The problem there was that the ACT documentation did not contain any single wavelength results. Since that avenue for testing of AGAus9 was closed, some other approach was needed, and was found through a copy of the MIE2 code.

The aerosol model used to generate table 1 was then passed through both AGAus9 and the MIE2 code using a wavelength of 0.40\mu m only. The results of those two runs are shown in table 2.**

Examination of table 2 reveals that the AGAus9 results and the MIE2 results are in much better agreement than those seen in table 1. Whereas table 2 shows discrepancies even in the first digit at many scattering angles, table 2

---

*The label ACT is used to refer to the document entitled "The Effectiveness of Obscuring Smokes," by Johnson, Forney and Dolce, and unpublished description of the JTCG/ME smoke obscuration model which was obtained from R. B. Gomez of ASL.

**The results of MIE2 have been multiplied by a factor of $10^2$ to offset different normalizations used in ACT and AGAus9.
### Table 1

Comparison of Scattering Fractions from AGAUS9 and ACT Report as Averaged for a Seven Wavelength Run

<table>
<thead>
<tr>
<th>Scattering Angle</th>
<th>Scattering Fractions</th>
<th>Scattering Fractions ACT Report</th>
</tr>
</thead>
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<tr>
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<td>0.5840074-02</td>
<td>0.530822-02</td>
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<td>Scattering Fractions</td>
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<td>4.947498-05</td>
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<tr>
<td>160°</td>
<td>8.643879-05</td>
<td>8.643865-05</td>
</tr>
<tr>
<td>170°</td>
<td>6.208783-05</td>
<td>6.208780-05</td>
</tr>
<tr>
<td>180°</td>
<td>7.644555-05</td>
<td>7.644557-05</td>
</tr>
</tbody>
</table>

*The MIE2 results have been multiplied by 10^2 to normalize them in the same way as found in the SOM document.*
shows that AGAUS9 and MIE2 agree to at least give and often six significant digits—the nominal accuracy which is used in terminating Mie series calculations in AGAUS9. The disagreements found in table 1 should be interpreted as differences either in the procedure for the integration over wavelength or the fact that a single precision version of MIE2 was used in the generation of the ACT data.

To avoid drawing erroneous conclusions on the cross-agreements between results produced by AGAUS9 and MIE2 on the basis of a single aerosol model, additional comparisons were made using a quite different aerosol model. The model chosen for this "test" was a "modified" gamma distribution:

\[ f(r) = Ar^\alpha \exp(-Br^\gamma), \quad \text{[for MIE2]} \quad (61) \]

with \( A = 1.0396 \times 10^8 \), \( \alpha = 7.5 \), \( B = 333333 \) and \( \gamma = 1.0 \). The input data used by AGAUS9 are the particle number density \( N_T \) and mode radius \( r_c \), rather than \( A \) and \( B \), but the various quantities are related to one another through:

\[ r_c = \left( \frac{\alpha}{\gamma B} \right)^{1/\gamma} \quad \text{and} \quad N_T = AB \quad \Gamma\left( \frac{\alpha + 1}{\gamma} \right). \quad (62) \]

For this comparison the minimum and maximum particle radii were taken to be 0.01\( \mu \)m and 1.5\( \mu \)m, respectively, and 200 individual values of particle radii were used. The run was made at a wavelength of 0.6\( \mu \)m using \( n = 1.53 - 0.006i \). Some results of the first runs of this type will be found in table 3.

Contrary to the excellent agreement found between MIE2 and AGAUS9, the data found in table 3 did not agree as well as had been expected being good only to about 4 digits. Further analysis indicated that the most probable source of these disagreements lay in the fact that AGAUS9 and MIE2 did not choose the
<table>
<thead>
<tr>
<th>Scattering Angle</th>
<th>Scattering Fractions</th>
<th>$I^*_{\text{avg}}$ (MIE2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0^\circ$</td>
<td>9.254421-08</td>
<td>9.254768-08</td>
</tr>
<tr>
<td>$10^\circ$</td>
<td>7.620680-08</td>
<td>7.620913-08</td>
</tr>
<tr>
<td>$20^\circ$</td>
<td>4.470319-08</td>
<td>4.470374-08</td>
</tr>
<tr>
<td>$30^\circ$</td>
<td>2.156754-08</td>
<td>2.156747-08</td>
</tr>
<tr>
<td>$40^\circ$</td>
<td>1.038258-08</td>
<td>1.038255-08</td>
</tr>
<tr>
<td>$50^\circ$</td>
<td>5.626184-09</td>
<td>5.626226-09</td>
</tr>
<tr>
<td>$60^\circ$</td>
<td>3.415889-09</td>
<td>3.415935-09</td>
</tr>
<tr>
<td>$70^\circ$</td>
<td>2.236736-09</td>
<td>2.236776-09</td>
</tr>
<tr>
<td>$80^\circ$</td>
<td>1.555144-09</td>
<td>1.555170-09</td>
</tr>
<tr>
<td>$90^\circ$</td>
<td>1.149602-09</td>
<td>1.149602-09</td>
</tr>
<tr>
<td>$100^\circ$</td>
<td>9.113908-10</td>
<td>9.114065-10</td>
</tr>
<tr>
<td>$110^\circ$</td>
<td>7.876338-10</td>
<td>7.876470-10</td>
</tr>
<tr>
<td>$120^\circ$</td>
<td>7.656564-10</td>
<td>7.656688-10</td>
</tr>
<tr>
<td>$130^\circ$</td>
<td>8.657526-10</td>
<td>8.657658-10</td>
</tr>
<tr>
<td>$140^\circ$</td>
<td>1.074210-09</td>
<td>1.074245-09</td>
</tr>
<tr>
<td>$150^\circ$</td>
<td>1.193137-09</td>
<td>1.193200-09</td>
</tr>
<tr>
<td>$160^\circ$</td>
<td>1.134702-09</td>
<td>1.134755-09</td>
</tr>
<tr>
<td>$170^\circ$</td>
<td>1.502157-09</td>
<td>1.502236-09</td>
</tr>
<tr>
<td>$180^\circ$</td>
<td>1.969069-09</td>
<td>1.969203-09</td>
</tr>
</tbody>
</table>

*The MIE2 results have been multiplied by $10^2$ to normalize them in the same way as found in the ACT document.
values of particle radii actually used in the calculation in the same way. Slight alterations to remove these differences were then made in AGAUS9, and the calculations were repeated, yielding the data presented in table 4.

In table 4 discrepancies between the AGAUS9 and MIE2 results again appear only in the fifth or sixth significant digit.

The above results indicate once again that code AGAUS9 is quite capable of yielding results which are as reliable as those of MIE2. The changes in AGAUS9 needed to bring about the level of agreement seen in table 4 involved only the choice of the values of the 200 radii used, and illustrates that the method of choosing the radii can have a significant effect on the values of the scattering fractions even when a relatively large number of radii are used. The matter will be discussed further in a subsequent section of this document.

EVALUATION OF PROGRAM AGAUSX

Introduction: In the development of the actual coding of program AGAUSX, continuous testing and comparison of results produced by the new codes and those yielded by other single scattering codes was carried out. The findings of a few such comparisons will be given next.

The supplementary codes used for evaluation of AGAUSX were the codes AGAUS9, and the code MIE2. In order to avoid the problem of deciding which of the three codes used was "correct" in the event that no two agreed well, all codes were run using aerosol models for which independent results could be found in Deirmendjian's book. The specific models used for comparison runs were Deirmendjian's cloud models C.1 and C.3 at a wavelength of 0.7μm. Additional comparison runs were made at 10.6μm using a simulated hygroscopic smoke model

---


TABLE 4

COMPARISON OF SCATTERING FRACTIONS PRODUCED BY MIE2 AND A SPECIAL VERSION†
OF AGAUS9 FOR A MODIFIED GAMMA DISTRIBUTION

<table>
<thead>
<tr>
<th>Scattering Angle</th>
<th>Scattering Fractions</th>
<th>I* (MIE2) avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>9.254772-08</td>
<td>9.254768-08</td>
</tr>
<tr>
<td>10°</td>
<td>7.620918-08</td>
<td>7.620913-08</td>
</tr>
<tr>
<td>20°</td>
<td>4.470380-08</td>
<td>4.470374-08</td>
</tr>
<tr>
<td>30°</td>
<td>2.156751-08</td>
<td>2.156747-08</td>
</tr>
<tr>
<td>40°</td>
<td>1.038257-08</td>
<td>1.038255-08</td>
</tr>
<tr>
<td>50°</td>
<td>5.626233-09</td>
<td>5.626226-09</td>
</tr>
<tr>
<td>60°</td>
<td>3.415938-09</td>
<td>3.415935-09</td>
</tr>
<tr>
<td>70°</td>
<td>2.336777-09</td>
<td>2.336776-09</td>
</tr>
<tr>
<td>80°</td>
<td>1.555171-09</td>
<td>1.555170-09</td>
</tr>
<tr>
<td>90°</td>
<td>1.149623-09</td>
<td>1.149622-09</td>
</tr>
<tr>
<td>100°</td>
<td>9.114071-10</td>
<td>9.114065-10</td>
</tr>
<tr>
<td>110°</td>
<td>7.876480-10</td>
<td>7.876470-10</td>
</tr>
<tr>
<td>120°</td>
<td>7.656697-10</td>
<td>7.656688-10</td>
</tr>
<tr>
<td>130°</td>
<td>8.657668-10</td>
<td>8.657658-10</td>
</tr>
<tr>
<td>140°</td>
<td>1.074245-09</td>
<td>1.074245-09</td>
</tr>
<tr>
<td>150°</td>
<td>1.193200-09</td>
<td>1.193200-09</td>
</tr>
<tr>
<td>160°</td>
<td>1.134755-09</td>
<td>1.134755-09</td>
</tr>
<tr>
<td>170°</td>
<td>1.502236-09</td>
<td>1.502236-09</td>
</tr>
<tr>
<td>180°</td>
<td>1.969203-09</td>
<td>1.969203-09</td>
</tr>
</tbody>
</table>

†Particle radii selected the same way as in MIE2.

*The MIE2 results have been multiplied by 10² to normalize them in the same way as found in the SOM document.
and several values of relative humidity. The latter comparisons involved only program AGAUS9 and AGAUSX. The objectives of all comparisons were not only to show that AGAUSX was working properly, but also to determine whether or not it would, in fact, offer significant reductions in overall running time.

Water Cloud Model Comparisons: Comparison runs of codes AGAUS9, AGAUSX and MIE2 for cloud models C.1 and C.3 were made using the same range of radii quoted for Deirmendjian's tables T.36 and T.30. In order to assure that any conclusions drawn about relative computation times would be valid in the context of ACT usage, scattering fractions were calculated at 2° increments between scattering angles of 0° and 180° in these runs. AGAUSX was also run for model C.1 using several different values of the convergence level DELTA.

Table 5 presents some of the results obtained for cloud model C.1. The scattering fraction entries for the "Deirmendjian" column were obtained by averaging his \(P_1\) and \(P_2\), and multiplying by the appropriate conversion factor. The AGAUSX run listed used \(\text{DELTA} = 0.01\). Examination of the tabulated data shows that none of the three runs yields exactly the same extinction coefficient that was printed by Deirmendjian, but all were within 0.3 percent of his results. Unfortunately, Deirmendjian's table T.36 did not include angles at 2° increments, so only forward and backward scattering fractions could be inferred accurately. It will be seen that all three codes gave scattering fractions which agreed well in the \(\theta = 0°\) direction, but the results are obviously not identical. The variations are, however, quite a bit larger at other scattering angles, although the variations are not terribly large when their magnitudes are compared to that of the forward scattering. For this particular model, it will be noted that AGAUSX convergence criterion led to its use of more radii than were used with the other codes. It will also be seen that MIE2 handled the 40 radii faster than did AGAUS9. MIE2's speed advantage over AGAUS9 probably results from the fact that MIE2 used non-uniform spacing of particle radii—a procedure which leads to a significantly smaller number of Mie calculations which must be done at large Mie size-parameters.
TABLE 5

COMPARISONS OF RESULTS AND CPU TIMES FOR THREE SINGLE SCATTERING CODES -

CLOUD MODEL C.1. (λ = 0.7µm)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>AGAUS9</th>
<th>AGAUSX</th>
<th>MIE2</th>
<th>Deirmendjian T.36</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Δ=0.01)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K_{ext} (km⁻¹)</td>
<td>16.7512</td>
<td>16.7223</td>
<td>16.780</td>
<td>16.73</td>
</tr>
<tr>
<td>K_{sca} (km⁻¹)</td>
<td>16.7512</td>
<td>16.7223</td>
<td>16.780</td>
<td>16.73</td>
</tr>
</tbody>
</table>

Scattering Fractions

<table>
<thead>
<tr>
<th>Angle</th>
<th>AGAUS9</th>
<th>AGAUSX</th>
<th>MIE2</th>
<th>Deirmendjian T.36</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>2.2438E0</td>
<td>2.2404E0</td>
<td>2.2534E0</td>
<td>2.237E0</td>
</tr>
<tr>
<td>44°</td>
<td>1.952E-3</td>
<td>1.784E-3</td>
<td>1.0875E-3</td>
<td></td>
</tr>
<tr>
<td>90°</td>
<td>6.1552E-5</td>
<td>4.8011E-5</td>
<td>5.6898E-5</td>
<td></td>
</tr>
<tr>
<td>136°</td>
<td>1.8252E-4</td>
<td>1.9026E-4</td>
<td>2.1120E-4</td>
<td></td>
</tr>
<tr>
<td>180°</td>
<td>8.9722E-4</td>
<td>8.3856E-4</td>
<td>8.9161E-4</td>
<td>8.457E-4</td>
</tr>
</tbody>
</table>

CPU Time (Seconds)

<table>
<thead>
<tr>
<th></th>
<th>AGAUS9</th>
<th>AGAUSX</th>
<th>MIE2</th>
<th>Deirmendjian T.36</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>86.86</td>
<td>82.81</td>
<td>75.35</td>
<td></td>
</tr>
</tbody>
</table>

No. of Radii

<table>
<thead>
<tr>
<th></th>
<th>AGAUS9</th>
<th>AGAUSX</th>
<th>MIE2</th>
<th>Deirmendjian T.36</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
<td>50</td>
<td>40</td>
<td>440</td>
</tr>
</tbody>
</table>

*NOTE: AGAUS9 and AGAUSX scattering fractions at 0°, when converted to phase functions have values of 1683, as compares to Deirmendjian's values of 1680.
It should be noted that the version of AGAUSX used in generating results shown in table 5 performed its "convergence test" on the total aerosol volume and not on the scattering fractions. (Results obtained by checking on both volume and the scattered intensity at 90° will be given below.)

Although AGAUSX appears to offer no computation speed advantage if the user knows how many radii are "enough", it does have the useful feature (not found in either MIE2 or AGAUS9) of giving the user some idea of how many radii were really required to achieve some minimum level of confidence in its results.

By repeating runs of AGAUSX and model C.1 using various values of DELTA, it has been possible to learn more about the sensitivities of the extinction coefficient and scattering fractions to the number of radii used in a calculation. Table 6 contains the results of a few runs of that type. The first four entries represent runs in which the quantity which was tested for convergence was the total volume of the aerosol particles.* The fifth and sixth entries are the results of runs in which testing was done on both volume and the scattered intensity at 90°; note that the sixth entry represents a run at 45° increments rather than 2° increments.

Examination of table 6 shows that the value of the extinction coefficient is not nearly as sensitive to the choice of particle radius values as are the scattering fractions at fairly large scattering angles, especially near 90°. The 90° results show "oscillations" of as much as 15 percent as the number of radii changes through the set (26, 50, 66, 98, 130, and 513).

It should also be noted that AGAUS9 and MIE2 runs shown in table 5 used only 40 radii, while Deirmendjian evidently used 440 radii. Even with that vastly larger number of radii, Deirmendjian's results are not so different from the present results to warrant, in many applications, an additional increase in computation time of a factor of eleven.

---

*Volume was used rather than extinction cross-section because its R^3 dependence appeared to make it a "more sensitive" test quantity.
TABLE 6

COMPARISON OF AGAUSX RESULTS OBTAINED WITH FOUR CONVERGENCE TEST LEVELS

USING CLOUD MODEL C.1. (λ = 0.7 μm)

<table>
<thead>
<tr>
<th>Convergence Level</th>
<th>NRADI</th>
<th>CPU (Seconds)</th>
<th>$K_{ext}$(km$^{-1}$)</th>
<th>Scattering Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0°</td>
</tr>
<tr>
<td>0.05</td>
<td>26</td>
<td>45.28</td>
<td>17.47</td>
<td>2.4521E0</td>
</tr>
<tr>
<td>0.01</td>
<td>50</td>
<td>82.81</td>
<td>16.72</td>
<td>2.2404E0</td>
</tr>
<tr>
<td>0.005</td>
<td>66</td>
<td>127.93</td>
<td>16.74</td>
<td>2.2395E0</td>
</tr>
<tr>
<td>0.001</td>
<td>130</td>
<td>245.13</td>
<td>16.73</td>
<td>2.2370E0</td>
</tr>
</tbody>
</table>

*0.05  | 98    | 220.91        | 16.73                | 2.2369E0 | 1.1814E-3 | 5.5012E-5 | 1.9213E-4 | 8.3975E-4 |
**0.005| 513   | 143.73        | 16.75                | 2.2411E0 | 5.5880E-5 | 8.8647E-5 |

NOTES: (a) In these runs, the quantity which was tested for convergence was the total volume of the aerosol particles.
(b) In these runs, scattering fractions were calculated at 2° increments.

*Special Version of AGAUSX with convergence checks on scattered intensity at 90° as well as on volume.
**Similar to * case, but only 5 angles used.
A similar set of comparative results obtained for cloud model C.3 are presented in table 7. For this model, AGAUS9 and MIE2 were run with the same number of radii as was used by Deirmendjian. This example illustrates the way in which AGAUSX can offer definite decreases in CPU time over codes requiring the user to make an a priori decision as to the number of radii needed. Using only 66 radii, AGAUSX produced an extinction coefficient to within better than 1 percent of Deirmendjian's value (with which AGAUS9 and MIE2 results are identical to the four digits given by Deirmendjian). AGAUSX, (with DELTA = 0.01), however, ran nearly four times faster than either AGAUS9 or MIE2. Furthermore, the AGAUSX run at DELTA = 0.01 yielded scattering fractions which, at worst, differed from those found by AGAUS9 and MIE2 by the order of 10 percent.

Cloud models such as C.1 and C.3 used at short wavelengths (≈ visible) are severe tests of single scattering codes because they typically involve some rather large Mie size-parameters (α ≈ 110 for the C.1 model). Calculations performed at infrared wavelengths for smaller particles than found in typical clouds are not quite so demanding. That fact is illustrated partially, by tables 8 and 9, which were compiled using a hypothetical model for a hygroscopic smoke having the particle size-distribution of white phosphorous smoke. The model used here was denoted as model A' in an earlier document. Table 8 shows extinction coefficients obtained from AGAUS9 (using 100 radii), and AGAUSX (using DELTA = 0.01) at seven different values of relative humidity. It also presents the results of a run of a special version of AGAUSX (labeled AGAUSXL) in which the Mie routine DOWN42 was used instead of routine MIEGEX. It will be seen that AGAUSX (and AGAUSXL) needed only 34 radii to reach extinction coefficients within 0.2 percent of those found by AGAUS9, but the AGAUS9 run used 340 percent more computer time than did AGAUSX. AGAUSXL's results were quite close to those of AGAUSX, but the relative slowness of DOWN42 brought the total time to treat 34 radii up to nearly the same time needed by AGAUS9 to treat 100 radii.

---

### Table 7
COMPARISONS OF RESULTS AND CPU TIMES FOR THREE SINGLE SCATTERING CODES -
CLOUD MODEL C.3 ($\lambda = 0.7\mu m$)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>AGAUS9</th>
<th>AGAUSX*</th>
<th>MIE2</th>
<th>Deirmendjian T.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{ext}$ (km$^{-1}$)</td>
<td>3.0212</td>
<td>3.0078</td>
<td>3.0182</td>
<td>3.021</td>
</tr>
<tr>
<td>$K_{sca}$ (km$^{-1}$)</td>
<td>3.0212</td>
<td>3.0078</td>
<td>3.0182</td>
<td>3.021</td>
</tr>
</tbody>
</table>

Scattering Fractions*:

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>AGAUS9</th>
<th>AGAUSX*</th>
<th>MIE2</th>
<th>Deirmendjian T.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0^\circ$</td>
<td>5.3970E-2</td>
<td>5.3569E-2</td>
<td>5.3966E-2</td>
<td>5.3946E-2</td>
</tr>
<tr>
<td>$44^\circ$</td>
<td>2.1276E-4</td>
<td>2.1398E-4</td>
<td>2.1220E-4</td>
<td>2.1182E-4</td>
</tr>
<tr>
<td>$90^\circ$</td>
<td>2.0787E-5</td>
<td>2.1668E-5</td>
<td>2.2180E-5</td>
<td>2.0366E-5</td>
</tr>
<tr>
<td>$136^\circ$</td>
<td>3.5852E-5</td>
<td>3.2756E-5</td>
<td>3.4983E-5</td>
<td>3.5562E-5</td>
</tr>
<tr>
<td>$180^\circ$</td>
<td>2.0350E-4</td>
<td>1.7792E-4</td>
<td>1.9798E-4</td>
<td>2.0269E-4</td>
</tr>
</tbody>
</table>

CPU Time* (Seconds):

<table>
<thead>
<tr>
<th></th>
<th>AGAUS9</th>
<th>AGAUSX*</th>
<th>MIE2</th>
<th>Deirmendjian T.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>289.79</td>
<td>71.49</td>
<td>131.5</td>
<td>266.36</td>
<td></td>
</tr>
</tbody>
</table>

No. of Radii: 280, 66, 130, 280, 280

*NOTES: (a) All runs calculated Scattering Fractions at $2^\circ$ increments between $0^\circ$ and $180^\circ$.
(b) The quantity tested for convergence was the total aerosol volume.
**TABLE 8**

**COMPARISONS OF RESULTS FROM PROGRAMS AGAUS9 AND AGAUSX**

**FOR SMOKE MODEL A' AT \( \lambda = 10.6 \mu m \) (Relative humidity = 0%)**

<table>
<thead>
<tr>
<th>Relative Humidity (percent)</th>
<th>AGAUS9 (100 radii)</th>
<th>Extinction Coefficients (per km)</th>
<th>AGAUSX (34 radii)</th>
<th>AGAUSXL (34 radii)</th>
<th>%Difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1838</td>
<td>0.1835</td>
<td>0.1835</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>0.2801</td>
<td>0.2797</td>
<td>0.2797</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>0.3020</td>
<td>0.3016</td>
<td>0.3016</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>0.3340</td>
<td>0.3335</td>
<td>0.3335</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>0.3887</td>
<td>0.3882</td>
<td>0.3882</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>95</td>
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<td>0.5343</td>
<td>0.5343</td>
<td>0.15</td>
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<tr>
<td>99</td>
<td>1.9295</td>
<td>1.9268</td>
<td>1.9268</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

| TOTAL CPU TIME             | 34.34 sec          | 9.83 sec                         | 34.98 sec          | 71.4               |

*NOTE: Percent differences are: \( \frac{|(AGAUS9 - AGAUSX)/AGAUS9| \times 100} \)
### TABLE 9

COMPARISON OF AGAUSX RESULTS FOR FOUR DIFFERENT CONVERGENCE LEVELS
AND A SIMULATED SMOKE MODEL - $\lambda = 10.6\mu m$ (Relative humidity = 0%)

<table>
<thead>
<tr>
<th>Convergence Level (DELTA)</th>
<th>No. of Radii Used</th>
<th>$K_{\text{ext}} ($km$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.05</td>
<td>18</td>
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<td>1.8353</td>
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<td>50</td>
<td>1.8345</td>
</tr>
<tr>
<td>.001</td>
<td>130</td>
<td>1.8377</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Convergence Level (DELTA)</th>
<th>Scattering Fractions</th>
<th>$\theta = 0^\circ$</th>
<th>$\theta = 90^\circ$</th>
<th>$\theta = 180^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>.05</td>
<td>1.5574E-6</td>
<td>6.9366E-7</td>
<td>1.2326E-6</td>
<td></td>
</tr>
<tr>
<td>.01</td>
<td>1.5610E-6</td>
<td>6.9555E-7</td>
<td>1.2365E-6</td>
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</tr>
<tr>
<td>.005</td>
<td>1.5605E-6</td>
<td>6.9533E-7</td>
<td>1.2361E-6</td>
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</tr>
<tr>
<td>.001</td>
<td>1.5621E-6</td>
<td>6.9613E-7</td>
<td>1.2376E-6</td>
<td></td>
</tr>
</tbody>
</table>
Table 9 demonstrates how the user's choice of DELTA affected runs of the simulated smoke model at a relative humidity of 0 percent. For that model, changes in the number of radii from 18 to 130 (a factor of seven) did not change either the extinction coefficient or the scattering fractions by more than 0.3 percent.

Discussion: One of the decisions which had to be made for program AGAUSX was that of determining just which "quantity" or set of quantities should be used in the test for convergence to within the level DELTA. The one which was finally chosen was the total volume of the aerosol particles. The volume was chosen because, being dependent on the cube of the radii, it might be a little more conservative choice than the extinction coefficient, although, as seen in tables 5 and 6, it is a less conservative test quantity than the scattered intensity at $\theta = 90^\circ$. Present experience is limited, but the use of the volume seems to be a good compromise unless highly precise scattering fractions are needed. If the latter situation arises in a particular application, users of the code should have no difficulty in coding in their own preferred test quantity. The quantities which are available at present are extinction, scattering, backscattering cross sections, and the average intensities at various angles. Careful study of the source listing for subroutine AGXPT2 will reveal how such changes can be made.

A major surprise which was revealed by these studies was the fact that the code MIE2 used less computer time to handle cloud models C.1 and C.3 than AGAUS9 needed (for the same number of radii). The reason for the surprise was that the basic Mie routine DOWN42 used by MIE2 was known to be usually appreciably slower than routine MIEGX. It was in fact, that difference in speed which caused AGAUSXL (see above, and table 8) to require more than three times as long to treat the smoke model than AGAUSX needed. The reason for MIE2's evident computation time advantage over AGAUS9 has been alluded to above, and appears to be the result of the differences in the ways in which the values of radii (at which the Mie calculations are to be done) are chosen in the two codes. In MIE2, the interval between successive values of particle radius is doubled as each additional value is assigned (at least for the generalized Khirgian-Mazin distribution), while AGAUS9 uses a constant increment. The MIE2 method therefore uses far fewer large values of radius
than the AGAUS9 method does. That difference, and the fact that the time required within the Mie subroutines DOWN42 and MIEGX increases rapidly with the size to wavelength ratio, appears to account for MIE2's (small) running time advantage over AGAUS9. That difference in how the radii are chosen definitely accounts for the disagreements between the MIE2 and AGAUS9 values for the scattering fractions for cloud models C.1 and C.3 (that disagreement is quite appreciable in table 5 in some cases). The latter conclusion has been verified by direct runs with a version of AGAUS9 which uses the MIE2 method for choosing the radii (the AGAUS9/MIE2 disagreements moved out to the fifth or sixth digit). The running time on a UNIVAC 1108 of the special version of AGAUS9 was 240 seconds as compared to 266 seconds for MIE2, demonstrating that the use of fewer large radii significantly decreases running time.

The questions raised above are, however, made somewhat academic by AGAUSX for many applications requiring single scattering calculations because of AGAUSX's clear speed advantage in handling distributions for which no a priori guide as to how many radii will be "enough" is available.

SOME EFFECTS OF THE NUMER OF SIZE INTERVALS USED IN AGAUSX

In the early development of AGAUSX, it was tentatively assumed that computation times might be substantially reduced by breaking the total ranges of radius values to be treated into more than one "size-interval" and then performing the halving calculations and tests separately within each size interval. That assumption was based upon the belief that the use of a single interval could result in unneeded computations in some size ranges brought about by slow convergence in other ranges. Consequently, all types of distribution functions which were known to be "peaked" were split into two size intervals: (a) one with radii smaller than the one at which the distribution was a maximum, and (b) one containing all larger values of particle radii. In some of the test runs, however, it was found that the interval containing the smaller radii required more halvings than the other interval, but contributed only a small fraction of the total extinction effects—thereby wasting computation time.
The effect of using just a single size interval, instead of two intervals, has been briefly explored using a special version of AGAUSX, and Deirmendjian's cloud models C.1 and C.3 at $\lambda = 0.7\mu m$. Computations were made with several different values for the convergence level ($\Delta$). Table 10 compares some of the results found with the special version (AGAUS1OS) and the regular version. The scattering fraction computations were made at $2^\circ$ increments in most cases shown in the table, and the column labeled "NI" explicitly shows the number of size intervals used. Also shown and labeled "REF CASE", are the results obtained with an AGAUSX run which used all 513 available values of particle radii.

The results seen in table 10 indicate that the special version (AGAUS1OS) required only one-third to one-half as much computation time to satisfy the different convergence levels as AGAUSX needed. It thus appears that the initial assumption that two intervals would be preferable to one interval may be false. However, a closer examination of the table shows that AGAUS1OS yielded substantially large scattering fractions (away from 0°) than did AGAUSX, with the latter code's values being closer to the "REF CASE" values at all choices of $\Delta$.

About the only conclusions which can be drawn at this point are that the NI = 1 version is by far the most efficient when only $k_{ext}$ is of interest, and that the NI = 2 version is preferable, in spite of its slower speed, if high accuracies are needed for the scattering fractions at large scattering angles. From another vantage point, however, the discrepancies between the NI = 1 and NI = 2 scattering fractions at $\theta = 90^\circ$ and $\theta = 180^\circ$ are an insignificant fraction of the $\theta = 0$ values.

A few similar comparisons for Deirmendjian's cloud model C.3 at $\lambda = 0.7\mu m$ are given in table 11.

Comparison of Results for the Analytic Phase Functions: Two models have been chosen to compare the two analytic phase functions, Henyey-Greenstein and Goedcke-Henyey-Greenstein with the 'true' or computed phase function. These models and selected wavelengths at which comparisons were made are: simulated
<table>
<thead>
<tr>
<th>DELTA</th>
<th>*</th>
<th>NI</th>
<th>NRADI</th>
<th>$K_{ext}$</th>
<th>CPU</th>
<th>0°</th>
<th>90°</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>2</td>
<td>26</td>
<td>17.47</td>
<td>45.28</td>
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<td>5.2019E-5</td>
<td>7.4914E-4</td>
</tr>
<tr>
<td>0.05</td>
<td>b</td>
<td>1</td>
<td>9</td>
<td>16.70</td>
<td>21.06</td>
<td>2.2353</td>
<td>6.9736E-5</td>
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</tr>
<tr>
<td></td>
<td>c</td>
<td>1</td>
<td>9</td>
<td>16.70</td>
<td>note-d</td>
<td>2.2353</td>
<td>6.9736E-5</td>
<td>1.2946E-3</td>
</tr>
<tr>
<td></td>
<td>a</td>
<td>2</td>
<td>50</td>
<td>16.72</td>
<td>82.81</td>
<td>2.2404</td>
<td>4.8011E-5</td>
<td>8.3856E-4</td>
</tr>
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<td>1</td>
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<td>38.72</td>
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<td>7.0311E-5</td>
<td>1.0222E-3</td>
</tr>
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<td></td>
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<td>9.1422E-3</td>
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<td>2.2395</td>
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<tr>
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<td>17</td>
<td>16.77</td>
<td>37.78</td>
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<td>7.0311E-5</td>
<td>1.0222E-3</td>
</tr>
<tr>
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<td>130</td>
<td>16.73</td>
<td>245.13</td>
<td>2.2370</td>
<td>5.4473E-5</td>
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<tr>
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<td>b</td>
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<td>75.71</td>
<td>2.2393</td>
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<td>&quot;Reference&quot;</td>
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<td>513</td>
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<td>note-d</td>
<td>2.2411</td>
<td>5.5880E-5</td>
<td>8.8647E-4</td>
</tr>
</tbody>
</table>

Deirmendjian | 1 | 440 | 16.73 | 2.2370 | 8.457E-4 |

*NOTES: (a) "Normal" AGAUXS convergence tests on aerosol volume; 2 size intervals. (b) AGAUS10S; convergence tests on extinction coefficient; 1 size interval. (c) AGAUS10S; convergence tests on extinction coefficient and scattered intensity at $\theta = 90^\circ$; number of size intervals given in column labeled "NI". (d) 45° angular increment runs; CPU times not directly comparable to other runs made at 2° increments.
TABLE 11

COMPARISON OF AGAUX RESULTS FOR CLOUD MODEL C.3 (λ = 0.7μm) USING ONE
AND TWO SIZE INTERVALS, SEVERAL CONVERGENCE LEVELS AND CONVERGENCE TESTS
ON EXTINCTION COEFFICIENT AND SCATTERING FRACTIONS AT 90°

<table>
<thead>
<tr>
<th>DELTA</th>
<th>NI</th>
<th>NRADI</th>
<th>K_ext</th>
<th>CPU(a)</th>
<th>0°</th>
<th>90°</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
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<td>1</td>
<td>33</td>
<td>3.042</td>
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<td>2.5350E-4</td>
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</tr>
<tr>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
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<td>68.71</td>
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</tr>
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<td>66</td>
<td>3.008</td>
<td>71.49</td>
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<td>2.1668E-5</td>
<td>1.7792E-4</td>
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<td>65</td>
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<td>72.67</td>
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<td>2.3498E-4</td>
<td></td>
</tr>
<tr>
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<td>--</td>
<td>--</td>
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<td>--</td>
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<td>--</td>
<td>--</td>
</tr>
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<td>3.015</td>
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</tr>
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<td>129</td>
<td>3.041</td>
<td>16.86</td>
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<td>2.1382E-5</td>
<td>2.3500E-4</td>
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<td>513</td>
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<td>62.83</td>
<td>5.3985E-2</td>
<td>2.0643E-5</td>
<td>2.0382E-4</td>
</tr>
<tr>
<td>Deirmendjian</td>
<td>280</td>
<td>3.021</td>
<td>5.396E-2</td>
<td>--</td>
<td>2.025E-4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scattering Fractions

<table>
<thead>
<tr>
<th>DELTA</th>
<th>NI</th>
<th>NRADI</th>
<th>K_ext</th>
<th>CPU(a)</th>
<th>0°</th>
<th>90°</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
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<td>--</td>
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<td>--</td>
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<td>--</td>
<td>--</td>
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<td>68.71</td>
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<td>3.008</td>
<td>71.49</td>
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<td>1.7792E-4</td>
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<td>65</td>
<td>3.041</td>
<td>72.67</td>
<td>5.4583E-2</td>
<td>2.2435E-5</td>
<td>2.3498E-4</td>
<td></td>
</tr>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<td>65</td>
<td>3.041</td>
<td>72.06</td>
<td>5.4583E-2</td>
<td>2.2435E-5</td>
<td>2.3498E-4</td>
<td></td>
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<tr>
<td>0.001</td>
<td>2</td>
<td>130</td>
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<td>5.3796E-2</td>
<td>2.2180E-5</td>
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<td>3.021</td>
<td>5.396E-2</td>
<td>--</td>
<td>2.025E-4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES:  
(a) CPU times in seconds, using 2° angular increments.
(b) Not comparable to other runs due to use of 45° increments.
(c) Cases for which dashes (---) appear were not run for NI=2
and convergence tests on both $K_{ext}$ and the scattered intensity
at $\theta = 90°$. 

54
white phosphorus\textsuperscript{7} at 1.06 and 10.6 microns; fog model WSMRF2 at wavelengths of 2.5, 10.0 and 11.0 microns; the parameters for each of the two fog models are tabulated below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius, Minimum</td>
<td>0.4 \mu m</td>
</tr>
<tr>
<td>Radius, Maximum</td>
<td>12.0 \mu m</td>
</tr>
<tr>
<td>Radius, Mode</td>
<td>4.0 \mu m</td>
</tr>
<tr>
<td>Alpha</td>
<td>6.0</td>
</tr>
<tr>
<td>Gamma</td>
<td>1.0</td>
</tr>
<tr>
<td>Particle Density</td>
<td>100.0 \text{cm}^{-3}</td>
</tr>
</tbody>
</table>

Values of the analytical phase functions HG and GHG, along with the computed phase functions are presented graphically in figures 1 through 5. A visual inspection of these figures shows that the GHG analytic phase function matches the computed phase function far better than the HG phase function near zero degrees, and that the GHG function apparently provides a better overall fit to the computed phase function than the HG function. Because the scales of the graphs usually do not permit sufficient resolution near 180°, the values of the computed and analytic phase functions are presented in table 12 at selected angles. Table 12 also presents the differences between the computed and analytic phase functions at the selected angles, and also the root mean square error for the points considered.

**Discussion:** Inspection of table 12 shows that the GHG analytic phase function is superior to the HG analytic phase function at angles near zero degrees.

Figure 1. Comparison of analytic phase functions HG and GHG with computed phase function for simulated white phosphorous at 1.06μm.

Figure 2. Comparison of analytic phase functions HG and GHG with computed phase function for simulated white phosphorous at 10.6μm.
Figure 3. Comparison of analytic phase functions HG and GHG with computed phase functions for fog model WSMRF2 at 2.5μm.

Figure 4. Comparison of analytic phase functions HG and GHG with computed phase functions for fog model WSMRF2 at 10.0μm.
Figure 5. Comparison of analytic phase functions HG and GHG with computed phase function for fog model WSMRF2 at 11.0\(\mu\)m.
TABLE 12
COMPARISON OF COMPUTED AND ANALYTIC PHASE FUNCTION VALUES AT SELECTED ANGLES FOR FOG MODEL WSMRF2 AND SIMULATED WHITE PHOSPHOROUS AT VARIOUS WAVELENGTHS

<table>
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<th>Wavelength (μm)</th>
<th>Model WSMR F2</th>
<th>Phase Function Values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5μm</td>
<td></td>
<td>True †</td>
</tr>
<tr>
<td>Angle(°)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.51</td>
<td>134.80</td>
<td>68.17</td>
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<tr>
<td>25.08</td>
<td>3.59</td>
<td>3.56</td>
</tr>
<tr>
<td>50.66</td>
<td>.49</td>
<td>.55</td>
</tr>
<tr>
<td>74.26</td>
<td>.13</td>
<td>.20</td>
</tr>
<tr>
<td>99.84</td>
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<td>.10</td>
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<td>125.41</td>
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<td>.09</td>
<td>.05</td>
</tr>
<tr>
<td>174.58</td>
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<td>.05</td>
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<tr>
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<td>.23</td>
<td>.05</td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Wavelength (μm)</th>
<th>Model WSMR F2</th>
<th>Phase Function Values*</th>
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</thead>
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<td>True †</td>
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</tr>
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<td>60.63</td>
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<tr>
<td>50.66</td>
<td>.38</td>
<td>.30</td>
</tr>
<tr>
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Table 12 (cont)

<table>
<thead>
<tr>
<th>Wavelength (μm)</th>
<th>Model WSMR F2</th>
<th>Phase Function Values*</th>
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<tr>
<td>Angle(°)</td>
<td>True†</td>
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<td>11.00</td>
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7.99           | .27

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<tr>
<th>Wavelength (μm)</th>
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<th>Phase Function Values*</th>
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<td>Phase Function Values*</td>
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<td>1.06 and 10.6μm</td>
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<tr>
<td>175.76</td>
<td>.17</td>
<td>.08</td>
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</table>

RMS# = 4.05 .31 .02 .03

*Rounded to two decimal points
†Computed via Mie Theory
*True minus analytic: 1 = Henyey-Greenstein; 2 = modified Henyey-Greenstein.
#RMS = Root Mean Square
However, as one approaches 180° the HG function sometimes provides a better fit to the computed phase function. Since for most of the distributions examined the backscatter is far less than the forward scattering, it becomes important to analytically fit the computed phase function more closely near the forward direction of scattering relative to the backscatter direction. Additionally since the HG analytic function fits the computed phase function best near 180° and the GHG analytic function is partially comprised of the HG function near 180°, we again find that the GHG analytic function will fit well near 180°. The root mean square error is also presented for the difference between the computed and analytic phase functions, and again indicates that the GHG analytic phase function provides a better fit. This is particularly so if the particular regime under consideration is near the incident (forward) direction.

STUDIES OF IR EXTINCTION IN HYGROSCOPIC AEROSOLS

Introduction: In a previous document some results of the modeling of IR extinction in hygroscopic aerosols were reported. Since then additional computations have been made to extend the range of relative humidities beyond that used previously and to examine the effects of "hysteresis" in the condensation and evaporation of droplets formed upon hygroscopic condensation nuclei. The new calculations were carried out using the simulated white phosphorous smoke model A' defined in the report referenced above.

Computations were carried out with an early version of program AGAUS9 at wavelengths of 0.55, 1.06, and 3.6um. Twelve values of relative humidity were used, and mass accretion coefficients were taken from Hanel for conditions of

---


Results: The data generated by the new computations are presented in graphical form in figures 6 through 8. Figure 6 shows the absolute extinction coefficients as a function of relative humidity at $\lambda = 0.55\mu m$ and $\lambda = 1.06\mu m$. The arrowheads indicate the direction in which relative humidity is changing; an arrowhead tilted toward the right represents increasing relative humidity, and an arrowhead tilted toward the left represents decreasing relative humidity. Figure 6 clearly shows the "hysteresis" effect mentioned above. It will be seen that for relative humidities between about 60 and 75 percent, the value of the extinction coefficient may vary by a factor of two between conditions of rising and falling relative humidity. For both wavelengths shown, figure 6 can be interpreted as suggesting that clearing (associated with droplet evaporation) of a smoke cloud under conditions of decreasing relative humidity is slower than its formation at any given relative humidity between about 50 and 75 percent. The figure also demonstrates that the sense of changes in relative humidity may be as important as its value in modeling hygroscopic aerosols.

In figure 7 one will find graphs of the ratios of the extinction coefficients at $1.06\mu m$ and $3.56\mu m$ to those at $0.55\mu m$ as a function of relative humidity, figure 7 is subject to various interpretations. One inference is that the aerosol model used for these calculations is almost always (all relative humidities = 99 percent) more "transparent" at $3.56\mu m$ than at $0.55\mu m$, but the same statement cannot be made at $1.06\mu m$. This particular aerosol, while more transparent at $10.6\mu m$ than at $0.55\mu m$ for relative humidities below about 59 percent, is comparatively less transparent for larger saturation ratios. Other features discernable from figure 7 are that extinction at $1.06\mu m$ as compared to its value at $0.55\mu m$ is much less sensitive to relative humidity than it is for $3.56\mu m$ radiation. In other words, the extinction at $1.06\mu m$ can be predicted more accurately from knowledge of the extinction at $0.55\mu m$ than can be the extinction at $3.56\mu m$ when no information on relative humidity is available. One further obvious inference from figure 7 is that extinction at $1.06\mu m$ will be greater than at $0.55\mu m$ if the smoke cloud is clearing because of decreasing relative humidity.
Figure 6. Computed extinction coefficients for smoke model A' as a function of relative humidity; $\lambda$ is the wavelength in $\mu$m. The solid curves and broken curves represent conditions of decreasing and increasing relative humidity, respectively.
Figure 7. Ratio of Model A' extinction coefficients at $\lambda = 1.06\mu m$ and $\lambda = 3.56\mu m$ to values at $\lambda = 0.55\mu m$ as a function of relative humidity. The solid curves represent increasing relative humidity, and the dashed curves represent decreasing relative humidity.

Figure 8. Attenuation coefficient per unit mass of Wet Aerosol at $0.55\mu m$ versus Relative Humidity for smoke model A'. The solid curve is for increasing relative humidity and the dashed curves represent decreasing relative humidity.
Finally, figure 8 shows the attenuation coefficient per unit mass of wet aerosol at $\lambda = 0.55\mu m$ as a function of relative humidity. If that figure is compared with figure 6, it will be seen that the attenuation per unit mass of the existing aerosol (WET + nuclei + accreted water) is much less sensitive to relative humidity than the attenuation per unit mass of dry aerosol material. It suggests that simultaneous in situ measurements of aerosol mass concentrations and extinction which preserve accreted water should yield less uncertainty or variation in extinction with changes in relative humidity than measurements made on dry aerosol materials alone.

Discussion: The results described above can, of course, be applied in detail only to the aerosol model used in generating them and at the specific wavelengths used. They do suggest, however, that extinction can, under some situations at least, vary by nearly a factor of two at a given relative humidity between conditions or rising and falling relative humidity, and that the relationship between extinction at two different wavelengths may also be dependent on the direction of changes in relative humidity. Consequently, it would seem that persons involved in both field measurements and numerical modeling should pay considerable attention to meteorological conditions, in particular when the relative humidity is rising or falling.

FURTHER DESCRIPTION OF THE "HALVING" METHODS OF AGAUSX

Basic Concept. A general idea of how program AGAUSX operates can be obtained by considering a numerical method for determining the area under a curve $g(R)$ versus $R$ such as that sketched in figure 9. The objective is to evaluate numerically an integral

$$G = \int_{R=0}^{R=\infty} g(R) \, dR$$

(61)

to some desired degree of accuracy using the smallest number of values of $R$ for the numerical calculations. The procedure adopted in AGAUSX is as follows (reference to figure 9 may be helpful):

65
Figure 9. Sketch of how values of particle radii are selected in the halving procedure of AGAUSX.
(1) An initial estimate $G_1$ of the value of the integral is made using three values of $R$ labeled by Roman numeral I and the "trapezoidal rule".

(2) A second estimate $G_2$ is then made using increments $\Delta R$ which are half as large as those used in getting $G_1$. In getting $G_2$, the two additional $R$-values labeled II are utilized.

(3) The values of $G_2$ and $G_1$ are compared to each other by calculating a quantity

$$\delta = \frac{|G_2 - G_1|}{|G_2|}$$  \hspace{1cm} (62)

and comparing it to a pre-set quantity $\Lambda$.

If $\delta < \Lambda$, then it is assumed that $G_2$ is a "sufficiently" accurate representation of $G$, and the computations are terminated. If on the other hand, $\delta > \Lambda$, one proceeds.

(4) A third estimate $G_3$ of $G$ is then made by again cutting the increments $\Delta R$ to half its previous value. This results in the addition of computations at the four new $R$-values labeled III in figure 9. A new value of $\delta$ is then calculated from

$$\delta = \frac{|G_3 - G_2|}{G_3}$$  \hspace{1cm} (63)
and $\delta$ is again compared to $\Delta$. If $\delta$ is still greater than $\Delta$, the spacing between $R$-values is cut in half once more, and the "estimation-comparison" process is repeated until either (a) $\delta < \Delta$, or (b) some maximum number of $R$-values has been reached.

In AGAUSX, the quantity used in the testing process is the total volume of the aerosol particles, namely,

$$V = \int \frac{4}{3} \pi R^3 f(R) dR,$$

(64)

in which $f(R)dR$ is the relative number of aerosol particles whose radii lie between $R$ and $R+dR$.

Extensions to the Basic Concept: It may happen that the function $g(R)$ illustrated in figure 6 will have a form which is much "smoother" over some range of $R$-values than over other ranges. Strict application of the halving procedure to such a situation could easily lead to the use of many more $R$-values in one of those ranges than are really needed because of behavior of $g(R)$ in other $R$-ranges. Such a situation seems especially likely with asymmetric size-distributions. One way of attempting to avoid unneeded computations in various $R$-ranges is to split the regions used in halving loops into several distinctive "intervals"—$R_A$ to $R_B$, $R_B$ to $R_C$, $R_C$ to $R_D$, and to do the halving operations and convergence tests separately for each "interval." AGAUSX has been coded to permit separate halving computations and convergence testing for up to eight "intervals" of that type. In fact, the present coding uses two radius "intervals" (ranges) for those distributions $f(R)$ known to show a single maximum, four "intervals" for bi-modal distribution models, and just one interval for other models.
DETAILED DESCRIPTION OF PROGRAM AGAUSX

Program AGAUSX is designed to calculate various light-scattering quantities such as phase functions (Mie theory), scattering fractions (ACT), extinction cross-section, attenuation coefficient, etc., for diverse natural and artificially created polydisperse atmospheric aerosols. The program consists of subroutines ANGLE, GUSET, AGXPT1, AGXPT2, AGXPT3, AGXPRT, MIEGS, GAUS, VERFY, WATER, GPHASX, GUSSTX, and PRINTX. The organization and operation of these subroutines is controlled by the MAIN program AGAUSX. Additionally program AGAUSX will produce an analytic (GHG) phase function if the user desires.

MAIN PROGRAM AGAUSX

The first input card contains the parameters NWAPE, NINDX, IDSTP, NRADI, IT, IANG, NCRDS, ITOT, NUNIT, MQRTE, and IAPX. These parameters will be explained in detail subsequently. The various modes of operation of AGAUSX that are possible, are controlled by some of these parameters. If IANG = 0, the subroutine GUSET is called to choose 'IT' scattering angles between 0° and 180° for use in numerical integrations using Gauss-Legendre quadrature. GUSET returns two arrays of numbers to MAIN. The array C(I) corresponds to the cosine of scattering angles and the array H(I) corresponds to the quadrature weights.

If IANG = 1 or 2, all the calculations of the previous paragraph are skipped. Instead subroutine ANGLE is called and returns arrays C(I) and H(I) to MAIN. For IANG = 1, H(I) corresponds to 'IT' equally spaced angles between 0° and 180°, and C(I) corresponds to the cosine of these angles. If IANG = 2, 'IT' user supplied angles are read in, again with H(I) corresponding to 'IT' angles and C(I) their cosines.

If IAPX is greater than zero AGAUSX will operate in a special 'approximation' mode. That is AGAUSX will construct the GHG analytic phase function at IAPX Gauss-Legendre angles. When approximate, quick phase functions are desired, this mode should be used.
Next, subroutine AGXPT1 is called. One or more input parameters are read at this point depending on the value of IDSTP, which indicates the type of distribution to be used. AGXPT1 calculates and returns two arrays R(I) and F(I) which describe the normalized size distribution, and VOL, the average 'dry' volume per particle. The array R(I) contains values of 'NRADI' particle radii, and the array F(I) contains values of the distribution for the corresponding R(I). For IDSTP = 3, 7, 8, 9, 10, 11, or 12 AGXPT1 also returns DENS, the particle number density (per cm$^3$). For other distribution types that do not have predetermined density values, the user supplied density, DENS, is less than $10^{-4}$; in this case the particle number density will be calculated from mass densities and mass concentrations.

The parameters WAVE, DWAVE, RELHUM, DENS, TEMP and DELTA are read next. The next do-loop indexed by NWAVE allows computations at several wavelengths during a single run. An additional looping option is available by assigning DWAVE any value less than $10^{-4}$; the same do-loop is used to handle several values or relative humidity (RELHUM) in a run.

A switch parameter LLLL is assigned a value 0 or 1, in a manner dependent upon the value of IDSTP and DENS. That is if the chosen distribution has fixed parameters and/or if number densities are to be calculated later from the average particle volume, mass density and mass concentration, then LLLL = 1.

In subroutine AGXPT2 optical and physical data (index of refraction and mass density) for the aerosol material are read. For the user's convenience, subroutine WATER has been added to provide the relevant data for water limited to the range 0.2 to 200 micrometers. If RELHUM and the growth factor (EMUA) are non-zero, AGXPT2 takes into account the particle growth and the change in density and indices of refraction of the aerosol material due to the absorption of water.

In AGXPT2, subroutine MIEGX is called for each 'adjusted' radius. MIEGX returns to AGXPT2 the values of extinction, scattering and backscattering.
efficiency factors, and the average intensity factors \((I_1 + I_2)/2\) for the 'IT' scattering angles chosen earlier. These scattering functions are weighted and integrated over the size distribution.

If the aerosol is a mixture of components having different physical and/or optical properties, the above calculation is repeated for each component and various functions are summed over NINDX (the number of components). In the end AGXPT2 returns to MAIN, for each wavelength, the average (sum/total particle number density) extinction, scattering and back-scattering cross-sections (CTSUM, CSSUM, CRSUM), the average intensities \(P(J)\), and the total mass concentration (TMASS, in gm/cc, which includes the mass of any liquid water absorbed by hygroscopic aerosols).

The next subroutine is called AGXPT3. AGXPT3 uses the numbers received from AGXPT2 and returns to MAIN the total extinction, scattering, and back-scattering coefficients, scattering fractions and phase functions. AGXPT3 also calculates the albedo for single scattering "ALBDO" = \(\tilde{\omega}_o = C_{sca}/C_{ext}\) and prints out all the single wavelength results. Later in AGXPT3, If IANG = 0, subroutine GAUS is called. Using the quadrature weights H(I) calculated earlier and calculating the Legendre polynomials PL(,), GAUS generates the Legendre expansion coefficients \(\tilde{\omega}_k\) for the phase functions, and places them in array OL(I). The \(\tilde{\omega}_k\)'s are then used to reconstruct phase functions, PC(I): GAUSS computes the root mean square deviation between the original phase functions and the reconstructed phase functions. If IANG = 1, the above calculation is skipped.

If NWAVE > 1, all the calculations of AGXPT2 and AGXPT3 are repeated (NWAVE-1) additional times. In MAIN, various scattering functions are summed and divided by NWAVE, and subroutine AGXPRT is called to print out all the averaged results. AGXPRT also calls GAUS once more (if IANG = 0) to generate the coefficients \(\tilde{\omega}_k\) for the averaged phase functions.

If IAPX is greater than zero, subroutine GPHASX is called to construct an analytic phase function, hereafter referred to as the GHG phase function. This requires the additional subroutines, GPHASX, GUSSTX, and PRINTX. This routine will construct the GHG analytic phase function at IAPX Gauss-Legendre
angles, and the subsequent Legendre coefficients may be written/punched on a unit specified by NUNIT if the user so desires.

Explanation of Symbols used in AGAUSX (MAIN)

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALBDO</td>
<td>single scattering albedo.</td>
</tr>
<tr>
<td>AMAX</td>
<td>the largest Mie size found in the aerosol distribution.</td>
</tr>
<tr>
<td>C( )</td>
<td>array holding cosines.</td>
</tr>
<tr>
<td>CATTN</td>
<td>the average (sum/NWAVE) attenuation coefficient in square meters per milligram of aerosol material.</td>
</tr>
<tr>
<td>CRSUM</td>
<td>the back-scattering cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns 'coefficients'.</td>
</tr>
<tr>
<td>CSSUM</td>
<td>the scattering cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns 'coefficients'.</td>
</tr>
<tr>
<td>CTSUM</td>
<td>the extinction cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns 'coefficients'.</td>
</tr>
<tr>
<td>DELTA</td>
<td>convergence criterion.</td>
</tr>
<tr>
<td>DENS</td>
<td>the particle number density (number per cubic centimeter). The value of DENS may be supplied by the user as an input parameter, DENSH. However, it will be ignored when IDSTP = 0 or greater than 6, because these distribution types carry predetermined values of DENS. In the case of IDSTP = 1, 2, 4, 5, the user supplied value of number density</td>
</tr>
</tbody>
</table>
will be ignored only if it less than $10^{-4}$. In such cases DENS is calculated from mass density and concentration and average volume per particle, and is represented by DENSOL.

DENSOL the user-supplied particle number density; units are particles per cubic centimeter. See discussion of DENS (above).

DRYVOL the average volume per particle of dry aerosol in cubic micrometers.

DWave the wavelength increment in micrometers, or relative humidity looping indicator.

ELWC the liquid water content in gm/cm$^3$ (used only for cases IDSTP = 6 and 12).

EMM the refractive index of the surrounding medium.

ENWAV DFLOAT (NWave).

FSUM the numerical result for the integral over the size distribution function with respect to radius; it is used to normalize the distribution function to one (equivalent) particle per cubic centimeter.

GNU wave number in cm$^{-1}$.

H( ) array containing angles.

IANG = 0, for the computation of phase functions at 'IT' Gauss-Legendre quadrature angles.
IANG = 1, for computation of phase functions and scattering fractions at 'IT' equally spaced angles between 0° and 180°. = 2, for computation of phase functions and scattering fractions at 'IT' user supplied angles.

IDSTP identified the type of aerosol size distribution to be used. It can only take values between 0 and 12. See AGXPT1 for more details.

IAPX the order of Legendre expression for the analytic, GHG, phase function expansion when IAPX is greater than zero.

IDBLE single or double precision mode indutor.

IT the order of Legendre expansion for phase functions when IANG = 0, or the number of equally spaced angles between 0° and 180° when IANG = 1, or the number of user supplied angles if IANG = 2.

ITOT works in conjunction with NCRDS and NAVEWAVE to write/punch either individual wavelength values of the phase function, (Legendre coefficients and/or scattering fractions) or averaged wavelength values or both on NUNIT: ITOT = 1 for individual wavelengths; ITOT = 2 for averaged wavelengths, ITOT = 3 for both.

KBKNT the average (sum/NAVE) back-scattering coefficient per km, integrated over the size distribution.

KEXTT the average (sum/NAVE) extinction coefficient per km, integrated over the size distribution.

KSCAT the average (sum/NAVE) scattering coefficient per km, integrated over the size distribution.
a switching parameter used to control whether or not particle number density is to be calculated from DRYVOL and mass concentration.

LMAX = 3*IFIX (AMAX). Integer estimate of the optimal order for Gauss-Legendre quadrature; used only for diagnostic message print.

MQRTE = 12345, will cause subroutine AGXPT2 to print efficiency factors QT, QS, and QR, and the normalized distribution function for every value of radius used.

NCRDS = 1 for write/punch only Legendre coefficients on NUNIT: = 2 write only phase functions and scattering fractions on NUNIT: = 3 write/punch both on NUNIT.

NINDX the number of aerosol components which will have different optical constants, mass density or mass concentration.

NRADI the number of values of particle radius to be used in the calculations. (In effect, points on the radius versus size distribution function plot).

NUNIT defines the device on which output data may be stored or punched; may be used to place nominal card output into data files, on tape, etc. The default value (NUNIT = 0) is 4.

NWAVE the number of wavelengths or relative humidity values to be treated in a given run. NWAVE has to be less than 10^-4 for the latter.

OL(I) the average Legendre expansion coefficients. OLT(I)/ENWAVE.
OLT(I) the total Legendre expansion coefficients (summed over all values of 'WAVE').

OUT( ) an array used for storing some of the numbers to be printed later.

PL(I,J) the Legendre polynomials of order (I-1) and argument C(J). C(I) are cosines of the scattering angles.

PSUM(I) the average phase functions integrated over the size distribution.

PSUMT(I) the total phase functions integrated over size distribution and summed over wavelength.

QATTEN the attenuation coefficient in square meters per milligram of aerosol material for each wavelength.

R(NRADI) the radius of the largest particle encountered.

RELHUM the relative humidity in percent.

SCAT(I) the scattering fractions as defined in ACT for each wavelength. 'IT' elements in the array.

SCATT(I) the average (sum/NWAVE) scattering fractions (ACT).

TEMP the temperature of the atmosphere in degrees C.

TMASS the total mass of aerosol in gm/cm³ in the atmosphere.

VOL the average volume per particle in cubic micrometers.

WAVE the first wavelength, in micrometers, at which calculations are to be done.
AGAUX (MAIN PROGRAM) - SIMPLIFIED FLOWCHART

Read control parameters card

Set-up size distribution parameters (Subroutine AGXPT1)

Read wavelength, wavelength increment, etc.

Do-loop indexed by NWAVE

Read optical and physical data; Perform Mie calculations and integrate over sizes (Subroutine AGXPT2)

Is IAPX Greater than Zero?

NO

Calculate scattering fractions, etc., at given wavelength and print results (Subroutine AGXPT3)

Sum results over wavelengths

YES

Average results over wavelength

Print averaged results (Subroutine AGXPRT)

END

END

END

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SUBROUTINE AGXPT1

Readers of the following descriptions of the mathematical procedures should bear in mind that the general AGAUS single scattering code computes a number of quantities associated with the Mie theory of the interaction of a single spherical scatter and then averages those quantities using the aerosol size distribution function, f(r), as a weighting factor. The following definitions may also be helpful.

The terms "component" or "aerosol component" apply to cases in which the overall aerosol may be a mixture of different materials whose optical properties, mass density, growth factors, or mass concentrations are not identical. The number of "components" to be used in a run is specified by input parameter NINDEX. An example of a multi-component aerosol might be one which is a mixture of hydroscopic and nonhydroscopic particles.

The terms "size interval" and/or "original interval" refer to subdivisions of the total range of aerosol radii \( R_{\text{minimum}} = \text{RLO} \) to \( R_{\text{maximum}} = \text{RHI} \) within which the halving and convergence testing procedures are applied independently.

Most averages that must be done are of the form

\[
G \equiv \frac{\int_{\text{RLO}}^{\text{RHI}} dr \ f(r)G(r)/\text{FSUM},}{(67)}
\]

where \( G(r) \) is some Mie theory quantity for a particle of radius \( r \), and a given optical type (refractive index \( m = m-ik \)), and

\[
\text{FSUM} = \int_{\text{RLO}}^{\text{RHI}} dr \ f(r).
\]
The size distributions $f(r)$, $RLO \leq r \leq RHI$, may be given in analytic form, or numerically on a set $\{ R(J)\}$ of values of $r$. They may or may not be normalized to unity (FSUM may equal 1.0, or not). The relevant Mie theory quantities include $C_{\text{ext}}(r)$, $C_{\text{sca}}(r)$, $p(r,\mu)$ for each Gauss-Legendre $\mu$, etc. Other averages that must be done have somewhat different forms, e.g.,

$$\tilde{\omega}_n = \frac{1}{C_{\text{ext}}} \int dr \, f(r) \tilde{\omega}_n(r) C_{\text{ext}}(r)/FSUM,$$  \hspace{1cm} (68)

for the coefficients $\tilde{\omega}_n$ of the phase function expression. $p(\mu) = \sum_{n=0}^{\infty} \tilde{\omega}_n P_n(\mu)$, in terms of the coefficients $\tilde{\omega}_n(r)$ of the phase function

$$p(r,\mu) = \sum_{n=0}^{\infty} \tilde{\omega}_n(r) P_n(\mu).$$

The above integrals over $r$ must be done numerically. In order to minimize computation time, the number of points in the numerical integration should be chosen as small as possible, consistent with adequate accuracy. Each value of $r$ that is used requires the full Mie calculation for the quantities $C_{\text{ext}}(r)$, $C_{\text{sca}}(r)$, $p(r,\mu)$ for each $\mu$, etc., these calculations absorb a large part of the total computation time. It has been found in this work that, instead of fixing the number of values of $r$ to be 500, adequate accuracy results, in many cases, for as few as 50 to 100 values of $r$; this reduction allows a reduction in total computation time by roughly a factor of 4 to 8.

The numerical integration method which was developed makes use of successive halving of intervals until a preset convergence criterion is met. This halving method allows an initial set of unequal intervals to be chosen. For example, suppose that the distribution function $f(r)$ is sharply peaked around some value of $r$, and also has a long tail, as in figure 10. Then it makes
FIGURE 10: Sketch of a hypothetical size-distribution.

The logical flow through the halving integration of AGXPT1 is as follows:

(1) Given RLO, RHI and $f(r)$, $RLO \leq r \leq RHI$, in analytic form; or $f(r)$ numerically on the equally spaced set $r = R(J)$, $J = 1, NRADI$.

(2) For the given $f(r)$, RLO, RHI, choose the number and size of the original intervals. That is, choos RR(I), $I = 1$, NLAST = 2**MIN + 1, with $RR(1) = RLO$, $RR(NLAST) = RHI$. Note that NI = number of initial intervals = 2**MIN = 1, 2, 4, 8, 16, ... . Then set NHALV = number of halvings in each interval = MAX-MIN, and NK = maximum number of points in each interval = 2**NHALV.

(3) The maximum number of points allowed in NMAX = 1+2**MAX. In this work, MAX = 9 was used, so NMAX = 513. Calculate $R(KK)$, $F(KK) = f(R(KK))$, $KK = 1$, NMAX, on all the points $R(KK)$ which might be used if
the halving goes all the way to NMAX points. For \( f(r) \) given numerically, this is done by linear interpolation.

(4) Calculate \( C_{\text{ext}}(I) = \int_{RR(I)}^{RR(I+1)} dr \ f(r)C_{\text{ext}}(r) \) in each interval number \( I, I = 1, NI \), by halving of that interval and the trapezoidal rule, until the convergence criterion is met in that interval, or until the halving has progressed all the way to NK points, the maximum number allowed in any interval.

At the same time, calculate \( FSUMG(I) = \int_{RR(I)}^{RR(I+1)} dr \ f(r) \), and all other needed averages \( G(I) = \int_{RR(I)} dr \ f(r)G(r) \), on the same set of points used for \( C_{\text{ext}}(I) \).

(This means that the convergence criterion is applied only to \( C_{\text{ext}}(I) \)). Then

\[
C_{\text{ext}} = \sum_{I=1}^{NI} C_{\text{ext}}(I), \quad FSUM = \sum_{I=1}^{NI} FSUM(I), \text{ etc.; then } C_{\text{ext}} = C_{\text{ext}} / FSUMG, \quad G = G / FSUMG.
\]

The last step is equivalent to making \( \int_{RLO}^{RHI} dr \ f(r) = 1.0 \).
sense to choose unequal initial intervals as shown. The numerical integration
then proceeds by halving each of the original intervals, until the convergence
criterion is met. The convergence criterion that was used is the requirement
that \(|G(n+1) - G(n)|/|G(n)| < \Delta\), where \(\Delta\) is some small preset number. Here
\(G(n)\) is the value of the integral \(G\) after the \(n\)th halving, separately in each
initial interval. The trapezoidal rule was used throughout. The value of the
integrand at any given point \(r\) is calculated just once; it does not have to be
recalculated on that point after halving.

Description of Types of Distributions

<table>
<thead>
<tr>
<th>IDSTYP</th>
<th>DESCRIPTION</th>
</tr>
</thead>
</table>
| 0      | This is an arbitrary user-supplied distribution. 'NRADI' + 1
cards will be read; the first card contains RLO and DELLR (\(\mu m\)).
The rest of the cards carry the values of \(F(J)\) and must be in
order of increasing radius value. |
| 1      | This is the zero-order log-normal distribution: the
distribution function is given by

\[
F(R) = \frac{1}{\sqrt{2\pi} \log_e(\sigma) R} \exp\left\{-\frac{1}{2} \left[\frac{\log_e(R/\bar{R})}{\log_e(\sigma)}\right]^2\right\}.
\]

\(R \equiv R\text{BAR}; \sigma \equiv \text{SIGMA},\) is the standard deviation. This
distribution type requires one input data card to read in the
values of \(\bar{R}, \sigma, \text{RLO}\) and \(\text{RHI}\).
This is called the double exponential distribution and its distribution function is given by \( F(R) = QA \exp(-AR) + (1-Q)B \exp(-BR) \). \( Q \equiv \text{CUE} \). This distribution type requires one input data card to read in the values of RLO, RHI, Q, A, and B. Q is dimensionless while A and B have units of \( \mu m^{-1} \).

This model (Deirmendjian's "Model C") does not require any input data card. It carries fixed value of DENS, RLO, and DELRD. RHI is determined by the input parameter NRADI.

\[
F(R) = 450.2 \\
= 2.251 \times \text{DELRD} \times R^{-4} \\
\text{R } \leq 0.08 \\
\text{R } > 0.08
\]

The distribution function of this model (Junge distribution) is given by \( F(R) = QR^{-A} \), \( Q \equiv \text{CUE} \). This distribution type requires one input data card to read in RLO, RHI, A, A.

The distribution function for the Modified Gamma/Generalized Khirgian-Mazin distribution is

\[
F(R) = R^\alpha \exp\left(-\frac{R}{R_c}\right) \gamma \cdot \gamma, \alpha \equiv \text{ALF}, \gamma \equiv \text{GAM}, \text{ and}
\]

\( R_c \equiv RC \). One input card is needed to read in RLO, RHI, RC, ALF, GAM, and ELWC. ELWC is not needed for type 5 distribution and therefore can be left blank.

The size distribution model (NMSU Fog or Cloud Model) is very similar to type 5, except that the user must supply one additional input parameter—namely, the liquid water content (ELWC) in gm/cc. This model can be used for treating situations involving liquid water aerosols like clouds or fogs. For type 6 runs one does not need to read in the values of EMA, CAYA, RHOA, CONC.
This distribution is essentially same as Junge's distribution (type 4) except that it has fixed parameters. One input card is needed to read in VIS (visibility in km); VIS is used in calculating DENS.

This is a fixed parameter Continental Bi-modal Model. It does not require an input data card.

This is a fixed parameter Maritime Bi-modal Model. It does not require an input data card.

This is a fixed parameter Urban Bi-modal Model. It does not require an input data card.

This is a user-supplied Bi-modal Model. This requires one input card to read in FOA, FOC, SGA, SGC, RBARA, RBARC. Types 8, 9, 10, and 11 use the sum of two log-normal distributions:

\[
F(R) = \sum_{i=1}^{2} \frac{N_i}{\sqrt{2\pi} \log_e(\sigma_i) R} \exp\left(-\frac{1}{2} \frac{\log_e(R/R_i)}{\log_e(\sigma_i)}\right)^2
\]

\(N_1 \equiv FOA, R_1 \equiv RBARA, \sigma_1 \equiv SGA\) with similar meaning for \(N_2, R_2,\) and \(\sigma_2\). Note that in Type 8, 9, 10 the values of SGA and SGC are \(\log_e(\sigma)\).

This model (Marshall-Palmer Rain Model) is a simple exponential model which assumes an empirical relationship between rain rate and droplet size distribution parameters:

\[
F(D) = N_0 \exp(-\Lambda D).
\]
\[ N_o = 0.08 \text{ cm}^{-4}, \text{ and } A = 41(RN)^{-0.21} \] in which RN = RAIN is the rain rate in mm/hour. Diameter D is in cm. The corresponding size distribution function of radius R is given by

\[ F(R) = 2N_o \exp(-2AR). \]

This distribution requires one input data card to read in RAIN. The values of RLO and RHI are fixed at 0 and 0.5 cm respectively. Due to the limitations on the range of Mie-sizes (subroutine MIEGEX) type 12 usage is limited to wavelengths of the order of 1 mm or larger. Since subroutine WATER does not contain optical data for wavelengths longer than 0.2 mm, type 12 runs require the user to supply the values of EMA, CAYA, and RHOA as if rain were a non-aqueous aerosol.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>parameter in several distribution types.</td>
</tr>
<tr>
<td>ALF</td>
<td>parameter in modified gamma distribution.</td>
</tr>
<tr>
<td>AVOL</td>
<td>the average volume per particle in cubic microns obtained via analytical integration over the limits RLO = 0 and RHI = \infty.</td>
</tr>
<tr>
<td>DENA</td>
<td>temporary storage.</td>
</tr>
<tr>
<td>DENC</td>
<td>temporary storage.</td>
</tr>
<tr>
<td>DENS</td>
<td>the particle number density in ( \text{cm}^{-3} ).</td>
</tr>
<tr>
<td>DELR</td>
<td>increment of radius for arbitrary distribution.</td>
</tr>
<tr>
<td>DELRD</td>
<td>= (RHI-RLO)/RADS; increment between successive values of R.</td>
</tr>
<tr>
<td>DELLR</td>
<td>increment in radius for the case IDSTP = 0.</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Explanation or Definition</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>DR ( )</td>
<td>initial size interval I = 1, NI.</td>
</tr>
<tr>
<td>EM</td>
<td>real part of refractive index of actual aerosol particle.</td>
</tr>
<tr>
<td>EMM</td>
<td>refractive index of medium in which scattering particles are deployed.</td>
</tr>
<tr>
<td>F(J)</td>
<td>the array containing 'NRADI' values of the size distribution function. See the description of AGXPT1 for more details.</td>
</tr>
<tr>
<td>FKK</td>
<td>value of distribution function at radius R(KK)/</td>
</tr>
<tr>
<td>FSUM</td>
<td>the numerical integral over the size distribution function with respect to radius between the limits RHI and RLO; used to normalize the distribution function.</td>
</tr>
<tr>
<td>GAM</td>
<td>parameter in modified gamma distribution.</td>
</tr>
<tr>
<td>GNUM</td>
<td>temporary storage.</td>
</tr>
<tr>
<td>GNUMA</td>
<td>temporary storage.</td>
</tr>
<tr>
<td>GNUMC</td>
<td>temporary storage.</td>
</tr>
<tr>
<td>IDSTP</td>
<td>identifies the type of aerosol size distribution to be used.</td>
</tr>
<tr>
<td>IW</td>
<td>switch for &quot;all water&quot; mode.</td>
</tr>
<tr>
<td>NCRDS</td>
<td>not used in this subroutine.</td>
</tr>
<tr>
<td>NHALV</td>
<td>maximum number of interval halvings allowed for each initial interval.</td>
</tr>
<tr>
<td>NI</td>
<td>number of initial intervals for halving integration.</td>
</tr>
<tr>
<td>NKG</td>
<td>maximum number of points which may be used in each initial interval.</td>
</tr>
<tr>
<td>NLAST</td>
<td>number of radii, RR(I), defining the NI basic size intervals.</td>
</tr>
<tr>
<td>NMAX</td>
<td>maximum number of points which may be used in halving method.</td>
</tr>
</tbody>
</table>

*The pre-coded (IDSTP = 8,9,10) values of SGA and SGC are the natural logarithms of the standard deviations.*
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRADI</td>
<td>the number of radius values to be used in describing the size distribution function for type zero and 3 only.</td>
</tr>
<tr>
<td>RAIN</td>
<td>parameter in Marshall-Palmer rain model.</td>
</tr>
<tr>
<td>RBAR</td>
<td>mean radius in log-normal distribution.</td>
</tr>
<tr>
<td>RBARA</td>
<td>mean radius of &quot;accumulation&quot; mode for bimodal distribution.</td>
</tr>
<tr>
<td>RBARC</td>
<td>mean radius of &quot;coarse&quot; mode for bimodal distributions.</td>
</tr>
<tr>
<td>RC</td>
<td>mode radius in modified gamma distribution.</td>
</tr>
<tr>
<td>RHI</td>
<td>maximum particle radius for any size distribution (μm).</td>
</tr>
<tr>
<td>R(J)</td>
<td>the array containing 'NRADI' values of radius (particle size) in micrometers.</td>
</tr>
<tr>
<td>RLO</td>
<td>minimum particle radius for any size distribution (μm).</td>
</tr>
<tr>
<td>RR(I)</td>
<td>lower radius of Ith initial interval: RR(1) = RLO, RR(NLAST) = RHI.</td>
</tr>
<tr>
<td>SGA</td>
<td>standard deviation* for user supplied bi-modal log normal distribution.</td>
</tr>
<tr>
<td>SGC</td>
<td>standard deviation* for user supplied bi-modal log normal distribution.</td>
</tr>
<tr>
<td>SIGMA</td>
<td>standard deviation in log-normal distribution: used later as ln (SIGMA).</td>
</tr>
<tr>
<td>VIS</td>
<td>visibility in km.</td>
</tr>
<tr>
<td>VOL</td>
<td>the average 'dry' volume per particle (in μm³) calculated numerically.</td>
</tr>
<tr>
<td>VOLA</td>
<td>particle volume.</td>
</tr>
<tr>
<td>VOLC</td>
<td>particle volume.</td>
</tr>
</tbody>
</table>
Subroutine AGXPT1 - Simplified Flow Chart

(Received Data IDSTP, NRADI from Main Program)

Branch to Read Data for Various Distribution Types; set-up number of size intervals to be used and end-point radii RR( ) for each size interval

Type 0  Type 1  .............  Type 11  Type 12

Determine the number of radii to be used for each size-interval-and the precise values for the radii R( )

Branch again to set-up the number density array F(L) - as determined for each type of distribution

Type 0  Type 1  ...  Type 11  Type 12

Integrate distribution function over sizes to determine normalization factor (FSUM) and average particle volume; re-normalize the array F( ); Print some information.

RETURN
SUBROUTINE AGXPT2

Subroutine AGXPT2 deals with the most important computational aspects of AGAUSX. If RELHUM and the growth factor (EMUA) are non-zero, AGXPT2 makes adjustments in particle radii, density and refractive index of aerosol material to account for the absorption of water by aerosol particles. These adjustments are made through the following equations:

Radius: \( RT = AC \times R(L) - BC/AC, \)

Index of Refraction:

i) Real part: \( EM = EMW + (EMA-EMW)/A, \)

ii) Imaginary part: \( CAY = CAYW + (CAYA - CAYW)/A \)

Density: \( RHO = RHOW + (RHOA - RHOW)/A, \)

All the symbols used above are explained in detail below.

Next, subroutine MIEGX is called to compute single particle scattering functions \( OR, QS, QT, \) and \( P(J) \) for each adjusted radius. These scattering functions are weighted and integrated over the size distribution by the trapezoidal method. The convergence of integration for volume and the extinction cross-section is checked, and warnings are printed if the final one or two contributions exceed 5 percent of the previous total values. If there is more than one component (NINDX>1) in the aerosol with different refractive index and density, the above calculation is carried out NINDX times, and results are summed and divided by the total particle number density. In the end, the attenuation coefficients in square meters per milligram of 'wet' aerosol material are calculated. The same value of extinction coefficient is used for calculating both attenuation coefficients.

If IAPX is greater than zero, only the first three coefficients of the Legendre expansion \( (\tilde{w}_0, \tilde{w}_1, \tilde{w}_2) \) are calculated and stored in array OL( ). This is for subsequent construction of the GHG analytic phase function.
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$1 + (\frac{\rho_a}{\rho_w}) \times \epsilon_{\text{UA}} \times \epsilon_H$; used in making adjustments due to water absorption by aerosol.</td>
</tr>
<tr>
<td>AC</td>
<td>$A^{\frac{1}{3}}$.</td>
</tr>
<tr>
<td>ALBDO</td>
<td>single scattering albedo.</td>
</tr>
<tr>
<td>ALPHA</td>
<td>$2\pi \epsilon_\text{M} \epsilon_\text{RT} / \text{WAVE}$. Mie size parameter for adjusted radii.</td>
</tr>
<tr>
<td>ALPHAD</td>
<td>temporary storage for ALPHA.</td>
</tr>
<tr>
<td>BC</td>
<td>$BHT \times \epsilon_H$; used in making adjustments in size growth.</td>
</tr>
<tr>
<td>BH</td>
<td>$1.056 \times 10^{-3}$.</td>
</tr>
<tr>
<td>BHT</td>
<td>$BHI(298/\text{TEMK})$.</td>
</tr>
<tr>
<td>CATTN</td>
<td>the total attenuation coefficient in square meters per milligram of 'dry' aerosol material for each WAVE. However, CTSUM corresponds to 'wet' aerosol.</td>
</tr>
<tr>
<td>CATTNW</td>
<td>the total attenuation coefficient in square meters per milligram of 'wet' aerosol material.</td>
</tr>
<tr>
<td>CAY</td>
<td>the imaginary part of refractive index of dry aerosol. (Assumed to be negative; do not enter a value with a negative sign on the data card(s)).</td>
</tr>
<tr>
<td>CAYO</td>
<td>temporary storage.</td>
</tr>
<tr>
<td>CAYW</td>
<td>the imaginary part of refractive index of pure water at a given TEMP (DEG C) and WAVE.</td>
</tr>
<tr>
<td>CH</td>
<td>$F_H / (1 - F_H)$.</td>
</tr>
<tr>
<td>CONC</td>
<td>the mass concentration in gm/cc of a component of dry aerosol. It is the number of grams of dry aerosol per cubic centimeter of &quot;cloud&quot; or &quot;fog&quot;, etc.</td>
</tr>
<tr>
<td>CONCT</td>
<td>the total mass concentration in mg/cc of dry aerosol.</td>
</tr>
<tr>
<td>CRGG</td>
<td>partial contributions to average radar cross section, for one</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>CRHH</td>
<td>component of aerosol.</td>
</tr>
<tr>
<td>CRSUM</td>
<td>the average (sum/DENST) back-scattering cross-section in square micrometers, integrated over the size distribution, for each WAVE.</td>
</tr>
<tr>
<td>CRSUMT</td>
<td>value of radar cross section for total aerosol.</td>
</tr>
<tr>
<td>CJS,</td>
<td>partial contributions to average scattering cross section for one component of aerosol.</td>
</tr>
<tr>
<td>CSNH</td>
<td>the average (sum/DENST) scattering cross-section in square micrometers, integrated over the size distribution, for each WAVE.</td>
</tr>
<tr>
<td>CSSUM</td>
<td>the average (sum/DENST) extinction cross-section in square micrometers, integrated over the size distribution, for each WAVE.</td>
</tr>
<tr>
<td>CTSUM</td>
<td>the total extinction cross-section in square micrometers, integrated over the size distribution, for each WAVE.</td>
</tr>
<tr>
<td>CTSUMT</td>
<td>the total extinction cross-section in square micrometers, integrated over the size distribution, for each WAVE.</td>
</tr>
<tr>
<td>DEL</td>
<td>fractional change in contribution to volume from ( n^{\text{th}} ) to ( n+1^{\text{st}} ) halving, for one initial interval.</td>
</tr>
<tr>
<td>DELTA</td>
<td>convergence criterion.</td>
</tr>
<tr>
<td>DENS</td>
<td>the particle number density per cubic centimeter. See DENS also.</td>
</tr>
<tr>
<td>DENS,</td>
<td>the particle number density per cc for each component of aerosol. It is calculated from mass density and concentration, and average volume per particle. If ( LLLL=1 ), the calculated value of DENS is replaced by DENS, the value of which has been determined or supplied elsewhere.</td>
</tr>
<tr>
<td>DENS</td>
<td>the total particle number density per cc. See also DENS.</td>
</tr>
<tr>
<td>DRYVOL</td>
<td>the average volume per particle in cc.</td>
</tr>
<tr>
<td>ELWC</td>
<td>the liquid water content in gm/cc.</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>EM</td>
<td>the real part of the effective refractive index of 'wet' aerosol. See CAY EM = (EMW + (EMA - EMW)/A).</td>
</tr>
<tr>
<td>EMA</td>
<td>the real part of refractive index of the dry aerosol.</td>
</tr>
<tr>
<td>EMASS</td>
<td>is 'wet' mass concentration in gm/cc of a component of an aerosol when RELHUM and growth factor are non-zero. EMASS and CONC should have some value if growth factor is zero.</td>
</tr>
<tr>
<td>EMM</td>
<td>the refractive index of the surrounding medium, set equal to 1 here implying no surrounding medium.</td>
</tr>
<tr>
<td>EMAA</td>
<td>Hanel's mass accretion coefficient μ. Values must be supplied by the user and depend on the type or composition of the aerosol being modeled as well as upon the value of the relative humidity.</td>
</tr>
<tr>
<td>EMW</td>
<td>the real part of refractive index of water at a given TEMR (DEG C) and WAVE.</td>
</tr>
<tr>
<td>F(I)</td>
<td>the normalized size distribution function (in micrometers⁻¹).</td>
</tr>
<tr>
<td>FF(J)</td>
<td>value of arbitrary distribution functions at radius RP = RLO * (J-1) + DELLR, J =1, NRADI.</td>
</tr>
<tr>
<td>FFT</td>
<td>contribution to integral of distribution function from one original interval.</td>
</tr>
<tr>
<td>FH</td>
<td>fractional relative humidity (saturation rates).</td>
</tr>
<tr>
<td>FKK</td>
<td>value of distribution function at radius R(KK).</td>
</tr>
<tr>
<td>FKKK</td>
<td>geometrical cross section of particle.</td>
</tr>
<tr>
<td>FT</td>
<td>partial contribution to integral of distribution function.</td>
</tr>
<tr>
<td>H( )</td>
<td>array containing angles.</td>
</tr>
<tr>
<td>IAPX</td>
<td>order of expansion for analytic phase function.</td>
</tr>
<tr>
<td>IDBLE</td>
<td>precision mode indicator.</td>
</tr>
<tr>
<td>IDSTP</td>
<td>identifies the type of aerosol size distribution being used in the run.</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Definition</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>IERROR</td>
<td>a flag which is set to unity if the number of terms reaches the maximum value allowed in the dimensions of the Mie-coefficients $a_n$ and $b_n$.</td>
</tr>
<tr>
<td>KEXOLD</td>
<td>the extinction coefficient per km summed over the number of components one less than the current value of the running loop index NK.</td>
</tr>
<tr>
<td>KEXT</td>
<td>the extinction coefficient per km for each component of the aerosol.</td>
</tr>
<tr>
<td>KEXTT</td>
<td>the total extinction coefficient per km for each WAVE.</td>
</tr>
<tr>
<td>LLLL</td>
<td>a switch parameter. If LLLL=0, the particle number density (DENSC) is calculated using mass density and concentration, and the average volume per particle (DRYVOL). If LLLL=1, a pre-calculated or pre-supplied value of DENS is used.</td>
</tr>
<tr>
<td>MERROR</td>
<td>an error counter: If MERROR exceeds 10, execution is terminated.</td>
</tr>
<tr>
<td>MQRTE</td>
<td>= 12345, QT, QS, QR and Fr are printed for each radius.</td>
</tr>
<tr>
<td>NCRDS</td>
<td>not used in this subroutine, but appears in a common block.</td>
</tr>
<tr>
<td>NHALV</td>
<td>maximum number of interval halvings allowed for each initial interval.</td>
</tr>
<tr>
<td>NINDX</td>
<td>the number of aerosol components which will have different optical constants, mass density or mass concentration.</td>
</tr>
<tr>
<td>NRADI</td>
<td>the number of points on the radius vs. size distribution function plot.</td>
</tr>
<tr>
<td>O1STAR</td>
<td>value of $\tilde{\omega}_1$ for a given size parameter.</td>
</tr>
<tr>
<td>O1STRD</td>
<td>temporary storage for O1STAR.</td>
</tr>
<tr>
<td>O2STAR</td>
<td>value of $\tilde{\omega}_2$ for a given size parameter.</td>
</tr>
<tr>
<td>O2STRD</td>
<td>temporary storage for O2STAR.</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>OL( )</td>
<td>Legendre coefficients.</td>
</tr>
<tr>
<td>OL1GG,</td>
<td>partial contributions to average $\tilde{\omega}_1$, for one component of</td>
</tr>
<tr>
<td>OLIHH</td>
<td>aerosol.</td>
</tr>
<tr>
<td>OL1HHT</td>
<td>contributes to $\tilde{\omega}_1$ of average particle from one original</td>
</tr>
<tr>
<td></td>
<td>interval.</td>
</tr>
<tr>
<td>OL1SUM</td>
<td>value of $\tilde{\omega}_1$ for one component of an aerosol.</td>
</tr>
<tr>
<td>OL2GG,</td>
<td>partial contributions to average $\tilde{\omega}_2$, for one component of</td>
</tr>
<tr>
<td>OL2HH</td>
<td>aerosol.</td>
</tr>
<tr>
<td>OL2HHT</td>
<td>contributions to $\tilde{\omega}_2$ of average particle from one original</td>
</tr>
<tr>
<td></td>
<td>interval.</td>
</tr>
<tr>
<td>OL2SUM</td>
<td>value of $\tilde{\omega}_2$ for one component of aerosol.</td>
</tr>
<tr>
<td>OLSTAR</td>
<td>second Legendre coefficient ($\tilde{\omega}_1$).</td>
</tr>
<tr>
<td>OM2</td>
<td>third Legendre coefficient ($\tilde{\omega}_2$).</td>
</tr>
<tr>
<td>P(J)</td>
<td>an array containing 'IT' average intensity factors $(i_1 + i_2)/2$ for</td>
</tr>
<tr>
<td></td>
<td>each radius.</td>
</tr>
<tr>
<td>PGG(I),</td>
<td>partial contributions to average intensity $(i_1 + i_2)/2$ for one</td>
</tr>
<tr>
<td>PHH(I)</td>
<td>aerosol component at abscessa value $\mu_1$.</td>
</tr>
<tr>
<td>PHHT(I)</td>
<td>average intensity at $\mu_1$ for one original interval.</td>
</tr>
<tr>
<td>PL( , )</td>
<td>Legendre polynomials.</td>
</tr>
<tr>
<td>PSNEW(J)</td>
<td>$= P(J) * F(L)$, where $p(J)$ corresponds to $L^{\text{th}}$ radius, $L \geq 2$.</td>
</tr>
<tr>
<td>PSOLD(J)</td>
<td>$= P(J) * F(L)$, where $P(J)$ corresponds to $(L-1)^{\text{th}}$ radius except when $L=1$; in that case $PSOLD(J) = P(J) * FF(1)$, and $P(J)$ corresponds to 1st radius.</td>
</tr>
<tr>
<td>PSUM(J)</td>
<td>average intensity factors integrated over the size distribution. They are then summed over NINDX components and divided by DENST.</td>
</tr>
<tr>
<td>PSUMT(J)</td>
<td>final average phase function.</td>
</tr>
<tr>
<td>QR</td>
<td>the back-scattering efficiency factor for each radius.</td>
</tr>
<tr>
<td>QRD</td>
<td>temporary storage for QR.</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>QS</td>
<td>the scattering efficiency factor for each radius.</td>
</tr>
<tr>
<td>QSD</td>
<td>temporary storage for QS.</td>
</tr>
<tr>
<td>QT</td>
<td>extinction efficiency factor for a given size parameter.</td>
</tr>
<tr>
<td>QTD</td>
<td>temporary storage for QT.</td>
</tr>
<tr>
<td>R(L)</td>
<td>the array containing 'NRADI' values of radius in micrometers.</td>
</tr>
<tr>
<td>RELHUM</td>
<td>the relative humidity in percent.</td>
</tr>
<tr>
<td>RHO</td>
<td>the specific density (in gm/cc) of 'wet' aerosol.</td>
</tr>
<tr>
<td>RHOA</td>
<td>the specific density (in gm/cc) of 'wet' aerosol.</td>
</tr>
<tr>
<td>RHOW</td>
<td>the specific density (in gm/cc) of water at the temperature TEMP (in DEG C).</td>
</tr>
<tr>
<td>RIT</td>
<td>the radius of a particle after taking into account its growth due to absorption of water.</td>
</tr>
<tr>
<td>RR(I)</td>
<td>lower radius of I\textsuperscript{th} initial interval.</td>
</tr>
<tr>
<td>TEMK</td>
<td>the temperature of surrounding medium in degrees Kelvin.</td>
</tr>
<tr>
<td>TEMP</td>
<td>the temperature of the surrounding medium in degrees Centigrade.</td>
</tr>
<tr>
<td>TMASS</td>
<td>the total mass concentration in gm/cc of 'wet' aerosol.</td>
</tr>
<tr>
<td>TVOL</td>
<td>is used to pass the value of DRYVOL from MAIN to subroutine.</td>
</tr>
<tr>
<td>VOL</td>
<td>total volume occupied by aerosol material distributed in 1 cm\textsuperscript{3} of space.</td>
</tr>
<tr>
<td>VOLGG</td>
<td>partial contributions to volume of average particle, for one</td>
</tr>
<tr>
<td>VOLHH</td>
<td>component of aerosol.</td>
</tr>
<tr>
<td>VOLHHT</td>
<td>contribution to volume of average particle from one original interval.</td>
</tr>
<tr>
<td>WAVE</td>
<td>the wavelength in micrometers at which all the scattering functions are computed.</td>
</tr>
</tbody>
</table>
Subroutine AGXFT2 - Simplified Flowchart

(Receives control data and size distribution data from main program)

- Initialize parameters used in integrations
- Determine optical constants and mass density for liquid water at given wavelength
  (Subroutine WATER; skipped for IDSTP = 12)
- Test to see if NINDEX aerosol components have been treated and summed
- Do final renormalization over components
- Read optical and physical parameter card for aerosol (skipped for IDSTP = 6)
- Begin loop over size intervals
- Treat end-point radii for size interval to get first estimate for C<sub>ext</sub>, etc.
- Perform Mie-calculation (Subroutine MIEGX)
- Begin "halving" for the current size interval
- Treat intermediate values of radii and integrate to get improved estimates of C<sub>ext</sub>, etc.
- Test to see if another "halving" is needed
  - YES (Loop 19)
  - NO
- Re-normalize results for interval I
  - NO (Loop 26)
  - YES
- Have all intervals been treated?
- Renormalize results over component NK
- RETURN

Loop 32

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SUBROUTINE AGXPT3

Subroutine AGXPT3 receives the values of various cross-sections and the integrated average intensity factors from AGXPT2 and converts them into directly useful quantities:

\[
\text{Coefficient (per km)} = 10^{-3} \times \text{DENS} \times \text{cross-section},
\]
\[
\text{Scattering fractions} = \frac{\lambda^2}{4\pi^2} \times \text{DENS} \times \text{intensity factors},
\]
and \[
\text{Phase function} = \frac{\lambda^2}{\pi C_{\text{ext}}} \times \text{intensity factors}.
\]

\( \lambda \) is in \( \mu \text{m} \). It then prints out all single wavelength results.

It also computes albedo for single scattering using equation (4). It then calls on subroutine GAUS which, among other things (see GAUS for details), also returns a value for albedo calculated differently. The two values are compared, and if they differ by more than 0.01 percent the user is advised to rerun the program using a larger value of IT.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALBEDO</td>
<td>= CSSUM/CTSUM; albedo for single scattering.</td>
</tr>
<tr>
<td>C(I)</td>
<td>the cosines of scattering angles. 'IT' elements in the array.</td>
</tr>
<tr>
<td>CAY</td>
<td>the ratio of the imaginary part to the real part of adjusted refractive index of the last component.</td>
</tr>
<tr>
<td>CAYNG</td>
<td>= -CAY.</td>
</tr>
<tr>
<td>CRSUM</td>
<td>the average back-scattering cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average scattering coefficient per km.</td>
</tr>
<tr>
<td>CSSUM</td>
<td>the average scattering cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average scattering coefficient per km.</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Explanation or Definition</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>CTSUM</td>
<td>the average extinction cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average extinction coefficient per km.</td>
</tr>
<tr>
<td>DENS</td>
<td>the total particle number density in cm(^{-3}).</td>
</tr>
<tr>
<td>EM</td>
<td>the real part of the adjusted refractive index of the last aerosol component.</td>
</tr>
<tr>
<td>EMM</td>
<td>the refractive index of the surrounding medium. It is set equal to 1 in AGAUSX.</td>
</tr>
<tr>
<td>GNU</td>
<td>the wave number in cm(^{-1}).</td>
</tr>
<tr>
<td>H(I)</td>
<td>the array containing 'IT' scattering angles (in degrees).</td>
</tr>
</tbody>
</table>
| IANG   | = 0, for computation of phase functions at 'IT' Gauss-Legendre quadrature angles.  
        | = 1, for computation of phase functions and scattering functions at 'IT' equally spaced angles between 0° and 180°.  
<pre><code>    | = 2, for computation of phase functions and scattering fractions at 'IT' user supplied angles.                                                          |
</code></pre>
<p>| IDSTP  | identities the type of aerosol size distribution to be used.                                                                                               |
| IT     | the order of expansion for phase functions when IANG = 0, the number of equally spaced angles between 0° and 180° when IANG = 1, or the number of user supplied angles when IANG = 2. |
| ITOT   | used for optional write/punch on NUNIT.                                                                                                                  |
| KRSUM  | the back-scattering coefficient per km integrated over the size distribution for each WAVE.                                                            |
| KSSUM  | the scattering coefficient per km integrated over the size distribution, for each WAVE.                                                                |</p>
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTSM</td>
<td>the extinction coefficient per km integrated over the size distribution, for each WAVE.</td>
</tr>
<tr>
<td>NCRDS</td>
<td>= 1 for write/punch only Legendre coefficients on NUNIT: = 2 write only phase functions and scattering fractions on NUNIT: = 3 write/punch both on NUNIT.</td>
</tr>
<tr>
<td>NINDX</td>
<td>the number of aerosol components which will have different optical constants, mass density or mass concentration.</td>
</tr>
<tr>
<td>NUNIT</td>
<td>defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files on tape, etc. The default value (NUNIT = 0) is 4.</td>
</tr>
<tr>
<td>OL(1)</td>
<td>the first coefficient in the Legendre expansion of phase functions. When OL(1) disagrees with ALBEDO by more than 0.01 percent program AGAUSX should be rerun using a larger value of IT.</td>
</tr>
<tr>
<td>PFACT</td>
<td>= WAVE<em>WAVE/(PI</em>CTSUM<em>EMM</em>EMM). When PSUM(J) is multiplied by PFACT we get the original phase functions.</td>
</tr>
<tr>
<td>PSUM(J)</td>
<td>the average intensity factors integrated over the size distribution when received by AGXPT3, but they are the original phase functions for each WAVE when returned to MAIN.</td>
</tr>
<tr>
<td>SCAT(J)</td>
<td>contains 'IT' values of scattering fractions for each WAVE.</td>
</tr>
<tr>
<td>SFACT</td>
<td>= WAVE<em>WAVE</em>DENS<em>10^-6/4</em>PI*PI. When PSUM(J) is multiplied by SFACT, one gets the scattering fractions of ACT code.</td>
</tr>
<tr>
<td>WAVE</td>
<td>the wavelength in microns.</td>
</tr>
</tbody>
</table>
Subroutine AGXPT3 - Simplified Flowchart

Calculate Albedo, scattering fractions, phase functions and various coefficients for each wavelength

IANG = 1

Print-all-the-results calculated in the above block

Print the values of various coefficients, phase functions and the cosines of scattering angles

Call GAUS

RETURN
**SUBROUTINE MIEGX**

Subroutine MIEGX computes various efficiency factors, and intensity factors $i_1$ and $i_2$ for each complex refractive index $m$, size parameters $a$ and also the first three Legendre coefficients ($\tilde{\omega}_0$, $\tilde{\omega}_1$, $\tilde{\omega}_2$) when IAPX is greater than zero. The Ricatti-Bessel functions and their derivatives in equations (5) and (6) are computed by the forward recursion method. The initial values used in forward recursion are:

$$\psi_0(z) = \sin z,$$

$$\psi_1(z) = \frac{\sin z}{z} - \cos z,$$

$$X_0(z) = \cos z,$$ and

$$X_1 = \frac{\cos z}{z} + \sin z.$$

[Note: $\xi_n(z) = \psi_n(z) + i\chi_n(z)$]

*A Mie-type routine utilizing a continued fractions method of calculation was obtained from W. J. Lentz of the Atmospheric Sciences Laboratory and modified slightly to substitute directly for MIEGX in AGAUSX, thereby eliminating the need for the forward recursion of the Ricatti-Bessel functions. The new routine is more accurate for larger Mie sizes and larger imaginary parts of the index of refraction. This new routine has been validated by New Mexico State University under contract DAAD07-79-M-6275. The rotation has been kept the same between the two routines as much as possible.*
The angular functions $\pi_n$ and $\tau_n$ are also computed by forward recursions from Equations (24) and (25). The initial values used are $\pi_0(\theta) = 0$, $\pi_1(\theta) = 1$, $\tau_0(\theta) = 0$, and $\tau_1(\theta) = \cos \theta$.

The Mie series is terminated either when two successive terms have 

$$\left( |\text{Re}(a_n)| + |\text{Im}(a_n)| + |\text{Re}(b_n)| + |\text{Im}(b_n)| \right) < 10^{-5},$$

or when the number of terms exceeds $(8 + 8\alpha)$. $F$ is 1.2 for $\alpha \leq 51$ and is $1 + 2.26\alpha^{-0.613}$ for $\alpha > 51$. The tolerance value of $10^{-5}$ could be decreased for higher precision, if the user so desires.

The subroutine computes and stores arrays of $a_n$ and $b_n$ until convergence is reached and then generates necessary $\pi_n$ and $\tau_n$ functions. Finally it computes values of $Q_{\text{ext}}$, $Q_{\text{sca}}$, $Q_{\text{abs}}$ (absorption) $i_1$, $i_2$, $Q_{\text{rad}}$ (backscatter), $p(\theta)$, and radiation pressure $Q_{\text{pr}}$.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPHA</td>
<td>Mie size parameter, $\alpha = 2\pi r/\lambda$.</td>
</tr>
<tr>
<td>C(K)</td>
<td>the array of cosine of the scattering angles. There are 'IT' elements in the array.</td>
</tr>
<tr>
<td>CAY</td>
<td>the ratio of the imaginary part to the real part of adjusted refractive index. See AG9PT2.</td>
</tr>
<tr>
<td>EM</td>
<td>the real part of adjusted refractive index.</td>
</tr>
<tr>
<td>EN</td>
<td>floating point representation of N.</td>
</tr>
<tr>
<td>EYE1(K)</td>
<td>$i_1$ (Eq. 15) at angles = Arc cos $</td>
</tr>
<tr>
<td>EYE2(K)</td>
<td>$i_2$ (Eq. 16) at angles = arc cos $</td>
</tr>
<tr>
<td>FACT</td>
<td>determines the cutoff criterion to terminate the Mie series. It is equal to 1.2 if $\alpha \leq 51$ and is $1 + 2.26\alpha^{-0.613}$ for $\alpha &gt; 51$. See Mie theory text.</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>FAN(N)</td>
<td>= \text{Im}(a_n) \text{; Equation (5)}.</td>
</tr>
<tr>
<td>FBN(N)</td>
<td>= \text{Im}(b_n) \text{; Equation (6)}.</td>
</tr>
<tr>
<td>GAMMA</td>
<td>the true imaginary part of adjusted refractive index.</td>
</tr>
<tr>
<td>IERROR</td>
<td>a flag which is set to unity if the number of terms (N) reaches the maximum value allowed in the dimensions of a_n and b_n.</td>
</tr>
<tr>
<td>ISW1</td>
<td>a switch parameter used in applying cutoff criterion.</td>
</tr>
<tr>
<td>O1STAR</td>
<td>= \tilde{\omega}_1 \text{; first order coefficient for Legendre expansion of the average intensity } P(K).</td>
</tr>
<tr>
<td>O2STAR</td>
<td>= \tilde{\omega}_2 \text{; second order coefficient for Legendre expansion of the average intensity } p(K).</td>
</tr>
<tr>
<td>P(K)</td>
<td>= (i_1 + i_2)/2, the average intensity at angles, \text{Arc cos } (C(K)).</td>
</tr>
<tr>
<td>PIN</td>
<td>= \pi_n(\theta) \text{; Equation (17)}.</td>
</tr>
<tr>
<td>REAN</td>
<td>= \text{Re}(a_n) \text{; Equation (5)}.</td>
</tr>
<tr>
<td>REBN</td>
<td>= \text{Re}(b_n) \text{; Equation (6)}.</td>
</tr>
<tr>
<td>RN</td>
<td>= \text{Re}(\psi_n(n\alpha)) \text{; Equation (7)}.</td>
</tr>
<tr>
<td>RNL1</td>
<td>= \text{Re}(\psi_1(n\alpha)) \text{; Equation (7)}.</td>
</tr>
<tr>
<td>RPN</td>
<td>= \text{Re}(\psi'(n\alpha)). Prime indicates differentiation with respect to the argument.</td>
</tr>
<tr>
<td>SGA</td>
<td>the absorption efficiency factor.</td>
</tr>
<tr>
<td>SGMAS</td>
<td>the average value of Cos(\theta), where \theta is the scattering angle.</td>
</tr>
<tr>
<td>SGMP</td>
<td>the radiation pressure factor Q_{pr}.</td>
</tr>
<tr>
<td>SGR</td>
<td>the back-scattering efficiency factor.</td>
</tr>
<tr>
<td>SGS</td>
<td>the scattering efficiency factor.</td>
</tr>
<tr>
<td>SGT</td>
<td>the extinction efficiency factor.</td>
</tr>
<tr>
<td>SN</td>
<td>= \text{Im}(\psi_n(n\alpha)) \text{; Equation (7)}.</td>
</tr>
</tbody>
</table>
SNL1 = $\text{Im}(\psi_0(n\alpha))$; Equation (7).

SPN = $\text{Im}(\psi'(n\alpha))$. Prime indicates differentiation with respect to the argument.

SUMII the imaginary part of the scattering amplitude $S_1(\theta)$;

$$\text{Im}S_1(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\text{Im}(\alpha_n)\pi_n(\theta) + \text{Im}(\beta_n)\tau_n(\theta)].$$

SUMII the imaginary part of the scattering amplitude $S_2(\theta)$;

$$\text{Im}S_2(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\text{Im}(\beta_n)\pi_n(\theta) + \text{Im}(\alpha_n)\tau_n(\theta)].$$

SUMII the real part of the scattering amplitude $S_1(\theta)$;

$$\text{Re}S_1(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\text{Re}(\alpha_n)\pi_n(\theta) + \text{Re}(\beta_n)\tau_n(\theta)].$$

SUMII the real part of the scattering amplitude $S_2(\theta)$;

$$\text{Re}S_2(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\text{Re}(\beta_n)\pi_n(\theta) + \text{Re}(\alpha_n)\tau_n(\theta)].$$

SUMR = $\sum_{n=1}^{N} (-1)^n(2n+1)\text{Im}(\alpha_n - \beta_n)$.

SUMRR = $\sum_{n=1}^{N} (-1)^n(an+1)\text{Re}(\alpha_n - \beta_n)$.

SUMS = $\sum (2n+1)(|\alpha_n|^2 + |\beta_n|^2)$.

SUMS1 = $\sum_{n=2}^{N} \frac{(n-1)(n+1)}{n} [\text{Re}(\alpha_n)\text{Re}(\alpha_{n+1}) + \text{Re}(\beta_n)\text{Re}(\beta_{n+1})$

$+ \text{Im}(\alpha_n)\text{Im}(\alpha_{n+1}) + \text{Im}(\beta_n)\text{Im}(\beta_{n+1})].$

SUMS2 = $\sum_{n=1}^{N} \frac{(2n-1)}{n(n-1)} [\text{Re}(\alpha_n)\text{Re}(\beta_n) + \text{Im}(\alpha_n)\text{Im}(\beta_n)]$.

SUMT = $\sum (2n+1)\text{Re}(\alpha_n + \beta_n)$. 
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAUN</td>
<td>$\tau_n(\theta)$; Equation (17).</td>
</tr>
<tr>
<td>TERMN</td>
<td>$</td>
</tr>
<tr>
<td>TN</td>
<td>$\psi_n(\alpha)$; Equation (7).</td>
</tr>
<tr>
<td>TNL1</td>
<td>$\psi_0(\alpha)$; Equation (7).</td>
</tr>
<tr>
<td>TPN</td>
<td>$\psi'(\alpha)$; prime indicates differentiation with respect to the argument.</td>
</tr>
<tr>
<td>UN</td>
<td>$\chi_n(\alpha)$; Equation (8).</td>
</tr>
<tr>
<td>UNL1</td>
<td>$\chi_0(\alpha)$; Equation (8).</td>
</tr>
<tr>
<td>UPN</td>
<td>$\chi_n'(\alpha)$; prime indicates differentiation with respect to the argument.</td>
</tr>
</tbody>
</table>
Subroutine MIEGX - Simplified Flowchart

1. Initialize SUMT etc; establish MIE series cutoff criterion

2. Generate Bessel's function of first order

3. Recurrence relations for unprimed functions $\psi_n$ and $\chi_n$

4. Recurrence relations for primed functions $\psi'_n$ and $\chi'_n$

5. Compute Mie coefficients $a_n$ and $b_n$

6. Apply cutoff criterion

7. Compute angular functions $\pi_n$ and $\tau_n$; then compute efficiency factors and the average intensities

RETURN
SUBROUTINE ANGLE

Subroutine ANGLE is called when IANG = 1 or 2. It is used to compute the values of 'IT' equally spaced scattering angles between 0° and 180° or a read in set of user-supplied angles. It places these angle values in the array, H(I). It also computes the cosines of those angles and places them in the array C(I).

<table>
<thead>
<tr>
<th>SYMBOLS</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(I)</td>
<td>the array containing the cosines of scattering angles in the array H(I).</td>
</tr>
<tr>
<td>H(I)</td>
<td>the array containing 'IT' scattering angles (in degrees).</td>
</tr>
<tr>
<td>IT</td>
<td>is the number of scattering angles chosen between 0° and 180°.</td>
</tr>
<tr>
<td>RADS</td>
<td>=PI/180.</td>
</tr>
</tbody>
</table>

SUBROUTINE GUSET

Subroutine GUSET uses the Davis and Rabinowitz algorithm\(^{11}\) to choose \(n\) values of \(\cos \theta_{kn}\) (\(k = 1,2,...,n\)) between the interval \(-1 \leq \cos \theta \leq 1\) and the corresponding values of quadrature weights \(a_{kn}\). The abscissas, \(\cos \theta_{kn}\) are the \(n\) zeros of the Legendre polynomials \(P_n(\cos \theta_{kn})\), while the weights are given by

\[
a_{kn} = \frac{2(1 - x_{kn}^2)}{[nP_{n-1}(x_{kn})]^2} \quad (65)
\]

\(^{11}\)P. Davis and P. Rabinowitz, 1956, J Res NBS, 56:35
Initial estimates of the zeros are obtained from the \( n \) successive zeros of the Bessel function \( j_0(j_k) = 0 \) via

\[
x_{kn} = \cos \left[ j_k / ((n + \frac{1}{2})^2 + (1 - (\frac{2}{\pi})^2)/4)^{1/2} \right].
\]

(66)

Final values of the \( x_{kn} \) are found by Newton-Raphson iteration. The tolerance of Legendre polynomial zeros is set at \( 10^{-14} \).

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AKN(k)</td>
<td>( a_{kn} ) (Eq. 32). 'IT' elements in the array.</td>
</tr>
<tr>
<td>IT</td>
<td>( n ); it is the order of Legendre expansion for phase functions.</td>
</tr>
<tr>
<td>P(N)</td>
<td>Legendre polynomials, ( p_n(x) ).</td>
</tr>
<tr>
<td>X</td>
<td>( x_{kn} ) (Eq. 33).</td>
</tr>
<tr>
<td>XKN(K)</td>
<td>( \cos^\circ_{kn}; p_n(\cos^\circ_{kn}) = 0 ) within ( 10^{-14} ).</td>
</tr>
<tr>
<td>TOL</td>
<td>the tolerance of zeros of Legendre polynomials = ( 10^{-14} ).</td>
</tr>
<tr>
<td>Z(I)</td>
<td>( j_k ) (Eq. 33). ( I, k = 1, 2, \ldots ) IT.</td>
</tr>
</tbody>
</table>

**SUBROUTINE GAUS**

Subroutine GAUS computes the Legendre polynomials as \( PL(\cdot) \) and computes Legendre expansion coefficients given by equation (31) numerically. To do that the integral in equation (31) is replaced by summation as follows:

\[
\omega_k = \frac{(2k+1)}{2} \sum_{k=1}^{n} p(\theta_{kn})p_n(\cos^\circ_{kn})a_{kn},
\]

where \( \theta_{kn} \) and \( a_{kn} \) have the meaning as given in subroutine GUSET.
Using the values of coefficients \( \tilde{\omega} \) and equation (30), the phase functions are reconstructed and called \( p_c(\theta_{kn}) \). GAUS then computes the root mean square deviation between the original phase functions \( p(\theta_{kn}) \) and the reconstructed phase functions \( p_c(\theta_{kn}) \) as each successive term is added to the series in equation (30). Finally it prints out the values of coefficients and rms deviations.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>is the array containing the original phase function ( p(\theta_{kn}) ).</td>
</tr>
<tr>
<td>IT</td>
<td>is the order of Legendre expansion for phase functions.</td>
</tr>
<tr>
<td>NCRDS</td>
<td>= 1 for write/punch only Legendre coefficients on NUNIT; = 2 write only phase functions and scattering fractions on NUNIT; = 3 write/punch both on NUNIT.</td>
</tr>
<tr>
<td>NUNIT</td>
<td>defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files or tape, etc. The default value (NUNIT=0) is 4.</td>
</tr>
<tr>
<td>OL(LL)</td>
<td>the array containing coefficients ( \tilde{\omega}_l ).</td>
</tr>
<tr>
<td>PL(,)</td>
<td>Legendre polynomials (equivalenced in MIEGX).</td>
</tr>
<tr>
<td>PC(I)</td>
<td>the array containing the reconstructed phase functions ( p_c(\theta_{kn}) ).</td>
</tr>
<tr>
<td>RMS(J)</td>
<td>the rms deviation between the original phase functions and the reconstructed phase functions.</td>
</tr>
</tbody>
</table>
SUBROUTINE WATER

The purpose of subroutine WATER is to relieve the user of program AGAUS of the task of looking up and keypunching data on the index of refraction and mass density of liquid water. This routine receives the wavelength (\(\mu m\)) and temperature (\(^{\circ}K\)) from the calling program as variables WVD and TEMPD. It returns the mass density through variable DENSd, and the real and imaginary parts of the refractive index of liquid water through the variables EMD and CAYD, respectively.

The data on optical constants coded into routine WATER were taken from the tabulation by Irvine and Pollack\(^9\) and the water densities were taken from a copy of the CRC Handbook of Chemistry and Physics. Tabulated values of the real (m) and imaginary (k) parts of the refractive index are available for the wavelength range 0.20\(\mu m\) to 200\(\mu m\), and are entered at uniform wavelength increments. Values of the real (m) and imaginary (k) parts of the refractive index at wavelengths other than found in the table are estimated through straight-line interpolation. Linear interpolation is also used between tabulated temperatures in calculating the mass density \(\rho_w\) ( = DENSd).

Methods Used

Subroutine WATER conducts separate binary searches of the wavelength table LAMBDA() and temperature table TEMP() to find the indices L and L+1 which bracket the received wavelength (WVD) and temperature (TEMPD). It then uses linear interpolation to get estimated values of EMT, (M), CAYT, (k), and RHODEN (\(\rho_w\)).

The interpolation formula can be written as

\[
y(x) = y(x_L) + \left[\frac{y_{L+1} - y_L}{x_{L+1} - x_L}\right](x-x_L),
\]

with \(y = m, k\) or \(\rho_w\) and \(x = \) wavelength or temperature.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAYD</td>
<td>imaginary part of refractive index k.</td>
</tr>
<tr>
<td>CAYT</td>
<td>the interpolated value of k in single precision form; used intermediately to hold summed quantities.</td>
</tr>
<tr>
<td>DENSID</td>
<td>interpolated result for the mass density of liquid water - $\rho_w$.</td>
</tr>
<tr>
<td>EMD</td>
<td>real part of index of refraction - m.</td>
</tr>
<tr>
<td>EMT</td>
<td>the interpolated result for the real part of the refractive index.</td>
</tr>
<tr>
<td>H</td>
<td>an indexing (integer) parameter.</td>
</tr>
<tr>
<td>L</td>
<td>an integer indexing parameter.</td>
</tr>
<tr>
<td>LAMBDA( )</td>
<td>array of wavelengths at which data are entered for m and k; [typed as &quot;real&quot;].</td>
</tr>
<tr>
<td>NSUBI( )</td>
<td>array of values for k (or, $n_{\text{imaginary}}$); [typed as &quot;real&quot;].</td>
</tr>
<tr>
<td>NSUBR</td>
<td>array of data entries for m (or, $n_{\text{real}}$) [typed as &quot;real&quot;].</td>
</tr>
<tr>
<td>P</td>
<td>an (integer) indexing parameter.</td>
</tr>
<tr>
<td>POINT</td>
<td>an (integer) indexing parameter.</td>
</tr>
<tr>
<td>TEMP( )</td>
<td>array of temperature values (°K) at which entries for $\rho_w$ exist.</td>
</tr>
<tr>
<td>TEMPD</td>
<td>temperature at which $\rho_w$ is to be found.</td>
</tr>
<tr>
<td>TMCHUR</td>
<td>temperature at which value of $\rho_w$ is desired.</td>
</tr>
<tr>
<td>RHODEN</td>
<td>interpolated result for $\rho_w$.</td>
</tr>
<tr>
<td>WAVE</td>
<td>single precision version of wavelength at which values of n and k are desired.</td>
</tr>
</tbody>
</table>
SUBROUTINE AGXPRT

Subroutine AGXPRT prints out all the averaged (sum/NWAVE) results essentially in the same way as AGXPT3 does for each wavelength if IAPX = 0. If IANG = 0, subroutine GAUS is called to generate Legendre expansion coefficients which are used to reconstruct the averaged phase functions. GAUS also computes the root mean square deviation between the original phase function and the reconstructed phase functions. See the section on subroutine GAUS for more details. If IANG = 1 or 2, the above calculation is skipped.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(I)</td>
<td>the cosines of scattering angles. 'IT' elements in the array.</td>
</tr>
<tr>
<td>CATTN</td>
<td>the average (sum/NWAVE) attenuation coefficient in square meters per milligram of aerosol material.</td>
</tr>
<tr>
<td>H(I)</td>
<td>the array containing 'IT' scattering angles (in degrees).</td>
</tr>
<tr>
<td>IANG</td>
<td>= 0, for the computation of phase functions at 'IT' Gauss-Legendre quadrature angles.</td>
</tr>
<tr>
<td></td>
<td>= 1, for the computation of phase functions and scattering fractions at 'IT' equally spaced angles between 0° and 180°.</td>
</tr>
<tr>
<td>IT</td>
<td>the order of Legendre expansion for phase functions when IANG = 0, or the number of equally spaced angles between 0° and 180° when IANG = 1, or the number of user-supplied angles when IANG = 2.</td>
</tr>
<tr>
<td>KBAKT</td>
<td>the average (sum/NWAVE) back-scattering coefficient per km, integrated over the size distribution.</td>
</tr>
<tr>
<td>KEXTT</td>
<td>the average (sum/NWAVE) extinction coefficient per km, integrated over the size distribution.</td>
</tr>
<tr>
<td>KSCAT</td>
<td>the average (sum/NWAVE) scattering coefficient per km, integrated over the size distribution.</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Explanation or Definition</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>NUNIT</td>
<td>defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files on tape, etc. The default value (NUNIT=0) is 4.</td>
</tr>
<tr>
<td>NWAVE</td>
<td>the number of wavelengths or relative humidity values to be treated in a given run.</td>
</tr>
<tr>
<td>PSUM(J)</td>
<td>the array containing the values of average (sum/NWAVE) phase function integrated over the size distribution.</td>
</tr>
<tr>
<td>SCATT(J)</td>
<td>the array containing the values of average (sum/NWAVE) scattering fractions.</td>
</tr>
</tbody>
</table>
Subroutine AGXPRT - Simplified Flowchart

1. Print the averaged results for various coefficients
2. IANG=1
3. Print scattering angles, phase functions and scattering fractions
4. IANG=0
5. Print phase functions and the cosines of scattering angles
6. If ISCAT=1, punch or write on NUNIT scattering fractions
7. Call GAUS
8. RETURN
SUBROUTINE GPHASX

Subroutine GPHASX constructs the GHG analytic phase function. The required input consists of the phase function at zero degrees, $\tilde{\omega}_0$, $\tilde{\omega}_2$, and the order of Legendre expansion, L. The parameter $g$, denoted by GI in the subroutine, is then determined by an iterative process: note $0 \leq g \leq 1$. We then determine $\alpha$ and subsequently proceed to construct the GHG phase function, checking to insure that the phase function does not go negative; if it does, we leave the current loop and starting from the previous value of $u$ (for which the phase function was positive), continue to construct the GHG phase function from the modified HG phase function. The GHG phase function is then renormalized and the appropriate Legendre coefficients are constructed.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPHA</td>
<td>$0.5[\tilde{\omega}_2/(\tilde{\omega}_o g^2)-1]$.</td>
</tr>
<tr>
<td>C</td>
<td>$P(1)/\tilde{\omega}_o$.</td>
</tr>
<tr>
<td>COEF</td>
<td>Array containing first three Legendre coefficients ($\tilde{\omega}_o$, $\tilde{\omega}_1$, $\tilde{\omega}_2$).</td>
</tr>
<tr>
<td>DELL</td>
<td>Iterative increment in determination of G</td>
</tr>
<tr>
<td>DEN</td>
<td>$1 + G^2 - 2\mu G; \mu = \cos \theta$.</td>
</tr>
<tr>
<td>DENOM</td>
<td>$(1 + G^2 - 2\mu G)^{1/2}$.</td>
</tr>
<tr>
<td>ELHS</td>
<td>$G[(1 - G^2)P(1)/\tilde{\omega}_o - 1 + 3G/2]$.</td>
</tr>
<tr>
<td>EMO</td>
<td>Array containing Gauss-Legendre angles.</td>
</tr>
<tr>
<td>EMU</td>
<td>Array containing cosines of Gauss-Legendre angles.</td>
</tr>
<tr>
<td>ERR</td>
<td>Error in integrated GHG phase function.</td>
</tr>
<tr>
<td>G</td>
<td>Parameter in GHG phase function.</td>
</tr>
<tr>
<td>GPFN</td>
<td>Array containing GHG phase function.</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Explanation or Definition</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>GSQ</td>
<td>G * G.</td>
</tr>
<tr>
<td>ITR</td>
<td>number of iterations in the determination of G; 100 iterations maximum.</td>
</tr>
<tr>
<td>NUNIT</td>
<td>Auxiliary unit for writing/punching Legendre coefficients for GHG phase function.</td>
</tr>
<tr>
<td>OM</td>
<td>Array containing GHG phase function Legendre coefficients.</td>
</tr>
<tr>
<td>OMO</td>
<td>Approximate $\tilde{\omega}_0$.</td>
</tr>
<tr>
<td>PA</td>
<td>Array of temporary values needed in subroutine GUSSTX.</td>
</tr>
<tr>
<td>PHASE0</td>
<td>GHG phase function at zero degrees.</td>
</tr>
<tr>
<td>PL</td>
<td>Array containing Legendre polynomials.</td>
</tr>
<tr>
<td>PSUM</td>
<td>Array containing true phase function at zero degrees; PSUM(1).</td>
</tr>
<tr>
<td>RHS</td>
<td>(0.5\tilde{\omega}_2/\tilde{\omega}_0).</td>
</tr>
<tr>
<td>SUM</td>
<td>integrated GHG phase function.</td>
</tr>
<tr>
<td>TRUEG</td>
<td>Asymmetry factor = (\tilde{\omega}_1 / (3\tilde{\omega}_0)).</td>
</tr>
<tr>
<td>W</td>
<td>Array containing weights for Gauss-Legendre integration.</td>
</tr>
</tbody>
</table>
SUBROUTINE GUSTK

This subroutine is essentially the same as GUSET: please see GUSET for details.

SUBROUTINE PRINTX

Subroutine PRINTX prints out various quantities for the analytic GHG phase function. It will also punch out the Legendre coefficients for the GHG function.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>Explanation or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>COEFS</td>
<td>Array containing GHG Legendre coefficients.</td>
</tr>
<tr>
<td>EMU</td>
<td>Array containing cosine of Gauss-Legendre angles.</td>
</tr>
<tr>
<td>ERROR</td>
<td>Percent error in the GHG integrated phase function.</td>
</tr>
<tr>
<td>G</td>
<td>Asymmetry factor; ( \tilde{\omega}_1/(3\tilde{\omega}_0) ).</td>
</tr>
<tr>
<td>NUNIT</td>
<td>Auxiliary unit for writing (punching) GHG Legendre coefficients.</td>
</tr>
<tr>
<td>PHASE</td>
<td>GHG phase function at zero degrees.</td>
</tr>
<tr>
<td>PHFN</td>
<td>GHG phase function.</td>
</tr>
<tr>
<td>PSUM</td>
<td>Array containing true phase function at zero degrees.</td>
</tr>
<tr>
<td>SUM</td>
<td>GHG integrated phase function.</td>
</tr>
</tbody>
</table>
INPUT DATA

There are nominally four data and control cards required for running program AGAUSX.

<table>
<thead>
<tr>
<th>CARD</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>A set of integers which select certain options available within the program.</td>
</tr>
<tr>
<td>IA</td>
<td>A user set of supplied angles.</td>
</tr>
<tr>
<td>II</td>
<td>A set of data describing the parameters of the particular size distribution function to be used. For cases other than the user-supplied &quot;arbitrary&quot; distribution (IDSTP = 0), only one card of this type is needed.</td>
</tr>
<tr>
<td>IIIA</td>
<td>A set of data describing the initial wavelength (μm) to be used, its increment, aerosol number density (particles per cc), relative humidity (percent), atmospheric temperature (degrees centigrade), and the desired convergence testing level.</td>
</tr>
<tr>
<td>IIIB</td>
<td>If the looping option for relative humidity is invoked then NWAVE-1 cards containing relative humidity and atmospheric temperature must be added.</td>
</tr>
<tr>
<td>IV</td>
<td>A set of data describing the optical and physical properties of the aerosol material. If the aerosol is a mixture of materials of unlike properties (NINDX &gt; 1), more than one card of this type is needed for each card of type III. No card of this type is used, however, for runs with parameter IDSTP equal to 6.</td>
</tr>
</tbody>
</table>
Remarks:

1. The simplest type of run (IDSTP=6, water cloud or fog model) requires one card each of types I, II, and III. For other IDSTP choices, at least one card of type IV is also needed.

2. If the run is to use several wavelengths (NWAVE > 1), then at least one card of type IV is required for each wavelength (more than one type IV card will be needed at each wavelength if the aerosol is a multicomponent mixture - NINDX > 1).

3. Two special "looping" modes of AGAUSX affect the number of cards of type III which are needed:

   a. For runs at constant relative humidity and several wavelengths, only one type III card is permitted. To activate this mode, the wavelength increment DWAVE on card type III must be larger than 10^-4.

   b. Runs at constant wavelength and a set of differing values of relative humidity require one card of types IIIA and IV for the first value of relative humidity; subsequently NWAVE-1 cards of types IIIB and IV are needed for each additional value of relative humidity. This option is invoked by setting the parameter "DWAVE" less than 10^-4 on the first card of type IIIA.

Description of Types of Distributions

<table>
<thead>
<tr>
<th>IDSTP</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>This is an arbitrary user-supplied distribution. 'NRADI' + 1 cards will be read; the first card contains RLO and DELLR ((\mu m)). The rest of the cards carry the values of (F(J)) and must be in order of increasing radius value.</td>
</tr>
<tr>
<td>1</td>
<td>This is the zero-order log-normal distribution: the distribution function is given by</td>
</tr>
</tbody>
</table>
\[ F(R) = \frac{1}{\sqrt{2\pi} \log_e(\sigma) R} \exp\left\{ -\frac{1}{2} \left[ \frac{\log_e(R/R)}{\log_e(\sigma)} \right]^{1/2} \right\}. \]

\( R \equiv \text{Rbar}; \sigma \equiv \text{SIGMA} \), is the standard deviation. This distribution type requires one input data card to read in the values of \( R, \sigma, \text{RLO} \) and \( \text{RHI} \).

This is called the double exponential distribution and its distribution function is given by \( F(R) = QA \exp(-AR) + (1-Q)B \exp(-BR) \). \( Q \equiv \text{CUE} \). This distribution type requires one input data card to read in the values of \( \text{RLO}, \text{RHI}, Q, A, \) and \( B \). \( Q \) is dimensionless while \( A \) and \( B \) have units of \( \mu m^{-1} \).

This model (Deirmendjian's "Model C") does not require any input data card. It carries fixed value of \( \text{DENS}, \text{RLO}, \) and \( \text{DELRD} \). \( \text{RHI} \) is determined by the input parameter \( \text{NRADI} \).

\[
F(R) = \begin{cases} 
450.2 & \text{if } R \leq 0.08 \\
2.251*\text{DELRD}*R^{-4} & \text{if } R \geq 0.08
\end{cases}
\]

The distribution function of this model (Junge distribution) is given by \( F(R) = QR^{-A} \), \( Q \equiv \text{CUE} \). This distribution type requires one input data card to read in \( \text{RLO}, \text{RHI}, A, A \).

The distribution function for the Modified Gamma/Generalized Khirgian-Mazin distribution is

\[
F(R) = R^\alpha \exp\left\{ -\left( \frac{R}{R_c} \right)^\gamma \cdot \frac{\alpha}{\gamma} \right\}, \alpha \equiv \text{ALF}, \gamma \equiv \text{GAM}, \text{and}
\]
$R_c = RC$. One input card is needed to read in RLO, RHI, RC, ALF, GAM, and ELWC. ELWC is not needed for type 5 distribution and therefore can be left blank.

6 The size distribution model (NMSU Fog or Cloud Model) is very similar to type 5, except that the user must supply one additional input parameter—namely, the liquid water content (ELWC) in gm/cc. This model can be used for treating situations involving liquid water aerosols like clouds or fogs. For type 6 runs one does not need to read in the values of EMA, CAYA, RHOA, CONC.

7 This distribution is essentially same as Junge's distribution (type 4) except that it has fixed parameters. One input card is needed to read in VIS (visibility in km); VIS is used in calculating DENS.

8 This is a fixed parameter Continental Bi-modal Model. It does not require an input data card.

9 This is a fixed parameter Maritime Bi-modal Model. It does not require an input data card.

10 This is a fixed parameter Urban Bi-modal Model. It does not require an input data card.

11 This is a user-supplied Bi-modal Model. This requires one input card to read in FOA, FOC, SGA, SGC, RBARA, RBARC. Types 8, 9, 10, and 11 use the sum of two log-normal distributions:

$$F(R) = \sum_{i=1}^{2} \frac{N_i}{\sqrt{2\pi} \log_e(\sigma_i)R} \exp \left\{ -\frac{1}{2} \frac{\log_e(R/R_i)}{\log_e(\sigma_i)} \right\}^2$$

$N_1 \equiv FOA$, $R_1 \equiv RBARA$, $\sigma_1 \equiv SGA$ with similar meaning for $N_2$, $R_2$, and $\sigma_2$. Note that in Type 8, 9, 10 the values of SGA and SGC are $\log_e(\sigma)$. 121
This model (Marshall-Palmer Rain Model) is a simple exponential model which assumes an empirical relationship between rain rate and droplet size distribution parameters:

\[ F(D) = N_0 \exp(-AD). \]

\[ N_0 = 0.08 \text{ cm}^{-4}, \text{ and } A = 41(RN)^{-0.21} \text{ in which } RN = \text{RAIN is the rain rate in mm/hour. Diameter } D \text{ is in cm. The corresponding size distribution function of radius } R \text{ is given by} \]

\[ F(R) = 2N_0 \exp(-2AR). \]

This distribution requires one input data card to read in RAIN. The values of RLO and RHI are fixed at 0 and 0.5 cm respectively. Due to the limitations on the range of Mie-sizes (subroutine MIEGX) type 12 usage is limited to wavelengths of the order of 1 mm or larger. Since subroutine WATER does not contain optical data for wavelengths longer than 0.2 mm, type 12 runs require the user to supply the values of EMA, CAYA, and RHOA as if rain were a non-aqueous aerosol.
SUMMARY OF DATA CARD REQUIREMENTS

<table>
<thead>
<tr>
<th>CARD TYPE</th>
<th>INPUT SYMBOLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Integer control parameters: NAVE, NINDX, IW, IDSTP, NRADI, IT, IANG, NCRDS, ITOT, MQRTE, IAPX, FORMAT (1215). NAVE: is the number of wavelengths, or relative humidity values to be treated in this run. See comments circa read of WAVE, DWAVE, etc. NINDX: is the number of aerosol components which will have different optical constants, mass densities or mass concentrations. IW: = 0 will set the refractive index of the dry aerosol equal to that of water at the input wavelength and temperature - see Card 4, EMA, CAYA. IDSTP: Identifies type of aerosol size distribution to be used. NRADI: Number of particle radii to be expected for IDSTP = 0 or 3: the input value of NRADI is ignored for IDSTP not zero or 3. NRADI must be less than 513. IT: is the number of Gauss-Legendre angles (order of expansion) if IANG = 0 or number of angles between 0 degrees and 180 degrees if IANG = 1. If only extinction coefficients, etc. are desired, i.e., not phase functions, then set -IT- equal to one. IANG: = 0 for computations of phase function at -IT- Gauss-Legendre quadrature angles: no scattering fractions will be printed. IANG = 1 for computations of scattering fractions and phase functions at -IT- equally spaced angles between 0 and 180 degrees. IANG = 2 will allow -IT- user supplied angles to be read - FORMAT (16F5.1). This requires at least one card of type IA.</td>
</tr>
</tbody>
</table>

123
NCRDS: = 1 write/punch Legendre coefficients and order of expansion on NUNIT - FORMAT (D25.14,1X,15): = 2 write/punch scattering fractions, phase functions, cosines and counter on NUNIT - FORMAT (3(D12.61X),15): = 3 write/punch both scattering fractions, phase functions, cosines, counter, and Legendre coefficients and order of expansion on NUNIT - FORMATS (3(D12.6.,1X),15) and (D25.14,1X,15): scattering fractions, phase functions, cosines and counter (respectively) are always written/punched before the Legendre coefficients and order of expansion (respectively).

ITOT: Works in conjunction with NCRDS and NAVE to write/punch either individual wavelength values or averaged wavelength values or both on NUNIT: = 1 for individual wavelengths;
= 2 for averaged wavelengths; = 3 for both.

NUNIT: defines device number. See previous comment card.

MQRTE: = 12345 will cause prints of Mie efficiency factors at every value of particle radius used in the Mie calculations;
set MQRTE = 0 if such prints are not desired.

IAPX: if GT zero the GHG (analytic) phase function will be constructed at IAPX Gauss-Legendre angles (order of expansion).

User supplied set of -IT- angles FORMAT (16F5.1) 16 values per card, more than 1 card may be needed. This card is only needed when IANG = 2.
<table>
<thead>
<tr>
<th>CARD TYPE</th>
<th>INPUT SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td></td>
</tr>
</tbody>
</table>

Distribution parameters: only one type per run. FORMAT (6E12.6).

For a more detailed description of these parameters see the previous discussions in AGXPT1. All units are in micrometers.

**TYPE 0. USER SUPPLIED - NRADI + 1 CARDS**

- RLO, DELLR
- FF(I), I = 1, NRADI

**TYPE 1. LOG-NORMAL**

- RBAR, SIGMA, RLO, RHI

**TYPE 2. DOUBLE EXPONENTIAL**

- RLO, RHI, CUE, A, B

**TYPE 3. DEIRMENDJIAN MODEL C**

- NO INPUT -

**TYPE 4. POWER LAW (JUNGE)**

- RLO, RHI, CUE, A

**TYPE 5. MODIFIED GAMMA**

- RLO, RHI, RC, ALF, GAM, ELWC

**TYPE 6. MODIFIED GAMMA FOG MODEL**

- RLO, RHI, RC, ALG, GAM, ELWC

**TYPE 7. POWER LAW**

- VIS

**TYPE 8. CONTINENTAL BIMODAL**

- NO INPUT -

**TYPE 9. MARITIME BIMODAL**

- NO INPUT -
II

TYPE 10. URBAN BIMODAL

- NO INPUT -

TYPE 11. USER SUPPLIED BIMODAL

FOA, RBARA, GSA, FOC, RBARC, SGC

TYPE 12. MARSHALL-PALMER RAIN MODEL

RAIN

III

Control Parameters: FORMAT (6E12.6) WAVE, DWAVE, RELHUM, DENS, TEMP, DELTA. For looping over different values of relative humidity set DWAVE = 0, and add NWAVE - 1 cards containing RELHUM and TEMP. FORMAT (2E12.6).

WAVE: is wavelength in micrometers

DWAVE: is the wavelength increment in micrometers. If DWAVE is less than 1.E-4, a special case applies used for looping over NWAVE values of RELHUM. For example in that case a card which carries the value of RELHUM and TEMP must be repeated NWAVE - 1 times; the first card of this type must contain WAVE, DWAVE, RELHUM, DENS, TEMP and DELTA.

RELHUM: is relative humidity in percent.

DENS: is particle number per cubic centimeter. User-supplied value of DENS will be ignored for IDSTP = 3 or greater than 6 because those distributions carry pre-determined density values. Also, if DENS is less than 1E-4, the particle number density will be calculated from mass densities and mass concentrations.
III  TEMP: is the temperature of the atmosphere in degrees C.
DELTA: is the convergence criterion. Within a particular
size range interval, halving is terminated when the quantity
DEL is less than DELTA.

IV  Optical and physical data (Read in AGXPT2) FORMAT (4F10.6E15.7)
EMA, CAYA, EMUA, RHOA, CONC.
EMA: is the real part of the index of refraction of dry aerosol.
CAYA: is the imaginary part of refractive index for dry aerosol.
   CAYA is assumed to be negative: do not enter CAYA with a
   negative sign.
EMUA: is Hanel's growth factor (ME-BAR)/accretion coefficient.
RHOA: is the mass density (sp. GRAV) of dry aerosol.
CONC: is the mass concentration (GM/CC) of dry aerosol.
   For looping over wavelength or relative humidity repeat this
   card NWAVE times and interleave with card 3: For looping over
   aerosol components also repeat nindx times. This card is not
   needed when IDSTP = 6. Also if IW = 0 EMA and CAYA will
   internally be set equal to the refractive index of water and
   therefore may be left blank: values for EMUA, RHOA, and CONC
   may be necessary to supply, depending upon the users needs.

Remarks:

1. Card Type IV is not required and is never read-in if IDSTP = 6
   (water cloud/for model) since the relevant data are obtained from subroutine
   WATER.

2. In the case IDSTP = 12, the rain model, card type IV must carry
   the optical data for liquid water as EMA and CAYA. The reason for that
   inconsistency is that the rain model will most likely be useable at
wavelengths for which no data appear in subroutine WATER (restricted to \( \lambda \leq 0.2\text{mm} \)). [The large droplet sizes to be found in the rain model will usually cause premature failure of the Mie routine at small wavelengths.]

3. Card type IV, with appropriately adjusted data values, must be repeated \((N\text{WAVE} - 1)\) times.

4. EMA and CAYA may be left blank on Card type 4 when \(IW = 0\) as they will internally be set equal to the value for water.

Incidental Remarks Regarding AGAUSX

(1) In AGAUSX, the average "dry volume per particle" is found using all available values for particle radii. It may differ from that printed in routine AGXPT2 since that routine might not proceed to the use of all available values.

(2) The "volume"-convergence tests in AGXPT2 use the volume inferred after any growth arising from non-zero saturation ratios has been included.

(3) It should be noted that the convergence tests used in AGAUSX do not really provide tests of the absolute accuracies achieved for the tested quantity. It is possible for "exit" to occur \((\delta < \Delta)\) even though the use of "another" halving might lead to \(\delta > \Delta\) again. If runs using some choice of \(\Delta\) might lead to what appear to be "unusual" or unexpected results, it is advised that, as a test, the case be re-run using a smaller value of \(\Delta\).

(4) Some users may wish to explore possible increases in computation efficiency which might result from changes in the number \((NI)\) of size-intervals, or, the ways in which they have been chosen (in AGXPT1).
Comments on Usage of AGAUX in the IANG = 0 Mode

AGAUX has been coded to preserve the option of creating the expansion coefficients, \( \tilde{\omega}_k \), which are needed by the multiple scattering codes STAR04, AGSCAT, and the thermal emission code CLEM70(8). Usage of the \( \tilde{\omega}_k \) coefficients for the above purposes, however, requires some caution on the part of the user. In particular, users must not assume that the absence of abnormal termination of runs of AGAUX guarantees that "all is well". Past experience has shown that "warnings" of possible problems printed by those programs may not be noticed or taken very seriously. In an attempt to overcome those oversights, additional tests and warnings have been incorporated in AGAUX. If those warnings are to be meaningful, users should examine printed outputs carefully for such warnings before using the results of runs as inputs to subsequent codes.

One particular point which should be checked is to see that the quantity printed under the heading ALBDO agrees reasonably well with the zeroth coefficient (\( \tilde{\omega}_0 \)) of the expansion coefficients. Substantial disagreement between those two quantities usually means that the parameter "IT" used in a run was too small to achieve a really accurate reconstruction of the phase function from only "IT" Legendre expansion terms.

Should possible inaccuracies be found, please contact R. C. Shirkey, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico 88002.
SAMPLES OF INPUT AND OUTPUT FOR AGAUSX

INPUT

The subsequent output section is based upon the following input.

Example 1: IDSTP = 0 (User supplied distribution data)

Column 5

```
2 1 9 0 11 5 0 0 0 012345 0
```

```
0.100000E-00 0.02000E+00
0.00000E-00
0.20000E-00
0.40000E-00
0.60000E-00
0.80000E-00
1.00000E-00
0.80000E-00
0.60000E-00
0.40000E-00
0.20000E-00
0.00000E-00
```

```
10.60000E+00 0.10000E-05 0.00000E+00 0.00000E-05 25.00000E+00 1.00000E-02
```

```
1.9530 .46800 0.00000 1.87000 1.00000E-09
```

```
75.00000E+00 25.00000E+00
```

```
1.9530 .468000 0.15900 1.87000 1.00000E-09
```

130
This example is set up to read 11 distribution data cards, and to run for two values of relative humidity at $\lambda = 10.6\mu m$. Since MQRTE = 12345, detailed Mie results for each of the 11 radii will be printed. Parameter 'IT' is 5, IANG = 1. Note that the second data card contains RLO (= 0.1\(\mu m\)) and DELLR (= 0.02). The next eleven cards contain F(RLO), F(RLO + DELLR, etc.). The remaining cards consist of two pairs of cards, two for each of the two values of N\*AVE. In all cases, DENSH is zero which means that particle number densities will be calculated from RHOA (1.87, above), CONC (10\(^{-9}\) gm/cc, above) and the average particle volume computed within the program.

Example 2: IDSTP = 1 (Log normal distribution)

<table>
<thead>
<tr>
<th>Column 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 3 9 5 4 5 0 0 0 0 0</td>
</tr>
</tbody>
</table>

3.70000E-01 1.54000E+00 0.00500E-00 1.00000E-00

10.6000E+00 0.10000E-05 0.00000E+00 0.00000E-05 25.0000E+00 1.00000E-02

1.9530 .46800 0.00000 1.87000 1.00000E-09

0.15900 1.87000 1.00000E-09

0.15600 1.87000 1.00000E-09

Remarks: The second card carries RBAR, SIGMA, RLO and RHI. If RLO and RHI are set to zero, the program itself will choose RLO and RHI. Particle number density will also be calculated from mass density and concentration.
Example 3: IDSTP = 3 (Deirmendjian's Model C)

Column 5

\[
\begin{array}{cccccccc}
2 & 1 & 0 & 3 & 100 & 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
10.6000E+00 & 0.100000E+05 & 0.000000E+00 & 0.000000E+05 & 25.0000E+00 & 1.000000E-02 \\
0.0000 & 0.0000 & 0.0000 & 1.87000 & 1.0000000-09 \\
75.00000+00 & 25.00000+00 \\
0.0000 & 0.0000 & 0.15900 & 1.87000 & 1.0000000-09 \\
\end{array}
\]

Remarks: 100 values of radii will be used for 2 values of relative humidity with different growth factors. Particle density will be calculated from mass density and concentration. Since IW = 0, the aerosol component is considered to be pure water; i.e., EMA and CAYA will be set equal to the values for water.

Example 4: IDSTP = 5 (Modified gamma distribution)

Column 5

\[
\begin{array}{cccccccc}
1 & 2 & 9 & 5 & 40 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
.0278520+00 & 1.225490+01 & 4.000000+00 & .6000000+01 & .1000000+01 \\
.7000000+00 & .0000000-04 & .0000000+00 & 1.000000+02 & 5.000000+00 & 1.000000-02 \\
1.3300 & 0.0000 & 0.0000 & 1.0000 & 1.000000+00 \\
1.4300 & 0.0000 & 0.0000 & 1.0000 & 1.0000000-01 \\
\end{array}
\]

Remarks: This example sets NINDX = 2, and treats a mixture of two aerosol components having different refractive indices and mass concentrations.
Example 5: IDSTP = 7 (Power Law)

Column 5

\[
\begin{array}{cccccccc}
1 & 1 & 0 & 7 & 0 & 1 & 1 & 3 & 1 \\
1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9
\end{array}
\]

\text{+6.000000+00}

\text{10.60000+00} \quad \text{.000000+00} \quad \text{.000000+00} \quad \text{.100000+03} \quad \text{25.00000+00} \quad \text{1.000000-02}

\text{0.0000} \quad \text{.000000} \quad \text{0.00000} \quad \text{0.00000} \quad \text{0.000000+00}

Remarks: The GHG analytic phase function will be constructed at eight Gauss-Legendre angles (IAPX = 8) for pure water (IW = 0). Scattering fractions (not computed), phase functions, cosines, a counter, and Legendre coefficients will be written on unit 23 for individual wavelengths only.
INTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP MRADI IT IANG NCRDS ITOT NUNIT NRTE IAPX
2 1 9 0 11 5 0 0 0 4 12345 0

AEROSOL PARAMETERS ARE

<table>
<thead>
<tr>
<th>RADIUS</th>
<th>RELATIVE NO.</th>
<th>RADIUS</th>
<th>RELATIVE NO.</th>
<th>RADIUS</th>
<th>RELATIVE NO.</th>
<th>RADIUS</th>
<th>RELATIVE NO.</th>
<th>RADIUS</th>
<th>RELATIVE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00000-001</td>
<td>+000000</td>
<td>2.00000-001</td>
<td>+000000</td>
<td>3.00000-001</td>
<td>+000000</td>
<td>4.00000-001</td>
<td>+000000</td>
<td>5.00000-001</td>
<td>+000000</td>
</tr>
<tr>
<td>2.00000-001</td>
<td>+000000</td>
<td>2.20000-001</td>
<td>+000000</td>
<td>2.30000-001</td>
<td>+000000</td>
<td>2.40000-001</td>
<td>+000000</td>
<td>2.60000-001</td>
<td>+000000</td>
</tr>
</tbody>
</table>

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = +9999988-001
AVERAGE NUMERICAL DRY VOLUME IS 3.769914-002 CUBIC MICROMETERS

SIZE-INTERVALS USED ARE AS FOLLOWS

<table>
<thead>
<tr>
<th>INTERVAL NO.</th>
<th>RMIN</th>
<th>RMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+1000</td>
<td>+3000</td>
</tr>
</tbody>
</table>

INPUT PARAMETERS

WAVE = +106000-002 MICRONS
ONFREE = +100000-005 MICRONS
RREL = +00000 PERCENT
ONFREE = +00000 PARTICLES/CC
ONFREE = +250000-002 DEG C
ONFREE = +100000-001

RELATIVE HUMIDITY OPTION IN EFFECT FOR 2 VALUES

RELATIVE HUMIDITY FOR THIS RUN = +00 PERCENT, WAVELENGTH = 10.600 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 = +0756201

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.00 GM/CC
INDEX = 1 = +953900 K = +468000+ MASS DENSITY = 1.870000 GROWTH FACTOR = +0000+ CONC = +1.00000-009 GM/CC

<table>
<thead>
<tr>
<th>RIMICRONS</th>
<th>DRY RADIUS</th>
<th>N(R)</th>
<th>MIE SIZE</th>
<th>Q (EXT)</th>
<th>Q (SCA)</th>
<th>Q (RADAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1000</td>
<td>1.00000-001</td>
<td>+00000</td>
<td>5.92753-002</td>
<td>3.76803-002</td>
<td>9.58810-006</td>
<td>1.43542-005</td>
</tr>
<tr>
<td>+3000</td>
<td>3.00000-001</td>
<td>7.15559-008</td>
<td>1.77826-001</td>
<td>1.17492-001</td>
<td>1.59851-004</td>
<td>1.15695-003</td>
</tr>
<tr>
<td>+5000</td>
<td>5.00000-001</td>
<td>1.00000-001</td>
<td>1.18551-001</td>
<td>7.63388-002</td>
<td>1.59079-004</td>
<td>2.29277-004</td>
</tr>
<tr>
<td>+1500</td>
<td>1.50000-001</td>
<td>5.00001-000</td>
<td>8.86130-002</td>
<td>5.68193-002</td>
<td>9.86250-005</td>
<td>7.26187-005</td>
</tr>
<tr>
<td>+2500</td>
<td>2.50000-001</td>
<td>5.00001-000</td>
<td>1.48188-001</td>
<td>9.63111-002</td>
<td>3.77213-004</td>
<td>5.85785-004</td>
</tr>
<tr>
<td>+3500</td>
<td>3.50000-001</td>
<td>2.50000-000</td>
<td>7.49492-002</td>
<td>4.72113-002</td>
<td>2.39271-005</td>
<td>3.50039-005</td>
</tr>
<tr>
<td>+5500</td>
<td>5.50000-001</td>
<td>1.03342-001</td>
<td>6.55223-002</td>
<td>9.01896-005</td>
<td>1.34913-004</td>
<td></td>
</tr>
<tr>
<td>+7500</td>
<td>7.50000-001</td>
<td>7.50001-000</td>
<td>1.33369-001</td>
<td>8.62483-002</td>
<td>2.47109-004</td>
<td>3.67018-004</td>
</tr>
</tbody>
</table>
TOTAL NUMBER OF RADIi USED WAS 17
ATTENUATION COEF = 1.53581-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

<table>
<thead>
<tr>
<th>TYPE</th>
<th>WAVELENGTH</th>
<th>REFRACTIVE INDEX</th>
<th>EXTINCTION X SECTION</th>
<th>SCATTERING X SECTION</th>
<th>AERMOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(MICRONS)</td>
<td>(SQ MICRONS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>10.0000</td>
<td>1.5358138-001</td>
<td>1.5618525-004</td>
<td>6.8411013-004</td>
<td>ALL PER KM</td>
</tr>
</tbody>
</table>

WAVENUMBER = 9.433942+002 CH-I  DENSITY = 1.418992+004 PARTICLES PER CC

PHASE FUNCTION
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

<table>
<thead>
<tr>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>+9061798680</td>
<td>+914052001-002</td>
<td>+538469315</td>
<td>+2926897054-002</td>
<td>+000000000</td>
<td>+2252592763-002</td>
<td>+538469315</td>
<td>+2884668502-002</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L</th>
<th>LTH COEFFICIENT</th>
<th>RMS DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.003523219136802-003</td>
<td>7.750136210233904-004</td>
</tr>
<tr>
<td>1</td>
<td>4.936977908152604-005</td>
<td>7.741395114874947-004</td>
</tr>
<tr>
<td>2</td>
<td>1.501870979502619-003</td>
<td>2.749890281272101-006</td>
</tr>
<tr>
<td>3</td>
<td>6.65944722863671-006</td>
<td>4.267121513027180-009</td>
</tr>
</tbody>
</table>

END OF RELATIVE HUMIDITY CYCLE NUMBER 1

RELATIVE HUMIDITY FOR THIS RUN = 75.00 PERCENT, WAVELENGTH = 10.600 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS 1.172200 - 0.0756201

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.000 GN/CC
INDX = 3, K = 1.953000 K = 4680001, MASS DENSITY = 1.870000 GROWTH FACTOR = 1.1590, CONC = 1.000000-009 GN/CC

(RMICRONS) DRY RADIUS (NM), MIE SIZE Q (EXT), Q(SCA), Q(RADAR)
<table>
<thead>
<tr>
<th>Component No.</th>
<th>1</th>
<th>Interval No.</th>
<th>1</th>
<th>Radii were used</th>
<th>Contribution to CTSUM</th>
<th>1.650363-002</th>
</tr>
</thead>
</table>

**FOR COMPONENT NO. 1**

**Interval No. 1**

- **Radii were used**: 17
- **Contribution to CTSUM**: 1.650363-002

**Total Number of Radii Used**: 17

**Attenuation Coef**: 2.3912-002

**Attenuation Coef**: 1.63926-004

**Distribution**:

<table>
<thead>
<tr>
<th>Type</th>
<th>Wavelength (Microns)</th>
<th>Refractive Index</th>
<th>Extinction X Section (Sq Microns)</th>
<th>Scattering X Section (Sq Microns)</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10.6000</td>
<td>1.5871(1)</td>
<td>1.5850878565697-002</td>
<td>5.3154297823936-005</td>
<td>3.2207615064063-003</td>
</tr>
<tr>
<td></td>
<td>2.3912-002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Wave Number**: 9.433962+002 cm^-1

**Density**: 1.918942+004 particles per cc

**Phase Function**

**Integral Normalized to 4 Pi Omega Zero**

<table>
<thead>
<tr>
<th>Mu</th>
<th>Phase Function</th>
<th>Mu</th>
<th>Phase Function</th>
<th>Mu</th>
<th>Phase Function</th>
<th>Mu</th>
<th>Phase Function</th>
<th>Mu</th>
<th>Phase Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>+906179800</td>
<td>+4959963704-002</td>
<td>+538469315</td>
<td>+3149036867-002</td>
<td>+000000000</td>
<td>+2415478662-002</td>
<td>+538469315</td>
<td>+3087851917-002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-906179853</td>
<td>+4338685889-002</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**L-Th Coefficient**

<table>
<thead>
<tr>
<th>L</th>
<th>Mu</th>
<th>RMS Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>8.315518498420715-004</td>
</tr>
<tr>
<td>1</td>
<td>6.0777158064958467-005</td>
<td>8.30946036861964-004</td>
</tr>
<tr>
<td>2</td>
<td>4.579665130677313-003</td>
<td>4.579665130677313-003</td>
</tr>
<tr>
<td>3</td>
<td>1.0819951886310-008</td>
<td>1.0819951886310-008</td>
</tr>
<tr>
<td>4</td>
<td>6.380311707921026-010</td>
<td>6.380311707921026-010</td>
</tr>
</tbody>
</table>

**Summary of Results for This Run**: Relative Humidity Cycle Number 2

**END OF RELATIVE HUMIDITY CYCLE NUMBER 2**
<table>
<thead>
<tr>
<th>WAVELENGTH (MICROMETERS)</th>
<th>REL HUMIDITY (PERCENT)</th>
<th>AEROSOL MASS (GM/SQ CM-KM)</th>
<th>K (EXTINCTION) (PER KM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.400000</td>
<td>0.000000</td>
<td>9.98266-005</td>
<td>1.53581-001</td>
</tr>
<tr>
<td>10.600000</td>
<td>75.000000</td>
<td>1.43246-004</td>
<td>2.34102-001</td>
</tr>
</tbody>
</table>

Results averaged over parameter N wave follow:

**Extinction Coef.** = 9.93892-001 (PER KM)

**Scattering Coef.** = 6.07637-004 (PER KM)

**Back-scattering Coef.** = 8.99163-004 (PER KM)

**Attenuation Coef.** = 9.3892-004 SQ-METERS/KG

<table>
<thead>
<tr>
<th>MU</th>
<th>Phase Function</th>
<th>Mu</th>
<th>Phase Function</th>
<th>Mu</th>
<th>Phase Function</th>
<th>Mu</th>
<th>Phase Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.906179840</td>
<td>930707852-002</td>
<td>9.38469315</td>
<td>3035466856-002</td>
<td>0.000000000</td>
<td>233935613-002</td>
<td>5.38469315</td>
<td>2986260195-002</td>
</tr>
<tr>
<td>1.906179853</td>
<td>9158527024-002</td>
<td>3.11235554091490-003</td>
<td>5.25734799791789-005</td>
<td>1.55623799019225-003</td>
<td>8.87847676767476-006</td>
<td>2.33428092073943-008</td>
<td>6.032697587623261-009</td>
</tr>
</tbody>
</table>

L-th Coefficient

<table>
<thead>
<tr>
<th>L</th>
<th>RMS Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8.024513663258909-009</td>
</tr>
<tr>
<td>1</td>
<td>7.627153123021435-009</td>
</tr>
<tr>
<td>2</td>
<td>7.581565348800055-010</td>
</tr>
</tbody>
</table>
INTEGER CONTROL PARAMETERS: NWAVE NINDEX IW IDESTP NRADI IT IANG NCRDS ITOT NUNIT NQRTIE IAPX
I 10 0 0 0 0 0 0

AEROSOL PARAMETERS ARE
RBAR = *370000+000 SIGMA = *159000+000 RLO = .500000-002 RH1 = *100000+001

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = *9893521+000

AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS 4.909499+001 CUBIC MICROMETERS
AVERAGE NUMERICAL DRY VOLUME IS 4.183917+001 CUBIC MICROMETERS

SIZE-INTERVALS USED ARE AS FOLLOWS

<table>
<thead>
<tr>
<th>INTERVAL NO.</th>
<th>RMIN</th>
<th>RMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00500</td>
<td>0.37000</td>
</tr>
<tr>
<td>2</td>
<td>0.37000</td>
<td>1.00000</td>
</tr>
</tbody>
</table>

INPUT PARAMETERS

WAVE = *104000+002 MICRONS
DWave = *000000 MICRONS
RELHUM = *000000 PERCENT
DENSH = *000000 PARTICLES/CC
TEMP = *250000+002 DEG C
DELTA (CONVERGENCE CRITERION) = *100000-001

*** PARTICLE NUMBER DENSITY WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION ***

RELATIVE HUMIDITY FOR THIS RUN = 90 PERCENT. WAVELENGTH = 10-400 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - 0.0754201

MASS DENSITY OF WATER AT 25 DEG C IS: 1.00 GM/CC
INDEX 1 K = -1.953000000 *4800001.0870000 GROWTH FACTOR = *0000.0 CONC = 1.0000000-009 GM/CC

FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADI I WERE USED. CONTRIBUTION TO CTSUM = 1.926828-002
FOR COMPONENT NO. 1 INTERVAL NO. 2 17 RADI I WERE USED. CONTRIBUTION TO CTSUM = 1.299031-001
FOR COMPONENT NO. 1 VPF = 5.390003-010 MASS CONCENTRATION = 9.98586-010 GM/CC KEV = 1.83533+001 PER KM

TOTAL NUMBER OF RADI I USED WAS 34
ATTENUATION COEF = 1.83533+004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

DISTRIBUTION WAVELENGTH REFRACTIVE EXTINCTION X SECTION SCATTERING X SECTION ALbedo

<table>
<thead>
<tr>
<th>TYPE (MICRONS)</th>
<th>INDEX</th>
<th>SCATTERING X SECTION</th>
<th>ALbedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 10-4000</td>
<td>1.9530(1 =23961.1)</td>
<td>1.93594585350979-003</td>
<td>9.149097553111193-003</td>
</tr>
<tr>
<td>1 16835269+001</td>
<td>K(EXT) = 1.83533+001</td>
<td>1.16835269+001</td>
<td>1.83535333+002</td>
</tr>
</tbody>
</table>

WAVELENGTH = 9.933942+002 CM-1 DENSITY = 1.278131+003 PARTICLES PER CC
PHASE FUNCTION
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

<table>
<thead>
<tr>
<th>( \mu )</th>
<th>PHASE FUNCTION</th>
<th>( \mu )</th>
<th>PHASE FUNCTION</th>
<th>( \mu )</th>
<th>PHASE FUNCTION</th>
<th>( \mu )</th>
<th>PHASE FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>.906179880</td>
<td>.9663867112-001</td>
<td>.538469315</td>
<td>.6419704887-001</td>
<td>.000000000</td>
<td>.4762377590-001</td>
<td>.538469315</td>
<td>.5691573909-001</td>
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<tr>
<td>-.906179853</td>
<td>.7764094944-001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( L^{\text{TH}} \) COEFFICIENT

<table>
<thead>
<tr>
<th>( L )</th>
<th>( L^{\text{TH}} ) COEFFICIENT</th>
<th>RMS DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.365473195910459-002</td>
<td>1.784613775089383-002</td>
</tr>
<tr>
<td>1</td>
<td>9.7042260101988278-003</td>
<td>1.6658439198471729-002</td>
</tr>
<tr>
<td>2</td>
<td>3.208455536514521-002</td>
<td>5.7898122031477449-004</td>
</tr>
<tr>
<td>3</td>
<td>1.4934317008684684-003</td>
<td>9.536866523164867-006</td>
</tr>
<tr>
<td>4</td>
<td>3.0186638468087648-005</td>
<td>1.2689590489500480-008</td>
</tr>
</tbody>
</table>

SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS:

<table>
<thead>
<tr>
<th>WAVELENGTH (MICROMETERS)</th>
<th>REL. HUMIDITY (PERCENT)</th>
<th>AEROSOL MASS (GM/(SQ*CM-KM))</th>
<th>K(EXTINCTION) (PER KM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.600000</td>
<td>.000000</td>
<td>9.98586-005</td>
<td>1.83533-001</td>
</tr>
</tbody>
</table>
**PROGRAM AGAUXS**

**WATER ONLY CASE**

**AEROSOL PARAMETERS ARE**

**NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = +135122.000**
**AVERAGE NUMERICAL DRY VOLUME IS 1.197754-002 CUBIC MICROMETERS**

**SIZE-INTERVALS USED ARE AS FOLLOWS**

<table>
<thead>
<tr>
<th>INTERVAL NO.</th>
<th>RMIN</th>
<th>RMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100000</td>
<td>10000</td>
</tr>
<tr>
<td>2</td>
<td>10000</td>
<td>20000</td>
</tr>
</tbody>
</table>

**INPUT PARAMETERS**

- **WAVE** = +106000+002 MICRONS
- **QWAVE** = 1000000+005 MICRONS
- **RELHUM** = -100000 PERCENT
- **DENS** = -100000 PARTICLES/CC
- **TEMP** = +250000+002 DEG C
- **DELTA (CONVERGENCE CRITERION) = 1000000+001**

**RELATIVE HUMIDITY OPTION IN EFFECT FOR 2 VALUES**

**PARTICLE NUMBER DENSITY WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION**

**RELATIVE HUMIDITY FOR THIS RUN = .00 PERCENT, WAVELENGTH = 10.600 MICRONS**
**INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - 0.075620**

**MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.000 GM/CC**

**INDEX = 1.000 000 000**
**MASS DENSITY = 1.870000 GROWTH FACTOR = 0.0000 CONC = 1.000000-009 GM/CC**

**FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 7.654085-005**
**FOR COMPONENT NO. 1 INTERVAL NO. 2 65 RADII WERE USED. CONTRIBUTION TO CTSUM = 9.7249075-009**

**FOR COMPONENT NO. 1 VPF = 1.6469-010 MASS CONCENTRATION = 3.0232-010 GM/CC KEXT = 1.9126-002 PER KM**

**TOTAL NUMBER OF RADII USED WAS 82**
**ATTENUATION COEF. = 4.57665-005 50-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL**

**DISTRIBUTION WAVELENGTH REFRACTIVE EXTINCTION X SECTION SCATTERING X SECTION ALBDDO TYPE (MICRONS) INDEX**

<table>
<thead>
<tr>
<th>3</th>
<th>10+6000</th>
<th>1.187211</th>
<th>-0.0421</th>
<th>1.025122866499+003</th>
<th>2.868628959937+005</th>
<th>2.776651043391+002</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-141261+002</td>
<td>K(SCA) = 3.9251818-009</td>
<td>K(RAD) = 9.038070-009</td>
<td>ALL PER KM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**WAVENUMBER = 9.43942+002 CM-1 DENSITY = 1+374000+004 PARTICLES PER CC**
PHASE FUNCTION
(INTEGRAL NORMALIZED TO 4 \pi OMEGA ZERO)

<table>
<thead>
<tr>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
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<tbody>
<tr>
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<td>5109181860-001-001</td>
<td>538469315</td>
<td>3195016971-001</td>
<td>000000000</td>
<td>2029759437-001</td>
<td>-538469315</td>
<td>2146602934-001</td>
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<tr>
<td>906179853</td>
<td>2482040236-001</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

L-TH COEFFICIENT  RMS DEVIATION

<table>
<thead>
<tr>
<th>L</th>
<th>PHASE FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.77765481659286-002</td>
</tr>
<tr>
<td>1</td>
<td>1.18461141510231-002</td>
</tr>
<tr>
<td>2</td>
<td>1.517573744058607-002</td>
</tr>
<tr>
<td>3</td>
<td>2.75371542029420-003</td>
</tr>
<tr>
<td>4</td>
<td>2.637724683153794-009</td>
</tr>
</tbody>
</table>

END OF RELATIVE HUMIDITY CYCLE NUMBER 1

RELATIVE HUMIDITY FOR THIS RUN = 75.00 PERCENT. WAVELENGTH = 10.600 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - 0.0754201

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.000 G/MCC
INDEX = 1.178200 K = -0.0754201 MASS DENSITY = 1.670000 G/MCC GROWTH FACTOR = 1.590 CONC = 1.000000-009 GM/CSC

FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADI1 WERE USED. CONTRIBUTION TO CTSUM = 1.327722-009
FOR COMPONENT NO. 1 INTERVAL NO. 2 4 RADI1 WERE USED. CONTRIBUTION TO CTSUM = 1.851981-003
FOR COMPONENT NO. 1 : VPF = 2.98743-010 MASS CONCENTRATION = 9.35500-010 GM/MCC KEXT = 2.67287-002 PER KM

TOTAL NUMBER OF RADI1 USED WAS 82
ATTENUATION COEF = 6.446000-005 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL
ATTENUATION COEF = 6.13797-005 SQ-METERS/MILLIGRAM OF WET AEROSOL MATERIAL

DISTRIBUTION WAVELENGTH REFRACTIVE EXTINCTION X SECTION SCATTERING X SECTION ALBEDO TYPE (MICRONS) INDEX (SQ MICRONS) (SQ MICRONS) (SQ MICRONS) (SQ MICRONS)
3 10-6000 1.178211-044211 1.93967259596159-003 8.686274773736259-005 4.47845021242745-002
K(EXT) = 2.6728681-002 K(SCA) = 1.1970307-003 I(RAD) = 9.93110402-004 ALL PER KM

WAVENUMBER = 9.933962+002 CM-1 DENSITY = 1.378000+004 PARTICLES PER CC

PHASE FUNCTION
(INTEGRAL NORMALIZED TO 4 \pi OMEGA ZERO)

<table>
<thead>
<tr>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
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</tr>
</thead>
<tbody>
<tr>
<td>906179840</td>
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<td>538469315</td>
<td>552553978-001</td>
<td>000000000</td>
<td>315388575-001</td>
<td>-538469315</td>
<td>3000225802-001</td>
</tr>
<tr>
<td>906179853</td>
<td>3528082650-001</td>
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<td></td>
</tr>
</tbody>
</table>

L-TH COEFFICIENT  RMS DEVIATION

<table>
<thead>
<tr>
<th>L</th>
<th>PHASE FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td></td>
<td>0.978499793532491-002</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>1</td>
<td>2.891276823569048-002</td>
</tr>
<tr>
<td>2</td>
<td>2.729756330869477-002</td>
</tr>
<tr>
<td>3</td>
<td>6.769836479290063-003</td>
</tr>
<tr>
<td>4</td>
<td>1.089149251620876-003</td>
</tr>
</tbody>
</table>

END OF RELATIVE HUMIDITY CYCLE NUMBER 2

SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS:

<table>
<thead>
<tr>
<th>WAVELENGTH</th>
<th>REL. HUMIDITY</th>
<th>AEROSOL MASS</th>
<th>K(EXTINCTION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MICROMETERS)</td>
<td>(PERCENT)</td>
<td>(GM/SQ.CM-KM)</td>
<td>(PER KM)</td>
</tr>
<tr>
<td>10.600000</td>
<td>0.000000</td>
<td>3.02322-005</td>
<td>1.91242-002</td>
</tr>
<tr>
<td>10.600000</td>
<td>75.000000</td>
<td>9.35500-005</td>
<td>2.67287-002</td>
</tr>
</tbody>
</table>

RESULTS AVERAGED OVER PARAMETER WAVENumber FOLLOW:

EXTINCTION COEF. = 2.04274-002 (PER KM)
SCATTERING COEF. = 7.94733-004 (PER KM)
BACK-SCATTERING COEF. = 6.97943-004 (PER KM)
ATTENUATION COEF. = 6.61099-005 SQ-METERS/MG

PHASE FUNCTION

<table>
<thead>
<tr>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
<th>MU</th>
<th>PHASE FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>+906179860</td>
<td>+7.2678610915-001</td>
<td>+906179853</td>
<td>+3.105061931-001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

L-TH COEFFICIENT

<table>
<thead>
<tr>
<th>L</th>
<th>L-TH COEFFICIENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.62852239388227-002</td>
</tr>
<tr>
<td>1</td>
<td>2.03911899332893-002</td>
</tr>
<tr>
<td>2</td>
<td>2.121649539168477-002</td>
</tr>
<tr>
<td>3</td>
<td>4.859276057684657-003</td>
</tr>
<tr>
<td>4</td>
<td>6.361324922181666-004</td>
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</table>

RMS DEVIATION

<table>
<thead>
<tr>
<th>RMS DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.810604903726757-002</td>
</tr>
<tr>
<td>1.1738003247173-002</td>
</tr>
<tr>
<td>2.014176124999073-003</td>
</tr>
<tr>
<td>2.09153358812910-004</td>
</tr>
<tr>
<td>9.65042254213690-009</td>
</tr>
</tbody>
</table>
**PROGRAM AGAUX**

**-----------------------------------------------------------------------------**

**INTEGER CONTROL PARAMETERS: NWAVE NINDX IWM.IDSTP NRAD IT IANG MCROS ITOT NUNIT MQRTE IAPX**

**AEROSOL PARAMETERS ARE**

RL0 = 2785+002 RHI = 1225+002 RC = 4000+001 ALF = 6000+001 GAM = 1000+001

**NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = 421041+002**

**AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS 6.255275+002 CUBIC MICROMETERS**

**AVERAGE NUMERICAL DRY VOLUME IS 6.182091+002 CUBIC MICROMETERS**

**SIZE-INTERVALS USED ARE AS FOLLOWS**

**INTERVAL NO. 1 RMIN = 0.02785 RMAX = 4.00000**

**INTERVAL NO. 2 RMIN = 4.00000 RMAX = 12.25490**

**INPUT PARAMETERS**

WAVE = 700000+000 MICRONS

D wave = 0000000 MICRONS

RELHUM = 000000 PERCENT

DENS = 100000+000 PARTICLES/CC

TEMP = 500000+000 DEG C

DELTA (CONVERGENCE CRITERION) = 1000000+001

**LOOPING OPTION IN EFFECT FOR 2 AEROSOL COMPONENTS**

**RELATIVE HUMIDITY FOR THIS RUN = 00 PERCENT. WAVELENGTH = 700 MICRONS**

**INDEX OF REFRACTION FOR PURE WATER IS: 1.330000 = 0000001**

**MASS DENSITY OF WATER AT 5000 DEG C IS: 1.00 GM/CC**

**INDEX 1 KM = 1.330000 K = 0000000 MASS DENSITY = 1.000000 GROWTH FACTOR = 000000 CONC = 1.000000 GM/CC**

**FOR COMPONENT NO. 1 INTERVAL NO. 1 33 RADII WERE USED. CONTRIBUTION TO CTSUM = 2.668859+001**

**FOR COMPONENT NO. 1 INTERVAL NO. 2 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.905387+002**

**FOR COMPONENT NO. 1 VPF = 6.17094-012 MASS CONCENTRATION = 6.17094-012 GM/CC. KEXT = 1.67229-003 PER KM**

**---------------------------------------------------------------------- END OF AEROSOL COMPONENT CYCLE NUMBER 1----------------------------------------------------------------------**

**INDEX 2 KM = 1.430000 K = 0000001 MASS DENSITY = 1.000000 GROWTH FACTOR = 000000 CONC = 1.000000-001 GM/CC**

**FOR COMPONENT NO. 2 INTERVAL NO. 1 33 RADII WERE USED. CONTRIBUTION TO CTSUM = 2.668959+001**

**FOR COMPONENT NO. 2 INTERVAL NO. 2 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.926240+002**

**FOR COMPONENT NO. 2 VPF = 6.17094-012 MASS CONCENTRATION = 6.17094-012 GM/CC. KEXT = 1.69517-003 PER KM**

**---------------------------------------------------------------------- END OF AEROSOL COMPONENT CYCLE NUMBER 2----------------------------------------------------------------------**
TOTAL MASS CONCENTRATION = 1.23419-011 GM/CC; TOTAL KEXT = 3.36746-003 PER KM

TOTAL NUMBER OF RADIUS USED WAS 100
ATTENUATION COEF. = 2.782356-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

*** WARNING *** OPTIMAL PF EXPANSION ORDER OF 42 EXCEEDS INPUT IT = 1. PF VALUES SHOULD BE USED CAUTIOUSLY
THIS IS A MIXED CASE * SUBSEQUENT REFRACTIVE INDEX PRINT-OUTS ARE NOT GENERALLY VALID

<table>
<thead>
<tr>
<th>DISTRIBUTION TYPE</th>
<th>WAVELENGTH KEXT</th>
<th>REFRACTIVE INDEX X !00!</th>
<th>EXTINCTION X SECTION</th>
<th>SCATTERING X SECTION</th>
<th>ALBEDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAVELENGTH KEXT</td>
<td>3.3674590-003</td>
<td>1.93099(1 -0000!1)</td>
<td>1.68372949600220+002</td>
<td>1.6837299600220+002</td>
<td>1+00000000000000+000</td>
</tr>
</tbody>
</table>

WAVENUMBER = 1.428571+004 CM-1  DENSITY = 2+000000-002 PARTICLES PER CC
SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :

<table>
<thead>
<tr>
<th>WAVELENGTH (MICROMETERS)</th>
<th>REL-HUMIDITY (PERCENT)</th>
<th>AEROSOL MASS (GM/(SQ*CH-KM))</th>
<th>K(EXTINCTION) (PEH KM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+700000</td>
<td>+000000</td>
<td>1.23419-006</td>
<td>3.36746-003</td>
</tr>
</tbody>
</table>
INTEGRAL CONTROL PARAMETERS: N wave MINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT NRME IAPX
1 1 0 7 0 1 0 3 1 23 0 8

*** WATER ONLY CASE ***

AEROSOL PARAMETERS ARE
RL0 = +1000+000 RH1 = +1500+002 CUE = +3000+002 A = +4000+001 VIS = +6000+001

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = +1128782+005
AVERAGE NUMERICAL DRY VOLUME IS 5.599874-002 CUBIC MICROMETERS

SIZE-INTERVALS USED ARE AS FOLLOWS

<table>
<thead>
<tr>
<th>INTERVAL NO</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000</td>
<td>11892</td>
</tr>
<tr>
<td>2</td>
<td>11892</td>
<td>150000</td>
</tr>
</tbody>
</table>

INPUT PARAMETERS
WAVE = +106000+002 MICRONS
D WAVE = +000000 MICRONS
REHUM = +000000 PERCENT
DENSH = +1000000+003 PARTICLES/CC
TEMP = +2500000+002 DEG C
DELTA (CONVERGENCE CRITERION) = +1000000+001

RELATIVE HUMIDITY FOR THIS INDEX OF REFRACTION FOR PURE WATER IS: 1+178200 - +0756201

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1-00 G/MCC
INDEX = 1 K = - +07562011 MASS DENSITY = 1000000 GROWTH FACTOR = +0000 CONC = +0000 G/MCC

FOR COMPONENT NO 1 INTERVAL NO 1 9 RADII WERE USED. CONTRIBUTION TO CTSUM = +1400058+009

CONVERGENCE LEVEL NOT REACHED FOR INTERVAL NO 2 ***

FOR COMPONENT NO 2 INTERVAL NO 2 257 RADII WERE USED. CONTRIBUTION TO CTSUM = +5693135+003
FOR COMPONENT NO 1 VPF = +139527-009 MASS CONCENTRATION = +139527-009 G/MCC KEXT = +1500820-001 PER KM

TOTAL NUMBER OF RADII USED WAS 266

OMEGA SUB-1 = +5699542978572+001
OMEGA SUB-2 = +7917496686707+001

ATTENUATION COEF = +108043+009 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL
DISTRIBUTION WAVELENGTH REFRACTIVE EXTINCTION X SECTION SCATTERING X SECTION ALBIDO
TYPE (MICRONS) INDEX (SG MICRONS) (SG MICRONS) 7 10-000 1+178211 -06421 6+05139698541808-003 1-95169653+19663-003 24398994696120
\( k_{\text{ext}} = 1.5081969 - 001 \); \( k_{\text{scat}} = 3.6180810 - 002 \); \( k_{\text{rad}} = 3.9616963 - 003 \) all per km

Wavenumber = 9.933962 - 002 cm\(^{-1}\)

Density = 2.992312 - 004 particles per cc

GHN phase function for asymmetry factor \( g \) = +78.43

Computation phase function at zero degrees is 5.2965

GHN phase function at zero degrees is 3.7157

<table>
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<th>( \mu )</th>
<th>Phase Function</th>
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<td>.2677733749 - 001</td>
<td>.796666488</td>
<td>.6179881915 - 000</td>
<td>.525532417</td>
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True \( \Omega_{\text{GHN}} = +23.99 \)

Integrated GHN phase function = 3.0146 and percent error = .0000

GHN coefficients

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<th>( \Omega )</th>
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<td>.239894 + 000</td>
<td>2</td>
<td>.590849 + 000</td>
<td>3</td>
<td>.723577 + 000</td>
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<td>.676869 + 000</td>
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<td>5</td>
<td>.569799 + 000</td>
<td>6</td>
<td>.947981 + 000</td>
<td>7</td>
<td>.306496 + 000</td>
<td>8</td>
<td>.153074 + 000</td>
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</table>

Percent errors: \( \Omega_{\text{GHN}} 0 = +000 \)

\( \Omega_{\text{GHN}} 1 = 5.960 \)

\( \Omega_{\text{GHN}} 2 = -2.419 \)
PROGRAM AGAUX

REVISION DATE 25 MAY, 1980
THAT YOU MAY HAVE OR FIND CONCERNING THIS PROGRAM,
PLEASE CONTACT DR. R.C. SHIRKEY, ATMOSPHERIC SCIENCES LAB.,
WSHR, N.M. 88002; PHONE (505) 678-4200 OR AUTOVON 778-4200.

A MAJORITY OF THE WORK FOUND HEREIN WAS PERFORMED AT NEW
MEXICO STATE UNIVERSITY, DEPT. OF PHYSICS, BY DR. A. MILLER.
THANKS ARE ALSO DUE TO DR. R.B. GOMEZ (ASL) AND
DON G.W. GOEDECKE (HNNU).

PURPOSE:
TO CALCULATE EXTINCTION COEFFICIENTS, ETC., AND PRODUCE
LEGENDRE EXPANSION COEFFICIENTS, PHASE FUNCTIONS, SCATTERING
FRACIONS UNDER A WIDE VARYITY OF CONDITIONS AND AEROSOL
DISTRIBUTIONS AT ONE OR MORE WAVELENGTHS. THE PHASE FUNCTION
IS NORMALIZED TO 9 PI Omega ZERO AND MAY BE RENORMALIZED BY
DIVISION BY THE APPROPRIATE CONSTANT(S).

********* INPUT *********

CARD 1 - INTEGER CONTROL PARAMETERS: NWAVE, NINDEX, IW, IDSTR, NNADP, I1, IANG, NCARDS, IOTL, NUNIT, MPHRT, IPX
FORMAT (I21S)

NWAVE: IS THE NO. OF WAVELENGTHS, OR REL. HUMIDITY VALUES TO BE
TREATED IN THIS RUN. SEE COMMENTS CIRCA READ OF WAVE, DWAVE, ETC.
N.B. NWAVE MUST BE ~LE 5
NINDEX: IS THE NBR OF AEROSOL COMPONENTS WHICH WILL HAVE DIFFERENT
OPTICAL CONSTANTS, MASS DENSITIES OR MASS CONCENTRATIONS.
IW: = 0 WILL SET THE REFRACTIVE INDEX OF THE DRY AEROSOL EQUAL
TO THAT OF WATER AT THE INPUT WAVELENGTH AND TEMP. IF IW#NE 0
AND MA=0, GROWTH FACTOR IS ZERO (MA#O = CARD 4), THEN THE
INPUT REFRACTIVE INDEX (MALCAYA) WILL BE USED FOR THE AEROSOL.
OTHERWISE THE REFRACTIVE INDEX IS ADJUSTED PER HANEL (SEE BELOW).
IDSTR: IDENTIFIES TYPE OF AEROSOL SIZE DISTRIBUTION TO BE USED.
INNADP: NO. OF PARTICLE RADIUS TO BE EXPECTED FOR IDSTR=0 OR 31
THE INPUT VALUE OF NNADP IS IGNORED FOR IDSTR NOT ZERO OR 31.
NNADP MUST BE LESS THAN 513.
I1: IS THE NUMBER OF GAUSS-LEGENDRE ANGLES (ORDER OF EXPANSION)
IF IANG#0 OR NBR OF ANGLES BETWEEN 0 DEG AND 180 DEG IF IANG = 1.
IF ONLY EXTINCION COEFFICIENTS, ETC., ARE DESIRED, I.E. NOT PHASE
FUNCTIONS, THEN SET -I1= EQUAL TO ONE.
IANG: = 0 FOR COMPUTATIONS OF PHASE FN. AT -I1- GAUSS-LEGENDRE
QUADRATURE ANGLES: NO SCATTERING FRACTIONS WILL BE PRINTED.
IANG=1 FOR COMPUTATIONS OF SCATTERING FRACTIONS AND PHASE
FUNCTIONS AT -I1- EQUALLY SPACED ANGLES BETWEEN 0 AND 180 DEG.
IANG=2 WILL ALLOW -I1- USER SUPPLIED ANGLES TO BE READ.
FORMAT (IAF5.1). THIS REQUIRES AT LEAST ONE CARD OF TYPE 1A.
NCARDS: = 1 WRITE/PUNCH LEGENDRE COEFFICIENTS AND ORDER OF EXPANSION
ON NUNIT = FORMAT (E25.14+IX,1S):
= 2 WRITE/PUNCH SCATTERING FRACTIONS, PHASE FUNCTIONS, COSINES AND
COUNTER ON NUNIT = FORMAT (3(E12.6+IX),1S):
= 3 WRITE/PUNCH BOTH SCATTERING FRACTIONS, PHASE FUNCTIONS,
AGXM0100
AGXM0110
AGXM0120
AGXM0130
AGXM0140
AGXM0150
AGXM0160
AGXM0170
AGXM0180
AGXM0190
AGXM0200
AGXM0210
AGXM0220
AGXM0230
AGXM0240
AGXM0250
AGXM0260
AGXM0270
AGXM0280
AGXM0290
AGXM0300
AGXM0310
AGXM0320
AGXM0330
AGXM0340
AGXM0350
AGXM0360
AGXM0370
AGXM0380
AGXM0390
AGXM0400
AGXM0410
AGXM0420
AGXM0430
AGXM0440
AGXM0450
AGXM0460
AGXM0470
AGXM0480
AGXM0490
AGXM0500
AGXM0510
AGXM0520
AGXM0530
AGXM0540
AGXM0550
AGXM0560
AGXM0570
AGXM0580
AGXM0590
AGXM0600
AGXM0610
AGXM0620
AGXM0630
AGXM0640
AGXM0650
COSINES, COUNTER, AND LEGENDRE COEFFICIENTS AND ORDER OF EXPANSIONAGXM0440
C ON NUNIT - FORMATS (3(1E12+6,1X),15) AND (E25.14,1X,15):
C SCATTERING FRACTIONS, PHASE FUNCTIONS, COSINES, AND COUNTER
C (RESPECTIVELY) ARE ALWAYS WRITTEN/PUNCHEE BEFORE THE LEGENDRE
C COEFFICIENTS AND ORDER OF EXPANSION (RESPECTIVELY).
C I0T: WORKS IN CONJUNCTION WITH NCRDS AND NWAVE TO WRITE/PUNCH
C EITHER INDIVIDUAL WAVELENGTH VALUES OR AVERAGED WAVELENGTH VALUES
C OR BOTH ON NUNIT; = 1 FOR INDIVIDUAL WAVELENGTHS; = 2 FOR AVERAGED
C WAVELENGTHS: = 3 FOR BOTH.
C NUNIT: DEFINES DEVICE NUMBER, SEE PREVIOUS COMMENT CARD.
C MWRT=12345 WILL CAUSE PRINTS OF MIE EFFICIENCY FACTORS AT
C EVERY VALUE OF PARTICLE RADIUS USED IN THE MIE CALCULATIONS.
C SET MWRT = 0 IF SUCH PRINTS ARE NOT DESIRED.
C IAPPX IF +GT 0, ZERO THE GGH (ANALYTIC) PHASE FUNCTION WILL BE
C CONSTRUCTED AT IAPPX GAUSS-LEGENDRE ANGLES (ORDER OF EXPANSION).
C CARD 1A - USER SUPPLIED SET OF -IT- ANGLES FORMAT (1DFF6+1).
C 16 VALUES PER CARD, MORE THAN 1 CARD MAY BE NEEDED.
C THIS CARD IS ONLY NEEDED WHEN IANG=2.
C CARD 2 - DISTRIBUTION PARAMETERS: ONLY ONE TYPE PER RUN.
C TYPE 0 - USER SUPPLIED - N RAD=1 CARDS
C TYPE 1 - RLO, DELLR, RBAR, SIGMA, RLO, RMI
C TYPE 2 - DOUBLE EXPONENTIAL
C RLO, RMI, CUE, A, B
C TYPE 3 - DEIRMENDJIAN MODEL C
C RLO, RMI, RC, ALF, GAM
C TYPE 4 - POWER LAW (JUNGE)
C RLO, RMI, CUE, A
C TYPE 5 - MODIFIED GAMMA
C RLO, RMI, RC, ALF, GAM
C TYPE 6 - MODIFIED GAMMA FUG MODEL
C RLO, RMI, RC, ALF, GAM, ELWC
C TYPE 7 - POWER LAW
C VIS
C TYPE 8 - CONTINENTAL BIMODAL
C - NO INPUT -
C TYPE 9 - MARITIME BIMODAL
C - NO INPUT -
C TYPE 10 - URBAN BIMODAL
C - NO INPUT -
C TYPE 11 - USER SUPPLIED BIMODAL
C RDA, RRMA, SG, FC, RBARC, SG
C TYPE 12 - MARSHALL-PALMER MAIN MODEL
C RAIN
C CARD 3 - CONTROL PARAMETERS: FORMAT (6E12+6)
C WAVE, DWAVE, RELHUM, DENS, TEMP, DELTA
C FOR LOOPTING OVER RELATIVE HUMIDITY ADD
C NWAVE-1 CARDS CONTAINING RELHUM, TEMP - FORMAT(2E12+6)
C SEE DWAVE BELOW
C WAVE: IS WAVELENGTH IN MICRUMETERS
C DWAVE: IS THE WAVELENGTH INCREMENT IN MICRUMETERS.
C IF DWAVE IS
LESS THAN 1.E-4, A SPECIAL CASE APPLIES USED FOR LOOPING OVER
AGXM1230
CONTAINING WAVE, D, M, W, DELTA, THE SECOND AND
AGXM1240
SUBSEQUENT TIMES IT MUST ONLY HAVE RELHUM AND TEMP ON IT.
AGXM1260
THIS REQUIRES REPETITION OF CARD 4.*
AGXM1270
RELHUM: IS RELATIVE HUMIDITY IN PERCENT.
AGXM1280
DENSH: IS PARTICLE NUMBER PER CUBIC CENTIMETER.
AGXM1290
USER-SUPPLIED VALUE OF DFNSH WILL BE IGNORED FOR IDSTP=9 OR GT 6
AGXM1300
BECAUSE THOSE DISTRIBUTIONS CARRY PRE-DETERMINED DENSITY VALUES.
AGXM1310
ALSO, IF DENSH IS LESS THAN 1.E-4, THE PARTICLE NUMBER DENSITY
AGXM1320
WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION.
AGXM1330
TMIN: IS THE TEMPERATURE OF THE ATMOSPHERE IN DEGREES C.
AGXM1340
DELTA: IS THE CONVERGENCE CRITERION WITHIN A PARTICULAR SIZE
AGXM1350
RANGE INTERVAL IF BALANCING IS TERMINATED WHEN THE QUANTITY DEL
AGXM1360
IS LESS THAN DELTA.
AGXM1370

CARD 4 - OPTICAL AND PHYSICAL DATA (READ IN AGXPT2)
FORMAT ('F10.5,E15.7')
AGXM1390
EMA, CAT, EMUA, RHOA, CONC
AGXM1400
REPEAT (NMPAUSE+MINUS) TIMES: IF IDSTP=6 THIS CARD IS NOT NEEDED.
AGXM1420
EMA: IS THE REAL PART OF THE INDEX OF REFRACTION OF DRY AEROSOL.
AGXM1430
CAT: IS THE IMAGINARY PART OF REFRACTIVE INDEX FOR DRY AEROSOL.
AGXM1440
***** DO NOT ENTER CATA WITH A NEGATIVE SIGN !!!!! ****
AGXM1450
EMUA: IS HANIEL'S GROWTH FACTOR (MU-BAR/ACCRETION COEF).
AGXM1470
RHOA: IS THE MASS DENSITY (SP, GRAV) OF DRY AEROSOL.
AGXM1480
CONC: IS THE MASS CONCENTRATION (G/M^3) OF DRY AEROSOL.
AGXM1490
AGXM1500
AGXM1510
AGXM1520
AGXM1530
AGXM1540
AGXM1550
AGXM1560
AGXM1570
AGXM1580
AGXM1590
AGXM1600
AGXM1610
AGXM1620
AGXM1630
AGXM1640
AGXM1650
AGXM1660
AGXM1670
AGXM1680
AGXM1690
AGXM1700
AGXM1710
AGXM1720
AGXM1730
AGXM1740
AGXM1750
AGXM1760
AGXM1770
AGXM1780
AGXM1790
IF (IW+EQ+0) WRITE (6,122)
C
INITIALIZE QUANTITIES USED IN SUMMATIONS
DO 2 I=1,IT
OLT(I)=0.E0
OLT(I)=0.E0
PSUM(I)=0.E0
SCATT(I)=0.E0
2 PSUM(I)=0.E0
KEXT=0.E0
KSCAT=0.E0
KBST=0.E0
CATT=0.E0
IT=IT+1
PI=3.141592653589792E+00
IF (IANG+EQ+1) OR (IANG+EQ+2) GO TO 3
C
WHEN IANG=0, ROUTINE GUSFT IS CALLED TO SET-UP THE ABSCISSAE AND
WEIGHTS USED FOR CALCULATING THE PHASE-FUNCTION AT -IT- POINTS.
C
USED FOR NUMERICAL INTEGRATION VIA GAUSS-LEGENDRE QUADRATURE AND
C
TO GET THE PHASE FUNCTION EXPANSION COEFS, OL(I).
C
THE WEIGHTS ARE PLACED IN THE ARRAY H(I), AND THE COSINES OF THE
C
ANGLES ARE PlACED IN THE ARRAY C(I).
CALL GUSFT(SCATT,F,PI)
C
IF (ITT+LT+3) ITTP+3
GO TO 7
3 CALL ANGLE(PI,IANG)
C
SUBROUTINE ANGLE IS CALLED WHEN IANG+1 OR 2 TO SET-UP THE ANGLES
C
AT WHICH PHASE FUNCTIONS AND SCATTERING FRACTIONS WILL BE
C
CALCULATED. ANGLES GO INTO ARRAY H(I) AND COSINES IN C(I).
C
CONTINUE
C
Determine details of aerosol size-distribution via AGAPT
CALL AGAPT(DENS,PSUM,OL,NDN)
C
IF (1STP+EQ.+6) OR (1STP+EQ.+7) ELWC=DENS
C
DRYVOL IS THE AVERAGE VOLUME OF THE DRY AEROSOL PARTICLES IN
C
CUBIC MICROMETERS
C
DRYVOL=VOL
C
*** READ INPUT PARAMETERS ***
READ (5,105) WAVE,DWAVE,RELUH,DENH,TEMP,DELTA
C
IF (NWAVE+EQ.+1) DWAVE+0.E0
AGXM1950
WRITE (6,106) WAVE,DWAVE,RELUH,DENH,TEMP,DELTA
AGXM1950
IF (NINDEX+GT+1) WRITE (6,107) NINDEX
AGXM1950
IF (IDWAVE+LT+1E-04) AND (INWAVE+GT+1) WRITE (6,108) NWAVE
AGXM1950
IF (IDWAVE+GT+1E-04) AND (INWAVE+GT+1) WRITE (6,109) NWAVE
AGXM1950
IF (DENS+LT+1E-09) WRITE (6,110)
AGXM1950
ENWAVE=FLOAT(NWAVE)
AGXM1950
IF (IDWAVE+LT+1E-04) GO TO 8
WAVE=WAVE+DWAVE
AGXM2150
8 DO 9 NW=1,NWAVE
AGXM2240
IF (DWAVE+GT+1E-04) GO TO 10
IF (NW+EQ+1) GO TO 11
AGXM2240
READ (5,105) RELUH,TEMP
AGXM2240
GO TO 11
AGXM2240
10 WAVE=WAVE+DWAVE
AGXM2310
11 VOL=DRYVOL
AGXM2320
C
Determine whether the user supplied particle number density DENS.
AGXM2330
C
SHOULD BE overridden because the chosen 1STP CASE has fixed.
AGXM2340
C
PARAMETERS, AND/OR IF NUMBER DENSITIES ARE TO BE CALCULATED LATER.
AGXM2350
C
FROM THE AVG PARTICLE VOLUME, MASS DENSITY, AND MASS CONCENTRATIONAGXM2360
LLL=0
IF (I(DSTP*EQ+6) GO TO 12
IF (I(DSTP*EQ+3)*OR(I(DSTP*EQ+7) LLLL=1
IF (LLL*EQ+11) GO TO 12
IF (DENS*LE+1.E-9) GO TO 12
LLL=1
DENS=DENS
2 CONTINUE
C RESTRICT RELATIVE HUMIDITY TO MAX OF 99 PERCENT.
IF (RELHUM*GE+99.E+00) RELHUM=99.0E+00
WRITE (6,111) RELHUM,WAVE
IF (DENS*EQ+0.0) DENS=1.0E+00
GNU=1.0E+0/WAVE
IF (I(DSTP*EQ+6)*OR(I(DSTP*EQ+12) DENS=ELWC
C DENS IS USED AS AN ALIAS TO PASS ELWC TO ROUTINE AGXPT2.
CALL AGXPT2(RELHUM,CTSUNM,CTSUNM,CTSUNM,CTSUNM,VLTMAS,DENSM,QTATN,TEMP,
1 DELTA,NINDX,IPX,1W)
IF (IANG*NE+0) GO TO 13
AMAX=2.*E+0*P1EMR(NRADI)/WAVE
LMAX=3.*IFIX(AMAX)
AGXM2560
IF (LMAX*GT+11) AND(IAPX*EQ+0) WRITE (6,112) LMAX,IT
AGXM2570
13 CALL AGXPT3(CTSUNM,CTSUNM,CTSUNM,GNU,DENS,NINDX,NUNIT,1ANG,1TOT,IPX) AGXM2580
C SUM QUANTITIES OVER INDEX NWV.
DO IN IF=X,IT
OLT(IK)=MOLT(IK)*OL(IK)
SCATT(IK)+SCAT(IK)+SCAT(IK)
19 PSUMT(IK)=PSUMT(IK)+PSUM(IK)
C KEKT BECOMES THE TOTAL EXTINCTION COEF. (PER KILOMETER).
AGXM2650
C KSCAT BECOMES THE TOTAL SCATTERING COEF. (PER KM).
C KBKT BECOMES THE TOTAL BACKSCATTERING (RAOM) COEF. (PER KM).
A ARAY OUT(I1) HOLDS SOME QUANTITIES FOR LATER PRINTOUTS
AGXM2670
KEKT=KEKT+CTSUNM
KSCAT=KSCAT+CTSUNM
KBKT=KBKT+KSCAT+CTSUNM
AGXM2690
CATTN=CATTN+QTATN
OUT(NWV,1)=WAVE
OUT(NWV,2)=RELHUM
OUT(NWV,3)=MASS*1.ES
OUT(NWV,4)=CTSUNM
C GPHAX WILL CONSTRUCT THE GPH ANALYTIC PHASE FUNCTION AT
C IAPX ANGLES.
IF (IAPX*GT=0) CALL GPHAX(PSUM,PL,OL,RMS,PC,1,SCAT,SCATT,OLT,PI,1,
+NUUNIT,1APX,NCROS)
C IF (INWAVE*GT=1) AND(IWAVE*LE+1.E-9) WRITE (6,113) NWV
IF (INWAVE*GT=1) AND(IWAVE*LT+1.E-9) WRITE (6,114) NWV
C CONTINUE
AGXM2700
C END OF NWAVE LOOP
IF (IAPX*GT=0) GO TO 20
IF (INWAVE*EQ+1) GO TO 15
C DIVIDE BY NBR OF VALUES OF NWV TO GET AVERAGED RESULTS.
DO 16 I=1,IT
OL(I1)=OL(I1)/ENWAV
SCATT(I1)=SCATT(I1)/ENWAV
PSUM(I1)=PSUM(I1)/ENWAV
AGXM2740
16 CONTINUE
C IF (INWAVE=EQ+2) OR(INWAVE=EQ+3) AND(I1TOT*EQ-2)*OR(I1TOT*EQ+2)
C AGXM2910
* + 1) WRITE (NUUNIT,15) SCATT(I1),PSUM(I1),C(I1),1
AGXM2920
86 CONTINUE
IF (IANG-NEQ.0) GO TO 21
  DO 17 I=11,1T
  IF (((NCRDS+EQ.1)+OR (((NCRDS+EQ.3))) AND (((ITOT+EQ.2)+OR (((ITOT+EQ.3)))))
    +1)) WRITE (UNIT=116) DL(1:1)
17 CONTINUE
  KEKT=KEKT/ENAV
  KSCAT=KSCAT/ENAV
  KBAKT=KBAKT/ENAV
  CATTN=CATTN/ENAV
  WRITE (16,117)
  WRITE (16,118)
  DO 18 J=1,NWAVE
  IF (NWAVE-NEQ.1) CALL AGXPNT(SCATT,KEKT,KSCAT,KBAKT,CATTN,IANG)+
    (ITOT,UNIT)
18 CONTINUE
  GO TO 19
19 STOP
F FORMAT (1H1,4QX,3H3H,24X,3H6H/1X),1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
F FORMAT (12I5)
F FORMAT (1I1) [1H1,3H3H,24X,3H6H/1X],1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
F FORMAT (12I5)
F FORMAT (1I1) [1H1,3H3H,24X,3H6H/1X],1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
F FORMAT (12I5)
F FORMAT (1I1) [1H1,3H3H,24X,3H6H/1X],1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
F FORMAT (12I5)
F FORMAT (1I1) [1H1,3H3H,24X,3H6H/1X],1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
F FORMAT (12I5)
F FORMAT (1I1) [1H1,3H3H,24X,3H6H/1X],1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
F FORMAT (12I5)
F FORMAT (1I1) [1H1,3H3H,24X,3H6H/1X],1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
F FORMAT (12I5)
F FORMAT (1I1) [1H1,3H3H,24X,3H6H/1X],1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
F FORMAT (12I5)
F FORMAT (1I1) [1H1,3H3H,24X,3H6H/1X],1X,4QX,3H3H,24X,3H6H/*,1X/*,
  '4QX,3H3H** PROGRAM AGAUSX**'***'4QX,3H3H,24X,3H6H/*,1X,4QX,3H3H,24X,3H6H*/
  '4QX,3H3H/1H1/*)
SUBROUTINE A6XPT1(DENS,FSUM,Vol,NRADI)
DIMENSION F(513),R(513),PSUM(100),DR(8),RR(9),FF(519),SCAT(100)
COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WEAVE,EM,EMM,P1,1DSTP,
/MONTE,NKG,NHALV,NI
WRITE (4,1) PTI00100
C
CHOOSE AND SET UP PARTICLE SIZE DISTRIBUTION
IF (I1DSTP NE 0) GO TO 112, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 1I1DSTP
C
** TYPE 0: ARBITRARY USER-SUPPLIED DISTRIBUTION. THE NRADI VALUES
C
OF FF(IJ) MUST BE GIVEN, ONE PER CARD, ON EQUAL INCREMENTS DELR
C
OF RADIUS AND READ IN ORDER, FROM SMALLEST RADIUS, RLO TO THE
C
LARGEST: NRADI MUST BE LESS THAN OR EQUAL TO 513.
WRITE (4,7) PTI00110
READ *(51,1) RLO,DELRR
DO 9 J=1,NRADI
9 READ *(51,1) FF(J)
DO 10 J=1,NRADI
10 JK=J+9
JK=J+9
C
IF (JK-5+NRADI) JK=NRADI
WRITE (4,11)(R(K),FF(K),K=J,JK)
11 WRITE (4,11)
FFN(RNRAI+1)=FFN(RNRAI)
R(1)=RLO
R(2)=RLO+DELRR*FLOAT(J-1)
MIN=0
GO TO 20
C
** TYPE 1: LOGNORMAL DISTRIBUTION
12 READ *(5,1) RBAR,SIGMA,RLO,RRH
C
SIGMA IS STANDARD DEVIATION, NOT LN(SIGMA)
SIGMA=SIGMA
SIGMA=SIGMA
SIGMA=ABS((EQ(12.5662836*SIGMA))
IF ((RRH-RLO)+LE+1,E-4) GO TO 13
RR(1)=RLO
RR(1)=RLO
RR(1)=RLO
GO TO 19
13 RR(1)=RVAR*EXP(-4*EO+SIGMA)
RR(1)=RVAR*EXP(-4*EO+SIGMA)
RR(1)=RVAR*EXP(-4*EO+SIGMA)
14 RR(2)=RVAR
RR(2)=RVAR
RR(2)=RVAR
MIN=1
WRITE (4,3) RVAR,SRMNN,RL0,RRH
AVOL=1.88760*RRH*3.0*EXP(4.506*SIGMA+SIGMA)
C
HERE AND ELSEWHERE, AVOL IS THE VOLUME OBTAINED VIA
C
ANALYTICAL INTEGRATION OVER THE LIMITS RLO TO RRH =
C
INFINITY: THAT CAN ONLY BE DONE FOR A FEW 1DSTP CASES.
GO TO 28
C
** TYPE 2: DOUBLE EXPONENTIAL F(R)=CUE*A*EXP(-A*R)+(-CUE)*B*EXP(-B*R)
C
RESTRICTIONS: RRH+GT+RLO; B+GT+A*GE+O; O+LE+CUE+LE+1+O.
B5 READ *(5,1) RLO,RRH,CUE,A,B
WRITE (4,4) RLO,RRH,CUE,A,B
RR(1)=RLO
RR(1)=RLO
RR(1)=RLO
MIN=1
GO TO 28
C
** TYPE 3: DEIRMENDJIAN MODEL C* F(R) = 1.0, RLO+LE+R+LE+9+DELRD,
PTI00120
PTI00130
PTI00140
PTI00150
PTI00160
PTI00170
PTI00180
PTI00190
PTI00200
PTI00210
PTI00220
PTI00230
PTI00240
PTI00250
PTI00260
PTI00270
PTI00280
PTI00290
PTI00300
PTI00310
PTI00320
PTI00330
PTI00340
PTI00350
PTI00360
PTI00370
PTI00380
PTI00390
PTI00400
PTI00410
PTI00420
PTI00430
PTI00440
PTI00450
PTI00460
PTI00470
PTI00480
PTI00490
PTI00500
PTI00510
PTI00520
PTI00530
PTI00540
PTI00550
PTI00560
PTI00570
PTI00580
PTI00590
PTI00600
PTI00610
PTI00620
PTI00630
PTI00640
PTI00650
C  F(R)=19*DELRD/R**4, R*GF=14*DELRD
C  NRADI IS READ IN EARLIER IN THE MAIN PROGRAM.
16  DENS=1.378E+09
DELRD=0.02EO
RLO=0.02EO
RHI=RLO+DELRD*FLOAT(NRADI-1)
RHI(1)=RLO
RR(I)=RHI
MIN=1
R(2)=RLO+4.0E0*DELRD
GO TO 28
C**  TYPE 4 AND TYPE 7: POWER LAW.  F(R) = CUE*R**-A
C  RLO=LE*+LE.RHI; VIS=VISIBILITY IN KILOMETERS
7  IF (IDSTP.EQ.4) GO TO 18
C**  TYPE 7 PRESCRIBED PARAMETER.
   READ (5,1) VIS
   RLO=0.1EO
   RHI=15.0EO
   CUE=30.0EO
   A=4.0EO
   DENS=11.0EO**5.0EO=ALOG10(VIS)
C**  TYPE 4 PRESCRIBED PARAMETERS.
8  IF (IDSTP.EQ.4) READ (5,1) RLO,RHI,CUE,A
    WRITE (6,5) RLO,RHI,CUE,A,VIS
    RHI(1)=RLO
    R(R)=KHI
    R(2)=EO*EO*(RLO**(-A)+RHI**(-A))**(-1.0E0/A)
    MIN=1
    GO TO 28
C**  TYPE 5: MODIFIED GAMMA/GENERALIZED KHIRGIAN-MAZIN
C  F(R) = [R**ALF]*EXP(-ALF*(R/RC)**GAM)/GAM
C  RLO=LE*+LE.RHI
C**  TYPE 6: SPECIAL CASE FOR WATER FOGS OR CLOUDS,
C  IN WHICH CASE ELWC IS LIQUID WATER CONTENT
C  IN GRAMS PER CUBIC CENTIMETER.
C  ELWC IS IGNORED IF IDSTP .EQ. 5
9  READ (5,1) RLO,RHI,RC,ALF,GAM,ELWC
   IF (IDSTP.EQ.6) DENS=ELWC
    WRITE (6,6) RLO,RHI,RC,ALF,GAM
    RRI(1)=RLO
    R(R)=RC
    R(R)=RHI
    MIN=1
    B=ALF/GAM+RC**GAM
    A0L=4.18828**(-3./GAM)*GAMMA((ALF+4.)/GAM)/GAMMA((ALF+1.)/GAM)
    GO TO 28
C**  TYPES 8,9,10: BIMODAL LOG-NORMAL DISTRIBUTIONS.
C  METHOD BELOW VALID FOR RRARC=EXP(-SGA)+GTRRARC*EXP(-SGA)
C**  TYPE 8: CONTINENTAL BIMODAL
   FOA=4.0EO3
   FOA=2.1EO3
   SG1=0.7EO3
   SG2=0.8EO3
   RRARC=0.0EO3
   RRARC=0.4EO3
   GO TO 23
C**  TYPE 9: MARITIME BIMODAL.
21  FOA=4*E02
    FOC=3*E00
    SGA=0.6*E00
    SGC=0.7*E00
    RBARA=0.0*E00
    RBARC=0.6*E00
    GO TO 23
C** TYPE 10: URBAN BIMODAL

22  FOA=2*E09
    FOC=0.6*E00
    SGA=0.6*E30
    SGC=0.7*E00
    RBARA=0.0*E00
    RBARC=0.6*E30
    C CALCULATE RADII FOR TYPES 8,9,10

23  RR(1)=RBARA*EXP(-4*E0*ABS(SGA))
    RR(2)=RBARA
    RR(3)=RBARA*EXP(4*E0*ABS(SGA))
    RR(4)=RBARC*EXP(-4*E0*ABS(SGC))
    RR(5)=RBARC*EXP(4*E0*ABS(SGC))
    MIN=2
    DO 60 J=1,4
    DO 60 I=1,9
       IF (RR(I+1)+GT+RR(I)) GO TO 60
       RR(I)=RR(I+1)
       RR(I+1)=HH
       60 CONTINUE
    GO TO 28
C** TYPE 11:
C USER SUPPLIED BIMODAL CASE: FOA AND FOC ARE THE NUMBER DENSITIES
C FOR THE ACCUMULATION (SMALLER RBAR) AND COARSE MODES;
C RESPECTIVELY, IN PARTICLES PER CMIC CENTIMETER.
C SGA IS STD.DEVIATION FOR MODE A ** NOT LN(SIGMA) ***
C SGC IS STD.DEVIATION FOR MODE C ** NOT LN(SIGMA) ***
C *** NOTE, HOWEVER, THAT SGA AND SGC ARE THE LOGS OF THE
C STANDARD DEVIATIONS IN THE PRE-CODE CASES TYPE 8-10*
24  READ (5,1) FOA,FOC,RBARA,RBARC,SGA,SGC
    WRITE (6,25) FOA,RBARA,SGA,FOC,RBARC,SGC
    SGA=ABS(LOG(SGA))
    SGC=ABS(LOG(SGC))
    GO TO 23
C** TYPE 12: MARSHALL-PALMER RAIN MODEL*
C C+F. MASON, PHYSICS OF CLOUDS, CH. ON RADAR METEOROLGY.*
C INPUT PARAMETER RAIN IS RAIN RATE IN MILLIMETERS/HOUR;
C ** EMA CAYA, AND HM3 ARE REQUIRED FOR THIS DISTRIBUTION*
26  READ (5,1) RAIN
    ENZERO=0.0*E00
    CAPL=4*E0+RAIN*1.0*E00
    DEN=ENZERO/CAPL
    AVOL=PI*(CAPL**(-3.0*E01))**1.0*E12
    C CONVERT UNITS FROM CM-4 TO (CM-3)*(MICROMETERS**(-1)):
C THE FACTOR OF 2 CONVERTS THE M-P FORMULA FROM DIAMETER=DATA TO
C RADIUS BASED FORM:
    RAIN=2*E-4*ENZERO
    CAPL=2*E-4*CAPL
    MIN=0
    GO TO 28

C IT SETS THE NMAX VALUES OF RADIUS, R(KK).
28 MAX=9
  NHALV=MAX-MIN
  NMAX=1.2*MAX
  NI=2**MIN
  NLAST=NI+1
  NKG=2**NHALV
  ENKG=FLOAT(NKG)
  DO 29 I=1,NI
    DK(I)=RR(I+1)-RR(I)
    DO 29 K=1,NKG
      KK(I)=1*(I-1)+NKG+K
      29 RRKK(I)=RR(I)*(FLOAT(K-1))*DK(I)/ENKG
      RINMAX=RR*(NLAST)

C BRANCH AGAIN CALCULATE THE DIFFERENT F(R) ON THE NMAX POINTS R(K)
IF (IDSTP+NEQ-0) GO TO (31,33,35,38,41,39,43,43,43,43,43,43,46),IDSTP
C** TYPE 0: ARBITRARY
DELR=(RR(I+1)-RLOI)/ENKG
DO 30 K=1,NMAX
  JKK=1*(FLOAT(K-1))*DELR/DELLR
  30 FK(I)=FF(JKK)+(R(K)-RRJ(KK))*FF(JKK)*1-FF(JKK))/DELLR
GO TO 48

C** TYPE 1: LOG NORMAL
31 DEN=2*EPS*SIGMA*SIGMA
DO 32 KK=1,NMAX
  GNUM=ALOG(R(KK)/RHR)
  32 FK(I)=EXP(-GNUM*GNUM/DEN)*A/R(KK)
GO TO 48

C** TYPE 2: DOUBLE EXPONENTIAL
33 DO 34 KK=1,NMAX
  FKK=1-EXP(-CUE+B*(R(KK)))
  34 FK(I)=KK*CUE*A*EXP(-A*R(KK))
GO TO 48

C** TYPE 3: DEIRMENDIJAN MODEL C*
35 DO 36 KK=1,NMAX
  36 FK(I)=1+ED
  NKG1=NKG+1
  DO 37 KK=NKG1,NMAX
    37 FK(I)=1*(R(R2)/R(KK)**4+EO)
GO TO 48

C** TYPES 4 AND 7: POWER LAW
38 GO TO 39
39 DO 40 KK=1,NMAX
  40 FK(I)=CUE*R(KK)**(-A)
GO TO 48

C** TYPE 5 AND TYPE 6: MODIFIED GAMMA
41 DO 42 KK=1,NMAX
  42 FK(I)=(EXP(-B*R(KK)**GAM)-EXP(-R(KK)**ALF)
GO TO 48

C** TYPES 8, 9, 10, 11: BIMODAL LOG-NORMAL DISTRIBUTIONS
43 DENA=2*EO*SGA*SGA
  DENC=2*EO*SGC*SGC

PT016000
PT016100
PT016200
PT016300
PT016400
PT016500
PT016600
PT016700
PT016800
PT016900
PT016A00
PT016B00
PT016C00
PT016D00
PT016E00
PT016F00
PT017000
PT017100
PT017200
PT017300
PT017400
PT017500
PT017600
PT017700
PT017800
PT017900
PT017A00
PT017B00
PT017C00
PT017D00
PT017E00
PT017F00
PT018000
PT018100
PT018200
PT018300
PT018400
PT018500
PT018600
PT018700
PT018800
PT018900
PT018A00
PT018B00
PT018C00
PT018D00
PT018E00
PT018F00
PT019000
PT019100
PT019200
PT019300
PT019400
PT019500
PT019600
PT019700
PT019800
PT019900
PT020000
PT020100
PT020200
PT020300
PT020400
PT020500
PT020600
PT020700
PT020800
PT020900
PT021000
PT021100
PT021200
PT021300
PT021400
PT021500
PT021600
PT021700
PT021800
PT021900
PT022000
PT022100
PT022200
PT022300
PT022400
PT022500
PT022600
PT022700
PT022800
PT022900
PT023000
PT023100
PT023200
PT023300
PT023400
PT023500
PT023600
C** TYPE 12: MARSHALL-PALMER MAIN MODEL

44 DO 49 KK=1,NMAX

49 FIKK=ENZERO*EXP(-CAPLR(KK))

C CALCULATE NORMALIZED FIKK AND SOME DRY VOLUMES USING ALL NMAX

C VALUES OF RADIJ =

C (VOL= AVERAGE PARTICLE VOLUME IN A DISTRIBUTION), THE

C NORMALIZATION AND FURTHER VOLUMES ARE RECALCULATED LATER

C BY THE HALVING INTEGRATION METHOD.

48 FSUM=0.E0

DO 49 J=2,NMAX

IF(FJ)=LT=0.E0)FJ)=0.E0

DO 50 J=1,NMAX

50 FJ=FJ/FSUM

WRITE (6,8) FSUM

NRAD= NMAX

IF(EIDSTP.EQ.1.OR.IDSTP.EQ.4) WRITE (6,51) AVOL

DO 52 J=2,NMAX

52 VOL=VOL+2.Q44#*FJ)*RJ)**3.DO*F(J-1)+R(J-1)**3.DO*(RJ=RJ-1)

WRITE (6,53) VOL

C THE VOLUME PER PARTICLE CALCULATED HERE IS OBTAINED USING

C ALL AVAILABLE (NMAX VALUS) VALUES FOR THE PARTICLE RADIJ.

WRITE (6,54) VOL

DO 56 INT=1,NI

INF=INT+1

WRITE (6,55) INT,KR(INT),KR(NF)

RETURN

1 FORMAT (6E12.13)

2 FORMAT (1H1,//24H AEROSOL PARAMETERS ARE )

3 FORMAT (1H1,,24X,HBAR=,E12.6,5X,HPSIGMA=,E12.6)

4 FORMAT (1H1,,24X,HSHL=,E10.4,1X,HSHF=,E10.4,1X,HSCUE=,E10.4,1X,HRSF=,E10.4,1X)

5 FORMAT (1H1,,24X,SHRLO=,E10.4,1X,SHRHI=,E10.4,1X,SHCUE=,E10.4,1X)

6 FORMAT (1H1,,24X,SHRL=,E10.4,1X,SHRHL=,E10.4,1X,SHRL=,E10.4,1X,SHRL=,E10.4,1X)

7 FORMAT (1H1,,24X,RAIDUS RELATIVE NO. )

8 FORMAT (1H1,,24X,NORM. SIZE DISTRIBUTION =,E10.4)

9 FORMAT (1H1,,24X,PE12.6,1X)
25 FORMAT (/1X,7HNN(A) = ,E12.6,2X,9H RBARA = ,E12.6,2X,12H SIGMA(A) =PT102940
  * ,E12.6/1X,7HNN(C) = ,E12.6,2X,9H RBANC = ,E12.6,2X,
  12H SIGMA(C) = ,E12.6/)
PT102950
27 FORMAT (/1X,42H MARSHALL-PALMER RAIN MODEL : RAIN RATE = ,1PE10.3,PT102970
  * 2H MM PER HOUR, DENS = ,1PE12.6,8H PART/CC)
PT102980
45 FORMAT (/1H,50H** BIMODAL DISTRIBUTION**EQUIVALENT DENSITY ISPT102990
  * ,1PE12.6,10H PARTICLES PER CC,/)
PT103000
91 FORMAT (/45H AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS ,3X,
  * 1PE12.6,18H CURIC MICROMETERS)
PT103010
93 FORMAT (/1X,47H HAVEMAGE NUMERICAL DRY VOLUME IS
  * 1PE12.6,18H CURIC MICROMETERS/)
PT103030
59 FORMAT (/1X,10X,35H SIZE-INTERVALS USED ARE AS FOLLOWS/)
PT103050
55 FORMAT (/1H,14H INTERVAL NO. ,13,5X,7HRMIN = ,F11.5,5X,8H HMAX =
  * ,F11.5)
PT103060
END
SUBROUTINE AGPZT2(RELHUM,CTSUM,CSSUM,CRSUM,TVO,TMAS,DENS,CATTN, PTX0100
1 TEMP,DELTA,MNIX,AP2X,IM)
PTX0110
DOUBLE PRECISION END:CA:ALPHA:QTD:QSD:QRD,OISTRO,O2STRD,DBLE
PTX0120
REAL KEXT,KEXTL,KEXOL
PTX0130
DIMENSION P(513),OM(8),RRM(100),P1(100),PSUM(100)
PTX0140
DIMENSION PL(100+100),OL(100),RMS(100),PC(100),H(100),PSUM(100)
PTX0150
DIMENSION PHT(100),PHTG(100),PSHT(100),SCAT(100)
PTX0160
EQUIVALENCE (PHH(11),PC(11),(PGG(11)),(PHT(11)),(OL(11))
PTX0170
COMMON /K3/KL,OLM,PM,SCAT,RRM,D,WAVE,EM,CAT,EMH,P1,ISTP,
PTX0180
1 COMMON /MORTE,NK,NCH,LML,HML)
PTX0190
C IN THIS SUBROUTINE THE FOLLOWING CONVENTIONS ARE USED IN
C PREFIXING VARIABLE NAMES:
C THE LETTER C IS USED FOR CROSS-SECTIONS
C THE LETTER D IS USED FOR EFFICIENCY FACTORS
C THE LETTER K IS USED FOR EXTINCTION COEFF. PER UNIT PATH (KM)
C THE LETTER T IS A SUFFIX FOR TOTAL VALUES
C THE LETTER O IS A PREFIX FOR OMEGA SUB 1 AND 2 CALCULATIONS
C FOR THE IDSTP=6 AND 12 CASES, DECS IS USED TO SUFFIX THE
C LIQUID WATER CONTENT FROM THE MAIN PROGRAM TO THIS SUBROUTINE:
C ELWC IS USED AS THE AEROSOL CONCENTRATION FOR THOSE CASES
C IF (IDSTP=EQ.6 OR IDSTP=EQ.12) ELWC=DECS
C
C OR=0.00
C OM=0.00
C CTSM=0.00
C CSSUM=0.00
C DECS=0.00
C CRST=0.00
C EMH=1.00
C NBLN=0
C RH=1.00E-3
C FACTORS BH AND CH ARE USED IN SIZE ADJUSTMENTS
C FH IS THE SATURATION RATIO
C FH=RELHUM/100.00
C CH=FHC/(1.00+FHC)
C CONCT=CH+FHC
C KECK=O0.00
C CONVERT VOL PER PARTICLE RECEIVED FROM MAIN PROGRAM VIA VARIABLE
C TVOL TO DRY VOLUME PER PARTICLE IN CUBIC CENTIMETERS
C TVOL=TVOL*1.00E-12
C DO 6 J=1,IT
C PSUM(J)=DECS
C PHTH(J)=DECS
C PHTG(J)=DECS
C PSUM(I)=DECS
C CONVERT TEMP* TO KELVIN FOR SUBROUTINE WATER USAGE
C TEMP=TEMP*273.16E0
C SKIP SUBROUTINE WATER FOR THE IDSTP # 12 CASE AND READ THE
C OPTICAL DATA FOR EMW AS EMWA,CAT OR ETC...NEEDED BECAUSE CASE
C IDSTP=12 MAY BE AT WAVELENGTHS LONGER THAN FOUND IN ROUTINE
C WATER.
C IF (IDSTP=EQ.12) GO TO 8
C CALL WATER(WAVE,EMW,CATW,EMH,TEMP,RHWO)
C SUBROUTINE WATER RETURNS INTERPOLATED VALUES FOR EMW, CATW AND
C RHOM AT WAVELENGTH = WAVE AND AT TEMPERATURE = TEMK (DEG K)*
C EMW IS REAL PART OF INDEX OF REFRACTION OF PURE WATER AT TEMPERATURE (DEG C)*
C CAYW IS IMAGINARY PART OF INDEX OF REFRACTION FOR PURE WATER:
C CAYW, HERE IS POSITIVE, BUT TREATED AS NEGATIVE IN MIE ROUTINE*
C RHOMW IS MASS DENSITY (G/M3) AT TEMPERATURE = TEMP (DEG C)*
C WRITE (6,9) EMW,CAYW,TEMP,RHOM
C BEGIN LOOP OVER AEROSOL COMPONENTS INDEXED BY NK
C DO 32 NK=1,NINDEX
C Bypass READ OF EMA,CAYA,EVA,CAYW FOR IDSTP=6 CASE USE WATER DATA
C IF (IDSTP=NEQ6) GO TO 10
C EMW = EMW
C CAYA = CAYA
C RHOMW = RHOM
C CONC = ELWC
C EMUA = D*0 = EMUO
C GO TO 11
C *** READ OPTICAL AND PHYSICAL DATA ***
C 10 READ (5,2) EMA,CAYA,EMUA,ROHA,CONC
C IF (IK1=EQ0) EMW = EMW
C IF (IK1=NEQ0) CAYA = CAYA
C IF (IDSTP=NEQ12) GO TO 11
C EMUA = D*0 = EMUO
C RHOMW = RHOM
C EMW = EMW
C CAYW = CAYA
C IF (RHOMW*LE*0 = EMUO*EQ1*EQ0)
C IF (EMA+LT:1*LE:30) GO TO 44
C WRITE (6,31) NK,EMA,CAYA,ROHA,EMUA,CONC
C BHT = RHOM/(2*RHOM+TEMP)
C IF (EMUA*LE*0 = 01) CH = 0
C RC = BHT*CH
C A**1 = EMUA/(RHOA/RHOM*EMUA+CH)
C A**3 = (1/EQ0*3*EQ0)
C ADJUST EM, RHO AND CAYA PER G. HANEL/ADVANCES IN GEOPHYS/1976
C RHO = RHOA/(RHOA-RHOMW/A)
C EM = EMW/(EMW/A)
C CAY = CAYA/(1CAYA-CAYW/A)
C CAY = CAY/EM
C INITIALIZE QUANTITIES USED TO HOLD RUNNING SUMMATIONS OVER
C RAD1 FOR THE CURRENT COMPONENT
C FSUM = D = EQ0
C CTSM = D = EQ0
C CSSM = D = EQ0
C CHSM = D = EQ0
C VOL = D = EQ0
C OLISUM = D = EQ0
C OLZSUM = D = EQ0
C D = I3 = I1/I1
C PRINT HEADER IF DETAILED MIE RESULTS ARE TO BE PRINTED
C IF (MORE = EQ12345) WRITE (6,5)
C BEGIN ACTUAL LOOP OVER RADIUS INTERVALS FOR THE CURRENT NK VALUE
C THIS LOOP IS THE ONE IN WHICH THE MIE CALCULATIONS ARE CALLED
C INTERVALS ARE INDEXED BY I. THERE ARE NI SUCH INTERVALS:
C DO 26 I=1,NI
C NRAD = 2
C MERROR = 0
C PTXX0460
C PTXX0470
C PTXX0480
C PTXX0490
C PTXX0700
C PTXX0710
C PTXX0720
C PTXX0730
C PTXX0740
C PTXX0750
C PTXX0760
C PTXX0770
C PTXX0780
C PTXX0790
C PTXX0800
C PTXX0810
C PTXX0820
C PTXX0830
C PTXX0840
C PTXX0850
C PTXX0860
C PTXX0870
C PTXX0880
C PTXX0890
C PTXX0900
C PTXX0910
C PTXX0920
C PTXX0930
C PTXX0940
C PTXX0950
C PTXX0960
C PTXX0970
C PTXX0980
C PTXX0990
C PTXX1000
C PTXX1010
C PTXX1020
C PTXX1030
C PTXX1040
C PTXX1050
C PTXX1060
C PTXX1070
C PTXX1080
C PTXX1090
C PTXX1100
C PTXX1110
C PTXX1120
C PTXX1130
C PTXX1140
C PTXX1150
C PTXX1160
C PTXX1170
C PTXX1180
C PTXX1190
C PTXX1200
C PTXX1210
C PTXX1220
D R1(1) = R1(1)
C R1T IS THE ADJUSTED RADIUS FOR THE RELATIVE HUMIDITY TO BE USED
C IN THIS PARTICULAR RUN OR PASS
R1T = R1(1) * AC = (BC/AC)
IF (R1T = R1(1) = 0 R1(1) = R1(1) LT = 0.0960) R1T = R1(1)
C ALPHA = 2*EQ = R1T/AC = WAVE
C ROUTINE MIEGK DOES THE ACTUAL MIE CALCULATIONS.
C NOTE THAT THE IMAG. PART OF THE REFRACTIVE INDEX (CAY) HAS BEEN
C NORMALIZED THROUGH DIVISION BY THE REAL PART (EM) BEFORE ITS
C VALUE IS PASSED TO THE MIE-Routine.
C MIEGK RETURNS THE EXTINCTION EFFICIENCY FACTOR AS QT
C MIEGK RETURN THE SCATTERING EFFICIENCY FACTOR AS QS
C MIEGK RETURNS THE RACK-SCATTERING (RADAR) EFFICIENCY FACTOR AS QR
C MIEGK RETURNS THE AVERAGE INTENSITY (11+12)/2 IN THE ARRAY P(I)
C AT ANGLES = ARCCOS(C(I)) WHERE C(I) IS SET-UP BY.
C SUBROUTINE ANGLE OR SUBROUTINE GUSET
C MIEGK ALSO RETURNS THE 2-ND AND 3-RO LEGENDRE EXPANSION COEF.
C (OMEGA SUB I AND OMEGA SUB 2) AS O1STAR AND O2STAR.
C ERROR IS RETURNED AS UNITY IF MIE-SERIES DID NOT CONVERGE
C AFTER 99 TERMS WERE COMPUTED.
C EM = DBLE (EM)
C CAY = DBLE (CAY)
C ALPHA = DBLE (ALPHA)
C CALL MIEGK(EM, CAY, ALPHA, GTD, QS, QR, P, O1STAR, O2STAR, IERROR, +
C IAPX)
C EM = SGNL(EM)
C CAY = SGNL(CAY)
C ALPHA = SGNL(ALPHA)
C QT = SGNL(QT)
C QS = SGNL(QS)
C QR = SGNL(QR)
C O1STAR = SGNL(O1STAR)
C O2STAR = SGNL(O2STAR)
C IF (ERROR = QM = 1) * ERROR = MERROR = IERROR = 1
C MERROR IS USED TO COUNT THE NUMBER OF TIMES IERROR HAS
C BEEN RETURNED WITH THE VALUE OF 1. EXECUTION WILL BE
C TERMINATED WHEN MERROR REACHES A VALUE OF 5.
C IF (QHTE = EQ = 12390) WRITE (6, 9) R1T, R1(1), P(I), ALPHA, 4T, Q5, QR
C CONTINUE
C KX = 1*(1) = NNG
C FKK = FK
C FKK = FKK + R1T**2*EQ
C VOLLHN = 1.86*FKK*K**3 + 3*EU
C O1HNN = O1STAR*FKK*QT
C O2HNN = O2STAR*FKK*QT
C CTHH = QT*FIIA
C CSIIH = QIIA*FK
C CHIIH = QIIA*FK
C DU = J = I = IT
C PHIIH(J) = SGNL(PH(J)) = FKK
C CONTINUE
C RIT = R1(1) + 0.0960
C IF (RIT = R1(1) = 0 R1(1) = R1(1) LT = 0.0960) RIT = R1(1)
+ (APIX)
EM=SNGL(EMD)
CAV=SNGL(CAYD)
ALPHA=SNGL(ALPHAD)
QT=SNGL(QTD)
QS=SNGL(QSD)
QM=SNGL(QRD)
O1STAR=SNGL(O1STRD)
O2STAR=SNGL(O2STRD)
IF (TERROR.EQ.1) TERROR=MERROR+1
K1=1*NKG1
FKK1=FKK1
IF (QMNT.EQ.12345) WRITE (6,4) RIT,RR1,1,FKK1,ALPHA,QT,QS,QR
FKK1=FKK1+PI*RIT+2.E0
VOLH=VOLH+.18RF*FKK1*RIT*3.E0*D*0.5E0
OLH=OLH+.18RF*FKK1+QT*0.1AR1*D*0.5E0
OL2H=OL2H+.18RF*FKK1+QT*0.2STAR1*D*0.5E0
CTHH=CTHH+QT*FKK1*1*D*0.5E0
CSHH=CSHH+QS*FKK1*1*D*0.5E0
CMHH=CMHH+QR*FKK1*1*D*0.5E0
DO 15 J=1,IT
PHH(J)=(PHH(J)+SNGL(P1J))*FKK1*1*D*0.5E0
15 CONTINUE
FF=Q*SEU*3*(FKK+FKK1)
NT=1
C** DEL1=Q*EO
N=1
16 NJ=NNT
NT=2*NT
D=Q*EO*D
VOLG=Q*QEO
OLG=Q*QEO
OL2G=Q*QEO
CTGG=Q*QEO
CSGG=Q*QEO
CRRG=Q*QEO
FT=Q*EO
DO 17 J=1,IT
P66(J)=Q*EO
17 P66(J)=Q*EO
C NEXT LOOP HANDLES INTERMEDIATE PARTICLE SIZES*THOSE LYING BETWEEN
C RMIN AND RMAX FOR THE CURRENT INTERVAL WHOSE INDEX IS I
C DO 19 JG=1,NJ
KK=(1*(I-1)*NKG+(2*JG-1)*NKG/NT)
RIT=RR1*(KK)*AC -(BC/AC)
IF (RIT.LT.RKK1).OR.RKK1.LT.Q*8QEO) RIT=RKK1
ALPHA=2*EO*PI*RIT/WAVE
EMD=DOUBLE (EMD)
CAYD=DOUBLE (CAYD)
ALPHAD=DOUBLE (ALPHAD)
CALL MIEGXI(EMD,CAV,ALPHAD,QT,QS,QR,P,O1STRD,O2STRD,TERROR, + (APIX)
EM=SNGL(EMD)
CAV=SNGL(CAYD)
ALPHAD=SNGL(ALPHAD)
QT=SNGL(QTD)
QS=SNGL(QSD)
QM=SNGL(QRD)
PT2X2190
PT2X2200
PT2X2210
PT2X2220
PT2X2230
PT2X2240
PT2X2250
PT2X2260
PT2X2270
PT2X2280
PT2X2290
PT2X2300
PT2X2310
PT2X2320
PT2X2330
PT2X2340
PT2X2350
PT2X2360
01STAR=SNGL
02STAR=SGNL
02STRD
IF (ERROR=EQ=1) MERROR=ERROR
IF (MERROR=GT=101) GO TO 39
IF (MQLTE=EQ=1235) WRITE (6,9) RIT,R(1:K),F(K),ALPHA,AQT,QT,GR
NRAD=NRAD+1
FFK=FFK+1
FKKA*FFK*K*K*K*K*K*K*K*K
OL1GG=OL1GG*0.81GG
OL2GG=OL2GG*0.81GG
CE=CE+1
DO 18 J=1,11
PGG(I,J)=PGG(I,J)+SNGL(P,I,J)*FKK
CONTINUE
19 FT=FT+FFK
C ADD RESULTS ACCUMULATED DURING PREVIOUS HALVINGS TO THOSE FOUND
C FOR THE NEW RADII TREATED WITHIN THE LOOP OVER INDEX JG
VOLHHT=0.5*E0*VOLHH*0.5*VOLGG
OL1HHT=0.5*E0*OL1HH*0.5*OL1GG
OL2HHT=0.5*E0*OL2HH*0.5*OL2GG
CFTHT=0.5*E0*CFHT*0.5*CTGG
CSHHT=0.5*E0*CSHHT*0.5*CSGG
CMHHT=0.5*E0*CMHHT*0.5*CRGG
DO 20 J=1,11
20 FT=FT+FFK
C DELETE THE C** FROM COLS 1-3 BELOW AND ABOVE, AND DELETE THE
C FOLLOWING IF STATED IN IMPLEMENT A DOUBLE CHECK FOR
C CONVERGENCE.
C** IF(DL=DELTA1) GO TO 22
C** IF(DL=DEL1) GO TO 24
C** DEL=DEL
C IF (DEL=DEL) GO TO 21
DO 21 J=1,11
21 IF (N=6) GO TO 24
C DO NOT ALLOW DEL LESS THAN DELTA EXIT UNLESS AT LEAST TWO
C HALVINGS HAVE BEEN DONE
C IF (N=EQ=HALV) GO TO 24
C MUST EXIT WHEN HALV HALVINGS HAVE BEEN DONE EVEN IF THE DELTA
C CRITERION HAS NOT BEEN SATISFIED, SINCE NO MORE VALUES OF RADII
C ARE AVAILABLE
FF=FET
CKH=CKHT
OL1HH=OL1HHT
OL2HH=OL2HHT
CSH=CSHHT
CMH=CMHHT
VOLH=VOLHT
DO 23 J=1,11
23 P(1,J)=P(J,1)
H(N)=H(N-1)
GTO 16
24 FSUMG=FSUMG+FFT
   IF(NH=0) THEN WRITE(6,124) I
   C SUM QUANTITIES OVER ALL INTERVALS TREATED UP UNTIL NOW
   C THIS IS POINT T, PNUM(I) IS THE RUNNING SUM OF THE AVG. INTENSITY
   C AS SUMMED OVER SIZES
   DO 25 J=1,IT
   25 PSUM(J)=PSUM(J)+PNUM(J)
   WRITE (6,27) NK,NH,RAD1,CHHT
   NPLINES=NPLINES+NRAUI
   END LOOP OVER HALVING INTERVALS INDEXED BY I
   26 CONTINUE
   C RENORMALIZE VALUES OF CTSUM, ETC.
   CTSUM=CTSUM/FSUMG
   CSSUM=CSSUM/FSUMG
   C RENORMALIZE VALUES OF CTSUM, ETC.
   VOL=VOL/FSUMG
   OL1SUM=OL1SUM/FSUMG
   OL2SUM=OL2SUM/FSUMG
   DO 28 J=1,IT
   28 PSUM(J)=PSUM(J)/FSUMG
   C CALCULATE PARTICLE NUMBER DENSITY NO. PER CC AS DENS
   DENS=CONC/(RHOA*DRYVOL)
   C OVERRIDE CALCULATED VALUE OF DENS WITH DENS IF LLLL=1
   IF (LLLL.EQ.1) DENS=DENS
   C RECALCULATE CONC FROM OTHER INPUT DATA IF LLLL=1
   IF (LLLL.EQ.1) CONC=DENS*RHOA*DRYVOL
   C REPLACE DENS BY DENS FOR LATER USE BY AGXPT3
   DENS=DENS
   C WEIGH CTSUM, ETC. BY NUMBER DENSITIES (DENS) FOR THIS COMPONENT
   CTSUM=CTSUM*DENS
   CSSUM=CSSUM*DENS
   CTSUM=CTSUM*DENS
   CRSUM=CRSUM*DENS
   VOL=VOL*DENS
   OL1SUM=OL1SUM*DENS
   OL2SUM=OL2SUM*DENS
   DO 29 J=1,IT
   29 PSUM(J)=PSUM(J)*DENS
   C NOW, SUM OVER COMPONENTS INDEXED BY NK
   C CONC IS THE TOTAL DRY-AMOSOL CONCENTRATION IN MG PER CC
   CONC=CONC+1.E3*CONC
   DENS=DENS*DENS
   OL1STAR=OL1SUM+OL1STAR
   OL2=OL2SUM+OL2
   CTSUM=CTSUM+CTSUM
   C AT THIS POINT, CTSUMT IS THE TOTAL EXTINCTION CROSS SECTION
   C (IN SQ. MICRONS) AS SUMMED OVER ALL COMPONENTS WHICH
   C HAVE BEEN DEALT WITH THUS FAR
   CTSUMT=CTSUM+CSSUM
   CRSUMT=CRSUM+CRSUM
   DO 30 J=1,IT
   30 PSUMT(J)=PSUMT(J)+PSUMT(J)
VOL=VOL*1.E-12
C VOL IS THE TOTAL VOLUME (IN CM**3) OCCUPIED BY THE AEROSOL
C PARTICLES. TVOL IS NOT ACTUALLY USED IN THIS VERSION OF
C PROGRAM AGAIN.
TVOL=TVOL+TVOL
EMASS=VOL*EMASS
THMSS=THMSS*EMASS
KEXOLD=KEXIT
KEXIT=CTSUM*1.E-3
KEXIT=KEXIT-KEXOLD
WHITE=(6,3) 1VOL,EMASS,KEXIT
C VPF(VOL) IS THE VOLUME PACKING FRACTION; THAT IS, THE FRACTION
C OF EACH CC OF SPACE WHICH IS FILLED BY AEROSOL MATERIAL BELONGING
C TO THE CURRENT COMPONENT NK.
C TMSS IS THE TOTAL MASS OF AEROSOL FOUND IN 1 CC OF SPACE.
C EMASS IS THE MASS OF AEROSOL MATERIAL PER CC ASSOCIATED WITH
C THE CURRENT COMPONENT NK.
C KEIT IS THE EXTINCTION COEFFICIENT PER KM WHICH IS ASSOCIATED WITH
C THE CURRENT COMPONENT AS IF IT ALONE WERE PRESENT.
C KEXIT IS THE SUM OF THE KEXIT'S OVER ALL COMPONENTS.
C END LOOP OVER AEROSOL COMPONENTS INDEXED BY NK.
IF (MINDX>GT-1) WRITE (6,42) NK
IF (NGKTE>EQ-12345) WRITE (6,43)
32 CONTINUE
IF(INDEXX*GT-1) WRITE (6,33) TMASS,KEXIT
WHITE=(6,34) NNLINES
DENST=DENST
THMSS=THMSS
C NOW, PERFORM THE FINAL REGULARIZATION TO OBTAIN CTSM, ETC.
C VALUES REPRESENTATIVE OF A SINGLE AVERAGE PARTICLE.
C CTSUM Becomes THE EXTINCTION CROSSSECTION IN SQ. MICROMETERS PER
C AVERAGE PARTICLE. THE OTHER QUANTITIES CARRY SIMILAR MEANINGS.
DO 35 J=1,11
35 PSUM(XJ)=PSUM(XJ)/DENST
OLSTAR=OLSTAR/CTSUM
OMZ=OMZ/CTSUM
IF (AJPX*GT-0) WRITE (6,36) OLSTAR,OMZ
C THE FOLLOWING 2 STMTS ARE FOR THE GGH ANALYTIC PHASE FUNCTION.
IF (AJPX*GT-0) OL1(0)=OLSTAR
IF (AJPX*GT-0) OL1(0)=OMZ
CTSUM=CTSUM/DENST
CSUM=CSUM/DENST
C THE FOLLOWING STMT IS FOR THE GGH ANALYTIC PHASE FUNCTION.
IF (AJPX*GT-0) OL1(0)=CSUM/CTSUM
C CALCULATE ATTENUATION COEFFS. IN SQ. METERS PER MILLIGRAM
CATTN=CTSUM*1.E-12/CNCT
CATTNW=1.E-12*KEXIT/EMASS
WHITE=(6,37) CATTN
IF (RELHUM*GT-1) WRITE (6,38) CATTNW
GO TO 41
39 WRITE (6,40)
STOP
44 WRITE (6,45) EMA
STOP
41 RETURN
2 FORMAT (9F10.8,E15.7)
3 FORMAT (IHQ,6H INDEX=13,4H M=F10.6,6H K=F10.6,9H I= MASS PT2X4980  
+ 10HDENSITY = F8.6,  
+ 17H GROWTH FACTOR = F8.9H CONC = FPE12.5,7H GM/CC/)  PT2X4900  
+ 4 FORMAT (IX,F10.5-6/2X,FPE12.5)  PT2X4910  
+ 5 FORMAT (/*/5H RMICRONS) DRY RADIUS N(R) MIE SIZE  PT2X4920  
+ 3NHQ (EXT) (WCA) Q(RADAR)/1  PT2X4930  
+ 9 FORMAT (1H0,3H INDEX OF REFRACTION FOR PURE WATER IS F8.6,  
+ 3H =F8.6,1IH/1X,25H MASS DENSITY OF WATER AT F6.2,  
+ 1IH DEG C IS F8.2H GM/CC)  PT2X4940  
+ 24 FORMAT(52H CONVERGENCE LEVEL NOT REACHED FOR INTERVAL NO.  
+ 13,4H */1)  PT2X4950  
+ 27 FORMAT(1H :19H FOR COMPONENT NO. 13,15H INTERVAL NO. 13,1H  
+ 14H 4H RADIi WERE USED, CONTRIBUTION TO CTSUM = FPE12.6)  PT2X4960  
+ 31 FORMAT (1H0,19H FOR COMPONENT NO. 12,12H VPF = FPE12.5,  
+ 2H MASS CONCENTRATION = F12.5,21H GM/CC) KEXT =  PT2X4970  
+ 32 FORMAT (1H0,28H TOTAL MASS CONCENTRATION = FPE12.5,7H GM/CC,  
+ 15H TOTAL KEXT = F12.5,7H PER KM)  PT2X4980  
+ 34 FORMAT (/1X,32H TOTAL NUMBER OF RADIi USED WAS 15)  PT2X4990  
+ 36 FORMAT (/16H OMEGA SUB-1 = FPE20.13,16H OMEGA SUB-2 =  PT2X5000  
+ 1PE20-13/)  PT2X5010  
+ 37 FORMAT (1H0,21H ATTENUATION COEF. = FPE12.5,12H SU-METERS/,  
+ 33HILLIGRAM OF DRY AEROSOL MATERIAL)  PT2X5020  
+ 38 FORMAT (1H0,21H ATTENUATION COEF. = FPE12.5,12H SU-METERS/,  
+ 33HILLIGRAM OF WET AEROSOL MATERIAL)  PT2X5030  
+ 40 FORMAT (/*/4H EXECUTION TERMINATING DUE TO MORE THAN TEN,  
+ 30H ERRORS IN MIE-SUBROUTINE //90)  PT2X5040  
+ 42 FORMAT (1H0,1X,11H 33H END OF AEROSOL COMPONENT CYCLE  
+ 7HNUMBER =13,2X,3U11M//)  PT2X5050  
+ 43 FORMAT (1H0)  PT2X5060  
+ 45 FORMAT (/*/1X,11H IS EITHER ZERO OR,  
+ 35HNEGATIVE = PROGRAM TERMINATED //9)  PT2X5070  
+ END  PT2X5080
SUBROUTINE AGXPT3(CTSUM,CSSUM,CRSUM,GNU,DENS,MIDX,NUNIT,ITANG, 
+   ITOT,IAPX)
DIMENSION F(1131),H(1131),C(1100),PSUM(100),RR(10),P(8)
DIMENSION PL(1100),DL(1100),MS(1100),PC(1100),H(1100),SCAT(100)
COMMON /AZ,PL,DLS,MS,PC,H,CSUM/ALBD0,LLLLL,CH,CH,CH,CH
COMMON /B3,FR,PSUM,SCAT,RDR,OMP+EM+AE+AT+EM+PT+ICP+1
I MORTC,NGK,HALV,N1
ALBD0=CSSUM/CTSUM
CALL=CAT
C PFACT IS USED TO CONVERT AVG+ INTENSITY PSUM(I) INTO PHASE-
C FUNCTION. SFAC IS USED TO CONVERT PSUM INTO SCATTERING
C FUNCTION. NORMALIZED PER THE SMOKE OBSCURATION MODEL (ACT).
C THE INTEGRAL OF SCATT OVER SOLID ANGLE SHOULD YIELD THE
C TOTAL SCATTERING CROSS SECTION IN SQ. METERS.
C PFACT*WAVE*WAVE/(P1*CTSUM*EMM*EMM)
C SFAC=WAVE/DENS*1.0/E/19*EM*EM*P1*P1
DO 15 J=1,11
  SCATT(J)=PFACT*PSUM(J)
  PSUM(J)=PSUM(J)/PFACT
IF ((ICRDS.EQ.2).OR.(ICRDS.EQ.3)) AND ((ITOT.EQ.1).OR.(ITOT.EQ.3)) WRITE (6,220)
  *(1+AND(IAPX.EQ.0), WRITE (NUNIT,3), SCATT(J),PSUM(J),C(J),J)
15 CONTINUE
IF (MIDX.GE.2) WRITE (6,12)
IF (IAPX.EQ.0) WRITE (6,10)
DO 4 J=1,11
  WRITE (6,14) GNU,DENS
  WRITE (6,15) CTSUM,CSSUM,CRSUM
  WRITE (6,16) GNU,DENS
  IF (I11+LT.2) GO TO 21
  IF (ICRDS.EQ.3) GO TO 18
  WRITE (6,17) CTSUM,CSSUM,CRSUM
C WRITE PHASE FUNCTION AT EQUAL ANGULAR INCREMENTS
  WRITE (6,18) GNU,DENS
  DO 16 J=1,11
    K=J+3
    IF (K.GT.11) N
16 WRITE (6,19) (H(N),PSUM(N),N=J,K)
C WRITE SCATTERING RATIOS AT EQUAL ANGULAR INCREMENTS
  WRITE (6,20)
  DO 17 J=1,11
    K=J+3
    IF (K.GT.11) N
17 WRITE (6,21) (H(N),SCATT(N),N=J,K)
  GO TO 21
C WRITE PHASE FUNCTION AT GAUSS-LEGENDRE QUADRATURE ANGLES
  DO 18 J=1,11
    K=J+3
    IF (K.GT.11) N
18 WRITE (6,22) (C(N),PSUM(N),N=J,K)
  WRITE (6,23)
PTX0100
PTX0110
PTX0120
PTX0130
PTX0140
PTX0150
PTX0160
PTX0170
PTX0180
PTX0190
PTX0200
PTX0210
PTX0220
PTX0230
PTX0240
PTX0250
PTX0260
PTX0270
PTX0280
PTX0290
PTX0300
PTX0310
PTX0320
PTX0330
PTX0340
PTX0350
PTX0360
PTX0370
PTX0380
PTX0390
PTX0400
PTX0410
PTX0420
PTX0430
PTX0440
PTX0450
PTX0460
PTX0470
PTX0480
PTX0490
PTX0500
PTX0510
PTX0520
PTX0530
PTX0540
PTX0550
PTX0560
PTX0570
PTX0580
PTX0590
PTX0600
PTX0610
PTX0620
PTX0630
PTX0640
PTX0650
CALL GAUSPSUM,NUNIT,ITOT
C ROUTINE GAUS GENERATES AND PRINTS/PUNCHES THE LEGENDRE
C EXPANSION COEFS (OMEGA) FOR THE PHASE FUNCTION.
C CHECK TO SEE IF 5% SCAT = ALBEDO (ALBEDO) COMPUTED DIRECTLY
C FROM CROSS-SECTIONS AGREES WITH THAT FOUND FROM THE LEGENDRE
C EXPANSION OF PHASE FUNCTION.
IF ((ABS50L1) ALBEDO/ALBEDO GT 1E-4) WRITE (6,20)

N FORMAT (//1H,5D14PHASE FUNCTION,1X,38X,4H(INTEGRAL NORMALIZED))
D TO PI OMEGA ZERO)///
2 FORMAT (1H,,37X,4HS/C/RECTION,1X,38X,4HSCATTERING (ACT NORMALIZATION)///)
3 FORMAT (3E12.6,1X,15)
4 FORMAT (1H0,4H D DISTRIBUTION WAVELENGTH REFRACTIVE,9X,
* 20HEXTINCION X SECTION,4X,20HSCATTERING X SECTION,12X,5HALBEDO/1H)
+ ,6X,4H TYPE,6X,9H MICRONS,1X,5H INDEX,16X,12H MICRONS,1X,
+ 12H (SQ MICROHNS)/1H,19X,F1E-4,F10-42H11,F7-9,2H11,
+ 1P3E25,141)
5 FORMAT (1H0,3X,9S/H MU,9X,1H PHASE FUNCTION )/
6 FORMAT (1H0,18X,4120H ANGLE PF-VALUE )/
7 FORMAT (1H0,18X,4120H ANGLE SCAT )/
8 FORMAT (1H0,4113-0,9X,17-11)
9 FORMAT (1H0,18X,411X,62,5X,12,71)
1: FORMAT (1H1)
11 FORMAT (1H0,,41X,25X,1H,29X,16X-TH COEFFICIENT,23X,5H RMS 
+ 9H DEVIATION )/
12 FORMAT (52H THIS IS A MIXED CASE SUBSEQUENT REFRACTIVE INDEX 
+ 39HPRTA ITEMS ARE NOT GENERALLY VALID///)
13 FORMAT (1H0,10H KEXT) = 1PE13.7,11H K(SCA) = ,E13.7,
+ 11H X (RAD) = ,E13.7,11H ALL PER KM//)
14 FORMAT (1H4,4H WAVELENGTH = 1PE12,5X CM=15X10DENSITY = ,E12-6,
+ 17H PARTICLES/CC//)
15 FORMAT (1S) WARNING ORDER OF QUADRATURE IS TOO SMALL ,
+ 39HFOR 6000 PHASE FUNCTION REPRESENTATION//12H VALUES
+ 55HOF ALBEDO AND OL(1) DISAGREE BY MORE THAN +1 PERCENT **PT30990
+ 39HLARGEST VALUE OF *IT* IS NEEDED ***/

END
SUBROUTINE MEGXEM,CAY,ALPHA,SGT,SGS,SGR,P,OISTAR,O2STAR,IERROR, MEGX0100
  I (APX)
  C TO CALCULATE BESSEL FUNCTIONS OF THE SECOND KIND ALSO
  C REMOVE THE C*5 FROM STATEMENTS CIRCA 124, 179 AND
  C CHANGE THE 'DO' PARAMETERS FOR STMT TO: DO 190 K=1,2,
  IMPLICIT DOUBLE PRECISION(A-H,O-Z)
  REAL PL0,L8,RS,P,C,C,HALD0,P,SNGL
  DIMENSION C(100),EYE1(100),EYE2(100),EYE3(100),EYE4(100),P(100)
  DIMENSION PL(100),L8(100),RS(100),PT(100),H(100)
  COMPLEX XA(1000),ACFN,CNUMZDENV,PDZ,ER0ZPZ,XANZAPY,RF,RRF,
  C RRFW,WM1,FN1,FBN,F1C,FNAP,FNB,FNAPP,FNBPP,FB1Z,TC2,WFN(2)
  DIMENSION T(5),TA(4),TB(2),TC(2),TD(2),TE(2),TF(2),TG(2)
  DIMENSION ELTRMX(19,100,2),PI(9,100),TAU(9,100)
  COMMON FB22PL,PL0PL,RS,PT,HC=HALD0,LLL,SNGLNRS1,T,T,NRAD
  EQUIVALENCE (WFN(1),TA(1)),(FN1,TD(1)),(FBN,TC(1)),(FNAP,TD(1))
  EQUIVALENCE (FN1,TE(1)),(FNAPP,TF(1)),(FNAPP,TF(1))
  EQUIVALENCE (ELTRMX(1),PL(1)),(PI(1),PL(1)),(PI(1),PL(1))
  EQUIVALENCE (A11,PL(132G1))
  X=ALPHA
  IERROR=0
  P1=3.19592653588898D+00
  CAY=CAY*EM
  NMX=0
  S=1.0D0
  RF=DCMPLX(EM-CAY)
  NMX=IFIX(X*(EM-CAY)+9)
  RF=1.0D0/RF
  RX=1.0D0/RF
  RXF=RFX+RX
  DO 1 J=1,IT
  PI(1,J)=U+D0
  PI(2,J)=U+D0
  TAU(1,J)=Q+D0
  TAU(2,J)=C(J)
  CONTINUE
  T1=DCOS(X)
  T2=DSIN(X)
  WM=DCMPLX(T1,-T2)
  WFN=DCMPLT(T1,T2)
  WFN2=RX*WFN-1-WM
  T1=CAY*E
  N=1
  NOIM=100
  IF (NMX+GT+NOIM) NOELTA=NMX
  IF (NMX+GT+NOIM) NOELTA=NOIM
  NMX=0
  IF (N+EA+1) GO TO 4
  2 EN=DFLOAT(N)
  T1=2.0D0*EN-1.0D0
  T2=EN-1.0D0
  T3=2.0D0*EN+1.0D0
  DO 3 J=1,IT
  PI(J)=PI(J,1)
  PI(2,J)=PI(2,J)
  CJ=C(J)
  THE FOLLOWING STMT IS FOR THE GHG ANALYTIC PHASE FUNCTION.
  MEGX0650
IF (1AP*GT*6) CJ*1.00
SMT*1.00+CD*CJ*CJ
P1(I*J+1+100)+P2(I+1)*CJ+EN*P1(I+1)/T(1)
TAU(I,1)=P1(I,J)*P1(I,J)*P1(I+1)*P1(I+1)+SMT*P2(I+1)*TAU(I+1)
3 CONTINUE
WMT=WFM(N,1)
WFM(N+1)=WFM(N)
WFM(N+2)=WFM(N+1)-WMT
4 CONTINUE
C CALCULATE RATIO OF BESSEL FNS OF CONSECUTIVE ORDER
IF (N+L+100+N+)GO TO 7
NMX=NMAX+NDELTA
NMIN=NMAX+1-NDELTA
V=DFLOAT(NMX)+D=250
Y=RFX
ZANP=Z+D/Y
ZNUM=ZANP*Y
ZPDT=ZNUM
V=Y+1.0
ZDEN=ZANP*Y
ZNUM=ZDEN=Z+1.0/D
ZPDT=ZNUM/ZDEN
5 CONTINUE
ZPDT=ZPDT/ZPDT
IF (1ABS(1*ZPDT-1.0)+L+1.0)GO TO 7
IF (V+L+2+QDO+OD)GO TO 6
WRITE (6,1000) ALPHA, EM, CAY
ERROR=1
GO TO 20
6 V=V+1.0
ZANP=Z+1.0/D
ZNUM=ZANP*Y
ZDEN=ZANP*Y
GO TO 5
7 CONTINUE
J=NMAX
8 JJ=J-NMAX+NDELTA
A1=JJ=-1.0DFLOAT(J)/Y*ZPDT
J=J+1
IF (J+L+100)GO TO 9
ZPDT=(2.0+1.0DFLOAT(J)+1.0)/Y*1.0/D*ZPDT
GO TO 8
9 CONTINUE
J=NMAX+NDELTA
ACAPN=A1+J
C THIS FRT FOR M EQUAL 1 ONLY
TC1=ACAPN*RF+RZ
TC2=ACAPN*RF+RZ
FNA=(TC1*TA(I)+1.0)/TC1*WFM(N)+WFM(N+1)
FNB=(TC2*TA(I)+1.0)/TC2*WFM(N)+WFM(N+1)
FMAP=FNA
FMBP=FNB
T(I+1)=T(I)+500
TB(1)=T(I)+T(1)
TB(2)=T(I+1)+T(2)
TC(I)=T(I)+TC(I)
TC(2)=T(I+1)+TC(2)
MEGX0460
MEGX0470
MEGX0480
MEGX0490
MEGX0500
MEGX0510
MEGX0520
MEGX0530
MEGX0540
MEGX0550
MEGX0560
MEGX0570
MEGX0580
MEGX0590
MEGX0600
MEGX0610
MEGX0620
MEGX0630
MEGX0640
MEGX0650
MEGX0660
MEGX0670
MEGX0680
MEGX0690
MEGX0700
MEGX0710
MEGX0720
MEGX0730
MEGX0740
MEGX0750
MEGX0760
MEGX0770
MEGX0780
MEGX0790
MEGX0800
MEGX0810
MEGX0820
MEGX0830
MEGX0840
MEGX0850
MEGX0860
MEGX0870
MEGX0880
MEGX0890
MEGX0900
MEGX0910
MEGX0920
MEGX0930
MEGX0940
MEGX0950
MEGX0960
MEGX0970
MEGX0980
MEGX0990
MEGX1000
MEGX1010
MEGX1020
MEGX1030
MEGX1040
MEGX1050
MEGX1060
MEGX1070
MEGX1080
MEGX1090
MEGX1100
MEGX1110
MEGX1120
MEGX1130
MEGX1140
MEGX1150
MEGX1160
MEGX1170
MEGX1180
MEGX1190
MEGX1200
MEGX1210
MEGX1220
DO 10 J=1,1,T
TAUJ=TAU(2,J)
ELTRMX(1,J,1)=TB(1)+TC(1)+TAUJ
ELTRMX(2,J,1)=TB(2)+TAUJ
ELTRMX(3,J,1)=TB(1)+TAUJ
ELTRMX(4,J,1)=TB(2)+TAUJ
C* ELTRMX(1,J,2)=TB(1)-TC(1)+TAUJ
C* ELTRMX(2,J,2)=TB(2)-TC(1)+TAUJ
C* ELTRMX(3,J,2)=TB(1)-TC(2)+TAUJ
C* ELTRMX(4,J,2)=TB(2)-TC(2)+TAUJ
10 CONTINUE

QEXT=Q+DO*(TB(1)+TC(1))
QSCAT[1+IB(1)+IB(2)+TB(1)+TC(1)+TC(2)+TC(2)+TB(2)]/Q*7.5D0
CBRO5=Q.DO
SUMW=Q.DO
OZSTAR=DO
SUMRA=2.DO*(TB(1)+TC(1))
SUMRI=2.DO*(TB(2)+TC(2))
N=2
GO TO 2

11 CONTINUE
TC1=ACAPN*RF*EN*NX
TC2=ACAPN*RF*EN*NX
FNA=(TC1+TA(1))/TC1*WPN(2)-WPN(1)
FNB=(TC2+TA(1))/TC2*WPN(2)-WPN(1)
T(5)=EN
T(9)=T(11)/T(5)+T(2)
T(2)=T(9)+T(11)+T(5)+T(2)
T(2)=T(2)+T(11)/T(5)
CBRO5=CBRO5+T(2)*TD(1)+TD(1)*TE(2)+TD(2)*TE(1)+TE(1)*TE(2)

I=TC(1)+T(1)+TD+TE(1)+TE(2)
S=-S
SUMR=SUMRA+S*T(1)+TB(1)+TC(1)
SUMI=SUMRK+S*T(1)+TB(2)+TC(2)
C OZSTAR CALCULATION
SUMW=SUMW+TB(1)+TB(2)+TD(2)+TE(1)+TE(2)
I=1+N+L+T+3
GO TO 12

12 CONTINUE
QEXT=Q+DO*(TB(1)+TC(1))
T(4)=T(1)+T(2)+T(3)+T(4)
QSCAT=QSCAT+T(3)+T(4)
T(2)=EN*EN+DO
T(I)=T(3)+T(2)
K=IN/2+2
DO 13 J=1,1,T
P(I)=P(I)+T(3,J)
TAUJ=TAU(3,J)
13 CONTINUE
ELTMX(1,J,1)=ELTMX(1,J,1)+T(1)*TB(1)*P(3,J)* TC(1)*TAUJ)
ELTMX(2,J,1)=ELTMX(2,J,1)+T(1)*TB(2)*P(3,J)* TC(2)*TAUJ)
ELTMX(3,J,1)=ELTMX(3,J,1)+T(1)*TC(1)*P(3,J)* TB(1)*TAUJ)
ELTMX(4,J,1)=ELTMX(4,J,1)+T(1)*TC(2)*P(3,J)* TB(2)*TAUJ)
C* IF (K=J+K) GO TO 30
C* ELTMX(1,J,2)=ELTMX(1,J,2)+T(1)*TB(1)*P(3,J)* TC(1)*TAUJ)
C* ELTMX(2,J,2)=ELTMX(2,J,2)+T(1)*TB(2)*P(3,J)* TC(2)*TAUJ)
C* ELTMX(3,J,2)=ELTMX(3,J,2)+T(1)*TC(1)*P(3,J)* TB(1)*TAUJ)
C* ELTMX(4,J,2)=ELTMX(4,J,2)+T(1)*TC(2)*P(3,J)* TB(2)*TAUJ)
C* GO TO 14.
C* 3: ELTMX(1,J,2)=ELTMX(1,J,2)+T(1)*(-TB(1)*P(3,J)* TC(1)*TAUJ)
C* ELTMX(2,J,2)=ELTMX(2,J,2)+T(1)*(-TB(2)*P(3,J)* TC(2)*TAUJ)
C* ELTMX(3,J,2)=ELTMX(3,J,2)+T(1)*(-TC(1)*P(3,J)* TB(1)*TAUJ)
C* ELTMX(4,J,2)=ELTMX(4,J,2)+T(1)*(-TC(2)*P(3,J)* TB(2)*TAUJ)
13 CONTINUE
IF (N+LT+5) GO TO 14
IF (T(1)+LT+1) GO TO 18
14 N=n+1
DO 15 J=1,IT
PI1(J,J)=PI1(J,J)+T(1)*PI1(J,J)
PI2(J,J)=PI1(J,J)+PI2(J,J)
TAU(J,J)=TAU(J,J)+T(1)
15 CONTINUE
FNAP=FNAP
FNAP=FNAP
FNAP=FNAP
FNAP=FNAP
GO TO 2
16 CONTINUE
C WRITE (6,RDQ) N
DO 18 J=1,IT
DO 18 K=1,1
DO 18 L=1,L
T(J,J)=ELTMX(1,J,K)
17 CONTINUE
ELTMX(1,J,K)=T(J,J)*T(J,J)*T(J,J)*T(J,J)
ELTMX(2,J,K)=T(J,J)*T(J,J)*T(J,J)*T(J,J)
ELTMX(3,J,K)=T(J,J)*T(J,J)*T(J,J)*T(J,J)
ELTMX(4,J,K)=T(J,J)*T(J,J)*T(J,J)*T(J,J)
18 CONTINUE
ELTMX(2,J,K)=T(J,J)*T(J,J)*T(J,J)*T(J,J)
C ELTMX(2,J,K) IS THE VERTICAL COMPONENT SCATTERING 1 (EYE1)
C ELTMX(1,J,K) IS THE HORIZONTAL COMPONENT SCATTERING 12
DO 19 J=1,IT
EYI(J,J)=ELTMX(2,J,J)
EYI(J,J)=ELTMX(1,J,J)
EYI(J,J)=ELTMX(1,J,J)
EYI(J,J)=ELTMX(1,J,J)
19 CONTINUE
T(J,J)=T(J,J)*T(J,J)*T(J,J)*T(J,J)
SQT=SQT*SQT
SQT=SQT*SQT
SQT=SQT*SQT
SQT=SQT*SQT
C TBR0S=T0+CTBR0S+T(1)
C OISTAR=T0+OISTAR+T(1)
C OISTAR=T0+OISTAR+T(1)
C OISTAR=T0+OISTAR+T(1)
SQT=SQT+SQT+SQT+SQT
SQT=SQT+SQT+SQT+SQT
SQT=SQT+SQT+SQT+SQT
SQT=SQT+SQT+SQT+SQT
20 RETURN
C 1000 FORMAT (52H V GT 20000 ERROR IN CONTINUED FRACTIONS MIE ROUTINE, 11H*** ALPHA = +D12+6,6H EM = +D12+6,7H CAY = +D12+6/) END
SUBROUTINE GAUS(F,NUNIT,ITOT)

DIMENSION C(100),F(100)
DIMENSION PL(110,110),OL(110),RMS(110),PC(110),H(110)

COMMON /K2/PL,OL,RMS,PC,LH,ALBD0,LLL,LNCRD5,IT,ITT,MRAD
c

C THE FOLLOWING STEPS CALCULATE THE LEGENDRE POLYNOMIALS PL(,)
C WHICH WILL BE USED BY SUBROUTINE GAUS IN FINDING THE GAUSS-
C LEGENDRE EXPANSION COEFFICIENTS FOR THE PHASE FUNCTION

DO 9 J=1,IT
   R(1)=D.E+00
   R(1)=D.E+00
   R(1)=PL(2,1)
   R(1)+=C(1)
   R(1)+=C(1)
   R(1)+=(2,E+00*EL-1,E+00)*C(1)*PL(LN-1,1)-(EL-1,E+00)*PL(LN-
   R(1)+=2,1)/EL
9 CONTINUE

C INITIALIZE ARRAY PC() USED FOR RUNNING SUMMATION

DO 1 J=1,IT
   J=0,E+00
   J=0,E+00
1 CONTINUE

C LOOPS 2 AND 3 CALCULATE EXPANSION COEFS. FOR FUNCTION F( )
C VIA GAUSS-LEGENDRE QUADRATURE. THE COEFS. GO INTO ARRAY OL()

DO 3 L=1,IT
   L=LL-1
   L=LL-1
   L=FLOAT(L)
   L=FLOAT(L)
   L=0,E+00
   L=0,E+00
   L=0,E+00
   L=0,E+00
2 CONTINUE

C LOOP 4 AND 5 RECONSTRUCT THE FUNCTION F( ) AS PC() USING THE
C COEFS. OL() FOUND ABOVE. AND THE RMS-DEVIATION BETWEEN F() AND
C PC() AS EACH ADDITIONAL TERM IN THE LEGENDRE SERIES IS ADDED.

DO 5 J=1,IT
   J=0,E+00
   J=0,E+00
   J=0,E+00
   J=0,E+00
   J=0,E+00
   J=0,E+00
4 CONTINUE

C WRITE/PUNCH THE VALUES OF THE EXP. COEFS. OL() ON NUNIT.
C IF (((NCRDS=EQ.1) OR (NCRDS=EQ.3)) AND (((ITOT=EQ.1) OR (ITOT=EQ.3))
C 7 WRITE (14,8) I,OL(I),RMS(I)
C RETURN
C FORMAT (E25.14,1X,15)
C FORMAT (IH,20X,16,1PE38.15,E35.15)
END
SUBROUTINE GUSET(Z,P,PI)
C THIS ROUTINE CALCULATES THE ABCISSAE XKN(I)
C AND GAUSS-LEGENDRE WEIGHTS AKNI) FOR NUMERICAL INTEGRATION
C VIA GAUSS-LEGENDRE QUADRATURE OF ORDER N
DIMENSION Z(100),P(100),PI(100),XKN(100),AKN(100)
DIMENSION PL(100),OL(100),RMS(100),PC(100),H(100),C(100)
EQUIVALENCE (C(1:100),XKN(1:100),AKN(1:100))
COMMON /BK2/PL,OL,RMS,PC,H,ALBDO,LLL,NCRDS,IT,ITT,NRAD
N=1
TOL=1.0E-14
AA=2.0E+00/P1**2.0E+00
AB=-6.0E+00/13.0E+00***P1**4.0E+00
AC=151.16-0.0E+00/(15.0E+00***P1**6.0E+00)
AD=-125.5474+0.0E+00/(105.0E+00***P1**8.0E+00)
P1=1.0E+00/0.0E+00
EN=FLOAT(N)
NP1=H1
U1=1.0E+00-(2.0E+00/PI)**2.0E+00
D=1.0E+00/SQRT((1.0E+00)**2.0E+00+U1**2.0E+00)
DO 1 I=1,N
S=FLOAT(I)
A0=4.0E+00*S-1.0E+00
AE=A0/A0
AF=A0+A0**2.0E+00
AG=A0+A0**3.0E+00
AH=A0+A0**4.0E+00
1 Z(I)=PI1*A0+AE+AF+AG+AH/4.0E+00
DO 6 K=1,N
X=COS/Z(K,10)
2 PI2=X
DO 3 N=3,NN
ENN=FLOAT(NN-1)
3 PN=ENN+2.0E+00*ENN-1.0E+00*ENP(ENN-1)+ENN-1.0E+00*ENP(NN-2))/ENN
PNP=ENN*ENP(NN)-ENN*ENP(NN-1)/(1.0E+00-XX)
XX=X-PI2/PPN
KD=ARSINX
XDD=XD+TOL
IF (XDD) 5,5,4
X=X
4 GO TO 2
5 XKN(K)=X
6 AKN(K)=2.0E+00*(1.0E+00*X)/ENP(NN)*ENP(NN)
DO 7 I=1,N
Z(I)=D0
7 PI1=0.0D0
RETURN
END
SUBROUTINE ANGLE(P1,IANG)
C THIS ROUTINE IS TO BE USED TO REPLACE GUSEX FOR THE PURPOSE
C OF USING AGAUSX TO DO PHASE FUNCTION CALCULATIONS AT -IT-
C ANGLES BETWEEN 0 AND 180 DEGREES, RATHER THAN AT THE 6-L
C QUADRATURE ABSCISSA VALUES.
C DIMENSION P1(100),PL(100),OL(100),RMS(100),PC(100),H(100),C(100)
COMMON /BK2/PL,OL,RMS,PC,H,ALBDO,LLL,NCRDS,IT,ITT,NRAD
RADS=PI/180.0
DEL=180.0/FLOAT(IT-1)
IF (IANG.EQ.2) GO TO 2
DO 1 I=1,IT
1 H(I)=DEL*FLOAT(I-1)
C(I)=COS(H(I)*RADS)
RETURN
2 READ (5,100) (H(I),I=1,IT)
DO 3 J=1,IT
3 C(J)=COS(H(I)*RADS)
IANG=1
RETURN
100 FORMAT (16F5.1)
END
CAYT=0;
POINT=0;
H=0;
WAVE=W0;
TMCHUR=TMCHUR;

IF (WAVE.LT.GT.2.0) GO TO 1
1 TMCHUR.GT.303.0) GO TO 11
TMCHUR.GT.273.0) GO TO 11

C BINARY SEARCH
L=1
H=125
1 POINT=(L+H)/2
TEST=ABS(LAMBDA(POINT)-WAVE)
IF (TEST.LE.0.0001) GO TO 4
IF (WAVE.GT.LAMBDA(POINT)) GO TO 2
H=POINT
GO TO 3
2 L=POINT+1
3 IF (L.NE.H) GO TO 1
L=L-1

C INTERPOLATION ROUTINE
EMT=NSUBR(L)+(NSUBR(L+1)-NSUBR(L))*((WAVE-LAMBDA(L))/(LAMBDA(L+1)-LAMBDA(L))
1 LAMBDA(L))
CAYT=NSUBR(L)*NSUBR(L+1)-NSUBR(L)*I(WAVE-LAMBDA(L))/(LAMBDA(L+1)-LAMBDA(L))
GO TO 5
1 LAMBDA(L))
4 CONTINUE
EMT=NSUBR(POINT)
CAYT=NSUBR(POINT)
GO TO 1

C SEARCH TEMP VS DENS
6 IF (TMCHUR.LT.273.0) GO TO 11
L=1
H=7
6 P=(L+H)/2
TEST=ABS(TMP(P)-TMCHUR)
IF (TEST.LT.0.0001) GO TO 9
IF (TMCHUR.GT.TMP(P)) GO TO 7
H=P
GO TO 8
7 P=P+1
8 IF (L.NE.H) GO TO 6
L=L-1
RHODEN=DENS(L+1)-DENS(L)*I(TMCHUR-TMP(P))/(TEMP(L+1)-
1 TEMP(L))
GO TO 10
9 RHODEN=DENS(P)
10 CONTINUE
END=EMT
CAYT=CAYT
DENS=RHODEN
GO TO 11

11 WRITE (6,12) TMCHUR,WAVE
12 FORMAT (10H TEMP* OF +E12.6,+14H OR WAVE* OF +E12.6,+19H BEYOND RAN
1 27H OF DATA IN WATER ROUTINE/22H EXECUTION TERMINATED )
13 RETURN
END
SUBROUTINE AGXPRT(SCATT,EXTT,SCAT,KBKT,SCATN,1ANGL,ITOT,NUNIT)
REAL EXTT,SCAT,KBKT
C DIMENSION F(513),H(513),C(100),PSUM(100),SCAT(100),SCAT(100)
C DIMENSION PL(100),OL(100),RMS(100),PC(100),H(100),DR(18),RR(9)
C COMMON /PKZ/PL,OL,RMS,PC,H,ALBDO,PLL,NCRD,SN,ITT,TRADI
C COMMON /PKZ/PL,OL,RMS,PC,H,ALBDO,PLL,NCRD,SN,ITT,TRADI
C
C MORTEN NEGREVINGH

WHITE (6,3)
WHITE (6,4) KEXTT
WHITE (6,5) SCAT
WHITE (6,6) KBKT
WHITE (6,7) CATTN
IF (IT+LT+2) GO TO 22
WHITE (6,8)
IF (IANG+EQ.0) GO TO 17
WHITE (6,11)
DO 16 J=1,IT,4
K=J+3
IF (K.GT.1IT) IT=I
WHITE (6,14) (H(I,I),PSUM(I),=J,K)
GO TO 1V
WHITE (6,10)
DO 18 J=1,IT,4
K=J+3
IF (K.GT.1IT) IT=I
WHITE (6,13) (C(I,I),PSUM(I),=J,K)
WHITE (6,9)
THE FOLLOWING PREVENTS AN EXTRA SET OF OL'S FROM BEING WRITTEN
OUT ON NUNIT.
C
ITOT=S
CALL GAPSUM,PSUM,NUNIT,ITOT
GO TO 22
WHITE (6,2)
WHITE (6,12)
DO 20 J=1,IT,4
K=J+3
IF (K.GT.1IT) IT=I
WHITE (6,14) (H(I,I),SCATT(I),=J,K)
RETURN
END
2 FORMAT (1HG//,1X, 9X,2M3LATTING FRACTIONS/)
3 FORMAT (1HG//,1X, 9X,2HL ATTATTING FRACTIONS/)
4 FORMAT (/1X,2HL EXTINCTIO N COEF. = \$X,1PE12, 5,9H (PEK KM))
5 FORMAT (/1X,2HL SCATTIRI NG COEF. = \$X,1PE12, 5,9H (PER KM))
6 FORMAT (/1X,2HL HACK-SCATTIRI NG COEF. = \$IPE12, 5,9H (PER KM))
7 FORMAT (/1X,2M3NLATTATION COEF. = \$4X,1PE12, 5,13H SMETERS/MG)
8 FORMAT (1HG//,1X, 9X,1M3PHASE FUNCTION/)
9 FORMAT (1HG//,1X, 9X,1M3PHASE FUNCTION )
10 FORMAT (1HG//,1X, 9X,1M3PHASE FUNCTION )
11 FORMAT (1HG//,1X, 9X,1M3PHASE FUNCTION )
12 FORMAT (1HG//,1X, 9X,1M3PHASE FUNCTION )
13 FORMAT (1HG//,1X, 9X,1M3PHASE FUNCTION )
14 FORMAT (1HG//,1X, 9X,1M3PHASE FUNCTION )
END
SUBROUTINE GPHAX(SUM,PL,COEF,EMU,EMD,W,PA,GPHN,OM,P,NUNIT,L,GPHX)
*NCDS)
C THIS ROUTINE WILL COMPUTE THE GXG ANALYTIC PHASE FUNCTION WHEN
C IA PX = NT IZ = 0, THE SPHERICAL PHASE SPECTRA AND PRINT IS ALSO NEEDED.
C DIMENSION SUM(L),PL(1:5,100),COEF(100),EMU(100),EMD(100),W(100)
* ,PA(100),GPHN(100),OM(100)
DO 1 I=1,L
PL(1)*=E0
EMU(I)*=E0
EMU(2)*=E0
W(I)*=E0
PA(I)*=E0
GPHN(I)*=E0
OM(I)*=E0
1 ASYMMETRIC FACTOR
C THE GAUSS-LEGENDRE WEIGHTS AND ANGLES, ORDER L
C CALL GUSTIX(EMD,EMU,PA,W,L,P1)
C CONSTRUCT ANGLE FROM COSINE
DO 2 I=1,L
2 EMU(I)*=ACOS(EMU(I))/PI
C CONSTRUCT LEGENDRE POLYNOMIALS
DO 15 J=1,L
PL(1,J)*=E0
PL(2,J)*=EMU(J)
15 PL(1,J)*=E0
DU 16 J=3,L
E1=1
DU 16 J=1,L
16 PL(1,J)*=(2*E1*EMU(J)*PL(1-1,J)-EMU(J)*PL(1-2,J))/E1
C PHASE FUNCTION AT ZERO DEGREES
C*SUM(I)/COEF(I)
ITR=0
DELL=0.1*E0
ONE=1.E-4
G=1.E0*DELL
TOLER=1.E-4
RHS=0.5*SUM/COEF(3)/COEF(1)
4 ITR=ITR+1
G=G*DELL
FAC1=1.E0*G
ELHS=G*FAC1+C*FAC1-C-1.E0+1.5*E0*G
TEST=ELHS-RHS
IF (ABS(TEST/RHS)+ABS(TOLER)) .GE. 1 GO TO 3
C THE FOLLOWING INSURES THAT G STARTS AT 1 AND GOES DOWNWARD
IF (ITR.EQ.1) AND (TEST.GT.0.E0) ONE=-ONE
TEST=ONE*TEST
IF (G.LT.0.E0) GO TO 19
IF (TEST.LE.0.E0) GO TO 4
G=G*DELL
DELL=DELL/P1
IF ITR.GE.100 GO TO 3
GO TO 4
3 GSQ=9*G
ALPHA=RHS/GSQ+0.5E0
FAC1=1.E0-GSQ
FAC2=1.E0-GSQ
GO TO 20
TWO=2*EDG
HALF=0.5*EDG
FAC=1.0-HALF
FAC=1.0+ALPHA-2.0*EDG

C GODEcke PART OF PHASE FUNCTION
DO 5 J=1,L
DEN*FAC2=TWOG*EMU(I)
DENOM*SUROI(DEN)
TEMP=HALF*FAC1/DENOM*DENOM

5 CONTINUE

C PFN GOES NEG: USE HG FOR LATTER PART
IF (TEMP*LT.0.0) GO TO 6

CONTINUE
6 CONTINUE

C GHG PFN NOT NEG: SKIP HG PART
GO TO 7

7 CONLUE

C INTEGRATE GHG PFN FOR APPROXIMATE OMEGA ZERO
DO 9 J=1,L
9 CONTINUE

C RENORMALIZE
DO 10 J=1,L

10 CONTINUE

C CONSTRUCT APPROXIMATE LEGENDRE COEFFICIENTS
DO 11 L=1,L

11 CONTINUE

C ANALYTIC PFN AT ZERO DEGREES
PHASE=PHASE+OM(I)

12 CONTINUE

C INTEGRATE ANALYTIC PFN OVER THETA
SUM=SUM+GFPNI(J)*W(J)

13 CONTINUE

C NOW OVER PHI
SUM=SUM+2*EDG*PI

14 CONTINUE

C ERRORS: SUM=SUM*4.0**(-15)+COEF(I)**1/4.EDG**PI*COEF(I)**1/2.0*EDG

15 CONTINUE

C WRITE(6,101)

10 FORMAT(1X,3H1,1X,1X,1X,26HPERCENT ERRORS: OMEGA 0 = ,FB.3/1X,26X,
1HOMEGA 1 = ,FB.3/1X,26X,1HOMEGA 2 = ,FB.3)

RETURN

WHITE(6,101)

FORMAT (1X,4H4H THERE EXISTS NO MATCHING G = PKG TERMINATED)

GPHX0060
GPHX0070
GPHX0080
GPHX0090
GPHX0100
GPHX0110
GPHX0120
GPHX0130
GPHX0140
GPHX0150
GPHX0160
GPHX0170
GPHX0180
GPHX0190
GPHX0200
GPHX0210
GPHX0220

GPHX0660
GPHX0670
GPHX0680
GPHX0690
GPHX0700
GPHX0710
GPHX0720
GPHX0730
GPHX0740
GPHX0750
GPHX0760
GPHX0770
GPHX0780
GPHX0790
GPHX0800
GPHX0810
GPHX0820
GPHX0830
GPHX0840
GPHX0850
GPHX0860
GPHX0870
GPHX0880
GPHX0890
GPHX0900
GPHX0910
GPHX0920
GPHX0930
GPHX0940
GPHX0950
GPHX0960
GPHX0970
GPHX0980
GPHX0990
GPHX1000
GPHX1010
GPHX1020
GPHX1030
GPHX1040
GPHX1050
GPHX1060
GPHX1070
GPHX1080
GPHX1090
GPHX1100
GPHX1110
GPHX1120
GPHX1130
GPHX1140
GPHX1150
GPHX1160
GPHX1170
GPHX1180
GPHX1190
GPHX1200
GPHX1210
GPHX1220
SUBROUTINE GUSSTX(EMO,EMU,PA,W,L,P1)

THIS ROUTINE IS ESSENTIALLY THE SAME AS GUSET
EMU IS COS ANGLE AND W ARE WEIGHTS, EMO,PA ARE TEMPORARY.
DIMENSION EMO(100),EMU(100),PA(100),W(100)
TOL=1.0E-14
NML
AA=2.0D/PI**2
AB=62.0/(3.*PI**4)
AC=151.0/(15.*PI**6)
AD=-1255.0/(105.*PI**8)
PA(1)=1.0D0+0.0
EN=N
NP1=N+1
U=1.0D0+Q=-1.0D0*Q0/PI**2
D=1.0D0+O/SQRT1((EN+O+5E+00)**2+U/4.0D0+0.0)
DO 11 I=1,N
SM=I
AZ=Q+SM-1.
AE=AA/12.
AF=AH/AZ**3
AG=AC/AZ**5
AH=AD/AZ**7
1 EMO(I)=25*PI*(AZ+AC*AF+AG+AH)
DO 6 K=1,N
X*COS(EMO(I)*D)
2 PA(I)*X
DO 3 NNN=3,NP1
ENN=NNN-1
3 PA(NNN)=((2.0D0+ENN-1.0D0+ENN)*PA(NNN-1)+(ENN-1.0D0+ENN)*
*PA(NNN-2))/ENN
4 PHP=EN*PA(N)-X*PA(NP1)/(1.0D0+D+X*X)
X=X-PA(NP1)/PHP
X0=AHS*(X-X)
X0D=X0+TOL
IF(X0D<.5,9,4)
4 X=F3
GO TO 2
5 EMO(I)=X
6 W(I)=2.0*(C+5D+O+Y*X)/(EN*PA(N)*EN*PA(N))
RETURN
END
SUBROUTINE PRINTXIFN(HPH,F,COEFS,PHASE2,SUM,ERROR,6,L,PSUM,NUNIT,NTX)
*NC0DS)
DIMENSION EM(U(2),I(2),J(1),K(1)),EMU(1),SUM(10),I(11)
WRITE (6,100) 6
WRITE (6,200) PSUM
WRITE (6,300) PHASE
WRITE (6,400) NUNIT
WRITE (6,500) I
WRITE (6,600) (EM(U(2),I(2),J(1),K(1)),SUM,ERROR,6,L,PSUM,NUNIT,NTX)
1 CONTINUE
I = I + 1
IF (I .EQ. 7) GO TO 2
WRITE (NUNIT,1111) SUM,SC,T,HME(1),SUM,ERROR,6,L,PSUM,NUNIT,NTX
2 CONTINUE
I = I + 1
IF (I .EQ. 8) GO TO 3
WRITE (NUNIT,1111) SUM,SC,T,HME(1),SUM,ERROR,6,L,PSUM,NUNIT,NTX
3 RETURN
100 FORMAT (11H,136X,3H4H GNG PHASE FUNCTION FOR ASYMMETRY ,
*1HFACTOER (G) = ,F7.4/)
101 FORMAT (136X,3H4H GNG PHASE FUNCTION AT ZERO DEGREES IS
*F9.4/)
102 FORMAT (136X,3H4H COMPUTED PHASE FUNCTION AT ZERO DEGREES IS
*F9.4/)
103 FORMAT (136X,3H4H GNG VALUES ,501H=70/)
104 FORMAT (136X,3H4H SUM,8X,1F8.4H, PHASE FUNCTION )/
105 FORMAT (136X,3H4H GNG VALUES ,501H=70/)
106 FORMAT (136X,3H4H GNG VALUES ,501H=70/)
107 FORMAT (136X,3H4H GNG VALUES ,501H=70/)
108 FORMAT (136X,3H4H GNG VALUES ,501H=70/)
109 FORMAT (136X,3H4H GNG VALUES ,501H=70/)
110 END
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