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SeaRad, A Sea Radiance Prediction Code

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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

OBJECTIVE

Develop a computer code to predict sea radiance (brightness).

APPROACH

Sea radiance is modeled by combining the methods of geometrical optics with the Cox-Munk statistical description of ocean capillary waves. The model is incorporated into the atmospheric transmittance/radiance code MODTRAN2 to provide numerical sea radiance predictions.

In this model each individual capillary wave facet is allowed to reflect the sky or sun and emit thermal radiation. The total radiance from the sea is obtained by applying the proper statistical weight to each facet and integrating over all facets within the observer's field-of-view.

RESULTS

The modified MODTRAN2 code, called *SeaRad*, calculates sea radiance for any viewing geometry in a spectral range from 52.63 cm^{-1} to 25000 cm^{-1}. Typical execution speeds are approximately 10 s per pixel on a Pentium/90 MHz personal computer. Preliminary comparisons show that *SeaRad* agrees to within several degrees Celsius (°C) with actual sea radiance measurements in the mid-wave and long-wave infrared bands.

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1. INTRODUCTION

SeaRad is a FORTRAN computer code that predicts the radiance (brightness) of the ocean surface. *SeaRad* is based on the Cox-Munk statistical model (Cox and Munk, 1954, 1956) for wind-driven capillary wave facets. An individual facet is chosen and assigned a specific slope with respect to the local horizon. The facet is allowed to reflect the sky and sun and emit thermal black body radiation toward an observer. The total radiance is obtained by applying the proper statistical weight to the facet and integrating over all facets within the observer's field-of-view.

SeaRad is valid for a spectral range extending from the visible to the far infrared. Preliminary comparisons show that *SeaRad* agrees to within several °C with actual sea radiance measurements in the mid-wave and long-wave infrared bands.

In its current form, *SeaRad* is a self-contained, DOS-compatible program that runs on a personal computer and computes radiance for a single pixel (rather than an entire image). It is a modified version of the Air Force program MODTRAN2 (Berk, et al., 1989; Kneizys, et al., 1988) that computes atmospheric transmittance and radiance. *SeaRad* operates exactly like the original MODTRAN2 code[1] except that a new logical parameter, "SeaSwitch", is required in the input file. Sun glint is included in the sea radiance prediction provided that the user has chosen to execute *SeaRad* in radiance mode with solar scattered radiance included (IEMSCT = 2).

2. HARDWARE CONSIDERATIONS

The size of the FORTRAN source code is 1.8 MB. When assembled by version 5.01 of the Lahey F77L/EM-32 DOS compiler, the size of the executable code is 0.8 MB. When run[2] on a Pentium/90 at low spectral resolution (LOWTRAN7) in multiple scattering mode, execution times are 4 s for a typical thermal long-wave case (830 to 1250 cm^{-1} in 21 spectral steps) and 17 s for a typical solar mid-wave case (2000 to 3340 cm^{-1} in 67 spectral steps). Source and executable codes are available on disk through correspondence with the author.

3. AN EXAMPLE

This section provides an example of how *SeaRad* is used to predict radiance of the ocean surface. An input file called "Tape5Rad.Std," shown on page A-2, employs a 1976 U. S. standard atmosphere to calculate ocean radiance observed at a zenith angle of 100° (a depression angle of 10°) from a height of 23 m. The Navy aerosol model is used. The calculation is done at low spectral resolution (LOWTRAN7) for a single wave number (945 cm^{-1}) in the long-wave band.

With this file present, the following three DOS commands will calculate ocean radiance and display results:

```
Copy   Tape5Rad.Std   Tape5
SeaRad
Type Out
```

1 This report assumes that the reader is familiar with MODTRAN2 operation.
2. The compiler requires the Lahey/Phar Lap 386 DOS Extender program (0.2 MB) to run on a personal computer.

These commands[3] produce the output file "Out" (Appendix A, page 3). Band-integrated radiance values in W m^{-2} sr^{-1} are listed at the end of the output file for each of four contributions to ocean radiance: path to footprint, sea emission, sky reflection, and sun glint. (In fact, no sun glint has been calculated in this instance since the input file specifies IEMSCT = 1 rather than IEMSCT = 2.) Please note that the parameter "TBOUND" in the input file has been reinterpreted by *SeaRad* as the sea temperature.

The input file shown in Appendix A on page 2 contains two new parameters at the end of the third line: "90.000" and "T". These will be discussed in reverse order of their appearance.

The "T", which may appear anywhere in columns 76 through 80 of the third line of the input file (at the end of Card 3), is a new logical parameter "SeaSwitch". It is required; that is, a fatal error will be generated if it is not present in the input file. "SeaSwitch" controls the sea radiance calculation. When "SeaSwitch" is equal to "T", the sea radiance calculation will be allowed provided certain other conditions are met. When "SeaSwitch" is equal to "F", the sea radiance calculation will be prevented under all conditions and the program will execute as originally released by the Air Force.

The "90.000", which may appear anywhere in columns 66 through 75 of the third line of the input file (near the end of Card 3), is a new floating point parameter, "Psi". It is optional; that is, the program will run whether this parameter is included in the input file or not. "Psi" is the azimuth of the upwind direction[4] measured from the line-of-sight in degrees positive East of North. If it is omitted (if the field is blank), and if all conditions for a sea radiance calculation are met, that calculation will proceed under the assumption that the value of "Psi" is zero, meaning that the observer is looking directly into the wind. For the input file in Appendix A, "Psi" is 90°, meaning that the wind is blowing from right to left, perpendicular to the direction of observation.

The modified version of Card 3 used by SeaRad is:

H1, H2, ANGLE, RANGE, BETA, R0, LEN, Psi, SeaSwitch
Format (6F10.3, I5, F10.3, L5)

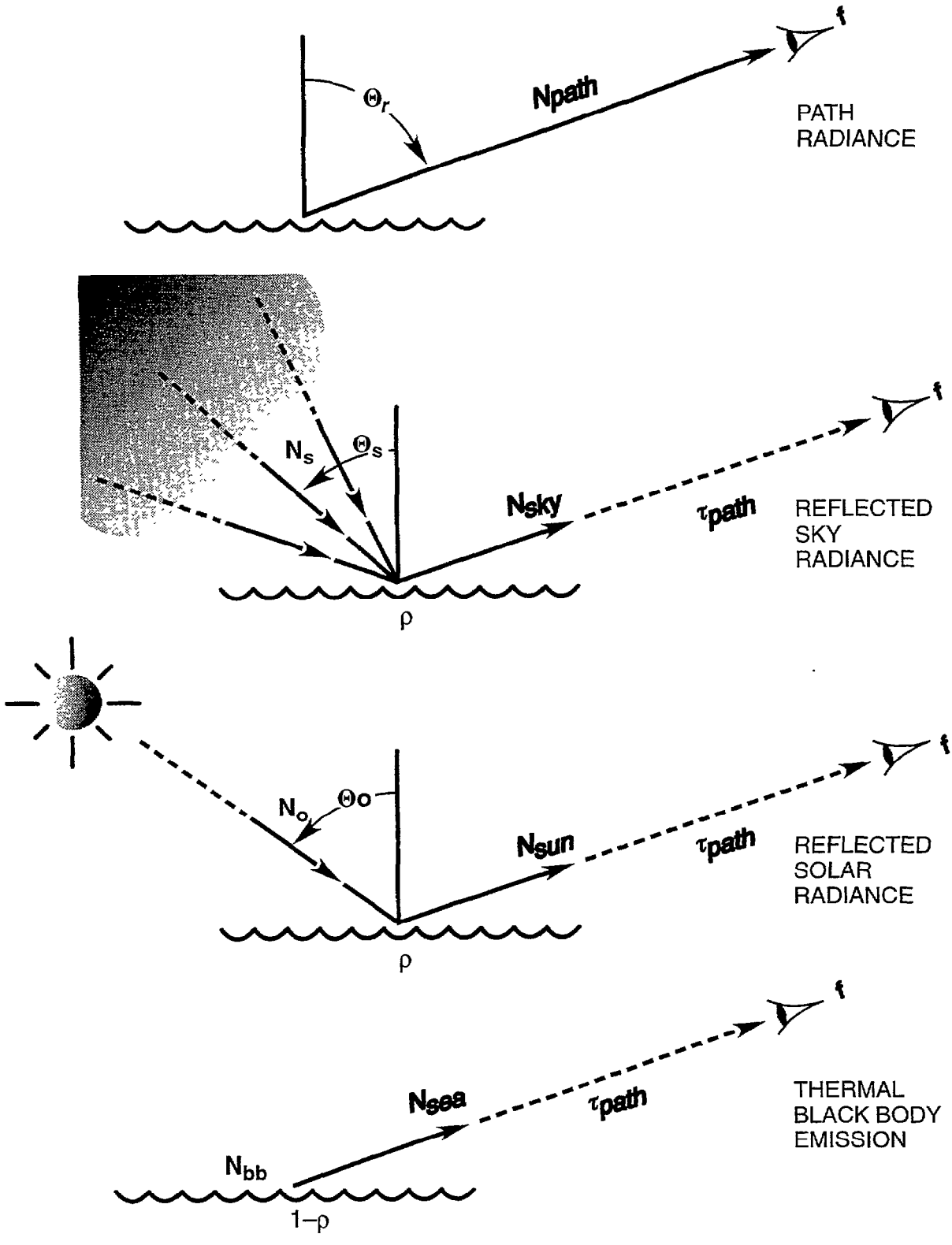
4. THE MODEL

The primary assumption of the model is that the strength of interaction between an optical ray and a capillary wave facet is given by the facet area projected normal to the ray. A feature (Zeisse, 1994. 1995) of the equations contained in *SeaRad* is that they predict a finite horizon radiance. *SeaRad* does not include multiple reflections, shadowing, or gravity waves. Polarization is ignored.

The model computes four contributions to sea radiance. Each of the four contributions is shown in figure 1. (For purposes of clarity, only two dimensions have been used in figure 1; however, all three dimensions are used in the actual calculation.)

The first contribution is path radiance, shown at the top of figure 1. The footprint of a single pixel in an image of the sea is indicated by the wavy line. The footprint is observed by a receiver at the end

3. The time for this particular test case was 3 s on a 486/50 MHz personal computer.
4. This information is required because the Cox-Munk capillary wave slope statistics are different in the upwind and crosswind directions.



$$\left(N_{sky} + N_{sun} + N_{sea}\right) \tau_{path} \cdot f + N_{path} \cdot f = N$$

Figure 1. Four contributions to sea radiance.

of a ray whose zenith angle at the footprint is θ_r. Let N_{path} designate the spectral radiance in W m^{-2} sr^{-1} $(cm^{-1})^{-1}$ along the path[5] from the footprint to the receiver.

The second contribution is reflected sky radiance. Spectral radiance N_s from a portion of the sky arrives at the footprint along a ray whose zenith angle there is θ_s. The footprint contains wave facets of different slopes, many that reflect the incoming sky radiance away from the receiver toward other parts of the sky. These facets are ignored. However, the footprint will contain some facets whose slope is correct for reflecting the incoming sky radiance toward the receiver along the path defined by the zenith angle θ_r. These facets are retained. The contributions from all portions of the sky are summed together after specular reflection by the appropriate facets within the footprint, and the sum leaving the footprint at zenith angle θ_r is designated N_{sky}. During its path to the receiver, the reflected sky radiance is attenuated by the path transmission τ_{path}.

The third contribution is reflected solar radiance, sun glint. The calculation is analogous to the calculation of sky radiance. Spectral radiance N_o from the solar center arrives at the footprint along a path whose zenith angle there is θ_o. Within the footprint, most facets deflect the solar ray away from the receiver and are rejected, but some facets are retained because they deflect the ray specularly toward the receiver along a path with zenith angle θ_r. N_{sun} is the spectral radiance leaving the footprint after summation over rays arriving from all portions of the solar disk. The reflected solar radiance is also attenuated by the path transmission τ_{path} before final reception.

The fourth contribution is thermal black body emission. Each facet emits a spectral radiance N_{bb} given by Planck's equation for a black body whose temperature is equal to the value of "TBOUND" in the input file. The spectral emissivity of a given facet in the direction of the receiver is specified by the slope of that facet and the value of θ_r. N_{sea} is the thermal spectral radiance leaving the footprint for the receiver after summation over all facets within the footprint. As before, N_{sea} is attenuated by path transmission after leaving the footprint.

Throughout figure 1, the symbol ρ represents the spectral reflectivity of sea water, which is required for the second and third contributions since they are governed by the process of optical reflection. On the other hand, the fourth contribution is governed by the process of optical emission. Fortunately, by application of Kirchoff's Law to an opaque medium, sea water, the emissivity is given by one minus the reflectivity. The reflectivity is calculated from Fresnel's equations (Stratton, 1941) with a complex optical index taken from the literature (Hale & Querry, 1973; Querry, et al., 1977). These data for the index, available between 52.63 cm^{-1} and 25000 cm^{-1}, set the spectral range of *SeaRad*.

The total spectral radiance N received at wave number ν (cm^{-1}) is given by

$$N(\nu) = N_{path}(\nu)\, f(\nu) + \left[N_{sky}(\nu) + N_{sun}(\nu) + N_{sea}(\nu)\right] \tau_{path}(\nu)\, f(\nu)\,, \qquad (1)$$

where $f(\nu)$ has been introduced to represent the spectral responsivity of the receiver.

The design of *SeaRad* is such that path (N_{path}, τ_{path},) and source (N_s, N_o, N_{bb}) values are taken from the original MODTRAN2 while Fresnel reflection (ρ) and slope integrated values (N_{sky}, N_{sun}, N_{sea}) are introduced in new subroutines. Integration of (1) over the wave number band specified in the input file is carried out in a modification of subroutine "TRANS" to produce the band-integrated values for sea radiance given in the output file.

5. In this report, the word path refers to only the optical path between the footprint and the receiver.

5. THE COORDINATE SYSTEM

The previous description neglected the azimuthal dependence of rays arriving and leaving the footprint. The full three-dimensional geometry will now be introduced.

Figure 2 shows the geometry of reflection. A coordinate system was chosen whose origin is the point of reflection with the X-axis pointing upwind, the Z-axis pointing toward the zenith, and the Y-axis pointing crosswind such that a right-handed system is formed. The X-Y plane is horizontal at the point of reflection. The tilted facet passes through the origin.

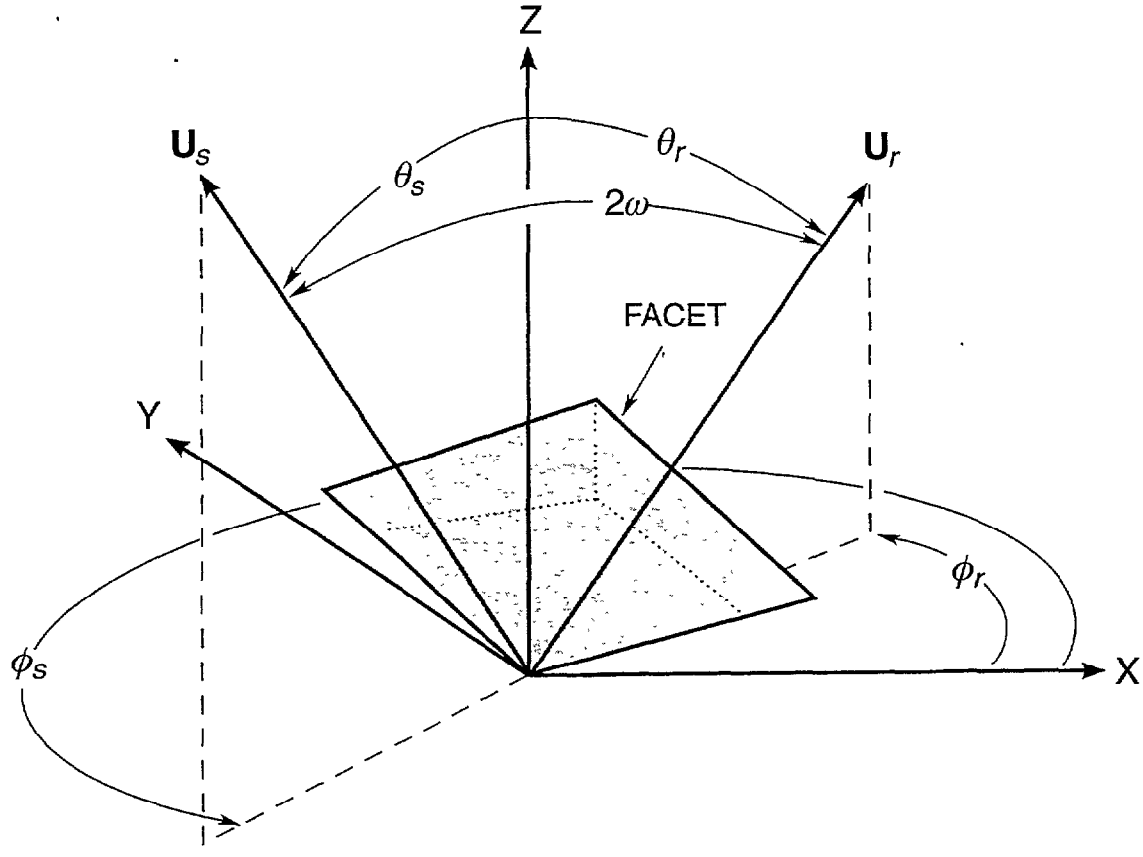


Figure 2. Coordinate system for facet reflection.

Define a unit vector $\mathbf{U} \equiv (\theta, \phi)$ with polar coordinates θ, the zenith angle, and ϕ, the azimuth. If we denote the Cartesian coordinates of $\mathbf{U}$ by (a, b, c), then we have

$$\begin{aligned} a &= \sin\theta\cos\phi \\ b &= \sin\theta\sin\phi \\ c &= \cos\theta \end{aligned} \tag{2}$$

for the Cartesian coordinates of $\mathbf{U}$ in terms of its spherical coordinates and

$$\begin{aligned} \theta &= \cos^{-1}(c) \\ \phi &= \tan^{-1}(b/a) \end{aligned} \tag{3}$$

for the spherical coordinates of **U** in terms of its Cartesian coordinates. Two unit vectors are shown in figure 2: $\mathbf{U}_s$, pointing from the origin to the source, and $\mathbf{U}_r$, pointing from the origin to the receiver. A third unit vector, $\mathbf{U}_n$, is normal to the facet at the point of reflection but was removed from the figure for clarity[6].

The facet slope in the upwind direction, ζ_x, is given by the slope of the line formed at the intersection of the facet with the *X-Z* plane. The facet slope in the crosswind direction, ζ_y, is given by the slope of the line formed at the intersection of the facet with the *Y-Z* plane. In terms of the Cartesian coordinates of the facet normal these slopes are

$$\begin{aligned} \zeta_x &= -\, a_n/c_n \\ \zeta_y &= -\, b_n/c_n \end{aligned} \tag{4}$$

6. SPECULAR REFLECTION

If a specular reflection occurs, the three vectors for source, receiver, and facet normal are connected by the law of reflection:

$$\mathbf{U}_s + \mathbf{U}_r = 2\cos\omega\ \mathbf{U}_n \tag{5}$$

where ω is the angle of incidence and the angle of reflection.

7. THE OCCURRENCE PROBABILITY

Following Cox and Munk, let *P* stand for the probability

$$P \equiv p(\zeta_x, \zeta_y, W)\ d\zeta_x d\zeta_y \tag{6}$$

that a wave facet will occur with a slope within $\pm\, d\zeta_x/2$ of ζ_x and $\pm\, d\zeta_y/2$ of ζ_y when the wind speed is *W*. The wave slope occurrence probability density, *p*, is proportional to the horizontal projection of the facet. Cox and Munk obtained an expression for *p* whose lowest order term is

$$\begin{aligned} p(\zeta_z, \zeta_y, W) &\approx \frac{1}{2\pi\sigma_u\sigma_c} \exp\left\{ -\frac{1}{2}\left(\frac{\zeta_x^2}{\sigma_u^2} + \frac{\zeta_y^2}{\sigma_c^2}\right)\right\} \\ \sigma_u^2 &= 0.000 + 3.16 \cdot 10^{-3} W \\ \sigma_c^2 &= 0.003 + 1.92 \cdot 10^{-3} W \end{aligned} \tag{7}$$

Here σ_u^2 and σ_c^2 are the variances in ζ_x and ζ_y respectively and *W* is the wind speed in m s^{-1}. Figure 3 shows the dependence of *p* throughout slope space for a wind speed of 10 m s^{-1}. The coordinate system of figure 2 has been inserted at the top of the figure to illustrate the relation between coordinates and slopes. Note that the first *X-Y* quadrant corresponds to negative slopes.

6. The zenith angle of $\mathbf{U}_n$ is the same as the tilt of the facet. The tilt is the angle of the steepest ascent within the facet.

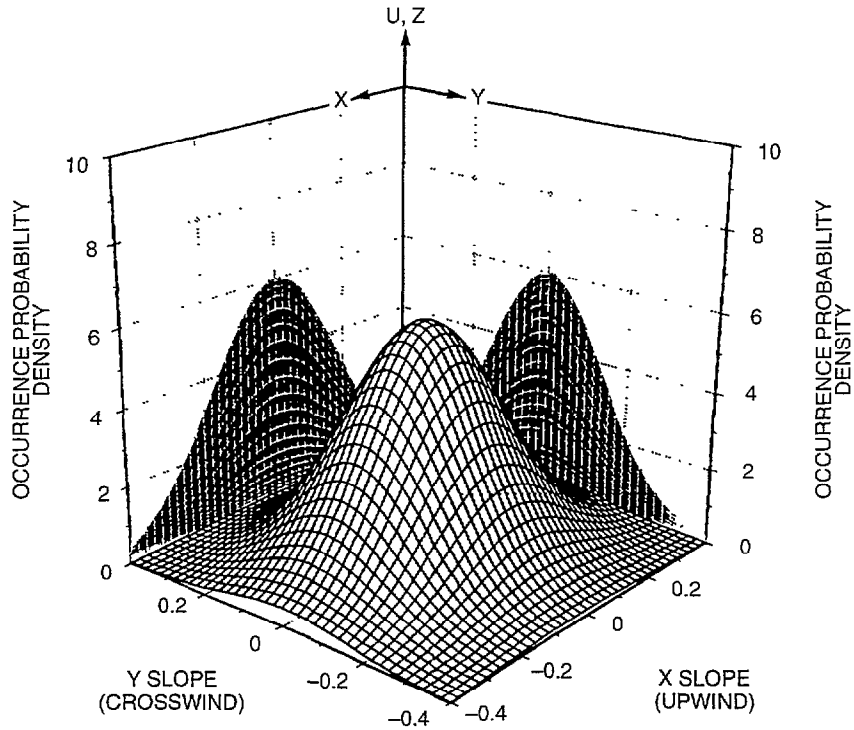


Figure 3. Cox-Munk occurrence probability density for a windspeed of 10 m s^{-1}.

8. THE INTERACTION PROBABILITY

Following a suggestion of Plass, et al. (1976), let Q stand for the (different) probability

$$Q \equiv q(\zeta_x, \zeta_y, \theta, \phi, W)\ \zeta_x\ d\zeta_y \tag{8}$$

that a facet whose slope is within $\pm d\zeta_x/2$ of ζ_x and $\pm d\zeta_y/2$ of ζ_y will interact with a ray arriving from the arbitrary direction $\mathbf{U} = (\theta, \phi)$ when the wind speed is W. The wave slope interaction probability density, q, is proportional to the facet area projected normal to the ray. It has previously been shown (Zeisse, 1994, 1995)[7] that

$$q(\zeta_x, \zeta_y, \theta, \phi, W) = \frac{\dfrac{\cos\omega}{\cos\theta_n} p}{\displaystyle\iint_{\substack{\omega \le \pi/2 \\ U = const}} \frac{\cos\omega}{\cos\theta_n} p\ d\zeta_x\ d\zeta_y} \tag{9}$$

Figure 4 is a graph of equation (9), also for a wind speed of 10 m s^{-1}, showing how facets with a specified slope interact with a ray pointing in the direction (80°, 270°).

7. Equation (9) is only defined for $\omega \le \frac{\pi}{2}$.

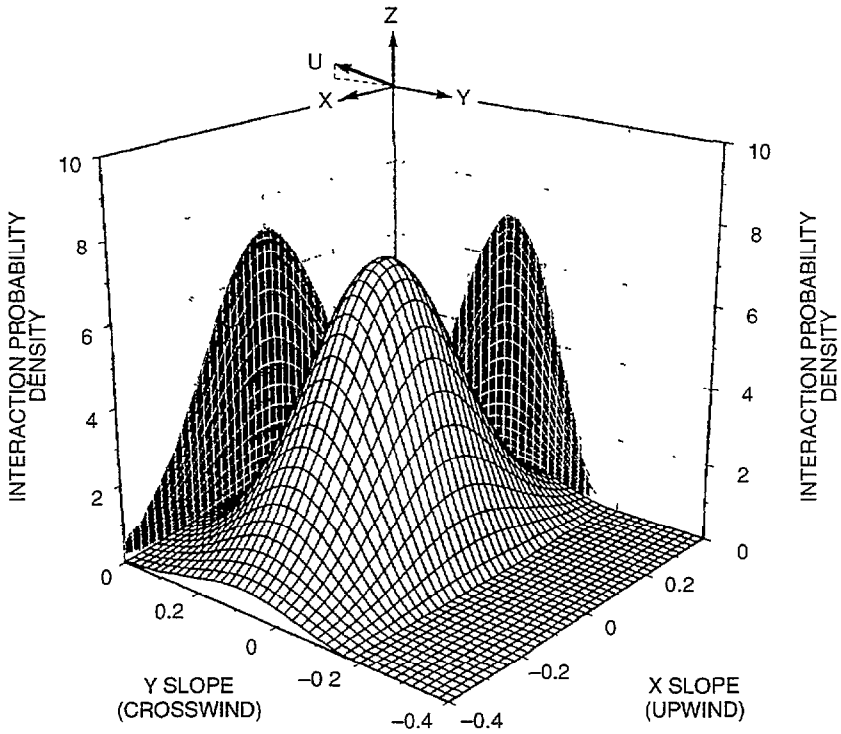


Figure 4. Cox-Munk-Plass interaction probability density for a windspeed of 10 m s^{-1}.

9. EQUATIONS FOR SEA RADIANCE

The capillary wave contributions to sea radiance are

$$N_{sky}(\theta_r, \phi_r, W, \nu) = \iint\limits_{\substack{\theta_s, \omega \le \pi/2 \\ U_r = const.}} N_s(\theta_s, \phi_s, \nu)\rho(\omega, \nu) q(\zeta_x, \zeta_y, \theta_r, \phi_r, W)\, d\zeta_x\, d\zeta_y \tag{10}$$

$$N_{sun}(\theta_o, \phi_o, \theta_r, \phi_r, W, \nu) \approx \frac{N_o(\theta_o, \phi_o, \nu)}{4} \cdot \tag{11}$$

$$\iint\limits_{\substack{disk \\ U_r = \text{const.}}} \rho\,(\omega, \nu)\ \sec\omega\ sec^3\theta_n\ q(\zeta_x, \zeta_y, \theta_r, \phi_r, W)\ sin\theta_s\ d\theta_s\ d\phi_s$$

$$N_{sea}(\theta_r, \phi_r, W, T_{sea}, \nu) = N_{bb}(T_{sea}, \nu) \iint\limits_{\substack{\omega \le \pi/2 \\ U_r = const.}} [1 - \rho(\omega, \nu)] q(\zeta_x, \zeta_y, \theta_r, \phi_r, W)\, d\zeta_x\, d\zeta_y \tag{12}$$

In each of the integrals (10) through (12), q plays the role of a weighting function attached to the facet. The weight is applied to the ray leaving the footprint and propagating toward the receiver, and

that ray and those receiver coordinates are held constant in all of the integrals. A physical description and some mathematical details of each equation will now be presented.

In the integrand of (10), the product of N_s and ρ represents the radiance leaving a single facet when $N_s(\theta_s, \phi_s, \nu)$ is the spectral sky radiance incident on that facet at zenith angle θ_s and azimuth ϕ_s. This product is weighted by q and integrated over all slopes in the ocean. During integration, a specular reflection occurs at one facet after another inside the footprint with the outgoing (receiver) ray held fixed. The source ray is swept across the sky and sun. Equation (10) will require explicit expressions for each of its variables in terms of slopes and receiver coordinates. From (2) and (4) it can be shown that the facet tilt is given in terms of the facet slopes by

$$\cos\theta_n = c_n = \frac{1}{\sqrt{1 + \zeta_x^2 + \zeta_y^2}} \tag{13}$$

while the fact that ω is the the angle between the facet normal and the receiver ray implies that

$$\begin{aligned} \cos\omega &= \mathbf{U}_n \cdot \mathbf{U}_r \\ &= a_n a_r + b_n b_r + c_n c_r \\ &= \left\{-\zeta_x a_r - \zeta_y b_r + c_r\right\} c_n \\ &= \frac{\left\{-\zeta_x \sin\theta_r \cos\phi_r - \zeta_y \sin\theta_r \sin\phi_r + \cos\theta_r\right\}}{\sqrt{1 + \zeta_x^2 + \zeta_y^2}} \end{aligned} \tag{14}$$

Equations (13) and (14) hold at all times, regardless of whether a specular reflection is taking place. When a specular reflection does occur, the Z component of the law of reflection

$$\mathbf{U}_s = 2 \cos\omega \ \mathbf{U}_n - \mathbf{U}_r \tag{15}$$

gives

$$\begin{aligned} \cos\theta_s &= 2 \cos\omega \ c_n - c_r \\ &= \frac{2\{\ \} - c_r/c_n^2}{1/c_n^2} \\ &= \frac{-2 \sin\theta_r \left(\zeta_x \cos\phi_r + \zeta_y \sin\phi_r\right) + \cos\theta_r \left(1 - \zeta_x^2 - \zeta_y^2\right)}{1 + \zeta_x^2 + \zeta_y^2} \end{aligned} \tag{16}$$

where { } represents the expression within curly braces in (14). Finally, the X and Y components of (15) give

$$\begin{aligned} \tan\phi_s &= \frac{b_s}{a_s} \\ &= \frac{2 \cos\omega \ b_n - b_r}{2 \cos\omega \ a_n - a_r} \\ &= \frac{2\zeta_y\{\ \} + b_r/c_n^2}{2\zeta_y\{\ \} + a_r/c_n^2} \\ &= \frac{\left(1 + \zeta_x^2 - \zeta_y^2\right) \sin\phi_r - \left(2\zeta_x\zeta_y\right) \cos\phi_r + \left(2\zeta_y\right) \cot\theta_r}{\left(1 - \zeta_x^2 + \zeta_y^2\right) \cos\phi_r - \left(2\zeta_x\zeta_y\right) \sin\phi_r + \left(2\zeta_x\right) \cot\theta_r} \end{aligned} \tag{17}$$

for the source azimuth during specular reflection by a facet (ζ_x, ζ_y) into a receiver at (θ_r, ϕ_r).

Equations (13), (14), (16), and (17) should be used in (10) [and in equation(9) when using (10)]. The Cartesian expressions are convenient for computer calculation while the spherical expressions are consistent with the form of equations (10) through (12).

In the integrand of (11), the product of N_o and ρ represents the spectral radiance leaving a single facet when $N_o(\theta_o, \phi_o, \nu)$ is the spectral radiance arriving at that facet from the sun whose center is at (θ_o, ϕ_o). The remaining factors in (11), apart from q, are the Jacobian of the transformation from ocean slopes to sky coordinates (Zeisse, 1994). As before, the integrand is weighted by q but now the integration is over the solar disk in the sky. (It is assumed in (11) that $N_o(\theta_o, \phi_o, \nu)$ does not vary during integration because the sun is a Lambertian source and the solar disk is small.) During integration, a specular reflection from the sun to the receiver occurs at those facets within the footprint with the correct slope. Explicit expressions for each of the variables in terms of source and receiver coordinates will be required in (11). The law of reflection

$$2 \cos \omega \ \mathbf{U}_n = \mathbf{U}_s + \mathbf{U}_r \tag{18}$$

gives the facet position in terms of the source and receiver positions whenever a specular reflection occurs. The components of (18) give

$$\begin{aligned} \zeta_x &= -\frac{a_n}{c_n} \\ &= -\frac{a_s + a_r}{c_s + c_r} \\ &= -\frac{\sin\theta_s \ \cos\phi_s + \sin\theta_r \ \cos\phi_r}{\cos\theta_s + \cos\theta_r} \end{aligned} \tag{19}$$

and

$$\begin{aligned} \zeta_y &= -\frac{b_n}{c_n} \\ &= -\frac{b_s + b_r}{c_s + c_r} \\ &= -\frac{\sin\theta_s \ \sin\phi_s + \sin\theta_r \ \sin\phi_r}{\cos\theta_s + \cos\theta_r} \end{aligned} \tag{20}$$

while its square gives

$$\begin{aligned} 2 \cos^2\omega &= 1 + \boldsymbol{U}_s \cdot \boldsymbol{U}_r \\ &= 1 + a_s \ a_r + b_s \ b_r + c_s \ c_r \\ &= 1 + \sin\theta_s \sin\theta_r \cos(\phi_s - \phi_r) + \cos\theta_s \cos\theta_r \end{aligned} \tag{21}$$

Finally, from (2), (4), and (18) we have

$$\begin{aligned}\tan^2\theta_n &= \zeta_x^2 + \zeta_y^2 \\ &= \frac{(a_s + a_r)^2 + (b_s + b_r)^2}{(c_s + c_r)^2} \\ &= \frac{\sin^2\theta_s + \sin^2\theta_r + 2\sin\theta_s \sin\theta_r \cos(\phi_s - \phi_r)}{(\cos\theta_s + \cos\theta_r)^2}\end{aligned} \tag{22}$$

Expressions (19) through (22) should be used in (11) [and in (9) when using(11)]. They apply only when there is a specular reflection.

In (12) there is no incident ray or specular reflection, and integration is over all slopes in the ocean. The integral in (12) is the effective spectral emissivity of the ocean. Explicit expressions in terms of slopes and receiver coordinates will also be required for each of the variables in (12) [and in (9) when using (12)]. Equation (13) is the expression for θ_n and equation (14) is the expression for ω.

10. *SEARAD*

SeaRad consists of new routines added to MODTRAN2 to compute the spectral values of N_{sky}, N_{sun}, and N_{sea} according to equations (10), (11), and (12), respectively. Through modifications to subroutine "TRANS", these values are assembled according to (1) and integrated over the wave number after obtaining proper path radiance and transmittance spectral values. *SeaRad* also introduces minor changes in subroutine "DPFNMN" and major changes in subroutine "DRIVER". These changes will now be considered in more detail.

The modifications to "DRIVER" are briefly shown in figure 5. After the normal call to "GEO", a test is conducted to see whether the ray chosen by the user has hit the surface of the sea. If so, geometry cards required for the sea calculation are issued by subroutine "Card" to file "Tape5.Sea", and input is temporarily redirected to "Tape5.Sea". An example of "Tape5.Sea" is given on page A-4, for the run initiated by the input file on page A-2. After the final card has been read from "Tape5.Sea", sea radiance is calculated in "TRANS". Then "TAPE5" is restored as the active input file and normal program execution is resumed. Please see Appendix B for a detailed flowchart of the modifications to "DRIVER" as well as the complete source code for the modified version of "DRIVER".

Conditions in "DPFNMN" determine whether or not the sea has been hit. "DPFNMN" is a subroutine reached by a sequence of calls beginning in the driver with a call to subroutine "GEO". Modifications to "DPFNMN" are summarized in figure 6. A logical variable "Sea", initially set false, is set true in "DPFNMN" if the following four conditions are met:

1. The program has reached the section of code following the comment line "Tangent path intersects earth."
2. The user has chosen a radiance mode.
3. The variable "HMIN" is equal to zero.
4. The variable "SeaSwitch" is true.

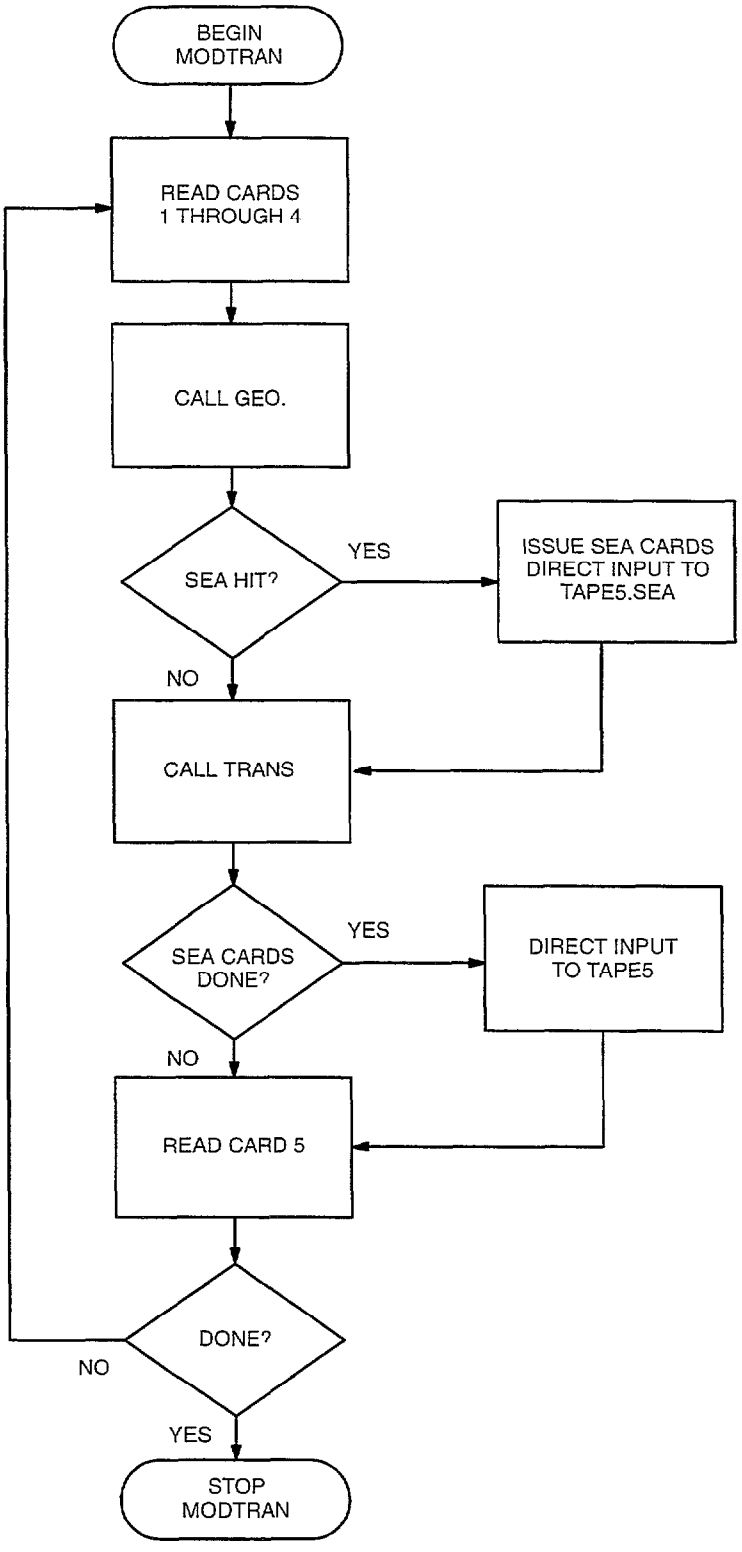


Figure 5. Flowchart for modifications to MODTRAN2 subroutine "DRIVER."

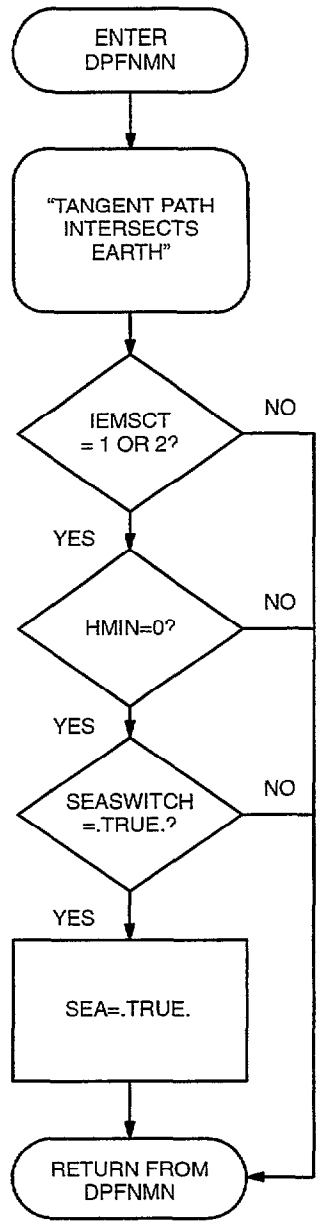


Figure 6. Flowchart for modifications to MODTRAN2 subroutine "DPFNMN."

The variable "Sea" is stored in a common block made available to the driver, which inspects "Sea" before and after each of its calls to "GEO". A change from false to true indicates that the ocean has been hit during that call. A hit induces a geometry calculation by a call to subroutine "Foot" (if IEMSCT = 1) or subroutine "SunFoot" (if IEMSCT = 2). This is followed in each case by a call to subroutine "Card".

The purpose of "Card" is to supply sources for the Cox-Munk routines "Sky" and "Sun." As shown in figure 7, geometry cards are issued here to file "Tape5.Sea" to obtain spectral radiance along paths to the sky at three separate zenith angles. These three cards, one for each zenith angle, are called "Sky Cards" in the flowchart. Later these data will be used by subroutine "Fit" to establish a two-parameter least squares fit at each wave number providing "Sky" with the sky dome radiance.

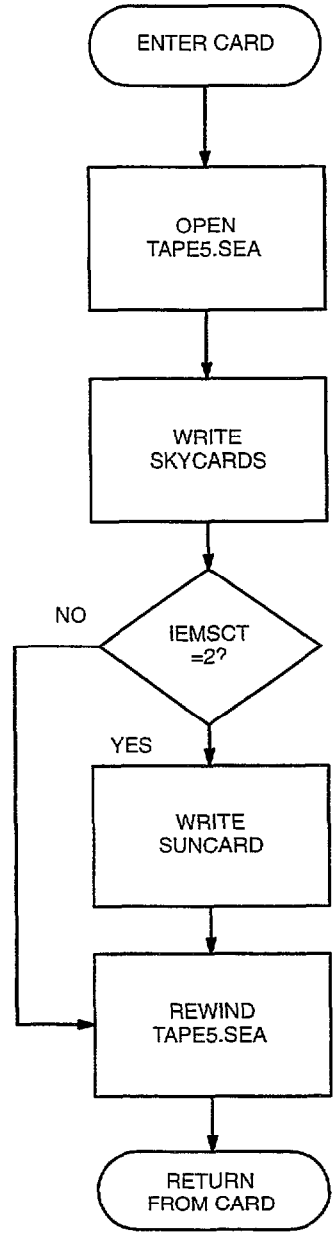


Figure 7. Flowchart for SeaRad subroutine "Card."

If the sun is involved, "Card" will issue a fourth and final Card 3, called a "Sun Card" in the flowchart, which provides solar irradiance for later use as a source by subroutine "Sun".

The modifications described to this point have, in effect, inserted three sky cards (followed by a sun card if necessary) into the user's input file without the user's knowledge. The insertion is made only if the user has chosen a Card 3 whose path terminates on the surface of the earth. Such a Card 3 is called a "Path Card" in figure C-1. Within the wave number integration loop in "TRANS", spectral values of transmission, incident sky radiance, and incident solar irradiance are stored in arrays Tau(V), Nsky(V), and Ho(V), respectively. Outside the wave number integration loop these values are recalled for the sea radiance calculation by subroutine "Sky" (or subroutine "Sun" if IEMSCT = 2).

The modified version of "DRIVER" is contained in Appendix B along with a detailed flowchart of its modifications. Appendix C contains the source code and a flowchart for the modified version of "TRANS", and Appendix D contains new code for the sea radiance calculation.

11. CONCLUSION

SeaRad, a modification of MODTRAN2, computes sea radiance between 52.63 cm^{-1} and 25000 cm^{-1}. Preliminary comparisons with data show that *SeaRad* has an approximate accuracy of several °C in the infrared.

SeaRad is currently designed for a single pixel and takes approximately 10 s to execute. Each time a new geometry is chosen by the user, *SeaRad* recalculates the source radiance and the path radiance and transmission. However, only the path properties change significantly from one pixel to the next in a typical ocean image. If *SeaRad* were redesigned to apply to sea images, the speed per pixel could be reduced, up to a factor of almost four, by calculating values of source radiance just once for the entire image.

12. REFERENCES

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APPENDIX A
SeaRad INPUT AND OUTPUT FILES

"TAPE5RAD.STD" INPUT FILE

C:\MOD2\TAPE5RAD.FIL 7/20/95

```
F   6    3    1    1    0    0    0    0    0    0    0    0    0  288.15   0.00
    3    0    0    5    0    0   10.000   10.000   10.000     .000     .000
    00.023      .000  100.000     .000     .000     0.00    0   90.000    T
       940      950       10        5
    0
```

"OUT" FILE

```
                    C:\MOD2\OUT.FIL 7/20/95

          ***** SEARAD, A MODIFICATION OF LOWTRAN7 *****

DATE: 07/20/95                                          TIME: 15:11:38

THERMAL RADIANCE MODE

MULTIPLE SCATTERING USED

MARINE AEROSOL MODEL USED

        WIND SPEED         =    10.00 M/SEC
        WIND SPEED         =    10.00 M/SEC, 24 HR AVERAGE
        RELATIVE HUMIDITY  =    50.00 PERCENT
        AIRMASS CHARACTER  =     5
        VISIBILITY         =    10.00 KM

SLANT PATH TO SPACE

         H1      =      0.023 KM
         HMIN    =      0.000 KM
         ANGLE   =    100.000 DEG

FREQUENCY RANGE

         IV1     =        940 CM-1  (  10.64 MICROMETERS)
         IV2     =        950 CM-1  (  10.53 MICROMETERS)
         IDV     =         10 CM-1
         IFWHM   =          5 CM-1
         IFILTER =          0

SUMMARY OF THE GEOMETRY CALCULATION

         H1      =      0.023 KM
         H2      =      0.000 KM
         ANGLE   =    100.000 DEG
         RANGE   =      0.133 KM
         BETA    =      0.001 DEG
         PHI     =     80.001 DEG
         HMIN    =      0.000 KM
         BENDING =      0.000 DEG
         LEN     =          0

SEA AT 288.15 K REPLACES BLACK BODY BOUNDARY

         UPWIND  =     90.000 DEG EAST OF LINE OF SIGHT

RECEIVED RADIANCE VALUES

         PATH TO FOOTPRINT          0.01814 W M-2 SR-1  (AV. TRANS. 0.9776)
         SEA EMISSION           =   0.70712 W M-2 SR-1
         SKY REFLECTION         =   0.06125 W M-2 SR-1
         SUN GLINT              =   0.00000 W M-2 SR-1

         TOTAL RADIANCE         =   0.78652 W M-2 SR-1
         BLACK BODY TEMP.       =       6.7 C
```

"TAPE5.SEA" FILE

C:\MOD2\TAPE5SEA.FIL 7/20/95

```
3
 0.000      0.000      57.296      0.000      0.000      0.000      0      90.000      T
3
 0.000      0.000      73.148      0.000      0.000      0.000      0      90.000      T
3
 0.000      0.000      89.000      0.000      0.000      0.000      0      90.000      T
```

APPENDIX B
MODIFIED SUBROUTINE "DRIVER"

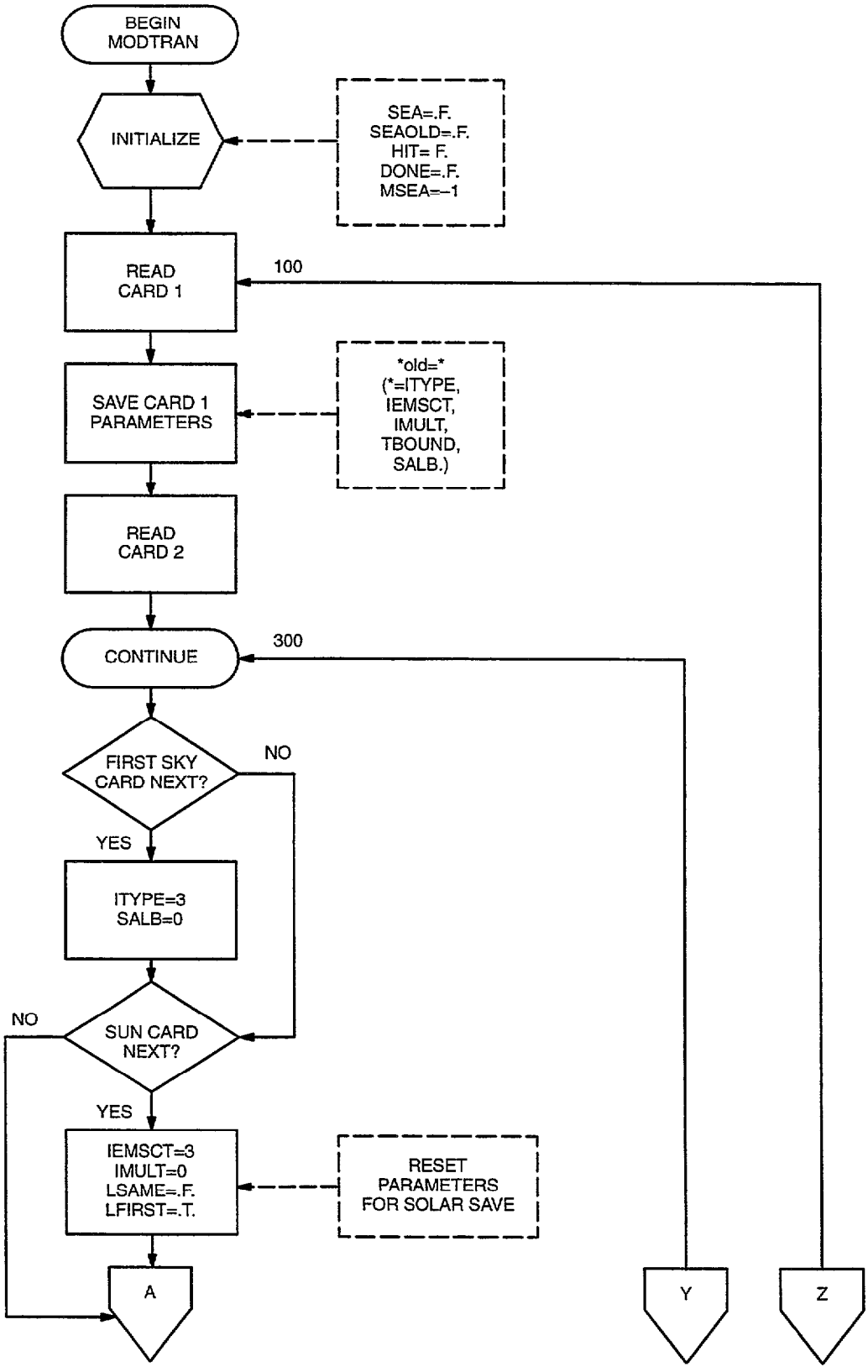

Figure B-1. Detailed flowchart for modified subroutine "DRIVER".

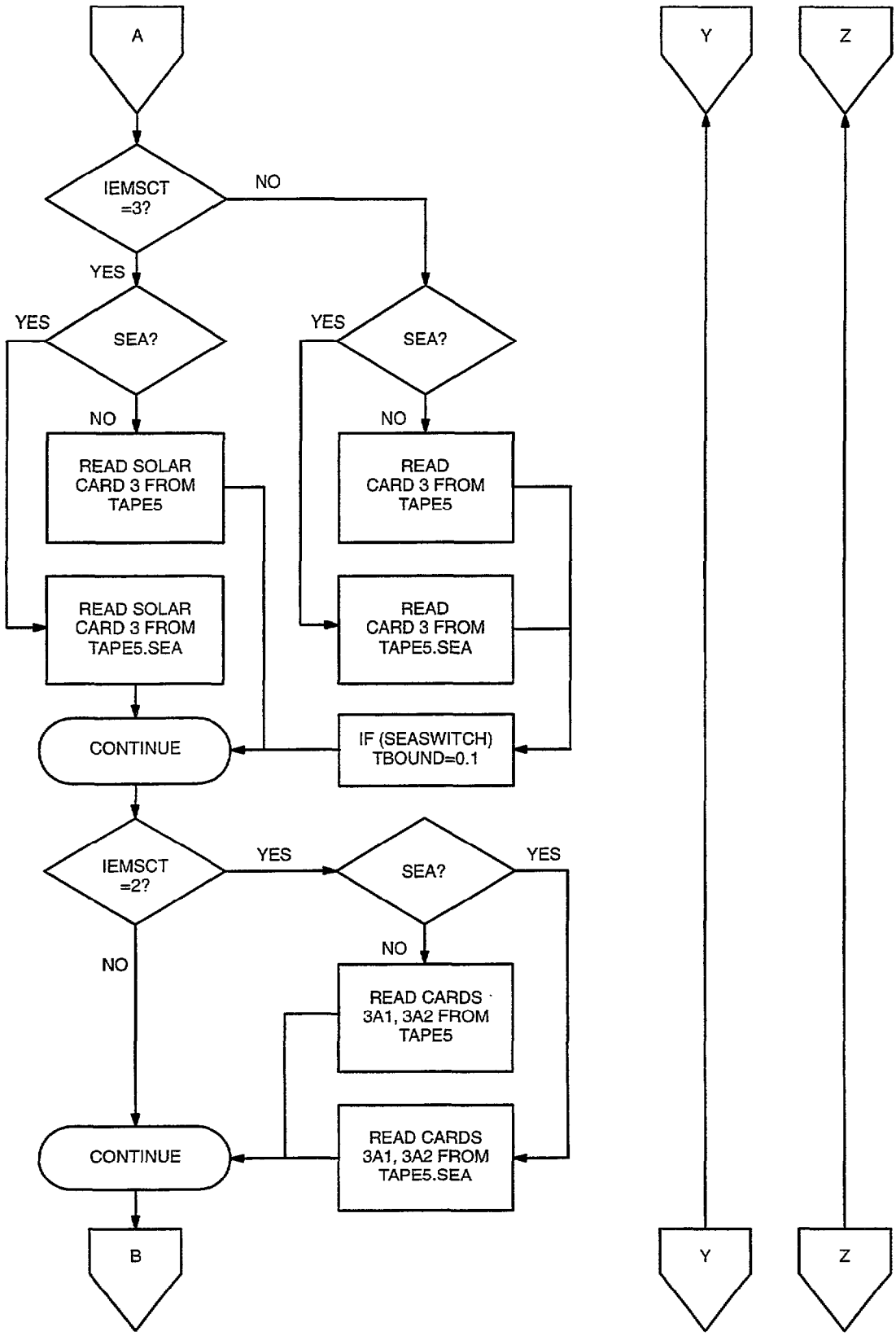

Figure B-1. Detailed flowchart for modified subroutine "DRIVER". (Continued)

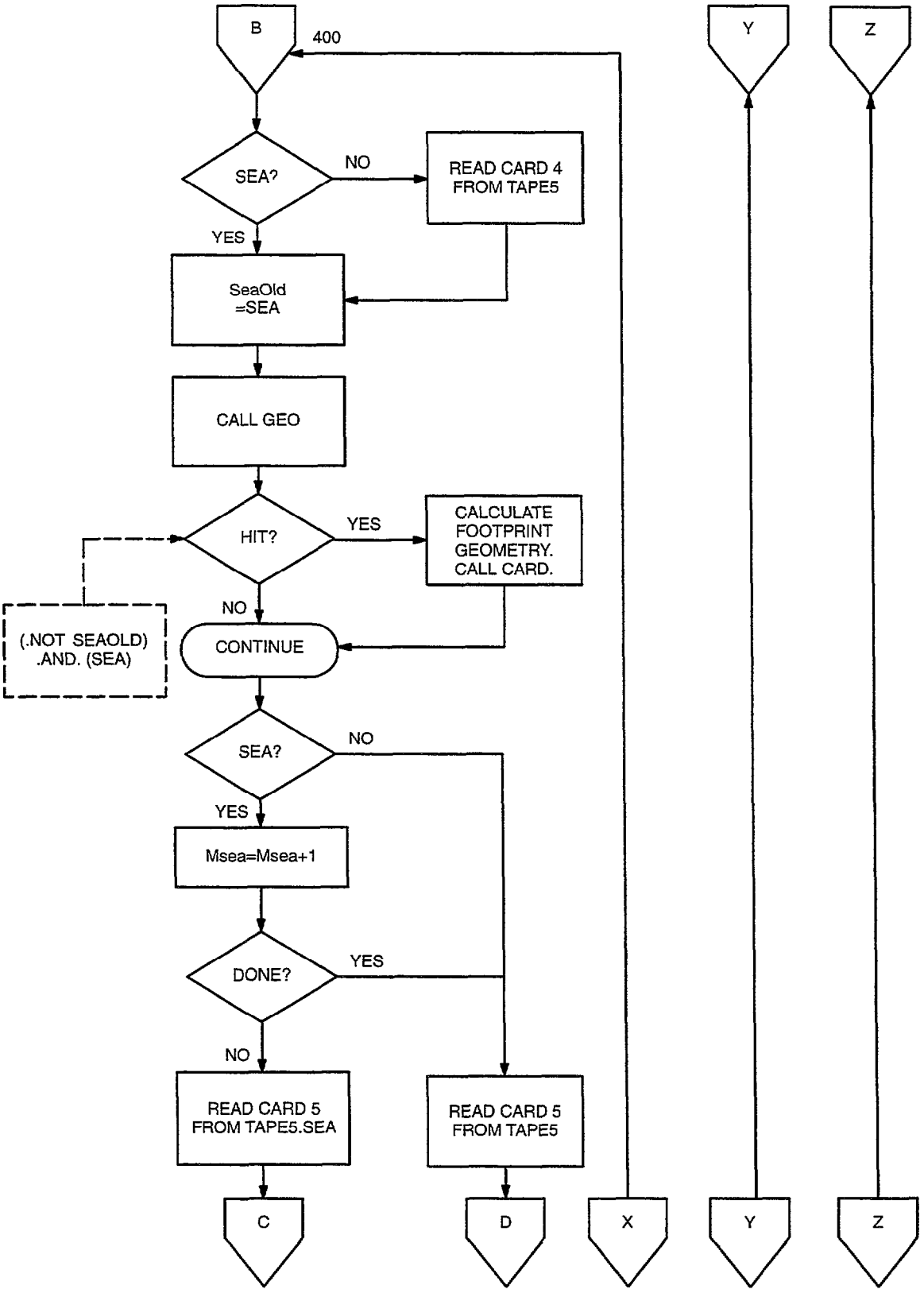

Figure B-1. Detailed flowchart for modified subroutine "DRIVER". (Continued)

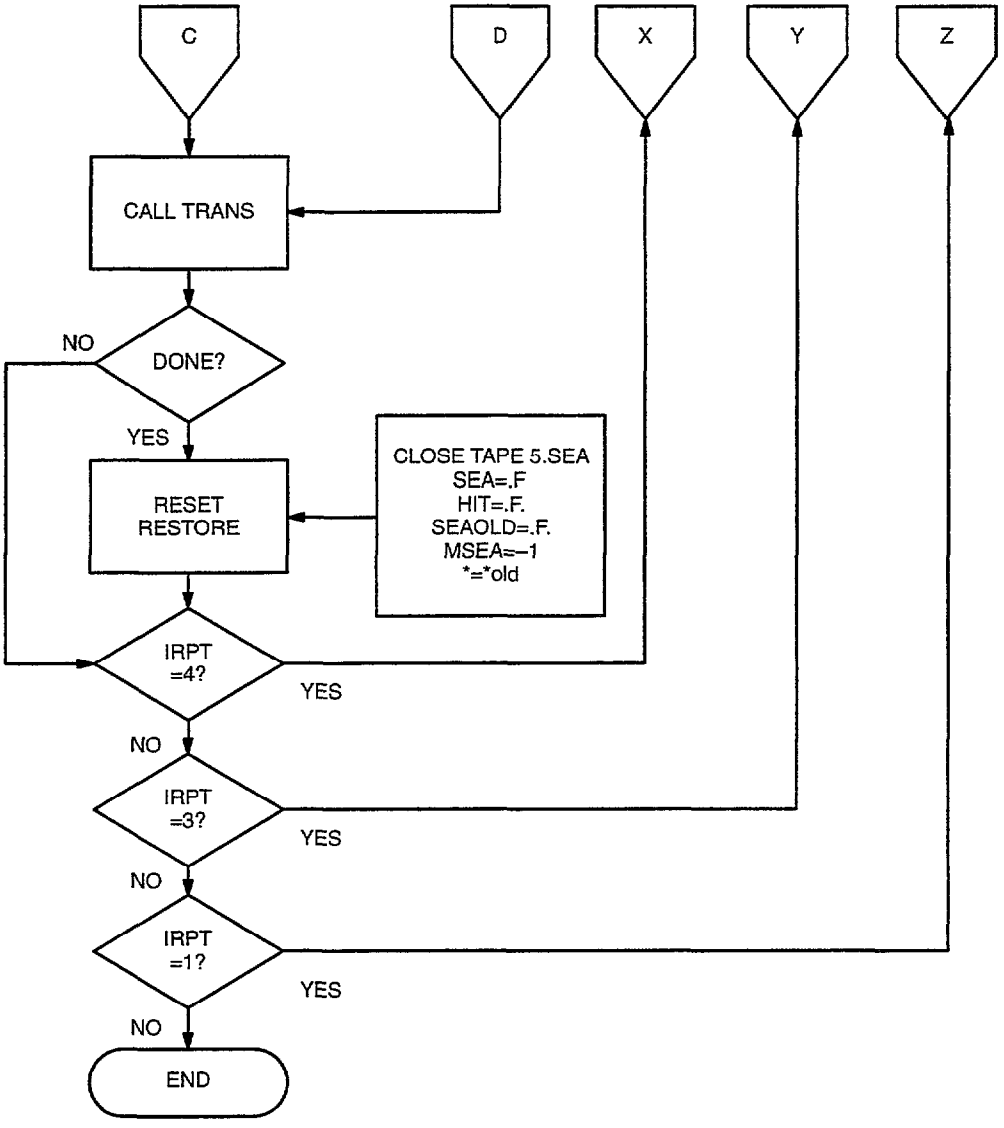

Figure B-1. Detailed flowchart for modified subroutine "DRIVER". (Continued)

```
      SUBROUTINE DRIVER                                                 driv 100
      COMMON RELHUM(34),HSTOR(34),ICH(4),VH(17),TX(63),W(63)            driv 110
C     COMMON              WPATH(68, 63),TBBY(68)                        driv 120
      COMMON IMSMX,WPATH(102,63),TBBY(102),PATM(102),NSPEC,KPOINT(12)   driv 130
      COMMON ABSC(5,47),EXTC(5,47),ASYM(5,47),VX2(47),AWCCON(5)         driv 140
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,ITR,
     +              Isky,Isun,Ipath
      COMMON /CARD1/ MODEL,ITYPE,IEMSCT,M1,M2,M3,IM,NOPRT,TBOUND,SALB   driv 160
     1  ,MODTRN                                                         driv 170
      LOGICAL MODTRN                                                    driv 180
      logical ground                                                    driv 190
      logical lsame                                                     driv 200
      LOGICAL SeaSwitch,Sea,SeaOld,Hit,Done
      COMMON /CARD1A/ M4,M5,M6,MDEF,IRD1,IRD2                           driv 210
      COMMON /CARD2/ IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,   driv 220
     1    RAINRT                                                        driv 230
      COMMON /CARD2A/ CTHIK,CALT,CEXT                                   driv 240
      COMMON /CARD2D/ IREG(4),ALTB(4),IREGC(4)                          driv 250
      COMMON /CARD3/ H1,H2,ANGLE,RANGE,BETA,RE,LEN,Psi,SeaSwitch
      COMMON /Card3A1/ IPARM,IPH,IDAY,ISOURC
      COMMON /Card3A2/ PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
      COMMON /CARD4/ IV1,IV2,IDV,IFWHM,IFILTER
      COMMON /CNSTNS/ PIX,CA,DEG,GCAIR,BIGNUM,BIGEXP                    driv 290
      COMMON /CNTRL/ KMAX,M,IKMAX,NL,ML,IKLO,ISSGEO,IMULT               driv 300
      COMMON /MODEL/ ZM(34),PM(34),TM(34),RFNDX(34),DENSTY(63,34),      driv 310
     1  CLDAMT(34),RRAMT(34),EQLWC(34),HAZEC(34)                        driv 320
      COMMON /SOLS/ AH1(68),ARH(68),                                    driv 330
     1  WPATHS(102,63),PA(68),PRX(68),ATHETA(35),ADBETA(35),LJ(69),
     2  JTURN,ANGSUN,CSZEN(68),TBBYS(102,12),PATMS(102,12)              driv 370
      COMMON /MART/ RHH                                                 driv 380
      COMMON /USRDTA/ NANGLS,ANGF(50),F(4,50)                           driv 390
      COMMON /MDLZ/ HMDLZ(8)                                            driv 400
      COMMON /ZVSALY/ ZVSA(10),RHVSA(10),AHVSA(10),IHVSA(10)            driv 410
      CHARACTER*4 HHAZE,HSEASN,HVULCN,BLANK,HMET,HMODEL,HTRRAD          driv 420
      COMMON /TITL/ HHAZE(5,16),HSEASN(5,2),HVULCN(5,8),BLANK,          driv 430
     1  HMET(5,2),HMODEL(5,8),HTRRAD(6,4)                               driv 440
      COMMON /VSBD/ VSB(10)                                             driv 450
C     COMMON /MNLT/TBBSS(68),TBBMS(34),WPMS(34,63),IMSMX,WPMSS(34,63)   driv 460
      COMMON /PATH/PL(68),QTHETA(68),ITEST,HI,HF,AHT(68),tph(68)        driv 470
      COMMON /AERTM/TAE7,TAE12,TAE13,TAE14,TAE16                        driv 480
      common /graund/gndalt                                             driv 490
      common /small3/small                                              driv 500
      common /solar/lsame                                               driv 510
      PARAMETER (Kr = 216, Kv = 400)
      COMMON /Filters/ FLIST(5,6),
     +                 FILTER1(45), BB1(Kr), FILTER2(54), BB2(Kr),
     +                 FILTER3(39), BB3(Kr), FILTER4(47), BB4(Kr),
     +                 FILTER5(101),BB5(Kr), FILTER6(75), BB6(Kr)
      COMMON /Constants/ pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      COMMON /Geometry/ Tsun,Psun,Tr,Pr
      COMMON /Sea/ Sea,Hit,Msea,TBOUNDold,IEMSCTold
      COMMON /SeaIndex/ Alpha01(100), Alpha02(20),
     +                  Beta01 (100), Beta02 (20)
      logical lfirst                                                    driv 530
      data lfirst/.true./                                               driv 540
      REAL infinity
      CHARACTER*8  Date$, Time$
```

```
      CHARACTER*14 Prog$
      INTEGER*4 Istart, Iend
C     First, get starting time to measure total execution time:
      CALL TIMER(Istart)
C                                                                       driv 550
C     lfirst is true when first solar parameters are read in a series   driv 560
C     of runs involving solar parameters.                               driv 570
C                                                                       driv 580
C*****HDATE AND HTIME CARRY THE DATA AND TIME AND MUST BE DOUBLE         driv 590
C*****PRECISION ON A 32 BIT WORD COMPUTER                               driv 600
C@    DOUBLE PRECISION HDATE,HTIME                                      driv 610
      DIMENSION PLST(68),CSENSV(68),QTHETS(68)                          driv 620
      DATA IRPT / 0 /                                                   driv 630
C*****IRD, IPR, AND IPU ARE UNIT NUMBERS FOR INPUT, OUTPUT, AND         driv 640
C*****IPR1 = OUTPUT OF MOLECULAR TRANSMITTANCE                          driv 650
      DATA        MAXGEO   /    68/                                    driv 660
      small =    2.0                                                    driv 520
      IP4 = 14
      IRD = 5                                                           driv 670
      IPR = 6                                                           driv 680
      IP6 = 16
      IP6S= 26
      IPU = 7                                                           driv 690
      IP7 = 17
      IPR1= 8                                                           driv 700
      IP8 = 18
      IRDS = 29
      ITR = 30
      ISCRCH = 10                                                       driv 710
      ITM   = 31
      Isky  = 32
      Isun  = 33
      Ipath = 34
      OPEN (IRD, FILE='TAPE5',     STATUS='OLD')                        driv 720
      OPEN (IPR, FILE='TAPE6',     STATUS='UNKNOWN')                    driv 730
      OPEN (IP6, FILE='OUT',       STATUS='UNKNOWN')
      OPEN (IPU, FILE='TAPE7',     STATUS='UNKNOWN')                    driv 740
      OPEN (IP7, FILE='TAPE7.PLT',STATUS='UNKNOWN')
      OPEN (IPR1,FILE='TAPE8',     STATUS='UNKNOWN')                    driv 750
      OPEN (IP8, FILE='TAPE8.PLT',STATUS='UNKNOWN')
      OPEN (IP4, FILE='OUT.PLT',   STATUS='UNKNOWN')
      OPEN (ITR, FILE='TRANS.PLT',STATUS='UNKNOWN')
      OPEN (ISCRCH,STATUS='SCRATCH',FORM='UNFORMATTED')                 driv 760
      OPEN (Isky, FILE='Sky.plt', STATUS='UNKNOWN')
      OPEN (Isun, FILE='Sun.plt', STATUS='UNKNOWN')
      OPEN (Ipath,FILE='Path.plt',STATUS='UNKNOWN')
      OPEN (ITM, FILE='TIME',      STATUS='UNKNOWN')

C                                                                       driv 770
C     ALTITUDE PARAMETERS                                               driv 780
C                                                                       driv 790
C     ZMDL  COMMON/MODEL/  THE ALTITUDES USED IN LOWTRAN                driv 800
C     ZCVSA,ZTVSA,ZIVSA  CARD 3.3 LOWTRAN FOR VSA INPUT                 driv 810
C     ZVSA  NINE ALTITUDES GEN BY VSA ROUTINE                           driv 820
C                                                                       driv 830
      Pix=2.0*ASIN(1.0)                                                 driv 840
      CA=Pix/180.                                                       driv 850
```

```
      DEG= 1.0/CA                                                       driv 860
      pi       = Pix
      r2d      = 180./pi
      d2r      = pi/180.
      epsilon  = d2r*0.2659
      delta    = 1.4E-6
      onem     = 1. - delta
      onep     = 1. + delta
      infinity = 999999
      RANGE=0.0                                                         driv 870
C*****GCAIR IS THE GAS CONSTANT FOR AIR IN UNITS OF MB/(GM CM-3 K)       driv 880
      GCAIR = 2.87053E+3                                                driv 890
C*****BIGNUM AND BIGEXP ARE THE LARGEST NUMBER AND THE LARGEST ARGUMENT driv 900
C*****EXP ALLOWED AND ARE MACHINE DEPENDENT. THE NUMBERS USED HERE ARE Fdriv 910
C*****A TYPICAL 32 BIT-WORD COMPUTER.                                   driv 920
      BIGNUM = 1.0E35                                                   driv 930
      BIGEXP = 87.0                                                     driv 940
C     THE VALUES FOR BIGNUM AND BIGEXP FOLLOW THE                       driv 950
C     DESCRIPTION UNDER EXP FUNCTION IN "IBM SYSTEM 360/                driv 960
C     AND SYSTEM 370 FORTRAN IV LANGUAGE"                               driv 970
C     BIGNUM = 4.3E68                                                   driv 980
C     BIGEXP = 174.6                                                    driv 990
      KMAX=63                                                           driv1000
C*****NL IS THE NUMBER OF BOUNDARIES IN THE STANDARD MODELS 1 TO 6       driv1010
C*****BOUNDARY 34 (AT 99999 KM) IS NO LONGER USED                       driv1020
      NL = 33                                                           driv1030
*******************************************************************
      Sea    = .FALSE.
      SeaOld = .FALSE.
      Hit    = .FALSE.
      Msea   = -1
      Done   = .FALSE.
*******************************************************************
C*****CALL TIME AND DATE:                                               driv1040
C*****THE USER MAY WISH TO INCLUDE SUBROUTINES FDATE AND FCLOCK WHICH   driv1050
C*****RETURN THE DATE AND TIME IN MM/DD/YY AND HH.MM.SS FORMATS         driv1060
C*****RESPECTIVELY. THE REQUIRED ROUTINES FOR A CDC 6600 ARE INCLUDED ATdriv1070
C*****THE MAIN PROGRAM IN COMMENT CARDS.                                driv1080
C@    CALL FDATE(HDATE)                                                 driv1090
C@    CALL FCLOCK(HTIME)                                                driv1100
      CALL DATE (Date$)
      CALL TIME (Time$)
C                                                                       driv1110
C*****START CALCULATION                                                 driv1120
C                                                                       driv1130
C                                                                       driv1140
100   DO 10 II = 1,4                                                    driv1150
10    IREG(II) = 0                                                      driv1160
      WRITE(IPR,1000)                                                   driv1170
1000  FORMAT('1',20X,'*****  MODTRAN  *****')                           driv1180
C@    WRITE(IPR,1010) HDATE,HTIME                                       driv1190
1010  FORMAT('1',20X,'*****  MODTRAN  *****',10X,2(1X,A8,1X))           driv1200
      DO 80 I=1,4                                                       driv1210
          DO 80 J=1,40                                                  driv1220
              ABSC(I,J)=0.                                              driv1230
              EXTC(I,J)=0.                                              driv1240
 80   ASYM(I,J)=0.                                                      driv1250
```

```
      JPRT = 0                                                          driv1260
      IKLO=1                                                            driv1270
C                                                                       driv1280
C*****CARD 1                                                            driv1290
C                                                                       driv1300
      READ(IRD,'(L1,I4,12I5,F8.3,F7.2)')MODTRN,MODEL,ITYPE,
     +         IEMSCT,IMULT,M1,M2,M3,M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB driv1340
 1110 FORMAT(13I5,F8.3,F7.2)                                            driv1350
********************************  Save parameters to restore them
      ITYPEold  = ITYPE
      IEMSCTold = IEMSCT
      IMULTold  = IMULT
      If (TBOUND .EQ. 0.) TBOUND = 0.1
      TBOUNDold = TBOUND
      SALBold   = SALB
********************************** in case new geometry cards are
C                                    later introduced via file TAPE5.SEA
      IF (MODTRN) THEN
              Prog$ = 'MODTRAN2 *****'
          ELSE
              Prog$ = 'LOWTRAN7 *****'
      END IF
      WRITE (IP6,  1018) Prog$
1018  FORMAT(15X, '***** SEARAD, A MODIFICATION OF ', A14)
      WRITE (IP6,  1020) Date$, Time$
1020  FORMAT (/, 'DATE:', 1X, A8, T60, 'TIME:', 1X, A8)
      SELECT CASE (IEMSCT)
          CASE (0)
              WRITE (IP6, '(/, 18HTRANSMITTANCE MODE)')
          CASE (1)
              WRITE (IP6, '(/, 21HTHERMAL RADIANCE MODE)')
          CASE (2)
              WRITE (IP6, '(/, 32HTHERMAL PLUS SOLAR RADIANCE MODE)')
          CASE (3)
              WRITE (IP6, '(/, 21HSOLAR IRRADIANCE MODE)')
      END SELECT
C
      SELECT CASE (IMULT)
          CASE (0)
              PRINT *, "IMULT = ", IMULT, ":  BEWARE OF BEN-SHALOM"
              WRITE (IP6, '(/, 22HSINGLE SCATTERING USED)')
          CASE (1)
              WRITE (IP6, '(/, 24HMULTIPLE SCATTERING USED)')
      END SELECT
C
      WRITE(IPR,'(15H0 CARD 1  *****,L1,I4,12I5,F8.3,F7.2)')MODTRN,MODELdriv1380
     1  ,ITYPE,IEMSCT,IMULT,M1,M2,M3,M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB driv1390
 1111 FORMAT('0 CARD 1  *****',13I5,F8.3,F7.2)                          driv1400
C     IF(IMULT .EQ. 1 .AND. NOPRT.EQ. 1) NOPRT = 0                      driv1410
C                                                                       driv1420
C     SET THE NUMBER OF SPECIES TREATED WITH THE 1 CM-1 BAND MODEL.     driv1430
C     ALSO, FOR EACH SPECIES, SET THE POINTER WHICH MAPS THE HITRAN     driv1440
C     NUMERICAL LABEL TO THE LOWTRAN NUMERICAL LABEL.                   driv1450
C                                                                       driv1460
      NSPEC=12                                                          driv1470
      KPOINT( 1)=17                                                     driv1480
      KPOINT( 2)=36                                                     driv1490
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      KPOINT( 3)=31                                                     driv1500
      KPOINT( 4)=47                                                     driv1510
      KPOINT( 5)=44                                                     driv1520
      KPOINT( 6)=46                                                     driv1530
      KPOINT( 7)=50                                                     driv1540
      KPOINT( 8)=54                                                     driv1550
      KPOINT( 9)=56                                                     driv1560
      KPOINT(10)=55                                                     driv1570
      KPOINT(11)=52                                                     driv1580
      KPOINT(12)=11                                                     driv1590
C                                                                       driv1600
      IRD1 = 0                                                          driv1610
      IRD2 = 0                                                          driv1620
      IF (MODEL.EQ.0) LEN = 0                                           driv1630
      IF((MODEL.EQ.0) .OR. (MODEL.EQ.7)) GO TO 110                      driv1640
      IF(M1.EQ.0) M1=MODEL                                              driv1650
      IF(M2.EQ.0) M2=MODEL                                              driv1660
      IF(M3.EQ.0) M3=MODEL                                              driv1670
      IF(M4.EQ.0) M4=MODEL                                              driv1680
      IF(M5.EQ.0) M5=MODEL                                              driv1690
      IF(M6.EQ.0) M6=MODEL                                              driv1700
      IF(MDEF.EQ.0) MDEF=1                                              driv1710
110   CONTINUE                                                          driv1720
      M=MODEL                                                           driv1730
      NPR = NOPRT                                                       driv1740
C*****CARD 2 AEROSOL MODEL                                              driv1750
      READ(IRD,1200)IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,    driv1760
     1  RAINRT,GNDALT                                                   driv1770
1200  FORMAT(6I5,5F10.3)                                                driv1780
      WRITE(IPR,1201)IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,   driv1790
     1  RAINRT,GNDALT                                                   driv1800
      IF(GNDALT.GT.0.) WRITE(IPR,1199)GNDALT                            driv1810
1199  FORMAT(1H0,'  GNDALT =',F10.2)                                    driv1820
      IF(GNDALT.GE.6.0) THEN                                            driv1830
          WRITE(IPR,1202)GNDALT                                         driv1840
          GNDALT=0.                                                     driv1850
      ENDIF                                                             driv1860
1201  FORMAT('0 CARD 2  *****',6I5,5F10.3)                              driv1870
1202  FORMAT('0 GNDALT GT 6.0 RESET TO ZERO, GNDALT WAS',F10.3)         driv1880
C                                                                       driv1890
      IF(VIS.LE.0.0.AND.IHAZE.GT.0) VIS=VSB(IHAZE)                      driv1900
      RHH= 0.                                                           driv1910
      IF(MODEL.EQ.0.OR.MODEL.EQ.7) GO TO 205                            driv1920
      IF((MODEL.EQ.3.OR.MODEL.EQ.5).AND.ISEASN.EQ.0) ISEASN=2           driv1930
C                                                                       driv1940
      IF(IVSA.EQ.1 .AND. IHAZE.EQ.3)                                    driv1950
     1  CALL MARINE(VIS,MODEL,WSS,WHH,ICSTL,EXTC,ABSC,1)                driv1960
      ICH(1)=IHAZE                                                      driv1970
      ICH(2)=6                                                          driv1980
      ICH(3)=9+IVULCN                                                   driv1990
205   IF(RAINRT.EQ.0) GO TO 210                                         driv2000
      WRITE(IPR,1205) RAINRT                                            driv2010
1205  FORMAT('0 RAIN MODEL CALLED, RAIN RATE = ',F9.2,' MM/HR')         driv2020
 210  ICH(4)=18                                                         driv2030
      IF(ICH(1).LE.0)ICH(1)=1                                           driv2040
      IF(ICH(3).LE.9)ICH(3)=10                                          driv2050
      IF(ICLD.GE.1 .AND. ICLD.LE.11) THEN                               driv2060
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          ICH(4)=ICH(3)                                                 driv2070
          ICH(3)=ICH(2)                                                 driv2080
          ICH(2)=ICLD                                                   driv2090
      END IF                                                            driv2100
      IFLGA=0                                                           driv2110
      IFLGT=0                                                           driv2120
      CTHIK=-99.                                                        driv2130
      CALT=-99.                                                         driv2140
      CEXT=-99.                                                         driv2150
      ISEED=-99                                                         driv2160
      IF(ICLD .LT. 18) GO TO 230                                        driv2170
C*****CARD 2A CIRRUS CLOUDS                                             driv2180
      READ(IRD,1210)CTHIK,CALT,CEXT,ISEED                               driv2190
1210  FORMAT(3F10.3,I10)                                                driv2200
      WRITE(IPR,1211)CTHIK,CALT,CEXT,ISEED                              driv2210
1211  FORMAT('0 CARD 2A *****',3F10.3,I10)                              driv2220
230   CONTINUE                                                          driv2230
C*****CARD 2B VERTICAL STRUCTURE ALGORITHM                              driv2240
      ZCVSA=-99.                                                        driv2250
      ZTVSA=-99.                                                        driv2260
      ZINVSA=-99.                                                       driv2270
C                                                                       driv2280
      IF( IVSA. EQ. 0 ) GO TO 240                                       driv2290
      READ (IRD,1230) ZCVSA,ZTVSA,ZINVSA                                driv2300
1230  FORMAT(3F10.3)                                                    driv2310
      WRITE(IPR,1231)ZCVSA,ZTVSA,ZINVSA                                 driv2320
1231  FORMAT('0 CARD 2B *****',3F10.3)                                  driv2330
C                                                                       driv2340
      CALL VSA(IHAZE,VIS,ZCVSA,ZTVSA,ZINVSA,ZVSA,RHVSA,AHVSA,IHVSA)     driv2350
C                                                                       driv2360
C     END OF VSA MODEL SET-UP                                           driv2370
C                                                                       driv2380
240   IF (MODEL.NE.0 .AND. MODEL.NE.7 ) ML=NL                           driv2390
      MDELS=MODEL                                                       driv2400
      DO 250 I=1,5                                                      driv2410
          IF(MDELS.NE.0)HMODEL(I,7)=HMODEL(I,MDELS)                     driv2420
250   IF(MDELS.EQ.0)HMODEL(I,7)=HMODEL(I,8)                             driv2430
C                                                                       driv2440
      IF(IM .EQ. 1) THEN                                                driv2450
          IF((MODEL.EQ.7.AND.IM.EQ.1) .OR.(MODEL.EQ.0)) THEN            driv2460
C                                                                       driv2470
C*****CARD 2C  USER SUPPLIED ATMOSPHERIC PROFILE                        driv2480
C                                                                       driv2490
              READ (IRD,1250) ML,IRD1,IRD2,(HMODEL(I,7),I=1,5)          driv2500
1250          FORMAT(3I5,18A4)                                          driv2510
              WRITE(IPR,1251)ML,IRD1,IRD2,(HMODEL(I,7),I=1,5)           driv2520
              IF(IVSA.EQ.1)CALL RDNSM                                   driv2530
1251          FORMAT('0 CARD 2C *****',3I5,18A4)                        driv2540
          ENDIF                                                         driv2550
      ENDIF                                                             driv2560
      M=7                                                               driv2570
      CALL AERNSM(JPRT,  GNDALT)                                        driv2580
      IF(ICLD .LT. 20) GO TO 260                                        driv2590
C                                                                       driv2600
C     SET UP CIRRUS MODEL                                               driv2610
C                                                                       driv2620
      IF(CTHIK.NE.0) IFLGT=1                                            driv2630
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      IF(CALT.NE.0)  IFLGA=1                                            driv2640
      IF(ISEED.EQ.0) IFLGT=2                                            driv2650
      IF(ISEED.EQ.0) IFLGA=2                                            driv2660
      CALL CIRRUS(CTHIK,CALT,ISEED,CPROB,CEXT)                          driv2670
      WRITE(IPR,1220)                                                   driv2680
1220  FORMAT(15X,'CIRRUS ATTENUATION INCLUDED (N O A A CIRRUS) ')       driv2690
      IF(IFLGT.EQ.0) WRITE(IPR,1221) CTHIK                              driv2700
1221  FORMAT(15X,'CIRRUS ATTENUTION STATISTICALLY DETERMENED TO BE',    driv2710
     1  F10.3,'KM')                                                     driv2720
      IF(IFLGT.EQ.1) WRITE(IPR,1222) CTHIK                              driv2730
1222  FORMAT(15X,'CIRRUS THICKNESS USER DETERMINED TO BE',F10.3,'KM')   driv2740
      IF(IFLGT.EQ.2) WRITE(IPR,1223) CTHIK                              driv2750
1223  FORMAT(15X,'CIRRUS THICKNESS DEFAULTED TO MEAN VALUE OF    ',     driv2760
     1  F10.3,'KM')                                                     driv2770
      IF(IFLGA.EQ.0) WRITE(IPR,1224)CALT                                driv2780
1224  FORMAT(15X,'CIRRUS BASE ALTITUDE STATISCALLY DETERMINED TO BE',   driv2790
     1  F10.3,' KM')                                                    driv2800
      IF(IFLGA.EQ.1) WRITE(IPR,1225) CALT                               driv2810
1225  FORMAT(15X,'CIRRUS BASE ALTITUDE USER DETERMINED TO BE',          driv2820
     1  F10.3,' KM')                                                    driv2830
      IF(IFLGA.EQ.2) WRITE(IPR,1226) CALT                               driv2840
1226  FORMAT(15X,'CIRRUS BASE ALTITUDE DEFAULTED TO MEAN VALUE OF',     driv2850
     1  F10.3,'KM')                                                     driv2860
      WRITE(IPR,1227)CPROB                                              driv2870
1227  FORMAT(15X,'PROBABILTY OF CLOUD OCCURRING IS',F7.1,' PERCENT')    driv2880
C                                                                       driv2890
C       END OF CIRRUS MODEL SET UP                                      driv2900
C                                                                       driv2910
260   CONTINUE                                                          driv2920
C                                                                       driv2930
C                                                                       driv2940
C*****CARD 2E                                                           driv2950
C                                                                       driv2960
      IF((IHAZE.EQ.7).OR.(ICLD.EQ.11)) THEN                             driv2970
C                                                                       driv2980
C*****    CARD 2E USER SUPPLIED AEROSOL EXTINCTION, ABSORPTION, AND     driv2990
C         ASYMMETRY                                                     driv3000
          CALL RDEXA                                                    driv3010
C                                                                       driv3020
      ENDIF                                                             driv3030
300   CONTINUE                                                          driv3040
                                                                        driv3050
      IPARM =-99                                                        driv3060
      IPH   =-99                                                        driv3070
      IDAY  =-99                                                        driv3080
      ISOURC=-99                                                        driv3090
C                                                                       driv3100
      PARM1 =-99.                                                       driv3110
      PARM2 =-99.                                                       driv3120
      PARM3 =-99.                                                       driv3130
      PARM4 =-99.                                                       driv3140
      GMT   =-99.
      PSIPO =  0.
      ANGLEM=-99.                                                       driv3170
      G     =-99.                                                       driv3180
C                                                                       driv3190
C*****CARD 3 GEOMETERY PARAMETERS                                       driv3200
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C                                                                       driv3210
      IF ((SEA) .AND. (Msea .EQ. 0)) THEN
C         the first sky card is next.
C         Set emissivity to zero (TBOUND is already zero) and ITYPE to 3
C         for calculations coming up with cards in TAPE5.SEA:
          ITYPE  = 3
          SALB   = 0.0
      END IF
*** Set mode to sun irradiance (if a sun card will be next) *********
      IF ((Sea) .AND. (IEMSCTold .EQ. 2) .AND. (Msea .EQ. 3)) THEN
          IEMSCT = 3
          IMULT  = 0
          LFIRST = .TRUE.
          LSAME  = .FALSE.
      END IF
      IF (IEMSCT .EQ. 3) GO TO 315                                      driv3220
***** Read introduced geometry cards from file TAPE5.SEA ***************
      IF (SEA) THEN
              READ(IRDS,1312)H1,H2,ANGLE,RANGE,BETA,RO,LEN,Psi,SeaSwitch
           ELSE
              READ (IRD,1312)H1,H2,ANGLE,RANGE,BETA,RO,LEN,Psi,SeaSwitch
      END IF
***** and remove the boundary (in sea AND sky) for a sea calculation ***
      IF (SeaSwitch) TBOUND = 0.1
1312  FORMAT(6F10.3,I5,F10.3,L5)                                        driv3240
      WRITE(IPR,1313)H1,H2,ANGLE,RANGE,BETA,RO,LEN,Psi,SeaSwitch
1313  FORMAT('0 CARD 3  *****',6F10.3,I5,F10.3,L5)                      driv3260
      GO TO 320                                                         driv3270
C
C*****CARD 3 FOR DIRECTLY TRANSMITTED SOLAR RADIANCE (IEMSCT = 3)       driv3280
C
  315 CONTINUE                                                          driv3290
********* Read introduced sun card from file TAPE5.SEA **************
      IF (Sea) THEN
                  READ(IRDS,1316) H1,H2,ANGLE,IDAY,RO,ISOURC,ANGLEM
           ELSE
                  READ(IRD, 1316) H1,H2,ANGLE,IDAY,RO,ISOURC,ANGLEM     driv3300
      END IF
*******************************************************************
 1316 FORMAT(3F10.3,I5,5X,F10.3,I5,F10.3)                               driv3310
      WRITE(IPR,1317) H1,H2,ANGLE,IDAY,RO,ISOURC,ANGLEM                 driv3320
 1317 FORMAT('0 CARD 3   *****',3F10.3,I5,5X,F10.3,I5,F10.3)            driv3330
      ITYPE = 3                                                         driv3340
      RANGE = 0.0                                                       driv3350
      BETA = 0.0                                                        driv3360
      LEN = 0                                                           driv3370
C*****RO IS THE RADIUS OF THE EARTH                                     driv3380
320   RE=6371.23                                                        driv3390
C      *********  ERRATA JULY 25                                        driv3400
          IF(H1. LT. ZM(1)  ) THEN                                      driv3410
          WRITE(IPR,905) H1,ZM(1)                                       driv3420
905       FORMAT('  H1 LESS THAN FIRST ALT RESET  ',/                   driv3430
     X    ' H1 WAS ',F10.2,' 1ST ALT = ',F10.2)                         driv3440
           H1 = ZM(1)                                                   driv3450
      ENDIF                                                             driv3460
C        *********  END  ERRATA                                         driv3470
      H1S    = H1                                                       driv3480
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      H2S    = H2                                                      driv3490
      ANGLES = ANGLE                                                   driv3500
      RANGS  = RANGE                                                   driv3510
      BETAS  = BETA                                                    driv3520
      ITYPES =ITYPE                                                    driv3530
      LENS   = LEN                                                     driv3540
      IF (MODEL.EQ.0) RO = RE                                          driv3560
      IF (MODEL.EQ.1) RE=6378.39                                       driv3570
      IF (MODEL.EQ.4) RE=6356.91                                       driv3580
      IF (MODEL.EQ.5) RE=6356.91                                       driv3590
      IF (RO.GT.0.0) RE=RO                                             driv3600
C                                                                      driv3610
      IF (IEMSCT.NE.2) GO TO 330                                       driv3620
C                                                                      driv3630
C*****CARD 3A1                                                         driv3640
C                                                                      driv3650
      IF (SEA) THEN
                 READ(IRDS,1320) IPARM,IPH,IDAY,ISOURC
            ELSE
                 READ(IRD,1320)  IPARM,IPH,IDAY,ISOURC
      END IF
1320  FORMAT(4I5)
      WRITE(IPR,1321) IPARM,IPH,IDAY,ISOURC
1321  FORMAT('0 CARD 3A1*****',4I5)
C                                                                      driv3700
C*****CARD 3A2                                                         driv3710
C                                                                      driv3720
      IF (SEA) THEN
                 READ(IRDS,1322) PARM1, PARM2, PARM3, PARM4,
     +                           GMT,PSIPO,ANGLEM,G
            ELSE
                 READ(IRD,1322)  PARM1, PARM2, PARM3, PARM4,
     +                           GMT,PSIPO,ANGLEM,G
      END IF
1322  FORMAT(8F10.3)                                                   driv3740
      WRITE(IPR,1323)PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
1323  FORMAT('0 CARD 3A2*****',8F10.3)                                 driv3760
C                                                                      driv3770
CSSISSISSISSISSI  CHANGES  BEGIN.                                      driv3780
c                                                                      driv3790
      REWIND(ISCRCH)                                                   driv3800
C                                                                      driv3810
      IF (LFIRST .AND. IMULT .EQ. 1) THEN                              driv3820
C                                                                      driv3830
C        SAVE SOLAR PARAMETERS FOR COMPARING LATER.                    driv3840
C        NOTE THAT LFIRST IS TRUE AND IMULT (MULTIPLE SOLAR SCATTERING) driv3850
         LFIRST = .FALSE.                                              driv3860
         CALL SVSOLA(IPARM,IPH,IDAY,ISOURC,PARM1,PARM2,PARM3,PARM4,    driv3870
     $        GMT,PSIPO,ANGLEM,
     $        ISAVE1,ISAVE2,ISAVE3,ISAVE4,SAVE1,SAVE2,SAVE3,SAVE4,     driv3890
     $        SAVE5,SAVE6,SAVE7)                                       driv3900
         LSAME = .FALSE.                                               driv3910
C                                                                      driv3920
      ELSEIF (IMULT .EQ. 1 .AND. IRPT .EQ. 3) THEN                     driv3930
C                                                                      driv3940
C        NOW COMPARE SOLAR PARAMETERS; LSAME IS TRUE IF THEY MATCH.    driv3950
         CALL COMPAR(IPARM,IPH,IDAY,ISOURC,PARM1,PARM2,PARM3,PARM4,    driv3960
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     $         GMT,PSIPO,ANGLEM,
     $         ISAVE1,ISAVE2,ISAVE3,ISAVE4,SAVE1,SAVE2,SAVE3,SAVE4,      driv3980
     $         SAVE5,SAVE6,SAVE7,LSAME)                                  driv3990
        CALL SVSOLA(IPARM,IPH,IDAY,ISOURC,PARM1,PARM2,PARM3,PARM4,      driv4000
     $         GMT,PSIPO,ANGLEM,
     $         ISAVE1,ISAVE2,ISAVE3,ISAVE4,SAVE1,SAVE2,SAVE3,SAVE4,      driv4020
     $         SAVE5,SAVE6,SAVE7)                                        driv4030
      ELSE                                                              driv4040
C                                                                       driv4050
C        GET READY FOR ANOTHER POSSIBLE FORTHCOMING SERIES OF MULTIPLE  driv4060
C        SOLAR SCATTERING RUNS.                                         driv4070
         LFIRST = .TRUE.                                                driv4080
         LSAME = .FALSE.                                                driv4090
      ENDIF                                                             driv4100
C                                                                       driv4110
CSSISSISSISSISSI  CHANGES  END                                          driv4120
C                                                                       driv4130
      IF(IPH. EQ . 0) THEN                                              driv4140
            IF(G. GE.  1.0) G =  .9999                                  driv4150
            IF(G. LE. -1.0) G = -.9999                                  driv4160
      ENDIF                                                             driv4170
      IF (IPH.NE.1) GO TO 330                                           driv4180
C                                                                       driv4190
C*****CARD 3B1 USER DEFINED PHASE FUNCTION                              driv4200
C                                                                       driv4210
C*****READ USER DEFINED PHASE FUNCTION                                  driv4220
C                                                                       driv4230
      READ(IRD,1326)NANGLS                                              driv4240
1326  FORMAT(I5)                                                        driv4250
      WRITE(IPR,1327)NANGLS                                             driv4260
1327  FORMAT(' CARD 3B1*****',I5)                                       driv4270
C                                                                       driv4280
C*****CARD 3B2                                                          driv4290
C                                                                       driv4300
      READ(IRD,1328)(ANGF(I),F(1,I),F(2,I),F(3,I),F(4,I),I=1,NANGLS)    driv4310
1328  FORMAT(5E10.3)                                                    driv4320
      WRITE(IPR,1329)(ANGF(I),F(1,I),F(2,I),F(3,I),F(4,I),I=1,NANGLS)   driv4330
1329  FORMAT('0 CARD 3B2*****',5E10.3)                                  driv4340
C                                                                       driv4350
  330 CONTINUE                                                          driv4360
C                                                                       driv4370
      IF (IRPT .EQ. 3) THEN                                             driv4390
          IF(IPARM .EQ. 1) CALL SUBSOL (PARM3,PARM4,GMT,IDAY)           driv4400
          GO TO 555                                                     driv4410
      END IF                                                            driv4420
C                                                                       driv4430
C*****CARD 4 WAVENUMBER                                                 driv4440
C                                                                       driv4450
  400 CONTINUE                                                          driv4460
      IF (.NOT. SEA) THEN
          READ(IRD,'(5I10)')IV1,IV2,IDV,IFWHM,IFILTER
      END IF
  401 WRITE(IPR,'(15H0 CARD 4  *****,5I10)')IV1,IV2,IDV,IFWHM,IFILTER
      IF(IDV . LE. 0)THEN                                               driv4530
         PRINT *,' ERROR IN IDV ',IDV                                   driv4540
         IDV = 1                                                        driv4550
      ENDIF                                                             driv4560
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      IF(IFWHM . LE. 0)THEN                                             driv4570
         PRINT *,' ERROR IN IFWHM ',IFWHM                               driv4580
         IFWHM = 2                                                      driv4590
      ENDIF                                                             driv4600
      IF ((IFILTER .GE. 1) .AND. (IFILTER .LE. 6)) THEN
C             reset wavenumbers to span filter passband:
              W1  = FLIST(1, IFILTER)
              W2  = FLIST(2, IFILTER)
              IV1 = INT(1E4/W2) - IDV
              IV2 = INT(1E4/W1) + IDV
          ELSE
C             filter data are absent.  Reset to no filter at all:
              IFILTER = 0
      END IF
      IF (SeaSwitch) THEN
C         Check number of wavenumber steps. Reset, if necessary, to
C         prevent sea arrays from overflowing in "TRANS".
          Nv = (IV2 - IV1)/IDV
          IF (Nv .GE. Kv) IDV = (IV2 - IV1)/Kv + 1
      END IF
      WRITE(IP4, '(1H\, T20, 22HOUTPUT FILE FOR FILTER, I2,
     +             2H: , I5, 3H TO, I5, 9H CM-1 IN , I2,
     +             12H CM-1 STEPS., /1H\)') IFILTER, IV1, IV2, IDV
      WRITE(IP4, '(1H\, T65, 18H FILTERED RADIANCE)')
      WRITE(IP4, '(45H\              ELEV.    ANGLE  RANGE    TRANS ,
     +        T49, 34H PATH      SEA       SKY       SUN,
     +        T88, 15H  TOTAL   TEMP.)')
      WRITE(IP4, '(45H\            (mrad)    (deg)   (km)      (--) ,
     +        T68,13H (W m-2 sr-1), T100, 3H(C), /)')
      IF(IHAZE.EQ.3) THEN                                               driv4610
C         IF(V1.LT.250.0 .OR. V2.LT.250.0) THEN                         driv4620
          IF(IV1.LT.250)THEN                                            driv4630
              IHAZE=4                                                   driv4640
              WRITE (IPR,1203)                                          driv4650
          ENDIF                                                         driv4660
1203      FORMAT('0**WARNING** NAVY MODEL IS NOT USABLE BELOW 250CM-1', driv4670
     1    /,10X,' PROGRAM WILL SWITCH TO IHAZE=4 LOWTRAN 5 MARITIME',//)driv4680
      END IF                                                            driv4690
      IF (IRPT.EQ.4)  GO TO 550                                         driv4700
cc    IF (IRPT.EQ.-4) GO TO 560                                         driv4710
500   CONTINUE                                                          driv4720
      IF (IRPT.EQ.3) GO TO 555                                          driv4730
      WRITE(IPR,1410) (HTRRAD(I1,IEMSCT+1),I1=1,6)                      driv4740
1410  FORMAT('0 PROGRAM WILL COMPUTE ',6A4)                             driv4750
      IF(ISOURC .EQ. 1) WRITE(IPR,1204)                                 driv4760
1204  FORMAT('   LUNAR SOURCE ONLY  ')                                 driv4770
      IF (IMULT .EQ. 1) THEN                                            driv4780
          IF(IEMSCT.EQ.0 .OR. IEMSCT.EQ.3 ) THEN                        driv4790
              WRITE(IPR,1411)                                           driv4800
1411          FORMAT('0 MULTIPLE SCATTERING HAS BEEN TURNED OFF ')      driv4810
              WRITE (IP6,
     +          '(/, 39HMULTIPLE SCATTERING HAS BEEN TURNED OFF)')
              IMULT=0                                                   driv4820
          ELSE                                                          driv4830
              WRITE(IPR,1412)                                           driv4840
          END IF                                                        driv4850
      END IF                                                            driv4860
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1412  FORMAT('0 CALCULATIONS WILL BE DONE USING MULTIPLE SCATTERING ')  driv4870
      MDEL=MODEL                                                        driv4880
      IF(MDEL.EQ.0)MDEL=8                                               driv4890
      MM1=MDEL                                                          driv4900
      MM2=MDEL                                                          driv4910
      MM3=MDEL                                                          driv4920
      IF(M1.NE.0)MM1=M1                                                 driv4930
      IF(M2.NE.0)MM2=M2                                                 driv4940
      IF(M3.NE.0)MM3=M3                                                 driv4950
      IF(MODEL.EQ.0) GO TO 510                                          driv4960
      WRITE(IPR,1500) MM1,(HMODEL(I1,MM1),I1=1,5),MM2,(HMODEL(I2,MM2),  driv4970
     1  I2=1,5),MM3,(HMODEL(I3,MM3),I3=1,5)                             driv4980
1500  FORMAT('0 ATMOSPHERIC MODEL',/,                                   driv4990
     1  10X,'TEMPERATURE = ',I4,5X,5A4,/,                               driv5000
     1  10X,'WATER VAPOR = ',I4,5X,5A4,/,                               driv5010
     1  10X,'OZONE       = ',I4,5X,5A4)                                 driv5020
      WRITE(IPR,1501) M4,M5,M6,MDEF                                     driv5030
1501  FORMAT(20X,'  M4 = ',I5,' M5 = ',I5,' M6 = ',I5,' MDEF = ' ,I5)   driv5040
C                                                                       driv5050
510   IF(JPRT.EQ.0) GO TO 520                                           driv5060
      IF(ISEASN.EQ.0)ISEASN=1                                           driv5070
      IF(IVULCN.LE.0) IVULCN=1                                          driv5080
      IHVUL=IVULCN+10                                                   driv5090
      IF( IVULCN .EQ. 6) IHVUL = 11                                     driv5100
      IF( IVULCN .EQ. 7) IHVUL = 11                                     driv5110
      IF( IVULCN .EQ. 8) IHVUL = 13                                     driv5120
      IHMET=1                                                           driv5130
      IF(IVULCN.GT.1)IHMET=2                                            driv5140
      IF(IHAZE.EQ.0) GO TO 520                                          driv5150
      WRITE(IPR,1510)(HHAZE(I,IHAZE),I=1,5),VIS,(HHAZE(I2,6),I2=1,5),   driv5160
     1  (HHAZE(II,6),II=1,5),(HSEASN(IA,ISEASN),IA=1,5),                driv5170
     2  (HHAZE(I3,IHVUL),I3=1,5),                                       driv5180
     3  (HVULCN(IB,IVULCN),IB=1,5),(HSEASN(IC,ISEASN),IC=1,5),          driv5190
     4  (HHAZE(I4,16),I4=1,5),(HMET(I5,IHMET),I5=1,5)                   driv5200
1510  FORMAT('0 AEROSOL MODEL',/,10X,'REGIME',                          driv5210
     A  T35,'AEROSOL TYPE',T60,'PROFILE',T85,'SEASON',/,/,              driv5220
     B  10X,'BOUNDARY LAYER (0-2 KM)',T35,5A4,T60,F5.1,                 driv5230
     C  ' KM VIS AT SEA LEVEL',/,10X,'TROPOSPHERE  (2-10KM)',T35,       driv5240
     D  5A4,T60,5A4,T85,5A4,/,10X,'STRATOSPHERE (10-30KM)',             driv5250
     E  T35,5A4,T60,5A4,T85,5A4,/,10X,'UPPER ATMOS (30-100KM)',         driv5260
     F  T35,5A4,T60,5A4)                                                driv5270
520   CONTINUE                                                          driv5280
      IF(ITYPE.EQ.1) THEN
          WRITE(IPR,1515) H1,RANGE                                      driv5290
          WRITE(IP6,1515) H1,RANGE
      END IF
1515  FORMAT(/,'  HORIZONTAL PATH',//,
     1  8X,'ALTITUDE = ',F10.3,' KM',/,
     2  8X,'RANGE    = ',F10.3,' KM',/)                                 driv5310
      IF(ITYPE.EQ.2) THEN
          WRITE(IPR,1516) H1,H2,ANGLE,RANGE,BETA,LEN                    driv5320
          WRITE(IP6,1516) H1,H2,ANGLE,RANGE,BETA,LEN
      END IF
1516  FORMAT(/,'  SLANT PATH, H1 TO H2',//,
     1  10X,'H1     = ',F10.3,' KM',/,10X, 'H2     = ',F10.3,' KM',/,  driv5340
     2  10X,'ANGLE  = ',F10.3,' DEG',/,10X,'RANGE  = ',F10.3,' KM',/,  driv5350
     3  10X,'BETA   = ',F10.3,' DEG',/,10X,'LEN    = ',I6,/)            driv5360
```

```
      IF(ITYPE.EQ.3) THEN
          WRITE(IPR,1517) H1,H2,ANGLE                                   driv5370
          WRITE(IP6,1517) H1,H2,ANGLE
      END IF
1517  FORMAT(/,'SLANT PATH TO SPACE',//,
     1  10X, 'H1      = ',F10.3,' KM',/,
     2  10X, 'HMIN    = ',F10.3,' KM',/,                                 driv5390
     3  10X, 'ANGLE   = ',F10.3,' DEG',/)                                driv5400
      IF (IEMSCT.NE.2) GO TO 550                                        driv5410
C                                                                       driv5420
C*****INTREPRET SOLAR SCATTERING PARAMETERS                             driv5430
C                                                                       driv5440
C                                                                       driv5450
      IF (IPARM.EQ.1) CALL SUBSOL (PARM3,PARM4,GMT,IDAY)                driv5460
C                                                                       driv5470
      WRITE (IPR,1530)                                                  driv5480
1530  FORMAT('0 SINGLE SCATTERING CONTROL PARAMETERS SUMMARY '/)        driv5490
      IF(IPARM.NE.2) WRITE (IPR,1532) PARM1,PARM2,PARM3,PARM4,GMT,PSIPO
     1,IDAY                                                             driv5510
1532  FORMAT(10X,'OBSERVER LATITUDE =',T35,F10.2,' DEG NORTH OF EQUATOR'driv5520
     1  ,/,10X,'OBSERVER LONGITUDE=',T35,F10.2,' DEG WEST OF GREENWICH',driv5530
     2  /,10X,'SUBSOLAR LATITUDE =',T35,F10.2,' NORTH OF EQUATOR',/,    driv5540
     3  10X,'SUBSOLAR LONGITUDE =',T35,F10.2,' WEST OF GREENWICH',/,    driv5550
     4  10X,'TIME (<0 IS UNDEF)=',T35,F10.3,' GREENWICH TIME',/,        driv5560
     5  10X,'PATH AZIMUTH =',T35,F10.3,' DEG EAST OF NORTH',/,          driv5570
     6  10X,'DAY OF YEAR =',T35,I10)                                    driv5580
      IF (IPARM.EQ.2) WRITE (IPR,1534)PARM1,PARM2,GMT,PSIPO,IDAY
1534  FORMAT(10X,'RELATIVE AZIMUTH =',T35,F10.3,' DEG EAST OF NORTH',/, driv5600
     1  10X,'SOLAR ZENITH =',T35,F10.3,' DEG ',/,                       driv5610
     2  10X,'TIME (<0 UNDEF) =',T35,F10.3,' GREENWICH TIME',/,          driv5620
     3  10X,'PATH AZIMUTH =',T35,F10.3,' DEG EAST OF NORTH',/,          driv5630
     4  10X,'DAY OF THE YEAR =',T35,I6)                                 driv5640
      IF (ISOURC.EQ.0) WRITE (IPR,1535)                                 driv5650
1535  FORMAT('0 EXTRATERRESTIAL SOURCE IS THE SUN')                     driv5660
      IF (ISOURC.EQ.1) WRITE (IPR,1536) ANGLEM                          driv5670
1536  FORMAT('0 EXTRATERRESTIAL SOURCE IS THE MOON, MOON PHASE ANGLE =',driv5680
     1  F10.2,' DEG')                                                   driv5690
      IF (IPH.EQ.0) WRITE (IPR,1538) G                                  driv5700
1538  FORMAT('0 H-G PHASE FUNCTION ,G=',F10.3)                          driv5710
      IF (IPH.EQ.1) WRITE (IPR,1540)                                    driv5720
1540  FORMAT('0 USER SUPPLIED PHASE FUNCTION')                          driv5730
      IF (IPH.EQ.2) WRITE (IPR,1542)                                    driv5740
1542  FORMAT('0 PHASE FUNCTION FROM MIE DATA BASE')                     driv5750
550   CONTINUE                                                          driv5760
C     V1 =FLOAT(INT(V1/5.0+0.1))*5.0                                    driv5770
C     V2 =FLOAT(INT(V2/5.0+0.1))*5.0                                    driv5780
C     TO AVOID THE DIFFICULTY FOR V1=0                                  driv5790
      ALAM1= 99999.98                                                   driv5800
C     IF(V1.GT.0.)ALAM1=10000./V1                                       driv5810
C     ALAM2=10000./V2                                                   driv5820
C     IF(DV.LT.5.)DV=5.                                                 driv5830
C     DV=FLOAT(INT(DV/5+0.1))*5.0                                       driv5840
C     WRITE (IPR,1555) V1,ALAM1,V2,ALAM2,DV                             driv5850
C1555 FORMAT('0 FREQUENCY RANGE '/,10X,' V1 = ',F12.1,' CM-1  (',       driv5860
C    1  F10.2,' MICROMETERS)',/,10X,' V2 = ',F12.1,' CM-1  (',F10.2,    driv5870
C    2  ' MICROMETERS)',/10X,' DV = ',F12.1,' CM-1')                    driv5880
      IF(.NOT.MODTRN)THEN                                               driv5890
```

```
          IV1=5*(IV1/5)                                                 driv5900
          IV2=5*((IV2+4)/5)                                             driv5910
          IDV=5+5*((IDV-5)/5)                                           driv5920
      ENDIF                                                             driv5930
      IF(IV2.LT.IV1+IDV)THEN                                            driv5940
          WRITE(IPR,'(/41H IV2 WAS LESS THAN IV1 + IDV AND HAS BEEN,    driv5950
     1      6H RESET,/)')                                               driv5960
          IV2=IV1+IDV                                                   driv5970
      ENDIF                                                             driv5980
CRZ      IF(MODTRN)THEN                                                 driv5990
CRZ          IV1SAV=IV1                                                 driv6000
CRZ          IV2SAV=IV2                                                 driv6010
CRZ          IDVSAV=IDV                                                 driv6020
CRZ      ENDIF                                                          driv6030
      IF(IV1.NE.0)ALAM1=10000./IV1                                      driv6040
      ALAM2=10000./IV2                                                  driv6050
      IF(IFWHM.LT.1)IFWHM=1                                             driv6060
      IF(IFWHM.GT.50)IFWHM=50                                           driv6070
      WRITE(IPR,'(17H0 FREQUENCY RANGE,/10X,8H   IV1 =,I10,8H CM-1  (,  driv6080
     1  F10.2,13H MICROMETERS),/10X,8H   IV2 =,I10,8H CM-1  (,F10.2,    driv6090
     2  13H MICROMETERS),/10X,8H   IDV =,I10,5H CM-1,/10X,8H IFWHM =,   driv6100
     3  I10,5H CM-1)')IV1,ALAM1,IV2,ALAM2,IDV,IFWHM                     driv6110
      WRITE(IP6,'(15HFREQUENCY RANGE,//10X,9HIV1     =,I11,8H CM-1  (,
     1  F7.2,13H MICROMETERS),/10X,9HIV2     =,I11,8H CM-1  (,F7.2,
     2  13H MICROMETERS),/10X,9HIDV     =,I11,5H CM-1,/10X,9HIFWHM   =,
     3  I11,5H CM-1,/10X,9HIFILTER =,I11)')
     4  IV1,ALAM1,IV2,ALAM2,IDV,IFWHM,IFILTER
C                                                                       driv6120
C*****LOAD ATMOSPHERIC PROFILE INTO /MODEL/                             driv6130
C                                                                       driv6140
      CALL STDMDL                                                       driv6150
C                                                                       driv6160
C    DEFINE COUNTER ITEST TO PREVENT ZENITH ANGLE QTHETA AND LAYER      driv6170
C    PATH LENGTH PL FROM BEING CHANGED DURING SOLAR CALCULATIONS        driv6180
555   DO 15 I=1,102                                                     driv6190
          DO 15 J=1,KMAX                                                driv6200
              WPATH(I,J)=0.0                                            driv6210
   15 WPATHS(I,J)=0.0                                                   driv6220
C                                                                       driv6230
      ITEST=0                                                           driv6240
C                                                                       driv6250
      IF (IMULT .EQ. 1) THEN                                            driv6260
          H1=ZM(1)                                                      driv6270
          H2=ZM(ML)                                                     driv6280
          ITYPE = 2                                                     driv6290
          ANGLE = 0.                                                    driv6300
          BETA = 0.                                                     driv6310
          RANGE =0.                                                     driv6320
          ISSGS = ISSGEO                                                driv6330
          ISSGEO = 0                                                    driv6340
C         CALL GEO (IERROR,BENDNG,MAXGEO)                               driv6350
          MSOFF=68                                                      driv6360
          CALL GEO (IERROR,BENDNG,MAXGEO,MSOFF)                         driv6370
          W15SV = W(15)                                                 driv6380
C                                                                       driv6390
C         W15SV  IS THE REL HUM FROM 0 TO SPACE                         driv6400
C         THIS REL HUM MAY BE DIFFERENT THAN THE PATH  REL HUM          driv6410
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C         WHEN REL HUM ARE DIFFERENT THE ANSWER CAN CHANGE                  driv6420
C                                                                           driv6430
          ISSGEO = ISSGS                                                    driv6440
          IMSMX=IKMAX                                                       driv6450
          DO 35 N=1,IMSMX                                                   driv6460
C             PLST(N)=PL(N)                                                 driv6470
C             DO 35 K=1,KMAX                                                driv6480
C35       WPMS(N,K)=WPATH(N,K)                                              driv6490
   35     PLST(N)=PL(N)                                                     driv6500
C                                                                           driv6510
          IF(IEMSCT.EQ.2)  THEN                                             driv6520
              CALL SSGEO(IERROR,IPH,IPARM,PARM1,PARM2,                      driv6530
C    1          PARM3,PARM4,PSIPO,G,MAXGEO)                                driv6540
     1           PARM3,PARM4,PSIPO,G,MAXGEO,MSOFF)                          driv6550
              DO 30 N=1,IKMAX                                               driv6560
                  CSENSV(N) = ABS(CSZEN(N))                                 driv6570
                  IF(CSENSV(N) .LT. 0.0174) CSENSV(N) = 0.0174              driv6580
   30         CONTINUE                                                      driv6590
C             DO 45 N=1,ML                                                  driv6600
C                 DO 45 K=1,KMAX                                            driv6610
C                     WPMSS(N,K)=WPATHS(N,K)                                driv6620
C  45         CONTINUE                                                      driv6630
          ENDIF                                                             driv6640
      ENDIF                                                                 driv6650
      H1      = H1S                                                         driv6660
      H2      = H2S                                                         driv6670
      ANGLE   = ANGLES                                                      driv6680
      RANGE   = RANGS                                                       driv6690
      BETA    = BETAS                                                       driv6700
      ITYPE   = ITYPES                                                      driv6710
      LEN     = LENS                                                        driv6720
C*****TRACE PATH THROUGH THE ATMOSPHERE AND CALCULATE ABSORBER AMOUNTS      driv6730
C                                                                           driv6740
      ISSGEO=0                                                              driv6750
      MSOFF=0                                                               driv6780
***** Save original value of SEA (false if earth not yet hit) ******
C
      SEAold = SEA
      CALL GEO(IERROR,BENDNG,MAXGEO,MSOFF)                                  driv6790
C
***** and set HIT true if the earth has been hit within FNDHMN: *****
      HIT = ((.NOT. SEAold) .AND. SEA)
      IF (HIT) THEN
          WRITE (IP6, '(/, 6HSEA AT, F7.2,
     +    31H K REPLACES BLACK BODY BOUNDARY,//,10X,9HUPWIND  =,F11.3,
     +    26H DEG EAST OF LINE OF SIGHT)') TBOUNDold, Psi
C         calculate geometry from point of view of the footprint
          IF (IEMSCTold .EQ. 1) Pr = Psi*d2r + pi
          IF ((IPARM .EQ. 0) .OR. (IPARM .EQ. 1)) THEN
                  ThetaO = PARM1
                  PhiO   = PARM2
                  ThetaS = PARM3
                  PhiS   = PARM4
                  CALL Foot(ThetaO,PhiO,ThetaS,PhiS,PsiPO,Beta,Psi)
              ELSE IF (IPARM .EQ. 2) THEN
                  Psi0   = PARM1
                  Del0   = PARM2
```

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                CALL SunFoot(Psi0,Del0,PsiPO,Beta,Psi)
            END IF
C           and issue new sky (and sun) cards in file 'TAPE5.SEA'
            CALL Card
        END IF
        IF ((SeaSwitch) .AND. (.NOT. Sea)) THEN
            WRITE (IP6, '(/, 13HTBOUND SET TO, F7.2,
     +      17H K FOR MARINE SKY)') TBOUND
        END IF
C
        CALL AERTMP                                                     driv6800
        IF(IMULT. NE. 1) W15SV = W(15)                                  driv6810
C                                                                       driv6820
C    SAVE TEMPERATURE AND PATH INFO FOR LATER USE                       driv6830
C                                                                       driv6840
        IF(IMULT .EQ. 1)  THEN                                          driv6850
            DO 25 N=1,IKMAX                                             driv6860
   25       QTHETS(N) = QTHETA(N)                                       driv6870
        ENDIF                                                           driv6880
C                                                                       driv6890
        IF(IERROR.GT.0) GO TO 630                                       driv6900
        IF(IEMSCT.EQ.3 .AND. IERROR.EQ. -5) GO TO 557                   driv6910
        GO TO 558                                                       driv6920
  557   CONTINUE                                                        driv6930
        WRITE(IPR,1557)                                                 driv6940
 1557   FORMAT('0 DIRECT PATH TO SUN INTERSECTS THE EARTH: SKIP TO ',   driv6950
      1     'NEXT CASE')                                                driv6960
        GO TO 630                                                       driv6970
  558   CONTINUE                                                        driv6980
C                                                                       driv6990
        IF(IEMSCT.EQ.2)CALL SSGEO(IERROR,IPH,IPARM,PARM1,PARM2,PARM3,   driv7000
C     1  PARM4,PSIPO,G,MAXGEO)                                          driv7010
      1  PARM4,PSIPO,G,MAXGEO,MSOFF)                                     driv7020
        W(15) = W15SV                                                   driv7030
C                                                                       driv7040
C       W15SV IS THE REL HUM  (FOR MULT SCAT THIS MAY BE DIFFERENT      driv7050
C       FROM PATH REL HUM)                                              driv7060
C                                                                       driv7070
C       THE SECOND CALL TO SSGEO IS TO GET THE CORRECT ANGLES FOR       driv7080
C       PHASE FUNCTIONS                                                 driv7090
C                                                                       driv7100
C       SAVE SOLAR PATH INFORMATION                                     driv7110
C                                                                       driv7120
        IF(IERROR.GT.0) GO TO 630                                       driv7130
C                                                                       driv7140
        IF(IMULT.EQ.1) THEN                                             driv7150
            DO 60 IK = 1,IMSMX                                          driv7160
                PL(IK)=PLST(IK)                                         driv7180
                IF(IEMSCT.EQ.2) CSZEN(IK)=CSENSV(IK)                    driv7190
60          CONTINUE                                                    driv7200
                DO 70 IK = 1,IKMAX
70              QTHETA(IK) = QTHETS(IK)                                 driv7170
        ENDIF                                                           driv7210
C                                                                       driv7220
C*****LOAD AEROSOL EXTINCTION, ABSORPTION, AND ASYMMETRY COEFFICIENTS   driv7230
C                                                                       driv7240
        CALL EXABIN                                                     driv7250
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C                                                                       driv7260
C*****WRITE HEADER DATA TO TAPE 7                                       driv7270
C                                                                       driv7280
C560  WRITE(IPU,1110)MODEL,ITYPE,IEMSCT,IMULT,M1,M2,M3,                 driv7290
C    1  M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB                              driv7300
 560  WRITE(IPU,'(L1,I4,12I5,F8.3,F7.2)')MODTRN,MODEL                   driv7310
     1  ,ITYPE,IEMSCT,IMULT,M1,M2,M3,M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB driv7320
C     WRITE(IPR1,1110)MODEL,ITYPE,IEMSCT,IMULT,M1,M2,M3,                 driv7330
C    1  M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB                              driv7340
      WRITE(IPR1,'(L1,I4,12I5,F8.3,F7.2)')MODTRN,MODEL                  driv7350
     1  ,ITYPE,IEMSCT,IMULT,M1,M2,M3,M4,M5,M6,MDEF,IM,NOPRT,TBOUND,SALB driv7360
      WRITE(IPU,1200)IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,   driv7370
     1  RAINRT,GNDALT                                                   driv7380
      WRITE(IPR1,1200)IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,  driv7390
     1  RAINRT,GNDALT                                                   driv7400
      WRITE(IPU,1210) CTHIK,CALT,CEXT,ISEED                             driv7410
      WRITE(IPR1,1210) CTHIK,CALT,CEXT,ISEED                            driv7420
      WRITE(IPU,1230)ZCVSA,ZTVSA,ZINVSA                                 driv7430
      WRITE(IPR1,1230)ZCVSA,ZTVSA,ZINVSA                                driv7440
      WRITE(IPU,1255) ML,(HMODEL(I,7),I=1,5)                            driv7450
      WRITE(IPR1,1255) ML,(HMODEL(I,7),I=1,5)                           driv7460
1255  FORMAT( I5,18A4)                                                  driv7470
      IF(MODEL.NE.0)WRITE (IPU,1312) H1,H2,ANGLE,RANGE,BETA,RO,LEN      driv7480
      IF(MODEL.NE.0)WRITE (IPR1,1312) H1,H2,ANGLE,RANGE,BETA,RO,LEN     driv7490
      HMDLZ(8) = RANGE                                                  driv7500

      IF(MODEL.EQ.0) WRITE(IPU,1560)(HMDLZ(K),K=1,8)                    driv7510
      IF(MODEL.EQ.0) WRITE(IPR1,1560)(HMDLZ(K),K=1,8)                   driv7520
1560  FORMAT(3F10.3,5E10.3)                                             driv7530
      WRITE(IPU,1320)  IPARM,IPH,IDAY,ISOURC                            driv7540
      WRITE(IPR1,1320) IPARM,IPH,IDAY,ISOURC                            driv7550
      WRITE(IPU,1322) PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
      WRITE(IPR1,1322)PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
C     WRITE(IPU,1400) V1,V2,DV                                          driv7580
C     WRITE(IPR1,1400)V1,V2,DV                                          driv7590
      WRITE(IPU,'(5I10)')IV1,IV2,IDV,IFWHM,IFILTER
      WRITE(IPR1,'(5I10)')IV1,IV2,IDV,IFWHM,IFILTER
C                                                                       driv7620
CRZ   IRAIN=0                                                           driv7630
CRZ   IF(RAINRT.GT.0) IRAIN=1                                           driv7640
CCC                                                                     driv7650
CCC   CALCULATE EQUIVALENT LIQUID WATER CONSTANTS                       driv7660
CCC                                                                     driv7670
      CALL EQULWC                                                       driv7680
      IF (SEA) THEN
              Msea = Msea + 1
              Done = (((IEMSCTold .EQ. 1) .AND. (Msea .EQ. 3))
     +          .OR. ((IEMSCTold .EQ. 2) .AND. (Msea .EQ. 4)))
              IF (Done) THEN
                      READ(IRD, 1600) IRPT
                  ELSE
                      READ(IRDS,1600) IRPT
              END IF
          ELSE
                  READ(IRD, 1600) IRPT
      END IF
 1600 FORMAT(I5)                                                        driv7720
      WRITE(IPU,1600) IRPT                                              driv7730
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      WRITE(IPR1,1600)IRPT                                              driv7740
C                                                                       driv7750
      ground=.false.                                                    driv7760
      if(h2.le.zm(1))ground=.true.                                      driv7770
      IF (Msea .GT. -1)
     +    PRINT '(35H Driver: Calling TRANS for sea card, I2, 1H.)',Msea
      CALL TRANS(IPH,ISOURC,IDAY,ANGLEM,ground)
C                                                                       driv7790
C     TRANS RETURNS IRPT = -4 IF THE SPECTRAL RANGE EXTENDS BEYOND THE  driv7800
C     BAND MODEL TAPE.  IN THIS CASE, A LOWTRAN 7 CALCULATION IS        driv7810
C     PERFORMED FOR THE SHORT WAVELENGTHS AND THEN THE ORIGINAL INPUT   driv7820
C     IS RESTORED.   (NOTE:  THIS FEATURE WAS COMMENTED OUT.)
C                                                                       driv7840
*************  Reset the parameters to their original values  ********
*************  from before TAPE5.SEA was introduced, provided ********
*************  all cards from TAPE5.SEA have been read. **************
C
      IF (Done) THEN
          CLOSE (IRDS, STATUS='KEEP')
          Sea      = .FALSE.
          SeaOld   = .FALSE.
          Hit      = .FALSE.
          Msea     = -1
          ITYPE    = ITYPEold
          IEMSCT   = IEMSCTold
          IMULT    = IMULTold
          TBOUND   = TBOUNDold
          SALB     = SALBold
      END IF
C
*********************************************************************
C*****WRITE END OF FILE ON TAPE 7                                     driv8050
630   IF(IERROR .GT. 0) THEN                                          driv8060
          READ(IRD,1600,END=900) IRPT                                 driv8070
          WRITE(IPU,1600) IRPT                                        driv8080
          WRITE(IPR1,1600)IRPT                                        driv8090
      ENDIF                                                           driv8100
      WRITE(IPU,1620)                                                 driv8110
      WRITE(IPR1,1620)                                                driv8120
1620  FORMAT(' -9999.')                                               driv8130
C                                                                     driv8140
      WRITE(IPR,1630)IRPT                                             driv8150
1630  FORMAT('0 CARD 5 *****',I5)                                     driv8160
      IF (IRPT.EQ.0) GO TO 900                                        driv8170
      IF (IRPT.EQ.4) GO TO 400                                        driv8180
cssi  IF (IRPT.GT.1 .AND. IEMSCT.EQ.3) THEN                           driv8190
cssi  PRINTg1,'/!! ERROR IN INPUT IEMSCT EQ 3 IRPT GT 1!'             driv8200
cssi          STOP                                                    driv8210
cssi  ENDIF                                                           driv8220
      IF (IRPT.GT.4) GO TO 900                                        driv8230
      GO TO (100,900,300,400), IRPT                                   driv8240
  900 Call Timer(Iend)
C     to find how long the calculation took:
      WRITE (ITM, 1880) (FLOAT(Iend)-FLOAT(Istart))/100.
 1880 FORMAT ('Elapsed time (sec) for the last run was ', F8.2)
      STOP                                                            driv8250
      END                                                             driv8260
```

APPENDIX C
MODIFIED SUBROUTINE "TRANS"

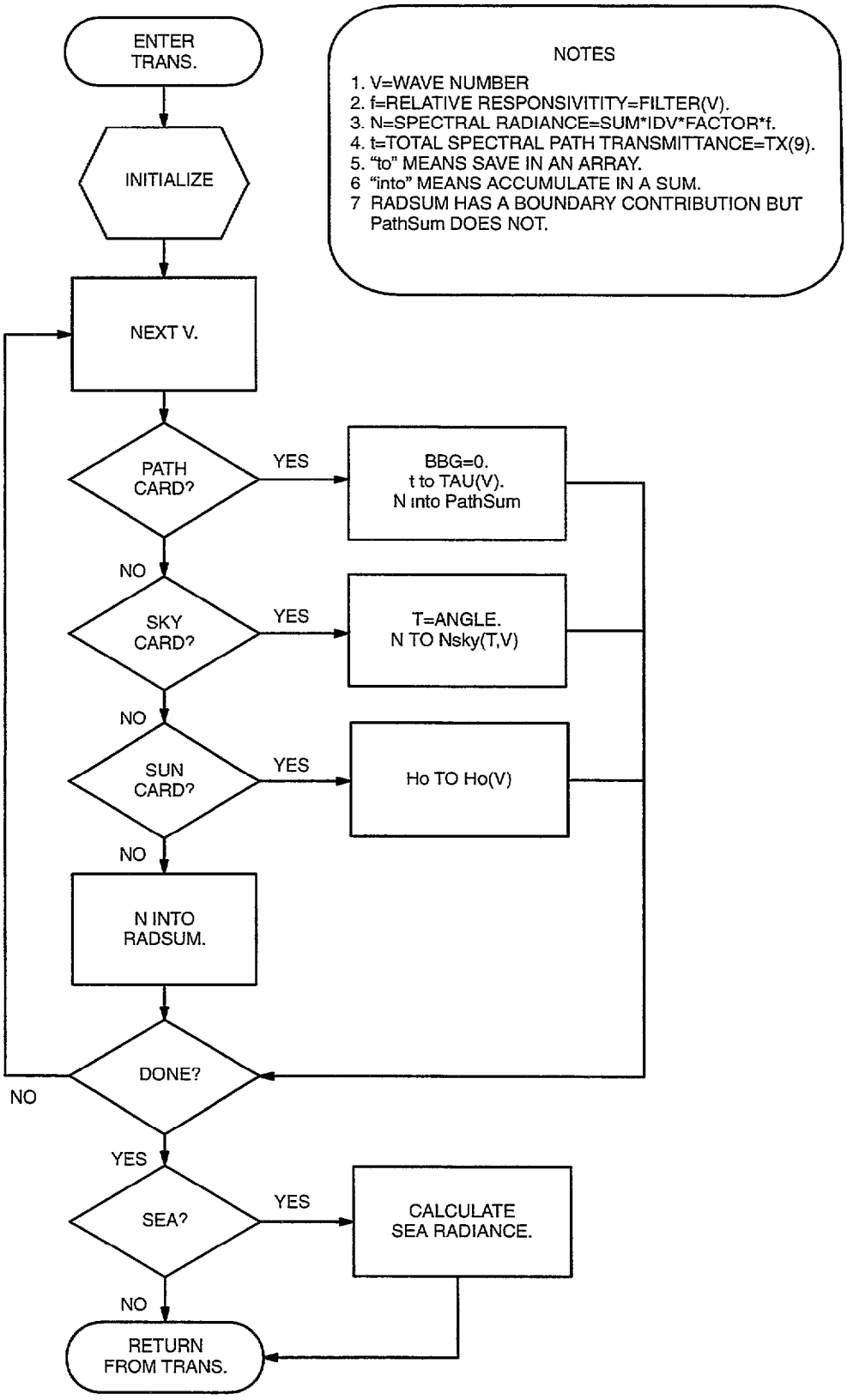

Figure C-1. Flowchart for modified subroutine "TRANS."

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      SUBROUTINE TRANS(IPH,ISOURC,IDAY,ANGLEM,ground)
C                                                                       tras 110
C     CALCULATES TRANSMITTANCE AND RADIANCE VALUES BETWEEN IV1 AND IV2  tras 120
C     FOR A GIVEN ATMOSPHERIC SLANT PATH                                tras 130
      parameter(nbins=99,iprint=50,maxv=50000)                          tras 140
      real WGT(nbins),SLIT(56,nbins)                                    tras 150
      LOGICAL IVTEST,loop0,ground,transm,modtrn                         tras 160
      COMMON RELHUM(34),WHNO3(34),ICH(4),VH(17),TX(63),W(63),IMSMX,     tras 170
     1  WPATH(102,63),TBBY(102),PATM(102),NSPEC,KPOINT(12),             tras 180
     2  ABSC(5,47),EXTC(5,47),ASYM(5,47),VX0(47),AWCCON(5)              tras 190
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,
     +              ITR,Isky,Isun,Ipath
      COMMON/CARD1/MODEL,ITYPE,IEMSCT,M1,M2,M3,IM,NOPRNT,TBOUND,SALB,   tras 210
     1  MODTRN                                                          tras 220
      COMMON /CARD2/ IHAZE,ISEASN,IVULCN,ICSTL,ICIR,IVSA,VIS,WSS,WHH,
     1    RAINRT
      COMMON/CARD3/H1,H2,ANGLE,RANGE,BETA,REE,LEN
      COMMON/CARD4/IV1,IV2,IDV,IFWHM,IFILTER
      COMMON/CNSTNS/PIX,CA,DEG,GCAIR,BIGNUM,BIGEXP
      COMMON/CNTRL/KMAX,M,IKMAX,NL,ML,IKLO,ISSGEO,IMULT                 tras 250
      COMMON/SOLS/AH1(68),ARH(68),                                      tras 260
     1  WPATHS(102,63),PA(68),PRX(68),ATHETA(35),ADBETA(35),LJ(69),
     2  JTURN,ANGSUN,CSZEN(68),TBBYS(102,12),PATMS(102,12)              tras 280
      COMMON/SRAD/TEB1,TEB2SV                                           tras 290
      COMMON/MSRD/TLE(34),COSBAR(34),OMEGA0(68),UPF(10,34),DNF(10,34),  tras 300
     1  TAER(34),ASYIK(68),ASYDM(68),STRN(0:34),DMOLS(68),DSTRN(0:68),  tras 310
     2  FDNSRT,FDNTRT,TAUT(34),UMF(34),DMF(34),UMFS(34),DMFS(34)        tras 320
      COMMON/ICLL/ICALL,FPHS,FALB,FORBIT                                tras 330
      PARAMETER (Kr = 216, Kv = 400)
      COMMON /Filters/ FLIST(5,6),
     +                 FILTER1(45), BB1(Kr), FILTER2(54), BB2(Kr),
     +                 FILTER3(39), BB3(Kr), FILTER4(47), BB4(Kr),
     +                 FILTER5(101),BB5(Kr), FILTER6(75), BB6(Kr)
      COMMON/Sea/ Sea,Hit,Msea,TBOUNDold,IEMSCTold
      COMMON/Geometry/ To,Po,Tr,Pr
      COMMON/Constants/pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      DIMENSION Tau(Kv), SkyN(3,Kv), Ho(Kv), Tsky(3), Rsky(3)
      LOGICAL Sea, PathCard, SkyCard, LastSky, SunCard, Hit
      REAL Npath, Nsky, Nvsky, Nsea, Nsun, Ntotal, Nbb, infinity, No
      T0 = 273.15
      common /solar/lsame                                               tras 340
      logical lsame                                                     tras 350
c                                                                       tras 360
c     Initialize slit function array                                    tras 370
      DO 10 I = 1,56                                                    tras 380
          DO 10 J = 1,nbins                                             tras 390
   10 SLIT(I,J) =0.                                                     tras 400
c                                                                       tras 410
c     Initialize radiance minimum and maximum parameters                tras 420
      RADMIN=bignum                                                     tras 430
      RADMAX=0.                                                         tras 440
c                                                                       tras 450
c     Initialize ground emissivity (one minus ground albedo)            tras 460
      EMISS=1.-SALB                                                     tras 470
C                                                                       tras 480
C     Store the number of path layers in ikmx                           tras 490
      IKMX=IKMAX                                                        tras 500
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c                                                                       tras 510
c     Initialize integrated absorption, radiance, solar irradiance and  tras 520
c     transmitted solar irradiance sums                                 tras 530
      SUMA=0.                                                           tras 540
      RADSUM=0.                                                         tras 550
      SSOL=0.                                                           tras 560
      STSOL=0.                                                          tras 570
      PathSum  = 0.
      PathCard = .FALSE.
      SkyCard  = .FALSE.
      LastSky  = .FALSE.
      SunCard  = .FALSE.
      IF (Sea) THEN
          IF (Msea .EQ. 0) THEN
                  PathCard = .TRUE.
              ELSE IF ((Msea .GE. 1) .AND. (Msea .LE. 3)) THEN
                  SkyCard  = .TRUE.
              ELSE IF (Msea .EQ. 4) THEN
                  SunCard  = .TRUE.
          END IF
          IF (Msea .EQ. 3) THEN
              LastSky  = .TRUE.
          END IF
      END IF
      IF (SkyCard) Tsky(Msea) = ANGLE*d2r
      Istore = 0
c                                                                       tras 580
c     Initialize integration weighting factor                           tras 590
      FACTOR=.5                                                         tras 600
c                                                                       tras 610
c     Initialize icount, used to determine when header must be printed  tras 620
      ICOUNT=iprint                                                     tras 630
c                                                                       tras 640
c     Do not perform a MODTRAN calculation if all sources are continuum tras 650
cssi  IF(IV1.GE.22655)modtrn=.false.                                    tras 660
      IF(IV1.GE.22681)modtrn=.false.                                    tras 670
      IF(modtrn)THEN                                                    tras 680
c                                                                       tras 690
c         WHEN THE band model or line-by-line option is used, call      tras 700
c         routine "bmdata" to INITIALIZE PARAMETERS AND TO SET THE      tras 710
c         FREQUENCY STEP SIZE "IDVX" TO THE BAND WIDTH (1 CM-1).        tras 720
          IDV5=5                                                        tras 730
          CALL bmdata(IV1,IFWHM,IDVX,IKMX,MXFREQ)                       tras 740
          IWIDM1=IFWHM/IDVX-1                                           tras 750
          IV=5*((IV1-IWIDM1)/5)                                         tras 760
          IF(IV.LT.0)IV=0                                               tras 770
          IVX=IV-IDVX                                                   tras 780
          IV=IV-5                                                       tras 790
          IVXMAX=IV2+IWIDM1                                             tras 800
      ELSE                                                              tras 810
          IDV5=IDV                                                      tras 820
          IDVX=IDV5                                                     tras 830
          IWIDM1=0                                                      tras 840
          IV=IV1-IDV5                                                   tras 850
          IVX=IV                                                        tras 860
          IVXMAX=IV2+IWIDM1                                             tras 870
          IF(IVXMAX.GT.maxv)IVXMAX=maxv                                 tras 880
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          IF(IDV.LT.5)IDV=5                                              tras 890
      ENDIF                                                              tras 900
      IWRITE=IV1+IWIDM1                                                  tras 910
      IWIDTH=IWIDM1+1                                                    tras 920
C                                                                        tras 930
C     PERFORM TRIANGULAR SLIT INITIALIZATION.  TRANSMITTANCES AT A       tras 940
C     GIVEN FREQUENCY CONTRIBUTE TO 2*IWIDTH-1 TRIANGULAR SLITS.         tras 950
C     THESE CONTRIBUTIONS ARE STORED IN ARRAY SLIT.  WGT IS THE          tras 960
C     NORMALIZED WEIGHT USED TO DEFINE THE TRIANGLE.                     tras 970
      NWGT=2*IWIDTH                                                      tras 980
      WNORM=1./(IWIDTH*IWIDTH)                                           tras 990
      DO 20 I=1,IWIDTH                                                   tras1000
          WGT(I)=I*WNORM                                                 tras1010
   20 WGT(NWGT-I)=wgt(i)                                                 tras1020
      NWGT=NWGT-1                                                        tras1030
      NWGTM1=NWGT-1                                                      tras1040
c                                                                        tras1050
c     Initialize ICALL (= 0 for initial call to subroutine source)       tras1060
      ICALL=0                                                            tras1070
c                                                                        tras1080
c     Initialize transm (.true. for transmittance only calculations)     tras1090
      transm=.true.                                                      tras1100
      IF(IEMSCT.EQ.1 .OR. IEMSCT.EQ.2)transm=.false.                     tras1110
c                                                                        tras1120
c     Print headers                                                      tras1130
      IF(IEMSCT.EQ.0)THEN                                                tras1140
          WRITE(IPU,'(46H \FREQ   TOTAL     H2O     CO2+ OZONE    TRACE,tras1150
     1      49H  N2 CON  H2O CON MOL SCAT AER-HYD HNO3   AER-HYD)')     tras1160
          WRITE(IP7,'(46H \FREQ   TOTAL     H2O     CO2+ OZONE    TRACE,
     1      49H  N2 CON  H2O CON MOL SCAT AER-HYD HNO3   AER-HYD)')
          WRITE(IPR1,'(45H  \FREQ  H2O     O3       CO2    CO       CH4,tras1170
     1      47H     N2O    O2     NH3      NO     NO2      SO2,/       tras1180
     2      55H  \1/CM  TRANS   TRANS    TRANS  TRANS    TRANS   TRANS, tras1190
     3      39H  TRANS  TRANS    TRANS  TRANS    TRANS)')
          WRITE(IP8, '(45H  \FREQ  H2O     O3       CO2    CO       CH4,
     1      47H     N2O    O2     NH3      NO     NO2      SO2,/
     2      55H  \1/CM  TRANS   TRANS    TRANS  TRANS    TRANS   TRANS,
     3      39H  TRANS  TRANS    TRANS  TRANS    TRANS)')
      ELSE IF(IEMSCT .EQ. 3) THEN                                        tras1210
          WRITE (IPU,'(32H \FREQ   TRANS     SOL TR  SOLAR)')            tras1220
          WRITE (IP7,'(2H \, T25,
     +                40HIRRADIANCE (W M-2) PASSED THROUGH FILTER,
     +                I2)') IFILTER
          WRITE (IP7,'(32H \FREQ   TRANS     SOL TR  SOLAR)')
      ELSE IF (IEMSCT .EQ. 1) THEN                                       tras1230
          WRITE(IPU,'(45H \FREQ   TRANS     ATMOS. RAD., T88,
     +                18H- LOG TOTAL TRANS.)')
          WRITE(IP7,'(2H \, T25,
     +                43HRADIANCE (W M-2 SR-1) PASSED THROUGH FILTER,
     +                I2)') IFILTER
          WRITE(IP7,'(30H \FREQ   TRANS     ATMOS. RAD., T88,
     +                18H- LOG TOTAL TRANS.)')
      ELSE IF (IEMSCT .EQ. 2) THEN
          WRITE(IPU,'(42H \FREQ   TRANS     ATMOS   PATH     SINGLE,    tras1240
     1      28H   GROUND DIRECT   TOTAL RAD)')                          tras1250
          WRITE(IP7,'(2H \, T25,
     +                43HRADIANCE (W M-2 SR-1) PASSED THROUGH FILTER,
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     +                I2)') IFILTER
          WRITE(IP7,'(42H \FREQ   TRANS     ATMOS   PATH     SINGLE,
     1      28H   GROUND DIRECT   TOTAL RAD, T88,
     +                18H- LOG TOTAL TRANS.)')
      END IF
      If (PathCard) then
              WRITE(IPath,'(1H\, T25,
     +        52HRADIANCE (W M-2 SR-1 (CM-1)-1) PASSED THROUGH FILTER,
     +        I2,/,1H\,/,40H\  V     T      f     Npath*f   INTEGRAL,
     +        /,1H\)') Ifilter
          Else if (LastSky) then
              WRITE(Isky,'(1H\, T25,
     +        52HRADIANCE (W M-2 SR-1 (CM-1)-1) PASSED THROUGH FILTER,
     +        I2,/,1H\,/,40H\  V     T      f    Nsky*T*f   INTEGRAL,
     +        22H   Nsea*T*f   INTEGRAL,/,1H\)') Ifilter
          Else if (SunCard) then
              WRITE(Isun,'(1H\, T25,
     +        52HRADIANCE (W M-2 SR-1 (CM-1)-1) PASSED THROUGH FILTER,
     +        I2,/,1H\,/,40H\  V     T      f    Nsun*T*f   INTEGRAL,
     +        /,1H\)') Ifilter
      End If
      IF(NOPRNT.EQ.-1)THEN                                              tras1270
          IF(IMULT.EQ.1)THEN                                            tras1280
              WRITE(IPR1,'(37H       \V   ALT1    UFLX        UFLXS,    tras1290
     1          50H       DFLX        DFLXS       DIRS          TRANS)')tras1300
              WRITE(IP8, '(37H       \V   ALT1    UFLX        UFLXS,
     1          50H       DFLX        DFLXS       DIRS          TRANS)')
          ELSE                                                          tras1310
              IF(IEMSCT.GT.0)WRITE(IPR1,'(23H       \V   ALT1   ALT2,    tras1320
     1          30H    B(V,T)     DTAU        TAU)')                   tras1330
                             WRITE(IP8, '(23H       \V   ALT1   ALT2,
     1          30H    B(V,T)     DTAU        TAU)')
          ENDIF                                                         tras1340
      ENDIF                                                             tras1350
C                                                                       tras1360
c     Initialize layer loop variables                                   tras1370
      loop0=.true.                                                      tras1380
      call loop(loop0,iv,ivx,ikmx,mxfreq,summs,transm,iph,              tras1390
     1  sumssr,ivtest,unif,trace,sumv,isourc,iday,anglem,frac)          tras1400
      loop0=.false.                                                     tras1410
C                                                                       tras1420
C     END INITIALIZATION, BEGIN OF FREQUENCY LOOP                       tras1430
C                                                                       tras1440
C     "IVX" IS THE FREQUENCY AT WHICH TRANSMITTANCE WILL BE CALCULATED. tras1450
C     DURING THE FIRST PASS, "IVX" AND "IV" MUST BE EQUAL.              tras1460
   30 IVX=IVX+IDVX                                                      tras1470
          IF(IV.LT.IVX)THEN                                             tras1480
              IV=IV+IDV5                                                tras1490
              IVTEST=.TRUE.                                             tras1500
          ELSE                                                          tras1510
              IVTEST=.FALSE.                                            tras1520
          ENDIF                                                         tras1530
C                                                                       tras1540
C         SET INTERPOLATION FRACTION.                                   tras1550
          FRAC=FLOAT(IV-IVX)/IDV5                                       tras1560
          IF(ICOUNT.EQ.iprint)THEN                                      tras1570
c                                                                       tras1580
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c             Reinitialize counter and print header                     tras1590
              ICOUNT=0                                                  tras1600
              IF(IEMSCT.EQ.0)THEN                                       tras1610
                 WRITE(IPR,'(1H1,/33H   FREQ WAVELENGTH  TOTAL     H2O,tras1620
     1             47H     CO2+     OZONE    TRACE  N2 CONT  H2O CONT, tras1630
     2             47H MOL SCAT  AER-HYD  HNO3    AER-HYD  INTEGRATED, tras1640
     3             //43H   1/CM  MICRONS    TRANS    TRANS    TRANS,   tras1650
     4             44H    TRANS    TRANS   TRANS    TRANS    TRANS,   tras1660
     5             40H     TRANS   TRANS    ABS     ABSORPTION,/)')   tras1670
              ELSEIF(IEMSCT.EQ.1)THEN                                   tras1680
                 WRITE(IPR,'(1H1,20X,28HRADIANCE(WATTS/CM2-STER-XXX),   tras1690
     1             /8H0   FREQ,T10,6HWAVLEN,T19,14HATMOS RADIANCE,      tras1700
     2             T39,9H INTEGRAL,T49,5HTOTAL,/2X,6H(CM-1),            tras1710
     3             T10,7H(MICRN),T19,6H(CM-1),T29,7H(MICRN),            tras1720
     4             T39,6H(CM-1),T49,5HTRANS,/)')                        tras1730
              ELSEIF(IEMSCT.EQ.3)THEN                                   tras1740
                 WRITE(IPR,'(1H1,22X,27HIRRADIANCE (WATTS/CM2-XXXX),    tras1750
     1             /7H0  FREQ,T11,6HWAVLEN,T23,11HTRANSMITTED,          tras1760
     2             T45,5HSOLAR,T61,10HINTEGRATED,T80,5HTOTAL,           tras1770
     3             /2X,6H(CM-1),T10,7H(MICRN),T20,6H(CM-1),             tras1780
     4             T30,7H(MICRN),T40,6H(CM-1),T50,7H(MICRN),            tras1790
     5             T60,6HTRANS.,T70,5HSOLAR,T80,5HTRANS)')              tras1800
              ELSEIF(IMULT.EQ.0)THEN                                    tras1810
                 WRITE(IPR,'(1H1,45X,28HRADIANCE(WATTS/CM2-STER-XXX),   tras1820
     1             /7H0  FREQ,T11,6HWAVLEN,T21,14HATMOS RADIANCE,       tras1830
     2             T41,14HPATH SCATTERED,T61,16HGROUND REFLECTED,       tras1840
     3             T85,5HTOTAL,T99,8HINTEGRAL,T110,5HTOTAL,             tras1850
     4             /2X,6H(CM-1),T10,7H(MICRN),T20,6H(CM-1),             tras1860
     5             T30,7H(MICRN),T40,6H(CM-1),T50,7H(MICRN),            tras1870
     6             T60,6H(CM-1),T70,7H(MICRN),T80,6H(CM-1),             tras1880
     7             T90,7H(MICRN),T100,6H(CM-1),T110,5HTRANS,/)')        tras1890
              ELSE                                                      tras1900
                 WRITE(IPR,'(1H1,45X,28HRADIANCE(WATTS/CM2-STER-XXX),   tras1910
     1             //6H0 FREQ,T10,6HWAVLEN,T20,14HATMOS RADIANCE,T40,   tras1920
     2             4HPATH,19H SCATTERED RADIANCE,T69,                   tras1930
     3             25HGROUND REFLECTED RADIANCE,T100,14HTOTAL RADIANCE,tras1940
     4             T118,8HINTEGRAL,T127,5HTOTAL,/T45,5HTOffL,T59,       tras1950
     5             6HS SCAT,T75,5HTOTAL,T89,6HDIRECT,/1X,6H(CM-1),T9,   tras1960
     6             7H(MICRN),T19,6H(CM-1),T29,7H(MICRN),T39,6H(CM-1),   tras1970
     7             T49,7H(MICRN),T59,6H(CM-1),T69,6H(CM-1),T79,         tras1980
     8             7H(MICRN),T89,6H(CM-1),T99,6H(CM-1),T109,7H(MICRN),  tras1990
     9             T119,6H(CM-1),T127,5HTRANS,/)')                      tras2000
              ENDIF                                                     tras2010
           ENDIF                                                        tras2020
c                                                                       tras2030
c          Determine layer loop maximum                                 tras2040
           IF(transm)THEN                                               tras2050
c                                                                       tras2060
c             For transmission calculations, skip over layer loop in tratras2070
              IKMAX=1                                                   tras2080
           ELSEIF(IMULT.EQ.1 .and. .not. lsame)THEN                     tras2090
c                                                                       tras2100
C             FOR MULTIPLE SCATTERING SET IKMAX TO IMSMX                tras2110
              IKMAX=IMSMX                                               tras2120
           ELSE                                                         tras2130
c                                                                       tras2140
C             IF NOT MULTIPLE SCATTERING, RESET IKMAX TO ORIGINAL VALUE tras2150
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            IKMAX=IKMX                                                  tras2160
        ENDIF                                                           tras2170
        SUMV=0.                                                         tras2180
C                                                                       tras2190
C       Initialize transmission array                                   tras2200
        TX(1)=1.                                                        tras2210
        TX(2)=1.                                                        tras2220
        TX(3)=1.                                                        tras2230
        DO 40 K=4,KMAX                                                  tras2240
   40   TX(K)=0.                                                        tras2250
        call loop(loop0,iv,ivx,ikmx,mxfreq,summs,transm,                tras2260
     1    iph,sumssr,ivtest,unif,trace,sumv,isourc,iday,anglem,frac)    tras2270
C                                                                       tras2280
C       THE PARAMETERS "UNIF", "TRACE", "SUMV", "SUMSSR", "SUMMS"       tras2290
C       AND "TEB1" ARE TEMPORARILY STORED IN "TX" SO THAT THEIR         tras2300
C       CONVOLUTION OVER THE TRIANGULAR SLIT CAN BE CALCULATED.         tras2310
        TX(2)=UNIF                                                      tras2320
        TX(3)=TRACE                                                     tras2330
        TX(8)=SUMV                                                      tras2340
        TX(12)=SUMSSR                                                   tras2350
        TX(13)=SUMMS                                                    tras2360
        TX(14)=TEB1                                                     tras2370
        DO 60 K=2,56                                                    tras2380
            IP1=NWGT                                                    tras2390
            DO 50 I=NWGTM1,1,-1                                         tras2400
                SLIT(K,IP1)=SLIT(K,I)+WGT(IP1)*tx(k)                    tras2410
   50       IP1=I                                                       tras2420
            SLIT(K,1)=WGT(1)*tx(k)                                      tras2430
   60   TX(K)=SLIT(K,NWGT)                                              tras2440
C                                                                       tras2450
C       CHECK IF VALUES ARE TO BE PRINTED                               tras2460
        IF(IVX.LT.IWRITE)GOTO30                                         tras2470
        IWRITE=IWRITE+IDV                                               tras2480
        IF(IWRITE.GT.IVXMAX)FACTOR=.5                                   tras2490
        ICOUNT=ICOUNT+1                                                 tras2500
C                                                                       tran2510
C       RENORMALIZE IF TRIANGULAR SLIT EXTENDS TO NEGATIVE FREQUENCIEStras2520
        IF(IVX.LT.NWGTM1)THEN                                           tras2530
            store=1.-.5*(NWGTM1-IVX)*(NWGTM1-IVX+1)*WNORM               tras2540
            DO 70 K=2,56                                                tras2550
   70       TX(K)=TX(K)/store                                           tras2560
        ENDIF                                                           tras2570
        UNIF=TX(2)                                                      tras2580
        TRACE=TX(3)                                                     tras2590
        SUMV=TX(8)                                                      tras2600
        SUMSSR=TX(12)                                                   tras2610
        SUMMS=TX(13)                                                    tras2620
        TEB1=TX(14)                                                     tras2630
        V=FLOAT(IVX-IWIDM1)                                             tras2640
        ALAM=1.0E+04/(V+.000001)                                        tras2650
        Istore = Istore + 1
        Width = IDV*FACTOR
        f = Filter(V,Ifilter)
        SUMA=SUMA+(1.0-TX(9))*f*Width
        ALTX9=BIGNUM                                                    tras2670
        IF(TX(9).GT.0.)ALTX9=-LOG(TX(9))                                tras2680
        GOTO(80,90,90,100),IEMSCT+1                                     tras2690
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C                                                                       tras2700
C         TRANSMITTANCE ONLY                                            tras2710
   80     TX(10)=1.-TX(10)                                              tras2720
          TX(7)=TX(7)*TX(16)                                            tras2730
          WRITE(IPR,'(F8.0,F8.3,11F9.4,F12.3)')V,ALAM,TX(9),TX(17),     tras2740
     1      UNIF,TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),SUMAtras2750
          WRITE(IPR1,'(F7.0,11F8.4,1PE10.3)')V,TX(17),TX(31),TX(36),    tras2760
     1      TX(44),TX(46),TX(47),TX(50),TX(52),TX(54),TX(55),TX(56)     tras2770
          WRITE(IP8, '(F7.0,11F8.4,1PE10.3)')V,TX(17),TX(31),TX(36),
     1      TX(44),TX(46),TX(47),TX(50),TX(52),TX(54),TX(55),TX(56)
          WRITE(IPU,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,        tras2780
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9    tras2790
          WRITE(IP7,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9
          GOTO110                                                       tras2800
C                                                                       tras2810
C         ATMOSPHERIC RADIANCE INCLUDING EMISSION OF BOUNDARY           tras2820
C         ATTENUATED BY TOTAL TRANSMISSION                              tras2830
C                                                                       tras2840
C         CALCULATE THERMAL RADIANCE CONTRIBUTION OF BOUNDARY AND       tras2850
C         ADD THE SCATTERED CONTRIBUTION TO THE THERMAL RADIANCE        tras2860
C         IF THE PATH INTERSECTS THE SURFACE                            tras2870
   90     IF ((TBOUND.LE.0.) .OR. (PathCard)) THEN
              BBG = 0.                                                  tras2890
          ELSE                                                          tras2900
              BBG=BBFN(TBOUND,V)*TX(9)*EMISS                            tras2910
              IF(IMULT.EQ.1 .AND. ground) THEN
                  BBG=BBG+SALB*FDNTRT*TX(9)/PI                          tras2920
              END IF
          ENDIF                                                         tras2930
C                                                                       tras2940
C         ADD THERMAL BOUNDARY AND MULTIPLE SCATTERED RADIANCE          tras2950
          SUMV=(SUMV+BBG)*f
          SUMVV=SUMV                                                    tras2970
          IF (V.GT.0.) THEN
              SUMV=(1.0E+08/V**2)*SUMV          !  W m-2 sr-1 (cm-1)-1
          END IF
          IF(IEMSCT.EQ.1)THEN                                           tras2990
              RADSUM=RADSUM + SUMV*Width
              WRITE(IPR,'(F8.0,F8.3,1P3E10.2,0PF9.4)')                  tras3010
     1          V,ALAM,SUMV,SUMVV,RADSUM,TX(9)                          tras3020
              WRITE(IPU,'(F7.0,F8.4,1PE15.8,T96,E10.3)')                tras3030
     1          V,TX(9),SUMV,ALTX9                                      tras3040
              WRITE(IP7,'(F7.0,F8.4,1PE15.8,T96,E10.3)')
     1          V,TX(9),SUMV,ALTX9
          WRITE(IPr1,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,       tras3050
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9    tras3060
          WRITE(IP8, '(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9
              SUMT=SUMV                                                 tras3070
              SUMTT=SUMVV                                               tras3080
          ELSE                                                          tras3090
C                                                                       tras3100
C             SOLAR SCATTERED RADIANCE                                  tras3110
              CALL SOURCE(V,ISOURC,IDAY,ANGLEM,SS)                      tras3120
C                                                                       tras3130
C             MULTIPLY SUMSSR BY THE EXTRATERRESTRIAL SOURCE STRENGTH SStras3140
```

```
              SUMSSS=SUMSSR*SS                                          tras3150
C                                                                       tras3160
C             CALCULATE TOTAL SINGLE SCATTERED + MULTIPLE SCATTERED     tras3170
C             SOLAR RADIANCE FOR EACH FREQUENCY [W/CM2-STER-MICROMETER] tras3180
              SUMSSR=SUMSSS+SUMMS                                       tras3190
              store=0.                                                  tras3200
              if(v.gt.0.)store=1.e8/v**2       ! [W m-2 sr-1 (cm-1)-1]
              SUMS=store*SUMSSR                                         tras3220
              SUMSSS=store*SUMSSS                                       tras3230
C                                                                       tras3240
C             RFLSOL IS GROUND-REFLECTED DIRECT SOURCE RADIANCE AND     tras3250
              RFLSOL=0.                                                 tras3260
              RFLS=0.                                                   tras3270
              RFLSS=0.                                                  tras3280
              RFLSSS=0.                                                 tras3290
              IF(ground .AND. TEB1.GT.0)THEN                            tras3300
                  IF(ANGSUN.GE.0.)RFLSSS=SS*TEB1*SALB*COS(ANGSUN*CA)/PI tras3310
                  RFLSOL=RFLSSS                                         tras3320
                  IF(IMULT.EQ.1)RFLSOL=RFLSOL+SALB*FDNSRT*TX(9)/PI      tras3330
                  RFLS=STORE*RFLSOL                                     tras3340
                  RFLSS=STORE*RFLSSS                                    tras3350
              ENDIF                                                     tras3360
              SUMT=SUMV+(SUMS+RFLS)*f
              SUMTT=SUMVV+(SUMSSR+RFLSOL)*f
              RADSUM=RADSUM + SUMT*Width
              IF (IMULT.NE.1) THEN                                      tras3400
                      WRITE(IPR,'(F8.0,F8.3,1P9E10.2,0PF9.4)')          tras3410
     1                 V,ALAM,SUMV,SUMVV,SUMS,SUMSSR,RFLS,RFLSOL,       tras3420
     2                SUMT,SUMTT,RADSUM,TX(9)                           tras3430
                  ELSE                                                  tras3440
                      WRITE(IPR,'(F7.0,F8.3,1P11E10.2,0PF7.4)')         tras3450
     1                V,ALAM,SUMV,SUMVV,SUMS,SUMSSR,SUMSSS,RFLS,        tras3460
     2                RFLSOL,RFLSS,SUMT,SUMTT,RADSUM,TX(9)              tras3470
              END IF                                                    tras3480
              WRITE(IPU,'(F7.0,F8.4,1P6E9.2,0P2F8.4,T96,1PE10.3)')V,    tras3490
     1          TX(9),SUMV,SUMS,SUMSSS,RFLS,RFLSS,SUMT,TEB1,TEB2SV,ALTX9tras3500
              WRITE(IP7,'(F7.0,F8.4,1P6E9.2,0P2F8.4,T96,1PE10.3)')V,
     1          TX(9),SUMV,SUMS,SUMSSS,RFLS,RFLSS,SUMT,TEB1,TEB2SV,ALTX9
          WRITE(IPr1,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,       tras3510
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9    tras3520
          WRITE(IP8, '(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9
          END IF                                                        tras3530
          IF (PathCard) THEN
                  Tau(Istore) = TX(9)
                  PathSum = PathSum + SUMT*Width
                  Write(Ipath, '(I5,2F7.3,2(1PE11.3))')
     +                          V, TX(9), f, SUMT, PathSum
          END IF
          IF (SkyCard) SkyN(Msea,Istore) = SUMT
C
          GO TO 110                                                     tras3540
C                                                                       tras3550
C         DIRECTLY TRANSMITTED SOLAR IRRADIANCE [WATTS/(CM2 MICROMETER)]tras3560
  100     CALL SOURCE(V,ISOURC,IDAY,ANGLEM,SOLIL)                       tras3570
          SOLIV=0.                                                      tras3580
          IF(V.GT.0.)SOLIV=SOLIL*1.E+8/V**2    !  [W m-2 sr-1 (cm-1)-1]
```

```
          TSOLIV=SOLIV*TX(9)*f
          IF (SunCard) then
              Ho(Istore) = TSOLIV
          END IF
          TSOLIL=SOLIL*TX(9)*f
          STSOL=STSOL+TSOLIV*Width
          SSOL=SSOL+SOLIV*Width
          WRITE(IPR,'(F8.0,F8.3,1P6E10.2,0PF9.4)')                          tras3640
     1      V,ALAM,TSOLIV,TSOLIL,SOLIV,SOLIL,STSOL,SSOL,TX(9)               tras3650
          WRITE(IPU,'(F7.0,F8.4,1P2E9.2,T96,E10.3)')                        tras3660
     1      V,TX(9),TSOLIV,SOLIV,ALTX9                                      tras3670
          WRITE(IP7,'(F7.0,F8.4,1P2E9.2,T96,E10.3)')
     1      V,TX(9),TSOLIV,SOLIV,ALTX9
          WRITE(IPr1,'(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,           tras3680
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9        tras3690
          WRITE(IP8, '(F7.0,11F8.4,1PE10.3)')V,TX(9),TX(17),UNIF,
     1      TX(31),TRACE,TX(4),TX(5),TX(6),TX(7),TX(11),TX(10),ALTX9
          SUMT=TSOLIV                                                       tras3700
          RADSUM=STSOL                                                      tras3710
  110     IF(IEMSCT.NE.0)THEN                                               tras3720
              IF(SUMT.GE.RADMAX)THEN                                        tras3730
                  VRMAX=V                                                   tras3740
                  RADMAX=SUMT                                               tras3750
              ENDIF                                                         tras3760
              IF(SUMT.LE.RADMIN)THEN                                        tras3770
                  VRMIN=V                                                   tras3780
                  RADMIN=SUMT                                               tras3790
              ENDIF                                                         tras3800
          ENDIF                                                             tras3810
          FACTOR=1.                                                         tras3820
      IF(IWRITE.LE.IVXMAX)GOTO30                                            tras3830
C                                                                           tras3840
C     END OF FREQUENCY LOOP                                                 tras3850
C                                                                           tras3860
      IVX=INT(V+.5)                                                         tras3870
C
      IF (IFILTER .EQ. 0) THEN
              Sumf = IVX - IV1
          ELSE IF ((1 .LE. IFILTER) .AND. (IFILTER .LE. 6)) THEN
              Sumf = FLIST(5, IFILTER)
      END IF

      IF ((.NOT. Sea) .AND. ((IEMSCT .EQ. 1) .OR. (IEMSCT .EQ. 2))) THEN
          IF (IFILTER .EQ. 0) THEN
                  V1 = FLOAT (IV1)
                  V2 = FLOAT (IVX)
                  dV = FLOAT (IDVX)
                  CALL RtoT (V1, V2, dV, RADSUM/1.E4, BBTEMP)
              ELSE IF ((IFILTER .GE. 1) .AND. (IFILTER .LE. 6)) THEN
                  CALL Planck (RADSUM/1.E4, IFILTER, BBTEMP)
          END IF
      END IF

      IF (Sea) THEN
          IF (PathCard) THEN
                  Npath     = PathSum
                  PathTrans = 1.-SUMA/Sumf
```

```
                PathRange = RANGE
                PathAngle = ANGLE
            ELSE IF (LastSky) THEN
                DO I = 1, Istore
                    DO K = 1, 3
                        Rsky(K) = SkyN(K,I)
                    END DO
                    CALL Fit(Tsky,Rsky,3,a,b)
                    V = IV1 + (I - 1.)*IDV
                    f = FILTER(V,Ifilter)
                    IF ((I .EQ. 1) .OR. (I .EQ. Istore)) THEN
                            Width = IDV/2.
                        ELSE
                            Width = IDV
                    END IF
                    Nbb = BBFN(TBOUNDold,V)*f*1E8/V**2
                    CALL Sky(Tr,Pr,WSS,a,b,V,BoverA,ev,Nvsky)
                    Nsky = Nsky +  Nvsky*Width*Tau(I)
                    Nsea = Nsea + ev*Nbb*Width*Tau(I)
                    Write(Isky, '(I5, 2F7.3, 4(1PE11.3))')
     +                   V, Tau(I), f, Nvsky*Tau(I), Nsky,
     +                   ev*Nbb*Tau(I), Nsea
                END DO
            ELSE IF (SunCard) THEN
                DO I = 1, Istore
                    V = IV1 + (I - 1.)*IDV
                    f = FILTER(V, Ifilter)
                    IF ((I .EQ. 1) .OR. (I .EQ. Istore)) THEN
                            Width = IDV/2.
                        ELSE
                            Width = IDV
                    END IF
                    CALL Sun(Tr,Pr,WSS,To,Po,V,sum4)
                    No = Ho(I)*sum4/(4.*pi*epsilon**2*BoverA)
                    Nsun  = Nsun + No*Width*Tau(I)
                    Write(Isun, '(I5,2F7.3,2(1PE11.3))')
     +                V, Tau(I), f, No*Tau(I), Nsun
                END DO
        END IF
        Ntotal = Npath + Nsea + Nsky + Nsun
        IF (IFILTER .EQ. 0) THEN
                V1 = FLOAT (IV1)
                V2 = FLOAT (IVX)
                dV = FLOAT (IDVX)
                CALL RtoT (V1, V2, dV, Ntotal/1.E4, TotalT)
            ELSE IF ((IFILTER .GE. 1) .AND. (IFILTER .LE. 6)) THEN
                CALL Planck (Ntotal/1.E4, IFILTER, TotalT)
        END IF
    END IF
C
    IF (.NOT. Sea) THEN
        WRITE(IPR,'(26HINTEGRATED ABSORPTION FROM,I5,3H TO,I5,          tras3880
     +      7H CM-1 =,F10.2,5H CM-1,/23HAVERAGE TRANSMITTANCE =,        tras3890
     +      F6.4,/)') IV1,IVX,SUMA,1.-SUMA/Sumf
        WRITE(IP6,'(
     +     /24HINTEGRATED ABSORPTION  =, F10.2,
     +      10H CM-1 FROM, I5, 3H TO, I5, 5H CM-1,
```

```
+        /24HAVERAGE TRANSMITTANCE  =, F12.4)')
+         SUMA,IV1,IVX,1.-SUMA/Sumf
      IF (IEMSCT .EQ. 0) THEN
              WRITE(IP4, '(T13,F7.2,F8.3,F10.3,F8.3)')
+                (90.-ANGLE)*pi/180.*1.E3,
+                ANGLE, RANGE, 1.-SUMA/Sumf
          ELSE IF ((IEMSCT .EQ. 1) .OR. (IEMSCT .EQ. 2)) THEN
              WRITE(IPR,'(22 HINTEGRATED RADIANCE =,1PE11.3,
+                10H WATTS M-2,7H STER-1,
+               /22H MINIMUM RADIANCE    =,E11.3,10H WATTS M-2,
+                19H STER-1 (CM-1)-1 AT,0PF11.1,5H CM-1,
+                /8H MAXIMUM,14H RADIANCE    =,1PE11.3,
+                29H WATTS M-2 STER-1 (CM-1)-1 AT,0PF11.1,5H CM-1,
+                23H BOUNDARY TEMPERATURE =, F11.2,2H K,
+               /22H BOUNDARY EMISSIVITY =,F12.3)')
+                RADSUM,RADMIN,VRMIN,RADMAX,VRMAX,TBOUND,EMISS      tras4020
              WRITE(IP6,'(
+                /24HMAXIMUM RADIANCE       =, 1PE11.3,
+                 23H W M-2 SR-1 (CM-1)-1 AT,  0PF8.1, 5H CM-1,
+                /24HMINIMUM RADIANCE       =, 1PE11.3,
+                 23H W M-2 SR-1 (CM-1)-1 AT,  0PF8.1, 5H CM-1,
+                /24HBOUNDARY TEMPERATURE   =, F11.2, 2H K,
+                /24HBOUNDARY EMISSIVITY    =, F12.3,
+                /24HFILTERED RADIANCE      =, 1PE11.3,
+                 11H W M-2 SR-1,
+                /24HBLACKBODY TEMPERATURE  =, 0PF11.1, 2H C)')
+                 RADMAX,VRMAX,RADMIN,VRMIN,TBOUND,EMISS,
+                 RADSUM, BBTEMP - T0
             WRITE(IP4,'(T13,F7.2,F8.3,F10.3,F8.3,5(1PE10.3),
+                                                    0PF8.1)')
+                (90.-ANGLE)*pi/180.*1.E3, ANGLE, RANGE,
+                1.-SUMA/Sumf, RADSUM, Nsea, Nsky, Nsun,
+                RADSUM, BBTEMP-T0
          ELSE
              WRITE(IPR,'(24H INTEGRATED IRRADIANCE =,1PE11.3,       tras3920
+                10H WATTS M-2,/24H MINIMUM IRRADIANCE    =,E11.3, tras3930
+                13H WATTS M-2 AT,0PF11.1,5H CM-1,/10H  MAXIMUM ,  tras3940
+                14H IRRADIANCE  =,1PE11.3,
+                23H WATTS M-2  (CM-1)-1 AT,0PF11.1,5H CM-1)')
+                RADSUM,RADMIN,VRMIN,RADMAX,VRMAX                   tras3960
              WRITE(IP6,'(
+                24HINTEGRATED IRRADIANCE  =, 1PE11.3, 6H W M-2,
+               /24HMINIMUM IRRADIANCE     =,   E11.3,
+                18H W M-2 (CM-1)-1 AT, 0PF8.1, 5H CM-1,
+               /24HMAXIMUM IRRADIANCE     =, 1PE11.3,
+                18H W M-2 (CM-1)-1 AT, 0PF8.1, 5H CM-1)')
+                RADSUM,RADMIN,VRMIN,RADMAX,VRMAX
      END IF
    END IF
C
    IF (((LastSky) .AND. (IEMSCTold .EQ. 1)) .OR. (SunCard)) THEN
      WRITE(IP6, '(/, 24HRECEIVED RADIANCE VALUES,
+    //, T10,24H PATH TO FOOTPRINT
=,    F10.5, 11H W M-2 SR-1,
+        T56,12H (AV. TRANS.,                F7.4,  1H),
+     /, T10,24H SEA EMISSION          =,    F10.5, 11H W M-2 SR-1,
+     /, T10,24H SKY REFLECTION        =,    F10.5, 11H W M-2 SR-1,
```

```
+     /, T10,24H SUN GLINT              =,   F10.5, 11H W M-2 SR-1,
+    //, T10,24H TOTAL RADIANCE         =,   F10.5, 11H W M-2 SR-1,
+     /, T10,24H BLACK BODY TEMP.       =,   F10.1,  2H C )')
+        Npath, PathTrans, Nsea, Nsky, Nsun, Ntotal, TotalT-T0
      WRITE(IP4, '(T13,F7.2,F8.3,F10.3,F8.3,5(1PE10.3),0PF8.1)')
+        (90.-PathAngle)*pi/180.*1.E3, PathAngle, PathRange,
+         PathTrans, Npath, Nsea, Nsky, Nsun, Ntotal, TotalT-T0
      Npath = 0.
      Nsea  = 0.
      Nsky  = 0.
      Nsun  = 0.
    END IF
C
    RETURN                                                          tras4100
    END                                                             tras4110
```

APPENDIX D
SOURCE CODE FOR NEW *SeaRad* SUBROUTINES

```
****************************** MOD22.FOR ******************************
*                                                                     *
*     New version of Cox-Munk routines with integration over sea      *
*     slopes and interpolation between three sky angles for estimation *
*     of incident sky radiance.                                       *
*                                                                     *
*     Last revised: July 14, 1995.                                    *
*                                                                     *
***********************************************************************

      SUBROUTINE Sky(Tr,Pr,W,a,b,v,BoverA,e,Nsky)
      REAL Nsky
CU    USES rho

C     Outputs:
C         Calculates (1) the normalization factor "BoverA" in the
C         denominator of the interaction probability, and spectral
C         values for (2) the effective emmisivity "e" of the ocean
C         surface, and (3) the sky radiance "Nsky" [W m-2 sr-1 (cm-1)-1]
C         reflected from the ocean surface.

C    Inputs:
C         The receiver spherical coordinates [rad] are (Tr,Pr). The
C         wind speed is W [m s-1]. v [cm-1] is the wavenumber. a and b are
C         coefficients of a least squares fit such that Ns, the spectral
C         sky radiance [W m-2 sr-1 (cm-1)-1] incident on the ocean
C         at zenith angle Ts [rad] , is given by

C                        Ns(Ts,v) = 1./[a(v) - b(v)*Ts**2].

C    Last revision:
C         January 27, 1995.

      COMMON/Constants/pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      REAL infinity, Ns
      if (W .ge. .01) then
C             use the Cox-Munk standard deviation for a real sea
              Su = sqrt(3.16E-3*W)
              Sc = sqrt(3.E-3 + 1.92E-3*W)
          else
C             use a delta function for an ideal calm sea
              Su = .01
              Sc = .01
      end if
      p0  = 1./(2.*pi*Su*Sc)
      Sav = (Su + Sc)/2.
      N   = 2
      M   = 7
      Smx = N*2.303*Sav
      dS  = Smx/M
      Ar  = sin(Tr)*cos(Pr)
      Br  = sin(Tr)*sin(Pr)
      Cr  = cos(Tr)

      sum1 = 0.
      sum2 = 0.
      sum3 = 0.
```

```
      do Sx = -Smx, Smx, dS
          Symx = sqrt(abs(Smx**2 - Sx**2))
          do Sy = -Symx, Symx, dS

C             For each position (Sx,Sy) in slope space:

C             calculate the occurrence probability density p:
              arg = ((Sx/Su)**2 + (Sy/Sc)**2)/2.
              if ((arg) .ge. log(p0/delta)) then
                      p = 0.
                  else
                      p = p0*exp(-arg)
              end if

C             calculate omega, the angle of incidence and Ts,
C             the zenith angle of the source ray.
              dd = Sx**2 + Sy**2
              f0 = - Ar*Sx - Br*Sy +Cr
              vv = f0/sqrt(1. + dd)
              if ((onem .le. vv) .and. (vv .le. onep)) then
                      omega = 0.
                  else if ((-onep .le. vv) .and. (vv .le. -onem)) then
                      omega = pi
                  else
                      omega = acos(vv)
              end if
              uu = (- 2.*Ar*Sx - 2.*Br*Sy + Cr*(1. - dd))/(1. + dd)
              if ((onem .le. uu) .and. (uu .le. onep)) then
                      Ts = 0.
                  else if ((-onep .le. uu) .and. (uu .le. -onem)) then
                      Ts = pi
                  else
                      Ts = acos(uu)
              end if

C             interpolate for Ns(Ts),
              Ns = 1./(a - b*(Ts**2))

C             define integrands,
              f1 = f0*p
              f2 = rho(omega,v)*f1
              f3 = Ns*f2

C             and accumulate integrals over all slopes.
              if (omega .le. pi/2.) then
                  sum1 = f1 + sum1
                  sum2 = f2 + sum2
                  if (Ts .le. pi/2.) sum3 = f3 + sum3
              end if
          end do
      end do
      sum1 = sum1*dS**2
      sum2 = sum2*dS**2
      sum3 = sum3*dS**2

      BoverA = sum1
      e      = 1. - sum2/sum1
```

```
      Nsky    = sum3/sum1

      return
      END

      SUBROUTINE Sun(Tr,Pr,W,To,Po,v,sum4)
CU    USES rho

C     Outputs:
C         Calculates a spectral solar reflectivity "sum4" for the
C         ocean surface apart from a normalization factor of
C         (4.*"BoverA") or (4.*"sum1").

C    Inputs:
C         The receiver spherical coordinates [rad] are (Tr,Pr). The
C         wind speed is W [m s-1]. The spherical coordinates [rad]
C         of the solar center are (To,Po). v [cm-1] is the wavenumber.

C     Note:
C         The larger the value of M, the y coordinate step size, the
C         more precise and slower the sum.  For fixed M precision
C         improves with wind speed.  For W = 1 m s-1 and M = 5, the
C         precision is better than 1.5 % around the center of the
C         glint pattern until the receiver zenith angle exceeds 89.5
C         degrees.

C     Bug:
C         Divides by zero when the sun is on the zenith.

C     Last Revision:
C         January 27, 1995.

      COMMON/Constants/pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      REAL infinity

C     Find the rectangular receiver coordinates
      Ar = sin(Tr)*cos(Pr)
      Br = sin(Tr)*sin(Pr)
      Cr = cos(Tr)

C     Find the Cox-Munk wind dependent slope standard deviations
      if (W .ge. .01) then
C             use the Cox-Munk standard deviation for a real sea
              Su = sqrt(3.16E-3*W)
              Sc = sqrt(3.E-3 + 1.92E-3*W)
          else
C             use a delta function for an ideal calm sea
              Su = .01
              Sc = .01
      end if
      p0  = 1./(2.*pi*Su*Sc)

      M = 5
      N = 2*M + 1
      sum  = 0.
      dY   = 2.*epsilon/N
      do I = 1, N
```

```
        Y    = epsilon - (I - 0.5)*dY
        Xmax = sqrt(epsilon**2 - Y**2)
        K    = int(2.*Xmax/dY + onem*0.5)
        dX   = 2.*Xmax/K
        do J = 1, K
            X  = Xmax - (J - 0.5)*dX

C           For each position (X,Y) (rectangular coordinates with
C           respect to the solar center) on the solar disk,

C           Find the spherical source coordinates:
            Ts = To - Y
            Ps = Po - X/sin(To)
            if (Ts .gt. pi/2.*onep) then
                print *, "Error from 'Sun': Part of solar disk"
                print *, "                  is below horizon."
                return
            endif

C           Find the the rectangular source coordinates:
            As = sin(Ts)*cos(Ps)
            Bs = sin(Ts)*sin(Ps)
            Cs = cos(Ts)

C           Find the slopes (Sx,Sy) for a specular reflection from
C           source (Ts,Ps) to receiver (Tr,Pr):
            if (abs(As + Ar) .le. delta) then
                    Sx = 0.
                else if ((Cs + Cr) .le. delta) then
                    Sx = sign(infinity, -(As + Ar))
                else
                    Sx = - (As + Ar)/(Cs + Cr)                    (A12)
            end if
            if (abs(Bs + Br) .le. delta) then
                    Sy = 0.
                else if ((Cs + Cr) .le. delta) then
                    Sy = sign(infinity, -(Bs + Br))
                else
                    Sy = - (Bs + Br)/(Cs + Cr)                    (A13)
            end if

C           Find the Cox-Munk occurrence probability density:
            arg = ((Sx/Su)**2 + (Sy/Sc)**2)/2.
            if ((arg) .ge. log(p0/delta)) then
                    p = 0.
                else
                    p = p0*exp(-arg)
            end if

C           Find the angle of incidence (omega) for the specular
C           reflection:
            dd = (1. + As*Ar + Bs*Br + Cs*Cr)/2.                  (A14)
            if (dd .le. delta) dd = 0.
            ss = sqrt(dd)                                         (A14)
            if ((onem .le. ss) .and. (ss .le. onep)) then
                    omega = 0.
                else if ((-onep .le. ss) .and. (ss .le. -onem)) then
```

```
                    omega = pi
                else
                    omega = acos(ss)                                    (A14)
            end if

C           Find the facet tilt (Tn) for the specular reflection:
            Tn = atan(sqrt(Sx**2 + Sy**2))                              (A6)

C           Integrate:
            sum = rho(omega,v)/(cos(Tn)**4)*p*dX + sum                  (32)

        end do
    end do
    sum4 = sum*dY
    return
    END

    SUBROUTINE Fit(x,y,n,a,b)
    DIMENSION x(*),y(*)

C       Given (x,y) pairs in the data arrays x(i) and y(i), where
C       1 <= i <= n, performs a least sqares fit of these data to
C       the equation

C                           y = 1/(a - b*x**2)

C       and returns the values of a and b.

C       Last revised:  March 13, 1995.

    DOUBLE PRECISION nn, bb, cc(4)
C                       where cc(1:4) = c01, c21, c20, c40.
    nn = FLOAT(n)

    do i = 1, n
        if (y(i) .eq. 0.) then
            a = 7.E5
            b = 0.
            return
        end if
    end do

    do i = 1, 4
        cc(i) = 0.d0
    end do

    do i = 1, n
        cc(1) = cc(1) + 1./y(i)
        cc(2) = cc(2) + x(i)**2/y(i)
        cc(3) = cc(3) + x(i)**2
        cc(4) = cc(4) + x(i)**4
    end do

    bb = (nn*cc(2) - cc(3)*cc(1))/(nn*cc(4) - cc(3)**2)
    a  = (cc(1) - cc(3)*bb)/nn
    b  = - bb
```

```
      END

      SUBROUTINE Foot(ThetaO, PhiO, ThetaS, PhiS, PsiPO, Beta, Psi)
CU    USES Angle, Side
      COMMON /Constants/ Spi,Sr2d,Sd2r,epsilon,delta,onem,onep,infinity
      COMMON /Geometry/ To,Po,Tr,Pr
      COMMON /Card2/ IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,W,WHH,
     +               RAINRT
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,
     +              ITR,Ipath,Isky,Isun
      COMMON /Sea/ Sea, Hit, Msea, TBOUNDold, IEMSCTold
      REAL infinity
C
*********************************************************************
*                                                                   *
*     This routine calculates zenith angles and azimuthal angles from *
*     the footprint, defined as the location where a hit has just   *
*     occurred.                                                     *
*                                                                   *
*     All the arguments are inputs, and all are angles in degrees:  *
*         ThetaO and PhiO are the observer latitude and longitude.  *
*         ThetaS and PhiS are the solar latitude and longitude.     *
*         PsiPO is the path azimuth (+ E of N) seen by the observer. *
*         Beta is the angle subtended at the center of the earth    *
*             between the observer and the footprint.               *
*         PsiW is the wind azimuth (+E of N) seen by the observer.  *
*                                                                   *
*     The outputs are To, Po, and Pr, angles in radians passed      *
*     through the common block "Geometry":                          *
*         To is the zenith angle of the center of the sun           *
*             from the footprint.                                   *
*         Po is the azimuth (+ W. of PsiW) of the center of the sun *
*             from the footprint.                                   *
*         Pr is the azimuth (+ W. of PsiW) receiver as seen         *
*             from the footprint.                                   *
*         Note: Tr has been calculated in DPFNMN and is used        *
*               in this subroutine only for printing to "OUT".      *
*                                                                   *
*     Last revision: June 15, 1995.                                 *
*                                                                   *
*********************************************************************

      DOUBLE PRECISION DThetaO, DPhiO, DThetaS, DPhiS, DPsiPO, DBeta,
     +                 DPsiW, DThetaF, DPhiF, Pi, Side, Angle, DTo, DPo

      Pi  = 4.*DATAN(1.)
      D2R = Pi/180.
      R2D = REAL(180./Pi)

C     First, convert to radians and increase precision:

      DThetaS = DBLE(ThetaS)*D2R
      DPhiS   = DBLE(PhiS)*D2R
      DThetaO = DBLE(ThetaO)*D2R
      DPhiO   = DBLE(PhiO)*D2R
      DPsiPO  = DBLE(PsiPO)*D2R
      DBeta   = DBLE(Beta)*D2R
```

```
      DPsiW    = DBLE(Psi+PsiPO)*D2R

C     then use the geometry of three spherical triangles connecting
C     the north pole, the observor, the sun, and the footprint:

      DThetaF = Pi/2. - Side(Pi/2.-DThetaO, -DPsiPO, DBeta)

      IF (DPsiPO .GE. Pi) THEN
              DPhiF  = DPhiO + Angle(Pi/2.-DThetaO,DBeta,Pi/2.-DThetaF)
          ELSE
              DPhiF  = DPhiO - Angle(Pi/2.-DThetaO,DBeta,Pi/2.-DThetaF)
      END IF

      DTo = Side(Pi/2.-DThetaS, DPhiS-DPhiF, Pi/2.-DThetaF)
      To  = REAL(DTo)

      IF (DPhiS .GE. DPhiO) THEN
              DPo = DPsiW + Angle(Pi/2.-DThetaF, Pi/2.-DThetaS, DTo)
          ELSE
              DPo = DPsiW - Angle(Pi/2.-DThetaF, Pi/2.-DThetaS, DTo)
      END IF
      Po = REAL(DPo)

      IF (DPhiF .GE. DPhiO) THEN
              DPr = DPsiW - Angle(Pi/2.-DThetaF, Pi/2.-DthetaO, DBeta)
          ELSE
              DPr = DPsiW + Angle(Pi/2.-DThetaF, Pi/2.-DthetaO, DBeta)
      END IF
      Pr = REAL(DPr)

C     Calculate specular slope (merely for print-out, not used for
C     further calculations):

C     Find the rectangular receiver coordinates,
      Ar = sin(Tr)*cos(Pr)
      Br = sin(Tr)*sin(Pr)
      Cr = cos(Tr)

C     Find the the rectangular source coordinates for the solar center,
      Ao = sin(To)*cos(Po)
      Bo = sin(To)*sin(Po)
      Co = cos(To)

C     Find the Cox-Munk wind dependent slope variances
      if (W .ge. .01) then
C             use the Cox-Munk variance for a real sea
              Vu = 0.000 + 3.16E-3*W
              Vc = 0.003 + 1.92E-3*W
          else
C             use a delta function for an ideal calm sea
              Vu = .0001
              Vc = .0001
      end if
      p0 = 1./(2.*pi*sqrt(Vu*Vc))

C     Find the slopes (Sxo,Syo) for a specular reflection from
C     source (To,Po) to receiver (Tr,Pr),
```

```
      if (abs(Ao + Ar) .le. delta) then
              Sxo = 0.
          else if ((Co + Cr) .le. delta) then
              Sxo = sign(infinity, -(Ao + Ar))
          else
              Sxo = - (Ao + Ar)/(Co + Cr)                                  (A12)
      end if
      if (abs(Bo + Br) .le. delta) then
              Syo = 0.
          else if ((Co + Cr) .le. delta) then
              Syo = sign(infinity, -(Bo + Br))
          else
              Syo = - (Bo + Br)/(Co + Cr)                                  (A13)
      end if

C     Calculate the Cox-Munk tilt and slope:
      arg = Sxo**2/Vu + Syo**2/Vc
      p  = p0*exp(-0.5*arg)
      Tn = atan(sqrt(Sxo**2 + Syo**2))

C     and print to "OUT":

      WRITE (IP6,1000)
      WRITE (IP6,1010) DBeta*R2D,DPsiPO*R2D,AMOD(DPsiW*R2D,360.)
      IF ((IEMSCTold) .EQ. 2) THEN
          WRITE (IP6,1020) DThetaO*R2D,DPhiO*R2D,DThetaF*R2D,DPhiF*R2D,
     +                     DThetaS*R2D,DPhiS*R2D
      END IF
      WRITE (IP6,1030)
      WRITE (IP6,1040) Tr*R2D,AMOD(Pr*R2D,360.)
      IF ((IEMSCTold) .EQ. 2) THEN
          WRITE (IP6,1050) To*R2D,AMOD(Po*R2D,360.),Sr2d*Tn,sqrt(arg),p
      END IF
C
1000  format(/,'SUMMARY OF OBSERVATION GEOMETRY'/)
1010  format (10X,'BETA                    =',F10.5,
     +            ' DEG',/,
     +        10X,'PATH AZIMUTH            =',F10.3,
     +            ' DEG EAST OF NORTH',/,
     +        10X,'WIND AZIMUTH            =',F10.3,
     +            ' DEG EAST OF NORTH',\)
1020  format (10X,'RECEIVER LATITUDE       =',F10.3,
     +            ' NORTH OF EQUATOR',/,
     +        10X,'RECEIVER LONGITUDE      =',F10.3,
     +            ' WEST OF GREENWICH',/,
     +        10X,'FOOTPRINT LATITUDE      =',F10.3,
     +            ' NORTH OF EQUATOR',/,
     +        10X,'FOOTPRINT LONGITUDE     =',F10.3,
     +            ' WEST OF GREENWICH',/,
     +        10X,'SUBSOLAR LATITUDE       =',F10.3,
     +            ' DEG NORTH OF EQUATOR',/,
     +        10X,'SUBSOLAR LONGITUDE      =',F10.3,
     +            ' DEG WEST OF GREENWICH',//)
 1030 format(/,'VALUES SEEN FROM FOOTPRINT'/)
 1040 format (10X,'RECEIVER ZENITH ANGLE =',F10.3,
     +            ' DEG',/,
     +        10X,'RECEIVER AZIMUTH        =',F10.3,
```

```
     +            ' DEG WEST OF UP WIND')
 1050 format (10X,'SOLAR ZENITH ANGLE    =',F10.3,
     +            ' DEG',/,
     +        10X,'SOLAR AZIMUTH         =',F10.3,
     +            ' DEG WEST OF UP WIND',/,
     +        10X,'SOLAR SPECULAR TILT   =',F10.3,
     +            ' DEG (', F6.2, ' SIGMA, PROB =',1PE10.3,')')

      return
      END

      SUBROUTINE SunFoot(Psi0, Del0, PsiPO, Beta, Psi)
CU    USES Angle, Side
      COMMON /Constants/ Spi,Sr2d,Sd2r,epsilon,delta,onem,onep,infinity
      COMMON /Geometry/ To,Po,Tr,Pr
      COMMON /Card2/ IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,W,WHH,
     +               RAINRT
      COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,
     +              ITR,Ipath,Isky,Isun
      COMMON /Sea/ Sea, Hit, Msea, TBOUNDold, IEMSCTold
      REAL infinity
C
*********************************************************************
*                                                                   *
*     This routine calculates zenith angles and azimuthal angles from *
*     the footprint, defined as the location where a hit has just   *
*     occurred, whenever the sun is involved. (PsiPO is not used in *
*     the calculation; it's passed in only to be printed out.)      *
*                                                                   *
*     All the arguments are inputs, and all are angles in degrees:  *
*         Psi0 is the solar azimuth measured from the observor's    *
*             line-of-sight (+E of N).                              *
*         Del0 is the solar zenith angle as seen by the observor.   *
*         Beta is the angle subtended at the center of the earth    *
*             between the observor and the footprint.               *
*         Psi is the wind azimuth measured from the observor's      *
*             line-of-sight (+E of N).                              *
*             (Psi is ASSUMED to be the same at the footprint.)     *
*                                                                   *
*     The outputs are To, Po, and Pr, angles in radians passed      *
*     through the common block "Geometry":                          *
*         To is the zenith angle of the center of the sun           *
*             from the footprint.                                   *
*         Po is the azimuth (+ W of PsiW) of the center of the sun  *
*             from the footprint.                                   *
*         Pr is the azimuth (+ W of PsiW) receiver as seen          *
*             from the footprint.                                   *
*         Note: Tr has been calculated in DPFNMN and is used        *
*               in this subroutine only for printing to "OUT".      *
*                                                                   *
*     Last revision: June 14, 1995.                                 *
*                                                                   *
*********************************************************************

      DOUBLE PRECISION DPsi0, DDel0, DBeta, Pi, Side, Angle, DTo, DPo

      Pi  = 4.*DATAN(1.)
```

```
      D2R = Pi/180.
      R2D = REAL(180./Pi)

C     First, convert to radians and increase precision:

      DPsi0 = DBLE(Psi0)*D2R
      DDel0 = DBLE(Del0)*D2R
      DBeta = DBLE(Beta)*D2R
      DPsi  = DBLE(Psi)*D2R

C     then use the geometry of the spherical triangle connecting
C     the observor, the sun, and the footprint:

      DTo = Side(DBeta, DPsi0, DDel0)
      To  = REAL(DTo)

      DPr = Pi + DPsi
      Pr  = REAL(DPr)

      If (DPsi0 .GT. 0.) then
              DPo = DPr + Angle(DTo, DDel0, DBeta)
          Else if (DPsi0 .EQ. 0.) then
              DPo = DPr + Pi
          Else
              DPo = DPr - Angle(DTo, DDel0, DBeta)
      End If
      Po  = REAL(DPo)

C     Calculate specular slope (calculations from now on merely for
C     print-out, not for further calculations):

C     Find the rectangular receiver coordinates,
      Ar = sin(Tr)*cos(Pr)
      Br = sin(Tr)*sin(Pr)
      Cr = cos(Tr)

C     Find the the rectangular source coordinates for the solar center,
      Ao = sin(To)*cos(Po)
      Bo = sin(To)*sin(Po)
      Co = cos(To)

C     Find the Cox-Munk wind dependent slope variances
      if (W .ge. .01) then
C             use the Cox-Munk variance for a real sea
              Vu = 0.000 + 3.16E-3*W
              Vc = 0.003 + 1.92E-3*W
          else
C             use a delta function for an ideal calm sea
              Vu = .0001
              Vc = .0001
      end if
      p0 = 1./(2.*pi*sqrt(Vu*Vc))

C     Find the slopes (Sxo,Syo) for a specular reflection from
C     source (To,Po) to receiver (Tr,Pr),
      if (abs(Ao + Ar) .le. delta) then
              Sxo = 0.
```

```
        else if ((Co + Cr) .le. delta) then
            Sxo = sign(infinity, -(Ao + Ar))
        else
            Sxo = - (Ao + Ar)/(Co + Cr)                                  (A12)
    end if
    if (abs(Bo + Br) .le. delta) then
            Syo = 0.
        else if ((Co + Cr) .le. delta) then
            Syo = sign(infinity, -(Bo + Br))
        else
            Syo = - (Bo + Br)/(Co + Cr)                                  (A13)
    end if

C   Calculate the Cox-Munk tilt and slope:
    arg = Sxo**2/Vu + Syo**2/Vc
    p  = p0*exp(-0.5*arg)
    Tn = atan(sqrt(Sxo**2 + Syo**2))

C   and print to "OUT":

    WRITE (IP6,2000)
    WRITE (IP6,2010) DBeta*R2D,PsiPO,AMOD((Psi+PsiPO), 360.)
    WRITE (IP6,2030)
    WRITE (IP6,2040) Tr*R2D,AMOD(Pr*R2D,360.)
    IF ((IEMSCTold) .EQ. 2) THEN
        WRITE (IP6,2050) To*R2D,AMOD(Po*R2D,360.),Sr2d*Tn,sqrt(arg),p
    END IF
C
 2000 format(/,'SUMMARY OF OBSERVATION GEOMETRY'/)
 2010 format (10X,'BETA                    =',F10.5,
     +            ' DEG',/,
     +        10X,'PATH AZIMUTH            =',F10.3,
     +            ' DEG EAST OF NORTH',/,
     +        10X,'WIND AZIMUTH            =',F10.3,
     +            ' DEG EAST OF NORTH',\)
 2030 format(/,'VALUES SEEN FROM FOOTPRINT'/)
 2040 format (10X,'RECEIVER ZENITH ANGLE =',F10.3,
     +            ' DEG',/,
     +        10X,'RECEIVER AZIMUTH        =',F10.3,
     +            ' DEG WEST OF UP WIND')
 2050 format (10X,'SOLAR ZENITH ANGLE     =',F10.3,
     +            ' DEG',/,
     +        10X,'SOLAR AZIMUTH           =',F10.3,
     +            ' DEG WEST OF UP WIND',/,
     +        10X,'SOLAR SPECULAR TILT     =',F10.3,
     +            ' DEG (', F6.2, ' SIGMA, PROB =',1PE10.3,')')

    return
    END

    SUBROUTINE Card
    COMMON /Card2/ IHAZE,ISEASN,IVULCN,ICSTL,ICLD,IVSA,VIS,WSS,WHH,
     +                RAINRT
    COMMON /Card3/ H1,H2,ANGLE,RANGE,BETA,RE,LEN,Psi,SeaSwitch
    COMMON /Card3A1/ IPARM,IPH,IDAY,ISOURC
    COMMON /Card3A2/ PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,ANGLEM,G
    COMMON /IFIL/ IRD,IPR,IPU,NPR,IPR1,IP6,IP7,IP8,IP4,IRDS,IP6S,
```

```
     +              ITR,Ipath,Isky,Isun
      COMMON /Constants/ pi,r2d,d2r,epsilon,delta,onem,onep,infinity
      COMMON /Geometry/ To,Po,Tr,Pr
      COMMON /Sea/ Sea,Hit,Msea,TBOUNDold,IEMSCTold
      REAL   infinity
      LOGICAL SeaSwitch

*********************************************************************
*                                                                   *
*     Issues new MODTRAN cards for the sea routines.                *
*                                                                   *
*     When IEMSCTold = 1, no sun is involved, and three new sky     *
*     cards are issued to "TAPE5.SEA": one for Tmin, the minimum sky *
*     zenith angle expected at the current wind speed, one for      *
*     for Tmax, the maximum zenith angle expected, and one for Tav, *
*     the sky zenith angle halfway between Tmax and Tmin.           *
*                                                                   *
*     When IEMSCTold = 2, the sun is involved, and after each new sky *
*     card the original cards 3A1 and 3A2 are reissued.  At the very *
*     end of the file there is one sun card.  Hence the number of new *
*     cards issued to 'TAPE5.SEA" is 10 when IEMSCTold = 2.         *
*                                                                   *
*     Last revised: February 28, 1995.                              *
*                                                                   *
*********************************************************************

      Irpt = 3

C     First, find the wind-dependent sky angles Tmin and Tmax:
      if (WSS .ge. .01) then
C             use the Cox-Munk standard deviation for a real sea
              Su = sqrt(3.16E-3*WSS)
              Sc = sqrt(3.E-3 + 1.92E-3*WSS)
          else
C             use a delta function for an ideal calm sea
              Su = .01
              Sc = .01
      end if
      S = 2.8
C         is the number of standard deviations to which the
C         wave slope integral will be carried; for S = 2.8
C         99 % of the volume under the distribution is captured.
      dT   = 2.02*(atan(S*amax1(Su,Sc)))
      Tmin = amax1(Tr - dT, 1.)
      Tmax = amin1(Tr + dT, d2r*89.)

C     Next, open TAPE5.SEA, the alternate file to TAPE5:
      open (Irds, file = 'Tape5.Sea', status = 'unknown')

C     then write the sky cards (IEMSCT = 2, ITYPE = 3):
      do Ts = Tmin, Tmax, onem*(Tmax-Tmin)/2.
          write (Irds, 150) Irpt
          write (Irds, 100) 0.,0.,Ts*r2d,0.,0.,0.,0,Psi,SeaSwitch
          if (IEMSCTold .eq. 2) then
              write (Irds, 400) IPARM,IPH,IDAY,ISOURC
              write (Irds, 500) PARM1,PARM2,PARM3,PARM4,GMT,PSIPO,
     +                          ANGLEM,G
```

```
          end if
      end do

C     write the sun card (IEMSCT = 3, ITYPE = 3) if necessary:
      if (IEMSCTold .EQ. 2) then
          write (Irds, 150) Irpt
          write (Irds, 200) 0.,0.,To*r2d,IDAY,0.,0,0.
      end if

C     and finally
      rewind Irds
C     so it can be read from the beginning by the driver.

      return

  100 format (6F10.3,I5,F10.3,L5)
  150 format (I5)
  200 format (3F10.3,I5,5X,F10.3,I5,F10.3)
  400 format (4I5)
  500 format (8F10.3)

      END

***************************** FUNCTIONS ********************************
*                                                                      *
*     Latest revision:  May 5, 1994 for Side and Angle.                *
*                                                                      *
************************************************************************

      FUNCTION Side(a,C,b)
C     is the Law of Cosines for a spherical triangle with sides a, b,
C     and c and opposite angles A, B, C.  The three parameters are
C     the two sides a and b and the included angle C. Side is the
C     value of side c opposite the included angle C. Angles are in
C     radians.

      double precision a,C,b,Side
      Side = dacos(dcos(a)*dcos(b) + dsin(a)*dsin(b)*dcos(C))
      END

      FUNCTION Angle(a,c,b)
C     is the Law of Cosines for a spherical triangle with sides a, b,
C     and c and opposite angles A, B, C.  The three parameters are
C     the three sides.  Angle is the value of angle C opposite side
C     c, the middle parameter in the list. Angles are in radians.

      double precision pi,a,b,c,Angle,Arg,aa,bb
      pi = 4.*datan(1.)
      aa = dmin1(a, b)
      bb = dmax1(a, b)

      if (abs(aa) .le. 1.D-5) then
              Angle = dacos(dtan(aa)/dtan(bb))
              if (abs(bb) .lt. abs(c)) Angle = pi - Angle
      end if
```

```
      Arg = (dcos(c) - dcos(a)*dcos(b))/(dsin(a)*dsin(b))
      if (abs(Arg) .ge. (1 - 1.D-14)) then
              Angle = 0.
          else
              Angle = dacos(Arg)
      end if

      END

      FUNCTION Rho(Omega, V)
CU    USES SeaData
      COMMON /SeaIndex/ Alpha01(100), Alpha02(20),
     +                  Beta01 (100), Beta02 (20)

*********************************************************************
*                                                                   *
*       Calculates reflectivity of sea water between 52.63 cm-1 and *
*  25,000 cm-1 using equations (74) and (78) of Stratton, "Electro- *
*  magnetic Theory", 1941, page 505, ff.  The sea water is assumed to *
*  be a conducting medium;  both real and imaginary parts of the    *
*  index of water are used.  The notation of Stratton is adhered to *
*  as closely as possible.                                          *
*                                                                   *
*       Omega is the angle of incidence in radians;  V is the wave- *
*  number in cm-1;  Rho is the reflectivity.                        *
*                                                                   *
*  Last revision:  November 28, 1994                                *
*                                                                   *
*********************************************************************

C     The four-point interpolation functions are:
      WM(X) = (X - 1.)*(X - 2.)*X/6.
      W0(X) = (X - 1.)*(X - 2.)*(X + 1.)/2.
      W1(X) = (X + 1.)*(X - 2.)*X/2.
      W2(X) = (X + 1.)*(X - 1.)*X/6.

      IF ((Omega .LT. 0.) .OR. (Omega .GT. 1.57080)) THEN
C     Omega is out of bounds; set reflectivity to 0% and return:
          Rho = 0.
          RETURN
      END IF

      IF (V .EQ. 0.) THEN
C     set reflectivity to 100% and return:
          Rho = 1.
          RETURN
      END IF

      W = 1.E4/V

      IF (W .LT. 0.399999) THEN
C     print error message and return:
          Rho = 0.
          WRITE (6, 1000) V
          RETURN
      END IF
```

```
      IF (0.4 .LE. W .AND. W .LE. 19.8) THEN
C     use Lagrange 4 point interpolation on Block 01 data which
C     are at 0.2 um spacing between 0.2 and 20 um:
          I  = INT(W/0.2)
          Fr = MOD(W, 0.2)/0.2
          Alpha1 = W2(Fr)*Alpha01(I + 2) - W1(Fr)*Alpha01(I + 1)
     +           + W0(Fr)*Alpha01(I)     - WM(Fr)*Alpha01(I - 1)
          Beta1  = W2(Fr)*Beta01 (I + 2) - W1(Fr)*Beta01 (I + 1)
     +           + W0(Fr)*Beta01 (I)     - WM(Fr)*Beta01 (I - 1)
      END IF

      IF (19.8 .LT. W .AND. W .LT. 190.) THEN
C     use Lagrange 4 point interpolation on Block 02 data which
C     are at 10 um spacing between 10 and 200 um:
          I  = INT(W/10.)
          Fr = MOD(W, 10.)/10.
          Alpha1 = W2(Fr)*Alpha02(I + 2) - W1(Fr)*Alpha02(I + 1)
     +           + W0(Fr)*Alpha02(I)     - WM(Fr)*Alpha02(I - 1)
          Beta1  = W2(Fr)*Beta02 (I + 2) - W1(Fr)*Beta02 (I + 1)
     +           + W0(Fr)*Beta02 (I)     - WM(Fr)*Beta02 (I - 1)
      END IF

      IF  (190. .LE. W) THEN
C     print error message and return:
          RHO = 0.
          WRITE (6, 1000) V
          RETURN
      END IF

      G = Alpha1**2 - Beta1**2 - SIN(Omega)**2
      H = 4*(Alpha1**2)*(Beta1**2)
      P = SQRT(0.5*(-G + SQRT(H + G**2)))
      Q = SQRT(0.5*(+G + SQRT(H + G**2)))

C     Stratton, Equation (74), p. 505:
      C  = (Q - COS(Omega))**2 + P**2
      D  = (Q + COS(Omega))**2 + P**2
      Rp = C/D

C     Stratton, Equation (77), p. 506:
      E  = ((Alpha1**2 - Beta1**2)*COS(Omega) - Q)**2
      F  = ((Alpha1**2 - Beta1**2)*COS(Omega) + Q)**2
      T  = (2*Alpha1*Beta1*COS(Omega) - P)**2
      U  = (2*Alpha1*Beta1*COS(Omega) + P)**2
      Rs = (E + T)/(F + U)

      Rho = (Rp + Rs)/2.

      RETURN
 1000 FORMAT (' ***** WARNING - INPUT FREQUENCY = ', 1PG12.5, 'CM-1',
     +      /, ' OUTSIDE VALID RANGE OF 52.63 TO 25,000 CM-1  ******',/)
      END

      BLOCK DATA SeaData
      COMMON /SeaIndex/ Alpha01(100), Alpha02(20),
     +                  Beta01 (100), Beta02 (20)
```

```
*********************************************************************
*                                                                   *
*     These data for the optical index of water have been taken from *
*     the literature.  From 0.2 to 2 microns (blocks 01 up to second *
*     entry of row B) and from 10 to 200 microns (blocks 02) the data *
*     are from G. M. Hale and M. R. Querry, "Optical Constants of Water*
*     in the 200-nm to 200-um Wavelength Region," Appl. Opt. 3, 555 *
*     (1973).  These data are for pure water.                       *
*                                                                   *
*     From 2.2 to 20 microns (blocks 01 from the third entry of row B *
*     to the end) the data are from M. R. Querry, W. E. Holland, R. C. *
*     Waring, L. M. Earls, and M. D. Querry, "Relative Reflectance and *
*     Complex Refractive Index in the Infrared for Saline Environmental*
*     Waters," J. Geophys. Res. 82, 1425 (1977), Table 3, Pacific   *
*     Ocean columns.  These data are for salt water.                *
*                                                                   *
*********************************************************************

C     Real part of the index of sea water from 0.2 to 20 microns in
C     steps of 0.2 microns:
      DATA Alpha01  /
     A      1.396, 1.339, 1.332, 1.329, 1.327, 1.324, 1.321, 1.317,
     B      1.312, 1.306, 1.303, 1.287, 1.251, 1.151, 1.384, 1.479,
     C      1.421, 1.388, 1.368, 1.355, 1.347, 1.339, 1.335, 1.335,
     D      1.332, 1.324, 1.312, 1.296, 1.268, 1.271, 1.371, 1.353,
     E      1.340, 1.330, 1.324, 1.319, 1.314, 1.307, 1.302, 1.297,
     F      1.291, 1.286, 1.279, 1.272, 1.268, 1.264, 1.258, 1.249,
     G      1.240, 1.229, 1.218, 1.204, 1.190, 1.177, 1.165, 1.151,
     H      1.140, 1.132, 1.124, 1.119, 1.121, 1.126, 1.134, 1.142,
     I      1.152, 1.164, 1.177, 1.189, 1.201, 1.212, 1.224, 1.234,
     J      1.242, 1.253, 1.261, 1.273, 1.284, 1.296, 1.309, 1.320,
     K      1.331, 1.339, 1.349, 1.358, 1.366, 1.379, 1.390, 1.399,
     L      1.408, 1.417, 1.426, 1.435, 1.443, 1.450, 1.458, 1.464,
     M      1.470, 1.474, 1.477, 1.480  /

C     Real part of the index of sea water from 10 to 200 microns in
C     steps of 10 microns:
      DATA Alpha02  /
     A      1.218, 1.480, 1.551, 1.519, 1.587, 1.703, 1.821, 1.886,
     B      1.924, 1.957, 1.966, 2.004, 2.036, 2.056, 2.069, 2.081,
     C      2.094, 2.107, 2.119, 2.130  /

C     Imaginary part of the index of sea water from 0.2 to 20 microns in
C     steps of 0.2 microns:
      DATA Beta01  /
     A      0.000, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000,
     B      0.000, 0.001, 0.000, 0.001, 0.003, 0.114, 0.263, 0.085,
     C      0.018, 0.005, 0.003, 0.004, 0.007, 0.011, 0.016, 0.016,
     D      0.013, 0.011, 0.010, 0.013, 0.032, 0.108, 0.087, 0.044,
     E      0.035, 0.033, 0.032, 0.031, 0.031, 0.032, 0.032, 0.033,
     F      0.034, 0.036, 0.038, 0.041, 0.044, 0.046, 0.046, 0.047,
     G      0.048, 0.050, 0.054, 0.060, 0.068, 0.079, 0.091, 0.107,
     H      0.125, 0.145, 0.166, 0.191, 0.216, 0.239, 0.260, 0.279,
     I      0.297, 0.313, 0.326, 0.338, 0.347, 0.357, 0.363, 0.371,
     J      0.377, 0.385, 0.393, 0.401, 0.407, 0.413, 0.417, 0.418,
     K      0.420, 0.422, 0.424, 0.427, 0.430, 0.432, 0.432, 0.432,
     L      0.431, 0.430, 0.429, 0.427, 0.425, 0.423, 0.420, 0.416,
```

```
     M       0.414, 0.410, 0.406, 0.393  /

C     Imaginary part of the index of sea water from 10 to 200 microns in
C     steps of 10 microns:
      DATA Beta02  /
     A       0.051, 0.393, 0.328, 0.385, 0.514, 0.587, 0.576, 0.547,
     B       0.536, 0.532, 0.531, 0.526, 0.514, 0.500, 0.495, 0.496,
     C       0.497, 0.499, 0.501, 0.504  /

      END
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REPORT DOCUMENTATION PAGE

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13 ABSTRACT *(Maximum 200 words)*

Sea radiance is modeled by combining the methods of geometrical optics with the Cox-Munk statistical description of ocean capillary waves. The model is incorporated into the atmospheric transmittance/radiance code MODTRAN2 to provide numerical sea radiance predictions.

In this model each individual capillary wave facet is allowed to reflect the sky or sun and emit thermal radiation. The total radiance from the sea is obtained by applying the proper statistical weight to each facet and integrating it over all facets within the observer's field-of-view

The modified MODTRAN2 code, called *SeaRad*, calculates sea radiance for any viewing geometry in the spectral range from 52 63 cm^{-1} to 25000 cm^{-1}. Typical execution speeds are approximately 10 s per pixel on a Pentium/90 MHz personal computer. Preliminary comparisons show that *SeaRad* agrees to within several degrees Celsius (°C) with actual sea radiance measurements in the mid-wave and long-wave infrared bands.

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