What You Need to Know to Run TOMRAD

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Document date: Aug. 30, 2000

Application: This document applies to Version 2.22 of the TOMRAD code, available from Code 916.0, NASA Goddard Space Flight Center, Greenbelt, MD.

1. Input files

TOMRAD is controlled by input files and (optionally) by command-line switches. There are two mandatory input files, and several optional input files.

1.1. Mandatory input files

TOMRAD requires two input files: The **profile file**, which contains a model of the atmosphere, view geometry specifications, and wavelength selection, and the **coefficient file**, which contains absorption coefficients for the primary absorber (ozone), and Rayleigh scattering and molecular depolarization coefficients. These two files are described in the following two subsections.

1.1.1 Profile file

The default name of the profile file is `PROF`. This may be changed either by an entry in the optional ENV file (see §1.2), or by a command line switch (see §3). This file contains 18 lines, which are described in the remainder of this section.

1. *Profile name.* The profile name is read in, and used in writing headers to some of the output files. Only the first 8 characters on the first line are used.
2. *Surface pressure.* (p_t, atm.) This is the surface pressure, in atmospheres, and it must be $\leq$ 1.0. A value of 1.0 corresponds to a surface pressure of 1013.25 mbar.
3. *Number of SZAs.* (N_{θ_0}, int.) This is the number of solar zenith angles (SZA) that are to be used, from those on the following line of this file. As supplied, the maximum number of thetas is 10, but this may be changed via the file `parameter.inc` (See §4.). This line may also be used to specify that the next line actually contains the cosines of the solar zenith angles. If the word '`mu`' appears anywhere on this line, then the next line is taken to specify the μ_o-values, *i.e.* $|\cos\theta_o|$.
4. *SZAs.* (θ_o, deg. or μ_o, dimensionless). The solar zenith angles are specified on this line. If the previous line specified fewer than the number of values present on this line, only the

specified number are used. Also, if the previous line contained the word '`mu`', the input values are assumed to be $\mu_o = |\cos\theta_o|$. The values of θ_o should be in the interval $[0°, 90°]$. The values of μ_o should be in the interval $[0, 1]$.

5. *Number of scans.* (N_θ, int.) This is the number of scan angles, (or "satellite zenith angles" or "look angles") at which the outgoing radiances at the top of the atmosphere are to be computed. The actual scan angles are read in from the subsequent line of this file. As supplied, the maximum number of scan angles is 9, but this may be changed via the file `parameter.inc` (See §4.). This line may also be used to specify that the next line actually contains the cosines of the satellite zenith angles. If the word '`mu`' appears anywhere on this line, then the next line is taken to specify the μ-values, *i.e.* $|\cos\theta|$.

6. *Scan angles.* (θ, deg. or μ, dimensionless). The scan angles are specified on this line. If the previous line specified fewer than the number of values present on this line, only the specified number are used. Also, if the previous line contained the word '`mu`', the input values are assumed to be $\mu = |\cos\theta|$. The values of θ should be in the interval $[0°, 90°]$. The values of μ should be in the interval $[0, 1]$.

7. *Number of azimuth angles.* (N_ϕ, int.) This is the number of azimuth angles to be used from the following line of the file. As supplied, the maximum number of azimuth angles is 7, but this may be changed via the file `parameter.inc` (See §4.).

8. *Azimuth angle.* (ϕ, deg.) These are the azimuth angles at which the outgoing radiances at the top of the atmosphere are to be computed.

9. *Number of albedoes.* (N_{R_s}, int.) This is the number of surface albedoes to be used from the following line of the file. As supplied, the maximum number of albedoes is 11, but this may be changed via the file `parameter.inc` (See §4.).

10. *Albedoes.* (R_s, frac.) This line specifies the surface albedoes to be used. They should be in the interval $[0, 1]$.

11. *Start and Stop wavelengths.* (Å) The **coefficient file** (see §1.1.2) may contain more wavelengths than are desired for the current run. This line specifies the two wavelengths that are used to determine which wavelengths are actually processed. They are treated inclusively: A wavelength in the coefficient file that matches the start or stop wavelength is processed. As supplied, the total number of wavelengths that can be processed in a single run is limited to 2,500, but this may be changed via the file `parameter.inc` (See §4.).

12. *Ozone profile.* (DU) This line must specify eleven layer ozone amounts, from the bottom of the atmosphere to the top. If the pressure of the reflecting surface (input on line 2) is less than 1 atm, then the ozone below that pressure is ignored. The following diagram illustrates the layer definition scheme used in TOMRAD . We also indicate the correspondence between

the TOMRAD indices and the umkehr layer numbers.

pressure (atm)	umkehr layer	TOMRAD index
0	10, 11, 12	11
1/1024	9	10
1/512	8	9
1/256	7	8
1/128	6	7
1/64	5	6
1/32	4	5
1/16	3	4
1/8	2	3
1/4	1	2
1/2	1	1
1		

13. *Temperature profile.* (K) This line must specify eleven average layer absolute temperatures, from the bottom of the atmosphere to the top. The layer numbering is identical to that shown just above. Note: Past versions of TOMRAD used a procedure that weighted the temperatures with the ozone profile. The current version allows the user either to use the temperature profile as is or to use the ozone weighting procedure. To make these two approaches more equivalent (but not exactly equal), the average layer temperature values, T_i, can be calculated from the following:

$$T_i = \int_0^{P_i} T(p) q_{oz}(p) dp / X_i$$

where P_i is the pressure at the bottom of the ith layer (see 1.1.1 item 12) , $T(p)$ is the absolute temperature of the **user input profile** as a function of pressure (p), $q_{oz}(p)$ is the ozone pressure mixing ratio divided by the product of the average molecular mass of the neutral atmosphere and the acceleration of gravity, ($m_{air}(p)g(p)$), and X_i is the total column amount of ozone from the top of the atmosphere down to P_i,

$$X_i = \int_0^{P_i} q_{oz}(p) dp \; .$$

14. *Print control switches.* This line contains ten digits, separated by spaces, which must each be 1 or 0. A switch value of 1 means turn on the controlled output; 0 means suppress the controlled output. These control the output produced by the program. The following table

summarizes the meaning of each of the switches.

Meanings of Print Control Flags (`jprint(`j`)`)

j	`Routines`	Write to
1	`evalitpol,intsumpol`	debugging file (unit33)
2	`evalrf`	debugging file (unit33)
3	`expone,exponesph`	debugging file (unit33)
4	`eva1pol,eva2pol,evalitpol,itratepol`	debugging file (unit33)
5	`opthik`	debugging file (unit33)
6	`relayr`	debugging file (unit33)
7	`slant`	debugging file (unit33)
8	`dtaus,tbprnt`	debugging file (unit33)
9	`matscn,evalitpol`	summary file (unit9)
10	`matscn`	N-value file (unit40)

Iteration control. The next three lines of the profile file affect the number of iterations that the algorithm takes. An iteration is defined as a multiple scattering event, eg. if the number of iterations is set to 1, then single scattering as well as one order of mulitple scattering will be done for a total of 2 scattering events (1 single plus 1 multiple). Single scattering corresponds to 0 iterations. So, if the single scatter radiance values are desired, then the number of iterations should be set to 0. The limit on the number of iterations taken may be made different for different ranges of wavelengths. The number on line 15 gives the number of ranges of the overall wavelength range (specified in line 11) that are to be specified in lines 16 and 17. Line 16 specifies the shortest wavelength for each range. Line 17 gives the corresponding maximum numbers of iterations.

15. *Number of iteration ranges.* This is the number of wavelength ranges in which the wavelength domain is to be divided for iteration purposes. As supplied, the number of iteration intervals is limited to 12, but this may be changed via the file `parameter.inc` (See §4.).
16. *Starting wavelengths for each iteration group.* (Å). If TOMRAD is calculating at a wavelength shorter than the shortest starting wavelength specified on this line, the maximum number of iterations will be made the same as that in the first group.
17. *Maximum number of iterations within each group.* (int.) The maximum number of iterations to be performed within each iteration group can be set independently for each group.
18. *Depolarization flag.* (int.) This line contains a single number, 1 or 0, which indicates whether to include (1) or exclude (0) molecular depolarization in the Rayleigh phase matrix.

An example of a typical **profile file** is as follows

```
NADIR000                                                ; prfnam
1.0                                                     ; Pressure
10                                                      ; # of Theta
0.0 30.0 45.0 60.0 70.0 77.0 81.0 84.0 86.0 88.0        ; Thetas
6                                                       ; # of scans
0.0 15.0 30.0 45.0 60.0 70.0                            ; Scan angles
1                                                       ; # Azimuth
0.0                                                     ; Azimuth angles
1                                                       ; # of Albedo
0.0 0.80                                                ;Albedo
2900.00 3420.00                                         ; start and stop Wavelengths
15.0   9.0   5.0   7.0  25.0  62.2  57.0  29.4  10.9   3.2   1.3
283.0 251.0 215.6 200.7 210.7 221.6 231.1 245.3 258.7 267.4 265.4
0 0 0 0 0 0 0 0 1 1                                     ; jprint
2                                                       ; number of iter ranges
2950. 3420.                                             ; wavelength range for iter
7     7                                                 ;iter
1                                                       ;Depolarization flag
```

1.1.2 Coefficient file

The default name of the coefficient file is `coe.dat`. This may be changed either by an entry in the optional ENV file (see §1.2), or by a command line switch (see §3). Each line of the coefficient file pertains to a single wavelength. There is no limit to the number of lines this file can contain, but the maximum number of wavelengths *actually processed* (considering the wavelength range stipulated in the profile file) is limited. As supplied, this limit is 2500, but this may be changed via the file `parameter.inc` (See §4.).

The coefficient file is assumed to have a single header line, which is simply discarded by the TOMRAD program.

Each subsequent line of the file contains six (6) data:

1. Wavelength

   (λ; Å).
2. Ozone absorption coefficient at $0°$ C

   (C_0; $\mathrm{atm}^{-1}\,\mathrm{cm}^{-1}$).
3. Linear temperature correction coefficient for ozone absorption coefficient

   (C_1; $\mathrm{atm}^{-1}\,\mathrm{cm}^{-1}\,\mathrm{C}^{-1}$).
4. Quadratic temperature correction coefficient for ozone absorption coefficient

   (C_2; $\mathrm{atm}^{-1}\,\mathrm{cm}^{-1}\,\mathrm{C}^{-2}$).
5. Molecular (Rayleigh) scattering coefficient

   (β; atm^{-1})
6. Molecular depolarization ratio (ρ_n).

The ozone absorption coefficient (α) at a temperature T, in centigrade, is calculated as

$$\alpha = C_0 + C_1\,T + C_2\,T^2\,.$$

1.2. Optional input files

There are five types of optional input files that are read by TOMRAD .

- The **environment file** (`ENV`) controls the behavior of the program. (§1.2.1)
- **Additional absorbing gas coefficient files** contain the absorption cross sections of gases other than ozone. (§1.2.2)
- **Additional absorbing gas profile files** describe the vertical distribution of absorbing gases other than ozone. (§1.2.3)
- The **user input profile file** contains the profile of pressure, ozone, temperature (all as a function of altitude) instead of the default profile in `PROF`. (§1.2.4)
- The **umkher layer input profile file** can have an arbitrary number of pressure layers, i.e. a 16 layer true Umkher profile or a 12 layer SBUV profile, instead of the 11 layers of the standard `PROF` file. (§1.2.5)

The **additional absorbing gas coefficient files** and **additional absorbing gas profile files** are only read if TOMRAD has read a value of 2 or greater for the parameter `ngas` in the **environment file** (`ENV`). The names of the **additional absorbing gas coefficient files** and **additional absorbing gas profile files** are of the form `gas`n`.prf` (profile) and `gas`n`.coe` (coefficients), where $n = 2, 3, \ldots,$ `ngas`

The **user input profile file** is used if the switch `prf_type` is set to `2` in the **environment file** (`ENV`) or the character sting `userfn` is set to the file name in either the **environment file** (`ENV`) or on the command line. The setting of `userfn` takes priority over that of `prf_type`. The default name is `user.prf` and is contained in the character string `userfn`. See 1.2.1 and 3.0 as to how this default file name may be changed.

The **umkher input profile** can be used in place of the standard 11 layer `PROF` input file if the switch `prf_type` is set to `1` in the **environment file** (`ENV`).

1.2.1 Environment file (`ENV`) The TOMRAD program recognizes an optional input file, called `ENV`, which contains switches that alter the behavior of the program. This file can also contain file names to override the default input and output file names.

When the program starts, it tests to see if the `ENV` file exists. If it does, it reads the file.

The file can contain values for switches, integers, and file names. Each line of the file may contain the name of one of these options, an equal sign, and the value to be used. Not all options need to be specified in the file. The following table presents the option names, their meanings, and their default values.

Options that can be set in the file ENV		
option name	**default**	**description**
lsphout	True	If **true**, calculate the outgoing beam using spherical geometry. If **false**, use a flat atmosphere.
lprtflx	True	If **true**, print the flux table.
ldown	False	If **false**, calculate the reflected radiance at the top of the atmosphere. If **true**, calculate the diffuse transmitted radiance at the bottom of the atmosphere.
lphiindep	True	The N-value table produced is azimuth-independent. (Must be set to **true** if ipsudo=2.)
write_iter_file	False	Produce an output file giving details of the iteration to the radiative transfer solution.
lo2abs	False	If **true** and ngas $>$ **1**, then compute an additional absorbing gas profile for diatomic oxygen using a constant mixing ratio and the internal, implicit neutral density profile. If lo4abs also **true**, then must have ngas $>$ **2**.
lo4abs	False	If **true** and ngas $>$ **1**, then compute an additional absorbing gas profile for diatomic oxygen pairs or O_4 using a constant mixing ratio and the internal, implicit neutral density profile. If lo2abs also **true**, then must have ngas $>$ **2**.
lnoextrap	False	If **true**, geometeric extrapolation of solution to infinite orders of scattering is **not** used. In which case the solution represents the solution after itmax orders of mulitple scattering.
lwgttmp	False	If **true**, temperature profile used for calculations of the ozone absorption coefficient is calculated by weighting the input temperature profile with the ozone profile.
lwgt11	False	If **true**, temperature profile used for calculations of the ozone absorption coefficient is calculated by weighting the input 11 layer temperature profile by the 11 layer ozone profile. For lwgt11 to work lwgttmp must be **true**.
lv7tab	False	If **true**, numerical procedures are done to exactly reproduce the master tables used for V7 TOMS algorithm. Additionally, one must set the following; lwgttmp=**true**, lwgt11=**true**, gc_type=**1**, prf_type=**0**. On SGI, must also compile with -32 -O2 option.
lv7tabout	False	If **true**, output file nvalfm is in format for TOMS v7 tables (see §2.2.1).
ngas	1	Number of absorbing gasses
ipsudo	1	Controls the correction of the direct solar beam. A value of **0** suppresses pseudospherical correction of the incoming beam (*i.e.* flat atmosphere). A value of **1** results in pseudospherical correction. A value of **2** results in single scattering calculations in a spherical atmosphere. The resulting radiance is the sum of spherical single scatter and flat multiple scatter.
prf_type	0	The ozone and temperature profile in PROF is used. If **1**, the umkher layer input profile is read from the file with the name contained in inprffn. If **2**, the profile is read from the file with the name contained in **userfn**, and the other information such as *SZAs* is still read from the standard PROF file with the name contained in inprffn.

Options that can be set in the file ENV		
option name	**default**	**description**
gc_type	2	If >**0**, correct the Rayleigh scattering optical depth for the change in gravity with height. A value of 1 uses the simple correction used for the V7 TOMS tables with a constant scale height of 6.95km and no correction of the total integrated number of molecules in a vertical column in the atmosphere (N_c). Hence no correction to the total scattering optical depth (τ_{ST}) is done. A value of 2 uses the input temperature/pressure profiles to calculate the total number of molecules within each layer. This does correct N_c, and hence τ_{ST} is also corrected. Typically τ_{ST} is $\approx 0.25\%$ greater than that calculated without accounting for the variation of gravity. A value of 3 uses a constant scale height of 6.95 km, and does not adjust τ_{ST} so that the correction factor at the surface is unity. A value of 4 proceeds the same as 3, but does adjust τ_{ST}. This is simlar to gc_type=2 except a constant scale height is used.
inprffn	PROF	Profile file name.
coeffn	coe.dat	Coefficient file name
nvalfn	tomnval.dat	Binary radiance output file name
outerrfn	dev_nul	Error message file name (unit 33)
outprffn	profil.dat	Output run parameters file
sumryfn	sumry.dat	File with summary of results
iterfn	iter.dat	Binary file to which iteration information is written
outflxfnasc	fluxout.asc	Ascii file with information used for calculating downward and actinic fluxes at the surface.
outflxfnbin	fluxout.bin	Binary file containing the same information as fluxout.asc
userfn	user.prf	Ascii file containing user input ozone, pressure, temperature and altitude profiles to be used instead of the profiles in PROF.

An example of a typical `ENV` file is as follows:

```
lsphout =T   !correct the outgoing beam using spherical geometry
gc_type=2  !perform the gravity correction to the Rayleigh optical depth.
lprtflx =T   !print the flux table
ldown= F     !calculate the reflected radiance at the top of the atmosphere
lphiindep =T  ! the table is az independent
write_iter_file =F  ! write file for each iteration
ngas =  1  ! only 1 absorbing gas
ipsudo = 1 ! 0=flat; 1=spherical solar; 2=spherical single-scattering
inprffn =PROF.ref380   !input profile file name
nvalfn  =tomnval.dat   !file name of output table of I0,Z1,Z2,T,Sbar
outerrfn  =dev_nul     !file name of output for debugging
outprffn  =profil.dat  !name of output run parameters file
sumryfn  =sumry.dat    !name of output file with summary of calculations
iterfn  =iter.dat      !name of the iteration file
coeffn  =../so2/coes/tomrad.380     !name of the absorb./scattering coe. file
```

1.2.2 Additional absorbing gas coefficients

If the option `ngas` is set to 2 or greater in the `ENV` file, then TOMRAD will read gas absorption coefficients from files whose names are `gas`*n*`.coe`. These are ASCII files whose records contain two columns of values (wavelength, coefficient). Wavelengths are in Ångstrøms (Å), and coefficients have units cm^2. As supplied TOMRAD interpolates this set of data to the wavelengths read from the **coefficient file**. If `lo2gas=T` and `lo4gas=T`, then `gas`*ngas-1*`.coe` should contain the absorption coefficients for O_2 and `gas`*ngas*`.coe` should contain the absorption coefficients for O_4. If just one of `lo2gas` or `lo4gas` is set to `T`, then `gas`*ngas*`.coe` should contain the absorption coefficients for whichever species is set to `T`.

Note: TOMRAD assumes the first record of any absorbing gas coefficient file contains data. These files should not contain headers.

1.2.3 Additional absorbing gas profiles

If the option `ngas` is set to 2 or greater in the `ENV` file, then TOMRAD will read absorbing gas profiles from files whose names are `gas`*n*`.prf`. These are ASCII files whose records contain pairs of values (height, concentration). Heights are in km, and concentrations are number densities in cm^{-3}. If `lo2abs` and/or `lo4abs` are set to `T`, then the profile for that species is taken from the implicit, internal neutral density profile and no external file is to be read. If `lo2gas=T` and `lo4gas=T`, then *ngas-1* corresponds to O_2 and *ngas* corresponds to O_4. If just one of `lo2gas` or `lo4gas` is set to `T`, then *ngas* corresponds to whichever species is set to `T`.

Note: TOMRAD assumes the first record of any absorbing gas profile file contains data. These files should not contain headers.

1.2.4 User input profile file

If the logical switch `prf_type` is set to **2** or the file name option `userfn` is set either in the `ENV` file or on the command line, then a profile other than the one contained in the `PROF` file will be input. When this is used, the file specified by the variable `userfn` is opened and read for the profile of altitude, pressure, temperature and ozone. The form of this file is as follows: The first line is a header, the second line is the total column ozone for the profile in atm-cm, the third line is another header, and the remainder of the file is the profile with 4 entries per level. The 4 entries are; pressure (mb), altitude (km), temperature (C), and ozone partial pressure (mPa). Currently the maximum possible surface pressure is 1 atm. An example is shown below.

```
Profile for actinic flux comparison
0.306
P(mb)  ALT(km) Tamb(C) OZ(mPa)
822.5   1.74    24.6    3.44
817.6   1.75    22.2    3.51
798.3   2.00    19.1    3.60
.
.
.
```

Other units for `OZ` can be used (`DU/km` or `cm-3`) if the units are included in the second line of the file, i.e.

```
Profile for actinic flux comparison
0.306
P(mb)  ALT(km) Tamb(C) OZ(cm-3)
822.5   1.74    24.6    8.4e10
817.6   1.75    22.2    8.6e10
798.3   2.00    19.1    8.9e10
.
.
.
```

1.2.5 Umkher input profile file

If the numerical switch `prf_type` is set to **1** then the file name in `inprffn` is assumed to be a general Umkher layer profile input file. This file is very similar to the standard `PROF` input file with the addition of two lines before the *Ozone profile* that describe the *Pressure profile*. The first additional line denotes the number of pressure layers (`n_p_lay`) and the second is the pressure (atm) of the bottom of the layer.

An example of a typical **Umkher input profile file** is as follows

```
NADIR000                                                ; prfnam
1.0                                                     ; Pressure
10                                                      ; # of Theta
0.0 30.0 45.0 60.0 70.0 77.0 81.0 84.0 86.0 88.0        ; Thetas
6                                                       ; # of scans
0.0 15.0 30.0 45.0 60.0 70.0                            ; Scan angles
1                                                       ; # Azimuth
0.0                                                     ; Azimuth angles
1                                                       ; # of Albedo
0.0 0.80                                                ;Albedo
2900.00 3420.00                                         ; start and stop Wavelengths
16                                                      ; # of pressure layers
1.0 0.5 0.25 0.125 0.0625 0.03125 1.5625e-02 7.8125e-03 3.90625e-03
1.953125e-03 9.765625e-04 4.8828125e-04 2.4414062e-04 1.2207031e-04
6.1035156e-05 3.0517578e-05                             ; pres. @ bottom of layer
15.0 9.0 5.0 7.0 25.0 62.2 57.0 29.4 10.9 3.2 1.07019e+00 1.89185e-01
3.34434e-02 5.91202e-03 1.04511e-03 2.24424e-04         ; layer ozone amount (DU)
283.0 251.0 215.6 200.7 210.7 221.6 231.1 245.3 258.7 267.4
265.4 255.4 245.4 235.4 225.4 215.4                     ; average layer temperature
0 0 0 0 0 0 0 0 1 1                                     ; jprint
2                                                       ; number of iter ranges
2950. 3420.                                             ; wavelength range for iter
7     7                                                 ;iter
1                                                       ;Depolarization flag
```

2. Output files

TOMRAD normally produces one output file each time it is run. By setting the `jprint` flags, and/or options in the `ENV` file, TOMRAD may be made to produce other optional files.

2.1 Normal output file

There is a single output file, the **run parameters output file**, which recapitulates the control information (whether or not overridden by command line parameters or an **environment file**), and the input **profile file**.

2.1.1 Run parameters output file

The run parameters file (default name, `profil.dat`) summarizes the run parameters (including options set in the command line and the `ENV` file), and the input from the **profile file**. The values of the logical options are explained in the text given at the top of the file. No radiative transfer results are included in the run parameters file. They are all in the various optional output files. The contents of the file are largely self-explanatory.

An example of a typical **run parameters output file** is as follows:

```
 The solution is corrected for the sphericity of the out-going beam.
 The direct solar beam is attenuated to the zenith in a SPHERICAL atmosphere.
 Only 1 absorbing gas is used in the model.
 Will compute the reflected radiance at the top of the atmosphere.
 Will use the standard 11 layer profile.
The logical switches are:
     lsphout                 T
     lprtflx                 F
     ldown                   F
     lphiindep               T
     write_iter_file         F
     lo2abs                  F
     lo4abs                  F
     lnoextrap               F
     lwgttmp                 T
     lwgt11                  T
     lv7tab                  T
     lv7tabout               T
The numerical settings are:
     ngas                    1
     ipsudo                  1
     gc_type                 2
     prf_type                0
The file names are:
     inprffn =          PROF
     nvalfn  =          test
     outerrfn  =        dev_nul
     outprffn  =        profil.dat
     sumryfn  =         sumry.dat
     iterfn  =          iter.dat
     coeffn  =          ../../coes/BASS_2.DAT
     outflxfnasc  =     fluxout.asc
     outflxfnbin  =     fluxout.bin
     userfn  =          user.prf
     (Not all these may be written in this run.)
 ***** NADIR0   *****
 ***** input *****
 pres....1.00
 nthet...  10
 nscan...   6
 nazim...   1
 nalb....   1
 wavelength range... 2800.00 to  3475.00
 evalit evalrf expone itrate opthik relayr  slant tbprnt  sumry   nval
    0      0      0      0      0      0      0      0      0      1
```

(continued on the next page)

```
 sbuv lay      1       2       3       4       5       6       7       8       9      10      11
 ozone amt    1.40    3.70   11.10   24.50   41.70   66.90   74.70   45.00   26.00   14.00   16.00
 ozone amt    0.00    0.00    0.00    0.00    0.00
 layer tmp  262.60  263.90  253.60  239.40  227.60  220.80  217.00  216.60  219.10  239.00  273.00
 layer tmp    0.00    0.00    0.00    0.00    0.00
 sza #           1       2       3       4       5       6       7       8       9      10
 sza          0.00   30.00   45.00   60.00   70.00   77.00   81.00   84.00   86.00   88.00
 scan angle   0.00   15.00   30.00   45.00   60.00   70.00
 azm  angle   0.00
 albedos      0.00
evalrf..sb,ipol  9.2570E-02  1.4013E-45
evalrf..sb,ipol  9.0081E-02  1.4013E-45
```

2.2 Optional output files

All TOMRAD's radiative transfer results are written to the optional output files. The output files that are written depend upon the `jprint` flags, and the option switches that are set in the file `ENV`.

2.2.1 N-value file

The N-value file is a binary file that contains wavelengths, and values of the radiative transfer results I_0, Z_1, Z_2, T, and S_b, which are necessary for calculating the radiances at the top of the atmosphere.

If the optical geometry is specified by (μ_o, μ, ϕ), where $\mu_o = \cos\theta_o$, $\mu = \cos\theta$, and ϕ is the azimuth angle between the solar beam and the viewing direction, and the surface reflectivity is R_s, then the radiance into the viewing direction can be formally written as

$$I = I_0 + I_1 \cos\phi + I_2 \cos 2\phi + \frac{R_s T}{1 - R_s S_b} .$$

To improve interpolations between calculated results, it is convenient to define

$$Z_1 = \frac{I_1}{-\frac{3}{8}\mu_0\sqrt{(1-\mu_0^2)(1-\mu^2)}}$$
$$Z_2 = \frac{I_2}{\frac{3}{32}(1-\mu_0^2)(1-\mu^2)/\mu} .$$

The N-value file consists of seven logical records. The first record may contain three or four words (all words are 4 bytes), depending upon whether the number of azimuth angles (N_ϕ) is explicitly given. If N_ϕ is not explicitly given, its value is 1. The file is written with explicit N_ϕ if the option `lphiindep` (set in `ENV`) is **false**. The following table details the structure of the N-value file.

Structure of N-value File		
Logical Record	Words	Contents
1	3	$N_\theta, N_{\theta_o}, N_\lambda$
	4	$N_\theta, N_\phi, N_{\theta_o}, N_\lambda$
2†	N_θ	$\theta(i_\theta)$
3†	N_{θ_o}	$\theta_0(i_{\theta_o})$
4⋆	N_ϕ	$\phi(i_\phi)$
3	N_λ	$\lambda(i_\lambda)$
4	$N_\lambda N_{\theta_o} N_\theta N_\phi$	$I_0(i_\lambda, i_{\theta_o}, i_\theta, i_\phi)$
5	$N_\lambda N_{\theta_o} N_\theta N_\phi$	$Z_1(i_\lambda, i_{\theta_o}, i_\theta, i_\phi)$
6	$N_\lambda N_{\theta_o} N_\theta N_\phi$	$Z_2(i_\lambda, i_{\theta_o}, i_\theta, i_\phi)$
7	$N_\lambda N_{\theta_o} N_\theta N_\phi$	$T(i_\lambda, i_{\theta_o}, i_\theta, i_\phi)$
8	N_λ	$S_b(i_\lambda)$

Note: The leftmost dimension increments the fastest in the storage of each array.
† Only written if `lv7tabout`=**false**.
⋆ Only written if `lv7tabout`=**false** & `lphi-indep`=**true** .

Note that the values of θ_o, θ, and ϕ are *not* written to this file.

2.2.2 Downward flux ascii file

The downward flux ASCII file contains all the information one needs to calculate the downward flux on a horizontal surface, or to calculate the actinic flux at the surface. The quantities recorded in the file are denoted: F_{0a}, the attenuated normalized flux parallel to the solar beam; G_g, the diffuse component of the downward flux; G_{gp}, the diffuse component of the actinic flux; S_b, the reflectivity of the atmosphere to isotropic illumination from the surface; and S_{bp}, the reflectivity of the atmosphere, weighted for actinic flux.

If the surface reflectivity (albedo) is R_s, then the total downward flux at the surface is given by

$$\frac{\mu_0 F_{0a} + G_g}{1 - R_s S_b} .$$

The total actinic flux (over 4π steradians) is

$$F_{0a} + G_{gp} + R_s(S_{bp} + 2)\frac{\mu_0 F_{0a} + G_g}{1 - R_s S_b} .$$

The downward actinic flux at the surface is

$$F_{0a} + G_{gp} + R_s S_{bp}\frac{\mu_0 F_{0a} + G_g}{1 - R_s S_b} .$$

The header of this file explains the quantities that are recorded in the file (those described above). The last line of the header contains a large number of asterisks. Each line following the header consists of eight numbers: (λ, θ_o, F_0, F_{0a}, G_g, S_b, G_{gp}, S_{bp}). F_0 is the extraterrestrial solar spectral irradiance. It is set to unity for all wavelengths, so the values in the other columns are normalized to unit incident spectral irradiance at any wavelength.

2.2.3 Downward flux binary file

The downward flux binary file contains all the information one needs to calculate the normalized downward flux on a horizontal surface, or to calculate the actinic flux at the surface. These

are identical to the values written to the **downward flux ascii file** (§2.2.2). However, they preserve more of the precision of the calculations.

Note that all fluxes in this file are normalized to unit incident spectral irradiance at the top of the atmosphere.

The file consists of 8 logical records. The following table details the structure of the downward flux binary file.

Structure of Downward Flux Binary File		
Logical Record	Words	Contents
1	2	N_{θ_0}, N_λ
2	N_{θ_0}	$\theta_0(i_{\theta_0})$
3	N_λ	$\lambda(i_\lambda)$
4	$N_\lambda N_{\theta_0}$	$F_{0a}(i_\lambda, i_{\theta_0})$
5	$N_\lambda N_{\theta_0}$	$G_g(i_\lambda, i_{\theta_0})$
6	N_λ	$S_b(i_\lambda)$
7	$N_\lambda N_{\theta_0}$	$G_{gp}(i_\lambda, i_{\theta_0})$
8	N_λ	$S_{bp}(i_\lambda)$

Note: The leftmost dimension increments the fastest in the storage of each array.

2.2.4 Debugging file

The debugging file is an ASCII file whose contents depend upon the settings of the `jprint` switches (See §1.1.1). The contents of this file will be meaningful only to those engaged in the further development of TOMRAD . Therefore, the content of this file will not be elaborated in this document.

2.2.5 Summary file

The summary file (default name, `sumry.dat`) contains tables giving the perpendicular and parallel Stokes components of the intensity ("`eir`" and "`eil`", respectively), the total intensity ("`eitot`"), and the degree of polarization ("`pol`") for each combination of solar zenith angle, wavelength, scan angle ("`the`"), azimuth angle ("`phi`") and surface albedo ("`alb`") specified in the **profile file**.

An example of a typical **summary file** is as follows (partial listing)

```
solar zenith angle=   0.0 wavelength= 2796.4
   the     phi          eil         eir       eitot      pol    alb
    0.0     0.0   5.208E-04  5.208E-04    0.00104      0.000  0.030
   15.0     0.0   4.979E-04  5.336E-04    0.00103      0.035  0.030
    0.0    30.0   5.208E-04  5.208E-04    0.00104      0.000  0.030
   15.0    30.0   4.979E-04  5.336E-04    0.00103      0.035  0.030
    0.0     0.0   5.208E-04  5.208E-04    0.00104      0.000  0.800
   15.0     0.0   4.979E-04  5.336E-04    0.00103      0.035  0.800
    0.0    30.0   5.208E-04  5.208E-04    0.00104      0.000  0.800
   15.0    30.0   4.979E-04  5.336E-04    0.00103      0.035  0.800
solar zenith angle=  30.0 wavelength= 2796.4
   the     phi          eil         eir       eitot      pol    alb
    0.0     0.0   3.745E-04  4.992E-04    0.00087      0.143  0.030
   15.0     0.0   2.560E-04  5.117E-04    0.00077      0.333  0.030
    0.0    30.0   4.057E-04  4.680E-04    0.00087      0.094  0.030
   15.0    30.0   3.006E-04  4.797E-04    0.00078      0.270  0.030
    0.0     0.0   3.745E-04  4.992E-04    0.00087      0.143  0.800
   15.0     0.0   2.560E-04  5.117E-04    0.00077      0.333  0.800
    0.0    30.0   4.057E-04  4.680E-04    0.00087      0.094  0.800
   15.0    30.0   3.006E-04  4.797E-04    0.00078      0.270  0.800
```

2.2.6 Iteration file

The iteration file is a binary file that contains the radiative transfer results after each iteration. It is provided when the flag `write_iter_file` is set to **true** in the **environment file** `ENV`. The number of records in the file is $N_\lambda N_{\theta_0} N_\theta N_\phi$. The records are written to the file with ϕ incremented the fastest, θ the next fastest, then θ_o, then λ.

The length of a logical record in this file depends upon the maximum number of iterations (M_{iter}) allowed for the wavelength, the number of azimuth angles (N_ϕ), and the number of albedoes (N_{R_s}). All words in this file are 4 bytes. The following table details the structure of the records in the iteration file. Variables that are internal to the code are identified with their names in `monospace type`.

Structure of Records in the Iteration File		
Ordinal Position	Words	Contents
1	1	λ
2	1	θ_o
3	1	θ
4	1	I_0/π
5	1	Z_1/π
6	1	Z_2/π
7	1	T/π
8	4	S_b
9	1	M_{iter}
10	M_{iter}	`tnstrz`(i_{iter})
11	M_{iter}	`e0za`(i_{iter})
12	M_{iter}	`ggz`(i_{iter})
13	M_{iter}	`sbz`(i_{iter})
14	1	F_s
15	1	G_g
16	1	`refdir`
17	1	N_ϕ
18	1	N_{R_s}
19	$N_\phi N_{R_s}$	`eittl`(i_ϕ, i_{R_s})
20	$N_\phi N_{R_s}$	`eittr`(i_ϕ, i_{R_s})
21	N_ϕ	`eitu`(i_ϕ)
22	1	N_ϕ

Note: The leftmost dimension increments the fastest in the storage of each array.

3. Command line

Names of files (input and output) to be used in the run may be specified in the command line. If any file names are specified in the command line and in the `ENV` file, *the command line specifications override the* `ENV` *file specifications.* One additional command line option (`-h`) causes TOMRAD to simply print out the list of command line options, and then quit. The following table lists the command line options:

TOMRAD Command Line Options		
Option	**Description**	**Default**
`-i` *filename*	use *filename* as the input profile file	`PROF`
`-c` *filename*	use *filename* as the input coefficient file	`coe.dat`
`-o` *filename*	use *filename* as the standard output file	`profil.dat`
`-d` *filename*	use *filename* as the debugging output file	`dev_nul`
`-n` *filename*	use *filename* as the output N-value file	`tomnval.dat`
`-f` *filename*	use *filename* as the ASCII file for downward flux	`fluxout.asc`
`-g` *filename*	use *filename* as the binary file for downward flux	`fluxout.bin`
`-s` *filename*	use *filename* as the summary output file	`sumry.dat`
`-t` *filename*	use *filename* as the iteration output file	`iter.dat`
`-h`	print out this list.	
`-u` *filename*	use *filename* as the user input profile file	`B1980619.dat`

4. Compilation parameters

The sizes of a number of arrays used by the program are determined by the `PARAMETER` statements in the file `parameter.inc`. These limit the number of values of certain variables that can be used in a single run. (See §§1.1.1 and 1.1.2.) The following table lists the compilation parameters, the values they have in the as-supplied version of the program, and a brief description of their purpose.

Compilation parameters defined in `parameter.inc`		
Parameter	**Value**	**Description**
`max_wave`	2500	Maximum number of wavelengths that will be treated from the **coefficient file**, starting with the starting wavelength specified in the **profile file**.
`max_sza`	10	Maximum number of solar zenith angles that can be treated in a single run.
`max_scan`	9	Maximum number of scan angles ("satellite zenith angles") that can be treated in a single run.
`max_az`	7	Maximum number of azimuth angles that can be treated.
`max_alb`	11	Maximum number of albedoes that can be treated in a single run.
`max_num_iter`	12	Maximum number of algorithm iterations that can be specified in the **profile file**.

5. Table of symbols

α Ozone absorption coefficient.

β Molecular (Rayleigh) scattering coefficient.

C_0 Ozone absorption coefficient at $0°C$.

C_1 Linear temperature correction for ozone absorption coefficient at $0°C$.

C_2 Quadratic temperature correction for ozone absorption coefficient at $0°C$.

F_0 Downward direct flux (irradiance) at the top of the atmosphere.

F_{0a} Downward direct flux through a surface perpendicular to the solar beam attenuated to the bottom of the atmosphere.

G_g Downward diffuse flux at the bottom of the atmosphere for unit flux at the top of the atmosphere, and zero surface albedo, weighted for a flat, horizontal surface.

G_{gp} Downward diffuse flux at the bottom of the atmosphere for unit flux at the top of the atmosphere, and zero surface albedo, weighted for actinic flux.

I Radiance into the viewing direction at the top of the atmosphere.

I_0 Azimuth-independent component of I.

I_1 Component of I proportional to $\cos\phi$.

I_2 Component of I proportional to $\cos 2\phi$.

p_t Pressure at the surface of the Earth (specifies terrain height).

R_s Albedo (reflectivity) of the surface.

ρ_n Molecular depolarization ratio.

S_b Fraction of light backscattered from the atmosphere when isotropically illuminated from below, weighted for a flat, horizontal surface.

S_{bp} Fraction of light backscattered from the atmosphere when isotropically illuminated from below, weighted for actinic flux.

θ Satellite zenith angle (also called look angle, or scan angle).

θ_o Solar zenith angle

λ Wavelength of light *in vacuo*.

M_{iter} Maximum number of iterations for a particular wavelength.

μ Cosine of satellite zenith angle (absolute value).

μ_o Cosine of solar zenith angle (absolute value).

ϕ Azimuth angle (the angle between the perpendicular projections of the vector from a point on the Earth to the Sun and the vector from the same point to the satellite, in the plane tangent to the Earth at the same point.)

N_θ The number of satellite zenith angles TOMRAD is to process

N_{θ_0} The number of solar zenith angles TOMRAD is to process

N_ϕ The number of azimuth angles TOMRAD is to process

N_{R_s} The number of surface albedoes TOMRAD is to process

T Temperature

T Transmission of atmosphere for unit downward irradiance at the top of the atmosphere, and unit surface albedo.

Z_1 $= I_1$, scaled by the corresponding Rayleigh phase factor.

Z_2 $= I_2$, scaled by the corresponding Rayleigh phase factor.

6. Major changes for v2.22

1. The file `tomnval.dat` now includes the θ_0 and θ values (§2.2.1).
2. Input temperature is used as is (not o3 weighted) (§1.1.1 item 13).
3. Gravity correction uses correct scale height for the particular temp/pres profile (§1.2.1 `gc_type`).
4. Changed format of user input profile file (§1.2.4).
5. Allow input of `PROF` with # of layers other than the standard 11 (§1.2.5).
6. Change some `ENV` parameters from logical to integer (§1.2.1).