SMARTS code, version 2.9.2

USER'S MANUAL

SMARTS

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1. INTRODUCTION

SMARTS (*Simple Model of the Atmospheric Radiative Transfer of Sunshine*) is a spectral model and Fortran code to calculate the direct beam, diffuse, and global irradiance incident on surfaces of any geometry at the Earth's surface. It covers the whole shortwave solar spectrum (280 to 4000 nm), thus includes the UVA, UVB, Visible and Near-Infrared bands. Besides the regular irradiance predictions needed for many possible applications, it can be used to simulate the spectral or broadband irradiance that would be measured by a radiometer, such as a spectroradiometer, a pyranometer, or a pyrheliometer. It can also predict the illuminance on any surface, the luminous efficacy of direct, diffuse, and global radiation, the UV index, as well as various UV action weighted spectra.

The first version of SMARTS2 was released in 1994 and was described in (Gueymard, 1994b, 1995). A peer-reviewed journal paper (Gueymard, 2001) also gives a partial but updated description of the model, current with version 2.8 released November 1996.

This User's Manual covers version 2.9.x, which includes considerable improvements over previous versions (see Section 14). A separate file ('History.txt') details the changes that occurred in the successive versions of the code before version 2.9.

2. FORTRAN LANGUAGE

Standard Fortran 77 has been used with none of its extensions except two: some character variables contain a "_" sign, and the source file uses tabs. The source code (in file 'SMARTS2.FOR') now contains more than 4200 lines of code. It calls 27 data files during a typical run.
The PC executable has been compiled with Lahey Fortran F90, and the MacIntosh "Classic" version has been compiled with Absoft Pro 5.0.
No executable is available yet for other platforms (e.g., Unix, Linux). The source code thus needs to be compiled with the appropriate software under such circumstances.

3. HARDWARE AND SOFTWARE REQUIREMENTS

See the file 'ReadMe.doc' for the latest information related to these issues. Basically, any recent PC or MacIntosh computer will produce results in a few seconds or less. *Daily calculations* (a new feature in version 2.9) being extremely processor intensive, a fast computer is recommended for such cases, which can take a few minutes or more.

4. SOFTWARE INSTALLATION

The distribution package is compressed. After decompression with appropriate software, follow the installation steps below.

4.1 Mac version

The SMARTS2 folder can be renamed if so desired.

All files need to be in a unique folder (i.e., 'SMARTS2', unless it has been renamed). Therefore, to use the sample input files contained in the Example subfolders, move the desired 'SMARTS2.INP' file to the root of the SMARTS2 folder, thus replacing any pre-existing file of the same name.

Use a text editor, or any word processor, to modify the input file ('SMARTS2.INP') according to your needs. Save it as TEXT, with the same filename—or any other of your choice—in the format 'filename.INP' (e.g., 'Test_for_July.INP'). The string 'filename.INP' must be less than 24 characters long.

4.2 PC version

The \SMARTS2 directory created after decompression can be renamed if so desired.

All files need to be in a single directory (i.e., \SMARTS2, if it has not been renamed). Therefore, to use the sample input files contained in the Example subdirectories, move the desired 'SMARTS2.INP' file to the root of the \SMARTS2 directory, thus replacing any pre-existing file of the same name.

Use WordPad, the DOS Editor, any similar text editor, or any word processor, to modify the input file ('SMARTS2.INP') according to your needs. Save it as TEXT, with the same filename—or any other of your choice—in the format 'filename.INP' (e.g., 'Test_for_July.INP'). The string 'filename.INP' must be less than 24 characters long.

5. RUNNING THE CODE

The only delicate step involved before actually running the code is to prepare a correct input file. Careful reading of Section 6 is thus recommended in a first step. Then, it is advised to start using one of the resolved examples provided. Their input files are commented for clarity.

☞ *IMPORTANT NOTES*:
1. An incorrect input file will result either in incorrect results, or in a runtime error. In the latter case, the executable will either quit abruptly, or engage in an infinite loop that needs to be stopped manually.
2. **Results** are located in one to three **output files** depending on the desired sophistication. The standard output displays only input echo and broadband results on **File 16** (e.g., 'SMARTS2.OUT'). Two optional spreadsheet-ready output files with spectral results can be requested: **File 17** (e.g., 'SMARTS2.EXT') and **File 18** (e.g., 'SMARTS2.SCN'). File 17 contains spectral results for up to 32 user-selectable variables. File 18 contains spectral smoothed results for 5 fixed variables.

Each of the sample runs resides in a single Example folder/subdirectory, with corresponding comments in a ReadMe file. These sample runs can be extremely valuable to get accustomed to the code and preview its capabilities.

In any case, it is important to become familiar with the different variables that constitute the input file. This is the goal of the next Section.

Once the input file is ready (e.g., 'SMARTS2.INP' or 'Test_for_July.INP') and correctly located in the main SMARTS2 folder/directory, double click on the executable application's icon ('SMARTS_292.EXE') to start execution.

A window appears immediately to ask if working in batch mode is what you want to do. If yes, just type "y" and execution will resume, using the existing input file 'SMARTS2.INP'.

If you rather want to use a differently named input file, type "n". A new question then appears, about the desired input and output filenames. Type the desired filename, but WITHOUT any extension (e.g., 'Test_for_July'), then confirm if OK. The main part of the execution will start.

In the Mac version, a STOP message appears when execution terminates. You need to quit (Cmd-Q) the SMARTS2 program before proceeding with another execution.

In the Windows version, a message appears ("Program completed") appears when execution terminates. Pressing the 'Enter' key will exit from the execution window.

To run the code in DOS, type 'SMARTS_292' at the C:\SMARTS2> prompt. When execution is finished the message ("Program completed") appears. Just press 'Enter' to continue working in DOS.

Note that a user-friendly interface for SMARTS2 is now available, with a separate User's Manual!

☞ ***IMPORTANT NOTES***:

1. For the *Mac version*, the program will execute even if output files ('filename.OUT', 'filename.EXT', and 'filename.SCN') already exist in this folder. The new output files will simply overwrite the existing ones. If you need to keep your results for later use, it is thus important to RENAME the output files before proceeding to a new run, or to move them to a different folder.

2. For the *PC version,* the program will NOT execute if output files ('filename.OUT', 'filename.EXT', and 'filename.SCN') already exist in this folder. An error message ('File specified STATUS = "NEW" already exists…') would result. It is thus important to RENAME the output files before proceeding to a new run, or to move them to a different folder.
   Moreover, SMARTS2 will not execute if an un-renamed input or output file from a previous run, e.g., 'SMARTS2.OUT') is in use by another application.

3. Power users who would like to run only in true batch mode would have to remove a clearly-indicated section (lines 166–194) in 'SMARTS2.FOR' and recompile. The program would then run directly, always using the input data in 'SMARTS2.INP'.

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6. INPUT PREPARATION

All inputs are contained in file 'SMARTS2.INP', but, as mentioned above, it can be renamed to 'filename.INP' where 'filename' stands for any user-defined name (e.g., 'Test_for_July').

The input file is constituted of a series of lines representing as many virtual "Input Cards". Their total number is variable, depending on the complexity of the requested calculations. *If a Card contains inputs for more than one variable, they must be separated by a blank space or a coma.*

All Card images and their content are described here in their prescribed order of appearance in the input file. Variable names, and their character value if applicable, appear in **`COURIER bold`** for easier recognition.

In the Mac version, quotes around text characters can be omitted (e.g., on Cards 1,3a, and 8).

There are two types of Cards: the *Main Cards*, which are mandatory and should exist in any input file, and the *Optional Cards*, whose presence and contents depend on the options selected on the preceding Main Card.

This is a sample Main Card: **CARD 3** : **`IATMOS`**

This is a sample Optional Card: CARD 3a (if **`IATMOS`** = 1): **`ATMOS`**

> Important discussions about the correct use of variables and data, sources of data, etc., appear in blue type with a red vertical border, just like this paragraph.

☞ *IMPORTANT NOTE*:

Some input cards and their content have been modified from version 2.8 or earlier. They appear in yellow *and are marked with a 'blue star' symbol,* ★. **Existing input files from version 2.8 or earlier will not be valid without proper alteration of these input cards.**

CARD 1 : **`COMNT`**

`COMNT` is a text string that can be any title for the current run, or any user's comments on atmospheric conditions, etc. It is limited to 64 characters max. Do not use spaces but rather underscores ('_') to separate words or character strings if necessary.

CARD 2 : **`ISPR`**

`ISPR` is an option for site's pressure.
`ISPR` = 0 to input **`SPR`** on Card 2a;
`ISPR` = 1 to input **`SPR`** and **`ALTIT`** on Card 2a;
`ISPR` = 2 to input **`LATIT`** and **`ALTIT`** on Card 2a.
The program calculates **`ALTIT`** from **`SPR`** if **`ISPR`** = 0, or calculates **`SPR`** from **`ALTIT`** and **`LATIT`** if **`ISPR`** = 2. The option **`ISPR`** = 1 provides more accurate results and is recommended.

CARD 2a (if **`ISPR`** = 0): **`SPR`**

`SPR`: Surface pressure (mb).

CARD 2a (if **`ISPR`** = 1): **`SPR, ALTIT`**

`SPR`: Surface pressure (mb).
`ALTIT`: Site's altitude (km); must be ≤ 4 km if **`IATMOS`** = 1 on Card 3.

★   <mark>CARD 2a</mark>   (if **ISPR** = 2): **LATIT, ALTIT**

LATIT: Site's latitude (decimal degrees, positive North, negative South); e.g., -17.533 for Papeete, Tahiti. If **LATIT** is unknown, enter 45.0.

ALTIT: Site's altitude (km); must be ≤ 4 km if **IATMOS** = 1 on Card 3.

Note: If **ISPR** = 2 and **IATMOS** = 1 on Card 3, the default **SPR** value generated by the reference atmosphere will ultimately replace the estimate from **ALTIT** and **LATIT** based on Card 2a information.

CARD 3 : **IATMOS**

IATMOS is an option to select the proper default atmosphere. Its value can be either 0 or 1.

Set **IATMOS** = 0 to define a non-reference atmosphere. Card 3a will then have to provide **TAIR, RH, SEASON, TDAY**.

Set **IATMOS** = 1 to select one of 10 default reference atmospheres. The shortened name of this atmosphere must be provided by **ATMOS** on Card 3a.

If **IATMOS** = 0 is selected, then **IH2O** should be 0 or 2; **IO3** and **IGAS** should be 0.

If **IATMOS** = 1 is selected, then **IH2O, IO3,** and **IGAS** may take any value. All user inputs have precedence over the defaults.

CARD 3a (if **IATMOS** = 0): **TAIR, RH, SEASON, TDAY**.

RH: Relative humidity at site level (%).

SEASON: Can be either **'WINTER'** or **'SUMMER'**, for calculation of precipitable water and stratospheric temperature.

TAIR: Atmospheric temperature at site level (°C).

TDAY: Average daily temperature at site level (°C).

CARD 3a (if **IATMOS** = 1): **ATMOS**

ATMOS is the name of the selected reference atmosphere; 4 characters max. This name can be one of the following:

> **'USSA'** (U.S. Standard Atmosphere)
> **'MLS'** (MidLatitude Summer)
> **'MLW'** (MidLatitude Winter)
> **'SAS'** (SubArctic Summer)
> **'SAW'** (SubArctic Winter)
> **'TRL'** (Tropical)
> **'STS'** (SubTropical Summer)
> **'STW'** (SubTropical Winter)
> **'AS'** (Arctic Summer)
> **'AW'** (Arctic Winter)

Note 1: Only the 6 first atmospheres are available in LOWTRAN or MODTRAN.
Note 2: The reference atmospheres determine pressure, temperature, relative humidity, ozone, and precipitable water *in the free atmosphere* at the altitude specified on Card 2. If this altitude is > 0, the reference atmospheres will consider the site as an aircraft or a very tall tower, i.e., will not consider any boundary-layer effect, which tends to increase temperature, relative

humidity, and precipitable water. For better results at most sites, it is preferable to define a non-reference atmosphere on Card 3 and specify precipitable water on Card 4 and ozone on Card 5.

CARD 4 : IH2O

IH2O is an option to select the correct water vapor data. All water vapor calculations involve precipitable water, **W**. The following values of **IH2O** are possible:
0, to input **W** on Card 4a;
1, if **W** is to be defaulted to a value prescribed by the selected reference atmosphere and the site altitude (thus if **IATMOS** = 1 on Card 3). If **IATMOS** ≠ 1, **USSA** will be defaulted for this step.
2, if **W** is to be calculated by the program from **TAIR** and **RH** (thus if **IATMOS** = 0 on Card 3).

★ CARD 4a (if **IH2O** = 0): **W**

W is precipitable water in units of cm, or equivalently, g/cm^2; it must be ≤ 12.

Precipitable water can be determined from radiosonde soundings, radiometric methods, remote sensing from space, or by using GPS positioning delay information. In the general case, such data is not available instantaneously on site. It is possible to use climatological averages, or empirical equations predicting **W** as a function of surface temperature, humidity and pressure. See (Garrison and Adler, 1990; Gueymard, 1994a; Myers and Maxwell, 1992) more specifically for U.S. or Canadian conditions, and many other references for empirical determinations in various other countries. **W** represents the total column of water vapor (if condensed) in the atmosphere above *site level*. This value is to be input directly if **IH2O** = 0. Alternatively, it will be calculated by the program from either the user-selected reference atmosphere if **IH2O** = 1 (assuming free-atmosphere conditions in this case), or from surface data of temperature and humidity if **IH2O** = 2.

CARD 5 : IO3

IO3 is an option to select the correct ozone abundance input.
IO3 = 0 to input **IALT** and **AbO3** on Card 5a;
IO3 = 1 to use a default value for **AbO3** according to the reference atmosphere selected by **IATMOS**. If **IATMOS** ≠ 1, **USSA** will be defaulted for this calculation.

CARD 5a (if **IO3** = 0): **IALT, AbO3**

IALT is an option to select the correct ozone column altitude correction.
IALT = 0 bypasses the altitude correction, so that the value of **AbO3** on Card 5a is used as is.
IALT = 1 should be rather used if a vertical profile correction needs to be applied (in case of an elevated station supplied with a sea-level value of **AbO3**).

This option is useful for instance when using ozone data from a ground-based instrument located at sea level to estimate the ozone abundance at a distant and elevated site.

AbO3: site-level (if **IALT** = 0) or sea level (if **IALT** = 1) ozone total-column abundance excluding tropospheric pollution (atm-cm).

The normal range for **AbO3** is 0.2 to 0.5 atm-cm. The present record lows over Antartica are just below 0.1 atm-cm. The range for the 10 reference atmospheres is 0.28 to 0.38, with an average of 0.3341 (close to USSA's value: 0.34379 atm-cm). Van Heuklon, (1979) proposed an equation to obtain the average ozone column as a function of latitude, longitude and day of the year. A better alternative is to use measured data, either from satellite-based sensors such as TOMS (http://jwocky.gsfc.nasa.gov/teacher/ozone_overhead.html) and GOME (http://www.knmi.nl/gome_fd/tm3/lvl4.html), or from ground-based spectrophotometers from the WOUDC network (http://www.msc-smc.ec.gc.ca/ woudc/meta_data/index_e.html).

Most measured total-column data in the present era are expressed in Dobson units. 1000 Dobson units are equivalent to 1 atm-cm.

AbO3 represents the total-column abundance of ozone above site level. It may be corrected by the program if **IALT** is set to 1. A correction with altitude is then applied to **AbO3** so that the apparent ozone column from an elevated site can be obtained from available sea-level data. Tropospheric ozone may be present in polluted areas, but it is normally a small fraction of the total ozone. Reference atmospheres indicate a sea-level ozone concentration of 0.018–0.030 ppmv. If the site's ozone concentration is appreciably higher, SMARTS now has an option to take this contribution into account through **ApO3** (see Cards 6 and 6a).

★ <mark>**CARD 6**</mark>: **IGAS**

IGAS is an option to define the correct conditions for gaseous absorption and atmospheric pollution.
IGAS = 0 if **ILOAD** on Card 6a is to be read so that extra gaseous absorption calculations (corresponding to the gas load in the lower troposphere due to pollution—or absence thereof) can be initiated;
IGAS =1 if all gas abundances (except carbon dioxide, ozone and water vapor—see Cards 4a, 5a, and 7) are to be defaulted, using average vertical profiles.

    ★ <mark>CARD 6a</mark> (if **IGAS** = 0): **ILOAD**

    ILOAD is an option for tropospheric pollution, only used if **IGAS** = 0.
    For **ILOAD** = 0, Card 6b will be read with the concentrations of 10 pollutants.
    ILOAD = 1 selects default *PRISTINE ATMOSPHERIC* conditions, leading to slightly *reduced* abundances of some gases compared to the initial default obtained with the selected reference atmosphere.
    Setting **ILOAD** to 2–4 will increase the concentration of the 10 pollutants to possibly represent typical urban conditions: *LIGHT POLLUTION* (**ILOAD** = 2), *MODERATE POLLUTION* (**ILOAD** = 3), and *SEVERE POLLUTION* (**ILOAD** = 4).

Note that these additional gas loads may not all correspond to realistic conditions because each site is different, and pollution conditions change rapidly over time. Thus, it may well happen that, for a specific site and time, some gases are in reality more abundant than what the default proposes, whereas other gases are less abundant. These loads must therefore only be considered as guidelines. If measured data are accessible, the option **ILOAD** = 0 is preferable.

The following table indicates the defaulted *additional* tropospheric concentrations (in ppmv) for each pollutant. The number within brackets indicates the value of **ILOAD**. Note that in the case of CH_2O, CO, HNO_2, NO_3, and O_3, their ground-level concentration under a Pristine

Atmosphere is lower than that for the standard conditions of the reference atmosphere, hence the *negative* values for the additional concentrations.

Gas	(1) Pristine	(2) Light Pollution	(3) Moderate	(4) Severe
CH_2O	-0.003	0.001	0.007	0.01
CH_4	0	0.2	0.3	0.4
CO	-0.1	0	0.35	9.9
HNO_2	-9.9E-4	0.0005	0.002	0.01
HNO_3	0	0.001	0.005	0.012
NO	0	0.075	0.2	0.5
NO_2	0	0.005	0.02	0.2
NO_3	-4.9E-4	1E-5	5E-5	2E-4
O_3	-0.007	0.023	0.053	0.175
SO_2	0	0.01	0.05	0.2

★ CARD 6b (if **IGAS** = 0 and **ILOAD** = 0): **ApCH2O, ApCH4, ApCO, ApHNO2, ApHNO3, ApNO, ApNO2, ApNO3, ApO3, ApSO2**

ApCH2O: Formaldehyde volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

ApCH4: Methane volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

ApCO: Carbon monoxide volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv), Card 6b.

ApHNO2: Nitrous acid volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

ApHNO3: Nitric acid volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

ApNO: Nitric oxide volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

ApNO2: Nitrogen dioxide volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

ApNO3: Nitrogen trioxide volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

ApO3: Ozone volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

ApSO2: Sulfur dioxide volumetric concentration in the assumed 1-km deep tropospheric pollution layer (ppmv).

Version 2.9 and newer consider separate gaseous absorption calculations for tropospheric gases typically trapped in a pollution layer. This layer is assumed to be 1-km thick above ground. Default values for the concentration of ten tropospheric gases are transparently used in the program when **IGAS** = 0 and **ILOAD** = 1–4. However, selecting **IGAS** = 0 and **ILOAD** = 0 allows the user to provide measured or otherwise estimated concentrations for these 10 gases through variables **ApCH2O, ApCH4, ApCO, ApHNO2, ApHNO3, ApNO, ApNO2, ApNO3, ApO3, ApSO2**. These concentrations need to be given in ppmv (parts per million per volume). The program converts these concentrations to equivalent total-column abundances, on the basis that each gas concentration is constant within the 1-km pollution layer. When data of average pollutant concentration are used and the pollution layer is known to be of a different

thickness than 1 km, the user needs to make a preliminary conversion, i.e., by multiplying the observed average concentration for a H-km layer by H.

To use concentration data provided in atm-cm for a H-km layer, multiply these values by (10 / H) to obtain the correspondence in ppmv.
To use concentration data provided in $\mu g/m^3$, multiply these values by (0.022414 / M) for any H to obtain the correspondence in ppmv, where M is the molar mass of the gas in grams.

Molar masses of the basic species are provided below:

C = 12, H = 1, N = 14, O = 16, S = 32.

Hence the molar mass of ozone is 48 g and that of NO is 30 g.

★ **CARD 7** : `qCO2`

`qCO2` is the carbon dioxide columnar volumetric concentration (ppmv).

The current average CO_2 concentration is about 370 ppmv, but fluctuates seasonally and increases over time (by about 2 ppmv/year). It was about 330 ppmv in 1976, hence the default value of 330 ppmv used in the U.S. Standard Atmosphere (Anon., 1976) and the LOWTRAN/MODTRAN family of atmospheric codes. Note that this concentration does *not* vary with altitude, but does vary slightly with location and season.

★ **CARD 7a** : `ISPCTR`

`ISPCTR` is an option to select the proper extraterrestrial spectrum. This option allows to choose one out of seven possible spectral files ('SPCTRM_n.DAT', where n =1–7).

The following table lists the source for each file, and the corresponding solar constant. The original data have been resampled and degraded to the best resolution achievable with SMARTS2, i.e., 0.5 nm between 280 and 400 nm, 1 nm between 400 and 1700 nm, and 5 nm between 1705 and 4000 nm.
Option 1 is a synthetic spectrum, revised from the previous SMARTS2 spectrum, and is recommended for normal use.
Options 2–7 are directly derived from the six high-resolution spectra selectable in MODTRAN 4.0 and thus allow better compatibility with any irradiance prediction obtained with this code.

Option	File	MODTRAN name	Source	Solar Constant (W/m^2)
1	'SPCTRM_1.DAT'	N/A	Gueymard (synthetic)	1367.00
2	'SPCTRM_2.DAT'	cebchkur	Cebula/Chance/Kurucz	1362.12
3	'SPCTRM_3.DAT'	chkur	Chance/Kurucz	1359.75
4	'SPCTRM_4.DAT'	newkur	New Kurucz	1368.00
5	'SPCTRM_5.DAT'	oldkur	Old Kurucz	1373.16
6	'SPCTRM_6.DAT'	thkur	Thuillier/Kurucz	1376.23
7	'SPCTRM_7.DAT'	MODTRAN 2	Wehrli/WRC/WMO	1367.00

CARD 8 : `AEROS`

`AEROS` selects the aerosol model, with one of the following ten possible choices:

    `'S&F_RURAL'`
    `'S&F_URBAN'`
    `'S&F_MARIT'`
    `'S&F_TROPO'`

These four choices refer respectively to the Rural, Urban, Maritime and Tropospheric aerosol models (Shettle and Fenn, 1979), which are humidity dependent and common with MODTRAN.

    `'SRA_CONTL'`
    `'SRA_URBAN'`
    `'SRA_MARIT'`

These three choices refer respectively to the Continental, Urban, and Maritime aerosol models of the IAMAP preliminary standard atmosphere (IAMAP, 1986).

    `'B&D_C'`
    `'B&D_C1'`

These two choices refer respectively to the Braslau & Dave aerosol type C and C1, themselves based on Deirmendjian's Haze L model.

> The optical characteristics of all these default aerosol models are calculated by the program from wavelength, as well as relative humidity in the case of the Shettle & Fenn aerosols.

    `'USER'`

This option is to be used if none of the above default aerosol model is appropriate. Card 8a is then necessary to input user-supplied aerosol information.

    CARD 8a (if `AEROS = 'USER'`): `ALPHA1, ALPHA2, OMEGL, GG`

    `ALPHA1`: Average value of Angstrom's wavelength exponent α for wavelengths < 500 nm (generally between 0.0 and 2.6).
    `ALPHA2`: Average value of Angstrom's wavelength exponent α for wavelengths $\geq$ 500 nm (generally between 0.0 and 2.6).
    `OMEGL`: Aerosol single scattering albedo (generally between 0.6 and 1.0).
    `GG`: Aerosol asymmetry parameter (generally between 0.6 and 0.9).

> CAUTION: These 4 variables must represent broadband average values only!

CARD 9 : `ITURB`

`ITURB` is an option to select the correct turbidity data input. The different options are:
0, to read `TAU5` on Card 9a
1, to read `BETA` on Card 9a
2, to read `BCHUEP` on Card 9a
3, to read `RANGE` on Card 9a
4, to read `VISI` on Card 9a.

    CARD 9a (if `ITURB` = 0): `TAU5`

    `TAU5`: Aerosol optical depth at 500 nm, τ_5.

$\boxed{\text{CARD 9a}}$ (if **ITURB** = 1): **BETA**

BETA: Angström's turbidity coefficient, β (i.e., aerosol optical depth at 1000 nm).

$\boxed{\text{CARD 9a}}$ (if **ITURB** = 2): **BCHUEP**

BCHUEP: Schüepp's turbidity coefficient, B (i.e., decadic aerosol optical depth at 500 nm).

$\boxed{\text{CARD 9a}}$ (if **ITURB** = 3): **RANGE**

RANGE: Meteorological range, V_R, based on Koschmieder's equation (km), must be between 1 and 999 km.

$\boxed{\text{CARD 9a}}$ (if **ITURB** = 4): **VISI**

VISI: Prevailing visibility, V, as visually observed at airports (km), must be between 0.77 and 764 km.

If **BETA** is not input, all possible alternatives (**BCHUEP, RANGE, TAU5, VISI**) are converted by the program first to β, then to a spectral aerosol optical depth, $\tau_{a\lambda}$, by use of equations such as:

$\tau_5 = 2.302585\ B$

$\beta = (0.5^{\alpha_2})\ \tau_5$

$V_R = 1.306\ V$

$\tau_{a\lambda} = \beta\ (0.5^{\alpha_1 - \alpha_2})\ \lambda^{-\alpha_1}$, if $\lambda < 0.5$ µm; $\tau_{a\lambda} = \beta\ \lambda^{-\alpha_2}$, if $\lambda \geq 0.5$ µm.

$\beta = (0.55^{\alpha_2})\ \mathrm{f}(V_R)$.

In the special case when **IATMOS** = 1 and **AEROS** = **S&F_RURAL**, however, $\tau_{a\lambda}$ is evaluated with Angström's equation, $\tau_{a\lambda} = \beta\ \lambda^{-\alpha}$, where α is obtained as a stepwise fit of the original data in (Shettle and Fenn, 1979). If this particular calculation does not appear appropriate, either set **IATMOS** to 0 (rather than 1) to define a **USER** atmosphere with **AEROS** = '**S&F_RURAL**', or set **AEROS** = '**USER**' to define a user aerosol along with **IATMOS** = 1.

★ $\boxed{\textbf{CARD 10}}$: **IALBDX**

IALBDX is an option to select the correct *zonal (or far-field) albedo*, **RHOX**, for backscattering calculations.

From the reflectance standpoint, the ground surface can be treated either as Lambertian (L) or non-Lambertian (NL). A Lambertian (or isotropic) surface reflects the incident irradiance equally in all directions. Most natural surfaces have a directional reflectance pattern (they reflect more in the direction of the solar beam) and are thus non-Lambertian to some degree.

The possible values of **IALBDX** are:
-1, to input a fixed broadband, Lambertian albedo, **RHOX**, on Card 10a.
0, to read user-defined spectral reflectance from file 'ALBEDO.DAT' with Lambertian characteristics (L);
1, if the same dataset from file 'ALBEDO.DAT' is to be considered non-Lambertian (NL);
2, if a spectral, non-Lambertian reflectance for water is to be *calculated* by the program at run time;

3 to 38, if spectral reflectance data are to be read from one of the available 36 default files described below, and considered non-Lambertian (NL).

All reflectance data are read in an appropriate data file, except for codes -1 and 2 (see above). All the possible codes are listed below:

-1	Fixed broadband albedo (L)
0	User-defined spectral reflectance from file 'ALBEDO.DAT' (L)
1	User-defined spectral reflectance from file 'ALBEDO.DAT' (NL)
2	Water or calm ocean, calculated in the program (NL)
3	Fresh dry snow, file 'SNOW.DAT' (NL)
4	Snow on a mountain neve, file 'NEVE.DAT' (NL)
5	Basalt rock, file 'BASALT.DAT' (NL)
6	Dry sand, file 'DRY_SAND.DAT' (NL)
7	Sand from White Sands, New Mexico, file 'WITESAND.DAT' (NL)
8	Bare soil, file 'SOIL.DAT'' (NL)
9	Dry clay soil, file 'DRYCLAY.DAT' (NL)
10	Wet clay soil, file 'WETCLAY.DAT' (NL)
11	Alfalfa, file 'ALFALFA.DAT' (NL)
12	Green grass, file 'GRASS.DAT' (NL)
13	Rye grass, file 'RYEGRASS.DAT' (NL)
14	Alpine meadow, file 'MEADOW1.DAT' (NL)
15	Lush meadow, file 'MEADOW2.DAT' (NL)
16	Wheat crop, file 'WHEAT.DAT' (NL)
17	Ponderosa pine tree, file 'PINETREE.DAT' (NL)
18	Concrete slab, file 'CONCRETE.DAT' (NL)
19	Black loam, file 'BLCKLOAM.DAT' (NL)
20	Brown loam, file 'BRWNLOAM.DAT' (NL)
21	Brown sand, file 'BRWNSAND.DAT' (NL)
22	Conifer trees, file 'CONIFERS.DAT' (NL)
23	Dark loam, file 'DARKLOAM.DAT' (NL)
24	Dark sand, file 'DARKSAND.DAT' (NL)
25	Decidous trees, file 'DECIDOUS.DAT' (NL)
26	Dry grass, file 'DRYGRASS.DAT' (NL)
27	Dune sand, file 'DUNESAND.DAT' (NL)
28	Fresh fine snow, file 'FINESNOW.DAT' (NL)
29	Green grass, file 'GRNGRASS.DAT' (NL)
30	Granular snow, file 'GRNLSNOW.DAT' (NL)
31	Light clay, file 'LITECLAY.DAT' (NL)
32	Light loam, file 'LITELOAM.DAT' (NL)
33	Light sand, file 'LITESAND.DAT' (NL)
34	Pale loam, file 'PALELOAM.DAT' (NL)
35	Sea water, file 'SEAWATER.DAT' (NL)
36	Solid ice, file 'SOLIDICE.DAT' (NL)
37	Dry soil, file 'DRY_SOIL.DAT' (NL)
38	Light soil, file 'LITESOIL.DAT' (NL)

The non-Lambertian effect is modeled as an increase of reflectance with zenith angle, such as:

$$Rhob = Rhob0 \, [1 - cosZ \, Ln(1 + 1/cosZ)] / 0.35$$
$$Rhod = 1.167 \, Rhob0$$

for nearly all surfaces (codes 1 and 5-18), and

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Rhob = Rhob0 (1 - 0.176 cosZ) / 0.94

Rhod = 0.939 Rhob0

for snow (codes 3, 4, 28 and 30). In these equations, Rhob is the reflectance for beam radiation, Rhod the reflectance for diffuse radiation, Rhob0 the reference reflectance in the data files, and cosZ the cosine of the zenith angle, **ZENIT**. The measured data are supposed to have been measured at zenith angles of about 20 deg. for snow (codes 3 and 4), and about 53 deg. for all other surfaces, including the user-defined data in file ALBEDO.DAT.

The spectral reflectance for water (code 2) is calculated by the program wavelength by wavelength and uses the Fresnel formula for specular reflectance. However, code 35 selects measured data for sea water with a non-Lambertian—rather than specular—reflectance.

CARD 10a (if **IALBDX** = -1): **RHOX**

RHOX: Zonal broadband Lambertian ground albedo (for backscattering calculations); usually between 0.12 and 0.60. See discussion for Card 10 above and for **RHOG** on Card 10d below.

CARD 10b: **ITILT**

ITILT is an option for tilted surface calculations. Select **ITILT** = 0 for no such calculation, **ITILT** = 1 to initiate these calculations using information on Card 10c.

★ CARD 10c (if **ITILT** = 1): **IALBDG, TILT, WAZIM**

IALBDG is identical to **IALBDX** (see Card 10) except that it relates to the foreground local albedo seen by a tilted surface. The list of options is identical to that of **IALBDG**.

TILT: Tilt angle of the receiving surface (0 to 90 decimal deg.); e.g. 90.0 for a vertical plane. Use -999 for a tracking surface.

WAZIM: Surface azimuth (0 to 360 decimal deg.) counted clockwise from North; e.g., 270 deg. for a surface facing West. Use -999 for a *sun tracking* surface.

CARD 10d (if **ITILT**=1 and **IALBDG**=-1): **RHOG**

RHOG: Local broadband Lambertian foreground albedo (for tilted plane calculations), Card 10d (if **IALBDG** = -1); usually between 0.05 and 0.90.

Under realistic conditions, **RHOX** (on Card 10a) is generally different from **RHOG**. Both may have large seasonal variations at high latitudes and in cold regions, due to snow.

The difference between **RHOG** and **RHOX** may seem subtle; they are frequently—but incorrectly—used interchangeably in the literature. **RHOX** corresponds to the *zonal albedo* (large scale, e.g., 10-100 km^2) used in backscattering calculations. **RHOG** corresponds to the *local albedo* (small scale, e.g., 1-1000 m^2) required when converting irradiance incident on a horizontal plane to that incident on a tilted plane. **RHOG** is then the broadband reflectance of the horizontal foreground immediately in front of the tilted receiver, itself assumed of small dimensions (e.g., a solar collector, a window...). In general, **RHOG** and **RHOX** have different values because the ground surface is rarely uniform over large areas. However, the value of **RHOX** can be used for **RHOG** if the tilted "receiver" has a nearly infinite area (e.g., a mountain slope).

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Note also that **RHOG** and **RHOX** are both broadband-average albedo values, i.e. spectrally-constant reflectances. Such a case is almost never found in nature, so that calculations based on these values will be simplistic. For more realistic spectral calculations, use the library of 36 spectral reflectance files for natural surfaces, all obtained from spectral measurements (see **IALBDG** and **IALBDX**), or use site-specific spectral albedo values with the user-defined ALBEDO.DAT file.

★ <mark>CARD 11</mark> : WLMN, WLMX, SUNCOR, SOLARC

WLMN, WLMX: Spectral range (in nm), or min and max limits between which all spectral calculations will be performed. **WLMN** should be ≥ 280.0 nm and **WLMX** should be ≤ 4000 nm; e.g., **WLMN** = 300.5, **WLMX** = 1810.

SUNCOR is a correction factor equal to the inverse squared actual radius vector, or true Sun-Earth distance; e.g., **SUNCOR** = 1.024.

SUNCOR varies naturally between 0.966 and 1.034, adding 3.4% to the irradiance in January and reducing it by 3.4% in July. It is calculated by the program if the solar position is calculated from date & time, i.e., if **IMASS** = 3 on Card 17, thus overwriting the input **SUNCOR** value on Card 11. If solar position is directly input instead (**IMASS** ≠ 3), **SUNCOR** should be set to 1.0 if the average extraterrestrial irradiance (or "solar constant", see **SOLARC**) is to be used, or to any other number between 0.966 and 1.034 to correct it for distance if so desired.

SOLARC is the selected Solar constant (W/m^2). The current WMO-accepted value is 1367 W/m^2. At runtime, all spectral irradiances are uniformly multiplied by a constant scaling factor equal to **SOLARC** divided by the total extraterrestrial irradiance corresponding to the selected spectrum. This one is chosen among the seven possible data files 'SPCTRM_n.DAT' with **ISPCTR** (Card 7a).

These seven files contain the best current estimates of the extraterrestrial spectrum in the 280–4000 nm spectral range. For each of these files, the solar constant is slightly larger than the integrated irradiance from 280 to 4000 nm because it also includes the contributions for wavelengths below 280 nm and above 4000 nm. The second line of each file indicates the corresponding solar constant, which is read by the program. For each wavelength, the program then multiplies the extraterrestrial irradiance by the scaling factor described above. This scaling process is identical to what is done in MODTRAN 4.0. See **ISPCTR** (Card 7a) for a description of each of the seven spectrum files.

CARD 12 : **IPRT**

IPRT is an option to select what results to print on Files 16 and 17. Only broadband results are output (to File 16) if **IPRT** = 0. Spectral results are added to File 16, and Card 12a is read, if **IPRT** = 1. Spectral results are rather printed to File 17 (in a spreadsheet-like format) if **IPRT** = 2. Finally, spectral results are printed to both File 16 and 17 if **IPRT** = 3. Cards 12b and 12c are read if **IPRT** = 2 or 3 (see **IOTOT** and **IOUT**).
Note that the spectral results printed on File 16 with **IPRT** = 1 are limited in scope to the direct, diffuse, and global irradiances. For improved control and a larger choice of printable variables, use **IPRT** = 2 or 3. Note also that the spectral results of the smoothing postprocessor (Card 14) are printed on another spreadsheet-ready file, File 18, irrespective of **IPRT**.

★ CARD 12a (if IPRT ≥ 1): **WPMN, WPMX, INTVL**

WPMN, WPMX: Spectral range, or min and max wavelengths (nm) between which results will be printed on File 16 ('SMARTS2.OUT'), and/or File 17 ('SMARTS2.EXT'), if **IPRT** = 1 to 3 on Card 12. Respect these conditions: **WPMN ≥ WLMN; WPMX ≤ WLMX**. Example: **WPMN** = 320.5, **WPMX** = 1100.

INTVL: Interval for printing spectral results on Files 16 and 17.

> Example 1: if **INTVL** = 0.5, the effective interval used by the program will automatically adapt to the maximum possible resolution in each spectral region: 0.5 nm (280–400 nm), 1 nm (400–1700 nm), and 5 nm (1705–4000 nm).
>
> Example 2: if **INTVL** is set to 2 nm, the effective interval will be 2 nm (280–1702 nm) and 5 nm (1705–4000 nm).
>
> Example 3: if **INTVL** is set to 10 nm, the effective interval will be 10 nm for all possible bands (280–4000 nm).

CARD 12b (if **IPRT** = 2 or 3): **IOTOT**

IOTOT is the total number of output variables to print on File 17; it must be between 1 and 32. A code defining these variables is read on Card 12c. Variables will be printed in the order selected.

★ CARD 12c (if **IPRT** = 2 or 3): **IOUT**

IOUT is a code number (1–32) to select the spectral variables to print on File 17. This code is to be selected among the following list.

1	Extraterrestrial spectrum
2	Direct normal irradiance
3	Diffuse horizontal irradiance
4	Global horizontal irradiance
5	Direct horizontal irradiance
6	Direct tilted irradiance
7	Diffuse tilted irradiance
8	Global tilted irradiance
9	Experimental direct normal irradiance (with circumsolar)
10	Experimental diffuse horizontal irradiance
11	Circumsolar irradiance within radiometer field of view
12	Global horizontal photon flux
13	Direct normal photon flux
14	Diffuse horizontal photon flux
15	Rayleigh transmittance
16	Ozone transmittance
17	Transmittance from all trace gases
18	Water vapor transmittance
19	Mixed gas transmittance
20	Aerosol transmittance
21	Beam radiation transmittance
22	Rayleigh optical thickness
23	Ozone optical thickness
24	Optical thickness from all trace gases

25	Water vapor optical thickness
26	Mixed gas optical thickness
27	Aerosol optical thickness
28	Aerosol single scattering albedo
29	Aerosol asymmetry factor
30	Zonal surface reflectance
31	Local ground reflectance
32	Atmospheric reflectance

The *trace gases* are: BrO^*, CH_2O^*, $ClNO_3^*$, HNO_2^*, HNO_3^*, NH_3, NO, NO_2, NO_3^*, SO_2^*. The *mixed gases* are: CH_4, CO, CO_2, N_2, N_2O, O_2, and O_4^*. An asterisk indicates a gas that is not considered, or only partially considered, in MODTRAN4.

CARD 13 : ICIRC

ICIRC is an option for circumsolar calculations.
ICIRC = 0 bypasses these calculations.
ICIRC = 1 indicates that a typical radiometer needs to be simulated. Its geometry must then defined on Card 13a.

CARD 13a (if **ICIRC** = 1): **SLOPE, APERT, LIMIT**

SLOPE: Slope angle (half cone) of the simulated radiometer, between 0.1 and 10 deg.
APERT: Half aperture (or "opening") angle of the simulated radiometer (deg.), between 0.1 and 10 deg.
LIMIT: Limit angle (half cone) of the simulated radiometer, between 0.1 and 10 deg.
These half angles define the geometry of the simulated radiometer and are bound by the condition: **SLOPE < APERT < LIMIT**.
If **SLOPE** *or* **LIMIT** is set to 0.0, the missing value will be calculated.
If **SLOPE** *and* **LIMIT** are set to 0.0, the penumbra function will be set to 1.0 (an average geometry is thus considered).
If **APERT** is unknown, it should be set to 0.0; the penumbra function will be calculated from **SLOPE** and **LIMIT** only.

Precise values for these quantities are provided in Table 1 of (Gueymard, 1998), reproduced below, in the case of the most widely used pyrheliometers. For instance, **SLOPE** = 1.78 deg., **APERT** = 2.91 deg., and **LIMIT** = 4.03 deg. for the Eppley NIP instrument.

The precise definition of **SLOPE, APERT, LIMIT** is illustrated in the figure below, where **SLOPE** is noted ε_S, **APERT** is noted ε_A and **LIMIT** is noted ε_L.

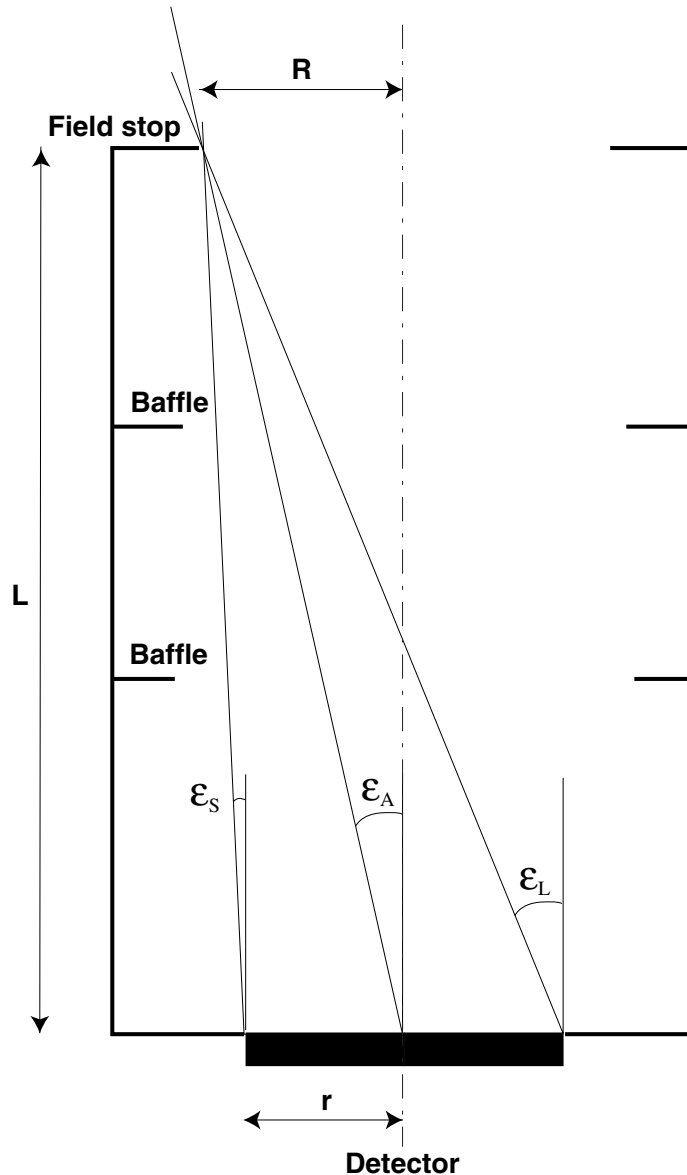| Make & model	Slope	Opening	Limit
Eppley NIP	1.78	2.91	4.03
Eppley H-F	0.804	2.5	4.19
Kipp & Zonen Linke-Feussner	1.0	5.08	9.11
Kipp & Zonen CH1	1.0	2.5	4.0
Abbott silver disk	0.8	2.9	4.9

Fig.1 Geometry of a collimated radiometer.

ISCAN: Option for using the scanning/smoothing routine using a virtual filter. The smoothed results are output on a spreadsheet-ready file, File 18. This postprocessor is activated if **ISCAN** = 1, not if **ISCAN** = 0. Card 14a is read if **ISCAN** = 1.

★ CARD 14a (if **ISCAN** = 1): **IFILT, WV1, WV2, STEP, FWHM**

IFILT: Option for the transmittance shape of the radiometer's filter. Select **IFILT** = 0 for a triangular shape; **IFILT** = 1 for a Gaussian (bell) shape.
WV1: Min wavelength (nm) to output the smoothed results.
WV2: Max wavelength (nm) to output the smoothed results.
Example: **WV1** = 320.5, **WV2** = 1100.

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To avoid transitional problems near these limits, follow these rules:

WV1 > WLMN+FWHM

WV2 < WLMX-FWHM

WV2-WV1 > 2*FWHM.

STEP: Interval (nm) at which the smoothed irradiance will be printed; e.g., **STEP** = 2.5.

FWHM: Full Width at Half Maximum, i.e., characteristic bandwidth of the filter transmittance or radiometer spectral response chosen to smooth the output spectral data; e.g., **FWHM** = 6.15.

CARD 15 : ILLUM

ILLUM: Option for illuminance and luminous efficacy calculations. These calculations take place if **ILLUM** = -1, 1, -2 or 2, and are bypassed if **ILLUM** = 0.

With **ILLUM** = -1 or 1, illuminance calculations are based on the CIE photopic curve (or Vlambda curve) of 1924, as supplied in File 'VLAMBDA.DAT'. With **ILLUM** = -2 or 2, the same calculations are done but the revised CIE photopic curve of 1988 is rather used (from File 'VMLAMDA.DAT'). Note that selecting **ILLUM** = 1 or –1 will override **WLMN** and **WLMX** (see Card 11) so that calculations are done between at least 380 and 780 nm.

Moreover, if **ILLUM** = 1 or 2, luminous efficacy calculations are added to the illuminance calculations. This overrides the values of **WLMN** and **WLMX** on Card 11, and replaces them by 280 and 4000, respectively.

CARD 16 : IUV

IUV: Option for special broadband UV calculations. Select **IUV** = 0 for no special UV calculation, **IUV** = 1 to initiate such calculations. These include UVA, UVB, UV index, and different action weighted irradiances of interest in photobiology.

Note that **IUV** = 1 overrides **WLMN** and **WLMX** so that calculations are done between at least 280 and 400 nm. The spectral results are also printed between at least 280 and 400 nm, irrespective of **IPRT**, **WPMN**, and **WPMX** values.

★ CARD 17 : IMASS

IMASS: Option for solar position and air mass calculations. Set **IMASS** to:

0, if inputs are to be **ZENIT, AZIM** on Card 17a

1, if inputs are to be **ELEV, AZIM** on Card 17a

2, if input is to be **AMASS** on Card 17a

3, if inputs are to be **YEAR, MONTH, DAY, HOUR, LATIT, LONGIT, ZONE** on Card 17a

4, if inputs are to be **MONTH, LATIT, DSTEP** on Card 17a (for a *daily* calculation).

> CAUTION: The option **IMASS** = 2 does not completely define the sun's position; therefore, the sun's azimuth is defaulted to 180.0 (equator facing). If tilted irradiance calculations are necessary (**ITILT** = 1), it is better avoiding the **IMASS** = 2 option. However, a sun-facing or a tracking surface can be simulated with this option without problem.

★ CARD 17a (if **IMASS** = 0): ZENIT, AZIM

ZENIT: Apparent solar zenith angle (0 to 90 decimal deg.), i.e., true astronomical zenith angle MINUS refraction correction.

AZIM: Solar azimuth (0 to 360 decimal deg.), counted clockwise from North (0.0) toward West (270.0).

Note: **AZIM** is only used to calculate radiation on a tilted plane. If such calculation is not relevant, any value (e.g., 0.0) can be input for this variable.

★ CARD 17a (if **IMASS** = 1): **ELEV, AZIM**

ELEV: Solar elevation (0 to 90 decimal deg.), i.e., true astronomical elevation PLUS refraction correction.

AZIM: Solar azimuth (0 to 360 decimal deg.), counted clockwise from North (0.0) toward West (270.0).

Note: **AZIM** is only used to calculate radiation on a tilted plane. If such calculation is not relevant, any value (e.g., 0.0) can be input for this variable.

★ CARD 17a (if **IMASS** = 2): **AMASS**

AMASS: Relative (i.e., non pressure-corrected) air mass, or Rayleigh optical mass (must be between 1.0 and 38.2),

★ CARD 17a (if **IMASS** = 3): **YEAR, MONTH, DAY, HOUR, LATIT, LONGIT, ZONE**

YEAR: A four-digit integer, e.g., 2002.
MONTH: Any integer between 1 and 12.
DAY: Day of the month (1–31).
HOUR: Local Standard Time (LST) in decimal hour (CAUTION: not to be confused with Local Apparent Time, Daylight Saving Time, or Universal Time).
LATIT: Site latitude (decimal degrees, positive North, negative South); e.g., -17.533 for Papeete, Tahiti.
LONGIT: Site longitude (decimal deg.). Counted positive East of Greenwich, negative West of Greenwich; e.g., -104.667 for Denver's International Airport, Colorado.
ZONE: International Time Zone related to Greenwich. Follows the same sign convention as **LONGIT**; e.g., **ZONE** = -5 for Eastern Standard Time (North America), **ZONE** = 2 for Greece.

The Local Apparent Time (LAT) corresponding to the input's Local Standard Time (LST) is calculated and printed to the main output file ('filename.OUT', or "File 16"). However, for some applications it might be necessary to relate to LAT rather than Local Standard Time (LST) as used here. Predicting irradiances exactly at solar noon (i.e., 12 LAT) is a typical example. Such a calculation is possible, but requires a preliminary run, where **HOUR** would be set to 12. From the LAT value that is printed on File 16, it is easy to obtain the difference between LAT and LST. The final run would be done after adjusting **HOUR** for this difference.
When **IMASS** = 3 the actual sun-earth distance is calculated form the supplied date and overwrites the **SUNCOR** value from Card 11.

★ CARD 17a (if **IMASS** = 4): **MONTH, LATIT, DSTEP**

MONTH : Any integer between 1 and 12.

LATIT: Site latitude (decimal degrees, positive North, negative South); e.g., -17.533 for Papeete, Tahiti.

DSTEP: Time interval (min) for the numerical integration of irradiation when a daily calculation is requested. **DSTEP** must be a real number and divisor of 60, hence this (non-exhaustive) list of possible values of **DSTEP**: 1, 2, 3, 4, 5, 6, 7.5, 10, 12, 15, 20, 30, 60. **DSTEP** ≤ 6 is recommended for better accuracy, whereas **DSTEP** ≥ 15 is recommended for speedier results. Tests have indicated that no real improvement in accuracy is obtained when **DSTEP** < 5.

Because of the large quantity of calculations involved with this daily option, only *broadband* results are output, irrespective of the value of **IPRT** on Card 12.

☞ *IMPORTANT NOTES*:
• As many 17a cards can be piled up as desired; the program will perform the spectral calculations sequentially. All other variables remain constant during these successive runs.
• It is recommended to insert a blank line after the last input card, or that card might not be read!

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7. INPUT VARIABLES LIST

For cross-reference purposes, all possible input variables are listed below in alphabetical order with the Card number on which they appear.

Variable	Card #	Variable	Card #	Variable	Card #	Variable	Card #
AbO3	5a	**COMNT**	1	**IOUT**	12c	**SPR**	2a
AEROS	8	**DAY**	17a	**IPRT**	12	**STEP**	14a
ALPHA1	8a	**DSTEP**	17a	**ISCAN**	14	**SUNCOR**	11
ALPHA2	8a	**ELEV**	17a	**ISPCTR**	7a	**TAIR**	3a
ALTIT	2a	**FWHM**	14a	**ISPR**	2	**TAU5**	9a
AMASS	17a	**GG**	8a	**ITILT**	10b	**TDAY**	3a
ApCH2O	6b	**HOUR**	17a	**ITURB**	9	**TILT**	10c
ApCH4	6b	**IALBDG**	10c	**IUV**	16	**VISI**	9a
ApCO	6b	**IALBDX**	10	**LATIT**	2a, 17a	**W**	4a
APERT	13a	**IALT**	5a	**LIMIT**	13a	**WAZIM**	10c
ApHNO2	6b	**IATMOS**	3	**LONGIT**	17a	**WLMN**	11
ApHNO3	6b	**ICIRC**	13	**MONTH**	17a	**WLMX**	11
ApNO	6b	**IFILT**	14a	**OMEGL**	8a	**WPMN**	12a
ApNO2	6b	**IGAS**	6	**qCO2**	7	**WPMX**	12a
ApNO3	6b	**IH2O**	4	**RH**	3a	**WV1**	14a
ApO3	6b	**ILLUM**	15	**RHOG**	10d	**WV2**	14a
ApSO2	6b	**ILOAD**	6a	**RHOX**	10a	**YEAR**	17a
ATMOS	3a	**IMASS**	17	**SEASON**	3a	**ZENIT**	17a
AZIM	17a	**INTVL**	12a	**SLOPE**	13a	**ZONE**	17a
BCHUEP	9a	**IO3**	5	**SOLARC**	11		
BETA	9a	**IOTOT**	12b				

8. USER-DEFINED ALBEDO DATA FILE

Data in File 19 ('ALBEDO.DAT') is user modifiable but need to follow a specific format. This file must contain two columns and any number of rows up to a maximum of 2002, and must be saved as TEXT. These two columns are respectively for: Wavelength (μm), Reflectance (0.0 to 1.0).

9. OUTPUT FILES

The OUTPUT to File 16 ('filename.OUT') is well documented and thus self explanatory. It gives an echo of the input data, as well as a series of results from the spectral and broadband calculations. The content of this output file is fixed.

The OUTPUT to File 17 ('filename.EXT') is formatted to create a spreadsheet-formatted file, the content of which can be tailored to the user's specific needs, according to:
- column 1: Wavelength (nm)
- column 2 to last (i.e., **IOTOT** + 1): depending on user's choice, from 1 to 24 spectral variables out of a possibility of 32 (see **IOUT** on Card 12c).

Columns of data are separated by a space and have a heading of 18 characters each.

The OUTPUT to File 18 ('filename.SCN') is also formatted to create a spreadsheet-formatted file, but its content is fixed, according to:
- column 1: WVLGTH [Wavelength (nm)]
- column 2: SPECTRUM [Extraterrestrial Irradiance (W/m^2)]
- column 3: BEAM NORM [True Direct Beam Irradiance at Normal Incidence (W/m^2)]
- column 4: BEAM NORM+ [Experimental Beam Irradiance at Normal Incidence (W/m^2)]
- column 5: GLOB HOR [Global Horizontal Irradiance (W/m^2)]
- column 6: GLOB TILT [Global Tilted Irradiance (W/m^2)].

Columns of data are separated by a space. A two-line header recapitulates the instrumental characteristics selected.

Output files 17 and 18 can be read directly (in TEXT format) by a spreadsheet program such as Microsoft Excel, or by plotting software such as Synergy's Kaleidagraph. Select a space separator in the Open or Import window if format recognition is not automatic.

10. SAMPLE RUNS AND PRINTOUT

Sample runs are provided and reside in separate *Example* folders/directories. Each one is documented with a ReadMe file. The input and output files are provided so that the user can test if his/her results are in complete agreement with these sample runs.

The printouts of files 'SMARTS2.INP' and 'SMARTS2.OUT' corresponding to the particular case described in *Example 6* of this package appear in the Appendix for reference purposes.

☞ *IMPORTANT NOTE*:
Example 6 allows to exactly reproduce the most recent reference spectra at air mass 1.5 adopted in 2003 by ASTM under standard G173.

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11. UV ACTION-WEIGHTED IRRADIANCES

Extra UV calculations are invoked when the option **IUV** is set to 1. For each wavelength, the global horizontal irradiance is then convolved with a specific biological action spectrum. When summed over all UV wavelengths, this provides an action-weighted irradiance, which can be of interest in different photobiological applications.

Fourteen such action-weighted irradiances are calculated by the program, as detailed below.
- Erythemal irradiance, according to five different studies. The most widely used erythema spectrum is that of (McKinley and Diffey, 1987), also known as the CIE erythema spectrum. Separate results using older erythema spectra are also reported by the program for comparative purposes. These include the fit proposed by (Green and Mo, 1975) from the original data of (Coblentz and Stair, 1934), the Diffey erythema spectrum (Diffey, 1982) modified by (Björn, 1989), the equation of (Green *et al.*, 1974) derived from the data of (Komhyr and Machta, 1973), and the equation of (Björn, 1989) obtained by fitting the data of (Parrish *et al.*, 1982).
- The biological action curve of (Caldwell, 1971) as fitted by (Green *et al.*, 1974).
- The ACGIH safety spectrum (ACGIH, 1978) as fitted by (Wester, 1981, 1984).
- The photosynthesis inhibition spectrum and the polychromatic action spectrum for higher plants, according to (Caldwell *et al.*, 1986).
- The plant DNA spectrum fit of (Green and Mo, 1975) from data of (Setlow, 1974).
- The systematic immunosuppression spectrum of (De Fabo *et al.*, 1990).
- The skin carcinogenesis spectra fro humans and mice of (de Gruijl and Van der Leun, 1994).
- The spectrum for DNA to protein crosslinks by (Peak and Peak, 1982).

The three latter datasets have been fitted to manageable functions by this author.

Two other results are further obtained from the CIE erythemal irradiance. The UV dose in MED/hr (where 1 MED = 210 J/m^2) is calculated to simulate the output of a Robertson-Berger biometer. Finally, the UV index—which is now used regularly in many meteorological reports and forecasts for public protection purposes—is obtained as 40 times the erythemal irradiance. Note that previous versions of SMARTS have been used in different countries to predict the UV index (Koepke *et al.*, 1998; Lehmann, 2001).

12. REVISED EXTRATERRESTRIAL SPECTRUM

The extraterrestrial spectrum used in the previous version of SMARTS has been significantly revised, and has been obtained as a synthesis from different sources. Motives for this revision were:
• To reflect the improved resolution of this version of SMARTS in the UV (0.5 nm rather than 1 nm before).
• To take into account the most recent data from different satellite sensors, particularly in the UV, using both published and unpublished data.
• To make sure that its integrated irradiance, when added to the far-UV part (below 280 nm) and the far-IR part (above 4000 nm), effectively totals 1367 W/m^2, the currently accepted value of the solar constant.

Figure 2 shows how the newly proposed spectrum compares to other existing spectra, namely the previous SMARTS spectrum, the Cebula/Chance/Kurucz composite spectrum developed for MODTRAN, and the recently revised ASTM standard (ASTM, 2000). The Cebula/Chance/Kurucz spectrum integrates to 1362.12 W/m^2, whereas the ASTM spectrum integrates to 1366.1 W/m^2.

Note that the IR part of all these spectra are based on a version or another of the Kurucz spectrum, hence their (not shown) good agreement there.
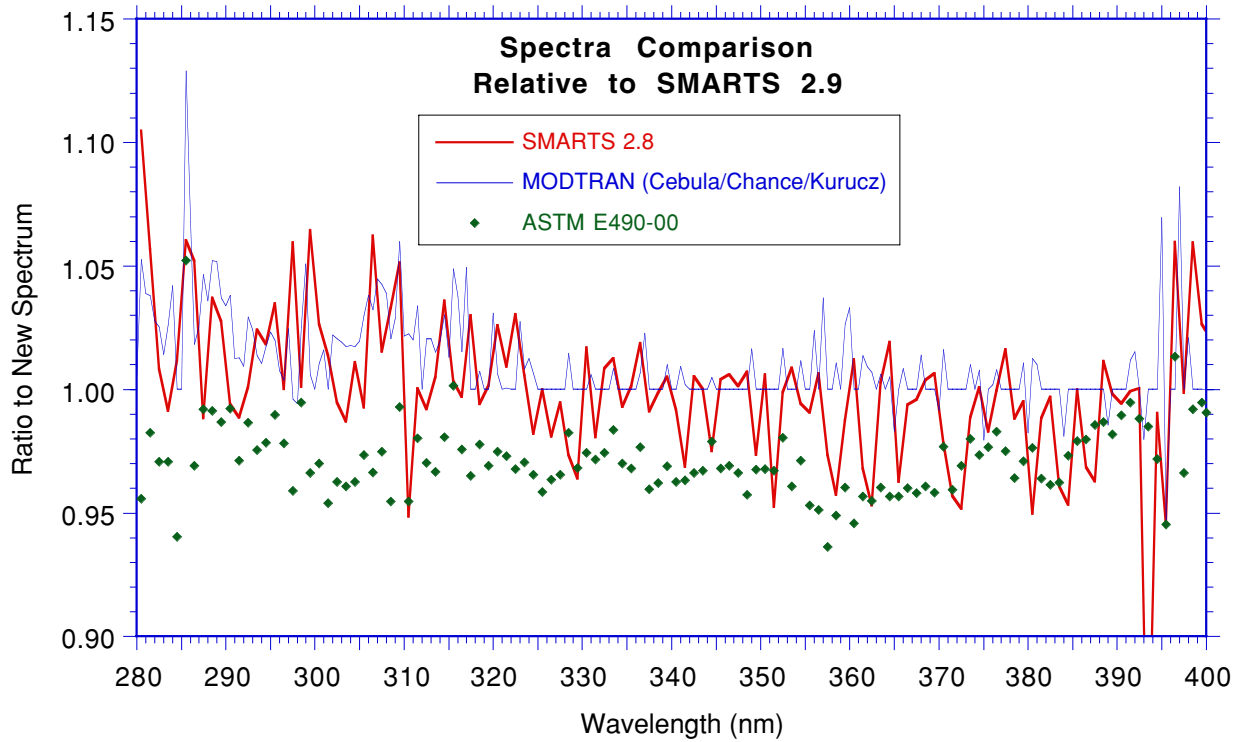
Fig. 2a Wavelength-by-wavelength irradiance ratios of some existing spectra to the revised default spectrum of SMARTS2 in the UV region.
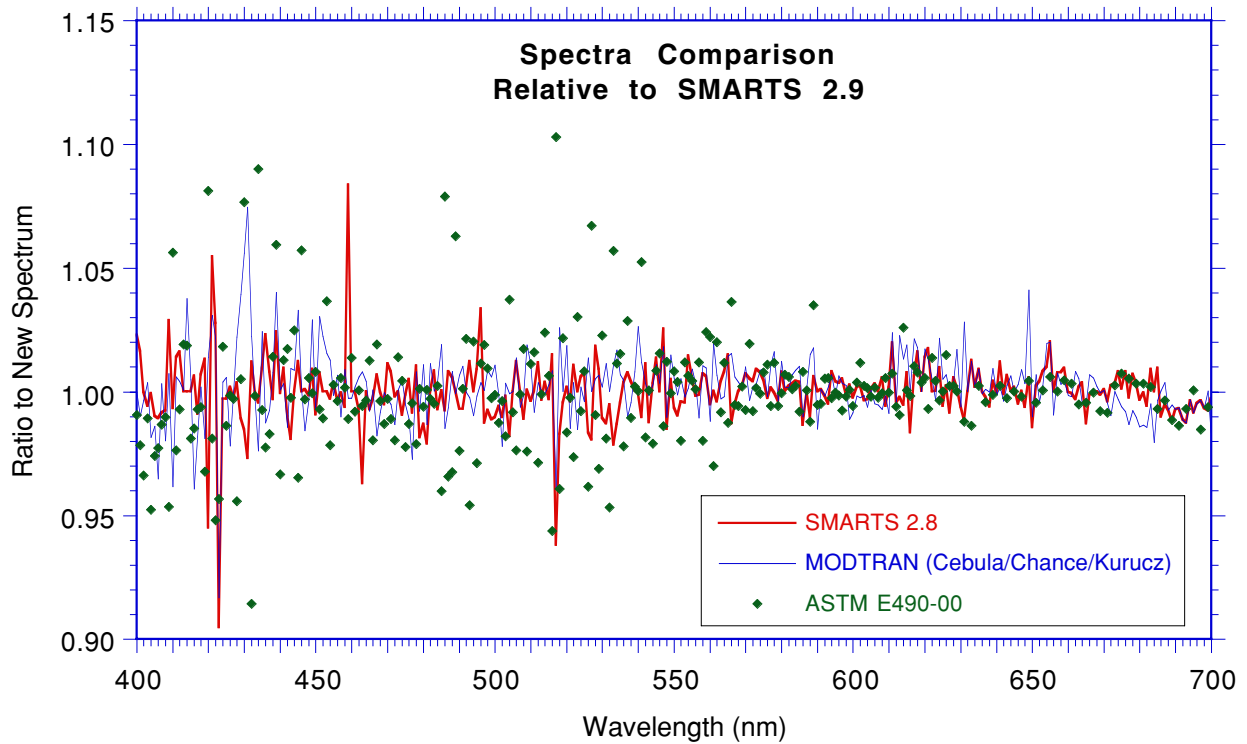
Fig. 2b Wavelength-by-wavelength irradiance ratios of some existing spectra to the revised default spectrum of SMARTS2 in the visible region.
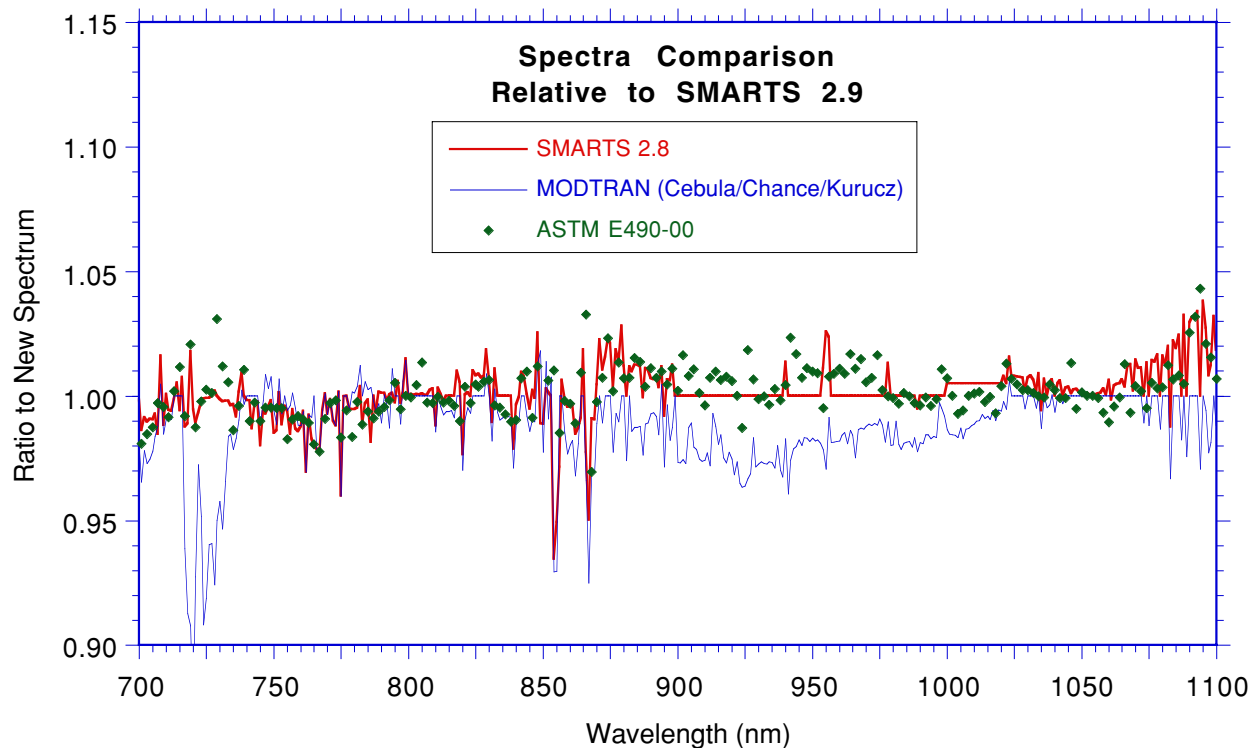
Fig. 2c Wavelength-by-wavelength irradiance ratios of some existing spectra to the revised default spectrum of SMARTS2 in the near IR region from 700 to 1100 nm.
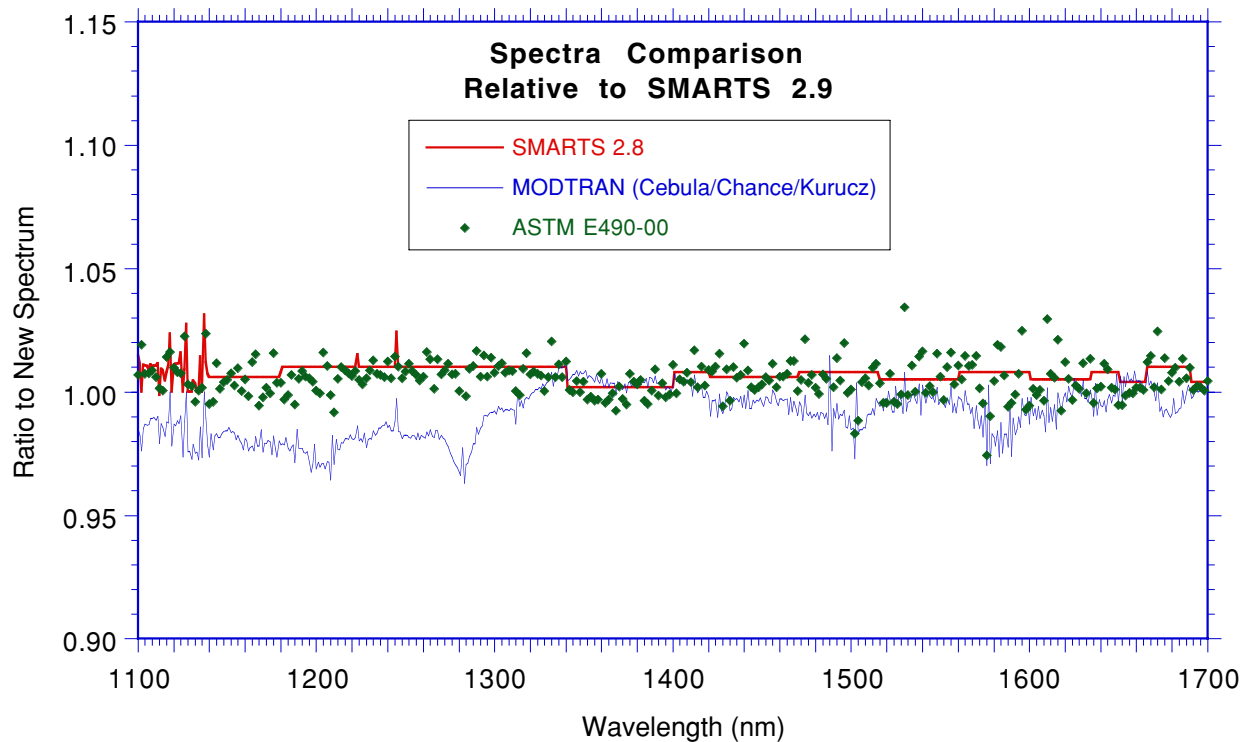

Fig. 2d Wavelength-by-wavelength irradiance ratios of some existing spectra to the revised default spectrum of SMARTS2 in the near IR region from 1100 to 1700 nm.

13. COMPARISONS WITH MODTRAN

It would be difficult to argue against the statement that the currently pre-eminent—if not *de facto* standard—radiative transfer code in atmospheric sciences is MODTRAN, developed by the Air Force Geophysics Laboratory of Hanscom, MA. The SMARTS algorithms have been revised in this version to improve the agreement between its predictions and those of MODTRAN, version 4.0. Although the algorithms in SMARTS are completely different than those in MODTRAN, both codes have some common ground, described below.

1. The six reference atmospheres used in MODTRAN are part of the library of ten reference atmospheres in SMARTS.
2. The different Shettle & Fenn aerosol models used in MODTRAN are also part of the library of default aerosols in SMARTS. Note, however, that only an approximate fit of the spectral variation of the optical characteristics of these aerosols has been voluntarily used in SMARTS. A notable exception has been made for the Rural Aerosol model, whose optical depth spectral variations have been closely reproduced with a stepwise regression method.
3. Absorption coefficients for some gases have been derived from MODTRAN4 results. This is the case for CH_4, CO, CO_2, H_2O, NH_3, NO, N_2, N_2O over the whole spectrum, and for O_3 and SO_2 in the IR only. In all other cases, cross section data from the recent spectroscopic literature have been used, and temperature correction functions have been considered wherever possible.
4. The optical masses for all extinction processes in SMARTS have been fitted to a common equation from slant column abundances obtained by varying the zenith angle in a series of MODTRAN runs.
5. The six default extraterrestrial spectra offered in MODTRAN are now also available in SMARTS for comparative and compatibility purposes. However, the revised, non-MODTRAN spectrum described in Section 11 is recommended for normal use.

Because MODTRAN4 incorporates many changes and improvements over MODTRAN2, on which the previous versions of SMARTS were based, it is interesting to compare the predictions of SMARTS (versions 2.8 and 2.9) to those of MODTRAN4 for typical atmospheric conditions. Such a comparison is not directly possible because MODTRAN outputs its results in equal steps of wavenumbers (with a minimum step of 1 cm^{-1}), rather than wavelengths. Thus it has been necessary to resample and degrade MODTRAN's outputs (using its maximum resolution) to fit SMARTS2's own resolution so that wavelength-by-wavelength correspondence could be achieved. The atmospheric conditions were chosen according to ASTM standard E891-87, reissued as standard G159-98 (ASTM, 1987, 1998) and ISO 9845-1 (ISO, 1992). These same conditions are used in Examples 1 and 3 for the user's benefit.

Figure 3 shows the percent deviation between the direct atmospheric transmittance predicted by the two versions of SMARTS and by MODTRAN. The improvement from version 2.8 to 2.9 is particularly obvious over the whole spectrum. A more detailed comparison between SMARTS 2.9 and MODTRAN 4.0 appears in Fig. 4. Structure in the difference curve is caused by different possible causes: the simplified algorithms used in SMARTS which can affect results in strong absorption bands (e.g., the water vapor bands around 940-nm and 1150-nm), the use of more recent or complete absorption data in this version of SMARTS (e.g., for the UV and visible ozone bands), and the consideration of more absorbing gases by SMARTS. Eight absorbing species now considered in SMARTS are not in MODTRAN yet: BrO, CH_2O, $ClNO_3$, HNO_2, HNO_3, NO_3, O_4, as well as SO_2 in the UV. As demonstrated by Fig. 4, the dips in the difference curve are attributable to the additional absorption caused by these gases, particularly O_4.
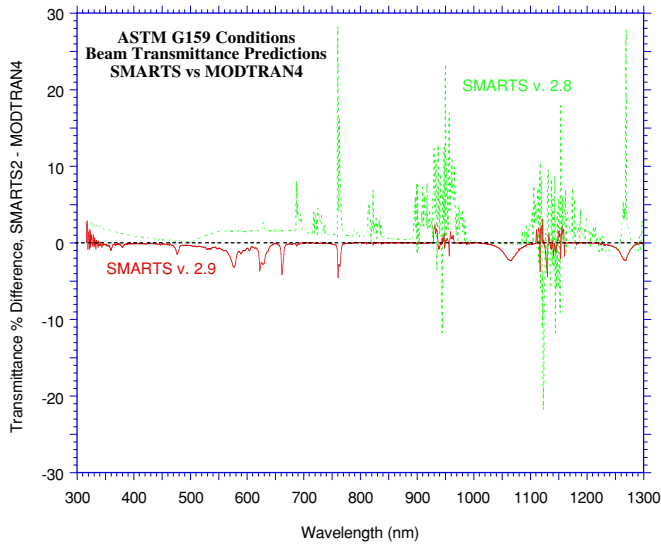
Fig. 3 Percent difference between the direct transmittance predicted by SMARTS, versions 2.8 and 2.9, and MODTRAN, version 4.0, for the same standard conditions.

Figure 5 shows a comparison between the direct irradiance for an air mass 1.5 and standard atmospheric conditions predicted by SMARTS2, and the absolute spectral difference (in W/m^2 nm) between the irradiance predictions of SMARTS and MODTRAN4. For this comparison, the Cebula/Chance/Kurucz spectrum has been used in both codes.

Finally, the data in Fig. 5 are shown in greater detail in Fig. 6, where the irradiance difference between the predictions of the Monte-Carlo BRITE code (that was originally used to develop the spectra in standards ASTM G159 and ISO 9845-1) and those of MODTRAN, is added for comparative purposes. It can be concluded that the gain in accuracy between BRITE and SMARTS is about an order of magnitude, at least for these particular conditions.

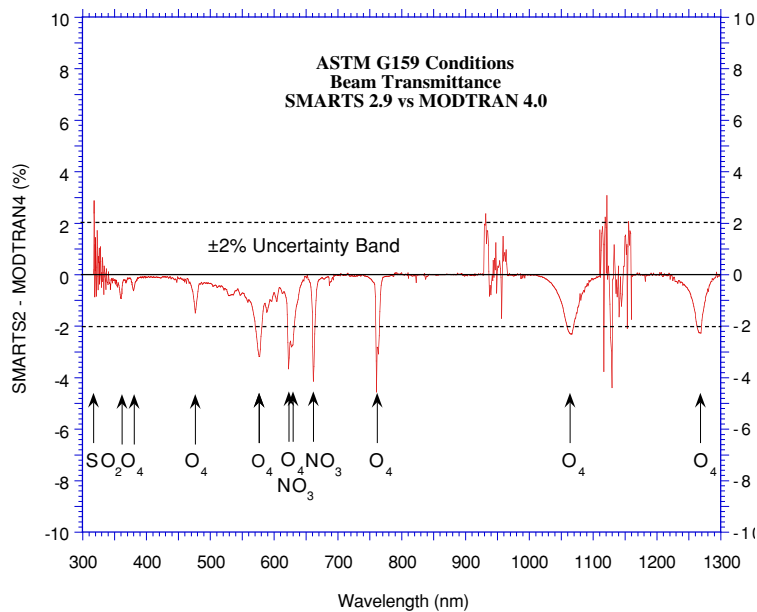Fig. 4 Percent difference between the direct transmittance predicted by SMARTS 2.9 and MODTRAN 4.0, showing the additional absorption bands (indicated by arrows and the corresponding gases) considered in SMARTS.
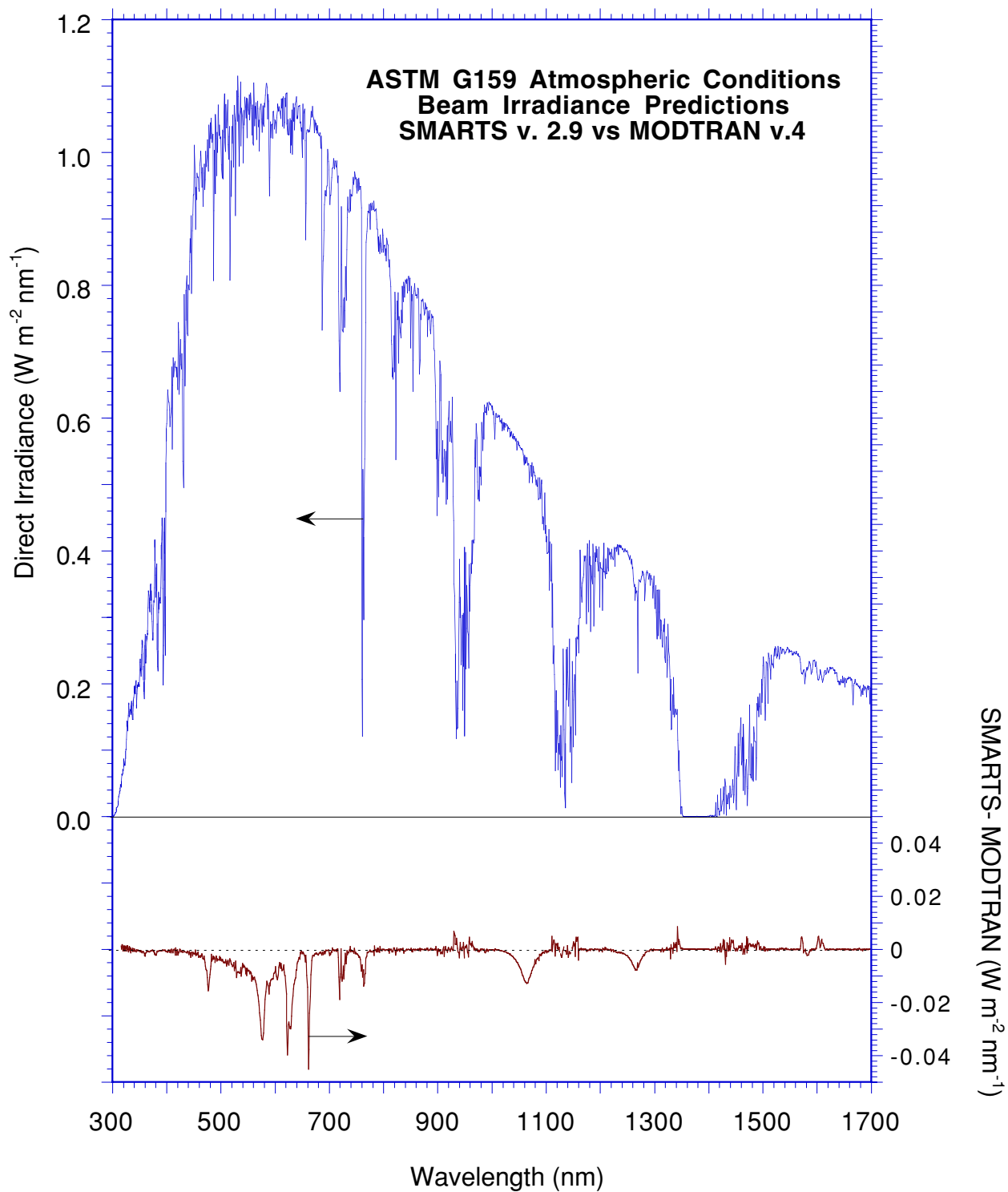
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Fig. 5 Direct irradiance at normal incidence predicted by SMARTS (top panel) and its absolute difference with that predicted by MODTRAN 4.0 (bottom panel) for the same standard conditions.
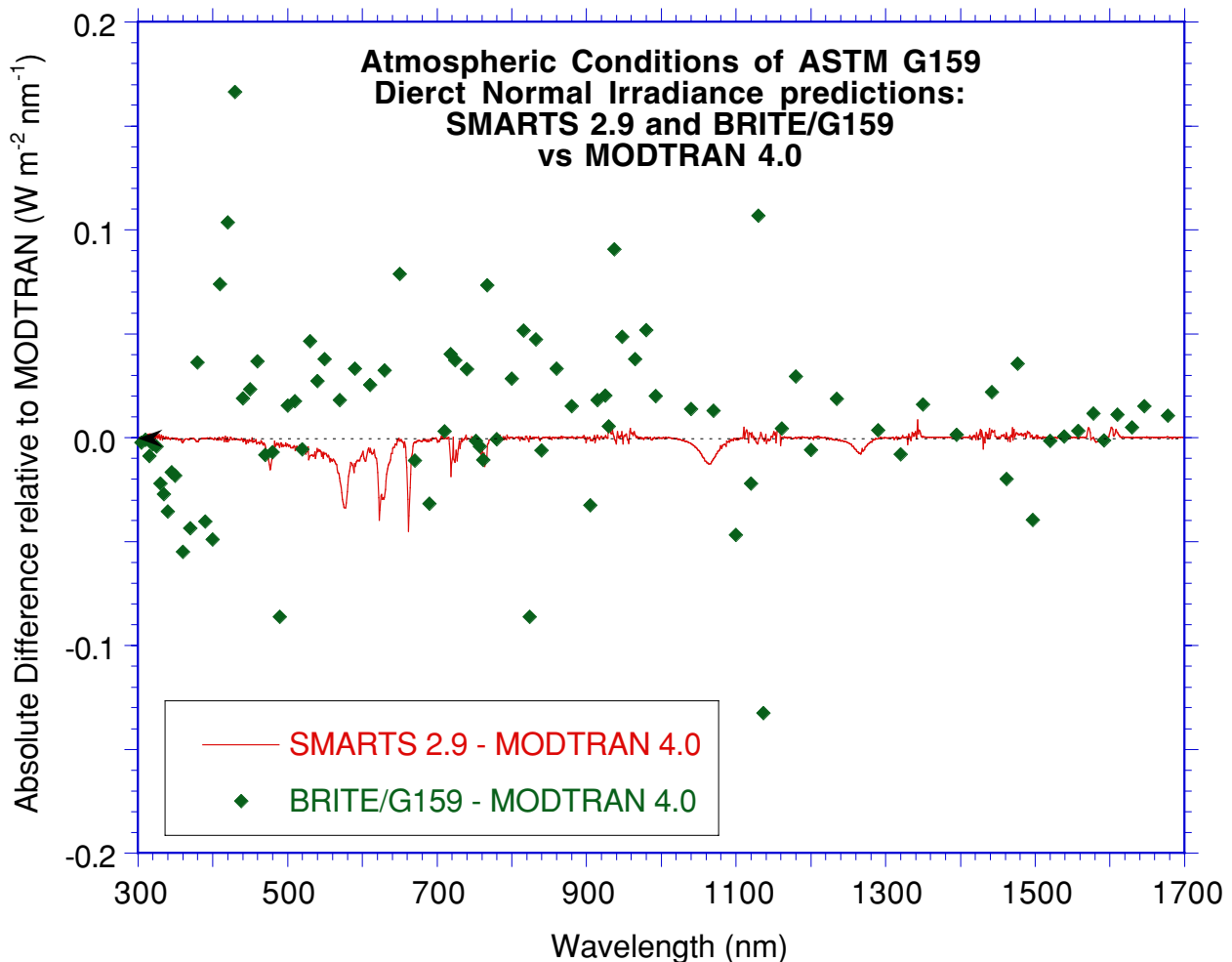
Fig. 6 Absolute difference between the direct irradiance predicted by SMARTS 2.9, BRITE (as per the ASTM G159 standard tabulations), and MODTRAN 4.0.

14. APPLICATIONS

Because of its versatility, SMARTS can be used in a large number of applications, covering a broad spectrum of activities. A detailed review is available elsewhere (Gueymard, 2003). One of these applications in particular is worth mentioning here because of its long-term impact. Following the development of SMARTS-based reference spectra (Gueymard et al., 2003), the American Society for Testing and Materials (ASTM) has recently adopted these reference spectra to replace those in the existing G159 standard (mentioned in Section 12). The new spectra in the G173 standard are specifically based on version 2.9.2 of the code, which then will be kept in a "frozen" state for permanent reference, even if new updates continue to be developed. Please consult http://www.astm.org/ and http://rredc.nrel.gov/solar/models/SMARTS/ for further information.

15. SUMMARY OF THE NEW FEATURES IN VERSION 2.9.x

Version 2.9.2

- *Bug correction*
  A bug in version 2.9.1 that affected calculations with one albedo file (**IALBDX** and **IALBDG** = 2) has been corrected. Another fix was a bug that potentially affected *all* previous versions and was causing numerical instability when calculating irradiances at large air masses. The spectral optical depths for water vapor and other gases are now correctly reported when more than one sub-run (solar position) is requested. The aerosol optical depths are now correctly reported on the main output file ('filename.OUT') and correspond exactly to the spectral values reported on the optional output file ('filename.EXT'). Finally, the output details for Day of Month and Day of Year are now correctly reported for both Local Time and Universal Time.

- *Turbidity inputs*
  An improved relationship between turbidity and meteorological range is now used, for better correspondence with MODTRAN results. It is season-dependent and takes the influence of tropospheric aerosols above the boundary layer into account.
  The aerosol optical depth at 550 nm is now calculated and printed in the input echo section of 'filename.OUT'. This wavelength corresponds to the peak of the photopic curve and is the effective wavelength used when deriving the aerosol optical depth from the meteorological range.

Version 2.9.1

- *Bug correction*
  A bug in version 2.9 affected all calculations with all reference atmospheres except USSA. It prevented the correct value of the default precipitable water to be used, so that the USSA value was rather used in all cases if **IH2O** = 1 was selected on Card 4.

- *Output variables*
  The number of spectral variables is no more limited to 24 by **IOTOT** on Card 12b. All 32 variables can now be printed on File 17 ('filename.EXT').

- *Scanning/smoothing output*
  Results of the scanning/smoothing routine (if **ISCAN** = 1 on Card 14) are now printed on a separate spreadsheet-ready output file, File 18 ('filename.SCN'), for more flexibility.

- *Main output file*
  Labelling and content of the main output file, File 16 ('filename.OUT'), has been slightly revamped for clarity.

Version 2.9

- *New algorithm for the sun position*
  The authors of the new algorithm (Blanco-Muriel et al., 2001) claim that it is more accurate than Michalsky's algorithm that was used in previous versions. *Month* and *Day of month* are now used as inputs rather than *day of year*, which might be easier. Local Apparent Time (LAT) is now an output of the program. The time zone sign convention has been reversed to become consistent with the longitude sign convention.

- *Improved resolution*
  Resolution has been doubled in the UV, below 400 nm (0.5 nm rather than 1 nm). The total number of wavelengths is now 2002, from 280 to 4000 nm.

- *Revised extraterrestrial solar spectrum*
  The new spectrum corresponds more closely to the currently accepted solar constant (1367 W/m^2). Additionally, there are 6 optional spectra, from as many possible default spectra in MODTRAN4 (Wehrli/WRC/WMO, oldkur, newkur, chkur, cebchkur, and thkur). These datasets have been resampled and degraded from their original resolution (1 cm^{-1}) to that of SMARTS, to accommodate the latter's resolution. As in MODTRAN, these spectral irradiances can now be scaled to 1367 W/m^2 or any other solar constant value if so desired.

- *Revised Rayleigh scattering function*
  The coefficients in the Rayleigh optical depth formulation,

  $$\tau_R = (p / p_0) / (a_0 \lambda^4 + a_1 \lambda^2 + a_2 + a_3 \lambda^{-2})$$

  have been revised to take new fundamental determinations into account (Bucholtz, 1995; Bodhaine et al., 1999). The functional form above guarantees a significantly better fit to the theoretical data than the polynomial ratio recommended by Bodhaine et al.

- *Revised optical masses*
  Each extinction process has now a separate optical mass, obtained as a function of zenith angle. The air mass takes the atmosphere's curvature and the vertical profile of each absorber or scatterer into account, and thus alleviates the limitations of the usual plane-parallel approximation.

- *New absorption coefficients*
  All absorption coefficients are either new or revised in this version, and are based on the latest spectroscopic data. There is now a total of 19 absorbing gases (a number of them new to SMARTS; some of them not considered in MODTRAN yet). Wherever possible, the absorption coefficients are temperature dependent. All gases are treated individually, with a separate input data file (hence the far larger number of data files in the present version).

- *Pollution mode*
  The abundance of all gases is defaulted to "standard" conditions calculated from pressure and temperature. The abundance of those 10 gases that are highly variable due to tropospheric pollution (e.g., O_3, NO_2, SO_2) can be modified with a "pollution index". Their real tropospheric abundance can be either user defined (in ppm), or defaulted to four representative levels (pristine conditions, light pollution, moderate pollution, and severe pollution).

- *Variable CO_2 concentration*
  Like in MODTRAN, the atmospheric CO_2 concentration (which is slowly increasing over time) is a user input.

- *Revised relationship between visibility and aerosol optical depth*
  It is now based on MODTRAN4 results.

- *Improved fits for Angström's wavelength exponent*
  More accurate fits of α = f(wavelength, humidity) have been obtained for Shettle & Fenn's aerosol models.

- *Improved albedo library*
  The number of albedo data files has been doubled, now incorporating some wide-range spectral datasets from JPL's ASTER Spectral Library, Version 1.2 (available on line or on CD-ROM from the Jet Propulsion Laboratory, http://speclib.jpl.nasa.gov).

- *More accurate smoothing*
  Improved accuracy and functionality for the SCAN smoothing postprocessor have been implemented. It has a better tail rejection (for wavelengths away from the peak wavelength), and can now cover the whole spectrum in one pass.

- *Daily run*
  A daily run can now be specified, to calculate the mean daily *broadband* irradiation (in MJ/m^2) for any month at a specified location.

- *UV Index*
  The *UV Index* is now reported when requesting the optional extra UV calculations.

- *Faster batch runs*
  A simpler interface is used to expedite batch runs.

- *Corrections*
  A few bugs that have been reported by users of version 2.8 have been corrected.

- *Examples*
  Nine documented Examples are now available with all the related input/output files, and a description in a ReadMe file.

- This User's Manual!

16. REFERENCES

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APPENDIX: PRINTOUTS FOR EXAMPLE 6

• *INPUT FILE*

```
'Example_6:USSA_AOD_0.084_ASTM_G173'      !Card 1 Comment
1                                          !Card 2 ISPR
1013.25 0.                                 !Card 2a Pressure & altitude
1                                          !Card 3 IATMOS
'USSA'                                     !Card 3a Atmos
1                                          !Card 4 IH2O
1                                          !Card 5 IO3
1                                          !Card 6 IGAS
370.0                                      !Card 7 qCO2
1                                          !Card 7a ISPCTR
'S&F_RURAL'                                !Card 8 Aeros
0                                          !Card 9 ITURB
0.084                                      !Card 9a Turbidity coeff. (TAU5)
38                                         !Card 10 IALBDX
1                                          !Card 10b ITILT
38 37. 180.                                !Card 10c Tilt variables
280 4000 1.0 1367.0                        !Card 11 Input wavelengths; solar spectrum
2                                          !Card 12 IPRT
280 4000 .5                                !Card12a Print limits
4                                          !Card12b # Variables to Print
8 9 10 30                                  !Card12c Variable codes
1                                          !Card 13 ICIRC
0 2.9 0                                    !Card 13a Receiver geometry
0                                          !Card 14 ISCAN
0                                          !Card 15 ILLUM
0                                          !Card 16 IUV
2                                          !Card 17 IMASS
1.5                                        !Card 17a Air mass
```

• *OUTPUT FILE*

***************** SMARTS2, version 2.9.2 ******************
Simple Model of the Atmospheric Radiative Transfer of Sunshine
Chris A. Gueymard, July 2002, Revised March 2003

This model is documented in FSEC Report PF-270-95
and in a Solar Energy paper, vol. 71, No.5, 325-346 (2001)

NOTE: These references describe v. 2.8 or earlier!!!
See the User's Manual for details on recent changes...
****

Reference for this run: Example_6:USSA_AOD=0.084_ASTM_G173

----

* ATMOSPHERE : USSA   AEROSOL TYPE: S&F_RURAL

* INPUTS:
    Pressure (mb) = 1013.25   Altitude (km) = 0.000
    Relative Humidity (%) = 45.45   Precipitable Water (cm) = 1.4164
    Ozone (atm-cm) = 0.3438 or 343.8 Dobson Units
    Season = SPRING/SUMMER
  AEROSOLS: Optical Depth at 500 nm = 0.0840   Optical depth at 550 nm = 0.0764
    Angstrom's Beta = 0.0333   Schuepp's B = 0.0365
    Visual Range (km) = 124.2   Visibility (km) =   95.1
    Alpha1 = 0.9640 Alpha2 = 1.4315   Mean Angstrom's Alpha = 1.1978

* TEMPERATURES:
    Ground Level, Instantaneous = 288.2 K
    Sea Level, Daily Average = 288.2 K
    Ozone (effective) = 225.4 K
    NO2 (effective) = 225.4 K

The following spectral variables will be output to file: SMARTS2.EXT

 * Global_tilt_irrad.
 * Direct+circumsolar
 * Difuse-circumsolar
 * Zonal_surf._albedo

 Spectral ZONAL albedo data: LIGHT_SANDY_SOIL
  with a reflection process: NON_LAMBERTIAN

* GEOMETRY (half-angles) OF THE SIMULATED RADIOMETER (deg.):
  Slope = 0.00   Aperture = 2.90   Limit = 0.00

** WARNING! The radiometer's Slope and Limit angles are not provided.
Circumsolar calculations will therefore be performed for
an average geometry corresponding to the Aperture angle.

 Spectral LOCAL albedo data: LIGHT_SANDY_SOIL
  with a reflection process: NON_LAMBERTIAN

==
==

* SOLAR POSITION (deg.):
  Zenith Angle (apparent) = 48.236 Azimuth (from North) = 180.00

 RELATIVE OPTICAL MASSES:
 - Rayleigh = 1.500
 - Water Vapor = 1.501
 - Ozone = 1.498
 - NO2 = 1.500
 - Aerosols = 1.501

 CO2 Mixing Ratio (ppmv): 370.0

 Total column abundances for all gases except H_2O (atm-cm) and normal/standard conditions:

BrO	CH2O	CH4	ClNO3	CO	CO2	HNO2	HNO3	NH3
0.2500E-05	0.3000E-03	0.1285E+01	0.1200E-03	0.8747E-01	0.2971E+03	0.1000E-03	0.3811E-03	0.1300E-03

NO	NO2	NO3	N2	N2O	O2	O3	O4	SO2
0.3211E-03	0.2044E-03	0.5000E-04	0.3719E+01	0.2385E+00	0.1678E+06	0.3438E+00	0.1678E+06	0.1071E-03

* ANGLES (deg.) FOR TILTED SURFACE CALCULATIONS:
  Surface Tilt = 37.000   Surface Azimuth (from North) = 180.000
  Incidence Angle = 11.236

 Diffuse irradiance ratios (tilted plane/horizontal):
   0.8993 (isotropic approximate conversion--for reference)
   1.2420 (anisotropic conversion model--used here)

* *
 * SPECTRUM:
 Total (0-100 μm) Extraterrestrial Irradiance used here = 1367.00 W/m2
 (i.e., 1.0000 times the selected solar constant, 1367.00 W/m2, due to the actual Sun-Earth distance.)
 Source for selected solar spectrum: SMARTS_Gueymard

Wavelength Range = 280.0 to 4000.0 nm ;   Number of Wavelengths = 2002

*** BROADBAND IRRADIANCES (W/m2):

* DIRECT BEAM AT NORMAL INCIDENCE:
 Extraterrestrial = 1347.94   Terrestrial = 897.91   Atmospheric Transmittance = 0.6661

* FOR THE HORIZONTAL PLANE:
 Direct Beam = 598.07   Diffuse = 94.72   Global = 692.79
 Diffuse irradiance components:
 Rayleigh scattering = 42.37   Aerosol scattering = 38.30   Backscattering = 14.04

* FOR THE TILTED PLANE:
 Direct Beam = 880.70 Sky Diffuse = 95.80   Ground Reflected = 23.87   Global = 1000.37

* EXPERIMENTAL (WITH CIRCUMSOLAR CORRECTION):
 Direct Beam, Normal Incidence = 900.14   Diffuse Horizontal = 93.23   Global Horizontal = 692.79