



1.1 Introduction and overview

The CESORA™ program is a versatile calculation tool and a new component of the Atlas Material Testing Technology, LLC ("Atlas") 'Network of Weathering'. It has been developed over the last few years under the management of Atlas and in close cooperation with Prof. Dr. Gerhard Manier and Dr. Chris Gueymard. The name of the CESORA program is derived from and refers to the *Calculation of Effective Solar Radiation*.

The CESORA computer program offers extensive and versatile calculations of the effective terrestrial solar radiation. It is designed to provide important information to users in numerous fields of application, in which knowledge of the spectral distribution of radiation is essential and must be simulated if it cannot be measured easily.

Rationale

The development of the CESORA program was stimulated by the obvious benefit that a whole community can find in such a program in terms of quality assurance, better knowledge of the physical processes involved, time and cost savings, and methodological improvements. The main application envisioned is the field of material testing under the influence of solar radiation, where the latter induces various effects (change of properties and degradation), which must be qualitatively and quantitatively evaluated as a function of each material's optical and thermal properties.

Knowledge of the actual solar radiation impacting a product sample in the field is most often insufficient and also relatively difficult (if not prohibitively expensive) to monitor. General information on solar radiation, like max/min/mean/dose for different regions and sites, is normally available. However, it is not enough to define the actual and effective exposure conditions, especially when intricate spectrally-selective processes are involved.

Achieving better effectiveness in this respect was the main goal and driving force behind the development of the CESORA program.

Applications

The possible applications of the CESORA program are directed to virtually all technologies where solar radiation and its spectral distribution can cause measurable effects. For example:

- Automotive & Transportation
- Plastics
- Coatings & Paints
- Solar Energy
- Cosmetics
- Agriculture
- Photochemistry
- Building & Construction.

Performance

For all these possible fields of applications, instantaneous (dubbed 'single case' in the CESORA program), as well as time-integrated ('diurnal variations', 'time series') spectral irradiances on surfaces of specifiable geometry exposed to sunlight/daylight at selectable times and locations under precise meteorological conditions, may be computed by the CESORA program.

Predictions of spectral irradiance can be obtained for direct, diffuse and reflected solar radiation, and displayed in freely specifiable wavelength ranges.

The 'Filter Function' tool can also be used to evaluate the spectral irradiance transmitted by any type of filter (e.g., window glass, automotive glazing, or semi-transparent cover) of known spectral transmission.

In addition to predictions of the incident spectral irradiance, evaluations of effective irradiance can also be performed, i.e., the irradiance after modification by some physical or biological process. In the 'Calculation mode' dialog the selection of a default 'action function' or 'action spectrum' (which can also be modified or defined by the user) enables calculation of the corresponding effective irradiance (e.g., UV Erythema).

CESORA vs experimental testing

Even though the calculation of effective spectral irradiance can provide estimations of potential property changes in various materials, the CESORA program is absolutely not a replacement for actual testing. The CESORA program is designed to be an estimation aid and a convenient resource to support the testing practice as a result of its predictive power and numerous functions.

For example, actual tests may be designed more effectively and their appropriate setup better tailored (with a focus on successful results) after a preliminary analysis is done based on the CESORA program calculations. Furthermore, the detailed information on effective spectral irradiance produced by the CESORA program may enable a better and more complete evaluation of the actual test results.

Calculation model

The present version of the CESORA program provides two calculation models to predict the solar spectral irradiance. The default model is named SMARTS, the internationally acknowledged model developed by Dr. C. Gueymard. This model has also recently been used for the development of two reference spectra by ASTM (American Society for Testing and Materials).

The proposed alternative model is named SPEKTRA. It is based on the VDI (German Association of Engineers) guideline 3789, parts 2 and 3, and was developed by Prof. Dr. G. Manier. Details on both calculation models can be found in the following sections of this manual.

Remarks

The CESORA program requires carefully selected and accurate input data so that the calculation models of the CESORA program may provide high-quality information on spectral solar irradiance. The SMARTS component of the CESORA program may be used to create official references. However, the accuracy of any such reference will be limited by the quality, specificity and accuracy of the input data.

Inaccuracy in the description of specific local conditions may result in differences between simulated irradiances and actual irradiances; regardless if all other input data is selected very carefully.

Furthermore, 'engineering' models such as the CESORA program depend on only a relatively small number of variables and always include simplifying assumptions, which are expected to be representative of 'normal' conditions. However, different models may use different assumptions, which may or may not be applicable or appropriate for all scenarios, situations or simulations. Moreover, not all possible parameters or constellations of possible fine-tunings that may influence spectral solar irradiance can be used in a model for practical reasons. The quality and accuracy of the results simulated by the CESORA program are dependent upon the correct entry of input parameters. We strongly suggest that the novice user should first develop a 'feel' of what the most influential inputs are for any particular application. For instance, in some simulations ozone may be the critical factor when dealing with UV-B spectra. In other simulations, turbidity (or visibility) may be the determining factor when dealing with the visible spectra under clear skies. In other simulations, precipitable water, determined indirectly by temperature and relative humidity may be the determining factor when dealing with the near infrared spectra.

Users may find the 'Parametric Runs' option to be an exceptionally powerful tool. Such option enables the automatic variation of one parameter at a time. However, this tool must be used very carefully to obtain meaningful results. This means that only realistic and logical combinations of inputs should be used, and selection of such can be difficult.

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1.2 About SMARTS

The Cesora-SMARTS option uses the SMARTS (*Simple Model of the Atmospheric Radiative Transfer of Sunshine*) spectral model. It can predict the clear-sky 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). Besides the regular irradiance predictions needed for many possible applications, it can be used to simulate the spectral irradiance that would be measured by a spectroradiometer, or the broadband irradiance that would be measured by a pyranometer or a pyrliometer.

Ever since its first stages of development, the main goals of SMARTS have been to offer accurate predictions of spectral irradiance for a variety of applications and without the complexities and hassles of rigorous atmospheric codes. The model uses parameterizations of the atmospheric transmittance characterizing each individual extinction process. These spectral transmittances completely describe the overall transfer of radiation through the different layers of the atmosphere. The resulting

direct and diffuse transmittances are then multiplied by the extraterrestrial solar spectrum to predict the desired terrestrial spectrum or spectra. This extraterrestrial spectrum corresponds to a solar constant of 1366.1 W/m² [1].

The SMARTS model and some of its applications are described in a series of publications [2-11]. Most of these publications include discussions on the performance of the model. Regular algorithm improvements have been integrated into the model to maintain its performance at the highest level, compared to both rigorous atmospheric codes (such as MODTRAN) and experimental spectra measured with high-quality instrumentation. Moreover, independent contributions have confirmed that the model could be considered a truly validated research tool for engineers and scientists [12-15].

One noted application of SMARTS has been the development of two reference shortwave spectra for standardization by the American Society for Testing and Materials [16]. These spectra (for direct normal irradiance and global tilted irradiance) have been obtained with version 2.9.2 of SMARTS and are accessible from Cesora for reference purposes. Another global spectrum based on the same version of SMARTS, but limited to the UV and of higher intensity, has also been standardized by ASTM [17].

Cesora, however, uses a calculation engine derived from the newest version (2.9.3) of SMARTS, which offers more capabilities than version 2.9.2. For identical atmospheric conditions, the irradiance predictions of these two versions may slightly differ. But, because the two versions have the same resolution and spectral step size, it is very easy to compare spectra calculated by Cesora to any of the ASTM standard spectra mentioned above.

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1.3 Installation

Installing Cesora from the installer package is quick and painless - it should be carried out by the user or by the system administrator with the necessary rights. In order to minimise unlicensed usage of Cesora, the program comes with a software copy protection. In order to obtain a key file for your computer, use your mouse to mark the 'Computer-dependent code' which is shown the first time you start an as-yet unlicensed version of Cesora, and, using copy-and-paste, send it to us via mail. In return, you will receive your personal licence key file, 'cesora.key', which you may install by double-clicking on it - agree to the dialogs which appear by pressing 'OK'. If any access-rights-related errors occur, please consult an administrator for your computer.

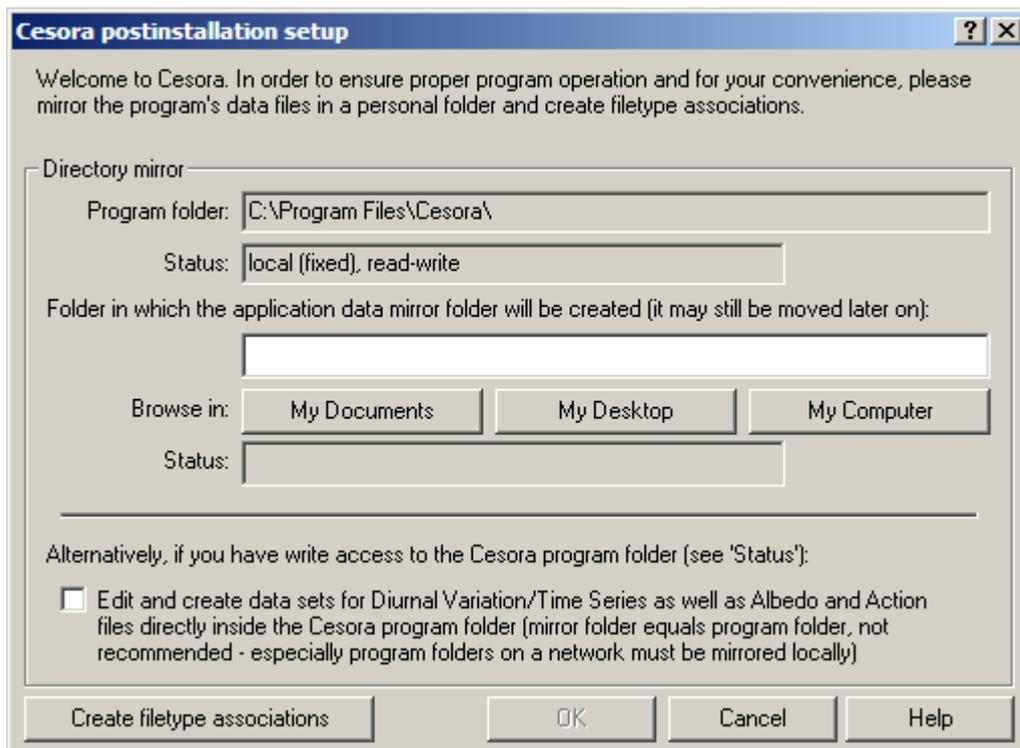
Demo version

The demo version of Cesora does not need a key to run, but it has limited

functionality (see 'Cesora Demo.txt') and can be started only 20 times. **For the first time it needs to be run by that user who is going to be using it afterwards.** If an administrator manages the installation but does not want to use the program afterwards, they may not, for instance, run the program from the administrator account to test it.

The mirror folder

When running Cesora for the first time, you are asked to specify a personal 'mirror folder' on your local machine. In this folder Cesora will keep all its internal data files, as well as some user-editable ones. You are also free to use this directory for your Cesora document files. You need to have write-access to the folder.



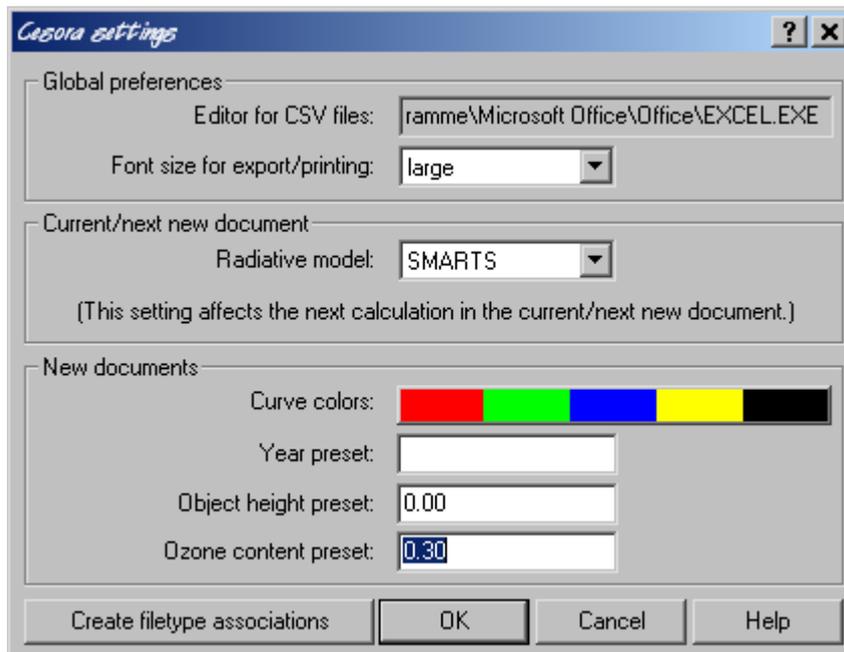
Select where the mirror folder is to be created. A possible mirror folder would be 'My Documents\Cesora', in which case you would select 'My Documents' as the location for the mirror folder. If at some point Cesora cannot find the mirror folder any more (because it was renamed or deleted), you are offered to look for it on your computer or to create a new mirror folder using the data in the installation directory.

You are also free to use the program folder itself as the personal 'mirror directory', however it is probably a better idea to have all those data files which may be edited later on in one place somewhere inside your personal folders.

Filetype associations

The filetype associations which are required for Cesora may be set up by clicking the button at the bottom left.

1.4 Editing program settings



Global preferences

In this section, the system-default editor for CSV files is displayed (you may change it e.g. in the 'Folder options' system dialog under the 'Filetypes' tab), and you can set the font size for exported or printed documents.

Current/next new document

Differences between the two models are described in the Appendix. SMARTS is the ASTM reference, while SPEKTRA is the VDI standard. SMARTS is the default choice. Note that after changing the model, the actual document's contents will be modified only after recalculating, if presently there are curves displayed.

New documents

Set default parameter choices and curve colors for new documents in this section. The 'Year' input applies to Single Case and Diurnal Variation documents, the 'Object height' input is relevant for Single Case, Diurnal Variation, and Time Series documents, while the 'Ozone content' input applies only to Single Case documents. The purpose is to provide presets for inputs which tend to be identical for a large number of calculations. Clicking on the color button will take you to a special dialog - see [Section 5.2](#) for more information.

2.1 File/document operations

Cesora offers the basic file/document operations of 'New', 'Open', 'Close', 'Save', 'Save as', 'Print'. All of these options may be selected from the menu (in some cases also by associated keyboard shortcuts), some via the toolbar, which is usually located in the top border of the main window:



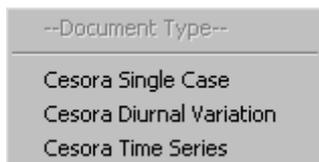
The buttons in the toolbar form five groups. From the left, the first group has the buttons 'New', 'Open', and 'Save as'. The second group contains 'New calculation', 'Copy to clipboard', 'Export graph as EPS (Enhanced Postscript file)', 'Export graph as BMP (Bitmap file)', and 'Export graph data as CSV (Comma-Separated Values file)'. The third group consists of 'Change display parameters', 'Change colors', and 'Display curve data table'. The fourth group of buttons contains 'Print' and 'Print preview', and finally, at the end the fifth group is formed by the 'Help' button.

Using the 'Copy to clipboard' and 'Export as ..' functions, the document's data and its graphic display may be saved in a number of different formats, allowing the user to use the results obtained with Cesora in a variety of ways. Data copied to the clipboard may be pasted into a word processor document, for example. The EPS format is popular for vectorized (i.e. freely scalable) graphics, BMP is a standard image format, and CSV files are easily loaded into spreadsheet applications.

If your spreadsheet program opens CSV files properly from inside the program but fails to do so when a CSV file is clicked on, it may be the result of an error in the operating system configuration. In the system settings, section 'Folder options', please select the 'File types' tab. In it, locate and select the CSV file type, click on 'Advanced' and edit the 'open' operation. Uncheck the 'DDE' option if it is checked, and make sure to enclose the %1 at the end of the input field in inverted commas: "%1".

2.2 Cesora document types

There are three basic types of documents which Cesora can process: the **Single Case** (extension .ecs), the **Diurnal Variation** (extension .tcs), and the **Time Series** (extension .zcs). When selecting 'New' from the toolbar or the menu, you are asked to select what type of document to create:



Each document contains geographical, meteorological and object specifications, along with up to five curves which are displayed in the document window. These curves contain information about the computed resultant irradiance.

In the Single Case document, the curves represent spectral distributions of irradiances, with x-values in the range of 250-4000 nanometers (nm) and y-values indicating the spectral irradiance in 'Watts per square meter per nanometer' ($W m^{-2} nm^{-1}$).

In the Diurnal Variation and Time Series cases, a number of Single Case calculations are performed, and the spectrally integrated broadband irradiances are calculated for each case. The broadband ranges for the spectral integration transparently performed by Cesora can be freely determined. This type of calculation runs over either one entire day (Diurnal Variation) or several entire days (Time Series). The desired meteorological parameters are specified in CSV (comma-separated values) files, which may be edited easily with a standard spreadsheet program (see [Section 3.3.1](#)). In the Diurnal Variation case and in the single-day view of Time Series, the time of day appears on the x-axis, and the broadband irradiance is displayed on the y-axis in Watts per square meter ($W m^{-2}$).

In the Entire-Series view of a Time Series, selectable via the menu 'View', the days are numbered on the x-axis (the time period is displayed in the legend), while the y value indicates the daily dosis of incident radiative energy. The complete energies for the individual curves are shown in the table directly below the graph. They are determined under the assumption that the daily doses between actually calculated days can be **interpolated linearly. Whether this is realistic depends also on the selected dates: in a linear interpolation between spring and autumn, summer is not taken into account!** Characteristic dates need to be chosen in order to get a meaningful total value.

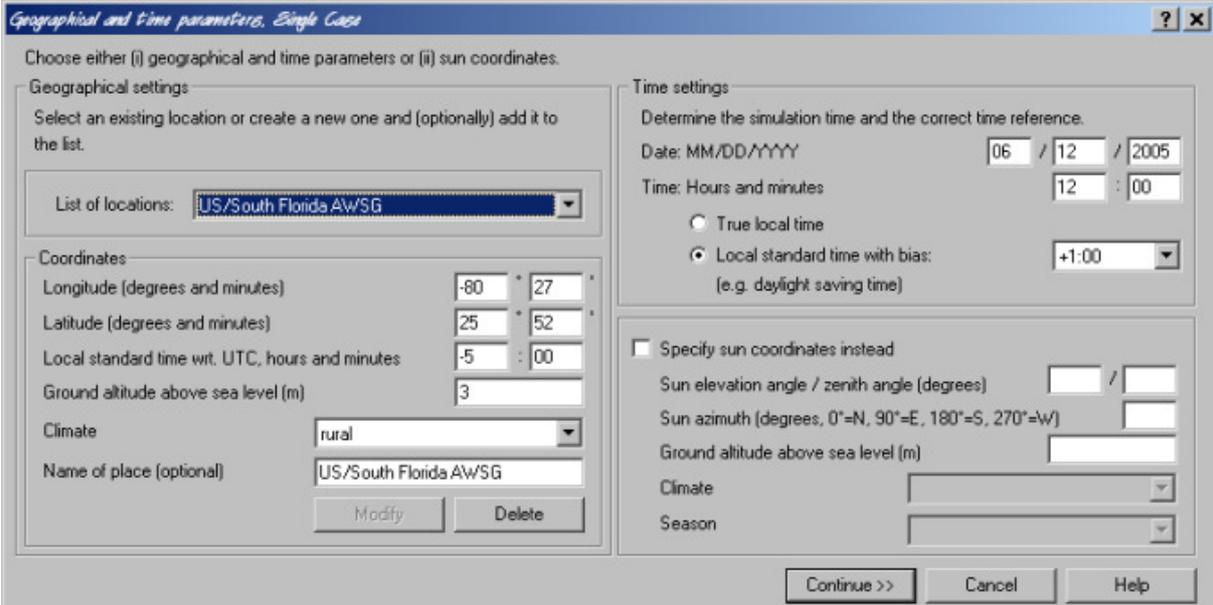
3.1 New vs. repeated calculations

To start a new calculation from scratch, select 'New calculation' via the button or from the menu when a new, empty document is selected. The dialogs in which you can specify all necessary data are described in the following sections. When there is a series of similar calculations to perform, you may not want to enter all data anew each time - and you don't have to: when a new calculation is started while an existing document is opened and selected, the previously entered values are filled into the selection fields as 'defaults'.

When a modified calculation has been completed, the new file may be saved under a different name by pressing the 'Save as' button in the toolbar, or the previous file may be overwritten by selecting 'Save' from the pull-down menu. To change only the parameters in a specific dialog, either press 'Enter' when the other dialogs are shown to simply accept all the values, or invoke only a specific kind of dialog, from the menu or by pressing 'Ctrl+1', 'Ctrl+2', or 'Ctrl+3' for geographical, meteorological, or calculation parameters, respectively.

3.2 Geographical and time parameters

In the first dialog which appears when a new calculation is started, the location of the object which is to be irradiated can be determined. For the Single Case, the date and time of the irradiation is requested too, for the Diurnal Variation, only the date, while for the Time Series, all date/time information is contained in an additional parameter file. Parameter files for Diurnal Variation / Time Series calculations are described in [Section 3.3.1](#), so in this section only the Single Case 'Geographical and time parameters' dialog will be dealt with. Self-explanatory items are marked with [SE]. Inputs which are specific to the SMARTS radiative model are marked with (SM).



Geographical settings

Location

The geographical setting can be defined either from a pull-down list of existing locations, which are stored with their coordinates for rapid access, or from a new location whose coordinates need to be specified. After this has been done, the new location can be added to the list by clicking on 'Add location'. This button changes to 'Modify' to edit the coordinates of existing locations.

Longitude

Enter degrees and minutes. East longitudes are counted positively. Therefore, add a minus sign for locations west of Greenwich. Limits are -180 to +180°. Example: The stored longitude for 'US/South Florida, AW/SG' (near the city of Miami) is -80°27'.

Latitude

Enter degrees and minutes. Northern latitudes are counted positively. Therefore, add a minus sign for locations in the southern hemisphere. Limits are -90 to +90°. Example: the stored latitude for Munich/München is 48°08'.

Local standard time with respect to UTC

This is also referred to as the Time Zone, and corresponds to the time difference (in hours) between Local Standard Time and UTC (previously known as Greenwich Mean Time). It varies between -12 (for western locations) and +14 (for eastern locations). Examples: 10 hours for Townsville (Australia), -3 hours 30 minutes for St Johns, Newfoundland (Canada). In case of doubt about the exact time zone of a distant location, help can be easily obtained online (see, e.g., <http://www.timezoneconverter.com>).

Altitude above sea level

This is the altitude of the ground level that the simulated receiver or object is overlooking, not necessarily of the object itself (see Height of object below). Limits: -400 to 10 000 m.

Climate (SM)

Select one climate from the pull-down list of four possible climates: Urban, Rural, Maritime, Desert. This in fact transparently defines the type of *aerosols* that is supposed to be prevalent above the chosen location. This is a relatively arbitrary choice because, for instance, an urban area can be affected by any one or all of the four types of aerosols at a given moment, therefore resulting in various mixtures from one day to the other. It can be good to play with this input to better understand the sensitivity of the results to it. For examples, see [Section 7.8](#) in the Appendix.

Time settings

Date: MM/DD/YYYY [SE]

Time: Hours and minutes [SE]

True local time

This is also known as Solar Time. By definition, the sun appears to cross the local meridian at exactly 12:00 Solar Time, also known as Solar Noon.

Local standard time

This is normally the same as Legal Time during winter. In this case, select 00:00 from the pull-down menu. If Daylight saving time is observed and is 1 hour ahead, select +1:00.

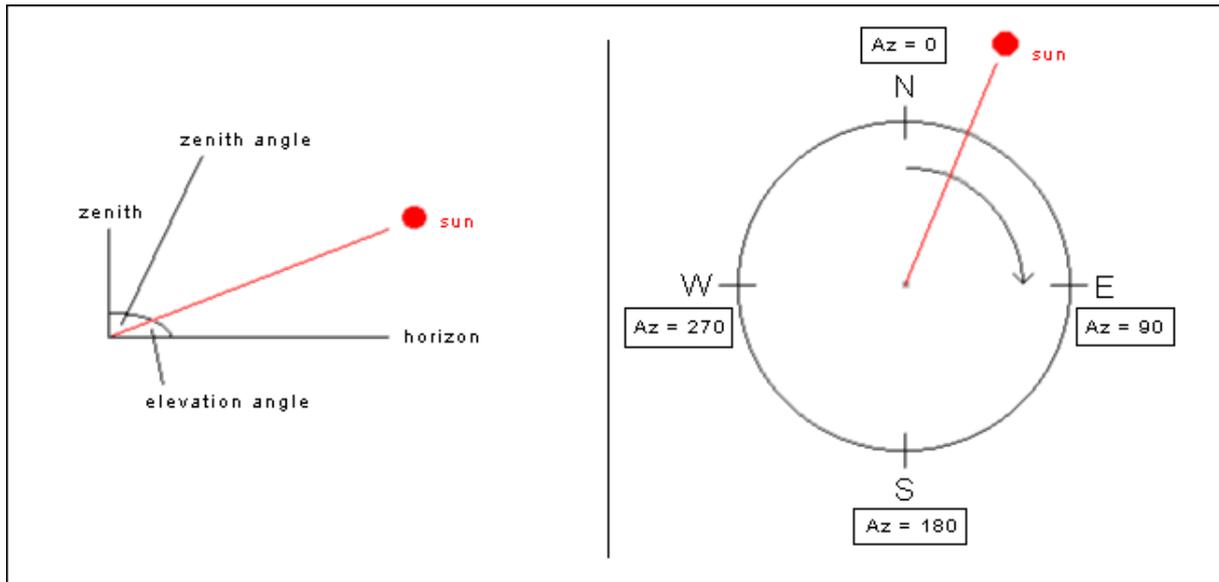
Sun coordinates

Sun elevation angle

This is the sun's height above the local horizon in decimal degrees.

Sun zenith angle

This is the complement of the sun elevation, evaluated from the zenith. If the sun elevation has been entered, this box will display the calculated value. Vice versa, if one enters the zenith angle, the solar elevation value will be calculated automatically.



Sun azimuth

This describes the position (or 'bearing') of the sun relative to the local meridian. The nautical/astronomical convention is used here, with North as the 0° reference. Turning clockwise, East is 90° , South is 180° and West is 270° . Limits: 0 and 360° .

Climate (SM)

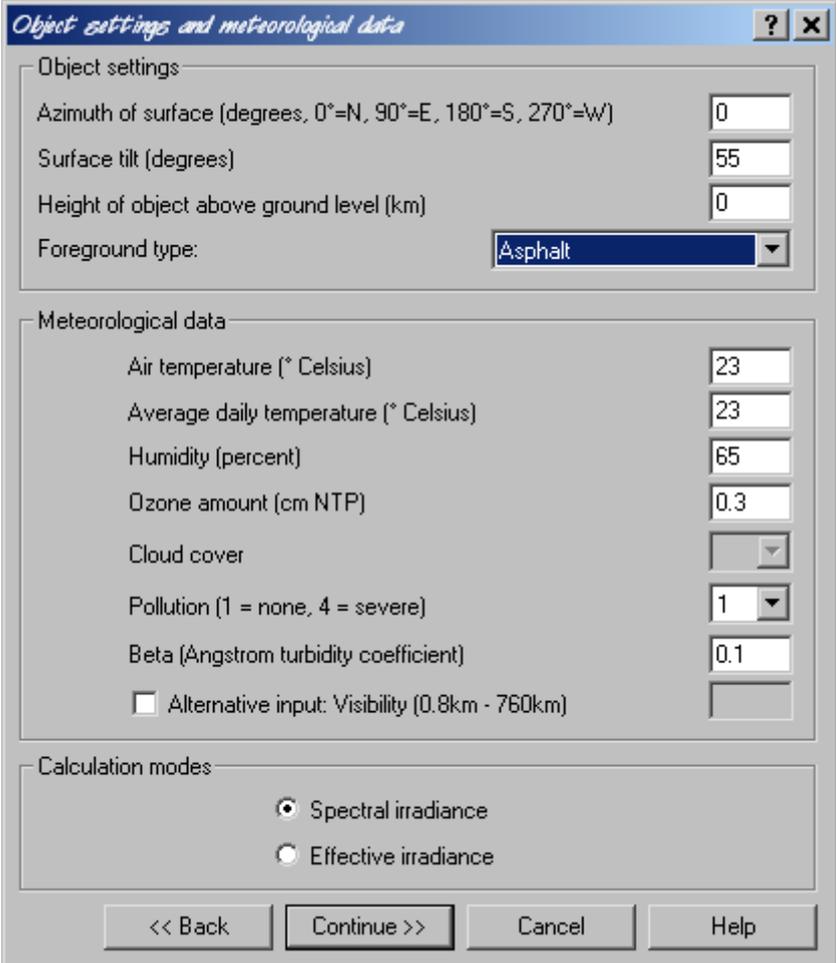
see above

Season (SM)

Select either Spring/Summer or Fall/Winter. This option fine-tunes the optical characteristics of the aerosols, and hence improves the relationship between visibility and turbidity, which is described in the Appendix ([Section 7.6](#)).

3.3 Object settings and meteorological data

The following is a description of the 'Object settings and meteorological data' dialog for a Single Case calculation. The [next subsection \(3.3.1\)](#) describes how to use CSV meteorological parameter files for the Diurnal Variation and Time Series cases - however, for the meaning of the parameters please refer to this section. Here, a short description of each parameter is given - in some cases along with a link to the Appendix, where more detailed information and help on determining parameter values may be found. Inputs which are used only by the SMARTS radiative model are marked with (SM), while those which are specific to SPEKTRA are marked (SP).



Object settings and meteorological data

Object settings

Azimuth of surface (degrees, 0°=N, 90°=E, 180°=S, 270°=W)

Surface tilt (degrees)

Height of object above ground level (km)

Foreground type:

Meteorological data

Air temperature (° Celsius)

Average daily temperature (° Celsius)

Humidity (percent)

Ozone amount (cm NTP)

Cloud cover

Pollution (1 = none, 4 = severe)

Beta (Angstrom turbidity coefficient)

Alternative input: Visibility (0.8km - 760km)

Calculation modes

Spectral irradiance

Effective irradiance

<< Back Continue >> Cancel Help

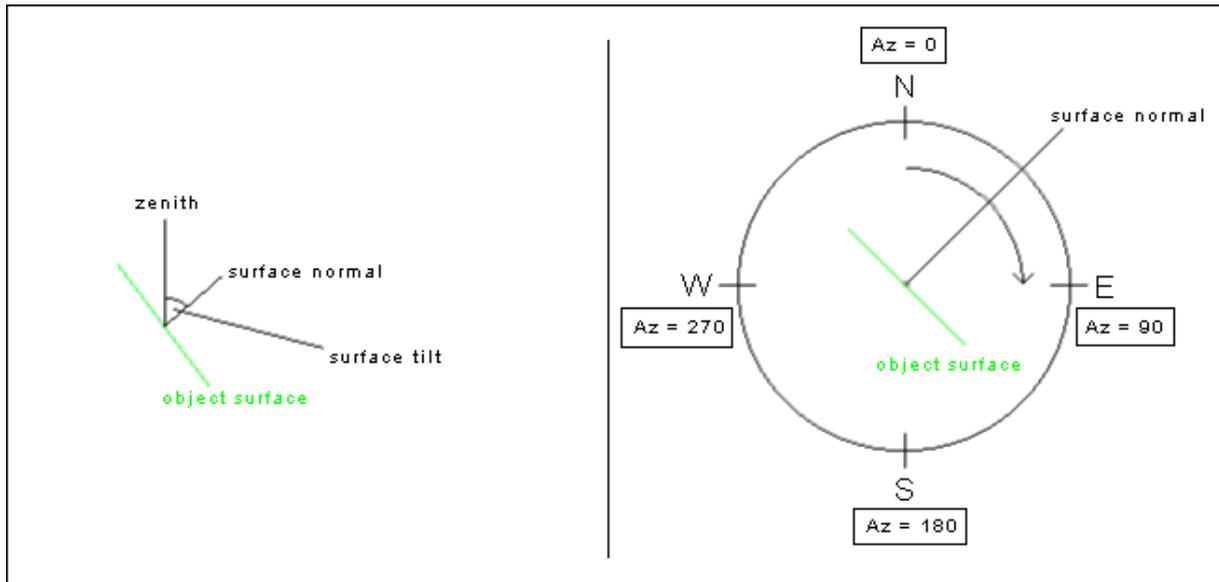
Object settings

Azimuth of surface

The same definition and convention as for the sun azimuth is used here.

Surface tilt

This is the tilt angle (or *slope*) of the surface relative to the horizontal plane. Examples: 0° for a horizontal surface, 90° for a vertical surface. Limits: 0-90°.



Height of object (SM)

This is the height (in km) of the simulated object or receiver with respect to the ground below it. The latter's elevation was specified above with the input 'Altitude above sea level'. The height is equal or close to 0 in most terrestrial applications, but can be considerably more in the case of a flying object. Therefore, the altitude of a flying object *above sea level* would be the sum of these two inputs. Note that they are defined with different units (m and km, respectively), but this is handled transparently by Cesora. Limits: 0-100 km.

Foreground type

Select a foreground type from the pull-down menu to define the proper spectral reflectance of this foreground. The reflectance (or 'albedo') library has been assembled from various sources of laboratory measurements. [Details..](#)

Meteorological data

Air temperature

This is the air temperature in °C at (or close to) the object's altitude and for the same time as specified above. Limits: -80 to +80 °C. Temperature is used for different calculations, particularly that of precipitable water (along with Humidity, see below).

Average daily temperature (SM)

Although this is self-explanatory, it must be pinpointed that a realistic value is needed here even though an instantaneous spectrum for a specific time is the calculation's goal. This input is particularly important whenever a flying object is simulated. Limits: -80 to +80 °C.

Humidity

This is the relative humidity (in %) at (or close to) the object's altitude and for the same time as specified above. Limits: 0-100%. [Details..](#)

Ozone amount

This is the reduced thickness of the vertical ozone column if ozone was at normal temperature and pressure (NTP) conditions. This is expressed in 'cm NTP' or 'atm-cm'. The normal range for this amount is 0.2 to 0.5 atm-cm. [Details..](#)

Cloud cover (SP)

This variable is given in oktas (1/8) and reflects the degree to which the sky is covered with clouds, where 0 corresponds to 'cloudless', 4 to 'half-covered', and 8 to 'completely covered'. If direct sunshine reaches the object for S percent of the time during one hour, it can be assumed that cloud cover $N = (S / 100) * 8$. When using this input, the computed spectral irradiance should be interpreted as being an hourly average.

Pollution (SM)

An atmospheric pollution index, from 1 to 4, determines the level of pollution for the site under scrutiny. These indices correspond to increasing pollution levels, from 1 = No pollution to 4 = Severe pollution. [Details..](#)

Beta

This is the Ångström turbidity coefficient, β , which describes the optical thickness (also referred to as 'turbidity') of the vertical column of atmospheric aerosols. It varies from a lower limit of ideally 0 for a perfectly aerosol-free atmosphere to more than 1 under very dense dust storms or forest fires. Only extremely remote, elevated and clean sites, such as Antarctica or the Mauna Loa Observatory, Hawaii, can experience very low turbidities ($\beta < 0.005$). Most locations experience turbidities varying between about 0.05 and 0.40. Industrial or polluted sites may experience high turbidities ($\beta > 0.3$) for significant periods of time, resulting in very hazy conditions and considerably reduced visibility [Details...](#)

Visibility

Visibility, V, is a common meteorological variable that is usually observed at airports. It decreases when the aerosol concentration increases. At visibilities lower than about 20 km, the sky looks hazy. Visibility is frequently used as a proxy for turbidity and a replacement for β , which is then estimated within the SMARTS model based on theoretical considerations [8] and ideally homogeneous atmospheric conditions. [Details..](#)

Calculation mode

Select 'Spectral irradiance' to calculate [spectral irradiances](#) or 'Effective spectral irradiance' for [calculations involving prefilters and action functions](#).

3.3.1 Meteorological parameter files

For Diurnal Variation and Time Series calculations, the meteorological parameters (see [Section 3.3](#)) are determined by parameter files. These files have the spreadsheet-compatible CSV format. Instead of determining the meteorological data once in the dialog, the user is asked to choose one of the data files in a corresponding directory. The files which are offered are those saved in the 'SMARTS\DiurnalVariation' and 'SMARTS\TimeSeries' subdirectories for SMARTS, or in the 'SPEKTRA\DiurnalVariation' and 'SPEKTRA\TimeSeries' subdirectories for SPEKTRA. New parameter files can be created inside these directories - they can be edited with any standard spreadsheet program, as shown in the following picture:

	A	B	C	D	E	F	G
1	Time	Air temperatu	Humidity	Turbidity	Ozone amour	Cloud cover	Foreground
2	0	8	65	0.2	0.3	0	Dry soil
3	1	8	65	0.2	0.3	0	
4	2	8	65	0.2	0.2	0	
5	3	9	65	0.2	0.2	0	
6	4	9	65	0.2	0.3	0	
7	5	9	65	0.2	0.3	0	
8	6	10	80	0.3	0.3	0	
9	7	10	90	0.3	0.3	0	
10	8	10	90	0.3	0.3	0	
11	9	11	90	0.3	0.3	0	Wet soil
12	10	11	80	0.3	0.3	0	
13	11	11	70	0.2	0.3	0	
14	12	13	65	0.2	0.3	0	
15	13	12	65	0.2	0.3	0	
16	14	12	65	0.2	0.3	0	
17	15	11	65	0.2	0.3	0	
18	16	11	65	0.2	0.3	0	
19	17	11	65	0.2	0.3	0	
20	18	10	65	0.2	0.3	0	Dry soil
21	19	10	65	0.2	0.3	0	
22	20	10	65	0.2	0.3	0	
23	21	10	65	0.2	0.3	0	
24	22	10	65	0.2	0.3	0	
25	23	10	65	0.2	0.3	0	

If it is preferred, the files can also be edited with a text editor that supports tabulators - in this case, separate the individual entries (including column headers) by a TAB and take care to still give the files a .csv extension, so that they are displayed in the selection box.

The first line, which contains the column headers, must generally be as in the included example files (all versions of Cesora understand column headers in any supported language). They are different for the two models, SMARTS and SPEKTRA. Each hour from 0 to 23 must have one line with all numerical parameters present - as long as the sun is not up, the meteorological parameters have no influence on the calculations, however. When using SMARTS, at least the temperature values must always be realistic, as they are used to calculate the

average temperature over the whole day before making the individual calculations. The last parameter, the Foreground, must only be specified on the first line, and then whenever it changes. If it is not given, the previous Foreground setting is kept.

The column containing information about the visibility may be labeled either 'Turbidity' or 'Visibility'. The numerical values are interpreted accordingly.

Before a parameter file is used in a calculation, it is tested whether each hour has one line, the number of parameters in the line is correct, and the parameters are in the accepted ranges. If these conditions are not fulfilled, the user is warned and the calculation is not continued.

CSV files are not identical in all localized versions of spreadsheet programs. In the US/English version, they use the comma as a separator between fields, faithful to the name ('comma-separated values'). In the German version, however, the separator is often the semicolon, for easier handling of the German decimal point, the comma. All localized versions of Cesora understand both of these file formats. Please do not use the semicolon inside data fields, however.

If your spreadsheet program opens CSV files properly from inside the program but fails to do so when a CSV file is clicked on, it may be the result of an error in the operating system configuration. In the system settings, section 'Folder options', please select the 'File types' tab. In it, locate and select the CSV file type, click on 'Advanced' and edit the 'open' operation. Uncheck the 'DDE' option if it is checked, and make sure to enclose the %1 at the end of the input field in inverted commas: "%1".

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3.3.2 Included parameter files

Several example parameter files are included for the document types *Diurnal Variation* and *Time Series*.

The parameter files for Diurnal Variations are described by their very names: *CoolHumid*, *CoolDry*, *WarmHumid*, *WarmDry*, *HotHumid*, *HotDry*. When creating them, care was taken to ensure a realistic ratio of relative humidity and air temperature. For specific calculations it should be checked if the values are appropriate for the location which is being considered, e.g. using the sources listed in the Appendix.

For Time Series' there are several data files which reflect entire annual cycles. For temperature and relative humidity, developments were assumed which are roughly characteristic for the latitudes indicated in the file names (50N, 30N, 10N and 30S, resp.). For specific calculations it should be checked if the values are appropriate for the location which is being considered, e.g. using the sources listed in the Appendix. Especially for the turbidity coefficient this is a good idea - new data files, which are

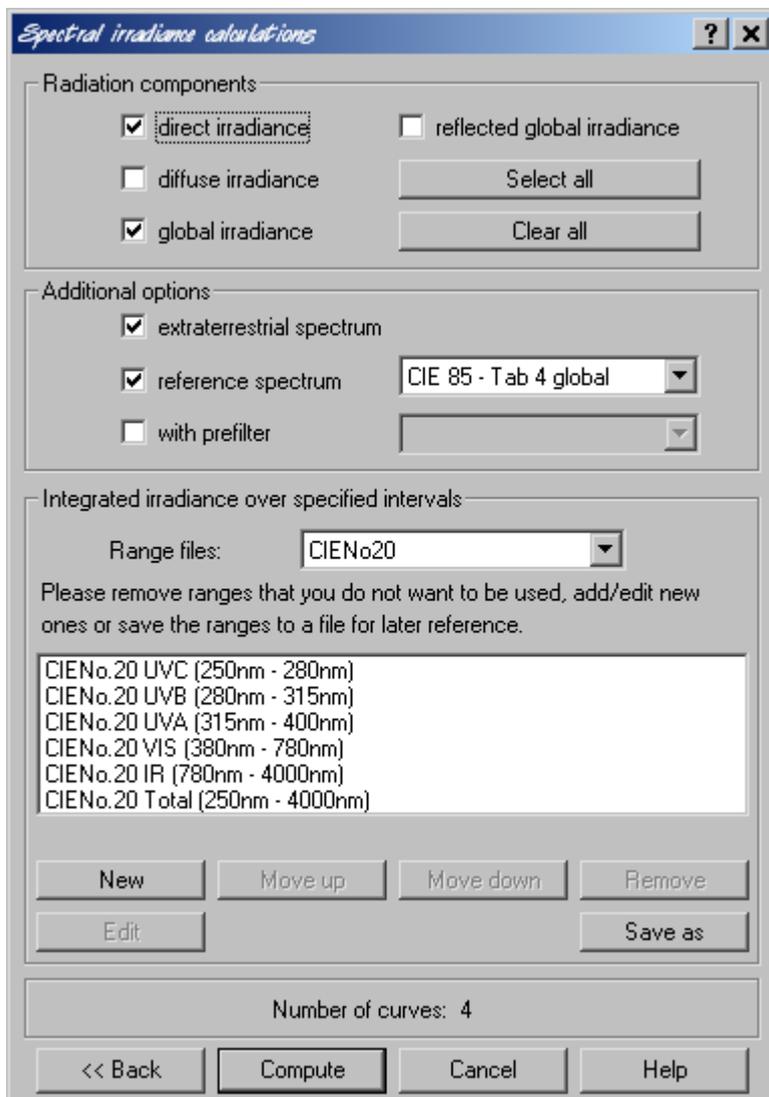
more suitable for a given individual case, may also be created by combining columns from the existing files, for example.

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3.4 Spectral irradiance calculations

The 'Spectral irradiances' dialog behaves slightly differently for Single Cases and other calculations, as outlined below.



Here, the user can select the radiation components to be computed, whether or not the extraterrestrial spectrum or a reference spectrum will be displayed along with the Radiation components' curves, and whether or not the terrestrial radiation is to pass through a prefilter before it reaches the object surface. **The total number of curves**

cannot be greater than 5. If otherwise there would be only one curve to be calculated (in addition to a reference or extraterrestrial spectrum), then for the remaining ones an input parameter may be varied ([Section 3.6](#)).

Broadband irradiances will be calculated according to the intervals specified in this dialog. In the Single Case, the broadband irradiances will be shown in the legend below the graph, while in the Diurnal Variation and Time Series cases, each curve in the graph will represent the broadband irradiance in one of the given intervals over one or several days.

The intervals in this list may be edited, moved up or down in the list, or removed. New ones may be added. Complete lists of intervals may be loaded and saved. **If you wish to have fewer broadband irradiance intervals displayed in the legend, remove some of them in this dialog.** Unless you save the list of intervals under the same name as before and thus overwrite the old file, your changes will only affect the current document.

As there can only be up to 5 curves per graph, for Diurnal variations and Time series' we have the natural limitation ' $C \cdot T \leq 5$ ', i.e. the number of selected radiation components, C, times the number of intervals in the list, T, may not be greater than 5. Furthermore, in the Diurnal variations and Time series cases, (constant) reference spectra and the (approximately constant) extraterrestrial spectrum cannot be included in the graphs.

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3.5 Effective irradiance calculations

If in the 'Object settings and meteorological data' dialog 'Effective spectral irradiance' was selected, the following dialog will appear:

A screenshot of a software dialog box titled "Effective irradiance calculations". The dialog has a blue header bar with the title in white italicized text. Below the header, there are several sections. On the left, under "Choose..", there are five radio button options: "photochemically effective spectral irradiance" (selected), "absorbed spectral irradiance", "photovoltaics, effective spectral irradiance", "transmitted spectral irradiance", and "other effective irradiances". Below these is a checked checkbox labeled "also show global irradiance". On the right, under "Computation modes", there are two checkboxes: "with prefilter" (checked) and "without prefilter" (unchecked). Below that, under "Parametrization type", there are two checkboxes: "variation of parameters" (unchecked) and "variation of materials/prefilters" (checked). At the bottom right, there is a text field containing "Number of curves: 2 - 5". At the bottom of the dialog, there are four buttons: "<< Back", "Continue >>", "Cancel", and "Help".

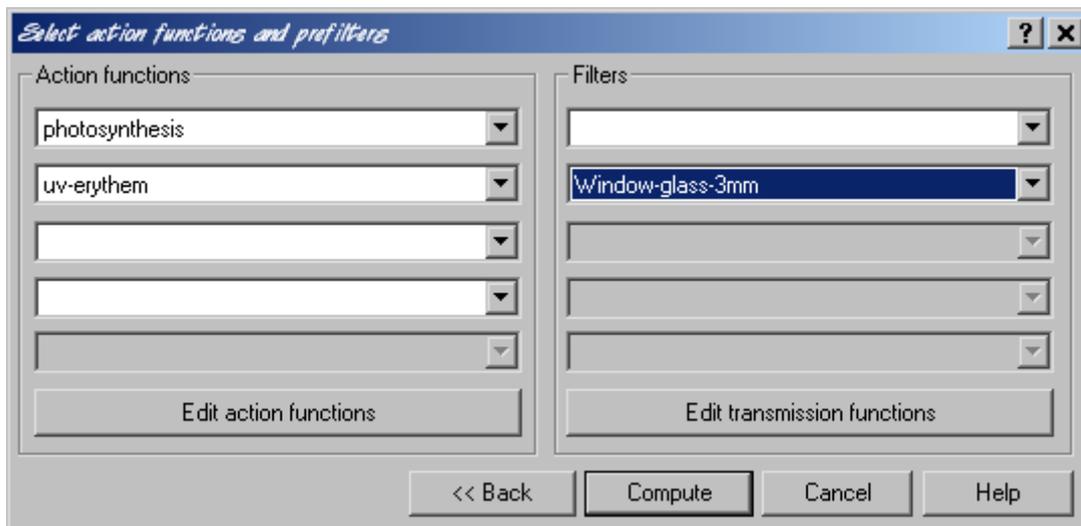
Select this mode of calculation if you are not so much interested in the different spectral ranges in which radiation of different kinds arrives at the object, but in how *global irradiance* is received by different kinds of objects/materials. The reception of

irradiation is determined by an object's/material's *action function*.

Action functions

A number of action functions reside in the 'Actions' subdirectory. They are divided into five groups - in the above dialog on the left, please select the group from which you will later on choose one or more action functions for the calculations. If the 'transmitted spectral irradiance' group of action functions is selected and an additional prefilter is activated, then the result will be the effective irradiance after passing through two filters.

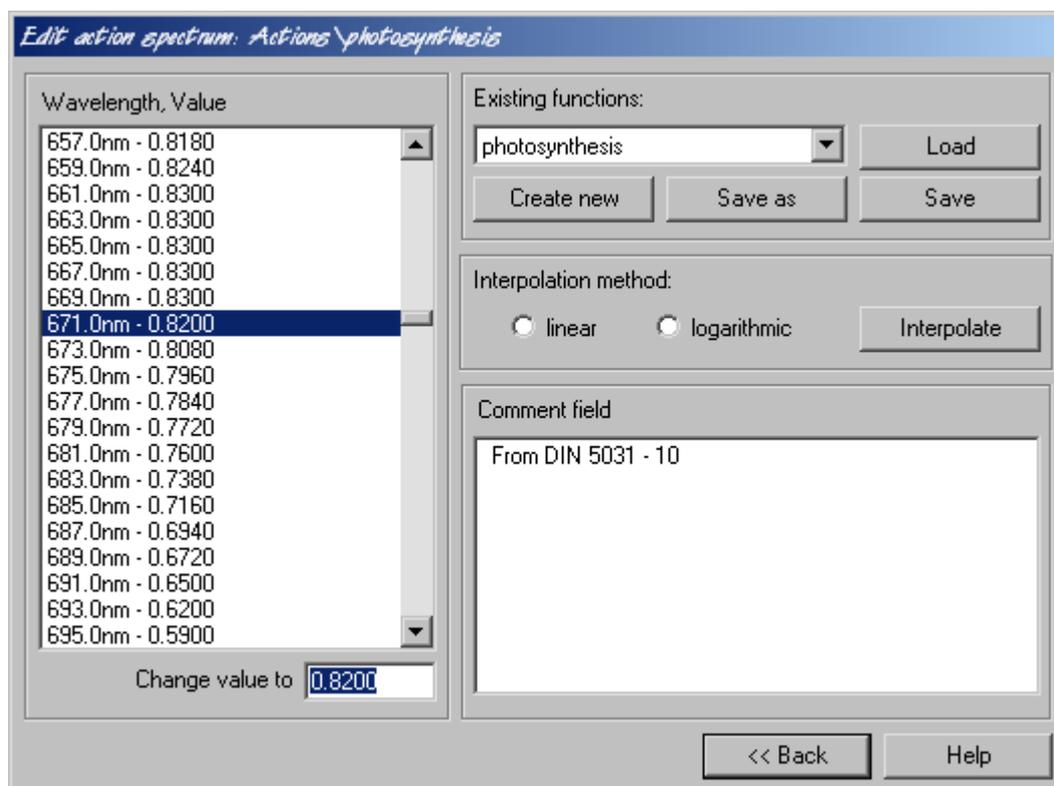
In this calculation mode it is possible to vary either (i) input parameters or (ii) materials and/or prefilters. Option (i) is described in [Section 3.6](#). For (ii) the corresponding dialog is shown in the next image:



On the left, the user may select up to five action functions of the type selected in the previous dialog, while on the right, prefilters may be added to the irradiation process.

3.5.1 Editing action functions

Action functions may be edited and newly created. When editing an action function, other functions *of the same type* can be loaded into the editor by selecting them in the drop-down box and pressing 'Load'.

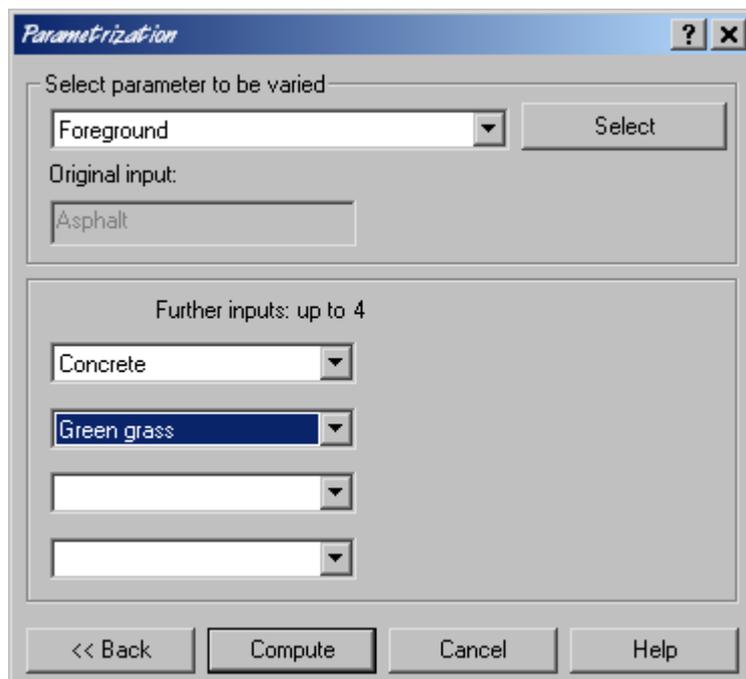


Note that an edited function will *not* be usable in irradiance calculations unless you press the 'Save' button. This applies also to the current calculation - changes in action functions need to be written to disk. If you exit the dialog with a changed but unsaved function, you are reminded about this.

Pressing the 'Create new' button causes an empty action function to be loaded. After defining individual data points in the list on the left hand side, the remaining values may be determined by linear or logarithmic interpolation. Linear interpolation is well suited for slowly varying functions (e.g. photosynthesis), whereas logarithmic interpolation is to be used with exponentially varying functions (e.g. erythema and other UV action spectra). They may then be written to disk using the 'Save as' function. It is perfectly legal to rename action function files in the Actions subdirectory, *however their extensions should be left as they are.*

3.6 Parametric runs

In this dialog you may choose which parameters you want to vary. There will be a different curve for each given parameter value, limited of course by the fact that there may only be up to five curves displayed in a document at a time.



WARNING

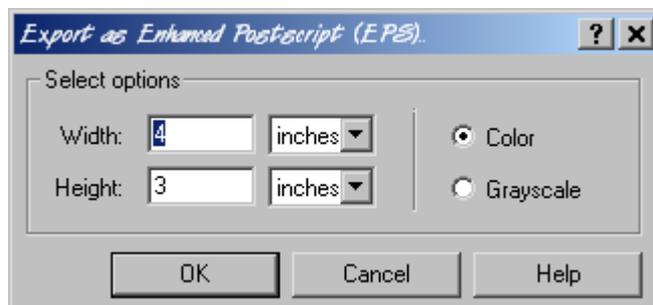
Be aware of the implications of your parameter variations and check if they are realistic. With unnatural values (of e.g. temperature for a given time and location), the results may have a *purely theoretical* character rather than resemble any realistically obtainable measurements.

4.1 Copy graph display to the clipboard

Using this function, the graph as it is currently displayed (with or without the legend) will be copied to the clipboard as a resizable vector image. This image may then be pasted into a word processor document, for example. The 'Font size for export/printing' option from the 'Program settings' dialog affects the relative size of the text in the image, compared with the area which is taken up by the curves. As such, the graph image naturally fits best onto a 'Landscape' page, however if you wish to print the entire image, consider using the 'Print' option instead ([Section 6.2](#)).

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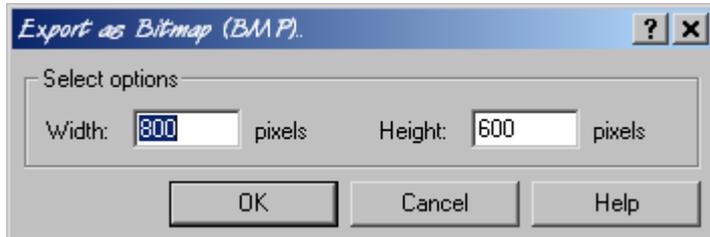
4.2 Export graph display as EPS



With this option you can export the graph display to an Enhanced Postscript file (with or without the legend, depending on whether it is currently shown). Use the input fields and the unit selectors to determine the default dimensions of the image when it is imported into another program. The 'Font size for export/printing' option from the 'Program settings' dialog affects the relative size of the text in the image, compared with the area which is taken up by the curves.

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4.3 Export graph display as BMP



If you want to export the graph display directly to a standard bitmap graphics format, displayable in anything from a web browser to a picture viewer or paint program, while avoiding the intermediate vector graphics, use this option. Specify the picture dimensions and save the file. Naturally, this option works best with a high resolution. Note that the resulting image will not scale very well.

4.4 Export document/curve data as CSV

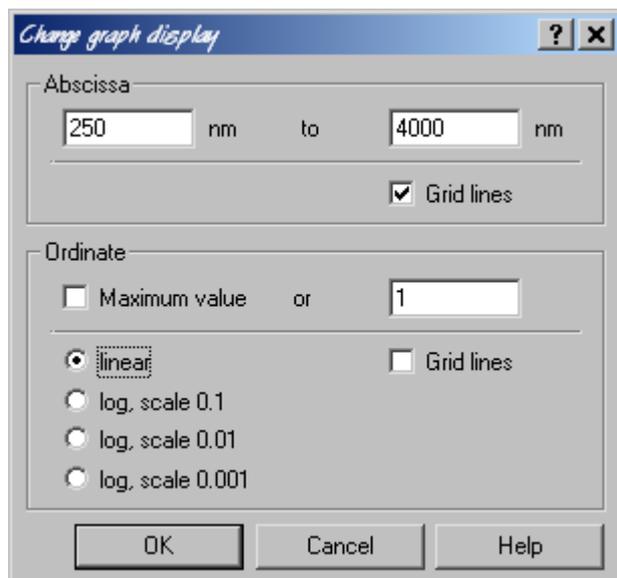


Using this option, all data making up the current document will be saved to a spreadsheet-compatible file for further processing. Select either a comma as the separator between data fields or a tabulator character (in which case the extension '.txt' will be suggested). All geographical and meteorological data and calculation options will be saved.

If your spreadsheet program opens CSV files properly from inside the program but fails to do so when a CSV file is clicked on, it may be the result of an error in the operating system configuration. In the system settings, section 'Folder options', please select the 'File types' tab. In it, locate and select the CSV file type, click on 'Advanced' and edit the 'open' operation. Uncheck the 'DDE' option if it is checked, and make sure to enclose the %1 at the end of the input field in inverted commas: "%1".

5.1 Change graph display parameters

Using this dialog you can change some properties of the graph display. In the 'Abscissa' section, the range of values on the x-axis can be modified, while the 'Ordinate' settings apply to the y-axis. In the Single Case the dialog looks like this:



For the Diurnal Variation and Time Series cases it is similar. You may also set the maximum value for the y-axis manually, which is useful for comparing two graphs. The possibility to have a logarithmic scale on the y-axis is useful to examine the curves in more detail where the values are smaller.

5.2 Change curve colors

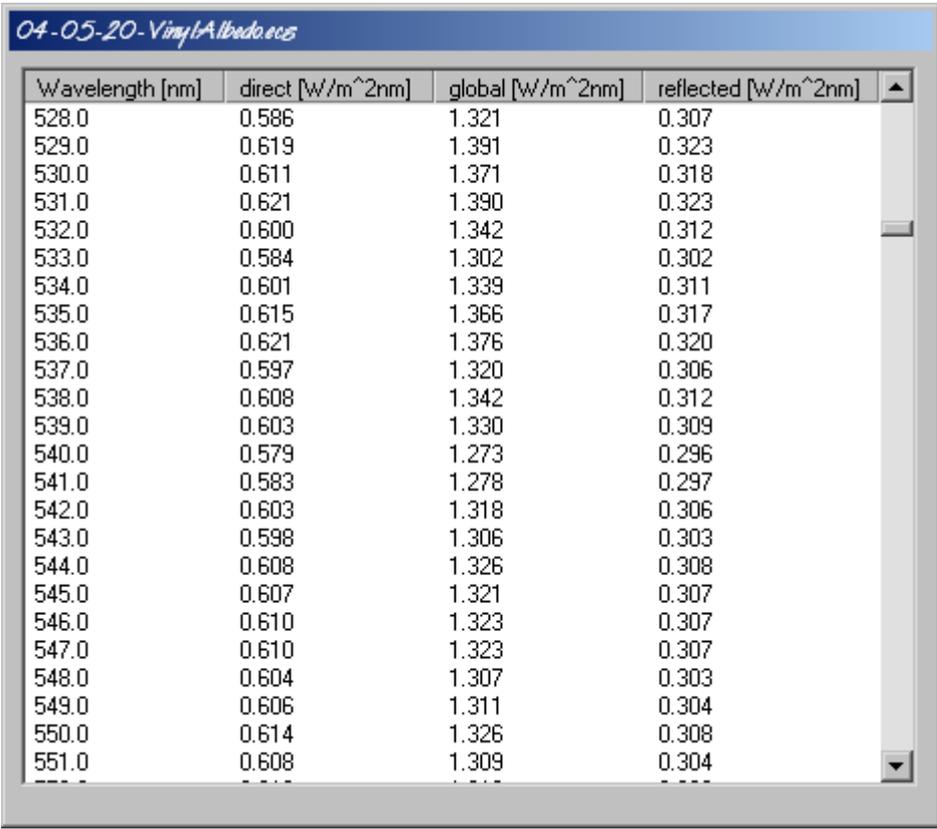
If you want to change the curve colors in your document, use this dialog.



The current curve colors are displayed in the first five boxes in the 'user-defined colors' section at the bottom. If you want to change one of these colors, first select it by clicking on its box, then adjust it using the controls on the right hand side of the dialog, then at the end press the 'Add' button. You will see that the color is replaced by the selected one.

5.3 Display data table on/off

In addition to the graph, the curve data may be shown in the form of a data table, as in the following example:



Wavelength [nm]	direct [W/m ² nm]	global [W/m ² nm]	reflected [W/m ² nm]
528.0	0.586	1.321	0.307
529.0	0.619	1.391	0.323
530.0	0.611	1.371	0.318
531.0	0.621	1.390	0.323
532.0	0.600	1.342	0.312
533.0	0.584	1.302	0.302
534.0	0.601	1.339	0.311
535.0	0.615	1.366	0.317
536.0	0.621	1.376	0.320
537.0	0.597	1.320	0.306
538.0	0.608	1.342	0.312
539.0	0.603	1.330	0.309
540.0	0.579	1.273	0.296
541.0	0.583	1.278	0.297
542.0	0.603	1.318	0.306
543.0	0.598	1.306	0.303
544.0	0.608	1.326	0.308
545.0	0.607	1.321	0.307
546.0	0.610	1.323	0.307
547.0	0.610	1.323	0.307
548.0	0.604	1.307	0.303
549.0	0.606	1.311	0.304
550.0	0.614	1.326	0.308
551.0	0.608	1.309	0.304

If you resize the data table window, all columns except the first one (which contains the x-values) are scaled proportionally. Also, if you manually change the width of a column by clicking on a header separator and dragging it, the columns to the right adjust in size proportionally.

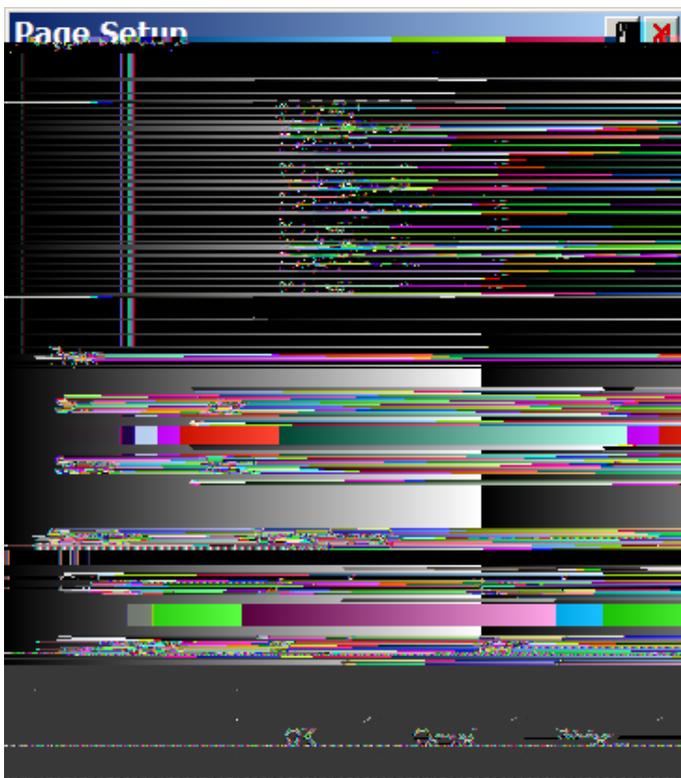
5.4 Display graph legend on/off

The legend, which is displayed at the bottom of the graph, may be switched on or off via the menu or the key combination Ctrl+L. This will also have an effect on exported/printed graphics

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6.1 Page setup

Select this option from the 'File' menu to determine the layout of printed documents, including the margins and whether they will be printed with 'portrait' or 'landscape' orientation. These settings are saved on exiting Cesora. They are program-wide, i.e. changes made to these settings will affect all open documents. The default orientation is 'landscape'.



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6.2 Print preview and printing

Use the 'Print preview' button or menu option to see how the printed document will look, using the margin and orientation settings determined in the 'Page setup' dialog. The 'Print' option sends the graph display in the currently active window to the printer. The 'Font size for export/printing' option from the 'Program settings' dialog affects the relative size of the text in the image, compared with the area which is taken up by the curves.

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7.1 Details: Foreground

Select a foreground type from the pull-down menu to define the proper spectral reflectance of this foreground. The reflectance (or 'albedo') library has been assembled from various sources of laboratory measurements.

To simplify calculations, the foreground must be understood as a very large area around the simulated object if it is horizontal, e.g., within a radius of about 10 km. In most cases, the foreground is in fact a mosaic of many different individual surfaces, whose reflectances are all also different. The more tilted the object is, the more influence the true foreground has, i.e., the 10-100 m of surface just in front of it, and therefore the more weight must be given to it when evaluating a spatial average for the mosaic. This can become a very tedious task, and is therefore rarely performed in practice.

Because of the complexity and subjectivity inherently attached to this input, it is recommended to 'play' with it. For instance, it can be good to select the most typical or prevalent foregrounds one after the other and run Cesora for otherwise fixed and typical conditions. If the results are sufficiently close, their sensitivity to the foreground type is limited and no other refinements are necessary.

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7.2 Details: Humidity

This is the relative humidity (in %) at (or close to) the object's altitude. Limits: 0-100%.

This input is used to estimate precipitable water and aerosol optical depth, two key atmospheric variables. The effect on the latter is non linear (important only for humidities above 80%), whereas precipitable water is directly proportional to humidity, per the table below. This table can be used to reverse the process, i.e., evaluate the temperature and humidity that would match specified precipitable water values, assuming ideally stable atmospheric conditions.

For instance, if a spectrum needs to be obtained for 1.416 cm precipitable water, the proper inputs could be chosen as (5 °C, 92%), (15 °C, 51%) or (25 °C, 28%), depending on context. Note that observed precipitable water values are usually in the range 0.05-6 cm, and that SMARTS cannot accept values in excess of 12 cm.

Table 7.2.1, Precipitable water (cm) as a function of Temperature (°C, horizontal entry) and Relative humidity (% , vertical entry), under ideal conditions.

RH \ T	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40
5	0.0 11	0.0 14	0.0 16	0.0 19	0.0 22	0.0 27	0.0 33	0.0 43	0.0 56	0.0 75	0.1 02	0.1 38	0.1 87	0.2 51	0.3 33	0.4 40	0.57 5
10	0.0 23	0.0 27	0.0 32	0.0 38	0.0 45	0.0 54	0.0 67	0.0 85	0.1 12	0.1 51	0.2 04	0.2 76	0.3 73	0.5 01	0.6 67	0.8 80	1.14 9
15	0.0 34	0.0 41	0.0 48	0.0 57	0.0 67	0.0 81	0.1 00	0.1 28	0.1 68	0.2 26	0.3 06	0.4 14	0.5 60	0.7 52	1.0 00	1.3 19	1.72 4
20	0.0 45	0.0 55	0.0 65	0.0 76	0.0 89	0.1 08	0.1 33	0.1 71	0.2 25	0.3 01	0.4 07	0.5 53	0.7 47	1.0 02	1.3 34	1.7 59	2.29 8
25	0.0 57	0.0 68	0.0 81	0.0 95	0.1 12	0.1 34	0.1 67	0.2 13	0.2 81	0.3 76	0.5 09	0.6 91	0.9 33	1.2 53	1.6 67	2.1 99	2.87 3
30	0.0 68	0.0 82	0.0 97	0.1 14	0.1 34	0.1 61	0.2 00	0.2 56	0.3 37	0.4 52	0.6 11	0.8 29	1.1 20	1.5 03	2.0 01	2.6 39	3.44 7
35	0.0 79	0.0 96	0.1 13	0.1 33	0.1 56	0.1 88	0.2 33	0.2 99	0.3 93	0.5 27	0.7 13	0.9 67	1.3 07	1.7 54	2.3 34	3.0 78	4.02 2
40	0.0 91	0.1 09	0.1 29	0.1 52	0.1 79	0.2 15	0.2 67	0.3 41	0.4 49	0.6 02	0.8 15	1.1 05	1.4 93	2.0 04	2.6 68	3.5 18	4.59 6
45	0.1 02	0.1 23	0.1 45	0.1 70	0.2 01	0.2 42	0.3 00	0.3 84	0.5 05	0.6 77	0.9 17	1.2 43	1.6 80	2.2 55	3.0 01	3.9 58	5.17 1

50	0.1 13	0.1 37	0.1 62	0.1 89	0.2 23	0.2 69	0.3 33	0.4 27	0.5 61	0.7 53	1.0 19	1.3 81	1.8 67	2.5 05	3.3 35	4.3 98	5.74 5
55	0.1 25	0.1 50	0.1 78	0.2 08	0.2 46	0.2 96	0.3 67	0.4 69	0.6 18	0.8 28	1.1 21	1.5 19	2.0 53	2.7 56	3.6 68	4.8 37	6.32 0
60	0.1 36	0.1 64	0.1 94	0.2 27	0.2 68	0.3 23	0.4 00	0.5 12	0.6 74	0.9 03	1.2 22	1.6 58	2.2 40	3.0 06	4.0 01	5.2 77	6.89 4
65	0.1 47	0.1 78	0.2 10	0.2 46	0.2 90	0.3 50	0.4 33	0.5 55	0.7 30	0.9 79	1.3 24	1.7 96	2.4 27	3.2 57	4.3 35	5.7 17	7.46 9
70	0.1 59	0.1 91	0.2 26	0.2 65	0.3 13	0.3 76	0.4 67	0.5 97	0.7 86	1.0 54	1.4 26	1.9 34	2.6 13	3.5 08	4.6 68	6.1 57	8.04 3
75	0.1 70	0.2 05	0.2 42	0.2 84	0.3 35	0.4 03	0.5 00	0.6 40	0.8 42	1.1 29	1.5 28	2.0 72	2.8 00	3.7 58	5.0 02	6.5 96	8.61 8
80	0.1 81	0.2 19	0.2 59	0.3 03	0.3 57	0.4 30	0.5 33	0.6 83	0.8 98	1.2 04	1.6 30	2.2 10	2.9 86	4.0 09	5.3 35	7.0 36	9.19 2
85	0.1 93	0.2 32	0.2 75	0.3 22	0.3 80	0.4 57	0.5 67	0.7 25	0.9 54	1.2 80	1.7 32	2.3 48	3.1 73	4.2 59	5.6 69	7.4 76	9.76 7
90	0.2 04	0.2 46	0.2 91	0.3 41	0.4 02	0.4 84	0.6 00	0.7 68	1.0 11	1.3 55	1.8 34	2.4 86	3.3 60	4.5 10	6.0 02	7.9 16	10.3 41
95	0.2 15	0.2 60	0.3 07	0.3 60	0.4 25	0.5 11	0.6 33	0.8 11	1.0 67	1.4 30	1.9 36	2.6 25	3.5 46	4.7 60	6.3 36	8.3 55	10.9 16
100	0.2 27	0.2 73	0.3 23	0.3 79	0.4 47	0.5 38	0.6 67	0.8 53	1.1 23	1.5 05	2.0 37	2.7 63	3.7 33	5.0 11	6.6 69	8.7 95	11.4 91

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7.3 Details: Ozone amount

The Ozone amount is the reduced thickness of the vertical ozone column if ozone was at normal temperature and pressure (NTP) conditions. This is expressed in 'cm NTP' or 'atm-cm'.

The normal range for this amount is 0.2 to 0.5 atm-cm. The present record lows over Antarctica are just below 0.1 atm-cm, which is the limit used to define an 'ozone hole'. Van Heuklon [18] 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.woudc.org/data_e.html). Although ozone can vary substantially from one day to the next, a mean daily value is usually sufficient for most applications.

Measured total-column data in the present era are generally expressed in Dobson units or DU. To convert DU into atm-cm, divide by 1000.

Example:

What was the ozone column amount on 14 June 2004 above the location coded as 'US/Central Arizona, AWSG' (near Phoenix) in the location pull-down menu?

Using the TOMS website and the coordinates of this site (longitude -112.13°, latitude 33.9°), a value of 296 DU (or 0.296 atm-cm) is found for that day. No GOME data were available for that day as of this writing.

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7.4 Details: Pollution

An atmospheric pollution index, from 1 to 4, determines the level of pollution for the site under scrutiny. These indices correspond to increasing pollution levels:

- 1 - No pollution
- 2 - Light pollution
- 3 - Moderate pollution
- 4 - Severe pollution.

For each index between 2 and 4, increasing gaseous pollutant concentrations are added to the base case (1 - No pollution). Ten radiatively-active pollutants are

considered and their spectral absorption calculated.

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. The pollution index must therefore be considered as an approximation for practical purposes.

The following table indicates the defaulted *additional* tropospheric concentrations (in ppmv) for each pollutant, assuming a 1-km high mixing layer. Note that, as far as the resulting spectra are concerned, the main effects can be expected from nitrogen dioxide (NO₂) between 300 and 550 nm, and from ozone (O₃), below 350 nm and around 600 nm.

Table 7.4.1: Default additional tropospheric concentration (in ppmv) above base case for each gas and each pollution level.

Gas	Light pollution (2)	Moderate pollution (3)	Severe pollution (4)
CH ₂ O	0.001	0.007	0.01
CH ₄	0.2	0.3	0.4
CO	0	0.35	9.9
HNO ₂	0.0005	0.002	0.01
HNO ₃	0.001	0.005	0.012
NO	0.075	0.2	0.5
NO ₂	0.005	0.02	0.2
NO ₃	1E-5	5E-5	2E-4
O ₃	0.023	0.053	0.175
SO ₂	0.01	0.05	0.2

7.5 Details: Beta (turbidity)

'Beta' is the Ångström turbidity coefficient, β , which describes the optical thickness (also referred to as 'turbidity') of the vertical column of atmospheric aerosols. It varies from a lower limit of ideally 0 for a perfectly aerosol-free atmosphere to more than 1 under very dense dust storms or forest fires. Only extremely remote, elevated and clean sites, such as Antarctica or the Mauna Loa Observatory, Hawaii, can experience very low turbidities ($\beta < 0.005$). Most locations experience turbidities varying between about 0.05 and 0.40. Industrial or polluted sites may experience high turbidities ($\beta > 0.3$) for significant periods of time, resulting in very hazy conditions and considerably reduced visibility.

Under cloudless skies, and at visible wavelengths more particularly, aerosols have the most profound attenuation effect on the solar spectrum. Therefore, β is possibly the most important atmospheric input among the whole list. Hence, to obtain realistic and accurate irradiance predictions with Cesora, it is imperative to provide an accurate value of β . Because of the very variable nature of aerosol production and transport (subject to a variety of meteorological and other effects), the difficulty here is to obtain such accurate input data for a specific date and location.

As of this writing, there is unfortunately no comprehensive, worldwide and easily searchable turbidity database that would be comparable to what is available for ozone, for instance. A detailed discussion about how to obtain β from ground-based sunphotometric measurements can be found elsewhere [8]. The easiest case to handle is when the site under scrutiny is close to an AERONET sunphotometry site, and that climatological data (rather than instantaneous data) can be used. Such data are available from

http://aeronet.gsfc.nasa.gov/Operational/climo_new/climo_index.html.

For instance, assume that aerosol data from Venice, Italy are needed. Click on the link for Venice (45N, 12E), then read the agreement and click on the Accept button. A page with tables appears; the first table is for the overall climatology for all the years listed (1999-2003 in this case). The other tables are for specific years. In each table, average values of a few variables are presented for each month. The most important variables are labeled τ_{a500} , $\alpha_{440-870}$ and PW. For example, the tabulated values for October 1999 read (from the second table): $\tau_{a500} = 0.51$, $\alpha_{440-870} = 1.51$ and $PW = 2.30$. More decimals are available from data files, which can be downloaded by clicking on either Overall Download (for the overall climatology) or from Years Combined Download (to obtain all available years separately).

The turbidity coefficient is obtained from $\beta = 0.5^\alpha \tau_{500}$, where α is $\alpha_{440-870}$ and τ_{500} is τ_{a500} . Thus, for this example, the result is $\beta = 0.179$.

Note that PW stands for precipitable water. This can be used (along with Table 1) to check if the input combination of temperature and humidity produces a value of precipitable water that is close to PW, the observed value.

Satellite data become progressively available on a large scale and fine grids, but their accuracy - over continents in particular - is still an issue [19-23]. With this caveat, and therefore essentially as an interim source of data, spectral optical depths from the

MISR instrument can be recommended. They are available from http://eosweb.larc.nasa.gov/PRODOCS/misr/level3/level3_CGAS_large.html. To convert the aerosol optical depth at 550 nm, τ_{550} , from this (or similar) dataset into β , use the defining relationship: $\beta = 0.55^\alpha \tau_{550}$. If the Ångström wavelength exponent, α , is not known for the same time and location, use $\alpha = 1$ as an approximation.

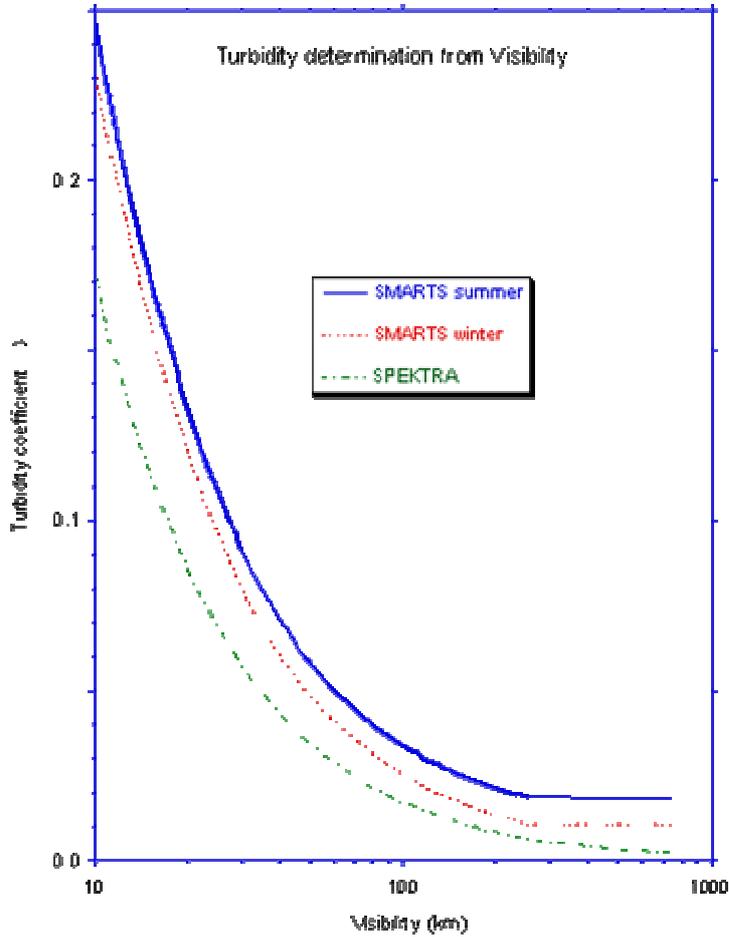
Note that, to keep Cesora easy to use, α is not directly modifiable by the user despite its important role in characterizing the aerosol optical characteristics. Nevertheless, it is transparently determined by the aerosol type, and hence by the Climate variable discussed above. This is why, for a fixed β and otherwise identical conditions, changing the Climate input has a noticeable effect (through α) on the shape of all predicted spectra. This is further discussed in [Section 7.8](#).

In Cesora, the acceptable limits for β are 0 and 2.

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7.6 Details: Visibility

Visibility, V , is a common meteorological variable that is usually observed at airports. It decreases when the aerosol concentration increases. At visibilities lower than about 20 km, the sky looks hazy. Visibility is frequently used as a proxy for turbidity and a replacement for β , which is then estimated within the SMARTS model based on theoretical considerations [8] and ideally homogeneous atmospheric conditions. Under such ideal conditions, the relationship between V and β is illustrated in Figure 7.6.1. The relationship depends slightly on season (summer vs winter). The different relationship used in the SPEKTRA model is also plotted for comparative purposes.



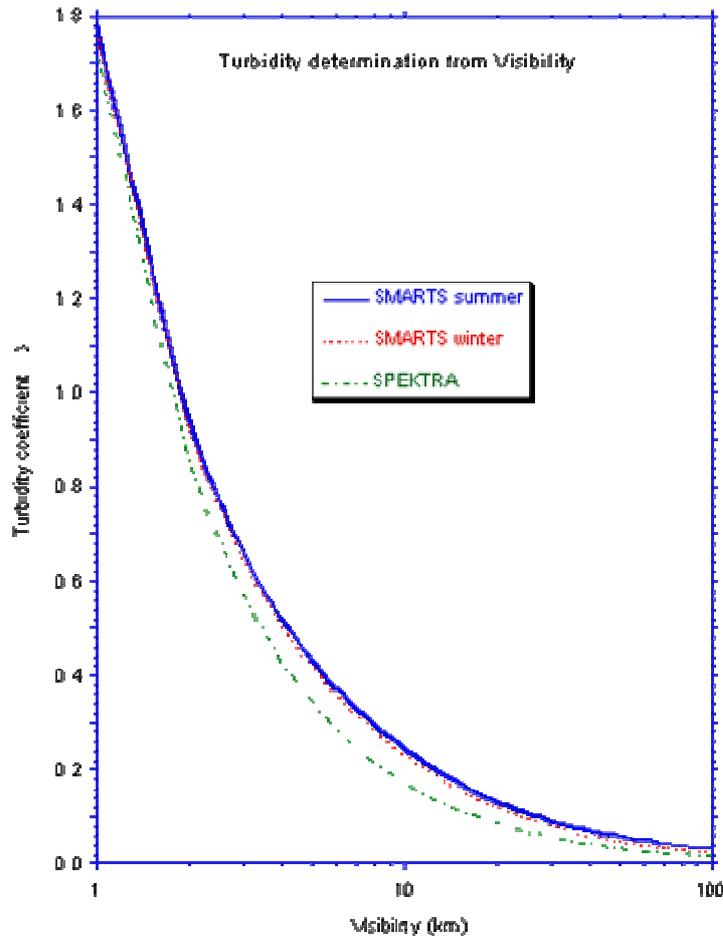


Fig. 7.6.1, Turbidity coefficient as a function of visibility under ideal conditions. (a) $V < 100$ km; (b) $10 < V < 760$ km.

This procedure to obtain β from V is not recommended because of the inherently very subjective and imprecise nature of most visibility observations, and the usual large noise in the correspondence between horizontal visibility and the needed vertical aerosol column optical depth. As a result, inconsistent and biased turbidity estimates are extremely frequent, which in turn can cause inconsistent irradiance predictions. These issues are further discussed in [Section 7.8](#). The acceptable range of visibility values is 0.8-760 km.

7.7 Comparison with measured spectra

Cesora's predictions of *broadband* irradiance can be directly compared to measurements by radiometers such as pyrhemometers and pyranometers that measure the full shortwave solar spectrum. Caution and extra steps, however, must normally be used when comparing predicted *spectral* irradiance to measurements from spectroradiometers or spectrometers. This is because of the normal mismatch in model-instrument resolution. The resolution of the SMARTS results is identical to their nominal step size:

- 0.5 nm in the range 280 - 400 nm
- 1.0 nm in the range 400 - 1700 nm
- 5.0 nm in the range 1700 - 4000 nm.

If the instrument's bandwidth is smaller than these values, the measured spectra will normally display more structure than the predicted spectra, particularly in the UV. Because the resolution of the Cesora-SMARTS model cannot be modified, the only way to improve the predicted/measured correspondence is to degrade the measured spectra by applying a Gaussian smoothing filter to the raw data, with a characteristic full width at half maximum (FWHM) identical to the values given above.

In general, however, spectroradiometers have a coarser resolution than Cesora-SMARTS. The predicted spectra therefore normally show more structure than the measured spectra. For easier comparison, it is then necessary to apply the same smoothing technique as described above, but this time rather applied to Cesora's spectral output. This is done by postprocessing the results: Cesora's raw spectral results need to be convolved with a virtual Gaussian filter whose FWHM matches that of the reference instrument over all its spectral range. Figure 7.7.1 provides an illustration of this effect when comparing raw and smoothed Cesora-SMARTS direct irradiance predictions to an actual UV-visible spectrum measured under clear conditions with a 5-nm FWHM Optronic OL-750 spectroradiometer in Golden, Colorado. The instrument was equipped with a baffled collimator and was oriented toward the sun to measure direct irradiance at normal incidence. The smoothed results were obtained by matching the smoothing filter's step size to that of the instrument, which was also 5 nm in this particular case.

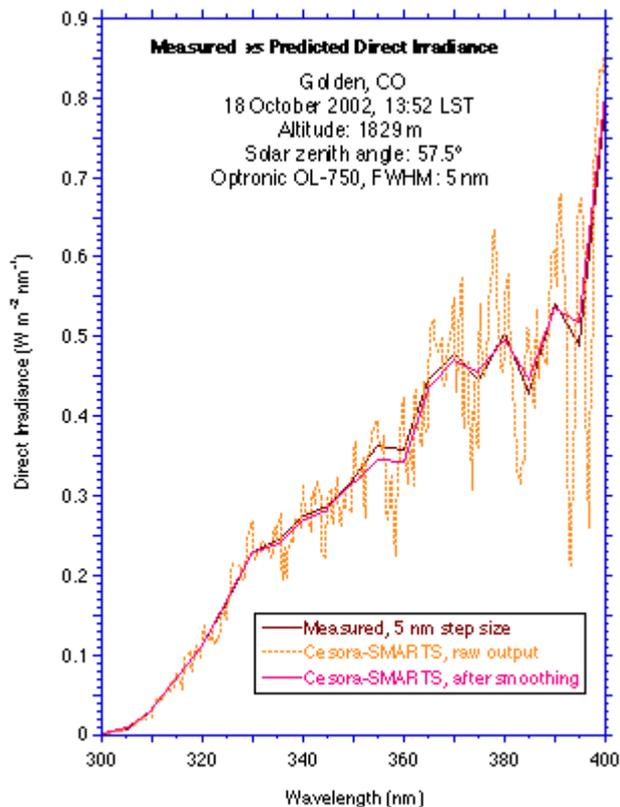


Fig. 7.7.1 Comparison between Cesora-SMARTS predictions and actual spectroradiometric measurements at Golden, Colorado, showing the effect of postprocessing the data to match the instrument's bandwidth and step size (5 nm for both).

Figures 7.7.2 and 7.7.3 show similar comparisons between measured and predicted (after smoothing) direct irradiance at normal incidence, for the same location and instrumentation as in Fig. 7.7.1. Many such comparisons have been undertaken, showing excellent agreement, which bring confidence in the capability of Cesora-SMARTS to accurately model direct irradiance, i.e., within the uncertainty of high-quality measurements.

Only very limited measured spectra are available for diffuse or global irradiance, especially for tilted surfaces, with all the numerous and diverse combinations of geometries and reflecting foregrounds. The few possible comparisons undertaken so far have shown good agreement, but there is still more validation work to do before any general statement about the accuracy of such spectra can be formulated.

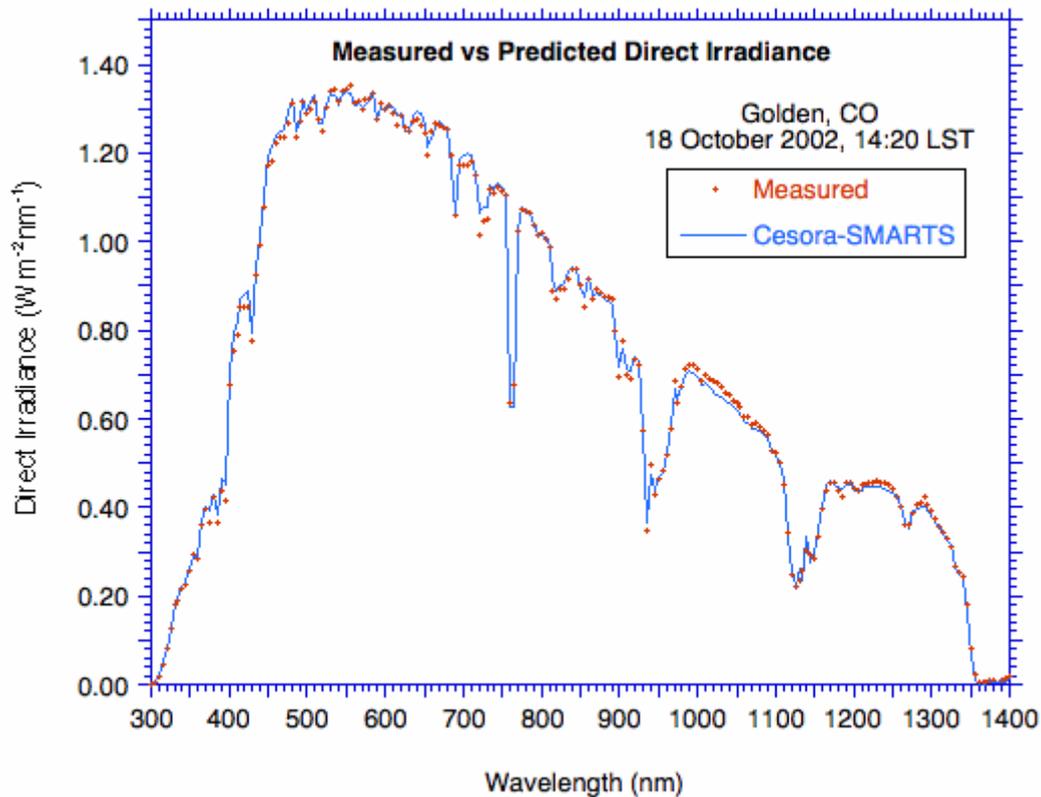


Fig. 7.7.2 Comparison between smoothed Cesora-SMARTS predictions and actual spectroradiometric measurements at Golden, Colorado, between 300 and 1400 nm.

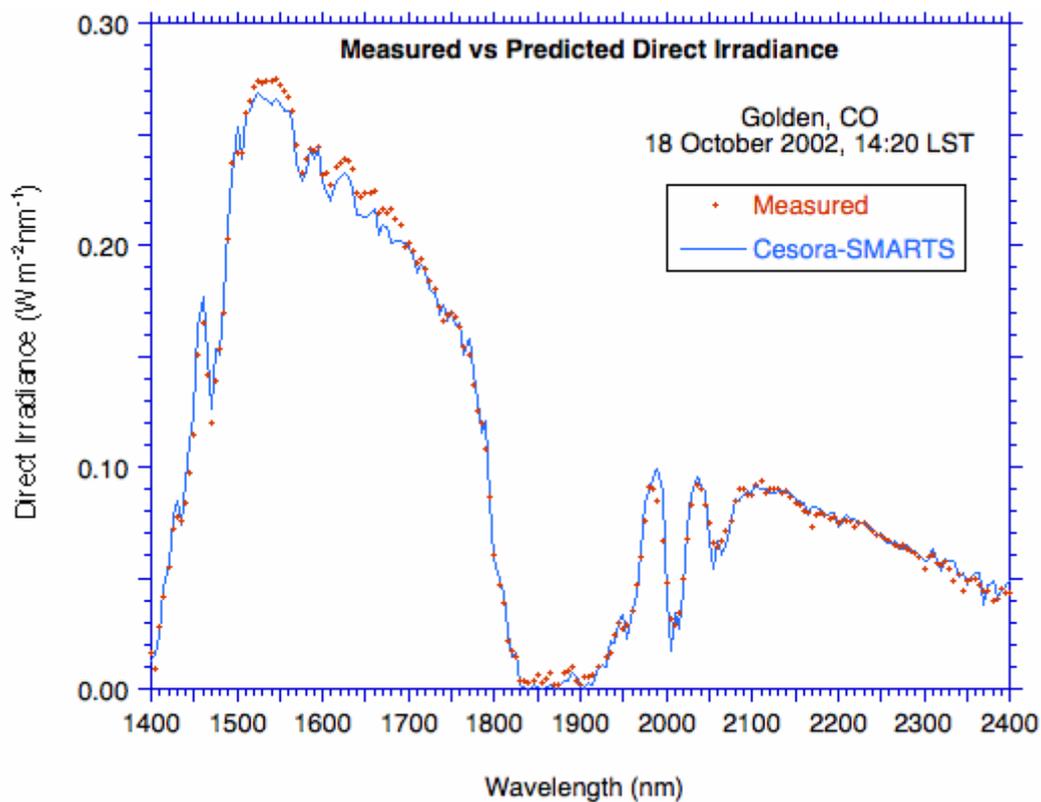


Fig. 7.7.3 Comparison between smoothed Cesora-SMARTS predictions and actual spectroradiometric measurements at Golden, Colorado, between 1400 and 2400 nm.

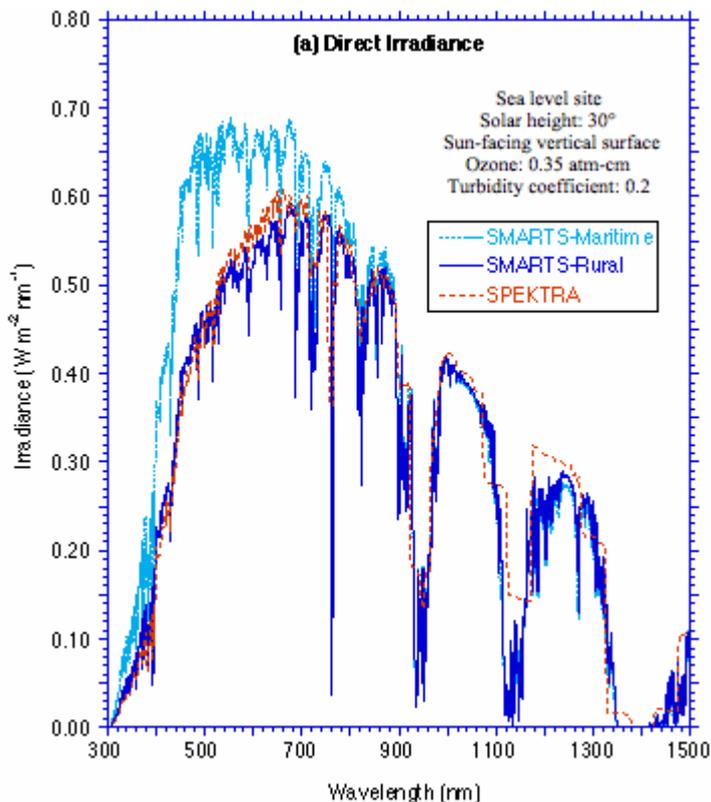
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7.8 Comparison SMARTS/SPEKTRA

The other modeling option in Cesora is the SPEKTRA model [24]. Although SMARTS and SPEKTRA both use the same modeling technique of 'transmittance parameterization', they differ in many important ways. For instance, SPEKTRA's resolution is coarser than the SMARTS resolution. Very different assumptions are also used to model both aerosol extinction and diffuse irradiance. It is therefore perfectly normal that, for identical atmospheric conditions, their respective predictions differ.

As an example, Fig. 7.8.1 compares the direct and diffuse spectra predicted by both models for identical conditions, with turbidity specified as $\beta = 0.2$. The effect of varying the Climate input (for SPEKTRA, Climate is always assumed to be rural) is particularly evident on direct irradiance (Fig. 7.8.1a), but SMARTS-Rural and SPEKTRA agree relatively well. However, the two models markedly disagree on diffuse irradiance, for any Climate selected in SMARTS, especially when considering sun-facing surfaces.



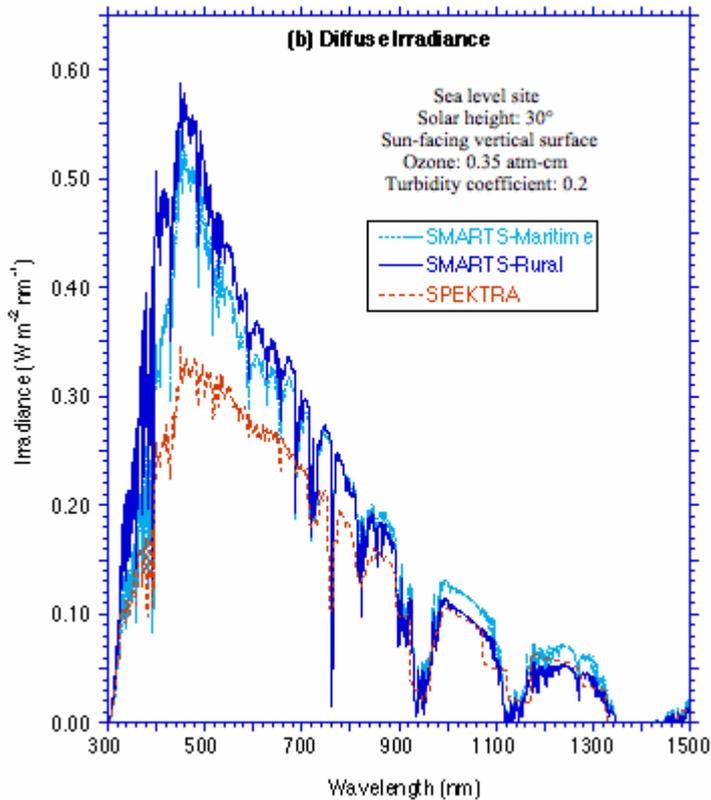


Fig. 7.8.1 Comparison of spectra obtained for a turbidity coefficient of 0.2 and different options: SMARTS with Maritime aerosol/climate, SMARTS with Rural aerosol/climate, and SPEKTRA; (a) direct irradiance; (b) diffuse irradiance.

As discussed in [Section 7.5](#), turbidity is an essential atmospheric variable, whose magnitude is far better described by β than by V . Compared to Fig. 7.8.1, Fig. 7.8.2 illustrates the generally larger disagreement between SMARTS and SPEKTRA when visibility is specified rather than turbidity. This is because the two models use different theoretical relationships to derive β from V (see Fig. 7.6.1). For the conditions of Fig. 7.8.1 ($V = 10$ km), the derived β is 0.232 according to SMARTS and 0.165 according to SPEKTRA. There is currently no known experimental data that can be used to resolve this issue, therefore caution is necessary when interpreting results based on visibility.

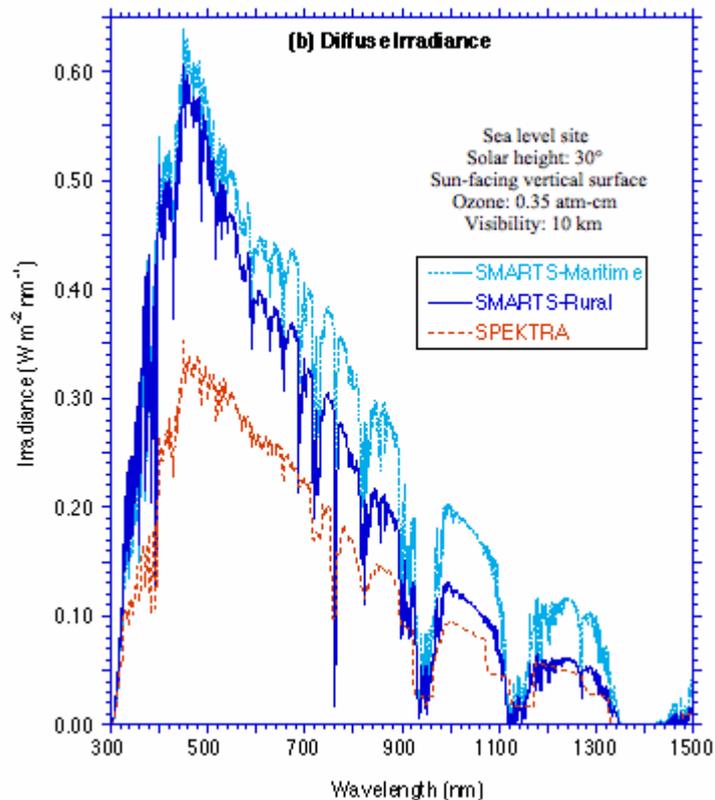
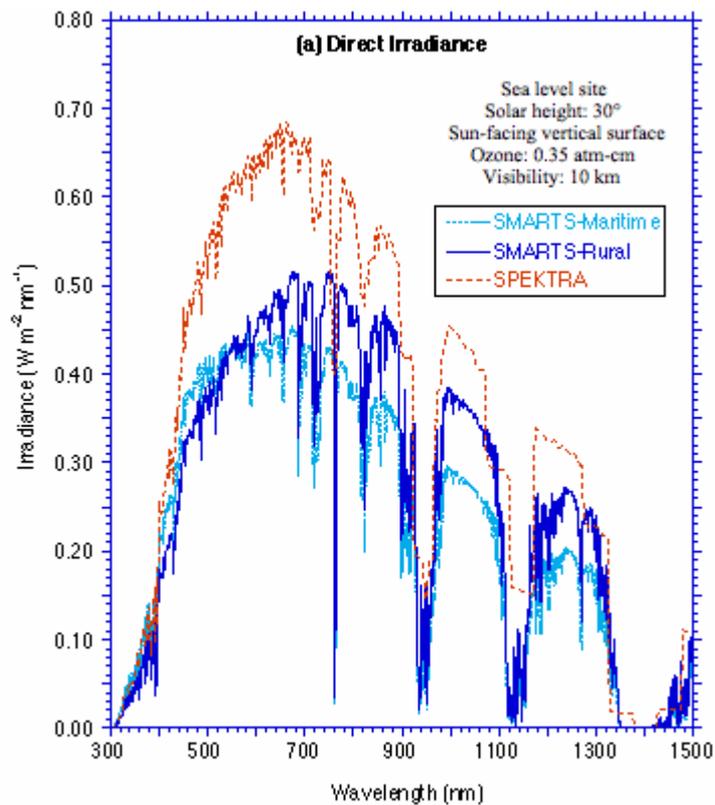


Fig. 7.8.2 Comparison of spectra obtained for a visibility of 10 km and different options: SMARTS with Maritime aerosol/climate, SMARTS with Rural aerosol/climate, and SPEKTRA; (a) direct irradiance; (b) diffuse irradiance.

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