SunCalculator 2.7

MANUAL VERSION 1.1

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1 Contents

2 Overview

SUNCALCULATOR is a program to calculate the angular and spectral distribution of measured integral values of direct and diffuse sunlight. This manual is intended to be used as a brief guide to run SunCalculator simulations and as a reference for the input and output files.

For a full description of the calculation procedure and example applications please refer to Ref. [1].

SunCalculator includes a pre-calculated SMARTS model [3, 4] database (Filename: *SMARTS_fine.bin*). It is mandatory to accept the SMARTS license agreement (http://www.nrel.gov/rredc/smarts/register.html) prior using the SMARTS database within SunCalculator.
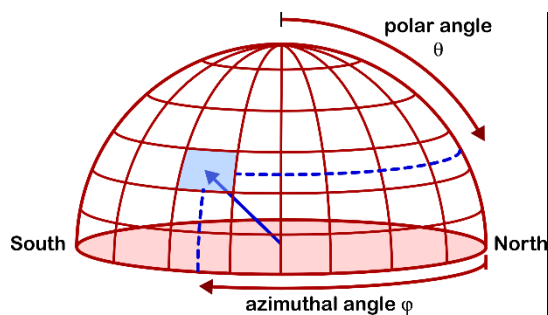

Figure 1 Binning into segments of the celestial hemisphere.

Figure 1 illustrates the segmentation of the celestial hemisphere and the corresponding angles. Each of the segments contains information about the integral values of direct and diffuse irradiance and direct and diffuse spectral distribution.

3 Graphical User Interface guide

SunCalculator is a GUI-based software using ASCII files to store and read input parameters and settings.

SunCalculator uses one input file (*.inp) to store the description of the solar panel (e.g. orientation and location) and one settings file (*.ini) to store simulation settings. This allows to use the same settings for different panel definitions. A detailed description of the input and output files is given in Chapter 4.

Figure 2 shows the general steps which are required to start a simulation.

1. Create input file
- Using the wizard
- Using the "Input file generator"
- Using any text editor

2. Define output settings
- Using the wizard
- Using the "Output settings" tab
- Load an existing settings file

3. Start process
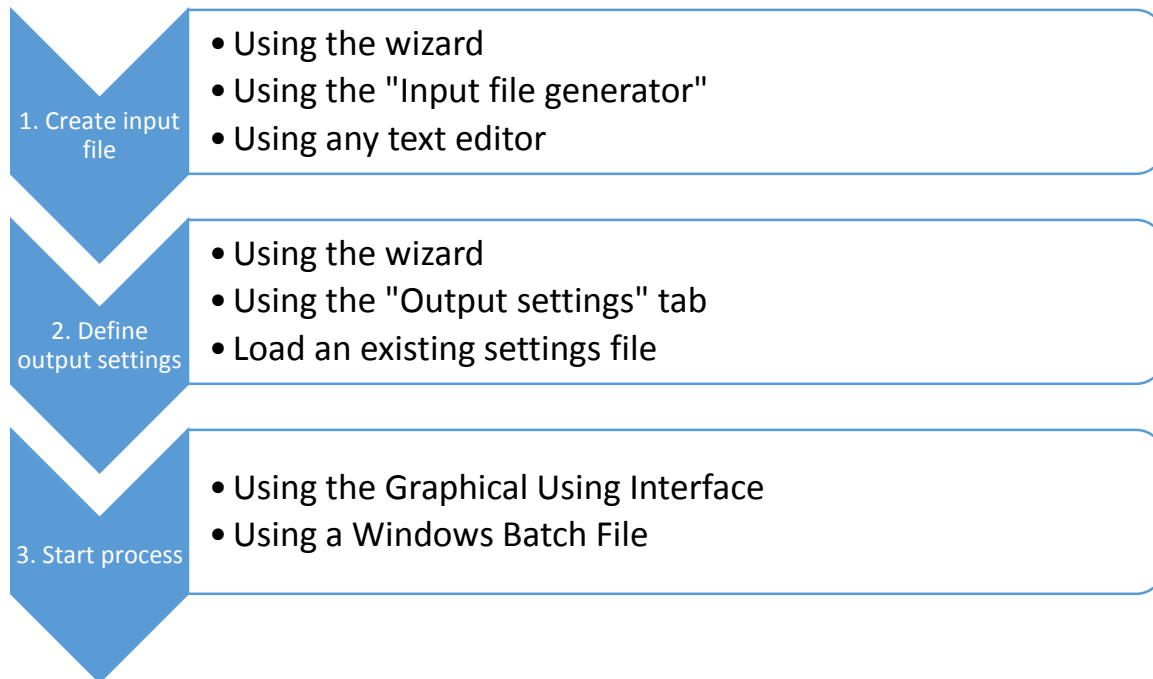- Using the Graphical Using Interface
- Using a Windows Batch File

Figure 2   SunCalculator steps

First, an input file needs to be created. SunCalculator offers a *Wizard* and an *Input file generator* to prepare an input file according to the file specifications. Alternatively, the input files can be created or modified in any text editing program.

Second, the simulation output settings have to be defined. The *Wizard* allows for an easy access to the most important settings. All options can then be accessed from the main window in the *Output settings* tab. Alternatively, an existing settings file (*.ini) can be loaded.

Finally, the output file needs to be selected and the simulation can be started from the GUI or using a Windows Batch File.

3.1   Wizard

SUNCALCULATOR is starting with a *Wizard* which guides through the setting up a new simulation. The wizard is divided into four tabs that will query all relevant information.

After successfully completing the dialog, the *Wizard* allows to save the input file and applies the settings to the main program window.
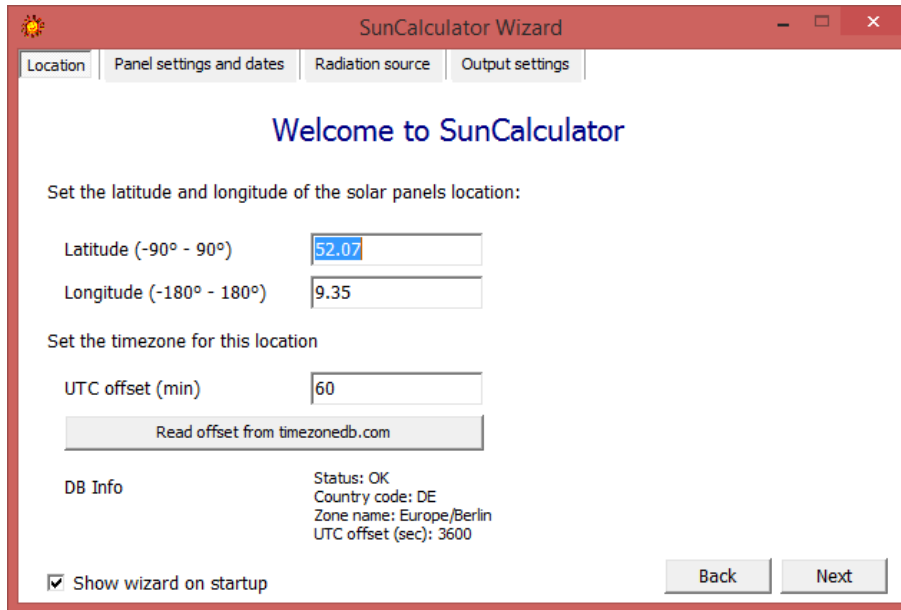
3.1.1 Location

Figure 3   SᴜɴCᴀʟᴄᴜʟᴀᴛᴏʀ Wizard: Location tab

In the first tab you can specify the location of the solar panel by changing the latitude and longitude values in decimal format (Figure 3).

In order to use the correct zone time, it is required to set the UTC offset for the selected location. The UTC offset can be either entered manually or read from an online database using the given location.

The wizard dialog is shown when starting SᴜɴCᴀʟᴄᴜʟᴀᴛᴏʀ. In order to avoid displaying the wizard you can uncheck the box and close the wizard. The default filename of the settings file is "SunCalculator.ini" and is saved in the program folder.

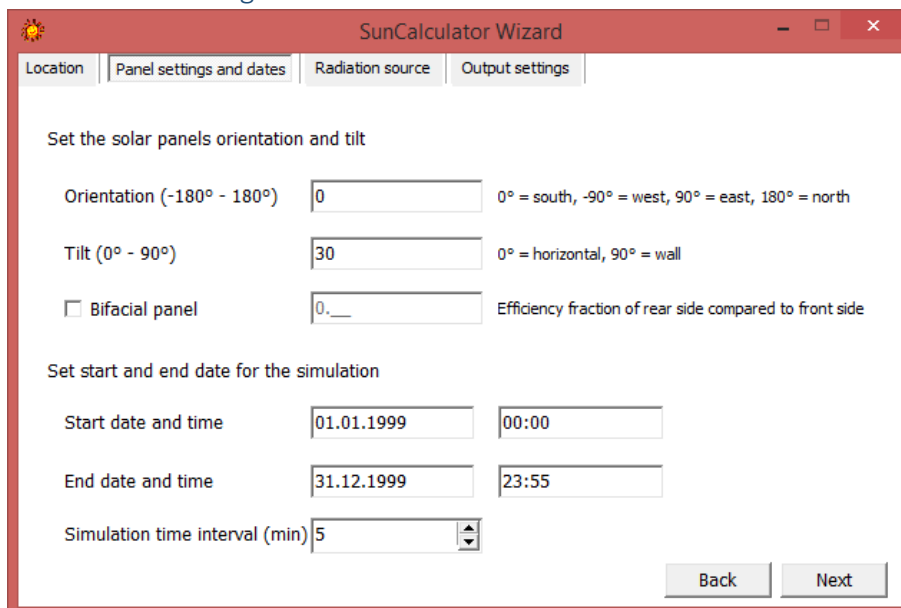### 3.1.2 Panel settings and dates

Figure 4   SᴜɴCᴀʟᴄᴜʟᴀᴛᴏʀ Wizard: Panel settings and dates tab

The Panel settings and dates tab (Figure 4) allows to set the orientation and tilt of the solar panel and the start and end dates for the simulation. Bifacial panels receive sunlight from both sides. If the

bifacial option is checked, photons received by the rear side will be taken into account and multiplied with an efficiency fraction of the rear side compared to the front side.

The start and end date and time is typically set for a full year as given in the example in Figure 4.

The simulation time interval defines the time steps in minutes for performing the simulations. A smaller interval increases the accuracy and simulation time.

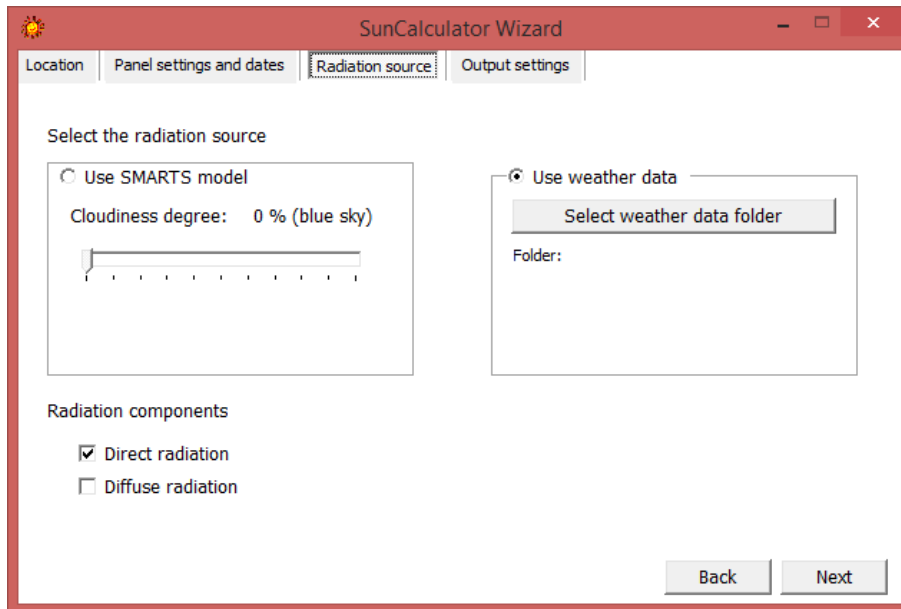### 3.1.3 Radiation source

Figure 5 SUNCALCULATOR Wizard: Radiation source tab

SUNCALCULATOR allows to choose between a clear-sky radiation source (using SMARTS model [3, 4]) and weather data files (Figure 5).

The SMARTS model is implemented as binary database of the direct and diffuse irradiance and spectral photon flux as a function of the sun's altitude. The implementation of the SMARTS model is described in section 3.7. The optional setting "cloudiness degree" allows to fit more realistic scenarios. It changes the weighting between the beam and diffuse radiation. This parameter is described in section 3.4.1.

The file structure of the weather data files is described in section 4.4.

For either radiation source, the simulated radiation components can be chosen. The calculations are significantly faster if restricted to the direct component only.
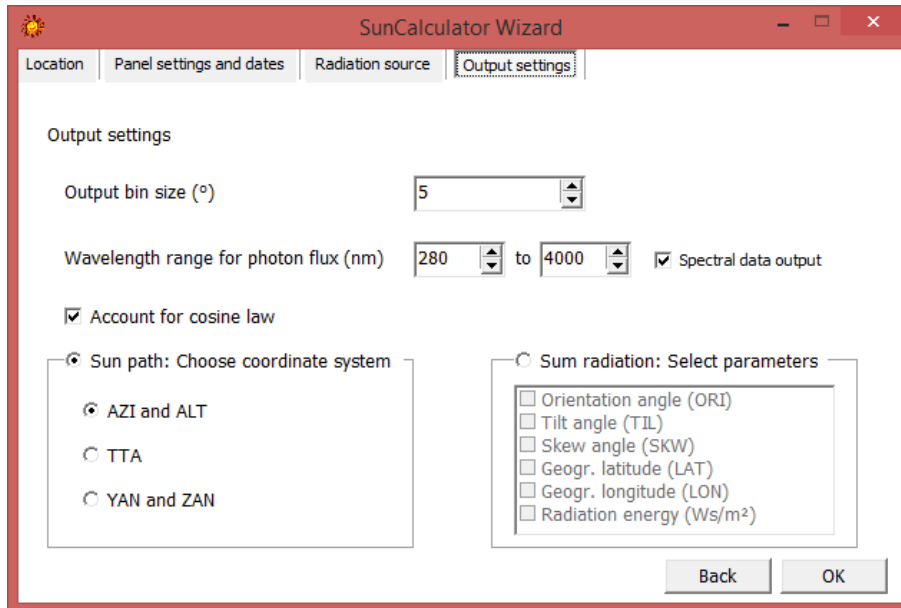
3.1.4 Output settings

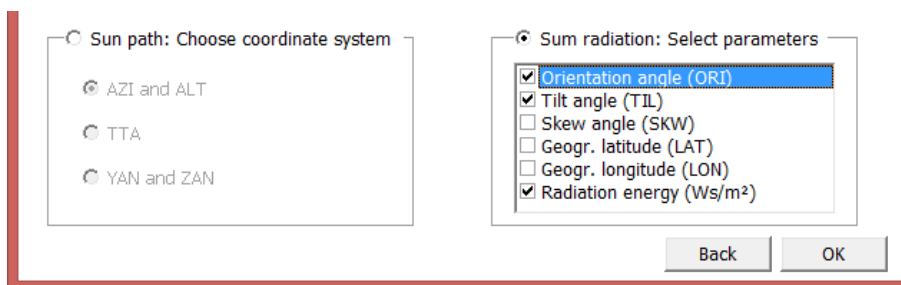Figure 6 SUNCALCULATOR Wizard: Output settings tab

Figure 7 SUNCALCULATOR Wizard: Sum radiation

In this tab you can choose the desired output bin size (Figure 6). A typical value is 5 °. Higher resolution will increase computing time.

SunCalculator allows to return the full spectral output data for direct and diffuse radiation based on the SMARTS model. The output data is always in 10 nm steps, but the spectral range can be chosen between 280 nm and 4000 nm.

In typical simulation scenarios you want to account for the cosine law when performing a simulation. In some cases, e.g. when your ray-tracing software will account for the cosine law, you can uncheck this box.

Finally, you can choose either a coordinate system or to sum the irradiance over the entire simulated time (Figure 7). The latter is used e.g. when you are varying the orientation of the solar panel to find the optimum orientation. Section 3.5 gives an introduction to the different coordinate systems.

3.2   Input file generator
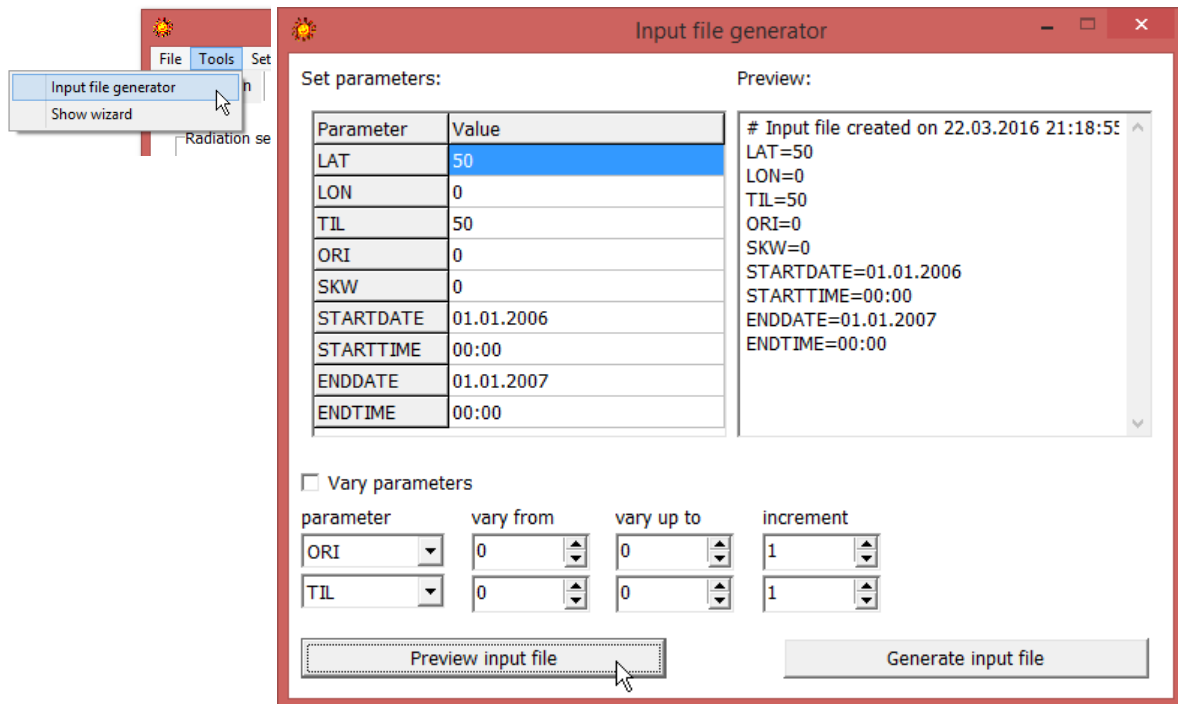
Figure 8   Screenshot of *Input file generator* which can be accesed via the *Tools* menu.

The program uses ASCII input files containing information about the panels location and orientation and period of time for the calculations. An *input file generator* is implemented in the software to easily create those input files. It can be accessed via the *Tools* menu (see Figure 8).

To create the input files by using the integrated file generator, fill out the value fields at first. To vary one or two parameters check the "Vary parameters" box and complete the corresponding fields. The parameters constraints are described in section 4.1.2. The input file will be generated once you click on "Preview input file" or "Generate input file". The latter will open a save-dialog to save the input file.

3.3 File selection
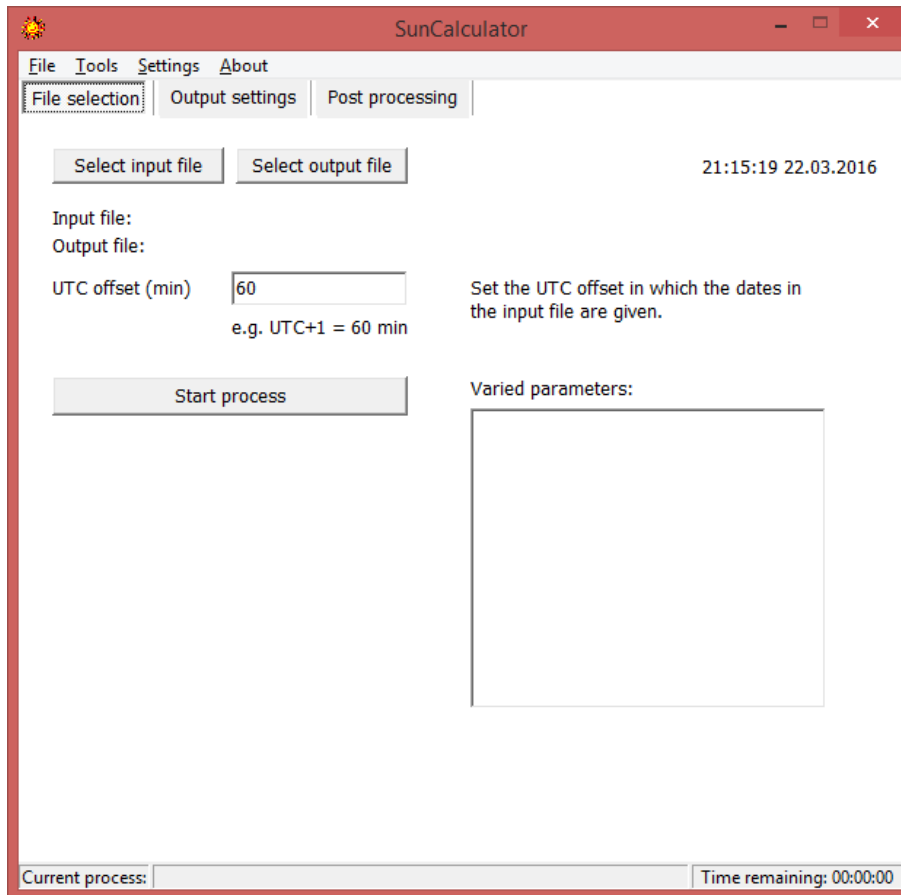
Figure 9 File selection tab.

To start the calculation process, the input file has to be loaded in the *File Selection* tab (Figure 9). In this tab you can also choose the output filename.

It is necessary to set the correct longitude in the input file. Enter the corresponding UTC offset for this location.

The "Varied parameters" box shows the parameters varied in your selected input file. To start the calculations click "Start process".

The date and time label in the top right corner of the window is showing the current time and will show the estimated time of finishing the process when a simulation is running.

The status bar displays the remaining time of the current simulation.

3.4 Output settings

Figure 10 Output settings tab.

In the *output settings tab* you are able to set all required parameters or change the settings as generated by the wizard (Figure 10).

You can choose either the SMARTS irradiance model or external weather data as a light source. Make sure your weather data to be in the correct data format, as described in section 4.4.
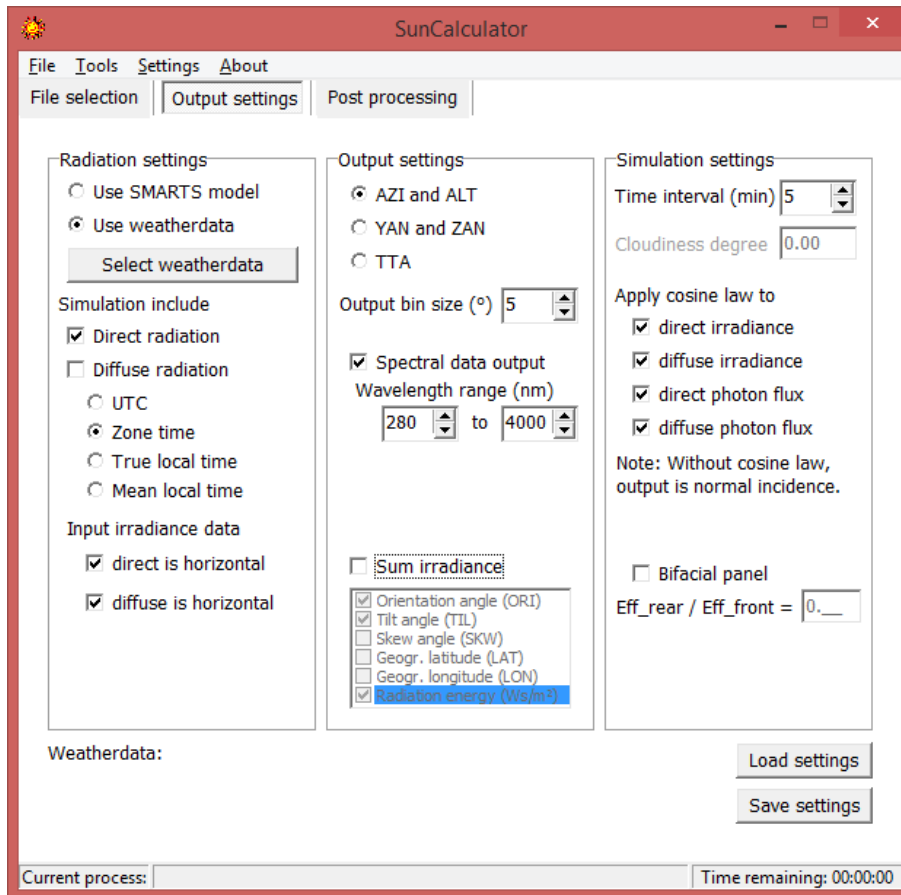
In the case of using weather data it is necessary to choose the folder where these data is located. In the first group box "Radiation settings" you can choose between direct radiation, diffuse radiation and both of them to be included in the calculations.

The output settings group let you choose between binning the calculated data in either horizon coordinate system (azimuthal angle AZI and altitude angle ALT), in perspective of the collector (YAN and ZAN) or by sun's inclination angle on panel (TTA). The binning precision can be chosen by setting the bin width value.

If spectral data output is wanted, the wavelength range can be set in 10 nm intervals from 280 nm to 4000 nm.

Checking the "Sum irradiance" respectively will produce only one output file with accumulated Radiation energy data. Activating this checkbox will enable the associated output parameter list in the output settings group. Each parameter set varied will produce one column in this output file.

In the "Simulation settings" section you can set the time interval of the simulations. Also, if the SMARTS model is selected you can set the cloudiness degree.

Typically the cosine law will be applied to the output irradiance and photon flux unless the corresponding boxes are unchecked.

Bifacial receivers may include an efficiency factor of the front and rear side of the panel.

The program's settings can be loaded or saved via the corresponding buttons in the lower right corner.

In the following subsections all setting possibilities are described further.

3.4.1 Cloudiness degree

The cloudiness degree parameter $f_{\text{cloudiness}}$ can be used as a fit parameter to match yearly global radiation for a specific location. It will reduce the beam irradiance I_{beam}

$$I_{\text{beam}} = \left(1 - f_{\text{cloudiness}}\right) \cdot I_{\text{beam}},$$

and sets the cloud opacity value $N_{\text{pt}} = f_{\text{cloudiness}}$. Please refer to Ref. [1] for more detailed information describing the cloud opacity value N_{pt}.

3.4.2 Use weather data

The radiation is read from the weather data files selected by clicking the "Select data folder" button. In section 4.4 the weather data file structure is described in detail.

3.4.3 Sum irradiance

This option is used to calculate the total irradiance for the simulation period given in the input file. In this case varying parameters will create a new line for every varied parameter with total irradiance data in your output file instead of creating single output files for every parameter set.

3.4.4 Cosine law

If the "Cosine law" box is checked, the software factors the cosine law into the calculations. Otherwise the radiation always hits the panel at normal incidence as if it were tracked by both axes.

While using weather data be sure the measurement was done perpendicular to the plane. Most measurement techniques already contain the cosine law in the measured irradiance data, so the usage of cosine law is not necessary.

3.4.5 Bifacial panel

Check this box, if you want to do the calculations with bifacial panels. The efficiency coefficient between the back and front of the panel is filled in the corresponding field below the check box.

3.4.6 Output values

Select either the coordinate system (horizon coordinates, panel coordinates, and inclination angle) or (when sum irradiance is checked) select the columns you want to add to your output files. The structure of the output files is described in section 4.3.

3.4.7 Bin width

This field changes the accuracy of the data binning. Smaller values yields in higher accuracy and longer calculation times.

3.4.8 Time interval

You can change the time interval (in minutes) by which the sun position is calculated. This setting is also possible when using weather data as light source, but it is recommended to set the same time interval as given in the weather data files. Longer time intervals is resulting in skipping some data

points, shorter time intervals forces the software to reuse the same data point multiple times (there is no interpolation implemented, as it will not increase the accuracy).
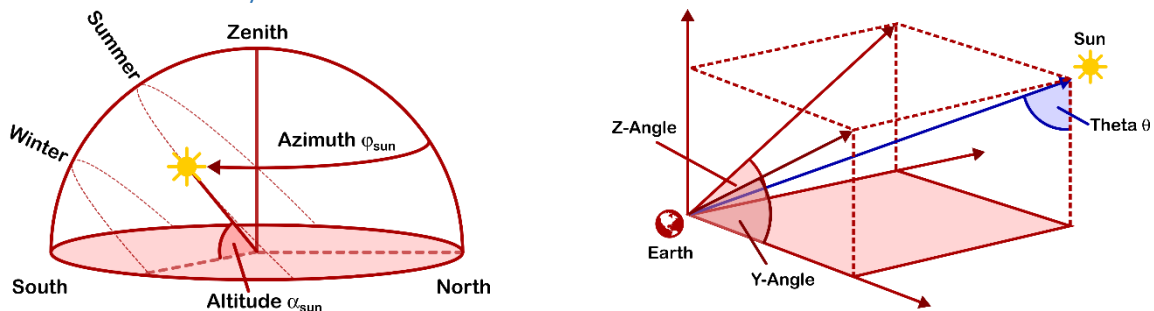
3.5 Coordinate systems

Figure 11 (left) Sun position as described by the altitude angle α_{sun} and azimuth angle φ_{sun}. (right) Representation of the angles of module coordinate system as derived in Ref. [1].

Figure 11 illustrates the three possible output coordinate systems. On the left hand side is shown the azimuthal / altitude angle system (*AZI and ALT*). The azimuth angle AZI is measured eastwards from north and the altitude angle ALT is measured from the horizon.

The *YAN and ZAN* coordinate system yields the two-dimensional coordinates of the sun as "seen" from the tilted, oriented and rotated panel as derived in Ref. [2].

The *TTA* coordinate is the rotationally symmetric inclination angle of the sun as "seen" from the tilted, oriented and rotated panel as derived in Ref. [2].

3.6 Post processing

This function allows to scale the last calculated simulation to user-defined yearly direct and diffuse irradiance values in kWh m^{-2} a^{-1}.
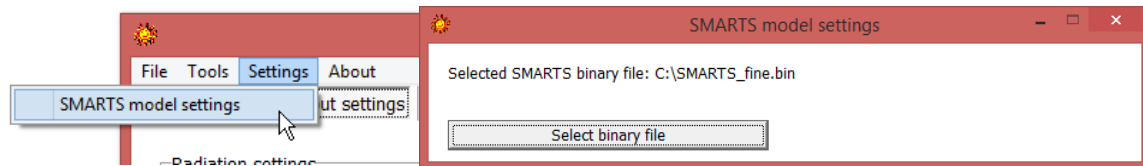
3.7 SMARTS model

Figure 12 Selecting SMARTS binary file.

The *Settings* menu allows to select the SMARTS binary file. The binary file is a pre-calculated database which includes spectrally resolved SMARTS irradiance in W m^{-2} nm^{-1} and photon flux data in m^{-2} nm^{-1} as a function of the altitude angle ALT of the sun.

The default SMARTS binary file *SMARTS_fine.bin* includes the pre-calculated values for altitude angle ALT of the sun within the interval from 0° to 90° with a resolution of 0.1°. The database contains the SMARTS spectral data from 280 nm to 4000 nm in 10 nm intervals. The SMARTS values have been calculated for SMARTS default settings with the variations listed in the following table:

Parameter	Setting / Value
Extraterrestrial spectrum	ASTM E490-00
Albedo	Grazing field (unfertilized)
Tilt Albedo	0°, Grazing field (unfertilized)
Solar constant	1366.1 W m^{-2}

Please refer to Ref. [1] for more details.

4 Input/Output file description

4.1 Input file (*.inp)

4.1.1 Required settings

The parameters listed in the following table are required to run a SunCalculator simulation.

Parameter	Description	Range
LAT	Geographical latitude	-90° - 90°
LON	Geographical longitude	-180° - 180°
ORI	Horizontal orientation angle of panel	-180° - 180°
		Measured eastwards from south, -90° = W, 0° = S, 90° = E, 180° = N)
TIL	Tilt angle of panel	0° - 90°
		0° if panel is horizontal; 90° if panel is a wall
SKW	Skewness angle of panel	0° - 360°
		Rotation of collector around surface normal
STARTDATE	Start date	DD.MM.YYYY
ENDDATE	End date	DD.MM.YYYY
		DD = two-digit day MM = two-digit month YYYY = four-digit year
STARTTIME	Start time	HH:MM:SS
ENDTIME	End time	HH:MM:SS
		HH = two-digit hour MM = two-digit minute SS = two-digit second

All rows starting with "#" are ignored when reading the input file.

4.1.2 Settings variation

SunCalculator allows to automatically vary one or multiple parameters. After setting all the required parameters as above, the command "VARPARAMS" will treat all subsequent rows in the input file as variation of the previous setting.

Every new set of parameters will generate a new output file where the changed parameters are added to the specified filename. If the sum irradiance (see section 3.4.3) is selected each parameter variation returns a new row in the output file.

The following example shows an input file with a parameter variation of the orientation angle (ORI) and the tilt angle (TIL):

```
# Input file example
LAT=50
LON=0
ORI=0
TIL=50
SKW=0
STARTDATE=01.01.2006
STARTTIME=00:00
ENDDATE=01.01.2007
ENDTIME=00:00
# Start parameter variation
VARPARAMS
ORI=0 TIL=50
ORI=10 TIL=50
ORI=0 TIL=40
ORI=10 TIL=40
```

4.2   Settings file (*.ini)

Default filename is "SunCalculator.ini" and stored automatically when closing the program.

4.3   Output file (*.dat)

The first row includes information about the location and module orientation and starts with "#".

The output data are columns separated by a semicolon ";". The decimal separator is a dot.

The second row is the header and includes information about the output parameter and unit.

The output files include the selected coordinate system and depending on the settings the direct and diffuse irradiance of the weather data, SMARTS model and on the tilted and oriented surface. Furthermore, it may include the direct and diffuse spectral photon flux (each one column per 10 nm interval).

4.4   Weather data file (*.dat)

The weather data files need to be separate files for each day of the year and located in the same directory. The files must be named "DDMM.dat" where DD is the two-digit day and MM is the two-digit month.

Each weather data file requires four columns separated by semicolons as listed in the following table:

Column title	Description
9999	Time interval (integer value starting at 1)
201	Global irradiance (W/m^2)
	This value is not imported by SunCalculator.
202	Horizontal/normal diffuse irradiance (W/m^2)
201-202	Horizontal/normal direct irradiance (W/m^2)

The first column (9999) contains an incremental integer value. The decimal separator is a dot for all numerical values.

Only the direct and diffuse irradiance data columns are imported by SunCalculator. The data can be given either as horizontal or normal incidence irradiance values in W/m^2.

Following example shows a compatible weather data file:

```
9999;201;202;201-202
1;0.733;0.704;0.029
2;0.732;0.684;0.048
3;0.713;0.668;0.045
4;0.717;0.682;0.035
5;0.725;0.693;0.032
...
```

4.5   Batch file (*.bat)

SUNCALCULATOR can be run in batch-mode when called from the windows console. Since all settings are managed by *.ini and *.inp files the program can be started with different settings from a batch file. The accepted batch parameters are listed in the following table:

Program parameter	Description
-i "input filename.inp"	Specify the input file (quotation marks only required if filename contains space character)
-o "output filename.dat"	Specify the output file (quotation marks only required if filename contains space character)
-ini "ini filename.ini"	Specify the ini file (quotation marks only required if filename contains space character)
-x	Automatically close program after simulation
-s	Automatically start simulation process on program start

All filenames may contain absolute or relative directories to the file, e. g. ".\inputfiles\file1.inp", "c:\suncalc\inputfiles\file1.inp" or "file1.inp". If you want to automatically start the process, be sure you properly passed the input and output file to the program.

The following example shows a batch file:

```
cls
@echo off
echo.
echo Batch SunCalc
echo.
echo %date% %time:~0,2%-%time:~3,2%-%time:~6,2% - Start batch processes
start /Wait SunCalculator.exe -i Example01.inp -o Output01.dat -ini IniFile01.ini -s -x
echo %date% %time:~0,2%-%time:~3,2%-%time:~6,2% - Second process
start /Wait SunCalculator.exe -i Example02.inp -o Output02.dat -ini IniFile02.ini -s -x
echo %date% %time:~0,2%-%time:~3,2%-%time:~6,2% - End of batch
```

5   References

[1]   M. Ernst, H. Holst, M. Winter, and P. P. Altermatt, "SUNCALCULATOR: A program to calculate the angular and spectral distribution of direct and diffuse solar radiation," Sol. Energy Mater. Sol. Cells **157**, 913–922, 2016, http://dx.doi.org/10.1016/j.solmat.2016.08.008.

[2]   D. Faiman and D. R. Mills, "Orientation of stationary axial collectors," Solar Energy **49** (4), 257–261 (1992).

[3]   C. A. Gueymard, "Parameterized transmittance model for direct beam and circumsolar spectral irradiance," Solar Energy **71** (5), 325–346 (2001).

[4]   C. A. Gueymard, "SMARTS, A Simple Model of the Atmospheric Radiative Transfer of Sunshine: Algorithms and Performance Assessment. Professional Paper FSEC-PF-270-95," in Florida Solar Energy Center (1679 Clearlake Rd., Cocoa, FL 32922, 1995).