SunCalculator 3.2

MANUAL VERSION 2.0

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1 Contents

2 Introduction

SunCalculator is a simulation tool for computing the angular and spectral distribution of direct and diffuse solar radiation for a given location, time period, and collector geometry. It is designed for applications that require direction-resolved irradiance data, such as ray-tracing simulations, optical system modelling, and photovoltaic performance analysis.

The software combines measured or modelled integral irradiance data with a pre-calculated SMARTS [3, 4] spectral database to generate angularly resolved radiation fields over the celestial hemisphere or in panel-based coordinate systems.

This guide focuses on the practical use of SunCalculator: how to define a simulation, select appropriate models, and interpret the resulting output files. A detailed description of the underlying methodology and validation examples is provided in Ref. [1].

3 Quick Start

A SunCalculator simulation is fully defined by a single JSON-based input file (*.sca), which can be created and edited either through the graphical user interface (GUI) or programmatically.

Minimum steps to run a simulation:

1. Open SunCalculator and select or create a new simulation file (*.sca).
2. Define the panel location and orientation (latitude, longitude, tilt, azimuth).
3. Select a radiation source:
    a. Clear-sky model (SMARTS), or
    b. Weather data (TMY file).
4. Choose the output coordinate system and angular bin width.
5. Select an output file format (*.dat, *.csv, or *.rls).
6. Start the simulation.

During execution, the status bar displays the remaining simulation time. Upon completion, the selected output files are written to disk.

4 Defining a Simulation

SunCalculator simulations are fully defined by a JSON-based input file (*.sca). This file stores all parameters describing the panel geometry, radiation source, simulation time range, and output configuration. The graphical user interface (GUI) provides a convenient way to create and modify these files; advanced users may also generate or edit them programmatically.

The GUI consists of five tabs, which together define a complete simulation.

4.1 File Selection

The File selection tab (Figure 1) is shown when SunCalculator starts. At startup, the software automatically checks for a valid license and available updates.

In this tab you can:

- Load an existing simulation file (*.sca)
- Save the current simulation settings
- Specify the output file name and format
- Start the simulation process

SunCalculator supports three output formats:

- *.dat
- *.csv
- *.rls (realistic light source container)

These formats are described in detail in Section 6. When the *.rls format is selected, interval output is enabled automatically in the Output settings tab.

To start a simulation, click Start process. During execution, the status bar shows the remaining simulation time. The time display in the top-right corner updates to indicate the estimated completion time.

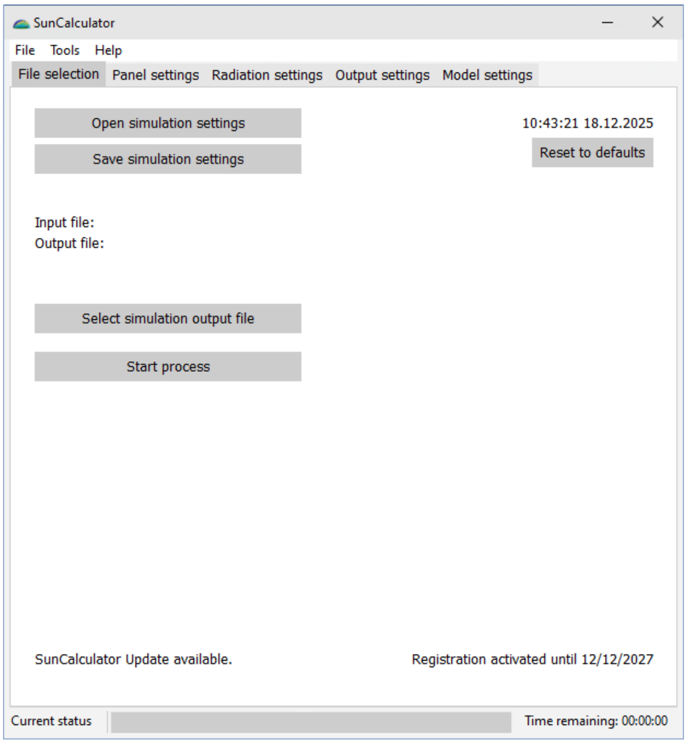

Figure 1 *File selection tab.*

4.2 Panel Settings

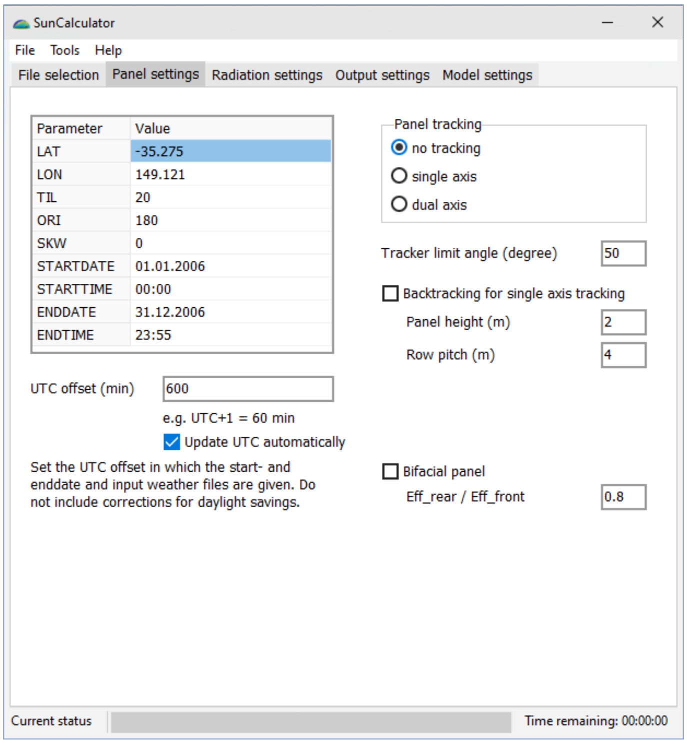

Figure 2 Panel settings tab

The Panel settings tab (Figure 2) defines the geometric and temporal configuration of the simulation.

Location and Orientation

You must specify:

- Geographic latitude (LAT) and longitude (<ON)
- Panel orientation (ORI)
- Panel tilt angle (TIL)

Time Range

The simulation time range is defined by start and end date/time. SUNCALCULATOR uses local standard time and does not apply daylight saving corrections.

To ensure correct time conversion, a UTC offset must be specified. The offset can be:

- Entered manually, or
- Retrieved automatically from an online database using the selected location

Panel Configuration

Additional options include:

- Bifacial panels: When enabled, irradiance incident on the rear side of the panel is included and scaled by a user-defined rear-side efficiency factor. Ground reflection is not considered.
- Tracking systems: Single-axis and dual-axis tracking are supported. For single-axis tracking, optional backtracking can be enabled to avoid self-shading.

4.3 Radiation Settings

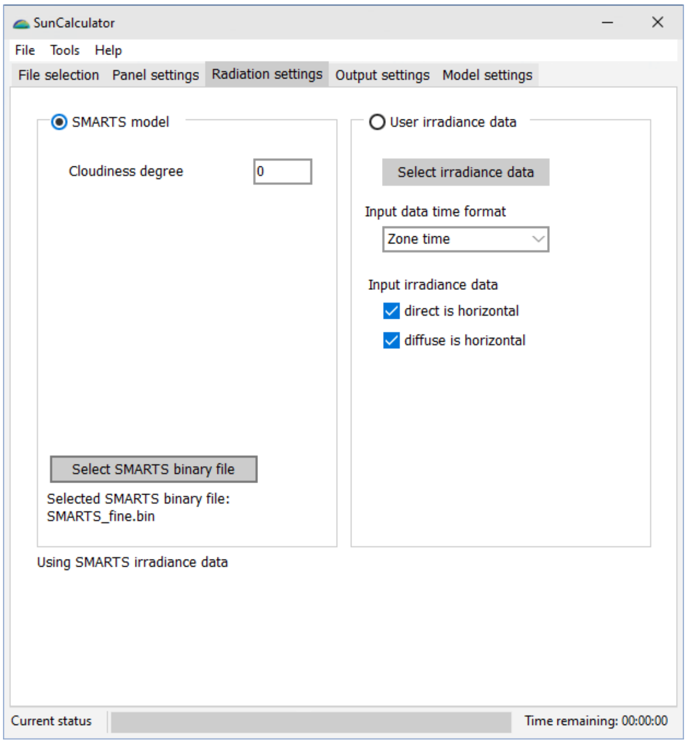

Figure 3 *Radiation settings tab*

The Radiation settings tab (Figure 3) defines the radiation source used in the simulation.

Radiation Source Options

Two radiation sources are available:

- Clear-sky model based on a pre-calculated SMARTS database
- Weather data from Typical Meteorological Year (TMY) files

The SMARTS database contains spectrally resolved direct and diffuse irradiance as a function of solar altitude. Details of the SMARTS implementation are given in Section 5.4.

Cloudiness Parameter

When using the SMARTS model, an optional cloudiness degree parameter can be applied. This parameter modifies the relative weighting of beam and diffuse radiation to better represent non-ideal atmospheric conditions. Its physical meaning and usage are described in Section 5.1.

Weather Data

Weather data files must follow the TMY format described in Section 6.3. When a TMY file is loaded, SUNCALCULATOR set local standard time, and assumes no daylight-saving correction.

4.4 Output Settings

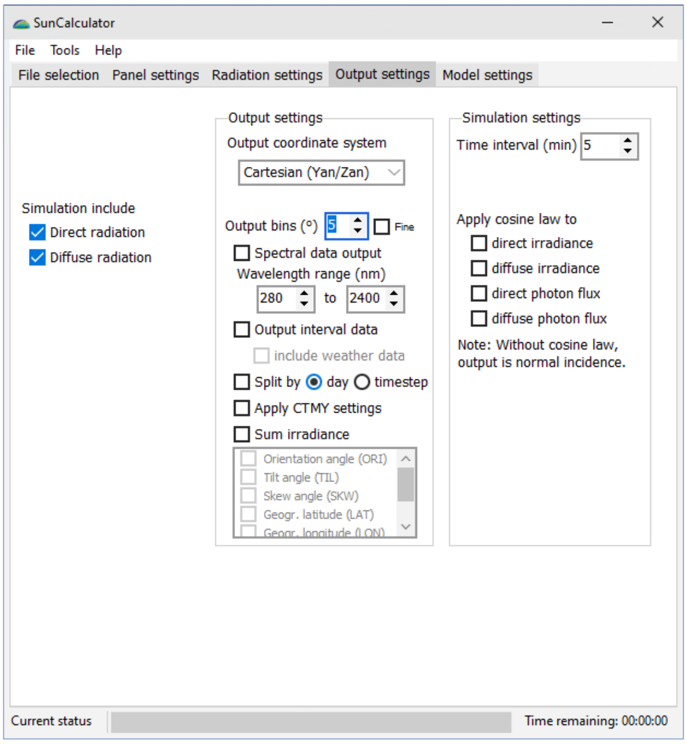

Figure 4 *Output settings tab*

The Output settings tab (Figure 4) controls which radiation components are calculated and how results are binned and written to disk.

Radiation Components

You may select direct and diffuse radiation components. Restricting calculations to the direct component significantly reduces computation time.

Coordinate System and Binning

Output data can be binned using one of the following coordinate systems:

- Horizontal azimuth and altitude (AZI, ALT)
- Panel-based azimuth and altitude
- Cartesian panel coordinates (YAN, ZAN)
- Inclination angle relative to the panel (TTA)

The bin width defines the angular resolution. A typical value is 5°. Smaller bin widths increase angular resolution at the cost of longer computation times. Coordinate systems are described in Section 5.3.

An optional Fine setting forces the diffuse radiation to be binned at 1° resolution, independent of the selected bin width for direct radiation.

Spectral Output

Enabling Spectral data output writes spectrally resolved irradiance and photon flux data based on the SMARTS model. Spectral data are provided in 10 nm steps over a selectable wavelength range from 280 nm to 4000 nm.

Interval and Summed Output

- Interval output produces time-resolved results and requires the *.rls output format.
- Sum irradiance produces a single file containing accumulated radiation energy. Each varied output parameter is written as a separate column. This option is not available when using the *.rls format.

Simulation Time Step

The simulation time step (in minutes) is defined in the Simulation settings group. Smaller time steps increase accuracy but also increase computation time.

By default, the cosine projection law is applied when computing irradiance on the panel surface. This can be disabled if cosine effects are handled externally (e.g. in downstream ray-tracing software).

4.5 Model Settings

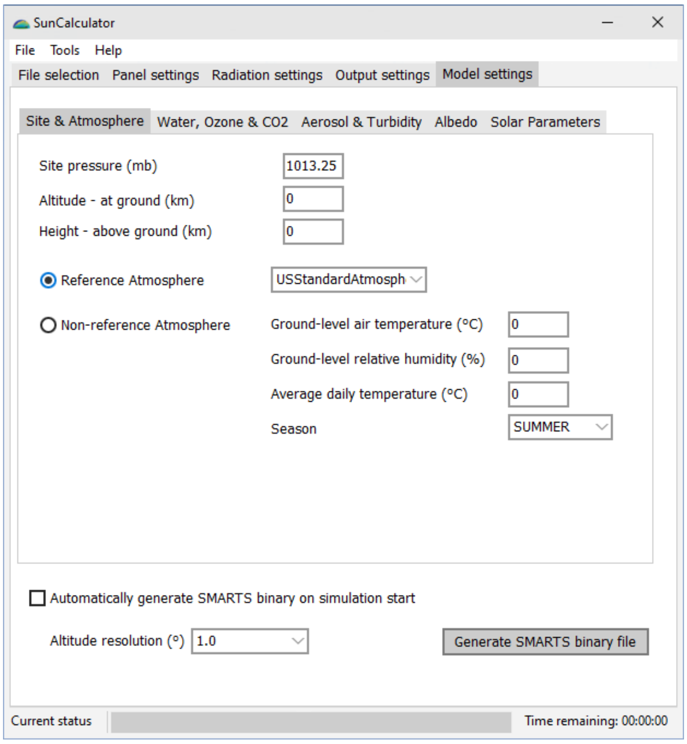

Figure 5 *Model settings tab.*

The Model settings tab (Figure 5) allows generation of SMARTS binary databases using SMARTS versions 2.9.8 or 2.9.9. This feature is available only in the Premium version of SUNCALCULATOR.

To use this functionality:

- The SMARTS executable must be placed in the smartsgen subfolder
- SMARTS license terms must be accepted separately from SUNCALCULATOR

Generated SMARTS binary files can then be selected in the Radiation settings tab.

5 Physical and Numerical Model

This chapter summarises the physical assumptions and numerical models used by SunCalculator. It is intended as a concise reference to support correct parameter selection and interpretation of simulation results.

5.1 Cloudiness Degree

The cloudiness degree parameter $f_{\text{cloudiness}}$ is an empirical fitting parameter used to adjust the relative contributions of beam and diffuse radiation when using the SMARTS clear-sky model:

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

Increasing $f_{\text{cloudiness}}$:

- Reduces the beam irradiance I_{beam}
- Increases the effective diffuse contribution

Internally, the cloudiness degree sets the cloud opacity parameter $N_{\text{pt}} = f_{\text{cloudiness}}$. This parameter can be calibrated to match measured global radiation at a given location.

The cloudiness degree does not represent a time-resolved cloud model; it is intended as a bulk correction for clear-sky conditions. For simulations requiring realistic temporal variability, weather data (TMY files) should be used instead.

A detailed description of the cloud opacity parameter N_{pt} and its physical interpretation is provided in Ref. [1].

5.2 Binning of the Celestial Hemisphere

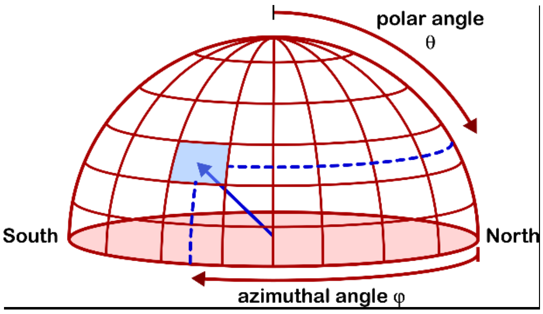

Figure 6 *Binning into segments of the celestial hemisphere.*

SunCalculator represents angularly resolved radiation by binning the celestial hemisphere into discrete angular segments (Figure 6). Each bin corresponds to a finite solid-angle element defined by the selected coordinate system and angular resolution.

For every bin, SunCalculator accumulates:

- Integral direct irradiance
- Integral diffuse irradiance
- Corresponding spectral distributions (when spectral output is enabled)

During the simulation, the instantaneous sun position and radiation contributions are mapped to the appropriate angular bin at each time step. Over the full simulation period, these contributions are integrated, resulting in a discretized angular radiation field.

The bin width specified in the Output settings controls the angular resolution of this segmentation. Smaller bin widths provide finer angular detail but increase computational cost and output file size. The choice of binning resolution should therefore be guided by the requirements of downstream applications (e.g. ray-tracing accuracy versus performance).

Binning is applied consistently across all supported coordinate systems, enabling direct comparison of angular distributions in different reference frames.

5.3 Coordinate Systems

SUNCALCULATOR supports multiple coordinate systems for binning angularly resolved radiation data. The choice of coordinate system depends on the intended downstream application (e.g. visualization, ray tracing, or panel-level analysis).

5.3.1 Horizontal Coordinate System (AZI, ALT)

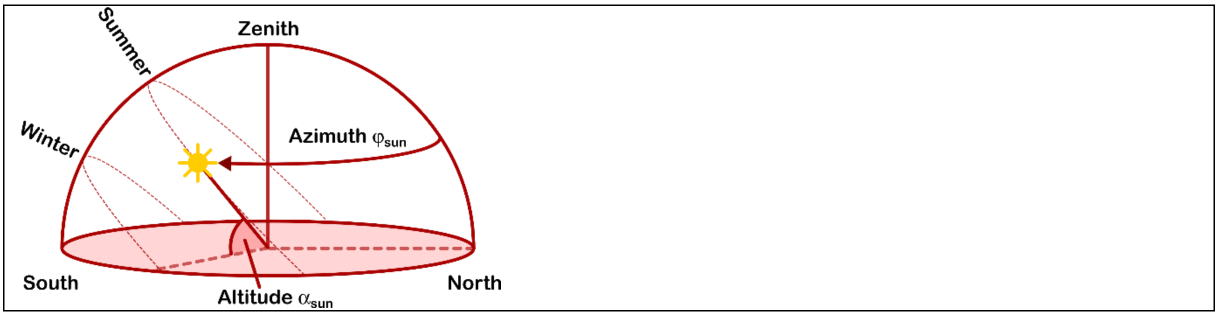

Figure 7 *Sun position as described by the altitude angle α_{sun} and azimuth angle φ_{sun}.*

The horizontal coordinate system (Figure 7) describes the sun position using:

- Azimuth angle (AZI): measured eastward from north
- Altitude angle (ALT): measured upward from the horizon

This system is independent of panel orientation and is useful for site-level analyses.

5.3.2 Panel Cartesian Coordinates (YAN, ZAN)

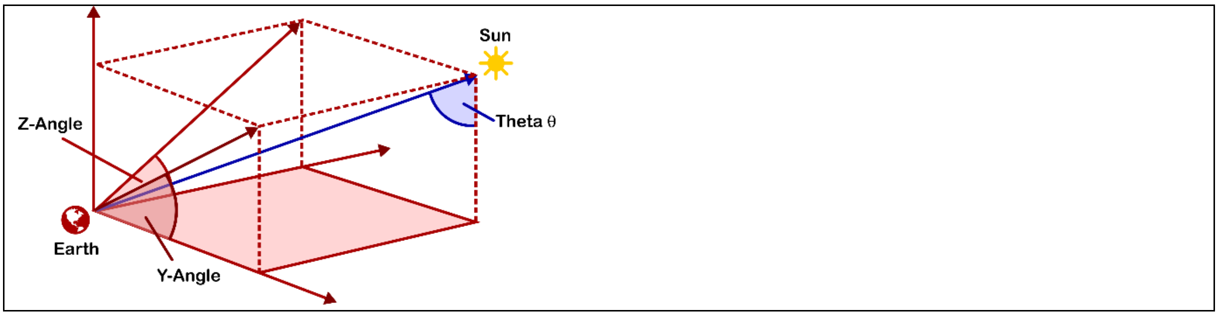

Figure 8 *Representation of the angles of module coordinate system as derived in Ref. [1].*

The YAN/ZAN coordinate system (Figure 8) represents the apparent position of the sun in the reference frame of the tilted and oriented panel.

- YAN and ZAN are Cartesian angular coordinates
- They correspond to the two-dimensional projection of the sun direction as "seen" by the panel
- The coordinate transformation is derived in Ref. [2]

This system is particularly suitable for ray-tracing and optical simulations where a planar detector is assumed.

5.3.3 Inclination Angle (TTA)

The TTA coordinate (Figure 8) represents the rotationally symmetric inclination angle between the sun direction and the panel normal.

- TTA is independent of azimuthal orientation
- It is useful when angular symmetry around the panel normal can be assumed

The mathematical definition of TTA is provided in Ref. [2].

5.3.4 Panel Azimuth and Altitude

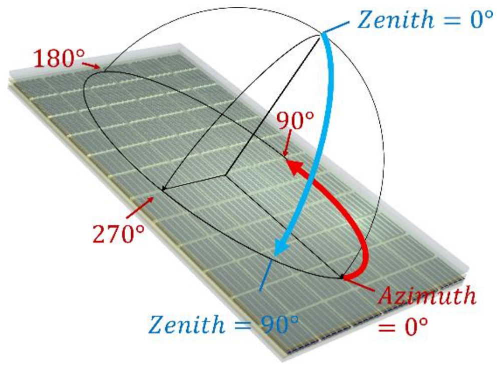

Figure 9 *Representation of the azimuth and altitude coordinates in plane of the panel.*

In this coordinate system, azimuth and altitude angles are defined relative to the plane of the panel rather than the horizontal plane (Figure 9). This representation is useful for analysing angular distributions

5.4 SMARTS Radiation Model

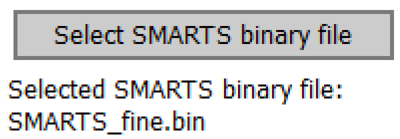

Figure 10 *Selecting SMARTS binary file.*

SUNCALCULATOR uses pre-calculated SMARTS radiation databases to obtain spectrally resolved direct and diffuse irradiance and photon flux as a function of solar altitude.

SMARTS Binary Database

The SMARTS database is stored as a binary file and contains:

- Spectral irradiance in units of W m^{-2} nm^{-1}
- Spectral photon flux in units of m^{-2} nm^{-1}
- Data tabulated as a function of solar altitude angle (ALT)

The default database file (SMARTS_fine.bin) covers:

- Solar altitude angles from 0° to 90° in 0.1° steps
- Wavelength range from 280 nm to 4000 nm
- Spectral resolution of 10 nm

Model Assumptions

The default SMARTS database was generated using SMARTS standard settings with the following parameters:

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}

Users requiring different atmospheric or surface conditions can generate custom SMARTS databases using the Model settings tab (Premium version only).

Further details on the SMARTS model configuration and validation are given in Ref. [1].

6 Input and Output Files

6.1 Simulation Input File (*.sca)

All simulation parameters are stored in a JSON-based input file with extension *.sca. This file fully defines a SunCalculator simulation and mirrors the settings available in the GUI.

The *.sca format is intended to be both human-readable and machine-editable, enabling automated parameter sweeps or batch simulations using external scripting languages.

Panel and Location Parameters

The table below lists key panel and location parameters. Angles follow the conventions described in Section 5.3.

The simulation parameters are described in a json-based file format, storing all settings made in the GUI. Below table provides description of some of the *Panel* parameters:

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	

Time Parameters

Parameter	Description	Range
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*

SunCalculator assumes times in the selected time format without daylight saving corrections.

6.2 Output Files

SunCalculator supports three output formats:

- *.dat: semicolon-separated text format
- *.csv: comma-separated text format
- *.rls: zipped container for realistic light source data

The first columns of each output file correspond to the selected angular coordinate system:

- Horizontal: Azimuth_(AZI), Altitude_(ALT)
- Panel Cartesian: Y-Angle_(YAN), Z-Angle_(ZAN)
- Inclination angle: Inclination-Angle_(TTA)
- Panel-based azimuth/altitude: PanelAzimuth_(AZI), PanelAltitude_(ALT)

6.2.1 Data Output File (*.dat)

The *.dat format is a semicolon-separated text file.

File structure:

1. First row: metadata starting with #, including location, orientation, and simulation settings
2. Second row: column headers with parameter names and units
3. Subsequent rows: binned simulation results

The decimal separator is a dot (.).

Example (standard output):

```
# Startparameters TIL=20 ORI=180 LAT=-35.275 LON=149.121 SKW=0 STARTDATE=01.01.2006
ENDDATE=31.01.2006 23:55:00 INTERVAL=300s
Y-Angle_(YAN);Z-Angle_(ZAN);"Direct Irradiance full spectrum (Ws m^-2)";"Diffuse Irradiance full
spectrum (Ws m^-2)";"Direct 280nm [#Photons/(cm^2*nm)]";...;"Diffuse 280nm [#Photons/(cm^2*nm)]";...
```

Example (summed irradiance output):

```
# Startparameters TIL=20 ORI=180 LAT=-35.275 LON=149.121 SKW=0 STARTDATE=01.01.2006
ENDDATE=31.01.2006 23:55:00 INTERVAL=300s
Y-Angle_(YAN);Z-Angle_(ZAN);"Direct Irradiance full spectrum (Ws m^-2)";"Diffuse Irradiance full
spectrum (Ws m^-2)";"Direct 280nm [#Photons/(cm^2*nm)]";...;"Diffuse 280nm [#Photons/(cm^2*nm)]";...
```

6.2.2 Data Output File (*.csv)

The *.csv format is functionally identical to the *.dat format but uses commas as separators.

```
# Startparameters TIL=20 ORI=180 LAT=-35.275 LON=149.121 SKW=0 STARTDATE=01.01.2006
ENDDATE=10.01.2006 23:55:00 INTERVAL=300s
Y-Angle_(YAN),Z-Angle_(ZAN),"Direct Irradiance full spectrum (Ws m^-2)","Diffuse Irradiance full
spectrum (Ws m^-2)","Direct 280nm [#Photons/(cm^2*nm)]",...,"Diffuse 280nm [#Photons/(cm^2*nm)]",...
```

6.2.3 Realistic light source (*.rls)

The *.rls format is a zipped container designed for applications requiring time-resolved and angularly resolved radiation data, such as ray-tracing simulations.

The container includes:

- The full *.sca input file
- rlsinfo.txt: JSON-based metadata
- One or more interval and distribution files, depending on the selected output mode

Daily Interval Mode (default)

When daily splitting is enabled, the container includes:

- Interval file ({input}_YYYY_M_D.int): time-resolved irradiance and optional weather data
- Diffuse distribution file ({input}_YYYY_M_D.csv): angular distribution of diffuse radiation for the corresponding day

Timestep Mode

When timestep-based output is selected:

- No interval file is generated
- A diffuse distribution file ({input}_timestep_YYYY_M_D_H_M.csv) is written for each timestep.

6.3 Weather Data Input (TMY data files)

Weather data input files must follow the Typical Meteorological Year (TMY) CSV format, as used in the TMY files at https://www.marcoernst.com/downloads/one-minute-tmy-data-australia.html.

Required columns:

Column	Content
1	Month
2	Day
3	Hour
4	Minute
13	Global horizontal irradiance (GHI)
14	Direct normal irradiance (DNI)
15	Diffuse horizontal irradiance (DHI)

Other columns are ignored. The header row is not parsed.

6.4 Batch Execution (*.bat)

SunCalculator can be executed in batch mode from the Windows command line. Since all simulation settings are stored in the *.sca file, batch execution enables automated processing of multiple simulations.

Supported command-line parameters:

Program parameter	Description
-i "input filename.sca"	Specify input file
-o "output filename.csv"	Specify output file
-s	Automatically start simulation
-x	Automatically close program after completion

Input and output paths may be absolute or relative. Quotation marks are required only if file paths contain spaces.

7 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).