A guide for the evaluation of the solar spectrum measurement uncertainty using array spectroradiometers

J. Dubard
R. Etienne

2013

This guide was compiled within the EMRP ENV03 Project “Traceability for surface spectral solar ultraviolet radiation”. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union
Contact addresses:
# Table of contents

1. Introduction .................................................................................................................. 4
2. Measurement model....................................................................................................... 4
   2.1 Calibration of the spectroradiometer ...................................................................... 4
   2.2 Measurement of the sun irradiance ....................................................................... 5
3. Uncertainty evaluation .................................................................................................. 6
   3.1 Spectroradiometer calibration uncertainty ............................................................... 6
   3.2 Sun spectral irradiance measurement uncertainty ................................................... 6
4. Software structure ......................................................................................................... 7
   4.1 Spectroradiometer calibration uncertainty software structure .................................. 7
   4.2 Sun irradiance measurement uncertainty ............................................................... 9
5. Characteristics of the software ..................................................................................... 10
   5.1 Wavelength range for uncertainty evaluation .......................................................... 10
   5.2 Requirements for input data files .......................................................................... 11
   5.3 Uncertainty evaluation steps .................................................................................. 11
   5.3.1 Uncertainty on the measured signal for the standard lamp ................................. 11
   5.3.2 Uncertainty for the stray light contribution ......................................................... 12
   5.3.2.1 Correlation between $S_{Std,j}$ terms ................................................................. 12
   5.3.2.2 Correlation between $(1-D)_{\lambda,j}$ terms ...................................................... 13
   5.3.2.3 Uncertainty evaluation of correlated entries ................................................... 13
   5.3.3 Uncertainty for the spectroradiometer calibration file ......................................... 13
   5.3.4 Uncertainty on the measured signal for the sun irradiance ................................. 13
   5.3.5 Uncertainty for the stray light correction when measuring the sun .................... 14
   5.3.6 Uncertainty on the sun irradiance measurement ................................................. 15
6. Running the software .................................................................................................... 15
   6.1 EnV03_CalibrationOfTheSpectroradiometer ......................................................... 15
   6.2 EnV03_MeasurementOfTheSunIrradiance ............................................................... 23
   6.3 III. Various informations ......................................................................................... 32
1 Introduction

This guideline is intended to provide the mean to determine the uncertainty related to the measurement of the solar UV irradiance using array spectroradiometer. Uncertainty evaluation is based on Monte Carlo technique as described in the IEC/ISO guide 98-3/suppl.1. The software for uncertainty calculation is developed under Matlab version R2012B.

The guideline includes the following parts:
- Part 1: Introduction
- Part 2: Description of the measurement model
- Part 3: Uncertainty evaluation process
- Part 4: Software structure
- Part 5: Software characteristics: how Monte Carlo technique is implemented?
- Part 6: Running the software

2 Measurement model

2.1 Calibration of the spectroradiometer

The spectroradiometer is calibrated using a standard lamp. When performing this calibration the parameters that are available are:

\( M_{\text{Std},i} \), the signal for pixel “i” corresponding to \( \lambda_i \) when measuring the standard lamp
\( M_{\text{DStd},i} \), the measured dark signal for pixel “i” corresponding to \( \lambda_i \) when measuring the standard lamp
\( T_{\text{Int,Std}} \), the integrating time when measuring the standard lamp

The signal \( S_{\text{Std},i} \) at \( \lambda_i \) is given by:

\[
1) \quad S_{\text{Std},i} = \frac{(M_{\text{Std},i} - M_{\text{DStd},i}) C_{\text{Lin}} C_{\lambda}}{T_{\text{Int,Std}}} \quad \text{(counts/s)}
\]

Where:
\( C_{\text{Lin}} \) is the correction due to non-linearity response of array detector of the spectroradiometer
\( C_{\lambda} \) is the correction due to wavelength accuracy

Stray light contributes to the signal and \( S_{\text{Std},i} \) can be written as:

\[
2) \quad S_{\text{Std},i} = S_{\text{True},i} + \sum_j S_{\text{True},j} d_{i,j}
\]

Where:
\( S_{\text{True},i} \) is the true signal at \( \lambda_i \)
\( d_{i,j} \) is the stray light contribution arising from light at \( \lambda_j \)

In matrix form this can be expressed as:

\[
3) \quad S_{\text{Std}} = S_{\text{True}} + S_{\text{True}} D
\]

Where:
$S_{\text{Std}}$ is the matrix representing the measured signal
$S_{\text{True}}$ is the matrix representing the signal corrected from stray light
$D$ is the matrix representing the stray light distribution function SDF

$S_{\text{True}}$ can be obtained by inverting this equation

$$4) \quad S_{\text{True}} = (1 + D)^{-1} S_{\text{Std}}$$

From this result it is possible to determine the calibration matrix $\text{CAL}$ of the spectroradiometer which element $\text{CAL}_i$ corresponding to pixel “i” and wavelength $\lambda_i$ is given by:

$$5) \quad \text{CAL}_i = \frac{S_{\text{True},i}}{E_{\text{Std},i}}$$

Where $E_{\text{Std},i}$ is the spectral irradiance of the standard lamp at $\lambda_i$
The unit of $\text{CAL}_i$ is: Counts/s/(W/m²/nm)

### 2.2 Measurement of the sun irradiance

When performing the measurement of a source the parameters that are measured are:

$M_i$, the signal for pixel “i” corresponding to $\lambda_i$ when measuring the sun
$M_{\text{D},i}$, the measured dark signal for pixel “i” corresponding to $\lambda_i$ when measuring the sun
$T_{\text{Int}}$ is the integrating time when measuring the sun

The signal $S_i$ at $\lambda_i$ is given by:

$$6) \quad S_i = \frac{(M_i - M_{\text{D},i}) C_{\text{Lin}} C_{\lambda}}{T_{\text{Int}}} \quad \text{(counts / s)}$$

$C_{\text{Lin}}$ is the correction due to non-linearity
$C_{\lambda}$ is the correction due to wavelength accuracy

Stray light contributes to the signal and $S_i$ can be written as:

$$7) \quad S_i = S_{\text{Sun},i} + \sum_j S_{\text{Sun},j} d_{i,j}$$

Where:
$S_{\text{Sun},i}$ is the true signal at $\lambda_i$

In matrix form this can be expressed as:

$$8) \quad S = S_{\text{Sun}} + S_{\text{Sun}} D$$

Where:
$S$ is the matrix representing the measured signal when measuring the sun
$S_{\text{Sun}}$ is the matrix representing the measured signal corrected from stray light
S\textsubscript{Sun} can be obtained by inverting this equation

\begin{equation}
S\textsubscript{Sun} = (1 + D)^{-1} S
\end{equation}

The sun spectral irradiance E\textsubscript{Sun,i} at \( \lambda \) is computed from the element S\textsubscript{Sun,i} of matrix S\textsubscript{Sun} using the following equation:

\begin{equation}
E_{\text{Sun,i}} = \frac{S_{\text{Sun,i}} \cdot E_{\text{Std,i}}}{C_{\text{AL,i}}} = \frac{S_{\text{Sun,i}} \cdot E_{\text{Std,i}}}{S_{\text{Trn,i}}}
\end{equation}

3 Uncertainty evaluation

Uncertainty evaluation is performed in two steps:
- Evaluation of the uncertainty associated to the calibration of the spectroradiometer: determination of CAL\textsubscript{i},
- Evaluation of the uncertainty associated to the measurement of the sun irradiance

3.1 Spectroradiometer calibration uncertainty

The calibration process implies 3 steps:
- Step 1: measurement of the signal and dark signal
- Step 2: applied corrections (linearity, stray light) to the signal corrected from dark signal
- Step 3: determination of the spectral responsivity of the spectroradiometer

Therefore uncertainty should be evaluated first using the measurement model described by equations 1) to 4), and then using the measurement model described by equation 5).

The uncertainty components to take into account are:
- Standard deviation of M\textsubscript{Std,i}
- Standard deviation of M\textsubscript{DSStd,i}
- Uncertainty associated to correction in linearity C\textsubscript{Lin} (depends on the value of M\textsubscript{Std,i} - M\textsubscript{DSStd,i})
- Uncertainty associated to correction of the time integration C\textsubscript{Int}
- The uncertainty due to the wavelength scale calibration of the spectroradiometer
- Uncertainty on the line spread function measurement
- The uncertainty on the absolute calibration of the standard lamp
- The uncertainty due to current supply of the standard lamp
- The uncertainty due to the distance of the standard lamp with respect to the entrance optics of the spectroradiometer

3.2 Sun spectral irradiance measurement uncertainty

The calibration process implies 3 steps:
- Step 1: measurement of the signal and dark signal
- Step 2: applied corrections (linearity, stray light) to the signal corrected from dark signal
- Step 3: determination of the sun spectral irradiance
Therefore uncertainty should be evaluated first using the measurement model described by equations 6) to 9), and then using the measurement model described by equation 10).

The uncertainty components to take into account are:
- Standard deviation of $M_{\text{Std,i}}$
- Standard deviation of $M_{D\text{Std,i}}$
- Uncertainty associated to correction in linearity $C_{\text{Lin}}$ (depends on the value of $M_{\text{Std,i}} - M_{D\text{Std,i}}$)
- Uncertainty associated to correction of the time integration $C_{\text{Int}}$
- The uncertainty due to the wavelength scale calibration of the spectroradiometer
- Uncertainty on the line spread function measurement
- The uncertainty on the absolute calibration of the spectroradiometer

4 Software structure

The software has two parts:
- One part for the evaluation of the uncertainty for the calibration of the spectroradiometer. This uncertainty is determined once upon calibration of the spectroradiometer and is valid until the next calibration.
- One part for the evaluation of the uncertainty for the sun irradiance measurement

4.1 Spectroradiometer calibration uncertainty software structure

The user interface will allow:
- To define the parameters for PDF of the different uncertainty components
- To load the calibration file of the standard lamp, the linearity correction file, the time integration correction file and the stray light correction matrix

The structure of the software is described on figure 1. The uncertainty for the calibration of the spectroradiometer is determined in 3 steps using MCM technique:
- Step 1: determination of the uncertainty associated to the measured signal including linearity correction. The output is the probability distribution function PDF1.
- Step 2: determination of the uncertainty of the signal from step1 corrected for stray light. This will take into account PDF1 and the correlation between the elements of the stray light correction matrix. The output is the probability distribution function PDF2.
- Step 3: determination of the uncertainty of the spectroradiometer calibration. This will take into account PDF2, the contribution of the standard lamp used for the calibration and the ambient temperature effect. The output is the probability distribution function PDF3.
Figure 1: Structure of the software for the evaluation of the uncertainty of the spectroradiometer calibration

Entries:
- Measurement files (signal and dark)
- Measurement models
- PDF of uncertainty components
- Standard lamp calibration file
- Linearity correction
- Time integration correction
- Stray light matrix
- Wavelength scale correction

Uncertainty on the spectroradiometer signal:
- Repeatability
- Wavelength scale calibration
- Linearity
- Time integration

⇒ PDF1

Uncertainty for stray light corrected signal:
- PDF1 of the uncertainty on the spectroradiometer signal
- Stray light correction
- Correlation on spectroradiometer signal and on stray light correction

⇒ PDF2

Uncertainty of the spectroradiometer calibration:
- PDF2 of the corrected signal
- Standard lamp
  - Calibration
  - Ageing
  - Distance
  - Current setting
- Temperature

⇒ PDF3
4.2 Sun irradiance measurement uncertainty

For this part of the software the additional entry is the integration time used during the measurement.

The structure of the software is described on figure 2. The uncertainty for the sun irradiance measurement is determined in 3 steps using MCM technique:

- Step 1: determination of the uncertainty associated to the measured signal including linearity and integration time corrections. The output is the probability distribution function PDF4.
- Step 2: determination of the uncertainty of the signal from step1 corrected for stray light. This will take into account PDF4 and the correlation between the elements of the stray light correction matrix. The output is the probability distribution function PDF5.
- Step 3: determination of the uncertainty of the sun irradiance measurement. This will take into account PDF3 from the spectroradiometer calibration, PDF5 from stray light correction and the ambient temperature effect. The output is the probability distribution function PDF6.

From PDF6 one can determine the estimate of the sun irradiance for the selected wavelengths. This estimate can be compared to the value determined from the measured signal after applying linearity, integration time, wavelength and stray light corrections, and the spectroradiometer calibration factor.
5 Characteristics of the software

5.1 Wavelength range for uncertainty evaluation

The measurement uncertainty is evaluated on the spectral range 280 nm- 400 nm. The wavelength step is 5 nm from 280 nm to 400 nm.
5.2 Requirements for input data files

Because of the large amount of data from array spectroradiometer the files that are used to evaluate the uncertainty must be re-sized to limit the number of data points. It is mandatory that spectral data files must be given with a 1 nm wavelength step over the whole spectral range of the spectroradiometer unless otherwise stated. The following files are concerned:

- Measurement files for the spectroradiometer calibration and sun measurement. These files should be corrected for linearity and wavelength accuracy
- Dark files
- Stray light correction matrix
- Spectroradiometer calibration file
- Sun measurement corrected for stray light
- Uncertainty of the stray light correction matrix
- Uncertainty for the wavelength scale calibration
- Standard lamp calibration (280 nm-400 mn)
- Uncertainty on standard lamp calibration (280 nm-400 mn)
- Uncertainty on standard lamp current setting (280 nm-400 mn)
- Uncertainty on standard lamp distance (280 nm-400 mn)

Additional files are not wavelength dependant:
- Uncertainty on linearity calibration
- Uncertainty on time integration calibration

5.3 Uncertainty evaluation steps

The software calculates the uncertainty for each wavelength $\lambda_0$ indicated in & 5.1 following the steps described in & 5.3.1 to 5.3.6.

5.3.1 Uncertainty on the measured signal for the standard lamp

Equation 1) is used to determine the PDF of the measured signal:

$$ S_{Std, \lambda_0} = \left( \frac{M_{Std, \lambda_0} - M_{DStd, \lambda_0}}{T_{Int, Std}} \right) C_{Lin} C_{\lambda} \quad (counts/s) $$

From the repeated measurement files and the dark measurement files are determined the average $M_{Std, \lambda_0}$ and $M_{DStd, \lambda_0}$, and the standard deviations $u_{Std, \lambda_0}$ and $u_{DStd, \lambda_0}$.

The PDF associated to $M_{Std, \lambda_0}$ and $M_{DStd, \lambda_0}$ is a Gaussian type in the form $N(M_{Std, \lambda_0}, u^2_{Std, \lambda_0})$ and $N(M_{DStd, \lambda_0}, u^2_{DStd, \lambda_0})$.

Gaussian PDF are also associated to linearity, time integration and wavelength scale corrections

Uncertainty evaluation is performed for the wavelengths over the whole spectral range of the spectroradiometer responsivity. This is necessary to evaluate the uncertainty contribution of the stray light correction (& 5.3.2).

The output of this step is PDF1.
5.3.2 Uncertainty for the stray light contribution

The true spectrum is obtained from:

\[
\begin{bmatrix}
S_{\text{True, 1}} \\
S_{\text{True, 2}} \\
\vdots \\
S_{\text{True, n}}
\end{bmatrix} = (1 + D) \begin{bmatrix}
S_{\text{Std, 1}} \\
S_{\text{Std, 2}} \\
\vdots \\
S_{\text{Std, n}}
\end{bmatrix}
\]

This matrix representation reduces to equation 12) for wavelength \( \lambda_0 \):

\[
S_{\text{True, } \lambda_0} = \sum_j S_{\text{Std, } j} (1 + D)^{-1}_{\lambda_0, j}
\]

To determine the uncertainty on \( S_{\text{True}} \) we need to assign an uncertainty to \( S_{\text{Std, } j} \) and to the line matrix of \((1+D)^{-1}\). Because off diagonal values are small compared to diagonal values then \((1+D)^{-1}\) can be approximated to \((1-D)\). Then we have to deal with:

\[
S_{\text{True, } \lambda_0} = \sum_j S_{\text{Std, } j} (1 - D)_{\lambda_0, j}
\]

In this equation the terms \( S_{\text{Std, } j} \) are correlated and the terms \((1-D)_{\lambda_0, j}\) are correlated. This has to be taken into account.

5.3.2.1 Correlation between \( S_{\text{Std, } j} \) terms

Equation 1) can be rewritten as:

\[
S_{\text{Std, } j} = C_i L_{\text{Lin, } j} C_{\lambda, i}
\]

The covariance between \( S_{\text{Std, } j} \) and \( S_{\text{Std, } k} \) is:

\[
u(S_{\text{Std, } j}, S_{\text{Std, } k}) = \frac{\partial S_{\text{Std, } j}}{\partial \text{Lin}} \frac{\partial S_{\text{Std, } j}}{\partial \text{Lin}} u^2(\text{Lin}) + \frac{\partial S_{\text{Std, } j}}{\partial \lambda} \frac{\partial S_{\text{Std, } j}}{\partial \lambda} u^2(\lambda) + \frac{\partial S_{\text{Std, } j}}{\partial T_{\text{ing}}} \frac{\partial S_{\text{Std, } j}}{\partial T_{\text{ing}}} u^2(T_{\text{ing}})
\]

\[
u(S_{\text{Std, } j}, S_{\text{Std, } k}) = \frac{C_i}{T_{\text{Int, Std, } j}} \frac{C_{\lambda, j}}{T_{\text{Int, Std, } i}} u^2(\lambda) + \frac{C_i}{T_{\text{Int, Std, } i}} \frac{C_{\lambda, j}}{T_{\text{Int, Std, } i}} u^2(\lambda) + \frac{C_i}{T_{\text{Int, Std, } j}} \frac{C_{\lambda, j}}{T_{\text{Int, Std, } i}} u^2(T_{\text{ing}})
\]
Because the measurement data are corrected for linearity and wavelength scale correction then $C_{\text{Lin, i}} = C_{\text{Lin, j}} = 1$ and $C_{\lambda, i} = C_{\lambda, j} = 1$. Equation 16) reduces to:

$$u(S_{\text{Std, i}}, S_{\text{Std, j}}) = \frac{C_i C_j}{T_{\text{Int, Std}}^2} u^2(Lin) + \frac{C_i C_j}{T_{\text{Int, Std}}^2} u^2(\lambda) + \frac{C_i C_j}{T_{\text{Int, Std}}^3} u^2(T_{\text{Ing}})$$

Where:

$$u^2(Lin) = u^2(Lin, i) + u^2(Lin, j)$$
$$u^2(\lambda) = u^2(\lambda, i) + u^2(\lambda, j)$$

5.3.2.2 Correlation between (1-D)$_{\lambda,0,i}$ terms

Stray light characterization is performed with the spectroradiometer. Therefore stray light contributions are fully correlated. Therefore:

$$r((1-D)_{\lambda,0,i}, (1-D)_{\lambda,0,j}) = 1$$

5.3.2.3 Uncertainty evaluation of correlated entries

The uncertainty and the value the correlated terms of equation 13) are obtained from a multivariate PDF (see GUM &6.4.8).

The output of this step is PDF2.

5.3.3 Uncertainty for the spectroradiometer calibration file

The calibration file is obtained from equation 5):

$$CAL_i = \frac{S_{\text{True, i}}}{E_{\text{Std, i}}}$$

The uncertainty associated to each element $CAL_i$ is obtained from the PDF2 determined in step 5.3.2 and the PDF determined for the standard lamp which takes into account the following contribution:

- Uncertainty on the calibration of the standard lamp (Gaussian PDF)
- Uncertainty on the current power supply of the standard lamp (Gaussian PDF)
- Uncertainty on the distance of the standard lamp with respect to the entrance of the spectroradiometer (Exponential PDF)

The output of this step is PDF3.

5.3.4 Uncertainty on the measured signal for the sun irradiance

Equation 6) is used to determined the PDF of the measured signal when measuring the sun irradiance:
From the repeated measurement files and the dark measurement files are determined the average \( M_{\lambda,0} \) and \( M_{D,\lambda,0} \), and the standard deviations \( u_{\lambda,0} \) and \( u_{D,\lambda,0} \). The PDF associated to \( M_{\lambda,0} \) and \( M_{D,\lambda,0} \) is a Gaussian type in the form \( N(M_{\lambda,0}, u_{\lambda,0}^2) \) and \( N(M_{D,\lambda,0}, u_{D,\lambda,0}^2) \).

Gaussian PDF are also associated to linearity, time integration and wavelength scale corrections.

Uncertainty evaluation is performed for the wavelengths over the whole spectral range of the spectroradiometer responsivity. This is necessary to evaluate the uncertainty contribution of the stray light correction (5.3.5).

The output of this step is PDF4.

### 5.3.5 Uncertainty for the stray light correction when measuring the sun

The true spectrum is obtained from:

\[
S_{\lambda} = \frac{(M_i - M_{D,i}) C_{Lin}}{T_{Int} C{Int}} \quad \text{(counts/s)}
\]

To determine the uncertainty on \( S_{\lambda} \) we need to assign an uncertainty to \( S_{ij} \) and to the line matrix of \((1+D)^{-1}\).

Because off diagonal values are small compared to diagonal values then \((1+D)^{-1}\) can be approximated to \((1-D)\). Then we have to deal with:

\[
S_{\lambda,\lambda_0} = \sum_j S_{ij} (1-D)_{\lambda_0,j}^{-1}
\]

The output of this step is PDF5.
5.3.6 Uncertainty on the sun irradiance measurement

The sun irradiance is determined from equation 10).

\[
E_{\text{Sun},i} = \frac{S_{\text{Sun},i}}{CAL_i}
\]

Uncertainty on the sun irradiance measurement must take into account the correlation between \(S_{\text{Sun},i}\) and \(CAL_i\). These two input quantities depend on the wavelength calibration and the time integration. Therefore the covariance is given by:

\[
u(S_{\text{Sun},i}, CAL_i) = \frac{\partial S_{\text{Sun},i}}{\partial \lambda} \frac{\partial CAL_i}{\partial \lambda} u^2(\lambda) + \frac{\partial S_{\text{Sun},i}}{\partial T_{\text{Int}}} \frac{\partial CAL_i}{\partial T_{\text{Int}}} u^2(T_{\text{Int}})
\]

\[23\]

\[
u^2(T_{\text{Int}}) = \frac{\partial S_{\text{Sun},i}}{\partial T_{\text{Int}}} T_{\text{S}} \frac{\partial CAL_i}{\partial T_{\text{Int}}} u^2(T_{\text{Int}}) + \frac{S_{\text{Sun},i}}{T_{\text{S}}} CAL_i u^2(T_{\text{Int}})
\]

Where \(T_S\) and \(T_{CAL}\) are the times integration used for sun irradiance measurement and for the spectroradiometer calibration respectively.

In equation 23):

\[24\]

\[
u^2(T_{\text{Int}}) = u^2(T_S) + u^2(T_{CAL})
\]

The uncertainty and the value of the correlated terms of equation 10) are obtained from a multivariate PDF (see GUM §6.4.8).

The output of this step is PDF6.

The outputs of the software are the value of the sun irradiance and the associated uncertainty at the wavelength \(\lambda\) by computing respectively the average and the standard uncertainty from PDF6.

6 Running the software

6.1 \textit{EnV03\_CalibrationOfTheSpectroradiometer}

This application is located in the folder : CalibrationOfTheSpectroradiometer

This folder must contain:

- the Matlab file “EnV03\_CalibrationOfTheSpectroradiometer.mat”: software
- the Matlab file “EnV03\_CalibrationOfTheSpectroradiometer.fig”: interface
- the Matlab file “OpenFile.m”: function for opening .xls files
- the Matlab file “avos\_C.mat. This file contains the “Dij Matrix by Zong (2048x2048) “ and this matrix is loaded automatically
- All the Excel files needed to use the software
- Run the application using
- Fill in the fields of the "User data panel":
  o Lambda min: first wavelength of your acquisition files in nm (integer)
  o Lambda max: last wavelength of your acquisition files in nm (integer)
  o Number of random draws: number of random draws for the Monte Carlo algorithm
  o Value of r matrix: value of the correlation matrix to calculate the covariance matrix \((U_x)\) needed for the Multivariate Gaussian random number generator

Floating value between 0 and 1

- Integration time of acquisition files: acquisition time of measurement
  - We need to define this parameter and its uncertainty associated to each integration time . . . maybe something like the “Linearity” file?

- Click on "Save user parameters", a standard dialog box for retrieving files appears:
  o Choose your “Wavelength file” in nm (2048x1 in Excel file)
Choose your “Uncertainty Wavelength file” in nm (2048x1 in Excel file)

Choose your “Linearity file” (2 columns in Excel file)
- first column: level in count between 1 and 65536
- second column: the uncertainty associated to each level

A message box appears, just wait few seconds for loading the Dij Matrix by Zong from file “avos_c.mat” (2048 x 2048) (automatically loaded)

Choose your “Udij Matrix by Nevas file”
Choose your “Spectral irradiance of the standard lamp file” in W/m²/nm (1x25 in Excel file)

Choose your “Spectral uncertainty on the irradiance of the standard lamp file” in W/m²/nm (1x25 in Excel file)

Choose your “Lamp current correction file” in % (1x25 in Excel file)
Choose your “Lamp distance correction file” in % (1x25 in Excel file)

- Your parameters are now saved in a .txt file: “SaveUserData.txt” in the current folder

- Click on "Preprocessing" : calculation of the matrix Ux
- Click on “Open dark files (*.xls)”, a standard dialog box for retrieving files appears.

Choose your “Dark file measurement” of the standard lamp in count (2048xX) or X : number of spectra acquired.
- Click on “Open measurement files (*.xls)"

  o Choose your “Signal file measurement” of the standard lamp in count (2048xX)
  or X : number of spectra acquired
- Click on “Random draws”: Launch the calculation of the different PDF and calculation of matrix Strue

- Click on “Calibration matrix of the spectroradiometer”:
  - Launch the calculation of the matrix CAL
  - Saving the matrix CAL in 25 .txt files. Each .txt file contains the PDF of the matrix CAL at each lambda_0 (280 nm to 400 nm by step of 5 nm)
Now, you can choose a wavelength and click on "PDF of the calibration matrix of the spectroradiometer" for displaying the PDF at the wavelength selected.

6.2 EnV03_MeasurementOfTheSunIrradiance

This application is located in the folder: MeasurementOfTheSunIrradiance

This folder must contain:

- the Matlab file “EnV03_MeasurementOfTheSunIrradiance.mat”: software
- the Matlab file “EnV03_MeasurementOfTheSunIrradiance.fig”: interface
- the Matlab file “OpenFile.m”: function for opening files .xls files
- the Matlab file “avos_C.mat. This file contains the “Dij Matrix by Zong (2048x2048)” and this matrix is loaded automatically
- All the Excel files needed to use the software

- Run the application using

- Fill in the fields of the "User data panel":
  - Integration time of acquisition files: acquisition time of measurement
    - We need to define this parameter and its uncertainty associated to each integration time . . . maybe something like the “Linearity” file?
  - Other parameters will be loaded in the next step from your “SaveUserData.txt”
- Click on "Load user parameters", a standard dialog box for retrieving files appears:
  - You have to select your “SaveUserData.txt” file:
    - Use this button
  - Select the folder called EnV03_CalibrationOfTheSpectroradiometer
- Select “SaveUserData.txt” file

- Choose your “Wavelength file” in nm (2048x1 in Excel file)

- Choose your “Uncertainty Wavelength file” in nm (2048x1 in Excel file)
Choose your “Linearity file” (2 columns in Excel file)
- first column with level in count between 1 and 65536
- second column the uncertainty associated to each level

A message box appears, just wait few seconds for loading the Dij Matrix by Zong from file “avos_c.mat” (2048 x 2048)

Choose your “Udij Matrix by Nevas file”
- Click on "Preprocessing" : calculation of the matrix Ux

- Click on “Open dark files (*.xls)”, a standard dialog box for retrieving files appears
Choose your “Dark file measurement” of the sun in count (2048xX) or X : number of spectra acquired

- Click on “Open measurement files (*.xls)”

Choose your “Signal file measurement” of the sun in count (2048xX) or X : number of spectra acquired
- Click on “Random draws”: Launch the calculation of the different PDF and calculation of matrix $S_{sun}$

- Click on “Load calibration matrix of the spectroradiometer”:  
  - Load the matrix $\text{CAL}$ calculated with \text{EnV03\_CalibrationOfTheSpectroradiometer}
- Click on “Calculation and saving Esun”, a standard dialog box for retrieving files appears

  Choose your “Calibration Matrix” (2 columns in Excel file)
  - first column: wavelength by step of 1 nm (example: 280-400 nm)
  - second column: value of your Calibration Matrix for each wavelength
Choose your “Ssun Matrix” (2 columns in Excel file)

- first column: wavelength by step of 1 nm (example: 280-400 nm)
- second column: value of your Ssun Matrix for each wavelength

Launch the calculation of the matrix Esun

Saving the matrix Esun in 25 .txt files. Each .txt file contains the PDF of the matrix Esun at each lambda_0 (280 nm to 400 nm by step of 5 nm)

Now, you can choose a wavelength and click on "PDF of the Esun matrix" for displaying the PDF at the wavelength selected.
6.3 III. Various informations

- Lambda_0 vector is 280 nm to 400 nm by step of 5 nm
- 25 is the number of lambda_0 (defined above)
- 2048 is the number of pixels