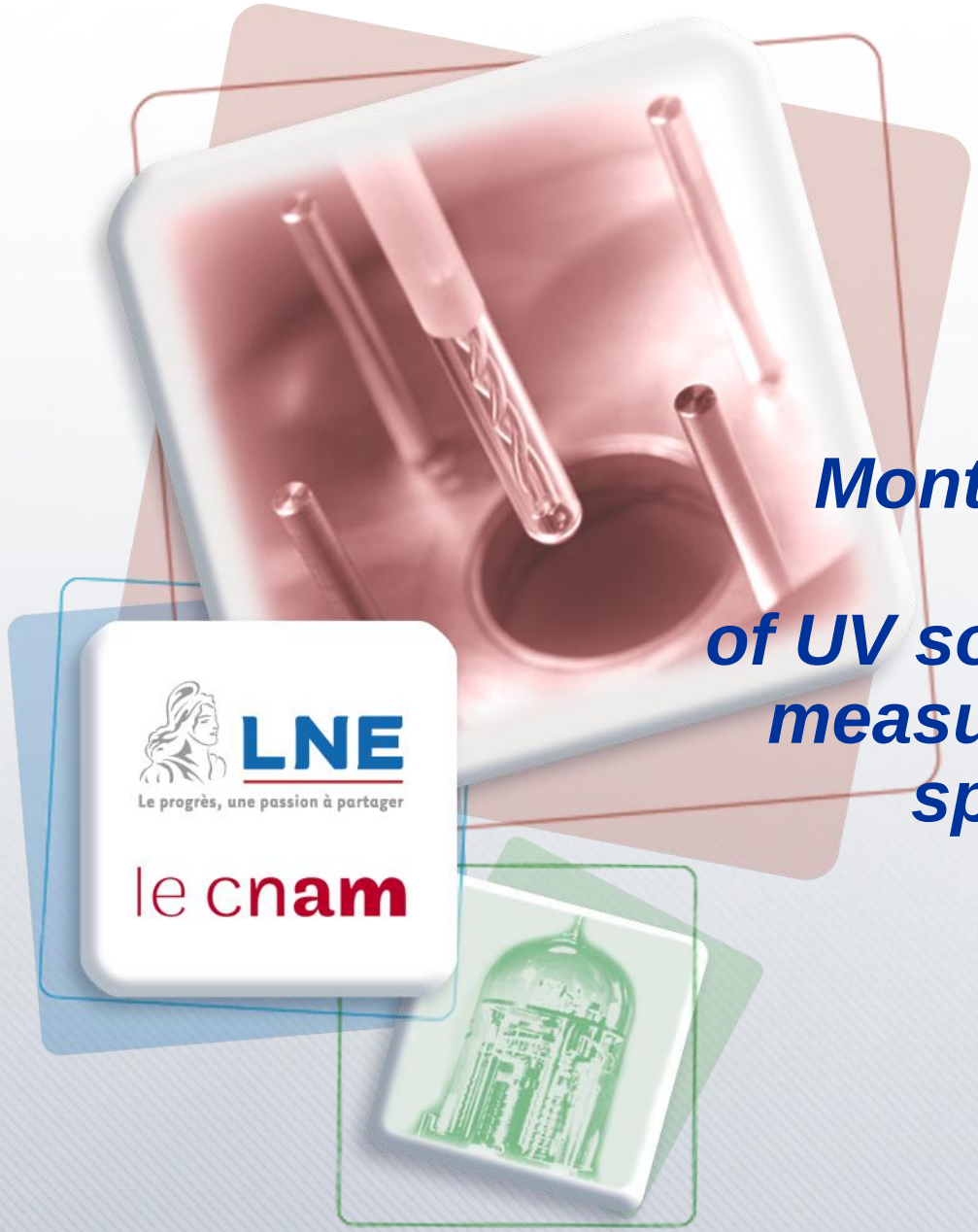

Monte Carlo uncertainty evaluation of UV solar spectral irradiance measurements using array spectroradiometer

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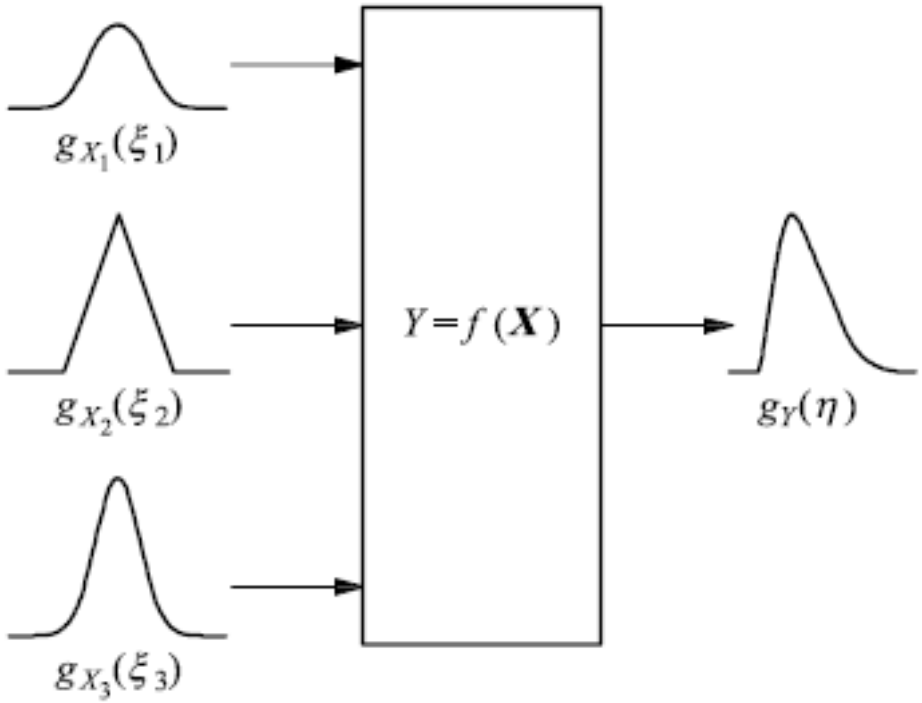
Outline

- Introduction
- Monte Carlo technique
- Measurement model
- Uncertainty evaluation
- Software
- Conclusion

Introduction

- **ENV03 SolarUV project, task 2.2**
- **Measurement of the spectral irradiance on the 280 nm-400 nm spectral range with array spectroradiometer**
  (sensitivity to a wider spectral range)
- **Measurement performed in two steps**
  - ✓ Calibration of the spectroradiometer
  - ✓ Measurement of UV irradiance
- **Uncertainty evaluation taking into account:**
  - ✓ Correlation
  - ✓ Correction matrix for stray light

Monte Carlo technique



- g_x probability distribution function (PDF) of inputs quantities
- *Y=f (X)* measurement model
- g_y probability distribution function of the output quantity
  - Mean value of Y
  - Standard deviation

Measurement model: Spectroradiometer calibration

- **Spectroradiometer signal**
  - ✓ Measurement, dark signal
  - ✓ Corrections: linearity, integration time, cosine response, wavelength scale

$$S_{Std,i} = \frac{\left(M_{Std,i} - M_{DStd,i}\right) C_{Lin}}{T_{Int,Std}} C_{Cos} \qquad (counts / s)$$

- **Stray light correction**

$$S_{Std,i} = S_{True,i} + \sum_j S_{True,j}\ d_{i,j}$$

$$S_{Std} = S_{True} + S_{True}\ D$$

$$S_{True} = \left(1 + D\right)^{-1}\ S_{Std}$$

- **Spectroradiometer calibration factor**
  - ✓ Standard lamp

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

Measurement model: Sun irradiance measurement

- **Spectroradiometer signal**
  - ✓ Measurement, dark signal
  - ✓ Corrections: linearity, integration time, cosine response, wavelength scale

$$S_i = \frac{(M_i - M_{D,i})\,C_{Lin}}{T_{Int}\,C_{Int}}\;C_{Cos} \qquad (counts/s)$$

- **Stray light correction**

$$S_i = S_{Sun,i} + \sum_j S_{Sun,j}\;d_{i,j}$$

$$S = S_{Sun} + S_{Sun}\,D$$

$$S_{Sun} = (1+D)^{-1}\,S$$

- **Sun irradiance**

$$E_{Sun,i} = \frac{S_{Sun,i}}{CAL_i}$$

Uncertainty evaluation

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

➔ PDF2

Uncertainty of the spectroradiometer calibration

- PDF2 of the corrected signal
- Standard lamp
  - Calibration
  - Ageing
  - Distance
  - Current setting
- Temperature

➔ PDF3

Uncertainty evaluation

Sun irradiance measurement

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

Uncertainty on the spectroradiometer signal
- Repeatability
- Wavelength scale calibration
- Linearity
- Integration time

➔ PDF4

Uncertainty of the stray light corrected signal
- PDF4 of the uncertainty on the spectroradiometer signal
- Stray light

➔ PDF5

Uncertainty of the sun spectral irradiance
- PDF3 of the spectroradiometer calibration
- PDF5 of the stray light corrected signal
- Temperature

➔ PDF6

Uncertainty evaluation software

Signal uncertainty PDF1

$$S_{Std,i} = \frac{\left(M_{Std,i} - M_{DStd,i}\right) C_{Lin}}{T_{Int,Std}}$$

Stray light correction PDF2

$$S_{True} = \left(1 + D\right)^{-1} S_{Std}$$

$$\begin{pmatrix} S_{True,1} \\ S_{True,2} \\ . \\ . \\ S_{True,n} \end{pmatrix} = \begin{pmatrix} \\ 1 + D \\ \\ \end{pmatrix}^{-1} \begin{pmatrix} S_{Std,1} \\ S_{Std,2} \\ . \\ . \\ S_{Std,n} \end{pmatrix}$$

- ✓ Zong treatment applied to determine the correction matrix
- ✓ Off diagonal terms of $(1+D)^{-1}$ are small compared to diagonal terms
- ✓ $(1+D)^{-1} = 1-D$

nm	280	290	300	310	320	330	340	350	360	370	380	390	400
280	**1.0E+00**	7.3E-06	2.7E-06	1.7E-06	1.6E-06	1.4E-06	1.0E-06	1.0E-06	1.1E-06	1.3E-06	1.2E-06	1.2E-06	1.2E-06
290	1.6E-05	**1.0E+00**	7.5E-06	2.7E-06	1.7E-06	1.5E-06	1.2E-06	1.4E-06	1.0E-06	1.1E-06	1.1E-06	9.2E-07	9.2E-07
300	7.4E-06	8.9E-06	**1.0E+00**	7.3E-06	2.8E-06	2.0E-06	1.4E-06	1.3E-06	1.3E-06	1.1E-06	8.7E-07	3.1E-07	3.1E-07
310	7.3E-06	3.1E-06	7.6E-06	**1.0E+00**	7.3E-06	2.9E-06	1.7E-06	1.5E-06	1.3E-06	1.1E-06	9.2E-07	8.0E-07	8.0E-07
320	1.6E-05	3.9E-06	2.7E-06	6.9E-06	**1.0E+00**	7.1E-06	2.3E-06	1.8E-06	1.6E-06	1.4E-06	7.3E-07	1.2E-07	1.2E-07
330	1.8E-05	4.3E-06	2.2E-06	2.1E-06	6.4E-06	**1.0E+00**	6.3E-06	2.4E-06	1.9E-06	1.1E-06	9.2E-07	7.4E-07	7.4E-07
340	1.8E-05	4.1E-06	1.8E-06	1.4E-06	2.0E-06	6.2E-06	**1.0E+00**	6.5E-06	2.1E-06	1.5E-06	9.4E-07	7.7E-07	7.7E-07
350	1.2E-05	2.9E-06	1.4E-06	8.8E-07	1.6E-06	1.9E-06	5.3E-06	**1.0E+00**	6.1E-06	2.2E-06	1.2E-06	9.1E-07	9.1E-07
360	7.4E-06	1.7E-06	6.5E-07	5.8E-07	7.2E-07	1.4E-06	1.2E-06	5.1E-06	**1.0E+00**	6.1E-06	2.0E-06	1.1E-06	1.1E-06
370	3.6E-06	6.7E-07	5.0E-07	1.6E-07	4.3E-07	4.5E-07	5.5E-07	1.4E-06	5.4E-06	**1.0E+00**	6.0E-06	1.9E-06	1.9E-06
380	1.3E-06	2.2E-07	1.0E-07	4.1E-08	1.2E-07	4.0E-07	1.8E-07	7.3E-07	1.5E-06	4.9E-06	**1.0E+00**	5.1E-06	3.4E-06
390	7.4E-07	1.7E-07	-9.0E-08	-6.1E-08	-2.7E-07	2.6E-07	-2.1E-07	4.5E-07	7.7E-07	1.3E-06	4.6E-06	**1.0E+00**	5.1E-06
400	5.3E-07	-2.5E-07	-5.3E-08	-5.2E-07	-6.4E-08	7.7E-08	-1.3E-07	1.4E-07	3.8E-07	8.4E-07	1.5E-06	3.4E-06	**1.0E+00**

- Stray light correction for λ_0 reduces to (j= 1 to N)

$$S_{True,\lambda_0} = \sum_j S_{Std,j} \left(1 - D\right)_{\lambda_0,j}$$

- Use of multivariate gaussian
  - ✓ To account for correlation between components of the stray light correction equation
  - ✓ Correlation between $S_{Std,j}$ (wavelength scale correction) and $(1\text{-}d)_{i,j}$ terms
  - ✓ Needs two matrices:
    - ✓ One matrix column for expected values
    - ✓ One NxN covariance matrix
  - ✓ Result: NxP matrix
    - ✓ N: number of wavelengths
    - ✓ P: number of trials

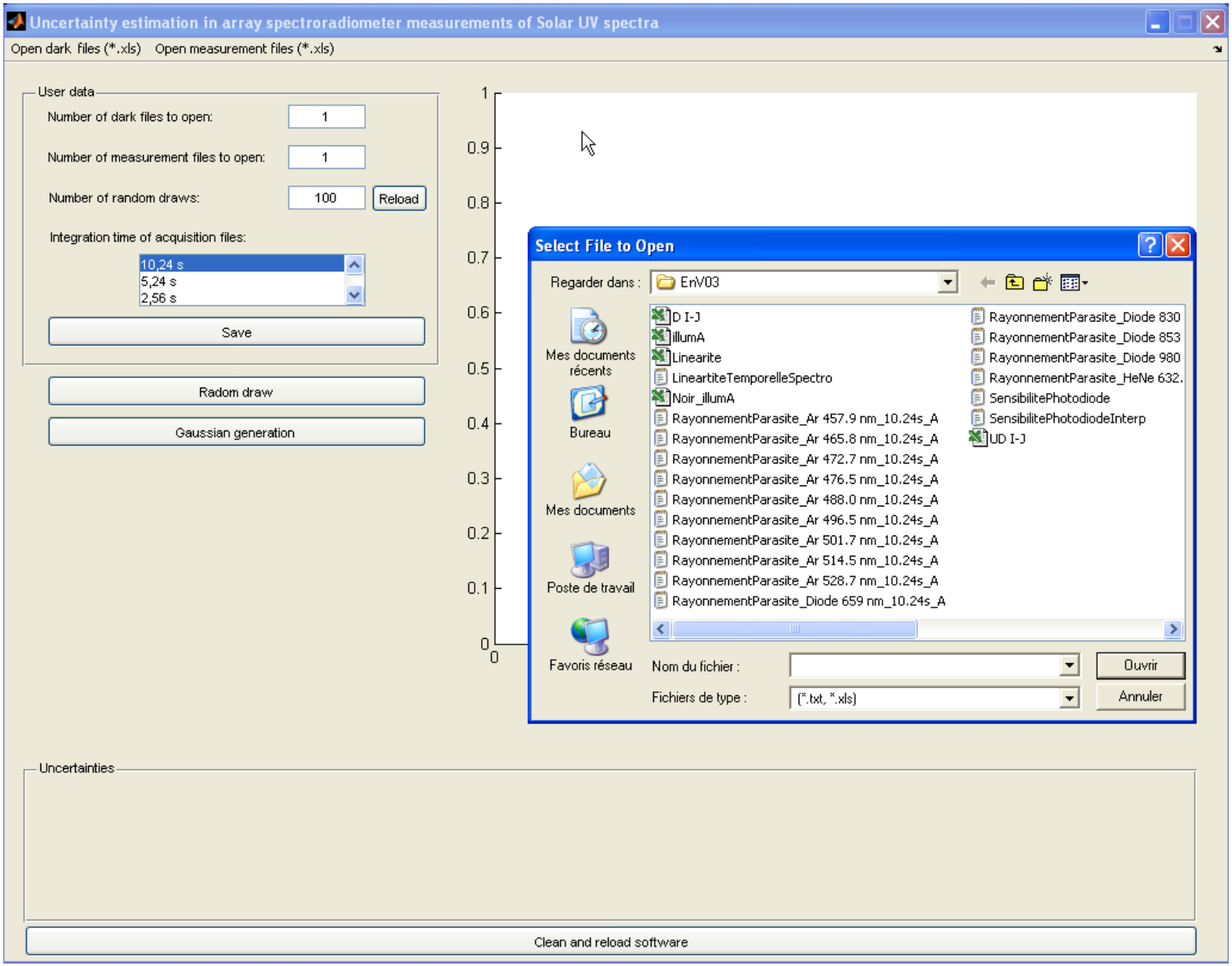
$$\boldsymbol{x} = (x_1, \ldots, x_N)^T$$

$$\boldsymbol{U}_x = \begin{bmatrix} u^2(x_1) & u(x_1,x_2) & \cdots & u(x_1,x_N) \\ u(x_2,x_1) & u^2(x_2) & \cdots & u(x_2,x_N) \\ \vdots & \vdots & \ddots & \vdots \\ u(x_N,x_1) & u(x_N,x_2) & \cdots & u^2(x_N) \end{bmatrix}$$

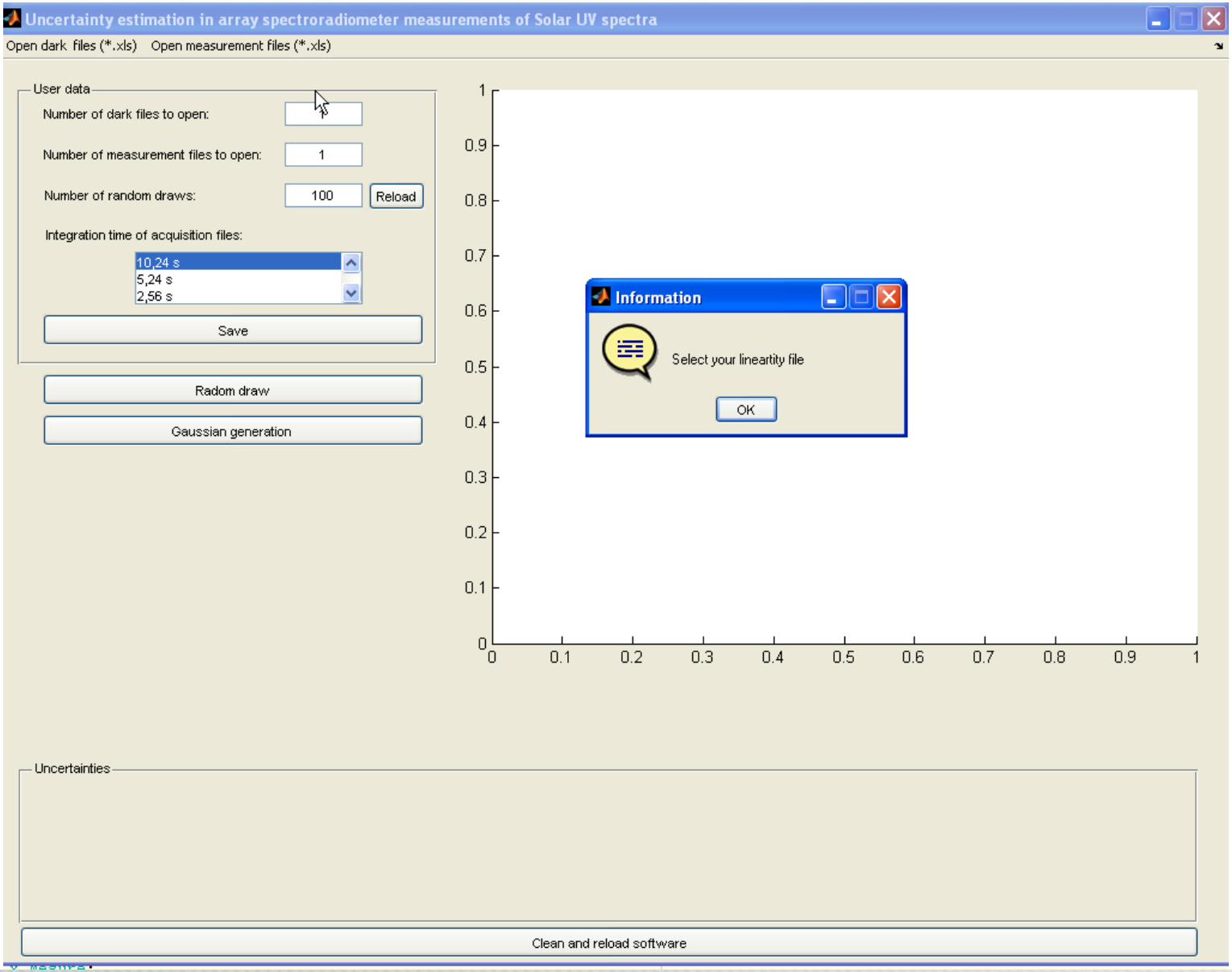
Uncertainty evaluation software

- **Spectral resolution**
  - ✓ Evaluation for a wavelength step of: 5 nm from 280 nm-300 nm, 10 nm from 310 nm-400 nm (14 points)
  - ✓ For each wavelength studied the spectral resolution (stray light correction) depends on computing time
- **Computing capacity**
  - ✓ Memory space: number of trials x spectral resolution < M0
  - ✓ Trade-off between number of trials and spectral resolution

Uncertainty evaluation software

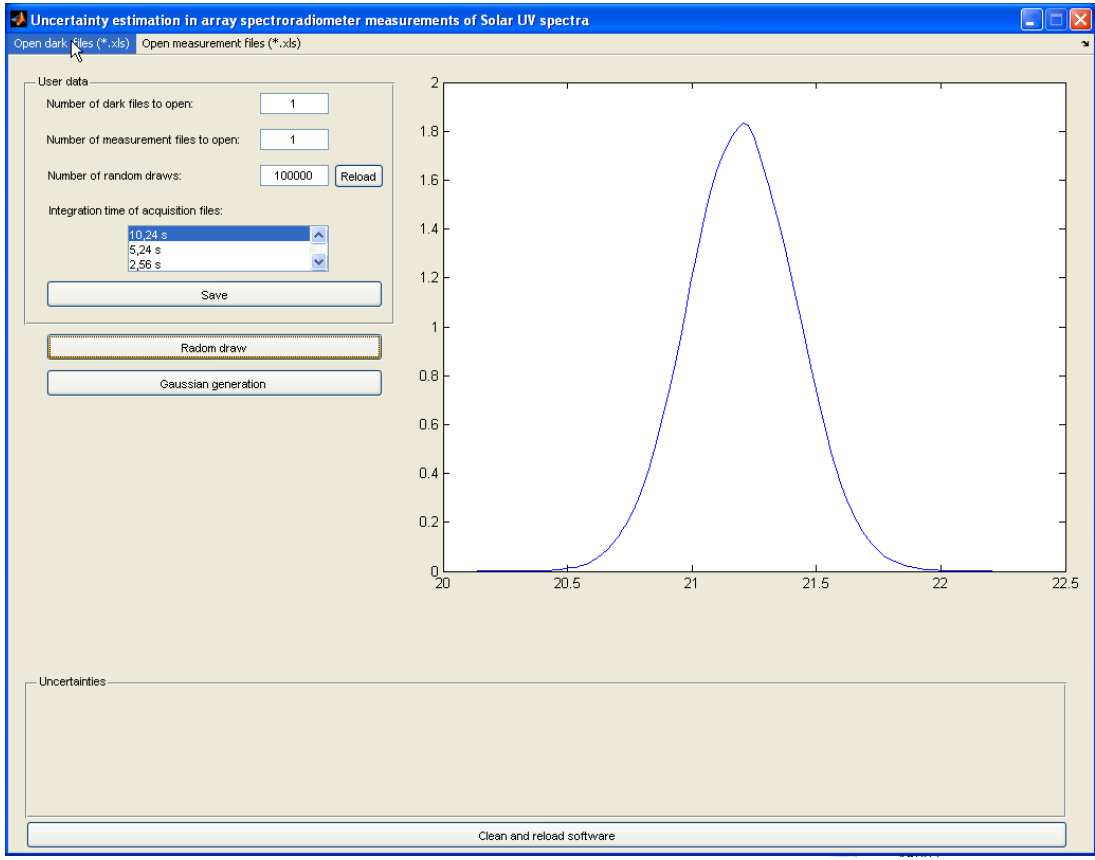


Uncertainty evaluation software



Uncertainty evaluation

- **Output**
  - ✓ Mean value
  - ✓ Standard deviation
- **Computation time 4.2 s**
  - ✓ For 1 wavelength
  - ✓ 10 nm spectral resolution
  - ✓ 100000 trials



Conclusion

- Matlab software available for uncertainty evaluation of spectroradiometer calibration. Extension to sun irradiance measurements will be performed upon validation of the present software
- Need more data from the WP2 tasks to validate the software
- Out of range stray light contribution?
- Trade-off between spectral resolution and computing time and capacity should be considered
- Writing of the guideline is in progress