Co-UDlabs

Building Collaborative Urban Drainage research labs communities

D6.3. UDMT – Urban Drainage Metrology Toolbox for sensor calibration, data validation and uncertainty assessment

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BACKGROUND: ABOUT THE CO-UDLABS PROJECT

Co-UDlabs is an EU-funded project aiming to integrate research and innovation activities in the field of Urban Drainage Systems (UDS) to address pressing public health, flood risks and environmental challenges.

Bringing together 17 unique research facilities, Co-UDlabs offers training and free access to a wide range of high-level scientific instruments, smart monitoring technologies and digital water analysis tools for advancing knowledge and innovation in Urban drainage systems.

Co-UDlabs aims to create an urban drainage large-scale facilities network to provide opportunities for monitoring water quality, UDS performance and smart and open data approaches.

The main objective of the project is to provide a transnational multidisciplinary collaborative research infrastructure that will allow stakeholders, academic researchers, and innovators in the urban drainage water sector to come together, share ideas, co-produce project concepts and then benefit from access to top-class research infrastructures to develop, improve and demonstrate those concepts, thereby building a collaborative European Urban Drainage innovation community.

The initiative will facilitate the uptake of innovation in traditional buried pipe systems and newer green-blue infrastructure, with a focus on increasing the understanding of asset deterioration and improving system resilience.

Executive summary

In Deliverable D6.3, Co-UDlabs presents, in detail and with examples of actual application, the UDMT – Urban Drainage Metrology Toolbox webapp, developed in Work Package 6, as the key outcome of Task 6.2, "Defining standard methods and protocols for metrology, and the associated open-source codes".

A first list of methods and protocols to be included in Task 6.2 was established and discussed by Co-UDlabs partners in Autumn 2021. After priorities were defined and validated by WP6 partners, a final list based on the following five groups of urban drainage metrological tools was created:

1. Sensor calibration / correlation
2. Calibration / correlation correction
3. Uncertainty assessment
4. Data validation
5. Tracing experiments.

Groups 1 to 4 include various methods and protocols.

The goal of Task 6.2 objective was to recommend a set of codes required to apply selected methods and protocols. It was additionally considered by WP 6 partners, however, that in order to facilitate the use of selected methods by the highest number of users as possible, a free online webapp with an easy-to-use interface would have been more effective than the simple collection of open-source codes. This is expected to require users, and practitioners in particular, fewer skills to use the Tool. It was then agreed to develop a web application, based on Matlab codes: this would also prevent users from having to locally install the codes and facilitate the use and maintenance of the software, among other advantages. At the end of the project, the final versions of all Matlab codes developed for the webapp will be made publicly available in Co-UDlabs' Zenodo repository.

The webapp, named UDMT (Urban Drainage Metrology Toolbox), is fully functional with all five groups of tools implemented. It can be accessed to by any user, for free and without any registration or sign-in requirement, at:
http://vps-7bc5cf87.vps.ovh.net:9988/webapps/home/session.html?app=coudlabs
(short link is coudlabs.alisonen.com).

Note: the UDMT will be further tested and developed during the year 2023, to account for feedback from users. A revised version of this deliverable will therefore be produced during the last quarter of 2023 to include the last modifications. The source-codes will be made publicly available on Zenodo at that moment.

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1. Introduction

This deliverable shows how to use the UDMT – Urban Drainage Metrology Toolbox web app, with basic examples for all main functionalities.

1.1. Access to UDMT and files

The UDMT version 2022a web app is available at

http://vps-7bc5cf87.vps.ovh.net:9988/webapps/home/session.html?app=coudlabs

All data files necessary to run the examples given in the UDMT user manual are available on pCloud at

https://u.pcloud.link/publink/show?code=kZegnQVZM53qyjRJ4cHn7Pi5WzrR9HJ0PL4V.

1.2. How does the UDMT work?

The UDMT is a web app developed with Matlab and installed on an OVH virtual machine.

Access to and use of the UDMT is free, without any registration (anonymous users). Raw data files are uploaded by the user, who then gets the results and can download them on his/her machine. Graphs are displayed for some UDMT functions. All uploaded and downloaded files are deleted after each use, which ensures that neither data nor information are kept on the virtual machine.

1.3. Files format

Files to be uploaded by the user in the UDMT must be text files saved as csv files, always with the date and time in the first column, in the format "dd-mmm-yyyy HH:MM:SS" (30 July 2022 at 14:45:00 must be written '`30-Jul-2022 14:15:00`'). The corresponding column header must be written '`Time`'. Users using Excel should take care about possible automatic change of date format.

The column separator in csv files must be the semicolon character `;`. The decimal separator in csv files must be the dot (`.`) and not the comma (`,`).

Files must have one and only one line of headers. Several examples are given in this user manual and can be used as templates.

Files of results generated by the UDMT are also csv files following the same rules.

The UDMT assumes that the input files uploaded by the users are correct, which means that the UDMT does not provide check of consistency and validity of the data in the csv files: this remains the full responsibility of the user.

1.4. Pre-requisites

This user manual is not a metrology training course: the user is invited to read chapters of the free open access book "Metrology in Urban Drainage and Stormwater Management: Plug and Pray", edited by Jean-Luc Bertrand-Krajewski, Francois Clemens-Meyer and Mathieu Lepot, at https://doi.org/10.2166/9781789060119, to learn the various methods implemented in the UDMT (theory, detailed examples of applications, Matlab codes).

The following include a few recommended reads as initiation to metrology:

- Uncertainty assessment: Chapter 8, at https://doi.org/10.2166/9781789060119_0263
- Sensor calibration / correlation: Chapter 7, section 7.6, at https://doi.org/10.2166/9781789060119_0203
- Data validation: Chapter 9, at https://doi.org/10.2166/9781789060119_0327
- Tracing experiments: Chapter 3, section 3.4.3, at https://doi.org/10.2166/9781789060119_0035, and also the paper https://doi.org/10.1016/j.flowmeasinst.2014.08.010
- PLS - Partial Least Squares regression: https://doi.org/10.1016/j.watres.2016.05.070

1.5. In case of blockage

In case of blockage of the webapp, the user should use the "cancel" button and return to the main page. If the blockage persists or if the "cancel" button does not work, the user should close the internet window with the webapp and restart from the beginning.

1.6. Contact email

The UDMT contact e-mail address for additional inquiries and/or technical assistance when using the webapp is: UrbanDrainageMetrologyToolbox@gmail.com.

2. Uncertainty assessment

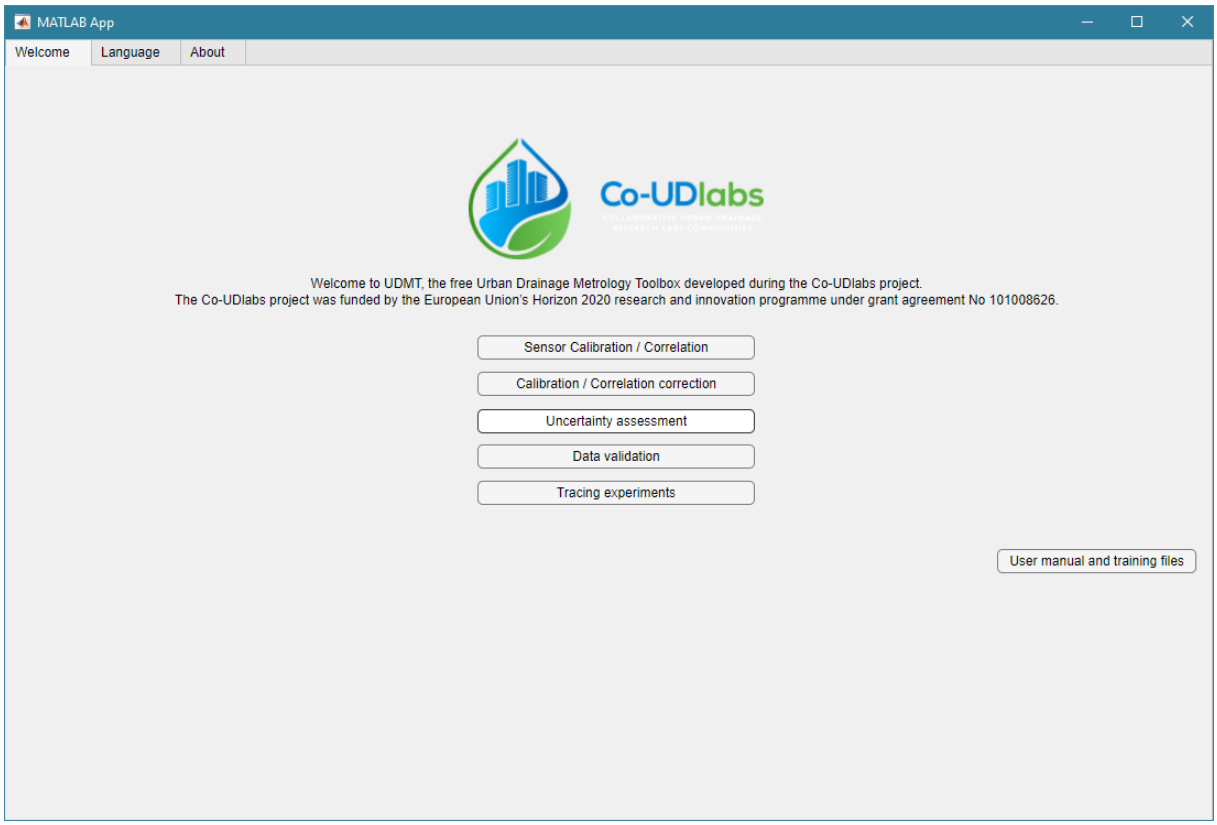

Figure 2.1: UDMT user interface.

Select "Uncertainty assessment" in the menu (Figure 2.1).

2.1. Type A method

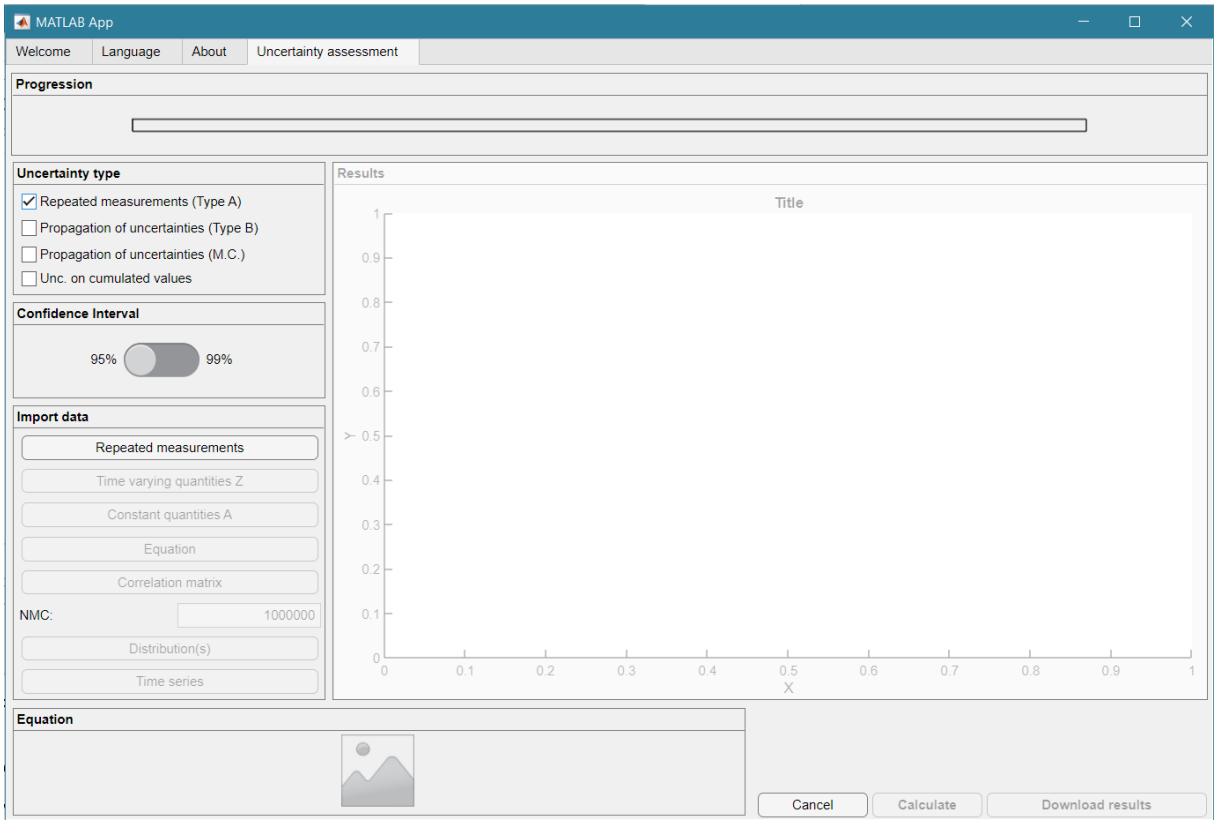

Figure 2.2: UDMT user interface.

Select "Repeated measurements (Type A)" (Figure 2.2).

The Type A method calculates the mean value of a quantity $\bar{Y}$, its standard uncertainty $u(\bar{Y})$ and the corresponding 95% coverage interval $[\bar{Y}_{low}, \bar{Y}_{high}]$ from *N* repeated measurements Y_i with *i* = 1:*N*.

Example: four repeated measurements of a circular pipe diameter *D* (mm).

Import data "Repeated measurements": select the file `dataTypeA.csv` (Table 2.1). Once the file is uploaded, the UDMT display its content in a new window (Figure 2.3): check and click "OK" if this is the right file. If not, click also "OK", then "Cancel" and re-start from the main window.

Table 2.1: File `dataTypeA.csv`.

Time	D_mm
28-Jun-2022 16:00:00	1002
28-Jun-2022 16:00:00	1000
28-Jun-2022 16:00:00	997
28-Jun-2022 16:00:00	1002

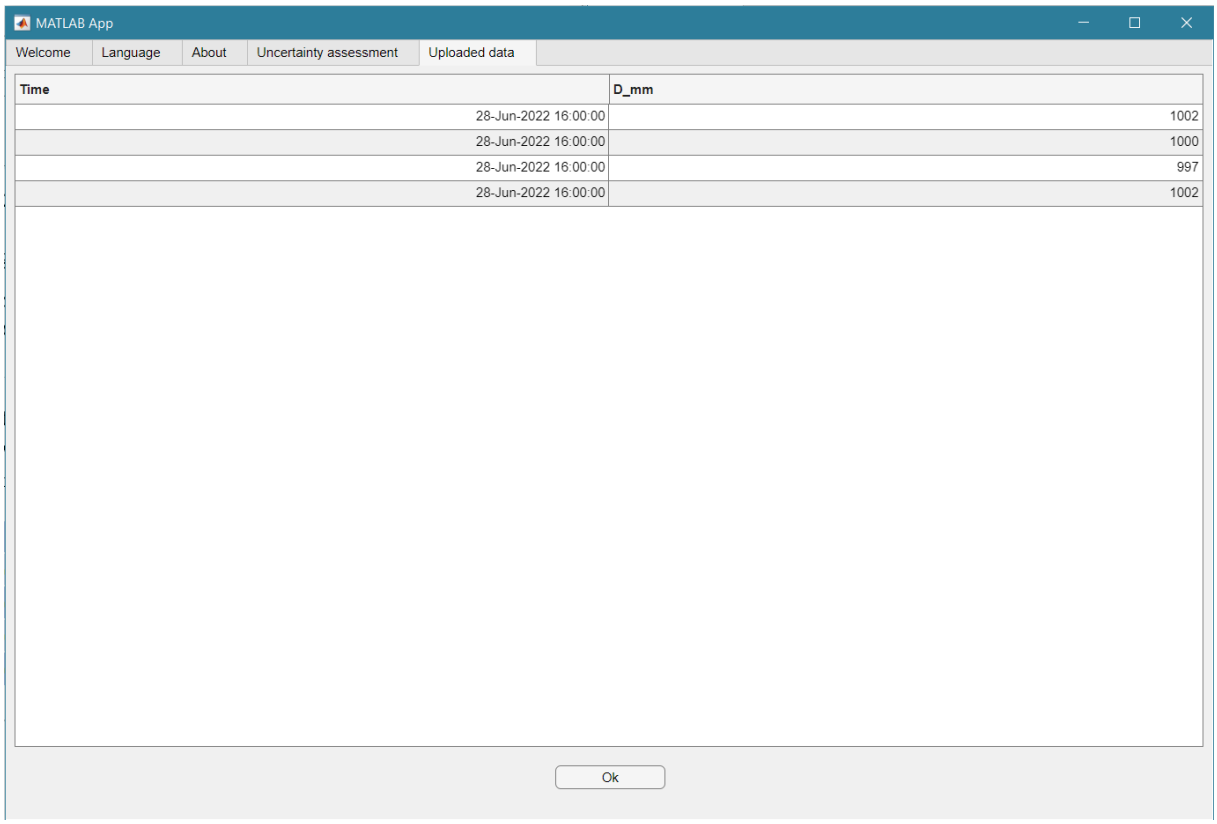

Figure 2.3: File `dataTypeA.csv` as shown by the UDMT.

If the file is the right one, click on “Calculate”. A green progress bar is shown until the calculations are finished (Figure 2.4).

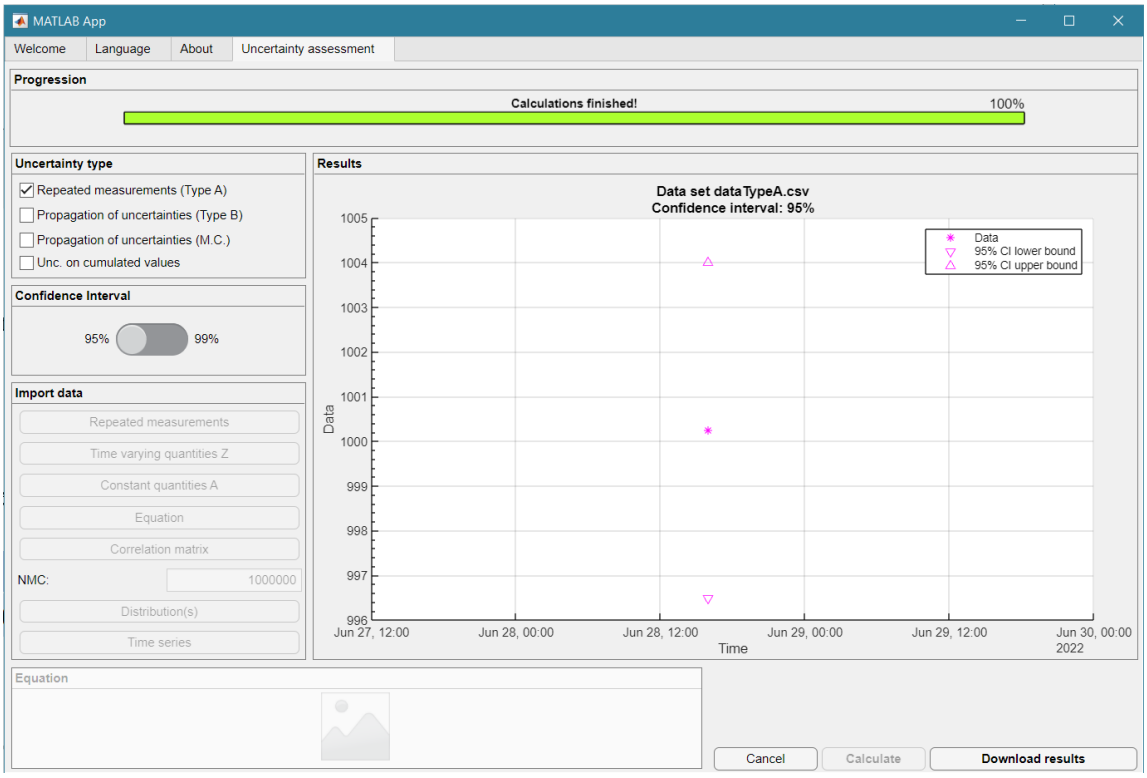

Figure 2.4: Progress bar and display of results.

Click on “Download results”. The tool retrieves (Table 2.2):

Table 2.2: Results of Type A UA example.

Time	Ybar	uYbar	Ybar_low	Ybar_high
28-Jun-2022 16:00:00	1000.3	1.2	996.5	1004.0

Mean value of D = 1000.3 mm, standard uncertainty u(D) = 1.2 mm, 95% coverage interval = [996.5, 1004.0] mm.

2.2. Type B method

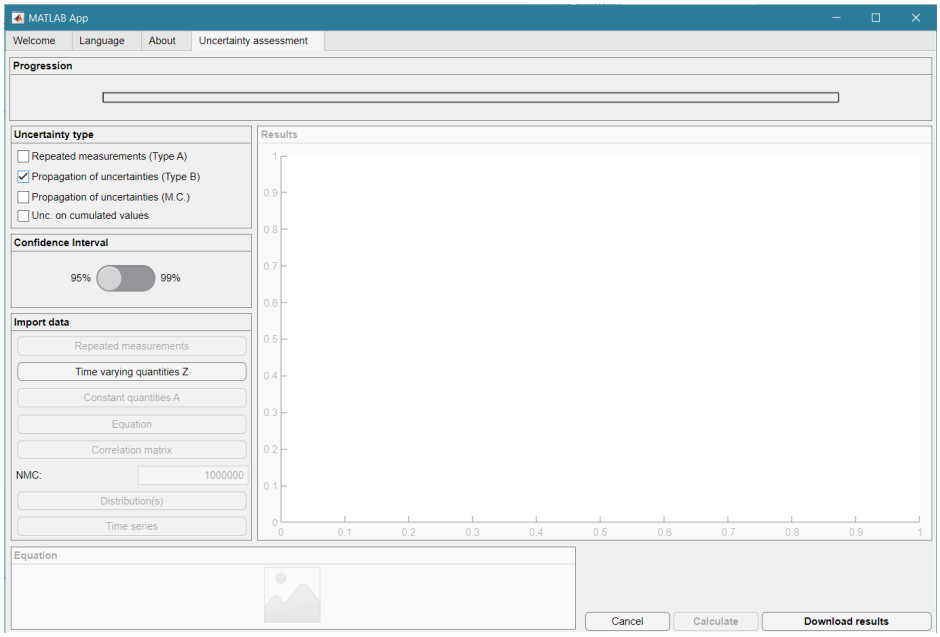

Figure 2.5: UDMT user interface.

Select “Propagation of uncertainties (Type B)” (Figure 2.5).

The Type B method (also named LPU – Law of Propagation of Uncertainties) calculates the quantity Y, its standard uncertainty $u(Y)$ and the corresponding 95% coverage interval $[Y_{low}, Y_{high}]$ from N quantities X_i given with their respective standard uncertainties $u(X_i)$ with i = 1:N. In the UDMT, two groups of quantities X_i are distinguished: i) quantities which vary over time during measurements (e.g. rainfall, water level, turbidity, etc.) and can be uploaded as a multiple lines time series file, named Z_j with j = 1:m, and ii) quantities which are constant during measurements (e.g. pipe diameter, weir angle, channel width, wall roughness, etc.) and are uploaded as a single line file, named A_k with k = 1:p and N = m+p. The user should also provide i) the equation (Box 2.1) calculating Y from all quantities X_i and ii) the correlation matrix between all quantities X_i.

Example: discharge Q (m^3/s) in a circular pipe of radius R_c (m) calculated from the water level h (m) and the mean flow velocity U (m/s), with known standard uncertainties for R_c, h and U.

Import data “Time varying quantities Z”: select the file `Zcp.csv` (Table 2.3).

Table 2.3: File `Zcp.csv`.

Time	h_m	uh_m	U_m_per_s	uU_m_per_s
08-Jul-2022 17:00:00	0.700	0.005	0.80	0.05

Import data "Constant quantities A": select the file `Acp.csv` (Table 2.4).

Table 2.4: File `Acp.csv`.

Time	Rc_m	uRc_m
08-Jul-2022 17:00:00	0.500	0.002

Import data "Equation": select the file eqcp.csv (Table 2.5). See Box 2.1 and Box 2.2 for more information about writing equations for the UDMT.

Table 2.5: File `eqcp.csv`.

equation_for_circular_pipe
Rc.^2.*(acos(1-h./Rc)-(1-h./Rc).*sin(acos(1-h./Rc))).*U

Import data "Correlation matrix": select the file MatCorcp.csv (Table 2.6).

Table 2.6: File `MatCorcp.csv`.

correlation_matrix_for_circular_pipe		
1	0	0
0	1	0
0	0	1

Click on "Calculate".

A green progress bar is shown until the calculations are finished (Figure 2.6).

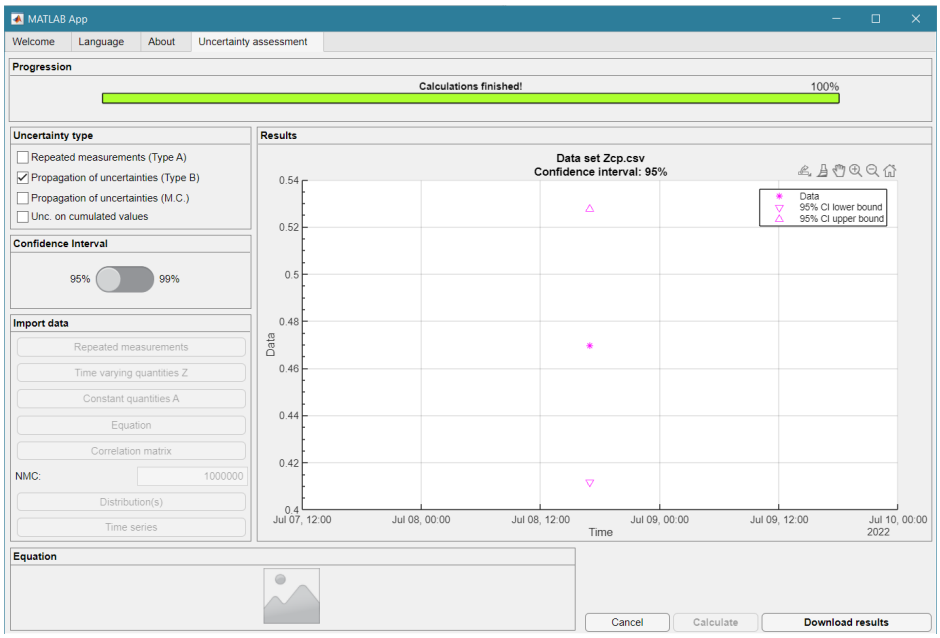

Figure 2.6: Progress bar and display of results.

Click on "Download results". The tool retrieves (Table 2.7):

Table 2.7: Results of Type B UA example.

Time	Ybar	uYbar	Ybar_low	Ybar_high
08-Jul-2022 17:00:00	0.4698	0.0296	0.4117	0.5279

Value of Q = 0.47 m^3/s, standard uncertainty $u(Q)$ = 0.03 m^3/s, 95% coverage interval = [0.41, 0.53] m^3/s.

Box 2.1: How to write equations in csv files for the UDMT?

Equations needed in sections 2.2 (Type B method) and 2.3 (Monte Carlo method) must be written according to specific rules to ensure they are properly used by the UDMT: i) being consistent with headers of Z and A csv files they are related to, and ii) applying Matlab syntax.

Consistency with Z and A csv files headers

Notations used in equations and in headers of Z and A csv files must be consistent. Each quantity in Z and A csv files shall be written as follows, with three parts in a string of characters: *part a*) quantity notation with upper- and/or lower-case letters and numbers, without any space and any other special character including underscore, *part b*) one underscore character to indicate that the rest of the string corresponds to the unit of the quantity, *part c*) after the first underscore, the description of the quantity SI unit with possible additional underscore characters for composed units. Part *a* is mandatory, parts *b* and *c* are optional but strongly recommended to be sure that all units are correct, consistent, and visible in all files.

Example:

In Table 2.3, the Z csv file includes two quantities: the water level h in m and the mean flow velocity U in m/s. According to the above rules, they are written respectively h_m and U_m_per_s. Similarly, in Table 2.4, the A csv file includes one quantity: the radius of the circular pipe R_c in m, which is written Rc_m.

The Matlab code of the UDMT reads the headers of Z and A csv files by applying the above rules to identify each quantity and its notation in front of the first underscore character. The UDMT will thus identify h, U and Rc respectively.

Accordingly, the equation to be written in the equation csv file must use the exact same notations, h, U and Rc respectively, which in addition correspond to usual and easy to understand notations.

Applying Matlab syntax

Equations must be written with the above notations by applying and respecting the Matlab syntax. It is particularly important to use the period character . in front of some operators like ×, /, ^, exponents, etc. for the Z quantities which, as they are considered as time series, are as interpreted as arrays in the Matlab code and not as vectors or matrices. In case of doubt, it is better to add unnecessary period characters (for example for A quantities which are scalars) rather than missing necessary ones.

Example:

The "hand-written" equation used in section 2.2 to calculate the discharge Q in m^3/s from h, U and R_c is

$$Q = R_c{}^2 \left[Arccos\left(1 - \frac{h}{R_c}\right) - \left(1 - \frac{h}{R_c}\right) sin\left(Arccos\left(1 - \frac{h}{R_c}\right)\right)\right] U \qquad \text{eq. 2.1}$$

In the equation csv file, under the line of header describing the equation, the equation must be written (with the left part being omitted) as follows:

```
Rc.^2.*(acos(1-h./Rc)-(1-h./Rc).*sin(acos(1-h./Rc))).*U
```
eq. 2.2

Note the presence of the seven period characters. before the ^, × and / operators. For more information about Matlab syntax, the user may read to the free online Matlab Help Center, in particular the following topics:

- MATLAB Operators and Special Characters
- Elementary Math operators and functions (including trigonometry, exponents and logarithms, etc.)
- Operator Precedence
- Array vs. Matrix Operations

Other recommendations

It is of particular importance to test and verify, for some existing known values, equations written in equation csv files before using them in the UDMT, by carefully checking i) notations, and ii) the positioning and balancing of opening and closing brackets.

Box 2.1: How to write equations to be used for uncertainty assessment in UDMT.

Box 2.2: Examples of equations written in the UDMT format

Manning-Strickler discharge equation for a rectangular channel

written according to the measured values of roughness *K* ($m^{1/3}/s$), slope *I* (m/m), water depth *h* (m) and channel width *B* (m).

Manual format:

$$Q = K\sqrt{I}SR_h^{\frac{2}{3}} = K\sqrt{I}Bh\left(\frac{Bh}{B+2h}\right)^{\frac{2}{3}} = K\sqrt{I}(Bh)^{\frac{5}{3}}(B+2h)^{-\frac{2}{3}} \qquad \text{eq. 2.3}$$

UDMT format:

```
K*sqrt(I).*(B.*h).^(2/3).*(B+2.*h).^(-2/3)
```

eq. 2.4

h is a Z type varying quantity, *K*, *I* and *B* are A type constant quantities.

Hydraulic conductivity K_s (m/s)

estimated from a field test in a rectangular open trench, with *L* (m) the length of the trench, *w* (m) the width of the trench, h_0 (m) the water level at the beginning of the infiltration experiment, *h*(*t*) the water level in the trench at time *t* (s).

Manual format:

$$K_s(t) = \frac{Lw}{2(L+w)t} Log\left(\frac{h(t) + \frac{Lw}{2(L+w)}}{h_0 + \frac{Lw}{2(L+w)}}\right) \qquad \text{eq. 2.5}$$

UDMT format:

```
L.*w/2./(L+w)./t.*log((h+L.*w/2./(L+w))./(h0+L.*w/2./(L+w)))
```

eq. 2.6

h and *t* are Z type varying quantities, *L*, w and h_0 are A type constant quantities.

Box 2.2: Examples of equations written in the UDMT format.

2.3. Monte Carlo method

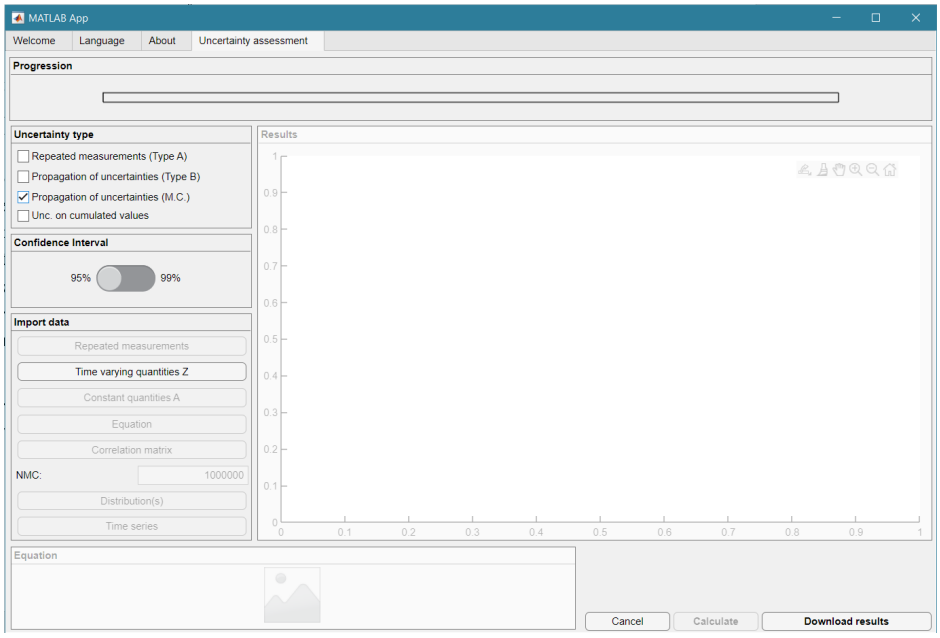

Figure 2.7: UDMT user interface.

Select "Propagation of uncertainties (M.C.)" (Figure 2.7).

The Monte Carlo method (MCM) calculates the quantity Y, its standard uncertainty $u(Y)$ and the corresponding 95% coverage interval $[Y_{low}, Y_{high}]$ from *N* quantities X_i given with their respective standard uncertainties $u(X_i)$ with *i* = 1:*N*. In the UDMT, two groups of quantities X_i are distinguished: i) quantities which vary over time during measurements (e.g. rainfall, water level, turbidity, etc.) and can be uploaded as a multiple lines time series file, named Z_j with *j* = 1:*m*, and ii) quantities which are constant during measurements (e.g. pipe diameter, weir angle, channel width, wall roughness, etc.) and are uploaded as a single line file, named A_k with *k* = 1:*p* and *N* = *m*+*p*. The user should also provide i) the equation (see Box 2.1) giving *Y* from all quantities X_i, ii) the correlation matrix between all quantities X_i., iii) the number of Monte Carlo runs (i.e. the size of the samples) and iv) the distribution (pdf - probability density function) of each X_i (1 for normal pdf, 2 for uniform pdf, 3 for triangular pdf, 0 for no pdf).

Example: discharge *Q* (m^3/s) in a circular pipe of radius R_c (m) calculated from the water level *h* (m) and the mean flow velocity *U* (m/s), with known standard uncertainties for R_c, *h* and *U*.

Import data "Time varying quantities Z": select the file `Zcp.csv` (Table 2.8).

Table 2.8: File `Zcp.csv`.

Time	h_m	uh_m	U_m_per_s	uU_m_per_s
08-Jul-2022 17:00:00	0.700	0.005	0.80	0.05

Import data "Constant quantities A": select the file `Acp.csv` (Table 2.9).

Table 2.9: File `Acp.csv`.

Time	Rc_m	uRc_m
08-Jul-2022 17:00:00	0.500	0.002

Import data “Equation”: select the file `eqcp.csv` (Table 2.10).

Table 2.10: File `eqcp.csv`.

equation_for_circular_pipe
Rc.^2.*(acos(1-h./Rc)-(1-h./Rc).*sin(acos(1-h./Rc))).*U

Import data “Correlation matrix”: select the file `MatCorcp.csv` (Table 2.11).

Table 2.11: File `MatCorcp.csv`.

correlation_matrix_for_circular_pipe		
1	0	0
0	1	0
0	0	1

Choose the number of Monte Carlo runs (default value = 1 million): keep the default value.

Import data “Distribution(s)”: select the file `distribcp.csv` (Table 2.12).

Table 2.12: File `distribcp.csv`.

MCdistrib_for_circular_pipe
1
1
1

All values are assumed to be normally distributed (value = 1).

Click on “Calculate”.

A green progress bar is shown until the calculations are finished (Figure 2.8).

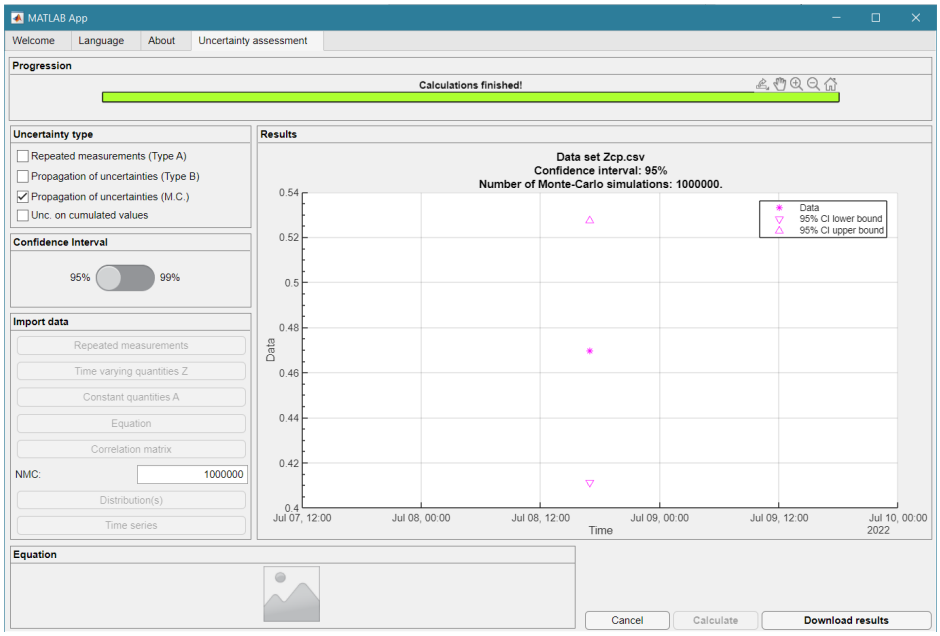

Figure 2.8: Progress bar and display of results.

Click on “Download results”. The tool retrieves (Table 2.13):

Table 2.13: Results of Monte Carlo UA example.

Time	Ybar	uYbar	Ybar_low	Ybar_high
08-Jul-2022 17:00:00	0.4698	0.0297	0.4114	0.5276

Value of Q = 0.47 m^3/s, standard uncertainty $u(Q)$ = 0.03 m^3/s, 95% coverage interval = [0.41, 0.53] m^3/s.

2.4. Uncertainties in cumulated values (sums or means)

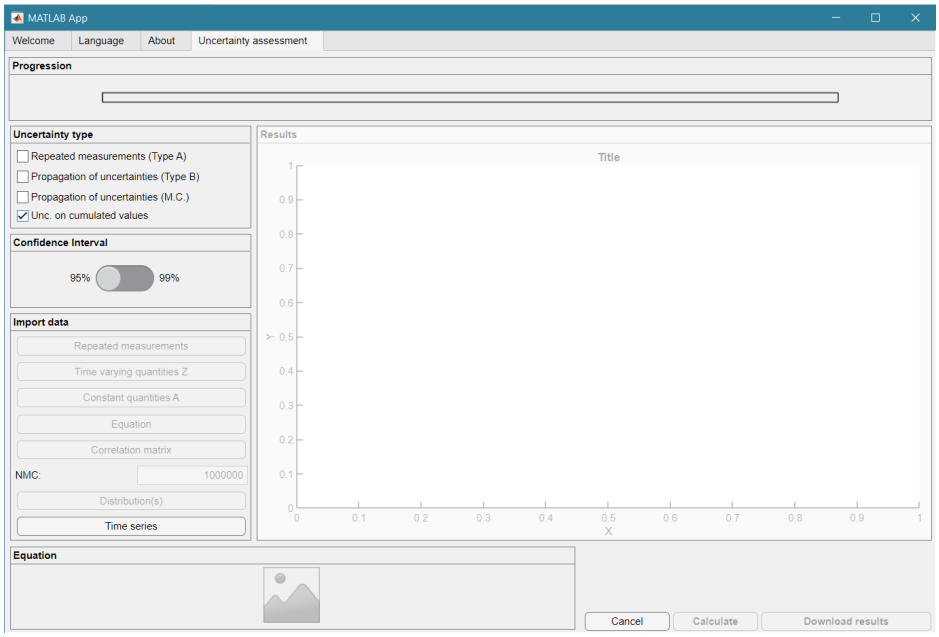

Figure 2.9: UDMT user interface.

Select "Uncertainties on cumulated values" (Figure 2.9).

This function calculates the sum $Y = \sum_{i=1}^{N} x_i$ of a time series of values x_i with i = 1:N given with their standard uncertainties $u(x_i)$ and the resulting standard uncertainty $u(Y)$ obtained with three assumptions about the values x_i in the time series: i) no autocorrelation, ii) full autocorrelation, and iii) partial autocorrelation calculated with the variograph method. The third assumption is the recommended one. By dividing the results by the length of the time series (i.e. the number of x_i values), one can apply the method for calculating the mean of the time series $\bar{x}$ and its standard uncertainty $u(\bar{x})$ with the same three assumptions.

Example: the mean value of measured infiltration hydraulic conductivity K_s (m/s), with its known standard uncertainty $u(K_s)$.

Import data "Time series": select the file `Ksbar.csv` (Table 2.14).

Table 2.14: File `Ksbar.csv`.

Time	Ksbar_m_per_s	uKsbar_m_per_s
06-Jul-2022 08:01:00	3.8901E-05	1.3759E-05
06-Jul-2022 08:02:00	3.9242E-05	6.9475E-06
06-Jul-2022 08:05:00	1.5697E-05	2.7790E-06
06-Jul-2022 08:10:00	1.1877E-05	1.4045E-06
06-Jul-2022 08:15:00	1.0653E-05	9.4724E-07
06-Jul-2022 08:20:00	7.9896E-06	7.1043E-07
06-Jul-2022 08:25:00	8.0629E-06	5.7547E-07
06-Jul-2022 08:45:00	7.3725E-06	3.3358E-07
06-Jul-2022 09:00:00	6.2813E-06	2.5417E-07
06-Jul-2022 09:15:00	5.6389E-06	2.0674E-07
06-Jul-2022 09:30:00	5.2213E-06	1.7531E-07

Click on “Calculate”.

Click on “Download results”. The tool retrieves the following results (Table 2.15 and Figure 2.10):

Table 2.15: Raw results of variograph Type B UA example.

Time	Sum	uSumNoCor	uSumFullCor	uSumVariograph
06-Jul-2022 09:30:00	1.5694E-04	1.5788E-05	2.8093E-05	2.5237E-05

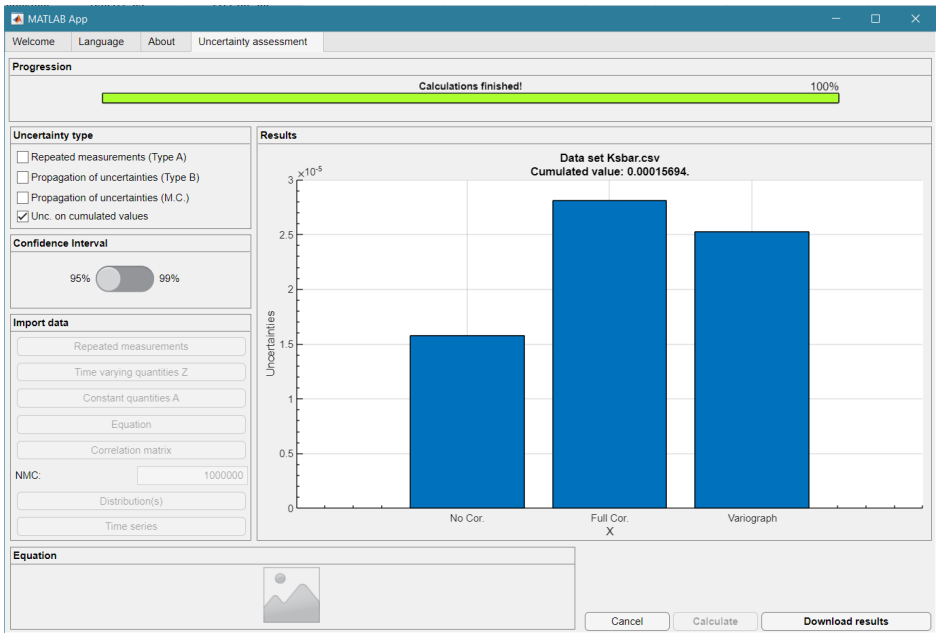

Figure 2.10: Progress bar and display of results.

The above raw results are given for the sum. The mean value of Ks is estimated from 11 values, so the raw results must be divided by 11 to obtain the end results (Table 2.16):

Table 2.16: Final results of variograph Type B UA example for the mean value of $K_{s\ bar}$.

Time	Sum	uSumNoCor	uSumFullCor	uSumVariograph
06-Jul-2022 09:30:00	1.5694E-04	1.5788E-05	2.8093E-05	2.5237E-05
	1.4267E-05	1.4352E-06	2.5539E-06	2.2943E-06

Mean value of $K_{s\ bar}$ = 1.43E-05 m/s, standard uncertainty assuming no autocorrelation in the time series $u(K_{s\ bar\ no\ cor})$ = 1.44E-06 m/s, standard uncertainty assuming full autocorrelation in the time series

$u(K_{s\ bar\ full\ cor})$ = 2.55E-06 m/s, and standard uncertainty assuming partial autocorrelation (variograph method) in the time series $u(K_{s\ bar\ variograph})$ = 2.29E-06 m/s.

Thus, the 95% coverage interval of $K_{s\ bar}$ with the variograph method is:

$[K_{s\ bar\ variograph} - 1.96 * u(K_{s\ bar\ variograph}), K_{s\ bar\ variograph} + 1.96 * u(K_{s\ bar\ variograph})]$ = [0.98, 1.88] E-05 m/s.

3. Sensor calibration / Correlation

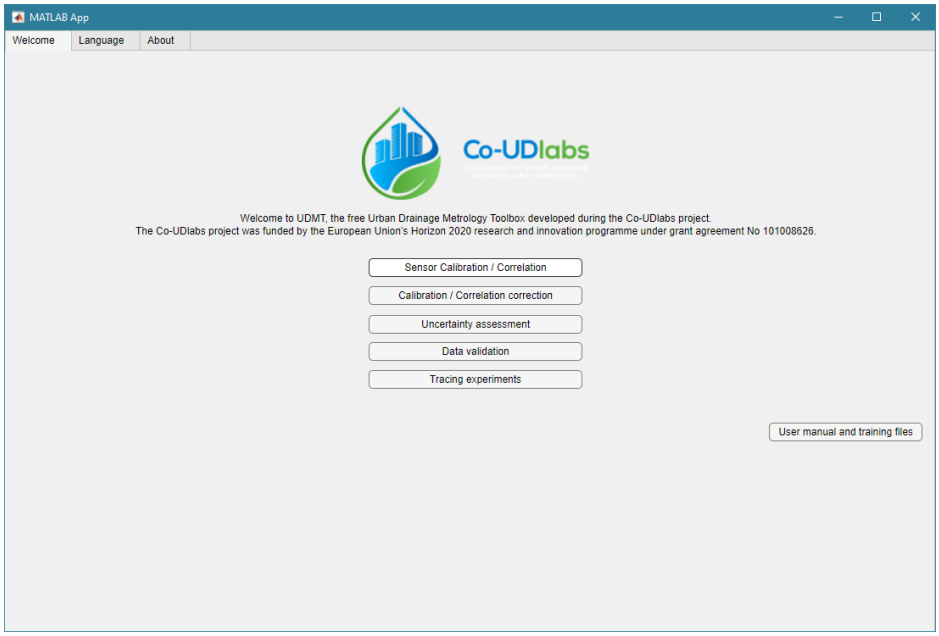

Figure 3.11: UDMT user interface.

Select "Sensor calibration / Correlation" in the menu (Figure 3.1).

Sensor calibration aims establishing a calibration function $y = f(x)$ between standard or references values x and the corresponding sensor outputs y. To estimate the sensor uncertainty $u(y)$, it is recommended to do N_y repeated measurements y_{ik} with $k = 1{:}N_y$ for each standard or reference value x_i with $i = 1{:}N_x$. Calibration functions are usually 1st to 3rd order polynomial functions (sections 3.1 and 3.2) or power functions (section 3.3). Variance tests allow choosing the optimal degree of polynomial functions. If uncertainties in x_i values are negligible or very low compared to uncertainties in y_{ik} values, ordinary least squares (OLS) regression is applicable. If this is not the case, Williamson least squares (WLS) regression should be applied. Once the calibration function is determined, raw values measured by the sensor y_m are converted to most likely true values $\hat{x}$ by using the reciprocal calibration function $\hat{x} = f^{-1}(y_m)$, with their standard uncertainties $u(\hat{x})$ and corresponding 95% coverage intervals (see sections 4.1 and 4.2).

Sensor correlation aims establishing a correlation function $y = f(x)$ between values x given by a sensor and corresponding values y obtained from sampling and laboratory analyses. For example, between turbidity values y of samples given by a turbidity sensor and TSS (total suspended solids) concentrations x obtained from laboratory analyses of the exact same samples. The correlation function is established with couples of data (x_i, y_i) with $i = 1{:}N$. Correlation functions are usually 1st to 3rd order polynomial functions (sections 3.4 and 3.5). Variance tests allow choosing the optimal degree

of polynomial functions. If uncertainties in (x_i, y_i) values are ignored, ordinary least squares (OLS) regression is applicable (section 3.4). If uncertainties in (x_i, y_i) are accounted for (recommended case), Williamson least squares (WLS) regression should be applied (section 3.5). Once the correlation function is determined, raw values x_m measured by the sensor are converted to most likely true values $\hat{y}$ of the pollutant of interest by using the correlation function $\hat{y} = f(x_m)$, with their standard uncertainties $u(\hat{y})$ and corresponding 95% coverage intervals (see section 4.3).

3.1. Sensor calibration (polynomial function, ordinary least squares)

Example: basic calibration of a turbidity meter with 8 NIST standard solutions (25 repeated measurements) over the range 0 - 3000 NTU, with ordinary least squares (OLS) regression and free intercept.

Import data "Select": select the file `TurbiDoua25CoUD.csv` (Table 3.1).

Table 3.17: File `TurbiDoua25CoUD.csv`.

Time	xi	u_xi	yi1	yi2	yi3	yi4	yi5	yi6	yi7	yi8	yi9	yi10	yi11
21-Jan-2014 10:00:00	0	0.1	7.81	7.81	7.81	8.78	7.81	7.81	7.81	7.81	7.81	7.81	7.81
21-Jan-2014 10:00:00	50	0.25	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66
21-Jan-2014 10:00:00	100	0.5	105.47	104.49	104.49	104.49	104.49	105.47	105.47	105.47	104.49	105.47	105.47
21-Jan-2014 10:00:00	300	1.5	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69
21-Jan-2014 10:00:00	500	2.5	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	501.96	501.96
21-Jan-2014 10:00:00	1000	5	1005.87	1007.82	1005.87	1005.87	1007.82	1007.82	1005.87	1005.87	1007.82	1007.82	1005.87
21-Jan-2014 10:00:00	2000	10	2158.23	2157.25	2156.28	2157.27	2157.25	2157.25	2158.23	2150.42	2147.49	2150.42	2151.39
21-Jan-2014 10:00:00	3000	15	3938.53	3935.6	3935.6	3937.56	3935.6	3938.53	3939.51	3939.51	3938.53	3937.56	3937.56

yi12	yi13	yi14	yi15	yi16	yi17	yi18	yi19	yi20	yi21	yi22	yi23	yi24	yi25
7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	8.78	7.81	8.78
55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	53.71	53.71	55.66
105.47	105.47	104.49	105.47	105.47	105.47	105.47	104.49	104.49	105.47	105.47	105.47	104.49	105.47
304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69
501.96	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93
1005.87	1004.89	1005.89	1004.89	1005.87	1005.87	1007.82	1004.89	1005.87	1007.82	1005.87	1005.87	1004.89	1005.87
2151.39	2151.39	2151.42	2151.39	2152.39	2150.42	2148.47	2151.39	2150.42	2150.42	2151.39	2151.42	2148.47	2148.47
3935.6	3938.53	3939.53	3938.53	3937.56	3935.6	3935.6	3934.63	3933.65	3933.65	3933.65	3932.67	3930.72	3929.74

Move the circular button to the left, on "Calibration". Select your method: choose "Ordinary least squares". Force to 0: don't tick the box (as we apply a free intercept calibration function) (Figure 3.2).

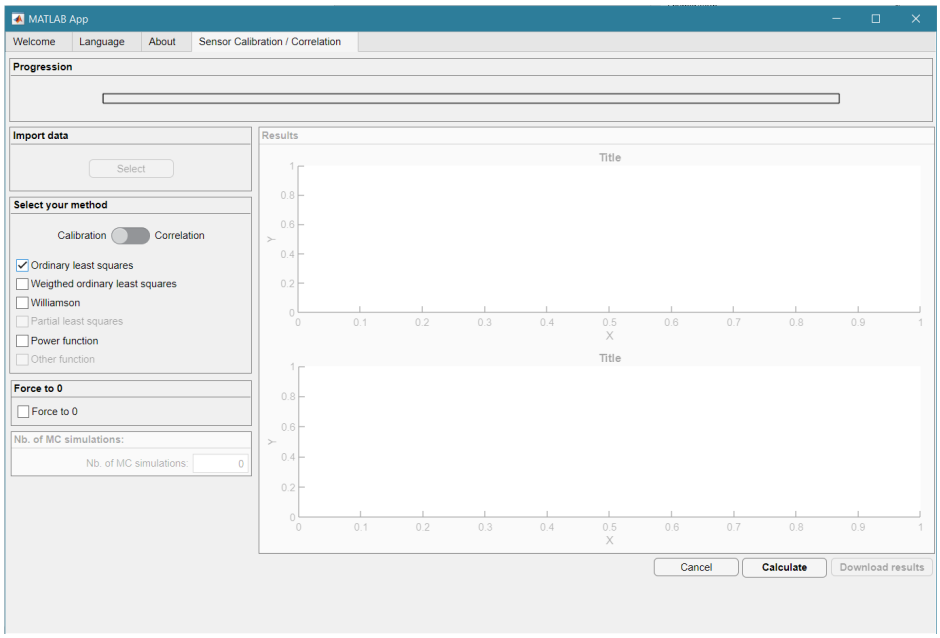

Figure 3.12: UDMT user interface.

Click on “Calculate”.

The tool retrieves (Figure 3.3):

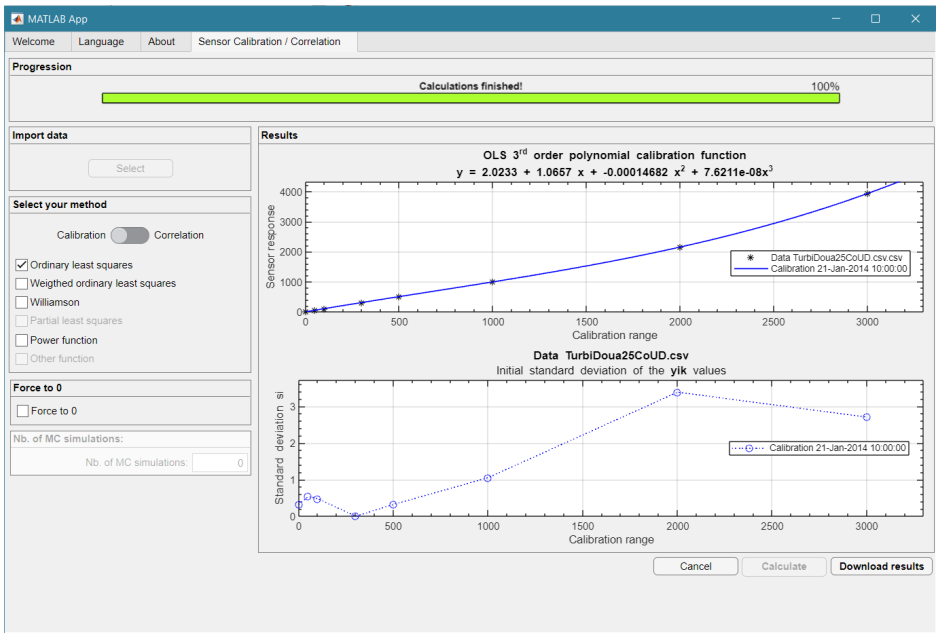

Figure 3.13: UDMT user interface.

According to the applied variance test, the recommended calibration function is a 3rd order polynomial function, with the following equation given in the upper graph:

$$y = 2.0233 + 1.0657\,x - 0.00014682\,x^2 + 7.6211E - 08\,x^3 \qquad \text{eq. 3.7}$$

The lower graph shows the standard deviation of the 25 repeated measurements for each standard solution: this is used to estimate the sensor standard uncertainty.

Click on “Download results”: the tool retrieves a text file containing all the detailed results of the calibration. Save this file as `TurbiDoua25CoUDCalFun.csv` for later use in section 4.1.

After transposition for easier display and readability, the text file of this example is shown hereafter, with added comments in the right column with light grey background (Table 3.2).

Table 3.18: Results of OLS sensor calibration example (free intercept).

Time	21-janv-2014 10:00:00	Comments
DegOpt	3	Recommended optimal degree of the polynomial function. Can be changed (1, 2 ou 3) by the user.
deg 1	1	Following lines are for the 1st order polynomial function b11 + b12 x
b11	-84.46578957	b11 value
b12	1.2585037	b12 value
u_b11	14.2809029	standard uncertainty in b11
u_b12	0.010661956	standard uncertainty in b12
var_b11_b12	-0.098757158	covariance (b11, b12)
ResVar1	23629.78138	residual variance
deg 2	2	Following lines are for the 2nd order polynomial function b21 + b22 x + b23 x^2
b21	42.92451182	b21 value
b22	0.725318075	b22 value
b23	0.000187181	b23 value
u_b21	5.18082159	standard uncertainty in b21
u_b22	0.012429954	standard uncertainty in b22
u_b23	4.21E-06	standard uncertainty in b23
var_b21_b22	-0.04344897	covariance (b21, b22)
var_b21_b23	1.21E-05	covariance (b21, b23)
var_b22_b23	-5.06E-08	covariance (b22, b23)
ResVar2	2156.626829	residual variance
deg 3	3	Following lines are for the 3rd order polynomial function b31 + b32 x + b33 x^2 + b34 x^3
b31	2.02328915	b31 value
b32	1.065716078	b32 value
b33	-0.000146824	b33 value
b34	7.62E-08	b34 value
u_b31	0.669166843	standard uncertainty in b31
u_b32	0.003078655	standard uncertainty in b32
u_b33	2.73E-06	standard uncertainty in b33
u_b34	6.14E-10	standard uncertainty in b34
var_b31_b32	-0.001453267	covariance (b31, b32)
var_b31_b33	1.04E-06	covariance (b31, b33)
var_b31_b34	-2.02E-10	covariance (b31, b34)
var_b32_b33	-8.02E-09	covariance (b32, b33)
var_b32_b34	1.68E-12	covariance (b32, b34)
var_b33_b34	-1.65E-15	covariance (b33, b34)
ResVar3	27.24824254	residual variance
maxStd	3.387467983	Maximum standard deviation of the repeated mesurement during the calibration experiment

Repeat the calculations with a zero intercept, by ticking the box “Force to 0”, and then click on “Calculate”. The tool retrieves the results shown in Figure 3.4.

According to the applied variance test, the recommended calibration function is again a 3rd order polynomial function, with the following equation given in the upper graph:

$$y = 1.0723\,x - 0.00015152\,x^2 + 7.7126E - 08\,x^3 \qquad \text{eq. 3.8}$$

Click on “Download results”: the tool retrieves a text file containing all the detailed results of the calibration. After transposition for easier display and readability, the text file of this example is shown hereafter, with added comments in the right column with light grey background (Table 3.3).

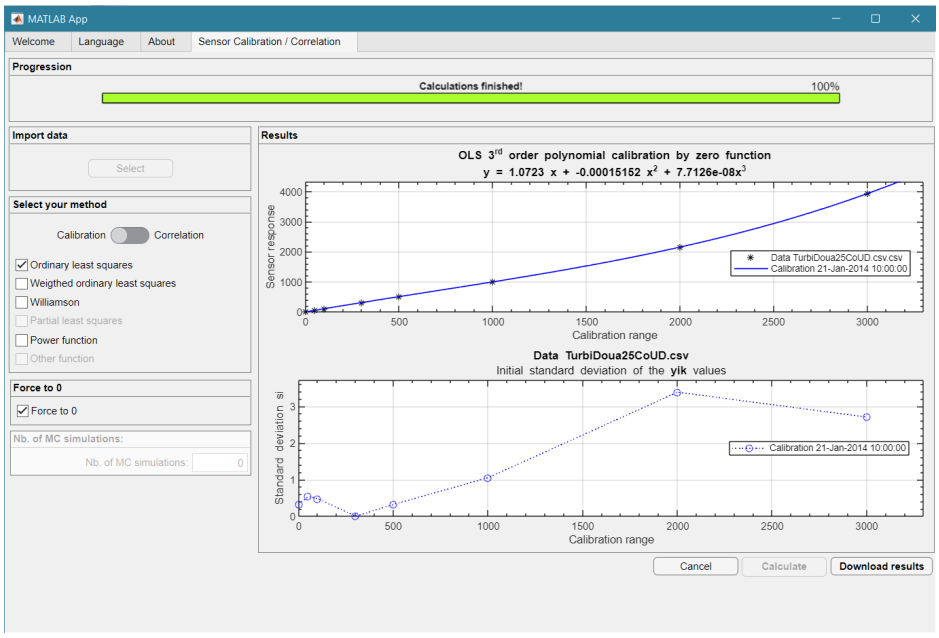

Figure 3.14: UDMT user interface.

Table 3.19: Results of OLS sensor calibration example (forced zero intercept).

Time	21-janv-2014 10:00:00	Comments
DegOpt	3	Recommended optimal degree of the polynomial function. Can be changed (1, 2 ou 3) by the user.
deg 1	1	Following lines are for the 1st order polynomial function b11 + b12 x
b11	0	b11 value
b12	1.217602308	b12 value
u_b11	0	standard uncertainty in b11
u_b12	0.008780741	standard uncertainty in b12
var_b11_b12	0	covariance (b11, b12)
ResVar1	27664.94785	residual variance
deg 2	2	Following lines are for the 2nd order polynomial function b21 + b22 x + b23 x^2
b21	0	b21 value
b22	0.794802517	b22 value
b23	0.000167848	b23 value
u_b21	0	standard uncertainty in b21
u_b22	0.010626699	standard uncertainty in b22
u_b23	4.07E-06	standard uncertainty in b23
var_b21_b22	0	covariance (b21, b22)
var_b21_b23	0.00E+00	covariance (b21, b23)
var_b22_b23	-4.16E-08	covariance (b22, b23)
ResVar2	2893.427695	residual variance
deg 3	3	Following lines are for the 3rd order polynomial function b31 + b32 x + b33 x^2 + b34 x^3
b31	0	b31 value
b32	1.072282586	b32 value
b33	-0.000151524	b33 value
b34	7.71E-08	b34 value
u_b31	0	standard uncertainty in b31
u_b32	0.002226746	standard uncertainty in b32
u_b33	2.29E-06	standard uncertainty in b33
u_b34	5.45E-10	standard uncertainty in b34
var_b31_b32	0	covariance (b31, b32)
var_b31_b33	0.00E+00	covariance (b31, b33)
var_b31_b34	0.00E+00	covariance (b31, b34)
var_b32_b33	-4.84E-09	covariance (b32, b33)
var_b32_b34	1.07E-12	covariance (b32, b34)
var_b33_b34	-1.23E-15	covariance (b33, b34)
ResVar3	28.37442808	residual variance
maxStd	3.387467983	Maximum standard deviation of the repeated mesurement during the calibration experiment

3.2. Sensor calibration (polynomial function, Williamson least squares)

Example: advanced calibration of a turbidity meter with 8 NIST standard solutions (25 repeated measurements) over the range 0 - 3000 NTU, with Williamson least squares (WLS) regression to account for the uncertainty in standard solutions, and with free intercept.

Note 1: the Williamson regression with hundreds or thousands of Monte Carlo runs can last a long time, be patient.

Import data "Select": select the file `TurbiDoua25CoUD.csv` (Table 3.4).

Table 3.20: File `TurbiDoua25CoUD.csv` (uncertainties in NIST standard solutions are given in column 3).

Time	xi	u_xi	yi1	yi2	yi3	yi4	yi5	yi6	yi7	yi8	yi9	yi10	yi11
21-Jan-2014 10:00:00	0	0.1	7.81	7.81	7.81	8.78	7.81	7.81	7.81	7.81	7.81	7.81	7.81
21-Jan-2014 10:00:00	50	0.25	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66
21-Jan-2014 10:00:00	100	0.5	105.47	104.49	104.49	104.49	104.49	105.47	105.47	105.47	104.49	105.47	105.47
21-Jan-2014 10:00:00	300	1.5	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69
21-Jan-2014 10:00:00	500	2.5	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	501.96	501.96
21-Jan-2014 10:00:00	1000	5	1005.87	1007.82	1005.87	1005.87	1007.82	1007.82	1005.87	1005.87	1007.82	1007.82	1005.87
21-Jan-2014 10:00:00	2000	10	2158.23	2157.25	2156.28	2157.27	2157.25	2157.25	2158.23	2150.42	2147.49	2150.42	2151.39
21-Jan-2014 10:00:00	3000	15	3938.53	3935.6	3935.6	3937.56	3935.6	3938.53	3939.51	3939.51	3938.53	3937.56	3937.56

yi12	yi13	yi14	yi15	yi16	yi17	yi18	yi19	yi20	yi21	yi22	yi23	yi24	yi25
7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	8.78	7.81	8.78
55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	55.66	53.71	53.71	55.66
105.47	105.47	104.49	105.47	105.47	105.47	105.47	104.49	104.49	105.47	105.47	105.47	104.49	105.47
304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69	304.69
501.96	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93	502.93
1005.87	1004.89	1005.89	1004.89	1005.87	1005.87	1007.82	1004.89	1005.87	1007.82	1005.87	1005.87	1004.89	1005.87
2151.39	2151.39	2151.42	2151.39	2152.39	2150.42	2148.47	2151.39	2150.42	2150.42	2151.39	2151.42	2148.47	2148.47
3935.6	3938.53	3939.53	3938.53	3937.56	3935.6	3935.6	3934.63	3933.65	3933.65	3933.65	3932.67	3930.72	3929.74

Move the circular button to the left, on "Calibration".

Select your method: choose "Williamson".

Force to 0: don't tick the box (as we apply a free intercept calibration function).

Set the number of Monte Carlo simulations to 500 which is the default minimum value (Figure 3.5).

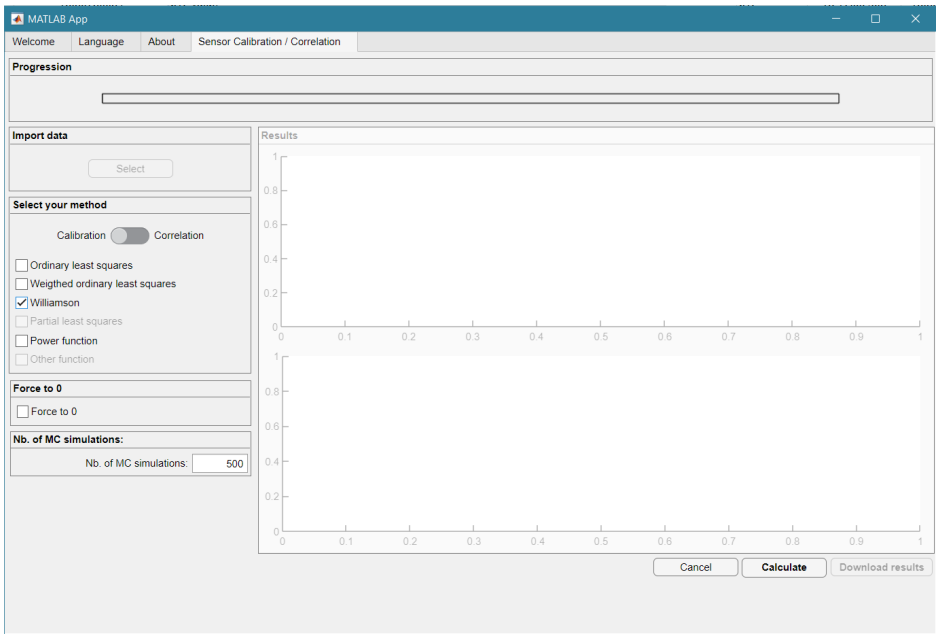

Figure 3.15: UDMT user interface.

Click on "Calculate".

The tool retrieves (Figure 3.6):

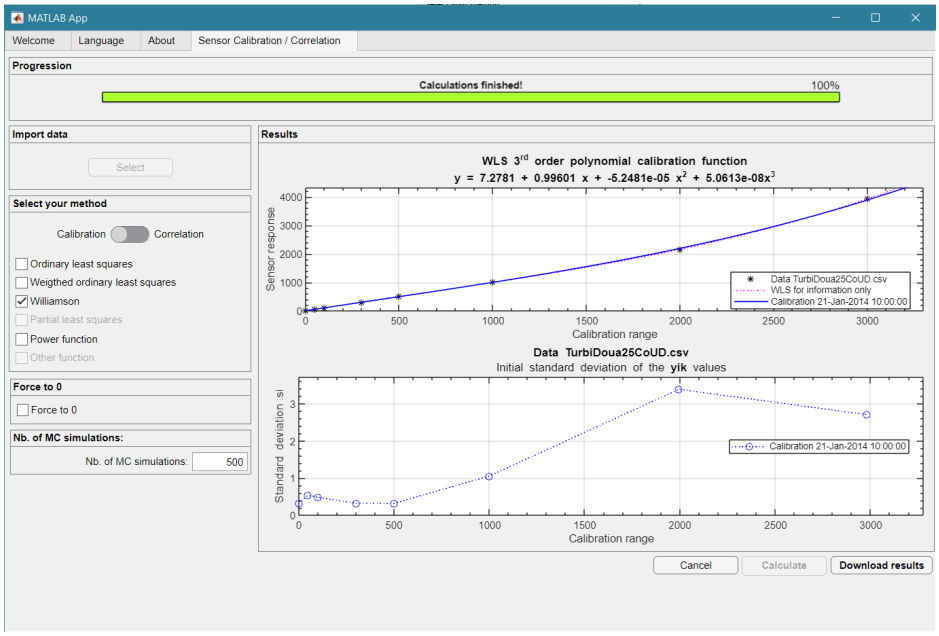

Figure 3.16: UDMT user interface.

According to the applied variance test, the recommended calibration function is a 3rd order polynomial function, with the following equation given in the upper graph:

$$y = 7.2781 + 0.99601\,x - 5.2481E - 05\,x^2 + 5.06013E - 08\,x^3 \qquad \text{eq. 3.9}$$

Note 2: the Williamson regression with Monte Carlo runs will provide results which slightly differ in each case, this is due to the random nature of the method.

The lower graph shows the standard deviation of the 25 repeated measurements for each standard solution: this is used to estimate the sensor standard uncertainty.

Click on "Download results": the tool retrieves a text file containing all the detailed results of the calibration. Save this file as `TurbiDoua25CoUDCalFunWLS.csv` for later use in section 4.1.

After transposition for easier display and readability, the text file of this example is shown hereafter, with added comments in the right column with light grey background (Table 3.5). Repeat the calculations with a zero intercept, by ticking the box "Force to 0", and then click on "Calculate". The tool retrieves the results shown in Figure 3.7.

Table 3.21: Results of WLS sensor calibration example (free intercept).

Time	21-janv-2014 10:00:00	Comments
DegOpt	3	Recommended optimal degree of the polynomial function. Can be changed (1, 2 ou 3) by the user.
deg 1	1	Following lines are for the 1st order polynomial function b11 + b12 x
b11	3.926417367	b11 value
b12	1.080786684	b12 value
u_b11	2.455302869	standard uncertainty in b11
u_b12	0.043595974	standard uncertainty in b12
var_b11_b12	-0.045700682	covariance (b11, b12)
ResVar1	61186.9791	residual variance
deg 2	2	Following lines are for the 2nd order polynomial function b21 + b22 x + b23 x^2
b21	8.580363604	b21 value
b22	0.933336995	b22 value
b23	0.000103556	b23 value
u_b21	0.671845672	standard uncertainty in b21
u_b22	0.018278922	standard uncertainty in b22
u_b23	1.40E-05	standard uncertainty in b23
var_b21_b22	-0.006354999	covariance (b21, b22)
var_b21_b23	2.05E-06	covariance (b21, b23)
var_b22_b23	-1.64E-07	covariance (b22, b23)
ResVar2	7441.626438	residual variance
deg 3	3	Following lines are for the 3rd order polynomial function b31 + b32 x + b33 x^2 + b34 x^3
b31	7.278133724	b31 value
b32	0.996009433	b32 value
b33	-5.24806E-05	b33 value
b34	5.06E-08	b34 value
u_b31	0.272629496	standard uncertainty in b31
u_b32	0.010848352	standard uncertainty in b32
u_b33	2.26E-05	standard uncertainty in b33
u_b34	7.84E-09	standard uncertainty in b34
var_b31_b32	-0.00158079	covariance (b31, b32)
var_b31_b33	2.08E-06	covariance (b31, b33)
var_b31_b34	-6.12E-10	covariance (b31, b34)
var_b32_b33	-1.99E-07	covariance (b32, b33)
var_b32_b34	5.85E-11	covariance (b32, b34)
var_b33_b34	-1.68E-13	covariance (b33, b34)
ResVar3	509.6879308	residual variance
maxStd	3.387467983	Maximum standard deviation of the repeated mesurement during the calibration experiment
NMC	500	Number of Monte Carlo runs
PreRel	1.00E-02	Relative precision of the bij coefficients for each MC run. Default value is 1e-2
silim	1.00E-06	Minimum significant variance. Default value is 1e-6

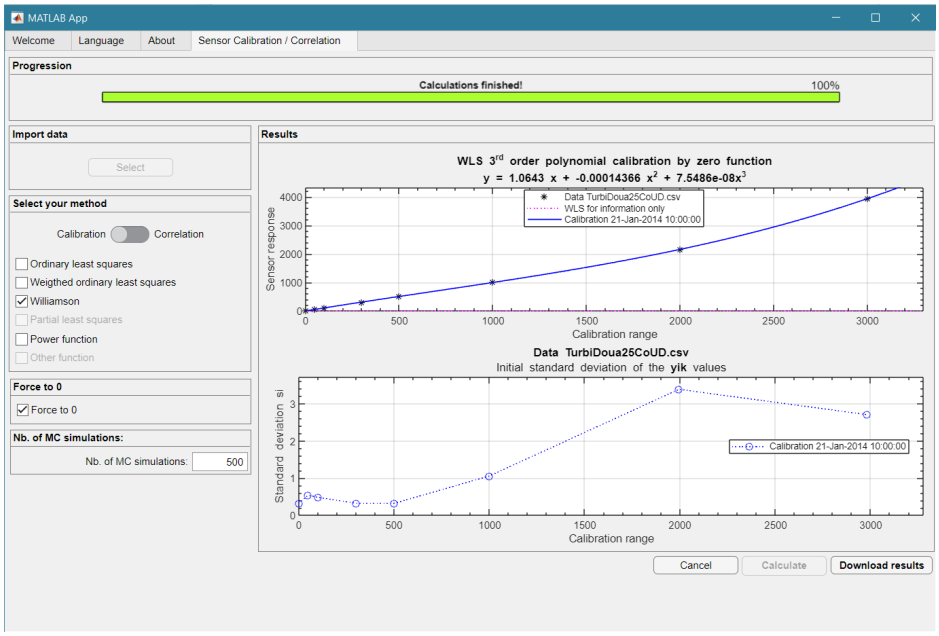

Figure 3.17: UDMT user interface.

According to the applied variance test, the recommended calibration function is again a 3rd order polynomial function, with the following equation given in the upper graph:

$$y = 1.0643\,x - 0.00014366\,x^2 + 7.5486E - 08\,x^3 \qquad \text{eq. 3.10}$$

Click on "Download results": the tool retrieves a text file containing all the detailed results of the calibration. After transposition for easier display and readability, the text file of this example is shown hereafter, with added comments in the right column with light grey background (Table 3.6).

Table 3.22: Results of sensor WLS calibration example (forced zero intercept).

Time	21-janv-2014 10:00:00	Comments
DegOpt	3	Recommended optimal degree of the polynomial function. Can be changed (1, 2 ou 3) by the user.
deg 1	1	Following lines are for the 1st order polynomial function b11 + b12 x
b11	0	b11 value
b12	1.091913236	b12 value
u_b11	0	standard uncertainty in b11
u_b12	0.043021393	standard uncertainty in b12
var_b11_b12	0	covariance (b11, b12)
ResVar1	56149.50826	residual variance
deg 2	2	Following lines are for the 2nd order polynomial function b21 + b22 x + b23 x^2
b21	0	b21 value
b22	0.983342261	b22 value
b23	8.31086E-05	b23 value
u_b21	0	standard uncertainty in b21
u_b22	0.034338297	standard uncertainty in b22
u_b23	2.60E-05	standard uncertainty in b23
var_b21_b22	0	covariance (b21, b22)
var_b21_b23	0.00E+00	covariance (b21, b23)
var_b22_b23	-5.40E-07	covariance (b22, b23)
ResVar2	10367.72632	residual variance
deg 3	3	Following lines are for the 3rd order polynomial function b31 + b32 x + b33 x^2 + b34 x^3
b31	0	b31 value
b32	1.064310725	b32 value
b33	-0.000143657	b33 value
b34	7.55E-08	b34 value
u_b31	0	standard uncertainty in b31
u_b32	0.036398054	standard uncertainty in b32
u_b33	8.24E-05	standard uncertainty in b33
u_b34	3.06E-08	standard uncertainty in b34
var_b31_b32	0	covariance (b31, b32)
var_b31_b33	0.00E+00	covariance (b31, b33)
var_b31_b34	0.00E+00	covariance (b31, b34)
var_b32_b33	-2.38E-06	covariance (b32, b33)
var_b32_b34	7.34E-10	covariance (b32, b34)
var_b33_b34	-2.38E-12	covariance (b33, b34)
ResVar3	31.45428926	residual variance
maxStd	3.387467983	Maximum standard deviation of the repeated mesurement during the calibration experiment
NMC	500	Number of Monte Carlo runs
PreRel	1.00E-02	Relative precision of the bij coefficients for each MC run. Default value is 1e-2
silim	1.00E-06	Minimum significant variance. Default value is 1e-6

3.3. Sensor calibration (power function, non-linear regression)

Example: calibration of a tipping bucket raingauge. For each true rainfall intensity I_t (mm/h) generated by a peristaltic pump, three repeated measurement of the rainfall intensity observed by the raingauge I_m are recorded.

Import data "Select": select the file `PowCal004.csv` (Table 3.7).

Table 3.23: File `PowCal004.csv`.

Time	It	uIt	Im1	Im2	Im3
11-Jan-2021 10:00	10.95	0.063219855	10.95	10.675	11.025
11-Jan-2021 10:00	27.6	0.159348674	27	26.25	27.25
11-Jan-2021 10:00	44.4	0.25634352	41.425	42	40.575
11-Jan-2021 10:00	63.75	0.368060797	56.7	57.3	57.025
11-Jan-2021 10:00	80.575	0.46519998	70.2	70.6	69.125
11-Jan-2021 10:00	102.5	0.591784026	86.5	85.675	86.95

Move the circular button to the left, on “Calibration”.

Select your method: choose “Power function”.

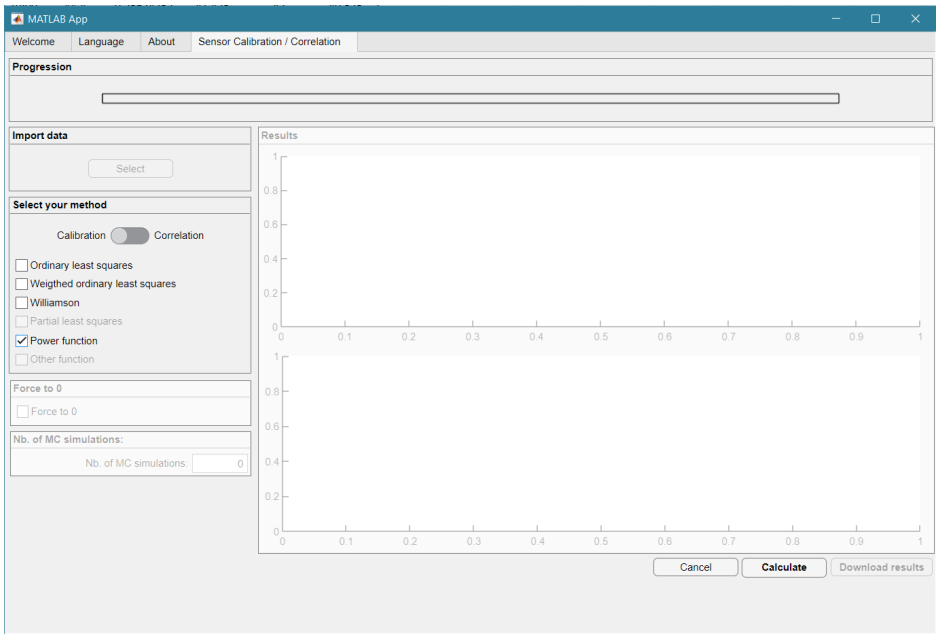

Figure 3.18: UDMT user interface.

Click on “Calculate”. The tool retrieves Figure 3.9.

The equation of the power calibration function is given in the upper graph:

$$I_m = 1.3774\, I_t^{0.89466} \qquad \text{eq. 3.11}$$

The lower graph shows the standard deviation of the 3 repeated measurements for each true intensity: this is used to estimate the sensor standard uncertainty.

Click on “Download results”: the tool retrieves a text file containing all the detailed results of the calibration. Save this file as `PowCal004_Function-Data.csv` for later use in section 4.2.

After transposition for easier display and readability, the text file of this example is shown hereafter, with added comments in the right column with light grey background (Table 3.8).

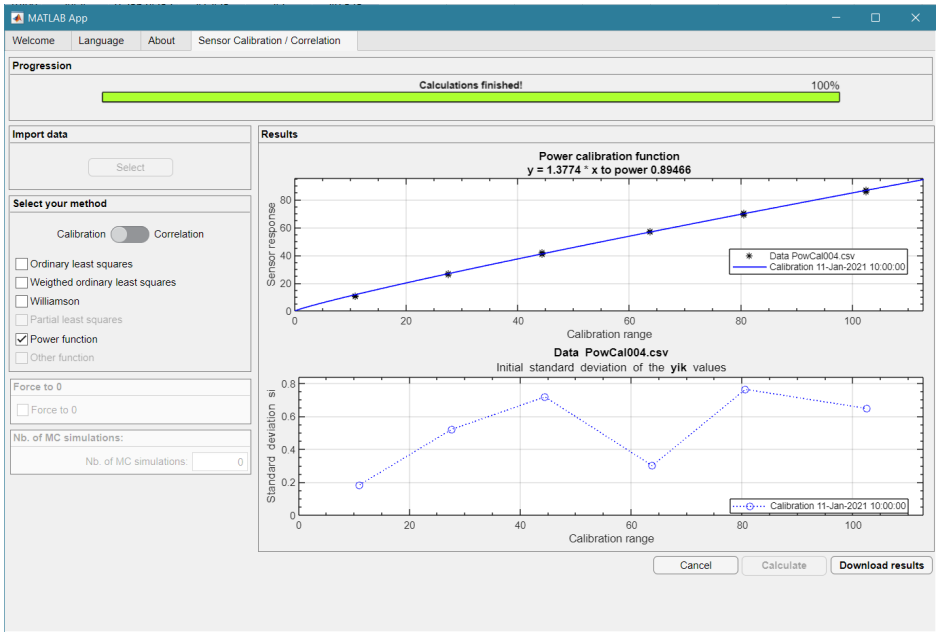

Figure 3.19: UDMT user interface.

Table 3.24: Results of power function calibration example.

Time	11-Jan-2021 10:00:00	Comments for power function b1 x^b2
b1	1.37744131	b1 value
b2	0.89466092	b2 value
u_b1	0.04510936	standard uncertainty in b1
u_b2	0.00752719	standard uncertainty in b2
var_b1_b2	-0.00033830	covariance (b1, b2)
MSE	0.42954811	residual variance
maxStd	0.76280732	Maximum standard deviation of the repeated mesurement during the calibration experiment

3.4. Sensor correlation (polynomial function, ordinary least squares)

Example: basic correlation between turbidity (noted TU) and TSS (total suspended solids) concentration, with standard uncertainties known for both turbidity and TSS concentration, with ordinary least squares (OLS) regression and free intercept.

Import data "Select": select the file `testcorrela.csv` (Table 3.9).

Table 3.25: File `testcorrela.csv`.

Time	TU	u_TU	TSS	u_TSS
08-Apr-2022 18:00:00	119.6412	5.978996571	273.9482	15.2103456
08-Apr-2022 18:00:00	87.3464	5.930354121	154.7512	10.22396047
08-Apr-2022 18:00:00	61.8733	6.028988307	139.2235	19.34328526
08-Apr-2022 18:00:00	74.807	5.986242561	165.3426	9.180826077
08-Apr-2022 18:00:00	77.4884	5.948604878	139.3477	11.74485326
08-Apr-2022 18:00:00	55.9191	6.044278286	121.0446	7.60570509
08-Apr-2022 18:00:00	82.8905	5.942701406	154.8417	17.70699209
08-Apr-2022 18:00:00	48.7515	6.052255778	110.9644	12.85316638
08-Apr-2022 18:00:00	36.7054	6.100860595	110.7524	6.667230483
08-Apr-2022 18:00:00	24.6913	6.159448027	76.0997	4.439634223
08-Apr-2022 18:00:00	19.8388	6.16916526	53.1434	2.73272107
08-Apr-2022 18:00:00	22.573	6.17025121	63.1721	11.18652465
08-Apr-2022 18:00:00	25.5769	6.145787175	83.0925	5.895835397
08-Apr-2022 18:00:00	53.7247	6.032702545	130.5573	8.775131043
08-Apr-2022 18:00:00	77.8673	5.938577271	149.0324	9.144351509
08-Apr-2022 18:00:00	64.6568	6.00148315	134.6847	9.406268443
08-Apr-2022 18:00:00	43.0563	6.076503929	111.0343	6.905104004
08-Apr-2022 18:00:00	83.876	5.920244927	118.1824	7.738691291
08-Apr-2022 18:00:00	48.1742	6.078749871	87.6976	5.141664375
08-Apr-2022 18:00:00	25.3451	6.146950463	72.926	6.874619355

Move the circular button to the right, on "Correlation". Select your method: choose "Ordinary least squares". Force to 0: don't tick the box (as we apply a free intercept correlation function) (Figure 3.10).

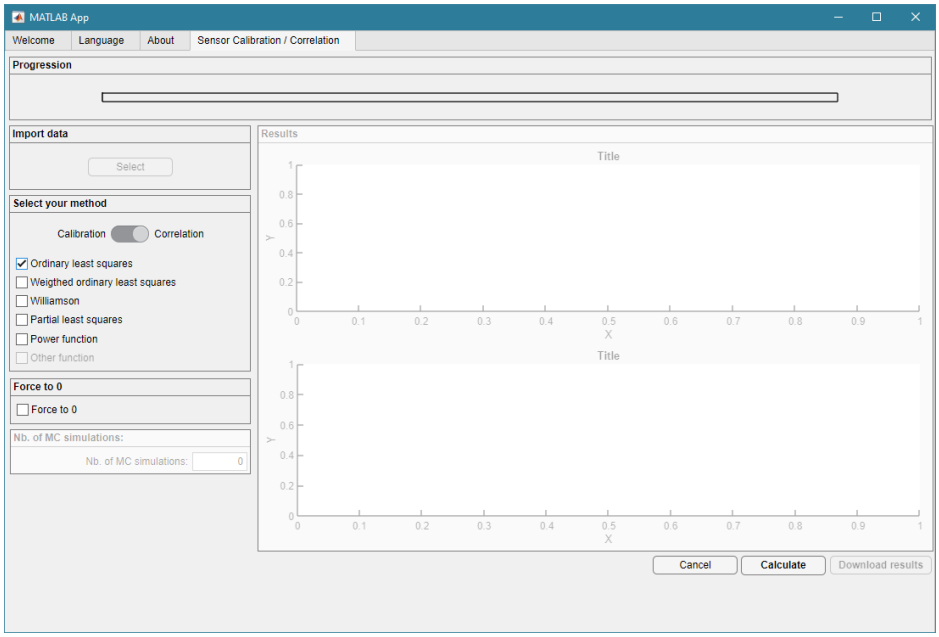

Figure 3.20: UDMT user interface.

Click on “Calculate”.

The tool retrieves (Figure 3.11):

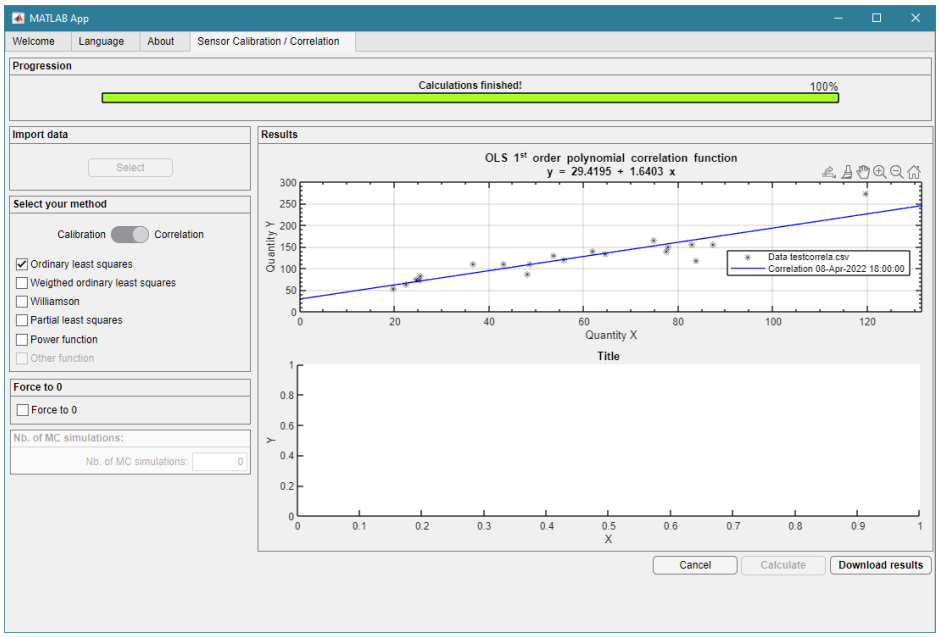

Figure 3.21: UDMT user interface.

According to the applied variance test, the recommended correlation function is a 1st order polynomial function, with the following equation given in the upper graph:

$$TSS = 29.4195 + 1.6403\,TU \qquad \text{eq. 3.12}$$

Click on “Download results”: the tool retrieves a text file containing all the detailed results of the calibration. Save this file as `testcorrelaCorFun.csv` for later use in section 4.3.

After transposition for easier display and readability, the text file of this example is shown hereafter, with added comments in the right column with light grey background (Table 3.10).

Repeat the calculations with a zero intercept, by ticking the box “Force to 0”, and then click on “Calculate”. The tool retrieves the results shown in Figure 3.12.

Table 3.26: Results of OLS sensor correlation example (free intercept).

Time	21-janv-2014 10:00:00	Comments
DegOpt	1	Recommended optimal degree of the polynomial function. Can be changed (1, 2 ou 3) by the user.
deg 1	1	Following lines are for the 1st order polynomial function b11 + b12 x
b11	29.4194905	b11 value
b12	1.640327495	b12 value
u_b11	10.62012825	standard uncertainty in b11
u_b12	0.169793541	standard uncertainty in b12
var_b11_b12	-1.635810111	covariance (b11, b12)
ResVar1	399.4199305	residual variance
deg 2	2	Following lines are for the 2nd order polynomial function b21 + b22 x + b23 x^2
b21	61.58642141	b21 value
b22	0.36199613	b22 value
b23	0.010318019	b23 value
u_b21	18.52917594	standard uncertainty in b21
u_b22	0.644477015	standard uncertainty in b22
u_b23	0.005046127	standard uncertainty in b23
var_b21_b22	-11.22519883	covariance (b21, b22)
var_b21_b23	0.079383396	covariance (b21, b23)
var_b22_b23	-0.003154739	covariance (b22, b23)
ResVar2	339.4349405	residual variance
deg 3	3	Following lines are for the 3rd order polynomial function b31 + b32 x + b33 x^2 + b34 x^3
b31	-46.91384696	b31 value
b32	6.991349288	b32 value
b33	-0.100255578	b33 value
b34	0.000535841	b34 value
u_b31	32.39890301	standard uncertainty in b31
u_b32	1.850478669	standard uncertainty in b32
u_b33	0.030020461	standard uncertainty in b33
u_b34	0.000144302	standard uncertainty in b34
var_b31_b32	-58.57042043	covariance (b31, b32)
var_b31_b33	0.915373159	covariance (b31, b33)
var_b31_b34	-0.004216372	covariance (b31, b34)
var_b32_b33	-0.054961551	covariance (b32, b33)
var_b32_b34	0.00025762	covariance (b32, b34)
var_b33_b34	-4.30E-06	covariance (b33, b34)
ResVar3	193.7098969	residual variance

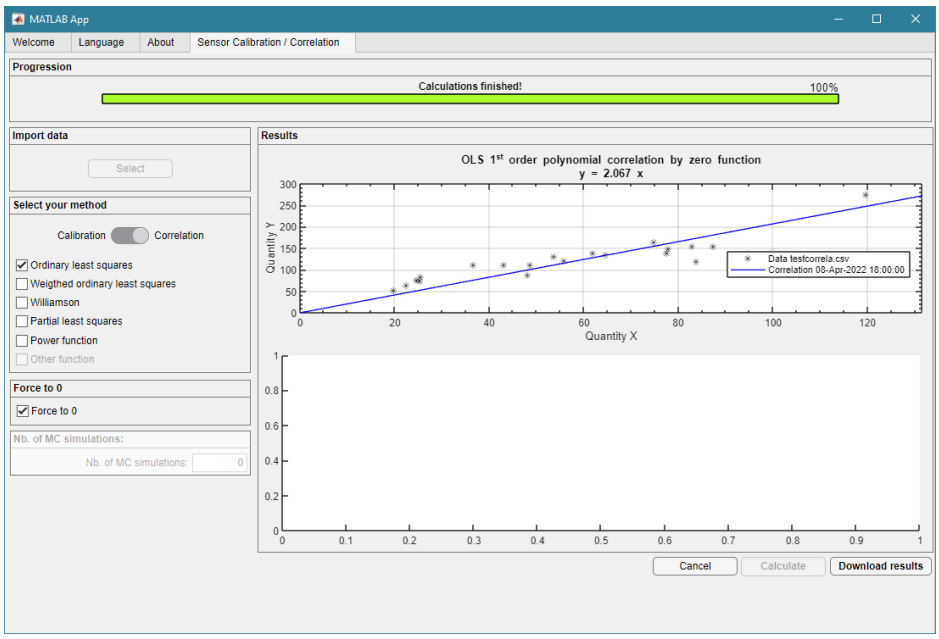

Figure 3.22: UDMT user interface.

According to the applied variance test, the recommended correlation function is a 1st order polynomial function, with the following equation given in the upper graph:

$$TSS = 2.067\ TU \qquad \text{eq. 3.13}$$

Click on "Download results": the tool retrieves a text file containing all the detailed results of the calibration. Save this file as `testcorrelaCorFunBy0.csv` for later use in section 4.3.

After transposition for easier display and readability, the text file of this example is shown hereafter, with added comments in the right column with light grey background (Table 3.11).

Table 3.27: Results of OLS sensor correlation example (forced zero intercept).

Time	21-janv-2014 10:00:00	Comments
DegOpt	1	Recommended optimal degree of the polynomial function. Can be changed (1, 2 ou 3) by the user.
deg 1	1	Following lines are for the 1st order polynomial function b11 + b12 x
b11	0	b11 value
b12	2.067013612	b12 value
u_b11	0	standard uncertainty in b11
u_b12	0.083053816	standard uncertainty in b12
var_b11_b12	0	covariance (b11, b12)
ResVar1	539.717342	residual variance
deg 2	2	Following lines are for the 2nd order polynomial function b21 + b22 x + b23 x^2
b21	0	b21 value
b22	2.375566454	b22 value
b23	-0.003921733	b23 value
u_b21	0	standard uncertainty in b21
u_b22	0.274456416	standard uncertainty in b22
u_b23	0.003328165	standard uncertainty in b23
var_b21_b22	0	covariance (b21, b22)
var_b21_b23	0	covariance (b21, b23)
var_b22_b23	-0.000871488	covariance (b22, b23)
ResVar2	528.9026254	residual variance
deg 3	3	Following lines are for the 3rd order polynomial function b31 + b32 x + b33 x^2 + b34 x^3
b31	0	b31 value
b32	4.373655895	b32 value
b33	-0.059344718	b33 value
b34	0.000347398	b34 value
u_b31	0	standard uncertainty in b31
u_b32	0.407726055	standard uncertainty in b32
u_b33	0.010470327	standard uncertainty in b33
u_b34	6.43237E-05	standard uncertainty in b34
var_b31_b32	0	covariance (b31, b32)
var_b31_b33	0	covariance (b31, b33)
var_b31_b34	0	covariance (b31, b34)
var_b32_b33	-0.004136342	covariance (b32, b33)
var_b32_b34	2.37974E-05	covariance (b32, b34)
var_b33_b34	-6.60E-07	covariance (b33, b34)
ResVar3	206.2067496	residual variance

3.5. Sensor correlation (polynomial function, Williamson Least Squares)

Advanced function, to be completed before summer 2023. It will be part of the final revised version.

3.6. Sensor correlation (Partial Least Squares)

The PLS (Partial Least Squares) regression aims at estimating a correlation function between a matrix of explanatory quantities X_i and a vector of explained quantity Y, for example between UV-visible absorption spectra at different wavelengths λ_i (as X_i) and a given Chemical Oxygen Demand - COD concentration (as Y). The eq. 3.8 gives the general expression of such a correlation function:

$$Y = b_0 + \sum_{i=1}^{N} b_i X_i \qquad \text{eq. 3.14}$$

Note: there are various options for PLS regression to select the number *N* of wavelengths to be included in eq. 3.8. Considering that the data file used to establish the UDMT PLS correlation function contains both spectra and pollutant concentrations measured in *m* samples, a set of PLS regressions are determined by the UDMT based on $N = \frac{2}{3}m - 1$ samples selected randomly among the *m* available samples. The UDMT final PLS regression is defined as the PLS regression with the highest level of explained variance. This random selection of *N* samples explains why successive UDMT PLS regressions may generate slightly different results.

Import data « Select »: select the file `SCC_PLS.csv` (Table 3.12, with only 30 lines and 8 columns represented for display purposes). The `SCC_PLS.csv` file contains data about 78 samples (78 lines), with, from left to right, the following columns (headers in first line):

- the time (written with the format dd-mmm-yyyy HH:MM:SS)
- the sample COD concentration (mg/L)
- the sample standard uncertainty u(COD) (mg/L)
- and 214 columns for the corresponding sample absorbance at wavelengths λ_i from 200 to 732.5 nm with a step of 2.5 nm.

Table 3.12: File SCC_PLS.csv (only the first 30 lines and 8 columns are shown).

Time	Concentration_mg_per_L	StandardUncertaintyOfConcentration_mg_per_L	200	202.5	205	207.5	210
19-Sep-2022 17:00:00	170.33	8.9712	480.14	425.91	378.5	340.55	309.25
19-Sep-2022 17:00:00	173.33	9.3511	481.12	428.53	381.96	344.67	313.93
19-Sep-2022 17:00:00	145.33	9.0092	450.63	399.75	355.65	319.8	289.96
19-Sep-2022 17:00:00	121.33	7.0876	430.76	380.99	337.71	303.47	275.14
19-Sep-2022 17:00:00	101.33	9.3384	371.82	327.02	288.16	257.78	232.7
19-Sep-2022 17:00:00	56	3.6813	267	230.79	200.53	177.86	159.91
19-Sep-2022 17:00:00	55.667	3.5389	238.84	206.41	179.55	159.9	144.4
19-Sep-2022 17:00:00	44.667	4.4982	215.73	184.93	160.45	142.61	128.7
19-Sep-2022 17:00:00	202.5	29.373	562.32	505.36	453.21	408.34	370.28
19-Sep-2022 17:00:00	389	70.417	717.09	649.02	584.77	528.79	480.9
19-Sep-2022 17:00:00	302	18.748	768.44	691.18	622.1	566.17	519.46
19-Sep-2022 17:00:00	245	20.889	716.69	640.91	573.72	523.43	481.96
19-Sep-2022 17:00:00	198.67	7.9292	692.86	615.44	548.75	497.12	455.61
19-Sep-2022 17:00:00	191	3.6949	678.16	601.53	533.32	480.73	438.74
19-Sep-2022 17:00:00	154.29	9.5264	635.72	561.59	496.27	446.46	406.96
19-Sep-2022 17:00:00	179	5.6702	609.41	537.43	475.37	426.82	388.85
19-Sep-2022 17:00:00	190	19.146	624.96	553.01	489.19	439.6	399.97
19-Sep-2022 17:00:00	165.71	8.0986	618.64	548.34	487.07	438.3	398.25
19-Sep-2022 17:00:00	156.19	17.934	638.21	567.14	503.63	451.68	409.23
19-Sep-2022 17:00:00	201.43	6.11	626.14	557.81	496.16	445.42	403.25
19-Sep-2022 17:00:00	135.24	5.3665	594.14	529.2	471.18	423.6	384.31
19-Sep-2022 17:00:00	112.29	8.6119	544.92	483.61	428.64	383.61	346.93
19-Sep-2022 17:00:00	78	19.527	437.8	385.86	340.11	303.5	273.57
19-Sep-2022 17:00:00	76.667	8.7054	404.38	353.64	309.69	274.52	245.51
19-Sep-2022 17:00:00	62.333	4.6672	328.15	285.65	249.79	222.61	201.13
19-Sep-2022 17:00:00	145.24	10.96	277.02	239.77	209.32	186.94	169.46
19-Sep-2022 17:00:00	264.48	10.895	403.04	359.09	319.12	286.09	258.43
19-Sep-2022 17:00:00	222	9.5806	762.74	694.21	626.26	566.5	515.67
19-Sep-2022 17:00:00	242	6.9787	684.83	618.16	555.42	503.11	458.54

Select your method: move the switch button to “Correlation” and then tick the box “Partial least squares” (Figure 3.13).

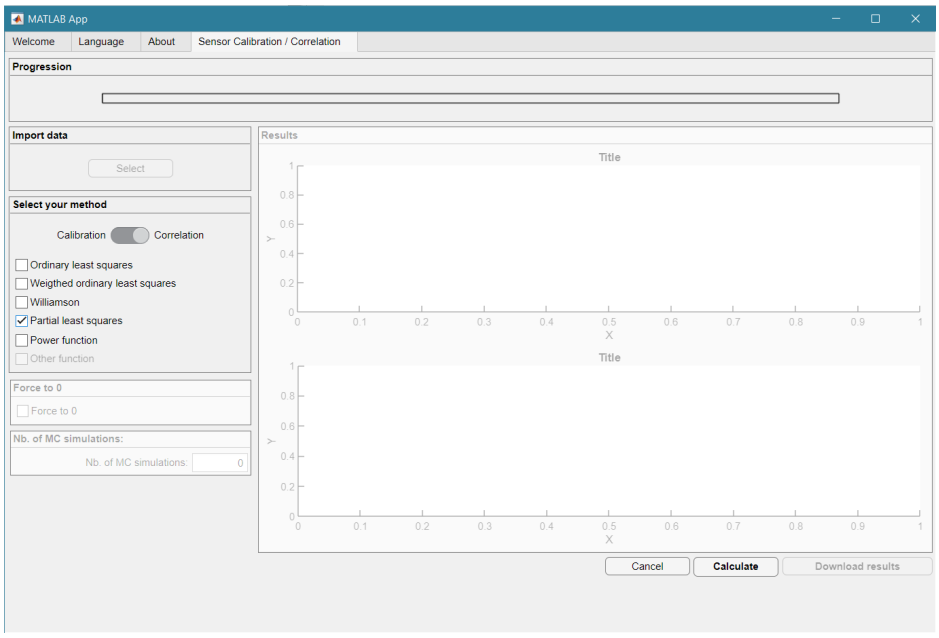

Figure 3.23 : UDMT user interface.

After user approval of the data displayed on the UDMT interface, click on “Calculate”.

The tool retrieves Figure 3.14.

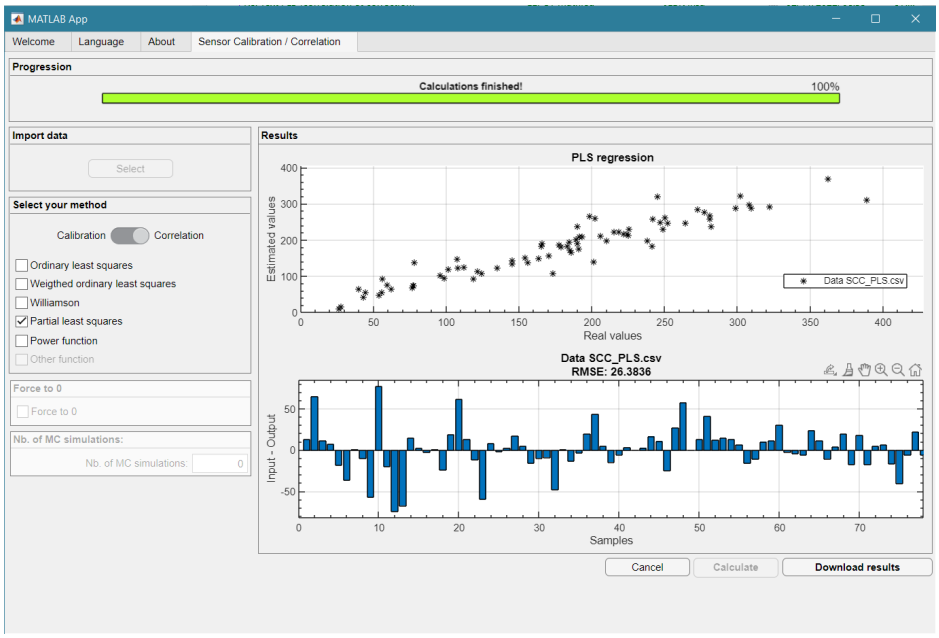

Figure 3.24 : UDMT user interface with PLS correlation results.

The upper figure represents the measured values (horizontal axis) versus the estimated ones (vertical axis). The lower figure depicts the variance between both estimated and measured values for each sample. The average RMSE (Root Mean Square Error) is given in the figure title.

Click on “Download results”: the tool retrieves a csv text file containing the detailed results of the correlation.

Save this file as `SCC_PLS_Function-Data.csv` (Table 3.13) for future use in section 4.4. Indexes of the *N* selected wavelengths in decreasing order of correlation with the pollutant concentration are given in the column labelled "Indexes" – NaN stands for the offset (index 0 in eq. 3.8). PLS coefficients b_i are given in the column labelled "b_i" (b_0 and b_i in eq. 3.8).

Table 3.28 : File `SCC_PLS_Function-Data.csv`.

Time	Indexes	b_i
19-Sep-2022 17:00:00	NaN	102.06700487525
19-Sep-2022 17:00:00	208	-12.841963377259
19-Sep-2022 17:00:00	210	10.0544690095389
19-Sep-2022 17:00:00	209	1.22957389064022
19-Sep-2022 17:00:00	202	25.8496424436286
19-Sep-2022 17:00:00	195	26.0796343955768
19-Sep-2022 17:00:00	207	-11.1626469228587
19-Sep-2022 17:00:00	211	4.64633564064499
19-Sep-2022 17:00:00	196	23.5057563204065
19-Sep-2022 17:00:00	203	-19.7881439065458
19-Sep-2022 17:00:00	199	2.86436503297029
19-Sep-2022 17:00:00	198	11.4777562155027
19-Sep-2022 17:00:00	201	23.8208881438666
19-Sep-2022 17:00:00	189	24.3019081512813
19-Sep-2022 17:00:00	214	3.22614872245146
19-Sep-2022 17:00:00	200	0.715449753318317
19-Sep-2022 17:00:00	213	-7.02781109498166
19-Sep-2022 17:00:00	212	12.2516364473268
19-Sep-2022 17:00:00	191	-5.12623450988557
19-Sep-2022 17:00:00	206	2.38123805661783
19-Sep-2022 17:00:00	190	7.04158116210909
19-Sep-2022 17:00:00	174	15.0822356249674
19-Sep-2022 17:00:00	188	-8.73036380050125
19-Sep-2022 17:00:00	192	15.9072716853623
19-Sep-2022 17:00:00	182	0.788302583532232
19-Sep-2022 17:00:00	197	-5.79042509782819
19-Sep-2022 17:00:00	185	4.66713903340288
19-Sep-2022 17:00:00	175	1.68234597236552
19-Sep-2022 17:00:00	169	13.8225528374007
19-Sep-2022 17:00:00	186	6.84762164800564
19-Sep-2022 17:00:00	178	12.5077179435031
19-Sep-2022 17:00:00	187	2.72129073057866
19-Sep-2022 17:00:00	194	-5.15848848578282
19-Sep-2022 17:00:00	179	3.10945934241386
19-Sep-2022 17:00:00	173	-16.1703128745782
19-Sep-2022 17:00:00	183	-3.03000689765681
19-Sep-2022 17:00:00	204	-30.9254303550676
19-Sep-2022 17:00:00	205	11.0654518421242
19-Sep-2022 17:00:00	177	5.71713100379317
19-Sep-2022 17:00:00	176	-3.75433953924329
19-Sep-2022 17:00:00	184	3.50059497487408
19-Sep-2022 17:00:00	168	-7.09154627730415
19-Sep-2022 17:00:00	193	6.03620000197589
19-Sep-2022 17:00:00	170	-5.27660394996456
19-Sep-2022 17:00:00	181	-15.5091599776448
19-Sep-2022 17:00:00	180	-21.7208312519085
19-Sep-2022 17:00:00	163	-10.0537248013201
19-Sep-2022 17:00:00	166	-37.7566046608373
19-Sep-2022 17:00:00	172	-41.3387162453614

4. Calibration/Correlation correction

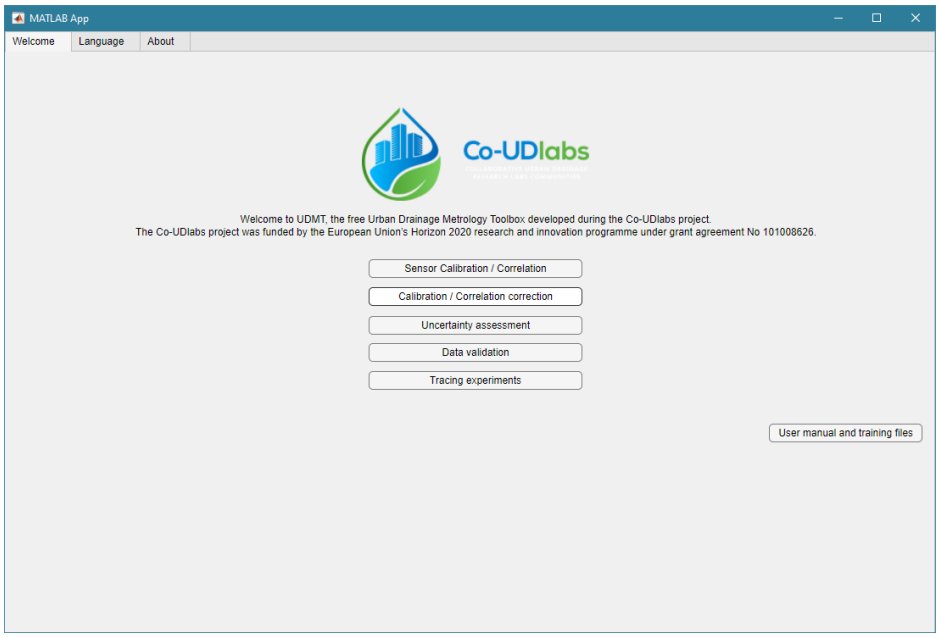

Figure 4.25: UDMT user interface.

Select "Calibration / Correlation correction" in the menu (Figure 4.1).

Correction allows to either:

- estimate most likely true values from raw data delivered by a sensor by applying its calibration function. Raw values measured by the sensor y_m are converted to most likely true values $\hat{x}$ by using the reciprocal OLS or WLS calibration function $\hat{x} = f^{-1}(y_m)$, with their standard uncertainties $u(\hat{x})$ and corresponding 95% coverage intervals (see sections 4.1 and 4.2).
- or estimate another quantity from raw data delivered by a sensor by applying its correlation function. Raw values x_m measured by the sensor are converted to most likely true values $\hat{y}$ of the pollutant of interest (e.g., estimating TSS from a turbidity) by using the correlation function $\hat{y} = f(x_m)$, with their standard uncertainties $u(\hat{y})$ and corresponding 95% coverage intervals (see section 4.3), e.g., estimating TSS from a turbidity sensor).

4.1. Correction with a polynomial calibration function (OLS or WLS)

Example: correct the raw data contained in the `data01.csv` file by the polynomial calibration function obtained in section 3.1.

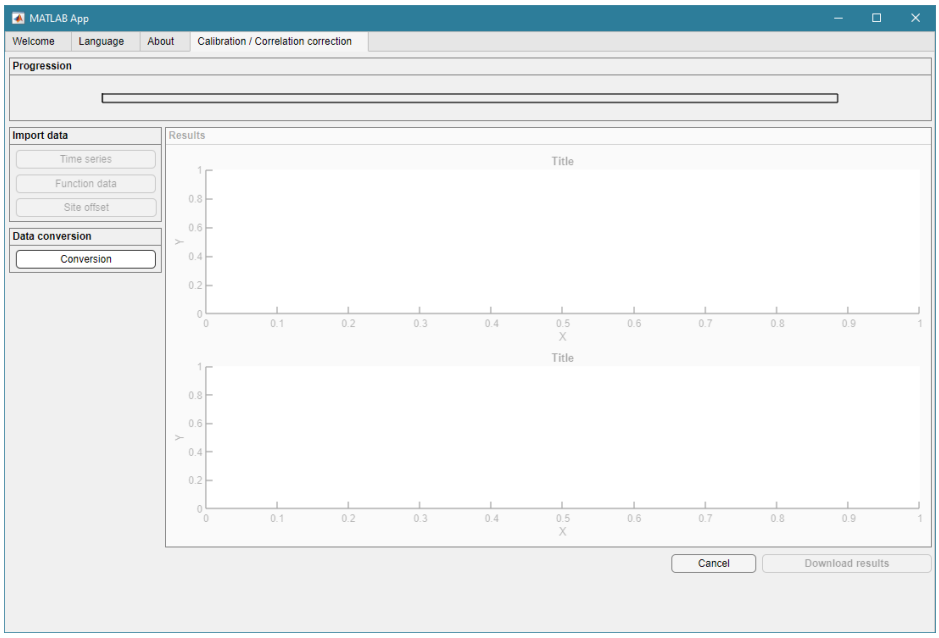

Figure 4.26: UDMT user interface.

Select “Calibration / Correlation correction” (Figure 4.2).

Import data “Time series”: select the file `data01.csv` (Table 4.1).

Table 4.29: File `data01.csv`.

Time	x	ux
25-Mar-2022 22:00:00	120	5
25-Mar-2022 22:05:00	39.1	1.955
25-Mar-2022 22:10:00	58.3	3.115
25-Mar-2022 22:15:00	7.25	4.236
25-Mar-2022 22:20:00	39.1	1.955
25-Mar-2022 22:25:00	18.256	0.752

Import data “Function data”: select the file `TurbiDoua25CoUDCalFun.csv` obtained in section 3.1 (Table 4.2). The selected polynomial degree is equal to 3.

Table 4.30: File `TurbiDoua25CoUDCalFun.csv` (transposed for legibility).

Time	21-janv-2014 10:00:00
DegOpt	3
deg 1	1
b11	-84.46578957
b12	1.2585037
u_b11	14.2809029
u_b12	0.010661956
var_b11_b12	-0.098757158
ResVar1	23629.78138
deg 2	2
b21	42.92451182
b22	0.725318075
b23	0.000187181
u_b21	5.18082159
u_b22	0.012429954
u_b23	4.21E-06
var_b21_b22	-0.04344897
var_b21_b23	1.21E-05
var_b22_b23	-5.06E-08
ResVar2	2156.626829
deg 3	3
b31	2.02328915
b32	1.065716078
b33	-0.000146824
b34	7.62E-08
u_b31	0.669166843
u_b32	0.003078655
u_b33	2.73E-06
u_b34	6.14E-10
var_b31_b32	-0.001453267
var_b31_b33	1.04E-06
var_b31_b34	-2.02E-10
var_b32_b33	-8.02E-09
var_b32_b34	1.68E-12
var_b33_b34	-1.65E-15
ResVar3	27.24824254
maxStd	3.387467983

Import data "Site offset": select the file `ConfigTest.csv` (Table 4.3).

Table 4.31: File `ConfigTest.csv`.

Time	SiteOffset	SiteU	SiteUnit
25-May-2022 09:25:00	0	10	1

A site offset csv file contains three columns, with respectively:

- The site offset: a constant value to be added to the measured value to calculate the final result. For example, if a water level sensor is installed 3 cm above the sewer invert, the site offset is equal to 0.03 m. This offset must be added to all measured values of the water level to calculate the exact water level.
- The site uncertainty: a value to account for heterogeneity of the quantity measured by a sensor at a given location. Let illustrate this concept with three examples.
    - Example 1 for water level measurement: in a sewer pipe, the free surface is neither perfectly flat nor immobile. On the contrary, there are always some wavelets which affect the exact position of the free surface. If, in dry weather conditions, the mean

wavelet height is ± 1 cm, then the corresponding standard uncertainty can be estimated to be equal to half of this value, i.e., 0.5 cm. Therefore, SiteU = 0.005 m and SiteUnit = 0 to indicate that SiteU is expressed in the same unit (m) as the measured water level.

- Example 2 for turbidity: across a wet section in a sewer pipe the turbidity is not homogeneous and therefore, depending on the turbidity sensor position in the wet section, the turbidity will differ. Experience has shown that this variability across the wet section is approximately 10% of the measured value. In such a case, SiteU = 10, and SiteUnit = 1 to indicate that SiteU is given in % of the measured value.
- Example 3 for conductivity: if the water is well mixed in a sewer pipe, the conductivity is assumed to be homogeneous across the entire wet section. In this case, any position of the conductivity sensor will deliver the same conductivity value. Therefore, one sets SiteU = 0 and SiteUnit = 0.

In the case of the `data01.csv` file data, let consider that there is no offset in the data and that the site local uncertainty (i.e., approximately the representativeness of the point where the sensor is located) is 10 percent of the measured values. The site offset matrix contains respectively SiteOffset = 0, SiteU = 10 and SiteUnit = 1.

Click on “Conversion”. The tool retrieves (Figure 4.3):

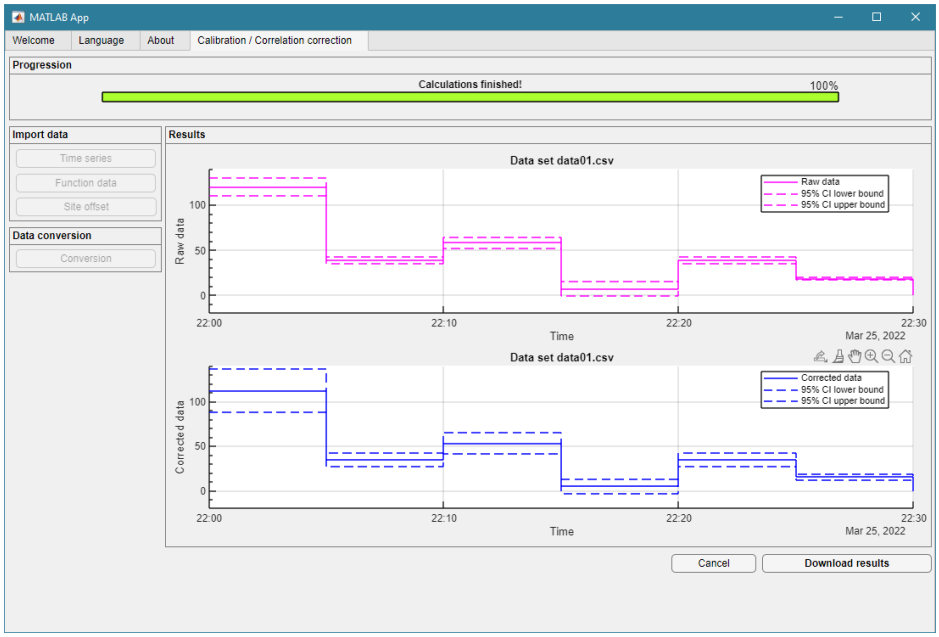

Figure 4.27: UDMT user interface.

The upper graph shows the raw data delivered by the sensor with its 95% coverage interval band. The lower graph shows the most likely true values obtained from the 3rd degree polynomial calibration function with its 95% coverage interval band including the uncertainty in both i) the raw data and ii) the 3rd degree polynomial calibration function.

Click on “Download results”. The tool retrieves (Table 4.4):

Table 4.32: Results of the 3rd degree polynomial calibration function correction.

Time	x	ux	Xc	uXc
25-Mar-2022 22:00:00	120	5	112.3391	12.2368
25-Mar-2022 22:05:00	39.1	1.955	34.9557	3.9964
25-Mar-2022 22:10:00	58.3	3.115	53.1854	6.1130
25-Mar-2022 22:15:00	7.25	4.236	4.9077	4.0578
25-Mar-2022 22:20:00	39.1	1.955	34.9557	3.9964
25-Mar-2022 22:25:00	18.256	0.752	15.2636	1.7867

4.2. Correction with a power calibration function

Example: correct the raw data contained in the `data01.csv` file by the power calibration function obtained in section 3.3.

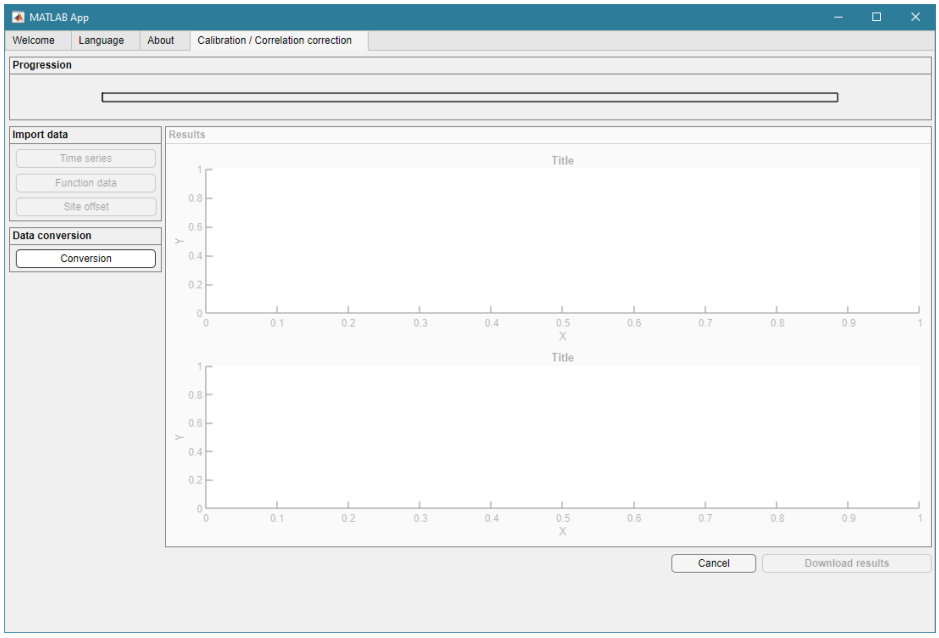

Figure 4.28: UDMT user interface.

Select "Calibration / Correlation correction" (Figure 4.4).

Import data "Time series": select the file `data01.csv` (Table 4.5).

Table 4.33: File `data01.csv`.

Time	x	ux
25-Mar-2022 22:00:00	120	5
25-Mar-2022 22:05:00	39.1	1.955
25-Mar-2022 22:10:00	58.3	3.115
25-Mar-2022 22:15:00	7.25	4.236
25-Mar-2022 22:20:00	39.1	1.955
25-Mar-2022 22:25:00	18.256	0.752

Import data "Function data": select the file `PowCal004_Function-Data.csv` obtained in section 3.3 (Table 4.6).

Table 4.34: File `PowCal004_Function-Data.csv`.

Time	b1	b2	u_b1	u_b2	var_b1_b2	MSE	maxStd
11-Jan-2021 10:00	1.3774	0.8947	0.0451	0.0075	-0.0003	0.4295	0.7628

Import data “Site offset”: select the file `ConfigTest.csv` (Table 4.7).

Table 4.35: File `ConfigTest.csv`.

Time	SiteOffset	SiteU	SiteUnit
25-May-2022 09:25:00	0	10	1

This indicates that, where the sensor is located, there is no offset in the data and that the site local uncertainty (i.e., approximately the representativeness of the point where the sensor is located) is 10 percent (SiteUnit: 1 is for %, 0 means same unit as the sensor data).

Click on “Conversion”. The tool retrieves (Figure 4.5):

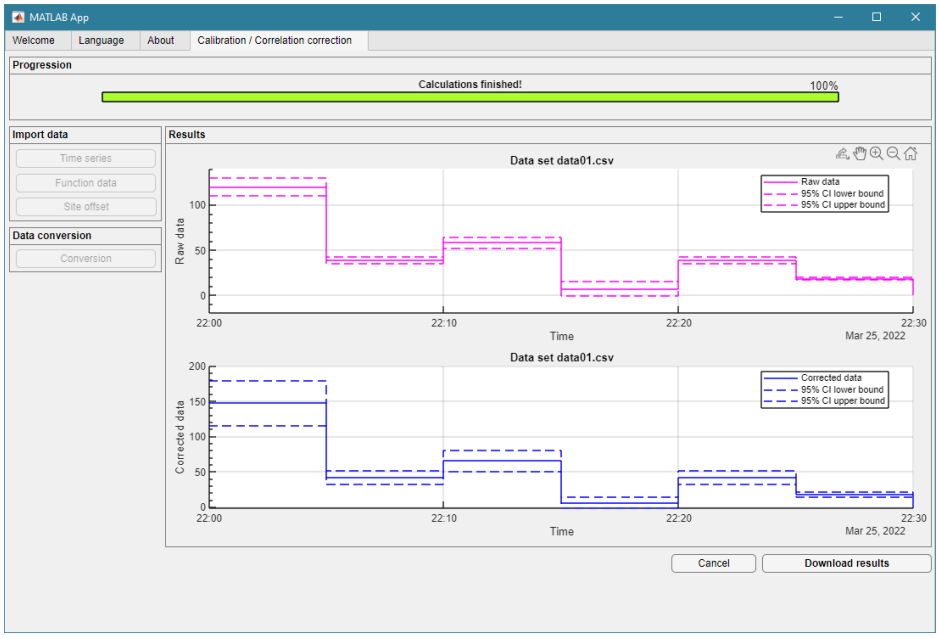

Figure 4.29: UDMT user interface.

The upper graph shows the raw data delivered by the sensor with its 95% coverage interval band. The lower graph shows the most likely true values obtained from the power calibration function with its 95% coverage interval band including the uncertainty in both i) the raw data and ii) the power calibration function.

Click on “Download results”. The tool retrieves (Table 4.8):

Table 4.36: Results of the power calibration function correction.

Time	x	ux	Xc	uXc
25-Mar-2022 22:00:00	120	5	147.4145	16.2888
25-Mar-2022 22:05:00	39.1	1.955	42.0915	4.8283
25-Mar-2022 22:10:00	58.3	3.115	65.7830	7.6654
25-Mar-2022 22:15:00	7.25	4.236	6.4001	4.2306
25-Mar-2022 22:20:00	39.1	1.955	42.0915	4.8283
25-Mar-2022 22:25:00	18.256	0.752	17.9671	1.9908

4.3. Correlation with a polynomial correlation function (OLS or WLS)

Example: correct the raw data contained in the `data01.csv` file by the 1st degree correlation function obtained in section 3.4.

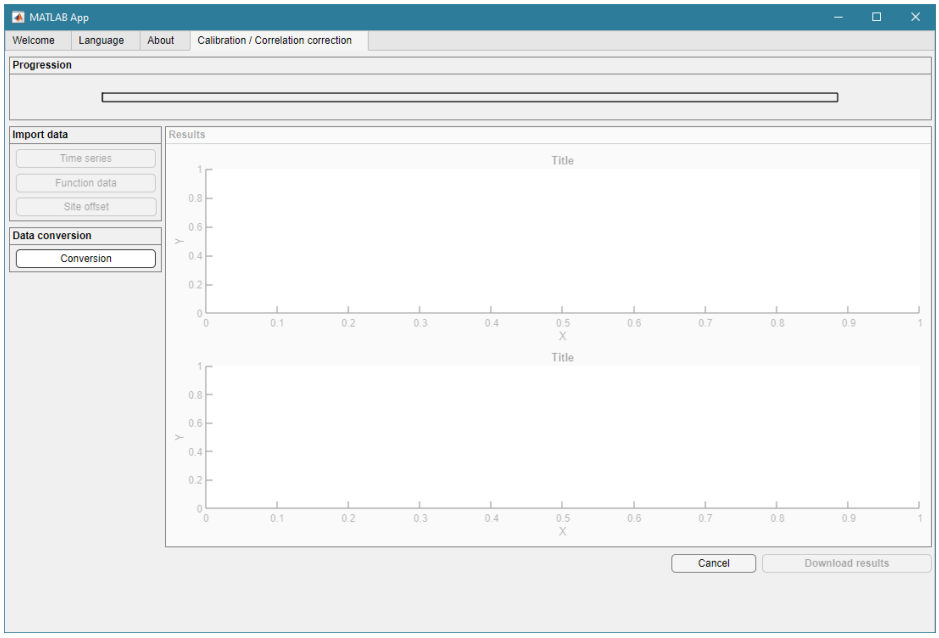

Figure 4.30: UDMT user interface.

Select "Calibration / Correlation correction" (Figure 4.6).

Import data "Time series": select the file `data01.csv` (Table 4.9).

Table 4.37: File `data01.csv`.

Time	x	ux
25-Mar-2022 22:00:00	120	5
25-Mar-2022 22:05:00	39.1	1.955
25-Mar-2022 22:10:00	58.3	3.115
25-Mar-2022 22:15:00	7.25	4.236
25-Mar-2022 22:20:00	39.1	1.955
25-Mar-2022 22:25:00	18.256	0.752

Import data "Function data": select the file `testcorrelaCorFun.csv` obtained in section 3.4 (Table 4.10).

Table 4.38: File `testcorrelaCorFun.csv` (transposed for legibility).

Time	21-janv-2014 10:00:00
DegOpt	1
deg 1	1
b11	29.4194905
b12	1.640327495
u_b11	10.62012825
u_b12	0.169793541
var_b11_b12	-1.635810111
ResVar1	399.4199305
deg 2	2
b21	61.58642141
b22	0.36199613
b23	0.010318019
u_b21	18.52917594
u_b22	0.644477015
u_b23	0.005046127
var_b21_b22	-11.22519883
var_b21_b23	0.079383396
var_b22_b23	-0.003154739
ResVar2	339.4349405
deg 3	3
b31	-46.91384696
b32	6.991349288
b33	-0.100255578
b34	0.000535841
u_b31	32.39890301
u_b32	1.850478669
u_b33	0.030020461
u_b34	0.000144302
var_b31_b32	-58.57042043
var_b31_b33	0.915373159
var_b31_b34	-0.004216372
var_b32_b33	-0.054961551
var_b32_b34	0.00025762
var_b33_b34	-4.30E-06
ResVar3	193.7098969

Import data “Site offset”: select the file `ConfigTest2.csv` (Table 4.11).

Table 4.39: File `ConfigTest2.csv`.

Time	SiteOffset	SiteU	SiteUnit
25-May-2022 09:25:00	0	0	0

This indicates that, where the sensor is located, there is no offset in the data and that no additional source of uncertainty is attributed to the raw data recorded in the `data01.csv` file.

Click on “Conversion”. The tool retrieves (Figure 4.7):

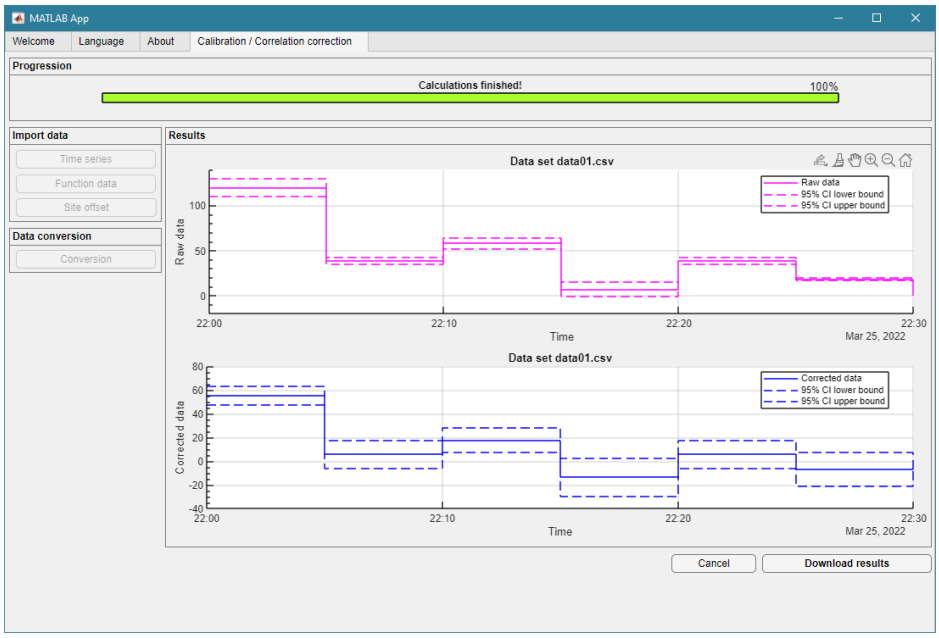

Figure 4.31: UDMT user interface.

The upper graph shows the raw data delivered by the sensor with its 95% coverage interval band. The lower graph shows the most likely true values obtained from the 1st degree correlation function with its 95% coverage interval band including the uncertainty in both i) the raw data and ii) the 1st degree correlation function.

Click on "Download results". The tool retrieves (Table 4.12):

Table 4.40: Results of the 1st degree correlation function correction.

Time	x	ux	Xc	uXc
25-Mar-2022 22:00:00	120	5	55.2210	4.0913
25-Mar-2022 22:05:00	39.1	1.955	5.9016	6.0445
25-Mar-2022 22:10:00	58.3	3.115	17.6066	5.2381
25-Mar-2022 22:15:00	7.25	4.236	3.515283118	8.1840
25-Mar-2022 22:20:00	39.1	1.955	5.9016	6.0445
25-Mar-2022 22:25:00	18.256	0.752	-6.8056	7.1344

4.4. Correction with a PLS correlation function

Example: convert the spectra raw data contained in the `CCC_Spectra.csv` file into COD concentration by means of the PLS correlation function `SCC_PLS_Function-Data.csv` obtained in section 3.6.

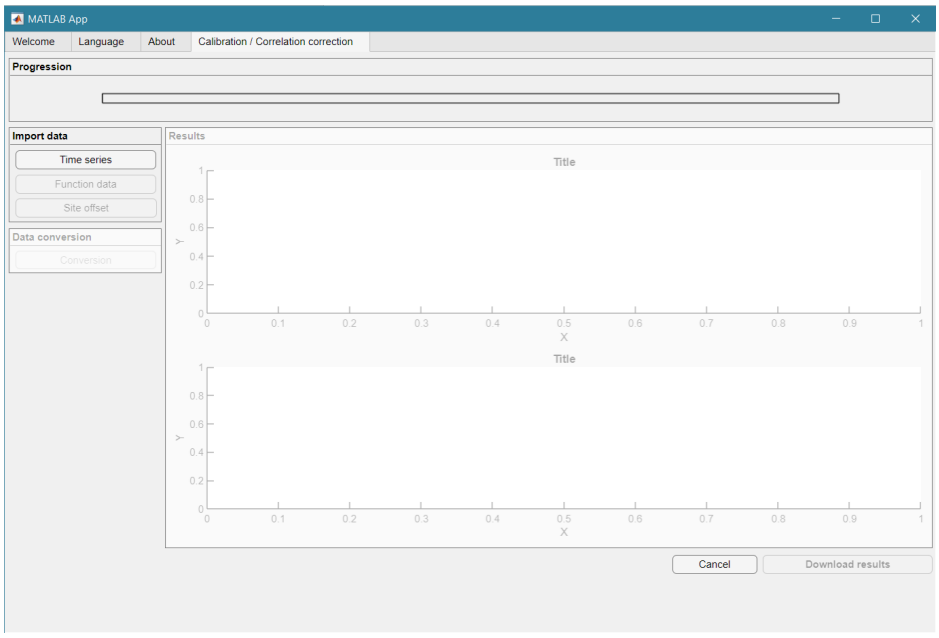

Figure 4.32: UDMT user interface.

Select “Calibration / Correlation correction” on the welcome menu (Figure 4.8).

Click on “Time series” and select the file `CCC_Spectra.csv` (Table 4.13). Click on “OK” to accept the data.

Table 4.41: File `CCC_Spectra.csv` (first 24 rows and 13 columns only) as shown by the UDMT user interface.

MATLAB App

Welcome | Language | About | Calibration / Correlation correction | Uploaded data

Time	Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var8	Var9	Var10	Var11	Var12	Var1
NaT	200.0000	202.5000	205.0000	207.5000	210.0000	212.5000	215.0000	217.5000	220.0000	222.5000	225.0000	227.5000	2
19-Sep-2022 17:00:00	480.1400	425.9100	378.5000	340.5500	309.2500	286.6300	271.3900	260.1400	251.7600	245.1400	237.5000	229.7500	2
19-Sep-2022 17:05:00	481.1200	428.5300	381.9600	344.6700	313.9300	290.7900	275.1200	263.8400	255.2500	248.0700	240.0500	232.4600	2
19-Sep-2022 17:10:00	450.6300	399.7500	355.6500	319.8000	289.9600	268.1900	253.6000	243.4400	236.2000	230.4700	223.7400	216.8300	2
19-Sep-2022 17:15:00	430.7600	380.9900	337.7100	303.4700	275.1400	254.2000	240.5800	230.9500	223.7500	218.1900	211.8300	205.5000	2
19-Sep-2022 17:20:00	371.8200	327.0200	288.1600	257.7800	232.7000	214.2600	202.3000	194.2300	188.6100	184.3700	179.1800	174.0000	1
19-Sep-2022 17:25:00	267.0000	230.7900	200.5300	177.8600	159.9100	147.1600	138.9500	133.8800	130.7800	128.8100	126.2100	123.0900	1
19-Sep-2022 17:30:00	238.8400	206.4100	179.5500	159.9000	144.4000	133.4400	126.4600	122.0700	119.4500	117.9000	115.7500	113.0200	1
19-Sep-2022 17:35:00	215.7300	184.9300	160.4500	142.6100	128.7000	118.9000	112.8800	109.1200	106.9100	105.9100	104.3100	102.1700	1
19-Sep-2022 17:40:00	562.3200	505.3600	453.2100	408.3400	370.2800	342.0400	322.6500	309.0300	298.8500	290.4000	281.9300	274.0600	2
19-Sep-2022 17:45:00	717.0900	649.0200	584.7700	528.7900	480.9000	445.4100	421.5900	404.4500	390.4300	378.4600	366.1600	354.9900	3
19-Sep-2022 17:50:00	768.4400	691.1800	622.1000	566.1700	519.4600	485.5500	462.4400	444.6600	430.2600	417.5500	403.3200	389.4400	3
19-Sep-2022 17:55:00	716.6900	640.9100	573.7200	523.4300	481.9600	451.6300	430.8700	415.4500	402.7700	390.7400	377.1500	363.8700	3
19-Sep-2022 18:00:00	692.8600	615.4400	548.7500	497.1200	455.6100	425.2700	404.1200	388.8400	376.3400	364.5800	351.5000	338.2400	3
19-Sep-2022 18:05:00	678.1600	601.5300	533.3200	480.7300	438.7400	408.3900	387.4600	372.1800	360.1100	349.2800	337.0400	324.9000	3
19-Sep-2022 18:10:00	635.7200	561.5900	496.2700	446.4600	406.9600	378.4100	359.0100	344.5800	333.4700	323.7400	312.4700	301.1500	2
19-Sep-2022 18:15:00	609.4100	537.4300	475.3700	426.8200	388.8500	361.7600	343.2500	329.9100	319.6100	310.2400	299.5000	288.6300	2
19-Sep-2022 18:20:00	624.9600	553.0100	489.1900	439.6000	399.9700	371.2200	351.7900	338.2600	327.5200	317.7100	306.7800	295.7400	2
19-Sep-2022 18:25:00	618.6400	548.3400	487.0700	438.3000	398.2500	369.6500	350.1000	335.9000	325.2200	315.7300	304.8800	293.9100	2
19-Sep-2022 18:30:00	638.2100	567.1400	503.6300	451.6800	409.2300	378.1900	357.1300	341.6200	329.6200	319.6600	308.5600	297.7100	2
19-Sep-2022 18:35:00	626.1400	557.8100	496.1600	445.4200	403.2500	371.8500	350.3300	335.0500	323.4600	313.7700	303.1500	292.6300	2
19-Sep-2022 18:40:00	594.1400	529.2000	471.1800	423.6000	384.3100	355.3300	336.0700	322.0500	311.0500	301.6700	291.3400	281.7500	2
19-Sep-2022 18:45:00	544.9200	483.6100	428.6400	383.6100	346.9300	319.9000	301.9100	289.2100	279.5000	271.3600	262.6100	254.1500	2
19-Sep-2022 18:50:00	437.8000	385.8600	340.1100	303.5000	273.5700	251.4200	237.0200	227.1400	219.9300	214.3400	208.2600	201.8200	1

Ok

Click on “Function data” and select the file `SCC_PLS_Function-Data.csv` (see section 3.6, Table 3.13). Click on “Site offset” and the select the file `ConfigPLS.csv` (Table 4.14).

Table 4.42: File `ConfigPLS.csv`.

Time	SiteOffset	SiteU	SiteUnit
25-Mar-2022 09:25:00	0	0	0

Click on “Conversion”. The tool retrieves Figure 4.9. The upper graph depicts the spectrum time series. The lower graph represents the COD concentration time series calculated from the spectra and the function data.

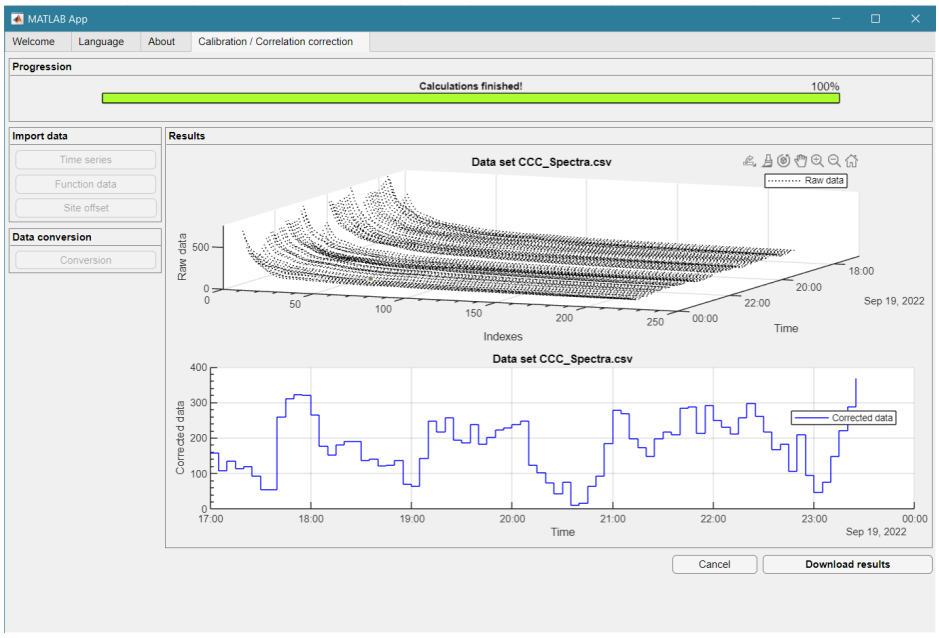

Figure 4.33: UDMT PLS correction outputs.

Click on “Download results” and save the file as `CCC_Spectra_corrected.csv` (Table 4.15, where X_c is the estimated outputs from the PLS conversion).

Table 4.43: File `CCC_Spectra_corrected.csv` (first 43 lines only).

Time	Xc	uXc
19-Sep-2022 17:00:00	157.306632453699	0
19-Sep-2022 17:05:00	108.816687062365	0
19-Sep-2022 17:10:00	134.195334793289	0
19-Sep-2022 17:15:00	114.14625214737	0
19-Sep-2022 17:20:00	119.345988254363	0
19-Sep-2022 17:25:00	92.251726540974	0
19-Sep-2022 17:30:00	54.8878779303834	0
19-Sep-2022 17:35:00	54.6610132259873	0
19-Sep-2022 17:40:00	259.749575683378	0
19-Sep-2022 17:45:00	311.744156406106	0
19-Sep-2022 17:50:00	321.807859501534	0
19-Sep-2022 17:55:00	319.626593090894	0
19-Sep-2022 18:00:00	266.008972282598	0
19-Sep-2022 18:05:00	176.390678212417	0
19-Sep-2022 18:10:00	151.970038146746	0
19-Sep-2022 18:15:00	181.59934767826	0
19-Sep-2022 18:20:00	189.778290176785	0
19-Sep-2022 18:25:00	190.186662643508	0
19-Sep-2022 18:30:00	137.216033932636	0
19-Sep-2022 18:35:00	140.162926737523	0
19-Sep-2022 18:40:00	122.40128087695	0
19-Sep-2022 18:45:00	124.248009420104	0
19-Sep-2022 18:50:00	137.70713957012	0
19-Sep-2022 18:55:00	69.0287551543875	0
19-Sep-2022 19:00:00	64.4896155617657	0
19-Sep-2022 19:05:00	142.967012051784	0
19-Sep-2022 19:10:00	247.331513615168	0
19-Sep-2022 19:15:00	217.000853991151	0
19-Sep-2022 19:20:00	257.631628009177	0
19-Sep-2022 19:25:00	194.491457159558	0
19-Sep-2022 19:30:00	186.490871162373	0
19-Sep-2022 19:35:00	237.953625647017	0
19-Sep-2022 19:40:00	182.757152930888	0
19-Sep-2022 19:45:00	202.269847859931	0
19-Sep-2022 19:50:00	222.087968501066	0
19-Sep-2022 19:55:00	229.634615137335	0
19-Sep-2022 20:00:00	238.306798860992	0
19-Sep-2022 20:05:00	247.032419577282	0
19-Sep-2022 20:10:00	122.674556479596	0
19-Sep-2022 20:15:00	101.616499015769	0
19-Sep-2022 20:20:00	73.8495492931584	0
19-Sep-2022 20:25:00	42.8966601400152	0

5. Data validation

Select “Data validation” in the menu (Figure 5.1).

Data validation includes several automated tests aiming to check ranges, and to detect outliers, unusual values, and suspicious evolutions (gradients, peaks, constant values, etc.) in time series. The output is a final qualification of each data with three possible grades: valid, not valid, or doubtful, the latter requiring a further investigation by the user to decide between valid and not valid final qualification. The basic tests, implemented in the UDMT, allow to check if the data are:

- within the physical range, i.e., within the physical boundaries of the measured phenomena in a given location;
- within the measuring range, i.e., within the measuring range of the sensor;

- within the expert range, i.e., within the measuring range an expert considers as valid for a given sensor installed in a given location under some given conditions;
- within the expected gradient range, i.e., the variations of the values are not abnormally fast or slow;
- affected by uncertainties higher than the maximum acceptable absolute uncertainty;
- affected by relative uncertainties higher than the maximum acceptable relative uncertainty;
- compatible with redundant data, i.e., with other measured or calculated data which are supposed to be close to the data under evaluation;
- outliers or not.

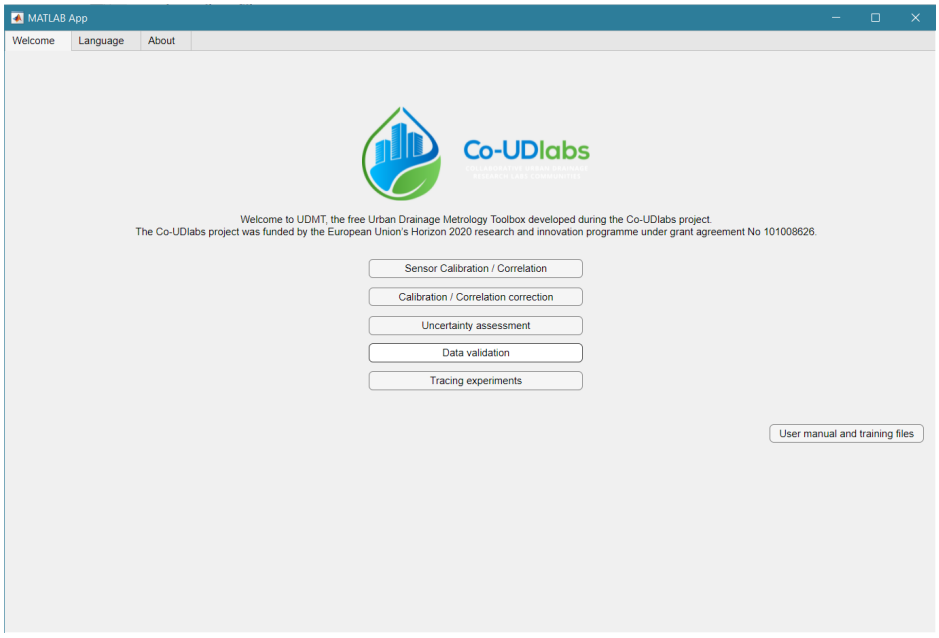

Figure 5.34: UDMT user interface.

Once the "Data Validation" page is active, four files must be uploaded (Figure 5.2):

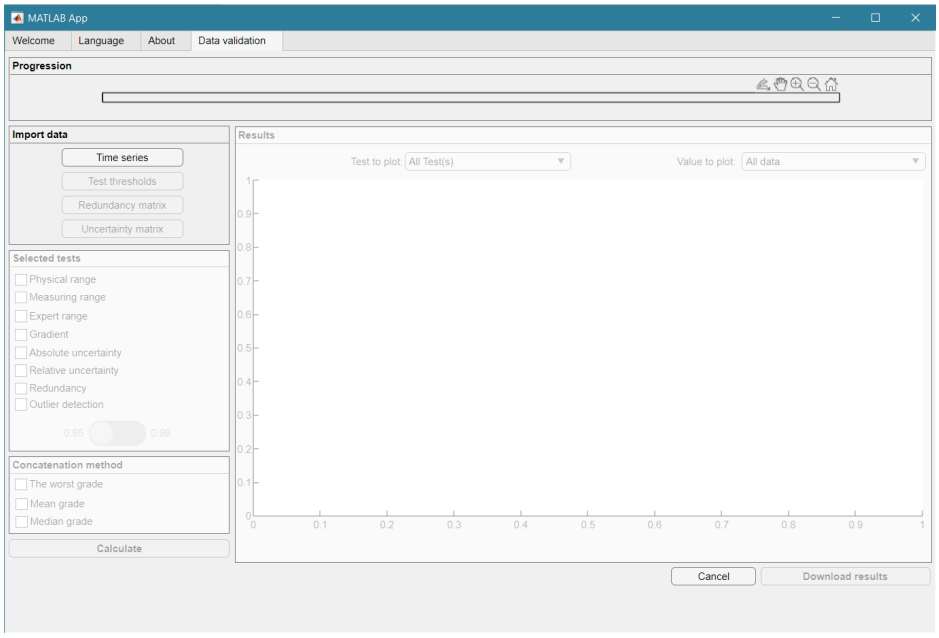

Figure 5.35: UDMT user interface (Data Validation page).

"Time series": select the file containing the data to validate. In this example, the file `DV_Testfile.csv` (Table 5.1), with 4 variables named V1 to V4 and their respective standard uncertainties uV1 to uV4.

Table 5.44: File `DV_Testfile.csv`.

Time	V1	uV1	V2	uV2	V3	uV3	V4	uV4
25-Mar-2022 00:00:00	120	5	240	2.5	122	1.666.666.667	236	5
25-Mar-2022 00:05:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 00:10:00	58.3	3.115	116.6	15.575	60.3	1.038.333.333	112.6	3.115
25-Mar-2022 00:15:00	7.25	4.236	14.5	2.118	9.25	1.412	10.5	4.236
25-Mar-2022 00:20:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 00:25:00	18.256	0.752	36.512	0.376	20.256	0.250666667	32.512	0.752
25-Mar-2022 00:30:00	120	5	240	2.5	122	1.666.666.667	236	5
25-Mar-2022 00:35:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 00:40:00	58.3	3.115	116.6	15.575	60.3	1.038.333.333	112.6	3.115
25-Mar-2022 00:45:00	7.25	4.236	14.5	2.118	9.25	1.412	10.5	4.236
25-Mar-2022 00:50:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 00:55:00	18.256	0.752	36.512	0.376	20.256	0.250666667	32.512	0.752
25-Mar-2022 01:00:00	120	5	240	2.5	122	1.666.666.667	236	5
25-Mar-2022 01:05:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 01:10:00	58.3	3.115	116.6	15.575	60.3	1.038.333.333	112.6	3.115
25-Mar-2022 01:15:00	7.25	4.236	14.5	2.118	9.25	1.412	10.5	4.236
25-Mar-2022 01:20:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 01:25:00	18.256	0.752	36.512	0.376	20.256	0.250666667	32.512	0.752
25-Mar-2022 01:30:00	120	5	240	2.5	122	1.666.666.667	236	5
25-Mar-2022 01:35:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 01:40:00	58.3	3.115	116.6	15.575	60.3	1.038.333.333	112.6	3.115
25-Mar-2022 01:45:00	7.25	4.236	14.5	2.118	9.25	1.412	10.5	4.236
25-Mar-2022 01:50:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 01:55:00	18.256	0.752	36.512	0.376	20.256	0.250666667	32.512	0.752
25-Mar-2022 02:00:00	120	5	240	2.5	122	1.666.666.667	236	5
25-Mar-2022 02:05:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 02:10:00	58.3	3.115	116.6	15.575	60.3	1.038.333.333	112.6	3.115
25-Mar-2022 02:15:00	7.25	4.236	14.5	2.118	9.25	1.412	10.5	4.236
25-Mar-2022 02:20:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 02:25:00	18.256	0.752	36.512	0.376	20.256	0.250666667	32.512	0.752
25-Mar-2022 02:30:00	120	5	240	2.5	122	1.666.666.667	236	5
25-Mar-2022 02:35:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 02:40:00	58.3	3.115	116.6	15.575	60.3	1.038.333.333	112.6	3.115
25-Mar-2022 02:45:00	7.25	4.236	14.5	2.118	9.25	1.412	10.5	4.236
25-Mar-2022 02:50:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 02:55:00	18.256	0.752	36.512	0.376	20.256	0.250666667	32.512	0.752
25-Mar-2022 03:00:00	120	5	240	2.5	122	1.666.666.667	236	5
25-Mar-2022 03:05:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 03:10:00	58.3	3.115	116.6	15.575	60.3	1.038.333.333	112.6	3.115
25-Mar-2022 03:15:00	7.25	4.236	14.5	2.118	9.25	1.412	10.5	4.236
25-Mar-2022 03:20:00	39.1	1.955	78.2	0.9775	41.1	0.651666667	74.2	1.955
25-Mar-2022 03:25:00	18.256	0.752	36.512	0.376	20.256	0.250666667	32.512	0.752

"Test thresholds": select the file with the different thresholds for the later tests. In this example, the file `DV_Thresholds.csv` (Table 5.2). The file must have the same number of columns as the "Time series" file. Each line specifies the thresholds for the tests to be run: PR for the Physical Range test, MR for the Measuring Range test, ER for the Expert Range test, GR for the GRadient test, AU for the Absolute Uncertainty test, and RU for the Relative Uncertainty test. Min stands for the minimum and Max for the maximum.

Table 5.45: File `DV_Thresholds.csv`.

T	V1	uV1	V2	uV2	V3	uV3	V4	uV4
PR_Min	0	NaN	0	NaN	0	NaN	0	NaN
PR_Max	1000	NaN	1000	NaN	1000	NaN	1000	NaN
MR_Min	0.03	NaN	0.03	NaN	0.05	NaN	0.05	NaN
MR_Max	1	NaN	1	NaN	1	NaN	1	NaN
ER_Min	0.05	NaN	0.05	NaN	0.1	NaN	0.1	NaN
ER_Max	0.7	NaN	0.7	NaN	0.7	NaN	0.7	NaN
GR_Min	0	NaN	0	NaN	0	NaN	0	NaN
GR_Max	0.02	NaN	0.05	NaN	0.1	NaN	0.1	NaN
AU	NaN	0.001	NaN	0.001	NaN	0.03	NaN	0.03
RU	NaN	0.01	NaN	0.01	NaN	0.1	NaN	0.1

"Redundancy matrix": select the file with the redundancy relations between the different columns of the "Time series" file. In this example, the file `DV_M_Redundancy.csv` (Table 5.3). 1 indicates a redundancy between values (e.g., V1 et V2 are redundant, V1 and V3 are not).

Table 5.46: File `DV_M_Redundancy.csv`.

M_R	V1	uV1	V2	uV2	V3	uV3	V4	uV4
V1	0	0	1	0	0	0	0	0
uV1	0	0	0	0	0	0	0	0
V2	0	0	0	0	0	0	0	0
uV2	0	0	0	0	0	0	0	0
V3	0	0	0	0	0	0	1	0
uV3	0	0	0	0	0	0	0	0
V4	0	0	0	0	0	0	0	0
uV4	0	0	0	0	0	0	0	0

"Uncertainty matrix": select the file with the uncertainty relations between the different columns of the "Time series" file. In this example, the file `DV_M_Uncertainty.csv` (Table 5.4). 1 indicates a link between a value and its standard uncertainty (e.g. the standard uncertainty of V1 is uV1, uV2 is not the standard uncertainty of V3).

Table 5.47: File `DV_M_Uncertainty.csv`.

M_U	V1	uV1	V2	uV2	V3	uV3	V4	uV4
V1	0	1	0	0	0	0	0	0
uV1	0	0	0	0	0	0	0	0
V2	0	0	0	1	0	0	0	0
uV2	0	0	0	0	0	0	0	0
V3	0	0	0	0	0	1	0	0
uV3	0	0	0	0	0	0	0	0
V4	0	0	0	0	0	0	0	1
uV4	0	0	0	0	0	0	0	0

Once the files are uploaded, the box(es) of the tests to apply need(s) to be ticked: later calculations will be run only with the selected tests (Figure 5.3).

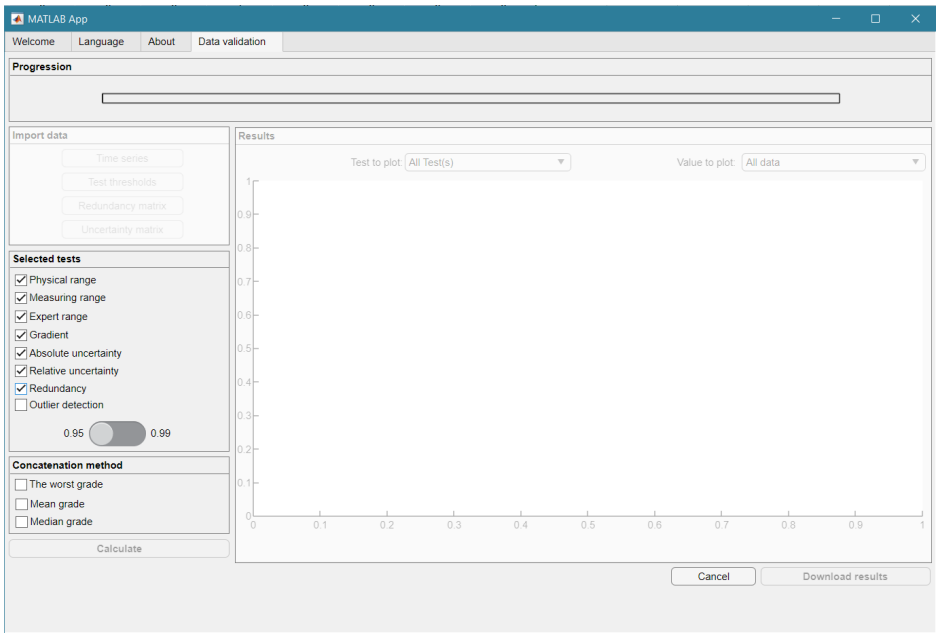

Figure 5.36: UDMT user interface (test selection).

For the redundancy and outlier detection tests, the confidence interval needs to be specified: the default value is 95% but it can be changed to 99% by moving the circular button to the right.

Each test gives an output for each data point, which could be labeled as Bad, Doubtful or Unsuitable depending on the applied test. Labels can be really different for each test (e.g., Good for the Physical Range but Doubtful for the Expert Range). To give a final label for the data point, the concatenation method must be chosen (Figure 5.4):

- "The worst grade": the most pessimistic approach.
- "Mean grade": standard approach discussed within the scientific community.
- "Median grade": the method we recommend – select this method for the test.

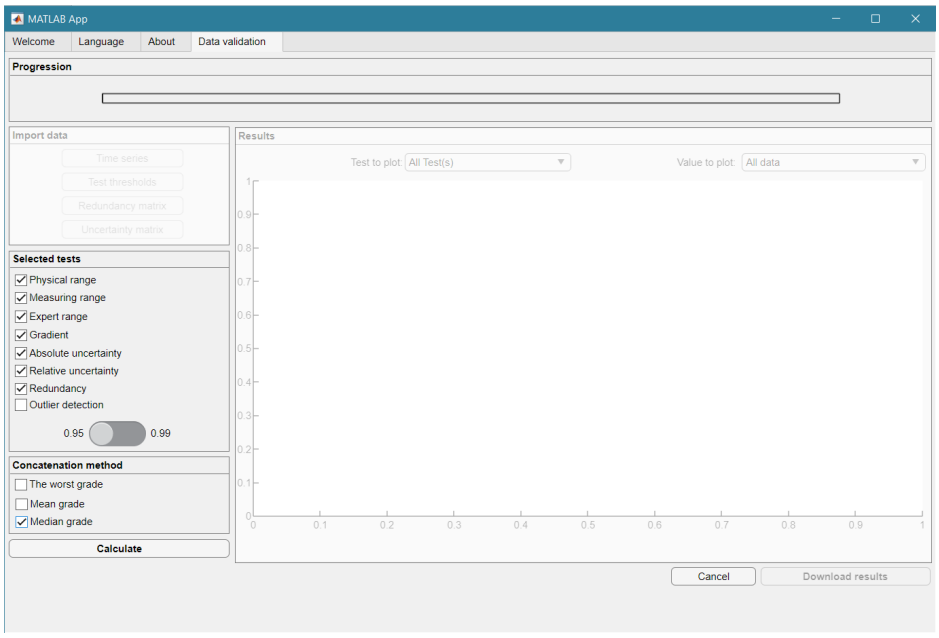

Figure 5.37: UDMT user interface (concatenation method selection).

Click on “Calculate”.

Once the calculations are done, the “Results” panel becomes active. Labels of each test or the final label can be plotted for any selected variable. Figure 5.5 shows an example for the value V2 and the Physical Range test.

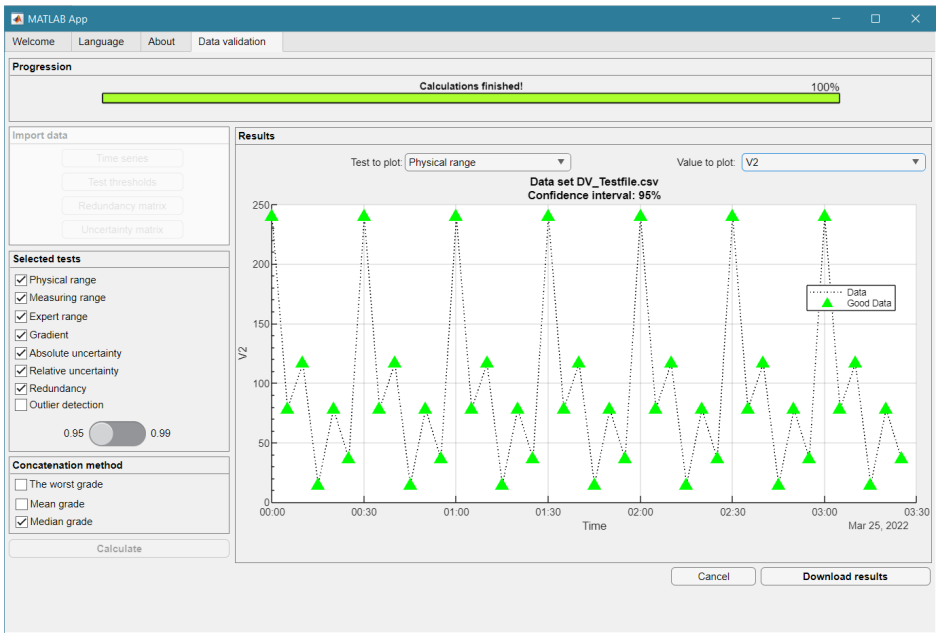

Figure 5.38: UDMT user interface (Label plotted for V2 and the Physical Range test).

Click on “Download Results”. Various files can be saved successively:

- A global file with data and final labels, recorded as `DV_Testfile_Median.csv` (Table 5.5): with the final grade for each data point (NG_V1, NG_V2, etc.) equal to 0 for Unsuitable label, 0.5 for Doubtful label and 1 for Good label.
- One file for each value Vi, recorded as `DV_Testfile_Vi_Median.csv` (Table 5.6), with the time series and its standard uncertainty and, in the following columns, the outputs of each test and the final label.

Table 5.48: File `DV_Testfile_Median.csv`.

Time	V1	V2	V3	V4	uV1	uV2	uV3	uV4	NG_V1	NG_V2	NG_V3	NG_V4
25-Mar-2022 00:00:00	120	240	122	236	5	2.5	NaN	5	0.5	0.5	0.5	0.5
25-Mar-2022 00:05:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 00:10:00	58.3	116.6	60.3	112.6	3.115	15.575	NaN	3.115	0.5	0.5	0.5	0.5
25-Mar-2022 00:15:00	7.25	14.5	9.25	10.5	4.236	2.118	1.412	4.236	0.5	0.5	0.5	0.5
25-Mar-2022 00:20:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 00:25:00	18.256	36.512	20.256	32.512	0.752	0.376	0.250666667	0.752	0.5	0.5	0.5	0.5
25-Mar-2022 00:30:00	120	240	122	236	5	2.5	NaN	5	0.5	0.5	0.5	0.5
25-Mar-2022 00:35:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 00:40:00	58.3	116.6	60.3	112.6	3.115	15.575	NaN	3.115	0.5	0.5	0.5	0.5
25-Mar-2022 00:45:00	7.25	14.5	9.25	10.5	4.236	2.118	1.412	4.236	0.5	0.5	0.5	0.5
25-Mar-2022 00:50:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 00:55:00	18.256	36.512	20.256	32.512	0.752	0.376	0.250666667	0.752	0.5	0.5	0.5	0.5
25-Mar-2022 01:00:00	120	240	122	236	5	2.5	NaN	5	0.5	0.5	0.5	0.5
25-Mar-2022 01:05:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 01:10:00	58.3	116.6	60.3	112.6	3.115	15.575	NaN	3.115	0.5	0.5	0.5	0.5
25-Mar-2022 01:15:00	7.25	14.5	9.25	10.5	4.236	2.118	1.412	4.236	0.5	0.5	0.5	0.5
25-Mar-2022 01:20:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 01:25:00	18.256	36.512	20.256	32.512	0.752	0.376	0.250666667	0.752	0.5	0.5	0.5	0.5
25-Mar-2022 01:30:00	120	240	122	236	5	2.5	NaN	5	0.5	0.5	0.5	0.5
25-Mar-2022 01:35:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 01:40:00	58.3	116.6	60.3	112.6	3.115	15.575	NaN	3.115	0.5	0.5	0.5	0.5
25-Mar-2022 01:45:00	7.25	14.5	9.25	10.5	4.236	2.118	1.412	4.236	0.5	0.5	0.5	0.5
25-Mar-2022 01:50:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 01:55:00	18.256	36.512	20.256	32.512	0.752	0.376	0.250666667	0.752	0.5	0.5	0.5	0.5
25-Mar-2022 02:00:00	120	240	122	236	5	2.5	NaN	5	0.5	0.5	0.5	0.5
25-Mar-2022 02:05:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 02:10:00	58.3	116.6	60.3	112.6	3.115	15.575	NaN	3.115	0.5	0.5	0.5	0.5
25-Mar-2022 02:15:00	7.25	14.5	9.25	10.5	4.236	2.118	1.412	4.236	0.5	0.5	0.5	0.5
25-Mar-2022 02:20:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 02:25:00	18.256	36.512	20.256	32.512	0.752	0.376	0.250666667	0.752	0.5	0.5	0.5	0.5
25-Mar-2022 02:30:00	120	240	122	236	5	2.5	NaN	5	0.5	0.5	0.5	0.5
25-Mar-2022 02:35:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 02:40:00	58.3	116.6	60.3	112.6	3.115	15.575	NaN	3.115	0.5	0.5	0.5	0.5
25-Mar-2022 02:45:00	7.25	14.5	9.25	10.5	4.236	2.118	1.412	4.236	0.5	0.5	0.5	0.5
25-Mar-2022 02:50:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 02:55:00	18.256	36.512	20.256	32.512	0.752	0.376	0.250666667	0.752	0.5	0.5	0.5	0.5
25-Mar-2022 03:00:00	120	240	122	236	5	2.5	NaN	5	0.5	0.5	0.5	0.5
25-Mar-2022 03:05:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 03:10:00	58.3	116.6	60.3	112.6	3.115	15.575	NaN	3.115	0.5	0.5	0.5	0.5
25-Mar-2022 03:15:00	7.25	14.5	9.25	10.5	4.236	2.118	1.412	4.236	0.5	0.5	0.5	0.5
25-Mar-2022 03:20:00	39.1	78.2	41.1	74.2	1.955	0.9775	0.651666667	1.955	0.5	0.5	0.5	0.5
25-Mar-2022 03:25:00	18.256	36.512	20.256	32.512	0.752	0.376	0.250666667	0.752	0.5	0.5	0.5	0.5

Table 5.49: File `DV_Testfile_V1_Median.csv`, for variable V1.

Time	V1	uV1	N_PR	N_MR	N_ER	N_G	N_AU	N_RU	N_R	N_O	N_D	N	N_Global
25-Mar-2022 00:00:00	120	5	1	0.5	0.5	1	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:05:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:10:00	58.3	3.115	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:15:00	7.25	4.236	1	0.5	0.5	0.5	0.5	0.5	1	NaN	NaN	NaN	0.5
25-Mar-2022 00:20:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:25:00	18.256	0.752	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:30:00	120	5	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:35:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:40:00	58.3	3.115	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:45:00	7.25	4.236	1	0.5	0.5	0.5	0.5	0.5	1	NaN	NaN	NaN	0.5
25-Mar-2022 00:50:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 00:55:00	18.256	0.752	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:00:00	120	5	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:05:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:10:00	58.3	3.115	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:15:00	7.25	4.236	1	0.5	0.5	0.5	0.5	0.5	1	NaN	NaN	NaN	0.5
25-Mar-2022 01:20:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:25:00	18.256	0.752	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:30:00	120	5	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:35:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:40:00	58.3	3.115	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:45:00	7.25	4.236	1	0.5	0.5	0.5	0.5	0.5	1	NaN	NaN	NaN	0.5
25-Mar-2022 01:50:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 01:55:00	18.256	0.752	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:00:00	120	5	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:05:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:10:00	58.3	3.115	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:15:00	7.25	4.236	1	0.5	0.5	0.5	0.5	0.5	1	NaN	NaN	NaN	0.5
25-Mar-2022 02:20:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:25:00	18.256	0.752	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:30:00	120	5	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:35:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:40:00	58.3	3.115	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:45:00	7.25	4.236	1	0.5	0.5	0.5	0.5	0.5	1	NaN	NaN	NaN	0.5
25-Mar-2022 02:50:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 02:55:00	18.256	0.752	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 03:00:00	120	5	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 03:05:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 03:10:00	58.3	3.115	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 03:15:00	7.25	4.236	1	0.5	0.5	0.5	0.5	0.5	1	NaN	NaN	NaN	0.5
25-Mar-2022 03:20:00	39.1	1.955	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5
25-Mar-2022 03:25:00	18.256	0.752	1	0.5	0.5	0.5	0.5	1	0.5	NaN	NaN	NaN	0.5

6. Tracing experiments

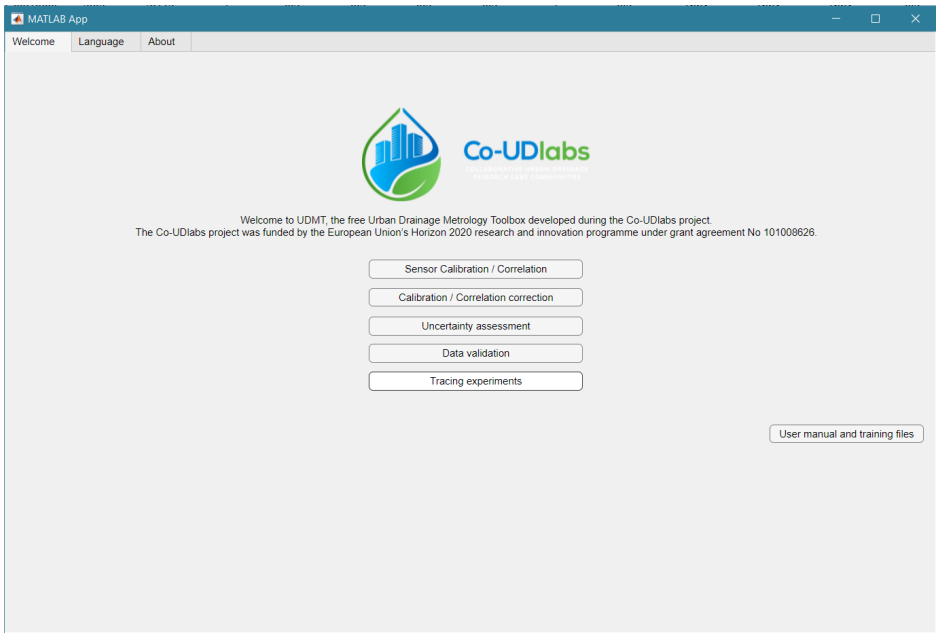

Figure 6.39: UDMT user interface.

Select "Tracing experiments" in the menu (Figure 6.1).

Tracing experiments, when and where they can be applied, allow to estimate a discharge with an uncertainty that is usually much lower than the uncertainty obtained with a measurement by means of most usual water level and flow velocity sensors in free surface flow conditions. Therefore, tracing experiments can be very useful to verify the values delivered by flowmeters, and to establish correction factors or function if necessary. For both types of tracer injection (one-shot instantaneous injection or continuous injection), four files need to be uploaded by the user (Figure 6.2):

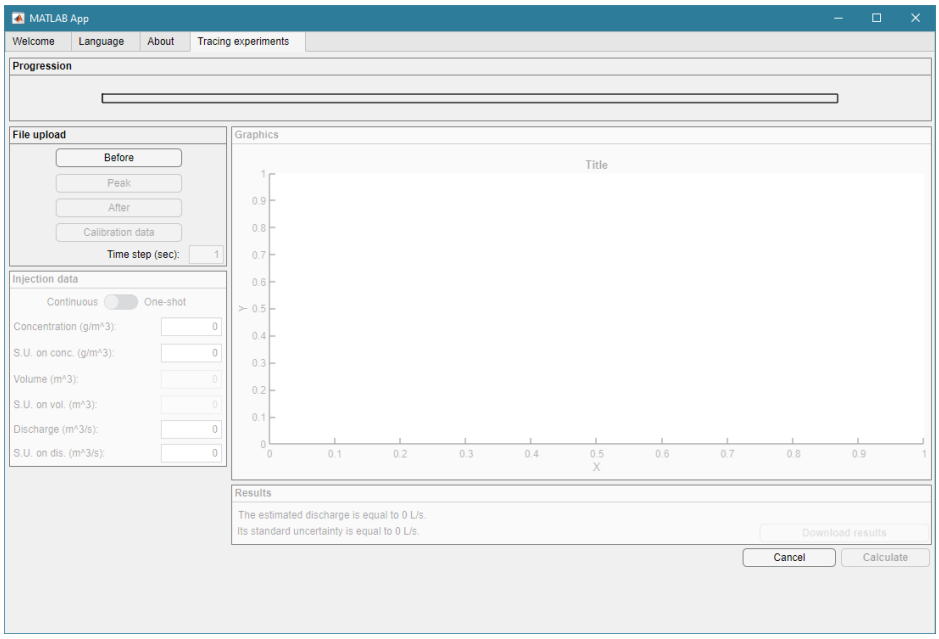

Figure 6.40: UDMT user interface.

Import data “Before”: background noise prior the tracer peak or plateau – select the file `Before.csv` (Table 6.1).

Table 6.50: First 20 lines of the file `Before.csv`.

Time	Cond	uCond
10-Jan-2022 10:00:00	105.6	0.1
10-Jan-2022 10:00:01	105.6	0.1
10-Jan-2022 10:00:02	105.6	0.1
10-Jan-2022 10:00:03	105.6	0.1
10-Jan-2022 10:00:04	105.6	0.1
10-Jan-2022 10:00:05	105.6	0.1
10-Jan-2022 10:00:06	105.6	0.1
10-Jan-2022 10:00:07	105.6	0.1
10-Jan-2022 10:00:08	105.6	0.1
10-Jan-2022 10:00:09	105.6	0.1
10-Jan-2022 10:00:10	105.6	0.1
10-Jan-2022 10:00:11	105.6	0.1
10-Jan-2022 10:00:12	105.6	0.1
10-Jan-2022 10:00:13	105.6	0.1
10-Jan-2022 10:00:14	105.6	0.1
10-Jan-2022 10:00:15	105.6	0.1
10-Jan-2022 10:00:16	105.6	0.1
10-Jan-2022 10:00:17	105.6	0.1
10-Jan-2022 10:00:18	105.6	0.1
10-Jan-2022 10:00:19	105.7	0.1

Import data “Peak”: tracer peak or plateau – select the file `Peak.csv` (Table 6.2).

Table 6.51: First 20 lines of the file `Peak.csv`.

Time	Cond	uCond
10-Jan-2022 10:02:30	105.7	0.1
10-Jan-2022 10:02:31	105.7	0.1
10-Jan-2022 10:02:32	105.7	0.1
10-Jan-2022 10:02:33	105.7	0.1
10-Jan-2022 10:02:34	105.7	0.1
10-Jan-2022 10:02:35	105.7	0.1
10-Jan-2022 10:02:36	105.9	0.1
10-Jan-2022 10:02:37	105.9	0.1
10-Jan-2022 10:02:38	105.9	0.1
10-Jan-2022 10:02:39	105.9	0.1
10-Jan-2022 10:02:40	105.9	0.1
10-Jan-2022 10:02:41	105.9	0.1
10-Jan-2022 10:02:42	105.9	0.1
10-Jan-2022 10:02:43	105.9	0.1
10-Jan-2022 10:02:44	105.9	0.1
10-Jan-2022 10:02:45	105.9	0.1
10-Jan-2022 10:02:46	105.9	0.1
10-Jan-2022 10:02:47	105.9	0.1
10-Jan-2022 10:02:48	106	0.1
10-Jan-2022 10:02:49	106	0.1

Import data “After”: background noise after the tracer peak or plateau – select the file `After.csv` (Table 6.3).

Table 6.52: First 20 lines of the file `After.csv`.

Time	Cond	uCond
10-Jan-2022 10:17:30	105.9	0.1
10-Jan-2022 10:17:31	105.9	0.1
10-Jan-2022 10:17:32	105.9	0.1
10-Jan-2022 10:17:33	105.9	0.1
10-Jan-2022 10:17:34	105.9	0.1
10-Jan-2022 10:17:35	105.9	0.1
10-Jan-2022 10:17:36	105.9	0.1
10-Jan-2022 10:17:37	105.9	0.1
10-Jan-2022 10:17:38	105.9	0.1
10-Jan-2022 10:17:39	105.9	0.1
10-Jan-2022 10:17:40	105.9	0.1
10-Jan-2022 10:17:41	105.9	0.1
10-Jan-2022 10:17:42	105.9	0.1
10-Jan-2022 10:17:43	105.9	0.1
10-Jan-2022 10:17:44	105.9	0.1
10-Jan-2022 10:17:45	105.9	0.1
10-Jan-2022 10:17:46	105.9	0.1
10-Jan-2022 10:17:47	105.9	0.1
10-Jan-2022 10:17:48	105.9	0.1
10-Jan-2022 10:17:49	105.9	0.1

Import data "Calibration data": Calibration or correlation function data, estimated by means of the procedure explained in section 3 (typically: de-icing salt concentration vs conductivity or fluorometer calibration curve – e.g. in Lepot *et al.*, 2014) – select the file `TE-ConductivityvsSaltconcentration_Function-Data.csv` (Table 6.4).

Then the acquisition time step of the recorded time series needs to be specified (duration in seconds: typically, 1 second – Figure 6.3).

Table 6.53: Transposed version of the file `TE-ConductivityvsSaltconcentration_Function-Data.csv`.

Time	19-May-2022 10:00:00
DegOpt	3
deg 1	1
b11	110.002109969451
b12	1.82272633903673
u_b11	10.3873797147243
u_b12	0.00765602778926153
var_b11_b12	-0.0611205425644949
ResVar1	1059.94107788974
deg 2	2
b21	126.326131186137
b22	1.72412786708629
b23	4.69849264221474e-05
u_b21	10.6273959703875
u_b22	0.0348058861223954
u_b23	1.62821947992055e-05
var_b21_b22	-0.239138775941587
var_b21_b23	9.21073933925375e-05
var_b22_b23	-5.56336464115827e-07
ResVar2	795.126108729504
deg 3	3
b31	106.099999999996
b32	1.96571916636496
b33	-0.000264095314600427
b34	9.73938378936329e-08
u_b31	0.837489635093409
u_b32	0.00460396324154928
u_b33	5.09077757208483e-06
u_b34	1.5500875152013e-09
var_b31_b32	-0.0025034609456304
var_b31_b33	2.08129655972521e-06
var_b31_b34	-4.98992222422732e-10
var_b32_b33	-2.19817058617585e-08
var_b32_b34	5.96021939320214e-12
var_b33_b34	-7.67455819361309e-15
ResVar3	4.20833333333333
maxStd	4.08248290463863

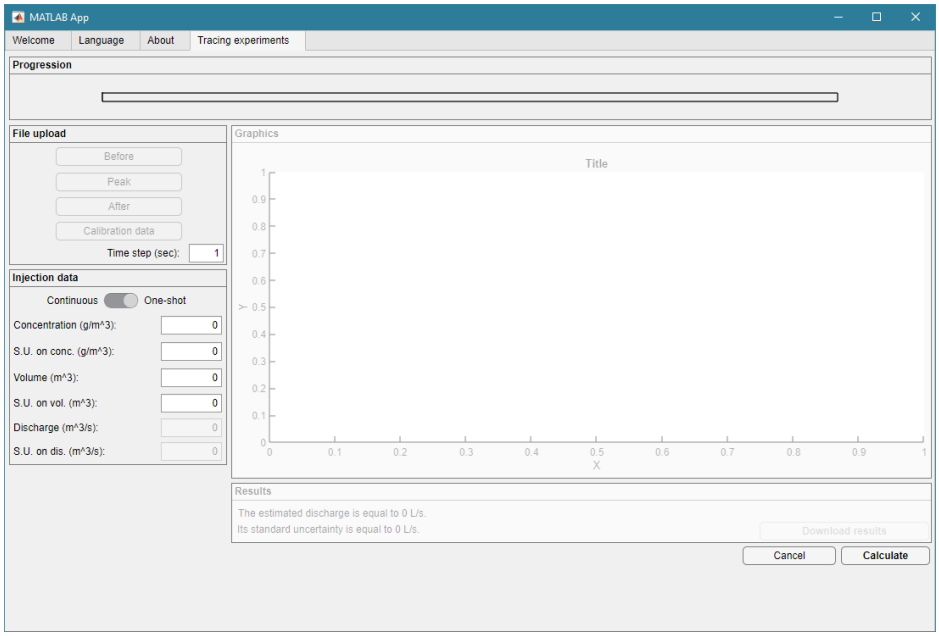

Figure 6.41: UDMT user interface.

Once the acquisition time step is specified, the type of injection must be specified: continuous (move the circular button to the left, on “Continuous”) or spike (move the circular button to the right, on “One-shot”) – select “One-shot” for this example.

Depending on the type, injection data must be fulfilled in the editable fields:

- For “Continuous” injection:
  - “Concentration (g/m^3)”: concentration of the injected tracer
  - “S.U. on conc. (g/m^3)”: standard uncertainty on the concentration of the injected tracer
  - “Discharge (m^3/s)”: discharge of the tracer injection
  - “S.U. on dis. (m^3/s)”: standard uncertainty on discharge of the tracer injection
- For “One-shot” injection (Figure 6.4):
  - “Concentration (g/m^3)”: concentration of the injected tracer – type here 180 000 for a brine at 180 g/L.
  - “S.U. on conc. (g/m^3)”: standard uncertainty on the concentration of the injected tracer – type here 1 for a standard uncertainty on the brine concentration of 0.001 g/L.
  - “Volume (m^3)”: volume of the tracer injection – type here 0.01 for a injected brine volume equal to 10 L.
  - “S.U. on dis. (m^3/s)”: standard uncertainty on the volume of the tracer injection – type here 0.000001 for a standard uncertainty of 1 mL.

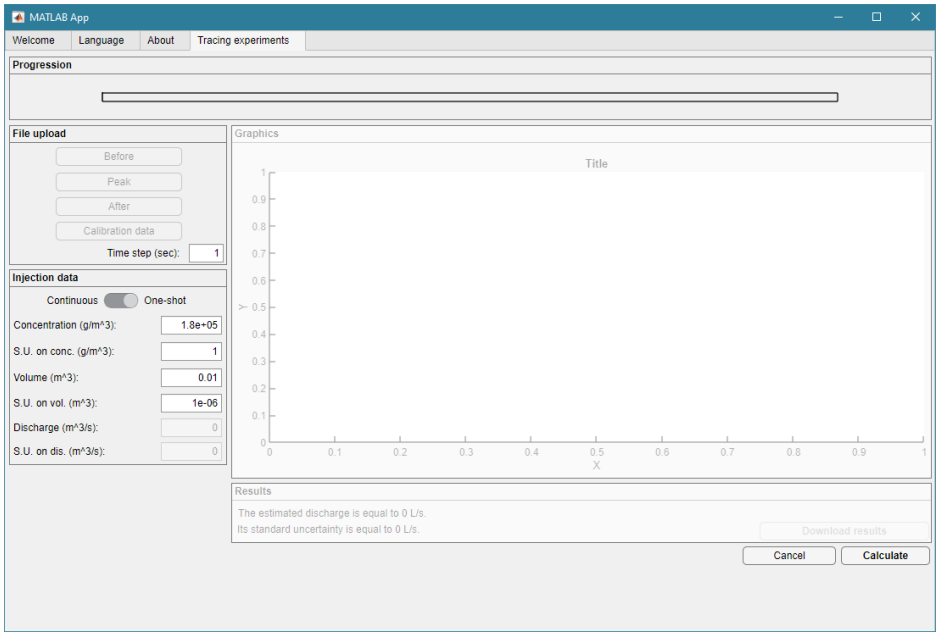

Figure 6.42: UDMT user interface.

Click on “Calculate”. The tool retrieves (Figure 6.5):

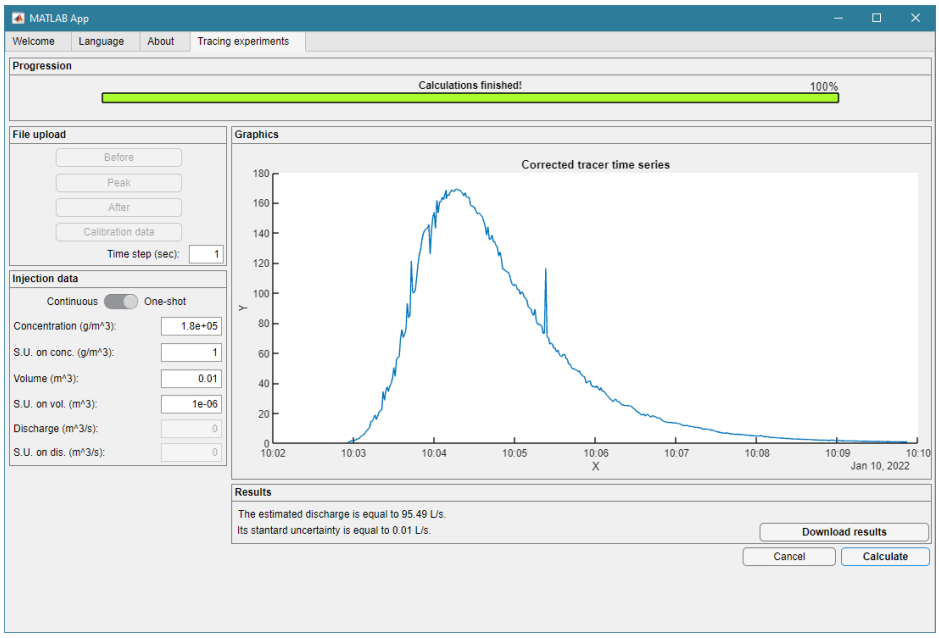

Figure 6.43: UDMT user interface.

The corrected tracer time series is plotted. The estimated discharges (95.49 L/s) and its standard uncertainty (0.01 L/s) are shown in the results panel.

Click on "Download results": the tool retrieves a text file containing all the detailed results of the tracer experiments. Save this file as `Peak_TE.csv`.

The text file of this example is shown in Table 6.5: the discharge Q (in m^3/s) and its standard uncertainty $u(Q)$ (in m^3/s) are then saved.

Table 6.54: Results of the tracing experiments, file `Peak_TE.csv`.

Time	Q	u_Q	Q_low95	Q_high95
10-Jan-2022 10:02:30	0.095486	9.5634E-06	0.095467	0.095504

Value of Q = 95.49 L/s, standard uncertainty $u(Q)$ = 0.01 L/s, 95% coverage interval = [95.47, 95.51] L/s.

7. Next steps

This document is the first version of Deliverable D6.3.

A revised version will be released before the end of year 2023 with the last development and adaptation of the UDMT based on both the Co-UDlabs partners and external first users' feedback. This revised version will include at least the following modifications:

- A sensor correlation advanced function, based on polynomial fitting with Williamson least squares method (the Matlab code already exists in April 2023, it requires only additional adaptation to be included in the webapp).
- In addition to English and French, the user interface will also be available in Spanish (Spanish translation done in April 2023, tests will be done in May-June 2023). A German language interface is also planned.