User's Guide to URESPONSE software – a tool for sensor response estimate of superconducting rock magnetometers

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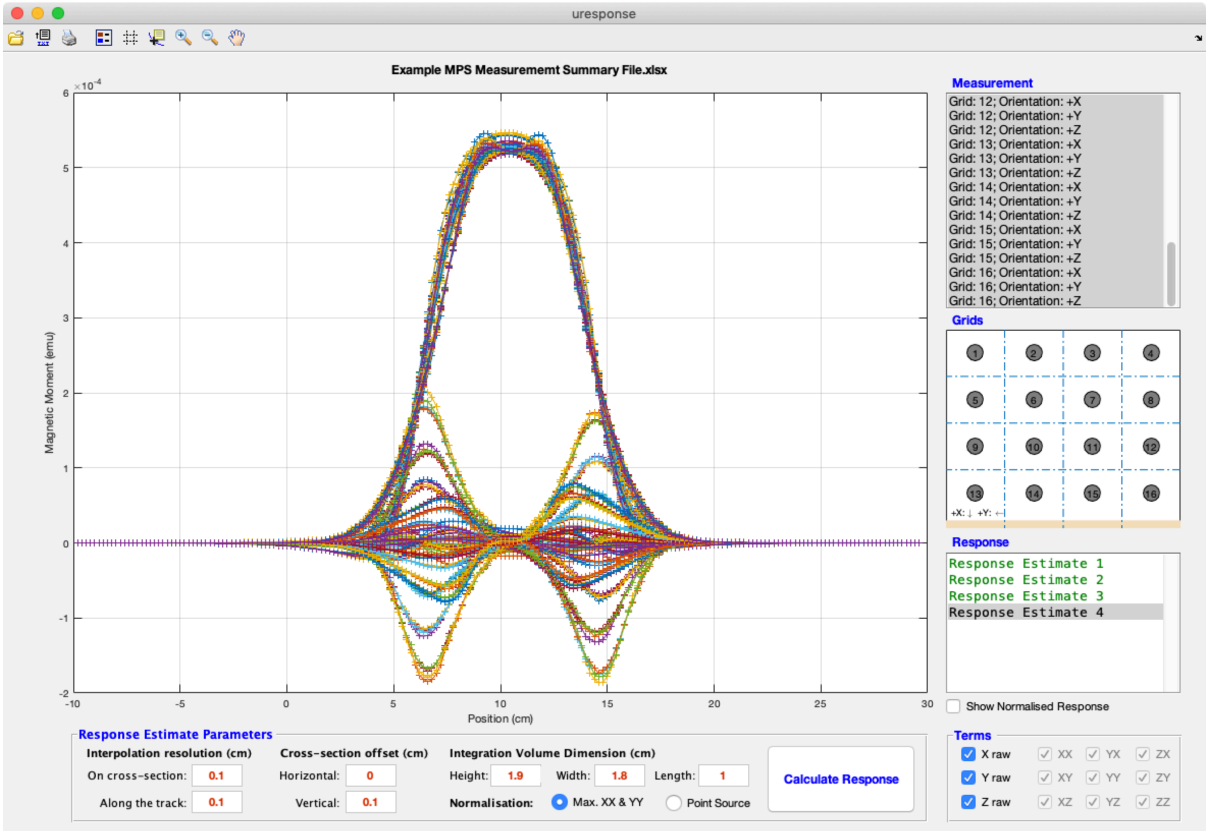

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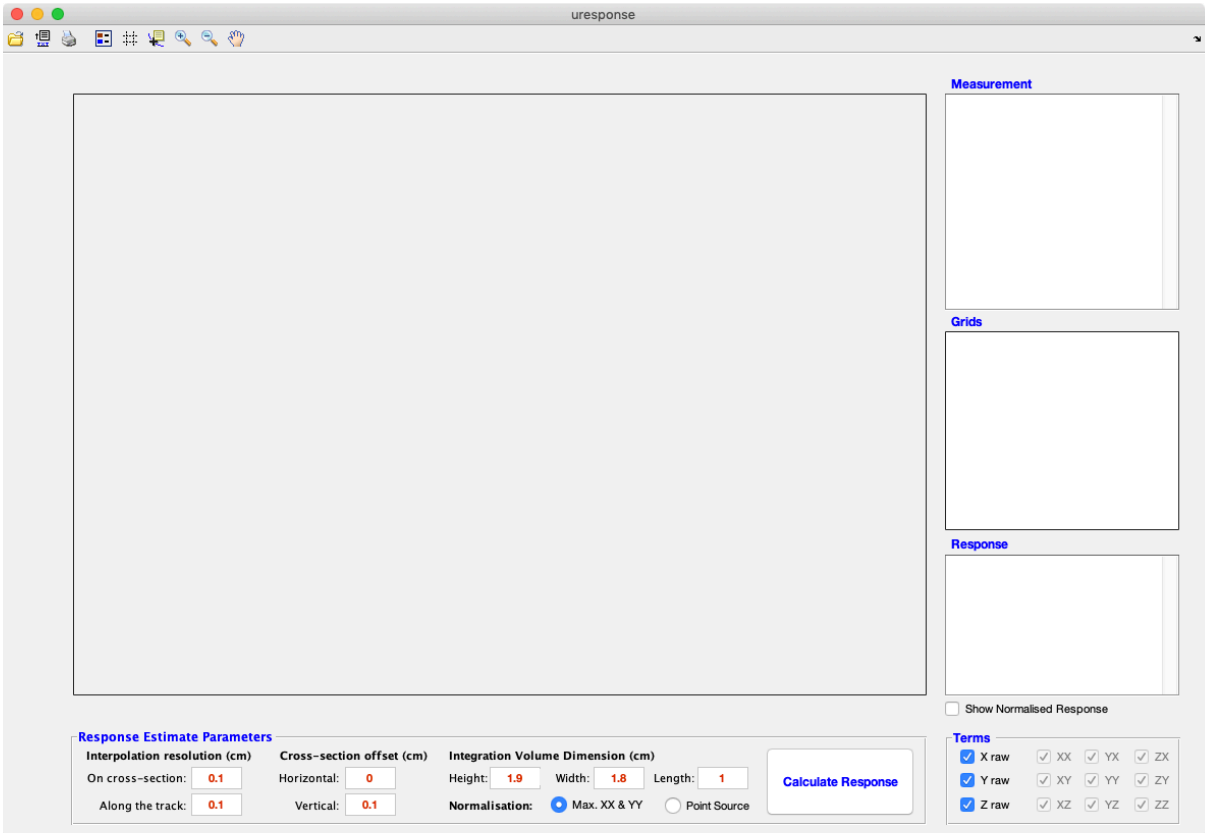
1. About the software

URESPONSE is a MATLAB program with graphical user interface (GUI) developed for sensor response estimate of superconducting rock magnetometers (SRM) based on measurements of a magnetic point source (MPS) sample. The software is associated with the following paper submitted to the journal *Geochemistry, Geophysics, Geosystems*. If you use URESPONSE, please cite the work below.

Xuan, C., & Oda, H. (2019). Sensor response estimate and cross calibration of paleomagnetic measurements on pass-through superconducting rock magnetometers. *Geochemistry, Geophysics, Geosystems.* (revision submitted)

2. Downloading and running URESPONSE

The URESPONSE software, examples of MPS measurement data files, Excel summary file, measurement data format file, as well as the user's guide of the software can be downloaded at https://earthref.org/ERDA/2396/. Download all files and folders using the link and place them together in the same folder. In MATLAB, go to the files folder containing the file 'uresponse.m'. Type `uresponse` in the MATLAB command window to run the URESPONSE program. The following GUI will show up.



3. Organizing MPS measurements and preparing input file for URESPONSE

This section explains how to organize MPS measurements on an SRM and prepare an input file for the URESPONSE software. An example set of MPS data files is provided for users to test run the software. The example MPS data were collected on a 2G Enterprises liquid-helium free SRM at the University of Southampton. If you are running URESPONSE using the provided example data files, you may proceed to section 4.

In order to use URESPONSE to estimate sensor response of an SRM, MPS measurements need to be conducted on that SRM first. Users are referred to Oda and Xuan (2014) and Oda et al. (2016) for details on MPS measurement procedures. We recommend to conduct MPS measurements at resolutions higher than 10 mm intervals (preferably at 1 mm or 2 mm intervals) over the possible sensor response range along the SRM Z-axis (typically about 40-50 cm). The MPS measurement block (see examples in Figure 1 in Xuan & Oda, 2019) should be larger than the cross-section of continuous paleomagnetic samples. MPS measurement data associated with each SRM run while the MPS sample is placed at one of the cross-section grids orienting parallel/antiparallel to one of the measurement axes should be stored in separated files. All measurement runs should be conducted using the same measurement resolution along the SRM Z-axis and over the same lengths. Users should check through individual MPS measurements to ensure there are no obvious flux jumps in the data that could significantly influence SRM sensor response estimates. If flux jumps are observed, users should either repeat those measurement runs or use the UPmag software to correct the flux jumps (Xuan & Channell, 2009).

To read the MPS measurement data into URESPONSE properly, users need to summarize relevant information about the MPS measurements and the SRM in the Excel file (see screen capture of an example Excel summary file below). The Excel table is grouped into three sections: the 'SRM information' section, the 'Point Source Measurement Setting' section, and the bottom section for information on each measurement run of the MPS (including grid IDs and coordinates on the cross-section, MPS magnetization orientation, and names of the measurement data files). The 'SRM information' section allows users to record relevant information about the SRM being investigated including laboratory where the SRM is located at, its model, installation date, and measurement coordinates (i.e. positive directions of the three orthogonal measurement axes).

In the 'Point Source Measurement Setting' section, users are requested to include information about ID and magnetic moment of the MPS sample used, date of measurements, shape and number of grids used for the measurements on the cross-section (e.g. Rectangular and 16 grids). This section also stores information on the SRM track movement direction during MPS measurements (i.e. into/out from the SRM), and the start and end positions as well as resolution (i.e. distance between neighboring positions) of MPS measurement runs along the track. Distance between grids center and tray surface and MPS position on the SRM track should also be recorded. A measurement format file same as that used by the UDECON software should be prepared (see Table 2 in Xuan & Oda, 2015). The format file allows URESPONSE to read data from each MPS measurement file properly. The name of the measurement format file must be specified in the Excel table. Users also should include information on the name of the folder where all individual MPS measurement files are stored. Note that all MPS measurement files should be stored in the same folder, and that folder together with the measurement format file should be stored in the same directory where the Excel summary file is located.

The bottom section of the Excel table requires users to list necessary information for each measurement run of the MPS sample including identification number of a cross-section grid where the MPS was attached to, coordinates of that grid along the X and Y measurement axes of the SRM, direction along which magnetization of the MPS was aligned to during the run, and full name of the file that holds corresponding measurement data associated with the run. Origin of the coordinates for grid positions is at the center of the grids. Note that identification numbers of cross-section grids range between 1 and the total number of grid points.

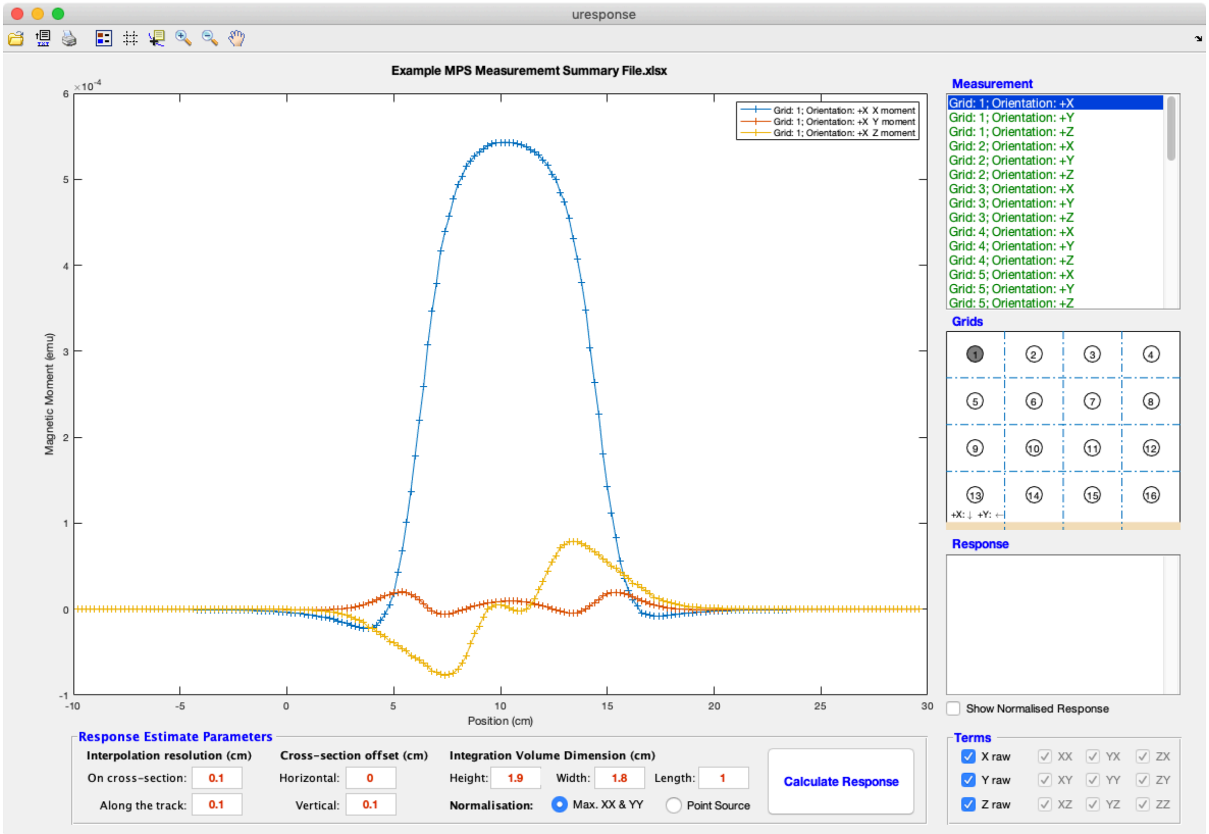
SRM Information	
Laboratory:	University of Southampton
SRM Model:	2G Enterprises 755 Liquid Helium Free u-channel
Installation Date:	September 2017
Positive X:	Down
Positive Y:	Right (facing SRM)
Positive Z:	Pointing out from SRM

Point Source Measurement Setting	
Point Source ID:	MPS-11
Date of Measurements:	Oct-17
Point Source magnetic moment (emu):	5.2440E-04
Positive Tracking Direction:	Into SRM
Grid Shape:	Rectangular
Number of Grids:	16
Distance between Grids center and tray surface (cm)	1.25
Measurement Start Position (cm):	-9.8
Measurement Resolution (cm):	0.2
Measurement End Position (cm):	29.6
Point Source Position (cm)	10
Measurement Format File:	SRM Measurement Data Format.txt
Measurement Data File Folder:	MPS Measurement Files

Cross Section Grid No.	Grid X Coordinate (cm)	Grid Y Coordinate (cm)	Point Source Orientation	Measurement Data File Name
1	-0.9	0.9	+X	Grid-Position-01_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
1	-0.9	0.9	+Y	Grid-Position-01_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
1	-0.9	0.9	+Z	Grid-Position-01_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
2	-0.9	0.3	+X	Grid-Position-02_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
2	-0.9	0.3	+Y	Grid-Position-02_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
2	-0.9	0.3	+Z	Grid-Position-02_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
3	-0.9	-0.3	+X	Grid-Position-03_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
3	-0.9	-0.3	+Y	Grid-Position-03_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
3	-0.9	-0.3	+Z	Grid-Position-03_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
4	-0.9	-0.9	+X	Grid-Position-04_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
4	-0.9	-0.9	+Y	Grid-Position-04_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
4	-0.9	-0.9	+Z	Grid-Position-04_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
5	-0.3	0.9	+X	Grid-Position-05_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
5	-0.3	0.9	+Y	Grid-Position-05_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
5	-0.3	0.9	+Z	Grid-Position-05_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
6	-0.3	0.3	+X	Grid-Position-06_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
6	-0.3	0.3	+Y	Grid-Position-06_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
6	-0.3	0.3	+Z	Grid-Position-06_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
7	-0.3	-0.3	+X	Grid-Position-07_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
7	-0.3	-0.3	+Y	Grid-Position-07_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
7	-0.3	-0.3	+Z	Grid-Position-07_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
8	-0.3	-0.9	+X	Grid-Position-08_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
8	-0.3	-0.9	+Y	Grid-Position-08_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
8	-0.3	-0.9	+Z	Grid-Position-08_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
9	0.3	0.9	+X	Grid-Position-09_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
9	0.3	0.9	+Y	Grid-Position-09_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
9	0.3	0.9	+Z	Grid-Position-09_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
10	0.3	0.3	+X	Grid-Position-10_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
10	0.3	0.3	+Y	Grid-Position-10_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
10	0.3	0.3	+Z	Grid-Position-10_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
11	0.3	-0.3	+X	Grid-Position-11_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
11	0.3	-0.3	+Y	Grid-Position-11_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
11	0.3	-0.3	+Z	Grid-Position-11_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
12	0.3	-0.9	+X	Grid-Position-12_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
12	0.3	-0.9	+Y	Grid-Position-12_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
12	0.3	-0.9	+Z	Grid-Position-12_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
13	0.9	0.9	+X	Grid-Position-13_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
13	0.9	0.9	+Y	Grid-Position-13_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
13	0.9	0.9	+Z	Grid-Position-13_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
14	0.9	0.3	+X	Grid-Position-14_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
14	0.9	0.3	+Y	Grid-Position-14_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
14	0.9	0.3	+Z	Grid-Position-14_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
15	0.9	-0.3	+X	Grid-Position-15_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
15	0.9	-0.3	+Y	Grid-Position-15_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
15	0.9	-0.3	+Z	Grid-Position-15_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
16	0.9	-0.9	+X	Grid-Position-16_Orientation+X_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
16	0.9	-0.9	+Y	Grid-Position-16_Orientation+Y_Resolution-2mm_UoS-SRM-new_Oct2017.DAT
16	0.9	-0.9	+Z	Grid-Position-16_Orientation+Z_Resolution-2mm_UoS-SRM-new_Oct2017.DAT

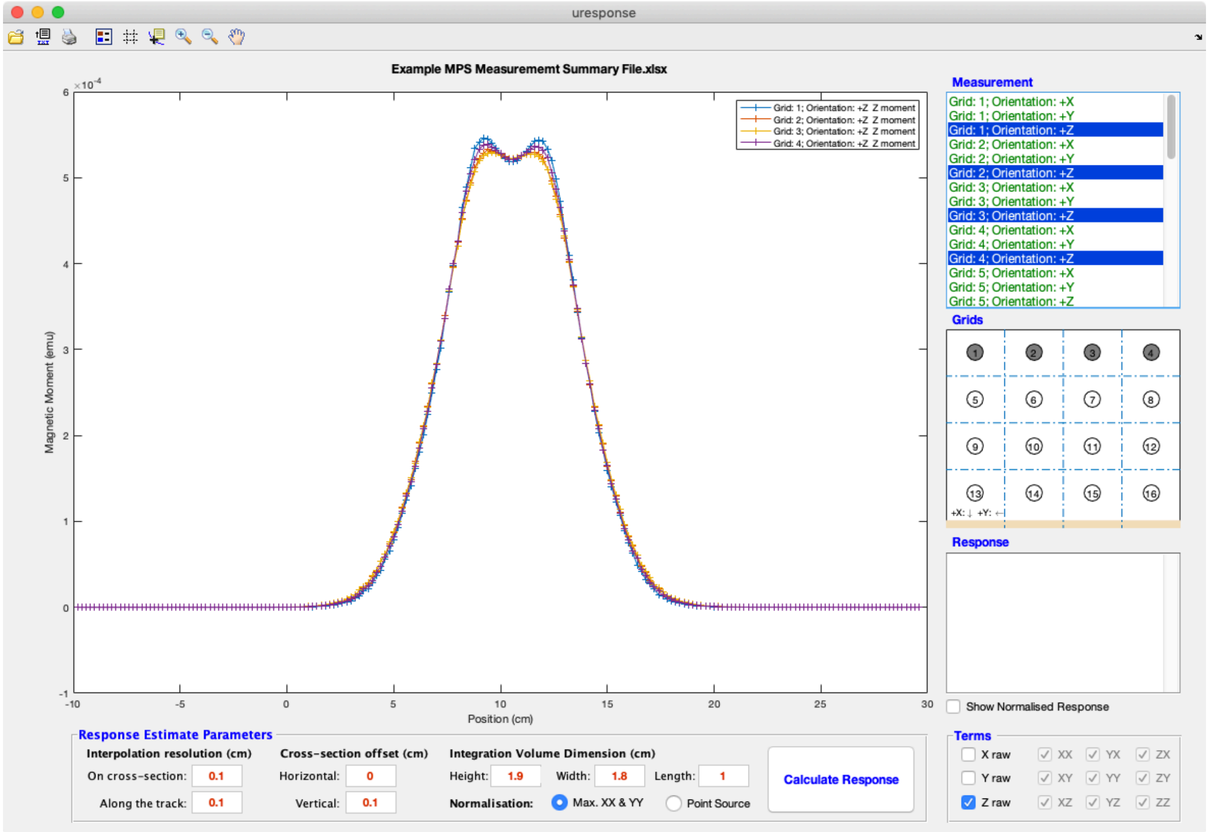
4. Visualizing and checking MPS measurements

After launching the URESPONSE software, the summary Excel file can be directly read by clicking 'Open Response Measurement Summary File' icon located on the leftmost in the software toolbar located on the top of the URESPONSE interface and then selecting the Excel summary file. Name of the summary file will appear on the top of the main plot, and all MPS measurements will be listed on the top right ‘Measurement’ panel. Measurements are labeled and organized according to grid positions and orientations of the MPS for individual runs. All grid positions used on the cross-section will be plotted on the middle right ‘Grids’ panel based on their coordinates along the X and Y measurement axes. Main plot area displays three-axis magnetic moment data measured at the first grid position with the MPS orienting towards the +X direction as an initial selection right after loading the MPS data (see screen capture below).



Users can choose to view measurements at different grid positions with different MPS orientations by either left clicking on the corresponding label on the ‘Measurement’ panel, or by using up and down arrow keys on the keyboard. Users can also plot and compare data from multiple measurement runs at the same time by pressing the Command key while left-clicking corresponding labels on the ‘Measurement’ panel for the runs (or pressing the Shift key while using arrow down/up keys). Grid position(s) associated with measurement data currently shown in the main plot area are highlighted on the ‘Grids’ panel below ‘Measurement’ panel. URESPONSE also allows users to show any combination of the data measured by the three-axes pick-up coils of an SRM using check boxes located in the ‘Terms’ panel on the bottom right side of the software (see screen capture below).

Users can use tools incorporated in the toolbar on the main plot area to pan and zoom in/out plots, turn on/off plot legends and axis grid lines. In addition, the data cursor tool can be used to conveniently find out values associated with any data points on the plots shown. Users can also use the ‘print’ tool to save a pdf version of the current URESPONSE interface including any plots shown in the main plot area.



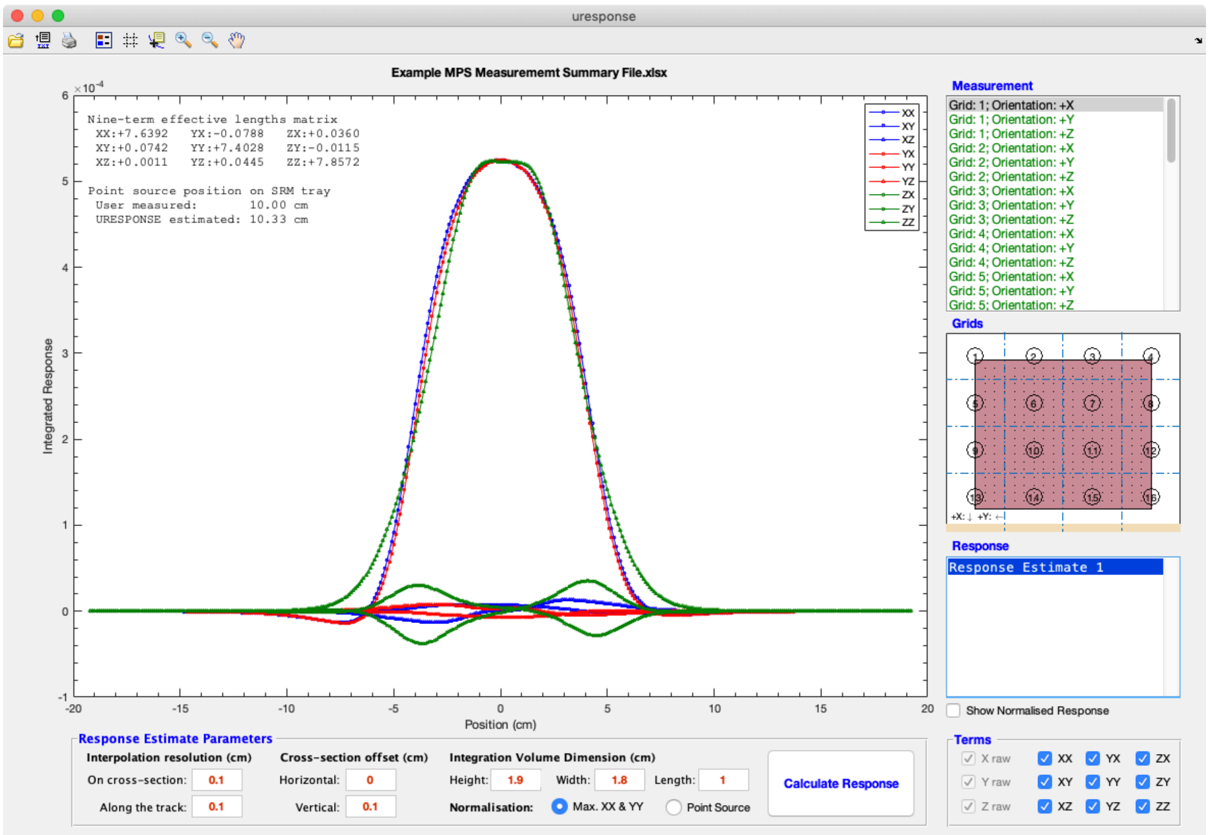
5. Estimating and exporting SRM sensor response for optimized deconvolution

The 'Response Estimate Parameters' panel on the bottom of the software interface includes parameters that can be adjusted for the SRM sensor response estimates. Response estimate involves interpolating the 3D matrix of all (nine) response terms acquired from MPS measurements onto finer 3D grids then integrating the interpolated data over volumes defined by actual sample geometry and measurement intervals. 'Interpolation resolution (cm)' boxes define the 3D grids for interpolation. Values in 'On cross section' and 'Along the track' boxes adjust grid resolution for interpolation in cross sectional directions and along the SRM track, respectively. These values should typically be smaller than values used for the MPS measurements.

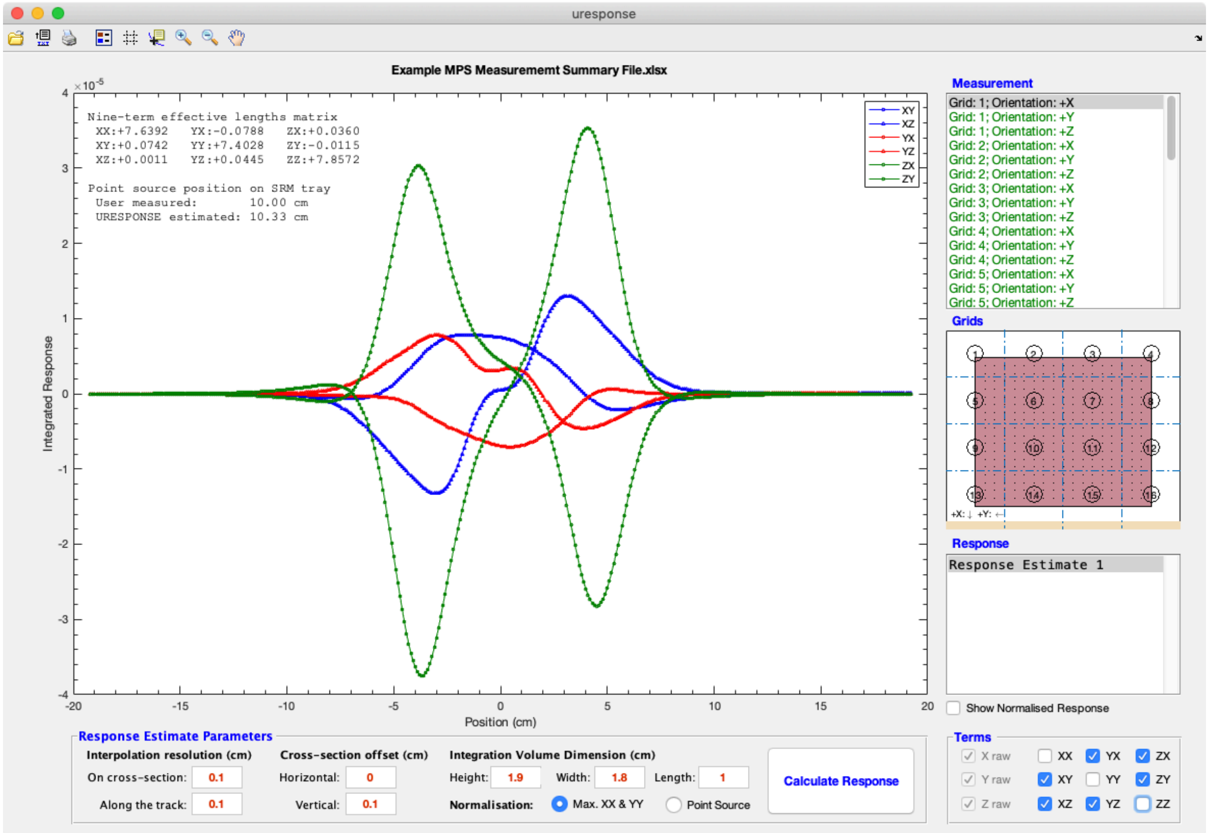
The 'Cross-section offset (cm)' and 'Integration volume dimension (cm)' boxes define the actual volume over which the integration is done for sensor response estimates. 'Height' and 'Width' values for 'Integration volume dimension' boxes should be entered based on measure of the cross-section of the continuous samples. For example, a typical u-channel sample may have inner dimension of ~1.9 cm (height) by ~1.8 cm (width) with a bottom wall thickness of ~2 mm (vertical offset of bottom of sediment sample from the tray). This may vary depending on manufacturer and production date of the u-channels. Value placed in the 'Length' box will be used as length of integration along the track (with the center of the intervals located at each interpolated position along the track) that will be integrated for response estimates. Note that this value must be larger than the interpolation resolution value in the 'Along the track' box.

'Horizontal' and 'Vertical' offset values for 'Cross-section center offset (cm)' is a measure of relative difference between the center of the MPS measurement grid positions (origin of the cross section defined by the user for the MPS measurements on an SRM) and the center of continuous samples (measurement of which the response estimate will be used for deconvolution) on the cross-section. For example, 'Vertical' offset could be used to account for the difference in thickness of the bottom of a plastic u-channel container, thickness of a paleomagnetic sample, and/or the distance between the origin of the MPS cross-section grids and the SRM tray surface. 'Horizontal' offset may exist if the large measurement block used for MPS measurement or the continuous samples were placed slightly off center of the SRM sample tray during measurement runs. Radio buttons are provided to choose between two options for normalization of the integrated raw sensor response: (1) the average of the maximum response value of the XX and YY terms; or (2) absolute magnetic moment of the MPS sample if provided in the Excel summary file. When magnetic moment value of the MPS sample is well calibrated, option (2) is preferred, especially if users intend to obtain response estimates to calculate and compare full EL matrix normalized and/or deconvolved data using measurements made on different SRMs.

When values are set for all boxes on the 'Response Estimate Parameters', users can press the 'Calculate Response' button to generate a sensor response estimate. Cross section area of the volume used for response estimate is shown as a red colored rectangle on the 'Grids' panel along with interpolated grid points on the cross section shown as small black dots. All terms of the sensor response will be plotted in the main plot area as an initial setting (see screen capture below). URESPONSE displays the nine-term effective length (EL) matrix as well as a comparison of estimated and user provided MPS position along the SRM track. The EL matrix can be used to acquire more accurate volume normalized magnetization data, and comparison of the estimated and user measured MPS position provide information on if measurement positions of the SRM are properly calibrated.

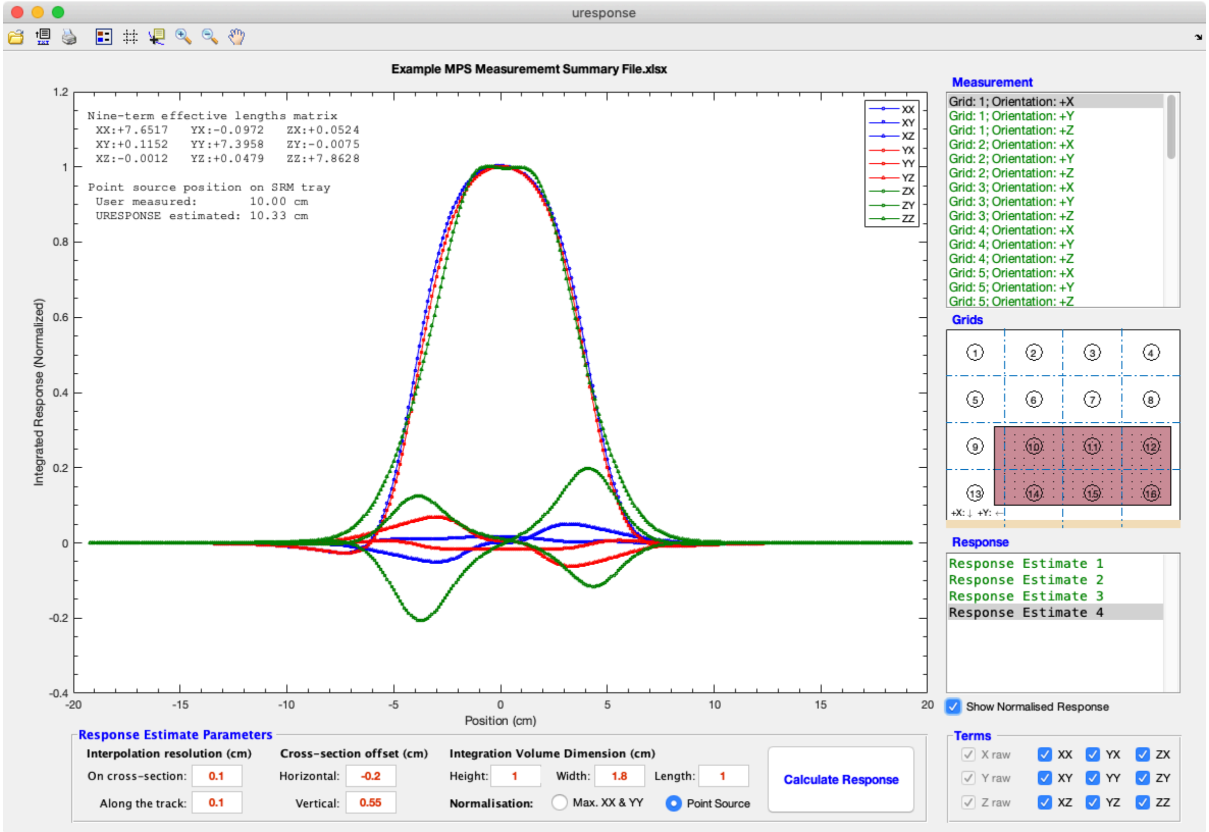


Check boxes on the ‘Terms’ panel can be used to conveniently view any combination of the nine response terms (see example below which only shows cross-terms of a response estimate).



Users can easily adjust the parameters and generate multiple versions of response estimates. Different response estimates can be viewed by clicking (or using the up/down arrow keys) corresponding labels on the ‘Response’ panel (note that only one estimate can be chosen at one time). When clicked, any terms checked on the ‘Grids’ panel will be shown in the main plot area, and parameters used for the response estimate will be shown in relevant boxes on the ‘Sample Cross Section Parameters’ panel. Response estimates that are no longer needed can be removed by selecting it on the ‘Response’ panel then pressing the delete key. The 'Show Normalized Response' checkbox on the right can be used to show the response estimate either before or after normalization. See screen captures below for examples of a normalized response estimate for continuous sample with a different cross-section geometry.

The ‘print’ tool on the tool bar (the third icon from the left) can be used to save a pdf version of the whole interface display including any response data shown in the main plot area. To save any of the response estimate data in a tab-delimited text format, users can choose that estimate in the ‘Response’ panel then click the second icon (from the left) on the toolbar to export the selected response estimate data to a text file. This text file can then be directly read by the UDECON software and used for optimized deconvolution.



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