Hysteresis – Instruction Guide

A MATLAB Code for Modelling and Elimination of Hysteresis Effect from Scintrex CG-3M Gravity Readings.

The code comprises the main function *hysteresis.m* and supplemental function *unos_mix.m*, for input of numerical and text data from the file with numeric and alphanumeric data. In addition, the script file *hysteresis_scr.m* is supplied with an example how to use *hysteresis.m* function for modelling and elimination of hysteresis effect from Scintrex CG-3M gravity readings.

The function *hysteresis.m* models, and depending on input variables, eliminates the hysteresis effect from observation series at different stations from several days. The observation series should last for at least 30 minutes. The function comprises iterative computational method that facilitates determination of exponential function of hysteresis from multiple observations series with different unknown offsets and significant noise that prevents conventional method to be applied.

Hysteresis effect is modelled by following function:

$$z_i = a_k + b \cdot \exp\left[c(t_i - d_k)\right], \tag{1}$$

where z_i is i-th gravity reading, b and c are coefficients of exponential function, a_k is offset (along ordinate) and d_k shift (along abscissa) of k-th observation series. Unlike other unknown parameters, offsets along ordinate are determined iteratively, not by adjustment according to least squares principle. The method is described in the manuscript "Modelling Hysteresis Effect in Scintrex CG-3M Gravity Readings" by M. Repanić and M. Kuhar.

Input variables and options

in_files   Cell array with names and paths to input files with gravity readings. The variable should involve only data file from one gravimeter. For second gravimeter it is necessary to call the function again with different input files. Each input file should consist only of one measuring day. If not so, please manually separate the data into several files. Observation series should last for at least 30 min. However, the length of observation series within one or in more files does not have to be constant. For better results it is advisable to start the readings immediately after setting up the gravimeter on station (without allowing certain time for gravimeter to stabilise).

nor   Number of readings (from beginning) from each observation series to include in calculations. If set to 0, all readings are included.

diagram   Numeric variable. If set to non-zero value, the function plots the diagram of modelled hysteresis function together with all respective observation series shifted in time. Gravity is given in μms^{-2} and time in minutes.

file_el   Numeric variable. If set to 0, the function does not create data files with hysteresis effect eliminated from the readings.
If set to 1, the function creates data files that are identical to input files, but with hysteresis effect eliminated from the readings. The format corresponds to original Scintrex CG-3M format. Therefore, the files can be used as input files to any application usually used for processing Scintrex CG-3M measurements.
If set to 2, the format of files is extended. It involves extra decimal place for gravity readings. This is useful for precise measurements when advanced Earth tide reduction is used.

New files are created in same folder as original file, but with suffix '_ELH' before extension. If the function is going to be executed again with same input file(s), the earlier '*_ELH.*' file(s) should be previously renamed or moved, otherwise it shall be overwritten.

Input variable

output_hyst   An array with first column containing the adjusted unknown parameters of hysteresis function and second column standard deviations of respective parameters. The order of parameters is: b, c, d_1, d_2, …, d_m. Shifts along abscissa (d_i) are ordered first according to the order of input files in 'in_files' variable, and within each file according to reference time of corresponding observation series. Units are μms^{-2}, 1/min and min for b, c and d_i respectively.

Notes

The code is tested on data described in accompanied manuscript. However, supplied test data represents original gravity readings (it includes Earth tide reduction according to Longman model built in the Scintrex gravimeters). Therefore, the results slightly differ from results presented in the manuscript, where more advanced Earth tide reduction is used.

The code is not tested on gravity readings with minor hysteresis effect or on data with increasing hysteresis function. It is possible that the algorithm would be unsuccessful in such cases.

For those interested in modifying the code

The MATLAB code is self-explanatory with lots of comments. However, for those who are interested in modifying the code, it can be helpful to list some of the variables used. For variables of least squares algorithm, the following symbols are used:

MATLAB code symbol	Dimensions	Mathematical symbols and equation	Description
`L+v`	n x 1	$\overline{\mathbf{L}} = \mathbf{L} + \mathbf{v} = \mathbf{F}(\overline{\mathbf{x}})$	Adjusted observations.
`v`	n x 1	$\mathbf{v} = \mathbf{A}\mathbf{x} - \mathbf{l}$	Residuals; Observation equations.
`ln`	n x 1	$-\mathbf{l} = \mathbf{F}(\mathbf{x}_0) - \mathbf{L}$	Reduced observations.
`x_def`	u x 1	$\overline{\mathbf{x}} = \mathbf{x}_0 + \mathbf{dx}$	Adjusted parameters.
`x0`	u x 1	$\mathbf{x}_0$	Approximate parameters.
`x`	u x 1	$\mathbf{dx}$	Parameter's correction.
`A`	n x u	$\mathbf{A}$	Matrix of coefficients of observation equations.
`P`	n x n	$\mathbf{P} = \mathrm{diag}(\mathbf{p})$	Weight matrix of the observations.
`p`	n x 1	$\mathbf{p}$	Weight vector.
`Qxx`	u x u	$\mathbf{Q}_{\mathbf{xx}} = (\mathbf{A}^{\mathrm{T}}\mathbf{P}\mathbf{A})^{+}$	Cofactor matrix of parameters.
`s0`	1 x 1	$\sigma_0 = (\mathbf{v}^{\mathrm{T}}\mathbf{P}\mathbf{v})/(n - u + d)$	Referent standard deviation, i.e. standard deviation of observation with unit weight.
`sx`	u x 1	$\boldsymbol{\sigma}_{\mathbf{x}} = \sigma_0 \cdot \mathrm{diag}(\mathbf{Q}_{\mathbf{xx}})$	Standard deviations of parameters.

If the variable is used in full and reduced form (elements corresponding to non-positive values of observations are excluded), suffix '_r' is used for reduced form.